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Memorandum

Draft chapter for Gemini history, "The Idea of Rendezvous", Hacker, 1968, published later in scrubbed-down version, courtesy of JSC History Office

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TO : See list attached

DATE: 12/18/68

FROM : BE4/Historical Office

[142]

SUBJECT: Comment draft chapters of Gemini narrative history

Chapter 1: "The Idea of Rendezvous" (by Hacker)
Chapter 2: "Rendezvous in NASA Planning" (by Hacker)

Rather than waiting to submit a complete manuscript to every reviewer, the procedure followed earlier with the Comment Edition of This New Ocean: A History of Project Mercury, the authors of the Gemini narrative history have decided to take a different tack. Drafts of each chapter, or related group of chapters, will be sent as they are finished to those whom we judge to have a special interest in the particular subject matter. We welcome comments in any form--marginal note, memorandum, telephone call, or whatever--on any aspect of the text--facts, style, interpretation, documentation. We will particularly appreciate having called to our attention factual errors, overlooked evidence, and events or individuals whose role we have slighted or exaggerated. Naturally we cannot promise to incorporate every suggestion we receive, but we will consider each on its merits, especially if supported by documentary evidence.

The Gemini history has two authors, Barton C. Hacker and James M. Grimwood, each of whom is drafting a separate section of the history. Hacker will cover the historical origins of Project Gemini and the development phase of the program itself through the first three Gemini flight missions. Grimwood's section will be Gemini operations, beginning with the Gemini IV mission and extending through the end of the program.

The two chapters accompanying this memorandum deal with the context of ideas and organization which eventually produced Project Gemini. Chapter 1, "The Idea of Rendezvous," is in the nature of an introduction. It considers the evolution of astronautical theory, focused on a particular idea, the use of orbital staging as an indispensable prelude to manned interplanetary flight. The scope of this chapter is broad, spanning six decades and two continents. Major topics are literary anticipations of the role of rendezvous, scientific speculations in the Soviet Union and Germany on the use of space stations, the beginnings of the idea of orbital operations as distinct from space stations in England, and the first quantitative studies of orbital maneuvering and rendezvous.

In Chapter 2, "Rendezvous in NASA Planning," the scope is narrower, the treatment fuller. This chapter explores NASA's institutional framework, emphasizing the influence of NASA organization and orientation on the reception accorded the rendezvous idea during the period of 1958-1961. Salient topics are NASA's administrative history, the character of NASA long-range planning, the role of the various NASA centers and of NASA Headquarters in furthering the study of orbital rendezvous, and the place of Project Apollo in the origins of Project Gemini.

Please forward comments, preferably with supporting evidence, to Historical Office, BE4, Manned Spacecraft Center, Houston, Texas, 77058, or telephone 483-7571

CHAPTER I

THE IDEA OF RENDEZVOUS

Behind the National Aeronautics and Space Administration's (NASA) initiation of Project Gemini in 1961 lay three related but distinct lines of development. The most recently begun and the most direct was technical. The Gemini spacecraft began its career as an advanced version of the Mercury capsule. This effort to improve and refine the Mercury capsule was chiefly pursued by elements of NASA's Space Task Group (STG), the organization responsible for directing Project Mercury. The main focus of NASA's future planning during this period, however, was the manned lunar mission, eventually christened Project Apollo. While STG engineers concentrated on developing a more versatile spacecraft, NASA planners concerned themselves with outlining a program to land Americans on the Moon. By 1961 NASA had come to recognize that some form of orbital rendezvous was the key to achieving this goal with dispatch and economy. The growing recognition of the crucial role of orbital rendezvous in the human exploration of space beyond the immediate vicinity of Earth produced a corresponding recognition of the need to develop the techniques of orbital rendezvous. NASA's primary justification for what became the Gemini program was the development of orbital techniques. During 1961 STG's efforts to improve the Mercury capsule merged with NASA's awareness of the importance of orbital techniques. The result was a rendezvous development program, Project Gemini, drawing on the technological capital laid up by Project Mercury but chiefly justified as a preliminary phase of Project Apollo. Project Gemini owed its existence to both its predecessor and its successor. We shall examine these two sources of Project Gemini in succeeding chapters.

In this chapter, however, we shall trace a third, and more general, line of development leading to Project Gemini. NASA's grasp of the significance of orbital techniques was surprisingly late in coming. As a scientific speculation, the idea was half a century old when NASA accepted it. Its literary antecedents were even a little older. NASA, of course, was only created in 1958, but its early planning for a manned lunar mission centered on direct ascent, a method largely discredited among knowledgeable space travel enthusiasts a decade earlier.

Here we are concerned with the origin, growth, and acceptance of a key idea in the theory of space flight. The idea, simply stated, is this: Without some form of orbital rendezvous, the human exploration of space beyond the immediate vicinity of Earth is impossible. Rendezvous is an exercise in orbit matching. When two objects in orbit are at rest with respect to each other--that is, their relative velocity is zero--and their distance from one another is negligible compared to their mean distance from the center of attraction, then the orbits of the two bodies have become one and rendezvous has been completed.[1] The importance of rendezvous is now unquestioned. The United States initiated its second manned space flight program, Project Gemini, in 1961 chiefly to develop the techniques of orbital rendezvous and demonstrate its feasibility.[2] Rendezvous also plays a central role in the U. S. manned lunar landing program, Project Apollo.[3] We can only infer the status of rendezvous in the Soviet space program from events, which suggest that it is just as important in Soviet as in American planning. A near approach to rendezvous was achieved

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1. See Krafft A. Ehricke, "Orbital Operations," Advances in Space Science and Technology, V (1963), pp. 239. Ehricke considers rendezvous "by far the most important class of general orbital operations," because of the many other operations it makes possible (ibid., p. 296). Rendezvous need not culminate in the connection of the vehicles (docking).

2. Although Project Gemini officially had three major objectives, including long-duration flight and controlled landing as well as rendezvous, officials of NASA persistently emphasized rendezvous in justifying the program. See, e. g., the testimony of James E. Webb (NASA Administrator), Robert C. Seamans, Jr. (NASA Associate Administrator), and D. Brainerd Holmes (Director, Office of Manned Space Flight) to House Subcommittee on Manned Space Flight of the Committee on Science and Astronautics, Hearings on H. R. 10100 (superseded by H. R. 11737), 1963 NASA Authorization, 87th Cong., 2nd Sess., Feb. 27, 28, and March 6, 26, 1962, pp. 4-5, 102-103, 250-51, 460-62.

3. For a brief account of the place of rendezvous in Apollo planning, see Wernher von Braun and Frederick I. Ordway III, History of Rocketry & Space Travel (New York: Thomas Y. Crowell Company, 1966), pp. 215-20.

quite early in the Soviet program, in August 1962 and June 1963, during the Vostok series of manned space flights.[4] More recently, in October 1967 and April 1968, the Soviet Cosmos series of unmanned spacecraft has demonstrated automatic rendezvous and docking, with the likely implication that orbital refueling is the Soviet answer to achieving manned lunar landing.

The current prominence of rendezvous concepts in space planning is a relatively recent outgrowth of an older idea. Until the late 1940s, rendezvous was an incidental, and often neglected, aspect of speculation on the role of the space station in interplanetary travel. The space-station idea was introduced to the literature of space flight by Kurd Lasswitz and Konstantin Eduardovich Tsiolkovskiy at the end of the 19th century. Lasswitz (1848-1910), a professor

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4. M. K. Tikhonravov, B. V. Raushenbakh, G. A. Skuridin, and O. L. Vaysberg, "Desyat' let issledovaniya kosmosa v SSSR," Kosmicheskiye Issledovaniya, V (1967), p. 668. In contrast, the first successful U.S. manned orbital rendezvous did not occur until December 1965. Nevertheless, the authors of this article single out rendezvous and docking in orbit as important U.S. achievements in space technology. (Ibid., p. 645.) This paper has been translated as "Ten Years of Space Research in the USSR," by Aztec School of Languages, Inc. (Washington: NASA TT F-11, 500, Feb. 1968). See also the comments of "the chief designer of the 'Vostok' spaceships," in Izvestiya, June 22, 1963, quoted in B. V. Lyapunov, Station Outside the Earth (Wright-Patterson Air Force Base, Ohio: translation FTD-MT-64-531, Jan. 27, 1966), p. 6: "The problem of rendezvous and connection, as we say, of joining spaceships, has been placed on the agenda of space navigation." The general problem of rendezvous (as related to the space station) is discussed, ibid., pp. 29-32.

of mathematics in Gotha, published his two-volume novel, On Two Planets, in 1897.[5] The significance of this novel was twofold. It quickly became a "permanent part of German literature," contributing notably to the predisposition of German scientists "to taking space-travel theory seriously."[6] Lasswitz also described, for the first time in Western European literature, the potential utility of a station positioned at some distance from the surface of a planet in easing the difficulties of interplanetary travel.[7] The effect of

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5. Kurd Lasswitz, Auf zwei Planeten: Roman in zwei Büchern (Leipzig; ~~B. Elischer,~~ 1897). Lasswitz was also the author of other fiction, as well as several scholarly works in the history and philosophy of science, most notably a classic history of atomism, Geschichte der Atomistik vom Mittelalter bis Newton (2 vols.; Hamburg and Leipzig, ~~L. Voss,~~ 1890.)

6. Willy Ley, Rockets, Missiles, and Space Travel (2d rev. ed.; New York; ~~Viking Press,~~ 1961), pp. 45-46, 114.

7. Ibid., pp. 48, 366; Alan R. Krull, "A History of the Artificial Satellite," Jet Propulsion, XXVI (1956), p. 369. Note, however, that Lasswitz' space station was not in orbit, and was therefore not a satellite; it was supported at a distance of one Earth radius above the North Pole by antigravity. The conquest of gravity made orbital motion superfluous. See Carsbie C. Adams, Space Flight: Satellites, Spaceships, Space Stations, and Space Travel (New York; ~~McGraw-Hill Book Company, Inc.,~~ 1958), pp. 12-13, 104-105. Edward Everett Hale's "The Brick Moon," a tale first serialized in Atlantic Monthly, XXIV (1869), pp. 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 satellite, prematurely launched and fortuitously manned, was an accident without significance (see von Braun and Ordway, History of Rocketry & Space Travel, pp. 18-21; Ley, Rockets, Missiles, and Space Travel, p. 366).

Lasswitz' stimulus, however, was not immediate. A full quarter-century, a generation in fact, elapsed before the space-station idea, and space-travel theory in general, flowered in Germany. In the meantime, a separate Russian tradition was founded by Tsiolkovskiy.

The transition from literary anticipation to scientific speculation in the history of space travel dates from about 1900. This step is epitomized in the work of Tsiolkovskiy (1857-1935), a provincial schoolmaster whose vision transcended his environment.[8] In 1895 Tsiolkovskiy published a science-fiction tale, Dreams of Earth and Sky and the Effects of Universal Gravity.[9] His primary concern was to illustrate the use of an artificial Earth satellite in providing an example of a gravity-free environment, but he also suggested the possible role of such satellites as platforms from which to launch interplanetary vehicles.[10] Eight years later

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8. See A. A. Kosmodem'yanskii, "K. E. Tsiolkovskii (The Character of His Discoveries and His Creative Manner)," in A. A. Blagonravov et al, (eds.), Soviet Rocketry: Some Contributions to its History, trans. and ed. H. I. Needler (Jerusalem, Israel Program for Scientific Translations, 1966), pp. 68-71.

9. K. E. Tsiolkovskiy, Grezy o zemle i nebe i effekty vsemirnogo tyagoteniya (Moskva, Izdatel'stvo A. N. Goncharova, 1895).

10. See V. N. Sokol'skii, "The Work of Russian Scientists on the Founding of a Theory of Interplanetary Flight," in Blagonravov et al, (eds.), Soviet Rocketry, p. 26; Kirill Stanyukovich, "Trip to the Moon: Fantasy and Reality," News: A Soviet Review of World Events, June 1, 1954, reprinted in F. J. Krieger, A Casebook of Soviet Astronautics (Santa Monica, Cal., RAND, 1956), p. 58.

Tsiolkovskiy published an article, "The Investigation of Space with Reactive Machines," which established the scientific framework for the use of rockets as a means of space travel.[11] The space-station idea did not appear in this article as first printed. In 1911-12, however, Tsiolkovskiy published another article with the same title, which was actually the second half of his argument. Here he discussed the artificial satellite and made the key observation that relatively little additional energy beyond that required to establish the satellite would then be needed to venture into interplanetary space.[12] Later still, in 1926, Tsiolkovskiy published these two articles privately with certain alterations and additions as a separate book, again under the same title. He proposed a master plan for the conquest of space which began with manned satellites, "a human settlement...in the ether, outside

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11. K. E. Tsiolkovskiy, "Issledovanie mirovykh prostranstv reaktivnymi priborami," Nauchnoe Obozrenie (May 1903), pp. 45-75, reprinted in A. A. Blagonravov, (ed.), Collected Works of K. E. Tsiolkovskiy, Vol. II: Reactive Flying Machines, trans. Faraday Translations (Washington: NASA TT F-237, 1965), pp. 72-117.

12. Tsiolkovskiy, "Issledovanie mirovkh prostranstv reaktivnymi priborami," Vestnik Vozdukhoplavaniya, Nos. 19-22, 1911, Nos. 2, 3, 5-7, 9, 1912, in Blagonravov, (ed.), Collected Works, II, pp. 150-51. In this paper, Tsiolkovskiy credits the fantastic novels of Jules Verne with turning his thoughts toward rocket computations (ibid., p. 118).

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 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." Such a base, Tsiolkovskiy pointed out, would require continual support from Earth. Regular traffic between base and planet would be needed to provide materials and exchange personnel.[13]

Tsiolkovskiy's space-station idea followed naturally from his fundamental achievement: He recognized that some form of rocket was the only feasible vehicle for interplanetary travel and rigorously formulated the theory of rocket motion. A simple chemically fueled rocket, however, could, even in theory, just barely attain orbital velocity, while escape velocity was out of the question. More efficient sources of energy than chemical fuels, such as the atomic generator, might provide an alternative, but that was a distant prospect.[14] Tsiolkovskiy, however, concentrated his

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13. Tsiolkovskii, <u>Issledovanie mirovykh prostranstv reaktivnymi priborami</u> (Kaluga, ~~The Author,~~ 1926), reprinted in Blagonravov, ed., <u>Collected Works</u>, II, pp. 338-39.

14. Tsiolkovskiy did suggest this possibility in his 1911-12 paper. See <u>Collected Works</u>, II, pp. 162-63, where he also mentioned the possibility of an electron rocket.

attention on a more practical solution to this problem, multistage rockets using conventional fuels. He first advanced the idea in a story published in 1918.[15] His calculations of the motion of a two-stage rocket appeared in the 1926 version of The Investigation of Space with Reactive Machines, and detailed descriptions of the structure and working principle of the multistage rocket, along with mathematical calculations of its most important flight characteristics, followed in 1929.[16] As in his other work, Tsiolkovskiy's contribution was in sophisticated analysis rather than invention: step-rockets had been known to fireworks makers for at least two centuries, and the idea may have been a century older yet.[17]

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15. Tsiolkovskiy, "Vne Zemli [Beyond the Earth]," Priroda i lyudi, Nos. 2-11, 1918.

16. Tsiolkovskiy, Kosmicheskie raketnye poezda [Cosmic Rocket Trains] (Kaluga: Izdatel'stvo Kollektiva Sekstii Nauchnykh Rabotnikov, 1929).

17. M. Subutowicz, "The Rocket Conceptions of K. Siemienowicz, 1650," Journal of the British Interplanetary Society, XIV (1955), pp. 245-47, reports finding the designs of several multistage rockets in Siemienowicz' Artis magnae artilleriae, pars prima.... (Amsterdam, 1650). Robert H. Goddard patented a multistage rocket in 1914 and Hermann Oberth pointed out its advantages in 1923. See also von Braun and Ordway, History of Rocketry & Space Travel, pp. 42-43. On the nature of Tsiolkovskiy's theoretical contributions, see V. N. Sokol'skiy, "The Works of the Russian Scientist-Pioneers of Rocket Technology (Historical Outline)," in T. M. Mel'kumov, (ed.), Pioneers of Rocket Technology: Selected Works, trans. Stemar Engineering Inc. (Washington: NASA TT F-9285, November 1965), pp. 134-40. For a detailed analysis of Tsiolkovskiy's work on multistage rockets, see V. F. Kotov, "K. E. Tsiolkovskii--Founder of the Theory of Multistage Rockets," in Blagonravov et al., (eds), Soviet Rocketry, pp. 85-126.

The attractiveness of the concept of staging as a means of overcoming the rocket's limitations was not limited to the rocket itself. It was at least equally attractive in the context of the rocket's journey. Interplanetary travel could be conducted as a staged operation, just as the spacecraft could be launched by a staged rocket. The basic advantage of such an approach, as we have seen, was pointed out by Tsiolkovskiy. Orbital velocity is significantly less than escape velocity, and can be achieved by a less powerful rocket. Launching an interplanetary voyage from orbit demands a relatively small velocity increment, compared to launching from Earth's surface, although the total energy requirement is no different. Tsiolkovskiy assumed that some kind of orbital base would be established before interplanetary travel was attempted and speculated extensively on the characteristics of such an artificial satellite. He did not, however, explore the staging function of a space station in any detail.

A younger contemporary of Tsiolkovskiy, Yuri Vasil'yevich Kondratyuk (1897-1942), considered this aspect of orbital staging more fully, and must also be credited with first addressing the rendezvous problem. Kondratyuk was a mechanic, largely self-educated though "cast off in some god-forsaken hole."[18] Although he published nothing until 1929, he had started his work more than a decade earlier, completing his first (untitled) manuscript on interplanetary flight in 1916 or 1917.[19] One of his major concerns was conserving fuel in interplanetary journeys. To this end he suggested that when the interplanetary 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

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18. Novosibirsk. The phrase is V. P. Vetchinkin's, in his review of Kondratyuk's manuscript: "Review by Mechanical Engineer V. P. Vetchinkin of Yu. Kondratyuk's article, 'On Interplanetary Voyages,'" April 12, 1926, in Mel'kumov, ed., Pioneers of Rocket Technology, p. 114. Kondratyuk had requested a publication grant from the government, which was denied despite Vetchinkin's favorable review. Kondratyuk published the manuscript, as edited by Vetchinkin, with a local Novosibirsk printer at his own expense in 1929, under the title Zavoyevaniye mezhplanetnykh prostranstv (The Conquest of Interplanetary Space). See below, page . On Kondratyuk's career and its frustrations, see also S. Yu. Protsyuk, "Pro razvytok litakobuduvannya ta raketobuduvannya v Ukrayini [The Development of Aircraft and Rocket Design in the Ukraine]," Visti Ukrayins'kykh Inzheneriv, XVII (1966), p. 85.

19. On the problems of dating Kondratyuk's writings, see Sokol'skiy, "The Works of the Russian Scientist-Pioneers of Rocket Technology," pp. 145-46.

[fuel] necessary for landing the inactive part and for subsequently rejoining the remainder of the vehicle."[20]

The fuel economy in this scheme depends on the fact that no energy is wasted in transporting fuel for the return journey to and from the surface of the destination, as Kondratyuk specifically pointed out in a revised and expanded version of this manuscript dating from 1918-19, entitled "To Whomsoever Will Read in Order to Build." Here he also raised the problem of rendezvous, at least implicitly, by considering methods for enhancing the visibility at large distances of the orbiting main vehicle.[21]

Kondratyuk stressed the advantages of man-made satellite bases and calculated the considerably smaller quantities of fuel required to launch from and return to the satellite base, rather than Earth's surface. He proposed establishing such a base by launching a fully supplied but unmanned satellite from Earth; a manned vehicle would follow, picking up supplies at the base and continuing

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20. Kondratyuk, mss (1st version), p. 18, quoted in Sokol'skiy, "The Works of the Russian Scientist-Pioneers of Rocket Technology," p. 151. This is, of course, the basic idea of the lunar-orbit-rendezvous plan in Project Apollo.

21. Yu. Kondratyuk, "Tem, kto budet chitat', chtoby stroit'," in Mel'kumov, ed., Pioneers of Rocket Technology, p. 44.

on its journey while the base continued to circle Earth. The returning vehicle would again stop at the orbiting base before completing its descent.[22]

Kondratyuk's first published work did not appear until 1929. In The Conquest of Interplanetary Space, he presented more polished versions of many of the ideas he had developed earlier. Conspicuously absent in the book was any mention of rendezvous in orbit at the destination of an interplanetary trip. His treatment of the satellite base, however, was quite detailed, with considerable attention paid to the basic rendezvous problem--i.e., matching the orbits of base and cargo delivery vehicle, using optical tracking from the base--and to control and guidance instrumentation.[23]

The third major figure in the development of Soviet astronautics, Fridrikh Arturovich Tsander (1887-1933), largely ignored the space-station idea in his published work. Yet some form of

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22. Ibid., pp. 44-45, 53. Kondratyuk's calculation of fuel savings and proposal for an Earth satellite are the author's later (1920, 1923-24) emendations of the original text. See also 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.

23. Kondratyuk, Zavoyevaniye mezhplanetnykh prostrantv, ed. Prof. V. P. Vetchinkin (Novosibirsk, The Author, 1929), in Mel'kumov, (ed.), Pioneers of Rocket Technology, pp. 107-11.

Earth-orbital flight was clearly implied by his plans for interplanetary travel. He specifically distinguished the type of rocket suitable for attaining orbital velocities (8 km/sec) from the type needed for interplanetary travel (11.1 km/sec). He suggested the rocket proper as the means to obtain orbital velocity, there "to stop the operation of the rocket and rest as on a natural station." For flight to the planets, some vehicle other than the chemical rocket would be more suitable.[24]

Tsiolkovskiy's early work attracted little attention in his homeland and none at all abroad until the mid-1920s. Kondratyuk's first published work did not appear until 1929, and his researches were unknown even in the Soviet Union until 1925. Although Tsander began his rocket researches early in the century, his first publication (aside from the very brief paper cited above) was in 1932.[25]

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24. Tsander, "Flights to Other Planets (Paper Two)," in Tsander, Problems of Flight by Jet Propulsion: Interplanetary Flights, ed. L. K. Korneev (Moscow, 1961), trans. staff of Israeli Program for Scientific Translations, ed. Y. M. Timnat (Jerusalem, IPST, 1964), pp. 228-29. Tsander originally wrote this paper in 1923, an abridged version appearing in Tekhnita i Zhizn', No. 13 (1924), pp. 15-16. See A. F. Tsander, "The Scientific and Engineering Legacy of F. A. Tsander," in Blagonravov et al. (eds.), Soviet Rocketry, pp. 136-137.

25. See "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," compiled by B. N. Vorob'yev, in Mel'kumov (ed.), Pioneers of Rocket Technology, pp. 156-62.

They founded Soviet astronautics, but had virtually no impact elsewhere until well into the 1920s.[26] The prominence of the space-station idea in Tsiolkovskiy's writings assured it a hearing, but the intellectual route which led from the speculations of Tsiolkovskiy and Kondratyuk to current Soviet interest in rendezvous remains a mystery. That such a route existed we can only infer from the fact that we can trace just such a course in the West, from the pioneer German space-station proposals to Project Gemini.

Russian (and Soviet) theorizing lay outside the mainstream of European and American developments, which proceeded independently. A generation and more separated Kurd Lasswitz' imaginative introduction of the space-station idea from its translation into scientific speculation. In 1923 Hermann Oberth (1894-) published The Rocket into Interplanetary Space, a mathematical investigation of the use of rockets for space travel. Oberth concluded his study with some remarks on the prospective uses of the rockets he described.

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26. The earliest mention of Tsiolkovskiy's work I have found in any non-Russian source is Walter Hohmann, Die Erreichbarkeit der Himmelskörper: Untersuchungen über das Raumfahrtproblem (Munich and Berlin: R. Oldenbourg, 1925), p. 16. Hohmann cited no particular work, but merely referred to Tsiolkovskiy as an early publicist for the idea of using the rocket vehicle for space travel. See below, page .

Unmanned flights seemed to lack adequate practical justification, but several valuable experiments might be performed from a manned vehicle. The large rockets required for manned flight would be very expensive, and Oberth suggested a manned Earth satellite as the project which could most readily be funded. This marked the introduction of the space-station idea into Western scientific literature. Oberth saw such stations as communications links and observatories and as a means of gathering solar energy. In the final paragraphs, almost as an afterthought, he pointed to their role as fueling stations for interplanetary flights. Though his remarks were brief, he mentioned most of the advantages: in particular, he pointed out that, without air resistance, the shape of the interplanetary vehicle was unrestricted and it would need only a small increment in velocity beyond that it already had as a result of being in orbit. A very efficient rocket could be constructed with detachable fuel tanks. These could be left in orbit at the destination, while the rocket descended to the surface. It could then re-attach itself to the fuel sphere and return. [27]

1923
29-yr old
Oberth

27. Hermann Oberth, Die Rakete zu den Planetenräumen (Munich and Berlin: R. Oldenbourg, 1923), pp. 92-97. Oberth published a much-enlarged 3d edition of this book in 1929, under the title Wege zur Raumschiffahrt (Munich and Berlin: R. Oldenbourg, 1929). His treatment of the station in space was much fuller but again focused chiefly on its role as observatory and energy collector.

Interest in rocketry and space travel swept Germany during the 1920s, largely stimulated by Oberth's first publication. The space-station idea soon became common currency, achieving its most elaborate presentation at the end of the decade in a book by Hermann Noordung, The Problem of Space Navigation. "Noordung" was actually the pseudonym of a mysterious Captain Potočnic, whose somewhat idiosyncratic notions tended to obscure the fact that he had given a good deal of thought to the engineering problems of a space station.[28] Noordung's concern was the space station as observatory. Shortly before Noordung's book appeared in print, however, a series of articles in The Rocket (the journal of the recently established Society for Space Flight) had initiated a shift in focus to the space station as a staging base for interplanetary flight. Count Guido von Pirquet, an Austrian engineer, demonstrated the impossibility of attaining space travel with chemically fueled rockets from the surface of Earth. He pointed out, as Tsiolkovskiy had done, that orbital velocity was

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28. Hermann Noordung (pseud.), Das Problem der Befahrung des Weltraums: Der Raketenmotor (Berlin: R. C. Schmidt and Co., 1929). Part of this work was translated into English by Francis M. Currier as "The Problems of Space Flying," Science Wonder Stories, I (1929), pp. 170-80, 264-72.

the first, and most difficult, step. Thereafter interplanetary travel required only modest further power. The space station had come to be not merely convenient but also essential.[29]

The true history of the rendezvous concept began with the publication, in 1925, of Walter Hohmann's mathematical exploration of The Attainability of Heavenly Bodies.[30] Hohmann (1880-), city architect of Essen-on-the-Ruhr, demonstrated, in effect, that interplanetary travel was impossible for chemically fueled rockets launched from Earth's surface because of the prohibitively high mass ratios required. Hohmann all but ignored the potential amelioration of this problem inherent in staging techniques, although he did suggest the advantages of the Moon, because of its low gravity, as a likely site for the initiation of an interplanetary voyage.[31] The lasting significance of Hohmann's work, however,

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29. Count Guido von Pirquet, "Fahrtrouten," Die Rakete: Zeitschifft des Verein für Raumschiffahrt, II (1928), ~~pp.~~ 117-21, 134-40, 155-58. See also Krull, "History of the Artificial Satellite," ~~p.~~ 370; Ley, Rockets, Missiles, and Space Travel, ~~pp.~~ 371-72; and John W. Massey, Historical Resume of Manned Space Stations (Redstone Arsenal, Ala.: Army Ballistic Missile Agency Report No. DSP-TM-9-60, June 15, 1960), ~~p.~~ 6.

30. Hohmann, Die Erreichbarkeit der Himmelskörper; translated as The Attainability of Heavenly Bodies by U. S. Joint Publications Research Service (Washington: NASA TT F-44, November 1960).

31. Ibid., ~~p.~~ 96.

lay in his calculations of trajectories for interplanetary travel and his demonstration that an elliptical trajectory tangent to the orbits of origin and destination was the most favorable (that is, required the least expenditure of energy) trajectory for transferring from one orbit to the other. Hohmann transfer orbits are the starting point for applied orbital mechanics and the starting point for orbital rendezvous, at least so long as the minimum use of energy remains a criterion.

By the end of the 1920s the theoretical foundations of space flight had been well established. This was as true in the Soviet Union as in Germany and the West. Investigators in both areas during the next decade and a half shifted their attention from theory to experiment. From about 1930 on, both in the Soviet Union and in the West, spaceflight enthusiasts concentrated on developing practical rockets.[32] Rocket experiments replaced space flight theorizing as the dominant concern of space societies on both sides of the Atlantic. Rocketry began very quickly to move from the realm of theory to the realm of technique, as most spectacularly exemplified in the German V-2 program.[33] During the 1930s and early 1940s, rocketry and

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32. On Soviet experimental work, see I. A. Merkulov, "A Contribution to the History of the Development of Soviet Jet Engineering During the 1930's," in Blagonravov et al, (eds), Soviet Rocketry, pp. 41-67; and E. K. Moshkin, "F. A. Tsander's Engineering Contributions to Rocketry," ibid., pp. 156-70. G. A. Tokaty, "Soviet Rocket Technology," Spaceflight, V (1963), reprinted in Eugene M. Emme, (ed), The History of Rocket Technology: Essays on Research, Development, and Utility (Detroit: Wayne State University Press in cooperation with the Society for the History of Technology, 1964), pp. 271-84, is less useful, though more accessible. American rocketry is briefly surveyed, with selected references to the work of Goddard and of the American Rocket Society, in G. Edward Pendray, "Pioneer Rocket Development in the United States," ibid., pp. 19-28. For German rocketry, see Ley, Rockets, Missiles, and Space Travel. Von Braun and Ordway, History of Rocketry & Space Travel, cover French, Italian, and British rocket experiments (as well as Soviet, American, and German) in Chapter 4, "The Legacy of the Pioneers," pp. 60-85.

33. Ibid., pp. 86-119, sketches the international development of military rocketry during World War II. On the V-2 specifically, see also Walter Dornberger, V-2, trans. James Cleugh and Geoffrey Halliday (New York: The Viking Press, 1954); and the same author's "The German V-2," in Emme, (ed), The History of Rocket Technology, pp. 29-45, which includes a bibliographical footnote, p. 29.

space travel thus temporarily parted company. Rocket science was well on its way to becoming rocket engineering while space travel remained a purely theoretical exercise.

Active interest in space flight, as opposed to rocketry, revived after World War II. The early postwar development of Soviet work on space flight, as of Soviet rocketry, remains largely unknown. In the late 1940s the focus of activity in the West migrated from Germany to Britain and the United States. Early U.S. work was secret,[34] but between 1948 and 1951 the British Interplanetary Society provided in its Journal a forum for the introduction and dissemination of an important new concept in interplanetary travel. The idea was "orbital technique" or "orbital operations," the two terms being synonymous.

In October 1948 two members of the British Interplanetary Society independently submitted papers to the Society's editorial committee which pointed out that the advantages of orbital staging need not depend on the prior establishment of a space station.[35] This was the essence of orbital technique.

These two papers are worth a closer look, since they established the conceptual framework for the subsequent development of

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34. See R. Cargill Hall, "Early U.S. Satellite Proposals," in Emme, (ed.), The History of Rocket Technology, pp. 67-93.

35. Kenneth W. Gatland, Development of the Guided Missile (London: published for Flight by Iliffe and Sons, Ltd., 1954 [2d ed.]), p. 218.

rendezvous techniques which led directly to Project Gemini, as well as Project Apollo. The first of the two papers to be published was Harry E. Ross' on "Orbital Bases."[36] It was initially read to the British Interplanetary Society in London on November 13, 1948. Ross' paper was an almost perfect illustration of the fundamental relation between the space-station and rendezvous ideas. In fact, it may be said to mark the transition from the generalized consideration (characteristic of the work done before 1930) of the utility of the space station to more narrowly focused work on the rendezvous problem (which subsequently became the subject of a specialized literature of its own). The chief subject of the paper was a space station designed by Ross and R. A. Smith, another B.I.S. member, but it included an extended digression on the advantages of staging in a trip from Earth to the Moon.[37] Ross pointed out that the problem of constructing a manned space station in orbit and of staging an Earth-Moon trip "are substantially similar."[38]

The Ross scheme called for three ships (A, B, and C) to be launched simultaneously from Earth. They would rendezvous in a

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36. H. E. Ross, "Orbital Bases," Journal of the British Interplanetary Society, VIII (January 1949), pp. 1-19. (This journal will hereafter be cited as JBIS.)

37. Ibid., pp. 4-7. The Ross/Smith space station, incidentally, was based on Noordung's design and was first published in the London Daily Express in November 1948 (personal communication, Ross to Barton C. Hacker, July 9, 1968). See also Michael Stoiko, Project Gemini: Step to the Moon (New York, Holt, Rinehart and Winston, 1963), pp. 34-36.

38. Ross, "Orbital Bases," p. 4.

500-mile circular orbit, where ships B and C would refuel ship A. Ship C would then be completely discarded, while ship B remained in orbit with the surplus fuel not required by ship A. Ship A, completely refueled, would depart for the Moon, enter lunar orbit, and detach fuel tanks needed for the return journey. These tanks would remain in lunar orbit while ship A descended to the lunar surface. Upon taking off, ship A would rerendezvous with the still-orbiting fuel tanks, re-attach them, and return to Earth orbit. Once in Earth orbit, ship A's crew would transfer to ship B for the descent to Earth's surface.

The basic requirements for such an Earth-Moon round trip were much the same as for the establishment of a space station. For either of these projects, Ross emphasized, "It will, of course, be appreciated that ability to rendezvous in space is an essential concomitant," adding that "although the difficulties are indeed formidable, they do not appear insuperable."[39] What made a scheme like this so attractive was its great reduction in the gross weight compared to what would be required for a direct trip from Earth to Moon and back. Whereas 30 pounds of fuel and hardware would be needed to

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39. Ibid., p. 7.

put one pound in Earth orbit, and 75 pounds to put the same pound in lunar orbit, one pound for a round trip (with lunar landing) would require about 1000 pounds at launch.[40] Ross estimated that his proposal would reduce Earth launch weight by a factor of 2.6 (1326 tons instead of 3460 tons).[41]

The second paper, Kenneth W. Gatland's "Rockets in Circular Orbits," dealt more directly with orbital technique, though in a somewhat different context.[42] Gatland's starting point was the proposed use of atomic-powered rockets. Such rockets would pose a serious radioactive contamination problem, which would probably be met by a combination of chemical boosters and orbital assembly and servicing. At the destination, too, contamination could be avoided by using chemical landing rockets while the atomic power plant remained in orbit. Thus the atomic rocket, once assembled, would always remain in space where it would retain a large energy potential for successive flights. But precisely this characteristic suggested the use of such a technique even without atomic rockets.

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40. Donald H. Heaton, "Approaches to Rendezvous," Astronautics, VII (April 1962), p. 25.

41. Ross, "Orbital Bases," p. 7.

42. Kenneth W. Gatland, "Rockets in Circular Orbits," JBIS, VIII (March 1949), pp. 52-59.

In effect, the interplanetary flight would be launched from Earth orbit, rather than from the ground, since the interplanetary vehicle would be using its own resources only after leaving Earth orbit. Establishing the circular orbit was by far the most expensive in terms of propellants, but this expense would be made up by refueling before the spaceship departed, which constituted the great advantage of orbital technique.

The publication of these two papers marked the point at which the rendezvous idea became, or was soon to become, an area of investigation in its own right. Certainly in these two papers it had not yet achieved that status, since both treated rendezvous in the context of a broader problem. For another decade, rendezvous continued to be justified chiefly in relation to establishing and maintaining the space station. But it was no longer limited solely to that context. As A. V. Cleaver pointed out just a year after the publication of Ross' paper, the essential utility of orbital technique did not at all depend on the prior establishment of a space station.[43] Like the space station itself, orbital technique was proposed as an answer to

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43. A. V. Cleaver, "The Calculation of Take-off Mass," JBIS, IX (January 1950), pp. 12-13. Cleaver concluded that in orbital technique "it is the writer's belief (shared with other members of the B. I. S. Technical Committee) that the most promising future line of development for astronautics has been touched upon."

the fundamental limitations of chemically fueled rockets. But while rendezvous had been an incidental consideration in space-station thought, it was a fundamental characteristic of orbital technique. Thus the rapid and universal acceptance of the utility of orbital technique led directly to thinking about the rendezvous problem specifically.

Just how rapid that acceptance was may be gauged from the following facts: In July 1949, the Journal of the British Interplanetary Society published "The Model Programme," describing the design for a circumlunar manned rocket using a hypothetical nuclear propulsion unit. A group of the Society's Technical Advisory Committee comprising Gatland, Anthony M. Kunesch, Alan E. Dixon, and R. E. Webb, in collaboration with the Technical Director, L. R. Shepherd, had "commenced a design analysis of 'Earth Escape' rockets, utilizing orbital stage technique."[44] Ross' rendezvous plan for achieving the trip to the Moon was enthusiastically endorsed by Arthur C. Clarke, then Chairman of the British Interplanetary Society, in his 1950 book on Interplanetary Flight. Clarke

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44. "The Model Programme," JBIS, VIII (July 1949), p. 165. A more detailed description of the program was presented in a paper read to the B. I. S. in London on January 7, 1950, and published later; see Gatland, Alan E. Dixon, and Anthony M. Kunesch, "Initial Objectives in Astronautics," JBIS, IX (July 1950), pp. 155-78.

stressed, in particular, the beauty of the idea of leaving fuel for the return trip in orbit while the ship descended to the lunar surface.[45] On January 6, 1951, Gatland amplified his original proposal by describing in detail the types of operations and spacecraft orbital technique would require.[46]

At the International Congress of Astronautics in Paris, September 1950, the representatives of all countries agreed that the "Earth-Satellite-Vehicle" was an appropriate subject for the following year's meeting, the proper theme to connect all the papers of the technical sessions. "The Artificial Satellite" was, in fact, the title of Shepherd's introduction to the symposium on satellite vehicles at the Second International Congress of Astronautics, which began in London on September 3, 1951. Shepherd, the Technical Director of the British Interplanetary Society, pointed out that an artificial satellite had a variety of potential uses sufficient to justify the immense cost of development. "But the real value of the orbital vehicle lies in its importance as an essential springboard in the supreme adventure of interplanetary flight.

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45. Arthur C. Clarke, Interplanetary Flight: An Introduction to Astronautics (New York: Harper and Brothers, 1950), pp. 54-55.

46. Gatland, "Orbital Rockets, I: Some Preliminary Considerations," JBIS, X (May 1951), pp. 97-107.

This without doubt must be regarded as the main reason for our interest in the device, all other purposes being of secondary importance."[47]

Shepherd's remarks, however, showed that he was thinking in terms of a space station as a refueling depot. But that station need not be a station in the usually accepted sense. In its report of the Congress, the British Interplanetary Society found the outstanding point about the London Congress to be "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."[48]

During the period encompassed roughly by the publication of Ross' "Orbital Bases" in January 1949 and the London congress in September 1951, astronautics passed the dividing line from speculation to science. The characteristics of the transition are much

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47. L. R. Shepherd, "The Artificial Satellite: An Introduction to the Symposium on Satellite Vehicles at the Second International Congress on Astronautics, London, 1951," JBIS, X (November 1951), p. 246.

48. "Second International Astronautical Congress, London, 1951," Annual Report of the B. I. S., in JBIS, X (November 1951), p. 326.

those delineated by Thomas S. Kuhn in The Structure of Scientific Revolutions.[49] During the early formative years of astronautics, say from 1903 to 1929, its seminal ideas regularly (though not exclusively) appeared between hard covers. Each writer began the subject anew, rehearsing the fundamental principles of rocket flight and deriving the basic rocket equation before proceeding to more esoteric matters. When astronautics emerged after the Second World War from its temporary eclipse by rocketry, however, its arenas were primarily the scientific meeting and the journal. Textbooks and popularizations now became the major hard-cover productions, while advanced work was published in proceedings and professional journals. Associated with this change was a rapidly developing specialization. Articles, by their nature, tend to focus on limited topics. Major concepts are broken down into more easily handled and restricted subdivisions treated in depth. Thus the space-station idea ramified into specialized studies of

49. Thomas S. Kuhn, The Structure of Scientific Revolutions (Chicago: University of Chicago Press, 1962), pp. 19-22.

manned orbiting laboratories, biomedical considerations, the rendezvous problem, and other areas, each of which developed an extensive literature in its own right.[50] Inevitably, further subdivision followed. The general rendezvous problem, for example, again divided, producing extensive literatures devoted to still more restricted aspects of rendezvous, such as rendezvous guidance, ascent trajectories, rendezvous simulation, and so forth. These specialized studies, in turn, provided the basis for actual mission planning, as they shifted from descriptive to quantitative treatment.

This process, as far as the rendezvous idea is concerned, is well illustrated by the progress of the idea of orbital technique. First formulated in 1948 and published early in 1949, by 1951 "the importance of 'orbital refuelling' has been unanimously accepted."[51] More specifically, rendezvous emerged as a field of study in its own right during the London congress. On September 7,

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50. The results of this process are indicated by the range of papers presented at a symposium on manned space stations in Los Angeles, April 20-22, 1960; see Proceedings of the Manned Space Stations Symposium (New York: Institute of the Aeronautical Sciences, 1960). See also Siegfried J. Gerathewohl, "Development of Manned Artificial Satellites and Space Stations," Advances in Space Science and Technology, IV (1962), pp. 203-317.

51. Clarke, Interplanetary Flight (3d impression, 1952), p. viii.

1951, R. A. Smith, co-author of the space-station concept reported by Ross in "Orbital Bases," presented the first paper specifically addressed to the problem of "Establishing Contact Between Orbiting Vehicles."[52] Smith considered the problem of bringing two objects together in orbit as dependent on the purpose for which contact was to be achieved, ranging from the destruction of a hostile object, through fuel transfer, to mechanical linkage and construction of objects in orbit. He also raised some general problems, including the role of a pilot in the final rendezvous maneuver and the limitation of changing motion only by impulsive thrust. Smith insisted that, whatever the value of a space station might be, orbital refueling was the least telling argument. Constructing a space 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 comparatively late in the development of Astronautics; after the Moon has been colonised in fact."[53]

The pioneering suggestions of Ross, Gatland, and Smith were followed, during the early and middle 1950s, by a revived interest in fundamental problems of orbital mechanics. The major work in

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52. R. A. Smith, "Establishing Contact Between Orbiting Vehicles, JBIS, X (November 1951), pp. 295-99.

53. Ibid., p. 299.

this area was done by Derek F. Lawden, who contributed, primarily to the Journal of the British Interplanetary Society, a series of mathematical papers on trajectories and orbits.[54] Lawden was not alone. The central theme of work related to rendezvous during this period concerned the mathematical exposition of orbital maneuvers.[55]

Rendezvous, however, represented a relatively advanced space flight technique. In much the same way that space flight

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54. Among the most frequently cited of Derek F. Lawden's papers: "Entry into Circular Orbits, I," JBIS, X (1951), pp. 5-17; "Inter-Orbital Transfer of a Rocket," JBIS, XI (1952), pp. 321-33; "The Determination of Minimal Orbits," ibid., pp. 216-24; "Orbital Transfer Via Tangential Ellipses," ibid., pp. 278-89; "Minimal Rocket Trajectories," Journal of the American Rocket Society, XXIII (1953), pp. 360-67; "Correction of Interplanetary Orbits, JBIS, XIII (1954), pp. 215-23; "Transfer Between Circular Orbits," Jet Propulsion, XXVI (1956), pp. 551-58.

55. Other significant papers include: Lyman Spitzer, Jr., "Interplanetary Travel Between Satellite Orbits," JBIS, X (1951), pp. 249-57; H. Preston-Thomas, "Generalized Interplanetary Orbits," JBIS, XI (1952), pp. 76-85; Preston-Thomas, "Interorbital Transport Techniques," ibid., pp. 173-93; H. S. Tsien, "Take-off from Satellite Orbit," Journal of the American Rocket Society, XXIII (1953), pp. 233-36; B. H. Paiewonsky, "Transfer Between Vehicles in Circular Orbits," Jet Propulsion, XXVIII (1958), pp. 121-23+. For a more complete bibliography on this subject, see Gary P. Herring, "Orbital Transfer and Rendezvous: A Bibliography," Chrysler Corp., Space Div., Huntsville Operations, Tech. Note HSM-N42-67, May 30, 1967. This work all proceeds from Hohmann's basic researches.

theory gave way to a concentration on rocketry after 1929, the concern with interplanetary travel by means of orbital technique gave way to a more focused interest in the first practical steps that could be taken to achieve space flight. This meant a minimum satellite vehicle. The notion of beginning space flight with an unmanned vehicle orbiting Earth was again not new, but it had only become a practical goal with the development of telemetry techniques in the 1930s and 1940s. The possibility of obtaining much useful data from high-altitude flights by instrument was the essential prerequisite for making unmanned space flight an attractive prospect, instead of merely an unpalatable necessity.[56]

Thus the period which saw the development and acceptance of the idea of orbital technique also saw a growing emphasis on minimum (or unmanned) Earth-orbital satellites. Both ideas were firmly endorsed at the London Congress in 1951, but during the next decade it was the unmanned satellite which attracted the most interest, chiefly because it was the obvious opening move in the assault on space. It was only after this move had been made that

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56. On the early development of telemetry, see Wilfred J. Mayo-Wells, "The Origins of Space Telemetry," in Emme, (ed.), The History of Rocket Technology, ~~pp.~~ 253-68.

rendezvous, as a logical next step, again became a major concern. The expansion of interest in rendezvous was immediate. No sooner had a satellite successfully been orbited than rendezvous studies began to appear, a trickle in 1958 became a stream in 1959 and a flood in 1960 and 1961. This literature was distinctly different, as I have suggested, from the seminal, but largely intuitive, formulations of the immediate postwar period. Firmly based on the capabilities of existing operational, or developmental, launch vehicles, it was highly quantitative and narrowly focused. It was also largely the product of work sponsored by large organizations, either industrial corporations or the U.S. Government. For the scene had also shifted. The major focus of activity had, by 1958, become the United States, where the money and the skills to turn theory into practice were available.