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A Short Review on ISRO Rocket Engines

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Abstract: The advancement of Indian-class rocket engines has marked a significant milestone, notably with the successful launch of a record-breaking number of satellites into orbit. This achievement is attributed to the successful development of robust rocket engines, such as the Vikas engine. The ongoing efforts to enhance rocket engine capabilities underscore the continuous progress in this domain. In light of this, we have conducted a comprehensive review of all indigenously developed rocket engines in India, assessing their developmental status and reliability. The objective of this study is to highlight the preparedness of ISRO's potent rocket engines and their potential for future orbital launch systems.

Table of Contents

1. Introduction

The Indian Space Research Organization (ISRO) embarked on its space research journey in the mid-1960s, initially focusing on sounding rockets. During this period, assembly facilities were lacking, and most launchers utilized solid rocket boosters. While attempts were made to deliver payloads through Satellite Launch Vehicles (SLVs), the initial efforts proved ineffective. Over the ensuing decades, ISRO demonstrated a progression of launch vehicles, evolving from SLV to the Polar Satellite Launch Vehicle (PSLV), with the latter emerging as the most successful launch vehicle in Indian space history. This success can be attributed to the development and incorporation of liquid and cryogenic rocket engines. ISRO's current portfolio boasts a diverse range of rocket engines that have significantly advanced the modern space era of the Indian space program. In order to thoroughly elucidate the features and efficiency of these rocket engines, we conducted a comprehensive review, spanning from the early SLV Solid Rocket engines to the high-thrust cryogenic engines, such as CE-20 [1-4]. The subsequent section will provide a concise overview of these powerful indigenous engines.

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2. ISRO's Rocket Engine Types

ISRO boasts a diverse array of rocket engines fueled by solid, liquid, and cryogenic propellants. These engines find application across a range of launch vehicles, including SLV, ASLV, PSLV, GSLV, and RLV-TDs. The notable variety of rocket engines includes: PS-4; S139; S200; Vikas; CE-7.5; C25; CE-20; L110; SCE-200.

3. PS-4 Engines

PS are small strap-on boosters attached around the most successful launcher PSLV. These engines were powered either via solid and liquid propellants.

4. S139 Engine

The S139, a Solid Rocket Booster developed by ISRO, weighs 139 tonnes and is manufactured at the Satish Dhawan Space Center in the SPROB facility. Originally designed for the Polar Satellite Launch Vehicle, it was later integrated into the GSLV MKII. Utilizing hydroxyl-terminated polybutadiene (HTPB) as propellant, it generates a maximum thrust of 4800 kN. This booster has been integral to the PSLV since 1993, serving as its core stage, and is also utilized in the Geosynchronous Satellite Launch Vehicle MKII. Furthermore, it is part of a variant of the Unified Launch Vehicle currently in development.

5. S200 Boosters

The S200 Solid Rocket Boosters serve as strap-on boosters for heavy lift-launch vehicles, specifically GSLV. An advancement from the earlier S139, which powered PSLV and GSLV Medium launch vehicles, the S200 is recognized as the world's third-largest solid rocket motor, following NASA's Space Shuttle motor (SRM) and ESA's Ariane-6 (P230). Constructed with maraging steel (M250), similar to the material used in the development of PSLV's S139 Motors, the S200 features a short head-end segment, a star grain, a cylindrical port, and a nozzle.

Figure-1 S200 at LPSC Static Fire Test Pad [Image Courtesy: LPSC, ISRO]

The S200 is powered by HTPB Propellant (200 tons in three segments), the S200 employs a flex nozzle control system and electro-hydraulic actuators to generate maximum thrust at sea level. Notably, it underwent a successful 130-second test firing on Jan 24, 2010, achieving a maximum peak thrust of 4900 kN at sea level. The test results, aligning with simulated outcomes, significantly contributed to the development of GSLV-Mark-III and LVM-3/CARE launch vehicles [5-6].

6. Vikas Engine

The Vikas engine stands out as one of the longest-serving rocket engines, having been successfully developed and tested by LPSC in the 1970s. Its enduring performance has propelled numerous launch vehicles, spanning all variants from PSLV to GSLVs. The propellant mass for the Vikas engine varies between 40-50 metric tons, and it relies on nitrogen tetroxide and unsymmetrical dimethylhydrazine to generate a maximum thrust of 800 kN, accompanied by a specific impulse of 290 seconds [7-9]. The table below illustrates different variants of the Vikas engine and their corresponding launch vehicles.

Table-1 Vikas Engine Variants

Name or Designation	Fuel	Concerned Launch Vehicles
Vikas-2	UDMH/N2O4	GSLV-Mark-I
Vikas-2B	UH25/N2O4	GSLV-Mark-II
Vikas-X	UH25/N2O4	LVM3
Vikas-4	UDMH/N2O4	GSLV-Mark-I
Vikas-4B	UH25/N2O4	GSLV-Mark-II

Figure-2 Vikas Engine at LPSC Complex [Image Courtesy: ISRO]

7. CE-7.5 Engine

The CE-7.5 cryogenic upper stage engine was designed for earlier versions of GSLV launch vehicles, specifically GSLV-Mark-II. It was developed as a replacement for the Russian class KVD1-1, which was utilized in GSLV-Mark-1. Employing a staged combustion cycle with liquid oxygen (LOX) and liquid hydrogen (LH2), the CE-7.5 engine achieves a maximum thrust of 73.55 kN and a specific impulse of 454 seconds in the vacuum of space. The engine's dimensions include a length of 2.14 meters, a diameter of 1.56 meters, and a gross mass of up to 435 kilograms. Successfully completing its inaugural flight on January 5, 2014, the CE-7.5 has since played a crucial role in GSLV-Mark-II launches **[10-11]**.

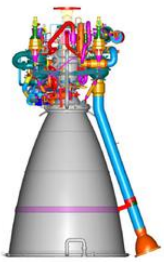
Figure-3 CE-7.5 Engine at Assembly Section [Image Courtesy: ISRO]

8. C25 Engine

The C25 engine is a cryogenic upper stage developed by ISRO for GSLV MkIII. Successfully tested for a flight duration of 640 seconds, the C25 stage employs Liquid Oxygen (LOX) and Liquid Hydrogen (LH2) propellant combination. It carries 27.8 tons of propellants in two independent tanks, presenting unique design challenges due to the extreme temperatures of the cryogenic fluids. The development, led by the Liquid Propulsion Systems Centre (LPSC), involved two phases of testing, including fluid mock-up and hot tests at ISRO Propulsion Complex. The successful hot test validated the stage's design and the robustness of the development facilities. The flight cryogenic stage, forming the upper stage of GSLV MkIII, is in the advanced stage of realization and is part of the next-generation launch vehicle capable of launching 4-ton class satellites into Geosynchronous Transfer Orbit (GTO) **[12]**.

9. CE-20 Engine

The CE-20 is renowned as a cryogenic upper stage engine for GSLV, meticulously developed and tested at the LPSC Complex in Mahendragiri, India. Operating on a mixture of Liquid Oxygen (LOX) and Liquid Hydrogen (LH2) with a ratio of 5.05, the CE-20 engine employs the Gas-generator cycle. This configuration allows it to achieve a maximum thrust of 200 kN, accompanied by a specific impulse of 443 seconds, over a burn time ranging from 640 to 800 seconds **[13]**.**Figure-4 (right) Conceptual Model of CE-20 Rocket Engine [Image Courtesy: ISRO]**



10. L110 Engine

The L110 serves as a second-stage booster for PSLV/GSLV, utilizing unsymmetrical dimethylhydrazine (UDMH) and nitrogen tetroxide as earth-storable propellants. This stage incorporates two Vikas engines, boasting a gross propellant mass of 110 metric tons and a maximum thrust of 1532 kN at sea level. With dimensions of approximately 21 meters in length and 4 meters in diameter, including a nozzle closure system, the L110 successfully completed its inaugural static fire test on March 6, 2010, with a burn duration of up to 150 seconds at the Liquid Propulsion Systems Centre (LPSC) **[14-15].**

Figure-5 L110 Strap-on Boosters at Assembly Section [Image Courtesy: ISRO]

11. SCE-200

The SCE-200 is a liquid-fuel rocket engine presently in the developmental phase, designed to propel the upcoming ULV and RLVs. Operating on Liquid Oxygen (LOX) and RP-1 (Kerosene) through a staged combustion cycle, the engine is anticipated to achieve a maximum thrust of 2030 kN in vacuum conditions. At sea level, it is expected to generate a maximum thrust of 1820 kN, accompanied by a specific impulse of 299 seconds. The engine's dry mass is approximately ~2700, excluding the propellant mass **[16]**.

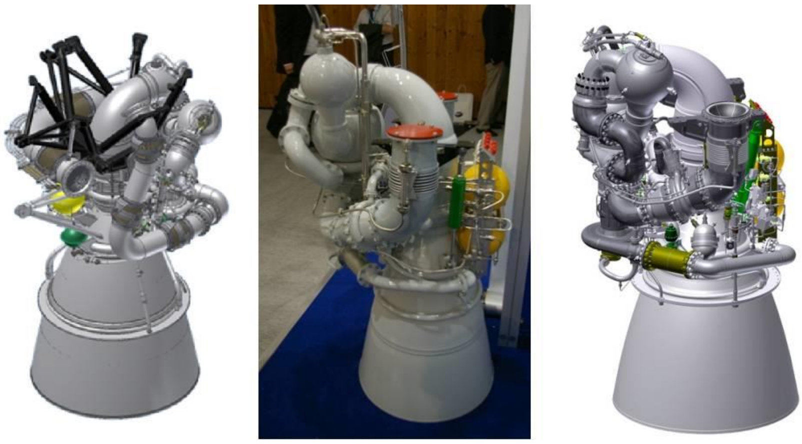


Figure-6 Conceptual Design of ISR’s SCE-200 Rocket Engine [Image Courtesy: ISRO/NASA]

12. Summary and Conclusion

In conclusion, the evolution of India's space exploration, spearheaded by the Indian Space Research Organization (ISRO), reflects a remarkable journey that began in the mid-1960s. The initial focus on sounding rockets, despite challenges in assembly facilities, laid the foundation for a series of advancements. The transition from Satellite Launch Vehicles (SLVs) to the highly successful Polar Satellite Launch Vehicle (PSLV) marked a turning point, showcasing ISRO's commitment to innovation.

The key to ISRO's success lies in the strategic development and incorporation of diverse rocket engines, utilizing solid, liquid, and cryogenic propellants. From the pioneering PS-4 to the powerful CE-20 and SCE-200 engines under development, each engine plays a crucial role in a range of launch vehicles, including GSLV and PSLV.

The robustness of ISRO's rocket engine technology is exemplified by engines such as the S139, S200, Vikas, CE-7.5, C25, CE-20, L110, and SCE-200. The S139, a solid rocket booster, has been integral to various launch vehicles, showcasing its versatility. The S200, recognized as the world's third-largest solid rocket motor, demonstrated its capabilities through successful tests, contributing significantly to the development of GSLV-Mark-III. The enduring performance of the Vikas engine, spanning several variants, underscores its importance in ISRO's space program.

The cryogenic engines, including the CE-7.5, C25, and CE-20, represent cutting-edge technology. The CE-7.5, with its specific impulse of 454 seconds, has been a key player in GSLV-Mark-II launches. The C25, a cryogenic upper stage engine, successfully tested for a flight duration of 640 seconds, presents a significant milestone in GSLV MkIII development, capable of launching 4-ton class satellites into Geosynchronous Transfer Orbit (GTO). The CE-20, a cryogenic upper stage engine, stands out for its advanced technology, achieving a maximum thrust of 200 kN and showcasing the capability to burn for up to 800 seconds.

The L110, as a second-stage booster, and the SCE-200, in the developmental phase, further exemplify ISRO's commitment to innovation and future advancements. The L110, powered by unsymmetrical dimethylhydrazine and nitrogen tetroxide, completed its inaugural static fire test successfully, demonstrating its reliability. The SCE-200, designed for upcoming ULV and RLVs, represents the next frontier in liquid-fuel rocket engines, aiming for impressive thrust and efficiency. In essence, ISRO's journey in space exploration is characterized by resilience, innovation, and a continual pursuit of excellence in rocket engine technology. The diverse range of engines, each with its unique capabilities, positions ISRO as a global player in the space exploration arena, poised for even greater achievements in the future.

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14. Biography

Prarthana S is currently an Acceleron Aerospace intern with a strong passion for planetary exploration and rocket engines. Her notable project involves a detailed review of ISRO rocket engines, showcasing her commitment to staying informed about cutting-edge developments in aerospace. Under the guidance of her research supervisor, Malaya Kumar Biswal M, Prarthana is gaining hands-on experience and contributing to the field's advancements. With a profound curiosity about the cosmos, she is becoming a promising force in aerospace engineering.

15. Acknowledgement

I extend my deepest appreciation and heartfelt gratitude to my mom (Tamil Selvi .A) for her unwavering emotional and kind support throughout my academic and professional journey. Her encouragement and understanding have been my anchor, providing strength during challenging times and celebrating triumphs together. Her love and belief in my abilities have fueled my perseverance, and I am profoundly thankful for her enduring presence in my life.

16. Conflict of Interest

The author have no conflict of interest to report.

17. Funding

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