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CFD in Sport - a Retrospective; 1992 - 2012

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Abstract

Since commercial Computational Fluid Dynamics, CFD, was first used in anger within sport in the early 1990s it has now evolved to become a dominant, if not indispensible, sports equipment design technology that can produce legal competitive advantage improvements and performance enhancement in elite sport – in effect it can be a killer engineering "app" in sport. This paper will trace the origins of CFD in Motor Sport, Americas Cup Yachting and various Olympic Sports up to its ubiquitous utilization today where it can yield near real-time fluid flow simulation predictions and virtual product development. Indeed, CFD has had a significant impact in the last 20 years on the design of sports stadia, various winter & summer sports equipment design, understanding of ball sports, all motor sport categories, world speed record attempts, numerous water sport equipment designs and various flying related sports activities. A comparison of CFD in sport capabilities between 1992 and 2012 will be offered in this paper and the underlying enabling technology trends described that have helped to make this transformation possible. Finally, the author offers future trend predictions for CFD (and associated multiphysics) technologies in sport for the next 20 years; such as virtual athletes, biomedical applications, enhanced training scenarios, on-the-day-of-the-race climate and landscape modeling, new materials and their fluid-structure effects, video & web based CFD solutions, and the increasing overlap of electronics and mechanics in sports engineering. Indeed, the cross fertilization of technologies from Hollywood movies, mobile phones, the internet and video games to CFD in sports engineering remains to be fully exploited.

Keywords: CFD; aerodynamics; hydrodynamics; CAE

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1. Introduction

This paper takes a retrospective look at the use of commercial Computational Fluid Dynamics (CFD) software tools in various sports over the last 20 years by reviewing what was possible in 1992 and juxtaposing it with what is possible today. Indeed, such are the benefits of CFD, as soon as CFD tools such as FLUENT, CFX, STAR-CD and FiDAP became available in a usable industrial form to the engineering community in the early 1990s, clever engineers and scientists started to use them in competitive sport to gain a design and performance advantage in terms of improved sports equipment design and elite athlete aerodynamic and hydrodynamic enhancements.

The commercial CFD industry started in the early 1980s as an esoteric discipline used by high-end turbomachinery, aerospace, combustion and mechanical engineers in particular. However, by the early 1990s it had matured to be a $50M/yr industry and the leading tools like FLUENT were relatively easy to use [1-2]. CFD software gave users the ability to have a virtual wind tunnel or water flume on their desktop workstation and permitted valuable fluid dynamic insight and foresight for the design of a product or a manufacturing process. It did not take long for highly competitive sports like Formula 1 to see the potential for commercial CFD to revolutionize their design process in order to gain competitive advantage [3]. Figure 1 describes the early inviscid and Reynolds-Averaged Navier-Stokes (RANS) CFD activities like those of the pioneering Benetton Formula 1 Team, and how F1 motor racing CFD has evolved over the last 20 years to full car simulations in an hour on 1,000+ processor datacenters (see also Appendix 1):

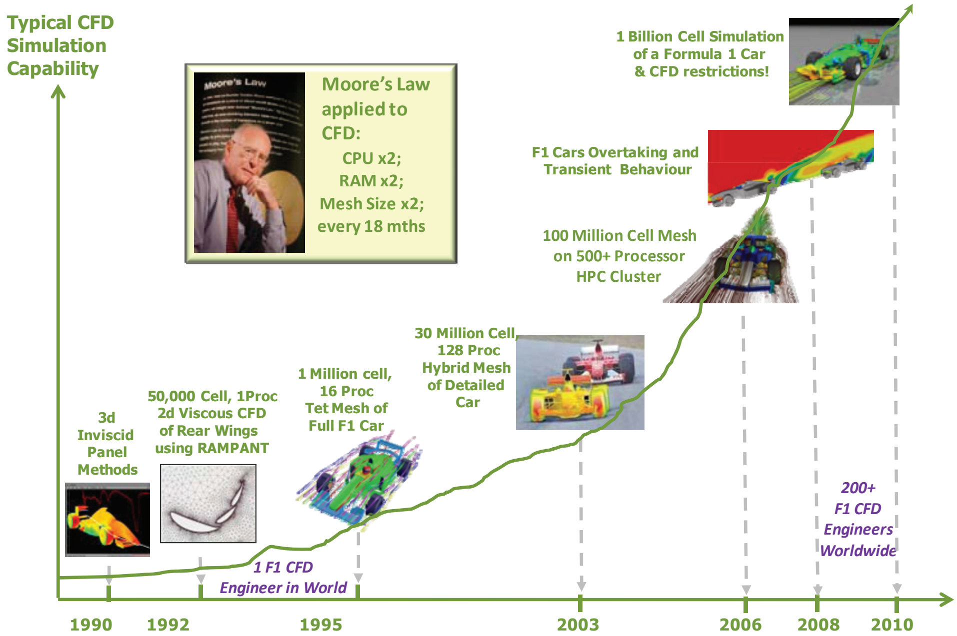

Fig. 1. Sports CFD has grown on the back of Computer Hardware Advances and Moore's Law– illustrated by Formula 1 Motor Racing CFD trends in the last two decades

Indeed, the most striking aspect of this schematic graph is the overwhelming impact of the CPU and RAM of computer hardware advances available to engineers and CFD users in Motor Sport over the last two decades. It alone has propelled CFD into being a "must-have" upfront engineering design tool for sports applications versus a nice-to-have-but-after-the-fact fluid flow analysis tool in the early years.

Perhaps the other single biggest underlying influence on the CFD market rising to be circa $800M/yr today has been the growth of 3D Mechanical CAD tools like CATIA, Pro/E, Autodesk, NX and Solidworks. They have enabled complex real-world geometries to be created and parameterized quickly within ever-shrinking product lifecycle management (PLM) environments – something that was simply impossible 20 years ago. Figure 2 also illustrates the many technology flows and allied strands that have fed into the steady double digit (13% CAGR) growth rate of the CFD industry in the last two decades:

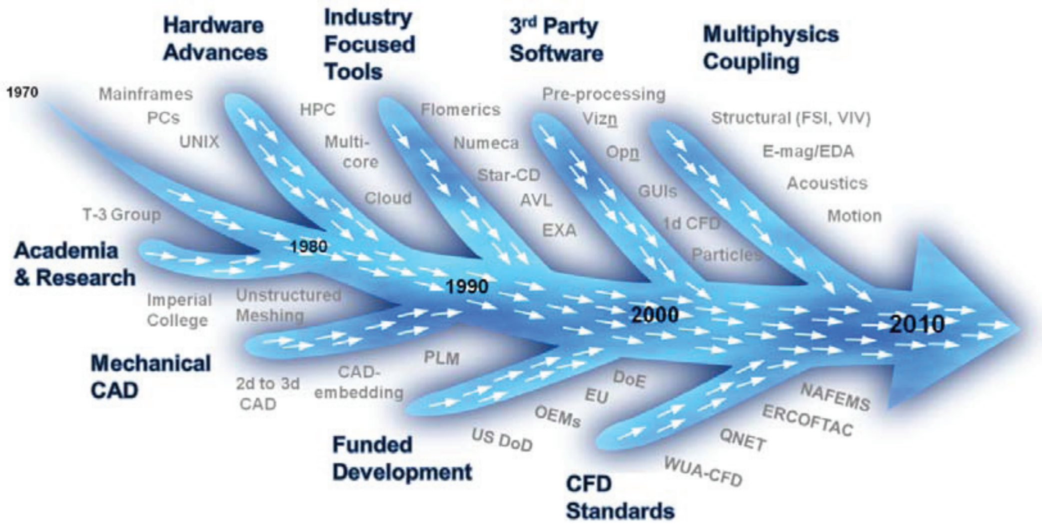

Fig. 2. Technology tributaries that have fed into the main river that is CFD growth since 1990

2. CFD Capabilities in 1992 versus 2012 for Individual Sports and Sporting Areas

Motor Racing (the richest division of 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 techniques in the early 1990s. Any part of their cars that a competitive advantage could be gained with a good return on investment by the application of CFD was considered to be a legitimate application – wings, bodies, wheels, radiators, intakes, exhausts, engines. Indeed, it can be argued that Formula 1 has been a major driver for technology innovation in CFD in general with high performance computing and pre-processing enhancements to CFD technologies being developed for ANSYS FLUENT, CD-Adapco's CCM+, EXA Powerflow, and latterly the OpenFOAM open-source CFD product. Certainly, some of the biggest Datacenters in the world (1,000+ CPUs) 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 a 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 CFD 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 CFD has become more and more critical for competitive advantage be it in hull, keel, appendage or sail designs, free surface water effects and even sailing tactics. Team NZ, then Alinghi and latterly BMW Oracle have pushed the envelope of sailing marine craft design and CFD has been a pivotal technology to their success. Other water sports like powerboat racing, water skiing, scuba diving, jet skis and even surfing have all been tackled by CFD in the last 10 years as a consequent trickle-down effect.

As far as Summer Olympic Sports are concerned, the influx of money into elite competition and by companies like Speedo International (swimming) and Adidas has had a profound effect on the last four Olympiads in particular. Speedo have had a long track record of technological innovations in elite swimsuit design since 1996 and its 2008 offering, the LZR Racer Swimsuit, was developed with the help of ANSYS FLUENT CFD software 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. Other Summer Olympic sports known to use CFD for performance enhancement include rowing, sailing, canoeing, kayaking, and even wheelchair racing in the Paralympics [4-5]. In the Winter Olympics (the poorer cousin of the summer event) bobsled, luge, skiing, ski jumping, and bob skeleton all started to use CFD in the early 2000s. Indeed, each Olympic cycle these sports in particular are seeing a greater and greater investment in CFD for performance enhancement.

Ball Sports since the late 1990s have been using 3D CAD and CFD extensively to gain a deeper understanding of the underlying physics and flow separations associated with ball seam and pattern designs [6]. Indeed, CFD simulation using ANSYS FLUENT determined and improved the aerodynamic features of the novel "figure of 8" panel structure used on the innovative 2006 World Cup Adidas Teamgeist soccer ball's surface (see Appendix 1). From the mid 1990s Sports Stadium Design has seen immense engineering as well as architectural effort put into them. There is hardly a stadium that is erected today that has not had a CFD analysis of some sort or other applied to it to predict what its performance will be like for different wind directions, use scenarios and crowd/athlete comfort parameters.

Many types of other Sports & Leisure Equipment are designed using CFD these days as a matter of course, including a vast range of sports balls, golf clubs & balls, running shoes, surf boards, hang gliders, flying suits, scuba diving kit, bicycles & helmets, and assorted pieces of training equipment. Manufacturers started to use CFD in the late 1990s but the advent of CAD-embedded CFD products such as FloEFD (from Mentor Graphics) has been used by the likes of Ping Golf to evaluate the aerodynamic design of their drivers showing how CFD is slotting into Sports manufacturing processes easily today as an upfront rapid design tool (see Appendix 1).

Finally, another manifestation of CFD in Sport emerged in the early 1990s, namely Breaking World Speed Records. Several land speed records including the current world record holders, THRUST SSC, have used CFD extensively to design their one-off vehicles. Indeed, such is the risk with record breaking attempts that trying to predict exact aerodynamic and hydrodynamic effects up front of manufacture of unique vehicles is almost mandatory. With CFD being used today to break 100mph+ water speed records and 1,000mph supersonic land speed records, CFD technology continues to break new and demanding barriers quite literally.

3. Whither CFD in Sport?

In the realms of fluid dynamics within sport the author [7] foresees continual, deeper and more expansive use of CFD technology (especially with coupling to other computer-aided engineering technologies) to eke out every competitive and design advantage possible in terms of fluid dynamic understanding, as well as competitive and training equipment design. Examples to look out for in the next 20 years should include:

- Custom CFD simulations of scanned athlete geometries (and enthusiastic amateurs) 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). Large Eddy Simulation as standard for aerodynamic CFD analyses will be more and more possible as multicore and HPC technologies evolve. CAD-embedded CFD will become the norm in sports and leisure equipment design & manufacture.
- "Virtual Athletes" will be a Holy Grail of the sports engineering field and great strides towards it should be possible in the next 20 years or so when CFD is coupled with more and more powerful computer hardware tools especially in multiphysics simulation scenarios and with Hollywood and Handheld Games Industry visualization technology advancements.
- Physically and biologically realistic CFD/multiphysics computer models of elite athletes to virtually test any proposed new sports surface, clothing, piece of equipment or possible injury scenario before they happen will be a compelling goal for the profession.
- CFD (and CAE) will virtually test and 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. Watch out for in-clothing (and even in-skin) monitors.
- 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 and will likely become commonplace.
- Whole cityscapes around stadiums and competing venues will be modeled with CFD on the day of an event to gain competitive advantage where weather variations in certain sports are important.
- HALT (Highly Accelerated Lifetime Testing) of sports & leisure equipment partially using CFD will become the norm before a product is manufactured to assess for lifecycle failures.
- The increasing use of "Smart" Materials in Sport and advanced intelligent materials for training purposes, if not for competition, will provide CFD engineering design opportunities for customized intelligent clothes and footwear. Expect more nanotech and specialist molecular materials & watch out for deforming surfaces.
- The crossover between Electronic and Mechanical innovation in Sport will occur more and more this decade especially in athlete monitoring and immersive technologies for sports experiences.

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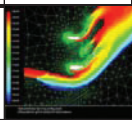
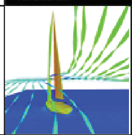
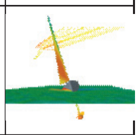
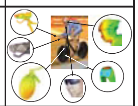
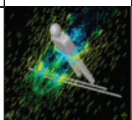
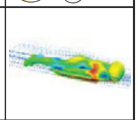
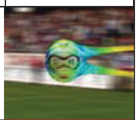
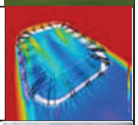
Appendix A. Comparing Usage of CFD in Different Sports: 1992 – 2012

SPORT	SUB-DISCIPLINES	1992 CFD Technology	1992 CFD Examples	2012 CFD Technology	2012 CFD Examples
MOTOR SPORTS	Formula 1, Indy Car, Nascar, Champcar, Go Carting, College Motor Sport, Motor Bikes, Le Mans 24 Hours	2D rear wing profile geometries, tri meshes, single processor& 60k mesh size restrictions in days		Full 3D models, HPC supercomputers, moving hybrid mesh, overtaking, free surface, FSI in hours	
YACHTING	Americas Cup, Round the World Racing, Catamarans	Simplified 3D geometries, tri/tet meshes, single processors; free surface & mesh size restrictions in weeks		Full 3D models, HPC supercomputers, moving hybrid mesh, overtaking, free surface in days	
OLYMPIC SUMMER SPORTS	Rowing, Sailing, Canoeing, Kayaking, Cycling, Athletics Equipment, Swimming, Diving, Paralympic Sports (Wheelchair Racing)	Not Used	Not Used	Full 3D models, HPC supercomputers, scanned geometries, moving mesh in days	
OLYMPIC WINTER SPORTS	Ski Jumping, Bob Sled/Sleigh, Bob Skeleton, Luge	Generic 3D human body shapes, tri/tet meshes, single processor & mesh size restrictions in weeks		Concurrent CAD-embedded 3D CFD, scanned geometries, parametric studies in hours	
BALL SPORTS	Golf, Soccer, Baseball, Cricket, Tennis, Badminton, Table Tennis	Not Used	Not Used	Scanned 3D geometries, boundary layer resolution of flow effects in days	
STADIUM DESIGN	Soccer, Rugby, Baseball, American Football, Cricket, Tennis, Athletic, Swimming Pools, Ice Rinks...	Not Used	Not Used	All stadia designed with 3D CFD today for air flows & spectator comfort in days	
WATER SPORTS	F1 and F2 Motor Boats, Surfing, Sailing, Scuba Diving, Jet Skis, Windsurfing, Water Skiing	Not Used	Not Used	Concurrent 3D CFD with conceptual design, structural & fluid analysis, and free surface in days	
WORLD RECORD BREAKING ATTEMPTS	Land Speed Records, Water Speed Records, Solar Cars	Inviscid 3D CFD, CRAY Supercomputer in weeks		Every world record attempt is virtually simulated with 3D CFD upfront of an attempt today	
MISCELLANEOUS SPORTS & LEISURE	Hang Gliders, Running Shoes, Golf Drivers, Clothing, Flight Suits, Frisbees, Heating & Cooling Pads	2D Sectional Profile RANS analysis at best in days		Concurrent 3D CAD-embedded CFD within product development lifecycles