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Chapter 23

WALTER HOHMANN'S CONTRIBUTIONS TOWARD SPACE FLIGHT: AN APPRECIATION ON THE OCCASION OF THE CENTENARY OF HIS BIRTHDAY*

Werner Schulz†

After World War II when the first attempts to be considered as serious as well as promising were made to put space flight into practice, including the planning of flights to the Moon and the neighboring planets, one could, as far as suitable orbits from Earth to Venus and Mars were concerned, fall back on studies carried out more than 30 years ago by German engineer Walter Hohmann.

During World War I Walter Hohmann had first begun to calculate the amounts of fuel, mass and flight time that would be required for flights from the Earth to other planets by vehicles with rocket propulsion. In 1925 the results of these calculations had been published in his book *The Attainability of Heavenly Bodies*. This book was intended to contribute to the recognition that space flight was to be taken seriously and that the final successful solution of the inherent problems could not be doubted if the existing facilities in the field of rocket technology were purposefully perfected.

Who was this Walter Hohmann, and what made him occupy himself with something the general public could only have considered as being utopian? What did Walter Hohmann achieve, and what further effects did his investigations have?

WALTER HOHMANN'S EARLY YEARS, HIS EDUCATION AND HIS CAREER

Walter Hohmann was born 18 March 1880, which means that he spent his formative years at a time when technology, industrialization and natural sciences expanded enormously and had an equally enormous impact. There always had been men, who had been fascinated by the idea of flying up into the air, of leaving the Earth and traveling to other planets. By the end of the 19th Century this age-old dream appeared no longer as a mere fantasy. Various plans were made in Europe as well as in America endeavoring to realize atmospheric flights with craft lighter or heavier than air. Some scientists, however, were more ambitious and thought even

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further: The German Hermann Ganswindt (1856-1934) and the Russian Konstantin Eduardovich Tsiolkovsky (1857-1935) developed in the 1880s and 1890s scientifically correct ideas on how to carry out space flight by means of rocket propulsion. The general public, however, was unaware of these plans for the future, and Hohmann too knew nothing of Ganswindt and Tsiolkovsky when he began to concern himself with the problem of space flight.

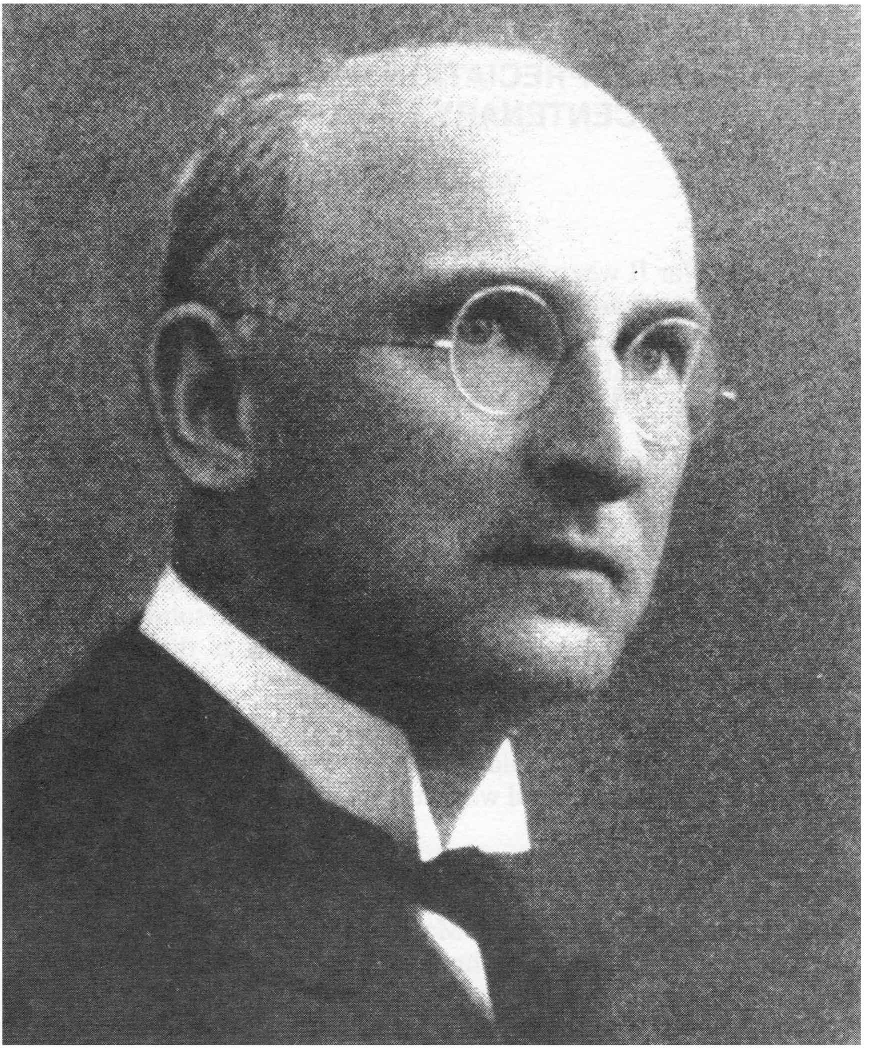

Figure 1 Walter Hohmann (March 18, 1880 - March 11, 1945).

Walter Hohmann was born in Hardheim, Odenwald, where his father was general practitioner and surgeon at the local hospital, at the same time acting as court physician to the Prince of Leiningen in the nearby Amorbach. The first six years of his life were spent in Hardheim, then, in 1886, the Hohmann family emigrated to South Africa, where his father set up a considerable surgery in Port Elizabeth and played quite a role in society.

The young Walter stayed with his parents in Port Elizabeth up to the age of 11, and it was there under the starry sky of the Southern Hemisphere that his love for astronomy was awakened. In 1891, when he had finished the English primary school in Port Elizabeth, his parents sent him to a tutor in Wuerzburg to enable him to obtain a classical education in Germany. In 1900, Walter Hohmann passed the Abitur and took up civil engineering at the Technical University of Munich from which he graduated with the diploma examination in 1904. During his course of studies he had also followed lectures on ballistics while still pursuing his particular interest in astronomy. As he stated in a letter of 30 December 1926 to the Russian rocket and space flight specialist Nikolay A. Rynin, who was editor of a rocket encyclopedia of several volumes, entitled *Interplanetary Traffic*, it was his pronounced interest in astronomy and ballistics that led to the studies which resulted in his investigating problems of space flight.

After taking his diploma examination in civil engineering Walter Hohmann worked with various firms in the fields of underground and surface engineering and bridge building in Vienna, Berlin and Hanover. From 1909 to 1911 he held a post as lecturer for statics, bridge building and reinforced concrete construction at the Technical University of Hanover. In 1911-12 he returned to industry to work with a firm in Breslau, but he found no fulfillment in his work for industry, his ideal being rather to exploit his talents and his knowledge for the benefit of the greater public. In 1912 he therefore took over a post as civil engineer at the Städtisches Hochbauamt (the Local Planning Authority) in Essen, where he had to set up and run the office for statics as well as the testing laboratory. At the same time, however, he continued to do research work in his own particular field of studies: In 1916 he completed his doctoral dissertation on the combining of old and new concrete in reinforced concrete structures, which he submitted at the Technical University of Aachen. Due to delays because of the war he did, however, not obtain his doctorate till 1920. In the meantime he had married in 1915.

Hohmann stayed in Essen for the rest of his life. In 1922 there were some negotiations about his taking up a professorship at the Badische Höhere Technische Lehranstalt, an advanced college of technology, in Karlsruhe, but these negotiations failed because of difficulties with regard to the recognition of the number of years he had been employed in the civil service.

Hohmann was a most conscientious worker. Even when, with World War II going on, working conditions changed for the worse because of the continuous air raids and the bombings of the city, and his health began to fail from lack of sleep and malnutrition, he refused to retire prematurely. By the beginning of March 1945 he had become so weak that he had to be taken to a hospital at the outskirts of Essen, where he died 11 March 1945, one week prior to his 65th birthday. He was laid to rest at Essen-Bredeney Cemetery.

HOHMANN'S WORK IN SPACE FLIGHT MECHANICS

From the years Hohmann spent in Breslau, 1911-12, two events are memorable which show him as a young man of some originality in his reflections on himself and on the world in general:

On 19 November 1911 he wrote a letter to himself which begins like this:

My dear friend,

Today is the day to realize the ideas of writing the "Letters to Myself" which you shall answer in ten years time, if you are still alive by then. If not, bad luck. Why do I write to myself? Firstly, because nobody else would take any interest, and secondly, because I regret not having already attempted ten years ago to put my innermost feelings on paper to enjoy myself rereading them now. For, really, almost everything I cherished then makes me smile now, though not always without some regret, and many things I objected to then, I take for granted today...

Another man might have started a diary, but Hohmann intended to verify his thoughts and ideas ten years later. He did, however, not carry out his plan but stopped after three years at the outbreak of World War I. There are about 90 pages of "Letters to Myself" bearing on such topics as love, marriage, education of children, honor, patriotism, and religions, showing how the author reflected critically on social and other problems of his time.

The second memorable event mentioned refers to Hohmann's decision of further pursuing his astronomical and physical interests which led him to his investigations of the theory of space flight. As far as being interested in questions of astronomy was concerned, Walter Hohmann was not the only one in his family to show such an inclination. Wilhelm Trabert (1863-1921), a cousin of his and 17 years his senior, held professorships in Innsbruck and Vienna and was director of the Central Meteorological Institute in Vienna. He was the author of the Göschen book *Meteorology* which was very well known at the time. In 1911 Trabert published a *Textbook on Cosmic Physics* dealing with the motions in the universe. Hohmann not only studied this book most carefully but also acquired further books on astronomy and astrophysics, on the Moon and on comets, on the genesis of stars, and even an edition of Ptolemy. He had also since 1908 subscribed to the popular scientific journal *Kosmos* published by the Franckh'sche Verlagshandlung in Stuttgart, and he had read Jules Verne's *Journey around the Moon* and the novel by Kurd Lasswitz *On Two Planets*. In Jules Verne's novel, mention was made of rockets which the travelers to the Moon carried with them to decelerate their vehicle, and Kurd Lasswitz even made use of the reaction principle carried to the extreme of radiation at the velocity of light. Thus, Walter Hohmann with his background of science, celestial mechanics and ballistics and with the knowledge of mathematics he had acquired in the course of his studies of civil engineering had at his disposal all fundamentals for developing the theory of space flight.

The leading questions from which Hohmann set out in his investigations of space flight mechanics were:

1. What data would one have to foresee if a body (space vehicle) were to be accelerated vertically from the surface of the Earth by means of expelling or radiating

parts of its mass up to a velocity which would allow it to attain in its following free flight a precalculated height? The borderline case which is of particular interest in the case in which the vehicle is accelerated up to the escape velocity which allows it to leave the gravitational field of the Earth, i.e., to attain an infinite summit height in its free flight.

2. What data would one have to foresee for the retardation of a space vehicle approaching the Earth in free flight from a great distance to the velocity zero?

3. Provided the answers to the first two questions are such as to indicate that the problem of space flight can be solved, the third question that arises is whether and in which way the conditions that apply in the case of the second question can be transferred to a vehicle being vertically accelerated to escape velocity.

4. The answers to all three questions proving satisfactory, the aim is then to study the conditions of flying from the Earth to other planets.

Leaving the Earth

In order to investigate the first question Hohmann supposed that the mass expelled per time unit, dm/dt, is always proportional to the mass still present, m, so that $dm/dt = am$, $a =$ const. If the mass is expelled with the exhaust velocity c, $c =$ const., the total acceleration of a space vehicle in vertical flight is the difference between ac and the gravitational acceleration. It presents no difficulties to determine the remaining mass after the duration of a certain time in relation to the initial mass, to calculate the time (at least approximately, because the integral is not to be solved elementarily) necessary to accelerate the vehicle to a velocity prescribed, e.g., the escape velocity, and to determine the height at which the required velocity will be reached.

The way Hohmann obtained the values for the vehicle's acceleration ac and the exhaust velocity c necessary for the numerical calculations was as follows:

The vehicle's acceleration had to be bearable for man for the duration of several minutes. A man jumping from a height of 2 m decelerates his velocity to zero within a fraction of a second and about half a meter's height by bending his knees upon touching the ground. This deceleration equals approx. 40 m/sec^2, i.e., four times the gravitational acceleration. Therefore, Hohmann considered an acceleration of about 30 m/sec^2 over a span of several minutes as feasible.

With regard to the exhaust velocity Hohmann referred to the fact known to him from ballistics that an artillery shell had at that time an initial velocity of up to about 1500 m/sec. He supposed that in the foreseeable future higher velocities might be attainable and therefore chose for his calculations a value of $c = 2000$ m/sec.

Based on these values the calculations for a vertical ascent to leave the gravitational field of the Earth led to the following values for the moment when the vehicle's acceleration ceases: height about the Earth = 2110 km, velocity = 9680 m/sec, required time = 448 sec.

The ratio of initial mass to final mass equaled 825. The mass to be expelled per time unit at the beginning was 12.4 times as much as the final mass, i.e., a quite considerable amount. If, for instance, the final mass is to be $m_1 = 2000$ kg, this means an initial mass $m_0 = 1{,}650{,}000$ kg and an expelled mass at the beginning of $dm_0/dt = 24{,}800$ kg/sec.

Hohmann considered the expulsion of particles of mass by way of firing artillery unsuitable, as the gun mass would only increase the final mass and thus also the initial mass. Quote:

> "To avoid this, the operational mass $m_0 - m_1$ may be arranged so to speak like a rocket that is burning slowly while the combustion products are expelled with the required velocity c into the space assumed empty."

The fuel was to be arranged as a tower of constant weight/area ratio, since the mass to be expelled per second must be proportional to the rocket cross-section as well as to the mass remaining, so that each cross-section is proportional to the mass resting above it. For the assumed case of the final mass of 2000 kg there follows that if the upper cross-section of the tower has a diameter of 0.65 m, the tower has a height of 27 m and a basic cross-section of 18.7 m.

Finally, Hohmann took into account how far the previously ignored air drag would influence the values he had arrived at. He found that the mass ratio would be raised from 825 to 933 and that the time required for expelling the mass particles would increase from 448 to 456 sec.

Thus, the answer to Hohmann's first question could be considered as favorable to the possibilities of space flight.

In this context it must be mentioned that Hohmann was not interested in rocket technology. His investigations related to the basic question of whether space flight would be possible. His calculations were based upon the assumption of the idealized case in which no unnecessary masses had to be carried during the flight. Thus he had arrived at the conception of the tower of powder and need not apply the principle of multi-stage rockets with separation of masses.

In a letter of 12 March 1958 Hermann Oberth referred to Hohmann's achievements saying:

> "The basic idea of constructing space vehicles that Hohmann had in mind has not been followed up since liquid fuel appeared more promising. Hohmann had suggested a powder rocket in its size and form like the Eiffel Tower."

The numerical values for the tower mentioned above show, however, that this reference to the Eiffel Tower was not quite appropriate. Oberth's error was probably the result of the fact that Valier, who supported the idea of realizing space flight by means of developing the airplane by rocket propulsion, had once described his conception of the launching device in a letter addressed to both, Oberth and Hohmann, saying:

> "Until recently I was thinking of take-off tracks with a sort of ski-jump. Now I am thinking of an Eiffel Tower with two or three tracks inside (as with an elevator) as leading tracks for the rocket that is to be launched vertically from the inside of this tower."

So it is in connection with Valier and not in connection with Hohmann that the Eiffel Tower was brought into the discussion.

Return to the Earth

Considering the second question, the return to the Earth, Hohmann realized at once that the deceleration of the space vehicle coming out of space and approaching the center of the Earth solely by expelling mass--this time expelling mass in the direction of motion--would result in an unfeasible ratio of initial mass at launching time and final mass at landing time. As a solution to this dilemma Hohmann considered using the Earth's atmosphere for retardation purposes.

For his calculations Hohmann needed data concerning the dependence of air pressure or air density on the height above the Earth. Results of balloon experiments were only available for up to a height of 10 km. On the basis of these experimental results and on the assumption that in a height of 400 km the air density is zero, Hohmann arrived at the necessary data by theoretical reflection.

Next, he recognized that the space vehicle approaching the Earth could not enter into the atmosphere vertically, as it would not be possible to decelerate its velocity of approx. 11 km/sec to zero within the short distance of 400 km without damage to the vehicle and/or its passengers. The entry into the atmosphere had to be approximately tangential. The trajectory of the returning vehicle would therefore have to be parabolic.

In order to determine the effectivity of retardation in various heights Hohmann estimated the air drag. To a vehicle entering into the atmosphere with parabolic velocity at heights above 100 km there is very little air drag. At heights below 75 km the air drag becomes excessive. The final result of his calculations was that with a parabolic orbit with its vertex at a height of 75 km the length of the retardation path between the heights of 100 km, 75 km and again 100 km amounted to 1610 km, the maximum deceleration equaling 19.5 n/sec^2. The vehicle then leaves the atmosphere again at the height of 400 km following, according to the first Keplerian law, an elliptical orbit around the Earth with a semi-major axis of 25,000 km and a semi-minor axis of 16,800 km. At a height of 400 km there occurs the second entry into the atmosphere and retardation is again experienced. After five such elliptical orbits the vehicle finally stays in the atmosphere and commences a gliding flight, which Hohmann also investigated with regard to deceleration and loading. Hohmann thought of using parachute-type breaks and wings of adjustable inclination to the horizon.

Hohmann also went into the problem of heating of space vehicles through atmospheric friction. His outline shows an understanding of the re-entry problem, all the more remarkable if one bears in mind that at that stage of knowledge he could not be in a position to oversee fully the problem of aerodynamic heating.

At the end of this chapter on the return to Earth, Hohmann mentioned briefly that the ellipses on which his calculations were based are only approximations of the real orbit which rather takes the form of a spiral.

Feasibility of Return after Vertical Ascent to Escape Velocity

Hohmann's third step then was to enquire whether after the escape velocity had been reached the space vehicle could be directed in such a way as to enable it to return to the Earth tangentially. He considered the case in which the space vehicle ascends vertically at escape velocity but not in order to continue flying infinitely but rather to be decelerated so as to reach a summit height of 800,000 km, i.e., about twice the distance to the Moon. The deceleration is to be achieved by firing a gun shot in the flight direction at a velocity of 1000 m/sec whereby 11% of the vehicle's mass is expelled. Upon reaching the desired height and having reduced the vehicle's velocity to zero, again by way of firing a shot, mass has to be expelled tangentially to the Earth's surface so as to make the trajectory an ellipse (instead of a parabola as in the previous sub-section). This ellipse is to be chosen in such a way as to have the point closest to the Earth at a height of 75 km. The velocity the space vehicle must reach is 90 m/sec. The further flight then develops as in the previous case with deceleration through the Earth's atmosphere at the height of between 100 and 75 km.

In this context Hohmann made the following original suggestion with regard to the position control of the space vehicle: If, for reasons of weight reduction, only a single gun that is firmly fixed can be used, it is possible to bring this gun into any position by rotating the space vehicle. This rotating can be achieved by having the passengers climb about the wall of the vehicle by means of rungs put there for this purpose.

Finally, Hohmann made a rough calculation as to the values for initial and final masses for such a flight with a crew of two, and all necessary equipment including a gun and ammunition for the directional shots. The result was a value for the initial mass that was 1.5 times as great as the value on which he had based his calculations in the first sub-section. That means that the dimensions of the powder tower for the propulsion would--bearing in mind also the influence of the air drag during the ascent--increase by the factor 1.192 as compared to the values for the former example: height of a tower = 32 m, upper diameter = 0.77 m, lower diameter = 22 m.

Interplanetary Travels

The results thus gained convinced Hohmann that it was worthwhile to tackle the fourth point, the problem of interplanetary space flight. Let us look at his notes on a flight from Earth to Venus.

Hohmann based his calculations on the assumption that the space vehicle has, as in the previous sub-section, to be brought up to a height of 800,000 km above the Earth. If at that point mass is expelled in such a way as to accelerate the space vehicle to a velocity of, e.g., 3 km/sec instead of 0.09 km/sec as in the case of the tangential return to the Earth, the trajectory becomes a hyperbola in relation to the

Earth and the vehicle pursues a path directed away from the effective range of the Earth's gravitation until it is finally subject only to the attraction of the Sun. Depending in which direction the vehicle is accelerated at a velocity of 3 km/sec, i.e. along or against the Earth's velocity, the vehicle describes an ellipse about the Sun either outside or inside the Earth's orbit.

Earth and Venus describe ellipses around the Sun with small eccentricities (e_{Earth} = 0.0167; e_{Venus} - 0.0068) in planes slightly inclined towards each other (3.4^0), and the planes are traversed in the same direction. Hohmann now made certain assumptions in order to simplify his calculations for the transfer trajectory from Earth to Venus without, however, falsifying the results with regard to the order of magnitude. He assumed that the orbits of Earth and Venus around the Sun were circular orbits within the same plane. Thus the transfer trajectory of the space vehicle leaving the Earth's orbit tangentially and entering tangentially into Venus' orbit became half an ellipse, which made it quite easy to determine that in order to leave the Earth's orbit the space vehicle must have a tangential velocity of 2.4 km/sec against the Earth's velocity. If the mass is expelled at a velocity of c = 2000 m/sec and if one adds to this an additional safety factor of 10% for correcting deviations by perturbations, the ratio of total mass before to mass after exhaust equals 3.65. According to the third Keplerian law the flight time from Earth to Venus is 146 days.

It was equally easy to determine when the space vehicle had to be launched, i.e., what the constellation of Earth to Venus had to be for the vehicle entering Venus' orbit to actually reach the planet.

If the space vehicle continued on its elliptical orbit it would re-enter the Earth's orbit, but not at a place where the Earth was to be found. Hohmann considered two possibilities to touch down upon the Earth again:

1. Circling Venus till it was suitable to return to Earth,
2. Returning to Earth by a detour leading first beyond the Earth's orbit on a half-ellipse and then consisting of a further half-ellipse tangent to the Earth's orbit.

The ellipse from Venus' orbit beyond the Earth's orbit has to be chosen so that the three half-ellipses from leaving the Earth's orbit to returning to it can be covered in 1.5 years. Only then will the space vehicle meet the Earth. The consumption of mass to be expelled is in both cases approximately the same. What makes Case 2 interesting is the fact that the ellipse leading beyond the Earth's orbit comes close to Mars' orbit so that with a suitable constellation of Earth, Venus and Mars a passage to both the Earth's neighboring planets at relatively small distances could be achieved in a single journey.

Hohmann realized that choosing a half-ellipse as transfer trajectory between orbits presents the most economic transfer with regard to the consumption of mass to be expelled. After space flight has been put into practice, this form of transfer is still of importance. It is known by the name of "Hohmann transfer".

A transfer consisting of two half-ellipses as described in the above-mentioned case (2) for the flight from Venus' orbit beyond the Earth's orbit to the vicinity of Mars' orbit and then back to the Earth's orbit is called a "bi-elliptical transfer".

HOHMANN'S PUBLICATIONS IN THE FIELD OF SPACE FLIGHT

Die Erreichbarkeit der Himmelskörper (The Attainability of Celestial Bodies)*

By the end of World War I Hohmann had reached most of his conclusions. For the time being--first the war and then the ensuing period of inflation in Germany--publication of these results in form of a book was, however, unthinkable. But when the monetary system in Germany was stabilized again on 1 December 1923, Hohmann immediately approached the Franckh'sche Verlagshandlung in Stuttgart and offered them his manuscript *On the Attainability of Celestial Bodies*. On 22 January 1924 he was turned down by the publishers. About a year later, however, he came across a reference in Vol. 12 (1924) of the Journal *Die Naturwissenschaften* (The Sciences) on Hermann Oberth's book *Die Rakete zu den Planetenräuman* (The Rocket into Planetary Space) published by R. Oldenbourg, Munich and Berlin. On 17 January 1925 he therefore turned to these publishers. Already two days later he received an answer from Oldenbourg saying that they were quite interested in any serious contribution to the problem of space flight and requesting to see his manuscript. The publishers then asked Max Valier, whose book *Der Vorstoss in den Weltenraum* (The Advance into Space) was also published by Oldenbourg, for his comment and suggested that Hohmann should also send a copy to Professor Oberth in Romania. Since, however, only one handwritten copy of the complete manuscript existed, Hohmann asked the publishers to forward his draft to Oberth.

Both references were highly favorable. On 13 February 1925 Max Valier sent Hohmann a letter of seven pages, praising the clarity of his outline, but at the same time suggesting to take into consideration also exhaust velocities of $c = 3000$ and 4000 m/sec as being not unrealistic if liquid rocket fuel were to be used and as having already been considered by Oberth in his book. Hohmann was quite willing to do so and in his answering letter to Valier of 18 February 1925 only expressed his regret not to have known about Valier's and Oberth's books earlier as he would have been much less reluctant in the assumptions he had made concerning the attainable exhaust velocities. For publication he based his calculations also on the values $c = 2500$, 3000, 4000 and 5000 m/sec, indicating only that with the use of liquid fuel rockets the engine, the fuel containers and the nozzle had to be carried as ballast, which had not been taken into account in his calculations.

Another of Valier's suggestions concerned the transfer ellipses. Valier thought that in order to reduce flight time it might be useful to investigate also transfer with ellipses not tangent to the planetary orbits but intersecting them.

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* **Editor's note:** The title of the translation published by NASA in 1960 is The Attainability of Heavenly Bodies.

Finally, Valier pointed out the possibility of landing without making use of retardation ellipses but using instead, immediately after entering into the Earth's atmosphere, an elevator to maneuver the vehicle into a circular orbit.

In a three-page letter of 7 July 1925 Oberth commented on Hohmann's manuscript, saying that there was no doubt that his reference for Oldenbourg was a positive one, but indicating at the same time that some points might be improved in order to avoid unnecessary criticism which is always based upon details that are unimportant. Among other things Oberth commented on the temperature balance of the space vehicle.

When all these additions had been incorporated, the book appeared by the end of 1925. It was entitled *Die Erreichbarkeit der Himmelskörper* (The Attainability of Celestial Bodies), and it was divided into five chapters subtitled: "Leaving the Earth", "Return to Earth," "Free-Space Flight", "Circumnavigation of Celestial Objects" and "Landing on Other Celestial Objects". In all it comprised 88 pages, including 28 diagrams. It had an edition of 2100 copies, of which 1200 were sold in the following years. In 1973 a reprint was published by Dr. Martin Saendig oHG in Walluf near Wiesbaden. A translation into English was commissioned by NASA and appeared in November 1960 as "Technical Translation F-44" under the title *The Attainability of Heavenly Bodies*. In 1977 appeared a book in the Russian language which contains, among other works of rocketry pioneers, also a translation of Hohmann's book.

Hohmann's Contribution to W. Ley's "Die Möglichkeit der Weltraumfahrt" (The Possibility of Space Travel): "Fahrtrouten, Fahrzeiten, Landungsmöglichkeiten" (Flight Routes, Flight Schedules, Landing Possibilities)[2]

In order to make the idea of space flight better known and more popular to a wide public, Willy Ley, a young author of 22 years, most enthusiastic about space travel, published his book *Die Möglichkeit der Weltraumfahrt* (The Possibility of Space Travel) in 1928, for the writing of which he obtained the cooperation of a number of competent authors such as Hermann Oberth, Franz von Hoefft, Walter Hohmann, Karl Debus, Guido von Pirquet, and Friedrich Wilhelm Sander. The book aimed at representing the various aspects of rocket technology in a clearly comprehensible way within everybody's grasp. Hohmann's contribution was a partly extended new version of the last two chapters of his book *Die Erreichbarkeit der Himmelskörper*. On 39 pages he outlined "Flight Routes, Flight Schedules and Landing Possibilities" in interplanetary missions. Of particular interest is the idea expressed in this article that in order to explore Mars or Venus it should not be the space vehicle with its entire crew that should attempt the landing at and restarting from the planet, but "some sort of lighter side boat only" with a single observer, the space vehicle meanwhile circling the planet. Thus Hohmann describes here already what the American astronauts realized when landing on the Moon more than 40 years later.

HOHMANN'S FURTHER ENGAGEMENT IN PURSUING THE IDEA OF SPACE FLIGHT

Although Hohmann published only the two studies mentioned above, he was involved in the subject of space flight up to the end of his life.

The publication of his book resulted in his getting into contact--either personally or by correspondence--with many of those who were engaged in the fields of rocket technology and space travel in Europe, either as technicians or as scientists on the experimental or on the theoretical side or as writers or journalists. Among them were, apart from Oberth, Valier and Ley, Rudolf Nebel, Johannes Winkler, Otto Willy Gail, Werner Bruegel, Konstantin Tsiolkovsky, Nikolay Rynin, Jakov Perelman, Robert Esnault-Pelterie, Ary Sternfeld, to name only those best known. Particularly close and friendly was Hohmann's relationship to Valier. They not only exchanged letters, but Valier also repeatedly visited Hohmann and, when coming to see him in Essen, stayed with him. Valier relied on Hohmann's help in solving mathematical problems, at times, apparently, to quite an extent, for one time, when he had raised one of his problems, he closed his letter to Hohmann saying:

> "But all this will take a lot of time, which you had much rather spend with your most charming wife. I really do fear your wife may resent my putting ever new problems before you."

As already mentioned when outlining his *curriculum vitae*, Hohmann was a most conscientious worker, who made a clear distinction between personal and professional interests. All his activities in the field of space flight he pursued in his spare time, never drawing on assistance in his official capacity, writing all his letters personally and by hand, so that indeed the time he spent on the problems of space flight was lost to his family. The only break he permitted himself each year was a short stay in the Alps mountaineering. There on clear nights he could watch the stars.

Among Hohmann's involvements in questions of space flight, mention should be made of his membership in the Verein für Raumschiffahrt (VfR) (Society for Space Travel) which had been founded in 1927 and whose number of members had risen to almost 500 within one year. When Hohmann put his name down for membership in October 1927, the president, Johannes Winkler, immediately suggested he become a member of the executive committee. Hohmann consented. But when in 1930 when asked by Oberth, then president of the VfR, to take over this office as he himself wished to resign from it and considered him, Hohmann, the suitable candidate, Hohmann declined, partly because too much of his time was taken up by his job, but also because he felt that Oberth had more scientific authority in opposing the most forward district group from Berlin, which he considered too voluble and somewhat lacking in seriousness.

On various occasions Hohmann gave lectures before technically or scientifically interested gatherings in the Ruhrgebiet. When asked for his opinion, he always made a point of answering the letters, which quite often came from abroad, in a most sympathetic and helpful manner. For a while he acted as tutor in theoretical questions of space flight to two young men working for Krupp in Essen.

Whereas the general public during the 1920s was quite openminded and even enthusiastic as far as the idea of space travel was concerned, scientists tended to be more reluctant and skeptical, or even showed a decidedly negative attitude, a phenomenon not uncommon when progressive ideas spring up, and up to a point certainly understandable, when one bears in mind how many "inventors" bother scientists with silly suggestions. In 1927 H. Lorenz, Professor of Technical Mechanics at the Technical University of Danzig and President of the Verein Deutscher Ingenieure (VDI) (Society of German Engineers), published an article entitled: "The Possibility of Space Flight"[3] in the Journal of the VDI, in which he came to the conclusion that only a very small part of the initial mass of the rocket would be able to leave the Earth's gravitational field, and that this would certainly put a stop to all plans of realizing rocket flights in the near future. Lorenz's article was based on rather arbitrary assumptions. The main point in Oberth's studies, namely, the use of a step rocket with separation of masses no longer needed, was completely overlooked. In his article the publication by Goddard, Oberth and Hohmann were referred to as studies in space flight by means of rocket propulsion carried out "quite scientifically".

On the appearance of Lorenz's, article not only Oberth but also Hohmann sent letters to the editors of the Journal of the VDI. Hohmann first appreciated the importance of the fact that Lorenz mentioned fuels which made exhaust doubts concerning the general validity of Lorenz's conclusions, indicating that the assumption that the mass expelled per time unit was to be proportional to the trajectory acceleration was arbitrary and not optimal, and that although mass ratios of $m_0/m_1 = 47$ or even 198 as resulted from Lorenz's calculations might be disconcerting on first view, they did by no means exclude the feasibility of rocket flight completely.

The editor declared that because of limited space available they could not print these letters, but that Professor Lorenz would comment on them in a postscript to his article. This postscript closed as follows:

> "To avoid further misunderstanding let me say that my insistence on the unfeasibility of the rocket with such mass ratios as calculated springs from economic and constructional considerations self-evident to every engineer."

In 1932 the writer Werner Bruegel informed Hohmann of his plan to edit a book on the most famous rocket specialists and asked for his cooperation. Hohmann declined not only because he lacked the time, but also because he felt that over the last years too much had been written about rocket specialists already. He wrote to Bruegel that a revival of the previous interest in space flight could in his opinion only be achieved through results of practical experiments. This attitude is characteristic of Hohmann's personal integrity.

APPRECIATION OF HOHMANN'S ACHIEVEMENTS

Walter Hohmann was the first to calculate the amount of fuel and flight time necessary for interplanetary flight missions as well as to indicate suitable flight trajectories, thus proving that a further development of rocket technology with a view to space flight was worthwhile.

Both of Hohmann's publications contain a number of most interesting ideas. Some of them proved to be of no further value for the realization of space flight, but his conception of making use of the Earth's atmosphere for deceleration purposes when a space vehicle returns to the Earth was followed up. It led to investigations of the so-called "skip trajectories" entering and leaving the atmosphere with a small flight path angle.

Of greatest importance, however, was Hohmann's suggestion of choosing a half-ellipse as transfer trajectory between two planetary orbits. This solution, which is optimal with regard to fuel consumption when transferring between two circular orbits within the same plane, is not only applicable to flights from the Earth to other planets but also to transfers from a circular parking orbit to a circular target orbit around any one celestial body. Countless space flight theoreticians have later investigated generalizations of this type of transfer in order to determine optimal transfer between any conics (circle, ellipse, parabola, hyerbola) under varying boundary conditions. In 1969 two Americans, F. W. Gobetz and J. R. Doll, published a survey on studies done in this field in which they quoted 316 respective references from the time up to 1968[4]. Since then a great many further publications have appeared, and there are still questions to which so far no answer has been found.

In the preface to his book Hohmann insists upon the fact that he is no mathematician but an engineer, almost excusing himself for making use at times of approximation instead of strict mathematical formulas. But there is no need for such self-consciousness, for it is exactly by making such competent use of simplifying assumptions and relying on approximations that he proves himself a most efficient applied mathematician with a clear sense for the essential. For his calculations he had but pencil, paper and slide rule. It was the ingenuity of conceiving the powered trajectory as vertical ascent and calculating this up to the summit height at the velocity of zero that led him to finding, by way of then expelling mass horizontally, the half-ellipse as transfer trajectory, which even proved to be the optimal solution with regard to fuel consumption. His simplifying assumptions were quite sufficient to let him reach the goal he had set himself.

Hohmann was always good at finding the simplest way and then estimating the faults resulting from "neglectance". Such a view of solving engineering problems results in not losing reality out of one's view. This mathematical ability of Hohmann was recognized by Valier who had himself studied mathematics, physics and astronomy, but still quite frequently fell back on Hohmann for advice and help in mathematical questions.

A number of honors have been bestowed upon Hohmann. His selection for the executive committee of the Verein für Raumschiffahrt has already been mentioned. In 1931 the Österreichische Gesellschaft zur Förderung der Raumforschung (Austrian Society for the Promotion of Space Research) made him an honorary member. After World War II, A. Ananoff informed Hohmann that he had been selected corresponding member of the Section Astronautique of the Association des Aéro-Clubs universitaires et scolaires de France. By then, however, Hohmann had been dead for more than a year.

In December 1970 Wernher von Braun informed Walter Hohmann's son, Dipl.-Ing. Rudolf Hohmann, in Essen that the International Astronomical Union had agreed to the proposal to name a crater of the backside of the Moon in the Mare Orientale after Walter Hohmann. His proposal had been made, as von Braun explained in his letter, by Fred C. Durant and Ernst Stuhlinger, as well as, doubtlessly, by von Braun himself. The Crater Hohmann on the Moon is situated 18^{o}S and 94^{o}W.

In Essen-Bredeney the observatory is named after Hohmann, and a street in Essen also bears his name. In Hardheim, where Hohmann was born, a memorial tablet was put up in 1971 in the town hall.

Had Hohmann lived to see all these honors bestowed upon him, he would have in all probability, true to his modesty, appreciated most the fact that the trajectories he had investigated are now known among astronautical scientists internationally as Hohmann trajectories and are thus referred to in all relevant textbooks of space flight mechanics and astrodynamics.

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