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AD-276123

ASD-TR-61-435

INVESTIGATION OF THE REPRESENTATION OF AIRCRAFT SERVICE LOADINGS IN FATIGUE TESTS

TECHNICAL DOCUMENTARY REPORT No. ASD-TR-61-435

JANUARY 1962

DIRECTORATE OF ENGINEERING TEST
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Project No. 1367, Task No. 14025

20060921007

(Prepared under Contract No. AF 33(616)-6575 by the
Lockheed-California Company, Burbank, Calif.; A. J. McCulloch,
M. A. Melcon, W. J. Crichlow, H. W. Foster and R. Rebman, authors.)

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200 - May 1962 - 33-1457 & 1458

FOREWORD

This report was prepared by the Lockheed-California Company, a Division of Lockheed Aircraft Corporation, Burbank, California, under USAF Contract No. AF 33(616)-6575. This contract was initiated under Project No. 1367, "Structural Design Criteria," Task No. 14025, "Structural Fatigue Design Criteria." The contract program was administered under the technical direction of the Aircraft Structures Test Laboratory by the Project Engineer, Mr. Sanford Lustig.

The program was conducted at the Lockheed-California Company, under the technical administration of Mr. M. A. Melcon, Department Manager, Structural Methods. Technical supervision was under the direction of Mr. W. J. Crichlow, Group Engineer, Structural Statics. Mr. A. J. McCulloch maintained technical direction of the overall analysis and test program and prepared the final report, with the assistance of other technical personnel in the Structural Methods Department. The statistical analysis of the S-N data was performed by Dr. F. M. Mueller.

The laboratory experimental program was under the technical administration of Mr. H. W. Foster, Division Manager,Lockheed Structures Research Laboratory. The design and assembly of the experimental equipment and the development of operational techniques were under the technical supervision of Mr. J. Rebman, Group Engineer, Structural Development Research, assisted by Mr. J. Fairchild. He was also assisted in the assembly of electronic equipment for magnetic tape signal analysis and the recording of special loading spectra, and for fatigue test machine control equipment by Mr. W. B. Brewer, Group Engineer, Electrical Instrumentation, aided by Mr. R. A. Meyer, Electrical Design; Mr. J. B. Harlan, tape equipment; Mr. P. A. Latham, electrical calibration, monitoring, and maintenance.

Testing was under the direct supervision of Mr. H. W. Grebe, Mr. R. H. Wells, and Mr. J. B. Ryan, assisted by Mr. R. J. Cox, Mr. R. L. Lowe, and Mr. L. Silvas.

The majority of the typing of the report was done by Mrs. Evelyn Stephenson and Mrs. Mary Ungerman.

The assembly of the electronic equipment for magnetic tape reading, counting, tape recording of special loading spectra, and for the magnetic tape controlled fatigue test equipment, along with the development of the calibration and monitoring techniques, and the testing of some of the spectrum loaded coupons, reported herein, was shared between this contract and the companion contract, No. AF 33 (616)-6574 "Research Study and Experimental Verification of Fatigue Life Prediction Theories."

ABSTRACT

An investigation was carried out of the effectiveness in fatigue tests of practical representations of aircraft service loadings. The investigation required the development of test apparatus capable of applying typical random loading histories. Using this equipment random gust loadings, military maneuver loadings, ground loadings, and composites of flight and ground loadings were applied. The results obtained were used to evaluate the adequacy of ordered, cyclic loading representations of the random loadings.

The evaluations indicate that spectra of cyclic loadings based on simple mean crossing peak counts of service loading records can be directly employed in tests in which the maximum values of applied stress are moderately high. In tests where lower peak stresses are generated, the test lives may provide an unconservative estimate of service life. The results obtained in composite loading tests indicate that the cumulative effect of flight loadings, ground loadings, and ground to air transitions is nonlinear. However, in one set of tests representing the service conditions in the wing root region of conventional transport aircraft, adequate simulations of the effect of composite random loadings were obtained.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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SECTION I

INTRODUCTION

The investigation of structural fatigue problems usually requires carrying out tests. Often, these tests provide purely comparative evaluations of similar structure using rather arbitrarily chosen test conditions. In such tests, the correspondence of test loadings to service loadings may be quite approximate. However, when the size and cost of a fatigue test specimen becomes large, such comparative testing is often not practical. In such a case, the test of one or of a very few specimens must provide information on the probable location of cracking in service use, the service time at which such cracking may be anticipated, the possible rate of crack propagation, and the adequacy of any provisions for crack stopping. If the attainment of these objectives is not likely, the cost of a test may be questioned.

To attain this ambitious test goal, all of the test conditions must be carefully selected. Of most importance, however, is the adequacy of the simulation of the service loadings. Since it has not been possible in a laboratory test to duplicate service loading time histories, the selection of adequate but attainable simulations of service loading histories poses many problems. The first of these problems - one of fundamental importance - is the adequacy of the reduction of any particular service loading history to numerical form. In this context the adequacy of the reduction must be defined in terms of the effect of the actual service loadings.

To illustrate the type of time history of load or stress which must be represented in flight vehicle fatigue work, a copy of a short length of loading trace is presented on Figure 1. This trace was recorded on an aircraft flying in turbulence. To use the information provided by the trace in test work, the trace movements must be replaced by simple cyclic motions which will have the same effect as the actual trace movements. This requirement is dictated by the general availability of test apparatus which produces simple cyclic loading histories.

Examination of such traces has led to the definition of several methods of trace interpretation. However, substantially all of the published data on service loading histories are based on the use of essentially one method of interpretation which is usually described as the peak count method.

Historically, the first reductions of service loading histories were made from V-G record cards or plates. The characteristics of such records permitted the reading and classification of only the major load peaks. These peaks were

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Manuscript released by the authors June 1961 for publication as ASD Technical Report

Figure 1 Sample Flight Loading Trace

considered to define load transitions from the 1g or steady state load. Furthermore, when the number of positive and negative excursions of particular magnitudes were approximately equal, it was convenient and desirable in fatigue work to couple a positive and negative excursion to form a cycle of loading acting about the mean (1g) value.

When continuous traces of the type shown on Figure 1 became available, the application of this general approach was continued. As a result, a large part of the fund of numerical data on service loading and service stress histories reflects the recording of peak values of excursions from a nominal mean value. In addition, in the use of these newer data in fatigue work, equal excursions of opposite sign are usually coupled to define simple loading or stress cycles. This coupling is usually arbitrary since the continuous recordings show that many of the positive and negative peaks of equal magnitude do not occur consecutively in service.

The adequacy, in fatigue evaluations, of this rather arbitrary method of representing service loading histories is suspect. In addition, many decisions must be made about the manner in which the representation is to be used in a test. For example, selections must be made of the sequence in which loadings of different types or loadings from different service conditions are to be applied, the degree of randomization of the different classifications of loadings must be decided upon and the utility of simplifications must be assessed.

Unfortunately, the usefulness in fatigue tests of the conventional numerical representations of service loading histories and of the multiple decisions required in selecting test load patterns has not been experimentally investigated on a comparative basis. This has been due to the lack of test equipment capable of applying the types of service loading histories recorded on aircraft. The development of an operational system adequate for this task was one of the main problems in the contract work. With the development of this system, comparisons of test lives obtained under flight recorded random loadings with those obtained under simple representations of such loadings are now possible.

This report presents the results of an investigation of the factors which have been described. However, since the number of variables is very large and the effects of single variables are probably not linearly cumulative, exhaustive evaluation of single variables has not been attempted. Rather, the aim has been to explore the applicability of readily attainable interpretations of each of several classifications of service loading histories, the usefulness of particular test loading pattern selections and the possibility of marked simplification of test plans.

More explicitly, the investigation was carried out in two stages. The objective of the preliminary stage was an evaluation of several methods of representing service loading records by spectra of discrete loadings. The methods were evaluated by simple comparisons of the spectra produced by each method and also by tests. In the tests both random loading records and spectral representations of these records were used to obtain comparative test lives.

The objectives of the second stage were, first, an evaluation of the choice of test variables and, secondly, an investigation of the effect of coupling flight and ground loadings with the ground to air to ground transitions which occur once per flight. As in the latter part of the first stage, the evaluations were based on comparisons of the test lives developed by use of random loadings with those obtained using ordered loading representations. Gust, military maneuver and ground loadings were investigated separately and then in combination.

SECTION II

PRELIMINARY INVESTIGATION

Random Loading Trace Selection and Interpretation

In the preliminary investigation, methods of concisely representing the loading histories on continuous service load recordings were evaluated. For this work the apparently simple task of selecting suitable records posed some difficulty. Any reduction of service loading histories involves an evaluation of a wide range of amplitudes with amplitude components acting over a range of frequencies. To obtain records with such characteristics, the output of a random noise generator might be used. However, in keeping with the general intent to keep the present investigation focused as directly as possible on the overall problems of immediate concern, it was considered desirable to obtain and use load recordings made on aircraft in flight. Some limitation of scope and increase in cost is dictated by this approach. However, the results to be obtained are clearly more directly applicable in the selection and interpretation of fatigue test loadings than those that would be obtained by the use of arbitrarily generated loading histories.

For the purpose of the investigation, traces of loading history recorded on magnetic tape were required. In this form the trace lends itself to multiple uses. It may be scanned, copied, filtered or otherwise manipulated by the use of electronic equipment. It can also be reproduced on paper for visual examination if required and it can be used directly to control the loadings applied in laboratory tests. However, at the time of initiation of this contract it was not widespread practice to record flight test data on magnetic tape. Consequently considerable difficulty was experienced in obtaining a suitable record for this work.

With the support of the Air Force project engineer on the contract, a record on magnetic tape of loadings on a B-47 aircraft during a complete flight was obtained from the Boeing Aircraft Corporation in Wichita. This record contained continuous traces of vertical accelerations at the center of gravity and of bending moments and strains at several locations on the structure. During the flight a substantial period of time was spent at an altitude of approximately 800 feet and at a speed of approximately 280 knots in substantially continuous turbulence. The record for approximately 96 minutes of this phase of the flight was selected for detailed examination.

Since, among other variables, the responses of different elements of an airframe to the same external loadings cover different ranges of frequencies, it was considered necessary to evaluate at least two traces showing substantially different frequency responses. This requirement led to the choice of the traces of bending moment at the wing root and fin root for use in this program. Visual examination of oscillographs of these two traces provided an adequate guide to these selections. A sample length of each trace is shown on Figure 2.

To obtain assurance that the record contained a reasonably continuous distribution of excursion magnitudes, an oscillograph of a five minute length of the wing root bending moment trace was given a detailed examination. To indicate the suitability of the traces, a conventional peak count interpretation of the trace variations on the five minute oscillograph is shown on Figure 3. These counts were obtained by visual scanning of the record and averaging several independent readings. While the methods used in interpreting traces and presenting data will be discussed in more detail in later paragraphs, the graph is presented as assurance that the traces selected for use do not represent discontinuous distributions of excursion magnitudes.

Visual scanning of the total lengths of the two traces chosen for use indicated variations in the mean values. To simplify the use of the record, each trace was reproduced in two parts. One part represented the variation in mean where the mean was defined by continuous integration of the area under the original trace over successive trace lengths of approximately 1.5 minutes. The second part was a copy of the dynamic motions of the trace measured with respect to the moving mean value just defined. For each record the two parts were recorded as separate signals on a new tape. In this way attention could be focused on the relatively slow changes in mean, on the dynamic portion of the record or, by simple electrical summing, each original record could be reproduced.

A plot of the variations in mean values is presented on Figure 4. The decrease in mean shown for the wing loading trace probably reflects the consumption of fuel carried in the wing. The changes in mean shown for the fin loading trace probably reflect changes in trim.

In making copies of the tapes, the original tape speed was changed so as to compress the record. This change, which was dictated by the need for minimizing tape handling time and test times, was guided by exploratory tests on equipment being developed for the program. These tests required restrictions on the average rate of testing which were imposed by the high rates of loading defined by the trace shapes. These restrictions led to the making of copies of the 96 minutes of wing loading history which could be applied in tests in approximately six minutes at the standard tape speed of seven and one-half inches per second. In the case of the fin loading record, the content of higher loading frequencies required recording so that the 96 minutes of real time history would be applied in approximately 30 minutes of test time using the same tape speed. These ratios of test to real time reflect the stiffnesses of particular specimen geometries and loading arrangements used in this program.

For routine use, multiple copies of each tape were prepared and spliced to fill a reel. Each reel had a running time of approximately one hour.

The dynamic traces of wing and tail loading, containing only the responses to turbulence and miscellaneous course correction loadings, were used in the major effort to evaluate trace reduction methods. In this effort, attention was concentrated on the use of three methods usually called the mean crossing peak count, the simple range count and the simple interval crossing count methods.

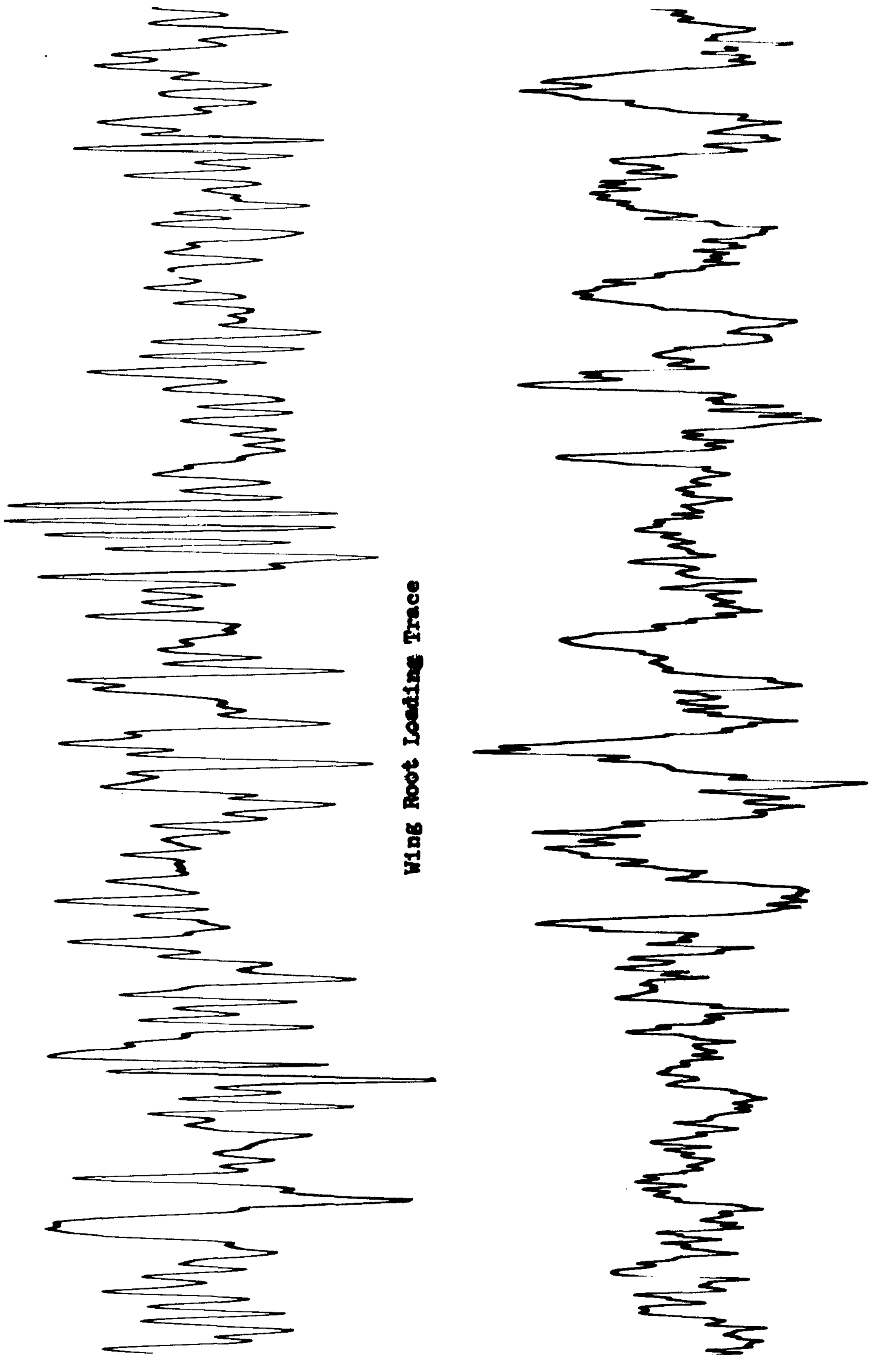


Figure 2 Structural Response Characteristics at Two Airframe Locations

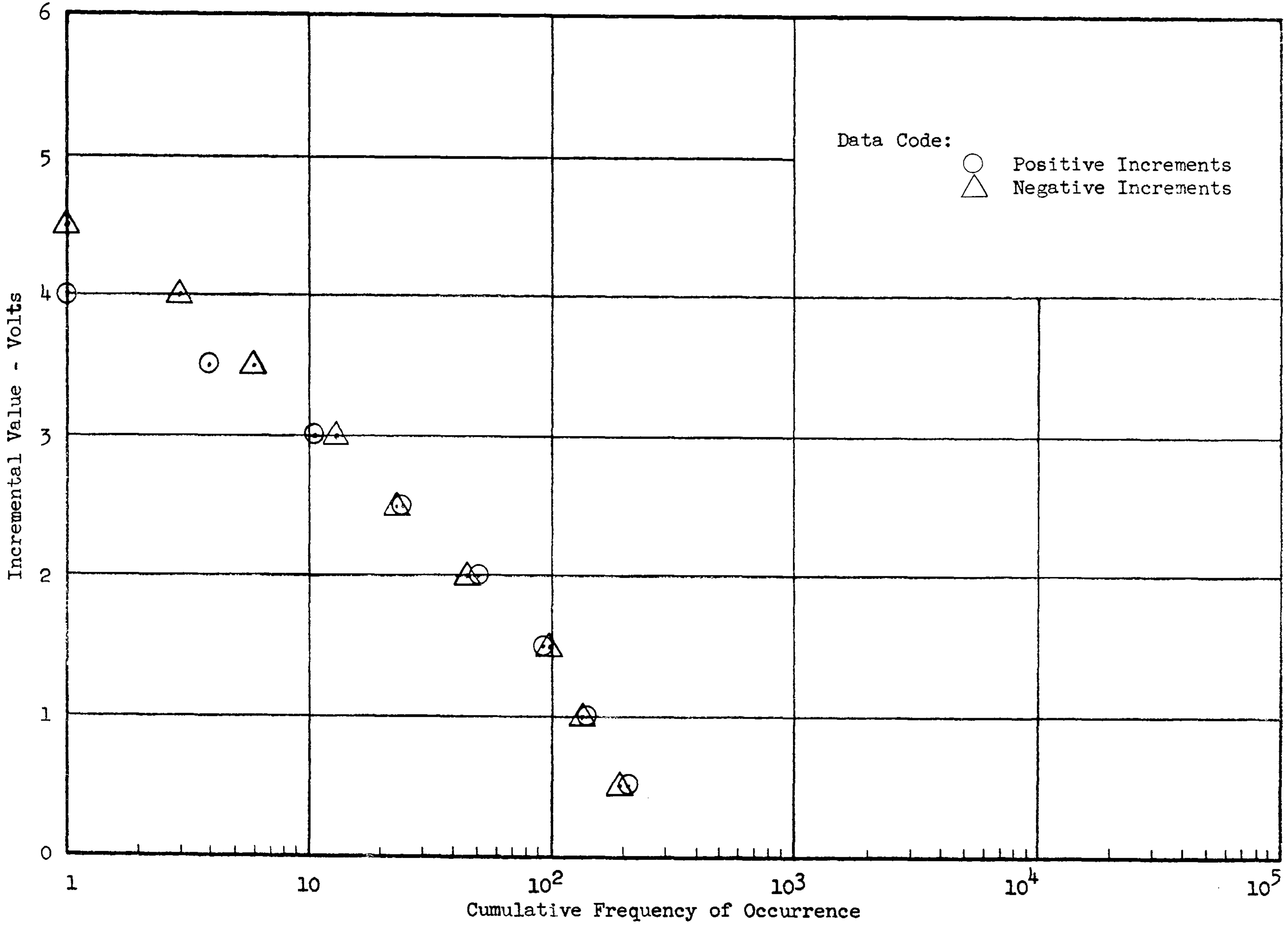


FIGURE 3 MEAN CROSSING PEAK COUNTS OF A 5-MINUTE SAMPLE OF WING ROOT TRACE

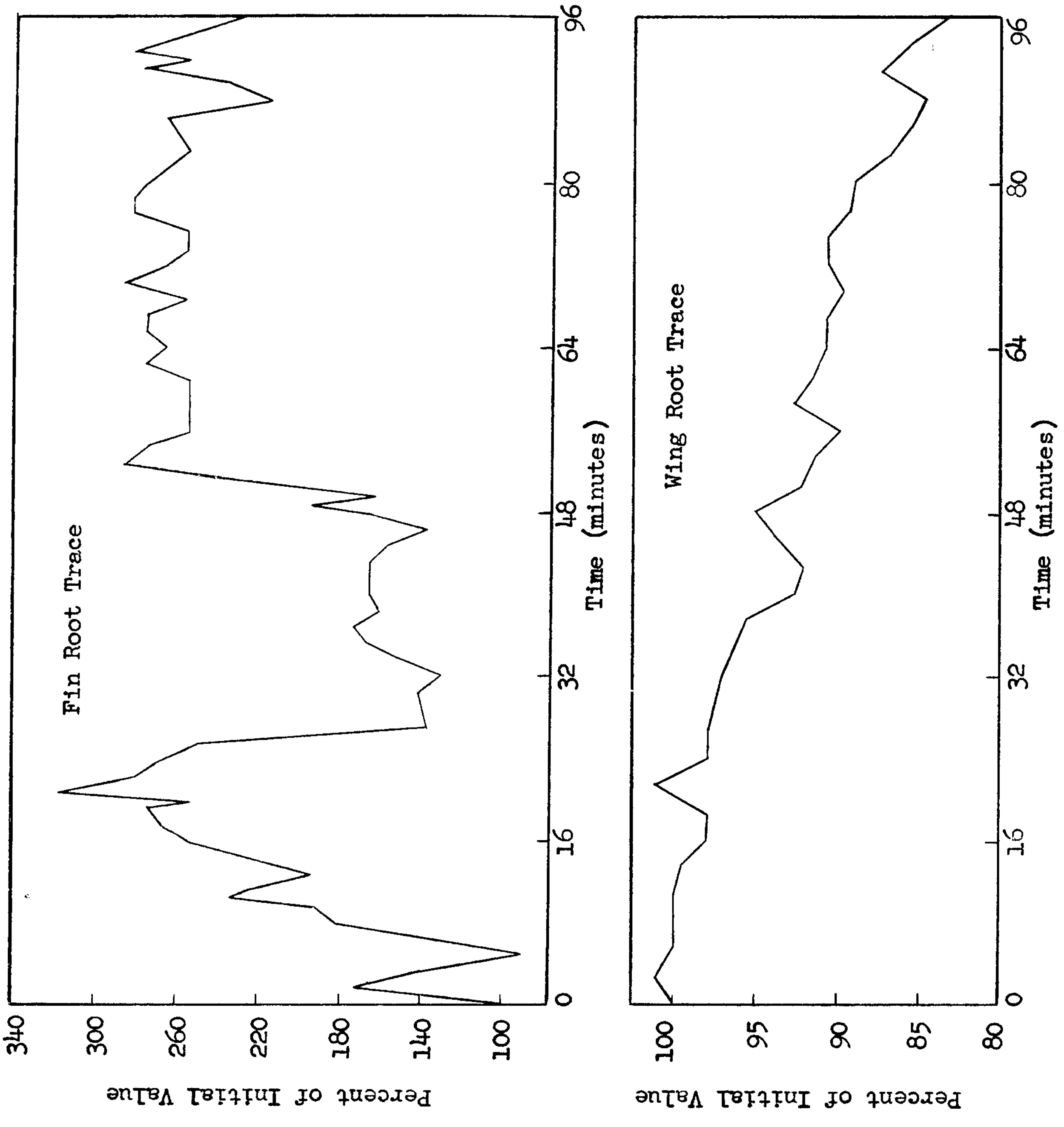


FIGURE 4 COMPARISON OF VARIATION IN MEAN VALUES

Mean Crossing Peak Count Method

In applying this method, only the maximum excursion of the trace which occurs between each crossing of the mean line is recorded. The values of subsidiary peaks occurring during the interval between crossings of the mean line are therefore ignored. This method is believed to be basically similar to the one used in the production of most of the published numerical data on load frequency distributions. Each value of excursion peak which is recorded is classified by sign and by magnitude and the number of occurrences of like sign are summed progressively from the higher to the lower magnitudes. This process produces a tabulation of the number of times a particular excursion peak has been equalled or exceeded. The tabulation thus defines a cumulative frequency of occurrence spectrum. When, as is often the case, the distribution of positive and negative excursions is approximately symmetrical, it is conventional to group excursions of the same magnitude to describe simple cycles. The end result is then often presented graphically as a cumulative frequency distribution of cyclic excursions from the mean value.

Simple Range Count Method

In applying this method, a particular magnitude of excursion range is selected. The trace is then scanned to establish the number of times it makes an excursion in the direction of increasing load magnitude which exceeds the selected range, followed, at some location on the trace, by a corresponding excursion of decreasing magnitude. This process is then repeated for several values of range to cover the maximum excursion on the record. In this type of reduction, the movements of the trace are followed without consideration of the existence of a mean value. The results obtained indicate merely the number of positive and negative excursions which equal or exceed a particular value. In using this information however, it is usually assumed that the difference between the mean value for each recorded excursion or range and the local value of the trace mean is not large. The value of the trace mean is then assumed to apply in interpretation and use of the spectrum of range values.

Simple Interval Crossing Count Method

In applying this method the maximum range of the excursion on the record is first divided into intervals. Every crossing of each interval boundary by the trace when it is moving in a positive direction is then recorded. The number of crossings recorded for a boundary at any one level may be subtracted from the number recorded for the next lower level to obtain an indication of the number of peak values occurring within the interval. For a trace defining a variety of amplitudes but produced at an approximately constant cyclic frequency (a smooth trace) the method should produce excellent agreement with simple peak counts. However, for a record containing irregular trace shapes with a range of frequency components, the difference in number of crossings described above probably indicates only the difference between the number of peak and valley occurrences within any interval. In any event, there is considerable current interest in the results which may be obtained with this method. It may be expected to produce a spectrum comparable to the estimated spectrum of discrete load occurrences which can be obtained from a power spectral representation of the record.

These methods are described and illustrated in more detail in Appendix I. Other methods and many variants of the three methods may be devised. However, the methods chosen for use are representative of those proposed and used in the past, they are readily adaptable to use on electronic tape scanning equipment and they provide different weightings of the characteristics of complex traces.

Although not employed directly in the investigation, power spectral density distributions of two short lengths of trace are presented in Appendix II. The spectra of discrete loadings derived from these distributions are also shown and compared with interval crossing and mean crossing peak count spectra for the same lengths of trace.

Each of the three methods described above were applied in the interpretation of the two dynamic loading traces selected for study. In this work, specially developed tape handling equipment was employed. The equipment is capable of tape copying, trace generation and trace analysis. It is described in detail in Appendix I which also presents a discussion of its use and an analysis of the accuracy attainable in the representation of trace content. A general view of the equipment is shown on Figure 5.

The results of the multiple interpretations of the two tapes are presented on Figures 6 and 7. On these figures the values obtained in each type of trace reduction have been presented in a consistent form. Each curve presents the conventional interpretation of the data as it would be used to define cyclic loadings acting about a constant mean load. To obtain the curves for the peak count and interval crossing count methods, substantial uniformity of the distribution of positive and negative values permitted their grouping in the conventional manner.

The degree of agreement obtained when the three count methods were applied to the two traces having quite different content was not anticipated. It was expected that each of the three count methods would produce spectra having generally similar shapes but widely different numbers of occurrence. In this event tests would be carried out using the cyclic loadings defined by one method and the test lives compared with those obtained using random loading. This comparison would indicate which of the three methods produced spectra which most nearly represented the actual severity of each random loading trace. However, when the probable scatter in test lives is taken into account, Figures 6 and 7 cast doubt on the possibility of obtaining a clear definition of superiority of one method over another.

To obtain additional information on the apparent uniformity of results produced by the use of different trace reduction methods, use was made of records on magnetic tape of accelerations at the center of gravity of a B-66 aircraft. These records, obtained while the aircraft was flown through turbulence at low

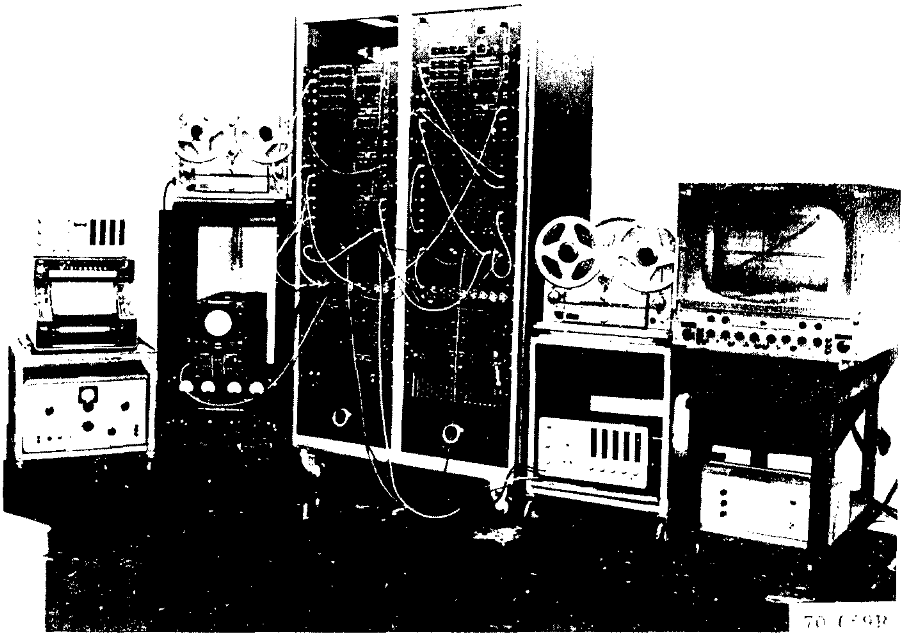


Figure 5 General View of Tape Handling Equipment

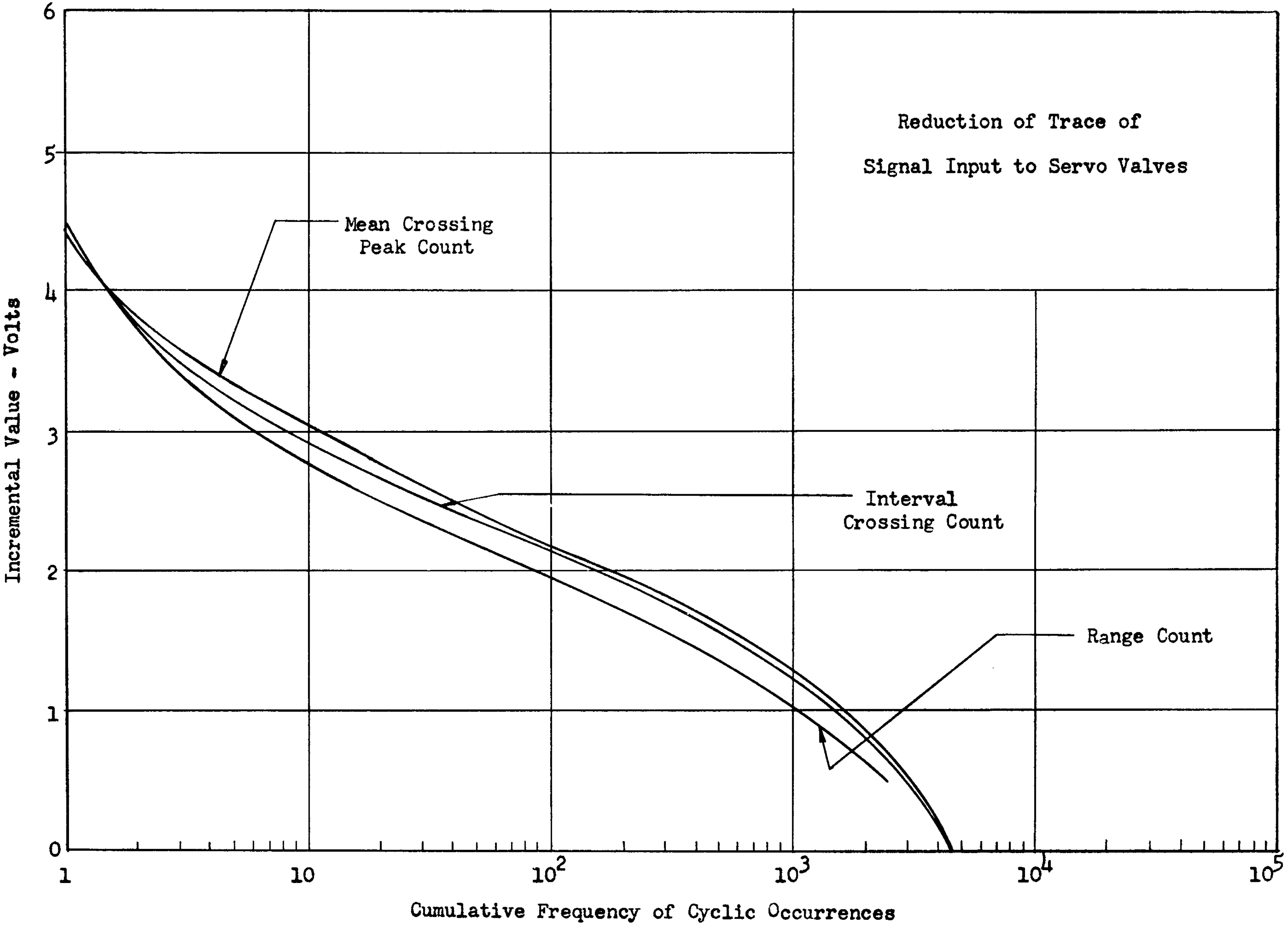


FIGURE 6 COMPARISON OF TRACE REDUCTIONS - WING ROOT RANDOM LOADING TRACE

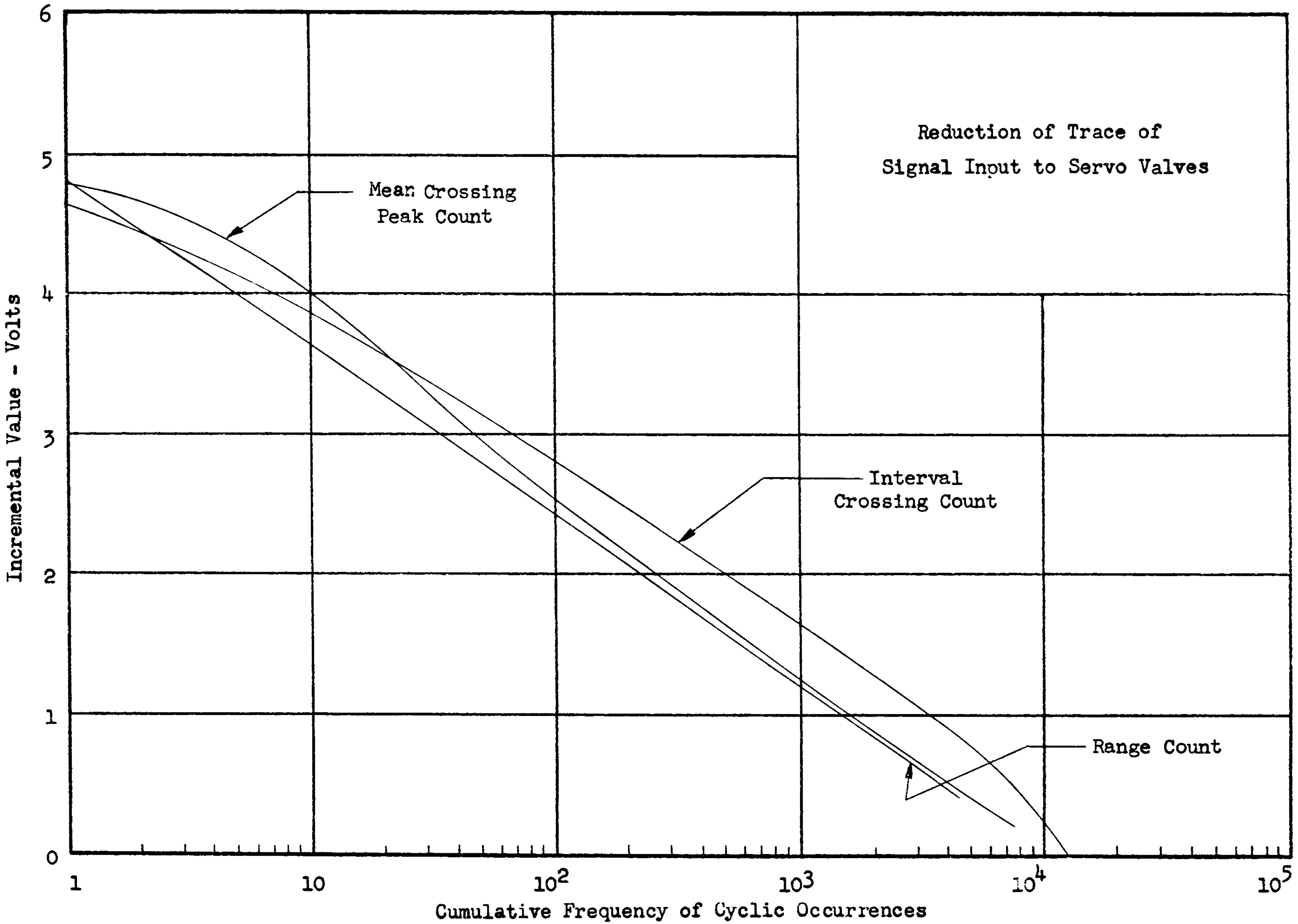


FIGURE 7 COMPARISON OF TRACE REDUCTIONS - FIN ROOT RANDOM LOADING TRACE

altitude, were supplied by the Douglas Aircraft Company in Santa Monica. A length of tape containing substantially continuous trace activity was selected and the type of peak and range counting previously described was used to produce spectra. These spectra, shown on Figure 8 indicate the same order of agreement as that shown for the wing loading trace on Figure 6. In a further effort to obtain a clear distinction between the results to be obtained by the different count methods, a random trace was generated. In this effort, the intent was to generate a record for which the shape of the derived spectra would be substantially different from those previously obtained. In other words, a marked change in the relative frequency of measured load occurrences was desired.

To obtain such a record, the trace of the B-47 wing root bending moment variations was amplified in a non-linear manner. This modified trace was then interpreted using each of the three methods. The results obtained are shown on Figure 9. Once again the three methods produced similar spectra.

It is unlikely that the similarities shown for the three count methods could be demonstrated for all traces or all trace lengths. Each method tends to weight particular aspects of trace histories. It would, for example, be possible to generate traces having particular shapes for which the three methods would describe quite different spectra. However, the interest in this investigation is restricted to the practical problem of the reduction of substantial lengths of trace whose frequency content is largely restricted to the range of relatively low frequencies which is characteristic of most flight vehicles. In terms of this problem, the spectra which have been presented indicate that the integrations of trace content provided by each of three methods are quite similar. This conclusion reflects the use of substantial lengths of trace of quite different content which can be described by spectra of quite different shapes.

These results do not, of course, throw light on whether or not any spectra derived from the tapes adequately reflect the severity of the random loading traces. For this aspect of the investigation, comparisons are required of the test lives obtained under random loadings with those obtained using simple cyclic loading simulations of the random history.

Test Specimen Descriptions

In the test work, simple coupon-type specimens containing stress concentrating holes were employed. Two magnitudes of stress concentration, identified by theoretical K_t values of 4.0 and 7.0, were obtained by varying the geometry of the holes. A sketch of the specimen is presented on Figure 10. All specimens were taken from .040 inch thick sheets of non-clad 7075-T6 aluminum alloy rolled from material obtained in a single heat. To identify the basic material strength and to gain assurance of uniformity, longitudinal grained tensile test specimens were taken along the longitudinal axis of each sheet. The test section of each specimen conformed to ASTM Standard E8-57T.

The results of static tests of these specimens are presented in Appendix III. They indicate quite adequate uniformity of material strength.

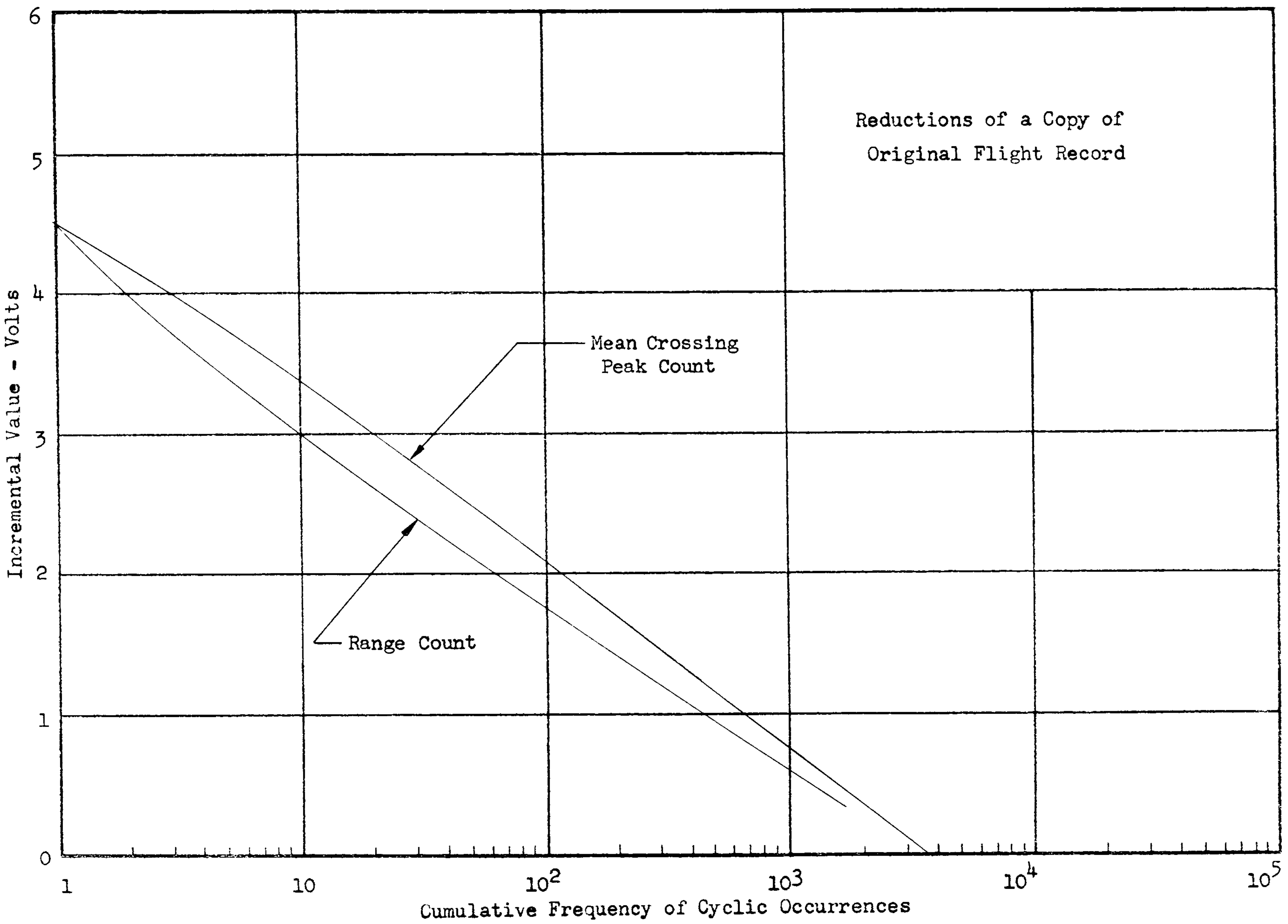


FIGURE 8 COMPARISON OF TRACE REDUCTIONS - B-66 ACCELERATION RECORD

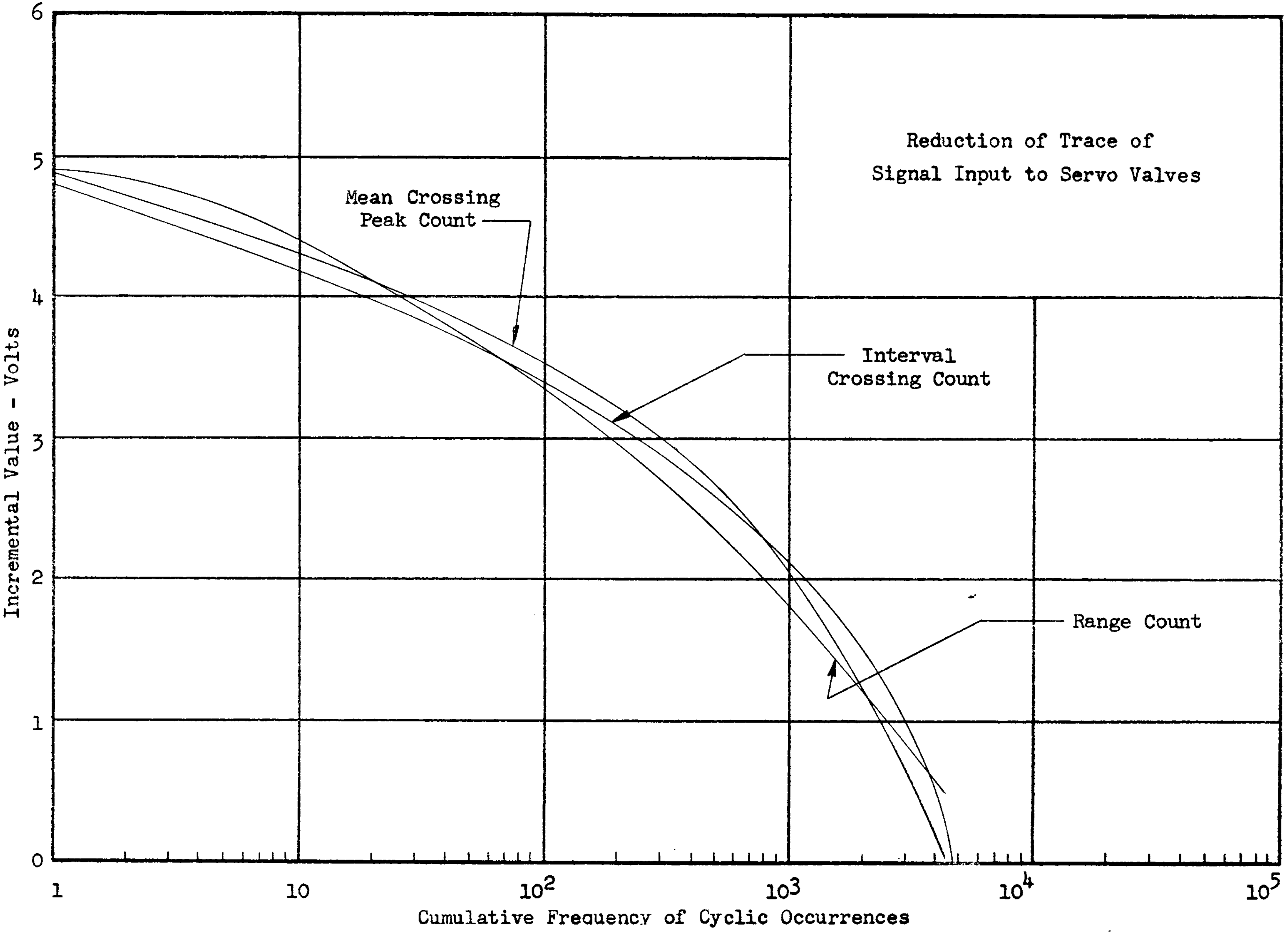
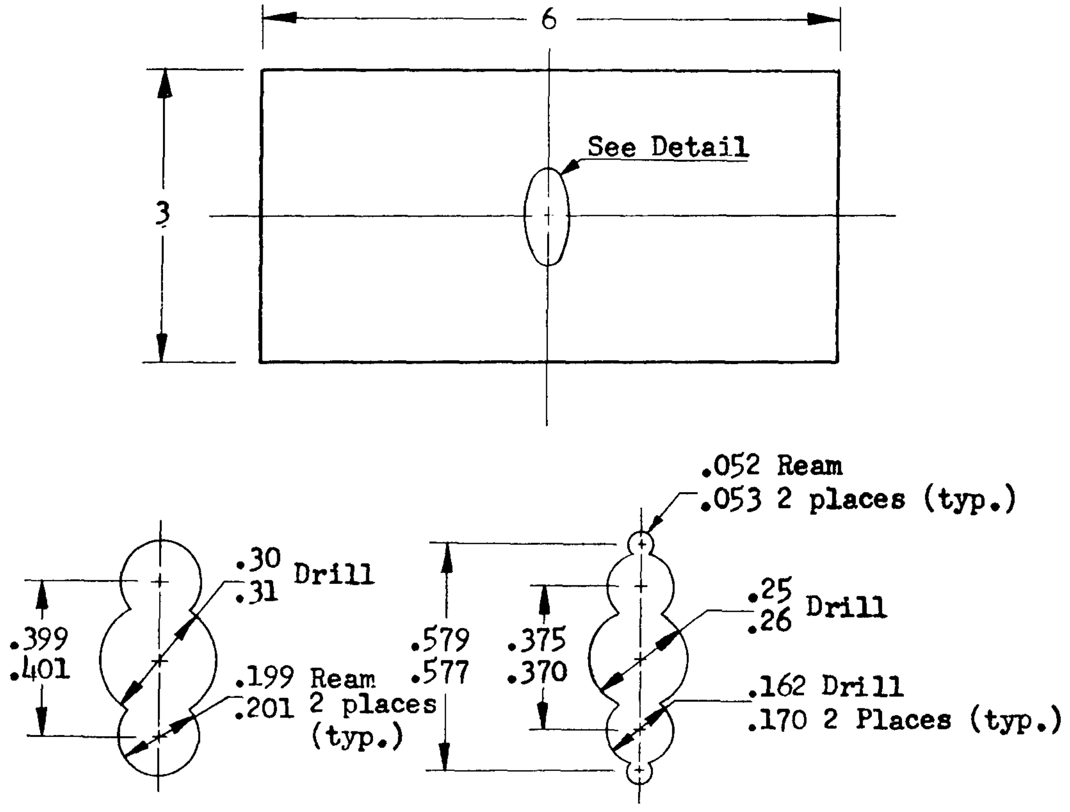


FIGURE 9 COMPARISON OF TRACE REDUCTIONS - MODIFIED WING ROOT RANDOM LOADING TRACE



$K_t = 4.0$ $K_t = 7.0$

NOTE: All Dimensions Given In Inches

MATERIAL: 7075-T6 Bare Aluminum Alloy Sheet (.04 inches thick)

FABRICATION: Specimen Blanks Sheared to Size
Holes Drilled and Reamed
Burrs Removed by Light Stoning

Values of Theoretical Stress Concentration Factor, K_t, are Based on Nomographs Presented in "Theory of Notch Stresses", by H. Neuber

Figure 10 Notched Sheet Test Coupons

Test Apparatus and Procedures

To apply to these test specimens the complex loading histories defined on the loading tapes, special equipment was required. This equipment was developed using available components and using control techniques which have been previously employed. However, the extreme range of trace shapes and of loading rates and the requirement for a high order of precision and repeatability imposed conditions which were difficult to meet. A description of this equipment is presented in Appendix I. A general view of the equipment is shown on Figure 11 and a close-up showing the mounting of a test specimen is presented on Figure 12.

In using this equipment considerable difficulty was encountered in adequately controlling and monitoring the loading histories of specimens. For a particular set of tests the programming signal, scaled by the electronic portion of the test apparatus and used to control the action of servo valves , was recorded. This signal, defined as the input signal, was scanned and counted - usually by the mean crossing peak count method - to determine compliance with the test requirements. However, small differences in the response of individual servo valves could substantially modify specimen loading histories. These difficulties led to the need for semi-continuous monitoring of specimen loadings. In addition to normal test control procedures, the monitoring involved recording the output of strain-gages mounted on calibrated load cells. These cells, which were loaded in series with the specimens, are visible on Figure 12. To illustrate the quality of machine response finally attained, a sample comparison of a simultaneously recorded machine input and load cell output signal is shown on Figure 13.

In general, the load cell output was scanned for any obvious evidence of malfunction and then the trace was reduced to spectral form. Since it was not practical to make and read complete recordings of the test histories of specimens covering many hours of test time, a record sampling procedure was adopted. The use of this procedure provided guides to the steps required for stabilization of the test system, the development of carefully controlled test routines and the generation of useful data. In the process of attaining this goal however, 268 specimens were used and approximately 40 reels of test programming and test history monitoring tapes were produced and read. A log of this test work, tabulations of data and a set of spectra obtained from the tapes are presented in Appendix IV. The values plotted for each spectrum represent a single length or single application of a basic trace length. For several records these reductions indicated a lack of symmetry of the largest positive and negative loadings. However, in reporting test lives, the interpretation of the loading history on the appropriate monitor tape is given by a single spectral line drawn to best represent the data points.

Preliminary Random Loading Test Data

Using the records described above, several results obtained in preliminary testing will be presented and discussed. These results do not bear directly on the evaluations of spectra. However, they provide some assurance that such evaluations may be restricted to traces containing constant mean values.

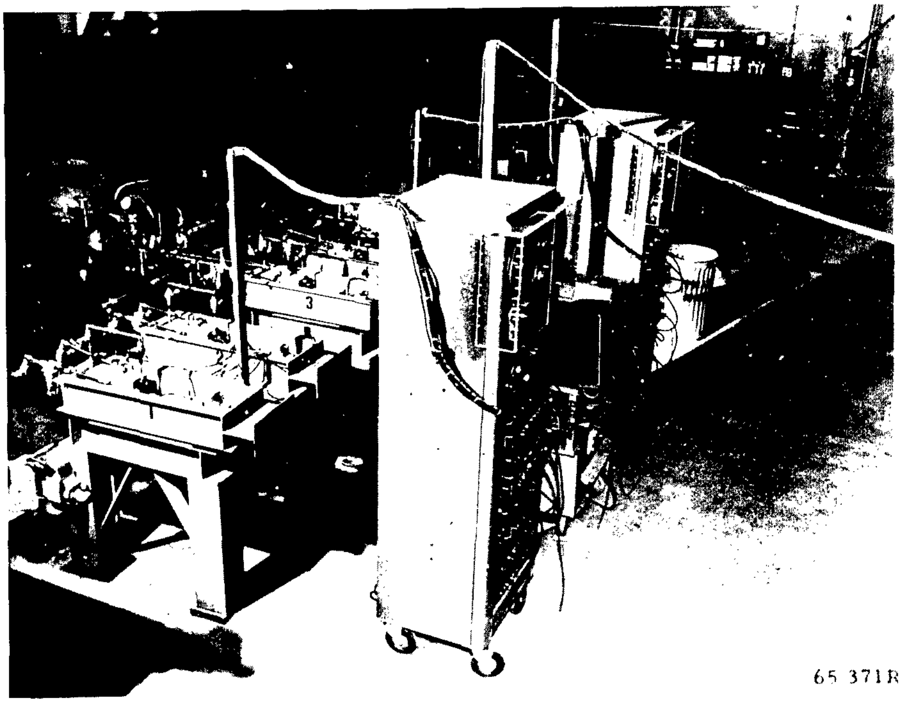


Figure 11 General View of Specimen Loading Apparatus

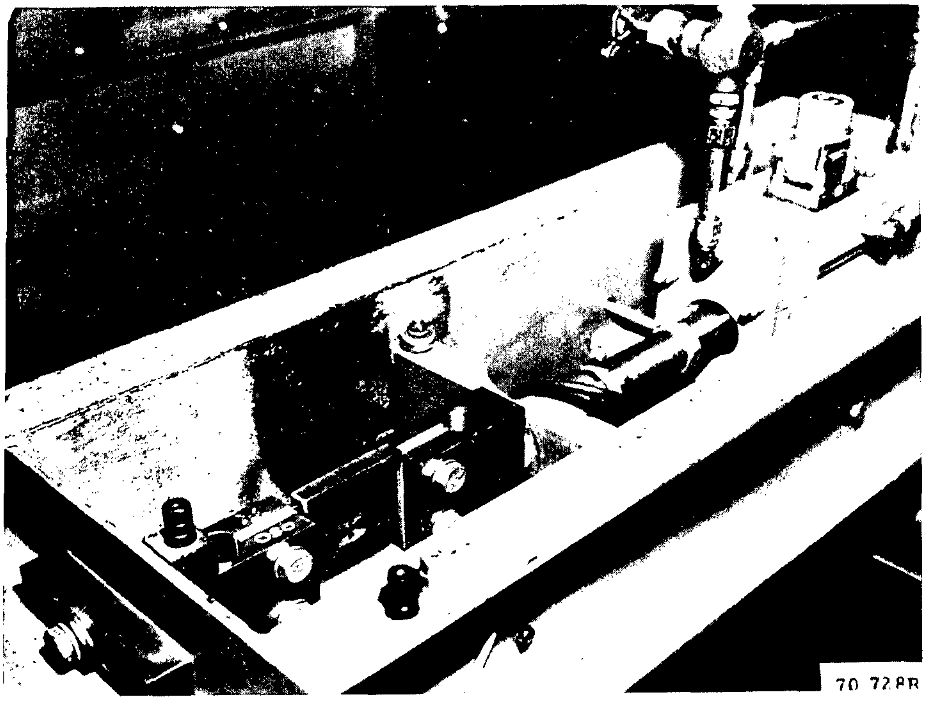
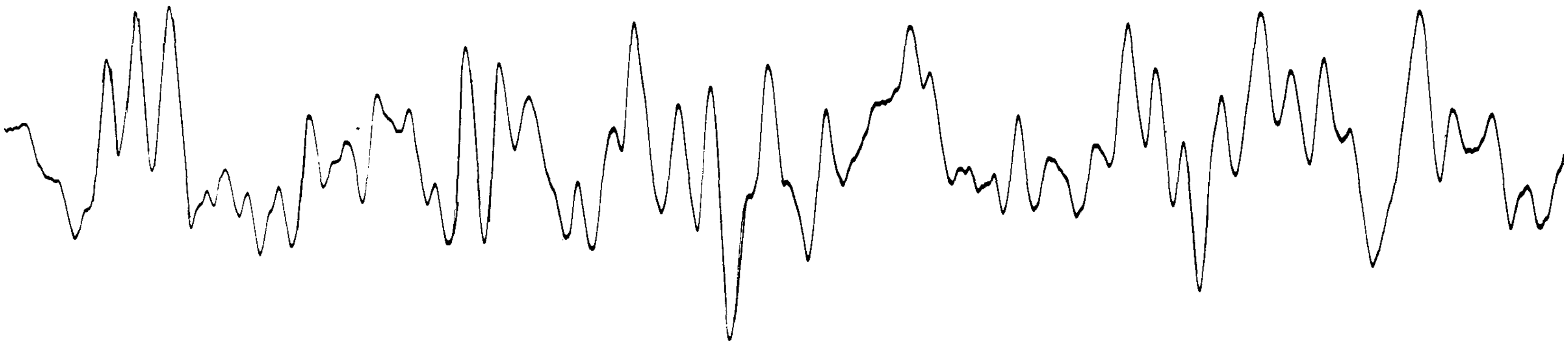


Figure 12 Close-up of Test Specimen Installation

Trace of Input Signal



Trace of Specimen Loading History

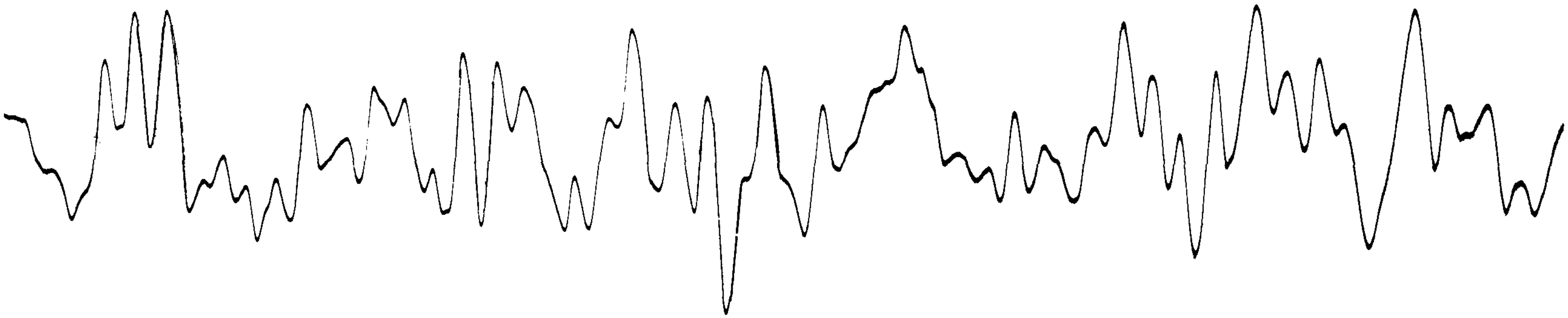


Figure 13 Comparison of Servo Valve Input Signal with Specimen Loading History

As described in a preceding section, the original B-47 records contained significant changes in mean load level during the 96 minutes of flight. Since such changes are characteristic of many service loading records, it was considered desirable to obtain an indication of their effect. For this purpose, the tape signals representing the variations in mean and the signals representing the dynamic loadings were electrically summed and used in tests.

When the wing loading tape was used, the initial value of mean stress during each repetition of the loading trace was 12,000 psi followed by a decrease to 10,000 psi. In these tests, in which the loading trace was repeated every 6 minutes, a peak incremental stress of approximately 12,000 psi was employed. When the fin loading tape was used, the initial value of mean stress during each trace repetition was 3,000 psi followed by variations of the order indicated on Figure 4 which produced temporary mean stresses as large as 10,000 psi. In this use of the fin loading trace, which required 30 minutes for each repetition, a peak incremental stress of approximately 19,000 psi was employed. The test loading histories which were obtained are listed in Table 12 in Appendix IV and are presented on Figures 14 and 16. In all such presentations of test loading histories in this report, the incremental value of stress in each cycle measured from the mean value is defined as the varying stress. The stresses shown are nominal values based on the specimen gross area. The spectral shapes reflect zero crossing peak counts of test loading monitor tapes.

To evaluate these test results, two groups of values are available from tests in which the wing and the fin tapes produced comparable varying stresses. In these tests, a constant mean stress of 12,000 psi was applied. The results obtained are listed in Table 12 in Appendix IV and are presented on Figures 15 and 17. A comparison of Figures 14 and 15 indicates that the moderate reduction of mean stress in one group of tests using the wing loading tape had little effect on the specimen test histories. A comparison of Figures 16 and 17 indicates that the substantial variation in mean stress applied to one set of specimens produced test lives covering a wider range but having approximately the same mean value as those produced by a higher, constant mean stress of 12,000 psi. It must be noted that, with an initial mean stress of 3,000 psi, Figure 4 indicates mean stress values of the order of 8,000 - 10,000 psi most of the test time.

The results obtained in these two groups of tests indicate that moderate reductions of mean stress - of the order of 20% - have minor effects on test lives and that relatively large but temporary reductions in mean may not be significant.

In addition to these preliminary random loading tests, several tests were carried out in which the wing loading tape was simply reversed. In these tests the magnitudes of varying stress and of the constant mean stress were nominally the same as those used in the tests which produced the results shown on Figure 15. A monitor record of the test loadings was not obtained but, as might be expected, the multiple applications of this reversed tape led to test durations which fell within the range of those obtained for normal use of the tape.

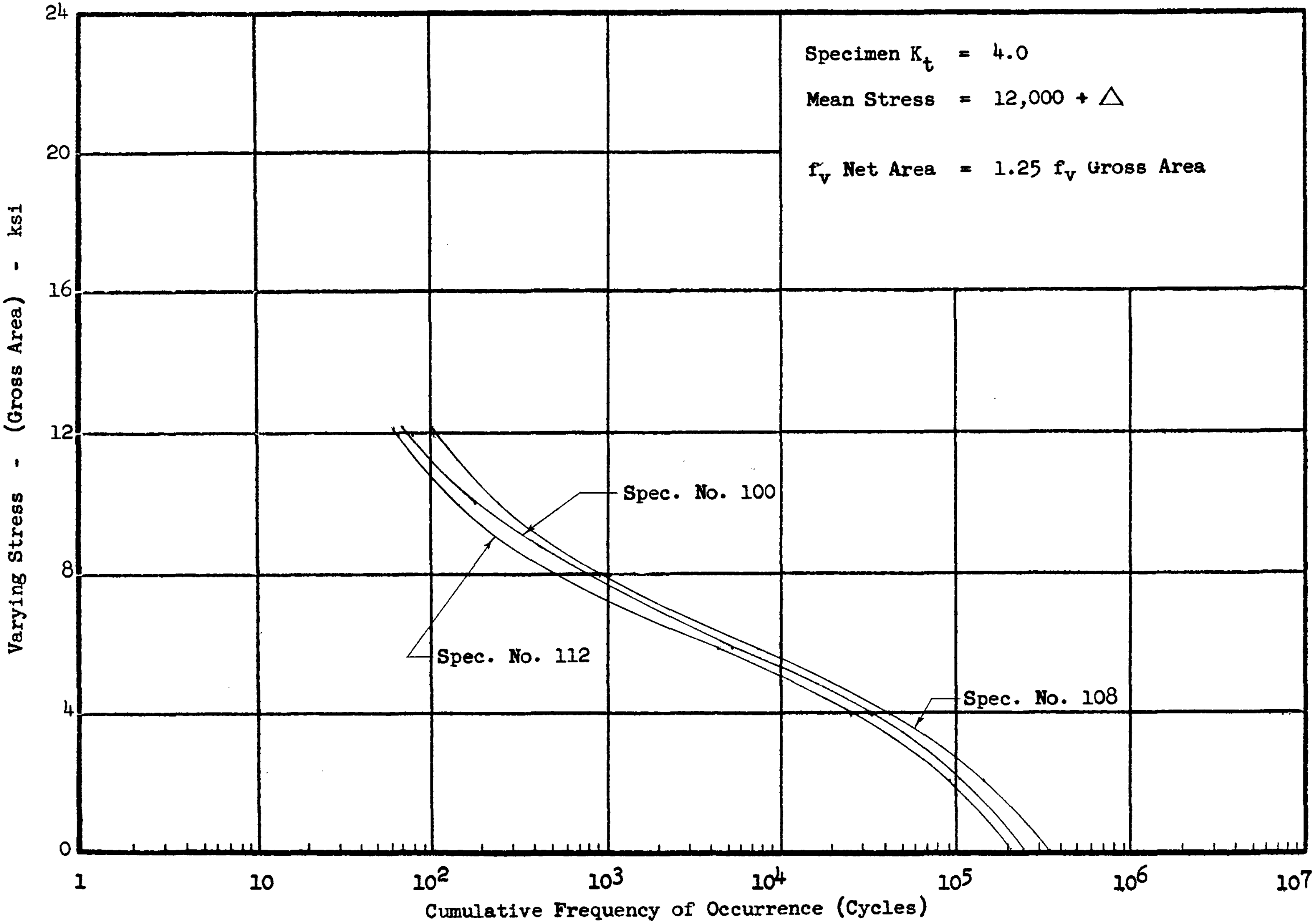


FIGURE 14 WING ROOT RANDOM LOADING TEST DATA WITH VARIABLE MEAN (MEAN CROSSING PEAK COUNT)

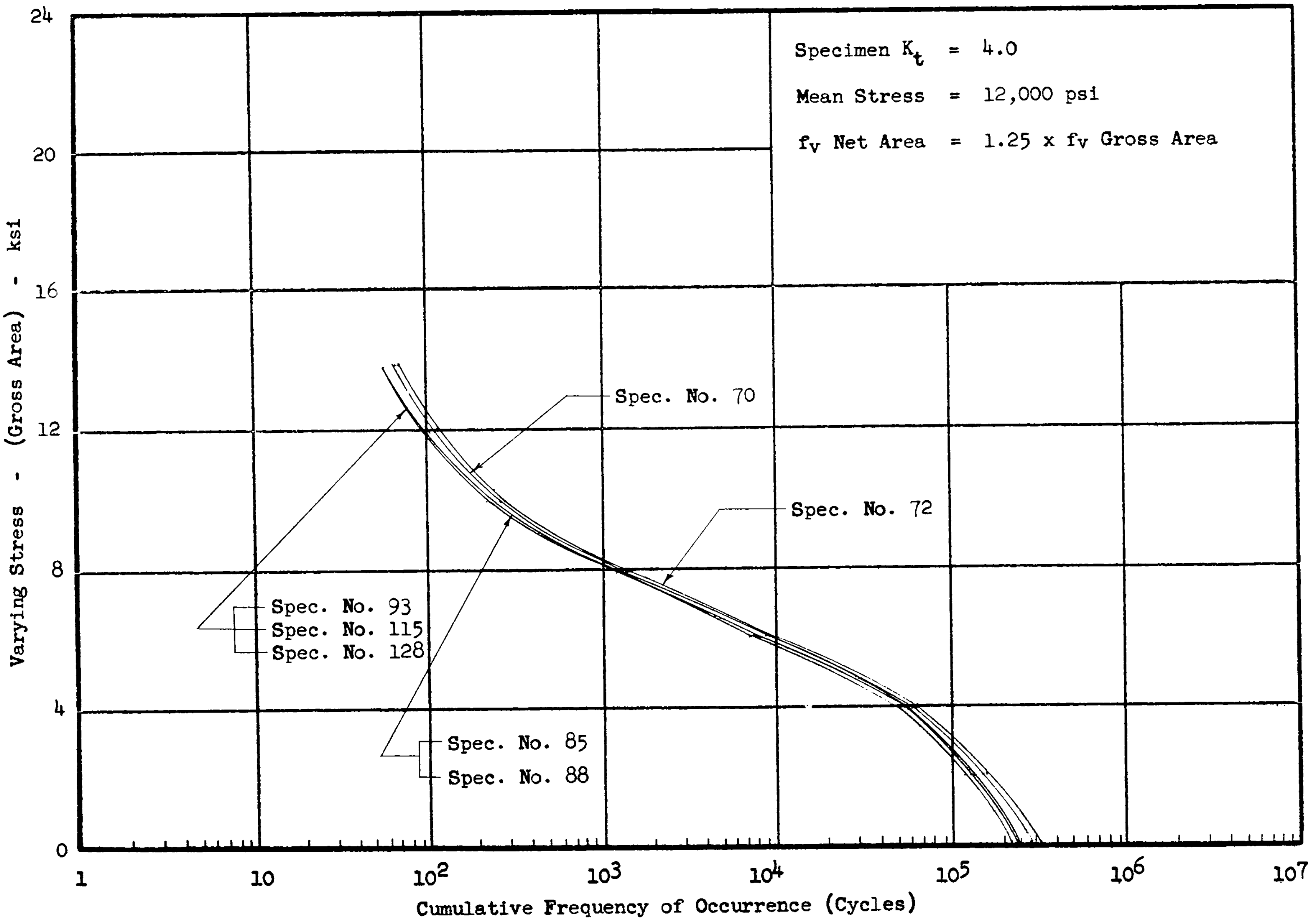


FIGURE 15 WING ROOT RANDOM LOADING TEST DATA (MEAN CROSSING PEAK COUNT)

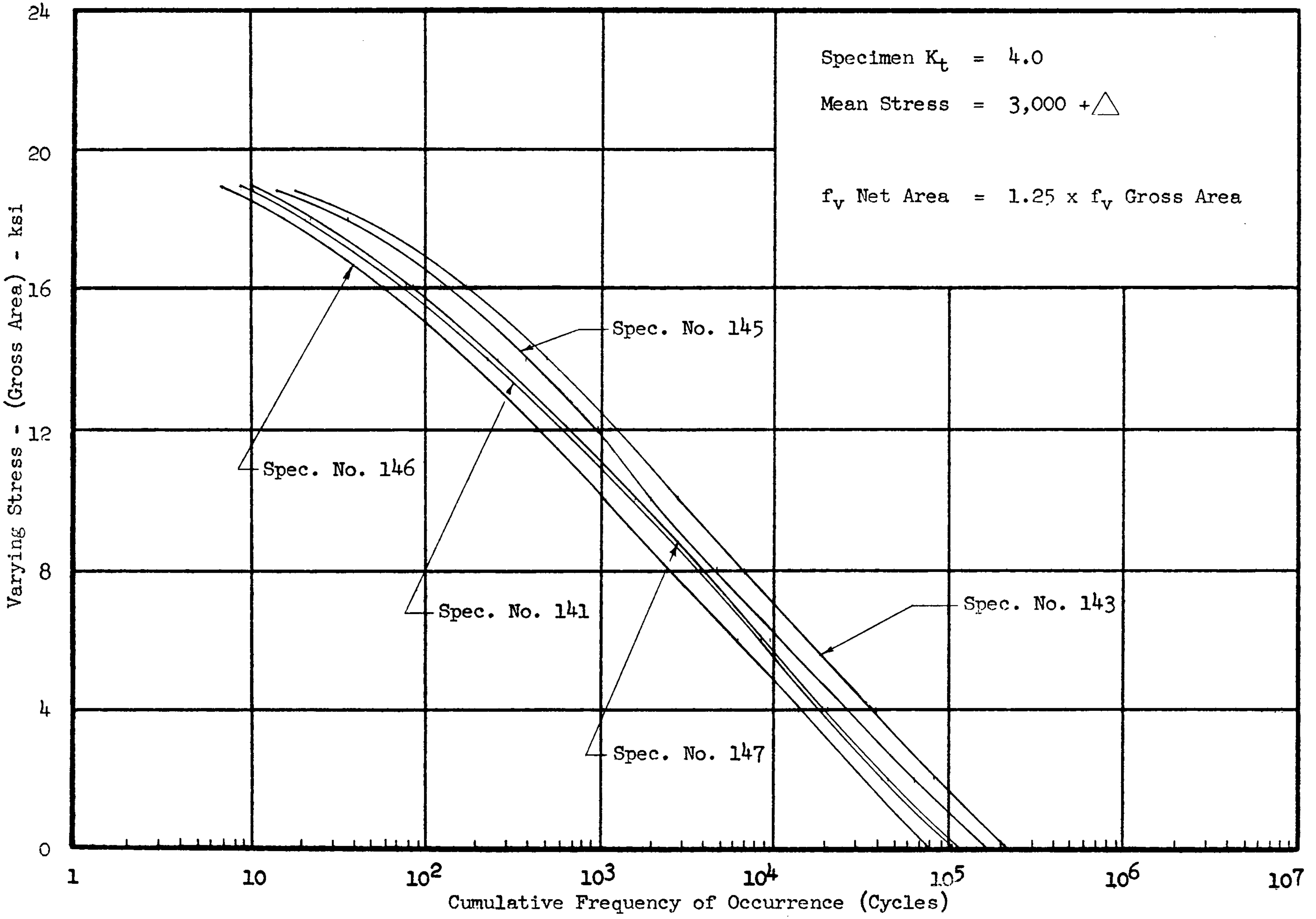


FIGURE 16 FIN ROOT RANDOM LOADING TEST DATA WITH VARIABLE MEAN (MEAN CROSSING PEAK COUNT)

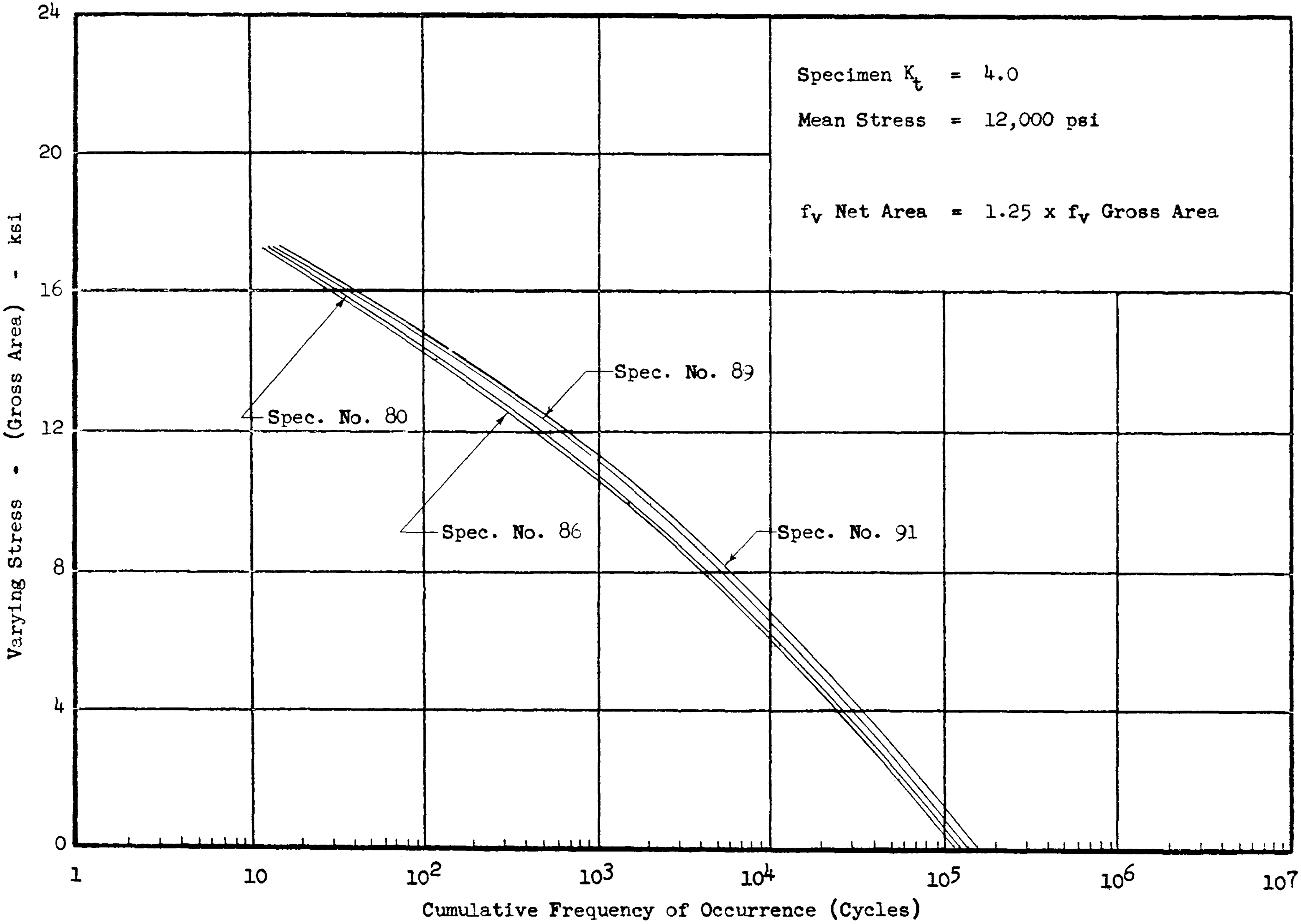


FIGURE 17 FIN ROOT RANDOM LOADING TEST DATA (MEAN CROSSING PEAK COUNT)

Ordered Loading Tape Preparation and Use

To resume the evaluation of trace reduction methods, comparisons of the methods based on fatigue tests are required. To obtain the data needed, an ordered, cyclic loading representation of the content of a random loading trace is first recorded on magnetic tape. This tape is used in tests to obtain specimen lives and these lives are compared with the lives obtained when the random loading trace is similarly used. This comparison can provide the most informative measure of the utility in fatigue work of the method used to deduce the ordered loading representation.

In this preliminary investigation it was considered desirable to minimize the effect on test comparisons of regularly encountered test variables. In particular, it was desirable to divorce the tests as much as possible from later tests in which principal variables are the size of the stress interval in the test loading spectrum and the size of the unit spectrum to be repetitively applied. To minimize the effect of stress interval, the ordered cyclic loading traces were generated so that the stress intervals in each unit spectrum were very small over substantially the full range of load magnitudes. A sketch of the loading pattern is shown on Figure 18 and a sample of the cyclic loading trace is presented on Figure 19. To minimize the effect of load sequence, the unit spectra recorded for repeated application were based on the unit length of random loading traces. Exploratory tests had indicated that a substantial number of repetitions of this unit (20-100) would be required to produce specimen failure.

To extend the scope of this phase of the investigation, random loading test lives were first obtained using the non-linearly amplified wing root random loading trace previously described. The results obtained are presented on Figure 20. Then, for each of the random loading test histories obtained using a constant mean stress of 12,000 psi, ordered loading representations were selected. In this work, the general similarity of the spectra deduced from the random loading traces by several methods suggested the use of mean crossing peak counts. Such counts were used in the preparation of test loading tapes and three groups of test data were obtained. These data are presented on Figures 21, 22, and 23. In addition, two test results were obtained using a loading tape containing the conventional, cyclic loading, representation of the simple range counts reported for the wing root bending trace. These results are presented on Figure 24 and the range count interpretations of the comparable random loading test lives are presented on Figure 25.

Comparisons of Ordered and Random Loading Test Lives

To evaluate the results obtained in these tests, comparisons of random loading and ordered loading test lives are presented on Figures 26, 27, 28, and 29.

Ideally, such comparisons are made between spectra of matching shapes. In preparing the programming tapes containing cyclic loadings, an exact match to a spectrum representing a random loading history was attempted but not always attained. Minor variations were considered to be acceptable since precise definition of the random trace content is not possible. In addition, modification of input signals by the test apparatus sometimes occurred. In early

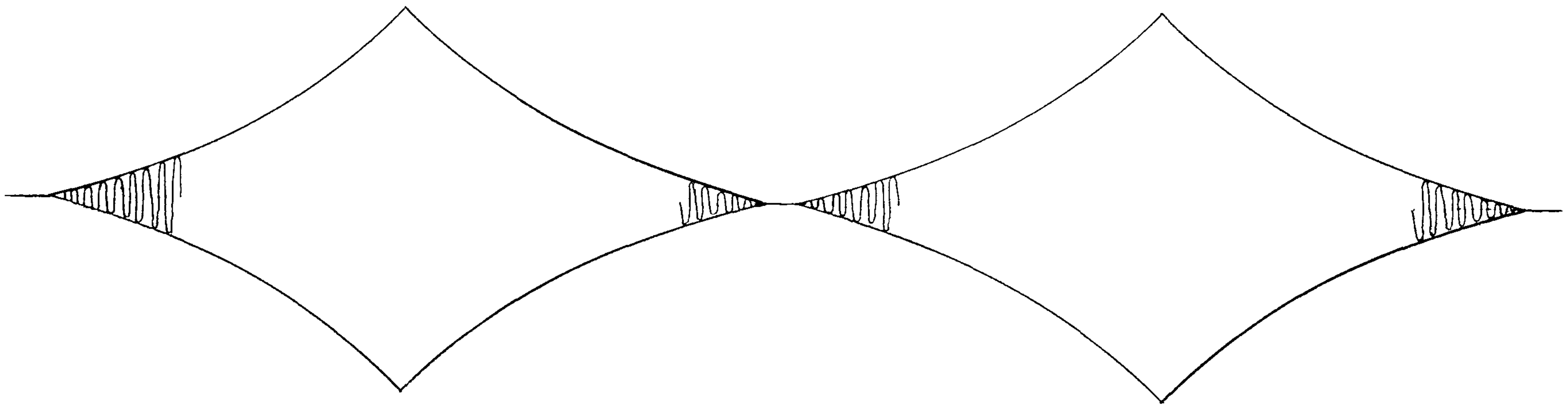


FIGURE 18 SIMPLE CYCLIC LOADING PATTERN USED IN PRELIMINARY INVESTIGATION

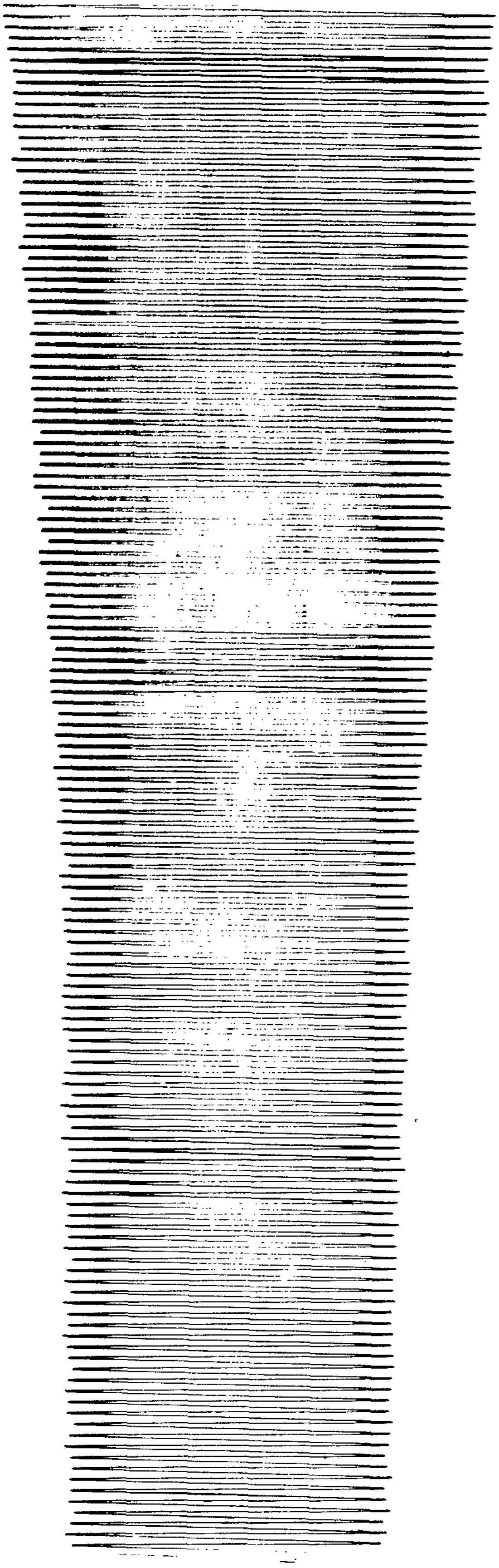


Figure 19 Sample of Ordered Loading Trace Used in Preliminary Investigation

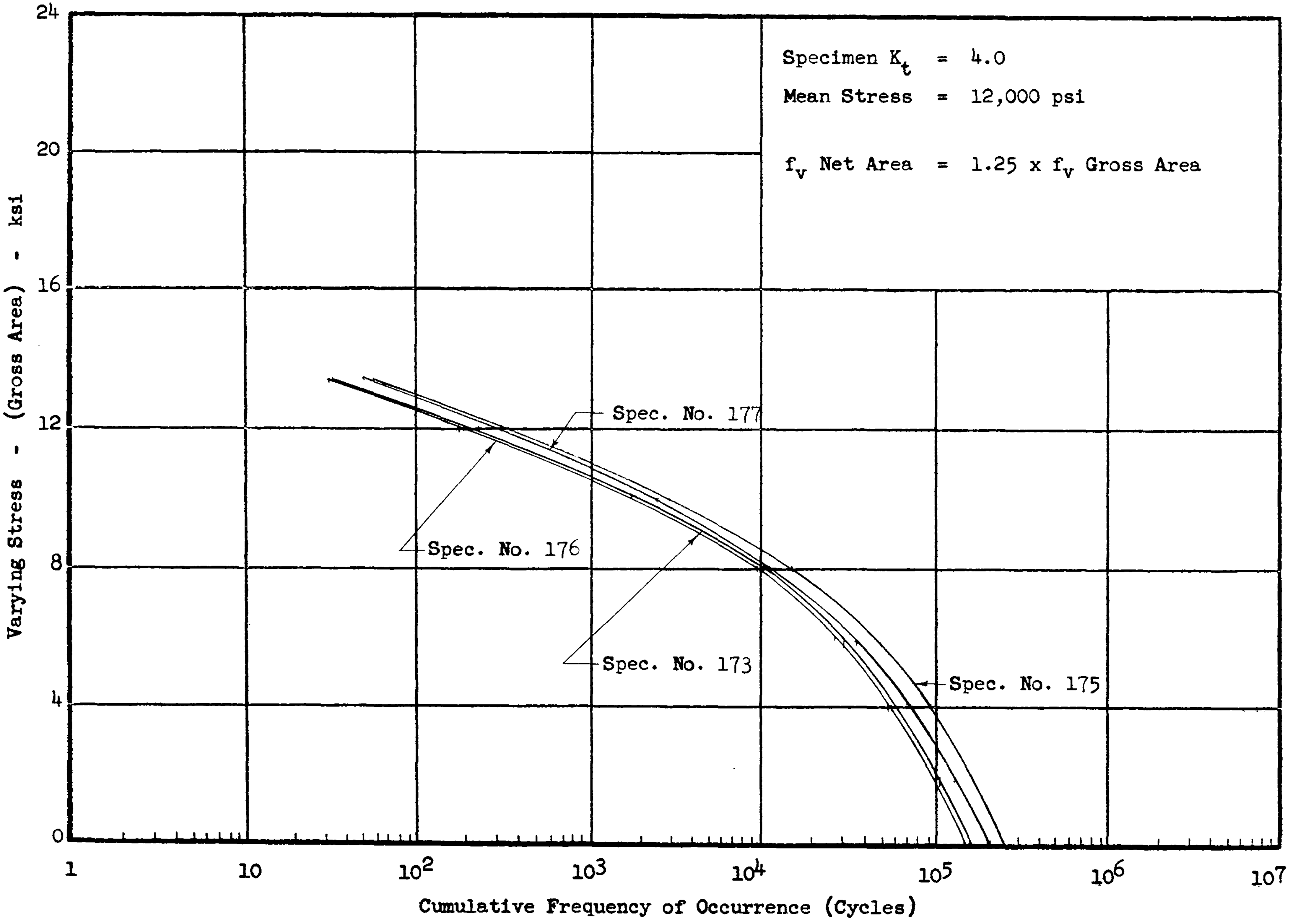


FIGURE 20 MODIFIED WING ROOT RANDOM LOADING TEST DATA (MEAN CROSSING PEAK COUNT)

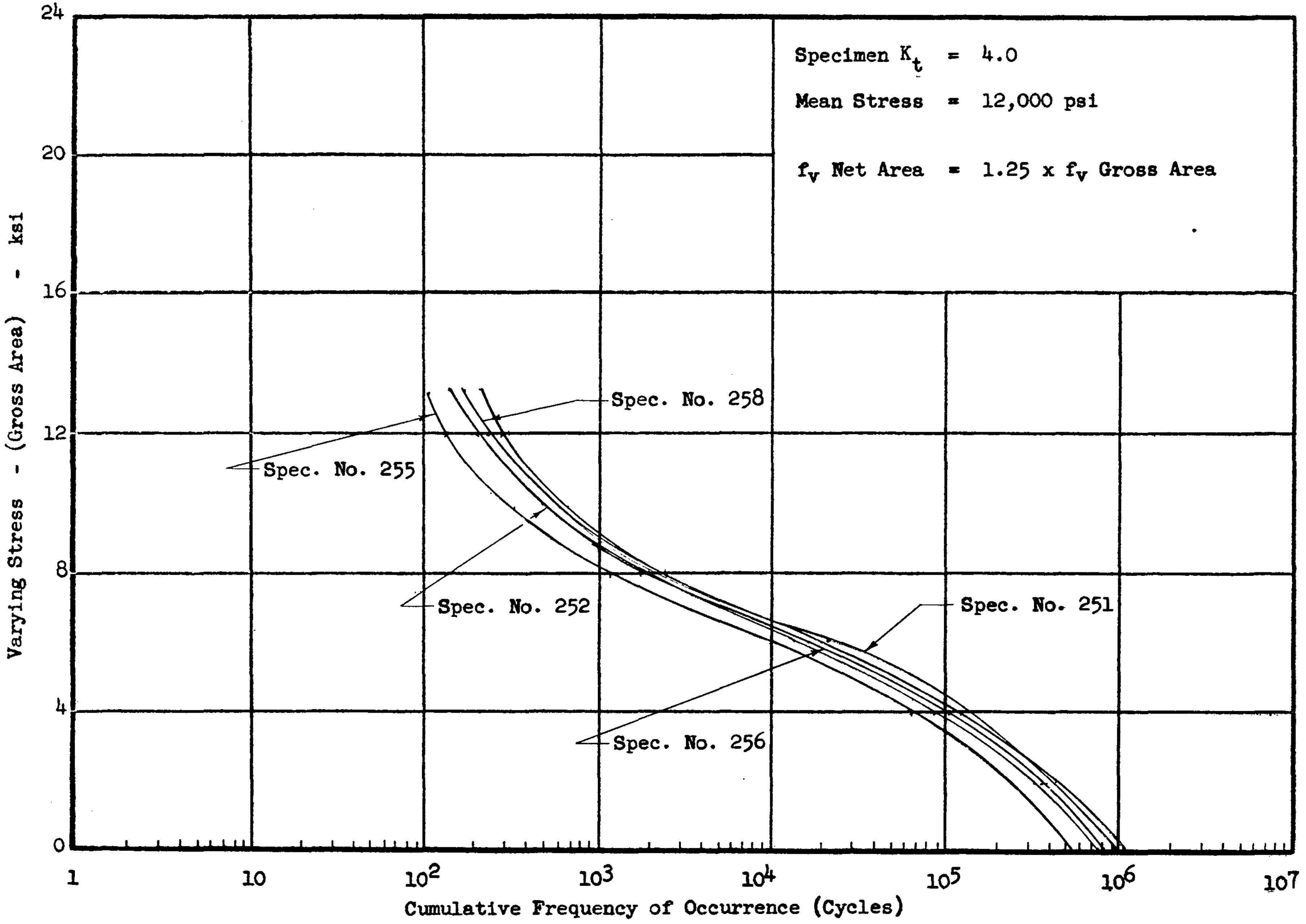


FIGURE 21 WING ROOT ORDERED LOADING TEST DATA (MEAN CROSSING PEAK COUNT)

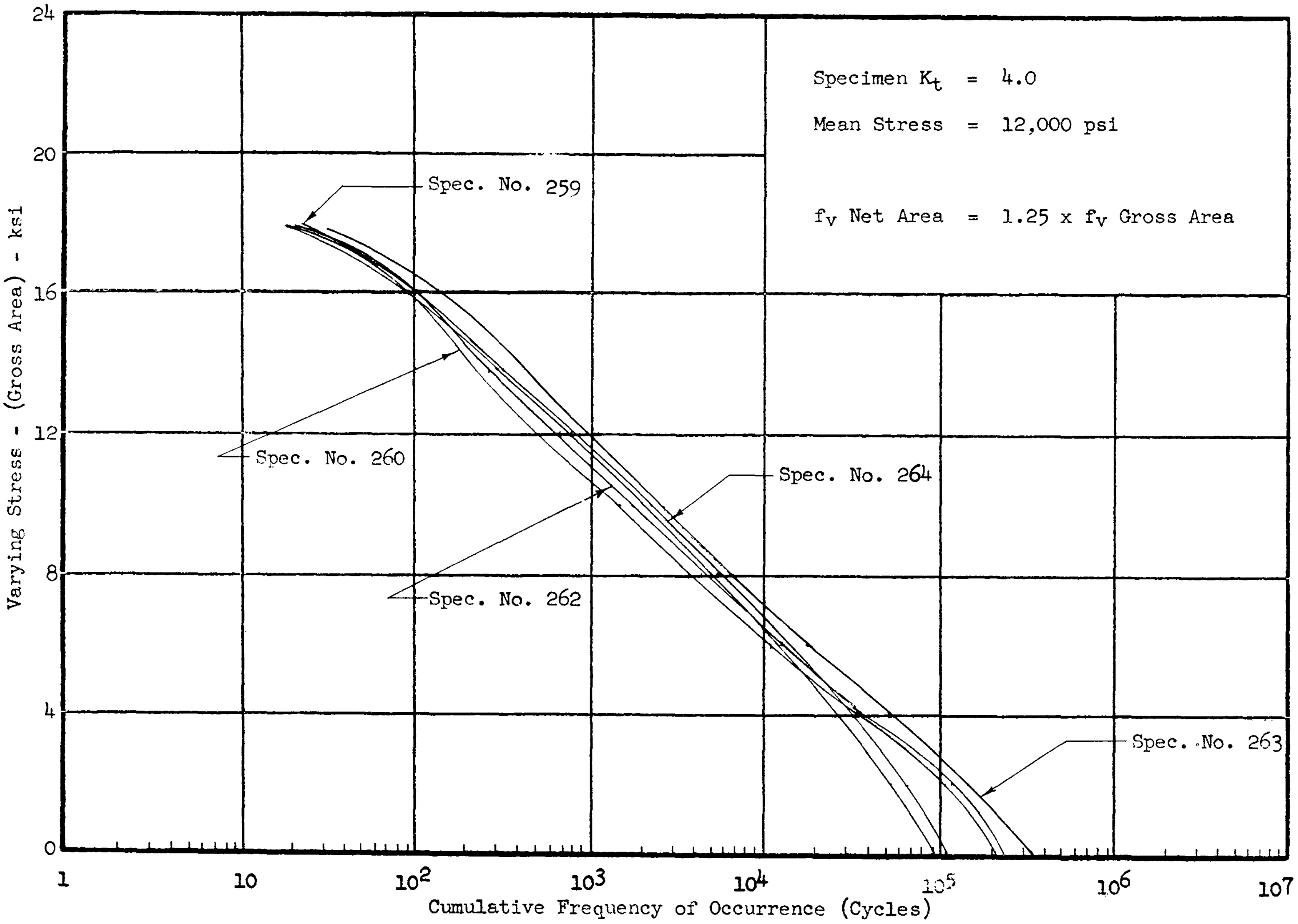


FIGURE 22 FIN ROOT ORDERED LOADING TEST DATA (MEAN CROSSING PEAK COUNT)

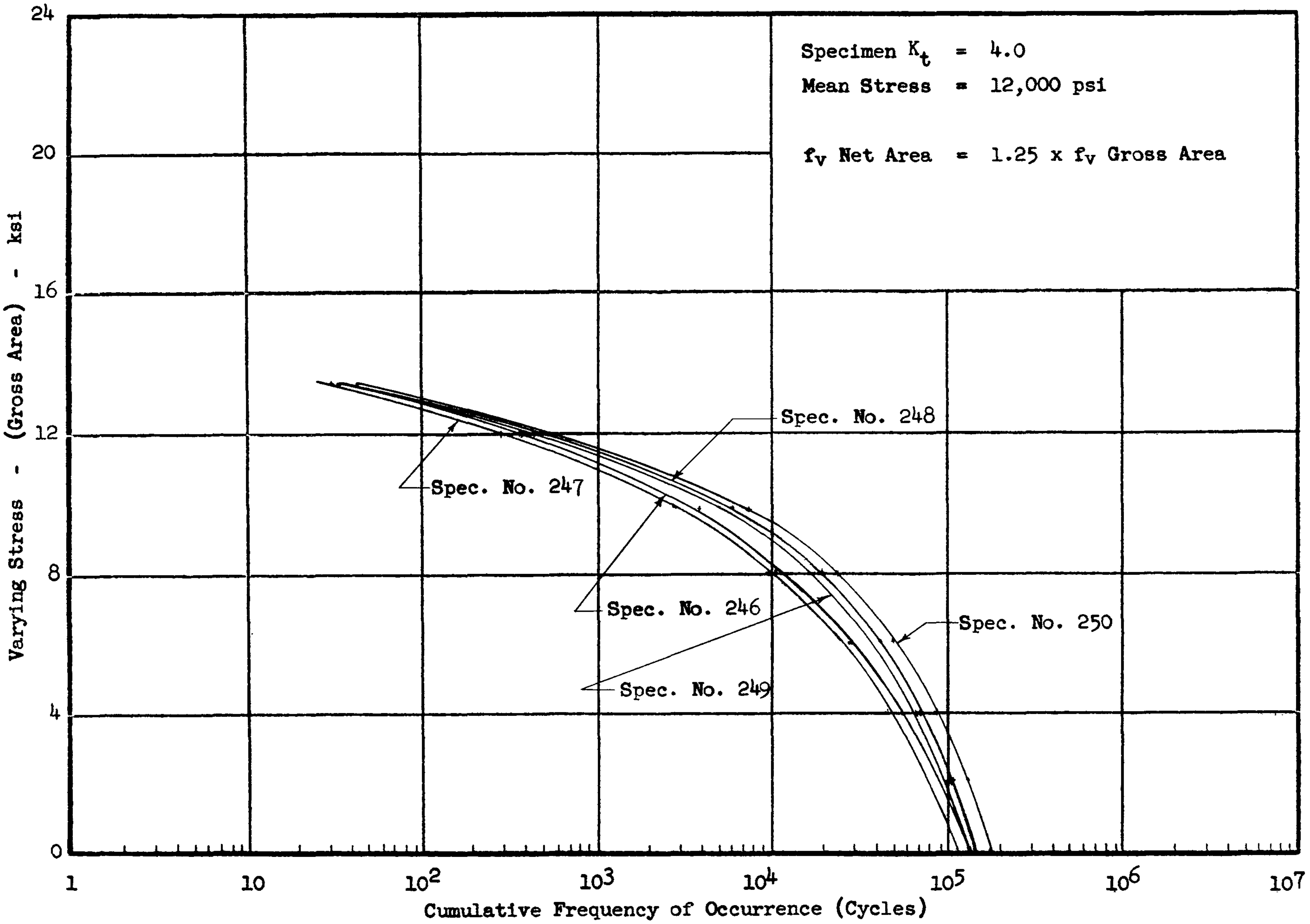


FIGURE 23 MODIFIED WING ROOT ORDERED LOADING TEST DATA (MEAN CROSSING PEAK COUNT)

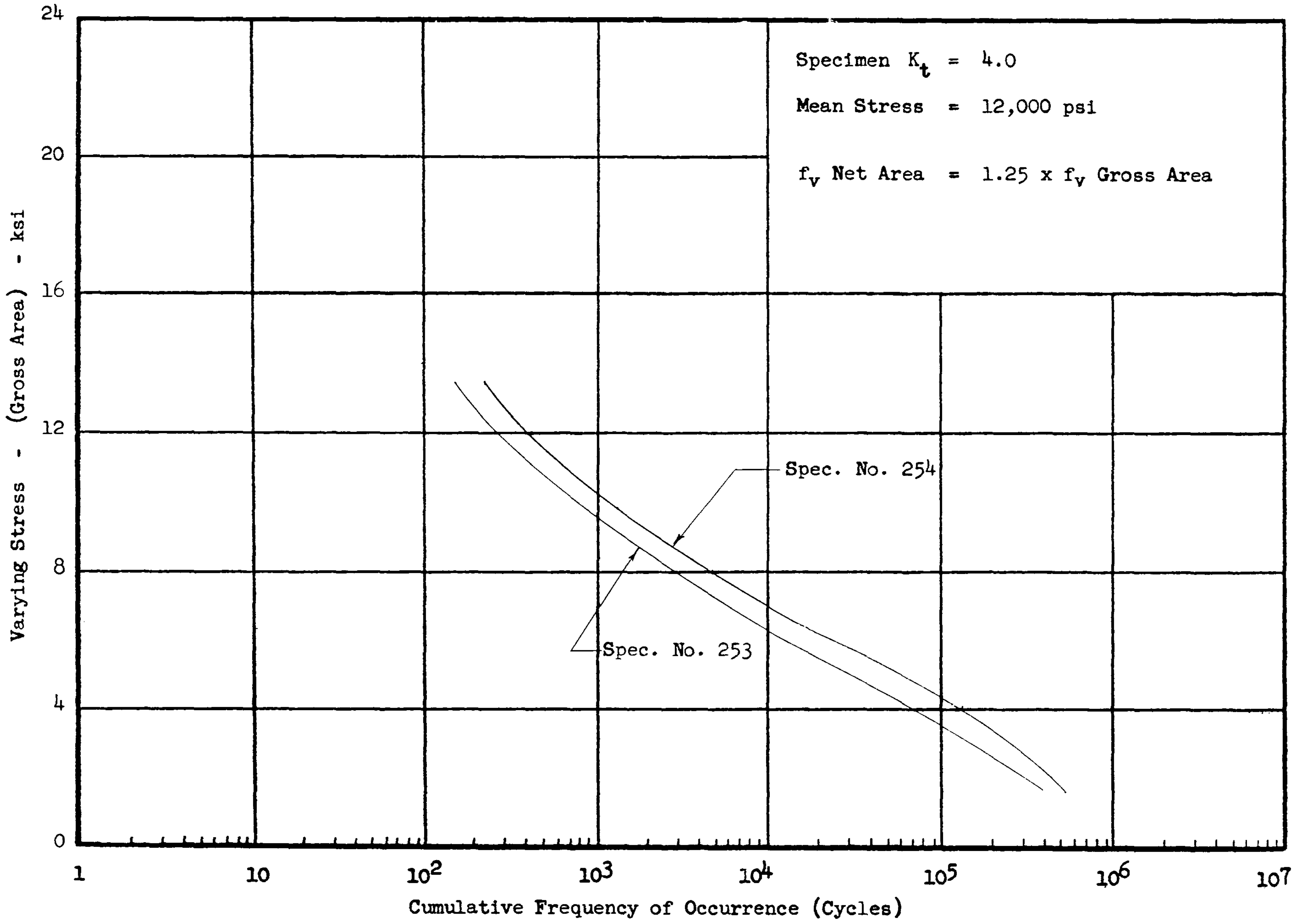


FIGURE 24 - WING ROOT ORDERED LOADING TEST DATA (RANGE COUNT)

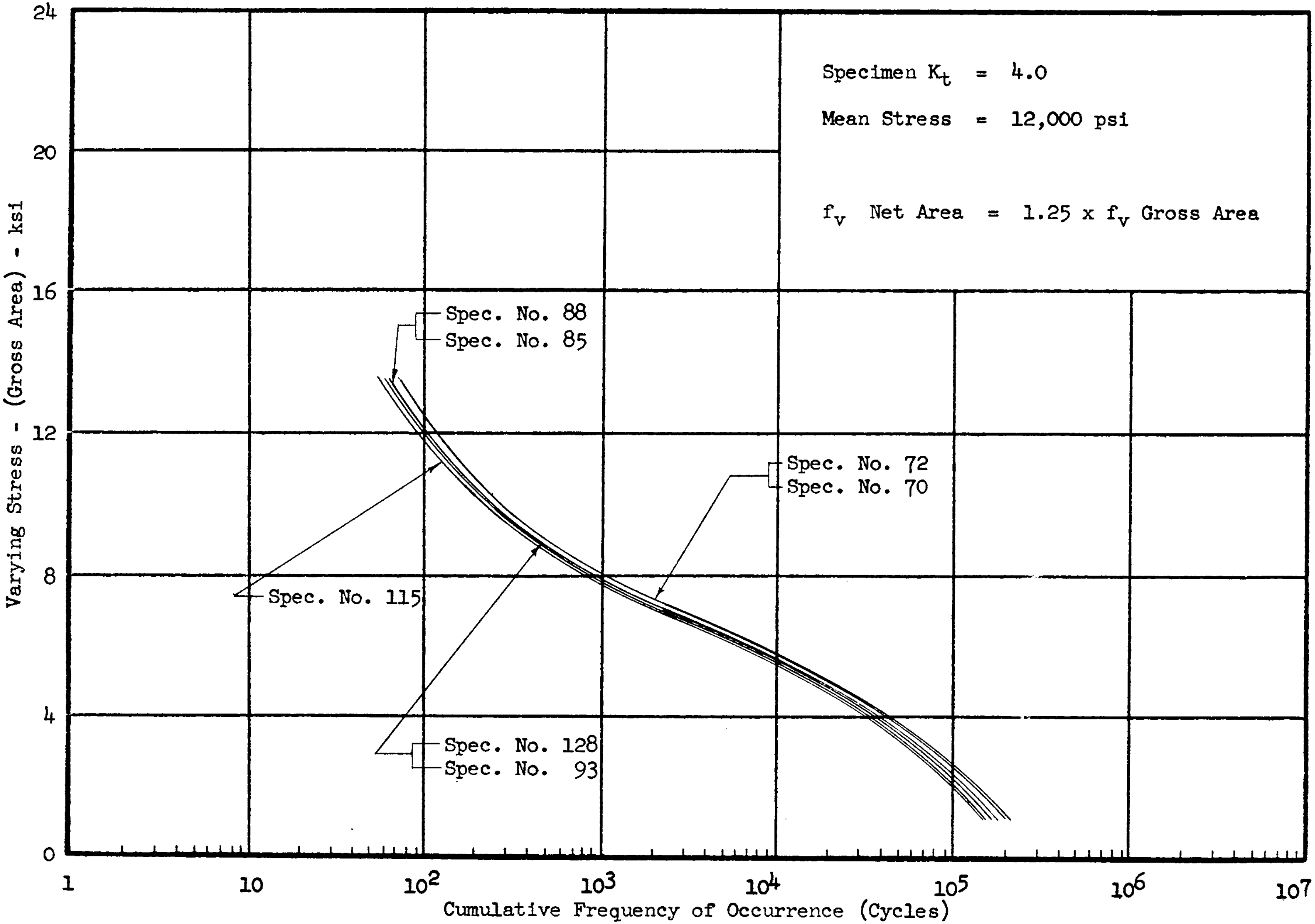


FIGURE 25 WING ROOT RANDOM LOADING TEST DATA (RANGE COUNT)

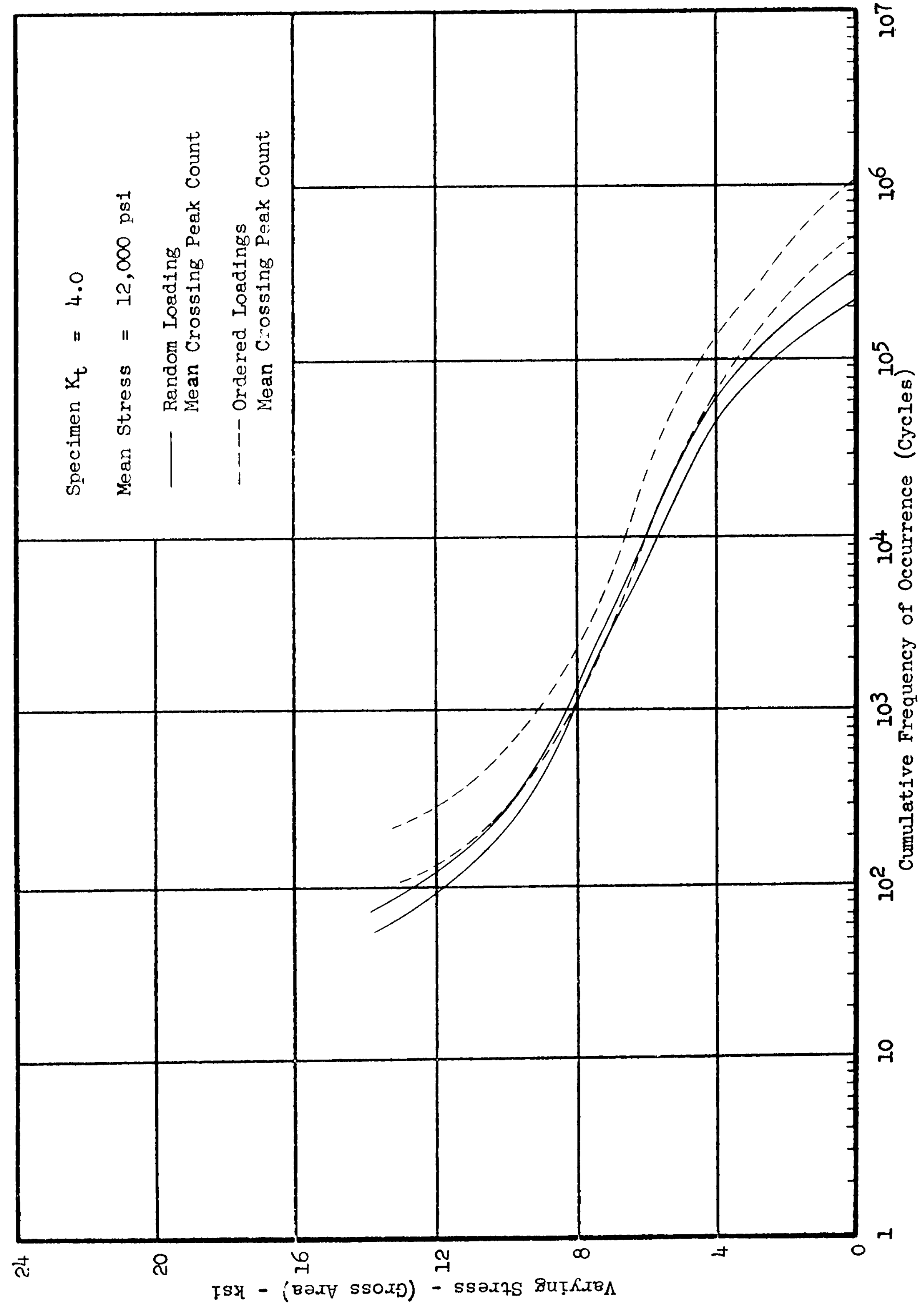


FIGURE 26 COMPARATIVE ENVELOPES OF WING ROOT RANDOM AND ORDERED LOADING TEST DATA

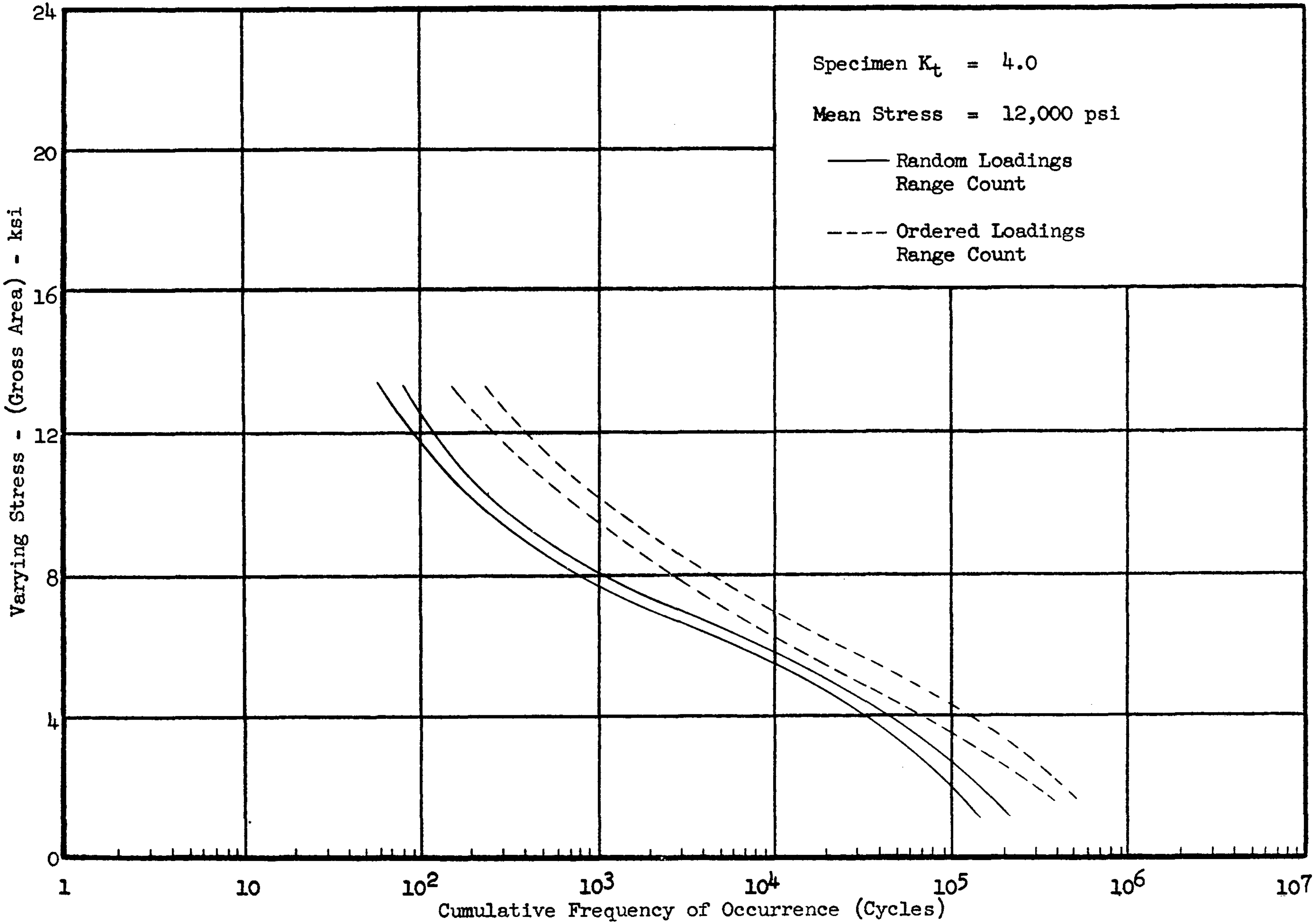


FIGURE 27 COMPARATIVE ENVELOPES OF WING ROOT RANDOM AND ORDERED LOADING TEST DATA

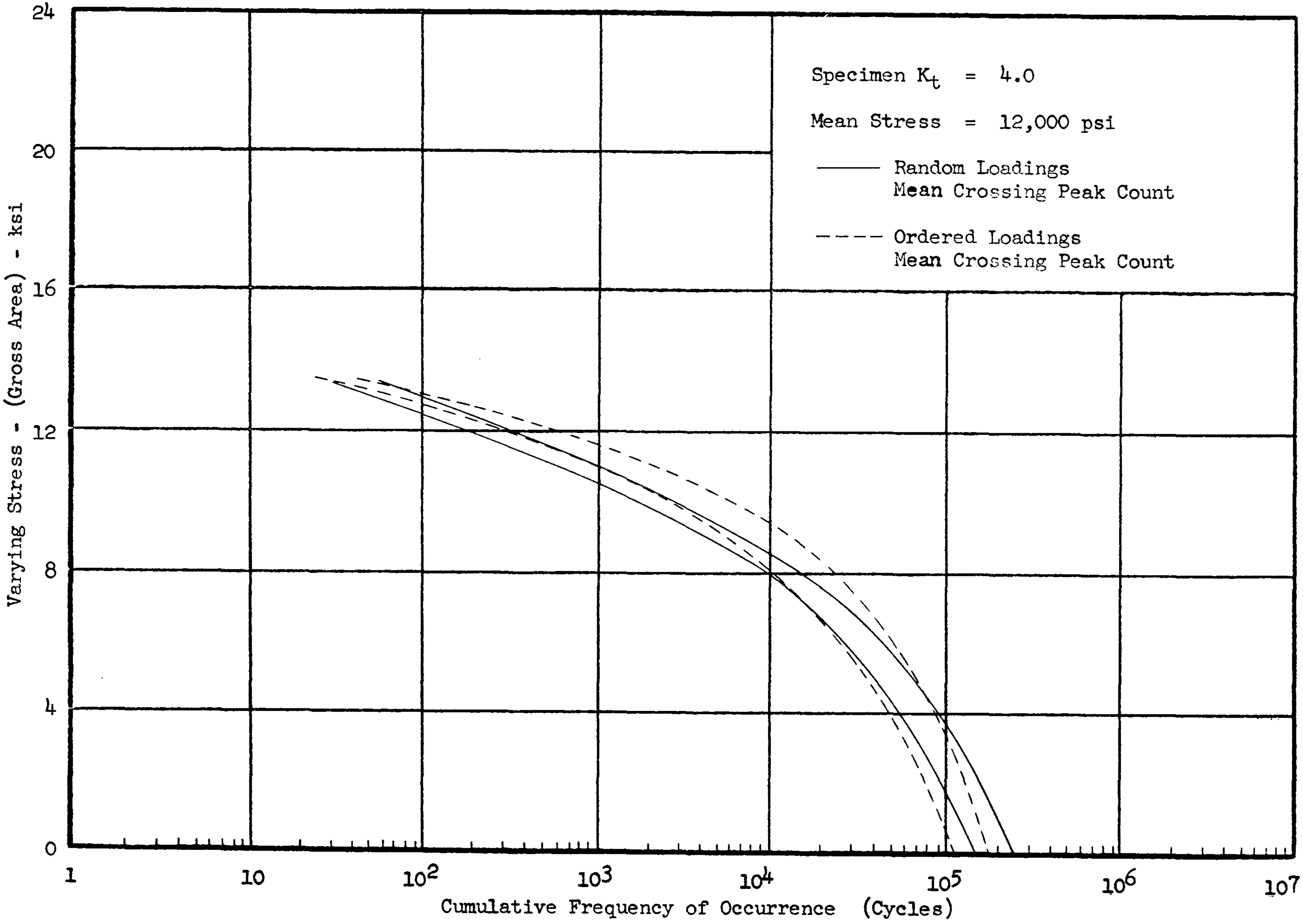


FIGURE 28 COMPARATIVE ENVELOPES OF MODIFIED WING ROOT RANDOM AND ORDERED LOADING TEST DATA

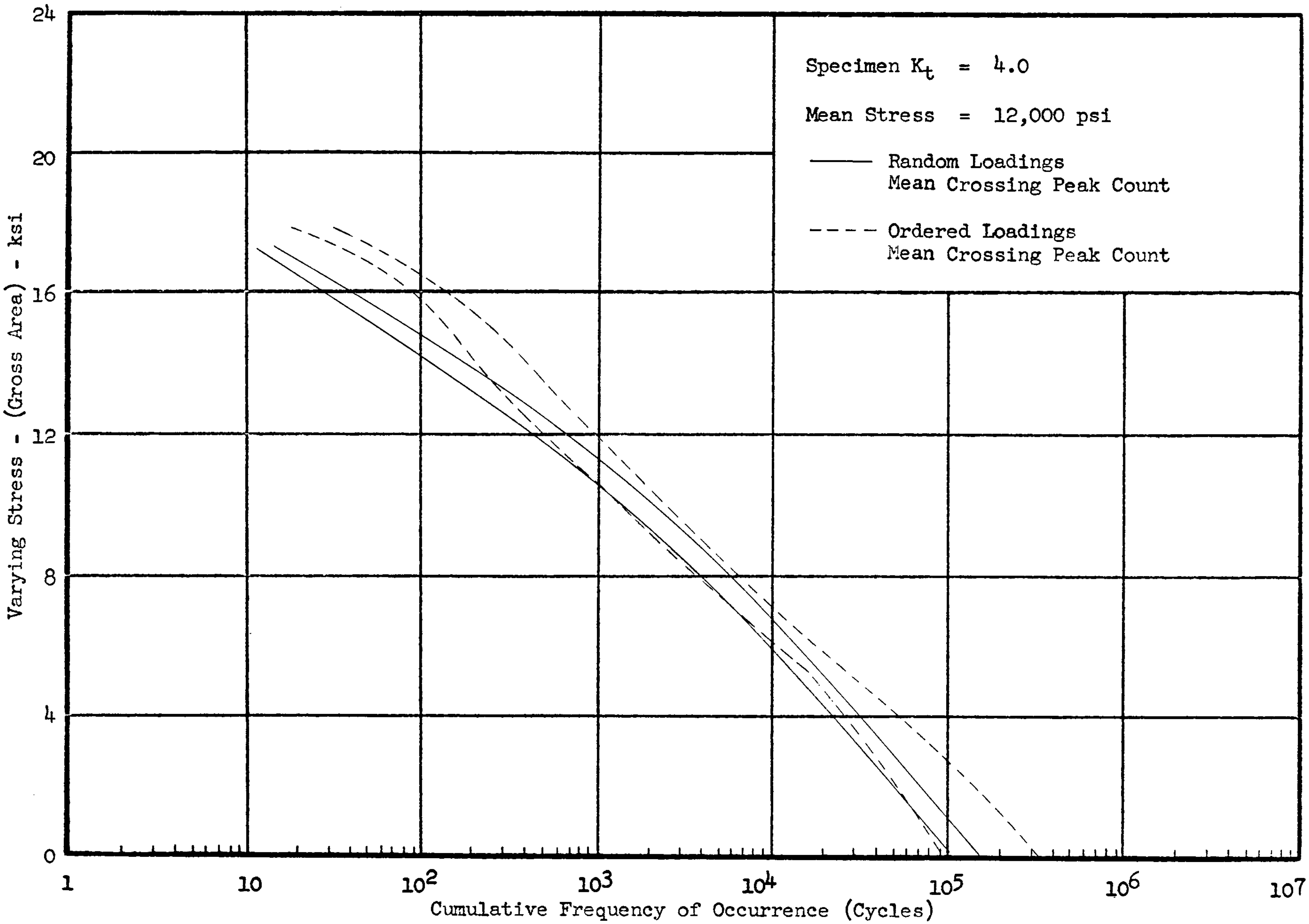


FIGURE 29 COMPARATIVE ENVELOPES OF FIN ROOT RANDOM AND ORDERED LOADING TEST DATA

work, such modifications, identified from reductions of test history monitor tapes, led to repeated preparation of programming tapes and multiple sets of tests. However, continuance of this effort to obtain better matching of spectral shapes was not considered to be justified. The comparative graphs, which are based on reductions of monitor tapes, are believed to provide definitions of test histories which are adequate for the comparisons being made.

Examination of these graphs led to the conclusion that the mean crossing peak count representation of random loading traces should be used in later phases of the investigation. The comparison of random trace representations previously presented as Figures 6 and 7 does not suggest that more consistent test comparisons would be obtained by the choice of a different method of trace reduction.

With the selection of a method of representing the load content on a random loading trace and the development of adequate test techniques, the preliminary investigation was considered to be complete. The scope of the work was then broadened to cover a wider range of the loading conditions and of the test variables which must be considered in fatigue investigations.

SECTION III

SCOPE OF MAIN INVESTIGATION

The complexity of loading histories of flight vehicles has led to several general data classifications. The oscillatory type of loadings developed during flight through turbulent air and those produced by minor course deviations and corrections are ordinarily reported as gust loadings. The loadings associated with significant, simultaneously occurring changes in altitude and/or speed are sometimes segregated and reported as maneuver loadings. In the case of fighter-trainer type military aircraft, all recorded flight loadings are often interpreted as maneuver loadings. The loadings recorded during and immediately following landing impact are identified as landing loads but are seldom reported in detail. The load-time histories are complex and are usually associated with rapid transitions in mean or steady state values. Finally, the loadings recorded during operation on the ground are usually grouped and reported as taxi loads. For some components, this list must be amplified by time histories of pressurization loadings, buffet loadings and temperature changes. In general, the loadings in each of these classifications reflect wide variations of vehicle weight and speed and, in the case of flight loadings, of altitude. The total history for even one flight is therefore complex with changes of mean loading which are too large to ignore. However, when data, classified as described above, are obtained for substantial periods of a particular type of service operation, a uniformity of load frequency distributions often appears. This uniformity suggests that useful results can be obtained in tests which employ integrations of available data for all load sources.

The proper use of these data has, however, been uncertain. As described in the preceding section of this report, there has been reasonable doubt as to the adequacy of the counting methods generally used to reduce service loading histories to spectral form. In addition, when a continuous spectrum of a particular type or classification of loadings has been obtained, there is uncertainty about the degree to which it can be simplified to define test loadings. Finally, many tests using very simple loading patterns have demonstrated non-linearity of load effects. This suggests that the simplification of tests cannot be based on the assumption that the effects of several classifications of loadings are linearly accumulative.

To explore these very practical aspects of the fatigue problem, comparisons of random loading and ordered loading test lives were obtained for gust loadings, for military maneuver loadings, for ground loadings and for composites of these loadings representing total service histories. Each of these test phases is described in detail in the following sections.

SECTION IV

COMPARISON OF RANDOM AND ORDERED GUST LOADING TESTS

Generation of Master Random Loading Tapes

To carry out this phase of the investigation, a random loading tape was required which would contain an adequate representation of the gust loading histories developed in long periods of service. The available records indicate that such histories can be described by a characteristic shape of spectrum, that they demonstrate a relatively slow increase of peak loading magnitudes and that they justify the assumption of symmetric positive and negative load distributions. These characteristics could not be expected in the 96 minutes of B-47 record which was employed in the preliminary investigation. However, these records did contain the variety of trace shapes and the continuity of excursion magnitude distributions which were required in the investigation. Modification of one of the traces was, therefore, necessary to obtain the type of record which was sought.

From the traces used in the preliminary investigation, the trace representing dynamic wing root loadings on the B-47 aircraft was selected for modification. This choice was suggested by the general interest in airframe fatigue work in the loadings for this region of wings.

The first step in the series of required modifications was the application of a non-linear amplification to the basic trace. The amplification system was tailored so that it had maximum effect on the largest trace excursion, a minor effect on slightly smaller excursions and a negligible effect on the remaining excursions. Using this approach the magnitudes of the largest positive and negative excursions were made equal while retaining the local trace shapes. The length of tape so produced was identified as tape A_1. The mean crossing peak counts obtained for this tape are shown on Figure 30. On this plot the values of voltage increments defined by the trace signals have been converted to values of incremental stress considered to be reasonably representative for wing root regions of large aircraft. Then, having a basic tape with adequate symmetry of excursion magnitudes, a second tape was produced on which all magnitudes were reduced to 75 percent of those on tape A_1. This tape, identified as A_2, was required for extension of the spectrum in the region of the lower excursion magnitudes. When the loading history on this tape is added to the history on tape A_1, a more representative frequency of occurrence distribution is obtained. This is illustrated on Figure 31 which shows the peak count distributions for tapes A_1 and A_2 and also the distribution when the two are used in sequence.

To provide for the relatively slow growth of peak excursions, additional tapes were generated. A non-linear amplification, tailored as described above so that its effect was restricted essentially to the maximum excursions, was applied to tape A_1. This operation produced a trace having peak magnitudes approximately 15 percent greater than those on tape A_1. This tape was identified as tape B_1. Similarly tapes C_1, D_1, and E_1, were produced having peak magnitudes approximately 20, 30, and 40 percent greater respectively than those on tape A_1. Finally,

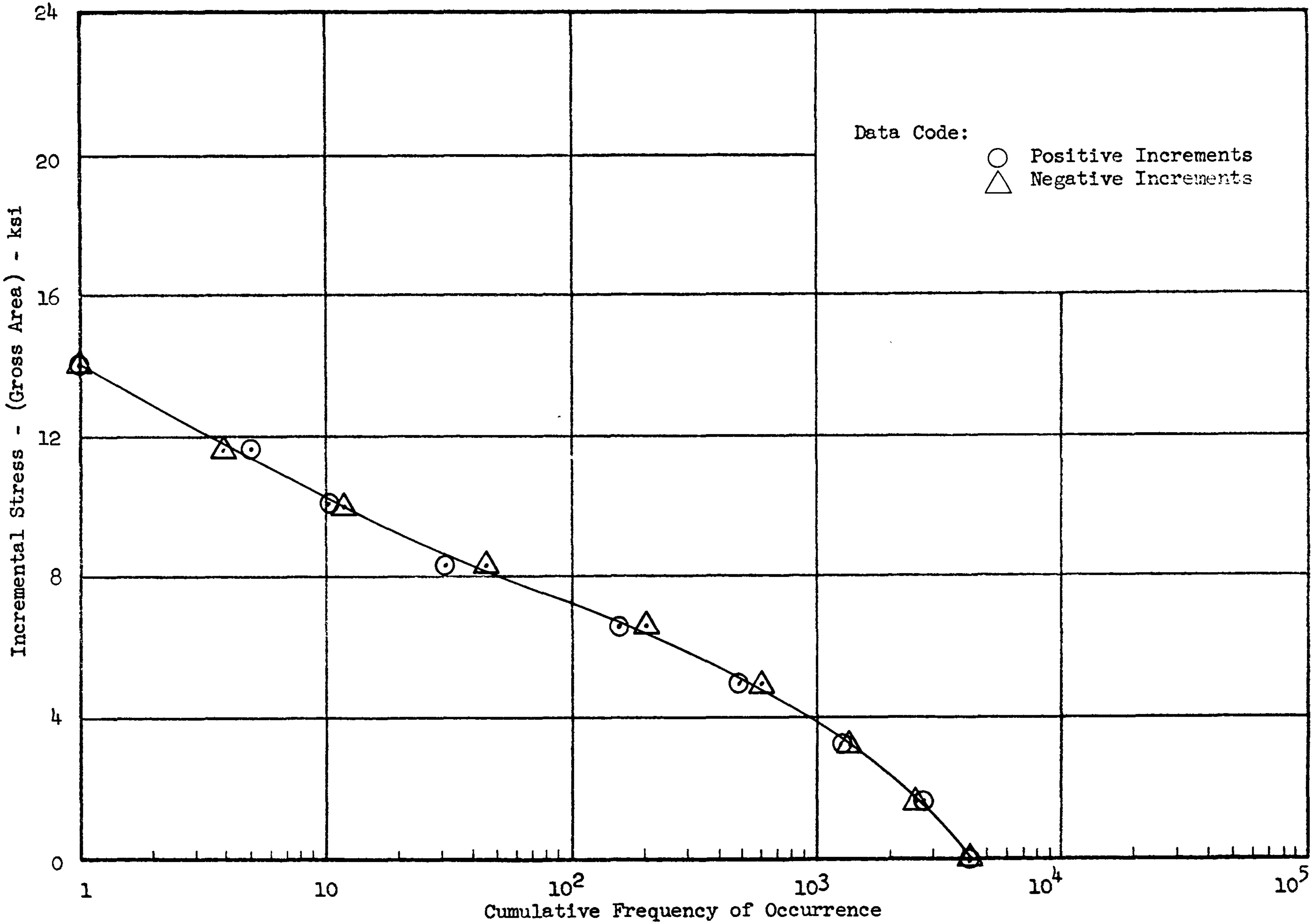


FIGURE 30 MEAN CROSSING PEAK COUNTS OF TAPE A_1

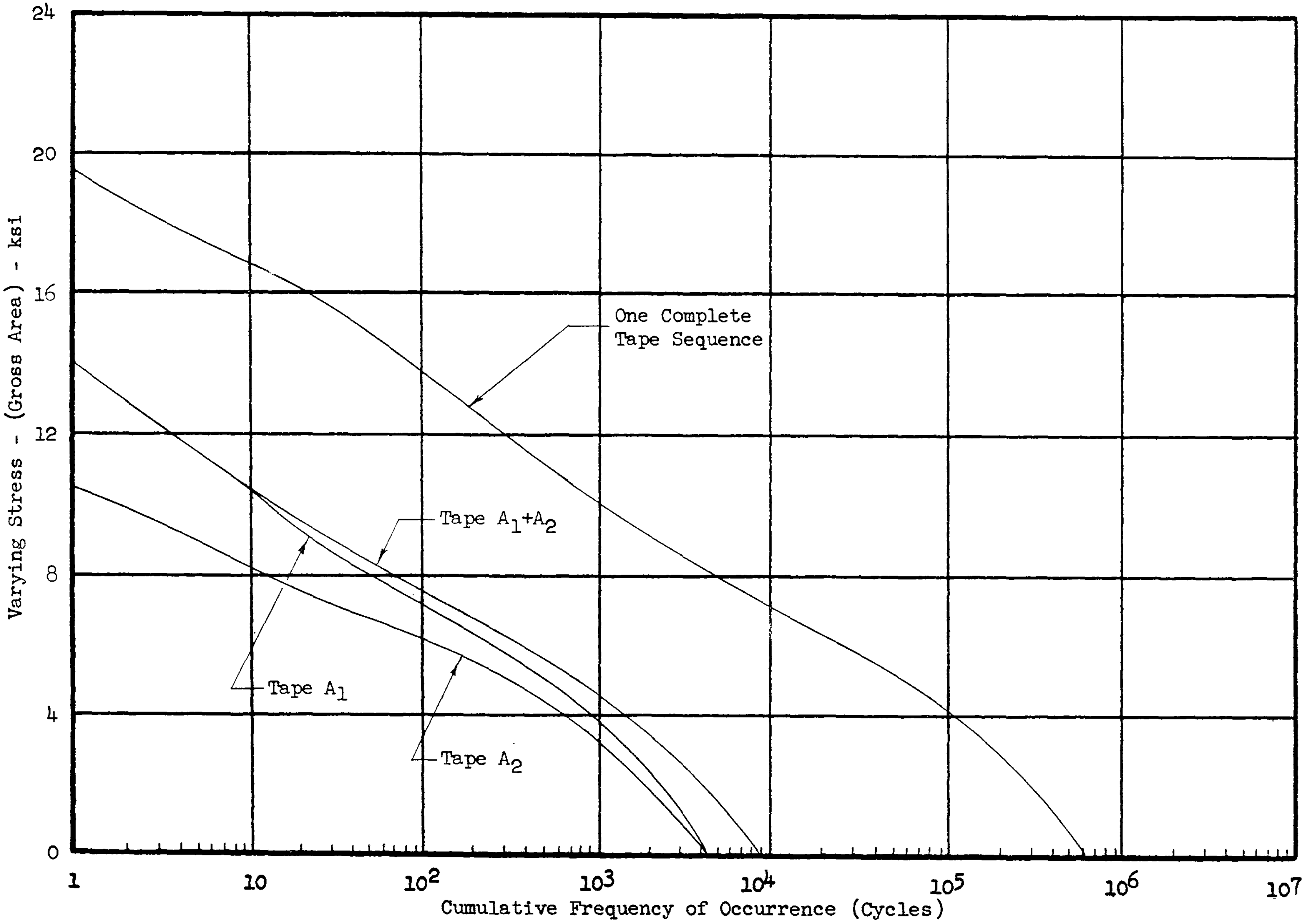


FIGURE 31 ILLUSTRATION OF TAPE COMPOSITION - MASTER GUST LOADING TAPE

tapes B_2, C_2, D_2 and E_2 were produced. The trace on each of these tapes was a copy of the trace on the similarly identified tape but with all excursion magnitudes reduced to 75 percent of those on the trace being copied.

Using multiple copies of these component tapes, four reels of tape identified as master tapes 49, 50, 51 and 52 were assembled. The sequence of component tapes making up each reel is indicated below. The running time for each reel is approximately one hour.

Tape 52

Component tapes	A_1	A_2	A_1	B_2	B_1	A_1	A_2	A_2	B_1	B_2
Relative Maximum Load	1.00	.75	1.00	.86	1.15	1.00	.75	.75	1.15	.86

Tape 49

Component tapes	A_1	A_2	A_1	A_2	C_1	A_2	A_1	A_2	A_1	C_2
Relative Maximum Load	1.00	.75	1.00	.75	1.20	.75	1.00	.75	1.00	.90

Tape 50

Component tapes	A_1	A_2	A_1	A_2	D_1	A_2	A_1	A_2	A_1	D_2
Relative Maximum Load	1.00	.75	1.00	.75	1.30	.75	1.00	.75	1.00	.975

Tape 51

Component tapes	A_1	A_2	A_1	A_2	E_1	A_2	A_1	A_2	A_1	E_2
Relative Maximum Load	1.00	.75	1.00	.75	1.40	.75	1.00	.75	1.00	1.05

The peak count interpretations of the loading history on each master tape are presented in Table 1. The stress values listed were obtained using the same voltage to stress conversion factor as that employed in the representation of tapes A_1 and A_2.

In the use of the master tapes to produce test histories containing increasing peak load magnitudes, it was considered desirable to apply each larger peak at approximately the mid point of the anticipated period for its occurrence. These periods, which are usually expressed in hours in practical problems, were read from the spectrum for tapes A_1 plus A_2 amplified to represent a longer service time.

TABLE 1

CUMULATIVE FREQUENCY OF OCCURRENCE OF CYCLIC LOADINGS MEAN CROSSING PEAK COUNTS OF RANDOM LOADING TRACES

VARYING STRESS (KSI)	TAPE NO. 52	TAPE NO. 49	TAPE NO. 50	TAPE NO. 51	ONE COMPLETE TEST SEQUENCE (14 reels)
0	43500	43500	43500	43500	610000
1.0	31200	31200	31000	31400	440000
2.0	21600	21550	21450	21860	290000
3.0	13500	13500	13400	13750	170000
4.0	7850	7800	7650	7900	100000
5.0	4130	4120	4070	4220	54000
6.0	1945	1870	1850	1920	27000
7.0	825	775	770	790	12000
8.0	355	322	322	328	5000
9.0	156	144	143	144	2100
10.0	77	75	76	77	1000
11.0	38	37	38	39	510
12.0	21	20	21	21	270
13.0	12	12	13	13	140
14.0	7	7	8	8	72
15.0	3	2	3	3	38
16.0	2	1	2	2	18
17.0			2	2	9
18.0			1	1	4
19.0				1	1
MAXIMUM VARYING STRESS (PSI)	16200	16800	18300	19500	19500

The sequence in which the master tapes were applied in test work is shown below.

Test Sequence (in hours)	Master Tape Number
1	52
2	49
3	52
4	52
5	50
6	49
7	49
8	52
9	50
10	52
11	52
12	52
13	49
14	51

Note that, using this sequence, 14 reels (approximately 14 hours) are required for the application of the maximum excursion in a random loading test. In tests of longer duration, the sequence is simply repeated so that a truncation of the loading spectrum is introduced.

The peak count spectrum for a 14 hour random loading test is also shown on Figure 31 to demonstrate the end result of the trace modifications and couplings which have been described. To illustrate the general character of the record, a sample trace is presented on Figure 32.

The general shape of the upper and mid range portions of the 14 hour spectrum presented on Figure 31 provide a reasonable representation of the gust loading spectral shapes often produced for tests of the wing root regions of transport aircraft. Such spectra represent integrations of the effects of the wide range of weights, speeds and altitudes associated with transport operations. As such, the spectrum is considered to be suitable for use in this investigation. However, in the region of minimum loadings, the spectrum is effectively truncated. The limitation on the number of lower loadings is not believed to be significant in tests of small, one-piece specimens in which fretting in the test region is not possible. In tests of complex specimens in which fretting may play a significant role in defining fatigue crack locations and test times, an amplification of the number of cycles of minimum magnitudes might be required to adequately simulate the effect of service loading histories.

Random Loading Test Data

Having generated a set of master random loading tapes, they may be put to multiple use. For example, they may be used to represent service loading histories at different points within a structure. For any one history of external loadings on a particular vehicle, the appropriate mean stresses

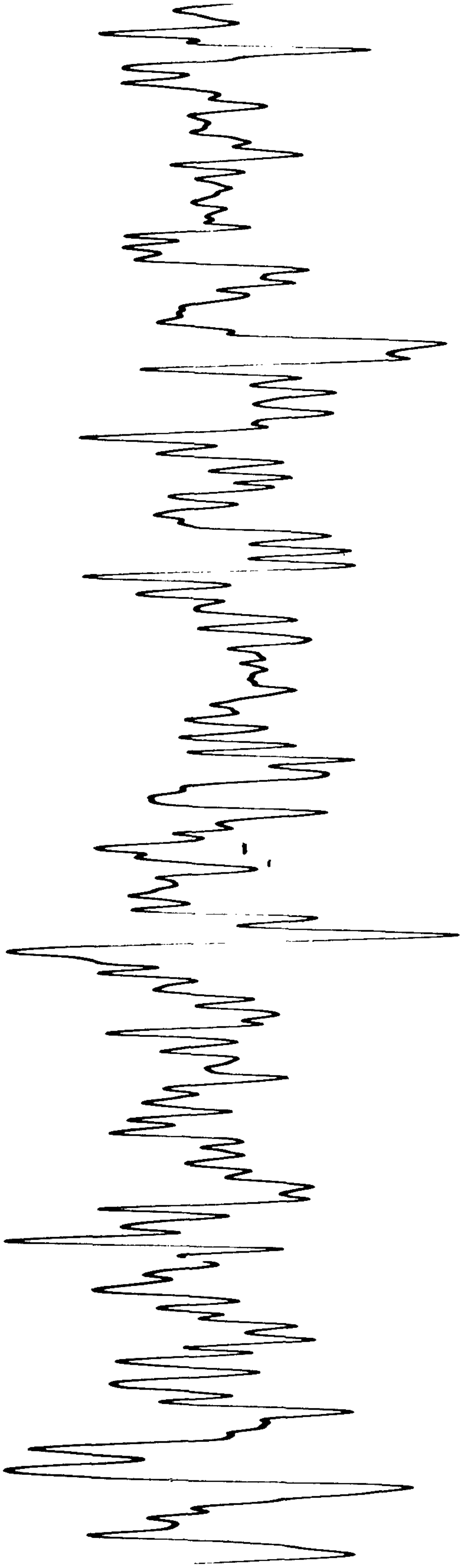


Figure 32 Sample of Master Random Loading Trace

and the spectra of incremental stresses will vary throughout the structure. In general, where the design stresses are high, the mean stress and the peak incremental stress will both be relatively high. Where the design stress is moderate both mean and peak incremental stress will be relatively low. Note, however, that differences in structural response frequencies may not produce a simple linear relationship between the magnitude of mean stress and the magnitude of peak incremental stress. In addition, for classes of aircraft having widely different design load factors, the general levels of stress due to gust loadings will be quite different. For example, in fighter aircraft, the normally high design load factor usually produces a low mean or 1g stress and relatively low peak incremental stresses due to gusts.

To investigate the importance of the differences in stress history which have been described, the master tapes were used in two sets of tests. In one set, the gross area specimen stress produced by the constant mean test load was 12,000 psi. In these tests the peak incremental stress recorded during the application of the first component tape (A_1) was approximately 14,000 psi. In the second set of tests, a constant mean stress of 6000 psi was applied and the peak incremental stress produced by the first tape component was approximately 10,000 psi. In each set of tests, two specimen geometries $K_t = 4.0$ and $K_t = 7.0$ were used.

The choice of test stress levels represented some compromise between most representative values and values indicated by the results obtained in exploratory tests carried out during the preliminary investigation. An extreme range of test conditions had been selected. These conditions varied from high stress histories applied to $K_t = 7.0$ specimens to relatively low stress histories applied to $K_t = 4.0$ specimens. A rather extreme range of test lives was therefor anticipated and it was necessary to guard against either excessively short or excessively long test times. The test times actually obtained ranged from slightly over one hour to 45 hours.

The representation of the random loading test lives was based on zero crossing peak counts of monitor tapes. These tapes contained the specimen loading histories produced by each component tape in the master series which was employed in the test. These partial histories were then multiplied by the number of times each component tape had been used. The test loading histories so obtained are listed in Tables 14, 15, 16, & 17 in Appendix V and are presented graphically on Figures 33, 34, 35 & 36. The moderate differences of spectrum shape shown on the figures reflect the differences in number of component tapes which had been applied at specimen failure.

The major distinction between the two spectra of applied loadings might be described by the difference between the average slopes of the high load portions of the spectra. However, to reflect the changes in mean stress and to emphasize the importance of stress magnitude, the two classes of loading histories are identified on the graphs as high peak and low peak. These terms are purely relative but may be used in this report because each term always identifies the same combination of mean and initial value of peak stress.

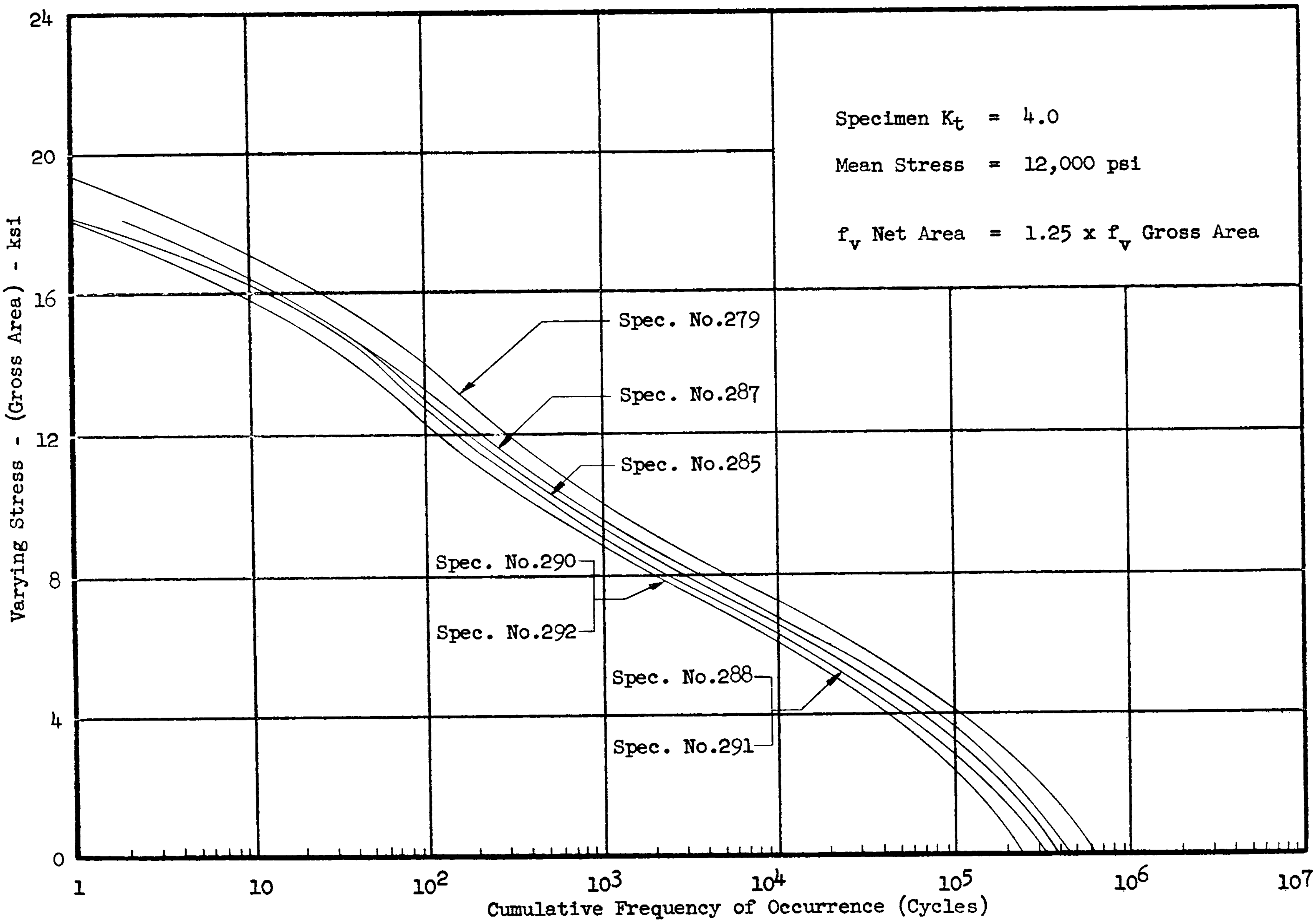


FIGURE 33 RANDOM HIGH PEAK GUST LOADING TEST DATA

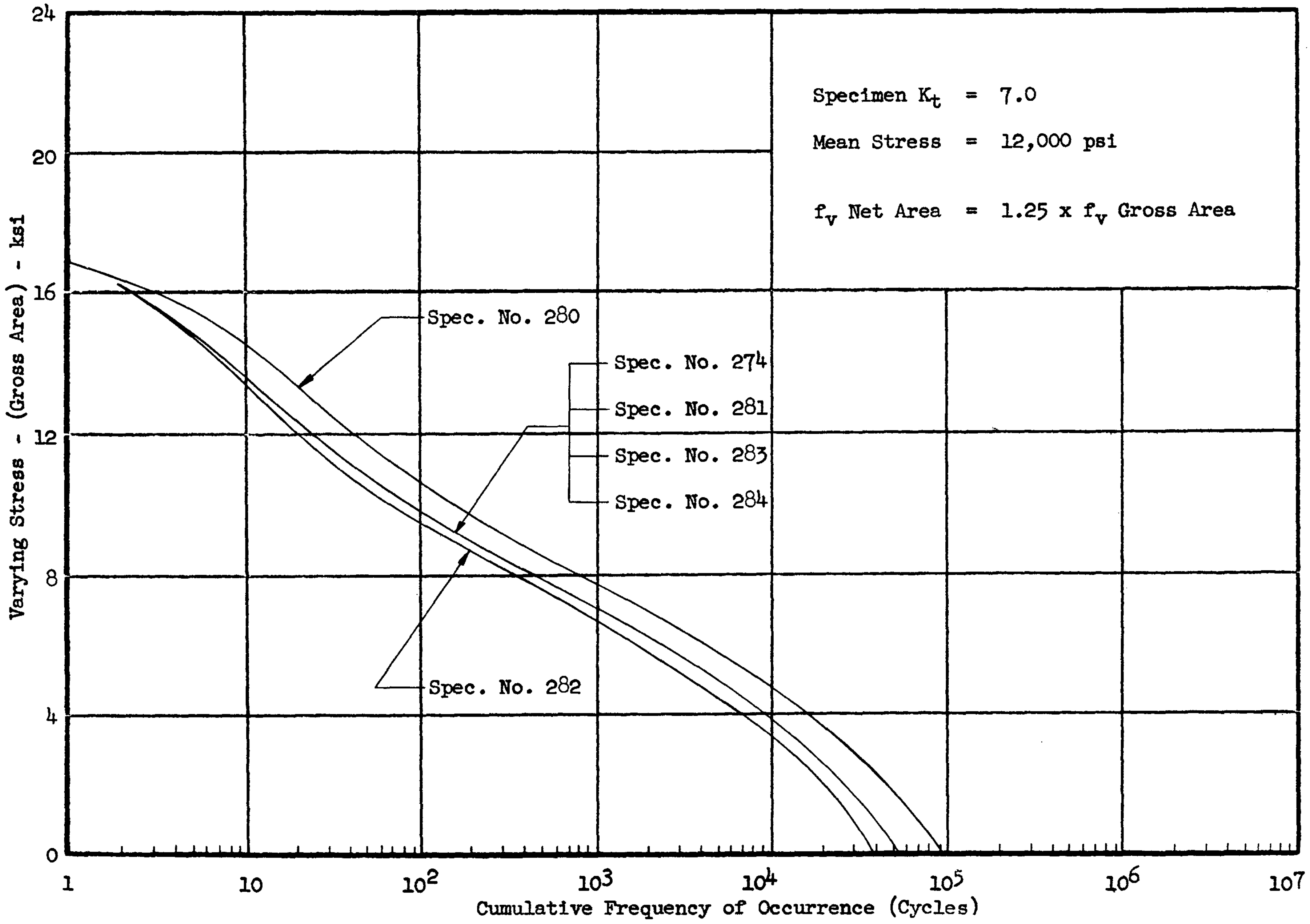


FIGURE 34 RANDOM HIGH PEAK GUST LOADING TEST DATA

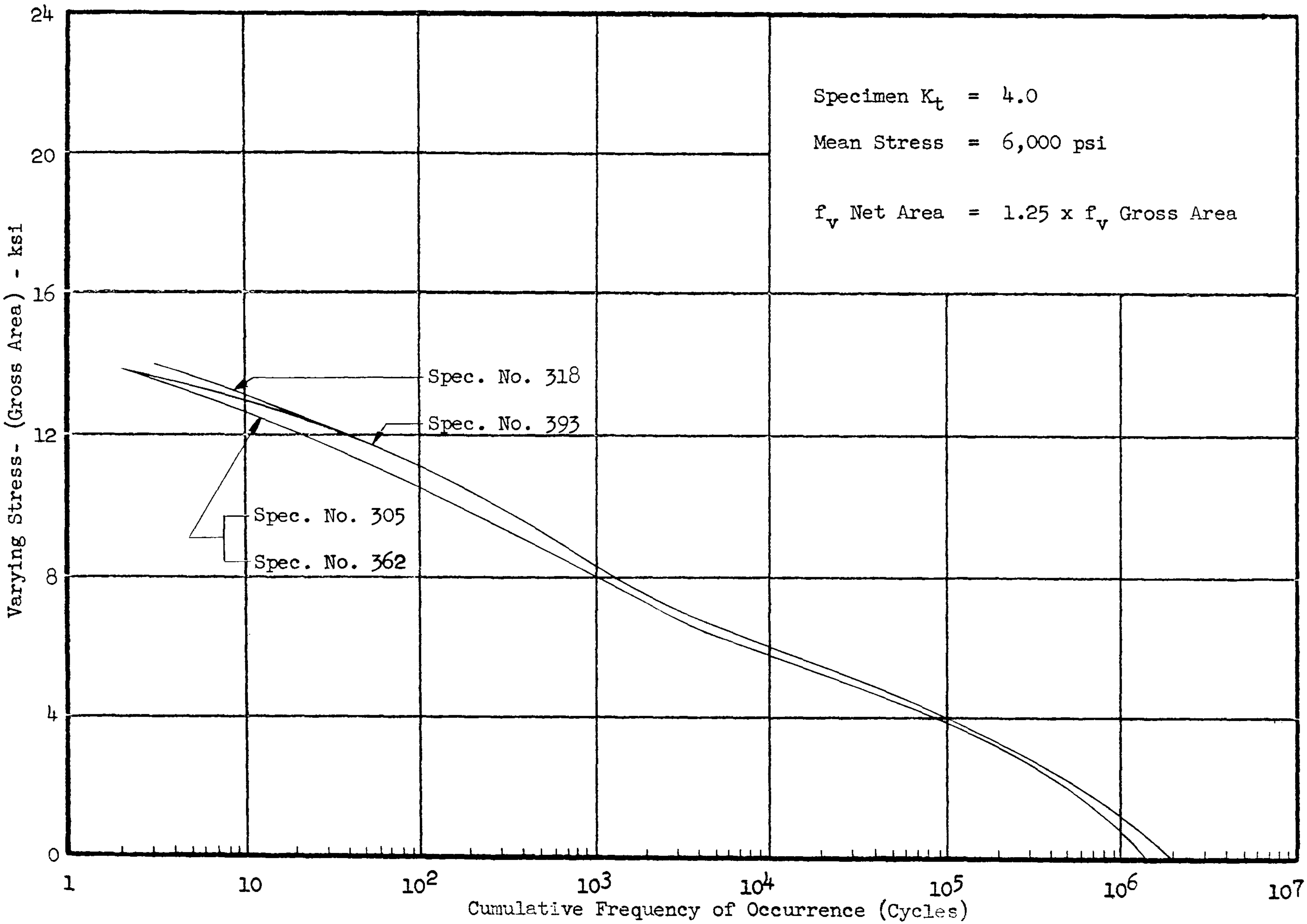


FIGURE 35 RANDOM LOW PEAK GUST LOADING TEST DATA

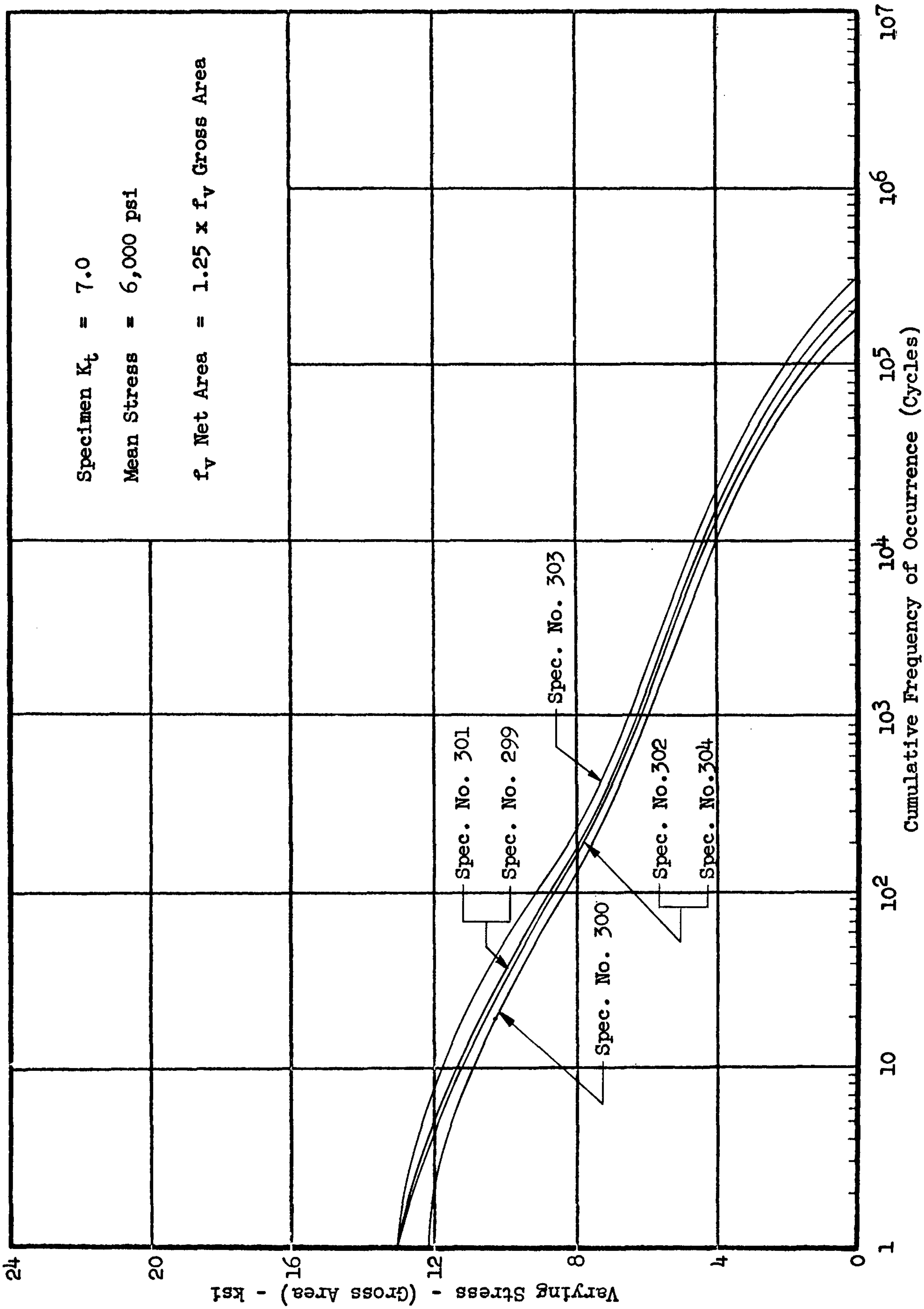


FIGURE 36 RANDOM LOW PEAK GUST LOADING TEST DATA

Generation of Ordered Loading Tapes

Based on the work reported for the preliminary investigation, zero crossing peak count representations of the random loading histories were selected for the preparation of ordered loading tapes. For each set of random loading test lives shown on Figures 33-36, the average test life was determined and its peak count representation was used in the generation of tapes containing ordered, cyclic loading patterns. As in all such simulations of random loading histories a particular sequence of application of cyclic magnitudes must be selected, a size of stress interval must be selected and a choice of the size of the unit spectrum to be repetitively applied must be made. Many tests have been reported in the literature which indicate that such decisions can have a marked effect on test lives.

Sequence of Ordered Loads

Since the general intent is to produce an adequate randomization of test loadings, the particular sequence of application of the loadings defined for a unit spectrum may not be important if the spectrum is repeated a reasonably large number of times. The particular sequence chosen for use is described as the low-high sequence. The loadings in the unit spectrum are applied in a sequence of increasing magnitudes.

Stress Interval Size

The choice of stress interval reflects a judgment of the precision with which the continuous spectrum of random loadings must be represented by a discontinuous spectrum. This choice is often guided by assumptions of linearly cumulative damage coupled with the restricted information provided by conventional S-N curves. In general, however, it appears to be obvious that a fairly detailed representation of a random loading history should produce the best simulation. The advantage of a fairly crude representation is in lowered test cost. However, since the total number of cycles of loading to represent a unit random loading spectrum should not be appreciably affected by the choice of stress interval, the reduction in cost made possible by the use of a reduced number of stress intervals is small if adequate test apparatus is employed. For these reasons, emphasis was placed on the use of a stress interval of 1000 psi. However, to obtain an indication of the effect of larger intervals, tapes were prepared on which a stress interval of 4000 psi was used.

These selections of the precision with which the spectrum is to be represented suggest similar choices of the minimum values of varying stress to be applied in tests. In the tests using a stress interval of 1000 psi the lowest varying stress was 1000 psi and, in tests using a 4000 psi stress interval, the lowest varying stress was 4000 psi.

Size of Unit Ordered Spectrum

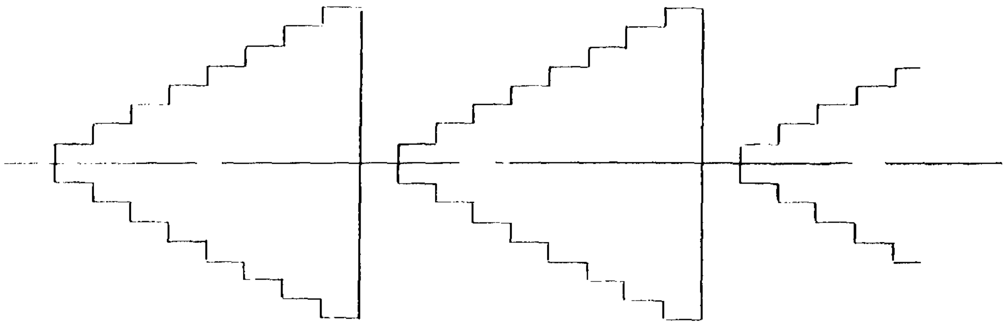
The choice of the size of the unit spectrum to be repetitively applied reflects an estimate of the degree of randomization required. For the test work, a unit spectrum representing one-twentieth of the average random test life was judged to be adequate. However, to obtain an indication of the effect of the choice of a larger unit, two tapes were prepared on which the unit spectrum represented one-tenth of the appropriate total random loading test life.

A schematic representation of the type of sequence used and of the significance of the stress interval and unit spectrum size variations is presented on Figure 37.

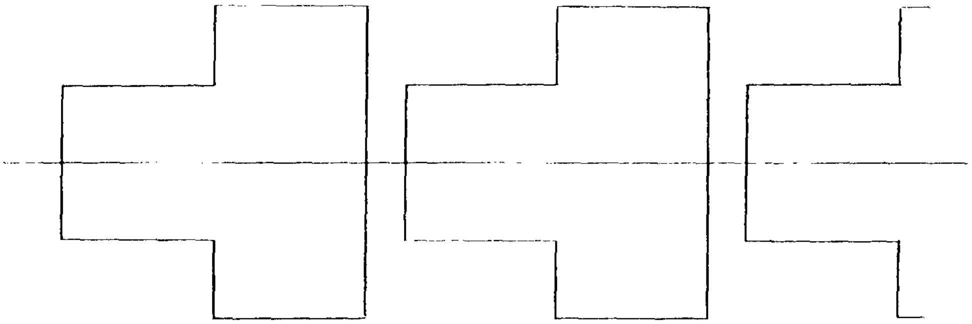
To illustrate the procedure followed in defining ordered loadings for a particular case, Figure 38 was prepared. The curve in this figure represents the average test life obtained in a series of random loading tests expressed in terms of cumulative frequency of load cycle occurrences. Having chosen a stress interval of 1000 psi and a minimum varying stress of 1000 psi, the cumulative number of cycles at 1500 psi was subtracted from the cumulative number at 500 psi to define the number of cycles occurring in the 500-1500 psi interval. It is conventionally assumed that an adequate representation of this partial history is obtained by considering all of the cycles in the interval to be applicable at the mid point of the interval. This assumption appears to be a reasonable one when the stress interval is small. The number of cycles in the 500-1500 psi interval was, therefor, assigned to cyclic loadings producing 1000 psi varying stress. This process was repeated over the range of magnitudes on the random loading test spectrum to produce the stepped graph shown in the region of the curve. The number of cycles indicated for each stress interval was then divided by 20 to obtain the lower stepped graph shown on the figure. This graph defines the stress levels and indicates the number of cycles at each stress level in a unit cyclic loading spectrum. The loading history so defined was recorded on tape using the low-high loading sequence previously described and then copied to provide the sequence of repetitions required. The larger varying stress magnitudes not represented in the unit spectrum were added to appropriate copies and a sequence of tapes was assembled. This sequence was selected so that the higher stresses appeared and were repeated at approximately the mid points of their intervals of occurrence as indicated by the random loading spectrum.

This general procedure was followed in the generation of a set of loading tapes. The range of test condition variables represented by these tapes is indicated below.

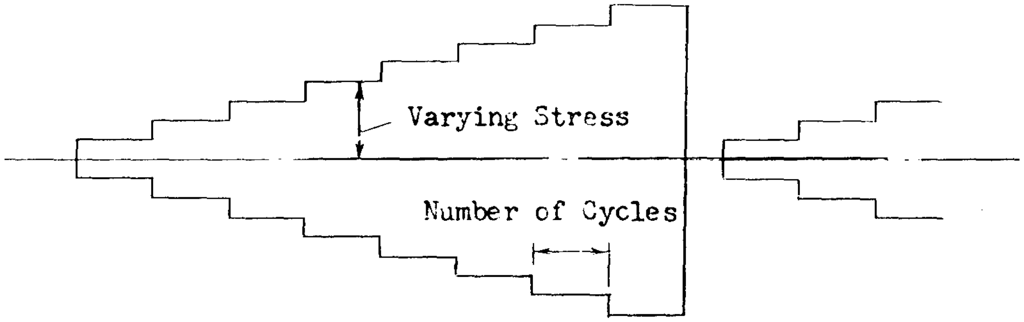
Stress Interval (psi)	Unit Spectrum Size	Ordered Loading Histories Based On			
		High Peak Random Loading Test Histories		Low Peak Random Loading Test Histories	
		$K_t=4.0$	$K_t=7.0$	$K_t=4.0$	$K_t=7.0$
1000	1/20	x	x	x	x
1000	1/10	x		x	
4000	1/20	x		x	



Low-High Sequence, Small Stress Interval, Small Unit Spectrum



Low-High Sequence, Large Stress Interval, Small Unit Spectrum



Low-High Sequence, Small Stress Interval, Large Unit Spectrum

Figure 37 Schematic Representation of Sequence, Stress Interval, and Unit Spectrum Size

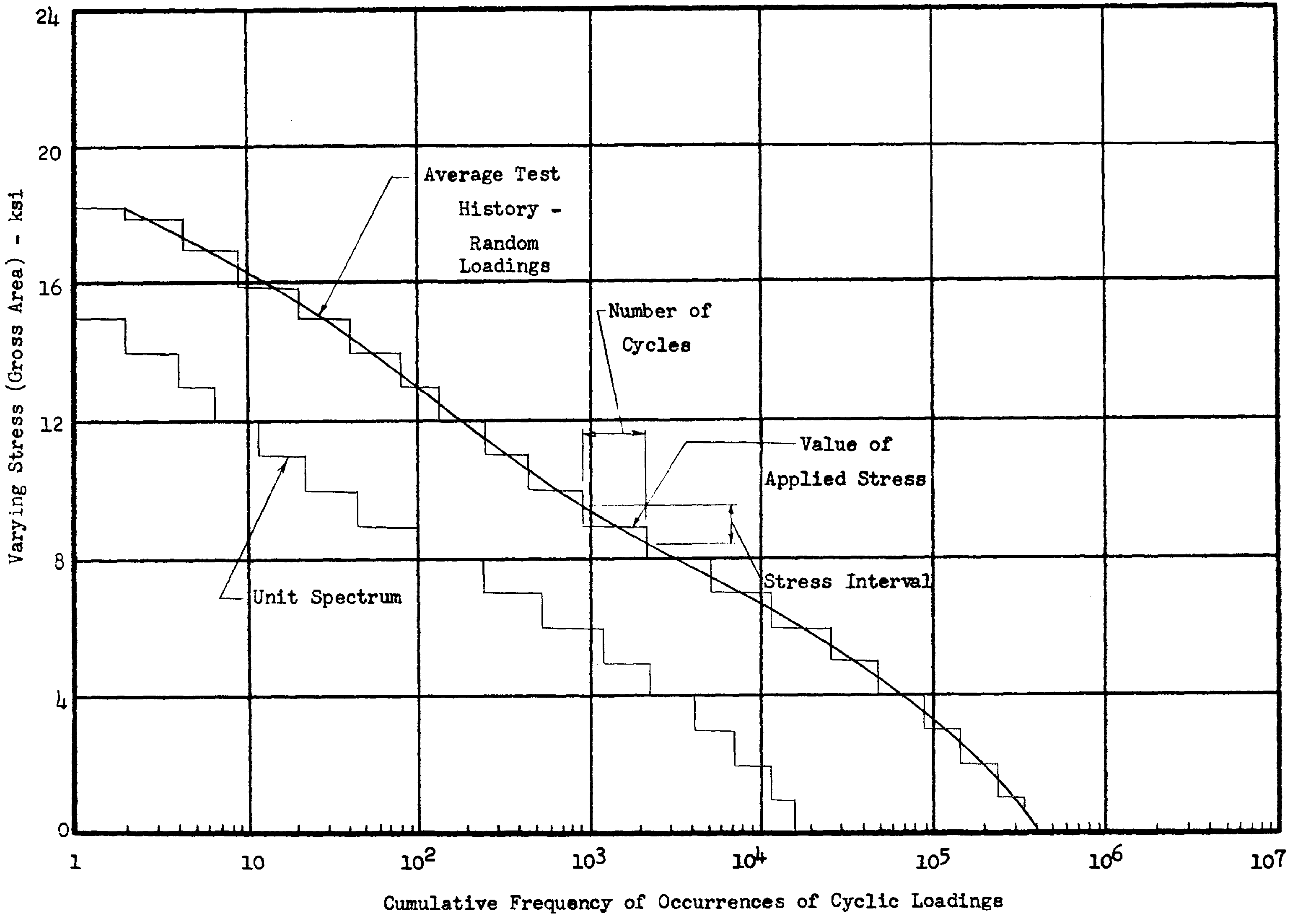


FIGURE 38 DEVELOPMENT OF ORDERED LOADING SPECTRUM

A sample trace showing a portion of an ordered loading history is presented on Figure 39.

Ordered Loading Test Data

Each ordered loading tape was employed to obtain a set of test data. The data describing the test loading histories are listed in Tables 21 through 28 in Appendix V. Since the loadings in these tests were applied at preselected stress levels, the loading distributions were not continuous. However, the purpose of the tests was to determine the ability of the ordered loading distributions to represent the continuous spectra of random loadings. To simplfy comparisons of ordered and random loading histories, the spectra were therefor presented, in the conventional way, as smooth cumulative frequency of occurrence curves on Figures 40 through 47. As in the representation of the random loading test histories, each spectrum was based on a count of a monitor tape. Because of the cyclic nature of the loadings, these counts were more precisely defined than those for a random loading history.

Evaluation of Test Data

One evaluation of the test data is presented in Table 2. This table lists the number of unit ordered loading spectrum repetitions attained in each test, the average number for each group and the ratio of this average number to the target value. As described in preceding paragraphs, each unit loading spectrum was based on a fraction of the appropriate average random loading test life. The application at specimen failure of exactly the number of repetitions defined by the reciprocal of this fraction would then indicate that the ordered loading representation had exactly represented the severity of the random loading trace. The use of this simple numerical index requires that the shapes of the ordered loading spectra match those of the random loading spectra. This matching of shapes was attempted but was not always attained in the limited time available for loading tape generation. To illustrate, the range of test lives obtained in each set of ordered loading tests is compared graphically with the range of the corresponding set of random loading test lives on Figures 48 through 55. This comparison must modify the significance of the ratios listed in Table 2. For example, the ratio reported for specimens having $K_t = 4.0$ which were tested using a high peak stress spectrum based on a 1000 psi stress interval and a relatively small unit spectrum size indicates an average ordered test life approximately twice that of the target value. This result would indicate that the particular ordered representation was only one-half as severe in its effect as the random loading history. However, the graphs of the results presented on Figure 48 indicates that, over the lower central portion of the spectra, the two sets of loading histories were quite similar. A simple numerical report of the results obtained in this set of tests would therefor be misleading.

By comparison with Figure 48 the results shown on Figure 49 indicate that for the same loading distribution an increase in severity was obtained when a larger unit spectrum was used. Figure 50 indicates that when a stress interval of 4000 psi was used results roughly comparable to those shown on Figure 48 were obtained

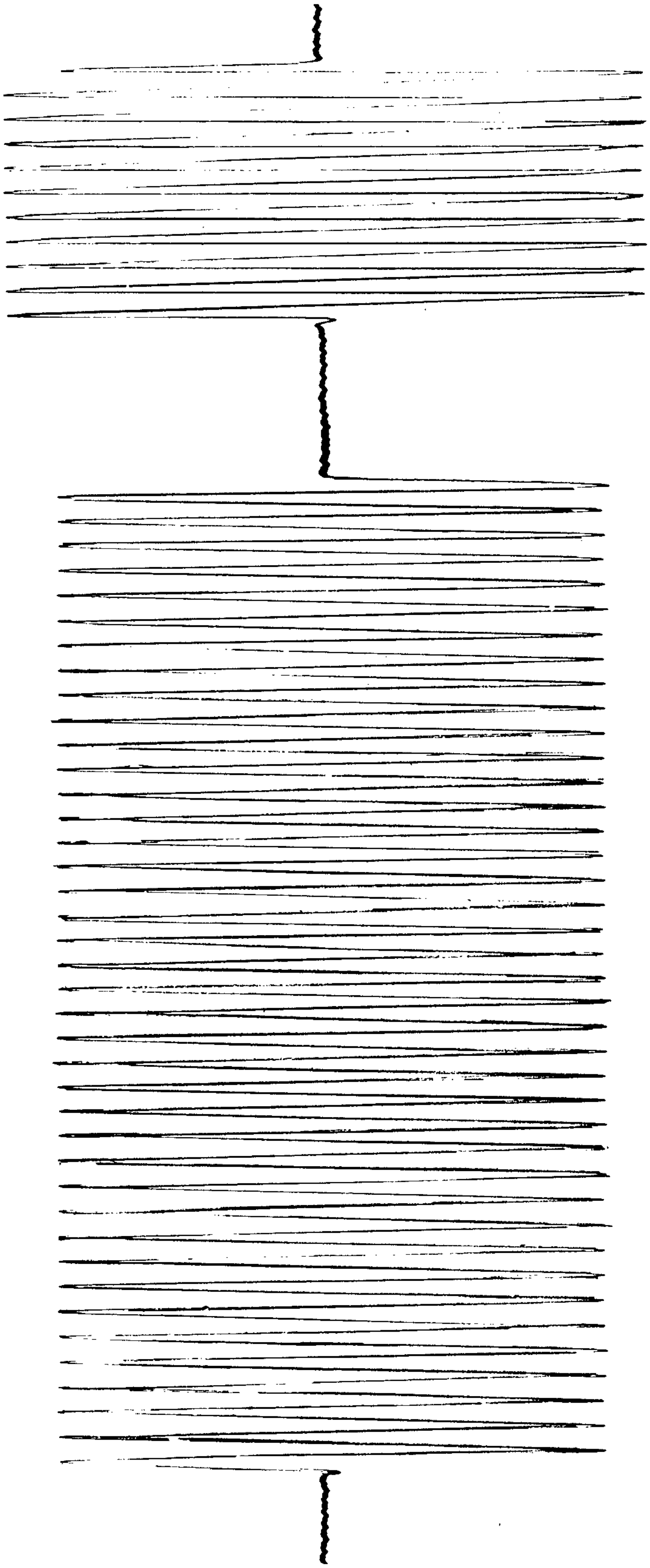


Figure 39 Partial Trace of an Ordered Gust Loading History

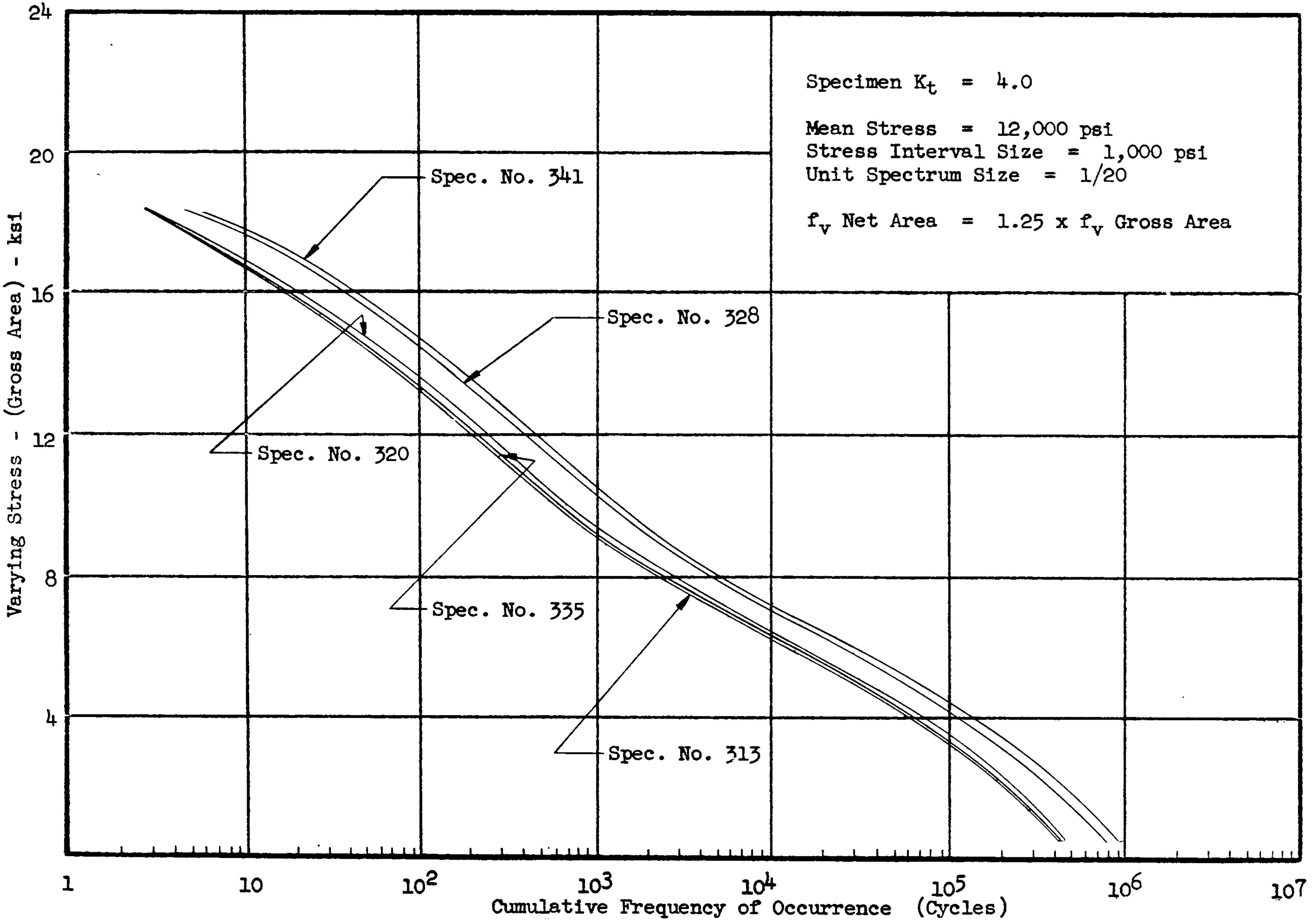


FIGURE 40 ORDERED HIGH PEAK GUST LOADING TEST DATA

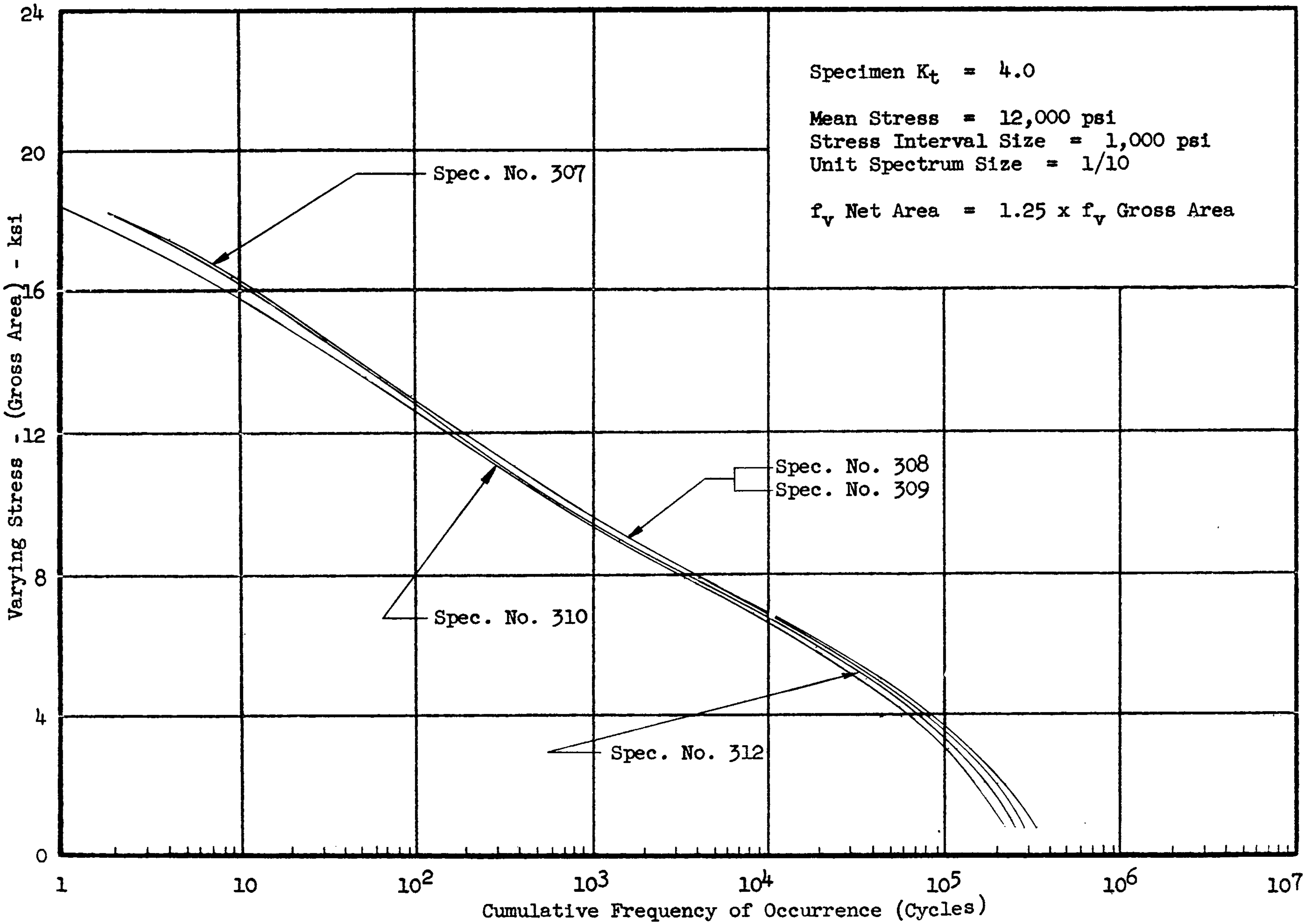


FIGURE 41 ORDERED HIGH PEAK GUST LOADING TEST DATA

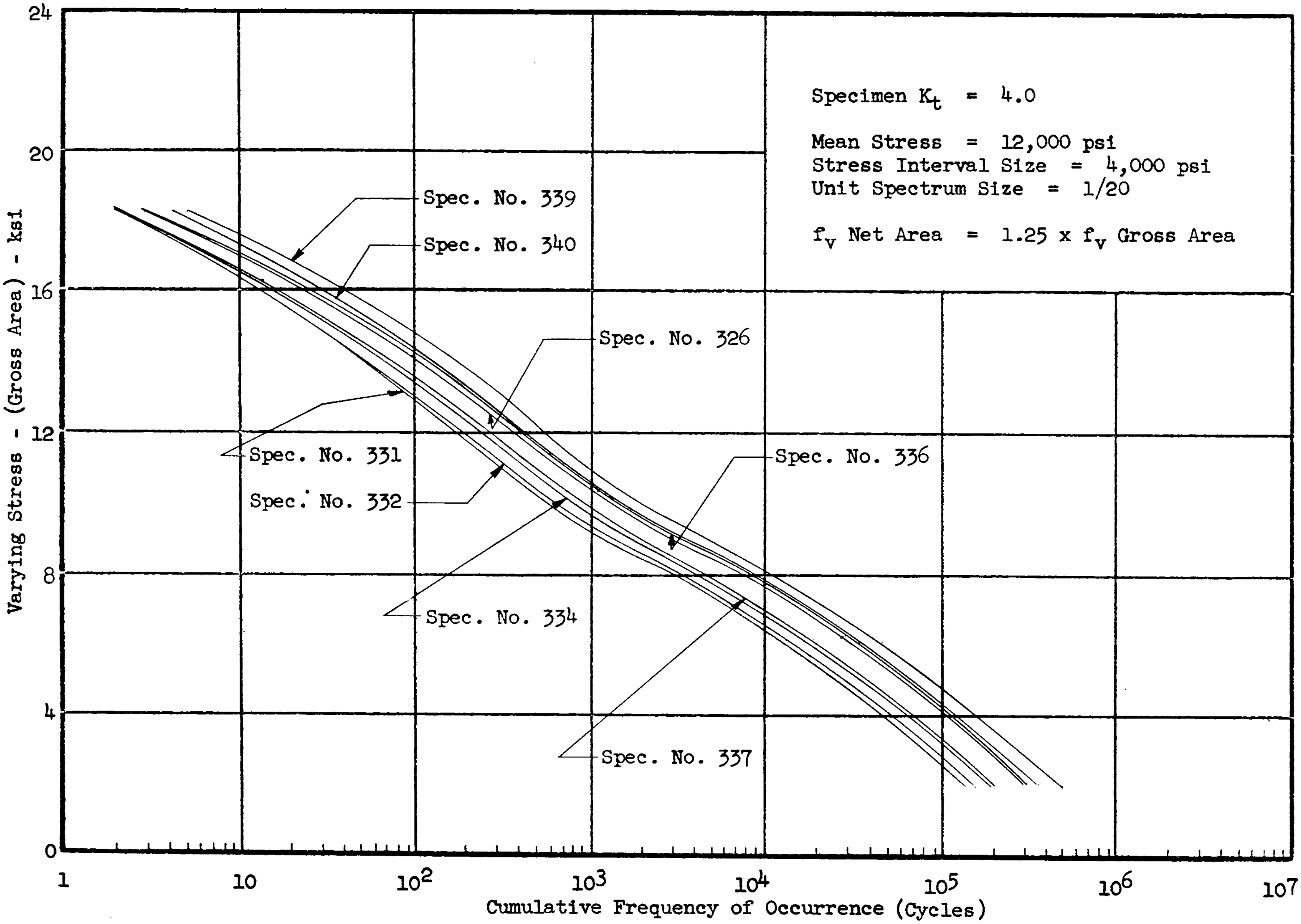


FIGURE 42 ORDERED HIGH PEAK GUST LOADING TEST DATA

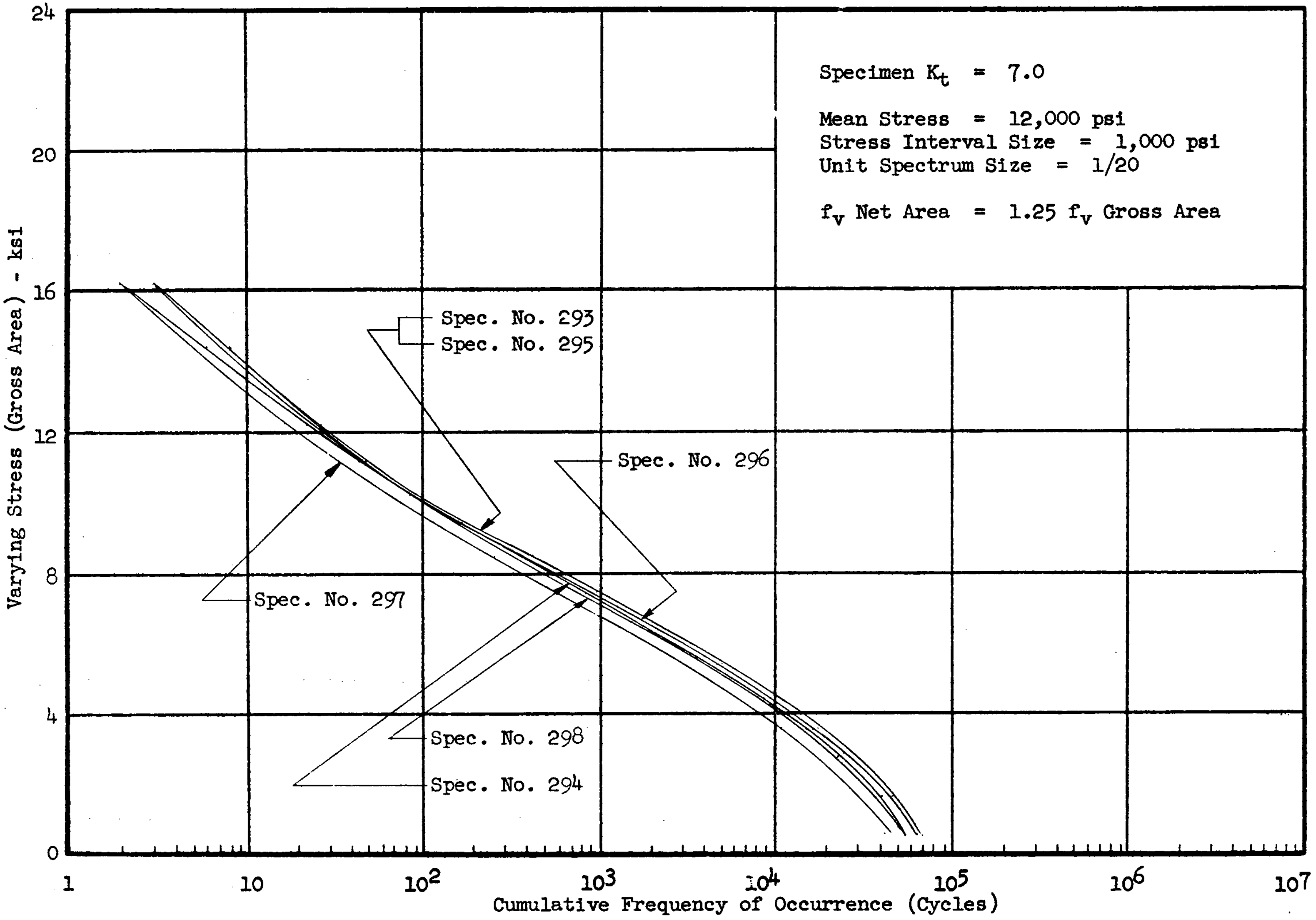


FIGURE 43 ORDERED HIGH PEAK GUST LOADING TEST DATA

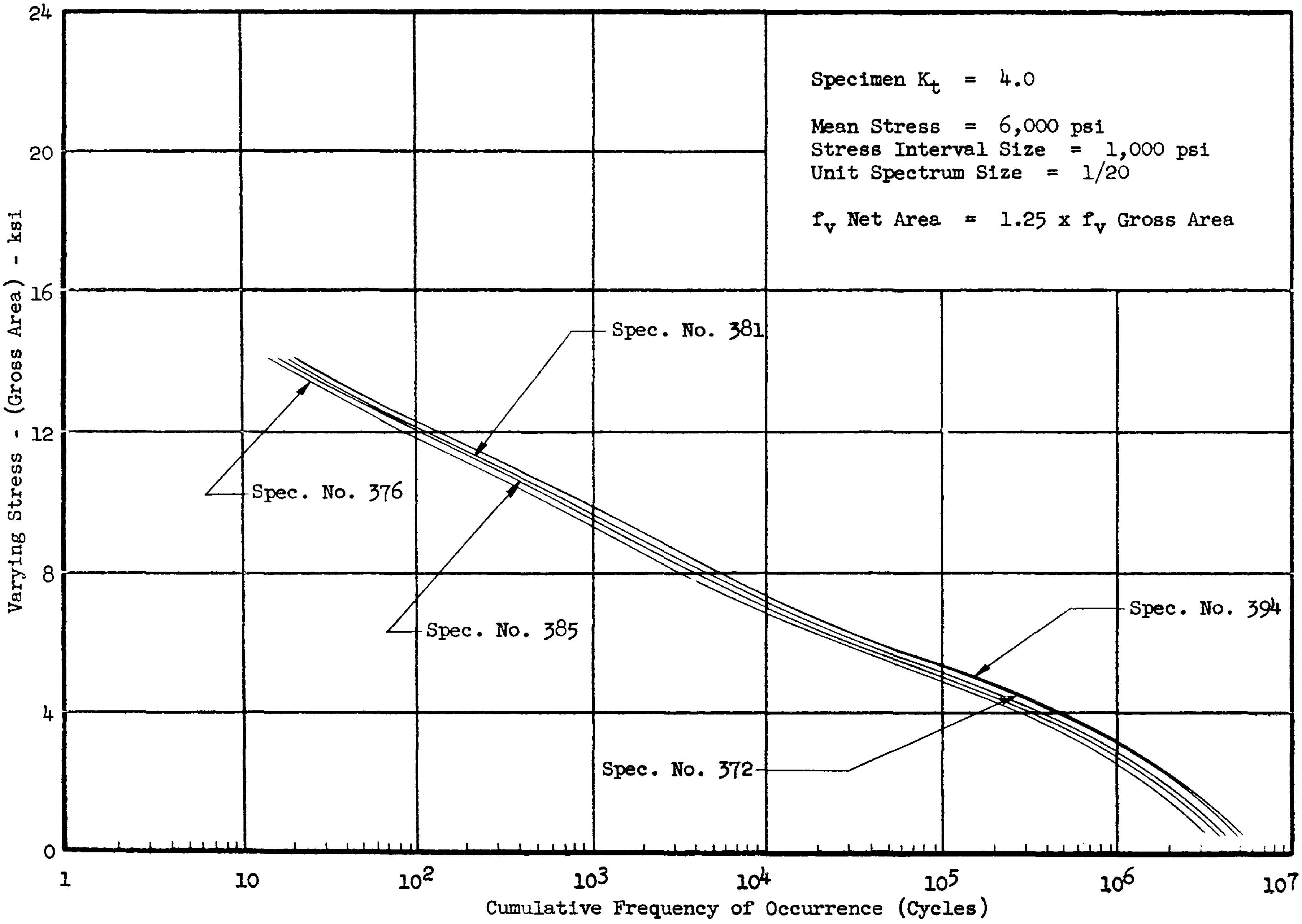


FIGURE 44 ORDERED LOW PEAK GUST LOADING TEST DATA

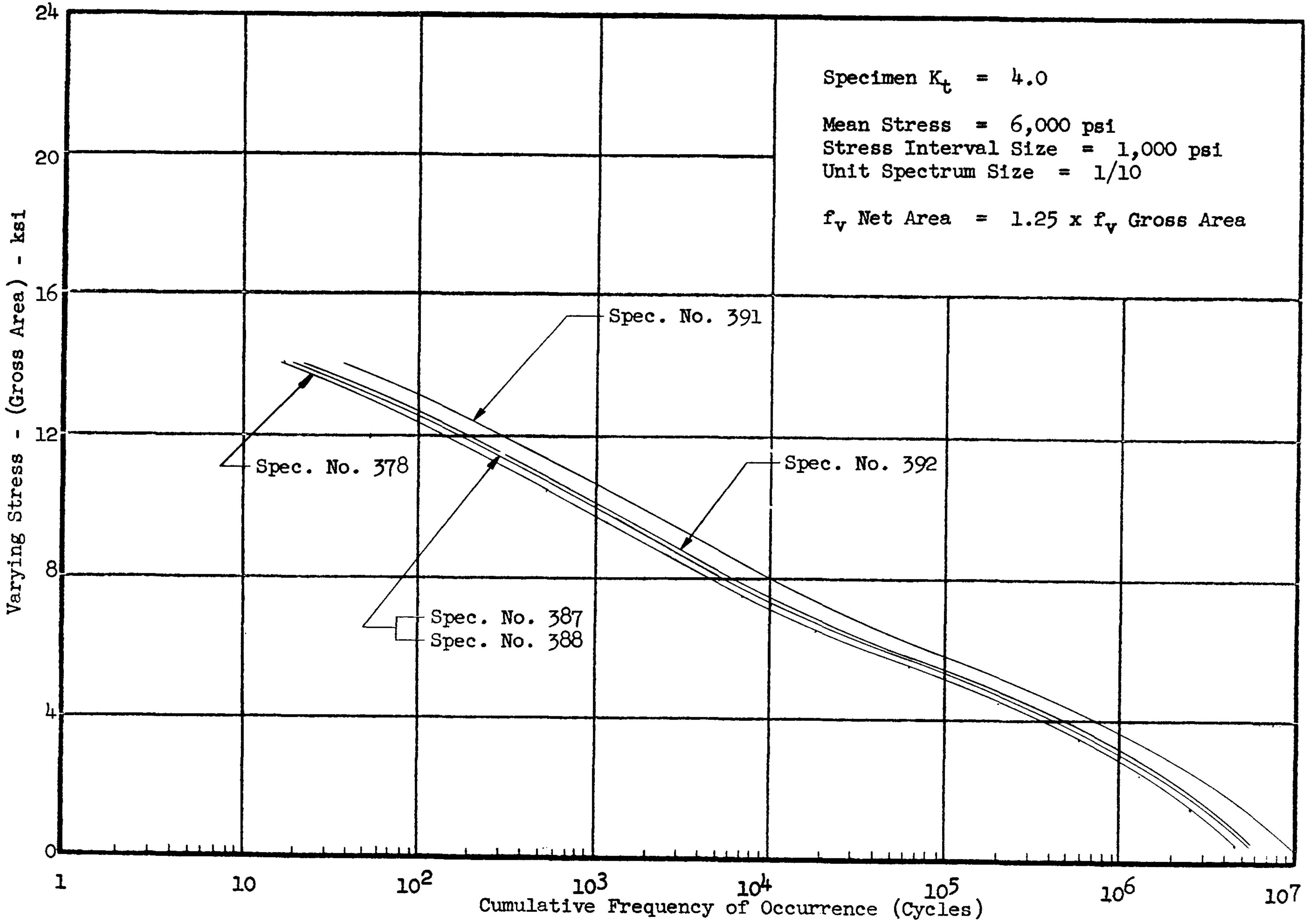


FIGURE 45 ORDERED LOW PEAK GUST LOADING TEST DATA

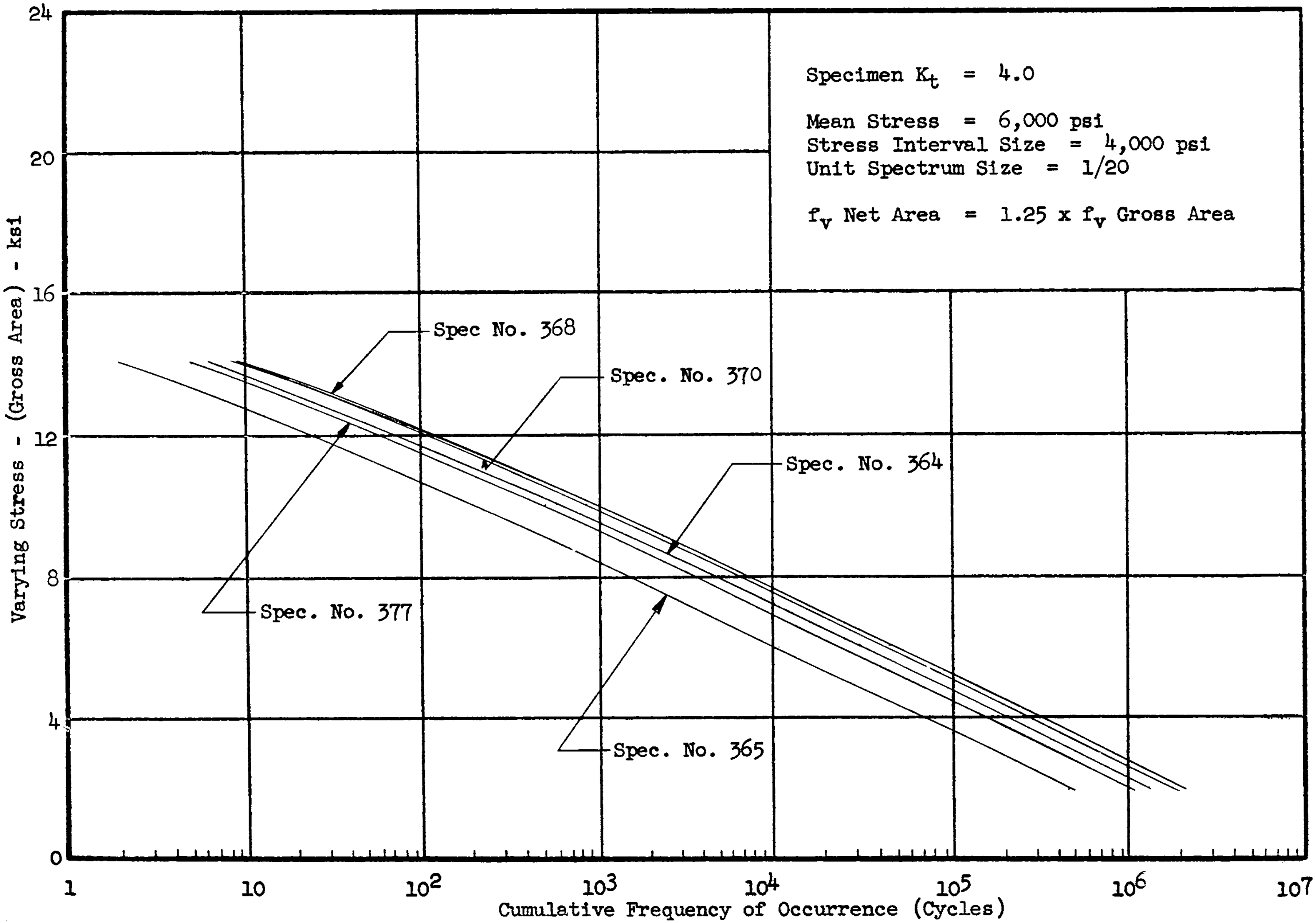


FIGURE 46 ORDERED LOW PEAK GUST LOADING TEST DATA

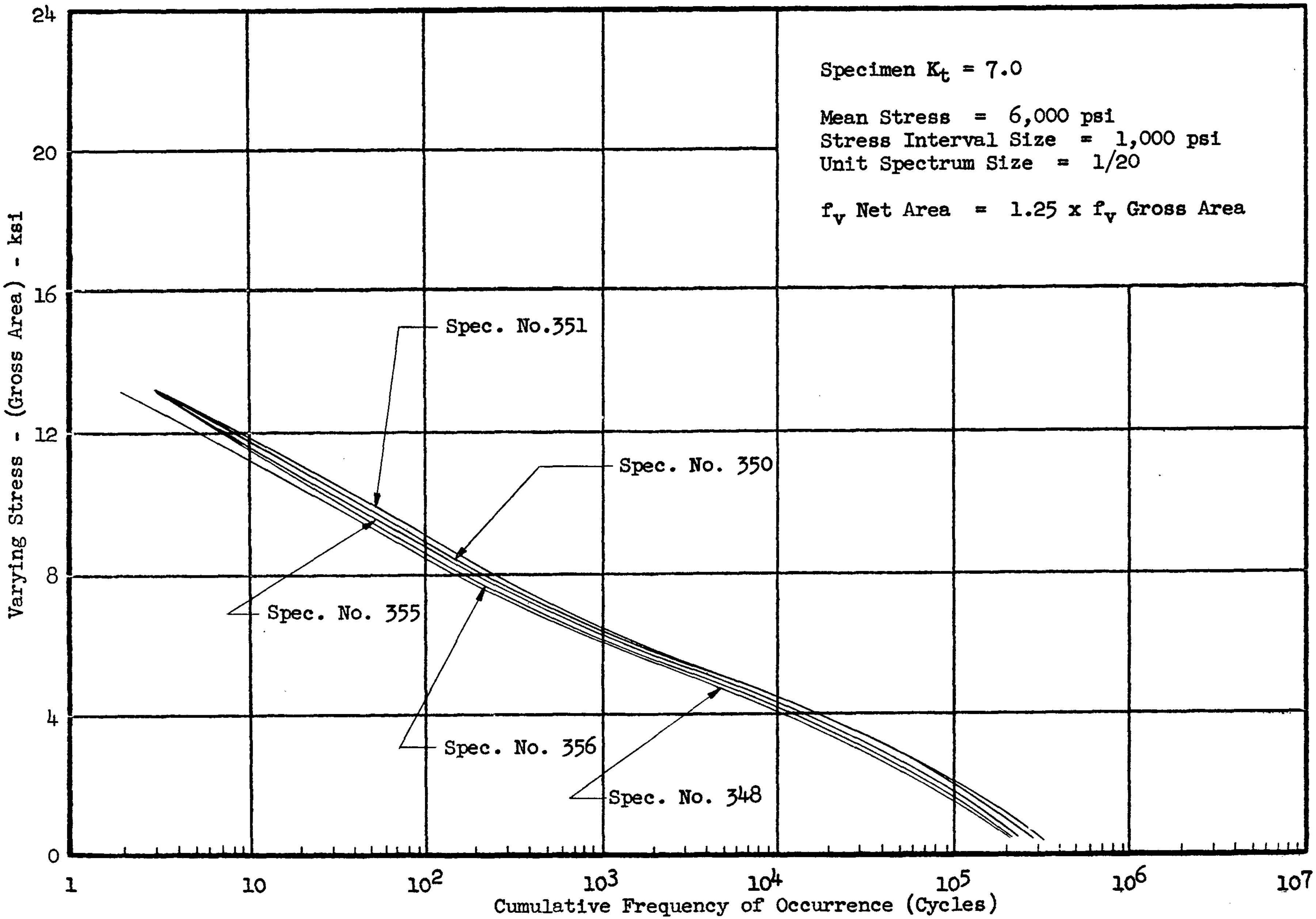


FIGURE 47 ORDERED LOW PEAK GUST LOADING TEST DATA

TABLE 2

COMPARISON OF ORDERED AND RANDOM GUST LOADING TEST DURATIONS BASED ON REPETITIONS OF UNIT ORDERED LOADING SPECTRA

Type of Loading	K_t	Stress Interval (psi)	Unit Spectrum Size	Spec. No.	Unit Spectrum Repe-titions	Average Number of Repe-titions	Target(1) Number of Repe-titions	Ratio of Average to Tar-get No. of Repe-titions
High Peak Gust	4.0	1000	1/10	307	9.97	8.61	10	.861
				308	9.03			
				309	9.00			
				310	7.01			
				312	8.03			
		1000	1/20	313	25.93	38.35	20	1.918
				320	29.40			
				328	50.85			
				335	27.58			
				341	98.01			
		4000	1/20	326	32.89	29.11	20	1.456
				331	15.63			
				332	16.51			
				334	20.34			
				336	33.05			
				337	22.43			
				339	53.80			
				340	38.20			
	7.0	1000	1/20	293	25.19	23.28	20	1.164
				294	23.29			
				295	25.19			
				296	27.24			
				297	16.52			
				298	22.23			

(1) Number of unit spectra repetitions required for nominally equivalent random and ordered test lives

(continued on next page)

TABLE 2 (Continued)

COMPARISON OF ORDERED AND RANDOM GUST LOADING TEST DURATIONS BASED ON REPETITIONS OF UNIT ORDERED LOADING SPECTRA

Type of Loading	K_t	Stress Interval (psi)	Unit Spectrum Size	Spec. No.	Unit Spectrum Repetitions	Average Number of Repetitions	Target(1) Number of Repetitions	Ratio of Average to Target No. of Repetitions
Low Peak Gust	4.0	1000	1/10	378	37.94	52.10	10	5.210
				387	44.88			
				388	44.92			
				391	83.80			
				392	48.95			
		1000	1/20	372	81.97	70.44	20	3.522
				376	52.96			
				381	69.82			
				385	62.95			
				394	84.50			
		4000	1/20	364	53.61	54.08	20	2.704
				365	17.61			
				368	80.89			
				370	78.68			
				377	39.60			
	7.0	1000	1/20	348	23.46	28.61	20	1.431
				350	32.12			
				351	33.93			
				355	28.17			
				356	25.36			

(1) Number of unit spectra repetitions required for nominally equivalent random and ordered test lives

(end of table)

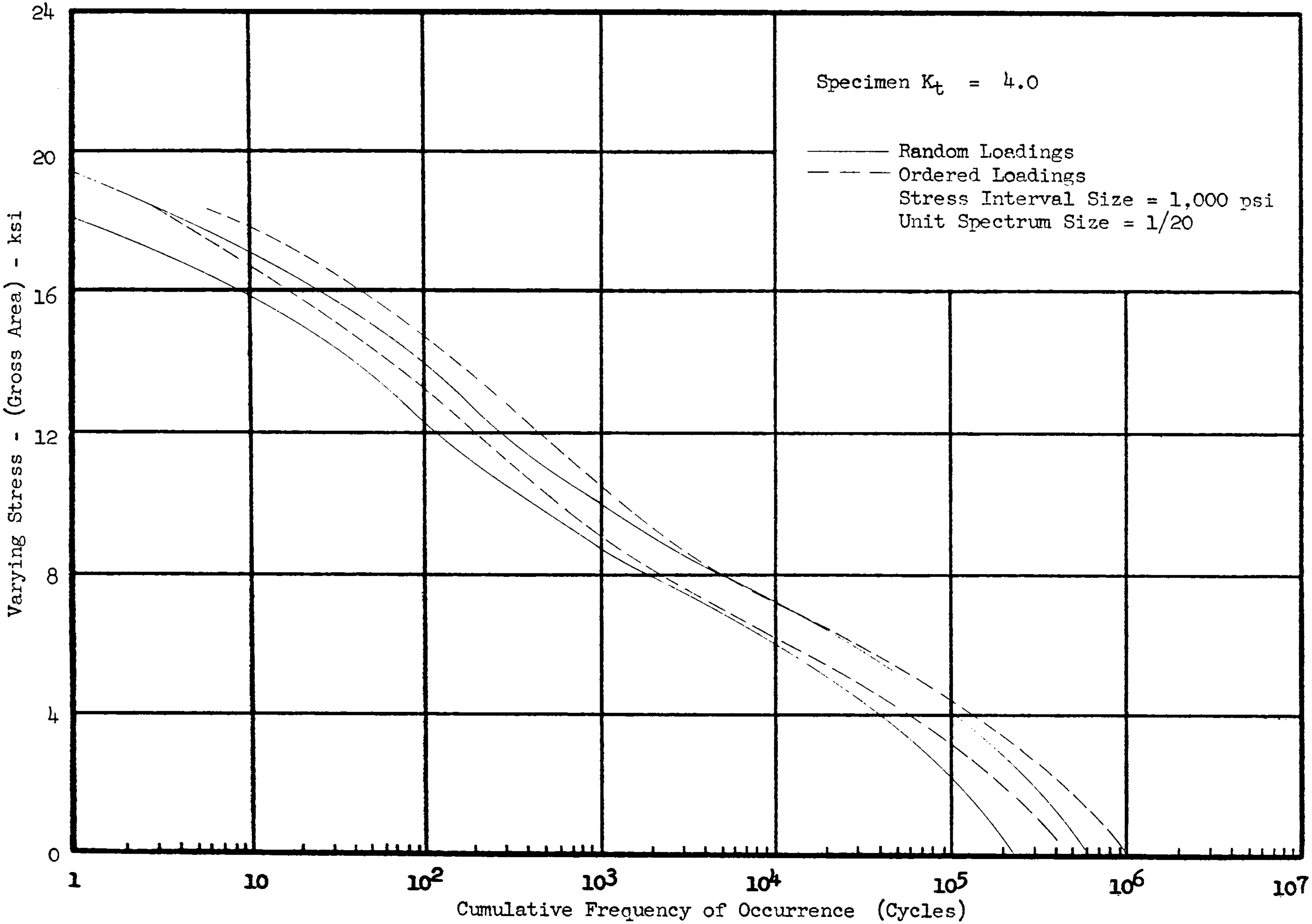


FIGURE 48 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED HIGH PEAK GUST LOADING TEST DATA

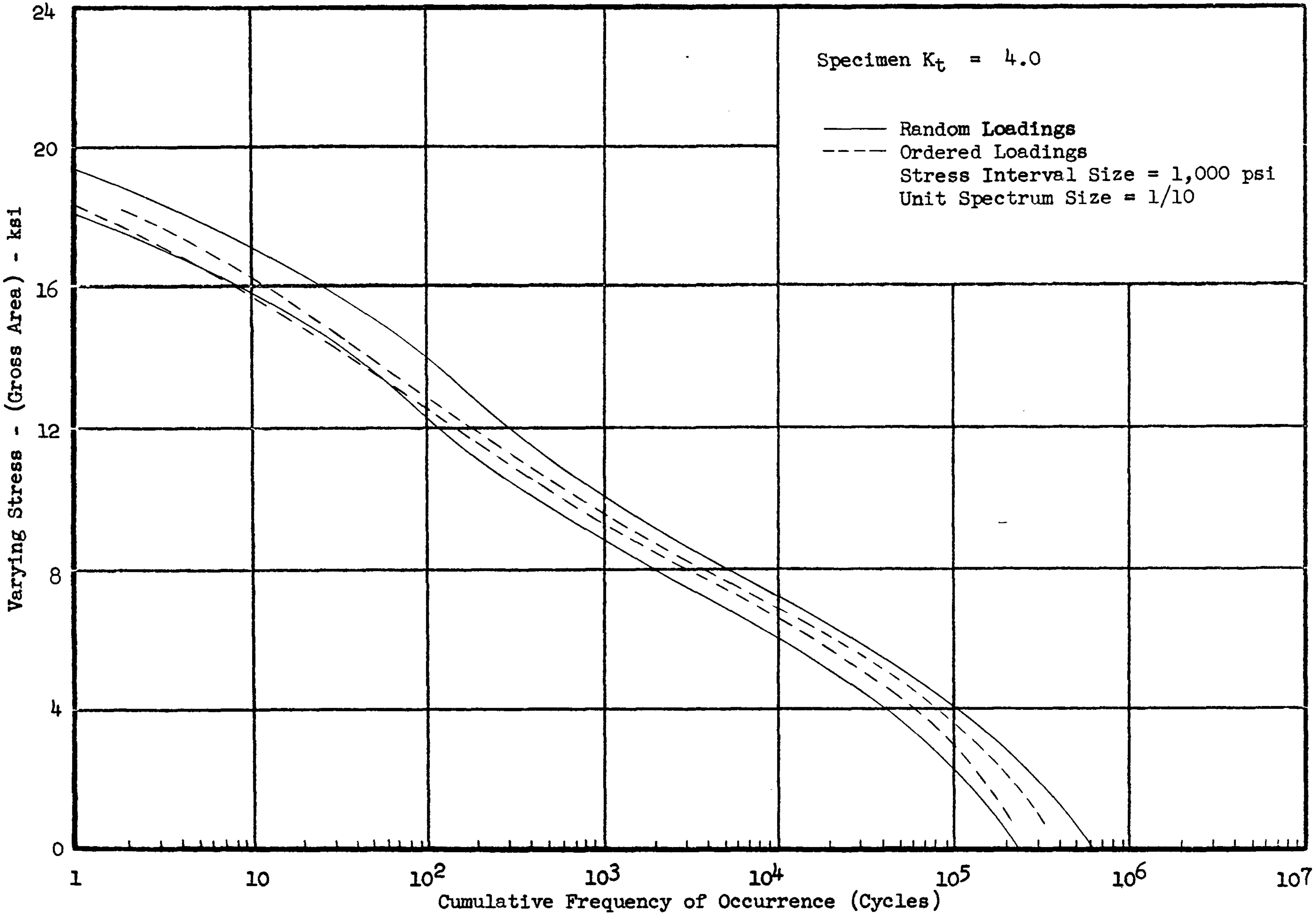


FIGURE 49 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED HIGH PEAK GUST LOADING TEST DATA

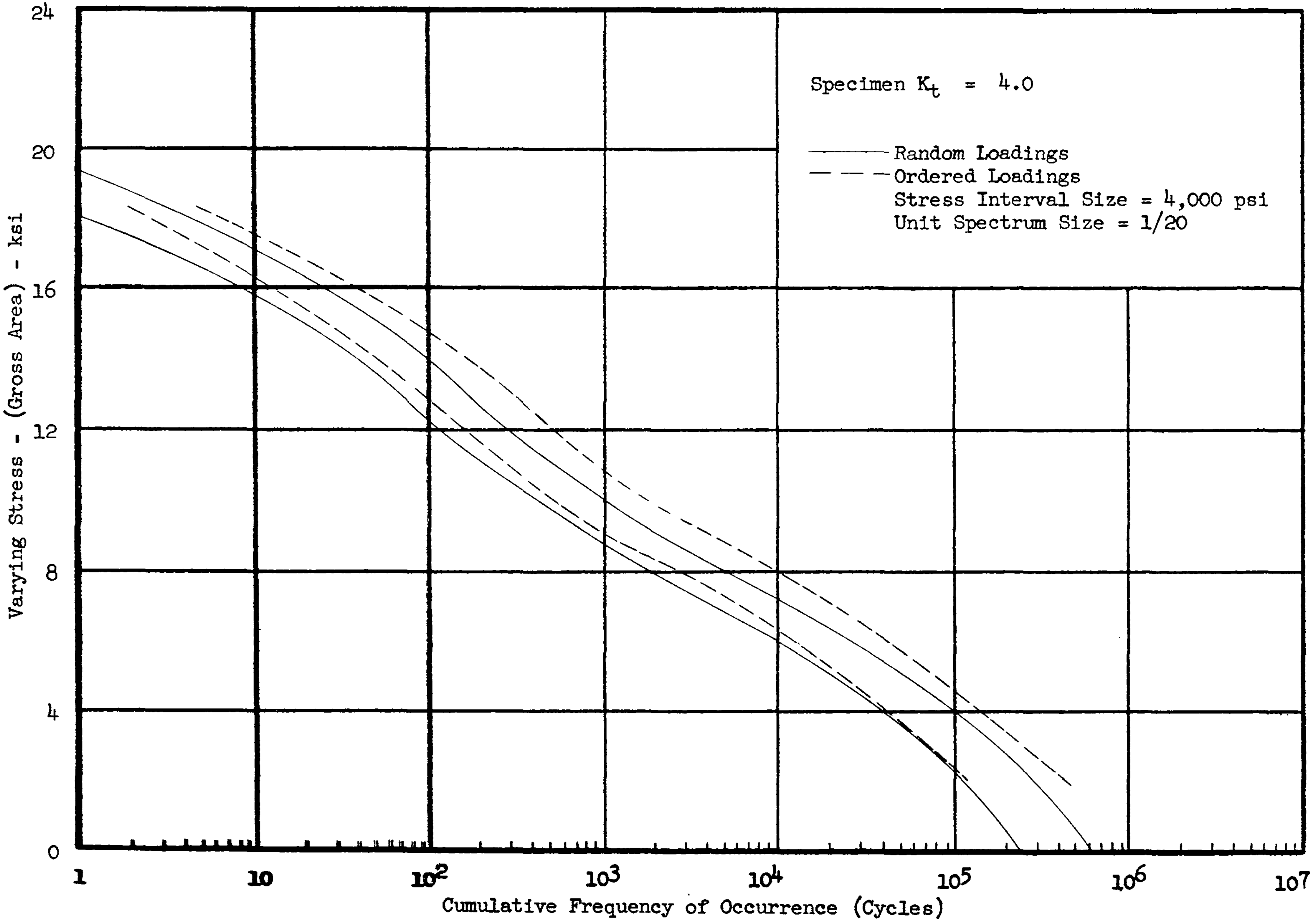


FIGURE 50 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED HIGH PEAK GUST LOADING TEST DATA

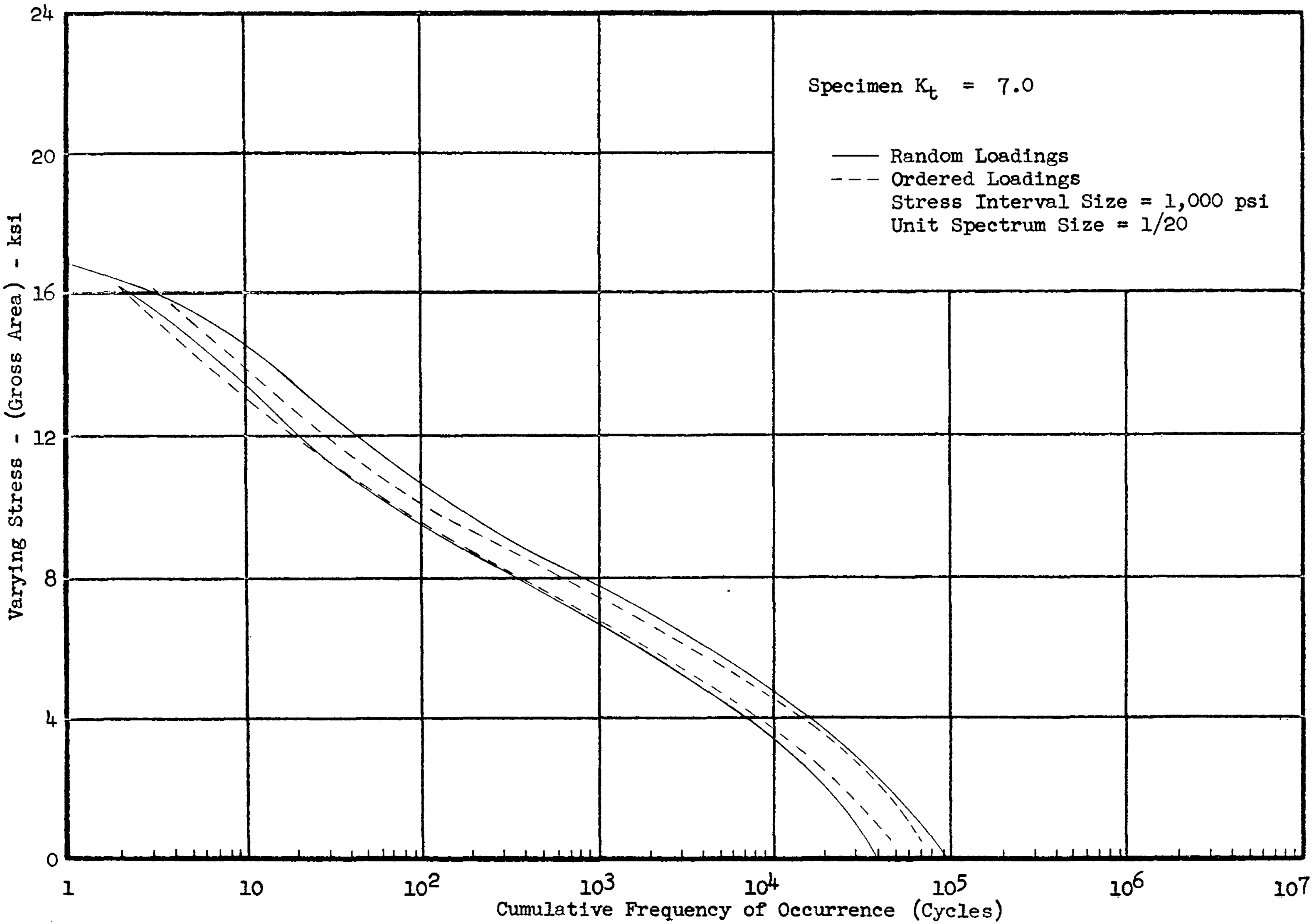


FIGURE 51 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED HIGH PEAK GUST LOADING TEST DATA

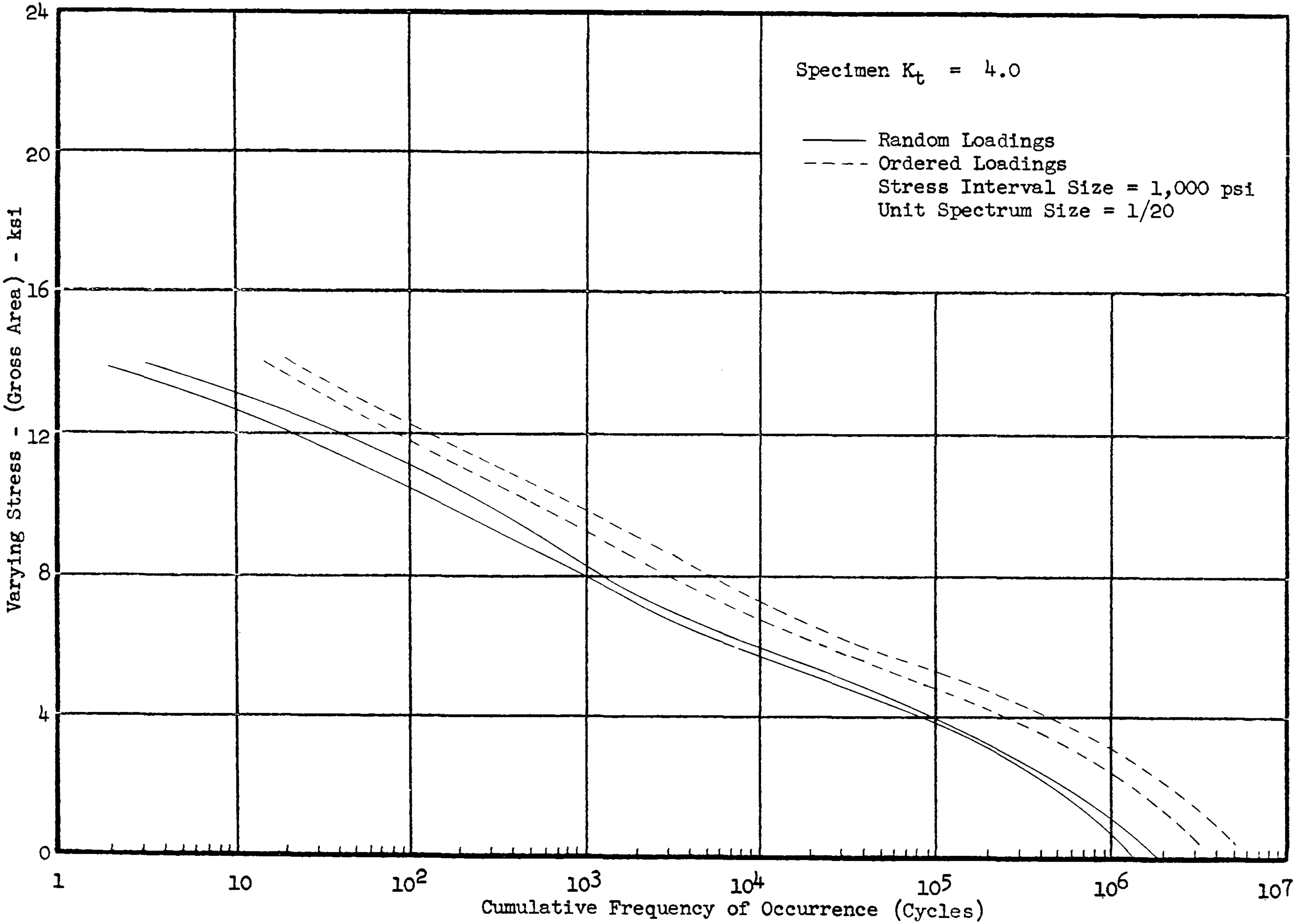


FIGURE 52 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED LOW PEAK GUST LOADING TEST DATA

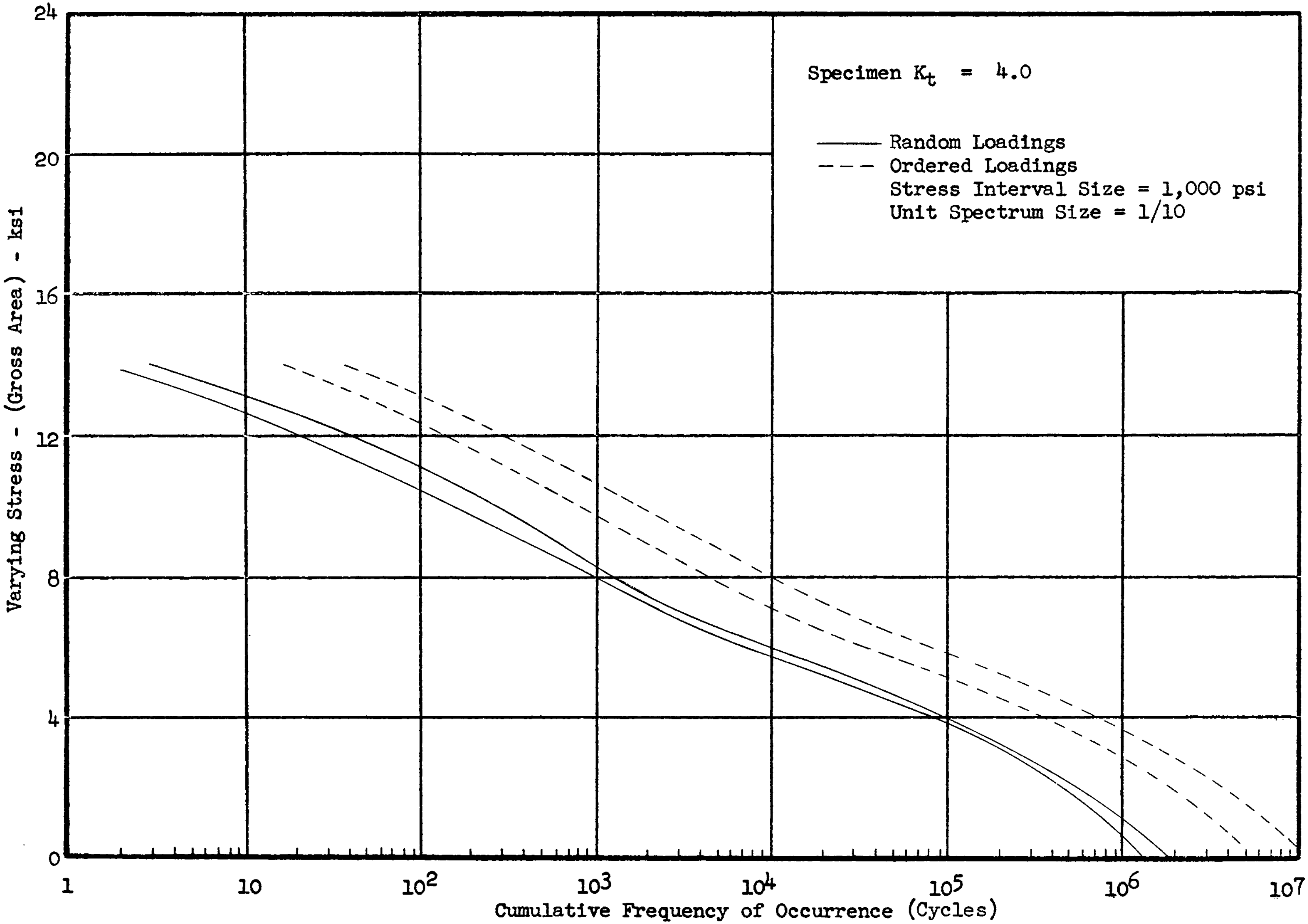


FIGURE 53 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED LOW PEAK GUST LOADING TEST DATA

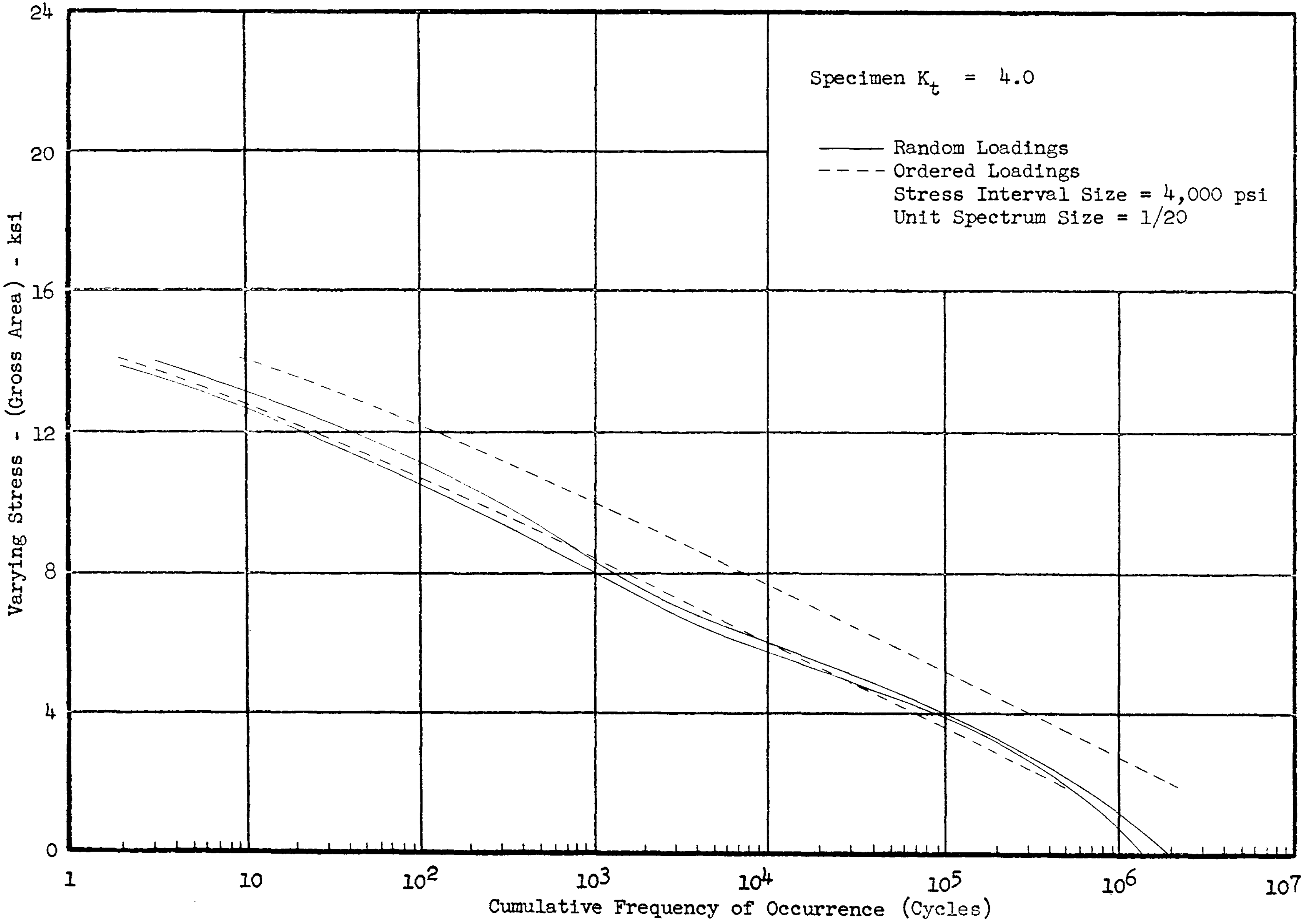


FIGURE 54 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED LOW PEAK GUST LOADING TEST DATA

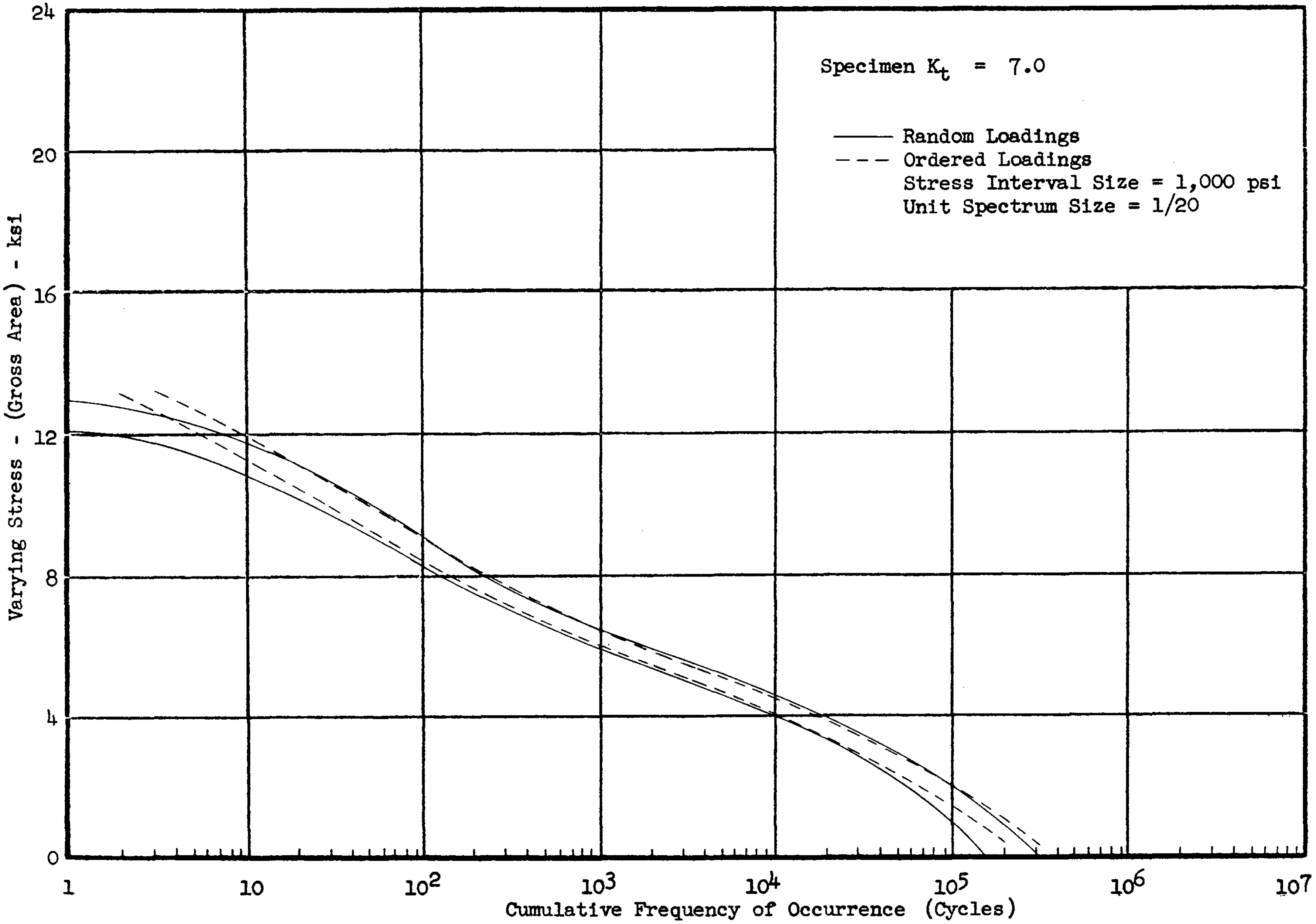


FIGURE 55 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED LOW PEAK GUST LOADING TEST DATA

but that the scatter was substantially larger. Figure 51 indicates that for specimens with $K_t = 7.0$ a good representation of the severity of the random loading trace was obtained when a stress interval of 1000 psi and a small unit spectrum was used.

For tests using low peak stress spectra, Figure 52 indicates that the ordered representation based on 1000 psi stress interval and small unit spectrum was significantly less severe than the random loadings being simulated. Figure 53 indicates that, for this low peak stress history, use of the larger unit spectrum reduced the severity still further. Figure 54 indicates that use of a 4000 psi stress interval improved the agreement with the random loading history but with a marked increase in scatter. Finally, Figure 55 indicates that for specimens with $K_t = 7.0$ the order of agreement with the random loading test histories is quite adequate when a 1000 psi stress interval and small unit spectrum was employed. For this last set of tests, the agreement shown by the graph is considered to be better than that indicated by the test ratio listed in Table 2.

As expected, the results of these experiments show that fatigue test results are affected by the choice of test variables. However, the results do not provide a clear definition of the best choice of the variables. Qualitatively the results suggest that an adequate representation of random gust loading histories which produce relatively high stresses has been attained. This representation was based on mean crossing peak count spectra applied using 1000 psi stress intervals and a small unit spectrum. For random gust loading histories which produce relatively low nominal stresses, this conclusion also applies to tests of specimens having a severe stress concentration. However, the results reported for such histories using specimens with $K_t = 4.0$ indicate that the ordered representations employed are substantially less severe than the random loadings being simulated.

It might be hypothesized that, in tests in which fairly high stresses are imposed, the reduction in effective stress concentration reduces the effect of those subsidiary load variations existing on the random trace which were ignored in obtaining the peak counts. In other words, when relatively high nominal stresses are produced by peak loadings, the importance of minor loadings is minimized. Conversely, in tests in which peak stresses of moderate magnitude are imposed, the modification of effective stress concentration is less complete and the effect of the subsidiary load variations existing on the random trace is significant. Since these subsidiary variations are not reflected by the peak count representation, their effect is not produced by the ordered loading patterns. Note that the agreement between ordered and random low peak stress test spectra for specimens with $K_t = 7.0$ was considered to be adequate. In terms of the hypothesis, this might be attributed to the greater relative effect of peak loadings of moderate severity on specimens having severe stress concentrations.

The hypothesis which has been advanced is quite tentative. Its implications in practical work should be explored in tests on relatively complex specimens.

The results reported in this section for random and ordered application of gust loadings will be used in the evaluation of more complex tests to be described in a later section.

SECTION V

COMPARISON OF RANDOM AND ORDERED MILITARY MANEUVER LOADING TESTS

Generation of Random Loading Tape

The data on gust loadings and on the course correction loadings on large cargo-transport type aircraft indicate that these loadings tend to oscillate about a substantially constant mean. However, for military fighter-trainer aircraft with high design load factors, the reported load history data are largely restricted to spectra of positive and of negative peak values of aircraft acceleration which are quite dissimilar. These dissimilar spectra usually represent the total flight loading history with no indication of the division of the history into gust and maneuver loading contributions.

Since the spectrum of negative accelerations is often quite mild, it is sometimes, as a matter of convenience, attributed entirely to gusts. This simplification is consistent with limited information supplied by loading traces. Traces showing the variation of acceleration in regularly produced maneuvers such as turns indicate that excursions below the 1g level are of relatively minor importance. These considerations have led to the fairly general practice of identifying all recorded positive trace excursions as due to maneuvers and representing them in fatigue work by loadings which extend above the 1g level. The 1g level is thus considered as a constant minimum value.

To investigate the effect of this type of loading pattern, the use of a suitable recording on magnetic tape was desirable. However, attempts to obtain a reasonably extensive service loading record on magnetic tape were not successful. It was necessary therefore to generate a trace.

To obtain a trace of adequate length having a range of excursion magnitudes but retaining reasonably representative trace characteristics, a gust loading trace previously employed in the investigation was selected and modified. Two modifications were made. The first modification effectively suppressed the negative excursions on the trace. This operation, performed by the use of a diode clipper produced the lack of symmetry conventionally attributed to military maneuver records. The type of trace obtained is illustrated on Figure 56. The second modification changed the relative frequency of occurrence distribution of peak magnitudes. In this operation the use of nonlinear amplification produced a distribution of peaks similar to that specified in the current (1960) version of specification MIL-A-8866.

To represent the content of this trace the positive peak value of each excursion from the 1g base was recorded, and the trace excursion amplitudes were arbitrarily converted to acceleration magnitudes. The spectrum obtained is shown on Figure 57. Although an exact matching of the specification spectrum was not essential for this investigation, this distribution is also shown for comparison.

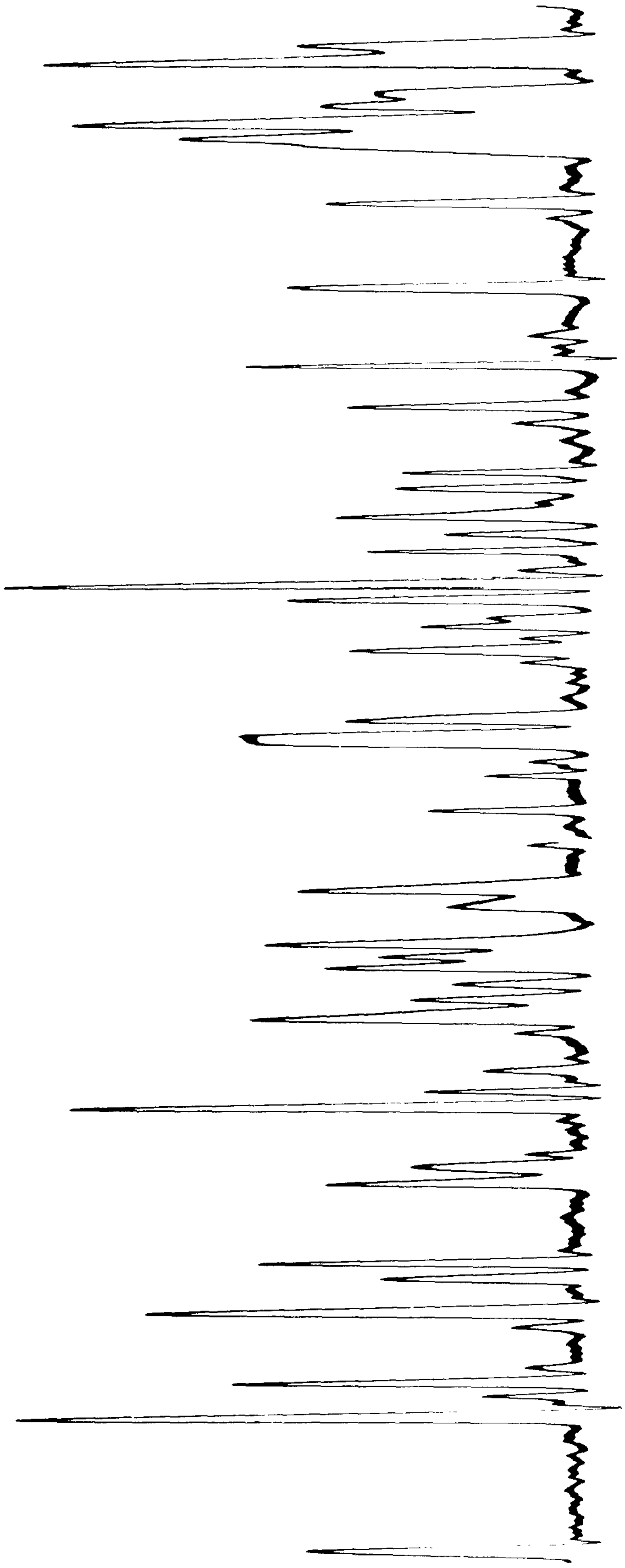


Figure 56 Sample of Random Military Maneuver Loading Trace

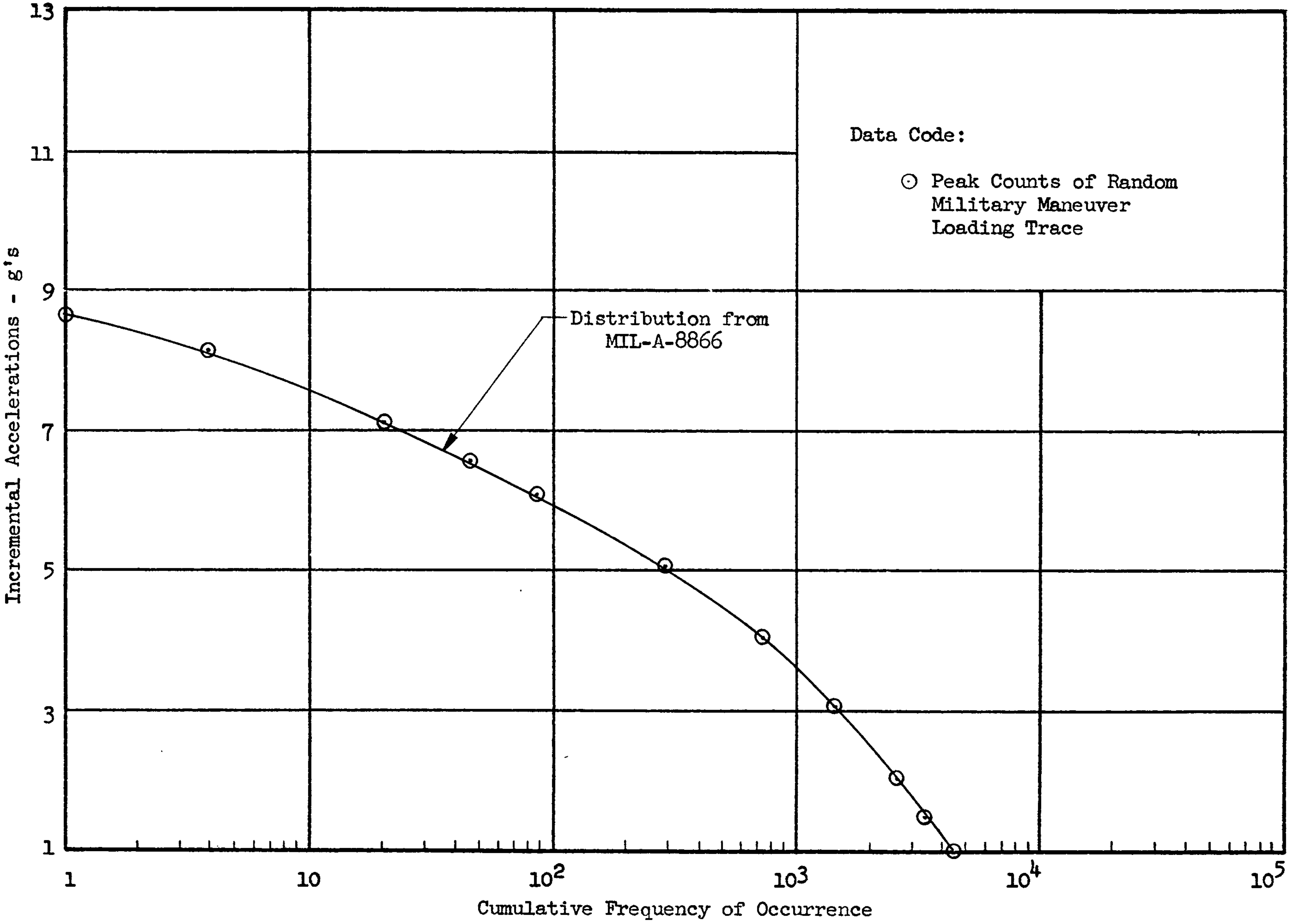


FIGURE 57 COMPARISON OF MILITARY MANEUVER LOADING SPECTRUM WITH DISTRIBUTION SPECIFIED IN MIL-A-8866 FOR CLASS "A" AIRCRAFT

Random Maneuver Loading Test Data

When the rate of maneuvering is moderate, the response of the structure may be assumed to be quasi-static and the acceleration history may be converted directly to a local loading history for at least some parts of the structure. Using this approach, it was assumed that the local 1g load produced a gross area stress of approximately 5450 psi and that the ratio of acceleration to nominal stress was constant. The use of this conversion factor indicated that an adequate maximum stress (approximately 47,000 psi) would be developed during the first application of the tape whose generation was described above. No provision for growth of the peak stress during repeated applications of the tape was required.

Using the selected acceleration to stress relationship to define the nominal, gross-area stresses to be developed in test specimens, the random maneuver loading trace was employed to obtain a set of test results. In these tests, one specimen geometry defined by $K_t = 4.0$ was used. The test loading histories are listed in Table 20 in Appendix V and are presented graphically on Figure 58.

Preparation and Use of Ordered Maneuver Loading Tapes

Two ordered maneuver loading tapes having unit spectra based on one-twentieth of the average random loading test life were produced. On one tape 1000 psi stress intervals were used while, on the second, 4000 psi intervals were used. These tapes were then employed in tests of specimens with $K_t = 4.0$. A sample section of a specimen loading trace is presented on Figure 59. The test loading histories obtained are listed in Tables 30 and 31 in Appendix V and are presented on Figures 60 and 61.

Evaluation of Test Data

To evaluate the test results, the number of repetitions of the unit spectrum endured by each specimen, the average number of repetitions for each group and the ratios of these average values to the target value of 20 are listed in Table 3. In addition, graphical comparisons of the test loading histories are presented on Figures 62 and 63. Both the tabulated values and the graphs show that the ordered peak count representations used in the tests were more severe in their effect than the random maneuver loadings. The range of test results for the two ordered loading groups is similar but the results when the stress interval was 4,000 psi are slightly less conservative than those for a stress interval of 1,000 psi.

Since the ordered representations did not reflect the subsidiary peaks on the random loading trace, the greater severity of the ordered representation was unexpected. This greater severity might be attributed to insufficient randomization of ordered loadings in tests in which the total number of loadings is small. To check this possibility, a substantially smaller unit spectrum could be used. However, time was not available for such an extension of the test work.

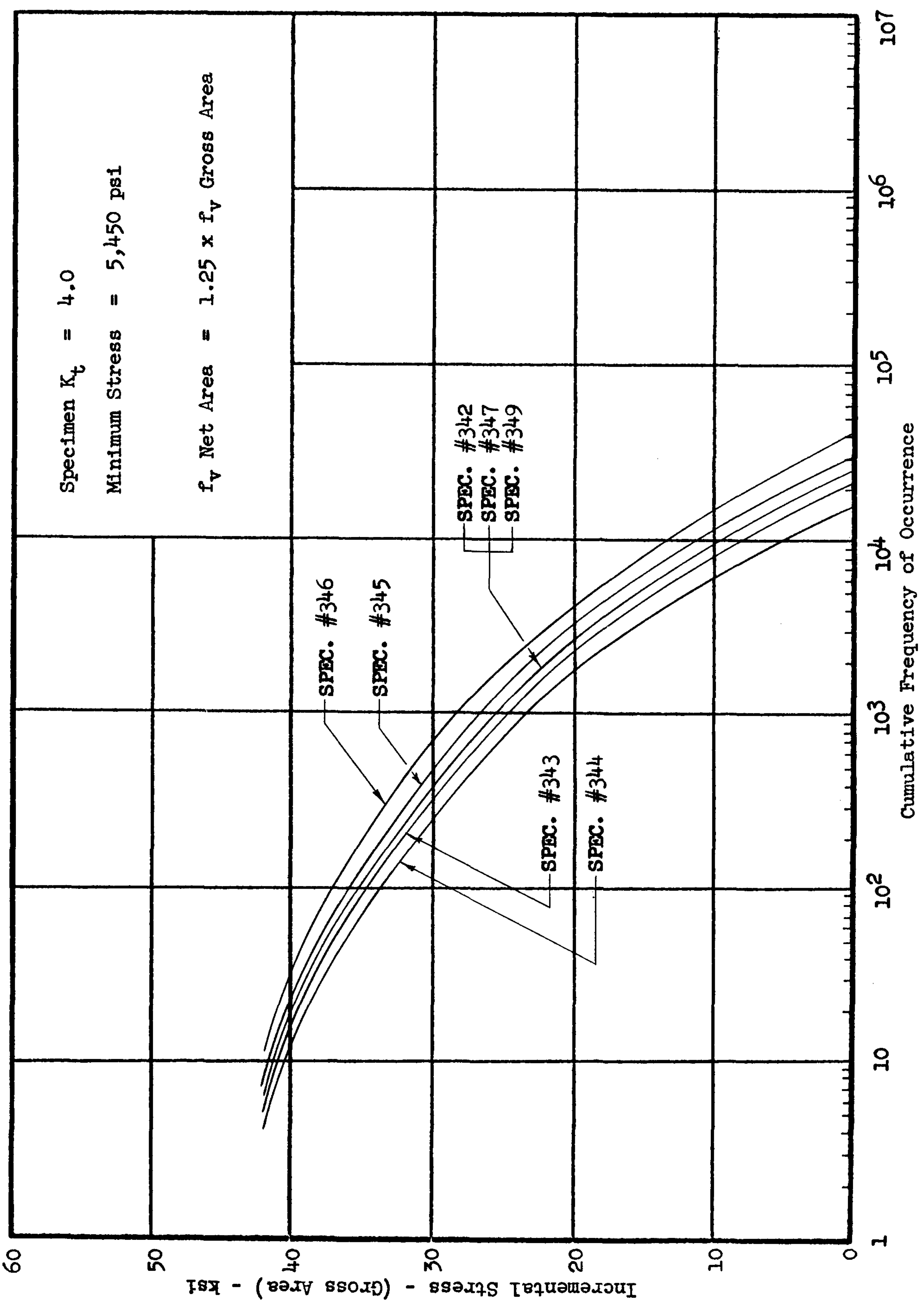


FIGURE 58 RANDOM MILITARY FLIGHT LOADING TEST DATA

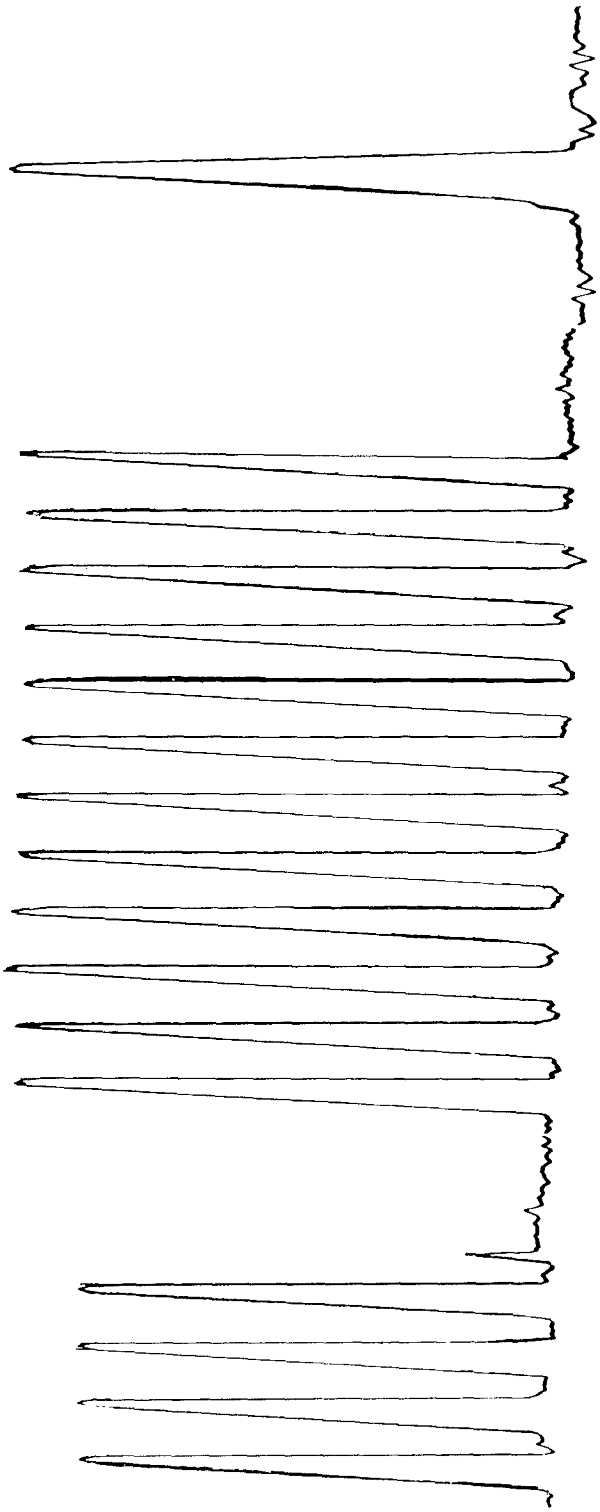


Figure 59 Sample of Ordered Military Maneuver Loading Trace

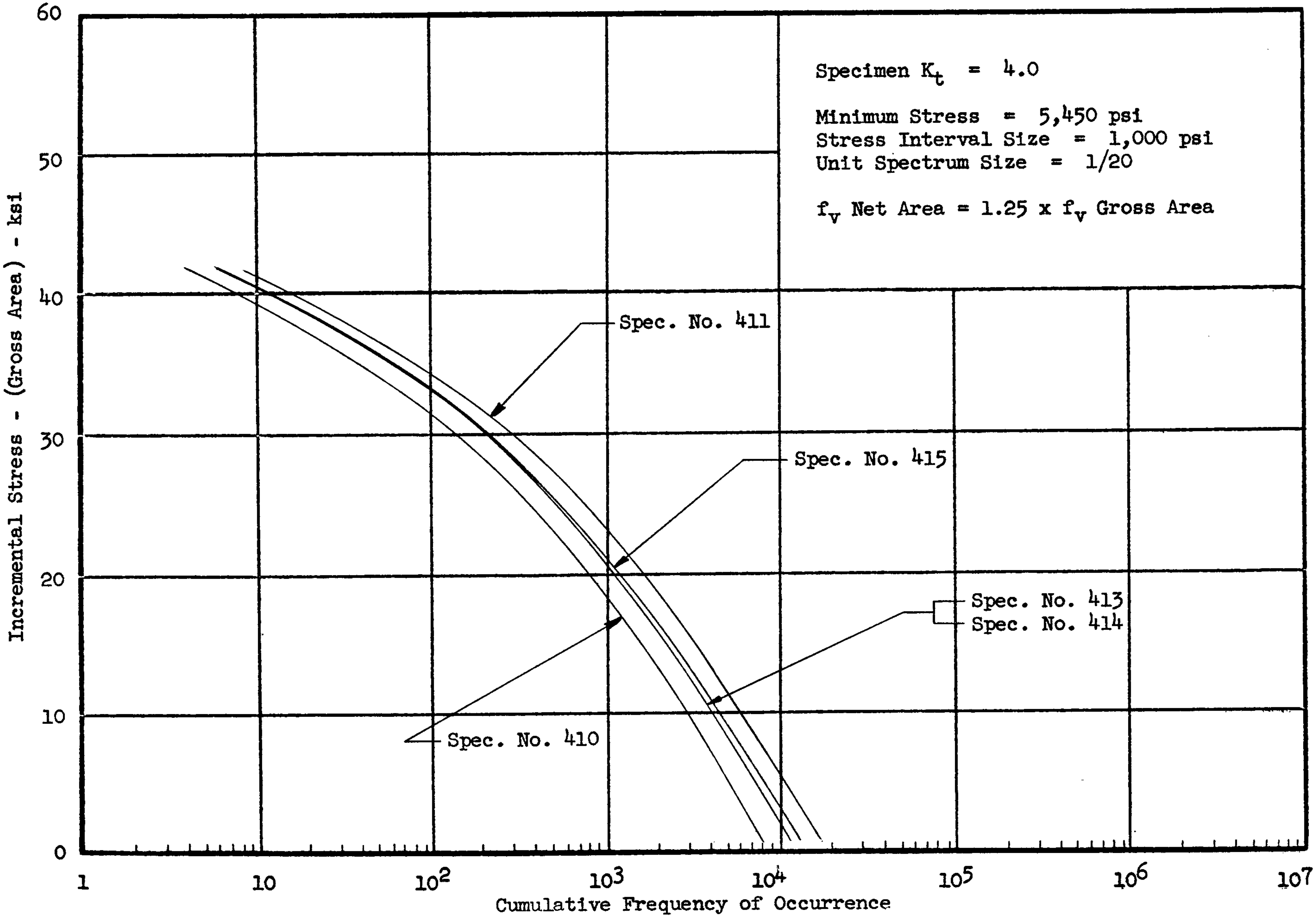


FIGURE 60 ORDERED MILITARY MANEUVER FLIGHT LOADING TEST DATA

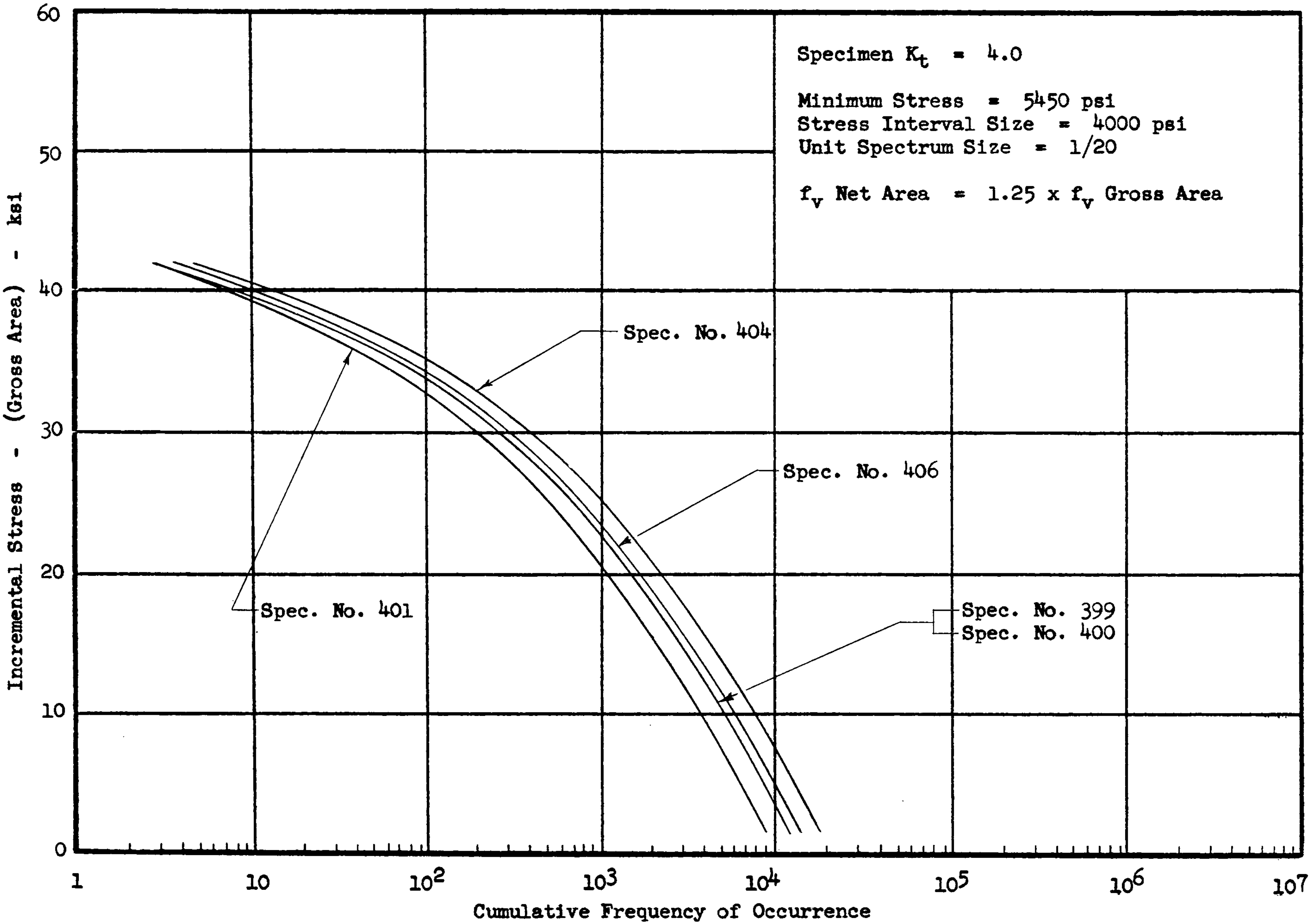


FIGURE 61 - ORDERED MILITARY MANEUVER FLIGHT LOADING TEST DATA

TABLE 3

COMPARISON OF ORDERED AND RANDOM MILITARY MANEUVER FLIGHT LOADING TEST DURATIONS BASED ON REPETITIONS OF UNIT ORDERED LOADING SPECTRA

Type of Loading	K_t	Stress Interval (psi)	Unit Spectrum Size	Specimen Number	Unit Spectrum Repetitions	Average Number of Repetitions	Target (1) Number of Repetitions	Ratic of Average to Target Number of Repetitions
Military Maneuver	4.0	1000	1/20	410	8.00	12.39	20	.620
				411	17.00			
				413	11.99			
				414	11.99			
				415	12.95			
		4000	1/20	400	11.99	12.99	20	.650
				401	9.00			
				404	17.99			
				406	13.95			

(1) Number of Unit Spectra Repetitions Required for Nominally Equivalent Random and Ordered Test Lives

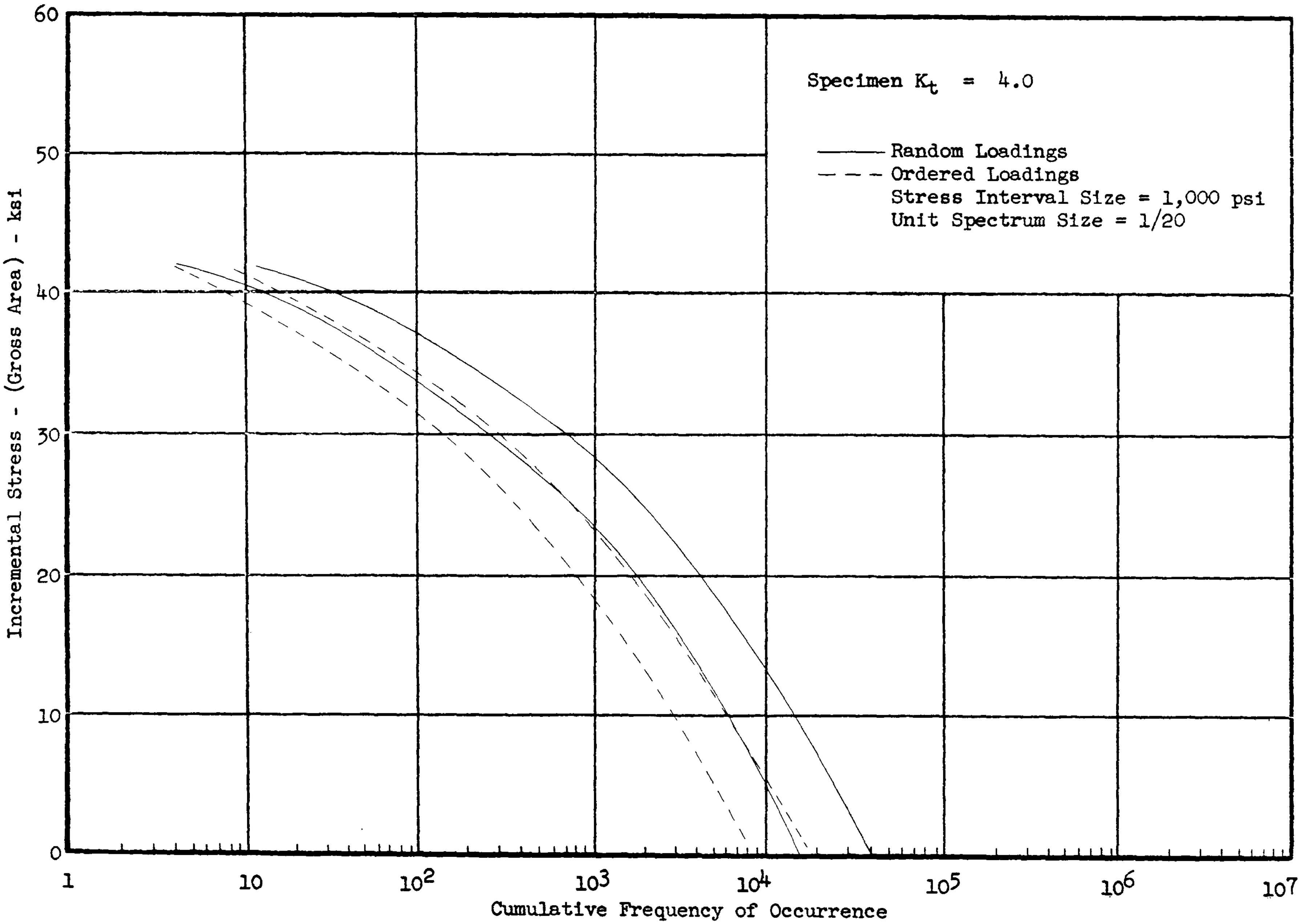


FIGURE 62 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED MILITARY MANEUVER FLIGHT LOADING TEST DATA

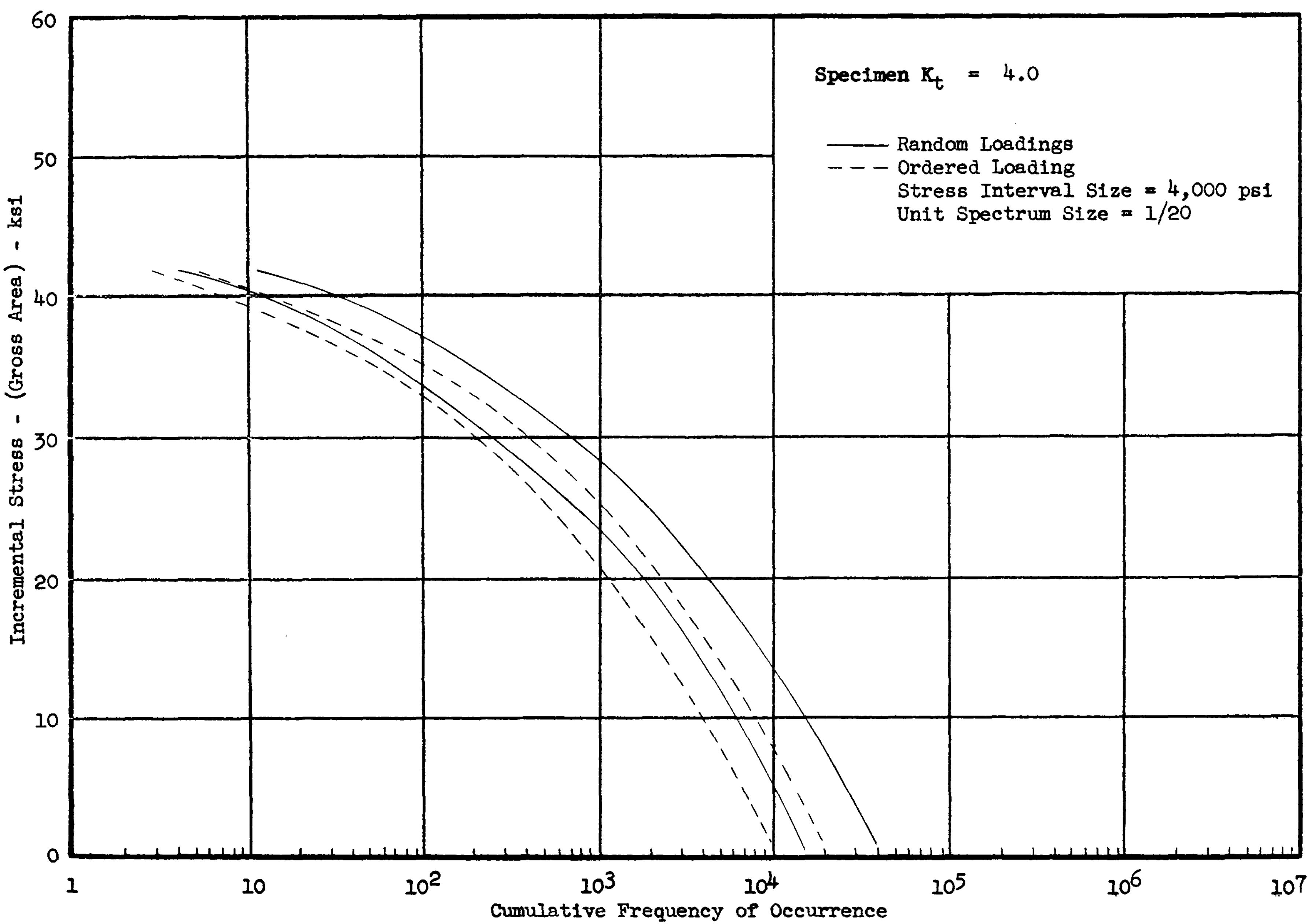


FIGURE 63 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED MILITARY MANEUVER FLIGHT LOADING TEST DATA

SECTION VI

COMPARISON OF RANDOM AND ORDERED GROUND LOADING TESTS

Random Loading Tests

Taxiway and runway loadings of airframe elements other than landing gear are sometimes assumed to have negligible importance. To obtain an indication by test of their importance and to provide a basis for comparative evaluations in later, more complex tests, the use of a suitable recording on magnetic tape was desirable. However, a search for such a recording was unsuccessful.

Since the general oscillatory character of ground loading records is similar to that of gust loading traces, such traces were adopted as adequate substitutes for service recordings of ground loadings. The traces used were those described in Section IV and employed in the evaluation of gust loading simulations. In the use of these traces, the relationship between signal voltage and specimen load was chosen to generate a reasonable representation of the incremental stresses produced in the wing root region of large aircraft. A constant mean stress of -3000 psi was selected.

The results obtained in prior use of the loading tapes which were reported in Section IV indicated that relatively long test lives could be anticipated. One specimen with $K_t = 4.0$ was tested for 65 hours without failure. This result coupled with the results reported in Section IV justified discontinuing tests of this specimen geometry. In tests of specimens with $K_t = 7.0$ test lives of moderate duration were obtained. The test results are listed in Tables 18 and 19 in Appendix V and are presented graphically on Figures 64 and 65.

Ordered Loading Tests

To represent the random loading histories attained for specimens with $K_t = 7.0$, ordered loading tapes were prepared. In this work the test condition variables were those which had produced adequate agreement of ordered and random test lives in previously reported tests of specimens with this value of K_t. One-twentieth of the average random loading test history was represented by a spectrum using 1000 psi stress intervals. The test results obtained by use of this tape are listed in Table 29 in Appendix V and are shown graphically on Figure 66.

Evaluation of Test Data

An evaluation of the test results is presented on Figure 67. This figure shows a deficiency in the match of ordered to random loading spectra but indicates that the ordered loadings were somewhat less severe than the random loadings. The ratio of ordered to random loadings lies in the region 1.0 to 2.0. Considering the marked reduction in the peak stresses developed in these tests as compared with those developed in previous tests of specimens with $K_t = 7.0$, the results obtained are consistent with the hypothesis advanced in Section IV

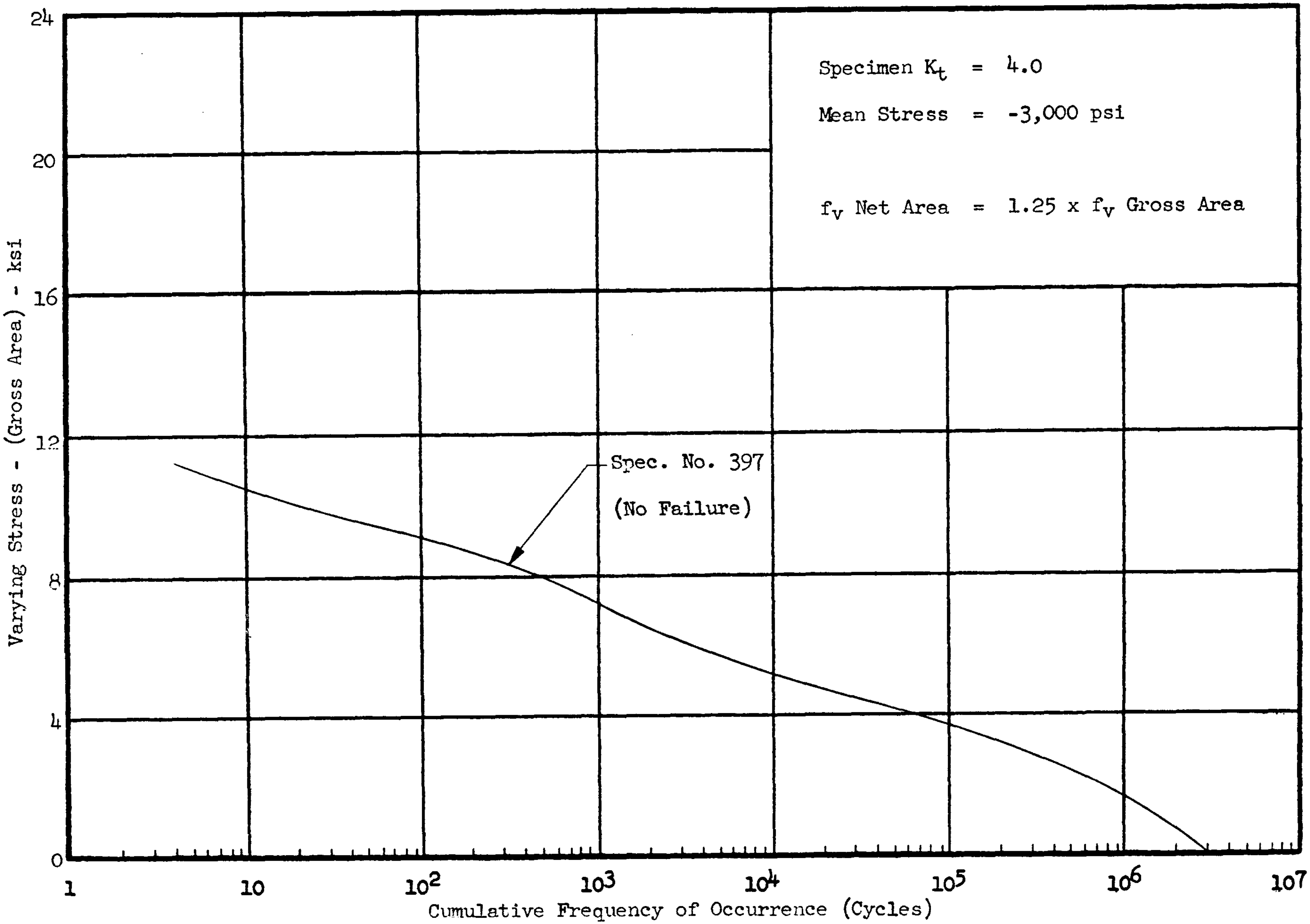


FIGURE 64 RANDOM GROUND LOADING TEST DATA

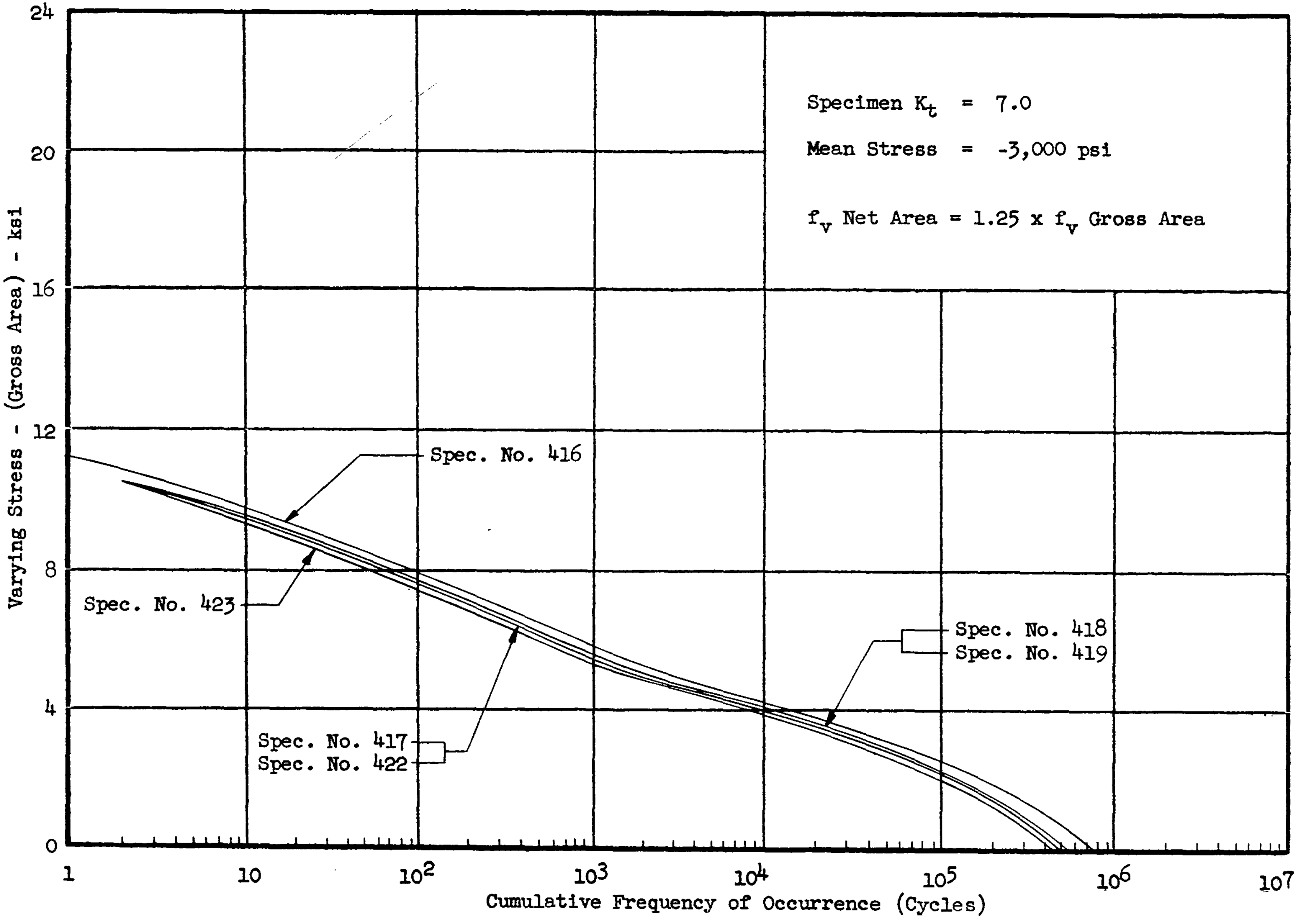


FIGURE 65 RANDOM GROUND LOADING TEST DATA

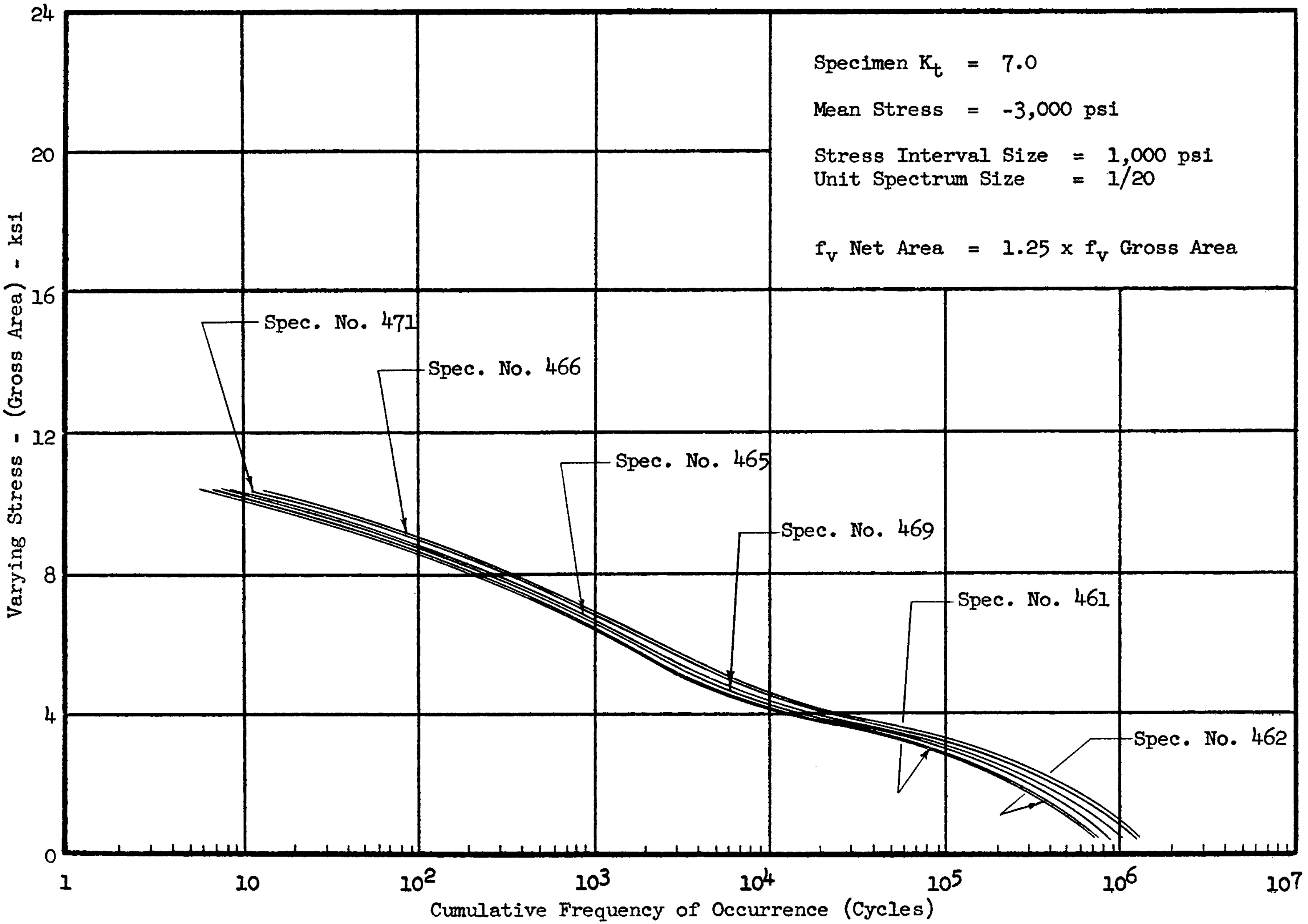


FIGURE 66 ORDERED GROUND LOADING TEST DATA

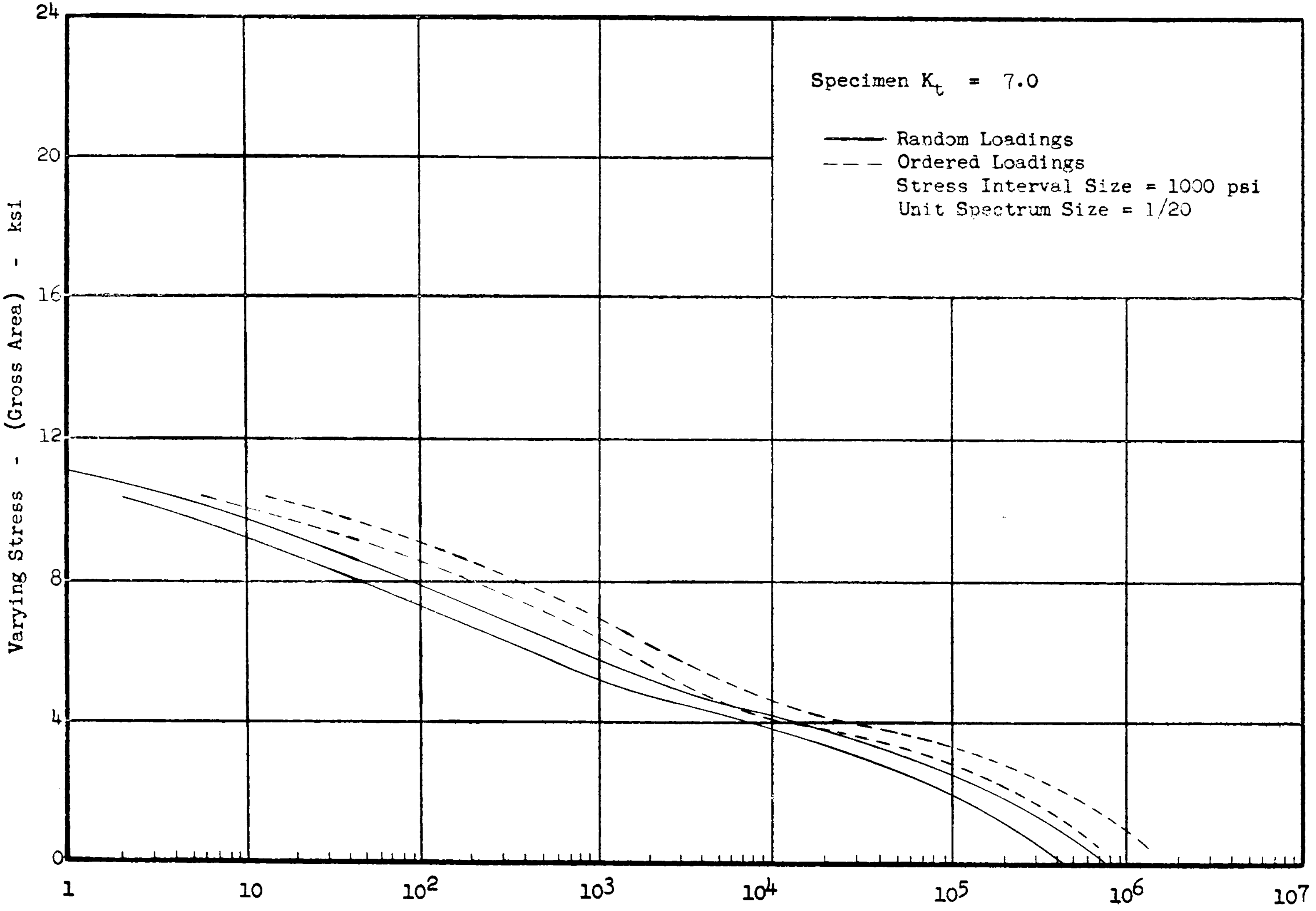


FIGURE 67 - COMPARATIVE ENVELOPES OF RANDOM AND ORDERED GROUND LOADING TEST DATA

SECTION VII

COMPARISON OF RANDOM AND ORDERED COMPOSITE LOADING TESTS

(Gust Loadings in Flight)

Generation of Random Composite Loading Test Histories

In fatigue evaluations of airframe structures, different phases of service operation distinguished by substantially different mean loads must be considered. In carrying out tests it is often assumed that each phase can be separately represented and that the transitions between phases can be ignored when they are relatively small or can be grouped to define distinct loading patterns effectively divorced from the main phases. For example, the transition in loading condition during takeoff of an airplane when the support of the vehicle is transferred from the landing gear to the lifting surface and the corresponding transition during the landing run is defined as the ground to air cycle. This term implies that the ground to air transition at the beginning of a flight and the air to ground transition at the end of the flight can be coupled to define a single cycle. This cycle is then treated independently of the ground and flight loadings which occur between each transition.

The significance of this large transition and its proper representation in tests has been the subject of considerable discussion. One difficulty has been posed by the lack of general agreement on the definition of the cyclic magnitude. The magnitude might be defined by the total range from the largest negative peak during ground operation to the largest positive peak encountered during a "representative" flight. This description of a flight is imprecise and its use can lead to the definition of a range of cycle magnitudes. Since the cycle is relatively large, small variations in its definition can indicate large changes in its significance.

In addition to the rather arbitrary nature of the definitions of ground to air cycles, a more fundamental aspect of the problem is the assumption that the effects of several groupings of service loadings are linearly cumulative. This convenient assumption has not been investigated by tests although many fatigue investigations have demonstrated a basic non-linearity of fatigue damage growth.

To explore this important and very practical aspect of fatigue work, the extended master random gust loading tapes developed for the tests reported in Section IV were used. In this use, the transitions described above were simulated by generating a flight-by-flight loading history. This history was generated by applying a series of varying ground loadings acting about the appropriate ground mean load, a transition to a flight load mean, a series of gust loadings acting about this mean, a transition to the ground loading mean and then repetitions of the sequence.

Since the oscillatory character of both flight and ground loading traces is similar, a single copy of the master random loading tape could be used to produce both ground and flight loading histories. In the use of this tape an electronic switching device was employed. This device, which is described in Appendix I , produced the change in mean load which separates ground and flight phases. With each such change the amplification of the dynamic or varying signal was also changed. In each group of tests, the amplification for each flight loading sequence was the same as that previously employed in a corresponding group of simple flight loading tests reported in Section IV. Similarly, the amplification for each ground loading sequence was the same as that employed in the ground loading tests reported in Section VI. With this arrangement, a length of the tape controlled the application of a series of ground loadings, the next length of tape controlled the application of a series of gust loadings, the next length controlled a series of ground loadings and so on. The history of each type of loading therefore represented a repeated sampling of short lengths of the master tape. A sample trace showing the general character of the flight-by-flight loadings is shown on Figure

In setting up the composite loading tests, data previously obtained during the simple gust loading and ground loading tests were used to obtain estimates of the test durations to be anticipated. In this work the ground to air cycle was defined by the change from the mean load on the ground to the mean load in flight and return. This range is more specifically defined in practical work than other ranges which have been suggested. The estimates employed the conventional assumption of direct, linear summation of the effects of flight loadings, ground loading and ground to air cycles. They indicated that very long test times would be developed for the least severe combination of loading histories to be investigated and indicated that, for the shorter test times of the more severe combinations, the number of transitions produced would not be adequate for an assessment of their importance. These estimates led to the conclusion that the number of loadings per flight should be reduced to a minimum consistent with clear resolution of the flight phases on the specimen load history tapes. In addition, the data reported in Section VI indicated that the relative importance of ground loadings in these tests was small. Test time could therefore be conserved by minimizing the number of loadings in each ground loading phase. These decisions led to the application of flight loadings for approximately 1.07 seconds providing approximately 13 gust cycles per flight, then a transition requiring approximately 0.03 seconds followed by the application of ground loadings for approximately 0.57 seconds. The total test time to represent one flight was therefore approximately 1.70 seconds. This pattern of loadings was shown on Figure 68.

Using this pattern, a series of fatigue tests was undertaken. In this series, high peak and low peak gust loading histories were each employed with ground loadings in tests of specimens with $K_t = 4.0$ and 7.0. The results obtained are listed in Tables 32, 34, 35 and 36 in Appendix V and are presented graphically on Figures 69, 70, 71, and 72.

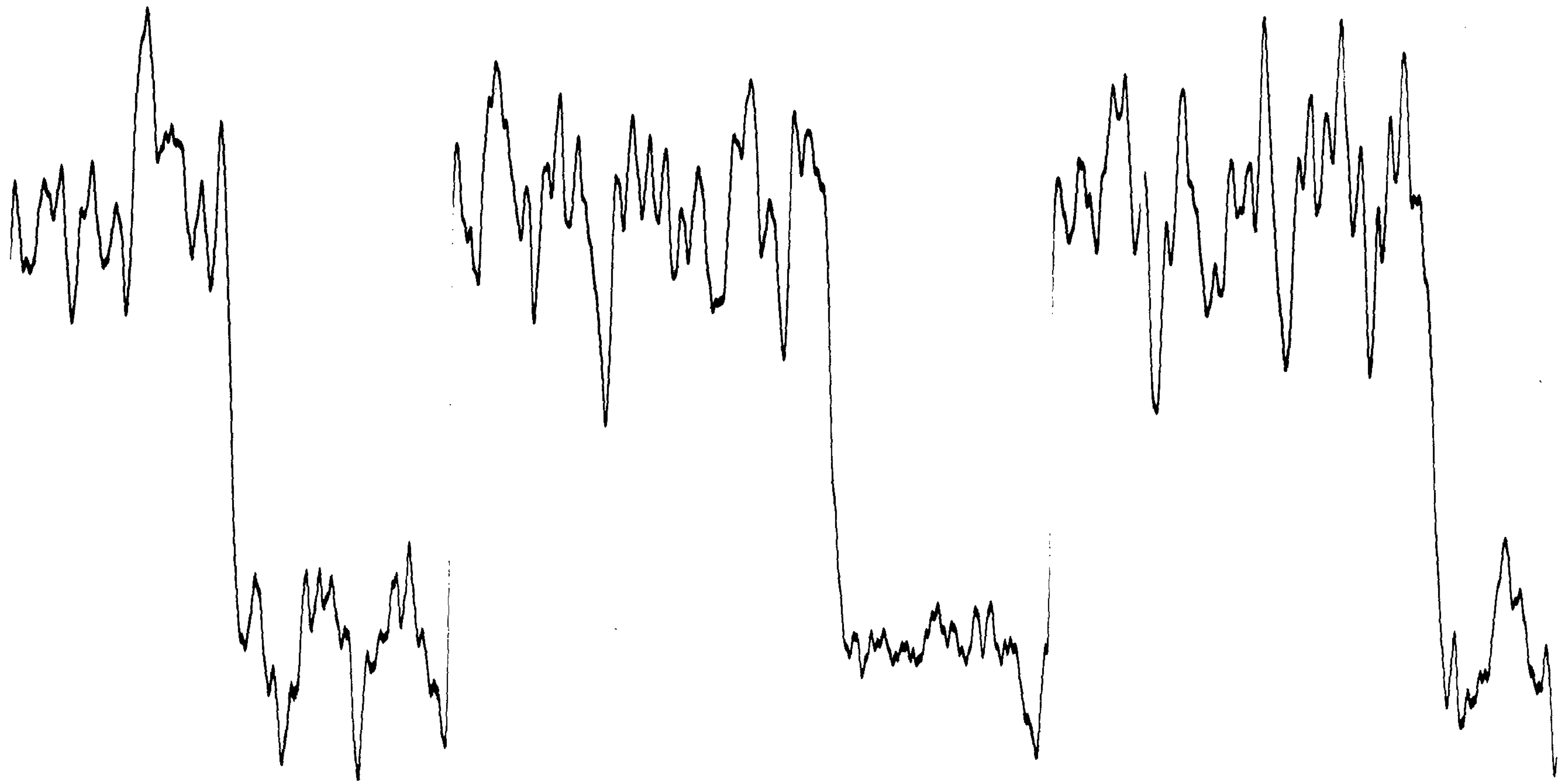


Figure 68 Sample Random Loading Trace - Composite of Gust and Ground Loadings

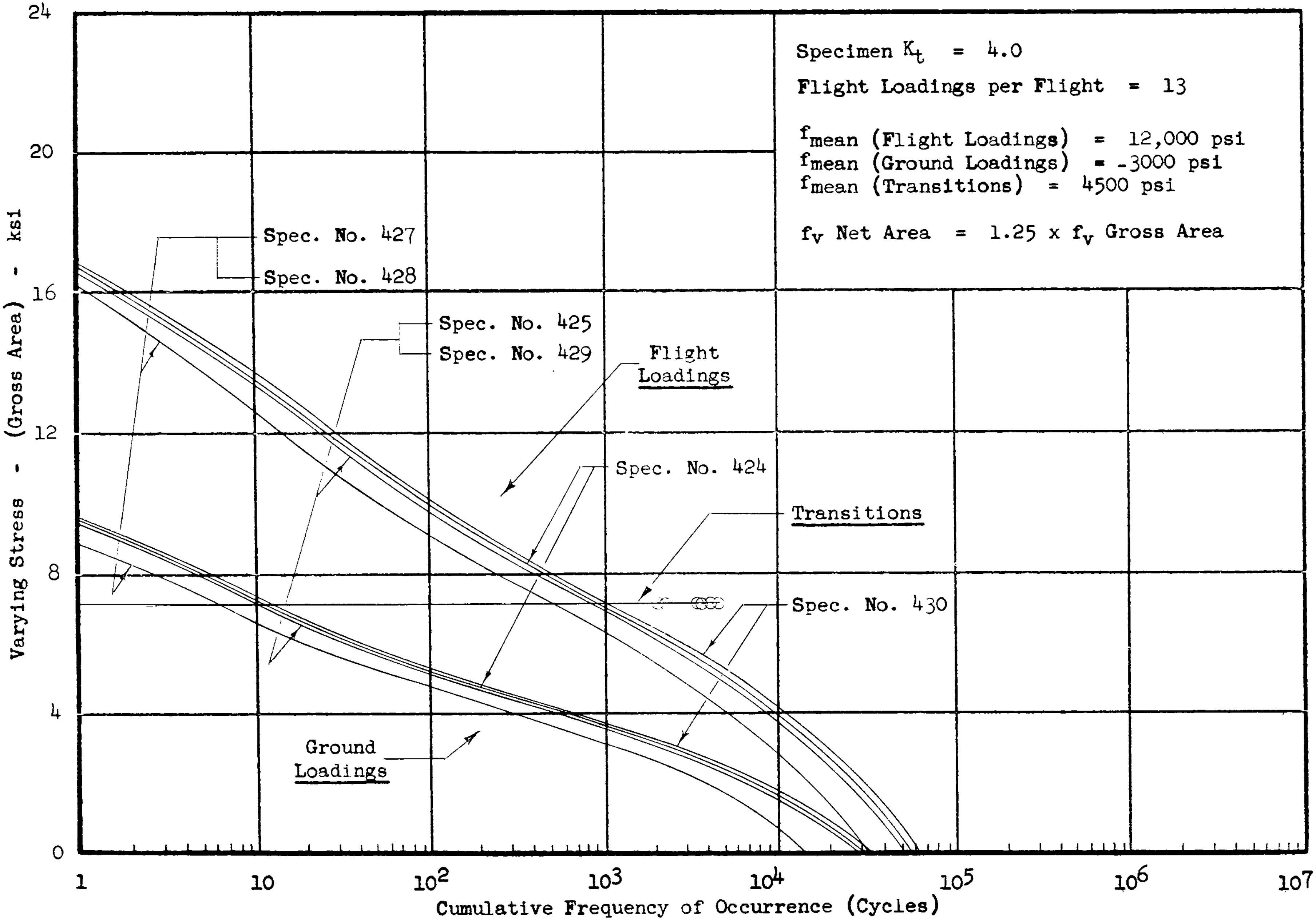


FIGURE 69 RANDOM COMPOSITE LOADING TEST DATA (HIGH PEAK GUST LOADINGS IN FLIGHT)

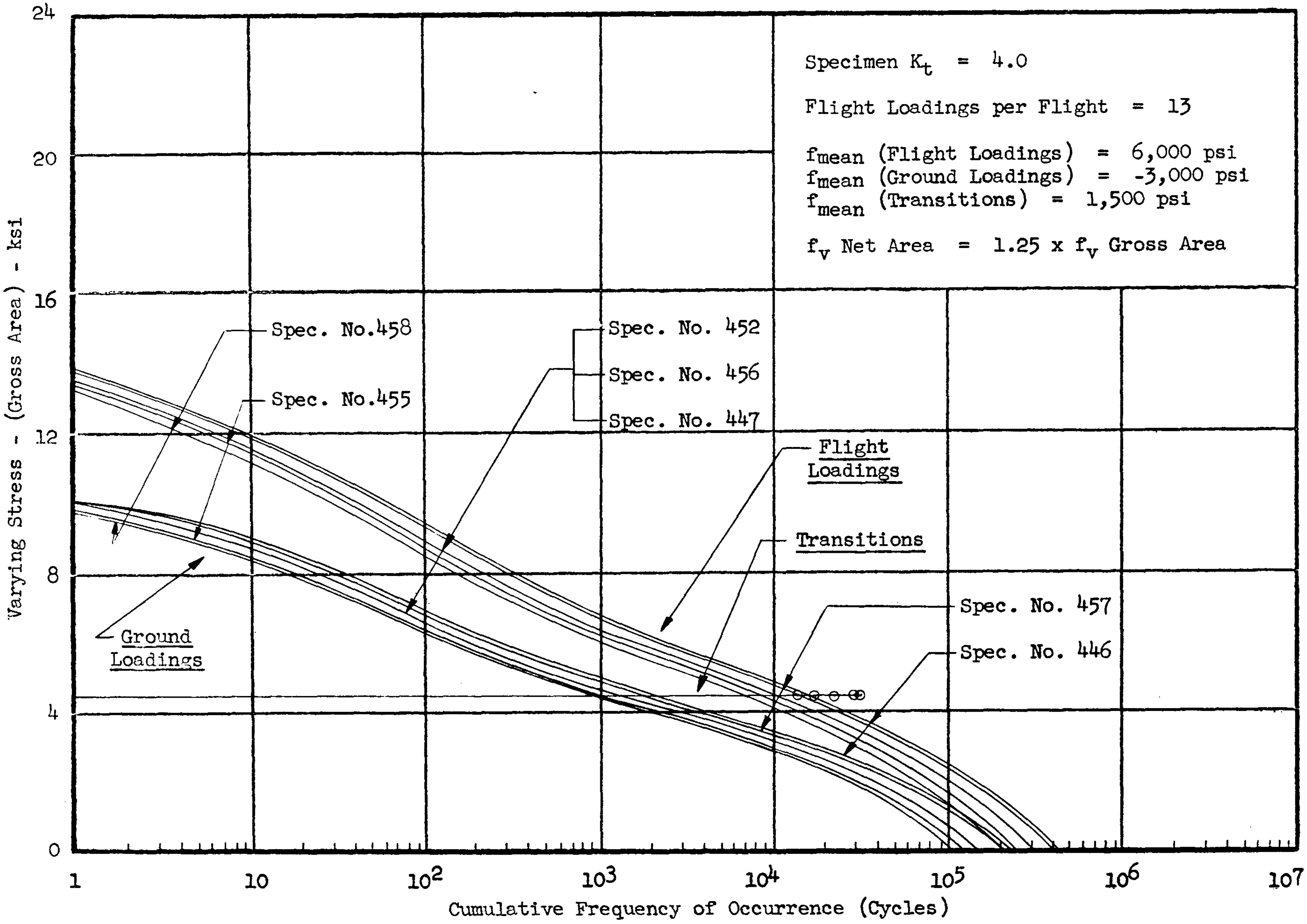


FIGURE 70 RANDOM COMPOSITE LOADING TEST DATA (LOW PEAK GUST LOADINGS IN FLIGHT)

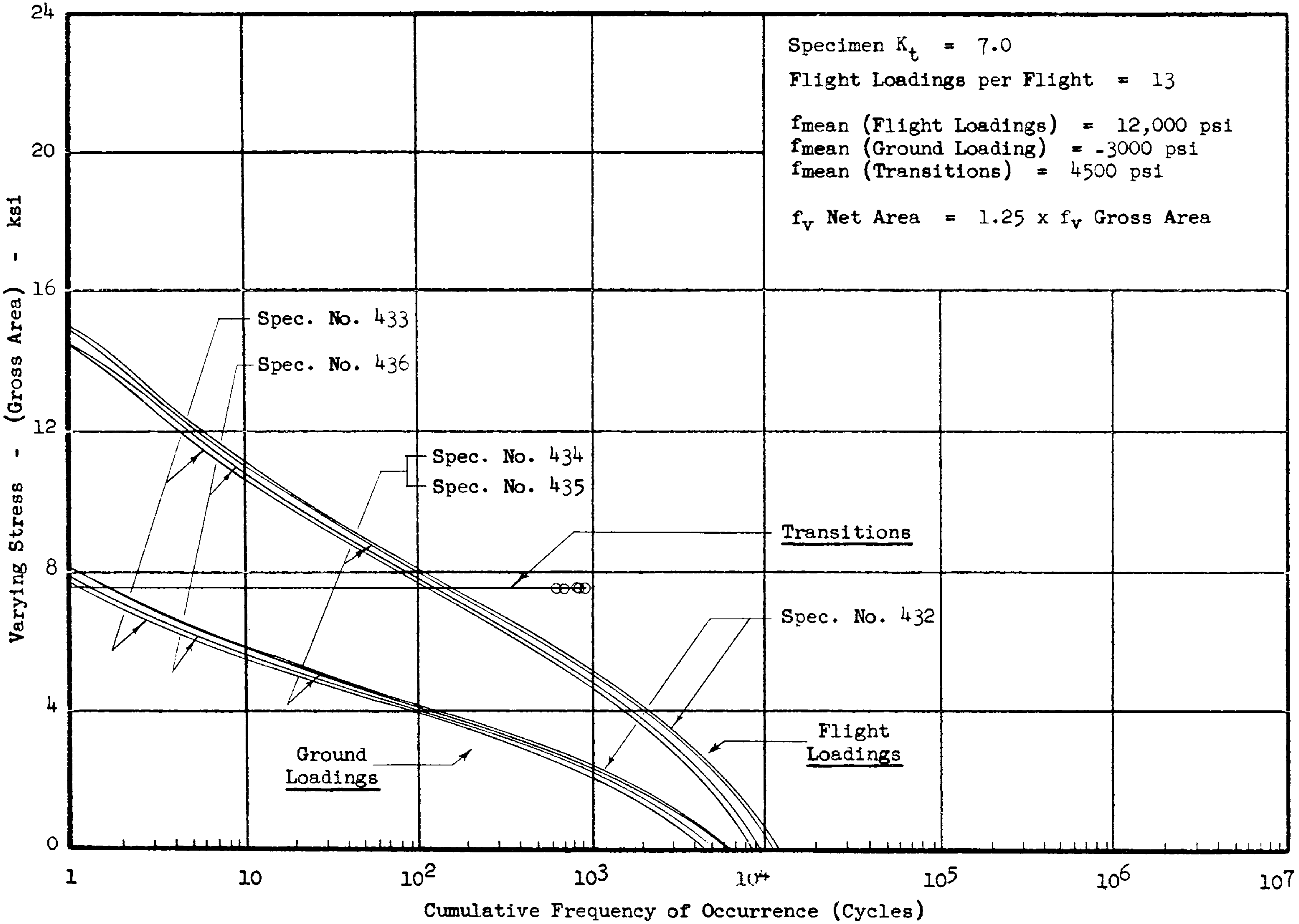


FIGURE 71 - RANDOM COMPOSITE LOADING TEST DATA (HIGH PEAK GUST LOADINGS IN FLIGHT)

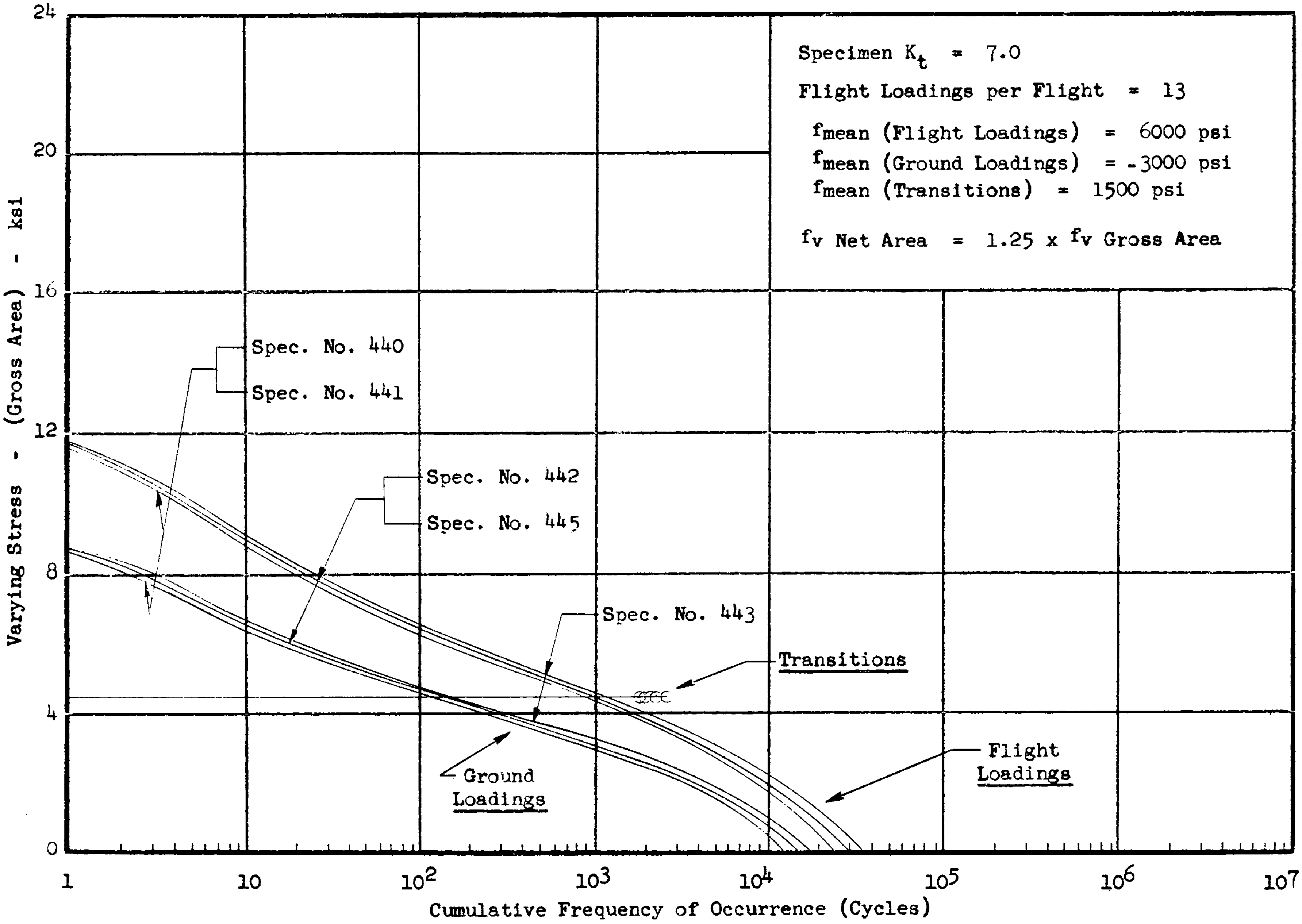


FIGURE 72 - RANDOM COMPOSITE LOADING TEST DATA (LOW PEAK GUST LOADINGS IN FLIGHT)

These descriptions of the test lives were based on the spectra reported for the master loading tape. In the application of this tape in these composite loading tests, a sampling of each component length of trace was obtained. During each of several repetitions of a component length, the first segment of trace selected by the switching device was different. Since the length of each segement is small, this change in the portions of the trace selected to represent flight loadings will provide a complete scanning of each component tape in a relatively small number of repetitions. The total time of application of flight loadings during a composite test then defines a spectrum. This spectrum is the same as that defined for the same length of time in a test in which the loadings were applied without interruption.

This use of the basic spectra for the master random loading tape is justified only when a reasonable number of repetitions of the component tapes in the master tape series is obtained in a test. This number of repetitions was not considered to have been attained in the short test times of the high peak stress composite loading tests of K_t = 7.0 specimens. The descriptions in tabular and graphical form of this set of random loading tests were not therefor considered to provide an adequate basis for the construction of ordered loading simulations. They are presented in this section nevertheless as an indication of the effect in such tests of the combination of several component loading histories.

The long test lives anticipated in several of the random loading tests did not materialize. Rather, the test lives were so short that the effect of the transitions appeared to be the predominant one. The test work was therefor extended. In this extension, the test time during which the high peak gust loadings were applied was increased to approximately 9 seconds providing approximately 110 gust cycles per flight. One group of these tests carried out on specimens with K_t = 4.0 was completed. The results of these tests are also tabulated in Appendix V and presented graphically on Figure 73.

Generation of Ordered Composite Loading Test Histories

To assess the adequacy of conventional groupings of flight loadings, ground loadings and ground to air cycles in fatigue tests, tapes containing ordered loading representations of the random composite test histories were prepared. The preparation followed the general pattern established in earlier work. For each group of random loading tests, one-twentieth of the average random loading history of flight and of ground loadings established a unit spectrum of each type of loading. These spectra were represented using stress intervals of 1000 psi. To represent the ground-air-ground transitions in the random loading tests, the change in mean load values was adopted and a block of cycles having this range was selected. In each such block the number of ground to air cycles was equal to one-twentieth of the average number of "flights"

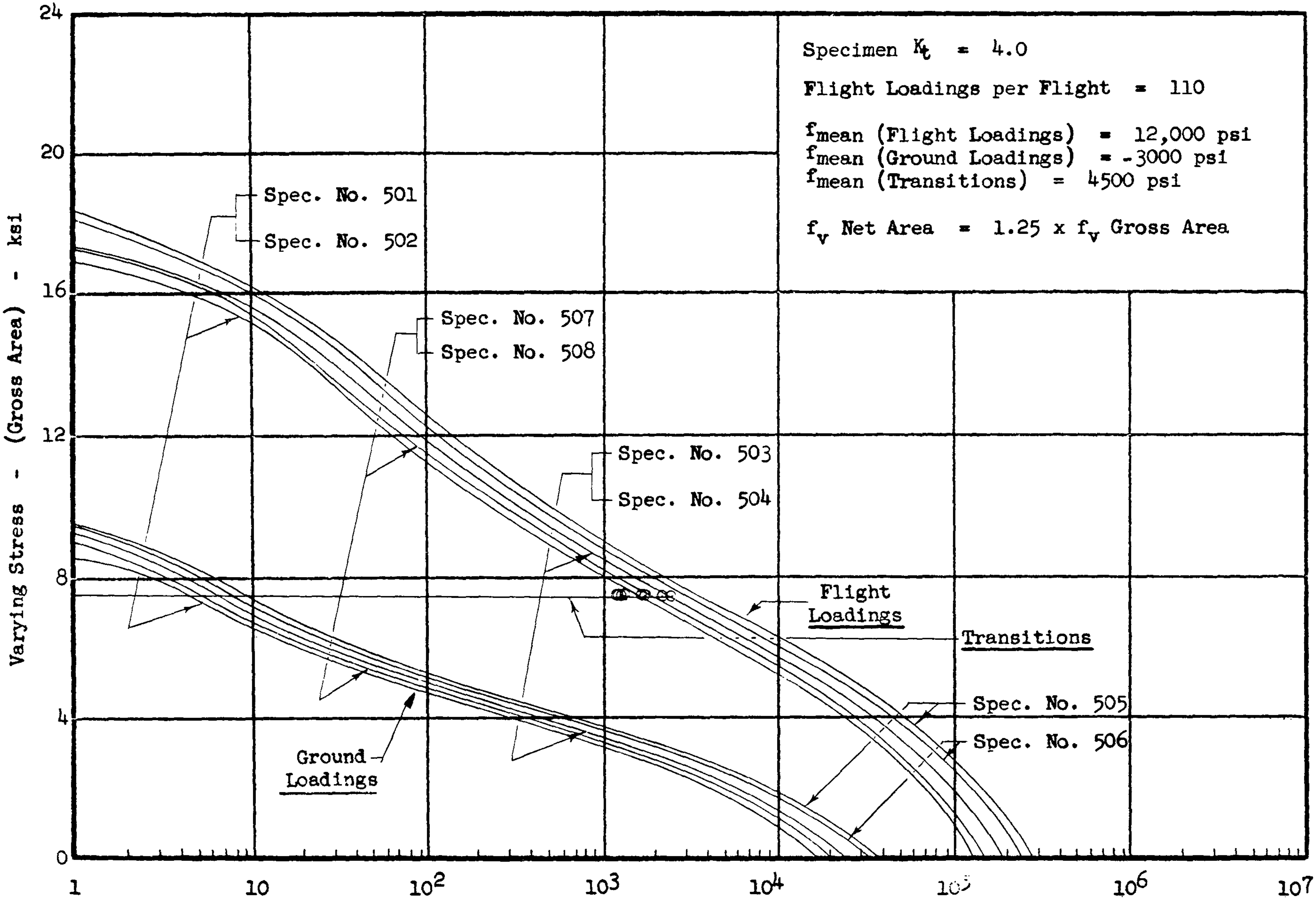


FIGURE 73 - RANDOM COMPOSITE LOADING TEST DATA (HIGH PEAK GUST LOADINGS IN FLIGHT)

attained in the random loading tests. A sketch illustrating this grouping of loadings and showing the sequence in which they were applied is shown on Figure 74. As in earlier tests the growth of peak magnitudes was represented by appropriate additions to the unit loading spectra.

The retention in this phase of the investigation of the one-twentieth unit spectrum and 1000 psi stress interval was considered to be justified on two counts. First, the need for comparative data dictated the choice of a combination used in earlier tests. Second, the qualitative evaluation presented at the end of Section IV indicated that the most suitable choice of a single combination of these variables had been made.

The ordered loading tapes were employed to obtain the fatigue test results listed in Tables 38, 39, 40, and 41 in Appendix V and presented graphically on Figures 75, 76, 77, and 78. Note that the ground loading spectra shown in Figure 76 resulted from an incorrect representation of the spectra applied in the corresponding random loading tests.

Evaluation of Test Data

The random loading test data provide the best available information on the effect of the large transitions in loading conditions which occur once per flight. To aid in interpreting these data, use will be made of the results obtained in tests in which only random gust loadings or random ground loadings were applied. These tests describe the potential of the specimens under the action of a single type of loading. The ratio of the flight loading histories obtained in the composite loading tests to the flight loading histories obtained in the simple tests will then be calcualted. This ratio will be assumed to define the fraction of total fatigue damage in the composite loading tests which can be attributed to flight loadings. The contribution of the ground loadings will be similarly assessed and the remainder of the damage must then be attributed to the transitions.

The results obtained when calculations based on these assumptions were made are shown in Table 4. The indicated contribution of the transitions is seen to be quite high for those tests in which the number of gust loadings per flight is small. For the group of tests in which a substantially larger number of gust loadings per flight were applied, the contribution attributed to the transitions is smaller but still substantial. These results emphasize the dependence of the relative importance of transitions on the number and severity of gust loadings per flight.

This effect is also illustrated on Figure 79. The figure shows the increase in the spectra of gust loadings as the number of such loadings per flight increases. The trend shown on the graph indicates that when the number of gust loadings per flight becomes large, the gust loading history can be expected to approach the potential defined by tests in which only gust loadings are applied. This trend is more clearly defined in Figure 80 and the resulting effect on the number of "flights" is shown on Figure 81.

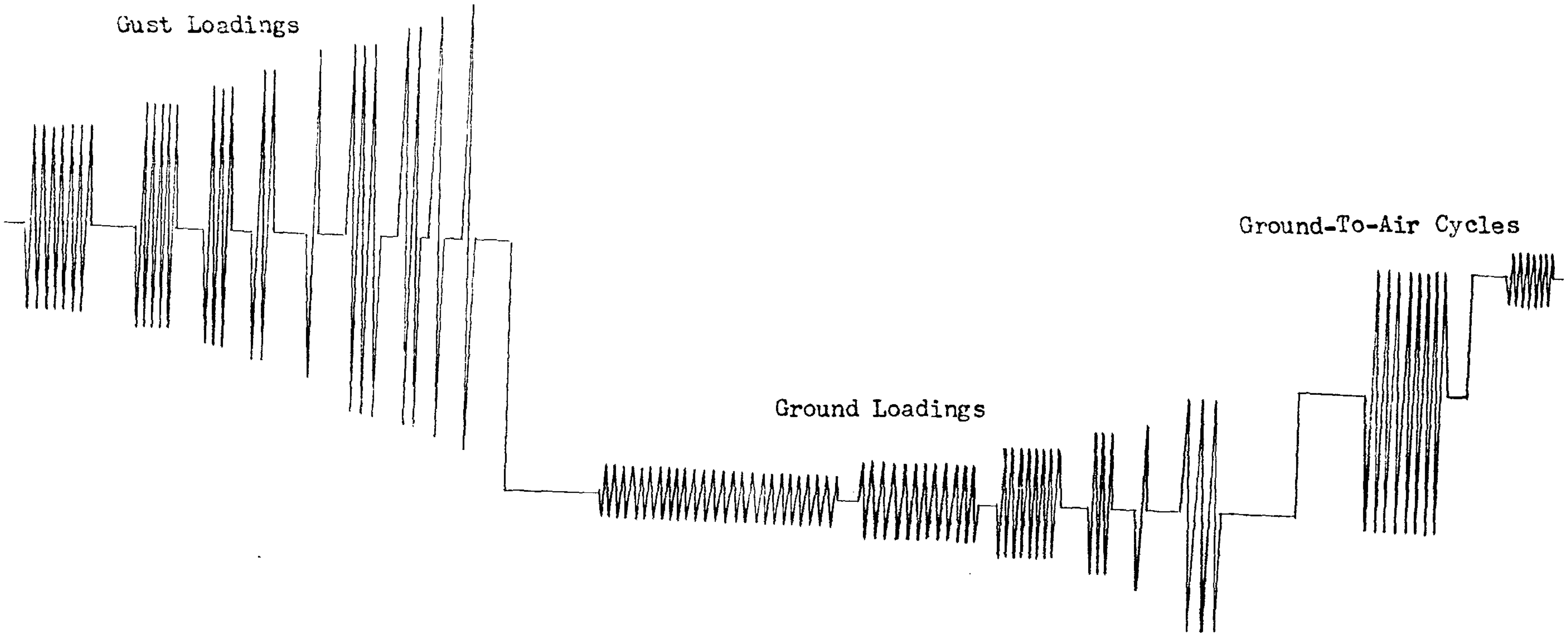


Figure 74 Schematic Representation of Ordered Loading Trace — Gust and Ground Loadings plus Ground-to-Air Cycles.

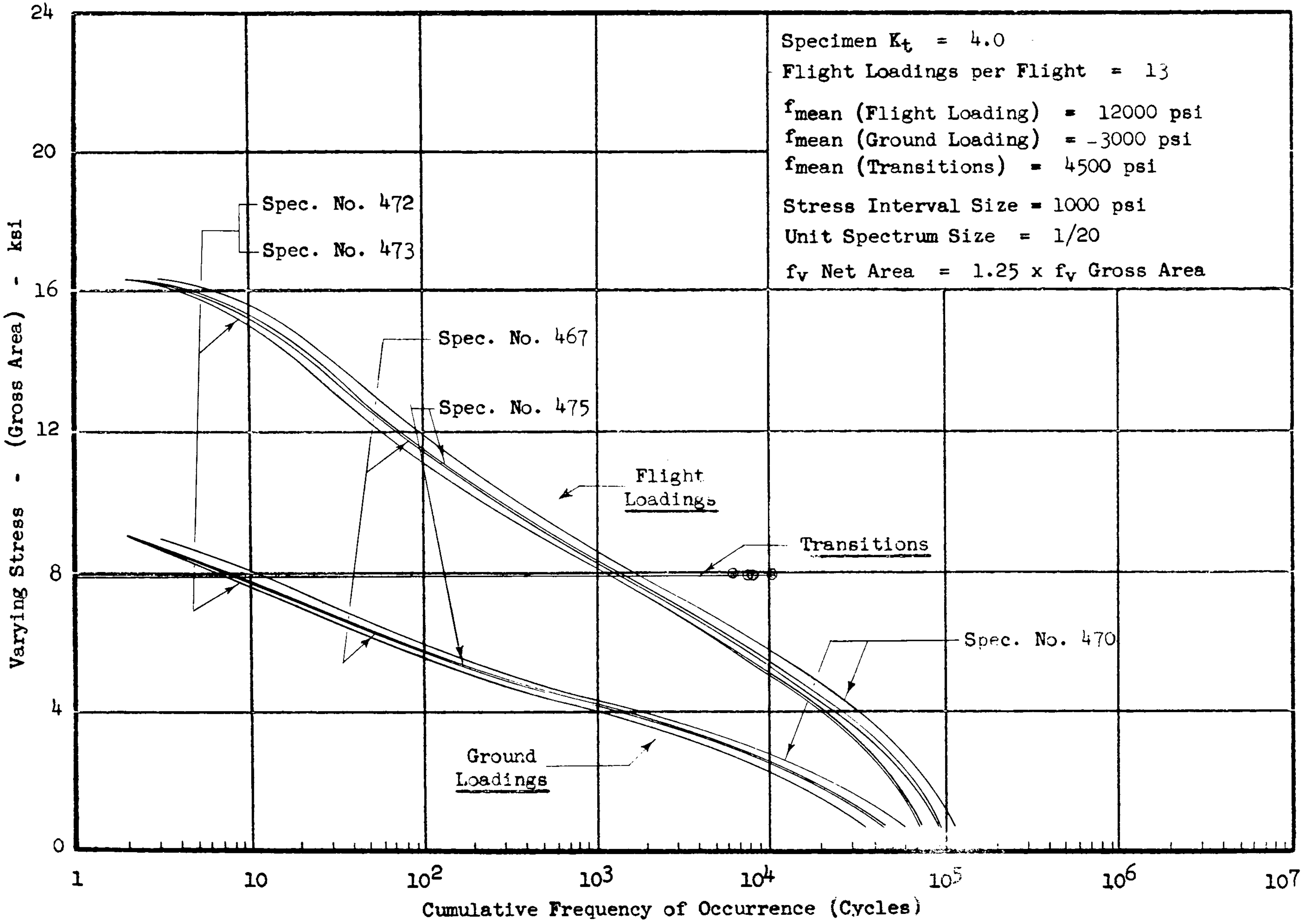


FIGURE 75 ORDERED COMPOSITE LOADING TEST DATA (HIGH PEAK GUST LOADINGS IN FLIGHT)

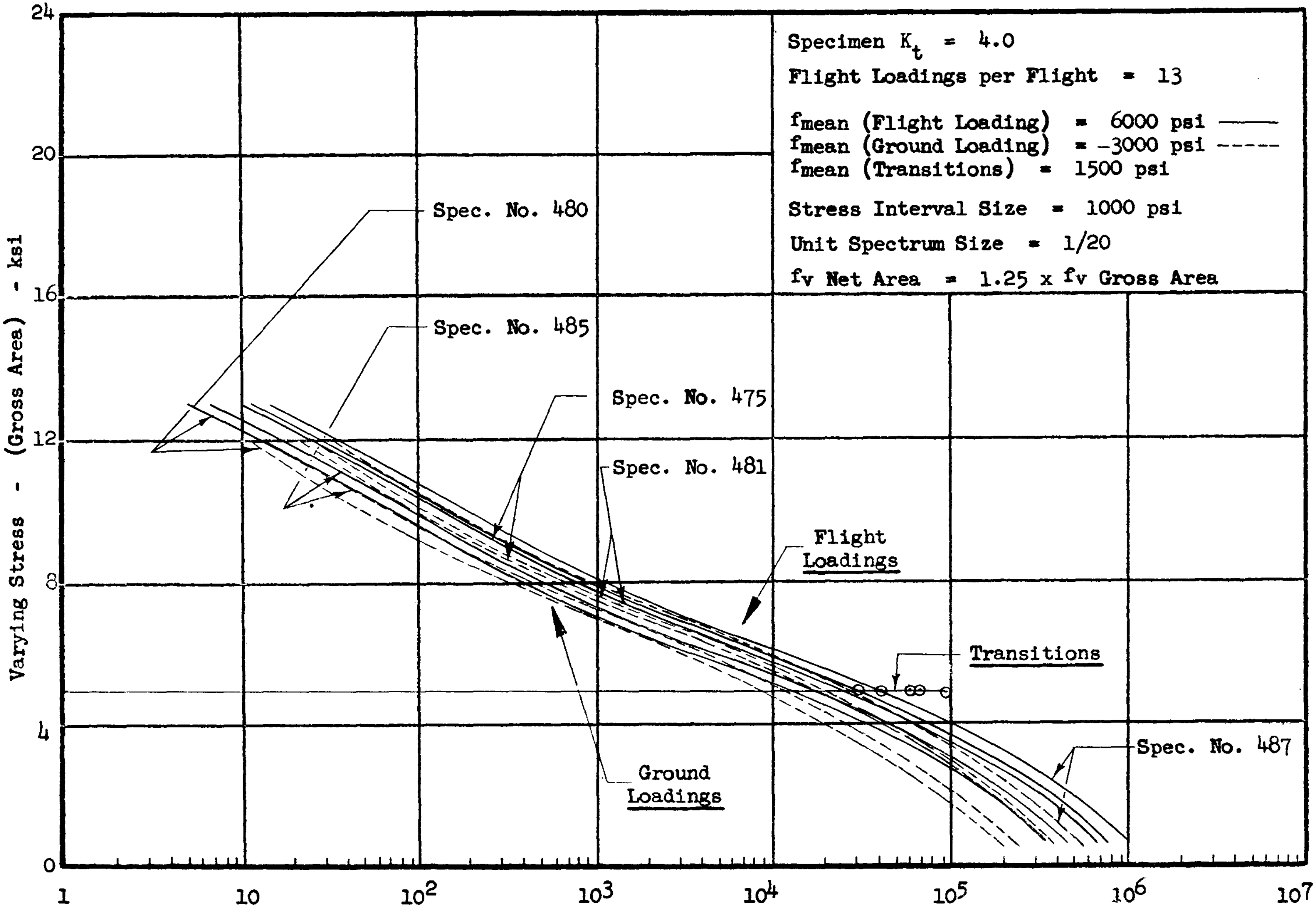


FIGURE 76 - ORDERED COMPOSITE LOADING TEST DATA (LOW PEAK GUST LOADINGS IN FLIGHT)

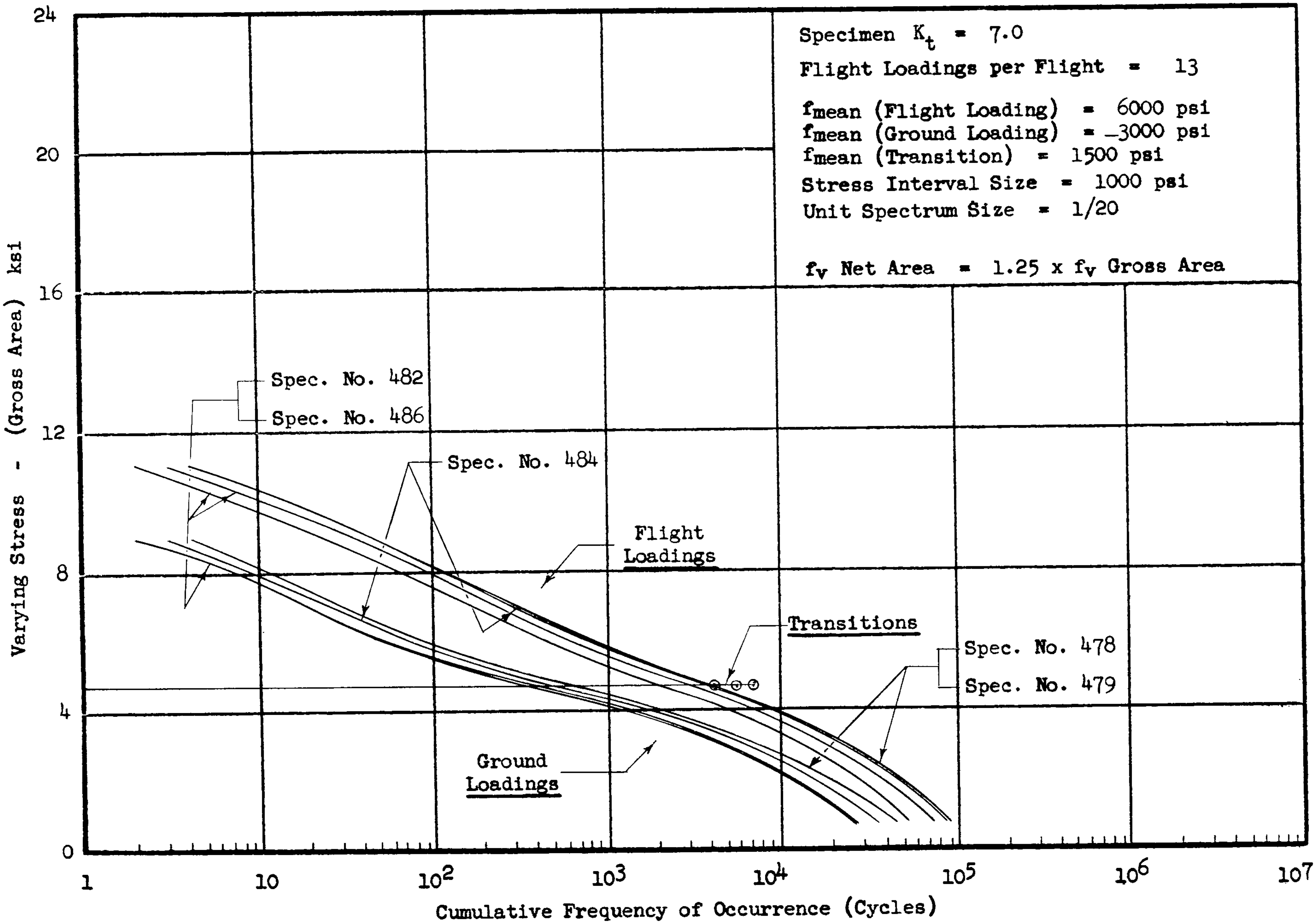


FIGURE 77 - ORDERED COMPOSITE LOADING TEST DATA (LOW PEAK GUST LOADINGS IN FLIGHT)

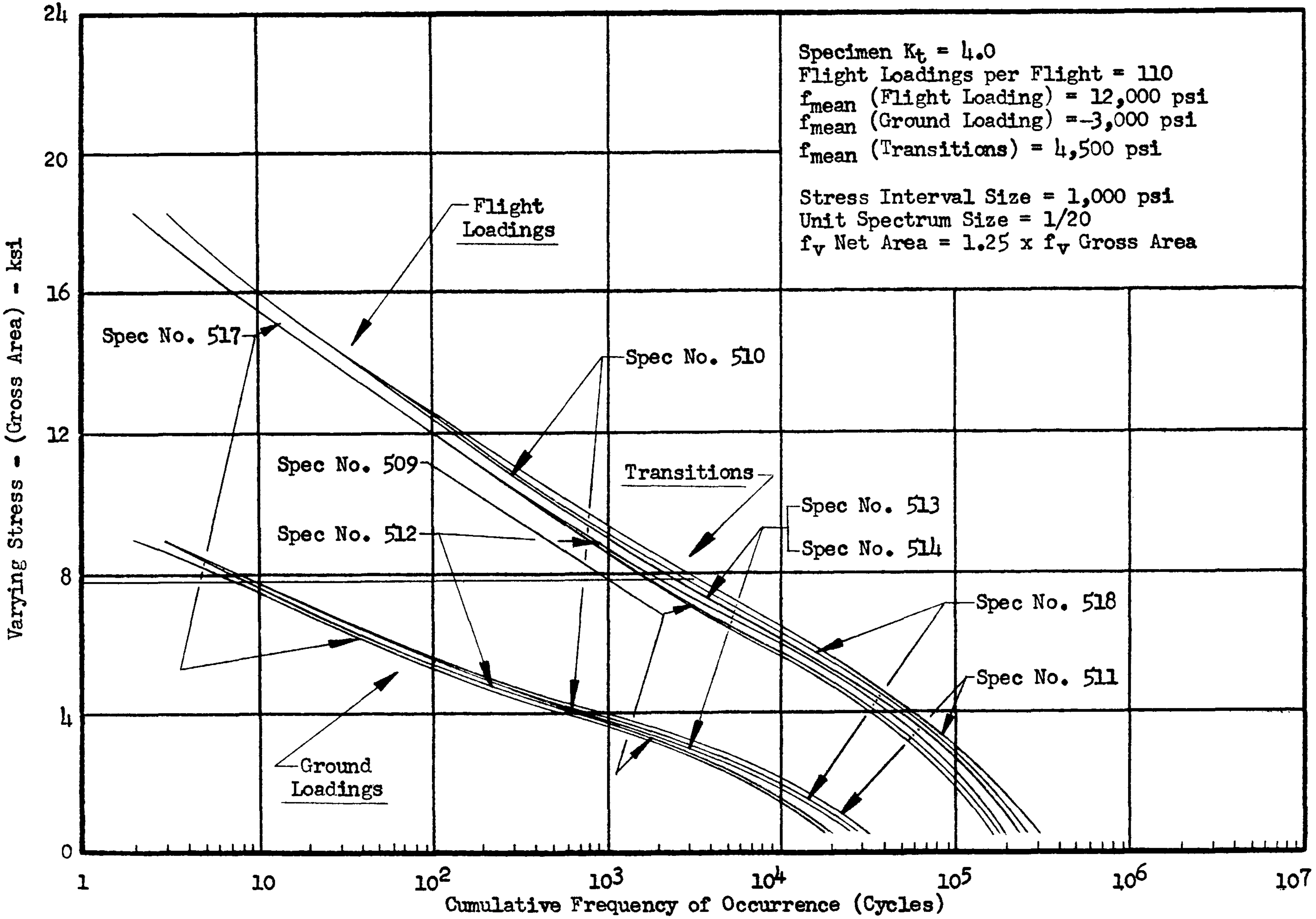


FIGURE 78 ORDERED COMPOSITE LOADING TEST DATA (HIGH PEAK GUST LOADINGS IN FLIGHT)

TABLE 4

CONTRIBUTION OF COMPONENT LOADINGS TO RANDOM COMPOSITE GUST LOADING TEST HISTORIES

Type of Flight Loadings		High Peak Gust			Low Peak Gust	
Specimen K_t		4.0		7.0	4.0	7.0
Number of Gust Loadings per "Flight"		13	110	13	13	13
Average Number of Test "Flights"		3496	1949	762	24250	2253
Flight Loading Ratio(1)	Minimum(4)	.122	.570	.217	.145	.149
	Average	.109	.510	.173	.185	.129
	Maximum(4)	.096	.450	.128	.225	.108
Ground Loading Ratio(1)	Minimum(4)	.003(3)	.004(3)	.010	.025(3)	.030
	Average	.005	.006	.009	.039	.027
	Maximum(4)	.007	.008	.008	.052	.024
Transition Ratio(2)	Minimum	.875	.426	.773	.830	.821
	Average	.886	.484	.818	.776	.844
	Maximum	.897	.542	.864	.723	.868
Effective Ground to Air Cycle Range (psi) (See Page 114)		+20000 -8000	+20400 -6400	+19200 -6600	+12300 -7500	+13200 -8200
Number of Times Effective Ground to Air Cycle Range is Equalled or Exceeded		250	1400	180	1200	45

(1) Ratio of test life in composite loading tests to test life in simple loading tests.
(2) Contribution required to reach a total ratio of unity.
(3) Based on evaluation of one random ground loading test.
(4) Ratio of minimum (maximum) composite loading spectrum to minimum (maximum) simple loading spectrum.

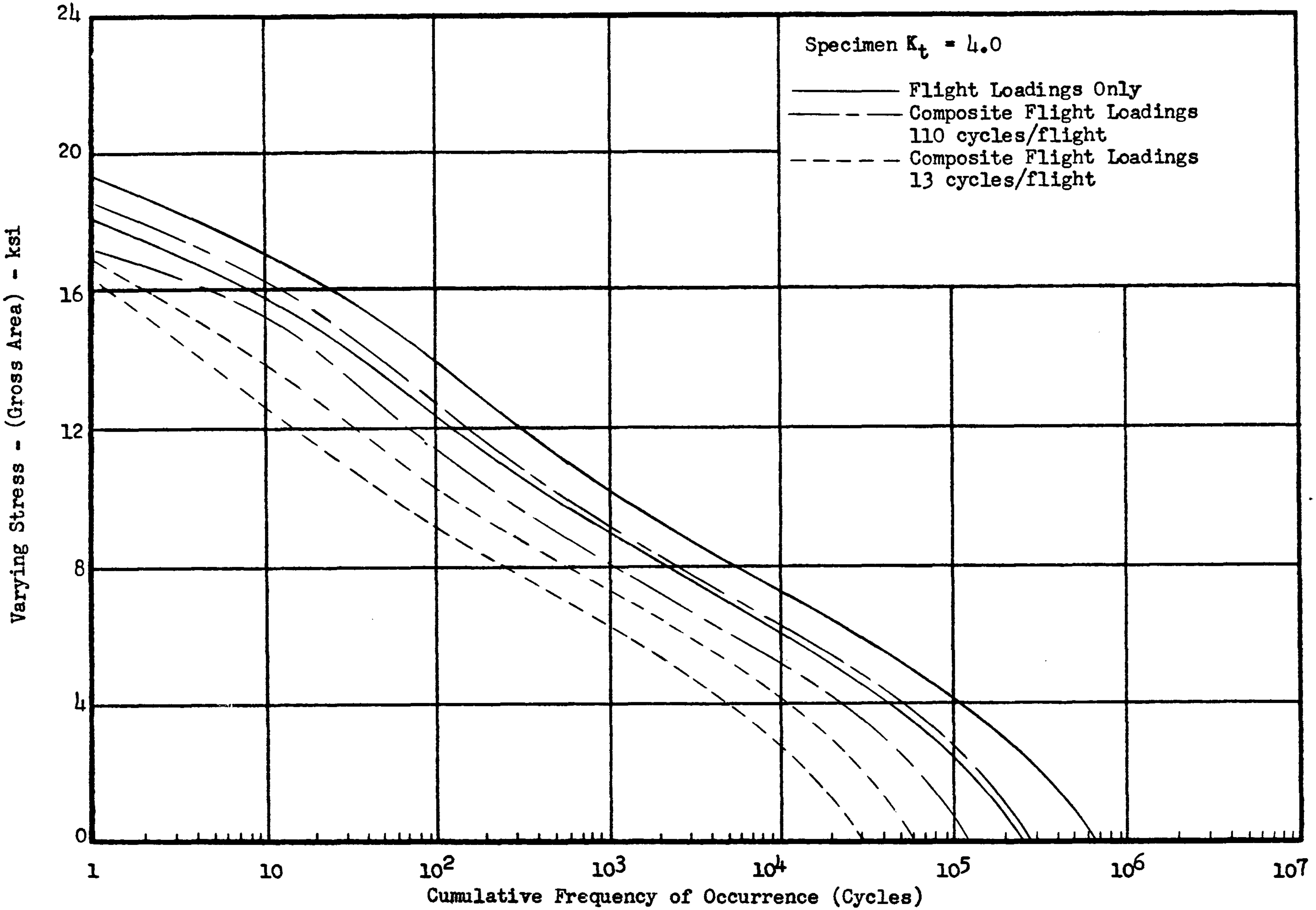


FIGURE 79 COMPARISONS OF FLIGHT LOADING ENVELOPES - RANDOM HIGH PEAK GUST LOADINGS

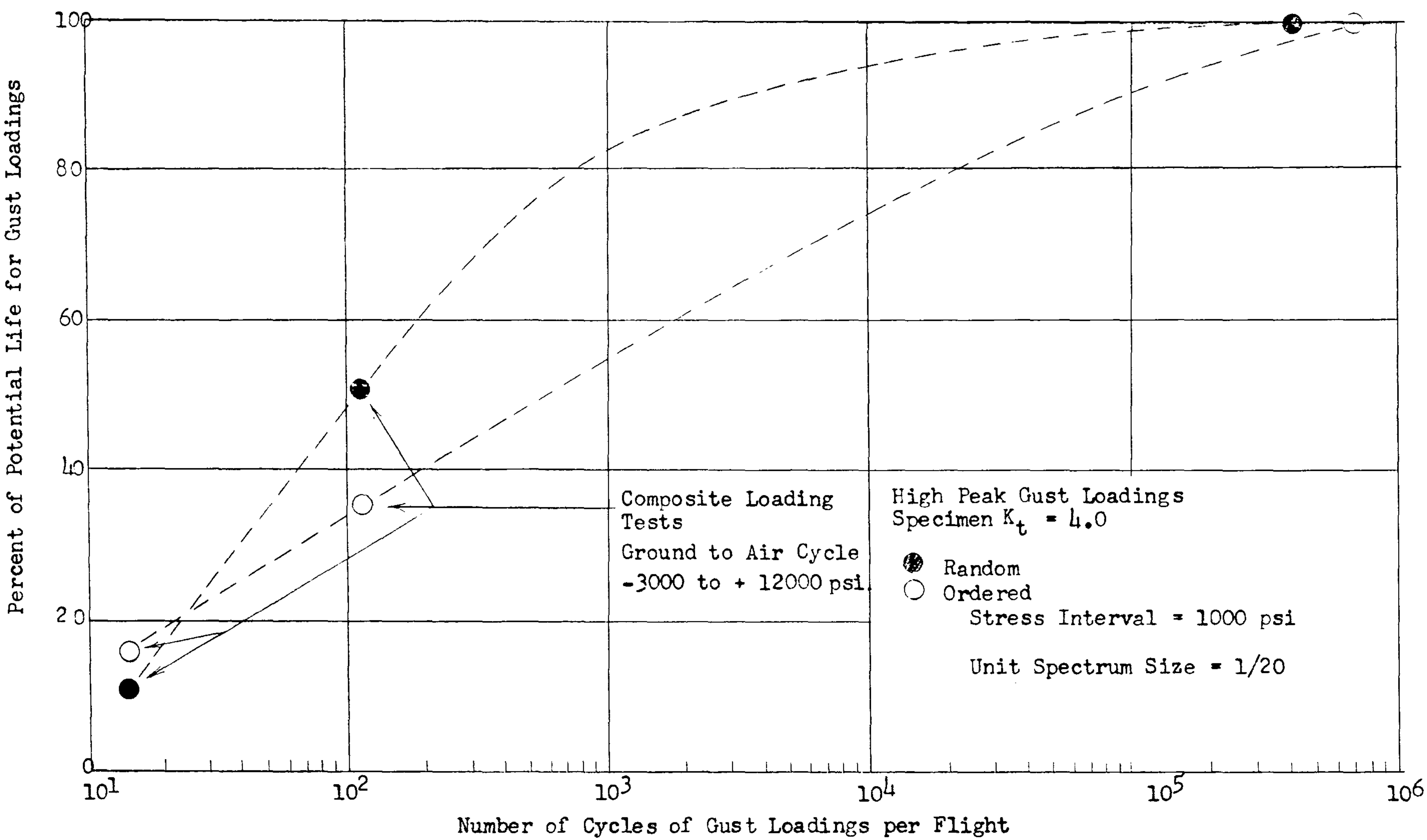


FIGURE 80 INDICATED EFFECT OF LENGTH OF "FLIGHT" ON TOTAL NUMBER OF GUST LOADINGS

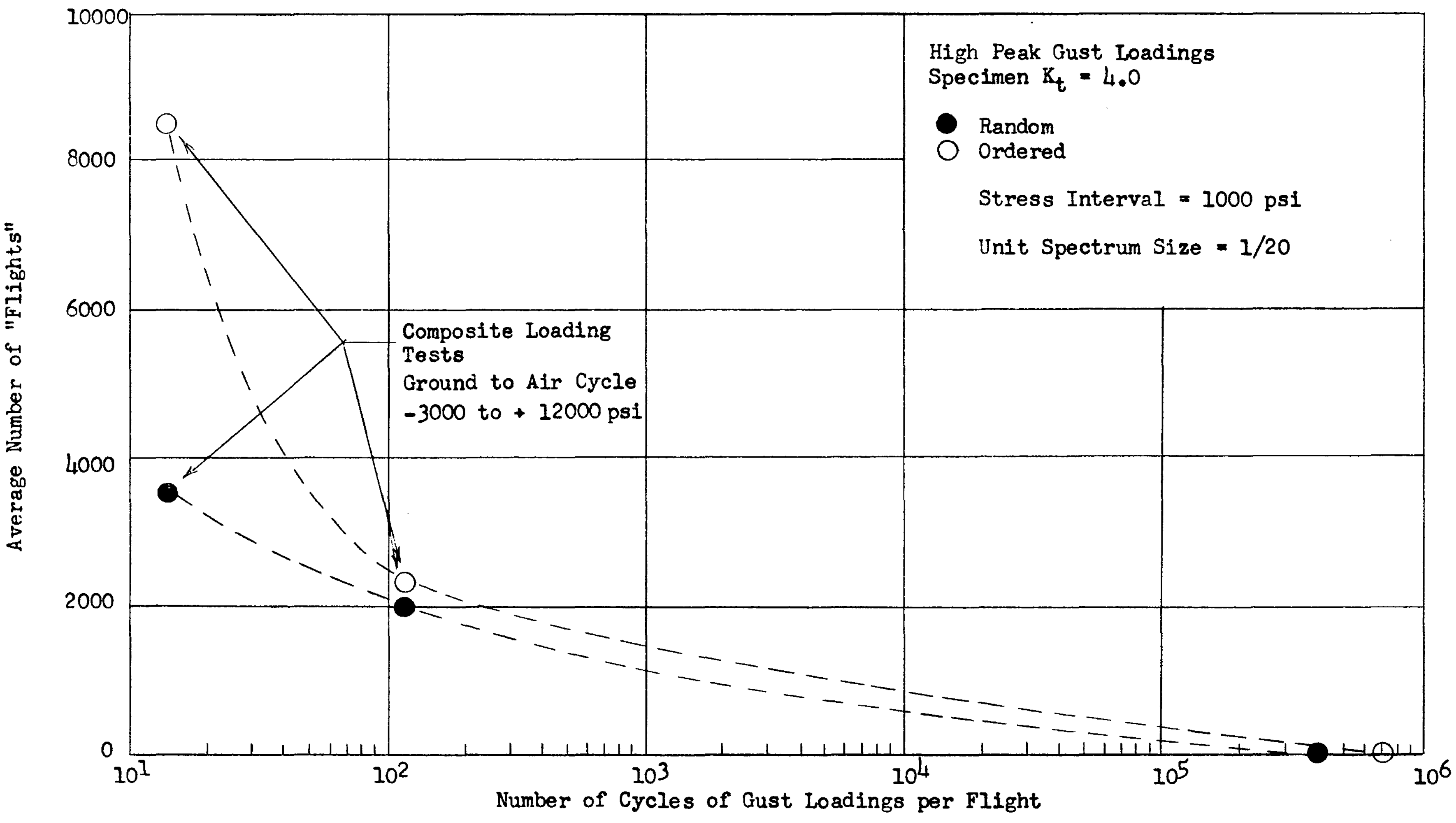


FIGURE 81 INDICATED EFFECT OF LENGTH OF "FLIGHT" ON NUMBER OF FLIGHTS

These figures provide one type of assessment of the transition effect. Another type is provided by assuming that the indicated effect of the transitions in the random loading tests can be represented by a constant amplitude ground to air cycle. To define such a cycle, S-N curves must be available which have been specifically determined for the test article and which cover the stress ranges of interest. To supply this type of test data, a series of constant load amplitude tests was carried out on specimens having the same geometry as those used in the random loading tests. The results of these tests are presented in Tables 43 and 44 in Appendix VI. An analysis of these data then led to the construction of the S-N curves also presented in this appendix. Using these curves to define the potential life of a specimen under the action of a constant load amplitude cycle, a ground to air cycle stress range was selected for each group of composite loading tests. In making these selections, each stress range was based on a maximum positive gust loading stress and a maximum negative ground loading stress which are equalled or exceeded the same number of times during the average random loading test life. Each selection was made to represent the indicated effect of the transitions. In other words, if this ground to air cycle was applied to a specimen a number of times equal to the average number of flights, the loading ratio for the cycle would equal the ratio attributed to the transitions in the composite loading tests. The range of stress in each such effective ground to air cycle is listed in Table 4.

Since the probability levels for the S-N curves are not well defined by the test data, values of the effective ground to air cycle stresses are shown only for the average contribution indicated for the transitions.

A search was made for an informative designation of these cyclic magnitudes in terms of the test loading histories. No single description was found to be applicable. However, to provide some indication of the frequency of occurrence of such magnitudes during the tests, the number of times each range was equalled or exceeded in the average test duration is listed in Table 4. These number of occurrences, which were obtained from composite test loading spectra previously presented, may be compared with the average number of "flights" which are also listed. These comparisons indicate the arbitrary nature of such ground to air cycle representations.

Another, somewhat similar interpretation of the test data is of interest. In preliminary assessments of the potential service life of a structure, it would be convenient to have a definition of a single cycle whose magnitude would reflect the effect of all loadings encountered during a representative flight. Then, when the spectra of loadings are known or can be estimated and when the applicable S-N curve is available, the potential number of applications of this equivalent loading cycle indicated by the S-N curve would provide an estimate of the potential number of flights in service.

To investigate the possibility that a single definition of such a cycle might be derived from the test data, each of several definitions were employed. The first definition required the selection of the maximum stress range which occurs once, on the average, during every flight. Knowing the number of flights represented by a set of flight and ground loading spectra, this range can be deduced from the spectra. The second definition requires the calculation of the range between the root mean square (rms) value of the positive flight loading increments and the rms value of the negative ground loading increments. The third definition requires use of the range between the mean stress for ground loadings and the mean stress for flight loadings. The fourth definition requires calculation, using the conventional assumption of linearly cumulative damage, of the gust loading cyclic magnitude which produces the largest damage.

The stress ranges obtained for each of these definitions are listed in Table 5 together with the potential number of cycles for each, read from the applicable S-N curves. For comparison, the number of flights in the random loading tests are also listed.

This effort suggested a fifth definition of the equivalent loading cycle as the average value of the maximum stress ranges produced during the random loading tests. This average was obtained from the test loading spectra as follows. Knowing the number of flights represented by the composite spectra, the minimum range is defined as that which is equalled or exceeded the same number of times as the number of flights. For example, this range can be determined for Specimen No. 504 from Figure 73 as follows; the graph is entered at a cumulative frequency of occurrence of 1741 (the number of flights). The incremental ground loading stress is found to be 3100 psi. The incremental gust loading stress is 7900 psi. This defines a range of +19900 psi to -6100 psi. The maximum range is similarly determined from the graph for a unit frequency of occurrence. The average of the minimum range and the maximum range defined by the spectra is then calculated. This average, obtained from the spectra for the mean of the test lives in a group, is listed in Table 5 together with the potential number of cycles of this magnitude indicated by the S-N curves presented in Appendix VI. The stress values listed are substantially larger than those provided by other definitions but appear to provide a moderately good estimate of the number of flights listed for each test group.

The general applicability of this last definition of an equivalent loading cycle needs further verification. In common with other definitions, an estimate of a life and a selection of an S-N curve must ordinarily be made before it can be applied. However, its use does provide a better fit to the available random loading data than that provided by any alternate definition which was investigated.

This evaluation of the random loading tests indicates that a large ground to air cycle range should be employed in ordered loading representations. The evaluation also indicates that the definition of the ground to air cycle becomes more significant as the number of gust loadings per flight decrease.

TABLE 5

ALTERNATE DEFINITIONS OF EQUIVALENT LOADING CYCLES FOR RANDOM COMPOSITE GUST LOADING TEST HISTORIES

Type of Flight Loading	High Peak Gust			Low Peak Gust	
Specimen K_t	4.0		7.0	4.0	7.0
Number of Gust Loading Cycles per "Flight"	13	110	13	13	13
Average Number of Test "Flights"	3496	1949	762	24250	2253
Maximum Stress Range which Occurs, on the Average, Once Every Flight (psi)	+16500 -5700	+19900 -6300	+16900 -5700	+10000 -5600	+9900 -5900
Number of Cycles(1)	11000	5500	1700	120000	11000
Stress Range Defined by the Root Mean Square Values of the Flight and Ground Loadings (psi)	+15000 -4800	+15000 -4800	+14900 -4700	+7900 -4700	+8200 -4800
Number of Cycles (1)	19000	19000	3300	500000	28000
Mean to Mean Stress Range (psi)	+12000 -3000	+12000 -3000	+12000 -3000	+6000 -3000	+6000 -3000
Number of Cycles(1)	80000	80000	10500	3000000	160000
Stress Range Defined at the Most Damaging Stress Level in the Flight Spectrum (psi)	+18500 +5500	+18500 +5500	+17500 +6500	+10500 +1500	+10500 +1500
Number of Cycles (1)	41000	41000	16000	750000	83000
Average Maximum Stress Range (psi)	+23300 -9100	+24800 -9200	+21600 -8200	+14300 -9300	+13400 -8800
Number of Cycles(1)	2000	1600	470	13000	2200

(1) Allowable number of cycles read from the applicable S-N curve for the indicated stress range.

However, in ordered loading tests it is conventional practice to group relatively large numbers of flight loadings, ground loadings and ground to air cycles to define unit test loading spectra. This grouping might be expected to produce an effect differing from that produced by a flight-by-flight sequence. This expectation was borne out by the results of the ordered loading tests in which the ground to air cycle was defined by the apparently mild, but easily defined, transition from the mean value for the ground loadings to the mean value for the flight loadings. This relatively small cycle appeared to be nearly as effective in curtailing the flight loading in the ordered loading tests as were the transitions in the random loading tests.

This result would not be anticipated even when, as in this investigation, the potential test life under the action of each type of loading is known. To illustrate this, tables similar to those presented for the random loading tests were prepared. Table 6 lists the fractions of the potential lives developed for each type of loading and the remaining fraction required to reach unity. This last fraction must be ascribed to a compounding effect due to the grouping of loadings and their sequence of application. Since the fraction is large and of positive sign, it indicates that a conventional prediction of test life based on a knowledge of the potential life for each type of loading would be unconservative.

Although the results indicate that the effects of each group of loadings are not linearly cumulative the stress ranges of equivalent ground to air cycles were obtained from the S-N curves. These ranges were selected for each test group so that the sum of the flight loading ratio, the ground loading ratio and the ground to air cycle ratio equals unity. The ranges and the number of times each range was shown by the test spectra to have been equalled or exceeded during an average test life are listed in Table 6. The magnitudes of these equivalent ground to air cycles and their indicated rate of occurrence emphasize the uncertainty of conventional estimations.

An investigation of definitions of a single cycle to reflect the effect of all loadings during a representative or average flight was also carried out. The results, listed in Table 7, indicate that, within the scope of the investigation, the average maximum stress range provides the best, single, estimate of the number of flights represented by an ordered loading test. The estimate, which was found to agree fairly well with the results of the random loading tests, is conservative for the ordered loading tests.

In the random loading tests, an increase in the number of gust loadings per flight increased the total number of flight loadings and decreased the number of flights. This trend was also demonstrated by the results of the ordered loading tests. The changes in total number of flight loadings are illustrated on Figures 80 and 82 and the effect on the number of "flights" is shown on Figure 81.

TABLE 6

CONTRIBUTION OF COMPONENT LOADINGS TO ORDERED COMPOSITE GUST LOADING TEST HISTORIES

Type of Flight Loadings		High Peak Gust		Low Peak Gust	
Number of Gust Loadings per "Flight"		13	110	13	13
Specimen K_t		4.0	4.0	4.0	7.0
Average Number of Test "Flights"		8510	2300	62800	5980
Flight Loading Ratio (1)	Minimum(4)	.179	.381	.111	.248
	Average	.155	.353	.158	.267
	Maximum(4)	.131	.325	.205	.286
Ground Loading Ratio(1)	Minimum(4)	.008(3)	.004(3)	.042(3)	.034
	Average	.011	.006	.083	.033
	Maximum(4)	.013	.007	.124	.033
Ground to Air Cycle Ratio(1) (Mean to Mean)	Minimum(4)	.092	.022	.022	.030
	Average	.121	.033	.045	.040
	Maximum(4)	.150	.044	.067	.050
Remainder (2)	Minimum	.721	.593	.825	.688
	Average	.713	.608	.764	.659
	Maximum	.706	.624	.704	.631
Effective Ground to Air Cycle Range (psi)		+17000 -5400	+21100 -7500	+10600 -6800	+10400 -6200
Number of Times Effective Ground to Air Cycle Range is Equalled or Exceeded		10000	1400	42000	3500

(1) Ratio of test life in composite loading tests to test life in simple loading tests.
(2) Contribution required to reach total ratio of unity.
(3) Based on extrapolation of one random ground loading test.
(4) Ratio of minimum (maximum) composite loading spectrum to minimum (maximum) simple loading spectrum.

TABLE 7

ALTERNATE DEFINITIONS OF EQUIVALENT LOADING CYCLES FOR ORDERED COMPOSITE GUST LOADING TEST HISTORIES

Type of Flight Loading	High Peak Gust		Low Peak Gust	
Specimen K_t	4.0		4.0	7.0
Number of Gust Loading Cycles "Flight"	13	110	13	13
Average Number of Test "Flights"	8510	2300	62800	5980
Maximum Stress Range Which Occurs, on the Average, Once Every Flight (psi)	+16800 -5800	+19700 -6500	+9900 -6100	+9900 -5900
Number of Cycles(1)	10000	5500	110000	11000
Stress Range Defined by the Root Mean Mean Square Values of the Flight and Ground Loadings (psi)	+15100 -4900	+15200 -5000	+8400 -5400	+8300 -5100
Number of Cycles (1)	19000	19000	270000	25000
Mean to Mean Stress Range (psi)	+12000 -3000	+12000 -3000	+6000 -3000	+6000 -3000
Number of Cycles (1)	80000	80000	3000000	160000
Stress Range Defined at the Most **Damaging Stress Level** in the Flight Spectrum (psi)	+18500 +5500	+18500 +5500	+10500 +1500	+10500 +1500
Number of Cycles (1)	41000	41000	750000	83000
Average Maximum Stress Range (psi)	+22800 -8800	+24800 -9200	+14700 +10500	+13500 -8900
Number of Cycles(1)	2300	1600	9500	2100

(1) Allowable number of cycles read from the applicable S-N curve for the indicated stress range.

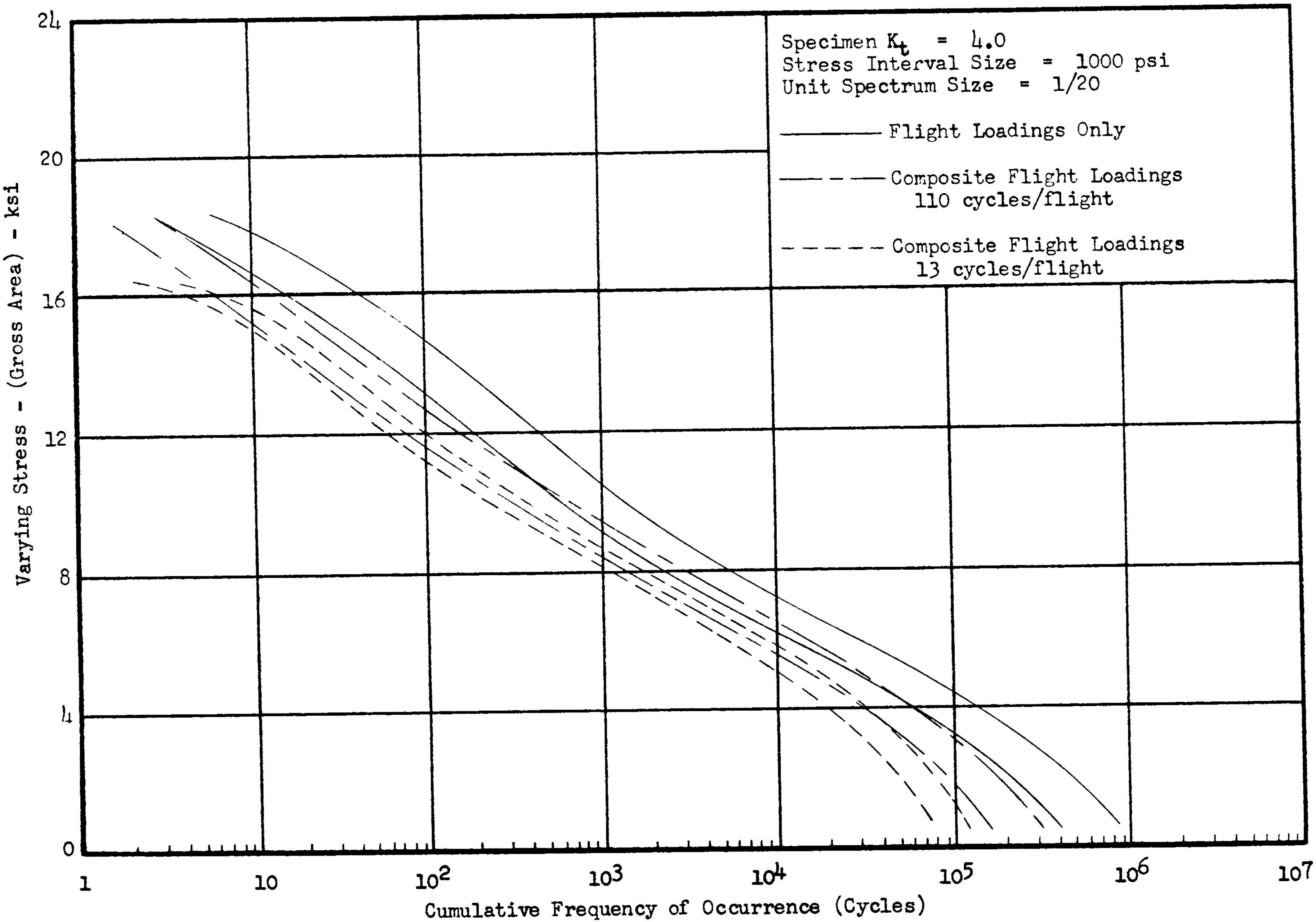


FIGURE 82 COMPARISONS OF FLIGHT LOADING ENVELOPES - ORDERED HIGH PEAK GUST LOADINGS

The evaluations of random and of ordered composite loading tests which have been presented indicate that combinations of loadings which act about substantially different mean load levels produce effects which are not readily predicted. The basic non-linearity of fatigue damage growth is, therefore, reemphasized.

Because of this non-linearity and the large number of interacting variables, an evaluation of the effect of individual variables is difficult. However, from the practical standpoint, it is only necessary to have assurance that a pattern of loadings suitable for laboratory use can reasonably duplicate the effects of the complex loadings anticipated in service.

To indicate the adequacy of the patterns chosen for this investigation graphical comparisons of the random and ordered test loading histories are presented on Figures 83,84,85 and 86. In addition, since each group of unit loading spectra was prepared to represent one-twentieth of the average test life obtained in a group of random loading tests, a simple numerical index to the adequacy of the ordered loadings is available. This index is defined by the ratio of the average number of unit spectra repetitions to the target number of twenty. The values of the index are listed in Table 8.

An examination of the index values and, in particular, of the graphical comparisons led to the following conclusions:

a). When composite ordered loading spectra were based on composite random loading test lives which reflected the preponderant effect of frequent ground-air-ground transitions, the choice of the mean to mean ground to air cycle stress range was not adequate. In tests using such ordered loading spectra, the test lives were significantly greater than those obtained using random loadings. However, the order of agreement obtained with this relatively small ground to air cycle stress range may be considered to be surprising in view of the large effect indicated for the transitions in the random loading tests.

b). When ordered loading spectra were based on random loading test lives which reflected the effects of a larger, more representative, number of gust loadings per flight and the resulting smaller number of loading transitions, the agreement between ordered and random loading test lives was considered to be quite adequate. Note that in these ordered loading tests, the ground to air cycle stress range was the same as that used in the preceding tests but the number of ground to air cycles in each unit spectrum was reduced. This reduction reflected the reduction in the number of flights in the random loading tests on which the unit spectra were based. The agreement between ordered and random loading test lives obtained in these tests may indicate that use of the simple mean to mean transitions to define ground to air cycles is appropriate only when

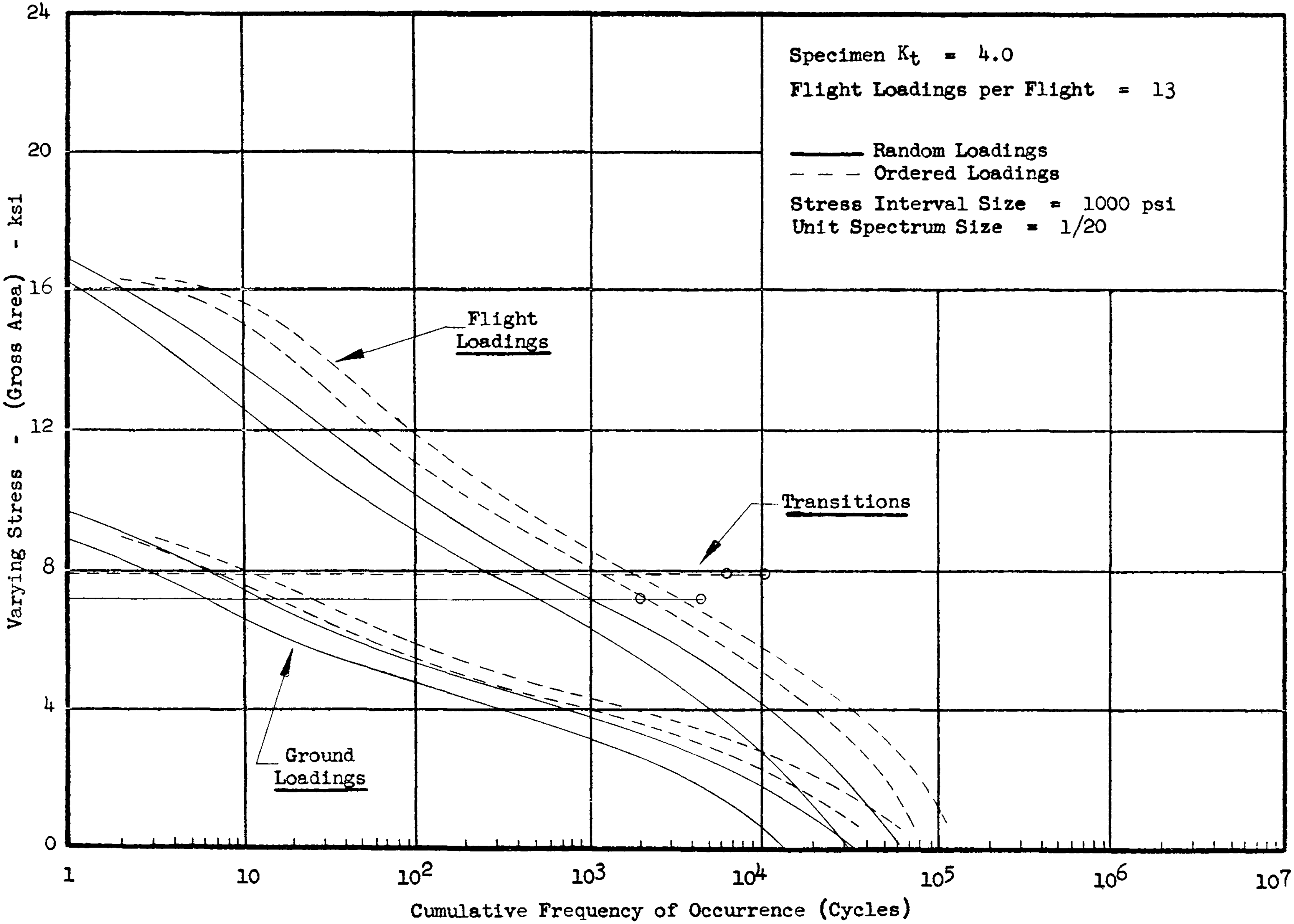


FIGURE 83 - COMPARATIVE ENVELOPES OF RANDOM AND ORDERED COMPOSITE LOADING TEST DATA (HIGH PEAK LOADINGS IN FLIGHT)

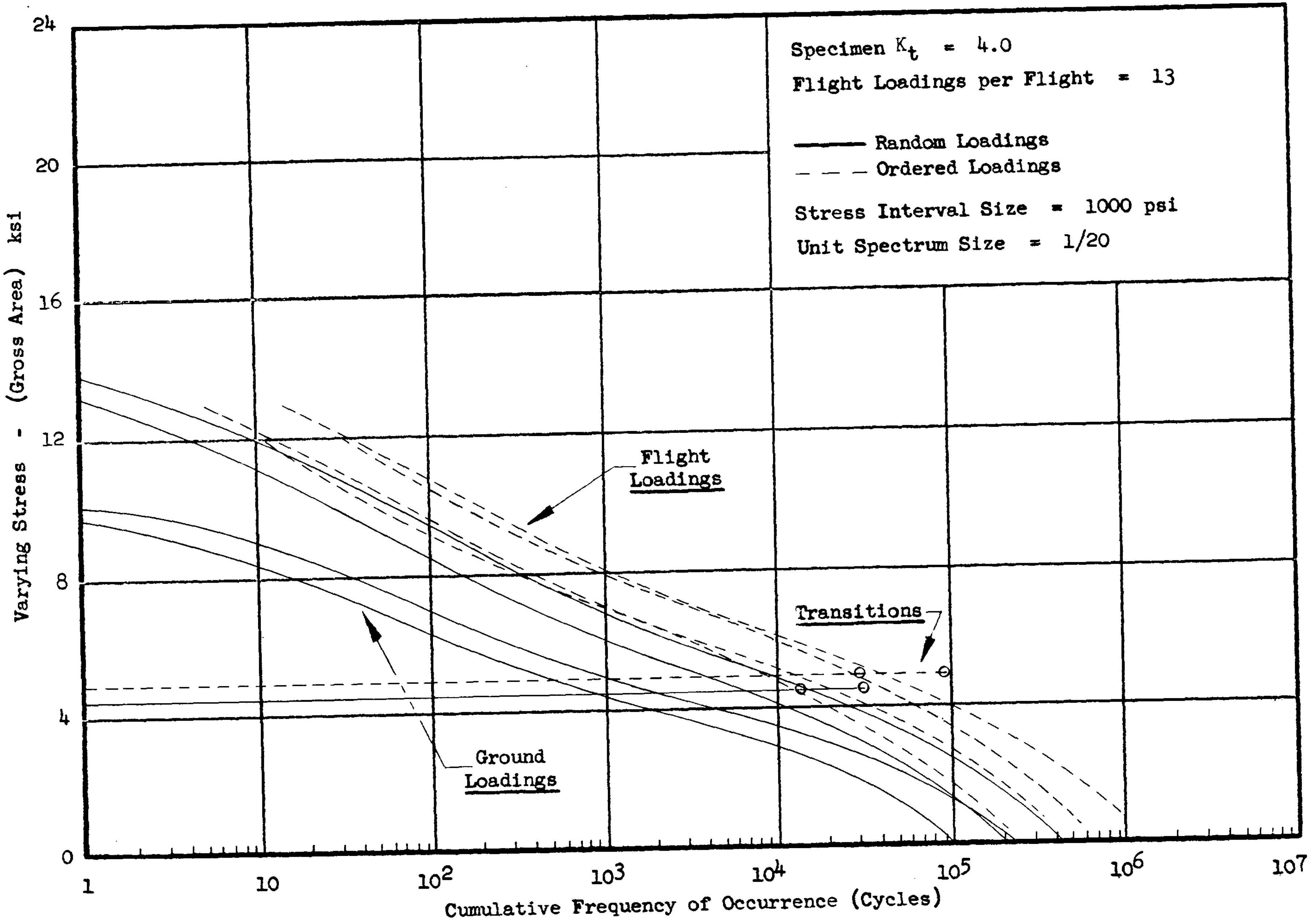


FIGURE 84 COMPARATIVE ENVELOPES OF RANDOM AND ORDERED COMPOSITE LOADING TEST DATA (LOW PEAK GUST LOADINGS IN FLIGHT)

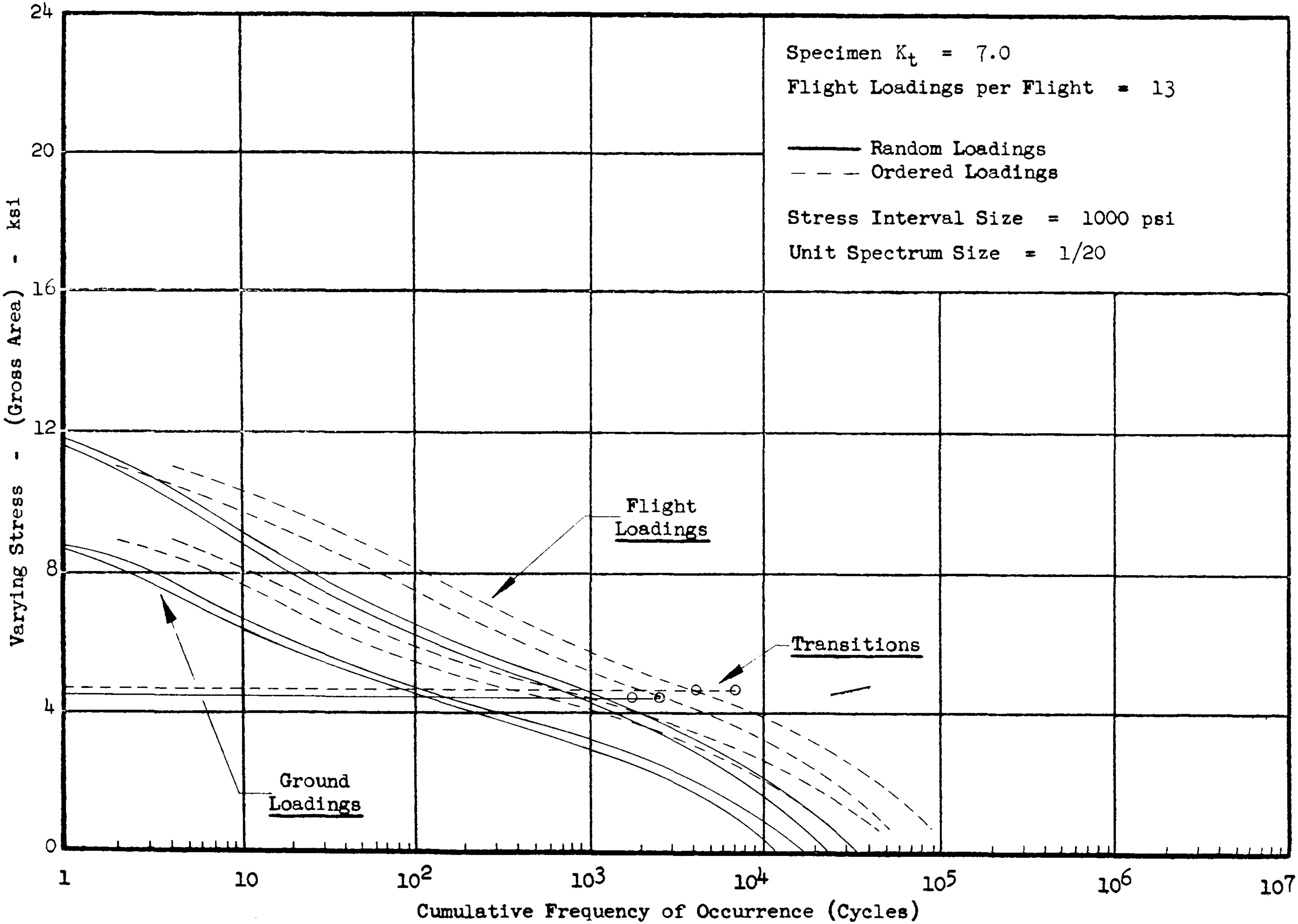


FIGURE 85 - COMPARATIVE ENVELOPES OF RANDOM AND ORDERED COMPOSITE LOADING TEST DATA (LOW PEAK GUST LOADINGS IN FLIGHT)

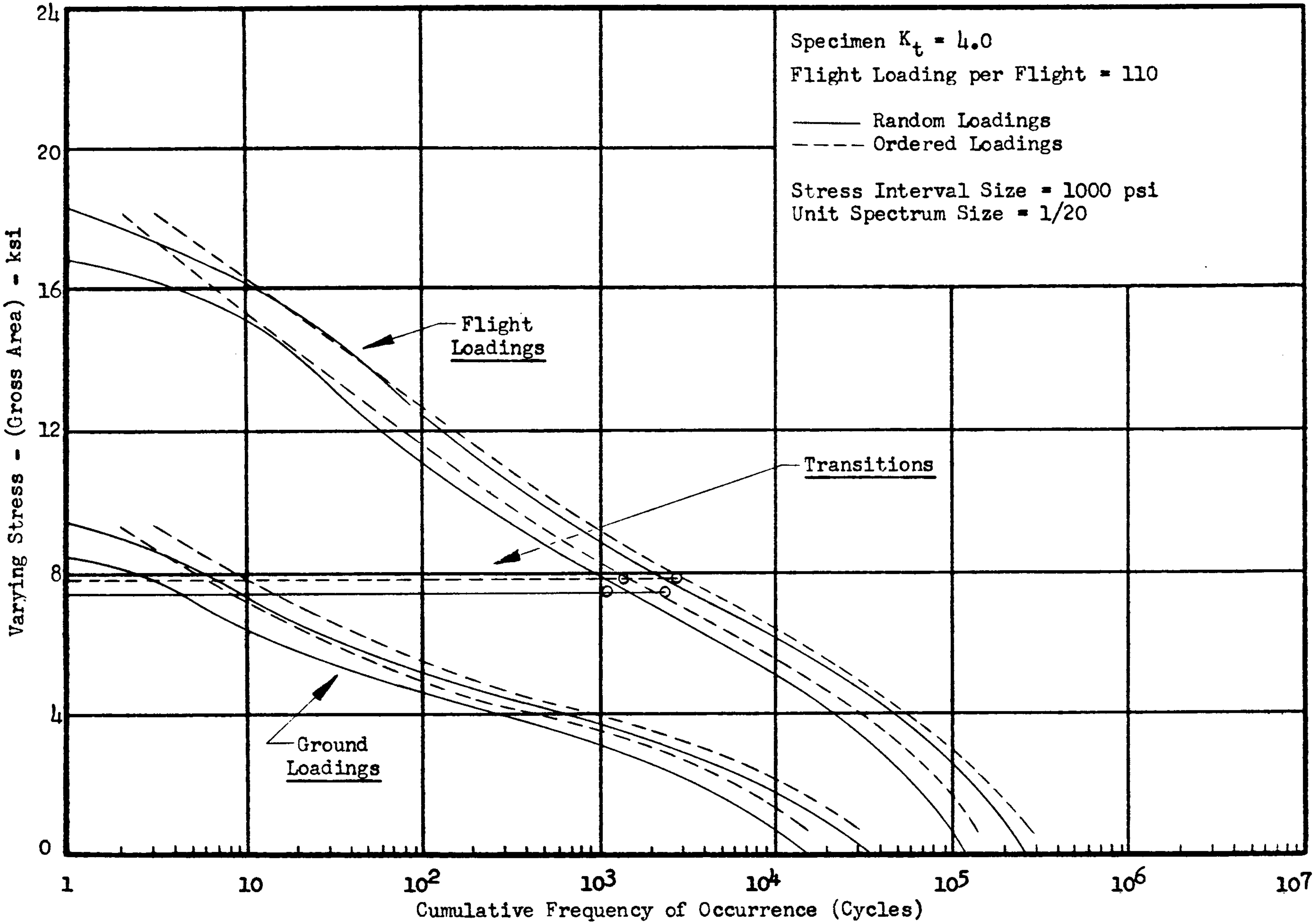


FIGURE 86 - COMPARATIVE ENVELOPES OF RANDOM AND ORDERED COMPOSITE LOADING TEST DATA (HIGH PEAK GUST LOADINGS IN FLIGHT)

TABLE 8

COMPARISON OF ORDERED AND RANDOM COMPOSITE LOADING TEST DURATIONS BASED ON REPETITIONS OF UNIT ORDERED LOADING SPECTRA

Type of Loading	K_t	Stress Interval (psi)	Unit Spectrum Size	Spec. No.	Unit Specimen Repetitions	Average Number of Repetitions	Target(1) Number of Repetitions	Ratio of Average to Target No. of Repetitions
High Peak Gust Loadings in Flight (13 cycles/flight)	4.0	1000	1/20	467 470 472 473 474	43.56 57.04 35.28 35.67 45.44	43.40	20	2.170
High Peak Gust Loadings in Flight (110 cycles/flight)	4.0	1000	1/20	509 510 511 512 513 514 517 518	19.85 25.67 33.54 21.89 27.31 26.63 17.58 29.82	25.29	20	1.265
Low Peak Gust Loadings in Flight (13 cycles/flight)	4.0	1000	1/20	475 480 481 485 487	51.54 26.96 58.62 35.59 79.97	50.54	20	2.527
Low Peak Gust Loadings in Flight (13 cycles/flight)	7.0	1000	1/20	478 479 482 484 486	70.54 72.61 43.57 57.93 43.98	57.73	20	2.887

(1) Number of unit spectra repetitions required for nominally equivalent random and ordered test lives

the ratio of the number of flight loadings to the number of ground to air cycle loadings in a unit spectrum is high - perhaps of the order of 70 to 300. The extent of this range should be determined by test.

These results may be interpreted to indicate that, for one case of considerable practical importance, the adequacy of a conventional representation of a random loading history has been substantiated. This case represents the standard problem of the evaluation, by test, of the wing root structure of aircraft whose service loading history is largely due to gust loadings encountered during flights of moderate length.

c). The extension of the preceding conclusion to apply to other areas of aircraft where gust loadings produce relatively mild stresses is uncertain. Additional testing reflecting a reasonably large number of gust loadings per flight is required.

All interpretations of the test results apply directly to the small, single-load-path specimens employed in the investigation. The applicability of these interpretations in evaluation of aircraft structure must be determined by tests of relatively complex specimens.

SECTION VIII

RANDOM COMPOSITE MILITARY MANEUVER LOADING TESTS

To investigate the effect of ground to air transitions on military maneuver loading test lives, a flight by flight sequence of loadings was selected and applied to specimens with $K_t = 4.0$. Since the flight and ground loadings in this sequence were basically different in character, the use of two tapes was required. The flight maneuver loading tape was the one generated and used in the test work reported under Section V. The ground loading history was produced by use of the master gust loading tape as described in Section VI.

With both tapes in use, the signal input to the servo control valves was selected by a cam controlled switch so as to produce approximately 30 flight loadings followed by approximately 7 ground loading cycles to represent one flight. This use of the tapes is described in more detail in Appendix I. The choice of 30 maneuver loadings per flight was based on consideration of a one-hour flight in a relatively severe service. The small number of ground loadings reflected the minor importance attached to such loadings.

A sample of the specimen loading traces is shown on Figure 87.

Since the test history for each specimen was made up of short samples of each input trace, a number of repetitions of each trace is required before the sampling can be considered to adequately define a test spectrum. Unfortunately, the duration of each test was too short to obtain the required definition and time was not available for any alternate reduction of the test histories to spectral form. Under these circumstances, the production of ordered loading representations of the random loading test histories was not undertaken. However, to provide some indication of the effect of the transitions on the test lives, a representation of each test history based on the number of trace lengths applied is listed in Table 37 in Appendix V and is shown graphically on Figure 88.

Figure 89 presents a comparison of the range of flight loading histories obtained in these composite loading tests with the potential maneuver loading histories which were shown on Figure 58. This comparison shows that the introduction of the ground to air transitions has reduced the maneuver loading history to approximately one-third of the potential. This magnitude of reduction again emphasizes the powerful effect of transitions on the lives obtained in composite random loading tests. However, the comparison of ordered and random representations of simple maneuver loading histories presented on Figure 62 showed a substantially shorter test life for the ordered representation. This suggests the possibility that the use of a relatively mild ground to air cycle in ordered composite tests will provide adequate test life agreement with a corresponding random composite. The ground to air cycle would be most simply defined by the transition from the ground loading mean to the maneuver loading minimum.

The hypothesis which has been advanced can be checked by tests in which the test conditions are modified to permit the development of random test lives of adequate length.

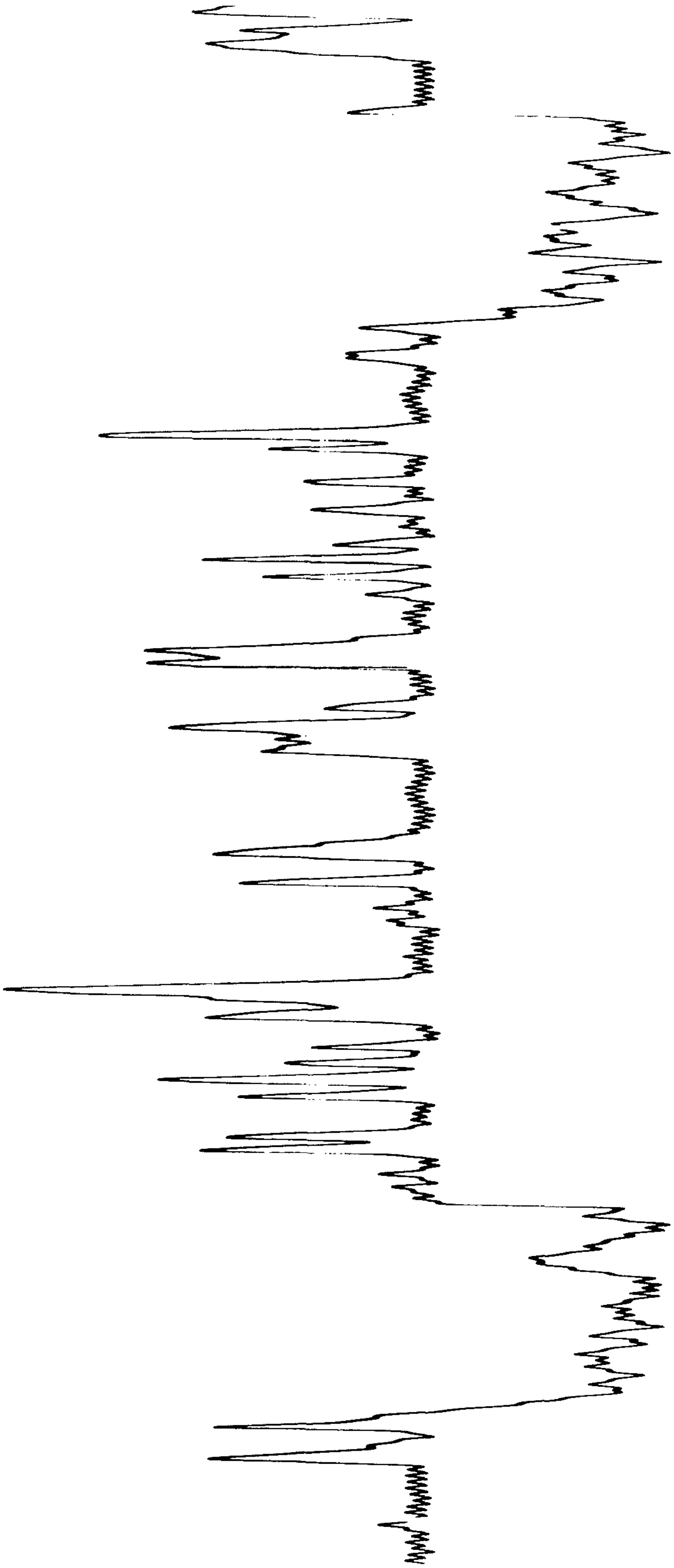


Figure 87 Sample Random Loading Trace - Composite of Military Maneuver and Ground Loadings

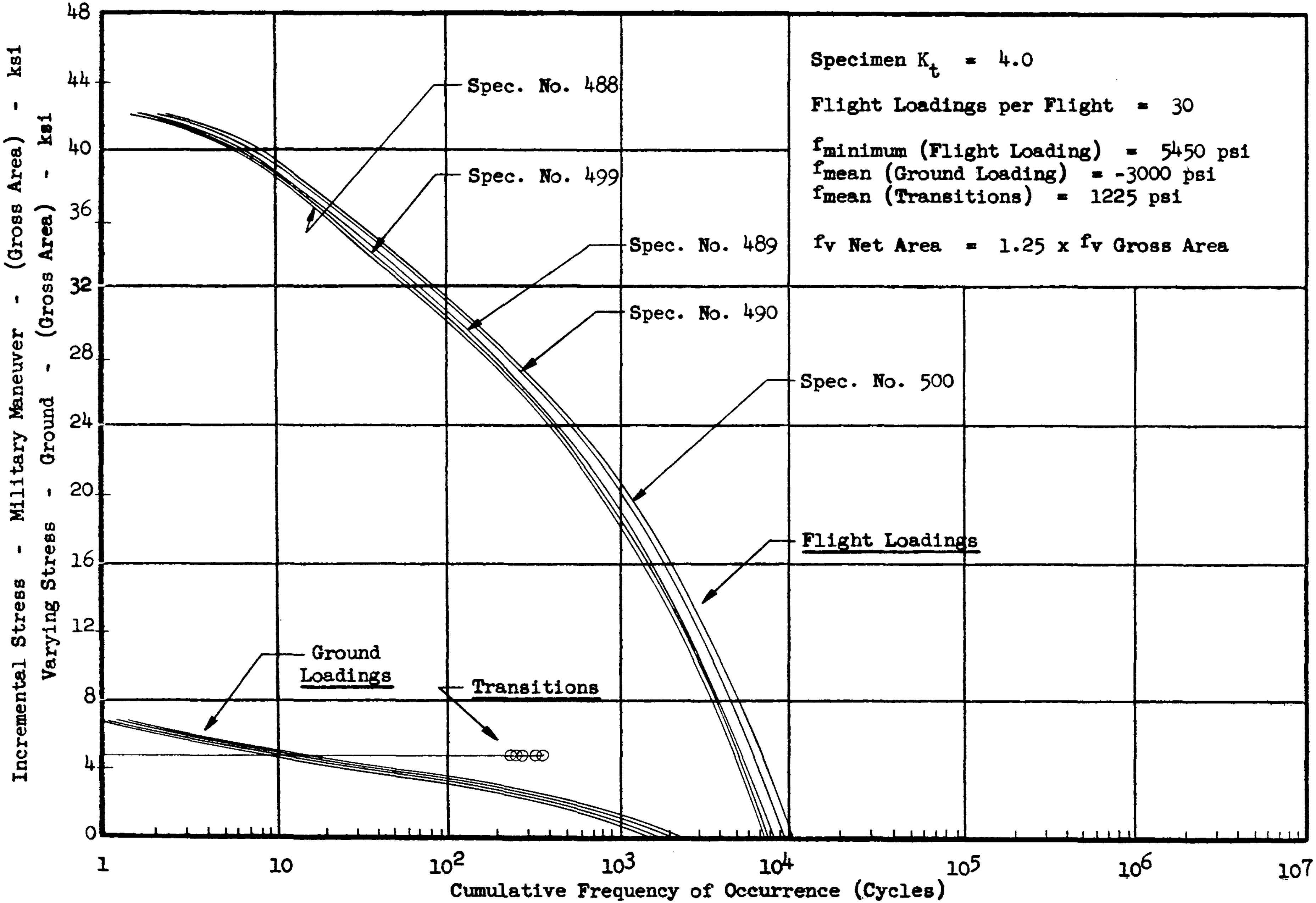


FIGURE 88 - RANDOM COMPOSITE LOADING (MILITARY MANEUVER FLIGHT LOADINGS)

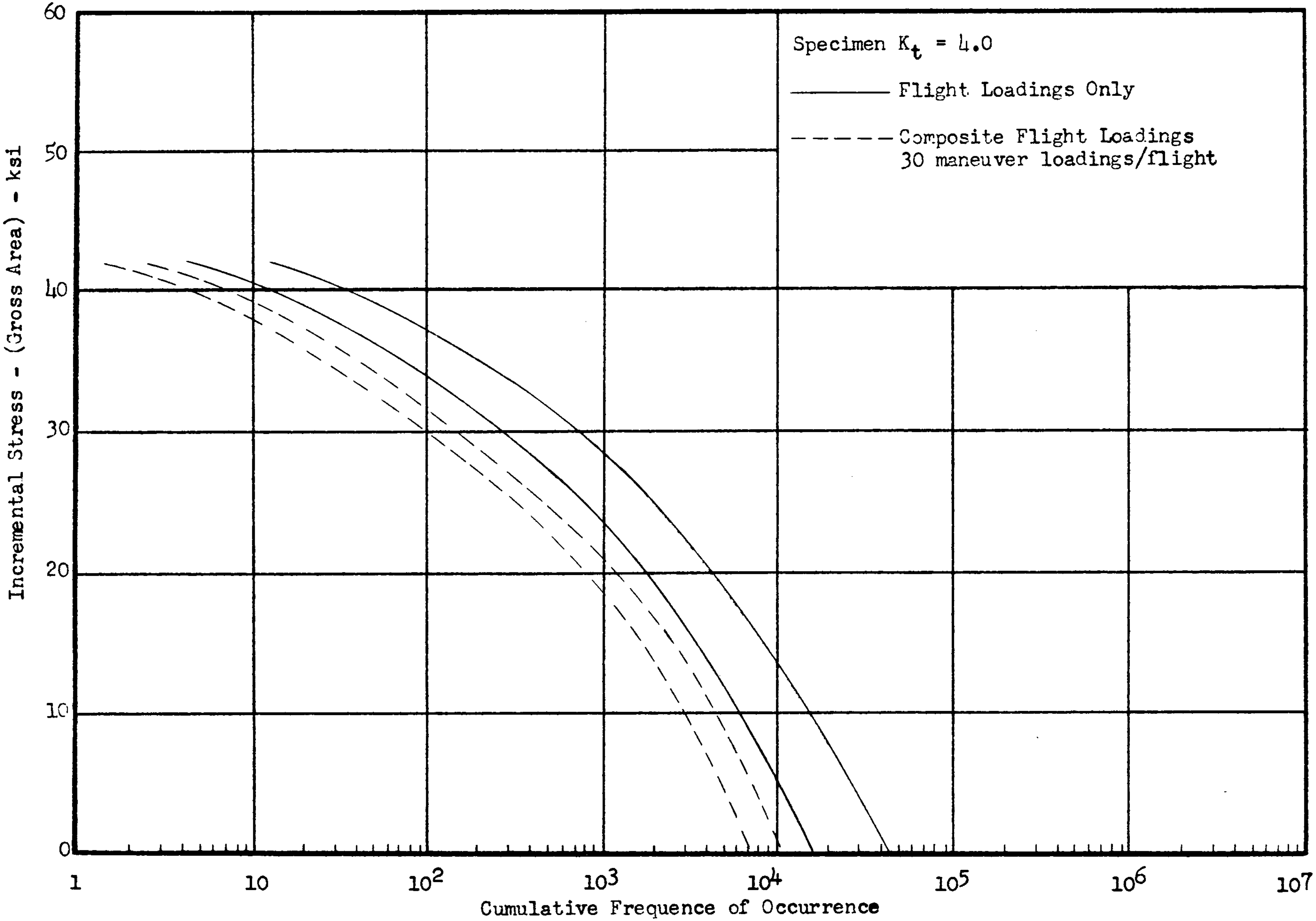


FIGURE 89 COMPARISON OF FLIGHT LOADING ENVELOPES - RANDOM MILITARY MANEUVER LOADINGS

In the discussion of composite loading tests in which gust loadings were applied, several definitions of a single cyclic magnitude were evaluated. This cycle was intended to represent the effect of all loadings during a flight and so was designated as an equivalent loading cycle. The results obtained when the definitions are applied to the composite maneuver loading tests are presented in Table 9. These results indicate that use of the average maximum stress range to define the equivalent loading cycle is most applicable. This definition is the same as that which produced best agreement with the composite gust loading tests.

TABLE 9

ALTERNATE DEFINITIONS OF EQUIVALENT LOADING CYCLES FOR RANDOM COMPOSITE MILITARY MANEUVER LOADING TEST HISTORIES

Specimen K_t	4.0
Number of Maneuver Loadings per "Flight"	30
Average Number of Test "Flights"	294
Maximum Stress Range Which Occurs on the Average, Once Every Flight (psi)	+ 19700 - 6300
Number of cycles (1)	5500
Stress Range Defined by the Root Mean Square Values of the Flight and Ground Loadings (psi)	+ 17000 - 4800
Number of Cycles (1)	11000
Mean to Mean Stress Range (psi)	+ 5450 - 3000
Number of Cycles (1)	4500000
Stress Range Defined at Most Damaging Stress Level in the Flight Spectrum (psi)	+ 27500 + 5500
Number of Cycles (1)	1700
Average Maximum Stress Range (psi)	+ 39900 - 7500
Number of Cycles (1)	200

(1) Allowable number of cycles read from the applicable S-N Curve for the indicated stress range.

SECTION IX

SUMMARY AND CONCLUSIONS

Equipment and Loading Tape Development

To perform an investigation of the representations of service loading histories in fatigue tests, special test equipment was required. To meet this need, equipment was developed which is capable of applying the complex, random loadings generated in service. In addition, a series of magnetic tapes containing random loading traces was prepared for use in the investigation. These tapes contain representative gust loading trace shapes and can be used to describe the slow growth of the peak value of loading which is a general characteristic of service loading records.

Use of the test equipment and the special loading tape provides a powerful tool for the evaluation of fatigue test loadings. Random loading test lives may be defined and then simpler, cyclic loading representations of these random loadings may be employed to define test lives. Comparisons of random and ordered loading test lives then provide the most direct and the most informative evaluations of the adequacy of the ordered loading representations.

Methods of Reducing Service Loading Data

A preliminary investigation of methods of reducing gust loading records to spectral form for use in fatigue work indicated that simple mean crossing peak counts provide an adequate representation of the severity of the records. This conclusion was based on comparisons of the interpretations of four random loading traces obtained using simple range counts and simple interval crossing counts in addition to the peak counts. The random loading traces covered a range of frequency content and their representations covered a range of spectral shapes. However, in later work it appeared that this conclusion must be limited to applications of gust loading peak counts in which relatively high nominal stresses are produced. When relatively low nominal stresses are produced, the use of spectra based on peak counts can lead to unconservative test results. This difference in effect is attributed to differences in the degree of modification of the effective stress concentration. When relatively high peak stresses are applied, the modification is large. This modification apparently reduces the importance of the subsidiary trace deviations which are not recorded when mean crossing peak counts are made. When relatively low peak stresses are applied, the modification of stress concentration is less pronounced and the relative importance of the subsidiary trace deviations is greater.

The results of the investigation of alternate methods of gust loading data reduction do not suggest the choice of a single method having general applicability.

A less extensive evaluation was made of the reduction to spectral form of the load content on a simulated random military maneuver loading trace. In this evaluation, a conventional count of the maximum values of excursions occurring between crossings or between contacts of the 1g level was used to define a spectrum. Use of this spectrum in tests in which representative, high nominal stresses were produced led to shorter test lives than those developed in comparable random loading tests. Since the ordered loadings did not reflect the trace deviations which were ignored in making the peak counts, the conservatism indicated for the peak count spectrum was unexpected. Additional testing employing more complete randomization of the ordered loadings may be required to explore the reason for the results obtained.

Effect of Variations in Mean Stress

A limited investigation was made of the effect of the variations in mean stress which occur in flight. The results obtained indicated that variations of the mean stress of the order of 20 percent and large but temporary reductions of mean stress have little effect on test lives.

Effect of Random Loading Sequence

In one set of tests in which the loadings defined by a random loading trace were repetitively applied in both the normal and the reversed sequence, no significant effect on test life was demonstrated.

Effect of Size of Unit Spectrum and of Stress Interval

Tests were carried out to evaluate the effect of alternate sizes of the spectrum repetitively applied in fatigue tests and of the size of the stress interval chosen in the construction of the test spectrum. In these tests, the use of unit spectra one-tenth and one-twentieth of the average random loading histories and use of stress intervals of 1,000 and 4,000 psi did not produce a clear-cut definition of a best choice of the combination of these test variables. However, the test data were interpreted to justify selection and continued use in ordered loading tests of the smaller unit spectrum and stress interval size.

The Representation of Gust Loadings

In tests in which only gust loadings were applied, moderately good agreement was obtained between random and ordered loading test lives when the nominal peak stresses were relatively high - approximately 30,000 psi maximum. When lower nominal peak stresses - approximately 20,000 psi maximum - were produced, the ordered loading representations produced significantly longer test lives than those produced by comparable random loadings. As discussed above, this stress level effect is tentatively ascribed to a deficiency in the spectrum of loadings deduced by use of mean crossing peak counts of the random loading trace.

The Representation of Military Maneuver Loadings

As discussed in the section dealing with data reduction methods, ordered representations of military maneuver loadings produced shorter test lives than did comparable random loadings.

The Representation of Ground Loadings

The loading histories used to represent ground (taxi) loadings produced a nominal mean stress of -3,000 psi and a maximum incremental stress of the order of 10,000 psi. For these stress levels the test results confirmed the general belief that ground loadings are not, in themselves, significant contributors to fatigue damage.

The ordered loading test lives were significantly longer than the comparable random loading test lives. This result is believed to be consistent with the hypothesis on the significance of subsidiary deviations on the random loading trace which was advanced in the discussion of data reduction methods.

The Representation of Total Loading Histories

To introduce the effect of the transition from the ground loading condition and return which occurs once per flight, random gust and maneuver loadings were applied on a flight by flight basis. From the test lives so obtained and a knowledge of the potential test lives for flight loadings alone and for ground loadings alone, the importance of the transitions was deduced. This deduction was based on the conventional assumption that the sum of the effects of several loading conditions can be obtained by linear accumulation.

The results obtained indicated that the effect of the transitions was large and, as would be expected, that the magnitude of the effect was a function of the length of flight or the severity of the flight loading history. In other words, when the number of flight loadings per flight is small, the effect of the transitions predominates. As the number of flight loadings per flight increases, the number of transitions during a test reduces and the effect of the transitions on the test life becomes smaller.

Using the linear accumulation assumption, an attempt was made to correlate the test lives with those obtained for simple loading conditions. This attempt required the selection of unrealistically large ground to air loading cycles to represent the effect of the transitions. This result was interpreted to indicate that the application of a combination of loading conditions distinguished by substantial differences in mean load produced non-linear effects.

The conventional interpretation of the effect of the transitions in the random loading tests suggested the use of large ground to air cycles in ordered, cyclic loading representations. However, the ground to air cycle magnitude actually used was the simply defined transition from the mean load on the ground to the mean load in flight. With this cycle and spectra of cyclic gust and ground loadings, ordered loading tests were carried out.

When the spectra represented service conditions in which the number of gust loadings per flight is quite small (13) so that the effect of the transitions is the predominant one, use of the relatively small ground to air cycle produced test lives significantly greater than those produced in the comparable random loading tests. Even so, an analysis of these results similar to the one described for the random loading tests indicated that the effect of the ground to air cycle was much larger than would be anticipated. When the spectra were based on more representative service conditions (110 gust loadings per flight) so that the effect of the transitions was reduced, use of the same ground to air cycle magnitude produced test lives in good agreement with those produced in the comparable random loading tests. Once again, the indicated effect of the ground to air cycle was much larger than would be predicted by conventional means.

These results re-emphasize the non-linear effect of a combination of loading conditions and suggest that the segregation of effects poses a difficult problem. However, the results do indicate that spectra of ordered, cyclic loadings can be selected which will produce test lives in good agreement with those produced by the random loadings which are being represented in the ordered loading test.

Test Simplification

An analysis of the flight by flight random loading test data indicated that, when the test loading spectra are known and the S-N curve for the specimen has been established, a good estimate of the test lives can be made. This estimate is obtained by calculating the average maximum stress range defined by the loading spectra and reading the allowable number of cycles for this range from the S-N curve. This number of cycles is the estimate of the number of flights to be demonstrated in a test. The procedure was also found to produce reasonable but conservative estimates of the number of flights represented by ordered, cyclic loading test results.

Although the application of this procedure requires knowledge of a test life or the assumption of a minimum acceptable test life and the use of S-N curves which are seldom defined for complex structure, it shows promise of usefulness in generalizations on fatigue problems. The usefulness in fatigue tests of a single loading cycle defined by this procedure is doubtful. Since the cyclic magnitude is large, its use in tests of complex but well designed structure might be expected to produce test results significantly different from those produced in service. In well-designed structure, no single point provides a stress concentration so large that cracking will quickly occur at the point under the action of any type or magnitude of loading. In such structure, the location of cracking and its rate of growth are undoubtedly affected by the interaction between the effects of large, seldom occurring loadings, the moderate, frequently occurring loadings and the small loadings which occur a very large number of times.

In view of the non-linearities of loading effects indicated by the test data, it is concluded that fairly detailed representations of the random loadings which occur in service are required in ordered, cyclic loading tests.

SECTION X

RECOMMENDATIONS

The investigation of service loading simulations in fatigue tests was carried out using small, single load path, coupon-type specimens. The results obtained are directly applicable to such specimens. While these results are informative and, no doubt, picture generally applicable trends, the extrapolation of the data to provide guides to the testing of typically complex structure is a large one.

The changes in effective stress concentration produced in relatively complex, multi-load path structure may differ significantly from those produced in single load path specimens. Since this difference may be quite important in evaluating fatigue test procedures, it is recommended that additional testing be carried out using small specimens containing a multi-fastener joint. The results of the present investigation provide the best available guides to the most useful employment of such specimens.

APPENDIX I

DESCRIPTION OF EQUIPMENT AND PROCEDURES FOR OBTAINING EXPERIMENTAL DATA

This appendix describes the procedures and equipment employed in accomplishing the experimental and data processing phases of this investigation. An analysis is also presented of the degree of accuracy of the specimen loading histories as a reflection of the command signal emanating from the programming tape. In addition, discussion is presented relative to significant problems encountered in development of methods and equipment.

CONSTRUCTION OF LOADING TAPES

PRELIMINARY INVESTIGATION

Random Gust Loading Tapes

A one-inch multi-channel magnetic tape recording of a complete flight of an instrumented B-47 airplane was obtained from the Boeing Airplane Company. A photograph of the equipment which was used for converting the flight data to test input tapes is shown as Figure 90. A full length oscillograph of this instrumentation tape was visually scanned to identify two signals of high cyclic activity but of different frequency content. The signals representing the bending moments occurring at the fin root and wing root during a 96-minute low altitude pass (800 feet at 280 knots) were selected for adaption to specimen loading signals for this preliminary investigation.

Each of the selected flight records was transcribed on dual-channel 1/4-inch magnetic tape, as shown schematically on Figure 91. The flight record was passed through an electronic scanning system which continuously determined and subtracted out variations of mean load from the initial mean value. The mean variations were recorded on Channel No. 2 and the resulting dynamic signal was recorded on Channel No. 1. To obtain the shortest testing time possible within the frequency limitations of the testing equipment, the 96-minute flight histories were compressed to about 6 minutes for the wing root trace and 30 minutes for the fin root trace. Ten copies of the transcribed wing root trace and two copies of the fin root trace were recorded and spliced together into two separate one-hour continuous programming tapes.

Statistical counts of the load content of the wing and fin traces produced spectra of similar shape. In an effort to obtain a random trace with a markedly different spectrum shape, the dynamic signal (Channel No. 1) of the wing root programming tape was rerecorded through a non-linear amplification system. To illustrate the change in shape produced, spectral representations based on mean crossing peak counts of the wing root, modified wing root and fin root unit programming tapes are shown on Figure 92.

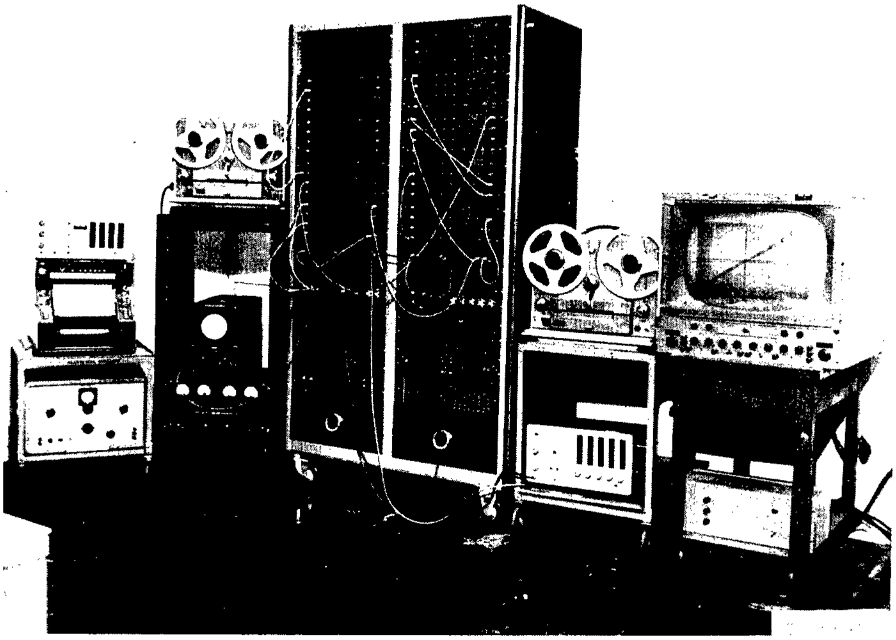


Figure 90 General View of Tape Construction and Data Reduction Equipment

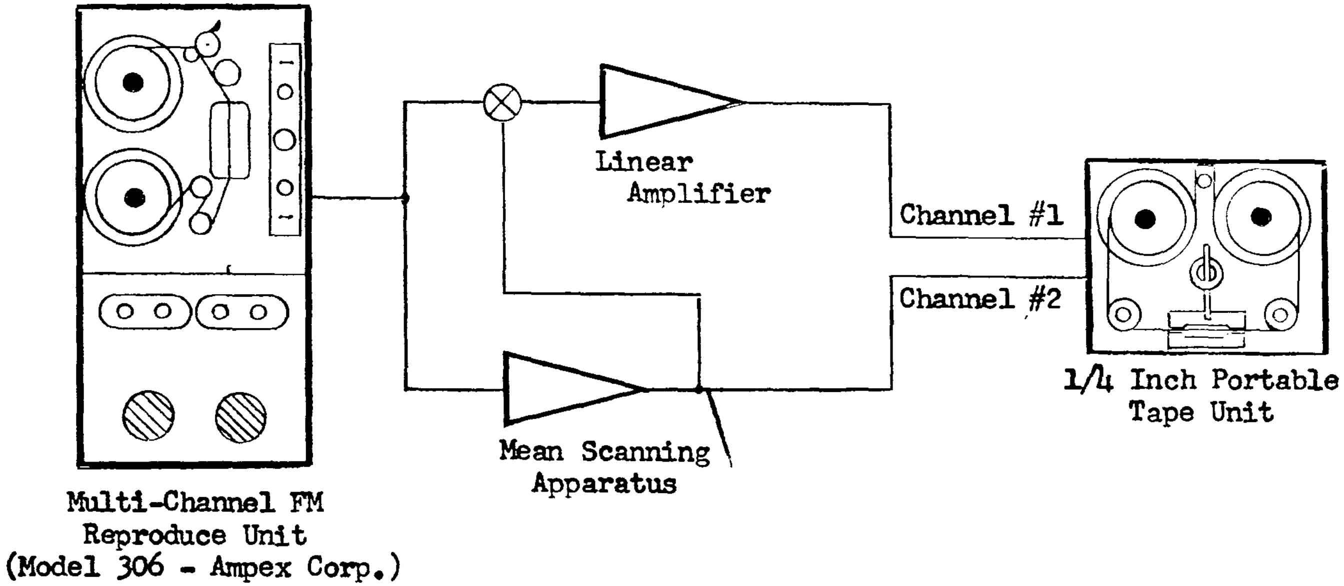


FIGURE 91 SCHEMATIC OF TRANSCRIPTION OF FLIGHT RECORD

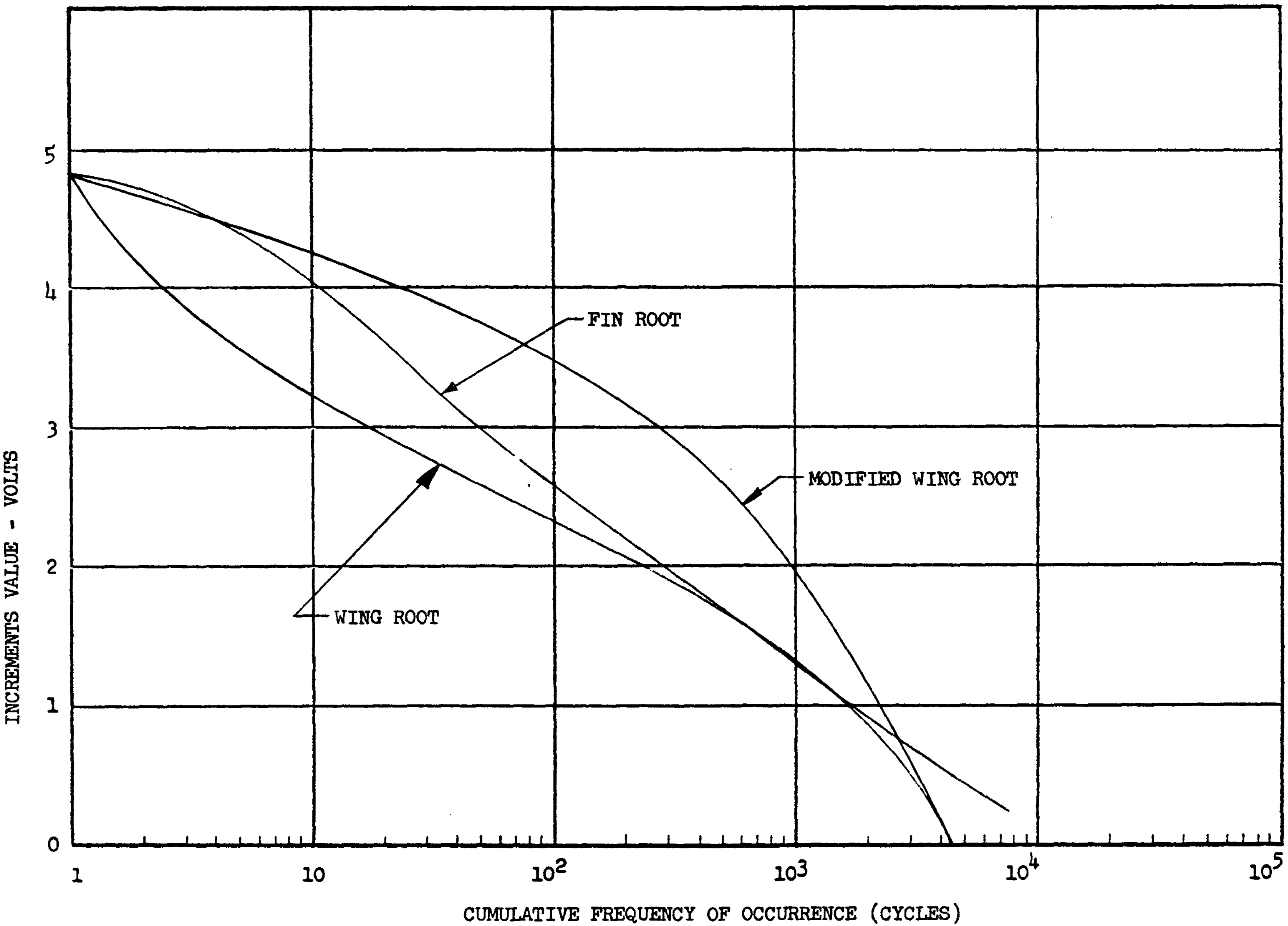


FIGURE 92 MEAN CROSSING PEAK COUNT—WING ROOT, MODIFIED WING ROOT AND FIN ROOT LOADING TRACES

The system used to electrically alter the spectrum shape of a random trace is shown schematically on Figure 93. A desired input-output voltage pattern was drawn on the oscilloscope display screen and the non-linear amplification system was calibrated to match this relationship. Spectrum modification was accomplished by rerecording the tape through this calibrated setup.

Ordered Gust Loading Tapes

Ordered cyclic loading tapes were constructed to contain spectral representations of mean crossing peak counts of the wing root, modified wing root, and the fin root unit programming trace. In addition, one ordered cyclic loading tape was constructed based on a range count representation of the unit wing root programming trace. The system used in constructing these ordered programming tapes is shown schematically on Figure 94.

These ordered cyclic loading spectra were constructed by feeding a constant amplitude sinusoidal signal into an arbitrary function generator which performed a prescribed time-amplitude modulation of the signal. The desired time amplitude relationship was graphed, using metallic conducting ink, and placed on a drum in the arbitrary function generator. A "pick-off" device, similar to a slide wire potentiometer, modulated the amplitude of the input signal as it traced the curve on the rotating drum.

PRINCIPAL FATIGUE TESTING PROGRAM

The limited flight loading histories recorded by the 96-minute wing and fin root traces were insufficient to provide the desired characteristics of a representative extended random service loading history. To obtain the desired loading history, the random wing root programming signal was modified. The maximum positive and negative loads were made symmetrical and larger loads were inserted so as to represent a longer service loading spectrum.

Repetitions of 10 basic sections of the random signal (identified as A_1, A_2, B_1, B_2 ..... E_1, E_2) were spliced together to make four programming tapes, each approximately one hour long. The A_1 section was obtained by rerecording the basic wing root signal through a non-linear amplifier such that the maximum negative excursion was limited to match the maximum positive excursion. This operation is similar to that used in making the unit modified wing trace and was shown schematically on Figure 93. The B_1 section was obtained by rerecording the A_1 section through the non-linear amplifier such that the maximum positive and negative excursions are increased about 15%, the next smaller excursions are amplified only slightly and the smallest excursions experience negligible change. The C_1, D_1 and E_1 sections are obtained in the same manner with the maximum positive and negative excursions increased by approximately 20%, 30% and 40% respectively, over the maximum A_1 excursions. The A_2 through E_2 sections were obtained by rerecording the A_1 through E_1 sections through a 75% linear amplification system. These 10 basic sections are summarized below.

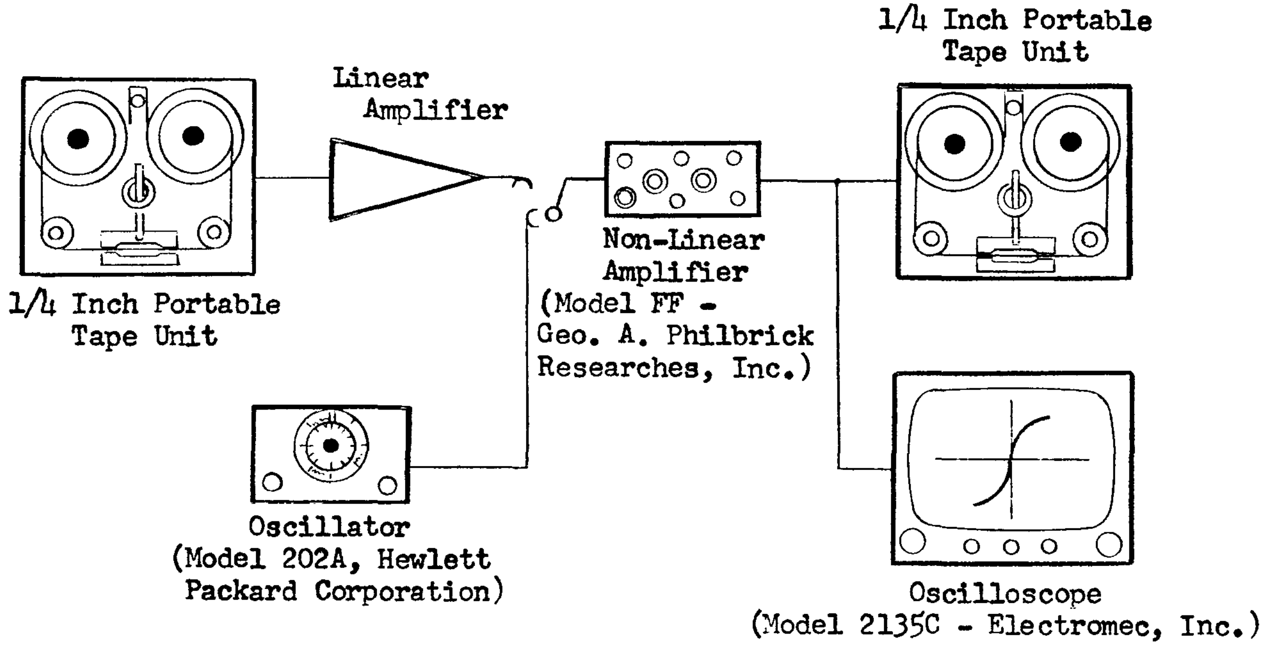


FIGURE 93 SCHEMATIC OF SYSTEM FOR ALTERING SPECTRUM SHAPES

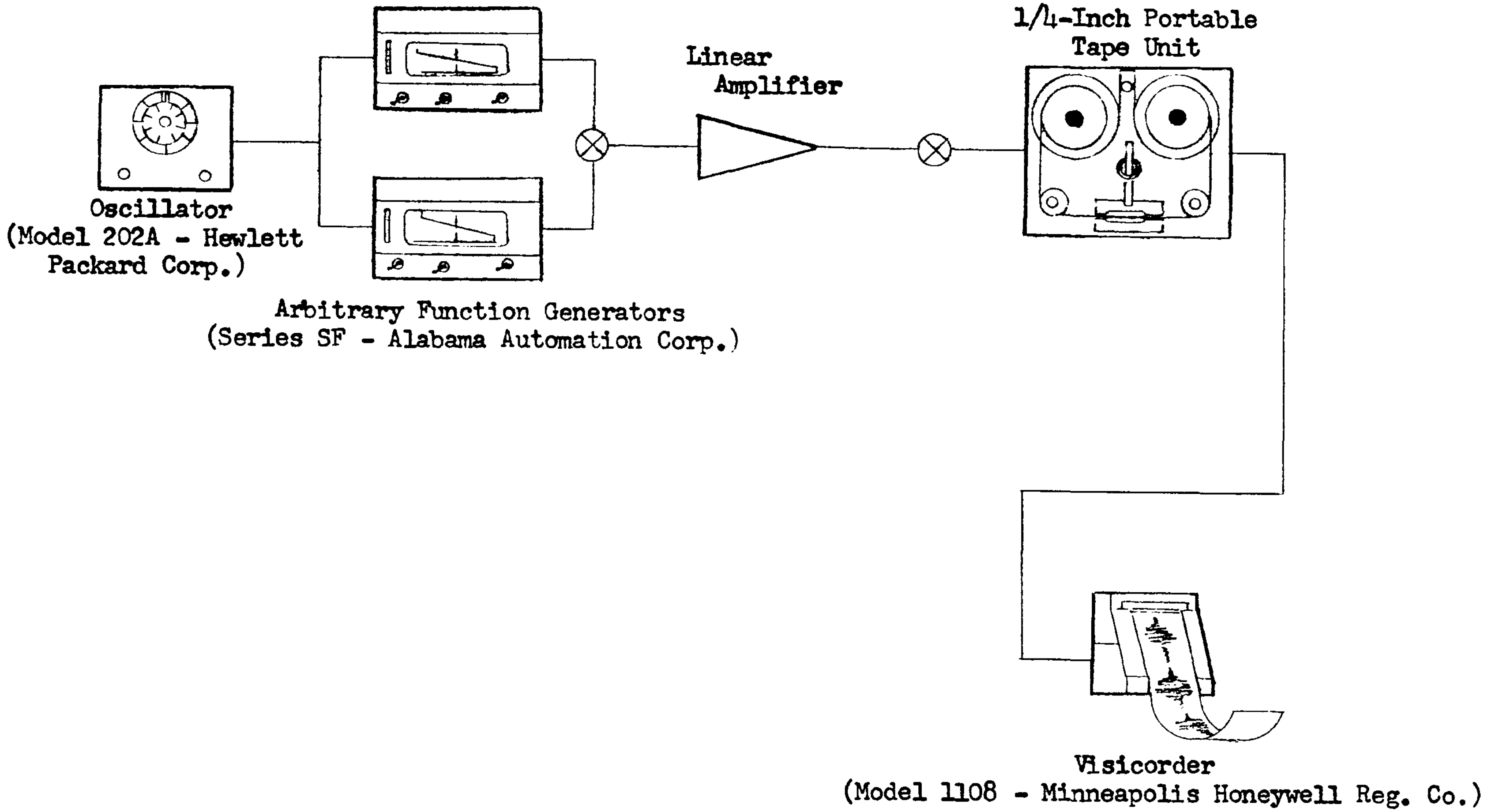


FIGURE 94 SCHEMATIC OF ORDERED TAPE GENERATION SYSTEM

A_1	Unit wing root signal modified so that maximum positive and negative excursions are approximately equal.
A_2	Section A_1 x 75% (linear amplifications)
B_1	Section A_1 modified so that maximum positive and negative excursions amplified approximately 15%.
B_2	Section B_1 x 75% (linear amplification)
C_1	Section A_1 modified so that maximum positive and negative excursions amplified approximately 20%
C_2	Section C_1 x 75% (linear amplification)
D_1	Section A_1 modified so that maximum positive and negative excursions amplified approximately 30%
D_2	Section D_1 x 75% (linear amplification)
E_1	Section A_1 modified so that maximum positive and negative excursions amplified approximately 40%
E_2	Section E_1 x 75% (linear amplification)

Four programming tapes (identified as Tape Nos. 49, 50, 51 and 52) were then constructed by splicing the 10 basic sections together in the following sequence.

Tape No. 49

A_1	A_2	A_1	A_2	C_1	A_2	A_1	A_2	A_1	C_2

Tape No. 50

A_1	A_2	A_1	A_2	D_1	A_2	A_1	A_2	A_1	D_2

Tape No. 51

A_1	A_2	A_1	A_2	E_1	A_2	A_1	A_2	A_1	E_2

Tape No. 52

A_1	A_2	A_1	B_2	B_1	A_1	A_2	A_2	B_1	B_2

These four tapes were utilized for testing specimens in the following 14-hour sequence to obtain the desired extended random gust loading spectrum.

Test Sequence	Loading Tape No.
1	52
2	49
3	52
4	52
5	50
6	49
7	49
8	52
9	50
10	52
11	52
12	52
13	49
14	51

Random Military Maneuver Tape

Because of the unavailability of an appropriate recording of representative military maneuver loadings, a tape was constructed to be consistent with the loading spectrum for fighter aircraft which is described in specification MIL-A-8866.

The unit wing root programming trace was played through the non-linear amplification system so that the negative excursions were suppressed and the positive excursions were modulated to match the spectrum described above. This operation was similar to that described in making the modified wing root trace which was shown schematically in Figure 93.

Step Ordered Gust Loading Tapes

Cyclic step-ordered loading tapes were constructed to simulate the average test life of a given group of random loading histories. Three combinations of stress interval and block size were used:

(1) 1,000 psi stress interval and 1/10 block size
(2) 1,000 psi stress interval and 1/20 block size
(3) 4,000 psi stress interval and 1/20 block size

The system used to construct the step-ordered loading tapes is shown schematically on Figure 94.

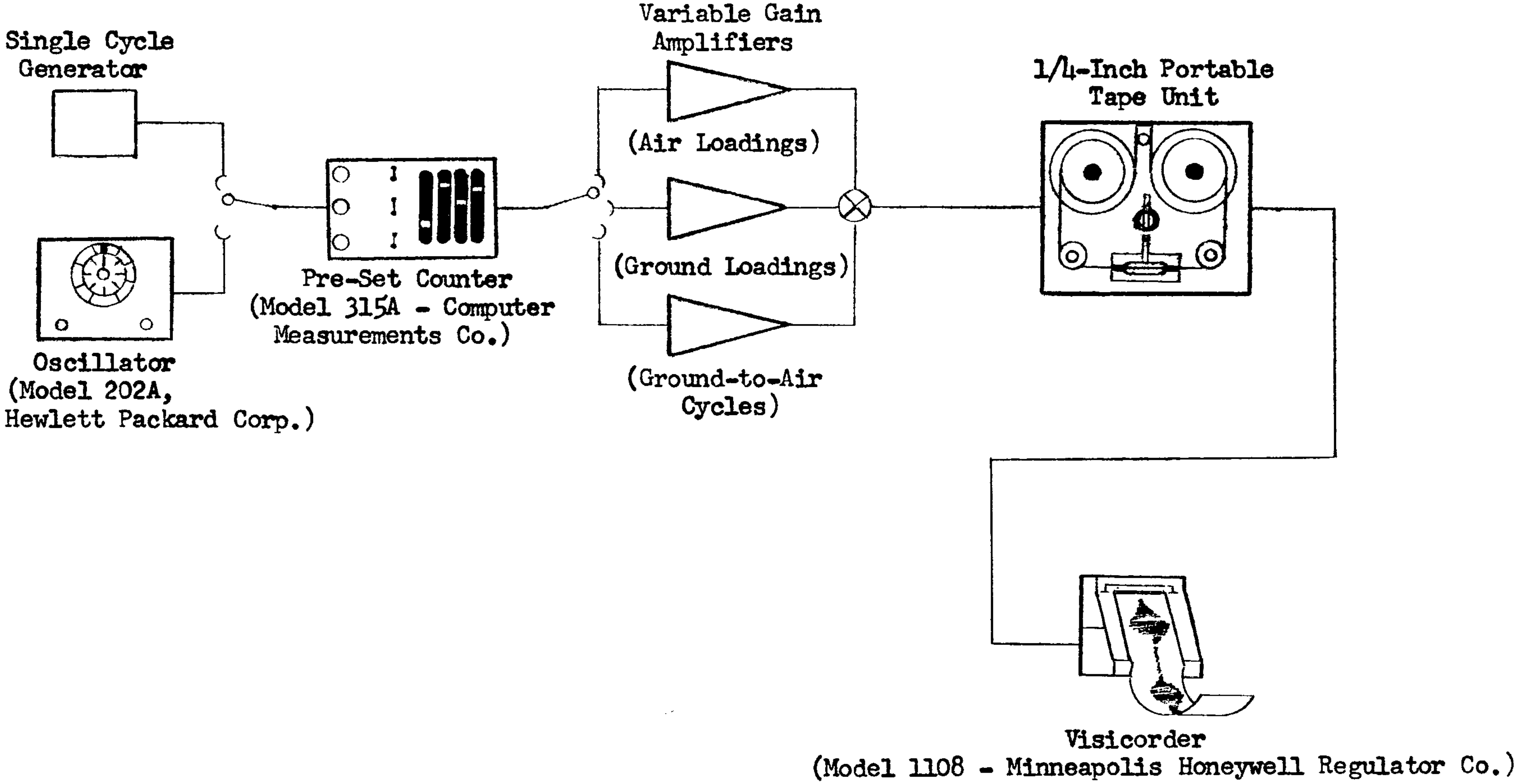
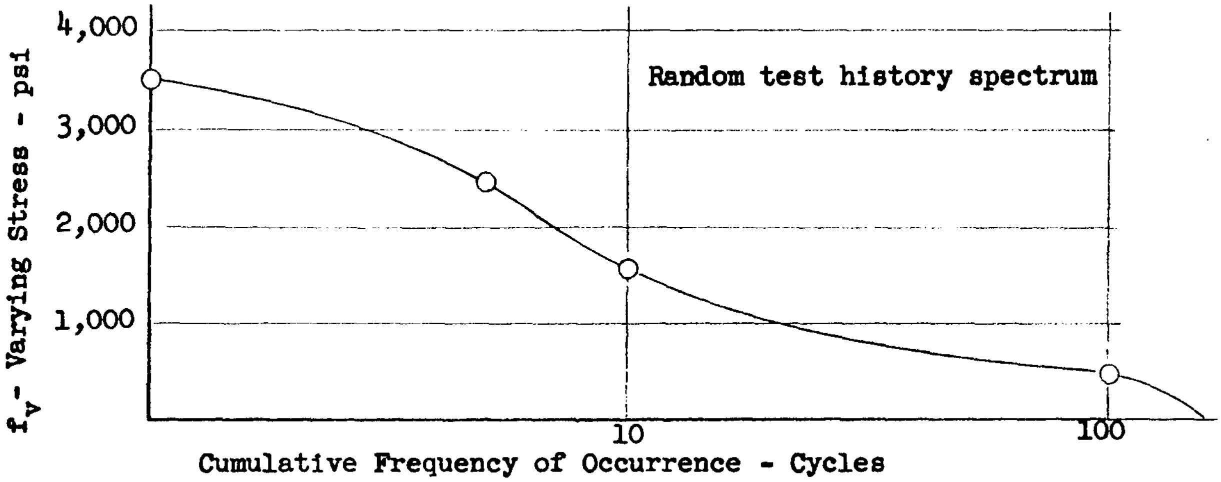


FIGURE 95 SCHEMATIC OF STEP ORDERED TAPE GENERATION

The procedure used in constructing an ordered loading tape is shown in the following example:

> For a given average random test history, construct an ordered programming tape of 1,000 psi stress interval size, and 1/10 block size.

(1) Graph the random test history spectrum.
(2) Observe and record in columnar form the cumulative frequency count at the half range intervals (500 psi, 1500 psi, 2500 psi, etc.) on the random spectrum.



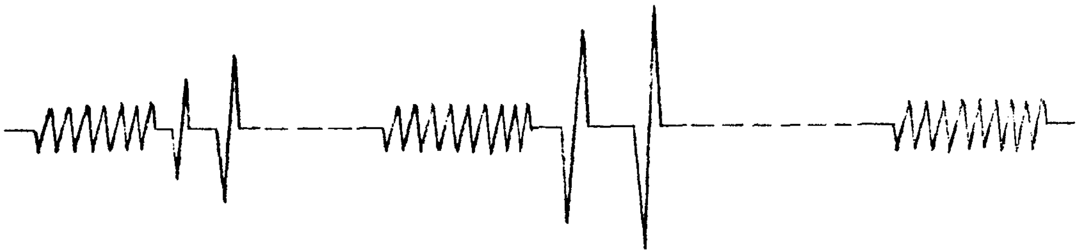
(3) Determine the total number of cycles to be applied at each stress level (1000 psi, 2000 psi, 3000 psi, etc.) by calculating differences between the cumulative counts observed in step (2).

(4) Divide the total number of cycles for each stress level calculated in step (3) by ten. This determines the number of cycles to be applied in each unit spectrum at each stress level. Distribute each fractional cycle at the corresponding half life.

(5) Construct a test programming schedule for the "stress level-cycle" combinations from step (4).

			Unit Spectrum Number									
f_v	$\sum n$	n	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
500	100											
1,000		90	9	9	9	9	9	9	9	9	9	9
1,500	10											
2,000		5	1		1		1		1		1	
2,500	5											
3,000		4	1			1		1			1	
3,500	1	1					1					

(6) Employing an "oscillator-preset counter-recorder" combination, (shown schematically in Figure 95) record the ordered loading tape as described in the programming schedule constructed in step (5).



Unit Spectrum No. 1

Unit Spectrum No. 2

Unit Spectrum No. 3

Step Ordered Military Maneuver Loadings

Step ordered loading tapes were constructed representing the average random military maneuver test histories. These ordered loading tapes were constructed utilizing the same procedure used in making the step ordered gust loading tapes except that the negative excursions were suppressed by passing the generated signal through a diode.

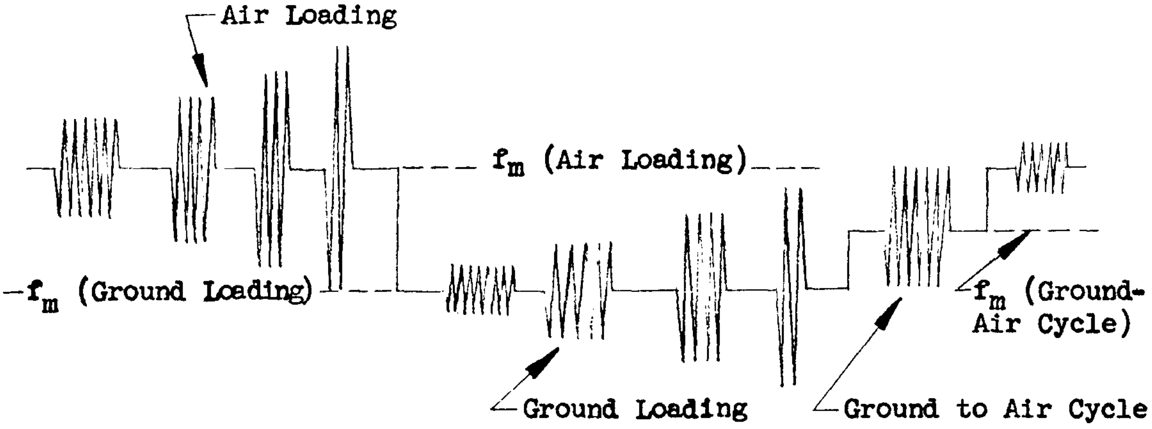
Step Ordered Composite Loading Tapes

Step ordered programming tapes were constructed representing random composite test histories. These ordered tapes were constructed for both gust and military maneuver type air loadings employing the same procedure described in the example above. Air loadings, ground loadings, and ground-to-air transitions were treated as three separate random spectra and separate programming schedules were made for each spectrum. The complete ordered composite tape was made as follows:

(1) The first unit spectrum of air loadings was recorded, as tabulated on its programming schedule, about the mean load for which the corresponding random air loadings were applied.

(2) The first unit spectrum of ground loadings was also recorded, as shown on its programming schedule, at the mean load at which the corresponding random ground loadings were applied.

(3) The first unit spectrum of ground-to-air cycles was recorded such that the peak-to-peak excursion extended from the air loading mean to the ground loading mean.



The procedure described above was used to generate the first unit composite loading spectrum. The succeeding spectrum units were constructed in the same manner.

The standard equipment items used in this tape construction work are indicated on the schematics on Figures 93, 94, and 95. The portable tape unit is a two-channel frequency-modulated 1/4-inch record and playback unit. The tape deck is a series 30 recorder manufactured by American Electronics, Inc. The electronics were designed and developed by Lockheed. Characteristic of this unit are:

Carrier frequency - 3,400 cps
Tape speed - 7 1/2 inches per second
Minimum signal to noise ratio - 40 db
Maximum record voltage - 9.0 volts
Playback filtering - 60 or 500 cps

SPECIMEN LOADING

The specimen loading system which was developed for this investigation was basically simple in mechanical detail, utilizing for the most part standard commercial equipment for signal input, hydraulic load control and loading readout. However, to appreciate the demands upon the system it must be realized that in this investigation the primary testing requirement involved application of specimen loadings which faithfully followed command signals of a very complex nature. The controlled application of such loadings dictated the selection and development of servo control circuitry and the development of special test monitoring techniques. A description of the loading system is presented below followed by a brief discussion of several problems encountered during testing.

DESCRIPTION OF SPECIMEN LOADING EQUIPMENT

Fatigue loading equipment was developed for the rapid application of the loadings defined by signals on the magnetic tapes described in preceding paragraphs. This equipment basically provides an electro-hydraulic servo system consisting of a test specimen in series with a servo valve-jack combination, with the loadings programmed by the signal from magnetic tape. This system is shown schematically on Figure 96.

As shown on this figure, the output signal from the programmer is fed into the servo loop through the summing junction. The amplified input signal programs the action of the servo valve in metering cyclic flow of oil to the fore and aft parts of the servo jack. The output signal of the load transducer strain gage is amplified and fed back into the summing junction closing the loop. The instantaneous summing of these two opposing signals at the input side of the servo valve ideally results in the specimen experiencing the loading history represented by the signal on the loading tape. In utilizing such a system due cognizance was given to inherent mechanical and electrical limitations of the entire system, especially with respect to frequency response and flow characteristics of the servo valve.

The 1/4 inch programming tape unit used for spectral loading input is the same basic unit as the 1/4 inch portable tape unit which was used for preparation of the program tapes except that it does not have recording capabilities. The servo loop command and feed-back electronics were basically Model K2-W operational amplifiers in series with Model K2-P chopper stabilizing amplifiers, manufactured by George A. Philbrick Researches, Inc. A diode clipper was mounted in the electrical circuit between the tape unit and the summing junction which limited the amplitude of the programming signal supplied to the summing junction in case of signal overload. This diode clipper was also basically a Model K2-W operational amplifier.

The servo jack was a Lockheed designed hydraulic actuator with a maximum static force rating of 17,000 pounds. The servo valve employed to program the action of the hydraulic actuator was a Model 26 Flow Control Valve, manufactured by Hydraulic Research and Manufacturing Company. This servo valve has a flow control range from 0.15 to 10 gpm for an operating pressure range of

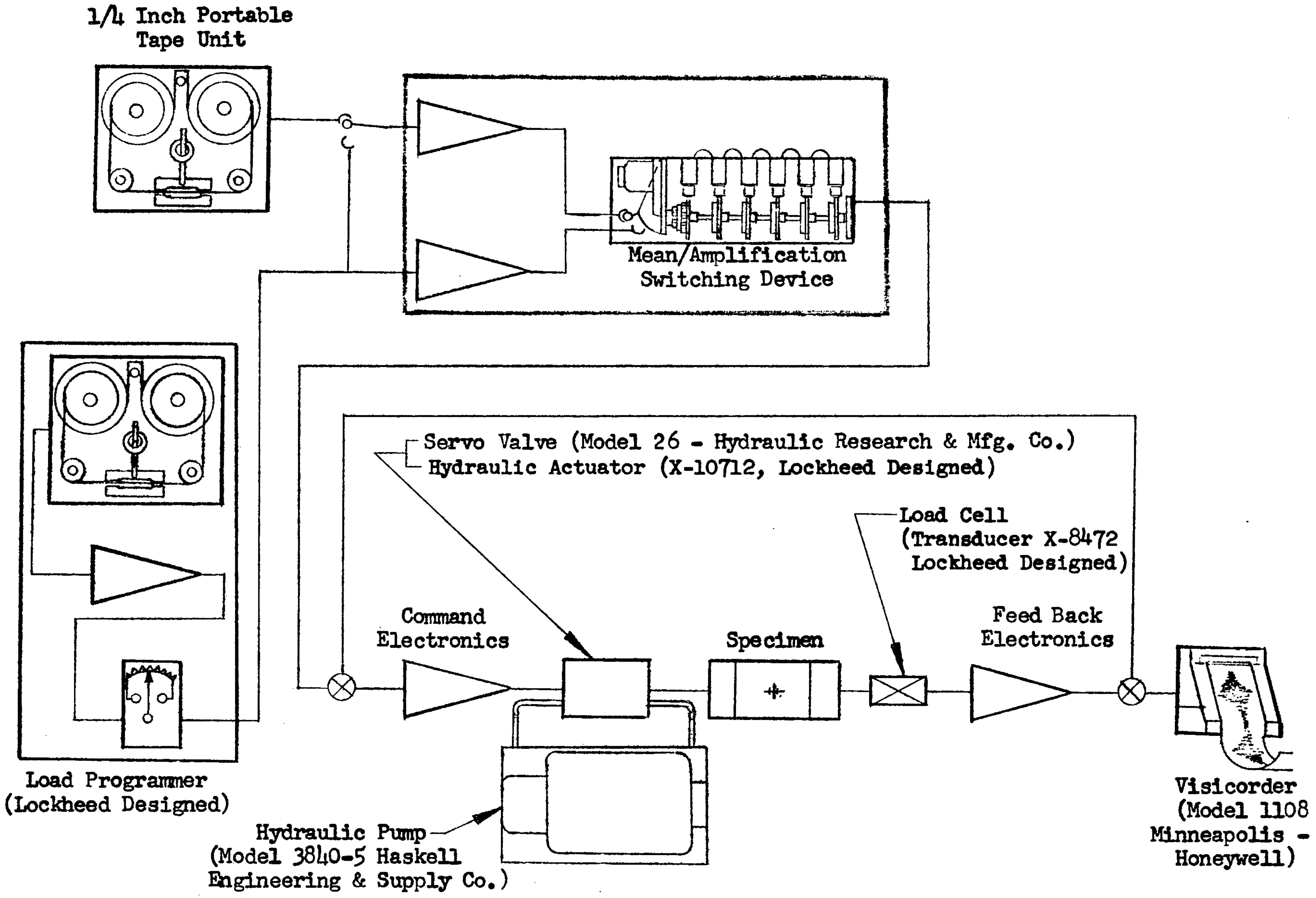


FIGURE 96 SCHEMATIC OF TEST LOADING SYSTEM

150 to 4,000 psi. The transducer used as the sensing unit in the system was a Lockheed designed strain gaged load cell. This transducer is cylindrical in constructional detail and is equipped with a full bridge gage installation, the electrical output being essentially insensitive to bending strain. Four complete loading systems were developed for this testing program and are shown in operation on Figure 97. The tape playback unit, the electronics and associated components for programming two separate servo loops were mounted in a self-contained unit as shown on Figure 98. A photograph of a valve-jack combination, load transducer and specimen, all rigidly mounted in one of the loading fixtures, is shown on Figure 99. The specimen was mounted in the test fixture by rigid friction grips, and floating stiffeners were used on the unsupported edges of the specimen to prevent buckling as shown in Figure 99. A failure wire was cemented to the specimen in the area of maximum stress concentration and connected to a relay. Upon initiation of a fatigue crack the failure wire circuit was interrupted, instantaneously blocking off hydraulic flow to the actuator.

PROCEDURE FOR SPECTRAL LOADING OF SPECIMENS

Prior to the application of loads to each specimen, the loading system was calibrated and adjusted to produce the applicable loading history represented on programming tape. Although several steps in the calibration and dynamic loading procedure were common to all spectral tests, certain steps were followed only for particular types of loading history. Outlines of the procedures follow.

Loading Histories Having Constant Mean Load Values

(1) From known transducer data, a calibration factor of load versus electrical output was determined which related the maximum signal voltage on the program tape to the highest load to be applied to the specimen. This maximum signal was recorded on an oscillograph for later reference.

(2) A dummy specimen, serving merely as a load link during calibration was installed in the test fixture and the static mean load was applied by dialing in the equivalent voltage to the servo valve circuit.

(3) The required dynamic signal amplification was set, based on the loading tape voltage calibration factor.

(4) The maximum dynamic load was applied to the dummy specimen and the load cell signal output was recorded on an oscillograph for comparison with the static signal previously recorded.

(5) Deviation of the maximum loading cycle from the desired load level was corrected by a compensating adjustment of the signal amplification, and step 4 was repeated.

(6) When the desired loading level for the maximum cycle was obtained the calibrating system was replaced by a test specimen.

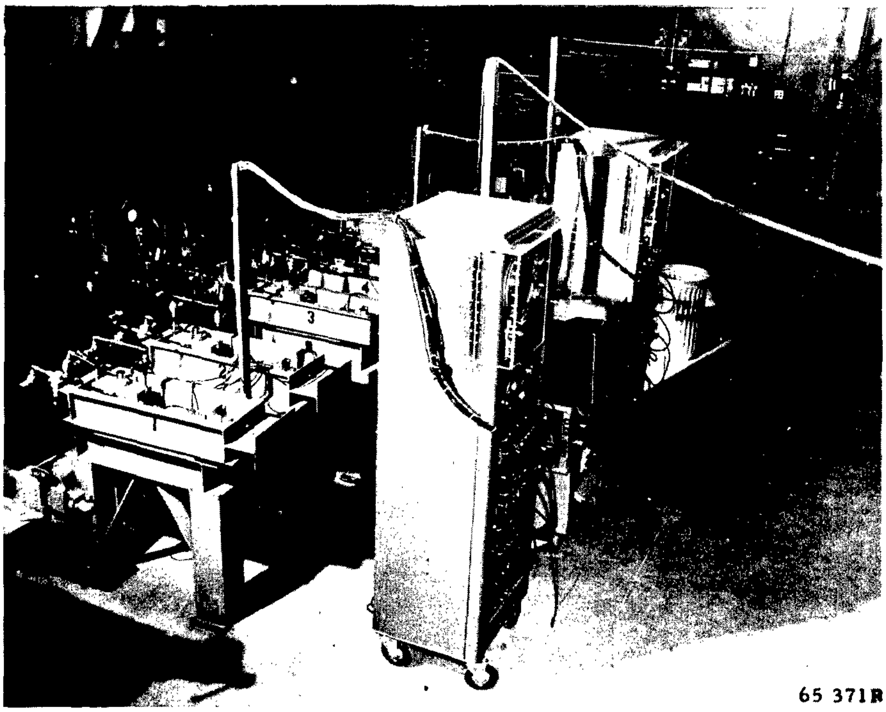


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Figure 97 General View of Specimen Loading Apparatus

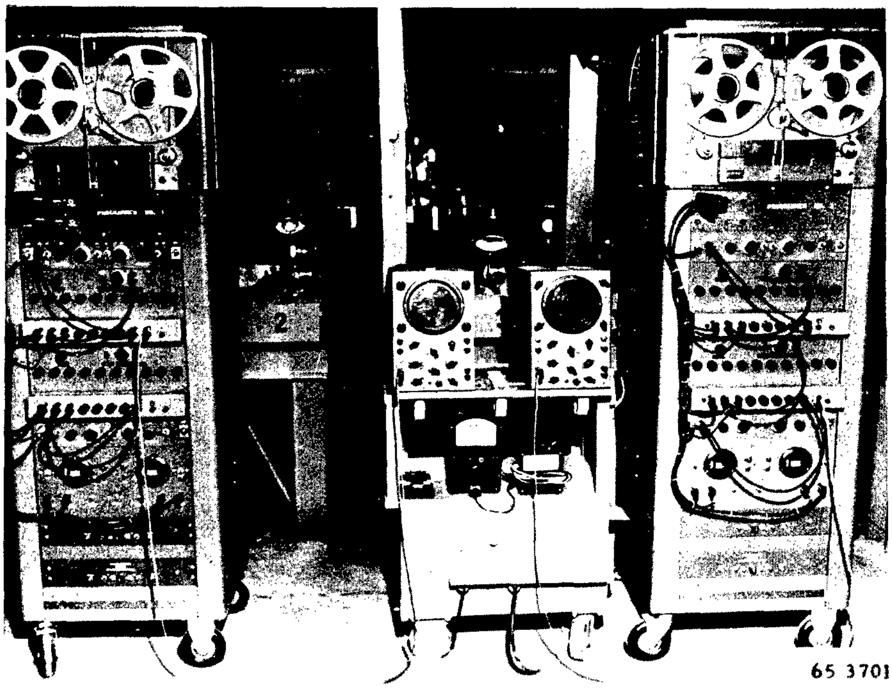

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Figure 98 Magnetic Tape Loading Control Units

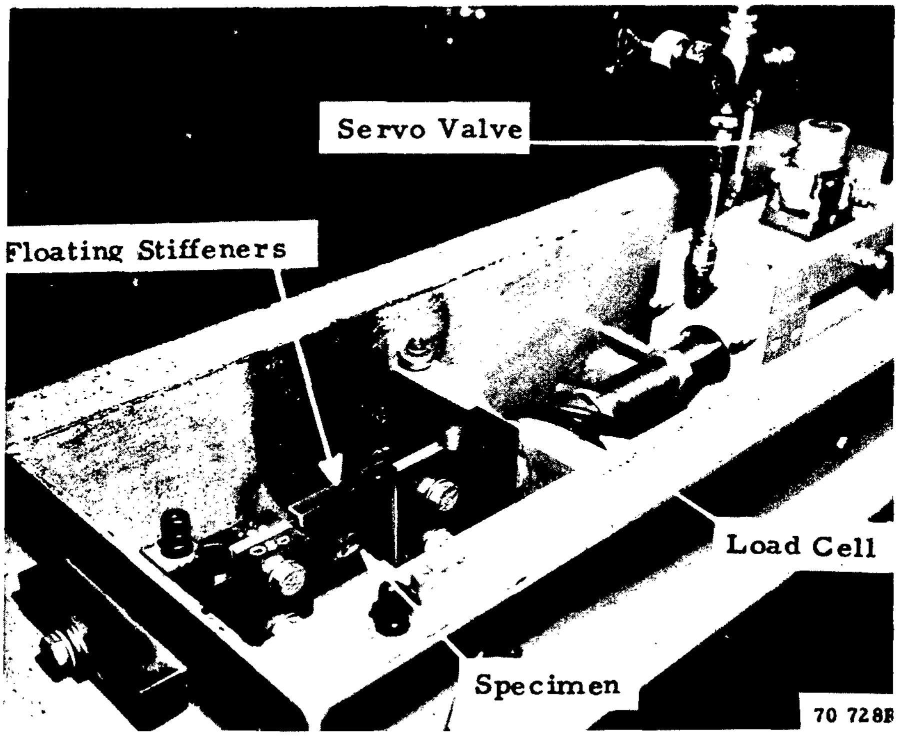


Figure 99 Close-up of Specimen Installation

(7) The loading trace was then applied to the test specimen. The maximum loading cycle was periodically monitored on the oscillograph and required adjustments made to the amplification of the dynamic signal to maintain the desired loading level.

(8) Testing was continued until the initiation of a fatigue crack interrupted the failure wire circuit terminating the loadings. In addition, interruption of the failure wire circuit cut off the power source to the electrical timing device recording the duration of specimen life.

The full range of random loadings applied to the test specimen were periodically monitored to determine the spectrum content of the applied loads, and as an added check on the stability of the frequency response of the loading system. Monitoring of these random loadings was accomplished by recording on magnetic tape the output signal from the load transducer for each unit loading trace applied. These unit monitor tapes were then electrically counted as described later in the data reduction section.

Periodic monitoring checks were also made of the ordered loadings applied to the specimen. Monitoring of the ordered loadings applied in the preliminary investigation was accomplished in the manner described above for the random loadings. Monitoring of the step ordered loadings consisted of periodic recording on an oscillograph of the load transducer output signal for the complete ordered loading trace. The loads for each group of cycles were calculated from the oscillographic record and compared with the schedule from which the loading tape was constructed.

Loading Histories Having Variable Mean Load Values

Random composite loadings with gust type air loadings were produced by using the same loading tape signal for both air loadings and ground loadings. The ground loading trace was similar to the air loadings except that different static mean load and amplification of the dynamic signal were used. The loading tape signal was routed through an electro-mechanical device which periodically shifted both static mean load and amplification of the dynamic trace. The procedure for alternately applying these two loading traces from the same input signal was as follows:

(1) A calibration factor for the load programming system was determined relating specimen load to loading tape voltage and a calibration signal was recorded on an oscillograph. The input voltage relationships required to define the desired loading history were then calculated.

(2) With a dummy specimen installed in the loading fixture, the switching device was locked in one of the spectrum loading positions and the static mean load was applied with a bias voltage.

(3) The required dynamic signal amplification was set based on the loading tape voltage relationships calculated in Step 1 above.

(4) The maximum dynamic signal was applied to the calibrating specimen and recorded on an oscillograph for comparison with the previously recorded loading system calibration factor.

(5) Deviation of the maximum loading cycle from the desired load level was corrected by a compensating adjustment of the signal amplification and the repetition of Step 4.

(6) The switching device was then locked in the second loading condition and Steps 2 through 5 were repeated to obtain its desired dynamic trace amplification.

(7) After the desired loading levels for the maximum loading cycle were obtained, the calibrating specimen was replaced by a test specimen.

(8) The loading trace was then applied to the specimen and the switching device was started at the commencement of the dynamic signal.

(9) The maximum composite loading cycle was periodically monitored on the oscillograph and the required adjustments were made to the amplification of the dynamic signal to maintain the desired loading level.

(10) Testing was continued until a fatigue crack developed. The loading was terminated by failure of the previously described failure wire and the test duration was recorded.

Random composite military maneuver loadings were produced by employing the signals from two separate loading tapes. To apply these loadings the portable tape unit used in the tape construction work was operated in parallel with the programming tape unit as shown schematically on Figure 96. These two signals were fed into the same switching device used in applying the random composite gust loadings. The switching apparatus alternately switched static mean loads and the dynamic signal inputs. The setup, calibration, testing and monitoring were also accomplished in the manner described above for random composite gust loadings.

Ordered composite loading tapes were constructed so that the relationship between the static mean load and the dynamic loading level was recorded on the tape. Thus only one signal amplification was required for the composite tape to apply the desired composite loading spectra. The procedure for setting the loading levels, testing and monitoring, was the same as described for the single spectrum loadings.

Discussion of Loading System Development

In developing this loading system a number of problems were encountered. The resolution of the overall problem of applying the same loading history to the specimen for repeated applications of the same loading trace required considerable effort. Many factors contributing to this overall problem complicated the development of a completely reliable loading system throughout a major portion of the preliminary investigation. Some of the contributing problems are discussed in the following paragraphs.

In order to extend the operating frequency range of the servo valve and system, electrical lead networks were developed. A flat frequency response over the range of 0 to 45 cps with attenuation of 3 db at 60 cps within a maximum allowable deviation of ±2% was set up as the performance standard. Values for the lead network components were determined from the frequency response of the basic system. In addition individual lead networks were tailored to compensate for the cumulative effect of the characteristics of each servo loop in order to meet these requirements.

In the continued effort to improve the overall loading system performance, the meter originally used in setting the level of the input loading trace was replaced by a direct reading oscillograph (Visicorder). The use of the oscillograph permitted utilization of a dynamic signal for calibrating the loading tapes. This more realistic method of setting the loading level with a dynamic signal in the frequency range of the applied loading cycles greatly improved the control of variations in frequency response.

Due to deterioriation in servo valve performance and aging of electronic components, it was necessary to monitor continuously the frequency response of the servo system. A function generator was used in conjunction with an oscillograph to check the servo system response and by adjustment of the forward and feedback gains of the servo amplifier, the system response could be maintained within the limits of the ±2% deviation.

Variations were noted, during the early testing stage, between loading histories sampled at discrete intervals for the same input trace. This was concluded to be due mainly to large fluctuations of the hydraulic oil temperature occurring over a normal operating period since corresponding fluctuations were also observed in the frequency response of the loading system. Stabilization of the hydraulic oil temperature through the use of an immersion heater or regulation of cooling water through a heat exchanger greatly reduced these response variations.

Proper mechanical operation of the servo valve demands that the hydraulic fluid be filtered of all particles which are greater than approximately 25 microns in diameter. In order to assure reasonable filter life the entire hydraulic system was maintained as free as practicable of contaminants. The formation of varnish or generation of corrosion particles results in costly shutdown periods and is a constant threat to the attainment of reliable test data. Therefore MIL H 5606-A hydraulic fluid was selected because of its stable and non-corrosive characteristics. This particular problem proved to be a costly one during the early stages of the testing phase of this investigation.

Bearing in mind that the specimen loading system was, of necessity, highly responsive to tape signal command, it can readily be seen that it was imperative that loading input tapes remain as free as possible of extraneous signals which might affect testing validity. These false signals may be of such strength to cause serious overloading or destruction of the specimen. In an effort to produce and maintain loading input tapes essentially free of false signals, special tape handling procedures were adopted. Electrical means were also employed to repress false signals of any significant magnitude, during load application.

In passing a magnetic tape across a signal reproduce-head any irregularity of the tape surface causes a momentary loss of playback signal known as a drop-out, resulting in the appearance of a maximum voltage at the output terminals of the tape unit reproduce-electronics. The response characteristics of an electro hydraulic servo loop are such that the loading system instantaneously applies the maximum possible load to the test specimen. The major causes of tape drop-outs are improper tape splices, flaking of the magnetic surface, and minute dust particles collecting on the tape surface. A method of completely eliminating drop-outs was not achieved, but by a continual effort in guarding against conditions conducive to their origin, their occurrence was effectively minimized.

The principal efforts extended in minimizing the occurrence of drop-outs were as follows:

1. Dust protective shields were installed around the area of the loading tape and signal reproduce-equipment. A practice of periodic cleaning was rigorously followed.

2. Multi-pass loading tapes were constructed by splicing together recorded sections of the unit loading trace. These loading tapes were rerecorded onto splice-free tape for use on the load programming units. In the event of accidental damage or flaking of the magnetic coating of the test loading tape, resulting in a permanent drop-out, a duplicate splice-free copy was made of the originally spliced multi-pass tape.

3. Where single drop-outs or other strong extraneous signals existed which were not the result of splicing, electrical means involving the use of diode clippers were utilized to subdue the strength of the signal. To this end the clipper circuit was adjusted to cut off all signal strength which was in excess of that signal representing the highest spectral load.

CONSTANT LOAD AMPLITUDE TESTING EQUIPMENT

As noted in the main body of the report, sets of S-N curves were developed as reference data for the random loading and spectrum loading tests. The S-N tests were conducted in resonant beam fatigue test machines. In this type of fatigue machine, loads are developed by means of a motor-driven rotating eccentric weight fastened at the free end of a pivoted beam. This beam is tuned to a frequency slightly higher than the driving frequency produced by the motor (1800 rpm). The test specimen is mounted normal to the axis of the beam and so is loaded axially by the beam displacements. Static and dynamic loads are measured and monitored using the output of strain gages mounted on a load cell which is loaded in series with the test specimen.

DATA REDUCTION

DESCRIPTION OF COUNT METHODS

At the start of this program a large number of count methods were reviewed in terms of their applicability. All of these methods were variations of three basic count methods: "Peak Count," "Range Count", and "Interval Crossing Count." One of each of these three basic types of count methods was then selected for further study as applied to gust data used in this study. The manner in which the selected count methods were applied is described below.

Mean Crossing Peak Count

Given load-time trace $y = f(t)$

(1) Establish load levels of interest $y_1, y_2, y_3 \ldots y_n$ above and below mean

$$\bar{y} = \frac{1}{T} \int_0^T f(t)dt$$

(2) Establish all points at which $y = \bar{y}$, that is, where load-time trace crosses mean.

(3) Between two successive crossings of the mean establish:

a) The maximum value of load-time trace for portions greater than mean (peak).

or b) The minimum value of load-time trace for portions less than mean (valley).

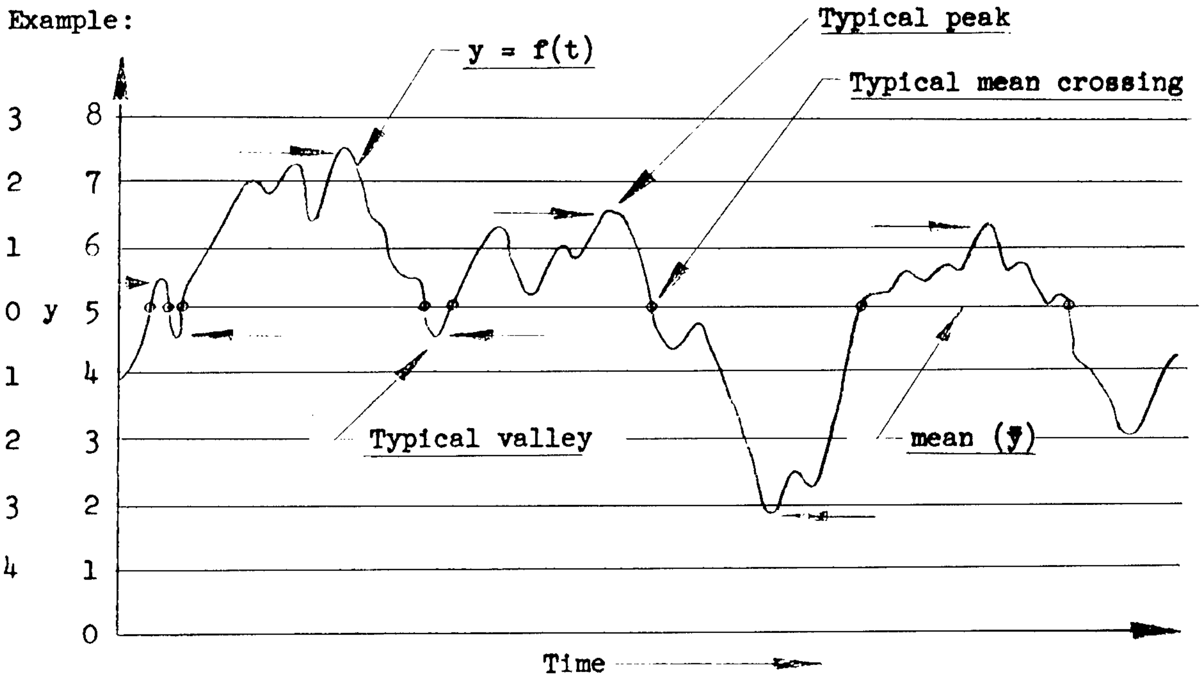
(4) Count the number of peak maximum values above any particular level of interest.

(5) Count the number of valley minimum values below any particular level of interest.

(6) Summarize counts.

(Illustrations of this procedure follow)

Example:



Level of Interest	0	1	2	3	4
Peak Count	4	3	1	0	0
Valley Count	3	1	1	1	0

Interval Crossing Count

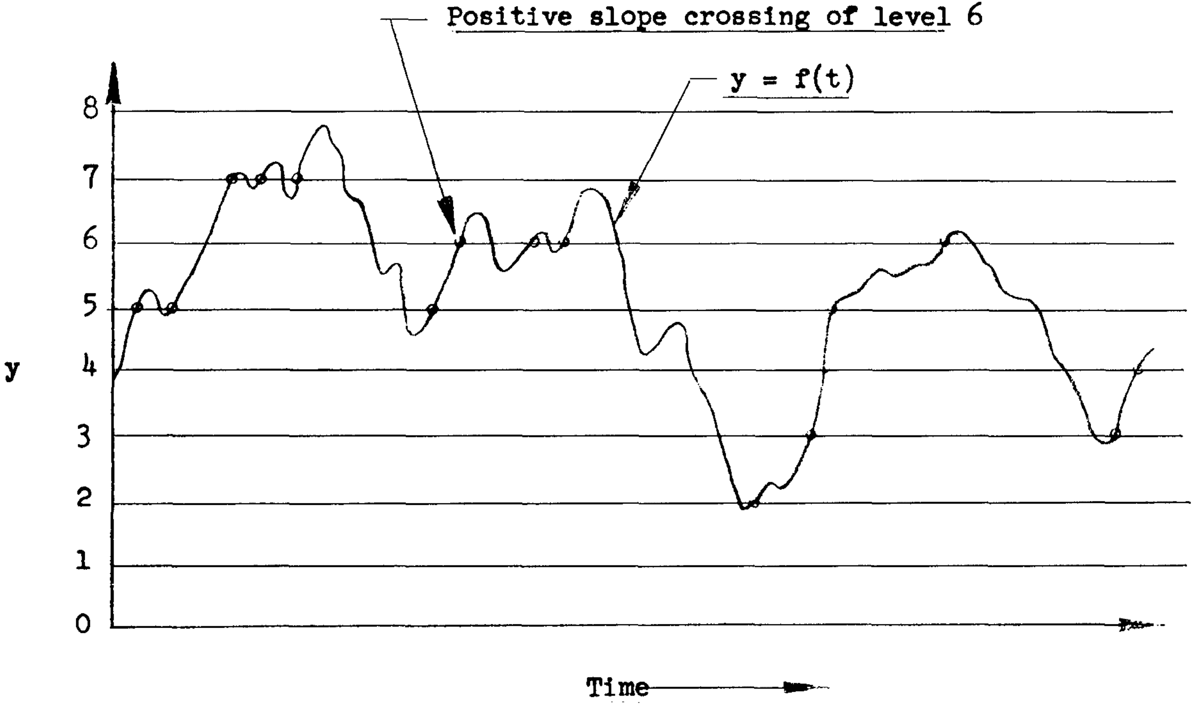
Given load-time trace y = f(t)

(1) Establish load levels of interest such as y_1, y_2, y_3 .... y_n.

(2) At each level of interest, count the number of times y = f(t) crosses the level of interest with a positive slope.

(3) Summarize the counts.

Example:



Level	0	1	2	3	4	5	6	7	8	Total
Number of crossings	0	0	1	2	3	4	5	6	7	18

Range Count

Given load-time trace $y = f(t)$

(1) Establish load ranges of interest y_1, y_2, y_3 .... y_n where y is only a change in load and refers to no particular value of y.

(2) A count should be recorded when all of the following conditions are met in the sequence listed below.

a) Let t increase from $t = o$ or the instant a count is made.

b) Maintain as a reference the minimum value of y (lowest valley) experienced.

c) As soon as $y = y_{min} + y_n$ the first condition is met.

d) Now as t increases, maintain as a reference the maximum value of y (highest peak) experienced subsequent to meeting the first condition.

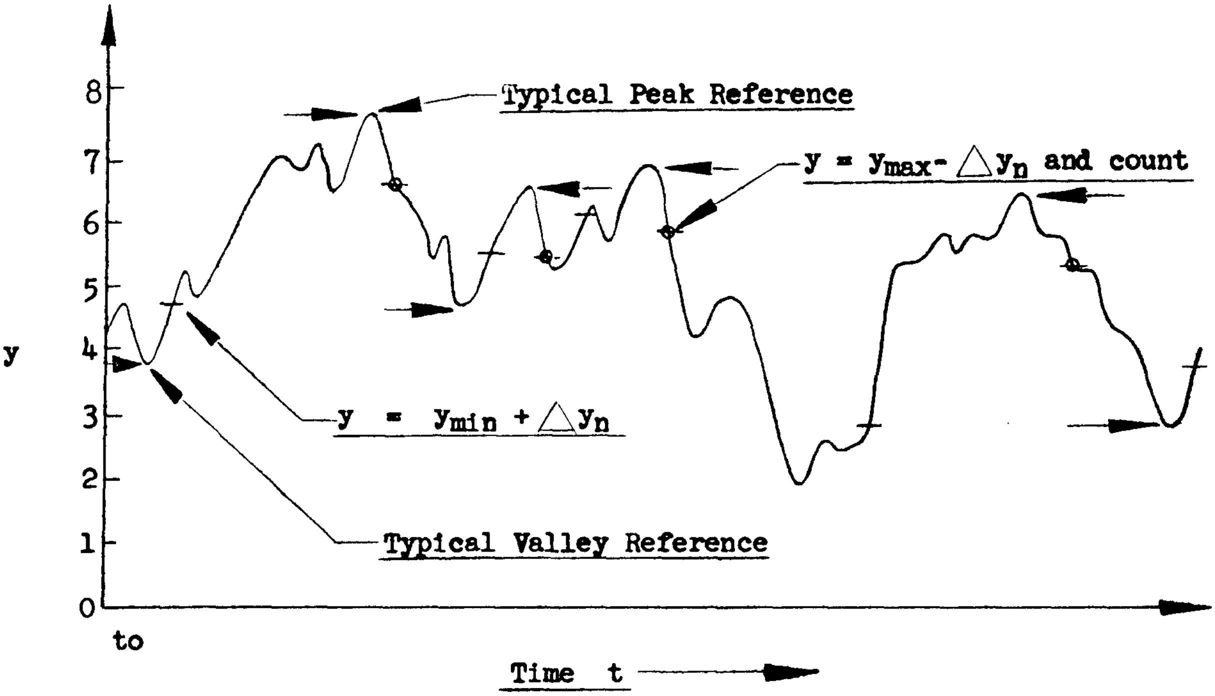
e) As soon as $y = y_{max} - \triangle y_n$ the second condition is met.

f) Record a count for range $\geqslant \triangle y_n$.

(3) Repeat sequence until entire history is scanned.

(4) Summarize counts.

Example: for $\triangle y_n = 1$



Range	1	2	3	4	5
Counts	4	3	2	1	0

ELECTRICAL COUNTING SYSTEMS

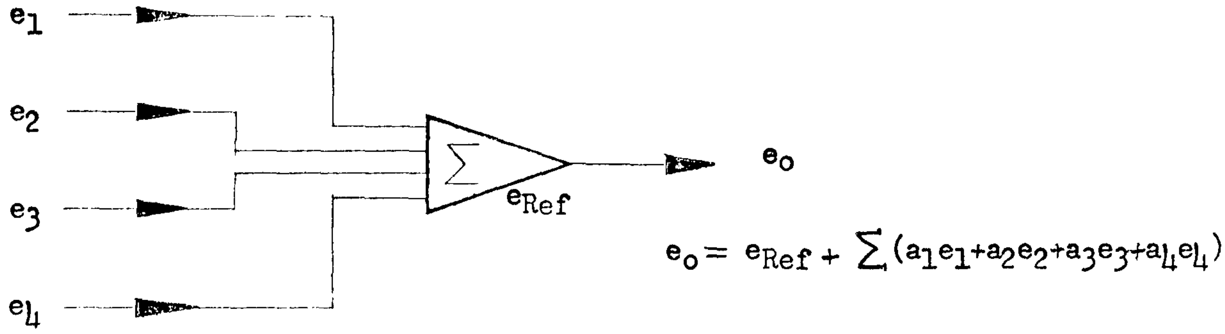
An integrated system was developed for high speed statistical analysis of random and ordered spectra employing analog methods. Counting systems were developed for obtaining mean crossing peak, range, and interval crossing counts at counting rates up to 500 cycles per second. This integrated system basically consists of a magnetic tape input unit, an analog computer and an electronic totalizing counter. Figure 90 shows this system programmed for counting.

The magnetic tape input unit was the 1/4 inch portable tape unit used in the construction of the loading tapes. A Model 521C electronic counter manufactured by the Hewlett Packard Corporation was employed to record the statistical data from the counting circuit.

The analog computer consists of eight standard K5-U computing amplifiers and twenty K2-W operational amplifiers manufactured and packaged in a self-contained unit by George Philbrick Researches, Inc. Four separate input signals can be scaled, the polarity inverted and then summed in the K5-U computing amplifiers. In addition, a reference voltage of either polarity can be subtracted from its final output. The K2-W is a basic operational amplifier in that no input or feedback resistors are associated with it. By adding resistors, capacitors and diodes externally the K2-W can be made to operate as an inverter, filter, mean integrator, buffer, peak follower or voltage crossing detector. Schematical representations are shown on Figures 100 and 101 for the operational configurations in which these amplifiers were employed in the counting circuits. In addition, the counting circuits developed for the mean crossing peak, range and interval crossing count methods are shown schematically in Figures 102, 103, and 104.

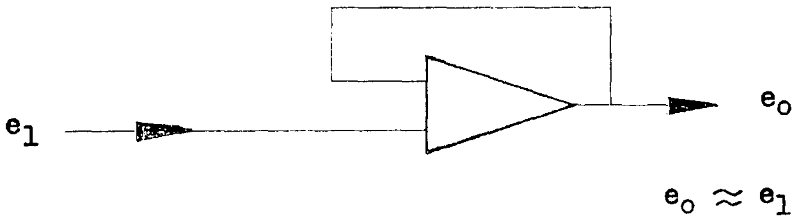
The initial calibration of these circuits was based on use of a five minute section of the original B-47 wing root loading trace. This trace was recorded on 1/4 inch magnetic tape suitable for electrical counting and an oscillograph was made. The visible trace was scanned and zero crossing peak, range and interval crossing counts were tabulated. These tabulations were then used as guides in assessing the performance of the counting circuits.

In the development of these counting systems certain problems were encountered which were largely due to the demand for unique applications of analog computer elements. A number of possible circuits were evaluated in the search for counting systems which were accurate and reliable. The selection and use of high quality components was a requisite to the reliable performance of all circuits. Precision carbon resistors and high quality mylar capacitors were used exclusively in all operational amplifier circuitry. Silicon crystal diodes were used in the initial phases of counting circuit development but later proved to possess insufficient reverse impedance to reset the peak follower in all instances. Vacuum tube diodes were substituted providing reliable operation of the peak follower circuit.



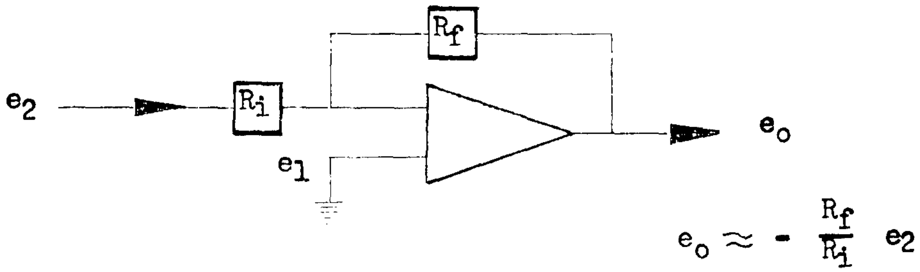
$$e_o = e_{Ref} + \sum (a_1e_1+a_2e_2+a_3e_3+a_4e_4)$$

K5-U Computing Amplifier



$$e_o \approx e_1$$

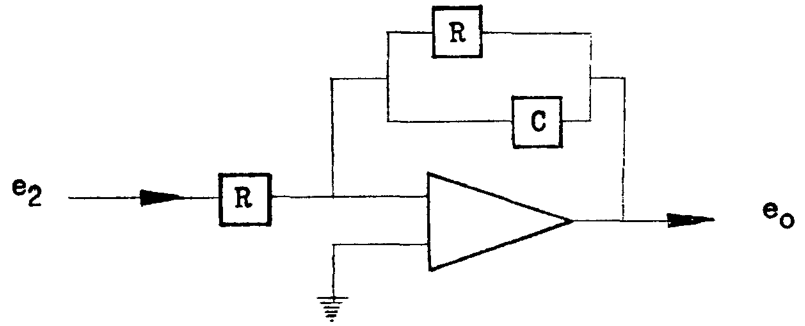
Buffer - K2-W Operational Amplifier



$$e_o \approx - \frac{R_f}{R_i} e_2$$

Inverter - K2-W Operational Amplifier

FIGURE 100 APPLICATIONS OF BASIC COMPUTER ELEMENTS

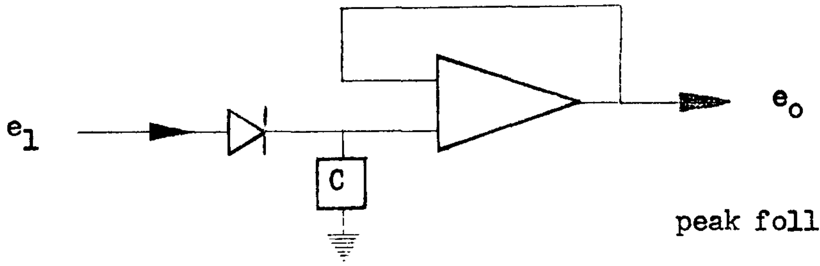


for filter RC $\ll 1$, $e_o \approx - e_2$

for mean integrator RC $\gg 1$,

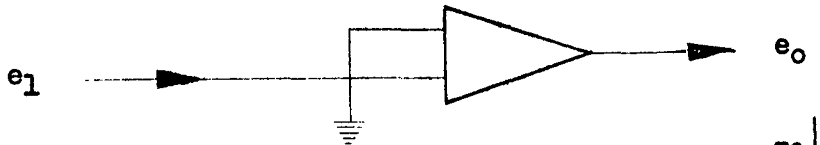
$$e_o = \frac{1}{t}\int_0^t e_2 dt$$

Filter and Mean Integrator
K2-W Operational Amplifier



peak follower $e_o \approx + \left| +e_{i_{max}} \right|$

Peak Follower - K2-W Operational Amplifier



$e_o = +70 \Big|_{e_1 > 0}$; $e_o = -70 \Big|_{e_1 < 0}$

Voltage Crossing Detector
K2-W Operational Amplifier

FIGURE 101 APPLICATIONS OF BASIC COMPUTER ELEMENTS

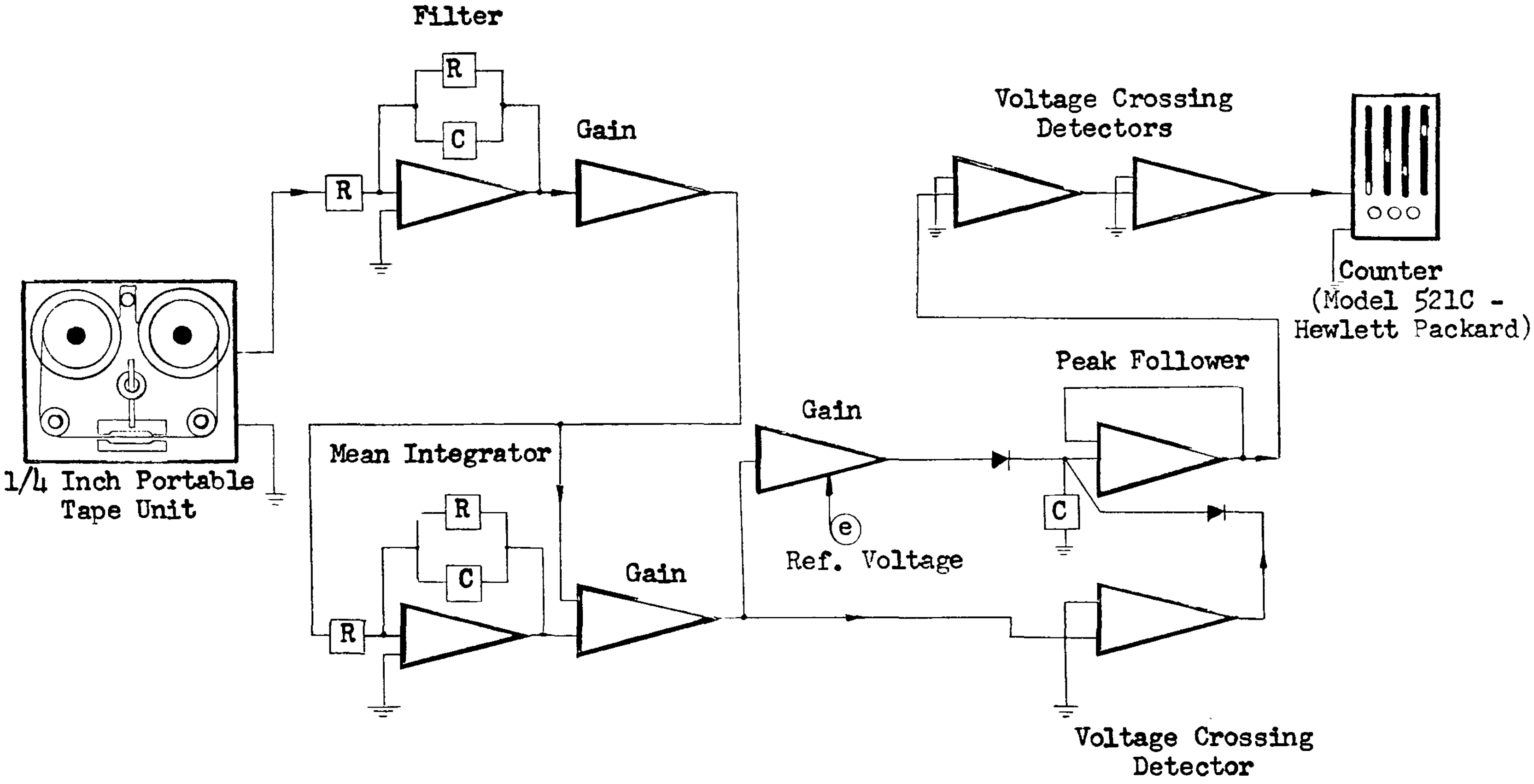


FIGURE 102 SCHEMATIC OF COMPUTING CIRCUIT FOR THE MEAN CROSSING PEAK COUNT

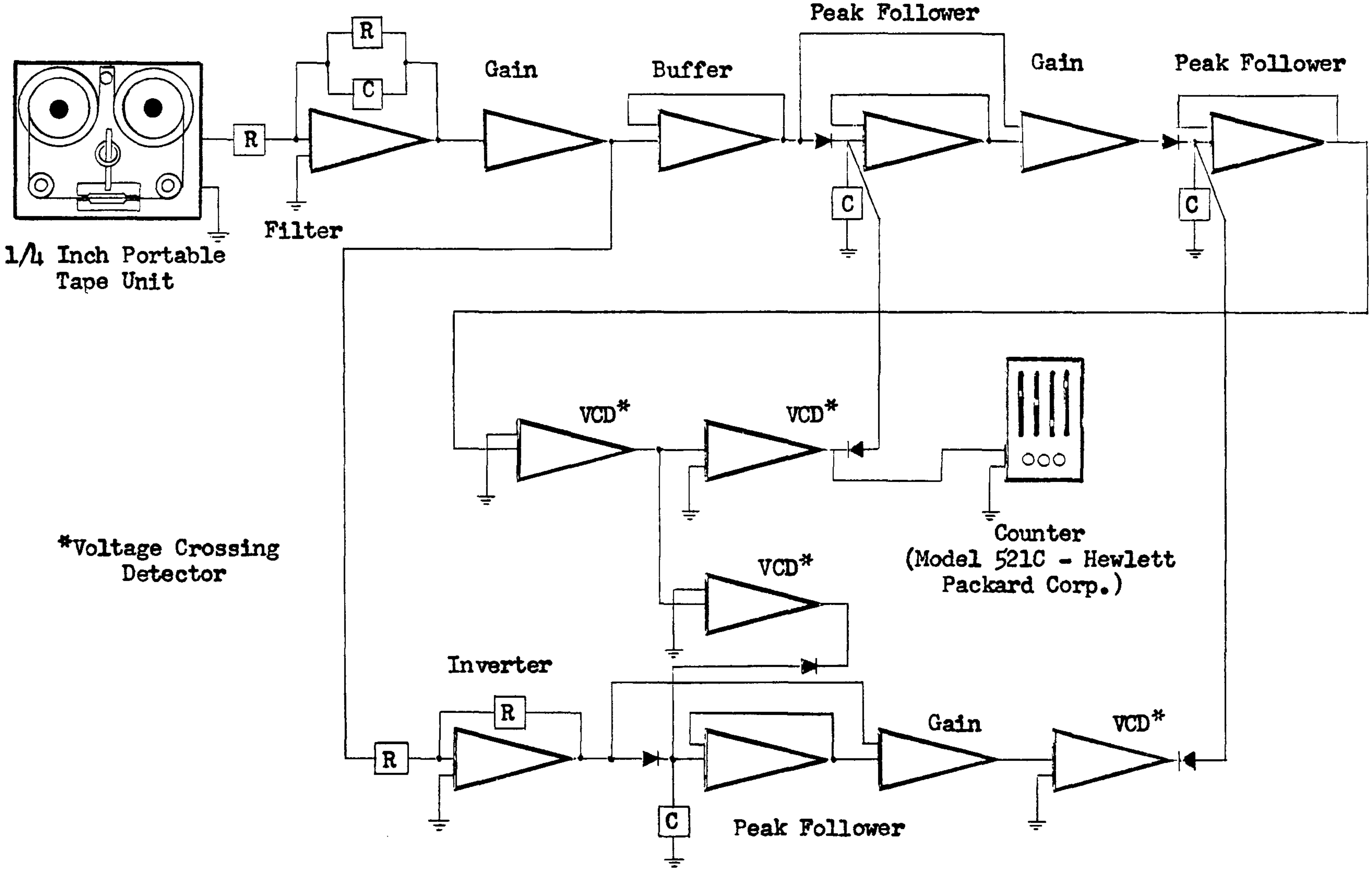


FIGURE 103 SCHEMATIC OF COMPUTING CIRCUIT FOR THE RANGE COUNT

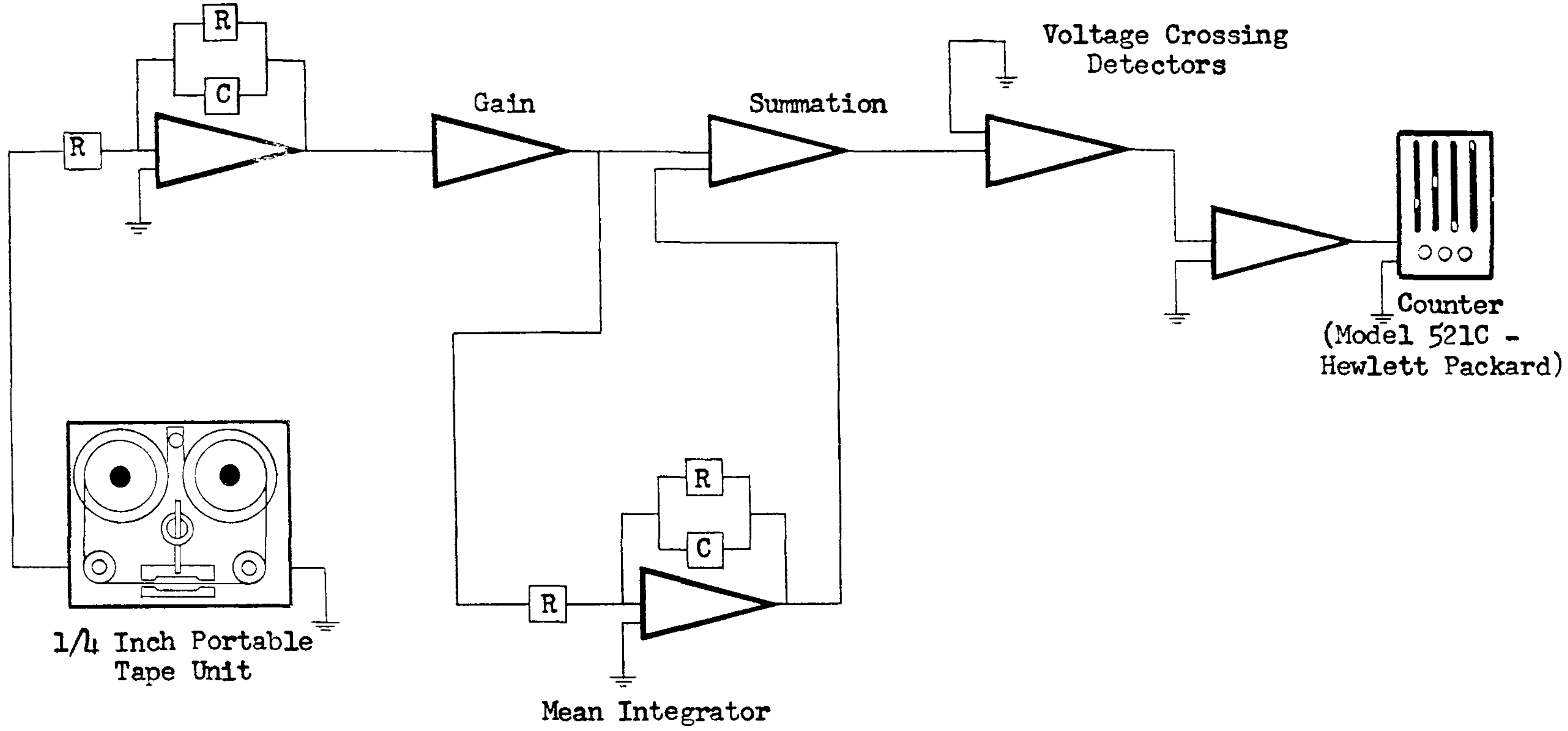


FIGURE 104 SCHEMATIC OF COMPUTING CIRCUIT FOR THE INTERVAL CROSSING COUNT

Procedure for Counting Random Spectra

Monitor tapes for the load transducer output signal, representing the specimen loading history, were recorded for a unit section of each random programming tape. These unit loading signals were then programmed through the appropriate computing circuit and their count distributions were recorded in columnar form.

The counting of a particular monitor tape was accomplished in the following manner:

(1) The appropriate counting circuit was installed on the analog computer and a schedule was made of the load levels at which counts were desired.

(2) The load level was dialed into the computer and the monitor tape signal was programmed to the counting circuit.

(3) Cumulative counts were displayed on the electronic counter as the unit section of monitor signal was transmitted through the computing circuit.

(4) When all of the monitor tape signals had been played through the computing circuit, the total cumulative counts were recorded for permanent record and the sequence was repeated for each load level in the counting schedule.

Procedure for Counting Ordered Spectra

Monitor tapes were also recorded from the load transducer output signal for a unit section of each ordered loading tape constructed in the preliminary investigation. These monitor tapes were counted in the same manner as described above for counting the random spectra.

Counting of the monitor tape output signal for the step ordered loading tapes constructed in the principal part of this investigation was obtained in the following manner.

(1) An oscillographic record was made of the load transducer output signal for the full length of each step ordered programming tape.

(2) The amplitude at each load interval was scaled and the load level determined by comparison with a known calibration.

ANALYSIS OF ACCURACY

A step by step procedure of the testing, monitoring, and counting operation is summarized below. The values of maximum possible error at each step in this procedure are shown. The nature of such error sources is noted in the procedure outline and also keyed to the schematic diagram shown in Figure 105.

These individual errors were added directly to obtain the maximum error limits shown graphically on Figure 106. However, a more realistic evaluation of the accuracy of the presented data is obtained from the 95% probability error limits presented graphically on Figure 107.

TEST PROCEDURE USING MULTI-PASS LOADING SPECTRUM PROGRAMMING TAPE	% of Error
(1) Apply static calibration of load cell H to Visicorder Ⓙ	
a) Load cell calibration	±1.0
(2) Start tape transport Ⓐ and play output signal thru tape electronics Ⓑ and servo loop (D-E-F-H) and record load cell Ⓗ output on Visicorder J . Compare maximum dynamic range to static calibration on Visicorder (step 1) and adjust gain pot C to apply desired maximum specimen stress	
a) Stability of programmer electronics Ⓑ	±0.5
b) Stability of servo command electronics Ⓓ	±0.02
c) Frequency response deviation Ⓔ	±2.0
d) Specimen cross sectional area variation Ⓕ	±1.5
e) Stability of load cell monitor electronics Ⓘ	±0.02
f) Visicorder frequency response Ⓙ	±3.0
g) Reading accuracy - comparison Visicorder calibrations Ⓙ	±2.0
(3) Continuous loading applied to specimen with calibration techniques (steps 1 and 2) applied periodically	
a) Variation of frequency response	±0.5

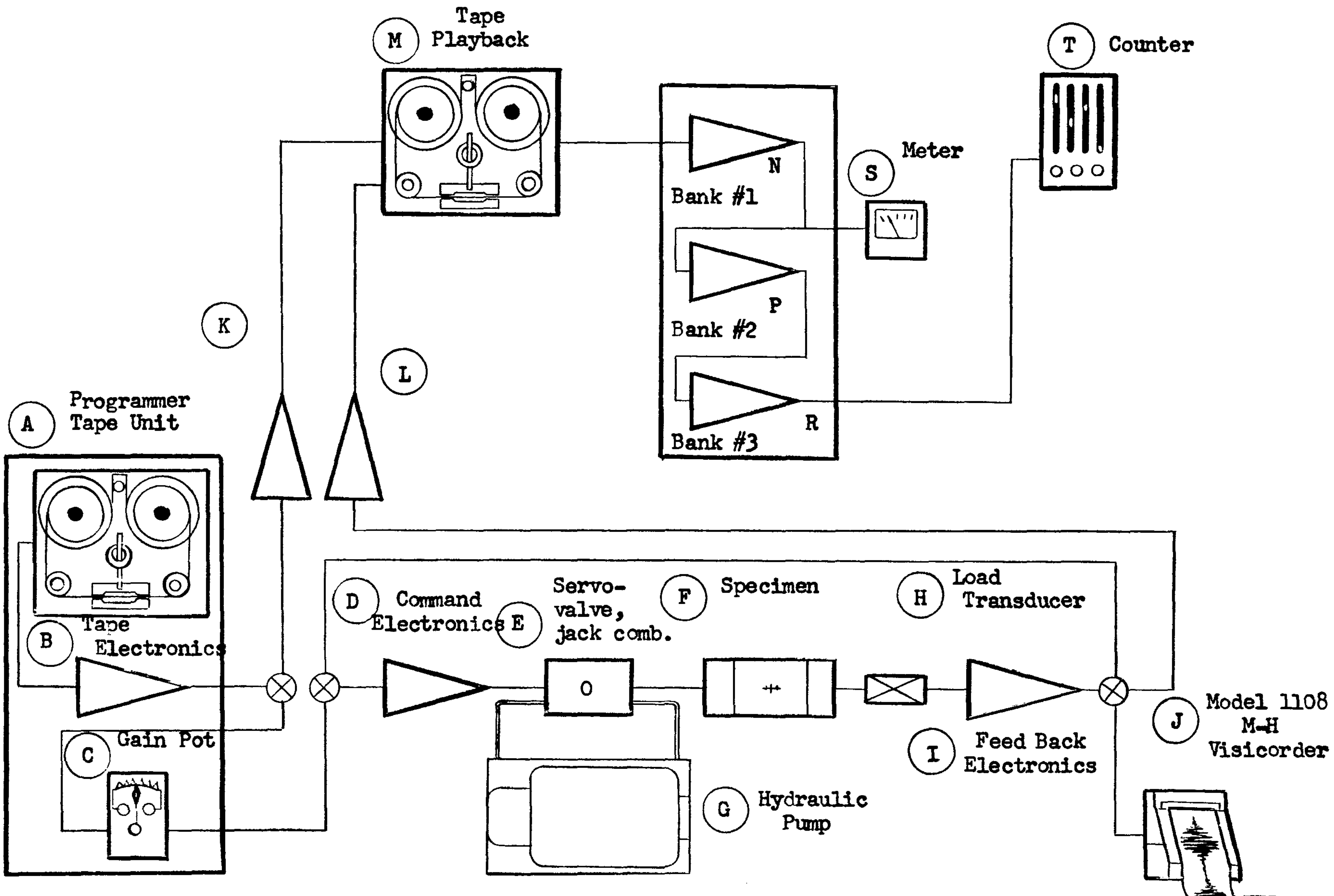


FIGURE 105 SCHEMATIC OF COMPLETE TESTING,MONITORING AND COUNTING PROCESS

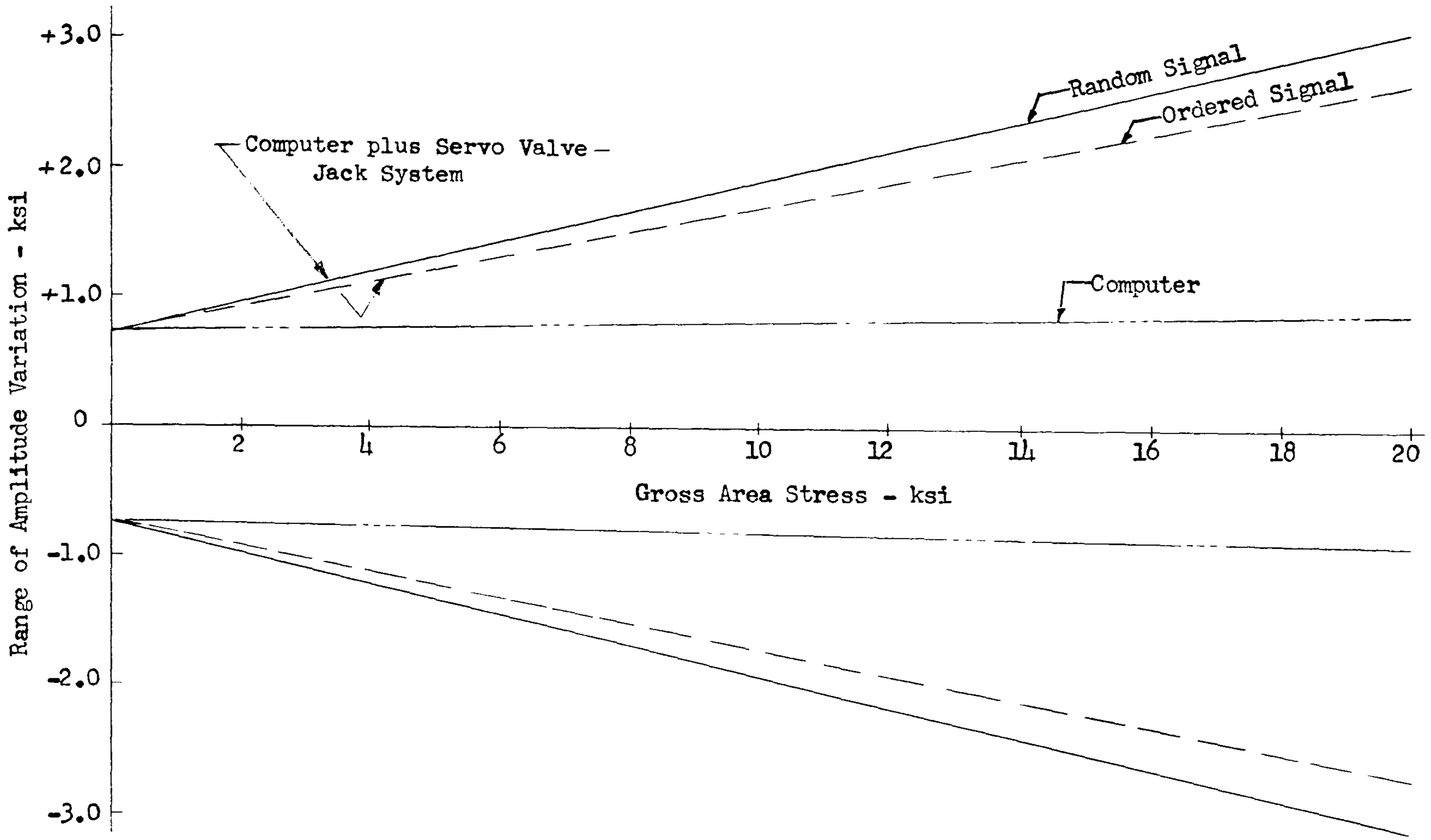


FIGURE 106 MAXIMUM ERROR LIMITS

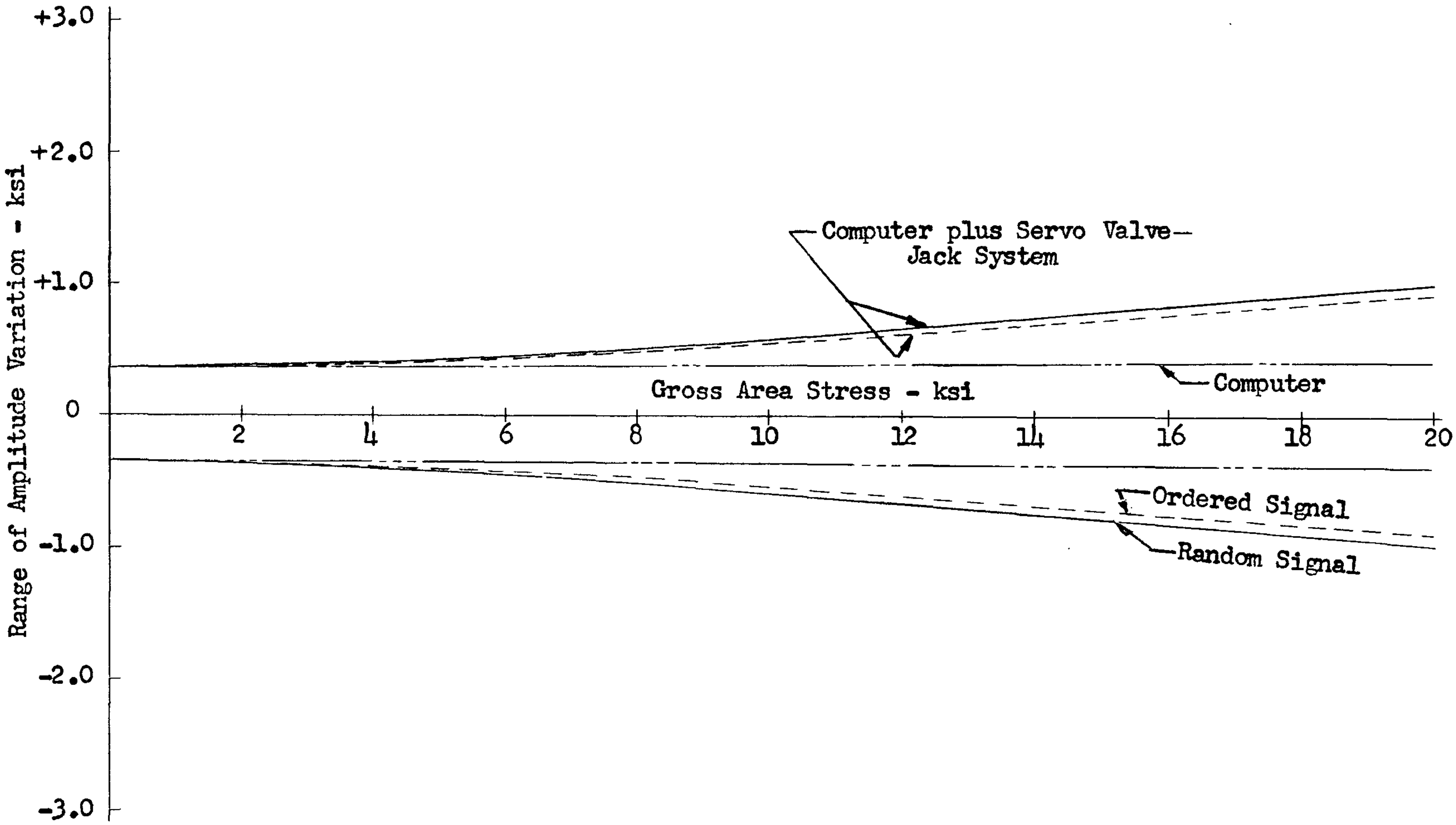


FIGURE 107 95% PROBABILITY ERROR LIMITS

PROCEDURE FOR RECORDING MONITOR TAPE OF SPECIMEN LOADING HISTORY

	% of Error
(1) Output signal of load cell Ⓗ played through monitor electronics Ⓛ and unit section of basic data recorded on recorder Ⓜ.	
a) Stability of load cell monitor electronics Ⓘ.	---
b) Stability of recorder electronics Ⓛ.	±0.5

PROCEDURE FOR COUNTING MONITOR TAPE

(1) Program monitor signal into computer Ⓝ, Ⓟ & Ⓡ and observe occurrences of data characteristics on counter Ⓡ.	
a) Balance computer bank No. 2 Ⓟ .	±0.09 *
b) Balance computer bank No. 3 Ⓡ .	±0.09 *
c) Zero output computer bank No. 1 Ⓝ (read meter Ⓢ) for "tape-zero" input.	±0.09 *
d) Adjust output computer bank No. 1 Ⓝ (read meter Ⓢ) for tape calibration input to desired signal amplification level.	±0.225 *
e) Dial desired signal count level in computer bank No. 3 Ⓡ and observe number of counts on counter Ⓣ.	---
f) Stability of computer bank No. 1 Ⓝ.	±0.5
g) Stability of computer bank No. 2 Ⓟ.	±0.2475 *
h) Stability of computer bank No. 3 Ⓡ.	±0.2

It should be noted that the error analysis described above applies to the complete testing-counting process. It therefore establishes the accuracy of the specimen test history curves presented in the report.

* KSI Constant

APPENDIX II

SAMPLE POWER SPECTRA

A limited investigation was made of the significance in fatigue work of power spectra based on short samples of flight records. For this purpose the dynamic signal of B-47 wing bending moments which had been used in the preliminary investigation of data reduction methods was employed. From the ninety-six minute record, two samples each covering two and one-half minutes of real time were selected.

The first sample was taken from a portion of the record containing relatively high peak loadings while the second sample was taken from a section showing only moderate loadings. An oscillographic copy of each sample was produced and the displacements of the trace from a constant mean value (measured in inches) were employed to describe the power spectrum for each sample. The method used was described in "The Measurement of Power Spectra from the Point of View of Communication Engineering" by R. B. Blackman and J. W. Tukey, which was presented in Volume 37 of the Bell System Technical Journal. The spectra are shown on Figure 108.

These power spectra, which present one type of interpretation of a loading record, can be used to provide an estimate of the spectrum of discrete loadings which is required in fatigue testing. This spectrum of discrete loadings describes the number of crossing of a given level by the loading trace and so is similar in nature to the interval crossing count spectra discussed and presented in Section II of the report.

In the paper, "Mathematical Analysis of Random Noise", by S. O. Rice, published in Volumes 23 and 24 of the Bell System Technical Journal, an expression for the number of crossings of a given level was presented. This expression is

$$2 N_c (X_1) = \frac{1}{\pi} \frac{\sigma_1}{\sigma} e^{-X_1^{2}/2\sigma^{2}}$$

where $2 N_c$ = sum of the crossings of positive level X_1 with positive slope and the crossings of negative level X_1 with negative slope.

σ = root mean square value of X

σ_1 = root mean square value of $\dot{X}$

or

$$\sigma = \left[\int_0^\infty \Phi_X(\omega)\, d\omega \right]^{1/2}$$

$$\sigma_1 = \left[\int_0^\infty \Phi_X(\omega) \cdot \omega^2 d\omega \right]^{1/2}$$

where Φ_X = power spectral density of X

and ω = frequency in radians per second.

Applying these expressions to the power spectral descriptions of the two record sample produced the values

σ = 0.612 inch σ_1 = 5.38 inch/second for Sample 1

σ = 0.555 inch σ_1 = 4.82 inch/second for Sample 2.

Using these values in the first expression given above, the theoretical frequency distributions of level crossings were computed. These distributions are shown by the curves drawn on Figures 109 and 110. For comparison, interval crossing counts of the record samples were made in the conventional manner and the results plotted on the two figures. Finally, to indicate the relationship of these two representations to the spectra described by simple mean crossing peak counts, such counts were made and the results were plotted on the figures in a form compatible with the other spectra.

An examination of the figures indicates that all three representations of the records are in reasonably good agreement up to values of the trace deviation of approximately one and one-half inches (approximately 2.5 σ). For larger trace deviations, the agreement between interval crossing counts and mean crossing peak counts is considered to be good, as might be expected. However, in this region of the figures, the estimates of discrete loading spectra which were deduced from the power spectra are unconservative.

These very limited evaluations of the significance of power spectra in fatigue work emphasize the need for additional work. In this additional work, the use of longer record samples should be evaluated.

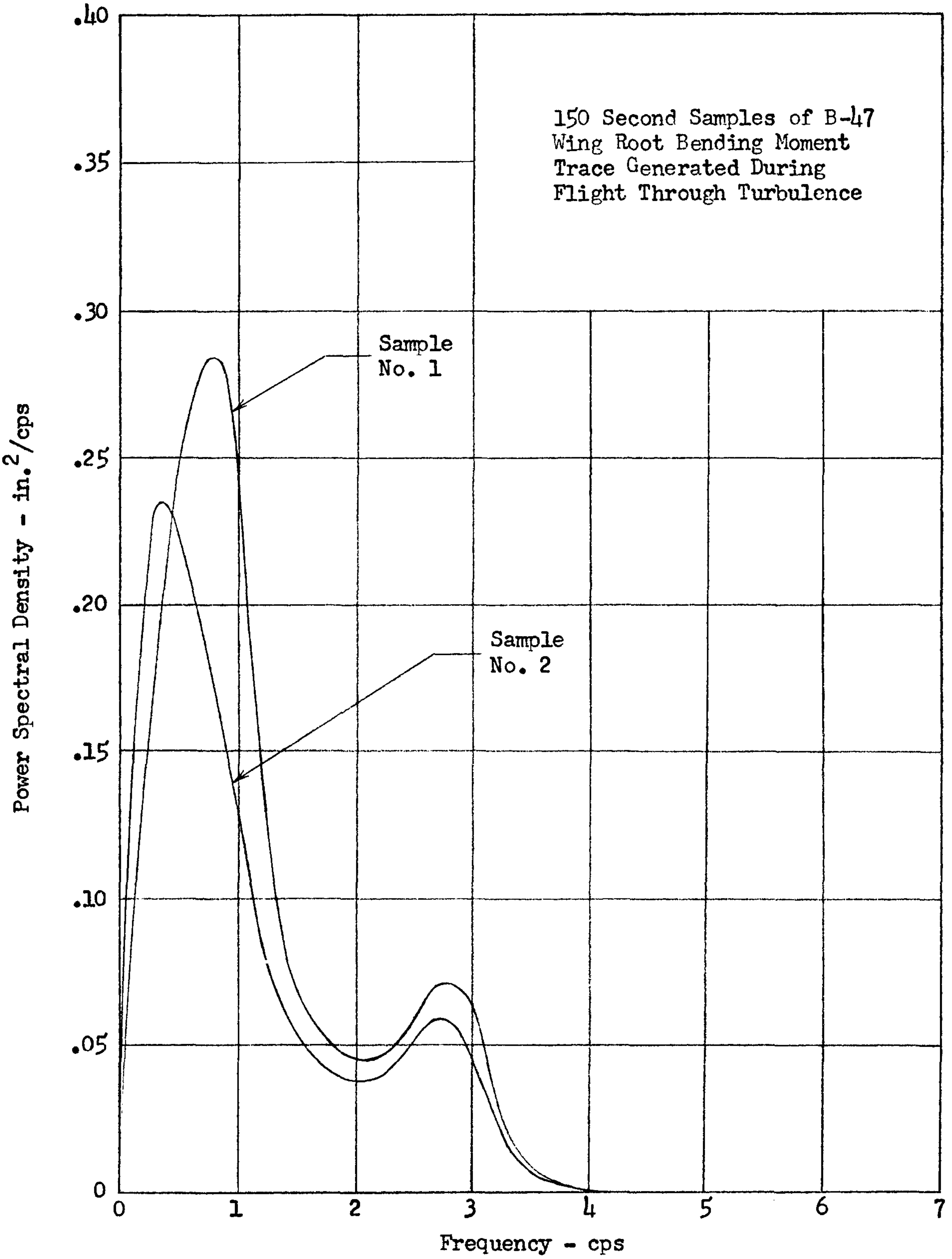


FIGURE 108 SAMPLE POWER SPECTRA

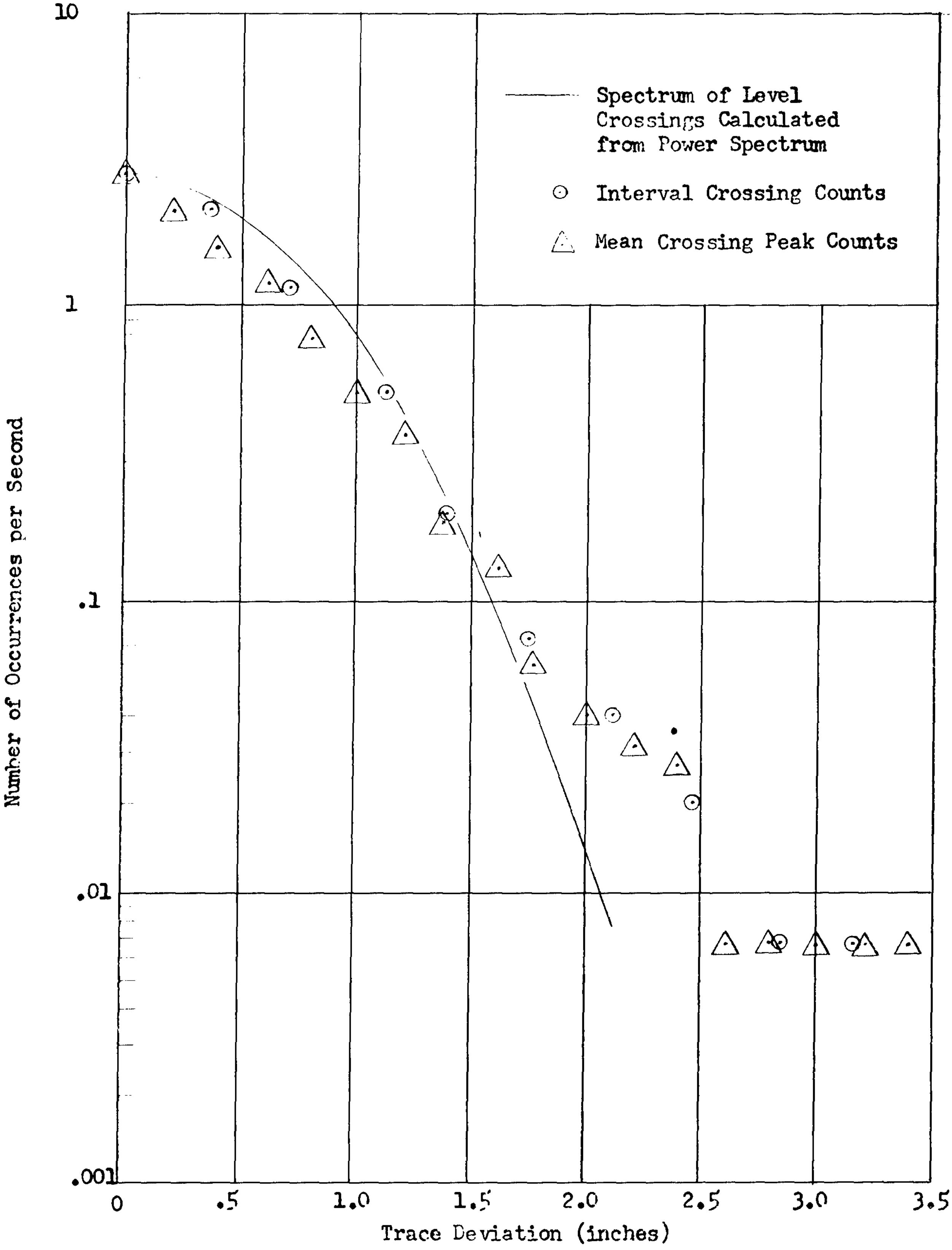


FIGURE 109 COMPARISON OF SPECTRA OF DISCRETE LOADINGS TRACE SAMPLE NO. 1

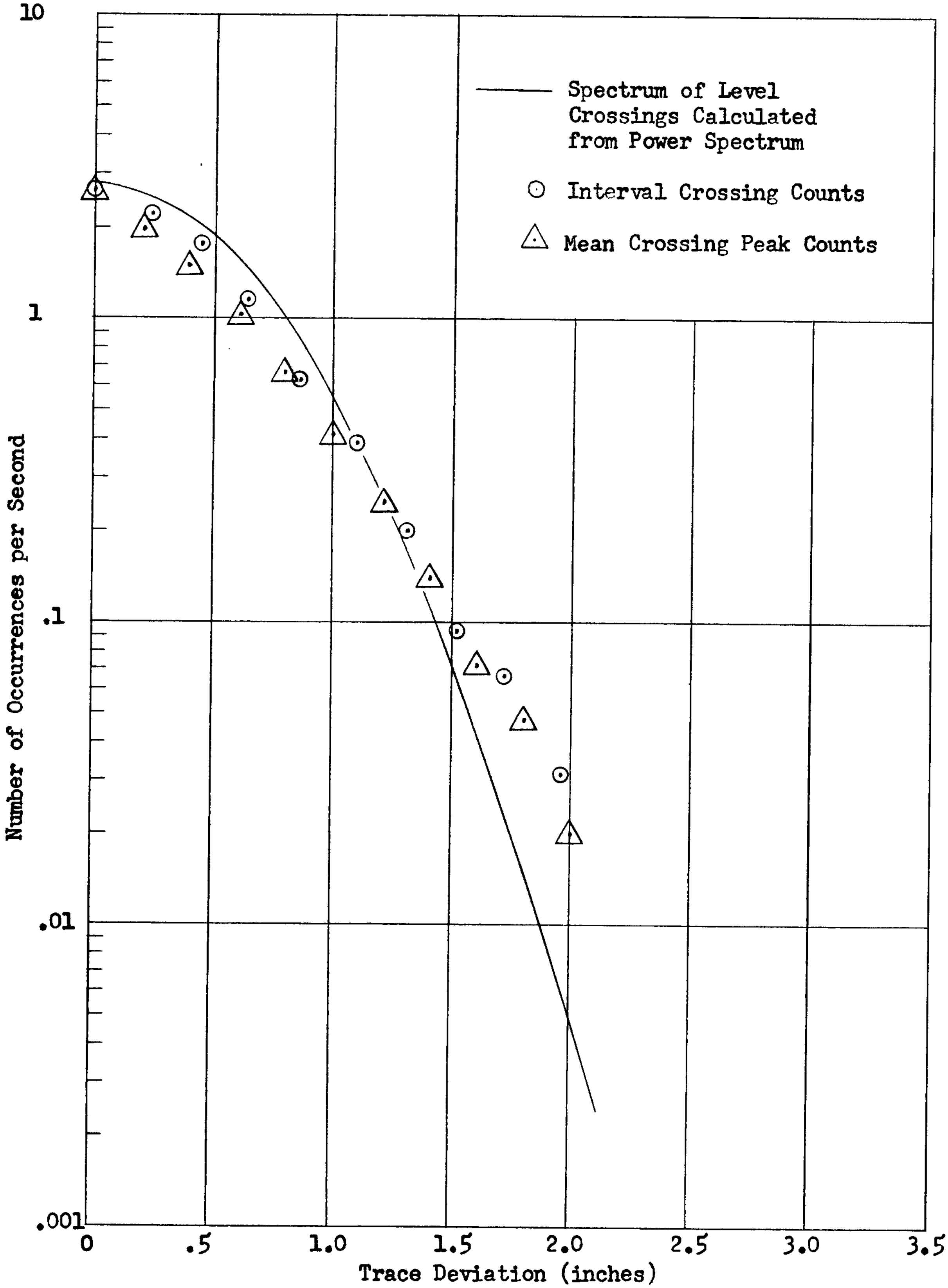


FIGURE 110 COMPARISON OF SPECTRA OF DISCRETE LOADINGS
TRACE SAMPLE NO. 2

APPENDIX III

MATERIAL STRENGTH

The results of static tensile tests on the 7075-T6 bare aluminum material used in the investigation are presented in Table 10. The geometry of the rectangular 2 inch gage length conformed to ASTM Standard E8-57T. The longitudinal grained tensile test specimens were taken along the longitudinal axis of each sheet of material.

TABLE 10

STATIC TENSILE PROPERTIES OF
7075-T6 BARE ALUMINUM SHEET, .040 GAGE

Spec. No.	Sheet No. 1			Sheet No. 2			Sheet No. 3			Sheet No. 4			Sheet No. 5		
	Ftu (ksi)	Fty (ksi)	% Elong.	Ftu (ksi)	Fty (ksi)	% Elong.	Ftu (ksi)	Fty (ksi)	% Elong.	Ftu (ksi)	Fty (ksi)	% Elong.	Ftu (ksi)	Fty (ksi)	% Elong.
1	85.4	78.2	11.0	85.4	78.5	11.5	85.8	78.6	11.0	84.9	77.2	11.0	85.7	78.6	11.0
2	86.1	79.0	12.0	85.2	78.3	10.5	84.8	77.7	11.0	85.4	78.3	11.0	85.5	78.4	10.5
3	85.4	77.8	11.0	84.5	77.1	11.0	85.1	78.3	11.0	85.4	78.5	10.5	86.0	78.1	11.0
4	85.7	78.7	10.5	84.3	76.2	11.0	85.9	78.8	11.0	84.8	76.5	11.0	84.5	76.7	9.0
5	85.0	77.4	11.0	85.1	77.9	11.5	85.9	78.7	12.0	85.6	78.3	12.0	84.5	76.4	10.0
6	85.2	77.2	12.0	84.7	77.9	11.0	85.4	77.0	10.5	85.8	78.7	11.0	86.1	79.2	12.0
7	85.2	78.3	11.0	84.7	77.4	11.5	85.5	78.5	11.5	86.1	78.8	11.0	85.9	78.7	11.0
8	85.6	78.1	12.0	85.3	78.3	10.0	85.1	78.2	11.5	85.4	78.5	11.0	86.0	78.8	12.5
9	84.8	76.8	13.0	84.0	76.3	11.0	85.1	77.5	10.5	85.6	78.7	11.5	85.9	76.6	11.0
10	85.3	78.1	11.0	85.6	78.5	11.0	85.8	79.1	11.0	85.4	78.5	11.0	85.3	78.0	11.0
11	84.8	77.2	11.5	85.2	77.9	11.5	85.1	78.1	10.5	85.0	77.9	11.0	85.7	78.2	11.0
12	85.7	78.3	12.0	85.3	78.1	12.0	84.1	76.5	11.5	85.4	78.5	11.0	85.6	78.5	11.0
13	85.1	78.1	12.0	84.9	77.2	12.0	85.0	78.0	10.5						
14	85.9	79.1	11.0	85.5	78.3	12.0	83.6	75.3	11.5						
15	83.7	76.3	12.0	84.5	77.8	11.0	84.4	77.6	12.0						
16	84.8	77.5	12.0	84.6	77.2	12.0	84.6	77.6	11.5						

Note: The static test specimens were selected along the longitudinal centerline of each 48 x 144 inch sheet. The longitudinal axis of each specimen was parallel to the direction of sheet rolling.

APPENDIX IV

PRELIMINARY DATA

A test log listing all the specimens used in the preliminary investigation is presented in Table 11. The specimen geometry, the type of loading spectrum applied, and an indication of the test results are presented. Specimens with unsatisfactory test results are identified by a code letter under the heading "Remarks". A description of this code is presented at the end of the table. The loading spectra for those specimens whose complete test histories can be defined are presented in Table 12. The unit spectra for these loading histories are shown on Figures 111 thru 161. These spectra are identified in the test log and in the test histories by record numbers. These unit spectra were obtained by monitoring the output signal from strain gages mounted on calibrated load cells mounted in series with the test specimens. Several unit spectra which were obtained by monitoring the input to the servo valves are also presented.

TABLE 11

TEST LOG - PRELIMINARY INVESTIGATION

Specimen Number	K_t	Trace	Type	Mean Stress (psi)	Test Load Record Number	Maximum Stress Range (psi)	No. of Unit Record Repetition	Remarks
1-2	4	Wing Root	Random	12000				C
3	4	Wing Root	Random	12000				A
4	4	Wing Root	Random	12000				C
5	4	Wing Root	Random	12000				A
6	4	Wing Root	Random	12000				E
7	4	Wing Root	Random	12000				E
8	4	Wing Root	Random	12000				C
9-10	4	Wing Root	Random	12000				A
11	4	Wing Root	Random	12000				B
12-14	4	Wing Root	Random	12000				A
15	4	Wing Root	Random	12000				C
16	4	Wing Root	Random	12000				G
17-18	4	Wing Root	Random	12000				A
19	4	Wing Root	Random	12000				E
20-21	4	Wing Root	Random	12000				A
22	4	Fin Root	Random	12000				D
23	4	Fin Root	Random	12000				A
24	4	Fin Root	Random	12000				C
25	4	Fin Root	Random	12000				E
26-31	4	Fin Root	Random	12000				A
32-33	4	Fin Root	Random	12000				C
34-44	4	Fin Root	Random	12000				A
45-49	4	Fin Root	Random	12000				A
50	4	Fin Root	Random	12000				K
51	4	Fin Root	Random	12000				A
52	4	Fin Root	Random	12000				A
53-54	4	Wing Root	Random	12000				A
55	4	Fin Root	Random	12000				A

TABLE 11 (Continued)

TEST LOG - PRELIMINARY INVESTIGATION

Specimen Number	K_t	Trace	Type	Mean Stress (psi)	Test Load Record Number	Maximum Stress Range (psi)	No. of Unit Record Repetition	Remarks
56	4	Fin Root	Random	12000				A
57-58	4	Wing Root	Random	12000				A
59-62	4	Fin Root	Random	12000				A
63	4	Fin Root	Random	12000				C
64	4	Wing Root	Random	12000				E
65	4	Wing Root	Random	12000				E
66	4	Fin Root	Random	12000				C
67	4	Fin Root	Random	12000	34M-P2-1	22000	52.3	-
68	4	Wing Root	Random	12000				E
69	4	Wing Root	Random	12000				A
70	4	Wing Root	Random	12000	17M-P/R4-4	27000	69.7	-
71	4	Fin Root	Random	12000				A
72	4	Wing Root	Random	12000	17M-P/R4-4	27000	71.8	-
73-79	4	Fin Root	Random	12000				A
80	4	Fin Root	Random	12000	34M-P1-2	34500	11.7	-
81	4	Fin Root	Random	12000	34M-P2-1	36000	17.8	-
82	4	Wing Root	Random	12000				E
83	4	Wing Root	Random	12000	17M-P3-3	26300	160.2	-
84	4	Wing Root	Random	12000				D
85	4	Wing Root	Random	12000	17M-P/R4-4	27000	60.5	-
86	4	Fin Root	Random	12000	34M-P1-2	34500	10.9	-
87	4	Fin Root	Random	12000	34M-P2-1	36000	17.3	-
88	4	Wing Root	Random	12000	17M-P/R4-4	27000	59.1	-
89	4	Fin Root	Random	12000	34M-P1-2	34500	12.9	-
90	4	Fin Root	Random	12000	34M-P2-1	36000	17.9	-
91	4	Fin Root	Random	12000	34M-P1-2	34500	15.0	-
92	4	Wing Root	Random	12000	17M-P3-3	27000	79.2	-
93	4	Wing Root	Random	12000	17M-P/R4-4	27000	55.7	-

TABLE 11 (Continued)

TEST LOG - PRELIMINARY INVESTIGATION

Specimen Number	K_t	Trace	Type	Mean Stress (psi)	Test Load Record Number	Maximum Stress Range (psi)	No. of Unit Record Repetition	Remarks
94	4	Fin Root	Random	12000				C
95	4	Fin Root	Random	12000				A
96	4	Wing Root	Random	12000				C
97	4	Wing Root	Random	12000				C
98	4	Fin Root	Random	12000				A
99	4	Fin Root	Random	12000				C
100	4	Wing Root	Random	12000 +	19M-P3-6	24500	73.0	-
101	4	Wing Root	Random	12000 +	19M-P4-4	27000	65.2	-
102	4	Fin Root	Random	12000 +				A
103	4	Fin Root	Random	12000 +	20M-P1-2	38000	7.4	-
104	4	Fin Root	Random	12000 +				D
105	4	Fin Root	Random	12000 +	20M-P1-2	38000	6.5	-
106	4	Fin Root	Random	12000 +				A
107	4	Wing Root	Random	12000 +	19M-P4-4	27000	59.5	-
108	4	Wing Root	Random	12000 +				C
109	4	Wing Root	Random	12000 +				C
110	4	Fin Root	Random	12000 +				D
111	4	Fin Root	Random	12000 +				E
112	4	Wing Root	Random	12000 +	19M-P3-6	24500	60.5	-
113	4	Wing Root	Random	12000 +	19M-P4-4	27000	59.8	-
114	4	Wing Root	Random	12000	17M-P3-3	27000	74.8	K
115	4	Wing Root	Random	12000	17M-P/R4-4	27000	53.0	K
116	4	Fin Root	Random	3000 +				C
117	4	Fin Root	Random	3000 +				C
118	4	Fin Root	Random	3000				A
119	4	Fin Root	Random	3000				A
120	4	Wing Root	Random	12000				G
121	4	Wing Root	Ordered	12000				F

TABLE 11 (Continued)

TEST LOG - PRELIMINARY INVESTIGATION

Specimen Number	K_t	Trace	Type	Mean Stress (psi)	Test Load Record Number	Maximum Stress Range (psi)	No. of Unit Record Repetition	Remarks
122	4	Wing Root	Random	12000	17M-P3-3	24600	84.3	K
123	4	Wing Root	Random	12000				F
124	4	Wing Root	Ordered	12000				F
125	4	Wing Root	Random	12000	17M-P4-4	29400	42.8	-
126	4	Wing Root	Random	12000	17M-P3-3	27000	102.5	K
127	4	Wing Root	Random	12000				F
128	4	Wing Root	Random	12000	17M-P/R4-4	27000	55.6	K
129-135	4	Wing Root	Ordered	12000				A
136	4	Fin Root	Random	3000	34M-P1-2	33200	14.7	-
137	4	Fin Root	Random	3000	34M-P2-1	36000	20.0	-
138	4	Fin Root	Random	3000	34M-P1-2	33200	13.0	-
139	4	Fin Root	Random	3000	34M-P2-1	36000	20.8	-
140	4	Fin Root	Random	3000	34M-P1-2	35000	19.2	-
141	4	Fin Root	Random	3000 +△	20M-P1-2	38000	8.9	-
142	4	Fin Root	Random	3000 +△				A
143	4	Fin Root	Random	3000 +△	20M-P1-2	38000	18.1	-
144	4	Fin Root	Random	3000 +△				C
145	4	Fin Root	Random	3000 +△	20M-P1-2	38000	14.1	-
146	4	Fin Root	Random	3000 +△	20M-P1-2	38000	6.6	-
147	4	Fin Root	Random	3000 +△	20M-P1-2	38000	9.8	-
148	4	Fin Root	Random	3000 +△				A
149-152	4	Wing Root	Ordered	12000				A
153	4	Wing Root	Ordered	12000				E
154-155	4	Wing Root	Ordered	12000				A
156	4	Wing Root	Ordered	12000				B
157-160	4	Wing Root	Ordered	12000				A
161	7	Wing Root	Random	12000	17M-P3-3	18800	14.2	-
162	7	Wing Root	Random	12000	17M-P3-6	15200	74.4	-

TABLE 11 (Continued)

TEST LOG - PRELIMINARY INVESTIGATION

Specimen Number	K_t	Trace	Type	Mean Stress (psi)	Test Load Record Number	Maximum Stress Range (psi)	No. of Unit Record Repetition	Remarks
163	7	Wing Root	Random	12000	17M-P3-3	20000	65.5	-
164	4	Wing Root	Random	6000	17M-P3-3	19200	61.0	H
164A	4	Wing Root	Random	6000	17M-P3-3	23100	77.4	-
165	4	Wing Root	Random	6000	17M-P4-4	19200	61.0	H
165A	4	Wing Root	Random	6000	17M-P3-6	20700	68.7	-
168	7	Wing Root	Random	6000	17M-P3-3	17200	76.8	-
169	7	Wing Root	Random	6000	17M-P4-4	19200	31.6	-
170-171	4	Wing Root	Random	12000				E
172	4	Wing Root	Random	12000				B
173	4	Modified Wing Root	Random	12000	30M-P4-4	27000	37.3	-
174	4	Wing Root	Random	12000				B
175	4	Modified Wing Root	Random	12000	30M-P4-4	27000	57.6	-
176	4	Modified Wing Root	Random	12000	30M-P4-4	27000	34.9	-
177	4	Modified Wing Root	Random	12000	30M-P4-4	27000	45.1	-
178	4	Wing Root	Random	12000				A
179	4	Fin Root	Random	12000				E
180	4	Fin Root	Random	12000				B
181	4	Fin Root	Random	12000				C
182-183	4	Fin Root	Random	12000				A
184	4	Wing Root	Random	6000				C
185	4	Wing Root	Random	6000	17M-P4-4	22000	157.0	-
186-187	4	Wing Root	Random	6000				C
188-189	4	Wing Root	Ordered	12000				A
190	4	Wing Root	Ordered	12000				E
191	4	Wing Root	Random	6000	17M-P1-2	22000	314.0	-
192-194	4	Wing Root	Ordered	12000				A
195	4	Wing Root	Ordered	12000				C
196-197	4	Wing Root	Ordered	12000				A

TABLE 11 (Continued)

TEST LOG - PRELIMINARY INVESTIGATION

Specimen Number	K_t	Trace	Type	Mean Stress (psi)	Test Load Record Number	Maximum Stress Range (psi)	No. of Unit Record Repetition	Remarks
198	4	Wing Root	Random	6000				C
199	4	Wing Root	Random	6000				A
200-201	4	Wing Root	Random	6000				C
202-207	4	Fin Root	Ordered	12000				A
208	4	Wing Root	Random	-3000	17M-P1-2	22000	279.0	-
209	4	Wing Root	Random	-3000				C
210-212	4	Wing Root	Ordered	12000				A
213	4	Fin Root	Ordered	12000				C
214	4	Wing Root	Ordered	12000				A
215	4	Fin Root	Ordered	12000				C
216	4	Wing Root	Ordered	12000				A
217	4	Fin Root	Ordered	12000				A
218	4	Wing Root	Ordered	12000				A
219	4	Fin Root	Ordered	12000				E
220	4	Fin Root	Ordered	12000				D
221	4	Fin Root	Ordered	12000				A
222	4	Wing Root	Ordered	12000				E
223-224	4	Fin Root	Ordered	12000				A
225	4	Wing Root	Ordered	12000	37M-P1-2	25400	121.7	-
226-227	4	Wing Root	Ordered	12000				A
228	4	Wing Root	Ordered	12000	37M-P1-2	23000	133.0	-
229	4	Wing Root	Ordered	12000	37M-P1-2	23000	124.7	-
230	4	Wing Root	Ordered	12000	37M-P1-2	22000	209.0	-
231	4	Wing Root	Ordered	12000	37M-P2-1	22000	225.0	-
232	4	Fin Root	Random	12000	34M-P1-2	36000	13.5	-
233	4	Fin Root	Random	12000	34M-P2-1	36000	18.1	-
234	4	Fin Root	Random	3000	34M-P2-1	36000	16.8	-
235	4	Fin Root	Random	3000				C

TABLE 11 (Continued)

TEST LOG - PRELIMINARY INVESTIGATION

Specimen Number	K_t	Trace	Type	Mean Stress (psi)	Test Load Record Number	Maximum Stress Range (psi)	No. of Unit Record Repetition	Remarks
236	4	Modified Wing Root	Random	12000	40M-P1-2	22000	26.8	-
237	4	Modified Wing Root	Random	12000	40M-P2-1	22000	23.4	-
238	4	Modified Wing Root	Random	12000	40M-P1-2	22000	49.5	-
239	4	Modified Wing Root	Random	3000				E
240	4	Modified Wing Root	Random	12000	40M-P1-2	22000	49.4	-
241	4	Modified Wing Root	Random	12000				C
242	4	Modified Wing Root	Random	12000	40M-P1-2	22000	23.8	-
243	4	Modified Wing Root	Ordered	12000				B
244-245	4	Modified Wing Root	Ordered	12000				A
246	4	Modified Wing Root	Ordered	12000	44M-P2-1	27000	31.1	-
247	4	Modified Wing Root	Ordered	12000	44M-P4-4	27000	27.4	-
248	4	Modified Wing Root	Ordered	12000	44M-P2-1	27000	34.1	-
249	4	Modified Wing Root	Ordered	12000	44M-P4-4	27000	32.7	-
250	4	Modified Wing Root	Ordered	12000	44M-P2-1	27000	43.5	-
251	4	Wing Root	Ordered	12000	46M-P4-4	27000	217.0	-
252	4	Wing Root	Ordered	12000	46M-P2-1	27000	156.0	-
253	4	Wing Root	Ordered	12000	45M-R4-4	27000	136.0	-
254	4	Wing Root	Ordered	12000	45M-R4-4	27000	231.0	-
255	4	Wing Root	Ordered	12000	46M-P4-4	27000	114.0	-
256	4	Wing Root	Ordered	12000	46M-P4-4	27000	172.0	-
257	4	Wing Root	Ordered	12000				A
258	4	Wing Root	Ordered	12000	46M-P2-1	27000	197.0	-
259	4	Fin Root	Ordered	12000	47M-P2-1	36000	17.8	-
260	4	Fin Root	Ordered	12000	47M-P4-4	36000	18.8	-
261	4	Fin Root	Ordered	12000				E
262	4	Fin Root	Ordered	12000	47M-P4-4	36000	21.2	-
263	4	Fin Root	Ordered	12000	47M-P4-4	36000	31.0	-

TABLE 11 (Continued)

TEST LOG - PRELIMINARY INVESTIGATION

Specimen Number	K_t	Trace	Type	Mean Stress (psi)	Test Load Record Number	Maximum Stress Range (psi)	No. of Unit Record Repetition	Remarks
264	4	Fin Root	Ordered	12000	47M-P2-1	36000	21.8	-
265	4	Fin Root	Random	12000				C
266	4	Fin Root	Random	12000				A
267	4	Fin Root	Random	12000	34M-P2-1	36000	14.9	-
268	4	Fin Root	Random	12000	34M-P2-1	36000	17.8	-

Remarks:
A) No monitor tape available
B) Machine malfunction
C) Overload
D) Operator error/incorrect set-up
E) Test history incomplete
F) Power failure
G) Clamp failure
H) No failure
J) Monitor tape incorrect
K) Tape reversed

TABLE 12

TEST LOADING SPECTRA - PRELIMINARY INVESTIGATION

	Cumulative Frequency of Occurrences (Cycles)							
Specimen No.	67	70	70	72	72	80	81	85
Trace	Fin Root	Wing Root	Wing Root	Wing Root	Wing Root	Fin Root	Fin Root	Wing Root
K_t	4	4	4	4	4	4	4	4
Record No.	34M-P2-1	17M-P4-4	17M-R4-4	17M-P4-4	17M-R4-4	34M-P1-2	34M-P2-1	17M-P4-4
Mean Stress (psi)	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Trace Repetitions	52.3	69.7	69.7	71.8	71.8	11.7	17.8	60.5
Varying Stress (Gross Area) ksi								
0	575,300	299,710		308,740		128,700	195,800	260,150
1.5			209,100		215,400			
2	151,670	153,340	153,300	157,960	157,960	58,500	76,540	133,100
4	33,995	66,215	41,820	68,210	43,080	24,570	32,040	57,475
6	6,799	9,061	7,667	9,334	7,898	11,115	14,240	7,865
8	1,412	1,533	1,045	1,580	1,077	4,680	5,518	1,331
10	209	293	223	302	230	1,755	2,136	254
11	52							
12		118	125	122	129	585	801	103
13.5		70	70	72	72			61
14						129	267	
16						29	91	
17.25						12		
18							18	

TABLE 12 (Continued)

Specimen No. Trace K_t Record No. Mean Stress (psi) Trace Repetitions	Cumulative Frequency of Occurrences (Cycles)							
	85 Wing Root 4 17M-R4-4 12,000 60.5	86 Fin Root 4 34M-P1-2 12,000 10.9	87 Fin Root 4 34M-P2-1 12,000 17.3	88 Wing Root 4 17M-P4-4 12,000 59.1	88 Wing Root 4 17M-R4-4 12,000 59.1	89 Fin Root 4 34M-P1-2 12,000 12.9	90 Fin Root 4 34M-P2-1 12,000 17.9	91 Fin Root 4 34M-P1-2 12,000 15.0
Varying Stress (Gross Area) ksi								
0		119,900	190,300	254,130		141,900	196,900	165,000
1.5	181,500				177,300			
2	133,100	54,500	74,390	130,020	130,020	64,500	76,970	75,000
4	36,300	22,890	31,140	56,145	35,460	27,090	32,220	31,500
6	6,655	10,355	13,840	7,683	6,501	12,255	14,320	14,250
8	908	4,360	5,363	1,300	887	5,160	5,549	6,000
10	194	1,635	2,076	248	189	1,935	2,148	2,250
12	109	545	778	100	106	645	806	750
13.5	60			59	59			
14		120	260			142	268	165
16		27	88			32	91	38
17.25		11				13		15
18			17				18	

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)							
Specimen No.	92	93	93	100	101	103	105	107
Trace	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Fin Root	Fin Root	Wing Root
K_t	4	4	4	4	4	4	4	4
Record No.	17M-P3-3	17M-P4-4	17M-R4-4	19M-P3-6	19M-P4-4	20M-P1-2	20M-P1-2	19M-P4-4
Mean Stress (psi)	12,000	12,000	12,000	12,000+△	12,000+△	12,000+△	12,000+△	12,000+△
Trace Repetitions	79.2	55.7	55.7	73.0	65.2	7.4	6.5	59.5
Varying Stress (Gross Area) ksi								
0	277,200	239,510		255,500	280,360	87,320	76,700	255,850
1.5			167,100					
2	67,320	122,540	122,540	116,800	130,400	35,520	31,200	119,000
4	39,600	52,915	33,420	30,660	35,860	16,280	14,300	32,725
6	8,712	7,241	6,127	5,840	7,172	7,400	6,500	6,545
8	1,584	1,225	836	1,168	1,304	2,960	2,600	1,190
10	396	234	178	197	241	1,184	1,040	220
12	135	95	100	80	104	518	455	95
12.25				73				
13.5	79	56	56		65			60
14						200	176	
16						67	58	
18						19	17	
19						7	7	

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)							
Specimen No.	108	112	113	114	115	115	122	125
Trace	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root
K_t	4	4	4	4	4	4	4	4
Record No.	19M-P3-6	19M-P3-6	19M-P4-4	17M-P3-3	17M-P4-4	17M-R4-4	17M-P3-3	17M-P4-4
Mean Stress (psi)	12,000+△	12,000+△	12,000+△	12,000	12,000	12,000	12,000	12,000
Trace Repetitions	102.5	60.5	59.8	74.8	53.0	53.0	84.3	42.8
Varying Stress (Gross Area) ksi								
0	358,750	211,750	257,140	261,800	227,900		295,050	184,040
1.5						159,000		
2	164,000	96,800	119,600	63,580	116,600	116,600	134,880	102,720
4	43,050	25,410	32,890	37,400	50,350	31,800	32,034	36,380
6	8,200	4,840	6,578	8,228	6,890	5,830	5,901	8,560
8	1,640	968	1,196	1,496	1,166	795	1,012	1,370
10	277	163	221	374	223	170	236	342
12	113	66	96	127	90	95	93	98
12.25	102	60						
12.3							84	
13.5			60	75	53	53		
14								47
14.7								43

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)							
Specimen No.	126	128	128	136	137	138	139	140
Trace	Wing Root	Wing Root	Wing Root	Fin Root	Fin Root	Fin Root	Fin Root	Fin Root
K_t	4	4	4	4	4	4	4	4
Record No.	17M-P3-3	17M-P4-4	17M-R4-4	34M-P1-2	34M-P2-1	34M-P1-2	34M-P2-1	34M-P1-2
Mean Stress (psi)	12,000	12,000	12,000	3,000	3,000	3,000	3,000	3,000
Trace Repetitions	102.5	55.6	55.6	14.7	20.0	13.0	20.8	19.2
Varying Stress (Gross Area) ksi								
0	358,750	239,080		161,700	220,000	143,000	228,800	211,200
1.5			166,800					
2	87,125	122,320	122,320	69,090	86,000	61,100	89,440	96,000
4	51,250	52,820	33,360	29,400	36,000	26,000	37,440	42,240
6	11,275	7,228	6,116	12,936	16,000	11,440	16,640	18,816
8	2,050	1,223	834	5,145	6,200	4,550	6,448	7,680
10	512	234	180	1,470	2,400	1,300	2,496	3,264
12	174	94	100	588	900	520	936	1,056
13.5	102	56	56					
14				132	300	117	312	269
16				24	102	21	106	67
16.6				15		13		
17.5								19
18					20		21	

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)							
Specimen No.	141	143	145	146	147	161	162	163
Trace	Fin Root	Fin Root	Fin Root	Fin Root	Fin Root	Wing Root	Wing Root	Wing Root
K_t	4	4	4	4	4	7	7	7
Record No.	20M-P1-2	20M-P1-2	20M-P1-2	20M-P1-2	20M-P1-2	17M-P3-3	17M-P3-3	17M-P3-3
Mean Stress (psi)	3,000+△	3,000+△	3,000+△	3,000+△	3,000+△	12,000	12,000	12,000
Trace Repetitions	8.9	18.1	14.1	6.6	9.8	14.2	74.4	65.5
Varying Stress (Gross Area) ksi								
0	105,020	213,580	166,380	77,880	115,640	49,700	260,400	229,250
2	42,720	86,880	67,680	31,680	47,040	14,200	48,360	72,050
4	19,580	39,820	31,020	14,520	21,560	2,556	2,976	13,100
6	8,900	18,100	14,100	6,600	9,800	170	238	1,244
7.6							74	
8	3,560	7,240	5,640	2,640	3,920	30		131
9.4						14		
10	1,424	2,896	2,256	1,056	1,568			66
12	623	1,267	987	462	686			
14	240	489	381	178	265			
16	80	163	127	59	88			
18	23	47	37	17	25			
19	9	18	14	7	10			

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)							
Specimen No.	164 + 164A	165 + 165A	168	169	173	175	176	177
Trace	Wing Root	Wing Root	Wing Root	Wing Root	Modified Wing Root	Modified Wing Root	Modified Wing Root	Modified Wing Root
K_t	4	4	7	7	4	4	4	4
Record No.	17M-P3-3 17M-P3-4	17M-P4-4 17M-P3-3	17M-P3-3	17M-P4-4	30M-P4-4	30M-P4-4	30M-P4-4	30M-P4-4
Mean Stress (psi)	6,000	6,000	6,000	6,000	12,000	12,000	12,000	12,000
Trace Repetitions	138.4	129.7	76.8	31.6	37.3	57.6	34.9	45.1
Varying Stress (Gross Area) ksi								
0	484,400	502,750	268,800	135,880	167,850	259,200	157,050	202,950
2	153,880	160,970	67,584	44,240	111,900	172,800	104,700	135,300
4	33,590	25,940	6,528	6,320	59,680	92,160	55,840	72,160
6	4,337	2,243	538	379	31,705	48,960	29,665	38,335
8	714	388	100	70	10,444	16,128	9,772	12,628
8.6			77					
9.6				32				
10	147	76			1,940	2,995	1,815	2,345
10.35		69						
11.55	77							
12					213	328	199	257
13.5					37	58	35	45

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)							
Specimen No.	185	191	208	225	228	229	230	231
Trace	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root
K_t	4	4	4	4	4	4	4	4
Record No.	17M-P4-4	17M-P1-2	17M-P1-2	37M-P1-2	37M-P1-2	37M-P1-2	37M-P1-2	37M-P2-1
Mean Stress (psi)	6,000	6,000	-3,000	12,000	12,000	12,000	12,000	12,000
Trace Repetitions	157.0	314.0	279.0	121.7	133.0	124.7	209.0	225.0
Varying Stress (Gross Area) ksi								
0	675,100	1,727,000	1,534,500	571,900	625,100	586,090	982,300	1,080,000
2	266,900	816,400	725,400	267,740	279,300	261,870	418,000	405,000
4	59,660	188,400	167,400	53,548	41,230	38,657	56,430	29,250
6	5,024	10,048	8,928	7,910	4,123	3,866	4,180	4,950
8	769	1,319	1,172	1,071	572	536	711	1,125
10	236	440	391	268	213	200	251	338
11	157	314	279	122			209	225
11.5					133	125		

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)							
Specimen No.	232	233	234	236	237	238	240	242
Trace	Fin Root	Fin Root	Fin Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root
K_t	4	4	4	4	4	4	4	4
Record No.	34M-P1-2	34M-P2-1	34M-P2-1	40M-P1-2	40M-P2-1	40M-P1-2	40M-P1-2	40M-P1-2
Mean Stress (psi)	12,000	12,000	3,000	12,000	12,000	12,000	12,000	12,000
Trace Repetitions	13.5	18.1	16.8	26.8	23.4	49.5	49.4	23.8
Varying Stress (Gross Area) ksi								
0	148,500	199,100	184,300	115,240	105,300	212,850	212,420	102,340
2	67,500	77,830	72,240	69,680	63,180	128,700	128,440	61,880
4	28,350	32,580	30,240	32,160	28,080	59,400	59,280	28,560
6	14,850	14,480	13,440	10,720	11,700	19,800	19,760	9,520
8	6,480	5,611	5,208	2,948	1,919	5,445	5,434	2,618
10	2,700	2,172	2,016	188	140	346	346	167
11				27	23	50	49	24
12	945	814	756					
14	230	272	252					
16	63	92	86					
18	14	18	17					

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)				
Specimen No.	246	247	248	249	250
Trace	Mod. Wing Root	Mod. Wing Root	Mod. Wing Root	Mod. Wing Root	Mod. Wing Root
K_t	4	4	4	4	4
Record No.	44M-P2-1	44M-P4-4	44M-P2-1	44M-P4-4	44M-P2-1
Mean Stress (psi)	12,000	12,000	12,000	12,000	12,000
Trace Repetitions	31.1	27.4	34.1	32.7	43.5
Varying Stress (Gross Area) ksi					
0	133,730	117,820	146,630	140,610	187,050
2	99,520	84,940	109,120	101,370	139,200
4	62,200	46,580	68,200	55,590	87,000
6	37,320	24,660	40,920	29,430	52,200
8	18,038	9,864	19,778	11,772	25,230
10	4,976	3,288	5,456	3,924	6,960
12	404	329	443	392	566
13.5	31	27	34	33	44

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)						
Specimen No.	251	252	253	254	255	256	258
Trace	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root	Wing Root
K_t	4	4	4	4	4	4	4
Record No.	46M-P4-4	46M-P2-1	45M-R4-4	45M-R4-4	46M-P4-4	46M-P4-4	46M-P2-1
Mean Stress (psi)	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Trace Repetitions	217.0	156.0	136.0	231.0	114.0	172.0	197.0
Varying Stress (Gross Area) ksi							
0	1,019,900	780,000			535,800	808,400	985,000
2	477,400	327,600	326,400	554,400	250,800	378,400	413,700
4	130,200	88,920	81,600	138,600	68,400	103,200	112,290
6	21,700	15,600	13,600	23,100	11,400	17,200	19,700
8	2,604	1,872	2,992	5,082	1,368	2,064	2,364
10	673	640	816	1,386	353	533	808
12	282	265	272	462	148	224	335
13.5	217	156	136	231	114	172	197

TABLE 12 (Continued)

	Cumulative Frequency of Occurrences (Cycles)						
Specimen No.	259	260	262	263	264	267	268
Trace	Fin Root	Fin Root	Fin Root	Fin Root	Fin Root	Fin Root	Fin Root
K_t	4	4	4	4	4	4	4
Record No.	47M-P2-1	47M-P4-4	47M-P4-4	47M-P4-4	47M-P2-1	34M-P2-1	34M-P2-1
Mean Stress (psi)	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Trace Repetitions	17.8	18.8	21.2	31.0	21.8	14.9	17.8
Varying Stress (Gross Area) ksi							
0	89,000	206,800	233,200	341,000	109,000	163,900	195,800
2	55,180	107,160	120,840	176,700	67,580	64,070	76,540
4	26,700	33,840	38,160	55,800	32,700	26,820	32,040
6	12,104	11,844	13,356	19,530	14,824	11,920	14,240
8	5,162	4,324	4,876	7,130	6,322	4,619	5,518
10	1,958	1,692	1,908	2,790	2,398	1,788	2,136
12	854	714	806	1,178	1,046	670	801
14	303	244	276	403	371	224	267
16	94	94	106	155	116	76	91
18	18	19	21	31	22	15	18

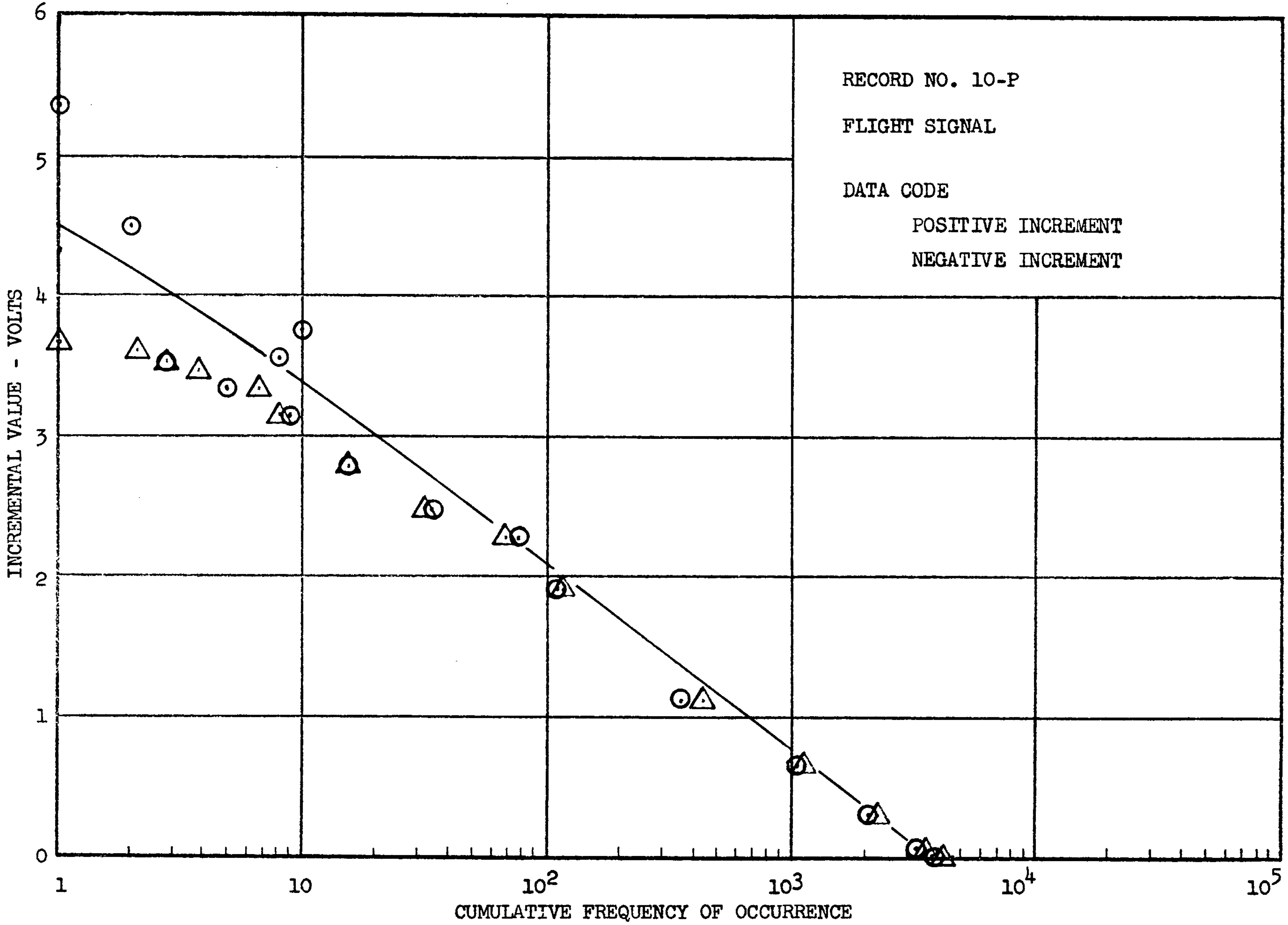


FIGURE 111   MEAN CROSSING PEAK COUNT - B-66 ACCELERATION TRACE

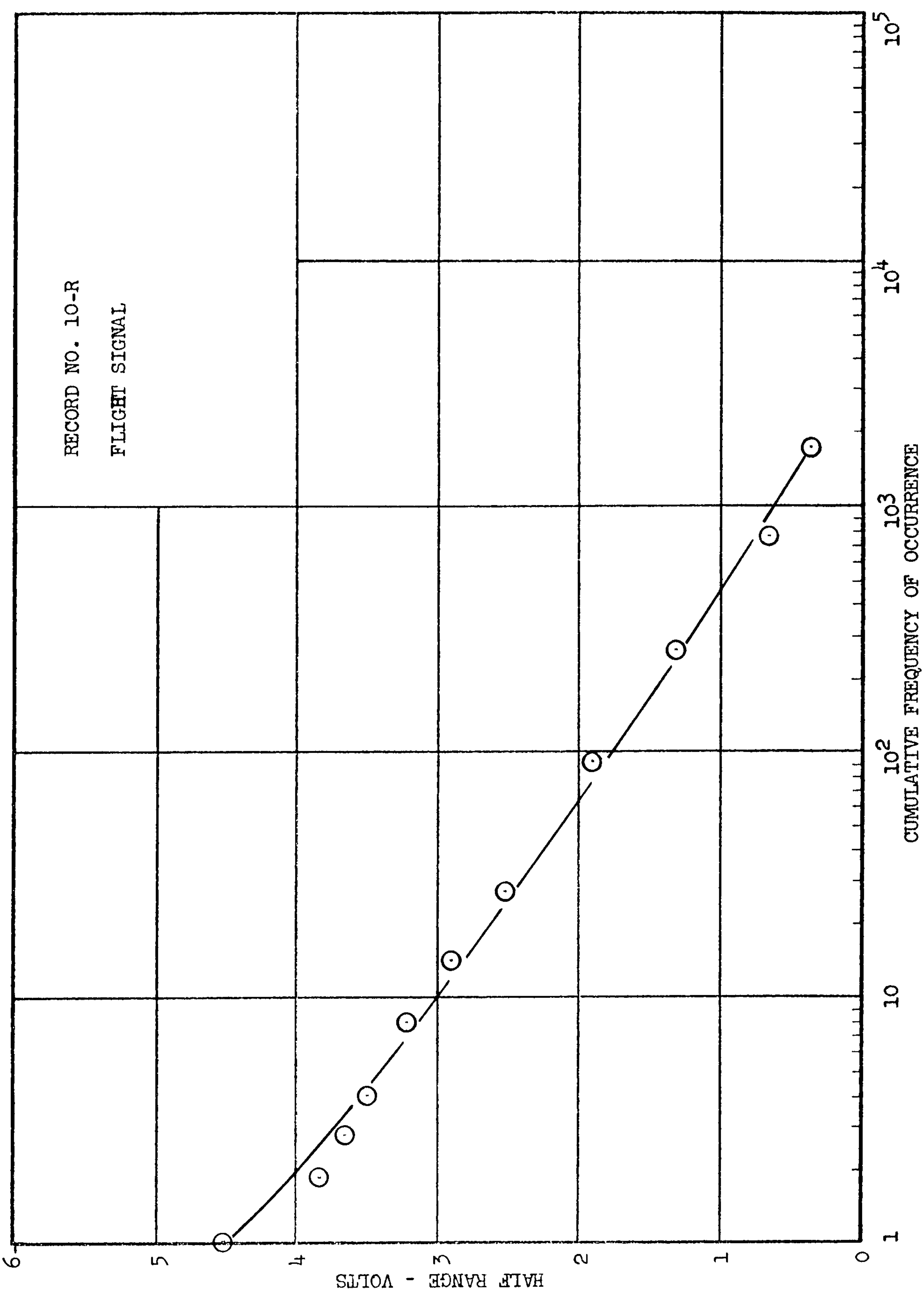


FIGURE 112 SIMPLE RANGE COUNT - B-66 ACCELERATION TRACE

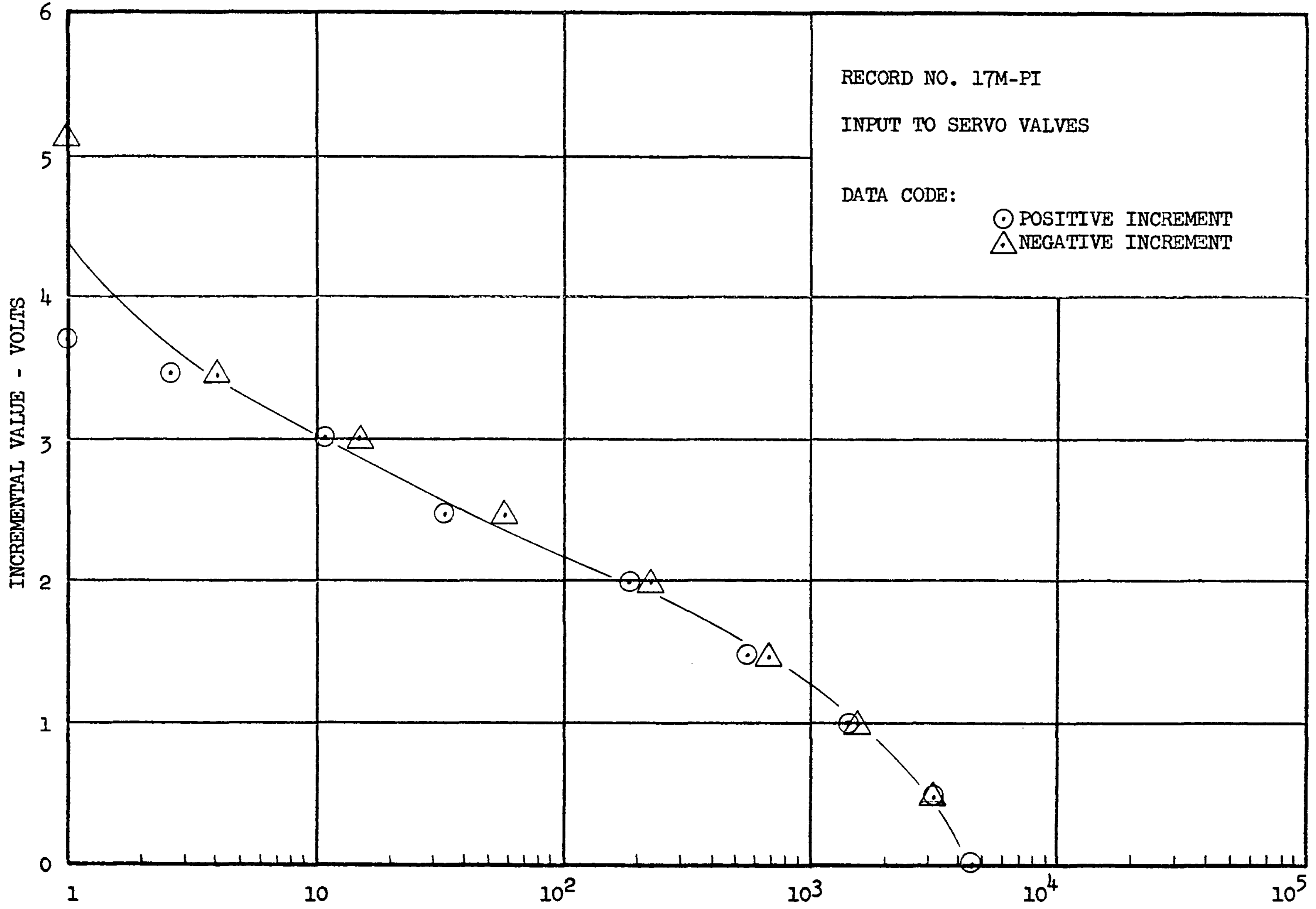


FIGURE 113 MEAN CROSSING PEAK COUNT - WING ROOT RANDOM LOADING TRACE

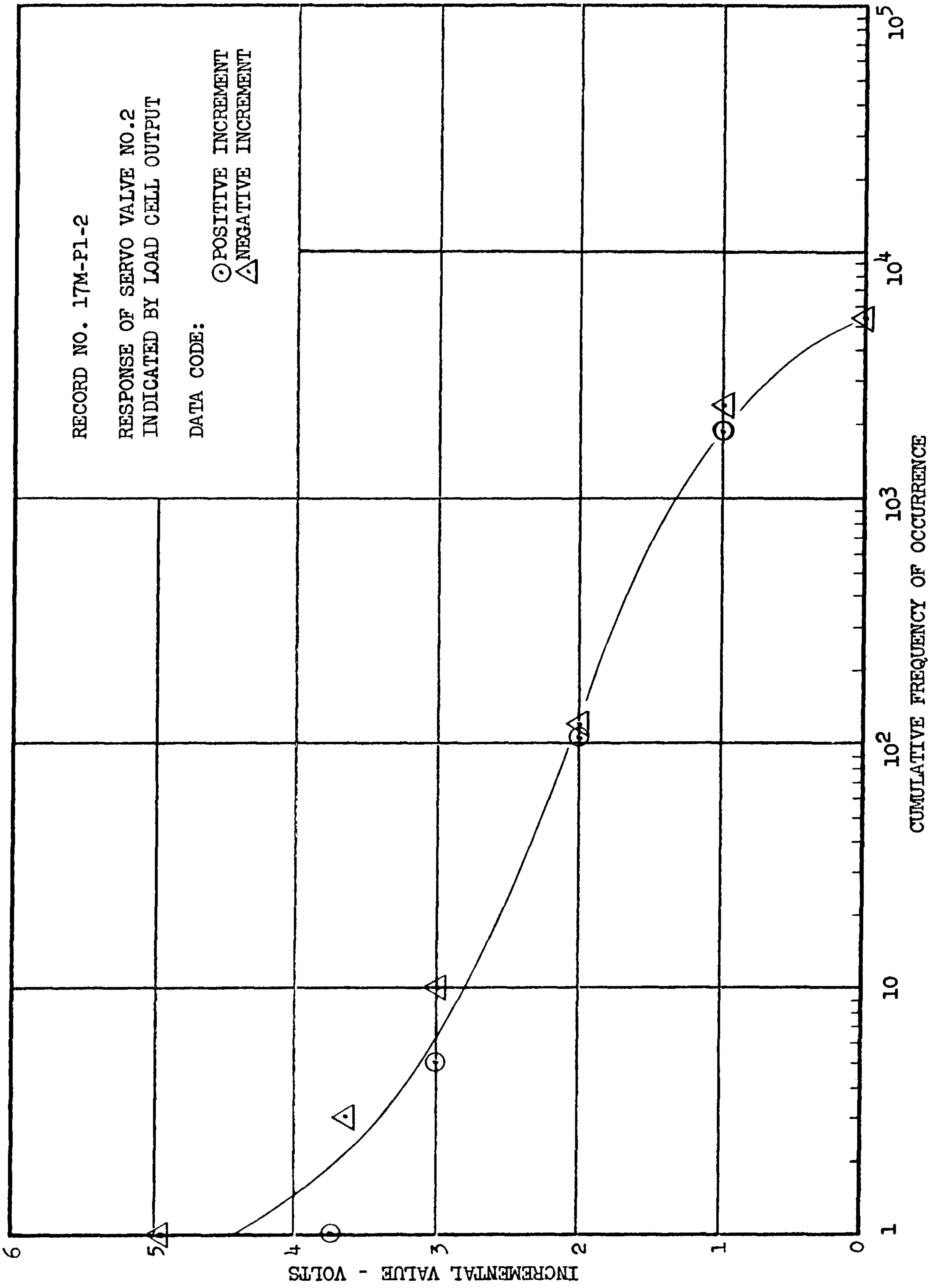


FIGURE 114 MEAN CROSSING PEAK COUNT - WING ROOT RANDOM LOADING TRACE

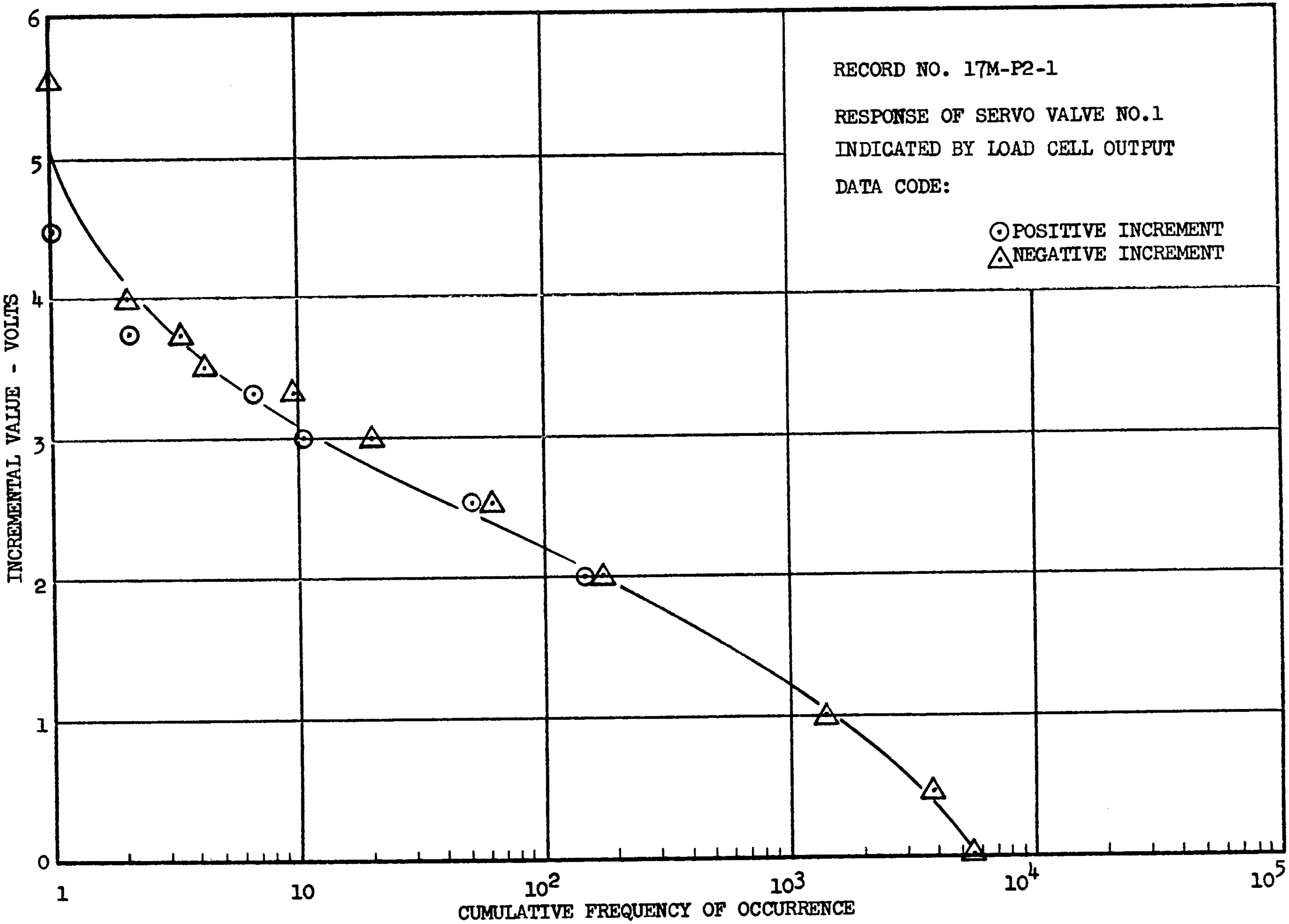


FIGURE 115 MEAN CROSSING PEAK COUNT - WING ROOT RANDOM LOADING TRACE

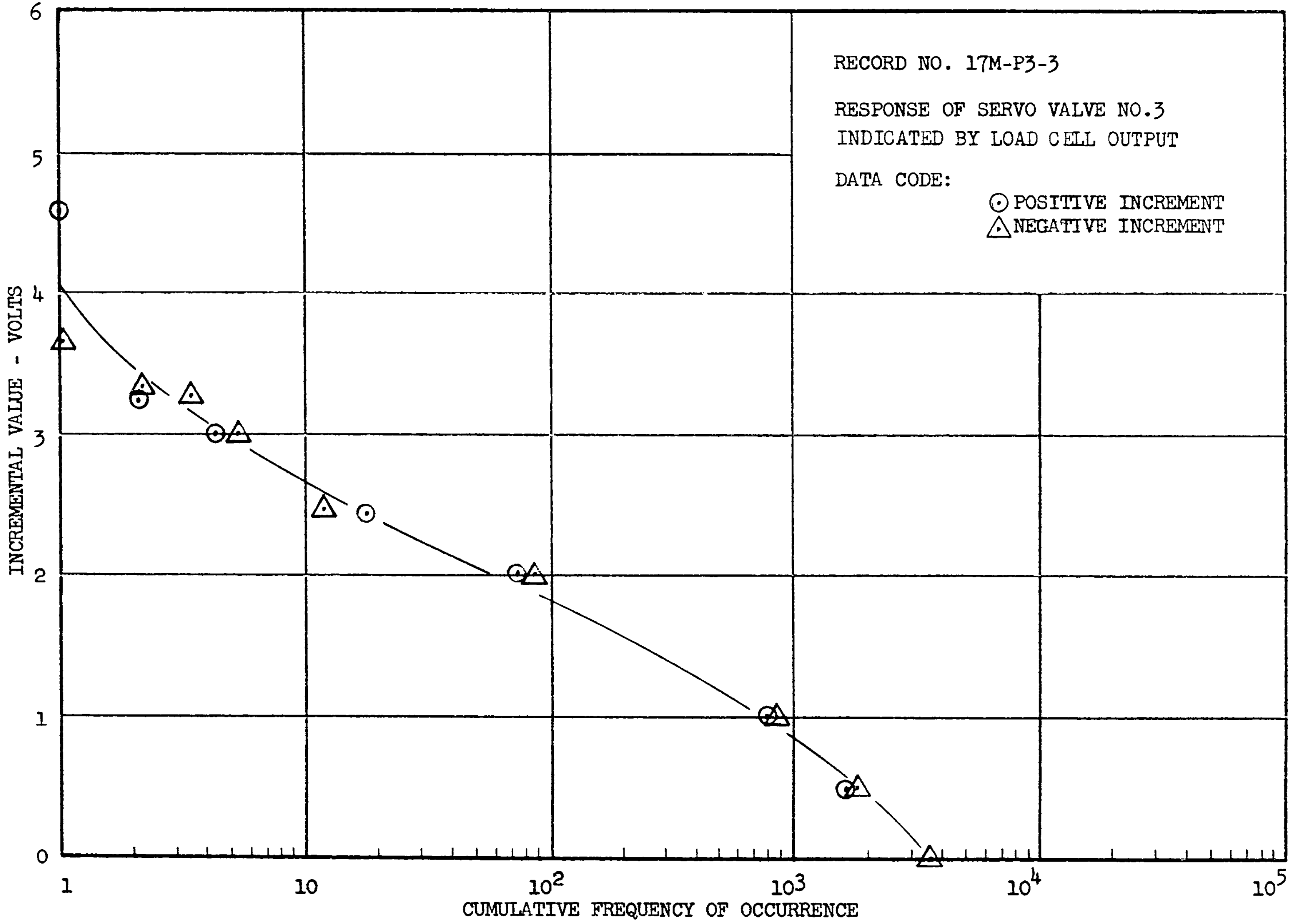


FIGURE 116 MEAN CROSSING PEAK COUNT - WING ROOT RANDOM LOADING TRACE

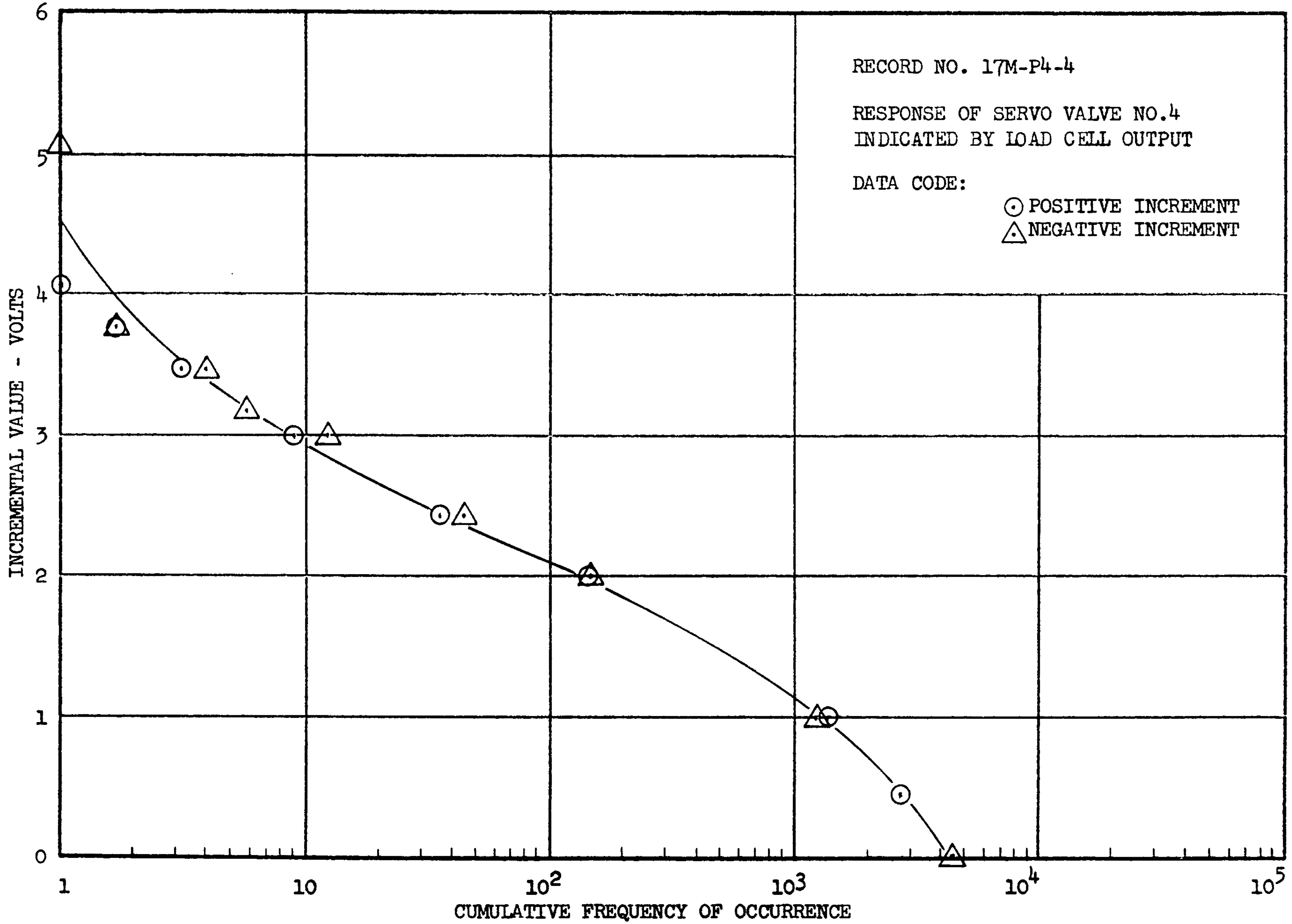


FIGURE 117 MEAN CROSSING PEAK COUNT - WING ROOT RANDOM LOADING TRACE

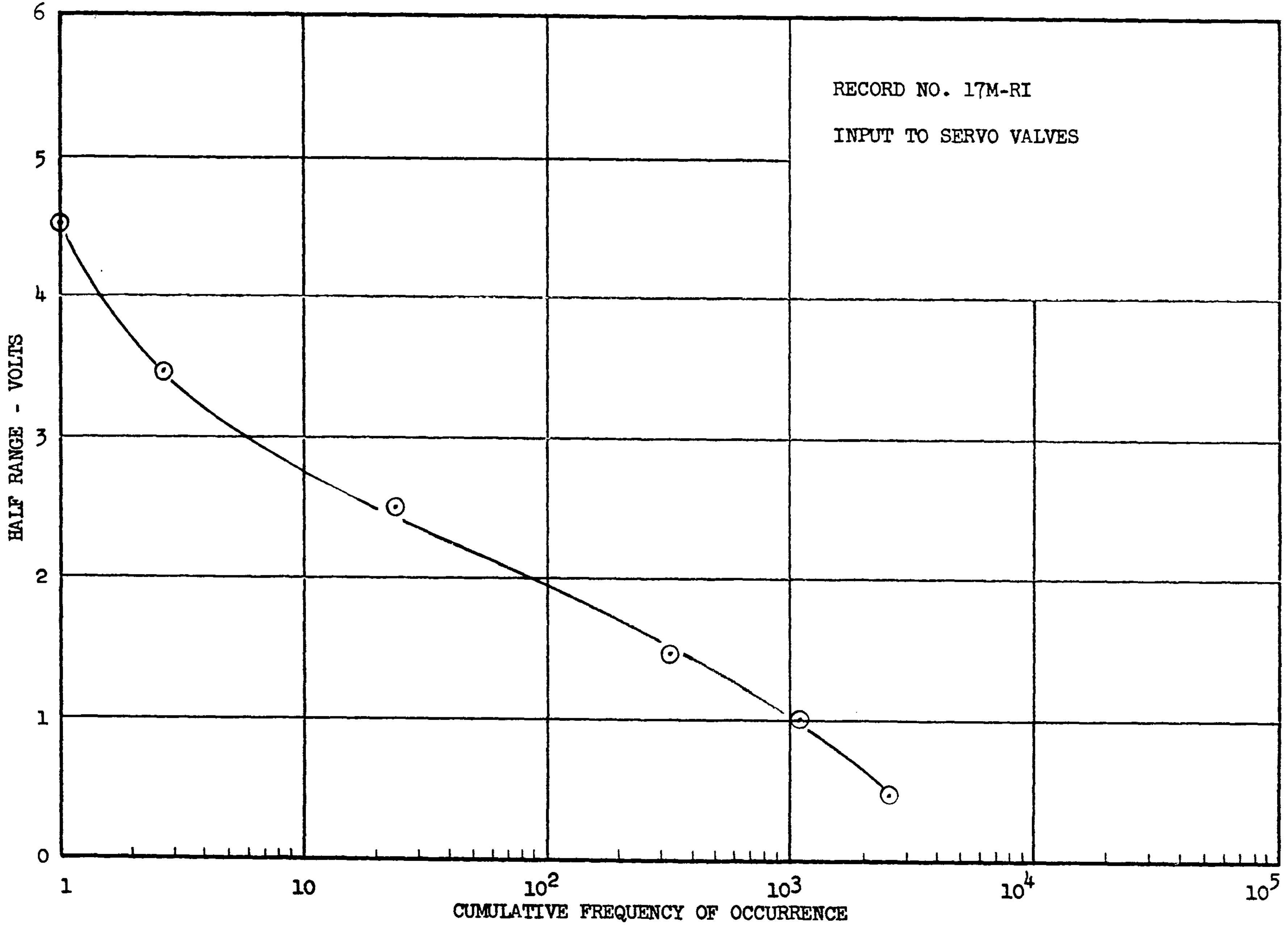


FIGURE 118 SIMPLE RANGE COUNT - WING ROOT RANDOM LOADING TRACE

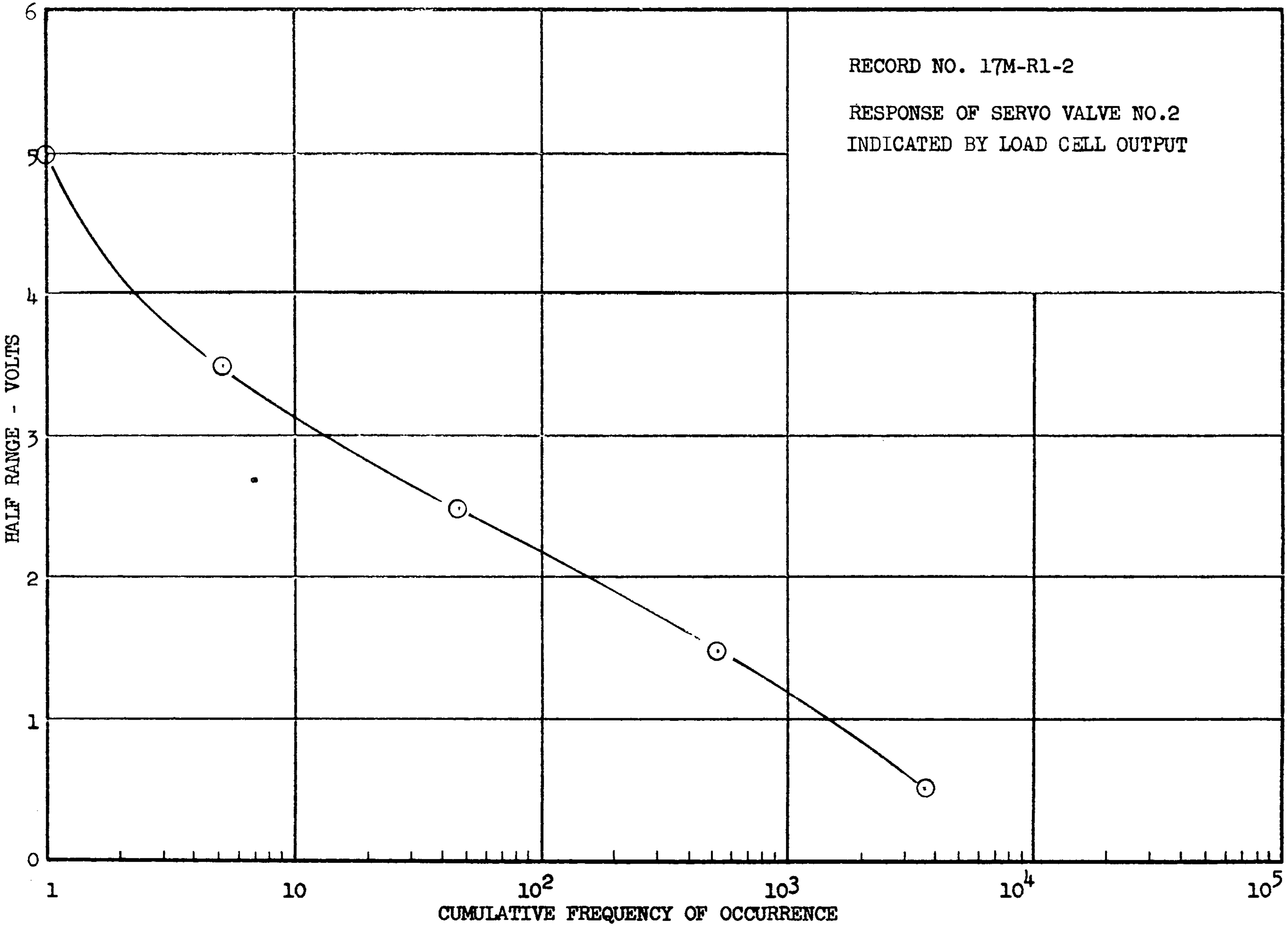


FIGURE 119 SIMPLE RANGE COUNT - WING ROOT RANDOM LOADING TRACE

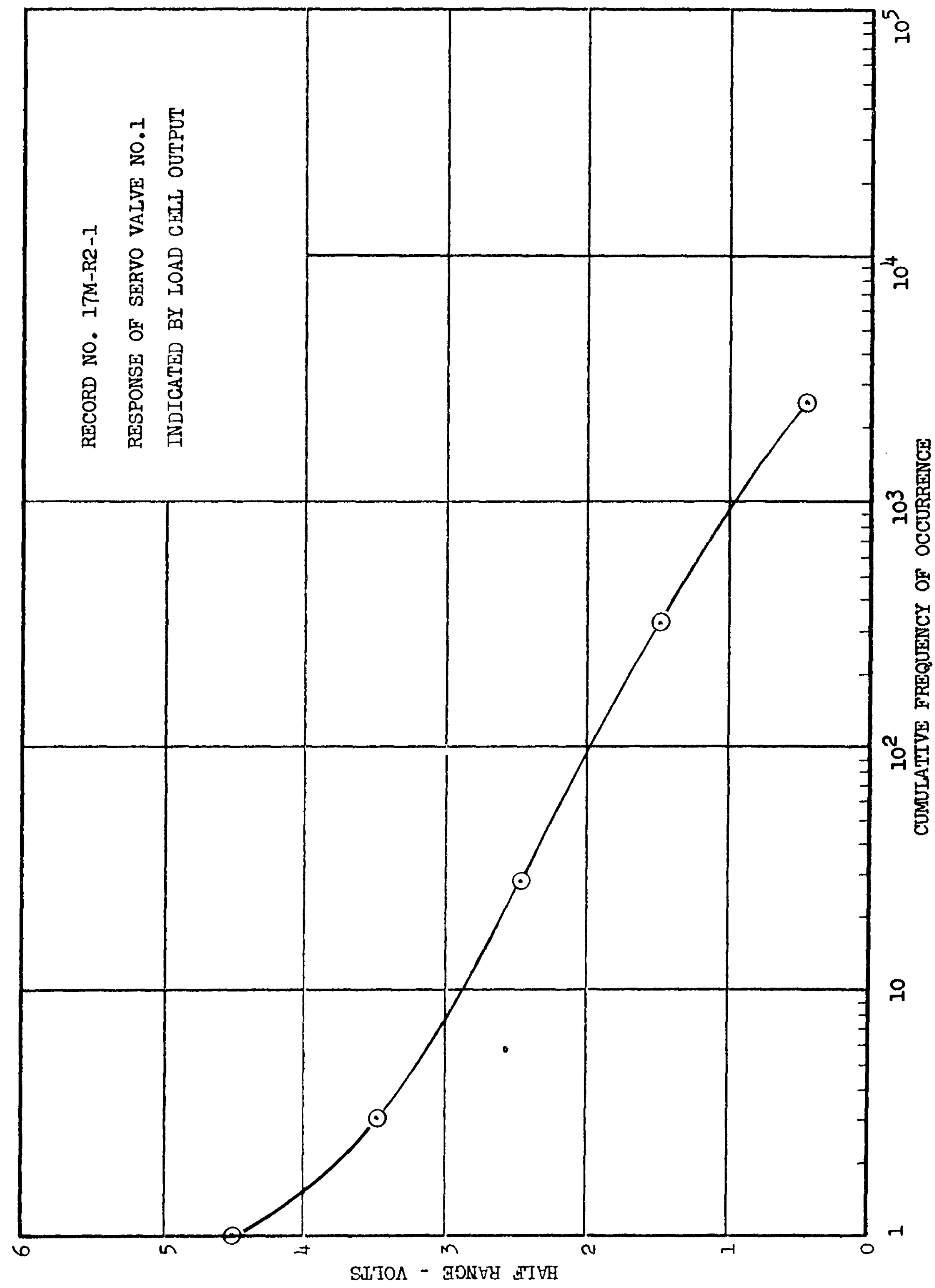


FIGURE 120 SIMPLE RANGE COUNT - WING ROOT RANDOM LOADING TRACE

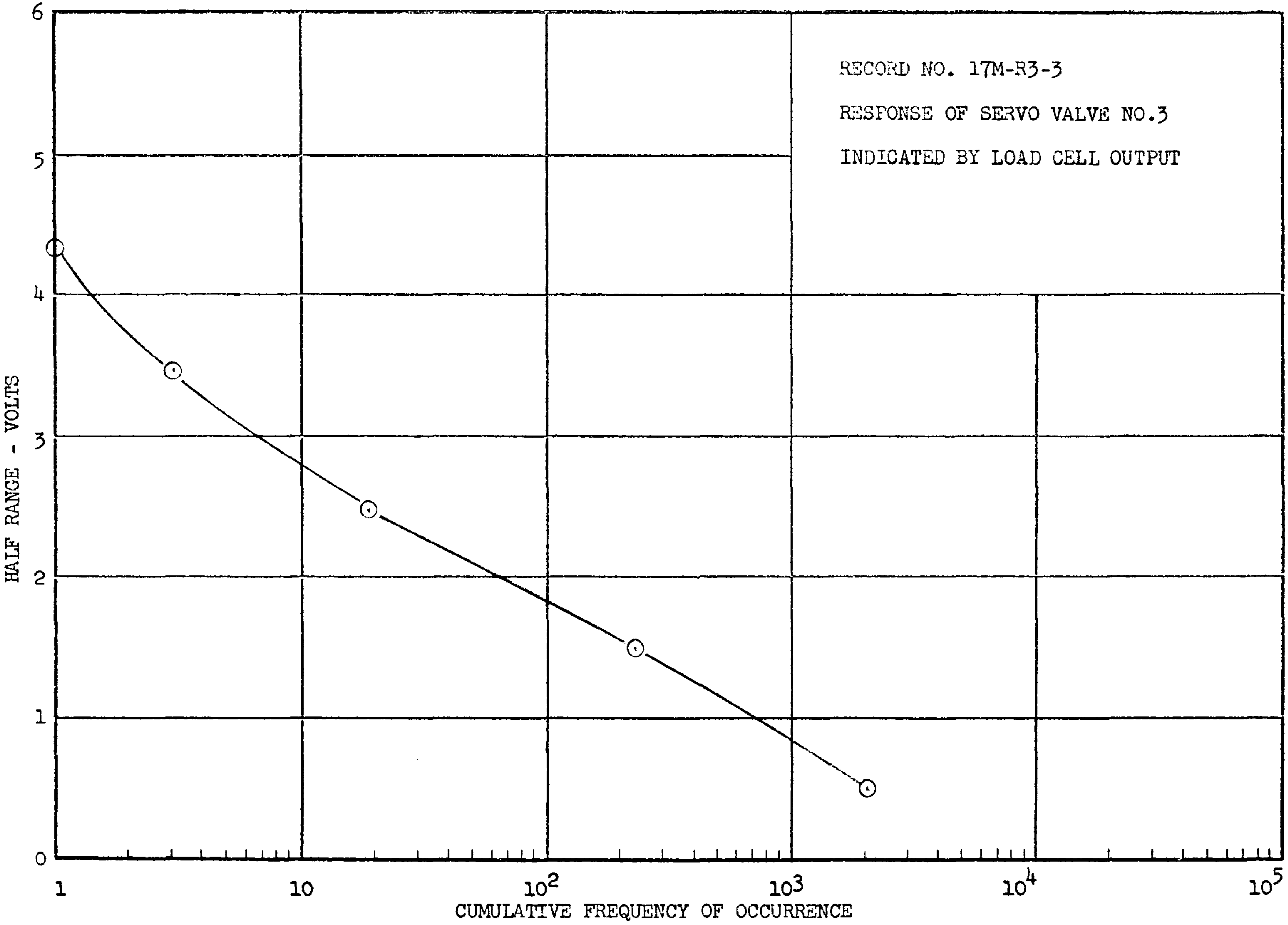


FIGURE 121 SIMPLE RANGE COUNT - WING ROOT RANDOM LOADING TRACE

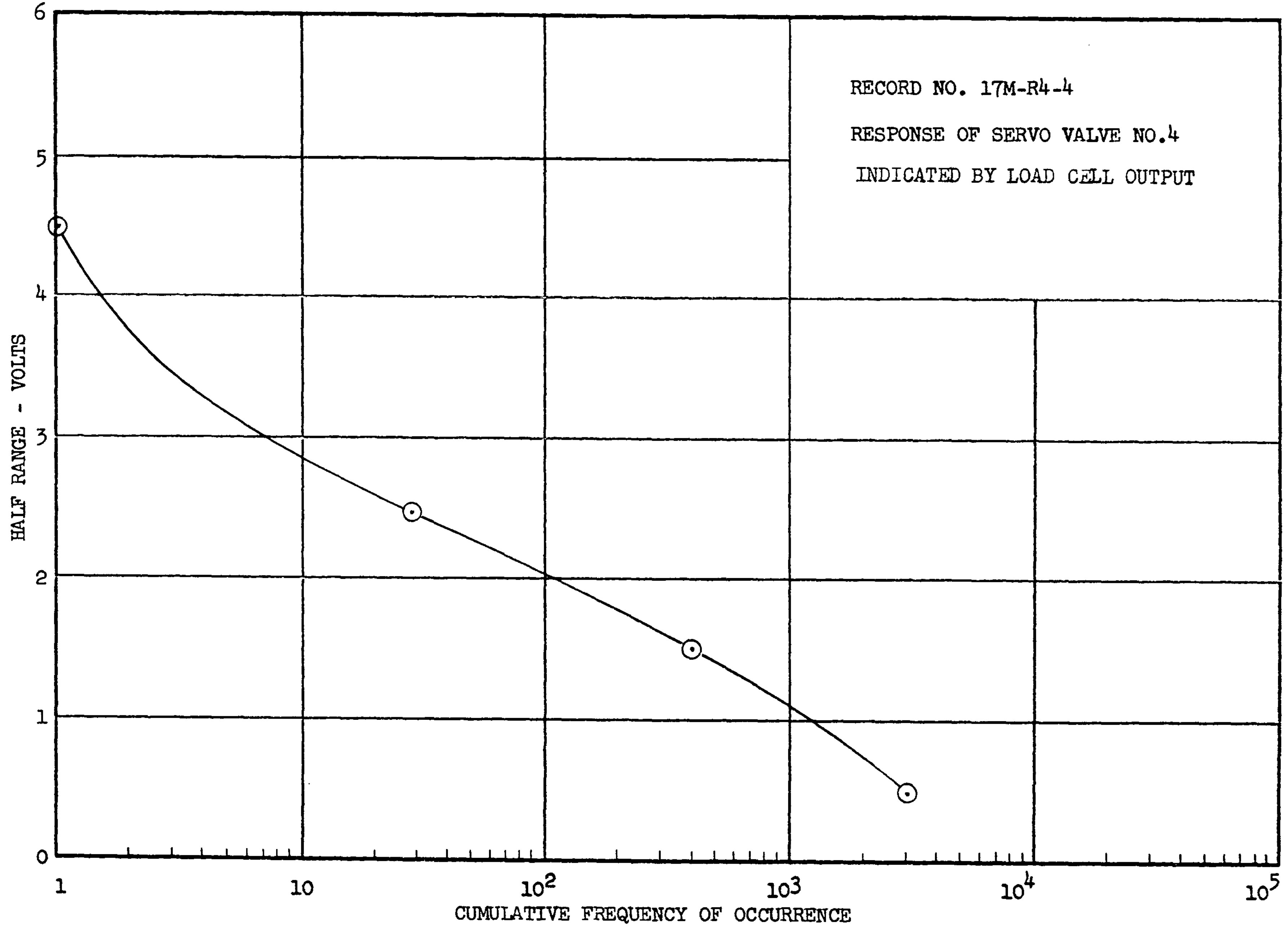


FIGURE 122 - SIMPLE RANGE COUNT - WING ROOT RANDOM LOADING TRACE

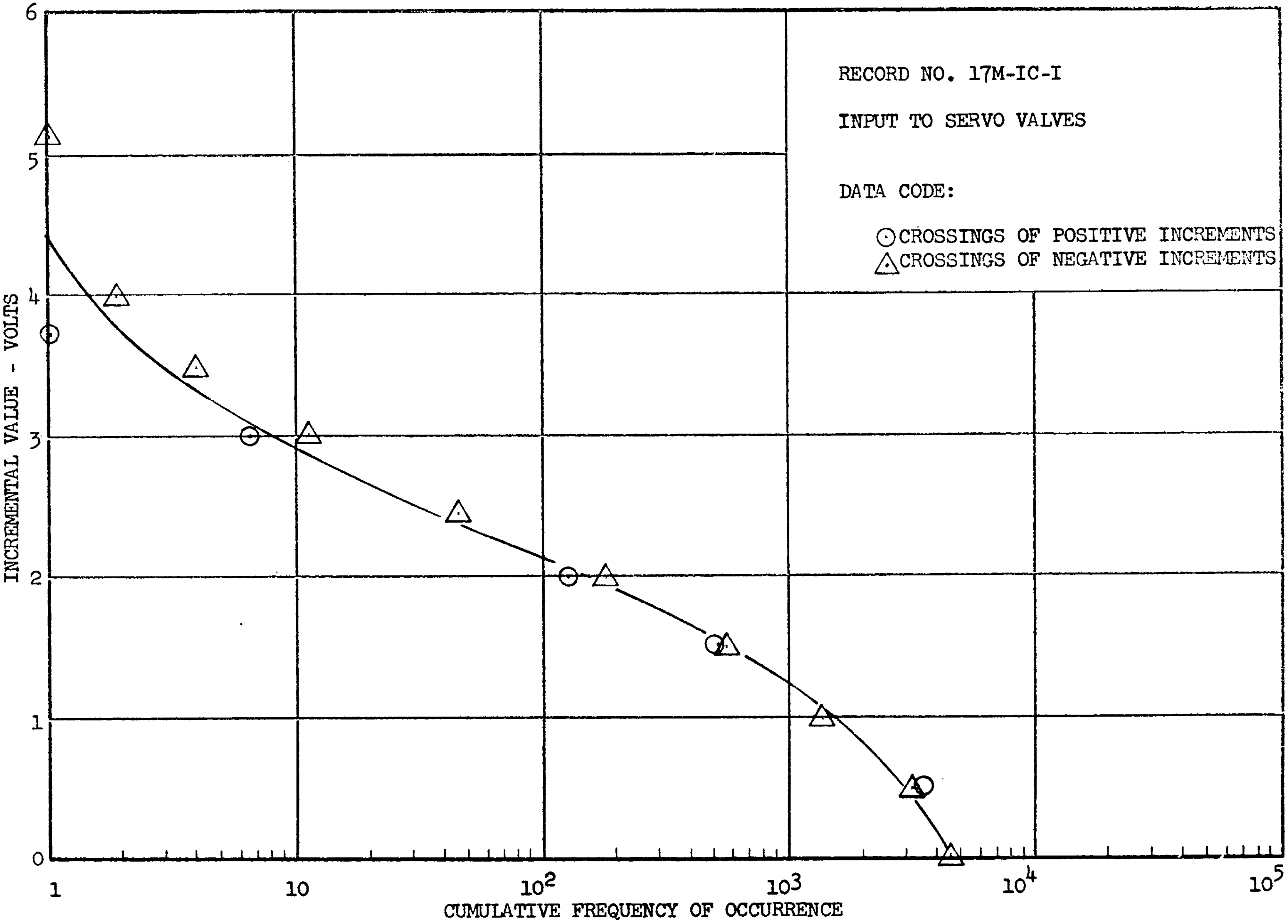


FIGURE 123 INTERVAL CROSSING COUNT - WING ROOT RANDOM LOADING TRACE

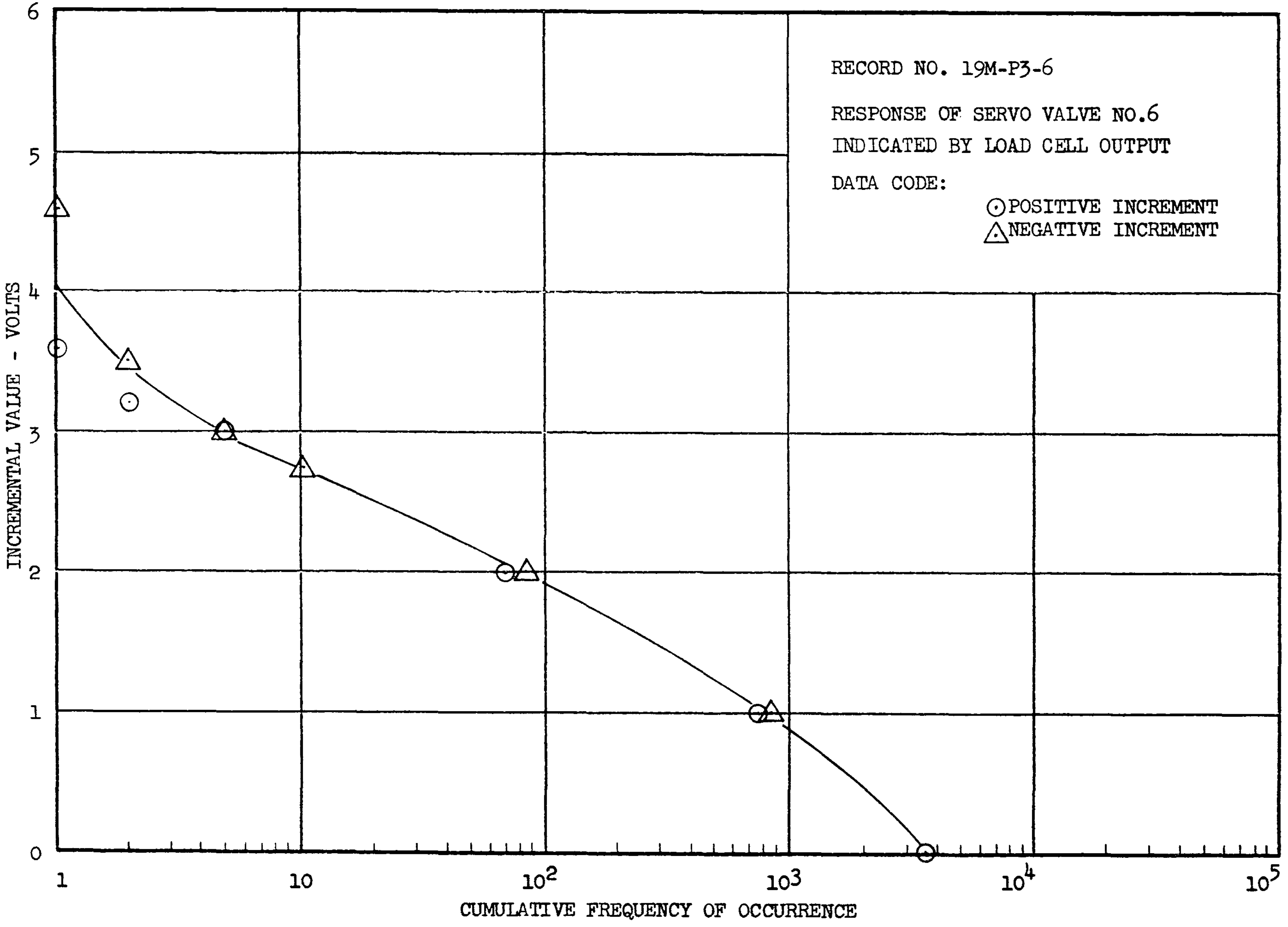


FIGURE 124 MEAN CROSSING PEAK COUNT - WING ROOT RANDOM LOADING TRACE WITH VARIABLE MEAN

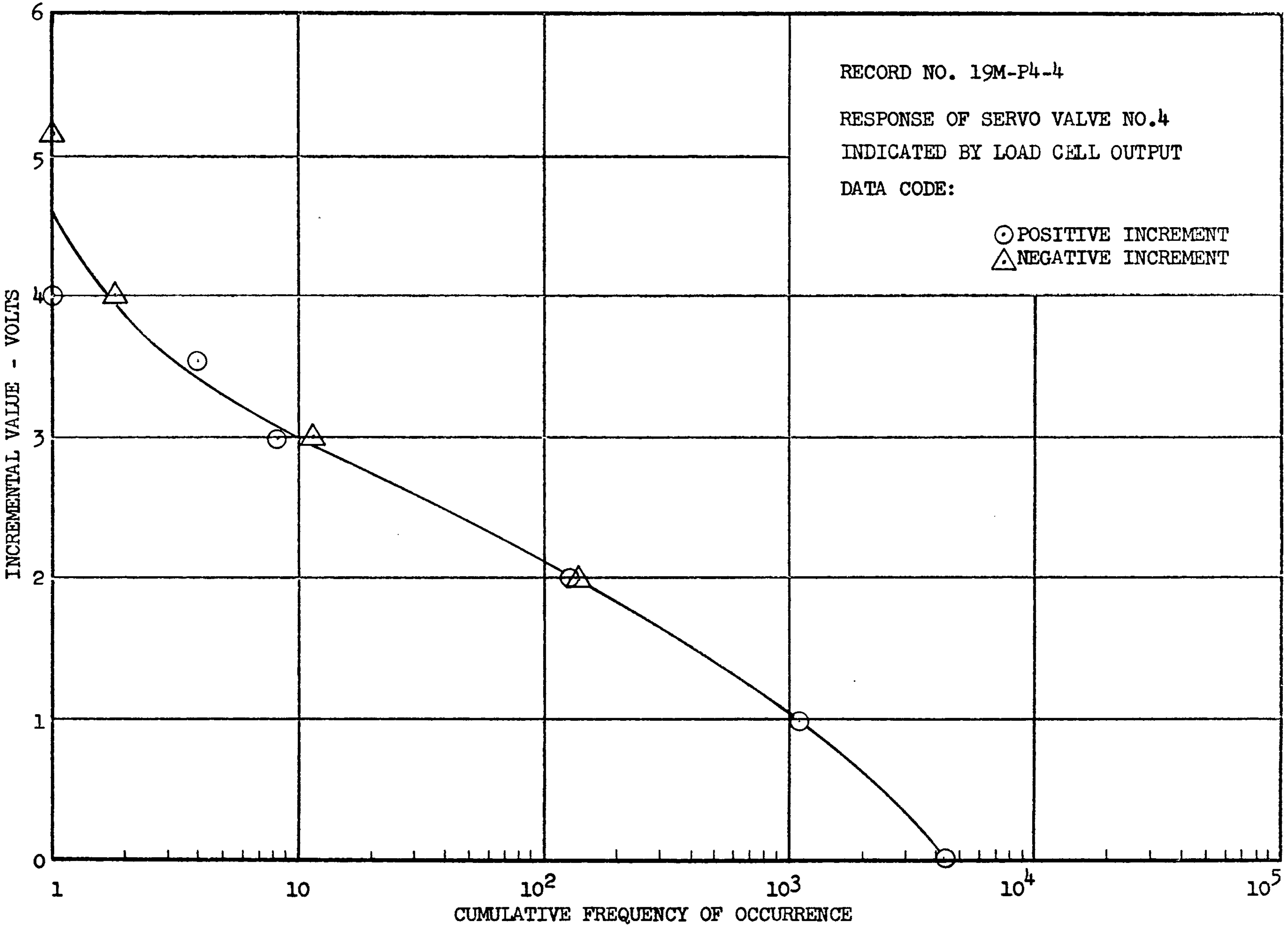


FIGURE 125 MEAN CROSSING PEAK COUNT - WING ROOT RANDOM LOADING TRACE WITH VARIABLE MEAN

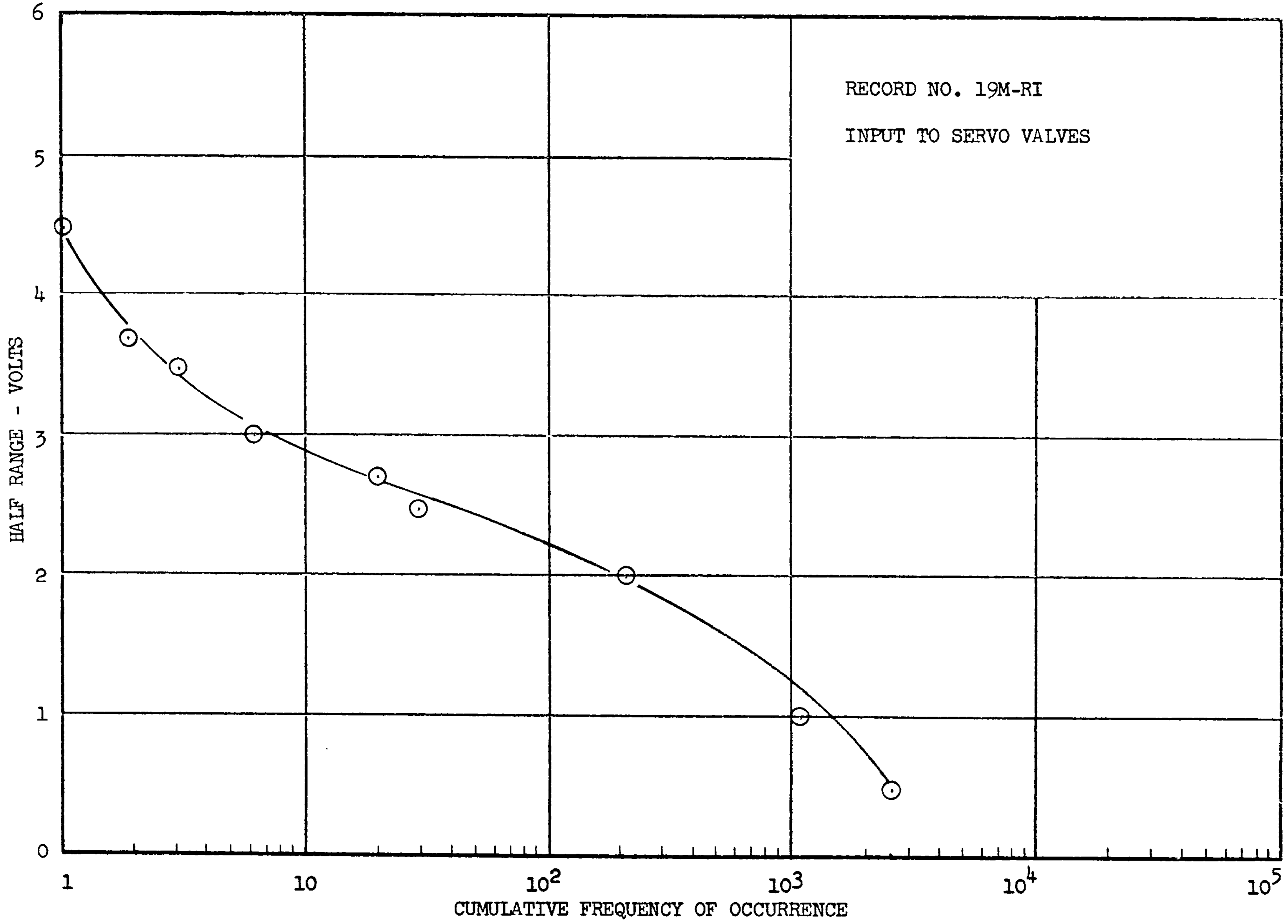


FIGURE 126 SIMPLE RANGE COUNT - WING ROOT RANDOM LOADING TRACE WITH VARIABLE MEAN

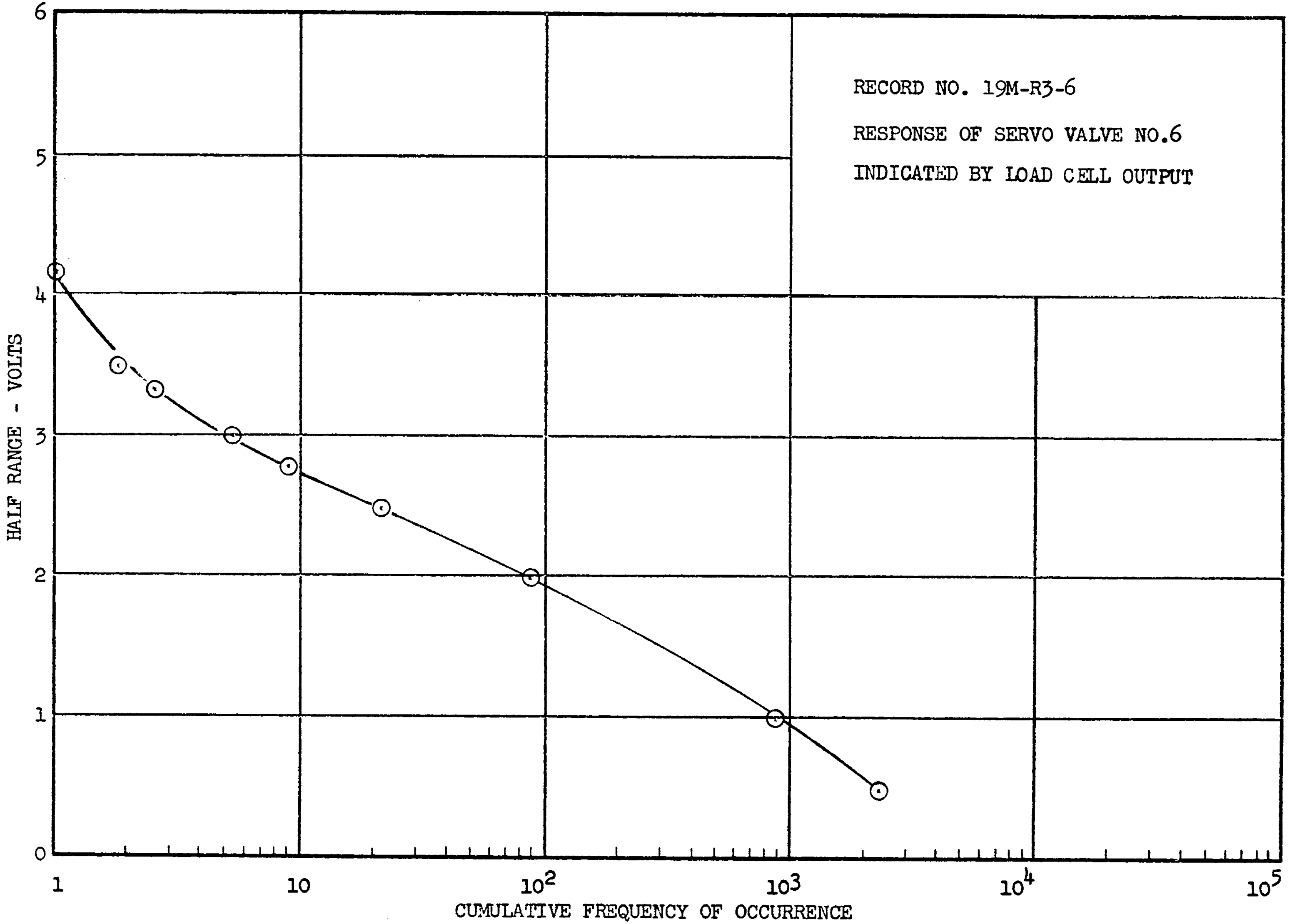
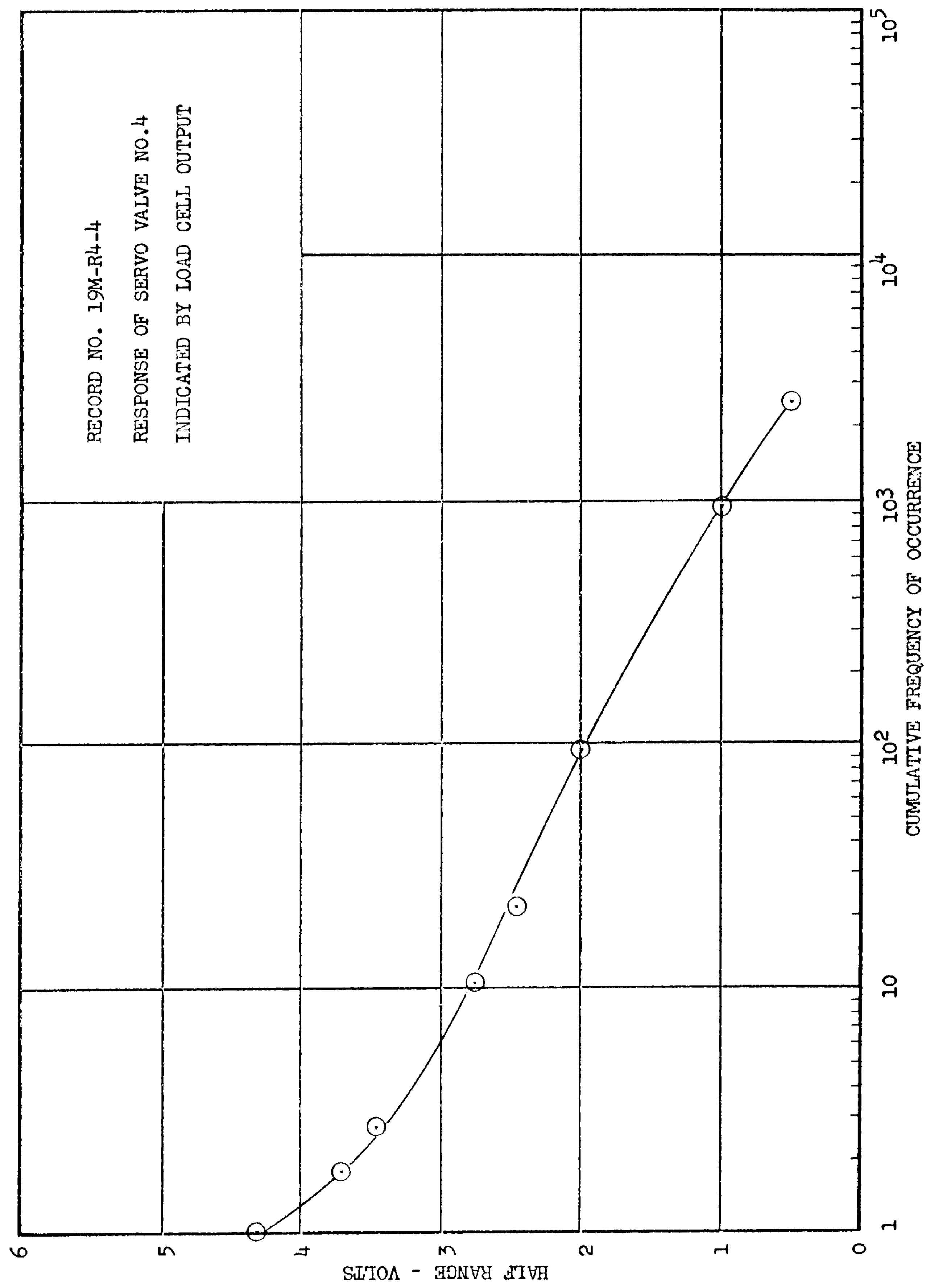


FIGURE 127 SIMPLE RANGE COUNT - WING ROOT RANDOM LOADING TRACE WITH VARIABLE MEAN



RECORD NO. 19M-R4-4

RESPONSE OF SERVO VALVE NO.4

INDICATED BY LOAD CELL OUTPUT

FIGURE 128 SIMPLE RANGE COUNT - WING ROOT RANDOM LOADING TRACE WITH VARIABLE MEAN

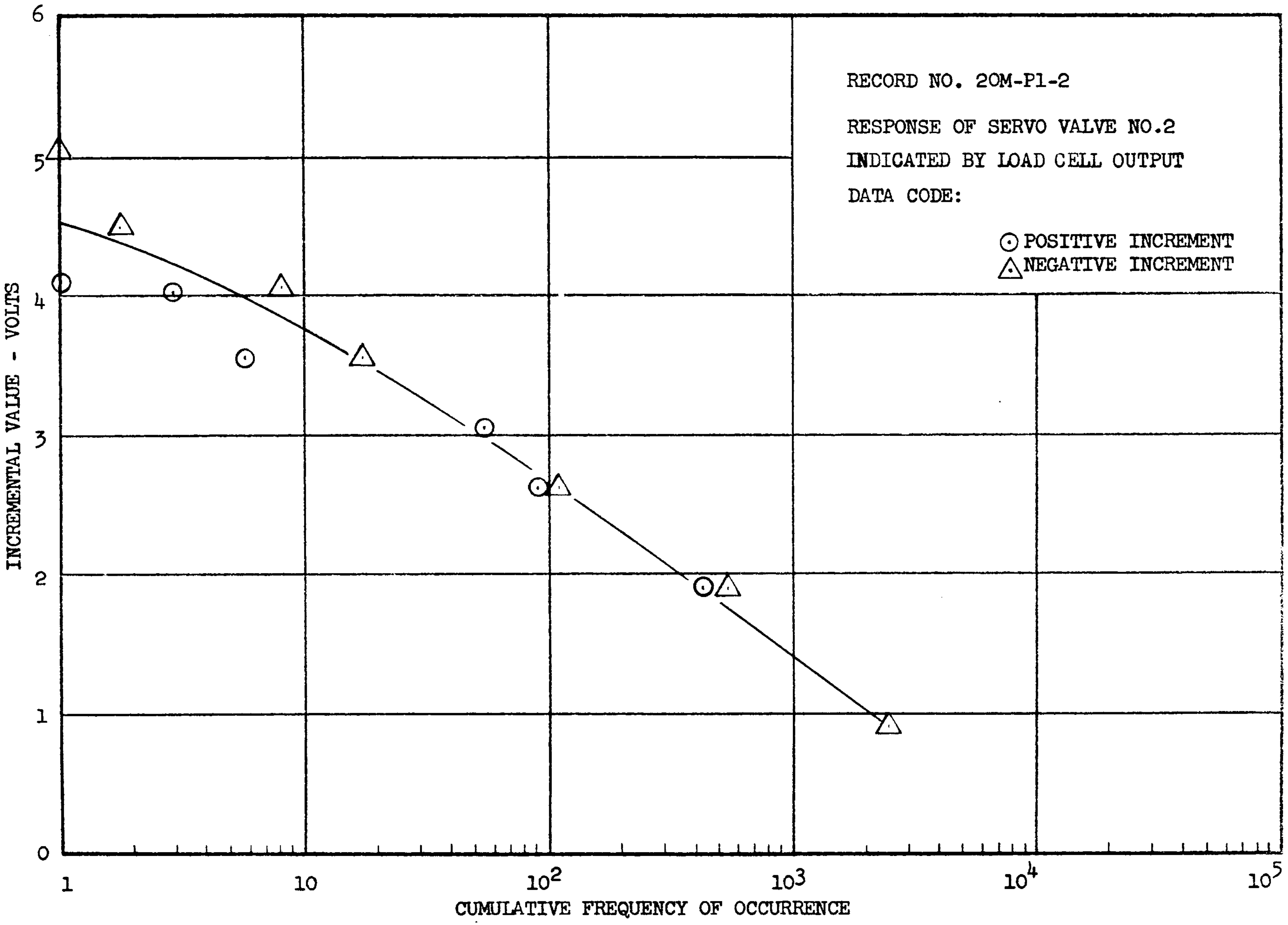


FIGURE 129 MEAN CROSSING PEAK COUNT - FIN ROOT RANDOM LOADING TRACE WITH VARIABLE MEAN

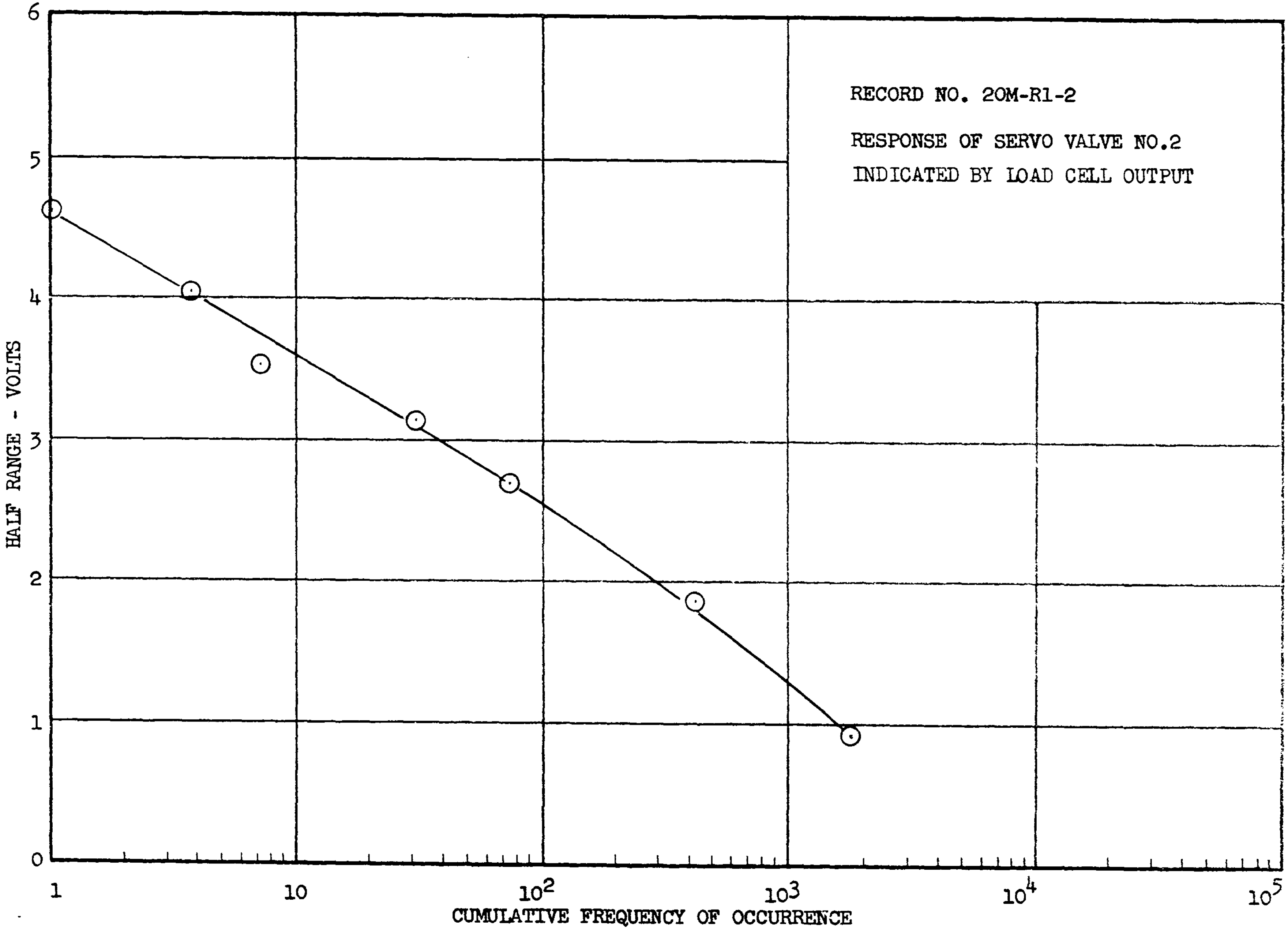


FIGURE 130 SIMPLE RANGE COUNT - FIN ROOT RANDOM LOADING TRACE WITH VARIABLE MEAN

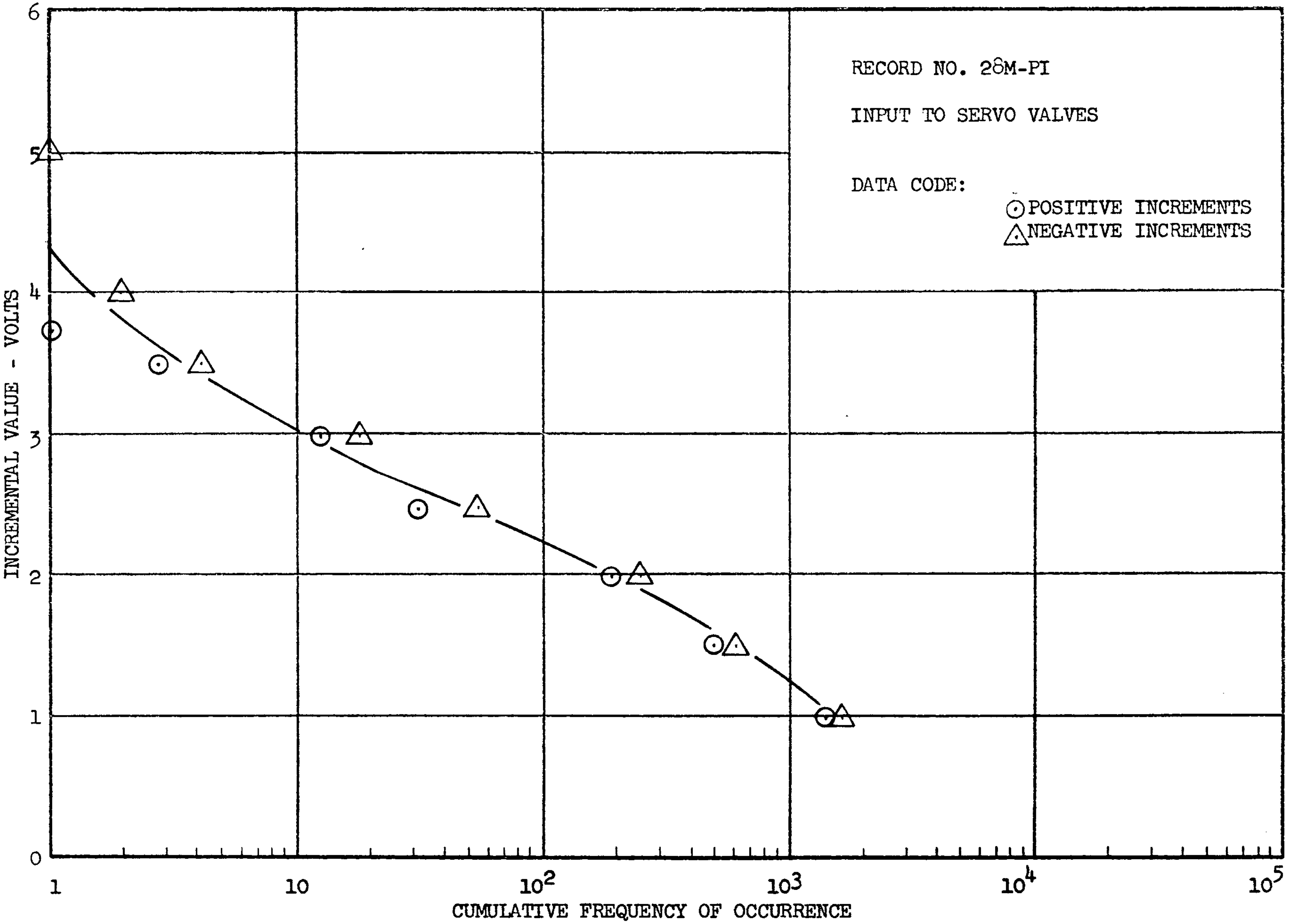


FIGURE 131 MEAN CROSSING PEAK COUNT - REVERSED WING ROOT RANDOM LOADING TRACE

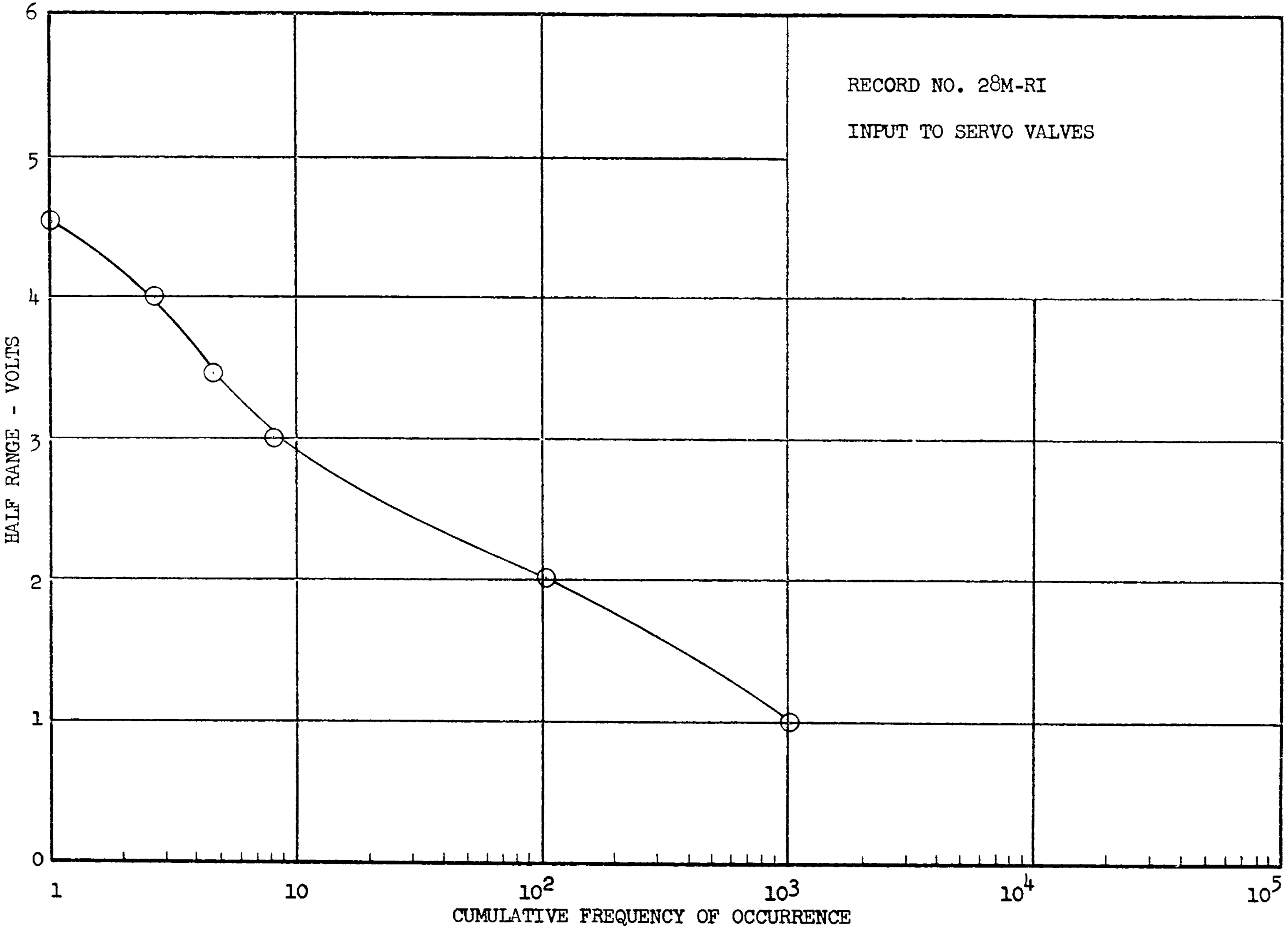


FIGURE 132 SIMPLE RANGE COUNT - REVERSED WING ROOT RANDOM LOADING TRACE

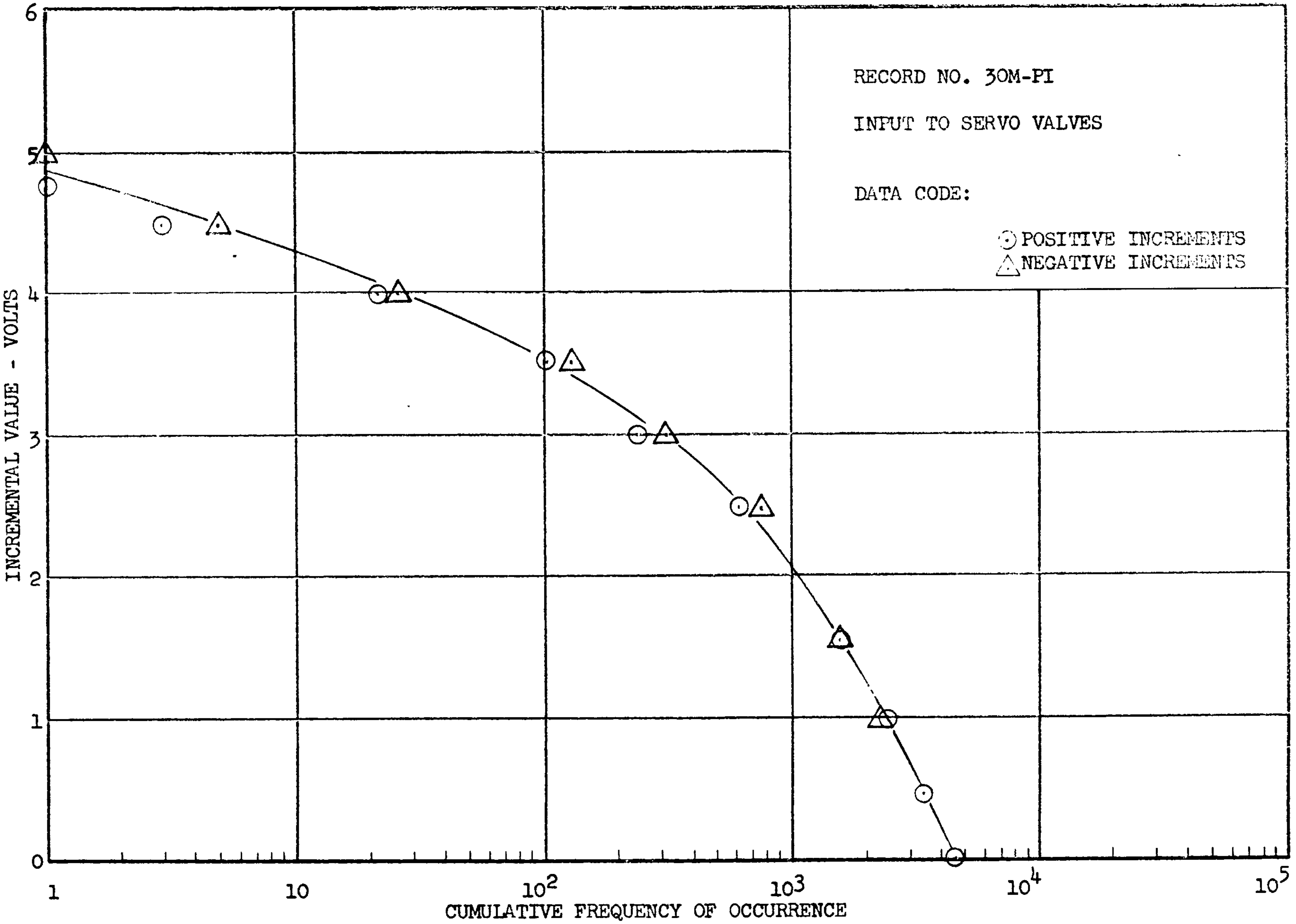


FIGURE 133 MEAN CROSSING PEAK COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

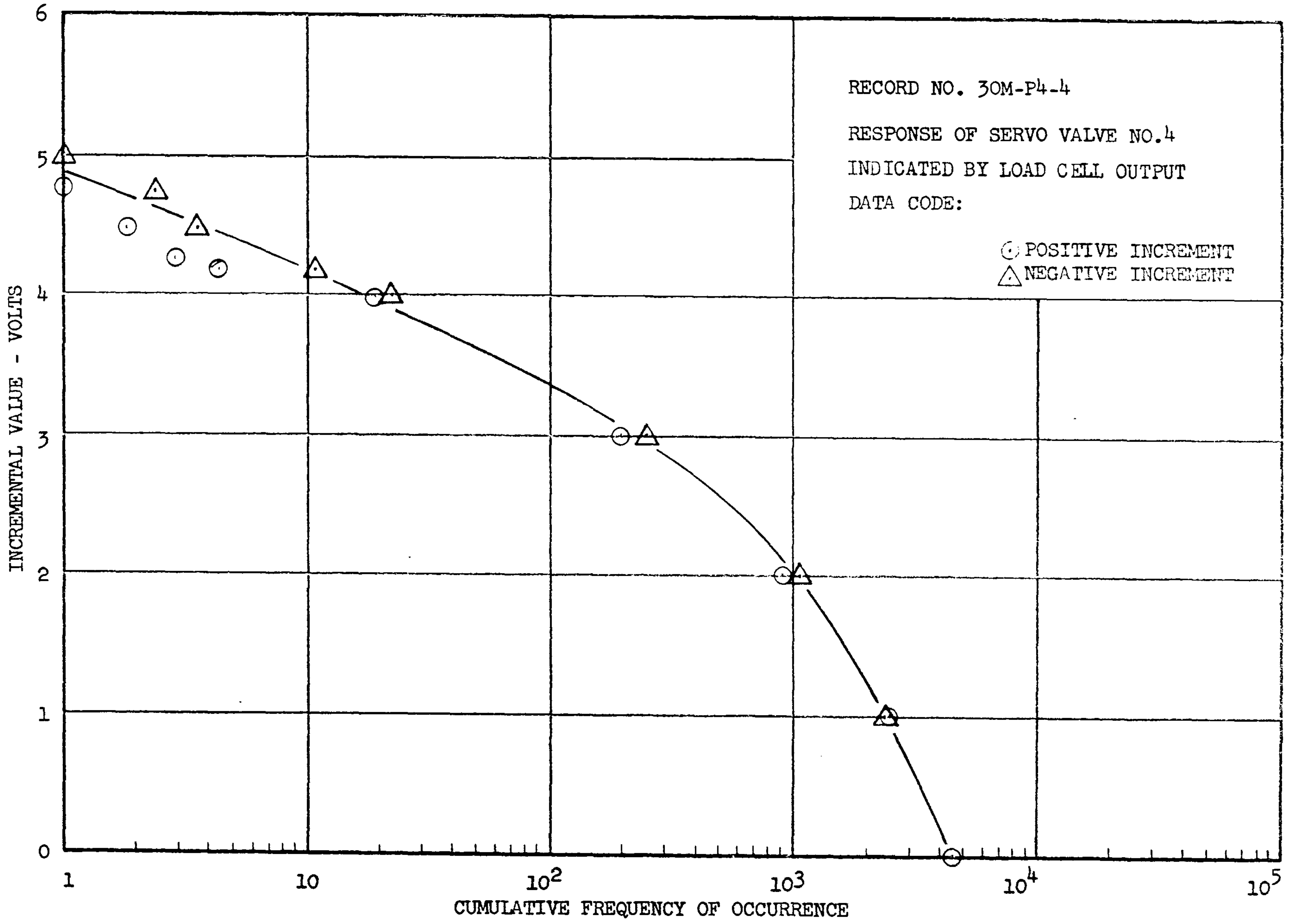


FIGURE 134 MEAN CROSSING PEAK COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

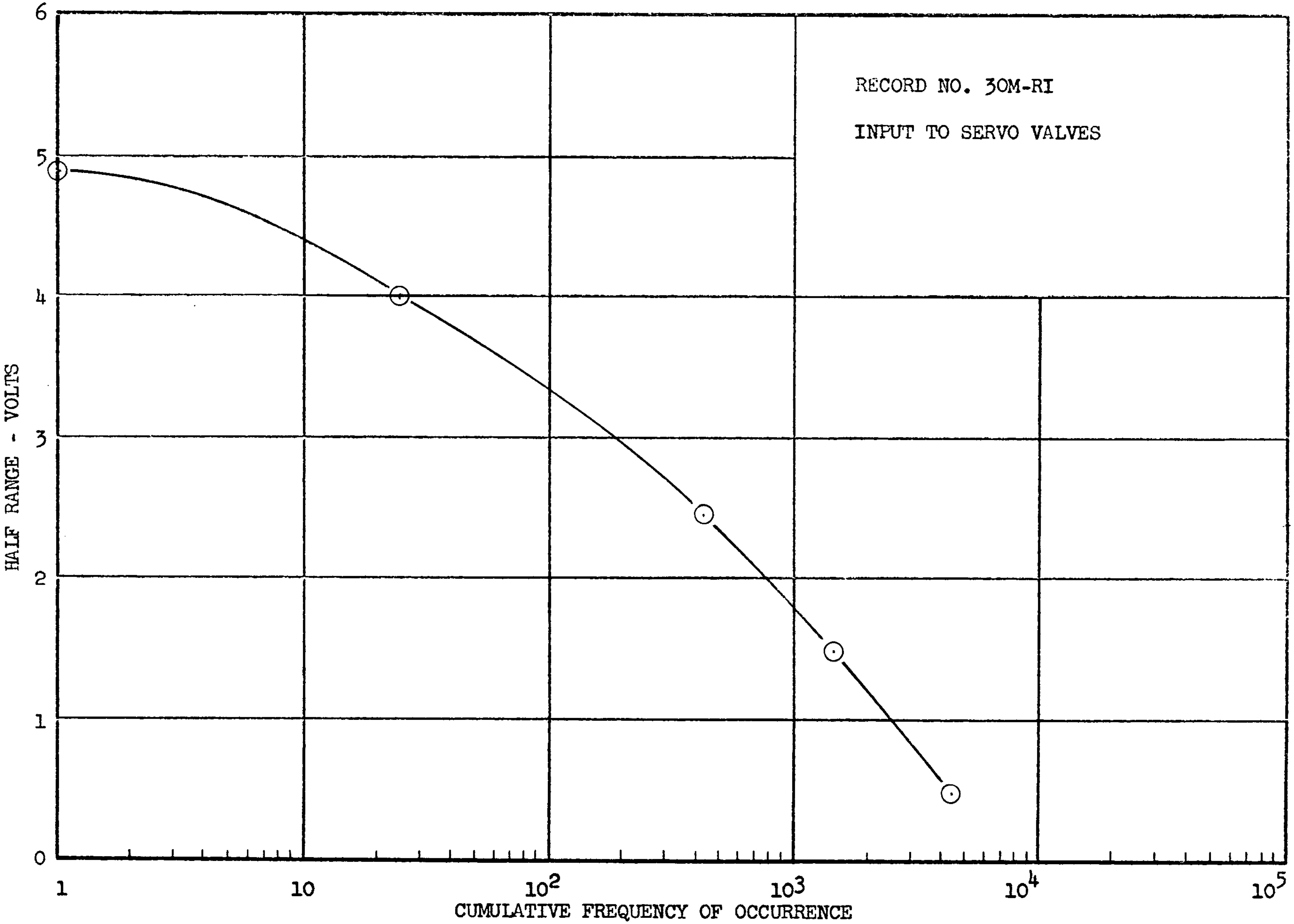


FIGURE 135 SIMPLE RANGE COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

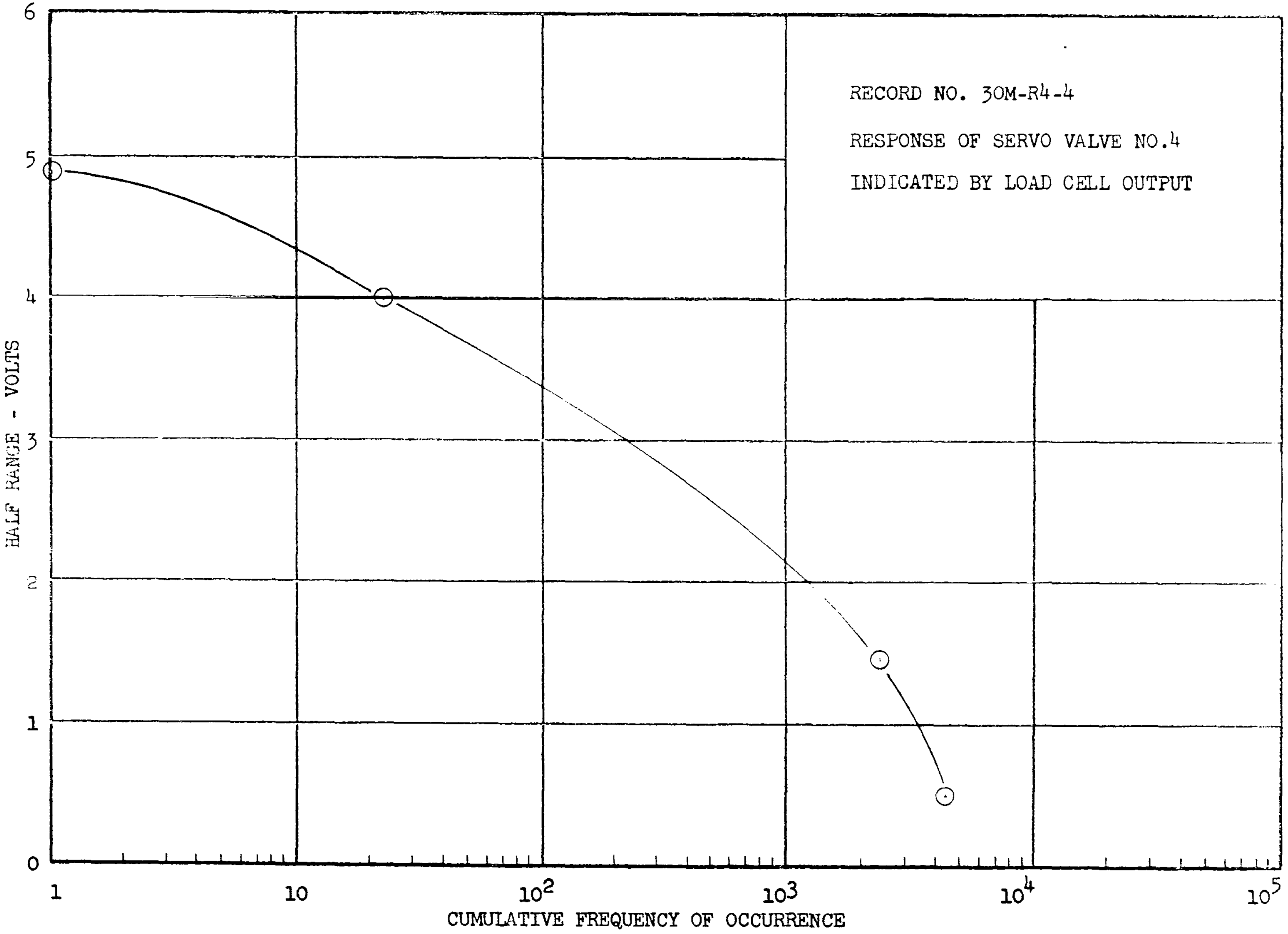


FIGURE 136 SIMPLE RANGE COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

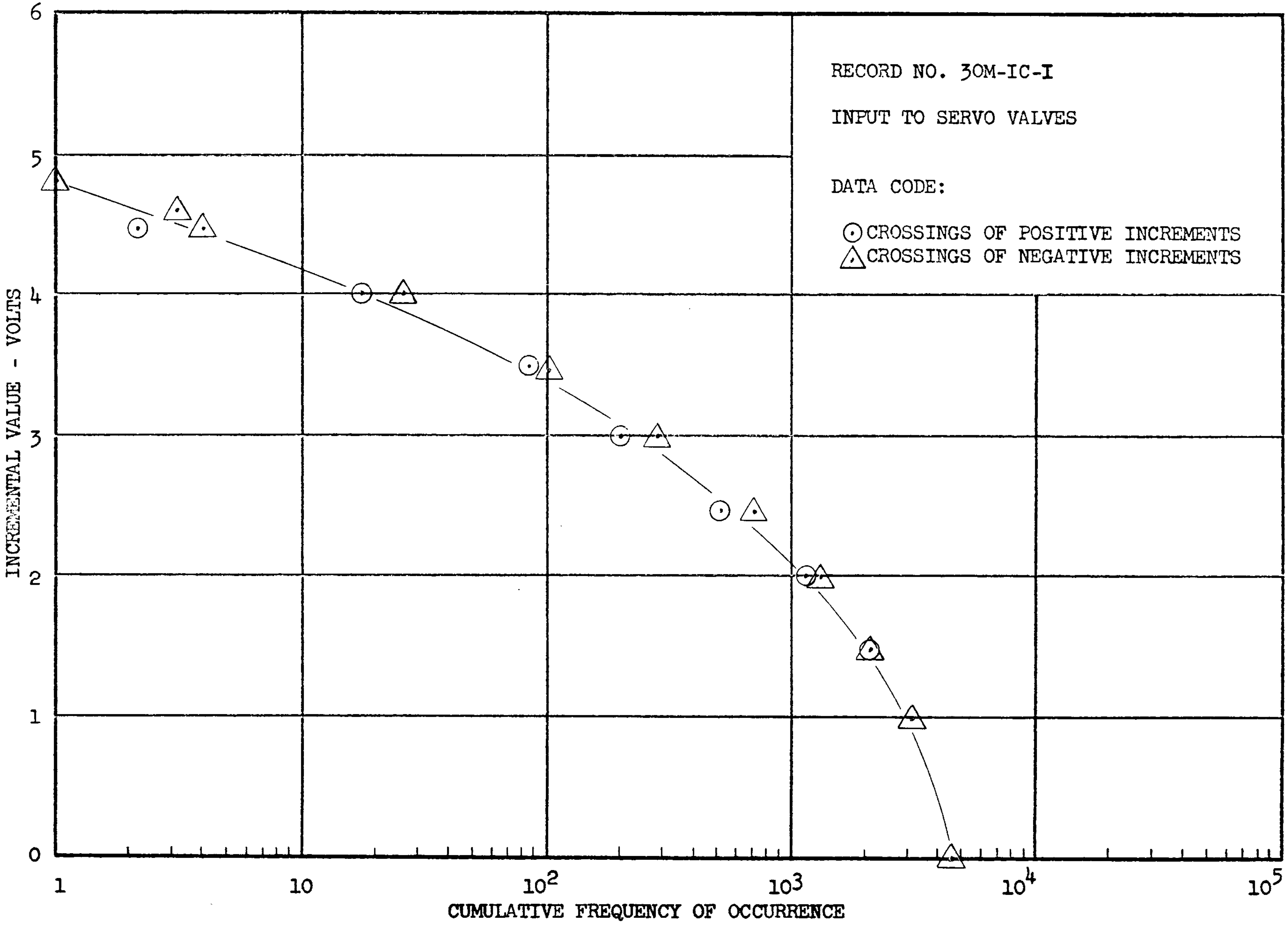


FIGURE 137 INTERVAL CROSSING COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

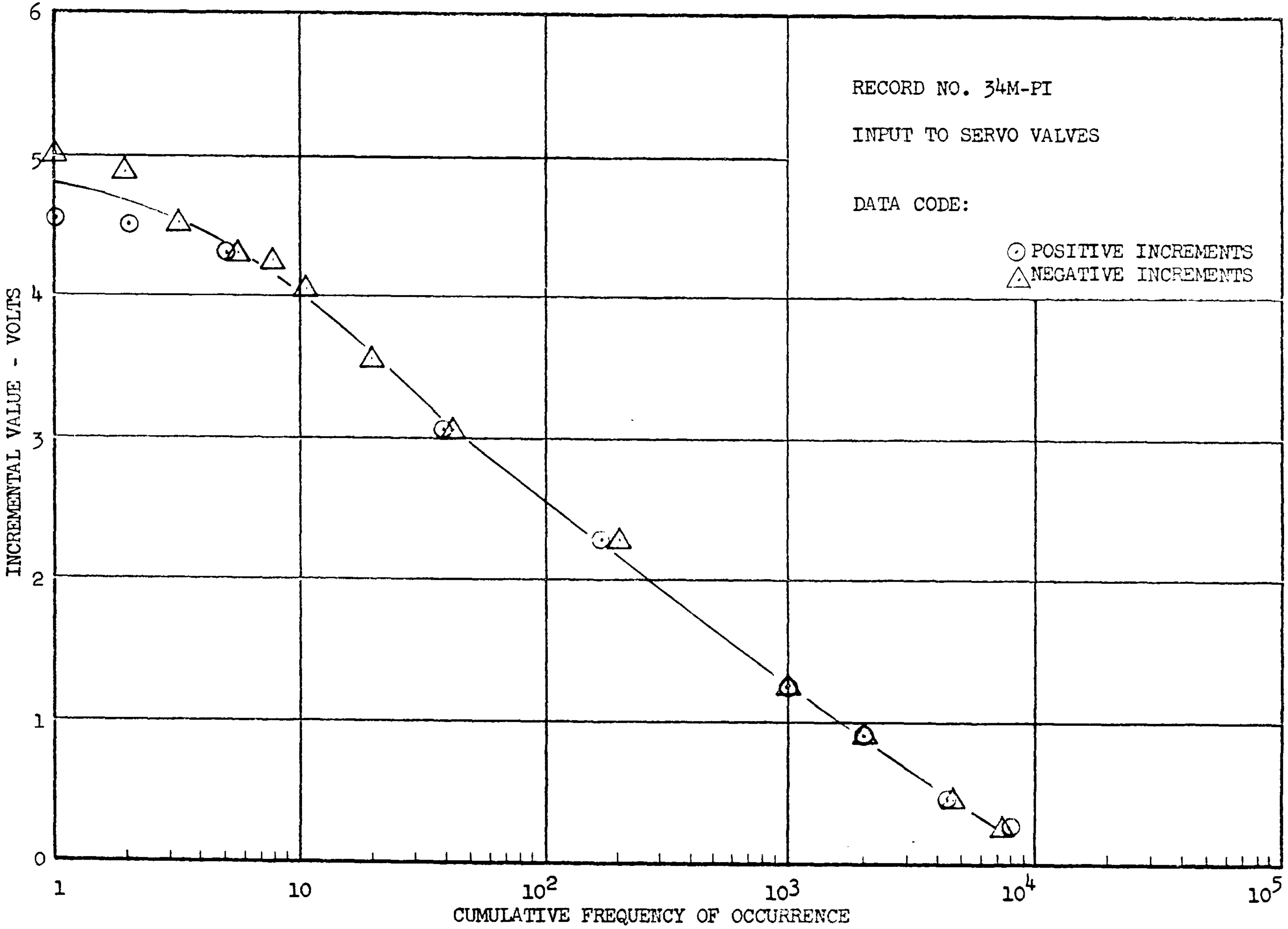


FIGURE 138 MEAN CROSSING PEAK COUNT - FIN ROOT RANDOM LOADING TRACE

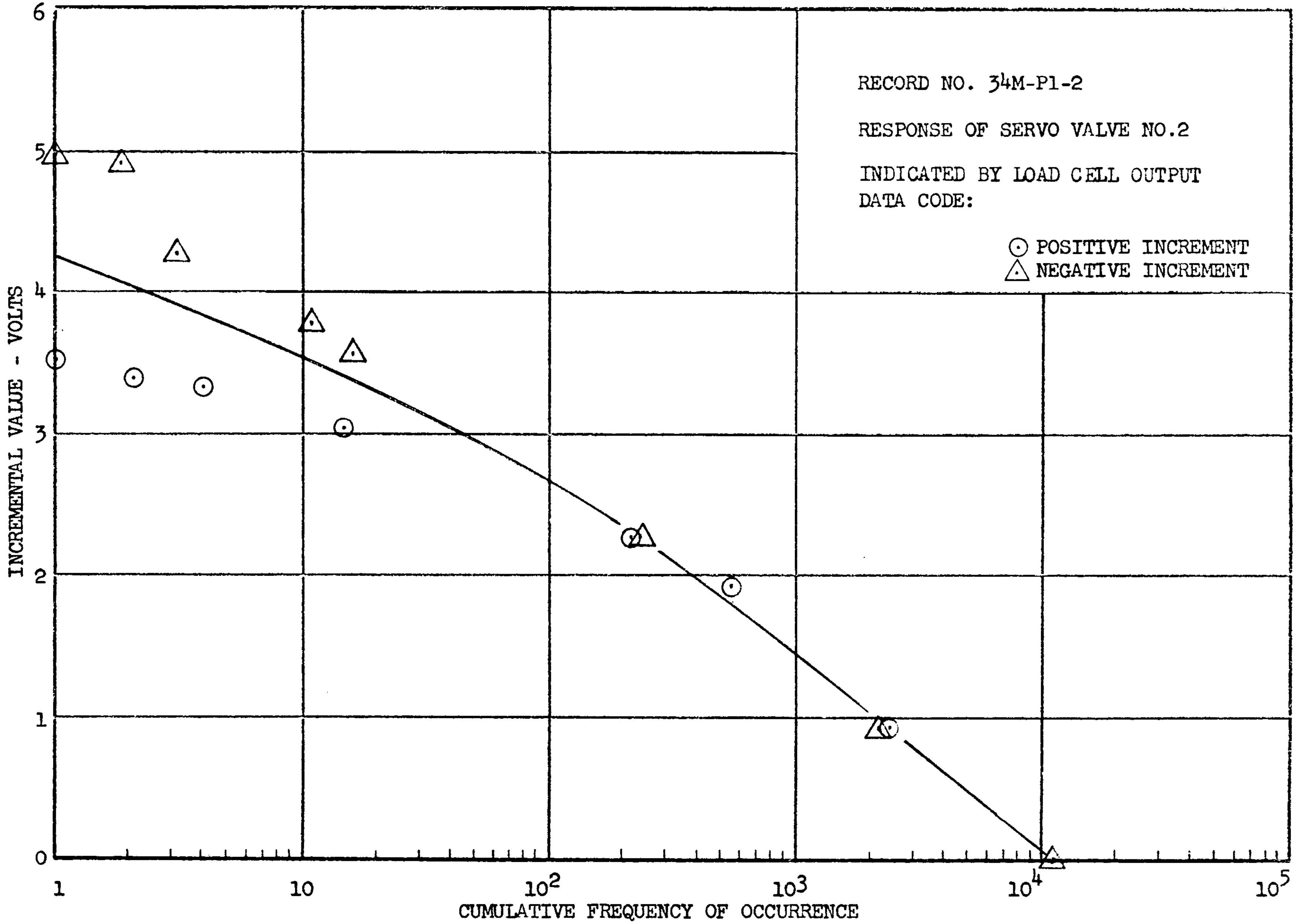


FIGURE 139 MEAN CROSSING PEAK COUNT - FIN ROOT RANDOM LOADING TRACE

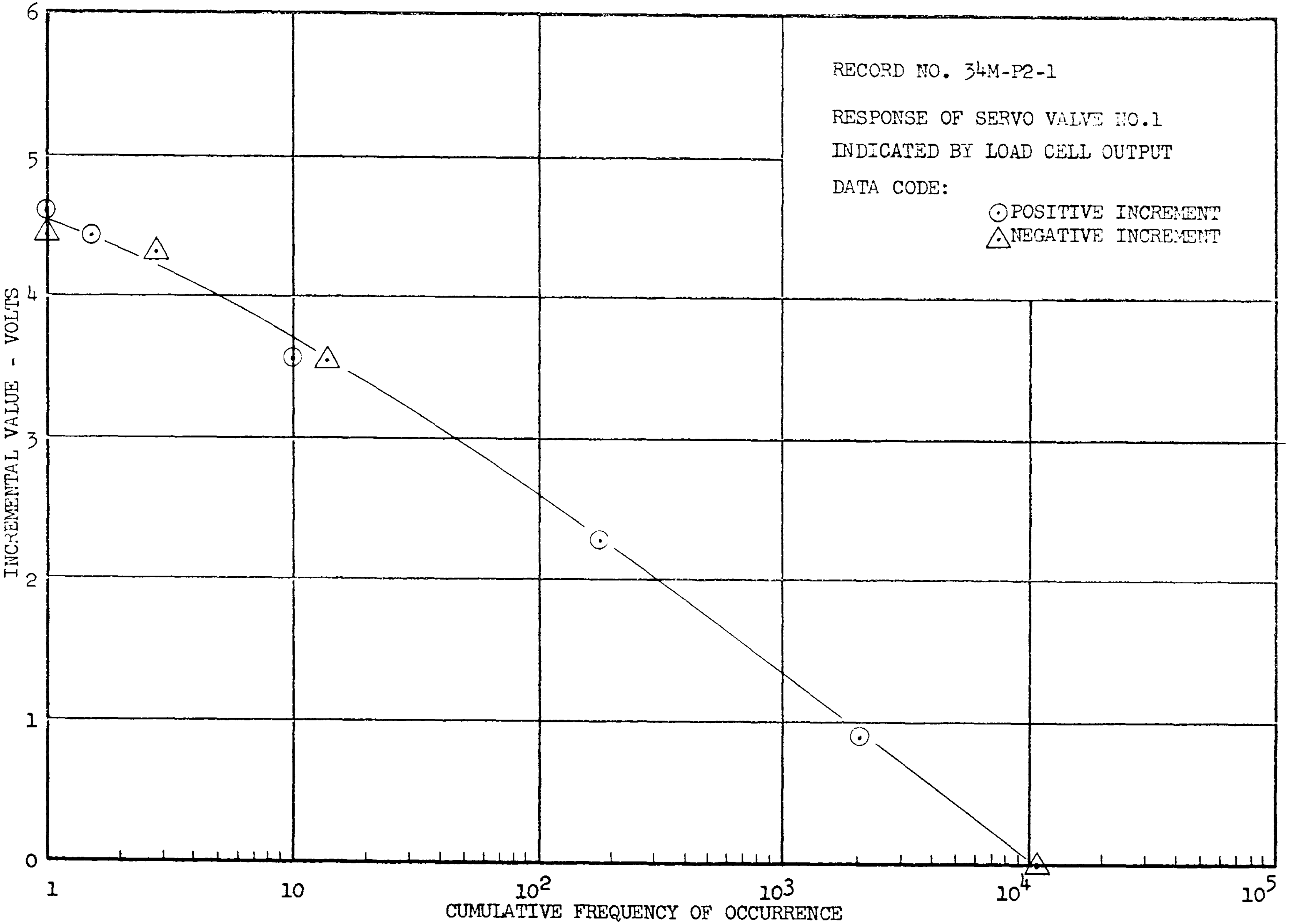


FIGURE 140 MEAN CROSSING PEAK COUNT - FIN ROOT RANDOM LOADING TRACE

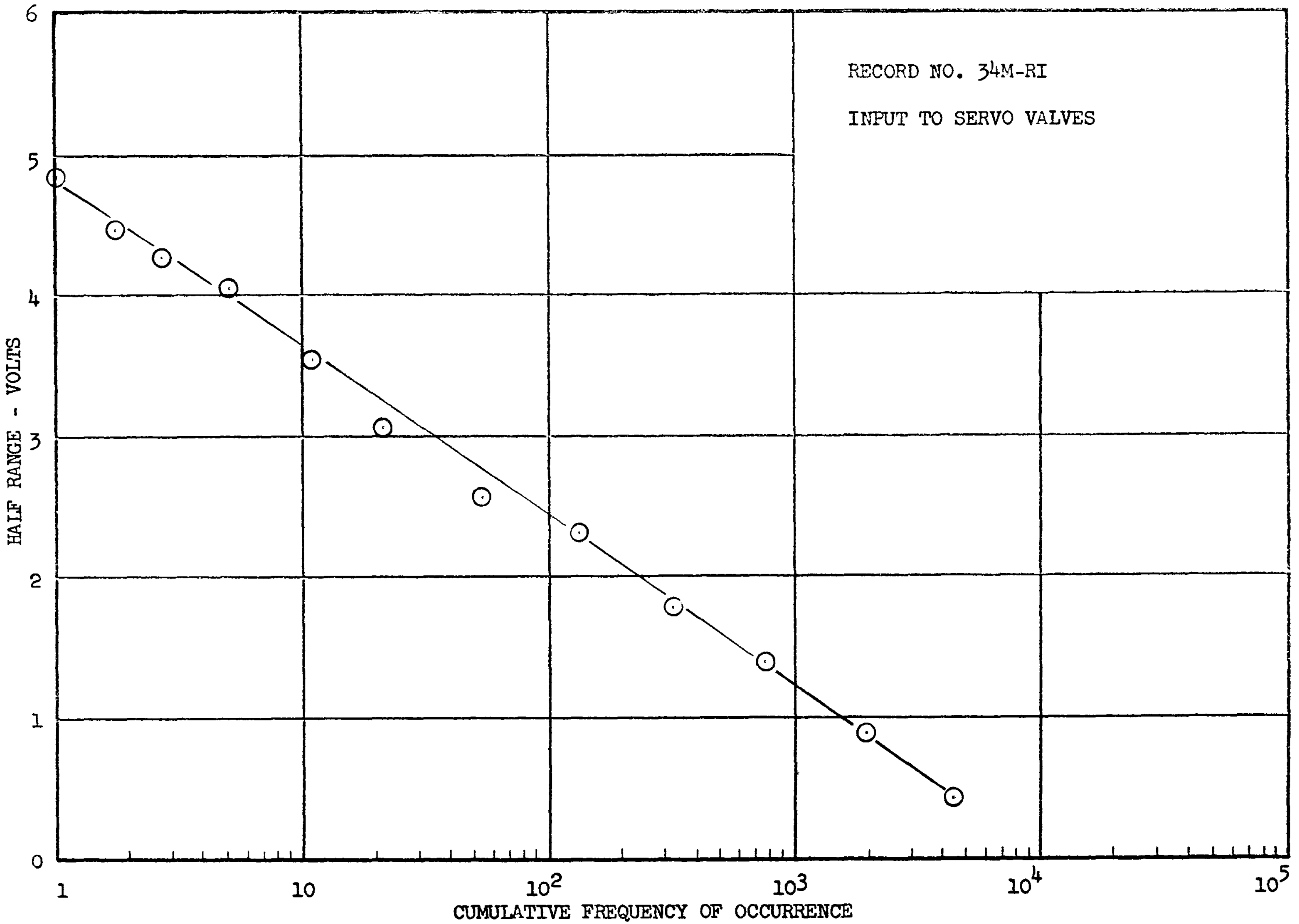


FIGURE 141 SIMPLE RANGE COUNT - FIN ROOT ROOT RANDOM LOADING TRACE

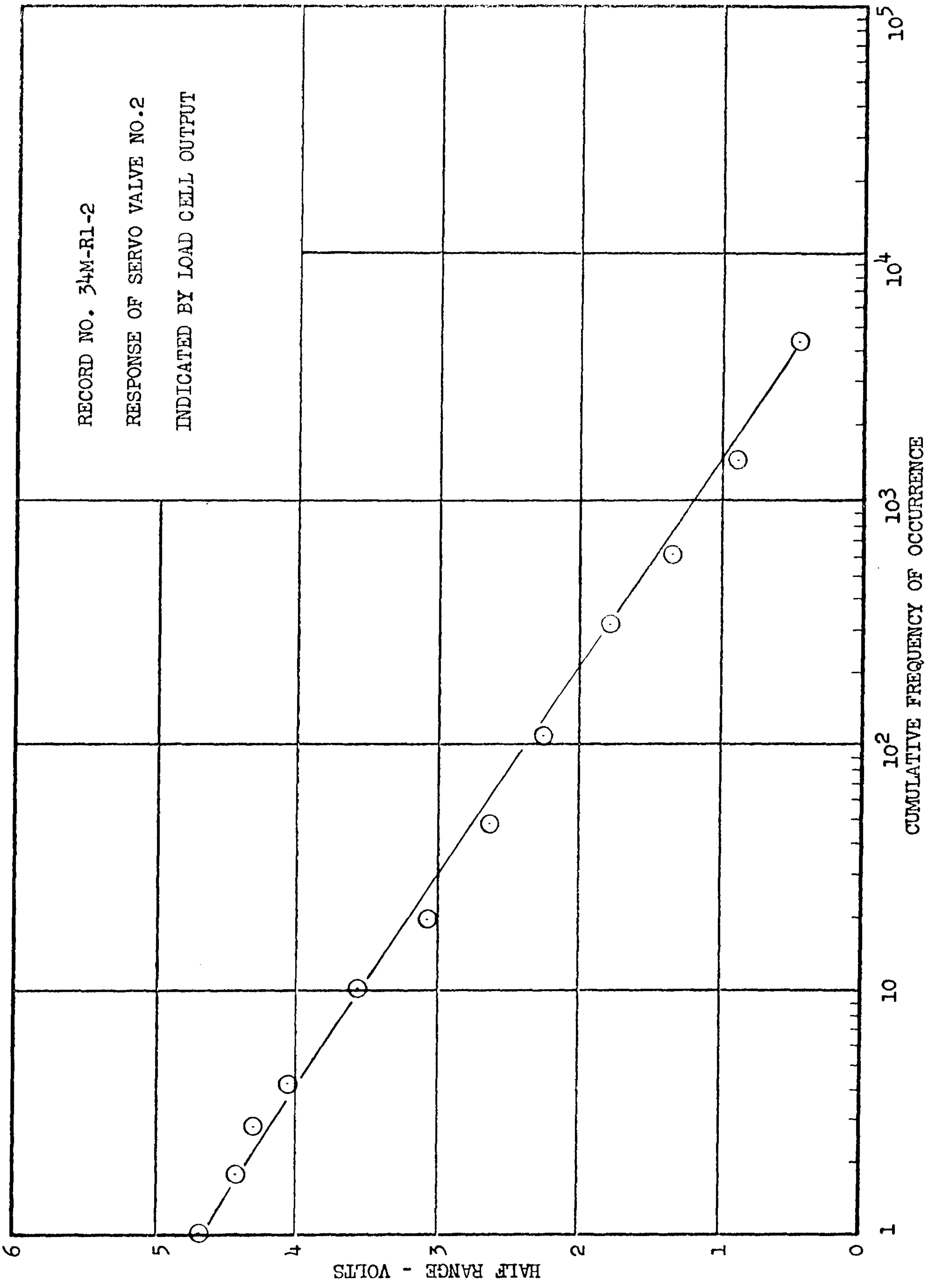


FIGURE 142 SIMPLE RANGE COUNT - FIN ROOT RANDOM LOADING TRACE

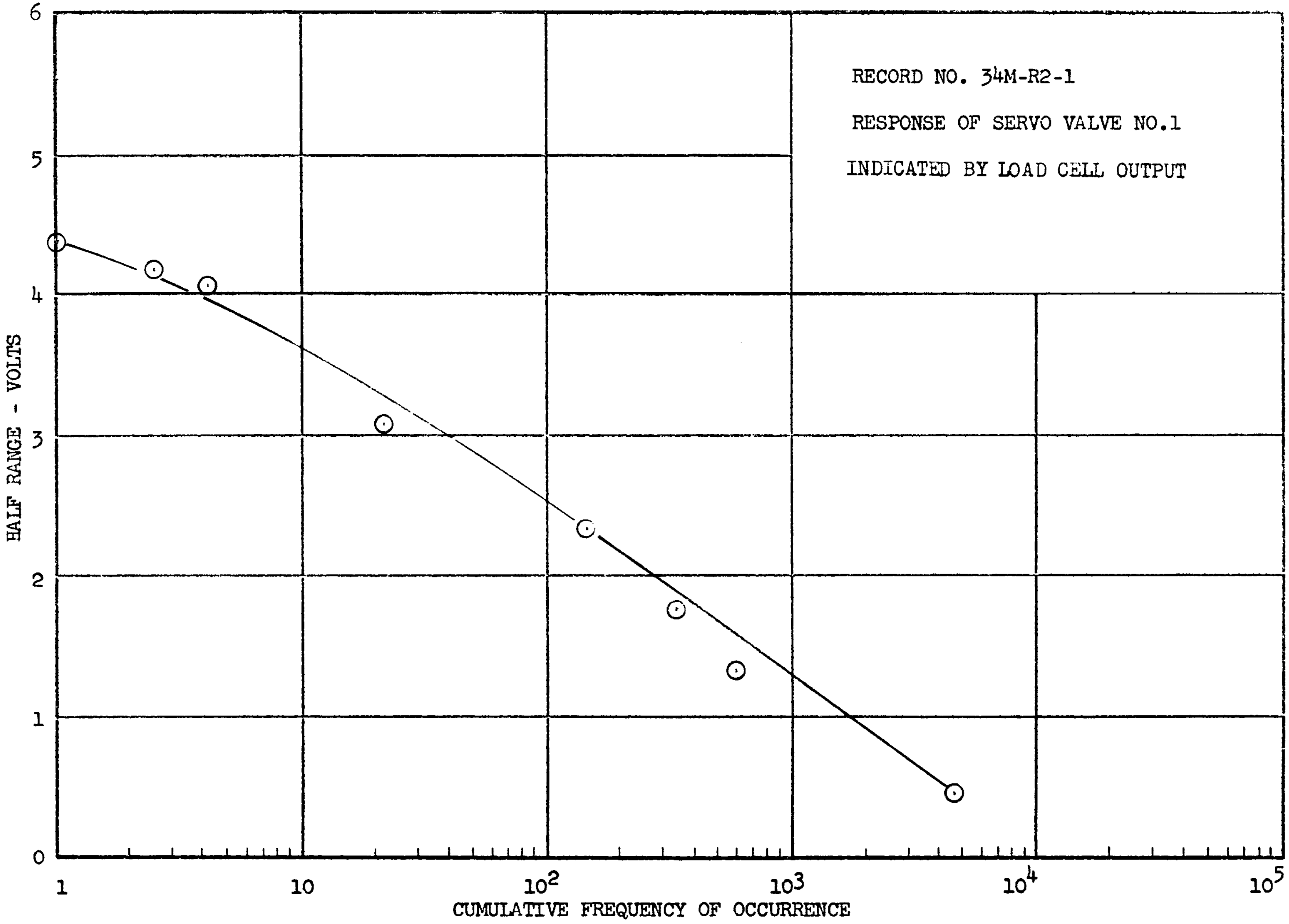


FIGURE 143 SIMPLE RANGE COUNT - FIN ROOT RANDOM LOADING TRACE

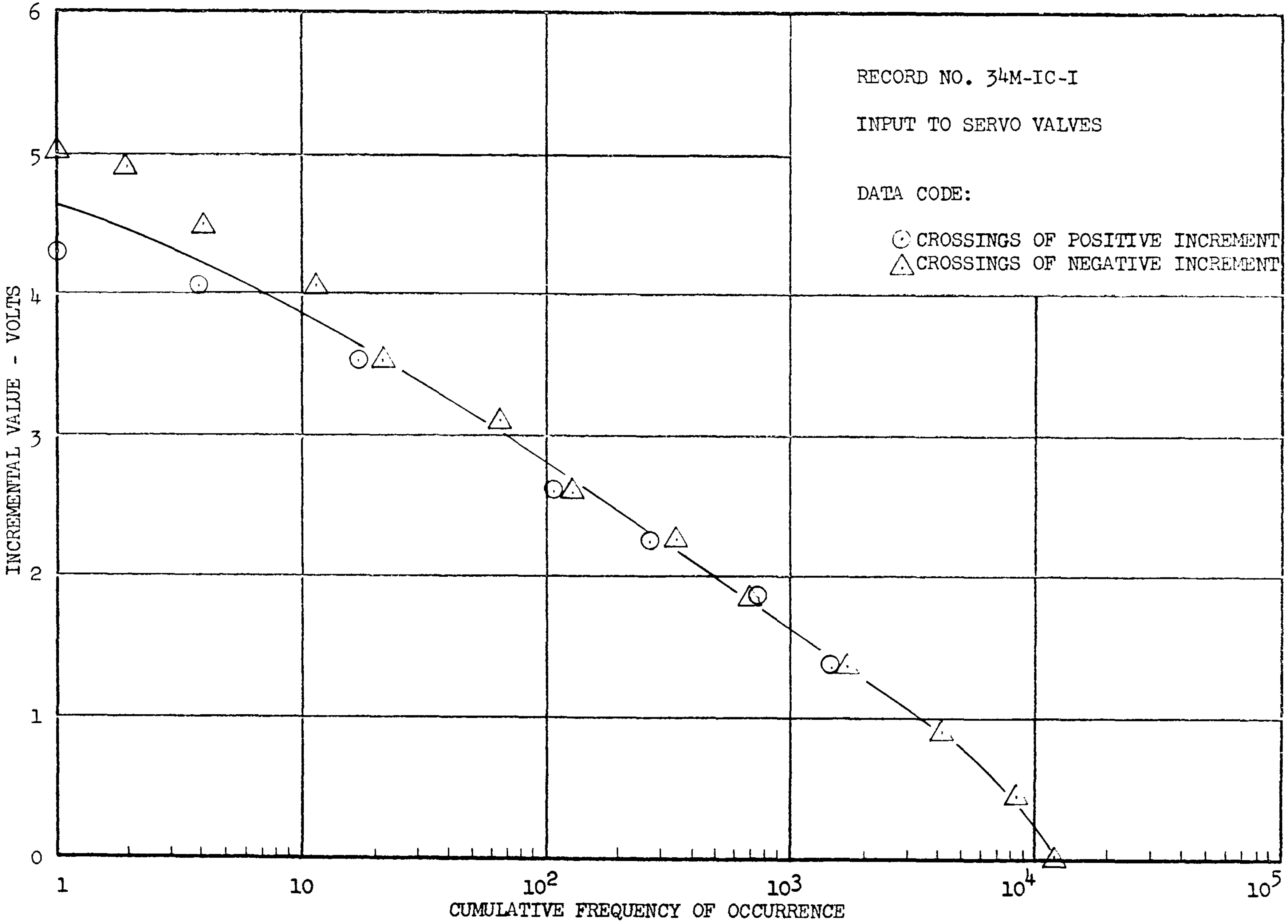


FIGURE 144 INTERVAL CROSSING COUNT - FIN ROOT RANDOM LOADING TRACE

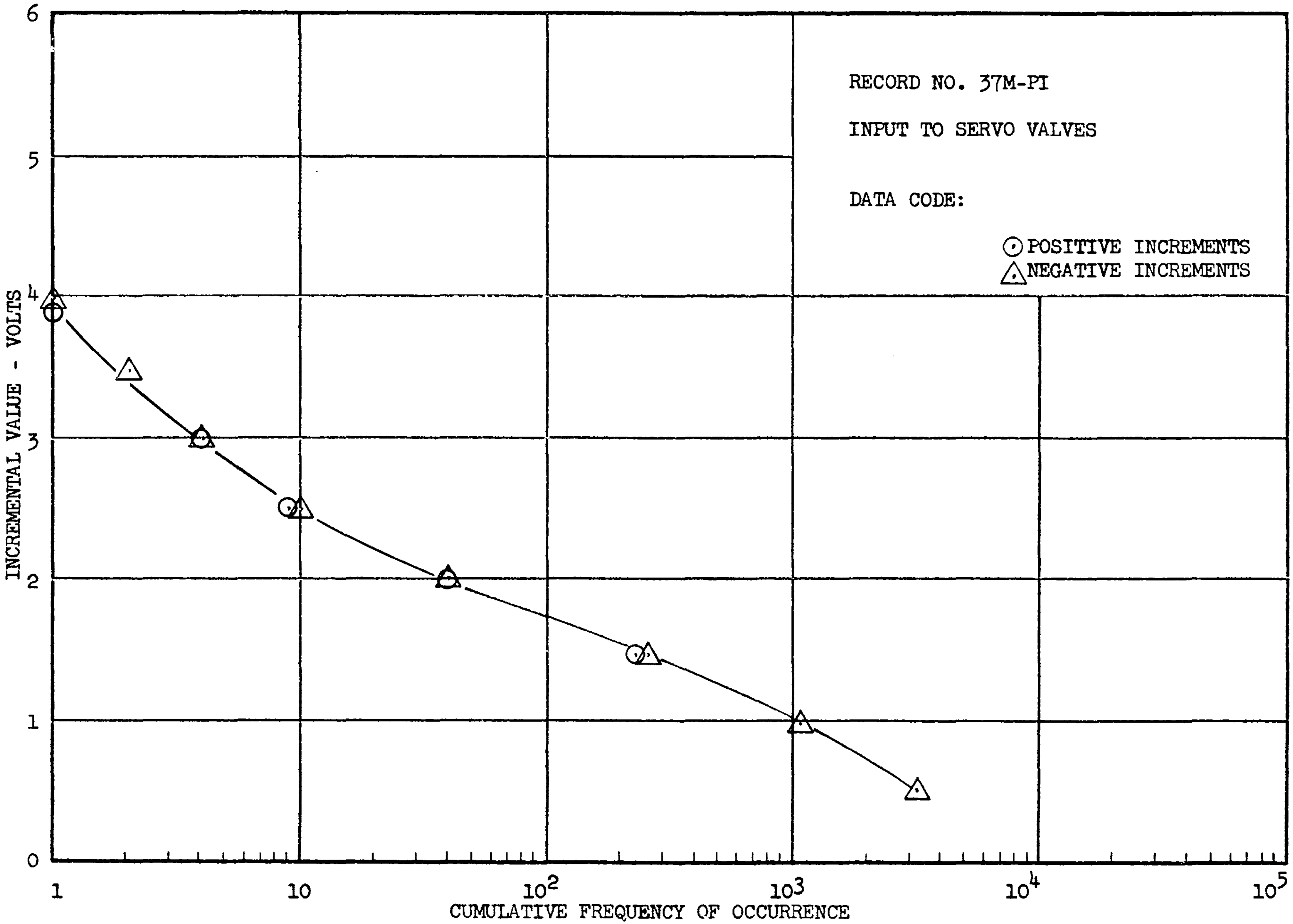


FIGURE 145 MEAN CROSSING PEAK COUNT - WING ROOT ORDERED LOADING TRACE

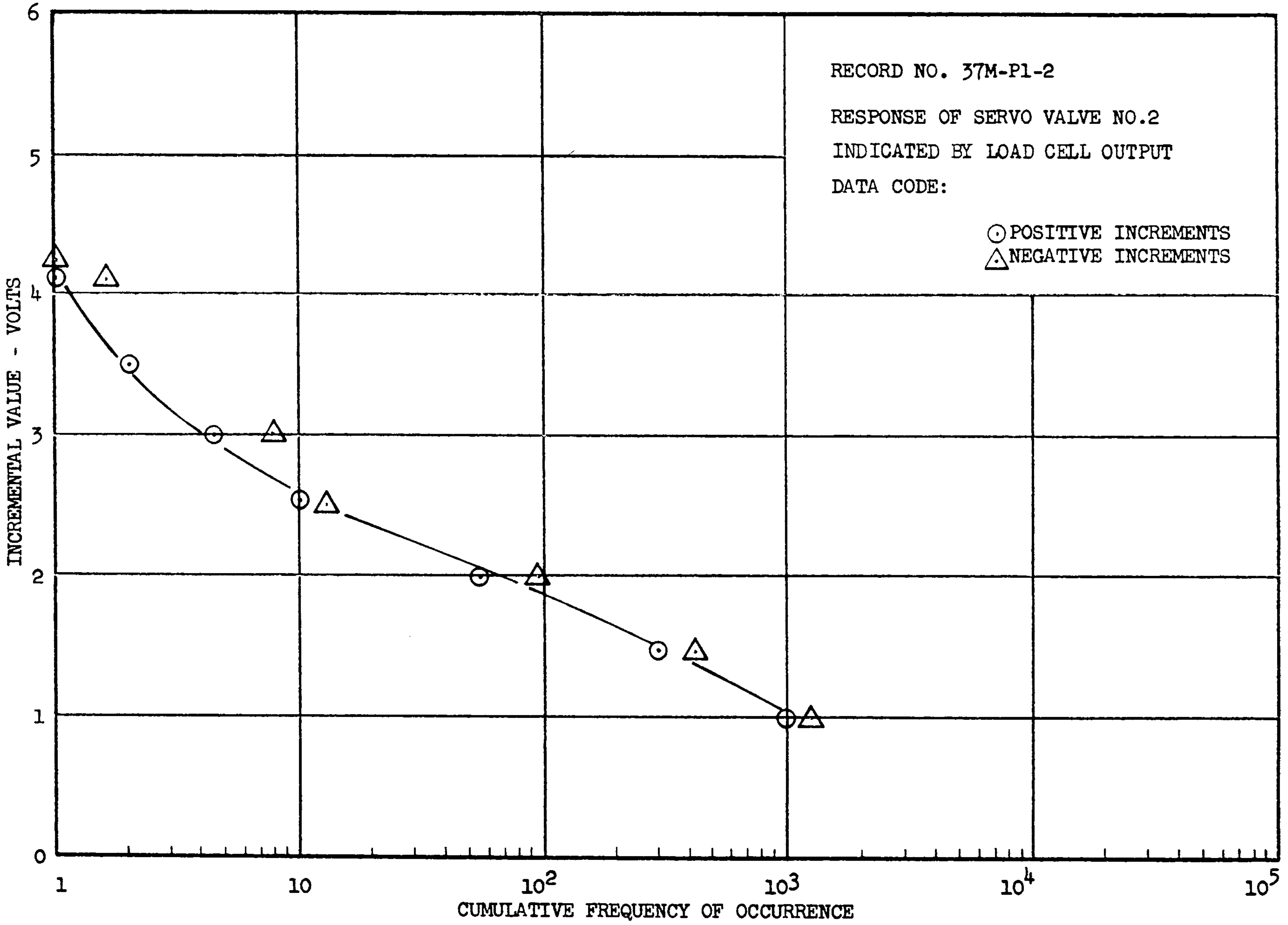


FIGURE 146 MEAN CROSSING PEAK COUNT - WING ROOT ORDERED LOADING TRACE

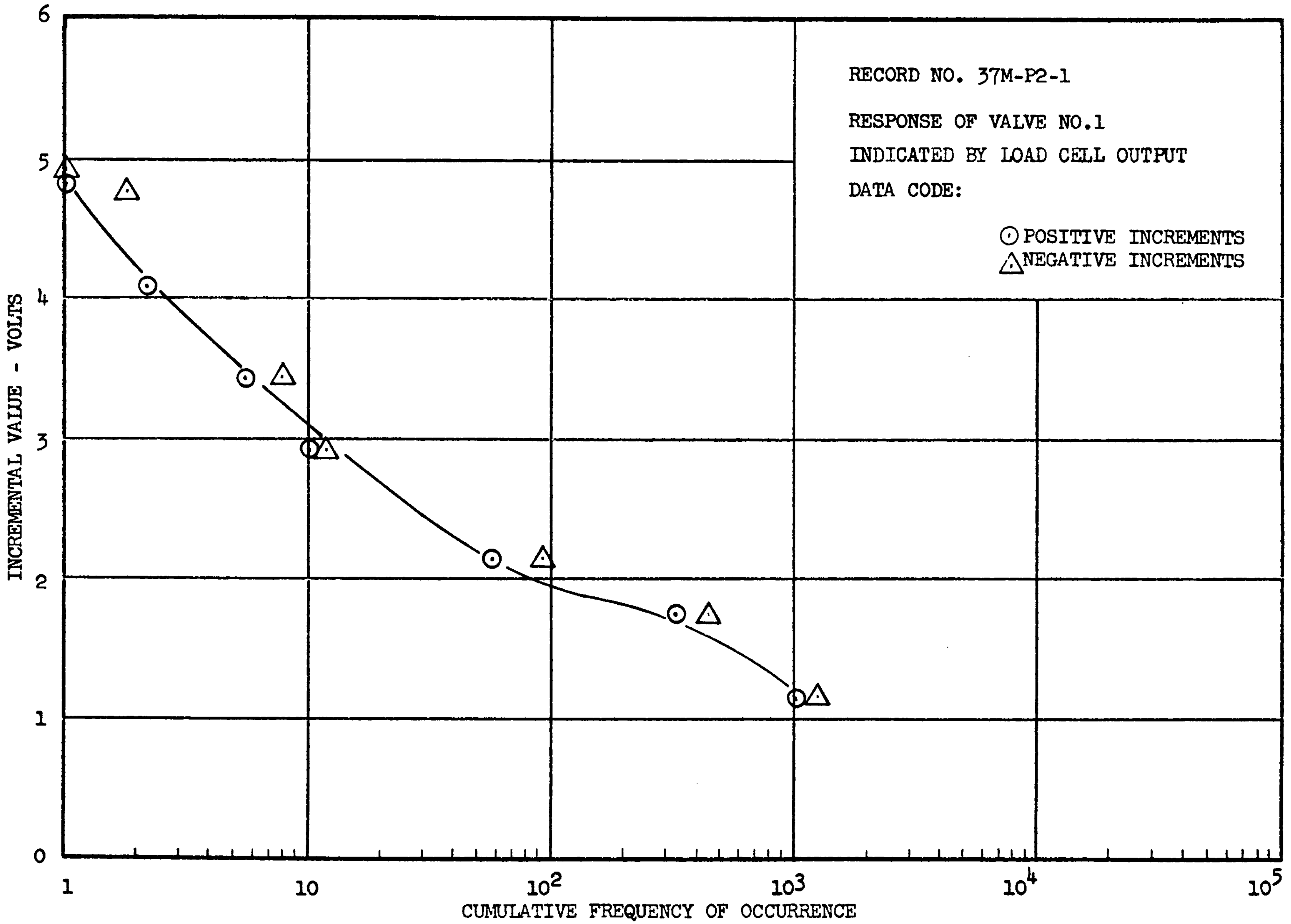


FIGURE 147 MEAN CROSSING PEAK COUNT - WING ROOT ORDERED LOADING TRACE

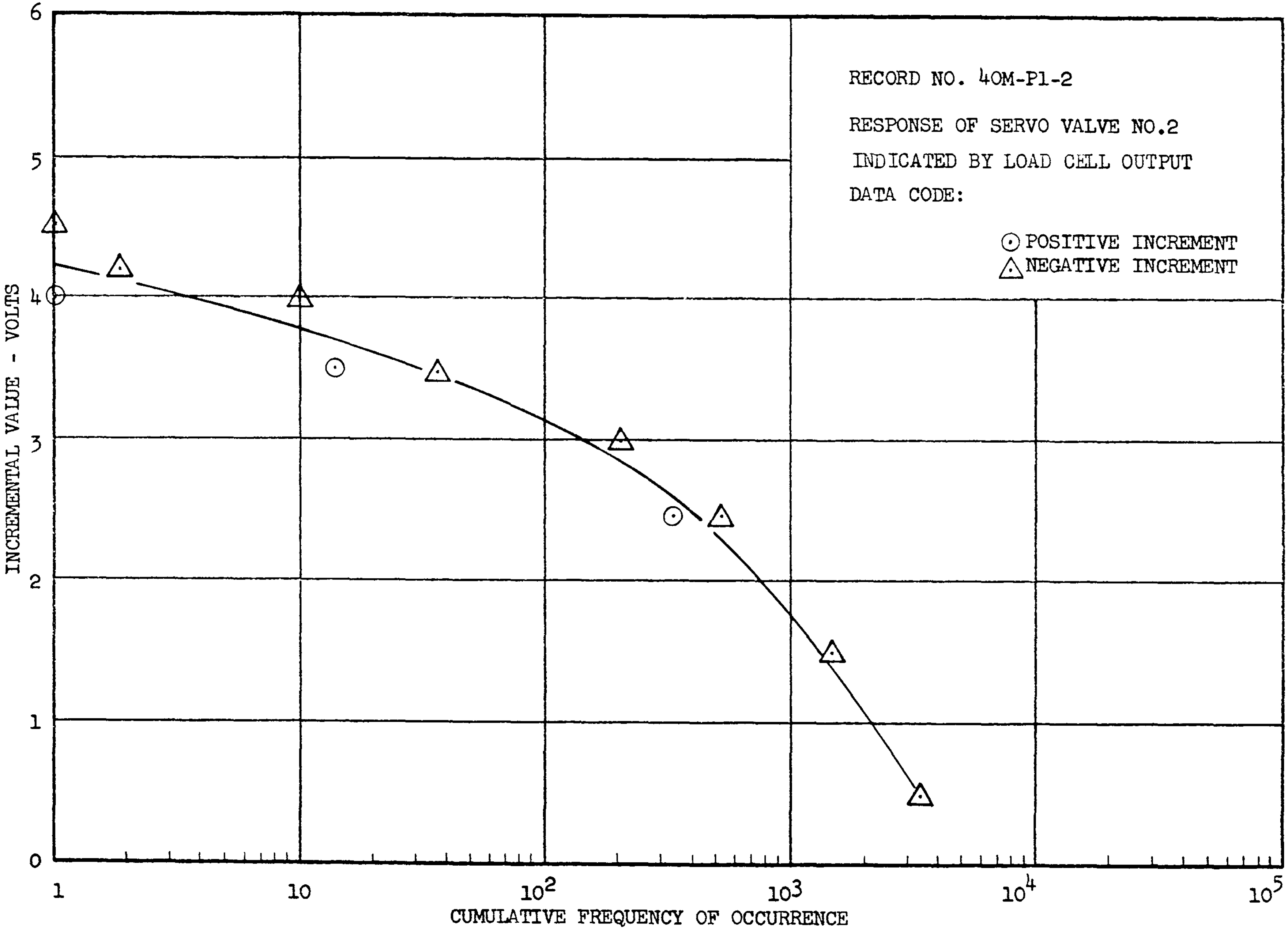


FIGURE 148 MEAN CROSSING PEAK COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

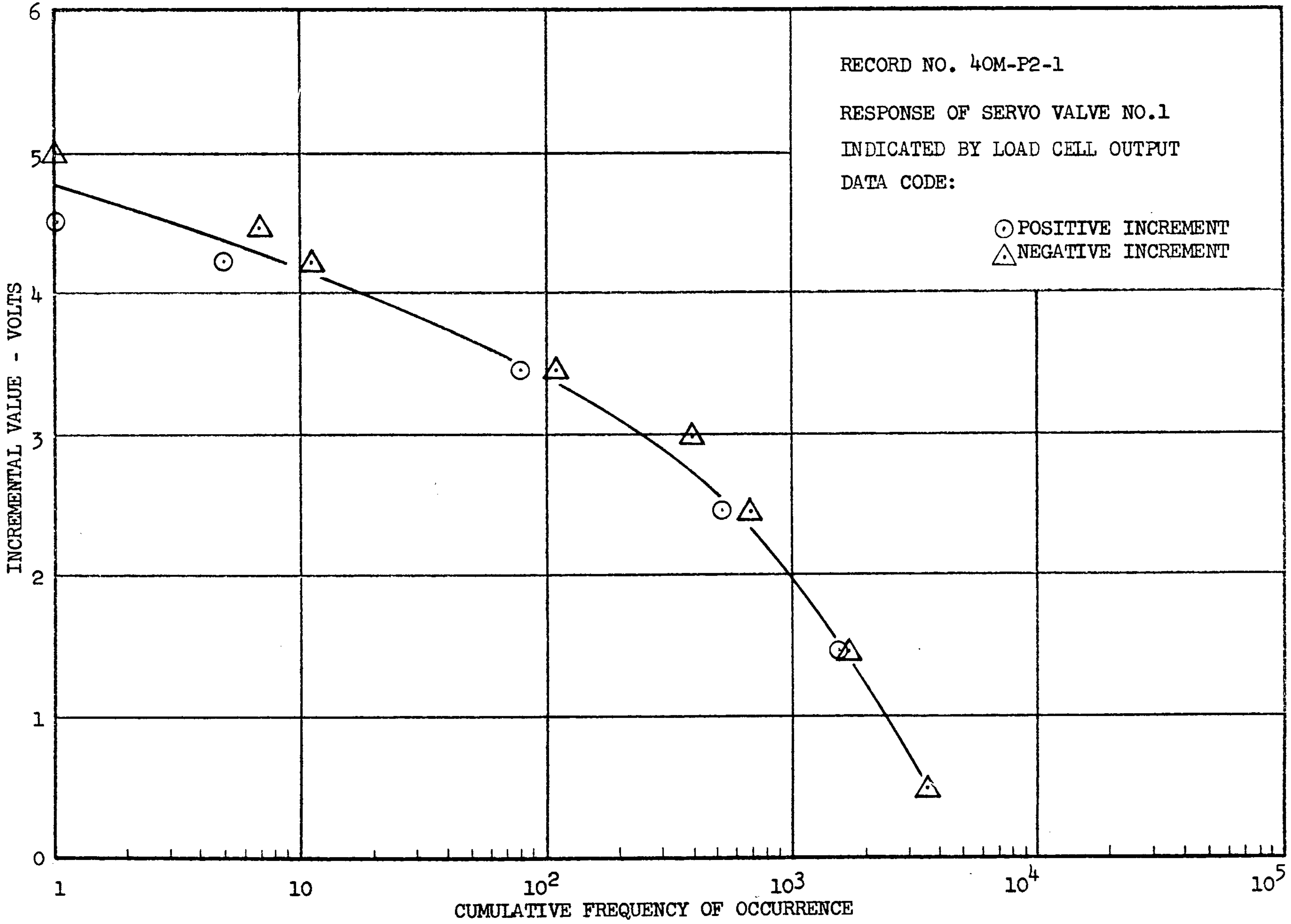


FIGURE 149 MEAN CROSSING PEAK COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

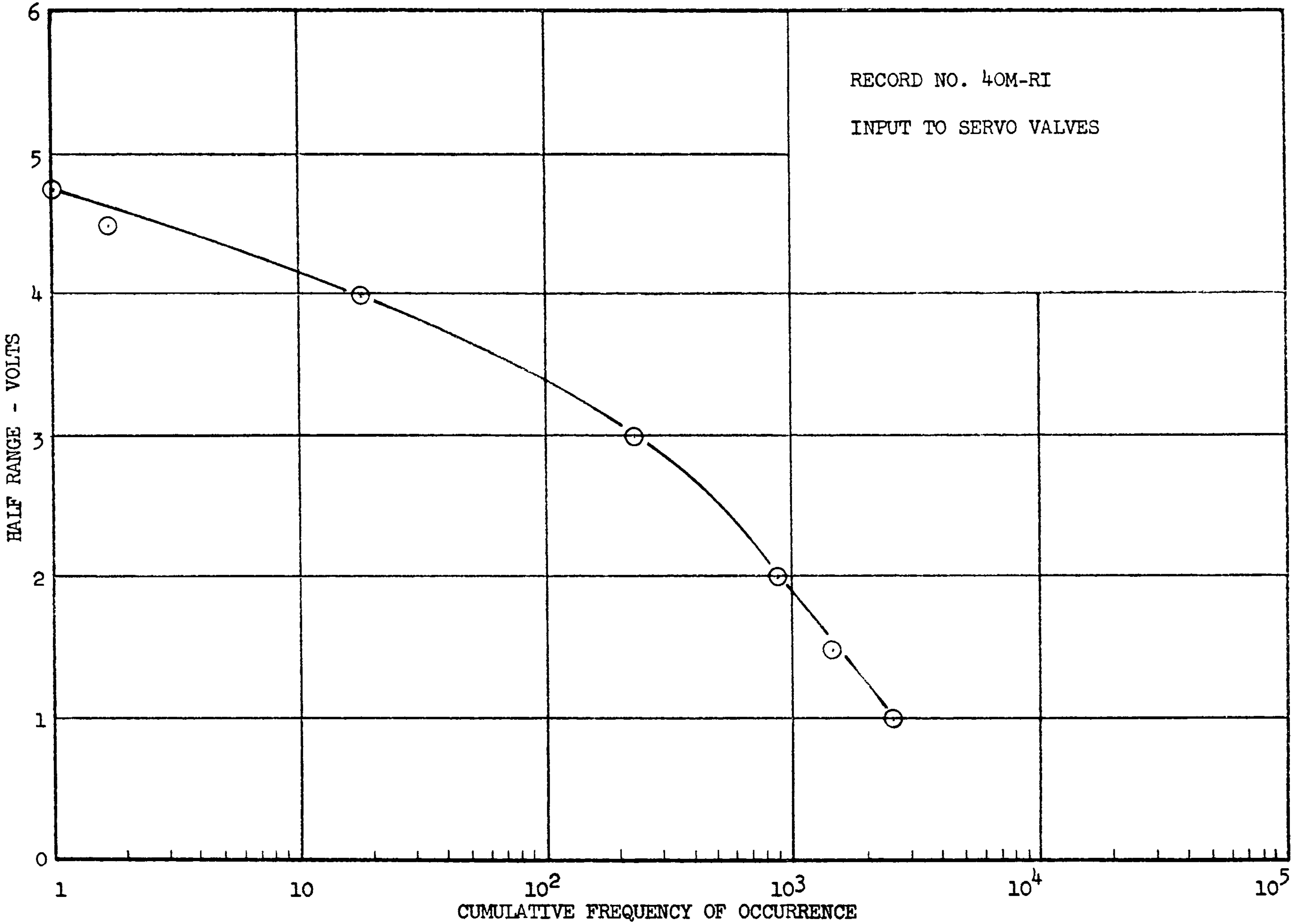


FIGURE 150 SIMPLE RANGE COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

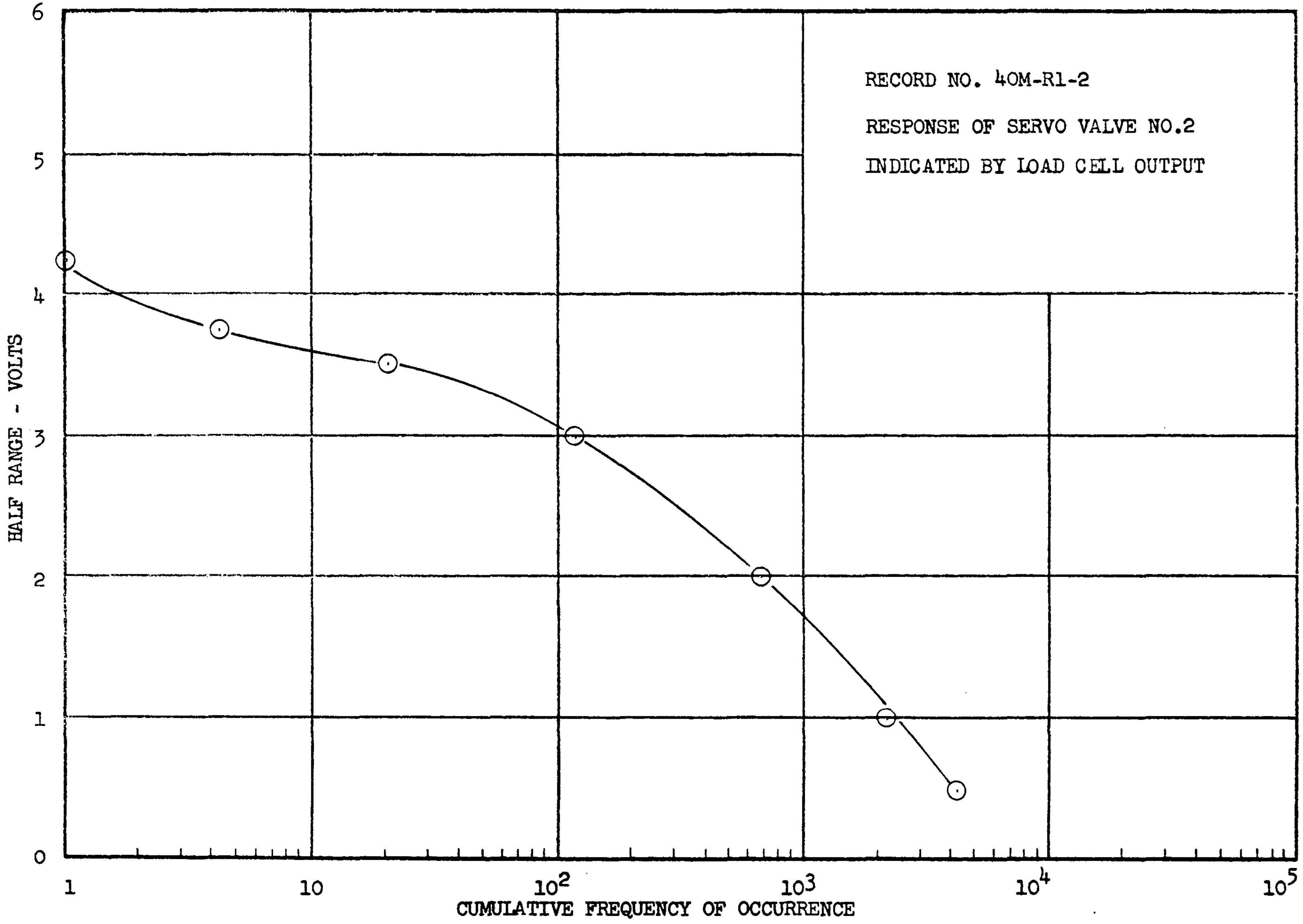


FIGURE 151 SIMPLE RANGE COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

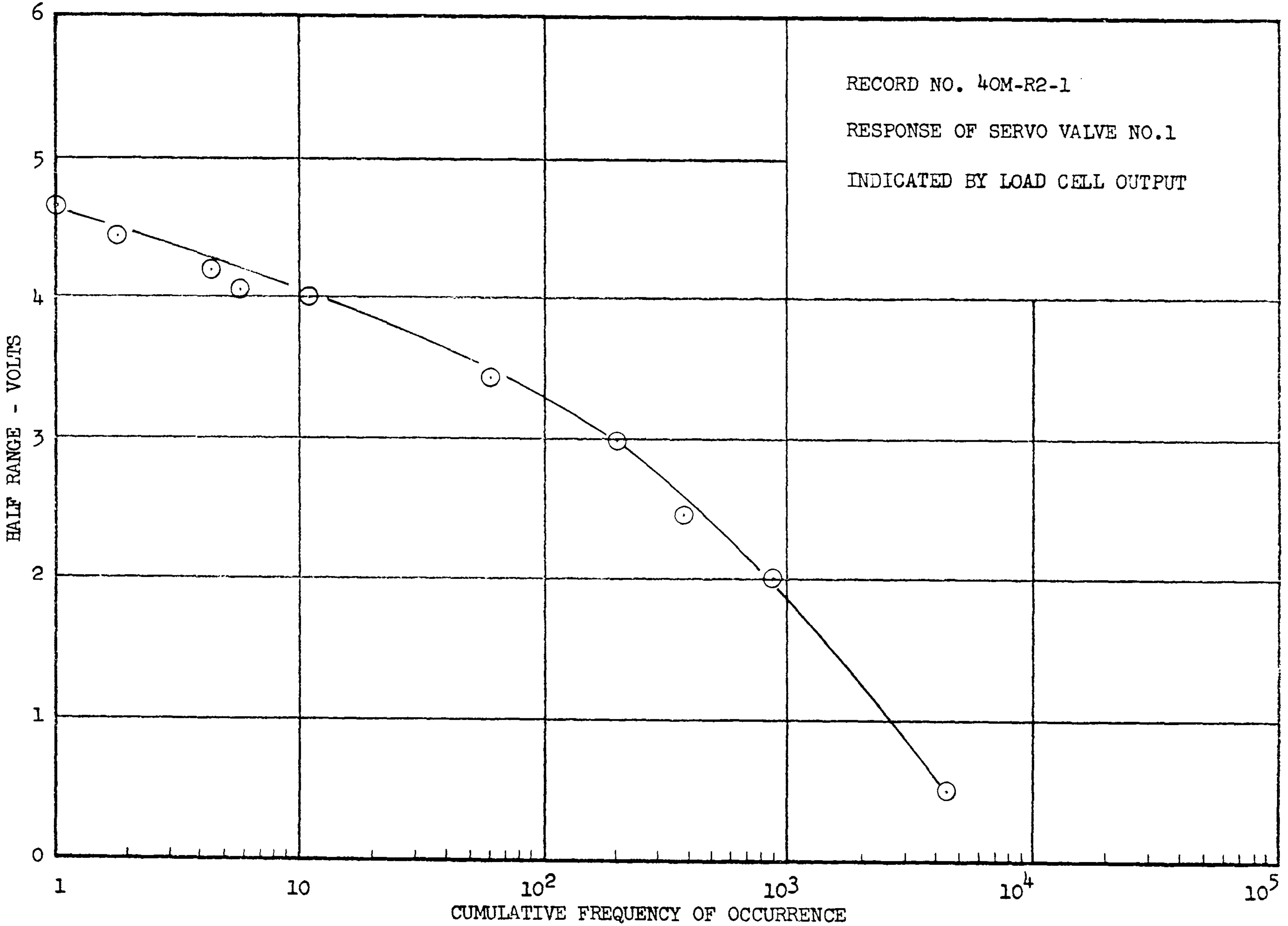


FIGURE 152 SIMPLE RANGE COUNT - MODIFIED WING ROOT RANDOM LOADING TRACE

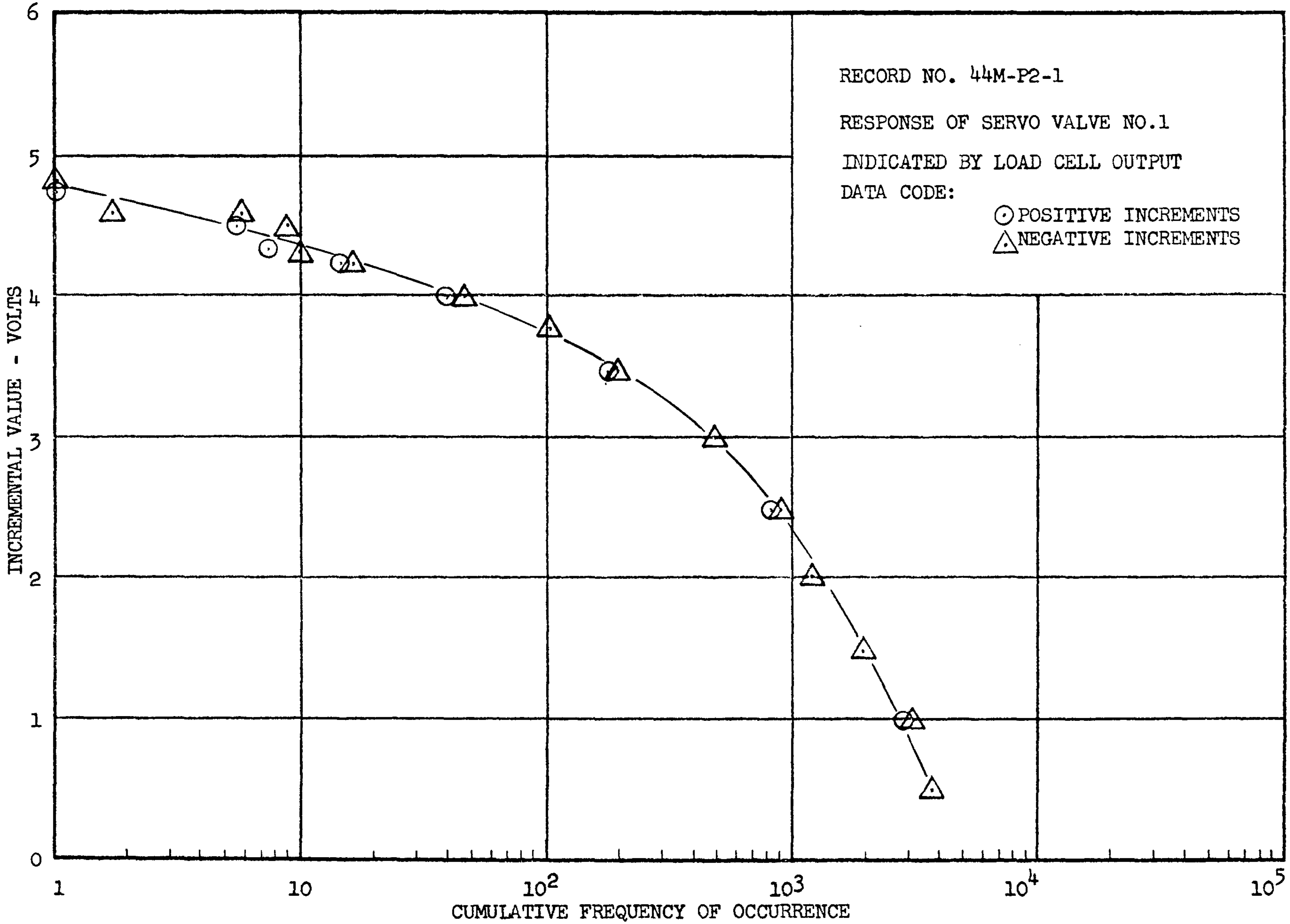


FIGURE 153 MEAN CROSSING PEAK COUNT - MODIFIED WING ROOT ORDERED LOADING TRACE

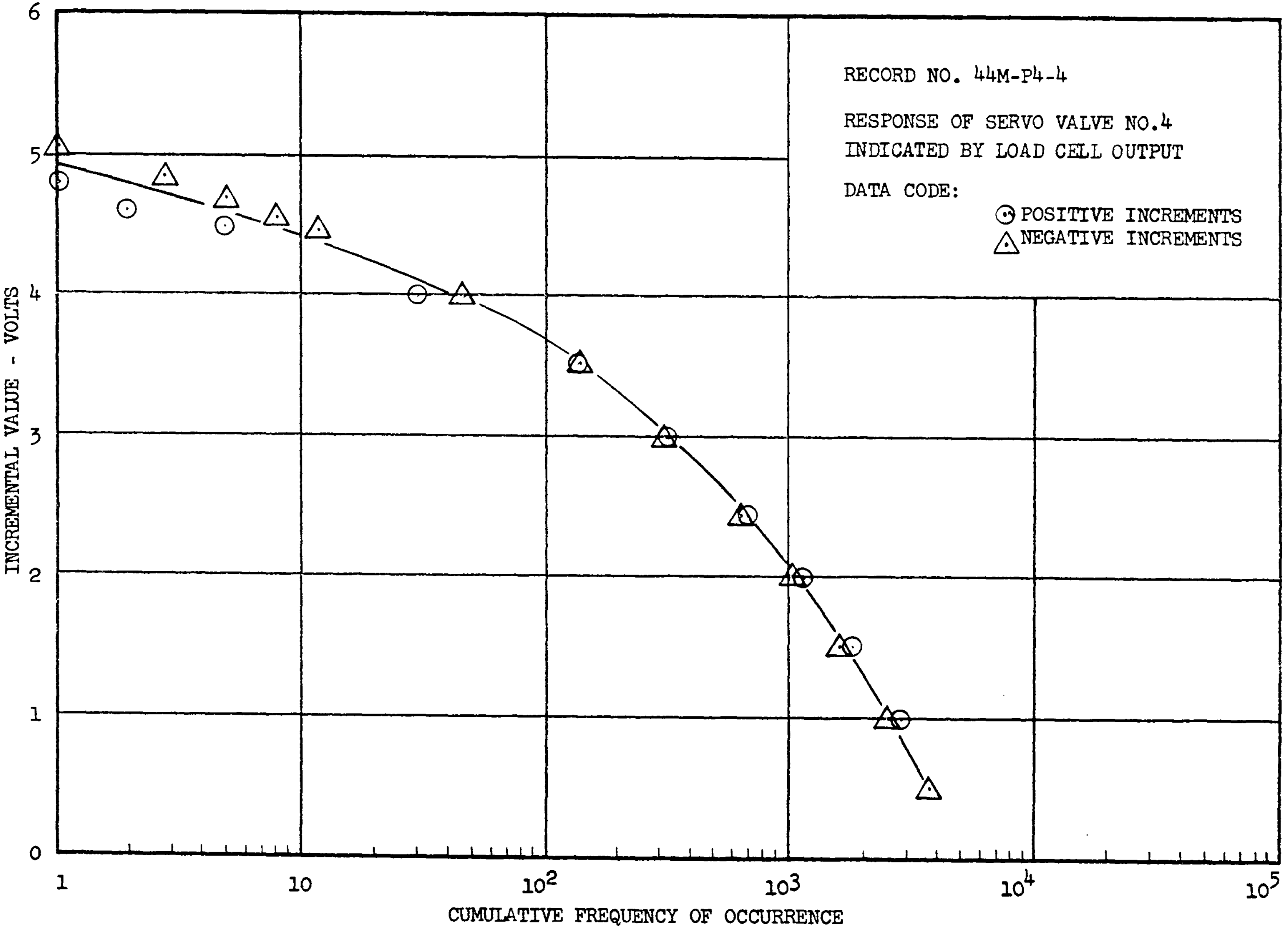


FIGURE 154 MEAN CROSSING PEAK COUNT - MODIFIED WING ROOT ORDERED LOADING TRACE

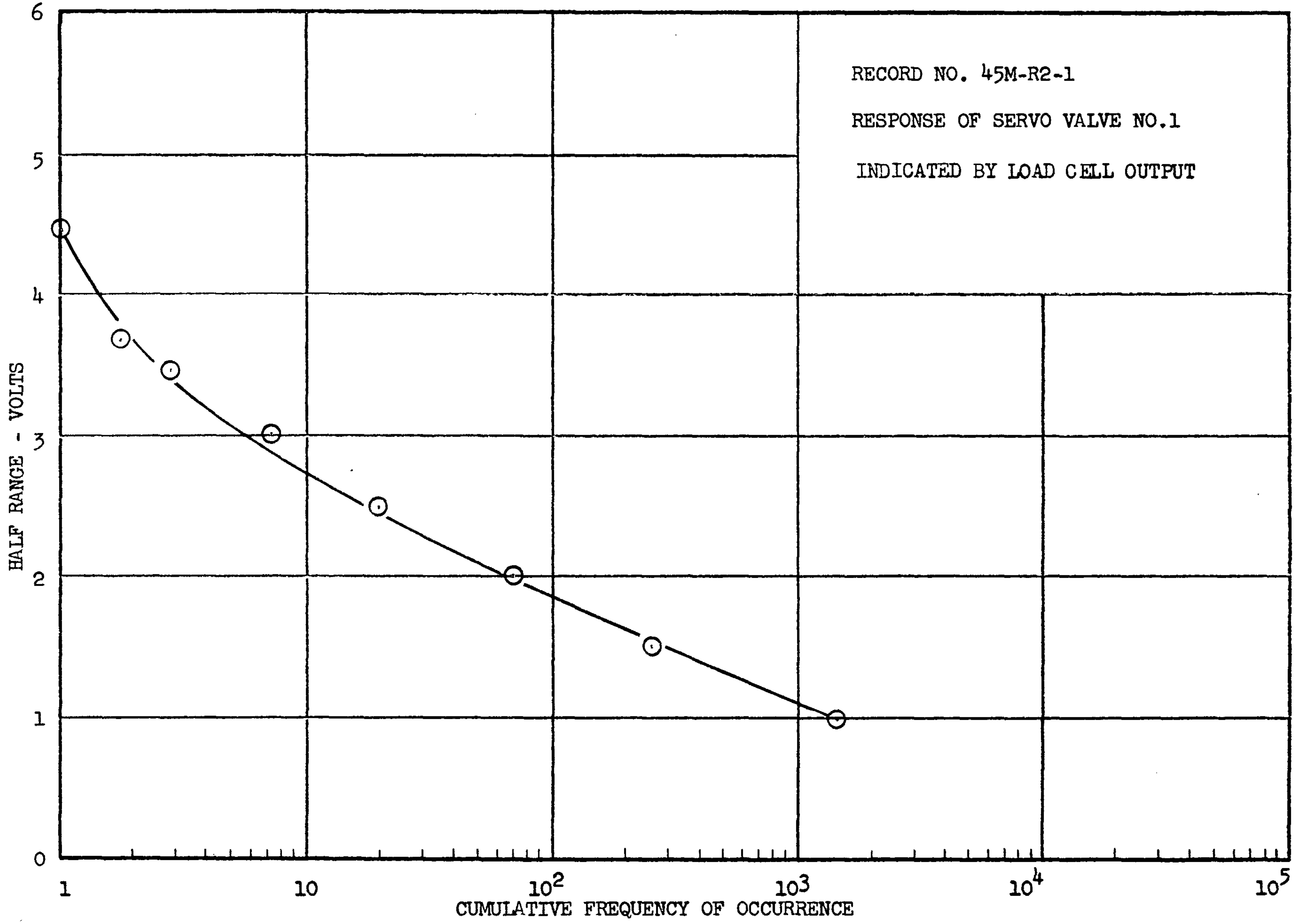


FIGURE 155 SIMPLE RANGE COUNT - WING ROOT ORDERED LOADING TRACE

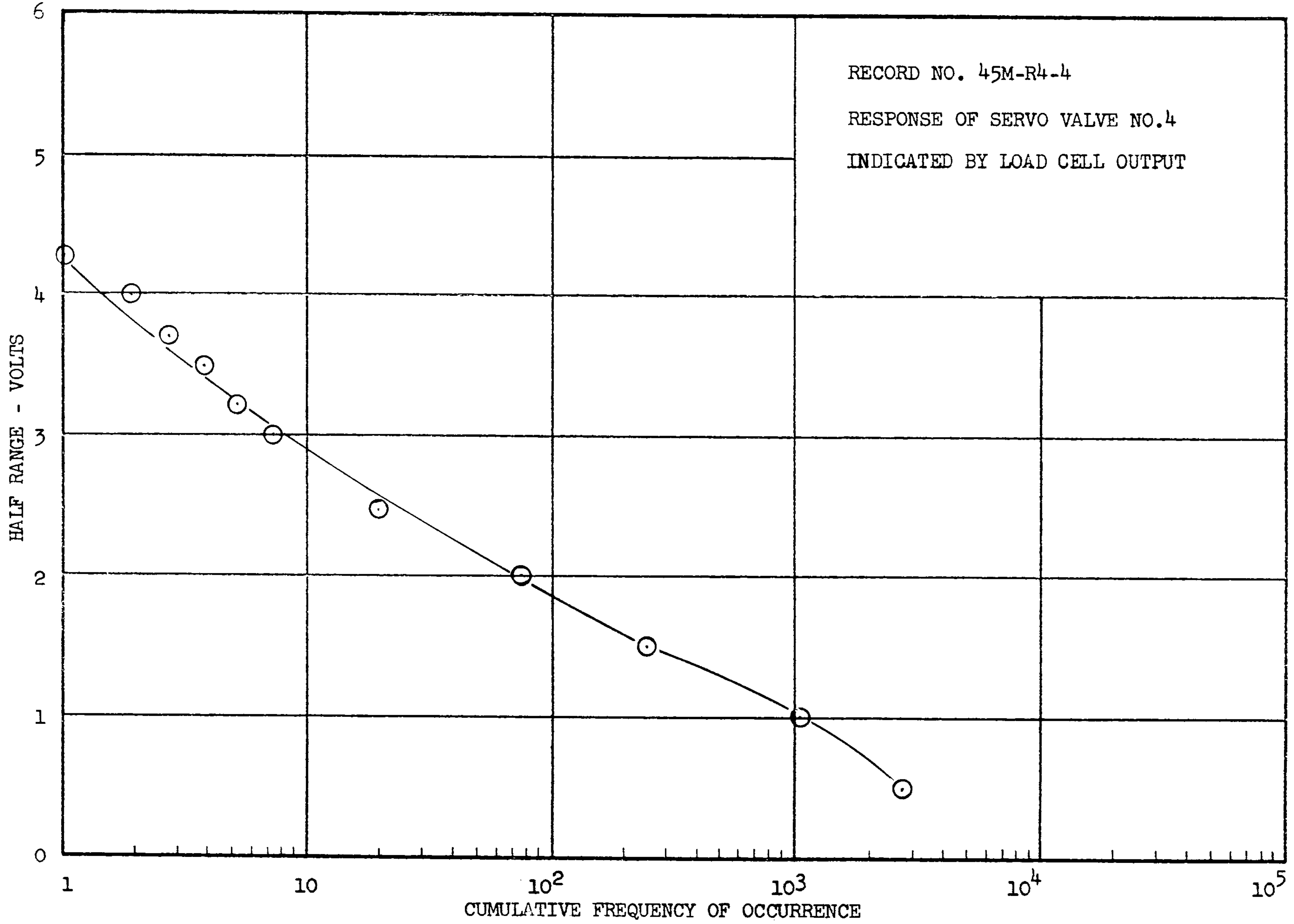


FIGURE 156 SIMPLE RANGE COUNT - WING ROOT ORDERED LOADING TRACE

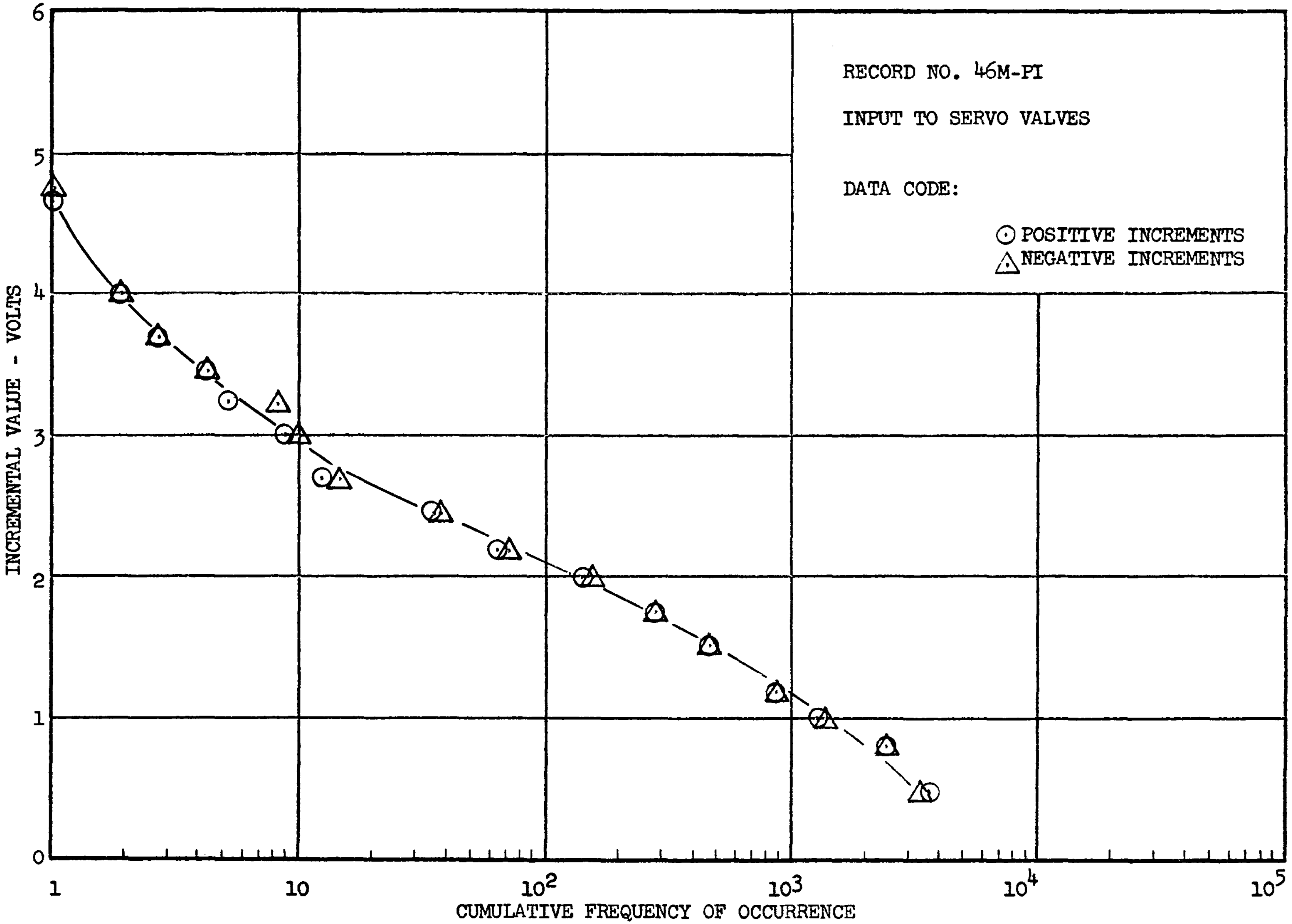


FIGURE 157 MEAN CROSSING PEAK COUNT - WING ROOT ORDERED LOADING TRACE

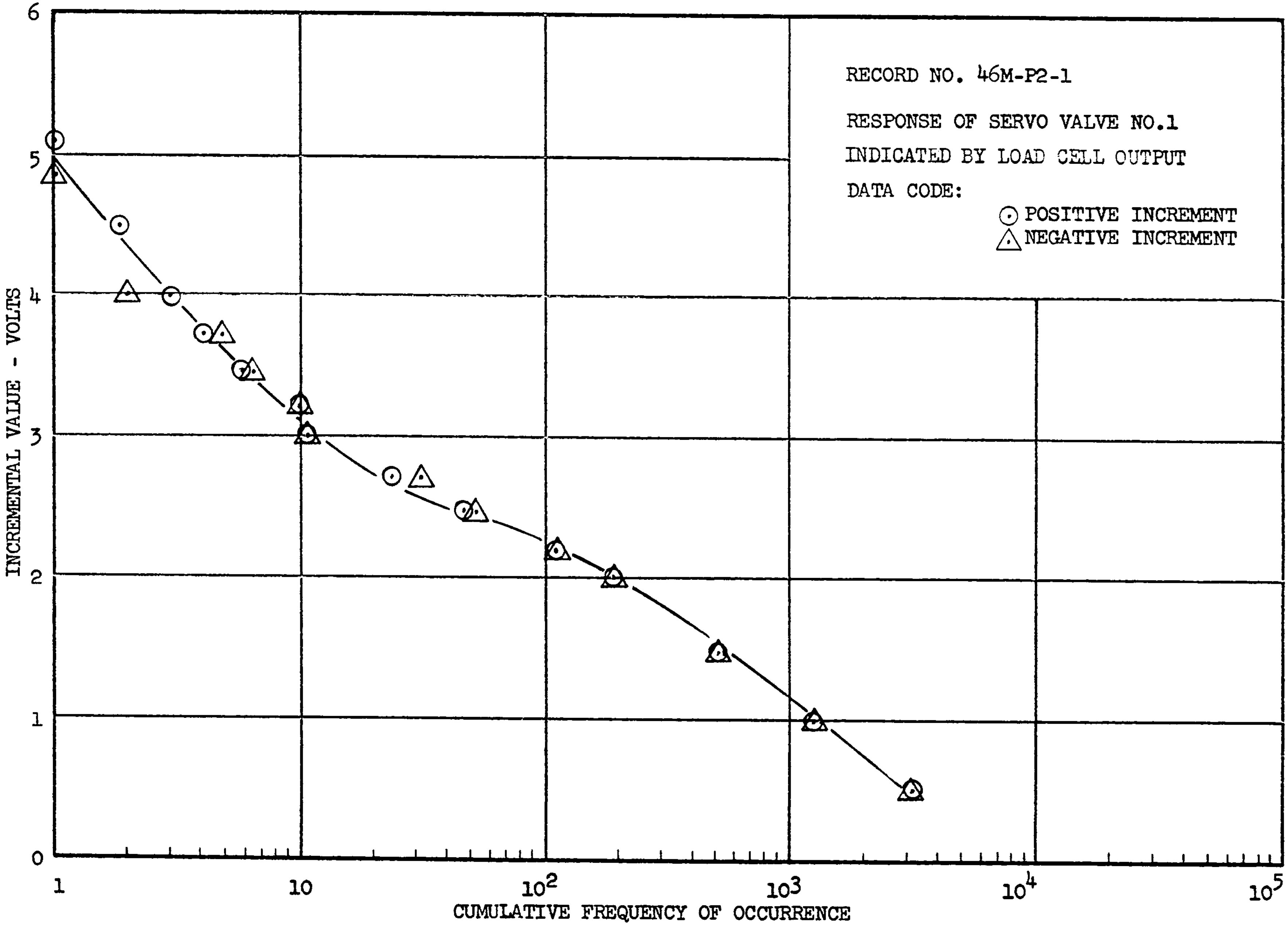


FIGURE 158 MEAN CROSSING PEAK COUNT - WING ROOT ORDERED LOADING TRACE

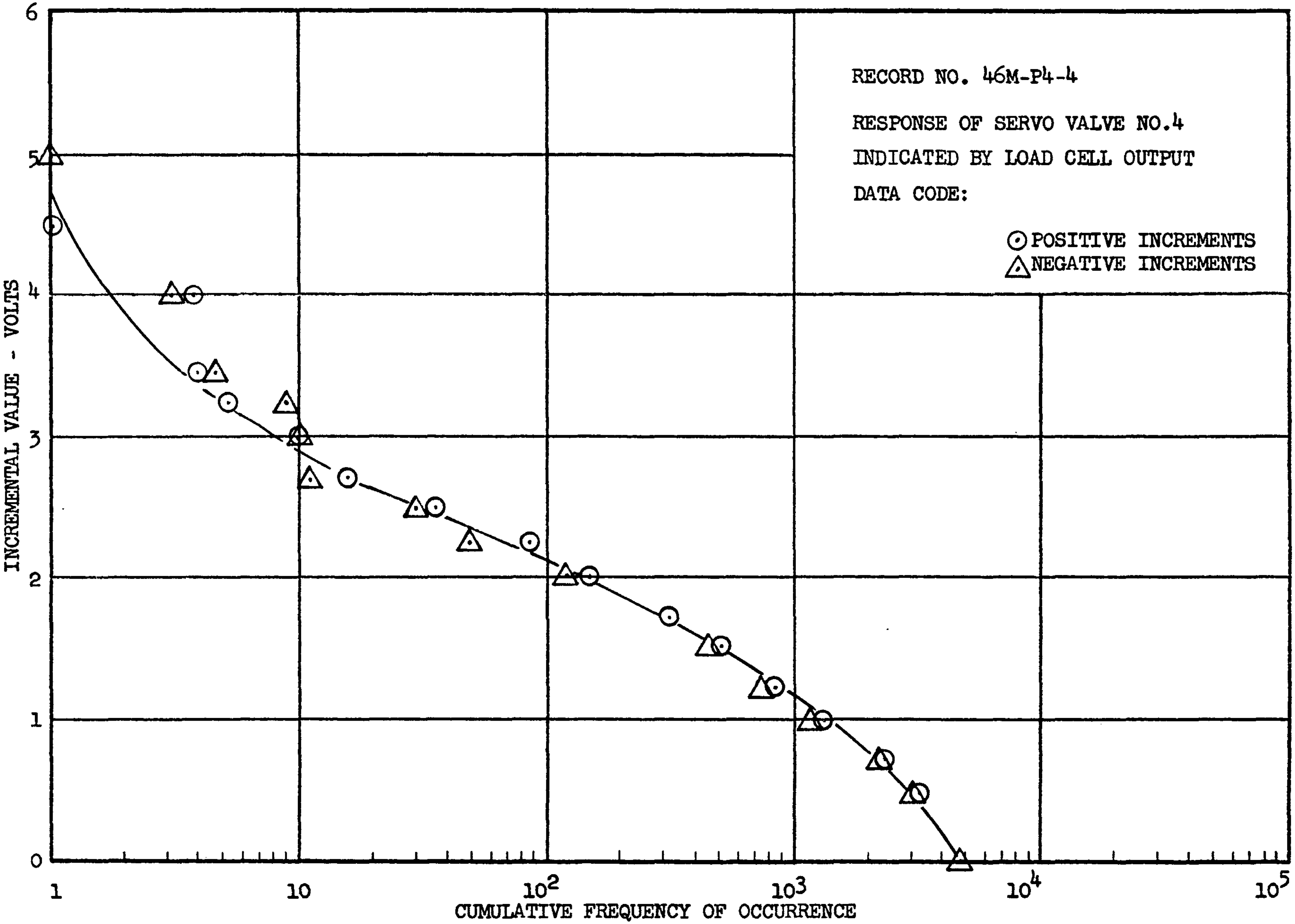


FIGURE 159 MEAN CROSSING PEAK COUNT - WING ROOT ORDERED LOADING TRACE

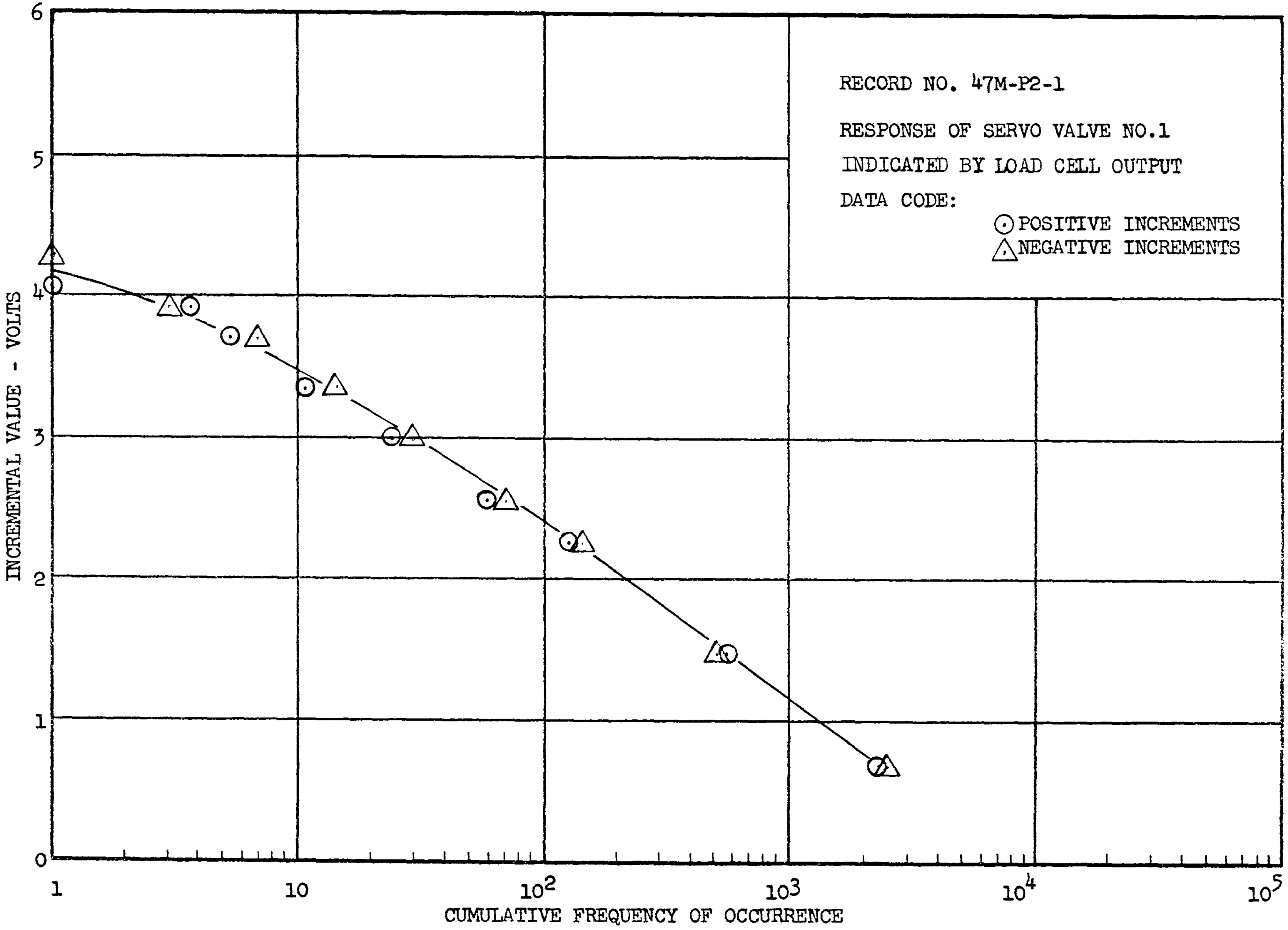


FIGURE 160 MEAN CROSSING PEAK COUNT - FIN ROOT ORDERED LOADING TRACE

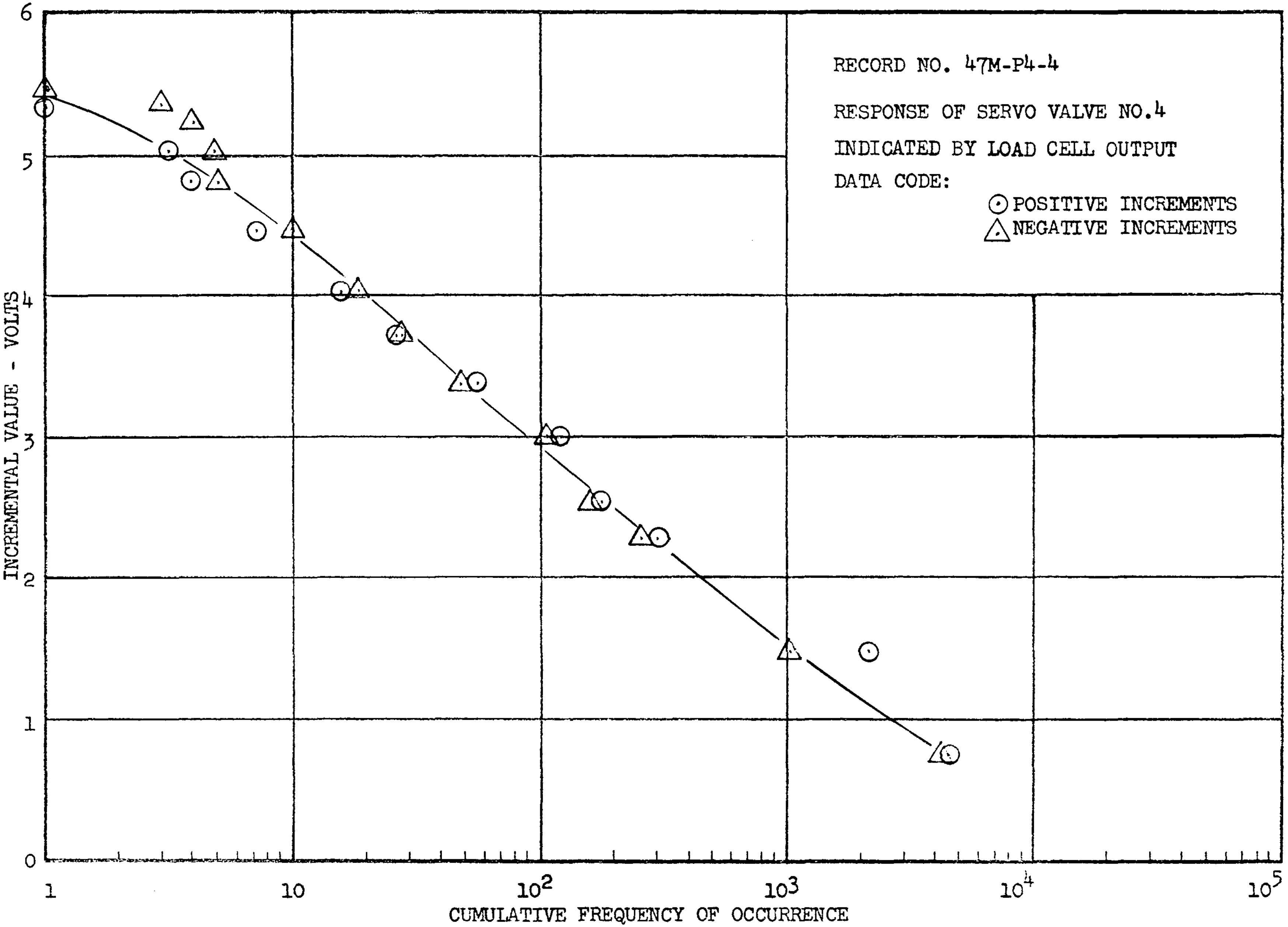


FIGURE 161 MEAN CROSSING PEAK COUNT - FIN ROOT ORDERED LOADING TRACE

APPENDIX V

TEST DATA FOR THE MAIN INVESTIGATION

A log of the specimen testing during the main investigation is presented in Table 13. The specimen geometry and the type of loading spectrum applied are listed. Those specimens whose test histories were not satisfactory are indicated under the heading "Remarks". An explanation of these remarks is presented at the end of the table. Test loading histories for the remainder of the specimens are presented in Tables 14 thru 41.

TABLE 13

TEST LOG

Specimen No.	K_t	Trace	Type*	Stress Interval (psi)	Unit Spectrum Size (psi)	Mean Stress** (psi) Loadings Flight	Ground	Remarks
269	4.0	High Peak Gust	R			12,000		
270	4.0	↑	R			↑		B
271	7.0		R					
272	4.0		R					
273	4.0		R					B
274	7.0		R					
275 - 276	7.0		R					B
277 - 278	4.0		R					B
279	4.0		R					
280 - 284	7.0		R					
285	4.0		R					
286	4.0		R					C
287 - 288	4.0		R					
289	4.0		R					B
290 - 292	4.0	↓	R			↓		
293 - 298	7.0	High Peak Gust	O	1,000	1/20	12,000		
299 - 304	7.0	Low Peak Gust	R			6,000		
305	4.0		R			6,000		
306	4.0	Low Peak Gust	R			6,000		B
307 - 310	4.0	High Peak Gust	O	1,000	1/10	12,000		
311	4.0		O	1,000	1/10	↑		C
312	4.0		O	1,000	1/10	↓		
313	4.0	High Peak Gust	O	1,000	1/20	12,000		

* R = Random, O = Ordered ** Minimum stress for military maneuvers

TABLE 13 (Continued)

Specimen No.	K_t	Trace	Type*	Stress Interval (psi)	Unit Spectrum Size (psi)	Mean Stress** (psi) Loadings Flight	Ground	Remarks
314	4.0	Low Peak Gust	R			6,000		H
315	4.0	↑	R			↑		B
316	4.0		R					C
317	4.0		R					B
318	4.0	↓	R			↓		
319	4.0	Low Peak Gust	R			6,000		B
320	4.0	High Peak Gust	O	1,000	1/20	12,000		
321	4.0	Low Peak Gust	R			6,000		B
322	4.0	High Peak Gust	O	1,000	1/20	12,000		E
323	4.0	High Peak Gust	O	1,000	1/20	12,000		F
324 - 325	4.0	Low Peak Gust	R			6,000		B
326	4.0	High Peak Gust	O	4,000	1/20	12,000		
327	4.0	↑	O	4,000	1/20	↑		B
328	4.0		O	1,000	1/20			
329 - 330	4.0		O	4,000	1/20			C
331 - 332	4.0		O	4,000	1/20			
333	4.0		O	1,000	1/20			C
334	4.0		O	4,000	1/20			
335	4.0		O	1,000	1/20			
336 - 337	4.0		O	4,000	1/20			K
338	4.0		O	1,000	1/20			B
339 - 340	4.0	↓	O	4,000	1/20	↓		K
341	4.0	High Peak Gust	O	1,000	1/20	12,000		
342 - 347	4.0	Military Maneuver	R			5,450		
348	7.0	Low Peak Gust	O	1,000	1/20	6,000		
349	4.0	Military Maneuver	R			5,450		

* R = Random, O = Ordered ** Minimum stress for military maneuvers

TABLE 13 (Continued)

Specimen No.	K_t	Trace	Type*	Stress Interval (psi)	Unit Spectrum Size (psi)	Mean Stress** (psi) Loadings		Remarks
						Flight	Ground	
350 - 351	7.0	Low Peak Gust	O	1.000	1/20	6,000		
352	7.0		O	1,000	1/20			B
353	4.0		O	1,000	1/20			H
354	4.0		O	1,000	1/20			E
355 - 356	7.0	Low Peak Gust	O	1,000	1/20	6,000		
357	4.0	High Peak Gust	O	4,000	1/20	12,000		B
358 - 359	4.0	Low Peak Gust	R			6,000		F
360 - 361	4.0		O	1,000	1/20			F
362	4.0		R					
363	4.0		R					B
364 - 365	4.0		O	1,000	1/20			
366	4.0		O	1,000	1/20			C
367	4.0		R					B
368	4.0		O	1,000	1/20			
369	4.0		O	1,000	1/20			D
370	4.0		O	1,000	1/20			
371	4.0		O	4,000	1/20			D
372	4.0		O	4,000	1/20			
373	4.0		O	4,000	1/20			F
374 - 375	4.0		O	1,000	1/20			C
376	4.0		O	4,000	1/20			
377	4.0		O	1,000	1/20			
378	4.0		O	1,000	1/10			
379	4.0		O	1,000	1/10			F
380	4.0	Low Peak Gust	O	4,000	1/20	6,000		F

* R = Random, O = Ordered ** Minimum stress for military maneuvers

TABLE 13 (Continued)

Specimen No.	K_t	Trace	Type*	Stress Interval (psi)	Unit Spectrum Size (psi)	Mean Stress** (psi) Loadings Flight	Ground	Remarks
381	4.0	Low Peak Gust	O	4,000	1/20	6,000		
382	4.0	↑	O	1,000	1/10	↑		F
383 - 384	4.0		O	4,000	1/20			F
385	4.0		O	4,000	1/20			
386	4.0		O	4,000	1/20			D
387 - 388	4.0		O	1,000	1/10			
389	4.0		O	4,000	1/20			C
390	4.0		O	4,000	1/20			B
391 - 392	4.0		O	1,000	1/10			
393	4.0	↓	R					
394	4.0	Low Peak Gust	O	4,000	1/20	↓		
395 - 396	4.0	Composite - Low Peak	R			6,000	-3,000	C
397	4.0	Ground	R				-3,000	H
398	4.0	Composite - Low Peak	R			6,000	-3,000	D
399 - 401	4.0	Military Maneuver	O	4,000	1/20	5,450		
402 - 403	4.0	Military Maneuver	O	4,000	1/20	5,450		C
404	4.0	Military Maneuver	O	4,000	1/20	5,450		
405	4.0	Composite - Low Peak	R			6,000	-3,000	H
406	4.0	Military Maneuver	O	4,000	1/20	5,450		
407	4.0	↑	O	1,000	1/20	↑		B
408 - 409	4.0	↓	O	1,000	1/20	↓		D
410 - 411	4.0	Military Maneuver	O	1,000	1/20	5,450		
412	4.0	Composite - Low Peak	R			6,000	-3,000	C

* R = Random, O = Ordered ** Minimum stress for military maneuvers

TABLE 13 (Continued)

Specimen No.	K_t	Trace	Type*	Stress Interval (psi)	Unit Spectrum Size (psi)	Mean Stress** (psi) Loadings Flight	Mean Stress** (psi) Loadings Ground	Remarks
413 - 415	4.0	Military Maneuver	O	1,000	1/20	5,450		
416 - 419	7.0	Ground	R				-3,000	
420 - 421	7.0	Ground	R				↕	D
422 - 423	7.0	Ground	R				↕	
424 - 425	4.0	Composite - High Peak	R			12,000	↕	
426	4.0	↕	R			↕	↕	C
427 - 430	4.0	↕	R			↕	↕	
431	7.0	↕	R			↕	↕	D
432 - 436	7.0	↕	R			↕	↕	
437	4.0	Composite - High Peak	O	1,000	1/20	12,000	↕	D
438	7.0	Composite - Low Peak	R			4,500	↕	D
439	4.0	Composite - High Peak	O	1,000	1/20	12,000	↕	D
440 - 443	7.0	Composite - Low Peak	R			6,000	↕	
444	7.0	↕	R			↕	↕	B
445	7.0	↕	R			↕	↕	
446 - 447	4.0	↕	R			↕	↕	
448	4.0	↕	R			↕	↕	C
449 - 451	4.0	↕	R			↕	↕	B
452	4.0	↕	R			↕	↕	
453 - 454	4.0	↕	R			↕	↕	C
455 - 458	4.0	↕	R			↕	↕	
459 - 460	7.0	Composite - Low Peak	R			6,000	-3,000	B

* R = Random, O = Ordered ** Minimum stress for military maneuvers

TABLE 13 (Continued)

Specimen No.	K_t	Trace	Type*	Stress Interval (psi)	Unit Spectrum Size (psi)	Mean Stress** (psi) Loadings		Remarks
						Flight	Ground	
461 - 462	7.0	Ground	O	1,000	1/20		-3,000	
463 - 464	7.0	Composite - High Peak	R			12,000	↑	B
465 - 466	7.0	Ground	O	1,000	1/20			
467	4.0	Composite - High Peak	O	↑	1/20	12,000		
468	7.0	Ground	O		1/20			B
469	7.0	Ground	O		1/20			
470	4.0	Composite - High Peak	O		1/20	12,000		
471	7.0	Ground	O		1/20			
472 - 474	4.0	Composite - High Peak	O		1/20	12,000		
475	4.0	Composite - Low Peak	O		1/20	6,000		
476 - 477	4.0	↑	O		1/20	↑		B
478 - 479	7.0		O		1/20			
480 - 481	4.0		O		1/20			
482	7.0		O		1/20			
483	4.0		O		1/20			B
484	7.0		O		1/20			
485	4.0		O		1/20			
486	7.0	↓	O	↓	1/20	↓		
487	4.0	Composite - Low Peak	O	1,000	1/20	6,000		
488 - 490	4.0	Composite - Maneuver	R			5,450		
491 - 494	4.0	Composite - Maneuver	R			5,450	↓	D
495 - 496	4.0	Composite - Low Peak	O	1,000	1/20	6,000	-3,000	B

* R = Random, O = Ordered ** Minimum stress for military maneuvers

TABLE 13 (Continued)

Specimen No.	K_t	Trace	Type*	Stress Interval (psi)	Unit Spectrum Size (psi)	Mean Stress** (psi) Loadings Flight	Ground	Remarks
497 - 498	4.0	Composite - Maneuver	R			5,450	-3,000	D
499 - 500	4.0	Composite - Maneuver	R			5,450	↕	
501 - 508	4.0	Composite - High Peak	R			12,000	↕	
509 - 512	4.0	↕	O	1,000	1/20	↕	↕	
513 - 514	4.0	↕	O	↕	1/20	↕	↕	
515 - 516	4.0	↕	O	↕	1/20	↕	↕	E
517 - 518	4.0	Composite - High Peak	O	1,000	1/20	12,000	-3,000	

Remarks:
A) No monitor tape available
B) Machine malfunction
C) Overload
D) Operator error/incorrect set-up
E) Test history incomplete
F) Power failure
G) Clamp failure
H) No failure
J) Monitor tape incorrect
K) Tape reversed

* R = Random, O = Ordered ** Minimum stress for military maneuvers

TABLE 14

HIGH PEAK RANDOM GUST LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)

f(mean) = 12,000 psi

K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences						
	Specimen No.279	Specimen No.285	Specimen No.287	Specimen No.288	Specimen No.290	Specimen No.291	Specimen No.292
0	652,500	395,850	456,750	334,950	239,250	326,250	247,950
1,000	467,800	283,800	327,500	240,300	171,700	234,100	177,900
2,000	323,760	196,350	226,600	166,250	118,700	161,950	123,000
3,000	202,550	122,850	141,750	104,050	74,250	101,350	76,950
4,000	117,200	71,020	82,020	60,220	42,960	58,670	44,510
5,000	61,880	37,520	43,300	31,800	22,720	30,970	23,550
6,000	28,660	17,345	20,075	14,710	10,585	14,335	10,960
7,000	12,030	7,285	8,445	6,180	4,455	6,025	4,610
8,000	5,100	3,082	3,582	2,615	1,893	2,550	1,958
9,000	2,250	1,364	1,583	1,157.5	833.5	1,129	862
10,000	1,145	697	805	590.0	424.0	575	439
11,000	567.3	346.2	400	292.6	210.2	285.6	217.2
12,000	311.4	190.2	219.6	160.2	115.7	156.6	119.3
13,000	179.7	109.5	126.4	91.9	67.1	90.0	69.0
14,000	108.4	65.7	76.0	54.8	40.6	53.8	41.6

(Continued on next page)

TABLE 14 (Continued)

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences						
	Specimen No.279	Specimen No.285	Specimen No.287	Specimen No.288	Specimen No.290	Specimen No.291	Specimen No.292
15,000	39.7	22.9	27.3	18.7	15.1	18.7	15.1
16,000	28.8	16.6	19.8	13.6	11.0	13.6	11.0
16,190	27.3	15.7	18.7	12.8	10.4	12.8	10.4
16,830	9.2	6.2	6.2	4.6	3.6	4.6	3.6
17,000	4.9	3.0	3.0	1.5	1.5	1.5	1.5
18,000	3.7	2.2	2.2	1.1	1.1	1.1	1.1
18,290	3.4	2.0	2.0	1.0	1.0	1.0	1.0
19,000	1.2						
19,520	1.0						

(End of Table 14)

TABLE 15

HIGH PEAK RANDOM GUST LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)

f(mean) = 12,000 psi
K_t = 7.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences					
	Specimen No.274	Specimen No.280	Specimen No.281	Specimen No.282	Specimen No.283	Specimen No.284
0	56,550	95,700	56,550	39,150	52,200	52,200
1,670	32,400	54,500	32,400	22,600	29,800	29,800
3,330	15,000	25,100	15,000	10,600	13,700	13,700
5,000	5,360	9,000	5,360	3,880	4,860	4,860
6,670	1,504	2,479	1,504	1,092	1,354	1,354
8,330	369	606	369	267.5	329	329
10,000	99.1	159.1	99.1	70.8	86.6	86.6
10,830	56.8	88.9	56.8	40.5	49.6	49.6
11,660	35.6	55.5	35.6	25.8	31.2	31.2
12,500	21.1	33.5	21.1	15.8	18.4	18.4
13,330	13.5	21.5	13.5	10.3	11.9	11.9
14,000	9.2	14.7	9.2	7.2	8.2	8.2
14,960	3.1	5.0	3.1	3.1	3.1	3.1
16,190	2.0	3.3	2.0	2.0	2.0	2.0
16,620		1.0				

TABLE 16

LOW PEAK RANDOM GUST LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)
f(mean) = 6,000 psi
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences			
	Specimen No.305	Specimen No.318	Specimen No.362	Specimen No.393
0	1,452,900	1,935,750	1,470,300	1,792,200
1,190	827,300	1,102,600	837,050	1,020,600
2,380	380,300	507,050	384,750	469,100
3,560	135,380	180,500	136,990	166,960
4,750	37,113	49,490	37,539	45,774
5,950	8,952	11,939	9,057	11,043
7,120	2,382.7	3,181.5	2,411.3	2,938.6
7,720	1,326.0	1,811.2	1,371.7	1,672.6
8,310	859.5	1,148.4	869.1	1,060.0
8,900	527.7	705.3	534.3	650.8
9,500	344.1	460.3	348.7	424.3
10,000	239.9	321.5	243.3	295.6
10,700	91.1	122.4	93.1	112.3
11,600	60.2	80.7	61.7	74.0
11,900	22.6	30.5	23.7	27.6
12,050	21.0	28.6	22.0	25.6
12,500	10.2	13.2	10.2	11.5
13,100	7.7	10.0	7.7	8.7
14,000	2.0	3.0	2.0	2.0

TABLE 17

LOW PEAK RANDOM GUST LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)
f(mean) = 6,000 psi
K_t = 7.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences					
	Specimen No.299	Specimen No.300	Specimen No.301	Specimen No.302	Specimen No.303	Specimen No.304
0	252,300	169,650	239,250	200,100	326,250	213,150
1,190	143,700	97,050	136,500	114,100	185,900	121,600
2,380	65,900	44,800	62,700	52,450	85,500	56,000
3,560	23,480	15,980	22,360	18,630	30,460	19.940
4,750	6,437	4,440	6,157	5,142	8,349	5,507
5,950	1,552	1,079.5	1,488	1,246	2,018.5	1,338
7,120	411.8	286.0	397.3	328.3	538.6	354.3
7,720	234.4	163.6	227.2	187.6	306.2	202.0
8,310	148.5	103.5	144.1	118.9	193.7	127.7
8,900	90.9	62.7	88.3	72.3	119.2	77.6
9,500	60.0	40.8	58.4	47.5	77.4	50.6
10,000	41.8	28.4	40.8	33.3	53.7	35.3
10,700	16.1	11.3	16:1	13.6	19.7	13.6
11,600	10.6	7.3	10.6	9.0	12.9	9.0
11,900	3.9	1.1	3.9	2.6	5.0	2.6
12,050	3.6	1.0	3.6	2.5	4.6	2.5
12,500	1.4		1.4	1.3	1.4	1.3
13,100	1.0		1.0	1.0	1.0	1.0

TABLE 18

RANDOM GROUND LOADING HISTORY
(MEAN CROSSING PEAK COUNT)

f(mean) = -3,000 psi
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences - Specimen No. 397
0	2,740,500
950	1,582,600
1,920	728,450
2,850	257,670
3,800	69,949
4,750	16,878
5,700	4,491.1
6,180	2,499.2
6,650	1,601.1
7,130	1,002.35
7,600	657.00
8,000	453.55
8,550	169.00
9,250	113.85
9,500	44.60
9,620	41.40
9,980	18.95
10,450	14.60
11,150	4.00
	(No Failure)

TABLE 19

RANDOM GROUND LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)

$f(\text{mean}) = -3{,}000$ psi
$K_t = 7.0$

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences					
	Specimen No.416	Specimen No.417	Specimen No.418	Specimen No.419	Specimen No.422	Specimen No.423
0	783,000	500,250	552,450	578,550	495,900	448,050
950	452,400	289,000	319,300	334,200	286,250	258,700
1,920	208,250	133,000	146,850	153,800	131,550	119,050
2,850	73,600	47,040	51,950	54,400	46,450	42,150
3,800	20,050	12,846	14,168	14,818	12,656	11,460
4,750	4,843	3,107.5	3,424	3,583	3,057.5	2,770
5,700	1,287	827.9	911.2	953.7	813.9	738.5
6,180	715.9	461.0	507.3	530.4	453.4	410.9
6,650	458.9	295.6	325.1	339.4	290.1	262.9
7,130	286.2	184.3	202.6	211.6	180.3	164.3
7,600	187.4	120.4	133.2	138.0	117.6	107.2
8,000	129.4	83.0	91.8	94.8	80.9	73.7
8,550	48.8	31.1	34.6	34.6	29.8	26.6
9,250	32.8	20.8	23.1	23.1	19.8	17.8
9,500	11.0	6.7	7.8	7.8	6.7	6.7
9,620	10.2	6.2	7.2	7.2	6.2	6.2
9,980	4.4	2.7	2.7	2.7	2.7	2.7
10,450	3.4	2.0	2.0	2.0	2.0	2.0
11,150	1.0					

TABLE 20

RANDOM MILITARY MANEUVER LOADING HISTORIES
(PEAK COUNTS)

Minimum Stress = 5,450 psi
K_t = 4.0

Incremental Stress (psi)	Cumulative Frequency of Load Cycle Occurrences					
	Specimen No.342	Specimen No.343	Specimen No.344	Specimen No.345	Specimen No.346	Specimen No. 347 & No. 349
0	26,400	22,000	17,600	30,800	44,000	26,400
2,840	20,700	17,250	13,800	24,150	34,500	20,700
5,680	16,100	13,450	10,760	18,830	26,900	16,100
11,400	9,360	7,800	6,240	10,920	15,600	9,360
17,000	4,560	3,800	3,040	5,320	7,600	4,560
22,700	1,830	1,525	1,220	2,135	3,050	1,830
28,400	540	450	360	630	900	540
31,200	288	240	192	336	480	288
34,000	132	110	88	154	220	132
39,800	24	20	16	28	40	24
41,200	12	10	8	14	20	12
42,050	6	5	4	7	10	6

TABLE 21

HIGH PEAK ORDERED GUST LOADING HISTORIES

Stress Interval = 1,000
Unit Spectrum = 1/10 avg. random test history
f(mean) = 12,000
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.307	Specimen No.308	Specimen No.309	Specimen No.310	Specimen No.312
750	319,040	288,960	288,000	224,319	256,961
1,980	219,040	198,000	198,000	153,999	176,001
2.900	149,040	135,000	135,000	104,999	120,001
3,920	83,040	75,600	75,600	58,799	67,201
4,900	46,040	42,300	42,300	32,899	37,601
5,830	23,040	21,600	21,600	16,799	19,201
6,850	11,040	10,800	10,800	8,399	9,601
7,880	4,320	4,320	4,320	3,359	3,841
8,950	1,890	1,890	1,890	1,469	1,681
10,000	810	810	810	629	721
11,050	396	396	396	307	353
12,050	216	216	216	167	193
13,050	126	126	126	97	113
13,700	72	72	72	55	65
14,450	36	36	36	27	33
15,500	18	18	18	13	17
16,450	9	9	9	6	9
17,500	4	4	4	2	4
18,300	2	2	2	1	2
Spectrum Units	9.97	9.03	9.00	7.01	8.03

TABLE 22

HIGH PEAK ORDERED GUST LOADING HISTORIES

Stress Interval = 1,000
Unit Spectrum = 1/20 avg. random test history
f(mean) = 12,000 psi
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.313	Specimen No.320	Specimen No.328	Specimen No.335	Specimen No.341
480	414,882	470,401	813,600	441,281	928,161
1,320	284,882	320,401	558,600	301,281	638,001
2,220	193,882	217,501	380,100	203,281	435,001
3,100	108,082	121,801	211,800	113,401	243,601
4,020	59,982	68,151	117,500	63,451	136,301
4,960	30,082	34,801	60,000	32,400	69,601
5,900	15,002	17,401	30,000	16,201	34,801
6,850	6,002	6,961	12,000	6,481	13,921
7,860	2,627	3,046	5,250	2,836	6,091
8,860	1,127	1,306	2,250	1,216	2,611
10,100	552	639	1,100	595	1,277
11,380	302	349	600	325	697
12,350	177	204	350	190	407
13,300	102	117	200	109	233
14,350	52	59	100	55	117
15,400	27	30	50	28	59
16,550	14	15	25	14	30
17,620	6	6	10	6	12
18,300	3	3	5	3	6
Spectrum Units	25.93	29.40	50.85	27.58	58.01

TABLE 23

HIGH PEAK ORDERED GUST LOADING HISTORIES

Stress Interval = 4,000 psi
Unit Spectrum = 1/20 avg. random test history
f(mean) = 12,000 psi
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences			
	Specimen No.326	Specimen No.331	Specimen No.332	Specimen No.334
2,070	304,232	144,578	152,718	188,145
6,190	28,000	13,126	14,001	17,500
10,350	1,056	496	529	660
14,200	96	46	49	60
18,300	3	2	2	2
Spectrum Units	32.89	15.63	16.51	20.34

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences			
	Specimen No.336	Specimen No.337	Specimen No.339	Specimen No.340
2,070	305,713	207,478	497,650	353,350
6,190	28,875	19,250	46,375	33,250
10,350	1,089	726	1,749	1,254
14,200	99	66	159	114
18,300	3	2	5	4
Spectrum Units	33.05	22.43	53.80	38.20

TABLE 24

HIGH PEAK ORDERED GUST LOADING HISTORIES

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 avg. random test history
f(mean) = 12,000 psi
K_t = 7.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences					
	Specimen No.293	Specimen No.294	Specimen No.295	Specimen No.296	Specimen No.297	Specimen No.298
530	63,002	58,249	63,002	68,001	41,253	55,501
1,550	43,752	40,249	43,752	47,251	28,503	38,501
2,500	28,127	25,874	28,127	30,376	18,003	24,751
3,450	16,877	15,524	16,877	18,226	10,803	14,851
4,400	9,627	8,854	9,627	10,396	6,163	8,471
5,350	4,702	4,323	4,702	5,077	3,011	4,137
6,300	2,127	1,954	2,127	2,296	1,363	1,871
7,400	902	827	902	973	579	793
8,500	402	367	402	433	259	353
9,400	177	160	177	190	115	155
10,200	84	75	84	90	56	73
11,150	49	43	49	52	33	42
12,200	26	22	26	27	18	22
13,300	16	13	16	16	11	13
14,450	8	6	8	8	6	6
15,500	4	3	4	4	3	3
16,200	3	2	3	3	2	2
Spectrum Units	25.19	23.29	25.19	27.24	16.52	22.23

TABLE 25

LOW PEAK ORDERED GUST LOADING HISTORIES

Stress Interval = 1,000 psi
Unit Spectrum = 1/10 avg. random test history
f(mean) = 6,000 psi
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.378	Specimen NO.387	Specimen No.388	Specimen No.391	Specimen No.392
540	4,552,819	5,385,622	5,390,422	10,056,042	5,874,024
1,620	2,652,819	3,135,622	3,140,422	5,856,042	3,424,024
2,590	1,360,819	1,605,622	1,610,422	3,000,042	1,758,024
3,540	600,819	705,622	710,422	1,328,042	778,024
4,540	203,519	242,022	242,022	456,542	264,024
5,540	66,619	79,222	79,222	149,442	86,424
6,530	19,629	23,342	23,342	44,032	25,464
7,540	7,419	8,822	8,822	16,642	9,624
8,600	2,979	3,542	3,542	6,682	3,864
9,660	1,277	1,518	1,518	2,864	1,656
10,420	537	638	638	1,204	696
11,000	204	242	242	457	264
12,000	56	66	66	125	72
14,000	19	22	22	42	24
Spectrum Units	37.94	44.88	44.92	83.80	48.95

TABLE 26

LOW PEAK ORDERED GUST LOADING HISTORIES

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 avg. random test life
f(mean) = 6,000 psi
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No. 372	Specimen No. 376	Specimen No.381	Specimen No.385	Specimen No.394
550	4,918,201	3,177,840	4,189,201	3,777,001	5,070,000
1,600	2,868,201	1,852,840	2,439,201	2,202,001	2,945,000
2,600	1,474,201	951,840	1,249,201	1,131,001	1,512,000
3,620	654,201	421,840	552,001	501,001	672,000
4,580	223,701	143,590	189,751	170,501	231,000
5,520	72,901	46,800	62,101	55,801	75,600
6,520	21,466	13,780	18,286	16,431	22,260
7,500	8,101	5,200	6,901	6,201	8,400
8,520	3,241	2,080	2,761	2,481	3,360
9,520	1,378	884	1,174	1,055	1,428
10,500	568	364	484	435	588
11,500	203	130	173	156	210
12,480	81	52	69	63	84
14,000	20	13	17	16	21
Spectrum Units	81.97	52.96	69.82	62.95	84.50

TABLE 27

LOW PEAK ORDERED GUST LOADING HISTORIES

Stress Interval = 4,000 psi
Unit Spectrum = 1/20 avg. random test history
f (mean) = 6,000 psi
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No. 364	Specimen No. 365	Specimen No. 368	Specimen No. 370	Specimen No. 377
2,100	1,393,865	457,862	2,103,148	2,045,688	1,029,604
6,180	31,805	10,202	48,008	46,808	23,404
10,080	588	189	888	866	433
14,000	5	2	8	8	4
Spectrum Units	53.61	17.61	80.89	78.68	39.60

TABLE 28

LOW PEAK ORDERED GUST LOADING HISTORIES

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 avg. random test history
f(mean) = 6,000 psi
K_t = 7.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.348	Specimen No.350	Specimen No.351	Specimen No.355	Specimen No.356
550	211,141	289,080	305,371	253,531	228,242
1,520	104,421	145,280	153,731	127,121	113,502
2,370	55,201	76,800	80,971	67,201	60,002
3,260	25,301	35,200	36,771	30,801	27,502
4,190	8,971	12,480	12,871	10,921	9,752
5,160	2,991	4,160	4,291	3,641	3,252
6,170	921	1,280	1,321	1,121	1,002
7,190	300	416	430	365	327
8,230	139	192	199	169	152
9,260	58	80	83	71	64
10,380	23	32	33	29	26
11,460	7	9	10	9	8
13,100	2	3	3	3	3
Spectrum Units	23.46	32.12	33.93	28.17	25.36

TABLE 29

ORDERED GROUND LOADING HISTORIES

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 avg. random test history
f(mean) = -3,000 psi
K_t = 7.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences					
	Specimen No.461	Specimen No.462	Specimen No.465	Specimen No.466	Specimen No.469	Specimen No.471
550	775,438	747,757	1,010,085	1,268,351	900,009	1,309,422
1,580	396,008	380,257	516,585	648,851	459,009	668,922
2,580	144,008	136,007	187,585	235,851	165,009	241,192
3,580	41,408	39,107	53,635	67,701	47,159	69,012
4,610	5,768	5,447	7,370	9,291	6,569	9,612
5,700	2,168	2,047	2,770	3,491	2,469	3,612
6,780	692	653	884	1,113	788	1,152
7,910	296	279	378	475	337	492
8,780	87	82	111	139	99	144
9,480	22	20	28	34	25	36
10,500	7	6	9	11	8	12
Spectrum Units	36.07	34.78	46.98	58.99	41.86	60.90

TABLE 30

ORDERED MILITARY MANEUVER LOADING HISTORIES

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 avg. random test history
Minimum Stress = 5,450 psi
K_t = 4.0

Incremental Stress (psi)	Cumulative Frequency of Load Cycle Occurrences			
	Specimen No.410	Specimen No.411	Specimen Nos.413&414	Specimen No.415
470	8,201	17,425	12,298	13,271
1,320	7,401	15,725	11,098	11,971
2,020	6,801	14,450	10,198	10,996
2,730	6,201	13,175	9,298	10,021
3,480	5,601	11,900	8,398	9,046
4,330	5,001	10,625	7,498	8,071
5,320	4,521	9,605	6,778	7,291
6,420	4,081	8,670	6,118	6,576
7,460	3,721	7,905	5,578	5,991
8,430	3,361	7,140	5,038	5,406
9,480	3,001	6,375	4,498	4,821
10,560	2,721	5,780	4,078	4,366
11,600	2,401	5,100	3,598	3,846
12,700	2,121	4,505	3,178	3,391
13,800	1,881	3,995	2,818	3,001
14,900	1,681	3,570	2,518	2,676
16,050	1,425	3,026	2,134	2,260
16,850	1,241	2,635	1,858	1,961
17,950	1,081	2.295	1,618	1,701
19,400	921	1,955	1,378	1,441
20,450	769	1,632	1,150	1,194
21,500	649	1,377	970	999
22,800	529	1,122	790	804
24,000	441	935	658	661
25,100	345	731	514	517
26,400	281	595	418	421
27,700	233	493	346	349
28,800	185	391	274	277
29,800	137	289	202	205
30,850	105	221	154	157
32,000	81	170	118	121
33,150	65	136	94	97
34,200	49	102	70	73
35,200	37	77	52	55
36,150	29	60	40	43
37,150	21	43	29	31
38,250	15	31	21	22
39,400	10	21	14	15
40,300	7	16	11	11
42,000	4	9	6	6
Spectrum Units	8.00	17.00	11.99	12.95

TABLE 31

ORDERED MILITARY MANEUVER LOADING HISTORIES

Stress Interval = 4,000 psi
Unit Spectrum = 1/20 avg. random test history
Minimum Stress = 5,450 psi
K_t = 4.0

Incremental Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.399	Specimen No.400	Specimen No.401	Specimen No.404	Specimen No.406
1,680	12,900	12,898	9,676	19,345	15,001
5,180	8,700	8,698	6,526	13,045	10,101
9,250	5,880	5,878	4,411	8,815	6,811
13,550	3,780	3,778	2,836	5,665	4,361
17,800	2,280	2,278	1,711	3,415	2,611
22,100	1,260	1,258	946	1,885	1,421
26,300	588	586	442	877	637
30,700	240	238	181	355	260
34,800	84	82	64	121	91
38,450	24	22	19	34	26
42,000	3	3	3	5	4
Spectrum Units	12.00	11.99	9.00	17.99	13.95

TABLE 32

RANDOM COMPOSITE LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)

HIGH PEAK GUST LOADINGS IN FLIGHT

$K_t = 4.0$

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences					
	Specimen No.424	Specimen No.425	Specimen No.427	Specimen No.428	**Specimen** No.429	Specimen No.430
	Gust Loadings (Approximately 13 Gust Loadings per Flight) f(mean) = 12,000 psi					
0	55,481	51,053	31,071	29,065	49,993	62,369
1,000	39,802	36,625	22,290	20,851	35,865	44,743
2,000	27,517	25,321	15,410	14,415	24,795	30,933
3,000	17,218	15,844	9,643	9,020	15,515	19,356
4,000	9,962	9,167	5,579	5,219	8,976	11,198
5,000	5,263	4,843	2,947	2,757	4,742	5,916
6,000	2,434	2,239	1,363	1,275	2,193	2,736
7,000	1,022	940	572	535	921	1,148
8,000	433	398	242	227	390	487
9,000	191	176	107	100	172	215
10,000	97.6	89.8	54.7	51.2	88.0	110
11,000	48.3	44.4	27.0	25.3	43.5	54.3
12,000	26.7	24.5	14.9	14.0	24.0	30.0
13,000	15.3	14.1	8.58	8.02	13.8	17.2
14,000	9.18	8.45	5.14	4.81	8.28	10.3
15,000	3.28	3.02	1.84	1.72	2.96	3.69
16,000	2.40	2.21	1.34	1.26	2.16	2.69
16,194	2.26	2.08	1.27	1.18	2.04	2.54
16,826	0.89	0.82	0.49	0.46	0.80	0.99
17,000	0.43	0.39	0.24	0.22	0.38	0.48
18,000	0.33	0.30	0.18	0.17	0.29	0.36
18,290	0.32	0.27	0.16	0.15	0.26	0.33

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TABLE 32 (Continued)

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences					
	Specimen No.424	Specimen No.425	Specimen No.427	Specimen No.428	Specimen No.429	Specimen No.430
	Ground Loadings (Approximately 7 Ground Loadings per Flight) f(mean) = -3,000 psi					
0	29,566	27,228	16,593	15,479	26,671	33,241
950	17,077	15,726	9,584	8,940	15,405	19,200
1,920	7,848	7,227	4,404	4,109	7,080	8,824
2,850	2,775	2,556	1,557	1,453	2,503	3,120
3,800	756	696	424	396	682	850
4,750	182	168	102	95.5	165	205
5,700	48.4	44.6	27.2	25.4	43.7	54.5
6,180	26.9	24.8	15.1	14.1	24.3	30.3
6,650	17.3	15.9	9.69	9.04	15.6	19.4
7,130	10.8	9.91	6.04	5.63	9.70	12.1
7,600	7.07	6.51	3.97	3.70	6.38	7.95
8,000	4.88	4.49	2.74	2.55	4.40	5.48
8,550	1.84	1.69	1.03	0.96	1.66	2.07
9,250	1.23	1.13	0.69	0.64	1.11	1.38
9,500	0.41	0.38	0.23	0.22	0.37	0.47
9,620	0.38	0.35	0.22	0.20	0.35	0.43
9,980	0.14	0.13	0.08	0.08	0.13	0.16
10,450	0.11	0.10	0.06	0.06	0.10	0.12
	Number of Flights					
	4,150	3,819	2,325	2,174	3,740	4,667

(End of Table 32)

TABLE 33

RANDOM COMPOSITE LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)
HIGH PEAK GUST LOADINGS IN FLIGHT

$K_t = 4.0$

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences							
	Specimen No.501	Specimen No.502	Specimen No.503	Specimen No.504	Specimen No.505	Specimen No.506	Specimen No.507	Specimen No.508
	Gust Loadings (Approximately 110 Gust Loadings per Flight) f(mean) = 12,000 psi							
0	136,772	146,725	202,054	192,290	252,275	293,829	157,246	161,560
1,000	98,120	105,261	144,954	137,949	180,982	210,793	112,808	115,903
2,000	67,835	72,771	100,213	95,370	125,121	145,730	77,989	80,129
3,000	42,446	45,535	62,707	59,676	78,292	91,188	48,800	50,139
4,000	24,557	26,344	36,279	34,525	45,295	52,756	28,233	29,008
5,000	12,974	13,918	19,167	18,241	23,931	27,873	14,916	15,326
6,000	5,999	6,436	8,863	8,434	11,066	12,888	6,897	7,087
7,000	2,518	2,701	3,720	3,540	4,645	5,410	2,895	2,975
8,000	1,067	1,145	1,577	1,500	1,968	2,293	1,227	1,261
9,000	471	506	696	663	870	1,013	542	557
10,000	241	258	356	338	444	517	277	284
11,000	119	128	176	167	219	256	137	141
12,000	65.7	70.5	97.1	92.4	121	141	75.5	77.6
13,000	37.7	40.5	55.8	53.1	69.6	81.1	43.4	44.6
14,000	22.6	24.3	33.4	31.8	41.8	48.6	26.0	26.7
15,000	8.10	8.68	12.0	11.4	14.9	17.4	9.31	9.56
16,000	5.91	6.34	8.73	8.31	10.9	12.7	6.79	6.98
16,190	5.57	5.98	8.23	7.83	10.3	12.0	6.41	6.58
16,830	2.19	2.35	3.23	3.07	4.03	4.70	2.51	2.58
17,000	1.05	1.12	1.55	1.47	1.93	2.25	1.20	1.24
18,000	0.80	0.86	1.17	1.12	1.47	1.71	0.91	0.94
18,290	0.72	0.78	1.07	1.02	1.33	1.55	0.83	0.85

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TABLE 33 (Continued)

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences							
	Specimen No.501	Specimen No.502	Specimen No.503	Specimen No.504	Specimen No.505	Specimen No.506	Specimen No.507	Specimen No.508
	Ground Loadings (Approximately 14 Ground Loadings per Flight) f(mean) = -3,000 psi							
0	17,484	18,764	25,836	24,611	32,294	37,584	20,100	20,657
950	10,098	10,838	14,922	14,215	18,653	21,708	11,610	11,931
1,920	4,641	4,981	6,858	6,533	8,572	9,977	5,336	5,483
2,850	1,641	1,761	2,425	2,310	3,031	3,528	1,887	1,936
3,800	447	480	660	629	826	961	514	528
4,750	108	116	159	152	199	232	124	127
5,700	28.6	30.7	43.3	40.3	52.9	61.6	32.9	33.8
6,180	15.9	17.1	23.5	22.4	29.4	34.2	18.3	18.8
6,650	10.2	11.0	15.1	14.4	18.9	21.9	11.7	12.1
7,130	6.36	6.83	9.40	8.95	11.8	13.7	7.31	7.52
7,600	4.18	4.49	6.18	5.89	7.73	8.99	4.81	4.94
8,000	2.88	3.10	4.26	4.06	5.33	6.20	3.32	3.41
8,550	1.09	1.17	1.61	1.53	2.01	2.34	1.25	1.28
9,250	0.73	0.78	1.07	1.02	1.34	1.56	0.83	0.86
9,500	0.25	0.26	0.36	0.35	0.45	0.53	0.28	0.29
9,620	0.23	0.24	0.33	0.32	0.42	0.49	0.26	0.27
9,980	0.09	0.09	0.13	0.12	0.16	0.18	0.10	0.10
10,450	0.06	0.07	0.09	0.09	0.12	0.14	0.07	0.07
	Number of Flights							
	1,238	1,328	1,829	1,741	2,284	2,660	1,424	1,463

(End of Table 33)

TABLE 34

RANDOM COMPOSITE LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)

HIGH PEAK GUST LOADINGS IN FLIGHT

$K_t = 7.0$

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.432	Specimen No.433	Specimen No.434	Specimen No.435	Specimen No.436
	Gust Loadings (Approximately 13 Gust Loadings per Flight) f(mean) = 12,000 psi				
0	12,271	8,516	11,355	11,548	9,382
1,630	7,031	4,879	6,506	6,616	5,375
3,330	3,255	2,259	3,012	3,063	2,489
5,000	1,163	807	1,076	1,095	889
6,670	326	227	302	307	250
8,330	80.1	55.6	74.1	75.3	61.2
10,000	21.5	14.9	19.9	20.2	16.4
10,830	12.3	8.55	11.4	11.6	9.42
11,660	7.73	5.36	7.15	7.27	5.91
12,500	4.58	3.18	4.24	4.31	3.50
13,330	2.93	2.03	2.71	2.76	2.24
14,000	2.00	1.39	1.85	1.88	1.5
14,960	.67	.46	.62	.63	.51
16,190	.43	.301	.40	.41	.33
	Ground Loadings (Approximately 7 Ground Loadings per Flight) f(mean) = -3,000 psi				
0	6,515	4,510	6,013	6,125	5,011
950	3,763	2,605	2,473	3,538	2,894
1,920	1,729	1,197	1,596	1,626	1,330
2,850	611	423	564	575	470
3,800	167	115	154	157	128
4,750	40.2	27.8	37.1	37.8	30.9
5,700	10.7	7.39	9.85	10.0	8.21
6,180	5.94	4.11	5.48	5.58	4.57
6,650	3.80	2.63	3.51	3.58	2.93
7,130	2.37	1.64	2.19	2.23	1.82
7,600	1.56	1.08	1.44	1.47	1.20
8,000	1.07	.744	.992	1.01	.827
8,550	.405	.280	.374	.381	.311
9,250	.270	.187	.249	.254	.21
9,500	.091	.063	.084	.086	.07
9,620	.08	.058	.08	.08	.07
9,980	.03	.02	.03	.03	.02
10,450	.02	.02	.02	.02	.02
	Number of Flights				
	916	636	848	862	701

TABLE 35

RANDOM COMPOSITE LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)

LOW PEAK GUST LOADINGS IN FLIGHT
$K_t = 4.0$

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences						
	Specimen No.446	Specimen No.447	Specimen No.452	Specimen No.455	Specimen No.456	Specimen No.457	Specimen No.458
	Gust Loadings (Approx. 13 Gust Loadings per Flight) f(mean) = 6,000 psi						
0	434,878	299,889	306,936	247,115	306,153	406,690	210,784
1,190	247,542	170,703	174,714	140,663	174,269	231,497	119,982
2,380	113,760	78,448	80,291	64,643	80,087	106,386	55,139
3,560	40,514	27,938	28,594	23,021	28,521	37,888	19,637
4,750	11,103	7,657	7,836	6,309	7,816	10,383	5,382
5,950	2,677	1,846	1,890	1,521	1,885	2,504	1,298
7,120	713.4	492	503.5	405.4	502.2	667.2	345.8
7,720	406	280	286.6	230.7	285.8	379.7	196.8
8,310	257.7	177.7	181.9	146.4	181.4	241.0	124.9
8,900	158.7	109.4	112	90.2	111.7	148.4	76.9
9,500	103.6	71.5	73.1	58.9	73	96.9	50.2
10,000	72.3	49.9	51.0	41.1	50.9	67.6	35.1
10,700	27.7	19.1	19.6	15.7	19.5	25.9	13.4
11,600	18.3	12.6	12.9	10.4	12.9	17.1	8.88
11,900	7.22	4.98	5.10	4.10	5.10	6.75	3.50
12,050	6.72	4.63	4.74	3.82	4.74	6.28	3.26
12,500	3.57	2.46	2.52	2.03	2.52	3.34	1.73
13,100	2.69	1.86	1.90	1.53	1.90	2.52	1.31
14,000	0.555	0.38	0.39	0.32	0.39	0.52	0.27

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TABLE 35 (Continued)

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences						
	Specimen No.446	Specimen No.447	Specimen No.452	Specimen No.455	Specimen No.456	Specimen No.457	Specimen No.458
	Ground Loadings (Approximately 7 Ground Loadings per Flight) f(mean) = -3,000 psi						
0	231,684	159,746	163,476	131,683	163,142	216,595	112,307
950	133,818	92,267	94,422	76,058	94,229	125,102	64,867
1,920	61,500	42,404	43,394	34,955	43,305	57,494	29,811
2,850	21,745	14,993	15,344	12,359	15,312	20,329	10,541
3,800	5,922	4,083	4,179	3,366	4,170	5,537	2,871
4,750	1,430	986	1,009	813	1,007	1,337	693
5,700	380	262	268	216	267	355	184
6,180	211	146	149	120	149	197	102
6,650	135	93.3	95.4	76.9	95.3	126	65.6
7,130	84.3	58.1	59.5	47.9	59.4	78.8	40.9
7,600	55.4	38.2	39.1	31.5	39.0	51.8	26.9
8,000	38.2	26.4	27.0	21.7	26.9	35.7	18.5
8,550	14.4	9.93	10.2	8.18	10.1	13.5	6.98
9,250	9.61	6.63	6.78	5.46	6.77	8.99	4.66
9,500	3.25	2.24	2.29	1.84	2.29	3.03	1.57
9,620	3.00	2.07	2.11	1.70	2.11	2.80	1.45
9,980	1.12	0.78	0.79	0.64	0.79	1.05	0.55
10,450	0.83	0.57	0.59	0.44	0.59	0.78	0.40
	Number of Flights						
	32,519	22,423	22,947	18,478	22,893	30,402	15,765

(End of Table 35)

TABLE 36

RANDOM COMPOSITE LOADING HISTORIES
(MEAN CROSSING PEAK COUNTS)

LOW PEAK GUST LOADINGS IN FLIGHT
$K_t = 7.0$

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.440	Specimen No.441	Specimen No.442	Specimen No.443	Specimen No.445
	Gust Loadings (Approximately 13 Gust Loadings per Flight) f(mean) = 6,000 psi				
0	26,194	25,244	30,085	35,038	29,180
1,190	14,915	14,374	17,130	19,951	16,615
2,380	6,850	6,601	7,867	9,162	7,630
3,560	2,440	2,349	2,800	3,261	2,716
4,750	671	646	770	897	747
5,950	162	156	186	217	181
7,120	43	41.5	49	57.6	48
7,720	24.5	23.6	28.2	32.8	27.4
8,310	15.5	14.9	17.7	20.8	17.3
8,900	9.47	9.13	10.9	12.6	10.6
9,500	6.16	5.94	7.07	8.24	6.86
10,000	4.29	4.14	4.93	5.74	4.78
10,700	1.63	1.57	1.88	2.18	1.82
11,600	1.07	1.03	1.23	1.43	1.19
11,900	0.32	0.31	0.37	0.43	0.36
12,050	0.30	0.29	0.35	0.40	0.33
12,500	0.16	0.15	0.18	0.21	0.17
13,100	0.12	0.11	0.13	0.16	0.13

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TABLE 36 (Continued)

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.440	Specimen No.441	Specimen No.442	Specimen No.443	Specimen No.445
	Ground Loadings (Approximately 7 Ground Loadings per Flight) f(mean) = -3,000 psi				
0	13,948	13,436	16,025	18,658	15,535
950	8,056	7,760	9,256	10,777	8,973
1,920	3,705	3,569	4,257	4,956	4,126
2,850	1,309	1,261	1,504	1,751	1,458
3,800	356	343	410	477	397
4,750	86	83	99	115	96
5,700	22.9	22.1	26.4	31	25.5
6,180	12.7	12.2	14.6	17	14.1
6,650	8.14	7.84	9.36	10.9	9.07
7,130	5.07	4.89	5.83	6.79	5.65
7,600	3.33	3.21	3.83	4.46	3.72
8,000	2.30	2.22	2.64	3.08	2.56
8,550	0.87	0.84	0.10	1.16	0.97
9,250	0.58	0.56	0.67	0.77	0.64
9,500	0.20	0.19	0.22	0.26	0.22
9,620	0.18	0.17	0.21	0.24	0.20
9,980	0.07	0.07	0.08	0.09	0.08
10,450	0.05	0.05	0.06	0.07	0.06
	Number of Flights				
	1,958	1,886	2,249	2,619	2,181

(End of Table 36)

TABLE 37

RANDOM COMPOSITE LOADING HISTORIES
(PEAK COUNTS)

MILITARY MANEUVER LOADINGS IN FLIGHT
$K_t = 4.0$

Dynamic Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No.488	Specimen No.489	Specimen No.490	Specimen No.499	Specimen No.500
(Incremental)	Military Maneuver Loadings (Approximately 30 Maneuver Loadings per Flight) Minimum Stress = 5,450 psi				
0	7,236	8,126	9,549	7,711	10,676
2,840	5,674	6,371	7,488	6,046	8,371
5,680	4,424	4,968	5,838	4,714	6,527
11,400	2,566	2,881	3,386	2,734	3,785
17,000	1,250	1,404	1,649	1,332	1,844
22,700	502	563	662	534	740
28,400	148	166	195	158	218
31,200	78	88	104	84.1	116
34,000	36.2	40.6	47.7	38.6	53.4
39,700	6.58	7.39	8.68	7.01	9.71
41,200	3.29	3.69	4.34	3.50	4.85
42,000	1.64	1.85	2.17	1.75	2.43
(Varying)	Ground Loadings (Approximately 7 Ground Loadings per Flight) f(mean) = -3,000 psi				
0	1,682	1,888	2,216	1,793	2,478
950	971	1,090	1,280	1,036	1,431
1,920	446	501	588	476	658
2,850	158	177	208	168	233
3,800	43.0	48.2	56.6	45.8	63.3
4,750	10.4	11.6	13.7	11.1	15.3
5,700	2.75	3.09	3.63	2.94	4.06
6,180	1.53	1.72	2.02	1.63	2.26
6,650	0.982	1.10	1.29	1.05	1.45
7,130	0.61	0.69	0.81	0.65	0.90
7,600	0.41	0.45	0.53	0.43	0.59
8,000	0.28	0.31	0.36	0.29	0.41
8,550	0.10	0.12	0.14	0.11	0.15
9,250	0.070	0.078	0.092	0.074	0.10
9,500	0.024	0.026	0.031	0.025	0.035
9,620	0.022	0.024	0.029	0.023	0.032
9,980	0.008	0.009	0.011	0.009	0.012
10,450	0.006	0.007	0.008	0.006	0.009
	Number of Flights				
	240	270	317	256	354

TABLE 38

ORDERED COMPOSITE LOADING HISTORIES
(Spectra Based on Tests having approx. 13 Random Gust Loadings per Flight)

HIGH PEAK GUST LOADINGS IN FLIGHT

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 avg. random test history
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycles Occurrences				
	Specimen No. 467	Specimen No. 470	Specimen No. 472	Specimen No. 473	Specimen No. 474
	Gust Loadings f(mean) = 12,000 psi				
580	91,835	120,914	74,142	75,449	95,632
1,780	65,435	86,114	52,542	53,849	68,032
2,900	43,435	57,114	35,002	35,849	45,032
3,850	24,735	32,776	20,127	20,549	25,876
4,850	13,545	17,956	11,027	11,187	14,176
5,880	6,665	8,836	5,427	5,427	6,976
7,000	3,010	3,991	2,452	2,452	3,151
8,100	1,247	1,654	1,017	1,017	1,306
9,050	516	685	422	422	541
10,080	258	343	212	212	271
11,050	129	172	107	107	136
12,050	69	92	58	58	73
13,100	39	52	33	33	41
14,200	22	29	18	18	23
15,100	13	18	11	11	14
15,600	6	9	6	6	7
16,300	2	3	2	2	2
	Ground Loadings f(mean) = -3,000 psi				
620	44,720	59,281	36,401	36,401	46,800
1,680	20,640	27,361	16,801	16,801	21,600
2,600	8,170	10,831	6,651	6,651	8,550
3,650	2,365	3,136	1,926	1,926	2,475
4,600	430	571	351	351	450
5,500	129	172	106	106	135
6,450	43	58	36	36	45
7,420	15	20	13	13	15
8,300	4	6	4	4	4
8,950	2	3	2	2	2
	Ground to Air Cycles f(mean) = 4,500 psi				
7,950	7,955	10,545	6,475	6,475	8,325
Spectrum Units	43.56	57.04	35.28	35.67	45.44

TABLE 39

ORDERED COMPOSITE LOADING HISTORIES
(Spectra Based on Tests having approximately 110 Random Gust Loadings per Flight)

HIGH PEAK GUST LOADINGS IN FLIGHT

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 avg. random test history
K_t = 4.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences							
	Specimen No. 509	Specimen No. 510	Specimen No. 511	Specimen No. 512	Specimen No. 513	Specimen No. 514	Specimen No. 517	Specimen No. 518
	Gust Loadings f(mean) = 12,000 psi							
550	179,556	231,785	302,418	197,951	246,129	240,364	158,896	269,287
1,700	129,556	166,785	217,418	142,951	176,129	172,864	113,896	194,287
2,650	79,556	101,785	132,418	87,951	108,002	107,864	68,896	119,287
3,450	47,556	60,185	79,201	52,751	64,802	64,664	40,803	71,287
4,350	25,556	32,503	42,901	28,551	35,102	34,964	22,103	38,287
5,320	13,556	17,503	23,101	15,351	18,902	18,764	11,903	20,302
6,420	5,702	7,503	9,901	6,551	8,102	7,964	5,103	8,702
7,500	2,377	3,128	4,126	2,701	3,377	3,251	2,128	3,627
8,500	952	1,253	1,651	1,051	1,352	1,301	853	1,452
9,600	477	628	826	526	667	651	428	727
10,620	230	303	397	253	326	313	207	350
11,580	135	178	232	148	191	183	122	205
12,580	68	90	116	74	96	92	62	103
13,520	39	52	66	42	55	53	36	59
14,450	20	27	33	21	28	27	19	30
15,450	10	14	16	10	14	14	10	15
16,420	4	6	6	4	6	6	4	6
18,300	2	3	3	2	3	3	2	3

(continued on next page)

TABLE 39 (Continued)

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences							
	Specimen No. 509	Specimen No. 510	Specimen No. 511	Specimen No. 512	Specimen No. 513	Specimen No. 514	Specimen No. 517	Specimen No. 518
	Ground Loadings f(mean) = -3,000 psi							
550	19,002	25,013	33,004	21,004	27,004	26,004	17,004	29,005
1,520	10,452	13,763	18,154	11,554	14,854	14,304	9,354	15,955
2,550	3,612	4,763	6,274	3,994	5,134	4,944	3,234	5,515
3,520	1,142	1,513	1,984	1,264	1,624	1,564	1,024	1,745
4,500	230	313	400	256	328	316	208	353
5,520	68	88	119	77	98	95	63	106
6,520	22	28	36	24	30	30	20	33
7,520	10	13	16	11	14	14	9	15
9,300	2	3	3	2	3	3	2	3
	Ground to Air Cycles f(mean) = 4,500 psi							
7,850	1,748	2,300	3,036	1,932	2,484	2,392	1,564	2,668
Spectrum Units	19.85	25.67	33.54	21.89	27.31	26.63	17.58	29.82

(End of Table)

TABLE 40

ORDERED COMPOSITE LOADING HISTORIES

(Spectra Based on Tests Having Approx. 13 Random Gust Loadings per Flight)

LOW PEAK GUST LOADINGS IN FLIGHT

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 average random test history
K_t = 4.0

Varying Stress (psi)	Cumulative Frequenty of Load Cycles Occurrences				
	Specimen No. 475	Specimen No. 480	Specimen No. 481	Specimen No. 485	Specimen No. 487
			Gust Loadings f(mean) = 6,000 psi		
580	674,501	351,000	766,987	467,505	1,040,000
1,680	388,501	202,500	442,487	269,505	600,000
2,720	180,501	94,500	206,487	125,505	280,000
3,800	76,501	40,500	88,487	53,505	120,000
4,850	28,051	14,850	32,437	19,305	44,000
5,880	8,161	4,320	9,427	5,600	12,800
6,920	2,296	1,215	2,647	1,575	3,600
7,850	919	486	1,054	630	1,440
8,700	408	216	464	280	640
9,650	205	108	232	140	320
10,680	82	43	93	56	128
11,620	31	16	35	21	48
13,000	10	5	12	7	16
			Ground Loadings f (mean) = -3,000 psi		
600	357,001	189,000	406,232	245,000	560,000
1,700	204,001	108,000	232,232	140,000	320,000
2,750	96,901	51,300	110,432	66,500	152,000
3,900	40,801	21,600	46,632	28,000	64,000
5,080	15,301	8,100	17,632	10,500	24,000
6,200	4,591	2,430	5,452	3,150	7,200
7,180	1,276	675	1,682	875	2,000
8,120	511	270	812	350	800
9,020	205	108	464	140	320
9,850	103	54	116	70	160
10,880	52	27	58	35	80
12,000	21	11	23	14	32
			Ground to Air Cycles f (mean) = 1,500 psi		
4,900	60,486	31,249	68,788	41,510	94,287
Spectrum Units	51.54	26.96	58.62	35.59	79.97

TABLE 41

ORDERED COMPOSITE LOADING HISTORIES
(Spectra Based on Tests having approx. 13 Random Gust Loadings per Flight)

LOW PEAK GUST LOADINGS IN FLIGHT

Stress Interval = 1,000 psi
Unit Spectrum = 1/20 avg. random test history
K_t = 7.0

Varying Stress (psi)	Cumulative Frequency of Load Cycle Occurrences				
	Specimen No. 478	Specimen No. 479	Specimen No. 482	Specimen No. 484	Specimen No. 486
	Gust Loadings f(mean) = 6,000 psi				
650	84,652	87,180	52,445	69,305	52,575
1,800	48,442	49,950	30,005	39,725	30,135
2,750	25,367	26,225	15,705	20,875	15,835
3,700	9,747	10,165	6,025	8,115	6,155
4,650	3,447	3,595	2,155	2,895	2,195
5,550	1,067	1,113	693	923	699
6,600	227	237	177	227	177
7,950	105	107	61	82	61
8,900	43	43	26	35	27
9,550	18	18	11	15	11
11,000	4	4	2	3	2
	Ground Loadings f(mean) = -3,000 psi				
650	42,002	43,201	25,811	34,765	26,395
1,800	21,702	22,321	13,341	17,945	13,635
2,800	8,402	8,641	5,171	6,925	5,275
3,800	2,522	2,593	1,559	2,053	1,585
4,750	492	505	312	400	309
5,720	121	123	74	98	76
6,750	40	40	24	32	25
7,800	15	15	9	12	9
8,850	4	4	2	3	2
	Ground to Air Cycles f(mean) = 1,500 psi				
4,650	7,280	7,488	4,472	5,928	4,545
Spectrum Units	70.54	72.61	43.57	57.93	43.98

APPENDIX VI

CONSTANT LOAD AMPLITUDE DATA

The results of constant load amplitude tests are presented in Tables 42,43 and 44 . These tests were performed on coupons with specimen geometries identical to those used in the spectrum testing. An analysis of these data led to selection of the S-N curves shown in Figures 162 and 163 .

TABLE 42

S-N TEST DATA FOR NOTCHED SHEET COUPONS - $K_t = 4.0$

f_{mean} = -10 ksi		f_{mean} = -5 ksi		f_{mean} = 0 ksi		f_{mean} = 10 ksi		f_{mean} = 15 ksi	
f_v (ksi)	N (cycles)	f_v (ksi)	N (cycles)	f_v (ksi)	N (cycles)	f_v (ksi)	N (cycles)	f_v (ksi)	N (cycles)
25	1,215	25	500	25	331	25	150	25	171
25	1,519	25	610	25	342	25	250	25	175
25	1,897	25	806	25	393	25	260	25	180
25	2,424	25	812	25	445	25	324	25	212
25	2,843	25	873	25	537	25	350	25	315
20	1,290	20	1,245	20	670	20	521	20	491
20	2,445	20	1,650	20	741	20	531	20	540
20	3,379	20	1,886	20	914	20	640	20	890
20	3,600	20	2,274	20	975	20	820	20	1,030
20	5,179	20	2,460	20	1,016	20	1,001	20	1,203
15	12,600	15	3,600	15	3,600	15	1,860	15	1,471
15	12,600	15	5,400	15	4,283	15	2,500	15	2,325
15	14,400	15	6,650	15	4,488	15	2,900	15	2,600
15	16,200	15	6,800	15	6,480	15	5,946	15	3,053
15	16,200	15	7,050	15	7,200	15	6,150	15	3,170
12.5	13,860	10	27,600	10	26,280	10	9,000	10	6,300
12.5	14,400	10	63,000	10	28,800	10	9,600	10	6,450
12.5	16,920	10	82,800	10	29,700	10	10,500	10	7,200
12.5	54,600	10	86,400	10	36,180	10	12,600	10	7,950
12.5	79,740	10	93,600	10	37,800	10	27,000	10	15,040
10	37,440	5.5	163,000	5	2,098,500	4	61,200	3	90,000
10	91,800	5.5	189,000	5	3,979,800	4	63,000	3	174,600
10	117,000	5.5	1,306,800	5	5,440,000	4	64,800	3	370,800
10	124,200	5.5	1,998,000	5	6,378,000	4	92,800	3	406,800
10	3,700,000	5.5	3,601,000	5	8,109,720	4	872,000	3	2,196,000

TABLE 43

S-N TEST DATA FOR NOTCHED SHEET COUPONS - $K_t = 7.0$

$f_{mean} = -10$ ksi		$f_{mean} = -5$ ksi		$f_{mean} = 0$ ksi		$f_{mean} = 10$ ksi		$f_{mean} = 15$ ksi	
f_v (ksi)	N (cycles)	f_v (ksi)	N (cycles)	f_v (ksi)	N (cycles)	f_v (ksi)	N (cycles)	f_v (ksi)	N (cycles)
20	343	25	36	20	142	20	100	20	90
20	450	25	119	20	215	20	130	20	160
20	516	25	140	20	224	20	240	20	180
20	590	25	172	20	277	20	250	20	190
20	664	25	183	20	360	20	350	20	230
15	474	20	195	15	386	15	383	15	360
15	743	20	228	15	413	15	425	15	430
15	1,006	20	247	15	573	15	440	15	460
15	1,200	20	293	15	636	15	668	15	480
15	1,883	20	296	15	884	15	708	15	1,033
10	9,540	15	485	10	1,200	10	1,500	10	500
10	12,600	15	672	10	1,800	10	2,450	10	900
10	14,400	15	748	10	2,310	10	3,600	10	1,510
10	41,400	15	753	10	3,150	10	4,189	10	1,880
10	52,200	15	813	10	4,633	10	4,950	10	2,040
7.5	14,580	10	6,150	7.5	14,400	5	12,600	5	10,800
7.5	40,140	10	6,300	7.5	16,740	5	12,600	5	12,600
7.5	102,780	10	7,872	7.5	19,800	5	14,400	5	12,960
7.5	147,600	10	8,100	7.5	32,400	5	17,460	5	14,250
7.5	148,500	10	8,620	7.5	34,200	5	25,200	5	17,280
5	185,000	4	178,200	5	51,400	2.5	88,200	2	84,600
5	248,000	4	847,800	5	101,500	2.5	88,200	2	84,600
5	390,400	4	911,700	5	102,600	2.5	129,600	2	185,400
5	651,600	4	1,000,000	5	111,900	2.5	691,000	2	342,000
5	691,700	4	*	5	941,600	2.5	1,296,000	2	*

* 10^7 cycles (no failure)

TABLE 44

S-N DATA FOR NOTCHED SHEET COUPONS

$K_t=4$; $f_{mean}=1.125$ ksi		$K_t=4$; $f_{mean}=4.5$ ksi		$K_t=4$; $f_{mean}=7$ ksi		$K_t=4$; $f_{mean}=2.4$ ksi	
f_v (ksi)	N (Cycles)	f_v (ksi)	N (Cycles)	f_v (ksi)	N (Cycles)	f_v (ksi)	N (Cycles)
4.225	$>10^7$	7.5	25200	15	3342	10.4	12015
4.225	$>10^7$	7.5	32400	15	3465	10.4	14856
4.225	$>1.5\ (10)^7$	7.5	41400	15	3537		
		7.5	43400	15	4075		
		7.5	43800	15	4330		
		7.5	45000				

$K_t=7$; $f_{mean}=1.125$ ksi		$K_t=7$; $f_{mean}=4.5$ ksi		$K_t=7$; $f_{mean}=7$ ksi		$K_t=7$; $f_{mean}=2.6$ ksi	
f_v (ksi)	N (Cycles)	f_v (ksi)	N (Cycles)	f_v (ksi)	N (Cycles)	f_v (ksi)	N (Cycles)
4.225	364000	7.5	9900	15	485	10.2	1356
4.225	144000	7.5	10600	15	502	10.2	1332
4.225	148000	7.5	11900	15	503		
4.225	$>10^7$	7.5	13700	15	529		
4.225	$>10^7$	7.5	14600	15	540		
4.225	$>10^7$	7.5	14700				

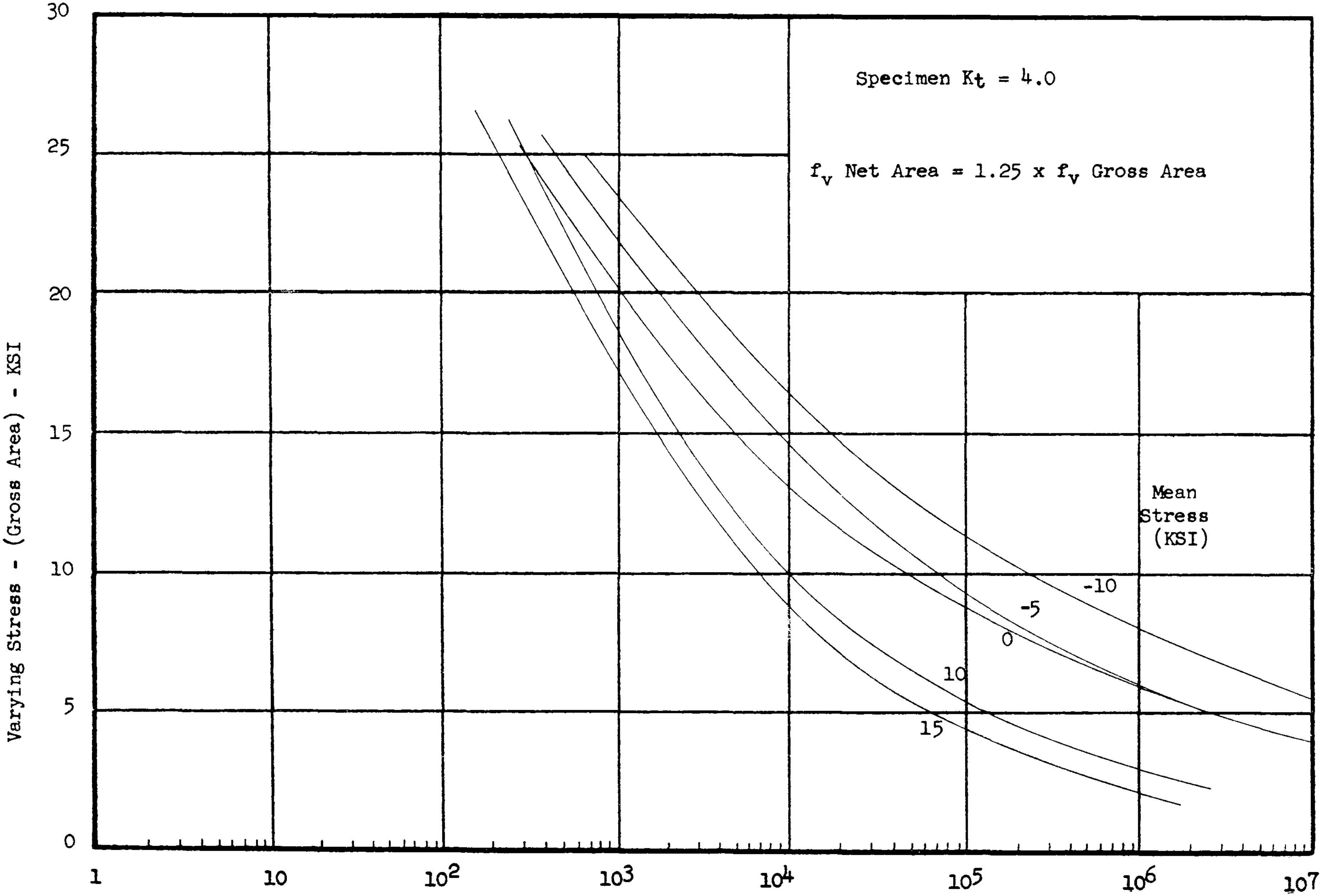

Figure 162 - S-N CURVES FOR NOTCHED SHEET COUPONS

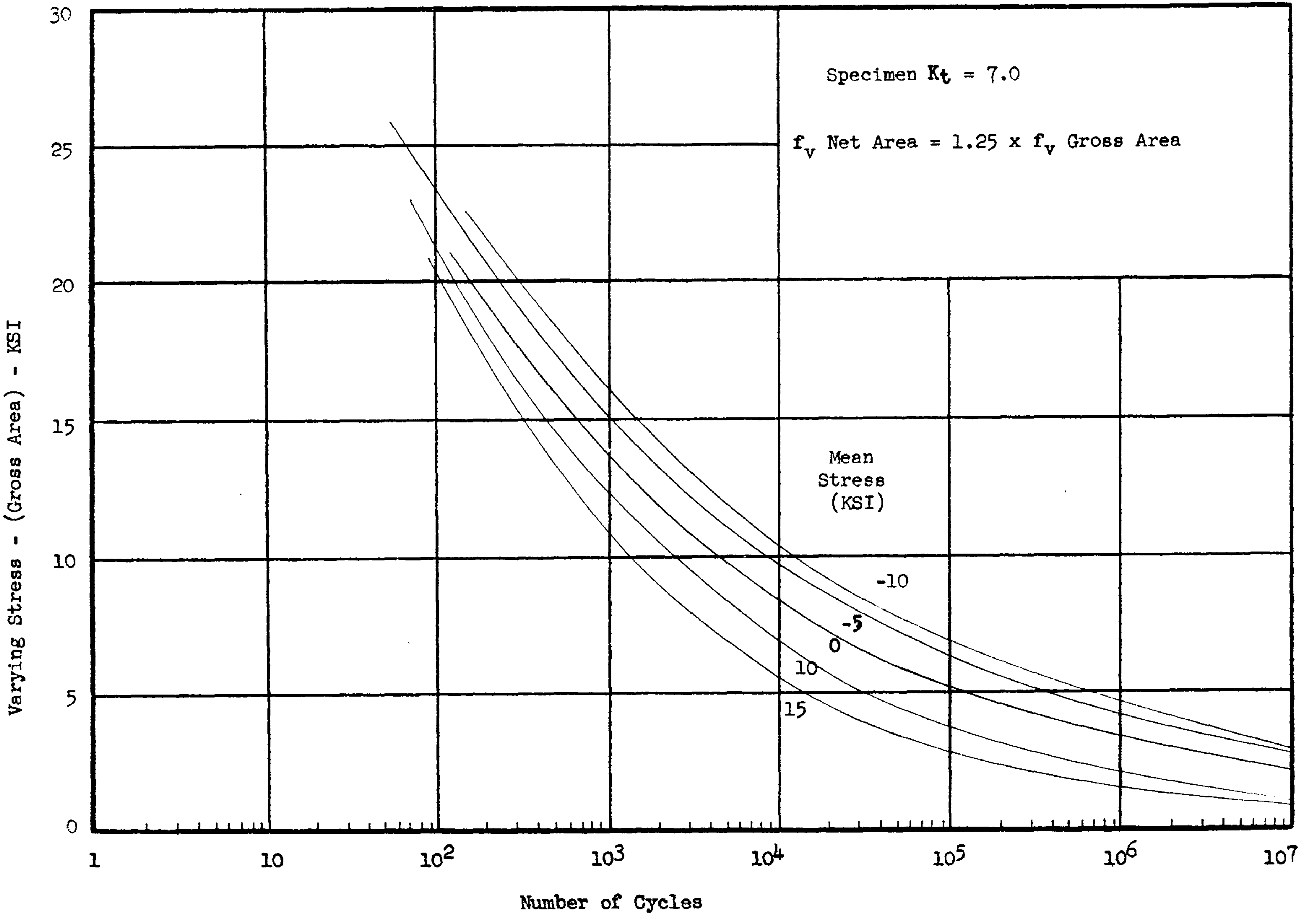

Figure 163 - S-N CURVES FOR NOTCHED SHEET COUPONS

Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt. No. ASD-TR-61-435. INVESTIGATION OF THE REPRESENTATION OF AIRCRAFT SERVICE LOADINGS IN FATIGUE TESTS. January 1962, 305p incl. illus.
Unclassified report

Fatigue tests of practical representations of aircraft service loadings were preferred. Apparatus was developed, capable of applying typical random loading histories. Random gust loadings, military maneuver and ground loadings were applied. The adequacy of ordered, cyclic representations of random loadings were evaluated; they indicated that spectra of cyclic loadings based on simple mean crossing peak counts of service loading records can be employed in tests where the maximum stress values are moderately high, but are unconservative estimates for lower peak stresses. The results of composite loading tests indicate the cumulative effect of flight loadings are nonlinear. Adequate simulations of composite random loadings were obtained for the wing root region of conventional transport aircraft.

(over)

UNCLASSIFIED

1. Fatigue testing
2. Tensile fatigue
I. AFSC Project 1367
   Task 14025
II. Contract AF 33(616) 6575
III. Lockheed Aircraft Corp., Burbank, Cal.
IV. A. J. McCulloch, M. A. Melcon, W. J. Crichlow
V. OTS not aval.
VI. In ASTIA collection

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Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Rpt. No. ASD-TR-61-435. INVESTIGATION OF THE REPRESENTATION OF AIRCRAFT SERVICE LOADINGS IN FATIGUE TESTS. January 1962, 305p incl. illus.
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