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Enabling technology for space transportation

INTRODUCTION

Although rockets have been in use for a thousand years, it was only 60 years ago when concrete plans were made to transport a package of scientific instruments to high altitudes with a rocket. In 1942, Professor Erich Regener in Stuttgart, Germany, a specialist in atmospheric research, ozone physics, ultraviolet spectroscopy, and cosmic rays, and Wernher von Braun, director of the Peenemünde Rocket Research and Development Center, jointly began to design a large scientific payload for the empty warhead of an A-4 test rocket to be launched into a near-vertical trajectory from the "Greifswalder Oie," a small island near Peenemünde. Regener and von Braun had worked together before on a project to try out radio communication between the ground and a transponder carried aloft with a high-altitude balloon. Instruments for the capsule were built and installed in a large aluminum container, called a "Regener Tonne" (Regener barrel). It contained pressure and density gauges, a UV spectrograph with quartz optics to determine the ozone content of the atmosphere, thermal sensors, containers for atmospheric samples to be taken during the parachute descent of the capsule at various altitudes, instruments to measure ion densities in the atmosphere, drum recorders, radio receivers and transmitters, and a parachute that unfolded under the stiffening force of pressurized tubes. While the quartz spectrograph, built at the Regener Institute, had the primary objective of determining the ozone content of the high atmosphere by measuring the intensity of solar UV radiation, it also promised to furnish the first solar spectrum deep into the ultraviolet, an objective in which solar astronomers, among them K.O. Kiepenheuer, were greatly interested. The capsule was ready for launch late in 1944, but by that time the Nazi government did not permit any activities not directly supportive of the war effort. Then, in January 1945, von Braun received orders to leave Peenemünde and move south; that terminated the Regener Tonne project.

Only one year later, Peenemünde rockets, shipped from Germany to White Sands in New Mexico, were launched with scientific payloads instead of warheads, prepared by scientists from numerous universities and research institutes all over the country. A very active period of high altitude research began which lasted for seven years. Besides its immediate success as a source of scientific results and discoveries, this project proved that rockets represent marvelous tools for scientific research in far-away regions that would not be accessible in any other way.

Stimulated by the successful research projects with the old Peenemünde rockets, several new rockets were developed during the 1940s, among them Van Allen's Aerobee and Aerobee High, and Milton Rosen's Viking, which continued a successful program of scientific space research. They were members of a very small number of rockets developed exclusively for scientific purposes. A large number of rocket projects evolved from about 1950 on in the United States, in Soviet Russia, and in other countries, but most of them were developed and built for military purposes. Some of them, such as the European Ariane and the American Delta II, and also the Space Shuttle, served exclusively, or at least primarily, commercial and other utilitarian uses; the big Saturn-Apollo rocket project arose under the pressure of political circumstances.

On the other hand, all the rockets and rocket technologies developed and built during the past fifty years for various

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Ernst Stuhlinger, The Century of Space Science, 59–114

purposes have also found applications in purely scientific endeavors. All those spacecraft which were built during the past five decades specifically for astronomical and astrophysical research, for lunar and planetary studies, and for solar and deep space investigations owed their launchings to rockets that had been built primarily for nonscientific purposes. This intimate relationship between technologies created for practical purposes, and the need of scientists who are driven primarily by their quest for knowledge, has been a characteristic feature of rocket and space activities during the past sixty years.

In this essay on enabling technologies for space transportation, the author tries to convey an impression of the multifaceted challenges, problems, failures, and successes the rocket people have encountered on their long way from the dreams of the 1930s to the satellites and the lunar, planetary and space probes that have come to life during the twentieth century, enriching our awareness and our knowledge of the Universe to an extent unforeseen when the century began.

1. EARLY THOUGHTS ABOUT SPACE TRAVEL

Transportation through space, without a firm substrate or a surrounding atmosphere, must rely on principles of propulsion different from those which allow people, and animals, to move from one place to another in our immediate earthly environment. Several ways to produce a propulsive force for travel through space beyond the atmosphere can be envisioned, such as gravitational forces generated by celestial bodies; light pressure; and the rocket principle.

Rockets did not originate from the desire to travel into and through space. History tells us that about one thousand years ago rockets appeared as weapons of war, first in Asia, then in Europe, and later on the American continent. Today, military rockets play major roles in the armaments of all countries that must be prepared for occasional involvement in military conflicts.

Independent of that situation, there have been humans, probably for thousands of years, whose minds dreamed about voyages to the Moon, to planets, and even to stars. Toward the end of the nineteenth century, some of these dreamers began to study whether it would really be possible, on the basis of well-established laws of physics, to travel to the Moon, and perhaps even to one of the nearest planets, with spacecraft built on Earth and propelled by a suitable rocket motor. Today, as the twenty-first century dawns, we realize that those early studies have led to a vast field of activities involving rockets. They gave the twentieth century its most characteristic feature: Mankind's outreach into the unfathomable expanses of space that surround the planet Earth.

This chapter will not present a comprehensive history of rocketry and space projects. Rather, it will highlight those specific events which gave origin to the fabulous evolution of space sciences by providing the technical means to send instruments, and even humans, away from Earth with its many disturbing influences, enabling them to make observations that would never be possible from the surface of the Earth. Also, some thoughts will be offered about the likely development of space flight in the foreseeable future, as seen by those who were actively involved in the development of rockets and spacecraft during past decades.

The first decisive step from dreams to realistic studies was made by a Russian schoolteacher, Konstantin Eduardovitch Tsiolkovskii (1857–1935). Based on Newton's laws of mechanics, he derived in 1895 a simple, but very elegant equation that allows one to calculate the terminal velocity, V_{term}, a rocket will reach in the vacuum of empty space, far away from any noticeable gravity field, when its total initial mass, M_{in}, its mass at burning cutoff, M_{c-o}, and the velocity of its exhaust gases, V_{ex}, are known. He found:

$$V_{term} = V_{ex} \ln [M_{in}/M_{c-o}]$$

Tsiolkovskii's work, remaining largely unknown for many years, did present the proof that rocket behavior is amenable to exacting mathematical analysis.

Around the end of the nineteenth century, a young American physics teacher, Robert Hutchings Goddard (1882–1945), engaged in an extremely active pursuit of rocket and space flight ideas. In 1902, he wrote an essay *The Navigation of Space*, and offered it to *Popular Science*, but his paper was not accepted for publication. Convinced that the key to space travel is a suitable propulsion system, and that space propulsion should be based on rocket principles, he devoted all his further work primarily to the study and development of rocket systems. In 1906, he wrote about "electrified jets" for planetary voyages, but from about 1909 on he concentrated his efforts predominantly on the theoretical and practical development of liquid-propellant rockets.

Beginning in 1914, Goddard applied for and received patents – 214 during the following thirty years – for an astounding variety of subjects: rockets with solid and liquid propellants, multistage rockets (a principle that was mentioned for the first time by Konrad Haas in Romania in 1529!), combustion chambers, nozzles, cooling systems, valves, tanks, propellant feed systems, gyroscopic guidance and control systems, air and jet vanes, and recovery by parachute. Like Tsiolkovskii ten years before him, and independently Hermann Oberth ten years after him, he found that liquid oxygen and liquid hydrogen would make the best propellant combination for high-altitude rockets.

Goddard (1919) described some of his ideas in a paper *A Method of Reaching Extreme Altitudes* which was published by the Smithsonian Institution in 1919. This essay, one of very few Goddard papers published during his lifetime, led to some support from the Navy, and to the permission from Clark University at Worcester, Massachusetts, where he was a professor of physics, to carry out his experiments under the auspices of the university. Goddard's paper, very unfortunately, also evoked some negative comments by the press which ridiculed his contention that humans may one day be able to travel to the Moon. This criticism hurt him deeply. He discontinued publishing his articles, and he put his patents, reports, and diaries in safes where they remained unseen until after his death in 1945. He refused to cooperate, and even to communicate with other rocket scholars, limiting his entire "team" to five persons, including his wife Esther.

Homer E. Newell, NASA Associate Administrator and Chief Scientist during the 1950s, wrote in 1980 (Newell 1980): "By his secrecy, Goddard not only dissipated most of his influence he might have had, he also deprived himself of the engineering expertise that he sorely needed to achieve his dream. The future of rocketry belonged to the team approach. It was, indeed, inextricably tied to the massive funding sources and particular purposes of the national security state … His reluctance to work openly with others deprived Goddard … of the kind of funding support from the military …" It deprived him also of the recognition of peers he would have deserved so abundantly. On March 16, 1926, a Goddard rocket, fueled with kerosene and liquid oxygen, rose to an altitude of 13 meters and covered a distance of 55 meters. It was history's first liquid-propellant rocket. Eleven years and numerous rockets later, Goddard and his co-workers launched a rocket in Roswell, New Mexico, which reached an altitude of 2700 meters (Goddard 1948).

It was several years after Goddard's death that his many prolific notes, diary entries, manuscripts, and patents became available to the public (Goddard *et al*. 1968). There is hardly any area of rocket technology that he did not discuss, and for which he did not propose designs and ideas for further studies. By the time, during the late 1940s and early 1950s, when details of his theoretical and experimental work became known, others had independently arrived at similar ideas, and had even developed them into modern, powerful precision rockets that transformed Goddard's dreams into reality.

Hermann Oberth (1894–1989) learned of Goddard's existence and work in 1922 through a brief note in a newspaper. He wrote Goddard a letter, asking for "a copy of your books." Goddard sent Oberth a copy of his Smithsonian paper. In return, Oberth wrote an appendix to his own book *Die Rakete zu den Planetenräumen* (The Rocket to Planetary Spaces) which was in press at that time (Oberth 1923), with the expression of great admiration and esteem.

For his book, Oberth had independently derived many of the basic formulae of rocketry, including the famous Tsiolkovskii equation. In spite of its small size – 92 pages – Oberth's book is an impressively rich compendium of facts and properties of rockets, most of them presented for the fist time, and also of ideas referring to the use of rockets. Oberth described two types of rockets in great technical detail, the "alcohol rocket," and the "hydrogen rocket." He mentioned the possibility of space stations that orbit the Earth indefinitely "like a little moon" without requiring any sustaining propulsion, providing opportunities to make large-scale weather observations, to communicate through light signals with inaccessible regions on Earth, to investigate the ultraviolet light from stars, to make experiments and study processes under weightlessness, and to carry out observations of strategic interest. "Telescopes of any size could be used in space, since the images of stars do not twinkle …; visiting other celestial bodies would certainly be of utmost scientific value …" And he added very cautiously: "Under certain economic conditions, construction of such machines" – space rockets and orbiting stations – "can be profitable. Such conditions may arise in some decades." How right he was!

2. SYSTEMATIC ROCKET TECHNOLOGY WORK IN GERMANY, 1923–45

Oberth's book of 1923 became the most important and influential book about rocketry ever. Many of the later rocket pioneers quoted it as their initiation into their own rocket career. At the time when it was published, young Wernher von Braun, eleven years old, lived in Berlin. As his mother later wrote, "He involved himself in numerous projects with his friends … they built all kinds of rockets, and they collected pieces of old automobiles from junkyards and built 'new' cars, with and without rocket propulsion …" (Stuhlinger *et al*. 1994). At 14, he wrote an essay *Journey to the Moon: Its Astronomical and Technical Aspects*, published in the *Journal for the German Youth*. One year later, the teenager wrote a letter to Oberth: "I know you believe in the future of rockets. So do I. Hence, I take the liberty of sending you a brief paper on rockets that I wrote recently." This was the beginning of a very close and warm friendship between the two men, based on great and genuine mutual admiration. It lasted until von Braun's death, fifty years later.

Shortly after he had decided to become a space pioneer in 1925, von Braun made another decision, typical of his clarity of thought. If we want to travel to the Moon and to Mars, he said, the most important requirement is a vehicle that can provide proper transportation over the vast distances in space, and that also offers accommodation first for instruments to make scientific observations, and later for human travelers who will live and work on their spacecraft during the voyage, and then on the surface of their celestial target. I will devote my efforts first of all to the development of a powerful precision rocket that is capable of providing an adequate and safe means of transportation through space.

Years later, recalling his early decision, he mentioned to some friends: “Look at the great events of discovery and exploration in our history. Each of them happened when proper means of transportation had become available, good ships for Columbus, horses for the early American pioneers, chuck wagons when the American West was opened for European immigrants, railroads when people began to settle there in numbers, automobiles and airplanes when the continent became a homestead for millions. So, have rocket, will travel through space!”

Von Braun’s serious and systematic rocket development work began in 1930 when, as a student at the Technical University of Berlin, he assisted Professor Oberth in his efforts to develop a proper combustion chamber and exhaust nozzle for a gasoline-liquid oxygen rocket motor. This was von Braun’s first encounter with a technical enterprise based on careful planning, and on exacting theoretical studies, an approach that was to become a trademark of von Braun’s own work in all of his ensuing projects.

Around the same time, von Braun joined a small group of young rocket enthusiasts in Berlin. They called themselves “Verein für Raumschiffahrt” (Society for Space Travel), and they built and tested their liquid-fueled rockets at their “Raketenflugplatz” (Rocket Proving Ground) in nearby Reinickendorf. Although it was a very small team with almost no financial means, they made noticeable progress with their rocket engines. But Rolf Engel, one of the members who later became a prominent rocket expert, remembered: “One day, Wernher told me: ‘Look, Rolf, we want to push this thing. But we have no money. The only way how we can get the money, the assistance, and all the means, is the Army’.” (Reisig 1997).

It so happened that during 1931–32, the German Army (Deutsche Reichswehr) also had a small rocket development program underway. By some mixture of fate and circumstamces (details are described by Reisig 1997), the Army group made contact with the Society for Space Travel and offered to von Braun a Civil Service contract to develop a rocket that could be used as a weapon replacing heavy artillery that at that time was forbidden to Germany. In 1932, von Braun and most of his few co-workers settled in a modest rocket testing facility in Kummersdorf near Berlin and developed a rocket with alcohol and liquid oxygen as propellants. Their work was successful; in December 1934, they launched Max and Moritz, rocket twins of the A-2 type. Each of them reached a planned altitude of 2500 meters. In 1935, the Army, in a joint enterprise with the Air Force, decided to build a larger rocket development facility at Peenemünde on the Baltic island of Usedom. Two years later, von Braun and his co-workers moved in and began work on a rocket for which the Army had specified a range of about 250 kilometers and a payload of about 1 ton. Von Braun, 25 years old, became the Technical Director of the Peenemünde Rocket Development Station; Colonel (later General) Walter Dornberger was named Commanding Officer. Under the Army’s auspices and protection, work at Peenemünde proceeded quickly and successfully, relatively undisturbed by the Nazi government and the Party.

In retrospect, the Peenemünde rocket project stands out as the first step in the realization of von Braun’s youthful dream, dreamed ten years earlier, to build a powerful precision rocket whose future descendants one day would enable human voyagers to travel into and through space. The basic features of that first rocket had taken shape in his mind before Peenemünde began: a rocket motor burning alcohol and liquid oxygen, the propellants being fed by centrifugal pumps; the walls of the combustion chamber and nozzle to be cooled by fuel; the attitude of the rocket to be sensed by gyroscopes and controlled by a combination of air and jet vanes; the shape of the rocket to be determined by careful wind tunnel experiments; and its velocity to be measured by a set of accelerometers and integrators.

Only rudimentary knowledge and experience existed in all these areas when work on the Peenemünde rocket started. From the beginning, von Braun organized his fast-growing work force in such a way that intense development work could be conducted simultaneously in all areas. Systems were continuously refined, tested, and further refined. Actually, the Peenemünde rocket grew and approached its definitive form in five distinct steps that had already started in Kummersdorf. Each of the steps utilized the experience gained in its simpler and smaller forerunners; the models were the A-1, A-2, A-3, A-5, and finally the A-4 which was built with the size and capability specified by the Army. Gradually, the A-4 rocket took shape, and after much testing of the instruments in the laboratories, and of the rocket engine with its jet vanes on test stands, flight testing of the A-4 began in the summer of 1942. After the first three launch attempts had failed, a test flight on October 3, 1942 was a full success.

Some improvements were planned and started in Peenemünde, but they were completed only years later when von Braun and part of his team continued their rocket development work in the United States. Among these systems were integral propellant tanks instead of the tank-within-a-shell design, an improvement that became possible after better aluminum alloys and welding techniques had become available; air bearings for the gyroscopes

http://www.springer.com/978-0-7923-7196-0

The Century of Space Science
Bleeker, J.A.; Geiss, J.; Huber, M. (Eds.)
2001, XLIX, 1846 p., Hardcover
ISBN: 978-0-7923-7196-0