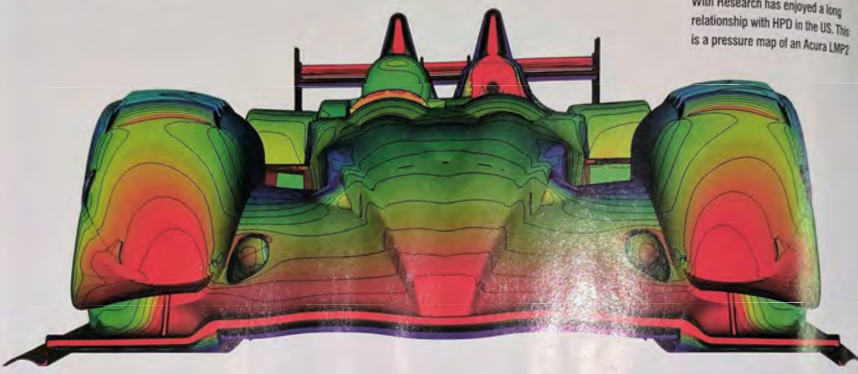
Wirth the effort

If you're in need of an overview of the development of CFD in motorsport, then you could do a lot worse than tracing Wirth Research's application of this technology over the years

By SIMON MCBEATH

With Research has enjoyed a long relationship with HPD in the US. This is a pressure map of an Acura LMP2



It is somewhat ironic that when Wirth Research decided to set up an in-house CFD department, shortly after the company was founded in 2003, the initial target was non-motorsport markets, for it is a well-known fact that the aerodynamics of the Virgin VR-01 Formula 1 car were entirely developed by Wirth Research (WR) with CFD.

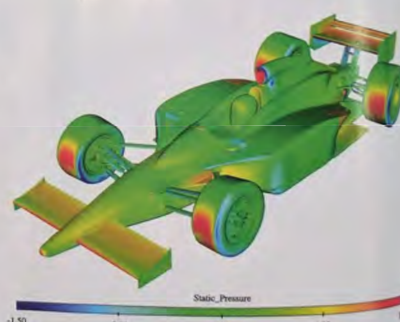
Perhaps less widely known is that cars in other top categories with which WR have been intimately involved have also been developed solely with CFD. But it is in part thanks to the company's involvement in non-motorsport markets that some of the developments that have helped improve its motorsport aerodynamics simulations have come about. We took a trip down memory lane with WR's engineering manager, Rob Rowsell, to see how the power of CFD has burgeoned in the intervening years.

Indy beginning

Wirth Research's early days at its Bicester, UK, headquarters saw it commence a long term partnership with Honda Performance Development (HPD) in the USA, working initially on the aerodynamics of the Dallara IndyCar, which in those days was competing with chassis from G-Force and Panoz. The programme used the 50 per cent scale wind tunnel at ARC, Indianapolis, and the full scale wind tunnel at FKFS, Stuttgart, Germany, out-sourcing its supporting CFD requirements at that time to Advantage CFD, in nearby Brackley.

Successful though this collaboration was, netting the 2004/5 Driver and Engine Manufacturers' Championships for HPD/Andretti Green Racing, a review of the different aerodynamic simulation tools revealed the manner in which each was applied and the relative standing of each. The tools were used according to their respective strengths at the time, so the 50 per cent scale wind tunnel was used for the majority of development work, supported by CFD to generate ideas and detail analysis, and the full-scale wind tunnel (FSWT) was used for validation. This basic process was to persist for the next few years.

At this stage the IndyCar CFD model featured a mesh of just 15 million cells



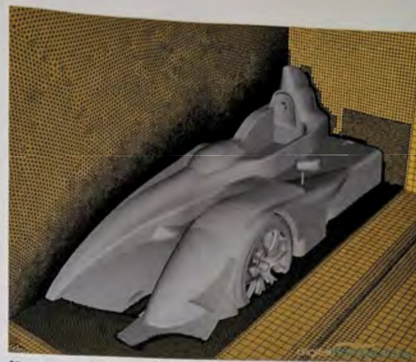
Early work: Wirth's surface pressure distribution plot of the 2004 Dallara IndyCar

(12 million for half car models) with no boundary layer modelling and a basic turbulence model.

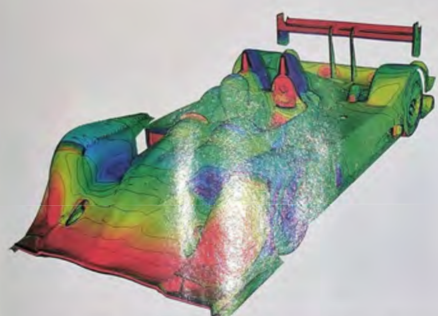
It still took a 24-node cluster around 20 hours to produce a converged solution, so at this stage the accuracy and productivity available from CFD simulations was subordinate to what could be done in the 50 per cent wind tunnel.

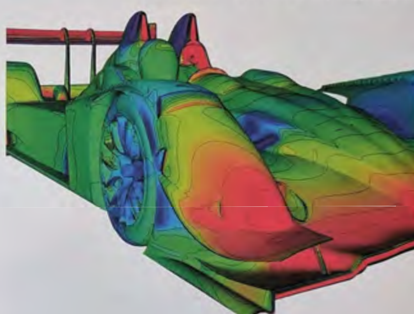
In 2004 Rob Rowsell was recruited to set up a CFD department for Wirth Research to invest in and develop in-house CFD technology beyond the level that other providers were able to offer. Despite the original plan being to cultivate markets outside motorsport, founder Nick Wirth persuaded HPD to use this now very capable in-house CFD department

The surface mesh and a slice through the volume mesh on the 2004 Dallara IndyCar



Slices through the volume mesh on the 2007 ARX-01a LMP2 sports prototype racer





Above and right: surface static pressure distribution over the 2008 ARX-01b LMP2

to look at the LMP2 sportscar aero development in the ALMS in 2006

The development would once again use the ARC 50 per cent scale wind tunnel, with the FKFS full-scale facility used for validation, but now the CFD development support would be carried out in-house using continually improving resources.

A pilot LMP2 aero project was set up using a known LMP2 car model (and wind tunnel data) as the basis, updated to the regulations then current, to develop the applicable CFD methodology while also building a knowledge base of LMP2 aerodynamics. WR was then tasked with evaluating a range of contemporary LMP2 customer cars.

This resulted in HPD choosing to purchase a Lola LMP2 car for engine development and WR was requested to use a Courage LC75 as the basis for chassis and aero development.

Rob Rowsell: 'We had expected small tweaks but having received both cars and assessed their aero in CFD, and physically in both the full scale wind tunnel and on track, we ultimately realised that we would have to develop all the bodywork to address fundamental issues including aero performance, porpoising, brake, engine and exhaust cooling, and the structural integrity of the splitter. We took on the works Porsche Spyders and became very competitive.'

The car, the Acura ARX 01a, later known as the HPD ARX 01, which was based on the Courage chassis, debuted at Sebring in 2007, winning the class and gaining second overall.

In preparation for the 2008 season, development of what became the ARX 01b began in mid-2007. 'The design encompassed a new one-piece magnesium alloy transmission and bellhousing, quick change front and rear bodywork, overall weight reduction, and all-new aerodynamics, this developed using CFD only. The result was a car that was over three seconds a lap faster than the previous car in testing at Sebring,' Rowsell says.

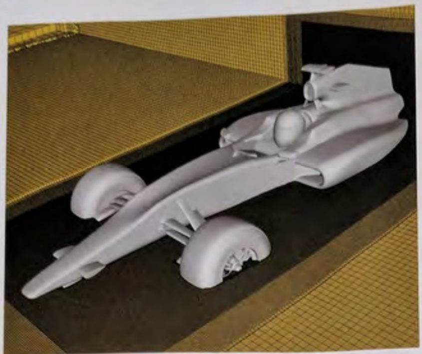
By now CFD mesh densities and boundary layer modelling at WR had seen significant improvements and results from CFD were closer to the full-scale wind tunnel results than were those from the 50 per cent scale wind tunnel. Furthermore, CFD was able to capture flow separations on the rear wing, and productivity had also overtaken what was possible with scale model testing, with the time from generating an idea to obtaining test results from a major part like a rear wing or a splitter being two to three times faster now with CFD.

'This,' says Rowsell, 'was partly down to chasing correlation issues with the 50 per cent scale tunnel, which wasted development time.' The ARX 01b won its class in the first race at Long Beach in 2008 and won overall for the first time at the North East Grand Prix, Lime Rock Park. It was beaten by just one point to the Manufacturers' title by Porsche.

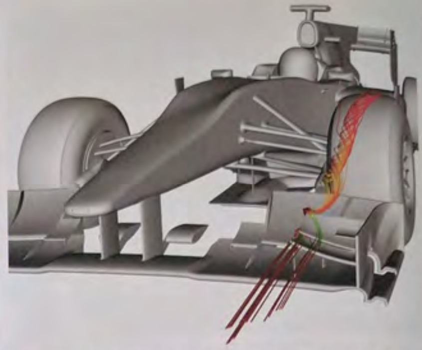
During 2008 development of the ARX 02a LMP1 car began. Much has been written in *RE* and elsewhere about the early curtailment of the 02a programme, but it did win the overall Drivers', Teams' and Manufacturers' ALMS titles in 2009. The car was essentially developed in CFD, now with track testing for validation, and required a strong front end aero package to help load up the front wheels, fitted with rear-sized tyres to increase contact patch area.

From the CFD standpoint, a switch was made to using full car models after issues on stall prediction were encountered in half-car simulations.

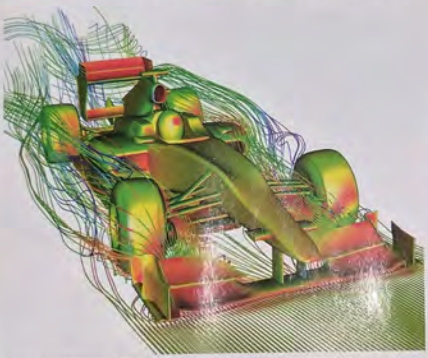
At this stage the IndyCar model featured a mesh of just 15 million cells



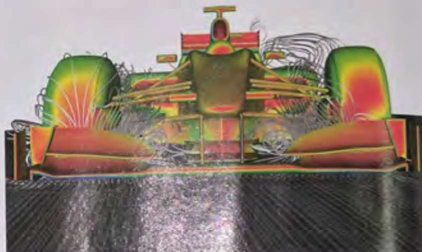
Slices through the volume mesh on the 2010 Virgin (Manor) VR-01 Formula 1 racecar



Streamlines show path of vortex formed from the front wing upper winglet on the VR-01



Surface static pressure distribution and streamlines over the 2010 VR-01 Formula 1 car



Here the y-250 vortex is readily a... emanating from the inboard end of the front wing flap of the VR-01 F1... dynamics were entirely designed in CFD

This necessitated significant hardware upgrades to handle the much bigger cell counts and solver burden.

A further internal review in 2009 of the state of the art in the aero development of ALMS cars found that CFD results were now matching full-scale wind tunnel testing results. Furthermore, CFD and track testing had identified issues with scale model testing, including solid tyres that did not correlate with real, deforming tyres; the low speed (low Reynolds number) of the scale wind tunnel causing problems with splitter results; and there were correlation issues with dive planes and the rear wing and rear end of the car. In short, 50 per cent scale wind tunnel testing was dropped. Even full scale wind tunnel testing had weaknesses sufficient to prompt the switch to track testing for validation. This experience clearly helped define the strategy that was employed on subsequent projects.

Formula 1 beckons

With wind tunnel testing now essentially a thing of the past, the spotlight was focussed on the sole use of CFD for aero development, and became a major talking point around the Manor GP/Wirth Research/Virgin Racing entry into F1 in 2010.

The aero development work on what became the Virgin VR-01 was obviously done pre-2010, and the car became one of three new teams' entries to appear on the 2010 grid. By now mesh cell counts had progressed from the tens to the hundreds of millions of cells, with hardware investment constantly having to keep up in order to achieve satisfactory solution times and productivity.

Having said that, wind tunnel testing had been dropped from the development phase, a project was run at Southampton University wind tunnel on wheels/tyres in isolation in order to gain force data and wake velocity data (using particle image velocimetry, PIV) to validate the CFD.

Flow separations and wake development on open wheels have always been challenging areas for CFD to handle, as well as being of much greater significance to aero performance than on closed wheel sportscars, so it's no surprise to learn that some validation was sought, and this would have been applicable to IndyCar as well as F1. Validation of the F1 car's aerodynamics was also carried out in the FKFS Stuttgart facility.

During the F1 development period WR increased the cell density in its simulations further to increase accuracy. At that time the maximum cell count was limited by the memory capacity of the computers used for meshing, so the increased mesh density necessitated a temporary switch back to using half-car models.

By 2011 the cell count on the Formula 1 model had reached 400 million cells. One of the benefits of this increase in cell density was that vortical flows were defined more effectively, this being a key aspect in the aerodynamic development of modern, high-level single seaters.

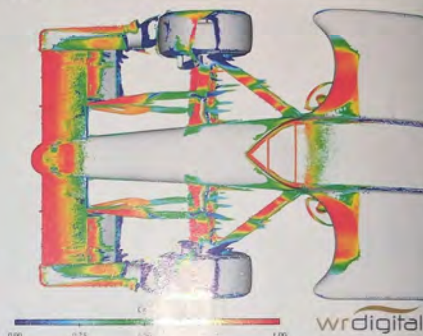
All the new developments implemented on the F1 CFD model were validated with flow visualisation tests on the real car on the race track, and were supplemented with pushrod loads, pressure tappings, flow visualisation fluid, and video footage of wool tufts. And, for example, flow separations on rear wings were found to tally well with reality.

CFD and track testing had identified issues with scale model work

While the design development for the F1 project was all CFD the validation work on isolated wheels and tyres was carried out in the wind tunnel at Southampton University

Some validation of the full-scale F1 car's aerodynamics was carried out in the FKFS Stuttgart facility in Germany. Flow visualisation validation at the track was also used

This shows the surface static pressure distributions on the 2012 Dallara IndyCar



This is the total pressure plot showing [illegible] details on the 2012 Dallara IndyCar

Among other ongoing developments around this time was automatic surface meshing using techniques developed in-house following months of R&D work on new CAD generation methods; bespoke data conversion software; surface mesh generation software and settings; and boundary layer generation settings. The result of this was tangible improvements in productivity. So while the stay in F1 may have been quite short, CFD methodologies were being pushed to new levels and other development programmes would feel the benefits.

This was true of the 2011 IndyCar aero development project on the latest car from Dallara, which directly benefited from the F1 recipe. The IndyCar was simpler than the F1 yet required a mesh count of 250 million cells at this stage to analyse the flows to the same level of detail. IndyCar had become an engine competition again, so WR was once again working with HPD, capitalising on the recent Formula 1 experience. The first year on this project was spent mapping the car and doing correlation work in the sophisticated full-scale Windshear wind tunnel in Concord, North Carolina to help provide teams with set-up data. This car started racing in 2012 but, as has been documented, the upgraded aero kits were delayed until 2015.

History can be a hard judge, but while many seem to perceive Virgin Racing's inability to score points during its two years in F1 as a failure, it can also be said that it succeeded in qualifying for, and finishing grands prix, on occasions beating the other two new entrants in 2010, Lotus Racing and Hispania Racing. And while, following its divorce from Wirth Research in mid-2011, Virgin Racing switched to the traditional use of scale wind tunnel testing to supplement CFD development, might it not have been possible that with better overall resources a CFD-developed F1 racecar could have been successful at that time? Today's restricted wind tunnel time and greater reliance on CFD suggests perhaps so.

Rowsell makes the pragmatic point that one of the big factors that pushed Wirth Research on the 'CFD only for development' route, with wind tunnel or track testing used for validation, was to allow customers' budgets to go further. 'One could spend a fortune using CFD, wind tunnel and track testing [for development]. When we stopped using scale model testing for the IndyCar and sportscar programmes it was a combination of correlation issues and cost that made CFD more cost effective, and ultimately it became more accurate. When we entered F1 one of the main reasons we adopted the much talked about "CFD only for development" approach was that the cost of a wind tunnel model to begin the aero programme would have eaten most of the budget before we even started.'

Beyond motorsport

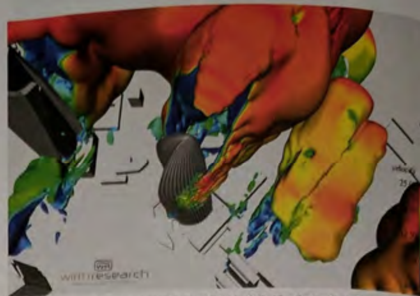
As part of the company's plan to diversify, forays into two very different industries ultimately led to improvements in the simulation methods WR could bring to its motorsport applications.

In 2011 a project with Eddie Stobart was started, the transport and distribution company now operating a fleet of over 2500 trucks from its English base on a pan-European network. The brief was simple: reduce CO_2 emissions (from which, obviously economy benefits would also accrue).

So WR applied the energy efficiency tools it had developed in its motorsport applications. In brief, a truck was scanned, a drag-reducing

Wirth Research CFD methodologies were being pushed to new levels

Steady and unsteady CFD simulations provided CO_2 emission reductions and economy improvements for Eddie Stobart, and over 400 of its trucks now sport WR's aero kits



Architecture has been a successful new field for WR. The Foster & Partners-designed 300 metre tall National Bank of Kuwait (NBK) Tower was the subject of CFD simulations

Studying various tall cylinder shapes helped refine the CFD methodology for architectural flow simulations. It's pretty much impossible to do work such as this in a wind tunnel

kit was developed in CFD, independent correlations were done at MIRA and a 14 per cent drag reduction was achieved, leading to a theoretical seven per cent fuel consumption reduction at the regulation maximum 56mph (90kph): 'At which speed aerodynamic drag is roughly half of total drag,' says Rowsell. The kit was then refined to the most economic to manufacture parts, correlated independently again at Millbrook test track and 20 kits were made and fitted to trucks. 500,000kms later a three per cent real fuel saving was achieved and 400 further kits were then made.

Two different CFD solvers were used during this work; using the '2010 LMP recipe', RANS, or Reynolds Average Navier Stokes steady state solutions were run, and these were compared to DES, or Detached Eddy Simulations. The former is the more widely used method in most CFD solvers, such as ANSYS CFD and OpenFOAM. The latter 'unsteady' solver method is much more hardware intensive than RANS methods, yet for capturing the nuances of inherently unsteady phenomena such as vortex generation around a body like a truck could be more applicable.

At around the same time WR also began working in another entirely new field: architecture. In a pilot project with world-renowned architect Foster and Partners, WR carried out an academic study on vertical cylinders and on a Commonwealth Advisory Aeronautical Council (CAARC) standard tall building to tune the CFD parameters and, like the commercial vehicle work, this also helped to advance WR's understanding of unsteady flow prediction.

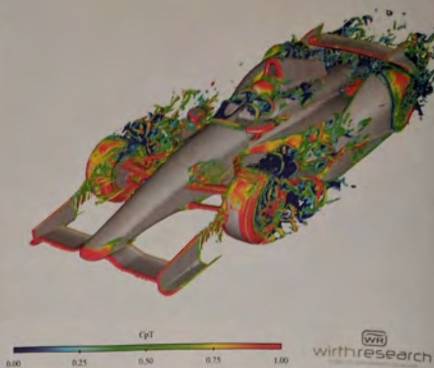
The architectural work focussed primarily on pedestrian 'comfort' near buildings and it's an aspect where CFD is taking over from wind tunnel work. One obvious, basic reason for supplanting wind tunnels is the ability to simulate the correct scale to achieve equivalent Reynolds numbers and, hence, 'flow similarity' in CFD, something which is impossible with scale models of buildings.

The first major project to come in for the WR CFD treatment was the Foster & Partners-designed, 300-metre tall NBK Tower in Kuwait. A practical wind tunnel model of such a body would be two orders of magnitude too small on Reynolds number. It was natural that these improved abilities to simulate unsteady flows were then brought to bear in motorsport simulations.

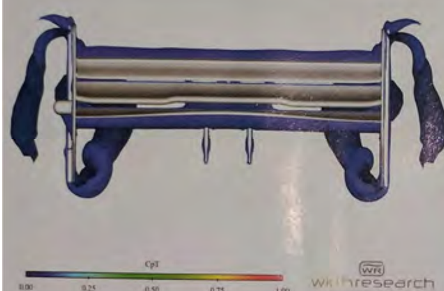
Improved vortex definition was obtained on the 2012 IndyCar model, for example, but there were costs in terms of resource requirements, and there were also some correlation issues as different development routes were followed.

One method of refinement that was used to accelerate small feature development on front and rear wings for the 2014 road course IndyCar was the adoption of sub-models. The model for developing the front wing comprised the front wing, the front wheels, the wheel internals, and a reduced detail rear body; the rear wing sub model was just that, the wing elements, end plates and mounting plates. The results were

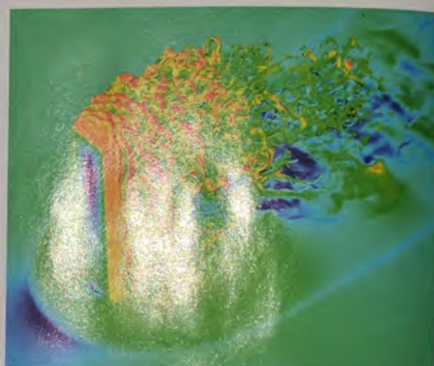
WR applied the energy efficiency tools it had developed in motorsport



Left and above: Unsteady flow methods that were honed with WR's work on tall buildings helped to improve the vortex simulation on the 2012 IndyCar model



Productivity was increased with the use of sub-models; such as this rear wing with end plate assembly and mounting plates. The results correlated closely with full car models



Further simulations in architectural projects (above) helped develop methods now being applied in motorsport. These saw use in the development of the HPD LMP2 cars in 2016

said to correlate closely with the full car models, within limits, but the approach was to significantly increase productivity.

In 2015 WR examined EXA Corporation's PowerFLOW solver. This CFD code uses the so-called Lattice Boltzmann-based physics and differs from RANS solvers (which solve the conservation equations of mass, momentum, and energy in a viscous fluid) by treating the fluid as consisting of imaginary particles, and simulating the flow as a Newtonian fluid in which particle collisions propagate throughout. Its adherents point to its inherently transient nature and claim greater accuracy. However, WR's evaluations showed a large jump in hardware resource requirements; where unsteady DES simulations were 10 to 15 times more resource-intensive than RANS simulations, the Lattice-Boltzmann solver requirement was approximately double that again. Furthermore, in comparisons of the aero gains made on the ARX 04b over the 03b LMP2 car, the results of WR's normal techniques and the Lattice-Boltzmann solver were similar.

Building business

Further architectural simulations saw the seeding of rain into the airflow around buildings using Eulerian multi-phase methods with discrete particle modelling. And another civil engineering project looked at tall, variously shaped prismatic buildings that required the use of unsteady simulations, which helped further develop methodologies that are now being applied in motorsport simulations, and which have been used in the development of the HPD LMP2 cars in 2016.

Among other diverse recent projects were an involvement with the Ford Transit van of motorbike racer turned TV presenter Guy Martin, as he tackled the 2016 Nevada Challenge in the 150mph class; and UAV (drone) development with US and Japanese clients, which have seen low Reynolds number wing and propeller developments which have increased understanding of laminar flow transition prediction, that once again will have wider application.

Method development in CFD at Wirth Research has seen numerous examples of cross-sector knowledge transfer benefiting the speed and accuracy of simulation techniques available for motorsport applications. And, unlike Formula 1 teams, for example, being unfettered by regulatory restrictions on the resources it can utilise WR now says it has 50 per cent more processing capability than a Formula 1 team, if that team was to put all its aero development resources into CFD.

Where once, not so long ago, it was F1 that had the highest level of computational aero resources in motorsport, now, it seems, the independent providers that are the powerhouses of this particular branch of simulation technology.

Wirth now has 50 per cent more processing capability than an F1 team