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Chapter 18

Ary Szternfeld: Pioneer of Space Navigation[1]

Władysław Geisler[2]

Ary Szternfeld was born in 1905 in the little town of Sieradz in Poland. He attended secondary school in Łódź, a city nearby, and then started his studies at the Jagiellonian University in Cracow. Afterwards he moved to France to continue his studies at the University of Nancy, where he obtained the degree of mechanical engineer in 1927, finishing second among 31 persons who passed the examination. From his early youth he was interested in mechanics, astronautics and space flight, and he was sure that soon people would begin to explore space.

In working on his doctor's degree at the Sorbonne University in Paris, he wrote his thesis on interplanetary flight. While working on this research, which took him three years, he encountered repeated attempts by his academic committee to dissuade him from dealing with astronautics and the movement of heavenly bodies. Committee members considered the subject impractical, that it involved too distant a future, and they offered other dissertation topics that carried prestigious scholarships. In spite of this, Szternfeld preferred to abandon obtaining his doctorate in favor of continuing the work of his life. Thus, he left Paris without a degree and went to stay at his parents' home in Łódź. For some time thereafter, he lived there in complete isolation from the world, working up to 20 hours a day on the subject that most fascinated him.

Using only logarithmic tables, or a simple manual counting machine borrowed for the weekends, he made thousands of laborious calculations and formulated his conclusions, as shown in Table 1. Basing his work on already known theoretical principles of the mechanics of rocket motion and on the calculations carried out by previous theoreticians and pioneers, Szternfeld thoroughly checked those earlier results and sometimes

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[2] Polish Astronautical Society, Katowice, Poland.

even discovered mistakes in the work of his predecessors. Accordingly, he developed and polished up new elements of rocket flight theory by derivation of dozens of his own formulas and gained an indisputable priority in the following fields and subjects:

1. Theory of multi-stage rockets and movement of such rockets in the atmosphere.
2. Method of increasing rocket flight ceiling, and, in aviation, of aircraft flights along the ballistic curve—with motors switched off.
3. Method of determining rocket fuel consumption during vertical flight through the atmosphere.
4. Principle of orbital or space rocket lift-off from the Earth surface vertically, followed by a curvature to a horizontal flight path tangent to the Earth, only after passing through the most dense layers of the atmosphere—generally used today for the reduction of fuel consumption necessary to overcome the force of gravity and air resistance.
5. Creating optimum conditions for maximum height of rocket ascent depending on the initial stock of propellant.
6. Optimum pressure in the combustion chamber.
7. Maximum rocket kinetic energy.
8. Formula for instantaneous rocket efficiency.
9. Total efficiency formula of rocket moving through a resisting medium.
10. Formula for total dynamic rocket efficiency depending on useful mass.
11. Maximum impulse of exhaust gases.
12. Calculation method of stratospheric rocket.
13. Laying out the flight path from the elliptical orbit to another heavenly body—the Sun or a planet—which allows for a reduction by half of the energy used in the case of a flight along the classical semi-ellipse.
14. Designing of an instrument for measuring the distance covered by the rocket, an odograph.
15. Optimum circum-Earth orbits, trajectories leading to the Moon and planets, and rocket speeds essential for putting artificial satellites around the Earth or space probes on interplanetary paths.
16. Calculation of path parameters for interplanetary probes with a foreseen automatic return flight to Earth, after a certain time.
17. Determination of the first space velocity essential for entering an artificial satellite of the Earth into orbit, and calculation of further minimum space velocities necessary for escaping from the Earth's gravitation range, for leaving the solar system, etc.
18. Ratio of achieved velocities and path distances-covered by the rockets with constant acceleration in conditions of Earth gravitation and beyond.
19. Minimization of fuel consumption during the flight from one point of the Earth to another, along a path in the form of a single elliptical arc or consisting of several arcs.
20. Determination of the nearest practical circular orbit for an artificial satellite of the Earth—an orbit located 200 km from the Earth. Also the perigee of elliptical orbits should not be nearer to the Earth than 200 km.
21. Perfection of Hohmann's spiral trajectory for circling Venus.

22. Proving the possibilities of reaching the stars during the lifetime of one generation, based on Einstein's theory of relativity.
23. Examples of paradoxes in rocket engineering: the possibility of achieving more favorable flight results by using, in given conditions, a pressure reduction in the combustion chamber, reduction of used propellant mass, increasing the rocket load, or by introducing intervals in rocket motor operation.
24. Conception of a space suit which would increase body resistance to acceleration, later used in aviation and spacesuits developed in the 1960s.

Table 1

Orbit no. No. in Szternfeld's book	Name of flight /of object/	Lift-off date	Parameter determination	In Szternfeld's book	Executed quantity	Deviation %
1 41	1st Artificial Planetoid USSR "Lunnik 1"	2.1.59	Perihelium/in AU/ Aphelium/in AU/ Big orbit semi-axis in AU Duration of one circle in years	1.000 1.321 1.160 1.250	0.979 1.319 1.149 1.232	2.14 0.15 0.96 1.46
2 36	1st Artificial Planetoid USA "Pioneer 4"	3.3.59	Perihelium/in AU/ Aphelium/in AU/ Big orbit semi-axis/in AU/ Duration of one circle in years	1.000 1.146 1.073 1.111	0.982 1.136 1.059 1.090	1.83 0.88 1.32 1.93
3 31	2nd Artificial Planetoid USA "Pioneer 5"	11.3.60	Perihelium/in AU/ Aphelium/in AU/ Big orbit semi-axis/in AU/ Duration of one circle in years	0.805 1.000 0.902 0.857	0.803 0.993 0.898 0.851	0.25 0.70 0.44 0.70
4 28	Interplanetary probe USSR Wenus 1 "ASM-2"	12.2.61	Perihelium/in AU/ Aphelium/in AU/ Big orbit semi-axis/in AU/ Duration of one circle in years	0.724 1.000 0.862 0.800	0.709 1.010 0.860 0.797	2.12 1.00 0.23 0.38
5 37	3rd Artificial Planetoid USA "Ranger 3"	26.1.62	Perihelium/in AU/ Aphelium/in AU/ Big orbit semi-axis/in AU/ Duration of one circle in years	1.000 1.163 1.082 1.125	0.995 1.164 1.074 1.113	0.50 0.09 0.74 1.08
6 46	3rd Artificial Planetoid USSR "Mars 1"	1.2.62	Perihelium/in AU/ Aphelium/in AU/ Big orbit semi-axis/in AU/ Duration of one circle in years	1.000 1.621 1.310 1.500	1.000 1.600 1.300 1.482	0.00 1.31 0.77 1.21

Some of these problems were developed and studied more thoroughly by Szternfeld in his later publications. However, his basic ideas and calculations appeared in the work that he prepared in Paris and completed early in his career in Łódź, called *Initiation à la Cosmonautique*, which was initially published in French in 1933. In his first book, which became his fundamental work, Szternfeld also dealt with many other different problems such as the history of rocket engineering development, the quantities of food and air essential for crews on long-lasting space expeditions, the idea of constructing space mirrors and orbiting settlements, interplanetary signaling, the problem of visibility of artificial satellites from Earth, and the like.

At first Szternfeld found little understanding for his ideas. After completing *Initiation à la Cosmonautique*, on 6 December 1933, Szternfeld presented its principal points at a meeting of the Polish Society of Astronomy at the Astronomical Observatory in Warsaw. In general, his ideas were received rather skeptically even though no errors in argumentation or calculations were raised.

This began to change later that same month, however, when Szternfeld went to Paris and presented his work to the French Astronomical Society where it met with greater interest and approbation. Two chapters of his treatise, one on the measurement of distance covered by a rocket by means of an odograph, and the other on the idea of applying a paradoxical but more economical trajectory—leading from Kepler's orbit to the central body—were presented during sessions of the French Academy of Sciences in Paris. This was an unprecedented event due to the completely new subject matter, never before discussed at meetings of this Academy. After discussion, the author's theses were accepted as correct. Szternfeld's lecture, entitled "Some New Ideas in Astronautics," which was delivered on 2 May 1934 in Descartes' Great Assembly Hall at the Sorbonne University in Paris, proved to be a great success for the young engineer from Poland.

Robert Esnault-Pelterie, the "father" of French astronautics, sincerely congratulated him, and Hermann Oberth and Walter Hohmann paid their tribute in writing, as did Konstantin E. Tsiolkovsky from the Soviet Union. A month later Ary Szternfeld received, also in France, the international astronautical R.E.P. Hirsch prize. However, he could not find a Polish publisher for his first book, even though he tried diligently.

In 1935 he accepted an invitation to visit Moscow, where leaders in the Soviet scientific community expressed an interest in his works. He went there with his wife, hoping to find the right conditions for continuing his work in astronautics and to meet Tsiolkovsky, with whom he had been corresponding. The unexpected death of Tsiolkovsky in September 1935, however, made any personal contact impossible. Nevertheless, Ary Szternfeld had the opportunity to remain and work in RNII (Scientific and Research Institute of Jet Propulsion) in Moscow, together with designers and constructors of Soviet rockets including S. P. Korolev, W. P. Glushko, M. K. Tichonorawow, G. E. Langiemak and J. Pobiedonoscew. This gave him an opportunity to get acquainted with rocket construction technology and its application in practice, thus enhancing his theoretical knowledge with practical experience. This experience also allowed him to supplement the contents of his book with a chapter on rocket engineering, in particular on multistage rockets and their flight into the atmosphere. G. E. Langiemak, Szternfeld's direct superior and friend, also translated his book from French into Russian and helped considerably in securing its publication in the Soviet Union in 1937.

In 1936 Ary Szternfeld and his wife became Soviet citizens. However, the following year he had to leave RNII to begin working in Moscow's machine industry, where he performed various other design and construction labor as mechanical engineer. During the war, 1941-1944, he also taught in a metallurgic technical school in Sicrow in the Ural Mountains. He could never during this period occupy himself professionally with rocket engineering and astronautics. As it was his passion, Szternfeld constantly tried to find a way to devote full time to rocketry, and he kept sending applications and suggestions to different institutes, stressing the need for taking up research work on the development of rocket engineering. He urged preparations be made for the forthcoming exploration of space, which, according to him, would become reality in the near future. All his endeavors proved to be without success. He could only continue his works and calculations in astronautics by staying up late at night and doing them in his leisure time. He elaborated many new problems from the sphere of intercontinental and space rockets launched at different angles in relation to the Earth. He also calculated many paradoxical, but economic, trajectories leading to other planets and heavenly bodies in the solar system.

These calculations won him the name, "Lord Paradox of Astronautics," similar to Oscar Wilde who was called "Lord Paradox of Literature." To show these paradoxical, in appearance, solutions to different problems which arise in rocket engineering and astronautics, the following examples can be given:

1. In certain cases the altitude of rockets flying above the Earth, after lifting-off horizontally, can be greater than those lifting-off vertically, with the same amount of fuel consumed.
2. Higher altitude of flight can be obtained by a rocket starting from Earth by temporarily reducing the pressure in the combustion chamber, or even by interrupting, for short periods, the process of fuel combustion.
3. Additional loading of the rocket during lift-off may give more favorable parameters during flights in the atmosphere at low *altitudes* than a rocket that is less loaded.
4. The increase of flight velocity of a rocket traveling along an elliptical orbit can cause it to reach its destination later than the rocket which is flying at a lower speed to the same destination point. A determined flight velocity increase gives a bigger increment of flight path length—the ellipse becomes proportionally longer to the square of velocity increase.
5. There also occur opposite cases. As an example, Szternfeld gave a precisely calculated flight from the Earth to the Moon along a semi-elliptical path, at a speed similar to that used today along that route. And so, in the case of minimum rocket flight acceleration—by only 0.8 percent—it will be possible to reduce the duration of the trip by half, or by 50 percent. The reduction of speed by that *same* small fraction of a percent (0.8 percent) will cause the rocket not to reach the Moon but to start falling towards the Earth.
6. Let us assume that a rocket lifts off at 12:00 noon from a given point of the Earth in a eastward direction and achieves escape velocity. Due to this velocity the rocket will start moving away from the Earth, so as never to return to it. If 12 hours later, at mid-night, an identical rocket starts from that same point in an eastward direction,

however with greater speed, it would seem that it would soon catch up with the first. Nevertheless, this will never happen. The first rocket will be moving away from the Sun aiming for the orbits of Mars and Jupiter, whereas, the second shall be heading for the Sun, after crossing the orbits of Venus and Mercury. This is so, since in one case there is a summation of the rocket motion velocity as *against the* Earth, and of the Earth around the Sun, whereas in the other case there is a subtraction of these two velocities. Thus their are completely different shapes of the trajectories of each rocket.

7. The shortest route to many destinations in space does not necessarily have to be the cheapest. It is usually connected with larger fuel consumption than is a route which is longer, but which has been chosen in such a way that most of it can be covered due to the action of the gravity force and with rocket motors switched-off. The motors *are only* switched on for a short distance, thus allowing for a considerable saving of fuel.

Szternfeld proved to be a master in discovering many such unexpected, and at the same time favorable, solutions, because of his unique understanding of the laws of physics and mechanics and their linking together through his remarkable insight and superb command of mathematics.

Szternfeld included several of these paradoxes in his first Russian book, *Wwiedienije w Kosmonawtiku* (Introduction to Astronautics), which was in general very well received in the U.S.S.R. M. K. Tichonoravov, the builder of the first Soviet rocket run by liquid propellants in 1938, among others, wrote the following words:

> All calculations made by Szternfeld are much more accurate than those of Oberth, Esnault-Pelterie and Hohmann. Whereas, one very important thing should be stressed at this point, and i.e., that A. Szternfeld's calculations from the point of view of interplanetary travel are much better than those of all the other scientists . . . . Whilst all scientific investigators of interplanetary flight routes did not go beyond the solar system, A. Szternfeld, by applying the relativity theory (which Esnault-Pelterie tried to do before, however, without success) calculated the routes to the nearest stars and obtained quite good results . . . . For the first time the theory of the multi-stage rocket was developed by A. Szternfeld in his book . . . . The author, also for the first time, elaborated the theory of interplanetary signaling.

The success that the 1938 book enjoyed, especially in the Soviet Union, did not make Szternfeld's life much easier. Not being able to work professionally in the field for which he had such a passion, he had to take up jobs in different technical and industrial establishments in order to earn a living and maintain his family. Even so, he continued to publish the results of his laborious calculations and studies in astronautics and rocket engineering, virtually all conducted during his free time, in articles and in popular scientific books. He tried to present the contents of these books, often containing the results of complicated scientific research, in the most comprehensible manner possible—and thus, he soon became well-known, first in the U.S.S.R. and then abroad.

In 1949 his book, *Poliot w Mirowoje Prostranstwo* (Flight into Space), was published in 50,000 copies. It quickly sold out. In 1950, Szternfeld's booklet, *K. E. Ciolk-*

owskij i Mieżplanetnyje Putieszestwija (K. E. Tsiolkovsky and Interplanetary Travel), was published. In 1955 his second popular scientific book, entitled simply *Mieżplanetnyje Polioty* (Interplanetary Travel), was issued in a large press run of 100,000 copies and had to be reprinted in an equal number of copies. His next book, *Iskusstwiennyje Sputniki Ziemli* (Artificial Satellites of the Earth)," was published in 1956. After *Sputnik I*, it was supplemented and again published in 1958 under the title *Iskusstwiennyje Sputniki* (Artificial Satellites) in a total of 150,000 copies and became in the Soviet Union something of an encyclopedia of knowledge on artificial satellites. These books presented a running compilation of Szternfeld's thinking on the calculations of orbits; principles of motion; types of artificial satellites (among them geostationary satellites); essential orbital velocities; visibility of artificial satellites from the Earth; lift-off and landing of these craft; carrier rockets; life of the crew on board artificial satellites of the Earth; future satellites; and space stations and laboratories on Earth's orbit. The 1958 book by Szternfeld, as well as his first work, *Wwiedienije w Kosmonawtiku* (Introduction to Astronautics), became obligatory reading for cosmonaut candidates in the U.S.S.R.

Iskusstwiennyje Sputniki (Artificial Satellites) was also published in other countries of Europe and in the United States, selling more than 200,000 copies, and gaining for Szternfeld an audience for his ideas outside the Soviet Union. Willy Ley, in his introduction to this book, when published in the United States under the title *Soviet Space Science*, wrote: "Considering its qualities, the book is one of the best reviews on the subject ever published in any country. . . ."

Szternfeld's next book *Ot Iskusstwiennych Sputnikow k Mieżplanietnym Poliotom* (From Artificial Satellites to Interplanetary Flights) had a more popular character and was also widely read. It was first published in 1957 in Moscow, in 100,000 copies, and a second edition appeared in 1959. Szternfeld followed this in 1960 with the publication in Bratislava, Czechoslovakia, of a collection of short popularized scientific stories entitled *Človek Pokoruje Vesmir* (Man Conquers Space) and in 1967 with a book called *Sladami Kosmonautycznych Koncepcji z lat 1929-1936* (Following the Astronautical Conceptions through the Years, 1929-1936), published in Szczecin, Poland, in the Polish language.

Szternfeld's publishing efforts over the years were impressive. Books written by Szternfeld have had a total of 85 printings in 36 languages, and total sales of more than one million copies in 29 countries of Europe, America, Asia, Africa, and the nine Soviet Republics. Apart from his books, Ary Szternfeld published more than 400 scientific articles and historical essays in many professional and scientific journals and in popular magazines of many nations, each adding to either the body of scientific knowledge or enhancing the popular perception of it. He also wrote for a variety of daily newspapers, mainly in the U.S.S.R., Poland, and France, but also in Italy, Czechoslovakia, East Germany, Bulgaria, Romania, the United States, Great Britain, Belgium, West Germany, Sweden, Switzerland, Finland, Portugal, Mexico, Brazil, Argentina, Korea and China. His most widely circulated article, "On Interplanetary Travel," was picked up by the United Press Agency and run in more than 2,500 dailies in Western Europe and both Americas.

More than a popularizer, although that was a valuable aspect of his work, Szternfeld remained professionally active throughout his career and participated in numerous conferences of scientific institutes in the Soviet Union, France, and Poland. For example, on 25 August 1945 he gave a lecture on the consumption of rocket propellant during a flight through the atmosphere at a predetermined angle to the Academy of Sciences of the U.S.S.R. in Moscow. He also gave the pathbreaking scientific papers:

1. 3 March 1951—during the 3rd Meteorite Conference in Moscow on the Tunguska Meteorite and on the dead navigation seasons in interplanetary space.
2. 26 May 1955—in the U.S.S.R. Academy of Sciences in Moscow "On the possibility of jump-reduction of space flight duration with a uniform increase of rocket velocity."
3. 4 September 1956—during a meeting of the Polish Astronautical Society at the Technical University in Warsaw, a paper on "Some Problems Connected with Sending Artificial Satellites of the Earth and with Choosing Interplanetary Trajectories."
4. 13 April 1961—in the Lorrainian Scientific Society in Nancy, France, a paper on "Ideas of Priority in Astronautics." This lecture was also delivered for a second time, in a more complete form, at the University in Warsaw on 27 July 1964.
5. 29 November 1976—lecture at the Technical University of Warsaw in Poland, entitled "Paradoxes in Astronautics".

Ary Szternfeld was also the author of several proposals for patents submitted in Belgium and the Soviet Union, referring among others to a remotely controlled robot that could perform difficult and dangerous-to-manage tasks both on Earth and in space flight. From 1953 to 1960 he was editor of the department of "Astronautics" in the bulletin, *Refieratywnyj Zurnal* (Journal of Abstracts), published by the Academy of Sciences of the Soviet Union. At the beginning of 1954, together with General Krasnojurczenko and Colonels Warwarow and Chlebcewicz, as well as several others, he founded the Astronautic Section attached to the Czkałow Aeroclub in Moscow, and for several years he conducted periodic seminars there on space navigation.

Even with these accomplishments Ary Szternfeld believed he had to fight for astronautics to be accepted by the scientific world as a legitimate field of human activity. He acted stubbornly and persistently for more than thirty years as an advocate of astronautical research, seeking to overcome the technical difficulties and human indifference. He did live, however, to see what he viewed as a great vindication—human space flight—and even more, the Yuri Gagarin flight in 1961 used many of the mathematical models Szternfeld had calculated and proved a quarter of a century earlier.

In 1974 his fundamental work *Wwiedienije w Kosmonawtiku* (Introduction to Astronautics) was published for the second time in the U.S.S.R., without any substantial changes from its first edition in 1937. It did, however, contain numerous additional data on space flight and on experiments carried out in the meantime, all of which confirmed the author's original theoretical expectations of 40 years earlier.

In the foreword to that second edition, the Academician Professor Dr. Jurij Pobiedonoscew wrote: "Not every scientist has the honor to have his book published again more than 30 years after its first edition. The second edition is an act of gratitude by a new generation of scientists to the pioneer of astronautics, who elaborated its principles at the time when many of the people going into space today were not yet born".

This Soviet scientist, with time, lived to receive international fame and several high distinctions and scientific honors of the Soviet Union, France, and Poland. Szternfeld obtained three Honoris Causa degrees—in 1961 in physical and mathematical sciences from the University of Nancy, in 1965 in Technical Sciences from the Academy of Sciences of the U.S.S.R. in Moscow, and in 1977 at the National Polytechnical Institute of Lorraine in France. The Astronomical Council of the Academy of Sciences of the U.S.S.R. gave him an honorary diploma in 1965 for his many years of studies and popularizing scientific knowledge in the field of astronautic works, as well as a commemorative award of "Meritorious Observer of Artificial Satellites." That same year, Szternfeld also obtained the honorary title of "Meritorious Worker Actively Engaged in Science and Technique of the RFSRR" for merits in the field of astronautics.

In addition to awards in the Soviet Union, in 1960 the Lorrainian Scientific Society in Nancy, France, awarded to the Soviet pioneer the rank of honorary member, and in 1966 similar status was also awarded by the Academy of Sciences and the Scientific Society in Nancy. The Polish Astronautical Society gave this scientist of Polish origin an honorary award, and his home town, Sieradz, commemorated him on 17 May 1963, by conferring on him the distinction of "Honorary Citizen of Sieradz." On 25 January 1965, the Municipal Council of Sieradz also conferred on him the title of "Merited for the Town of Sieradz." Also in January, he received the Robert Esnault-Pelterie Medal from France, and in 1978 he was awarded the Gold Medal of the Eastern Industrial Society in France. Two years later, on 5 July 1980, Ary Szternfeld died in Moscow at the age of 75.