International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 10, Issue 1, pp 152-159, January-2026

https://doi.org/10.47001/IRJIET/2026.101019

Rocket Launch and Re-Landing Model (Reusable Rocket)

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***Abstract* - The increasing cost and inefficiency of expendable launch vehicles have driven the aerospace industry toward the development of reusable rocket systems capable of vertical takeoff and controlled re-landing. Reusable Launch Vehicles (RLVs) significantly reduce mission costs, improve launch frequency, and promote sustainable space exploration. This project presents the design and development of a scaled Rocket Launch and Re-Landing Model that demonstrates the fundamental principles of controlled vertical ascent, autonomous guided descent, and safe vertical landing.**

The proposed system integrates electrical and control engineering concepts such as sensor-based feedback, embedded systems, propulsion control, and autonomous flight algorithms. Key components include a microcontroller-based flight controller, inertial measurement sensors, altitude sensing, thrust control mechanisms, and a mechanical landing buffer system. Advanced control strategies such as PID control and Model Predictive Control (MPC) are employed to ensure stability, trajectory optimization, and precise landing under varying conditions.

The project also focuses on analyzing landing dynamics, load distribution on landing legs, and shock absorption techniques to minimize impact forces during touchdown. Simulation studies are used to model flight behavior and optimize control parameters before experimental validation. The prototype demonstrates repeated launch and re-landing cycles, validating the feasibility of reusable rocket concepts at a low-cost experimental scale.

This work serves as an educational and practical platform for understanding modern reusable rocket technologies while bridging the gap between theoretical aerospace concepts and hands-on engineering implementation. The proposed model contributes to the advancement of cost-effective, reliable, and sustainable space transportation systems and provides a foundation for future research in reusable launch vehicle technology.

Keywords: Reusable Launch Vehicle (RLV), Rocket Re-Landing, Vertical Takeoff and Vertical Landing (VTVL), Autonomous Control, Model Predictive Control (MPC), Trajectory Optimization, Embedded Systems, Sensor-Based Feedback, Landing Dynamics, Shock Absorption System.

I. INTRODUCTION

The exploration of space has long been one of humanity's most ambitious scientific and technological endeavors. At the core of this pursuit lies the development and advancement of rocket launch systems complex machines designed to transport payloads, satellites, and even humans beyond Earth's atmosphere. Traditionally, these rockets were single-use: once launched, their stages were discarded, burning up in the atmosphere or falling into the ocean. This method, while effective, proved to be highly expensive and wasteful.

However, in recent years, the field of aerospace engineering has undergone a revolutionary transformation with the advent of reusable rocket technology. Companies like SpaceX, Blue Origin, and others have pioneered the design of re-landing modules, which allow the first stage of a rocket—the most expensive part—to return safely to Earth for refurbishment and reuse. This development has not only drastically reduced the cost of space missions but has also marked a significant step toward sustainable space travel.

The rocket launch process involves several critical phases, including ignition, liftoff, stage separation, and orbital insertion. The re-landing module, typically the rocket's first stage, follows a carefully calculated reverse trajectory, using grid fins, autonomous guidance, and retro- propulsion burns to slow its descent and land vertically on a designated platform—either on land or a floating drone ship at sea.

This capability represents a new era in spaceflight, with profound implications for satellite deployment, scientific missions, human space exploration, and even future interplanetary travel. As space becomes increasingly accessible, understanding the principles, mechanisms, and challenges of rocket launch and re-landing systems is crucial for engineers, researchers, and the next generation of innovators.

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In recent years, the global aerospace industry has witnessed a major technological transformation with the development of reusable launch vehicles (RLVs). These advanced rocket systems are designed not only to deliver payloads—such as satellites, cargo, or crew—to space but also to return key components, especially the first stage (booster), safely back to Earth for reuse. This concept, commonly referred to as a rocket launch and re-landing.

The development of reusable rocket systems also underscores the importance of interdisciplinary innovation. It brings together principles from propulsion engineering, aerodynamics, control systems, materials science, and computer technology. The integration of artificial intelligence, autonomous navigation, and advanced telemetry has made it possible for rockets to perform highly complex maneuvers with exceptional precision. These advances are paving the way toward even more ambitious goals—such as fully reusable two-stage rockets, lunar cargo systems, and Mars colonization missions.

As space exploration moves into a new era of commercialization and sustainability, understanding the mechanics, design principles, and challenges of rocket launch and re-landing systems becomes increasingly essential. For students, researchers, and engineers, studying these systems provides valuable insights into how technological innovation can overcome some of humanity's most demanding challenges. It also inspires a vision of the future where space travel becomes not just a rare scientific feat, but a routine and accessible endeavor for all.

In conclusion, the evolution from expendable to reusable rocket systems marks a historic turning point in the story of space exploration. The progress achieved by modern aerospace companies has not only reduced costs and increased reliability but has also brought humanity closer to realizing long-held dreams—such as establishing permanent settlements on other planets and exploring the far reaches of our solar system. The study of rocket launch and re-landing mechanisms thus stands as a cornerstone of 21st-century engineering innovation, driving forward the quest for sustainable and scalable space transportation.

Traditionally, rockets were expendable, meaning the majority of their structure—engines, fuel tanks, and control systems—were destroyed or lost after each mission. This made space exploration an expensive and unsustainable venture. However, with companies like SpaceX, Blue Origin, and ISRO investing in reusable launch technology, the focus has shifted toward engineering rockets that can perform vertical takeoff and vertical landing (VTVL). This evolution demands the integration of high-precision electrical and control systems, making it a compelling and relevant topic for electrical engineering studies.

II. RELEVANCE

The development of reusable rocket systems is essential for reducing launch costs and increasing mission frequency. Mukai *et al.* [1] demonstrated the feasibility of reusable rockets through flight tests, emphasizing controlled re-entry and precision landing. Their work highlights the engineering challenges and recovery mechanisms that form the foundation of this project. Modeling these phases accurately ensures vehicle safety and reusability. This project builds upon their practical insights to develop a reliable launch and landing model. It aims to enhance the overall effectiveness of reusable rockets.

Mehta and Pandey [2] focus on the simulation of vertical landing control, which is critical for stable and safe rocket recovery. Their work provides valuable algorithms to maintain vehicle stability during descent under varying aerodynamic forces. This project utilizes their modeling approach to design control systems that achieve smooth and accurate landings. Effective vertical landing control minimizes vehicle damage and refurbishment needs. Their research supports the development of robust, real-time landing control strategies. This ensures mission success and vehicle reusability.

Autonomous control for vertical landing, as studied by Crawley *et al.* [3], integrates sensor feedback and adaptive algorithms to manage real-time disturbances. This autonomy reduces human intervention, increasing landing precision and safety. The project adopts these autonomous strategies to enable dynamic responses during descent, essential for unpredictable environments. Real-time control adjustments improve robustness and landing accuracy. This enhances system reliability and operational efficiency. Such autonomous capabilities are crucial for future reusable rockets.

Trajectory optimization during re-entry and landing, examined by Srinivasan and Sharma [4], improves fuel efficiency and landing precision through nonlinear control. Their approach addresses vehicle dynamics and uncertainties to optimize descent paths.

The project incorporates these techniques to balance propellant use with accurate landing, reducing mission costs. Optimized trajectories also contribute to safer recovery by managing stresses on the vehicle, this research is vital for enhancing the performance of reusable rocket missions. Efficient trajectory control supports sustainability in space access.

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Amato *et al.* [5] present a model predictive control (MPC) approach that enables rockets to anticipate future states and adjust control inputs proactively. Their simulation and experimental results validate MPC's effectiveness in stabilizing vertical landings despite disturbances. This project uses MPC to improve landing stability and robustness under real-world constraints. Predictive control enhances system adaptability and resilience during descent. Implementing MPC bridges theory and practical rocket landing applications. This contributes significantly to the reliability of reusable launch vehicles.

Overall, the integration of these studies creates a strong foundation for developing an advanced rocket launch and re-landing model. The project leverages proven design principles, control algorithms, autonomous systems, trajectory optimization, and predictive control. This multidisciplinary approach addresses the key challenges in reusable rocket technology. The relevance lies in improving cost-effectiveness, safety, and sustainability of space missions. By building on these research efforts, the project aims to advance the future of space exploration. It supports the broader industry shift toward reusable, reliable launch vehicles.

III. LITERATURE REVIEW

Mukai *et al.* [1] focus on the development and flight demonstration of a reusable rocket system. They discuss key engineering challenges related to vehicle recovery and highlight the significance of precise control during re-entry and landing. Their work serves as an important foundation for reusable launch vehicle technology by demonstrating practical feasibility. The study emphasizes how controlled descent and landing can enhance reusability and reduce mission costs. It also provides valuable flight data supporting further system improvements. Overall, this research is crucial for understanding early reusable rocket system design.

Mehta and Pandey [2] present modeling and simulation efforts for vertical landing control of reusable launch vehicles. Their research centers on designing control algorithms that ensure vehicle stability during the critical landing phase. The simulations help predict vehicle behavior and optimize control parameters for smooth touchdown. This study addresses the importance of robustness and responsiveness in landing control systems. Their approach provides insights necessary for achieving reliable and repeatable vertical landings. It contributes significantly to reusable rocket development by improving control system reliability.

Crawley *et al.* [3] explore autonomous control strategies for vertical landing of reusable launch vehicles. They focus on integrating sensor feedback with control algorithms to manage real-time adjustments during descent. Their work underlines the challenges of precise landing in dynamic environments and the need for adaptive control. The study advances the understanding of how autonomous systems can enhance landing accuracy and vehicle safety. It also discusses the practical implementation of control systems in flight hardware. This research is key to enabling fully automated rocket recovery operations.

Srinivasan and Sharma [4] investigate trajectory optimization for rocket re-entry and landing using nonlinear control techniques. Their approach improves fuel efficiency and landing precision by addressing complex vehicle dynamics. The study highlights how nonlinear control can handle uncertainties and disturbances encountered during descent. It contributes to trajectory planning by balancing performance and robustness requirements. Their work provides valuable tools for optimizing reusable rocket flight paths. This research is instrumental in enhancing mission success rates and reducing operational costs

Amato *et al.* [5] propose a model predictive control (MPC) approach for vertical landing, supported by simulation and experimental validation. MPC enables predictive decision-making that improves landing stability despite external disturbances. Their study demonstrates the effectiveness of advanced control methods in real-world rocket landing scenarios. The experimental results validate the model's ability to handle system constraints and maintain robust control. This research bridges the gap between theoretical control design and practical application. It offers promising techniques for improving reusable launch vehicle reliability.

C. Thies [6] focused on the structural aspects of reusable rocket landing systems. The research investigated the landing dynamics and load distribution on the landing legs during touchdown. Using analytical and simulation methods, the study provided design guidelines for determining the load-bearing capacity and stiffness requirements of landing legs. The results revealed that optimizing shock absorption and flexibility in landing structures reduces impact loads and potential vehicle damage. This work supports the mechanical design phase of any rocket re-landing system.

W. Dongliang, Q. Cui, L. Haijun, and M. Li [7] analyzed various landing buffer systems that protect reusable rockets during touchdown. Their research compared spring, hydraulic, and airbag mechanisms for energy absorption. The study showed that a combination of active control and passive buffering effectively minimizes landing impact and enhances rocket reusability. The results are vital for designing safe and damage-resistant landing mechanisms, complementing the control system research presented in earlier studies.

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Ki-Wook Jung *et al.* [8] introduced a fuel-optimal predictive guidance algorithm for reusable rocket landing. Their method employed sequential convex programming and model predictive optimization to achieve high-precision descent with minimal fuel usage. The system was tested through simulations that demonstrated robust performance under uncertain conditions. This study represents the latest advancement in autonomous guidance technology, combining efficiency, adaptability, and real-time computation for next-generation reusable launch systems.

IV. THE PROPOSED WORK

Problem Statement:

In modern aerospace engineering, the cost and inefficiency of single-use launch vehicles have long posed significant challenges to the sustainability and affordability of space missions. Traditional rockets are often discarded after a single use, resulting in high costs, wasted materials, and increased space debris. With the global shift towards reusable launch systems, aerospace organizations such as SpaceX, Blue Origin, and ISRO have demonstrated the technical and economic feasibility of reusing rocket components through controlled re- landing techniques.

However, at the educational level, particularly within diploma programs, there exists a gap in the practical understanding and implementation of such complex systems. Most academic curriculums lack hands-on exposure to concepts such as autonomous flight control, sensor- based feedback systems, stabilization algorithms, and safe re-landing mechanisms, all of which are critical components of reusable launch vehicles.

Furthermore, integrating electrical engineering principles—including power management, motor control, embedded system design, and real-time data processing—into a functional prototype of a reusable rocket system remains a technical challenge for students. There is a clear need for a simplified, scalable, and educationally viable model that can simulate the core functionalities of launch and vertical re-landing in a safe and controlled environment.

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Studies by Crawley et al. (2014) and Srinivasan & Sharma (2020) highlight the difficulties in precise attitude and thrust vector control during descent, while Thies (2022) and Dongliang *et al.* (2019) emphasize the importance of landing leg design and buffer systems for stable touchdown. Moreover, Amato et al. (2019) and Jung et al. (2024) point out the need for advanced predictive control algorithms to minimize fuel consumption and ensure accurate landing under uncertain environmental conditions.

Hence, the core problem is to design and develop a scaled Rocket Launch and Re-Landing Model that demonstrates the principles of controlled vertical takeoff, guided descent, and safe landing using integrated control systems and mechanical landing mechanisms. The project seeks to replicate, at a prototype level, the essential functions of reusable rockets — combining aerodynamic design, sensor-based feedback control, and impact absorption systems — to contribute toward the advancement of reusable space technology at a low-cost experimental scale.

Objectives:

1. Design and Development of a Reusable Rocket Prototype

The first objective is to design and construct a small-scale prototype of a reusable rocket system capable of demonstrating vertical launch and controlled re-landing. Based on the study by Mukai *et al.* (2014), this involves developing a modular structure that simulates real-world reusable rockets. The prototype will focus on achieving stability during ascent, stage separation simulation (if applicable), and the safe reusability of major components. This model will serve as a foundation for testing flight control and re-landing mechanisms in a cost-effective laboratory setup.

2. Simulation and Implementation of Vertical Landing Control

The second objective is to simulate and implement an effective vertical landing control mechanism for the rocket model. Drawing inspiration from Mehta and Pandey (2018), this includes designing a control system that can manage thrust output and orientation during descent using sensors like accelerometers and gyroscopes. The simulation will help in predicting system response, tuning PID or feedback

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controllers, and achieving a soft vertical touchdown without damage to the structure or landing gear.

3. Development of Autonomous Control Strategies

The third objective is to integrate autonomous guidance and control algorithms that enable the rocket to re-land without manual input. As discussed by Crawley, Dugan, and Knauss (2014), such systems rely on real-time sensor data and attitude correction mechanisms to maintain stability. The project aims to design a microcontroller-based autonomous system that governs the rocket's flight path, ensures accurate positioning, and compensates for wind or thrust imbalances during descent.

4. Trajectory Optimization and Nonlinear Control

The fourth objective is to optimize the rocket's re-entry and landing trajectory using nonlinear control methods. Based on the research of Srinivasan and Sharma (2020), this involves calculating the most efficient descent path that minimizes energy consumption while maintaining stability. The project will analyze flight parameters such as velocity, thrust vector, and altitude to achieve a controlled descent curve that ensures safe and precise landing within the desired zone.

5. Implementation of Model Predictive Control (MPC)

The fifth objective focuses on the implementation of a Model Predictive Control (MPC) approach to enhance landing accuracy and dynamic stability. As presented by Amato, Ulivi, and Giordano (2019), MPC uses predictive modeling to anticipate future states and adjust control inputs accordingly. In this project, MPC principles will be simulated and adapted for microcontroller use to reduce oscillations and improve landing precision, ensuring smooth deceleration and attitude correction during the final landing phase.

6. Analysis of Landing Dynamics and Load Distribution

The sixth objective is to study the landing dynamics and load distribution experienced by the rocket's structure during touchdown. According to Thies (2022), analyzing the mechanical loads on the landing legs is critical for ensuring durability and stability. This project will calculate the impact forces and stresses acting on the landing mechanism and determine appropriate material dimensions to prevent failure or tipping during landing on different surfaces.

7. Design of Landing Buffer and Shock Absorption System

The seventh objective is to design an effective landing buffer or damping system that can absorb impact energy during touchdown. Following the research of Dongliang *et al.* (2019), the system will utilize springs, shock absorbers, or pneumatic dampers to minimize impact forces. The aim is to protect the rocket body, control electronics, and payload from mechanical shocks while achieving smooth contact with the landing surface.

8. Fuel-Optimal Predictive Guidance System

The eighth objective is to implement a fuel-efficient predictive guidance system that ensures safe and accurate landing with minimal propellant usage. Drawing from Ki-Wook Jung *et al.* (2024), this involves using algorithmic prediction of thrust requirements during descent to optimize fuel consumption. The guidance system will adjust the rocket's trajectory in real-time based on velocity and altitude data, achieving a balance between precision and efficiency.

9. Experimental Validation of Launch and Re-Landing Cycle

The final objective is to experimentally validate the complete rocket launch and re-landing cycle through repeated prototype testing. The goal is to demonstrate successful vertical takeoff, stable flight, controlled descent, and safe re-landing with reusable components. This process will help verify theoretical models, evaluate system reliability, and contribute to future research in cost-effective reusable rocket technology for academic and practical aerospace applications.

Methodology:

a) Block diagram

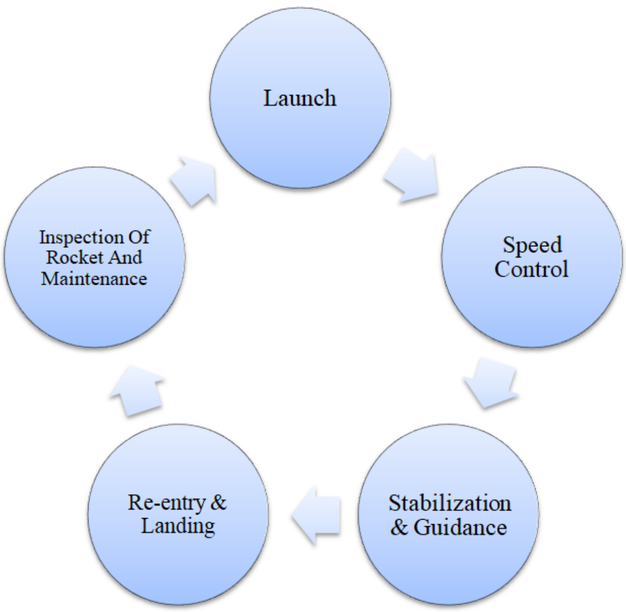

Figure 1

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https://doi.org/10.47001/IRJIET/2026.101019

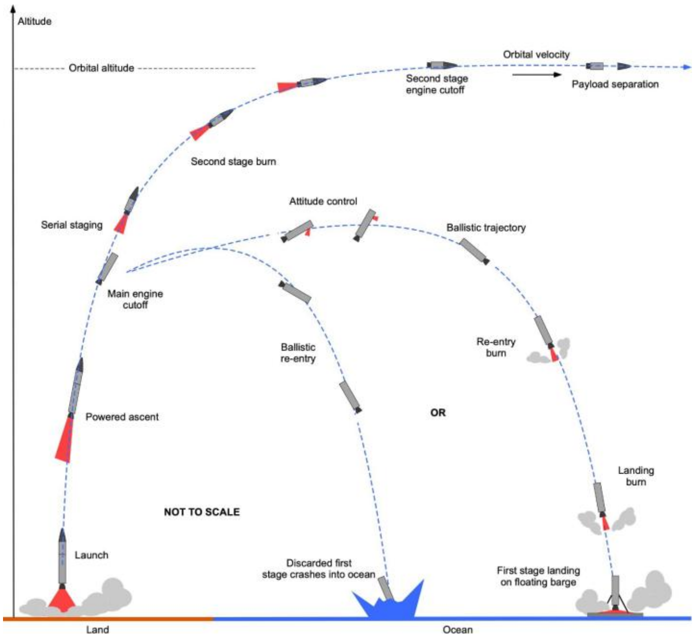

Figure 2: Working of Re-landing model

b) Block diagram Explanation:

1) Launch

- The launch phase is the initial stage where the rocket takes off from the ground.
- The propulsion system (motor or thrust mechanism) generates sufficient upward thrust to overcome the gravitational force.
- The rocket's flight controller ensures stable and vertical ascent.
- Sensors such as accelerometers and gyroscopes record real-time flight data like altitude, velocity, and orientation.
- This phase focuses on achieving a controlled and steady liftoff.

2) Speed Control

- During ascent, the rocket's speed must be precisely controlled to maintain balance between thrust and aerodynamic drag.
- PWM (Pulse Width Modulation) or similar control techniques adjust the motor's power.
- Speed control prevents excessive acceleration and helps maintain a safe flight path.
- This stage ensures fuel efficiency and stability during upward motion.

3) Stabilization and Guidance

- This is a crucial phase where the rocket maintains its orientation and direction.
- The onboard IMU (Inertial Measurement Unit), gyroscope, and accelerometer provide feedback on angular motion and tilt.
- A PID (Proportional–Integral–Derivative) or Model Predictive Control (MPC) algorithm corrects deviations by adjusting control surfaces or thrust vectoring.
- The guidance system ensures the rocket remains aligned with its desired trajectory and prevents oscillations or spin.

4) Re-entry and Landing

- After reaching the desired altitude, the rocket begins its descent phase (re-entry).
- The propulsion system reverses or reduces thrust to control the descent speed.
- A soft landing mechanism such as thrust braking or deployable fins stabilizes the rocket.
- Controlled descent ensures a safe and damage-free landing for reuse.
- This stage replicates real-world re-entry and re-landing procedures used in reusable rockets like SpaceX's Falcon 9.

5) Inspection of Rocket and Maintenance

- Once the rocket lands, a post-flight inspection is performed.
- Components such as motors, sensors, and control electronics are checked for wear, overheating, or physical damage.
- Any required maintenance, calibration, or component replacement is done before the next launch.
- This process ensures the system's reliability and extends the rocket's operational life.

6) Launch and Cycle Continuation

- After successful inspection and maintenance, the rocket is ready for the next launch cycle.
- The reusability aspect makes the system cost-effective and sustainable.
- This continuous cycle — Launch → Flight → Landing → Inspection → Reuse
- Represents the practical application of modern reusable rocket technology.

V. FACILITIES REQUIRED

a) For our drone project, a clean and well-ventilated workspace with enough room for assembly and wiring is essential.
b) An electronics workstation equipped with a soldering station, multimeter, wire strippers, and other tools is

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needed to handle electronic connections safely and precisely.

c) A mechanical workshop with basic hand tools, cutting instruments, and possibly a 3D printer is important for fabricating or customizing parts like the frame and landing legs.

d) A safe testing and calibration area is necessary to run motor and sensor tests, ideally including an open space for flight trials.

e) A dedicated power and charging station with a reliable LiPo battery charger and safety equipment like a fire blanket ensures safe battery management.

f) Finally, a computer setup with the required software for programming microcontrollers and flight controllers is crucial for configuring and controlling the drone.

VI. APPROX EXPENDITURE

Table 1

Sr. No.	Component	Approx. Cost(₹)	Remarks
1	Main Frame	₹3,000	The foundation of our rocket
2	Thrust engine	₹6,000	Critical for propulsion and efficiency
3	Grid fins	₹2,000	EDFs offer more realistic jet
4	Flight Controller	₹4,000	Essential for smooth flight and autonomous operations.
5	Microcontroller	₹1,500	Handles custom control logic and Sensor integration
6	IMU Sensor	₹600	Measures orientation and movement
7	Altimeter/Barometer	₹500	Altitude data for better altitude
8	Battery (LiPo)	₹3,500	High-quality LiPo batteries are vital for safety and performance.
9	Landing Legs	₹1,500	Protects the drone and payload during landings
10	Miscellaneous	₹1,000	Essential for assembly and reliability
11	RC Transmitter & Receiver	₹4,000	Needed for manual control
12	Ground Safety Kit	₹1,000	Especially when handling batteries and during crashes.
13	**Total**	**₹27,100**	

VII. TIME SCHEDULE

Table 2

Month	Work Schedule
Aug 25 – Sept 9	Finding problem in searching place (hospital, agriculture, petrol pump, MSEB etc.).
Sept 10 - Sept 23	Discussion on effective problems and identification of most real problem.
Sept 24 – Oct 9	Final selection of problem.
Oct 10 – Oct 24	Collect references (books, journals, research papers, online sources).
Oct 25 – Nov 10	Fixing suitable project title.
Nov 11 – Dec 10	Literature review (study of past work, existing solutions, gap).
Dec 11 – Dec 31	Discussion on costing of project and estimation of budget (~25k).
Jan 1 – Jan 19	Preparation of block diagram (input–process–output).
Jan 20 – Feb 18	Methodology and flowchart preparation.
Feb 19 – Mar15	Draft report preparation (Intro, Problem statement, Literature, Costing, Block diagram, Methodology)
Mar 16 – Apr10	Correction, editing, and final report writing
Apr 11 – Apr26	Final submission, viva and presentation.

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https://doi.org/10.47001/IRJIET/2026.101019

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Citation of this Article:

A.M.Shelake, S.B.Jamdade, V.M.Kumar, P.T.Chothe, & A.R.Pattankude. (2026). Rocket Launch and Re-Landing Model (Reusable Rocket). *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 10(1), 152-159. Article DOI https://doi.org/10.47001/IRJIET/2026.101019

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