Rocket: A Ticket to Space

Ananda S

Space Books Series for Children
U R Rao Satellite Centre
Bengaluru-560017

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Chairman's Message

Scientific literature for children is an essential and distinctive literary work. It is to observe all the happenings around us from a scientific point of view and explain it in simple words. This endeavour can make a high school student understand complex subjects like astronomy, satellite and rocket technology, which is highly appreciable.

In this regard, U R Rao Satellite Centre, a prestigious research Institute in Bengaluru, has launched a new program called "Space Books Series for Children". Through this effort, it plans to bring out pocket-books on "Space Technology, Space Science and Space Scientists". This book, which is now in your hands, is one such work. This work is a significant step toward enriching science literature for children.

Explaining various scientific and technical topics in simple language is necessary to inculcate interest in science among children. Similarly, it is essential to explain the scientific achievements of our organization to the masses and create awareness about it. The "Space Books Series for Children" programme will fulfil these requirements.

I congratulate the Director of U R Rao Satellite Centre for conceiving and implementing this programme. I hope more topics will be covered and reach more children and commoners in the coming days.

S. Somanath

Chairman, ISRO

Director's Message

Satellite, space science, technology and related topics should be explained in simple language so everyone can easily understand them. Such a literary effort will provide essential and authentic information, especially to the young talents of rural areas. Thus, it is a significant step in providing them with better opportunities and building a great future.

This work should be done by the skilled and experienced scientists of U R Rao Satellite Centre who have been working in this field of technology for five decades. To educate children about space science and technology, U R Rao Satellite Centre is bringing out the "Space Books Series for Children".

Our enthusiastic colleagues have written books on these topics in response to this idea. It is a pleasure to put seven pocket-books of this series in your hands today. I congratulate the authors for their efforts and wish the program success. I want the students to develop interest and curiosity in these subjects. I also hope they understand the principles, get inspiration and create a better future, thereby contributing to the country's and society's overall development. I am confident that our objective will be realized and the desired result will be achieved.

M Sankaran

Director

U R Rao Satellite Centre

Editorial Board

Space Books Series for Children

Dear Children,

U R Rao Satellite Centre (URSC) celebrated its Golden Jubilee in 2022. On this occasion, the Karnataka Rajyothsava Committee of URSC had taken up the task of publishing a series of Kannada books on Space and Space Scientists, which have been translated into English for the benefit of students across the country.

Our committee plans to publish pocket-books in simple language to make school children easily understand many topics like space science, rocket and satellite technology, etc. The scientists of our organization have written these books. Seven books are published as the first set of books in this series. We aim to provide children with an electronic version of the books through our website.

Our committee is grateful to Shri M Sankaran, Director, URSC, who is the key person behind the successful realization of these books. Our heartfelt thanks to Shri H N Suresh Kumar, Shri K V Govinda, Dr. M Ravindra, Smt. Lalitha Abraham, Smt. Anuradha S Prakasha and Smt. Sreedevi S, for having reviewed all seven books in detail and suggested suitable modifications.

We are grateful to all the authors who took time off from their work and authored the books. We are thankful to all colleagues of our Centre who helped us to bring out these books.

If you read them and give your suggestions and comments, we will be able to incorporate the same in the next set of books in this series.

Ramanagouda V Nadagouda

President

From Author's Desk

U R Rao Satellite Centre, ISRO is making efforts to publish a series of books on space technology through "Space Books Series for Children" series. This book aims at introducing rockets to young minds.

Come Deepavali, the festival of lights, we remember the cracker rockets which rush into the night sky. Some of you may have witnessed the rockets blast off into the sky carrying spacecrafts. What are these rockets? How do they work? What technologies are involved? Which are the present rockets going to space? Where does India stand in this arena? - These and many more questions are answered in this book.

My efforts are always encouraged by my mother, Smt. Rama and my father, Late Srinivasa Murthy. My wonderful wife, Veena, and my ever-curious son Pranav Bharadwaj constantly support my endeavors.

My earlier work on rockets with my co-authors Sri Sreenivasa Prasad and Smt Uma

has directly influenced this book. I am thankful to them.

I express my gratitude to Sri M Sankaran, the Director of U R Rao Satellite Centre.

I am indebted to the editorial committee headed by Sri Ramanagouda V Nadagouda, my seniors, Sri K V Govinda and Dr. M Ravindra, and my colleagues.

I thank Smt Sreedevi S, Smt Anuradha Prakasha, and Smt Lalitha Abraham for keenly reviewing the English version of my book.

- **Ananda S**

Contents

1. Introduction

We all like the light and sound show of crackers in the night sky during Deepavali. We get thrilled watching a rocket launch by ISRO on TV. The rockets have ushered in the space age by taking spacecrafts and humans beyond atmospheric limits. This book tries to glimpse some of the aspects of rockets.

1.1 Long Ago

The human race imagined visits to the realms of space long ago. In the Hindu epic "Ramayana", the toddler Hanuman becomes hungry while playing. Looking at the evening sun and thinking it must be a big orange, he leaps into the sky to catch it. He reaches very close, gets sun-stroked, and falls back to the Earth, and the story continues. The story of Icarus going toward the sun is equally well-known in Greek mythology.

The Chinese were famous for using the mixtures of Salt Peter, Coal, Sulphur, and Realgar for making crackers by the first century AD. The first historical account of the use of rockets in wars dates back to 1232. In the China-Mongol war of “Kai-Keng”, such rockets were used by the Chinese.

In Europe, Jean Froissart of France experimented with “Bazooka” rockets. An Italian scientist, Joanes de Fantana, designed rocket-powered torpedoes. In 1449, Joan of Arc used these torpedoes in the Battle of Orleans. In 1696, Robert Anderson of England published an article on solid fuel-driven rockets (“Solid Rockets” in short).

Indian history witnessed the rise of Haider Ali and Tipu Sultan in Mysore. Both war experts emphasized the use of rockets. Haider Ali used them in the 1781 war against the British. Tipu Sultan used improved rockets in the 1792 and 1799 Mysore wars to a great deal (Fig.1). Brits were impressed with Tipu's rockets and ferried back a few to their homeland after their victory. William Congreve studied them, adapted the techniques in his missiles and employed them during European wars.

Figure 1: Tipu's rockets during 2nd Mysore war

2. Rocket Science

Let us understand what makes a rocket fly. Modern rocketry is highly influenced by the Laws of Motion propounded by Sir Isaac Newton (Fig.2.1). He published them in his seminal work in “Principia Mathematica”. Newton’s third law of motion states that action has an equal reaction and is in the opposite direction. Newton’s second and third laws of motion are clubbed together: “When two bodies act on each other, they experience acceleration in the opposite direction, and the ratio of accelerations remain constant”.

The rocket gets propelled forward in reaction to the hot gases propelled out of it. For example, a rocket weighing 100 kg will move at 1 km/s if 1 kg of hot gas is expelled at 100 km/s. In summary, the rocket and the expelled gas accelerate in opposite directions, following the laws of motion.

Tsiolkovsky of Russia gave Newton's laws a practical form: the rocket (Figure 2.2). Tsiolkovsky is called the "Father of Rocket Theory". In 1903, he proposed the rocket equation and the method of rocket flight: "Combine two combustible materials in one section of a long metal tube to produce an instantaneous burst of air. This hot air would be ejected from the bell-shaped nozzle, and the body would fly like a rocket."

Tipu's rockets in Nagara

In 2002, rusted tubes were unearthed from a well in Nagara fort in Shivamogga district. By 2013, it became clear that the tubes were part of rockets used by Tipu Sultan. Later, more than 3000 rockets have been found. It is conclusively derived that apart from Srirangapattana, other places like Nagara housed the rocket manufacturing workshops.

Rocket Equation

The rocket equation includes the natural logarithm, a field of advanced mathematics. A rocket accelerates by ejecting gas from its nozzle and loses weight. In a rocket these two actions are complementary which helps in attaining high speed.

$$\Delta v = v_e \times \ln (m_0 / m_1)$$

where, Δv = Change in speed

v_e = Exhaust velocity

m_0 = Initial mass

m_1 = Final mass

$\ln$ = Natural Logarithm

3. Real Technology

Now let us learn about the technology required to realize the rocket. In America, Robert Hutchings Goddard (Figure 2.3) was the first to engage in rocketry experiments using solid fuel (also known as solid rockets). In 1915 he concluded that rockets using liquid fuel (also known as liquid rockets) are better for carrying heavier loads to higher altitudes. In 1919 he published his research paper on the best methods for reaching great heights. This essay alone is enough to identify Goddard as the “Father of modern rocketry”.

At the same time, liquid rocket-related experiments were being conducted by Werner von Braun in Germany. He was under the guidance of Hermann Oberth, affiliated with VFR (meaning Space Flight Society).

A solid rocket contains a mixture of solid fuel and oxidants (propellants). This mixture is glued to the wall of the rocket, and a hole exists in the middle. This mixture is ignited with the help of an igniter to start combustion. Combustion produces hot gas. This gas is expelled from the exhaust nozzle. The resulting kinetic force or thrust causes the rocket to move forward.

In solid rockets, velocity can be predetermined by designing different propellent pellet shapes. For example, if the solid propellent burns over more surface area as time passes, it will increase the speed.

Caution: Solid propellent is like an arrow released from a bow. Once ignited, it cannot be doused.

A liquid rocket has two storage tanks: one for the fuel and the other for the oxidant. These reach the combustion chamber in a controlled manner with the help of valves. The ratio of fuel and oxidant reaching the combustion chamber could be controlled to vary the speed of the rockets or even stop the combustion process before the liquid propellants are entirely used up.

Solid and liquid rockets use different types of fuels and technologies. Their uses differ. A comparison between these rockets is summarised in Table 1.

Table 1: Comparison of solid and liquid rockets

No	Description	Solid rocket	Liquid rocket
1	Fuel	Solid	Liquid
2	Valve	Absent	Present
3	Speed control	Predetermined	Can be varied in Real-time
4	Shape of fuel	As designed	none
5	Stopping combustion when commanded	No	Yes
6	Application	Rocket	Rocket, Spacecraft

A rocket is built with multiple stages. In one stage, once the fuel is exhausted, the engine, storage tanks, and combustor are useless. By removing these and reducing the rocket's weight, the remaining stages can proceed smoothly with greater efficiency. The small parts attached to each stage are called retro rockets. The retrorockets are fired to move the separated stage in the opposite direction to avoid colliding with the upper stage. This multi-stage design is one of the main reasons for increasing the efficiency of the rocket and helping realize the space dream faster.

In addition to the rocket's propellent system, various electronic systems help rockets reach their desired position in space. For example, there are control, guidance, and navigation systems to achieve correct speed and direction. Gyroscopes, which measure direction, are a part of this system. There are controllers which open and close the rocket's valves to change the nozzles' direction and control the speed. In addition, there are speed boosters, hardware actuated by explosives for stage separation, a telemetry system that monitors the rocket's health, a telecommand system that sends orders from the ground control station, batteries that provide electricity for all these electronic systems and so on.

At the beginning of the launch, the direction of the rocket may vary, and there are chances of failure. In that case, the rocket can crash into the Earth and cause casualties. To avoid such an eventuality, the explosive system in the rocket is provided. It alleviates such a scenario by self-destructing the rocket in its path on command from the ground station.

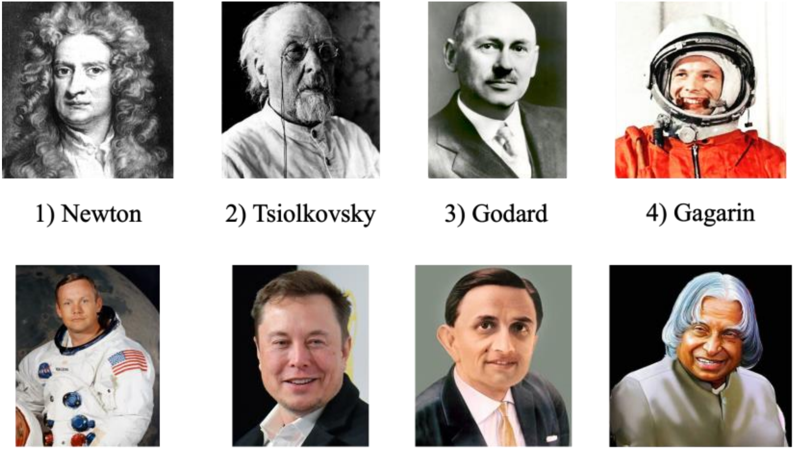

Figure 2: Rocket Pioneers

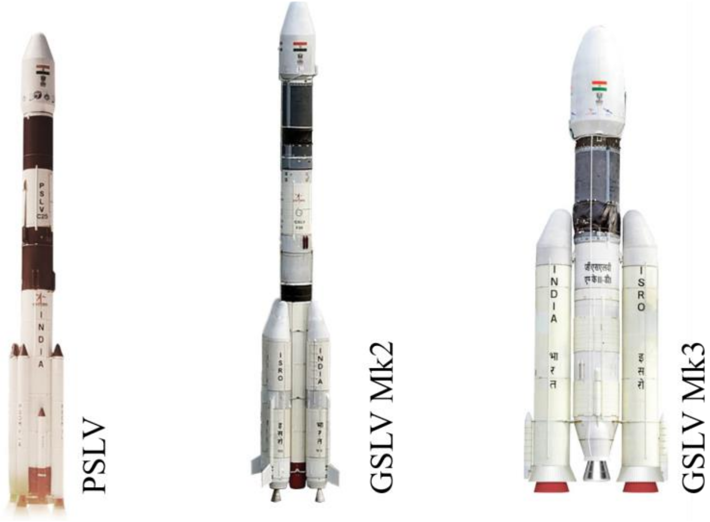

Figure 3: ISRO rockets

4. Rockets: past and present

There are many rockets in the world capable of launching a spacecraft. Let us look at the most important ones, historically and in the present.

On October 4, 1957, the first rocket R-7, was launched. It put Sputnik-1, an 84 kg satellite, into low Earth orbit, ushering in the space age. This rocket had two stages. The four strap-on boosters in the first stage and the core engine in the second stage used liquid oxygen and RP-1 fuel. The total weight of this rocket was 267 tons, and its height was 30 m. The weight that can be delivered to space (called payload capacity) was 500 kg. It was very similar to the R-7 Semyorka, an intercontinental ballistic missile.

Later, the United States achieved its first success by launching a satellite called Explorer-1 in 1958 using a Jupiter-C rocket. The leaders of this program were William

Pickering (Jet Propulsion Laboratory), James Van Allen (University of Iowa) and Werner von Braun (Army Ballistic Missile Agency), who was originally from Germany.

Post that, Russia became the first country to send humans into space and bring them back. On April 12, 1961, Yuri Gagarin (Fig-2.4) made this journey. Vostok-1 was the rocket he used. It used space-grade kerosene and oxygen as fuel. On May 3 of the same year, Alan Shepherd became “America’s first astronaut” after flying aboard Freedom-1 spacecraft carried by Redstone rocket.

Moon was the next step in the space race between the two superpowers. America succeeded in landing men on the Moon. Neil Armstrong (Figure 2.5) and Buzz Aldrin walked on the Moon for the first time on July 24, 1969. Remember what Neil Armstrong said while ascending on the Moon, “One small step for a man, one giant leap for mankind". The rocket responsible for this achievement was Saturn V. Its height was about 111 m., weight was 3,039 tons.

Saturn-V was a 3-stage rocket. It had (1) an instrument module, (2) a moon module for landing on the Moon, (3) a service module to carry the moon module and bring the astronauts back to Apollo, (4) the Apollo Command Module to return to Earth and (5) the Launch Escape System to rescue the astronauts in case of emergency. The Moon Module portion landed both astronauts on the Moon and brought them back to the Service Module. Michael Collins was a co-passenger with the astronauts above in the Apollo command module that later returned to the Earth.

Some prominent rockets are Space Shuttle, Ariane, Delta, Falcon, Soyuz, Proton, Long March, and H-5. ISRO has developed three mighty rockets in its tenure: PSLV, GSLV-Mark II, and GSLV-Mark III (See Figure 3). Let us find out about their present status.

4.1 Space Shuttle

America’s unique reusable rocket, the Space Shuttle, was a part of the Space Transportation System (STS). It was a vehicle that could carry people and satellites into space and return to Earth. The large solid fuel tank and booster parts could only be used once. The shuttle portion is like an aircraft. It would deliver the satellite to its destination and return to Earth after completing the mission with or without the crew (Figure 4). The 5 number of space shuttles saw a total of about 135 flights. They were retired in 2011 due to two major disasters and the high cost of maintaining the remaining shuttles.

Features of Space Shuttle

- Space shuttles and launch dates:
  Challenger (1983 – accident in 1986),
  Colombia (1981 – accident in 2003),
  Discovery (1984 – Retired in 2011),
  Atlantis (1985 – retired in 2011),
  Endeavor (1992 – retired in 2011).
- The first experimental prototype was "Enterprise". It was retired in 1977 after five launches.
- Kalpana Chawla and Colombia: Indian-born astronaut Kalpana Chawla was involved in the successful 1997 expedition. In 2003, she died in the accident of Columbia space shuttle while returning to earth.

Spacecrafts Launched by Space Shuttle

Space Lab, Hubble Telescope, Mir's Docking Module, Galileo, Magellan, Crompton Gamma Ray Observatory, Chandra X-Ray Observatory. parts of the ISS etc.

4.2 Delta

Delta is another rocket built by the USA. The first rocket of the Delta series was launched in 1960. Delta series has completed 300 launches to date with 95% success. India’s INSAT-1D satellite was launched by a Delta rocket on June 12, 1990. The Delta-4 version is currently in use.

4.3 Falcon

Falcon rockets are built by an American private company called SpaceX. The CEO of this organization is Elon Musk (Figure 2.6). SpaceX was initially funded by NASA, Défense Research Projects Agency (DRPA), US Air Force and private investors. The agency has built three series of rockets: Falcon-1, Falcon-5 and Falcon-9. Among these, Falcon-9 is the most powerful.

Falcon-9 can place satellites weighing about 26,610 kg into polar satellite orbit or up to 15,010 kg into geostationary orbit. What is extraordinary is that the stages of this series of rockets are completely reusable!

4.4 Soyuz

Russia has launched the greatest number of satellites in the world. Soyuz is the most important of the rockets built by Russia. The Soyuz rocket has three main stages. All three stages use liquid fuel. The Soyuz series has delivered the most satellites (~ 1900) into orbit. It also has the distinction of being the first to carry a space traveller to the space station. This achievement made space travel accessible to the untrained but wealthy who could afford it.

Main reasons for failure of rockets

- Low efficiency of stages
- Non-opening of valves
- Software errors
- Failure of pumps
- Mishaps during flight, etc

4.5 Proton

Proton is also a Russian-made rocket. Its launches so far have been more successful than any other rocket. It has successfully deployed all types of spacecrafts into various kinds of Earth orbits (for example, pole-to-pole elliptical Molniya orbit, the geostationary orbit, and near-Earth orbit) and interplanetary orbits. The advancement of technology will discontinue the Proton series. Advanced rockets of the Angara type will be launched soon.

4.6 Ariane

Ariane rockets are developed by the European Space Agency (ESA). The First Ariane rocket was launched in December 1979. Since then, about 250 rockets of the Ariane series have delivered several spacecrafts into orbit. Ariane series is the most successful launch system in terms of profit margin. Ariane is also a robust and reliable system. Ariane-5, the current version of this series, has two main stages. It can directly insert a satellite weighing up to 7,400 kg into geostationary orbit.

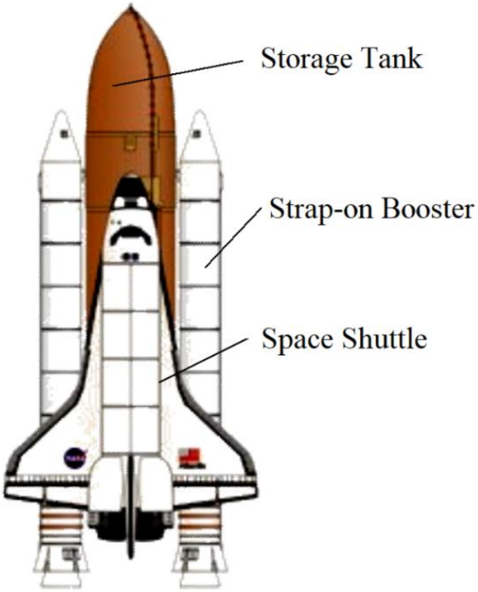

Figure 4: Space Transportation System with Space Shuttle

4.7 Long March

Long March is China’s rocket. The First Long March rocket was launched in 1970. The latest Long March-8 rockets have solid and liquid fuel stages. Some of these stages are reusable. China has mastered many technologies required for human spaceflight and spacecraft launch.

4.8 H rocket series

Japan manufactures the H series of rockets. They have put more than a hundred spacecrafts into orbit so far. These include stages using solid and liquid fuels. The H-2A rocket series has seen nearly 60 successful launches. They can deliver spacecrafts weighing 15 tonnes to near-Earth orbit and 6 tonnes to geostationary transfer orbit.

A cost-effective and advanced version called the “Epsilon” rocket is currently under development. It uses solid fuel. It can deliver satellites weighing up to 590 kg into near-Earth orbit.

5. India in space

Vikram A Sarabhai (Figure 2.7) was the first to realize the importance of space technology in India. He is the chief architect of the space program for India. He is called the father of Indian space technology. ‘Rohini 75’, built under his leadership, was India’s first rocket. It was launched in 1967 from the Kerala launch site ‘Thumba’. The number ‘75’ represents the diameter of the rocket in millimeters.

Enthused by its success, scientists launched the ‘Centura’ rocket in 1971 to measure atmospheric parameters. Later, a series of Rohini, Nike Apache, Petrol, Skua, and Centaur rockets were launched from here. RH series of sounding rockets are still being launched.

The Indian Space Research Organization’s (ISRO) campaign began with sounding rockets that probe the atmosphere. ISRO developed the Satish

Dhawan launch site in Sriharikota to launch spacecrafts aboard its own rockets. SLV-3 was India’s first rocket to launch a satellite into orbit. This achievement was spearheaded by APJ Abdul Kalam (Figure 2.8). He was awarded the Bharat Ratna in 1997. He went on to become the President of India. He breathed his last in Shillong in 2015 while delivering a lecture. His acumen, simplicity and connection with society make him the most loved scientist even today.

ISRO has made the country proud with ASLV, PSLV and GSLV rockets. It has designed and developed several remote sensing, communication, and scientific spacecrafts. Let us know about the current PSLV and GSLV rockets.

5.1 PSLV

PSLV is said to be the workhorse of ISRO and is considered the most reliable rocket (Figure 3). PSLV stands for Polar Satellite Launch Vehicle. The series has seen nearly

50 successful launches till 2023. It has four stages. The first and third stages use solid fuel. The remaining stages use liquid fuel. The number of stages, design and fuel choices are determined by the rocket's trajectory, the distance to be covered and the satellite's weight.

Typically, the PSLV has six strap-on boosters. It has the thrust to deliver a 1.4-tonne satellite into an elliptical orbit for geostationary transfer or a 1.7-tonne satellite into a near-Earth orbit. The height of this rocket is 44 m, its diameter is 3.4 m., and its launch weight is 250-330 tons. The total flight time of the rocket is about 20 minutes.

The height of the orbit in which the remote sensing satellite is placed is 600-1000 km above the Earth's surface. When putting the satellite into orbit, the rocket gives it a speed of 7.5 km/s (equivalent to 27,000 km per hour)! In comparison, the fastest aircraft does not exceed 3,500 km per hour.

Many satellites have been launched by PSLV rockets. Examples: Chandrayaan-1, Mangalyaan, Astrosat, Chandrayaan-2, Kalpana-1, GSAT-12 and the NavIC series (IRNSS).

5.2 GSLV – Mark I and II

GSLV is a high-capacity Indian rocket that delivers satellites weighing over 2000 kg into geostationary orbit. It has three stages. The first is the S-139 stage, which burns solid fuel. Four boosters are also fitted to this stage. Boosters contain liquid fuel. The second stage has liquid fuel. The third stage consists of liquid hydrogen and oxygen stored separately at cryogenic (super-freezing) temperatures.

Mark I is a rocket developed in collaboration with Russia. Mark II is an indigenously developed rocket (Fig-3). Rockets of this series are currently being prepared for several launches. The GSLV has the thrust to deliver a 2.5-tonne satellite into an elliptical orbit to be transferred to a geostationary orbit. Alternately, a 5-tonne satellite would be placed into a near-Earth orbit. The height of this rocket is 49 m, its diameter is 3.4 m., and its weight is 415 tonnes.

5.3 GSLV Mark III

GSLV Mark III, with three stages and two boosters, is twice as powerful as Mark II (Figure 3). When the orbit to be reached is not geosynchronous, then the rocket is called LVM-3. This rocket can launch a 4-tonne satellite into an elliptical orbit for geostationary transfer or a 10-tonne satellite into a near-Earth orbit. The height of GSLV Mark III is 43 m, the diameter is 4 m., and the weight is 640 tonnes.

A total of four Mark III rockets have successfully put CARE, GSAT-19, GSAT-29, and Chandrayaan-2 satellites into their designated orbits.

5.4 SSLV

ISRO designed SSLV (Small Satellite Launch Vehicle) for economic launch vehicle development. The specifications of this rocket are:

- Quick turnaround time of design to realization
- Ability to launch multiple satellites from a single rocket
- Stored in readiness and to be flown whenever required
- Designed to be launched with minimum ground support.

The first launch of SSLV happened in August 2022. Improvements to SSLV are being carried out to deliver small satellites into orbit.

The second developmental flight of SSLV successfully launched three satellites into designated orbits in February 2023.

5.5 RLV

RLV (Reusable Launch Vehicle) is a new rocket being developed by ISRO. It has an airplane-like design that returns to Earth for the next trip to space. Unlike an airplane, RLV carries fuel and oxidants in its hull to make it suitable for working in space outside the atmosphere. A booster aids RLV during lift-off. The booster is not reusable.

RLV's success requires mastering cruise at supersonic speed, automatic landing, use of lightweight composites and optimal temperature control. A rocket named RLV-TD was launched in 2016 to test these technological capabilities.

RLV is planned to be realized and reused with greater size and capability in the coming years.

ISRO's successful Rockets

PSLV, GSLV Mark I, GSLV Mark II, GSLV Mark III (LVM-3), SSLV

6. Future trend

Rocket development is taking new dimensions due to the advancement in technology.

6.1 Safe Nuclear Rocket

Nuclear technology is being used in satellites to generate electricity. Prominent examples are the Voyager series, launched in the 1970s and working even today. New Horizons satellite that recently passed Pluto used nuclear power.

NASA's Nerva, Project Rover, Project Timberwind and Project Prometheus are conceived to get more thrust from nuclear power for rocketry. Russia is developing nuclear-powered plasma engines. Typically, a nuclear rocket would take just one month to reach Mars compared to 6 months when using chemical propulsion.

6.2 Solar Sail

A solar sail is a rocket technology that uses solar radiation pressure. The technology was first used in the Icarus satellite launched in 2010. It is intended to be used for broadcasting once it goes near the distant stars. But as the solar pressure decreases with distance, a more expansive sail may be required.

6.3 M-Drive

The most controversial futuristic rocket technology is the M-drive. The purpose of this technology is to generate thrust from the reflection of microwave beams in a thruster. In 2011, it was announced as successful by scientists Robert Schaer, Guido Fetta and Juan Young independently. They claimed to have achieved some level of thrust.

If M-drive produces thrust without hot air from the nozzle, it will contradict the fundamental scientific theories. It is now clear that measurement errors, temperature effects, or electromagnetic effects could be the cause of the thrust readings in these experiments.

Hence a new methodology is needed to get clarity on M-drive.

Present and Future Technologies

- Solid fuel stage
- Liquid Fuel Stage
- Cryogenic stage

- Safe Nuclear Technology
- Solar Sail Technology
- M-Drive (?) Technology

7. Conclusion

Rockets, ushering in the space age, are the pinnacle of human achievement. Rocket technology combines the capabilities suitable for satellite launch and human spaceflight. These improvements will help to build habitation on other planets in the coming years.

Safer nuclear rockets, solar-powered solar sails, or even the controversial M-Drive-based rockets will hopefully lead to interplanetary space travel in the future.

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Ananda S is working as a scientist at U R Rao Satellite Centre, ISRO, since 1998. He is an expert on batteries, related electronics, and power systems. Presently, he is the Head of the Battery Division.

He has published about 13 scholarly articles in leading international journals and conference proceedings. He has written many popular science articles and invited essays in Kannada. He has published four (4) books on space technology to reach out to students and enthusiasts.

Space Books Series for Children

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