ESTIMATION OF RATE OF AIRFLOW STREAMING THROUGH A FALLING GERDIEN CONDENSER IN THE UPPER ATMOSPHERE FROM A SIMULATION EXPERIMENT

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1. Introduction

It is important to extend our knowledge of the electrical nature of atmosphere near the ground to the upper atmosphere, especially to mesosphere, where the nature varies drastically with increasing altitude. Because of the transitional nature of this region, there are many difficulties in measuring the atmospheric electricity in it. It is recommended for the measurement in mesosphere that we do not adhere much to the conventional method used in the ground based observation. In this respect, we made a small rocket observation of atmospheric ion density and electric conductivity using a modified simple Gerdien condenser (Ishikawa et al. 1968). The experiment seemed to be successful up to 55 km in altitudes, however, it turns out to be necessary to estimate the rate of airflow flowing through the condenser while a drop sonde system is going down through the upper atmosphere. Pedersen (1965) used a drop sonde Gerdien condenser to measure the ion density in D region of the ionosphere, however, he did not take into account the deviation of actual wind velocity profile inside the condenser from a parabolic. Paltridge (1965) stressed the importance of the correction to be made on airflow rate estimation which is obtained on the assumption of a flat velocity profile. It is the purpose of this paper to describe a method of airflow rate estimation of a dropping Gerdien condenser from a laboratory simulation experiment.

2. Simulation principle and experimental result

To secure the same pattern of stream lines inside a Gerdien condenser model in the laboratory experiment as it is in the actual upper atmosphere, it is necessary to keep Reynolds number of the model equal to that of the condenser dropping through the upper atmosphere. If we take $\overline{u}$ and $\overline{u}_0$ dropping velocity of a sonde system including the Gerdien condenser and that simulated on the ground respectively, we easily get

$$\overline{u}_0 = \overline{u}.\ \ F(p,\ t)$$

$$F(p,\ t) = (p/p_0)\ (T_0/T)$$

where $\overline{u}$ as a function of altitude, is given by the previous experiment of ion density measurement with a small rocket in 1966 (Ishikawa et al. 1968), and p, t as functions of geometric altitude, are taken from a table of model atmosphere given in Handbook of Geophysics, 1961.

Table 1 gives $\overline{u}$ and $\overline{u}_0$ values thus obtained along with the Reynolds number profile. We see that the reduced velocity $\overline{u}_0$ decreases down to a few centimeter per second as the altitude goes up to 60 km. Considering, this, we have constructed a low speed wind tunnel to be operated under an atmospheric pressure in our laboratory as indicated in Fig. 1.

H:km	U:m/s	U_0:m/s	R
10	6.0	2.0	1.7×10^4
15	6.0	9.6×10^{-1}	8.2×10^3
20	6.6	4.8	4.0
25	8.4	2.8	2.4
30	1.4×10	2.0	1.6
35	2.2	1.5	1.2
40	3.2	1.0	8.5×10^2
45	4.5	7.2×10^{-2}	5.3
50	5.8	4.8	3.6
55	7.8	3.6	2.7
60	1.2×10^2	3.1	2.4

$R = \frac{LU}{\nu}$ $\qquad$ $L = 0.1\text{m}$

The two types of Gerdien condenser which was partly adopted in our rocket experiment are indicated in Fig. 2. The wind velocity distribution inside the condenser model was measured with a sensitive hot-wire anemometer. But the airflow velocity in the upper atmosphere which can be simulated with our wind tunnel is very much limited with respect to the altitude, because the wind tunnel is designed to be operated at the normal atmospheric pressure. The attainable altitude limit of our simulation experiment

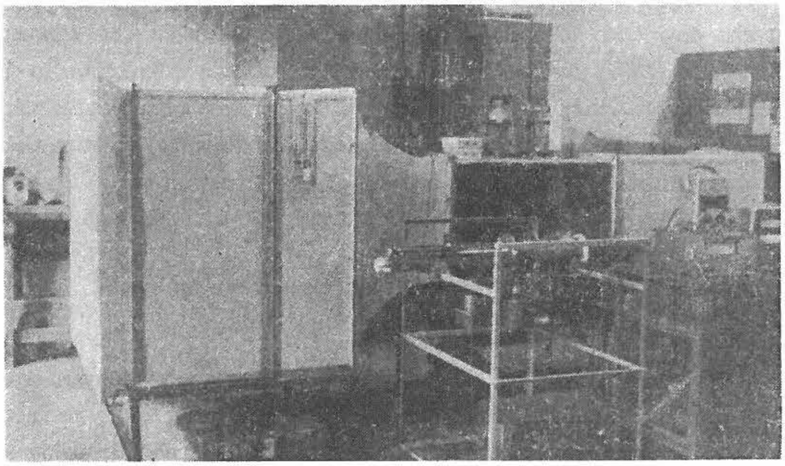

Fig. 1. The external aspect of a low speed wind tunnel.

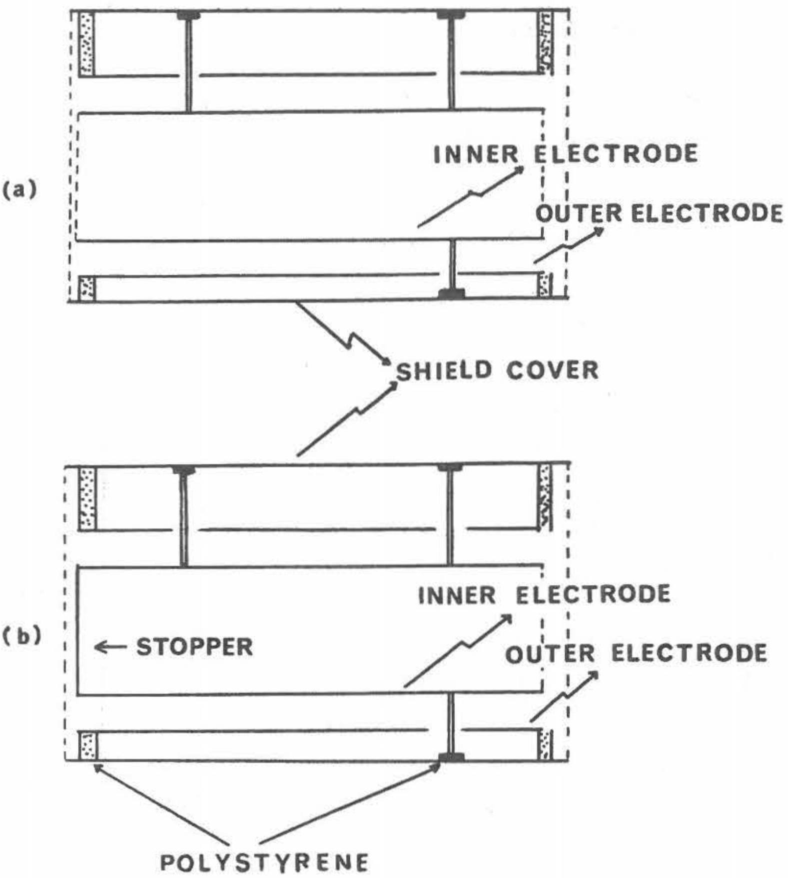

Fig. 2. The construction of the two model Gerdien condensers.

is roughly up to 40 km. Fig. 3 shows an example of wind velocity distribution along a radius inside the two condenser models indicated in Fig. 2, where (A) and (B) in Fig. 3 respectively correspond to (a) and (b) in Fig. 2. The rate of airflow Q in the upper atmosphere can be estimated, if we know the wind velocity distribution $\overline{u_0}\ (r)$ along a condenser radius inside, where $\overline{u_0}$ is determined with a simulation experiment, and if we integrate it as follows :

$$Q = (1/F\ (p, t)) \int_r^R \overline{u_0}\ (r)\ dr$$

where r and R are the radii of inner and outer electrode of the condenser respectively. The results of the estimation are given in Table 2 and Fig. 4, where Q_a, Q_b represent the rates of airflow which respectively correspond to the condenser models (a) and (b) in Fig. 2. Q′ represents the case of a parabolic velocity distribution is given by

$$Q'=\frac{2}{3}\overline{u}\,\pi\,(R^2-r^2)$$

where $\overline{u}$ is the dropping sonde system velocity. C_a and C_b in the last two columns of Table 2 show the deviation of the two airflow rates, Q_a and Q_b, from the case of a parabolic profile Q' and are given by

$$C_a = Q_a/Q',\ C_b = Q_b/Q'$$

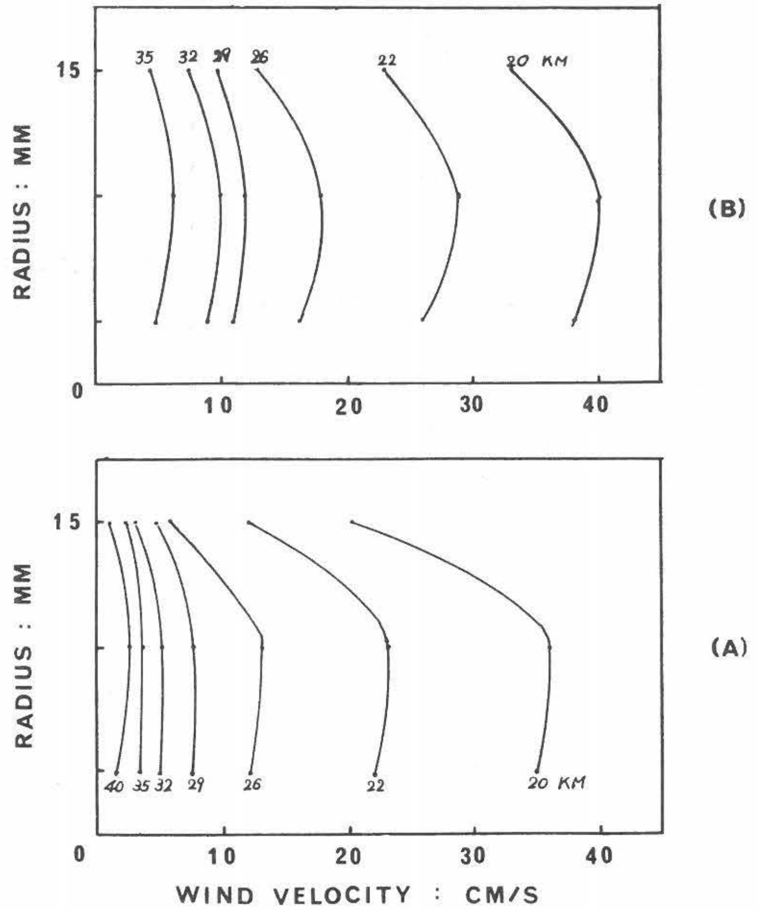

Fig. 3. The wind velocity profiles versus radius in the Gerdien condenser, (A) and (B) correspond to the two models (a) and (b), respectively in Fig. 2.

H: km	Q_a:cm³/S	Q_b	Q'	C_a	C_b
20	1.3×10^4	1.5×10^4	1.4×10^4	0.93	1.1
25	1.1	1.7	1.7	0.65	1.0
30	1.2	2.0	2.8	0.43	0.72
35	1.5	2.5	4.6	0.33	0.54
40	1.9	3.4	6.7	0.28	0.51
45	2.5	4.4	9.2	0.27	0.48
50	3.6	6.0	1.2×10^5	0.30	0.50
55	4.3	7.7	1.6	0.27	0.48
60	6.0	10.0	2.4	0.25	0.42

It is surprising to see that the actual airflow rate in the present model more rapidly decreases with increasing altitude than what we can expect in the case of a parabolic profile.

Therefore the significance should be stressed on the correction to be made on a parabolic profile. To supplement the airflow rate estimation in the upper atmosphere we observed stream line patterns inside the condenser model using a technique of smoke stream line method.

There was no turbulence inside the condenser model observable in the simulation experiment up to the altitude above 25 km, although the turbulent airflows were much observed in the wake of the model.

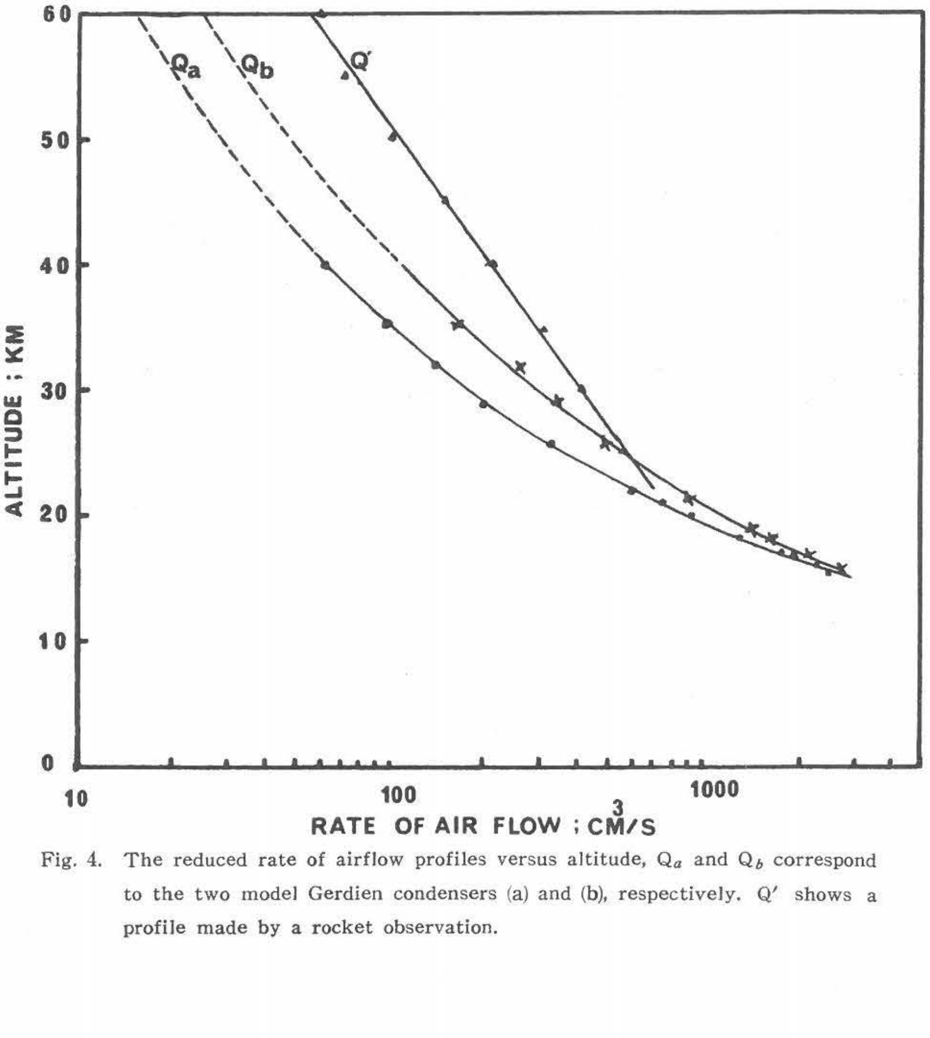

Fig. 4. The reduced rate of airflow profiles versus altitude, Q_a and Q_b correspond to the two model Gerdien condensers (a) and (b), respectively. Q' shows a profile made by a rocket observation.

3. Conclusion

As a result of the simulation experiment of airflows inside the models, we have obtained the correction factors the results of ion density measurement. A comparison made on the two types of the model showed a better airflow patterns to be obtained on the model which has a circular wind stopper at the front of the inner electrode of it.

4. Acknowledgement

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References

Ishikawa, H., T. Takeuti, A. Iwata and Y. Morita, : Preliminary experiment of atmospheric ion measurement in the transitional region of the atmosphere, Proc. Res. Inst. Atmospherics, Nagoya Univ., **15**, 29-41 (1968)

Paltridge, G. W., : Experimental measurement of the small ion density and electrical conductivity of the stratosphere, J. Geophys. Res. **70**, 2751-2761 (1965)

Pedersen, A., : Measurement of ion concentration in the D region of the ionosphere with a Gerdien condenser rocket probe, Tellus, **17**, 1-45 (1965)