CAE IN SPORT – PERFORMANCE ENHANCEMENT WITHOUT DRUGS

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THEME

CAE in Sport, Technology in Sport's Performance, Ethics of Technology in Sport, Drugs in Sport

KEYWORDS

CFD Computational Fluid Dynamics, Structural Mechanics, CAD/PLM, CAE Industry Trends, Multiphysics, Simulation Driven Design, Product Manufacturing, Design Processes, Process time Compression, Future Sports Industry Needs, Visualization, HPC, Drugs in Sport

SUMMARY

The modern Sports & Leisure Products business sector is a $500bn globally expanding industry with some sports like motor racing, golf and soccer creating millionaires (and even billionaires) in their wake. It is no surprise then that with all this money associated with winning or being number one in the world in a given sport, all sorts of legal (and sometimes illegal) performance enhancement boosts are being sought by elite athletes and competitors at an ever increasing rate. Sadly, doping and drug abuse has over the last ten years thrown a long shadow over many sports and three letter acronyms for drugs such as EPO, THG, HGH and AAS have become very familiar as they dominate newspaper column inches and the lips of lawyers. However, some three letter acronyms familiar to engineers and technologists are having a positive impact on sport: CFD, CAE, CAD, HPC, SDM and PLM being a few. They have over the last decade become embedded in many sporting application areas and equipment design processes providing aerodynamic, hydrodynamic, structural, and customized multiphysics solutions for competitive advantage in sport (within the boundaries defined by Sporting Regulatory Bodies). Indeed, whole sub-industries of engineering applications have emerged in the last 20 years or so to deal with these specialist application areas and an International Sports Engineering Association (ISEA) has been formed to both support the community and standardize & regulate research and development efforts and practices.

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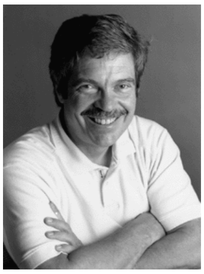
This paper will illustrate how CAE has evolved within the Sports & Leisure Industry over the last 20 years; how underlying technologies like CFD, structural mechanics, and other lesser-known techniques have become ensconced in design processes by way of appropriate CAE examples from the motor sports, water sports, and Olympic sports and equipment design areas. Sports equipment manufacturing design processes today are being time-compressed, enhanced and transformed by embracing modern rapidly-expanding CAE technologies and methodologies. Indeed, in the cauldrons of certain sports, like motor racing for instance, they are driving the CAE industry forward by their incessant demands for accurate, quick, leading edge, competitive and constantly innovative products and solutions. Finally, some future trends in Sports CAE usage will be offered for applications that involve elite competition, equipment manufacturing and training scenarios.



> ***"In sport, the convergence of digital technologies and computers, as well as improvements in biomaterials and medicine have revolutionised sports performance and it's continuing to do so. Ideas thought far fetched five years ago are now routine."***
>
> *Alan Kay, Pioneering Univ. of California Computer Science Professor*

GLOSSARY of Three Letter Acronym Terms used in this paper:

EPO: Erythropoietin, a hormone used for increasing red blood cells and oxygen uptake in blood

THG: Tetrahydrogestrinone, an anabolic steroid

HGH: Human growth hormone, a steroid for dwarfism

AAS: Anabolic-Androgenic Steroids, a collective name for steroids

CFD: Computational Fluid Dynamics

CAE: Computer-aided Engineering or mechanical design analysis

CAD: Computer-aided Design

HPC: High Performance Computing (covering distributed clusters, shared multicore and cloud computing platforms)

SDM: Simulation Data Management

PLM: Product Lifecycle Management

MBD: Multibody Dynamics

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1: Introduction

Whether it's wall-to-wall football on TV; commercials selling razor blades, clothes or beer; acres of tabloid newspaper speculation and incessant talk on the Radio; sport is ubiquitous in our modern digitally connected world. It has the capacity to inspire us, to shock us, to seduce us and ultimately even to entertain us. Over the last two decades an evolution has happened in sport with its move away from amateur roots to the world we see today of a cut-throat multibillion dollar industry invading every aspect of our lives. The ultra-professionalism we now see has brought with it new para-sport disciplines covering every facet of an elite athlete's nutritional, psychological, medical, biomechanical, and performance metric driven world.

In the last decade the amount of money being poured into elite sports in particular has hit staggering heights. English Premier League soccer players typically earn up to $300,000 per week these days (win, lose or draw) compared to equivalent players some 30 years ago who earned just $1,000 each week and only if they got their "win bonus". The German seven times Formula 1 Motor Racing World Champion, Michael Schumacher, a modern all-time great, is estimated to have earned well over $1,000,000,000 throughout his 15 year career from both his competitive racing and product endorsement activities, and the American golfer, Tiger Woods, exceeded him (until some unfortunate personal activities last year clipped his wings, curtailed his fortune and diminished his earning capacity somewhat). Sports like baseball, basketball, tennis, golf and boxing yield up to $40M/yr for their top performers. Big sporting events are also linked with big business opportunities, and the worldwide Sports & Leisure Industry is estimated to be worth something like US$500bn per year with the Olympics and the Soccer World Cup the biggest events on the planet. The Sports & Leisure Industry globally is as big as the Aerospace Industry and in the US alone, the Sports Industry is seven times bigger that the Movie Industry and twice as big as the Automotive Industry.

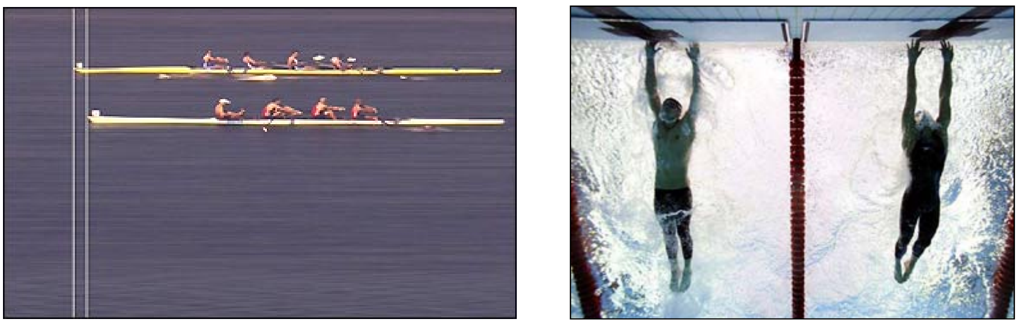

Figure 1: The Difference between Winning & Losing in Sport (2004 Olympics Men's Rowing Fours, 2008 Olympics 100m Butterfly)

It comes as no surprise then to learn that with victory in sport, and the ensuing adulation and money thrown at those at the top of their field, performance improvements measured in millimetres or milliseconds are highly prized. Increasingly therefore, modern engineering technologies have been embraced wholeheartedly by numerous sports in an elite athlete's or an elite team's quest for world championships, prestigious trophies or Olympic gold. Any legal, cost-effective technology that can lead to enhancements in personal performance or improved equipment design and functionality is being utilized. Indeed, as long as technology advances stay within the sometimes arcane boundaries afforded by the rules set down in some instances many decades ago by their governing bodies, these same rules can be taken up as design envelopes to be creatively explored by a growing band of professional sports technology engineers. In any sport the capacity to beat the opposition with innovative equipment design and radical new engineering solutions that help solve age-old problems only comes about through a greater understanding of the underlying physics and chemistry associated with that sport. One obvious area for improvement in many sports is the aerodynamics, hydrodynamics and structural integrity of sports equipment inherent within them and it is in the ruthless exploitation of new technologies in the pursuit of competitive advantage that is the driving force for engineering advances in those sports. The reader is referred to a number of papers in the References for more details on the applications and issues cited in this paper.

2: Drug Doping in Sport

Even in the ancient Greek Olympiads of over 2,000 years ago historians inform us that athletes were not averse to looking for any sort of competitive advantage to help them gain that winning edge by fair means or foul - Olympians would eat lizard meat, prepared in a special way, in the hope that it would give them an athletic edge! And although drug cheating was strongly suspected during the Cold War era of the 20th Century, particularly with East German athletes (subsequently proven to be true), it was not until the shock of the 100m men's race in Seoul in 1988 when the Canadian Champion and World Record Holder, Ben Johnson, had his gold medal stripped away from him and a ban imposed, that steroids in sport came under the media spotlight. Since then, a litany of elite athletes in a wide range of sports (Wikipedia, 2011) including champions like Marion Jones, Justin Gatlin, Barry Bonds, Floyd Landis, and Diego Maradona were caught cheating. Indeed, persistent suspicions remain over the performances of famous athletes such as Lance Armstrong (Cycling) and Michelle Smith (Swimming), not to mention some women's athletics world records that have survived for over 20 years. The pinnacle of cycling, the Tour de France, was thrown into disarray in 2007 such were the number of failed drug tests during the race.

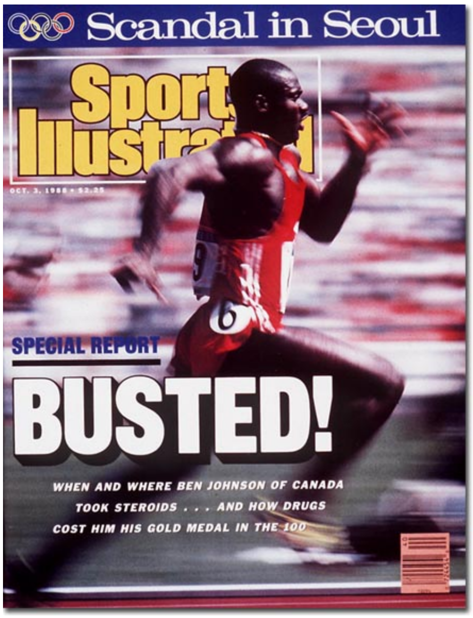

Figure 1: The Famous 1988 Sports Illustrated Seoul Olympic Magazine Cover

Three letter acronyms, such as EPO, THG, HGH and AAS, for performance enhancing drugs, and those of masking agents, do still pepper newspapers and media outlets when elite sports events are broadcast still. This paper aims to counter these negative three letter acronyms in sport to show how computer simulation techniques familiar to engineers and technologists are having a positive impact on sport: CFD, CAE, CAD, HPC, SDM and PLM being a few. Over the last decade these engineering simulation tools have become embedded into many sporting application areas and equipment design processes yielding significant aerodynamic, hydrodynamic, structural, and customized multiphysics solution enhancements for competitive advantage in various sports.

3: CAE (and particularly CFD) in Sport

As soon as computer-aided engineering and CFD became available in a usable industrial form to the engineering community, it was being used in competitive sport. Structural analysis, CFD, MBD and crash analysis CAE tools all have important applications in sport. Hulls and appendages in Americas Cup yachting (the richest sailing event in the world) were being designed by FEM methods in the 1980s, Formula 1 Motor Racing (the richest division of motor sport) started to use CFD and FEM in the early 1990s, Olympic Sports started to use CAE in the mid 1990s along with sporting & leisure equipment manufacturers in the same era. Basically, anywhere that a competitive advantage could be gained with a good ROI by the application of CAE was considered to be a legitimate application – wings, bodies, wheels, radiators, sails, intakes, exhausts, engines. Indeed, CAE has been used to elucidate much of the fundamental physics going on in sport.

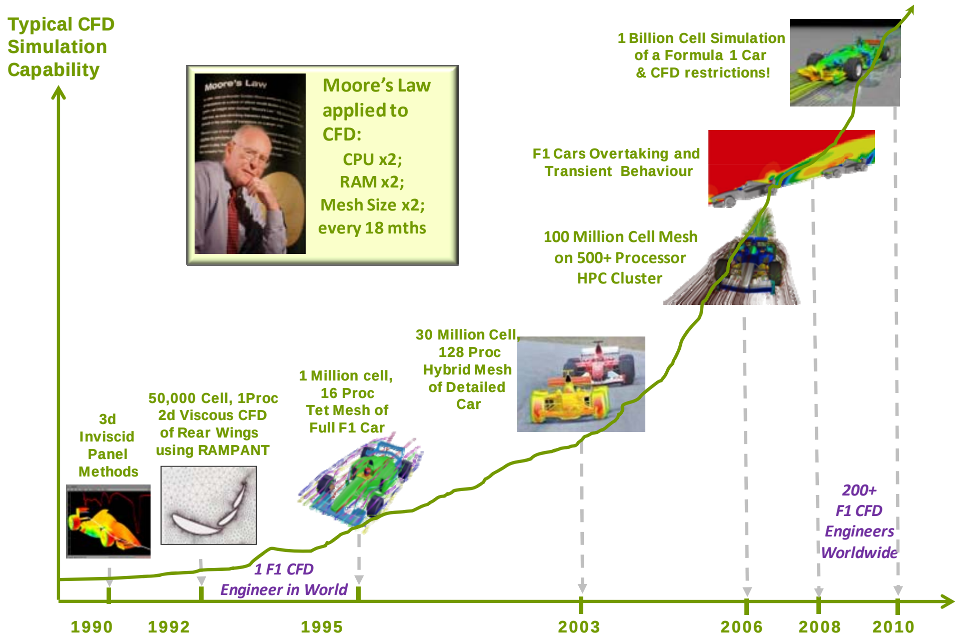

Figure 2: CFD has grown on the back of Hardware Advances – illustrated by Formula 1 Motor Racing CFD trends 1990 – 2010

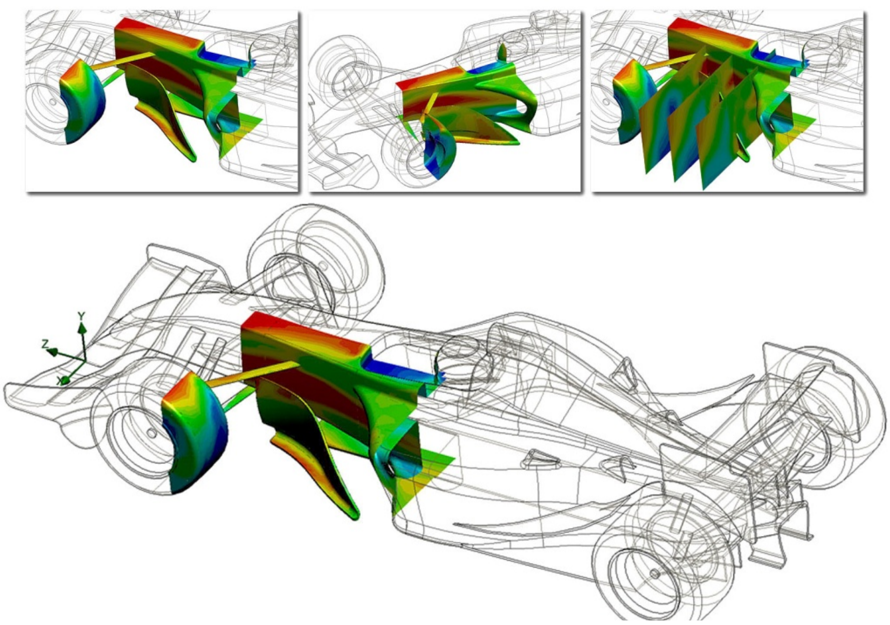

Figure 3: Modern CAD-embedded Motor Racing CFD simulation of aerodynamic components of an Indy Car simulated in FloEFD (Courtesy of Voxdale)

Motor Sport was one of the first professional sports to adopt commercial CFD tools for competitive advantage; first inviscid panel methods in the 1980s and then RANS-averaged Navier-Stokes techniques in the early 1990s (see Figures 2 and 3). Indeed, it can be argued that Formula 1 has been a major driver for technology innovation in CFD with high performance computing and pre-processing enhancements to CFD technologies being developed for ANSYS FLUENT, CD-Adapco's CCM+ and latterly the OpenFOAM product. Certainly, some of the biggest Datacenters in the world have been developed to harness the power of CFD in motor sport because of its relative cheapness and knowledge scalability relative to building further wind tunnels (more engineers and more CFD equals more flow predictions by and large with linear scaling). However, the governing body of motor sport, the FIA, has started in the last few years to put brakes on the use of CFD in some motor sports and an age of austerity in CFD usage may be appearing in Formula 1. Motor racing teams are creative and they are likely to develop workarounds. In terms of what still needs to be done with CAE in motor sport; true multiphysics simulation (eg FSI, aquaplaning), transient overtaking and wheel manoeuvres (and tactical simulations) still need to be carried out at a production level within the motor racing CFD community.

The Americas Cup is the oldest, most prestigious, and richest sailing event in the world. It is competed for roughly every 4 years and over the last 20 years CAE has become more and more critical for competitive advantage be it in hull, keel or sail designs, free surface effects and sailing tactics. Team NZ and then Alinghi (see Figure 4) and latterly BMW Oracle (who used CD-Adapco CFD software) have pushed the envelopes of marine craft design - and CAE has been pivotal to their success.

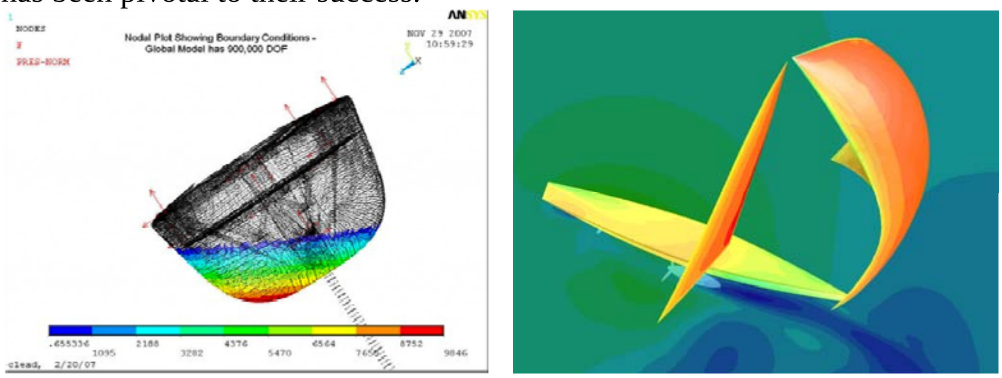

Figure 4: Structural & CFD Simulations Associated with the Double Americas Cup Winning Team Alinghi Boat (Courtesy of ANSYS Inc.)

The Summer and Winter Olympics are usually considered to be the pinnacles of an elite athlete's career and winning a gold medal is very prestigious. The 1996 Summer Olympics, however, was a nadir for the British Olympic team – a haul of one gold medal and fifteen medals in total left Team GB 36th in the Global Medals Table (see Figure 5) provoking much national soul searching and a political reaction. The British Olympic Team had always been good at some technology dominated summer Olympic sports such as sailing and rowing and sporadically in cycling (the famous Team GB Lotus Bike in 1988 being an being an example). The UK Sports Institute was therefore established later that year as a response to the public reaction, Olympic Sport was restructured (not least giving budgetary ownership to Performance Directors for individual sports), $100 million's of National Lottery funding (in a 4 year cycle) was pumped into Olympic Sport at a national level, new world class coaches (mainly from Australia, the US and Eastern Europe) were hired on high salaries, promising young athletes paid a living stipend for the first time for their full-time training and living costs, and better nutritional and psychological support was offered; but also, crucially, a "Technology & Innovation" Director was recruited. This Director was tasked with identifying leading edge British technologies, companies and organizations with possible transferrable technologies that could be harnessed to give the British Team and elite athletes a measurable competitive advantage and performance differences (cost effectively) in Olympic sports where the UK already excelled or could realistically "medal" in over the next 2 Olympic cycles.

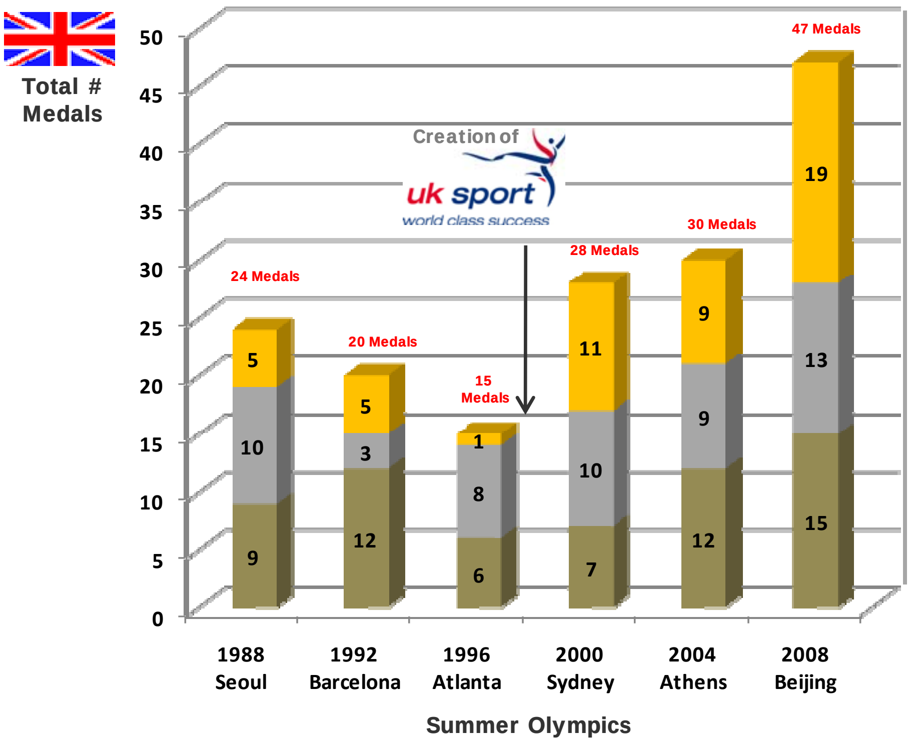

Figure 5: Team GB Olympic Medal Winning Numbers 1988 – 2008

The 2000 Sydney Olympics saw an immediate impact of over 3 year's funding on the British team's performance resulting in it exceeding its Barcelona medal haul and creating a "feel good" factor with the UK public back home. By the

2004 Olympics, Dr. Scott Drawer had taken over as R&I Director at UK Sport (with a budget of $18M) and his philosophy was to investigate sources of technologies and to outsource effort from the Performance Director budgets to centres of excellence and started to pay dividends. For CFD, Totalsim Ltd, Sheffield Hallam and Southampton Universities along with BAE Systems were chosen to support various disciplines with aerodynamic and hydrodynamic research. The UK team maintained its performance level in difficult competing conditions of an Athens Summer and increased its medal haul further to 30 medals in total in 2004; 9 being gold. By the 2008 Olympics in Beijing the UK Sport Performance Director system was fully bedded in, plus technology and innovation (especially CFD tools) were delivering competitive advantages. In Sailing, Cycling (see Figure 6 to illustrate how aerodynamic improvements helped deliver medals) and Rowing disciplines, Team GB dominated their respective fields helping to bring back the best medal haul the team had seen for over 80 years rising to an unheard of fourth place in the Medals Table with 47 medals including 19 gold medals. Indeed, it has been calculated that China won 100 medals in its home Olympics but invested some $3Bn in the funding cycle – a cool $30M for any color medal – whereas the UK was averaging $7.5M/medal which was more cost effective per medal won. Maintaining this level of performance and overhauling the Russian Olympic Team, perennial #3 in the Summer Olympics Medals Table, will be the goal of Team GB for their home Olympics in London next year – and CAE innovations will be a big part of any successes they will gain. The UK government is also sinking about $700M into the current Olympic funding cycle (Syed, 2008).

2008 Olympic Cycling Medals

Country	Gold	Silver	Bronze	Total
GBR	8	4	2	14
ESP	2	1	1	4
SUI	1	0	2	3
USA	1	0	1	2
SWE	0	2	0	2

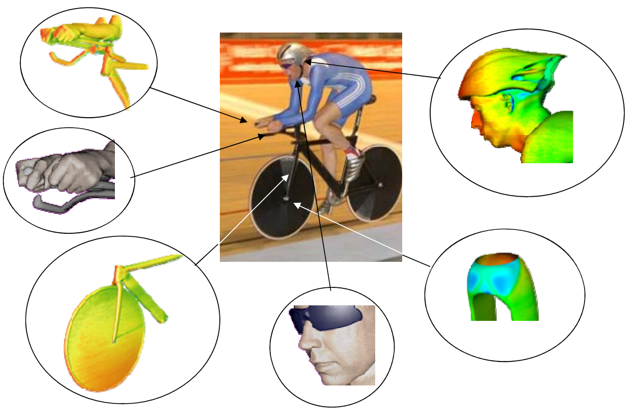

Figure 6: British Olympic Cycling Team 2008 Medal Performance and example Cycling CFD Application Areas (Simulated by UK Sport, Sheffield Univ & Totalsim Ltd using ANSYS FLUENT software)

Many other Summer & Winter Olympic sports are also known to use CAE for performance enhancement including rowing, sailing (Figure 7), canoeing, kayaking, bobsled (EXA in 2010 helped the American 4 Man Bob to victory), luge, ski jumping, bob skeleton (Figure 8), and even wheelchair racing in the Paralympics.

Figure 7: Medal Winning Summer Olympic Finn Class Sailing Simulation in FloEFD for the Swedish Olympic Team (Courtesy of WB Sails)

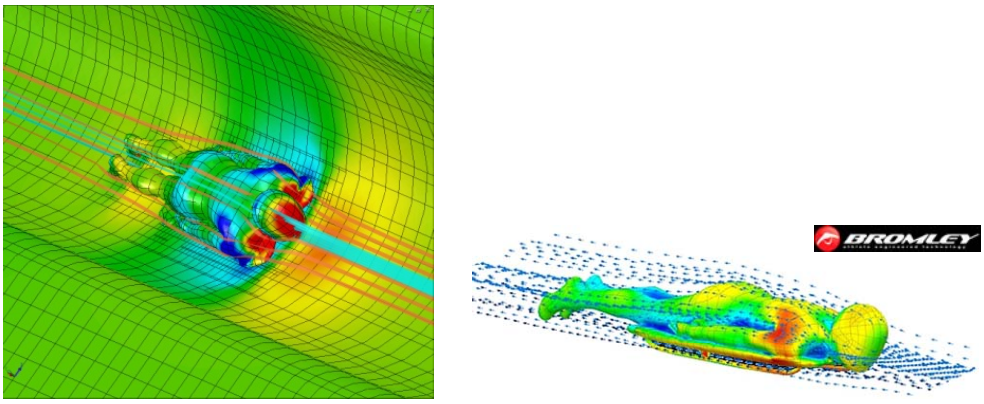

Figure 8: Bromley Technologies Ltd use the FloEFD Concurrent CFD code CAD-embedded inside Pro/E to simulate their Gold Medal winning Sleds

As far as Summer Olympic Swimming is concerned, Speedo International has a long track record of technological innovations in elite swimsuit design over several Olympiads and its 2008 offering, the LZR Racer Swimsuit, was developed with the help of ANSYS FLUENT CFD software (see Figure 9) for the Beijing Games where it created an immense stir (and ultimately rule changes banning certain types of full-body swimsuits). With the use of CFD, Speedo were able to make their suit 5% better in passive drag than the best 2004 suit and swimmers were going on average 2% faster overall after its launch. An unprecedented number of world records (over 70) were broken by athletes wearing the LZR Racer in the 9 months after it came out. Over 90% of all gold medallists and 89% of all medallists wore the suit in Beijing to the detriment of all other competitive garment manufacturers. Coaches were starting to call its use “technological doping” such was the controversy over its success. In truth, all athletes had the opportunity to wear the swimsuit in the games, and, without an elite athlete inside the LZR Racer, they did not go that fast in the water.

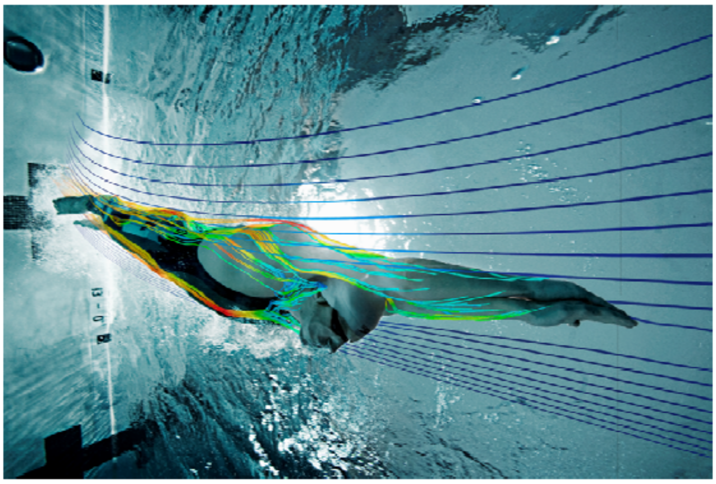

Figure 9: Seven Times 2008 Olympic Champion, Michael Phelps, in a Speedo LZR Racer with CFD prediction of flowlines around his body and swimsuit (Courtesy of Speedo International & ANSYS Inc.)

Many types of other sports and leisure equipment are designed using CFD and CAE these days, including a vast range of sports balls, golf clubs & balls, running shoes, baseball bats & helmets, surf boards, skis and snowboards, ice axes, bicycles, mouthguards, training equipment, and tennis racquets using products from ANSYS, LS Dyna, SIMULIA, MSC & Mentor Graphics' FloEFD tool to cite a few. Figure 10 shows how SIMULIA's Abaqus structural analysis product is used to understand the deformation of a soccer ball.

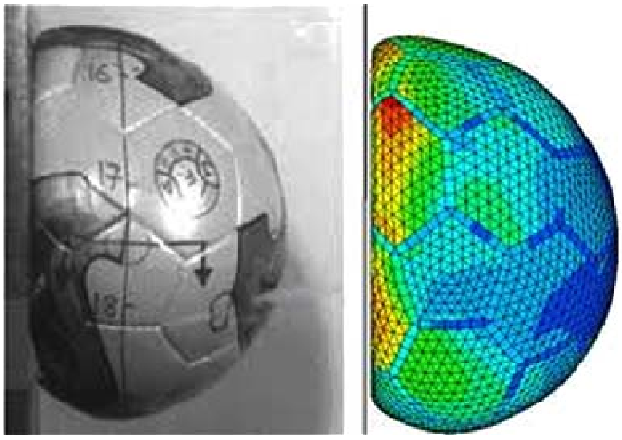

Figure 10: ABAQUS simulation of a soccer ball deforming on impact at a wall (Courtesy of SIMULIA)

FEA software from Simulia was used to design the Teamgeist soccer ball for the 2006 FIFA World Cup. It was engineered to behave consistently wherever it was struck with the interior of the ball being a carcass structure made from

12 pentagonal panels of fabric that fold up to form a sphere. This design led to large improvements in stiffness distribution. The FEA software modeled the behaviour of the ball when kicked at up to 160 kilometres an hour (100mph), helping to determine the effect of even small structural changes on the ball's overall performance. Separate CFD simulation using the ANSYS FLUENT determined and improved the aerodynamic features of the novel "figure of 8" panel structure used on the ball's surface.

In the Sports Products Industry, Figure 11 illustrates how CAD-embedded CFD inside FloEFD has been used by Ping Golf to evaluate the aerodynamic design of one of their drivers and the hydrodynamic design of a leisure product such as an underwater scooter showing how CFD is slotting into manufacturing processes inside this niche consumer product sector.

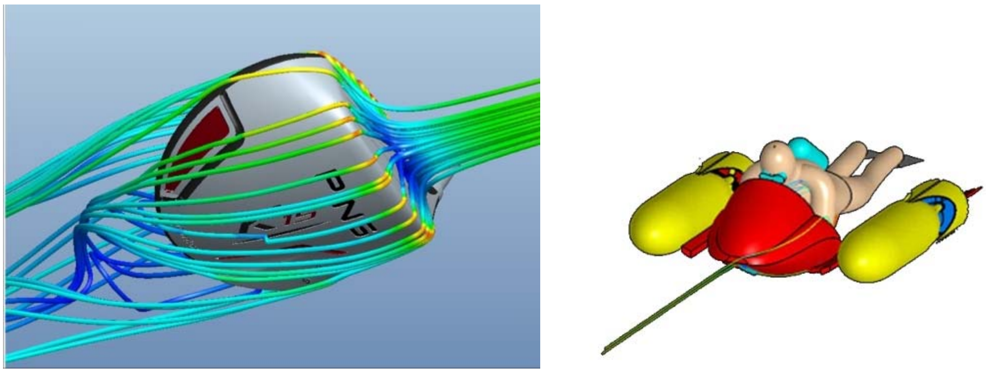

Figure 11: Airflow around a Ping K15 Driver Head and Flowlines near an Underwater Scooter Design in FloEFD (Courtesy of Ping)

Finally, Figure 12 depicts an illustration of another manifestation of CAE in Sport, namely breaking world records for speed. Several land speed records including the current world record holders, THRUST SSC, have used CAE extensively to design their one-off vehicles. Here we see a CFD rendering of a 100mph world record breaking Formula 2 Boat design for Bernico International by Voxdale BV in Belgium designed using CAE from Pro/E and FloEFD.

Figure 12: 100mph World record Breaking Bernico Boat at Coniston Waters, 2008

5: Whither CAE in Sport?

Certainly, abuse of drugs in sport is unlikely to go away for the foreseeable future, not least because of the amount of money associated with winning in sport. The World Anti Doping Authority (WADA) will have its hands full in future keeping abreast of performance enhancing pharmaceutical advances (and that of masking agents) but it and regulatory authorities must be successful if clean sport is to prevail. Sadly, genetic modification of humans leading to elite high performing athletes in the future is likely to be already happening in children being born today and how that factor will play out remains to be seen. Nevertheless, in the realm of CFD and CAE in sport the author foresees continual, deeper and more expansive use of these technologies to eke out every competitive advantage possible in terms of fluid dynamic understanding, as well as competitive and training equipment design. Custom CAE simulations of scanned athlete geometries will become the norm rather than the exception and CFD will become part of the talent identification process for certain sports (where transient aerodynamic or hydrodynamic posture have a pronounced impact on performance).

The “Virtual Athlete” is one of the targets of sports engineering and great strides towards it should be possible in the next 20 years when CAE is coupled with more and more powerful computer hardware tools. The ability to produce physically and biologically realistic multiphysics computer models of elite athletes which will be able to virtually test any proposed new sports surface or piece of equipment or injury scenario must be a compelling goal for the engineering profession. Indeed, CAE will help to elucidate issues such as core body temperature, custom motion analysis, breathing and lung modeling, blood and sweat flows, and the analysis of biologically important fluid-structure based processes in elite athletes will also become more common.

Real-time virtual modeling of athletes and equipment at competitive events, probably on cloud computing platforms far away from the arena, by coaches and managers to gain competitive advantage on the day of competition will become possible. The increasing use of “smart” materials in Sport and advanced intelligent materials for training purposes, if not for competition, will provide engineering design opportunities for customized intelligent clothes and footwear. The author foresees whole cityscapes around stadiums and competing venues being modelled with CFD on the day of an event to gain competitive advantage from weather variations in certain sports. Indeed, the famous Californian Professor, Alan Kay, summarizes well the essence of CAE in Sport and where it is today with his observation that what was considered far-fetched 5 years ago is now normal and what we consider far-fetched today will be commonplace within a generation.

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