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Space Exploration – The Contributions of Major Scientists

Konstantin Eduardovitch Tsiolkovsky (1857-1935)

Tsiolkovsky, a mathematics teacher at Borovsk, Kulaga Province, became interested in space flight after reading Jules Verne's "From the Earth to the Moon". At just 16, Tsiolkovsky was struck with an amazing idea: "Why not use centrifugal force to launch a spacecraft from Earth?" Although later, he saw the flaw in this concept, it was this that compelled him to undergo work on the theory of rocket flight.

On March 28th 1883, he demonstrated the very first principles of reaction engines by experimenting with opening a cask full of compressed gas, and from this, he discovered that he was able to control the speed of the cask by alternating the pressure of the gas released. Tsiolkovsky's first draft of a reaction thrust motor was completed on August 25th, 1898.

In his 1903 paper, "*Isslyedovanye mirovykh prostranstv ryeaktivnymi priborami*" ("Investigation of World Spaces with reactive devices"), in the journal *Science Review*, he first presented his concept of liquid-fuel rockets, and the theory of flight of a rocket with changing mass (rocket equation), used to escape the bounds of the Earth.

This equation is: **a = (T – mg)/m**

Where a = acceleration
T = upwards thrust of the rocket
m = mass
g = gravity

This formula shows that the acceleration of a rocket is not uniform, it increases logarithmically as the launch proceeds. (See Fig. 1) This is because a lot of the rocket's mass is fuel, and as fuel is burnt off, mass decreases.

Fig. 1 – Acceleration of a rocket over time (DE Booklet)

This is proved by Newton's Second Law, stating that Force is equal to mass times acceleration (**F = ma**). Force in the equation can be thought of as the thrust of the rocket engine. Mass in the equation is the amount of rocket fuel being burned and converted into gas that expands and then escapes from the rocket. Acceleration is the rate at which the gas escapes. Inside the rocket, the gas does not really move, but as it leaves the engine it picks up speed. So therefore, as thrust (force) increases, and mass decreases due to the fuel being burnt, acceleration must increase, and as thrust is continuous until shut off, the rate of mass reduction will also be continuous and therefore the rate of acceleration will increase logarithmically.

Also during 1903, Tsiolkovsky drafted the first design of the liquid-fuel rockets that he outlined in his paper. It would be powered by liquid oxygen and hydrogen, creating an explosive mixture in the narrow end of a tube. This would then be combusted, creating heated condensed gases, which would quickly cool and rarefy, escaping through a nozzle and creating a great force (thrust) that propels the rocket. Liquid oxygen-hydrogen fuel appealed to Tsiolkovsky because the thermal energy released in its reaction was the highest he knew. He appeared to disregard the problems with liquefied gases and the effect of low temperatures on metal. Tsiolkovsky also speculated using other fuels to replace hydrogen such as acetylene or petroleum, and as he became increasingly aware of the difficulties associated with hydrogen, he moved further away from the idea, and chose other alternatives.

Another of Tsiolkovsky's ideas was that of multi-staged rockets. His design of the "passenger rocket train of 2017" employed 20 single-engine rocket stages, each carrying it's own fuel supply. He stated it would be 300 ft long and 12 ft wide, and built from 3 layers of metal.

A year before his death, Tsiolkovsky submitted a paper which summarised his theories about fuels for rockets. He listed six properties a fuel should have:

- Maximum work per unit mass on combustion
- Gaseous combustion products
- Low combustion temperature to prevent chamber burnout
- High density
- Liquid that readily mixes
- If gaseous, must have high critical temperature and low critical temperature in liquid form.

He also stated that costly compounds should be avoided, and analysed the suitability of different fuels, such as hydrogen-oxygen, methane, benzene, acetylene, ethylene, methanol, ethanol, ether and turpentine. He also considered other oxidisers such as ozone, oxygen, nitrous oxide, nitrogen dioxide and nitrogen tetroxide. He also considered solid-propellant rockets, but dismissed them on the basis of their low-energy and danger of unexpected explosion.

Tsiolkovsky was only a theorist, and he never tested out, or physically proved his ideas, but his ideas inspired many others, one of which was Russian Chief Controller Sergi Korolev during the Space race years of 1950 – 1960, who formed a group that studied the fundamentals of rocket science. He later lead the USSR to put the first artificial satellite into space (*Sputnik*) and living creatures into orbit (Laika the dog), as well as the first man in space, Uri Gagarin.

Robert Hutchings Goddard (1882 – 1945)

Goddard was inspired by Jules Verne's "From the Earth to the Moon" and "War of the Worlds," by HG Wells, at an early age. While a student at South High School in Worcester, in 1902, he submitted an article speculating on possibility of rocketry and space travel called "The Navigation of Space".

Goddard first obtained public notice in 1907 in a cloud of smoke from a powder rocket fired in the basement of the physics building in Worcester Polytechnic Institute, where he graduated from in 1908.
He received a doctorate of Physics at Clark University in 1909, and, during his studies there, began to make detailed calculations regarding liquid-fuelled rocket engines, theorizing that liquid oxygen – liquid hydrogen would make an ideal propellant. In 1913, Goddard compared the explosive fuel, guncotton, to liquid hydrogen-oxygen, pointing out the difficulties incurred with keeping oxygen solid, and hydrogen liquid for the sake of lightness. He recognised a practicality problem with obtaining and working with the liquefied gases, and stated guncotton, while having less energy, would be more practical.

In 1914, Goddard received two U.S. patents. One was for a rocket using liquid fuel. The other was for a two or three stage rocket using solid fuel. He also patented many of his other designs such as combustion chambers, exhaust nozzles and propellant feed systems. He began to make systematic studies about propulsion provided by various types of gunpowder. He wrote a document in 1916 requesting funds of the Smithsonian Institution so that he could continue his research, entitled "A Method of Reaching Extreme Altitudes." In this paper, he detailed his search for methods of raising weather-recording instruments higher than sounding balloons. In this search he developed the mathematical theories of rocket propulsion - he proved that a rocket could fly in a vacuum, due to Newton's law of action and reaction.

This meant, that as every action, had a reaction, the forced on the rocket had to equal the negative force on the gases. ($\mathbf{F_{rocket} = -F_{gases}}$). Even though the forces are equal and opposite, the rocket only experiences the thrust force from the gases. (See fig. 2).

Fig 2. Forces Pairs influencing a rocket after lift-off (DE Booklet)

This forward momentum can be explained by the Law of Conservation of Momentum. As the states that during any interaction in a closed system the total momentum of the system remains the same, then the increase in forward thrust momentum must equal and oppose the increase in momentum of the exhaust gases, in one period of time (e.g. 1 sec). The equation that represents this is as follows:

Total p for a closed system = 0

$$p_{rocket} = - \quad p_{gases}$$

$$(mv)_{rocket} = - \quad (mv)_{gases} \quad \text{since } p = mv$$

Where:

 p = change in momentum

m = mass in kg

v = velocity in ms

Also in 1915-1916, Goddard conducted a series of unsuccessful experiments, trying to fire solid propellant rockets, activating them with a succession of charges, much like machine guns, which not only turned out to be too difficult, but very heavy as well. Goddard then went back theorizing about liquid hydrogen-solid oxygen mixtures, pointing out that they had greater capability than smokeless powder. He suggested that the liquid hydrogen-solid oxygen mixture could be encased within a smokeless powder capsule. However, this was not tested.

Towards the end of his 1920 report, Goddard outlined the possibility of a rocket reaching the moon and exploding a load of flash powder there to mark its arrival.

Ellie Lugsdin

Goddard's work largely anticipated in technical detail the later German V-2 missiles, including gyroscopic control, steering by vanes in the jet stream of the rocket motor, gimbalsteering, power-driven fuel pumps and other devices.
In 1922, he experimented with ether and oxygen in continuous combustion, rather than his earlier interest, hydrogen-oxygen, mainly due to the difficulties with obtaining, handling and price of liquid oxygen and hydrogen. He then went on to work on other problems such as building and flying a complete rocket vehicle into space.

His rocket flight in 1929 carried the first scientific payload, a barometer, and a camera. Goddard also developed and demonstrated the basic idea of the "bazooka". In World War II, Goddard offered his services and was assigned by the U.S. Navy to the development of practical jet assisted takeoff and liquid propellant rocket motors capable of variable thrust.

Goddard was the first scientist who not only realized the potential of missiles and space flight but also contributed directly in bringing them to practical realization.

Wernher Von Braun (1912 – 1977)

Von Braun was also inspired by reading the science fiction of Jules Verne and H.G. Wells, and from the science fact writings of Hermann Oberth, whose 1923 classic study, "By Rocket to Space", compelled Von Braun to master calculus and trigonometry so he could understand the physics of rocketry.

After graduation from Gymnasium (high school), he entered Berlin Institute of Technology in 1930, where he began his early experiments with testing of liquid-fueled rocket engines under the direction of Professor Hermann Oberth, and later under the sponsorship of the German Society for Space Travel.

In 1929, Von Braun became involved in the German rocket society, Verein fur Raumschiffarht. In 1932, he went to work for the German army to develop ballistic missiles, as a means of furthering his desire to build large and capable rockets. While working in this field, Von Braun received a Ph.D. in aerospace engineering. Throughout the 1930s, he continued to develop rockets for the German army.

Wernher Von Braun's rocket team developed the V-2 rocket, operating at a secret laboratory at Peenemunde on the Baltic coast. This rocket was the immediate model that rockets used in space exploration programs in the United States and the Soviet Union are based on.
The V-2 was first flown in October 1942, it was employed against targets in Europe beginning in September 1944. On the sixth, for instance, more than 6,000 Germans deployed to Holland and northern Germany to bomb Belgium, France, and London with two newly developed V-2s.

By the beginning of 1945, it was obvious to Von Braun that Germany would not achieve victory against the Allies, and he began planning for the postwar era. Before the Allied capture of the V-2 rocket complex, Von Braun engineered the surrender of 500 of his top rocket scientists, along with plans and test vehicles, to the Americans.

For fifteen years after World War II, Von Braun would work with the United States army in the development of ballistic missiles. As part of a military operation called Project Paperclip, he and his rocket team were scooped up from defeated Germany and sent to America where they were installed at Fort Bliss, Texas.

The world's most powerful rockets at the time were developed at the Huntsville facility under Von Braun's guidance. He was directly involved in the continuing American space exploration efforts, including the development of the Saturn 1 and the Saturn V boosters, the Gemini managed-flight project, and the Apollo Moon Flight project.

Accordingly, Von Braun became director of NASA's Marshall Space Flight Center and the chief architect of the Saturn V launch vehicle, the superbooster that would propel Americans to the Moon. Von Braun also became one of the most prominent spokesmen of space exploration in the United States during the 1950s. In 1970, NASA leadership asked Von Braun to move to Washington, DC, to head up the strategic planning effort for the agency.

Current Research in Space Exploration

The developments of technologies that advance fields such as space exploration are ongoing and rapid. In particular, NASA in America, is researching many different aspects of space exploration, including:

- <u>Rocket propulsion engines</u> such as the Variable-Specific-Impulse Magnetoplasma Rocket (VASIMR), a high-power, electric, thermal plasma engine, employing hydrogen propellant and continuous thrust to achieve high-speed during long space missions. It has possibilities as an orbital transfer rocket and an interplanetary booster for robotic or manned payloads. It contains 3 magnetic cells, the forwards cell is where the hydrogen is injected and ionized into plasma, the central cell heats plasma with radio-frequency excitation and acceleration through magnetic fields, and the aft cell is a magnetic nozzle that converts thermal energy of the plasma in a directed flow, while protecting nozzle walls. The total system is a low-mass engine that achieves high-vehicle speeds through continuous thrust.
- Solar wind particle collection and research by Genesis, which has a special collector array launched to catch solar particles from the solar wind, and take them back to Earth for research after 2 years.
- Observations by various satellites, including observation of Jupiter’s moon Io, by Galileo, and of Venus, by the Chandra X-ray observatory.
- Chemical analysis of other planet’s atmosphere by the Hubble Space Telescope

Ellie Lugsdin

- Detection and research of gravitational waves by the Cassini spacecraft.
- Construction of the first comet orbiter, Rosetta, for research on how gases escape from the nucleus of a comet
- Research into the effects of weightlessness on the Human Skeletal system

Timeline

13th C	Chinese fire-arrows were the first simple solid-fuel rockets. (Tubes of gunpowder, sealed at the top end and attached to a long stick) When the gunpowder was ignited, it burned rapidly to produce flame, smoke and – most importantly – gases that escaped from the rear of the tube and created the thrust that pushed the rocket forward. The stick kept the rocket going in the right direction. First use of rockets as weapons in Europe.
1650	Johann Schmidlap, a German fireworks maker, invented a multi-stage ‘step rocket’ to create more spectacular displays. A large first-stage rocket carried a smaller second-stage rocket aloft. When the first-stage burned out, the second-stage carried on up and threw out glowing cinders.
1686	Isaac Newton publishes his three laws of motion, which explain - among many other things - how rocket propulsion works.
18th C	Scientists in Russia and Germany experiment with rockets with masses of 40 kilograms or more.
1903	Russian schoolteacher Konstantin Tsiolkovsky realises that liquid propellants would give rockets the speed and range they would need to escape the Earth’s atmosphere and into space, & develops rocket equation.
1926	The first successful flight of liquid-propellant rocket designed by the American Robert Goddard and fuelled by petroleum and liquid oxygen, made a 2.5 second flight, landing just 50 metres from the launch site.
1931	Sergei Pavlovich Korolev forms a Moscow group for the investigation of jet propulsion.
1932	Germany takes on Werner Von Braun to develop rocket-powered weapons.
1942	The first A4 rocket, known later as the V2, is launched by Von Braun, and rose only about 100 metres, then crashed into the sea, just over a

Ellie Lugsdin

	kilometre from the launch site.
1942	At their third attempt at launching an A4, Von Braun's team was successful, as the alcohol/liquid oxygen propellant carried the A4 200km to strike the selected target.
1945	Sergei Korolev witnesses US-sanctioned test launches of V2 rockets in liberated Europe, and signaled the starting point for the Soviet Space Program, culminating in the first man in space and the first manned space station.
1946	Werner Von Braun's rocket team relocates to the US to work on new US Space Program. The first V2 is launched in the United States.
1948	The launch of the first Soviet R-1 rocket, based on V2 design.
1949	The first entirely Soviet-designed rocket, R-2E, is launched. First launch of US Viking rocket.
1950	First launch of Bumper, a two-stage US designed rocket combining a V2-type first-stage and a WAC Corporal second-stage.
1957	The USSR launches Sputnik 1, the first artificial satellite to orbit the Earth. Laika, a Soviet dog, becomes first living creature to orbit the Earth.
1958	America's first satellite is launched into orbit. A Jupiter-Redstone rocket, essentially a highly refined development of the V2, launches Explorer I - America's first orbiting satellite. America launches the first unmanned lunar probe. The launch vehicle is an Atlas first-stage with an Able second-stage. Unfortunately it fails 45 seconds after lift-off when part of the structure tears away.
1959	Soviets launch Luna 1, which flies past the Moon in January
1961	Uri Gagarin becomes the first man to orbit Earth, and is in space for 108 minutes. The first American, Alan Shepard, makes a short sub-orbital flight into space, returning immediately to Earth. Russia starts development of the Proton launcher, which remains in use today.
1962	An Atlas rocket launches the first American into orbit. Mariner 2 is the first space probe to fly past another planet - Venus.
1963	A Russian, Valentina Tereshkova, becomes the first woman in space.
1965	The first manned Gemini flight. A Titan II rocket powers Virgil Grissom and John Young into space to make three orbits of the earth - the first of a long series of flights which paved the way for the Apollo Moon program.
1967	The Soviets assemble the first N1 rocket using NK-15 engines, and was the first successful closed-cycle rocket engine, developing an

	extra 25 percent lifting power by channeling the exhaust products from the pre-burner into the combustion chamber to be re-fired.
1968	The launch of Apollo 7, which orbits the earth for 11 days.
1969	The first test flight of unmanned N1 rocket, which explodes 40 kilometres from the launch site. A second unsuccessful launch takes place in July. Apollo 11 blasts off carrying the first humans to land on the surface of the Moon and Neil Armstrong and Buzz Aldrin become the first men on the Moon.
1970	A Long March rocket launches Mao1, China's first space satellite
1971	The third and fourth N1 rockets both explode in mid-air
1972	The launch of Pioneer 10, destination Jupiter
1973	A new NK33 engine introduced for N1 rocket, which is the most powerful liquid oxygen/kerosene engine ever built. The Saturn V booster launches Skylab 1 into orbit
1974	The Soviet Politburo abandons the N1 program and order rockets to be dismantled.
1975	Viking 1 makes the first trip to Mars.
1977	Voyagers 1 and 2 set off to explore the outer regions of the solar system.
1981	The first launch of the US Space Shuttle.
1987	Russia's Energia rocket is launched.
1988	A Long March 4 rocket launches a Chinese weather satellite into orbit. China also launches a new Weaver Girl 1 rocket.
1993	The first of Atlas Centaur rockets' series of 46 successful missions. US rocket scientists are taken to see stored NK33s, and find 60 pristine engines, of a compact design that they had never seen before. What surprised them most was that the engines used the closed-cycle technology that had been rejected by American rocket scientists as being too risky.
1995	The first static test firing in the USA of a Russian-built NK33 engine.
1999	The latest version of China's Long March rocket launches an unmanned prototype of a re-useable capsule which has been designed to carry humans into orbit in 21st century.
2000	An American Atlas rocket equipped with a single Russian RD180 rocket engine successfully blasts off from Cape Canaveral. The RD180 is the latest development in closed-loop rocket technology. It is so powerful that a single engine replaces five of the US-designed engines used for previous Atlas rocket launches.
2001	Atlas V, a new family of US rockets incorporating the Russian RD180 engine developed.

Ellie Lugsdin

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NOTE: Some of the material was given to me by a student who finished her HSC this year, and their source is not stated on the articles.