



PLA - PIGEON

A 3D Printable Shatter Resistant Airbourne Target

ABSTRACT

This project outlines the design and fabrication of a lightweight yet durable airborne target, engineered as a 3D-printed alternative to traditional sporting clays, capable of withstanding impacts with minimal deformation to geometry or flight path. PLA and PLA+ served as the primary materials, and iterative prototyping was used to refine print orientation, structural integrity, and overall geometry, ensuring repeatable performance and resilience during testing. The results highlight the broader applicability of polymer-based additive manufacturing in producing scalable solutions where durability, precision, and efficiency are critical.

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Overview:

The PLA-Pigeon is a 3D printed alternative to a traditional sporting clay, while designed to replicate the appearance and behavior of a standard target, the PLA-Pigeon is resistant to shattering or deviating in its trajectory following an impact. Durability was a primary concern in the design process as to allow for reuse in training / practice scenarios; or if so inclined to simulate a miss despite an impact occurring.

Design Objectives:

- Mimic the appearance & behavior of a standard sporting clay.
- Survive a direct impact midflight without shattering, deforming in a noticeable manner, or deviating in trajectory.
- Be reliably producible with consistent quality.

Prototyping Summary:

Initial prototyping of the PLA-Pigeon began with the goal of creating a durable airborne target capable of maintaining flight trajectory post impact. The earliest variants focused on approximating the geometry and mass distribution of a standard clay pigeon. While these prototypes were far from identical to commercial clays, they provided valuable benchmarks for flight stability and material performance. Testing confirmed that even rough approximations could sustain stable flight but also revealed the shortcomings of standard PLA under repeated impacts. Nonetheless, these early trials validated the concept and highlighted opportunities for improvement through refined geometry, optimized wall thickness, and the adoption of more resilient materials. See appendix for illustrations and posttest documentation.

With confidence that comparable flight behavior and impact resistance were achievable using the established methodology, the design effort pivoted toward fine-tuning the PLA-Pigeon's appearance to replicate the form of a traditional clay pigeon more closely (Appendix Figures 1–3). Alongside aesthetic improvements, further refinements were made to the manufacturing process. Most notably printing at 100% infill yielded a considerably closer mass match to standard clays, while a 45° print orientation reduced the severity layer-line shearing at impact points, improving overall durability and consistency across tests. In addition, printing at this orientation improved overall layer quality and reduced scarring that could in theory impact flight behavior.

Material Selection & Design Considerations:

Initial Testing / Prototyping:

Standard PLA was chosen for early prototypes due to its low cost, availability, and ease of printing. This allowed rapid iteration to confirm the overall geometry and flight profile before committing to more robust materials. Once the concept proved practical, alternative materials were evaluated to improve durability and post-impact stability.

Material Evaluation:

- **PLA+:** Possesses a higher modulus of elasticity (~3–3.5 GPa) compared to PETG, providing the stiffness needed to preserve flight geometry while incorporating additives that improve toughness over standard PLA. In testing, PLA+ absorbed impacts through localized pellet embedding and short micro-fractures, allowing the disc to support trajectory after being struck.
- **PETG:** Lower modulus (~2–2.2 GPa) and higher ductility. While highly fracture-resistant, PETG's flexibility makes it more prone to broad, permanent deformations under impact. These deformations can alter lift/drag balance, resulting in post-impact wobble or deflection.
- **ABS:** Lower density (~1.04 g/cm³) and modulus (~2.0 GPa), with higher shrinkage during printing. These properties reduce its ability to match the mass and stiffness of a standard clay target, while also complicating print consistency.

Impact Considerations:

Because a primary goal of this project is to preserve flight trajectory following impact. In this case, a more inelastic collision is preferable, as it allows the projectile's kinetic energy to be absorbed locally rather than redistributed through broad structural deformation. PLA+'s stiffness and moderate toughness promote localized pellet embedding and micro-fracturing, with minimal to moderate deformation in most impact scenarios thus preserving aerodynamic stability. In contrast, PETG's higher ductility tends to distribute force over a larger area, reducing fracture risk but increasing the likelihood of permanent shape changes that can alter lift/drag balance and cause post-impact deviation.

Sustainability / Environmental Considerations:

PLA+ is derived from renewable resources such as corn starch, giving it a smaller carbon footprint compared to petroleum-based plastics like ABS or PETG. PLA+ is biodegradable only under industrial composting conditions and does not degrade rapidly in typical outdoor environments. For this reason, retrieval and reuse are strongly encouraged to minimize environmental impact.

Final Selection:

PLA+ was selected as the production material for its optimal balance of stiffness, toughness, and density, enabling it to mimic the flight characteristics of a standard clay while maintaining post-impact stability for repeated use. Fully infilled prints were used to closely match the mass of commercial targets, further supporting trajectory consistency.

Optimization Strategies:

Following the selection of PLA+ as the preferred material, the focus shifted to refining print methodology and geometry to maximize durability, as well as verify that alterations in geometry did not impede the target's ability to maintain trajectory post impact. Final target geometry was established with Version 12 (Figure 2), which incorporated minor dimensional changes and corrected a known weak point at the 90° connection between the dome and bottom torus / ring. This issue, caused by a thin cross-section aligned with layer lines, was addressed by adding a fillet and reinforcing the connection with additional material.

With Version 12 serving as the production baseline, three primary print methodologies were tested:

- **Vertical Print with 100% infill**
The original production philosophy validated during early prototyping (Figures 6–7).
- **45° Oriented Print with 100% infill**
Introduced to reduce stress concentrations along horizontal layer lines by redistributing them at a 45° angle, thereby reducing the likelihood of layer line shearing.
- **Vertical Print with Variable Infill**
The most complex strategy, employing eight perimeter walls combined with variable infill ranging from approximately 70–85%. This approach was intended to concentrate density in high-stress regions likely to sustain impacts while reducing material use elsewhere.

Testing:

Physical testing was performed at a licensed shooting facility under supervised conditions using standard sporting-clay launch systems and at typical engagement ranges utilizing 12g #8 shot traveling at 1200 ft/s to evaluate impact response. Targets were evaluated on three key criteria:

1. Durability: The target's ability to survive mid-flight impacts without noticeable failure.
2. Trajectory Preservation: The target's ability to maintain a consistent flight path post impact.
3. Consistency Across Variants: Ensuring identical prints perform consistently.

Results:

Four units of each methodology were produced for both observational and destructive testing. All targets were launched at the same angle under similar conditions within the same test day.

Moderate winds of approximately 10–13 mph revealed that PLA-Pigeons were somewhat more susceptible to wind interference than standard clay targets, likely due to slightly reduced weight (78.8g); however, comparative trajectories between test groups showed minimal variation.

In destructive testing, all variants survived multiple impacts with only minor to moderate damage:

- Vertical Print (100% Infill): Withstood impacts without catastrophic failure but displayed minor stress cracking along layer lines.
- 45° Oriented Print (100% Infill): Demonstrated superior durability, showing markedly reduced layer-line shearing and less overall deformation (Figure 9-10).
- Vertical Print (Variable Infill): Survived multiple impacts with slightly more visible deformation and non-catastrophic layer-line cracking, similar to the 100% vertical prints. Considering the reduced material use, the results remained comparable to the 100% infilled version thus showing promise (Figure 11-12).

Mathematical Considerations:

This section explains the PLA-Pigeon's observed behavior via first-order models for mass/inertia (flight stability), pellet impact energy (localized damage), FFF anisotropy (why 45° helps), wind sensitivity (why lighter targets drift more), and junction reinforcement (fillet reducing stress concentration).

Mass From Perimeter & Infill as It Pertains to Weight and Stiffness:

$$m = \rho(V_{shell} + \phi V_{infill})$$

Where:

- m denotes the mass of the target.
- ρ denotes the density of the material, (PLA+ = 1.24-1.27 g/cm³)
- V denotes the volume of the shell and the infilled portions.
- ϕ denotes the infill percentage.

This serves as means to not only verify the estimates provided by the slicing software (Orca), but to more efficiently match target values by targeting infill percentage and shell / wall count.

Moment of Inertia

Due to the complexity of the PLA-Pigeon's geometry metrics pulled from the CAD software (OnShape) used to produce the model.

CAD properties give the following:

$$I_z = 1.386 \times 10^{-4} \frac{kg}{m^2}$$

At $m = 88.7g$ this mass is within range of slicer and production numbers for 100% infill (85-86.8). Normalizing by mR^2 yields $\eta \approx 0.52$ indicating a disk like mass distribution, which supports the idea that rim-based density is a more efficient means of effecting spin inertia than mass alone.

Impact Energy & Localized Damage

The energy a #8 lead pellet weighing approx. 1.07grains or 0.069g traveling at 1200 ft/s or approx. 366 m/s can be modeled by:

$$E = \frac{1}{2}mv^2$$

$$E = 4.6J$$

Energy decays with range, however even a single pellet at typical engagement range (15-20 yards) maintains enough energy to exceed the local strength of PLA+ if the contact area is small this is shown by the following approximation:

$$E = F_{avg}\delta \rightarrow \frac{E}{\delta}$$

$$F_{avg} = \frac{E}{\delta}$$

Assuming an embedded depth of $\delta = 0.5 - 2mm$

$$F_{avg} = 2.3 - 9.2kN$$

Wind Sensitivity:

The lateral force of wind can be modeled by the following:

$$F_w = \frac{1}{2}\rho C_d A_{lat} V_w^2, \quad a = \frac{F_w}{m}$$

Assumptions:

- Diameter: $D = 0.11m$
- Thickness: $t = 0.025m$
- Cross Sectional Area: $A \approx D * t = .00275m^2$
- Drag Coefficient: $C_d \approx 1$
- Air Density: $\rho = 1.225 \frac{kg}{m^3}$
- Windspeed: $V_w \approx 5 \frac{m}{s}, \approx 11mph$
- Flight time: $t_f = 1s$

Wind Force:

$$F_w = \frac{1}{2}(1.225)(1)(0.00275)(5^2)$$

$$F_w \approx 0.042N$$

Accelerations:

$$a_{pla} = \frac{F_w}{m_{pla}} = \frac{0.042N}{0.085kg} = 0.494 \frac{m}{s^2}$$

$$a_{std.} = \frac{F_w}{m_{std}} = \frac{0.042N}{0.105kg} = 0.40 \frac{m}{s^2}$$

While small this difference of 0.094 m/s^2 validates the heightened impact of winds as seen in testing.

Drift Distance over 1 second:

$$x_{pla} = \frac{1}{2}a_{pla}t_f^2 = 0.247m$$

$$x_{std.} = \frac{1}{2}a_{std.}t_f^2 = 0.20m$$

$$\Delta x = .047m$$

For comparable geometry, $a \propto \frac{1}{m}$

With $m_{pla} \approx 78 - 85g$ and $m_{standard} \approx 105g$

[Note: 78g is representative of the optimized variant used in limited testing]

$$\frac{a_{pla}}{a_{std}} \approx \frac{m_{pla}}{m_{std}} \approx 0.743 - 0.81$$

Conclusion:

The PLA-Pigeon project achieved its core objective of producing a reusable, 3D-printed sporting clay capable of withstanding impacts while maintaining stable flight. Iterative prototyping demonstrated that geometry, print orientation, and infill strategy each significantly influenced durability and trajectory preservation. All three tested methodologies vertical 100% infill, variable infill, and 45° 100% infill proved viable, with the angled orientation offering the most significant improvement in layer-line resilience and overall post-impact stability albeit with a slightly increased print time.

Testing confirmed that impacts caused only localized cratering and minor stress fractures rather than catastrophic failure, validating PLA+ as a suitable material for repeated use. Mathematical modeling supported these results: pellet kinetic energy calculations explained the localized nature of damage, while moment of inertia analysis ($\eta \approx 0.52$) showed a disc-like mass distribution consistent with observed wind sensitivity. Wind drift calculations further quantified this, estimating ~19–22% greater lateral acceleration in crosswinds, or approximately 4–6 cm of additional drift over a one-second flight compared to standard clays.

Overall, the PLA-Pigeon demonstrates that additive manufacturing can produce functional, durable parts and assemblies while opening opportunities for rapid and dynamic iterative refinement. Future development will focus on increasing rim-biased mass to raise moment of inertia efficiency, thereby reducing wind sensitivity and more closely matching the flight behavior of commercial clays.

In summary, these results highlight the value of combining CAD analysis, mathematical modeling, and physical testing in iterative engineering design, and illustrate the potential for 3D printing to deliver practical, scalable solutions.

Appendix:



Figure 1 3D model of V4, the first PLA-Pigeon iteration tested for impact resistance. Results confirmed concept viability and demonstrated potential for further refinement.



Figure 2 Top isometric view of V12, the final iteration, showing improved geometric and aesthetic consistency.

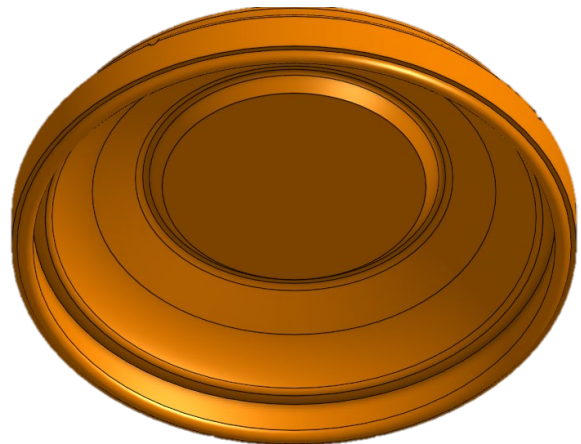


Figure 3 Bottom iso view of V12, the final iteration.

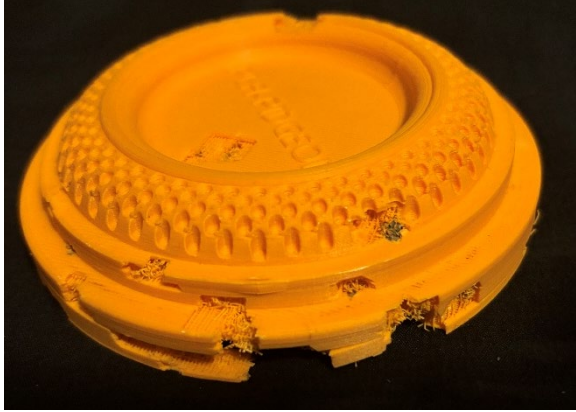


Figure 4 V4 tested at ~75% infill. Example shows close range direct impact on lighter infill as proof of concept.



Figure 5 Despite increased surface damage, overall geometry remained consistent. Performance at > 100% infill showcased promise for improvements in durability.



Figure 6 V4 tested at 100% infill. Impact occurred while flying from a standard sporting clay tower.



Figure 7 Vertical layer line shearing observed at impact points.



Figure 8 Weak point in V11 caused by sharp corners aligned with layer lines, resulting in catastrophic failure.



Figure 9 Post-test documentation of V12, 45° orientation. Target shows minimal deformation and no pellet embedding, demonstrating enhanced durability from angled layer orientation.



Figure 10 Pellet embedding on the 45° variant of V12, showing lack of layer-line shearing and a minimal entry wound.



Figure 11 Most extensive damage observed on the variable-infill V12. Despite severe local deformation, the geometry remained intact and testing was successful.



Figure 12 Pellet embedding on the optimized V12 with variable infill, showing reduced layer-line shearing compared to vertical 100% infill prints.

