

Pittsburgh

Fall 2014

ENGINEER

Quarterly Publication of the Engineers' Society of Western Pennsylvania



Engineering *in* Athletics



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Pittsburgh ENGINEER

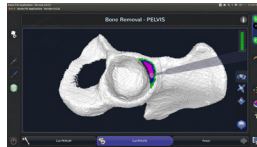
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In this issue... FALL 2014

4 Guest Editor Column



6 Engineers Get an Assist in the Operating Room



8 Improving Football Helmets thru Engineering

12 Advances in ACL Repair



14 Baylor's McLane Stadium

17 Catapult GPS Technology

21 Big in Texas



24 Concussion Assessment and Management

27 So, you're building a field?

30 Engineering Spectator Safety

33 Spotlight on ACE Mentoring Program



Why ESWP? 10

Engineering Materials for Peak Performance 11

Corporate Members 18

Building a Better Soccer Ball 20

Keeping Spectators Safe from Robots 29

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Guest Editors Column

By Steven Reinstadtler and Anthony M. DiGioia, III

This issue of the Pittsburgh ENGINEER focuses on some of the ways the engineering profession impacts athletics. “Engineering in Athletics” is an examination of two main areas: medicine and materials, and how the people and places of sport benefit. To gather relevant content for the magazine, we identified two individuals considered to be leaders in their respective field, and invited them to share their thoughts (and contacts) with our readers.

Steven Reinstadtler is a Construction Marketing Manager with Bayer MaterialScience, a German-owned company whose North American headquarters are located in Robinson Township, PA.



Steven Reinstadtler

Welcome to the “Engineering in Sports” issue of Pittsburgh ENGINEER magazine. As you read through the following articles, you will find a host of examples where engineers have contributed to the safety, aesthetics and long-term durability of the people, equipment and venues associated with the sports world.

Advancements in material science allow professional and amateur athletes to continue to push their skills to the limit every time they walk on to the field. Innovative materials give them the technology, comfort and protection they need to perform at their absolute best. When it comes to performance and safety, these innovations may come in the form of smart textiles engineered to breathe and wick perspiration away from the skin to keep athletes drier and more comfortable, or compressive polymer-based textiles that store the wearer’s energy and release it back to improve their stamina. There has been a lot of news lately about the cumulative effects of sports-related concussions both in professional athletes as well as weekend warriors and student athletes. Medical studies are focused on characterizing and treating concussions. Materials engineers have begun to look at ways to eliminate the jarring forces through advancements such as multi-layer composite helmet upgrades designed to absorb and redirect helmet-to-helmet impact energy for football players to protect them from concussions. Even the shoes we wear to exercise and play in have become high tech, sporting advanced engineered polymers that last longer while cushioning the foot pad from impact and injury.

Modern-day stadiums and sports venues are meant to rival the ancient coliseums in their grandeur, while creating a memorable game-day experience. But

Anthony M. “Tony” DiGioia, MD is a world renowned orthopedic surgeon who initially chose the civil engineering program at Carnegie Mellon University to begin his career path. Along the way, young “Tony” suffered a knee injury while playing tight end for the CMU football team. Although that injury did not require a surgical repair (he resumed his football play the next year) there was little evidence at that time that Tony would later pursue such treatment as his life’s work. And the medical profession has benefited from this “re-direction” because of the innovation Dr. DiGioia has since introduced to orthopedic surgery through his engineering background.



Anthony M. DiGioia, III

Although we knew of Dr. DiGioia’s impressive curriculum vitae — he was awarded ESWP’s “Engineer of the Year” award in 2000 — we wanted to examine the merger of engineering and medicine and how athletes, both professional and the weekend warrior have benefited, from the prospective of the prevention and treatment of injuries and degenerative problems. DiGioia began this merging of these disciplines while in the biomedical engineering Master’s program at CMU. What started as computer analysis of a novel joint replacement system in the Orthopaedic Biomechanics Lab at UPMC, soon turned into attending Grand Rounds with the orthopedic residents. It was here that Dr. Albert Ferguson, the grandfather of Pittsburgh orthopaedics, encouraged him to pursue a career in medicine and “bridge the gap” between engineers and surgeons, which led him to attend Harvard Medical School, in Boston, MA. However, the synergies between engineering and medicine weren’t as clear then as it might be considered now; Tony had to explain to interviewers and admission committees why an engineer was applying to medical school. “Now, engineering is a very accepted pathway in medicine....a very good thing!” Blazing this new trail, Tony never failed to remember the synergies and important collaboration he believed needed to exist between engineering and medicine.

unlike the ancient venues of Greece or Rome, today's stadiums are made of modern materials such as steel, aluminum, concrete and polymers. They are engineered with durability, safety and accessibility in mind. These contemporary behemoths can sport huge structural steel roofs, arching pedestrian bridges and host 50,000-100,000 sports fans. For the fans, ease-of-access disruptions, parking-related traffic jams or maintenance down times can result in the facility managers being 'fed to the lions.' Therefore, engineers carefully and methodically consider items like pedestrian flow rates, 100-year floods, steel corrosion rates and weather effects on exposed surfaces. The result is stadiums that are designed to incorporate logistics, safety and long-term durability using analysis tools, engineering controls and state-of-the-art, modern protective coatings technology.

Even the ubiquitous ball has been recently re-engineered. You may recall the "Brazuca" soccer ball used at the 2014 World Cup® games this past summer

in Brazil. You may not know that several polymers were engineered to re-imagine the design and functionality of the ball. Eight layers of bladder, adhesive and polymer films make up this new design. Factors such as elasticity, storage modulus, water absorption, abrasion and aerodynamics were all considered and incorporated to make this one of the most engineered pieces of sports equipment to date.

What's next? Well, just watch any one of a dozen recent science fiction and fantasy movies, and you'll see possibilities for new and more intense sports – from high-altitude jumps to flying broomsticks. Whether there is an increasing desire for more aesthetically pleasing stadiums or awareness around the health effects of both repetitive as well as high-impact sports, there will always be a need for engineers to develop solutions to new and existing problems. I am quite sure our modern-day engineers will be more than capable of stepping up to the plate. **PE**

Upon returning to Pittsburgh to start his orthopedic practice, Tony took the bold step of starting a new type of research lab which gathered engineers and computer experts to advance surgical practices. The outcome was a combination of robotics and computer-aided "smart" surgical tools, allowing for a higher degree of precision when doing joint replacement surgery, a "GPS system for surgeons" as described by DiGioia. One of the results of this collaboration is the focus of one of the articles for this edition – the Bluebelt hand held robotic tool. This is a nice connection that goes from research and design with collaboration between technologists and surgeons to prototype development to an actual company and commercial tool for everyday use and all a Pittsburgh effort! This led to better patient outcomes and less invasive surgical techniques, evidenced by shorter hospital stays, more rapid rehabilitation and reduced pain during the recovery phase – in all, a quicker return to a normal lifestyle for patients. Tony credits this intersection between engineering and medicine to his engineering education. "The best training to prepare me as a physician and surgeon came from my engineering background since engineering training focuses on learning how to learn and problem solving rather than just memorizing information."

With a clear understanding of the power of collaboration, DiGioia has further enhanced patient care by examining and re-designing new care delivery systems that focus on meeting the needs of patients and families. He noted that too many times, surgeons isolated themselves from the total patient experience, and focused only on the surgery they performed. With his critical thinking skills, DiGioia analyzed the patient's journey thru a full cycle of care and decided it was right to end such "isolation" and become fully immersed in the complete patient experience. This pushed him to gather care givers from all phases of the patients experience and created a comprehensive approach to "care delivery by design" called the "Patient

and Family Centered Care Methodology and Practice." Again, Tony's engineering roots combine with his medical career to better care for patients. "Engineers and surgeons working closely together have advanced the care for all patients. These collaborations have resulted in new technologies as well as new processes in care delivery."

One recent improvement in the delivery of "engineered" health care has benefited athletes and those weekend warriors as well as many other patients as well. "Total joint replacement in the treatment of arthritis remains one of the true medical wonders of our lifetimes." It is this type of advancement that impresses DiGioia. "We can actually cure patients of their arthritic disease and return them to very active and productive lifestyles which when you think about it is rare in most areas of medicine that deal with chronic diseases."

Looking ahead, engineering and medicine have an unlimited future together. DiGioia is excited about new advances in tissue engineering, personalized medicine, and gene therapy, which will influence both diagnosis and treatment of many diseases. "The areas of personal body metrics/data collection and with remote data retrieval...and now with technologies like the Apple watch we can expect this area to progress even more quickly. The most important paradigm shift will be to combine technology with processes that meet the needs and wants of our end users – our patients and their families.

We believe the collection of articles in this issue of the Pittsburgh ENGINEER, as invited from our Guest Editors, reflects the interaction between engineering, athletics and medicine and are all perfect examples of how engineers working together with other professions result in better care of all of our patients whether they be high performance athletes, the weekend warriors and from prevention to the treatment of injuries and support them in their own personal journeys to wellness. **PE**

Engineering Gets an Assist in the Operating Room

By Adam Simone, Branko Jaramaz, Costa Nikou and Anton Plakseychuck

Introduction

Femoroacetabular impingement (FAI) is a major etiologic factor in the pathogenesis of hip osteoarthritis¹⁻⁴. In FAI, deformities of the femoral head-neck junction, acetabulum, or both, produce abnormal contact around the periphery of the joint.

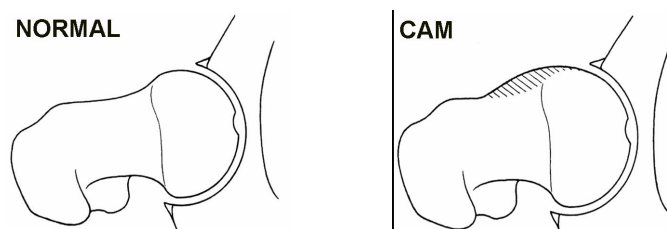


IMAGE 1: Femoroacetabular Impingement (FAI) Forms, Lavigne et al. 2004 "Caption: (a) the normal anatomy of the femoral head-neck junction within the acetabulum, and (b) anatomy that is typical of presenting with FAI disease, note the abnormal shape of the bone around the femoral head-neck junction"

For the patient, the result is pain and dysfunction. This can cause the patient to alter their normal activities to accommodate the disease, find themselves with range-of-motion restrictions that affect sports or every-day-life activities, and can cause mild to serious pain. Furthermore, the presence of this disease may cause articular cartilage damage and disease, progressing to secondary joint deterioration. This means, the presence of FAI in the joint which is largely characterized as a bone deformity may lead to a disease state for the patient necessitating total hip replacement. FAI is now being diagnosed more commonly, and there is an increasing need for joint preservation surgical treatment. Good clinical outcome is dependent on accurate resection of the affected lesions.

Hip arthroscopy is becoming the standard for treatment of FAI. However, failures of arthroscopic FAI surgery due to inaccurate and inadequate resection are reported to be increasing⁵. A high level of arthroscopic skills and good visualization are required for a successful intervention. Potential technical errors are present in almost every part of the procedure from positioning, cannulation, visualization, and osseous resection. Postoperative instability, dysplasia, dislocation and femoral neck fracture have also been reported after hip arthroscopy and are likely caused by over-resection⁵. Current state of the art is to combine fluoroscopy with arthroscopy to perform an intraoperative assessment of optimal resection⁵. The problem with this approach is that 2D modalities are being utilized to define and/or assess a 3D morphology. These technical limitations, in combination with the increasing number of reports on failures, are driving the demand for improvements offered by navigated and robotics-assisted devices.

Larger autonomous robots have had difficulty gaining acceptance, partly because of their economic disadvantages, their size and cumbersome presence in the operating room. Recently, "semi-active" class of robots is gaining popularity. These robotic devices combine the advantages of robots – repeatability and accuracy, with the flexibility, adaptability and intelligence of a surgeon⁶.

"Engineering challenges run the spectrum from clinical process management, software algorithm development, robotic-assisted integration within existing hardware paradigms"

In development of a technological approach to treat FAI, engineering challenges run the spectrum from clinical

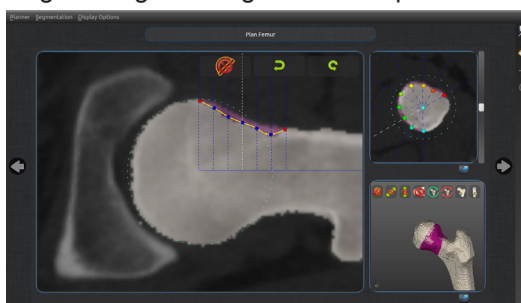


IMAGE 2: xyz "Blue Belt Technologies" products apply the precision, accuracy and guidance of robotic-technology ontop of normal surgical instrumentation. Their solution for FAI is powered by the proprietary box pictured above

process management, software algorithm development, robotic-assisted integration within existing hardware paradigms, all while balancing usability from the

perspective of the surgeon and operating room staff.

Clinical Process Management

Integration of technology solutions into practice typically requires a holistic assessment of the operating environment and use case scenarios. Successful technology enhancements of existing approaches can find success by applying benefits while remaining either invisible to the user, or minimally disrupting traditionally instrumented approaches.

Technologies like Precision Freehand Sculpting, developed by Blue Belt Technologies (Not yet submitted to or approved by FDA) have an intuitive and user friendly approach to robotic-assisted surgical devices. Using proprietary algorithmic approaches combined with computer navigation hardware, precision results can be achieved with minimal changes to tools, operating room setup, and surgical flow – avoiding typical pitfalls that plague larger industrial-style robotic technologies. These types of advancements are important in achieving commercial and clinical traction, especially within highly constrained economic environments like medical technology.

Software Engineering Development

In treatment of FAI, robotics-assisted solutions will guide the user in pre-operative surgical planning, visualizing the three-dimensional pathology in all three dimensions

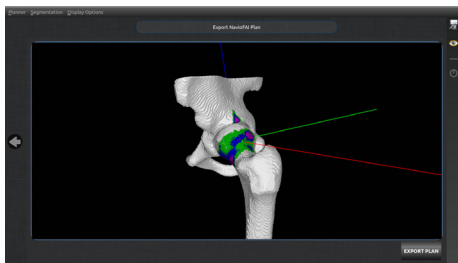


IMAGE 3: The software utilizes a pre-operative CT Scan to recreate a 3D image of the anatomy, allowing the surgeon to interact with the bones and plan the surgery

A patient-specific plan based on multi-modal inputs is developed and transferred into the operating room. The surgeon can then enter surgery with a high-degree of confidence in both understanding the state of the patient's disease, as well as in having a pre-defined plan that should return the patient to normal activities, reduce pain, and preserve their existing joints for maximum return to function.

In the operating room, technology can provide the surgeon with what amounts to a three-dimensional map of the patient's anatomy and disease, overlaid with a surgical plan to track their progress

The software is the surgeon's GPS, delivering more information than was ever possible before. Software algorithms and robotic control

remain invisible to the user until activated out of necessity to prevent resecting bone that the surgeon did not intend to remove. This invisible overlay of control allows the user to perform the procedure as they have been trained. The visualization can inform them when the surgical plan is realized.

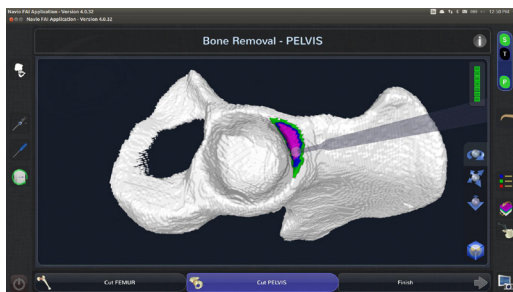


IMAGE 4: During the surgery, computer navigation shows the progress to the pre-operative plan, the technology accurately limits bone removal as well.

Hardware Engineering Challenges

Engineering solutions that must function properly within user, design, economic and environmental constraints force designers to consider many inputs through the design process. A robotic-assisted solution to treat FAI while maintaining a typical surgical approach forces engineering outputs that are elegant and invisible to the user during the procedure. The company developing a next generation solution for this treatment, Blue Belt Technologies, engineers hardware that enable a computer to track and navigate the relative position of a cutting implement with the patient's bone and pathology.

Conclusions

The state of the art for surgical instrumentation continues

to advance, driven by mutually beneficial opportunities between industry and surgical practitioners. Engineering challenges abound, especially within the constraints of highly controlled user environments and within a heavily regulated industry. Teams focused on delivering cohesive solutions that apply advanced technology to promote accurate, precise and reproducible results will be able to drive further adoption of traditionally difficult procedures.

Hip arthroscopy is one of the fastest growing orthopedic procedures according to the American Academy of Orthopaedic Surgeons, and joint preservation techniques play into patient-focused macro-trends in orthopedics of satisfaction, return to function and increased quality of life. Patients are expecting faster recoveries, less invasive procedures and rapid return to normal activities – expectations that practitioners are suspecting can be delivered by increased utilization of certain procedures enabled by technology solutions.

About the authors...

Adam Simone runs Blue Belt Technologies' Marketing and Clinical services groups, supporting the growth and acceptance of robotic-assisted surgery in orthopedics through innovative, handheld solutions.

Branko Jaramaz, PhD is one of the pioneers of Computer Assisted Orthopaedic Surgery, and a co-developer of HipNav, the first surgical navigation system for total hip replacement. His professional and research interests encompass the areas of simulation for surgery and rehabilitation, medical image processing and medical robotics.

Costa Nikou has contributed to the field of computer assisted orthopedics since 1996, and has served as Blue Belt Technologies' Director of Software Development since the company's inception. Mr. Nikou holds a bachelors of science in Computer Science and a masters of science in Robotics, both from Carnegie Mellon University.

Dr. Anton Plakseychuck MD, PhD is an orthopaedic surgeon at Magee-Womens Hospital of UPMC in Pittsburgh, PA. He has sub-specialty focus in hip surgery, orthopaedic trauma, and pediatric orthopaedic surgery. Dr. Plakseychuck has additional interest in joint preservation techniques and has offered these solutions in his practice for a number of years.

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Improving Football Helmets

through the use of
**Chemistry,
Physics and
Engineering**



By: Lee Hanson, P ChE and Dr. David P. VanSickle; Ph.D. Bioengineering, M.D. Neurosurgeon

The goal with helmet-to-helmet collision is that accelerations transmitted to the brain must be minimized. The Guardian Cap works by adding a soft, inelastic outer layer over a football helmet's hard shell to reduce these very accelerations. Reduced brain acceleration translates directly to reduced forces acting on the brain tissue, and possibly a lessened probability of concussion. We utilize chemistry to create the best, lightest polymers for impact attenuation and low coefficient of friction, physics to design the ideal product that reduces linear and rotational forces and engineering to manufacture the product that has the most utility yet is still economical to the average user.

The Guardian Cap soft cover consists of an arrangement of 39 closed foam padded cells that surround the helmet shell. The soft cover weighs approximately 7 ounces and is attached to a conventional football or lacrosse helmet using four elastic straps with snaps that loop around the edges of the facemask with an additional adjustable Velcro strap at the rear. A key feature is that the soft cover is made from a low coefficient-of-friction fabric on both the inner and outer surfaces that allows it to slip on the helmet and off objects such as an opposing team helmet. By purposely not rigidly attaching to the helmet shell, the cover can move and stretch such that portions of the cover can slide along the surface of the helmet.

We have two fundamental principles of physics at work with the Guardian Cap design aimed at reducing linear and angular accelerations of the head respectively. First, the 39 individual cells made of EVA/Urethane Foam in the Guardian Caps are designed to deform up to ½ inch, absorbing energy in an inelastic collision and reducing linear acceleration. This is in stark contrast to the near elastic collision of

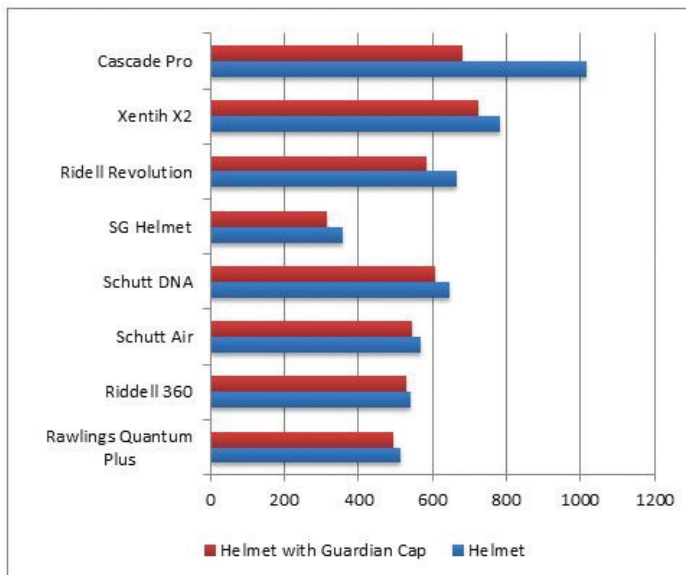
two rigid bodies. While we have often heard helmet sales reps telling coaches that you want a hard shell so that colliding players will bounce off each other, this unfortunately is just misunderstood physics. In such an elastic collision, the accelerations will actually be at a maximum as with Newton's colliding steel balls. Rather than the conventional design, which nicely emulates a pool ball, a perfect helmet would shatter on a single hit absorbing kinetic energy like the crush zone of a car. While a helmet that breaks on the first hit isn't too practical, it is entirely possible to design using materials with hysteresis that absorb significant kinetic energy in an inelastic collision process.

While the first design principle is rather obvious, the second design principle of the Guardian Cap is likely more important and so far has been elusive in football helmet design. The coefficient-of-friction of the Guardian Cap is lower so there is less grab than a polycarbonate shell thereby reducing angular acceleration. Furthermore, the Cap is decoupled from the helmet floating above the helmet shell, moving independently, deflecting the energy away from the head. We utilize polyurethane spun fibers (Lycra and Spandex) that have been specially sized to obtain coefficients-of-friction (COF) of 0.27 versus polycarbonate's higher COF of 0.31. Coaches see the difference when the athletic tape commonly used to label helmets refuses to stick on Guardian Caps.

The Holy Grail for helmet makers is establishing the best materials to dissipate and redirect accelerations at the point of contact between helmet collisions. These concepts are of course the mainstay of automotive crash protection. Crumple zones absorb kinetic energy by making the collision inelastic and zones are specifically designed to fail

causing forces to be redirected away from the occupants. The only real difference between designing for a football helmet and an automobile is that a football helmet must allow for reuse where a car suffers a severe impact only once. Even nearly two-thousand years ago the Carthaginians knew that deflecting a blow was advantageous in their shield design known as parrhas and scutum. As Dr. Eric Nauman, PhD Bio ME and a Purdue University Neurotrauma Group co-investigator stated, “Anytime you can get [the helmet’s outside material] to flex or deform without doing damage to the helmet, it will absorb energy and transfer less energy to the skull or brain.”¹

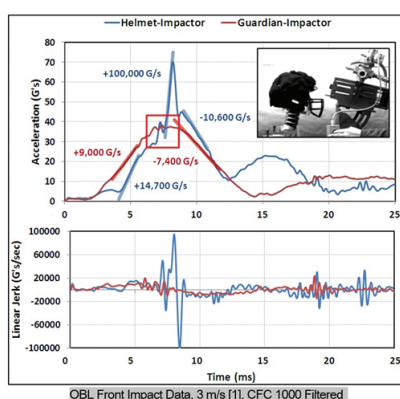
We tested the Guardian Cap with seven different helmet models from five different manufacturers at NOCSAE certified ICS Laboratories, Inc. For every model, the results demonstrated that helmets with Guardian Caps in place had a reduced Severity Index (SI) compared to the helmets without. All helmets with Guardian Caps attached passed the SI threshold set by NOCSAE. (Drop tests were per-



NOCSAE Severity Index (SI) for commonly available football helmets with and without the Guardian Cap.

formed at ICS Laboratories, Inc. (Brunswick, OH) utilizing a Cadex twin wire test platform in accordance with NOCSAE 001-11m13. A NOCSAE medium head form and MEP pads were utilized. Testing procedures were followed within NOCSAE 002-11m12 with two deviations: Helmet facemasks were attached to the helmets and some of the tests included the soft cover.)

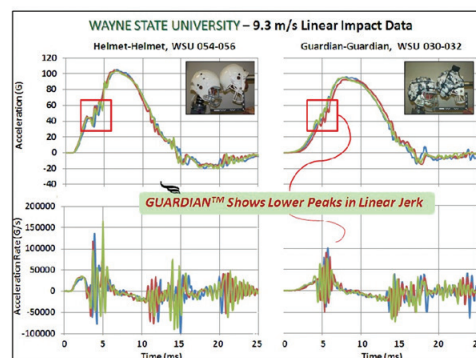
There is more going on with the addition of a soft-shell cover. In addition to the reduced impact forces and the ability to re-



OBL Front Impact Acceleration and Jerk with and without a Guardian Cap in place.

duce rotational forces by being decoupled from the helmet and head, the soft cover also mitigates the vibrational and harmonic frequencies that occur when two helmets collide. These harmonic frequencies have been shown to be triggers for Traumatic Brain Injury (TBI) for soldiers during improvised explosive device (IED) blasts in war zones.² Impact test data shows the presence of high frequency vibrations and high rates of change in acceleration – known as “jerk”. The Guardian Cap significantly reduced these high frequency vibrations and high jerk values. Jerk has been proposed as a metric for assessing head impacts on surfaces³ and high values for jerk along with the momentum analog, jolt have been associated with increased brain injury in models.⁴

Wayne State University (WSU) front impact data at 9.3 m/s passed through a Channel Frequency Class (CFC) 1000 Hz filter. Peak values for jerk do not correspond with peak acceleration values. With the Guardian Cap, the initial change in acceleration, near the beginning of the impact, is



WSU helmet-to-helmet linear impact Acceleration and Jerk with and without the Guardian Cap in place.

lowering of the peak acceleration.

To gain further insight into these processes, high-speed video footage of the WSU frontal impacts near the acceleration peak was examined. Frame to frame comparisons of head form and helmet position show relative motion between the head forms and helmets, and contact forces between the helmet shells cause compression of the helmet padding between the head forms and helmet shells. Flattening or cupping of the helmet shells over the contact area demonstrates elastic deflections of the helmet shells. These elastic deflections store and release energy like

a) OBL Linear Impact Test Summary



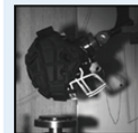
- Helmet-Impactor
- GC-Impactor
- Front, Side, Rear
- 2.6 m/sec
- Hybrid III Headform
- Schutt AIR IV Helmet, Youth Regular

b) WSU Linear Impact Test Summary

- Helmet-Helmet
- GC-Helmet
- GC-GC
- Front, Lateral-Front, Lateral-Rear
- 7.6, 9.3 m/sec
- Hybrid III Headforms
- Riddell Revolution Helmets, Adult Large



c) ICS Drop Test Summary



- Helmet-Anvil
- GC-Anvil
- Front, RSide, Rear, Top
- 26, 66, 124 inch Drops
- NOCSAE Headform
- Riddell Revolution, 360 Helmets, Adult Large

Illustrations of a) OBL linear impact test, b) WSU helmet-to-helmet linear impact test, and c) ICS drop test.

gentler – even at a relatively high impact speed, and the peak value for jerk is lower at 60 kG/s versus 100 kG/s. These changes appear to be caused by a lengthening of the duration of the impact combined with a



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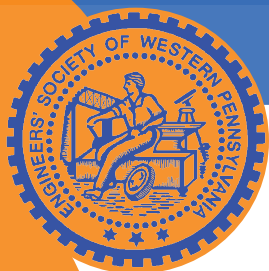
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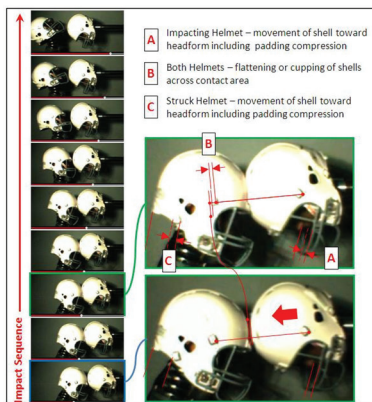
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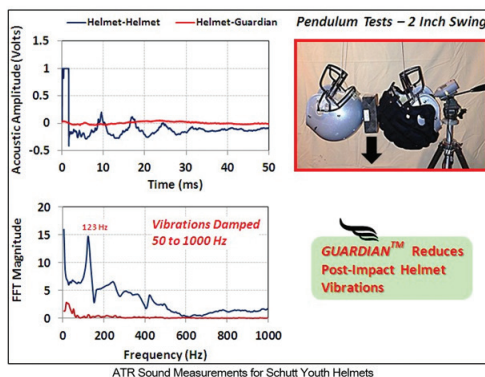
Impact sequence during Wayne State helmet-to-helmet testing demonstrating spring-like loading and release.

a spring transferring a near maximal amount of energy to the helmet. The Guardian Cap acts as an inelastic member surrounding the helmet shell, thereby reducing the energy transfer and associated acceleration and jerk peak values.

The impact noise from Guardian Cap-equipped helmets is audibly different than the impact noise from bare helmets. Investigating this phenomenon

further we used helmet to helmet pendulum impact tests to make a quantitative assessment of the associated audible vibrations. We used two Schutt Youth helmets suspended from thin nylon cords in a pendulum arrangement. The bare helmets were separated by 2 inches then allowed to impact together with noise being measured inside one helmet using a digital acoustic meter, laptop soundcard (19.2 kHz sampling) and laptop based oscilloscope software. The test was then repeated with the Guardian Cap installed on just the noise-measured helmet. Using Fast Fourier Transform (FFT) analysis of the measured noise signal shows that Guardian dampens nearly all vibration from 50 Hz to at least 1000 Hz.

In conclusion, the Guardian Cap reduces the Severity Index for all commonly available helmet designs. Both peak acceleration values and peak jerk values are reduced and significantly higher frequency (audible) vibrations are greatly dampened.



Guardian Cap sound dampening in helmet-to-helmet impacts.

Contributors

Robert F. Hoskin, Advanced Technical Research, Inc.; Dr. Robert S. Cargill II, Cargill Bioengineering LLC; Justin Greeley, Oregon Ballistic Laboratories LLC; Christopher Andreovich, Biomedical Engineering Department, Wayne State University; Dr. Michael McHugh, McGill University, Canada, Physics Department

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Engineering Materials Help Athletes Achieve Peak Performance

Manufacturers of sports apparel and footwear are constantly looking for innovative ways to engineer enhancements into their products and in doing so, help athletes – both professionals and weekend warriors – achieve peak athletic performance.



Techfit™ Powerweb™ from adidas®, for example, is a special kind of underwear with a compression function. While the shirts and shorts fit close to the skin – almost like a second skin – athletes hardly feel them at all. The trick is elastic bands incorporated in the garments that have a special coating based on Impranil® raw materials from Bayer MaterialScience, a science-based company with its North American headquarters based in the Pittsburgh region. The clothing gives an athlete improved posture and helps prevent premature fatigue. When the bands stretch, the material temporarily stores that energy, giving it back to an athlete as he or she continues to move – an effect that enhances strength and stamina. At the same time, the compression helps the avoidance of unwanted muscle vibration that can influence performance.



Bayer materials have also been utilized for decades to produce lightweight and durable athletic footwear. Take the Copa Mundial from adidas®. Now in production for more than 30 years with more than 10 million pairs sold to date, it is the most successful shoe in soccer history.

This does not happen by chance: pros and amateur athletes alike prefer its excellent forefoot flexing and comfort. These properties are primarily imparted by the engineered design of the sole, which is made of a very durable thermoplastic polyurethane (TPU) from Bayer. With its good traction, the shoe offers optimal damping and pressure distribution that is particularly easy on the joints, ligaments and muscles. These physical advantages are attributable in part to the flexible and wear-resistant TPU sole.

Engineering comfort combined with high functionality, athletic clothing and shoes are helping amateurs and pros alike stay one step ahead of the competition.

Advances in ACL Repair

By: Garth Walker

Adrian Peterson, Derrick Rose and Ricky Rubio are three internationally known athletes with one painfully common thread: the anterior cruciate ligament, alias ACL. Each of them suffered the injury considered one of the most devastating to any athlete, a rupture of the ACL. Given the ligament's critical role in stabilizing the knee, as many well know, an ACL injury has the potential to derail the long-term trajectory of an athlete's professional career.

Even beyond the scope of professional athletics, the injury can have a drastic effect off the field as well. ACL injuries are in fact quite common among the general population, affecting more and more individuals every day. Indeed, up to 250,000 ACL procedures occur daily, and threatening long term knee health drastically. Fortunately, successful repair of the ACL can provide an optimal outlook on knee stability and successful return to athletic activity.

What is the ACL?

The ACL is one of the most important ligaments in the human body, working to stabilize the knee by preventing the tibia from leaning forward from the femur to avoid symptoms of instability and giving out. The ligament originates on the lateral portion of the femur and inserts on the front portion on the tibia. Rupture of this crucial ligament usually occurs when the knee is compromised in a position that stresses the ligament and overcomes the forces that causes the acl to rupture. Most often, this injury is seen in pivoting and shifting sports such as basketball, soccer, lacrosse, and football.

Marriage of Multiple Disciplines

Pittsburgh has developed a strong relationship with the ACL, and has been home to the most prolific research regarding clinical, basic science, and biomechanical research relative to the ligament. UPMC is home to one of the first sports medicine programs and became fertile ground in which to study and advance recovery from such injuries and surgeries as the ACL. In 1982, Dr. Freddie Fu paved the way to develop UPMC Sports Medicine fellowship and change the trajectory of how sports medicine was viewed by the general public. The combination, in his words, of doing the right thing and finding the right people set the stage for a future of innovative research and progression.

Over time, UPMC Sports Medicine and its partner the University of Pittsburgh Department of Orthopaedic Surgery

were regarded as pioneers in sports research, and securing a reputation as one of the premier programs across the nation. Part of the success was due to focus on research early on, and translating information to the public to advance ACL reconstruction and circumvent the outcomes of patients experiencing this devastating injury. Early vision laid the groundwork to provide a research environment that encouraged thought, leadership, and an eye for finding talent that could strive for answering questions that befuddled surgeons in operating technique, treatment and management.

The marriage of basic science, biomechanical, and clinical research has created a melting pot of ideas resulting in the influence of how ACL reconstruction is viewed anatomically, functionally, and conceptually. One of the most glaring examples is from Dr. Scott Tashman, head of the Biodynamics Laboratory, who stated prior to his recruitment to Pittsburgh: "When I was doing kinematic research I had no idea that the ACL can be completed anatomically, and after meeting Dr. Fu this provided a whole new set of questions in how ACL surgery can influence knee kinematics". The Tashman Lab provides some of the most translatable research in answering the question on how to restore the natural movement and kinematics of the knee, adding to the body of anatomic ACL research. Additionally, Dr. Patrick Smolinski leadership works with the collaboration of orthopedics and the department of biomechanical engineering. His interest include the development of new computational simulation methods and the application of computational methods to problems in manufacturing and biomechanics. Both have helped developed the quality and productivity of biomechanical research.

Basic science research has always been at the forefront in Pittsburgh, where, just a few blocks down from the UPMC Center for Sports Medicine, Dr. Johnny Huard has been leading the way to understand the role stem cells play in the ACL. His research helped to answer the question about when to operate and when not, opening the door to a whole new array of inquiries such as: Why some knee ligaments heal and other do not? How can stem cells impact the ACL therapeutically? Or cell-based therapy to revitalize the ACL graft. Lastly, clinical and surgical outcome research has served as a basis to allow such questions to be answered. Dr. Fu, noted for his tireless work ethic, intelligence, and

curiosity, has projected these characteristics to continue to push the envelope by starting the conversation right at the clinic. With his partner, Dr. James Irrgang, the basic but intricate and detailed questioning of the patient history, combined with a holistic review of Dr. Fu's surgical technique, and patient follow-up in his own practice, has provided fruit for a plethora of research questions that continues to motivate.

One prime example was the transition in the 1990s observed with arthroscopic ACL surgeries. The beneficial technology also provided a disruptive negative externality

by surgeons, moving the tide of focus from anatomy to an obsession of efficiency and output. Understanding, that this was impacting patient care, the anatomic ACL reconstruction was revived, which simply was defined as restoring the ACL to its original insertion sites. While simple in explanation, the understanding of anatomy takes patience to master, and corroboration of multiple clinical and biomechanical studies has only added to an acceptance across physicians world wide. The Anatomic ACL reconstruction has garnered mainstream acceptance globally due to the research produced here at Pittsburgh from multiple disciplines. As research progressed the Double Bundle concept

was meant to individualize the ACL surgery to a patient's unique anatomy. While still in its infancy, the Double Bundle concept is providing an understanding for all surgeon to use to improve outcomes for their patients.

Pushing the Limit: Answering Questions while Creating More

The University of Pittsburgh Medical Center has set itself apart by producing the most research for ACL reconstruction, accounting for a significant amount of published studies, but it is all based off the premise of challenging

dogma, and asking the relevant question of how to improve. Here at Pittsburgh you find the perfect combination of bluecollar attitude coupled with intellectual curiosity that has provided an ideal environment for leaders in orthopedics. The motivation to continue is marked in the leadership of expert research across multiple discipline of basic science, biomechanical, and clinical research. While many question have been answered bringing ACL reconstruction near perfect, more questions arise to continue the challenge that motivates many here in Pittsburgh to continue to study and engineer the perfect ACL. **PE**



Left to Right: Dr. Scott Tashman, Dr. Johnny Huard, Dr. Freddie H. Fu, Dr. James Irrgang, Dr. Patrick Smolinski



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Baylor's McLane Stadium:

Designing for More than Game Day

By Jeff Spear

Baylor University's campus is nestled in Waco, Texas, just off I-35 and adjacent to the Brazos River. The quiet campus, with its classic Georgian architecture, has been on the verge of establishing themselves as one of the preeminent collegiate football schools in the country - an effort that started with the hiring of beloved coach Art Briles, was followed by the development of Heisman winner and NFL Quarterback Robert Griffin III and now appears to be complete with the opening of McLane Stadium. The university debuted one of the most innovative stadiums in the country - McLane Stadium, named after Drayton McLane, longtime donor to the school and former owner of the Houston Astros - on August 31. A defining moment for the university, the city and Central Texas, the stadium, while designed to house Baylor's football team, represents something far greater.

The intimate 45,000 seat, \$266 million facility that began construction in September of 2012 represents the future of a university, a city and a region. Its far-reaching impact made possible largely because of the stadium's site. Located on the



Brazos River, with the stadium gates less than 150 feet from the water, and directly adjacent to the I-35

Corridor, it serves as the new front door for the university and for Waco. It visually and physically represents Baylor's campus and is on a site millions drive by yearly, offering huge brand awareness opportunities for the university. The stadium has been lauded as having "the most beautiful setting in its sport" by USA Today and has been part of a visionary development strategy for both the university and the city. Understanding the stadium's design and impact starts with the site.

Site Opportunities

I-35 is one of the most traveled interstates in the nation, with more than 43 million people passing by Baylor's campus in Waco each year. The stadium's site, in addition to

being as close to this well-populated corridor as possible, also features another advantage: water. The design was inspired by a framework to allow the city of Waco and the university to connect to one another through their union of the Brazos River. A sculpted architectural landscape and plaza, complete with an amphitheater adjacent to 16 boat slips in the harbor next to the stadium, creates usable open spaces that have become an important part of Baylor's campus on non-game day. The stadium sits on a newly acquired part of campus - an area that used to have overgrown foliage and a dated hotel - and was separated from campus by the Brazos. The site was cleared and two bridges were constructed - a sculpted, curved pedestrian bridge that helps create game day pageantry and leads students and fans from campus directly to the South Plaza, and a second bridge that connects an extensive tailgating plaza to the stadium.

But while the site location was ideal, it wasn't without its complications. Geotech, structural and civil engineers came on board to assist with issues that arose from the nature of the Texas soil, which includes extensive amounts of both expansive clays and sand. Fortunately, bedrock was just 50 feet below grade, allowing the construction team to use auger cast piles to create a stable foundation system for the stadium. The water table was eight feet underground and the site was in a 100 year flood plain, something the design team was aware of prior to selecting the site. To address this, the design team built a plinth around the stadium, wrapping the field with an earthen berm to raise the majority of the interior spaces above the flood plain. The field remained at existing grade and therefore in the flood plain, so a 20,000 gpm pump system was integrated to handle keeping the field from flooding in the event of a 100 year flood event.

Game Day and Traffic Considerations

In addition to evaluating potential complications of the soil, flood plain and water table, Populous worked closely with traffic and parking engineers to analyze the load in and load out process and anticipate the amount of time fans traveling to the game would spend in traffic. This process took into account how parking in each lot adjacent to the stadium would be accessed and how these lots on the stadium site would mesh with existing traffic along I-35 and Martin Luther King Jr. Blvd. as fans entered and left the site. Populous also established walk distances from existing parking that would be utilized on campus as well as in downtown Waco. The pedestrian bridge from campus was

designed to provide the primary access point, accommodating up to 28,000 fans who would be a mixture of students and alumni. The available parking in downtown Waco also plays an important part in this scheme. The location of tailgating for students and 300 tailgating spots for the general public just southeast of the stadium required a separate bridge to connect this part of the site to the stadium. The bridge was sized to accommodate the anticipated demand and to allow for additional foot traffic from campus.

The coordination process also took into account construction of additional bridges along I-35 by TxDOT, and the widening of the existing Martin Luther King Jr. parkway, extending it east to connect to another major existing thoroughfare, in turn providing multiple access points by car to the stadium site.

Audio / Visual Parameters

A major component of the building is a sunshade canopy, a must for Baylor University and its location in the scorching central Texas sun. The canopy is important for shade coverage for the fans and to amplify crowd noise toward the field. An in-depth sun study was undertaken to understand where the sun would be at various times of the day and to maximize the amount of shade on the seats throughout the day, driving the eventual design of the asymmetrical canopy that covers nearly 60 percent of seats during the heat of the day. Larger on the east side of the stadium, the largest cantilever is 95' and the canopy is constructed of a mixture of prefinished structural metal deck and PTFE fabric. The selection of these materials helped to lighten the structure and add character to the design.

But the canopy served another important purpose. It provided a structure that would further enhance the fan noise in the cozy, 45,000 seat stadium, and create a home-field advantage that the team's previous stadium – Floyd Casey – simply did not have. The angle of the canopy relative to the field was an important consideration, and Populous desired to direct stadium noise back to the field as much as possible.

Other technology considerations came along with befitting the entire facility with high-density Wi-Fi and installing a distributed antenna system for cell phone use. The stadium features the most technologically advanced experience in collegiate football with the use of Yinz-Cam, an in-game app that allows fans to view parking and traffic information, view instant replays from various angles and see stats on the performance of players by game and career. Complete

connectivity through Wi-Fi was critical to the successful integration of Yinz-Cam and impacted the design and placement of antennas throughout the stadium. On opening day, thousands connected to Yinz-Cam through the Wi-Fi system.



Structural Challenges

As design began, Populous analyzed the site, choosing to orient the stadium north-south to allow for a visual connection to campus and to utilize prevailing winds to help cool the stadium concourses. A thorough wind study was con-

ducted and along with the sun study to understand where the sun would be strongest at various times of day, driving the design of the asymmetrical canopy to get at least 60 percent of the seats covered from the at times scorching Texas sun.

39 exterior steel columns, measuring 42" in diameter and 115' tall, combined with 39 interior columns are tasked with primarily supporting the sunshade canopy. The exterior columns act primarily in tension to counteract the 95' cantilever of the sunshade canopy, however, the columns also act in compression to address wind loading concerns that were evaluated during the wind study. The columns are major design elements of the building, mirroring some of the traditional Georgian architecture on campus and adding to the overall elegance of the structure.

Cast in place concrete portals provide a modern twist on the viewing porches across Baylor's campus. They were designed to look like shadow boxes, providing visual and physical connections back to the campus and the city of Waco. These portals were cast in place void slabs to reduce weight and help create sleek, smooth lines with integrally colored white concrete. In addition, sweeping, serrated walls – 38 in total, each 65' tall by 50' long – provide additional snapshot views of campus and help to combat the Texas heat by allowing wind to flow in and cool down the open concourse.

Just outside the stadium walls, the pedestrian bridge is the only physical connection to the main campus. Ultimately the design team settled on a plate girder structure spanning up to 150'. Bridge piers were added in the Brazos to meet the spans as well as provide an elegant structure to support the bridge.

The Future of McLane Stadium

Each of these components – the portals and columns, the bridge and the plazas – while challenging, were critical to

the stadium's success. They established a sense of place, character and an experience that will forever change Waco and on opening day, the site and stadium proved as successful as anticipated. Dozens of boats entered the harbor adjacent to the stadium by way of the Brazos River; the amphitheater was alive with hundreds of fans taking in the revelry of game day and scenic surroundings; hundreds of kayakers and paddleboarders pulled up to the flood wall to take it all in; and tens of thousands of fans crossed the pedestrian bridge from campus in green and gold to partake in new game day traditions – and a new future for the university and the city of Waco.

The stadium provided a memorable game day atmosphere – with a raucous crowd, incredible views of the campus and

riverfront and an energy that was palpable, but it was what was happening outside the stadium walls that was truly special. McLane Stadium, with its connectivity to campus and downtown, has become an authentic representation of Central Texas – of what the university, the city of Waco and the region will become and the experience that visitors, students and citizens alike can come to expect.



About the author... Jeff Spear, AIA, is a project architect and Principal with architecture firm Populous. During his more than 25 years with the firm, he has designed impactful sports stadiums and collegiate athletic

facilities, overseeing master planning, conceptual and schematic design, programming and design development for more than 15 stadiums. He has served as lead designer for iconic stadiums like McLane Stadium, Sporting Park, BBVA Compass Stadium, Gillette Stadium, M&T Bank Stadium and University of Phoenix Stadium. www.populous.com 

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CATAPULT CAPITALIZES ON GPS TECHNOLOGY

Long the bailiwick of civil engineering, GPS is now a valuable tool for enhancing athletes' performance

By Pete Geissler

The Steelers are one of at least 13--perhaps as many as 21-- NFL teams, and one of more than 400 soccer, basketball, and rugby teams worldwide that are competing at high levels that have embraced GPS with a high-tech twist. Its immediate primary purpose is to enhance players' preparation for performance; in the future, information derived from it could be used to help prevent injuries and accelerate rehabilitation.

The new technology, dubbed Catapult, is described by its developer, Australian company Catapult Sports, as "precision engineering at the intersection of sport science and analytics." Catapult is rapidly replacing motion-tracking cameras and super slo-mo video as the hi-tech way to analyze performance. It utilizes GPS to measure movements in athletes--speed, distance, direction, acceleration, articulation, force and so on--producing literally thousands of data points that can be used in thousands of ways.

In use, players wear, between their shoulder blades, Catapult's small, matchbook-sized, 3.5 ounce GPS sensor/transmitter, called OptimEye, during practice and when working out. Unlike other sports such as soccer and rugby, the NFL prohibits its use during football games. Data are transmitted to a computer that compares them to a benchmark for each player that was established earlier, when the player was rested and performing at maximum potential. Significant deviations from maximum raise a red flag for coaches and trainers.

Catapult verifies, with detailed data, answers to questions that trainers have known intuitively or sensed for years: How far do receivers and other position players run during a typical practice session? How fast does a running or defensive back run? How much impact can a body withstand? In short, what, specifically, do players do.

Players have embraced the technology; they correctly see it as a way to extend their careers and to perform at their best, which of course increases their earnings.

Typical, Generic Applications

1. Measuring distance and speed: Wide receivers and defensive backs typically run more than other players. Not long ago a trainer with another NFL team measured how far and fast a wide receiver ran intermittently during practice, and came up with 2000 yards at a maximum or burst speed of 18-19 miles per hour. The trainers also noted that

he ran slower as the number of yards increased, indicating fatigue and diminished performance. Coaches used the data to adjust this player's practice time and intensity to not overtax him and to help assure his optimum performance on game day.

Coaches and trainers can monitor total distance for each player for the day. Then they can measure high intensity running, which is typically defined as above 12--15 miles per hour, equate it with total distance, and adjust practice and playing time accordingly.

2. Measuring the force and frequency of collisions: Clearly there is a balance, on the one hand, between the number of collisions needed to adequately prepare players for the demands of the game and that are needed to improve skills and conditioning, and, on the other hand, the maximum number of collisions that the player can tolerate before the player is fatigued and performing at a lower level. Therefore, the number and force of collisions are measured during practice by accelerometers (not OptimEyes) mounted inside a football helmet; they report such data as time and location of impact and linear acceleration of the center of gravity of the player's head.

3. Adjusting practice and workout routines: Position coaches were able to equate poor performance of linemen on game day, as measured by low-acceleration outputs and force, to Thursday practices that featured high volumes of work at low intensities. The coaches decided that this was not the way to train 72 hours before a game and adjusted the practice routine to be less demanding. When strength and conditioning coaches found that some players were standing around for 80 percent of practice time, tightening backs and hamstrings, they encouraged coaches to keep the players moving, even at low intensities. And data from practice enables strength and conditioning coaches to define go-home workouts, helping players to train more efficiently.

4. Activating players after rehab: When a point guard playing for an NBA team was injured and rehabilitated, trainers attached an OptimEye to his jersey to be sure that he was performing up to his maximum potential before permitting him to play.

5. Planning the game itself: Using player-specific data, coaches can craft game plans and individual plays to maximize use of players who are performing their best, in turn

Catapult verifies, with detailed data, answers to questions that trainers have known intuitively or sensed for years

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More than 80 firms are represented in the Corporate Member program of the Engineers' Society of Western Pennsylvania (ESWP). Memberships are available at 3 levels: Gold, Silver and Bronze. Gold members are entitled to 14 memberships that can be exchanged by employees; Silver, 9; and Bronze, 5 — annual dues are \$2400, \$1700, and \$1000 respectively. In addition, ESWP Corporate Member Firms may add 2 additional individuals in our Under-35 age category at no additional cost. More information can be found at eswp.com. Please contact the ESWP Office (412-261-0710) for additional details.

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maximizing the performance of the team. And, because they know what to expect in the way of drop-offs in performance as the game progresses, they can adjust plans accordingly.

GPS technology is highly versatile and useful, and it promises to be more so. Catapult is an infant that is rapidly becoming an adult; trainers and coaches are still discovering new ways to use the mountains of data that Catapult generates. Perhaps Catapult's evolution can be compared to the evolution of the Internet, which grew in a few years from a cumbersome curiosity to an everyday necessity for many of us. Catapult could grow as rapidly and be as far-reaching and impactful within the world of competitive sports

The author wishes to acknowledge and thank Garrett Giemont and Marcel Pastor, the Steelers' Strength and Conditioning Coaches, for their contributions to this article. For more, visit www.catapultsports.com **PE**

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Players Get a Kick Out of High-tech World Cup Soccer Ball

All eyes were on Brazil this summer as soccer clubs throughout the world converged there for the 2014 World Cup®. While rooting on their favorite team, fans in the stands or glued to their TVs likely did not realize the high-tech engineering behind the "Brazuca"® – the official match ball.

The "Brazuca" from adidas® has its roots in tradition with a decidedly modern spin. The ball's structure begins with an air-filled latex bladder. This is covered with a textile fabric that serves as a substrate for the outer layers. The five outer layers are based on polyurethane raw materials that ensure optimal ball contact and prevent any moisture absorption. They are also responsible for the fact that the shape and appearance of the ball are retained for a long period of time.

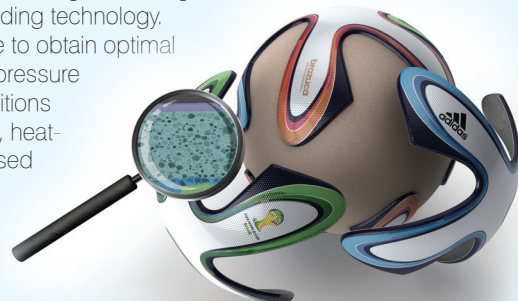
The innermost layer of the skin is an adhesion coating that connects the textile substrate to the layers above. On top of this is a polyurethane foam layer, roughly 1 mm thick, made up of millions of gas-filled microspheres. This foam is highly elastic so that the ball, after being deformed from being kicked, immediately returns to its spherical shape to ensure an optimal trajectory.

The outer skin comprises three compact layers of polyurethane with different thicknesses. These layers are responsible for the outstanding resistance to external influences and abrasion, and for the ball's high elasticity. They also help preserve its unique appearance.

While the surface of conventional soccer balls consist of 12, 16 or 32 panels, the "Brazuca" is made of six identically shaped panels creating perfect symmetry. Greatly reducing the number of panels translates into fewer seams making the ball more durable and resistant to the elements. Players like fewer panels for another reason: fewer elements mean better ball control.

The six panels are bonded together using a patented thermobonding technology. Manufacturers are able to obtain optimal results under defined pressure and temperature conditions and with an advanced, heat-activated adhesive based on Dispercoll® U, a polyurethane dispersion technology raw material from Bayer MaterialScience.

The "Brazuca" is the most tested ball in adidas' history and not only meets the demands



of players, but it also exceeded all standards set by the international governing body of soccer. Although the World Cup has ended, the "Brazuca" will continue to be in play in the Champions League and other top divisions. The next time you watch, you will know the secrets behind the ball.



Dallas Cowboys Stadium Ensures Everything Stays

BIG IN TEXAS

Complex steel fabrication project requires unprecedented team effort

Many people have probably heard – and even used – the phrase, “Everything’s bigger in Texas.” This was the case for the construction of the new \$1.1 billion Dallas Cowboys retractable roof stadium – an icon of a structure which hundreds of thousands of fans across the country expected to be bigger, better and more beautiful than any National Football League (NFL) stadium.

These expectations meant enormous pressure on the teams involved with the build, including the need to finish the massive project prior to the 2009 home opener against the New York Giants.

Ground broke in April 2006 for the stadium, which featured design elements such as the familiar blue and silver color scheme, the infamous star and a retractable roof like their previous stadium, Texas Stadium. These aesthetic elements needed to last long term and require little maintenance.

HKS, Inc. from Dallas was selected as the project architect, alongside Blue Star Land LP – the developer on the project, owned by the Dallas Cowboys owner Jerry Jones. HKS was tasked with the responsibility to deliver upon these design requirements coupled with ensuring the stadium held long-term curb appeal. Oklahoma-based Manhattan Construction was selected as the general contractor. W&W Steel from Oklahoma City and Prospect Steel from Little Rock were chosen as the steel fabricators for the project. The lead structural engineer was Texas-based Walter P. Moore.

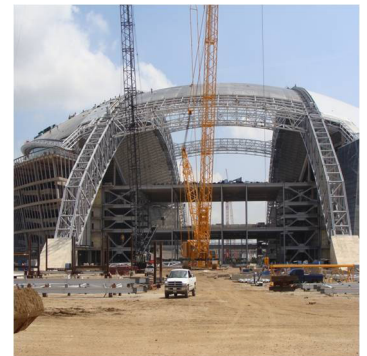
Go Big or Go Home

The design of the stadium comprised 15,000 tons of structural steel, which included two arches that peaked almost 300 feet above the playing field. The arches, each weighing 3,200 tons, supported the retractable roof measuring nearly 661,000 square feet. More than 50,000 bolts were needed to construct a single arch.

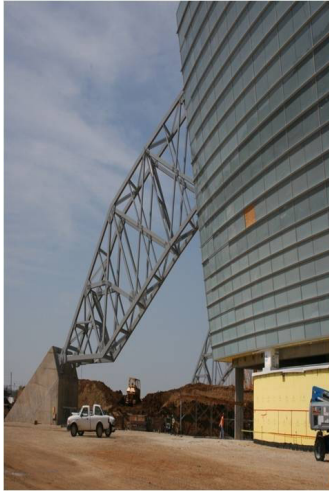
With the arches and the retractable roof elements, the Dallas Cowboys’ new stadium would be the largest single-span roof structure in the world at the time of its build. In addition to setting this world record, it would also be the largest and steepest domed structure in the world, with a two-panel retractable roof that could open in no more than 12 minutes.

It would also have the largest operable glass doors measuring 180-feet wide and 120-feet high with five movable, overlapping panels, each weighing 115,000 lbs. For the structure of the stadium, wide flange beams sizes up to W14 X 730, weighing 730 lbs per foot, were used – the heaviest structural steel shape rolled in the world.

“The size of this project didn’t even get close to outweighing how prestigious it was to be a part of building the new



Dallas Cowboys stadium,” said Earl Baker, corrosion specification specialist, Sherwin-Williams Protective and Marine Coatings. “We knew it was imperative that, whatever coatings were supplied, they lasted long-term to make this stadium an icon of sports for years to come.”



Finding the Perfect Match

Finding the perfect color to match the team’s iconic blue and silver was a key factor in the coatings selection for this project. After reviewing hundreds of colors, a light gray was chosen for the arches of the stadium in a coating that would ensure consistent color and gloss.

However, color wasn’t the only factor taken into account when determining the proper coatings system for the project.

Selecting the most appropriate system for the stadium’s structural steel package meant finding products that would provide maximum aesthetic properties while addressing the production schedule and other field issues, such as Texas’ summertime heat that often brought steel temperatures up to a scorching 135 F.

As such, the coatings system would need to provide superior color and gloss retention, corrosion resistance, rapid cure for steel throughput and scheduling, damage resistance for transporting the steel from the fabrication shop to the stadium site, and the ability to be touched up easily once it had been transported to the construction site.

“The Cowboys stadium was described as a complex project,” said Baker. “Its design featured many angles, bolts, welds and other edges at which corrosion would be more apt to form. An edge-retentive coating would be necessary for the project. The light gray selected for the stadium would show even the tiniest amount of corrosion, taking away from its aesthetic appeal.”

In addition, with a stadium so visible to the public eye, it was important that the coatings color would not fade from long-term exposure to damaging UV rays. Finally, the coatings would need to provide resistance against abrasion and scratches during transport from the steel fabrication shop to Dallas for the build.

HKS asked the fabricators to write the specifications for the coatings and place them into their bids. W&W Steel chose a two-part coating system that would ensure quick cure alongside a durable, attractive finish – Sherwin-Williams’ Macropoxy 646 Epoxy and FastClad Urethane. This was approved as the official system for the project.

Macropoxy 646 Fast Cure Epoxy is a high solids, fast drying epoxy coating designed to protect steel in industrial exposures. It is ideal for fabrication shop applications. Its high solids content ensures adequate coverage of sharp edges,

corners and welds in just one coat. Because it is available in a wide range of colors through tinting, it was also an ideal choice for this unique application. Its fast-cure qualities meant the steel would be ready to handle in as little as four hours in temperatures of 77 F and two hours in temperatures of 100 F. Additionally, the coating has high abrasion resistance, making it a perfect fit for the steel when it would be transported to the construction site.

FastClad Urethane is a fast dry, single coat, polyaspartic urethane, specifically formulated for accelerated painting. It allows entire coating systems to be completed in one shift with a high film build achieved in one coat. The coating is ideal for use on projects that require rapid return to service and is most often used in high-performance architectural applications. It, too, came in a wide range of colors.

“The combination of these two coatings delivered the edge-retentive qualities, high color and gloss retention, and UV ray protection critical to completing the job,” said Randy Kerans, marketing director for Light Industrial Segments, Sherwin-Williams Protective and Marine Coatings. “It was the ideal combination, as these coatings, when used together, would protect the stadium from corrosion while maintaining the stadium’s high-quality appeal.”

The slip-critical steel connections for the stadium structure were designed by W&W Steel. These connections were coated with Sherwin-Williams’ Zinc Clad III HS 100 in the



fabrication shop, then brought to the construction site to be erected.

Zinc Clad III HS 100 is a three-component, polyamide epoxy, zinc-rich coating. It has a low VOC level and contains 90.3 percent by weight of zinc dust pigment in its dry film. The coating meets Class B requirements for slip coefficient and creep resistance, an important element in making sure the stadium was structurally sound. In addition, the coating provides cathodic protection on steel through its sacrificial and self-healing properties. If the steel were to get scratched or damaged in transport, the zinc coating would heal itself, re-filling the scratch or abrasion and lessening the need for ongoing maintenance.

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"The performance of the Zinc Clad III HS was crucial because connections were designed as slip critical," said Warren Stickrod, senior project manager, W&W Steel. "That's a very good primer that we've had a lot of success with."

Once in place, the connections were top-coated with the same Fast Clad Urethane used in the heavy structural pieces. But with the summer heat at full blast, the team faced some challenges touching up coatings on site. These weather conditions brought the pot life of a coating from what would ordinarily be 45 minutes to a small 15-minute window. Teams had to work quickly and efficiently in the heat to ensure no coatings were wasted.

"Despite the Texas heat, the quick cure time of Fast Clad means onsite crews were able to better identify windows in which the weather would cooperate and quickly complete a topcoat cure before it got too hot," said Kerans.

In addition, with tens of thousands of bolts on each arch, touch-up coating was a significant part of this project. Touch-ups on the archways required the service of nearly 30 painters and 200 W&W Steel personnel at the site. Additionally, at more than 730 pounds per foot, the steel used in truss and arch assembly made onsite coatings work necessary, especially when it came to touch-ups. This was because many of the connections were so large, they had to be coated onsite; whereas smaller connections may

have been able to be done at a fabrication shop.

No Small Feat

After being coated in the steel fabrication shops, steel began arriving to the construction site by the truckload – some structural pieces were so large, they took up an entire load on their own. Once the steel was on site, the arches were assembled and erected section by section. A series of trusses were assembled on the ground, then secured in the air and attached to the arches.

After the erection of the stadium structure, the steel was touched up by 40 painters over a two-and-a-half-year period. During this time, the 50,000 bolts on each arch were coated. Sherwin-Williams' customer service team trained the onsite painting staff to ensure the bolts would match the steel coated in the fabricator shop perfectly.

The stadium was completed in May 2009, well in time for pre-season football to begin in the fall and ready to mark the team's 50th anniversary in the NFL. With a capacity of 80,000 people that can expand to nearly 100,000, the Dallas Cowboys stadium, now known as AT&T Stadium, continues to be a spectacular venue for football fans nationwide.

Special thanks to Sherwin-Williams Protective and Marine Coatings for providing this case study to the readers of Pittsburgh ENGINEER. 

Use of Technology in Concussion Assessment and Management

By: Anthony P. Kontos, PhD; Kelly Pearce, PhD; Michael W. Collins, PhD

Introduction

Concussion is a heterogeneous injury that involves many different symptoms- such as headache, dizziness, nausea, fogginess, irritability, sleep difficulties, and attentional concerns. The injury can result in a myriad of impairments across multiple domains, including cognitive, vestibular, oculomotor, and psychological. Consequently, no two concussions are alike. The individualized nature of the injury necessitates a comprehensive approach to assessment that can better inform the most effective and targeted treatments and rehabilitation strategies for patients. Such an approach involves an interdisciplinary team of health-care providers using multimodal tools that assess specific clinical subtypes of concussion such as cognitive-fatigue, vestibular, oculomotor and post-traumatic migraine. We recently published a paper outlining a model for comprehensive assessment and targeted approaches to treat concussion, which illustrates the heterogeneity of the injury and serves as a clinical guide for treatment providers (see Collins, Kontos, Reynolds, Murawski, & Fu, 2014).

It's More than Just Symptoms

Since concussions were first documented in ancient Rome and Greece, self-reported symptoms have been the primary source of information used to assess patients with this injury. In fact the use of symptom reports continues to be an important part of any clinical assessment of concussion. However, one of the problems in relying primarily on self-reported symptoms – especially in a population such as athletes – is that individuals may underreport or have poor insight into their symptoms. Researchers (Broglio et al., 2007) have documented lingering cognitive deficits in asymptomatic athletes following a concussion. In short, an individual who is asymptomatic may still be experiencing impairment associated with their injury, and should not return to normal cognitive and physical activity to avoid potentially worsening their injury. Consequently, more objective assessments for concussion were needed. One approach to assessing concussion that affords more objective data is computerized neurocognitive testing.

Computerized Neurocognitive Testing: Technology-based Objectivity

In the late 1990s, several neuropsychologists and other clinician-scientists began to develop computer-based neurocognitive tests for use with their concussed patients. Among those individuals, were Mark Lovell, PhD (CEO of ImPACT Applications, Inc.), Joseph Maroon, MD (Neurosurgeon at UPMC), and Michael Collins, PhD. (Executive

Director of UPMC's Concussion Program), who over the course of the late 1990s and early 2000s at Henry Ford Hospital in Detroit, MI and later at the University of Pittsburgh/UPMC, developed one of the first computerized neurocognitive tests- the Immediate Post-concussion Assessment and Cognitive Test (ImPACT)- for use specifically for quantifying the cognitive effects of concussion. The ImPACT test includes tests of verbal and visual memory, processing speed, reaction time, as well as symptom reports and demographic information (Figure 1). The use of this type of test afforded several advantages over the lengthy paper and pencil neuropsychological tests previously in use with concussed athletes including decreased cost, immediate availability of results, group administration, and

improved precision for time-sensitive tasks such as reaction time (e.g., Bauer, Iverson, Cernich, Binder, Ruff, & Nau- gle, 2012). The approach adopted by Lovell, Collins and Maroon was also unique in that they advocated for pre-injury or baseline testing, which allows clinicians to look at how a concussed patient performs on a series of cognitive



Figure 1. Sample neurocognitive test screens from the ImPACT test.

tests compared to their normal or baseline level of performance. This intra-individual approach is now a standard part of concussion care for millions of athletes at thousands of high schools, colleges and professional sports teams throughout the US and beyond. The ImPACT test is also supported by empirical evidence from nearly 200 peer-reviewed publications. Not long after the introduction of computerized neurocognitive testing and baseline assessments for use with concussion, several additional computerized neurocognitive tests were developed. Among the currently available tests in addition to ImPACT are AXON, CNS-Vital Signs, and CogState. One common thread among these tests is that they are all designed for use primarily with adults and adolescents. Current tests are limited to kids older than 11 or 12 years due to reading and other developmental limitations.

Younger (<12 year) kids present a unique challenge in the assessment and management of concussion, as they often lack insight about their symptoms and injury and can be an unreliable source of information. In fact, one of the

authors of this article remarked that his 9 year old often acts concussed on a daily basis. As a result, it is critical to obtain objective data to assess and monitor recovery from concussion in these younger patients. This is a place where technology has begun to play a key role, especially because today's kids are growing up in a world filled with iPads, cell phones, and constant access to technology. To that end, ImPACT Applications, LLC is currently piloting the first pediatric-specific computerized neurocognitive assessment for kids with concussion. This new, pediatric test will measure the same aspects as the full version of ImPACT, but will do so using visual based, videogame-like instructions and engaging tasks that will allow clinicians to more objectively assess concussion in kids as young as 5 year. Moving forward computerized neurocognitive tests will continue to evolve and embrace newer technology platforms that are more user-friendly and accessible including phone and iPad-based Apps that are age appropriate for children, adolescents, and adults alike.

Advances in Neuroimaging: Trying to “See” Concussion

The use of technology in the assessment of concussion also extends to neuroimaging. Unlike a fracture—which is visible on X-ray—or a tumor—which is visible on a computerized tomography (CT) scan—concussion is not visible using conventional imaging methods such as CT or structural magnetic resonance imaging (MRI). In fact, currently there is no accepted clinical imaging protocol for patients with a concussion. The lack of an accepted clinical imaging protocol is due in part to the fact that concussions may involve both metabolic injury – think “energy crisis”, where supply is exceeded by demand – and damage to axons and neurons. As a result, the brain's connections and ability to perform tasks- such as cognitive tests or maintain balance- are impaired. However, concussions are subtle in their presentation of this damage, making it challenging to “see” this injury using current neuroimaging techniques. As a result, concussion has been referred to as a “functional injury” that is measured using functional outcomes such as symptoms, as well as cognitive, vestibular, oculomotor and other impairments.

However, any functional impairment related to concussion should indirectly reflect the underlying changes in the brain discussed previously. These changes in the brain should be detectable using imaging. The problem is, we need a better “camera” to take a better “picture” of the injured brain following a concussion. Two recently developed imaging tools



Figure 2. The BNA analysis involves collecting EEG data during the performance of cognitive tasks.

that have shown promise in providing a better “picture” of the injured brain following concussion are: 1) brain network activation (BNA) analysis- which uses neurophysiological data collected during a cognitive task to map electrical connections in the brain (Figure 2), and 2) high-definition fiber tracking (HDFT) – which uses MRI technology to show damage to specific tracks of white matter fiber, where axons reside, within the brain (Figure 3). Our research team in the Concussion Research Lab at the University of Pittsburgh recently conducted a research project with EIMindA, Ltd (Tel Aviv, Israel) using BNA



Figure 3. HDFT image showing the different tracks of white fiber in the brain.

in concussed patients and healthy controls. Our preliminary findings indicate that the BNA analysis is useful in showing how the concussed brain is less activated (i.e., “connected”) during cognitive tasks than the non-concussed brain. We also found that individuals with post-traumatic migraine after a concussion, which results in worse outcomes, had even less activation than patients with less severe concussions. The BNA technology may help to identify patients with concussion and track brain network recovery following injury.

Our research team in the Department of Orthopaedic Surgery along with collaborators from Psychology and Neurosurgery at the University of Pittsburgh were recently awarded two grants to study the effectiveness of HDFT imaging (developed by Walt Schneider, PhD- Professor of Psychology and colleagues at the University of Pittsburgh) for concussions in both military and sport populations. The military study, which was funded by the Department of Defense, focuses on comparing HDFT and clinical findings to see if they match up. For example, in an individual with damage to the word memory fiber track as shown on HDFT imaging, we would expect that they would also perform poorly on verbal memory tasks on the ImPACT test. In the sports study, which was funded by the National Football League (NFL) and General Electric (GE) as part of the NFL-GE Head Health Challenge, we will determine if we can “see” damage in the brain's fiber tracks on HDFT immediately following a sports concussion in youth and young adult athletes. We will also determine if the damaged tracks will “repair” by the time athletes are medically cleared to return to their sport. The use of new imaging technologies such as BNA and HDFT may augment our current approaches to assessing concussion, and provide a better “picture” of the changes in the brain that accompany a concussion.

Measuring Impact Forces to the Head

Another area in which technology is playing a key role in understanding concussion is in the assessment of the

head impact accelerations experienced by athletes who play concussion risk sports such as football and ice hockey. Concussions are the result of linear and/or angular (i.e., rotational) biomechanical forces acting on the skull and brain. An example of a linear force is when two football players collide head-on helmet-to-helmet. An ice hockey player being checked from the side such that the player's skull and brain

rotate rapidly is an example of a rotational injury. During the past two years, we partnered with Bauer Performance Sports, Inc. on a research study to examine the nature and effects of linear and rotational head impact accelerations among male and female youth ice hockey players.

The players' helmets in our study were equipped with an accelerometer that wirelessly streamed head acceleration data to a smartphone App on the bench (Figure 4). Our preliminary data suggest that on average players experienced relatively minor linear and rotational impact accelerations to the head when playing ice hockey. We also found that on average older (15-18 years) players and males experience higher accelerations per impact than younger (11-14 years) players and females. In addition, we found no support for cumulative effects of impacts across a season.



Figure 4. Helmet accelerometers and wireless data system used in a recent study of linear and rotational head accelerations in youth ice hockey players.

the accelerations affecting the skull and brain, we can better understand the mechanics behind this injury.

About the authors...

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Conclusion

Moving forward, technology will continue play a key role in shaping the way in which we assess and treat concussion. Given the heterogeneous nature and comprehensive approach needed to assess this injury, advances in areas such as computerized neurocognitive testing and neuroimaging assessments will continue to shape and advance the clinical care of patients with concussion. Although concussions can never be fully prevented, by learning more about



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So, You're Building a Field?

By: James T. Sauer, RLA

Recreation development especially sports fields are many times an afterthought to the project and thus they turn out as such. Sports fields are a tricky subject. It is just a field of grass or synthetic turf or so we think. This field of grass or synthetic turf will have more sets of eyes on it than most buildings ever will. More people will examine this 80,000-100,000sf area than any parking lot, grading plan, or commercial development. Every uneven spot, irregularity, and settlement will be looked upon with great anger from many people. Mistakes will get blown out of proportion and the most minor issue to you will be a major issue to the coach. You will have people compare your smaller budget project against professional fields that they have seen and expect the same results. This is what you have with sports field, so you have to prepare for this and have the right team of people to work with you on this project.

There is more to sports field design than just a great stormwater/grading engineer. That will get you the permits, but that is it. First item is a team leader who understands and can relate to the sports staff, players, and community. I like to say that fifty percent of a sports venue is happening off the field of play. Sports are about the athletes and the spectators. Many people in the smaller venues forget about this, but trust me the Division One colleges and professional organizations understand this perfectly. A successful field needs to showcase the team while making the environment appealing for people to enjoy themselves and wish to come back again. You will always get the parents of the athletes, but they rotate every 3 to 4 years and this is not enough attendance to get return revenue on your investment. It is not even enough to make this an exciting crowd for the players. Entrances, seating, plazas, and restrooms all combine together to make a great field and exciting venue. No one sits for the total game on smaller level sports. It is a community thing, a tight network of people, and this event is a social event as well as a game. Areas to move around in, congregate, and talk while watching the game will be one of the most important items to plan in your sports complex. A good team leader with experience in sports field will help guide you through this. He will talk the same language as the coaches and athletic directors and allow their visions to be worked into the field and complex. He will insure your focus is on the total game experience for the spectators and players alike.

Building a sports field has many variables which your

team leader must check off. Type of field is one of the first. Synthetic Turf or Natural Grass. Natural grass is an excellent surface, if managed and programmed correctly, it can be the best surface for almost every sport. Synthetic turf is a great surface; it provides an almost all weather and all-purpose field. However, each has their advantages and limitations.

Natural Grass:

Natural Grass fields when managed and maintained correctly will have a low G-Max rating (an ASTM test which gravitation force units are measured using a specific instrument which uses a 20lb weight dropped 24 inches from ground for impact testing), equal surface to air heat index, and a surface which will provide peak performance. When selecting Natural Grass, you need to know how many seasons and sports they will be proposing for this. The old stadium reserved for Friday night, is not so common anymore. So you will need to know what your impacts will be. Successful natural grass fields prefer a growing season with no play on it, to recover the root system and allow for successful reseeding. A growing season is Spring or Fall. So you try and have the field programmed for minimum activity during one of these seasons. The natural grass field will require a regular maintenance and fertilization package in order to provide that dark green look and thick coverage over the field. In addition, it is normally accompanied with a sprinkler and drainage system to maximize growth and maintain healthy root temperatures during the summer.

When you start your design, a soil survey for infiltration is recommended for natural grass. With the infiltration rates you will be able to space your underdrainage system and

determine your soil modification for topsoil and subsoil to achieve optimal drainage. The engineer can use the ellipse equation to aid in the calculation of underdrainage spacing. However a standard spacing is going to be 10-15 feet for saturated fields and 20-25 feet of spacing for adequately



Turf trenching for natural grass field underdrains

draining a field. Fields with high sand values within soils may require little to no drainage at all. I prefer the field drainage for natural grass field to be similar in style to the older field tiles used in agriculture. The field drainage is spaced per existing conditions and the sub-soil sloped with a slightly higher percentage than the final topsoil. The drainage is a 4" circular pipe is set in 12"x12" boxes of

AASHTO 57 stone with fabric placed only in the sides and bottom of the trench. The pipes are run at 0.35% minimum percent slope and are taken to a collector drain system which ranges from 8" to 15" in size and normally flows at a minimum of 0.5% slope. With this set up you have a good drainage base to start from. Your sprinkler systems are run parallel to the underdrains to avoid crossing trenches as much as possible and place the heads in the gaps between drainage rows. You topsoil is added with about 40-50 tons of sand, (refer to your geotechnical report to determine how much infiltration your soils have). This is placed at a 1.5% slope minimum and 2.0% slope maximum for optimal playing conditions. If you can place your topsoil and allow it to sit, for

a rain fall or two and dry before you seed it is recommended. Rolling the field followed with aeration can be done after the turf is fully established to help level the turf,

but if aeration is not performed the compaction will ultimately stunt your future turf growth. If you are using sod, make sure you develop your sub-soil with organics and sand. Sod is a great way to achieve immediate green, but it is not an instant surface as you must water and have the correct fertilized subsoil for the root system to grow into. Either seed or sod, talk to a specialist at the location you are specifying your seed mix from, a good sports field mixture is not the same seed you use in your backyard. A correctly graded Natural Grass field will provide surface flow of water in combination with infiltration and sub-surface drains. However, after the field is built, that is when the work begins. Correct irrigation, fertilization, aeration, seeding repair, and programing is needed. With that, you will have the best surface possible.

BEFORE



AFTER



Synthetic Turf:

To many schools, do not have the staff, money, or even desire to manage a natural grass field properly. Successful natural grass fields require training, effort, weekly up-keep, and can, pending the level of play, be very costly to continuously add sand, sod, and repair. This is where synthetic turf has its market. Synthetic Turf can provide the school with a professional looking field which is available for multiple sports over all four seasons of

play. However, there are draw backs to this product too. Synthetic Turf has a life span. At the end of its use, it cannot be extended with a bag of seed and staying off of it for a year. Pending use, in an 8 to 12 year time span the turf will break down and need replaced. As the turf breaks down, it loses its fibers and durability of the fibers which remain. The field begins to climb the G-Max scale and eventually can become unplayable. (Don't jump to conclusion yet, as a natural field with no grass and only compacted dirt will also exceed G-Max safety ratings.) At this time it will be

very costly for the school to replace the turf. So if the school raised a once in a lifetime amount, synthetic turf may not be the best selection as it has an 8-12 year timer which at its end will require another +/- \$350-\$400,000.00 financial injection. If the school is prepared for it, then a turf field will require design and drainage much different than natural grass fields. A turf field should be looked at for stability and permeability as this surface will be judged by your local officials much differently.

BEFORE



AFTER



The synthetic turf surface requires in most communities a geo-technical report for infiltration. It is recommended during this time either a test dig is conducted or you re-

quest your geotechnical engineer to give you their recommendation for this soil in its use for heavy highway. There will average a minimum of 3,200 cubic yards of soil re-

moved from the field and 2,500 tons of stone placed on this field so you must have a surface which can handle this weight and still provide a 0.5% slope at the end of the day without any sags. In addition to this, your local municipalities will want to know what your infiltration rates are for the field as that will determine many times the depth of aggregate which is placed on the fields as the environmental review will want to have opportunities to store water within the field for a given period of time for ground water infiltration opportunities. The field's design is typically a 0.5% cross slope on the sub-surface

...if the school raised a once in a lifetime amount, synthetic turf may not be the best selection as it has a timer which at its end will require another \$350-\$400,000 financial injection

of the field with 6 inch aggregate storage and stability layer with your turf carpet placed on top of the aggregate surface. For higher level fields, a 0.75% to 1.0% slope can be placed on the subsurface with a 0.5% slope finish stone providing better sub-surface drainage rates, but this method requires a good quantity of extra stone and will up your field cost by +/- \$35-\$40,000.00. Your turf fields generally use a 1"x12" flat panel drain laid flat on geo-textile fabric on subsoil. This is spaced in a pattern to the ultimate outfall. This drainage only helps aid the water movement and it is the stone and sub-surface slope which the water primarily flows through. This is why grading of the field is so important as it cannot be mended through stone. Finally, the stone of the field must be selected so it interlocks and provides fluid drainage. Many turf companies will try and have the designer lock the field up with tons of sand as it makes installation of the turf very easy. I don't recommend this, as it defeats the purpose of a free flowing field. Work with the turf providers to review mixtures of fine stone with little amounts of sand keeping the 100s and 200s at a couple percent maximum. Finally, learn a little about synthetic turf and at least what monofilament and slit film are. This will allow you to aid in the turf selection to match the project and not just what the turf provider is trying to pitch that week.

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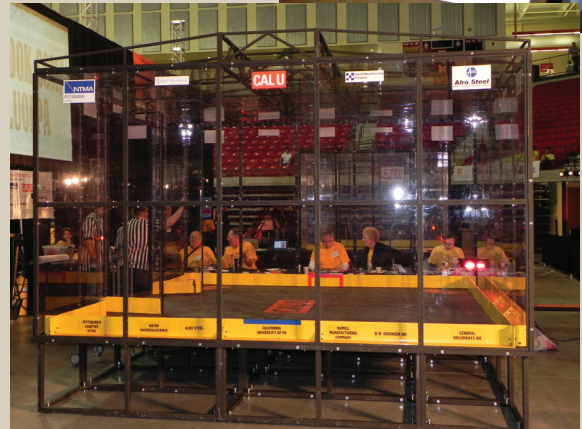


POLYCARBONATE SHEET ENGINEERED TO KEEP SPECTATORS SAFE DURING ROBOT COMPETITION

A robot competition sounds friendly enough, but these "bots" weren't programmed to play nice, and the only thing standing between them and a room full of spectators was tough and durable plastic sheet.

The robots were designed and built by high school students to battle in a gladiator-style arena as part of the Southwestern Pennsylvania BotsIQ program. This educational robotics competition provides students with a unique and fun way to explore the possibilities of a career in the science, technology, engineering or math (STEM) fields.

Roughly 800 students representing 51 schools participated in this year's program. The growing participation, coupled with more advanced robots, called for an arena that could withstand wear and tear without sacrificing clarity. The solution was polycarbonate sheet donated by Bayer MaterialScience. Strong,



lightweight, transparent and impact resistant, polycarbonate sheet is a versatile material widely used in the signage, architectural, security, transportation, industrial and recreational markets.

The type of plastic sheet donated by Bayer was a good fit for this particular application: it is virtually unbreakable and has an excellent hard coat to protect against abrasions and scratching that could cloud spectators' views.

The new arena debuted April 25 during a two-day finals competition at California University of Pennsylvania. Weighing no more than 15 pounds, the bots proved to be scrappy and fast competitors. The half-inch-thick plastic walls and ceiling formed a transparent cage (connected together with steel supports), allowing spectators to witness the action without fear of being hit with flying debris.

Similar grades of polycarbonate sheet have been featured in a number of high-profile sports venues across the globe — including the Estadio Nacional stadium, one of the sites for this year's World Cup in Brazil. You can be sure that whether contestants are striving for a gold medal, World Cup trophy or robot superiority, you'll find polycarbonate sheet in the thick of the action.



Engineering SPECTATOR SAFETY

By Toby Sargant, CEng and Don Nusser, PE, PP, ENV SP

Setting the Field

Sports stadiums are complex, multifunctional buildings that must provide a venue allowing tens of thousands of people to gather and watch ball games, concert events, and other mega-programs in an atmosphere of fun and safety. We often marvel at the complex engineering and architectural designs that are aesthetic, provide “views of the field” from all locations and angles, and also satisfy the attendees’ needs for comfort, convenience, unimpeded movement, quick access to food and beverage, and other human necessities.

However, it is unlikely that, as a spectator enters a stadium

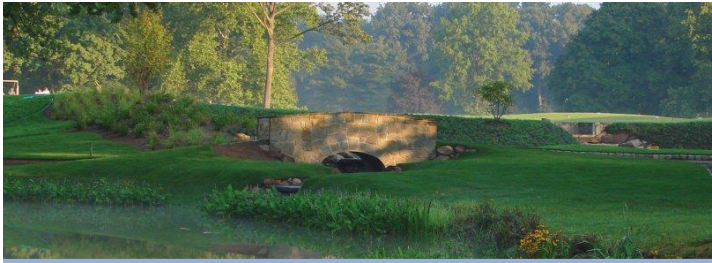
*...it is unlikely that as a spectator enters
a stadium the millions of calculations
that went into the stadium design are on
his or her mind...*

and moves through security screening and food lines, and proceeds to the seating areas, the millions of calculations that went into the stadium design are on his or her mind. In fact, by the time the fans arrive at their seats, they will most likely have already traversed pedestrian flow routes that were analyzed extensively, some using 3D computer modeling techniques.

Computer modeling techniques are frequently used to evaluate the crowd during entrance and exit events and especially during emergency evacuations. The design of stadium elements such as entry turnstiles, doorways, and stairways, and operational elements such as the crowd management techniques employed by ushers and police, all need to be considered singularly, but more importantly as one cohesive crowd management system.

What happens when crowd management systems fail was tragically illustrated in the 1989 Hillsborough disaster in the UK, when 96 spectators were crushed to death at a soccer match. A lack of sufficient entrance capacity resulted in the police opening gates just before the match kickoff, which created a surge of spectators into a standing terrace that was fully enclosed by fencing, resulting in a fatal crush. The disaster has had a deep impact on safety standards for stadia in the UK, including the elimination of perimeter and lateral fencing and the removal of standing terraces at all major soccer stadia.

Crowd modeling is not just for preventing such catastrophes. From a financial perspective, operators seek to maximize the revenue generated by the stadium, with gift shops and food concessions that require free and easy access. Many stadiums frequently host non-sporting events such as music concerts, trade fairs, and seminars, each with its



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own unique usage profile, and whose crowds are frequently larger than sporting events due to additional seating on the field.

The Rules

The complex and unique environment of sports arenas, parks, and stadiums has produced significant worldwide research exploring how to understand and manage crowds. This information is used in various ways around the world. Currently in North America, regulations governing stadium design conform to a mixture of codes, including the International Building Code (IBC), National Fire Protection Association (NFPA), and local building codes. These codes contain overall design guidance aimed generally at all buildings, but do not specifically provide details for assessment of crowd movements at sporting events.

The NFPA has allowed the use of crowd modeling to justify the implementation of performance-based approaches to fire safety designs. Crowd modeling techniques provide design validation information, graphically demonstrating that performance-based designs satisfy the intentions of the relevant code. These techniques can not only improve the stadium's performance in the event of an emergency, but also produce cost savings during construction.

Outside the US, agencies and governments have created specific codes and standards dedicated to sporting grounds. The "Guide to Safety at Sports Grounds," created by the Department for Culture, Media and Sport in the UK, also known as "The Green Guide," provides detailed guid-

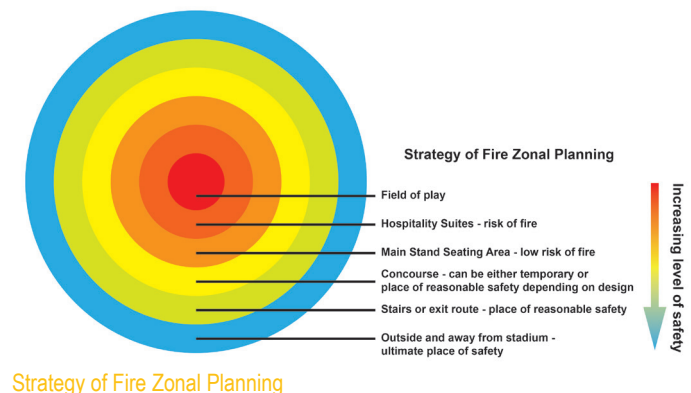
ance ranging from capacity calculations and crowd movement guidelines to medical and media requirements.

The Green Guide considers the time of leaving the sports ground as a period of great risk, defining both an "egress time" and an emergency "evacuation time". The egress time is defined as the time taken in normal conditions for all the spectators to be able to leave the viewing area and enter a "free flowing exit system", normally equaling a maximum time of eight minutes. The emergency evacuation time is defined the time taken to get "a place of safety or reasonable safety" from the viewing area in the event of an emergency, which can vary between two and a half and eight minutes. Neither represents the time take to exit the stadium entirely.

Where the place of "reasonable safety" is located depends on the overall design concept of the stadium. It should be safe from the effects of fire, from where occupants can make their way to a place of ultimate safety. If a concourse area has sufficient safety systems in place, such as shutters on concession stands and sprinklers, or other performance based measures providing equivalent safety to the prescriptive recommendations, then this can be designated a place of "reasonable safety".

People should not be held in this place of "reasonable safety" for a prolonged period of time, since "crowd impatience" sets in after eight minutes of queuing. There should be perceived movement towards exits with slowing or stopping increasing the probability of panic, stampede and violence. From a fire engineering perspective, the exit route being taken should be moving along a route of increasing safety to a place of ultimate safety.

The "Strategy of Fire Zonal Planning" indicates the different zones that might exist in a stadium and their increasing levels of safety: note that some jurisdictions, sensibly, also see an open field of play as a place of relative safety.



Strategy of Fire Zonal Planning

Simulating a Win

Given the complexities inherent in the design and operation of a typical sports venue, how can 3D crowd modeling rise to the challenge of improving crowd safety?

The average sports stadium presents a very different set of circumstances compared to most other applications of crowd modeling such as in airports or even subway plat-

forms. No software or spreadsheet analysis can simulate fully every variable on display at a stadium. Partisanship and the influence of alcohol create situations that are impossible to program and thus difficult to model. Yet by

The average sports stadium presents a very different set of circumstances compared to most other applications of crowd modeling such as in airports or even subway platforms.

using modern tools to analyze crowd dynamics through the design process, engineers can help minimize the trigger factors that contribute to crowd unrest and the resulting disorderliness and potential stampeding.

Static spreadsheet analyses can provide basic information such as a maximum stadium capacity, the number of stairways required, the stairway widths, numbers of ticket gates, and so on. It is possible to calculate an approximate time taken for people to reach a place of reasonable safety, providing a good indication on a global level of how the overall system will perform.

However, 3D crowd dynamic computer modeling provides more powerful insights, highlighting issues such as areas with long periods of stationary masses of people, pinch-points, conflicting crowd flows, and other constrictions. It allows the testing of different crowd control measures, and it can also provide an indication of the experience of each individual in the crowd. A wide range of metric data detailing how each element of the system is performing can be produced for both the normal and emergency operations of the stadium. Engineers can test many scenarios quickly and effectively in the virtual environment.

How to Score Success

As with all simulations, it is critical to define the objectives of the analysis before any work is carried out. The objectives and analysis should be structured such that they can address the requirements of all the relevant codes and standards as well as provide more detail regarding flows as the owner and operator requires.

The analysis should be undertaken with reference to the

codes involved, and should be seen as the minimum test requirements. For the emergency evacuation scenario, calculations should concentrate on the following:

- Clearance time for the seating area to the associated place of reasonable safety
- Clearance time from that place of reasonable safety to ultimate safety
- Clearance time for any other areas
- Level of congestion on evacuation routes
- Ingress and egress calculations should consider:
- Time taken to traverse each level or element
- Queue lengths at each significant element and the associated queuing times
- Delays at concession stands, restrooms or other facilities
- The performance of turnstiles and exits

“Half time” pedestrian flows are somewhat different in nature, and do not represent mass movements into or out of the stadium. Instead they are characterized by people using restrooms, purchasing food, and using bars and other concessions. The codes do not outline clear guidance for such periods of flow. The analysis of these periods should consider the recording of queue lengths and delays at concessions and restrooms as well as the Level of Service (LOS) experienced by the individual in the simulation.

The term LOS is one widely used in pedestrian modeling with LOS calculations being a measure of the density of people categorized into bands ranging from the least dense (Level A) through to the most dense (Level F). The LOS bands are associated with different densities, walking speeds and flow rates, with different criteria being applied depending on the specific use of the area.

The Final Score

3D crowd modeling analyses can provide significant benefits in the design of a modern multipurpose stadium. Factors such as pinch-points and uneven usage of exits can be identified using such techniques, allowing for modifications in the design of a stadium or, in the case of existing facilities, area roping, signs, and/or posting of staff at key locations to guide and assist spectators.

In addition, when 3D pedestrian modeling is combined with the use of applicable codes such as the Green Guide and NFPA, a risk-based approach to fire engineering can be employed. This approach helps produce safer and more cost-effective stadium design compared to simply using equivalent prescriptive-based design methods. **PE**

About the authors...

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SPOTLIGHT ON...



ACE MENTOR PROGRAM
ARCHITECTURE CONSTRUCTION ENGINEERING

Make a Difference – Be a Mentor

By Jon O'Brien

Mentoring is the best gift a professional can give to their industry. In the construction industry, the ACE Mentor Program is an excellent organization for you to give your gift of knowledge to future professionals while demonstrating you are a future leader of your organization.

ACE – which is an acronym for Architecture, Construction & Engineering – unites professional volunteers and high school students, who may be interested in careers in design and construction. Founded in 1994, ACE is a partnership among industry professionals aiming to develop a new generation of talent. Since its launch in 1994, the program has grown to its current level of 64 affiliates covering 40 states and over 200 cities. The program runs annually in conjunction with the school calendar year and it is anticipated that over 8,000 students and 5,000 mentors will participate in ACE this year; amongst the participants 70% are minorities and 40% are female. Over its two decades of existence ACE has awarded over \$14 million in scholarships. As for our local affiliate, the Pittsburgh chapter was founded in 2006 and it attracts around fifty students a year from a half dozen high schools.

While the ACE Mentor Program is extremely valuable to the students, being a mentoring can be beneficial to the mentor

too. “I get involved with ACE because I want to help kids to get into the AEC industry. Plus it helps to remind me why I got into this industry in the first place,” said Anastasia Herk, Executive Director of the local ACE affiliate.

Some other ways the professional can benefit from being a mentor include building one’s leadership skills and improving communication abilities. The mentor steers the ship for one or more of the sixteen after school sessions each year so mentors will need to be able to motivate and encourage attendees and this can help someone become a better manager and team member. As for communication, because the mentees have various backgrounds and different education levels, you may find that you do not speak the same language and this may force you to analyze the material you deliver to assure it is communicated in a manner that is understood by all. This internal communication exercise will help you better understand your message and how to convey it in a way that is comprehended by others, which is an ability that could help you in your career when it comes to delivering presentations on you and your firm’s capabilities.

Additionally, mentors can benefit by learning new perspectives. At Jendoco Construction Corporation, a commercial

general contractor and real estate developer, they have been involved with the ACE program since its inception when the local chapter launched. Jendoco is supportive of the program because they feel it is making an impact on the future AEC industry. "Our original reason for supporting ACE was to inspire and mentor the next generation of leaders in our industry, but in time it has become a give-and-take mentoring process," said Michael Kuhn, President of Jendoco. "Jendoco employees have learned so much as the students have challenged our industry's current processes. Our company is better off due to our involvement in ACE and together, with the students, we all are shaping a better tomorrow for our industry."

While there many interpersonal reasons to be a mentor and encourage future generations to enter the AEC industry, perhaps the most gratifying reason is the students themselves. All of the hours volunteering to operate ACE and all the dollars donated to the program are well justified after receiving letters from the students, like this one from one of last year's scholarship recipients:



For the ACE hands on activities, the local union apprenticeship training centers host sessions. Seen in the photographs is a session last year being held at the Carpenters Training Center on framing.

"I am pleased to say that I will be attending Purdue University next year. I was accepted into the 'First Year Engineering' program. For the longest time I wanted to be an engineer so I could work on robotics and create new robotic technology to make things simpler. However, after joining ACE, I am not so sure if I want to continue down that route. My experience with ACE has sparked my interest in a mechanical engineering degree and possibly receiving a degree in business as well. I'm sure that the lessons I have learned at ACE will provide invaluable in my studies."

The local ACE affiliate receives help from associations, companies and individuals. This help comes in the form of professionals getting involved and committing to be a mentor or serving on a committee to improve the finances and/or operations of the program. The ACE chapter is fortunate to get assistance from generous volunteers but ACE could use more. If you feel your talents could be utilized by ACE please do not hesitate to contact them today to join your



Prior to each hands on session, the importance of safety in construction is discussed.

peers. "I believe in the mission of ACE. ACE provides a tremendous opportunity for high school students to understand the basic concepts in architecture, engineering and construction so that they can be better informed about their potential career in the construction industry," said Danny Cerrone, Senior Attorney, Clark Hill PLC.

For more information on the local ACE affiliate, and for contact information, visit www.acepittsburgh.org. Also for information on the overall program visit www.acementor.org.

About the author...

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