

# Modeling FDM-Printed TPU Energy Absorption for Impact-Resistant Armor in Combat Robotics

## Problem Statement

- Develop a Python-based discrete simulation to visually simulate FDM-printed TPU components for impact-resistant combat-robot armor and bridge theory of discrete elastic structures from MAE 263F with real-world soft armor applications

## Background

- Combat robots experience repeated high-energy impacts that fracture rigid armor and transmit shocks to electronics.
- To mitigate such, TPU (Thermoplastic Polyurethane) 's unique flexibility, high elongation, superior abrasion resistance properties + FDM tunability (through infill, density, and wall thickness) allow for performance optimization under strict weight constraints, where every ounce affects energy efficiency and impact mitigation.

## Motivation

- Further understanding TPU's deformation behavior enables design optimization of lightweight, resilient, and repairable armor systems for competitive robotics at lower weight classes  $\leq 30\text{lbs}$ .
- Aim to visualize and quantify the energy absorption capabilities of various TPU geometries and print configurations to guide design choices in combat robotics.



ASME at UCLA FLAGSHIP 2023 15 lb Flywheel Flipper Combob



## Literature Review

- FDM-Printed TPU Printing Parameters & Mechanical Properties
  - Bruère V. M. et al. (2023) - The influence of printing parameters on the mechanical properties of 3D printed TPU-based elastomers
  - Birosz M. T. et al. (2022) - Effect of FDM infill patterns on mechanical properties
- Hyperelastic and Constitutive Modeling of TPU
  - Reppel T. et al. (2018) - Experimental Determination of Elastic and Rupture Properties of Printed Ninjaflex
  - Gallup L. et al. (2023) - Predicting the Bending of 3D Printed Hyperelastic Polymer Components
- Energy Absorption and Lattice Design
  - Khatri N. R. et al. (2024) - Energy Absorption of 3D Printed ABS and TPU Multimaterial Honeycomb Structures

## Proposed Approach

- Begin with thin-wall plate simulation using discrete stretching and bending energies
- Extend to geometric shell model to represent 3D TPU armor
- And then explore incorporation of simple internal infill patterns (grid,hex) to study how topology affects deformation and damping.
- Implement all stages in Python using energy-based formulation.

## Anticipated Contributions

- Establish a computational framework for predicting deformation and damping in FDM-printed TPU armor, building design intuition for flexible protection.
- Analyze design optimizations and weight trade-offs between simple infill structures; quantify how infill topology (grid vs hex) affects impact absorption.
- Provide practical guidelines/insights for creating soft, modular, and printable energy-absorbing components in combat robotics.

## References

1. Bruère, V. M., Coelho, C. P., Vera, S. F., & Mata, M. T. (2023). The influence of printing parameters on the mechanical behaviour of thermoplastic polyurethane (TPU) printed by fused filament fabrication. *International Journal of Advanced Manufacturing Technology*, 127(7–8), 3157–3172. <https://doi.org/10.1007/s00170-023-11224-1>
2. Birosz, M. T., Piszczek, M., & Kwiatkowski, K. (2022). Effect of fused-deposition-modeling infill patterns on mechanical properties of thermoplastic materials. *Polymer Testing*, 111, 107640. <https://doi.org/10.1016/j.polymertesting.2022.107640>
3. Reppel, T., Al-Ketan, O., & Rowshan, R. (2018). Experimental determination of elastic and rupture properties of thermoplastic polyurethane (TPU) and Ogden-model identification. *Technische Mechanik*, 38(2), 150–160. <https://doi.org/10.24352/UB.OVGU-2018-038>
4. Gallup, L., Noriega, A., & Starr, R. (2023). Predicting the bending of 3D-printed hyperelastic polymer components. *Polymers*, 15(3), 688. <https://doi.org/10.3390/polym15030688>
5. Khatri, N. R., Zhou, J., & Parthasarathy, T. (2024). Energy absorption of 3D-printed ABS and TPU multimaterial honeycomb structures. *3D Printing and Additive Manufacturing*, 11(2), 123–135. <https://doi.org/10.1089/3dp.2023.0056>