Landing Mechanism

Abstract

This report compiles a comparative study of various landing gear options and presents the selection of design and implementation of a lightweight landing mechanism for drones utilizing a locking leg system combined with limit switches at each leg.

The primary objective is to enhance the drone's landing capabilities on uneven terrains while minimizing weight and complexity. This innovative mechanism improves stability during landings, reduces the risk of rollover, and supports safe operation in challenging environments

Introduction

A critical challenge in drone operations is ensuring safe and stable landings, especially on sloped or uneven terrains. Traditional fixed landing gear systems often fail to provide the required adaptability, leading to potential rollover accidents or damage to the drone. This challenge becomes even more critical in extraterrestrial environments, such as the Martian surface, where uneven terrain, loose soil, and extreme slopes pose unique challenges to landing stability.

To address these issues, this report introduces a *novel lightweight landing mechanism* designed to ensure safe and reliable landings in harsh environments. The proposed system integrates locking legs equipped with limit switches, ensuring that the drone can adapt dynamically to Martian terrains while maintaining its stability and functionality.

Common Landing gear options:

1. **Fixed Landing Gear**

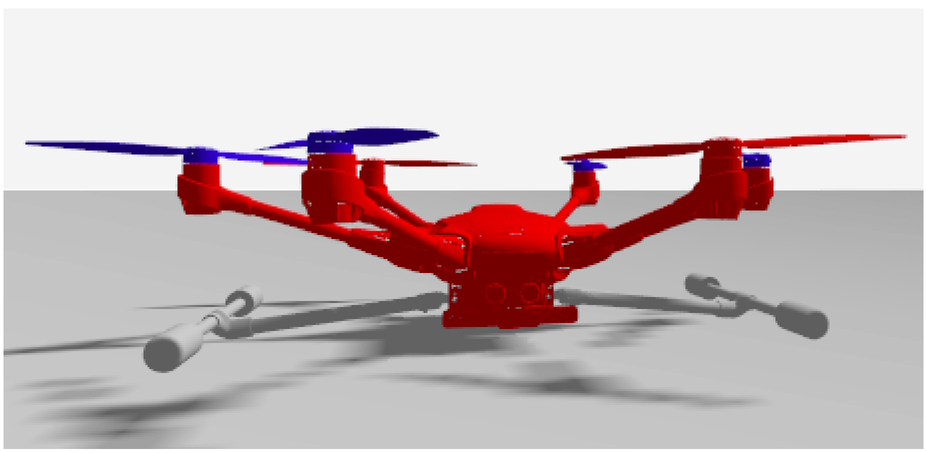
Overview	Rigid structure that is permanently attached to the drone.
Advantages	Lightweight and durable. Low cost and easy to install.
Disadvantages	Cannot retract; creates drag
Material	ABS
Total weight	80 g
Extra accessories	None

2. Skid Landing Gear

Overview	Long, flat legs (like helicopter skids) that distribute weight over a larger area.
Advantages	Simple design and sturdy.

	Suitable for uneven surfaces.
Disadvantages	Adds weight. Bulky, affecting portability.
Material	ABS
Total weight	230 g
Extra accessories	None

3. Retractable Landing Gear



Can be achieved with any leg design

Overview	Motorized or servo-operated legs that fold during flight to improve aerodynamics and camera view.
Advantages	Reduces drag. Clears the view for cameras or sensors.

Disadvantages	Heavier and more complex. Requires additional power and control mechanisms
Material	ABS
Total weight	200-300 g
Extra accessories	MG996R Servo x 2/4

4. Adaptive Landing Gear

Overview	Intelligent gear that adjusts to terrain or stabilizes dynamically during landing.
Advantages	Works on uneven or sloped surfaces. Enhances landing stability.
Disadvantages	High complexity and weight.
Material	ABS

Total weight	300-600 g
Extra accessories	MG996R Servo Motors (varies)

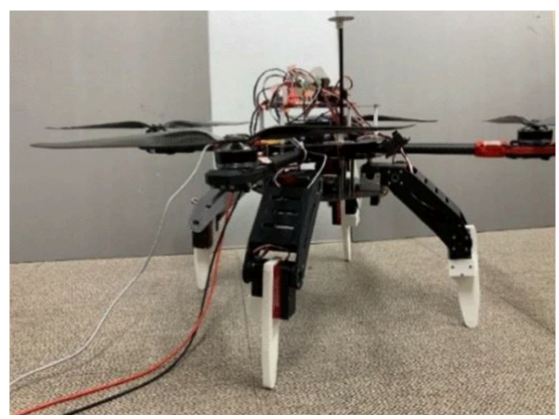
Some Implementation of Adaptive Landing Mechanisms along with video and reference link

1.

Title	Passive adaptive leg
Description	Using ratchet and pawl mechanism to lock legs in specified positions
Electronics	Servo motors x 4, Limit switch x 4
Expected Weight	170 g
Reference	Website access to paper Video available

2.

Title	Robust landing control
Description	Use of Servo motor and force sensor
Electronics	Servo Motor x 4, force sensor x 4
Expected Weight	Not specified, expecting 300 g
Reference	Website access to paper No video



3.

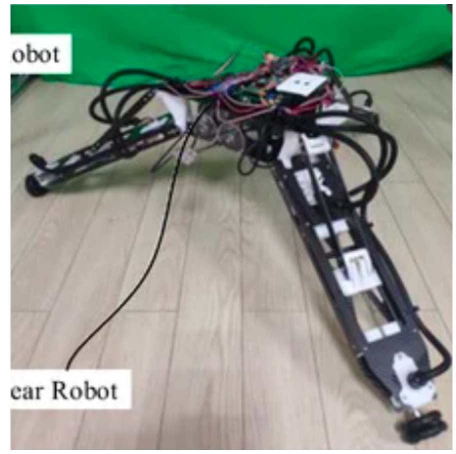
Title	Search & rescue drone with adaptive leg
Description	Use servo motor to adjust angle and then use DC motor to adjust leg length using screw lead mechanism
Electronics	Servo motor x 4, Micro DC x 4
Expected Weight	Not specified, expecting 600 g
Reference	Website access to paper Video available

4.

Title	Adaptive leg for helicopters
Description	Using 1 dof servo motor and force sensor. Mechanism not clear
Electronics	Servo motor x 4
Expected Weight	Not specified, expecting 300 g
Reference	Website access to paper Video available

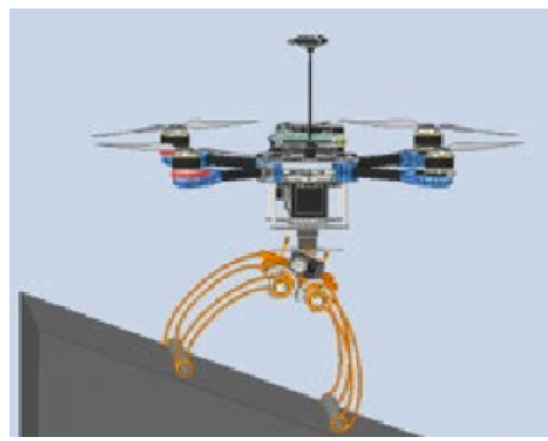
5.

Title	Adaptive leg with Multi sensor data fusion
Description	Using 1 dof micro dc motor to adjust length of leg, hip joint manipulation not clear
Electronics	Micro DC motor x 4
Expected Weight	Not specified, expecting <300 g
Reference	Website access to paper No video



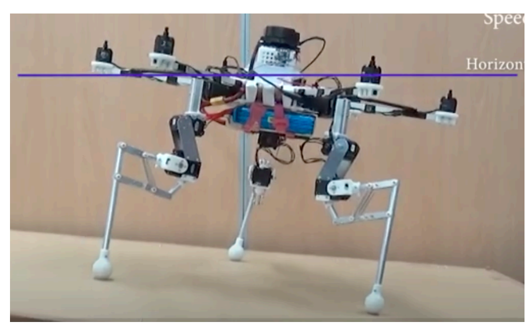
6.

Title	None
Description	Using single actuator to stabilize drone body with fixed leg
Electronics	Servo motor x 1
Expected Weight	Not specified, expecting >250 g
Reference	Website access to paper No video



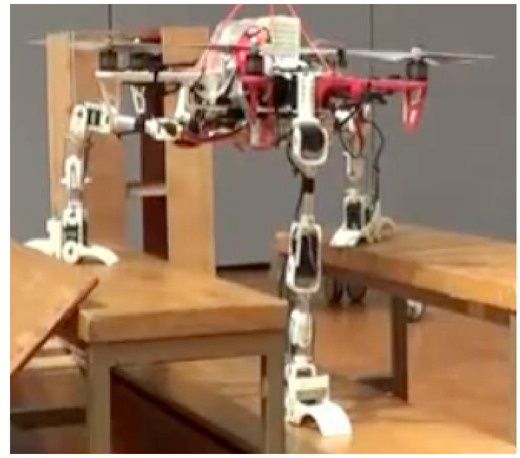
7.

Title	Versatile Aerial Manipulator
Description	Using 2 dof servo leg to adjust. (Similar to one discussed earlier)
Electronics	Servo motor x 8
Expected Weight	Not specified, expecting >300 g
Reference	No website No access to paper Video available



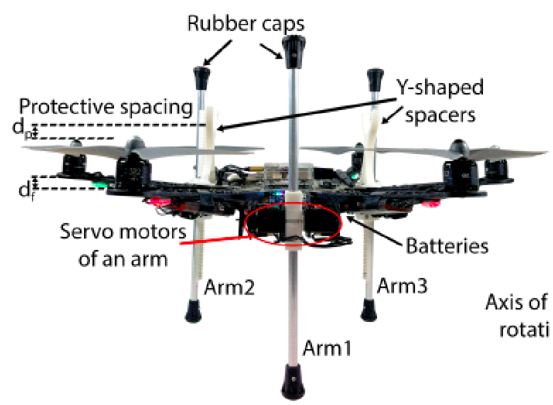
8.

Title	Landing of Multirotor aerial vehicle
Description	Using 3 dof legs to adjust on any given terrain and also has capabilities of grabbing objects and perching on branches
Electronics	Servo motor x 12
Expected Weight	Not specified, expecting >800 g
Reference	No website No access to paper [Video available]



9.

Title	Lightweight multipurpose arm
Description	One dof leg using a pinion and rack mechanism to adjust leg height for stable landing.
Electronics	Servo motor x 3
Expected Weight	Not specified, expecting <300 g
Reference	No website access to paper [Video available]



Title	Adaptive leg
Description	Using 2 dof servo leg to adjust. (Similar to one discussed earlier). And has adaptive feet end with integrated IMU
Electronics	Servo motors x 4, Limit switch x 4, IMU x4
Expected Weight	>350 g
Reference	Website access to paper Video available

Based on the above comparative study and prioritizing weight constraint, we have decided to use the following design:

Design Overview

The lightweight landing mechanism consists of four adaptive legs, each equipped with a limit switch. The legs are designed to extend and lock in response to ground contact, providing a stable base for the drone. This section provides an overview of the key components and their functions.

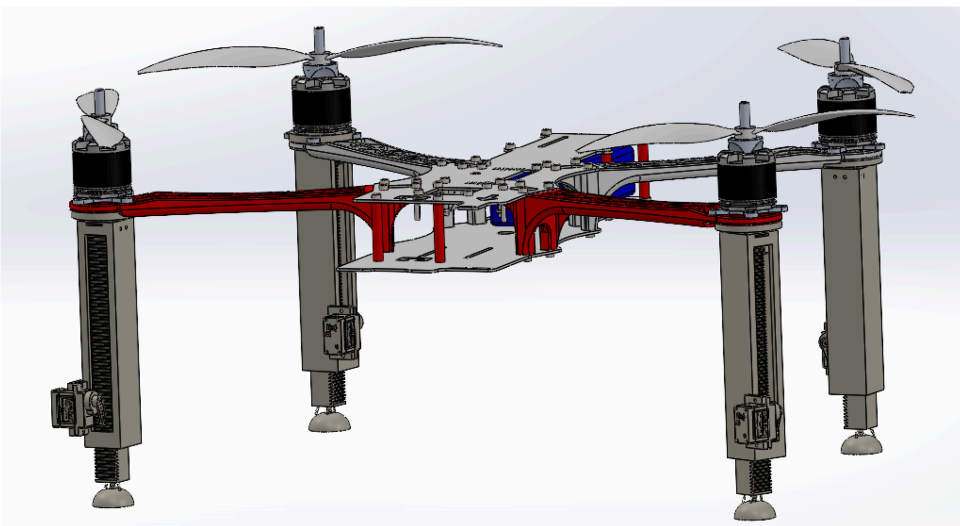


Fig 15.
All legs in **Close** Position

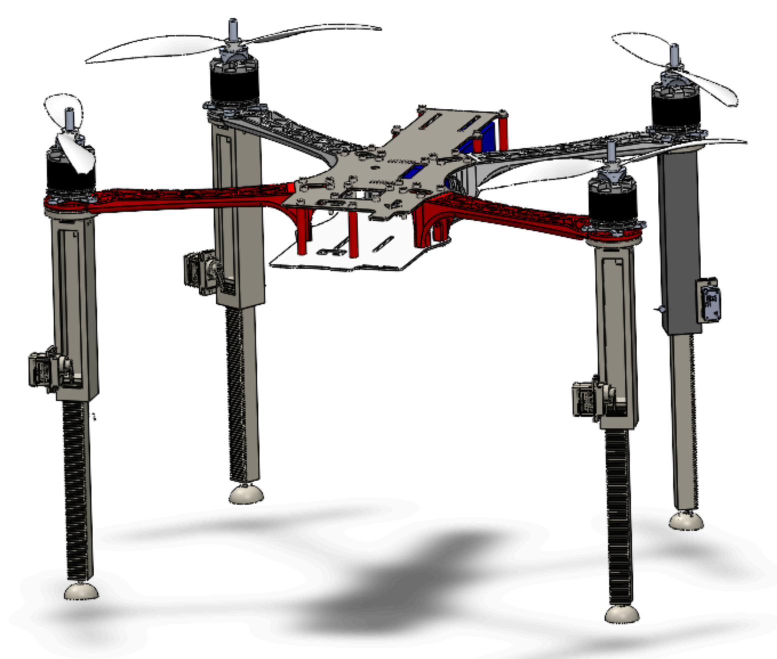
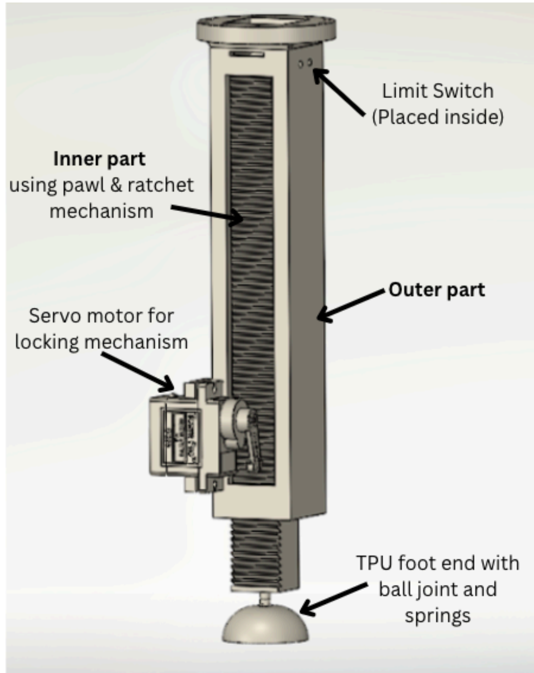


Fig 16.
All legs in **Open** position

Fig 17.
Leg design overview



Key Components

1. **Leg Mechanism:** The legs are articulated to allow movement and adjust based on ground contact. The design ensures that each leg can independently adapt to varying surface heights.

Fig 18.
Open position
Maximum leg
length
300 mm

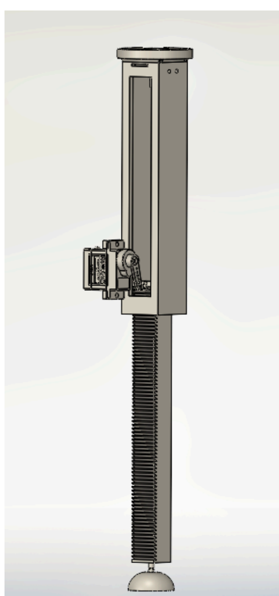
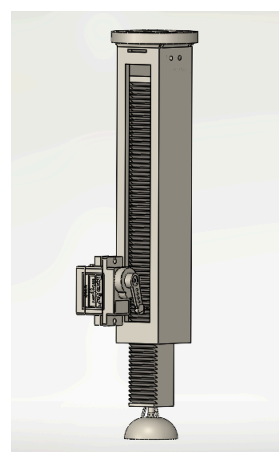


Fig 19.
Closed position
Minimum leg length
180 mm



2. **Limit Switches:** Positioned at the upper side of the legs, these switches detect when a leg has reached maximum compression and sends a signal to the control system.

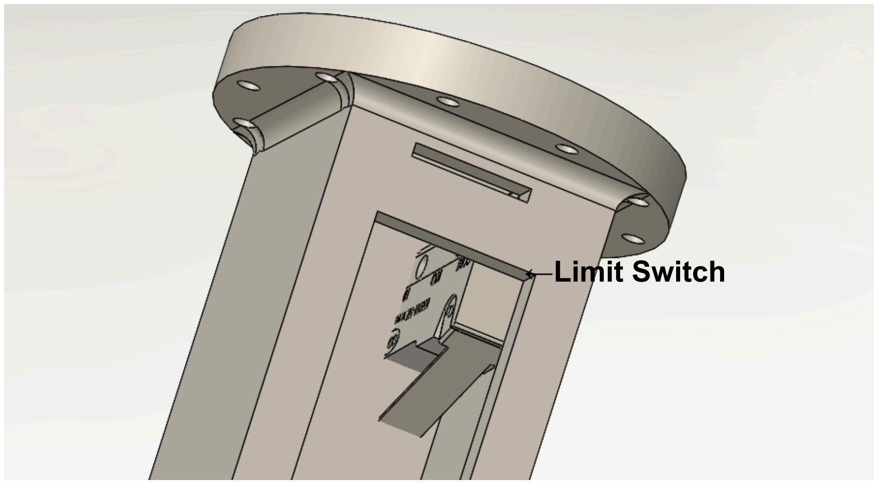
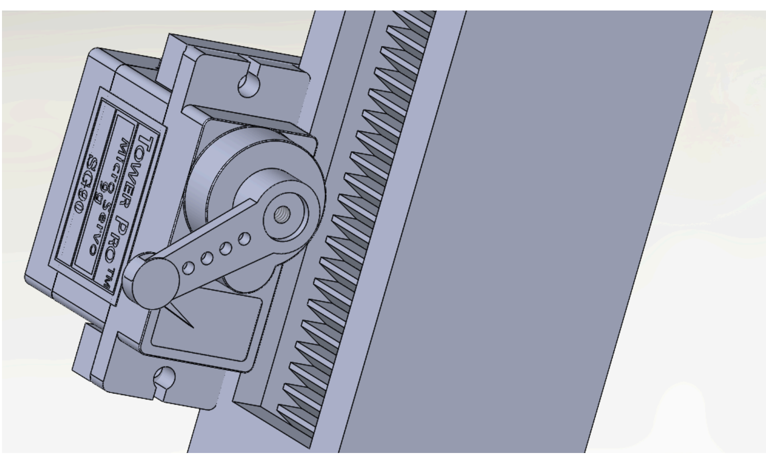


Fig 20.

Limit Switch position

3. **Servo Motor:** Each leg is controlled by a servo motor that locks the leg in place once it receives the command or when the limit switch is activated.



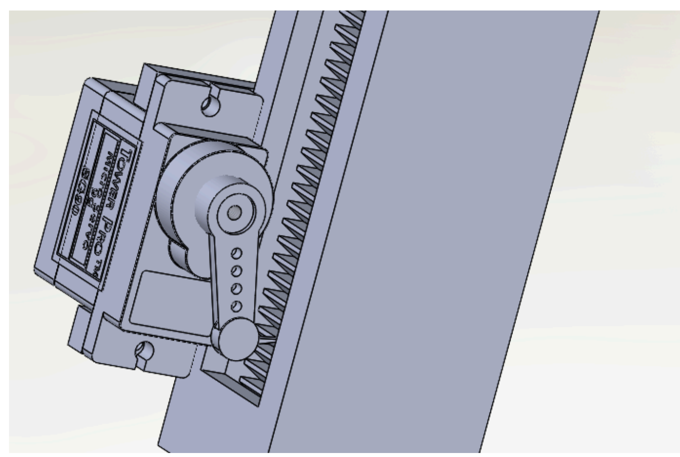


Fig 21. Open

Fig 22. Locked

3.**Locking Mechanism:** It consists of a *linear Ratchet and Pawl mechanism* where the pawl is attached to the servo tip, while the ratchet varies its length.

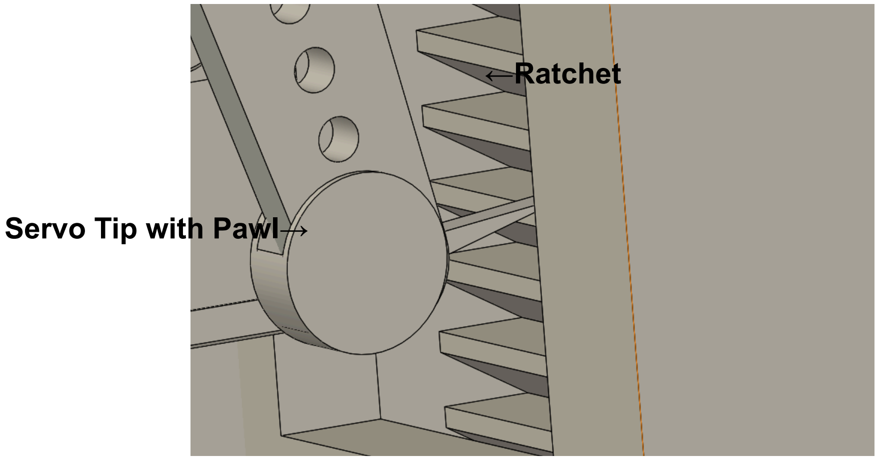


Fig 23.
Pawl and Ratchet mechanism

3.**Foot end:** 3D printed using TPU to enhance grip and is designed with a rough surface. It is connected with the upper leg using a ball joint. Additionally, 3 equally spaced springs are attached to it to maintain grip on inclined surfaces.

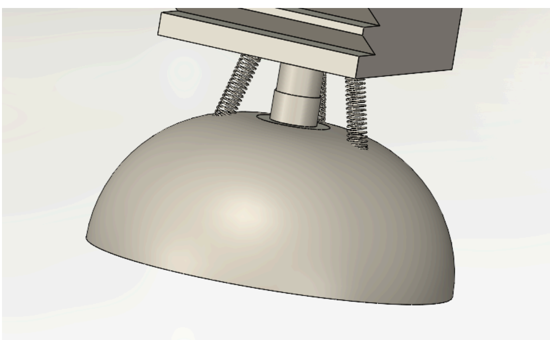


Fig 24.
Foot at rest position

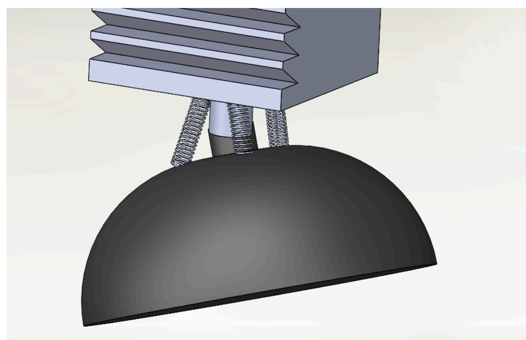


Fig 25.
Compressed due to external reactions

Parts and Dimensions

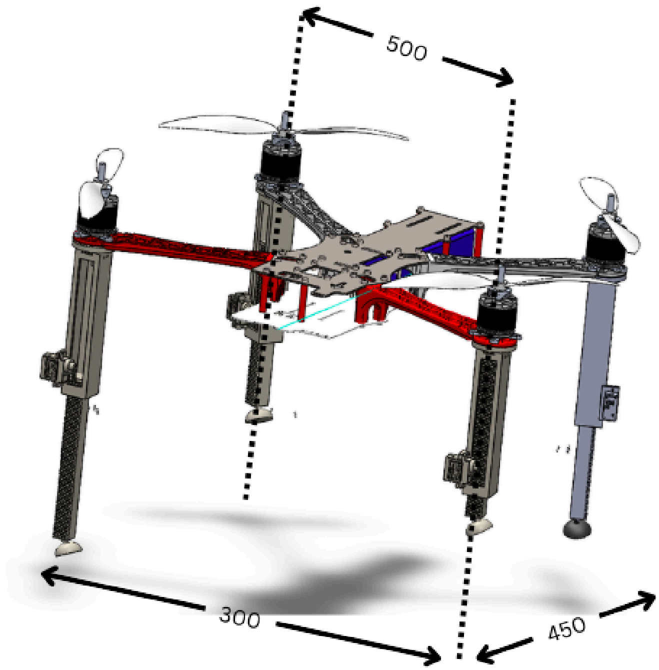


Fig 26.
Frame dimensions
Leg length varies from 180 mm to 300 mm

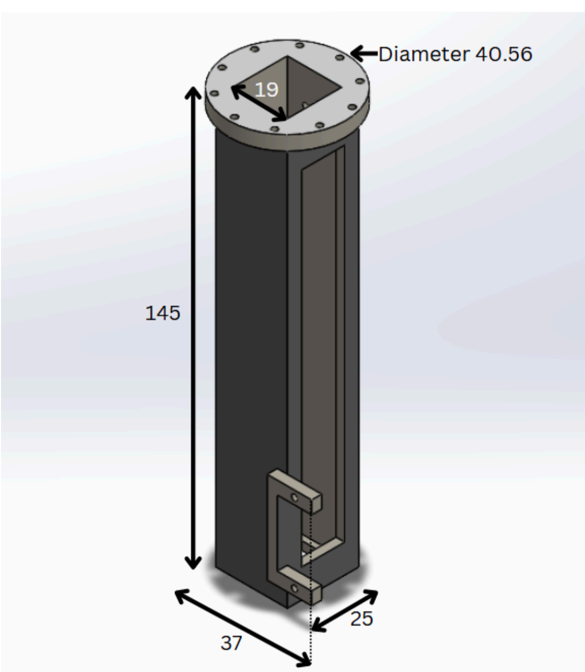
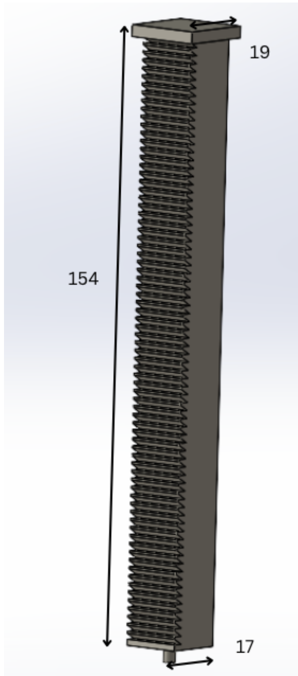


Fig 27.
Outer part with servo mount

Fig 28.
Inner part



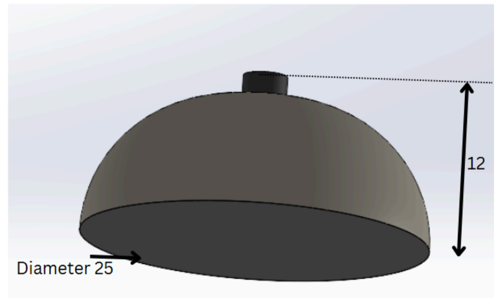


Fig 29.
TPU
Foot

Mechanism Operation

The landing mechanism operates in three primary phases:

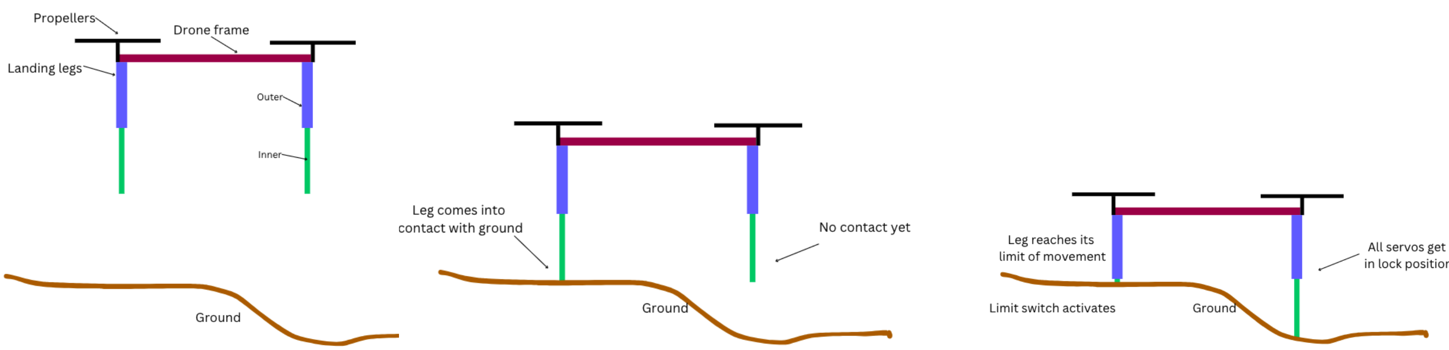
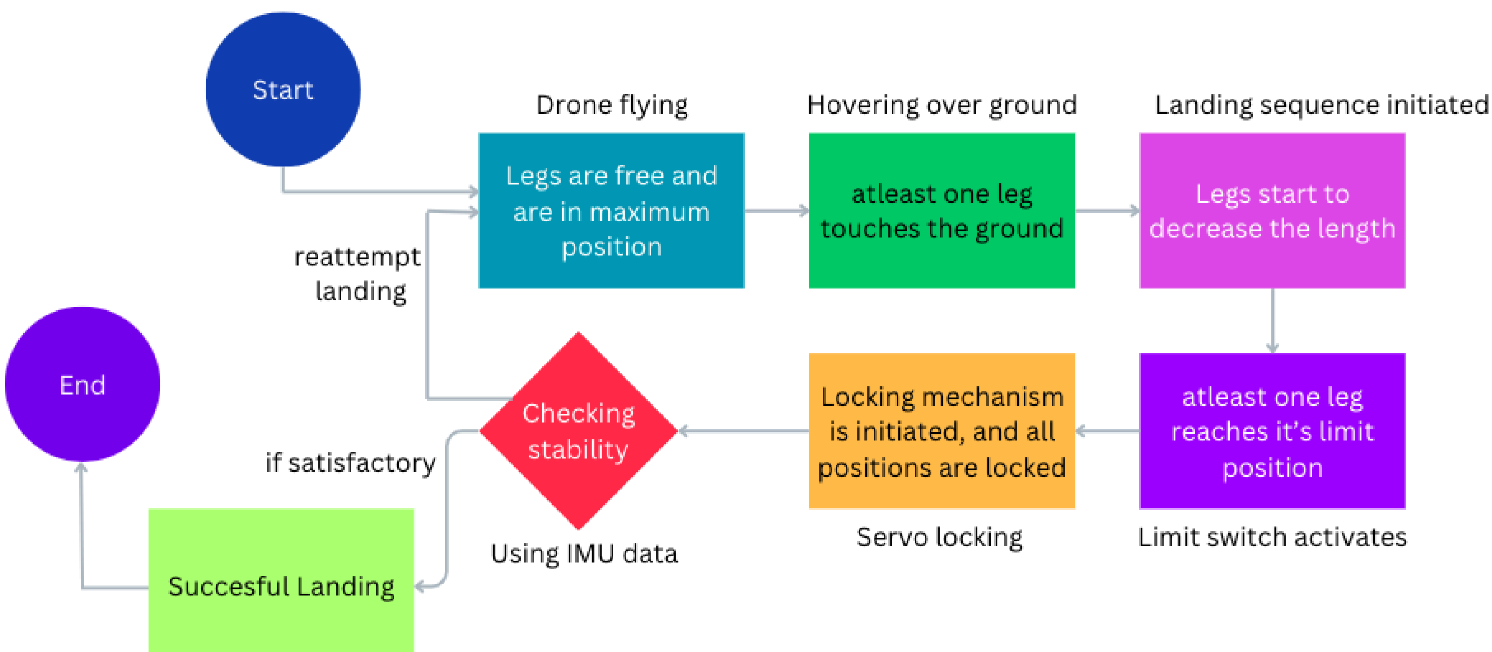


Fig 30.
Landing stages



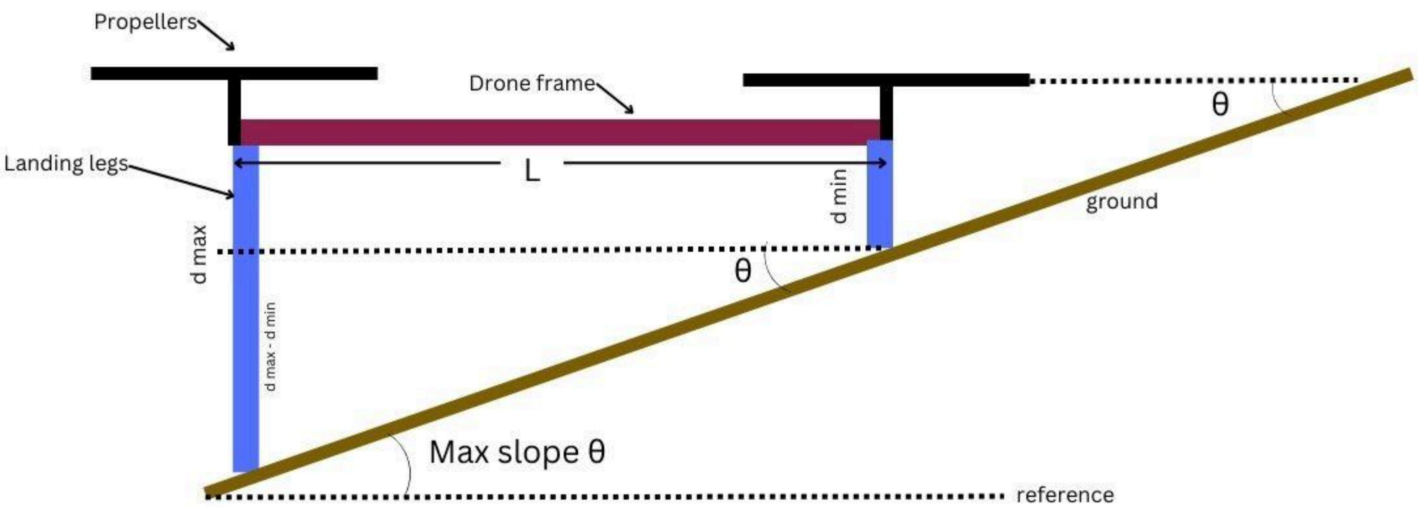
1. **Hovering mode:** Drone hovers in air and searches for *safe spots*.
2. **Landing sequence:** Once the safe spots are detected, landing sequence is initiated and the drone begins to descend.

3. **Locking & stabilization:** When at least one leg reaches its limit position, this is signalled by activation of the limit switch, and all the servos undergo lock position. Stabilization is confirmed from IMU data. If stability is not found, landing is reattempted.

The system adapts to the terrain's slope and unevenness, preventing tilting or rollover.

Stability angles and leg length selections

These equations provide a quantitative framework for assessing the mechanism's performance on sloped and uneven terrains.



$$\theta = arctan((d\_max - d\_min) / L)$$

Here;
θ : Angle with the ground
d_max : Length of leg at max extension
d_min : Length of leg at min extension = 180 mm

L : Length of drone frame
This has three cases (as mentioned in fig 26.), drone landing:

- diagonally => L = 500 mm
- on front => L = 300 mm
- on side => L = 450 mm

Let d_max = 2 x d_min —- [1]

Since θ is inversely related to L, for maximum L, θ will be minimum. This means if in case the drone lands diagonally, the maximum inclination angle would be less. Therefore we use this case to calculate lengths of the leg.

i.e for L = 500 mm, corresponding values are

θ in degrees	d_max in mm
60	1732.04
45	1000
30	577.34
20	**364**
15	268
10	176.32

Keeping in mind the weight limit (since longer lengths => more weight)

From equation [1]
=> length of closed leg ~ 182 mm ~180 mm

This gives the angle at which drone lands **perfectly stable** is 20 degrees
It can land stably even on inclinations of 30 degrees with minor tilt.

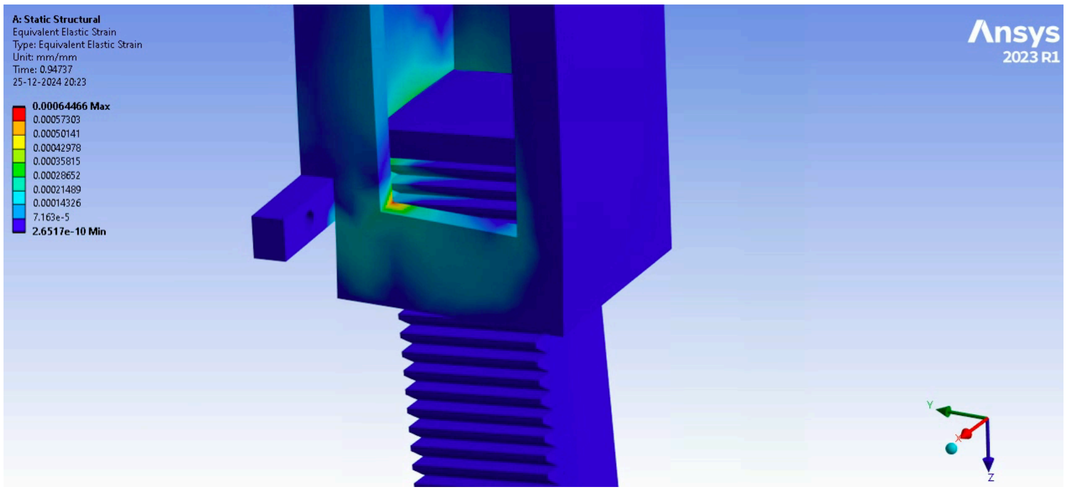
Weight Budget

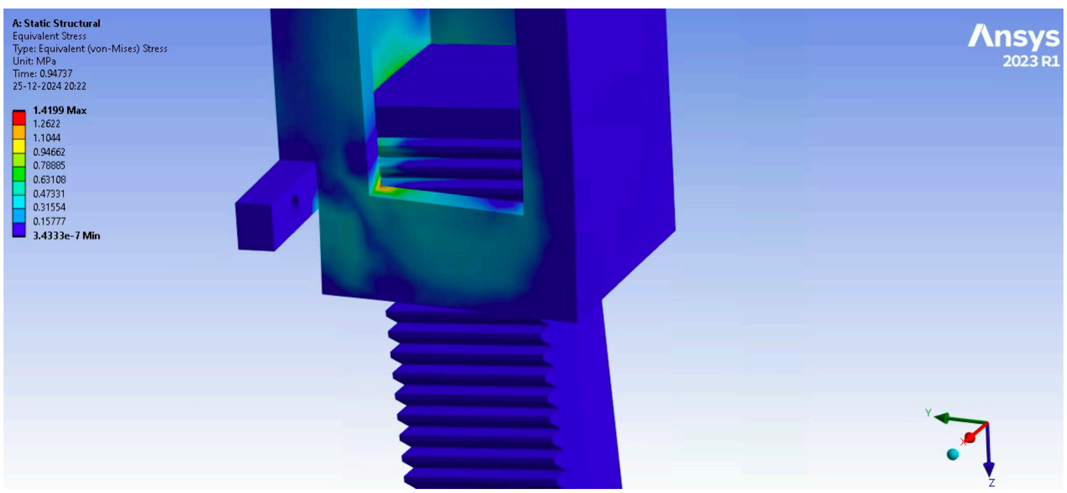
Component	Quantity	Unit Weight	Total Weight	Unit Price	Total Price
SG90 Servo Motors	4	9 g	36 g	Rs 90	Rs 360
KW10-Z1P Limit Switch	4	1 g	4 g	Rs 4	Rs 16
Compression Spring 25mm	12	1 g	12 g	Rs 20	Rs 240
M3 Screws	32	0.375 g	12 g	Rs 3.75	Rs 120
Outer*	4	13.8 g	55.2 g	-	-
Inner*	4	12.3 g	49.2 g	-	-
TPU Parts*	4	1.52 g	6.08 g	-	-
		Total Weight	**174.48 g**	Total Price	Rs 736

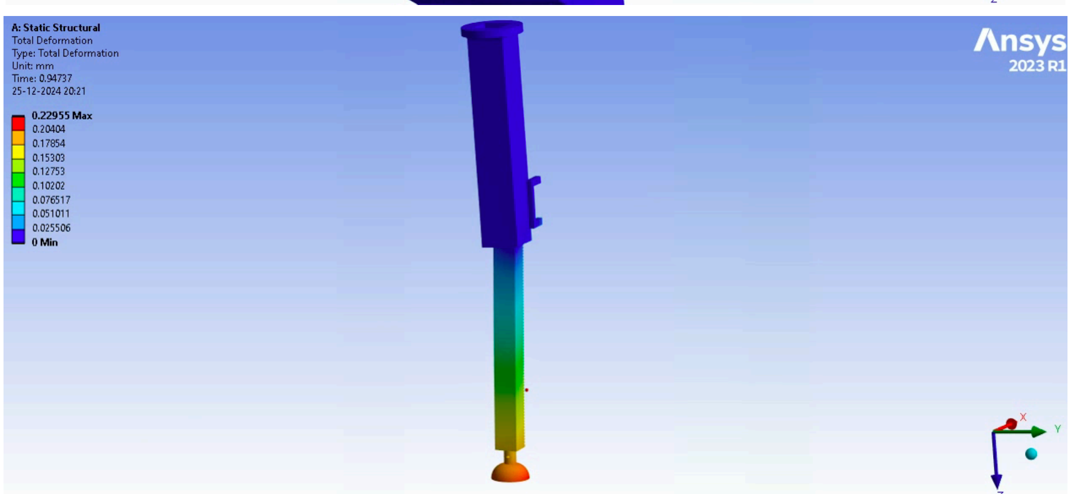
*Calculations of 3d printed parts done at 30% infill

Experimental Validation

Structural analysis on the legs is performed, keeping in mind that each leg should atleast support 500 g of load (max drone weight is 2 Kg). This is approximately equal to 4.9 N of force on the legs. To simulate rough or impact landing, a safe margin of 20 N perpendicular force is tested on the legs. Following results are obtained:



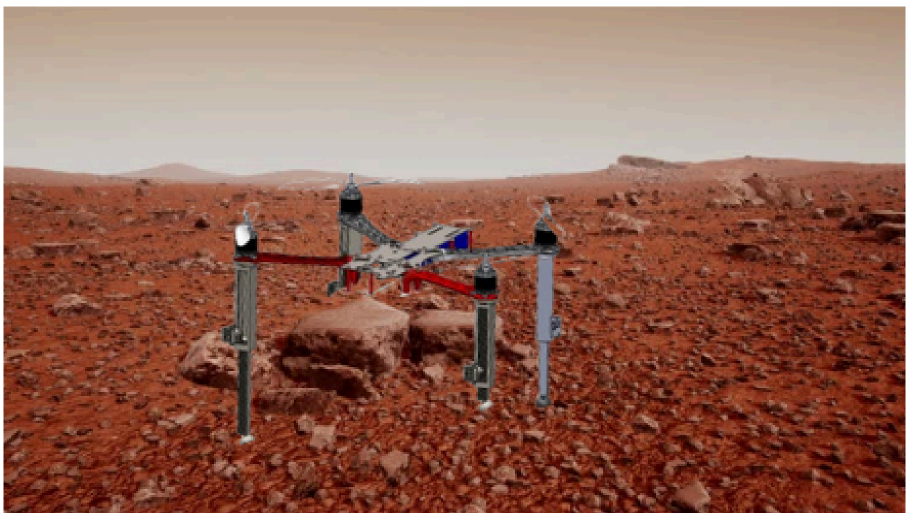


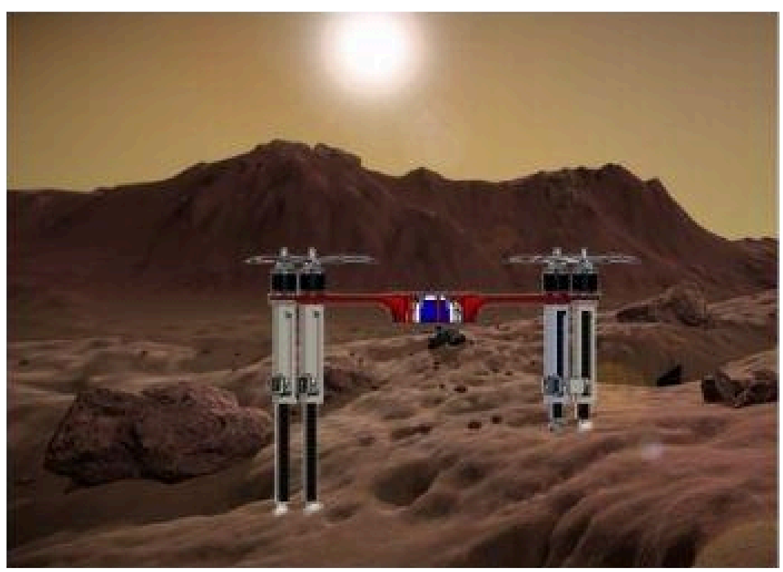


Maximum deformation of 0.23 mm is observed under impact. This makes the landing gear reliable for our use.

Further tests are planned to assess the mechanism's performance under varying environmental conditions, such as wet or loose terrain.

Conclusion
The proposed lightweight landing mechanism offers a practical and innovative solution to enhance the landing stability of drones on uneven terrains. By integrating a locking leg system with limit switches, the mechanism ensures safe and reliable landings while maintaining a lightweight design. Future work will focus on optimizing the mechanism's design, improving component durability, and conducting extensive field tests across diverse terrains.





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