On the right track

While the IndyCar 2018 Universal Aerokit hit its target window for aerodynamic performance, improving it and modelling its effect on racing is proving to be a very complex task

By ANDREW MOSEDALE

When IndyCar introduced the Universal Aerokit (UAK18) last year to try and encourage cost-effective, safer, more pure racing than when Honda and Chevrolet produced their own kits, there were a range of reactions. The one thing everyone agreed on, though, was it would make things different.

Certainly, the 2018 edition of the Indy 500 was a different kind of spectacle to the previous years, requiring patience, stability and commitment to work one's way up the field. The drivers and teams relished the challenge of getting the best out of the new package throughout the year as they continued to discover more about how UAK18 behaved.

Meanwhile, that same learning was feeding into the aerodynamic development group at IndyCar as they got to work on what changes could be made for 2019.

Aerodynamic development is rarely a straightforward task, even when in control of the regulations. The Universal Aerokit landed in the target window for aerodynamic performance, but there is more to consider than simple calculations of drag and downforce. Safety has remained paramount in planning any changes and this usually requires modelling the aerodynamic behaviour of the car in unexpected positions, as crashes rarely happen for a lone car powering down the straight. Matters of cost and weight distribution also have to be factored in.

With a benchmark level of expectation from the first season of the new Aerokit, any changes had to meet, or exceed, these measures of performance, while also proceeding on track to deliver better racing. And with the launch of the traffic study, in partnership with the Reynard-owned Auto Research Center LLC (www.arcindy.com) and R Systems NA Inc (www.rsystemsinc.com), IndyCar had a new way to predict if developments would correlate with better on-track entertainment.

In the March issue of *Racecar* we saw how the shift in downforce production from the wings to the floor in the UAK18 had a knock-on effect for the car in traffic. Drivers reported having less front grip than they were used to when following another car, and also a lack of stability. Analysis of the forces with CFD (computational fluid dynamics) from ARC's Elements software with two cars in multiple positions showed evidence for this shift in balance towards the rear axle, and revealed some interesting features of the front wing.

Figure 1a shows the flow under the wing for a car running in isolation. The main-plane element is unremarkable, but the flow inside the concave surface under the end plate draws attention. In simplest terms, the area for the air to travel through is expanding too quickly and loses too much momentum to remain attached to the surface. The resulting turbulent flow bleeds onto the main plane, as clearly seen in track testing (**Figure 1b**).

This flow feature is useful in creating low pressure to reduce drag on the front tyres, but **Figures 1** and **2** do not tell the whole story. The flow separation is inconsistent. While the wind tunnel can provide the overall forces on the car, and the track visualisation captures the extent of the turbulent region, neither method is ideal for measuring how steady and reliable those forces are.

Flow sensitivity itself is nothing new. Teams regularly test to see how performance varies with different wing angles and suspension settings. But these tests usually assume the forces don't change if the car is held still. Regardless of the effect on drag or downforce, a car needs to have stable and predictable aerodynamics. This was not the case with the

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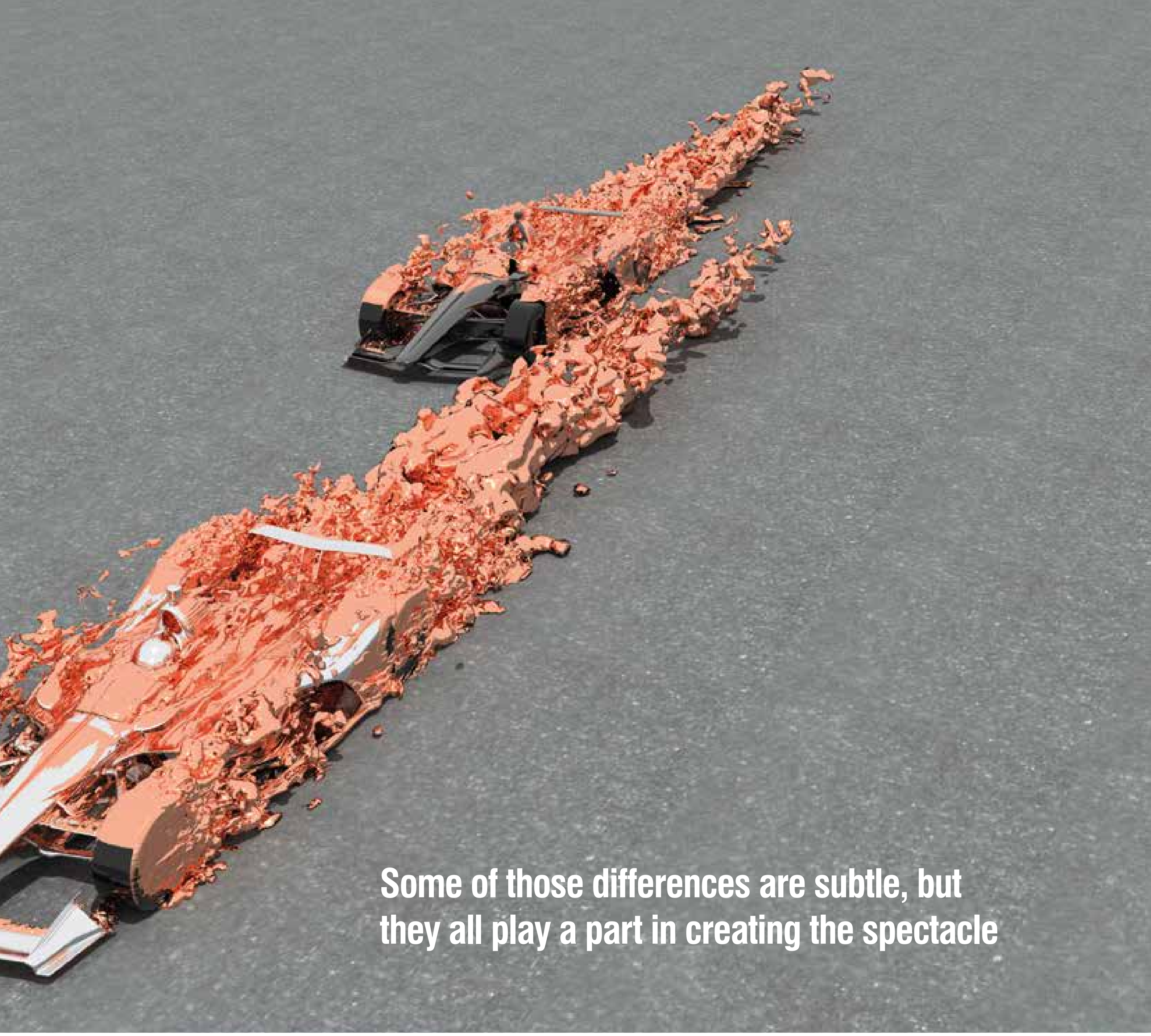

Some of those differences are subtle, but they all play a part in creating the spectacle

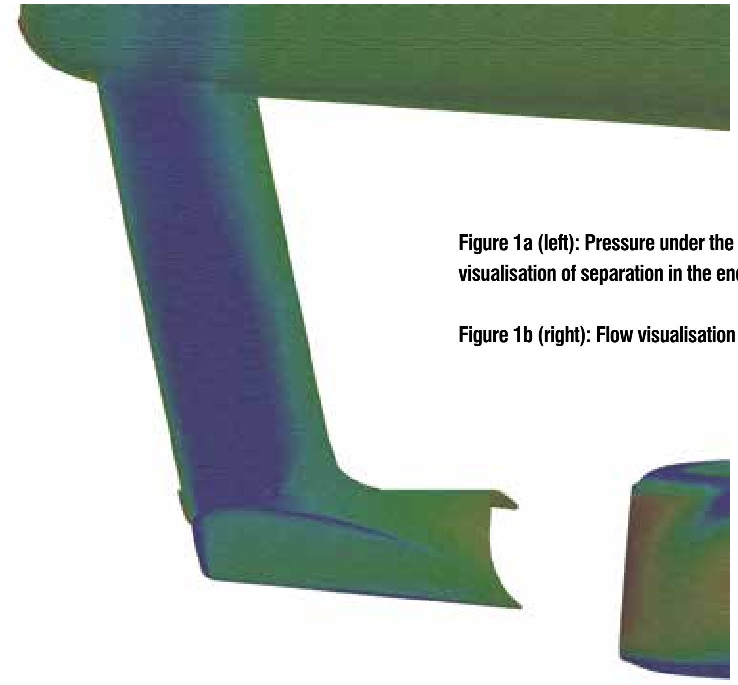

Figure 1a (left): Pressure under the UAK18 wing and visualisation of separation in the end plate

Figure 1b (right): Flow visualisation from track testing

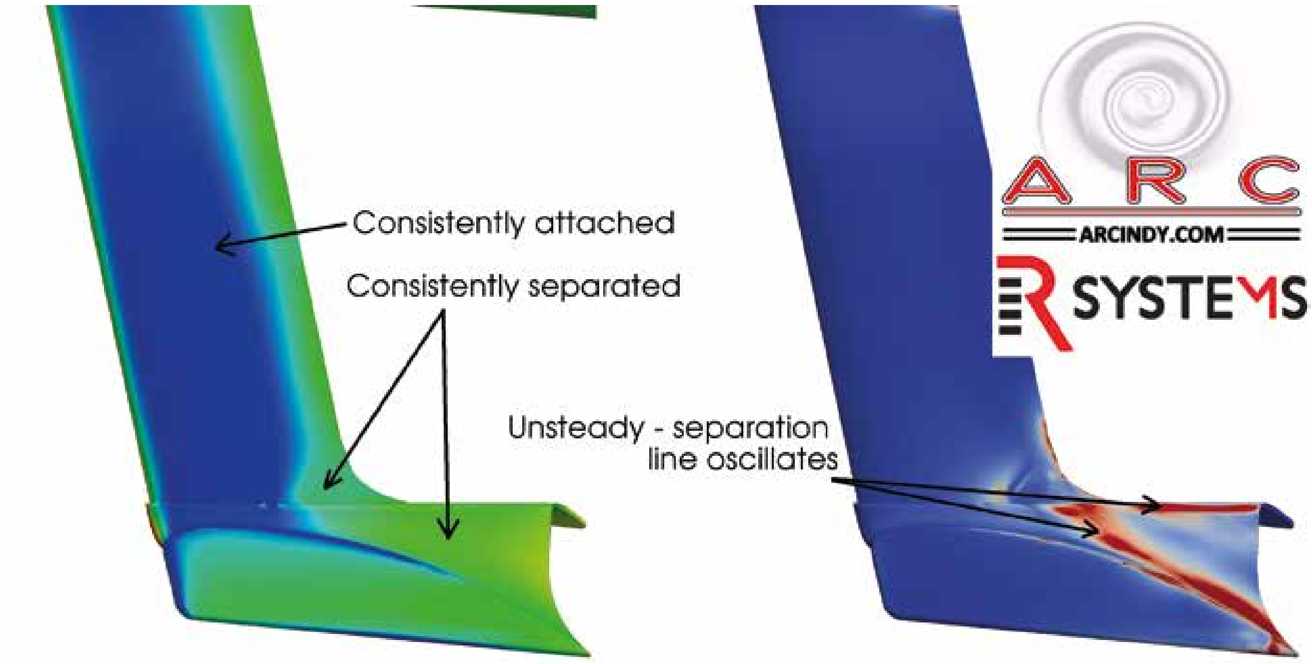

Figure 2: Mean surface pressure (left) and regions of pressure fluctuation (right) under UAK18 wing

The size of the separated region, and the wing area affected, fluctuated significantly over time

Figure 3a: Surface flow of 2019 notch wing from testing

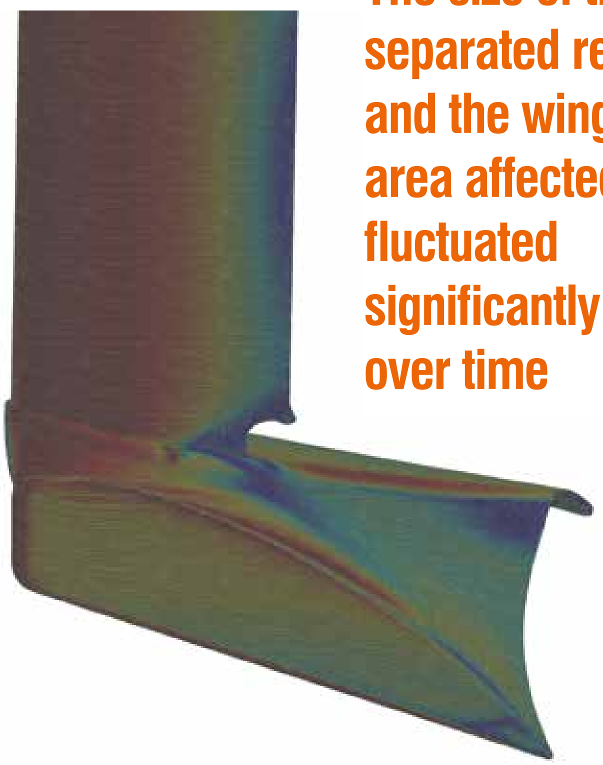

Figure 3b: CFD surface velocities on notch wing

UAK18 front wing end plate. The size of the separated region, and the wing area affected, fluctuated significantly over time. Aside from the feedback from the drivers, the evidence for this is from the transient CFD solution.

Figure 2 shows the average pressures under the wing, alongside the variation in that pressure with time. Some regions show very low variation, and in these the flow is steady and can be well modelled with steady techniques. But a large section of the wing cannot be properly predicted without accounting for how flow changes over time.

Given how important this area is to predicting the flow past the front wheels and onto the rest of the car, selecting appropriate CFD methods can make a big difference to understanding car performance, and is critical to being able to simulate effects downstream on a following car (see side panel on p66).

Stepping up a notch

Having identified that the intersection of the wing element and end plate was underperforming, several changes were considered. One such change can be seen on the 2019 cars in the form of a notch at the end of the wing, as shown in **Figures 3**.

This cut reduces the wing area and allows air to leak through to the suction side of the wing. This is normally a bad idea, but the high pressure air in this case stabilises the flow and leads to better performance. **Figure 3a** shows the flow in the end plate region during testing, and **Figure 3b** its correlation with CFD, while **Figure 4** indicates that the influence of the concerning transient separation is now greatly reduced. While a simple change, the notch in the front wing passes the combined

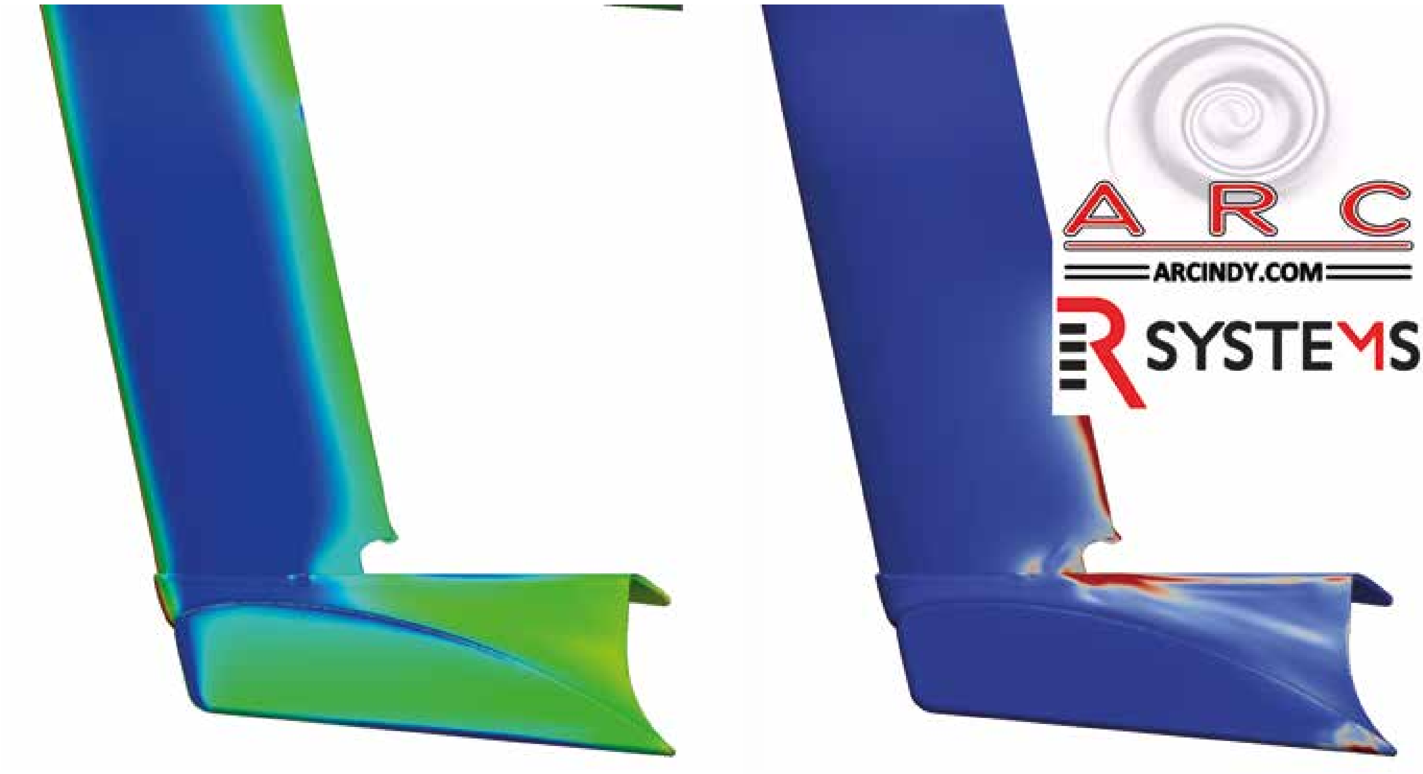

Figure 4: Notch in 2019 wing significantly reduces unsteady separation in end plate

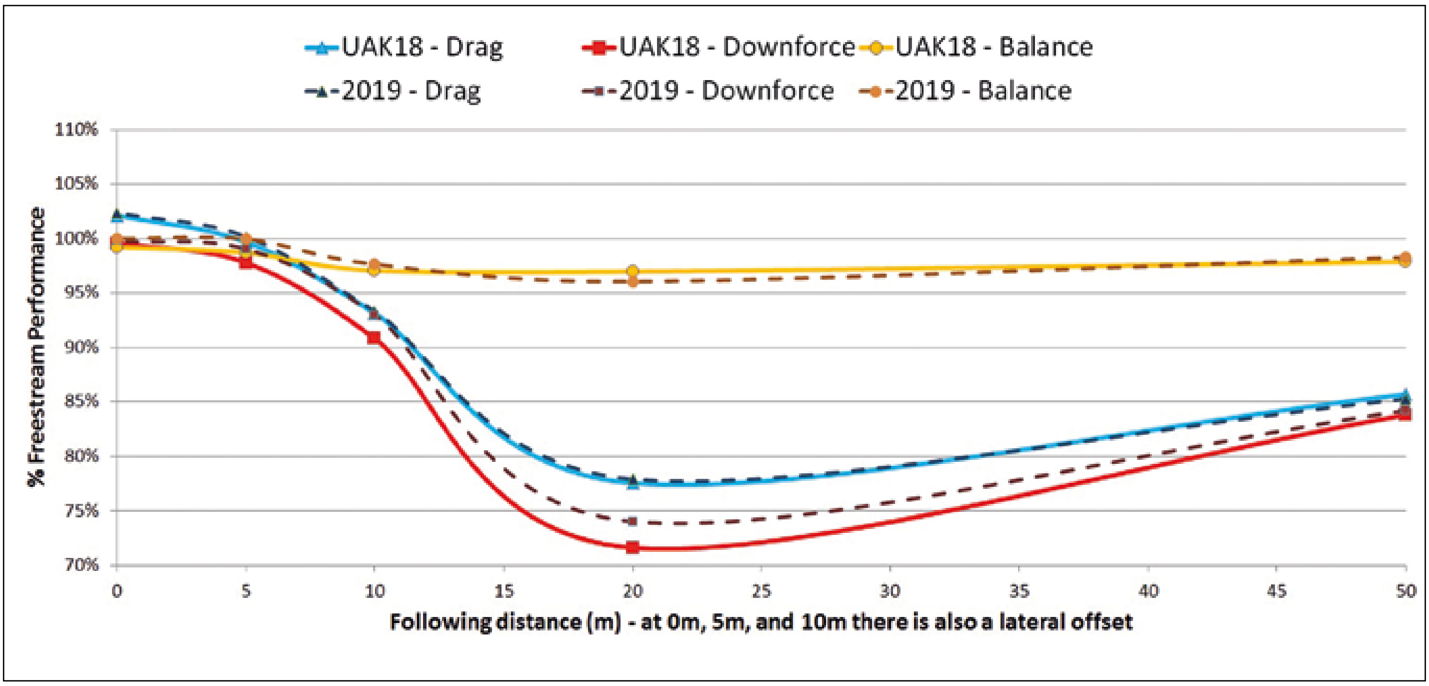

Figure 5: Change in aero performance of car due to position in overtaking manoeuvre

Front downforce recovers more quickly as you move out from behind the car ahead, providing better balance at the crucial moment

tests of improving outright performance, being cost-effective and not compromising safety. But does it improve racing?

In the past, that question would have to wait until the cars are on track at the speedway. Now, with the CFD traffic study, we can assess part changes for overtaking potential before they are even made. As part of the study, a generic overtaking trajectory was determined from GPS data of previous iterations of the Indy 500 race. By simulating the changes in the drag, downforce and balance of the car at key points along this trajectory we can anticipate what the effect of new geometry will be in the race. The results are shown for UAK18, and with the 2019 notched wing, in **Figure 5**.

The points relate to specific parts of putting together an overtaking manoeuvre. Drafting is a fundamental part of overtaking at the speedway, so it is good to see that drag was unaffected. Last year showed that downforce and handling were still critical to follow through the corners, as it took longer than a single straightaway to close the gap. The more

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stable wing shows more consistent downforce available as you close in from 50m to 20m.

The next two points are critical to evaluating driveability of the car as it pulls out of the wake of the leader. With the 2019 wing, the front downforce recovers more quickly as you move out from behind the car ahead, providing better balance at the crucial moment. Once alongside, knowing if you should expect oversteer or understeer may influence whether you want to hold on to the inside line or go high.

Take the high road?

As is seen from just this one simple change, there are many things to consider in your race strategy, on the pit wall and for the driver. Making the car stronger in one area will almost always compromise you somewhere else.

An example of this is **Figure 6**, which shows a sample of other configurations available to teams in 2019. These have all be designed to give the same bottom line performance in free air, but react in different ways in traffic. Some of those differences are subtle, but they all play a part in creating the spectacle.

Deciding whether to sacrifice some drafting benefit for more downforce behind the car, or taking oversteer when you pull alongside in exchange for less understeer as you close the gap, these trade-offs have always been part of the set up on race day, but now they go to the heart of what it means to design and develop not just a fast car, but an entertaining racecar.

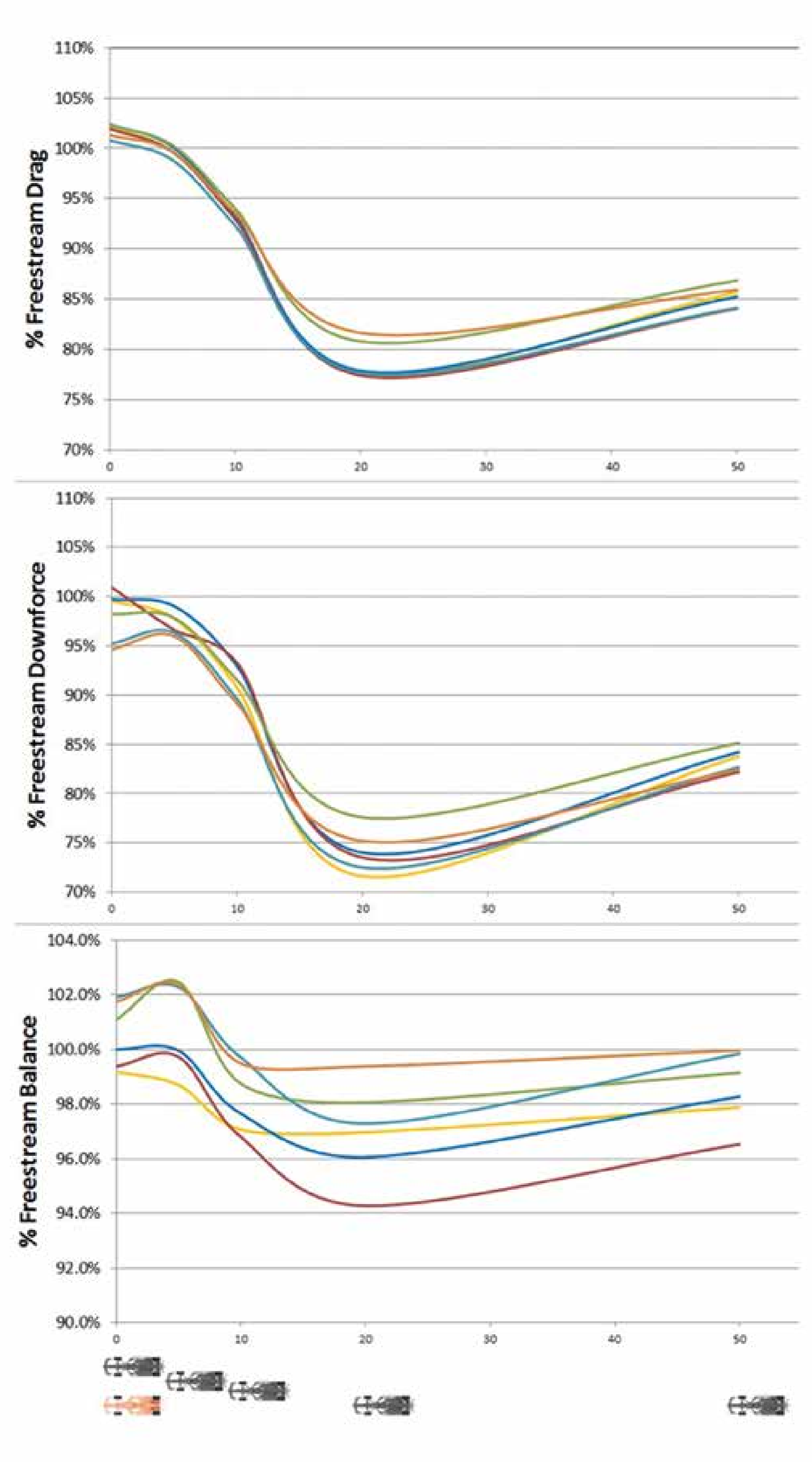

Figure 6: A range of configurations that give the same performance in isolation, but behave radically differently in traffic

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Choosing CFD carefully

Despite the progress made in computational methods in the past decade, there is still a level of compromise required by the CFD engineer in determining how best to model the real world. While the aerospace industry has developed highly specific and efficient models for its streamlined bodies, the automotive industry has almost entirely transitioned to a physically accurate, but more expensive option of resolving large-scale turbulence in both time and space. Due to the influence of large areas of turbulent flow on the forces of ground vehicles, these models are seen as necessary to move development forward.

The CFD used in IndyCar's traffic study uses such a turbulence model in its detached eddy simulation (DES), but the older approximations from aerospace that solve the simpler Reynolds-averaged Navier-Stokes (RANS) equations are still regularly used in some areas of motorsport. Identifying which model to use in different situations requires a comprehensive understanding of the errors associated with each.

The difference between an instantaneous snapshot of the DES flow, the average of the flow, and the output of a RANS model (k-ω SST) is shown in **Figure 7**. The most immediate observation is that the averaged views give a much stronger impression of big flow structures that may not relate intuitively to the 'real-time' picture.

Detail of the flow structures under the car in **Figure 8** shows how the front wing generates coherent vortices in both models, but immediately the resolution of the front wheel wake changes the picture with the RANS model implying much more outwash from the front of the car than is realistic.

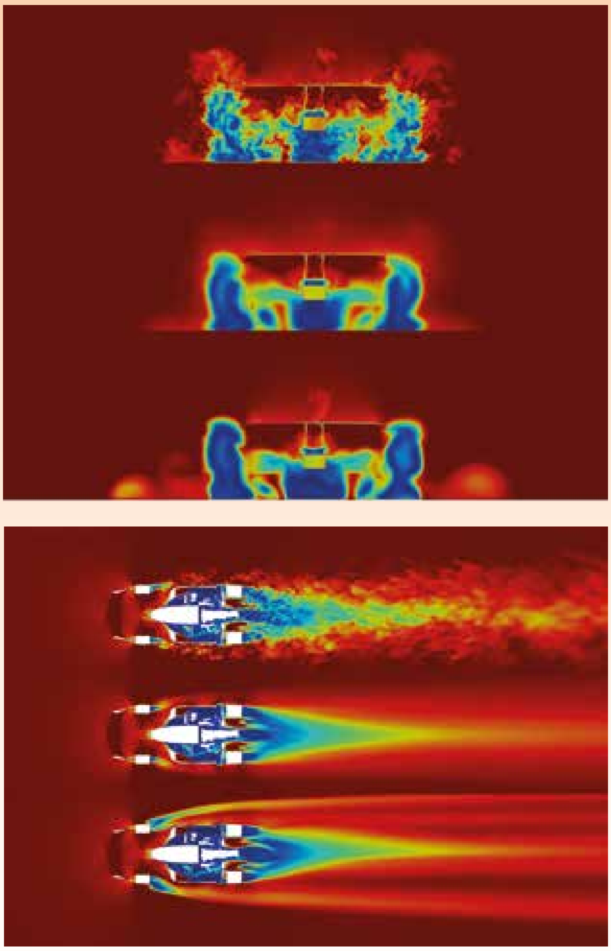

Figure 7: Instantaneous velocities during a typical transient simulation (top), compared to the mean flow field (middle) and the output of a RANS solver (bottom)

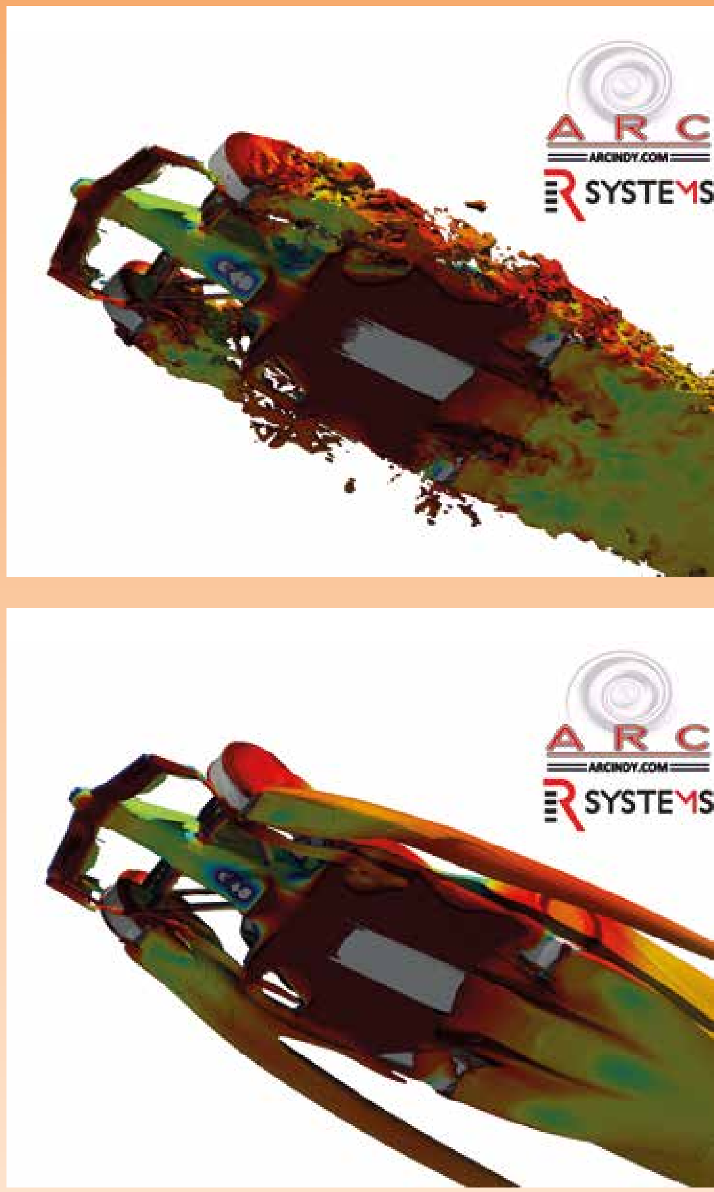

Figure 8: Total pressure isosurfaces from DES (top) and RANS (bottom). Much of the flow is broadly similar, but for certain areas the differences are significant

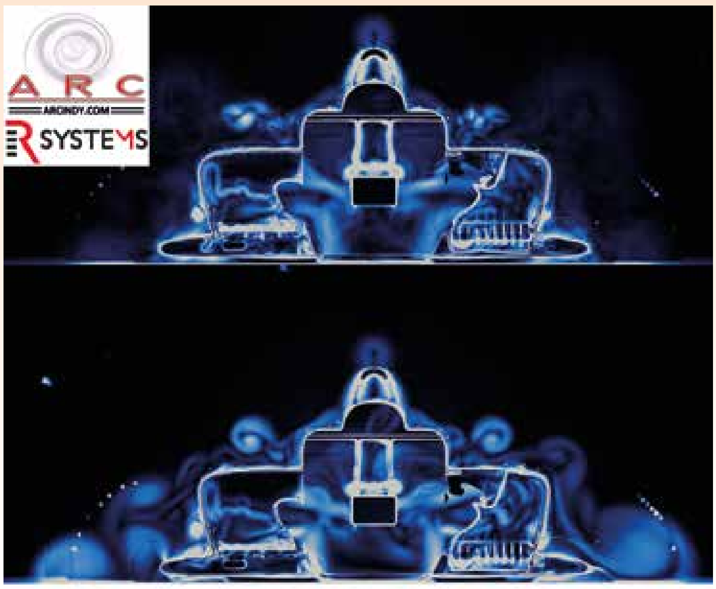

Figure 9: Resolved mean vertical structures in DES (top) vs RANS (bottom)

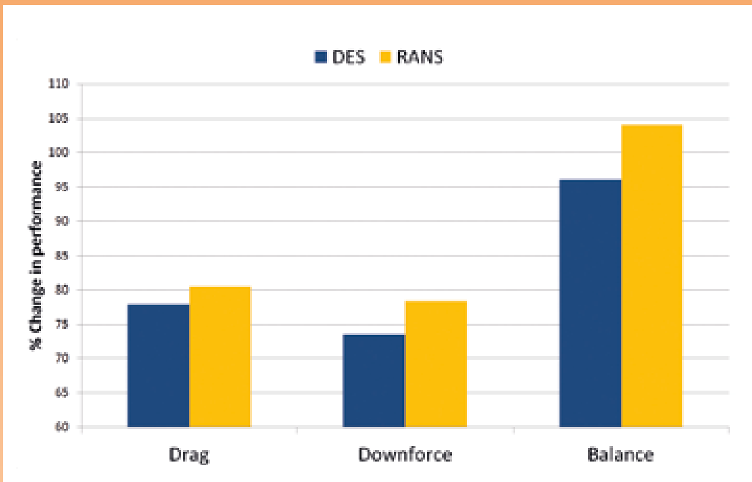

Figure 10: At 20m following distance, RANS under predicts wake effects and significantly indicates a forward shift in balance. This is the opposite trend to that reported by the teams and observed in the DES study

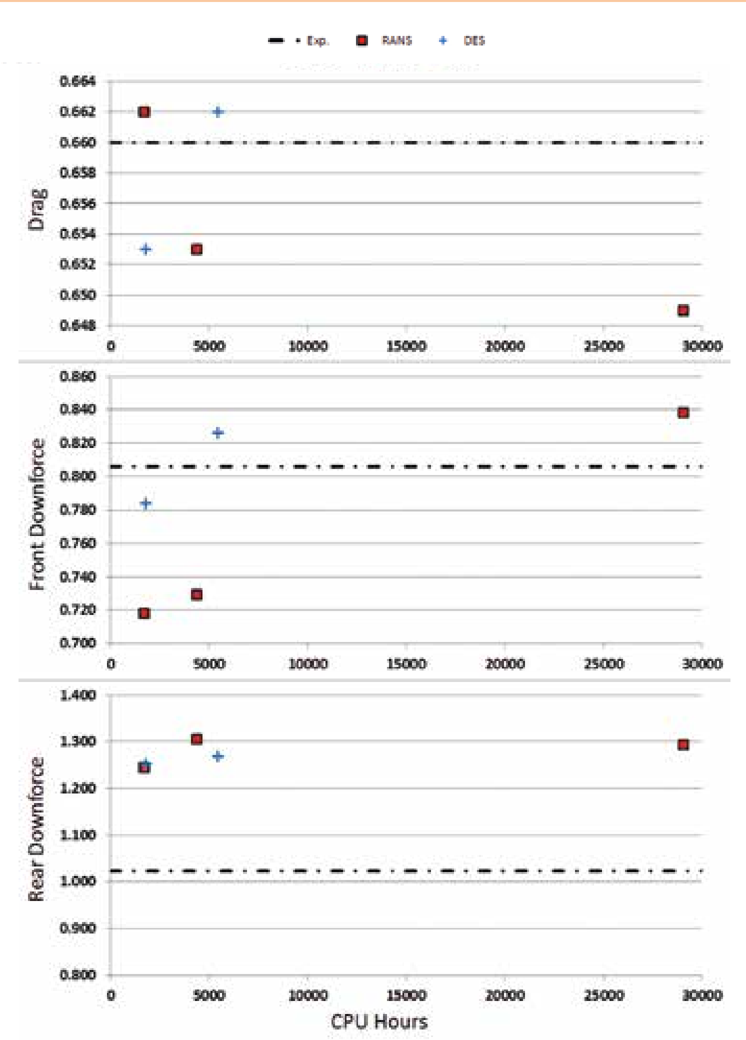

Figure 11: Accuracy of simulation to wind tunnel data of UAK18 by method and compute time

In a cost-equal analysis, a low-resolution DES result is typically more accurate than high-resolution RANS

While the time-averaged DES is simply a post-processing technique, the coherent structures in the RANS (**Figure 9**) are seen as real, and can come to dominate and skew the final result. This can lead into a vicious circle with engineers chasing artificial vortices that may not represent the underlying physics well at all.

Using RANS methods to model the impact of a following car can result in misleading information. The data in **Figure 10** shows the trend for balance is in fact reversed in this case from both the DES result and the reported on-track behaviour. The impact of the wake on drag and downforce is also understated, a consequence of the idealised vortices persisting rather than breaking down into smaller turbulent structures.

A strong argument in support of RANS is that it is quicker and cheaper for a given size of simulation. This allows for studying more options that may outweigh the loss in accuracy. However, this advantage can be undermined without great care. Without knowing which trends to trust from RANS simulation, time is lost in wind tunnel testing and on track attempting to verify ideas, and over half the output can be wasted.

Also, the tendency historically has been to tackle the lack of physical accuracy by minimising the error in the simulation from numerical dissipation. The nature of RANS is that the results are sensitive to using smaller cells in the computational mesh. It is routine to use hundreds of millions of these cells, even for a single car, but this increases the cost and cannot capture the type of transient physics needed to correlate fully to the real world. Although DES is often assumed to have even higher mesh requirements for accuracy, in practice only the largest eddies need to be resolved correctly to characterise the underlying physics of open-wheel racing to a high degree.

In a cost-equal analysis, a low-resolution DES result is typically more accurate than high-resolution RANS. In effect, the error caused from numerical dissipation is not as significant as the error introduced from the turbulence model.

Of course, this conclusion is dependent on the physics involved, but it has been observed repeatedly to be true for a range of motorsport applications, and **Figure 11** demonstrates its relevance to IndyCar.

Drag is captured fairly well, although the RANS solution trends in the wrong direction, even with a significant increase in computational effort. This longer run time is necessary for the RANS approach to get close on front downforce, although it is still not as accurate as either of the quicker DES results. Rear downforce is similar between the different solvers.

So in conclusion, for the purposes of rapid development, the DES approach gives a better prediction of overall forces in a matter of hours, and also allows for multi-car studies with good correlation to the track. To see the effect on the racing spectacle, we will have to wait a little longer.

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