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REPORT ON EUROPEAN AERONAUTICAL LABORATORIES

(With Eleven Plates)

BY
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GENERALITIES

Places visited.—During August and September, 1913, in company with Jerome C. Hunsaker, Assistant Naval Constructor, U. S. N., I visited the principal aeronautical laboratories near London, Paris, and Göttingen, to study, in the interest of the Smithsonian Institution, " the latest developments in instruments, methods, and resources used and contemplated for the prosecution of scientific aeronautical investigations." Incidentally we visited many of the best aerodromes (flying fields) and air craft factories in the neighborhood of those cities, and took copious notes of our observations. We also visited many aeronautical libraries, book-stores, and aero clubs, in order to prepare a comprehensive list of the best and latest publications on aerial navigation and its immediately kindred subjects. In each of the countries, England, France and Germany, we spent about two weeks. We were made welcome at all the places visited, and thus established personal relations which should be valuable in future negotiations with the aeronautical constructors and investigators in those countries. But these incidental visits and studies, though they may prove serviceable, do not seem germane to the present report. Neither does it seem advisable to take more than passing notice of the aeronautical laboratories themselves in those manifold details which have been already published in large and comprehensive reports now accessible in the Smithsonian Library.

Organization, resources, and scope of laboratories.—The laboratories examined by us are in particular (1) the aeronautic research and test establishments of the British government near London; (2) the Institut Aerotechnique de St. Cyr, and the Laboratoire Aerodynamique Eiffel, both near Paris; (3) the Göttingen Modelversuchsanstalt at Göttingen; and (4) the newly organized laboratory adjoining the flying field at Johannisthal near Berlin, known as the "Deutsche Versuchsanstalt für Luftfahrt zu Adlershof."

These establishments resemble each other in some important features, but differ in others. All are devoted to both academic and engineering investigations. All are directed by highly trained scientific and technical men. The directors are not merely executives; they are the technical heads—scientists or engineers specifically qualified by superior training in aeronautical engineering and its immediately cognate branches—who initiate the researches, and assist their technical staffs in devising apparatus, interpreting results, and making systematic reports.

The establishments differ in their organization, resources, and equipments, and, to a considerable extent, in the scope and character of their investigations. Of the five institutions mentioned, the one in England and the one at Göttingen are now supported largely by governmental appropriations; and the other three are maintained by private capital, allotted as required, or accruing from fees or endowment funds. Again, the laboratories near London, at St. Cyr, and at Adlershof are practically unlimited in the scope of their researches, while Eiffel's and the Göttingen laboratory have confined their activities substantially to wind-tunnel experiments.

The aeronautical researches of the British government are in charge of the British Advisory Committee for Aeronautics, a self-governing civilian organization which was appointed by the Prime Minister of England to work out theoretical and experimental problems in aeronautics for the army and navy, and comprises twelve to fourteen expert men, under the presidency of Lord Rayleigh. This committee initiates and directs investigations and tests at the Royal Air Craft Factory, at the National Physical Laboratory, at the Meteorological Office, at Vickers Sons and Maxim's, etc. It expends, in performing its regular functions, a sum exceeding the income of any private aeronautical laboratory, and received directly from the government treasury.

The committee is primarily occupied with work for the government, but also performs researches and tests for private individuals, for suitable fees, but without guaranteeing secrecy as to the results. The work of the committee is manifold and comprehensive. Whirling-table measurements, wind-tunnel measurements, testing of engines, propellers, woods, metals, fabrics, varnishes, hydromechanic studies, meteorological observations, mathematical investigations in fluid dynamics, the theory of gyroscopes, aeroplane and dirigible design—whatever studies will promote the art of air craft construction and navigation may be prosecuted by this committee. A detailed program and the results of actual investigations have been published in the annual report of this committee.

M. Eiffel has paid from his personal fortune all the expenses of his plant and elaborate researches, though it is understood that he may sometimes charge nominal fees for investigations made for private individuals who wish exclusive rights to the data and results obtained. The general director of the laboratory is Eiffel himself—who initiates the researches and publishes the results. He has in immediate charge two able engineers, MM. Rith and Lapresle, aided by three trained observers who are skilled draughtsmen. Two mechanics and one janitor complete the personnel. The work of the laboratory is all indoors, and is confined to researches in aerodynamics alone, or more specifically to wind-tunnel measurements and reports thereon.

The institute at St. Cyr was founded by Deutsch de La Meurth, who gave $100,000 for the original plant and has provided $3000 per year, during his life, for maintenance. It was presented by him to the University of Paris, and is now under the general direction of the professor of physics, M. Maurain, aided by a technical staff and a large advisory council of eminent engineers, scientists and officers of the university, officers of the French government and members of various clubs and aeronautical organizations. The staff comprises the director in charge and his assistant, together with such students, two or three at a time, as may come as temporary volunteers from the University of Paris.

The institute conducts large-scale experiments in the open field as well as indoor researches, makes investigations for general publication or for private interests, on payment of suitable fees, and permits private persons to conduct researches in the laboratory. The scope of the work is practically unlimited, as is the case in the English aeronautical laboratories. A special feature of the institute is its three-quarter mile long track with electric cars for tests on large screws, large models and full-size aeroplanes.

The Göttingen aerodynamical laboratory was begun as a private enterprise, but is now to be enlarged and maintained in part by financial aid of the Kaiser Foundation. The original building, with its wind-tunnel, was erected in 1908 after the plans of its director, Prof. Prandtl, of the University of Göttingen, at a cost of 20,000 marks, supplied by the Motorluftschiff-Studiengesellschaft. Its available income is said to be $7,000 a year. The enterprise was inaugurated on a small scale because of the uncertainty, at that date, as to the practical value of such an establishment. The work of this laboratory, as in Eiffel's, has been practically limited to wind-tunnel experiments, though Prof. Prandtl has written some valuable theoretical investigations, and is reported to be undertaking large-scale experiments in the open air by use of a car on a level track, as at St. Cyr.

The Deutsche Versuchsanstalt für Luftfahrt zu Adlershof has been recently founded by the Verein Deutscher Ingeniure. The laboratory adjoins the great Flugplatz, with its two square kilometer flying field surrounded by numerous air craft factories, scores of hangars, an aero club house and a grand stand. Major Von Tschudi, a retired German officer, is general manager of the organization, which operates the flying field in the interest of all aero manufacturers and experimentalists, whether civilian or governmental. Dr. Eng. F. Bendeman is director of the laboratory and has ten assistants, comprising, among others, Dr. Fuhrman, who was formerly assistant in the Göttingen laboratory. I have not ascertained the financial resources of the laboratory; but a prelude to its present operations was a competition, involving some three score German aeronautical motors, for the Kaiser Prize and additional contributions from the country at large, aggregating in all 125,000 marks. It is understood that the laboratory is liberally supported, is unlimited in the scope of its work, and will conduct both indoor researches and field experiments similar to those at St. Cyr.

After this general view, a technical account of the foregoing aeronautical establishments may be useful.

BUILDINGS, EQUIPMENT AND OPERATION

ENGLISH AERONAUTICAL LABORATORIES

Aeronautical laboratories used by the British government.—Of the various aerotechnical plants supervised or used by the British Advisory Committee for Aeronautics, we visited the one at the National Physical Laboratory, at Teddington, and the one at the Royal Air Craft Factory, at Farnborough; but not the meteorological stations, nor the plants of private concerns working for the committee, such as Vickers Sons and Maxim.

The National Physical Laboratory, which corresponds to the U. S. Bureau of Standards, is under the directorship of Dr. R. T. Glazebrook, F. R. S., Chairman of the Advisory Committee for

Aeronautics; its engineering department is directed by Dr. T. E. Stanton; and the subdivision of this assigned to aeronautic investigation is in general charge of Mr. L. Bairstow.

The part of the National Physical Laboratory devoted exclusively to aeronautics comprises the whirling-table house, the large wind-tunnel house and the small wind-tunnel house with its liberal space for minor apparatus. The parts available for aeronautics, but not exclusively devoted thereto, are the general grounds, the large marine model tank, the ample shops for wood and metal working, the store rooms, the offices and library, the heating and lighting system, etc.

The whirling-table house, a separate building, is a corrugated iron shed some 80 feet square, having an earth floor, and at its center a motor driven vertical shaft which supports a trussed horizontal arm and causes it to whirl at any desired speed, its outer extremity describing a circle about 60 feet in diameter, and carrying in steady flight any model that has to be tested. The most important use of this whirling tabel hitherto made seems to have been to prove what was demonstrated and published in America by myself about one decade previously, viz., that a suitably designed pressure-tube anemometer is competent to measure the velocity of a uniform air current accurately to one per cent, or less,[1] and needs no calibration when its readings are interpreted in accordance with Bernouili's theorem. The whirling arm has also been used to test model screw propellers, but is not necessary for this work, and is much less convenient for the purpose than the wind-tunnel, as used by Eiffel, for example. It is therefore questionable whether the Smithsonian Institution will require a whirling table for its aerodynamic studies.

The large wind-tunnel house, a wing of the engineering laboratory, is a concrete structure 100 feet long, 40 wide and 30 high, having a wooden horizontal wind-tunnel placed equidistant from the side walls, and midway between floor and ceiling, and supported between concrete columns reaching from floor to ceiling.

The large tunnel is some 80 feet long and 7 feet square in cross-section from its mouth to its middle; it expands considerably through the rest of its length. Its larger extremity abuts against the end wall of the room, while its mouth stops well short of the opposite wall. At mid-tunnel, just aft the enlargement, is placed a low-pitch wooden screw actuated by a 30-horse electric motor, and designed to give a current of 60 feet a second in the fore part of the

[1] The calibration made at the British laboratory is reported to be reliable to one-tenth of one per cent.

tunnel. The screw sucks the air of the closed room through the mouth of the tunnel, which is somewhat flaring, thence through a metal honeycomb, into the experimental part of the tunnel where the models are placed for study. Thence the air flows into the expanded half of the tunnel, passing first through the screw, then laterally outward through innumerable holes in the tunnel wall, thence in uniform circulation through the unobstructed room till it curves again easily into the mouth at the opposite end. The air stream so produced is, where it emerges from the honeycomb, uniform in velocity at all parts of a section, at least to a fraction of one per cent, if due care be taken. The expanded and perforated part of the tunnel is said to be the final outcome of long months of trial and study by the technical staff, and has enabled them to produce the steadiest aerodynamic current in the world; thus removing one of the greatest difficulties in the accurate determination of the flow and pressure of air about wind models. The current velocity is reported to be uniform to one-half per cent both in time and in space.

The complete structure of the tunnel need not be delineated here, as it may be had better from the general plans and detailed working drawings which the director of the laboratory has kindly offered to furnish the Smithsonian Institution. It may be explained, however, that the "honeycomb," just within the flaring mouth of the tunnel, consists of crossed metal sheets forming, post-office-box-like, a tubular partition of many cells through which the air entering the tunnel is straightened and deprived of eddies. It may also be observed that a glass door is placed on the side of the tunnel, through which one may take observations, or enter to adjust the models to be tested.

The cost of the seven-foot wind-tunnel is given as about $2,000, and of its wind balance about $2,000. This, with an expenditure of $12,500 for the building, makes a total of $16,500 for the plant.

The velocity of the air flow in the unchecked current, near the model held inside the tunnel, is computed from the observed pressure difference between the inside and outside of the tunnel wall. The accuracy of this method was experimentally proved by me in 1902 at the request of the Navy Department, and, together with a mathematical proof, was set forth in the *Physical Review* the following year. It was there shown that the speed of air rushing steadily through a horizontal cylindrical tube from the quiet atmosphere of the room into a chamber at low pressure is, for ordinary transportation speeds, given truly to a fraction of one per cent by the formula $V = \sqrt{\frac{2g}{\rho}(p_o - p)}$, $p_o - p$ being the pressure difference between the room and chamber, V the speed[1] of inrush, and ρ the nearly constant density. The method has since been adopted at Eiffel's laboratory and at the National Physical Laboratory.[2] This for the speed of flow; the direction may be shown by fine silk threads moored in the current, or by floating particles, fine streams of smoke, etc. In passing it may be mentioned that the direction of flow in the unchecked current is parallel to the tunnel walls truly to a fraction of one degree.

The pressure difference in question is found by connecting the interior of the tunnel wall by means of external nipple and hose, to one branch of a U tube manometer whose other branch opens into the quiet air of the room; then observing the difference of level of the liquid in the two arms. Manometers are made in many forms, according to the accuracy desired. The English one, known as the "Chattock tilting gauge," made public in 1903, measures barometric pressure differences truly to one five hundred thousandth of an atmosphere. My gauge, made in 1902 on a different principle, was graduated to millionths of an atmosphere and for the most accurate measurements of static pressure differences was always read to tenths of a graduation. At Eiffel's Laboratory, and at various other places, a less accurate, but somewhat simpler, manometer gauge is used. It consists merely of an inclined alcohol tube suitably mounted beside a graduated scale. The latter instrument, a long known type of gauge, I would recommend for its convenience; but where great precision is required the English gauge or mine would perhaps serve better.

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[1] More strictly speaking, V is the *increase* of velocity of the air as it flows from the room into the tunnel; but as the air starts from near rest, the increase of velocity is practically the whole velocity of inflow. A considerable error may ensue if V be taken as the true speed of inflow for the case of a tunnel of goodly section as compared with that of the room. Thus for the new English tunnel the cross-section is 7 x 7 feet in a room whose section is 30 x 40 feet. Hence the average speed of flow through the room is 4 per cent of the speed through the tunnel. Hence something like 4 per cent must be added to the speed computed from the true static pressure difference in question.

[2] At the National Physical Laboratory, the velocity along the axis of the tunnel as computed from the pressure difference inside and outside the tunnel wall is corrected by use of a small calibration constant obtained by placing a Pitot tube in the center of this tunnel before the place where the models are tested.

Such gauges are equally useful for measuring the difference between some standard pressure and the actual pressure at various points on the surface of a model, or elsewhere. Thus one arm of the U tube may be connected with the internal surface of the tunnel while the other arm is connected successively to various points on the surface of a model. The difference between the standard wall pressure and that at each point of the model surface may then be plotted giving a diagram of surface pressure distribution all over the model.

The wind balance.—Besides the pressure distribution and resultant pressure on models, it is desirable to determine also the total wind force, which is composed of both the pressure and the friction of the air. To this end the English experimentalists use a bell-crank balance which is a modification of the type devised and used in my laboratory, and now employed also by Eiffel for the accurate measurement of small wind forces. The English balance consists of two horizontal weighing arms, one parallel to the tunnel, the other perpendicular, attached to a round vertical tube, or arm, supported at its center on a conical pivot just beneath the tunnel floor. The vertical arm of the bell-crank balance has its upper half extending through the tunnel floor up to the center of the current and is duly shielded by a stream-line encasing sheath, while its lower half extends downward from the pivot and dips into a pail of oil intended to damp the oscillations. The upper half supports at its extremity the wind model and near the pivot has a graduated joint, so that it can be rotated about its own axis, and thus orient the model as desired. Sliding weights on the two weighing arms are made to measure the components of wind force parallel to the flow and perpendicular thereto. If the wind force tends to rotate the balance about the vertical axis, this tendency, or wind moment on the model, is determined by observing what horizontal restraining force must be applied to one of the horizontal arms to prevent such turning. Thus the balance may be used to measure lift, drift and center of pressure. There are numerous ingenious and important details, such as those for studying stability coefficients, which can best be obtained from the British Aeronautical Committee's technical report for 1913, or from the working drawings which the laboratory has furnished the Smithsonian Institution. Though this aerodynamic balance is accurate and moderately convenient, I am of the opinion that several new types can be devised which shall be equally precise and probably more expeditious, requiring less adjustment at each change of model. Such new types I have had in contemplation since first devising the bell-crank aerodynamic balance, in 1902.

The small wind-tunnel house, a wing of the engineering building, is of structural iron and covers rather more space than the room just described. Its chief apparatus is a four-foot wind channel for testing small models. Other apparatus in this room are an engine testing plant, now dismantled; a horizontal water channel, described in the Advisory Committee's report for 1912-13; and a small vertical tube down which tobacco smoke, formed at its top, can be sucked by an up-draft in a parallel pipe beside it having a burning gas jet in the bottom to maintain a heated column, the purpose of the descending air mingled with the smoke being to delineate the flow about models immersed therein and visible through the glass sides of the tube.

The small wind-tunnel is the working prototype of the seven-foot tunnel already described. Made of one inch lumber, it measures some 40 feet in length and is supported more than 6 feet above the floor by heavy angle iron trestle work which also forms the framing for the wooden tunnel wall. The first half of the tunnel measures 4 feet square; the second half, joined to it by an expanding metal cone, measures 6 feet square, is thickly perforated with inch square holes in its sides, and has its farther end abutting against the brick wall of the room. In the expanding cone at mid-tunnel is a low-pitch four-blade wooden screw driven by a steel shaft proceeding from a ten horse-power electric motor on a wall bracket at the large closed end of the tunnel, and capable of maintaining an air current of 40 feet per second in the four-foot tunnel. The character of the air flow and the instruments used are practically the same for the small as for the large tunnel. Some $20,000 was expended in developing and constructing this small tunnel and its appurtenances.

The small water channel, some 4 inches square in cross-section, has been used to exhibit the stream-line flow about models of ships' hulls, aeroplane posts, inclined wing forms, etc. By photographing the stream, duly dotted with tiny particles of foreign matter, clear pictures of the stream-lines and eddies have been obtained. These serve to show what forms are likely to encounter least resistance in moving through a fluid. But it can hardly be supposed that the phenomena of flow about a model slightly submerged in a shallow stream of water are identical with those for deep submergence in the atmosphere, unless for very slow speeds.

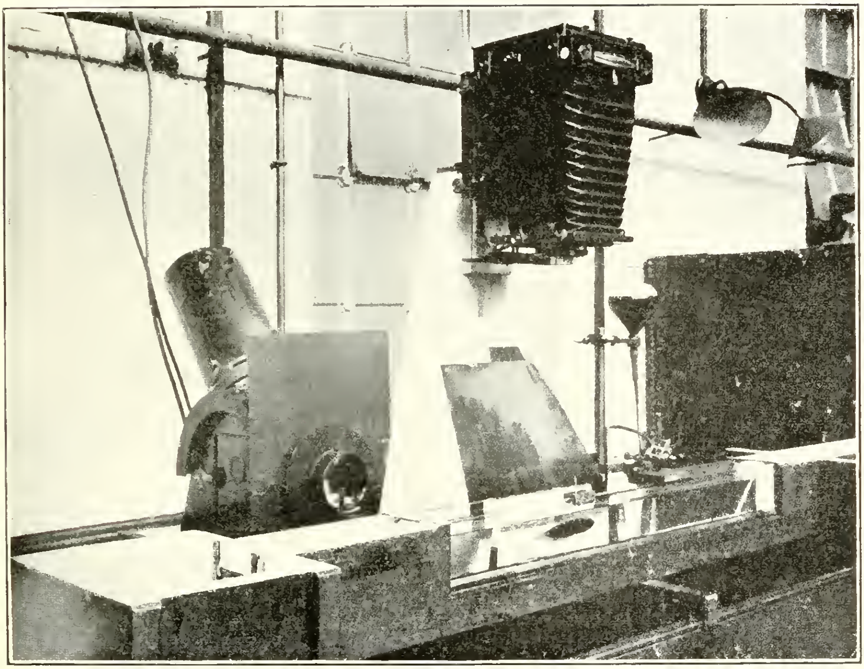
Wind towers.—On the ground to the west of the National Physical Laboratory buildings, two wind towers, each 60 feet high and provided with rotating platforms 20 feet long, are used to determine the flow and pressure of free air about large-scale models. The first results of such determinations were published by Dr. Stanton in the proceedings of the Institution of Civil Engineers for 1907, and later studies may be found in the reports of the Advisory Committee. The Smithsonian Institution can doubtless obtain a like service from the three tall radio towers in its neighborhood.

The Royal Air Craft Factory, under the direction of Mr. Mervin O'Gorman, member of the Advisory Committee, is adjacent to the headquarters and flying grounds of the Military Wing,[1] at South Farnborough. Its work is coordinated with the aeronautical researches of the National Physical Laboratory, and is professedly concerned with the scientific improvement of air craft construction, though in reality directed at times to the manufacture, on a large scale, of aeroplanes, propellers and parts of dirigibles. The factory construction and research are in charge of a civilian staff which cooperates with the Advisory Committee for Aeronautics in performing aerotechnical work for the naval and military branches of the aerial service. The close coordination of the Air Craft Factory with the Flying Corps and with the Advisory Committee is an obvious advantage to the progress of aerotechnics, which might be still further enhanced if all the experimental plants were in one locality as proposed for the United States.

Apparently no very sharp line separates the aerotechnical work of the Royal Air Craft Factory from that of the National Physical Laboratory. Both have a whirling table; both have an engine testing plant; both have studied the materials of construction; both design instruments. But this overlapping is not excessive. Broadly speaking, the laboratory investigates models; the factory full-scale air craft, their parts and appurtenances.

The factory investigates, develops, manufactures, and tests air craft. It is a mammoth plant, covering many acres and comprising half a dozen large buildings. It is said to expend half a million

[1] It may be noted that the entire military aerial service of England is known as "The Royal Flying Corps," and is under general supervision of the Air Committee, itself a subcommittee of the Committee on Imperial Defense. The Flying Corps comprises at present four branches: The Central Flying School; the Naval Wing; the Military Wing; the Reserve. The Advisory Committee for Aeronautics is an independent body, appointed by the Prime Minister, and receiving its appropriations directly from the Lord of the Treasury.



WATER CHANNEL AT NATIONAL PHYSICAL LABORATORY, ENGLAND

dollars per year and to employ 700 men, 400 of them working on aeroplanes. It has facilities for producing daily one complete aeroplane, excepting the engine, which at present is bought elsewhere. Its air craft are systematically tested on the great flying field nearby, bearing instruments which reveal their complete working in practical maneuver. One instrument alone, called the "ripograph," records simultaneously the angles of pitch, roll and yaw, the speed through air, the altitude, the three control movements and the time. The stress in the wires, the propeller thrust and the pressure distribution on the wings and other surfaces may likewise be recorded.[1] The establishment does in fact the work planned in the United States for both the field laboratory and the experimental air craft factory. But the Royal Air Craft Factory lacks some of the facilities planned for our plant, such as an expanse of water for testing naval aeroplanes, and the immediate accessibility of allied laboratories, workshops and other resources.

The result of the full-scale experiments has been to disclose the defects of the leading types of aeroplanes, and to indicate means of betterment. Substantial improvement has been made in the efficiency, stability, factor of safety and range of speed of the aeroplanes specially studied at the factory. The final outcome has been to produce a stable, efficient and safe biplane having a range of speed of 40 to 80 miles an hour. It is expected shortly that a standard control will be adopted after the best types have been given a comparative test. The type at present most in favor is the Deperdussin control, which rotates a wheel for warping, shoves it for elevating, and uses a foot lever for steering. Such practical full-scale work cannot be too strongly recommended for the Smithsonian Institution, especially if the army and navy will, as already intimated, furnish for such tests their typical air craft and their experienced pilots.

Reports.—The scope and character of the activities of both the factory and the laboratory can best be gathered from the annual reports of the Advisory Committee. These set forth all the work initiated by the committee, including, besides reports of experiments, all the theoretical researches, and all the summaries made by its members, in any form, whether of elaborate memoirs, translations or abstracts. The catholic character of these reports is praiseworthy, but their literary form and editing could well be improved. In this latter respect Eiffel's reports form more elegant models.

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[1] All these measuring and recording devices can be purchased from the Cambridge Scientific Instrument Co.

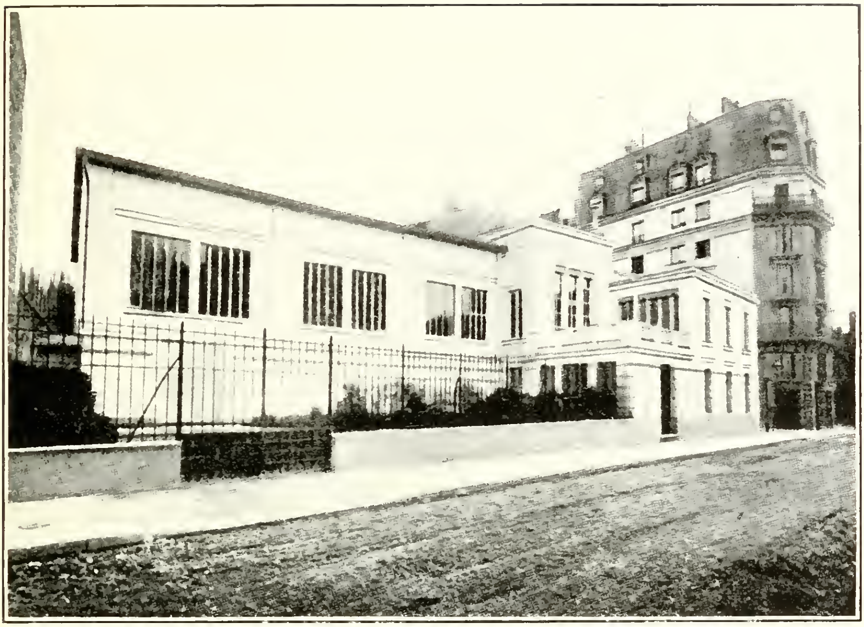
Other English aeronautical laboratories worth mentioning are those of the Northampton Polytechnic Institute, London, and of the East London College. For want of time I did not investigate these; but as their resources are very moderate and their reports have been irregular and meager, it is doubtful whether they contain any equipment materially worth adding to what has been hitherto described.

FRENCH AERONAUTICAL LABORATORIES

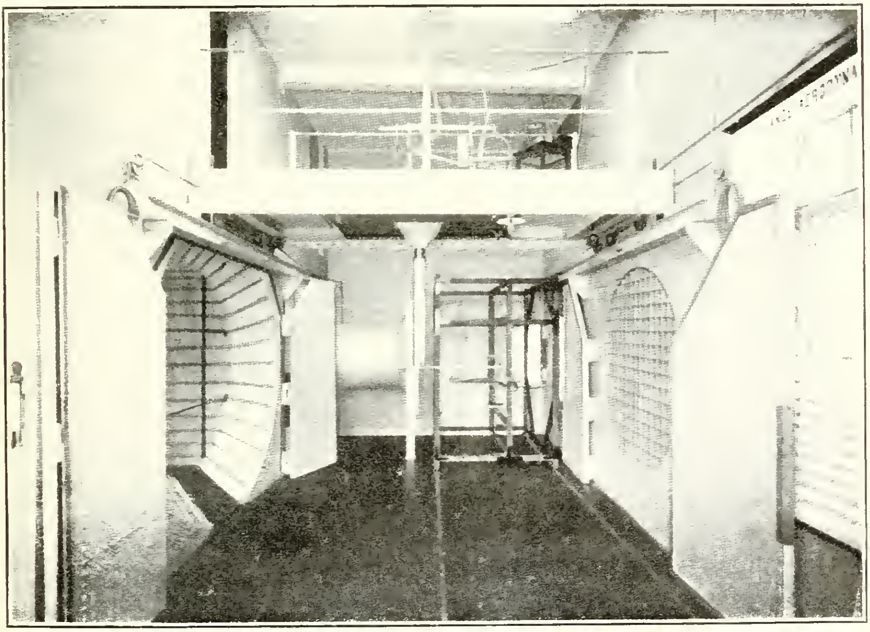
The Laboratoire Aerodynamique Eiffel consists of a single building with offices, a wind tunnel and various appurtenances, there being no workshops in the establishment. The wind-tunnel room measures, in round numbers, 40 by 100 feet, by 30 feet high; the three office rooms and garden cover about half as much additional space. Two wind-tunnels, a large and a small one, placed side by side, occupy the center of the room. They are placed well above the floor, to admit of a more nearly symmetrical flow of air. Considerable furniture—shelves, drawers, etc.—is placed about the walls; but the body of the room is kept somewhat free of obstructions to secure a less disturbed circulation.

Each tunnel comprises three main parts: the short bell-mouth intake, the model chamber, the long bell-mouth exit. The air from the room traverses the intake through honey-combs placed at either end of the bell-like form; then passes at its maximum speed in uniform rectilinear current across the model chamber; then flows in gently expanding stream and with diminishing speed onward to the larger end of the exit, where it encounters the fan which drives it with replenished energy into the open room. The model chamber is thus seen to be an enlargement of the tunnel proper, spacious enough to accommodate observers, and so sealed from the surrounding room as to have the same barometric pressure as the inflowing current at its narrowest section.

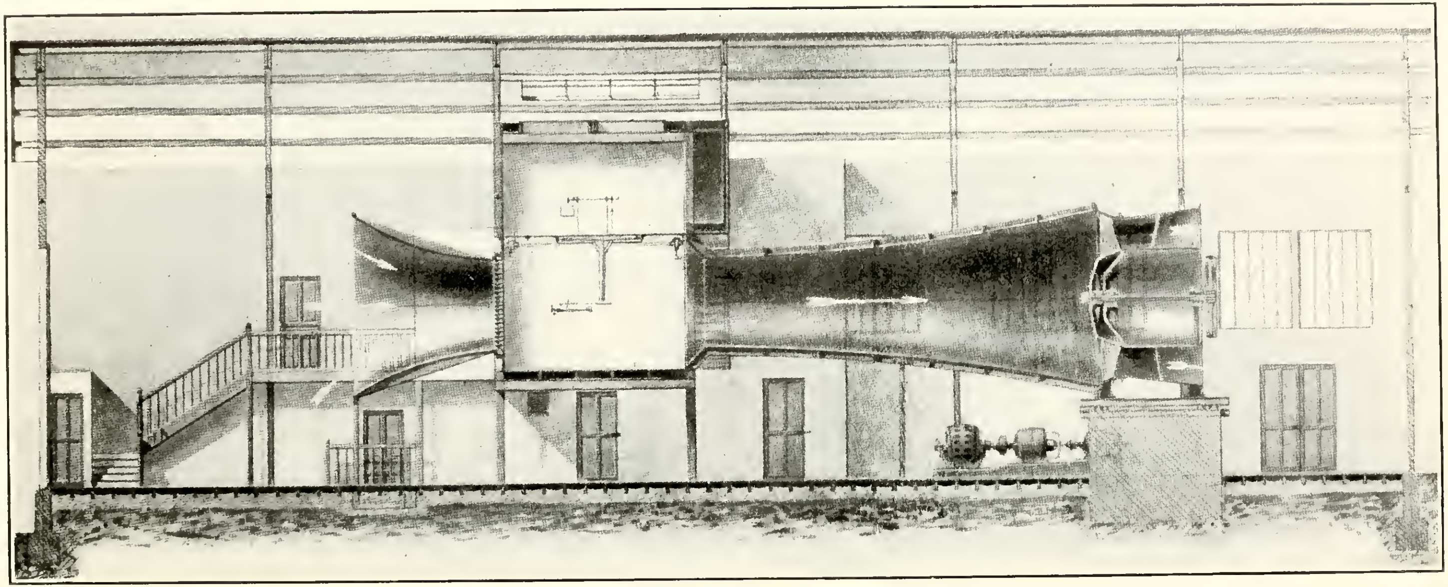
This type of tunnel, adopted by Eiffel after mature experience, has been patented by him as having features of considerable value. He prizes particularly the vacuum chamber for the observers, and for the freer flow of air about the models, uninfluenced by constraining walls. He also prizes the expanding exit, or "diffusor," for slowing the air as it approaches the fan and exhausts into the room, thus realizing great economy of power in maintaining the circulation. It is doubtful, however, whether any of the main features of Eiffel's tunnel are patentable in America. The bell-mouth entrance and exit have been known here many years. The vacuum chamber



EIFFEL AERODYNAMICAL LABORATORY



EXPERIMENT ROOM, EIFFEL AERODYNAMICAL LABORATORY



LONGITUDINAL SECTION OF THE LARGE WIND TUNNEL, EIFFEL AERODYNAMICAL LABORATORY was employed by Mr. Mattullath and myself in our wind-tunnel constructed in 1901; was disclosed to many others then; and shortly thereafter was described in public prints.

The true function of the "diffusor," or expanding exit, seems to be to prevent turbulence, and thus to promote economy of flow, rather than to increase the pressure of the stream before it reaches the fan, as taught by Eiffel. In other words, the economy of circulation can be achieved by placing the screw at a narrower part of the exit cone, if the pitch of the blades be properly adapted to the stream at that section. But Eiffel's present arrangement presents structural advantages.

The circulation in the large tunnel is maintained by a Rateau screw suction ventilator with helicoidal blades. The screw is driven by a fifty-horse electric motor, which is found sufficient to maintain a constant flow at any desired speed up to 32 meters per second, or say up to 70 miles an hour. This is a notable result, since the air stream at its swiftest section measures two meters in diameter. Though the motor takes its current from the public mains, it requires little adjustment of the rheostat to maintain steady speed for the time of an observation, though it may vary in longer periods.

The air velocity in Eiffel's tunnel seems to be satisfactory while used for engineering studies rather than for exact researches in physics. The velocity at all points of a cross-section is uniform in magnitude to within two per cent, and varies but little in direction. A fine silk thread, however, moored in the current, plays a trifle to and fro in both the horizontal and the vertical direction. The current velocity also fluctuates in time, say 1 to 2 per cent.

The velocity is determined, as in the English and other laboratories, from the pressure difference between the vacuum chamber and the large room enclosing the tunnel. This pressure difference is measured with a Shultze manometer, or inclined tube containing alcohol and provided with a graduated scale. In ordinary practice the end of the alcohol column plays several per cent above and below a mean reading, but can easily be located on the scale to within 4 per cent by a capable observer. This means that the velocity can be determined truly to within two per cent.

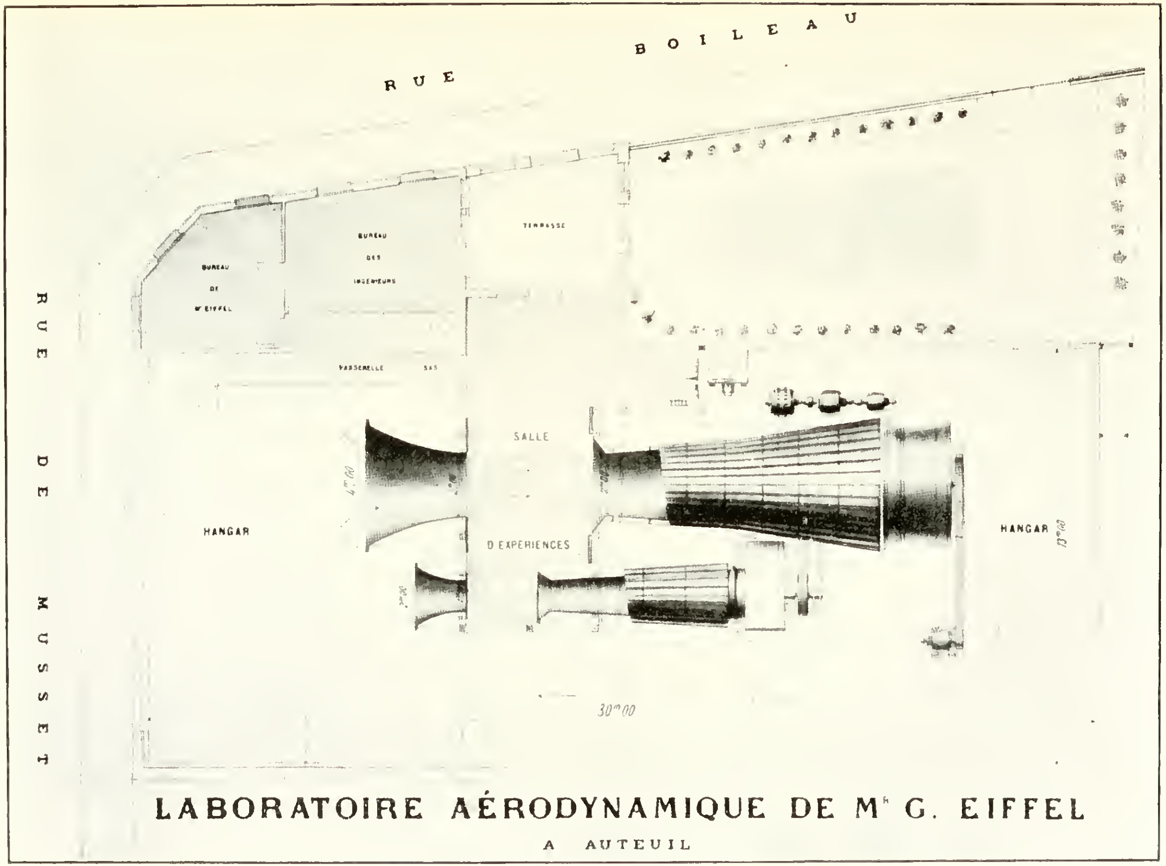
For convenience, in the determination of the wind effect on the various kinds of models, Eiffel places his measuring instruments on a platform, or bridge, spanning the vacuum room, and supported on either side by wheels resting on iron rails secured to the walls, so as to be moved aside when desired. Sometimes also the models are supported on a frame which can be wheeled along the floor. Thus apparatus can be adjusted outside the tunnel, quickly run into place, and again removed without dismantling. This is a unique advantage of Eiffel's arrangement. The main apparatus so employed are the aerodynamic balances, the propeller tester, and the instruments respectively for finding the distribution of pressure and the magnitude and line of action of the total wind force.

Of the *two balances* the simple bell-crank one for the precise measurement of smaller forces has been sufficiently explained as to principle in describing the English laboratory. The large aerodynamic balance, invented by Eiffel himself for determining the lift and drift of the whole wind force, and its line of action, is elaborate in theory, structure, and practical operation, and is well explained in Eiffel's book, "The Resistance of the Air and Aviation." It is not sensitive enough for measuring the smaller forces on inclined planes and on small models.

The propeller tester is elegantly simple in design and operation. A vertical electric motor, mounted on the bridge above the tunnel, and having its shaft extended down through a wind shield to the center of the air stream, there engages, through bevel gearing, with the horizontal shaft of the model propeller. The shafting of the armature and the propeller are encased in a sheathing which also contains the bearings, and transmits the propeller thrust and torque to the base of the motor. The motor, in turn, is so mounted on pivots and hydraulic gauges as to measure the thrust and torque without material displacement At the same time the motor speed is indicated by a tachometer attached to the upper end of the armature shaft. The wattmeter method, however, has lately replaced the direct method of measuring propeller torque.

The apparatus for measuring the distribution of air pressure over the surface of models has long been used by others, and in principle is like that employed in the English laboratory, and hitherto described in this report. The instrument for finding directly the line of the resultant air force, or "center of pressure," on a model surface is also an old contrivance, and need not be explained here. It is fully described in Eiffel's book.[1]

[1] It may be noted, however, that Eiffel's and the English method of allowing a model to rotate about a vertical axis by supporting it on a step bearing is not very delicate, even when a jewel step is used. A more accurate way is to suspend the body from a wire, or float it on a liquid. The writer, in 1901, discarded the jewel pivot and supported his models on a fine steel wire, an oil damper being provided to deaden oscillations. With a float no damper is needed.



PLAN OF WIND-TUNNELS

The Institut Aerotechnique de l'Universite de Paris is described in sufficient detail as to its material plant and operation in its prospectus, and in the following article published in the *Engineering Magazine* for October, 1911:

The area of the site occupied is about eighteen acres. The buildings comprise a central hall, surrounded on three sides by workshops, stores, laboratories, and a power house. In the central hall will be installed experimental apparatus devoted to the study of aerial phenomena, which will include a large fan, six feet six inches in diameter, and an aerodynamic balance, whereby the pressure of a jet of air on surfaces of various shapes will be determined. There will also be an air chamber supplied by another fan wherein it will be possible to measure the strength, the center of pressure, the components, and the resultant of the reaction of a current of air at any speed up to 65 feet per second. A tunnel similar to that used by Colonel Renard will also be erected for studying the stability of models. An arrangement for measuring the friction of air on surfaces of various natures when the air is moving at all velocities, an electric dynamometer for measuring the torque of propellers fixed in position, apparatus for studying helicopter screws, and a test bench for trials on the output, endurance, and fuel consumption of aeronautical motors will also be installed. A closed chamber is to be erected, wherein the resistance of helical screws at speeds far in excess of those normally arranged for, and almost at the rupturing speed, will be investigated.

In the chemical laboratory the study of light gases, suitable for balloon work, will be carried on, and questions relating to their manufacture, purification, properties, etc., will be investigated. The chemical features of various envelope materials, the changes which occur in them under the influence of heat, light, and humidity, the properties and features of the various varnishes applied to render the material airtight and to preserve it, and similar subjects will also be studied. In the physical laboratory the instruments used in aeronautical work, the accuracy of their indications, their reliability and the modifications which are called for in their design to meet aeronautical conditions, will be investigated, while the densities and coefficients of expansion of light gases, and the best means of storing and transporting them will also receive attention.

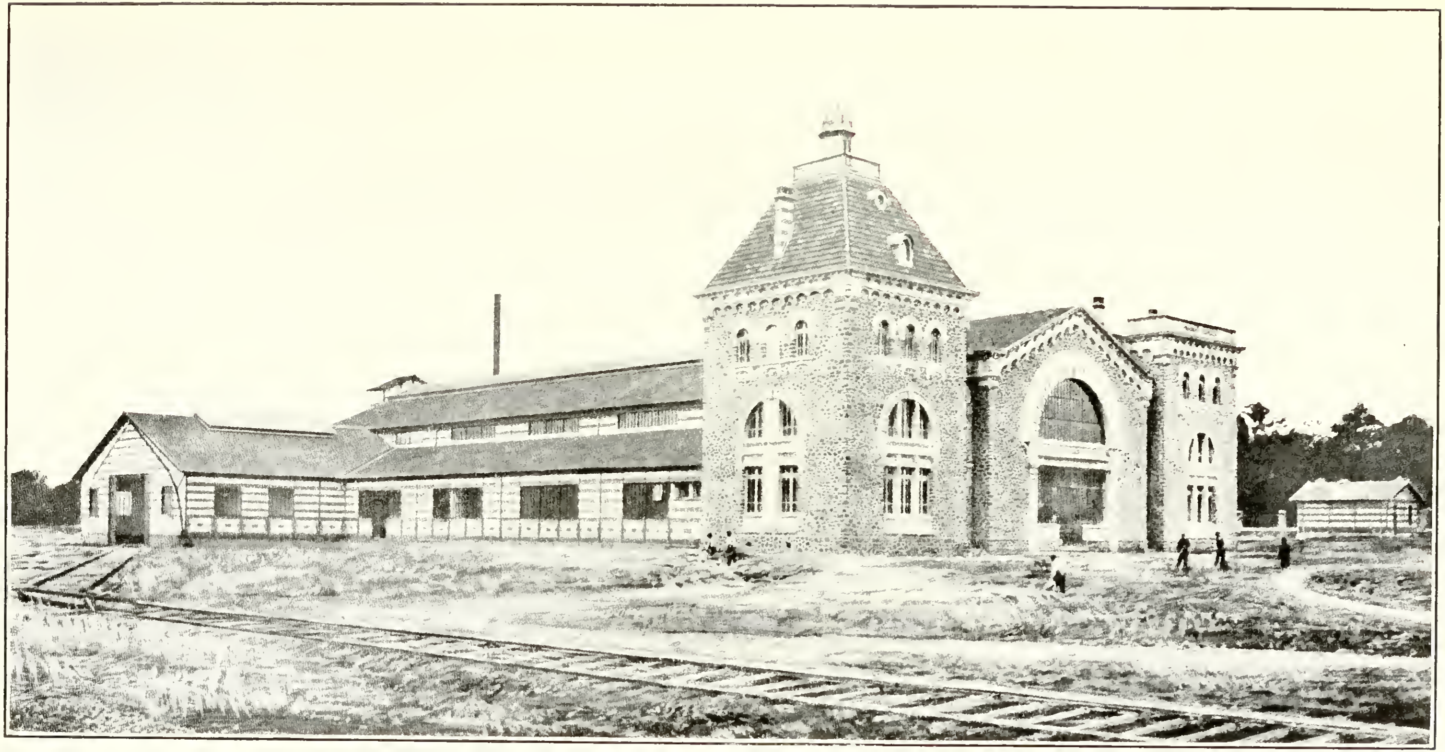
A photographer's department has been provided next to the physical laboratory. In the workshops it will be possible to manufacture and repair all the experimental appliances required by the institution. A part of one wing is reserved for the installation of machines designed specially to test the materials employed in the construction of aircraft. In the power house, situated at the west end of the building, are two vertical compound steam engines coupled directly to dynamos supplying power and light to the entire institute.

One of the most interesting features of the institute is the provision made for certain large-scale experiments with planes and propellers. To this end a long, narrow strip of ground is laid out with a normal gauge railway about seven-eighths of a mile in length. The rails are laid on oak sleepers, and are bonded in pairs by the aluminothermic process. The line is level over its entire length, with the exception of an incline at each end. At the starting point the line for a length of about 235 feet is given a slope of 1 to 100 to facilitate the starting of the vehicles. At the terminus a slope of half this amount, but extending over about 490 feet, is provided to facilitate the arrest and return of the carriage. On each side of the line and extending along its full length is laid an electrical conductor, whereby current is fed to the motor of the carriage. The return circuit is made by way of the rails. For the last 300 feet or so of the track an additional pair of rails is laid down alongside the running rails. On these additional rails, slippers carried by the vehicle bear so that over this distance, or at least a portion of it, the carriage skates instead of rolling. This facilitates stopping, and in addition furnishes a safety device in case of emergency.

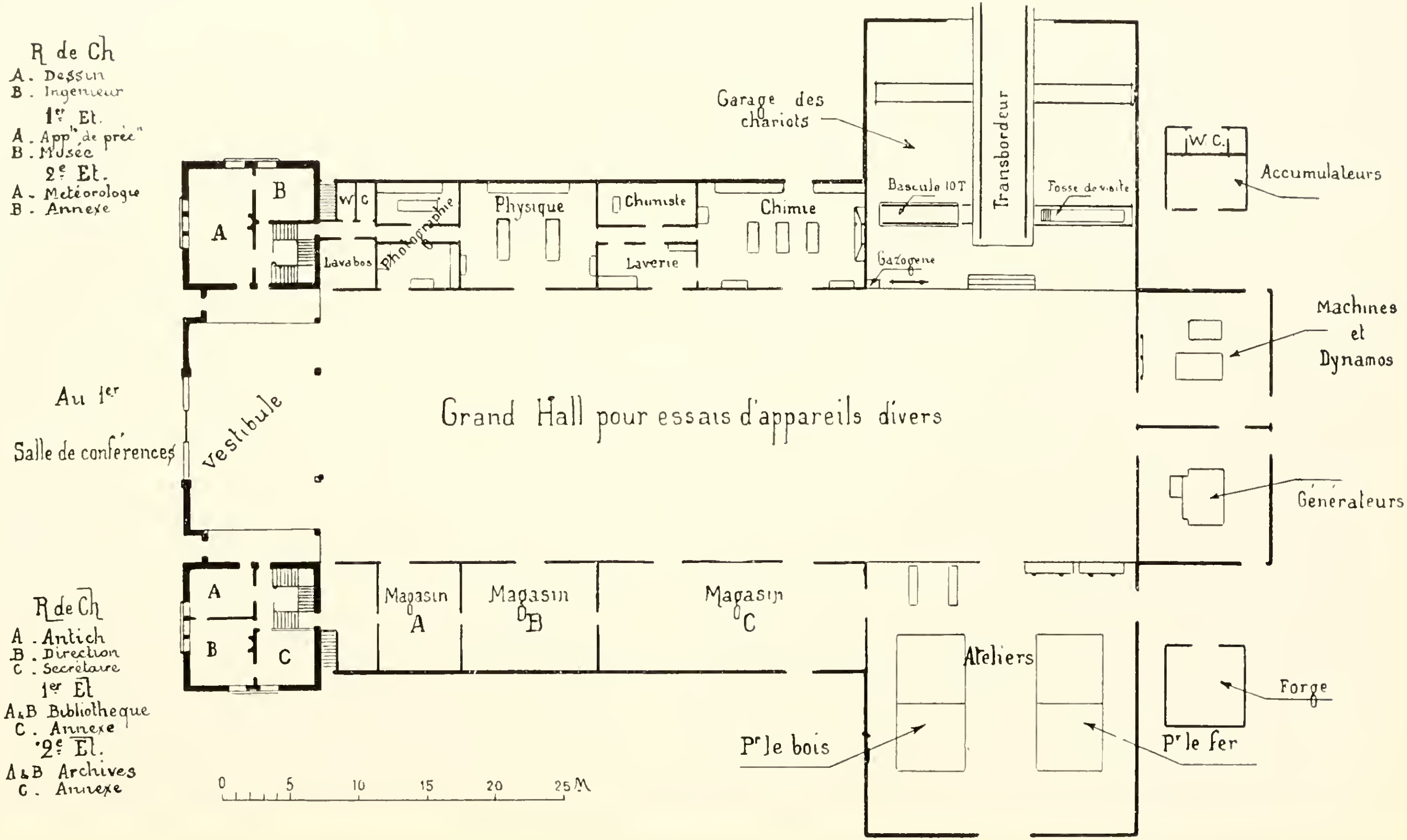
It is intended ultimately to have four electric carriages to work on the line described above. One has already been constructed, and has been used for a number of experiments. The employment of four carriages has been adopted in view of the fact that each series of experiments requires a different equipment of the carriage and different registering apparatus. If only one were used the time lost in dismantling and remounting it with each series of experiments would be very considerable. It is essential also that each vehicle should be specially designed to meet the conditions of the particular class of experiment for which it is intended. According to present intentions the first carriage will be used to measure the horizontal and vertical components and the resultant of the air pressure on surfaces of sustentation, whether plane or curved, simple or compound. The determination of the direction of the resultant, the center of pressure, its displacement when the angle of incidence is changed and the "angle of attack" will also be undertaken with this carriage. The second and third vehicles are intended for experiments on propellers or tractors, one being used for the large screws employed for dirigible balloons and the other for the smaller aeroplane screws. The tractive effort, the power absorbed and the mechanical efficiency of each type of propeller will be determined at all speeds. A further important subject of study with these two carriages will be the effect of the translational motion on the output and efficiency of the propellers. A comparison will be instituted between the efficiency, etc., of a propeller when rotating on a fixed axis and when moving with the same speed of rotation, but with various different speeds of translation. The fourth carriage will be specially equipped for measuring the resistance or "drift" of the various parts of a flying machine.

The weight of the first carriage is about three and three-fourths tons, excluding the motor, and a little less than five tons with the motor. The body of the carriage is built up of steel plates stiffened with angle irons and measures twenty feet in length and six feet six inches between the longitudinal members of the frame. Current is supplied to the motor by means of two pairs of sliding contacts carried in the side of the truck. The movement of the carriage is controlled from a lookout-post commanding the whole line.

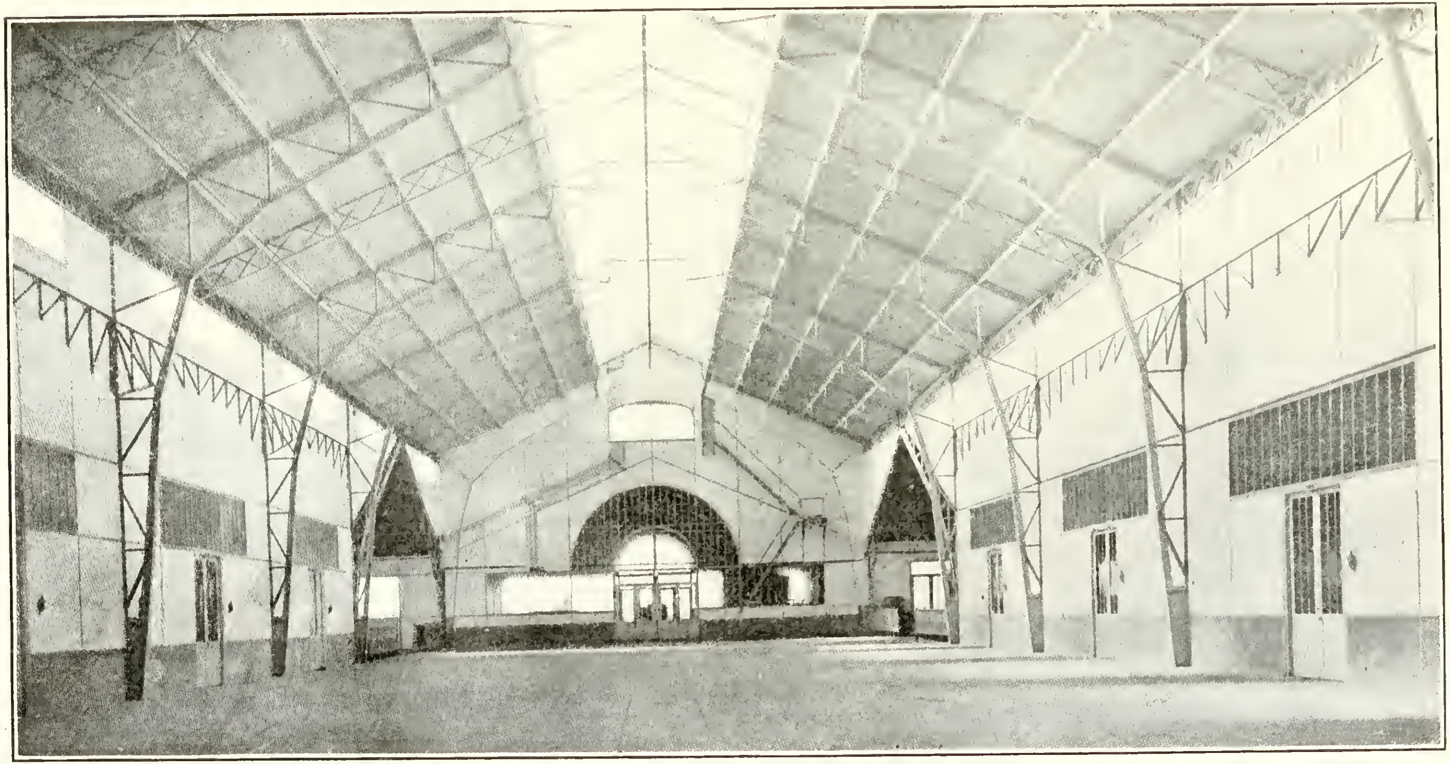
All the carriages will be furnished with appropriate measuring instruments. A chronograph will register the number of revolutions of the wheels in a given time, from which the speed will be deduced. In addition there will be a direct speed recorder registering the value of ds/dt at each instant of the travel. A recording watt meter will register the power furnished to the motor either on a time or a distance basis. One or more recording dynamometers will also be carried whereby the particular data being determined will be measured. The efficiency of the whole plant at all speeds, the frictional



THE AEROTECHNIC INSTITUTE OF SAINT-CYR



AEROTECHNIC INSTITUTE OF SAINT-CYR. GENERAL PLAN



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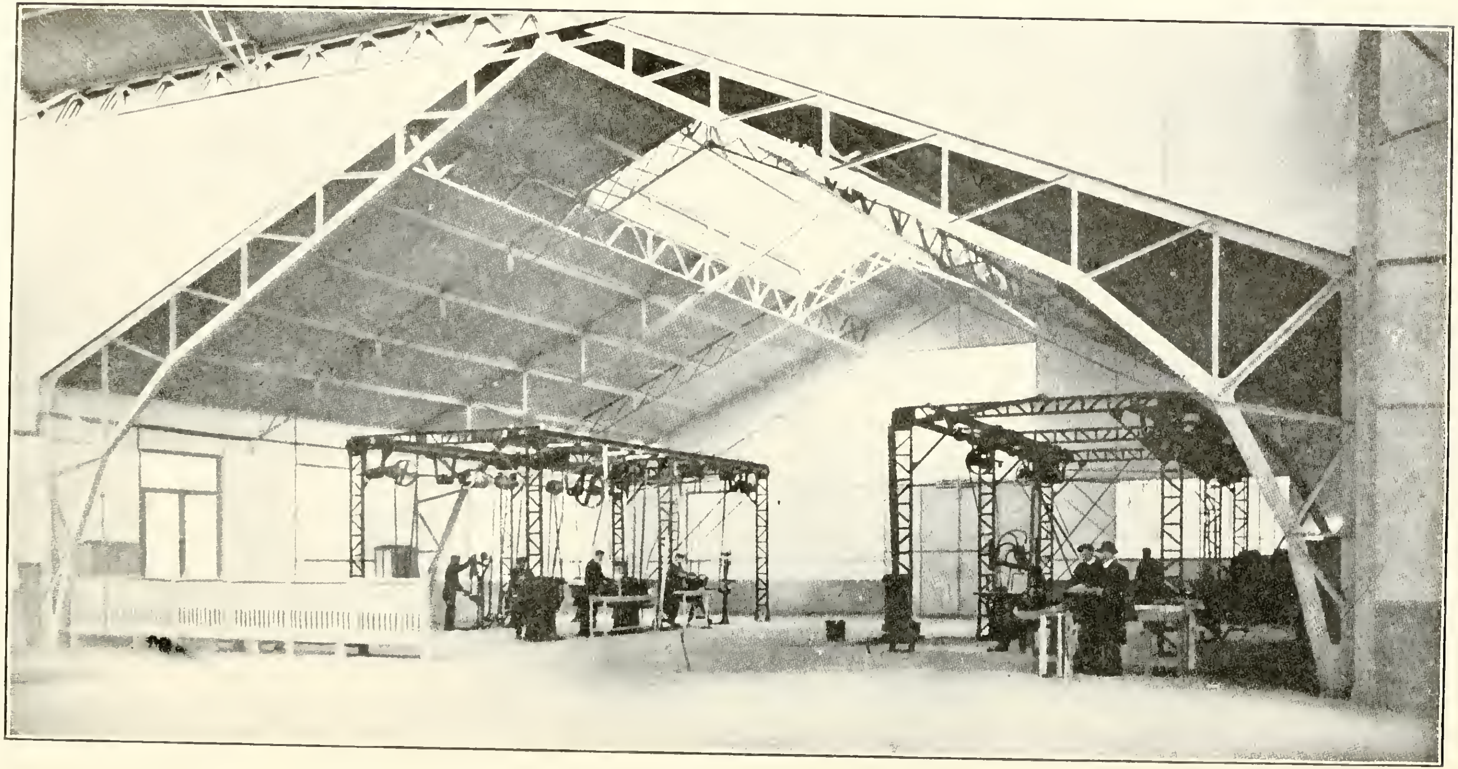

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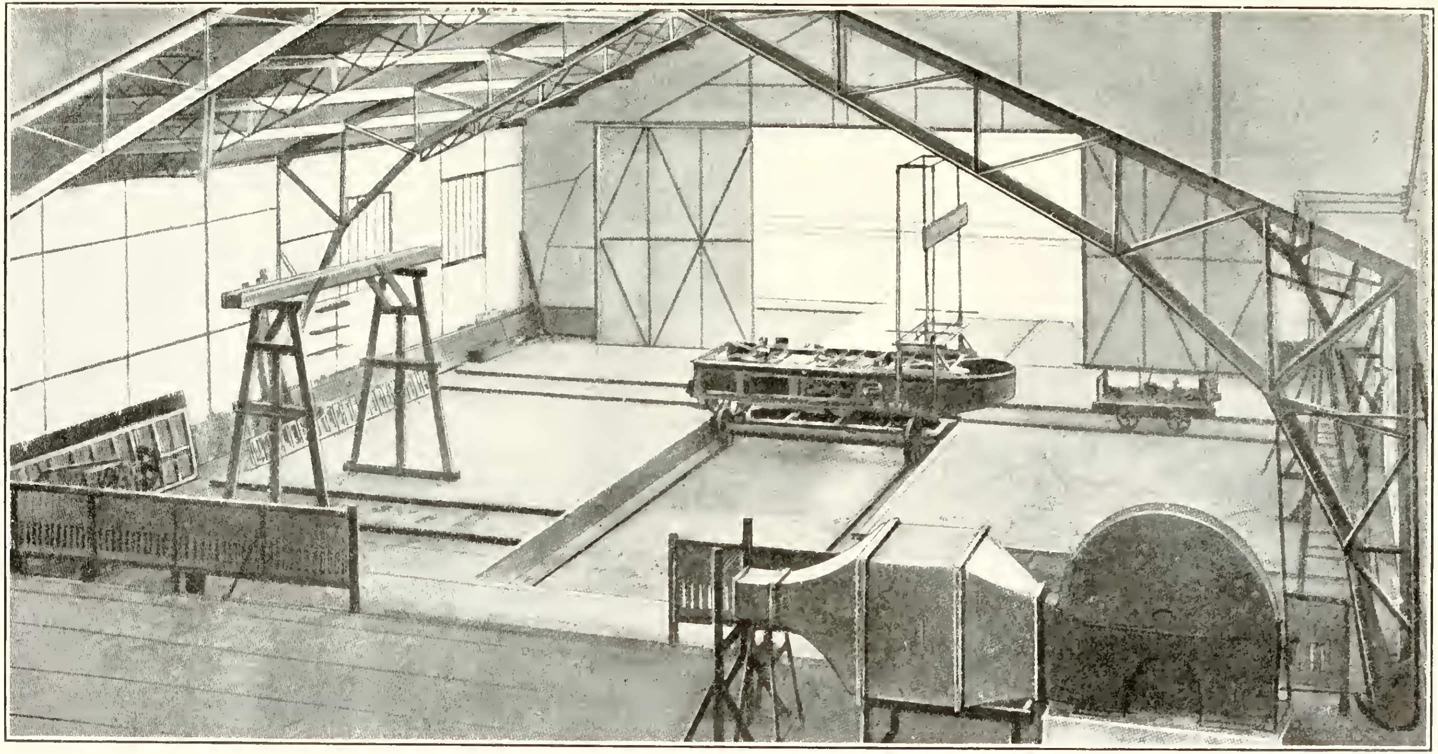

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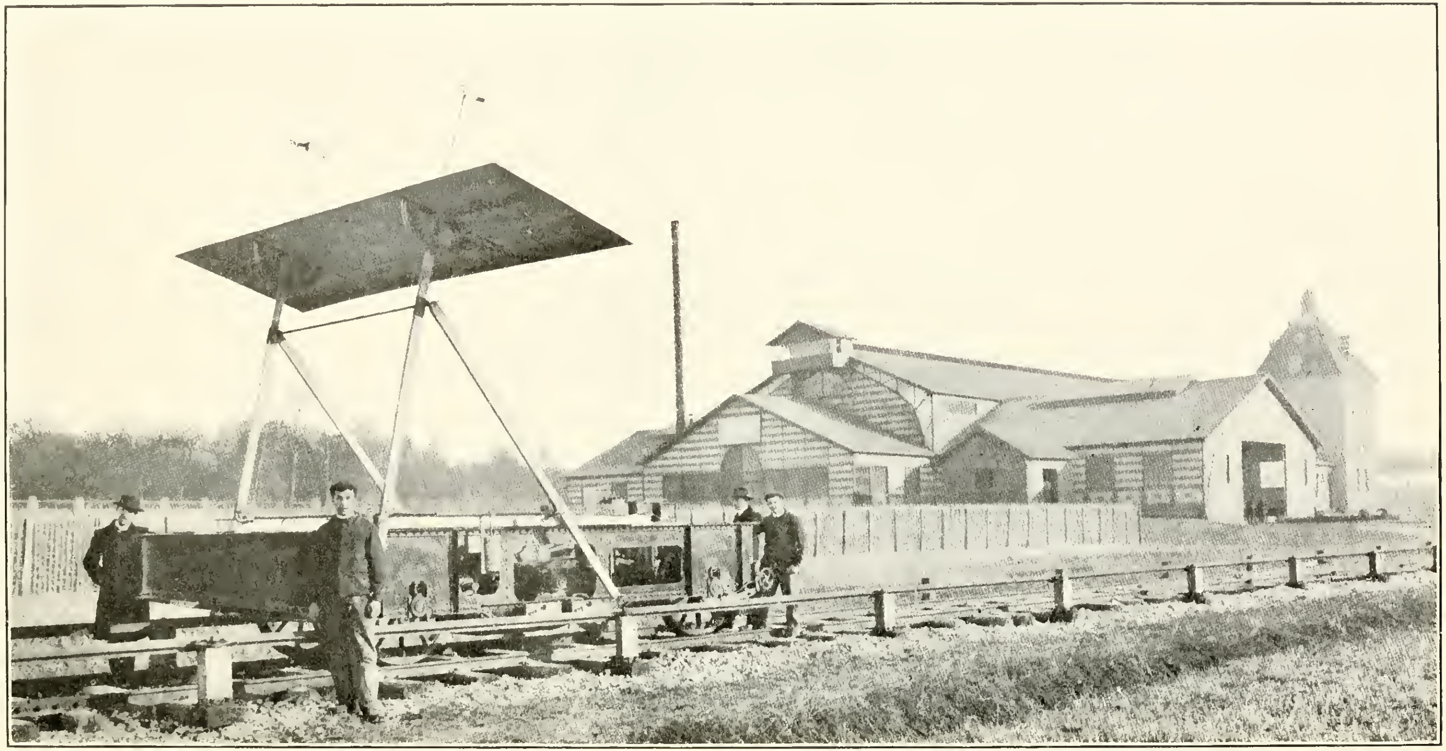


AEROTECHNIC INSTITUTE OF SAINT-CYR. VIEW OF FIRST PLATFORM EQUIPPED FOR A TRIAL resistance of the driving and recording gear, the resistance to rolling of the carriage and the air resistance of its elements, will all be determined once for all, so that the power actually absorbed by the surfaces or screws under test may be readily determinable.

Full-scale measurements.—We saw a full-scale Bleriot monoplane mounted on one of the electric carriages in such manner that its lift, drift and moment, or center of pressure, could be determined at one time, as it speeds across the field. The speed through the air is measured by means of a pressure-tube anemometer whose pressure collector is a Venturi tube, and has to be calibrated, since its readings are larger than those of a standard instrument such as used by Eiffel, Prandtl and others. The relative importance of such large scale experiments as compared with model tests, or full scale flights with instruments mounted on the aeroplane, has yet to be determined. If of new type, the full-scale machine may be tested more safely on a car. The measurements of lift here are said to be in error about 5 per cent; the drift measurements are much less accurate.

A roundhouse, which measures 120 feet in diameter, shelters a whirling table, the extremity of whose whirling arm describes a circle 300 feet in circumference, and carries the models subject to aerodynamic study. This can be used in any weather, while the electric road can be used only at special times, and most effectively only during fair and calm weather. The whirling table, however, does not seem to be so popular in the leading aerotechnical laboratories as the wind-tunnel and large field track. It is not an indispensable part of an aeronautical laboratory, except where studies in circular motion are to be made.

Ancillary buildings have been erected on the grounds near the main laboratory, one for the director immediately in charge, another for the caretaker, who is also a workman assisting in the experiments.

The reports of the investigations are published in the *Bulletin de l'Institut Aerotechnique de l'Universite de Paris.* The annual issues for 1912 and 1913 are in the Smithsonian library.

Other French aeronautical laboratories, operating on a smaller scale, are worth mentioning, though unvisited by me for want of time.

The military establishment at Chalais-Meudon, in charge of the Engineer Corps, and under direction of Commandant Dorand, resembles the English Royal Air Craft Factory, in developing experimental air craft and making full scale tests; but it does not manufacture air craft on such a large scale, and does not compete with commercial firms in building for the government, but rather stimulates and helps them to do their best work.

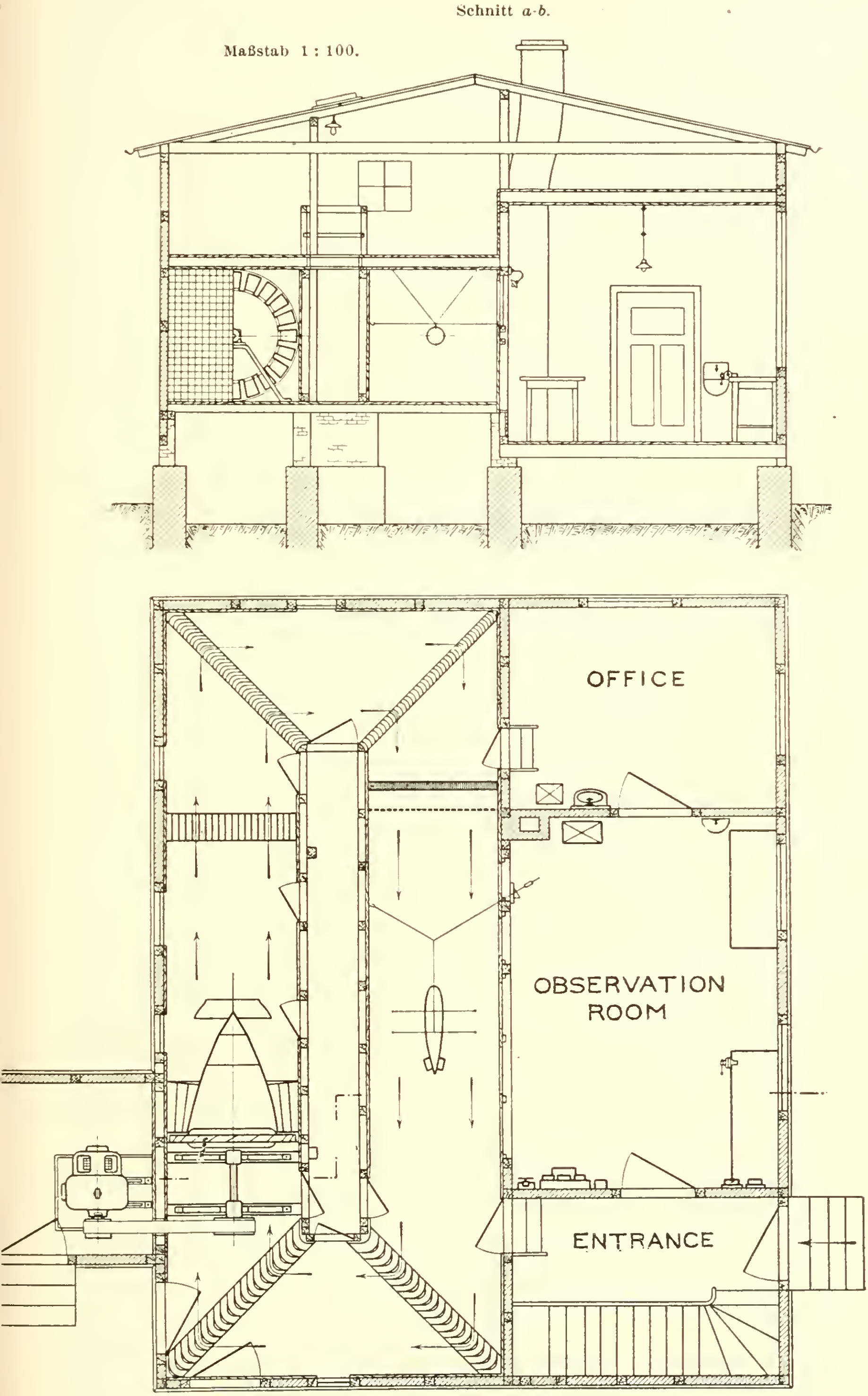
The Conservatoire National des Arts and Metiers, corresponding to our Bureau of Standards, does some aeronautical work in calibrating instruments, testing materials and motors, and furnishes a " mouline Renard "—a standardized revolving bar with paddles at either end—for attachment to a motor to determine its power at various speeds of rotation.

By the use of automobiles on a smooth road Chauviere has tested screw propellers mounted above the vehicle and advancing at natural working speed, and the Duc de Guiche has measured the lift, drift and pressure distribution on aerofoils of considerable size. The accuracy of the automobile method has, however, still to be proved satisfactory. The Chauviere propeller experiments are now made at St. Cyr Institut; but the researches of the Duc de Guiche still continue, and are reviewed from time to time in aeronautical literature. The earlier reports comprise two volumes published by Hachette, Paris.

GERMAN AERONAUTICAL LABORATORIES

The Göttingen aerodynamical laboratory, apart from the constructional and executive departments, is a one-story brick building, in size about 30 by 40 feet, comprising a wind-tunnel and two rooms, one for desk work, the other for instrumental observations. It stands alone, in a remote little meadow on the outskirts of the city, about fifteen minutes walk from Prof. Prandtl's university headquarters. It is very cheaply constructed, lighted by electricity, and heated by a little stove in one office.

The wind-tunnel consists of a continuous closed channel, two meters square in cross-section, running round the four walls of the main room. Through this tunnel the air is forced in a steady closed circulation by a screw ventilator two meters in diameter, belt driven from a thirty-horse electric motor placed in a little off room. As the blast from the blower is too fast along the tunnel walls, it is accelerated at the center of the stream by use of sheet metal fixtures placed in it near the screw, which also help to eliminate whirls. The air stream next passes through a honeycomb (fig. 1), made of 400 equal sheet metal cells, each about 4 inches square and 20 long, the sheet metal being in two thicknesses, or two ply, so that either cell can be constricted at will by spreading the cell wall inwardly. Actually, many of the cell walls were so constricted. In fact, the honeycomb looked badly distorted as if much time had been spent in adjusting the cells so that each should deliver



GOETTINGEN AERODYNAMICAL LABORATORY

the same amount of air. The adjustment once made assures, we were told, an air stream uniform in velocity at all points of a cross-section and at all speeds. One would think that a considerable change of speed would require a new adjustment of the cells to maintain uniformity. Emerging from the first honeycomb, the air passes through vertical sheet metal guide blades, each a double sheet and of turbin blade form, which turn the stream 90°, without eddies; thence through similar blades giving 90° more turn; thence through a much finer honeycomb to remove minor eddies. This last comb, placed just before the test part of the tunnel where the models are inserted, is made of sheet metal strips 10 centimeters wide reaching from floor to ceiling of the tunnel, and held in position by their

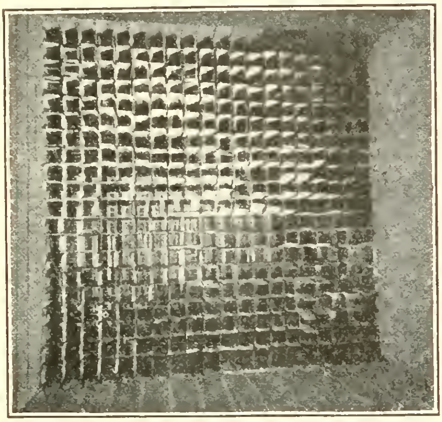


FIG. 1.—Prandtl's Honeycomb in Wind-tunnel

mutual pressure, comprising among them 90,000 cells. The stream of air issuing from the last honeycomb is said to be uniform, and has a speed ranging up to 10 meters per second.

The measuring instruments employed are numerous; but as several of them resemble the ones already described, they need not be noticed. One favorite method used by Prandtl to measure the resistance of a model, say of balloon form, is to suspend it in the current by fine wires, and hold it against stream by horizontal mooring wires whose tension is measured in the adjoining room by means of a bell crank and sliding weight. Very accurate measurements can be made without the mooring wires, if the weight and displacement of the model along stream be observed, as in my experiments of 1902. This method, as extended by Mr. Mattullath, has been adopted at Göttingen to measure the resistance of hulls, etc., held obliquely to the current. Prandtl's differential pressure gauge, consisting of inverted cups suspended from opposite arms of a balance,

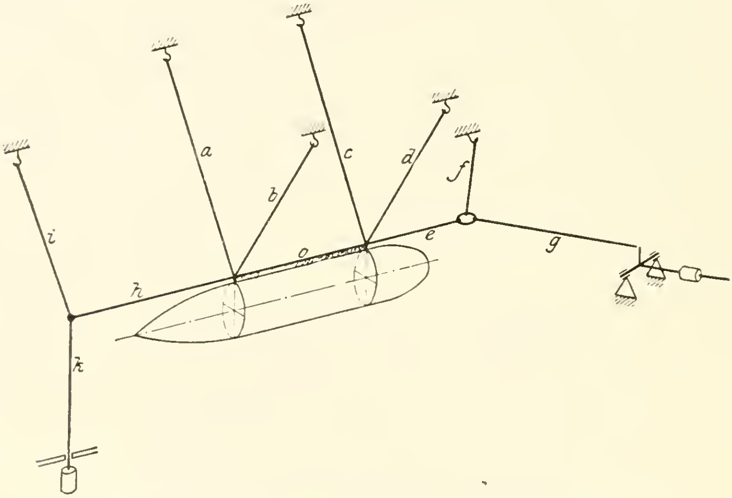


FIG. 2.—Prandtl's Suspension for Measuring Head Resistance

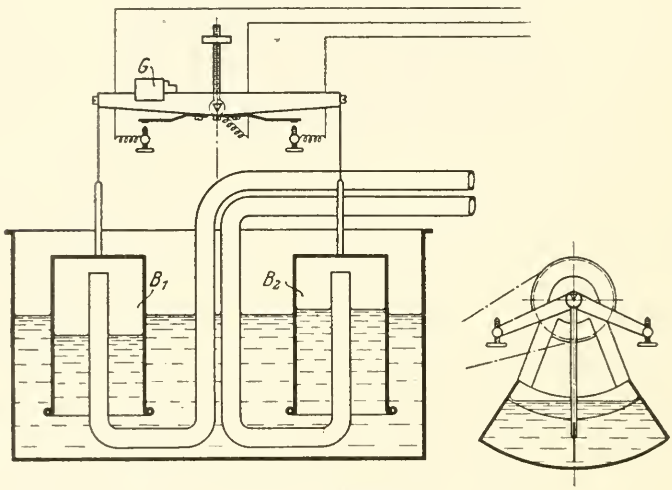


FIG. 3.—Prandtl's Manometric Balance

and dipping into a liquid, is like the one devised and used by me early in 1902, and found capable of measuring differential pressures truly to one millionth of an atmosphere, or less. This gauge was described in the *Physical Review* for December, 1903, half a decade before Prandtl's experiments.

The pressure distribution over model screw propellers having perforated hollow blades was measured by transmission through a hollow shaft to a pressure gauge. The screws were made of copper electrically deposited on wax models, and were then emptied of the wax by heating. To show the direction of air flow past the blades,

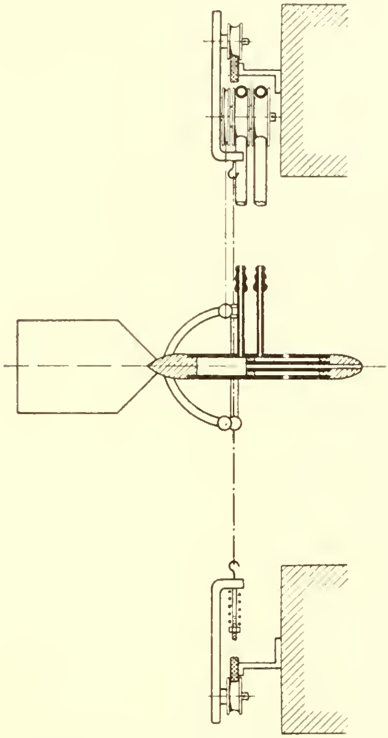


FIG. 4.—Prandtl's Pressure-tube Anemometer

sulphureted hydrogen was allowed to exude from perforations in their surfaces, and thus to stain them. The staining streaks extend fore and aft and very slightly outward radially along the screw blades.

The results of the experiments in the Göttingen laboratory have been published in various German periodicals, and in part translated and republished in *Engineering*, London, for 1911 and 1912, all of which are on file in the Smithsonian library. Particularly interesting are Prandtl's determination of pressure distribution on models of balloon hulls designed in accordance with hydrodynamic theory; also his measurements of the resultant wind force on oblique hulls and wing forms by the method devised and used by H. Mattullath in 1902; also the resistance of wires and ropes, etc. Prandtl found in fair shapes a large difference between total resistance and the pressural resistance, and ascribed the difference to skin-friction; but this he did not attempt to measure directly.

The Deutsche Versuchsanstalt für Luftfahrt zu Adlershof comprises one main building used for offices and full-scale aeroplane testing; one used for construction; and five small houses each con-

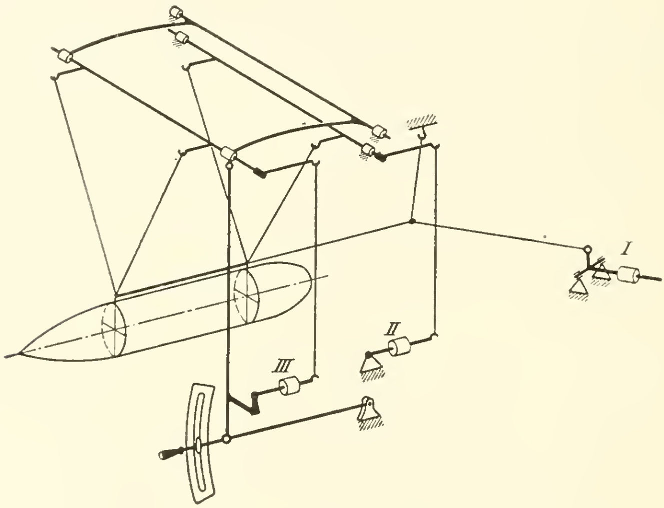


Fig. 5.—Prandtl's Suspension for Measuring Side Force

taining an engine testing apparatus. In addition to this plant, it is intended to fly full-scale machines with measuring instruments, and to mount large apparatus on an aerodynamic car pushed by a locomotive on a railway.

The laboratory of the main building is a large square room with a tower in its center 100 feet high, on top of which wind observations may be made, and inside of which suspension cords run down to support an aeroplane just above the floor, to determine its moment of inertia. In a corner of the room an aeroplane inverted and weighted with sand, as in Langley's method, was under test for stress and strain of its wing framing. In another corner was an apparatus for measuring the force applied to the controls of an aeroplane by a pilot in practical flight. This instrument may help to determine the most suitable mechanism for a standard control.

The shop and the engine testing houses contain nothing that need be reported. The engine torque and thrust were measured by ordinary mechanical methods, and no special apparatus was used to furnish a stream of cooling air, as in the British laboratory.

Other German aeronautical laboratories worth passing mention are: the testing department of the Zeppelin Airship Co.; the aerodynamical laboratory used by Prof. Reissner of the technical high school at Achen; the laboratory in charge of Major v. Parseval in the high school at Berlin; the experimental plant of Prof. Dr. Fr. Ahlborn, at Hamburg. The Zeppelin laboratory is not, under any consideration, open to visitors from abroad; and as to the others just mentioned, I had time only for a brief visit to Ahlborn's place. Ahlborn's experiments have been confined mainly to determinations of flow about models in a tank of water. The results are well portrayed in numerous excellent photographs and publications, the best of which are in the Smithsonian Institution. His apparatus and photographs and those at the National Physical Laboratory in England are, for hydromechanical studies, the most instructive that have yet come to my notice, except perhaps the more restricted ones of Hele-Shaw. For stream-line delineation in air, however, the classical apparatus and methods of Marey have not yet been surpassed, though more precise instruments of this nature are much to be desired.

CONCLUSION

In closing I would gratefully acknowledge the courteous assistance extended to Lieut. Hunsaker and myself, by the American Embassies at London, Paris and Berlin, by the aero clubs in those cities, and by the directors of the laboratories and factories we visited. We are especially indebted to Mr. G. F. Campbell Wood, foreign representative of the Aero Club of America, at Paris, and to Major G. J. F. Von Tschudi, of the German Army, Director of the Flug und Sportplatz at Johannisthal, for many kind services which enlarged our opportunities and facilitated our work in France and Germany.