

## Eiffel's Recent Experiments on the Resistance of the Air

BY JACQUES BOYER

Eiffel's first experiments on the resistance of the air, a problem which is now engaging the attention of many scientists because of its importance in aeronautics, were made in 1907-8 at the famous Eiffel Tower, which was constructed for the Paris Exposition of 1889. The surface on which the pressure of the air was to be studied was allowed to fall from the platform of the second story of the tower, in connection with a chronographic apparatus, which recorded the resistance opposed by the air at each instant. The surface was carried downward by a heavy and dense mass, offering little resistance to the air. This mass was placed above the surface, with which it was connected by springs, which were compressed more or less, according to the air resistance. The velocity of fall ranged from 50 to 130 feet per second. The apparatus was guided in its fall by a vertical cable, and was prevented from striking the ground by a progressive enlargement of this cable beginning at the height of about 70 feet from the ground. In this way the falling body was gradually brought to rest by the action of spring brakes. A tuning fork, making 100 vibrations per second, was attached to the surface. To one of the prongs of this tuning fork was attached a style, which, as the fork vibrated, moved vertically over the surface of a vertical cylinder, which was covered with paper coated with lampblack, and was caused to revolve with a speed proportional to the velocity of fall. Hence the record takes the form of a fine sinusoid, the median line or axis of which forms an irregular line around the cylinder. Each point of this axis corresponds to a certain position of the falling body. The number of undulations between this point and the beginning of the trace, gives the time; the ordinate of the point indicates the tension of the springs, and consequently the pressure of the air on the surface, at that instant; and the abscissa is proportional to the distance through which the body has fallen. Hence the trace gives the position and velocity of the body and the resistance opposed to its motion by the air at every instant. Eiffel experimented in this way with plane surfaces of various forms, square, oblong, circular, continuous, and cut or perforated, with groups of superposed plane surfaces, and even with spherical and conical surfaces. He arrived at the following conclusions: For velocities between 60 and 130 feet per second, the resistance of the air is very approximately proportional to the square of the velocity. The exponent of the velocity differs very slightly from 2 and appears to increase regularly with the velocity, passing through the value 2, at the velocity of 110 feet per second. The pressure per square inch was furthermore found to increase with the area of the surface.

The influence exerted by superposed surfaces on

each other is very great. In some cases the resistance is smaller for a group of surfaces than for a single surface. For surfaces inclined to the direction of the wind, Eiffel formulated in 1908 the following law: For inclinations to the horizon varying between 0 and 30 degrees, the pressure is proportional to the angle, while for inclinations greater than 30 degrees, the resistance is constant.

In order to extend these observations (which have

an upward pull at  $f$ , produced by the weight  $P$ , in the balance above. When equilibrium is established the moment of the forces which tend to move the experimental surface and its support round the knife edge  $A$ , can be computed from the weight in the scale pan. Two weighings are made, when the air is at rest and when it is in motion at known velocity. The moment produced by the air current is the difference of the two results. The other end of the

rod  $E$  carries a second knife edge  $B$ , which is directed upward and which can be brought to bear against its seat by shortening the rod  $H$ , by means of the eccentric  $G$ . In this way the moment of the air pressure around  $B$  can be measured. Thus it is possible to measure the moments of the pressure with respect to two points; furthermore, as the rod  $C$  can be rotated about its axis, the elements of the resultant pressure upon an inclined surface can be determined by making four measurements, at azimuths differing by a right angle. The vertical part  $D$  is a rod of cast steel, which is capable of slight motion in a sheath attached to the floor of the room above, on which the balance stands. This sheath, which is very narrow and is beveled in front and behind, protects the vertical rod from the air current, without appreciably affecting the latter. The horizontal part  $E$  is provided with a pair of knife edges at each end. The knife edges at the front or windward end  $A$  are directed downward and backward, while those of the other end  $B$  are directed upward and back-

ward. The seats of these knife edges have projections, which prevent the knife edges from moving along the grooves in which they turn. By moving a lever, the knife edges in front can be lifted from their seats to protect them from wear, except during the actual experiment. The rod  $H$ , which connects the frame  $E$  with the beam of the balance, touches these parts only by means of knife edges. In short, all the moving parts of the apparatus turn on knife edges, and the friction is negligible. The T-shaped piece  $DE$  weighs more than 100 pounds. This great weight is not an inconvenience, but serves two useful purposes, by lessening and damping the secondary oscillations, due to small variations in the force of the air currents, and by making the equilibrium of the balance stable in every relative position of the current and the surface. The entire apparatus is supported by a massive wooden platform, about 8 feet square, which rests on a double layer of sleepers, buried 10 feet below the floor of the room and lying parallel with the direction of the air current.

The current of air is drawn through a tube 6½ feet in diameter, and every precaution is taken to keep its strength uniform during the experiment. The air is drawn from a large closed room in which the surface

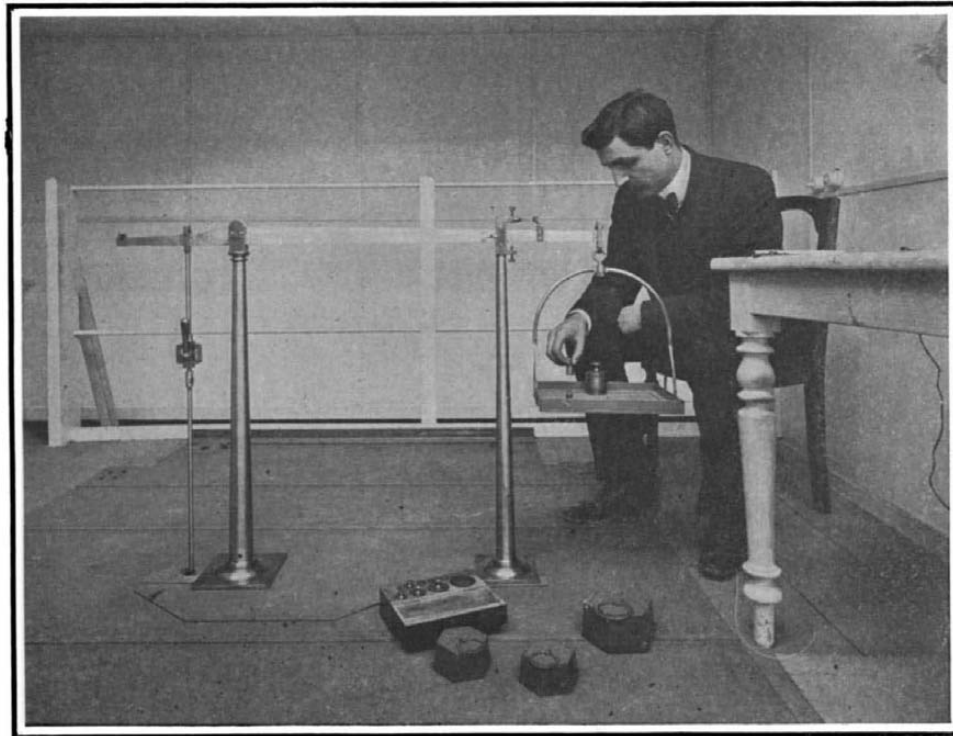


Fig. 9.—The Eiffel aerodynamic balance placed above the experiment room.

been fully described in the SCIENTIFIC AMERICAN) Eiffel constructed in 1909 an aerodynamic laboratory at the Champ de Mars, Paris, where he has subsequently conducted experiments with fixed surfaces, exposed to air currents produced by a blower of 50 kilowatts power. By this method he was able not only to obtain the resultant pressure, but to determine the distribution of pressure on both sides of the surface and the movement of the air in its vicinity.

In order to place the surface in conditions as nearly as possible identical with those produced by a natural wind or by movement in the open air, the air current must have so large a cross section that its exterior filaments will not be affected by the presence of the surface. The pressures experienced by the surface are measured by an aerodynamic balance, by which it is possible to determine the horizontal and vertical components, as well as the center of pressure; data which are very important in the construction of aeroplanes. The aerodynamic balance is shown in diagram in Figs. 1 and 2. The experimental surface is attached to the rod  $C$ , which is placed parallel to the air current. This rod is attached to a rigid T-shaped frame  $DE$ , which is capable of motion around a knife edge  $A$ . The action of the air current is opposed by

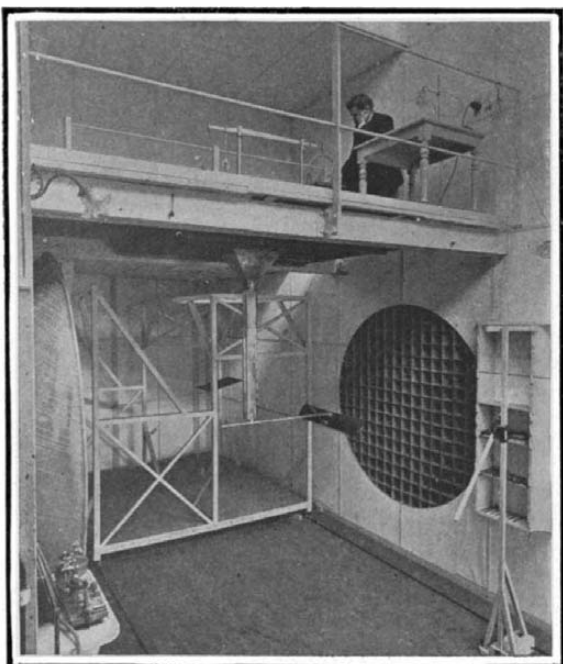


Fig. 6.—Experiment room of Eiffel's aerodynamic laboratory.

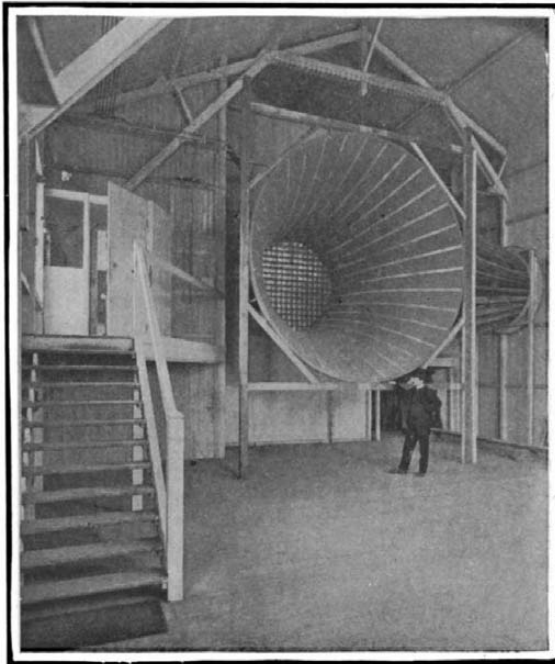


Fig. 7.—The inlet of the blower.

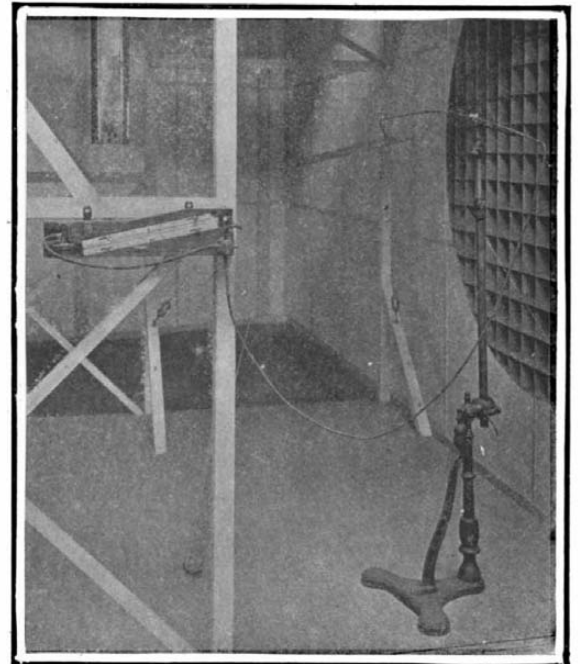


Fig. 8.—Arrangement of apparatus for measuring pressures at various points of the surface.

EIFFEL'S RECENT EXPERIMENTS ON THE RESISTANCE OF THE AIR.

is placed near the inlet of the blower, and not at its outlet, as is usually done. The air which leaves a blower is subjected to irregular disturbances, which cannot be overcome sufficiently to produce uniform and constant velocity over the entire surface. The pressure exerted upon the surface is transmitted to the balance in the room above, where the observer is stationed. The air enters the experiment room through a cellular diaphragm in parallel filaments. At the opposite end of the room is the mouth of the conduit which leads to the blower and which contains two iron-wire gratings of 2/5-inch mesh, placed about 40 inches apart, which almost completely eliminate all irregularities of flow. The air leaves the blower through a conduit which gradually enlarges and serves still further to assure regularity of flow. Hence, the velocity and direction of the air current are uniform throughout its whole section and, as the apparatus is entirely inclosed, it is not affected by the wind outside.

The velocities of the air current are deduced from the readings of manometers, and the results have been verified in the following manner: One of the surfaces exposed to the current was perforated with a large number of holes, in each of which was countersunk a screw, having at its center an orifice, 1/50 inch in diameter. By measuring with a small manometer the pressure produced behind each of these orifices, and integrating the result, the same resultant force that had been indicated by the balance was obtained.

We cannot here relate in detail all the interesting results which Eiffel and his assistant Léon Rith have already obtained in this laboratory. We will mention only a few of the more important conclusions.

Eiffel has proved that the value of the horizontal component, or resistance to the advance of an aeroplane, increases continually with the inclination of the surface to the horizon, while the vertical component attains a maximum at an inclination of 15 degrees, and thereafter diminishes very rapidly, and vanishes at 90 degrees, i. e., when the plane is vertical.

The surfaces employed in these experiments had a plane of symmetry parallel to the wind. In order to determine the directions of the air filaments in this plane, a short and very light wire, attached to the end of a thin rod, was placed at various points of the plane, and the position and direction of the wire were determined as accurately as possible. In most cases it was found that, especially near the front edge of the surface, the direction of the wire fluctuated rapidly between two fixed limits. This fluctuation in the direction of the wire is due to the fact that at any instant the air flows according to a definite, but not very stable, system, so that only a very small influence is required to pass from one system to another. The various possible systems of flow could be approximately determined by careful observation and comparison of the directions of the wire.

Fig. 3 shows the directions of the air filaments near a square surface, the plane of which makes an angle of 40 degrees with the direction of the current. Fig. 4 shows the directions of the stream lines near a surface inclined 80 degrees to the current. It will be observed that these lines are very variable and consequently very instable. The same fact is shown when the surface is perpendicular to the current. Fig. 5 shows the average direction of the air at various points in this case. In the two regions inclosed by the dotted lines, the disturbance is so great that no mean direction of flow could be determined.

In regard to the center of pressure, this coincides with the center of figure if the surface is horizontal, gradually moves forward as the inclination increases

to 15 degrees, and thence recedes as the inclination is increased, and again attains the center of figure when the surface becomes perpendicular to the current. Finally, Eiffel indorses the almost universal preference of aviators for curved sustaining surfaces, and proves that, for a given resistance to forward movement, the curved surface always develops a greater lifting power than the plane surface, especially at small inclinations.

#### The Transit of Halley's Comet.

The transit of Halley's comet and the expected immersion of the earth in the tail of that historic body have proven once more what may happen to the best-laid plans of mathematicians. The transit undoubtedly occurred, but whether or not the earth really encountered the tail seems to be a matter of considerable doubt. When the night of May 18th came, and the scientific world was all agog, the tail was so curved that the passage of the earth through it seemed only remotely possible. On the morning of the 20th a broad band of light that stretched along the horizon for a distance varying from 120 to 160 degrees pro-

way, affect the aurora borealis. The failure of his expedition, which it is almost safe to assert, still leaves that theory unproved.

Similarly unsuccessful must be all the elaborate preparations made by meteorologists, navigators and physicists. The more important meteorological stations of the world sent up sounding balloons at frequent intervals on the 18th and 19th of May, for the express purpose of bringing down from the upper strata of the atmosphere some record of unusual happenings which might safely be attributed to the influence of the comet. All this labor is now in vain. Similarly, it is very unlikely that the instructions sent forth by the United States Hydrographic Office to wireless operators, charging them to note any curious and unusual effects on their instruments, will prove barren.

The expedition which was sent to the Hawaiian Islands by the Astronomical and Astrophysical Society of America for the purpose of observing the transit cables a preliminary report of complete inability to note any transit whatever. This was more or less expected. In 1882 a transit occurred which was fortunately

observed by Mr. Finlay at the Cape of Good Hope. The comet of 1882 was followed by him "continuously right into the boiling of the limb." No sooner had it touched it, than it vanished as if destroyed. So sudden was the disappearance, that the comet was at first believed to have passed behind the sun. As a matter of fact, the observers at the Cape had witnessed a genuine transit. The experience of the observers at the Hawaiian Islands with Halley's comet seems to have been exactly similar. On the whole, this apparent failure to observe the creeping of a black speck across the face of the sun may be deemed a confirmation of our present theories that the bulk of a comet is much too flimsy to be detected in the blinding glare of our central luminary.

Although the passage of the earth through the tail of Halley's comet turned out to be an extraordinary disappointment, it is unfair to charge our mathematical astronomers with incompetence. A comet's tail is so capricious, so fluctuating a structure, it changes with such startling rapidity, that the predictions of any astronomer with regard to its behavior must always be stated with some reserve.

The tail of Halley's comet has conducted itself in a most whimsical fashion. In the middle of February, it was some fifteen million miles long. In April, it seemed to have vanished entirely.

Then it grew again, until finally it attained a length that has been variously placed at twenty to forty million miles. It seems to have split longitudinally into three more or less well defined parts. When we consider that Morehouse's comet of 1908 (comet C, 1908) exhibited some extraordinary changes; that it repeatedly formed tails, which were discarded to drift out bodily into space, until they finally melted away; that in several cases tails were twisted or corkscrew shaped, as if they had gone out in a more or less spiral form; that areas of material connected with the tail would become visible at some distance from the head, where apparently no supply had reached it from the nucleus; that several times the matter of the tail was accelerated perpendicularly to its length; and that at one time the entire tail was thrown forward and violently curved perpendicularly to the radius vector in the general direction of the tail's sweep through space (a peculiarity opposed to the laws of gravitation), it is evident that a comet presents important problems for the future astronomer to solve. It is no wonder that Halley's comet should have disappointed us.

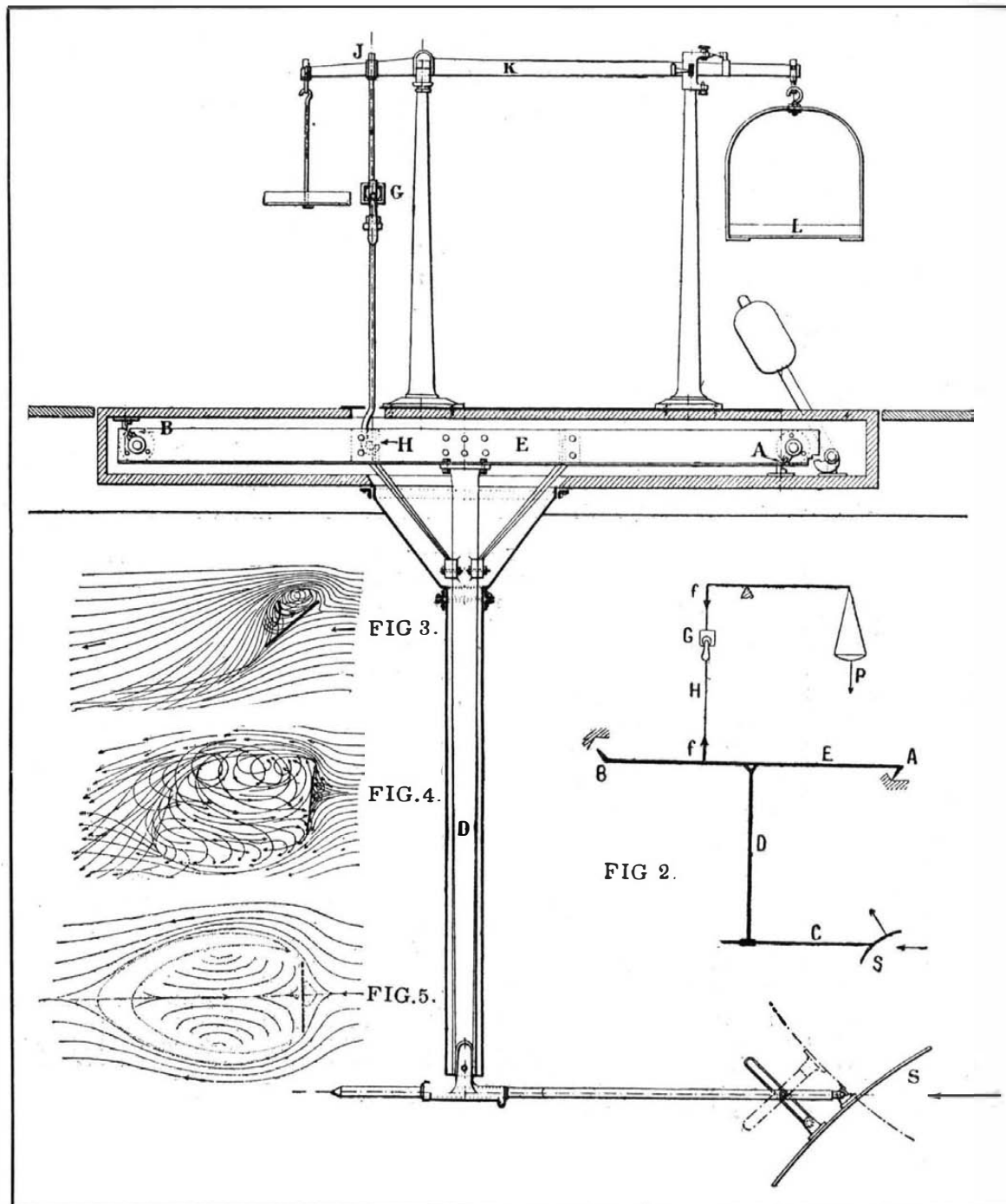


Fig. 1. The Eiffel aerodynamic balance. Fig. 2. Diagram of the balance. Fig. 3. Direction of stream lines near a square plate inclined 40° to the air current. Fig. 4. Stream lines near a square plate inclined 80° to the air current. Fig. 5. Stream lines near a square plate perpendicular to the air current.

claimed indubitably that the earth was still untouched, and that contrary to expectations, the comet was still in the east. Prof. W. W. Campbell, of the Lick Observatory, saw the comet visibly in the eastern sky. According to him, the tail was at least 140 degrees long and lagged far behind the radius vector. Because of the angle of 18-odd degrees which separates the earth's orbit from that of the comet, the curvature of the tail, to which this extraordinary misadventure may probably be traced, probably prevented the earth from coming in contact with it.

All the scientific expeditions which have been sent out to various parts of the earth will probably come back with nothing to report. Some of these scientific parties must have proceeded to their destinations at considerable expense. Thus Prof. Birkeland, of the University of Christiania, went to Kaafjord, in the northern part of Norway, for the purpose of noting whatever electrical and magnetic effects might be attributed to the comet's tail, and particularly to observe the relation of the aurora borealis to the comet. He has his own theory that the particles of a comet's tail are so highly electrified that they may, in some