FOREWORD

The science of aviation is one the most exciting areas of human knowledge. Modern aviation as we know it has been made possible as a result of vast scientific research that has been carried out in different countries over the last century.

This book gives its readers the opportunity to learn about the history of the science of aviation in Russia, from the early beginnings to the present time. This history is inherently connected with the history of the Central Aerohydrodynamic Institute named after Professor N.E. Zhukovsky (TsAGI) which is presently one of the leading research centers worldwide. This book will open to the reader some previously unknown pages, which for different reasons were kept secret until recently.

The book tells the story of science through the life stories of individual people, who have contributed to its progress in different periods of time. The book also tells the story of the creation of one of the most important testing facilities in the world which is still operational and which has made great strides in aerospace research.

Since this book is based on native Russian material, the reader may find some differences not only in setting out common subjects but also in conventional characters. For example, in place of C_L widely used in Western countries C_Y is used in Russia, instead of C_D we use C_X, while "lift-to-drag ratio" is referred to in Russia as "aerodynamic quality" designated by the letter K.

This book is based on the Russian Edition* dedicated to the 90th Anniversary of TsAGI. The idea to create an English version belongs to one of us, but we enthusiastically worked together as a single team to make it happen. We would like to express our appreciation to our colleagues who previously contributed to several chapters of this book. They are: Evgeny Vozhdaev, Vladimir Sokoliansky, Anatoly Munin, Sergey Kusakin, Konstantin Kosminkov and others. Our profound gratitude goes to them for their efforts.

Now, when science in general, and the science of aviation in particular, are assuming an ever more global dimension, transcending national boundaries, the authors hope that this book will be a stimulus for expanding cooperation between TsAGI and its foreign partners, as well as establishing new contacts to which TsAGI's scientists are always open.

Hopefully you will enjoy reading this book.

Sincerely Yours,
Georgy Bushgens & Sergey Chernyshev
Moscow, 2011

---

* G.S. Bushgens, E.L. Bedrzhitsky "At the Turn of Two Centuries", "NAUKA" Publishing, Moscow 2008.

Chapter 1

ORIGINATION OF AVIATION SCIENCE IN RUSSIA

The chapter is devoted to the origins of aviation science in Russian before 1917 – the year of the revolution in the country. It deals with the main achievements of Russian scientists, the first being Professor N.E. Zhukovsky – an engineer with a world-wide reputation. Data concerning the creation of the first aerodynamic laboratories in Russia are given a brief description, including Russia's achievements in the field of aircraft engineering.

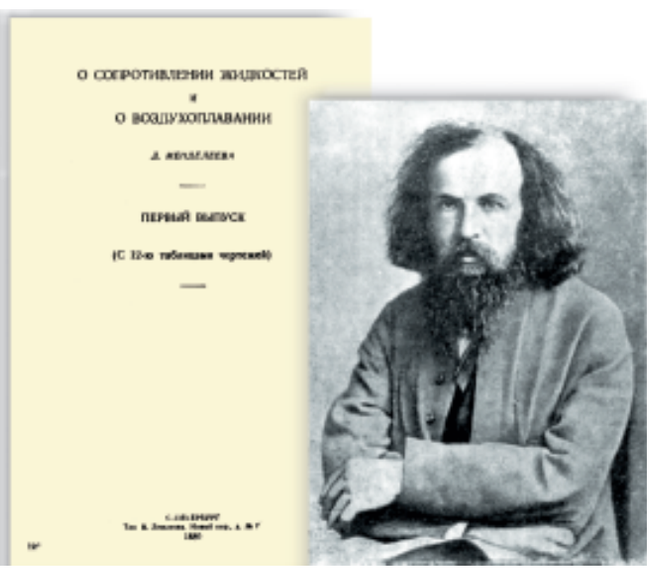
By the end of the 19th century many attempts to create a steam powered aircraft had been made. Due to the considerable weight of such an aircraft propulsion system none of those attempts were successful. The first such attempt is probably the aircraft built by A.F. Mozhaisky in Russia. His airplane was distinguished by its general layout (monoplane wings, fuselage, horizontal and vertical tail units) and presence of basic airplane elements, such as controls.

The creation of the internal combustion engine in the early 20th century immediately encouraged the development of aviation. Nowadays, most admit that the first positive results were obtained by the Wright brothers in the USA, who made the first flight on December 17, 1903, although significant success was achieved only in 1905–1908. Meanwhile, every country had its own air pioneers who achieved similar results soon after the Wright brothers. Russia also had its pioneers. They are A.S. Kudashev, I.I. Sikorsky, and Ya.M. Gakkel, who built their airplane in 1910.

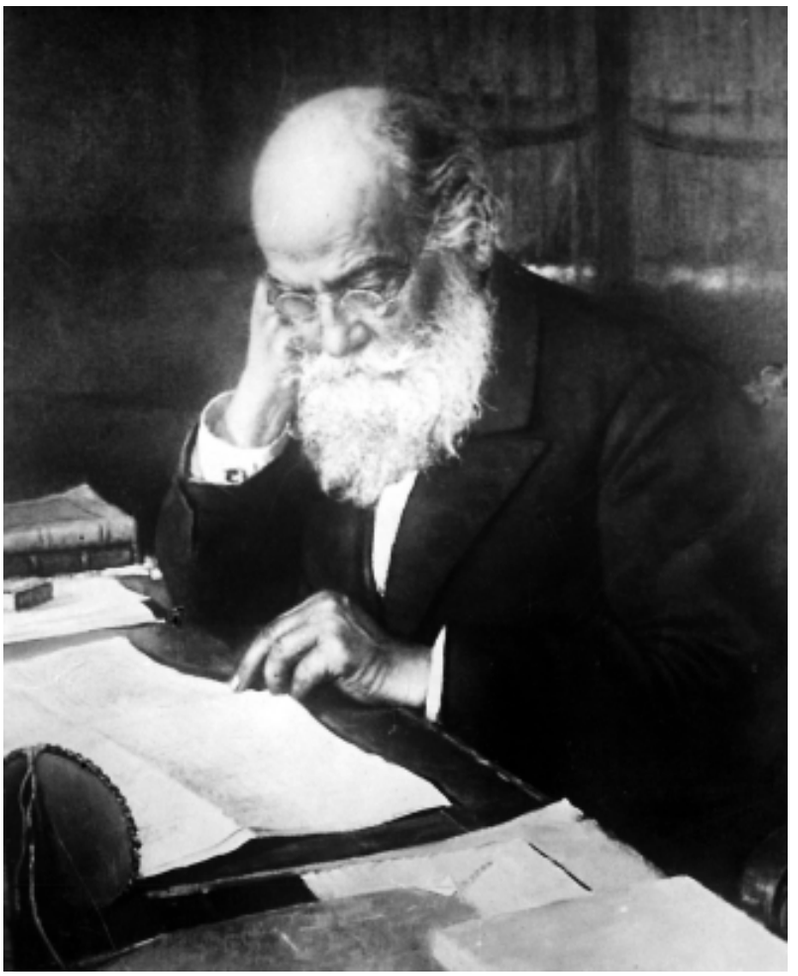
At that time all design engineers, as a rule, relied upon their own experimental data and their intuition, because there simply was no scientific basis for airplane design. In the field of aerodynamics airplane creators were interested in body drag, lift, propeller thrust, efficiency of controls and flight stability. Material strength also had its challenges, which required analytical methods, since it was clear that the weight problem was a very acute one in aviation.

One of the first scientists studying air drag was D.I. Mendeleev, the well-known creator of periodic table of elements (1834–1907). He wrote; "Beginning to study the drag I, to tell the truth, hadn't expected to find such inconsistencies in the theory and experiments, which I further revealed."

At the end of 1879 he delivered a speech at the Russian Physicochemical Society, "Fluid Resistance," and in April of 1880 he published a monograph, now a classic, "Fluid Resistance and Aeronautics." Almost 30 years later an outstanding Russian mechanical engineer N.E. Zhukovsky said the following about this study of Mendeleev: "Russian literature owes him the fundamental monograph on fluid resistance, which even nowadays may



D.I. Mendeleev and his paper "Fluid Resistance and Aeronautics," 1880



Professor N.E. Zhukovsky, the founder of TsAGI (Central Aerohydrodynamic Institute), (1847–1921)

be used as the main guide for persons involved in shipbuilding, aeronautics and ballistics." The results of extensive study made by Mendeleev reinforced his views of various types of airplane, and he stated them in the letter to the Main Engineering Command of the Military Department. Mendeleev's authority in the scientific world was so highly regarded that his position with respect to "two types of aeronautics" certainly had influence both on aircraft inventors and governmental authorities. Mendeleev encouraged experiments in the field of heavier-than-air aircraft in every way, but he thought that building a full-scale craft should not be done until a reliable theory was developed, and verified experimental data were obtained.

In the late 19th century Russian scientists began conducting active investigations.

That time the absolute scientific leader of Russia was an outstanding engineer Nikolai Egorovich Zhukovsky. Putting aside the details of his fruitful scientific, tutorial and public work, we note his main fields of interest.

The first field. N.E. Zhukovsky became one of the first engineers who went from abstract problems of theoretical mechanics to solving actual problems imposed by the development of technology. Engineers have always looked for applications of methods already developed. During the 18–19th centuries these were problems of astronomy and then problems of physics. Vigorous development of technology at the end of the 19th century raised attention and interests of engineers to real problems, which required mathematical treatment and analytical methods for designing.

In Moscow these problems were worked out by N.E. Zhukovsky on a wide range of problems. Actually, his miscellaneous activities and full-scale studies created the basis for a series of new applications of mechanics, including:

- Shipbuilding;
- Hydrology (ground water filtering and motion theory);
- Structural mechanics;
- Hydraulics (solving problems of hydraulic impact and analysis of fluid flow in pipes);
- Railway transport;
- Aerodynamics and aviation;
- Kinematics and dynamics of mechanisms;
- Artillery (ballistics, gyroscope theory); and
- Theory of elasticity.

The doctorate thesis of N.E. Zhukovsky (1882) was dedicated to actual problems of the stability of motion and was a significant step forward in the field of science. This problem in its general formulation was solved ten years later by A.M. Liapunov, an outstanding Russian mathematician, in his paper "The general problem of the stability of motion" (1892).

Thus, N.E. Zhukovsky is legitimately considered to be the father of a series of new branches of science. All his studies were based on advanced mathematics. Little wonder he was vice president and then president of the Moscow Mathematical Society.

The second field. N.E. Zhukovsky was the founder of the basic branches of aviation science, starting with the very basis of aviation – aerodynamics. Neither drag, nor lift determined by the theories of Newton, Rayleigh and Kirchhoff conformed to facts. As a consequence, the Theorem of Lift was published by Zhukovsky in 1906 in his paper "Bound Vortices" and in a subsequent paper of 1910, "Geometrical Investigations of Kutta Flow," is a fundamental result. Here we should give a brief explanation. The point is that the paper by Martin Kutta published somewhat earlier had not contained the general enunciation for the definition of lift, but using a particular example of circle arc flow with zero angle of attack it had given the definition of lift via the hypothesis of finiteness of velocity at the sharp rear edge and the hypothesis of equality of velocities at the upper and lower surfaces. He defined it for the given particular case, which was then generalized by S.A. Chaplygin, the follower of N.E. Zhukovsky, for the case when there is an angle of attack.

Introducing the quantity of velocity circulation, G, defined as an integral of velocity along a profile contour, Zhukovsky found the precise expression of lift as a product of density times flow velocity times circulation: $Y = \rho \cdot V \cdot G$. In the paper by N.E. Zhukovsky this theorem was formulated for the general case. That is why the term used in foreign literature, "The Kutta–Zhukovsky Theorem", seems to be unfair.

We should also point out the fundamental contribution of N.E. Zhukovsky to the development of the vortex theory of propellers (four articles dated

Cover Pages of Some Papers Written by N.E. Zhukovsky

1912–1918), where the full range of methods of designing aerodynamic and screw propellers and fans is given. The methods developed by Zhukovsky became classics and were accepted in international practice.

An outstanding event was the published monographic treatise by Zhukovsky, "Aeronautics Theory," in Moscow in 1912 and in Paris (in French) in 1916. The book became the first summary of both theory and experimental results on aerodynamics of wings, bodies of revolution and an airplane as a whole. The second part of it contained critical descriptions of airplanes that had been built by that time. The book was sent by Zhukovsky to such famous scientists as Ludwig Prandtl, Alexandre Gustave Eiffel, Stefan Drzewiecki, etc.

Thus, Zhukovsky together with Prandtl laid the foundation of wing and propeller theory.

In the article "Bird Hovering" (1892) and in two articles "Elementary Airplane Dynamics" a foundation of aerodynamic analysis of the airplane, wing theory and airplane flight dynamics was laid.

Moreover, Zhukovsky created the basis for the development of the theory of bombing, structural mechanics of airplanes, design of a series of instruments (for measurement of velocity, navigation, autopilots, etc.).

Vigorous public activity of Zhukovsky in the field of development of aviation sciences, his participation in various conventions and conferences on aeronautics in Russia and abroad, contacts with designers of different air tools in Russia and in other countries had certainly contributed to the development of aviation in Russia.

The third field. Following his methods of perception of nature and technical processes, Zhukovsky used experience and experimental studies of phenomena naturally or with the use of models as the basis of his work. Analyzing results

Aerodynamic tunnel built in MSU (Moscow State University) at the initiative of N.E. Zhukovsky

he created a theory or analytical method which was then verified by experience. Theory and experience in his investigations were inextricably connected. In order to realize such an approach he created the first aerodynamic tunnels and various mechanical models intended for studying new phenomena. Thus, the first aerodynamic tunnel in Russia was built by Zhukovsky at Moscow State University (MSU) in 1902.

In 1904, at Zhukovsky's suggestion, the world's first Aerodynamics Institute was founded in Kuchino, which was equipped with a series of instruments intended for experimental studies of wing, propeller and airplane models.

In 1910 at the Moscow Higher Technical School (MVTU) Zhukovsky arranged (partly at his own expense) an aerodynamic laboratory, where he involved a large group of students in his investigations who subsequently became his staff: V.P. Vetchinkin, A.N. Tupolev, K.A. Ushakov, B.N. Yuriev, G.M. Musiniants, etc. These enthusiasts subsequently became famous scientists and engineers who designed and manufactured instruments and equipment.

Finally, in 1918, Zhukovsky with the help of A.N. Tupolev and other team members founded the Central Aerohydrodynamic Institute (TsAGI), which is now named after him.

The fourth field. The rapid development of aviation, especially during World War I, required trained human resources for the army, as well as for airplane design and building. Zhukovsky understood it at once and organized training courses at MVTU and then, after the revolution of 1917, he established a technical college, which soon was reorganized into the Air Force Engineering Academy. It is also named after him. The academy became the base for the training of highly qualified personnel for aviation. Until this problem was resolved Russian aviation could not continue developing.

At his Chair in MVTU and in MSU Zhukovsky trained upper-class engineers. His popularity in these institutions was huge. As was referred to by eyewitnesses, MSU students often hesitated in their choice between the course of mechanics conducted by Zhukovsky and the course of mathematics conducted by B.K. Mlodzeevsky, another enthusiast

Academician S.A. Chaplygin

of science, and they often chose Zhukovsky. But even in the case when they chose mathematics, Zhukovsky's influence infested them with "mechanics bacillus" and engineering sciences lugged them away. As a result, due to Zhukovsky's activities and then due to activities of his student, fellow worker and follower, S.A. Chaplygin, in MSU, MVTU and then at TsAGI a top-rank team of engineers, whose names are well-known, was created, and its traditions have been passed from generation to generation.

Further development of wing theory in the period from 1910 to 1921 is basically related to the names of Prandtl, Munk, Betz, etc.; it was initially little-known due to war time, making information exchange difficult.

Ludwig Prandtl is an outstanding German scientist, mechanical engineer and aerodynamicist. His basic works relate to aerohydrodynamics, particularly to wing and propeller theory, theory of turbulence and meteorology. In 1904 one of the classic works by Prandtl, "Fluid Flow in Very Little Friction," was published. In this paper for the first time he introduced differential equations describing fluid flow in laminar boundary layer (the Prandtl

equations) that set the stage for modern boundary-layer theory. In 1914 he began his investigations of turbulent boundary layer. Prandtl considerably contributed to the finite-wing theory and gave answers to many practical issues of wing calculation.

It should be noted that papers by Lanchester (England) and his published book "Aerodynamics" contained many general ideas of vortex theory of the wing, explanation trailing vortices formation and significance of circulation itself (1907).

In the early 20th century in Russia there were two main centers of aviation science development: one in Moscow and one in Saint-Petersburg. The leader and organizer of the basic investigations in Russia was the professor of the Imperial Moscow Technical School (ITU or MTU) and MSU, famous mechanical engineer, N.E. Zhukovsky. He was the center of several societies composed of aviation enthusiasts; he headed all-Russian conventions on aeronautics; and, he oversaw the building of special installations and experimental studies. N.E. Zhukovsky gave all his creative powers to various aspects of aviation science.

In 1909 N.E. Zhukovsky began a course of lectures on aeronautics, and that was the first course introduced into the program of the Russian technical school at ITU. In October similar courses were held at the Petersburg State University of Means of Communication, Petersburg, Kiev and Donskoy (Novocherkassk) Technological Universities. Soon after reading these lectures student societies on aeronautics began emerging in these and other institutions. On September 28, 1909, the constitution of such a society at ITU was approved. N.E. Zhukovsky was elected as honorary chairman of the society, and among its members are A.N. Tupolev, B.N. Yuriev, V.P. Vetchinkin, V.A. Slesarev, G.Kh. Sabinin, G.M. Musiniants, K.A. Ushakov, V.L. Alexandrov, A.A. Arkhangelsky, B.S. Stechkin, etc.

The members of the society built a glider and an airplane, designed aerodynamic tunnels, organized aeronautics exhibitions, built a helicopter and delivered reports at conventions on aeronautics. In July 1916, they were admitted to Aviation Design Testing Bureau created at MTU. Simultaneously, a circle society "Aerosection" named after L.M. Matsievich was created at Kharkiv Polytechnical Institute (KhPI). His chairman and research supervisor was G.F. Proskura, a KhPI professor, student of N.E. Zhukovsky, who made a considerable contribution to the development of aviation in Ukraine. Proskura was the founder of the Aeronautics Chair in KhPI.

In 1909 the First All-Russian Convention on Aeronautics was held in Saint-Petersburg. This convention gathered over 400 representatives of 21 organizations, i.e. almost all aeronautics organizations in Russia. The chairman of the convention was N.E. Zhukovsky and his co-partner (i. e., vice-chairman) was V.F. Naidionov. The convention covered five subjects: heavier-than-air aircraft, aerostatic balloons, engines and propellers, aeronautics application in various fields of technology and general issues (management, organizational and legal issues). The total number of reports of this convention was 32, and 12 of them were delivered by the Moscow school headed by N.E. Zhukovsky (he himself delivered 4 reports) and S.A. Chaplygin. These reports showed a high level of Russian scientists' knowledge in the field of originating aviation. The main goal of the convention was to unite all the disjointed forces engaged in aeronautics issues into an integrated All-Russian Aeronautical Union. At the final general meeting of the convention the Union Statute was adopted. However this Union turned out to be "dead on arrival:" the All-Russian Imperial Flying Club (IVAK) did not want to loose its privileges as the head organization and provincial clubs did not want to loose their independence.

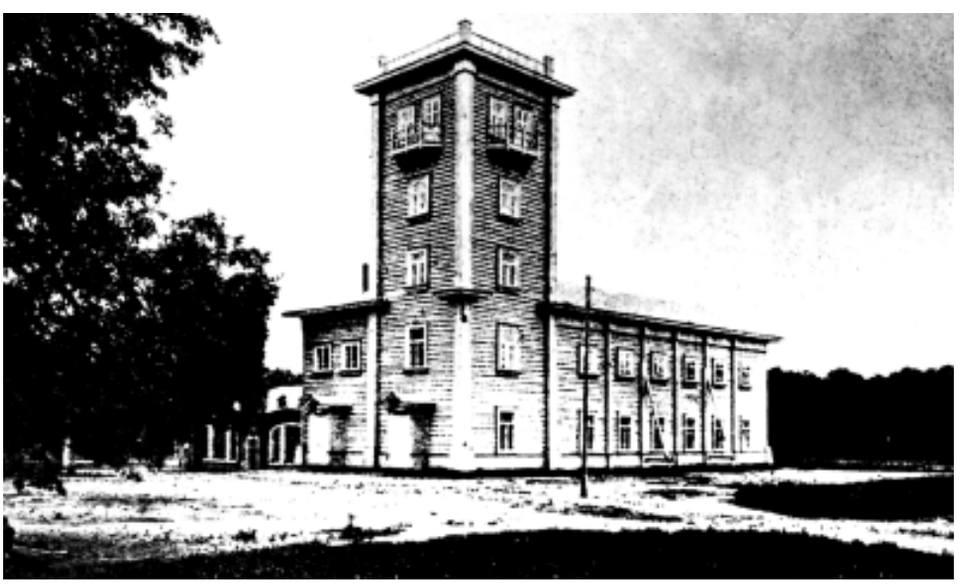
At the general meeting of participants of the First All-Russian Convention on Aeronautics N.E. Zhukovsky suggested a resolution on unionization of all Russian technicians in order to develop an efficient type of Russian airplane. His suggestion was accepted "to long-lasting applause."

However, after the Council of Ministers under the chairmanship of P.A. Stolypin had contemplated the problem of "Measures to Be Taken to Develop Aeronautics in Russia" it concluded that "*organization of large production institutions along with*

theoretical courses and expansive experiments on aeronautics would have been untimely... Realization of very similar suggestions on setting up of an aerodynamical institution at Donskoy Technological University received from the Department of Trade and Industry and on organization of the Institute of Aeronautical Science received from the Ministry of Public Enlightenment should be considered yet unpractical." On February 5, 1910, this decision of the Council of Ministers was approved by the Tsar, signed by P.A. Stolypin and, thus, became the guide for action for government institutions when they dealt with nascent aviation in Russia. Denial of government support in aircraft experimental design and the creation of scientific and experimental capability (aerodynamic institute) for a scientific approach to the development of aircraft had a negative impact on the progress of aeronautics in Russia, delayed the creation of real airframes by pioneer inventors and the development of a theoretical basis for aviation. The idea of an aerodynamic institute, the necessity of which was clearly realized by the progressive scientific community, was embodied in Russia only a decade later, when the Central Aerodynamic Institute was founded. It happened only after the revolution of 1917.

Professor D. P. Riabushinsky
(1882–1962)

Earlier, in 1904, due to financial participation of Dimitri Pavlovich Riabushinsky, a student of Zhukovsky at MSU and one of the members of the family of a well-known Russian businessman, professor Zhukovsky took part in the organization of an aerodynamics institute in Kuchino, Moscow region. The institute was founded, and during the period from 1904 to 1906 N.E. Zhukovsky performed

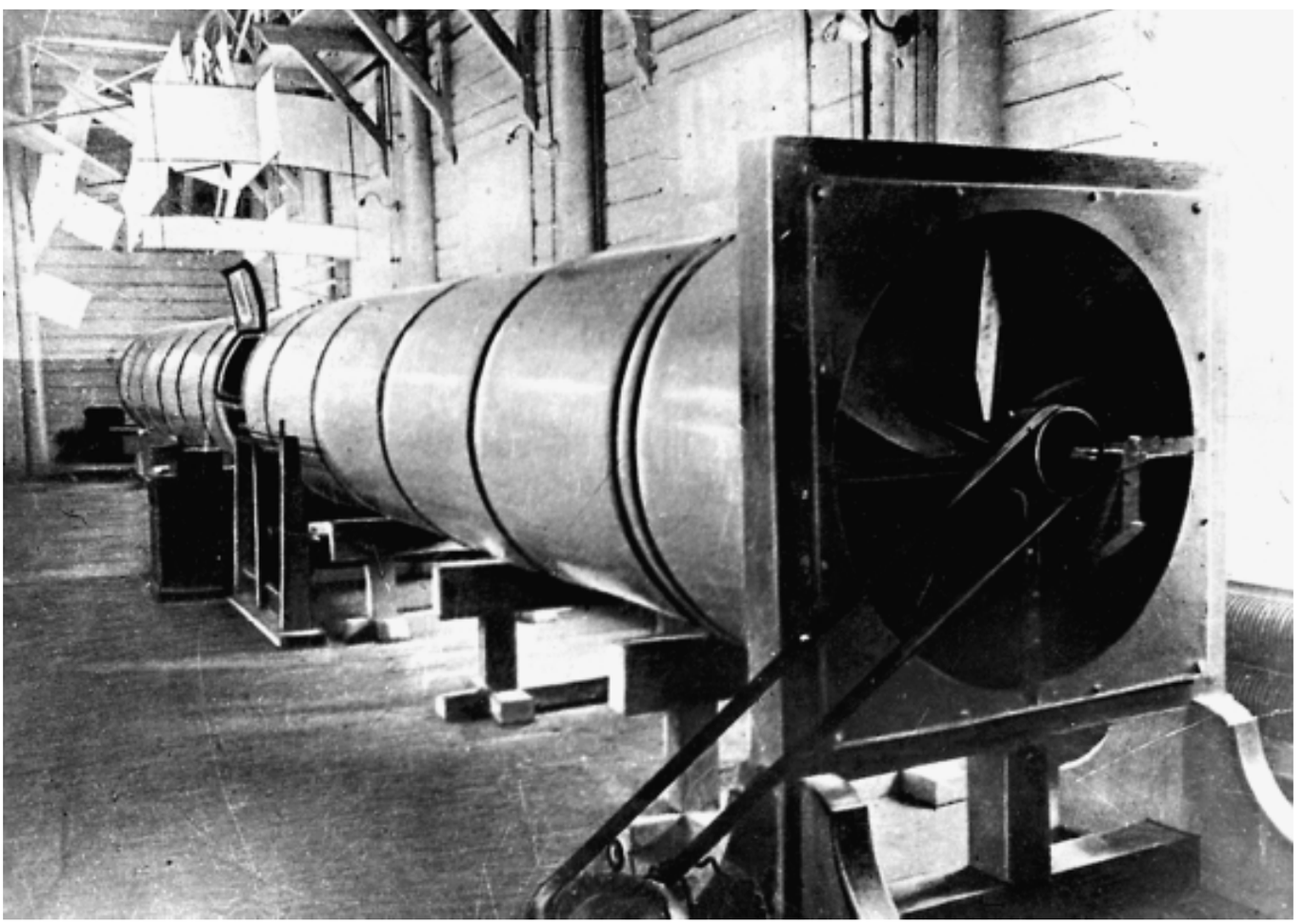


Aerodynamic Institute in Kuchino

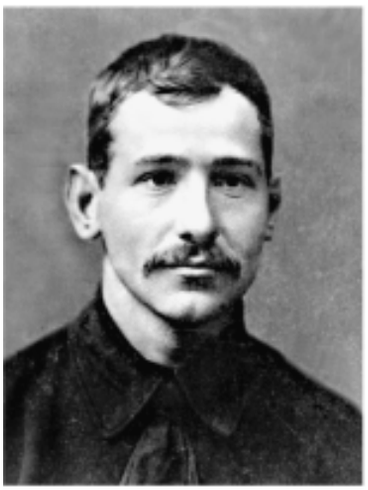
its scientific management. The head of the institute was its owner, D.P. Riabushinsky. The institute created various experimental installations intended for investigation in aerodynamics. Further, Riabushinsky apparently decided to completely take on management of the institute and Zhukovsky retired from these activities.

At that time Riabushinsky had no specific education and only in 1912 did he graduate from the Department of Physics and Mathematics of MSU and was left Zhukovsky's Chair. After the revolution of 1917 Riabushinsky at his own initiative conveyed the institute in Kuchino to the government. In order to determine the future of the institute, in June 1918 a committee including N.E. Zhukovsky, S.A. Chaplygin, P.P. Lazarev and others was founded. This committee acknowledged that the institute in Kuchino is applicable for aerodynamic, aerological, geophysical and physical investigations, provided that it would be further developed. Soon after the institute was conveyed, D.P. Riabushinsky moved abroad where he lived until the end of his life (he died in Paris in 1962). Working in the field of aerodynamics in France he always made efforts to promote Russian science. The Aerodynamics Institute in Kuchino existed until 1921, when it was conveyed to geophysicists.

It should be noted that in the period of initial development of aviation scientific organizations, working in the field of aeronautics began emerging in some countries. The institute in Kuchino was apparently the first one; the Eiffel laboratory was founded in 1908 in France; in England in 1909 an advisory committee for aeronautics was organized;

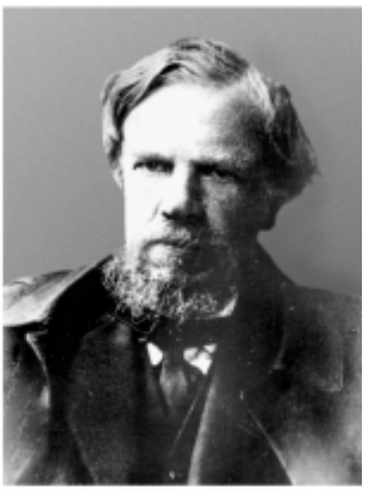


Laboratory of the Aerodynamics Institute in Kuchino



A.N. Tupolev

N.E. Zhukovsky



S.A. Chaplygin

V.P. Vetchikin

A.A. Arkhangelsky

G.M. Musiniants

K.A. Ushakov

N.V. Krasovsky

B.S. Stechkin

B.N. Yuriev

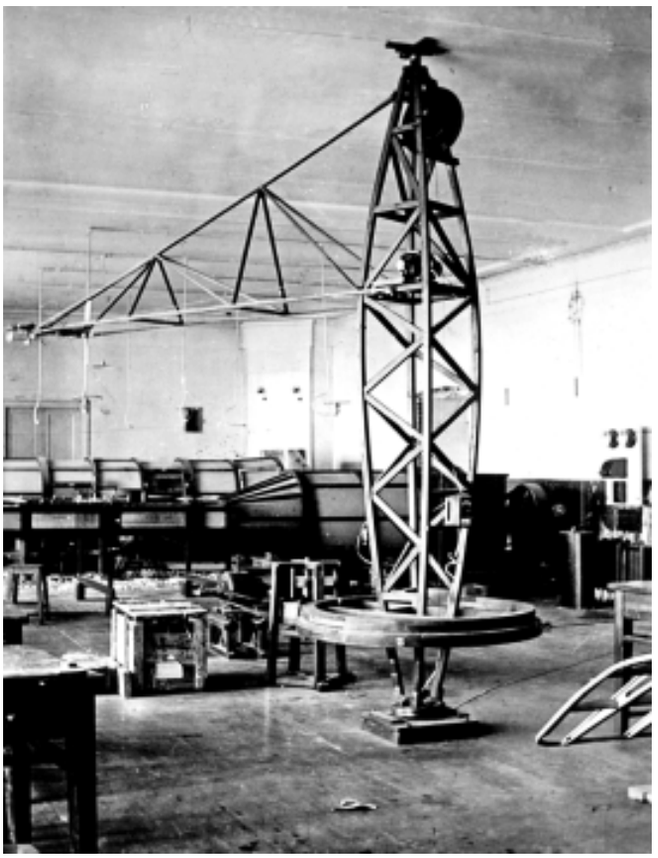
G.Kh. Sabinin

I.I. Sidorin

I.I. Vorogushin

A.M. Cheremukhin

N.E. Zhukovsky and his closest students



Aerodynamic Laboratory
of the Imperial Moscow Technical School

investigations were also held in the National Physics Laboratory (NPL), and the Royal Aerospace Establishment (RAE) was formed. Beginning from 1908, investigations were conducted in the Prandtl laboratory in Gottingen, Germany, and in 1912 Deutsche Versuchsanstalt f r Luftfahrt (DVL; German for "German laboratory for aviation") was organized near Berlin. In 1915 NACA (now NASA) was created in the USA.

These research establishments held international conferences, conventions and exhibitions related to aviation and aeronautics, and Russian scientists took part in them as well.

In 1912 in Moscow N.E. Zhukovsky published his book "Aeronautics Theory," the final result of his long-term studies in aerodynamics, the basis of aviation. This book demonstrated the methodology developed by Zhukovsky and consisting in close relation of physical experience (experiments) and theory and development of approximate computations on the basis of the phenomenon model. This method was further accepted as the basis of TsAGI investigations.

Zhukovsky's tireless activity in developing aviation had many directions. Before the war of 1914 he organized an aeronautics society at MTU, design testing bureau, constructed aerodynamic tunnels at MTU and MSU and more. Before the revolution a group of young enthusiasts of Zhukovsky's Chair, aeronautics society and aerodynamic laboratory at MTU conducted investigations in the field of aviation. Due to Professor N.E. Zhukovsky the laboratory and a scientific team was established in Moscow State University as well.

In early 1918 Zhukovsky and his team of young scientists and engineers continued calculations and testing of airplane models while they fulfilled the tasks set by the Technical Committee of the Air Forces Agency (GUVVF) at the Design Testing Bureau (RIB) founded in 1916. The results of these works were published in the "RIB Works."

As late as 1917 N.E. Zhukovsky expressed concern for the issue of aviation staff training and suggested the organization of a technical college and an institute for this purpose. In April 1918, Zhukovsky applied to the All-Russian Board of Workers' and Peasants' Red Air Fleet with a request for the assignment of appropriate monetary assets. The Board assigned Zhukovsky 10,000 rubles for the foundation of a technical college.

The other center of aviation science was formed in Saint-Petersburg. There, as early as the late 19th century D.I. Mendeleev founded a Department of Aeronautics at the Imperial Russian Technical Society (IRTO), which received approval from the government.

Many remarkable scientists worked in the field of aeronautics in Saint-Petersburg. Among them we should mention M. A. Rykachiov, who conducted a study of main rotors as early as 1870 and published his book "The First Experiments with Air-Rotated Propeller Lift." Mikhail Alexandrovich Rykachiov (1849–1919) was a Lieutenant, a member of the Main Physical Observatory and subsequently it director, an academician, leading scientist in the

Academician M.A. Rykachiov
(1840–1919)

Professor S.K. Drzewiecki
(1843–1938)

Professor A.P. Fan-der-Flit
(1870–1941)

Professor G.A. Bothezat
(1882–1940)

Professor S.P. Timoshenko
(1878–1972)

field of meteorology, terrestrial magnetism and aeronautics. He made several flights on free balloons in order to study upper atmosphere and noted the main disadvantage of these aircraft – their uncontrollability: "This disadvantage suggested that we could replace the balloon lift with rotating wings which could sustain the actuating mechanism in air." Rykachiov measured the lift produced by propellers and the power they consumed. This way he made a conclusion on the proportionality of the lift produced by a blade installed at some angle to air flow and air flow velocity squared, noted the existence of angle of attack at which the lift-drag ratio would take the maximum value, and obtained some other aerodynamic characteristics of a blade in air flow. He correctly distinguished the two most actual problems of manufacturing a helicopter: improvement of aerodynamics of main rotors and creation of light aircraft engines. He correctly indicated the way to generate propulsive force on a helicopter, but in his description of the craft he did not take into account the absence of balancing the means for the reactive moment of the main rotor. This disadvantage of the aircraft was highlighted by the lieutenant general G.E. Pauker who reviewed the Rykachev work in 1872.

Another outstanding engineer and scientist of the Saint-Petersburg school was S.K. Drzewiecki (1843–1938). He generally studied and lived in

France, actively worked in the field of aeronautics, air mechanics and other branches of mechanics. He published a series of papers in aerodynamics: on air drag, on optimal angle of attack of airplane wing. His investigations were highly appreciated by N.E. Zhukovsky. Drzewiecki also conducted experimental studies of screw propellers and developed the aerodynamic propeller theory, which related the propeller shape to its basic characteristics. He popularized papers written by Zhukovsky and his school abroad, and made several translations of his essays. S.K. Drzewiecki also published some of his works on the theory of flight.

In the early 20th century on the basis of the shipbuilding department of the Peter the Great Polytechnical Institute, the dean of which was Professor K.P. Boklevsky, investigations in aviation began. Along with that, the main trend of investigations in Saint-Petersburg was aeronautics. The initiator of the aerodynamic laboratory in Saint-Petersburg was N.A. Rynin. In 1908 he organized a student aeronautics society at the Polytechnical Institute. Then, under the guidance of Dean K.P. Boklevsky, staff training for aeronautics was organized. In order to prepare a course of theoretical air mechanics he involved professors A.P. Fan-der-Flit and I.V. Meschersky, to prepare a course on engines – A.A. Lebedev, and to prepare a course on structures and their strength – V.F. Naidionov and N.A. Rynin.

In 1909 A.P. Fan-der-Flit published his book "Air Mechanics" where he paid special attention to the results of the scientific research of Moscow scientists. Of great help were Moscow scientists in the creation of a aerodynamics laboratory at the Polytechnical Institute. N.E. Zhukovsky made special visits to the Polytechnical Institute in Saint-Petersburg to give some advice and forwarded his talented student, V.A. Slesarev, to manage the building of the laboratory, which was commissioned in 1911. The laboratory occupied a four-story building, was equipped with a large aerodynamic tunnel (test section diameter ≈ 1.8 m), withstanding air flow speed of 20 m/s and with other devices. In 1912 an engine laboratory was opened under the guidance of A.A. Lebedev.

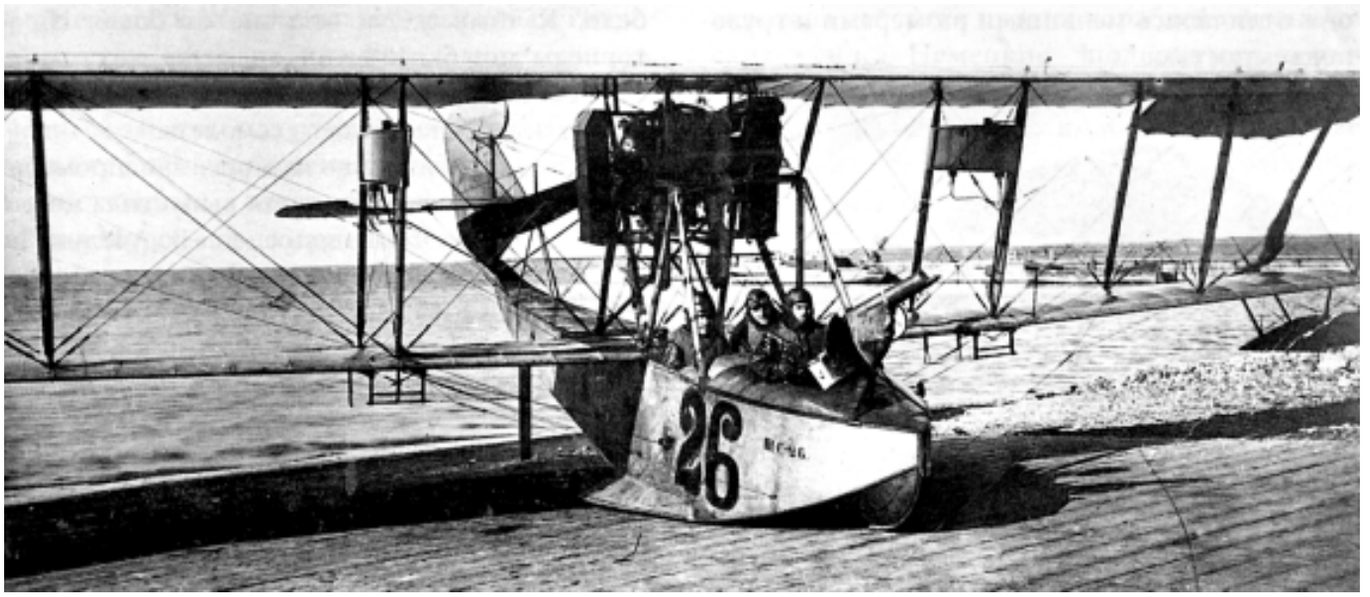
Among Saint-Petersburg scientists who took part in the development of aviation science we should also mention S.P. Timoshenko, a well-known scientist in the field of structural strength. He wrote a book "Airplane Strength" which, unfortunately, was not published, but a copy of the manuscript has been saved.

Close to World War I, S.P. Timoshenko organized the first laboratory for testing structural strength at the military department. He planned to build there a large aerodynamic tunnel with a test section of 6 m. This tunnel was designed by Zhukovsky's students in Moscow. The tunnel was built in Moscow but it was not transported to Saint-Petersburg – it was burnt in a fire during revolutionary events.

Before the war began Saint-Petersburg received another scientist, G.A. Bothezat, who began teaching at the Polytechnical Institute in 1911 after studying in several European countries and maintaining his thesis on airplane stability at the Sorbonne under the guidance of a famous mechanical engineer, professor Paul Painlev . In this thesis the author used the method of airplane motion equation linearization to solve the problem of estimation of its stability in compliance with the methods developed by Routh, Vyshnegradsky, Maxwell and other scientists. A similar approach was developed in the paper by Brian (1912) published in England at that time. This thesis by G.A. Bothezat was highly appreciated by N.E. Zhukovsky who used the results with some corrections in his lectures (1912) on stability. Bothezat's thesis won appreciation from the famous engineers Painlev and Appell.

Further, G.A. Bothezat took active part in studies conducted by the Department of Air Fleet of the Special Committee and by the Technical Committee of the Air Forces Agency of the Military Department from 1911 to 1918, when he emigrated to the USA. In the period from 1911 to 1918 he carried on heavy organizational activities in the creation of some institutions and realization of some propositions in the field of aviation, but for various reasons his undertakings were not realized in practice.

Saint-Petersburg is associated with the highest achievements of Russia in the field of practical



Flying boat M-9 designed by D. P. Grigorovich

aircraft construction of that time. It is the place where close to and during the World War I some of the best airplane of that time were designed, for example, flying boats M-5 and M-9 designed by D.P. Grigorovich and the world's first heavy multiengine airplane, an outstanding creation of young Russian design engineer I.I. Sikorsky.

That time, when experts in aviation held discussions on the mere possibility of creation of heavy airplane, I.I. Sikorsky in March 1913, produced a four-engine airplane Grand. In June of the same year he produced its modification Russky Vityaz and, finally, in December 1913, the most accomplished airplane of this series, Ilya Muromets, went aloft. A fleet of these airplane used as bombers and air scouts took an active part in World War I, being used until 1920. It is remarkable that models of Grand and especially Ilya Muromets airplane were subject to comprehensive tests in Saint-Petersburg aerodynamics laboratory at the Polytechnical Institute. When Sikorsky designed these airplanes, he cooperated with Timoshenko. “Heavy aviation is a child of Russia...” said Zhukovsky, meaning Sikorsky's airplane.

Heavy four-engine airplane Ilya Muromets

I.I. Sikorsky (left) in the cockpit of "Grand" airplane gives an interview to a member of the press

* * *

Thus, in prewar years and during World War I aeronautic science in Russia was intensively developed. Laboratories of different types were created, in-flight investigations were carried out. The leading role was played by N.E. Zhukovsky and his school created on the base of the Moscow State University and Moscow Technical School, and a group of scientists and military organizations of Saint-Petersburg.

MAIN MONOGRAPHS BY TSAGI SCIENTISTS (postwar period)

1. S.A. Khristianovich, M.D. Millionschikov, L.A. Simonov, V.G. Galperin – Applied Gas Dynamics. Parts I and II. – Moscow: TsAGI, 1948.
2. S.M. Belotserkovsky – Thin Lifting Surface in the Subsonic Gas Flow. – Moscow: Nauka (Science), 1965.
3. G.A. Grodzovsky, V.V. Tokarev, Yu.N. Ivanov – Low-Thrust Space Flight. – Moscow: Nauka, 1966.
4. G.S. Bushgens, R.V. Studnev – Dynamics of Aircraft Spatial Motion. – Moscow: Mashinostroenie (Mechanical Engineering), 1967.
5. G.L. Grodzovsky, A.A. Nikolsky, G.P. Svischev, G.I. Taganov – Supersonic Gas Flows in Perforated Boundaries. – Moscow: Mechanical Engineering, 1967.
6. M.N. Kogan – Dilute Gas Dynamics. – Moscow: Nauka, 1967.
7. G.E. Kuzmak – Researches of Optimal Multiburn Transfer Missions between Nearest Quasi-Circular Noncoplanar Orbits // Space Researches. 1967. Issue 5.
8. G.S. Bushgens, R.V. Studnev – Aircraft Stability at Steady Roll Rotation // TsAGI Works. 1968. Issue 1098.
9. G.E. Kuzmak – Dynamics of Aircraft Coasting at Atmospheric Entry. – Moscow: Nauka, 1970.
10. S.M. Belotserkovsky, B. K. Skripach, V. G. Tabachnikov – Wing in the Unsteady Gas Flow. – Moscow: Nauka, 1971.
11. V.P. Agafonov, V.K. Verkhushkin, A.A. Gladkov, O.Yu. Pomensky – Non-Equilibrium Physico-Chemical Processes in Aerodynamics / Under the editorship of G.I. Maikapar – Moscow: Mechanical Engineering, 1972.
12. A.K. Martynov – Applied Aerodynamics. – Moscow: Mechanical Engineering, 1972.
13. A.N. Petunin – Methods and Procedures for Measurement of Gas Flow Parameters. – Moscow: Mechanical Engineering, 1972.
14. TsAGI – Basic Scientific Work Stages. 1918–1968. – Moscow: Mechanical Engineering, 1976.
15. K.K. Fediaevsky, A.S. Chepevsky, A.V. Kolesnikov – Calculation of Turbulent Boundary Layer of Incompressible Liquid. – Leningrad: Sudostroenie (Ship Building), 1972.
16. L.M. Shkadov, R.S. Bukhanova, V.F. Illarionov, V.P. Plokhikh – Mechanics of Optimum Spatial Motion of Aircraft in Atmosphere. – Moscow: Mechanical Engineering, 1972.
17. Experimental Studies of Helicopter Aerodynamics / Under the editorship of A.K. Martynov – Moscow: Mechanical Engineering, 1972 – First edition; 1980 – Second edition.
18. Aviation Acoustics / Under the editorship of A.G. Munin and V.E. Kvitka – Moscow: Mechanical Engineering, 1973.
19. L.S. Vildgrube, E.S. Vozhdaev, B.E. Baskin, G.I. Maikapar – Main Rotor Theory / Under the editorship of A.K. Martynov – Moscow: Mechanical Engineering, 1973.
20. P.P. Krasilschikov – Practical Aerodynamics of Wing. – Moscow: TsAGI, 1973.
21. A.I. Baranov, L.G. Belozerov, Yu.S. Ilin, V.F. Kutinov – Static Structure Testing of Supersonic Aircraft. – Moscow: Mechanical Engineering, 1974.
22. N.A. Zlatin, A.P. Krasilschikov, G.I. Mishin, N.N. Popov – Ballistic Installations and Their Application in Experimental Studies. – Moscow: Nauka, 1974.
23. K.S. Kolesnikov, V.N. Sukhov – Flexible Aircraft as Automatic Control Object. – Moscow: Mechanical Engineering, 1974.
24. Aeromechanics of Supersonic Flow about a Power-Shaped Body of Revolution / Under the editorship of G.A. Grodzovsky – Moscow: Mechanical Engineering, 1975.
25. A.A. Makarevsky, N.N. Korchemkin, T.A. Frantsuz, V.M. Chizhov – Aircraft Strength. Methods to Rate Design Conditions for Aircraft Strength / Under the editorship of A.I. Makarevsky – Moscow: Mechanical Engineering, 1975.
26. V.A. Ilin, G.E. Kuzmak – Optimal Transfers of Spacecrafts. – Moscow: Nauka, 1976.
27. V.I. Biriuk, E.K. Lipin, V.M. Frolov – Design Methods for Aircraft Structures. – Moscow: Mechanical Engineering, 1977.
28. L.S. Vildgrube – Helicopters – Calculation of Integral Characteristic and Flight Performance. – Moscow: Mechanical Engineering, 1977.
29. V.A. Kozhevnikov – Automatic Stabilization of Helicopters. – Moscow: Mechanical Engineering, 1977.
30. K.P. Petrov – Aerodynamics of Missiles. – Moscow: Mechanical Engineering, 1977.
31. V.A. Yaroshevsky – Uncontrolled Motion of a Body in the Atmosphere. – Moscow: Mechanical Engineering, 1978.
32. G.S. Bushgens, R.V. Studnev – Aircraft Aerodynamics. Longitudinal and Lateral Motion Dynamics. – Moscow: Mechanical Engineering, 1979.
33. Yu.P. Gouskov, G.I. Zagainov – Flight Control of Aircraft / Under the editorship of G.V. Alexandrov – Moscow: Mechanical Engineering, 1980.
34. A.G. Munin, V.M. Kuznetsov, E.A. Leontiev – Aerodynamic Noise Sources. – Moscow: Mechanical Engineering, 1981.
35. A.A. Nikolsky – Theoretical Research of Liquid and Gas Mechanics. – Moscow: TsAGI, 1981.
36. Aerodynamics and Dynamics of Passenger Airliner Fligh / Under the editorship of G.P. Svischev and G.S. Bushgens – Moscow: Mechanical Engineering, 1982.

37. A.I. Makarevsky, V.M. Chizhov – Strength and Aeroelasticity Foundations. – Moscow: Mechanical Engineering, 1982.
38. V.Ya. Borovoi – Gas Flow and Heat Exchange in Zones of Shock Waves Crossing the Boundary Layer. – Moscow: Mechanical Engineering, 1983.
39. G.S. Bushgens, R.V. Studnev – Aircraft Dynamics. Spatial Motion. – Moscow: Mechanical Engineering, 1983.
40. V.K. Sviatodukh, P.M. Cherniavsky – Dynamics of Two-Channel Control Aircraft. – Moscow: Mechanical Engineering, 1983.
41. V.A. Bashkin – Triangular Wings in Hypersonic Flow. – Moscow: Mechanical Engineering, 1984.
42. V.M. Ordyntsev – Automation Systems in Experimental Scientific Studies. – Moscow: Mechanical Engineering, 1984.
43. K.P. Petrov – Aerodynamics of Aircraft Components. – Moscow: Mechanical Engineering, 1985.
44. I.V. Brusilovsky – Aerodynamic Design of Axial Fans. – Moscow: Mechanical Engineering, 1986.
45. V.V. Sychev, A.I. Ruban, Vik.V. Sychev, G.V. Korolev – Asymptotic Theory of Separated Flow / Under the editorship of V.V. Sychev – Moscow: Nauka, 1987.
46. K.K. Fediaevsky, L.Kh. Bliumina – Hydrodynamics of Detached Flow of Bodies. – Moscow: Mechanical Engineering, 1987.
47. Aviation in Russia / Under the editorship of G.S. Bushgens – Moscow: Mechanical Engineering, 1988.
48. V.A. Yaroshevsky – Atmospheric Entry of Spacecrafts. – Moscow: Nauka, 1988.
49. E.L. Bedrzhitsky, B.S. Dubov, A.N. Radtsig – Theory and Practice of Aerodynamic Experiment. – Moscow: MAI, 1990.
50. N.P. Klokova – Resistance Strain Gages. – Moscow: Mechanical Engineering, 1990.
51. A.D. Smirnov – Computing Architecture. – Moscow: Nauka, 1990.
52. A.P. Krasilschikov – USSR Gliders. – Moscow: Mechanical Engineering, 1991.
53. E.L. Bedrzhitsky, A.V. Egorshev, V.D. Kuznetsov – Aerodynamic and Strength Tests of Aircraft. – Moscow: Mechanical Engineering, 1992.
54. G.S. Bushgens, E.L. Bedrzhitsky – TsAGI. Aviation Science Center. – Moscow: Nauka, 1993.
55. Aircraft Industry in the USSR. 1917–1945. Volumes 1 and 2 / Under the editorship of G.S. Bushgens – Moscow: TsAGI, 1992, 1994.
56. Aerodynamics and Dynamics of Airliner Flight / Under the editorship of G.S. Bushgens – TsAGI, Aviation Publishing House of China, 1995.
57. TsAGI. Basic Scientific Work Stages. 1968–1993. – Moscow: Fizmatlit (Physics and Mathematics Literature), 1996.
58. Aerodynamics, Stability and Controllability of Supersonic Aircraft / Science editor and originator G.S. Bushgens – Moscow: Nauka – Fizmatlit, 1998.
59. L.V. Ushakov, V.I. Grishin – Calculation Methods for Airframes Local Strength. – Moscow: Arktika (Arctic), 1999.
60. G.I. Scherbakov – Coaxial Arc Gas Heaters with Stiff Discharge Stabilization. – Moscow: Mechanical Engineering, 1999.
61. Urgent Problems of Aeroacoustics, Hydrodynamics and Industrial Aerodynamics // TsAGI Works. 1999. Issue 2634.
62. K.P. Petrov – Aerodynamics of Space Transportation Systems. – Moscow: Editorial URSS, 2000.
63. V.A. Bashkin, G.N. Dudin – Spatial Hypersonic Flow of Viscid Gas. – Moscow: Nauka – Fizmatlit, 2000.
64. V.G. Dmitriev, G.S. Bushgens – About TsAGI Works. Years of 1970–2000 and Prospects. – Moscow: TsAGI, 2001.
65. Yu.K. Arkadov – New Gas Ejectors and Ejection Processes. – Moscow: Fizmatlit, 2001.
66. A.S. Ginevsky, E.V. Vlasov, R.K. Karavosov – Acoustic Control of Turbulent Jets. – Moscow: Fizmatlit, 2001.
67. Flight Aerodynamics, Dynamics and Strength. V. 21, B. 1. Aircraft and Helicopters. Editor and originator G.S. Bushgens. Volume editor V.G. Dmitriev / Encyclopedia of Mechanical Engineering. – Moscow: Mechanical Engineering, 2002.
68. N.K. Remeiev – Aerodynamics of Supersonic Aircraft Air Intakes. – Zhukovsky: TsAGI, 2002.
69. E.U. Repik, Yu.P. Sosedko – Flow Turbulence Level Control. – Moscow: Fizmatlit, 2002.
70. TsAGI – Basic Scientific Work Stages. 1993-2003. – Moscow: Nauka, 2003.
71. Mathematical Models of Aircraft. Origin and Development of Aviation Computer Methodology. Major Works of 1954–1999 / Under the editorship of S.M. Belotserkovsky. – Moscow: Novy Tsentr (New Center), 2003.
72. G.S. Bushgens, V.A. Barinov, V.G. Dmitriev, V.G. Zhivov, A.V. Klimin, V.G. Mikeladze, G.A. Pavlovets, Yu.A. Sheliukhin – Research Efforts by TsAGI in Aerodynamics, Stability, Controllability of New-Generation Airliners. – Moscow: TsAGI, 2003.
73. B.S. Dubov – Quality Assurance Foundations for Aerodynamic Tunnel Tests. – Moscow: TsAGI, 2003.
74. L.G. Belozerov, V.A. Kireiev – Composite Shells under Force and Heat Impacts. – Moscow: Fizmatlit, 2003.
75. G.N. Lavrukhin – Air Gas Dynamics of Exhaust Nozzles T.1. Internal Characteristic of Nozzles. – Moscow: Fizmatlit, 2003.
76. G.S. Bushgens, E.L. Bedrzhitsky, V.G. Dmitriev – Aviation Science Center. – Moscow: TsAGI, 2004.
77. G.N. Zamula, A.S. Kretov – Strength of Aircraft High-Temperature Structures. – Kazan: Publishing House of Kazan State Technical University, 2004.
78. V.Ya. Neiland, V.V. Bogolepov, G.N. Dudin, I.I. Lipatov – Asymptotic Theory of Viscid Gas Supersonic Flows. – Moscow: Fizmatlit, 2004.
79. V.G. Dmitriev, V.M. Chizhov – Strength Foundations and Design of Aircraft Basic Structure. – Moscow: TsAGI, 2005.
80. Problems of Advanced Aviation and Space Materiel Creation / Under the editorship of V.G. Dmitriev, V.A. Kargopoltsev, V.I. Mavritsky and others. – Moscow: Fizmatlit, 2005.
81. A.A. Kazarian – Film Pressure Switches. – Moscow: Bumazhnaia Galereia (Paper Gallery), 2006.