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HOW INDIA ACHIEVES SPACE MISSION SUCCESS ON A SHOESTRING BUDGET: A LESSON IN ECONOMIC EFFICIENCY

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Abstract: **In the realm of space exploration, India has emerged as a true contender, defying conventional wisdom by achieving remarkable success on a shoestring budget. While global superpowers like the USA, Russia, and China pour massive resources into their space endeavors, India has showcased the art of achieving efficient and effective space missions without overspending. This unique approach to space economics not only highlights India's technical prowess but also underscores the importance of economic pragmatism in an arena historically marked by extravagant expenditures.**

I. INTRODUCTION

Space exploration plays a vital role in a country's development. It has spurred a growing commercial space sector, creating jobs and economic opportunities in fields related to space technologies like satellite communication, asteroid mining, and space tourism. Space assets are decisive for national security, encompassing communication, surveillance, and navigation. Furthermore, space exploration aids in tracking space debris, and potential threats and studying climate change, ensuring the safety of space assets. Additionally, it enables us to deflect objects that could impact Earth. It also enhances our knowledge of the cosmos, including the origins of stars, galaxies, and planets. Planetary science provides insights into geology, atmosphere, and the potential for harboring life or valuable resources. Moreover, it is imperative to develop advanced technology that is compact, energy-efficient, and inexpensive.

It is essential to consider the cost associated with space exploration. The space economy, which plays a significant role in the development of space, varies from country to country depending on various factors. The space economy represents a substantial and growing sector with the potential to contribute to economic growth and job creation. The commercial space industry is rapidly expanding with companies like SpaceX, Blue Origin, and numerous other startups entering the space market. The industry offers investment opportunities, job prospects, and potential returns for businesses and investors. Studying space economics helps researchers and the government to comprehend the scale of the overall growth of the country.

Studying space economics assists nations and organizations in navigating partnerships, agreements, and collaboration, in space endeavors, promoting peaceful cooperation in the cosmos. Understanding and assessing the economic incentives and mechanisms for space sustainability are vital to secure the long-term usability of Earth's orbital environment. Government policies and regulations shape the space industry. Understanding the evolving regulatory landscape, including funding and other policies, is important for comprehending the overall picture of the development taking place in this sector. It is indispensable to bring alterations in laws and policies to safeguard space assets and maintain global security along with keeping economic objectives.

Currently, there are 77 space agencies worldwide, with 16 of them possessing launch capabilities. Among these agencies, NASA(National Aeronautics and Space Administration) stands out as the most notable. Other important agencies are India- ISRO (Indian Space Research Organisation), Europe - ESA (European Space Agency), Canada -CSA (Canada Space Agency), Russia-Roscosmos (The Russian Federal Space Agency), China-CNSA (China National Space Administration), and Japan- JAXA (Japan Aerospace Exploration Agency). [1]

NASA was established on July 29, 1958, with a mission to pioneer the future in space exploration, scientific discovery, and aeronautic research. Its specific objectives include exploring the solar system and beyond, understanding and protecting our home planet, and developing innovative technologies. Notably, NASA is the largest player in the field of space technology boasting an annual budget exceeding $ 24.04 billion for 2030.

A few of the remarkable achievements of NASA include the successful landing of the Perseverance Mars rover on February 18, 2021. To continue its further research in the

same NASA will require at least two more projects currently being planned by NASA and the European Space Agency.
In addition to this, it launched its mega Moon rocket for the first time, sending uncrewed Orion spacecraft around the Moon. The Webb Space Telescope, another groundbreaking project, provided record-breaking new images from the cosmos. Additionally, NASA conducted humanity's first-ever planetary defense demonstration by successfully altering the course of an asteroid.
One of NASA's upcoming missions, Artemis 2, is scheduled for 2024 and will send the first astronauts around the Moon in nearly 50 years. This mission will involve launching four astronauts on a lunar fly-board and an Orion spacecraft using a space System rocket [2-4].
The Indian Space Research Organisation (ISRO) was established on August 15, 1969, through the merger of two government organizations. ISRO's primary objective is to develop indigenous space technology and applications for the benefit of society and the economy. Among ISRO's achievements are the successful launch of its PSLV and GSLV rockets, the Chandrayaan -3 mission, and the deployment of several satellites into orbit. ISRO launched Aditya L1, India's first space mission to study the Sun, marking the nation's foray into solar research. Moreover, India has plans to launch Shukruyaan to map the surface of Venus and Gaganyaan human space (manned) flight missions. Before this historic mission, ISRO had planned two unmanned missions as part of its preparations, underlining India's growing presence in space exploration and space economy.
Other important missions include XPoSat (X-ray Polarimeter Satellite), which represents India's first dedicated polarimetry mission, aiming to study various dynamics of bright astronomical X-ray sources in extreme conditions. ISRO is collaborating with NASA on the development of NISAR (NASA-ISRO SAR) a low Earth orbit (LEO) observatory. Its mission is to map the entire globe in just 12 days, discovering valuable insights.[5-8]
The European Space Agency (ESA) established in 1975 is another influential player in the field of space exploration. ESA is a multinational space organization currently composed of 23 member states, and it is open to any European Union country that meets specific criteria. Much like NASA, ESA has a strong track record of developing successful spacecraft and satellites.
One of the biggest collaborations between ESA and NASA was the launch of the James Webb Space Telescope. ESA provided the Arian 5 spacecraft for this groundbreaking mission, emphasizing international cooperation .[9]
Currently, ESA is actively involved in developing a Mars rover called ExoMars. This mission has ambitious objectives including the search for biosignatures of past Martian life and detailed study of the surface of Mars. Some of its upcoming missions include Plato, Earthcare, Flex, and many more.
The Canada Space Agency (CSA) was established in 1989 and has a rich history of collaboration with international partners in space exploration. CSA has been an active participant in numerous successful missions. One of its remarkable collaborations is with the International Space Station (ISS), where the renowned Canadarm, built by MDA, has played a crucial role in station operations. The industry is also employed in robotic exploration of Mars, demonstrating its capabilities in planetary exploration.
Several exciting mission of CSA is CASTOR, which has seen ongoing investments in critical technology development since early 2021, with an anticipated completion date in December 2023. This $2.25 million which is a huge investment encompasses work on various aspects, including telescope optical and structure design, focal plane and large are detectors, a fine steering misto, etc.[10]
ROSCOSMOS the Russian Federal Space Agency was established in 1992 following the dissolution of the Soviet Union. It has taken a leading role in developing Russia's satellite navigation system, known as GLONASS. One of the significant contributions to space exploration is its operation of the Baikonur Cosmodrome in Kazakhstan, from where the renowned Soyuz rocket is launched. For many years, NASA depended on the Soyuz to transport astronauts to the International Space Station (ISS), underlining the international collaboration in space endeavors.
The industry is also renowned for space tourism. The agency has enabled six space tourists to travel to space, with each trip costing an estimated fee of at least $20 million (USD). In August 2023, Roscoms initiated Luna 25 mission to the moon. The launch was conducted using Russia's own Soyuz -2.1 b rocket. However, the mission encountered a setback due to engine malfunction. The industry further aims for the Luna-Glob mission. It is also setting its sights on Venus. The industry is planning to launch an orbiter to explore and study Venus, marking its continued involvement in ambitious space missions .[11]
China National Space Administration (CNSA) founded in 1993 stands as one of the younger space agencies globally but has rapidly made significant strides in space exploration. China became the third country, following Russia and the USA to independently send a human into orbit with its spacecraft. China has seen great success in various areas including lunar exploration. The Chang'e lunar landers and rovers have significantly contributed to our understanding of the moon's surface.
China has ambitious plans concerning human spaceflight which include constructing three module space stations. The Tianhe core module, Launched in late April, is currently hosting its first crew, marking a substantial step forward in China's human space flight. CNSA has also planned to launch a near-Earth - asteroid sample return mission to small body 469219 Kamo'oalewa around 2025. It also aims to improve national civil space infrastructure, supporting ground facilities, and enhancing communication and broadcasting, navigation, and positioning facilities. The major aim behind all this is to

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boost economic development further solidifying the presence of China in space exploration.[12]
In 2003 the Japan Aerospace Exploration Agency (JAXA) was established through the merger of three Japanese organizations. JAXA's mission statement emphasizes its commitment ' to contribute to peaceful use and exploration of space, while also on Earth-related issues'. One of its recent missions Hayabusa-2 achieved significant success and is aimed to bring samples from the Ryugu asteroid. Hayabusa- 2 is now embarked on a journey to explore 2 more asteroids. It will provide live coverage of the launch of two important missions: the X-ray Imaging and Spectroscopy Mission (XRISM) and the smart Lander for Investigating Moon (SLIM) . [13]
The primary objective of the research paper is to analyze India's space exploration economy and budget profoundly and to draw insightful comparisons with major international space agencies. It is building on the preceding discussion about space agencies such as NASA, ESA, Roscosmos, JAXA, and CSA. This section will specifically focus on India's current space economy, anticipated developments, policy and regulatory shifts, overarching goals, and notable achievements within the sector. The paper will also provide a comparative examination of India's space economy and budgetary considerations in contrast to those of prominent space agencies worldwide. This analysis will shed light on the financial dummies of space exploration in India and its global standing.

II. ANTICIPATED DEVELOPMENTS POLICY AND REGULATORY SHIFTS OVERARCHING GOALS AND NOTABLE ACHIEVEMENTS

A. Role of the private sector

In The Indian government has taken major steps to include the private sector in the space industry. While the government has historically driven the space sector, the involvement of the private sector is inevitable for advancing satellite-based services and ground-based systems. Increased private sector involvement brings in new resources and talent, expanding the capabilities of the space industry. This will lead to an increase in planetary exploration. Moreover, it will all lead to better exploration of resources and space assets. Enhanced private sector participation can position the Indian industry as a key player in the global space economy, leading to substantial employment opportunities in the technology sector and making India a global technology powerhouse.
The steps taken by the government to include the private sector are: In the 2019 budget, New Space India Limited was established to mass-produce small satellite launch vehicles and polar satellite launch vehicles in collaboration with the private sector through technology transfer. The Draft National Policy 2020 aimed to foster public-private partnership in space research and exploration activities, granting private access to ISRO's infrastructure, technical resources, and data. The Union Cabinet in 2020 approved the creation of the Indian National Space Promotion and Authorisation Center (IN-Space) to serve as a single-window agency for space resources. Additionally, recently India's space agency unveiled a draft " Humans in Space Policy 2021" to enable the participation of non-traditional players in space activities.
But these steps also include various challenges: Regulatory complexity is one of them. Companies often need help with the multiplicity of approvals and the cumbersome process involving procedural ambiguity. Moreover, there is a lack of clear regulations, and access to "patient " capital, necessary for long-term space projects, is crucial. Also, if there is a conflict of interest, ISRO acting both as a regulator and operator may face conflicts of interest during dispute resolution with private players. Although IN-SPACE is intended to be independent, its connection with ISRO raises potential concerns regarding conflicts of interest.
It is important to note that a stable long-term policy framework is crucial for realizing the potential of India's space sector and achieving the goal of ' Aatmanirbhar Bharat'. The government is incessantly working on attracting investments from foreign resources and expanding collaboration with them indicating the sector's potential for growth and innovation [14].

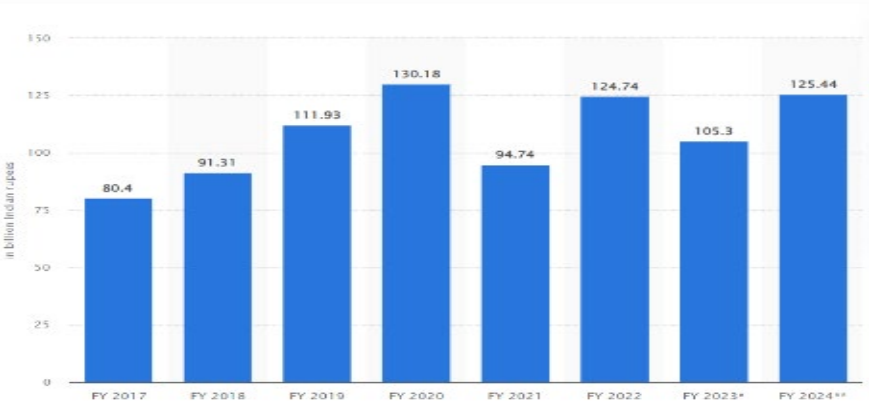

Fig. 1. Government expenditure on the space sector in India fro the financial year 2017- 2024 in billion Indian Rupees

B. Reforms

In June 2020, the Government of India (GOI) approved private enterprise participation in all phases of space activities and established the Indian National Space Promotion and Authorisation Centre
(IN-SPACE) within the India Space Research Organisation to support their independent space endeavors. Furthermore, India now boasts 368 private space firms, ranking fifth globally. The number of private company proposals in the space section increased by 30% in 2021.
Efforts to engage young entrepreneurs and students include the Atal Tinkering Lab (ATL) Space Challenge and the development of world-class learning facilities and space museums promoting STEM education. The government is also working to simplify the process of foreign investment to attract strong nations. The Indian Space Association (ISpA), launched in October 2021, aims to facilitate independent space activities, technology transfer from ISRO, and support for startups, MSMEs, and academia.
An MoU between the Department of Space (DoS) and NewSpace India Limited (NSIL) facilitates the transfer of ISRO technologies for commercialization with over 363 technologies transferred as of October 2021.
ISRO has adopted a demand-driven approach to space asset development and has opened its facilities for private sector use, allowing satellite testing at various centers and facilities, with IN-SPACe serving as the nodal agency for private engagement [15].
Facilities for testing, tracking, telemetry, launch pads, and laboratories, created by ISRO, would also enable the private space industry to climb the value chain. A mechanism has been created, where industries can approach IN-SPACe for utilizing the ISRO facilities [16].
A transition is taking place in the Indian space sector. Pawan Goenka the chairman of the Indian National Space Promotion Authorization Centre (IN-SPACe), said at a forum at the 74th International Astronautical Congress in Baku, on Oct 5 that ‘ we are moving from ISRO being the sole player in the space sector to the private sector taking on a more meaningful role’[17].

C. Laws and Regulations

India still does not have a space law to govern its activities in outer space. The government has its monopoly in India's space sector, which is led by the ISRO. The private sector has requested the government several times to open up the Indian space program. So businesses can invest to build India's space caliber.
The Indian Government introduced the Space Activities Bill 2017 to make a change in terms of space policies, but it has now been sent for further approval.
The Department of Space has entirely governed the space sector in India since its establishment in 1972 and before that, the Department of Atomic Energy took care. Outer space is no longer a domestic issue but has become an international issue. Hence the need for regulations is imperative. India now has big dreams to conquer with space technology. Henceforth, the laws and regulations should be accordingly established [18].
India is steadily emerging as a potential player in the global commercial space market, but several key legal and regulatory issues need attention. These include authorization, contacts, dispute resolution, licensing, data processing and distribution for earth observation services, insurance, certification of space technology, and legal matters related to launch services. Additionally, the revision of domestic laws is essential to address space law-related concerns.
There is a lack of legal protection for operators or the government in case of damages, intellectual property heights such as patents and data rights generated by ISRO, are not yet adequately addressed in space-related laws. Therefore, India’s domestic space legislation should encompass provisions for the peaceful use of outer space, ensuring holistic benefits for humanity.
India holds the 5th position in global space technology, signifying its valuable achievements in the field of space. Therefore space legalization is very crucial for its security. The current framework is shaped by the government of India’s policies and procedures, including the Remote sensing data policy of 2011, which removed restrictions on satellite data supply up to 1-meter resolution. Other policies include norms related to SATCOM and technology transfer by ISRO .[19]

D. Vision Mission Objectives

ISRO’s vision is to harness, sustain, and augment space technology for national development, while simultaneously advancing the frontiers of space, science research, and planetary exploration
ISRO’s mission encompasses various critical objectives for instance they are focused on designing and developing cutting-edge launch vehicles and related technologies to ensure reliable and cost-effective access to space. Additionally, they are computed to advance satellite technology, and associated systems for the earth are observation, communication, navigation, meteorology, and space science. Their communication program aims to establish robust telecommunication, television broadcasting, and developmental applications for effective national connectivity. Furthermore, their satellite-based remote sensing program plays a pivotal role in managing natural resources and monitoring the environment. Through space-based imagery promoting sustainable practices, they are dedicated to maintaining a space navigation system for precise and reliable navigation services across various applications. Leveraging space-based technologies. They aim to address societal challenges and enhance citizen’s quality of life. Their commitment to space, science, research, and planetary exploration drives ongoing research and development efforts expanding our understanding of the cosmos. Finally, they actively promote and authorize private firms to contribute to the global space market [20].

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E. Policy 2023

The government of India introduced the National Space Policy in 2023 aimed at harnessing India's distinctive expertise in the field of space exploration. This comprehensive policy serves as a dynamic framework to realize the government's vision for reforming the space sector. The key aspect of this policy is to grasp the attention of the private sector in space exploration. This will automatically boost the space economy and eventually the country's overall economy.

The guiding principles of the reforms include: firstly the policy seeks to establish a mechanism through which industries can engage with IN-SPACe for utilizing ISRO facilities. Additionally, it focuses on optimizing the utilization of space assets, including satellites and launch capacity, and defining accountability among various stakeholders. Importantly, the policy aims to create a favorable regulatory environment that provides equal opportunities for players within the Indian private sector. The policy aims to enhance India's space capabilities and promote a thriving commercial presence in space. The policy envisioned using space technology as a catalyst for technological advancements and driving benefits in related areas. It also emphasizes fostering international relations among all stakeholders.

Furthermore, under this policy, ISRO will concentrate on developing new technologies, systems, and research and development initiatives. NewSpace India Limited (NSIL) will carry out strategic activities in the space sector in a demand-driven mode moreover, IN-SPACe will interface with ISRO and non-government entities (NGEs), facilitating collaboration and engagement.

However, it is also important to understand the various challenges associated with this, including its capital-intensive nature, which may necessitate government investment in development. Furthermore, the limited allocation of funds for research and development poses obstacles. Additionally, the absence of space science programs in universities and colleges contributes to a shortage of skilled manpower in the sector [21].

F. National Security

In the 1960s when India initiated its space program, it was a developing nation grappling with limited resources and poverty. The essential focus was on leveraging space technology to advance social and economic development. However, over the past decade, there has been a change in perspective as development in other sectors proceeded: the pursuit of ambitious space exploration endeavors and an increased emphasis on space for national security purposes. This led to a completely new approach of India towards space and its economy. Space economy has now started accommodating these expenses as well. The transition was from morality and sovereignty-driven considerations to a more strategic and security-oriented perspective. Rather than being solely motivated by socio-economic development, India's space program now aligns itself with national security considerations.

Recognizing the evolving space security landscape, India is increasingly engaging with like-minded Partners. A notable avenue for cooperation is the Quadrilateral Security Dialogue. Or Quad. A crucial area where India can collaborate with Quad is enhancing Space Domain Awareness (SDA). SDA involves the capacity to monitor and track the space environment for potential threats, including both natural events and international attacks. [22-23]

India's space program has evolved from its humble beginnings driven by development goals to a multifaceted endeavor encompassing space exploration and national security imperatives. This transformation reflects the nation's pragmatism and changing priorities.

III. COMPARISON

A. INDIA VS CHINA

China's space capabilities have seen notable growth outpacing many nations in the global space race. In 2021, China made a significant mark by conducting an impressive 55 space missions, setting a record for the number of launches. This number far surpassed the total number of launches of the US and all other Asian countries combined, showcasing China's increasing prominence in space exploration.

In contrast, India's space activities in 2021 were marked by fewer launches, with just two missions. However, India's private space sector has seen remarkable success, standing in contrast to China's private space company, iSpace, which was incorporated in 2016 and has faced struggles. Despite a lower number of launches, India has been making strides in the space industry with a range of space capabilities.

India is positioning itself as a reliable alternative to companies like SpaceX, leveraging the geopolitical isolation of China and Russia with the hope of making lucrative business in the space sector leading to a rise in the overall economy. Concerns about Beijing's access to Western technology have led many satellite operators to avoid Chinese rockets boosting India's appeal. With ambitions to expand its role in the lucrative space industry, India is making steady progress.

When comparing space assets as of March 2020 China owned 13.6% of all earth-orbiting satellites, while India has a smaller share at 2.3%. China has been actively launching communication satellites with companies like GalaxySpace and Galactic Energy successfully placing satellites into low-earth orbit. On the other hand, India's launches have been primarily conducted by the commercial sector that is ISRO and NewSpace, with fewer launches. [24-25]

B. INDIA VS USA

The NASA budget represents less than half of the US space budget, with the rest being spent largely by the Department of Defense. Military interests have also played a significant role in the history of space activities. Between 1978 and 1986,

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about $ 10 billion of the $ 21 billion in sales and savings to the US industry, attributed to NASA's work, came from additional sales of commercial aircraft.

India's expenditure on space activities is remarkably smaller compared to NASA's budget. However, it's important to note that the Department of Space spent 15% of the central government's research budget in 2009-10, second only to the US which was 17 % in 2013, while European Union Countries allocated less than 5 % for space research. Given India's relatively low overall spending on research and development. This raises doubts about the inappropriate spending on space activities is the most acceptable and efficient allocation.

Narayan Prasad has highlighted critical and different concerns by stating that a dollar spent on NASA yielded $10 for the American economy however no such worthy trend could be noticed for ISRO. In the case of India understanding the relationship between expenditure and return is quite complex to determine. India's Mars mission in contrast cost only $ 74 million a fraction of the cost incurred by others, including NASA's $ 108 million budget for the Hollywood film " The Martian". Despite having a budget of 20 times smaller than NASA, ISRO has excelled in terms of efficiency, proficiency, resourcefulness, and cost-effectiveness.

While NASA and ISRO initially competed in the space race, they have now shifted towards collaboration, working together to advance space exploration for the benefit of humanity. This collaboration exemplifies the changing landscape of international space efforts, emphasizing the collective pursuit of knowledge and progress beyond national boundaries.[26-28]

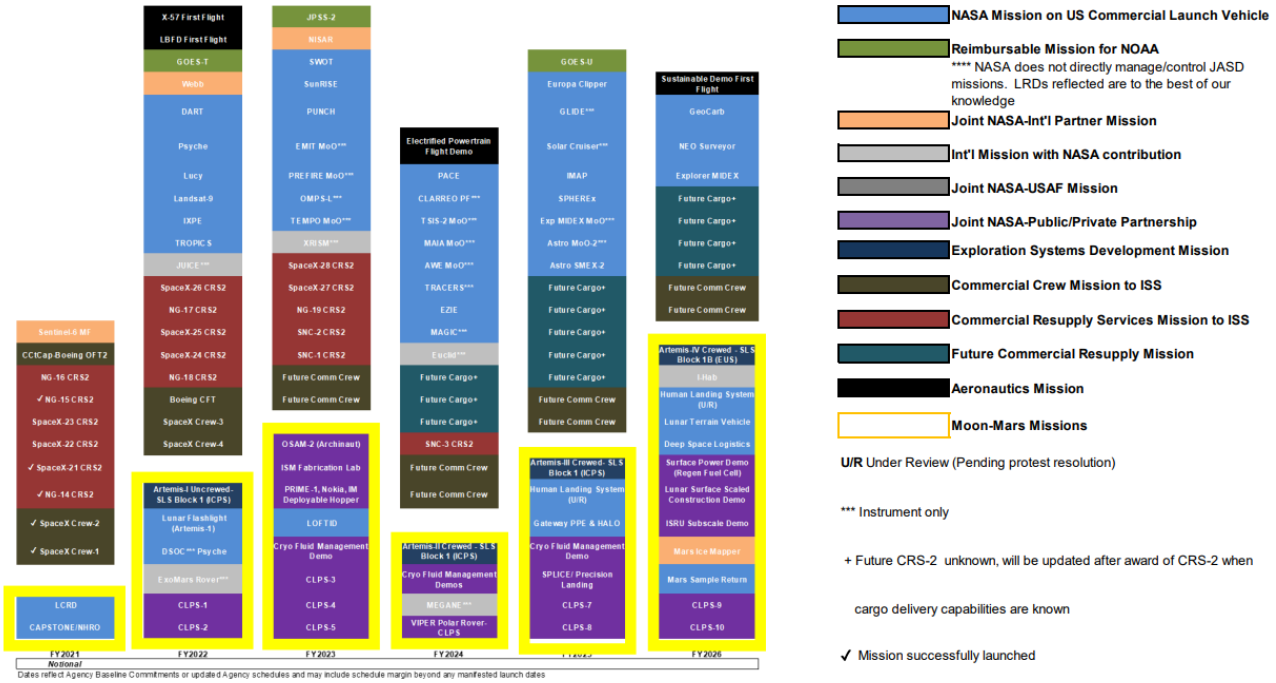

Fig. 2. NASA Mission planning manifest: FY2021 - 2026

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Budget Authority ($M)	FY 2020[1]	FY 2021[2]	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Deep Space Exploration Systems	5,959.8	6,517.4	**6,880.4**	7,014.1	7,263.7	7,514.9	7,772.8
Exploration Systems Development	4,512.8	4,544.6	**4,483.7**	4,384.0	4,219.0	3,888.0	3,867.0
Exploration Research & Development	1,447.0	1,972.8	**2,396.7**	2,630.1	3,044.7	3,626.9	3,905.8
Space Technology	1,100.0	1,100.0	**1,425.0**	1,454.5	1,486.4	1,519.2	1,552.9
Space Operations	4,134.7	3,988.2	**4,017.4**	4,109.3	4,103.3	4,103.3	4,103.3
International Space Station	1,516.1	1,321.6	**1,327.6**	1,309.7	1,279.4	1,284.5	1,284.5
Space Transportation	1,746.2	1,872.9	**1,771.7**	1,827.1	1,849.0	1,843.7	1,843.7
Space and Flight Support	857.4	776.6	**817.0**	786.4	788.8	789.0	789.0
Commercial LEO Development	15.0	17.0	**101.1**	186.1	186.1	186.1	186.1
Science	7,143.1	7,300.8	**7,931.4**	8,095.6	8,272.9	8,455.7	8,643.4
Earth Science	1,971.8	2,000.0	**2,250.0**	2,343.5	2,398.3	2,573.0	2,702.3
Planetary Science	2,712.6	2,699.8	**3,200.0**	3,196.3	3,266.5	3,226.9	3,168.7
Astrophysics	1,306.2	1,356.2	**1,400.2**	1,461.8	1,491.5	1,512.3	1,594.1
Heliophysics	724.5	751.0	**796.7**	803.3	816.6	833.6	858.5
James Webb Space Telescope	423.0	414.7	**175.4**	172.5	172.0	172.0	172.0
Biological and Physical Sciences	5.0	79.1	**109.1**	118.1	128.0	137.9	147.8
Aeronautics	783.9	828.7	**914.8**	933.7	954.1	975.2	996.8
STEM Engagement	120.0	127.0	**147.0**	150.0	153.3	156.7	160.2
Safety, Security, and Mission Services	2,913.3	2,936.5	**3,049.2**	3,112.3	3,180.5	3,250.8	3,323.0
Mission Services & Capabilities	1,849.7	1,918.3	**2,028.8**	2,070.8	2,113.7	2,157.6	2,202.4
Engineering, Safety, & Operations	1,063.6	1,018.2	**1,020.4**	1,041.5	1,066.8	1,093.2	1,120.6
Construction & Envrmtl Compl Restoration	432.5	428.5	**390.3**	398.4	407.1	416.1	425.3
Construction of Facilities	357.8	370.4	**315.6**	322.2	329.3	336.7	344.2
Environmental Compliance and Restoration	74.7	58.1	**74.7**	76.2	77.8	79.4	81.1
Inspector General	41.7	44.2	**46.0**	47.0	48.0	49.1	50.2
NASA Total	22,629.0	23,271.3	24,801.5	25,314.9	25,869.3	26,441.0	27,027.9

1/ - FY 2020 reflects funding amounts specified in Public Law 116-93, Consolidated Appropriations Act, 2020, as adjusted in NASA's FY 2020 Initial Operating Plan, except Exploration Ground System Development and Exploration CoF. Table does not reflect emergency supplemental funding provided for NASA and included in the Safety, Security, and Mission Services account, as specified in Public Law 116-136, the Coronavirus Aid, Relief, and Economic Security Act, totaling $60.0 million.

2/ - FY 2021 reflects funding amounts specified in Public Law 116-260, Consolidated Appropriations Act, 2021, as adjusted by NASA's FY 2021 Initial Operating Plan.

Fig. 3. FY 2022 Budget request: Agency

C. INDIA VS RUSSIA

The race between Russia's and India's space economies encompasses elements of science, national pride, and the pursuit of financial gains. India is strategically positioning itself within the expanding space industry, taking advantage of the geopolitical isolation of China and Russia. Furthermore, India has cultivated closer ties with the US, Australia, Japan, and other regional powers, while offering more cost-effective launch services compared to others.

Russia boasts a rich history in space activities and its Soyuz rockets are renowned for their reliability, Years of under-investments have started revealing cracks in its capabilities. The war between Russia and Ukraine is also a failure regarding the space budget. However Russia's caliber in human spaceflight is unmatched, but this is a highly complex engineering challenge.

On the other hand, India's growing economy contrasts with Russia's ongoing economic contractions. Russia relies on technology from the first space race, while India is developing modern tools that reflect recent advancements. Moreover, India's receptiveness to international collaboration and commerce in space blisters its position. Due to war, Russia will require a lot of years to recover from the loss despite regaining access to global funding and high-tech components as the economic damage is huge.[29-33]

D. INDIA VS JAPAN

India and Japanese space agencies have jointly assessed collaboration in various space domains, such as earth observation, lunar missions, etc. This partnership comes from the strong economy of India which has grasped the interest of the Japanese corporate sector. The interest can also count on the expanding market of India, abundant Human Resources, and cost-effectiveness.[34]

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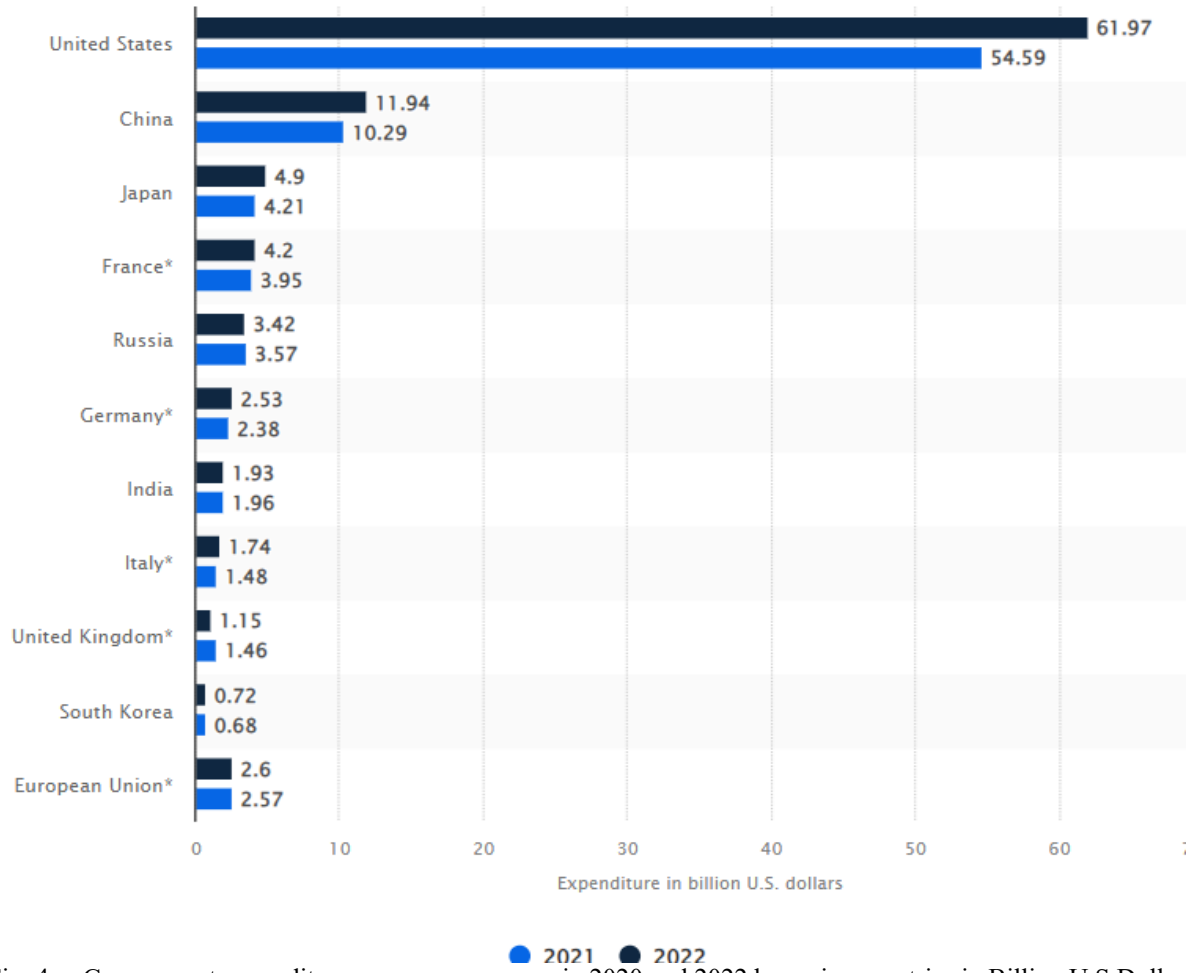

Fig. 4. Government expenditure on space programs in 2020 and 2022 by major countries in Billion U.S Dollars

India has traditionally not been able to spend a lot on its space endeavors. Today the government has aimed to spend a sufficient amount of money and make India a space power. India's space spending as a share of its GDP is relatively low. The US spends 0.28% of GDP, Russia is second at 0.15% while India is seventh in the world at 0.04% [35].

A recent EY report has put the global market size of the space sector at $ 447 billion in 2020 and is estimated to touch $ 600 billion by 2025.

According to the reports the Indian market size in 2020 amounted to $ 9.6 billion, which was 0.5 % of the GDP of the country.

The Indian government citing a study done by a global consulting firm told the parliament that the revenue generated by the the global space industry may increase to over $ 1 trillion by 2040.

Nekkanti, one of the research associates stated " By 2025, the satellite manufacturing segment will be the second fastest growing in the Indian space economy. Having proven our full stack technologies capabilities through our Thybolt Mission in November 2022, we are very excited to be a key player here,". [36-37]

IV. INDIA'S LOW-COST EDGE

India's success can be measured not only in its successful missions but also in its low-cost budget. India's budget-friendly space missions are the major highlight of ISRO's success. In 2024, Prime Minister Narendra Modi drew a dramatic comparison. He said India's Mars Orbiter Mission Mangalyaan at $ 74 million had cost less than the movie ' Gravity' which had cost nearly $ 100 million. NASA's similar Mars Mission, Maven, had cost nearly 10 times more.

India's leaders like Sarabhai had clear objectives for ISRO which is to work for the society, for the poor and not to compete with economically developed nations. From the very start, ISRO focused on the overall development of its countryman, and with this clear objective and working in a country which was badly ridden by poverty during those days their goal was to produce maximum benefits from minimum resources and efforts. Since 1947 India has struggled with

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paucity that has created a mindset against lavishness. The cost has to be kept in check always against lavish spending at NASA or the European Space Agency where costs can run away beyond initial estimates.

Then ISRO chairman Dr K Sivan had explained the economic nature of the space industry to TOI a few years ago." Simplifying the system, miniaturizing the complex big system, strict quality control, and maximizing the output from a product make our space missions frugal and cost-effective. We keep a strict vigil on every stage of development of a spacecraft or a rocket and therefore, we can avoid wastage of products, which helps us minimize the mission cost" he said.

In space engineering, where conditions are tough and costs of failure are high, it is not easy to adapt technology. It also involves more risk, but ISRO has been willing to take- and manage -that risk.

ISRO is well aware of optimizing the resources. Then ISRO chairman G . Madhavan Nair had told TOI " There are some tests that Americans would have done six times and we did only thrice. We scrutinized every parameter and optimized the tests. Yes, you may call it a calculated risk, but, touch wood, we have been successful with this approach so far. "

Moreover, ISRO has lighter payloads and heavier, slower, and less powerful rockets than the space agencies of the US and Russia. Russia's Luna, which failed to soft-land on the Moon a few days ago, took nearly one-fourth of the time to reach as compared to the time taken by Chandrayaan-3 to land.

India's low-cost manufacturing plays to the advantage of ISRO. Over time, ISRO has reduced imports and tried to domestically produce components as much as possible. This leads to major savings. This also leads to the development of the Indian economy by promoting the space market and creating employment. Participation of local industry in ISRO's projects for designing, manufacturing, and testing critical components and systems is well-known. L&T, Godrej Aerospace, Tata Consulting Engineers Limited, Mishra adha tu Nigam, and BHEL have supplied critical components for various missions including the recent ones at a fraction of the cost of imported components.

ISRO's surprisingly low costs are also attributed to the relatively low salaries of scientists. India's scientists have salaries of almost one-fifth of the scientists in the developed world.

The low cost is also associated with strategic partnership, ISRO actively engages in strategic collaboration with academic institutions, research organizations, and the private sector.[38-42]

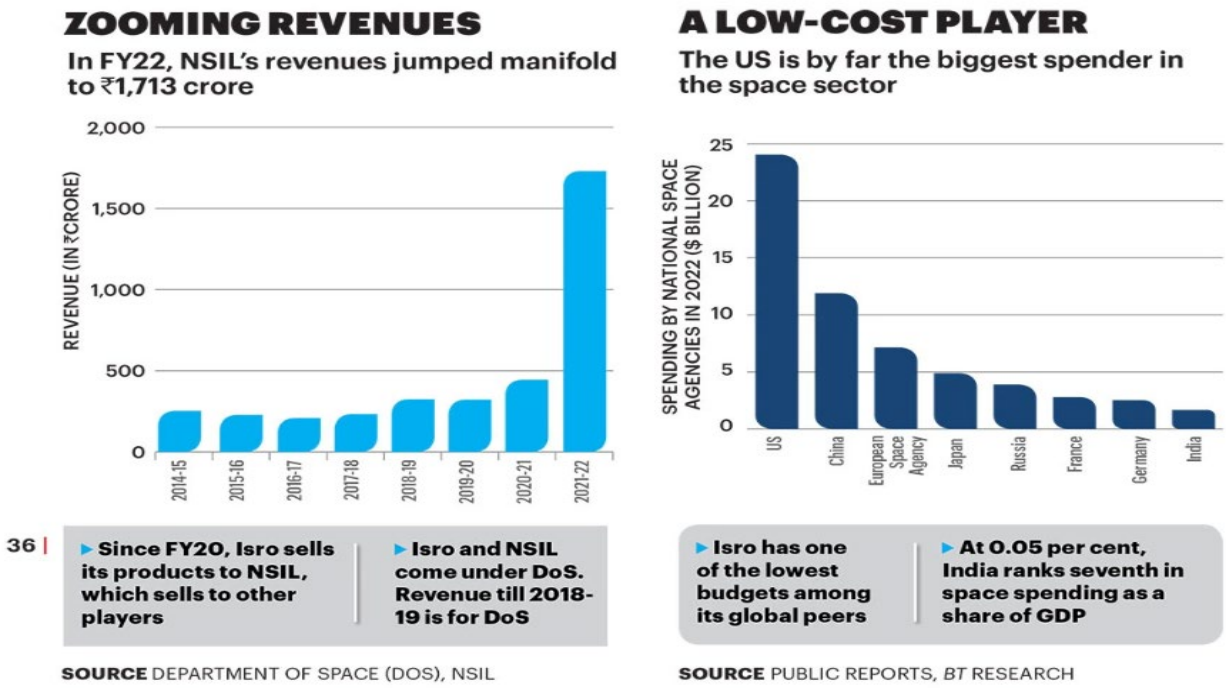

Fig. 5. Revenues vs Low-cost player

The satellite internet market is expected to touch a 27% share of the global space industry by 2040. A massive increase over its current share of less than 1 %, according to a Deloitte study. Moreover, satellite manufacturing, satellite launch, commercial human space flight, and commercial remote sensing are also likely to gain substantially. Crucially, the government spending component, which has been considerable all these years, is expected to fall from 27% in 2021 to less than 18% by 2040. ISRO will cede space to the private sector to drive future growth.

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ISRO has never been managed as a company as it always worked with a somewhat altruistic agenda. For example, the revenue earned from foreign and domestic satellite launches would earlier go into the Department of Space's (DOS) balance sheet. After NewSpace India Ltd (NSIL) was formed in 2019, it took care of all commercial activities after buying ready-made assets and services from ISRO. That money makes an entry in the balance sheet of the DOS, which in turn funds ISRO. NSIL is a profitable entity- in FY 22, it recorded a profit after tax of Rs 342.98 crore. Its revenue zoomed from Rs 321.77 crore in the financial year 2020 to Rs 1,731 crore in the financial year 2022.

ISRO has turned from a supply-based model to a demand-based model, after opening the Indian space ecosystem to private participation since 2000. It has already started helping with capacity building through the development of new technologies and capabilities, technology transfers to private players, and sharing its facilities with NSIL and Non-Government Private Entities.

Due to all these reasons the orbit economy booms, the cost of satellite launches continues to decline, and competition promises to get even more cut-throat, but the country remains in the reckoning.[43]

The low-cost budget has given India an edge in the global launch industry eventually attracting big economies. Under a pooch drive by our Prime minister, India is following NASA's lead in opening launch and other space businesses to private investment. India is aiming to increase its share of the global satellite launch market by fivefold within the next decade. While India can't compete with American private players like SpaceX, India's low cost will certainly help it compete with Russia and China who are ahead of India in launches.

But cutting down on cost leads to other consequences that cannot be ignored: It means India can collect less data and its missions are time-consuming. The entire process of space exploration is compromised, Chaitanya Girir, a fellow for space and ocean studies at Gateway House, stated.

Now that India has started opening up the space sector to private companies, ISRO may not remain solely dependent on government funding and thus would be able to spend more in the future. But more money would mean ISRO will chart out for itself and not it will lose its cost advantage .[44]

V. INTERNATIONAL COOPERATION

Over the years, ISRO's growing experience and technological advancements have expanded the opportunities for cooperation. International cooperation has been an integral part of India's space program from its inception. Initiatives such as the Thumba Equatorial Rocket Launching Station (TERLS), the Satellite Instructional Television Experiment (SITE), the Satellite Telecommunication Experiment Project (STEP), etc all included components of international cooperation.

ISRO actively fosters bilateral and multilateral relationships with space agencies and related organizations to enhance existing partnerships, tackle new scientific and technological challenges, refine space policies, and establish international frameworks for the peaceful use of outer space.

International cooperation is also vital to expand its budget and economy and achieve power. Developing countries try to take the help of ISRO to build their space technologies. ISRO's recent success has broadened the scope of international cooperation.

Few players in the space sector launch space vehicles at such a low cost as ISRO. Mc Dowell said, " And that is not Russia or China." ISRO has earned $ 94 million in foreign exchange from January 2018 to November 2022. From January 2018 to November 2022, ISRO has successfully launched 177 foreign satellites belonging to countries like Australia, Brazil, Canada, Colombia, Finland, France, Israel, Italy, Japan, Lithuania, Luxembourg, Malaysia, Netherlands, Republic of Korea, Singapore, Spain, Switzerland, UK, and the US. ISRO carried out two launches of its largest and heaviest rocket, in record time- on October 23, 2022, and on March 26, 2023. Both were commercial missions, where the LVM3 rocket ferried a total of 72 satellites of UK-based telecom firm One Web, thus earning ISRO a total revenue of more than Rs1100 cr or $ 137 million".[45]

Fig. 6. Value of exports in the space technology sector in India from FY 2015 - 2022. (In Billion Rupees).

VI. CONCLUSION

While India's model of cost-effective space exploration is commendable, it's essential to recognize that different nations have distinct goals, resources, and geopolitical considerations. Superpowers like the USA, Russia, and China often pursue broader strategic objectives, necessitating larger budgets for space programs. These countries also contribute to global technological advancements and scientific discoveries that benefit humanity as a whole.

India's success demonstrates that space exploration doesn't necessarily demand astronomical budgets. By embracing innovation, collaboration, and efficiency, countries can achieve significant milestones while containing costs. The economics of space travel are a delicate balance between ambition, necessity, and fiscal responsibility.

In a rapidly evolving landscape, as space becomes more accessible to a diverse range of nations and private entities, the lessons of India's economic approach could pave the way for a future where space exploration is focused on quantitative data mining and strategizing for future manned missions.[46]

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