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

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

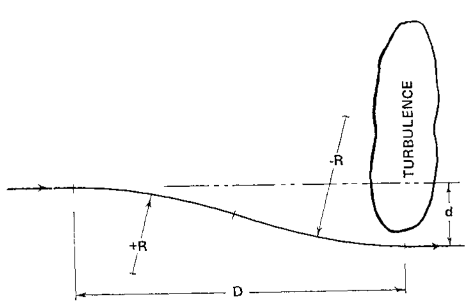

Fig. 1 Flight-path geometry, plan view.

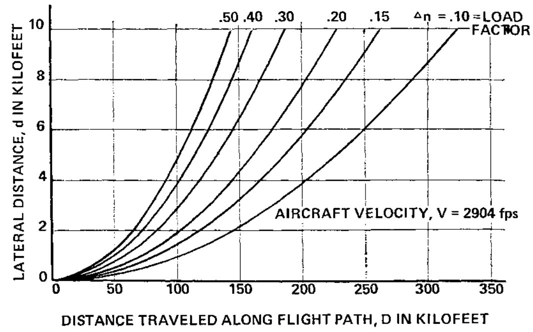

Fig. 2 Distance required to make flight-path deviation.

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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t_f = time from full line stretch to end of full-blossom inflation, sec
v_s = snatch velocity (velocity at time of full line stretch), ft/sec
V = canopy volume at end of initial-phase inflation, ft^3
θ = flight-path angle, deg or rad

Superscript

$\wedge$ = average value during initial-phase inflation

Background Data

IN 1964, Berndt published a work[1] in which 1) results were summarized from 28 flight tests of 28-ft-diam solid flat parachutes at snatch velocities from 153 to 356 ft/sec and at altitudes from 6000 to 21,000 ft, 2) canopy development during the initial inflation phase was described, based on motion pictures of the inflation sequence, and 3) empirical, mathematical correlations were given, inter alia, for S_p/S_0 vs t/t_f for inflation of the 28-ft chutes. As noted by Berndt, canopy inflation (after full line stretch) takes place in two major phases. These phases are characterized by 1) filling of the canopy from the skirt to the vent (the initial phase of inflation) and, subsequently, by 2) filling of the canopy from the crown to the skirt as the canopy inflates to full blossom (the final phase of inflation).

Berndt's data are invaluable for 28-ft solid flat parachutes used within the range of test conditions considered in Ref. 1. However, the question arises: How may the data be extrapolated to other sizes of chutes tested at other conditions? The purpose of this paper is to present a partial answer to this question; that is, to present a physical rationale, to indicate the proper scaling law, and to provide statistics for the initial phase of inflation. Only incompressible flow will be considered.

Table 1 Summary of experimental and calculated data

Test no.[a]	v_s, ft/sec[a]	t_i, sec[b]	Calculated value for v_st_i/D_0
1	154.5	0.355	1.959
2	159.0	0.313	1.778
3	161.1	0.289	1.663
4	203.0	0.285	2.066
5	220.0	0.222	1.744
6	251.6	0.175	1.573
7	255.0	0.189	1.721
8	256.8	0.184	1.687
9	281.6	0.175	1.760
10	153.5	0.318	1.743
11	211.5	0.219	1.654
12	219.0	0.188	1.470
13	224.7	0.205	1.645
14	227.8	0.254	2.067
15	230.1	0.246	2.022
16	243.0	0.210	1.823
17	331.0	0.187	[c]
18	351.0	0.170	[c]
19	356.0	0.167	[c]
20	220.0	0.232	1.823
21	254.0	0.193	1.751
22	241.0	0.171	1.472
23	268.3	0.148	1.418
24	275.0	0.181	1.778
25	285.0	0.172	1.751
26	286.6	0.207	2.119
27	287.5	0.154	1.581
28	334.0	0.219	[c]
			42.068

[a] Verbatim from Ref. 1, Table 1, p. 305. All tests were with 28-ft D_0 canopy and with "canopy loading" between 0.4 and 0.7 lb/ft^2. Test numbers 1–9, 10–19, and 20–28 correspond to nominal deployment altitudes of 6000; 13,000; and 21,000 ft, respectively.
[b] Which is the same as the product $T_2 t_f$ in the nomenclature of Ref. 1.
[c] Omitted from the summation because the chutes were observed to squid at $v_s \geq 300$ ft/sec.

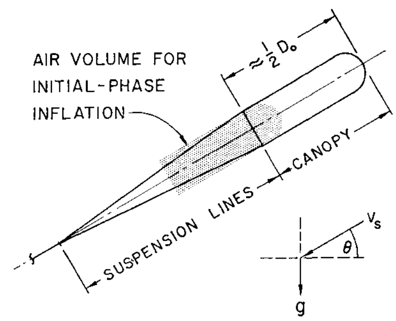

Fig. 1 System geometry.

Theory

The initial phase of inflation begins at the time of full line stretch, i.e., when the chute has been deployed at full extension and is at velocity v_s in the airstream. It is assumed that system velocity remains sensibly constant during the initial phase of inflation. The assumption appears reasonable because the system remains in a relatively low-drag configuration during the phase and because elapsed time for the phase is on the order of but 1 sec even for the largest chutes now in use. Let t_i be the time required for initial-phase inflation, with system geometry as in Fig. 1. In Fig. 1, if the canopy remains constant in cylindrical cross section during initial-phase inflation, it is evident that the system would have to move a distance $v_st_i \approx \frac{1}{2} D_0$ to fill the canopy volume with air from the skirt to the vent. Thus, for a given type of parachute, one would expect the dimensionless parameter v_st_i/D_0 to characterize the initial phase of inflation, barring squidding of the chute.

In the actual case, the canopy cross section does not remain constant during initial-phase inflation: both effective canopy skirt inlet area S_{ie} and canopy volume vary. For the actual case, Berndt's correlation of data from photographs of inflating 28-ft D_0, solid flat circular chutes indicates that the average skirt inlet area during initial filling is [see Ref. 1, Eq. (20)]

$$\hat{S}_{ie} = 0.006091 S_0 = 0.004784 D_0^2 \tag{1}$$

For the same chute, the data show that canopy volume at the end of initial filling is [Ref. 1, Eq. (32)]

$$V = 0.006255 D_0^3 \tag{2}$$

For the actual case, it is therefore calculated that (volume change) = (velocity) $\times$ (average skirt inlet area) $\times$ (time) $\times$ ($\hat{c}_v$), i.e.,

$$V_s = v_s \hat{S}_{ie} t_i \hat{c}_v \tag{3}$$

The coefficient of velocity c_v has values from 0.7 to 0.8 for a roughly comparable case from hydraulics,[2] so that $\hat{c}_v \approx 0.75$. Substitution of this value for $\hat{c}_v$ and of Eqs. (1) and (2) into Eq. (3) is used to calculate

$$\begin{aligned} v_st_i/D_0 &= V/\hat{S}_{ie}\hat{c}_v D_0 \\ &= (0.006255 D_0^3/(0.004784 D_0^2)(0.75)(D_0) \\ &= 1.74 \end{aligned} \tag{4}$$

Comment on squidding

Squidding describes a situation in which the canopy fails to inflate after attaining full line stretch. It consists essentially of a stable hold or stall in the normal inflation process and its occurrence is a function of several factors.[3] From experience and from Berndt's test data, it appears that squidding must occur near the end of the initial phase of inflation (see, e.g., Ref. 1, Fig. 4). The effect of squidding is thus to extend the distance (or, equivalently, the time) required for the initial phase of inflation. Consequently, the

Table 2 Expected variation from nominal in $v_s t_i / D_0$

Variation from nominal value $v_s t_i/D_0 = 1.75$	Expected frequency of occurrence of a variation larger than in the preceding column
$\pm 7.4\%$	Half of the time
$\pm 18.5\%$	Once in 10 tests
$\pm 30.3\%$	Once in 100 tests
$\pm 40.7\%$	Once in 1000 tests

relationship given in Eq. (4) is not valid for a squidding chute.

Test Data

Berndt's experimental data on the initial phase of inflation for 28 tests are summarized in Table 1. Excluding those four tests in Table 1 with $v_s \geq 300$ ft/sec (because of squidding), the remaining 24 tests give a mean value of 1.75 for the parameter $v_s t_i/D_0$, with a standard error† of ± 0.19. That is, from the experimental data it is found that

$$v_s t_i/D_0 = 1.75 \pm 11\% \text{ standard error} \tag{5}$$

As indicated by the data of Table 1 and as known from experience, parachute inflation is a statistical phenomenon. Application of statistics† to the data of Table 1 indicates that one may expect variations in the parameter $v_s t_i/D_0$ in accordance with Table 2.

Summary and Conclusions

To recapitulate, we agree with Berndt[1] that the parachute inflation sequence occurs in two major phases. Elementary considerations show that the dimensionless parameter $v_s t_i/D_0$ should characterize the initial phase of inflation in incompressible flow. With the use of Berndt's data on average skirt inlet area and on canopy volume change during initial inflation, we calculated that one would expect a value of $v_s t_i/D_0 = 1.74$. We then used Berndt's experimental data for initial-phase inflation times and snatch velocities for 24 tests of 28-ft D_0 chutes to calculate that, for those tests, the parameter $v_s t_i/D_0$ actually exhibited an average value of 1.75.

Physically, $v_s t_i/D_0$ is the ratio of distance required for initial-phase inflation to parachute diameter. The results obtained in this paper show that $v_s t_i/D_0$ is constant in incompressible flow. Thus, for a given parachute, the distance for initial-phase inflation is constant, regardless of the velocity or altitude of deployment and regardless of the suspended weight (so long as squidding is not encountered).

It is intuitively evident that $v_s t_i/D_0$ should remain very nearly the same for any flat circular type of chute (e.g., solid, ring-slot, ribbon) if $\hat{c}_v$ remains sensibly constant. We would expect $\hat{c}_v$ to so remain constant as long as the chutes were similar in (suspension line length/diameter) and (number of lines/diameter) ratios.

Berndt correlates his experimental data by presenting empirical curves which permit one to calculate S_p/S_0 vs t/t_f. The empirical curves are entirely adequate for use with a chute for which t_f is known. However, their nature is such that t_i or t_f cannot readily be calculated for given arbitrary values of v_s and D_0. The utility of the dimensionless parameter $v_s t_i/D_0$ developed in this paper is that it allows calculation of t_i for any size chute and any v_s (barring squidding), once the value of $v_s t_i/D_0$ has been established for a particular class or type of chute.

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[2] Daughterty, R. L., *Hydraulics*, 4th ed., McGraw-Hill, New York, 1937, p. 123, Fig. 91-c.

[3] Brown, W. D., *Parachutes*, Pitman & Sons, London, 1951, pp. 67–86 and 100–102.

[4] Arkin, H. and Colton, R. R., *Statistical Methods*, 4th rev. ed., Barnes and Noble, New York, 1956, Chap. XIII, pp. 115, and 126–127.

† Using statistics of small samples.[4]

A Midair-Deployed Buoyancy Suspension System for the Briteye Battlefield Illumination Flare

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Visual target illumination for both ground forces and air strikes by combat aircraft employs the use of light emitting pyrotechnic candles. These candles, more commonly called flares, are delivered to the target in two basic modes, ground to ground and air to ground. Ground-to-ground flares are ballistically deployed by various means ranging from hand held signals to large guns (i.e., the 105-mm howitzer) whereas air-to-ground flares are deployed by aircraft. Air-to-ground flares are delivered from external stores on attack aircraft or internal dispensers in cargo aircraft.

Since the basic function of a target illumination flare is to provide visible light in and over an area, it is necessary to maintain the flare in an airborne state during the burn time duration of the flare candle once it has been released from the aircraft. Parachutes of various sizes and design configurations are used to decelerate and provide a slow descent rate to enable a flare to remain airborne during the candle burn duration. The Mark-45 flare, which is a modification of the standard Mark-24, will be the basic flare used by both cargo- and fighter-type aircraft. It is compatible with dispenser and external store carriage and delivery techniques. The Mark-45 aircraft flare has a rated light output of 2 million candle power and a candle burn duration of 2 min. This updated version of the Mark-24 flare will be the primary aircraft delivered flare system used by the Armed Forces.

In the early 1960's studies were conducted to determine the illumination requirements for the support of night air attack missions and the capability of existing flares to meet these requirements. These studies, when combined with the operational requirements of the Navy and Air Force, led to the technical development of the Briteye Flare System. The requirements called for a flare system with a light output of 5 million candle power and a burn time duration of 5 min. An average descent rate of 5 fps was also included as an operational characteristic.

Analysis of the decelerator requirements for a long-duration, high-light-output flare indicated that the use of a parachute to provide a descent rate in the 5-fps range would result in critical parachute canopy loading. Preliminary experiments in the use of a balloon-type flare suspension system to provide both initial deceleration and very low terminal descent rates

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