CHAPTER 1

History of Rockets

1. 1. INTRODUCTION

Action-Reaction Principle

Take any technology and you always find that its practical demonstration had been realized much before the theory was established. However, you may note that the fast and effective refinement of a technology begins only after its theory, explaining the underlying basic principles, has been established. The action-reaction principle that is fundamental to jet propulsion, which includes airbreathing- as well as rocket-propulsion, was theoretically explained only in 1687 by the English scientist Sir Isaac Newton by his famous publication "Philosophiae Naturalis Principia Mathematica ("Mathematical Principles of Natural Philosophy"). But, approximately 2100 years before this, Archytas, a Greek philosopher, mathematician, astronomer, statesman, and strategist, had demonstrated the action-reaction principle by his toy pigeon in the city of Tarentum, Fig. 1. 1. Archytas suspended on a wire his wooden pigeon that contained hot steam at an elevated pressure in its belly cavity. The other end of the wire was hooked on to the top of a tall pole. On releasing a plug, a jet of steam escaped through a hole from the rear of the pigeon to produce a thrust that made the toy pigeon fly in circles around the pole. Thus Archytas mystified and amused the citizens of Tarentum by his flying toy-pigeon and demonstrated the fundamental principle of propulsion: "every force has an equal and opposite reaction".

The second recorded-demonstration of the action-reaction principle was in the first century B.C. Hero of Alexandria, a Greek mathematician and scientist, constructed a device known as aeolipile. The device comprised of a kettle of water and a spherical chamber that had been horizontally pivot-mounted at the ends of the two conduits rising from the kettle, Fig. 1. 2. The spherical chamber had two L-shaped tubes fixed 180 degrees apart with their outlets pointing in the opposite directions in a plane perpendicular to the rotational axis of the chamber. On heating the water to boil, the steam entered the spherical chamber through the conduits and escaped as jets in opposite directions from the two outlets. The two equal but opposite components of thrusts that the exiting jets produced gave a torque to rotate the spherical chamber. The aeolipile did not produce any useful power. The pressure in the not-so-strong kettle would have been a little above atmospheric and quite a lot of steam could have leaked through the two crude pivot-joints, but the aeolipile effectively demonstrated the action-reaction principle. The garden water sprinklers of today are nothing but the water aeolipiles that demonstrate the working principles of airbreathing- as well as rocket-propulsion systems!

Fig. 1. 1. Archytas demonstrating the action-reaction principle.

Arrows of Flying Fire

As noted previously, jet propulsion includes airbreathing- and rocket-propulsion. As its name implies, airbreathing propulsion “breaths” air and uses the oxygen contained in the air as the oxidant for combustion with the fuel stored within. Examples of airbreathing propulsion systems are the ramjets and the aircraft gas turbines in various forms such turboshaft, turbofan, and turbojet with reheat. As these propulsion systems need air they cannot operate outside the atmospheric air layer. On the other hand, rocket propulsion systems, or non-airbreathing propulsion systems, store the required oxidant and fuel within. These systems, therefore, can operate independent of the environment ─ within the air layer, under water, or in space.

In general literature, the term rocket is used for the rocket propulsion-system as well as the rocket vehicle that comprises of a rocket propulsion-system, a payload, and a guidance and control system. In this book we use the term rocket engine or rocket motor to represent rocket propulsion system. The rocket-engine-propelled vehicle is written simply as rocket or where more clarity is required as rocket vehicle.

Having noted the earliest demonstrations of action reaction principle, let us now briefly look at the history of how the rocket technology was born and how it was spread all over the world.

Fig. 1.2. Hero engine.

Chinese were the first to develop rockets and they called them as arrows of flying fire. As early as 1300 B.C. fireworks were used in China during religious and other festive celebrations. For firecrackers, the Chinese used to fill crude explosives in bamboo tubes and seal them with fuses. They tossed the firecrackers into fires during the celebrations. The explosive powder, on ignition, burned and instantaneously produced hot combustion gases. The resulting steep rise in the internal pressure exploded the sealed bamboo tubes with big noise. The Chinese believed that the explosions would drive away evil sprits.

Fig. 1. 3. A Chinese soldier igniting an "arrow of flying fire." (Image redrawn from the one found in http://history.msfc.nasa.gov/rocketry/)

It is conjectured by many that the invention of rockets could be by accident. Possibly some of the firecrackers were not properly sealed. In such a typical case the weakest point of the sealed tube could be the fuse hole that was sealed after the fuse had been inserted. At the consumption of the fuse on ignition and the subsequent immediate-enlargement of the weak fuse-hole, the hot high-pressure combustion gases escaped as a jet without causing explosion. Such unsuccessful firecrackers got propelled and skittered out of the fire due to the escaping jets and these gave the clue for the arrows of flying fire.

In order to transform the firecrackers into the arrows of flying fire, burnt clay-closures with holes were provided at the rear ends of the bamboo tubes, which were otherwise sealed all over. The holes were used as the access passages for the loosely mounted fuses. Long bamboo sticks attached to the explosive-filled tubes provided the stability in flight. No sooner they had been lit, the arrows of flying fire were launched from bows. Before long it was found that the arrows of flying fire need not be launched from bows but could launch themselves by the power of the escaping jets. Thus the first avatar of rocket was born.

A typical arrow of flying fire comprised of a bamboo-tube rocket motor as its propulsion system, Fig. 1. 3. It could be with a payload of a pack of explosive, which, at the end of flight, would give with or without an explosion a shower of glowing cinders. But for the long bamboo stick to provide stability in flight there was no guidance and control system.

Although the Chinese were using some crude explosives in their fireworks for many centuries before Christ, the first recorded-development of explosives happened during the rule of the Emperor Wu Di (156-87 B.C.) of the Han dynasty. Under the emperor's sponsorship, the Chinese alchemists experimented with sulfur and saltpeter (a mineral containing potassium nitrate, KNO_3) to heat up and transform substances. In the 8^{th} century, during the Chinese Tang dynasty, sulfur and saltpeter were combined with charcoal powder to create an explosive called the "huoyao" or gunpowder. The modern gunpowder — also known as black powder — is a mixture of about 75% potassium nitrate, 15% charcoal, and 10% sulfur.

The Rocket Route

Undoubtedly, the arrows of flying fire were used during religious and other festive celebrations for many centuries before Christ. Considering this fact, we may say that the arrow of flying fire is also one of the earliest systems to demonstrate the action reaction principle. It is not known when the Chinese started using the arrows of flying fire in battles. The first recorded-usage of them as weapons was in 1232 at the battle of Kai-fung-fu where the Chinese Sung Dynasty repelled the invading Mongols.

The Mongols, repelled by the Chinese at the battle of Kai-fung-fu in 1232, realized the power of the arrows of flying fire and started developing their own rockets. In 1241 at the battle of Sejo, Mongols used their rockets against Magyar (Hungarian) forces to capture Budapest. And in 1258 the Mongols used their rockets against Arabs to capture the city of Baghdad. Arabs in turn quickly learned to construct their own rockets and used them during the Seventh Crusade in 1268 against the French Army of King Louis IX. In the late 1260s Bacon Roger, an English philosopher and scientist, worked on improved forms of gunpowder. Thus, within four decades after the battle of Kai-fung-fu the rocket found its route to the entire Europe.

In 1370s Jean Froissart, a French chronicler, noted that more accurate flights could be achieved by launching rockets through tubes or canisters and this paved the way for the modern bazooka. In 1420 Joanes de Fontana of Italy designed a surface-running rocket-powered torpedo for setting enemy ships on fire. Almost in the last phase of the Hundred Years' War between the French and the English (1337-1453), the French army led by Saint Joan of Arc broke the siege of Orléans in 1429 and in this the French were reported to have used rockets.

In 1591, a German fireworks-maker Von Schmidlap invented the “step rocket”, a large rocket having on its top a small rocket. The large rocket on ignition climbed to a high altitude, and just before its burnout and separation, ignited the small rocket to climb still higher altitude. At its burnout, the small rocket showered the sky with glowing cinders. Schmidlap’s idea of step rocket is the forerunner to the present day multistage rockets used for satellite-launch vehicles and intermediate range ballistic missiles (IRBMs) and intercontinental ballistic missiles (ICBMs). In 1650, Kazimierz Siemienowicz, a Polish artillery expert, released drawings for a staged rocket.

Fig. 1. 4. Rockets of Tippu Sultan.
(Courtesy NASA; http://history.msfc.nasa.gov/rocketry/)

After the battle at the siege of Orléans, there appears to be no record of rockets being extensively used in battles until the war in India between the Muslim ruler Tippu Sultan and the British forces at the two battles of Srirangapatnam, 1792 and 1799. The British forces won the battles but they had initially experienced serious reverses due to the usage of large number of rockets by Tippu Sultan, Fig. 1. 4. Although the British learned the use of rockets in battles as early as 13th century, the superiority of Tippu’s rockets made the British to realize once again the importance of rocket weaponry.

How the technology of rocket weaponry entered India is not clear. The Mongol emperor Genghis Khan invaded India in the early 13th century and the Mongols were in India for the next three centuries. From Kabul, the emperor Baber, a descendent of Tamerlane and Mongol rulers, invaded India and established the Mughal dynasty (1526-1858). Baber was known to have used superior artillery in his battles. Either the Mongols or the Mughals or both could have brought rockets into India.

The initial success of Indian rocket barrages against British forces at the two battles of Srirangapatnam resulted in the revival of rocket development in England. In 1800s Sir William Congreve, an English artillery-expert, began development of rockets weighing up to about 140 kg with iron cases and almost 5 meter long stability sticks. In 1806, Claude Ruggiere, an Italian living in Paris, launched small animals in rockets equipped with parachutes. Congreve rockets were used in the Napoleonic Wars as the British attacked Copenhagen and Denmark in 1807. On August 24th 1814, British forces used their rockets against American forces at Bladensburg, Maryland to capture Washington DC and the White House. Again, on September 13th the same year the British forces unsuccessfully bombarded with their rockets the Fort McHenry in Baltimore harbor. The rocket attacks by the British against Americans in the War of Independence inspired Francis Scott Key to write the words "rockets' red glare" in his famous poem "Star Spangled Banner" which became the National Anthem of the United States of America.

In 1821, sailors found another use for rockets by using rocket-propelled harpoons to hunt whales. In 1826, Sir William Congreve, continuing his rocket developments of three decades, experimented with staged rockets as originally setout by Von Schmidlap in 1591.

In those days, the devastating nature of war depended mainly on the number of rockets used and not on their precision. More than the damages, it was the fear and confusion in the army and cavalry ranks caused by the fire and explosions of the descending rockets that demoralized the enemies in the battles. Despite the six centuries of rocket-weaponry usage since the battle of Kai-fung-fu, the long sticks were the only means to provide stability to the rockets and they were messy and did not provide the desired accuracy. In 1844, a British inventor William Hale invented "stickless rocket". In stickless rockets, the rocket jet was made to impinge on small vanes fixed at the jet exit. The reactive force due to the impingement made the rocket to spin and provided better stability and precision in rocket flight. Many variations of this spin-stabilization concept are used in present day rockets.

After the War of Independence, Americans developed their own rockets for use in their war against Mexicans in 1847 at the Siege of Veracruz and the capture of Chapultepec Castle. Also, Americans used rockets to fight among themselves during their Civil War from 1861 to 1865.

Thus, from the battle of Kai-fung-fu in 1232, it took about 600 years for the rockets to travel around the world.

1. 2. THE TRINITY OF ROCKET TECHNOLOGY: TSIOLKOVSKY, GODDARD, AND OBERTH

The modern astronautics and rocketry owes to its development to the pioneering works of three great scientists: Konstantin Eduardovitch Tsiolkovsky (1857-1935) of Russia, Robert Hutchings Goddard (1882-1945) of the United States of America, and Hermann Oberth (1894-1989) of Germany. With undaunted determination and dedicated perseverance, these eminent men worked tirelessly against many odds such as delayed recognition or total disapproval, acute shortage of research funding, rebuke, criticism, and personal ill health. Tsiolkovsky, Goddard, and Oberth stand out as pioneers because of their greatness in evolving the underlying scientific principles, projecting technically the application of rocket propulsion for space exploration, and visualizing the associated challenges. Brief biographical sketches of these great men are given here. The fourth pioneer in this line could be Wernher von Braun (1912–1977), the designer of German V-2 bomb and the space age architect of the United States of America. The drawing of his adventurous biography that is a World War II sensation is left as an exercise for the reader.

Konstantin Eduardovitch Tsiolkovsky (1857-1935)

Konstantin Eduardovich Tsiolkovsky was born to a Polish immigrant on September 17, 1857 in the village of Ijevskoe, Russia. His portrait is shown in Fig. 1. 5. Tsiolkovsky's parents were not rich and had a large family of 18 children. At the age of 10, Tsiolkovsky lost his hearing almost completely as the result of scarlet fever. Throughout his life this disability made him to work very hard to prove to himself and others that he was cleverer than others. Tsiolkovsky never had any formal education but was a ferocious reader. He was greatly inspired by the novels of the French author Jules Verne (1828-1905), who is considered as the father of science fiction.

Young Tsiolkovsky was dreaming of human space travel not only for the humanity to go into outer space but to establish space civilization there. At the age of 22, he wrote his first manuscript "Astronomical Drawings" to explain the Solar system indicating the planets, and the distances between the planets and their satellites. The self taught Tsiolkovsky obtained his Teacher's Certificate and went to Borovsk, Kaluga Province in 1880 to work there as a mathematics teacher for the next twelve years. During his spare time he continued to work on his favorite subject of space travel. In 1883, he wrote his second manuscript "Free Space" in which he described the life and ways of motion in space, zero gravity, a spacecraft with cosmonauts floating within due to weightlessness, gyroscopes for attitude control, and an airlock for exit from the spacecraft into free space, Figs. 1.6 and 1.7.

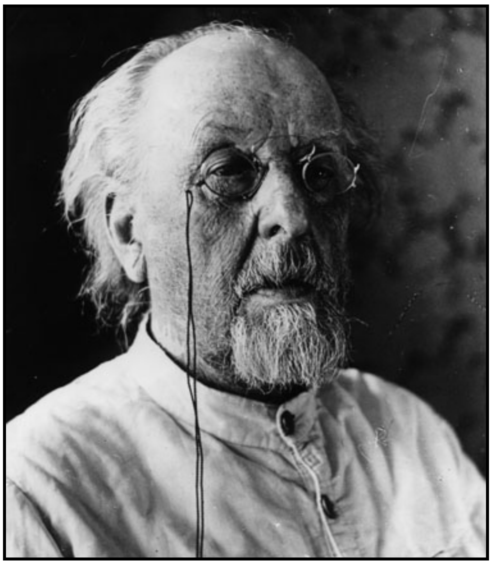

Fig. 1. 5. Konstantin E. Tsiolkovsky (Courtesy: The Memorial House Museum of Konstantin E.Tsiolkovsky; http://www.informatics.org/museum/tsiol.html): "The Earth is the cradle of the mind, but we cannot live forever in a cradle."

On a promotion in his teaching job, Tsiolkovsky moved to Kaluga in 1892 and lived there until his death. During the early 1890s, he wrote articles on a metal dirigible (1892) and an airplane (1894). It was in Kaluga that Tsiolkovsky became a well-known scientist by publishing his studies on space flight and inter-planetary travels.

Inspired by the Eiffel tower in Paris, Tsiolkovsky proposed in 1895 a “celestial castle” at the geosynchronous altitude, which is equal to 35786 km. A tower with an elevator would connect the castle and the ground station right “below”. The castle at the geosynchronous altitude would be static with respect to its ground station as the castle’s orbital period would be exactly equal to one day. The celestial castle would serve as a geosynchronous space station. Cosmonauts and objects could be sent to the castle through the elevator. The objects could be assembled into spacecraft and launched into outer space from the castle. Following this proposal many interesting studies have appeared on the possibility of building the Tsiolkovsky’s space tower or its variants. However, up till now such a concept remains only fictional for want of super strength materials and cheaper ways of executing such a colossal venture.

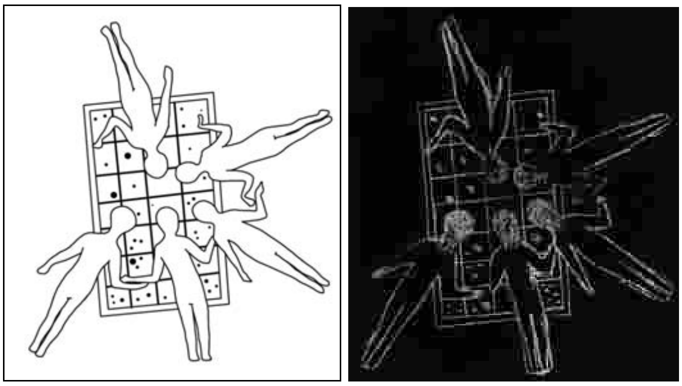

Fig. 1. 6. A duplicate copy given in the left for better image-clarity and the copy of the original drawing of Tsiolkovski showing astronauts in weightlessness looking through their window at the stars (Courtesy: The Memorial House Museum of Konstantin E.Tsiolkovsky; http://www.informatics.org/museum/tsiol.html).

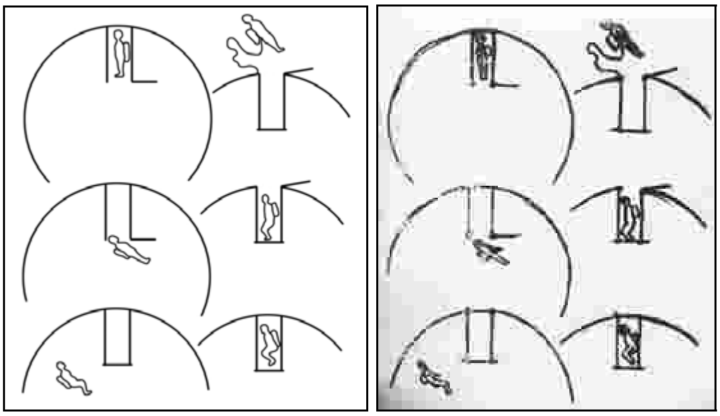

Fig. 1. 7. A duplicate copy in the left for better image-clarity and the copy of the original drawing of Tsiolkovski showing the cosmonaut with a space suit using an airlock to exit a space vehicle in weightlessness(Courtesy: The Memorial House Museum of Konstantin E.Tsiolkovsky; http://www.informatics.org/museum/tsiol.html) .

In 1897, Tsiolkovsky wrote the manuscript entitled, “Exploration of the Universe with Reaction Machines”, in which he accurately explained the state of weightlessness, the need to employ rockets for space exploration, and the importance of using liquid propellants. Furthermore, in this manuscript, he derived the famous equation governing rocket-motion in zero-gravity vacuum-space:

$$\Delta v = u_e \ln\left(\frac{M_0}{M_0 - M_p}\right) = u_e \ln\left(\frac{M_0}{M_l + M_s}\right) \qquad (1.\ 1)$$

where Δv is the velocity increment of rocket vehicle; u_e is the velocity of exiting gases from rocket engine, which also represents the most often talked about energy-parameter, namely, specific impulse; M_0 is the initial mass of rocket vehicle; M_p is the propellant consumed or expelled into the vacuum by way of exiting gases, M_l is the payload, and M_s is the structural mass. The Tsiolkovsky-equation, Eq. (1. 1), clearly brings out the two fundamental principles of vehicle motion in zero-gravity vacuum space: (1) the required velocity increment to the vehicle can be achieved by spending less propellant if the velocity of the exiting gases or the specific impulse is more, and (2) the velocity increment to the vehicle can be greater than the velocity of the exiting gases. Tsiolkovsky submitted this manuscript to the journal, “Science Review” in St. Petersburg in 1897 but the editors took almost 6 years to publish it.

Tsiolkovsky was made a member of the Soviet Academy of Science in 1919. Although Tsiolkovsky had been writing technical papers and science fictions on space travel from 1879, his works did not attract serious attention in Russia until 1923, in which year Hermann Oberth in Germany published his book “Die Rakete zu den Planetenraumen” (The Rocket into Interplanetary Space). In this work Oberth explained in great detail the application of rocket propulsion to spaceflight. Following the publication by Oberth, Germans started to take great interest in the development of rockets. As this news spread to Russia, Tsiolkovsky's earlier works were sought out and avidly studied by Russians.

In 1926 Tsiolkovsky published the book, “Plan of Space Exploration” in which he gave sixteen steps for the humanity to leave the Earth’s “cradle” that is finite to the far-off less-finite worlds of “other suns” in the Milky Way Galaxy and perhaps beyond. The interesting sixteen steps are the following.

(1) Creation of rocket airplanes with wings.

(2) Progressively increasing the speed and altitude of these airplanes.
(3) Production of real rockets-without wings.
(4) Ability to land on the surface of the sea.
(5) Reaching the orbital velocity about 8 km/second, and the first flight into Earth orbit.
(6) Lengthening rocket flight times in space.
(7) Experimental use of plants to make an artificial atmosphere in spaceships.
(8) Using pressurized space suits for activity outside of spaceships.
(9) Making orbiting-greenhouses for plants.
(10) Constructing large orbital habitats around the Earth.
(11) Using solar radiation to grow food, to heat space quarters, and for transport throughout the Solar System.
(12) Colonization of the asteroid belt.
(13) Colonization of the entire Solar System and beyond.
(14) Achievement of individual and social perfection.
(15) Overcrowding of the Solar System and the colonization of the Milky Way Galaxy.
(16) The Sun begins to die and the people remaining in the Solar System's population go to other suns.

The vision charter by Tsiolkovsky for space exploration is amazing in that in the last eight decades except for the last four steps, space scientists have seriously addressed the other steps and achieved success in most of them.

In 1929, Tsiolkovsky wrote “The Space Rocket Trains” in which he proved that multi-stage rockets are required to reach velocity to orbit around Earth. The drawings in the “Album of Space Travels” written in 1932, Tsiolkovsky revealed his brilliant ideas about life in space, including zero gravity, air pressure locking, space habitats, and rocket guidance.

In addition to the subject of space travel, Tsiolkovsky was interested in philosophy and aptly it was the philosophy of space. His main work of this subject was "Ethics or the Natural Foundations of Morality" (1902-1918). In 1932 Tsiolkovsky wrote "The Cosmic Philosophy" to achieve “Universal Happiness”, the happiness not only for the humanity, but also for all the living beings in the Cosmos, for the entire Universe.

Tsiolkovsky wrote over 500 scientific papers. Although he never constructed any rocket himself, he influenced many young Russian engineers and designers. Konstantin E. Tsiolkovsky died in Kaluga at the age of 78 on September 19, 1935. He was buried in the old Kaluga Cemetery, not far from the Museum that honors his life and work. A large crater on the far side of the moon of about 240 km in diameter, first identified by the Russian unmanned spacecraft Luna III (1959), is named after Tsiolkovsky.

Robert Hutchings Goddard (1882-1945)

Robert Hutchings Goddard (Fig. 1. 8) was born at Maple Hill, Worchester, Massachusetts, USA on October 5, 1882 in a family of British ancestry. As a teenage boy, he was greatly inspired by the science fictions of H. G. Wells (1866-1946), an English author and political philosopher. On October 19, 1899, climbing on a tall cherry tree to trim its dead limbs, young Goddard day-dreamt of making some device which had even the possibility of ascending to Mars. When he descended the tree he was a different boy and started to find how to get off the planet earth. The day of cherry-tree dream became Goddard's "Anniversary Day" and he remembered it throughout his lifetime.

Fig. 1. 8. Robert Hutchings Goddard (Courtesy NASA; http://grin.hq.nasa.gov/UTILS/search.cgi): "It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow."

During 1904 to 1908 Goddard studied at the Worchester Polytechnic Institute for his bachelor's degree. Here he conducted experiments on solid rocket motors with steel casings and convergent nozzles. After his bachelor's degree and while working as an instructor in physics at the Institute, Goddard determined that liquid hydrogen and liquid oxygen would be a very efficient propellant-combination. Goddard went to Clark University in 1909 to do his Ph. D. The Ph. D. thesis that he submitted in 1911 was "On the Conduction of Electricity at Contacts of Dissimilar Solids." For the next one year he was at Clark University as an honorary fellow in physics and for the academic year 1912–1913 he was at the Princeton University as a Research Instructor in Physics. In 1912, Goddard explored mathematically the possibility of using rocket propulsion to reach high altitudes and attain escape velocity.

In the year 1913 Goddard took ill with tuberculosis and many including his doctor thought that the illness would kill him. However, Goddard became better after battling it for many months.

After recovering from his illness, Goddard returned to Clark University in 1914 as an Instructor in Physics and rose to the position of full Professor in 1920 and then in 1923 became Professor and Director of the Physical Laboratories there to serve until 1943. In 1914, Goddard was awarded two patents, the first one was on "A Multistage Step Rocket" using solid propellants and the second was on "Liquid Fuel Gun Rocket." Although the second patent mainly concerned with his concept of cartridge rockets, a brief section fully outlined the concept of liquid rocket propulsion. During 1915 and 1916, using a portion of his own pay and the money provided by Clark University, he tested rockets using convergent-divergent or DeLaval nozzles with different types of gunpowders and measured their exhaust velocities. Thus it appears that although Tsiolkovski had sketched his rocket engines with divergent nozzles, Goddard was the first to have adopted convergent-divergent nozzles in working rocket engines.

In 1916, Goddard applied to Smithsonian Institution for a grant to support his rocket research and in January next year, the Institution gave him a grant of 5000$. During 1917-1918, he was working on the construction of various types rocket weaponry; important among them was a small rocket weapon that could be shot from a hand held launcher. By this time the use of double base propellant was found to be better than that of gunpowder. In November 1918, Goddard demonstrated his rockets before the US armed services at the Aberdeen Proving Ground. In this demonstration, to the great disappointment of Goddard, only the shooting of the rocket weapon from a hand held launcher was of interest to them and all the other concepts of rocketry were ruled out to be of any relevance to military applications. However, this hand held rocket launcher, after further development, became quite successful in World War II as the modern bazooka.

In January 1920, Smithsonian Institution published Goddard's closure-report of the project, it funded. "A Method of Reaching Extreme Altitudes" was the title of the report, where Goddard explained mathematically the theory of rocket propulsion and the methods of using rockets to measure atmospheric conditions at altitudes higher than that possible at that time using balloons. This was the concept of the present day meteorological sounding rockets. The report contained the results of other research carried out under the project. Also at the end of the report, Goddard indicated the possibility of a rocket reaching the moon and exploding a load of flash powder there to mark its arrival.

"The possibility of a rocket reaching the moon" caught the attention of many and several newspapers published articles about the report. This resulted in an unfortunate yet historic journalistic-controversy. On January 13, 1920, the New York Times printed an editorial that laughed at Goddard and his assertion that a rocket could produce its thrust in a vacuum beyond the earth's atmosphere. The most pejorative statement in the editorial was: "Professor Goddard, with his 'chair' in Clark College and the countenancing of the Smithsonian Institution, does not know the relation of action to reaction; and of the need to have something better than a vacuum against which to react. Of course, he only seems to lack the knowledge ladled out daily in high schools." In his inimitable style Goddard responded to this editorial and his other critics saying, "Every vision is a joke until the first man accomplishes it; once realized, it becomes commonplace." On July 17, 1969, more than 49 years after its editorial that the rocket fraternity frequently cited and laughed for the impetuous criticism and three days before man's first landing on the moon, the New York Times published "A Correction" stating, "It is now definitely established that a rocket can function in a vacuum as well as in an atmosphere. The Times regrets the error."

It is believed by many that several score of the copies of the Smithsonian report of Goddard and the related newspaper articles reached Europe in the early 1920s and this goaded quite a few European countries, particularly Germany, to enhance their activities of rocket developments.

In June 1924, Goddard married Esther Christine Kisk. Esther was the secretary of Clark University's president. After their marriage, Esther devoted her time in documenting Goddard's rocket research by filming and photographing his experiments.

During 1920 to 1925, Goddard was developing a liquid propellant rocket engine using liquid oxygen and gasoline. In December 1925, he successfully tested on a test bed a small liquid-propellant rocket engine of dry mass of about 5½ kg and pressure of around 6 atmospheres. During the test, the engine could lift itself by about 25mm by its own thrust and Goddard noted in his diary, “This test, being the first in which a liquid propelled rocket had operated satisfactorily and lifted its own weight, is of much significance, for it shows that a larger rocket constructed on the same plan could raise itself to considerable altitudes."

A few months later, on March 16, 1926, Goddard had the momentous first-flight of a liquid-propellant rocket at the farm owned by his distant relative “Aunt” Effie Ward in Auburn, Massachusetts, Fig. 1. 9. The vehicle rose about 12½ meters and traveled a distance of around 56 meters in 2.5 seconds after the lower half of nozzle had burned off. Although his first rocket had the engine above the propellant tanks to keep the “the nozzle above the centre of gravity of the rocket” the flight was not stable and Goddard reverted to having the nozzle at the bottom of his later liquid-rockets.

Fig. 1. 9. Goddard and a liquid oxygen-gasoline rocket in the frame from which it was fired on March 16, 1926, at Auburn, Massachusetts. (Courtesy NASA; http://grin.hq.nasa.gov/UTILS/search.cgi)

In July 1929, at Aunt Effie’s farm in Auburn, Goddard launched the first liquid-rocket with a scientific payload, a camera and a barometer. This attracted a wide public attention. Sensing the danger involved in rocket launches in crowded places the local fire marshal banned further rocket launches in Auburn. However, as a positive result, Charles A. Lindberg, a famous American-aviator, engineer, and writer, became an avid supporter of Goddard's rocket-experiments. Until 1929, Goddard funded his research through his own pay, the support coming from Clark University, and the grants from the Smithsonian Institution and the Carnegie Institution. Evidently, the funds coming from these sources were fairly small. Now, with the recommendation of Lindberg, Goddard could get a relatively liberal funding from the Daniel and Florence Guggenheim Foundation. In the summer of 1930, Goddard shifted his rocket experiments from his Aunt Effie's farm in Auburn to Mescalero Ranch, a 10-acre farm at the edge of Roswell, New Mexico, where "we would not bother anyone and no one would bother us," said Mrs. Goddard. A photograph of Goddard's workshop in Roswell is shown in Fig. 1. 10. Note the most inadequate facilities that existed in Goddard's workshop where many path-breaking achievements could be made.

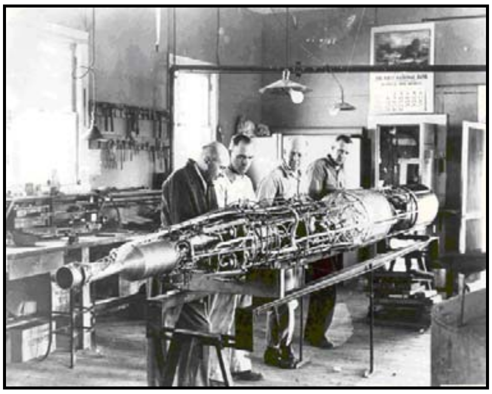

Fig. 1. 10. Goddard examining one of his P-series rocket (turbopump fed liquid oxygen and gasoline engine) in Roswell, New Mexico, in 1940 (Courtesy NASA; http://grin.hq.nasa.gov/UTILS/search.cgi).

For the next twelve years, Goddard, with the support of Guggenheim Foundation and the Smithsonian Institution, achieved many firsts by his rocket experiments in Roswell and elsewhere, and important among them are: film cooling of rocket combustion chamber (1930, Goddard called it "curtain cooling"); gyro stabilization and deflector vanes at the rocket exhaust for control and guidance (1932); liquid propellant rocket attaining supersonic speeds (1935); and turbo pump fed liquid rockets (1938-'41).

In 1936, Smithsonian Institution published Goddard's classic report on "Liquid Propellant Rocket Development," reviewing his liquid-propellant rocket research and flight-testing since 1919. The same year, US Military sent Lt. John Sessums to assess the military value of Goddard's rocket developments. Again to the disappointment of Goddard, Lt. Sessums reported that there was little military value in the rocketry, but combustion gases produced by burning rocket propellants would appear useful to drive turbines. Undeterred by this negative report, Goddard offered in 1940 all his research data, patents, and facilities for use by the armed services at a meeting with US military representatives arranged by his main sponsor, Harry Guggenheim. The result of the meeting was uninspiring except an expression of possible use of liquid rocket engines in jet-assisted take-offs (JATOs) of aircraft.

By the end of 1941, Goddard and his team completed in all 103 static tests of liquid rocket engines and attempted 48 liquid rocket flights of which 31 resulted in flights. With the determination and optimism of an undeterred scientist, Goddard used to refer to the failed rocket-tests as "valuable negative information." From 1942 to 1945, Goddard was the Director of Research at the Naval Engineering Experiment Station at Annapolis, Maryland, where in 1943 he and his team successfully developed and flight-tested a liquid-propellant JATO rocket engine. However, US Navy abandoned this project in 1944. While at Annapolis, Goddard also developed liquid rocket engines with variable thrust capability, which were later successfully used on the Bell X-2 rocket planes during 1955-'56. Apparently due to the ill health of Goddard, the work of Goddard's rocket team came to an end by July 1945. After fighting throat cancer for several months, Robert Goddard died on August 10, 1945, four days after the first atomic bomb was dropped on Japan.

Robert H. Goddard had a rare talent in rocketry in both theoretical and practical engineering-realization. Rocket scientists of his time had known many concepts in rocket propulsion, such as canister launching (Jean Froissart, 1370s), multistaging (Von Schmidlap, 1591), and spin stabilization (William Hale, 1844). However, the eminence of Goddard lies in the engineering realization of rocket hardware involving these old as well as his many new concepts. The dedicated perseverance of this self-effacing scientist went largely unrecognized in the United States during his lifetime. It is reported that when Wernher von Braun and his team of 500 German rocket-experts, who had surrendered to an American private, were brought to America after the World War II and questioned about rocketry, many stared in amazement and asked why American officials did not inquire of Goddard, from whom they had learned virtually all they knew.

Goddard is credited with 214 patents, of which his widow Esther Goddard filed 131 after his death. In 1951 Mrs. Goddard, who worked tirelessly at keeping alive the memory of her husband's pioneering research, and the Guggenheim Foundation, which largely funded Dr. Goddard's research, filed a joint claim against the U.S. government for infringing upon Goddard's patents. In June of 1960 Mrs. Goddard and the Guggenheim Foundation were given a $1,000,000 settlement, at that time the largest patent settlement that the government had ever given.

In memory of Professor Robert H. Goddard, a major space science laboratory, NASA's Goddard Space Flight Center, Greenbelt, Maryland, was established on May 1, 1959. On September 16, 1959, the 86th Congress authorized the issuance of a gold medal in the honor of the brilliant scientist.

Hermann Julius Oberth (1894-1989)

Hermann Julius Oberth (Fig. 1. 11) was born on June 25, 1894 in the city of Hermannstadt in Hungary. Hermannstadt is the old German-name, and the city's present name is Sibiu and it is in the central Romania. When Hermann was two years old, his family moved to Schaessburg where his father, a physician, had been appointed Director of the City Hospital. Like Tsiolkovsky, also Oberth was greatly inspired by the science fictions of Jules Verne. Hermann's mother, who had keen interest in scientific and technical matters, was mainly responsible for kindling the scientific interest in him. She bought the novels of Jules Verne and gave them to the twelve years old Hermann to read. In his science fiction of 1865, "From the Earth to the Moon," Jules Verne had written that spacecraft containing astronauts were shot to the escape velocity using large gun barrels. Hermann at the age of thirteen calculated from fundamentals the escape velocity mentioned by Verne and found it to be correct to his great exhilaration and self-assurance. He went on further to compute the acceleration that the Verne's astronauts would experience — a point not considered by Verne — and found it to be 47000 times the earth's gravitational acceleration. Hermann then concluded that the space travelers would be flattened into pancakes with such acceleration, and hence Verne's space gun was not the solution but rockets should be used to launch the spacecraft.

In his spare time during his school days in Schaessburg, Hermann studied rockets and space flight and came out with the details of a manned spacecraft to be launched by rockets. He noted that solid propellant rocket motors were not suitable for launching space ships but rocket engines using liquid hydrogen and liquid oxygen were to be adopted. Furthermore, he concluded that spacecraft were to be launched by multistage rocket vehicles.

Fig. 1. 11. Hermann Julius Oberth (Courtesy NASA; http://grin.hq.nasa.gov/UTILS/search.cgi): "To make available for life every place where life is possible. To make inhabitable all worlds as yet uninhabitable, and all life purposeful."

After completing his school education in 1912, Hermann went to the University of Munich to study medicine. During the First World War (1914-'18), Hermann Oberth served in the medical corps, mostly in army hospitals in Hungary. Here again, he spent most of his free hours on the study of rockets. At the end of the First World War, a part of Hungary with Schaessburg was given to Romania and hence Oberth became Romanian citizen.

On returning from the World War I assignment, Oberth, in line with his insatiable interest in rockets and space travel, left medicine to study physics and mathematics in Klausenburg, Munich, and Gottingen. Professors in these places considered Oberth's ideas on rockets and space travel to be mostly fantasies. However Oberth consolidated his research findings in a concise manuscript entitled "The Rocket into Interplanetary

Space" (Die Rakete zu den Planetenraumen) and submitted it as a doctoral thesis to the University of Heidelberg. The University rejected the thesis outright, and the examiners criticized and even ridiculed Oberth's work. Professors of physics told him that rockets did not work in empty space, liquid propellants would explode on contact with liquid oxygen, and flight could not be controlled in supersonic speeds. One bright exception in this deluge of negative comments was Professor Ludwig Prandtl, the giant and genius of aerodynamics in Gottingen. He gave Oberth encouragement and praise, and he urged him to continue his work, regardless of the critics.

Against many adversaries, Oberth continued his studies on rockets and space travel. In 1922, with great respect and recognition for Professor Goddard's work and accomplishments in the United States, Oberth wrote to him for a copy of his 1920 book, "A Method of Reaching Extreme Altitudes". Goddard, basically a shy and secretive person, did send him a courtesy copy although not without some apprehension.

When Oberth wanted to publish his doctoral thesis, no publisher was willing to accept it. However, Oberth's wife Mathilde with her indomitable faith in her husband took the task of publishing her husband's work using her personal fund that she had saved over the years from the monthly provisions that she received for household expenses. The book, "The Rocket into Interplanetary Space" was published in 1923. In this book of 87 pages Oberth discussed all the aspects of rocket propulsion (combustion, pump and pressure feed system, and design of propellant-tanks), flight mechanics (air and jet vanes, gyro control, inertial guidance, and aerodynamics), and space travel (life support systems, zero-gravity effects, re-entry, meteorite danger, and radiations in space). Among the uses of rockets and satellites, he mentioned mail service, meteorology, earth observations, astronomy, radio relays, astronautical research, solar and planetary studies, and general space sciences. The book contained for the first time a serious scientific non-fictional treatment of space travel.

Against the backdrop of Goddard's 1920 Smithsonian report and the related newspaper articles that had possibly reached Europe, Oberth's book got the attention of many in Europe and caused much discussion about rocket and space technology. In fact the popularity of the book goaded Russians to look at the reports of Tsiolkovski that were a few decades old and start serious studies on rockets.

In the year 1923, Hermann Oberth became a professor of physics and mathematics at the high school in Schaessburg. Around this time, in their firm belief in open discussions and exchange of information Oberth and Tsiolkovsky exchanged their papers and had a series of very friendly letters. In June 1927 the Society for Space Travel (Verein fuer

Raumschiffahrt or VfR) was formed in Breslau, Germany and Oberth was one of its early members.

In 1928, UFA, a Berlin film studio, requested Oberth to be its technical adviser for its science fiction "The Woman in the Moon" ("Frau im Mond"). The film studio asked Oberth to construct one 2-meter oxygen-gasoline rocket to be launched in 1929 at the movie premiere. Oberth lost sight in his left eye while working on an experiment related to this project. Although the rocket launch was a failure at the premiere, the movie was a box-office hit and created a quite lot of awareness among people on rockets and space travel.

Oberth published in 1929 his second book entitled, "Path to Space Travel" (Wege zur Raumschiffahrt). Even though this book was considered to be an elaboration of his first book, it contained quite a few innovative ideas such as electric propulsion and methods of fabrication in orbits including that of large reflective-mirrors. The book fetched the coveted French REP-Hirsch Prize and gave international recognition to Oberth's scientific contribution in the field of space technology.

In July 1930 Oberth under VfR successfully tested a liquid oxygen gasoline rocket engine of 70 N thrust for a thrusting time of 90 s. The engine used only a convergent nozzle. The development of the 70-N engine was a tremendous step forward in the German rocket development. After this success, Oberth worked for a brief period in Berlin under VfR with a group of enthusiastic assistants. One of these assistants was an 18-year-old student by the name of Wernher von Braun who went on to successfully develop many rocket weaponries for Germany and later became the space age architect of the United States. Because Oberth had to support a large family, he could not continue his work under VfR and had to return to his teaching job in Romania.

By 1930 German Army was looking for a flying weapon that did not contravene the 1919 Treaty of Versailles, a peace settlement signed after the World War I. As per the treaty, Germany was not allowed to have an air force. Therefore it was interested in developing a rocket-force in place of the prohibited air force. In 1932, VfR successfully fired Mirak II rockets fitted with engines of 600-N thrust. Following this, the German Army Ordinance Office formalized its rocket development by placing Captain Walter Dornberger as the officer-in-charge. He in turn enlisted the help of Wernher von Braun. The association of Dornberger and von Braun was historic and led to the successful development of the Vengeance Weapon Number 2 or popularly known as the V-2 bomb.

In Romania, Oberth was teaching and continuing his rocket development work in his free time. Then he moved to Vienna Institute of Technology to initiate a research program on rockets. When the World War

II broke out, Oberth moved to Dresden, Germany. In 1941, after acquiring German citizenship, Oberth joined the group of his once assistant Wernher von Braun in Peenemuende and contributed to the success of V-2 bomb development. At the end of World War II, Oberth moved to a small town near Nuremberg, Feucht, where his family had been living during the war years. For brief periods, Oberth worked in Switzerland (1948) and also in Italy (1950-'53), where he developed a smokeless ammonium nitrate rocket.

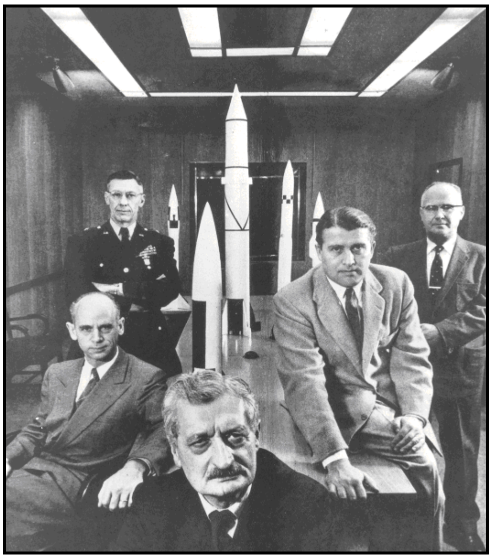

Fig. 1. 12. Hermann Oberth (forefront) at the Army Ballistic Missile Agency at Huntsville, Alabama in 1956. Clockwise starting from Oberth: Dr. Ernst Stuhlinger, an electric-propulsion pioneer (seated); Major General H.N. Toftoy, who took rocket scientists and engineers out of Germany after World War II to design rockets for American military use; Dr. Eberhard Rees, and Dr. Wernher von Braun. [Courtesy NASA; http://grin.hq.nasa.gov/UTILS/search.cgi]

In 1955, Wernher von Braun, now the Director of Rocket Development Operations, invited his mentor to join his team in Huntsville, Alabama, USA. Oberth participated in the team's program on satellite-launch development, Fig. 1. 12. In February 1958 this culminated in the successful launch of Explorer I, the first earth-satellite of the USA. Soon afterwards, Oberth returned to Germany to lead a pensioner life at Feucht, Nuremberg. However, on several occasions he visited USA after 1958. In

1961 for nine months he served as a consultant to Convair in Santiago, USA. Also, he came on invitation to Cape Canaveral in Florida in July 1969 to see the launching of Saturn Apollo 11 rocket with astronauts Neil A. Armstrong, Michael Collins, and Edward E. Aldrin that enabled the first landing of man on moon.

When he advanced in age, Oberth, like Tsiolkovski, became interested in philosophy and wrote many treatises on this subject. Most notable among these is the book entitled "Primer for Those who Would Govern." Hermann Oberth died in Nuremberg on December 28, 1989 at the age of 95.

In appreciation of the contributions of Hermann Oberth, the Hermann Oberth Society founded in 1971 the Hermann Oberth Space Museum in Feucht, Nuremberg. A crater on the moon is named after Oberth.

1. 3. SUMMARY

The practical demonstrations of a technology mostly precede its theory. However, the fast and effective technology-refinement begins only after the theory, explaining the underlying basic principles, is established. The technology of jet propulsion, which includes airbreathing- and rocket-technology, is not an exception to this.

Chinese were the first to develop rockets many centuries before Christ. However, the first recorded use of their rockets as weapons was in 1232 at the battle of Kai-fung-fu against the invading Mongols. The rocket technology, mostly as its application to weapon technology, spread to the entire world in about six centuries.

The modern astronautics and rocketry owes to its development to the pioneering works of three great scientists: Konstantin Eduardovitch Tsiolkovsky of Russia, Robert Hutchings Goddard of the United States of America, and Hermann Oberth of Germany. With undaunted determination and dedicated perseverance, these eminent men worked tirelessly against many odds such as delayed recognition or total disapproval, acute shortage of research funding, rebuke, criticism, and personal ill health. It is amazing that in spite of their different origins, all the three had one view in common, namely, the rocket technology will be more useful to mankind as the tool for space exploration to "colonize the entire solar system and beyond."

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