

## **AN OVERVIEW OF SPORTS ENGINEERING: HISTORY, IMPACT AND RESEARCH**

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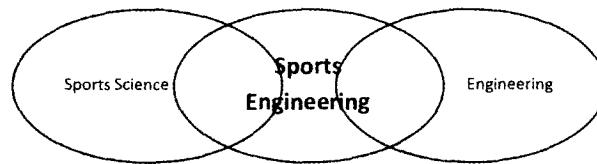
### **Abstract**

Sports engineering can be considered as a new engineering discipline. It bridges the gap between two distinctive fields: sport science and engineering. Sports engineers are responsible in designing and building new equipment based on athlete's demands, besides measuring the performance of the athlete, the equipment itself, as well as their interaction. It is without doubt that engineering and technology have played an important role not only in improving the performance of an athlete, but also in making sports more entertaining and safe. This article provides an insight into how engineering and technology have affected sports in many ways transforming it from just a past time to more exciting and competitive world events. Apart from the impact of engineering in sports, the history of the application of engineering and technology in sports is also elaborated. Furthermore, research conducted in related fields worldwide is highlighted. A brief overview of sports engineering research in Malaysia is also presented.

*Keywords:* Sports engineering, sports technology, history, impact, research.

### **Introduction**

Sports engineering is a relatively new engineering discipline that has made inroads over the past couple of decades. However, the existence of its essence predates centuries ago. Sports were used by great scientists to describe the phenomenon of science and vice versa. It is not uncommon that the general public could not distinguish between the difference between sports engineering and sports science. Sports engineering may be defined as the technical application of mathematics and physics to solve sporting problems by means of design, development and research into external devices used by athletes to enhance their performance. Conversely, sports science is defined as the analysis in terms of motion, physiology, biomechanics and psychology of an athlete. The best sports engineering research applies sound engineering principles to equipment and uses sports science expertise to assess the improved performance of both the athlete and the equipment. Figure 1 best describes sports engineering.



**Figure 1:** The relationship between sports engineering and sports science (Haake, 1999)

Sports engineers are the individuals who conduct studies in design and built of new equipment based on the requirements of athletes. They gauge the behaviour of equipment, athletes and their interaction in a controlled environment. Besides, they also model and simulate the forces acting on athletes and their equipment (Finite Element Analysis) or simulate the airflow around equipment (Computational Fluid Dynamics). Some of them collaborate with governing bodies to assess the effects of rule changes or understanding injury risks.

In the late 1990's, Sheffield University is credited as being a strong proponent in starting the field by organising the 1st and 2nd International Conferences on the Engineering of Sport, held in Sheffield, UK in 1996 and 1998 respectively. The international Sports Engineering Association (ISEA) was established on the 2nd conference. The 3rd conference was held in Sydney in 2000 and the 4th in Japan in 2002. The conference continues to gain attraction and interest from sports engineers worldwide. A total of 181 oral presenters involved in the 6th conference held in Germany in 2006, which was the highest number of participation recorded. The 10th conference of the series will be held on July 2014 at the Sheffield Hallam University (UK). One of the aims of the ISEA is to coordinate sports engineering research and to act as a global discussion forum. Sports Engineering is the official journal of the ISEA, which begins its publication in 1998 and is the longest running journal in the field of sports engineering and technology.

Sports engineering has a large following in the UK where over 20 universities are offering degree programmes, both Bachelor and Masters and many countries are following including Germany, Austria, Singapore, Japan, Sweden and Australia. Students' feedback from a sports engineering course in Australia was very positive (Medwell et al. 2012). In Sweden, the students were given the opportunity to expand their career with 40 local and international sports companies (Bäckström et al. 2013). In Malaysia, sports engineering is also considered to be relatively new. In 2011, the Malaysian Ministry of Higher Education (MOHE) opined that engineering based research should be carried out on the equipment used by Malaysian athletes and Universiti Malaysia Pahang (UMP) was given the mandate to be the pioneer in sports engineering research in Malaysia.

### **History of Engineering in Sports**

The term sports engineering was coined in the 1990's but from a historical standpoint, its inception has existed as far back as three centuries ago. Newton's famous remark on the flight mechanics of a tennis ball in his letter to Oldenburg in 1671 may indirectly be regarded as the earliest contribution of engineering to the field of sports (Newton, 1671). The theories regarding the ball's spinning properties were further developed and explained in the following centuries by Magnus as well as Lord Rayleigh (Haake, 1999)(Rayleigh, 1877).

The industrial revolution circa 1760 further propelled the sports industry with the inroads of sports equipment production alongside other main productions by manufacturers. Instead of merely being a game that was meant to be championed by the physically astute, the inclusion of improved equipment has apparently been a game changer. Manufacturers took this cue seriously, as improved equipment translates into the increase of sales volume, which in turn, leads into the experimentation on different designs and materials on sports equipment. Here, lies the fusion of engineering knowledge, which evolves the world of sports. The instances where this unification transpires are briefly described in this article with respect to its involvement from the early of the 19th century till this present day (Bhanian et al. 2012).

In 1898, Coburn Haskell invented the rubber golf also known as the ‘Haskell golf ball’. The ball is made of a solid rubber core wrapped in rubber thread, which replaced the universally used gutta-percha ball. This particular golf ball allows the players to have a greater control and it is much easier to hit. Frank Bryan, a London sporting goods manufacturer, created the rubber-faced Atropos table tennis bat in 1901. The ‘new’ bat allows players to spin the ball easily and at pace, which changed table tennis from a minor pastime into a genuine athletic sport. Tullio Campagnolo revolutionised the bicycle industry by creating and patenting the quick release mechanism in 1930, which became a standard and still in use today. In 1933 he created the derailleur bicycle gear. This invention, allows cyclists to change gears without stopping and removing the back wheel, a practice that is done prior to existence of this invention.

Post-world war two saw the existence of carbon fibre invented by Union Carbide in 1958. This material is used in the creation of lightweight and strong composite materials, which are now found in plenty sports equipment. In 1968 at the Mexico City Olympics, the first all-weather ‘Tartan’ running track made of polyurethane was used for athletics events. Prior to this, rubber and asphalt made tracks used were deemed unsuitable in bad weather conditions. At the Munich Olympic Games in 1972, the world was shocked as 21 of the 22 swimming world records were broken. The swimmers who broke the records wore Speedo’s nylon/elastane swimwear material, which is still the most popular commercial swimwear material today. The first computerised time keeping was implemented in the Seoul Summer Olympics and Calgary Winter Olympics in 1988. In 1992, an ultra-lightweight full carbon-fibre ‘superbike’ designed by Lotus aided Chris Boardman in securing the gold medal along with breaking the men’s individual pursuit world record at the Barcelona Olympic Games. The late 19th century saw the inception of The International Sports Engineering Association (ISEA), which establishes the importance of the role of engineering in sports.

The dawn of the 20th century witnessed the utilisation of Hawk-Eye, an advanced ball-tracking system at the US Open. It was the first grand slam tennis tournament to allow players to utilise such technology to challenge the umpire’s decisions. In 2008, only 6% of the swimmers who did not wear Speedo’s LZR Racer swimsuits secured gold medals, whilst the rest went to those who use them at the Beijing Olympics. The swimsuit was made of 100% polyurethane. The Fédération Internationale de Natation (FINA) banned further use of nontextile materials, after the polyurethane suits were used to break 29 world records at the World Championships the following year. Recently, in 2011 at the Tour de France Green Jersey, Mark Cavendish won the tour by using the McLaren S-Works Venge bicycle. The bicycle was built from a single piece of carbon fibre whilst the design incorporated advanced computational fluid dynamics and wind tunnel. It is apparent that throughout history, the element of engineering has somewhat propelled and evolves the sports industry. The following section will highlight the impact of engineering in the world of sports.

## **The Impact of Engineering in Sports**

Humans have used tools and technology to enhance the things we do. In sports, it is without doubt that engineering and technology have played an important role not only in improving the performance of an athlete, but also in making sports more entertaining, yet safe. There are huge numbers of technology being applied in various sports. Hence, to name a few, we have categorised the technologies applied in sports into four distinctive engineering disciplines, namely materials engineering, computational modelling, instrumentation, as well as design and ergonomics.

### *Materials engineering*

Materials engineering in sports includes the development of new textile materials that are used in sportswear, invention of new materials to be used in sports equipment and development of new materials for sports playing surface. Advances in textile for swimsuit are an example of textile engineering in sports that has produced significant impact on athlete's performance. Early advances in swimsuit design were to make the swimsuit as small as possible to reduce drag. Then, nylon was invented in 1950's, which replaced the conventional woollen fabric that tends to absorb water during the race. The introduction of Lycra in 1980's enabled suits to be cheaper, better fitting and more comfortable to wear.

Swimsuit designers then realise that reshaping the body and using textured swimsuits was more advantageous than trying to minimise the suit. In the early 2000's, Speedo developed a new swimsuit that was inspired by the skin texture of a shark. It was worn by swimmers at the Sydney and Athens Olympics. In 2008, Speedo in collaboration with NASA introduced a breakthrough swimsuit called the LZR. It comprises of polyurethane panels that are ultrasonically welded together. The seamless design was meant to ensure the flow of water would not be disturbed. The polyurethane panels also help to trap air, thus increasing the buoyancy of the swimmer. The tight structure of the body suit helped reduced the effects of drag by moulding the swimmer into a more streamlined shape.

The LZR suit and other polyurethane full body suits were worn for 2 years (2008 – 2009) over which more than 130 world records were broken. In 2010, FINA introduced new rules that limited the coverage of the suits (waist to knee for men, and shoulder to knee for women) and prevent the use of polyurethane or non-knitted textile panels. Despite the ban, nine world records were broken in the 2012 Olympics in London, which proves that the suit is not the only equipment that plays important role in increasing swimmers' performance. Thus, researchers have already started focusing on hydrodynamics of goggles and swim caps.

Apart from textile, the invention of composite material has also produced significant impact on sports, such as the pole vault. In 1900 Olympics, the pole vault was won with a height of 3.30 m. In 1994, Sergey Bubka set the world record for pole vault at the height of 6.14 m, an 86% improvement (Haake, 2009). The substantial increase in pole vault height is the result of material development. Early vaulting poles were made from solid wood. It was heavy, and this limits the run up speed of the athletes, which subsequently slows down their launch velocity. The pole must be able to store large amounts of energy without breaking, whilst its mass is kept to the minimum (Haake, 2012).

Besides solid wood, various materials such as bamboo, aluminium and steel were used in fabricating the poles since the International Association of Athletics Federations (IAAF) allows the pole to be made from any material or combination of materials with no specified length or diameter. The biggest improvement in jumping heights came in the 1960's with the introduction of fibreglass poles. The fibreglass poles were more flexible, lighter and enabled various fibre lay-up orientations that increase the twisting resistance. The fibreglass and later carbon fibre poles are used by all athletes today and for many are considered the biggest technological leap in athletics.

Another example of advanced material engineering in sports is the development of artificial playing surface, with field hockey being a prominent example. Field hockey was originally played on natural grass pitches. Artificial grass based on polyamide/nylon material was introduced on field hockey pitches in the 1970's. It was ideal for field hockey as the synthetic turf pitches provided a flatter playing surface than natural grass. This in turn provided better ball control as it prevented the ball from shooting off into various directions. Sand was spread between the fibres to create enough firmness and stability for the players. These key characteristics resulted in artificial turf being used in field hockey games for the first time in the 1976 Olympics.

However in 1980's, water based turfs were seen as more beneficial to the game as it enabled the ball to be transferred more quickly than on the original 'sand based' surfaces. Water based surfaces proved also to be less abrasive than the 'sand based' variety and hence reduce the level of injury to players when they came into contact with the surface. The International Hockey Federation (FIH) today mandates all international field hockey competitions be played on artificial turf. In 2012 Olympics in London, the artificial turf for field hockey featured a high performance system resulting from collaboration of multiple companies that includes high-performance linear low-density polyethylene resin used to produce soft, tear resistant grass yarn. It is then turned into rolls of hockey turf along with other components for improved impact response and durability.

### *Computational modelling*

Computational modelling is commonly used in all engineering disciplines to represent complex systems. Among notable computational modelling methods are computational fluid dynamics (CFD) and finite element analysis (FEA). CFD is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems that involve fluid flows, whereas FEA is a numerical technique for finding approximate solutions to boundary value problems for differential equations.

Cycling is a noteworthy example of sports, which has been greatly influenced by CFD. CFD analysis has been used to assess the aerodynamics of the bike, rider and clothing. It is used to model how air flows over an object and return useful values such as drag coefficients and pressure maps. CFD analysis indicates how slight changes in bike design will influence its drag without having to go through the manufacturing process. By using 3D body scanning of the riders on the bikes, CFD analysis can tell coaches how to order cyclists in team events to make full use of the drafting effect. In terms of bike design, each component on the bike can be optimised to reduce the drag coefficient.

Equipment can be essential not only in making sure the success of an athlete, but also in preventing injury. FEA is one of the state-of-the-art engineering tools that have been widely used in understanding the physics of sports equipment. Testing sports equipment typically requires dynamic finite element (FE) models to represent events such as a tennis strike. FE model of tennis racket and ball for example, are capable of analysing the five-millisecond impact during which the ball is in contact with the racket. The FE model, which takes into account real racket geometry attained from a non-contact 3D laser scanner and material characteristics obtained from materials testing, is capable of predicting all aspects of the impact including the vibrations in the racket, the compression of the ball, the deformation of the string bed and the rebound dynamics of the ball (James, 2011). The FE model can be used as a design tool to optimise racket geometry and material properties prior to production.

### *Instrumentation*

Instrumentation that involves sensors and electronic components also plays a major role in advancing sports to a whole new level, for instance, the video technology that assists official's decisions. A prominent example would be the Hawk-Eye system used in tennis. Hawk-Eye uses a network of on court cameras to track the trajectory of the ball and use modelling techniques to predict where it lands. Hawk-Eye was introduced in 2005 and the system now offers players three challenges to umpire decisions. Controversial line calls can now be resolved by calling up the Hawk-Eye referral system. Hawk-Eye decision stands even if it differs from that of the umpires. The acceptance by players, officials and spectators for the use a computational Decision Review System indicates that the sport of tennis is one that is constantly evolving, embracing technology and using it to improve the game for all involved.

Another recent example of instrumentation in sports is laser-timing technology developed for cycling. Previously used break-beam system was unable to differentiate between individual cyclists racing around the track at the same time. Thus, BAE Systems has developed a new laser timing technology derived from a battlefield identification system that allows individual performance tracking of up to 30 riders racing each other simultaneously second-by-second in real time. A retro reflective tag containing personalised code is attached to each bike, which is read by the laser. The technology enables individual timings to be captures with milliseconds accuracy. This is a major step forward in cycling training that has played a key role in the British Cycling Team's success in international competition in recent years.

### *Design and Ergonomics*

The ways of running, biking and skiing for instance, have developed and improve day by day, and so do the athletes' demands of ergonomic clothing. In 2008 Beijing Olympics, the British cycling team won seven of the ten gold medals offered. One of the factors contributing to this remarkable performance by British cyclists was the suit that they were wearing. One notable feature of the suit is the 'hot pants'. Cyclists warm up their muscles before the race. But due to the practicalities of racing, they have to stop about 10 minutes before the race to prepare and be in the right place. This causes their muscles to cool down. The suit that was made of Lycra-like material is equipped with battery-powered strips that heat up the muscles to 35 degree Celsius, thus deliver an increase in power when the race begins.

The latest cycling suit introduced by adidas AG for the British cycling team is claimed to be very aerodynamics, in which it features the 'bolero', a one piece aerodynamic leading edge, just like the front of an aeroplane's wing. This design is said to deliver maximum efficiency and speed for the rider. Another notable feature is the ClimaCool technology that is based on body-mapping technique for better ventilation on the backside of the jersey. Body-mapping technique is used to map the body's sweat zones. By knowing where the athletes sweat the most, the suit is designed to direct the airflow through the clothing and into these perspiration zones, and thus ensuring that the body does not overheat. In addition, the suit is also equipped with elastic grippers across the range to ensure that the apparel doesn't slip out of place.

Sports engineering and technology have an important role to play in sport. New technologies can keep a sport alive and relevant. Sports engineering has made things that we, ten years ago, might think impossible, possible. For instance the controversy of Oscar Pistorius, the fastest man on earth without legs. New technologies have enabled individuals with profound disabilities to compete at the very highest levels. The world has witnessed an amputee runner, wearing running blade, trying to qualify for 2012 London Olympics. However, Pistorius was unfortunate not to qualify to the Olympics by just a mere 60 milliseconds.

### **Sports Engineering Research Worldwide**

Amongst notable research conducted in this field is the research project of Daniel Price funded by adidas AG which focus on advanced modelling of soccer ball at the Sports Technology Institute, Loughborough University that was completed in 2005. It involves the design and development of a soccer ball modelling using FE techniques. The purpose of the project was to improve the understanding of the dynamic impact characteristics of soccer balls. The resulting FE models serve as an engineering design tool to assist the soccer ball product development process. As each ball panel consists of a textile reinforced composite material, work was carried out in modelling the mechanical behaviour of fabrics brought about by material anisotropy. A series of dynamic impact tests were developed which utilised high-speed video techniques, and force measurement methods to ascertain impact characteristics including restitution, deformation, and vibration properties. These metrics were successfully used to validate the model. The validated ball models were subsequently used as a predictive design tool to assist in the development of the +Teamgeist 2006 World Cup match ball.

Centre for Sports Engineering Research (CSER), University of Sheffield Hallam is one of the active universities in sports engineering research. CSER has developed a software that can be used to calculates the spin magnitude and axis of a sports ball using high speed video footage for use in house and for sale to major sports equipment manufacturers. This project started from June until December 2011. The impact of this software is used as the analysis tool during staff research projects and MSc projects in CSER. The software was sold to three major sports manufacturers such as adidas AG, Prince and IsoSport.

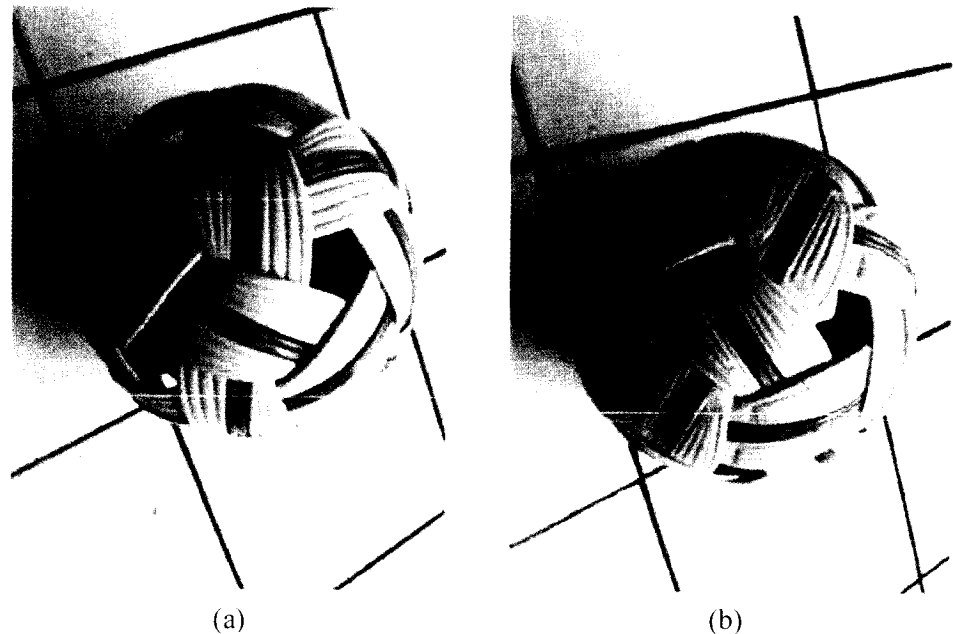
CSER also has contributed in the development of field-based system. The aim of field-based gait retraining is to reduce lower extremity loads in runners by measuring tibial shock and providing biofeedback for gait retraining. The significance of this project is to prevent stress injuries such as stress fracture due to the muscle fatigue and inability to absorb shock. Greater tibial shock during landing is a predictor of stress injuries in runners and modifying gait could reduce shock,

hence decrease risk. The system comprises a tri-axial accelerometer, which is worn on the leg, a bluetooth unit, and power source, which is worn on the laces of the running shoe. The data from the accelerometer are sampled at 1000 Hz and transmitted via bluetooth to an Android smartphone. Users are prompted to adapt their running technique to reduce excessive loads when receiving audio feedback via headphones.

The next example of sports engineering research that has been conducted is the development of bike test structure. The research was conducted at the Centre for Sports Innovation, Massachusetts Institute of Technology (MIT). A test structure was developed to minimize its interference on the bike or rider. A data acquisition system was installed that records, analyses, and presents data specifically needed by each participant. A rider feedback system was developed that provides video feedback of the rider's position along with real-time data so that the rider can observe the effect of subtle position changes on their drag.

### **Sports Engineering Research in Malaysia**

The incidents of 24th SEA Games in Korat, Thailand, 2007 saw the Malaysian Sepak Takraw Association (PSM) withdrew from the championship due to complains of headaches believed to be caused by the new sepak takraw ball used in the competition that is impregnated with rubber. A research to investigate this phenomenon found that the ball made of plastic impregnated with rubber (Figure 2) has four times more probability of causing mild traumatic brain injury compared with ball without impregnated rubber (Taha et al. 2008). In a complimentary study using CFD technique, the new ball was found to travel at a faster speed compared with the ball without impregnated rubber due to its smaller diameter. It was reported that the new ball descends at steeper angle since it generates negative lift due to the inclusion of rubber as shown in Figure 3 (Taha & Sugiyono, 2009).



**Figure 2:** (a) Ball made of plastics; (b) Ball made of plastics with impregnated rubber (Taha et al. 2008)



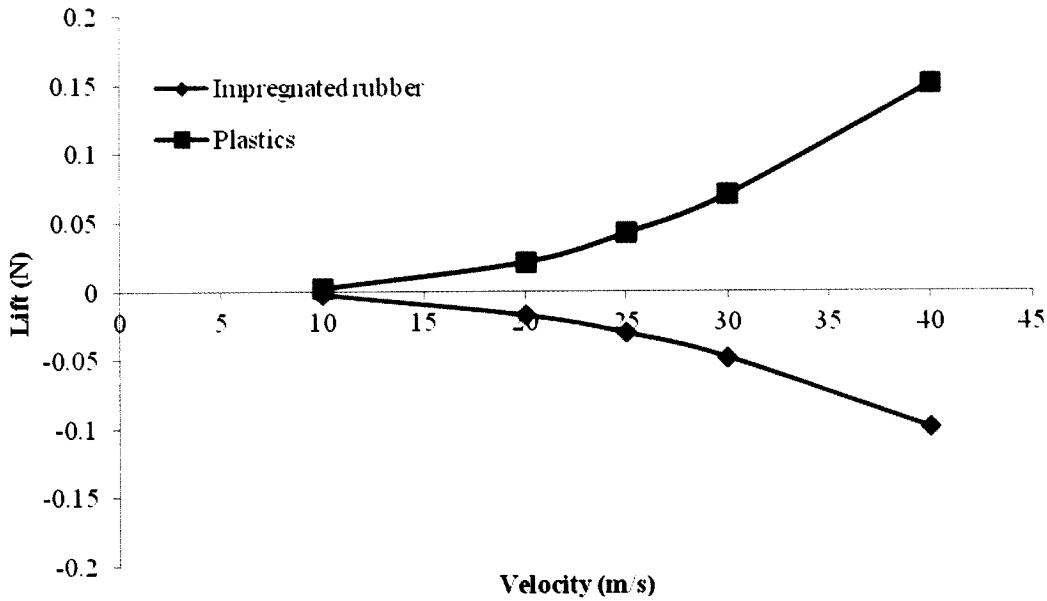


Figure 3: Lift of sepak takraw balls at various velocities (Taha & Sugiyono, 2009).

As a consequence of previous studies, another study was performed to model and analyse the effect of sepak takraw balls on the player's brain. The research employs FEA technique to develop scalp, skull, cerebrospinal fluid (CSF) and brain model as shown in Figure 4. Three model of heading were front-forehead, side-forehead and top-forehead impact and its effect on the frontal-brain and occipital-brain was observed. In addition, analysis of the sepak takraw ball characteristics, drop ball test on dummy skull as well as human subjects for validation purpose were performed. As a result from simulation the maximum impact force on the head recorded was 688.1 N resulting in a maximum brain displacement of 0.80 mm (Iskandar, 2013).

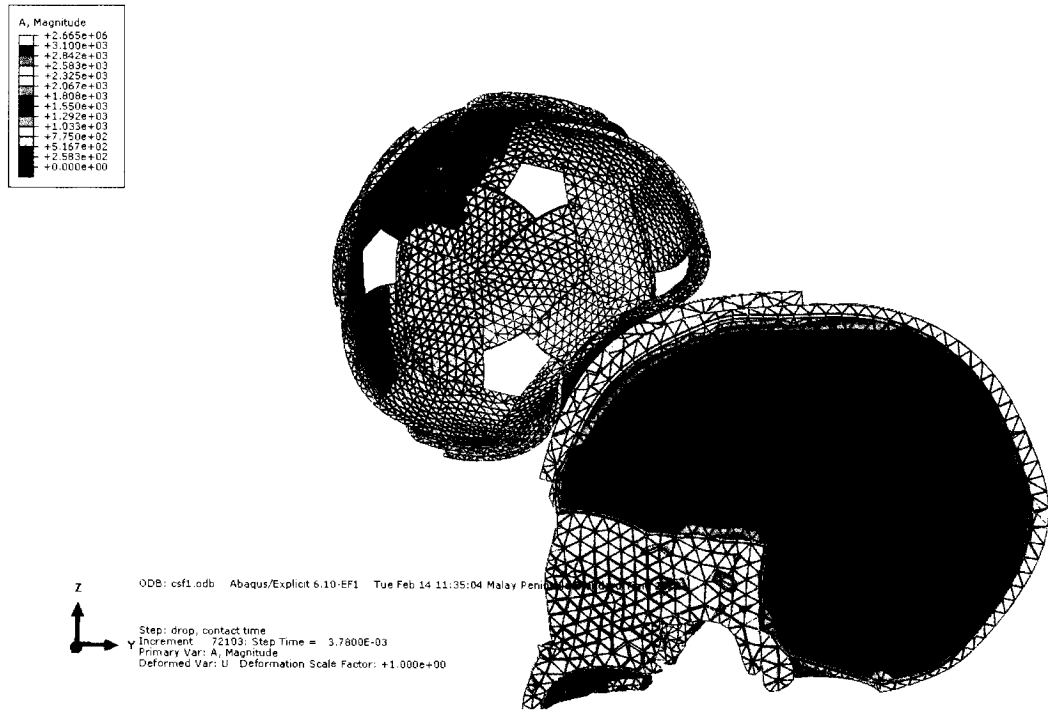


Figure 4: FE analysis of sepak takraw ball-to-head impact (Iskandar, 2013).

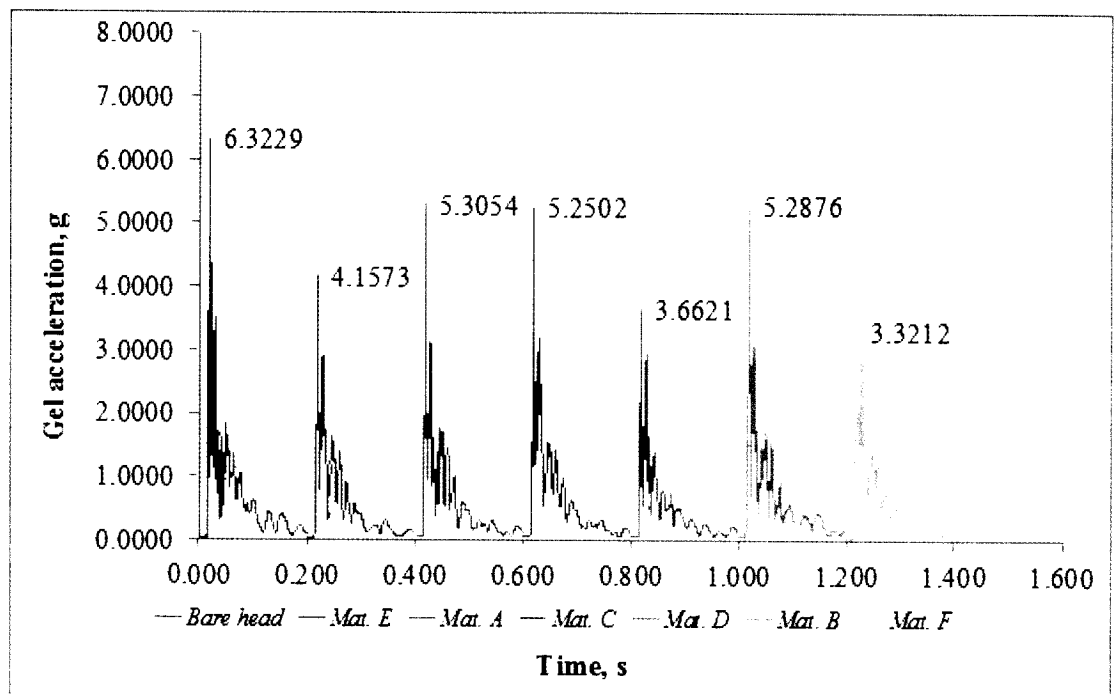
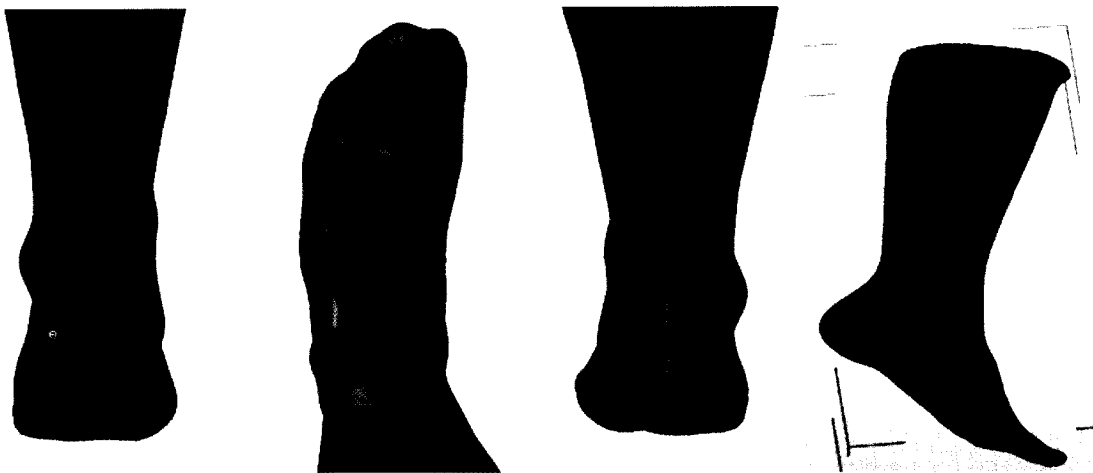


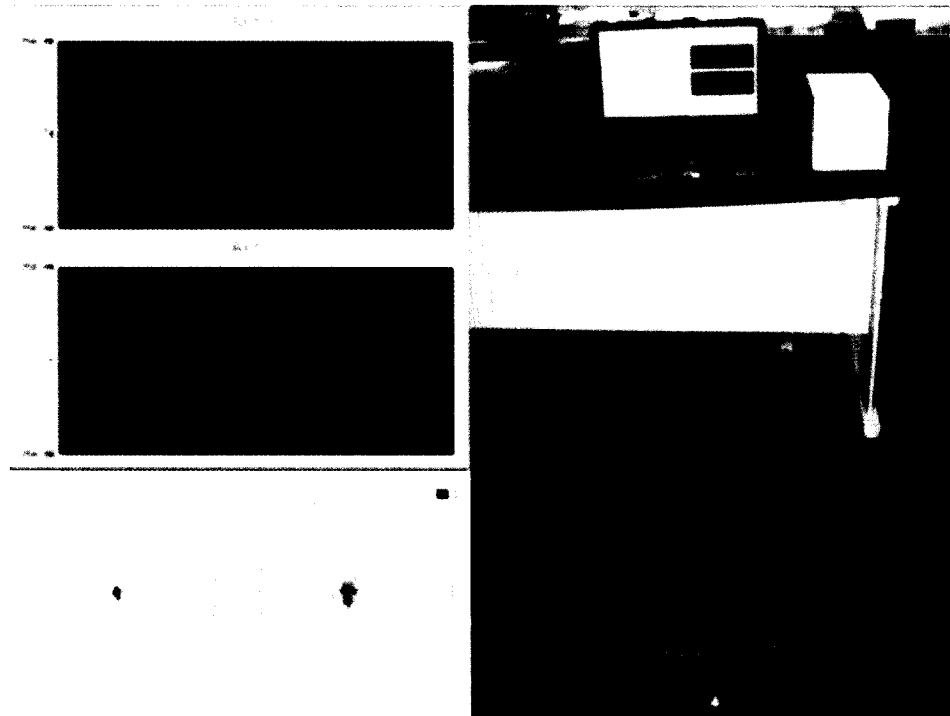
Figure 5: Gel's vibration recorded from drop ball test on dummy skull.

In accordance to the aforementioned findings, a head protection gear for sepak takraw and soccer players are currently developed. The objective of this project is to find the suitable material that can be used in the design of the protective head gear. Both takraw and soccer balls are dropped from various heights onto a force platform to measure the impact force and dropped onto the instrumented skull to measure brain vibration. High-speed camera is used to capture the motion of the ball throughout the impact. The ball velocity, contact duration and ball deformation are determined from the high-speed videos. Several materials were tested and the best material was used in fabricating the initial prototype of the protective head gear. Apart from reducing brain vibration and peak impact force, the prototype maintains the ball velocity after impact, which implies that the performance is not compromised (Taha, Hassan, et al. 2014). It was found that different materials exhibit different vibration levels as depicted in Figure 5. Analysis of different types of materials is the subject of current investigation.

In addition, a preliminary study to develop custom size soccer shoe is actively being conducted. The objective of the project is to produce 3D foot model using low cost 3D scanner as shown in Figure 6, which will be used in producing custom size soccer shoe (Taha, Aris, et al. 2014). Post processing work has been performed to validate the 3D foot model measurements against the conventional anthropometry measured. The results obtained were found to be in good agreement as the discrepancy recorded are less than 5%. This observation demonstrates the high accuracy of the 3D model produced by this method.



**Figure 6:** Scanned foot model (Taha, Aris, et al. 2014).



**Figure 7:** Postural Balance Monitoring System

A postural balance monitoring system has also been developed for archery in order to aid archery coaches during training (Figure 7). This system is designed to monitor and evaluate the swing of Centre of Pressure (COP) of an archer. The swing performance of an athlete can therefore be evaluated quantitatively. Industrial-level PC/104 and QNX operating systems were used to develop this system. This device is very precise, stable, user friendly and low cost. Figure 7 depicts the prototype of the Postural Balance Monitoring System.

### **Conclusion**

This paper dealt with the historical aspect, the impact as well as current research with regard to sports engineering. Sports engineering, in essence, is the fusion between the knowledge of sports science and the principles of engineering. It is apparent that, although sports engineering has been considered/deemed as a relatively new field of study, its presence or the philosophy behind it could be traced back centuries ago. It is evident that this field has an immense impact on sports and even more so at this present day. With the rapid advancement of technology and state of the art research, sports engineering has indeed become a game changer, redefining sports perceived by man once before.

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# MOVEMENT

## HEALTH & EXERCISE