TsAGI Science Journal, 42 (2): 135–140 (2011)

FOR THE 100th ANNIVERSARY OF THE MSTISLAV V. KELDYSH'S BIRTH. THE BEGINNING OF CREATIVE WAYS: WORK AT TSAGI

B. S. Alyoshin

Central Aerohydrodynamic Institute (TsAGI), Zhukovsky Str. 1, Zhukovsky 140180, Russia; E-mail:info@tsagi.ru

The Central Aerohydrodynamic Institute (TsAGI) has been one of the most famous and influential scientific, engineering, aviation centers in the world for decades. For this legacy it is in debt to outstanding people such as N. E. Zhukovsky, S. A. Chaplygin, A. N. Tupolev, B. N. Yuryev, A. N. Nekrasov, N. E. Kochin, L. S. Leybenzon, M. A. Lavrentyev, S. A. Khristianovich, and M. V. Keldysh.

February 10, 2011, marks 100 years since the birth of academician Mstislav V. Keldysh (1911–1978), the outstanding scientist in mathematics and mechanics. M. V. Keldysh arrived at TsAGI in 1931 after working in the Department of Physics and Mathematics of the Moscow State University. Then and later, major mathematicians who knew the measure of his talent in the field, in particular Academician Luzin, considered it a mistake that he did not focus on abstract, "pure" mathematics but on the applied fields. But history has shown that it is due to his work in applied mathematics and engineering that Mstislav V. Keldysh reached the heights of a truly world class scientist, and it was his work at TsAGI which became for him an important milestone and a reliable starting point for his further impressive scientific ascent.

Those who worked at TsAGI in the early 1930s admired the atmosphere of high science, optimism, and mutual respect that prevailed at the Institute. This atmosphere was formed around those at the intellectual and spiritual core of the Institute, the disciples of Zhukovsky and, above all, academician Sergei A. Chaplygin, who became for the young Keldysh a close and shining example.

The irreplaceable chairman of the board of TsAGI, a brilliant mathematician and mechanician, Chaplygin, led the famous seminar of general theoretical groups of TsAGI for many years. In regular sessions of the seminar, in keenly critical style while maintaining an objective and benevolent atmosphere, subsequent outstanding researchers-engineers, future academicians such as N. E. Kochin, M. A. Lavrentyev, L. S. Leybenzon, L. I. Se-

1948–2590/11/$35.00

dov, and S. A. Khristianovich, made presentations on a variety of topics. According to eyewitnesses, Keldysh, with his deep and quick mind, soon became one of the most active participants.

Chaplygin was a wonderful example for Keldysh in many ways, including his skill as a brilliant organizer of science, which was especially important afterward. In 1930 he began the creation of the new TsAGI, Zhukovsky in the future. It was as bold as the TsAGI Building Design Bureau in Moscow (1920), headed by A. N. Tupolev, but it was a much more ambitious project. The massive construction of TsAGI, including aerodynamic and strength complexes, as well as an unprecedented aerodrome, laid the foundation of the science-based concepts of aviation science and technology needed to bring the country to the forefront of aviation.

The intellectual elite of TsAGI were the blossom of the entire national mechanics field. The many outstanding young scientists in the early 1930s, with Keldysh among them, were able to create a unique atmosphere of enthusiastic, productive work at the Institute and were pioneers in many areas of science.

In the summer of 1937, the famous scientist-engineer Theodore von Karman, a student of Ludwig Prandtl, visited TsAGI and commended on what he saw: ”Russian scientists are able to combine brilliantly mathematical theory with experimental studies and to implement them.” These words had a direct effect on Keldysh, successfully reflecting the important principles of his scientific work.

In TsAGI is stored a handwritten list of Mstislav Keldysh’s scientific works, which he delved into in a number of ways. In the five years from 1932 to 1937, the young scientist published in *Proceedings of TsAGI*, *Air Force Technique*, *Reports of the Academy of Sciences*, and other publications his fundamental investigations in the field of unsteady motions of an aircraft wing, the hydrodynamics of a heavy liquid, the area of conformal transformation and series of polynomials, the complex field of potential theory, and the Laplace equation — a total of twenty-four works!

After 1937 Keldysh paid more and more attention to development of the theory of flutter, a new and extremely dangerous phenomenon. In five years Keldysh published twelve core papers on this urgent problem, which ensured the safety of our aircraft from flutter much more efficiently than, for example, in Germany. It is amazing when you consider that in Germany, as in England, scientists engaged this challenge much earlier than in our country. This is even more surprising because together and in parallel with the problem of flutter, Keldysh continued intensive scientific research in other provocative directions which interested him, publishing about fifteen works, including some which were purely mathematical. Especially important for the formation of Keldysh’s career as a scientist was scientific cooperation in the field of mechanics and mathematics with one of his senior comrades, M. Lavrentiev.

A fundamental approach to the solution of challenges in aerodynamics in combination with common engineering analysis played a central role in the investigation of flutter. This is a terrible and mysterious phenomenon, much like an explosion, which can collapse aircraft in mere moments, and sometimes new aircraft are associated with a noticeable rise of maximum flight speed due to this phenomenon. The essence of the flutter is the dynamic structural loss of stability due to the complex interaction of three types of forces—aerodynamic, mass and inertial forces, and the elastic aircraft structure. When the flight speed exceeds a certain value called "critical," there are fluctuations with increasing amplitude on the plane. From 1935 to 1943 around 150 accidents and disasters in Germany took place due to flutter, and in the U.S. from 1940 to 1950 more than 100 heavy-flight accidents occurred for the same reason. In contrast, our loss from flutter in the 1930s and 1940s was on the order of a magnitude smaller than for Germany. For this we are obliged, above all, to the talent and years of energetic work of Mstislav V. Keldysh and his associates at TsAGI.

Chaplygin not only understood the scale of danger, but also pursued the most promising solutions to solve this complex problem. Keldysh, who was one of his best students, was attracted to the theory of this mysterious and confusing phenomenon of flutter and had showed more than once his amazing ability to penetrate deeply into the essence of the most complex and varied phenomenon using not only a fine intuition, but also mastery of the rich arsenal of mathematical physics. Chaplygin did not consult Keldysh in "his" general theoretical group; instead he wisely directed him to an experimental aerodynamic department (EAC) at TsAGI, where he set up a strong group of theorists and experimentalists aimed at solving the most important problem at the moment—flutter.

Characteristically, in their scientific research and in the studies of their colleagues and students, Nekrasov, Lavrent'ev, Keldysh, and Chaplygin presciently gave great importance to the study of aerodynamics of unsteady wing motion. Later Keldysh, along with E. Grossman, J. Parkhomovskii, L. Popov, and other researchers of TsAGI, studied the scientific and organizational procedures in vibrations, creating a recognized domestic school (theoretical, as well as experimental) of study with regard to flutter and other problems in aeroelasticity. Captured German materials have shown that in Germany the most common method of calculating critical flutter speed was the method of possible displacements. This method (in fact, the Galerkin method) was borrowed, as admitted by the German experts themselves, from Soviet investigations of flutter.

The greatest difficulties which faced Keldysh and his colleagues at TsAGI from the very beginning were associated with the aerodynamic part of the problem of flutter. Forces and moments acting on a vibrating wing could not be correctly identified in adopted stationary aerodynamic theory to date. There was a need to solve the nonstationary problem. However, to obtain this solution for an aircraft of finite wing span using available methods and means of calculation was impossible at that time. The obvious scientific goal was to find a reasonable simplification of the scheme of this phenomenon. One option was to use a nonstationary theory for the profile (excluding extremities of wing span), and the second option was to use so-called "hypothesis of stationarity," that is, ignoring nonstationarity but taking into account the finite span. In accordance with the hypothesis of stationarity, the true flow is replaced by a steady, constant circulation equal to its instant value and the prehistory of the motion is disregarded. Keldysh chose the second option, and a short but still famous article in 1935, ”Hydrodynamic Derivation of Rauscher,” gave theoretical justification of the core relationships. The subsequent works of Keldysh and colleagues, based the ”hypothesis of stationarity,” became the basis for solving the most practical problems of the time related to antiflutter.

Considerable difficulties were associated with the choice of the computational wing model. TsAGI researchers decided to simulate the wing by an elastic beam. This idea was not at all trivial in the era of thick multispan wings, but it turned out to be productive. It is now possible to formulate the problem of flutter as a problem of dynamic stability of a mechanical elastic-mass system with distributed parameters (the system with an infinite number of degrees of freedom) and flutter speed to determine how the boundary divides regions of stability and instability.

Keldysh proposed to approximate the deflection and the twist angle of the wing in the flow by a combination of only the first tones of its own vibrations in vacuum and to use the forms as coordinate functions for the Galerkin method. Keldysh gave justification of iterative processes for calculating the eigenfunctions and eigenvalues of distributed systems with variables along the span lifting surface and defining the number of characteristics, including the case when neighboring eigenvalues are close.

Later Keldysh analyzed applicability of the solution of the Galerkin boundary-value problems for nonconservative systems. In the case of the variational problems, the Galerkin method is identical in substance to the known method of Ritz. However, the way of applying Galerkin’s method is not associated with the variational problem, defined by differential equations, and can be applied to the non-self-adjoint problems. Thus, a very effective and practical system of performing complex calculations was established, despite the fact that only an abacus, the logarithmic ruler, and calculator were in service.

Formulation of relevant experimental investigations was of considerable complexity. In the foreign press the conviction that flutter in a wind tunnel like that which occurs in a real airplane was impossible. Theoretically proving the opposite and showing the principal possibility of modeling flutter in a wind tunnel and creating a reliable research tool, elastic-dynamic model-like wings, Keldysh proposed a summary of similarity criteria for flutter based on the theory of mechanical similarity.

The next significant step in this direction was taken on this basis by the scientist-specialist in strength, V. Belyaev, who offered a so-called ”barbecue” model configuration. The stiffness characteristics of the bearing surface were reproduced by the single-longeron model. However, mass (and geometric) characteristics were modeled by a set of rigid sections, each of which was fixed to the longeron at one point.

In 1937, in the wind tunnel of TsAGI T-5, a dynamically similar model aircraft wing, An-25, was tested. It is curious that even a few years later, foreign researchers considered modeling flutter impossible and soon began to use the ”barbecue” scheme in the construction of dynamically similar models.

The intense research activity of Keldysh ended in 1940 before the war with the establishment of special guidelines for engineers detailing the effective methods for calculating flutter and proven best practices to prevent a dangerous phenomenon. In 1941, in the midst of war, M. Keldysh and E. Grossman were awarded the Stalin Prize for research in the area of flutter.

During the war, the talents of Keldysh were evident not only as a scientist, but his gifts as an engineer also became clear. Throughout the war, as chief of the Dynamic Durability Department of TsAGI, he promptly participated in the constructor's bureau in the immediate development of practical measures to fight against all sorts of vibrations in production and prototypes and in solving other problems of durability.

At the end of the war, the logical conclusion of Keldysh's research at TsAGI was fundamental work devoted to fight with another sharply manifested phenomenon of dynamic instability of the time—the so-called ”shimmy” of the tricycle gear front wheel. Shimmy is the self-oscillations of rolling wheels of pneumatic tire aircraft (or other vehicles), manifested in the form of intense vibrations: the wheels turn about a vertical axis associated with the movement of the wheel in a lateral direction and inclination of the longitudinal axis (as well as in the case of asymmetric wheel suspension, in movements along the longitudinal and vertical axes).

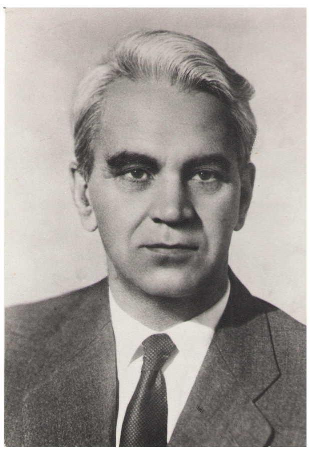
By the beginning of 1940 large volumes of empirical data were already collected and attempts were made to understand the nature of shimmy as a very dangerous phenomenon, but it took years to build a satisfactory theory that mathematically rigorously explained the physical mechanism of stability loss of straight rolling pneumatic wheels. Essential progress in the development of efficient calculation methods of research were made by Keldysh in his basic theory of the rolling tire. This was of crucial importance, since it is due to the nonconservative interaction of the rolling tire with the surface energy which supplies possible movement of the wheel axis (due to the kinematic freedom or design of gear flexibility). A fundamental study of shimmy of by Keldysh in 1946 was noted by another Stalin Prize.

There are similarities in the general approach of Keldysh to problems of flutter and shimmy. It was again required to identify the secondary factors that can be ignored and to simplify the equations describing the phenomenon so as to enable the solution of these equations using the limited computing facilities of the time in order to achieve sufficient accuracy for practice.

The rapid development of computer technology and computational methods in recent decades dramatically changed the possibilities of solving problems of flutter and shimmy, but these effects did not become less dangerous due to their acutely manifested dependence on the substantially larger number of flight parameters and systems than before the much more advanced and sophisticated aircrafts. However, years later, after Keldysh left TsAGI to pursue work at other scientific institutions, including the Academy of Sciences of the USSR to meet new and increasingly relevant scaling problems, the scientific systems and engineering structural safeguards created by Keldysh in

TsAGI to keep aircraft safe from the terrible effects of aeroelasticity continued to operate effectively.

One more member of this famous family, Mstislav Keldysh's younger sister, talented aerodynamics scientist Vera V. Keldysh, worked at TsAGI for most of her professional life. She told how warmly her brother recalled the early years of his work at TsAGI, years which laid the foundation of his further unique scientific and organizational achievements. In articles and speeches on the institution, Keldysh expressed his appreciation to the school of TsAGI, its founders, and major scholars—N. E. Zhukovsky, S. A. Chaplygin, M. A. Lavrentyev, and S. A. Khristianovich. TsAGI, in turn, has always admired and appreciated the outstanding contributions of one of the brightest sons of the Institute and all of Soviet and Russian science, Academician Mstislav V. Keldysh, to the worldwide scientific community.



Mstislav V. Keldysh (1911–1978)