Thermophysics and Aeromechanics, 2007, *Vol. 14*, *No. 3*

150th anniversary of K.E. Tsiolkovsky

FOUNDER OF COSMONAUTICS

A.I. MAKSIMOV

Khristianovich Institute of Theoretical and Applied Mechanics SB RAS, Novosibirsk, Russia

(*Received August 6, 2007*)

The paper described the creative path of K.E. Tsiolkovsky, the founder of theoretical cosmonautics, who devoted his life to solving various problems in the field of aerodynamics and rocket engineering, creating dirigibles with a metallic shell, jet planes, and air-cushioned trains, and studying the origin of planets, the Sun, and the Universe. The main engineering proposals of a scientist of great originality, which found applications in modern rocket and space engineering, are briefly analysed. The versatility of his interests is demonstrated; his research is shown to deal with many fields of science and technology, including the kinetic theory of gases, geology, cosmology, biology, philosophy, sociology, theology, and language science.

The founder of theoretical cosmonautics K.E. Tsiolkovsky (Fig. 1) was born on September 17 (September 5 in the Julian calendar), 1857 in a family of a forester in a village called Izhevskoe of the Spasskii Uezd of the Ryazan’ Guberniya. The first part of his life involved frequent relocations from one place to another and moving from one apartment to another. Konstantin Eduardovich acquired a permanent residence place only in 1904, when he bought a house in the Korovinskaya Street in the city of Kaluga (now 79 Tsiolkovsky Street), which later became his museum.

In the beginning of 1858, the family of Eduard Ignatievich and Maria Ivanovna Tsiolkovsky moves from the village to the city of Ryazan’. Being an inquisitive boy, Konstantin was always very much interested in various engineering mechanisms. To find out their arrangement, he dismantled and broke to pieces all his toys. Konstantin started learning the alphabet when he was five and could read a year later. The first years of his school, however, were extremely difficult for him. In the beginning of 1867, he went sledging, caught a cold, and got ill with scarlet fever, after which he became almost deaf for the rest of his life. For this

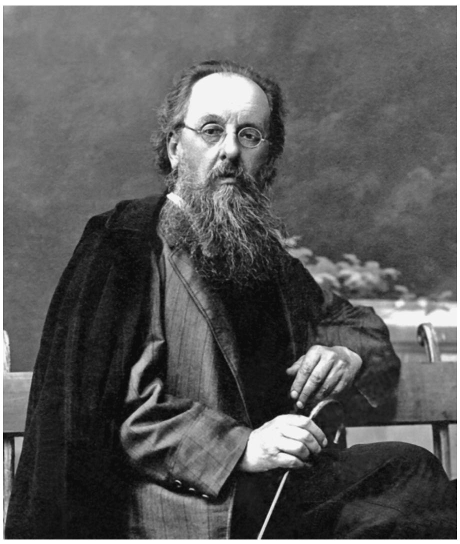

Fig. 1. K.E. Tsiolkovsky (1927).

reason, it was extremely difficult for him to study at school, and he had to pursue self-education. As he admitted himself, his deafness was the whipmaster and slave-driver that hunted Tsiolkovsky throughout all his life. The deafness separated Konstantin Eduardovich from ordinary people, made him devoid of conventional human happiness, and made him completely "concentrate and follow his thoughts and those inspired by science" [1, p. 56].

After moving to Vyatka, Konstantin and his brother Ignaty entered the first class of boys' high school in 1869. After studying for four years and graduating yet from the third class, K.E.Tsiolkovsky quitted the school, and his father brought him to Moscow to continue education. In 1873–1876, Konstantin Tsiolkovsky lived in Moscow and applied great effort to study physics and mathematics at a level of medium and high school without attending them. He spent most of the money his parents sent to him on buying books and various chemicals and instruments for his experiments; therefore, his food was mainly brown bread and water. It was in those years that Tsiolkovsky became interested in creating flying metallic balloons, access to space, and many other academic and engineering problems of his time. Back to Vyatka, he started experiments on studying the influence of an elevated gravity force on living creatures, using a self-made centrifuge for tests with cockroaches and chickens. At the same time, K.E. Tsiolkovsky started to give special lessons in algebra and chemistry for poorly learning students and used the thus-earned money to make machine tools, various instruments, and mechanisms. Somewhat later he glued a large paper balloon and made his "montgolfier" fly through heating air by burning rods placed in a wire grid under the balloon. Once the thread tied to the balloon burnt down, and the freely flying montgolfier was close to start fire in the city [1, p. 43]. When he was young, Konstantin liked to go boating in summer and skating in winter.

In 1878, the Tsiolkovskys returned to Ryazan'. In September 1879, Tsiolkovsky passed the exams to get the title of a teacher in mathematics in secondary schools. Since 1880, he worked as a teacher of arithmetics and geometry in Borovsk (Kaluga Guberniya). In August 1880, Konstantin Tsiolkovsky married Varvara Evgrafovna Sokolova, a priest's daughter, and spent the rest of his life with her, though he confessed that he did not feel passionate love to her [1, 2].

A typical feature of Tsiolkovsky's lessons was clear and understandable presentation of the material to be studied. His teaching techniques were aimed at the development of students' self-consistency. The lessons often included experiments and were well learned by his students. Konstantin Eduardovich was recognized as a good teacher, and his students respected him. On the request of the Director of secondary schools of Kaluga Guberniya, Tsiolkovsky was appointed as a teacher in a secondary school in the city of Kaluga in February 1892 and spent all his further life in this small city.

Neglecting his family and even his own health, Tsiolkovsky devoted all the time when he was not busy with teaching to his favorite activities: manufacturing of various mechanisms and model, scientific research and experiments in the field of aerodynamics, research in the kinetic theory of gases and rocket dynamics, biology, cosmology, philosophy, sociology, and even theology, though he was not a believer. Based on his ideas on the future of the humankind, he also worked on the development of a universal alphabet [1, 3]. His long speculations and investigations were finally summarized in the "Space philosophy" aimed at formation of an ideal society of the future.

Tsiolkovsky wrote his first scientific paper entitled "Graphical presentation of feelings" in 1880. In this paper he made an attempt to identify the relation between positive and negative feelings. He failed to publish the paper in the journal "Russkaya Mysl," and the manuscript was lost. After that, Konstantin Tsiolkovsky started writing the paper "Theory of gases," which was considered at the meeting of the physical department of the Russian Physical and Chemical Society on October 26, 1882 and was approved by the scientists. His next papers were “Mechanics of a similarly changing organism” (September 1883) and “Duration of emission of the Sun. Pressure inside the stars (Sun) and their compression owing to elasticity of matter” (1884). These papers were also discussed at the meetings of this society, where it was noted that the author is extremely industrious and talented to obtain independently some conclusions on the kinetic theory of gases, which were already known to science. These three investigations were impressive, and Tsiolkovsky was proposed to become a member of the Russian Physical and Chemical Society, which he did not feel appropriate to accept (most probably, because of his deafness, which made him feel physically challenged).

The first thoughts on rocket dynamics were described by Tsiolkovsky in his diary in the period from February 20 to April 13, 1883. He performed a detailed study of straight and curvilinear motion, as well as rotation of solids in the absence of the gravity force and atmospheric drag. By an example of exhaustion of a compressed gas from a barrel, he demonstrated the principle of jet engine. He also prepared a description sketch of a flywheel system designed for controlling the angular position of a space vehicle [3]. This paper entitled “Free space” was first published in the second volume of his papers in 1954. After that, for the next 13 years, the basic research activities of Konstantin Tsiolkovsky were associated with creating a full-metal controlled balloon (dirigible) and a monoplane aircraft with a full-metal frame.

On April 24, 1887, Tsiolkovsky made a presentation at the meeting of the Society of natural science fans at the Polytechnical Museum in Moscow with a presentation prepared on the basis of the paper entitled “Theory and practice of a balloon with an extended shape in the horizontal direction.” In 1890, Tsiolkovsky started working on the paper “On a possibility of constructing a metallic balloon that can change its shape and even collapse into a plane.” He submitted this paper together with a paper model of the balloon for consideration to the Russian Engineering Society in September 1890.

In autumn 1890, Tsiolkovsky started experiments aimed at studying the effect of an air flow on a flat plate (a prototype of an aircraft wing) at various angles of attack. He managed to find the influence of the aspect ratio on the lift force of the wing. In the first half of 1891, Tsiolkovsky sent his paper on aerodynamics entitled “On flying by means of wings” to be reviewed by N.E. Zhukovskii and A.G. Stoletov. The paper entitled “Fluid pressure on a uniformly moving plane,” which was written on the basis of the paper mentioned above, was published in the same year in “Collected papers of the Department of physical sciences of the Society of natural science fans” (Moscow, 1891, Vol. IV, No. 2). The same issue (p. 17–18) contained another paper of Tsiolkovsky: “How to prevent brittle and fragile things from impacts and shocks,” where he suggested that a vessel filled by a liquid should be used to prevent the action of elevated gravity [3]. In spring 1892, the first paper “Controlled metallic balloon” was published as a separate brochure, and the second paper with the same title was published next year. Beginning from 1893, Tsiolkovsky’s papers, notes, and science fiction stories dealing with aerodynamics and space flight, creation of metallic balloons, aviation, and air-cushioned trains, and also the evolution of the Universe were regularly published in local and central periodicals.

Tsiolkovsky wrote his first science fiction story “On the Moon” in 1886–1887 and published as an appendix to the journal “Vokrug Sveta” (Around the World) in 1893. At the end of the same year, the journal “Nauka i Zhizn” (Science and Life) published his papers “Gravity as the main source of the world energy” and “Is a full-metal balloon possible?” At that time, in his science fiction story “Dreams about the Earth and the sky and effects of universal attraction,” he started considering the issues concerning the transformation of the ambient worlds by human beings and other intelligent inhabitants of the Universe. In this story, Tsiolkovsky used the term “artificial satellite of the Earth” for the first time and estimated the orbital velocity (8 km/s). “Dreams about the Earth and the sky…" were first published in 1895. The idea of humankind expansion over the entire Solar system and the Universe for the solar and stellar energy to be used to the maximum possible extent, which was put forward in that book, was finally shaped only at the end of 1920s.

Already in 1894, in his paper "Airplane or bird-like (aviation) flying machine," Tsiolkovsky definitely concluded that an airplane with fixed wings has many advantages over a vehicle with winnowing wings. Concerning this question, it is worth noting that he was right to tell that creating a flapping wing is extremely difficult. For more than a century-long story of aviation development, no viable flying vehicle with flapping wings was created, while the use of rigid fixed wings gave rise to a wide range of airplanes designed for various purposes, including highly efficient transcontinental liners, which could carry significant amounts of cargo or a large number of passengers. By the beginning of World War II, high-velocity multi-motor transport planes completely replaced huge flammable dirigibles used for transcontinental flight. Numerous attempts to revive dirigibles on the basis of the latest achievements of science and technology (thin and strong synthetic films, composite materials, and advanced control systems) did not lead to any noticeable results.

After learning the progress of science in the field of the kinetic theory of gases, Tsiolkovsky finally refused to continue activities on this topic in 1894. He noted: "It is unpleasant to discover America for the second time" [2, p. 39]. In what follows, he paid most of his attention to dirigibles with a thin metallic shell, problems of cosmology, and various philosophical issues. For example, in his paper "Second law of thermodynamics" published as a separate brochure in 1914 (the first version being written back in 1905), Konstantin Tsiolkovsky disproved the then-fashionable theory on the thermal death of the Universe because of permanent growth of entropy. In contrast to this theory, he concluded that inherent features of nature are continuous periodic repetition of phenomena and reversibility of energy processes, which lead to quenching and recurrence of stars and galaxies. The thoughts of the Russian self-made scientist are actually close to the today's opinion of astrophysicists who attribute the emergence of the Universe to the so-called "Big Bang" and gradual concentration of energy in "black holes." Simultaneously with the general issues of the Universe structure, Tsiolkovsky studied the problems of formation of the Sun and planets. In 1907, he started working on the paper entitled "Universe in essays and pictures" with several chapters about the Earth including "Matter, structure, and life of the Earth." In 1915, Tsiolkovsky published a series of papers under a common title "Formation of the Earth and solar systems" as a separate brochure.

In 1896, Tsiolkovsky made a wind tunnel and paid for that from his own budget and performed a large cycle of experiments in winter 1897–1898, which were aimed at determining the drag of bodies of various shapes. The results obtained in these tests formed the basis for several papers.

For a long time, Tsiolkovsky's requests for financing manufacturing of a non-flying model of a full-metal balloon (dirigible) and aerodynamic experiments were not satisfied. The Russian Academy of Sciences allocated the first funding in the amount of 470 rubles for aerodynamic research only in 1900. Tsiolkovsky used this money to construct a new test bed and continued his experiments on determining the drag of differently shaped bodies in a low-velocity air flow. In the same year, Tsiolkovsky quitted his work in the Kaluga secondary school because of his health problems, but he continued his teaching activities. For the 20-year irreproachable service, he was awarded with a pension of 324 rubles per year [2, p. 48].

In 1896, Tsiolkovsky started systematic research on rocket dynamics, which made the Russian scientist famous all over the world. He confessed that the impetus was given by Jules Verne, a science fiction writer, who triggered "brain activities in this direction" [3, p. 111, 188], and the brochure of A.P. Fedorov "New principle of aeronautics eliminating the atmosphere as a supporting medium” [2, p. 40; 3, p. 189]. Indeed, the novel of the famous Frenchman “From the Earth to the Moon” written in 1874 played an important role in propagation of ideas on interplanetary journeys at the end of the 19th century and beginning of the 20th century. Soon after this novel was published, it was not only Tsiolkovsky but also other scientists and talented inventors who tried to find possibilities of implementing the idea of space flight.

By the end of the 19th century, the list of researchers trying to create a vehicle for space journeys was extended by the German inventor Hermann Ganswindt (1856–1934). His first known presentation on this topic was made in 1891 [4, p. 5]. Notes on Ganswindt’s activities aimed at solving space flight problems were published in 1893, and his monograph “Das jungste Gericht” was published in Berlin in 1899. In this book, in addition to other materials, Ganswindt proposed a description of the structure of a space vehicle using shots from a small gun for its motion. Ganswindt continued studying space flight problems, but he never made any serious theoretical and experimental investigations in the field of rockets and rocket engines, though he put forward several interesting ideas, for example, obtaining artificial gravity by rotating the vehicle and creation of intermediate interplanetary stations.

At the end of November 1896, Tsiolkovsky started writing a science fiction story, which was first published under the title “Outside the Earth” in 1918 (Nos. 2–14 of the journal “Priroda i Lyudi” (Nature and People). In this story, Konstantin Tsiolkovsky considered details of the initial stage of space conquering, which he thought to be fairly possible. He described details of technical devices used on space vehicles, feelings of the first conquerors of space, and conditions of their existence in microgravity. He also tried to imagine how the human society would be organized in the future. In this and many other subsequent stories, Tsiolkovsky’s ideas were based on his global postulate that, “looking for light and room,” the humankind would not stay on the Earth forever and would “conquer the entire near-solar space” with time (see the excerpt in Fig. 2 taken from [5]).

Tsiolkovsky started working on his fundamental paper on rocket dynamics “Study of the global space by jet-propelled devices” in August 1898. As he was extremely busy, preparing this paper took several years. Apparently, this delay was also caused by the personal tragedy: poisoning and death (in December 1902) of his son Ignaty, a student of the Moscow University.

The first part of the paper “Study of the global space by jet-propelled devices” was published in the May issue of the journal “Nauchnoe Obozrenie” (Scientific Review) in 1903 (Fig. 3). Unfortunately, because of the tragic death of the editor of this journal, M.M. Filippov, the journal was closed in June 1903, and most part of the fifth issue was lost. Tsiolkovsky did not receive copies of his paper, which were promised to him instead of the honorarium. Nevertheless, as it turned out later, this paper published in 1903 became known to F.A. Tsander and V.P. Glushko, famous specialists in rocket engineering of the later times. Some issues of the “Nauchnoe Obozrenie” No. 5 somehow appeared in the libraries of the Slavonic Institute of the University in Heidelberg, Leipzig University, and Congress of the USA in Washington [2, p. 53–54].

Though not all copies of the issue were lost, the first Tsiolkovsky’s paper on rocket dynamics became almost unavailable and remained little known for most of the readers. In addition, because the

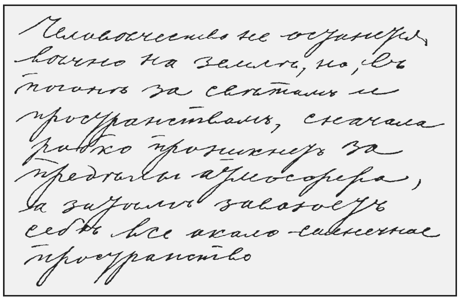
Человѣчество не останется вѣчно на землѣ, но, въ погонѣ за свѣтомъ и пространствомъ, сначала робко проникнетъ за предѣлы атмосферы, а затѣмъ завоюетъ себѣ все около-солнечное пространство

Fig. 2. Excerpt from K.E. Tsiolkovsky’s letter to B.N.Vorob’ev dated 12.08.1911.

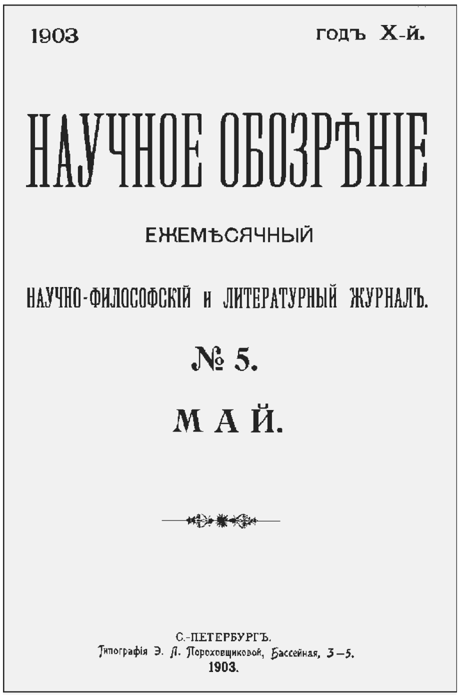

Fig. 3. Cover of the journal “Nauchnoe Obozrenie” where Tsiolkovsky’s paper was published.

journal was closed, it was not possible to publish the second part of the paper “Study of the global space by jet-propelled devices” in due time. The second part of the paper under the same title was published in the journal “Vestnik Vozdushnogo Flota” (Air Force News) only eight years later (Nos. 19–22, 1911 and Nos. 2,3,5,6,7, and 9, 1912). Appendices to these two parts of the “Study…” were published in 1914. The complete version of the paper “Study of the global space by jet-propelled devices” [3, p. 188–273] was published as a separate brochure in Kaluga only in 1926.

In his paper published in 1903, Tsiolkovsky gave the first description of the structure of his space rocket and the basic formula of rocket dynamics relating the ideal (maximum possible) velocity of a single-stage rocket to the velocity of combustion products exhausted from the engine and to the ratio of the burnt fuel mass to the final mass of the rocket. The mathematical expression

$$V = W \cdot \ln(1 + M_2/M_1)$$

was later called Tsiolkovsky’s formula. In this expression, V is the final (characteristic) velocity of the rocket, W is the effective velocity of exhaustion of combustion products from the nozzle of the rocket engine, M_2 is the mass of the consumed fuel, and M_1 is the mass of the rocket proper and payload (final mass of the rocket). The ratio M_2/M_1, which actually characterizes the perfection of the rocket structure, is now known as the Tsiolkovsky number.

Analyzing this dependence, Tsiolkovsky demonstrated that, by increasing the exhaustion velocity and the mass of the fuel used, it is theoretically possible to obtain velocities as large as desired, including the orbital velocity for inserting the rocket to the near-Earth orbit and escape velocity (~11.2 km/s) necessary for overcoming the Earth gravity and for flying to other celestial bodies of the Solar system.

Powder-fed rockets, which appeared in China approximately one thousand years ago, became disseminated almost all over the world and widely used in military actions. Nevertheless, nobody but Tsiolkovsky tried to prove that they can be used for space flight and interplanetary travel. Almost simultaneously with Tsiolkovsky, other scientists were also involved in studying the motion of bodies of variable mass, i. e., equations of rocket dynamics, but none of them considered these equations as applied to space flight. One of these scientists was a famous Russian mathematician I.V. Meshcherskii (1859–1935), who derived all the basic equations of rocket dynamics in his papers “Dynamics of a point of variable mass” (1897) and “Equations of motion of a point of variable mass in the general case” (1904) [6]. Many pioneers of rocket engineering, including R. Goddard (1882–1945), R. Esnault-Pelterie (1881–1957), and G. Oberth (1894–1989), independently derived the basic formula of rocket dynamics, but later than Tsiolkovsky did.

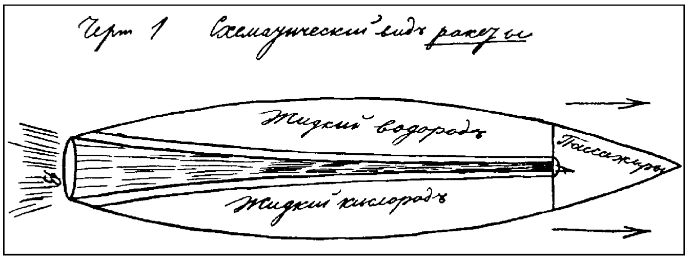

Fig. 4. Sketch of the liquid-propellant rocket proposed by Tsiolkovsky.

In his paper “Study of the global space by jet-propelled devices,” Tsiolkovsky described the conceptual sketch of a liquid-propellant rocket with an engine powered by the hydrogen-oxygen propellant, which is the most efficient propellant for today. He showed that the maximum efficiency of using chemical energy of the propellant (65 %) is reached with the ratio of the fuel mass to the final rocket mass $M_2/M_1 \approx 4$. The sketch of the rocket (Fig. 4) drawn by Tsiolkovsky when he prepared this paper was published much later, during studying Tsiolkovsky’s papers after his death. This sketch is close to the structure of the first heavy liquid-propellant rockets, which appeared almost half a century after Tsiolkovsky’s description. For example, the German ballistic missile A-4 or V-2 (Fig. 5) first launched on 13 June 1942 is almost identical to Tsiolkovsky’s rocket in appearance and structure. Naturally, the long nozzle mouthpiece proposed by Tsiolkovsky for acceleration of fuel combustion products was replaced by a more efficient and compact Laval nozzle, which was first used by the Swedish engineer in constructing steam turbines. Instead of the oxygen-hydrogen liquid-propellant rocket engine created only two decades later, in early 1960s, V-2 was equipped with a less efficient oxygen-alcohol liquid-propellant engine. Nevertheless, as was proposed by Tsiolkovsky, a compact turbo-pump device consisting of a powerful gas turbine and pumps was used to inject the fuel and oxidizer into the combustor at high pressure, and the engine was cooled by means of the fuel (75 % alcohol).

As was foreseen by Tsiolkovsky, the German designers headed by Werner von Braun used air and gas rudders, in addition to automatic instrumentation, for controlling the missile flight. The first idea of Tsiolkovsky was to use deflection of the end part of the nozzle for these purposes. In real configurations, gimballed engines and movable nozzles appeared somewhat later, when the rocket designers faced an urgent problem of further increasing the efficiency of engines for missiles and launchers. Application of gimbal suspensions and swiveling nozzles made it possible not only to avoid the aerodynamic and gas rudders, which were responsible for large losses of thrust and final velocity

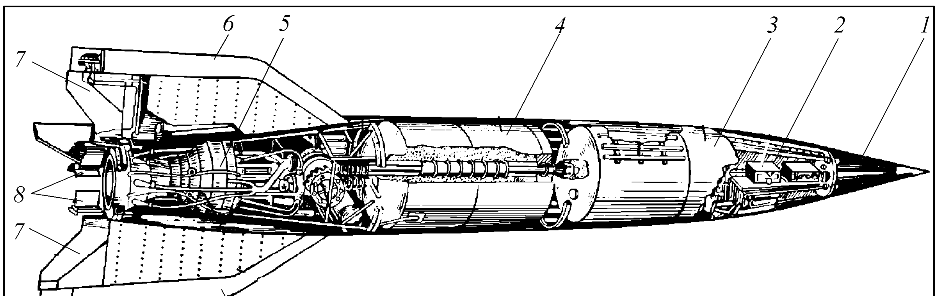

Fig. 5. First heavy ballistic missile V-2 (1942).

1 — warhead, *2* — instrumental module, *3* and *4* — fuel tanks, *5* — engine, *6* — stabilizers, 7 — air rudders, *8* — gas rudders.

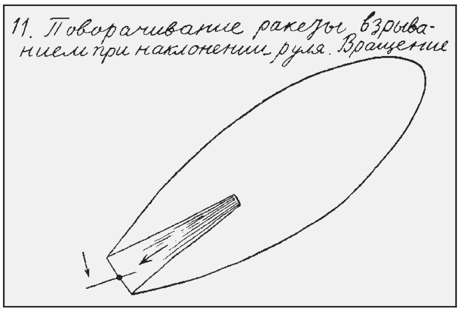

Fig. 6. Application of the gas rudder (figure by Tsiolkovsky from his manuscript “Album of Space Travel” prepared in 1933–1934.

because of their additional mass and considerable drag, but also to almost completely cancel the use of the special vernier engines. The gas rudder located ahead of the nozzle exit section (Fig. 6) was proposed by Tsiolkovsky as the simplest tool for rocket flight control in his paper in 1911 [3, p. 113]. Combinations of aerodynamic and gas rudders were used not only in V-2 but also in other missiles of the first generation, including R-2 designed by S.P. Korolev and Redstone designed in the USA.

For landing on celestial bodies and returning to the Earth, Tsiolkovsky proposed using the same jet propulsion (Fig. 7). Actually, landing on other celestial bodies devoid of the atmosphere is performed by jet propulsion, but a more beneficial method was found for landing on the Earth from the very beginning of space activities: atmospheric braking. Wide application in space engineering was also found for massive whipping-tops — load-bearing flywheels or gyroscopes (Fig. 8), which were considered by Tsiolkovsky back in his paper “Free space.” In our country, ball flywheels were used for the first time on the “Almaz” (Diamond) military manned space station in 1973. Gyros are currently used on many space vehicles that require exact orientation, including the International Space Station, saving the precious fuel and extending the lifetime of these vehicles. In his papers, Tsiolkovsky also considered the possibility of using spontaneous fission of atoms, i.e., nuclear energy [3, p. 170].

Certainly, not all Tsiolkovsky’s discoveries were put into practice. For instance, no application was found for his method of rocket launching at a small angle (10–15°) to the horizon, which would require constructing long inclined elevated structures (Fig. 9) and significantly reinforce the structure of the rocket itself. The only vehicles that are launched at an angle to the horizon are cruise missiles, which use the lift force of the wing for their motion, and comparatively small solid-propellant missiles, which have a large initial thrust. Almost all heavy missiles and launchers have always started strictly vertically, and it is only after they acquire a certain velocity and altitude that they gradually begin to deflect towards the horizon, which is aimed at faster acceleration in a more efficient regime. Up to now, only Japanese comparatively small solid-propellant launchers have been launched with a deviation from the vertical. For example, the Lambda-4S-5 launcher with the first Japanese satellite Ohsumi was launched on February 11, 1970 with a launching beam mounted at an angle of 63° to the horizon.

After 1903, Tsiolkovsky studied the problems of rocket dynamics and space

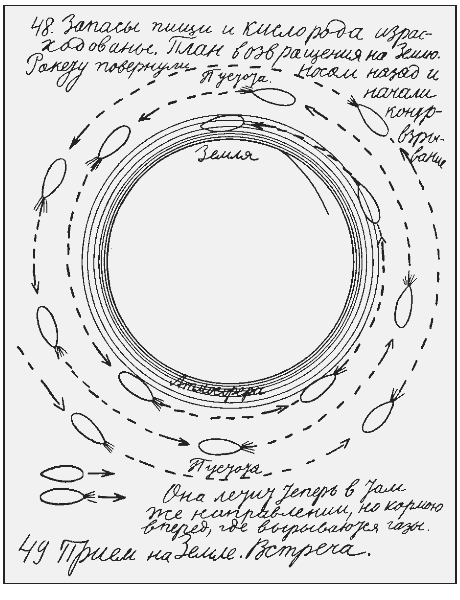

Fig. 7. Diagram of returning of a space rocket to the Earth.

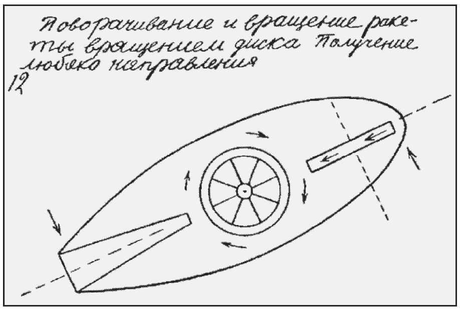

Fig. 8. Use of massive flywheels (gyroscopes) for rocket flight control.

flight only occasionally, because he spent most of his time and effort for developing metallic dirigibles and philosophic speculations. His interest in space research was revived by the first publications of foreign pioneers of rocket engineering R. Esnault-Pelterie (1913) and R. Goddard (1919). Tsiolkovsky was especially anxious about the book of H. Oberth “Rocket to planets” («Die Rakete zu den Planetenräumen»), which was published in Munich in 1923. In this book, the German scientist considered the main equations of rocket dynamics and conditions of its functioning, flight control, design and structural features of a multistage rocket, various types of liquid propellant, projects of orbital stations, and some other issues of rocket engineering [4]. A brief note about Oberth’s book was published in the USSR on October 2, 1923, in the “Izvestiya” newspaper (No. 223). Tsiolkovsky felt for the first time that he may lose his priority in rocket engineering developments.

To preserve the priority, Tsiolkovsky had urgently to publish again his first publication on rocket dynamics, which was issued in 1903 [7]. The brochure entitled “Rocket to space” included a preface written in German by a young scientist A.L. Chizhevsky, an article “Fate of thinkers or twenty years in a napkin” written by Tsiolkovsky, and a slightly revised text of the paper “Study of the global space by jet-propelled devices” published in 1903. In his article, the founder of cosmonautics noted: “Possibly, the rockets will escape from the atmosphere in several decades, and in several centuries the people will reach the Moon and other planets and will make settlements on celestial deserts. The people will enjoy almost infinite space, incredibly great solar energy, and permanent heat and light” [1, p. 94]. The majority of the copies of the new brochure printed in Kaluga in March 1924 was intended to be shipped abroad, first of all, to Germany.

Owing to the urgent second edition of the paper first published in 1903, support of Russian scientists and engineers, and numerous publications in Soviet press, Tsiolkovsky managed to defend his priority in the development of theoretical fundamentals of cosmonautics. In private letters to Tsiolkovsky, H. Oberth had to recognize Tsiolkovsky’s priority in the development of rockets for space flight [3, p. 21]. Now Tsiolkovsky is rightfully recognized almost all over the world as the founder of modern cosmonautics, though some attempts are still made to dispute his priority.

As was indicated earlier, the full text of the “Study of the global space by jet-propelled devices” was published in 1926. Most important subsequent papers of Tsiolkovsky dealing with rockets and space flight were published in 1927 (“Space rocket. Experimental prepatation”), 1929 (“Space rocket trains” and “Objectives of space travel”), 1930 (“To star travelers”), and 1932 (“Theory of jet propulsion” and “Starprobe

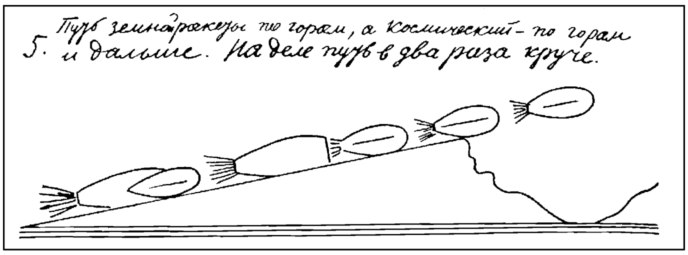

Fig. 9. Rocket launch, as assumed by K.E. Tsiolkovsky.

vehicle”). Simultaneously, he published papers related to creation of jet planes designed for reaching high altitudes and even for space flight. These include the papers “Jet-propelled airplane” and “Semi-jet-propelled stratoplane” published as separate brochures in 1930 and 1932, respectively [3]. In the same years, various journals and newspapers published Tsiolkovsky’s numerous notes, reviews, and small articles dealing with creation of a metallic dirigible and development of aviation and cosmonautics. Some previous papers were published again. Most of his draft or uncompleted papers appeared already after Tsiolkovsky’s death, in 1947 and later, when the Soviet government undertook to ultimately secure Tsiolkovsky’s priority in the field of rocket engineering. Philosophic works of the self-made scientist based on a curious mixture of materialism and idealism, utopism and socialist ideas contradicted the Marxism-Leninism postulates, and these papers could be published only after USSR disintegration. The major part of these papers were collected in the book entitled “Genius among people” only in 2002 [1].

Tsiolkovsky always anticipated only the peaceful use of rockets. For instance, on May 12, 1905, in his letter to the editorial board of the newspaper “Birzhevye Novosti” (News of Stock Exchange), he emphasized: “Working on jet-propelled devices, I had peaceful and high purposes: to conquer the Universe for the wellbeing of the humankind, to conquer space and energy emitted by the Sun” [8, p. 16].

Many technical ideas, which found subsequent practical applications, were proposed by Tsiolkovsky in his science fiction stories. For example, in his story “Outside the Earth,” he considered the arrangement of a space suit designed for space walks. Tsiolkovsky did not take into account, however, that the person himself is a powerful source of heat and paid the main attention to prevention of space cold rather than cooling the cosmonaut from overheating, though he suggested that black space suits should be covered by white light-reflecting overalls. He also foresaw the use of thermoregulators, regenerators, and other necessary devices for the life-support system.

With extensive use of various plants grown in space greenhouses (Fig. 10), Tsiolkovsky hoped to create a completely closed life-support system for inhabitants of space dwelling. He was confident that microgravity will relieve the fetters of the Earth gravity and will allow the people to feel well in space and to assemble huge buildings for gradual expansion of the humankind over the entire Universe. The material for building these structures was assumed to be the matter of asteroids traveling between the Mars and Jupiter orbits.

Unfortunately, space turned out to be not as hospitable for long-time residence of people as it was expected. The first hazard for living organisms is powerful radiation belts surrounding the Earth and space radiation. Because of the radiation belts of the Earth, manned spacecraft and stations have to fly at altitudes smaller than 400 km, though this is extremely cost-inefficient from the viewpoint of fuel consumption because of the resistance of the upper atmospheric layers. For instance, the International Space Station loses 200–300 m of altitude daily by flying in a very rarefied atmosphere, which has to be compensated by regular raising its orbit with the use of rocket engines.

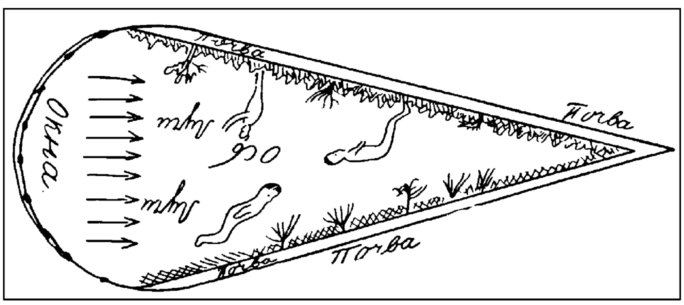

Fig. 10. Space greenhouse.

Microgravity also turned to be insidious for human beings used to standard gravity conditions, though Tsiolkovsky believed it to be a blessing. In long-time flight, cosmonauts have to take special medicines and practice intense exercises to prevent washout of calcium from bones and preserve the muscular tonus. After their returning to the Earth, cosmonauts have to stay in hospital for re-adaptation to the Earth gravity. Though the longest duration of uninterrupted residence at the near-Earth orbit is 438 days (flight of V. Polyakov at the Mir station in 1994–1995), the problems of cosmonaut protection from microgravity and space radiation are far from being ultimately resolved.

It should also be noted that people failed to use plants (at least partially) in the life-support systems of orbital stations for the half a century of the space era started after the first artificial satellite was launched. Despite great efforts, it was not even possible to ensure partial provision of station crew with oxygen and food owing to green plants, leaving aside creation of huge greenhouses in space. Nevertheless, the humankind was able to have the first people landing on the Moon in 1969, and unmanned probes have already reached the outskirts of the Solar system. It takes more than 14 hours for radio signals from these probes to reach the Earth (for example, signals from the American probe Voyager-1 flying now at a distance of more than 100 astronomical units, i. e., 15.5 billion kilometers from the Earth. Despite the high cost, the idea of a manned Martian mission is now under serious consideration again; this event may take place approximately in a quarter of a century.

Most ideas and projects developed by Tsiolkovsky were much ahead of time, and they could not be immediately implemented into real structures. Moreover, Tsiolkovsky thought many of his draft projects and designs to be already finalized and dreamed about their fast implementation. Though measures were taken for aviation and even dirigible-building in early 1930s (during the period of industrialization in the USSR), all attempts of creating a flying model of Tsiolkovsky's dirigible with a small volume of 1000–3000 m^3 failed. The reason was the absence of the technology for fabricating thin leak-proof metallic shells of large volume rather than obstacles from the government, scientists, or engineers. For instance, it was extremely difficult to weld corrugated steel sheets, which were only 0.1–0.15 mm thick. There were no appropriate instruments, technologies, and skilled specialists for such an important work. For the same reasons, Tsiolkovsky had to refrain from the very beginning from using aluminum, a lighter and promising material, whose welding was not yet a well-mastered technology.

Though Tsiolkovsky was arrested in November 1919, based on a false accusation in belonging to the White-Guard underground organization and had to stay on Lubyanka for two weeks, in the last years of his life, Tsiolkovsky experienced much care and attention from both numerous enthusiasts of interplanetary flights and representatives of the Soviet authorities. Finally a decision was made to construct a dirigible based on Tsiolkovsky's draft design, and a special team of approximately 50 specialists was created for this purpose. Based on petitions of various organizations, Tsiolkovsky was allocated a personal pension and academic allowance. There were ceremonies devoted to the 75th anniversary of Tsiolkovsky in Moscow and Kaluga. On November 27, 1932, he was awarded an Order of the Red Banner of Labor at the meeting of the Central Executive Committee of the USSR. A collection of selected papers of the founder of cosmonautics was also prepared on the occasion of his anniversary. The street of Brut (former Korovinskaya street) was renamed to Tsiolkovsky street, and several organizations in Kaluga were named after the famous countryman. In November 1933, the Tsiolkovskys moves to a newly repaired house granted to the scientist by the Kaluga city soviet on the occasion of his anniversary.

In 1930s, the name of Konstantin Tsiolkovsky became famous all over the country. He was contacted by many specialists of various teams studying jet propulsion. In February 1934, I.T. Kleimenov, the Head of the Jet Propulsion Research Institute, and

M.K. Tikhonravov, the Head of one of institute departments, visited K.E. Tsiolkovsky. Soon after that, Tsiolkovsky was elected as an honorary member of the Technical Council of the Jet Propulsion Research Institute.

Though Tsiolkovsky was a creative personality talented in many areas and a broad-minded person and was offended when other people could not accept his new and unusual ideas, he also could not grasp new scientific theories that seemed strange to him. For example, he had never assimilated Einstein's relativity theory and remained an adherent of Newton's classical mechanics until his last days. It should also be noted that Tsiolkovsky used letters of the Russian alphabet in his works rather than the Latin notation commonly used in science, which made his papers difficult to read and required changes in later editions.

Since February 1935, Tsiolkovsky felt permanent pain in the upper part of his stomach. Despite these tortures, he continued to work intensely on his papers and other materials. On September 8, he had his stomach operated with a diagnosis of cancer. On September 13, Tsiolkovsky signed a letter to I.V. Stalin prepared by B. Monastyrev, which contained the following enthusiastic words frequently cited later: "I give all my works on aviation, rocket travel, and interplanetary communications to the party of Bolsheviks and Soviet authorities, who are real leaders of the progress of human culture." On September 17, at the day of his 78th anniversary, Tsiolkovsky received hundreds of telegrams; one of them was a telegram from the government signed by Stalin with wishes of health and further fruitful activities. Two days later, the great Russian scientists and the founder of cosmonautics recognized all over the world died.

In 1954, the Academy of Sciences of the USSR instituted a gold medal named after Tsiolkovsky "For outstanding activities in the field of interplanetary communications." Tsiolkovsky's papers were widely popularized in the USSR after the first artificial satellite of the Earth was launched on October 4, 1957. A crater on the back side of the Moon 183 km in diameter was named after Tsiolkovsky [6]. Since 1966, Tsiolkovsky's Readings are held in Kaluga every year; these readings are aimed at developing the scientific heritage and ideas of Konstantin Tsiolkovsky. The proceedings of these scientific conferences are published in special collections of papers [9]. This year, Russian rocket industry celebrated the 150th anniversary of the great scientist by launching the Progress-M-61 cargo spacecraft named "Konstantin Tsiolkovsky." On August 5, this spacecraft successfully docked with the International Space Station and brought food, equipment, and materials for scientific experiments, and fuel for orbit correction to the 15th permanent mission (ISS-15) of the International Space Station.

REFERENCES

1. **K.E. Tsiolkovsky,** Henius Among People, Mysl, Moscow, 2002.
2. **T.N. Zhelnina,** K.E. Tsiolkovsky (detailed chronicles of life and research activities), Znanie, Moscow, 1999.
3. **K.E. Tsiolkovsky,** Flying Vehicles with Jet Propulsion, Nauka, Moscow, 1964.
4. **Pioneers** of Rocket Engineering. Selected Papers (1891–1938). Ganswindt, Goddard, Esnault-Pelterie, Oberth, Hohmann, Nauka, Moscow, 1977.
5. **K.E. Tsiolkovsky,** Study of the Global Space by Jet-Propelled Devices, Mashinostroenie, Moscow, 1967.
6. **Cosmonautics.** Encyclopedia, Sovetskaya Entsiklopediya, Moscow, 1985.
7. **A.L. Chizhevsky,** On the Bank of the Universe. Years of Friendship with Tsiolkovsky. Memoirs, Mysl, Moscow, 1995.
8. **A.A. Kosmodem'yanskii,** Konstantin Eduardovich Tsiolkovsky, Nauka, Moscow, 1988.
9. **Ideas** of K.E. Tsiolkovsky and the Present. Selected Papers of VI–VIII Tsiolkovsky's Readings, Nauka, Moscow, 1979.