Walter Hohmann's Roads In Space

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Abstract

Walter Hohmann (1880–1945) was a professional engineer who eventually became the city architect of Essen, Germany. In 1925 he published his masterpiece, *Die Erreichbarkeit der Himmelskörper* (*The Attainability of Celestial Bodies*), in which he demonstrated that the interplanetary trajectory requiring the least expenditure of energy is an ellipse tangent to the orbits of both the departure and the arrival planets. The "Hohmann transfer ellipse" has endured, but his investigations in interplanetary mission design go far beyond that result and represent a milestone in the development of space travel. Hohmann was a leading member of *Verein für Raumschiffahrt* (Society for Space Travel), the first important entrant in the genre of "space society." He died as the result of an Allied bombing raid on Germany near the end of the war.

I. Introduction. Isaac Newton (1642–1727), building on the work of Galileo Galilei (1564–1642) and Johannes Kepler (1571–1630), created the modern science of celestial mechanics. The progress of the discipline in the eighteenth century is crystallized in the *Traité de Mécanique de Céleste* of Pierre-Simon Laplace (1749–1827), while that of the nineteenth century is represented by Francois Felix Tisserand's (1845–1896) work of the same name.

Two significant branches have grown from this trunk.

1. In the late nineteenth century, Henri Poincaré (1854–1912) initiated an alliance between celestial mechanics and newly developing areas of mathematics such as topology. (Poincaré also played an important part in the founding of topology.) This branch has flourished throughout the twentieth century; see, for example, a critical edition in English (Poincaré 1993) of *Les Méthodes Nouvelles de la Mécanique Céleste* and Arnol'd et al. 1997.
2. At about the same time, Konstantin Tsiolkovsky (1857–1935) started the analytical study of the flight-path arts necessary for space travel, forging a second alliance for celestial mechanics, this time with engineering. New topics and new emphases were established in order to accommodate, for example, propulsive events and close encounters with the Moon and planets. This branch grew rapidly after the launch of Sputnik in 1957 and has subspecialties in trajectory mechanics, orbit determination, and maneuver analysis (e.g., Fortescue and Stark 1992).

Walter Hohmann in his seminal *Die Erreichbarkeit der Himmelskörper* (Hohmann 1925) created a work in the second category, showing how to travel from Earth to the Moon and planets and return. *The Attainability of Heavenly Bodies* (Hohmann 1960) is a translation into English of the 1925 book. The trajectory that realizes minimum energy, he demonstrated, is an ellipse tangent to the orbits of both planets. As a principle of mechanics, the "Hohmann transfer ellipse" is not restricted to interplanetary flight and applies, for example, to transfer from a circular low Earth orbit to a higher circular orbit.

The interest in minimum-energy trajectories continues to the present time—energy is a prized resource—but this class was especially important in the eyes of early researchers in astronautics. Many obstacles to space travel were apparent to these pioneers, but none more formidable than the requirement for large amounts of energy; therefore, the significance of Hohmann's discovery was immediately apparent to those who were technically versed in the mechanics of space flight.

Walter Hohmann's great contribution to astronautical progress was the discovery of a new use for an old object, the ellipse. However, his involvement in the development of concepts for space travel extended well beyond that discovery: energy and mass requirements; spacecraft design; atmospheric modeling; maneuver analysis; crew safety; extraterrestrial in-situ propellant production, and more. In addition to conducting research, Hohmann belonged to *Verein für Raumschiffahrt* (Society for Space Travel), or VfR, and participated in its work. VfR activities in education presented reasoned views of an undertaking which appeared fantastic to most people. The society also carried out a series of experiments with rockets.

II. LIFE. Walter Hohmann was born March 18, 1880 in Hardheim, a small town 40 kilometers southwest of Würzburg, in Germany. Rudolph, his father, was a physician and surgeon in the local hospital. Hohmann's mother, Emma, gave birth to two children prior to Walter: Eleonore in 1875 and Caroline in 1876. The family moved to Port Elizabeth, South Africa in 1885, staying until 1891; during this time young Walter went to an English elementary school. The young man resumed his education in Germany, attending high school in Würzburg and preparing for college entrance examinations, which he successfully passed in 1900. He studied at the Technical University in Munich and in 1904 became a certified civil engineer (*Diplom-Bauingenieur*).

Until shortly before the onset of World War I, Hohmann was employed as an engineer in various companies in Vienna, Berlin, Hanover, and Breslau. In 1912, he began a long association with the city of Essen as "*Baurat und Leiter der statischen Abteilung der Baubehörde und Material-prüfstelle der Stadt Essen*" or, as encapsulated by Ley 1957, p. 113, "city architect," and by Burrows (1998, 54), "the city engineer."

He was not a soldier during the 1914–1918 war, filling, instead, a war-service position for eight months in 1915.

In 1916, Hohmann submitted a civil-engineering dissertation on the subject of concrete structures, but it was not accepted until 1919 (Technical University of Aachen), due to wartime priorities. Now he was entitled to represent himself as "Dr.-Ing. Walter Hohmann." After the war he sought to become a professor at a technical institute in Karlsruhe and, unsuccessful in obtaining this position, remained in Essen for the rest of his life.

Walter Hohmann and Luise Juenemann were married in 1915 and had two children, Rudolf in 1916 and Ernst in 1918.

The engineer's interest in space flight began in 1912 when he read a book on astronomy (Ley 1969, 18). His son, Rudolf, recalls that during the 1920s this hobby of his father was a part of everyday life within the Hohmann family: poems, bookmarks decorated with rockets, and even birthday celebrations were infused with extraterrestrial enthusiasm.

The coming to power of the Nazis in 1933 began Hohmann's isolation from German space and rocket activity; he did not participate in developing rockets for military applications, such as the work done at Peenemünde.

Walter Hohmann died on March 11, 1945 as a result of an Allied bombing raid on Essen, a week before his 65th birthday and less than two months before the end of the war in Europe. He was preceded in death by Ernst, a soldier.

III. WORK. The category "work" refers, here, to Hohmann's efforts in furtherance of space travel, not his professional work in civil engineering. There are two divisions within this category: (1) membership in the VfR and (2) published research.

Many factors fostered the spurt of space activity within Germany after World War I. Three are of importance to the setting in which Hohmann did his work: the *Lebensphilosophie* of the period; science fiction as a cultural force; and the wizardry of Hermann Oberth (1894–1989).

While Tsiolkovsky was affected by the nineteenth-century Russian doctrine of "Cosmism," with its mystical connotations (McLaughlin 1999, 43–48), the influence of the more rationalistic "*Lebensphilosophie*" ("Philosophy of Life") colored the Weimar period (1919–1933). This set of attitudes had a romantic core in common with Cosmism, but also had sunk deep roots into technology and science (Winter 1983, 15). Walter Gropius (1883–1963) and his modernist Bauhaus school profoundly affected the development of twentieth-century architecture and exemplify, like the concepts of Hohmann and his colleagues, a tradition-breaking tendency within Weimar culture. One component of *Lebensphilosophie* was expressed through science fiction. Within that genre, the influence of Kurd Lasswitz (1848–1910), writer and philosopher, was felt by the nascent space community within Germany (Ley 1957, 45–48; Clute and Nichols 1993, 692). In Ley's estimation, "German scientists [were] preconditioned by Lasswitz to taking space-travel seriously" (Ley 1957, 114). This writer's ideas have continued to be suggestive: Johnnie Driver, a JPL engineer, adapted Lasswitz's arctic space-station concept to a contemporary setting (McLaughlin 1984, 306–307). Finally, Hermann Oberth, one of the greatest of the space pioneers, published his *Die Raketen zu den Planetenträumen* (*The Rocket Into Planetary Space*) in 1923, two years prior to Hohmann's treatise. Oberth achieved international recognition for his ideas about space travel and was a leading figure in the VfR.

Hohmann conducted research in this fertile setting and became one of the luminaries of his time and, indeed, of astronautical history.

The VfR, founded in Breslau in July 1927, was not the first of that new species, the rocket society, but it was the first one of importance (Winter 1983, 35–37). It included Hohmann, Oberth, Willy Ley (1906–1969), who was a founding member, Wernher von Braun (1912–1977) and, indeed, most in Germany who were involved in early space and rocket work. Hohmann and Oberth were inducted not long after the founding of the VfR when, in the November 15, 1927 edition of the society's publication, *Die Rakete* (*The Rocket*), they were announced as members of the directorship of the organization (Winter 1983, 37).

In 1929, the society ceased publication of *Die Rakete* in order to focus its resources on rocketry experiments; its membership decreased as a result, but the series of designs and tests served to advance the discipline from infancy to a credible branch of engineering. See Chapter 6 of Ley 1957 for a description of this work. Hohmann was offered the presidency of the VfR after Oberth left the post, but turned it down on the grounds that it would conflict with his professional duties in Essen (Winter 1983, 40).

What can be said of the consequence of Hohmann's association with the VfR? His engineering responsibilities in Essen certainly differed from the challenges posed by the new field of rocketry, but there would be common ground. An engineer of his experience would have acquired judgment about the vagaries of mechanisms, materials, and budgets. (In our time, judgment as to the traps and pitfalls of computers and computer code is a complementary virtue.) Second, Hohmann was a member of the *Verein deutscher Ingenieure* (Society of German Engineers) (Ley 1957, 118), held a responsible position with the city of Essen, and had published an important work in astronautics. That is, Walter Hohmann was in the mainstream of German engineering and had done important work within rocketry; his presence in the VfR constituted an endorsement of that organization and of the ambitions of rocketry in general.

Thus, the program of the VfR was advanced by his mind and by the fact of his membership.

Two monographs contain Hohmann's basic results. The first, as mentioned above, is his book, *Die Erreichbarkheit der Himmelskörper*, while the second is a chapter (Hohmann 1928) in an anthology compiled by Willy Ley, featuring contributions from Hohmann, Oberth, and others. The 1928 article is summarized in Ley 1957, pp. 389–396, in English.

In order to show the wide-ranging nature of Hohmann's work, which is usually telescoped into a statement about the "Hohmann-transfer principle," a synopsis of *Die Erreichbarkheit der Himmelskörper* is given. Two preliminary comments are appropriate: 1) most of the 88 pages (104 pages for the 1960 translation) are filled with mathematical calculations, a point not apparent from the synopsis, and 2) his mathematical approach is not sophisticated, using simple calculus, simplifying assumptions, and numerical experimentation. As Hohmann says in the preface: "Since the writer is an engineer, not a mathematician, clumsy approximations in place of mathematical formulas occasionally appear in the calculations; this should not affect the results." Despite Hohmann's modesty, his style of analysis is well fitted to the subject at hand: it allows the main ideas to be seen with clarity, without having to pierce a veil of mathematical formalism.

The English headings for the five sections of the treatise are taken from Hohmann 1960, followed by the headings in German, and the (original) page on which it appears. The cover and title page are reproduced as Figures 1 and 2, respectively.

Synopsis of *Die Erreichbarkeit der Himmelskörper*

<u>Preface</u>

Hohmann alludes to a version he wrote ten years earlier and says that at the time he believed the highest exhaust velocity obtainable from a rocket engine would be 2 km/sec. However, work by Robert H. Goddard (1882–1945), Oberth, and Max Valier (1895–1930) have convinced him that higher velocities might eventually be possible and he has extended the numerical range of his calculations accordingly. See Ley (1964, 39) and Ley (1969, 19) for a few notes on the development of Hohmann's book.

He thanks Valier and Oberth "concerning intersecting ellipses at the end of Section V," which indicates they may deserve some credit for the proof of his optimization result.

The preface is dated October 1925, at Essen.

Figure 1. The design of the cover for this 1925 book exemplifies modernist culture within the Weimar Republic. The paper cover is approximately 17.6 cm × 25.4 cm, with white figures on a dark blue background

DIE ERREICHBARKEIT DER HIMMELSKÖRPER

UNTERSUCHUNGEN ÜBER
DAS RAUMFAHRTPROBLEM

VON

DR.-ING. W. HOHMANN, ESSEN

MÜNCHEN UND BERLIN 1925
DRUCK UND VERLAG R. OLDENBOURG

Figure 2. Title page

Chapter 1. Leaving Earth (*Loslösung von der Erde*, p. 1)

The analysis begins with consideration of a spacecraft moving in empty space, subject only to the thrusting of its rocket motor. The gravitational attraction of Earth is introduced into this scenario, and basic dynamical results are summarized in the following table (taken from *Die Erreichbarkeit der Himmelskörper)* for various values of engineering parameters: 1) exhaust velocity, 2) acceleration of the vehicle, and 3) the "mass ratio" (the ratio of the total system mass before launch to the mass of the payload that is delivered to space). The results are not conducive to optimism. In fact, Ley (1957, 394) writing 30 years later asserted "Hohmann proved here, without quite realizing it himself, that space

Tabelle I.

Eigenbeschleunigung ca (m/sec²)		15	20	25	30	40	50	100	200
$r_1 = r_0\left(1 + \frac{g_0}{ca}\right)$ (km)		10 600	9 510	8 860	8 490	7 950	7 640	7 000	6 680
$v_1 = \sqrt{\frac{2 g_0 r_0}{1 + \frac{g_0}{ca}}}$ (m/sec)		8 660	9 150	9 470	9 680	10 000	10 200	10 650	10 890
$\beta = ca - \frac{g_0}{3}\left(2 + \frac{r_0^2}{r_1^2}\right)$ (m/sec²)		7,27	12,00	16,76	21,61	32,35	41,18	90,76	190,46
$t_1 = \frac{v_1}{\beta}$ (sec)		1 192	762	565	448	319	248	117	57
Verhältnis $\frac{m_0}{m_1} = e^{a t_1}$ für die Ausstrahlungsgeschwindigkeit c	$c =$ 1 000 m/sec	58 700 000	4 160 000	1 545 000	675 000	346 000	240 000	120 300	89 130
	$c =$ 1 500 »	149 000	25 000	12 000	7 750	4 950	3 840	2 400	2 000
	$c =$ 2 000 »	7 570	2 010	1 160	825	587	495	347	299
	$c =$ 2 500 »	1 270	438	282	216	164	143	108	95,5
	$c =$ 3 000 »	388	159	110	88	70	62	49	44,7
	$c =$ 4 000 »	87,3	44,8	34,1	28,7	24,2	22,2	18,7	17,2
	$c =$ 5 000 »	35,7	20,9	16,7	14,6	12,8	11,9	10,4	9,8
	$c =$ 10 000 »	6,0	4,6	4,1	3,8	3,6	3,5	3,2	3,1

The entries in the lower-right block of the table are mass ratios (prelaunch mass of the system divided by mass of the payload delivered to space). These mass ratios are functions of the (engine) exhaust velocities, c, at left, and launch vehicle accelerations (assumed to be constant throughout powered flight), ca, top line. (Hohmann, 1925, p. 6, Table 1)

Legend:

r_1 distance from center of Earth to point where powered flight ends

v_1 velocity of vehicle at r_1 (escape velocity is 11.2 km/s)

t_1 time corresponding to r_1 and v_1

r_0 radius of Earth (6,380 km used)

c exhaust velocity

a a constant such that ac equals the acceleration of the launch vehicle

g_0 acceleration at sea level due to gravity (9.8 m/s used)

m_0 mass of system before launch

m_1 mass of payload delivered to space

b approximate total acceleration from propulsion and gravity

Figure 3. This table summarizes a parametric case study of launch (with no atmospheric modeling)

travel without a space station cannot be realized with chemical fuels." Ley was, of course, wrong: multistage chemical rockets serve quite nicely for access to the Moon and planets. More likely, considering Hohmann's lack of *angst*, is that he had faith in the progress of technology and the advent of new concepts to erase obstacles. (In Section V, Hohmann does call out the utility of the Moon as an intermediate base for planetary exploration.) Such confidence was common among the space pioneers: Arthur C. Clarke (1950, 38) says "Much of technological progress consists of pincer movements around insoluble problems which eventually become left so far behind that their very existence is forgotten."

The effects of air resistance on the ascending vehicle are added to those of thrusting and gravity. (The analysis will serve later when it comes time for him to consider landing on planets with atmospheres, including Earth.) This development requires a model of the atmosphere; Hohmann builds a simple one that is appropriate to the task. The pressure is assumed to decrease from its mean value at sea-level to zero at an altitude of 400 km by a polynomial law. (This model is developed in full in Section II; elements needed in Section I are imported from there.)

At the close of Section I, Hohmann invokes precedents for the concept of a rocket-in-space in science fiction (e.g., Verne and Lasswitz), engineering (e.g., Oberth, Tsiolkovsky, Hermann Ganswindt, and Valier), and science (e.g., Newton).

Chapter 2. Return to Earth (*Rückkehr zur Erde*, p. 14)

Calculations similar to those in Section I show that decelerating a spacecraft for the purpose of returning to the surface of Earth would be costly in terms of fuel, so Hohmann uses the atmosphere as an agent of retardation (i.e., aerobraking). At this point he develops a mathematical model of the atmosphere. (See the synopsis of Section I.) By design, the returning vehicle is required to enter the atmosphere tangentially (fig. 4). Perigee is at an altitude of 75 km, a height at which, by his calculation, the atmosphere is sufficiently dense to provide adequate drag for capture but not enough to harm the vehicle or its passengers. The spacecraft, after the initial parabola, orbits Earth in a sequence of braking ellipses.

The next phase of return to Earth is gliding to the landing site using a variable-pitch wing for dynamic control. Extensive mathematical analysis of this phase is carried out, including the effects of a braking parachute. The entire landing period, from entry to touchdown, is 22.6 hours.

Hohmann revisits the design, altering various assumptions, and produces a more direct entry, without braking ellipses, reducing the time from 22.6 hours to only 40 minutes. He cautions:

> "A landing without breaking [*sic*] ellipses is therefore very well possible. However, the forced orbit, during which the passengers, because of centrifugal force, are pressed against the upper wall, represents an inverse flight, during

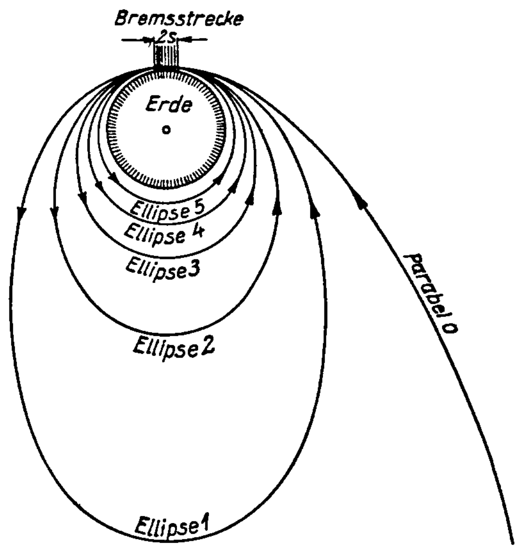

Figure 4. The parabolic trajectory of a spacecraft returning to Earth is transformed by atmospheric drag into a series of braking eclipses prior to landing (Hohmann 1925, 23, fig. 9)

> which safety of maneuverability is perhaps impaired. The pilot however will have to see to it that he does not get into too low a strata, since this, according to Figure 11, could lead to a crash. If he, however, remains too high, then he will in the worst case bring his vehicle out of the atmosphere temporarily and enter a smaller or larger elliptical orbit, after which he can again, duly relaxed, attempt a landing" (Hohmann 1960, 45).

The section finishes with a thermodynamical analysis addressing heat generated during reentry. Hohmann concludes that spare parachutes (or nose cones, a suggestion he credits to Valier) must be provided for safety and that the vehicle should have cooling fins of metal, in addition to wings.

Chapter 3. Free-Space Travel (*Freie Fahrt im Raume*, p. 41)

Entry into the domain of space affects the crew: "… the passengers will with the sudden cessation of gravity first of all sense in all probability the fear of a steady fall, which after some experience will go over into the more pleasant feeling of floating" (Hohmann 1960, 49).

The emphasis of this section is not upon reaching other planets, treated in the concluding sections, but rather upon the fundamentals of motor burns in space: "maneuver analysis."

He envisages a vehicle departing radially from Earth and designs maneuvers which will place it on a parabola (Section II) suitable for reentry. (Here, he introduces the important concept of ΔV ("delta vee"): change in velocity of a spacecraft by means of propulsion.)

Realizing that for various reasons a spacecraft can stray from its planned course, Hohmann discusses trajectory-correction maneuvers.

He estimates the mass of the system through an inventory of its parts and contents. A few items in the several-page exercise are:

- two crew members (2 × 100 kg)
- 4 kg/person/day of food and water
- oxygen for breathing (carried as a liquid), 0.6 kg /person/day
- a spacecraft shell with an interior volume of 4.5 m^3

The total mass delivered to space is 3,000 kg; the mass at reentry is estimated to be 1760 kg. (The habitable volume of the two-person, Earth-orbiting Gemini spacecraft was 2.55 m^3. This vehicle had a mass at launch of 3850 kg, of which 455 kg was propellant.)

The usual way to orient a spacecraft now is by means of thrusters that expel hot or cold gas—little rocket engines—or, in Earth orbit, through interaction with the planetary magnetic field. Hohmann devised a method whereby the two crew members clamber about the walls of the vehicle in order to cause it to rotate (fig. 5)!

Section III concludes with a long tutorial on celestial mechanics, for subsequent use.

<u>Chapter 4. Circumnavigation of Other Heavenly Bodies</u> (*Umfahrung anderer Himmelskörper*, p. 63)

For most of the analysis, the orbits of the planets are assumed to be circular and situated in the plane of the ecliptic.

The first interplanetary trajectory to be designed carries the spacecraft from Earth to the vicinity of Venus using what we would now call a Hohmann transfer ellipse. Similar calculations are done for a trip to Mars.

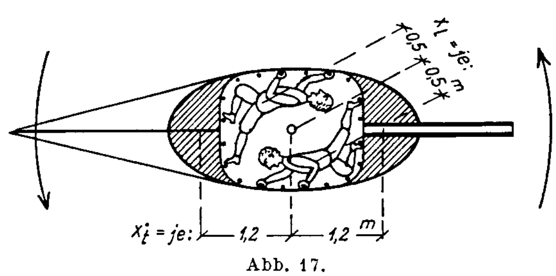

Figure 5. Rotation, for the purpose of reorienting the spacecraft, was to be achieved through crew motion along the walls, using a series of hand holds! (Hohmann 1925, 55, fig. 17)

Hohmann remarks that, after a flyby of Venus, the spacecraft, in its elliptical orbit about the Sun, would return very nearly to the point of departure except, of course, Earth would have moved on. He considers two remedies: (1) maneuver into a holding orbit about Venus and, waiting until Earth is suitably positioned, thrust out of Venusian orbit and rendezvous with Earth or (2) conduct a space maneuver and return to Earth without going into orbit about Venus. Detailed calculations are done in support of these two options.

A trip to Mars is similar in principle, but he notes that the greater eccentricity (compared to Earth and Venus) of the Martian orbit must be taken into account.

A single trajectory, departing Earth and passing by Venus and Mars before returning home, is possible when the three planets are suitably configured: the length of the journey is 580 days. Hohmann adapts his previous estimate of spacecraft mass and arrives at a figure of 16,720 kg, not including fuel.

Chapter V. Landing on Other Celestial Objects (*Landung auf anderen Himmelskörpern*, p. 76)

Venus, once again, draws Hohmann's attention. He judges its atmosphere to be similar, in terms of density, to that of Earth, and that gravitational conditions are also similar. Thus, the earlier analysis of landing on Earth can be readily adapted to apply to landing on Venus. Concerned about onerous requirements with regard to mass for landing and return to Earth (humans are aboard), Hohmann specifies, "The fuel necessary for a return [should] be manufactured by simple means of raw materials available [on Venus]" (Hohmann 1960, 91). This technique of "in-situ propellant production" is under consideration for certain NASA missions.

Landing on Mars is analyzed, but without aerobraking: the engine is used to decelerate the vehicle and place it on the surface. The results, in terms of mass and energy requirements for the system are, of course, less favorable than for landing on Venus. Again, in-situ propellant production is prescribed for powering the return to Earth.

The Moon is the third body beyond Earth to be considered as a landing site, and Hohmann, as with Venus and Mars, prepares mass estimates for the spacecraft under various sets of assumptions (achievable exhaust velocity, etc.). The relative ease of departing from the Moon leads him to propose its use as an intermediate station for exploration of the planets (Ley's "space station" of sorts). *En passant*, Hohmann touches upon lunar infrastructure in general and, in particular, a factory for producing fuel.

Both Hohmann and Oberth proposed use of a lander that would be detached from the planetary orbiter and sent to the surface (Ley 1957, 396); presumably Hohmann's proposal is contained in his 1928 paper. This has proved to be a fruitful concept, being employed on numerous robotic missions and, notably, in the form of the Lunar Excursion Module, central to the Apollo program.

Only toward the end of this final section does Hohmann address the problem of optimal transfer orbits between planets: "For simplicity, we have up to now only discussed those connecting elliptic segments between planets, which touch the two planets, which are to be connected…It is not obvious that these tangential ellipses constitute the most favorable connection. Rather it is conceivable that other ellipses, intersecting planetary orbits, would be more expeditious, since without doubt they would provide shorter connections." (Hohmann 1960, 98)

By comparing tangential transfer orbits with ellipses that cross one or both of the planetary orbits, he establishes his famous result that the smallest ΔV is required for the tangential case.

End of Synopsis

IV. AFTER HOHMANN. Walter Hohmann's name appears frequently within astronautical literature: (1) in technical contexts as a label for his optimal, tangential ellipse and (2) in historical tracts, where the publication of his 1925 treatise is noted. In discussions of the historical development of astronautics, though, little attention is usually paid to the full range of his work.

He was honored by being in the first class of inductees, in 1976, into the International Space Hall of Fame at the Space Center in Alamagordo, New Mexico. A 16-km lunar crater is named for him, along with the Walter Hohmann Sternwarte (observatory) in Essen. R. Oldenbourg lists the publication of Hohmann's 1925 book (and Oberth's *Die Rakete zu den Planetenräumen* of 1923) among the firm's major milestones.

Hohmann's achievements have been underestimated, perhaps because of the absence of popular writings by him and because of the hypnotic attraction of his optimization result. The breadth of his interplanetary mission designs plus foundational work in maneuver analysis suggest that a reevaluation is in order. A proper assessment of Hohmann's place in the history of astronautics would be facilitated by reissue of his 1925 and 1928 publications, preferably in a dual-language format (German and English).

Acknowledgments

The Archives, California Institute of Technology, granted me access to their copy of *Die Erreichbarkeit der Himmelskörper.* The website of the Erfatal Museum in Hardheim has an abundance of material on Hohmann, from which I obtained many biographical details. (Websites for Hardheim and the Walter Hohmann Sternwarte were also useful.)

References

1. Arnol'd, V. I., V. V. Kozlov, and A. I. Neishtadt (1997), *Mathematical Aspects of Classical and Celestial Mechanics*, Second Edition, Springer, Berlin.
2. Burrows, W. E. (1998), *This New Ocean*, Random House, New York.
3. Clarke, A. C. (1950), *Interplanetary Flight*, Temple Press, London.
4. Clute, J. and P. Nichols, editors (1993), *The Encyclopedia of Science Fiction*, St. Martin's Press, New York.
5. Fortescue, P. and J. Stark (1992), *Spacecraft Systems Engineering*, John Wiley and Sons, Chichester and New York.
6. Hohmann, W. (1925), *Die Erreichbarkeit der Himmelshkörper*, R. Oldenbourg, Munich and Berlin.
7. Hohmann, W. (1928), Fahrtrouten, fahrtzeiten, landungsmöglichkeiten künstlicher raumflugkörper, in *Die Möglichkeit der Weltraumfarht*, Willy Ley, editor, Hachmeister and Thal, Leipzig.
8. Hohmann, W. (1960), *The Attainability of Heavenly Bodies* (translation of *Die Erreichbarkeit der Himmelskörper*), NASA Technical Translation F-44, Washington, D. C.
9. Ley, W. (1957), *Rockets, Missiles, and Space Travel* (revised and enlarged edition), Viking Press, New York.
10. Ley, W. (1964), *Our Work In Space*, MacMillan Company, New York.
11. Ley, W. (1969), *Events In Space*, Popular Library, New York.
12. McLaughlin, W. I. (1984), An Arctic Polesitter, *Spaceflight* **26**:306–307 (July/August).
13. McLaughlin, W. I. (1999), The first space mission architect: Tsiolkovsky, *Journal of Space Mission Architecture* **1**:43–48.
14. Poincaré, H. (1993), *New Methods of Celestial Mechanics* (annotated and translated edition of *Les Méthodes Nouvelles de la Mécanique Céleste*, D. L. Goroff, editor), American Institute of Physics.
15. Winter, F. H. (1983), *Prelude to the Space Age, The Rocket Societies: 1924–1940*, Smithsonian Institution Press, Washington, D. C.

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