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Chapter 4

ANALYSIS OF K. E. TSIOLKOVSKY'S IDEAS ON SPACE
INDUSTRIAL DEVELOPMENT AND EXPLOITATION*T. N. Zhelnina[†]

In K.E. Tsiolkovsky's works, much attention is paid to questions of the industrial exploitation of space. Up to the present time the study of this trend in the scientist's creative activities was fragmented and superficial; thus, much is still not known concerning this subject, not only to foreign, but also to many Soviet researchers. However, today in connection with the growing scale of extraterrestrial industry developments, Tsiolkovsky's ideas and proposals in the field of space industrialization acquire special urgency. Science and technology historians are faced with the task of studying them profoundly with the aim to comprehend and master. It seems reasonable to examine these ideas in action, and also as a total summary of more than 50 years of the scientist's creative work, this being a necessary prerequisite for research into the heritage of the founder of cosmonautics with a view of appreciating the importance of his works.

The analysis of Tsiolkovsky's works show that, meditating upon the possibility of spreading mankind "over the face of the Universe" [1, L.102], the scientist meant man's active entrance into extraterrestrial space, encompassing, inhabitation and activity, primarily scientific, research, and industrial. This had to be, inevitably, accompanied by drawing into the process of production a material wealth of conditions, processes, factors, substance and energy of space, otherwise the egress beyond the planet would lose its sense. In other words, the notions "exploration of space" and "industrial exploitation of space" were equivalent for Tsiolkovsky. It is not surprising that the first ideas connected with extraterrestrial production were expressed by him long before he found a means of transport capable of overcoming the gravitational force and flying beyond the atmosphere. Yet not knowing the way in which it was possible to achieve cosmic speed, but believing in the possibility of mankind spreading beyond the Earth, the scientist believed this process to be intimately connected with the creation of space industry. Thus, in his work *Svobodnoe prostranstvo* [2], written from February 20 to April 13, 1883, Tsiolkovsky gave a consistent exposition of the foundations of zero-G physics, showing the technical potential of weightlessness in combination with the vacuum, thus scientifically sub-

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† No Biographical data was available on the author, T. N. Zhelnina, U.S.S.R.

stantiating the possibility of production activity away from the planet. The theme of that paper suggested the idea that weightlessness and vacuum did not serve as obstacles for life and work, but that the new environment had great advantages in comparison with the planet's conditions: it was only necessary to utilize its possibilities.

In his *svobodnoe prostranstvo*, leaving aside for the future the subject of the means of reaching space by man, the scientist concentrated his ideas on a technical device, permitting man to live and work in space that he has already reached. He postulated his idea on a vehicle combining the functions of an extraterrestrial transport and an artificial planet. Thus, the idea of an inhabited space station with the possibility to move 'to any star' was formulated and its approximate outlines were given.

Ten years later Tsiolkovsky started his systematic studies in the field of cosmonautics. In his paper, "Grezy o Zemle i nebe i efekty vseirnogo tyagoteniya," written in the summer of 1893 and published in 1895 [2], he gave a vivid picture of rational beings remaking space and the bodies therein. The scientist had as yet no date which could convince the readers that in the future human beings would have to make themselves at home in space; this was three years before his great discovery: the discovery of a possibility of space flight with the help of a rocket. This is the reason why in his "Grezy. . .," space was explored and exploited not by human beings, but by representatives of some other civilizations, and the question of a specific technical device allowing them to overcome the planets' force of gravitation was not answered. But in principle this activity and its purpose was formulated by Tsiolkovsky, and formulated rather precisely. It is characteristic that the leading idea in his proposed conception of space exploration was the idea of its industrialization. In his "Grezy. . ." the scientist outlined definite phases, and a number of directions, for the exploration and exploitation of the planet system, the realization of which inevitably suggested certain production operations. Thus, the process of settling the planets' inhabitants in the planetary system space, he showed in two phases: the creation of living and manufacturing complexes on the near-planet orbits; and, the creation of similar complexes on the near-star orbits. These complexes adjoined each other, forming circular structures, surrounding a star or a planet. The construction material for these structures, according to Tsiolkovsky, was the substance from asteroids and planets' satellites. The energy necessary for all operations for the creation of space settlements, their building and maintenance, could be received by the transformation of solar radiation energy.

Not only did the scientist outline in his "Grezy. . ." the general features of gigantic space objects, namely the living and manufacturing complexes, which provided rational beings with a possibility of spreading within their planetary system borders, but he also developed here the idea of the principal link of such complexes — an inhabited space station with closed ecological cycle, plants being an important element therein, and with artificial gravity [3, s.56].

In his work Tsiolkovsky also touched on temperature control methods within the space station, proposing for their realization employment of single-layer and multi-layer screens with the corresponding coatings (possessing necessary values of

radiation and solar energy absorption coefficients), and also mirror-type concave reflectors for concentration of solar energy [3, pp.117-118]. These installations were to be used not only to provide normal living conditions for station inhabitants, but also to carry out some technological processes, i.e. glass melting, chemical decomposition of complex substances, production of new states of matter (the solid from the gaseous), and transformation of solar energy into other types of energy.

Thus, in 1893, Tsiolkovsky took a serious step in propounding the problem of industrial exploration and exploitation of space. Summarizing the ideas put forward by him in his works "Svobodnoe prostranstvo" and "Grezy o Zemle i nebe i efekty vseirnogo tyagoteniya," it can be considered that in 1893 the scientist outlined the main contours of the industrial space development model. Namely, he had already realized and stated the idea of drawing extraterrestrial nature into the production process; after considering the specific features of various physical processes in weightlessness, he scientifically substantiated the possibility of production activity in space; he also found the advantages of the space environment from the point of view of the space industry.

Tsiolkovsky determined the principal directions of industrial space development:

1. Construction and maintenance of the living and industrial complexes;
2. Drawing extraterrestrial resources into the production process:
 - A. Solar radiation energy (the ways of solar energy utilization were outlined: direct use of solar radiation with the help of concentrators, and its transformation into other types of energy); and
 - B. matter of asteroids and of planets' satellites;
3. Drawing into the production process specific conditions of space, primarily weightlessness and the vacuum;
4. Obtaining superlow and superhigh temperatures under space conditions with the aid of special technological installations.

Later Tsiolkovsky was going to intensify and work out details of the outlined space industrialization model, but its principal elements were already stated in 1893.

Substantial addition to the problem of space industrialization already analyzed was made by Tsiolkovsky during the period from 1902 to April, 1917, when he worked on the article "Issledovanie mirovykh prostranstv reaktivnymi priborami," published in 1911-1912 [4], and in his work "Vne Zemli," published in 1918 [5]. In these works, the scientist put forward proposals on assembly and construction operations when creating installations outside the Earth, on construction of bases on the Moon and in the near-lunar orbits, thus formulating the idea of industrialization of the natural satellite of our planet; he vividly described the welding process of bulky space structures, and pointed out the possibility of fulfilling other production processes in space, namely obtaining metals from ores, forging, casting and rolling.

From 1919 to 1929 Tsiolkovsky continued the elaboration of the space industrial development model. This was a new stage in the history of the scientist's study of the problem of extraterrestrial environment industrialization. The characteristic features were: the desire to substantiate, as thoroughly as possible, the importance, expediency, law-governed nature and inevitability of space industrial development; the intensity of research in this direction. It was a remarkably wide range of problems discussed. This allowed Tsiolkovsky to substantially coalesce and develop the principles previously stated, demonstrating convincingly that egress into space would be a natural step of mankind on the way to conquering the surrounding world; he also showed that transformation of the space environment into a new inhabited environment could not be done without its industrialization, widening the scale of the latter more and more. Tsiolkovsky successively pursued this thought in a number of his works written during the period considered [6-13], but it took shape most vividly and precisely in the article "Issledovanie mirovykh prostranstv reaktivnymi priborami" published in 1926: "Muscles were necessary for the transfer to the land, but transfer from the air into the vacuum requires development of industry. . ." [11, p.89]. And further on: "In the ether, the kingdom of continuous light and hexagonal expanse, industry and the evolution of rational beings . . . must make prodigious achievements" [11, p.90].

Describing colossal prospects of development and utilization of space and celestial bodies, the scientist continued to look into the specific problems of space industrialization. Specifically, he continued studying the peculiarities of physical processes under conditions of extraterrestrial environment, the influence of solar radiation intensity temperature balance in space vehicles and the methods of temperature control in space, pointing out the possibility of obtaining outside the Earth a temperature within range of minus 273°C to plus 6,000°C, and even up to plus 20,000°C and more [11, p.90]. His conclusion of the possibility of obtaining electric energy by transformation of solar radiation energy was further developed in the years 1919 to 1929. Tsiolkovsky outlines several ways of solar power engineering development, namely the direct one (with the aid of solar thermo-electric battery), and machine transformation of solar energy into electric energy. As an installation for the latter method realization, the scientist proposed a closed cycle solar engine, pointing out the possibility of developing in such plants power on the order of 100 h/p. To obtain higher power he proposed to combine the energy of several engines.

Considerable attention in Tsiolkovsky's research on space industrial development problems, which took place in the years of 1919 to 1929, was devoted to the cycle of problems connected with space production organization and the principal directions of its development. Within the mentioned scope, the scientist showed that different stages of extraterrestrial industry deployment were characterized by different degrees of its dependence upon the raw and technical base of Earth. At the first stage, the stage of industrial development of our planet's surroundings, such dependence is maximum, since all space objects would be constructed on Earth and put into space, either ready-made or in parts to be assembled in space, their production being developed at the expense of Earth's resources. But with the spread of mankind in space throughout the Solar System, and by conquering the Moon, the asteroids, and other small celestial bodies, dependence upon the Earth

for the raw material for space production would gradually decrease, and its full independence would be achieved.

Tsiolkovsky did not confine himself to the repetition of his thought on utilization in space production of materials obtained from asteroids and the planet's satellites. He attempted to describe the composition of mineral material of extraterrestrial nature, foretelling the existence on celestial bodies of various mineral resources:

In the substance of those small planets" he wrote, "pure metals as well as alloys will be found. These will be many ores of heavy and light metals. It hardly [seems possible] there will be clay, sand, chalk and other substances formed on the large planets under the influence of air, water, and life. We will rather have to deal with granite and other fiery rocks, and also with ores and native metals and their alloys. It is doubtful that we shall find coal or free gases. [6, s.55-55].

Thereafter, the scientist described in detail the methods of processing extraterrestrial mineral resources to extract components necessary for life and production, including their thermal treating in special "heat-proof chambers" or "fiery stoves" [6, s.55 and, 9, s.2], crushing them and obtaining liquid fertilizers for plants. Tsiolkovsky wrote about the development outside the Earth of such industries as tube rolling, clay firing, production of cement, soda, saltpeter, and some other materials.

Of great interest is the scientist's reasoning about space factories design, distribution therein of industrial equipment and the peculiarities of its operation, safety engineering practices, features of machine-tools and mechanism control, as well as peculiarities of technical personnel operations and work-place organization. He imagines a space object for industrial purposes as "an isolated sphere-shaped, cylindrical or coned chamber" (other "more complex compound form" was possible), provided with "gases necessary for breathing, heat, light, machinery, mechanics, and any necessary energy" [6, s.59]. To clean the workshops of production waste and dust, artificial gravity was created in the structure; also, the workshops were provided with various devices for waste collection, i.e., magnet containers, nets, filters, and devices for withdrawing the dust by warm air flow [7, s.5 ov.]. Tsiolkovsky paid attention to the necessity of either fixing the worker's body in weightlessness, or its occupying a position that made it easy to find a point of support to catch, so as not to fly away from the work-place. He especially pointed out that the fixing of a worker should not limit his freedom of action, while fulfilling operations, allowing him at any moment to quickly change his pose, or to shift from one place to another. Taking these considerations into account, the scientist proposed the following fixing methods under conditions of weightlessness: fastening (providing body movement within certain limits) with foot slots in the surfaces along which a man moved; special movable supports for feet and body; footgear with air suction cups; special "hooks, grips, tongs, vices, and something alike, in order to fasten immediately to the body, and just as simply to get free" [6, s.18 ov.].

Tsiolkovsky did not forget to make suggestions concerning such important aspects of production work organization as the safety of technical personnel working in space. He envisaged the use of individual protection means, such as glass hel-

mets, nets, and soft bandages, as well as fencing of dangerous places, and remote control of machinery and units, stating: "Machine parts may be controlled from outside the machines, in a special place" [13, p.33]. When fulfilling operations under conditions dangerous to man's health and life, the scientist proposed to use robots [6, p.59 ov. - 60].

From 1919 to 1929, Tsiolkovsky considered, in detail, the problem of peculiar functioning of various machines and instruments in weightlessness. The question was formulated by him as follows: "Will the machines work without gravity?" [13, p.13]. The scientist gave a well-founded answer, pointing out that either the machines worked in space as perfectly as on the Earth, or even better, or weightlessness and other space conditions were not unsurpassable obstacles for the operation of machines; only their design should be modified.

Thus, Tsiolkovsky's research in the field of space industrialization during the period from 1919 to 1929 contained ideas and suggestions which were a logical continuation of principles put forward by him in 1883 through 1918. At the same time, these ideas and proposals so greatly developed the model of industrial exploitation of space (worked out by the scientist by 1919), that the second period might be considered as a new, particularly fruitful stage of Tsiolkovsky's creative activities, directed at the all-round substantiation of the importance of industry development outside Earth for the progress of mankind.

Ideas of industrial development of space were also put forward by Tsiolkovsky at the beginning of the 1930s, when he worked on the materials for his paper "Kosmicheskie puteshestviya"; however, they contained no principally new positions in comparison with the preceding works, being, in fact, the repetition of his conclusions reached from 1883 through 1929.

Now let us sum up. An attempt to analyze Tsiolkovsky's ideas about the industrial development of space in progress, as well as total results of more than 50 years of the scientist's creative activity, allowed us to trace the development of the space industrialization model, singling out two main stages in this process:

1. 1881-1918. The model of industrial development of space was, in general, outlined by Tsiolkovsky: the idea of inevitable extraterrestrial environment involvement in the process of material goods production was put forward; the possibility of production activities in space was substantiated; the principal stages and directions for the industrial development of space were outlined – the creation and maintenance of bulky space objects, namely space stations of living and industrial types and greenhouses, the use of solar radiation energy with the aim of solving the problems of electric and thermal supply in space, wide employment of space raw resources (the matter of planets' satellites, asteroids, other celestial bodies), the realization under space conditions of various technological operations (assembly, welding, smelting, forging, rolling, casting, production of glass and reaching various desirable temperatures).
2. 1919-1929 (the period of the most intensive and fruitful research by Tsiolkovsky in the field of space industrialization). The model of industrial development of space was substantially advanced and elaborate details were given. Many well-founded arguments, exposing technological advantages of space environment, were presented; the purpose, the role, and the place of space industrialization in the development of

human civilization were shown; characteristic features of man's work and technological equipment functioning under space conditions were demonstrated.

On the whole, the undertaken research allows us to draw the conclusion that it is to the credit of Tsiolkovsky, who created a well-balanced, integrated, scientifically-substantiated program of space industrialization, which assumed the development of space with the aim of turning it into an environment inhabited by mankind, and which outlined definite prospects of man's industrial activities outside the Earth.

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