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CENTRAL AEROHYDRODYNAMIC INSTITUTE OF MOSCOW, RUSSIA

By W. Margoulis

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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CENTRAL AEROHYDRODYNAMIC INSTITUTE OF MOSCOW, RUSSIA.*

By W. Margoulis.

This institute is the central establishment of the U.S.S.R. (Union of Socialist Soviet Republics) for making, in its many laboratories at Moscow, all scientific and technical researches relating to aeronautics. It comprises six sections, as follows:

- Section for Theoretical Researches;
- Section for Aerodynamic Researches;
- Windmill Section;
- Section for Engine-Propeller Groups;
- Section for Material Testing;
- Section for Instrument Making.

The president of the faculty is Professor Tchapliguine and the section chiefs are former pupils of Professor Joukowski, who, at the beginning of the war, as instructors in the aerodynamic laboratory of the Moscow Technical High School, formed, under the direction of Professor Joukowski, a "Bureau for Aeronautical Calculations and Tests." This bureau was first changed to the "Aerodynamic Section of the Institute of Ways and Communications" and subsequently became, always under the direction of Professor Joukowski, the "Central Aerohydrodynamic Institute," which since

* From "L'Aéronautique," August, 1926, pp. 263-269.

the death of its founder, bears the name of Professor Joukowski.

We will now consider the work of the first three sections, with the expectation of taking up the work of the remaining sections in a future article.

Work of the Section for Aerodynamic Researches

Before describing the present equipment of the institute, we will say a few words about the work done since 1914 in the aerodynamic laboratory of the Moscow Technical High School, which since the founding of the institute, has been directed by the Section for Aerodynamic Researches of the institute. The description of this laboratory was given in the French translation of Professor Joukowski's "Course in Aeronautics" (Paris, 1916, Gauthier-Villars, publishers).

Modifications in the prewar wind tunnels.- There were three wind tunnels: one having a circular cross section of 1 m (3.28 ft.) diameter, a wind velocity of 18.5 m (60.69 ft.) per second, 9.6 HP., and an energy factor of 0.43; one having a rectangular cross section 0.3 × 1.5 m (0.98 × 4.92 ft.), a "Sirocco" propeller, a velocity of 24.7 m (81.04 ft.) per second, 14 HP., and an energy factor of 0.4; lastly, a large wind tunnel of square cross section, running along the main room of the laboratory and originally designed for testing propellers and windmills.

The rectangular wind tunnel was used the most. In 1916, the exit cone (diffuser) was rebuilt according to a design by Professor Toupolef, and the "Sirocco" propeller was replaced by Professor Joukowski's eight-bladed propeller of the constant circulation type, which produced a wind velocity of 44 m (144.4 ft.) per second, with 23 HP.

The aerodynamic balance, described on p. 157 of "L'Aérodynamique" (1926), consisted of a frame supported by steel balls rolling on glass. It has subsequently been modified by making the frame pivot on points and supplemented by a mechanical device for controlling the angle of attack. The balance worked satisfactorily, but the determination of the components of the resultant of a wing for a dozen angles of attack demanded considerable time (up to three-quarters of an hour). It was replaced in 1919 by a device with a parallelogram, which enabled the direct measurement of the lift and drag.

At the beginning of 1921, there was tried a new balance ("à étalon") invented by Mr. Ushakoff and based on a geometric summation of the stress undergone by the wing with the lift of the air on a disk ("étalon") placed in the tunnel. The value of the angle between this lift and the resultant of the lift and of the stress on the wing gives the magnitude and direction of the stress. The time required to make the measurements was reduced to one-fourth the time necessary with the old balance. The new balance was fully described by Mr. Ushakoff in No. 5 of

"Travaux de l'Institut," with particular attention to its stability and precision. A new model, with automatic registration is now being constructed.

Very complete tests of wings of the Tchapliguine-Joukowski type, obtained by the inversion of the parabola, were made in the rectangular tunnel. The results were discussed by Miss N. Lesnikova in Nos. 3-4 (1923) of the "Bulletin de la Flotte aérienne." They demonstrated that, due to the small space between the wing and the walls of the tunnel, the lifts were not those of a wing of infinite aspect ratio, but of a wing with an aspect ratio of 7.5. This tunnel is now used only for testing struts and stay wires.

Adamtchik wind tunnel.- Most of the tests of wings and airplane models were made in a wind tunnel having a circular cross section (Fig. 1) and a diameter of 1.5 m (4.92 ft.), built in 1915, according to Adamtchik's design, to replace the above-mentioned tunnel 2.5 m (8.2 ft.) square.*

It had a 47 HP. motor, a six-bladed Joukowski propeller of 3 m (9.84 ft.) diameter, exit-cone angle of 19°, wind velocity 36 m (118 ft.) per second, energy factor 1.53.

The balance, designed by Professor A. Toupolef, now chief

* Mr. Adamtchik made, in 1912-1914, in the laboratory of the Moscow Technical High School, a series of tests with models of wind tunnels and especially on the effect of screens placed in front of the entrance cone (collector) a device which, in certain cases, increases the energy factor and straightens the air current.

of the Aeronautical Construction Section of the Institute, consisted of a steel-tubing parallelogram, one arm of which entered the experiment chamber. The measurements were made by the method of the three moments.

The propeller tests were made with a device designed by Mr. Tcheremouchine. This device consisted of an electric motor placed outside the tunnel on a vertical mount which extended into the tunnel and supported the propeller shaft. The mount could oscillate in two perpendicular directions and its balancing by weights enabled the determination of the thrust and torque. The device is similar to the one long used at the Moscow University and which was invented by Professor Joukowski.

Joukowski's large wind tunnel.- Likewise in 1915, Professor Joukowski caused the construction of a wind tunnel of reinforced concrete (Fig. 2) having a diameter of 3 m (9.84 ft.), a 350 HP. electric motor, a propeller of 6 m (19.68 ft.) diameter, an anticipated wind velocity of 50 m (164 ft.) per second, and an energy factor of 3.1. The tunnel was entirely finished, but the motor could not be built during the war and this wind tunnel, which was the largest in the world in 1915, has not yet been used.

It is particularly remarkable because Professor Joukowski applied in it new ideas on the shape of the cones, which ideas he explained in his article, "Collecteurs et Diffuseurs des Buses pour Souffleries Aérodynamiques," published in "Travaux du Bureau des Calculs et Essais aéronautiques de l'École Supérieure Technique de Moscou," No. 6, 1918).

Professor Joukowski demonstrated that, in a non-turbulent current flowing through a conduit with parallel generatrices, the velocities are constant throughout the whole diameter of any given section. It is necessary therefore to give to the entrance cone such a shape that the trajectories of the fluid will be nearly rectilinear in the section of the experiment chamber near the mouth of the entrance cone.

In his article, Professor Joukowski indicates how it is necessary to design the entrance cone for a tunnel with a rectangular or circular cross section, the entrance to which is free or in front of which a wall or screen is placed.

As regards the exit cone, Professor Joukowski indicates the shape of the cone itself, as also of the spinner on the propeller hub, which is determined by the constancy of the velocity at the entrance of the exit cone and the non-turbulent flow of the air in the exit cone.*

These wind-tunnel shapes are of double importance because, by eliminating the guide vanes, they render it possible to diminish the power required and because the suppression of the guide vanes makes it possible to obtain a non-turbulent current, a condition already assured by the shape of the tunnel.

* Professor Witoszynski, of the "Institut Polytechnique de Varsovie" (Warsaw) has published, during the last few years, similar articles on the shape of the cones in closed wind tunnels.

This is an important contribution to the theory of aerodynamic wind tunnels, which should be supplemented by the consideration of the effect of friction on the walls, because one might be led to adopt wind-tunnel shapes promoting detachment of the boundary layer and consequent loss of power.

In 1916-1917, Professor Toupolef made a series of tests on models of exit cones of various lengths. As a result of these tests, he designed a closed wind tunnel, in which the air was returned through an annular space surrounding the wind tunnel proper, similar to the plan of the wind tunnel of the National Advisory Committee for Aeronautics, just built at Langley Field (U.S.A.), for making tests in air of variable density.

New wind tunnel of the Moscow Technical School.- The 1.5 m (4.92 ft.) circular wind tunnel did not give complete satisfaction, due to the irregularity of the current. It was therefore replaced in 1924 by a wind tunnel of a new type, proposed by Mr. Juricff, Chief of the Section for Aerodynamic Researches, and built according to the calculations and drawings of Ushakoff and Bounkine. A model having one-quarter the dimensions of this wind tunnel is represented by Fig. 3.* Fig. 4 shows the full-

* This figure is taken from an article by Mr. Baulin, "Recherches experimentales sur les souffleries aérodynamiques" in "Travaux de l'Institut central aérohydrodynamique," No. 7, 1924. This work, performed in the aerodynamic laboratory of the Moscow Technical High School, dealt (aside from tests of the model of the Jurieff wind tunnel) with the cross-sectional shapes (circular, square and octagonal), the generatrices (straight and parabolic) of the exit cones, the effect of the contraction of the air stream behind the propeller, the calculation of the latter, and the energy factor of the wind tunnel.

size tunnel, as seen from the entrance-cone end.

The wind tunnel has two experiment chambers, one with a diameter of 1.5 m (4.92 ft.) and the other 2.25 m (7.38 ft.). When working in the large chamber, part 4 of the exit cone is removed and the air enters through the annular opening thus formed. With a 48 HP. electric motor, driving a four-bladed propeller with constant circulation along the radius and revolving at 960 R.P.M., there was attained, in the 1.5 m (4.92 ft.) section, a velocity of 48 m (157.5 ft.) per second, corresponding to an energy factor of 3.5, which is one of the highest, if not the highest, for any existing wind tunnel. In the 2.25 m (7.38 ft.) section, the energy factor is 0.75, likewise a very high value for a wind tunnel without an exit cone and due to a good arrangement of the return air conduits.

The experiment chamber, shown in Fig. 4, is designed to protect the experimenters from the returning air stream, the velocity of which may reach 7 m (23 ft.) per second. It is streamlined, with the propeller in the larger end, in such a way as to direct the air symmetrically with respect to the tunnel and thus obtain in the experiment chamber a good regularity in both time and space. In fact, we thus succeeded in obtaining, without guide vanes, a very regular field in both experiment chambers.

The balance, with a horizontal parallelogram suspended from the ceiling by three rods, has an electromagnetic device for varying the angle of attack of the model.

A larger wind tunnel of the same type, with an experiment chamber 3 m (9.84 ft.) in diameter, is now under construction at the institute. Fig. 5 shows the aerodynamic laboratory of the institute in process of construction.

In addition to the above-mentioned tests of Joukowski's wings, we must mention, among the experiments performed by the Section for Aerodynamic Researches:

1. Experiments on the longitudinal static stability of airplane models, for the purpose of determining practically the dimensions of the control surfaces and to supplement the work of Professor Wettchinkine on the general calculation of the control surfaces.

2. Experiments with models of exit cones for wind tunnels, the exit cone consisting of two sheets of cardboard placed between two glasses, which renders it possible to vary its shape easily.

3. Determining the distribution of wind pressures on buildings. A theory of Professor S. Tchapliguine renders it possible to determine the air flow about edifices of different shapes.

4. Mr. Korostelef invented an instrument for tracing the profiles of wings and propellers and named it "Espérographe" (Fig. 6), which enabled very rapid tracing (up to 100 profiles per minute) in a continuous manner (not by points, as ordinarily done) of profiles of widely differing shapes, including some

very similar to the ones obtained by Professor Tchapliguine, by inverting the ellipse, and for which Mr. Wesselowsky had discovered a method of tracing by points similar to that of Trefftz. The aerodynamic section proposes to make very complete systematic wind-tunnel tests of the profiles traced with this instrument.

5. Experiments with lifting-propellers of constant circulation, for the purpose of verifying Professor Joukowski's vortex theory of the propeller and determining the experimental coefficients. Prof. Jurieff has invented a very ingenious method for measuring the real angle of attack in any section of the blade. This method is based on the fact that the ratio of the pressure differences at three points of any section does not depend on the speed, but only on the angle of attack. It is only necessary therefore to measure these differences, in order to determine the angle of attack. For this purpose, openings are made in each section and the pressure differences are determined by means of tubes sunk in the propeller and of a special hub enabling the transmission of the pressures to a manometer.

Professor Jurieff's "relative" propeller theory.- Other experimental researches were made on Professor Jurieff's "relative" theory of propellers.*

* "Bulletin de la Flotte aérienne," No. 5, 1923. The writer is now publishing a complete work on aircraft propellers, the first part having already appeared in No. 11 of the "Travaux de l'Institut."

Sabinine and Jurieff first entertained the idea of determining the stresses undergone by an element of the propeller blade, by assuming that the velocity along the propeller shaft was equal to the translational velocity plus a certain velocity of aspiration, as determined by the theorem of the quantity of motion. Thus they combined, for the first time, W. Froude's theory of the element of the blade (1878) and R. E. Froude's theory of the ideal propeller (1889). Their work, dating from 1911, was recounted by Joukowski in his lecture course of 1911-1912, at the Moscow Technical High School.

It is known that Joukowski's vortex theory of the propeller, developed by Professor Wettchinkine, considers the absolute motion of the fluid with respect to the circle swept by the propeller and calculates the mean "induced" velocities by the action of an infinity of helicoidal vortices distributed over concentric cylindrical surfaces (Fig. 7), of an infinite number of vortices "bound" to the blades in the plane of rotation and by an axial vortex behind the propeller.*

In his first dissertation on the vortex theory of the propeller, published in 1912, Joukowski wrote: "The fundamental idea of bound vortices, which constitutes the basis of my work, would

* See my article, "A la mémoire du Professeur Joukowski," in "L'Aéronautique," August, 1921. In addition to the works mentioned in this article, it is necessary to note a fourth dissertation by Professor Joukowski on the vortex theory and a second dissertation by Professor Wettchinkine on the calculation of propellers, both published in the "Travaux du Bureau d'essais et des calculs de l'École Supérieure Technique de Moscou" (1918, Nos. 3-4).

render it possible to make calculations founded on the real relative velocities of the fluid, but this discussion would be too complicated."

Having found that Joukowski's theory, in certain cases, gave results slightly different from the experimental results, Professor Jurieff formulated a new propeller theory founded on the considerations of the relative motion of the fluid, with reference to the blade, and of the momentary velocities. Professor Jurieff considers the action of the helicoidal vortical surface produced by a propeller in the same way that we study the action of the vortical surface developed behind a wing (Fig. 8). He thus comes to the very important conclusion that a propeller, with a constant circulation along its radius, does not give, in front of the propeller, the constant induced axial velocities assumed by the old vortex theory, but velocities increasing toward the circumference. Fig. 9 shows the distribution of these velocities for a wing (likewise with uniform circulation) and a propeller. From these the writer draws the conclusion that we can not make a propeller with uniform circulation, since the velocities at the blade tips can not be infinite and that, in a propeller with uniform circulation, designed according to Joukowski, the circulation and the real axial induced velocity have values as shown in Fig. 10.

This brief summary will render it possible to comprehend the importance of the new theory, whose development and experimental verification are now being pursued by the Section for Aerodynamic Researches.

Work of the Windmill Section

The windmill section, directed by Mr. Krassovsky, studies the construction and functioning conditions of windmills, as also the structure and distribution of the winds.

The first work of this section was done, since 1921, at the "Institut de Physique cosmique de Koutchino" (the former "Institut Aérodynamique" of Mr. Riabouchinski). It consisted in the determination of the functioning conditions (moments and revolution speeds) of different windmills and especially of an American eighteen-bladed windmill and a six-bladed windmill made according to an article by Professor Joukowski, "Windmills of the NEJ type," in which the writer applied to windmills his vortex theory of the propeller.* These tests were made either in a natural wind on a special tower, or on models in a wind tunnel.

Following these researches, the section built, according to the patents of Mr. Sabinine, a windmill of 3.6 m (11.8 ft.) diameter with orientable blades and then another of the same type 6 m (19.68 ft.) in diameter, which was exhibited at the Moscow agricultural exposition. Fig. 11 pictures the first one of these windmills.

* Published in No. 1 of "Travaux de l'Institut de Physique cosmique de Koutchino,"

The position of the blades is controlled by tail planes and by the action of additional masses on the tail planes, in such manner as to assure a maximum motive moment when the windmill was set in motion, a high constant rotational speed, whatever the wind velocity and the moment of resistance, and a good utilization (40%) of the wind energy.* This windmill had nothing to fear from tempests, because the blades straightened out in the wind so as to offer only a slight resistance.

One investigation made by this section, at the request of the "Azneft" Company (petroleum wells of Azerbaïdjan) showed it to be possible, by means of windmills, to diminish appreciably the cost of producing petroleum. A windmill with three adjustable blades of 14 m (46 ft.) diameter and giving 50 HP., was placed in service and tested in a wind of 18 m (59 ft.) per second. Subsequently it withstood a tempest of 25 m (82 ft.) per second.

This section made a thorough investigation of the question of utilizing the energy of the wind, especially by means of hydraulic accumulators. For this purpose, tables and graphics of the wind velocities were prepared for all Russia.

Most of these investigations were recounted in Nos. 2 and 4 of the "Works" of the Central Aerohydrodynamic Institute, comprising the "Problems of the Utilization of the Energy of the Wind" by N. Krassovsky and G. Sabininc; "A New Blade for Russian

* According to Professor Joukowski's theory, the maximum value of the energy factor is 0.592.

Windmills" by N. Krassovsky; and "Instructions for Mounting Windmill Blades" by W. Utkin Egoroff.

Work of the Section for Theoretical Researches

Among the works of the Section for Theoretical Researches, the first place is occupied by those of Professor W. Wettchinkine, Chief of the Section, on the "Dynamics of Airplane Flight," the "Calculation of the Dimensions and Effects of the Control Surfaces" and the "Strength of the Materials Employed in the Construction of Airplanes."

We will note:

1. His experiments with a non-recording "accelograph," made in 1918 for measuring the stresses undergone by airplanes during acrobatic maneuvers.* Subsequently, Mr. Wesselowsky, an engineer in the section, made a recording accelograph which gave excellent results.

2. A theoretical treatise on the "Landing and Take-Off of Airplanes" and especially, on the motion of an airplane when, before landing and after having taken the angle of attack producing the maximum lift, it is flying parallel with the ground. By assuming that the aerodynamic resultant has a fixed direction in space, the writer arrived at a differential equation of the Riccati type, whose integration enabled him to establish tables

* "Travaux du Laboratoire volant," founded by the pilot, B. Rossinsky, No. 1, 1918.

giving the vertical speed at the instant of touching the ground, in terms of the horizontal speed (corresponding to the maximum lift), of the fineness, and of the altitude at which the landing maneuver began.* In connection with this work, the section studied the construction of landing gears and especially the different kinds of shock absorbers: oil and air, oil and sandows, and oil springs.

3. Researches on the looping and turning of airplanes ("Bulletin de la Flotte aérienne," Nos. 3, 4, 6, 1923).

4. Researches on the calculation of the tail surfaces and ailerons, which showed that the determination of their dimensions must be based principally on considerations of maneuverability and not of stability ("Bulletin de la Flotte aérienne," No. 5, 1923).

It is known that the elementary methods of starting with the strength of the materials does not enable the calculation of most of the airplane parts, since they fail from local deformation. Professor Wettchinkine has given special attention to the solution of questions of stability of "shape" of these parts. His last work** related to the buckling of struts of variable

* "Bulletin de la Flotte aérienne," Technical Supplement, No. 2, 1924.

** Mr. Wettchinkine has been working a long time on these problems. He has published: "Le choix des matériaux de construction pour les avions" ("Travaux du Bureau des calculs et essais, 1918, No. 7) and "Calculs de résistance des avions" (Publications of the "Institut C.A.H., 1924).

cross section. He discovered a form of strut which, for a finite value of the fineness ratio (fleche), gives equal tensions at all points of the length and which enables a saving of 13% in weight and 8% in aerodynamic resistance (drag), as compared with a similar strut of uniform cross section subjected to the same stress.

Another research was on the stability of twisted sheet metal (ventilator vanes, for example).

Mr. Wettchinkine also investigated the flexure of parts with double curves. The first part of this work was published in the "Bulletin des Ingenieurs," 1924; the second part is now in press.

Lastly, we will mention an instrument for measuring moments of inertia and for determining the effect of the mass of air, oscillating with the airplane, on its moment of inertia.*

Mr. Walther, one of the assistants in this section, made an important investigation of the forces acting on the vanes of hydraulic turbines plunged in a convergent current.** The writer demonstrates that, for the fixed vanes (guides), the forces obey a law perfectly analogous to the famous theorem of Joukowski on the lifting forces of wings. As regards the movable vanes, the writer obtains formulas, which are likewise analogous to Joukowski's, but these vanes are also subjected to other forces, whose work is zero.

* W. Wettchinkine and N. Tchentsow, "Travaux de l'Institut C.A.H.," No. 3.
** "Travaux de l'Institut C.A.H.," No. 12.

Of the dissertations on technical questions published in the "Travaux de l'Institut," we will mention: "Sur le mouvement de l'eau dans les canaux et des gaz dans les conduites" by Professor Joukowski (No. 1); "Application de la théorie des persiennes a l'hélices" by W. Alexandrof (No. 6); "Le calcul des pales d'hélices à la torsion" by L. Leibenson (No. 8); "Tempêtes de neige avec et sans chute de neige" by F. Bouchkowsky (No. 11).

The institute has published since 1923, 18 dissertations in Russian with summaries in English. It also proposes to publish in foreign languages certain particularly important works, notably the French translation of Professor Joukowski's four dissertations on his "Vortex Theory of the Propeller," and the English translations of two dissertations of Professor Tchapliguine on the "Theory of the Slotted Wing" and on the "General theory of the Monoplane Wing."

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

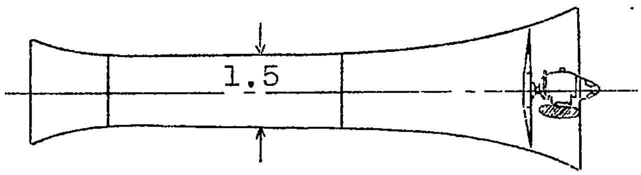

Fig.1 Adamtchik wind tunnel.

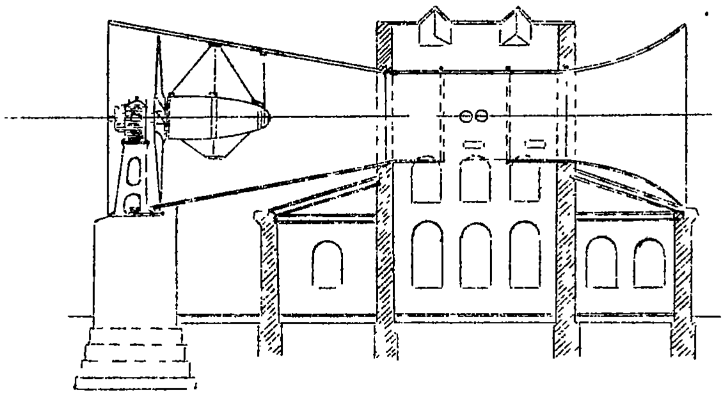

Fig.2 Joukowski wind tunnel.

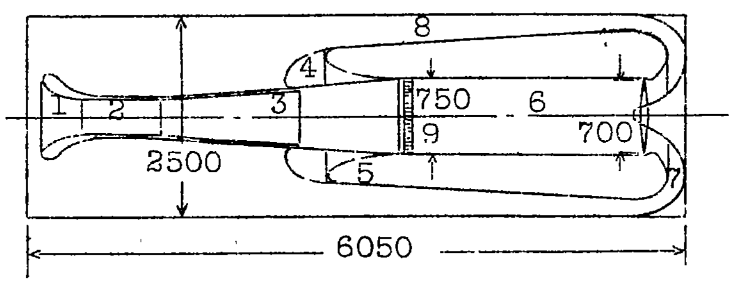

Fig.3 Model of new wind tunnel of the Moscow Technical School.

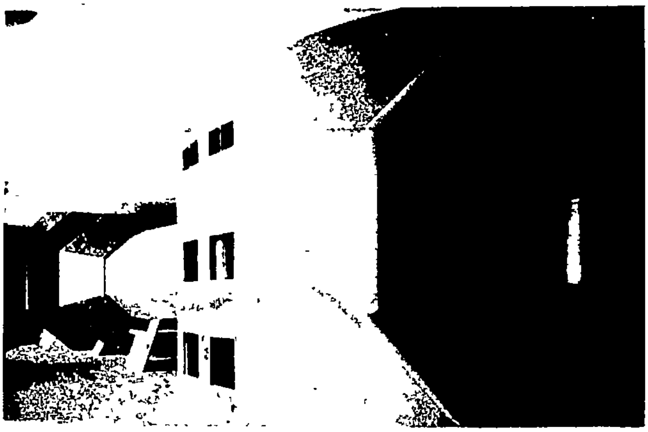

Fig.4 View from entrance-cone end of new wind tunnel of Moscow Technical School.

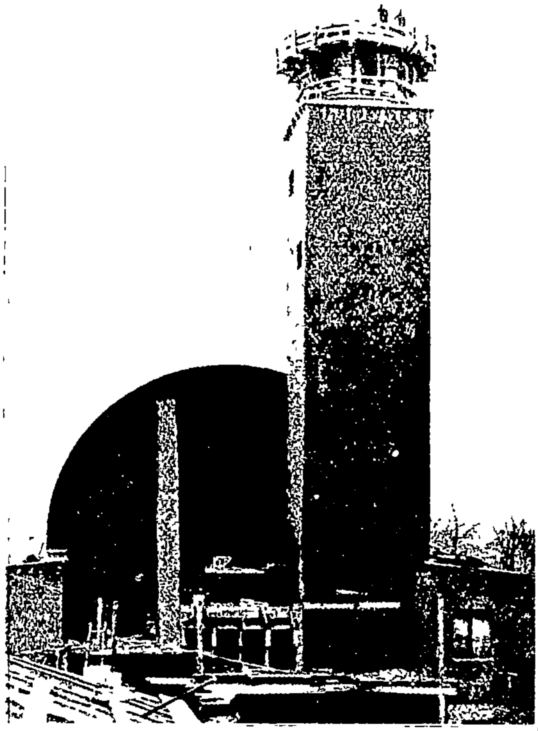

Fig.5 New aerodynamic laboratory with the tower for testing windmills.

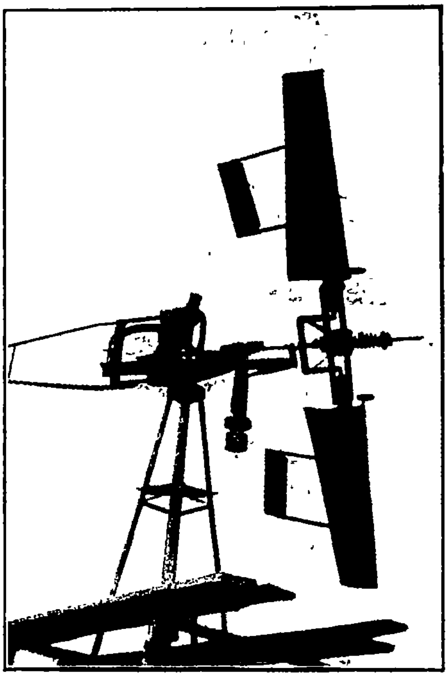

Fig.11 First Sabinine windmill.

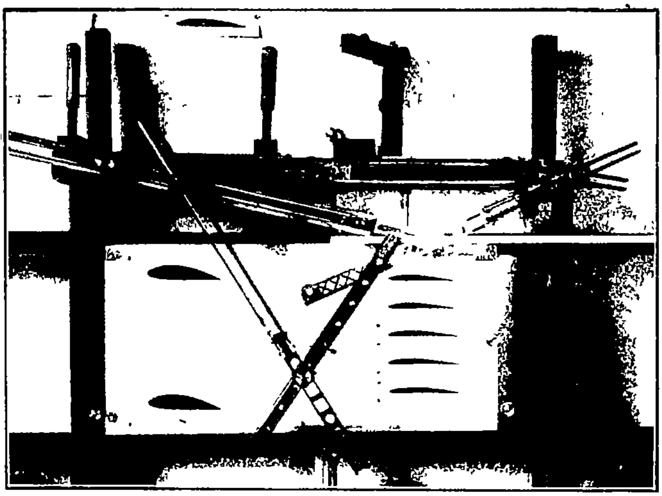

Fig.6 The Korostelef esperograph

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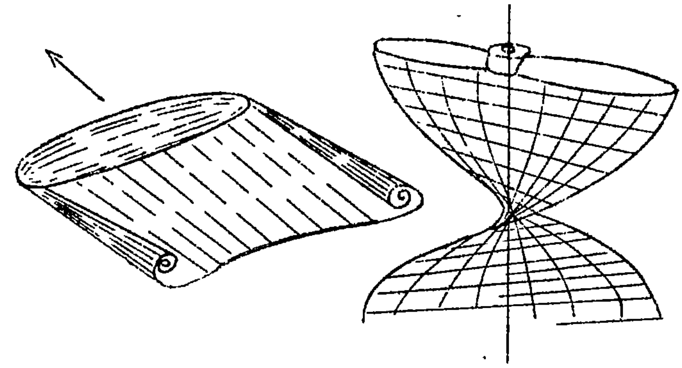

Fig.8 Vortical surface behind a wing and behind a propeller.

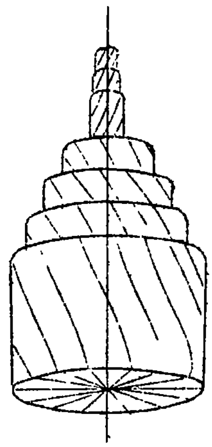

Fig.7 The helicoidal vortices of Jonkowski's vortex theory of the propeller.

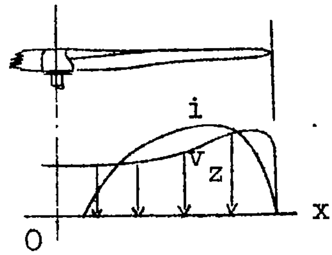

Fig.10 Circulation and axial induced velocity in a propeller with circulation uniform.

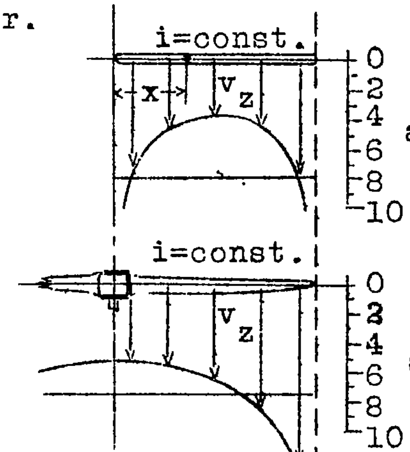

Fig.9 Values of the induced velocities according to the formula $v_z = a \frac{i}{4\pi R}$.