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THE RELATION BETWEEN THE HEIGHT REACHED BY A PILOT BALLOON AND ITS ASCENDING VELOCITY,

BY

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THE RELATION BETWEEN THE HEIGHT REACHED BY A PILOT BALLOON AND ITS ASCENDING VELOCITY.

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The following calculations were suggested by some experiments made by Mr. L. H. G. Dines at Valencia Observatory on the possibility of increasing the height of a pilot balloon ascent by using a smaller upward velocity. The quality of the rubber sets the limit in the majority of cases to the height to which a balloon will ascend, because pin-hole leaks ultimately develop as the rubber becomes more and more stretched. By using a smaller rate of ascent the balloon is not so much extended at the start and, therefore, should rise to a greater height before the limit of expansion is reached.

The excess of pressure within a balloon due to the tension in the rubber is practically negligible. Some rough experiments recently made with a 30 gm. balloon showed a decrease in the internal pressure once the rubber had become sufficiently stretched while the highest pressure reached was 14 cms. of water, which fell to 9·5 cms. when the balloon was fully inflated, the pressure due to 1 cm. of water being, approximately, equal to 1 millibar. In general, the internal pressure was found to be about 9 mb. for the 30 gm. balloons, and 5 mb. for the smaller balloons when normally inflated for an ascent. The greatest heights given in the table which follows are about 11 or 12 kilometres and correspond with pressures of about 200 mb. The greatest volumetric error introduced by neglecting the internal pressure would, therefore, be of the order of 5 per cent. for a 30 gm. balloon and $2\frac{1}{2}$ per cent. for the smaller balloons.

It will be necessary to know the relation between the volume of a hydrogen-filled balloon and its free lift.

Let W be the weight of the balloon,

L the free lift,

ρ the density of the air,

n the ratio of the density of air to that of hydrogen. [For dry air $n = 14 \cdot 385$],

V the volume of the balloon.

Then by the principle of buoyancy,

$$L = V\rho - (W + \frac{1}{n} V\rho),$$

$$= \frac{n-1}{n} V \rho - W,$$

whence $$V = \frac{n}{n-1} \frac{1}{\rho} (L + W) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For the purposes of calculating the height at which a leak will occur, the balloon may be supposed filled with air. Since the pressure due to the tension in the rubber is assumed to be negligibly small, the air inside the balloon has the same pressure and density as the atmosphere, a condition which will hold at all heights since the temperature of the enclosed air will not differ sensibly from that of the surrounding air. Leaks will develop when the balloon attains a critical size dependent on the quality of the rubber, in other words, when the density of the air inside the balloon falls to a certain value ρ' and this will occur when the density of the air outside the balloon also has the value ρ'. The average height corresponding with this value ρ' may be read off from the curve in Figure 1, which gives the average relation between height and density in the atmosphere. It is not possible to specify an absolute value for the density ρ' at which a leak will occur, but by making certain assumptions for the case of an upward velocity of 150 m/min. we can calculate the change in critical height corresponding with a change in the ascensional velocity.

The table overleaf gives the heights to which balloons of varying sizes may be expected to rise before commencing to leak when given ascensional velocities of 140 m/min. and 160 m/min., assuming that pinhole leaks would develop in these balloons at heights of (i) 4km., (ii) 6km., (iii) 8km., (iv) 10km., if they were filled for an ascensional velocity of 150 m/min.

The following example will show how the figures in the table are derived :—

Let W be 20 gm.

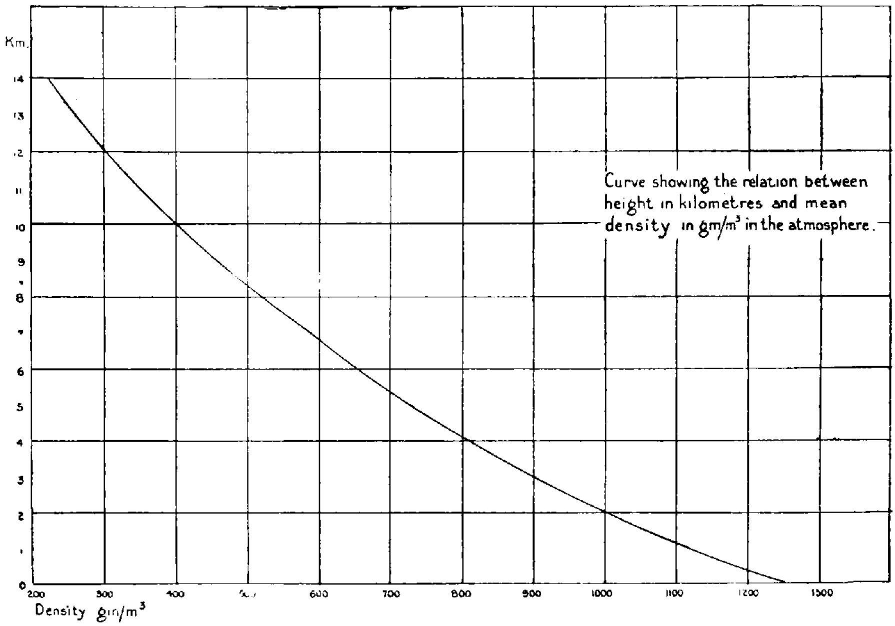
For an upward velocity of

150 m/min., $W + L = 78$ gm. (*See* Figure 2.)
140 m/min., $W + L = 65$ gm.

Hence, from equation (1), the ratio of the initial volumes of the balloon in the two cases is 65 : 78.

The balloon filled to rise at 150 m/min. springs a leak at 4km., where the density of the atmosphere is 813 gm/m^3. The balloon filled to rise at 140 m/min., is less inflated than the other in the ratio 65 : 78, and will reach the same extension when the density of the atmosphere is $\frac{65}{78} \times 813$ gm/m^3, or 678 gm/m^3, which occurs at an average height of 5·6km., this height being obtained from the curve showing the average variation of density with height (Figure 1).

FIG. 1

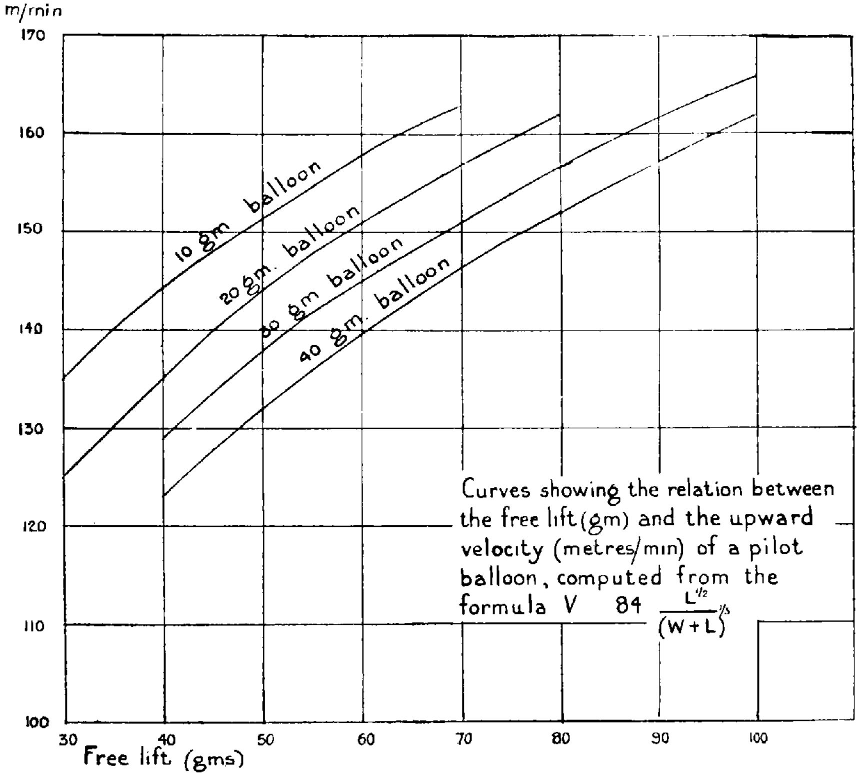


The table below shows that a variation of 10 m/min. in the velocity of ascent has a very marked effect on the ultimate height attained by the balloon. At least a kilometre is gained in every case by the use of an upward velocity of 140 m/min. in place of 150 m/min., while a corresponding loss in height, always more than one kilometre, occurs when the higher velocity of 160 m/min. is used. In some cases the difference in height is more than 2km.

TABLE SHOWING THE HEIGHT TO WHICH BALLOONS MAY BE EXPECTED TO RISE BEFORE COMMENCING TO LEAK when filled to give ascensional velocities of 140 m/min. and 160 m/min., assuming that a leak would occur at 4, 6, 8 or 10km., when the initial conditions give an ascensional velocity of 150 m/min. :—

	4km.	6km.	8km.	10km.
Density of air (gm/m³) - - -	813	657	523	403
10 gm. balloon 140 m/min. - -	6·4	8·2	9·9	11·7
160 ,, - -	1·7	3·7	5·8	8·1
20 gm. balloon 140 m/min. - -	5·6	7·6	9·4	11·3
160 ,, - -	2·0	4·0	6·1	8·4
30 gm. balloon 140 m/min. - -	5·5	7·4	9·3	11·2
160 ,, - -	2·3	4·2	6·4	8·6
40 gm. balloon 140 m/min. - -	5·4	7·2	9·1	11·0
160 ,, - -	2·5	4·6	6·7	8·8

FIG. 2



Note on Figures 1 and 2.

The data for Figure 1 were extracted from *The Computer's Handbook* (M.O. 223, Section II., 1917, p. 57).* The pressures and temperatures used for the diagram are the means of the values there given for the mean high pressure system and the mean low pressure system.

The curves in Figure 2 show the relation between the free lift (L) and upward velocity V of a balloon. They are constructed from the formula

$$V = k\,\frac{L^{\frac{1}{2}}}{(L + W)^{\frac{1}{3}}}$$

where k is a constant (equal to 84 when the velocity V is in metres per minute) and W is the weight of balloon.

* Cf. *Geophysical Memoirs No.* 13 (M.O. 220c), p. 63, Table X, England, S.E., and London Advisory Committee for Aeronautics, *Reports and Memoranda.*

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