TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 45

EXTRACT FROM A REPORT ON THE RESISTANCE OF SPHERES OF SMALL DIAMETER IN AN AIRSTREAM OF HIGH VELOCITY.

By

Capt. Toussaint and Lt. Hayer,
Aerotechnical Institute of Saint Cyr.

Translated from the French,
by
Paris Office, N.A.C.A.

March, 1921.

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1. - WIND TUNNEL - For our experiments we used an Eiffel type tunnel comprising (See Fig. 1):

A cone, converging at an angle of about 40°.

A working section, cylindrical, 0.30 m. in diameter and 0.66 m. in length.

A cone, diverging at an angle of 7-1/2 degrees.

A suction fan, actuated by an electric motor by means of a belt.

The various parts of the flue are made of sheet metal with autogenous welding and are joined together by flanges with bolts and joints.

To increase the efficiency of the fan (previously used as a blower), holes were bored round its casing in order to facilitate the evacuation of the exhaust air.

The velocity of the airstream in the working section is practically proportional to the number of fan revolutions. It reaches 90 m. per second for 585 revolutions and for a total power of the electric motor of about 20 HP, which corresponds to a coefficient of utilization of 2.15 including the efficiency of the engine, of its belt transmission and of the fan.

Instead of having a working section with a diameter of 0.30 m., we can have one of 0.20 or 0.40 m. This is managed by having junction flanges of convenient diameter on the converging and diverging cones.

With a working section of 0.20 m. the velocities obtained are smaller for the same number of fan revolutions than with a section of 0.30 m. Furthermore, the diameter of 0.20 m. is much too small to allow of neglecting the influence of the walls on the bodies being tested.

The steadiness of the airstream is not very good, and this makes it necessary to repeat the experiments. We observe variations of 2 to 3 % at speeds of 80 to 90 m/sec. Steadiness may be improved by giving the collector at the entrance a suitable form and by placing a honeycomb at the entrance of the working section.

2. - BALANCE - We used the balance previously used by M. Maurain in his experiments on spheres (see Bulletin of the St Cyr I.A.T. - No. II). It consists of a vertical frame of steel tubing, oscillating on two knife-edges fixed to a wooden stand. Two horizontal tubes fixed to the vertical frame support the scale-pan mounted on a knife-edge, and

the regulating counterweight.

The whole device is very light and very sensitive (sensitiveness 0.5 gramme). The spheres to be tested are welded to a steel wire 1 mm. in diameter which can be hooked on the frame of the balance. A turnbuckle is used for giving the required rigidity to the supporting wire. The wire enters and leaves the experimental chamber by two longitudinal slots 2 mm. wide and 30 mm. long. These slots allow the wire to oscillate freely, but they also let in air. The resulting perturbation is taken into account, as stated below, by gauging the resistance of the supporting wire by direct measurement.

REMARK - The advisability of constructing an enclosed space to include that part of the tunnel containing the working section, has been considered. If that were done, the outside pressure would be in equilibrium with the pressure inside the tunnel, and thus the inlet of air through the slots would be avoided.

MEASURING THE VELOCITY OF THE AIRSTREAM - The velocity of the airstream in the working section is measured by means of a micromanometer connected with a small hole bored perpendicularly through the wall of the section at a certain distance in front of the sphere being tested. The hole being thus placed, the micromanometer registers the static pressure of the stream.

We have checked the indications given by the micromanometer connected with the hole with those given by another micromanometer connected with a STANDARD PITOT TUBE, and found them to agree. The Pitot tube in question is of the Brabbee type and gives indications of the form:

$$h = k \frac{d\ V^2}{2g}$$

h being the quantity of water (in mm.) read on the micromanometer,

d the density of the air,

g the acceleration of gravity.

For the Standard Pitot tube used, we assumed $K = 1$. The velocity of the airstream is then given by the relation:

$$V = \sqrt{\frac{2g\ h}{d}}$$

At 15° and 760 mm. we have $d = 1.225$

and $V_{15^\circ,760} = 4\sqrt{h}$

For any conditions whatever of temperature and pressure, we shall have:

$$V_{t,H} = V_{15^\circ,760} \sqrt{\frac{1.225}{d_{t,H}}}$$

From comparisons made between the indications h given by the Standard Pitot tube and the indications H given by the static pressure opening, we have the relation:

$$H = 1.06\ h.$$

This relation holds good even when the spheres being tested are interposed in the airstream.

REMARK I. - In our early experiments we measured the velocity of the airstream direct with the Pitot tube, but we had to give up this method because the perturbation caused in the stream, especially at high velocities, by the Pitot tube placed forward of the sphere reacted on it and distorted the measurements.

REMARK II. - For calculating the velocity by the relation:

$$V_{t,H} = V_{15^\circ,760} \sqrt{\frac{1.225}{d_{t,H}}}$$

the pressure H must be taken equal to the actual pressure of the airstream in movement. For a surrounding barometrical pressure equal to H_o, the pressure H will be given by:

$$H = H_o - \frac{dV^2}{2g}$$

At low speeds, (below 40 m/sec.), $\frac{d\,V^2}{2g}$ is less than 100 mm. of water, that is, 7.4 mm. of mercury. Now, H_o is of the order of 750 mm. The error in H by neglecting $\frac{d\,V^2}{2g}$ does not exceed 1%. The error in the speed will not exceed 0.5%.

At high speeds, the error in H and in V cannot be neglected. For instance, for V = 80 m., we have $\frac{d\,V^2}{2g}$ = 400 mm. of water, that is, 29.5 mm. of mercury.

The error in H is 4% and the error in V will be of the order of 2%. It is, therefore, necessary to allow for them.

We have thus calculated the speeds, taking into account the actual pressure H.

REMARK III. - The values of the total resistance R have been brought to the normal conditions 15^o and 760 mm. If a measure R_{tH} has been found in any conditions whatever of temperature t and pressure H, we have first calculated:

$$V_{tH} = V_{15^o,760} \sqrt{\frac{1.225}{d_{t,H}}}$$

we then calculated:

$$R_{15^o,760} = R_{t,H} \times \frac{1.225}{d_{t,H}}$$

with d determined as stated above, and we made $R_{15^o,760}$ correspond to the speed $V_{t,H}$.

4. - PREVIOUS MEASUREMENT OF THE RESISTANCE OF THE SUPPORTING WIRE - We have measured for different speeds the resistance of the supporting wire placed, without sphere, in the experimental chamber.

The coefficient $K = \frac{R}{SV^2}$ calculated by these measurements varies slightly. Its mean value is $K = 0.063$, a figure near to those found by M. Eiffel for the resistance of wires.

To deduce the resistance of the sphere itself from the measurement made with the sphere and its supporting wire, we have taken into account that part of the wire subjected to the action of the airstream outside of the sphere.

If D is the diameter of the sphere in mm., the correction to be applied to the total measurement R_t in order to find the resistance R_s of the sphere itself, will be given by the relation:

$$R_s = R_t - R_f \times \frac{300 - D}{300}$$

The spheres tested were of polished steel. Their diameters were respectively: 19.8 mm.; 28.5 mm.; 39.5 mm.; 50.5 mm.; 59.8 mm.; 69.8 mm.

5. - COMPARISON WITH PREVIOUS RESULTS.- On the graph given in Fig. 2 we have laid off the values of K found in our experiments as a function of the product VR (V, speed in m/sec.; R, diameter in m.)

On the same graph we have reproduced:

a) The results found by M. Eiffel on spheres of 160, 244, and 330 mm. in diameter, respectively, in a tunnel with a diameter of 2.00 m.

b) The results found by Captain Costanzi on a sphere 44.4 mm. in diameter in a tunnel 0.36 m. in diameter.

c) The results found by M. Maurain on spheres of various diameters in a WIND TUNNEL.

d) The results found by M. Loukiannof on spheres having respective diameters of 56 mm., 168 mm., 118 mm. and 240 mm. in the tunnel of the Imperial Technical School at Moscow.

It will be noticed that there is a notable disagreement between our experiments and previous experiments, on the following points:

1st. The coefficient K before the critical speed is reached has been found notably higher in our experiments.

2nd. The product VR for which is produced the rapid variation of the coefficient K is also much larger in our experiments.

3rd. The value of the coefficient K after the critical speed is greater in our experiments than in those of M. Eiffel and M. Maurain, but smaller than in Loukiannof's experiments. Only Captain Costanzi's experiments on the 44.4 mm. sphere are in partial agreement with outs, at least so far as regards the high value of the coefficient K before the critical speed.

DISCUSSION. - On the whole, we see that the different experimenters are far from agreeing with each other. Only the experiments of M. Maurain and M. Eiffel give results fairly analogous both as to the absolute value of K and the course of the variations of K with VR.

M. Eiffel's experiments were made in a tunnel with a diameter of 2.00 m. with an airstream not bounded by material walls.

M. Maurain's experiments were made in a wind tunnel with a SUCTION flue. The air drawn in escapes into the surrounding atmosphere, and at the place where the spheres are being tested it is not limited by material walls.

Is the agreement between these two experimenters due to this circumstance of the absence of material walls?

M. Loukiannof operated in a tunnel 1.00 m. in diameter with material walls, but it is to be feared that, for the sphere of 240 mm., the walls exercised a notable influence. On the other hand, for the spheres of 56 mm. and 118 mm. he worked under the same conditions as M. Eiffel for his spheres of 160 and 240 mm. There is, however, a notable discrepancy between the results of M. Loukiannof and those of Eiffel and Maurain, especially after the critical speed.

As regards our own results, we consider that the sole objection of the action of the walls is not sufficient to account altogether for the disagreement with the results of other experimenters. For the spheres of 19.8, 28.5, and 39.2 mm. the dimension of the tunnel (300 mm.) is in the same ratio as that of the Eiffel tunnel with the spheres of 160 and 244 mm.; even the sphere of 50.5 mm. is admissible by the same right as the sphere of 330 mm. in the Eiffel tunnel.

We are thus unable to explain, for the moment, the cause of these discrepancies. We consider that the question should be taken up again very methodically, defining clearly all the experimental conditions and utilizing various dimensions of tunnel for the same spheres.

TOUSSAINT AND HAYER
RESISTANCE OF SPHERES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS PARIS OFFICE

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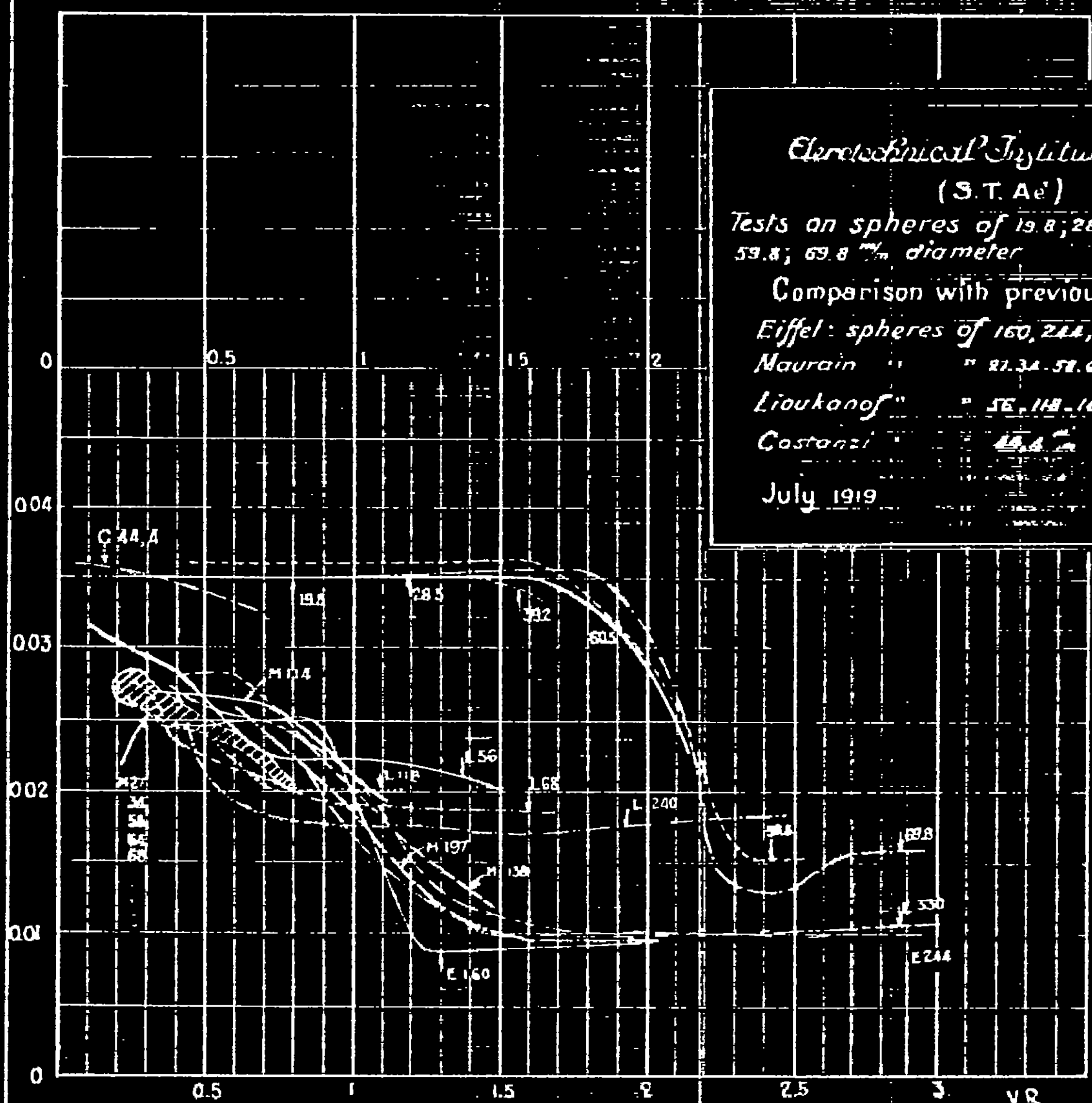
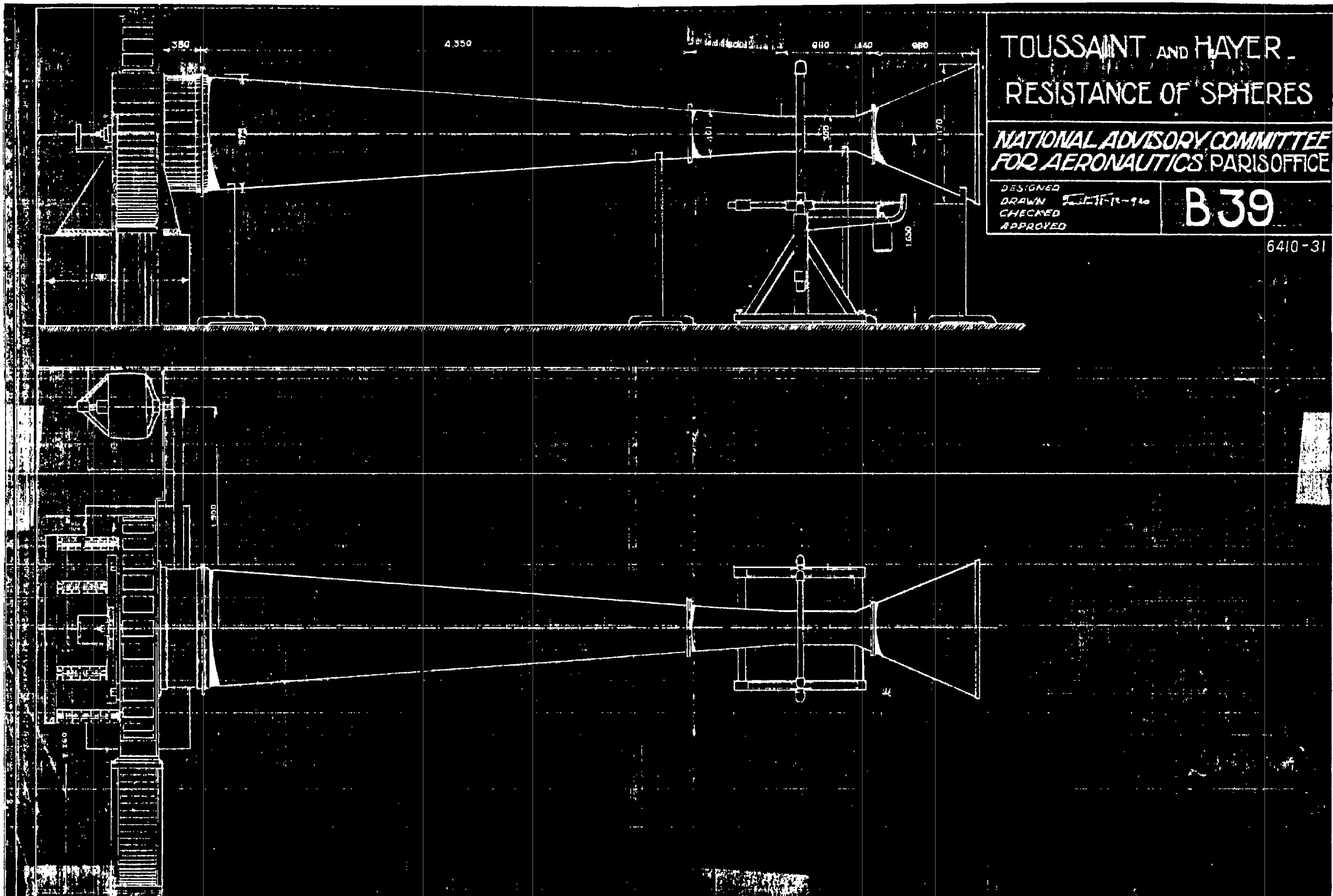


Aerotechnical Institute St Cyr
(S.T. Aé)
Tests on spheres of 19.8; 28.5; 39.2; 50.5; 59.8; 69.8 m/m diameter
Comparison with previous tests:
Eiffel: spheres of 160, 244, 330 m/m
Maurain " " 27.34.58.64.68.114.138.197 m/m
Lioukanof " " 56.118.168.240 m/m
Costanzi " " 44.4 m/m
July 1919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