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Design of a Shell to Protect Sensors and Drones

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Abstract

This paper presents a novel protective shell system designed to safeguard both the drone and its accompanying sensors. The objective of this project is to develop and test the shell-shaped container to check its capability of securely housing the drone. The system may incorporate a circuit board housing a processor that receives data from sensors and controls the opening and closing motions of the container. By analyzing the sensor information, the system may intelligently respond to adverse weather conditions by automatically closing the container to ensure the drone's protection. This innovative solution addresses the challenges associated with deploying drones in outdoor environments and offers enhanced safety and durability for extended drone operations.

Keywords: UAV (Unmanned Aerial Vehicle), Drone, Shell, Plastic

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1. Introduction

Drones have become increasingly prevalent in various industries due to their versatility and ability to perform tasks in diverse environments [1]. However, operating drones in outdoor settings presents numerous challenges, such as adverse weather conditions, which can pose risks to both the drone and its integrated sensors. To address these challenges, this paper proposes a novel shell system designed to protect the drone and its sensors during flight.

The objective of this project is to create an automated system for an aerial drone by incorporating a uniquely designed shell-shaped container. This container serves as a protective enclosure, ensuring the drone's safety and preserving its integrity. The system can be employed with a circuit board equipped with a low-power processor, such as an Arduino, which would analyze data gathered from various sensors. These sensors may be, including those for temperature, humidity, air pressure, and rainfall, would play a crucial role in monitoring the surrounding weather conditions in real-time. By collecting and processing this data, the system can accurately assess the weather situation and identify unfavourable conditions that may hinder the drone's operation. However, it is important to note that for the scope of this paper, the focus will be primarily on the shell itself, and not on the processors and sensors used in the system.

The following section will illustrate how the shell will be used, how the material and design help the shell to finish its job, and finally some simulation will be done, and the results will be shown to showcase the shell's protection effect.

2. Literature Review

The application is dependent on the drone, but the design of the box can give it an advantage in completing routine tasks, and with a little research, several ideas for how this shell could be used were discovered. According to the research of Y. Huang, W. C. Hoffmann, Y. Lan, W. Wu, and B. K. Fritz [2], drones might be used to replace planes in spraying pesticides for some smaller farms to minimize expenses and contamination to the environment, as

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spraying pesticides is a task that needs to be done on a regular basis and it might not be ideal to operate in heavy weather, thus the design of the box might help with these activities. Furthermore, according to C Y N Norasma's [3] research, UAV (Unmanned Aerial Vehicle) with sensors can complete a variety of agricultural tasks.

Aside from agriculture, such a device may also perform building activities. According to the research of Gilles Albeaino, Masoud Gheisari, and Bryan W. Franz [4], UAV can assist engineers in regular inspection because the speed of the drone is faster than that of humans, and the drone can go to locations that humans cannot.

Drones could also be utilized in future smart cities and surveillance, as Bozcan and E. Kayacan [5] have begun a study of using UAV on receiving data of traffic surveillance, as UAV have a wider vision and could help reveal the complete number of cars that pass through the road. N. Mohamed, J. Al-Jaroodi, I. Jawhar, A. Idries, and F. Mohammed [6] studied a future scenario in which various tasks that needed to be done on a regular basis may be replaced by UAV.

Sinha J.P. [7] explore enhanced agricultural monitoring through drone-based remote sensing, emphasizing the potential of drones to replace planes in pesticide spraying for smaller farms, reducing costs and environmental contamination. Additionally, Erman et al. [8] discuss the use of drones and wireless sensor networks for disaster management and rapid response. D Liu et al. [9] highlight the application of augmented reality-based inspection of construction sites using drones. Yuan C. et al. [10] focus on automated detection and monitoring of forest fires using drones with remote sensing techniques.

W.Y. Yi et al. [11] investigate the utilization of drones and protective shells for urban air quality monitoring. Lastly, Gómez, C., & Green, D. R. [12] explore the application of drones and protective enclosures for oil and gas pipeline inspection, while J. Li et al. [13] study power line inspection and maintenance using UAVs.

These studies provide valuable insights into the diverse range of tasks that can benefit from the integration of drones with protective shells, showcasing the potential for increased efficiency, safety, and accuracy in various industries and domains.

Table 1. Literature Review

Source	Application
Y. Huang, W. C. Hoffmann, Y. Lan, W. Wu, and B. K. Fritz [2]	Replacement of planes in pesticide spraying for smaller farms.
C Y N Norasma [3]	Completion of various agricultural tasks.
Gilles Albeaino, Masoud Gheisari, and Bryan W. Franz [4]	Engineers' regular inspection tasks and inaccessible locations.
Bozcan and E. Kayacan [5]	UAV for traffic surveillance and gathering comprehensive data.
N. Mohamed, J. Al-Jaroodi, I. Jawhar, A. Idries, and F. Mohammed [6]	Replacement of various regular tasks with UAV.
Sinha J.P. (2020) [7]	Enhanced agricultural monitoring through drone-based remote sensing.
Erman, A. T., van Hoesel, L., Havinga, P., & Wu, J. (2008) [8]	Disaster management and rapid response using drones and their wireless sensor networks.
Liu, D., Xia, X., Chen, J., & Li, S. (2021) [9]	Augmented reality-based inspection of construction sites using drones.
Yuan, C., Zhang, Y., & Liu, Z. (2015) [10]	Automated detection and monitoring of forest fires using drones and remote sensing techniques.
Yi, W. Y., Leung, K. S., & Leung, Y. (2017) [11]	Urban air quality monitoring using drones and their protective measures.
Gómez, C., & Green, D. R. (2017) [12]	Oil and gas pipeline inspection using drones and their protective enclosures.
Li, J., Wu, H., Hu, C., & Yu, C. (2021) [13]	Power line inspection and maintenance with a system of UAVs.

3. The Shell

3.1 Material

The design of the shell aims to provide protection and housing for the aerial drone, ensuring its safety and functionality in various environmental conditions. The choice of material for the shell is a crucial aspect of the design. Considering that the shell will be 3D printed, polymer plastic is identified as the ideal material due to its common use in the 3D printing process and its lower material density, which offers advantages in terms of weight.

Among the various types of polymer plastics commonly used for creating plastic casings, five options were considered: ABS, PS (High Impact Polystyrene), PC (Polycarbonate), PMMA (Acrylic), and PVC. The selection process involved comparing these materials under different scenarios.

To make an informed decision, several factors were taken into account. In terms of pricing, research by Chris DeArmitt [14] revealed that PMMA and PC are the most expensive, costing approximately 3 euros per litre, followed by ABS at around 1.5 euros per litre, PVC at approximately 1 euro per litre, and PS as the least expensive at about 0.8 euros per litre.

Apart from pricing, the recyclability of the materials was considered. According to relevant studies, all five materials can be recycled and repurposed for other applications.

Elastic modulus, a measure of a material's stiffness, was also evaluated. PMMA and PS exhibited the highest elastic moduli, both around 3.2 GPa, while PVC and ABS had elastic moduli of approximately 2.75 GPa. PC performed the poorest, with an elastic modulus of around 2.45 GPa.

Tensile strength, which indicates a material's resistance to breaking under tension, was another important criterion. PMMA demonstrated the highest tensile strength at 70 MPa, followed by PC at 70 MPa. PVC, ABS, and PS had tensile strengths of 50 MPa, 48 MPa, and 46 MPa, respectively.

Heat deflection temperature (HDT), which measures a material's resistance to deformation under heat, was also considered. PC performed exceptionally well in this category, with an HDT of 1.8 MPa at approximately 140°C. PMMA ranked second, with an HDT of 1.8 MPa at around 92 °C. ABS, PS, and PVC exhibited HDTs of 1.8 MPa at approximately 90°C, 85°C, and 62°C, respectively.

In terms of impact force resistance, PC outperformed the other materials, with a Notched Charpy Impact of 50 kJ/m^2. ABS followed in second place with a Notched Charpy Impact of 20 kJ/m^2, while PVC, PMMA, and PS displayed Notched Charpy Impacts of 7.5 kJ/m^2, 3 kJ/m^2, and 2 kJ/m^2, respectively. Additionally, only PC and PMMA offered transparency among the options.

Considering the overall performance, reasonable pricing, and few shortcomings compared to other materials, ABS was selected as the preferred material for constructing the shell. Its well-rounded characteristics enable the shell to operate effectively under various outdoor conditions, while its relatively higher heat deflection temperature helps prevent deformation due to extreme temperatures. Another influencing factor in choosing ABS was its widespread use in 3D printing, as it is the most commonly employed material in this manufacturing process according to an online source [15]. This ensures a more predictable outcome when producing the shell through 3D printing.

Table 2. Comparative Analysis of Polymer Materials for Protective Shells

	Price	Elastic Modulus	Tensile Strength	Heat Deflection Temperature	Impact Force	Transparency
PS	1	4	1	2	1	0
PVC	2	3	3	1	3	0
ABS	3	2	2	3	4	0
PC	4	1	4	5	5	4
PMMA	5	5	5	4	2	5

(5 will be the highest and 1 will be the lowest, 0 means without that ability.)

3.2 Dimensions

The shell measures 45.3cm high, 60cm wide, and 52cm deep. The Shell has an effective inner volume of more than 10 litres and a weight of around 4.2kg without any additional add-ons. The Shell can accommodate a wide range of commercially available drones, with maximum dimensions of around 40cm high, 58cm wide, and 50cm deep.

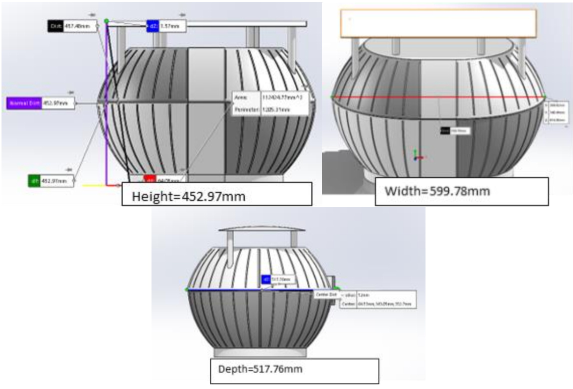

Fig. 1. Dimensions of the Shell

4. Design

The shell is constructed in the shape of a seashell and opens and closes like a clam shell. The next sections will introduce the five separate pieces that comprise the shell's design: the upper portion of the shell, the lower portion of the shell, the top portion of the hinge, the lower portion of the hinge, and a shaft.

The Upper Half of The Shell is made up of two primary components: an upper shell that protects the droid and a roof-shaped structure that protects the sensors and mother board that is positioned above the shell. The upper shell is built differently than the lower shell to ensure that the entire shell does not tumble while opening and shutting. To meet the above specifications, the center of gravity should remain in the lower half of the shell. To meet the aforementioned criterion, one method is to reduce the bulk of the upper part of the shell in comparison to the lower part of the shell; the thickness of the upper shell has been reduced by half from 10mm to 5mm, making it lighter in weight. A smaller weight also means that less force is required to open the upper half of the shell, preserving strength while reducing weight. To ensure that the upper half of the shell does not collapse, some groves are carved on the outer rim of the shell, and [16] ribs like structure are placed into the flat surface of the shell to offer strength. Six poles are used to support the shell, the distance between the shell and the roof is 10cm, so there is enough room for installing the sensors and mother board above the shell, the thinnest part of the roof is 2mm to suit the minimum thickness of 3D printing requirement, and a curve design is also applied in the roof so puddle will not appear on the roof.

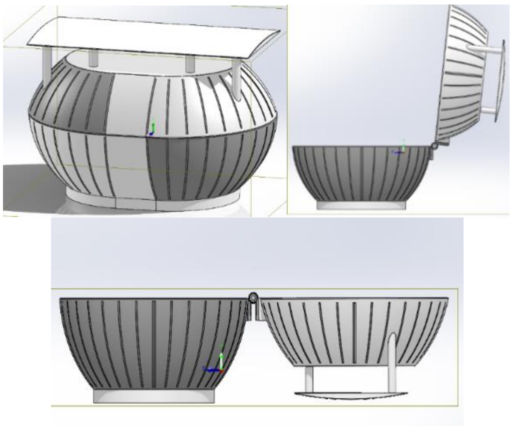

Fig. 2. Change in the Centre of Gravity when Shell opens/closes

The Lower Part of The Shell is utilized as a container for the drone; it is somewhat taller than the upper part of the shell; the shell thickness is 10mm; and groves are carved on the outer rim of the shell to provide greater protection for the drone. A solid foundation was also designed for the shell in order to increase the weight and retain the center of gravity in the lowest section of the shell; it also helps to enhance the height of the shell so that it may be opened at 180 degrees.

The Upper Part of The Hinge has nearly the same design as the lower part of the hinge, in fact the only difference is the hole for the shaft to go through the upper part of the hinge fully match with the shaft key, so when the shaft turns it can bring the upper part of the shell to move, to ensure the hinge could tightly fit on the shell, 8 M4 screws are used to fix the hinge on the shell, the hinge will be placed in a small extrude on the shell to ensure the open and close

The Lower Part of The Hinge has nearly the same design as the lower part of the hinge, the only difference is only the hole for the shaft to go through the lower part of the hinge is a circle whose radius matches the radius of the shaft key, so when the shaft turns it can bring the upper part of the shell to move, 8 M4 screws are used to fix the hinge on the shell, the hinge will be placed in a small extrude on the shell

The Shaft is used to connect the servomotor and the hinge so that when the servomotor turns, the hinge can move the upper shell. The male end of the shaft is designed to the shape of the hole on the upper part of the hinge, while the female end was designed to be an M5 Allen key. This shape was chosen because there is no information about the design of the servomotor, so a universal shape like M5 Allen key was putted in. This component may be modified further to meet the design of the servomotor; a small hole for an M4 bolt was constructed to secure the M5 Allen key to the shaft.

5. Methodology

The purpose of the shell is to protect it from accidental stomping of the shell by humans or any wild animal such as foxes or dogs, so the pressure that the shell needs to suffer may not exceed 1KPa, which equals being pressed by a mass of 102kg, also because the shell is placed on the floor, the two possible sources of impact are from the top surface, the rear surface, and the front of the box, the following will be the relationship of the of pressure, stress, strain.

5.1 Simulation on top

In this Simulation an even force will be provided on the top of the roof, the base of the shell is fixed, the force was gradually increase from 100 N/m^2 to 1000 N/m^2.

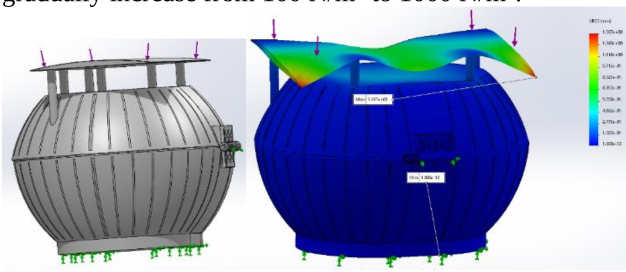

Fig. 3. Force and fixture set and the result of deformation on the Simulation on top

5.2 Simulation on front

In this Simulation an even force will be provided on the front of the shell, the back of the shell and the base is fixed, the force will gradually increase from 100 N/m^2 to 1000 N/m^2.

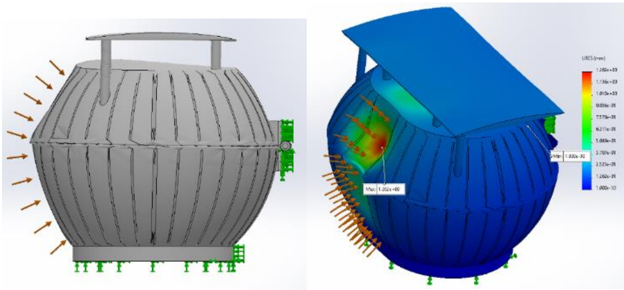

Fig. 4. Force and fixture set and the result of deformation on the Simulation on front

5.3 Simulation on rear

In this Simulation an even force will be provided on the left rear of the shell, the back of the shell and the opposite rear is fixed, the force will gradually increase from 100 N/m^2 to 1000 N/m^2.

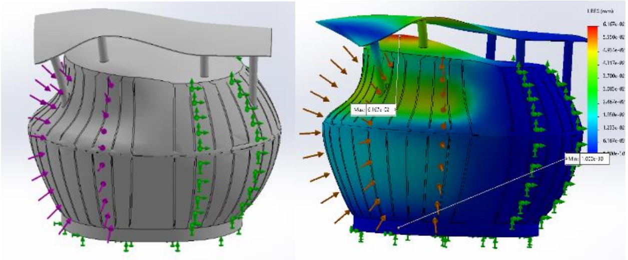

Fig. 5. Force and fixture set and the result of deformation on the Simulation on rear

6. Results

6.1 Simulation result of test done on Top Part

The graphs from above show the maximum stress when 1KN/m^2 was applied on the shell will be 4324000 N/m^2 and the max strain will be 0.001495mm, also the maximum displacement that would appear on the shell will be 1.387mm, from the graphs we could see that the Force and deformation graph and Force and strain graph, have a liner growth, while the stress and strain graph and the Force and stress graph have a different curve, a slightly intrude was observed at the point 600 N/m^2 on the Force and stress graph but after 600 N/m^2 the increase rate have return to the increase rate before 600 N/m^2, the same intrude also appears on the stress and strain graph when strain have reach 0.0008985mm/mm, as there are no any turndown of the graph so it might not reach the elastic limit of the design so plastic deformation might not appear when a maximum force 1 KN/m^2 was applied on the shell.

Table 3. Mechanical Properties of the Top Part under Applied Force

Force (N/m^2)	Stress max (N/m^2)	Strain max (mm/mm)	Deformation max (mm)
100	432500	0.0001495	0.1389
200	865200	0.0002992	0.2779
300	1298000A	0.0004488	0.4172
400	1732000	0.0005986	0.5567
500	2165000	0.0007485	0.6963
600	2299000	0.0008985	0.8362
700	3033000	0.001049	0.9762
800	3468000	0.001199	1.116
900	3891000	0.001346	1.249
1000	4324000	0.001495	1.387

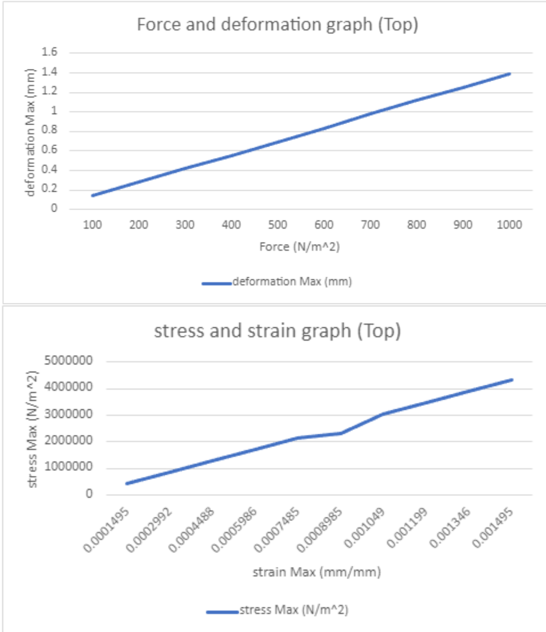

Fig. 6. Force-deformation and stress-strain graph on Top Part simulation

6.2 Simulation result of test done on Front Part

The graphs from above show the maximum stress when 1 KN/m^2 was applied on the shell will be 15520000 N/m^2 and the max strain will be 0.004157mm, also the maximum displacement that would appear on the shell will be 1.262mm, from the graphs we could see that the Force and deformation graph, Force and strain graph, stress and strain graph and the Force and stress graph have a liner growth, as there are no any turndown of the graph so it might not reach the elastic limit of the design so plastic deformation might not appear when a maximum force 1 KN/m^2 was applied on the shell.

Table 4. Mechanical Properties of the Front Part under Applied Force

Force (N/m^2)	Stress max(N/m^2)	Strain max(mm/mm)	Deformation max (mm)
100	1557000	0.0003927	0.1162
200	3118000	0.00079	0.2344
300	4682000	0.001192	0.3546
400	6171000	0.001599	0.4774
500	7722000	0.002011	0.602
600	9275000	0.002448	0.729
700	10830000	0.002851	0.8584
800	12390000	0.00328	0.9903
900	13960000	0.003715	1.125
1000	15520000	0.004157	1.262

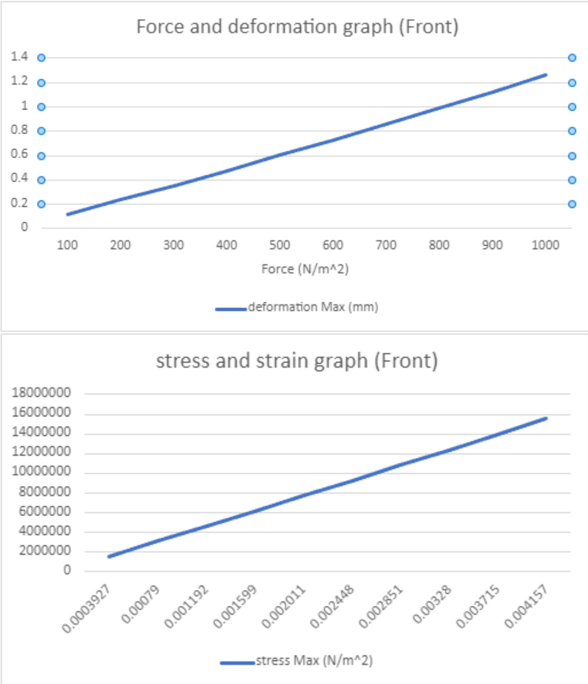

Fig. 7. Force-deformation and Stress-Strain graphs on Front Part simulation

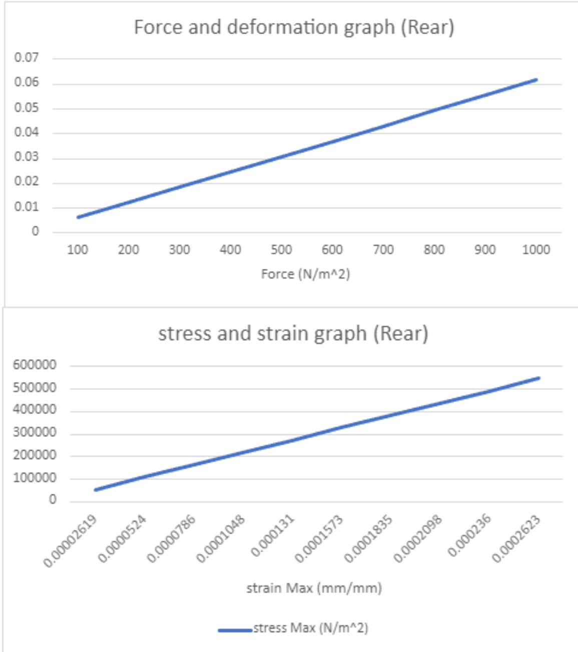

Fig. 8. Force-deformation and stress-strain graph on Rear Part simulation

6.3 Simulation result of test done on Rear Part

The table from above show the maximum stress when 1 KN/m2 was applied on the shell will be 547300 N/m^2 and the max strain will be 0.0002623 mm, also the maximum displacement that would appear on the shell will be 0.06167 mm, from the graphs we could see that the Force and deformation graph, Force and strain graph, stress and strain graph and the Force and stress graph have a liner growth, as there are no any turndown of the graph so it might not reach the elastic limit of the design so plastic deformation might not appear when a maximum force 1KN/m2 was applied on the shell.

Table 5. Mechanical Properties of the Rear Part under Applied Force

Force (N/m^2)	Stress max (N/m^2)	Strain max (mm/mm)	Deformation max (mm)
100	54680	0.00002619	0.006156
200	109400	0.0000524	0.01231
300	164100	0.0000786	0.01848
400	218800	0.0001048	0.02464
500	273500	0.000131	0.0308
600	328300	0.0001573	0.03697
700	383000	0.0001835	0.04314
800	437800	0.0002098	0.04932
900	492600	0.000236	0.05549
1000	547300	0.0002623	0.06167

7. Discussion and Conclusion

The results on the above graph and table have mostly shown liner results, this shows that the result from the simulation is likely to be correct, furthermore in the stress and strain graph three simulations have shown liner results, it proves that under the condition made in the simulations the shell will not reach its yield strength and plastic deformation would not happen under these conditions.

As noted in the paper [17], there is currently a high demand for UAVs capable of inspecting outdoor environments. The proposed shell system presented in this paper could prove to be an important solution to mitigate problems associated with deploying drones and sensors in outdoor environments.

8. Limitations and Future Work

From the above information we could see how the shell was designed and distinctive features it got. The simulations also show that it can finish its job of protecting the drone that will be kept in the shell. Although the shell can finish its work, some improvements could still be made, in the future design it might be possible to reduce its weight, the second improvement that could be done will be increasing the area of its base, as the base in the current design is smaller than the body, toppling might happen if someone hit on it. A solar panel can also be installed on the top of the shell to supply long-term power to the sensors while also charging the drone. It is believed that making the above improvements could let the shell fulfill its duty better.

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