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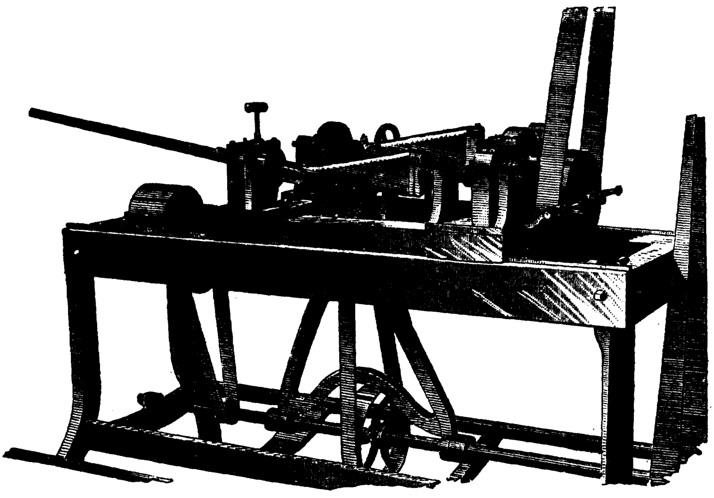

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# *The Idea of Rendezvous: From Space Station to Orbital Operations in Space-Travel Thought, 1895–1951*

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Late in 1961, the U.S. National Aeronautics and Space Administration (NASA) announced its plans for a new manned spaceflight project aimed at proving the techniques of orbital rendezvous.[1] The first U.S. manned program, Project Mercury, was then on the eve of its attempt to put a man in orbit; and Project Apollo, intended to land Americans on the Moon within the decade, was already under way.[2] During 1961, NASA planners had come to see the vital role that orbital rendezvous might play in a lunar mission.[3] They expected the new project, soon dubbed "Gemini," to prove that a piloted spacecraft and an unmanned target, separately launched from the Earth's surface, could meet in space—matching their orbits so that they were virtually at rest with respect to each other and no significant distance remained between them.[4]

Controversy had surrounded the idea of orbital rendezvous almost from NASA's birth in late 1958 and was yet to be resolved. Should the flight to the Moon be launched directly from the Earth's surface, or could some form of rendezvous allow lunar landing to be achieved

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[1]*Houston Post,* December 8, 1961, p. 1.

[2]Loyd S. Swenson, Jr., James M. Grimwood, and Charles C. Alexander, *This New Ocean: A History of Project Mercury,* NASA SP-4201 (Washington, D.C., 1966), p. 409; Ivan D. Ertel and Mary Louise Morse, *The Apollo Spacecraft: A Chronology,* vol. 1, *Through November 7, 1962,* NASA SP-4009 (Washington, D.C., 1969), pt. II, "Design—Decision—Contract: August 1960 through November 1961."

[3]Ertel and Morse; John M. Logsdon, *NASA's Implementation of the Lunar Landing Decision,* NASA Headquarters Historical Note HHN-81 (Washington, D.C., 1969), pp. 40–69.

[4]James M. Grimwood and Barton C. Hacker with Peter J. Vorzimmer, *Project Gemini Technology and Operations: A Chronology,* NASA SP-4002 (Washington, D.C., 1969), pp. 18–20; Krafft A. Ehricke, "Orbital Operations," *Advances in Space Science and Technology* 5 (1963): 239. The actual coupling of the two vehicles (docking), which Ehricke points out as a logically distinct operation, was also part of NASA's Gemini plans.

with greater dispatch and economy? Much depended on how difficult an operation rendezvous proved to be, and Gemini was designed to provide an answer.[5] Ironically, from 1959 to 1962, the NASA advocates of rendezvous for Apollo were largely recapitulating the case argued by an earlier generation of space-travel enthusiasts who had foreseen a key role for that technique for trips to the Moon and beyond. That earlier case—its sources, growth, and widespread acceptance in the first half of the 20th century—is the subject of this essay.

## I

The concept of rendezvous had its roots in a still older idea. Until the late 1940s, it existed only as a corollary to the space station, conceived as a staging base for voyages to the Moon and beyond. The space-station idea had entered space-travel thinking in the closing years of the 19th century, like so many ideas later to bear fruit, clothed as fiction. Two stories published in the 1890s, one the work of Kurd Lasswitz (1848–1910) in Germany, the other by K. E. Tsiolkovskii (1857–1935) in Russia, advanced the idea.

Lasswitz published *On Two Planets* in 1897.[6] He was an unlikely writer of romantic novels. Scion of a well-to-do merchant family of Breslau in Prussian Silesia, where he attended the university before completing his studies at Berlin, Lasswitz had become professor of mathematics at the Gymnasium Ernistinum in Gotha. He capped a solid reputation as a philosopher and historian of science in 1890 with his masterpiece, the now-classic *History of Atomism from the Middle Ages to Newton*.[7] Scholarly treatises, however, provided far too restricted a framework for Lasswitz's profound utopian vision, grounded in Kantian idealism, of a society perfected through the progress of science and technology.[8] He sought freer rein for his ideas in fiction, but

[5]Eugene M. Emme, *Historical Perspectives on Apollo,* NASA Headquarters Historical Note HHN-75 (Washington, D.C., 1967); John M. Logsdon, *The Decision to Go to the Moon: Project Apollo and the National Interest* (Cambridge, Mass., 1970); Barton C. Hacker, "The Genesis of Project Gemini: The Idea of Orbital Rendezvous, 1929–1961, in *Actes du XII^e congrès international d'histoire des sciences* (Paris, 1968), tome XB, *Histoire des techniques* (Paris, 1971), pp. 41–46.

[6]Kurd Lasswitz, *Auf zwei Planeten: Roman in zwei Büchern* (Leipzig, 1897). A later version, abridged by Erich Lasswitz (Kurd's son), *Auf zwei Planeten: Roman* (Donauwörth, 1948), is now available in English under the title *Two Planets: Auf zwei Planeten,* trans. Hans H. Rudnick (Carbondale, Ill., 1971).

[7]Kurd Lasswitz, *Geschichte der Atomistick vom Mittelalter bis Newton,* 2 vols. (Hamburg and Leipzig, 1890).

[8]Edwin M. J. Kretzmann, "German Technological Utopias of the Pre-War Period," *Annals of Science* 3 (1938): 417–30; Franz Rottensteiner, "Kurd Lasswitz: A German Pioneer of Science Fiction," *Riverside Quarterly* 4 (August 1969): 4–18, reprinted in

unlike most didactic writers, Lasswitz wrapped them in a lively and gripping story that was "devoured" by more than one German youth "with curiosity and excitement,"[9] and soon became "a permanent part of German literature."[10]

*On Two Planets* dramatized the value of a space station in easing the rigors of travel between two planets. Until the station was built, the Mars-Earth trip was fraught with peril; the station reduced the journey from adventure to routine.[11] This was the station's crucial role, as a natural staging point for interplanetary travel. But a quarter-century and more elapsed before the idea flowered in Germany. Ultimately, Lasswitz's novel "preconditioned" a new generation of Germans "to taking space-travel theory seriously."[12] In the meantime, however, Tsiolkovskii was founding a distinct Russian tradition.

Konstantin Eduardovich Tsiolkovskii might have seemed less likely than Lasswitz to probe space with his mind. Born into a poor family and further handicapped by deafness from a childhood bout with scarlet fever, he had little in the way of formal schooling. He did manage to become certified as a teacher and supported himself and his family precariously as a provincial schoolmaster in Kaluga, some 100 miles southwest of Moscow.[13] During the 1890s, Tsiolkovskii, like

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Thomas D. Clareson, ed., *SF: The Other Side of Realism: Essays on Modern Fantasy and Science Fiction* (Bowling Green, Ohio, 1971), pp. 289–306; Mark R. Hillegas, "Afterword," in Erich Lasswitz, pp. 397–405. See also Hermann A. Ludwig Degener, *Wer ist's: Zeitgenossenlexikon* (Leipzig, 1905), p. 482.

[9]Wernher von Braun, "Epigraph, " in Erich Lasswitz, p. vii; Rudolf Hermann, in conversation with the author, June 28, 1969. The book's impact was not limited to Germany; it was translated into a half-dozen other languages within ten years (Rottensteiner, p. 289).

[10]Willy Ley, *Rockets, Missiles, and Men in Space*, 3d rev. ed. (New York, 1969), p. 65. The first liquid-propelled rocket built by the Verein für Raumschiffahrt (literally, Society for Spaceship Travel, but more commonly known in English as German Rocket Society) was called *Repulsor* after Lasswitz's device for steering the interplanetary spaceship (Ley, pp. 143, 176).

[11]Erich Lasswitz, pp. 16, 41. The Lasswitz space station was not a satellite, since it was supported by antigravity, which made orbital motion superfluous (see Carsbie C. Adams, *Space Flight: Satellites, Spaceships, Space Stations, and Space Travel* [New York, 1958], pp. 12–13, 104–5). Edward Everett Hale's "The Brick Moon," first serialized in *Atlantic Monthly* 24 (1869): 451–60, 603–11, 679–88, is now generally acknowledged to have been the first literary anticipation of the manned Earth satellite; but Hale's Moon, prematurely launched and fortuitously manned, was an accident without significance (cf. Ley, pp. 362–63; Wernher von Braun and Frederick I. Ordway III, *History of Rocketry and Space Travel*, rev. ed. [New York, 1969], pp. 18–20; Alan R. Krull, "A History of the Artificial Satellite," *Jet Propulsion* 26 [1956]: 369).

[12]Ley, p. 140.

[13]"The Autobiography of K. E. Tsiolkovskii," in N. A. Rynin's *Interplanetary Flight and Communication*, vol. 3, no. 7, *K. E. Tsiolkovskii: Life, Writings, and Rockets* (Leningrad, 1931), trans. Israel Program for Scientific Translations (IPST), NASA TT F-646 (Jeru-

Lasswitz, turned to fiction to express a utopian vision—human evolution moving from the cradle of the Earth to maturity in the infinite reaches of the universe. Part of that vision emerged in his 1895 story, *Dreams of Earth and Sky and the Effects of Universal Gravity,* which portrayed natural and man-made satellites as platforms for launching flights to the planets.[14]

## II

In sharp contrast to Lasswitz, however, Tsiolkovskii could not rest content with the idea alone. As the 19th century gave way to the 20th, Tsiolkovskii stepped over the line that divided fiction from science. He subjected his intuition to industrious calculation and emerged convinced that a liquid-propelled rocket of proper design could be the means of crossing the airless void. He began to publish his results with an article on "The Exploration of Space with Reaction Machines" in the May 1903 issue of *Science Survey.*[15] No space station appeared in this article, but he returned to that idea when he published the second half of his argument under the same title in the *Herald of Aeronautics* serially during 1911 and 1912.[16] Tsiolkovskii discussed the artificial satellite and observed that a venture farther into space from such a platform required little extra energy.[17] Once orbit had been attained, in other words, interplanetary travel became easier than if launching occurred directly from the Earth's surface.

Tsiolkovskii enlarged this insight in 1926 when he published these two articles himself, revised and expanded, as a book, still with the same title.[18] He proposed a master plan for the conquest of space which began with manned satellites, "a human settlement . . . in the ether, outside the atmosphere." From the "satellite base, . . . we will find it easier to modify our velocity, escape from the Earth and the Sun and, in general, depart on voyages in any desired direction. The

salem, 1971), pp. 2–8; also available as "K. E. Tsiolkovskii—an Autobiography," trans. A. N. Petroff, *Astronautics* 4 (May 1959): 48–49, 63–64; cf. A. A. Kosmodem'yanskii, "K. E. Tsiolkovskii (The Character of His Discoveries and His Creative Manner)," in *Soviet Rocketry: Some Contributions to Its History,* ed. A. A. Blagonravov et al., trans. and ed. H. I. Needler, NASA TT F-343 (Jerusalem, 1966), pp. 68–71.

[14]In Tsiolkovskii, *The Call of the Cosmos,* trans. and ed. V. Dutt (New York, 1962); cf. Rynin, *Tsiolkovskii,* pp. 24–25; V. N. Sokol'skii, "The Work of Russian Scientists on the Founding of a Theory of Interplanetary Flight," in Blagonravov et al., *Soviet Rocketry,* p. 26.

[15]A. A. Blagonravov, ed., *Collected Works of K. E. Tsiolkovskiy,* vol. 2, *Reactive Flying Machines,* trans. Faraday Translations, NASA TT F-237 (Washington, D.C., 1965), pp. 72–117.

[16]Ibid., pp. 118–67.

[17]Ibid., pp. 150–51.

[18]Ibid., pp. 212–349.

point is that, once we are a satellite of the Earth or Sun, the application of very small forces will suffice to increase, reduce or otherwise modify our velocity, and hence our position in space."[19] Tsiolkovskii saw that such a base, at least in the beginning, "will require continual support from the Earth" and "a regular traffic between the base and the planet" for supplies and "the frequent exchange of personnel."[20] His central concern, however, was the base itself. Its staging function and the need to keep it supplied, either of which might have brought the problem of rendezvous to the fore, Tsiolkovskii never explored in any detail.

That task, however, captured the interest of his younger contemporary, Yuri Vasil'yevich Kondratyuk (1897–1942). Kondratyuk was a Ukrainian who, through the fortunes of war and revolution, was "cast off in some god-forsaken hole"—Novosibirsk in Siberia.[21] A mechanic and inventor with only limited formal schooling, he published nothing until 1929, when, tired of waiting for a promised government grant that never materialized, he paid a local printer to set up his manuscript and published it himself.[22] By then, over a decade had passed since completion of the first untitled version of the manuscript in 1916 or 1917.[23]

The largely self-taught Kondratyuk had become concerned about how a spacecraft was to carry enough fuel for its voyage. As a means of saving fuel, he suggested that when the spacecraft arrived at its destination, "the entire vehicle need not land, its velocity need only be reduced so that it move uniformly in a circle as near as possible to the body on which the landing is to be made. Then the inactive part separates from it, carrying the amount of active agent [fuel] necessary for landing the inactive part and for subsequently rejoining the remainder of the vehicle."[24]

[19] Ibid., p. 338.

[20] Ibid., p. 339.

[21] "Review by Mechanical Engineer V. P. Vetchinkin of Yu. Kondratyuk's Article, 'On Interplanetary Voyages,'" in *Pioneers of Rocket Technology: Selected Works*, ed. T. M. Mel'kumov (Moscow, 1964), trans. Stemar Engineering Inc., NASA TT F-9285 (Washington, D.C., 1965), p. 114; cf. S. Yu. Protsyuk, "Pro razvytok litakobuduvannya ta raketobuduvannya v Ukrayini" [The development of aircraft and rocket design in the Ukraine], *Visti Ukrayins'kykh Inzheneriv* 17 (1966): 85.

[22] Kondratyuk to Rynin, May 1, 1929, in Rynin, *Interplanetary Flight and Communication*, vol. 3, no. 8, *Theory of Space Flight* (Leningrad, 1932), trans. Ron Hardin, NASA TT F-647 (Jerusalem, 1971), pp. 327–31. Kondratyuk's book, *The Conquest of Interplanetary Space*, ed. V. P. Vetchinkin (Novosibirsk, 1929), now has an English version in Mel'kumov, ed., *Pioneers of Rocket Technology*, pp. 57–115.

[23] V. N. Sokol'skii, "The Works of the Russian Scientist-Pioneers of Rocket Technology (Historical Outline)," in Mel'kumov, pp. 145–46.

[24] Kondratyuk MS (1st version), p. 18, as quoted in Mel'kumov, p. 151.

This is a fair statement of the basic concept behind the scheme of lunar-orbit rendezvous later adopted by NASA for Project Apollo. The economy of the scheme depends on wasting no energy in bearing propellants for the return journey to and from the surface of the destination, as Kondratyuk specifically pointed out in a revised and expanded version of his manuscript dating from 1918 or 1919 with the cryptic title "To Them That Will Read in Order to Build."[25] He also discussed an aspect of the rendezvous problem, at least implicitly, in writing about methods to enhance the visibility at large distances of the orbiting main vehicle.[26]

Kondratyuk stressed the value of man-made satellite bases and computed the greatly reduced amount of propellant a spacecraft needed if launched from, and returned to, such a base rather than the Earth's surface. He proposed establishing the base by launching a fully supplied but unmanned ship from earth to orbit. A crewed ship would follow, picking up supplies at the base, and then proceed with its journey while the base remained in orbit about the Earth. On its return, the manned craft was to stop at the base before its descent and landing.[27]

When Kondratyuk's work finally appeared in print in 1929 as *The Conquest of Interplanetary Space,* many of his earlier ideas had been polished. Conspicuously absent from the book was any mention of rendezvous in orbit at the destination of an interplanetary trip.[28] Kondratyuk's treatment of the satellite base, however, was detailed, and he paid close attention to the basic problem of rendezvous—that is, matching the orbits of base and cargo vessel (using optical tracking from the base)—and to instruments for control and guidance.[29]

[25]Ibid., pp. 15–56.

[26]Ibid., p. 44.

[27]Ibid., pp. 44–45, 53. The calculation of fuel savings and the proposed satellite base are Kondratyuk's later (1920, 1923–24) emendations of the original text; cf. B. N. Vorob'ev and V. N. Trostnikov, "Yu. V. Kondratyuk's Unpublished Paper 'To Them That Will Read in Order to Build,' " in Blagonravov et al., eds., *Soviet Rocketry,* pp. 171–92.

[28]Neither Sokol'skii nor Vorob'ev and Trostnikov explain this absence, for which there is no evident reason. Ley (pp. 128–29) suggests that the upsurge of interest in rocketry and space travel in Germany after 1923 prompted Soviet attention to Tsiolkovskii's work, which had been previously neglected. Since the Soviet rediscovery of Kondratyuk's early work came some two years after the United States announced its plans to rely on a basically similar concept for Project Apollo, the same process may have been involved. This general problem is discussed in Robert K. Merton, "Priorities in Scientific Discovery: A Chapter in the Sociology of Science," *American Sociological Review* 22 (1957): 635–59; reprinted in Bernard Barber and Walter Hirsch, eds., *The Sociology of Science* (New York, 1962), pp. 447–85, with special attention to the Russian pattern, pp. 457–58.

[29]Kondratyuk, "The Conquest of Interplanetary Space," in Mel'kumov, pp. 107–11.

The third major figure in the early development of Soviet space-travel theory, Fridrikh Arturovich Tsander (1887–1933), a graduate in mechanical engineering of the Riga Polytechnical Institute,[30] said nothing about the space-station concept in his published work. Yet some form of orbital operation was clearly implied by his plans for space travel, which carefully distinguished between the type of ship suitable for travel from Earth to orbit and the type needed to travel between the planets. In a brief 1924 paper on "Flights to Other Planets," Tsander accepted the chemically propelled rocket as the proper device for reaching orbit, there "to stop the operation of the rocket and rest as on a natural station," but suggested that the journey might best continue in another kind of vessel.[31]

Tsiolkovskii's work had attracted little notice in his homeland and none at all abroad until the mid-1920s, even though he was the best known of the Russian theorists.[32] But Tsiolkovskii and his fellows touched a responsive chord in the Russian character that eventually won them a wide and believing audience.[33] This meant a hearing for the space-station concept, but the intellectual route that led from these early writings to the Soviet space program with its distinct stress on orbital rendezvous, both manned and unmanned, has yet to be traced historically.[34] That such a route existed, however, may be in-

[30]"Autobiography of Friedrich Arturovich Tsander, Mechanical Engineer," in Rynin, *Interplanetary Flight and Communication,* vol. 2, no. 4, *Rockets* (Leningrad, 1929), trans. T. Pelz, NASA TT F-643 (Jerusalem, 1971), pp. 185–88.

[31]In F. A. Tsander, *Problems of Flight by Jet Propulsion: Interplanetary Flights,* ed. L. K. Korneev (Moscow, 1961), trans. IPST, ed. Y. M. Timnat (Jerusalem, 1964), pp. 228–29; cf. Rynin, *Rockets,* pp. 181–84; A. F. Tsander, "The Scientific and Engineering Legacy of F. A. Tsander," in Blagonravov et al., eds., *Soviet Rocketry,* pp. 136–37.

[32]See n. 28, above. The earliest mention of Tsiolkovskii's work I have found in any non-Russian source was in Walter Hohmann, *Die Erreichbarkeit der Himmelskörper: Untersuchungen über das Raumfahrtproblem* (Munich and Berlin, 1925), p. 16. Hohmann cites no particular work; he merely refers to Tsiolkovskii as an early publicist for the idea of using the rocket for space travel. Tsiolkovskii was, in any case, the only one of the three who had published at all extensively before the end of the 1920s (see B. N. Borob'yev, "Bibliography of the Published Works of N. I. Kibal'chich, K. E. Tsiolkovskiy, F. A. Tsander, and Yu. V. Kondratyuk on the Problems of Reactive Flying Machines and Interplanetary Travel," in Mel'kumov, pp. 156–62).

[33]William Shelton, *Soviet Space Exploration: The First Decade* (New York, 1968), pp. 13–15.

[34]A near approach to rendezvous was achieved quite early in the Soviet program, in August 1962 during the Vostok series of manned spaceflights; the automatic rendezvous and docking of unmanned spacecraft in the Kosmos series was demonstrated in October 1967 (Shelton, pp. 139–46, 210–12). For Soviet statements on the importance of rendezvous in the current program, see M. K. Tikhonravov et al., "Ten Years of Space Research in the USSR," trans. Aztec School of Languages, Inc., NASA TT F-11, 500, from *Kosmicheskiye Issledovaniya,* vol. 5 (1967) (Washington, D.C., February 1968), pp. 645, 668; B. V. Lyapunov, *Station Outside the Earth,* its translation FTD-MT-64-531 (Dayton, Ohio, January 27, 1966), pp. 6, 29–32.

ferred from the similar course that can be traced in the West from the pioneer German space-station proposals to Projects Gemini and Apollo.

III

The seeds Lasswitz had planted began to sprout in 1923 when Hermann Oberth (b. 1894) published his mathematical demonstration of the feasibility of space travel by rocket, in a small book called *The Rocket into Interplanetary Space.*[35] The son of a physician from the German-speaking enclave of Hermannstadt in Romanian Transylvania, Oberth first planned to follow in his father's footsteps. The war intervened, however, and he turned instead to physics and astronomy, which led him back eventually to Transylvania and a post as gymnasium professor of mathematics and physics. The 1923 book was his thesis, and Oberth himself paid a good share of the printer's costs.[36] Oberth concluded his study with some remarks on using the rockets whose feasibility he had proved. He proposed a manned Earth satellite as a space-borne communications link, observatory, and solar-energy collector. In his final paragraphs, almost as an afterthought, Oberth brought up the satellite's role as a fueling station for interplanetary flights. He pointed out that the form of a station-launched spaceship need not be constrained by air resistance, and that only a small increment in velocity beyond what the ship already had because it was in orbit would suffice to send it on its way. He further noted in print what Kondratyuk was then working over in his manuscripts: the gains to be realized by a rocket equipped with detachable fuel tanks that could be left in orbit at the destination while only the rocket landed.[37]

Weimar Germany welcomed the prospect of space travel with the exuberance it accorded myriad other exotic ideas.[38] Oberth's book, despite an uncompromising mathematical format, sold out its first edition (admittedly small) and brought in enough orders nearly to exhaust the second before it was printed.[39] The space-station concept soon became common currency. It was presented most elaborately at

[35]H. Oberth, *Die Rakete zu den Planetenräumen* (Munich and Berlin, 1923).

[36]Oberth, "From My Life," *Astronautics* 4 (June 1959): 38–39, 100–6; "Professor Hermann Oberth," *Journal of the British Interplanetary Society* 8 (1949): 166–68 (hereafter cited as *JBIS*); Ley, p. 134.

[37]Oberth, *Die Rakete,* pp. 92–97. Oberth published a second edition in 1925 little changed from the first, and a much enlarged third edition in 1929 entitled *Wege zur Raumschiffahrt* (Munich and Berlin). His treatment of the space station was much fuller, but again focused on its role as observatory and energy collector (pp. 350–71).

[38]Peter Gay, *Weimar Culture: The Outsider as Insider* (New York, 1970).

[39]Ley, p. 135.

the end of the decade in a book called *The Problem of Space Navigation.*[40] The name of the author on the title page, Hermann Noordung, was a pseudonym for Hermann Potočnic (1892–1929), a young career army officer who died in Vienna at almost the same time his book was published.[41] Whatever his technical qualifications may have been, he had clearly given a good deal of thought to the engineering problems of a space station. He proposed a sophisticated three-unit structure linked by pressure hoses and electric cables. The book's occasional eccentricities and the author's anonymity deprived it of much immediate impact. Noordung's focus was the space station as observatory, along the lines sketched by Oberth.

Shortly before Noordung's book appeared, however, a series of articles on "Interplanetary Travel Routes" in the journal of the newly formed German Rocket Society had argued that the key role of the space station was as a staging base.[42] The author, Count Guido von Pirquet (1880–1966), had gone from Schloss Hirschstetten, the family castle on the outskirts of Vienna, to studies in Vienna and Graz that qualified him as a mechanical engineer.[43] Pirquet had computed the tonnage of a rocket designed to launch an interplanetary flight directly from the Earth's surface and found the mass prohibitively large. But that need not rule out the journey. Noting what he called the "cosmonautical paradox"—that the power required to reach orbit a few hundred kilometers above the Earth was greater than that required to cover the millions of kilometers between planets—he proposed launching an interplanetary flight from a station in orbit. He pointed out, as had Tsiolkovskii, that orbital velocity was the first, and by far the hardest, step. Once the station was in orbit, it could serve as a fuel depot, and flight to the planets from Earth orbit with its lesser power demands became feasible. The space station, in other words, had come to seem not merely convenient but essential.[44]

Pirquet had also concerned himself with another problem, the one suggested by the title of his articles: What is the best path for a space-

[40]Hermann Noordung, *Das Problem der Befahrung des Weltraums: Der Raketenmotor* (Berlin, 1929). Part of this work was translated into English by Francis M. Currier as "The Problems of Space Flying," *Science Wonder Stories* 1 (1929): 170–80, 264–72.

[41]Fritz Sykora, "Guido von Pirquet: An Austrian Pioneer of Astronautics" (paper presented at the Fourth International History of Astronautics Symposium, Constance, West Germany, October 4–10, 1970), p. 1.

[42]Guido von Pirquet, "Interplanetare Fahrtrouten," *Die Rakete: Zeitschrift des Verein für Raumschiffahrt* 2 (1928): 117–21, 134–40, 155–58.

[43]"Ing. Guido von Pirquet," *JBIS* 9 (1950): 204–6; Sykora, p. 2.

[44]Sykora, pp. 7–9. On the work of Noordung and Pirquet, see also Krull, p. 370; Ley, pp. 367–69; John W. Massey, *Historical Résumé of Manned Space Stations*, Army Ballistic Missile Agency Report DSP-TM-9-60 (Redstone Arsenal, Ala., 1960), p. 6.

craft to follow on its trip from Earth to another planet? This question had first been raised by Walter Hohmann (1880–1945) in a study of *The Attainability of Heavenly Bodies.*[45] The son of a physician, Hohmann had studied mathematics and theoretical mechanics in Munich before making a career in construction engineering that eventually brought him to Essen as city architect.[46] His studies, begun a decade before he published, convinced him, as Pirquet was convinced, that an Earth-launched chemical rocket could not reach the planets. Hohmann failed to notice the relief for this problem inherent in staging techniques.[47] He looked nevertheless to making the journey as economically as possible. Careful calculations of interplanetary trajectories showed that an elliptical path tangent to the orbits of origin and destination was the most favorable—that is, required the least expenditure of energy—for transferring from one orbit to another.[48]

The lasting significance of Hohmann's work lies in this demonstration. Hohmann transfer orbits are the starting point for applied celestial mechanics, and thus for orbital rendezvous, at least as long as the minimum use of energy remains a major criterion. But it was only a starting point. A long road stretched between demonstrations of theoretical feasibility and the rise of a precise astrodynamics to deal with real satellites and probes.[49] By the end of the 1920s, the theoretical foundations of space travel had been laid. The next step was clear. "Further fruitful research on interplanetary flight by purely theoretical methods is obviously impossible," Kondratyuk observed in 1929. "Experimental studies must now be made."[50] Before theory could become practice, the rocket had to be transformed from the toy it then was into a reliable device of enormously greater power.

The next decade and a half saw spaceflight enthusiasts shelve their theories for the time being and focus their efforts on rocket experiments. Robert Hutchings Goddard (1882–1945), the American physicist who shared with Tsiolkovskii and Oberth credit for founding modern astronautics, had long before taken this step. Although his

[45]Hohmann, *The Attainability of Heavenly Bodies,* trans. U.S. Joint Publications Research Service, NASA TT F-44 (Washington, D.C., 1960).

[46]"Biographical Note on Walter Hohmann," in Rynin, *Theory of Space Flight,* p. 182; Ley, p. 138.

[47]He did, however, suggest the advantages of the Moon, because of its low gravity, as a likely site for launching an interplanetary voyage (*The Attainability of Heavenly Bodies,* p. 96), a view which Pirquet forcefully rejected in favor of an artificial satellite (Sykora, p. 7).

[48]Hohmann, *The Attainability of Heavenly Bodies,* pp. 98–104.

[49]William R. Corliss, *Space Probes and Planetary Exploration* (Princeton, N.J., 1965), p. 11.

[50]Kondratyuk letter, May 1, 1929 (n. 22 above).

private papers reveal that he also shared the space-travel dreams of his fellow pioneers, Goddard avoided all but the slightest hint in public of what lay behind his work on rockets, the first results of which were published in 1919 by the Smithsonian Institution as *A Method of Reaching Extreme Altitudes.*[51] His thoughts on space travel were restricted to a series of unpublished reports during the 1920s which show his concern over the enormous mass of an Earth-launched spaceship. Goddard's solution was a scheme for manufacturing the propellants for the return trip at the spaceship's destination.[52] Neither space station nor rendezvous seem to have captured his notice.[53]

Goddard's head start in the development of liquid-propelled rockets failed to survive the 1930s. Space travel was always the goal, but means took precedence over ends as enthusiasts everywhere turned to experiment.[54] In contrast to the previous decade, the 1930s produced little writing on space travel, partly because experiment was the order of the day and partly because renewed military interest in rockets as weapons of war cloaked in secrecy much of the work being done. When Captain Walter R. Dornberger was put in charge of the German army's project to develop liquid engines for military rockets, his sole instructions came in a three-line order from his superiors which concluded: "Secrecy of the development is paramount."[55] Large-scale government support quickly shifted the status of liquid-propelled rockets from theory and experiment to proved technique, most spectacularly in the German V-2 program that Dornberger headed.[56] By the end of World War II, the existence of such rockets

[51]*Smithsonian Miscellaneous Collections*, vol. 71, no. 2 (1919); reprinted in *The Papers of Robert H. Goddard: Including the Reports to the Smithsonian Institution and the Daniel and Florence Guggenheim Foundation*, ed. Esther C. Goddard and G. Edward Pendray, 3 vols. (New York, 1970), 1:337–406.

[52]"Report to Smithsonian Institution concerning Further Developments of the Rocket Method of Investigating Space," March 1920, in ibid., 1:413–30; "Report to the Trustees, Clark University, on the Principles and Possibilities of the Rocket Developed by R. H. Goddard," August 1, 1923, in ibid., 1:509–17; "Supplementary Report on Ultimate Developments," March 1924, in ibid., 1:531–40; "Report on Conditions for Minimum Mass of Propellant," August 27, 1929, in ibid., 2:688–98.

[53]My examination of *The Papers* through the 1930s has revealed nothing on space stations or rendezvous. G. Edward Pendray has briefly surveyed the whole range of "Pioneer Rocket Development in the United States" in Eugene M. Emme, ed., *The History of Rocket Technology: Essays on Research, Development, and Utility* (Detroit, 1964), pp. 19–28.

[54]Von Braun and Ordway, pp. 60–85.

[55]Walter R. Dornberger, "The Lessons of Peenemuende," *Astronautics* 3 (March 1958): 18.

[56]Dornberger, *V-2*, trans. James Cleugh and Geoffrey Halliday (New York: Viking Press, 1954), and "The German V-2," in Emme, ed., *History of Rocket Technology*, pp.

convinced many that space travel was imminent, spurring a new round of speculation on the forms it might take by a new generation of enthusiasts.

## IV

The early postwar years found the revived British Interplanetary Society (B.I.S.) and its *Journal* serving as forum for some important new space-travel ideas. Founded in 1933, the society had suspended activities at the start of World War II. Restored in 1945, it quickly assumed a major role in the late 1940s and into the 1950s as sponsor of a journal devoted to serious and realistic discussions of future programs and technology.[57] In October 1948, two members of the society independently submitted papers to the society's editorial committee, both dealing with the concept of "orbital technique" or "orbital operations." The first of the two to reach print was "Orbital Bases" by Harry E. Ross in January 1949.[58] Kenneth W. Gatland's "Rockets in Circular Orbits" followed in March.[59]

The heart of the new idea was simply that staging in orbit need not demand a space station. In response to the limits of chemically propelled rockets, earlier workers had concluded that some form of stopover point in orbit was the only feasible place for launching an interplanetary flight. For most, this meant a space station. Ross and Gatland pointed out that the logic of stopping over depended only on a meeting place in orbit, not a fully constructed depot. They had arrived at that view from quite distinct starting points.

Ross, in fact, began with a space station. The forty-three-year-old radio operator and production-control man, a member of the B.I.S. since 1937, had joined forces with Ralph Andrew Smith, another long-time B.I.S. member who was working as a design draftsman in the British government's new Rocket Propulsion Research Establishment, to update Noordung's 1929 space-station design.[60] This design

29–45; Ley, pp. 228–78; T. Benecke and A. W. Quick, eds., *History of German Guided Missiles Development* (Brunswick, 1957). Von Braun and Ordway, pp. 86–119, survey the international development of military rocketry through World War II.

[57] See especially A. V. Cleaver, "Rocketry and Space Flight," *Journal of the Aeronautical Society* 70 (1966): 292, for a thoughtful assessment of the role of the B.I.S. during this period.

[58] Harry E. Ross, "Orbital Bases," *JBIS* 8 (1949): 1–19.

[59] Kenneth W. Gatland, "Rockets in Circular Orbits," *JBIS* 8 (1949): 52–59.

[60] "Know Your Council: H. E. Ross; Ralph Andrew Smith," *JBIS* 8 (1949): 123–24. Neither Ross nor Smith read German, forcing them to rely chiefly on the illustrations in Noordung's book, although a translation was later prepared at their behest for the library at B.I.S. headquarters in London. The Ross-Smith design was first published in the London *Daily Express* in November 1948 (see also Ross to B. C. Hacker, July 9, 1969; Michael Stoiko, *Project Gemini: Step to the Moon* [New York, 1963], pp. 34–36).

was the chief subject of the paper, but Ross also digressed on the virtues of staging a trip from the Earth to the Moon, which presented problems "substantially similar" to building a space station.[61] He proposed a lunar mission based on orbital operations. Three ships would rendezvous in Earth orbit to refuel one of their number, which would then depart for the Moon. The moonship would leave fuel tanks for the return journey in lunar orbit, to be picked up on the way back.[62] This scheme, Ross estimated, required only 1,326 tons launched from the Earth, instead of the 3,460 tons needed for a direct trip from the Eath to the Moon and back. "It will, of course, be appreciated that ability to rendezvous in space is an essential concomitant," Ross noted, but that was just as true of building a space station, and, "although the difficulties are indeed formidable, they do not appear insuperable."[63]

Gatland's views arose from other concerns. The twenty-four-year-old technical writer for Hawker Aircraft had become interested in problems related to the use of atomic-powered rockets.[64] One problem he foresaw was radioactive contamination of launch sites. This could be avoided by using chemical boosters, the atomic rocket being built and serviced in orbit. The same line of reasoning suggested using chemical landing rockets at the end of the journey, the atomic power plant staying in orbit about the destination. Once built, in other words, the atomic rocket stayed in space, where it retained a large energy potential for further flights. But if that were true, Gatland argued, then the technique was just as useful for conventional rockets. In effect, the interplanetary trip could be launched from orbit rather than from the ground, with the greater part of escape velocity already achieved.[65]

The elegance of the idea quickly converted the B.I.S. to its support. It was praised as "the most promising future line of development for astronautics,"[66] accepted as the basis for the society's design analysis of a lunar rocket,[67] and enthusiastically endorsed by the society's chairman in a widely read book.[68] By September 1951, the concept had achieved international recognition. In its report on the Interna-

[61]Ross, p. 4.

[62]Ibid., pp. 4–7.

[63]Ibid., p. 7.

[64]"Know Your Council: K. W. Gatland," *JBIS* 8 (1949): 168–69.

[65]Gatland, pp. 52–59.

[66]A. V. Cleaver, "The Calculation of Take-off Mass," *JBIS* 9 (1950): 12–13.

[67]"The Model Programme," *JBIS* 8 (1949): 165; cf. Kenneth W. Gatland, Alan E. Dixon, and Anthony M. Kunesch, "Initial Objectives in Astronautics," *JBIS* 9 (1950): 155–78.

[68]Arthur C. Clarke, ***Interplanetary Flight: An Introduction to Astronautics*** (New York, 1950), pp. 54–55.

tional Congress of Astronautics held in London September 3–7, 1951, the B.I.S. noted as the outstanding point "the unanimity of opinion shown by the technical representatives from all countries regarding the significance of the 'Earth-Satellite-Vehicle.' . . . All the contributors believed that interplanetary flight must, or at least should, involve refueling at some sort of orbital base, whether it be a 'space station' in the usually accepted sense, or simply a rendezvous position for a fleet of tanker rockets."[69] Rendezvous had been lifted to a new prominence in astronautical thought. Like the space station itself, orbital technique offered a means of sidestepping the basic limitations of chemical rockets. But while rendezvous problems had tended to be glossed over in space-station thinking, they were at the very core of orbital technique.

The new status of rendezvous as a field of study in its own right won a sort of formal ratification at the London Conference itself. R. A. Smith, Ross's collaborator, presented the first paper specifically addressed to the problem of "Establishing Contact between Orbiting Vehicles."[70] Smith insisted that, whatever the value of a space station might be, orbital refueling was the least-telling argument. Building a station in orbit was a far more complex task than simply transshipping fuel. The space station, in other words, could wait, and Smith predicted that it would "come relatively late in the development of Astronautics; after the Moon has been colonised in fact."[71]

By the end of 1951, the potential role of orbital rendezvous in future space travel had been widely accepted. But "space travel" was already giving way to "astronautics" as the proper name for a field of study that was crossing the line from qualitative and intuitive speculation to quantitative and systematic science. That line was not to be crossed by the likes of Gatland, Ross, and Smith, however eye-opening their ideas might prove to be.[72] They were the last of the talented amateurs. Their articles were seldom cited by the new breed of professionals who, early in the 1950s, were beginning to make

[69]"Second International Astronautical Congress, London, 1951" (annual report of the B.I.S.), *JBIS* 10 (1951): 326.

[70]Smith, "Establishing Contact between Orbiting Vehicles," *JBIS* 10 (1951): 295–99.

[71]Ibid., p. 299.

[72]John D. Bird, one of the workers at NASA's Langley Research Center who helped to promote the lunar-orbit-rendezvous plan for Project Apollo's Moon-landing mission, directly credits Ross and Smith with first presenting and discussing extensively the essentials of this approach, citing "Orbital Bases" and "Establishing Contact between Orbiting Vehicles" (see Bird, "A Short History of the Development of the Lunar-Orbit-Rendezvous Plan at the Langley Research Center," September 6, 1963 [as supplemented February 5, 1965, and February 17, 1966], p. 1 [unpublished MS in files of Historical Office, Manned Spacecraft Center, Houston, Texas]).

astronautics an accepted science and whose approach to rendezvous was the rigorous mathematical exposition of orbits and trajectories.[73] This was a far cry from the dreams that had often sustained space-travel enthusiasm in the past and, to many, like the anonymous author of "The Subscriber's Lament" in the April 1958 issue of *Spaceflight,* a sorry turn of events:

> I joined the British Interplanetary Society to go to the Moon—
> Reasonably soon.
> I wanted to hear about landings on Venus and Mars
> And thrilling Einsteinian flights to the stars.
> But, whenever I open the infernal
> B.I.S. Journal,
> Instead of pictures of exciting, space-suited people
> Setting off in some great, gleaming ship as tall as a steeple,
> All I find is a welter of maths
> Describing their paths.[74]

But, of course, it was just this shift that ultimately made the dream come true.

While the subscriber lamented, NASA was already in gestation. The new agency began with a staff of aeronautical engineers experienced in the several aspects of high-speed flight and rocketry. However useful such a background might be for NASA's first tasks —Mercury, for example, was a straightforward engineering project—it condemned NASA to recapitulate during its early years a compressed version of the history explored in this essay. NASA began with a plan to reach the Moon via direct ascent from the Earth's surface, rendezvous being ignored save for its relevance to space stations. Only in 1961, a full decade after the idea had swept European astronautics, did NASA tentatively commit itself to a role for orbital rendezvous in flight to the Moon.[75] But with that decision, the idea

[73]This trend clearly shows in the *JBIS* itself, notably in a series of papers by Derek F. Lawden through the 1950s. Current bibliographies in this area are striking for the absence of any reference to work before 1950 (see Gary P. Herring, "Orbital Transfer and Rendezvous: A Bibliography," Chrysler Corporation, Space Division, Huntsville Operations, Technical Note HSM-N42-67, May 30, 1967; and the following articles, which include substantial bibliographies: E. M. Dowlen and J. Seddon, "Orbital Rendezvous Techniques," *JBIS* 19 [1963–64]: 498–510; Ehricke, pp. 231–325; John C. Houbolt, "Problems and Potentialities of Space Rendezvous," *Astronautica Acta* 7 [1961]: 406–29).

[74]As quoted in Hugh L. Dryden, "Space Exploration and Human Welfare," *Advances in Astronautical Sciences* 4 (1959): 16. For a more scholarly exposition of this phenomenon, see Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago, 1962), pp. 19–22.

[75]Project Gemini's approval symbolized that tentative commitment; the background

that had begun as a casual insight of idealistic philosophy and had been transmuted through successive stages of scientific effort from speculation to mathematical rigor, now became the basis for an engineering solution to a concrete problem.

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is outlined in Hacker, "The Genesis of Project Gemini," and treated with greater detail in the first three chapters of Hacker and James M. Grimwood, *On the Shoulders of Titans: A History of Project Gemini,* NASA SP-4201 (Washington, D.C., forthcoming 1974).