Journal of the Indian Institute of Science, V28, 1- 9, (1946)
Measurement of Turbulence and pitch of the airstream in the 5' * 7' tunnel of Indian Institute of Science, V. M. Ghatage, and G. V. Ramana Rao

MEASUREMENT OF TURBULENCE AND PITCH OF THE AIRSTREAM IN THE 5′×7′ TUNNEL OF INDIAN INSTITUTE OF SCIENCE

BY V. M. GHATAGE AND G. V. RAMANA RAO

Introduction

To know the conditions under which a model is tested in a wind tunnel, it is necessary to know the characteristics of the tunnel completely. Only then is it possible to reduce the experimental results to a case where the influence of the tunnel is removed. The velocity distribution in the experimental section and the losses in different parts of the tunnel of the Indian Institute of Science with its general description are published in a previous paper by one of the authors.[1] This paper is devoted to the measurement of the turbulence present in the experimental section and the pitch of the airstream. The former is necessary to determine the effective Reynolds Number of the test while the latter determines the correct geometrical angle of attack of the aerofoil with respect to the direction of the airstream, which may be flowing at an angle to the axis of the tunnel. These measurements are of vital importance to the accuracy of the experimental data obtained from the experimental work in the tunnel. A detailed account of how these measurements are made and what values are obtained in each case are therefore presented in this paper.

Turbulence in the Tunnel

The turbulence of an airstream is the fluctuation of the velocity ΔV presented as a percentage of the average velocity V of the airstream. This can be measured directly by a hot wire anemometer and the average value of the fluctuation found out over a considerable length of time for a given velocity of the airstream as measured by its dynamic pressure. This method, though direct, is not very convenient as it involves a large amount of labour. It has been found that the drag of spheres is very susceptible to the turbulence present in the airstream and this fact can be used to determine the turbulence by finding the critical Reynolds number (defined as the Reynolds number which gives C_D for the sphere to be $0 \cdot 3$) for spheres in a given fluid stream. Dryden and Kuethe[2] have conducted tests on spheres and measured the turbulence at the same time with hot wire anemometers. Their results show that the critical Reynolds number in the case of a sphere is related to the free turbulence of the airstream.

Values taken from their report are used to determine the percentage turbulence of the tunnel.

Two spheres one of 4″ and one of 5″ diameter made of aluminium alloy were used to determine the critical Reynolds number. Care was taken to see that the diameters do not vary more than ·002″ from the nominal value. The surface was polished to a high degree of smoothness and every care was taken to maintain it.

It was found that the usual bifilar suspension used in earlier experiments in mounting the spheres in the tunnel was not very satisfactory. In our measurement the spheres were mounted on one of the struts of the wind tunnel balance by a rigid rod (" sting "), keeping the sphere in front of the strut by at least a length of one diameter of the sphere. This arrangement is shown in Fig. 1.

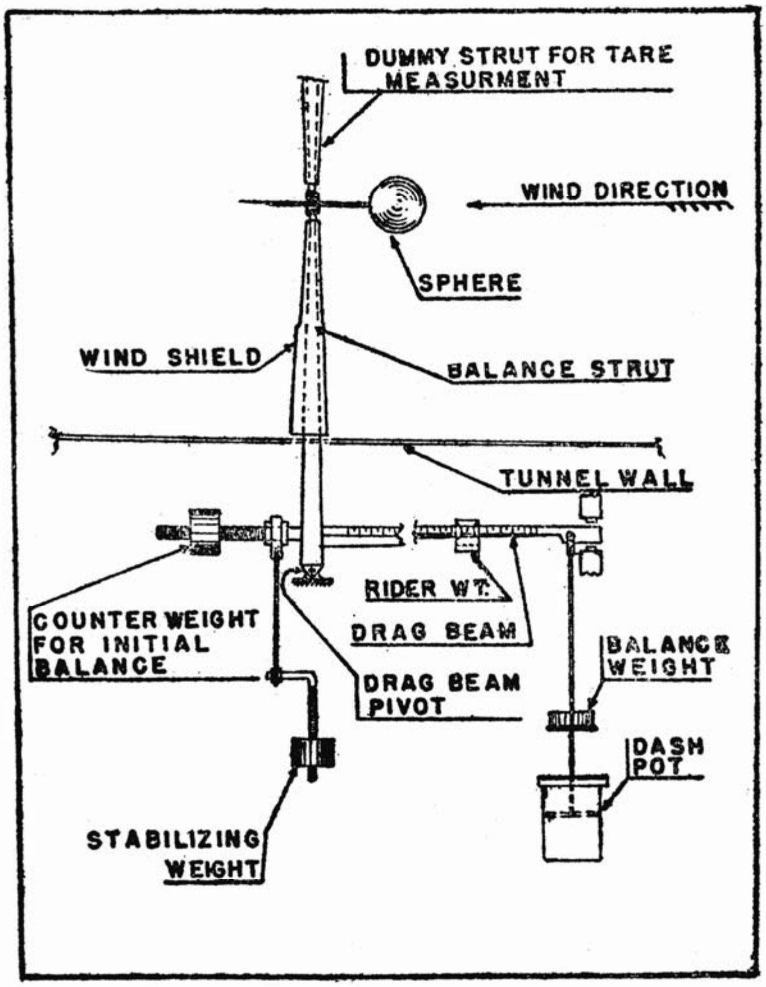

FIG. 1

The dummy strut shown above the balance strut is used to suspend the sphere in the same position when determining the tare drag of the suspension. The drag beam is initially balanced by the counter-weight and the drag of the sphere is measured by the weights in the pan and a small rider weight sliding on the drag beam. The beam is provided with a dash-pot damper to reduce any vibration that might arise during the experiment.

Three experiments were done to get the sphere drag without the tare drag of the support and any possible influence of the mounting on the drag of the sphere. In the first experiment the sphere was mounted on the balance strut and the dummy strut above it was removed. This gave the drag of the sphere together with the tare drag of the support and the influence of the support on the drag of the sphere if any. In the second experiment the dummy strut was introduced to occupy the position of the mirror image of the balance strut about the tunnel axis. It is assumed here that this dummy strut, as it is not connected to the drag beam, only influences the flow round the sphere in the same manner as the balance strut and probably by an equal amount. Thus the second experiment gives the sphere drag together with the tare drag and twice the interference drag due to struts. In the third experiment the sphere was mounted on the dummy strut and the sting was kept in the same position with respect to the sphere but was not connected to it. This gave the drag of the mounting under the influence of the sphere and the dummy strut.

From these experiments the drag of the mounting and the interference of the strut on the flow round the sphere was eliminated to get the drag of the sphere alone. The change in drag of the sphere due to the interference, as shown by these experiments, was not very constant. It showed a variation from a small difference to a difference of 6% in the sphere drag values at certain speeds. As even the maximum difference due to this cause forms a small percentage of the total drag, the results will not be affected much by either considering or neglecting this cause.

All the three experiments were carried out at different velocities, taking readings of the drag values both at the time of increasing and decreasing velocities. This was necessary because at the time of taking readings when the tunnel was running for some time the drag value may be different, due to a different amount of eddies being present in the flow. Taking the average of these readings gave a better average value of the turbulence present in the tunnel. The drag coefficient C_D of the sphere was defined as

$$C_D = \frac{\text{Sphere drag,}}{\frac{1}{2}\,\rho\, V^2\, \pi\, \frac{d^2}{4}} \text{ where}$$

V is the velocity in ft./sec.
d is the diameter in ft. of the sphere.

The Reynolds number $R = \frac{Vd}{\nu}$ where ν is the kinetic velocity of the air in the tunnel at the time of the experiment.

In order to get the average density and viscosity of the air in the tunnel, the atmospheric pressure was recorded at the time of the experiment and a number of readings of the temperature of the airstream during the experiment were taken to determine the average temperature. The values of air density and the kinematic viscosity of air were calculated for these average values of temperature and pressure and used in determining the Reynolds number and the drag coefficients of the sphere.

Fig. 2 shows the curves of C_D against the Reynolds number in the cases of 4 inch and 5 inch diameter spheres. In the region of the critical Reynolds number ($C_D = 0 \cdot 3$), both the curves give approximately the same value of C_D. The following values of the critical Reynolds number are obtained from these experiments.

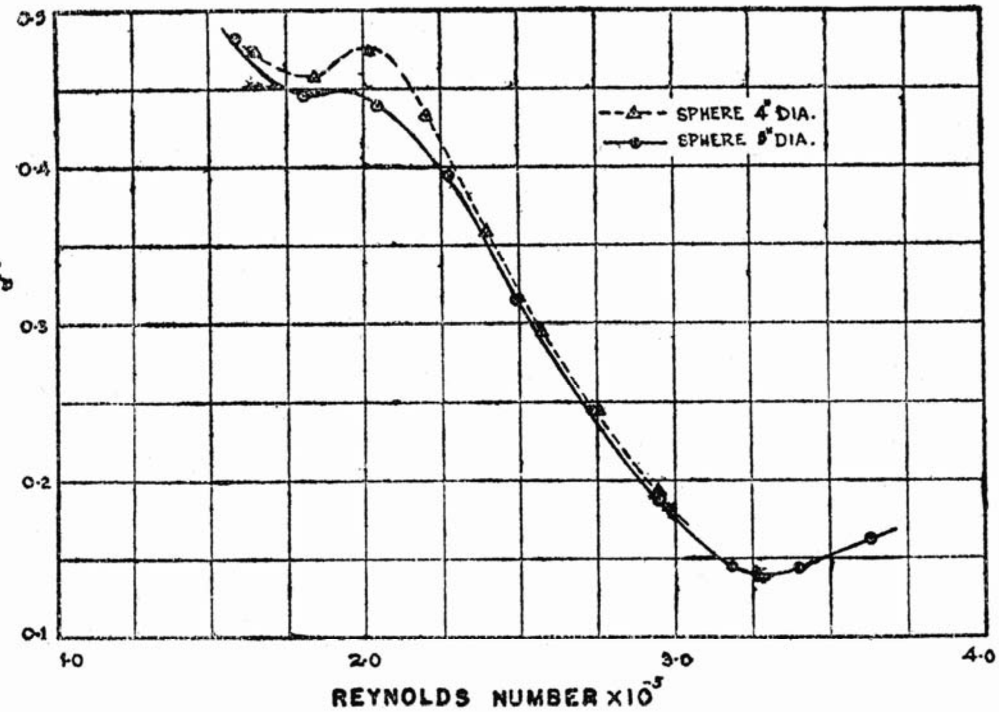

FIG. 2

	Critical Reynolds number
4 inch diameter sphere	$2 \cdot 56 \times 10^5$
5 inch diameter sphere	$2 \cdot 55 \times 10^5$

The relation between the critical Reynolds numbers and the percentage turbulence in the tunnel, as taken from the investigations of Dryden and Kuethe, is represented in Fig. 3.

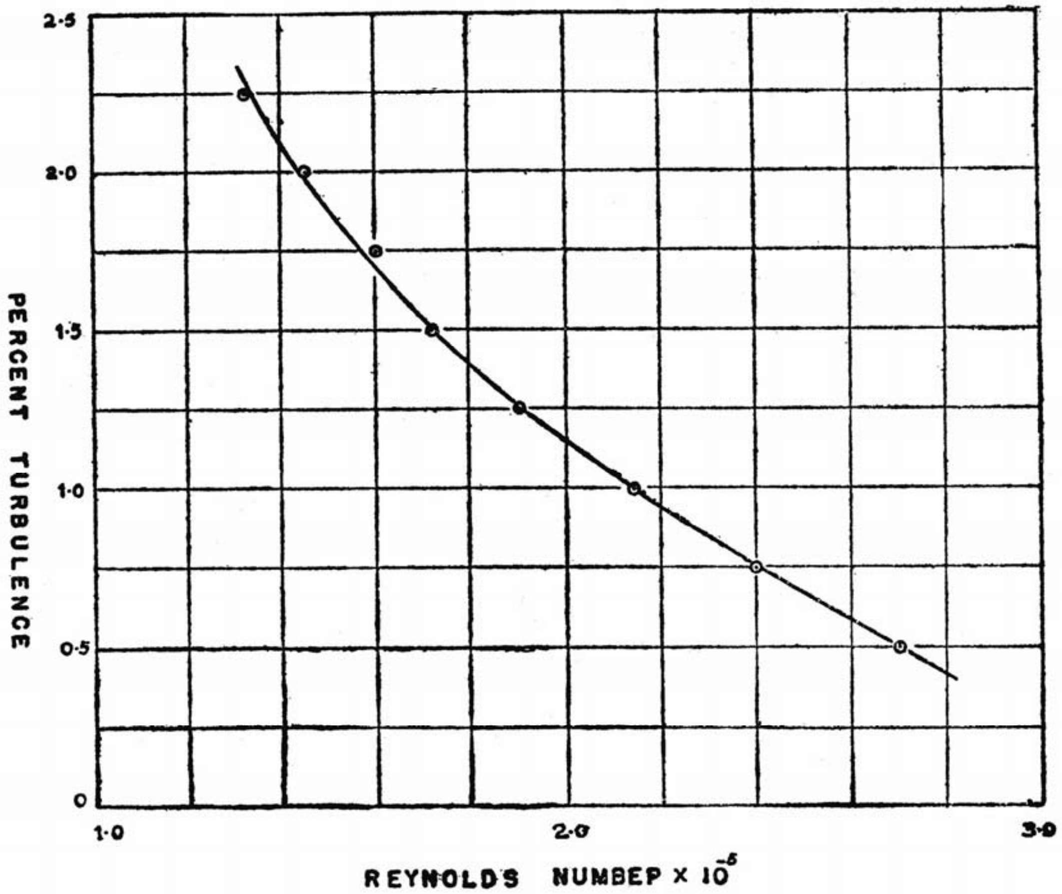

FIG. 3

The turbulence corresponding to the critical Reynolds number of 4″ and 5″ spheres comes to 0·6%. This figure is fairly good considering the fact that no honeycomb is used in the tunnel to reduce the fluctuations of the airstream. Values of turbulence in other tunnels in Europe and America are given in Table I for comparison.

TABLE I

Tunnel	Critical Reynolds Number	Per cent Turbulence
R. A. E. five foot ..	$2 \cdot 3 \times 10^5$	0·8
Göttingen ..	$2 \cdot 7 \times 10^5$	0·5
Calf. Inst. Tech. ..	$3 \cdot 2 \times 10^5$	0·2
N. P. L. England ..	$1 \cdot 50 \times 10^5$	2·2
VDT closed throat ..	$1 \cdot 20 \times 10^5$	2·5
I. I. Sc. closed throat ..	$2 \cdot 55 \times 10^5$	0·6

Pitch of the Airstream

In measuring the forces on the model in a wind tunnel the model is kept stationary and a stream of air is maintained in the experimental section of the tunnel. It is convenient to fix two perpendicular directions for the measurement of the two important forces, the lift and the drag of the model. Obviously the vertical, *i.e.*, along the direction of the gravitational force and the horizontal, *i.e.*, perpendicular to the direction of the gravitational force, are the most suitable directions for this purose. If the axis of the experimental section of the tunnel is kept horizontal and the stream of air is maintained parallel to it, the vertical component of the forces on the model will give the lift and the horizontal component will give the drag. It is very convenient in practice to arrange the balance to record these components as these directions can be determined accurately with the help of a sensitive level. However, arranging the direction of the airstream parallel to the horizontal tunnel axis is not always so easy, especially in the case of the rigid attachment of the experimental section to the convergent cone and the diffuser section. It is generally necessary to determine the inclination of the airstream to the axis of the tunnel, which is arranged to be horizontal.

Fig. 4 shows the conditions when the airstream makes a small angle with the tunnel axis. This angle is designated as the pitch of the airstream. The wind tunnel balance measures the forces **L′** and **D′** as the lift and the

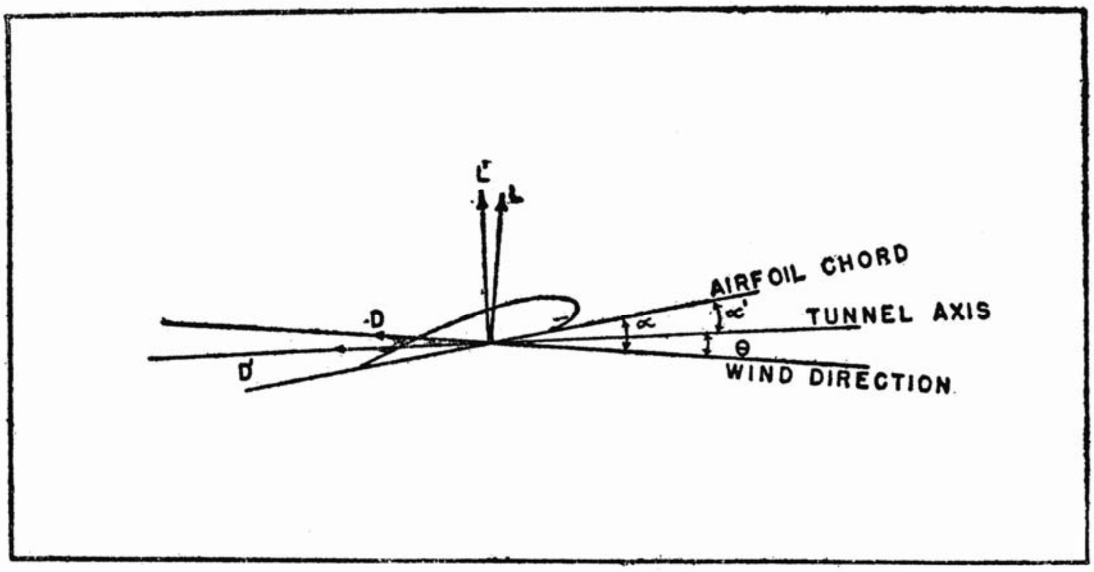

Fig. 4

drag of the model. These are not the true values of the lift and drag, as the latter forces are defined as perpendicular and parallel to the airstream respectively. If **L** and **D** are the true values of these forces, then the following relations will hold:

$$L = L' \cos \theta \mp D' \sin \theta$$
$$D = L' \sin \theta \pm D' \cos \theta$$
$$\alpha = \alpha' \pm \theta$$

where α and α' are the angles which the chord makes with the wind direction and with the tunnel axis respectively.

The deviation of the actual forces from the measured ones will depend upon the magnitude and direction of θ. In the above relation the upper sign represents a flow directed upwards and the lower sign represents one directed downwards. In most cases θ is very small and so $\cos \theta$ can be taken to be unity without affecting the results to an appreciable extent. The relations between the true and the apparent forces can then be taken as

$$L = L' \mp D' \sin \theta$$
$$D = L' \sin \theta \pm D'$$
$$\alpha = \alpha' \pm \theta$$

As the pitch angle θ is generally very small, it must be determined by an indirect experiment. For this purpose an aerofoil is tested in the tunnel, once with its pressure side up and once with the pressure side down and keeping other conditions precisely the same in both cases. If the pitch angle θ is not zero, and the angles of attack are measured from the axis of the tunnel, the aerofoil is being tested at angles $\alpha' + \theta$ in one case and at $\alpha' - \theta$ in the other. If the tests are conducted within a range where the relations between the lift coefficients C_L and α the angle of attack is linear, any given value of C_L would give two values of the angles of attack measured from the axis of the tunnel. If α_1' and α_2' are the two values then the true angle of attack must be equal once to $\alpha_1' - \theta$ and once to $\alpha_2' + \theta$

$$i.e., \ \alpha_1' - \theta = \alpha_2' + \theta$$
$$\text{and } \theta = \frac{\alpha_1' - \alpha_2'}{2}.$$

The conditions are slightly different when a symmetrical aerofoil is used. The pressure and suction sides in this case are identical and the reference chord is also the zero lift chord of the aerofoil. If good care is taken in maintaining the symmetry of the aerofoil, all values of C_L measured by reversing the aerofoil lie on one and the same curve. The only difference one gets when θ is not equal to zero is that this straight line does not pass through the origin but is shifted to the left or to the right according to the air-stream is inclined upwards or downwards.

A symmetrical aerofoil can be used to measure the pitch directly by finding out the position at which it gives no lift at all. The inclination of the aerofoil chord in this position to the tunnel axis gives the pitch angle. There is a difficulty in this method; owing to the force being zero the accuracy of measurement is very doubtful due to small forces being always present in the mechanical system of measurement.

In order to avoid these difficulties, a symmetrical aerofoil of 6 per cent. thickness was used for this purpose. The readings in the neighbourhood of zero lift were not allowed to influence the location of the curve between the C_L and the angle of attack. To avoid the influence of the balance struts on the lift of the aerofoil, two aerodynamically similar dummy struts were placed above the balance struts and were not connected to the aerofoil. Readings of C_L at different angles of attack were then taken by reversing the upper and the lower surfaces of the aerofoil. Similar experiments were conducted at four different air speeds to cover the normal range of speeds used in the tunnel. All these results were then plotted as shown in Fig. 5.

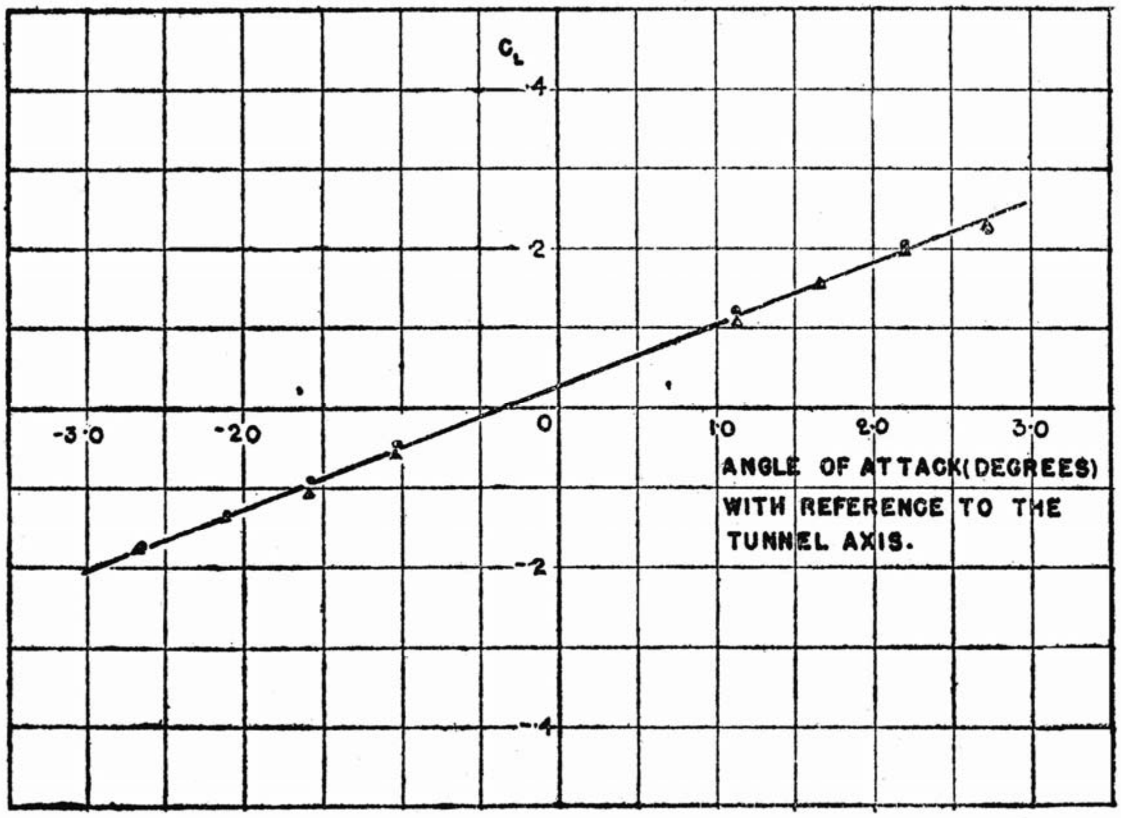

FIG. 5

The results show that the pith angle is fairly independent of the stream velocity within the range investigated and there is an inclination of the airstream upwards giving a pitch angle of 0·33 degrees or roughly 20 minutes.

As the cosine of this angle is 0·99998 and sine is 0·00582 the approximate relations between the true and measured forces can be used without any fear of introducing inaccuracy in the results.

The authors express their thanks to the wind tunnel operators and the staff of the departmental workshop, who co-operated in running the tunnel and making the necessary models and rigging them up.

References

1. V. M. Ghatage .. "Characteristics of the 5′ × 7′ closed throat wind tunnel of the Indian Institute of Science, Bangalore," *Jour. Ind. Inst. Science*, **25 B**, Part I.

2. Dryden, H. L. and Kueth, A. M. .. "Effect of Turbulence in wind tunnel measurements," *U.S. N.A.C.A. Technical Report* No. 342, 1930.

Department of Aeronautical Engineering,
Indian Institute of Science,
Bangalore.

Received 31st July 1946.