EFFECT OF SPANWISE GUST VARIATIONS

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The left side of Figure 1 depicts the assumption commonly used in power spectral treatments of gust encounter; that is, the turbulence is considered random in the flight directions but uniform in the spanwise direction The right side of the figure depicts the more realistic situation wherein the turbulence is considered to be random in both the flight and spanwise directions.

The top sketch of Figure 2 indicates that we can consider the random gusts to be composed of the sum of a number of sinusoidal gust components. It has been found that the long wavelengths and the very short wavelengths do not contribute significantly to airplane loads or response. The intermediate wavelengths, on the order of from one to ten times the span of the airplane, are found to be the major contributors. The middle two sketches show the result of the uniform spanwise gusts assumption on the vertical force and rolling moment. The left sketch shows that the entire span is effective in producing a vertical force. The right sketch shows that the right and left wings produce equal upward forces, and thus no rolling moment is produced. Thus a failing of the uniform spanwise gust assumption is that no rolling moment can be produced. For the lower two sketches we show the influence of a sinusoidal gust component which has a wavelength roughly equal to the airplane span. On the left we see that the upward force is essentially cancelled out by equal downward forces. Thus for this component, and for the smaller wavelength components, there is very little vertical force production. On the right we see in contrast that this wavelength component is a major producer of rolling moment. We thus need to take into account all the spanwise components to accurately establish the rolling moment produced by gusts.

Figure 3 gives three of the key reasons why spatial or spanwise variation of gust is important. Item 1 deals with the N_0 parameter, which refers to the number of times per second the response quantity of interest crosses the 1-g load level with a positive slope. This N_0 value is found as the radius of gyration of the area under the output spectra about the vertical axis. If the gusts are treated as uniform in the spanwise direction, N_0 evaluates to infinity by our normal analytical approach procedures. If we alter the non-steady aerodynamics we can make the tail of the output spectra converge faster; a finite but unrealistically high value of N_0 results. If we take into account the spanwise variation, the tail of the spectra converges much faster due to the cancelling effects discussed in Figure 2; the N_0 value is now found to be correctly evaluated. Item 2 indicates that the proper treatment

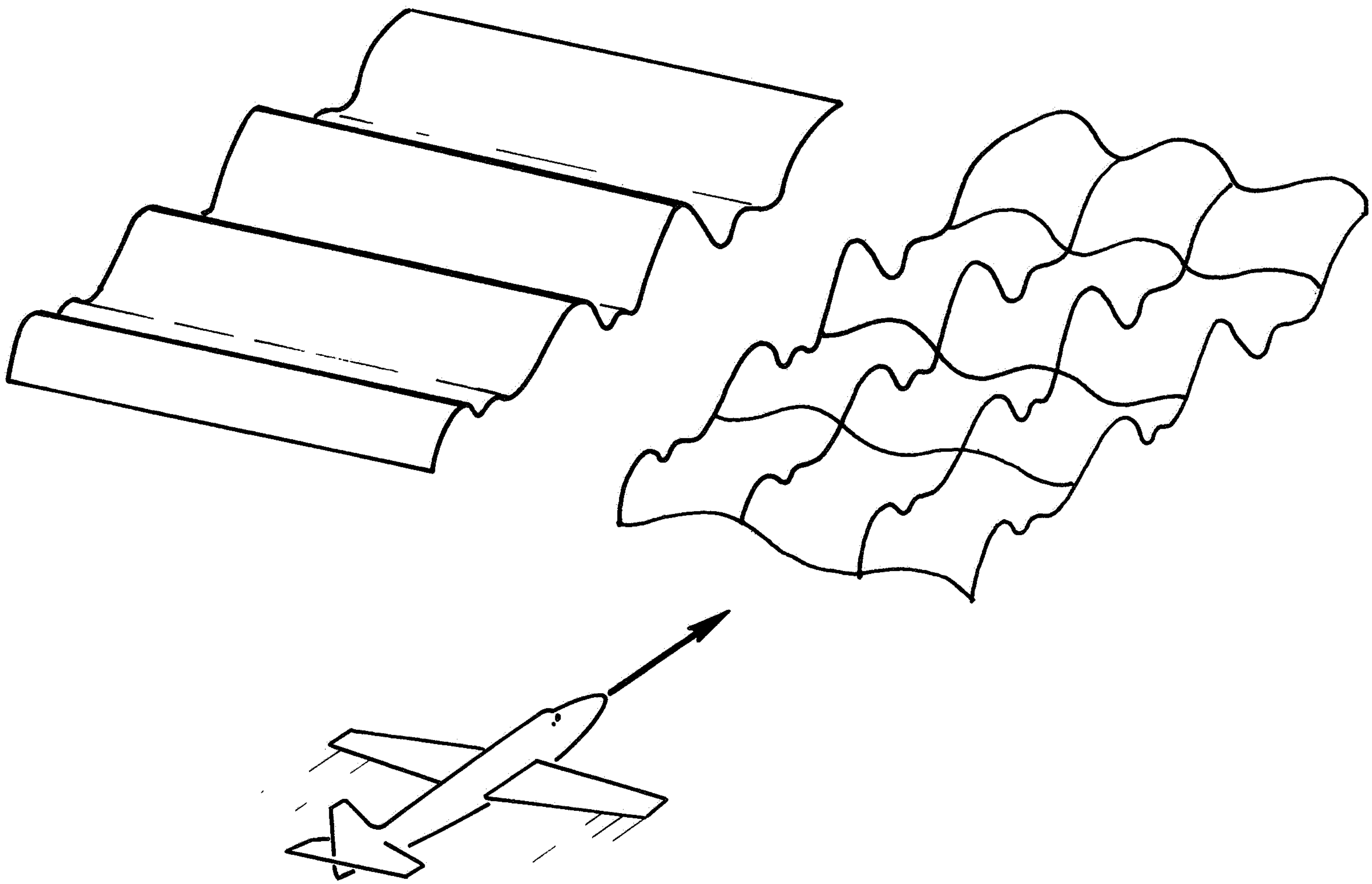
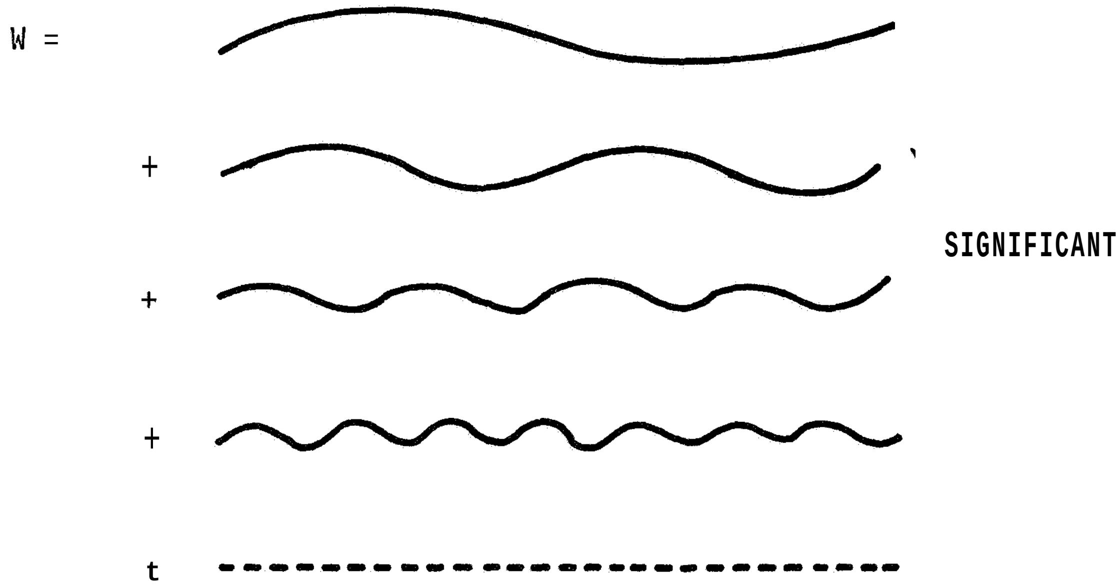


FIGURE 1. ASSUMPTION OF TURBULENCE MODELS.



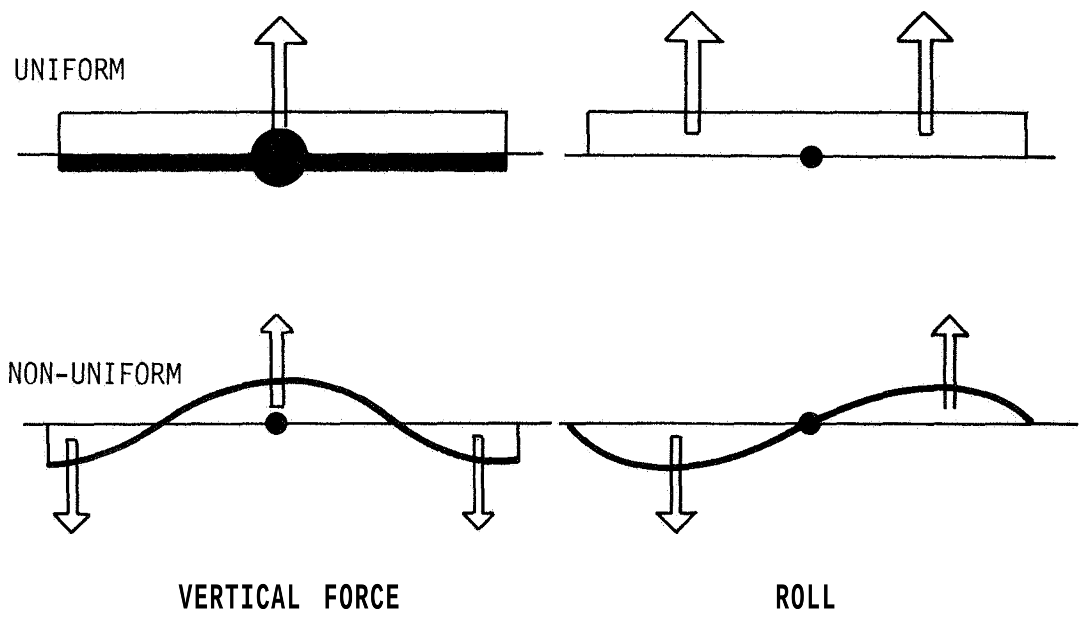
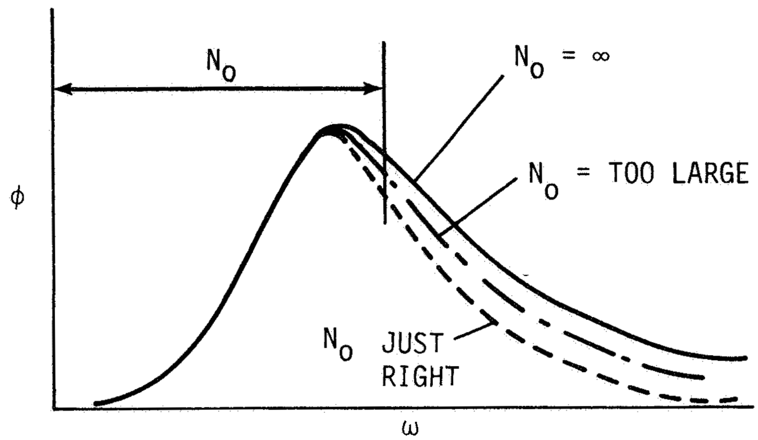


FIGURE 2. RANDOM GUSTS ASSUMED TO BE COMPOSED OF SINUSOIDAL GUSTS.

(1) N_o



(2) ROLLING MOMENTS

(3) CROSS-CORRELATION

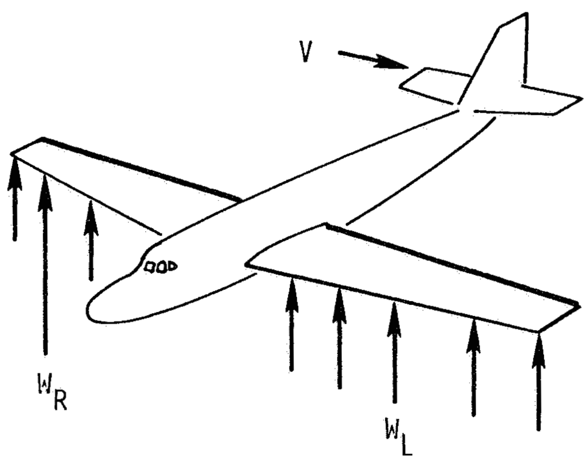


FIGURE 3. THREE OF THE KEY FEATURES OF SPATIAL OR SPANWISE GUST VARIATIONS.

of non-uniform spanwise gusts does lead to a rolling moment. Item 3 indicates that we are interested in general about the cross-correlations of the gust velocities that are found across the span of the wing and in the cross-correlations between vertical and lateral gusts. We need experimental confirmation of our analytical assumptions with respect to the makeup of these cross-correlation functions.

Figure 4 shows a way for generating realistic turbulence velocities from a random number source. The right side of the equation represents the random numbers (which have a white noise type spectra). Solution of this equation for w gives a sequence of numbers which have a character similar to atmospheric turbulence velocities. The spectra of the w values, shown in the bottom, is a good practical approximation to the spectra of gust velocities found for the atmosphere.

Figure 5 shows the type of results that have been found in an analytical study to evaluate the rolling moment spectra that develops on an aircraft due to the spanwise gust variations. The characteristic shape of the spectra is as shown. The peak is found to be associated with turbulence wavelengths slightly larger than the wing span, as depicted in Figure 2. The parameter X is seen to be a function of the frequency ω, the forward speed V, the scale-to-chord ratio L/c, and the wing aspect ratio A.

Figure 6 shows the equation that was also derived in the study which allows for the generation of a timewise history of the random rolling moment that is felt by the airplane due to gusts. The quantity y in this figure represents an input gust time history, as found by the technique shown in Figure 4; the quantity X in this figure represents the rolling moment. Thus, a step-by-step solution of this equation gives a time history of the rolling moment impressed on the airplane due to gusts. The power spectrum of X is the power spectrum shown in Figure 5. The dependence of the coefficients of the equations on velocity V, chord c, and scale-to-chord ratio L/c is also shown.

$$\dot{W}_n + aW_n = r_n$$

$$a = \frac{V}{L}$$

r_n - from random number generator

W_n - gust velocity

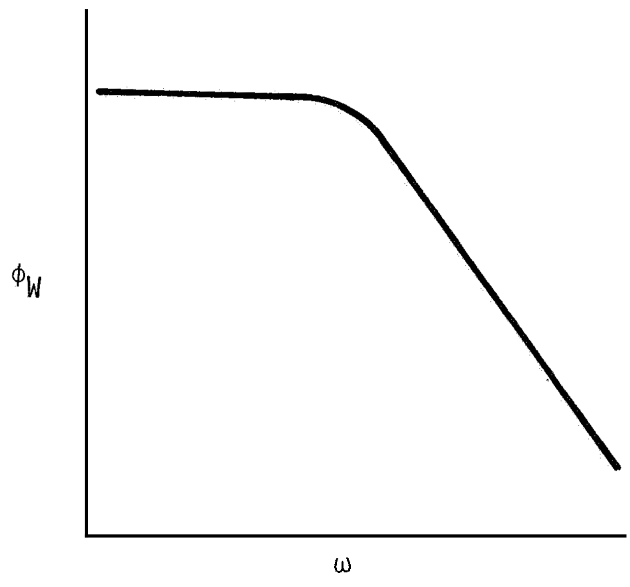
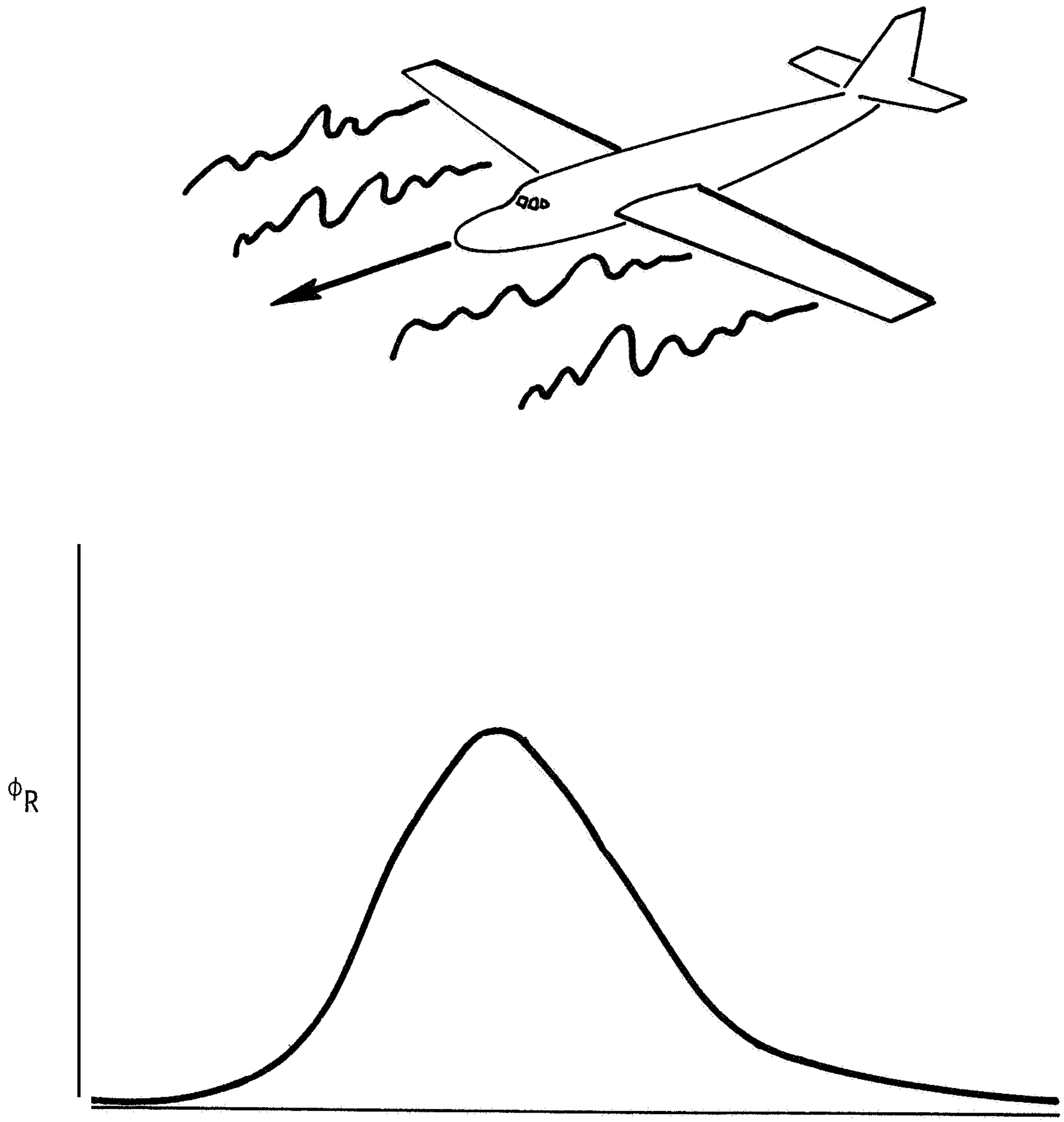


FIGURE 4. GUST SIMULATION.



$$X = \frac{C}{2L} A\sqrt{1 + \left(\frac{\omega C}{2V}\right)^2 \left(\frac{2L}{C}\right)^2}$$

FIGURE 5. ROLLING SPECTRA.

$$\underset{\dfrac{C^2}{V^2}}{\underset{\Big\downarrow}{a\,\ddot{X}}} \quad + \quad \underset{\dfrac{C}{V}}{\underset{\Big\downarrow}{b\,\dot{X}}} \quad + \quad c\,X \quad = \quad \underset{\dfrac{C}{V^2}}{\underset{\Big\downarrow}{d\,\dot{y}}} \quad + \quad \underset{\dfrac{2L}{C}}{\underset{\dfrac{1}{V}}{\underset{\Big\downarrow}{e\,y}}}$$

FIGURE 6. ROLL MOMENT GENERATION.