Case Study

Upfront Simulation using Ansys Discovery Software

Developed and curated by the Ansys Academic Development Team

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Ansys Software Used

This resource uses Ansys Discovery™, a 3D product simulation software.

Summary

Upfront Simulation has many benefits for Engineers and Designers including improvements in productivity, innovation and the quality of their product designs. In this case study, we will explore the benefits of upfront simulation using the Ansys Discovery software.

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1. The Traditional Usage of Simulation in the Product Life Cycle

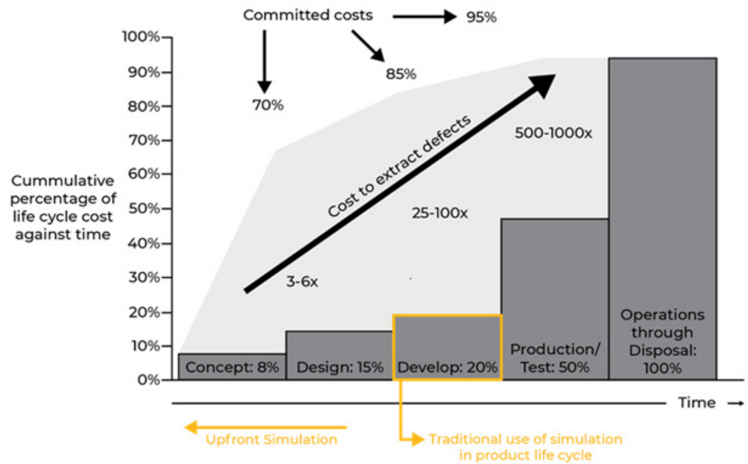


Figure 1: The use of simulation in the product life cycle [1]

The above chart shows how much product development costs at each stage of a product's life cycle. The y-axis represents the budget assigned to developing the product, while the x-axis represents time. The bars depict the stages of a product's life cycle from concept to use/disposal.

The percentages in the bars indicate the average actual costs of product development at each stage. We derive the actual costs from the committed cost represented by the curve. The committed costs estimate how much of the budget we could spend at each stage. For example, by the end of the design phase, we could have spent up to 85% of the budget on product development. The percentage assigned to the committed costs depends on the design decisions made by engineers and designers.

The arrow indicates how much it costs to correct any errors present in a product's design. Such errors are most likely to occur during the early stages of design. During the concept and design phases, engineers and designers can make decisions flexibly as they explore various ideas and potential solutions to problems, often with limited or incomplete information. As a design progresses through each stage of the cycle, the decisions harden and become rigid and difficult to change. If there is an error in the design of the product, the cost of correcting it increases significantly in the later stages of design, as indicated by the large gray arrow on the chart. The yellow box depicts the stage in which engineers and designers traditionally use Computer Aided Design (CAD) and simulation tools to provide crucial information and analysis of a generated design.

The chart suggests that using CAD and simulation tools in the early stages of design would be beneficial. Engineers and designers would have access to crucial information and analysis at the stages in which they make most design decisions. This leads to reduced costs of error correction, increased efficiency, and improved quality of the final product.

However, conventional thinking deems CAD and simulation too inflexible for use in the early stage of design due to their expense and difficulty of operation. Engineers and designers often need specialist knowledge and training to use CAD and simulation tools effectively. The Ansys Discovery software is a new kind of CAD and simulation tool that has the flexibility for upfront simulation.

"Upfront simulation is a design process that uses simulation to reduce prototyping and testing and minimizes engineering change orders while maximizing design and ideation focus. The software's GPU live solver allows you to explore different design ideas in real-time with instantaneous results." [3]

In this case study, we will explore the benefits of upfront simulation using the Ansys Discovery tool.

2. The Benefits of Upfront Simulation During the Product Life Cycle

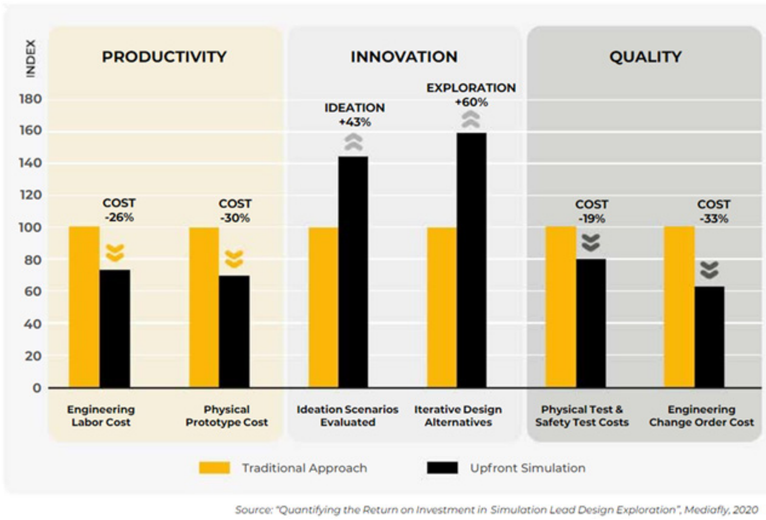


Figure 2: Return on investment for upfront simulation [2]

Research previously commissioned by Ansys (shown in Figure 2) followed the experiences of the engineering team of a reputable energy services company over 12 months. The engineering team focused on designing electrical, mechanical, optical, and safety products. The yellow bars indicate the cost of the traditional usage of simulation. The black bars display the use of upfront simulation. The team reported significant improvements in the areas of productivity, innovation, and quality.

Upfront simulation enables engineers and designers to explore the design space of potential solutions more widely and efficiently compared to the traditional approach. They can consider and evaluate the feasibility of an initial concept during the concept and design phases of the cycle. Engineers and designers can use upfront simulation to make better design decisions early in the cycle or even use upfront simulation to indicate future performance or identify and correct errors.

3. Upfront Simulation Use cases

Below are links to examples highlighting further benefits of upfront simulation:

- Infinitum Develops Sustainable Motors
- Techfit Creates Surgical Solutions for Quicker Patient Recovery

4. Design Exploration of Soccer Shoe Outsole

Upfront simulation is most advantageous when engineers and designers use it as an iterative process, allowing them to quickly modify their designs based on information received from previous simulations. For example, consider the design of the outsole for a soccer shoe. Engineers conducted a series of simple static simulations in the Ansys Discovery Software Explore mode (with a fidelity of 0.29 mm) to assess how variations in the design of the outsole coped with displacement and Von Mises stress through different phases of the footstep, from heel strike to toe push-off.

4.1 Design Parameters

The playing surface is a firm ground grass soccer pitch.

- The average weight of a professional footballer is 170.2 lbs (77.2 kg) (World Cup 2018). [4]
- A US size 10 soccer shoe measures 10.63” (27.0 cm) in length and 4.01” (10.2 cm) in width.
- An arbitrary plantar foot map to calculate foot pressure.
- The outsole material is injection-molded plastic, PI (thermoplastic).

The material properties of plastic, PI (thermoplastic) are:

- Density: 1379 kg/m³
- Young’s Modulus: 2.478e9 Pa
- Poisson’s Ratio: 0.399
- Shear Modulus: 8.86e8 Pa
- Bulk Modulus: 4.07e9 Pa
- Tensile Yield Strength: 87.9 MPa
- Tensile Ultimate Strength: 92.4 MPa

4.2 Baseline Pressure Calculations

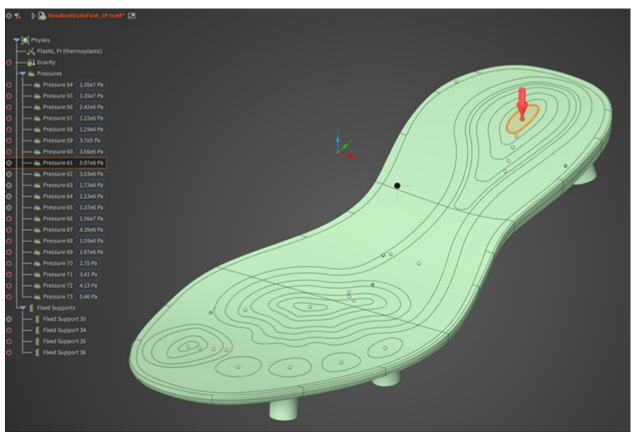


Figure 3: Outsole with foot plantar split into Toe-Push Off, Mid Foot and Heel Strike sections

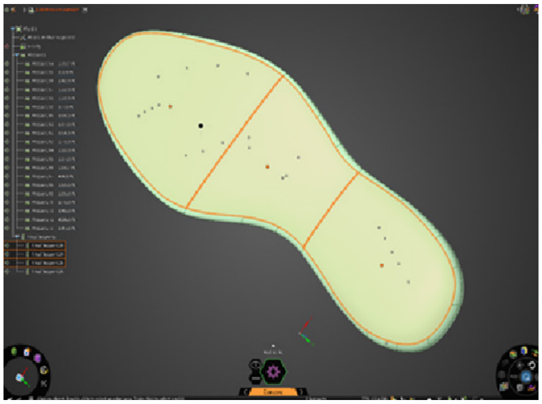
4.2.1 Steps to Calculate Pressure

Pressure (MPa) = Force (N) / Area (m²).

1. Convert the mass to force using gravity (9.81 m/s²):
   - Force (N) = 77.2 kg × 9.81 m/s² = 756.732 N
2. Convert the highlighted area from mm² to m²:
   - Area (m²) = Area (mm²) × 10^{-6}
   - Area = 126.7622 mm² × 10^{-6} = 0.0001267622 m²
3. Calculate the pressure in Pascals (Pa):
   - Pressure (Pa) = Force (N) / Area (m²)
   - Pressure = 756.732 N / 0.0001267622 m² = 5,974,430.863 Pa
4. Convert the pressure to Megapascals (MPa):
   - Pressure (MPa) = Pressure (Pa) / 10^6
   - Pressure = 5.974 MPa

The pressure on the highlighted area is 5.974 MPa. All areas of the foot plantar map were calculated using the same formulas. The outsole is split into three sections: toe push-off, mid-foot, and heel, to simplify the study. Fixed supports were used to simulate parts of the outsole in contact with the playing surface during the phases of footstep transition (Figure 4a). Another fixed support was used on the rim of the upper surface of the outsole to simulate the soccer shoe upper (Figure 4b). The study was performed on three types of outsoles pictured shown in Figure 5.

(a)



(b)

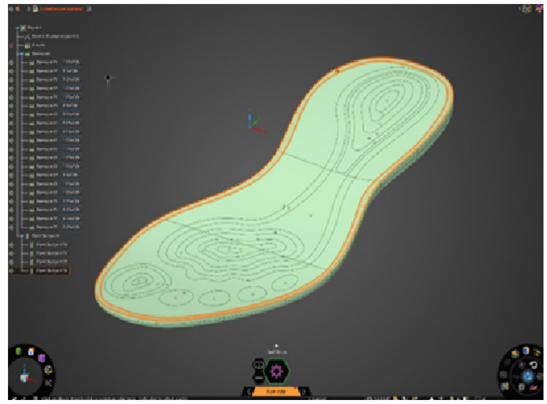


Figure 4: Fixed Support Locations
(a) Soccer Shoe Underside and Sections (b) Soccer Shoe Upper Rim and Sections

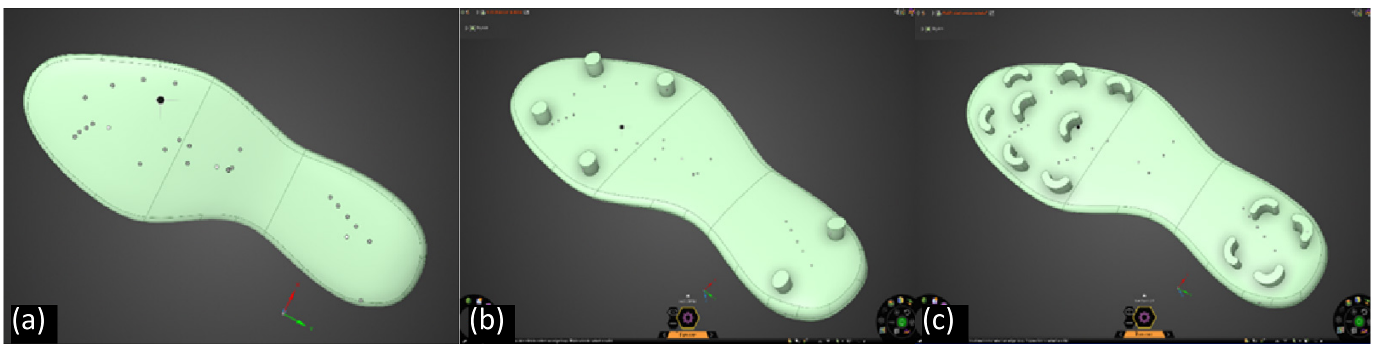


Figure 5: Outsole Designs for Study
(a) 0-cleat (b) 6-cleat (c) multi-cleat

4.3 Baseline Simulation Results for Five Loading Conditions

Five loading conditions were used in this study: heel strike, heel and mid foot, whole foot, toe and mid foot, and toe push off. The simulations, displacement magnitude, and Von Misses Stress results for each load case using the baseline outsole (0-cleat) are shown below.

4.3.1 Heel strike

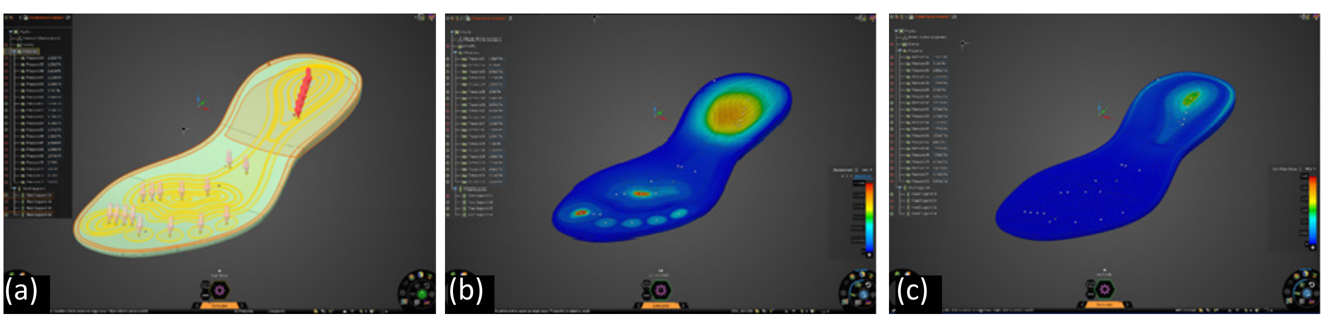


Figure 6: Heel Strike Simulation Results
(a) Static Footstep Phase (b) Displacement Magnitude (mm) (c) Von Misses Stress (MPa)

Key Findings:

- Displacement Magnitude = 0.0244 mm
  - During heel strike, the outsole experiences initial contact with the ground, resulting in moderate displacement.
- Von Mises Stress = 3.73 MPa
  - The stress is concentrated at the heel area, where the force is first applied. Engineers may analyze how the material properties and design variations handle this stress to prevent deformation or failure.

4.3.2 Heel and Mid-Foot

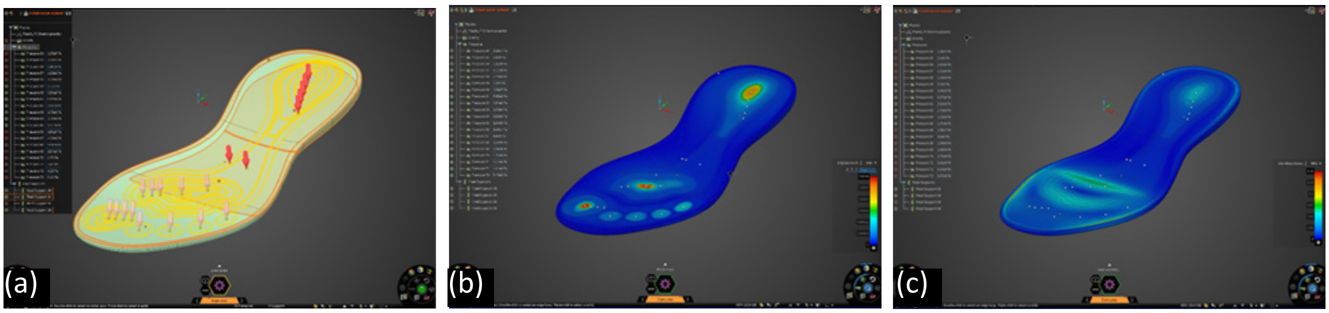


Figure 7: Heel and Mid-Foot Loading Simulation Results
(a) Static Footstep Phase (b) Displacement Magnitude (mm) (c) Von Misses Stress (MPa)

Key Findings:

- Displacement Magnitude = 0.101 mm
  - As the foot transitions from heel to mid-foot, the displacement magnitude increases slightly.
- Von Mises Stress = 6.15 MPa
  - Stress distribution shifts towards the mid-foot area. Engineers can assess how well the sole-plate design maintains structural integrity and comfort during this phase.

4.3.3 Whole Foot

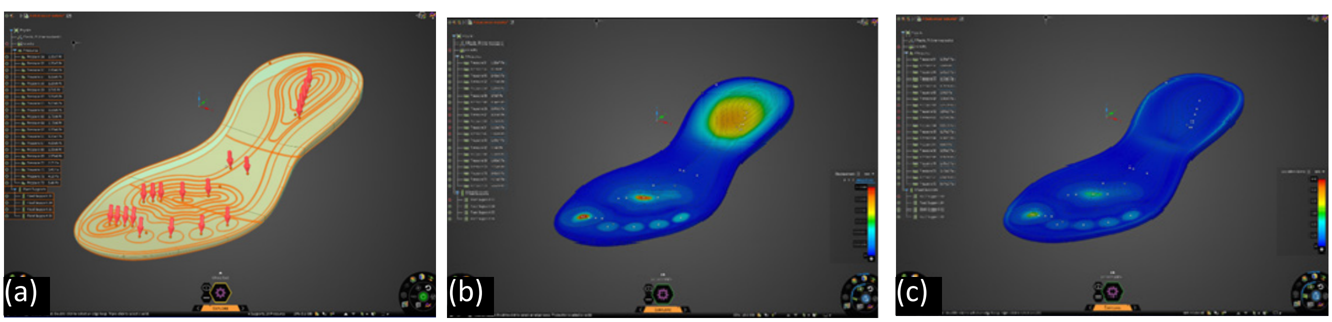


Figure 8: Whole Foot Loading Simulation Results
(a) Static Footstep Phase (b) Displacement Magnitude (mm) (c) Von Misses Stress (MPa)

Key Findings:

- Displacement Magnitude = 0.0244 mm
  - When the entire foot is in contact with the ground, the displacement magnitude is more evenly distributed. This phase tests the overall stability and support of the sole-plate design.
- Von Mises Stress = 9.97 MPa
  - Stress is spread across the entire sole-plate, with particular attention to areas that bear the most weight. Engineers evaluate the sole-plate's ability to handle this distributed stress without compromising performance.

4.3.4 Toe and Mid-Foot

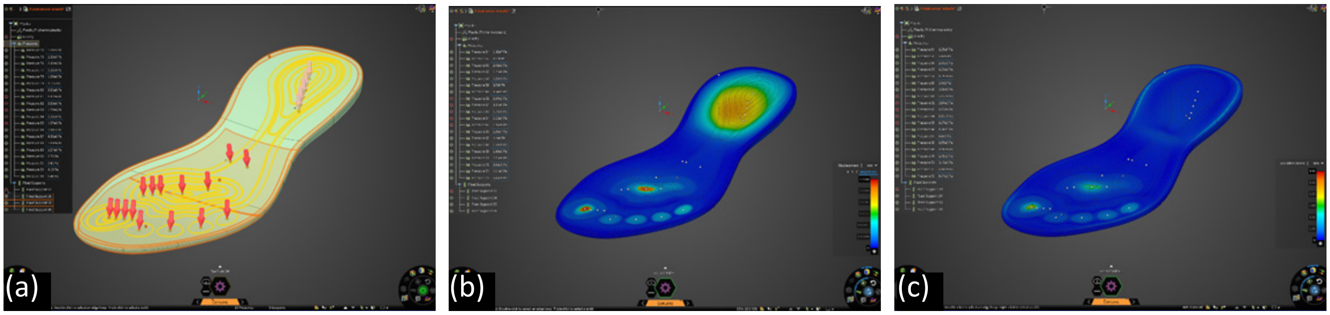


Figure 9: Toe and Mid-Foot Loading Simulation Results
(a) Static Footstep Phase (b) Displacement Magnitude (mm) (c) Von Misses Stress (MPa)

Key Findings:

- Displacement Magnitude = 0.0244 mm
  - As the foot prepares for push-off, the displacement magnitude increases at the toe and mid-foot areas. This phase tests the sole-plate's ability to provide flexibility and support during the transition.
- Von Mises Stress = 9.97 MPa
  - Stress is concentrated at the toe and mid-foot areas, where the force is applied for push-off. Engineers assess the sole-plate's ability to withstand this stress and maintain performance

4.3.5 Toe Push-Off

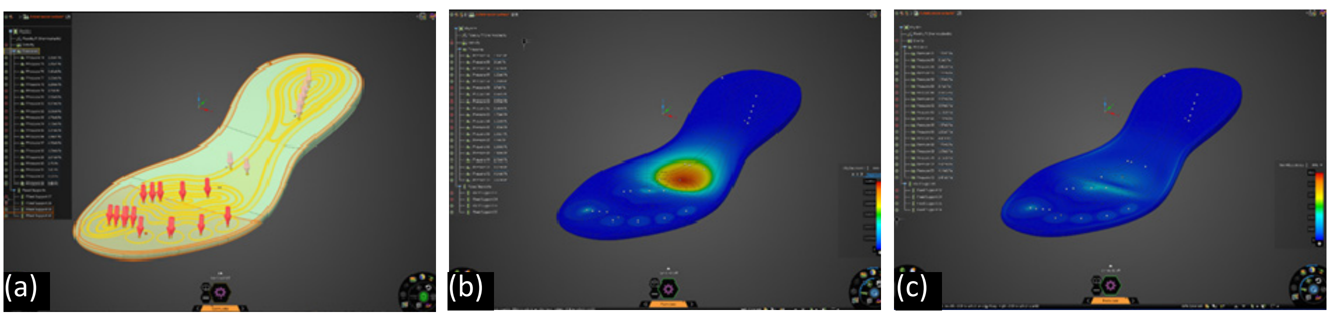


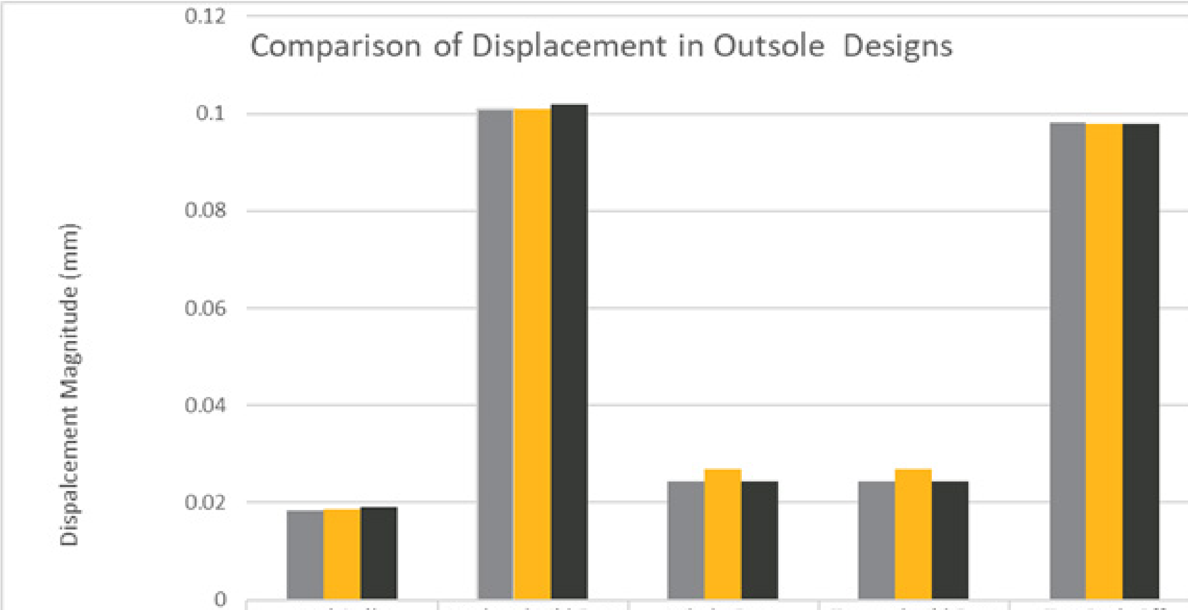
Figure 10: Toe Push-Off Simulation Results
(a) Static Footstep Phase (b) Displacement Magnitude (mm) (c) Von Misses Stress (MPa)

Key Findings:

- Displacement Magnitude = 0.0982 mm
  - During toe push-off, the displacement magnitude reaches its peak as the foot exerts maximum force to propel forward. The sole-plate design must accommodate this high displacement while providing stability.
- Von Mises Stress = 26.6 MPa
  - Stress is concentrated at the toe area, where the force is applied for push-off. Engineers evaluate the sole-plate's ability to handle this stress without compromising durability and performance.

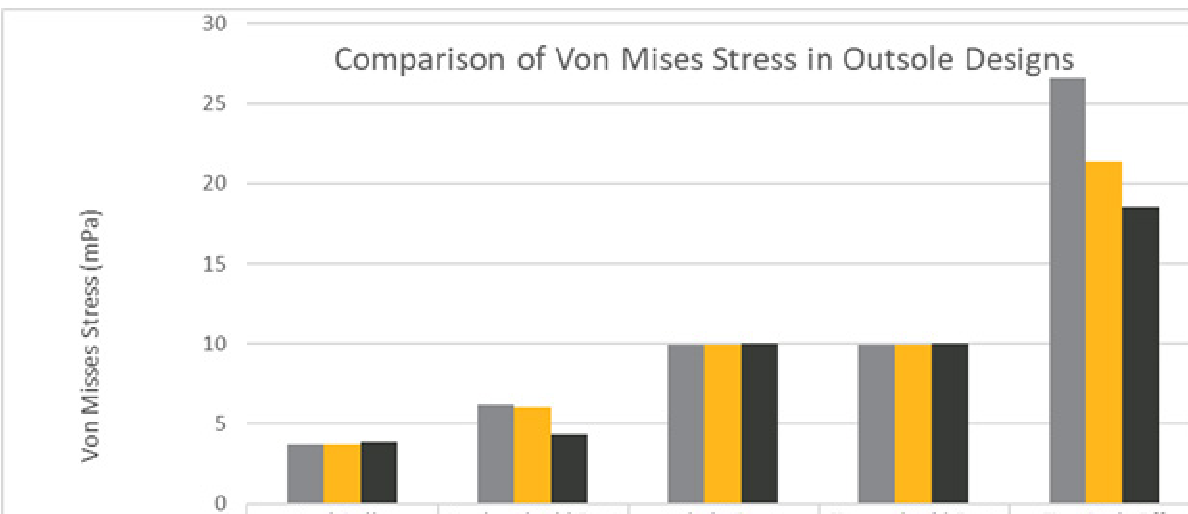
4.4 Design Study Analysis

Below are the comparison between the three designs and the five loading conditions for displacement (Figure 11) and Von Mises stress (Figure 12). Values are shown in the tables below each plot.



	Heel Strike	Heel and Mid Foot	Whole Foot	Toe and Mid Foot	Toe Push Off
0 Cleat Outsole	0.0184	0.101	0.0244	0.0244	0.0982
6 Cleat Outsole	0.0186	0.101	0.0268	0.0268	0.098
Multi Cleat Outsole	0.019	0.102	0.0243	0.0243	0.098

Figure 11: Comparison of Displacement in outsole designs



	Heel Strike	Heel and Mid Foot	Whole Foot	Toe and Mid Foot	Toe Push Off
0 Cleat Outsole	3.73	6.15	9.97	9.97	26.6
6 Cleat Outsole	3.73	6.03	9.95	9.95	21.4
Multi Cleat Outsole	3.88	4.33	9.98	9.98	18.5

Figure 12: Comparison of Von Mises stress in outsole designs

The Von Mises stress values in all three designs are well below the tensile yield strength (87.9 MPa) and tensile ultimate strength (92.4 MPa) of the cleat material. This indicates that the cleats should not experience yielding or failure under the given loading conditions, making all three designs robust.

However, we used the 0-cleat design only as a control in this study, and it is not suitable for use on firm ground grass pitches due to a lack of grip and a greater risk of injury.

Based on the simulation results, the best design is the multi-cleat outsole. It has the lowest Von Mises stress values, indicating a lower likelihood of injury due to material failure during the toe push-off, which is the most critical phase of the footstep. During this phase, the forefoot, especially around the metatarsal heads, experiences the most significant forces and movement. To provide adequate support and reduce the risk of injury, we should design the outsole with enhanced support and cushioning in the forefoot area. This can help absorb the high forces during toe push-off and improve overall comfort and performance

5. Conclusion

The purpose of this case study was not to provide an exhaustive account of designing soccer shoe outsoles but to show the utility of using simulation during the concept and design phases of the product life cycle. The 0-cleat outsole provided a blank canvas upon which we could efficiently sketch and extrude cleats of different configurations, shapes, widths, lengths, and depths. This allowed designers and engineers to gain a deeper visual understanding of their designs and obtain the values and stress types needed to make informed design decisions. For instance, the design study indicated that we needed more support in the forefoot. By identifying the need for improvements at an early stage, designers and engineers can prevent errors and save time and costs in the later stages.

6. References

[1] INCOSE (2015) Systems Engineering Handbook: A Guide for Systems Life Cycle Processes and Activities. 5th Edition, John Wiley & Sons, I., Hoboken.

[2] Ansys Inc. (2020) Ansys Discovery Quantifying the return on Investment in Simulation-Led Design Exploration Benefits of 3D Design at a Top Renewable Energy Services Company.

[3] Ansys FAQs What is Upfront Simulation? (2025) https://www.ansys.com/products/3d-design/ansys-discovery Accessed 17 March 2025

[4] Anthropometry of the Players at the 2018 World Cup." Topend Sports Website, first published June 2018, https://www.topendsports.com/sport/soccer/anthropometry-worldcup2018.htm , Accessed 17 March 2025

[5] FIFA (2018) List of Players 2018 World Cup Russia https://www.topendsports.com/sport/soccer/images/wc2018-player-list.pdf, Accessed 17 March 2025

[6] Sole, M., Barber, P. and Turner, I., (2022). Sustainable Design: Using Physical Prototypes to Most Benefit Design Students and Environment? DS 118: Proceedings of NordDesign 2022, Copenhagen, Denmark, 16th-18th August 2022, pp.1-12.

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Document Information

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