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von Braun and the lunar-orbit rendezvous decision: finding a way to go to the moon☆

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Abstract

Wernher von Braun's historic talk at Huntsville on June 7, 1962, when he endorsed "lunar-orbit rendezvous" (LOR) as the mode for landing on the Moon, has long been seen as one of the most critical dates in the Apollo program. It effectively ended a months-long, divisive debate inside NASA over LOR versus "earth-orbit rendezvous" (EOR) versus "direct ascent" (a single huge rocket to launch a lander directly at the Moon, with no rendezvous). Von Braun and his Marshall Space Flight Center had a long-standing commitment to EOR. While historians have long emphasized the significance of this surprise endorsement of LOR, there has been little analysis of how and when he arrived at that decision.

This paper will discuss the process by which von Braun finally picked LOR in the spring of 1962 and attempts to pinpoint the date of that decision. However, it also examines his long prehistory of Moon proposals, beginning in public with his October 1952 *Collier's* articles. In 1961, after President Kennedy's endorsement of the Apollo landing goal, he leaned toward EOR primarily because he did not want to build the huge launch vehicle required for direct ascent. He only gradually and somewhat reluctantly changed his mind. How that came about is the fundamental substance of this paper.

1. Introduction

When Wernher von Braun stood up at a NASA meeting in Huntsville, Alabama, on June 7, 1962, and endorsed "lunar-orbit rendezvous" (LOR) as the way to land on the Moon, it became one of the critical turning-points of the Apollo program [1]. In doing so, he overrode the preference of his subordinates for "earth-orbit rendezvous" (EOR), i.e., assembly of the landing vehicle in Earth orbit, and ended a months-long divisive debate inside the agency over LOR versus EOR versus "direct ascent" (a single huge rocket to launch a lander directly at the Moon, with no rendezvous).

While historians have long emphasized the significance of von Braun's surprise endorsement of LOR, there has been little analysis of his earlier commitments so far, nor has anyone explained exactly when and why he arrived at his decision [2]. I will thus survey his

Abbreviations: BAK, Bundesarchiv Koblenz; CM, Command Module; CSM, Command and Service Modules; DJ, daily journal; EOR, earth-orbit rendezvous; HRC, Historical Reference Collection, NASA History Division; JSC, Johnson Space Center (former MSC); LH_2, liquid hydrogen; LOR, lunar-orbit rendezvous; MJN, Michael J. Neufeld; MSFC, Marshall Space Flight Center, Huntsville, AL; MSFC/ULMF, Marshall Space Flight Center, Upper-Level Management Files; MSMC, Manned Spaceflight Management Council; NASA, National Aeronautics and Space Administration; NASA/HD, NASA History Division; NASER, National Archives South-East Region, Morris, GA; OHI, oral history interview; UHCL, University of Houston-Clear Lake, Texas; USSRC, US Space and Rocket Center, Huntsville, AL; WvB, Wernher von Braun; WvBP, Wernher von Braun Papers

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earlier Moon proposals, all of them some version of EOR or direct ascent, and then examine in detail von Braun's evolving position in the 1961–1962 NASA debate. In the process, I will attempt to pinpoint the date of his decision—only 1–3 weeks before his speech—and I will discuss the motivating factors behind it. The most important were: (1) the inability of the Manned Spacecraft Center (MSC) to find a workable design for a Moon-landing vehicle using the Apollo Command Module as a crew cabin, something that would be required for either EOR or direct ascent as they had evolved by 1962; (2) President John F. Kennedy's timetable of "before this decade is out," which impelled the fastest solution that was technologically feasible by 1969; (3) the simplification of the interface between the booster and spacecraft and with it, the relationship between MSC and his Marshall Space Flight Center (MSFC); and (4) the promise of an informal quid pro quo from NASA Headquarters that Marshall would develop a Lunar Logistics Vehicle in return for giving up its work on rendezvous vehicles and tankers needed for EOR. In making this decision, von Braun discarded his usual management technique of building consensus within his inner, German-dominated engineering group, feeling a decision was absolutely critical if Kennedy's goal was not to be lost. In doing so, he made a fundamental contribution to the success of Apollo and to the consolidation of NASA as an effective R&D agency [3].

2. von Braun's early moon proposals

The German–American rocketeer had long been obsessed with going to the Moon—if possible, personally. In the course of the writing a biography of him, it slowly became clear to me how central to his blinding ambition was his dream of landing on the Earth's only natural satellite. It was a dream that came to him as a teenager in late-1920s Weimar Germany. When Daniel Lang of *The New Yorker* magazine interviewed him in late 1950, von Braun particularly remembered an article in a German astronomy periodical "that described an imaginary trip to the moon.... It filled me with a romantic urge. Interplanetary travel! Here was a task worth dedicating one's life to! Not just to stare at the moon and the planets but to soar through the heavens and actually explore the mysterious universe! I knew how Columbus had felt." Several anecdotes attested to his continuing fascination with a human landing on the Moon throughout the Nazi period; one or two even speak of a specific proposal, but we have no details as to whether he was speaking of a direct launch from Earth or an assembly in Earth orbit near his space station, another major obsession. He may have contemplated both. Brief comments he made to the press and the public in El Paso, Texas, in winter 1946/1947, however, described the station as a "refueling" stop on the way to the Moon—a form of EOR [4].

Thereafter, von Braun turned his attention for several years to an elaborate proposal for a Martian expedition, even though he told Lang that "I'd rather go to the moon than to Mars"—in part because it seemed a much more realistic personal objective. But he felt that if he could prove that his utopian-sounding "Mars Project" was feasible, based on conservative extrapolations of late-1940s rocket technology, it would show the public that interplanetary travel was not so fantastic after all. He set out to write a (rather bad) science-fiction novel based on his detailed calculations. Most relevant for the future LOR debate, he pictured three winged "landing boats" descending from the 10 orbiting ships, just as Apollo would later use a specialized Lunar Module (LM). Yet he never imagined a mothership/lander configuration for Earth's atmosphere-less satellite, as going straight in with rocket braking seemed intuitively obvious to him, as it did for many other space advocates [5].

von Braun's first detailed public discussion of a human lunar expedition thus did not come until the October 18 and 25, 1952, issues of *Colliers* magazine. "Man on the Moon: The Journey," and "Man on the Moon: The Exploration," were no less audacious than his groundbreaking March 22 article on the space station—he only wished to imagine space exploration on a gigantic scale. The very first human landing would be a 3-ship, 50-man expedition, requiring six months of assembly in orbit next to his station. "Each ship is 160 feet long (9 feet more than the height of the Statue of Liberty) and about 110 feet wide. Each has at its base a battery of 30 rocket motors, and each is topped by the sphere which houses the crew members, scientists and technicians on five floors." All three ships would descend directly to the lunar surface together. As he described in the second article, credited jointly to Harvard astronomer Fred Whipple, the expedition also had several tracked vehicles to carry out its scientific work. In one case, 10 men set off to explore a crater almost 200 miles away. After 6 weeks on the surface, all 50 crewmembers would lift off from the Moon in the two return ships, the other being a one-way cargo vehicle. As was typical of von Braun's visions, his Moon flight was marked by highly optimistic estimates of the cost (half a billion dollars, not counting the space station), and by a timetable that also seemed quite optimistic: within 25 years, i.e., by 1977 [6].

It was not until after the Soviet Sputnik that he made his next public landing proposal—this time using direct ascent [7]. Thanks in large part to his role in launching the first US satellite, his now-magnified celebrity allowed him to realize his frustrated ambitions as a science-fiction writer. In fall 1958 and spring 1959 the Sunday newspaper supplement *This Week* published his novella, *First Men to the Moon*, in four parts, detailing a two-man expedition to that body using a huge rocket and a direct launch from Earth. Turning around as it approached the Moon, his spacecraft ignited a landing stage to alight on the lunar surface without going into orbit; that stage provided the launch platform for the two astronauts in their winged reentry vehicle to propel themselves back to Earth. It seems likely that this concept went back to some of his original German ideas. The story was skillfully illustrated by one of his *Collier's* collaborators, Fred Freeman. Padded out with popular science material on spaceflight, it appeared as a short book in 1960 [8].

At almost exactly the same time as *First Men to the Moon* was first published, in 1958–1959, von Braun and his associates at the Army Ballistic Missile Agency (ABMA—they would not be formally transferred to NASA until July 1960) developed their first sophisticated and detailed lunar exploration plans. The context was the red-hot "space race" with the Soviet Union, interservice rivalry with the US Air Force, and a search for missions for the new Saturn launch vehicle, then going into development. It would combine eight engines in the first stage for an unprecedented 1.5 million lb (6.67 millions N) of thrust. Lacking the authority to develop the gigantic launcher needed for direct ascent, which NASA would soon call Nova, and needing to justify Saturn, von Braun and his advanced missions people, Ernst Stuhlinger and H.H. Koelle, favored assembling and fueling the lunar landing vehicle in orbit around the home planet—i.e., EOR—using many launches. This was the conservative approach that von Braun advocated to NASA at the end of 1958 when trying to sell Saturn, and it came up again in Project Horizon, an ABMA lunar base study carried out in 1959, and in an early 1960 proposal derived from it, "A Lunar Exploration Program Based upon Saturn-Boosted Systems" [9].

As NASA began to formulate its post-Mercury human spaceflight program in 1959, many in the agency wanted to beat the Soviets to the Moon too. A study committee in mid-year picked the lunar goal, which bolstered the space agency's interest in Saturn just as the fate of ABMA was again being debated. Later in 1959, former Vanguard technical director Milton Rosen, who had moved to the launch vehicles office at NASA Headquarters, pushed direct ascent and the use of liquid hydrogen (LH_2) in all upper stages, in an IAF paper with a co-author. According to Rosen, that paper influenced Space Flight Programs chief Abraham Silverstein's decision to force LH_2 upper stages on von Braun at the end of 1959 in an examination of NASA's launch vehicles. Rosen would remain an advocate of direct ascent, which seemed the most straightforward approach, but that would require a Nova of at least 9 million lb (40 million N) of thrust in the first stage, grouping six of the new 1.5-million-lb-thrust F-1 liquid-oxygen/kerosene engines that North American Aviation's Rocketdyne Division was developing. Later analyses indicated that his spacecraft weights were too low; however, so Nova as it was vaguely conceived in 1960–1961 was usually based on an initial thrust of 12 million lb (53 million N), which would require a first stage of around 50 ft (15 m) in diameter! [10].

The alternative that von Braun presented was multiple launches of the Saturn C-2, which would be an improved version of the basic Saturn, now called the C-1. (The "A" and "B" versions, with non-hydrogen upper stages, had been discarded in the Silverstein committee.) The eight-engine, kerosene/lox first stage, labeled the S-I, would be increased from 1.5 to 2 million lb of thrust (9 million N) in the C-2, and further liquid-hydrogen stages would be added. As the direct result of Silverstein's body, von Braun initiated two projects for NASA at the beginning of 1960. First, for the C-1, a contractor would develop a LH_2/lox second stage confusingly called the S-IV (under the building block concept, it would move up to be a third or fourth stage in C-2 and later versions). Douglas Aircraft of Santa Monica, the famed airliner company and contractor for the Thor IRBM, won the competition [11].

The second project was a liquid-hydrogen engine of up to 200,000 lb (890,000 N) of thrust, ultimately dubbed the J-2, which Rocketdyne had already been working on. Up to this point, the only LH_2 rocket engine under development was the 15,000-lb. (67,000 N)-thrust RL-10, at famed aero-engine manufacturer Pratt & Whitney; two were to be used in the Centaur upper stage for Atlas (when mounted on a Saturn, Centaur would be called the S-V). The S-IV ultimately got six RL-10s for 90,000 lb (400,000 N) of thrust, but the much bigger J-2 engine was needed for the projected S-II and S-III stages in C-2 and later, bigger Saturns [12].

Of course, this alphabet soup of designations was bewildering for anyone on the outside at the time, let alone for later observers, but the bottom line for von Braun was that he would much rather contemplate the C-2 or

larger versions of Saturn than jump to the truly monstrous Nova. NASA Headquarters and Robert Gilruth's Space Task Group, which was running the Mercury program out of Langley Research Center in Virginia, had meanwhile concluded that the Nova was still a distant prospect, and the Eisenhower Administration was not going to fund a lunar landing project anyway, so Apollo was announced in July 1960 as an Earth orbit and circumlunar project with the potential to become a Moon-landing vehicle in the 1970s. The boosters would be the Saturn C-1 and C-2. But Eisenhower would not fund Apollo at all, so there was also no money for the J-2-powered S-II stage, which was the first item von Braun wanted if the C-2 was to become feasible in the mid-sixties [13].

3. From direct ascent to EOR

As is well known, incoming President John F. Kennedy threw out Ike's conservative space policy after two Cold War humiliations, Yuri Gagarin's spaceflight and the failed US Bay of Pigs invasion of Cuba, motivated him to decide in April/May 1961 "to land a man on the Moon" by the end of the decade. Von Braun played an important role in this decision by testifying that the booster requirements were so demanding—an order-of-magnitude leap in rocket power—that the Soviets would not have much of a head start. The Marshall Director wrote a letter to Vice President Lyndon Johnson on April 29 that probably did not have much direct influence, but it encapsulated the evaluation he had already given verbally to Johnson's ad hoc working group and key NASA leaders [14].

Inside the space agency, the immediate reaction to Kennedy's decision was that an all-out crash program meant the revival of Nova and direct ascent. That was certainly the conclusion of the first, emergency study committee organized at Headquarters in early May, but it would prove to be only the first of many study committees. NASA Administrator James Webb and Deputy Administrator Hugh Dryden, in their news conference on the afternoon of the May 25 presidential speech, went so far as to announce that Nova would be the launch vehicle for the lunar landing program [15].

In Huntsville, von Braun unleashed a blizzard of studies to plan for Nova and for a Saturn C-3 based on a two-F-1 first stage (3 million lb or 13.3 million N of thrust), as the C-2's payload capability was looking increasingly marginal. He told his father on June 22, apologizing for the belated letter: "Ever since Kennedy declared his intent to go to the Moon, all hell has broken loose here. At the moment, we are working on plans which put in the shade everything we have done before and against which even our 'Saturn' [C-1] pales...." The Nova, if it had the eight F-1 first stage, would not only be about 50 ft (15 m) in diameter, it would be around 400 ft (122 m) tall, and would create so much noise during static testing and launching, and such a blast danger if it blew up, it was dubious if it could even be tested or launched at Cape Canaveral. Perhaps they would have to go to some uninhabited island or off-shore platform [16].

Then there was the manufacturing problem. Any plant would have to have a "hook height" for overhead cranes higher than the 50-ft stage lying on its side, which meant the factory space would have to be taller than that. Yet already in May, MSFC had begun looking into an enormous, empty, government-owned factory at Michoud in eastern New Orleans, Louisiana, which had been built to assemble landing craft in World War II, but had been used for aircraft, tank engines and other military equipment. Its hook height was not nearly high enough for Nova without a major reconstruction project. By June von Braun and his bosses had already decided that Michoud was too good a deal to turn down, especially as it was conveniently located for barge traffic of rocket stages, in one direction to Huntsville via the Mississippi, Ohio and Tennessee rivers, in the other to Cape Canaveral via sea. As von Braun also pointed out several times, crash program or no, NASA also did not have the resources to develop the C-3 and Nova simultaneously. Over the summer and fall, practical considerations thus piled up against Nova until it began fading as an option. This result suited von Braun and his associates, whose conservative engineering philosophy led them to believe it was too big a technological jump [17].

As Nova and direct ascent declined in popularity, EOR made a comeback, much to their relief. Two more study committees at NASA Headquarters in June and July, to which Marshall sent representatives, looked at the rendezvous problem, which seemed intimidating and complicated. How were they going to bring two or several large vehicles together in space and gently link them up to form the lunar landing vehicle and its Earth departure stage? But the second committee concluded, in the words of notes that von Braun took: "Rendezvous less formidable than lunar landing." It was not the "pacing item" and could certainly be solved, although overall it looked simpler to just link up modules (soon called "connecting mode") rather than transferring propellants from one vehicle to another (soon called "tanking mode"). This group also recommended a Saturn C-4, with four F-1s or 6 million lb (26.6 million N) of thrust in the first stage, double the C-3, as it could

halve the number of vehicles to meet in Earth orbit from four to two. Every extra launch, in those days of frequent, spectacular rocket failures, increased the odds that the whole lunar landing would be derailed by one failed firing [18].

Yet von Braun remained loyal to the C-3 concept for far too long, perhaps because of the perceived difficulties of building an even bigger, more complicated vehicle, but also likely because the constantly changing picture made Saturn management a headache. It certainly made the S-II competition messy, because the diameter of the stage kept growing along with the first stage on which it would sit. At the outset, the S-II was to be 260 in (660 cm) in diameter for the C-2. In June, von Braun told Harrison "Stormy" Storms, president of North American Aviation's new space division and leading candidate for the S-II contract, to base their design on a 320-inch-diameter stage (813 cm), and explain how they would cope with an increase to 360 (914 cm). By the time Storms and NAA won the contract in September, von Braun was telling him: plan for 360, but it could get bigger. The S-II, and the first stage underneath it soon called S-IC, would end up at an imposing 396 in (1006 cm), almost six times the diameter of von Braun's Redstone ballistic missile and just big enough to fit under the roof at Michoud [19].

On the morning of October 27, 1961, the first Saturn C-1 (later called Saturn I) thundered away from its new pad in Florida. The TV networks thought it important enough to carry it live, as it was the biggest and most powerful rocket ever launched at 162 ft (49 m) tall, 460 ton (420 MT) in weight, and 1.3 million lb (5.8 million N) of thrust. Watching from the new, spacious Saturn blockhouse, von Braun and his Germans were not disappointed. The S-I first-stage cluster of nine tanks and eight engines, carrying two water-filled dummy stages representing the S-IV and S-V, powered through "max Q," when aerodynamic forces were at their peak, and kept on going, setting off wild celebrations in the blockhouse. The vehicle reached a peak altitude of 95 mile (154 km) and dropped into the Atlantic. The perfect flight on the first try astonished the Marshall crew. It was also a propaganda triumph at a terrifying moment of the Cold War: Soviet and American tanks were gun barrel to gun barrel across the newly constructed Berlin Wall [20].

Ironically, even as the C-1 scored its spectacular success, it was already being orphaned as a launch vehicle. NASA had lost interest in the S-V Centaur stage as it did not suit Apollo, but the heavier the spacecraft got on paper, the more inadequate was a two-stage version of C-1 for even Earth orbital operations. Soon NASA would decide to build a more powerful version called C-1B (Saturn IB). Meanwhile, the Air Force wanted its own heavy rocket and did not want to depend on NASA, so it came up with a proposal for a Titan III, strapping two huge solid-propellant rockets on the side of a two-stage Titan II ICBM, which gave a cheaper vehicle with the lifting power of a C-1 [21].

To add insult to injury for Huntsville, Gilruth's group, now renamed the MSC and preparing to move to Houston, picked the Titan II to lift their two-astronaut Mercury Mark II spacecraft, soon called Gemini. The lunar objective made it urgent that there be a gap-filler between Mercury and Apollo, one that would give human experience in rendezvous and docking. Von Braun, however, was furious because MSC had initiated a rendezvous program without any consultation with Marshall, which was studying the same topic for lunar mission EOR. He was also annoyed that MSC had not considered Saturn as a booster, but it was really too big for what was supposed to be a scaled-up Mercury. Von Braun told Gilruth that he would take no responsibility for Titan II if it got into trouble, as he did not want to repeat his ongoing experience with Atlas–Centaur and Atlas–Agena. As NASA's designated booster center, Marshall had assumed management of these vehicles from the Air Force and now both programs were mired in technical problems—problems exacerbated by incompatible management styles between Huntsville and the USAF. Leaving MSFC out of Gemini–Titan II was fine by Gilruth, as MSC was used to contracting directly with the Air Force for Mercury–Atlas. He had already terminated Mercury–Redstone after the second manned suborbital hop on July 21 in order to concentrate on orbiting an astronaut, ending what little influence von Braun had on Project Mercury. Relations between the two centers were at their nadir [22].

November–December 1961 at least brought the resolution of one central issue for the lunar landing project: the choice of the large launch vehicle. All through the fall von Braun had wavered between C-3 and C-4, 3 versus 6 million lb of initial thrust. The answer would turn out to be neither. Milt Rosen, by then heading the launch vehicles section of the new Office of Manned Spaceflight under Brainerd Holmes, came down to Huntsville to discuss the situation. He spent several days convincing his counterparts and then von Braun that in any of the rendezvous scenarios for Apollo, the biggest rocket possible was needed short of direct ascent, which Rosen still favored. As designed on paper, the C-4's first stage could easily accommodate a fifth engine in the center, making it a C-5. In fact, the "hole" in the middle of the C-4 might well lead to tail-heating problems

and, thanks to MSFC's conservative structural design, there was a big crossbeam there that could easily absorb the thrust of another F-1 engine. Von Braun became a convert, even telling Holmes at the first meeting of the Manned Spaceflight Management Council in December that "the hole in the center was crying out for another engine." The final configuration chosen was (1) the S-IC, a five F-1 first stage with 7.5 million lb (33 million N) of thrust, to be built by Boeing; (2) the S-II, a five-J-2-engine, liquid-hydrogen second stage totaling 1 million lb (4.5 million N) of thrust, to be assembled by North American; and (3) the S-IVB, a single J-2-powered third stage with 200,000 lb (890,000 N) of thrust, to be derived by Douglas from the S-IV. Later known as the Saturn V, the C-5 was really a small Nova, a monster that would be 363 ft. (111 m) tall with the spacecraft on top, weighing over 6 millions lb (2700 MT)—the displacement of a small warship. Von Braun had backed into a much larger vehicle than he had originally wanted to build [23].

At this point, the MSFC Director just assumed that Apollo would have to be done by EOR, as his many speeches attest. Headquarters felt pretty much the same way—no other scenario seemed very credible except direct ascent, which had already been pretty much ruled out for booster reasons. Yet a new and surprising contender arose in late 1961: LOR. It was in fact not so new. A Langley Center aeronautical engineer, John C. Houbolt (pronounced "Ho-bolt"), had been championing the idea since at least 1960 on behalf of a small group there. He pointed out the fundamental physics. Whether you went direct or by EOR, and whether you went into lunar orbit first or not, the entire vehicle descended to the lunar surface. That meant that you had to carry a lot of propellants to get the big vehicle down, plus all the propellants needed to lift the Apollo spacecraft off the surface and back to Earth. Why not leave the propellants needed to get back to Earth in lunar orbit, and for that matter the whole main spacecraft, and descend to the Moon in a light vehicle designed simply for that job [24]?

Houbolt did not do himself a favor, however, by outlining lunar landers of unrealistically low weights, from under 15,000 lb (6800 kg) for a pressurized LM down to 2500 lb (1140 kg) for an open platform in which one astronaut would descend in his pressure suit! Someone joked the astronaut should wrap an aviator's silk scarf around his neck. When Houbolt had presented these ideas at Headquarters a year earlier, in December 1960, Gilruth's design genius, Max Faget, had apparently jumped up and exclaimed: "His figures lie." Von Braun was present. As the MSFC Director later said regarding Houbolt's most elaborate proposal, the only one anyone took seriously: "[I]f... you have to have one extra crew compartment, pressurized, and two additional guidance systems, and the electrical power supply for all that gear,... will you still be on the plus side of your trade-off?" The advantages of LOR just did not seem intuitively obvious to him or Faget [25].

Moreover, almost everyone thought that the method was inherently more dangerous, because if the lander astronaut(s) failed to make the rendezvous with the mother ship, he or they were dead. In Earth orbit, if the rendezvous failed, then the astronauts would simply come home in their reentry vehicle. At this point no American had yet been in orbit and no one had ever done a rendezvous. So Houbolt found he could get little respect from most of the committees that met in 1961; LOR was rated at or near the bottom in their reports. Out of frustration, Houbolt violated all channels by sending two long, pro-LOR letters directly to Associate Administrator Robert Seamans in 1961, one in May and one in November [26].

The accounts of the principals diverge at this point as to how important Houbolt's November letter was to getting LOR taken seriously. Von Braun, for one, later agreed with Gilruth and Faget that they were already coming around without Houbolt's new intervention. Supporting that contention is a rather tense phone conversation that von Braun and Gilruth had on November 24, mostly about Gemini–Titan II. The MSFC Director mentioned the fifth-engine idea for C-4 (i.e., C-5) that had just come up in the Rosen visit. Gilruth said: "If you can go to lunar rendezvous then you can go direct with C-4 and with C-3 you couldn't." So he, Faget and the MSC people had obviously run the weight calculation and concluded that even with a bigger lander, Houbolt was not far wrong. The weight savings were potentially so large one could launch the whole spacecraft on one C-4 or C-5, whereas EOR required two of them. Von Braun did not react. He later claimed that "I had never committed myself to EOR," and that is true in the narrow sense that he never made a final decision and formally recommended it to Washington. But from fall 1961 until spring 1962 he acted as if it was the way to go [27].

4. The "mode decision": von Braun changes his mind

The relentless, exhausting pace of the Apollo–Saturn program continued in the new year. Manned spaceflight chief Brainerd Holmes had hired a brilliant, 35-year-old Irish–American engineer from New York

City, Dr. Joseph Shea, to be his deputy for systems engineering. He was to pull together the mode decision. Touring the centers early in the year, he found that NASA was still more an agglomeration of organizations than an integrated agency. In particular, "you almost can't imagine the animosity" between MSC and MSFC, Shea later said, especially from Gilruth's side. Holmes organized dinners to accompany the Management Council meetings and Shea found himself sitting at "some of the most strained tables I've ever been at." Moreover, EOR concepts at the two centers were fundamentally incompatible. "It was all booster oriented when Marshall presented it; and it was all spacecraft oriented when Houston did." He tried to get each side to analyze parts of the other. He also asked for assistance and found Huntsville markedly more cooperative than MSC (then in the middle of its move to Texas). Von Braun, always the gentleman and good soldier, volunteered the services of Arthur Rudolph, recently transferred from the Army, and 10–15 other engineers to help Shea's systems analysis, if they could remain at MSFC. Faget, on the other hand, told Shea to get lost and Gilruth backed him up [28].

After Shea had toured the human spaceflight centers in January, he came away "impressed with the overall competence" of von Braun's organization, but "MSFC has not paid any attention to LOR and was not in a good position to comment on the mode. Their instinctive reaction, however, was negative. This is to be expected, since use of LOR would lessen the MSFC role in the manned lunar program significantly." By this he meant, Marshall would no longer have a piece of rendezvous operations in Earth orbit. Shea's statement pretty much captures von Braun's attitude, so the question as to when and why he really began to take LOR seriously is important, but difficult to determine. He was exposed to the strongly pro-LOR presentation by Houbolt of Langley and Charles Matthews of MSC in the Manned Spaceflight Management Council meeting on February 6, but that was not the first such talk he had heard [29].

For many, including von Braun, it was the spacecraft design argument that finally decided the issue. Faget and his people were never able to satisfactorily solve the problem of how to land the big EOR vehicle on the Moon. Originally it was something like 90 ft long. On February 20, the Mercury team had at last succeeded in launching John Glenn on his three-orbit trip around the world, yet here they were trying to figure out how to back a vehicle the size of the entire Mercury–Atlas rocket down to the lunar surface! To reduce the lander's size, Faget and his designers proposed a separable "lunar crasher" stage—a module under the Apollo Command and Service Modules (CSM) that would contain enough propellant to slow the spacecraft into lunar orbit, then lower it from lunar orbit down to near the surface, before being jettisoned in a hair-raising, low-altitude separation. Even with a smaller vehicle, in which the cylindrical Service Module would have legs and a base for landing and launch, the designers still faced a very difficult problem giving the astronauts any kind of visibility. The Command Module was a flat conical reentry vehicle in which the crew would lie on its back for landing. Faget and company tried putting a "porch" on it or some other arrangement to allow the commander to stand up and see the surface as the vehicle came in, but they never found an adequate solution. Another proposal was for the vehicle to land on its side, but that meant launching from the Moon's surface almost horizontally, a dangerous proposition. Long before that time, MSC leaders were all LOR converts [30].

At the March 27 Management Council meeting, von Braun asked Gilruth to present their arguments to a briefing in Huntsville, perhaps impressed by what he had heard. On April 16, Marshall got the full, all-day MSC viewgraph presentation, nicknamed "Charlie Frick's Road Show," after the Apollo spacecraft project manager who organized it. Present were a large Houston group that included Gilruth, Faget, Frick and two Mercury heroes, Alan Shepard and John Glenn. A Langley engineer who arrived immediately afterward states: "Apparently the presentation was well received by von Braun, since he made several favorable comments." Frick remembers von Braun making "a very gracious speech thanking us and saying he understood the advantages of the system." Max Faget came away with the even stronger impression of the MSFC Director "very generously throwing in the towel" [31].

It seems that they were misled by von Braun's gift for diplomacy, as April 16 was by no means his unambiguous moment of conversion. In early May, in the midst of his usual round of incessant travels to Washington, the Cape and to speeches around the country, he became infatuated with a proposal for "C-5 Direct" from TRW Space Technology Laboratories. A Saturn C-5 would launch a two-man spacecraft to land directly on the Moon. A "mission module" incorporating windows would be mounted on top of a small reentry vehicle. But that required throwing out the existing Apollo CSM, already contracted to "Stormy" Storms' division of North American Aviation, and using liquid hydrogen in the Moon-landing vehicle to gain higher rocket efficiencies, which was technologically risky. The idea

really was a non-starter, although with Shea's support, Marshall did briefly study it [32].

By this time even manned spaceflight chief Brainerd Holmes was pretty much a convert to LOR after hearing the "Road Show" in Washington on May 3. According to Shea, Holmes told him to feel von Braun out regarding a quid pro quo for accepting this mode. Houston would get another spacecraft, the LM as it was later called, while Marshall would lose all its tanker and orbital rendezvous work. Lacking any other projects, Huntsville faced its perennial problem of dependence on developing new, large rockets to keep the place going. While von Braun later denied that he made any deal for LOR, as he wanted to remember his motives as pure, Shea insists that they had a frank conversation in his office. It could only have occurred on May 15, when von Braun was in the capital again. Shea had already pushed the idea of a "lunar logistics vehicle," a one-way, robotic lander to deliver a load of supplies to the Moon for use later, longer-duration stays of astronauts or a lunar base. From what happened immediately afterward, it is clear that giving Marshall the dominant role in that became the basis for a deal. Von Braun's conversion to LOR may have been sincere, but he was a canny bureaucratic politician when it came to defending the interests of his organization [33].

The moment at which one can definitely verify his decision to accept LOR is May 31, the first day in the office after the Management Council met in Huntsville on the twenty-ninth. Right after he got in, "Dr. Von Braun called Tom Markley—MSC, requesting that someone from MSC come to Huntsville to see if some method can be devised to insert the MSC in-house bug into the Saturn." The "bug" was the LM's nickname because of the insect-like appearance of this oddly shaped vehicle with legs. "If this can be done it will save total vehicle weight and length, and make more payload available than if the bug has to ride on top." He was searching for a way to put the LM inside the shell-like adapter that joined the Apollo CSM to the "guidance slice"—Marshall had recently decided to put the guidance system for the whole rocket into a separate ring, later called the Instrument Unit (IU), mounted atop the S-IVB. Curiously, von Braun had not given the "bug" problem any thought, although its position had already been discussed in a Shea-organized LOR review in Washington. But he had not been there [34].

Von Braun's formal coming-out as an LOR supporter was on Thursday, June 7, at the end of a long day in Huntsville presenting Marshall's mostly pro-EOR studies to Joe Shea. It is a date justly remembered as one of the most critical in the history of Apollo. Apparently the shock in the room was palpable as von Braun got up and said, by Shea's account, "Well, gentlemen, I have listened to the arguments; I'm proud of the work you have done. Now I'll tell you the position of the center." The question is why anyone at MSFC should have been surprised. The previous 3 days had witnessed a grueling set of reviews. On Monday the fourth, there had been an all-day practice session for the seventh, followed on the fifth and sixth by visits from the President's Science Advisory Committee and a delegation of congressional staffers. To the latter committees Marshall presented broader surveys that included Saturn, Nova and the launch complex at the Cape. Von Braun later plausibly speculated that, as NASA had not formally made a mode decision, he and his staff withheld any conclusions in presentations to outsiders. As for the earlier dress rehearsal, he apparently did not reveal his decision to his chief EOR analyst, Ernst Geissler, or anyone else at that meeting, perhaps because he had not quite decided whether to suddenly end the debate. Although von Braun normally operated by consensus with his inner, German-dominated group, apparently June 7 was one of those rare occasions when he decided that a decision was so urgent, he had to lead [35].

We do not have the original transcript or notes, but we do have a polished version that von Braun dictated on the Saturday after. He began by listing MSFC's preferences in order: (1) LOR, preferably with "the development of an unmanned, fully automatic, one-way C-5 (lunar) logistics vehicle"; (2) EOR (Tanking Mode); (3) C-5 Direct; (4) Nova direct. He preferred LOR because it had "the highest confidence factor of successful accomplishment within this decade," "an adequate performance margin" based on conventional, storable hypergolic propellants in the CSM and LM, and the ability to separate the reentry vehicle from the lunar landing vehicle—MSC's spacecraft design argument. Moreover, LOR offered "the cleanest managerial interfaces" between MSC, MSFC, the Cape and the contractors. "There are already a frightening number of interfaces in existence in our Manned Lunar-Landing Program" necessitating too many "coordination meetings, integration groups, working panels, ad hoc committees, etc." He concluded this section by noting that "John Houbolt of Langley" had been the first advocate. "Against this background it can, therefore, be concluded that the issue of "invented here" versus 'not invented here' does not apply to either" MSFC or MSC as "both Centers have embraced a scheme suggested by a third source." This latter argument appears to be aimed at the pro-EOR

people in his own center who may have found his conclusions a sell-out to Houston. Indeed, he faced a "storm" of criticism at the next Board meeting, according to Stuhlinger [36].

As for EOR, von Braun noted that all the studies had concluded that "tanking mode," in which one C-5 would launch a liquid-oxygen tanker to fuel the Earth departure stage of the spacecraft, had a much bigger performance margin than "connecting mode," where the spacecraft and stage would link up. But even then, EOR would require two launches, raising costs and lowering the probability of success, while making the interface between the centers more complicated. Finally there was simply the design problem; the present CM was "simply unsuited for lunar landing because of the poor visibility conditions and the undesirable supine position of the astronauts during landing" [37].

Von Braun went on to discuss the two versions of direct ascent in a part of the speech that is all but forgotten now. He showed himself still enamored of "C-5 Direct," but the marginal weight factors and the need to develop a "high energy" (liquid hydrogen) propulsion system for the lunar spacecraft made it impossible to do it "within this decade"—Kennedy's all-important deadline. As for the Nova, the time factors for development were even worse, it would be completely disruptive to the current plans for the Michoud factory and the Saturn C-5 program. He hoped instead it would later become an even more gigantic "Supernova" successor vehicle for launching a lunar base or manned interplanetary program. He concluded by recommending LOR, a lunar logistics vehicle, and the Saturn C-IB (an S-IVB on top of an uprated C-1 first stage), which Houston needed for Apollo rendezvous tests in Earth orbit.

Wernher von Braun's June 7 remarks were fundamental in closing the long, drawn-out "mode decision," which was threatening NASA's ability to meet the President's objective. In formal bureaucratic terms, the decision would go on until Holmes sold it to the Webb-Dryden-Seamans triumvirate later in June, but the unity of the manned space centers and von Braun's convincing arguments made that pretty much a foregone conclusion. His speech had another salutary effect; it improved Houston–Huntsville relations. There would be no bitter battle at Headquarters over competing modes and the booster–spacecraft interface would be straightforward. According to Shea, von Braun's talk was no less than "a major element in the consolidation of NASA, really" [38]. Now, would come a challenge that von Braun and his colleagues anticipated but still could not quite fathom: how to manage such a gigantic program successfully.

5. Conclusions

Over 30 years of dreaming about landing on the Moon did not prepare Wernher von Braun for the LOR decision. Lunar-orbit rendezvous did not seem intuitively obvious to him, any more than it did for most other engineers in NASA. Since the vehicle had to descend to the lunar surface on rocket power alone, going straight in seemed simplest. When he and they thought about the extra complexity of a separate lander and the danger factor of separating the astronauts from their return vehicle and making them do a rendezvous, it also seemed obvious that this was not a wise choice. Since he and his Marshall associates felt that Nova was too large a technological leap, they rapidly concluded that building or refueling the landing vehicle in Earth orbit was the only way to go; they brought much of the NASA leadership along with them.

Several factors propelled von Braun to change his mind, although only slowly and reluctantly and several months behind his MSC counterparts. First and foremost came the spacecraft design argument: Faget and his designers never found a feasible way to design a large landing vehicle based on the conical Apollo CM already contracted to North American. Behind this factor was a second, fundamental reality: the overwhelming pressure of meeting the Kennedy timetable. There was simply no time to go back and reconsider the core Apollo spacecraft design, as would have been required by "C-5 Direct." Moreover, the deadline also militated against the riskier choice of using liquid hydrogen in the spacecraft and it favored the fewest number of launches. The fact that LOR required only one C-5 (Saturn V) instead of two reduced launch risk and with it, the likelihood of making the deadline.

By early May, von Braun appears to have recognized that LOR was superior to EOR, at least within the constraints of 1962, but was not quite ready to commit. He briefly flirted with the idea of "C-5 Direct," which in some aspects resembled his *First Men to the Moon* scenario of 1958. The final factor thus was the offer of an informal quid pro quo by Shea and Holmes at NASA Headquarters—give up EOR work in return for a "C-5 logistics vehicle," a very large, one-way, automated lander to provide equipment and supplies to expeditions or bases on the lunar surface. That project would soon fade away because of rapidly escalating costs in the Apollo budget, but von Braun could not know that in spring 1962. Von Braun thus made up his mind sometime between May 15 and 31—the former being the probable date he met Shea in Washington and the latter being the day he talked to Houston about the "bug."

We are left with one mystery: why should he have withheld his change-of-heart from key associates in Huntsville, especially in view of his general management practice of making all technical decisions through long-drawn-out discussions with his German-dominated Development Board? Part of the answer has long been obvious from his prepared remarks: he was worried that the mode decision had already gone on too long and that the President's timetable was under threat. He decided he had to lead. But that still does not explain why, during the previous week, he never informed Ernst Geissler and the other MSFC lecturers of his decision. He let them stand up on June 7 and give pro-EOR arguments for 6 h before his surprise summary. Ultimately, that question is unanswerable on the basis of the surviving documents, so any historian or biographer is left to speculate. Perhaps he had decided to wait till the next Board meeting to discuss it with his staff, but then changed his mind when the Shea briefing was held. Perhaps he did not want to undercut his presenters' enthusiasm by telling them in advance that their hard work was perhaps irrelevant. Or perhaps the week prior to June 7 had been so hectic he had no time to properly think through how and when he was going to declare his pro-LOR sentiments.

The matter is of no great consequence, but the substance of the decision was. It was one of the rare occasions in a long career as a brilliant engineering manager when he simply decided that he knew what was right and that he would have to commit several thousand people to it, whatever they thought. Several aspects of Wernher von Braun's life are disturbing, notably his opportunism, his technocratic amorality, his involvement with National Socialism, and his post-World-War-II advocacy for nuclear bombs in orbit [39] but no one can deny that his LOR decision was one of his fundamental contributions to the success of Apollo.

References

[1] This paper is based on modified excerpts from M.J. Neufeld, Von Braun: Dreamer of Space, Engineer of War, Alfred A. Knopf, New York, 2007. All rights reserved.

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[3] This judgment should not be construed as general approval of von Braun in all aspects. My work, notably The Rocket and the Reich, The Free Press, New York, 1995, Wernher von Braun, the SS and concentration camp labor: questions of moral, political and criminal responsibility, German Studies Review 25 (2002) 57–78, and the biography cited above, discuss his memberships in the Nazi Party and SS and involvement in "crimes against humanity" in the treatment of concentration-camp workers.

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[6] Collier's, 18 October, 51–58, 60, and 25 October 1952, 38–40, 42, 44–48. These articles were expanded into a book edited by Cornelius Ryan, Conquest of the Moon, Viking, New York, 1953.

[7] I leave aside here his contribution to a December 1955 Disney TV program, "Man and the Moon," about a simple manned circumlunar voyage, staged again from the space station—see the Disney DVD *Tomorrowland*. This scenario included no landing.

[8] "First Men" corr. in USSRC, WvBP, file 200-31; WvB, First Men to the Moon, Holt, Rinehart and Winston, New York, 1960.

[9] Brooks, et al., Chariots, 4–6; F.I. Ordway III, M.R. Sharpe, R.C. Wakeford, Project horizon: an early study of a lunar outpost, Acta Astronautica 17 (1988) 1105–1121. See also WvB presentation to Joint Chiefs of Staff's Joint Space Logistics Conference, 20 May 1959, in USSRC, WvBP, file 801–21.

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[11] WvB Memo for Record, 22 December 1959, and Hyatt to Horner, 11 January 1960, w/WvB marg. comments, in NASER, RG255, MSFC/ULMF, #89-064, Box 13; Hyatt to WvB, 18 January 1960, in: NASA/HD, HRC 2563; R.E. Bilstein, Stages to Saturn, NASA, Washington, DC, 1980, pp. 48–50, 157–159.

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[17] WvB DJ, 9 and 14 June 1961, in: NASA/HD, HRC 13256; Brooks, et al., Chariots, pp. 44–45, 50–51; Murray and Cox, Apollo, pp. 109–110.

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[37] WvB Concluding Remarks..., 7 June 1962, copy in NASA/HD, HRC 13263.

[38] Shea OHI by Emme, 6 May 1970, in: NASA/HD, HRC 2011.

[39] MJN, 'Space Superiority': Wernher von Braun's campaign for a nuclear-armed space station, 1946–1956, Space Policy 22 (2006) 52–62. See above, note 3, for the Nazi question.