NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2663

THE GUST AND GUST-LOAD EXPERIENCE OF A TWIN-ENGINE LOW-ALTITUDE TRANSPORT AIRPLANE IN OPERATION ON A NORTHERN TRANSCONTINENTAL ROUTE

By Harry Press and Robert L. McDougal

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
April 1952

1T

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2663

THE GUST AND GUST-LOAD EXPERIENCE OF A TWIN-ENGINE LOW-ALTITUDE TRANSPORT AIRPLANE IN OPERATION ON A NORTHERN TRANSCONTINENTAL ROUTE

By Harry Press and Robert L. McDougal

SUMMARY

An analysis of the gust and gust-load experience of a low-altitude transcontinental transport airplane, based on 834 hours of VGH record, is presented. The relation of gust experience to airspeed, altitude, season of the year, and flight condition is considered. An estimate of the over-all gust history for the present type of operations is derived from a synthesis of the VGH data and available V-G data.

INTRODUCTION

In recent years, the design ultimate strength of the primary structure of some types of airplanes, notably the transport airplanes, has to a large extent been determined by their anticipated gust experience. In addition to the problem of overstress due to the occurrence of a single load above design strength, a problem of designing against fatigue failures due to repeated loads of small intensities also exists. One important part of the analysis of the fatigue problem is the definition of the gust experience of an airplane, since atmospheric gusts are perhaps the most prolific source of repeated loads. Furthermore, since the resultant loads in gust encounters are, to a large extent, a function of operating conditions such as airspeed, weight, and altitude, information is also needed on the operating conditions under which gusts are encountered.

Extensive studies have been made of the larger gust loads by means of the well-known NACA V-G recorder, which yields an envelope-type record from which only the larger loads and associated airspeeds may be read. The smaller and more frequent gusts and gust loads have, however, not been studied in detail. Estimates of gust and gust-load histories have been made in reference 1, but they are based on limited and incomplete data. The need for determining more precisely the detailed experience of airplanes in service operation has led to the development of an instrument for operational use that records a time history of airspeed, acceleration, and altitude (NACA VGH recorder). See reference 2.

The first service installation of an NACA VGH recorder was made in a twin-engine low-altitude airplane flown in scheduled passenger operation on a northern transcontinental route of the United States. Preliminary summaries of the early data from these operations have been published in reference 3. The present analysis is based on a much larger sample covering 834 hours of record and considers the relation of the gust and gust-load experience to the airspeed, altitude, season of the year, and flight condition. The measured results, supplemented by available V-G data, have been used to derive predictions of the gust history for the type of operation investigated.

GENERAL CONSIDERATIONS

General problems.- Research on gust and gust-load experience in normal operations is aimed principally at the prediction of the gust and gust-load histories for new airplanes. Investigations of the present type are concerned primarily with the following problems:

(1) The gust and gust-load experience for the particular operations

(2) The frequency and intensity of atmospheric gustiness and their variation with such factors as season of the year, altitude, and geographic or climatic region

(3) The definition of the operating conditions which have a large effect on the accelerations and loads applied to the airplane in gust encounters, such as the airplane weight, airspeed, and altitude

(4) Finally, since this type of operational research is still in an exploratory stage, the development of techniques of data evaluation and the determination of what constitutes adequate scope and size of samples

The determination of the gust and gust-load experience for the particular airplane from the VGH records is the first step in these investigations. Owing to the nature of the gust-load experience, simple approximate procedures, which will be described subsequently, are used for the smaller gust intensities which form the preponderance of gust encounters.

The selection of parameters with which gust intensities may be expected to vary depends largely upon meteorological information on the characteristics of turbulence and the weather. Past work has indicated that the frequency and intensity of turbulence vary with season of the year, geographic location, and altitude. Marked differences in atmospheric gustiness associated with changes in these factors not only would have important implications in airplane design and operation, but also would affect the requirements for the collection of representative samples of data.

The operating conditions include the airspeed, the weight, the flight condition, and the altitude at which the gusts are encountered. All of these affect both the maximum loads and the number of loads experienced. For example, a 10-percent increase in speed results not only in a 10-percent increase in the magnitude of all the gust loads encountered but also in a 100- to 200-percent increase in the number of loads above a given intensity.

Finally, many problems are involved in determining the types and quantity of data required for reliable results and the best methods of data evaluation. One of these problems is the determination of adequate sample size. Obviously, larger samples permit the prediction of future experience with greater reliability. However, accuracy of predictions increases rather slowly with increasing sample size so that compromises become necessary between accuracy and practical considerations. For given levels of accuracy, the appropriate sample sizes are frequently not apparent before the investigations are under way or until the character of the data is established. The first set of data of a given type provides information on what constitutes an adequate sample size. Available information also indicates that at the initial stages samples of broad scope will be required in order to assess the relative importance of such factors as geographic area, altitude of operation, and variations in operating conditions.

Assumptions and restrictions.- In the present analysis the following assumptions apply: (1) The airplane on which the records were taken is a representative low-altitude, short-haul, transcontinental airliner and the sample is representative of routine operations. (2) The acceleration and gust experiences of an airplane may be adequately defined by their respective frequency distributions; that is, the frequency with which various values of acceleration or gust velocity are experienced. Although the sequence of accelerations in gusts may be of interest in some problems, it is beyond the scope of the present study.

The present investigation was restricted to values of acceleration increment Δn above 0.3g and the equivalent levels of gust intensity, since reading to a lower level increases tremendously the amount of work without yielding a corresponding increase in the value of the data. Because of the relative infrequency of the larger values of acceleration and gust velocity, very long sampling periods would be required to obtain enough data for reasonable accuracy at the higher values. The present investigations with the NACA VGH recorder are therefore not aimed at determining the frequency of the very large gusts and accelerations but are restricted to the lower values of gust velocity and acceleration. Supplementary information on the frequency of the larger gusts and gust loads, as may be obtained from V-G records, is therefore required for use with the VGH data to obtain a complete gust and gust-load frequency distribution.

INSTRUMENTATION AND AIRPLANE

The data presented herein were collected with an NACA VGH recorder, which is described in detail in reference 2. The instrument consists of three main parts, a base containing the recording elements and a 1-minute timer, a film drum, and a remote acceleration transmitter. The film drum contains a 200-foot roll of recording photographic paper which is driven at the rate of approximately 2 feet per hour to obtain a time history of acceleration, airspeed, and altitude. The accelerometer transmitter was mounted rigidly within 2 feet of the operating center of gravity of the airplane. A photograph of a sample portion of a record is shown in figure 1.

The characteristics of the airplane are described in the following table:

Design gross weight, pounds	39,900
Wing span, feet	93
Mean aerodynamic chord, feet	10.1
Wing area, square feet	864
Aspect ratio, A	10.1
Design level airspeed, miles per hour	256
Never-exceed airspeed, miles per hour	292
Slope of lift curve per radian	5
Limit load factor, g units	2.89
Alleviation factor, K (reference 1)	1.16

Most of the airplane characteristics were obtained from the design manual. The slope of the lift curve was estimated from the relation $\frac{6A}{A + 2}$, where A is the aspect ratio. The alleviation factor K was based on an average operating weight estimated as 85 percent of the gross weight.

PRECISION

The accuracy of the data presented herein depends on three factors:

(1) Inherent instrument errors

(2) Installation errors

(3) Reading errors

The inherent instrument errors and a general discussion of installation errors are covered in reference 2. The inherent errors of the accelerometer transmitter depend on the dynamic response of the instrument and the accelerometer temperature. The operating temperature for the present tests was generally above the minimum temperature required for satisfactory operation. Over the range of the present acceleration-increment data (from ±0.3g to ±1.4g and up to 5 cycles per second), the instrument is accurate to within ±0.02g. The airspeed cell has an inherent accuracy of from about ±2 miles per hour at 100 miles per hour to about ±1.5 miles per hour at 250 miles per hour. The altitude cell has an inherent accuracy which varies from about ±30 feet at 2000 feet to about ±65 feet at 20,000 feet.

The particular installation met the basic installation requirements given in reference 2 and the installation errors are believed to be negligible for present purposes. The reading errors could be of a systematic or a random nature, but all check readings have indicated that most of the reading errors were of a random nature. Reading accuracy was estimated to be within about ±0.01 inch. For the accelerometer trace the maximum reading error was therefore estimated at ±0.03g. The maximum reading error of the airspeed trace was estimated to vary from ±3 miles per hour at 100 miles per hour to ±1 mile per hour at 250 miles per hour. The maximum reading error of the altitude trace was estimated to vary from ±120 feet at 2000 feet to ±235 feet at 20,000 feet.

Based on the foregoing considerations, the following maximum total error was estimated for each of the quantities:

Acceleration, g	±0.05
Airspeed, miles per hour	
at 100 miles per hour	±5
at 250 miles per hour	±2.5
Altitude, feet	
at 2000 feet	±150
at 20,000 feet	±300

The derived results in the analysis are averages of a number of observations, so that the random errors would be expected largely to disappear. The over-all errors listed in the table are small and would have only a minor effect on derived results. The sampling variations might be expected to have larger effects on the results; their magnitude is discussed in a subsequent section.

SCOPE OF DATA

The sample consisted of 14 VGH records covering 834 hours of scheduled transport operations. The airplane was used as a short-haul passenger airliner and was flown over a northern transcontinental route of the United States. Records were obtained during the 9-month period from April 1949 to December 1949 and their scopes are summarized in table I. The distribution of the flight hours by month (fig. 2) indicates that, except in June, more than 50 hours of record were obtained for each of the 9 months of the period covered, with a maximum of about 180 hours for October.

The cabin of the airplane was not pressurized and the operating altitudes were generally less than 10,000 feet above mean sea level except for very short periods when the airplane was flown above this altitude for the purpose of terrain clearance or the avoidance of turbulence. The average flight duration was roughly 1 hour. The distribution of flight distance by altitude above terrain for each month (fig. 3) indicates that about 65 percent of flight distance was within 5000 feet of terrain and less than 2 percent was more than 10,000 feet above terrain. These figures are approximate because the actual path of each of the flights could not be reproduced by simple means.

During part of the period covered by the record (from April through June), the airplane was operated under special cautionary restrictions: "do not operate the aircraft in excess of ninety percent of the placard V_{ne} [never-exceed speed] and V_{no} [normal operating speed] speeds . . . In the event any turbulence is encountered in flight, immediately reduce the speed to a maximum of 170 MPH and further reduce the speed to a maximum of 150 MPH dependent upon the severity of the turbulence." These restrictions, which are discussed subsequently, may have influenced the representativeness of the data obtained both while they were in force and afterward.

EVALUATION OF RECORDS

For the purpose of evaluation, each flight of the record was subdivided into three flight conditions, climb, en route, and descent (as illustrated in fig. 1 and described in reference 3). The climb condition was considered to begin at take-off and to end when the record indicated that the airplane began maintaining a relatively constant altitude. The descent condition was assumed to commence when the record indicated that the airplane began consistently losing altitude and to end when the airplane landed. The en-route condition was considered to be in effect during the interval between the climb and descent conditions and necessarily contained some changes in altitude for such reasons as avoidance of turbulence and terrain clearance.

The evaluation of data on operating altitudes was based on altitude above terrain in order to correlate the turbulence encountered with proximity to the ground. Inasmuch as the relation of turbulence to broad altitude ranges was of primary interest, the figures for altitude above terrain were based on terminal altitudes, without consideration of variations of terrain between terminals. For the climb condition, the pressure altitude at the point of take-off was subtracted from the climb pressure altitudes. For the en-route condition, the average pressure altitude of the take-off and landing points was subtracted from the en-route pressure altitudes. For the descent condition, the pressure altitude at the point of landing was subtracted from the descent pressure altitudes.

The evaluation of the accelerometer trace consisted in counting all acceleration increments above a threshold of ±0.3g. In addition, all acceleration increments above 0.5g and their corresponding airspeeds and altitudes were tabulated. Comparison of the frequency distribution of positive and negative gusts on several of the records indicated that the differences were minor. It was assumed in this analysis, therefore, that positive and negative acceleration increments occurred with equal frequency, and hence/they have been combined.

The effective gust velocities were evaluated from the acceleration increment and the associated airspeed by means of the sharp-edge gust equation:

$$U_e = \frac{2W\,\Delta n}{K\rho_o V_e aS}$$

where

Δn acceleration increment measured at center of gravity, g units

ρ_o sea-level density of air (0.238×10^{-3} slug per cubic ft)

K gust alleviation factor (fig. 1 of reference 1)

a slope of lift curve per radian

W operating weight, pounds

S wing area, square feet

U_e effective gust velocity, feet per second

V_e equivalent airspeed, feet per second

Since detailed information on the operating weights was not available, an average operating weight of 85 percent of gross weight, which available information indicates as representative, was used in the evaluation of effective gust velocities.

The determination of the airplane gust and gust-load history from center-of-gravity measurements of acceleration can be influenced by dynamic effects of wing flexibility on such measurements. A flight investigation of the effect of transient wing response in rough air upon acceleration measurements at the center of gravity of this type of airplane was reported in reference 4. The results indicated that under dynamic conditions the center-of-gravity measurements of acceleration increments in rough air are about 20 percent higher, on the average, than the wing nodal-point accelerations, which are considered to be more representative of the airplane accelerations. This 20-percent amplification appeared to be independent of the weight and speed of the airplane. The results of reference 4 were applied in the present investigation and the airplane acceleration increments Δn^* were obtained from the center-of-gravity measurements Δn by the relation

$$\Delta n^* = \frac{\Delta n}{1.2}$$

In order to preserve the integrity of the original data for the purpose of statistical calculations, the center-of-gravity accelerations Δn are given in the tables. In the figures, however, the corrected airplane accelerations Δn^* and the corresponding gust velocities U_e^* are used.

The distributions of airspeed were obtained from a tabulation of the indicated airspeeds at 1-minute intervals. This simple, rapid procedure has been found to give a good approximation of the distribution obtained by a more detailed evaluation.

RESULTS

Distribution of acceleration increments.- The frequency distribution of acceleration increments by altitude brackets of 5000 feet for the last nine records was evaluated and the results are summarized in table II. These results are considered representative of the present tests. The frequency distributions of acceleration increment Δn by flight condition and season of the year for the entire sample are summarized in tables III and IV, respectively. The over-all cumulative frequency distribution of Δn^* (fig. 4) indicates the number of times a given value of acceleration increment Δn^* was exceeded. The smooth curve shown in the figure represents a faired line inasmuch as the distribution appeared to follow no simple analytic form.

Distribution of effective gust velocity.- The frequency distributions of effective gust velocity for 5000-foot altitude brackets, flight condition, and season of the year are summarized in tables V, VI, and VII, respectively. These distributions were based on the evaluation of gust velocities for acceleration increments greater than 0.5g. The over-all cumulative frequency distribution of U_e^* is shown in figure 5. For comparison, estimates of the frequency distribution of U_e^* for the present tests based on the A and B distribution curves of reference 1 and the average path ratio of 0.1 derived therein are also shown on the figure. The cumulative frequency distributions of U_e^* by altitude, flight condition, and season of the year are shown in figures 6 to 8 in terms of the average frequency with which given values of U_e^* were exceeded per mile of flight.

The procedure of evaluating gust velocities for only the acceleration increments Δn^* based on values of Δn greater than 0.5g necessarily yields incomplete counts of the lower gust velocities U_e^* (7 to roughly 10 feet per second). Additional gusts of these magnitudes undoubtedly occurred at lower-than-average airspeeds and higher-than-average airplane weights and accordingly yielded acceleration increments below 0.5g. These gusts consequently were not evaluated. In order to correct the results for this deficiency and extend the data to lower values of gust velocity, the average gust velocity corresponding to $\Delta n^* = 0.25g$ (the frequency of which is known) was estimated from the sharp-edge gust equation for an airspeed of 200 miles per hour, the approximate average speed in rough air for the present data. The result (roughly 5 feet per second) is plotted in figure 5.

Distribution of airspeed.- Figure 9 gives the frequency distribution of airspeed for each flight condition. In order to compare these data with the airspeeds used in rough air, the distributions of airspeed at which the acceleration increments Δn greater than $\pm 0.5g$ were encountered have been plotted as dashed curves.

STATISTICAL RELIABILITY OF RESULTS

The reliability of results obtained from the sampling of operational gust-load experience depends upon two considerations, the quality and the quantity of the data collected. If interest is in a certain type of operation, the sample chosen must cover all the important conditions which make up that type of operation. The adequacy of the present sample in representing low-level transcontinental transport operations may be subject to some question because of the special restrictions placed on the operations. These restrictions were not considered to influence unduly the frequency with which gusts, particularly those of small intensity, were encountered but might have had a significant effect on the operating airspeeds in rough air.

In addition to being representative of the operations under consideration, the sample must be of sufficient size to insure that the random or sampling fluctuations are largely removed. Statistical theory provides means of arriving at quantitative estimates of the reliability of sampling results in terms of "confidence bands." Statistical methods were therefore applied to the available data to arrive at confidence bands for some of the results. The frequency distributions of Δn for each of the individual records are shown in table VIII. The frequencies with which the given values were exceeded for each record may be considered random and independent measures of the average loading frequency. The general methods of reference 5 were applied to the data of table VIII to estimate 95-percent confidence bands for the over-all distribution of Δn^* (fig. 4). These confidence bands or lines provide a measure of the over-all sampling reliability of the present results and indicate the range within which the true value (value for extended operations) may be expected with a probability of 95 percent.

DISCUSSION

Acceleration increment.- The cumulative frequency distribution indicates that roughly 20,000 acceleration increments Δn^* greater than 0.25g were experienced during the 834 hours of operation (fig. 4). The largest acceleration increment was about 1.1g and only two values were greater than 1g. The observed distribution is fairly regular and to a first approximation appears linear on the semilogarithmic plot. The data seem to indicate that the larger accelerations occur more frequently than would be expected from a linear distribution.

The 95-percent confidence bands shown in figure 4 for the present data covering 834 hours of flight cover a range of roughly 2 to 1 at 0.25g, increasing to a range of roughly 15 to 1 at about 0.6g. If the determination of the frequency of applied loads within a range of 2 to 1 is considered adequate, the present results indicate that samples of roughly 1000 hours are required to determine the loading frequency at the smaller intensities (0.25g to 0.4g). In order to obtain the same precision at higher values, say 0.6g, much larger samples of VGH data, covering perhaps 5000 hours, would be required.

Gust velocity.- The frequency distribution of U_e^* (fig. 5) indicates that roughly 20,000 gusts greater than about 5 feet per second (an average of one per 8 miles of flight) were encountered. Comparison with estimates obtained from the A and B curves of reference 1 indicates that the present results are substantially lower than would be predicted by the results of the reference. The figure shows that the gust frequency is very sensitive to a change in gust velocity; a small change in U_e^*, say 10 percent, may change the frequency by a factor of 2. The correction of the present data for dynamic-response effects and the different practices used in determining the slope of the lift curve account in large part for the differences between the present results and the A and B curves of reference 1.

Effects of altitude.- Comparison of the gust experiences for operations above and below 5000 feet above terrain (fig. 6) indicates that the frequency of encountering the smaller gusts per mile of flight is almost twice as great below 5000 feet as between 5000 and 10,000 feet. The observed differences are statistically significant, being appreciably larger than might be expected from sampling variations.

At the larger gust velocities the present data (fig. 6) suggest that the gust frequency may be greater between 5000 and 10,000 feet than below 5000 feet. This result may be due partly to the tendency of the pilot to fly at the higher altitudes when trying to avoid turbulence, but it may also be associated with the physical processes which suggest that turbulence should be more severe at the higher altitudes, where thermal currents and clouds may be expected to be more fully developed.

Flight condition.- Consideration of figure 7, in which the gust distributions are separated on the basis of the three flight conditions - climb, en route, and descent - indicates that per mile of flight the greatest number of gusts are encountered in the climb condition and the least number during the en-route condition. The greater frequency of gusts in climb and descent than in the en-route condition is statistically significant and appears to be a result of the proximity of terrain during these conditions; the greater frequency of gusts at the lower levels has been noted previously. The differences between the climb and descent conditions appear small and may be the result of some systematic discrepancy in the evaluation.

Season of the year.- The separation of the data by season (fig. 8) indicates that at the lower gust velocities (9 to 11 feet per second) fewer gusts per mile of flight were encountered during the summer season than during any of the other seasons considered. The frequency of gust encounters for the summer season averaged roughly half the frequency for each of the other two seasons, whereas the largest number of small gusts per mile of flight was experienced during the spring season. These results are somewhat surprising since it might be expected that turbulence would be most frequent during the summer season when convective activity is at its highest. Figure 3 indicates that the pilots had some tendency to fly at higher altitudes during the summer. If this higher altitude level for summer flying is the result of attempts to climb above low-level rough air, the present indications that the frequency of the lower gust velocities is least for the summer season may be due largely to the operational practices and may not reflect the real differences in the frequency of turbulence between seasons.

The data of figure 8 indicate that the larger gust velocities were encountered most frequently during the fall season and least frequently during the summer season. These results may be due in part to the higher winds during the spring and fall, particularly over mountainous terrain. Another factor probably of importance is the prevalence during the fall and spring seasons in the United States of well-developed convective clouds, associated with frontal systems and squall lines, which are difficult to avoid. In contrast, the generally more isolated thunderstorms of the summer months are, as a rule, easily circumnavigated.

The absence of data for the winter season is unfortunate, since unpublished V-G data indicate that this season may be the most turbulent for the present type of operations. As a consequence, the present results may underestimate the over-all gust frequency. The discrepancy is estimated, however, to be at most 20 percent of the gust frequency.

Airspeed.- The airspeed distributions of figure 9 indicate that for any given flight condition appreciable variations in airspeed exist. As expected, the climb speeds are in general lower than the en-route and descent speeds. The very low speeds noted during the descent, ranging from 120 miles per hour to perhaps 160 miles per hour, are probably associated with maneuvering during approach and landing, which under the present classification was included in the descent condition.

Comparison of the over-all distributions of airspeed with the distribution of airspeeds at which accelerations greater than 0.5g were encountered indicates that some reduction of airspeed was practiced in rough air during the descent and en-route conditions. These reductions do not appear consistent and were probably influenced by the gust intensity, but they appear to average about 15 and 20 miles per hour for the en-route and descent conditions, respectively. The small magnitude of the average airspeed reduction is probably due in part to the pilots' inability to anticipate rough air and also to the time required to slow down once rough air is encountered. For the climb condition, the results indicate that the pilots had a tendency to increase airspeed in rough air. This increase is probably due to the pilots' desire to maintain better control and avoid an accidental stall.

These results support previous indications that in normal transport operations many pilots reduce airspeed in rough air during descent and en route. The reduction of airspeed in the present data is, however, not large, averaging only about 10 percent of the average airspeed.

Over-all gust history.- Structural design considerations require an estimate of the gust history for the entire life of an airplane. As previously mentioned, VGH records do not provide a very practical means of obtaining information on the frequency of the larger gust velocities because of the large sample sizes required to obtain reliable estimates. V-G records for the present airplane type, flying the same route, are available for some 40,000 hours of operation. The information on the frequency of encountering gusts of various intensities, obtained from the present VGH data and the V-G data, is summarized in figure 10 in terms of the average flight miles required to exceed given values of effective gust velocity. The values were obtained by dividing the total number of miles flown by the number of times given values of gust velocity were exceeded. Although the results for the two sets of data are not directly comparable, owing to differences in evaluation techniques, theoretical considerations indicate that they should be asymptotic near the largest value recorded in the V-G data. The faired line in figure 10 indicates the approximate relation over the entire range of U_e^* and takes into account the tendency of V-G data, due to the envelope nature of the record, to underestimate the frequency of all but the largest gust velocity encountered. The results shown indicate that the average number of flight miles required to exceed values of U_e^* increases rapidly from about 8 miles for gusts of 5 feet per second to 20,000 miles for gusts of 20 feet per second and 4,000,000 miles for gusts of 40 feet per second.

The V-G data seem to reflect somewhat higher gust velocities than the VGH data (fig. 10). This result may be partly due to the absence of VGH data for what may be the most turbulent portion of the year, the winter season, but it may also be the result of the evaluation techniques used in deriving gust data from V-G records.

Limitations.- The present results represent conditions for low-level operations over land in a temperate climate and are not applicable to airplanes operating under other conditions, such as at higher altitudes and over water routes, since available evidence suggests that the gust experience and operating conditions may be very different for these operations. A need therefore exists for additional data on the frequency of gustiness and the operating practices for these other types of operations.

SUMMARY OF RESULTS

An evaluation of 834 hours of VGH records from normal operations of a low-altitude transcontinental transport airplane has yielded the following results:

1. Roughly 20,000 acceleration increments greater than 0.25g and effective gust velocities greater than 5 feet per second (an average of one per 8 miles of flight) were encountered during the operations.

2. A synthesis of V-G and VGH data for the present operation, made in order to extend the VGH results to the larger gust velocities, indicates that the average number of miles required to exceed various effective gust velocities were: 8 miles for gusts greater than 5 feet per second, 20,000 miles for gusts greater than 20 feet per second, and 4,000,000 miles for gusts greater than 40 feet per second.

3. Between altitudes of 5,000 and 10,000 feet above terrain, about one-half as many gusts per mile of flight were encountered as at altitudes below 5,000 feet.

4. The least number of gusts per mile of flight were encountered during the en-route flight condition, for which the gust frequency averaged roughly one-third to one-half that for the climb and descent conditions.

5. For the three seasons covered by the present data (winter excluded), the least number of gusts per mile of flight were encountered during the summer months, when the average gust frequency was about half as great as during the spring and fall months.

6. The airspeeds in rough air during the en-route and descent conditions were on the average about 10 percent lower than the over-all airspeeds for each condition. During the climb condition, however, the airspeeds in rough air were on the average higher than the over-all airspeeds in that condition.

7. Sample sizes of the order of 1000 hours of time-history record permit the determination of the gust-loading frequencies for the smaller intensities (0.25g to 0.4g) within a range of frequency of about 2 to 1. Much larger sample sizes are required, however, to obtain the same precision at the higher intensities.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., November 19, 1951

REFERENCES

1. Rhode, Richard V., and Donely, Philip: Frequency of Occurrence of Atmospheric Gusts and of Related Loads on Airplane Structures. NACA ARR L4I21, 1944.

2. Richardson, Norman R.: NACA VGH Recorder. NACA TN 2265, 1951.

3. Steiner, Roy, and McDougal, Robert L.: Summary of Normal Accelerations, Gust Velocities, and Operating Practices from April to August 1949 of a Twin-Engine Airplane in Commercial Transport Operations. NACA RM L50B02, 1950.

4. Shufflebarger, C. C., and Mickleboro, Harry C.: Flight Investigation of the Effect of Transient Wing Response on Measured Accelerations of a Modern Transport Airplane in Rough Air. NACA TN 2150, 1950.

5. Hoel, Paul G.: Introduction to Mathematical Statistics. John Wiley & Sons, Inc., 1947.

TABLE I

SCOPE OF VGH RECORDS

Record number	Date installed	Date removed	Number of flights	Number of hours	Average indicated airspeed (mph)	Indicated flight miles
1	[a]4-15-49	[a]5-1-49	75	65.2	197.3	12.9×10^3
2	5-1-49	5-13-49	71	63.6	202.0	12.8
3	[a]5-13-49	[a]5-19-49	36	34.9	201.6	7.0
4	[a]6-28-49	[a]7-10-49	66	65.9	201.2	13.3
5	[a]8-5-49	[a]8-17-49	51	51.9	196.4	10.2
6	[a]8-17-49	8-30-49	72	65.3	199.3	13.0
7	[a]8-30-49	9-8-49	70	61.1	199.8	12.2
9	[a]9-25-49	[a]10-2-49	71	64.7	202.3	13.1
10	[a]10-2-49	10-10-49	66	62.8	201.8	12.7
11	[a]10-13-49	10-26-49	66	61.2	207.9	12.7
12	[a]10-26-49	11-5-49	63	61.1	210.6	12.9
13	[a]11-6-49	11-19-49	71	58.1	203.0	11.8
14	11-19-49	12-1-49	56	61.0	207.0	12.6
15	12-1-49	12-16-49	60	57.1	209.4	12.0
Total	---------	--------	894	833.9	-----	169.2×10^3
Average	---------	--------	64	59.6	[b]202.8	12.1×10^3

[a]Estimated date.

[b]Weighted average.

TABLE II

FREQUENCY DISTRIBUTION OF ACCELERATION INCREMENTS BY ALTITUDE ABOVE TERRAIN

[Last nine records]

Δn (g units)	Frequency distribution		Total
	0 to 5000 ft	5000 to 10,000 ft	
0.30 to 0.49	10,370	1472	11,842
.50 to .59	400	91	491
.60 to .69	126	32	158
.70 to .79	38	13	51
.80 to .89	14	5	19
.90 to .99	10	6	16
1.00 to 1.09	3	0	3
1.10 to 1.19	0	1	1
1.20 to 1.29	0	1	1
1.30 to 1.39	1	0	1
Total	10,962	1621	12,583
Distance flown (miles)	77.6×10^3	35.4×10^3	113.0×10^3

NACA

TABLE III

FREQUENCY DISTRIBUTION OF ACCELERATION INCREMENT

BY FLIGHT CONDITION

Δn (g units)	Frequency distribution			Total
	Climb	En route	Descent	
0.30 to 0.49	1655	8311	9440	19,406
.50 to .59	58	400	368	826
.60 to .69	27	127	99	253
.70 to .79	8	36	33	77
.80 to .89	3	9	9	21
.90 to .99	3	13	3	19
1.00 to 1.09	1	1	1	3
1.10 to 1.19	0	2	0	2
1.20 to 1.29	0	1	0	1
1.30 to 1.39	1	0	0	1
Total	1756	8900	9953	20,609
Distance flown (miles)	12.8×10^3	109.7×10^3	46.7×10^3	169.2×10^3

NACA

TABLE IV

FREQUENCY DISTRIBUTION OF ACCELERATION INCREMENT BY

SEASON OF THE YEAR

Δn (g units)	Frequency distribution			Total
	Spring 3-21 to 6-21	Summer 6-21 to 9-21	Fall 9-21 to 12-21	
0.30 to 0.49	5849	4081	9,476	19,406
.50 to .59	238	170	418	826
.60 to .69	71	46	136	253
.70 to .79	22	12	43	77
.80 to .89	2	2	17	21
.90 to .99	3	0	16	19
1.00 to 1.09	0	0	3	3
1.10 to 1.19	1	0	1	2
1.20 to 1.29	0	0	1	1
1.30 to 1.39	0	0	1	1
Total	6186	4311	10,112	20,609
Distance flown (miles)	32.7×10^3	48.7×10^3	87.8×10^3	169.2×10^3

NACA

TABLE V

FREQUENCY DISTRIBUTION OF EFFECTIVE GUST VELOCITY BY

ALTITUDE ABOVE TERRAIN

U_e (fps)	Frequency distribution		Total
	0 to 5000 ft	5000 to 10,000 ft	
9.0 to 9.9	113	24	137
10.0 to 10.9	122	35	157
11.0 to 11.9	88	37	125
12.0 to 12.9	61	21	82
13.0 to 13.9	50	7	57
14.0 to 14.9	35	7	42
15.0 to 15.9	28	3	31
16.0 to 16.9	5	3	8
17.0 to 17.9	5	4	9
18.0 to 18.9	9	1	10
19.0 to 19.9	7	0	7
20.0 to 20.9	3	2	5
21.0 to 21.9	3	1	4
22.0 to 22.9	2	1	3
23.0 to 23.9	0	1	1
28.0 to 28.9	1	0	1
Total	532	147	679
Distance flown (miles)	77.6×10^3	35.4×10^3	113.0×10^3

NACA

TABLE VI

FREQUENCY DISTRIBUTION OF EFFECTIVE GUST

VELOCITY BY FLIGHT CONDITION

U_e (fps)	Frequency distribution			Total
	Climb	En route	Descent	
9.0 to 9.9	4	139	62	205
10.0 to 10.9	10	160	151	321
11.0 to 11.9	22	86	100	208
12.0 to 12.9	12	84	58	154
13.0 to 13.9	21	34	42	97
14.0 to 14.9	11	19	28	58
15.0 to 15.9	10	15	17	42
16.0 to 16.9	3	4	4	11
17.0 to 17.9	1	6	6	13
18.0 to 18.9	2	6	2	10
19.0 to 19.9	1	3	3	7
20.0 to 20.9	2	2	1	5
21.0 to 21.9	1	2	1	4
22.0 to 22.9	0	2	1	3
23.0 to 23.9	0	1	0	1
28.0 to 28.9	1	0	0	1
Total	101	563	476	1140
Distance flown (miles)	12.8×10^3	109.7×10^3	46.7×10^3	169.2×10^3

NACA

TABLE VII

FREQUENCY DISTRIBUTION OF EFFECTIVE GUST

VELOCITY BY SEASON OF THE YEAR

U_e (fps)	Frequency distribution			Total
	Spring 3-21 to 6-21	Summer 6-21 to 9-21	Fall 9-21 to 12-21	
9.0 to 9.9	36	54	115	205
10.0 to 10.9	120	72	129	321
11.0 to 11.9	62	45	101	208
12.0 to 12.9	57	30	67	154
13.0 to 13.9	29	16	52	97
14.0 to 14.9	15	2	41	58
15.0 to 15.9	10	4	28	42
16.0 to 16.9	3	1	7	11
17.0 to 17.9	4	0	9	13
18.0 to 18.9	0	1	9	10
19.0 to 19.9	0	0	7	7
20.0 to 20.9	0	1	4	5
21.0 to 21.9	0	0	4	4
22.0 to 22.9	1	0	2	3
23.0 to 23.9	0	0	1	1
28.0 to 28.9	0	0	1	1
Total	337	226	577	1140
Distance flown (miles)	32.8×10^3	48.7×10^3	87.7×10^3	169.2×10^3

NACA

TABLE VIII

FREQUENCY DISTRIBUTIONS OF ACCELERATION INCREMENTS FOR INDIVIDUAL RECORDS

Δn (g units)	Frequency distribution for record -														Total
	1	2	3	4	5	6	7	9	10	11	12	13	14	15	
0.30 to 0.49	2827	2419	603	503	1212	1260	1106	985	3313	1204	1116	519	1477	862	19,406
0.50 to 0.59	130	92	16	29	68	34	39	43	159	37	39	14	105	21	826
0.60 to 0.69	41	28	2	10	14	12	10	9	82	6	10	0	24	5	253
0.70 to 0.79	5	15	2	2	2	6	2	4	24	1	1	2	10	1	77
0.80 to 0.89	0	2	0	0	0	1	1	1	13	1	1	0	1	0	21
0.90 to 0.99	0	1	2	0	0	0	0	0	12	0	1	0	3	0	19
1.00 to 1.09	0	0	0	0	0	0	0	0	2	0	0	0	1	0	3
1.10 to 1.19	1	0	0	0	0	0	0	0	1	0	0	0	0	0	2
1.20 to 1.29	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
1.30 to 1.39	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Total	3004	2557	625	544	1296	1313	1158	1042	3608	1249	1168	535	1621	889	20,609
Distance flown (miles)	12.9×10^3	12.8×10^3	7.0×10^3	13.3×10^3	10.2×10^3	13.0×10^3	12.2×10^3	13.1×10^3	12.7×10^3	12.7×10^3	12.9×10^3	11.8×10^3	12.6×10^3	12.0×10^3	169.2×10^3

NACA

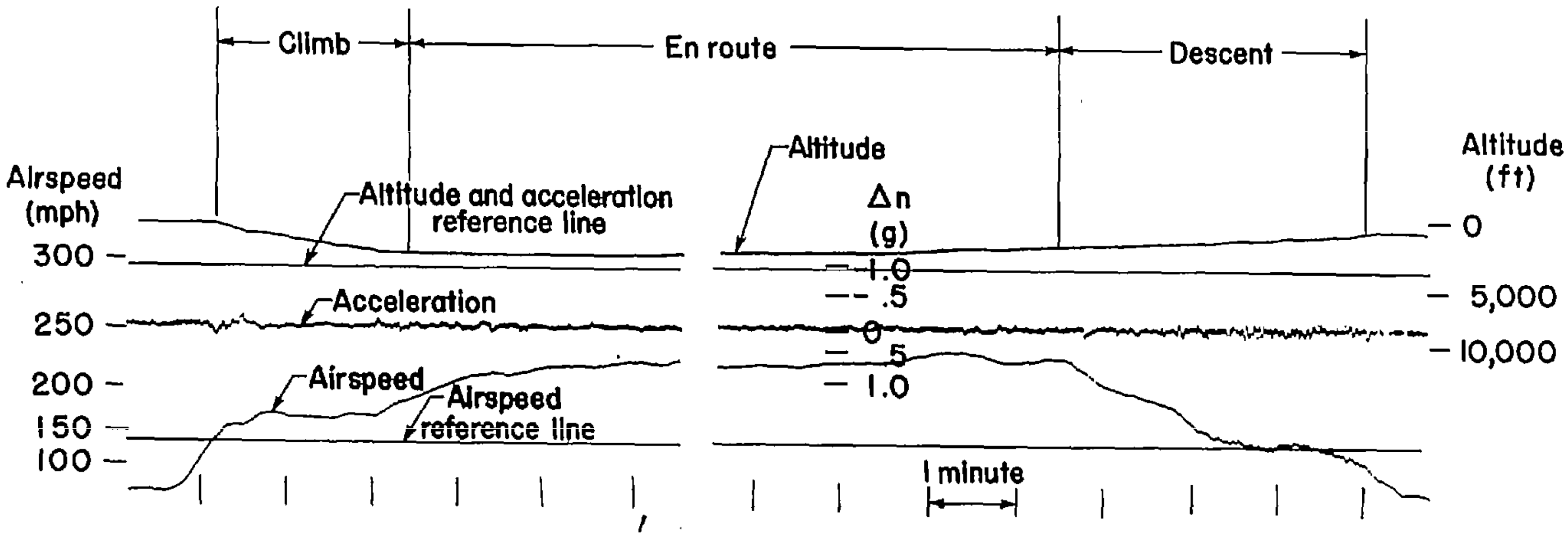

Figure 1.- Sample VGH record.

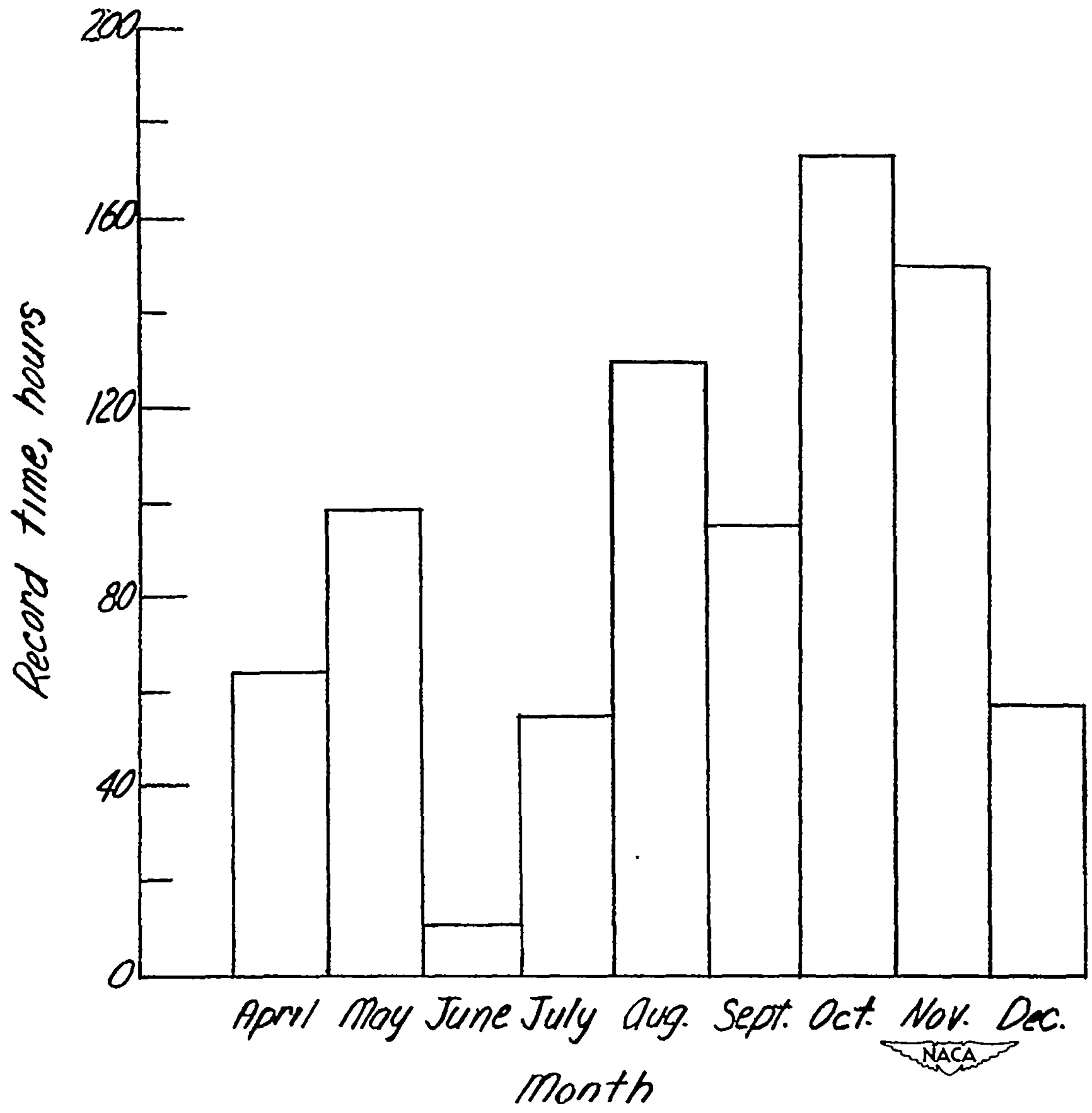

Figure 2.- Number of hours of VGH record obtained each month.

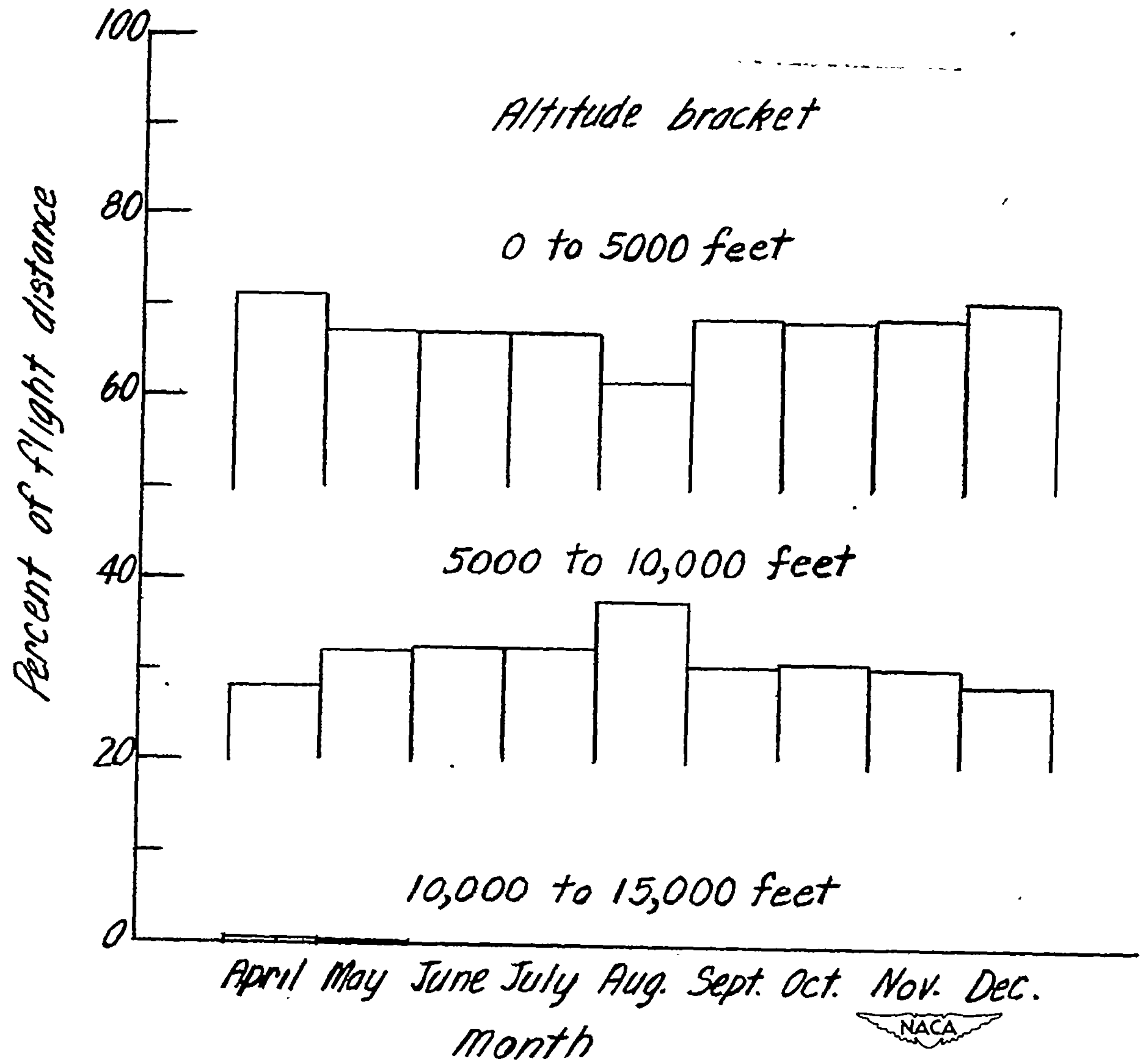

Figure 3.- Distribution of percent of flight distance by altitude for each month.

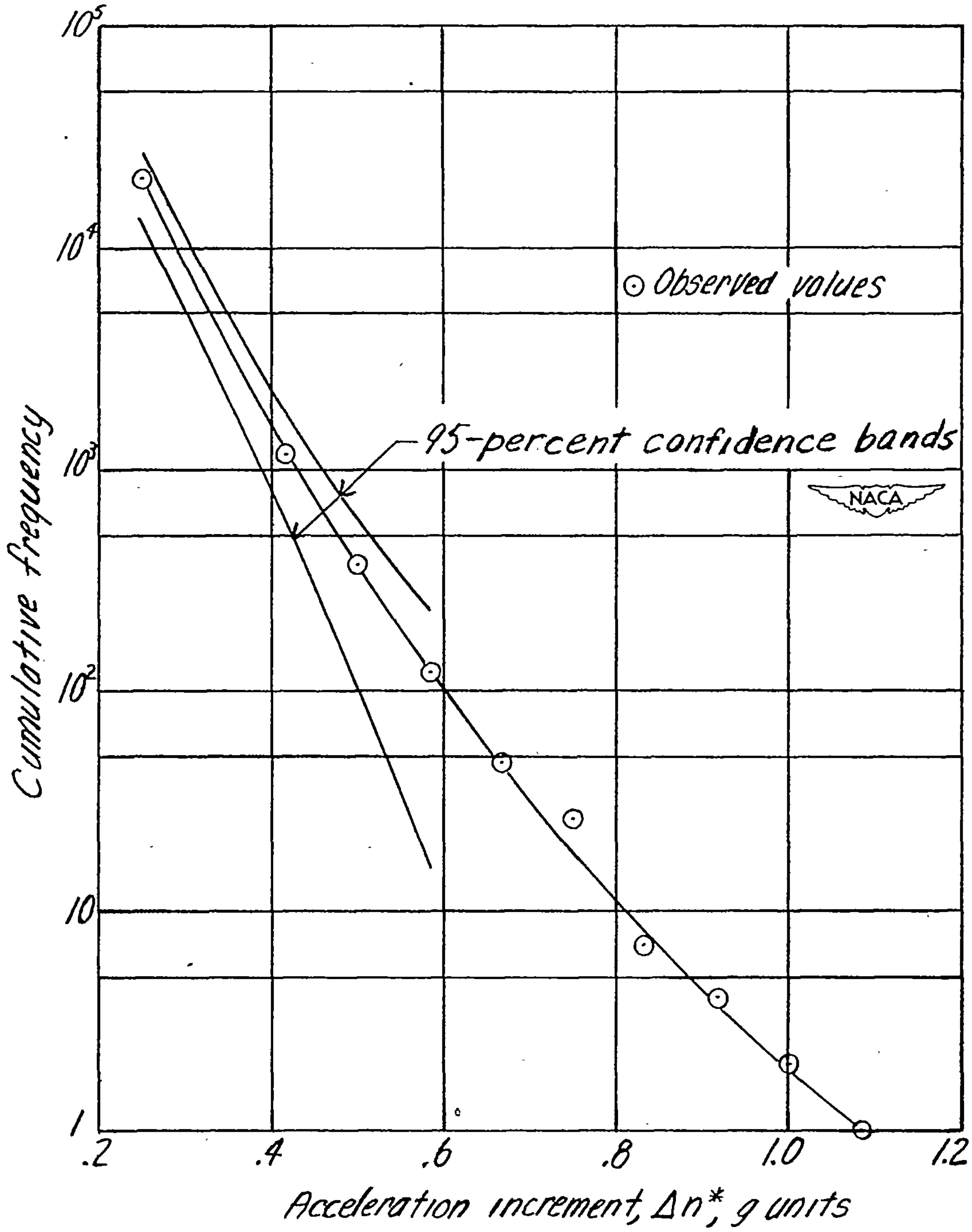

Figure 4.- Cumulative frequency distribution of acceleration increment for 169.2×10^3 miles of flight.

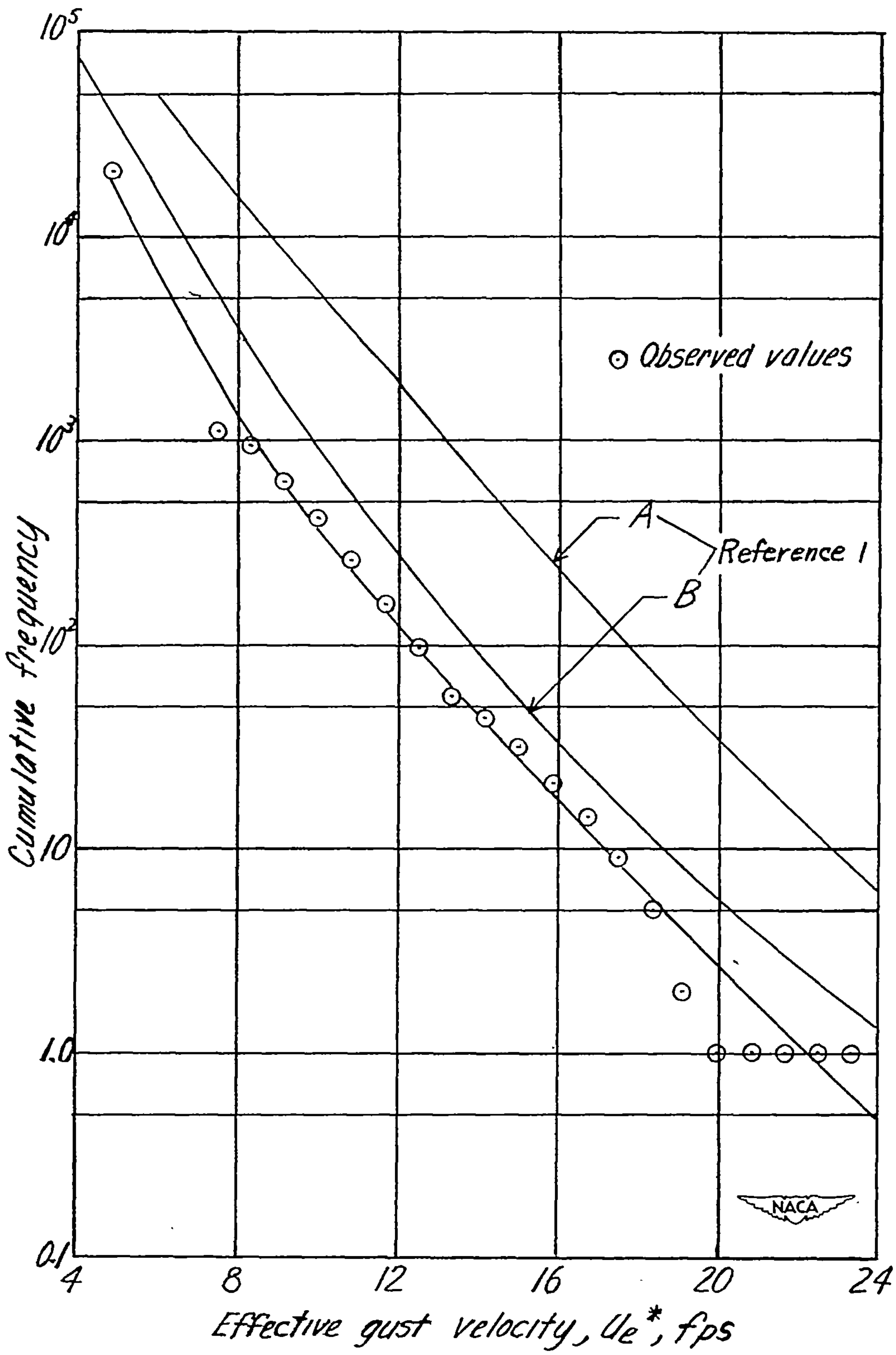

Figure 5.- Cumulative frequency distribution of effective gust velocity for 169.2×10^3 miles of flight.

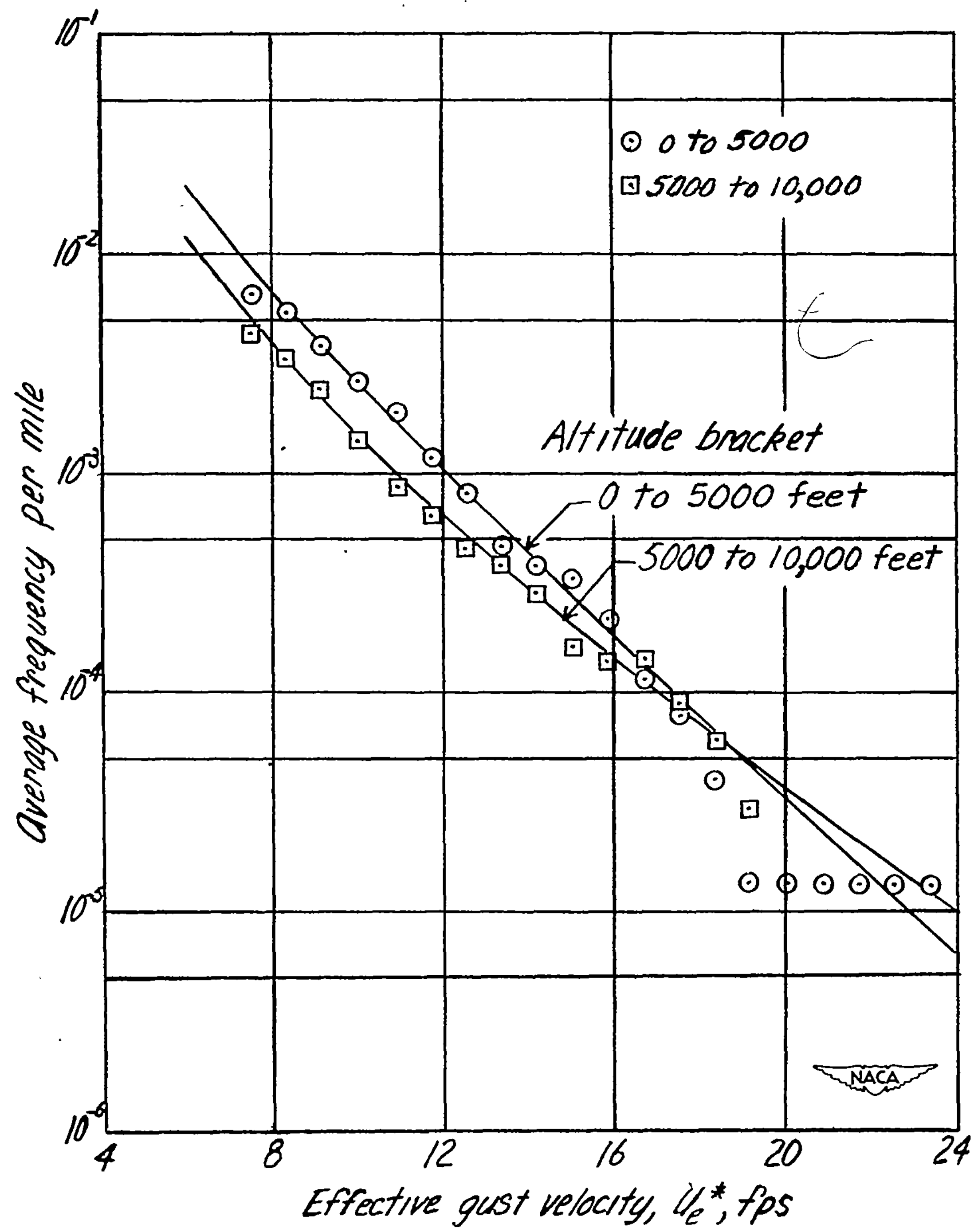

Figure 6.- Average frequency of exceeding given values of effective gust velocity per mile of flight by altitude.

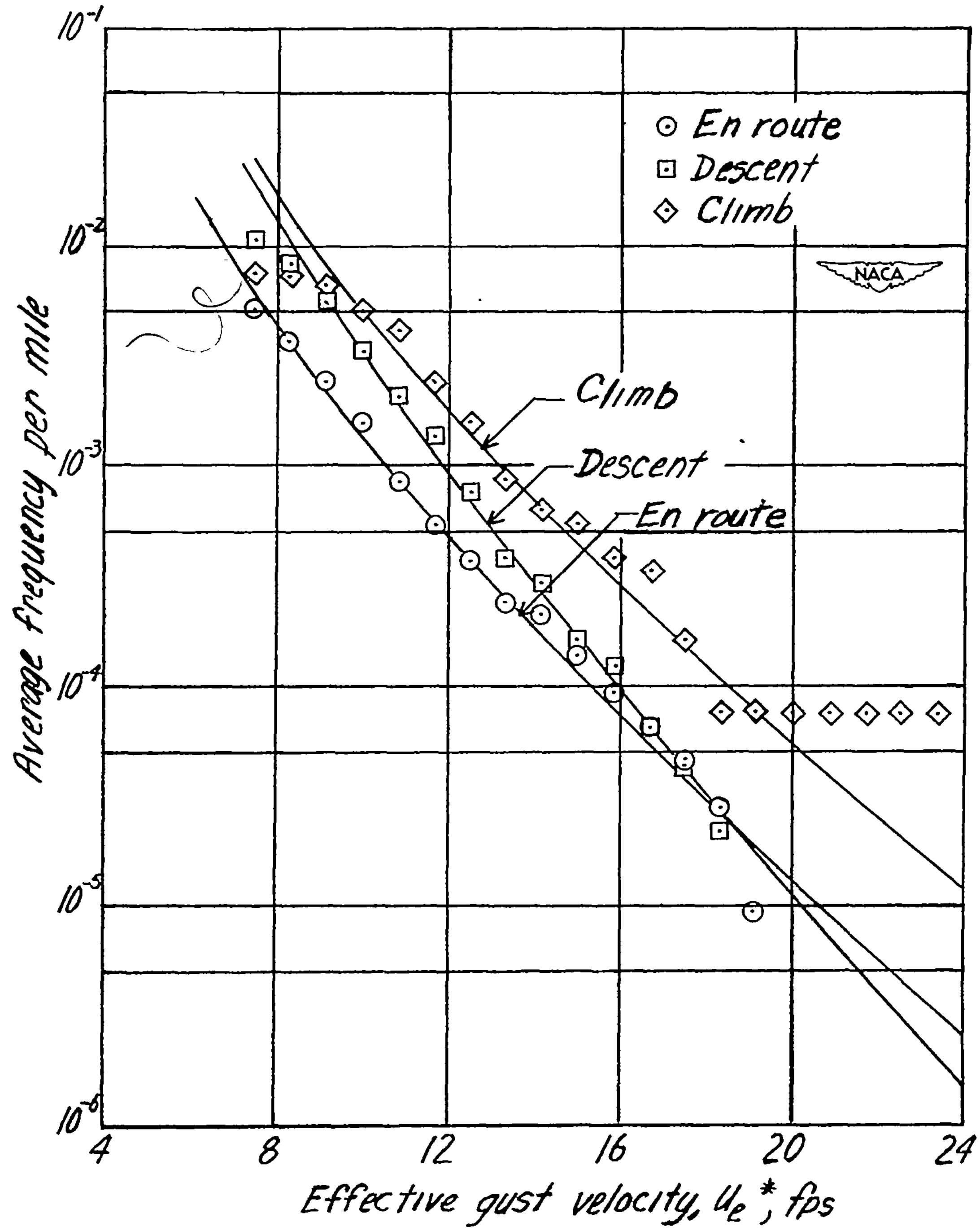

Figure 7.- Average frequency of exceeding given values of effective gust velocity per mile of flight by flight condition.

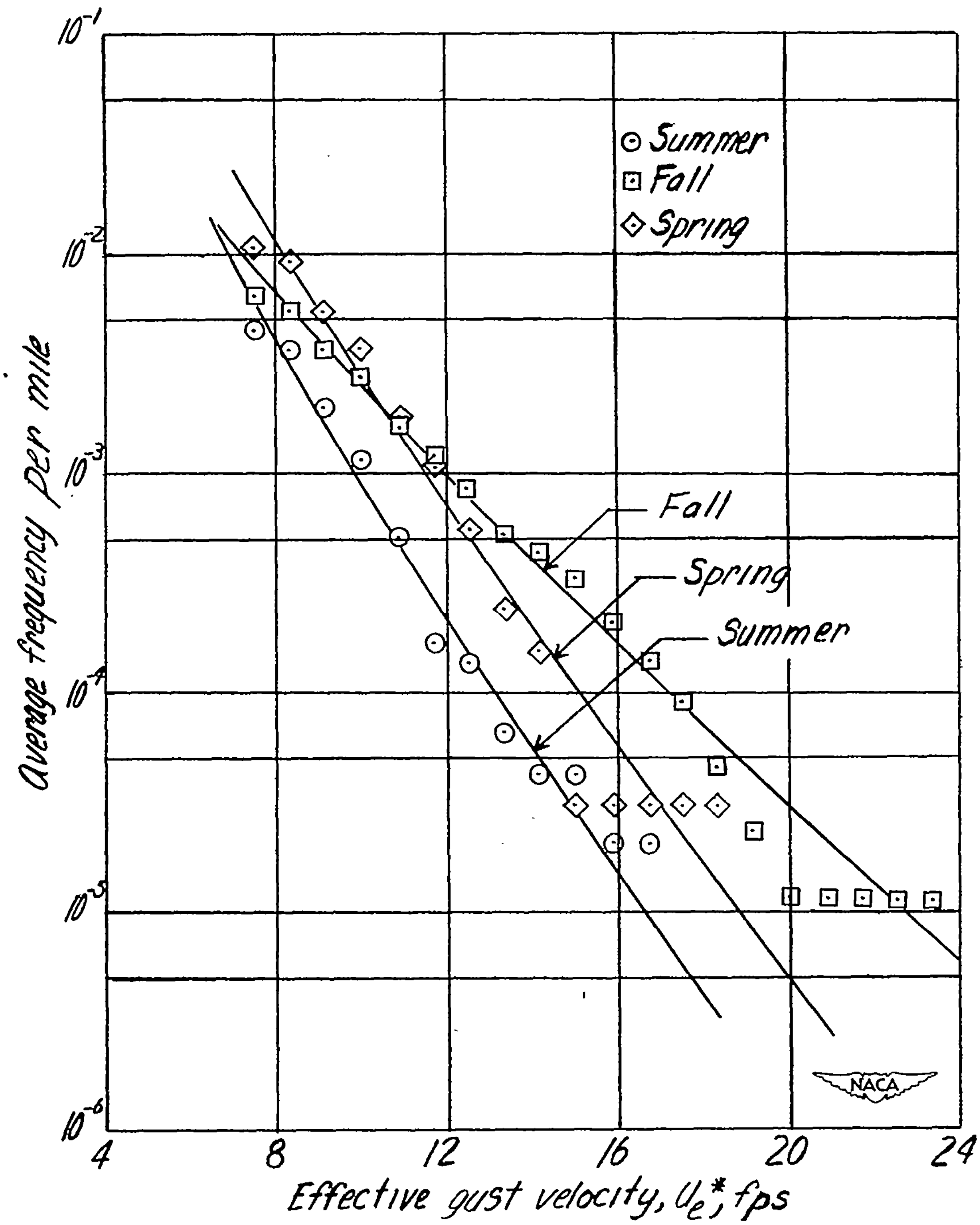

Figure 8.- Average frequency of exceeding given values of effective gust velocity per mile of flight by season.

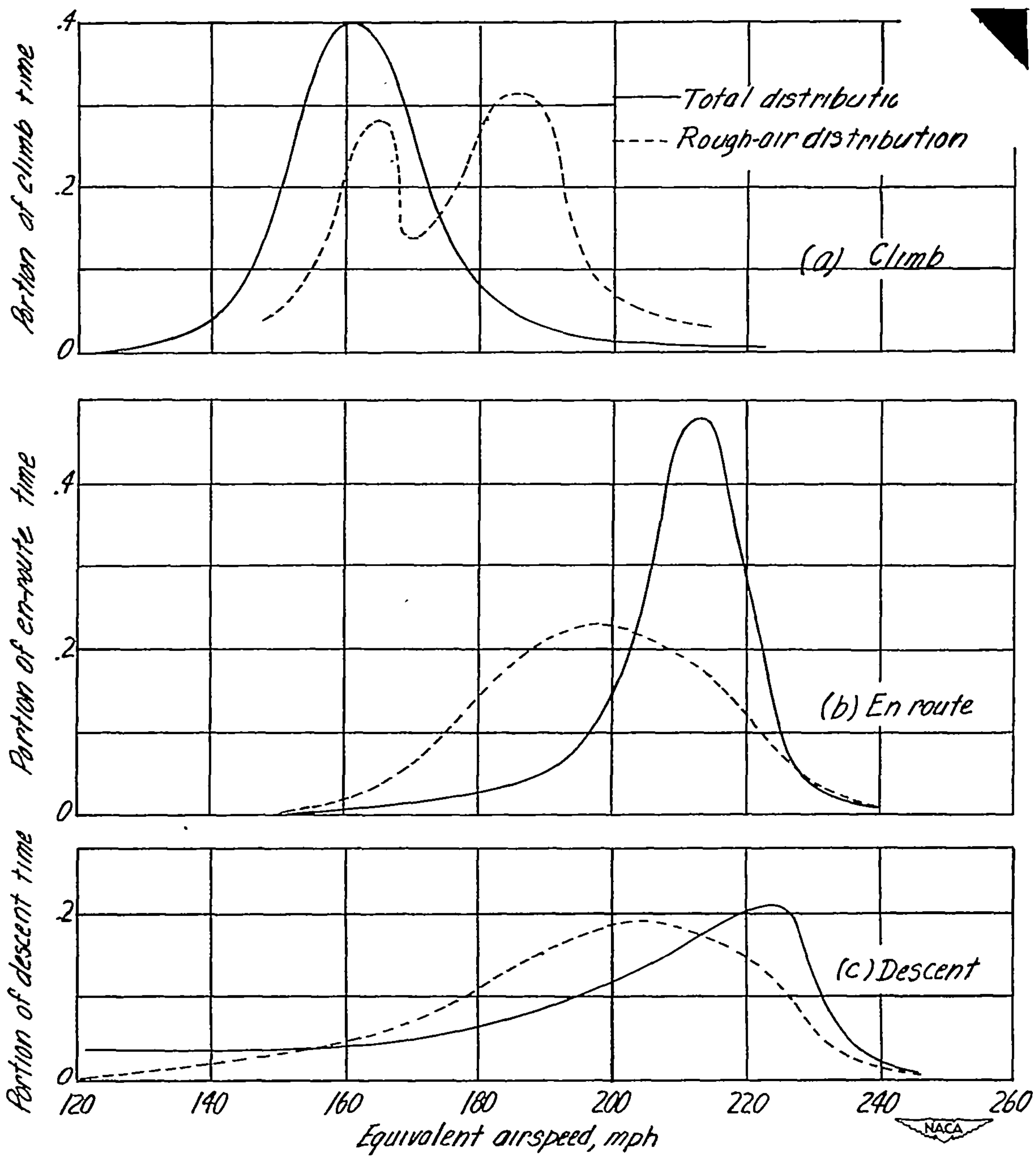

Figure 9.- Comparison of distribution of over-all airspeed with the distribution of airspeed in rough air by flight condition.

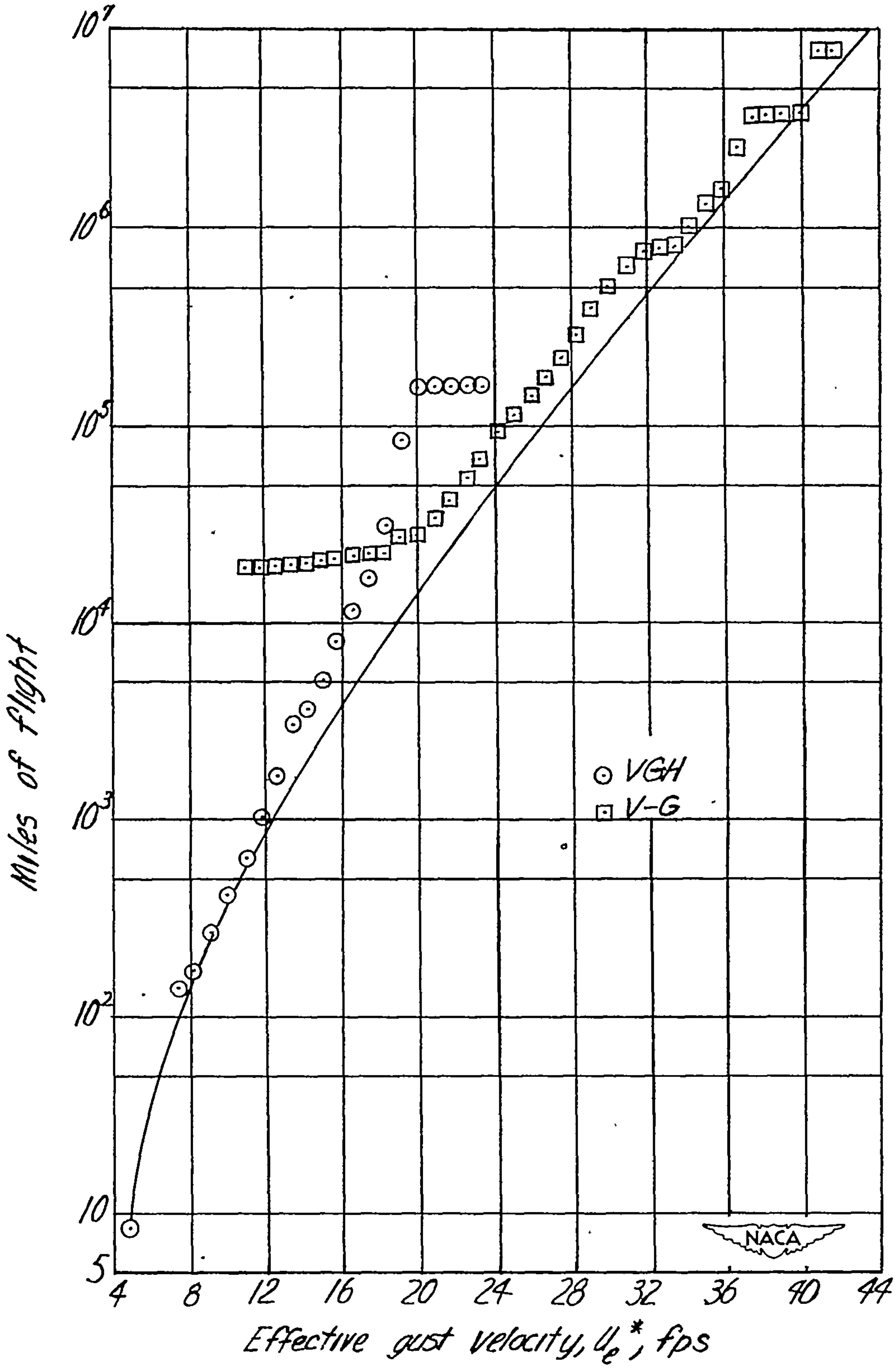

Figure 10.- Composite curve of the miles to equal or exceed a given gust velocity.

NACA-Langley - 4-22-52 - 1000