title page at rear

Chapter 2

Heylandt's Rocket Cars and the V-2: A Little Known Chapter in the History of Rocket Technology*

Frank H. Winter and Michael J. Neufeld†

Introduction

When the German Army's Ordnance Office began its liquid-fuel rocketry program in 1931-1932, the technology was barely in its infancy. The Army thus turned to two "expert" groups to learn what it could. One was the German Space Travel Society (VfR); the other was the Aktiengesellschaft für Industriegasverwertung, a company established by Paul Heylandt for the production of liquefied gas storage and transport containers. As is well known, the Army primarily gained experienced personnel from the VfR. Hitherto little documented is the Heylandt company's role in furnishing the Army's first test motors, as well as two key engineers. Heylandt was the only industrial firm developing liquid-fuel rocket motors during this period, and it traced its expertise to rocket-car work. As a result, the Heylandt company was a significant technological bridge between the amateur experimenters of the early 1930s and the V-2. Heylandt's

*Presented at the Twenty-Sixth History Symposium of the International Academy of Astronautics, Washington, D.C., U.S.A., 1992.

†National Air and Space Museum, Washington, D.C., U.S.A.

pioneering work in cryogenics is also not without its relevance to the history of rocket technology.

Paul Heylandt

Paul Heylandt, also named Christian W. P. Heylandt or Paulus Heylandt, was born 6 February 1884, at Bad Sulza, Thuringia, Germany, the son of an official of the local salt works. Paul possessed a natural gift for mechanics and a strong interest in science, though his parents did not have income sufficient for him to obtain much of a formal education. Rather, he was largely self-educated, especially in chemistry, physics, and mathematics. The major turning point of his life occurred in 1898, at age 14, when he read an article in a local Erfurt newspaper about the 1895 experiments of his countryman, Karl Linde, with the liquefaction of air. Young Heylandt was so intrigued with this account that he chose to make the commercial development of liquefied gases his life's work.[1]

As a young man, Heylandt obtained a modest job in a large machine factory in Erfurt; one reference says he began as an apprentice locksmith. During his spare time, Heylandt undertook private technical studies, made technical drawings for the company's foreman, and conducted experiments in a small laboratory at home. But his salary was insufficient, so funds for his experiments were provided by his widowed mother and sisters. He also earned money by lecturing and giving demonstrations on liquid air to schools. In this way he developed a showmanship that was manifest during the later rocket-car period. Heylandt's early experiments with the liquefaction of gases were not without hazards, and they resulted in explosions that placed him in the hospital. "The police were not too enthusiastic about my experiments," he later recalled, and he was obliged to report to the police station from time to time.[2]

Eventually the experiments proved fruitful. He felt confident enough to sign to take out his first patent, DRP 165,682 of 6 February 1903, for "Trans- port- und Aufbewahrungsgefäss für flüssige Luft oder dgl." ["Transport and Storage Vessel for Liquid Air, etc."]. Heylandt continually improved upon his ideas, which led to many other German and foreign patents. He also improved techniques for producing liquefied gases, though he was most known for developing methods of storing and transporting liquid oxygen, nitrogen, hydrogen, and air. At the time, liquefied gases were mainly used in breathing apparatus, refrigeration, welding, and beer and other alcoholic production. The storage and transport of liquefied gases was commercially viable because they did not require heavy high-pressure storage tanks that were more expensive to build and transport. Heylandt thus made a valuable contribution to improving a technology that later became important to liquid-fuel rocket technology as well.[3]

Heylandt also began taking out patents for the liquefaction process in 1908. His method differed from Linde's, although both relied upon the expansion of high-pressure air, because Linde used a valve system, while Heylandt employed a compressor. Heylandt compressed the air to 150-170 atmospheres, then expanded it to low pressure and temperature in one stage. Linde's system was more reliable, though Heylandt's was very useful for special applications. A company was formed in Hanover, about this time, for the development of his method, and it was called the Flüssige Luft-Machinen und Apparate—System Paulus Heylandt G.m.b.H.[4]

This enterprise, as well as another in Hamburg, seems to have been short-lived, but in 1912, Heylandt founded the more successful Heylandt-Gesellschaft für Apparatebau in Berlin-Mariendorf. Then in 1921, he established an additional company, the Aktiengesellschaft für Industriegasverwertung [Industrial Gas Utilization Company] at Berlin-Britz. In the meantime, from his earliest chemistry studies and experiments, Heylandt was well aware of the combustible, or rather explosive nature of liquid oxygen and other liquefied gases when mixed with hydrocarbons. Indeed, the controlled mixing and ignition of these substances constitutes the basic liquid-propellant rocket engine, though the liquid-fuel rocket motor does not seem to have occurred to Heylandt early in his career. He did recognize the application of liquefied gases for more powerful and greatly improved explosives. During the First World War, he consulted with a number of explosives engineers, which led to his patent of a liquid air bomb. It does not appear that Heylandt's liquid air or oxygen bombs progressed beyond the conceptual or experimental stage.[5]

By the mid-1920s, Heylandt's machines and plants improved to the point where he was able to produce 99.5 to 99.8% pure liquid oxygen and 1,000 to 8,000 liter transportation tanks for liquefied gases. His patented processes were licensed in 20 countries, particularly the U.S., Britain, Belgium, and Switzerland. Heylandt, who had started off in very modest circumstances, thus became a notable pioneer in a new technology, as well as a prosperous industrialist. During the late 1920s, he was made an honorary doctor by the Technische Hochschule Berlin. It was also in this period that the theoretical foundations of the newer technology of liquid-propellant rocketry were laid.[6]

The Rocket Cars

In the wake of the emerging international spaceflight and rocketry movement of the 1920s, a number of faddish, and not very scientific, experiments were conducted with rocket-powered cars, ice sleds, bicycles, and gliders. In 1928, German automobile magnate, Fritz von Opel, attracted considerable publicity by having various models of his Opel Rak rocket cars race along Berlin's Avus Speedway, railway tracks, and elsewhere. All the vehicles up to the Opel Rak IV were fitted with batteries of electrically ignited, low impulse, gunpowder-filled, lifesaving rockets provided by the F. W. Cordes pyrotechnical firm of Wesermünde near Bremen. (The Opel Rak V was built, but the authorities prohibited further experiments with it on a railroad track due to mishaps with previous cars.)[7]

It was the Austrian spaceflight and rocketry pioneer, Max Valier, who introduced rocketry to von Opel. Von Opel was naturally motivated by the publicity it would bring his company. Valier sought, albeit naively, a way to study the "laws governing rocket performance" and to demonstrate "rocket power," which he believed could eventually be used in aircraft and spacecraft.[8]

Valier had always intended to use liquid propellants, as Hermann Oberth had advocated, but Oberth parted with Valier over the latter's unscientific detour into solid rockets and stunts. But by spring 1929, Valier began moving back in the direction of liquid fuels, though the stunt aspect remained. In his own words, he now applied himself "to the high-pressure steam-jet rocket-propelled automobile, since the development of the reaction engine with liquid-fuel was not yet sufficiently advanced." Consequently, he had a test car, 5.5 m (18 ft) long by 60 cm (23.6 in) wide, built to his specifications by the Möllers engineering firm of Essen-Stoppenberg. But despite his scientific pretensions, Valier was at first vague about his new propulsion system and silent as to its propellant. Only later, on 3 January 1930, was it revealed that the "fuel" was carbon dioxide. Just why the normally open Valier was so secretive is unknown. His biographer only hints that he was somewhat embarrassed over the many breakdowns with the solid-fuel system and wanted to make sure, after a trial period, that the newer carbon dioxide system worked.[9]

The system was actually quite simple. To be used in the car as a propelling force, the carbon dioxide, which Valier obtained in liquefied form in steel cylinders, had to be in gaseous state at 100 atmospheres pressure. In the case of one of Valier's rocket runs, this was done through the cooperation of a nearby restaurant owner who provided a large container with warm water in which the cylinders were immersed until sufficient carbon dioxide was evaporated to raise the pressure to the required level. The cylinders were placed back in the car and Valier, when ready, simply depressed a foot pedal. This opened a valve, releasing the carbon dioxide through the nozzle as a non-flammable, harmless gas propelling the car forward on the classic reaction principle.[10]

Valier went through several modifications of the car, which became known as the Opel Rak VI. The first had a single cylinder with 10 kgs (22 lbs) of carbon dioxide fuel. The second was fitted with three cylinders, each with 20 kgs (44 lbs) fuel. Its three main valves had to be opened by assistants. This car ran on 13 October and 29 November 1929, at Essen, attaining up to 70 km/hr (43 mph). The Valier Rak VI (or Rak 6) apparently made its final public run on the Avus on 3 January 1930.[11]

In the meantime, Valier had approached the Heylandt company for support toward developing a liquid-propellant rocket car. According to his biographer, Valier was returning to a former idea:

> In the summer of 1924, he had advised Hermann Oberth that, once enough financial backers had declared themselves willing to support the construction of the rocket, he should begin his work in the vicinity of a large liquid air factory, firstly because this would spare him the very high costs of transport for liquid oxygen, and secondly because such a factory would be interested in the rocket as a prospective large-scale consumer of liquid oxygen and might support the project. At that time he proposed Linde's Eisfabrik in Munich.

But in 1929, Valier did not go to Linde, but rather to Heylandt. Again, according to Valier's biographer: "Heylandt appreciated Valier's plans, and, after some thinking the matter over well, he was prepared to make it possible for Valier to develop a liquid rocket engine on his factory grounds, and even to give the project financial backing." The costs of the tests were to be paid provisionally for a period of three months and up to a total of 6,000 Marks.[12]

Heylandt went further, providing Valier the assistance of a test and development engineer, Walter Riedel, then working on new patents for the transport of liquid oxygen. Valier thus began his liquid-fuel developmental work at Heylandt's plant in Britz in January 1930, though there is no indication Heylandt himself was involved with the experiments. Riedel, later Chief of the Design Bureau with Wernher von Braun's team at Peenemünde, claims this was the first liquid-fuel rocketry undertaken in Germany. Although it cannot be corroborated, Friedrich Sander is alleged to have researched liquid-fuel systems earlier, and to have secretly launched such a rocket on 10 April 1929; in the same year he allegedly attained a thrust of 300 kg (660 lbs) for up to thirty minutes, as Valier himself mentioned in his book *Raketenfahrt* (1930). Whatever Sander's accomplishments—and they are undocumented—Valier's work with Riedel, at least, led to significant developments.[13]

According to a manuscript history by Riedel, recently given to the Imperial War Museum in London, Valier (with Riedel's assistance) started in January 1930 with a modified blowtorch. The propellants were gaseous oxygen and alcohol. The "engine" naturally did not produce usable thrust (only a few grams), but it did give the experimenters fundamental experience in the relatively controlled combustion of a liquid and gas; they wished to eventually switch to liquid oxygen (lox) and alcohol. They also learned about propellant injection. In order to get better mixing, Valier and Riedel began experimenting with injecting the alcohol against the gaseous oxygen flow from the head of the motor.[14]

After less than two months' work, they arrived at a unitary combustion chamber, a standard steel tube with an elongated and slightly diverging de Laval exhaust nozzle at one end and a new injector system at the other. According to Riedel: "The oxygen was fed into the combustion chamber from an annular space at the rear of the chamber through a number of small holes. The fuel was injected [by gas pressure] in[to] the chamber against the oxygen gas-stream. A resistance disk retarded the velocity of flow of the oxygen gas stream by creating turbulence." The purpose of the so-called resistance disc was thus to hold up the flow of oxygen, thereby encouraging more complete mixing of the propellants and preventing the loss of too much unburned fuel and oxygen. (The nozzle itself lacked a smooth convergence toward the interior of the chamber that would have encouraged better mixing and combustion.)[15]

Riedel describes how the tests were done:

> Pictures of this time show with what ignorance of possible dangers the tests were carried out. . . After filling the tank with fuel, the tank was pressurized [by compressed air or nitrogen] and by opening the fuel valve and reducing valve on the oxygen side[,] small quantities of propellants were fed into the combustion chamber. With the flame of an ordinary blowlamp the mixture was now ignited near the nozzle exit so that a small flame developed in the combustion chamber. The propellant valves were slowly opened, thus increasing the chamber pressure and the thrust. The thrust was measured by mounting the chamber on one side of a pair of scales and counterbalancing by weights on the other side. When one thinks with what precautions present-day [ca. 1950] rocket experiments are carried out, one can only wonder at the carelessness with which the early experiments were performed.

Valier (and Riedel's) larger model motor was tried with different nozzles of generally 15-20 mm (0.6-0.8 in.) interior exit diameter. Thrust varied widely, but the average appears to have been 10 kg (22 lbs). Burn durations were correspondingly quite long, which would be expected from a low thrust, gaseous system. The average was 250 seconds (4 minutes), though on 22 March 1930, the motor was fitted in the Rak 6 automobile and made a test run of a very long 22 minutes on the Heylandt factory grounds. Gaseous oxygen and alcohol were again used and must have produced a very feeble thrust. As another measure of the low output of this type of motor and fuel system, the average exhaust velocity was 1,400 meters/sec. (4,600 ft/sec).[16]

Riedel precisely dates their first use of liquid oxygen on the test stand to 26 March 1930. Valier and Riedel exclusively used the all-liquid system thereafter. The overall performance of the motor gradually increased, so that by early April a thrust of 21 kg (43 lbs) was recorded. Essers says that the first (liquid-propellant) automobile test run was made 29 March, and it "went off perfectly," and he adds that the motor was "provisionally installed," probably meaning that it was merely added to the car and did not replace the old carbon dioxide system just yet. Riedel adds that by April, 1930, "we began the reconstruction of the rocket car for liquid-fuels and it received the designation Rak 7." More exactly, the car was named "Valier-Heylandt Rak 7." Among other changes, the 25 liter (6.6 gallon) alcohol tank replaced the carbon dioxide tanks under the front hood, while a bottle of compressed nitrogen was installed adjacent to it for feeding the fuel into the combustion chamber. The 50 liter (13 gallon) lox container was placed behind the driver's seat. The motor may have undergone further modification before installation as well. It is said to have weighed 4 kg (8.8 lbs) and, according to Riedel, produced 20-30 kgs (44-66 lbs) for 8-10 minutes. On 17 and 19 April 1930, the car was successfully demonstrated before the press at the Heylandt works.[17]

Figure 1 Valier-Heylandt Rak 7 rocket car at the Heylandt plant at Berlin-Britz, Germany, 17 April 1930. At left is Dr. Paul Heylandt and at right, Max Valier. Deutsches Museum photo.

Figure 2 Max Valier (1895-1930) experimenting with a gaseous oxygen/alcohol rocket motor, probably at the Heylandt plant, March 1930. Imperial War Museum photo.

A widely circulated photo of Heylandt and Valier standing beside the car near a Heylandt lox storage tank was taken at the time. Again, it is doubtful Heylandt himself played any direct technical role in the development of this motor, although less than a week earlier, on 12 April 1930, he applied for a patent entitled "Fuel Tank for Aircraft with Reaction Propulsion." Its brief text mainly concerns the use of insulated fuel tanks for liquefied gases for use in any "vehicle" operating on the rocket or reaction principle. Accompanying the patent is a quaint drawing depicting a wheelless, generic rocket-propelled "vehicle" that could be either a car or plane.

What were Heylandt's motivations for this patent and for his support of the apparently frivolous rocket car work? Clearly, he saw promise in rocket motors (using his lox tanks) for aircraft and wanted to get in his priority claims early. The rocket car, he reasoned, was merely a beginning evolutionary step toward this goal. According to Rolf Engel, one of Heylandt's conditions for his "collaboration" with Valier was that "All patents for new inventions . . . should go under the name of Dr. Heylandt," but in this case, the patent seems to have originated from Heylandt himself.[18]

As he stated on 18 April to the Associated Press:

> My real interest in Valier's car is that it affords a means of testing our rocket motor out practically. . . . The next step will be to build a rocket motor into an airplane driven by an ordinary [reciprocating] motor . . . then, as it reaches high altitudes, switch on the rocket motor. After this has proved successful, the next step will be to construct a plane with a rocket motor only. We plan at present to shoot across the English Channel with it as the first large test.

In the same press interview, he predicted the time not far off "when airplanes will be shot thousands of feet into the sky by means of a new type rocket motor and will reach the United States from Europe in from six to eight hours [which would imply speeds up to 600 mph, or 965 km/hr]." Heylandt's ideas were really only derivative of Valier's, who idealistically proposed the step-by-step evolution of the airplane to spacecraft. In brief, Heylandt was looking strictly at terrestrial (transportation) applications of rocket power, not spacecraft.[19]

On 19 April 1930, Rak 7 made its last demonstration at Tempelhof. Riedel, looking back 23 years later at these events, commented that although the rocket "had no practical application to wheeled vehicles," the experiments and the first public showings "are noteworthy because of their historical importance—for the first time in Germany a rocket motor using liquid propellants was shown."[20]

During the early part of the testing, in February and March, Valier briefly went to St. Moritz, Switzerland, and The Hague, Holland, to interest Sir Henry Deterding, Director-General of the Shell Oil Company, in financially supporting the research. Deterding was encouraging but insisted on the use of a Shell petroleum product, kerosene (in British terminology, paraffin). Valier was at first reluctant to do this since it is almost impossible to mix kerosene with water; when this is tried, an emulsion forms in which the two ingredients mix, then quickly separate again. Valier wanted to continue using water additive for cooling purposes and this new fuel would complicate matters. He soon found a solution—to pass the kerosene through an emulsion chamber before it entered the combustion chamber. As noted by Gartmann, this kept the solution constantly mixed, "and the device appeared satisfactory." Consequently, Valier made the switch to the new fuel in early May. This proved fatal. During the evening of the 17th, he was preparing a static run on a chamber with a new 40 mm (4 in.) diameter nozzle. Riedel, who was present, described what happened next:

> The chamber was ignited and using the normal test procedure the chamber pressure was increased to 7 atmospheres (gauge) by regulating the hand-valves for the propellants and water. This pressure had just been reached when a violent explosion occurred. I immediately shut the propellant valves and sprang to Valier, who had collapsed. I just managed to catch him and laid him on the ground. While Arthur Rudolph, a machinist and my co-worker, looked after him, I looked for a car. When I returned 10 minutes later Max Valier was dead. A very small splinter had hit the main artery near the lungs.[21]

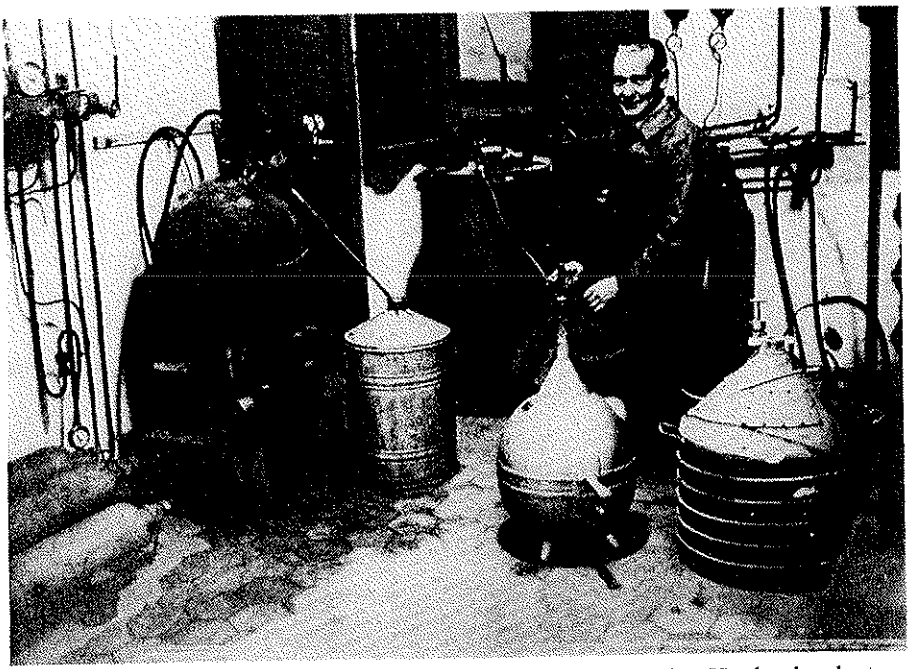

Figure 3 Walter Riedel (1902-1968), shown in the Heylandt plant, ca. 1931. Imperial War Museum photo.

Post-Valier Experiments

Valier's death was a shock to the spaceflight movement. Heylandt delivered the funeral oration and allegedly vowed never to participate in rocketry again. According to Ley, the tragedy also led to public demands to outlaw rocket research. It also induced Heylandt to break off negotiations toward collaboration with the VfR, the German Society for Space Travel. The VfR began its experimentation anyway the very next month, in June 1930.[22]

Rudolph, who had joined the Heylandt firm a short time before Valier's death, began his own technical inquiry into the cause of the explosion, but he had to do this clandestinely, he contends, because of Heylandt's insistence upon no further rocketry work. He says he studied flow patterns of kerosene and lox with a special apparatus set up in an "abandoned" Heylandt lab. "One day Dr. Heylandt walked by at just the wrong time and saw me." Heylandt questioned what he was doing, adding the warning: "If I see you again doing rocket work, I will fire you." This did not stop Rudolph, because the problem intrigued him. "I concluded," he says, "that the injection system was the main culprit. And so I decided to redesign the whole thing." The old Valier injector was egg-shaped with many holes drilled in it. But since its surface was curved, it was difficult to drill the holes and the Heylandt shops were not equipped to do precision machining. The fuel therefore came out "very irregular" with some fuel hitting the wall at one point and causing dangerous "hot spots." When these were discovered, "Valier had to give the sign to change volume and pressure, so it wouldn't burn through. . ." There were also extreme pressure spikes, resulting in severe explosive jolts. "I redesigned the fuel injector so that the fuel came in like a lampshade," Rudolph continued. "And I did the same for the oxygen." By this he meant a diverging cone from the center of the injector, the cone being mounted on a shaft so that the whole looked like a mushroom and was often called so. The fuel and oxidizer was sprayed through ring slots around the mushroom head, which allowed even propellant distribution away from the combustion chamber wall and towards the chamber center. The combustion would be more even and controllable, with hot spots and pressure spikes eliminated. The new design also simplified manufacture of the injector.[23]

It may be that Rudolph undertook the post-accident rocket engine investigations out of his own pocket. Riedel says that Heylandt did not do anything in rocketry for about a year after Valier's demise, but he was ambitious and decided to resume this activity in order to recover the money he expended on the Valier experiments. This decision led Heylandt to sanction a new project—another rocket car. An extant list of the Heylandt Company's early expenditures on rocket developments does, however, indicate that the company spent more money on rocket projects within six months after Valier's death, that is, before the end of 1930. Indeed, a press release by Heylandt from 23 March 1931, announced that he (in reality, the Heylandt Company) had been developing a new rocket motor for use in either planes or cars since the Winter of 1930-1931.

In fact, Riedel and Rudolph developed the engine for the new car while Heylandt's chief engineer, Alfons Pietsch, may have designed the vehicle.[24]

In addition to the mushroom injector, Riedel and Rudolph adopted the regenerative cooling technique for the engine. Regenerative cooling was not a new concept. Konstantin Tsiolkovsky included it in his 1903 space-rocket design, while Oberth independently proposed the idea in his book *Die Rakete* of 1923. The American, Robert H. Goddard, appears to have briefly tried regenerative cooling in March, 1923, although this went unreported, and, in any case, he soon reverted back to other cooling methods. VfR experimenters apparently began using the regenerative technique in their Repulsor IV rockets late in 1931. Riedel and Rudolph were therefore very likely the first to create a kind of operational regeneratively-cooled motor. Rudolph recalls that the cooling jacket for the Heylandt rocket car was a sheet metal form welded at the nozzle end and it was designed for expansion and contraction "otherwise the different expansions of the inner chamber and the cooling jacket would create cracks. . . ."[25]

Further detailed information on the Heylandt car and its motor is found in the Riedel manuscript cited in footnote 10. A drawing shows that the car's combustion chamber was 300 mm (11.75 in.) long by 65 mm (2.5 in.) interior diameter. The thrust range was 160-200 kg (350-440 lbs). The motor weighed 20 kg (44 lbs), while the car itself was 2,010 kg (4,430 lbs), including 325 kg (716 lbs) for the oxygen container, 145 kg (320 lbs) for the alcohol container, plus 270 kg (595 lbs) for the alcohol fuel and 365 kg (805 lbs) for the oxygen. As in the Rak 7, pressurizing nitrogen was also carried, but the ignition system was now a 10 volt battery and a spark plug.[26]

In his 23 March 1931, press statement, Heylandt suggested that the improved rocket car might be demonstrated by May or June of that year, probably at Berlin's Tempelhof Air Field. Heylandt kept his word. Prior to the demonstration, a static test of the motor was presented on 11 April 1931, at the Berlin-Britz plant. The papers said the steel motor was secured on "a block with instruments registering the recoil." From behind protective steel walls, newsmen reportedly saw it fire up thrust for a total run of two minutes, though it was said to be capable of 12 minutes. Possibly on this day, too, there was a showing of the car without its skin, revealing—beneath trooped wooden body ribs—the propellant tanks and motor. Finally, on 30 April, the completed car was demonstrated at Tempelhof before a small crowd. To the *Berliner Tageblatt*, the streamlined red and yellow vehicle resembled an ordinary race car, except for a fist-sized nozzle at its rear that was the only sign of it being rocket powered. "Suddenly, with a deafening noise, a blue-yellow flame about three to four meters [10-13 ft] long came out the back as the car shot forward." The vehicle ran at 60-70 km/hr (40-45 mph) and made a trouble-free four circuits along the track. Another paper contradicts this and alludes to a "white mist" and fire that came from the car, although the driver (Pietsch) put the fire out.[27]

Figure 4 The Heylandt rocket car beside a Heylandt liquid oxygen transport truck and Ju 52 aircraft, at Tempelhof Air Field, Berlin, probably 30 April 1931. Imperial War Museum photo.

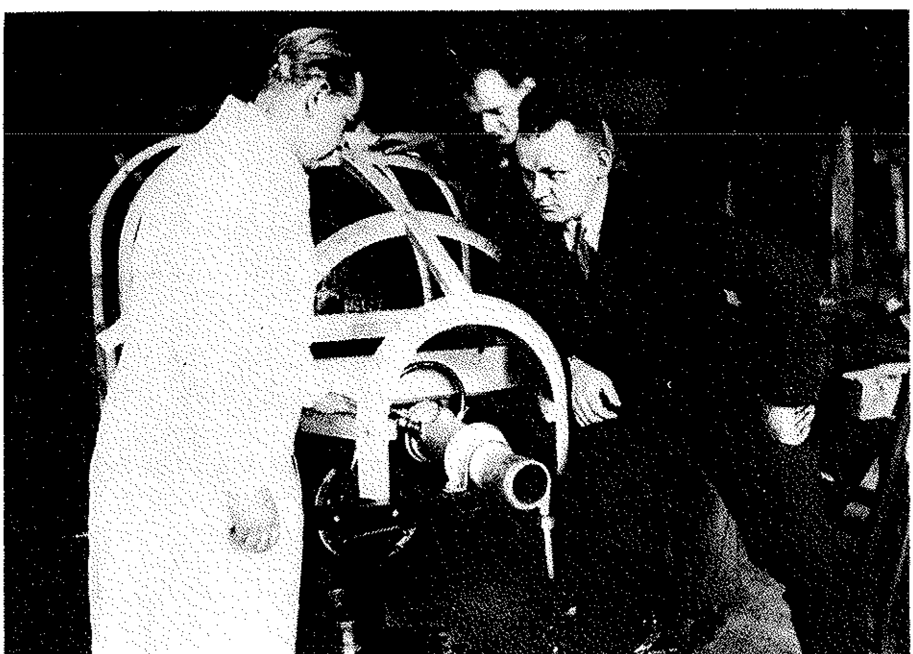

Figure 5 Left to right: Walter Riedel, Arthur Rudolph, and probably Alfons Pietsch, inspecting motor on the Heylandt rocket car, at the Heylandt plant, April 1931. Imperial War Museum photo.

Ley remembered the motor as "the most powerful liquid-fuel motor then in existence and the duration of the test was remarkable too." But he notes that this was paid for by poor combustion and low exhaust velocity as the flame was red and smoky. The car made its best-known public run at Tempelhof on 3 May, but Riedel adds, interestingly, that the car actually made "many runs" at Tempelhof up to late summer of 1931 and even recouped some of the money Paul Heylandt spent on the project.[28]

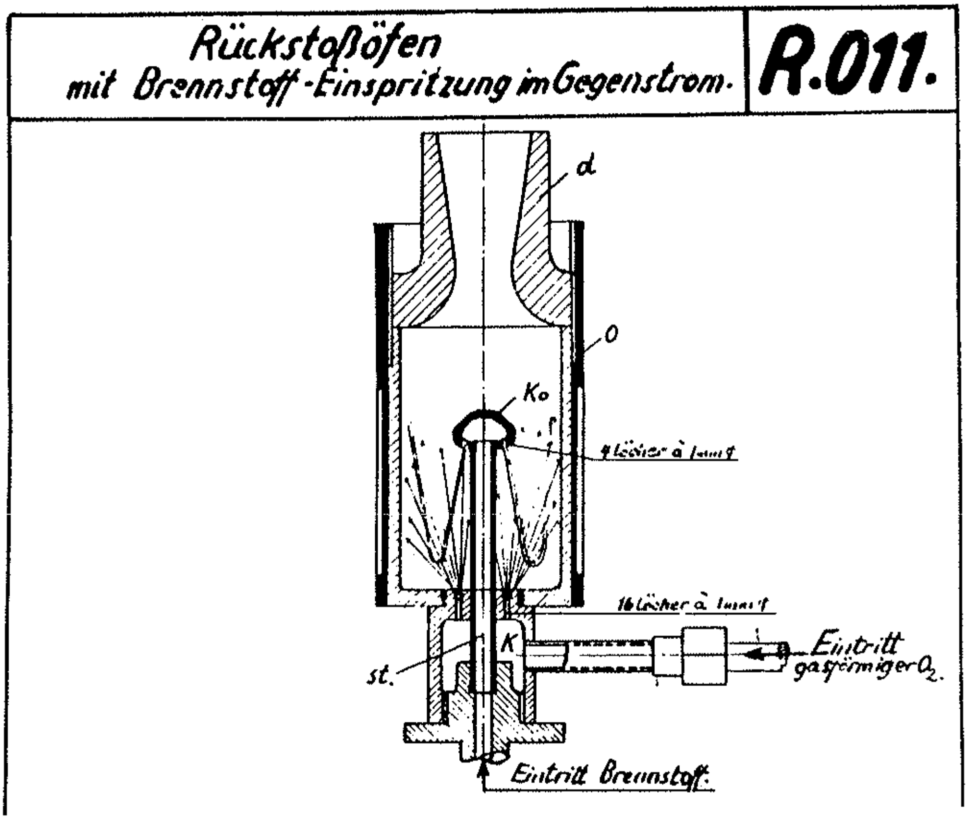

Figure 6 Drawing, by Walter Riedel, of mushroom injector of the type used in the Heylandt rocket car. From manuscript *Die Raketenentwicklung* by Riedel, in Imperial War Museum.

It was also in 1931—the exact date is unrecorded—that Rudolph, Pietsch, Riedel, and a Heylandt manager, Hermann Ehms, were invited by the VfR to their famous Berlin *Raketenflugplatz* [Rocketport] testing facility to witness a launch. They stayed all day and into the night but saw nothing—the VfR experimenters had a day of total failures. (*Raketenflugplatz* had been established in September, 1930.)[29]

The Heylandt Company-German Army Connection

As a result of meager turnout for the rocket-car runs, but mainly because of the worsening world economic situation, neither the company nor its members worked on rocket cars anymore. Prospects for continuing the experiments dried up. It was fortuitous that the Army approached Heylandt about the firm's rocketry work. Ley credits Captain Walter R. Dornberger with asking Heylandt to develop a small liquid-fuel motor for testing fuel combinations for the Army's own rocket program, which began with solid-fuel rockets in 1929-1930. Actually, on 16 October 1931, Colonel Karl Emil Becker, head of Wa Prüf 1 (Ballistic and Munitions Section, Testing Division, German Army Ordnance) wrote the Heylandt company that his second-in-command, Captain von D'Aubigny Engelbrunner Ritter von Horstig, be allowed to have a confidential meeting with Dr. Heylandt on the "Flüssigkeitsgebläse" (liquid-fuel blowpipe)—awkward terminology that showed Becker's unfamiliarity with liquid-fuel rocket technology. Wa Prüf 1's liquid-fuel rocket program—which, until 1935, was supervised by Captains von Horstig and Erich Schneider, not Dornberger—had not even begun its experimental phase, although the Army had already started solid-fuel work. At the time, the Heylandt company was literally the world's first and only industrial firm involved with liquid-fuel rocketry (with the possible exception of Sander's alleged experiments).[30]

Von Horstig's confidential meeting with Heylandt was evidently exploratory, that is, its purpose was to determine how far Heylandt's Aktiengesellschaft had actually come in the development of the rocket motors. (The press accounts of the rocket-car runs provided only sparse and often distorted details.) Von Horstig's report to Becker was positive. On 28 October 1931, the colonel again contacted Heylandt and informed him that the Army wished to enter negotiations. Becker wanted a cost proposal for a motor like that in the rocket car—or even the car engine itself. It would undergo a test at the Army's test range at Kummersdorf, which was, in his words, "highly modern," safe, and equipped with the latest measuring instruments.[31]

Becker and his staff decided, however, to carry out their liquid-fuel rocketry program on a scientific and systematic basis, rather than to seek quick results. On 9 November 1931, Becker wrote Heylandt that Army Ordnance wished to issue a contract to the company for compressed-air tests through nozzles of different angles and proportions, in order to determine the most efficient nozzle form. If the tests were satisfactory, the letter stated, true combustion tests would probably be pursued. Riedel comments that "It was never completely clear to us [at Heylandt] why we should carry out these experiments." He maintains the best nozzle forms could as well be calculated from the known laws of thermodynamics of gases. It may be the Army was seeking a probationary or bridging contract prior to committing itself to *bona fide* rocket engine development. (It must be borne in mind that the Army probably still considered Heylandt Company's experience with rocket cars to have been amateurish.)[32]

The company was to carry out the compressed air tests under a study contract of less than six months duration with no guarantees of a further contract. On 5 December, the contract was sent to Heylandt under Army stipulations that it be kept secret from "other companies" unless approved by Ordnance Testing Division. Moreover, Becker intoned, "all publications in the press are to be avoided," as well as all contracts with "non-Reich Germans and all personalities from international Societies . . . that involve themselves with this or similar problems." In other words, the Army wanted to impose complete secrecy and to isolate Heylandt from the amateur rocketry and spaceflight movement.[33]

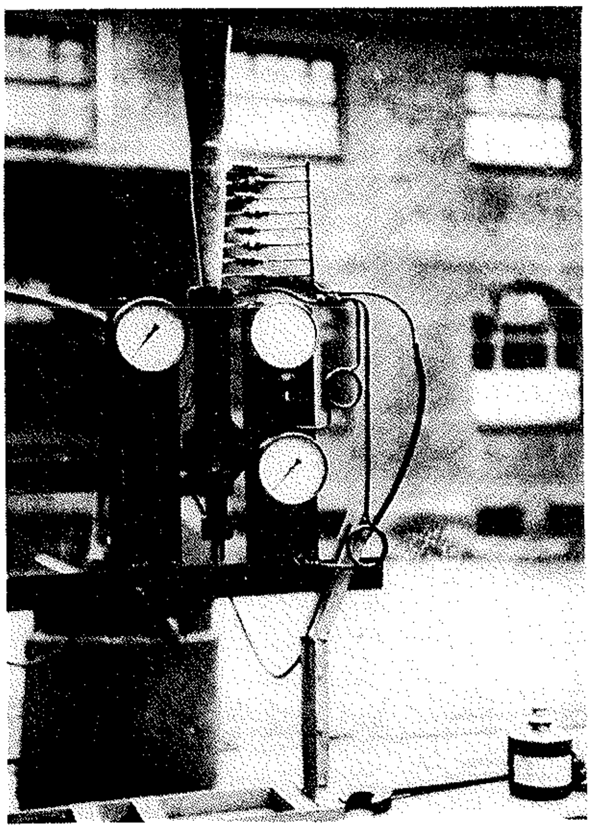

Figure 7 Compressed air rocket motor built and tested for the German Army's rocket program by the Heylandt Company, 1931-1932. Note the pressure sensors on the nozzle. Photo from the Imperial War Museum.

On 18 December, Heylandt thanked the Reich Defense Ministry for the contract and reported that the experiments had begun. According to a Heylandt document dated 19 January 1932, only four of the company's personnel were then involved with the experiments—Heylandt, Dipl. Ing. (Diploma Engineers) Appelmann and Ehms, and engineer Riedel, though the latter was not informed that this was an Army project. He must have learned of the truth soon after. By 29 April 1932, the Heylandt Company reported that, in tests with nozzles with divergences of 5, 10, and 15°, excessive length led to turbulence and reduced thrust. On 2 May, von Horstig summarized the results. The highest thrust, 12 kgs (26.4 lbs), was obtained with a nozzle of 15° angle and 20 mm (0.78 in.) length. The widest angle nozzles were therefore the best and were also shorter and more useful for compact construction. He also believed that these nozzles were suitable for both liquid and solid fuels and indicated that (liquid-fuel) combustion tests would be conducted in the following weeks.[34]

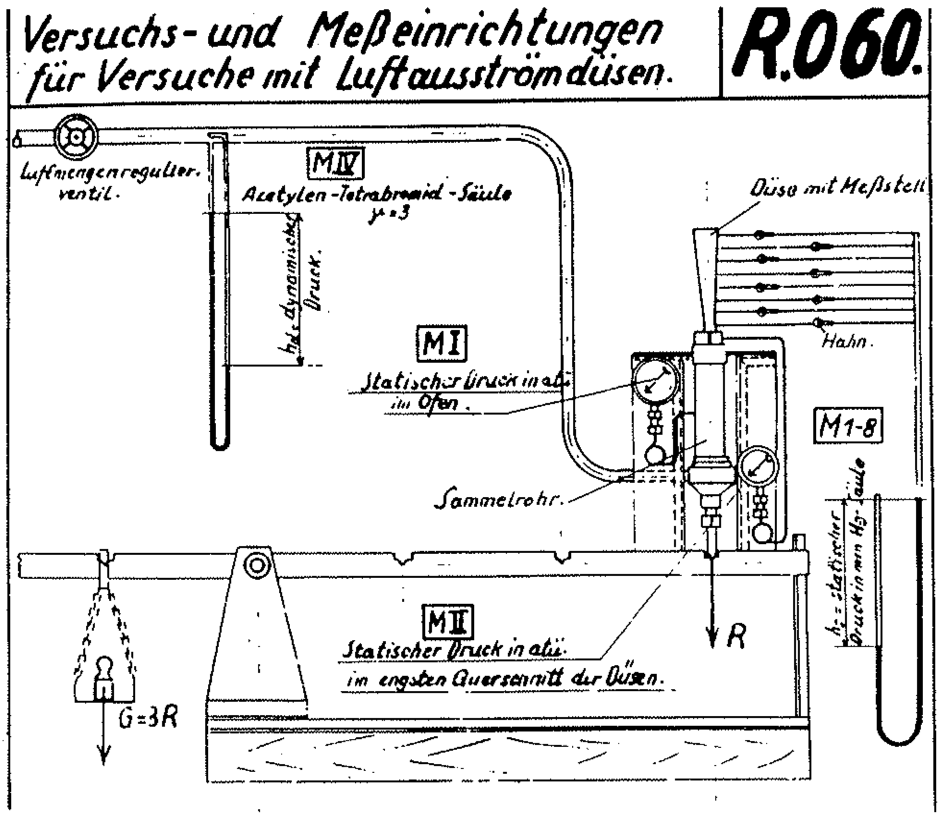

Figure 8 Drawing, arrangement of test of the compressed air rocket motor. From Walter Riedel manuscript, *Die Raketenentwicklung*, Imperial War Museum.

In spite of the satisfactory outcome of the compressed-air experiments, Becker's group did not proceed immediately to a contract with Heylandt for a liquid-fuel motor, possibly because the Army was negotiating at precisely this time (Spring 1932) with Rudolf Nebel and the Raketenflugplatz for a demonstration of their rockets. But in anticipation of such a contract, Paul Heylandt ordered his rocket team, in mid-1932, to start a series of systematic, independent experiments with a liquid-propellant system. Due to the lack of capital, however, they were compelled to build a motor of only about 20 kg (44 lb) thrust. The date of the completion of this basic motor is unknown, although Riedel's manuscript contains results of static tests carried out, beginning on 16 September and lasting to 7 December. Thrust ranged from 10-24.5 kg (22-54 lbs) and duration from 30 to 980 seconds (16 min.), in duration, with an average of 20 kg over two minutes. Heylandt's perseverance paid off because, on 1 October, the new head of Wa Prüf 1, Major von Horstig, requested, "on the basis of Dipl. Ing. Appelmann's experiments [with the 20 kg motor] to give [Heylandt] a contract for a liquid oxygen/alcohol unit. . ." The Army wished to use it, or a modified version, as their own laboratory test motor and specified a minimum thrust of 20 kg (44 lbs) with (liquid) fuel consumption of 8 grams/kg sec. up to a total of 2,000 kg sec. (thrust-time integral). The motor was to be separate from the tanks, with automatic regulation of pressure. For safety and efficiency's sake, the Army also required that the engine not be operated by hand, except for its ignition, and they preferred light metal (aluminum alloy) construction, although this was not absolutely necessary. Finally, the engine tests were to be carried out by Appelmann at Kummersdorf. (Judging by his repeated signature on the early drawings, Riedel likely did most of the design work.)[35]

The finished Heylandt motor was simply referred to as the "20 kg [44 lb] motor." Hitherto, Dornberger provided its only known description: "In 1931 [actually 1932], we had given Heylandt an order to develop a small liquid-propellant rocket motor for our basic experiments. It had a thrust of 45 pounds, was double-walled for [regenerative] cooling, cylindrical in shape, and made of steel." Drawings and other documents located by the authors offer further details. The motor was 360 mm (14 in.) long, 67 mm (2.6 in.) outside diameter (not including the three equidistant hollow ridges around the cooling jacket), 50 mm (1.9 in.) inside diameter of chamber, with an outside nozzle diameter of 41 mm (1.6 in.). The ridges were apparently to regulate the fuel flow in the cooling jacket. Inside the chamber was fitted a single, long, centrally-placed mushroom type injector of the Rudolph/Riedel design, in which the fuel sprayed convergently toward the top of the chamber. An ignition sparkplug was screwed onto the outside middle part of the motor, facing the injector. The propellant lines fed directly into the injector from the top. There were also lines tapped into the nozzle and elsewhere for pressure measurements during the static firings. Combustion temperatures appear to have been calculated from this data, as were exhaust velocities.[36]

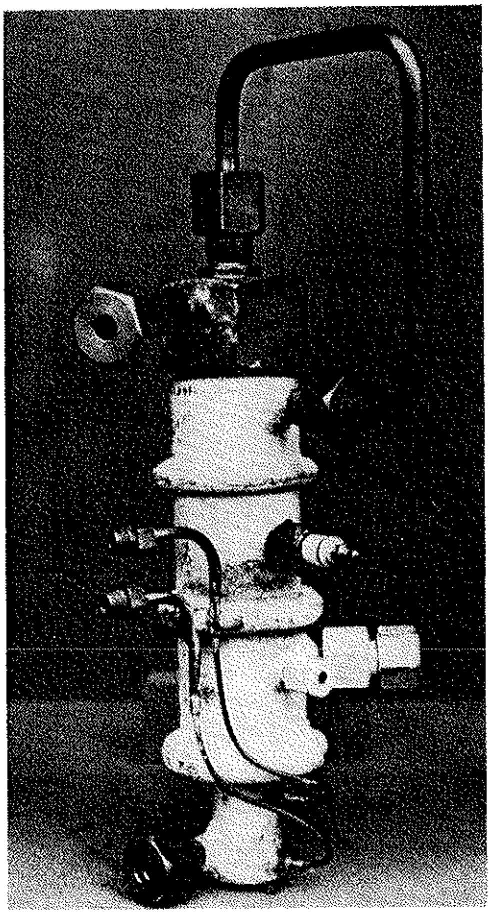

Figure 9 Heylandt 20 kg rocket motor. From Ernst Klee and Otto Merk, *The Birth of the Missile* (photo originally from the Deutsches Museum).

On 7 October 1932, the Heylandt firm reported that it had conducted three experiments with the engine, and that the exhaust velocity had been raised from 1,100 to 1,400 m/sec (3,600-4,600 ft/sec). Performance diagrams accompanied the report. In the meantime, Becker and Wa Prüf 1 had completed arrangements with the Raketenflugplatz for a secret test, which was done at Kummersdorf on 22 June 1932. The rocket launch was unsuccessful, but it ultimately led to the Army's hiring of young Wernher von Braun in late 1932. His rocket engine designs, influenced by Walter Riedel's later arrival at Kummersdorf, ultimately were the main-line of development from which the A-4 powerplant grew. The Heylandt motor was thus an earlier, separate development, which enabled the Army to learn the fundamentals of rocket propulsion; it was also used for additional combustion investigations as late as 1937.[37]

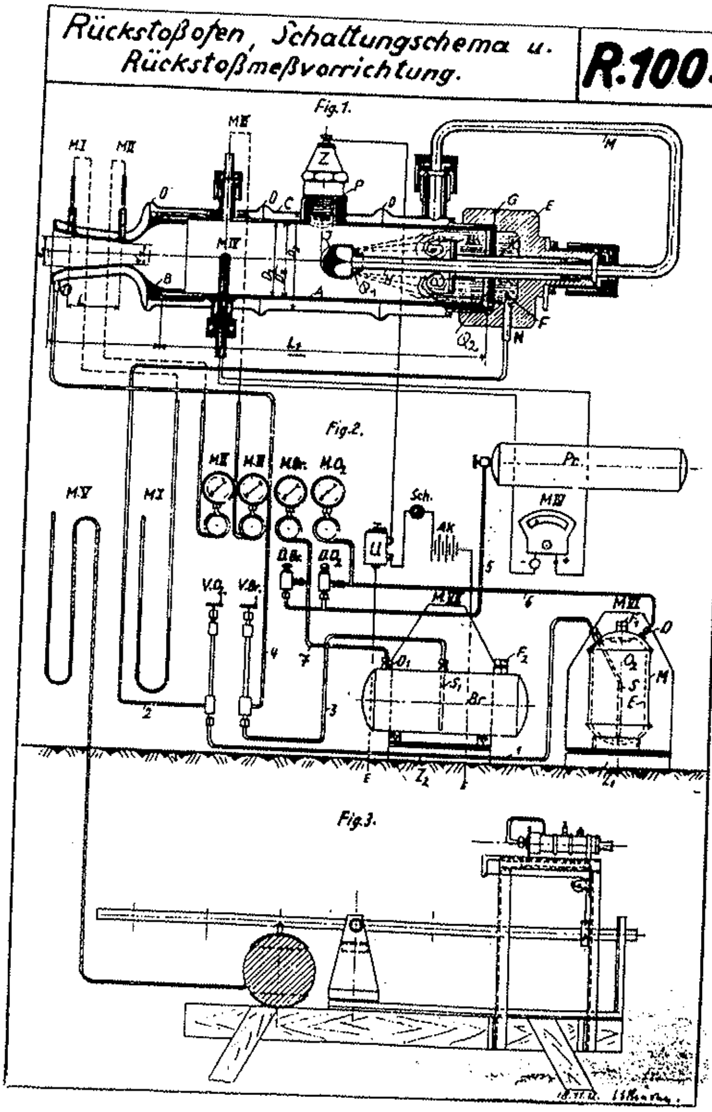

Figure 10 Heylandt 20 kg motor and test stand, drawing, In FE microfilm (file FE 724/a), National Air and Space Museum.

On 21 November 1932, the Heylandt Company reported: "We will be making a number of final experiments this week and will finish the contract at the end of this month." Yet the Heylandt experiments were not kept entirely secret. They were made known to Dr. Fritz Schmidt, an instructor at the Technische Hochschule Berlin and a technical consultant to Ordnance Testing Division. On 23 November 1932, he evaluated the experiments conducted from 29 September to 22 November. Schmidt's overall conclusions were that a larger combustion chamber was required, the injection system needed improvement, and there was incomplete combustion. He recommended experiments introducing a second oxygen injector in the center of the combustion chamber, behind the fuel injector. Apparently, however, his recommendations were not adopted.[38]

The initial contract concluded, the Heylandt Company naturally sought others, especially as it faced serious financial difficulties in the Depression. On 30 November 1932, it proposed the construction of "safe" rocket engines of 15-400 kgs (33-880 lbs) thrust that could burn for long durations. Because of structural limitations, the maximum chamber pressure would be 10 atmospheres. Ordnance was interested, and on 15 December they asked the Heylandt firm for a bid on a rocket with a 200 kg (440 lb) thrust, 20 second duration, motor weighing 30 kg (66 lbs) and with light metal tanks. But the company's proposal was not adopted, in all probability because von Braun had started work at Kummersdorf on his own engine of 160 kg (350 lb) thrust. Meanwhile, Heylandt's original 20 kg thrust motor continued to serve as a standard research tool; a 13 April 1933 note by von Braun refers to a drawing he had just borrowed of this engine.[39]

The day before, 12 April, Heylandt had made another engine proposal. At first, this too led nowhere, but the firm continued to develop it in the hope the Army would once more turn to them. Finally, after a follow-up letter from the company, Ordnance issued a contract for the 60 kg (132 lb) thrust engine on 17 June. Ordnance did not particularly need it, but gave in to the firm's desperate plea for a contract "so that our specialists working on your projects do not have to be laid off." (The Army probably felt Heylandt's, or at least Walter Riedel's, services might still be of value and wanted the company to stay in business.)[40]

The 60 kg model thus became the second and largest rocket motor made for the Army by Heylandt. It was similar to the 20 kg type, featuring an elongated *Stiel*, or post type mushroom injector placed in the middle of the combustion chamber, but it was different from the older system in having five additional injector nipples mounted to the inside top of the chamber and facing towards the injector. The injector also sprayed the fuel at a wider total angle (80°) towards the top of the chamber. The 60 kg thrust motor weighed 5.3 kg (11.6

lb) and was 370 mm (14.5 in.) long, with a 79 mm (3 in.) outside diameter. It too was regeneratively cooled. Von Braun witnessed three successful tests with the motor at the Heylandt plant on 28 September 1933. On 17 November, Heylandt, reporting on further tests, stated that the fuel consumption had been reduced, but admitted that unstable combustion showed up after stable and successful experiments, leading to explosions that made measurements impossible. At this juncture, the motor's injectors were modified, and it was then shipped to Kummersdorf for study. Evidently, it was fabricated of steel, for on 28 November Heylandt offered a lighter version of Elektron (a light, aluminum alloy) for 1,345 Reichmarks. But Schneider made the marginal note that the Ordnance Testing Division had "no interest in this [particular] light metal motor"—possibly because it was subject to corrosion and because Ordnance was losing interest in working with Heylandt. The separate development of the aluminum alloy rocket motor under von Braun was proceeding well.[41]

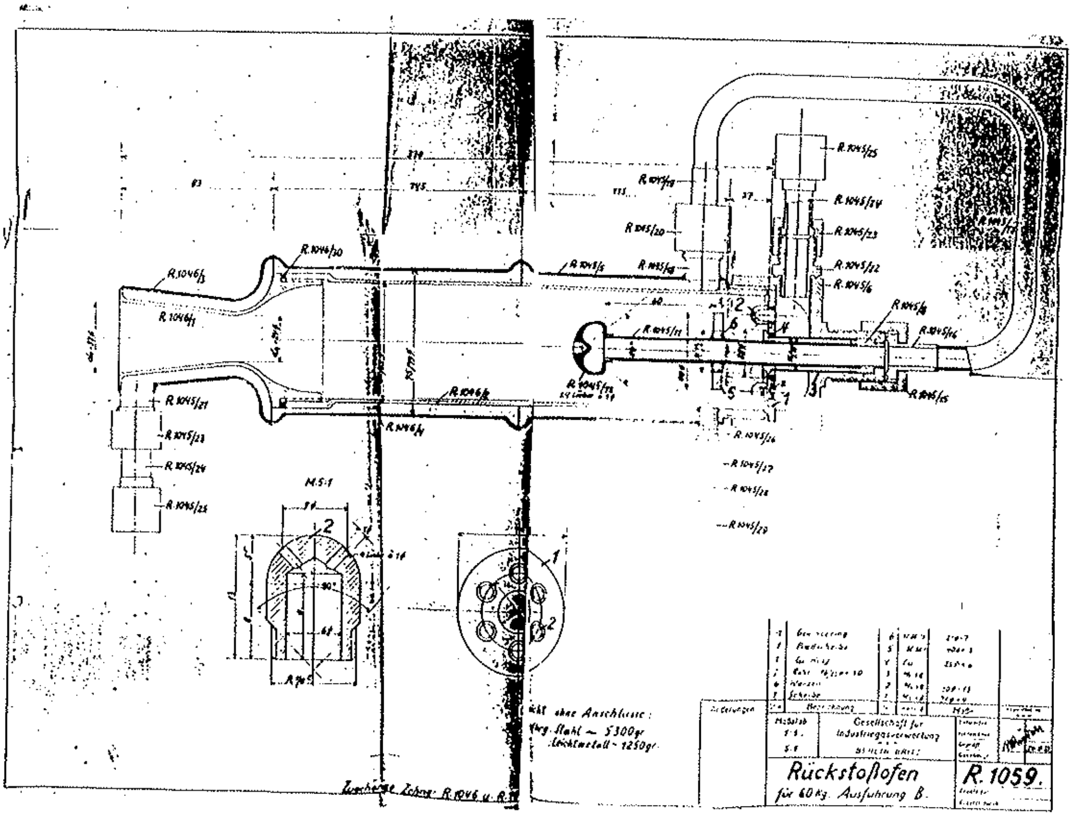

Figure 11 Heylandt 60 kg motor motor, drawing, in FE microfilm (file FE 724/c), National Air and Space Museum.

On 17 November, the Heylandt firm made a new offer, a 400 kg (880 lb) thrust motor with a 20 minute life (i.e., apparently a reusable motor lasting for 20 minutes) for 3,000 Reichmarks. They added that, if developed into a flying version, it was available for 6,900 Reichmarks. The planned burn duration was 20 seconds, the tank weight 12 kgs (26 lbs), propellant weight 48 kgs (105 lbs), and payload 5.5 kg (12 lb) for a total of 65.5 kgs (144 lbs). The company said it could be delivered in eight weeks. Dornberger made a marginal note on the offer that a contract "should not be given out for the moment." Schneider agreed.[42]

The last communication of this sort was on 12 December 1933, when Schneider curtly informed the company that: "[You] also cannot at this time expect any contracts for further development." The company drew the correct conclusion that "the Reichwehrministerium will continue development on its own. . ." and that it would likewise continue, but at "our own expense." The letter ended with an attempt to salvage some business by offering Heylandt's machine shops for the production of special valves, coppersmithing, welding, and the like. Von Braun commented that Heylandt parts and valves were of good quality, but the company had not so far done stamped or welded work as desired by Army Ordnance.[43]

Whatever Heylandt's intent, the Army's decision effectively meant the end of rocket development at the company. Its most important contribution thereafter was its two leading rocket engine designers and experimenters. Walter Riedel joined the Army's rocket program in January 1934, immediately after the contract ended, and Arthur Rudolph joined in December of that year. But the 20 kg motor continued to do yeoman service for a few years. According to Dornberger, the motor was utilized for alternative propellant studies by the Research Section of Army Ordnance. Dr. Kurt Wahmke was in charge of rocket experiments with the Section, assisted by the chief pyrotechnician, Mr. Voellmecke, and some students. Unfortunately, the testing program was still largely empirical and conducted under a small budget, which inevitably led to low safety standards. Dornberger says the Wahmke group used "a small test stand hastily improvised . . . out of boards and planks sheathed with armour plate." In March of the same year, Wahmke tried an experiment with 90% hydrogen peroxide and alcohol. He decided to pre-mix the propellants in a steel tank before they were fed into the rocket chamber for combustion. Few safeguards were taken and those who helped him smoked cigarettes. The result was an explosion, killing Wahmke and two assistants.[44]

Another propellant experimental program was undertaken with the Heylandt 20 kg motor in 1936, but on a more scientifically rigorous basis. On 28 April of that year, the Research Section requested two more of them and four extra "mushroom" injector heads for experiments by Dr. Walter Thiel, Wahmke's successor and later head of A-4 (V-2) engine design. Working with Thiel was a doctoral student in chemistry named Seifert. He used the Heylandt engine to make systematic tests of different fuels and mixture ratios for his dissertation. This investigation included combustion processes, disassociation (ionization) of gases, and comparisons to theory. The Research Section was particularly eager to explore whether more energetic propellants—including 96% alcohol, benzene, butane, propane, and diesel oil—could be employed in then current motor types without extensive changes. Seifert found that, while it was theoretically possible to get 10% better performance from butane, propane and benzol, it was not possible to produce a standard engine for all fuels that was equally efficient. Possibly this was the last use of the original Heylandt laboratory engine.[45]

The legacy of the engines derived from the Heylandt team did not end there. The A-1/A-2 and A-3/A-5 motors, developed from 1933 to 1937—the precursors of the A-4 (V-2) engine—used a modification of the old Heylandt mushroom injector. The retention of this feature was no doubt due to the influence of Rudolph and Riedel. (In his 1950 manuscript, Riedel himself acknowledges that the A-3 injection system was a "Berlin-Britz" development.) Apart from this, the A-1/A-2 300 kg (660 lb) and A-3/A-5 1,500 kg (3,300 lb) thrust motors had the elongated combustion chambers found in all Heylandt motors, although this appears to have been the standard configuration at the time (for example, in the 1933-34 motors of Eugen Sänger). By 1937, however, Thiel eliminated the mushroom injector altogether. This was apparently on a modification of the A-3 motor. Following Dornberger's suggestion, he decided to use "centrifugal" nozzle injectors, which produced a very fine atomization and sprayed the propellants in a rotational motion; this produced better mixing. He also removed the injector unit from the combustion chamber and mounted both the fuel and oxidizer injectors on the top of the chamber, thereby providing an unobstructed mixing compartment and keeping the flames at a safer distance from the injectors. Thiel made later modifications in the A-3 motor by reducing the chamber length from 6 ft (1.8 m) to about 1 ft (0.3 m), making it more compact and enabling more efficient combustion. The Heylandt influence in German Army rocket engine development therefore ended in 1937, but the 1,500 kg (3,300 lb) motor designed for the A-3 was used until 1942 in the A-5, which served as a basic workhorse vehicle for testing guidance and control systems.[46]

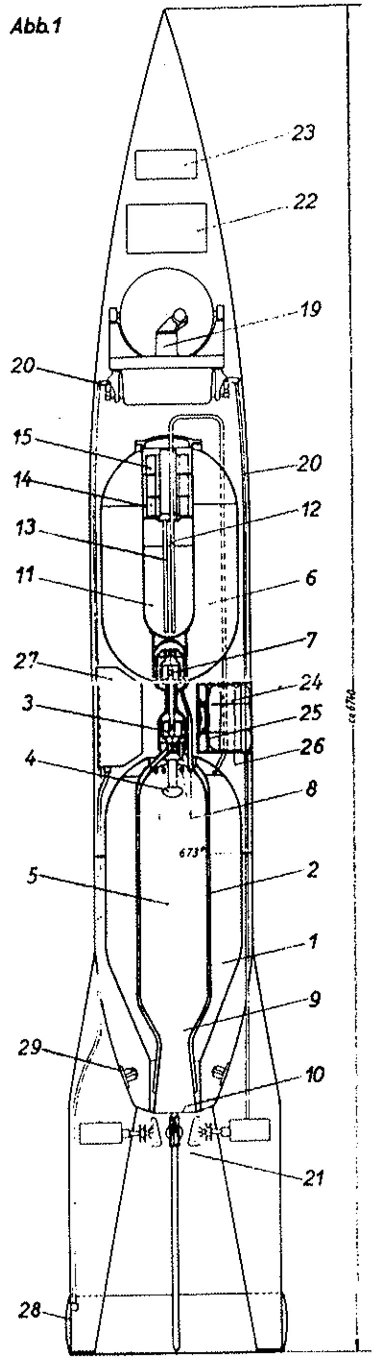

Figure 12 Drawing, A-3 and A-5 rocket, showing in part No. 4 the mushroom type injector. From 1937 unpublished MS. by Wernher von Braun, "Das Aggregat III," in Deutsches Museum.

This later use of Heylandt's rocket technology did not, of course, do the company any good. The Depression devastated its main business in the construction of equipment for the liquefaction, storage and transport of liquefied gases, and the loss of the small engine contracts at the end of 1933 hurt the company further. When Captain Leo Zanssen, the future commander of Peenemünde, visited the firm on 25 January 1935, he found a pathetic state of affairs. The company had 13,000 square meters (42,650 sq. ft.) of empty space and only four workers left; 20-30 skilled turners and welders were unemployed but could be immediately rehired. Yet at its height, in 1927-1932, the company had about 100 workers. Zanssen had gone to inspect the factory, accompanied by an engineer from the Procurement Division of Army Ordnance, because Heylandt had pleaded for new work during negotiations over the firm's patent rights that had begun in the fall of 1934. Spurred by the Reich Patent Office's belated award of a patent on the 1931 rocket-car engine, Ordnance sought to keep rocketry secret and to prevent Heylandt from commercially exploiting its patents. Eventually these negotiations concluded in the fall of 1935, with a payment of 72,000 Reichmarks to the company—65,000 for Heylandt's uncompensated investments in rocketry ever since Valier and 7,000 for the cost of maintaining the patents. The company had been willing to settle for half the 65,000 Reichmarks plus a guarantee of machinery and other contracts from the Army, but the latter refused to give a guarantee of work.[47]

Eventually, however, the expansion of the Army rocket program at Peenemünde and elsewhere provided the Heylandt company with a large number of new contracts in its core business. The company was called upon to build the second liquid-oxygen plant at Peenemünde for the missile production plant. At the beginning of 1940 it had 114 employees at the rocket center working on that project alone. In 1941-1942, the firm helped build the lox plant at the Friedrichshafen Zeppelin plant on Lake Constance for A-4 production there. As Armaments Minister Albert Speer later remarked during the war, "I had enough difficulty as it was to obtain oxygen for industrial purposes," without supplying the requirements for the rocket program. Indeed, by 1942 Heylandt "liquid-oxygen generators" were in operation at several locations; each generator supplied enough lox for one A-4 a day. Heylandt himself came to the Ministry and was placed under severe pressure to maintain a critical wartime schedule to produce the required quantities of lox apparatus.[48]

The Rudolph Motor

Although Army Ordnance ended the Heylandt Company's rocket development in December 1933, there was an interesting "spinoff" of the Valier-Heylandt connection, which throws additional light on early developments at Kummersdorf and Peenemünde. Following his discharge from the Heylandt company in about May 1932, Arthur Rudolph regularly reported to the unemployment office. On one visit he met his former supervisor, Alfons Pietsch, who had earlier lost his job. They naturally talked of their rocket work at the Heylandt plant and Pietsch proposed that they begin experimenting independently. They arrived at a verbal agreement, whereby Rudolph would produce a design while Pietsch would find a paying sponsor. Rudolph says they first approached the local Nazi SA (*Sturmabteilung* [Storm Troopers]) commander, Graf Helldorf, to sell the project. (Rudolph had been a member of the Party and SA Reserve since June 1931.) Helldorf was interested but lacked money to support it. Pietsch next went to private industry and then the Kaiser-Wilhelm Gesellschaft, a prominent research organization. Here too funds were unavailable. Finally, he succeeded in getting a contract from Army Ordnance. We may accurately date it since the relevant document has been located. On 15 May 1933, Pietsch received a five year contract for the "development of a liquid-propellant rocket (rocket chamber together with tanks and equipment)." Upon the completion of this project, he was to be paid costs plus 10%. Pietsch was sworn to secrecy in the arrangement. Rudolph was not mentioned in the contract, presumably because Pietsch negotiated it. He was a senior engineer and was well known to Ordnance because of his public association with the 1931 car. Neither was Rudolph mentioned in a patent issued to the German Reich in 1936, applied for on 19 May 1933, but it contains a drawing signed by him. According to accounts of both Dornberger and Rudolph, Pietsch was advanced money from the Army for project materials, but he eventually disappeared and was not seen again. Rudolph claims he used about half the money for himself and did not repay the rest, so he (Rudolph) had to borrow money from his wife to finish the job.[49]

The engine was completed the following year. Essentially, it was another improved version of Riedel and Rudolph's modified Valier motor. It used the mushroom injector and featured regenerative-cooling, but there were marked differences from earlier models. Dornberger describes it as "made entirely of copper, with the oxygen tanks above the alcohol [fuel] tanks, enclosing and cooling the combustion chamber, below." The fuel tank was spherical, while the lox tank was bullet-shaped. Rudolph says the motor also had its combustion chamber set inside the alcohol tank. This helped cool it, but the main reason was to reduce costs—if the chamber were outside, an extra structure would have been required. On 3 August 1934, the engine made three demonstration firings. A von Braun note about the third test shows that it produced a maximum thrust of 270 kgs (595 lbs), which declined to 100 kgs (220 lbs) during a total firing time of 50.5 seconds. Von Braun liberally interpreted this, accepting the integral of thrust over time rather than the motor's exact performance. He observed that since the requirement was 200 kgs (440 lbs) thrust for 30 seconds, the total performance of over 6,000 kgs/sec (13,230 lbs/sec) amounted to "conditions . . . fulfilled." The engine was therefore accepted by Army Ordnance. One immediate result of this acceptance, according to Dornberger, was that "We found we could use Rudolph and took him into our organization, where he became one of our top experts."[50]

The Rudolph motor ultimately exerted no obvious influence on A-4 (V-2) engine design, but Rudolph claims it did affect the progress of the 1,000 kg (2,200 lb) thrust engines built for the joint Army-Luftwaffe (rocket-aircraft) project that started early in 1935. The Heinkel Aircraft Company was brought into the project in mid-1935. But the complex stories of the He 112 and He 176 rocket-propelled aircraft are entirely separate developments requiring further study.[51]

Conclusion

In conclusion, the Heylandt firm and its small band of rocketeers of the early 1930s materially contributed in several significant ways to the German Army's rocket program that ultimately led to the V-2, the acknowledged ancestor of all large-scale liquid-propellant vehicles. Besides carrying out the Army's initial gaseous and liquid-fuel experiments and furnishing Ordnance with its first laboratory test motors, Heylandt's development of one of the earliest regeneratively cooled liquid-propellant rocket motors may have been influential in the incorporation of that technique in some of the Army's subsequent engines. But there is no question that the Company's well-established expertise in handling lox and cryogenic equipment, plus its involvement in the rocket experiments, afforded ideal training grounds for Walter Riedel and Arthur Rudolph, who became two key people in the development of the A-4.

Dr. Walter Thiel, who headed up the A-4 engine design, likewise gained useful data on rocket dynamics in 1936, through the supervision of a graduate student working on rocket combustion using the 20 kg (44 lb) Heylandt motor. Early Heylandt work on liquid-fuel engines also indirectly exerted an influence in pre-A-4 designs as well, through the use of Riedel and Rudolph's "mushroom" injector in the A-1 to A-3. While this system was discarded in 1937, it was an important and necessary first step in the development of modern injectors. The Heylandt firm likewise developed and manufactured liquid oxygen components and helped build an A-4 liquid oxygen plant. Finally, the Heylandt Company contributed to the development of lox production and cryogenic storage and transportation, technologies which are so crucial to liquid-propellant rocket motor technology.

Postscript

The post-wartime fate of Paul Heylandt is a mystery. We know that the Aktiengesellschaft was purchased by the Linde firm in 1941, and that the other original Heylandt company—Heylandt Gesellschaft—existed in Höllriegelskreuth near Munich from 1946 to at least the early 1970s. Heylandt himself went to the U.S.S.R. to undertake "manufacturing and research." He died in Moscow on 24 June 1947. He must have been involuntarily sent to the Soviet Union to assist in liquid oxygen production for that country's own emerging missile program.[52]

Reference Notes

[1]"Heylandt, Paul," *Neue Deutsche Biographie* (Berlin: Duncker & Humbolt, 1971), 9, 84-85; C. W. Paul Heylandt, "Die Verwertung der Luft," *Chemiker-Zeitung*, 1, 2 January 1937, 10.

[2]"Heylandt," 85-86; Heylandt, 10.

[3]"Heylandt," 85-86; Heylandt, 10; Paulus Heylandt, U.S. Patent No. 797,577 of 22 August 1905.

[4]"Heylandt," 85; Paulus Heylandt, U.S. Patent No. 914,954 of 9 March 1909; Heylandt's system of liquid air manufacture is more completely explained in E. F. Burton, *et. al.*, *Phenomena at the Temperature of Liquid Helium* (New York: Reinhold Publishing Corp., 1940), 18-19; and Mansel Davies, *The Physical Principles of Gas Liquification* (London: Longmans, Green and Co., 1949), 72, 135. 139.

[5]"Heylandt," 85; Paul Heylandt, U.S. Patent No. 1,439,237 of 19 Dec. 1922.

[6]Heylandt, 11: "Sees Lightning Speed for Liquid Gas Planes," *New York Times*, 19 April 1930.

[7]I. Essers, *Max Valier - A Pioneer of Space Travel*, NASA Technical Translation TTF-664 (Washington, D.C.: National Aeronautics and Space Administration, 1976), 141.

[8]Willy Ley, *Rockets Missiles and Space Travel* (New York: The Viking Press, 1959), 119-123, and other editions.

[9]Essers, 182-183, 198-199.

[10]*Ibid.*, 181-183, 198-199; Walter Riedel, "Die Raketenentwicklung . . . 1930-1942," unpub. MS (July 1950), Imperial War Museum, German Misc. Document 148, hereafter cited as Riedel MS.

[11]Essers, 181-183, 198-199.

[12]*Ibid.*, 195-196.

[13]*Ibid.*, 192, 199-209; W. H. J. Riedel, "A Chapter in Rocket History," *Journal of the British Interplanetary Society*, 13, July 1954, 211; W. H. J. Riedel, "Ein Kapitel Raketengeschichte der neueren Zeit," *Weltraumfahrt*, 3, July 1953, 89 (the former article is merely translation of the latter); Max Valier, *Raketenfahrt* (Munich: R. Oldenbourg, 1930), iv. Riedel was

nicknamed "Papa" and was identified as Riedel I in Peenemünde documents, so as not confuse him with Klaus Riedel, formerly of the Raketenflugplatz (Riedel II), or his 1942 successor as Chief of the Design Bureau, Walther Riedel (Riedel III).

[14]Riedel MS. Valier used liquid oxygen (lox) as the oxidizer and alcohol mixed with water as the fuel. Oberth suggested the combination in *Die Rakete* (1923). Oberth also recommended the water additive for lowering combustion temperatures. It is appropriate to note that the lox-alcohol combination was used in many German rocket developments including VfR, Heylandt, and Peenemünde motors.

[15]*Ibid.*; Riedel, "A Chapter," 211; Riedel, "Ein Kapitel," 88-89. For clarity, the last line in the quote by Riedel is the authors' own translation.

[16]Riedel, "A Chapter," 206, 209, 211; Riedel, "Ein Kapitel," 88-89; Essers, 205-206; Riedel MS.

[17]Essers, 204-205, 207; Riedel, "A Chapter," 211; Riedel, "Ein Kapitel," 89; Riedel MS. The original car is now on display in the Deutsches Museum in Munich. One of the authors (Winter) inspected the motor (which, however, is a replica) and found the following dimensions: 21.25 cm (8.3 in.) long motor tube and fitting on top, or 26 cm ((10.2 in.) total, including fuel and oxidizer leads projecting from the car; inside diameter, 49 mm (2 in.) and outside diameter 59 mm (2.3 in.).

[18]C. W. Paul Heylandt, German Patent No. 535417 Klasse 62b Gruppe 37, "Betriebsstofftank für Luftfahrzeug mit Reaktionsantrieb," granted 24 September 1931; Essers, 206; Rolf Engel, "Spaceflight Projects As I Saw Them Nearly 50 Years Ago," unpub. MS. in NASM Library in "Rolf Engel" file.

[19]"Sees Lightning Speed for Liquefied Gas Planes," *New York Times*, 19 April 1930; "Heylandt Predicts Fast Rocket Plane," *Newark Star-Eagle* (Newark, N.J.), 18 April 1930; "Rocket Planes May Cross Sea, *The Star* (Washington, D.C.), 1 June 1930.

[20]Essers, 206-208; Riedel, "A Chapter," 211; Riedel, "Ein Kapitel," 89.

[21]Essers, 209; Riedel, "A Chapter," 212; Riedel, "Ein Kapitel," 90; Heinz Gartmann, *The Men Behind the Space Rockets* (New York: David McKay Co., Inc., 1956), 81.

[22]Essers, 212; Ley, 136, 146.

[23]Oral history interview of Arthur Rudolph by Michael Neufeld, Hamburg, West Germany, 4 August 1989, Space History Department, National Air and Space Museum, Washington, D.C.; Thomas Franklin (pseud.), *An American in Exile - The Story of Arthur Rudolph* (Huntsville, Ala.: Christopher Kaylor Co., 1987), 24-27.

24. Riedel MS.; AG to Reichswehrministerium, 20.11.34, FE 737; "German Develops 14-lb Plane Motor," *New York Times*, 23 March 1931, *New York Herald Tribune*, and other papers. Rudolph's accounts of how the Heylandt rocket car came about are somewhat confusing and inaccurate. In sum, he says the car was built without Heylandt's knowledge when Heylandt was on an extended trip to the U.S. He was forced to accept the vehicle as a *fait accompli* upon his return and then supported the project since it was good publicity for the Heylandt Company. However, Heylandt's trip to the U.S. is recorded in the *Passenger & Crew Lists of Vessels Arriving at New York, 1897-1942*, National Archives, Washington, D.C., RG 85, Microcopy T-715, Roll 4933, Vol. 10669, p. 32, line 25, and shows him arriving in the *Europa* on 29 March 1931. He stated that he intended to stay in the country for only four weeks. There is no record of his making another trip to the U.S. in 1931. The construction of the car itself did begin in March, when he was on the trip, but Heylandt's press release published in *The New York Times* on 23 March 1931—a week before his arrival in the U.S.—quotes him at length promoting a new rocket motor his company had

been developing for several months and which could be used for a rocket car or other means of transportation.

[25]Rudolph interview; Frank H. Winter, *Rockets into Space* (Cambridge, Mass. and London: Harvard University Press, 1990), 11, 16, 20, 30; Esther C. Goddard and G. Edward Pendray, eds., *The Papers of Robert H. Goddard* (New York: McGraw-Hill, 1970), I, 507; Irene Sänger-Bredt and Rolf Engel, "The Development of Regeneratively Cooled Liquid Rocket Engines in Austria and Germany, 1926-42," in Frederick C. Durant, III and George S. James, eds., *First Steps Toward Space*, Smithsonian Annals of Flight No. 10 (Washington, D.C.: Smithsonian Institution Press, 1974), 222 (also reprinted as Vol. 6, *AAS History Series*, San Diego, CA: American Astronautical Society, 1985). In the process of working out the regenerative system, Rudolph and Riedel apparently stumbled across another cooling method, film cooling. According to Rudolph, cracks formed within the jacket even though it was designed to expand and contract. The fuel leaked out of these cracks and "we had much less problems with burn-through . . ." The fuel flowed over the inner wall of the combustion chamber and helped cool the motor. Film cooling was invented for the A-4 (V-2) by Moritz Pöhlmann in 1939 but had no connection with Rudolph and Riedel's alleged accidental discovery of this technique; neither developed the idea further.

[26]Riedel MS.

[27]"German Develops"; Riedel MS.; "Mit der Rakete. Bei Osnabruck fliegt Raketen-Flugzeug, in Britz fahrt Raketen-Auto," *Berliner Morgenpost*, 16 April 1931; "Raketen-Wagen startet," *Berliner Tageblatt*, 1 May 1931; "Motor for Flight In Stratosphere Shown in Berlin," *New York Herald Tribune*, 12 April 1931; "New Rocket Motor Has 400-Pound Push," *New York Times*, 12 April 1931.

[28]Ley, 146; Essers, 250; Riedel MS.

[29]Franklin, 28-29; Rudolph interview.

[30]Ley, 199; Becker to AG, 16 Oct. 1931, FE 724/a.

[31]Becker to Heylandt, 28 Oct. 1931, FE 724/a.

[32]Becker to Heylandt, 9 Nov. 1931 and Heylandt to Becker, 20 Nov. 1931, FE 724/a; Riedel MS.

[32]Becker to Heylandt, 9 Nov. 1931 and Becker to Heylandt, 5 Dec. 1931, FE 724/a; Riedel MS.

[33]Becker to Heylandt, 9 Nov. 1931 and Becker to Heylandt, 5 Nov. 1931, FE 724/a.

[34]AG to Reichswehrministerium, 18 Dec. 1931 and 19 Jan. 1932, FE 724a; AG Report, 29 Apr. 1932, FE 724/a; Report, von Horstig [?], on Heylandt studies, 2 May 1932, and von Horstig to Heylandt, 1 Oct. 1932, FE 724/a.

[35]Riedel MS.; von Hortig to Heylandt, 1 Oct. 1932, FE 724/a; and miscellaneous Riedel drawings in Riedel MS. and FE 724/a.

[36]Walter R. Dornberger, *V-2* (New York: Bantam Books, 1979), 29; drawing R.1029, 20 kg engine, FE 724a.

[37]AG to Wa Prüf 1, 7 Oct. 1932, FE 724/a; Schneider report, 23[?] Jun. 1932, in Imperial War Museum, MI 14/801(V); Franklin, 38; Frank H. Winter, *Prelude to the Space Age: The Rocket Societies 1924-1940* (Washington, D.C.: Smithsonian Institution Press, 1983), 52-53; Ernst Klee and Otto Merk, *The Birth of the Missile* (New York: E. P. Dutton, 1965), 11, 14.

[38]AG to Wa Prüf 1, 21 Nov. 1932, FE 724/a; Schmidt report, 23 Nov. 1932, FE 724/a.

[39]AG to Wa Prüf 1, 30 Nov. 1932; Wa Prüf 1 to AG, 15 Dec. 1932; and W. von Braun notes, 13 Apr. 1933 and 11 Sept. 1933, FE 734/a.

[40]AG to Wa Prüf 1, 1 Jun. 1933, FE 724/a.

[41]AG to Wa Prüf 1, 17 Nov. 1933; AG to Wa Prüf 1, Wa Prüf (Dornberger) to AG, 21 Nov. 1933; AG to Wa Prüf, 28 Nov. 1933; drawing R.1059, 60 kg engine, FE 724c; Wa Prüf 1 (Schneider) to AG, 12 Dec. 1933 and AG to Wa Prüf 1, 15 Dec. 1933, FE 724/a.

[42]AG to Wa Prüf 1, 17 Nov. 1933, FE 724/a.

[43]Wa Prüf 1 (Schneider) to AG, 12 Dec. 1933, FE 724/a; AG to Wa Prüf 1, 15 Dec. 1933, FE 724/a.

[44]Riedel MS.; Rudolph interview; Dornberger, 30.

[45]Wa Prüf 11 to Wa Prüf 1, 28 Apr. 1936, FE 752; Report, Thiel and Seifert, 8 Feb. 1937, FE 403.

[46]Riedel MS.; Werner Buedler, *Geschichte der Raumfahrt* (Kunzelsau: Sigloch Edition, 1979), 274; Dornberger, 52-53, 57, 67.

[47]Zanssen to Wa B. 28 Jan. 1935, FE 749; Wa B 4 to B 4 L, 31 Jan. 1935, FE 749; Winter, *Rockets*, 11, 30. There were actually three rocket patents taken out by Heylandt or the Heylandt Company, plus an additional patent applied for in April 1935, although evidently not completed. Besides patent 535417 already described in footnote 19, these patents are: No. 608242, applied for on 13 April 1930 and granted 27 December 1934, for "Method of Creating Propulsive Gases for the Forward Movement of Vehicles by Means of Reaction Effect"; secret patent A 67.850 I/17 titled "Method of Sustaining the Pressure in Liquid Oxygen and Liquid Fuel Tanks, in Particular for Reaction Devices Driven by Hot Gas Streams"; and "Method of Propelling Reaction Vehicles." The latter patent is found in draft form only and does not have a number. Patent 608242 is a crude and inefficient injector design, based upon Rudolph and Riedel's work; also claimed is the resistance disc for creating turbulent mixing of the propellants. The secret patent, which was given to Wa Prüf on 25 January 1934 but confiscated by the Reichswehr Ministry, appears to have been lost during the war. The patent drafted in 1935 is a design of a crude liquid-propellant flying rocket featuring an elongated combustion chamber with mushroom injector and nitrogen-fed fuel.

The Heylandt rocket patent negotiations can be found in Aktiengesellschaft für Industrie-gasverwertung (cited as AG) — Wa Prüf correspondence, 1934-35, in FE 749. The original file is in the Bundesarchiv/Militärarchiv Freiburg (hereafter cited as BA/MA), RH 8/v. 1253.

Itemized costs of Heylandt's early rocket experimentation include 12,377.77 Reichmarks for the Valier experiments (including his fees or "wages" of 3,264.01 Reichmarks); and 19,123.83 Reichmarks for the rocket car work from March-September 1931.

[48]Report, unsigned, "Nachweisung," 1 Jan. 1940[?], FE 349, and Minutes of meeting of 30 Mar. 1942 in FE 728e; David Irving, *The Mare's Nest* (Boston: Little Brown and Co., 1964), 310; Dornberger, 117-118.

[49]Rudolph interview; Franklin, 39-40; Draft contract, Heereswaffenamt and Alfons Pietsch, 15 May 1933, BA/MA, RH8/v.1225; Reichspatentamt, Patentschrift R 87 975 I/46 g geh.Rs., Klasse 46 g, [applied for, 19 May 1933, issued 23 July 1936], FE 188; Dornberger, 30-31.

[50]Rudolph interview; Klee and Merk, 14; W. von Braun note, 18.8.34, FE 727c; Dornberger, 31.

[51]The history of the interservice rocket aircraft program and the Army liquid fuel rocket program are discussed in Michael J. Neufeld, *The Rocket and the Reich: Peenemünde and the Coming of the Ballistic Missile Era* (New York: The Free Press, 1995).

[52]"Heylandt," 85.

History of Rocketry and Astronautics

Proceedings of the Twenty-Sixth History Symposium of
the International Academy of Astronautics

Washington, D.C., U.S.A., 1992

Philippe Jung, Volume Editor

Donald C. Elder, Series Editor

AAS History Series, Volume 21

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 13

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 1997

ISSN 0730-3564

ISBN 0-87703-439-7 (Hard Cover)
ISBN 0-87703-440-0 (Soft Cover)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198

Printed and Bound in the U.S.A.