

History of Rocketry and Astronautics

**Proceedings of the Thirty-First History Symposium of
the International Academy of Astronautics**

Turin, Italy, 1997

**Donald C. Elder and George S. James
Volume Editors**

Donald C. Elder, Series Editor

AAS History Series, Volume 26

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 17

Copyright 2005

by

AMERICAN ASTRONAUTICAL SOCIETY

**AAS Publications Office
P.O. Box 28130
San Diego, California 92198**

**Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation**

First Printing 2005

ISSN 0730-3564

ISBN 0-87703-518-0 (Hard Cover)

ISBN 0-87703-519-9 (Soft Cover)

**Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198
Web Site: <http://www.univelt.com>**

Printed and Bound in the U.S.A.

Chapter 2

Konstantin Tsiolkovski and the Origin of the Space Elevator*

Jerome Pearson[†]

Introduction

The space elevator variously called the “orbital tower,” a “heavenly funicular,” or even a “beanstalk,” has been dreamed of and invented many times. Arthur Clarke gave a review of the space elevator history at the 1979 IAF Congress in Munich, Germany.¹ Clarke mentioned that Konstantin Tsiolkovski envisioned tall towers on the Earth and asteroids in his writings at the turn of the century.

However, it was not until 1960 that the St. Petersburg engineer Yuri Artsutanov first proposed an actual engineering structure that would support elevators in geostationary orbit.² Artsutanov did not publish in the technical literature, however, and the concept was not known in the West. A group of oceanographers led by John Isaacs also conceived of a “skyhook” on a very small scale, using twin diamond wires to “jockey” payloads into space, and published a short article in *Science*,³ but this did not penetrate into the realm of spaceflight engineering. It was the invention of the “orbital tower” by Jerome Pearson,⁴ published in *Acta Astronautica* in 1975, that brought the space elevator to the attention of the spaceflight community.

* Presented at the Thirty-first History Symposium of the International Academy of Astronautics, Turin, Italy, 1997. Copyright © 1997 by Jerome Pearson. Published by the American Astronautical Society with permission.

[†] Senior Scientist, Ball Aerospace & Technologies Corporation, Fairborn, Ohio, USA.

After this publication, events happened rapidly. Pearson⁵ applied the space elevator concept to the moon, followed by Artsutanov,⁶ Artsutanov⁷ extended the stationary space elevator to the “rolling satellite,” followed by Moravec.⁸ Hyde⁹ elaborated on this “bolo” satellite concept, and Pearson¹⁰ combined the rolling satellite with rocket launches. Even two science fiction novels appeared, by Clarke and Sheffield, featuring space elevators. NASA created its series of tether workshops and later international tether conferences, leading to the tethered satellite launches and many ideas for tether launching of payloads, orbit transfer, and so forth.

The general lack of knowledge of the history of the space elevator has hampered efforts for further development, and has led to confusion about its origins. Reviews of space tethers have often attributed the space elevator to Tsiolkovski, and the review by Carroll¹¹ even missed reference 4. Other authors have equated Tsiolkovski’s thought experiment with an actual invention of the space elevator.

Because of this lack of knowledge, a more thorough review of Tsiolkovski’s writings was warranted, to understand exactly what Tsiolkovski had in mind as part of his famous thought experiments, and to put his thoughts into context with more recent developments.

Tsiolkovski’s Early Years

Konstantin Eduardovich Tsiolkovski was born on 17 September 1857 in a small village south of St. Petersburg, Russia, the son of a forester. He became deaf from scarlet fever at age 9, which prevented his continued public schooling. At age 14, he started his self-education, using his father’s library.¹²

Inspired by the writings of Jules Verne,¹³ he soon envisioned the conquest of space, and studied technology in Moscow, where his father sent him at age 16. Like many would-be space conquerors, he imagined that centrifugal force could be used to explore space.

“I was so excited, so shaken, that I could not sleep all night. I wandered through Moscow, thinking all the time about the great consequences of my discovery. But by dawn I had already realized the error in my reasoning. I felt the disappointment just as keenly as the elation. That night left its impression on my entire life; now, 30 years later, I still sometimes dream of rising to the stars on my machine and experience the same elation as on that unforgettable night.”¹⁴

In 1879 he passed the examination for teachers, and in 1880 was appointed teacher of arithmetic and geometry in Borovsk.¹⁵ Here he began his first scientific and technical writing. T’s technical writing occurs in four broad areas: aerodynamics, dirigibles, reactive flying machines, and speculations, or

“dreams.” These are correspondingly summarized in a three-volume compendium¹² of the first three, and a one-volume collection of the last one.¹⁶

The last area is akin to early Western science fiction, in which the “cardboard” characters are there only as a backdrop to the scientific speculations. Konstantin Tsiolkovski was so intent on the scientific content of his speculations that sometimes he even dispensed with the characters altogether! However, he did not stray far from his scientific musings in writing his speculative work. The two are strongly intertwined, especially in the area of free space, weightlessness, and the effects and methods of spaceflight.

In addition to scientific speculation, Tsiolkovski performed experiments to verify his theories. He built a wind tunnel to test airships, and spinning devices to generate higher gravity. Early in his thinking, Tsiolkovski was concerned about the crew. He experimented by spinning insects and chickens in hemispherical bowls. He subjected a cockroach to 300 g and a chicken to about 5 g, and noted that they both survived.

Tsiolkovski’s Thought Experiments

Tsiolkovski carried out a series of “thought experiments,” in the tradition of his contemporary Albert Einstein, to illustrate his conclusions on space conditions and travel. Einstein’s “gedankenexperiment” is well known, exemplified by his famous elevator on a cable in space to demonstrate the equivalence of gravity and inertia, and his streetcar that traveled nearly the speed of light to demonstrate the effects of special relativity.

Similarly, Tsiolkovski used impossibly tall towers, stacked railroad trains encircling asteroids, and long tethers in free space to illustrate the effects he predicted in the new environment of space. Even before the Wright Brothers’ airplane, he postulated multi-stage rockets, space suits, pressurized space stations, and closed environmental control systems.

In 1893, Konstantin Tsiolkovski wrote an extended technical essay¹² on “free space,” which was his way of describing areas far from gravitating bodies, where the local acceleration of gravity is orders of magnitude less than at the surface of a planet. He examined the motions of connected bodies in free space, and methods for translating and rotating, with or without the loss of reaction mass. He discovered ways in which a spacesuited person alone in space could translate to capture another object, and rotate to any desired attitude.

Tsiolkovski followed these thought experiments with some speculative essays, “Changes in Relative Weight,”¹⁶ “Dreams of Earth and Sky, and On Vesta.”^{16,17} They are called works of science fiction, but they are scientific essays dealing with the gravitational and dynamics effects we will encounter on the small bodies of the solar system. In these essays, Tsiolkovski is focused upon ways to defeat gravity and get into free space. In them, he anticipated

some of the proposals now heard for electromagnetic launching of payloads into space, and for the use of space tethers in launching payloads into different orbits.

“Dreams of Earth and Sky” has an extensive set of essays on defeating gravity. In Essays 17-22, he imagines the Earth turned into a hollow sphere, with everyone and everything inside. There would be no gravity there. He then goes through a complete examination of how his everyday bed, room, house, neighborhood, and village would be changed with the absence of gravity. He even calculates how, in free space, two balls or two people would revolve about each other due to their own gravitational attraction, with periods of many hours. He describes artificial gravity achieved by rotating two spheres about the ends of a chain in Essay 35. Depending on the length of the chain and the rotational velocity, any desired gravity could be achieved.

Tsiolkovski found the asteroids, with their small size and low gravity, ideal for thinking about these topics. He also speculated about asteroids and planets with tall mountains. He imagined an asteroid with a mountain so tall that it extended beyond the critical point, or synchronous orbit altitude. He then described the gravitational effects a person would note in climbing such a mountain.

Asteroid Ring-Trains

Konstantin Tsiolkovski performed some extensive thought experiments on rapidly moving trains, the best example of high-speed vehicles in his day. He used the train analogy in discussing his staged rockets, calling them “cosmic rocket trains.” In addition, he used the train analogy to imagine ways to overcome gravity on asteroids.

In Chapter 7, “In the asteroid belt,” Essay 32, he says: On an asteroid 56 km in diameter, imagine a smooth road around the equator, with a moving belt on wheels, moving along at 4 m/s. Constructing another platform on the first could support another carriage on wheels, moving at a relative velocity of 4 m/s, for a total of 8 m/s. Continuing in this way for a total of 9 platforms gives a total of 36 m/s, which is enough to overcome gravity. One could run alongside the trains, jump on, and move upward on them all, reaching orbital velocity, and jumping off the top one to be in orbit.

This is a linear equivalent of the rolling satellite invented by Artsutanov⁷ and later, independently, by Moravec.⁸ The rolling satellite literally rolls around the Earth, with the spokes touching the ground, picking up payloads, then releasing them at high velocity when they reach the top. In the same way, the lowest Tsiolkovski train can pick up a passenger, transfer him to successively higher and faster trains, and then release him at high velocity from the top train.

In Essay 36, Tsiolkovski continues the discussion of asteroid ring-trains on platforms. He notes that if the platforms are continued above the critical point, they tend to fall upward. At this point, the trains could be run on the inside of tracks mounted on top of the train at the critical point, with all levels fastened together. The top train could have a negative gravity equal to the surface gravity of the asteroid. These top circular trains could throw off objects to any direction and speed desired.

In "Changes in Relative Weight," Tsiolkovski discusses the weight of a person on different bodies, such as Mercury, Mars, Ceres, Vesta, and Pallas. He goes into great detail about a set of trains about Pallas, talking in terms of their inhabitants and how they populated the space around it to get more sunlight.

"On the Rings of Pallas" discusses an equatorial train moving at 14 m/s, with another on top of it at a relative 14 m/s, and so on up to the 10th train, which moves at 141 m/s, which is equal to circular velocity. The train with orbital velocity is only 22 meters above the surface! The series of trains continues, but the velocity does not change much after circular velocity is reached. The top train is 800 km from the surface, and moves at 53 m/s. By letting go of the right train at the right time, a person could fly off from Pallas at any desired speed in any direction. He has a native tell the story of how this developed, from a mountain that rose 800 km high, and how gravity dropped off as one climbed it, until gravity completely disappeared at a height of 750 km. The story tells of a person who climbed to the top and pushed off. He fell off into orbit, and did not return to the mountain for two terrestrial months, which meant that he pushed off with a relative velocity of 1 m/s. This observation led the natives to develop the trains, and to eventually get rid of the mountain to stop its interference with the trains, and its gravitational perturbations.

Tsiolkovski continues the calculation of the asteroid ring trains for a series of larger asteroids. In Essay 33, he notes: On an asteroid with a diameter of 560 km, 10 trains with a velocity of 36 m/s would be needed for escape velocity.

In Essay 37, Tsiolkovski extends the discussion to cover transportation about the asteroid belt using what we would call space tethers. Pairs of vehicles could push off with chains. If they separate, one goes to a higher orbit, and one to a lower orbit. If one of the vehicles again split into two on a long chain, it could propel one of the masses to an even more elliptical orbit, to approach the sun more closely, for example. An asteroid could change its rotation speed and direction, its orbital eccentricity and inclination and distance, by losing mass thrown off with long chains. This is very similar to the rolling satellite used as a "velocity bank" to catch and throw payloads, as envisioned by Moravec⁸ for Earth orbit operations and by Penzo¹⁸ for Mars tether operations. Tsiolkovski develops ideas on long ring tethers called "necklaces," and on moving from asteroid to asteroid and from "necklace" to "necklace." He states that asteroid inhabitants could break up an asteroid into a ring world about the sun, like "solar necklaces." The technique would be done on an asteroid with ring-trains. First

they would create a ring to capture more solar energy, and use it to make a disk about the asteroid, and then finally make it into a ring with a series of habitats circling the sun. Tsiolkovski postulates that asteroid inhabitants have built them, but we can't see them because they are so thin. This concept of space necklaces is very reminiscent of the concept of Polyakov.¹⁹

Space Elevators

In Essay 26, "The Apparent and Prolonged Elimination of Terrestrial Gravity is Impossible in Practice," Tsiolkovski speculates on the elimination of gravity. He notes that a train moving at 8 km/s on the Earth's equator would nullify gravity, but air resistance makes this impossible. A platform surrounding the Earth at 300 km high could do it, but, he noted, of course this idea is absurd. (This was proposed later by Paul Birch,²⁰ using a super-orbital speed conductor inside the tubular platform for support by centrifugal force, just as in Tsiolkovski's early dreams of conquering space with centrifugal force!) What other ways are there, Tsiolkovski wonders—high towers, or cannon balls, like Jules Verne? On a tall tower, gravity diminishes. At 5.5 earth radii, it vanishes (at the geosynchronous altitude, 35,800 km above the surface). Above that altitude, gravity is reversed. He calculates the critical distance for imaginary towers on the five visible planets, and for the sun. For the sun, the critical distance at which gravity is balanced by the tower's angular momentum is 1/8 the distance to the Earth.

Obviously, he is not envisioning real towers, for later he says, "There is no need to speak of the possibility of such towers existing on planets, ..." ²¹ In contrast, Artsutanov and Pearson were thinking from the first about engineering structures when they envisioned their "heavenly funicular" and "orbital tower," respectively.

Artsutanov's original idea for the space elevator came when a colleague gave him a sample of a very strong material, and he wondered how high a tower could be built with it.²¹ Pearson's concept arose upon hearing Arthur Clarke describing the geostationary communication satellite as "perched atop imaginary towers 36,000 km high," and thought: why not drop a line down and make a real tower? Both Artsutanov and Pearson then worked out the material strength requirements for building real structures.

Later, in Essay 38.2, Tsiolkovski imagines an asteroid with a tall tower, thin at the top and the bottom, like a spindle, not touching the surface. It is in balance about the critical point. This is reminiscent of the Collar and Flower extended geostationary comsat,²² and it is exactly the balanced situation of the Artsutanov/Pearson space elevators, but of course Tsiolkovski is not thinking of a real, engineered structure.

In contrast, Landis²³ recently proposed actually building Tsiolkovski's imaginary tower! Landis found that by using high-strength materials in a combination of a tensile structure balanced about the geostationary altitude and a tower in compression on the ground, the combination required less mass than the tension-only structures of Artsutanov and Pearson.

Many interesting Tsiolkovski drawings illustrating the effects of gravity, acceleration, and weightlessness are to be found in the supplements to "The Call of the Cosmos,"²⁴ published in 1924.

Conclusions

Konstantin E. Tsiolkovski had a very fertile imagination, which he applied with great intensity to airships and space travel. He was ahead of his time, and he was not part of the scientific establishment, so his ideas were not fully recognized and appreciated by his contemporaries. His thoughts on overcoming gravity and traveling into free space have presaged many of our later concepts for space tethers, tether launching, and the development of long tethers in space. These thought experiments were not fully appreciated in the West.

Tsiolkovski used the concept of the "thought experiment" as effectively as Einstein to develop, understand, and improve his scientific speculations. He imagined many things, like towers reaching above stationary orbit, but he did not think of them as real structures, any more than Einstein thought of his elevator in space, accelerating on an infinite cable, as a real object.

Tsiolkovski originated many fundamental concepts, including ring trains, tether launching, and even beamed optical power to launch vehicles into orbit, but not the space elevator; it was invented by Artsutanov and Pearson.

References

- ¹Clarke, A. C., "The Space Elevator - Thought Experiment, Or Key To The Universe," *Advances In Earth Oriented Applications Of Space Technology*, Vol. 1, No. 1, pp. 39-48, 1981.
- ²Artsutanov, Yuri, "V Kosmos na Elektrovoze," *Komosomolskaya Pravda*, 31 July 1960. (The contents are described in English by Lvov in *Science*, Vol. 158, pp. 946-7, 1967.)
- ³Isaacs, J., Vine, A. C., Bradner, H., and Bacchus, G. E., "Satellite Elongation into a True Skyhook," *Science*, Vol. 151, pp. 682-3, 1966.
- ⁴Pearson, Jerome, "The Orbital Tower: A Spacecraft Launcher Using the Earth's Rotational Energy," *Acta Astronautica*, Vol. 2, pp. 785-799, Sep./Oct. 1975.
- ⁵Pearson, Jerome, "Anchored Lunar Satellites for Cislunar Transportation and Communication," *Journal of the Astronautical Sciences*, Vol. 27, pp. 39-62, 1979.
- ⁶Artsutanov, Yuri, "Trakka 'Luna-Zemlya'," ("Railway 'Moon- Earth'"), *Technika Molodishi*, No. 4, p. 21, 1979.

- ⁷Artsutanov, Yuri, "V Kosmos bez Raket," *Znanije-Sila*, No. 7, p. 25, 1969. ("Into Space Without Rockets: A New Idea for Space Launch") Foreign Technology Division Technical Translation FTD-ID (RS)T-1495-79, 26 October 1979).
- ⁸Moravec, H., "Non-Synchronous Orbital Skyhook," *Journal of the Astronautical Sciences*, Vol. 25, No. 4, pp. 307-322, 1977.
- ⁹Hyde, R. A., "Earthbreak: Earth to Space Transportation," *Defense Science 2003+*, Vol. 4, pp. 78-92, 1985.
- ¹⁰Pearson, Jerome, "Low-Cost Launch System and Orbital Fuel Depot," *Acta Astronautica*, Vol. 19, pp. 315-320, 1989.
- ¹¹Carroll, J. A., "Tether Applications In Space Transportation," *Acta Astronautica*, Vol. 13, No. 4, pp.165-174, 1986.
- ¹²Tsiolkovski, Konstantin E., *Sobraniye Sochineniy. Tom II. reaktivnyye Letalel'nyye Apparaty.* (collected Works of K. E. Tsiolkovski, Volume II—Reactive Flying Machines). Izdatel'stvo Akademii Nauk SSSR, Moscow, 1954. NASA Technical Translation TT F-237.
- ¹³Tsiolkovskiy, K. E., "Works on Rocket Technology," Chief Editor M. K. Tikhonravov, Editor G. I. Sedlenek, and Technical Editor T. N. Trofimova, Publishing House of the Defense Industry, Moscow, 1947. NASA Technical Translation TT F -243, 1965.
- ¹⁴N. A. Rynin, "K. E. Tsiolkovskiy, His Life, Work and Rockets," p. 10. Leningrad, 1931.
- ¹⁵Kosmodemyansky, A. A., "Konstantin Tsiolkovsky, His Life and Work," Translated by X. Danko, Foreign Languages Publishing House, Moscow, 1956.
- ¹⁶Starchild, Adam, Ed., *The Science Fiction of Konstantin Tsiolkovsky*, University Press of the Pacific, Seattle, 1979.
- ¹⁷Tsiolkovski, Konstantin E., *Grezy O Zemle I Nebe [i] Na Veste* (Speculations of Earth and Sky, and On Vesta, science fiction works, 1895). Moscow, Izd-vo AN SSR, 1959.
- ¹⁸Penzo, Paul A., "Tethers for Mars Space Operations," AAS Paper 84-174, in *The Case for Mars II*, C. P. McKay, ed., *Science and Technology Series*, Vol. 62, pp. 445-465, 1985 (Paper originally presented at The Case for Mars Conference held July 10-14, 1984, Boulder, Colorado).
- ¹⁹Polyakov, G., "Kosmicheskoye' Ozherel' yi' Zemli," *Tekhnika Molodezhi*, No. 4, pp. 41-43, 1977. NASA Translation, TM-75174, "A Space 'Necklace' About the Earth."
- ²⁰Birch, Paul, "Orbital Ring Systems and Jacob's Ladders," *Journal of the British Interplanetary Society*, Vol. 35, pp. 475-497, 1982.
- ²¹Artsutanov, Yuri N., personal communication to Arthur Clarke, April, 1979.
- ²²Collar, A. R., and Flower, J. W., "A (Relatively) Low Altitude Geostationary Satellite," *Journal of the British Interplanetary Society*, Vol. 22, pp. 442-457, 1969.
- ²³Landis, G., and Cafarelli, C., "The Tsiolkovski Tower Reexamined," IAF Paper 95-V.4.07, 1995, Oslo, Norway.
- ²⁴Tsiolkovsky, K., *The Call of the Cosmos*, Foreign Languages Publishing House, Moscow, 1924.