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A REEVALUATION OF GUST-LOAD STATISTICS FOR APPLICATIONS IN SPECTRAL CALCULATIONS

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SUMMARY

The available information on the spectrum of atmospheric turbulence is briefly reviewed. On the basis of these results, a method is developed for the conversion of available gust statistics normally given in terms of counts of gust peaks into a form appropriate for use in spectral calculations. The fundamental quantity for this purpose appears to be the probability distribution of the root-mean-square gust velocity. Estimates of the variation of this distribution with altitude and weather condition are also derived from available gust statistics.

INTRODUCTION

During the last 20 years, a considerable body of statistical data on the gust and load experience of airplanes in transport operations and in special flight tests has been collected by the National Advisory Committee for Aeronautics. These data have in the past, for simplicity, been reduced on the basis of simple airplane gust-response theory and the so-called "effective gust velocities" determined. In the last few years, it has been considered desirable to redefine these gust velocities in order to account more fully for the variations with altitude in the airplane response to gusts. The term "derived gust velocities" (ref. 1) has been applied to these redefined values, and the conversion of the gust data into this form is now largely completed (see, for example, refs. 2, 3, and 4). The gust data in this form have been analyzed in detail, and the airplane gust experience for various types of operations and for various flight altitudes and weather conditions has been established (ref. 5). These results are finding useful application in the calculation of gust loads for arbitrary flight plans.

Even more recently, it has been desirable in many gust-response problems both to account explicitly for the continuous character of atmospheric turbulence and to account in greater detail for the airplane dynamics. For this purpose, the techniques of generalized harmonic analysis or spectrum analysis appear particularly appropriate and they are finding increasing application (refs. 6 to 15). The application of these techniques to the gust-load design problem requires detailed information on the spectral characteristics of atmospheric turbulence. The purpose of this paper is to describe the information available on the spectral characteristics of atmospheric turbulence and, in particular, to adapt the large amount of statistical data on gust loads already available into a form suitable for use in spectral calculations. First, the available measurements of the spectrum of atmospheric turbulence are reviewed. Then, a technique for the reevaluation of the gust statistics is outlined and some results obtained by the application of this technique are presented.

SPECTRAL CHARACTERISTICS OF ATMOSPHERIC TURBULENCE

Figure 1 contains a summary of most of the available airplane measurements of the power spectrum of atmospheric turbulence. The first of these measurements was made by Clementson at the Massachusetts Institute of Technology (ref. 6) and subsequent measurements were made by the National Advisory Committee for Aeronautics (refs. 10 and 11), the Douglas Aircraft Company, Inc. (ref. 12), and Summers at the Massachusetts Institute of Technology (ref. 13). The curves shown represent the various power spectra and were obtained under different weather conditions. The abscissa is the frequency argument Ω which has the dimensions of radians per foot and is equal to 2π divided by λ, the gust wavelength. (The data shown cover a range of gust wavelengths from about 10 feet to 3,000 feet.) The ordinate is the power density normalized to the power-density values at $\Omega = 0.01$. This normalized ordinate is used in order to facilitate comparison of the various spectral shapes.

The spectra in all but one case are for the vertical component of the turbulence. In one case marked by the letter H, the spectrum is for the horizontal or longitudinal component of turbulence. Examination of these results indicates that the spectral shapes appear to be relatively consistent; in all cases, the power decreases rapidly with increasing frequency. In fact, in most cases, the spectra appear to be inversely proportional to the square of the frequency. This spectral shape of $1/\Omega^2$ is in reasonable agreement with theoretical results obtained for the spectral shape at the higher frequencies in the theory of isotropic turbulence. At the lower frequencies, the situation is not so clear, few measurements being available for frequencies of $\Omega < 0.005$. Some additional measurements obtained at the Cornell Aeronautical Laboratory do cover these lower frequencies and indicate a flattening of the spectrum in this frequency region.

In addition to these variations in spectral shape, the various measurements also differ in turbulence intensity. The individual root-mean-square values are estimated to vary from roughly 1.5 to perhaps 8 feet per second, which, as will be seen, represent the relatively lighter levels of atmospheric turbulence.

Another source of information on the spectral characteristics of atmospheric turbulence is the measurements at lower altitudes made from meteorological towers. A large number of such spectral measurements have now been obtained. A few representative measurements from reference 16 are shown in figure 2 and were obtained at an elevation of about 300 feet and for various conditions of average wind speed V as shown in figure 2. These measurements extend to lower frequencies (longer gust wave lengths) than the available airplane measurements. At the higher frequencies these results approximate the same $1/\Omega^2$ form, characteristic of the airplane measurements. In addition, at the lower frequencies, a definite tendency toward a flattening of the spectra can be noted. The variation in the spectrum intensity with wind speed should also be noted.

Because of the general characteristics of these spectral measurements, it has been convenient in theoretical studies to use the following analytical expression for the turbulence spectrum

$$\Phi(\Omega) = \sigma_U^2 \frac{L}{\pi} \frac{1 + 3\Omega^2 L^2}{\left(1 + \Omega^2 L^2\right)^2} \tag{1}$$

where $\Omega = 2\pi/\lambda$ and λ is the gust wavelength. This expression has been useful in wind-tunnel studies of turbulence and, as will be seen, has the general characteristics of the measured spectra of atmospheric turbulence. The equation has two parameters: the mean-square gust velocity σ_U^2 which describes the overall intensity, and the so-called scale of turbulence L which, in a rough sense, can be considered to be proportional to the average eddy size. Curves for this expression are shown in figure 3 for values of L of 200, 600, and 1,000 feet. At higher frequencies, these curves all approach a shape of $1/\Omega^2$ but differ in the frequency at which the flattening occurs. For increasing values of L, the curves flatten out at lower frequencies. Comparison of these curves with those of figures 1 and 2 and other measurements of the spectrum for atmospheric turbulence has suggested that representative values of L for atmospheric turbulence are from at least several hundred feet to over 1,000 feet.

For design purposes, the overall gust experience in operations is of concern. Presumably, the overall experience consists of various exposure times to each of the spectra shown in figures 1 and 2 as well as to other spectra associated with different weather conditions. It thus appears important to determine the proportion of flight time spent under these various conditions of turbulence. In the remainder of this paper, some results derived from available gust statistics on this problem will be described. The basic approach used is described in detail in reference 14 and will only be outlined for present purposes.

RELATIONS BETWEEN PEAK COUNTS AND SPECTRA

It will be recalled that available gust-load statistical data are normally given in the form of counts of acceleration peaks exceeding given values. It is therefore necessary to relate such peak counts to the spectra of the turbulence. For this purpose, it appears necessary and reasonable to make some simplifying assumptions. First, it will be assumed that the turbulence for a given weather condition is a Gaussian process. This assumption implies that the turbulent velocity fluctuations and also the airplane response for linear systems have a normal or Gaussian probability distribution; this distribution appears from available measurements to be a reasonable approximation. The Gaussian character for the turbulent velocity fluctuations for a given weather condition will be used as a building block to construct the operational load history which covers many weather conditions and, in the overall, is far from a simple Gaussian process. Secondly, it appears necessary to make some simplifying assumptions on the form of the power spectrum of the gust velocity. On the basis of the available measurements, it appears reasonable to assume that the spectral form is given by equation (1). These assumptions and available relations between peak counts and spectra for the Gaussian case provide the basis for the analysis to be presented.

Homogeneous Case

For a Gaussian process $y(t)$, the number of peak (maxima) values $N(y)$ per second exceeding given values (for large values of y) is given by the following relation (ref. 17):

$$N(y) = \frac{1}{2\pi}\left[\frac{\int_0^\infty \omega^2\Phi(\omega)\,d\omega}{\int_0^\infty \Phi(\omega)\,d\omega}\right]^{1/2} e^{-y^2/2\sigma^2} \tag{2}$$

where

y a random variable

ω frequency, radians/sec

$\Phi(\omega)$ power spectrum of y

σ root-mean-square value of y

When this relation is applied to the acceleration history of an airplane in homogeneous turbulence, the spectrum of normal acceleration for a linear system is, in turn, related to the spectrum of atmospheric turbulence by the relation

$$\Phi_a(\omega) = \Phi_U(\omega)T^2(\omega) \tag{3}$$

where $\Phi_a(\omega)$ and $\Phi_U(\omega)$ are the power spectra of the normal acceleration and vertical gust velocity, respectively, and $T(\omega)$ is the amplitude of the airplane acceleration response to unit sinusoidal gusts encountered at frequency ω. Equations (2) and (3) thus relate the number of peak accelerations per second exceeding given values to the spectrum of the turbulence. When these relations are applied to an airplane in flight through turbulence of a given spectrum (which in the present application can be considered to be given by equation (1)), the number of peak accelerations per second exceeding given values of acceleration a, as illustrated by the sketch on the upper left of figure 4, may be expressed as

$$N(a) = N_0 e^{-a^2/2\sigma_a^2} \tag{4}$$

where

$$N_0 = \frac{1}{2\pi}\left[\frac{\int_0^\infty \omega^2 \Phi_U(\omega)T^2(\omega)\,d\omega}{\int_0^\infty \Phi_U(\omega)T^2(\omega)\,d\omega}\right]^{1/2} \tag{4a}$$

If the expression for the turbulence spectrum given by equation (1) is applied in equation (4a), the quantity N_0 may be seen to depend upon the value of the scale of turbulence L and the airplane transfer function but is readily seen to be independent of the turbulence intensity or root-mean-square gust velocity. Thus, for a given airplane and a given value of L, N_0 is a constant, independent of turbulence intensity. The quantity N_0 has the dimensions of a frequency and can be considered to be a characteristic frequency of the airplane response to the given turbulence. In addition, the number of peaks $N(a)$ is seen from equation (4) to depend also on the acceleration level a and the root-mean-square acceleration σ_a which, as will be seen, depends directly on the turbulence intensity.

Composite Case

So far, the turbulence has been assumed to be homogeneous and Gaussian. Now, if the airplane is assumed to fly for given flight times t_1, t_2, and t_3 through turbulence of different intensities but of the same spectral form, the acceleration histories for each flight time would differ in intensity or in root-mean-square acceleration value as indicated by the sketches on the lower left of figure 4. Equation (4) may be extended for this composite case in order to obtain the overall average number of peaks exceeding given values as follows:

$$N(a) = N_0\left[\frac{t_1}{t_T} e^{-a^2/2\sigma_{a_1}^2} + \frac{t_2}{t_T} e^{-a^2/2\sigma_{a_2}^2} + \frac{t_3}{t_T} e^{-a^2/2\sigma_{a_3}^2}\right] \qquad (5)$$

where

$$t_T = t_1 + t_2 + t_3$$

Equation (5) is essentially a sum of terms of the form of equation (4) weighted by the relative exposure times $\frac{t_1}{t_T}$, $\frac{t_2}{t_T}$, and $\frac{t_3}{t_T}$.

Continuous Case

If the airplane is now assumed to encounter turbulence of all intensities (continuous variations in the root-mean-square gust velocity) but of the same spectral shape (fixed value of L for present applications), equation (5) may be extended for the continuous case to yield the following relation:

$$N(a) = N_0 \int_0^\infty f(\sigma_a) e^{-a^2/2\sigma_a^2} d\sigma_a \qquad (6)$$

In this case the sum of the terms of equation (5) becomes a continuous integral. The expression for the continuous case contains the same characteristic frequency N_0, which is independent of the turbulence intensity, the same exponential term as the earlier expressions but, in addition, contains the function $f(\sigma_a)$. This function is the counterpart of the ratios $\frac{t_1}{t_T}$, $\frac{t_2}{t_T}$, and $\frac{t_3}{t_T}$ in equation (5) and is the probability distribution of σ_a which can be considered to define the proportion of total flight time spent at values of σ_a between σ_a and $\sigma_a + d\sigma_a$. A sketch of $f(\sigma_a)$ is shown in figure 5. The total area under the curve is, of course, equal to one with the percentage of the total time between any two values given by the area under the curve between the two values as indicated by the hatched area.

Equation (6) relates the probability distribution of the root-mean-square acceleration to the overall number of peak accelerations per second. Since gust-load statistical data are usually summarized in the form of number of peak accelerations per unit time (or distance) exceeding given values, this relation may be used to determine the appropriate distribution of the root-mean-square acceleration $f(\sigma_a)$ from the available data without recourse to the reevaluation of the original records.

For a given airplane, the root-mean-square acceleration is also simply related to the root-mean-square gust velocity. This relation may be expressed simply as

$$\sigma_a = \bar{A}\sigma_U \tag{7}$$

where $\bar{A}$ may be considered a transfer function between root-mean-square gust velocity and root-mean-square acceleration and for a given case is a constant depending upon the gust spectrum and the airplane response characteristics. For the gust spectrum used in the present analysis, $\bar{A}$ is given by the following integral

$$\bar{A} = \left[\frac{L}{\pi}\int_0^\infty \frac{1 + 3\Omega^2L^2}{\left(1 + \Omega^2L^2\right)^2} T^2(\Omega)\,d\Omega\right]^{1/2} \tag{8}$$

The value of $\bar{A}$ for this case is seen to depend only upon the value of L and the airplane transfer function. Thus, the root-mean-square values of acceleration for a given airplane and a given value of L may be used directly to determine the root-mean-square gust velocities.

Equation (7) may be applied directly to determine the distribution of root-mean-square gust velocity for a given distribution of root-mean-square acceleration. The relation between these distributions is given by

$$\hat{f}(\sigma_U) = \bar{A}f(\sigma_a) \tag{9}$$

where $\sigma_a = \bar{A}\sigma_U$. Thus, the final result desired, the distribution of the root-mean-square gust velocity, may be obtained by the solution of equation (6) for $f(\sigma_a)$ and the application of equation (9).

These relations can, of course, also be used to calculate the number of peak loads for a given operation, if the probability distribution of the root-mean-square gust velocity $\hat{f}(\sigma_U)$ is known. In terms of the distribution of root-mean-square gust velocity, the number of peak accelerations per second exceeding given values is given by

$$N(a) = N_0 \int_0^\infty \hat{f}(\sigma_U) e^{-a^2/2\left(A\sigma_U\right)^2} d\sigma_U \tag{10}$$

where N_0 is given by equation (4a). Thus, in this approach, the probability distribution of the root-mean-square gust velocity is the fundamental quantity and takes the place in spectral calculations of the counts of gust peaks used in the discrete gust calculations.

SOME RESULTS OBTAINED IN THE REEVALUATION OF GUST DATA

In this section, the results obtained by the application of the relations derived in the preceding section to available statistical data on gust loads are presented. Three principal problems are encountered in such applications and involve the choice of an appropriate value of the scale of turbulence L, the determination of the airplane acceleration transfer function for gusts $T(\omega)$ (or, more particularly, the value of $\bar{A}$), and the determination of the value of the characteristic frequency N_0. The value of L chosen for present purposes was 1,000 feet which, on the basis of available data, appears to be a reasonable estimate for an average value for atmospheric turbulence. In the determination of the airplane transfer function and the values of $\bar{A}$ for the various airplanes involved, the airplane accelerations were assumed to be due entirely to the vertical gusts and the airplane was assumed to respond in vertical motion only (no pitch, rigid-body condition). A justification for this restriction to the one-degree-of-freedom response for this purpose is given in reference 14. Finally, it was found simple and expedient to obtain good estimates of the characteristic frequency N_0 directly from the flight records of acceleration for the various airplanes in accordance with the method given in reference 14.

Variation With Type of Operation

In reference 14, the foregoing techniques were applied to derive estimates of the distribution of root-mean-square gust velocity $\hat{f}(\sigma_U)$ from data for eight transport operations. As might be expected, little difference was noted in this distribution for similar types of operation. A distinctive difference was noted, however, between the results for a feeder-line low-altitude operation and the normal higher altitude transport operations, as might be expected. The results obtained for the feeder-line operation and one of the more normal transport operations are compared in figure 6 in order to illustrate the type of variations in the distribution. The feeder-line operation consisted of short-haul low-altitude flights over the rough terrain in the western part of the United States and was known to spend much time in rough air. The other operation was a four-engine transcontinental operation mostly flown at moderate altitude and was known to be a relatively smooth operation. In each case, the results are shown for a range of values of σ_U from 0 to 20 feet per second. Since the individual gust peaks in rough air of a given root-mean-square value can be three or four times the root-mean-square value, the results shown cover peak gust velocities up to perhaps 80 feet per second.

The curves both indicate a rapid decrease in the probability with increasing root-mean-square value. It is clear that the transcontinental operation includes more time at very low values of σ_U, less time at the moderate values of σ_U, and perhaps more time at the very large values of σ_U. However, since the proportion of flight time between given root-mean-square values is given by areas under the curves, the significant areas are distorted by the logarithmic plot and direct comparison of the curves is made difficult. For this reason, the significant points obtained from these curves are summarized in the table on the upper right-hand side of figure 6. The table gives the percent flight time for the two operations in smooth air $(\sigma_U < 1$ foot per second), and in moderate to severe rough air $(\sigma_U > 5$ feet per second). The table clearly indicates that the transcontinental operation is a much smoother operation with almost twice the percentage time of the feeder-line operation in smooth air and only about one-eighth the percentage time in moderate to severe turbulence. At the very high values of root-mean-square gust velocity, there is some indication that the transcontinental operation may encounter very severe turbulence, associated with the more violent thunderstorms, more frequently than the feeder-line operation. The time above 20 feet per second is small, however, being only about 1/100,000 of the total flight time.

The description of the gust experience in this form is directly applicable to load calculations for other airplanes in similar types of operation by reversing the procedures used in obtaining these results. However, direct application of these results would only apply to operations having the same type of flight plan. In order to obtain results that are more flexible and applicable to arbitrary flight plans, it would be desirable to determine the variations in these distributions with altitude, weather condition, and perhaps geography. Efforts in this direction are being made.

Variation With Altitude

In order to arrive at some rough estimates of the variation of $\hat{f}(\sigma_U)$ with altitude, use was made of the summary of gust statistics given in reference 5. Figure 6 of reference 5 presents estimates of the average gust experience at various altitudes that are representative of contemporary types of transport operations. In order to estimate the associated distributions of root-mean-square gust velocity, these results which are in terms of derived gust velocities were, for convenience, first converted to accelerations by using the characteristics of a representative transport airplane. The charts of reference 14 were then used to estimate the appropriate distribution form and scale value for the root-mean-square gust velocity. It was found that, for each altitude bracket, the number of peak accelerations for the various altitude brackets could be approximated by the following distributions for $\hat{f}(\sigma_U)$:

$$\hat{f}(\sigma_U) = 0.99\frac{1}{1.56}e^{-\sigma_U/1.56} + 0.01\frac{1}{3.18}e^{-\sigma_U/3.18}$$

for the altitude bracket of 0 to 10,000 feet,

$$\hat{f}(\sigma_U) = \frac{1}{2(0.34)^2}e^{-\sqrt{\sigma_U}/0.34}$$

for the altitude bracket 10,000 to 30,000 feet, and

$$\hat{f}(\sigma_U) = \frac{1}{2(0.31)^2}e^{-\sqrt{\sigma_U}/0.31}$$

for the altitude bracket 30,000 to 50,000 feet. These distributions are shown in figure 7. These distributions are a minor refinement of results presented earlier. The two-term approximation for the lowest altitude bracket was found desirable in order to represent the data over the whole range of gust velocity adequately.

The results in figure 7 indicate that, except for the lowest altitude bracket, little difference exists in the distribution of σ_U

for the various altitude brackets. Perhaps the most important points, which are obscured by the logarithmic scale, are the relatively large amount of time spent in essentially smooth air ($\sigma_U < 1$ foot per second) at the higher altitudes and the relatively large amount of time spent in moderate to severe turbulence ($\sigma_U > 5$ feet per second) at the lowest altitude bracket. The time spent above 5 feet per second for the lowest altitude bracket is roughly five times as great as that for the higher altitude brackets.

It should be remembered that these results are in terms of true gust velocity. If equivalent gust velocities which are more directly related to the airplane response are used, the decrease in turbulence intensity with altitude would, of course, be even more pronounced than is indicated here.

As a check on the consistency of these results, the acceleration histories were calculated for two hypothetical operations: a moderate-altitude transport operation and a high-altitude operation perhaps representative of jet transport operations. In the calculation of the value of $\bar{A}$, theoretical results for a single degree of freedom (vertical motion only) (ref. 9) were used. The results obtained in this manner were roughly equivalent to those obtained by discrete gust calculations which would be expected for this single-degree-of-freedom case.

The method of application of these results to the calculation of load histories for arbitrary flight plans is parallel to that used for the discrete gust case described in reference 5. The sequence of steps is: (1) The appropriate distribution of $\hat{f}(\sigma_U)$ is selected for each altitude bracket. (2) The values of $\bar{A}$ are determined for each significant portion of the flight plan in accordance with equation (8). (3) Each of the distributions of $\hat{f}(\sigma_U)$ is transformed in order to obtain the associated distributions of acceleration $f(\sigma_a)$ by the relation

$$f(\sigma_a) = \frac{1}{\bar{A}} \hat{f}(\sigma_U)$$

where

$$\sigma_U = \sigma_a / \bar{A}$$

(4) The values of N_0 are determined in accordance with equation (4a) or directly from flight records as described in reference 14. It should be noted that the value of N_0 is infinite for the one-degree-of-freedom

case treated in reference 9 and therefore the results obtained in that analysis cannot be used for this purpose without some modification. For a rigid airplane, the value of N_0 appears to be larger but of the same order as the period of the longitudinal short-period oscillation. (5) The distributions of σ_a and the values of N_0 are then used in equation (6) to derive the number of peak accelerations per second or per mile for each condition. (These calculations can be facilitated by the use of charts such as given in ref. 14.) (6) The results obtained in step 5 are then weighted in accordance with the flight distance in each condition and then summed for all conditions in order to obtain the overall acceleration history.

Variation With Weather Condition

In the preceding discussion, the variation in the gust experience with flight altitude was considered. Another breakdown of the gust experience which may be useful in some problems is the variation in gust experience with weather conditions. Figure 8 shows estimates of the variations in $\hat{f}(\sigma_U)$ that have been obtained for several types of turbulent weather conditions. The curve labeled "clear-air turbulence" was based on data obtained in flight through clear and turbulent air at the lower altitudes. The curve labeled "cumulus clouds" was based on data obtained in flight under moderate convective conditions such as represented by bulging cumulus clouds. Finally, the curve labeled "thunderstorms" was based on data obtained in flight in the immediate vicinity of and within severe thunderstorms. The distributions obtained appear to have the same general form but are seen to vary widely in intensity. A simple measure of the relative intensity of the turbulence for these conditions may be obtained by comparing the root-mean-square values at the lower probability levels. It will be noted that, at these probability levels, the values for the cumulus and thunderstorm conditions are roughly two and three times the values of σ_U for the clear-air condition.

It has been estimated that contemporary transport operations spend about 10 percent of their flight time in this clear-air turbulence condition, 1 percent in the cumulus condition, and perhaps 0.05 percent in thunderstorms. These results may therefore find some application in evaluating the effects on the overall load experience of operational procedures which would tend to modify this weather experience. For example, the introduction of airborne radar for weather avoidance may be expected to reduce the exposure time to the severe turbulence conditions of thunderstorms. Also, high rates of climb and descent through the lower and more turbulent altitude layers may cause a drastic reduction in the 10 percent of the flight time attributed to clear-air turbulence conditions and thereby cause a marked reduction in the overall gust experience.

CONCLUDING REMARKS

The foregoing analysis has served to demonstrate that the gust statistics may, under reasonable assumptions, be converted into a form appropriate for spectral-type calculations. The significant and fundamental quantity, for this purpose, appears to be the probability distribution of the root-mean-square gust velocity. The results obtained in defining the variations of this function with type of operation, flight altitude, and weather condition provide at least a starting basis for their application to response calculations in arbitrary operations. These results should serve to supplement the discrete-gust techniques in current use and be particularly appropriate in problems requiring a more detailed accounting for the airplane dynamics than is possible by discrete-gust techniques.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 10, 1955.

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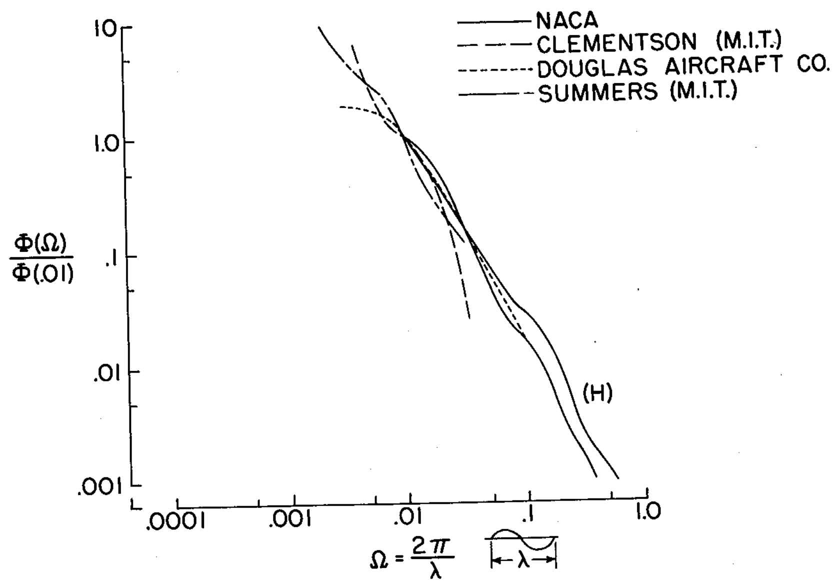


Figure 1.- Summary of airplane measurements of the power spectrum of atmospheric turbulence.

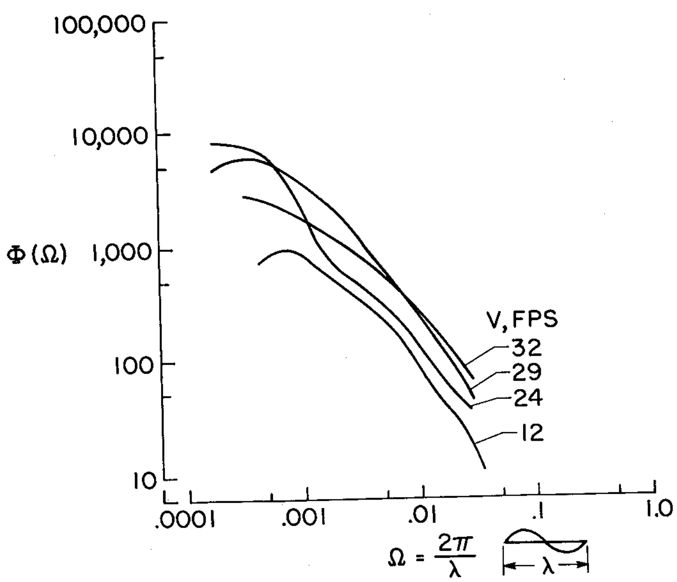


Figure 2.- Measurements of the power spectrum of atmospheric turbulence obtained at 300 feet from a meteorological tower (ref. 16).

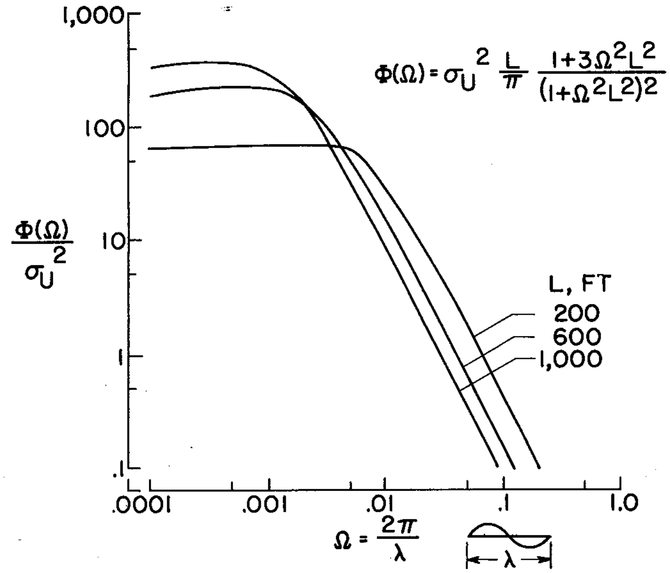


Figure 3.- Analytic representation of the spectrum of atmospheric turbulence.

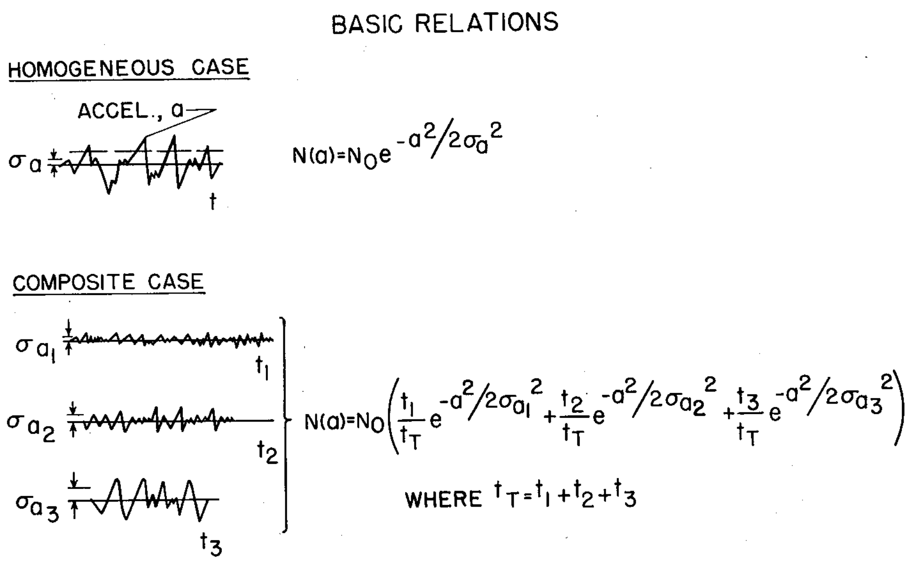


Figure 4.- Relations between counts of acceleration peaks and root-mean-square acceleration values for the homogeneous and composite cases.

CONTINUOUS CASE

$$N(a) = N_0 \int_0^{\infty} f(\sigma_a)\, e^{-a^2/2\sigma_a^2}\, d\sigma_a$$

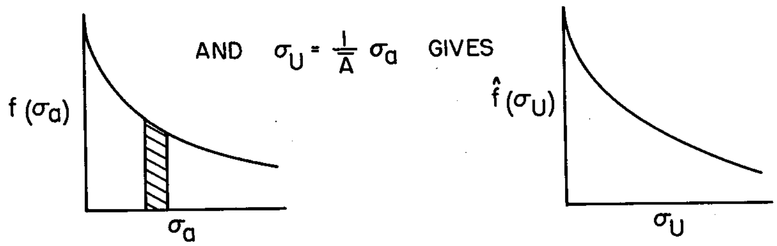
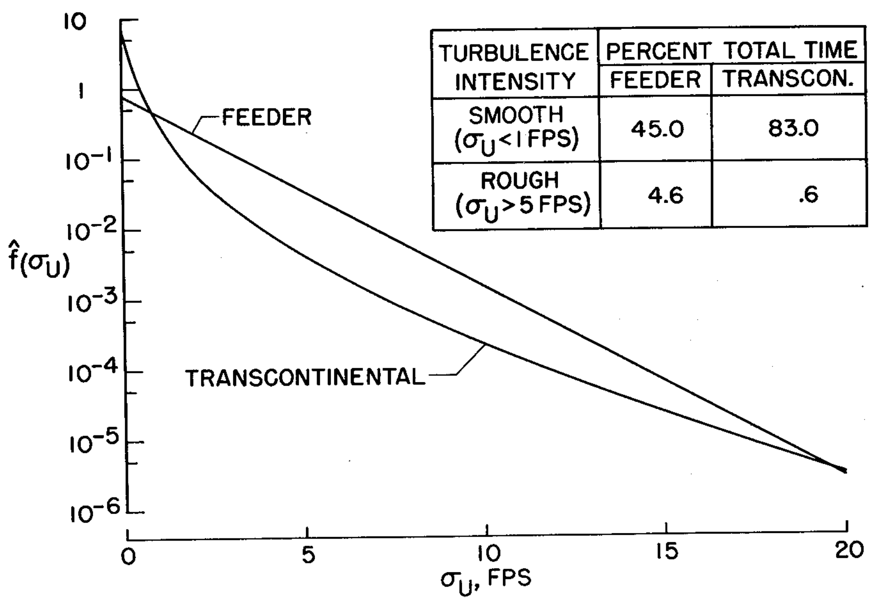


Figure 5.- Relations between counts of acceleration peaks and the probability distribution of the root-mean-square gust velocity.



TURBULENCE INTENSITY	PERCENT TOTAL TIME	
	FEEDER	TRANSCON.
SMOOTH (σ_U<1 FPS)	45.0	83.0
ROUGH (σ_U>5 FPS)	4.6	.6

Figure 6.- The probability distribution of the root-mean-square gust velocity for a transcontinental and a local feeder-line operation.

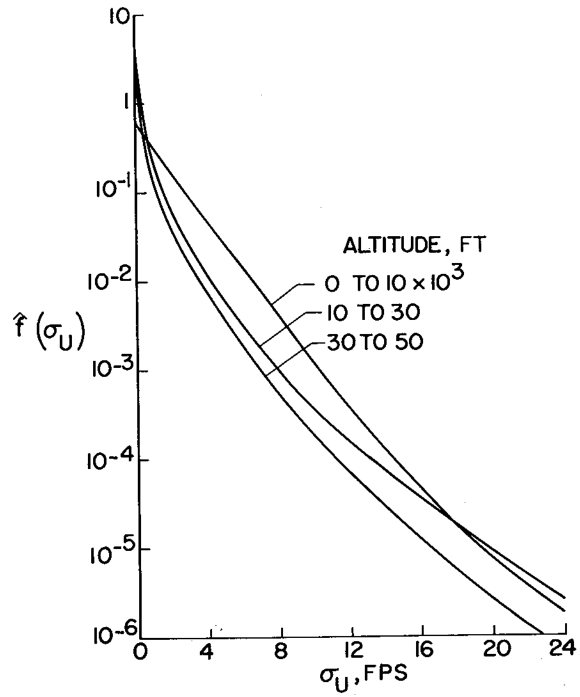


Figure 7.- The variation of the probability distribution of the root-mean-square gust velocity with altitude.

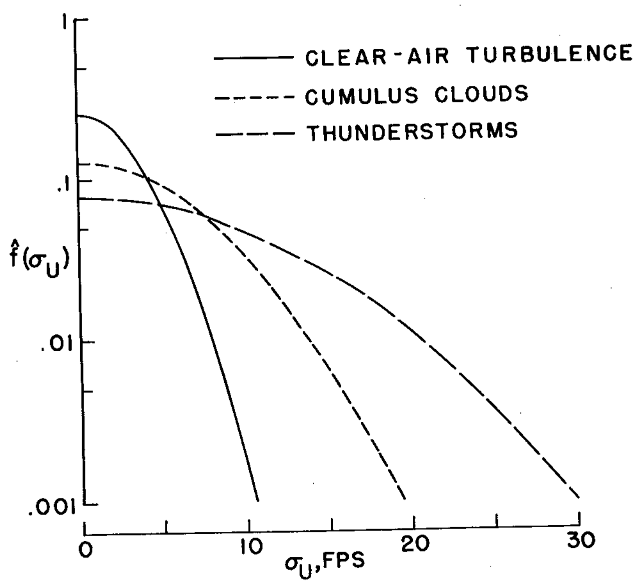


Figure 8.- The variation of the probability distribution of the root-mean-square gust velocity with weather condition.

NACA TN 3540
National Advisory Committee for Aeronautics.
A REEVALUATION OF GUST-LOAD STATISTICS FOR APPLICATIONS IN SPECTRAL CALCULATIONS. Harry Press and May T. Meadows. August 1955. 19p. diagrs. (NACA TN 3540)

The available information on the spectrum of atmospheric turbulence is briefly reviewed. On the basis of these results, a method is developed for the conversion of available gust statistics normally given in terms of counts of gust peaks into a form appropriate for use in spectral calculation. The fundamental quantity for this purpose appears to be the probability distribution of the root-mean-square gust velocity. Estimates of the variation of this distribution with altitude and weather condition are also derived from available gust statistics.

Copies obtainable from NACA, Washington

1. Loads, Gust - Wings (4.1.1.1.3)
2. Loads and Stresses, Structural - Dynamic (4.3.7.7)
3. Gusts, Atmospheric (6.1.2)

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