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# COMPARISON OF DISCRETE AND CONTINUOUS GUST METHODS FOR THE DETERMINATION OF AIRPLANE DESIGN LOADS

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## ABSTRACT

The discrete and continuous gust methods often have different results. The P.S.D.-method becomes the critical one for modern aircraft with high mass parameter and large dimensions. The character of the turbulence or the response behaviour are not the main sources of the discrepancy. It is mainly due to the difference in the relation between gust velocity and gust length in the two methods.

## INTRODUCTION

The problem of the determination of airplane loads due to atmospheric gusts is an old one, and this problem certainly has not been solved. This probably can best be illustrated with the requirements of FAR 25 (1) and JAR 25 (2).

The loads must be determined assuming a discrete "one-minus-cosine" gust with a length of 25 chords and prescribed velocity for the various airplane flight envelope conditions. In JAR 25, change 7, effective 24 November 1980, a tuned gust length was prescribed for aircraft for which the structural flexibility effects were not negligible.
This requirement was not applicable for French type certification. It has now been deleted, except in the U.K.

The requirements also prescribe that the dynamic response of the airplane to continuous gust must be taken into account. FAR 25 prescribes that the continuous gust design criteria must be used to establish the dynamic response.
JAR 25 offers the continuous gust criteria as a means of compliance with this requirement. The principle of the application is to establish whether the structure exhibits characteristics leading to design loads that substantially deviate from the results of the discrete gust analysis.

The criteria for continuous gust, both in JAR 25 and FAR 25, should be applied to a Mission Analysis or a Design Envelope Analysis.

These requirements express the various views that exist regarding the merits of different descriptions of atmospheric turbulence and analysing methods.

These requirements therefore can easily lead to a conflict situation as the design loads obtained with the discrete gust concept and the continuous gust concept usually will be different. First short descriptions of the methods will be presented. A more extensive historical review is given in reference 3. It will become clear that the requirements in fact are inter- or extrapolation methods. New airplanes are compared on a certain basis to older airplanes, assumed to have a satisfactory safety record.
Comparisons of the requirements, based on a relatively simple airplane model will then be made. It will be shown that, even for this simple model, a direct relation between the discrete gust method and the continuous gust method does not exist. The sources of the discrepancy between the results obtained with these two methods will be investigated. It will be shown that neither the character of atmospheric turbulence, nor the response behaviour of the airplane, as probably might be expected, are the main sources of the discrepancy.

## THE DISCRETE GUST CONCEPT

In the discrete gust concept it is assumed that the airplane is subjected to gusts with the following shape.

$$U = \frac{U_{de}}{2}\left(1 - \cos\frac{2\pi Vt}{H}\right) \qquad (1)$$

The gust length H is equal to 25 mean geometric wing chords.
$U_{de}$ is the derived, equivalent, gust velocity.
At the design cruising speed $V_c$ the prescribed(1,2) values for $U_{de}$ are

$U_{de}$ = 50 fps for altitudes between sealevel and 20000 ft, and decreasing to 25 fps at 50000 ft.

In the absence of a more rational analysis the gust loads must be computed with

$$\Delta n = \frac{a\rho_o V_e U_{de} S}{2mg} K_g$$

$$= \frac{aV_e U_{de}}{498 W/S} K_g \quad \text{in the ft-sec-knot-slug-lb system} \qquad (2)$$

$$\text{or} \quad \Delta n = \frac{aSV_e U_{de}}{16m} K_g \quad \text{in the kg-m-s system} \qquad (3)$$

$K_g$ is the gust alleviation factor and is equal to

$$K_g = \frac{0.88\,\mu_g}{5.3 + \mu_g} \qquad (4)$$

with

$$\mu_g = \frac{2m}{\rho S c a} \qquad (5)$$

The gust alleviation factor $K_g$ as given in equation (4) has been derived by Pratt(4,5). It is an approximation to the gust alleviation factor for a rigid airplane model with one rigid body mode, namely plunge, for which unsteady aerodynamics have been taken into account.

Other airplane models and other gust lengths will lead to different values for $K_g$ in equation (2).
The gust length H = 25 chords is a rather arbitrary one and therefore may give rise to feelings of uncertainty. This has led to the concept of the tuned gust, that has been required in JAR 25 for some

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time. The gust length H should be varied between the limits as agreed with the Authority and the most unfavourable response of the airplane should be used. This requirement can have a large effect on the design gust load and it may depend largerly on the agreed limits, see figure 1. Now this requirement has been deleted in JAR 25.

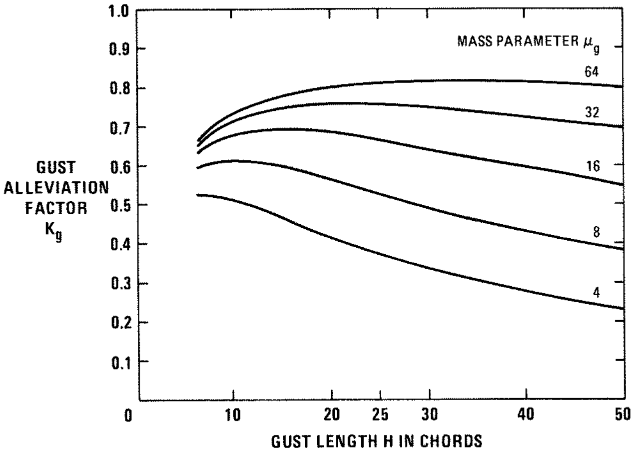

Figure 1. Gust alleviation factor $K_g$ as function of gust length

This figure shows that airplanes with low values of the mass ratio $\mu_g$ are more sensitive to short gusts, airplanes with high $\mu_g$-values to long gusts.

The concept of discrete gusts acting on an airplane has been and is still being used for the determination of gust design loads for airplanes. It should be realized that the methods described above act as extrapolation formula. New airplanes are compared to older, satisfactory ones. As long as the new airplanes do not differ too much from the old ones, concerning influence of pitch mode and flexible modes, and if they are in the same bracket of mass parameter values, this extrapolation may be meaningful. However the conviction grew that the concept of a discrete one-minus-cosine gust with a gust length H = 25 chords is unable to describe the irregular behaviour of atmospheric turbulence and that extrapolation formulae used for the definition of design gust loads should be based on a physically more consistent description of the gust phenomenon.

## THE CONTINUOUS GUST CONCEPT

The continuous gust concept is based on the assumption that atmospheric turbulence can be described as a quasi-stationary Gaussian process and that the airplane can be regarded as a linear system. Based on these assumptions the power-spectral-density (P.S.D.)-method for the derivation of airplane design loads and fatigue loads has been developed in references 6 and 7, written under contract for the Federal Aviation Agency. The proposed design values are based on the actual strength of existing airplanes, assumed to have a satisfactory safety record. This work has resulted in the requirements for the dynamic response of the airplane to continuous gust (1,2).

It is assumed that the power spectrum of the turbulence can be described with the isotropic or Von Karman spectrum

$$\phi_{ww}(\Omega) = \frac{\sigma_w^2 L}{\pi} \frac{1 + \frac{8}{3}(1.339L\Omega)^2}{[1 + (1.339L\Omega)^2]^{11/6}} \qquad (6)$$

with L = 2500 ft = 750 m

Two types of criteria can be used.

a. Mission Analysis
   With a criterion for the total number of exceedances of the design load level. This criterion will not be discussed.

b. Design Envelope criterion
   Limit gust loads are determined with

$$y = \bar{A}_y U_\sigma \qquad (7)$$

$\bar{A}_y$ is the ratio of the standard deviations of the load y and the turbulence. It can be calculated with

$$\bar{A}_y = \frac{\sigma_y}{\sigma_w} = \frac{1}{\sigma_w}\left[\int_0^\infty |H_{yw}(j\Omega)|^2 \, \phi_{ww}(\Omega)\, d\Omega\right]^{\frac{1}{2}} \qquad (8)$$

in which $H_{yw}(j\Omega)$ is the transfer function of the load y.

$\bar{A}_y$ for the most critical design envelope condition must be used in equation (7).

At design cruising speed $V_c$ the prescribed values for $U_\sigma$ are

in FAR 25 (1)

$U_\sigma$ = 85 fps (= 25.9 m/s) on the interval 0-30000 ft and is linearly decreased to 30 fps (9.1 m/s) at 80000 ft.

Under certain conditions, it will be acceptable to select a $U_\sigma$-value not less than:

$U_\sigma$ = 75 fps (= 22.86 m/s) in the interval 0-20000 ft linearly decreasing to 30 fps (= 9.1 m/s) at 80000 ft.

and in JAR 25 (2)

$U_\sigma$ = 25 m/s on the interval 0-9150 m and is linearly decreased to 9 m/s at 24400 m.

## COMPARISON OF THE METHODS

The requirements as laid down in FAR 25 and JAR 25 contain both the discrete gust and the continuous gust concept. However, there seems to be a difference in appreciation of the two methods. Both FAR and JAR, prescribe that limit gust loads must be determined on the basis of a one-minus-cosine gust with a length of 25 chords.

Both also prescribe that the dynamic response to continuous turbulence must be taken into account.

FAR 25 then prescribes that the continuous gust design criteria must be used to establish the dynamic response unless more rational criteria are shown.

JAR 25 prescribes that when effects of dynamic response to turbulence are assessed by the continuous turbulence method, the criteria, as described in this paper, can be used. The principle of the application of this P.S.D.-method is to establish whether the structure exhibits characteristics substantially deviating from the results of the discrete gust analysis. If so the implication should be discussed with the Authority.

The situation probably can be described by stating that FAR and JAR both demand that limit loads are determined with the discrete gust method. FAR requires the P.S.D.-method as an obligatory complement and JAR regards it as a supplementary requirement.
Nevertheless, application of the two methods may result in a conflict situation if the results of these methods are different.

In the following the P.S.D.-Design Envelope method and the discrete gust method will be compared on the basis of simple airplane models.

The comparison will be made for an airplane at design cruising speed $V_C$ and the design value $U_\sigma$ = 85 fps, true gust velocity, from sealevel to 30000 ft, and decreasing to 30 fps at 80000 ft, will be used for the P.S.D.-method.

A first comparison will be made for an airplane model as used by Pratt. This model is rigid and only free to plunge. Unsteady aerodynamic forces are taken into account using an approximation. The limit load factor for a discrete gust, with one-minus-cosine gust shape and 25 chords length, is

$$\Delta n = \frac{a\rho_o V_e S}{2mg} K_g U_{de} \tag{9}$$

with gust alleviation factor $K_g$ as given in equation (4) and $U_{de}$ as prescribed $^{(1,2)}$.
Application of the P.S.D.-method to the same airplane model, gives as result.

$$\Delta n = \frac{a\rho VS}{2mg} K_\varphi U_\sigma \tag{10}$$

with $K_\varphi$ as given in figure 2. $K_\varphi$ is a function of $\mu_g$ and c/L.

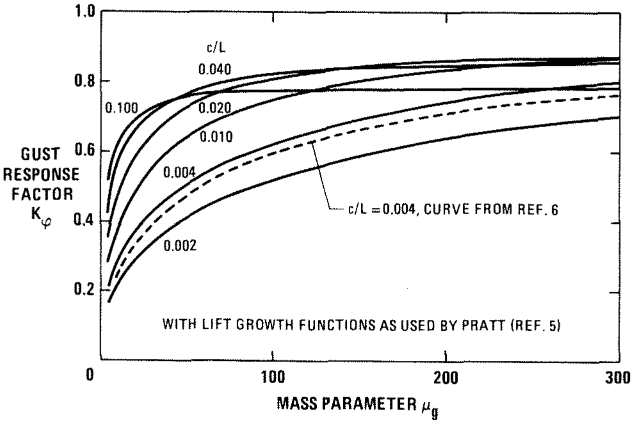

Figure 2 Gust response factor for isotropic turbulence

From equations (9) and (10) follows that the $U_\sigma$-value that would give the same limit load factor as the discrete gust, with given shape and length, is

$$U_{\sigma d} = \sqrt{\frac{\rho_o}{\rho}} \frac{K_g}{K_\varphi} U_{de} \tag{11}$$

$K_g$ and $K_\varphi$ are functions of the mass parameter

$$\mu_g = \frac{2m}{\rho acS} = \frac{\rho_o}{\rho} \frac{2m}{\rho_o acS} = \frac{\rho_o}{\rho} \mu_{go} \tag{12}$$

$U_{\sigma d}$ is depicted in figure 3 as function of altitude, with $\mu_{go}$ and c/L as parameters. The design value $U_\sigma$ is also given.

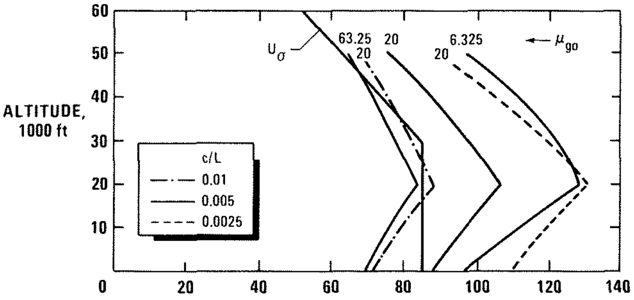

Figure 3. $U_{\sigma d}$-values for an airplane with one degree of freedom

From this figure follows that $U_{\sigma d}$-values, giving the same limit load as the discrete gust, tend to become lower for

- higher values of $\mu_g$ - a similar result is given by Jones$^{(10)}$
- higher values of c/L
- lower altitudes

This implies that for these cases the P.S.D.-method may become the critical one.

It is thought that another type of presentation is more convenient.
The curves in figure 3 are a function of $\mu_{go}$ with c/L as parameter. Both depend on chord length c. The mass parameter $\mu_g$ is the time constant of the airplane pertaining to nondimensional time $r = Vt/c$ and frequency $\lambda = c\omega/V$. In the following the quantity

$$T_n = \frac{c}{L} \mu_g = \frac{2m}{\rho aLS} = \frac{\rho_o}{\rho} T_{no} \tag{13}$$

will be used. It is the time constant of the airplane pertaining to nondimensional time $T = Vt/L$ and frequency $\nu = L\omega/V$.

Results will be given as function of $1/T_{no}$, because also airplane models with two degrees of freedom and natural frequency $\nu_n$ will be considered.

$U_{\sigma d}$-values as obtained with equation (11) for an altitude of 20000 ft are given in figure 4 as function of $1/T_{no}$ and with c/L as parameter. One curve for c/L = .005 at sealevel is also given.

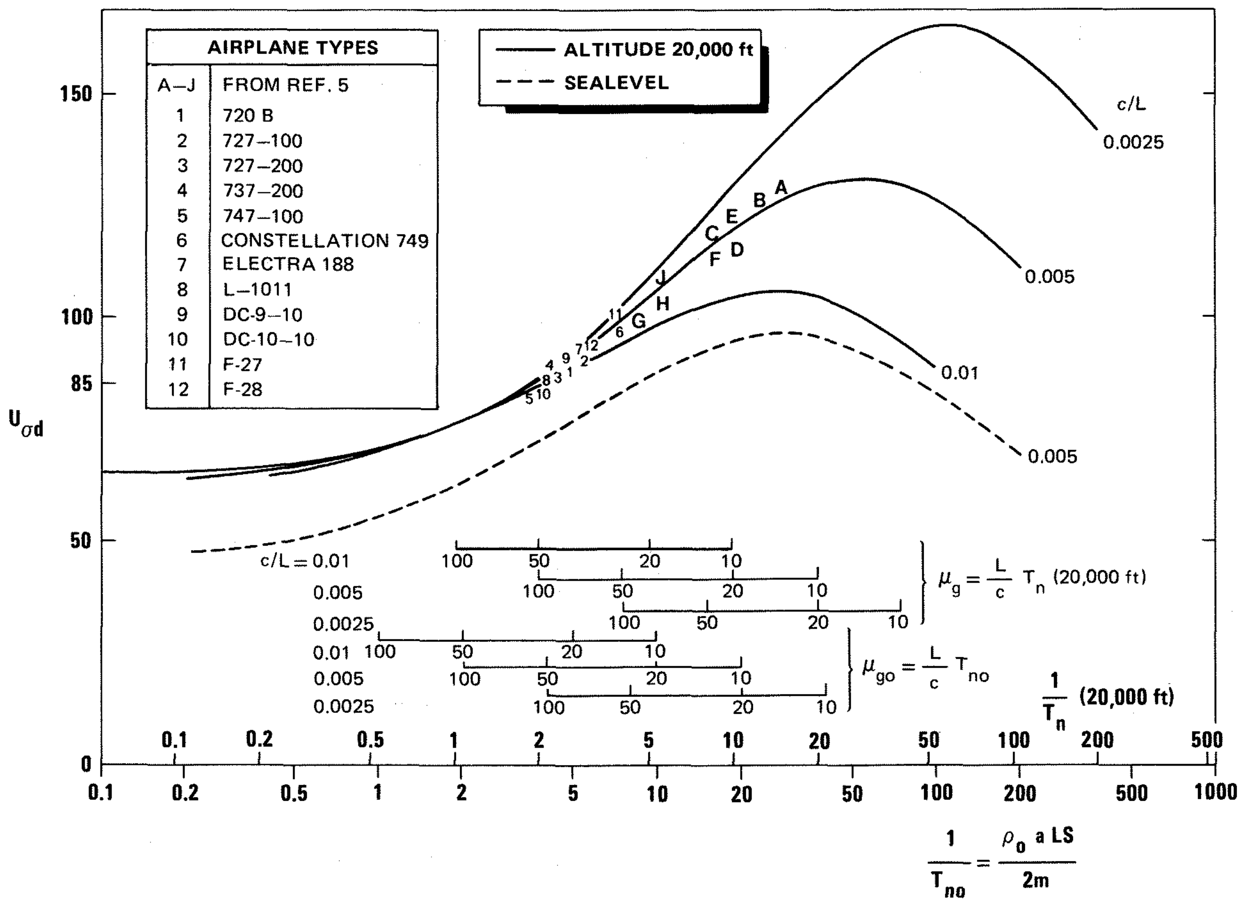

Figure 4. $U_{\sigma d}$-value equivalent to discrete gust velocity $U_{de}$ for an airplane with one degree of freedom

In this figure have been plotted the approximate values $1/T_{no}$ and c/L of

- the older airplanes A-J as used by Pratt and Walker(5) for the reevaluation of V-G data
- the newer airplanes 1-12, the names of which are given in the legend in the same figure.

The time constants $T_n$ of these airplanes are based on design gross weight or maximum take-off weight and with a equal to 6A/(A + 2), in which A is the aspect ratio.

Of course figure 4 offers only a crude way to compare the two methods. The curves are only valid for one altitude and are related to the acceleration for a simple airplane model with one degree of freedom. Thus, if for a certain airplane $U_{\sigma d}$ is greater than 85 ft/s it should not be concluded that for that airplane the discrete gust method gives higher limit loads than the P.S.D.-method. However, this figure clearly shows some trends. For the older types of aircraft the discrete gust method is the critical one. For the newer types of aircraft the P.S.D.-method may lead to limit loads that are equal to or higher than those obtained with the discrete gust method (if for both methods the same simplified airplane model is used).

For a one-degree-of freedom airplane the P.S.D. design method becomes the critical one for airplanes with low values if $1/T_{no}$ (high $\mu_g$-values). It also becomes the critical one for large values of c/L (large airplanes) if $1/T_{no}$ is not low, and if the critical design envelope condition is at a low altitude.

The same method will now be applied to an airplane model with two degrees of freedom, namely pitch and plunge. Unsteady aerodynamic forces will be taken into account, using Pratt's approximation.

The transfer function for this airplane model is (3)

$$G(j\nu) = \frac{1}{VT_n}\,\frac{\{-\nu^2 + 2j\nu\zeta_m\nu_n C(j\nu)\}D(j\nu)}{-\nu^2 + 2j\nu\zeta\nu_n C(j\nu) + \nu_n^2 C^2(j\nu)} \qquad (14)$$

C(jν) and D(jν) are the transformed Wagner and Küssner functions.
$\nu_n$ and $\zeta$ are approximately the nondimensional natural frequency ($\nu_n = L\omega_n/V$) and the damping coefficient of the short period motion. For $\zeta = 1$ and $\zeta_m = 0.5$ equation (14) reduces to the transfer function of a one-degree-of-freedom airplane model, with $1/T_n = \nu_n$.

The $U_{\sigma d}$-value that with the P.S.D.-method gives the same limit load factor as the prescribed discrete gust, is given in figure 5 as function of the nondimensional frequency $\nu_{no} = \frac{L}{V}\frac{\rho_o}{\rho}\omega_n$, for an altitude of 20000 ft.

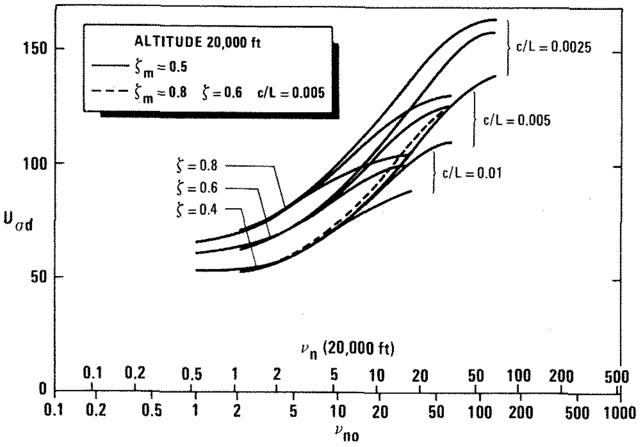

Figure 5. $U_{\sigma d}$-value equivalent to discrete gust velocity $U_{de}$ for an airplane with two degrees of freedom

The curves in figure 5 are given for $\zeta_m = 0.5$ with c/L and $\zeta$ as parameter. Lower values of $U_{\sigma d}$ are obtained for lower values of the damping-coefficient $\zeta$ of the short period motion.
In the same figure the curve for $\zeta_m = 0.8$ (with c/L = 0.005 and $\zeta = 0.6$) is given. This coefficient also has an influence on the $U_{\sigma d}$-curve. $U_{\sigma d}$ decreases with increasing $\zeta_m$.

From the foregoing can be concluded that there exists no direct relation between the P.S.D.-method and the discrete gust method.
Generally different results will be found if the two methods are applied and it is a coincidence if the two methods give approximately the same results. The P.S.D.-method will tend to be the critical one, giving the highest design loads, under the following conditions:

1. If the critical design envelope condition is at a lower altitude.
2a. For low values of $1/T_n$ (high $\mu_g$-values), for an airplane with one-degree-of-freedom (d.o.f.).
2b. For low values of the natural frequency of the short period motion $\nu_n = L\omega_n/V$ for an airplane with two d.o.f.
3. For high values of c/L (large airplanes) if $1/T_{no}$ (one d.o.f.) or $\nu_{no}$ (two d.o.f.) are not low.
4. For low values of the damping coefficient $\zeta$ (two d.o.f.).
5. For high values of $\zeta_m$ (two d.o.f.).

## CAUSES OF THE DISCREPANCY

In the foregoing it has been shown that the discrete gust method and the P.S.D.-method generally lead to different results.
Both methods can be regarded as extrapolation methods. Design loads for a new airplane are calculated on the basis of a method that has been used (or could have been used) to calculate the design loads for older, satisfactory airplanes. Such an extrapolation method should be based on a fairly good description of atmospheric turbulence and the airplane response. The design values for gust strength can then be derived from older airplanes.

However, even for a rigid airplane with one degree of freedom, the two methods already give different results. It therefore is to be expected that, as long as both methods are prescribed in the requirements, conflict situations will arise.

The differences between the two methods can be attributed to the following causes.

1. The character of atmospheric turbulence.
   In the discrete gust method only one gust with prescribed shape is considered. In the P.S.D.-method atmospheric turbulence is assumed to be a random process.
2. The response behaviour.
   In the discrete gust analysis the maximum response peak is considered. The transient behaviour of the airplane is decisive. In the P.S.D.-method the steady state response is used. It is assumed that transients have died out.
3. Relation between gust velocity and gust length.
   In the requirements for a discrete gust analysis only one gust lenght, expressed in chord lengths, is prescribed. This implies that for large airplanes the prescribed gust length is larger than for small airplanes. The gust velocity is assumed to be independent of gust length. In the P.S.D.-method a power spectrum for atmospheric turbulence is assumed. The shape of this spectrum is such that the energy at lower frequencies (large gust lengths) is higher than at high frequencies.
4. Variation of gust velocity with altitude.
   In the requirements for the discrete gust analysis an equivalent gust velocity $U_{de}$ is prescribed, and for the continuous gust analysis a true gust velocity $U_\sigma$.

The last cause is independent of the method that is used. It depends only on the requirements. This cause of the discrepancy between the two methods can be taken away by prescribing a constant ratio of the design gust velocities at all altitudes.

It will now be shown that the main cause of the discrepancy between the two methods is the third one, given above. Although probably unexpected, the first two causes only have a secondary effect.
The discrete gust method assumes that the one-minus-cosine gust has a certain prescribed velocity that is independent of gust length. It has been known already for a long time that gust velocity depends on gust length. This will be shown by quoting Rhode(8)

quote,..... , let us assume that each particle or small unit volume of air contains, at a given isobaric level, the same amount of energy as do all other similar unit volumes at the same level within the sphere of action. Now if, under the action of some more or less general influence associated with the weather conditions in force, these unit volumes are caused to transform their energy into turbulent energy, each at the same rate at any instant, each gust will receive an amount of energy at a rate appoximately proportional to the total volume of air involved in the gust. The power available for each gust under these conditions is therefore approximately proportional to $H^3$. Such a state of affairs could only be transitory as the energy transferred to the gusts would be, in turn, transformed into some other form of energy until a condition of equilibrium was attained, when the atmosphere would become quiescent.

Now in any unidirectional gust of a given shape, the power of the gust is proportional to the cube of the velocity and to the cross-sectional area through the gust, namely, $P \propto U^3H^2$. We have, then, equating the instantaneous power available to the instantaneous power of the gust:

$$U^3H^2 \propto H^3$$

or $U^3 \propto H$

, unquote.

Rhode also showed that measured gust data were reasonably in accordance with this law.
Of course this has to be interpreted statistically: The probability of observing a gust with length $H_1$ and velocity $U_1$ is equal to observing a gust with length $H_2$ and velocity $U_2 = U_1(H_2/H_1)^{1/3}$.

This concept is worked out by Jones in the Statistical Discrete Gust (S.D.G.)-method. A description of the theory is given in reference 9. The maximum response F(H) of an airplane to a discrete gust is calculated as function of gust length H. The weighted gust response is

$$\gamma(H) = F(H).H^{1/3} \tag{15}$$

The maximum value $\gamma(\bar{H})$ of this function is the response value that has to be multiplied by an appropriate design value for gust intensity to provide the gust design load. Jones has extended his theory, especially for lightly damped airplanes, by considering a sequence of discrete gusts. A formulation of gust load requirements, based on the S.D.G.-method is given in reference 10.

The maximum response of an airplane to a one-minus-cosine gust with length H is

$$\Delta n(H) = \frac{a\rho VS}{2mg} K_g(H)U_d \tag{16}$$

It will now be assumed that

$$U_d = \left(\frac{H}{L}\right)^{1/3} .U_L \tag{17}$$

The maximum response will be found for a gust length $(\bar{H})$ and is equal to

$$\Delta n(\bar{H}) = \frac{a\rho VS}{2mg} \left(\frac{\bar{H}}{L}\right)^{1/3} K_g(\bar{H}).U_L \tag{18}$$

Application of the P.S.D.-method gives

$$\Delta n_{PSD} = \frac{a\rho VS}{2mg} K_\varphi U_\sigma \tag{19}$$

For an airplane with one degree of freedom and with unsteady aerodynamic forces, according to Pratt's approximation, the ratio

$$\frac{\Delta n(\bar{H})/U_L}{\Delta n_{PSD}/U_\sigma} = \frac{\left(\frac{\bar{H}}{L}\right)^{1/3} K_g(\bar{H})}{K_\varphi} \tag{20}$$

is given in figure 6 as function of $1/T_n$.

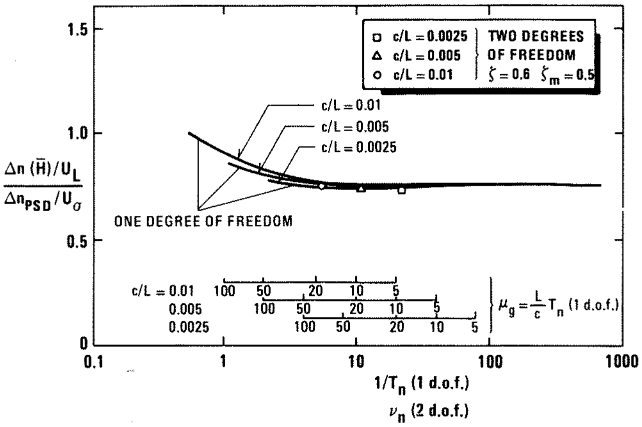

Figure 6. Ratio $\Delta n(\bar{H})/\Delta n_{PSD}$ as function of $1/T_n$ and $\nu_n$

This ratio is approximately equal to 0.75, except for small values of $1/T_n$.

In the same figure some values for this ratio for an airplane model with two degrees of freedom are also given.
The influence on the value of the ratio, both due to changes in c/L and aircraft model are relatively small.

It can be concluded that a class of airplanes exists, namely rigid airplanes with one degree of freedom, for which the P.S.D.-method and a discrete gust method give approximately the same results, provided that in this discrete gust method a tuned gust with the following relation between gust velocity and gust length is used.

$$U = \left(\frac{H}{L}\right)^{1/3} U_L \simeq \left(\frac{H}{L}\right)^{1/3} U_\sigma/0.75 \tag{21}$$

The main difference between the P.S.D.-method and the discrete gust method is caused by not taking into account the relation between gust velocity and length in the latter. The shape of the power spectrum as used in the P.S.D.-method implies that more energy is available at low frequencies (long gusts) than at high frequencies. Both methods are comparable if the relation $U \propto H^{1/3}$ is taken into account. Other differences between the two methods, especially the description of the character of atmostpheric turbulence and the response behaviour, have a secondary effect.

The relation between gust velocity and gust length was derived by Rhode using energy considerations.
The Von Karman power spectrum is proportional to $\Omega^{-5/3}$ for higher frequencies. This is related to the relation $U \propto H^{1/3}$ for discrete gusts (10,3). Measurements of atmospheric turbulence show the same trends (3).
Although this relation has been known for many years it never has been integrated in the requirements for the discrete gust method. Jones advocates the use of the Statistical Discrete Gust (S.D.G.)-method that takes into account this relation.

The foregoing is not a plea to use this S.D.G.-method, but it is intended as a warning against further reliance on the discrete gust method as described in the requirements.

## CONCLUSIONS AND RECOMMENDATIONS

Both FAR and JAR demand that limit loads are determined on the basis of a discrete one-minus-cosine gust with a length of 25 chords.
To take into account the dynamic response to continuous turbulence, FAR requires the P.S.D.-method as an obligatory complement and JAR regards it as a supplementary requirement. Numerical values for $U_\sigma$ are still in discussion.

The comparison of a P.S.D.-Design Envelope Analysis and a discrete gust analysis, based on simple airplane models, indicate that the P.S.D.-method tends to become the critical one for large aircraft with high mass ratio or low natural frequency and/or low damping of the short period motion. This is especially so if the critical design envelope condition is at a low altitude.

It is not possible to make a direct link between the two methods, discrete gust and P.S.D., not even for simple airplane models. Four possible sources for the discrepancy can be indicated

1. The character of atmospheric turbulence
2. The response behaviour
3. Relation between gust velocity and gust length
4. Variation of gust velocity with altitude.

To overcome the last cause of the discrepancy the requirements should prescribe true or equivalent gust design velocities that have a constant ratio for all altitudes.

The wording of the requirements suggests that the character of atmospheric turbulence and the response behaviour are the main sources of the discrepancy between the results obtained with P.S.D.-method and the discrete gust method.
It turns out however that the main source of the discrepancy between the two methods is the relation between gust velocity and gust length.
In the discrete gust method the velocity is independent of length. In the P.S.D.-method the energy for high frequencies is lower than for low frequencies.

If the discrete gust method is applied, using a tuned gust and taking into account that gust velocity is proportional to gust length to the power 1/3, then the two methods give approximately the same results for simple airplane models. Of course if more complex airplane models are used, the results of the P.S.D.-method and the discrete gust method (with $U \propto H^{1/3}$) may deviate much more from each other.
Indications for the relation $U \propto H^{1/3}$ exist.

If this relation is true then those airplanes for which the P.S.D.-method is the critical one, may be relatively less strong than (older) airplanes for which the P.S.D.-method is not critical. The discussion on the relative merits of the discrete gust method and the P.S.D.-method should in the first place be devoted to the relation between gust velocity and gust length. Agreement on this property of atmospheric turbulence should then result in either adopting a discrete gust method in which this relation is incorporated, for example the Statistical Discrete Gust method as developed by Jones, or in raising the Power Spectral Density method as being decisive for the determination of design loads.

## REFERENCES

1. Anon., Federal Aviation Regulations - Part 25 - Airworthiness Standards: Transport Category Airplanes, Change 15, Eff 10/14/80 Department of Transportation - Federal Aviation Administration Washington DC.
2. Anon., Joint Airworthiness Requirements, JAR-25, Large Aeroplanes, Civil Aviation Authority, Cheltenham.
3. Noback, R., Review and comparison of discrete and continuous gust methods for the determination of airplane design loads NLR TR 82134 U, 17-XII-1982.
4. Pratt, K.G., A revised formula for the calculation of gust loads, NACA Technical Note 2964, June 1953.
5. Pratt, K.G., Walker, W.G., A revised gust load formula and a re-evaluation of V-G data taken on civil transport airplanes from 1933 to 1950. NACA Report 1206, 1954.
6. Hoblit, F.M., Paul, N., Shelton, J.D., Ashford, F.E., Development of a power-spectral gust design procedure for civil aircraft, FAA-ADS-53, January 1966.
7. Fuller, J.R., Richmond, L.D., Larkins, C.D., Russell, S.W., Contributions to the development of a power-spectral gust design procedure for civil aircraft. FAA-ADS-54, January 1966.
8. Rhode, R.V., Gust Loads on Airplanes, S.A.E. Journal (Transactions) Vol. 40, No. 3, March 1937, pp. 81-88.
9. Jones, J.G., Statistical discrete gust theory for aircraft loads. A progress report. RAE TR 73167, November 1973.
10. Jones, J.G., On the formulation of gust load requirements in terms of the statistical discrete gust method. RAE Technical Memo FS 208, October 1978.