Project Team

DANIEL HARRINGTON
harrind@purdue.edu
B.S. Mechanical Engineering '23

NOLAN HORGAN
horgan@purdue.edu
B.S. Mechanical Engineering '22

ANNA GIESLER
giesler@purdue.edu
RESEC Director

Dual-purpose shoe sole system: *Improved Impact Damping & Energy Restitution*

• Impact • Landing • Jumping

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Athletes everywhere are stronger, faster, and arguably better than ever before, breaking records left and right. With improvements in their training, coaching, and technique, athletes are doing more than was ever thought possible. Improvements in the technologies of sports equipment, specifically in footwear, have helped as well. Athletic shoes today are light and comfortable yet still offer the necessary support and traction to perform cuts, jumps, and sprints, which are widely prevalent movements in basketball and volleyball. These sports also rely on jumping and landing movements as players fight for rebounds over their opponents or reach above the net to block the spike from an opposing team. As athletes continually jump higher, greater loads – upwards of 8 body weights (BW) of force – are placed on their bodies when they land. During the lifecycle of volleyball and basketball athletes, injuries can take place if loading from repetitive jumping and landing is great enough. Therefore, a shoe sole that can allow an athlete to jump higher while also absorbing impacts effectively is highly desirable. This project explores how materials can be applied in different system designs to exhibit both energy restitution and damping effects with the end goal of implementing them in an athletic shoe.

Fig. #1 View of Former Purdue Basketball Player Carsen Edward's Nike Shoes

LITERATURE REVIEW

A thorough review of the information necessary for the development of an innovative shoe sole system targeted for damping and energy restitution was performed.

JUMP-LANDING SEQUENCE

Each time an athlete lands a jump, a ground reaction force (GRF) acts on the athlete. It is important to recognize that GRFs do not reflect the true loads place on bones, muscles, and joints. However, GRF metrics can be correlated with the loading on these internal structures to quantify injury risk. For jump-landing sequences, vertical ground reaction force (VGRF) profiles can be obtained from force plate data as seen in Figure 2. When performing mechanical testing on the shoe sole systems, it will be important to replicate the entirety of these curves to analyze the responses of system designs to simulated jump-landing conditions.

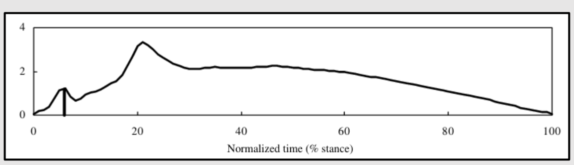


Fig. #2 VGRF Profile During Jump Sequence

Hip, knee, ankle, and feet biomechanics play a key role in executing a safe, effective jump-landing sequence. Gender differences are present in such lower extremity biomechanics and should be kept in mind when shoe sole systems are designed and tested. Common injuries associated with jumping and landing include stress fractures, tendonitis, PCL and ACL tears, and ankle sprains, which result in significant time lost to recovery.

PREVIOUS DESIGNS

Several technologies and commercially available products are aimed at damping and energy restitution improvements in athletic footwear. One such technology, pictured in Figure 3, has been shown to absorb impact loads through shear deformation in the forefoot. The current research project will focus on absorbing impact loads in both the forefoot and heel, where VGRFs are the greatest during landing.

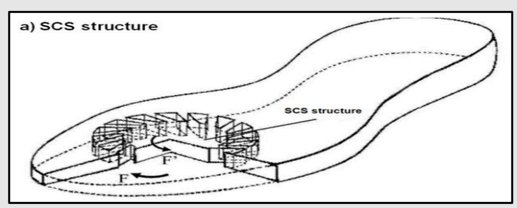


Fig. #3 Shear-Cushioning System Technology

MATERIAL CONSIDERATIONS

Shear thickening fluids (STFs) have been explored as the material to address the damping aspect of the shoe sole systems. As a non-Newtonian fluid, STFs display a nonlinear relationship between shear rate and viscosity. At high enough shear rates, known as critical shear rates, the viscosity of STFs jumps sharply as energy is absorbed. Figure 4 portrays the shear thickening effect in which viscosity drastically increases at a critical shear rate of approximately 100 (1/s).

Sole system designs will focus on eliciting critical shear rates to activate this energy absorption property of STFs to reduce landing impacts on athletes. To address jumping performance, the use of carbon fiber plates in sole system designs has been explored. Carbon fiber plates allow for greater stiffness and greater foam compression of the sole, which result in greater energy return for improved jumping. The geometry and positioning of carbon fiber plates within the sole systems will be designed, tested, and iterated to optimize energy return for improved jumping performance.

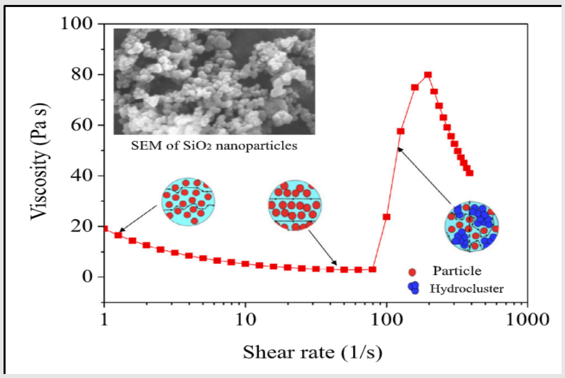


Fig. #4 STF Viscosity vs Shear Rate Behavior

TESTING

To examine a shoe sole system's response to the loading of a jump-landing sequence, a procedure inspired from research by Lippa (2017) is suggested. In this study, force plates captured loading data during a runner's gait cycle, which was replicated in a mechanical tester to observe the mechanical aging of shoe foams. The mechanical test setup from this study is shown in Figure 5. In the current research project, loading data from a runner's gait cycle could be substituted for jumping and landing data, thus allowing for an analysis of the response of shoe sole system designs to simulated jumping and landing loads.

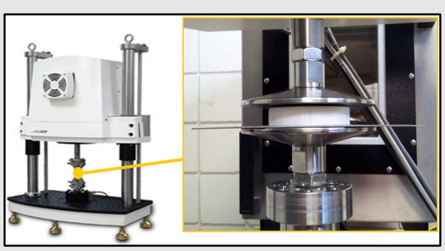


Fig. #5 Proposed Mechanical Tester Setup

INITIAL DESIGNS

Many designs have been produced to explore damping and energy restitution solutions in shoe sole systems. Seen in Figure 6, one design focuses on damping in which a foam sole would contain a series of teeth and a matrix of STF. During a landing impact, the teeth would slide past one another at the necessary critical shear rate. This would activate shear thickening behavior and absorb a portion of the impact loads before they act on an athlete.

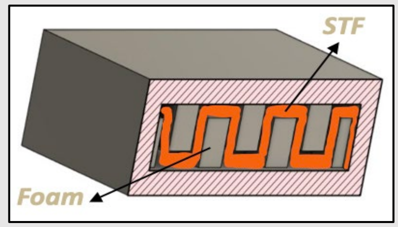


Fig. #6 CAD Model of Damping Design

The design in Figure 7 addresses energy restitution with a carbon fiber plate shaped to rest beneath the metatarsophalangeal (MTP) joints to stiffen the forefoot, which has been linked to improved jumping performance.

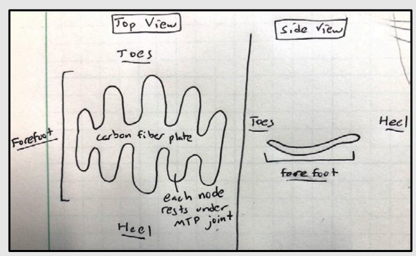


Fig. #7 Sketch of Energy Restitution Design

CONCLUSIONS AND FUTURE WORK

Conclusions

- Jump-landing sequences are complex biomechanical maneuvers that result in high impact loads that cause serious athletic injuries
- Smart shoe sole system designs can absorb impact loads, reducing injury risks, and promote improved jumping performance through proper energy restitution

Future Work

- Explore other materials and mechanisms for damping, including auxetic foam which has a negative Poisson's ratio, and energy restitution
- Investigate methods for improving shoe stability

1105 Endeavour Drive Suite 400, West Lafayette, IN 47906
Dr. Jan-Anders Mansson, Executive Director
jmansson@purdue.edu
WWW.ENGINEERING.PURDUE.EDU/ENGR/EWRY

ABOUT RESEC

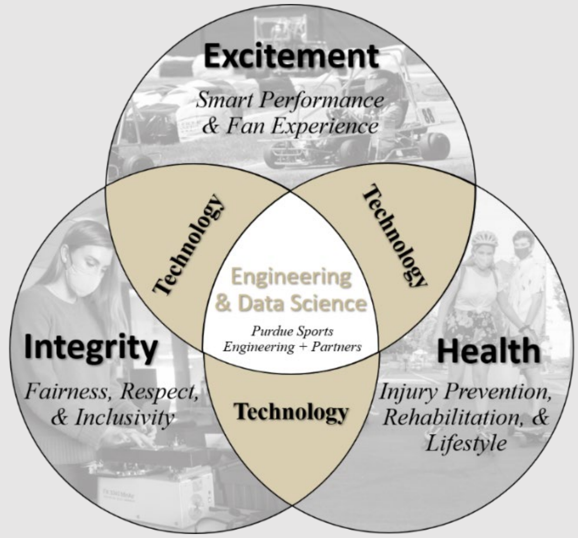
The Ray Ewry Sports Engineering Center (RESEC) was launched as a joint collaboration between Purdue College of Engineering and Purdue Intercollegiate Athletics, highlighting Purdue's reputation as the Cradle of Quarterbacks and Astronauts.

Sports have the power to unite, to teach, to challenge, and to initiate change, and those are our goals for RESEC. We are driven by our passion for sport and a deep understanding of the influence it has in shaping society. As technology continues to advance, there is enormous room for opportunity to rethink how athletes train, coaches coach, fans engage, and event organizers plan events. We collaborate closely with partners in athletics, industry, academia, and more to create the solutions that will help bring sports into the future, specifically in the three key research areas highlighted below.


Smart Performance & Fan Experience


Injury Reduction & Rehabilitation


Sports Integrity, Fairness, & Societal Integration



WHAT IS SPORTS ENGINEERING?

Sports engineering is a global, fast-paced, and multidisciplinary industry that brings people from different backgrounds, cultures, and experiences together. It is an industry that is heavily influenced by advances in other sectors as well as societal pressures and shifts, making working as a sports engineer very exciting. However, it also means being keenly aware of how these innovations and discoveries can be integrated and applied, especially as digitalization expands and what people – the athletes, fans, coaches, governing bodies – expect from sport evolves.

Engineering and data science are at the center of excitement, health and safety, and the integrity of sport, and by bringing a data-driven, human-centered approach to this industry, we can address the growing need and desire to increase participation and engagement of athletes and fans.

WHO IS RAY EWRY?

A Boilermaker track and field athlete, Ewry (1873-1937) won eight gold medals in three Olympic Games from 1900 to 1908. But his story is relatively unknown: at the age of five he became an orphan, and at seven he contracted polio and was confined to a wheelchair. Doctors had little hope he would be able to walk. Later nicknamed "The Human Frog," Ewry won gold in the standing long and high jumps and standing triple jump. By the end of the 1908 Games, Ewry had set a medal count record that lasted more than 100 years.

RESEC

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jmansson@purdue.edu

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