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Average gust frequencies Subsonic transport aircraft

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AVERAGE GUST FREQUENCIES. SUBSONIC TRANSPORT AIRCRAFT

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AVERAGE GUST FREQUENCIES. SUBSONIC TRANSPORT AIRCRAFT

1. NOTATION

a	rate of change of wing lift coefficient with incidence, corrected for Mach number	rad^{-1}	rad^{-1}
A	aspect ratio		
b	wing span	m	ft
$\bar{c}$	geometric mean chord, S/b	m	ft
d	gust gradient distance for unswept wings	m	ft
d_e	effective gust gradient distance for swept wings given by $d_e = d + \frac{b}{2} \tan \Lambda$	m	ft
D	distance flown in a given flight stage	km	n miles
f_c	cumulative frequency		
f_1	natural frequency of wing in first bending mode	Hz	cycles/s
F_M	gust alleviation factor in compressible flow for ramp shaped gust defined in Section 2 (iv)		
F_0	gust alleviation factor in incompressible flow for ramp shaped gust defined in Section 2 (iv)		
g	gravitational acceleration	m/s^2	ft/s^2
H_p	pressure altitude	m	ft
k	ratio of up-gusts to down-gusts		
l_{10}	average distance flown to meet an up- or down-gust of $v_e \geq 10 \text{ ft/s (3.05 m/s)}$	km	n miles
M	bending moment	N m	lbf in
M_m	mean bending moment (1g level flight)	N m	lbf in
M_{max}, M_{min}	maximum and minimum bending moments, respectively	N m	lbf in
ΔM	change in bending moment, $(M_{max} - M_m)$ for an up-gust or $(M_m - M_{min})$ for a down-gust	N m	lbf in
$(\Delta M)_{10}$	value of ΔM arising from a 10 ft/s (3.05 m/s) up-gust	N m	lbf in

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r	relative gust frequency expressed as ratio of gusts $\geq v_e$ to gusts ≥ 10 ft/s (3.05 m/s)		
Δn	increment of normal load factor		
S	wing area (associated with wing lift coefficient)	m ²	ft ²
v	true airspeed of gust	m/s	ft/s
v_e	equivalent airspeed of gust, $v\sqrt{\sigma}$	m/s	ft/s
V_e	equivalent airspeed of aircraft	m/s	ft/s
W	weight of aircraft	N	lbf
Λ	angle of sweep of wing 1/4 chord line relative to aircraft transverse (pitching) axis	degrees	degrees
ρ	air density	kg/m ³	slugs/ft ³
ρ_0	standard sea-level air density	kg/m ³	slugs/ft ³
σ	relative density, ρ/ρ_0		

Suffixes

d	relates to a down-gust
u	relates to an up-gust
fl	indicates per flight

Both SI and British units are quoted.

2. GENERAL NOTES

The results presented have been derived from the accelerometer, VG and VGH records reported in Derivations 2 to 18 summarised in Table 7.1. These data are drawn mainly from subsonic transport aircraft in scheduled operations and should therefore be used with discretion for aircraft otherwise engaged. The balance of the data represents either special gust investigations at high and low altitude, or contour flying.

In converting accelerations to the gust velocities used in Figures 1 to 6, the procedure of Derivation 1 has been followed and the following assumptions have been made.

- (i) The gust produces an increase of lift on the wing alone.
- (ii) The aircraft is rigid and can rise vertically but does not pitch.

- (iii) The equivalent airspeed of the gust, v_e , is given by the formulae

$$\Delta n = \frac{\frac{1}{2}\rho_0 V_e S a F_0 v_e}{W} \quad \text{for incompressible flow,} \quad (2.1)$$

$$\Delta n = \frac{\frac{1}{2}\rho_0 V_e S a F_M v_e}{W} \quad \text{for compressible flow.} \quad (2.2)$$

- (iv) The gust alleviation factors F_0 and F_M are given by Figure 7, which assumes that the gust velocity rises linearly from zero to v_e in distance d_e , and thereafter remains constant.

- (v) The gust gradient distance, $d = 100$ ft or 30.5 m.

- (vi) The effective gust gradient distance for a swept wing aircraft is given by

$$d_e = d + \frac{b}{2} \tan \Lambda. \quad (2.3)$$

No direct allowance has been made for structural flexibility, which can increase both wing strains and the accelerations at the aircraft centre of gravity from which the gust data are derived. An indirect allowance is made in that the dynamic characteristics of the aircraft studied were similar, and wing strains determined on the basis of the above assumptions generally agree with measured values. These data can therefore be used to calculate gust loads on other similar aircraft provided the same assumptions are made.

In deciding whether or not a given aircraft is effectively similar to those from which the present data were obtained, consideration must be given to the centre of gravity accelerations caused by turbulence. A flexible aircraft, subject to the ramp gust defined in (iv) above, may be treated as a simple mass-spring system having a natural frequency equal to the frequency f_1 of the aircraft wing in the fundamental bending mode. For such a system dynamic effects may be neglected provided that the time taken for the gust to reach its peak value is greater than about $0.75 \times$ the wing period in bending.

The concept is represented by the expression*

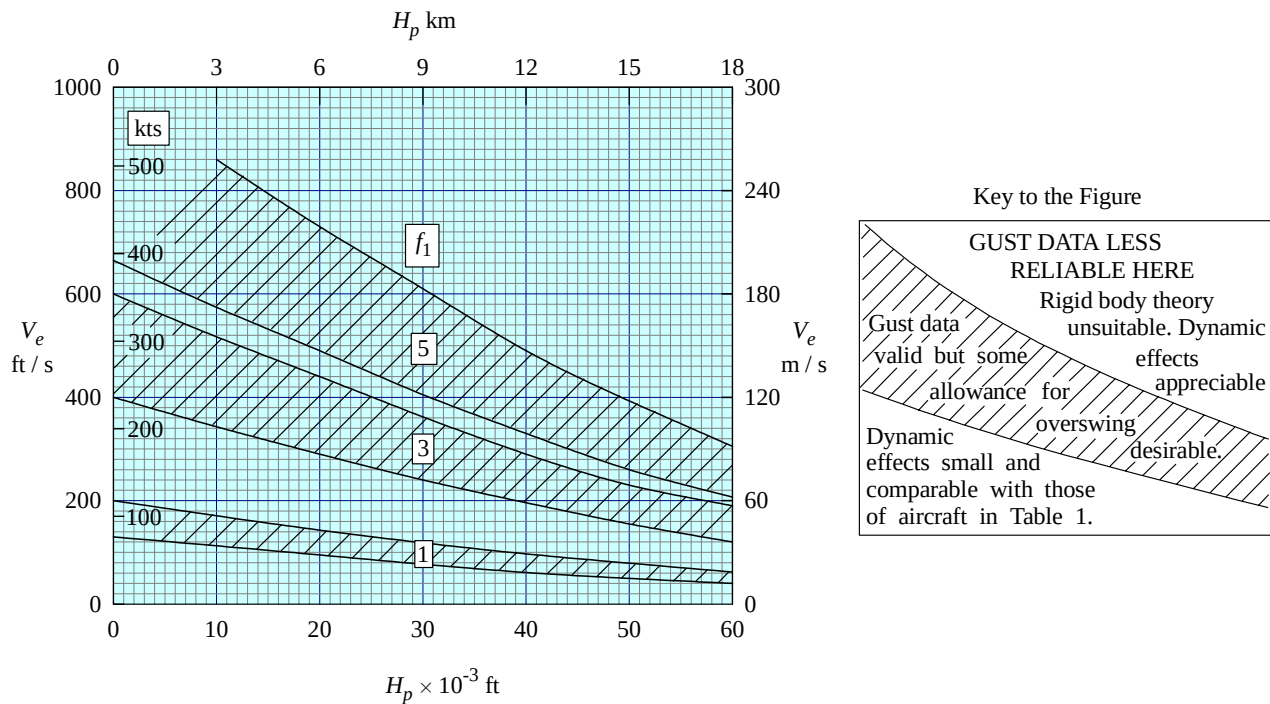
$$\frac{d\sigma^{1/2}f_1}{V_e} > 0.75, \quad (2.4)$$

which, for $d = 100$ ft (30.5 m), is given by the area below the lower bound of the shaded areas in Sketch 2.1 below. As the rise time of the gust is reduced, dynamic overswing increases, becoming appreciable when*

$$\frac{d\sigma^{1/2}f_1}{V_e} \leq 0.5. \quad (2.5)$$

This expression, represented by the area above the bold curves in Sketch 2.1, defines those combinations of V_e and H_p for which the rigid body theory used in the gust analysis becomes unsuitable.

* These expressions are deduced in Appendix A.



Sketch 2.1

It should be emphasised that the curves of Sketch 2.1, relating as they do to the gust defined arbitrarily by assumption (iv) above, provide a general rather than a specific indication of the influence of dynamic effects on a given aircraft or operation. Similarly, they concern centre of gravity accelerations only.

In considering the effects of flexibility on wing stresses account should be taken not only of resonant modes other than the wing fundamental, but also of the possibility of significant dynamic stresses in those regions where the rigid body assumption is acceptable for the correlation of centre of gravity accelerations. Note also that a single gust load cycle may give rise to a number of stress cycles when wing resonance is excited in any mode, thus destroying the direct relationship between the frequencies of occurrence of stress and gust that exists for the rigid body case.

3. NOTES ON THE CURVES

Figures 1 and 2 show the average distance flown by aircraft without cloud warning radar at various altitudes in order to experience a positive or negative gust ≥ 10 ft/s E.A.S. (3.05 m/s). The aircraft are listed in Table 7.1. The curves represent an overall average drawn through the mean of the data for the various altitude bands as shown in Figure 3. A distinction is made in Figures 1 and 2 between data obtained in climb and descent as compared with cruise, and between general operations, those carried out exclusively over the sea, and those obtained on special missions. The special missions data are taken from special investigations of gust frequencies at high and low altitude by military aircraft, and contour flying by civil aircraft. The averages given in Figure 3 for scheduled transport aircraft take climb, descent and cruise together above 5000 ft (1500 m) but separate curves are given below this altitude to identify the more severe loading experienced during stand-off cruise. A separate curve is also given for aircraft cruising at altitudes of less than 10 000 ft (3050 m) over the sea, but frequencies above this altitude are essentially given by the overall average curve. The curve given for special missions should be regarded as tentative owing to uncertainty regarding the manoeuvre load contributions.

Figure 3, in addition to summarising the data of Figures 1 and 2, also presents data for aircraft fitted with cloud warning radar. The curve that has been drawn through these data blends with the overall average curve at 5000 ft (1500 m).

In determining fatigue load spectra it is normally acceptable to assume that each up-gust is followed by a down-gust of equal magnitude. The distance flown to experience a gust cycle $\geq \pm 10$ ft/s (3.05 m/s) is, on this basis, twice the value of l_{10} given by Figures 1, 2 and 3. However, the values of the ratio of up-gusts to down-gusts plotted in Figure 4 show that there is a positive bias to loading spectra for altitudes lower than about 10 000 ft (3050 m). Where this becomes appreciable, as at low altitudes, it should be taken into account, and for this purpose it may be assumed that the curve given applies for all values of v_e . It is likely that the positive bias results partly from manoeuvring accelerations associated with take-off and landing, and it is assumed that this is a consistent feature of scheduled transport operations.

The relative frequencies of occurrence of gusts of various magnitudes are given in Figures 5 and 6 respectively for aircraft with and without cloud warning radar. Note that for both cases the maximum relative frequencies usually occur in the intermediate altitude range (see the dashed curves for 17 500 ft (5250 m)). These data can be used with those of Figures 1 to 4 to predict the number of gusts of each magnitude likely to be reached or exceeded on a given flight path.

In Figure 7, the gust alleviating factor for incompressible flow is plotted against the aircraft mass parameter for a range of wing aspect ratios and values of $\bar{c}/d_e$. A correction factor, dependent on Mach number, is given for the determination of the alleviating factor in compressible flow.

4. USE OF THE CURVES

The example, Section 6, illustrates how the curves of Figures 1 to 7 may be employed to compile cumulative frequency gust spectra for a wing. The example chosen has been deliberately kept short and is only intended to illustrate the basic procedure. In practice, more flight stages may be introduced and different flight patterns investigated. The example is presented in terms of a wing bending moment but in some cases it may be more convenient to consider other parameters. In all cases it is necessary to repeat the calculation for various sections along a wing to obtain a complete picture of the overall fatigue loading.

In order to facilitate calculations, Appendix B provides equations for the curves of Figures 5 and 6. The equations only apply over the regions covered by the curves on their respective figures and may become unreliable if extrapolated beyond those regions.

5. DERIVATION

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6. EXAMPLE

It is required to generate cumulative frequency versus wing root bending moment curves for an aircraft. The aircraft has a wing area of 200 m², a wing span of 41.24 m and a wing sweep angle on the 1/4 chord line of 30 degrees. The flight plan details are provided in the first 9 columns of Table 6.1. The aircraft is assumed not to carry cloud warning radar.

6.1 Calculation Procedure

The gust data presented are normalised with respect to the 10 ft/s (3.05 m/s) gust. The first step is therefore