A Low-cost Model of a Poly Picosatellite Orbital Deployer for Satellite Technology Education in Developing Nations

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Abstract- This paper reports on the design, fabrication, and experimental validation of a low-cost model Poly Picosatellite Orbital Deployer (P-POD) developed to enhance satellite engineering education in resource-limited settings. Recognizing the lack of affordable infrastructure for practical training in developing nations, the model was constructed using locally available materials, specifically Perspex and mild steel, to provide a functional yet economical alternative to flight-grade systems. The structural design was modelled and analyzed in SolidWorks to verify its mechanical integrity under simulated loads before fabrication. Performance evaluation in controlled laboratory conditions demonstrated the successful deployment of a 2U CubeSat model, achieving an average ejection velocity of 1.25 m/s within one second, closely approximating the operational standards of certified P-POD units. These results highlight the potential of such models to deliver safe, cost-effective, and pedagogically valuable tools for building local capacity in space science and engineering education, thereby bridging the gap between theoretical instruction and practical skill development.

Index Terms- CubeSat, Deployment Systems, Low-cost P-POD Model, Poly Picosatellite Orbital Deployer (P-POD), Satellite Technology Education

I. INTRODUCTION

The rapid evolution of satellite technology in the 21st century has significantly lowered barriers to space, enabling universities, research institutions, and even high schools to actively participate in satellite missions. At the forefront of this transformation is the CubeSat – standardized, miniaturized satellites designed in units of 10 × 10 × 10 cm (1U). CubeSats are cost-effective, versatile, and suitable for a wide range of applications, including academic research, technology demonstrations, Earth observation, and scientific experiments [1].

Central to the successful deployment of CubeSats is the P-POD, a standardized mechanical interface between CubeSats and their launch vehicles. Developed at California Polytechnic State University, the P-POD ensures that CubeSats are securely stowed during the extreme conditions of launch and safely deployed once in orbit. Over time, P-PODs and similar deployers have become a reliable standard in satellite missions, providing safe, repeatable deployment mechanisms [2].

Despite the accessibility of CubeSat programs in developed countries, many educational institutions in developing regions remain excluded from meaningful, hands-on participation. While countries such as Nigeria have launched satellites through agencies like the National Space Research and Development Agency (NASRDA), university students often engage with satellite deployment only in theory. A major reason for this gap is the lack of affordable, practical infrastructure for training in the mechanical and systems engineering aspects of deployment. Full-scale, flight-grade deployers are prohibitively expensive and typically manufactured abroad, creating significant barriers to entry [3].

Addressing this challenge requires the development of low-cost, functional models that simulate real-world deployment systems. Such models can serve as critical educational tools, enabling students to gain experiential learning opportunities that deepen their understanding of space systems engineering, mechanical design, and integration processes. Beyond supporting classroom instruction, these models contribute to local capacity-building by fostering innovation and problem-solving within the constraints of local resources.

This paper presents the design, fabrication, and testing of a low-cost educational P-POD model, developed specifically for laboratory and classroom use. The deployer was constructed from locally sourced materials, primarily Perspex and mild steel, to maximize accessibility and minimize cost. The design was modeled and analyzed in SolidWorks to verify structural integrity under simulated load conditions, after which the system was fabricated and tested in controlled laboratory environments. Performance evaluation focused on deployment velocity, mechanical stability, and repeatability using a 2U CubeSat model. Results demonstrate that the system achieved deployment velocities averaging 1.25 m/s in under one second, closely approximating the performance of flight-grade systems.

By providing a safe, cost-effective, and replicable alternative to commercial deployers, this work contributes to the growing body of educational tools for satellite engineering. The proposed model bridges the gap between theoretical instruction and practical application, offering institutions in resource-limited settings a viable pathway to engage in meaningful, hands-on space science education.

II. RELATED WORK

The revolution in satellite technology has been driven by miniaturization, which has significantly reduced costs, shortened development timelines, and standardized spacecraft interfaces [4]. This shift is most evident in the rise of the CubeSat; a small satellite built from 10 × 10 × 10 cm cubic units. As Sweeting [5] observed, CubeSats have enabled a "new space economy," fostering applications that range from academic research and technology demonstrations to large-scale commercial constellations.

In 1999, Professor Jordi Puig-Suari (California Polytechnic State University) and Professor Bob Twiggs (Stanford University) introduced the CubeSat standard. Their goal was to transform imaginative classroom concepts into practical spacecraft that students could design, assemble, and even launch within an academic program [6][1]. This innovation made space accessible to universities and colleges worldwide, sparking a wave of hands-on education in aerospace engineering.

Recent developments have further expanded educational opportunities. Swartwout [7] analyzed over 100 university CubeSat missions, finding that educational programs consistently produced better learning outcomes when students engaged with physical hardware rather than purely theoretical studies. This finding has driven increased interest in developing cost-effective educational infrastructure.

The success of educational CubeSat programs has been well-documented in developed nations. Klofas et al. [8] demonstrated that Cal Poly's CubeSat program produced graduates with significantly enhanced systems engineering skills compared to traditional curricula. Participation in CubeSat initiatives has proven effective in boosting student retention within aerospace engineering and related STEM disciplines. According to the National Academies of Sciences, Engineering, and Medicine [9], hands-on engagement in CubeSat projects can enhance retention by 20-25% over three to five years, as evidenced by evaluations from NSF-funded programs. These initiatives promote practical skills in design and teamwork, leading to higher graduation rates, with over half of participants pursuing STEM careers. Such experiential learning opportunities are particularly impactful in resource-constrained academic settings, supporting the development of skilled engineers. This aligns with regional efforts, such as those in Nigeria, to integrate practical space technology training into educational curricula.

Beyond their technical role, CubeSats have emerged as a powerful educational tool. Woellert et al. [3] emphasized that small satellites deliver outsized educational returns by allowing students to engage directly with the design, testing, and operation of spacecraft. Programs like NASA's CubeSat Launch Initiative (CSLI) further reinforce this, offering academic team opportunities to place CubeSats into orbit while following standardized guidelines [10][11]. Such initiatives demonstrate the value of CubeSats as catalysts to educate future aerospace professionals.

Critical to CubeSat success is a safe and standardized deployment mechanism. The P-POD, from

California Polytechnic State University, uses a spring-ejection system to mechanically separate CubeSats from the rocket during launch, providing a safe, non-explosive deployment method [2]. The P-POD not only enabled safe integration but also established a deployment standard that has since inspired a wide range of compatible deployers. Commercial providers such as ISISPACE introduced systems like the ISIPOD and QuadPack, which offer expanded deployment capacities up to 16U while maintaining CubeSat-standard interfaces. For deployments from the International Space Station (ISS), specialized systems such as JAXA's J-SSOD and Nanoracks deployers employ robotic arms and airlock operations, offering students unique exposure to orbital mechanics and human–spacecraft interaction [12].

The high cost and complexity of flight-grade deployers have limited their use in educational settings, especially in developing nations. To address this, several institutions have developed simpler, more affordable alternatives for laboratory use. For instance, the University of Stuttgart's Institute of Space Systems has a long history of designing and fabricating simplified, ground-based deployer prototypes. These testbeds are crucial for students to test the structural integrity and ejection systems of their CubeSat models before a full-scale mission can be considered. Similarly, the University of Witswatersrand in South Africa developed a low-cost, portable CubeSat launcher and testbed to make space technology more accessible. By using readily available materials and simplified mechanical components, their design allows students to learn about satellite deployment dynamics without the need for expensive, commercial-grade equipment.

More recently, additive manufacturing has enabled new approaches to educational space hardware. Several studies have explored 3D-printed components for educational satellite systems, demonstrating that rapid prototyping technologies can significantly reduce costs while maintaining educational value [13][14]. However, despite global progress, many institutions in developing countries remain excluded from hands-on participation in satellite projects. In Nigeria, for example, students contributed to the EduSat-1 project launched in 2017 as part of the BIRDS-1 collaboration. While the mission was a success, much of the Nigerian student involvement was limited to theoretical design and systems engineering, with little exposure to the physical hardware [15]. This disconnect between theory and practice deprives students of critical "hands-in-the-hardware" experiences, such as troubleshooting and iterative testing, which are essential for building engineering intuition and problem-solving skills.

Recent research has explored using locally available materials for educational space hardware. Several studies have investigated the feasibility of substituting expensive aerospace-grade materials with more accessible alternatives for educational applications. Chaichuenchob and Chusri [16], and Heidt *et al*, [1] demonstrated that common engineering materials could effectively replicate space system functions in educational contexts. Their work showed that aluminum substitutes like steel and plastic could provide adequate performance for ground-based educational systems while dramatically reducing costs. The use of standard machining techniques rather than specialized manufacturing processes has also been explored. Traditional machine shop capabilities available at most universities can produce functional educational hardware when properly designed [17].

Existing literature also highlights gaps in the systematic development of region-specific educational tools. Studies rarely address how to design deployers or training systems using local materials, indigenous manufacturing capabilities, or curricula tailored to local contexts. The United Nations Office for Outer Space Affairs [18] has emphasized the importance of locally sourced resources, noting that projects built with accessible materials not only reduce costs but also foster innovation by encouraging students to design within their own constraints. Commercial deployers typically achieve payload capacities up to 24 kg and deployment velocities in the 0.8–1.8 m/s range, providing clear performance benchmarks that low-cost educational replicas can safely emulate.

Emerging manufacturing technologies further broaden opportunities for democratizing space education. Additive manufacturing, coupled with accessible computer-aided design (CAD) tools, enables institutions to develop affordable, customizable models tailored to their educational needs. Recent work has demonstrated how low-cost 3D printing and CAD software can support the creation of deployer models and satellite mockups for hands-on training [19][14].

Bridging this gap between the enormous educational potential of small satellites and the persistent barriers faced by institutions in developing regions requires low-cost, functional educational models that replicate the essential functions of systems like the P-POD using local materials and fabrication techniques. Such tools can empower students with experiential learning opportunities, strengthen problem-solving skills, and contribute to building local capacity for sustainable space programs.

III. MATERIALS AND METHOD

The design and construction of the low-cost P-POD model followed a systematic engineering process that included computer-aided design, theoretical analysis, and physical fabrication. The primary goal was to create a functional deployer that could safely eject a 2U CubeSat model using locally sourced, affordable materials.

Table 1: Components, materials, and factors for their selection

Component	Material(s)	Rationale
POD Cage	Perspex (Acrylic)	Easy to machine, lightweight, transparent for demonstration, and low cost.
Main Spring	Mild Steel	Provides necessary compression force; locally available.
Hinges, Bolts, & Nuts	Mild Steel	Chosen for strength, durability, and corrosion resistance.
Hold & Release Mechanism	Plastic, Aluminum, Steel	A custom-built rack-and-pinion system for demonstrative purposes.
Electronics	Printed Circuit Board (PCB), Transformer, Resistors, Transistors, Integrated Circuits, Remote Control	Off-the-shelf components for a simple, functional control system.
Fasteners	Solder Lead, Strong Adhesive	Used for electrical connections and non-load-bearing joints.

A. *Materials and Components*

Table 1 shows the list of components, materials and reasons for their selection.

Unlike flight-ready deployers typically made from Aluminum 7075 for its high strength-to-weight ratio, this model was constructed from materials chosen for their cost-effectiveness, accessibility, and ease of machinability.

B. *System Description*

Similar to its flight-grade counterpart, the educational P-POD model is a system of interconnected mechanical and electronic components designed for the reliable deployment of a CubeSat model. The major components are as illustrated in the system diagram in Figure 1.

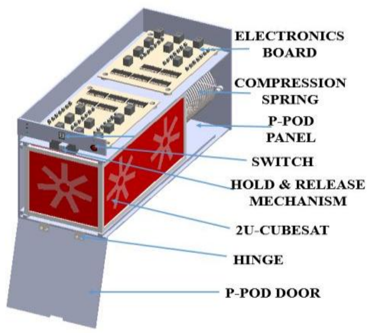

Figure 1: Components of P-POD model

1. The POD Cage

The cage is a rectangular tubular structure designed to house the CubeSat model, the main spring, and the internal electronic and mechanical subsystems.

It consists of four main panels (top, bottom, and two sides), along with a front door and a back lid. The cage is fabricated from Perspex (acrylic), which was chosen for its ease of machinability, low cost, and transparency for educational demonstrations.

2. The Main Spring

The spring is a helical compression spring, designed to provide the force necessary for CubeSat ejection. It is made of mild steel wire with a diameter of 2.5 mm and has seven turns. The spring is secured to the back lid using a Perspex bar and two pairs of bolts and nuts, ensuring the spring remains in a fixed position during operation.

3. Hinges

The two hinges are integral to the deployer's door mechanism. They are made of mild steel for their strength and resistance to friction. The hinges allow for a 270-degree rotation of the door, ensuring a full and unobstructed path for the CubeSat upon ejection.

4. Hold and Release Mechanism

This mechanism is a critical component responsible for holding the CubeSat securely within the deployer and initiating its release upon command. While flight-grade deployers often use high-reliability mechanisms like Line Cutters or Pin Pullers, this educational model utilizes a rack-and-pinion mechanism for its simplicity and demonstrative value (Figure 3). The system turns the rotary motion of a servo motor into the straight-line movement of a rack. which is used to retract a hook that secures the door.

5. Printed Circuit Board (PCB)

The custom-designed PCB serves as the central electronic platform for the deployer's control system.

It is populated with various electrical components, including a transformer, resistors, transistors, and integrated circuits. The PCB is responsible for receiving the wireless signal from the remote control, processing it, and triggering the servo motor of the hold and release mechanism after a predefined countdown.

C. Operational Sequence

The P-POD model is a tubular configuration with internal rails that guide the CubeSat during ejection to prevent spinning upon deployment. Figure 2 illustrates a P-POD model showing guide rails.

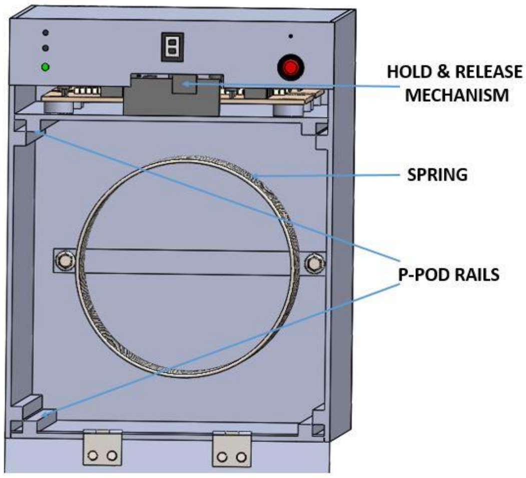

Figure 2: P-POD model showing guide rails

The operational sequence is as follows:

1. Stowage: The CubeSat model is loaded into the deployer and compressed against the door. The hook of the rack-and-pinion mechanism firmly secures the door in its closed position.
2. Command: A wireless signal is sent from the remote control to the PCB.
3. Countdown and Release: Upon receiving the signal, the PCB initiates a countdown. Once the countdown expires, the servo motor is activated, causing the rack to retract its hook from the door.
4. Deployment: With the door unlocked, the stored energy in the compressed spring is released, ejecting the CubeSat along the guide rails. The door rotates open fully, providing a clear exit path.

D. Design Analysis

The P-POD model was designed and analyzed using SolidWorks, a computer-aided design (CAD) software. This allowed for the accurate modeling of all structural components and virtual prototyping to verify mechanical integrity before physical fabrication. The virtual model was used to check for component interference and to simulate the deployer’s behavior under load.

A key design objective was to replicate the deployment dynamics of a flight-grade P-POD. The energy transfer from the compressed spring to the CubeSat model was analyzed using the principles of conservation of energy. The design equation for the ejection velocity was derived from the assumption that all potential energy stored in the spring is converted into the kinetic energy of the ejected satellite.

1. Determination of Spring Constant

The helical compression spring used was sourced from local shop. With a proposed Cubesat size (2U) having the dimension 10cm x 10cm x 20cm, the spring constant (K) was calculated using equation (1) [20].

$$K = \frac{Cd^4}{8D^3n} \qquad 1$$

where, K is the spring constant, determined by the modulus of rigidity (G) of the spring material, the wire diameter (d), the mean coil diameter (D), and the number of active coils (n).

From Equation (1), with the parameters of the helical spring given as:

- Spring Deflection (δ) = 17.4 cm
- Free Length = 21 cm
- Inner Diameter (D) = 8 cm
- Core Diameter of wire (d) = 2 mm
- Number of turns (n) = 8
- Modulus of rigidity (C) = 79×10^9 Pa

$$K = \frac{82 \text{ x } 10^9 \text{ x } 0.002^4}{8 \text{ x } 0.06^3 \text{ x } 8} = 38.57N/m$$

2. Determination of Force Produced by the Spring

The force produced by the spring is given by Equation (2) [20].

$$K = \frac{F}{\delta} \qquad 2$$

$$F = 38.57 \times 0.174 = 6.71N$$

3. Minimum Holding Force of the Door Stopper

Figure 3 shows the free body diagram of the door of the P-POD model.

F_{Bolt} = Holding force of the door stopper

F_{Cubes} = Payload generated forces acting on the door = 6.71N

S_{Bolt} = Perpendicular distance of stopper holding force from the fulcrum = 16cm

S_{Cubes} = Perpendicular distance of payload force from the fulcrum = 7cm

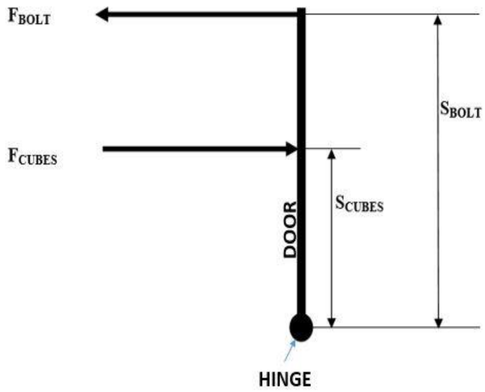

Figure 3: Free Body Diagram of the door

Taking moment about the hinge:

$$0 = (F * S)_{bolt} - (F * S)_{cubes}$$
$$(F * S)_{bolt} = (F * S)_{cubes}$$
$$F_{bolt} * 16 = 6.71 * 7$$
$$F_{bolt} = \frac{6.71 * 7}{16}$$
$$F_{bolt} = 2.94\text{N}$$

4. Determination of the Capacity of the Cage

The P-POD was designed to deploy two (2) Picosatellites of size 10cm x 10cm x 20cm at a time. With the dimensions of the satellites in mind, the capacity of the P-POD was arrived at using Equation (3):

$$Volume\ of\ the\ Cage = H \times W \times L \qquad 3$$

where, height, width, and length of the P-POD are: $H = 12.5cm$; $W = 12cm$, and $L = 28cm$

$$Volume = 12.5 \times 12 \times 28 = 4200cm^3$$

5. CubeSat Model Mass Measurements

Measurement of the mass of the 2U CubeSat model was conducted across five trials. The recorded mass was 0.69 kg for Trial 1 and 0.68 kg for Trials 2 through 5. The CubeSat model's average mass (m) was calculated to be 0.68 kg.

6. Determination of Ejection Velocity

The primary design equation is the energy transfer from the P-POD's compression spring to the CubeSat with the assumptions that:

1. The system is frictionless.
2. Total potential energy stored in the spring is converted into the kinetic energy of the ejected satellite [20].

$$E_{potential} = E_{kinetic} \qquad 4$$

where, $E_{potential}$ is the stored potential energy in the compressed spring, and $E_{kinetic}$ is the kinetic energy of the CubeSat just after ejection.

The potential energy of the spring ($E_{potential}$) is determined by the spring's stiffness and how much it is compressed, and can be expressed as:

$$E_{potential} = \frac{1}{2} k \Delta x^2 \qquad 5$$

where, k is the spring constant = 38.57 N/m, and Δx is the change in spring length from its relaxed state = 0.174 m.

The kinetic energy of the satellite ($E_{kinetic}$) is the energy of the satellite in motion as it leaves the P-POD, expressed as:

$$E_{kinetic} = \frac{1}{2} m v^2 \qquad 6$$

where, m is the mass of the CubeSat = 0.68 kg, and v is the ejection velocity (m/s).

By setting Equation (5) equal to Equation (6), we can solve for the ideal ejection velocity (v):

$$v = \Delta x \sqrt{\frac{k}{m}} \qquad 7$$

From Equation (7);

$$v = 0.174 \sqrt{\frac{38.57}{0.68}} = 1.31\ m/s$$

The CubeSat model is expected to have an average release velocity of 1.31m/s.

E. Fabrication

The fabrication process integrated both manual and power-tool operations to shape and assemble the components. The Perspex panels for the POD cage were first marked using precision tools such as scriber, steel rule, and Vernier caliper. They were then cut to size using a hacksaw and a cutter. A pillar drilling machine was used to create precise holes in the side panels, which were later fastened with bolts and nuts. Grinding with a hand machine and files ensured that all edges were smooth and accurate. The final assembly involved securing the Perspex panels, mounting the spring and the hold-and-release mechanism, and integrating the electronic circuitry. A strong adhesive was also used for non-load-bearing joins to ensure structural integrity and a clean finish.

The orbital deployer, having been fully designed and fabricated as shown in Figure 4, was subsequently tested to verify the efficiency of its deployment. All design concepts and calculated results were strictly adhered to, with little or no observed variations. An experiment was developed to study the motion of a 2U CubeSat model released from a P-POD deployer, focusing on the time and distance traveled during deployment. Using precise tools like digital stopwatch and measuring tape, the study ensures accurate data collection on a 2m × 1m flat surface.

Figure 4: Fabricated P-POD and its circuitry

IV. TESTING

The methodology outlines a controlled setup and a detailed procedure for conducting 10 trials to capture reliable time-distance relationships. This empirical data will enable analysis of the CubeSat's motion under consistent conditions. The results aim to enhance understanding of P-POD deployment dynamics for space applications. The pre-test setup involved three key steps.

1. A flat, 2-by-1 meter test area was prepared and marked with distance intervals from 0.25 to 2.0 meters.
2. The P-POD deployer was securely positioned on a stable platform, aligned with the marked measurement axis.

3. All equipment, including the stopwatch and remote control, was calibrated and tested through practice deployments to ensure everything was ready for accurate data collection.

To begin a trial, the 2U CubeSat model was manually inserted into the P-POD cage against the main compression spring as shown in Figure 5, ensuring a consistent loading technique each time.

Figure 5: P-POD manual loading

The door was closed and its lock was engaged securely, and the countdown system was verified to be in a ready state.

For deployment and timing, once the remote was pressed, the P-POD model's seven-segment display initiated a countdown from 5 to 0. The stopwatch was started precisely when the CubeSat model began to move, which corresponded to the display showing 0. The model was then tracked visually throughout its flight, and the stopwatch was stopped once it came to a complete rest.

The horizontal distance from the P-POD's exit point to the CubeSat model's final rest position was measured and recorded to the nearest centimetre. Any observations or anomalies were also noted.

Finally, the trial number, deployment time in seconds, and distance travelled in meters were recorded as shown in Table 2. The CubeSat model was then retrieved and checked for damage, and the P-POD system was reset for the next trial, with a minute rest period allowed to prevent operator fatigue.

V. RESULTS AND DISCUSSION

Table 2 shows the trial number, deployment time in seconds, and distance travelled in meters by the CubeSat model.

Table 2: Velocity experimental results

Trials	Time (s)	Distance (m)	Velocity (m/s)
1	0.75	0.94	1.2533
2	0.76	0.95	1.2537
3	0.77	0.96	1.2540
4	0.76	0.95	1.2500
5	0.78	0.98	1.2546
6	0.79	0.98	1.2423
7	0.74	0.90	1.2162
8	0.77	0.95	1.2338
9	0.77	0.97	1.2597
10	0.76	0.97	1.2763
	Average Velocity		1.2494

From Table 2;

$Mean\ Velocity = 1.2494$

$Standard\ Deviation = 0.0160$

$$Margin\ of\ Error = 2.262 \times \frac{0.0160}{\sqrt{10}} = 0.0115$$

$Lower\ Bound: 1.2494 - 0.0115 = 1.2379\ m/s$

$Upper\ Bound: 1.2494 + 0.0115 = 1.2609\ m/s$

We can be 95% confident that the true average velocity lies between 1.2379 m/s and 1.2609 m/s.

A. Comparative Analysis and Performance Assessment

Table 3 presents the performance validation by comparising the design results with the experimental result.

Table 3: Design result versus experimental result

Parameter	Average Velocity (m/s)
Design result	1.31
Experimental result	1.25
Difference (%)	4.77

The effectiveness of the orbital deployer was evaluated against established performance criteria for CubeSat deployment systems. The device successfully released its payload consistently across all trials, demonstrating reliable mechanical operation and repeatable performance characteristics.

Table 4: P-POD model versus flight-grade systems

	Specification	
Parameters	P-POD Model	MK1
Mass (Empty)	1.13kg	2.23kg
Mass (loaded)	3.59kg	5.23kg
Deployment Force	29.93N	44.4N
Deployment Time (s)	< 1	< 1
Exit Velocity	1.25m/s	2m/s
Door Opening	270^{o}	270^{o}

The laboratory test results validate that the low-cost P-POD model successfully replicates the core function of a professional satellite deployer. The measured average ejection velocity of 1.25m/s closely approximates the theoretical velocity of 1.31 m/s, with the minor difference attributed to non-ideal factors like frictional losses along the internal rails and aerodynamic drag.

The theoretical calculation for ejection velocity assumes a frictionless system where all the potential energy stored in the spring is converted into kinetic energy for the CubeSat model. However, in a real-world, non-vacuum environment like a laboratory, a portion of this energy is lost due to friction. This occured in two main areas:

1. Friction along the guide rails: The CubeSat model slides along the internal rails of the P-POD cage during ejection. This contact creates a frictional force that opposes the motion, converting some of the spring's energy into heat instead of forward movement.
2. Friction in the mechanism: Minor friction in the mechanical components, such as the hinges or the hold-and-release mechanism, could also absorb a small amount of the stored energy.

These frictional losses mean that the kinetic energy of the ejected CubeSat is slightly less than the potential energy stored in the spring, resulting in a measured velocity that is lower than the ideal theoretical calculation.

The theoretical model did not also account for the effects of air. As the CubeSat model is ejected and travels through the air in the laboratory, it encounters a force known as aerodynamic drag acting in the opposite direction of the CubeSat's motion, slowing it down. While minimal, this air resistance continuously works against the CubeSat as it moves from the P-POD's exit point until it comes to a stop. The energy required to overcome this drag is another reason the experimental velocity is slightly lower than the theoretical one. The presence of air makes the system non-ideal, causing a decrease in the observed performance compared to the frictionless, vacuum-based prediction.

Even with loses caused by the factors above, this performance is particularly significant as it falls squarely within the operational range of flight-grade CubeSat deployers, which typically eject satellites at speeds between 0.8 and 1.8 m/s. The ability of the model to achieve this target velocity confirms its suitability as a realistic training tool, allowing students to experience and analyze a key operational parameter of actual space missions. Beyond its functional accuracy, the model provides a safe platform for students to test and validate their CubeSat designs without the prohibitive costs associated with commercial hardware. This successful demonstration of a fundamental deployment characteristic proves the model can serve as a robust and reliable platform for future, more complex educational exercises.

B. Door Simulation

The structural integrity of the P-POD door was evaluated using a stress analysis simulation in SolidWorks. The primary objective was to ensure the door would not fail under the maximum load exerted by the compressed ejection spring.

A solid tetrahedral mesh was generated for the P-POD door model. To improve accuracy, fine mesh controls were applied to critical regions such as corners, fillets, and bolt holes to capture stress concentrations. The global element size was set to approximately 4.05 mm, with local refinements down to 0.20 mm. Mesh quality was verified to ensure acceptable element aspect ratios and Jacobian values.

Figure 6 shows the Finite Element Analysis of the door. The result of the FEA indicated that the design of the P-POD's door is robust and capable of withstanding the applied loads within acceptable limits. The simulation results, based on a simulated load of 30 N (which exceeds the spring's maximum force of 29.93 N), indicated a maximum stress concentration of 5.8 MPa at the hinge and stopper-hook interface. This value is well below the ultimate tensile strength of mild steel (approximately 400 MPa), confirming the design's structural safety.

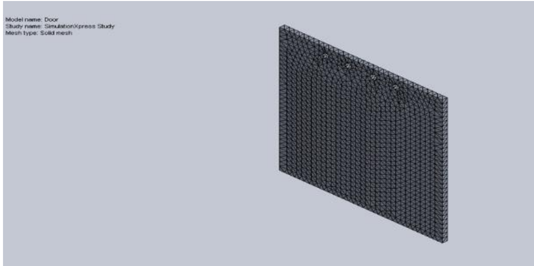

Figure 6: Finite Element Analysis of the P-POD's door

Name	Type	Min	Max
Stress	VON: Von Mises Stress	634.721 N/m^2 Node: 12263	1.10221e+006 N/m^2 Node: 17716

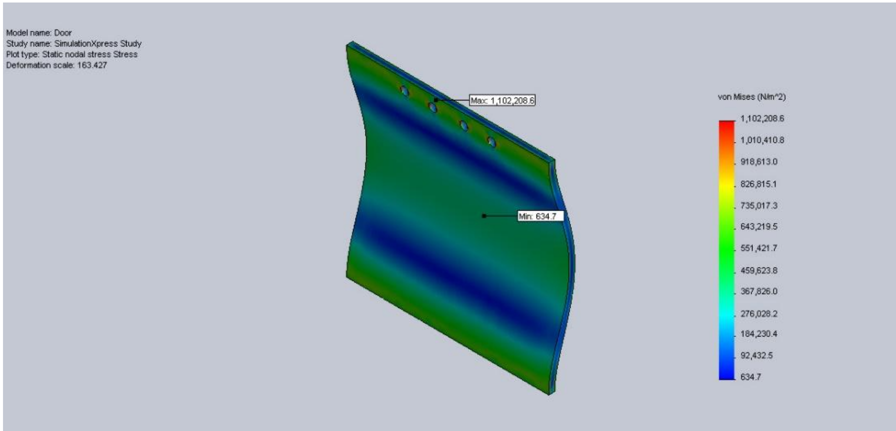

Figure 7: Stress – stress study of the P-POD's door

Figure 7 shows the stress – stress study of the door. The tensile strength of Perspex is $7.5 \times 10^7\ N/m^2$, whereas the maximum Von Mises stress obtained from the analysis was $1.1 \times 10^6\ N/m^2$. This value is significantly lower than the tensile strength of the material, confirming its structural adequacy under the applied load.

Figure 8 illustrates the displacement – displacement study of the door. The highest total displacement recorded was 0.080 mm, occurring at the centre of the door. This level of displacement is acceptable and does not affect the door's functionality or sealing ability.

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 61	0.0795464 mm Node: 17458

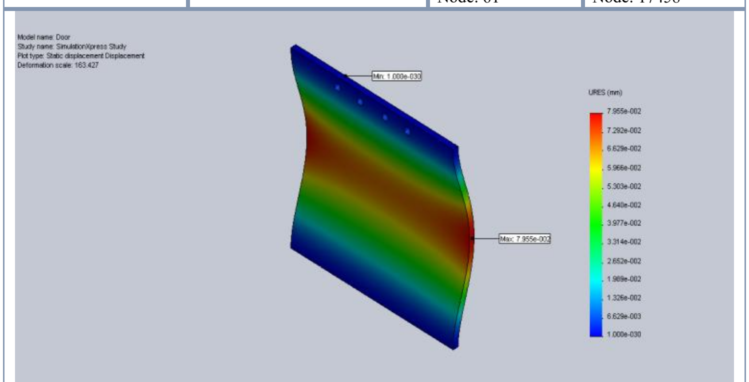

Figure 8: Displacement – displacement study of the door

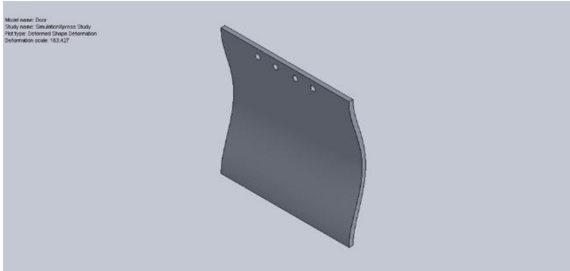

Figure 9: Displacement – deformation study of the door

Figure 9 illustrates the displacement – deformation study of the door. The displacement of 0.080 mm is a direct result of the door's elastic deformation. This indicates that the material temporarily deformed under the force of the spring but remained well within its elastic limit, meaning it returned to its original shape once the load was removed. Consequently, this minimal displacement ensures the door's functionality and structural integrity are not compromised.

CONCLUSION

The design, fabrication and testing of a low-cost P-POD model developed to address the lack of hands-on satellite technology training tools in developing nations were presented in this paper. By using locally available materials such as Perspex and mild steel, the project demonstrates that functional, affordable deployment systems can be built at a fraction of the cost of commercial alternatives.

Laboratory validation confirmed the model's effectiveness, with consistent ejection of a 2U CubeSat at an average velocity of 1.25 m/s – well within the operational range of flight-grade deployers. This proof of concept confirms that a high-fidelity educational tool for satellite deployment mechanics can be realized without reliance on imported, space-qualified components.

Beyond its technical success, the model holds substantial educational value. It provides students with direct, hands-on exposure to structural design, fabrication, and performance testing, thereby bridging the gap between theoretical study and practical skill development. Such experiential learning strengthens problem-solving ability and fosters engineering intuition in environments where access to professional-grade systems is limited.

The study also acknowledges its limitations: the model was tested under atmospheric laboratory conditions and constructed from non-space-qualified materials. These constraints, however, do not undermine its educational purpose; rather, they open avenues for further innovation. Future work will explore scaling the design to 3U, integrating more advanced release mechanisms, and assessing additive manufacturing approaches.

By lowering barriers to participation in space engineering, this work provides a replicable framework for affordable, practical education. In doing so, it contributes to local capacity building and supports the democratization of space by empowering the next generation of engineers and scientists in regions where access to space technology has traditionally been restricted.

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