Range Requirements for Airborne Turbulence Detectors

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Introduction and Purpose

HIGH-SPEED, high-altitude aircraft are expected to encounter turbulent atmospheric conditions that may produce undesirable aircraft motions and loads. It has been suggested that such turbulence can be avoided by use of an airborne detector system (e.g., forward-looking radar or laser). The detector would "see" the turbulence ahead, and the aircraft would then be maneuvered to fly around the contaminated area (see Fig. 1).

The purpose of this Note is to alert the designers of CAT (clear air turbulence)-sensing equipment to be aware that in their definition of range requirements for airborne CAT detectors they must consider 1) the comfort of the passengers, 2) the geometry of the to-be-avoided CAT areas, 3) the maneuver capability of the aircraft, and 4) the decision-making process of the pilot. Some back-of-the-envelope calculations were made to obtain an indication of the range requirements for such detectors—assuming that they were to be used onboard a supersonic aircraft (e.g., the SST). Each of the four aforementioned considerations is included in the calculations. The results of this exercise are summarized below and in Fig. 2 (for a Mach 3 airplane).

Technical Discussion

It is assumed that the airplane is moving at a constant altitude (not specified) and at a constant velocity V (in this example $V = 2904$ fps, Mach 3). To make a lateral displacement of d ft, the craft is maneuvered through two constant-radius, constant-altitude turns; one is at radius $R = +V^2/\Delta ng$ and the other is at radius $R = -V^2/\Delta ng$. $g = 32.2$ ft/sec^2 and Δn = lateral load factor. The time-to-go into and out of a bank, and to reverse the bank angle in the middle of the maneuver is, initially, assumed to be zero. Also, the time for decision (i.e., "Shall I turn, which way, and how much?") is also, initially, assumed to be zero. The output of the calculation is the distance D, the amount of flight path consumed during the double-radius maneuver.

From the foregoing assumptions, it can be shown that

$$D = [4V^2(d/\Delta ng) - d^2]^{1/2} \text{ ft} \tag{1}$$

For small values of the ratio d/D (e.g.,<0. 1), Eq. (1) reduces to

$$D = 2V(d/\Delta ng)^{1/2} \text{ ft} \tag{2}$$

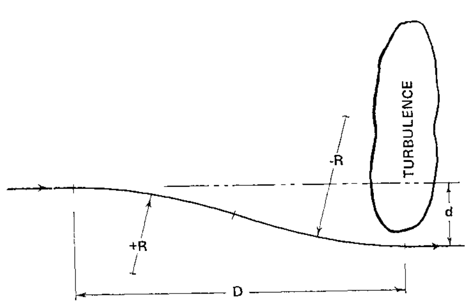

Fig. 1 Flight-path geometry, plan view.

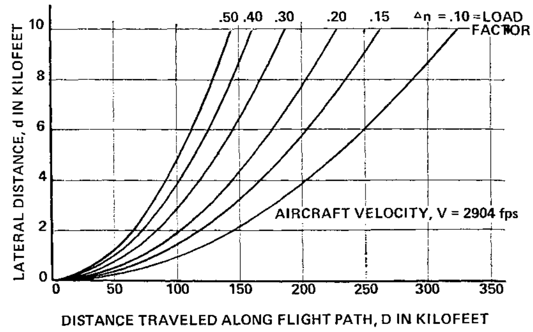

Fig. 2 Distance required to make flight-path deviation.

It is this variation that is plotted in Fig. 2.

Because it takes the pilot a certain amount of time t_p to formulate a decision and an additional amount of time t_a to bank the aircraft left and right, an increment $V(t_p + t_a)$ must be added to D to obtain the total range X. Hence,

$$X = 2V(d/\Delta ng)^{1/2} + V(t_p + t_a) \tag{3}$$

One example of how the foregoing procedure may be used is the following. A pilot detects turbulence at a distance D up ahead; to avoid same he decides (in zero time) to displace his flight path a distance $d = 8000$ ft. For passenger comfort Δng is to be limited to 12.8 ft/sec^2 (i.e., $\Delta n = 0.4$). (Incidentally, the bank angle in a level turn would be about 22° and the delta load factor normal to the passenger's seat would be about 0.08.) For this double maneuver, the distance $D = 145{,}200$ ft (about 24 naut miles).

It should be noted that for every second it takes the pilot to ponder his decision and to bank the aircraft, another 2900 ft slips by. If, in the preceding example, this delay time were 10 sec, then another 29,000 ft (about 5 naut miles) must be added to the range of the turbulence detector. Hence, for this example, the onboard detector unit must have a range X of at least 29 naut miles.

In summary, a simple formula, Eq. (3), has been derived to compute the range requirement for an airborne turbulence detector. Account has been taken of passenger comfort (the Δng term), the geometry of the turbulence (the d term), the aircraft maneuver capability (the t_a term), and the decision-making process of the pilot (the t_p term).

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Initial Phase of Parachute Inflation

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Nomenclature

c_v = velocity coefficient for incompressible flow, dimensionless
D_0 = parachute nominal diameter, ft
g = acceleration of gravity, ft/sec^2
S_{ie} = effective skirt inlet area, ft^2
S_0 = parachute nominal reference area ($= \frac{1}{4}\pi D_0^2$), ft^2
S_p = parachute projected area, ft^2
t = time, sec
t_i = time from full line stretch to end of initial-phase inflation, sec

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