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The coefficient of aerodynamic resistance of large balloons used in radiosonde-rawin ascents

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ABSTRACT. The coefficient of aerodynamic resistance in the case of the large balloons that are employed for radiosonde-rawin flights has been worked out here with the help of the radiosonde observations.

1. Introduction

Various ways and means have been employed from time to time by different workers for determination of the coefficients of the aerodynamic resistance of spheres at different Reynolds numbers, lying beyond the range of validity of Stoke's law. A number of workers like Eiffel (1912), Maurain (1913), Prandtl (1914), Constanzi (1914), Loukianof (1914), Riabouchinsk (1914) Pannell (1916) and others used the laboratory wind channel and measured the resistance offered on a solid body by air directly by means of special balances, while Shakespear (1913) dropped small celluloid spheres from high towers, Lunnon (1926) let steel spheres fall down in the coal mines and Richardson (1924) shot steel spheres up in the air from the gun and they thus found out the resistance offered by the air.

Experiments were also made in this line by means of gas filled rubber balloons. Cave and Dines (1919), Brazier (1921) Horiguti (1923), Ludlam (1953) and others measured the effect of the air resistance on the rate of ascent of the pilot balloons rising freely in still or open air. Saha (1956) employed the tethered balloons as the means for determining the values of the coefficient of aerodynamic resistance at different Reynolds numbers. Sinha (1958)employed the empirical formula that is used for computing the rate of ascent of the balloons in connection with the pilot balloon observations and found out the value of the coefficient of aerodynamic resistance in the case of the pilot balloons.

In the present note, an attempt is made to utilise the radiosonde observations for finding out the coefficient of aerodynamic resistance of the large balloons that are employed in radiosonde-rawin work.

2. Expression for aerodynamic resistance

Following Lamb (1932) and Shaw (1942), the resistance R offered to a body moving through air may be expressed as —

$$R = \rho L^2 V^2 f(LV/\nu) \qquad (1)$$

where ρ is the air density, L a linear dimension of the body, V the speed of the moving body, ν the coefficient of kinematic viscosity, f a function of the Reynolds number LV/ν, and $f(LV/\nu)$ the coefficient of aerodynamic resistance. In the case of the spherical body, L is equal to d, the diameter of the sphere. Thus, the resistance R in the case of gas filled spherical balloon of diameter d may be represented by—

$$R = \rho d^2 V^2 f(dV/\nu) \qquad (2)$$

Hence, the coefficient of aerodynamic resistance

$$K = \frac{R}{\rho d^2 V^2} \qquad (3)$$

Amongst the parameters on the right hand side of equation (3), the diameter can be measured directly and the density can be worked out from the prevailing pressure and temperature. The problem of determination of the coefficient of aerodynamic resistance thus reduces mainly to the determination of the resistance R and the velocity V.

3. Resistance in the case of uniformly rising balloon

In the case of the gas filled balloons, rising uniformly in the air, the resistance offered by the air to the balloon can be found out in terms of the free lift given to the balloon. Because, when the balloon moves up with more or less uniform velocity,

$$R = Fg \qquad (4)$$

where, R is the resistance, F the free lift and g the acceleration due to gravity.

4. Expression for the coefficient of aerodynamic resistance in the case of uniformly rising balloon

On substituting the value of R in the case of uniformly rising balloon from equation (4) in equation (3), the coefficient of the aerodynamic resistance K is given by —

$$K = Fg/\rho\, d^2\, V^2 \qquad (5)$$

5. Vertical velocity (V) of the balloon from radiosonde data

The vertical velocity of the rising radiosonde-rawin balloons may be worked out from the radiosonde data. Heights of the rising balloon at different times are obtainable from the pressure and temperature data of the radiosonde record, and from the height-time graph of the balloons, thus constituted, the vertical velocity of the balloon may be obtained.

6. Experimental data

To obtain the value of the coefficient of aerodynamic resistance from the radiosonde observations, some measurements were made in respect of the diameters of the gas filled radiosonde-rawin balloons and the corresponding effective free lifts were noted. The vertical velocity of the balloon was worked out from the height-time graph of the balloon from the radiosonde record. The density of the air was calculated from the pressure and temperature records of the radiosonde flight. The balloons are generally observed to attain more or less uniform velocity within a short while after their release. Because of this reason, and also to avoid the complication that may arise due to the use of the radiosonde records of the high levels as the diameter of the balloon that takes part in the calculation of the coefficient of aerodynamic resistance, may change to a considerable extent at great heights, the records of the radiosonde for the lower levels were utilised for getting the vertical velocity of the balloon and the density of air so that they might fairly well correspond to the measured diameter of the balloon. The vertical velocity of the balloon was obtained by averaging the values for the first five minutes of the ascent, and the pressure and temperature corresponding to about the middle of this period were used for calculating the density. Ignoring the small effect of the vapour pressure, the density of the air was calculated from the standard relationship $\rho = 348 \cdot 4\, P/T$, where P and T are air pressure (mb) and air temperature (°A) respectively. The value of the coefficient of aerodynamic resistance was then calculated with the help of equation (5). The resistance of the attachment has, however, not been taken into account.

The relevant experimental data and the values of V, calculated by the above method, are shown in Table 1.

7. Results

The average value of the coefficient of aerodynamic resistance, as evaluated in Table 1, comes out to be about ·12 . In the case of rising balloons, the upper limit of the Reynolds number for which the coefficient of the aerodynamic resistance has been determined experimentally earlier was upto the Reynolds number 4×10^5. It is seen from Table 1 that the Reynolds numbers, for which the values of the coefficient of the aerodynamic resistance have been determined by utilising the radiosonde-rawin balloons and the radiosonde observations, are quite high and much higher than those worked out earlier in the case of the rising balloons from pilot balloon flights.

TABLE 1

Balloon type	Diameter of inflated balloon (cm)	Effective freelift (gm)	Rate of ascent from radio-sonde record averaged for first 5 min. (cm/sec)	Pressure at 3rd min. of ascent (mb)	Temperature at 3rd min. of ascent (°F)	Calculated air density (gm/cc)	Kinematic viscosity ($cm^2 sec^{-1}$)	Reynolds number	Coefficient of aerodynamic resistance
NR 875	217	2290	594	874	72	·001032	·156	$8 \cdot 3\times10^5$	·13
NR 875	213	2310	630	861	63	·001033	·153	$8 \cdot 7\times10^5$	·12
NR 875	217	2360	610	865	68	·001029	·155	$8 \cdot 6\times10^5$	·13
NR 875	219	2350	599	873	65	·001045	·153	$8 \cdot 6\times10^5$	·13
NR 875	213	2435	721	840	61	·001012	·152	$10 \cdot 1\times10^5$	·10
NR 875	215	2500	711	851	67	·001014	·155	$9 \cdot 9\times10^5$	·10
Beritex (500)	202	1890	605	873	68	·001038	·155	$7 \cdot 9\times10^5$	·12
Beritex (500)	206	1900	635	861	63	·001033	·153	$8 \cdot 5\times10^5$	·11
Beritex (500)	203	1890	610	870	73	·001025	·158	$7 \cdot 8\times10^5$	·12

8. The value of the coefficient of aerodynamic resistance by the present method and its comparison with those obtained by other methods

The curves showing the values of the coefficient of aerodynamic resistance, obtained from tethered balloons by Saha, from pilot balloon observations of Brazier, Horiguti etc, and by Bairstow (1913) using the experimental results of Eiffel and Shakespear and by Pannell are reproduced in Fig. 1.

It would be seen that the values of the coefficient of the aerodynamic resistance obtained by different methods are different. The results of the different methods, however, show a general agreement to the effect that the coefficient of the aerodynamic resistance decreases with increasing Reynolds numbers upto a certain limit and it remains practically constant after that limit. As seen from the curves in Fig. 1, the constant value of the coefficient of the aerodynamic resistance after the limiting Reynolds number is about ·17 in the case of the curve obtained by pilot balloons, ·07 by tethered balloons, ·11 according to the curve by Pannell and ·06 from the curve by Bairstow.

The difference in the values of the coefficient of aerodynamic resistance obtained by different methods may to some extent be attributable to the changes in the shape of the balloons under different exposure conditions. Whereas the solid sphere suffers from no deformation in the shape due to the air resistance, certain deformation occurs in the case of the balloons depending upon the nature of the exposure. Rising balloons, without any attachments, are flattened at the top by air pressure whereas the tethered balloons take up somewhat conical shape on the side facing the winds with spherical shape in the rear. The effect of attachment on balloon shape would be to a certain extent like tethering and the shape of the balloon with attachment may thus be in between that of the rising balloon without attachment and the tethered balloon.

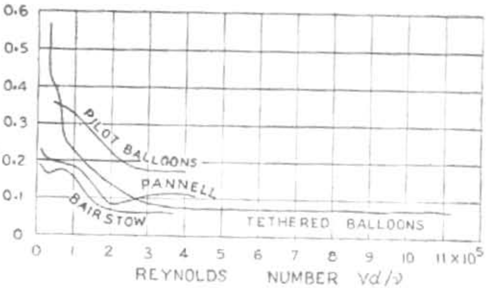

Fig. 1. Curves showing the values of the coefficient of aerodynamic resistance by different methods

The average value of ·12 of the coefficient of aerodynamic resistance at higher Reynolds number, obtained in the case of the large radiosonde-rawin balloons from the radiosonde observations is midway between the corresponding values from the curves obtained by pilot balloons and tethered balloons.

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REFERENCES

Bairstow, L.	1913	*Rep. adv. Comm. Aero.*, pp. 41-44.
Brazier, C. E.	1921	*Comptes Rendus*, Oct. 17, pp. 644-646.
Cave, C. J. P. and Dines, J. S.	1919	*Quart. J.R. met. Soc.*, **45**, 192, p. 277.
Constanzi	1914	*Rass. aero. maritt.*, April.
Eiffel, G.	1912	*Comptes Rendus*, Dec. 30, pp. 1597-1599.
Horiguti, Y.	1923	*Mem. imp. Mar. Obs.*, Kobe, Japan, **1**, 2, pp. 37-51.
Lamb, H.	1932	*Hydrodynamics*, sixth Edition, pp. 682-683.
Ludlam, F. H.	1953	*Met. Mag.*, London, 82, pp. 306-308.
Loukianof	1914	*Imp. Tech. Sch.*, Moscow.
Lunnon, R. C.	1926	*Proc. roy. Soc.*, A, 110, p. 302.
Maurain	1913	*Bull. Inst. aerotech Univ. Paris*, Fasc III.
Pannell, J. R.	1916	*Rep. Mem. adv. Comm. Aero.*, 190, pp. 19-29.
Prandtl, L.	1914	*Gottingen Nachrichten Math. Phy.*
Riabouchinsky	1914	*Inst. Aero.*, Koutchino., Fasc. V.
Richardson, L. F.	1924	*Proc. phys. Soc. Lond.*, 36, pp. 67-80.
Saha, K. R.	1956	*Indian J. Met. Geophys.*, **7**, 3, pp. 241-252.
Sinha, K. L.	1958	*Ibid.*, **9**, 1, pp. 47-50.
Shakespear, G. A.	1913	*Brit. assoc. Rep.*, p. 402.
Shaw, N.	1942	*Manual Met.*, **4**, pp. 26-27.