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UxV/35 Flight Basket Temperature Stability

Summary:

The Kairos Autonomi UxV-35 flight basket orb is designed to protect drones from collision damage, providing a robust and efficient shield that enhances safe drone operation. The orb, constructed as a truncated icosahedron using thermoplastic polyurethane (TPU) vertices and carbon fiber rods, was subjected to a series of experiments to evaluate its performance under various conditions. These experiments were divided into three phases: **initial testing, temperature COR value comparison, and force of removal testing**.

Initial testing focused on comparing the bounce height of the orbs based on different points of contact during collisions. The experiments included various models of the orb to validate the effectiveness of the current design. The results indicated that bounce height varied significantly depending on the point of contact and the material used. Orbs with black Cycoloy vertices consistently failed during drops, breaking apart upon impact. In contrast, orbs with white TPU vertices demonstrated greater resilience. Additionally, including a center rod influenced the bounce height, with direct collisions with the center rod (DCR) producing different results compared to off-axis collisions (OCR).

Temperature Coefficient of Restitution (COR) testing was conducted to assess the orb's response to environmental temperature changes. The tests generally showed consistent COR values across the temperature range, suggesting that the orb maintains its effectiveness under varying conditions. However, some performance variations were observed over time, likely due to temperature fluctuations or the cumulative effects of repeated drop tests. Notably, the frequency of rods being displaced increased, directly leading to the next phase of testing.

Force of Removal Testing measured the force required to remove a carbon fiber rod from a TPU vertex, focusing on three factors: repeated removals, temperature, and the method of pressing. It was observed that higher temperatures did not cause an immediate reduction in the grip of the vertices on the rods. Additionally, the method of pressing—whether by hand or mechanical means—had no significant effect on the force of removal. Throughout ten removals, no significant change in the force of removal was observed in new rods and vertices. However, a comparison between new and old sets of rods and vertices indicated that previous testing phases did affect the grip on vertices, although this change was not evident within the scope of the current tests.

The findings from this study indicate that the UxV-35 flight basket orb demonstrates robust performance under a variety of testing conditions, particularly with the use of TPU vertices. However, the experiments also suggest that there may be a gradual reduction in grip strength over time, possibly due to the cumulative effects of repeated collisions and temperature fluctuations. This reduction in grip strength, which was not immediately evident within the scope of the tests, points to potential long-term wear and tear on the orb's components.

Given these observations, it is likely that the UxV-35 flight basket orb has a finite shelf life, influenced by factors such as time, stress, and environmental conditions. The breakdown of microstructures within the TPU vertices appears to contribute to a gradual decline in the orb's integrity, which could eventually affect its ability to protect drones effectively. Further research is necessary to accurately determine the orb's lifespan. Despite these concerns, the current study provides reassurance that the orb can withstand typical operational conditions without immediate degradation, making it a reliable protective measure for drones in the short to medium term.

Introduction:

The Kairos Autonomi UxV-35 flight basket orb is an advanced protective solution designed to shield drones from damage during collisions. Structurally, it is designed as a truncated icosahedron, often referred to as a buckyball, and resembles the pattern of a soccer ball. This innovative design provides significant benefits for beginner drone pilots by offering a robust protective framework that reduces the risk of damage from inadvertent collisions. As a result, it minimizes repair time and extends operational flight periods.

The current model of the flight basket is constructed from 60 thermoplastic polyurethane (TPU) vertices and 90 carbon fiber rods, making it both lightweight and resistant to wind interference. Although it has demonstrated effectiveness in mitigating collision damage, the full extent of its protective capabilities is not completely understood. Further research is needed to explore its performance under various conditions and to better understand its mechanics in different collision scenarios.

For optimal effectiveness, flight baskets must perform reliably across varying temperature conditions and withstand collisions from multiple angles. This work outlines three key experiments, each building upon the findings of the previous one, to develop a comprehensive understanding of how the orb protects drones during collisions.

The first experiment investigates the bounce height of the orb from a set drop height. This test includes comparisons with previous models to ensure that Kairos has the most effective flight basket orb. Various points of contact are analyzed to identify similarities and differences in how the orb interacts during collisions.

The second experiment evaluates the coefficient of restitution (COR) across different temperatures. The objective is to determine whether the orb's performance remains consistent across the tested temperature range.

Following these tests, further investigation into the force of removal of a rod from a vertex was conducted. This experiment measures the force required to remove rods from vertices under various conditions to understand how repeated collisions and temperature variations affect the grip strength of the rods within the vertices. Each experiment contributes valuable insights, helping to ensure the effectiveness of the flight basket orb.

To fully appreciate the experimental findings and their implications, it is essential to understand the underlying principles that govern the flight basket orb's performance. This includes a detailed examination of the orb's geometry, the physics of collisions, and the statistical methods used to analyze the data. By delving into these background topics, we can gain a deeper insight into how the orb functions and the validity of the results obtained from our tests. The following section provides crucial background information on the orb's geometry, collision physics, and the statistical analysis techniques employed in this study. Understanding these elements will help contextualize the experiments and enhance our comprehension of the orb's protective capabilities.

Important Facts:

Before progressing, it is imperative to examine the geometry of the flight basket and become familiar with the essential terms utilized in this study.

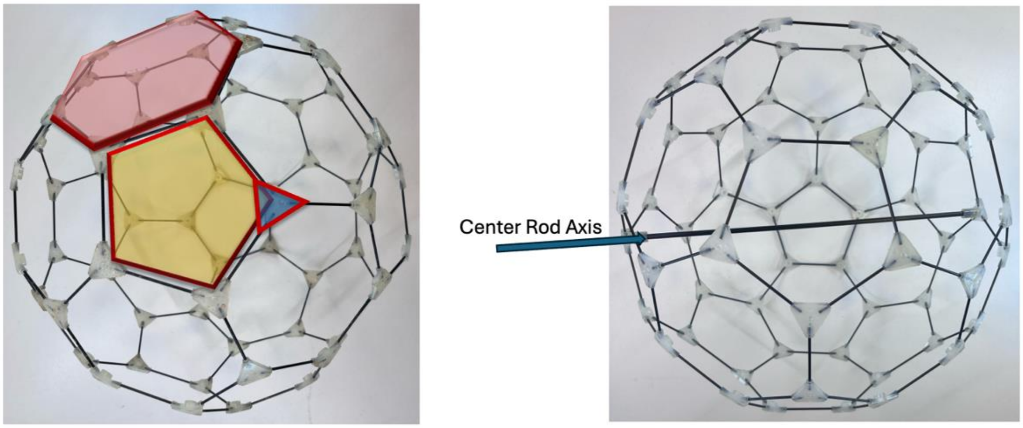
Orb Geometry:

The flight basket is designed as a truncated icosahedron, an Archimedean solid known for its regularity and high symmetry. This geometric shape, often referred to as a buckyball, is composed of 12 pentagonal and 20 hexagonal faces. Despite its symmetry, the flight basket's geometry introduces variations in collision dynamics depending on which face, or vertex makes contact during an impact.

Given that the truncated icosahedron is not a perfect sphere, collisions can occur at different points: the pentagonal or hexagonal faces, or even at the vertices where multiple faces converge. This variability means that each point of contact could result in a different collision response, making it essential to test collisions at various points on the orb.

Moreover, the presence of the central carbon fiber rod within the structure adds another layer of complexity to the collision dynamics. A distinction is made between direct collisions with the center rod (DCR) and off-axis collisions with the center rod (OCR). These scenarios were considered during initial testing to provide comprehensive feedback on the orb's performance. Figure 1 illustrates the buckyball's geometry providing a visual reference for the shape and structure discussed.

Figure 1: The image below illustrates the potential points of contact during collisions with the orb. The left side highlights the three different surface shapes that serve as contact points: hexagonal faces (red), pentagonal faces (yellow), and vertices (blue). On the right, the orb is shown with a center rod. There are two potential types of contact: direct collisions with the center rod (DCR) and off-center rod collisions (OCR), where any collision that does not align with the center rod axis is classified as OCR.



Collision Physics:

Collisions can generally be categorized into two types: elastic and inelastic. In an elastic collision, the total kinetic energy of the system is conserved, meaning the energy before and after the collision remains the same. In contrast, an inelastic collision is characterized by the conversion of some kinetic energy into other forms of energy, such as heat or sound, resulting in a loss of kinetic energy.

Most collisions are partially inelastic—they exhibit some degree of elasticity but also dissipate energy due to the inherent properties of the materials involved, the force of impact, and the duration of contact. The elasticity of a collision varies depending on these factors.

Although the direct observation of energy transfer during a collision can be challenging, methods have been developed to classify collisions by their degree of elasticity. One widely used method is the calculation of the coefficient of restitution (COR). The COR measures the elasticity of a collision by comparing the relative velocities of two objects before and after the impact as a ratio:

$$Equation\ 1: COR = \frac{Velocity\ After\ Collision}{Velocity\ Before\ Collision}$$

A COR value close to 1 indicates a highly elastic collision, where little kinetic energy is lost. Conversely, a COR value near 0 signifies a highly inelastic collision, where most of the kinetic energy is dissipated.

The COR can be further simplified when analyzing vertical collisions, where the relationship between kinetic energy and gravitational potential energy becomes more straightforward. In such cases, the COR can be calculated using the drop height and the bounce height of an object:

$$Equation\ 2: COR = \sqrt{\frac{Bounce\ Height}{Drop\ Height}}$$

This equation is particularly useful as it allows for a standardized comparison of collision outcomes by measuring the bounce height after a set drop height. When both the drop and bounce heights are measured in the same units, no further conversions are necessary, making the calculation process more efficient.

Throughout this document, COR values are used as a standardized metric to compare the collision characteristics of the flight basket in different environmental conditions.

Statistical Analysis

To improve accuracy and validate hypotheses throughout this experiment, several statistical methods and tests were employed. The significance level for all statistical tests was set at 95%, meaning results were considered statistically significant if the probability of them occurring by chance was less than 5% ($p < 0.05$).

A critical aspect of the analysis was the creation of large data sets, with each variable being tested at least 10 times. This repetition allowed for the calculation of key statistical metrics, including the average (mean) and standard deviation, as well as the confidence interval, providing a measure of the precision of the estimated average.

Data Cleaning:

Data cleaning was essential to ensure the reliability of the results. Outlier data points were identified and removed using the Grubbs test, which is particularly suited for moderate-sized data sets under the assumption of normal distribution. The Grubbs test identifies outliers by comparing each data point to the mean of the data set. If a point's calculated Grubbs value exceeds the critical Grubbs value (determined by the significance level and the number of data points), it is classified as an outlier and subsequently removed.

Hypothesis Testing:

Two primary statistical tests were used for hypothesis testing: the t-test and ANOVA (Analysis of Variance).

t-Test: The t-test was used to compare the means of different samples to determine if they are statistically similar. In Excel, the t-test function returns a probability value (p-value). If this p-value is greater than 0.05, the null hypothesis (which states that there is no significant difference between the sample means) is accepted, indicating that the samples are statistically similar.

ANOVA: ANOVA is typically used when comparing more than two groups. It tests for differences among group means and helps in identifying whether any of the differences between the means are statistically significant. It will also return a p-value and, similarly to the t-test, if this p-value is greater than 0.05, the null hypothesis is accepted, indicating that the samples are statistically similar.

These statistical tools ensured that the findings of this experiment were both robust and reliable, with results that could be confidently interpreted and applied.

Initial testing:

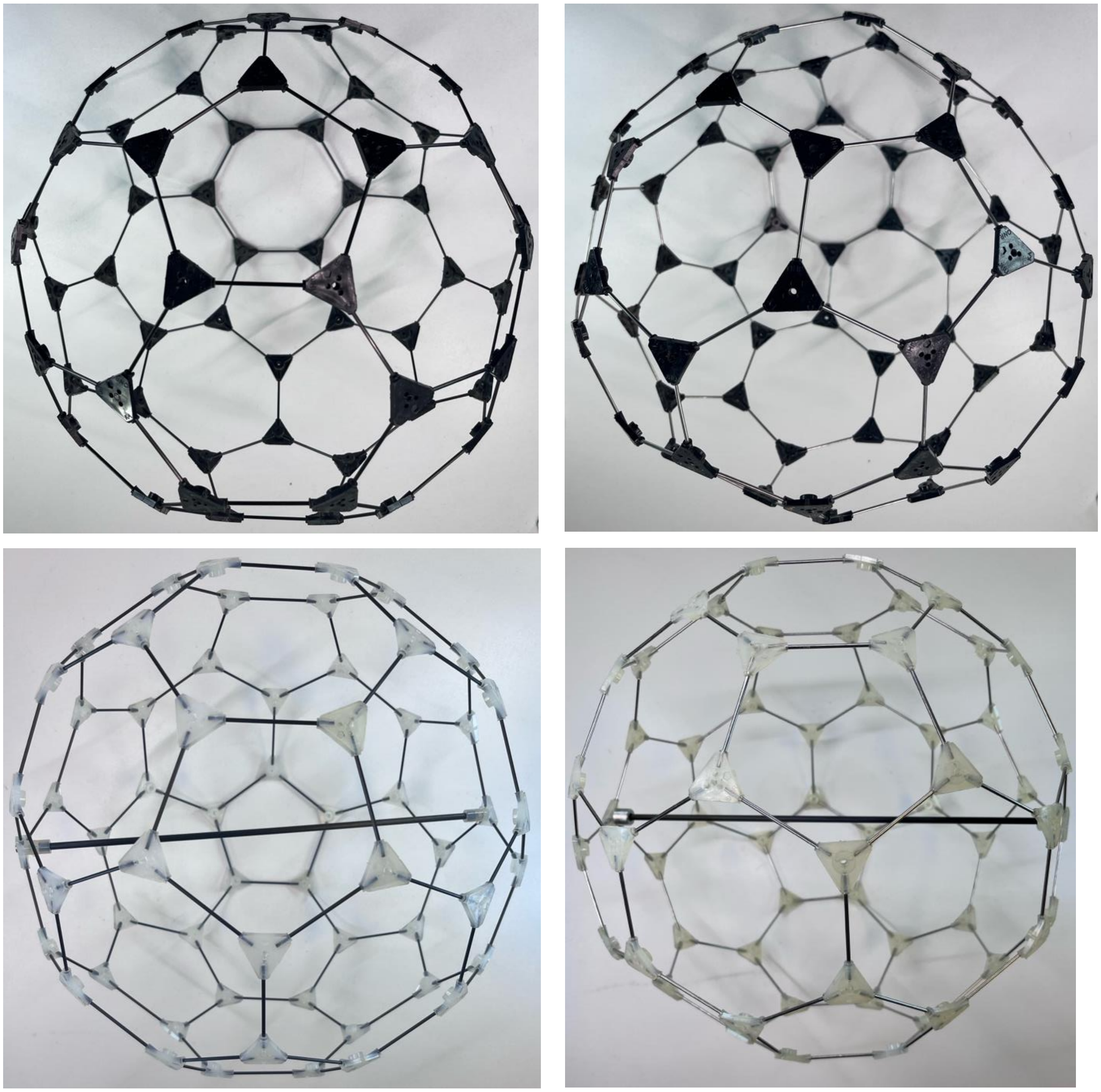
Introduction:

The initial testing phase focused on evaluating four distinct orbs, as shown in Figure 2, which were differentiated by the materials used for the rods and vertices. Specifically, the rods were either made of carbon fiber or stainless steel, while the vertices were constructed from two different materials: black Cycoloy (a type of polycarbonate plastic) and white thermoplastic polyurethane (TPU).

The choice of materials plays a crucial role in the orb's performance, particularly in its response to collisions. The black Cycoloy vertices are characterized by their rigidity, which, while providing structural stability, also makes them more prone to fracturing under stress. On the other hand, the white TPU vertices exhibit greater elasticity, allowing them to absorb and dissipate impact energy more effectively, which might account for the observed differences in the testing outcomes.

These initial tests were essential in identifying how material properties influence the orb's overall durability and collision response, laying the groundwork for more in-depth analyses in subsequent testing phases.

Figure 2: Shown below are the four possible orb combinations. The top shows the orbs with black Cycoloy vertices while the bottom has white TPU vertices. The right side has stainless-steel rods while the left has carbon fiber rods.



Procedure:

Each orb was subjected to a drop test from a height of approximately 65 inches, with the bounce captured on video. The drops were conducted in front of a testing stand, as shown in figure 3. After each drop, any edges of the flight basket that had come undone were fixed before performing the next drop. This process was repeated several times for each orb.

The recorded video was subsequently analyzed to determine the bounce height for each drop. The bounce heights were averaged, and statistical analysis was conducted to evaluate the consistency and reliability of the results.

The testing protocol differed slightly between the orbs based on the vertex material. The two black vertex orbs were dropped randomly, allowing for a broad range of collision scenarios. In contrast, the two white vertex orbs underwent a more controlled testing process. Initially, they were dropped without the center rod, ensuring that each potential collision face—hexagonal, pentagonal, and vertex—was tested individually.

After the initial drops, a center rod was added to the white TPU vertex orbs. These orbs were then dropped in two specific manners: (1) direct collisions with the center rod (DCR) and (2) off-axis collisions with the center rod (OCR).

The statistical data collected from these tests, including bounce heights and other relevant metrics, are presented in tables within the results section.

Figure 3: Shown below is the test stand used for determining the bounce height of the orbs after being dropped. The stand is used throughout the testing completed in this document.

Results:

During testing, the black orbs consistently exhibited a significant issue: they would break apart upon nearly every drop from a height of 65 inches. As noted earlier, these black vertex orbs were tested without a center rod and at random collision angles. Due to the repeated failure of the orbs under these conditions, further testing of the black vertex orbs was discontinued.

This result also aligns with Kairos's decision to discontinue the use of black vertices in favor of the white vertices, which demonstrated better performance and durability in subsequent tests. The resulting bounce height from the black vertex orbs being dropped is shown in table 1.

Tables 2-6 go through some of the other key findings obtained during testing.

Table 1: The table below presents the average bounce height of the orbs equipped with stainless steel or carbon fiber rods combined with black Cycoloy vertices. Alongside the average bounce heights, the margin of error for each measurement is also provided. Notably, these orbs consistently broke apart after almost every drop during testing. A t-test was conducted to compare the bounce heights of the orbs with stainless steel and carbon fiber rods. The resulting p-value of 0.671 exceeds the threshold for statistical significance, indicating that the two data sets are statistically similar in terms of bounce height.

Units (inches)	Stainless Steel	Carbon Fiber
Average Bounce Height	12.9	11.7
Margin of Error (±)	4.3	2.2

Table 2: The table below presents the average bounce height of the orbs equipped with white TPU vertices and stainless-steel rods. The average bounce height is analyzed across each potential point of collision: pentagonal faces, hexagonal faces, and vertices. Additionally, the table includes data comparing collisions involving the center rod, distinguishing between direct collisions with the center rod (DCR) and off-axis collisions with the center rod (OCR). The margin of error for each of these comparisons is also provided.

Units (inches)	Pentagon	Vertices	Hexagon	OCR	DCR
Average Bounce Height	26.0	27.1	27.4	25.6	20.7
Margin of Error (±)	0.8	0.5	1.0	1.3	0.9

Table 3: The table below presents the average bounce height of the orbs equipped with white TPU vertices and carbon fiber rods. The average bounce height is analyzed across each potential point of collision: pentagonal faces, hexagonal faces, and vertices. Additionally, the table includes data comparing collisions involving the center rod, distinguishing between direct collisions with the center rod (DCR) and off-axis collisions with the center rod (OCR). The margin of error for each of these comparisons is also provided.

Units (inches)	Pentagon	Vertices	Hexagon	OCR	DCR
Average Bounce Height	25.8	33.5	28.7	12.4	35.1

Margin of Error (±)	2.8	0.6	2.8	3.5	1.1

Table 4: The table below presents the results of t-tests comparing the average bounce heights from various collision scenarios involving orbs with white TPU vertices and carbon fiber rods. The analysis reveals that only collisions on the pentagonal and hexagonal faces resulted in statistically similar bounce heights. All other collision scenarios showed significant differences in their bounce height outcomes.

DCR	OCR	8.19E-09
Vertices	Hexagons	7.62E-03
Vertices	Pentagons	8.88E-05
Pentagons	Hexagons	2.21E-01
DCR	Hexagons	9.89E-04
DCR	Vertices	3.67E-02
DCR	Pentagons	8.96E-06
OCR	Hexagons	5.02E-07
OCR	Vertices	4.89E-08
OCR	Pentagons	1.07E-05

Table 5: The table below presents the results of t-tests comparing the average bounce heights from the different collision scenarios involving orbs with white TPU vertices and stainless-steel rods. The t-test results indicate significant differences in bounce height when comparing direct collisions with the center rod (DCR) to every other potential collision angle. Conversely, when comparing the other potential collision angles against each other, the results show statistically similar bounce heights.

DCR	Hexagons	1.15E-09
DCR	Vertices	1.25E-12
DCR	Pentagons	4.45E-09
OCR	Hexagons	6.67E-02
OCR	Vertices	9.00E-02
OCR	Pentagons	6.49E-01
Vertices	Hexagons	5.63E-01
Vertices	Pentagons	7.50E-02
Pentagons	Hexagons	7.08E-02
OCR	DCR	3.12E-06

Table 6: The table below displays the results of a t-test comparing stainless-steel rods and carbon fiber rods, both used with white TPU vertices. The analysis shows that only collisions involving the hexagonal and pentagonal faces exhibited statistically similar outcomes between the stainless steel and carbon fiber rods.

OCR	2.50E-13
DCR	9.31E-04

Hexagons	4.76E-01
Pentagons	9.13E-01
Vertices	2.44E-14

Conclusions:

The initial tests reveal that the average bounce height varies depending on the point of contact during the collision. Notably, the center rod has a significant impact on the collision outcomes. While differences in bounce height were observed between various points of contact without the rods, further testing has focused on the center rod. This focus is based on operable flight baskets which always include center rods.

One issue identified during the analysis was the potential variability in drop height, which affects the precision of the test results. Efforts have been made to enhance the precision of future tests, as detailed in the following sections. The experiment highlights that bounce height differences are influenced by the point of contact.

The initial tests and subsequent research have raised several questions, leading to the development of a more accurate testing procedure and improved results.

Temperature and COR Values:

Introduction:

To improve the precision of our testing procedure, we introduced drop height as a measurable variable. Although the orb was previously dropped from a nominally consistent height, the variability in actual drop height could significantly affect the results. By incorporating an additional drop height, we created two sets of Coefficient of Restitution (COR) values to enhance comparison accuracy. The testing rig and analysis methods remained the same. The video recordings for measuring bounce heights expanded to include the added drop height measurement. We ensured precision in video analysis by using still frames and independently leveling the camera and ruler for each series of drops.

Additionally, we aimed to explore the influence of temperature on COR. An environmental chamber was used to simulate different temperature conditions, providing a controlled environment for our testing.

Procedure

To enhance the precision of our testing, we introduced a new method for measuring drop height, incorporating it as a crucial variable in our analysis. We maintained the existing testing rig and video analysis techniques to measure drop and bounce heights but focused on improving accuracy by adding drop height. This allowed us to generate two sets of COR values ensuring a more reliable comparison.

Each orb was subjected to a series of tests within an environmental chamber to assess the impact of temperature on COR. The orbs were placed in the chamber for 3-hour intervals at temperatures of -10°C, 0°C, 10°C, 25°C, and 40°C. After each exposure, the orbs were removed and tested on the rig. To minimize temperature fluctuations during testing, filming was initiated before the orbs were taken out of the chamber. The drop tests were conducted at two distinct points of contact, DCR and ORC, with each point tested ten times. Following these tests, the orbs were returned to the chamber for another 3-hour block at the new height before repeating the process. This approach ensured that we could accurately compare the effects of temperature and drop height on bounce behavior across the different conditions.

Figure 4: The figure below shows some of the sequence of still frames taken in the video of the dropped orb. From this we can see the height of the drop (1), and the bounce height (6).

Results:

Figure 5: The graph below illustrates the average Coefficient of Restitution (COR) values for the stainless-steel orb during OCR collisions as a function of temperature. The t-test results indicate that the COR averages from drops at 1.5 meters and 1.0 meters are statistically similar. Additionally, ANOVA results from Excel confirm that COR values across all tested temperatures do not show significant differences for drops at 1.5 meters. Consequently, there appears to be no statistically significant change in the average COR value with varying temperatures within the tested range.

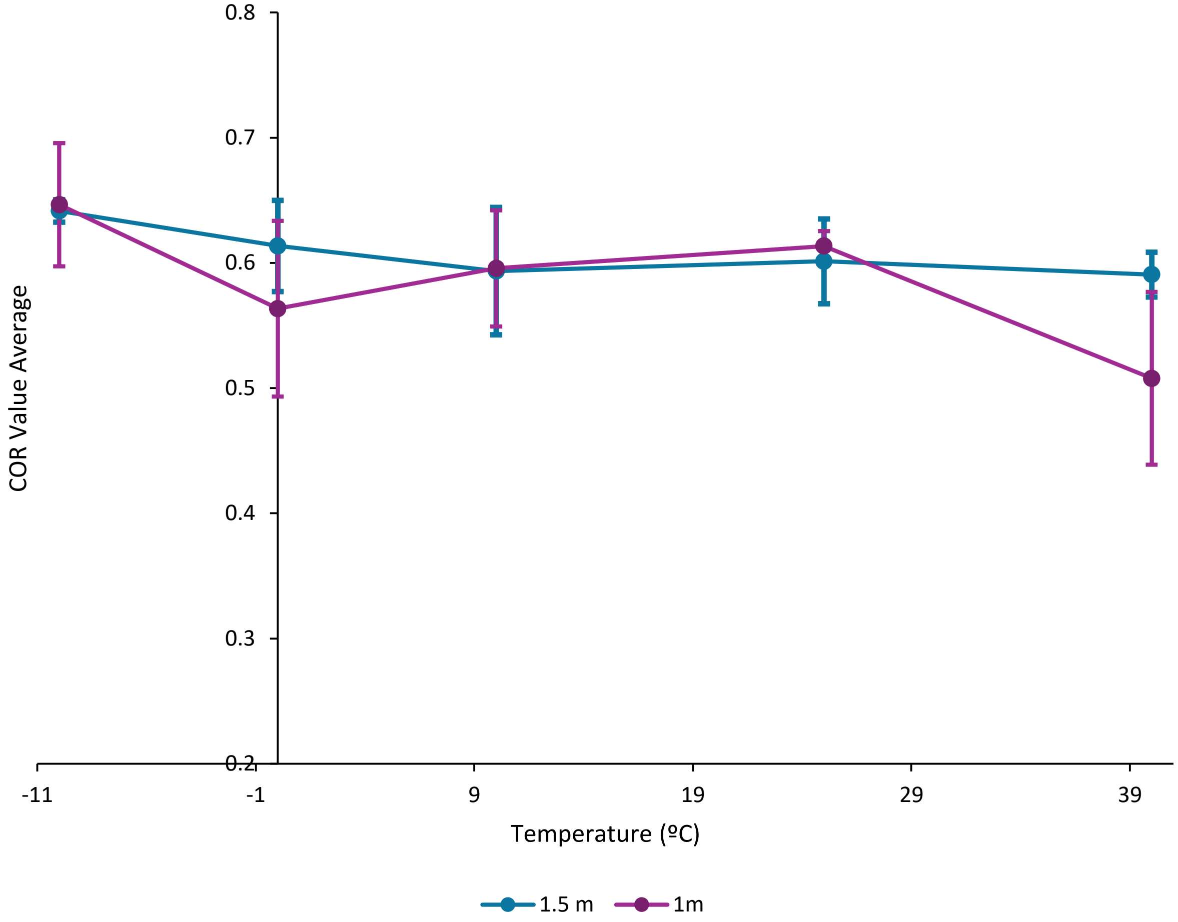


Figure 6: The graph below presents the average Coefficient of Restitution (COR) values for the stainless-steel orb during DCR collisions as a function of temperature. The t-test results show statistically significant differences in COR averages between drops at 1.5 meters and 1.0 meters at temperatures of 0°C, 10°C, and 25°C. Conversely, ANOVA results from Excel indicate that COR values across all temperatures are statistically similar for drops at 1.0 meters. This suggests that, despite some temperature-dependent variations, the overall change in average COR value remains statistically minor.

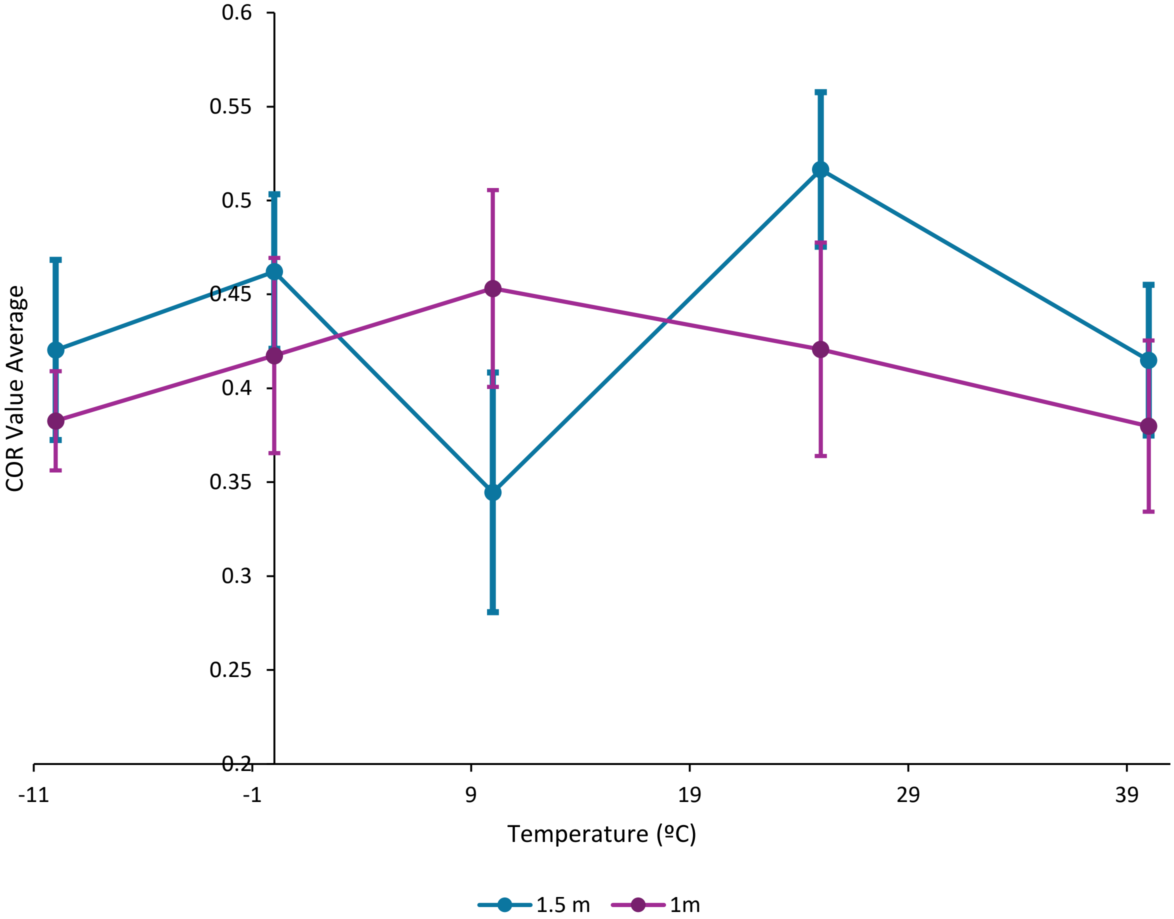


Figure 7: The graph below displays the average Coefficient of Restitution (COR) values for the carbon fiber orb during OCR collisions as a function of temperature. The t-test results indicate statistically significant differences in COR averages between drops at 1.5 meters and 1.0 meters at temperatures of -10°C and 40°C. ANOVA results from Excel also reveal significant differences in COR values across all temperatures for both drop heights. However, when the 40°C data is excluded from the ANOVA analysis, no significant differences in average COR values are observed. This suggests that the COR value at 40°C is notably different from the values at other temperatures.

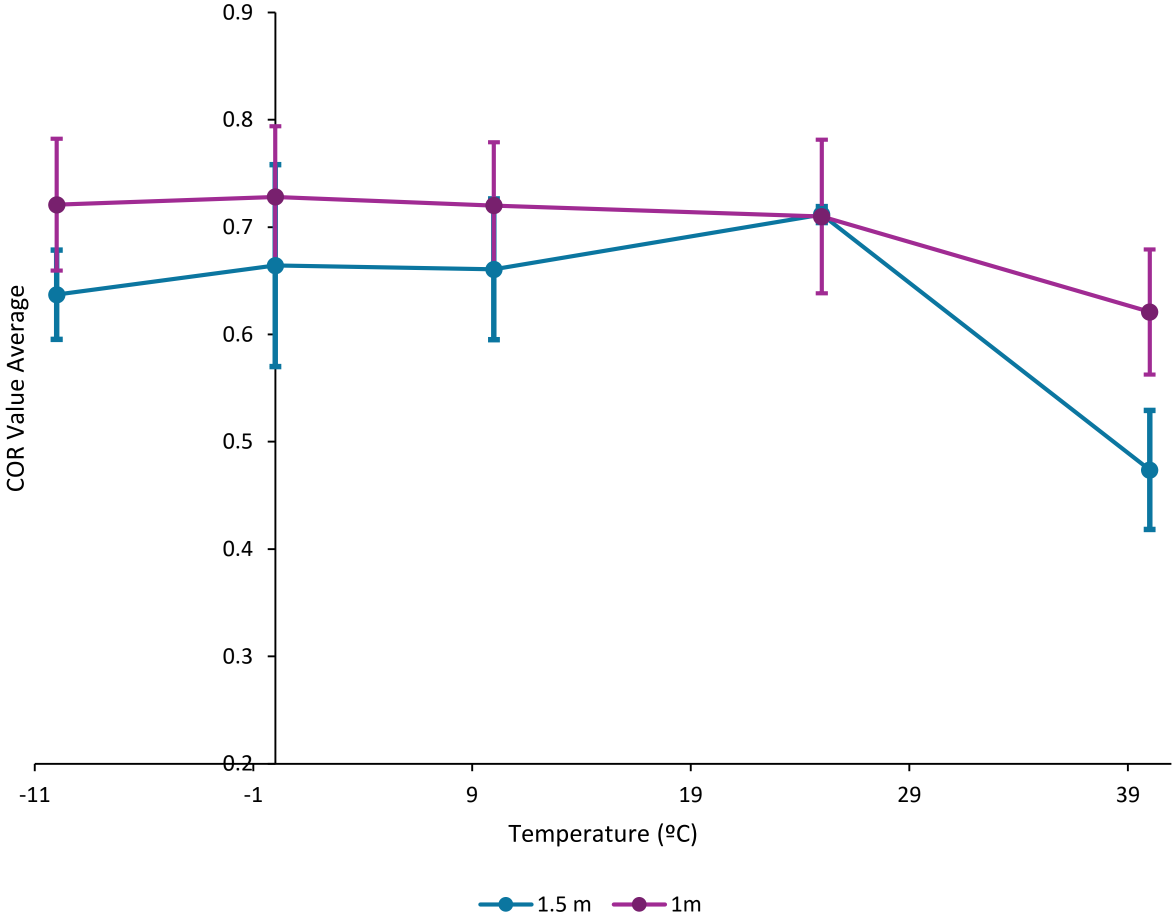
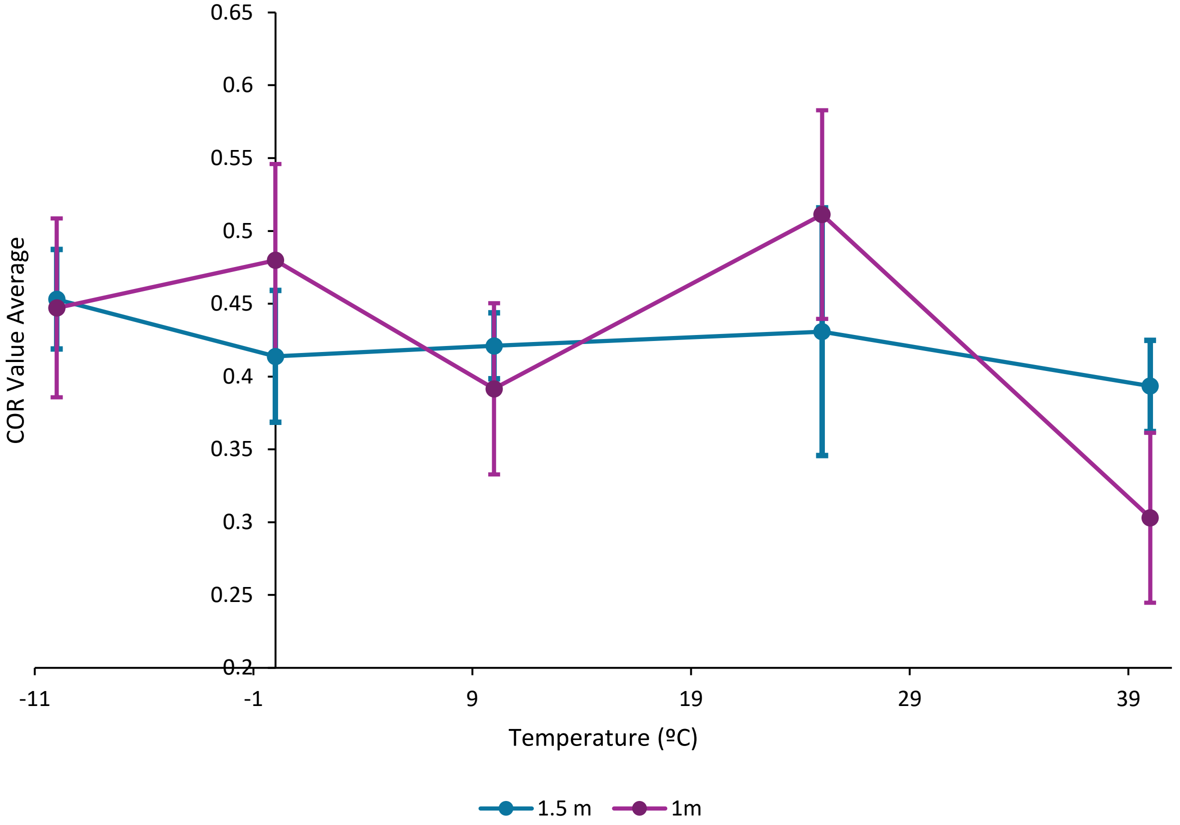


Figure 8: The graph below illustrates the average Coefficient of Restitution (COR) values for the carbon fiber orb during DCR collisions as a function of temperature. The t-test results reveal statistically significant differences in COR averages between drops at 1.5 meters and 1.0 meters only at 40°C. ANOVA results from Excel indicate that COR values across all temperatures are statistically similar for drops at 1.5 meters. Excluding the 40°C data from the ANOVA test at 1.0 meters shows no significant differences in average COR values. This suggests that the average COR value at 40°C differs minimally from values at other temperatures.



It’s worth noting a potential issue with the testing method, orbs might have warmed up during the drop testing at different temperatures. To address this, a control test was performed. Since each orb was dropped ten times at either DCR or ORC before switching the point of contact, a control was conducted by starting with the point of contact that was second in the previous test. The results of this control were compared using a t-test to analyze each point of contact collision and set height against each other. These results are detailed in Table 7.

Table 7: The table below shows the t-test results for the control test. This table compares each point of contact collision and sets heights against each other at 0ºC. For the initial test both the carbon fiber and stainless-steel rods were dropped first in DCR then the OCR at 1.5m. After cooling again for a three-hour block, the orbs were dropped OCR followed by DCR at 1.0 m. This process was repeated but reversed for both the 1.5 m and 1.0 m drops. From the series of t-tests, we can see that the only statistically different result was the stainless-steel orb. This indicated that the environmental warming had a statistically insignificant effect on the COR values obtained during testing.

Approximate Drop Height	Point of Collision Contact	Rod Material	t-test Value
1.5	DCR	Carbon Fiber	0.39
1.5	DCR	Stainless-Steel	0.32
1.5	OCR	Carbon Fiber	0.84
1.5	OCR	Stainless-Steel	0.72
1	DCR	Carbon Fiber	0.58
1	DCR	Stainless-Steel	0.01
1	OCR	Carbon Fiber	0.98
1	OCR	Stainless-Steel	0.32

An observation during testing revealed an increase in the number of rods becoming detached from the vertices, particularly during DCR collisions. This issue was notable when the center rod caused the orb to flex, leading to some rods becoming dislodged. This observation raises two important questions for further investigation: First, do repeated collisions affect the integrity of the vertices? Second, does temperature influence the grip of the plastics on the rods?

To address these questions, a control test was conducted, as detailed in Table 8 below. This test compared COR values measured initially with those measured under the same conditions after testing at various temperatures. The purpose of this control is to demonstrate that repeated drops do not significantly alter COR values. The testing conditions, including temperature and methodology, were kept consistent with previous tests to ensure accurate comparisons.

Table 8: The table below presents t-test results for the TPU orbs maintained at room temperature. The t-test compares COR values from the initial test with those obtained from the final test. The results indicate that there is a statistically significant probability that most of the compared averages differ, suggesting that repeated drops may indeed affect the COR values.

Approximate Drop Height	Point of Collision Contact	Rod Material	t-Test Value
1.5	DCR	Carbon Fiber	0.016
1.5	DCR	Stainless-Steel	0.044
1.5	OCR	Carbon Fiber	0.000
1.5	OCR	Stainless-Steel	0.961
1	DCR	Carbon Fiber	0.013
1	DCR	Stainless-Steel	0.569
1	OCR	Carbon Fiber	0.001
1	OCR	Stainless-Steel	0.010

The results from the table suggest that repeated collisions likely affect the rods, leading to a gradual loss of grip strength in the vertices over time. This finding implies that the impact of temperature on COR values may be less significant than previously indicated. To further investigate this theory, additional testing focusing on the force of removal was conducted, which is discussed in detail in the following section.

Force of Removal Testing

Introduction:

As noted earlier, two key questions emerged from the testing: Do repeated collisions affect the integrity of the vertices? Does temperature influence the grip of the plastics on the rods? To address these questions, a method was developed to measure the force required to remove a carbon fiber rod from a TPU vertex, referred to as the force of removal. This measurement helps to understand the grip strength of the rods within the vertices and how it might be affected by factors such as repeated collisions and temperature changes.

Procedure:

To test the force of removal, a carbon fiber rod was pressed into a TPU vertex. The vertex, with the rod inserted, was then suspended from a mass scale, which allowed the measurement of the force required to pull the rod out. The testing considered several variables: the temperature at which the rods and vertices were stored before removal, the method used to press the rods into the vertices, and the number of pull iterations. Additionally, comparisons were made between old rod pairs and new rod pairs. For the comparisons involving new rods, both rods and vertices were replaced to eliminate any potential effects of repeated removal on the force of removal. Sample size was also a factor, as the force of removal varied across different pulls. Therefore, average values were calculated for each test to determine if the average force required to remove the rods changed under different conditions.

Results:

Four distinct comparisons were evaluated, as outlined below:

1. **Old vs. New Rod Pairs:** This comparison examines old rod pairs taken from the carbon fiber TPU orb used in earlier testing against new rod pairs consisting of fresh carbon fiber rods and TPU vertices.

2. **Hot vs. Cold:** This comparison assesses the performance of fresh rod pairs at two different temperatures: room temperature (25°C) and an elevated temperature (40°C).

3. **Hand vs. Mechanical Press:** This comparison evaluates the difference between fresh rod pairs that were pressed mechanically versus those that were hand-pressed.

4. **Repeated Removal:** This comparison looks at the force of removal over multiple pull iterations on a fresh set of rod pairs.

Table 9: The table below presents the p-values for these comparisons using t-test and ANOVA. P-values greater than 0.05 indicate that the averages being compared are statistically similar. All comparisons, except for the old versus new rod pair, show p-values greater than 0.05, suggesting that the averages are comparable. The discrepancy observed in the old versus new rod pair comparison is discussed in greater detail below.

Comparison		P-Value
Cold (25 ºC)	Hot (40 ºC)	0.273
Press	Hand Pressed	0.407
Repeated Removal		0.138
Old Rod Pairs	New Rod Pairs	3.95E-17

Figure 9: The graph below illustrates the force required to remove a carbon fiber rod from a TPU vertex. The force of removal was measured across 10 pull iterations to assess whether the removal force declined rapidly. The results indicate no statistically significant change in the average force of removal over these iterations.

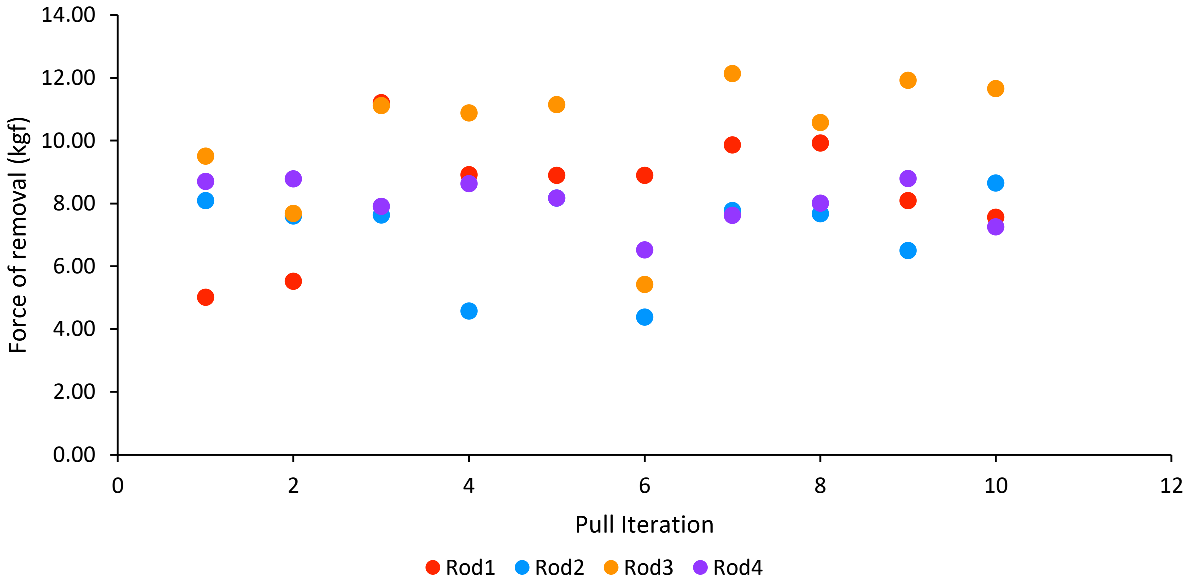
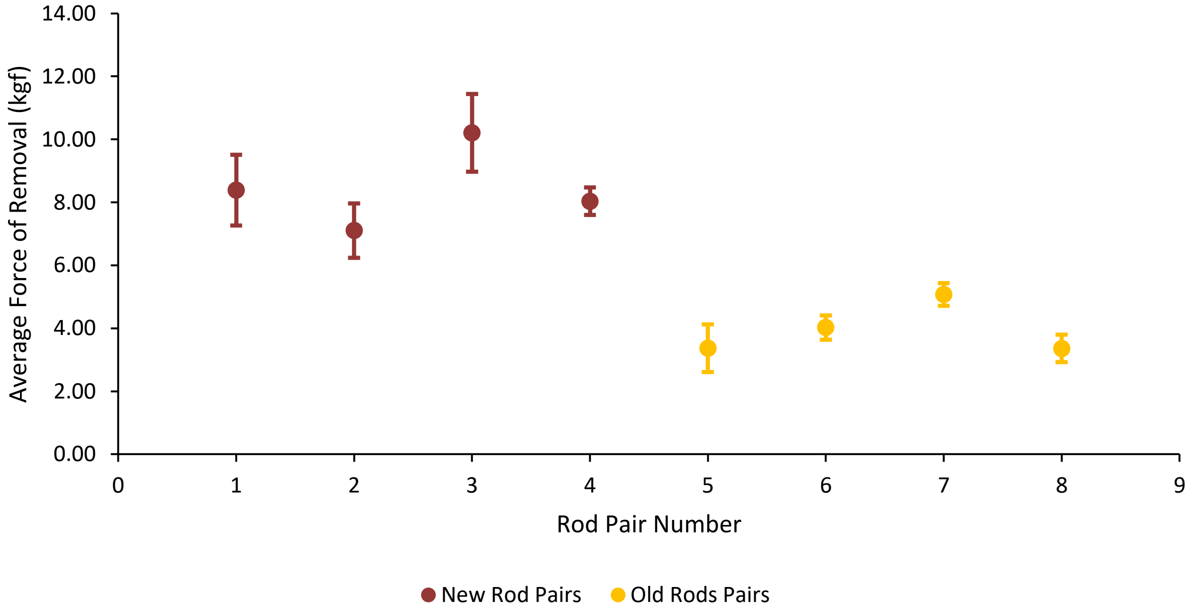


Figure 10: The graph below shows the average force required to remove a carbon fiber rod from a TPU vertex across 10 iterations for 8 different rod pairs. Two types of rod pairs are compared: new rod and vertex pairs, and old rod pairs taken from the TPU carbon fiber orb used in the COR testing. The results reveal a statistically significant difference in the average force of removal between the old and new rod pairs.



Conclusion:

From the data collected, no clear conclusions can be drawn. However, the following observations can be made:

1. **Hand Pressing vs. Machine Pressing:** There is no statistically significant difference in the force of removal between rods that are hand-pressed and those that are machine-pressed.

2. **Temperature Effects:** Temperature does not appear to play an immediate role in altering the force of removal.

3. **Force Consistency Over Iterations:** The force of removal shows no statistically significant change over ten removal cycles.

Despite these findings, further research is needed to determine when a statistically significant change in the average force of removal occurs. Previous studies on TPU suggest that material fatigue and creep could be factors influencing this change. TPU is known to undergo permanent deformation in its microstructures due to external stresses, including temperature variations. Even minor stresses, such as inserting a rod into a vertex, can lead to changes in the microstructure over time, potentially reducing grip strength.

The current testing method does not fully replicate the conditions experienced during a collision. During a collision, the ORB flexes at the TPU vertices, which may affect the force of removal in ways not captured by the current tests. Testing this removal method under collision conditions is beyond the capabilities available for the flight basket orbs at this time.

Conclusion

This study thoroughly examined the performance of the Kairos Autonomi UxV-35 flight basket orb, designed to protect drones during collisions. Through a series of experiments, the orb's behavior under various conditions was evaluated to understand its effectiveness and durability.

The initial testing phase revealed significant variations in bounce height depending on the point of contact and the material composition of the orbs. The black Cycoloy vertices consistently failed, breaking apart upon impact, while the white TPU vertices demonstrated greater resilience. The presence of a center rod also influenced the bounce height, particularly in DCR versus OCR collisions.

The temperature COR testing indicated that the orb maintains its effectiveness across different temperatures, with general a consistency in COR values observed. A gradual increase in the frequency of rod displacement was noted over time, suggesting that either repeated collisions or temperature, impact the orb's long-term performance.

Force of removal testing further explored the orb's durability, revealing that neither higher temperatures nor the method of pressing (hand or mechanical) had an immediate effect on the grip strength of the TPU vertices. However, it became apparent that repeated insertions and removals, as well as prior testing phases, could contribute to a decrease in grip strength, although this decline was not immediately visible within the test's scope.

The experiments collectively highlight the UxV-35 flight basket orb's robustness under various operational conditions, particularly with TPU vertices. However, the study also points to a potential reduction in grip strength over time, likely due to cumulative stress and environmental factors. This suggests that while the orb is reliable for short to medium-term use, its effectiveness may diminish with prolonged exposure and use, indicating a finite shelf life.

To ensure the continued effectiveness of the UxV-35 flight basket orb, further research is recommended to accurately determine its lifespan. Additional testing could explore the long-term effects of temperature fluctuations, repeated collisions, and stress on the orb's materials, ultimately leading to a full understanding of orb performance. This testing should be conducted only after a comprehensive review of the literature on TPU and carbon fiber has been done. Testing should focus on how grip is reduced over extended periods. It should include a focus also on the cyclic performance of the vertices. Testing of this scope may also require the inclusion of factors such as temperature and UV light exposure. Another interesting aspect of this test would be the observation of different vertices under a high-power microscope (confocal and potentially atomic force microscopes). This would allow for visual analysis of the microstructures present.

Overall, the research underscores the importance of ongoing evaluation and refinement of the flight basket orb to maximize its protective capabilities for drones. The insights gained from this study are crucial for ensuring the longevity of drone operations.

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Revisions

Name/Signature	Date	Description
Cameron H Miller	August 14, 2024	1st Draft Completed