Dramatic Changes in Sports: The Contribution of Engineering Simulation

Sports professionals, coaches and amateur participants always explore ways to boost performance, ensure comfort and minimize the risk of injury. At the same time, sporting equipment manufacturers must investigate technologies to innovate faster and maximize the reliability of products that sometimes face extremely challenging conditions. Engineering has long been one of the tools used, but, for the past few years, the sport engineering community has been paying closer attention to engineering simulation.

Engineering simulation is a proven technology able to predict the behavior of a device or an athlete, or a system comprising the athlete, devices and equipment, under specific conditions. Through computer-based modeling, it is possible to determine and understand how influential parameters impact athletic performance, or minimize or amplify injury. By varying these influential conditions and predicting the consequences of these modifications, equipment designers can select the best set of conditions to optimize performance and reduce injury. In addition, sporting goods manufacturers can release these improved goods to market faster and at a lower cost.

The quest for the best performance

For most people, sports trigger two visions: the elite athlete on TV during the Olympic Games, world championships or any other major event, and the amateur enthusiast jogging down the street, visiting a local sports center or biking in the forest (people like you and me). Both types of sports participants are consciously or unconsciously driven by three strong motivations:

1. **The unquenchable thirst to do better** and possibly break his or her own record(s). This quest to always improve can be achieved through more training, acquiring advanced equipment (or improving existing equipment) and determining better positions or movements to maximize accomplishment.
2. **The continuous fear of or concern about excessive pain or injury** that would prevent practicing a sport. Unlike in the past, today's athletes are not interested in one exceptional performance alone. Maintaining a high level of skill for the longest period of time possible is an equally or even more important goal. It is possible that a world-class athlete may never again regain his/her best level after a bad injury experienced while pushing his/her body a little bit too far. However, an athlete must push his/her body to set world records. A sports amateur must balance the fear that an injury will prevent practice of a favorite sport for an extended period of time with the desire to push beyond the limits. How far is too far is a constant concern, so both recreational and professional athletes must employ equipment to minimize the negative impact of pushing the limits.

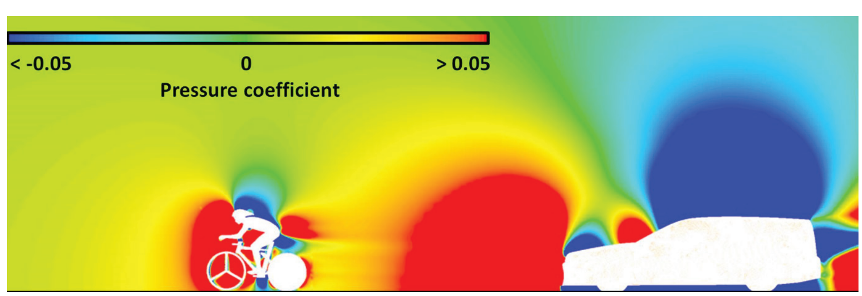
3. **The strong desire for fair sport.** Athletes need to compete based on intrinsic physical and mental capabilities rather than a technology advantage. This is one of the challenges of elite sport for both viewers and practitioners. Fair play requires strong regulations along with appropriate controls. An example is the ban on full-body swimsuits after the Beijing games when it appeared that the technology within some swimsuits provided an unfair competitive advantage. Those participating in sports at the amateur level pursue access to the same best-in-class equipment that their professional idols employ. This requires democratization of new advanced technologies much faster than before. Today, cyclists don't need to compete in the Olympic Games to want to have and be able to ride a carbon and composite bike.

Huge amounts of money are invested in sports engineering to satisfy these three major trends and to try to find the tiniest competitive advantage to make the difference between gold and missing the podium. Yet a technology that has been widely and successfully used in many industries for close to 50 years, and has triggered myriad innovations and performance improvements, is not yet used systematically in sports engineering (with the exception of motor sport and a few other activities). That technology is engineering simulation.

An "emerging" technology in the world of sport

Engineering simulation uses the rapidly growing computational power now readily available to simulate and therefore predict behavior. Engineering simulation employs a computer-based model of a system that could include athlete(s), equipment and the surrounding environment. To predict the behavior of these models, the technology solves fundamental equations such as mass conservation, energy conservation, Newton's second law or Hooke's law of elasticity to calculate quantities such as velocity, pressure, stress, deformation, etc. Even simple models can provide a treasure trove of valuable insight. But, because real-life physics is extremely complicated, a highly complex model might be required to mimic real-world behavior. Software companies, academic leaders and sports equipment designers continuously create more and more advanced models (including factors like material properties and interacting components) to better predict behaviors. They also add new capabilities to encompass more of the surrounding environment and increase the fidelity of the models. Furthermore, they can incorporate combinations of the product, the athlete and the environment in a system-based simulation. They include, when possible, the many physical conditions that interact in a multiphysics simulation. This yields even more information to better predict behavior to improve product or athlete performance.

A system of a cyclist, car and the air. The colors show the air pressure. The study revealed that a car closely following a cyclist literally pushes the cyclist forward (Blocken and Toparlar, 2015).



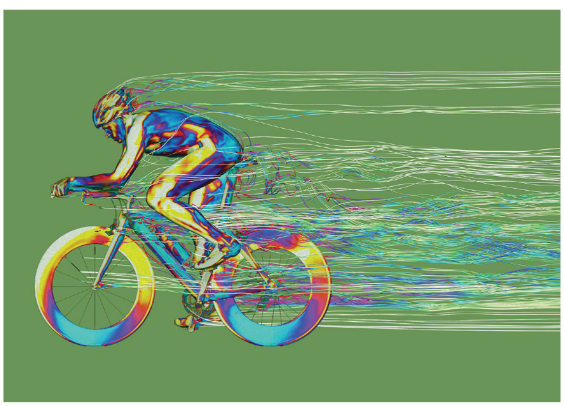
For example, a cyclist followed by a car was recently studied by Professor Blocken's team from the Eindhoven University of Technology and KU Leuven. Engineering simulation started with the geometry of the car and the bike. Then engineers added a generic (or an athlete-specific) cyclist body on top of the bike and included the surrounding air because it is expected to play a key role. The model specified the motion of the different components and the necessary material properties (e.g., air density, viscosity and humidity). The result of the simulation not only provided velocity and air pressure throughout the region studied, but also predicted the forces and drag experienced by the cyclist and revealed the interactions between the different components. By modifying parameters such as the shape and the size of the car, and the distance between the car and the bike, it was possible to quantify the impact of this variation on the cyclist and therefore select the best possible option.

What can simulation really bring to sport?

Numerous sports have already — sometimes occasionally and sometimes more systematically — adopted an engineering simulation approach to better understand activities, improve the performance of equipment or reduce the risk of injuries.

Cycling

Two major technical parameters drive a cyclist's performance: aerodynamics and weight. (Although some may argue that the structural strength of the bike plays an important role for some activities such as mountain biking.) Reducing the weight of bike without compromising wind resistance and increasing its rigidity can be achieved by varying the geometry of different components and using different materials, including composites. It is essential to predict the structural behavior of the modified bike or its components to ensure the bike still fulfils its primary mission.



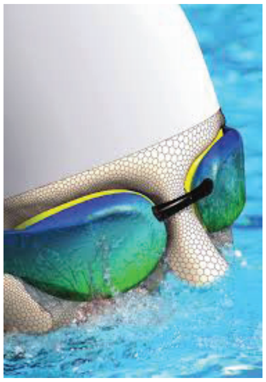
John Hart and his team at Sheffield Hallam University have investigated the aerodynamics of elite cyclists for years. Small modifications of critical components might have a large impact of the drag, and hence the performance of the athlete.

For aerodynamic optimization, both the position of the cyclist and the shape of each component of the bike are essential. The position of the cyclist requires a compromise among minimizing drag, maximizing propulsion power of the cyclist in that position, and his/her comfort. To improve aerodynamic performance of the equipment, designers optimize each component in a prioritized manner that might play a role in increasing the drag and therefore slow down the athlete. Since each component is a subsystem (or part of one), it is even more important to optimize the performance of the entire system (the bike) rather than optimizing each component separately.

Additional reading: Going Strong, Floating on Air, Speeding Up Development Time for Racing Cycles

Swimming

Swimsuit manufacturers use engineering simulation extensively to better investigate the interaction between water and the swimsuit. By adjusting the texture of the suit in areas where water generates a lot of drag, it is possible to minimize this decelerating force and improve the performance of the swimmer.



Designers also pay attention to caps and goggles. Optimizing their shape can minimize the number of bubbles carried away by the swimmer penetrating into the water. These bubbles apply a force that slows the athlete. Minimizing bubbles translates into better performance.

The position of the swimmer can also play a key role, especially the position of his/her fingers. Engineering simulation studies reveal the ideal space between the fingers to maximize the hand surface area so it can push back water optimally while preventing water flow between the fingers.

Additional reading: Dressed for Success, Simulating Swimwear for Increased Speed

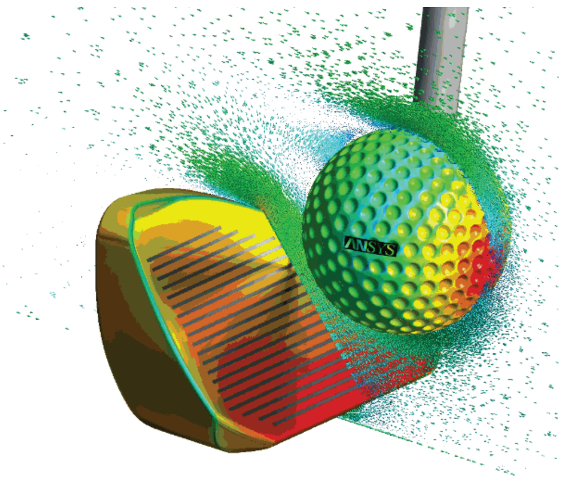
Sailing and Rowing

Sailing has invested in engineering simulation quite significantly, both to improve performance and maximize equipment reliability for long races. Teams and boat designers pay specific attention the interactions between the sail and the wind to better capture wind energy regardless of its strength and direction. They also study interactions between the hull and water to minimize drag.

The robustness of the boat while experiencing adverse conditions is also essential. Simulation allows designers to model the mast, the hull and the sails under the forces of nature to ensure reliability. Alternatives such as switching to composites enable design engineers to simultaneously reduce weight for improved performance while increasing resistance for reliability. These tradeoffs can be effectively studied, allowing engineers to make informed decisions on the changes.

Though less widespread, those who model rowing investigate and optimize the performance of the oar interacting with the water surface (water–air– oar interaction), as well as hydrodynamic drag on the hull.

Additional reading: The Simulation Race for America's Cup, Getting the Mast from Virtual Prototyping, Catching a Better Oar Design, Going for the Gold



Golf

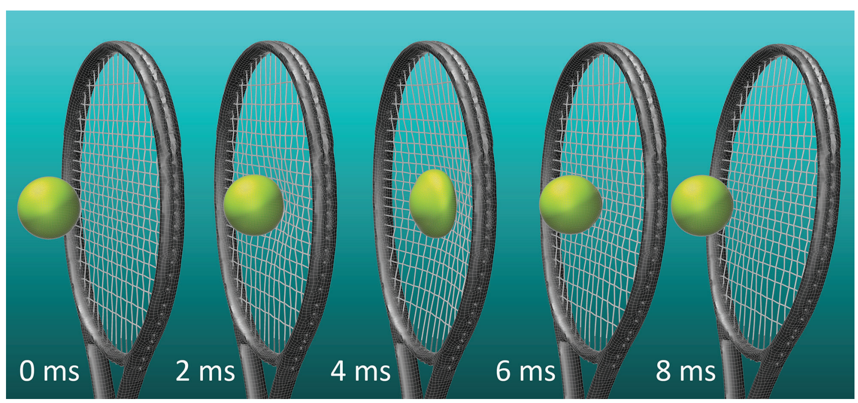
From a technology perspective, golfing involves both impact between the club and the ball, and flight of the ball. Aerodynamics plays a very important role. Numerous cavities on the golf ball enable air separation much further downstream on the ball than if it were smooth, and therefore significantly decrease air resistance and increase the length of flight.

The impact between club and ball provides the necessary energy to drive the ball. The energy delivered at impact depends on the speed of the club (where aerodynamics plays a role) and the deformable structure of both the club and the ball. The structural rigidity of the club is designed to maximize the transfer of energy to the ball. Materials used for either the ball or the club often include composite materials that can dramatically modify the energy transfer. However, strict regulations ensure fair competition no matter how the technology progresses.

Additional reading: On the Ball, Modeling the Acoustics of a Golf Ball Impacting a Titanium Plate

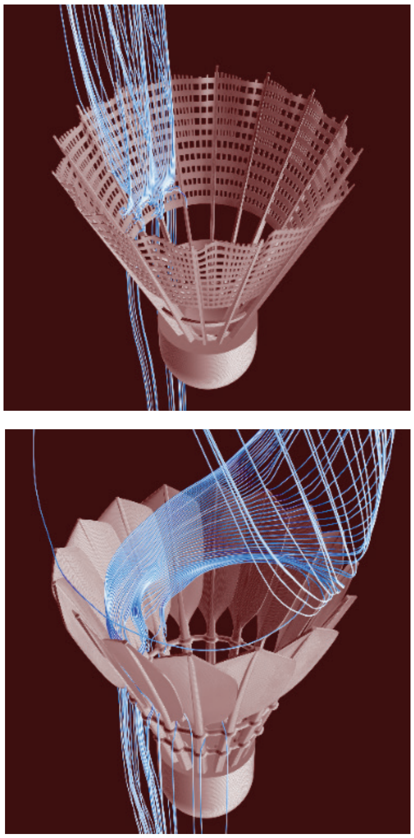
Racket Sports

In tennis, badminton and squash equipment, racket designers must minimize weight and maximize strength while still conveying the necessary vibrations that allow the player to "feel" the characteristics of the impact. The increasing adoption of new materials and the overwhelming presence of composite materials in today's rackets opens the way for major innovations, but also makes it more difficult for designers to understand how changes will affect performance. Engineering simulation is used to create a detailed parameterized model of the new prototype and test literally millions of different variations to create the best possible racket.



Impact of the ball on a tennis racket as investigated by the team of Tom Allen, Manchester Metropolitan University

The impact of the tennis ball or badminton shuttle is also important. Tom Allen is now leading the Sport Engineering Simulation team at Manchester Metropolitan University. His team has extensively investigated how energy and the player's "special touch" is transferred to the projectile during the impact. The shaft must properly translate the athlete's intention to ball or shuttle with regard to speed, direction and other special effects, despite the elasticity of the shaft and the deformability of the projectile.



The aerodynamics of a shuttlecock as investigated by John Hart and his team at Sheffield Hallam University.

The aerodynamics of a shuttlecock is largely influenced by its synthetic or feather structure, leading to quite different trajectories as investigated by John Hart and his team at Sheffield Hallam University.

The aerodynamics of the badminton shuttle, especially during the critical time just after impact when the rotation movement could dissipate a lot of energy, is another area of interest. Feather or synthetic shuttles will behave differently based on how air flows across the structure.

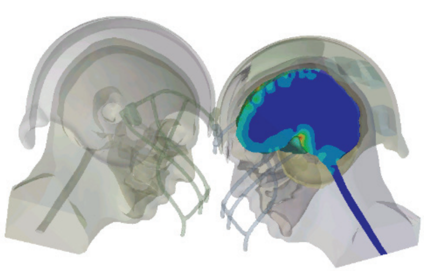
Additional reading: Good Vibrations, The Ball's in your Court

Winter Sports

Skiing, snowboarding, ice skating, ice hockey and relatively less popular Olympic sports like bobsleigh or skeleton all take advantage of engineering simulation. Most are characterized by the need for speed. Therefore, anything that slows the athlete, such as poor aerodynamics or bad contact with the snow or ice, should be carefully investigated. If the position of the athlete, especially a skier, might play a key role, then each component of the equipment contributes to the performance. The texture of the suit, shape of the shoes or boots, helmet, or the design of skis or bobsleigh, for example, might create a competitive advantage that could make a difference to the athlete. In elite sports even fractions of a second matter. In addition, contact of skis to snow can be negatively affected by excessive vibrations.

The safety and the comfort of amateurs and professionals are extremely important in high-speed sports where any mistake, any failure can be dramatic. Engineers can model any likely impact, possibly including the human body in the model to better assess damages and trauma. Using simulation to vary specifics of the equipment design to minimize injuries and maximize comfort under a wide range of conditions can lead to significant competitive advantages. The robustness of the materials composing equipment can be guaranteed or improved through quick and cost-effective computer-based testing.

Additional reading: Giving Ski Racers an Edge



Clothing and Protective Equipment

Clothing plays two key roles. First, it protects the athlete against the external environment (cold, rain, wind, etc.) and possibly impact. Second, apparel should maximize comfort during exertion by, ideally, regulating temperature and moisture within the environment. More recently, clothing has been modified to improve the aerodynamics by adjusting its roughness on body areas generating the biggest drag.

Clothing also includes protective equipment such as helmets, gloves, leg and arm protection, and glasses or goggles. For this equipment, resistance to potential impact or friction is the primary concern, so that trauma can be avoided or minimized. However, the comfort of the amateurs or professionals who may have to wear this equipment for a long period of time remains an important consideration. This equipment should be as light as possible while impact resistant. It should also enable heat and moisture exchange and facilitate fresh air flow, particularly in a helmet, during long and sometimes intensive effort.

Additional reading: Taking a Bite of Sport Injuries

Courtesy Sheffield Hallam University.

Paralympic Sports

Unfortunately, there is a major sport discipline where engineering simulation is largely underexploited despite the commitment of these athletes to their sport and the benefits simulation could bring: paralympic sports. Because computer-based models in the medical device industry have been widely adopted to design and optimize new prostheses, there is no doubt that this technology could bring new perspectives to customizing traditional sport or medical equipment to the specificities of these activities.

All modeling capabilities previously noted — such as external aerodynamics, stress and fatigue-resistance of components, impact modeling and, of course, clothing and protection equipment — could be used and increasingly adopted to maximize performance, comfort and safety of paralympic athletes.

Many other sport disciplines have benefited from engineering simulation; more examples are available in the literature. Computer-based models are also extensively employed to design and optimize sport facilities for the ability to sustain earthquakes or maximize the comfort of the spectators during precipitation.

Additional reading: Dry Run, Knowing the Score, Scoring an HVAC Goal for Hockey Spectators

More recently, the sport Internet of Things (IoT) and the connected athlete are growing more successful. Devices wirelessly monitor the performance of professionals and amateurs and carefully determine the risk of injury. Being connected enables the athlete's support team to share encouragement and advice or simply record performance for future analysis and adjustment to the training program. Connectivity, however, provides some inconvenience that could be minimized by applying appropriate simulation that leads to miniaturization of the connecting device, decreasing the electromagnetic energy absorbed by the body and prevention of the discomfort that sport IoT equipment could introduce.

Progressive Adoption of Simulation

The numerous examples described above are certain to trigger the interest of many eager to start using engineering simulation. Adopting this technology and obtaining meaningful results might, at first glance, look intimidating. Engineering simulation software appears to have a rather advanced interface, and modeling requires device and athlete geometries compatible with computer-aided engineering (CAE) tools. Simulation requires meaningful material properties that may not be simple to determine, and entails establishing correct operating conditions which can trigger a lot of questions.

These challenges can and have been addressed by many, leading to fantastic and impactful results. The automotive, aeronautic, high-tech and energy industries, to mention a few, have long been tackling much more complex cases. Pragmatically, experience with engineering simulation has proven that it is not always necessary to develop the most advanced and complex models to obtain very valuable insights. To the contrary, relatively simple models that include the right physics and influential parameters can quickly provide key competitive advantages. By building on this experience with simplified models, designers can add new parameters, new physics and new components to provide further insight to boost athletic performance, ensure reliability and operation of sporting equipment, reduce the risk of injuries, and decrease the cost of gear. The real challenge is to determine what is essential to include in these investigations.

Because engineering simulation is still an emerging discipline in the sports industry, most companies and research groups that do not have a long history with simulation might be tempted to avoid it. However, engineering simulation is already changing the way sports engineering is performed. A delay in investing in this technology means that the benefits provided will be postponed. The result might be that other groups in the world employ simulation technology first and gain a critical competitive advantage. ANSYS and numerous academic leaders have acquired ample experience to assist newcomers in their initial steps and first modeling tasks. The important step is to contact them.

What is Next?

Engineering simulation is a proven technology that predicts the behavior of any device, athlete or system in any given situation. Through computer-based modeling, it is possible to understand how different parameters impact performance or minimize/amplify injuries. By varying influential parameters and predicting the consequences of these modifications, designers can make the right decisions to optimize performance, minimize risk of injury or decrease cost of equipment for a large-scale deployment.

Considering the huge success experienced by this technology in other industries during the last 50 years, there is no doubt that it will play an increasingly influential role in sports engineering. It is essential that sporting equipment manufacturers, professional and amateur sports teams, engineering simulation software providers, and academic leaders join forces to anticipate and accelerate the adoption of this technology.

Reference

Blocken, B, Toparlar, Y. A Following Car Influences Cyclist Drag: CFD Simulations and Wind Tunnel Measurements. **2015**. *Journal of Wind Engineering and Industrial Aerodynamics.* Volume 145, pp 178–186.

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