SHORT COMMUNICATIONS

THE HAZARD OF ATMOSPHERIC WIND SHEARS DURING PARACHUTE RECOVERY OF INSTRUMENTS*

By M. N. Brearley†

In the preceding paper (present issue, pp. 263–84) some aspects of the behaviour of a high altitude experimental system were considered. The system consists of a balloon with gondola, from which a small instrument package is suspended by a fine nylon yarn several miles long. To recover the instruments at the end of a flight the gondola is cut loose from the balloon, the whole system of gondola, yarn, and package then descending by a parachute attached to the gondola. If the balloon is a small one the upper instruments are contained in a small box instead of a gondola.

The Physics Department, RAAF Academy, has found on a number of occasions (Hopper *et al.* 1963) that after successful high altitude operation the yarn supporting the instrument package has broken during the descent, resulting in loss of the package and the data recorded by its instruments. The objects of this note are to show that such failures can be attributed to passage of the yarn through a wind shear layer during its descent, and to obtain an estimate of the shear strength that could cause destruction in a typical case. The wind shear velocities will be determined relative to the parachute, so that if the parachute is moving at uniform velocity under the tension in the yarn the calculated shear velocities will still apply.

All of the results quoted below are either explicit in or immediately deducible from the preceding paper. The maximum tension in the yarn will occur at its highest point, and is given by

$$T = \{(W+W_1)^2+(D_W+D_1)^2\}^{\frac{1}{2}}, \tag{1}$$

where W and W_1 are the weights of the package and yarn and D_W and D_1 are the air drag forces on the package and yarn.

Provided the Reynolds number R_1 of the air flow relative to the package lies in the range

$$2\times10^3 < R_1 < 2\cdot5\times10^5, \tag{2}$$

the air drag on the package is given by

$$D_W = c_1\,V^2, \tag{3}$$

where V is the wind shear velocity at the package relative to the balloon and c_1 is a parameter depending on the air density ρ_0 at the package altitude.

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† RAAF Academy, RAAF Base, Point Cook, Vic. 3029.

For a particular class of wind shear velocity profiles relative to the balloon, the air drag on the whole yarn is

$$D_1 = c_2 l_1 V^{2-n}, \tag{4}$$

where l_1 is the height difference between balloon and package, n is a parameter depending on the Reynolds number R_2 of the air flow relative to the yarn, and c_2 is a parameter depending on R_2, the altitude, and the wind shear structure. If the Reynolds number is such that

$$R_2 \leqslant 100, \tag{5}$$

the value of n may be taken as

$$n = 0\cdot5. \tag{6}$$

As R_2 increases beyond 100, n decreases, and the yarn drag D_1 given by (4) increases, resulting in an increased tension in the yarn. To enable earlier experimental results to be used, the value $n = 0\cdot5$ will be employed even though R_2 will exceed 100 over the lower part of the yarn in the particular example to be considered later. This simplification means that, in practice, wind shears of even smaller intensity than those determined in this note could lead to yarn failure.

As the system consisting of gondola, yarn, and package descends it passes through air of gradually increasing density. The drag forces given by equations (3) and (4) also increase in general, since the parameters c_1 and c_2 increase with air density. If T_{B} is the breaking load of the nylon yarn, failure will occur when the sum $D_W + D_1$ in equation (1) is such as to make $T = T_{\mathrm{B}}$. On solving (1) for $D_W + D_1$ and using (3), (4), and (6), the failure condition is seen to be

$$c_1 V^2 + c_2 l_1 V^{3/2} = \{T_{\mathrm{B}}^2 - (W + W_1)^2\}^{\frac{1}{2}}. \tag{7}$$

Equation (7) may now be solved to yield the relative wind shear velocity that can be expected to cause breakage of the yarn.

To illustrate the method in a typical particular situation, the system described in the preceding paper will be used. This consists of an 840 denier woven nylon yarn of natural length 20 000 ft and breaking load 10 lb wt, to which is attached a rectangular package of dimensions 6 by 6 by 8 in. and mass 2 lb. Since meteorological data show that the most intense wind shears in temperate latitudes of the southern hemisphere usually occur in the height range 20 000 to 30 000 ft, the package will be taken to be at a height of 20 000 ft; at this altitude the air density is $\rho_0 = 0\cdot642$ kg m^{-3} (Gray 1963).

It is necessary to assume a wind shear structure of specific form, since the value of the parameter c_2 depends upon the velocity profile. For the purpose of illustration a nonlinear velocity profile relative to the balloon will be used, for which the relative velocity gradient decreases gradually from balloon to package (this corresponds to the case $p = 1$ and Fig. 8(a) in the preceding paper). The numerical form of equation (7) in MKS units for this illustrative example is then

$$1\cdot254 \times 10^{-2} V^2 + 1\cdot673 \times 10^{-4} l_1 V^{3/2} = 41\cdot93. \tag{8}$$

The presence of the vertical height separation l_1 in (8) provides a minor complication, since it is evidently a function of the velocity V for which (8) is to be solved.

If a preliminary estimate for l_1 is used in (8), the equation may be solved numerically to yield a first approximation for V, from which a more refined value of l_1 may be found by a method described in the preceding paper. The new value of l_1 may then be used in (8), and the equation solved again for V. Two such successive approximations for V are enough to give a result of adequate accuracy, since the convergence of the process is very rapid. It was found that

$$V = 20\cdot 9 \text{ m sec}^{-1} \simeq 40 \text{ knots}.$$

It follows that a velocity gradient of about 40 knots over the height range 20 000 to 27 500 ft would cause the yarn to break during descent in this particular experiment.

The Reynolds number for the air flow past the package at the velocity V determined above is $R_1 = 1\cdot 52\times 10^5$, which lies within the range (2) for which (3) is valid. The maximum Reynolds number for the flow past the yarn occurs at the lowest point and has the value $R_2 = 380$, which is beyond the range (5) for which the value of n in (6) is applicable. The drag on the lower part of the yarn will therefore be greater than that used in the above analysis, so that yarn failure would result from a smaller value of V than 40 knots; revised calculations based on a more appropriate value of n show that $V \simeq 30$ knots will cause breakage.

The foregoing conclusions may be reinforced by considering other wind shear velocity profiles, such as a rectangular one corresponding to a layer of air moving with uniform velocity V relative to the balloon. In such a case a numerical integration may be used to determine the yarn drag when the layer extends upwards from the 20 000 ft level. It is found that if $V = 40$ knots in a wind layer 4000 ft deep the breaking load of the yarn is exceeded.

Wind shears of 30–40 knots between altitudes of 20 000 and 27 500 ft are fairly common in the vicinity of the balloon launching sites at Mildura and Laverton, so that it is not surprising that yarn failures have occurred. The yarn used in such experiments should evidently be selected to ensure against its failure during descent rather than for its capacity to survive the stratospheric work.

References

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