

Where science meets art

How IndyCar has worked, and is still working, to find that tricky balance between making on-track passing possible at Indianapolis while retaining the fundamental racer's skill of overtaking

By **STAN SANDOVAL**



Many of the most iconic moments in the history of the Indianapolis 500 have been overtakes; daring passes completed at the last possible second by the bravest drivers in the world. Other times, the biggest drama comes when the pass isn't quite completed, and instead the race back to the finish line is lost by mere inches, coming up agonizingly short.

There is an art and a science to overtaking at the Indianapolis 500, and mastering this skill is often the difference between glory and heartbreak. But perfecting overtaking has

always been a moving target; as technology evolves and the cars change, the type of racing seen during the Indy 500 changes as well.

In May of 2017 slipstreaming reigned supreme as the go-to method for passing. The suck up effect was powerful, which made the leader a sitting duck. Therefore, *when* a driver made a move seemed to be more important than *how* that driver made a move.

Fast forward to May 2018, and the technique to set up a pass was now a lot more nuanced: it was all about setting up your prey and pouncing at the last possible second. Tactics and bravery

became the requisite skills to overtaking at Indianapolis for the 2018 race.

The difference in how overtaking at this great race plays out can be largely attributed to two things: tyres and aerodynamics. The 2017 season marked the last year of manufacturer-developed aero kits and 2018 saw the start of the universal aero kit, called the UAK18. This new outfit for the Dallara DW12 chassis brought a huge aesthetic change, but also an interesting opportunity for IndyCar: the chance to dictate the aerodynamic behaviour of the entire field, and therefore, improve the racing. With the

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UAK18, IndyCar’s main goal was clear: to make overtaking exciting, dramatic, and skilful.

With all this in mind IndyCar has implemented a study to understand how aerodynamics affects overtaking by conducting two-car CFD simulations of both the UAK18 and manufacturer aero kits from 2017. Given the difference in the racing between the 2017 and 2018 Indy 500s, the objective was to understand any aerodynamic characteristics that led to the large slipstream effect in 2017 and the increased difficulty in following closely in 2018.

Using a CFD software suite designed specifically for automotive aerodynamics called Elements, developed by Indianapolis-based Auto Research Center (ARC), various following two-car configurations were simulated for each aero kit. IndyCar and ARC have spared no expense in conducting these simulations. Each was modelled considering turbulent, unsteady, and incompressible flow, making these some of the most advanced automotive computer simulations in the world.

Calculating simulations with this level of complexity required serious computing power. R Systems NA Inc’s experience in motorsport, large capacity, and in cluster configuration created an optimal solution. IndyCar ran hundreds of jobs on its Broadwell E5-2697Av4 nodes with 32 cores each, 256GB RAM, and Non-Blocking FDR Infiniband. With the CFD simulations in place and the proper computing power now acquired, hundreds of simulations were carried out. From these simulations, some striking aero differences between the two IndyCar aero kits were revealed.

Initial single-car CFD simulations of both the 2017 and 2018 aero kits were validated against moving ground wind tunnel results conducted by ARC in Indianapolis. Once this baseline check had been completed, two-car simulations began. Multiple two-car simulations were carried out for both aero kits, with the position of the following car varied in order to get a sense of how each aero kit behaves when battling with another car on track.

Analysing the wake

The wake generated by each aero kit was a hugely influential factor on how each car raced during the Indy 500. Understanding the differences in the wakes generated by the 2017 and 2018 aero kits would be key to understanding why the type of racing and overtaking seen at Indianapolis changed.

To start, the wake created by each aero kit in isolation was visualised and assessed. Using the Honda aero kit from 2017 and this year’s UAK18, plots of total pressure coefficient were created to show where energy loss in the flow was most prevalent behind the car. From these visualisations, the size, strength, and shape of



Bravery and skill is needed when passing at Indianapolis; as Alexander Rossi certainly demonstrated at the 2018 Indy 500



The 50 per cent scale UAK18 model in the ARC Wind Tunnel during aerodynamic testing. *Courtesy of ARC*

the wake created by each aero kit could then be observed and compared (see p24).

When viewed from above, **Figure 1** showed that the UAK18 generally had a much larger wake. The wake of the UAK18 also widened as it travelled further downstream. The wake of the 2017 Honda narrowed as it travelled further downstream, and it also appeared to weaken while the UAK18 wake maintained a relatively

consistent strength. In **Figure 2**, the 2017 Honda wake grew taller as it travelled downstream, whereas the UAK18 wake maintained a relatively consistent height.

To give some insight into why each wake takes on the shape that it does, streamlines were plotted and colour-coded by velocity for both aero kits in **Figure 3**. These streamlines show that the rear tyres were influential in



Some striking differences between the two aero kits were revealed

determining the shape of the wake. The wheel guards on the 2017 Honda kit were able to control the flow behind the rear tyres; however, for the UAK18, the rear tyres were left exposed. This was a contributing factor as to why the wake of the UAK18 continued to widen while the 2017 Honda wake narrowed.

Similarly, the streamlines behind the 2017 Honda rose as they travelled downstream, while for the UAK18 they stayed in close proximity to the ground, which was also consistent with the shape of the wake. This was due to the 2017 Honda generating more rear wing downforce and therefore upwash, while the UAK18 created a larger percentage of its downforce using the underwing. Still, while some obvious differences in the wake characteristics were found, how these differences affected a racecar following closely behind another and attempting to overtake remained to be seen.

Performance in traffic

One of the most important factors for overtaking is how a car behaves when following closely behind another car. This is when aerodynamic effects like dirty air and slipstream are greatest, but also when an overtake is most likely to occur. IndyCar, ARC, R-Systems and Parallel Works have worked together to use these CFD simulations to quantify how drastically the performance of each aero kit changes when following in traffic by comparing downforce, drag, and balance when in traffic to when running alone. Using the two-car simulation where the following racecar is directly behind the leading car at a following distance of one car length, the change in performance was calculated; see **Figure 4**.

At a following distance of one car length, the UAK18 showed a six per cent greater downforce loss than the 2017 Honda, but the slipstream effect was seven per cent stronger. However, the centre of pressure of the UAK18 moved rearward

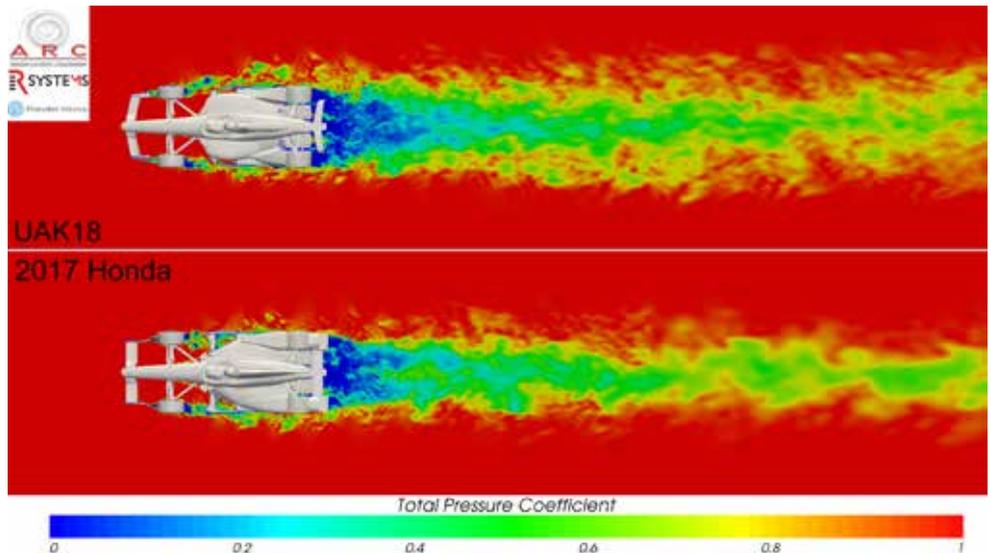


Figure 1: Comparison of total pressure coefficient for the single-car case at the height of the front wing airfoil, as seen from above. The UAK18 bodykit generally had a much larger wake and this also widened as it travelled further downstream

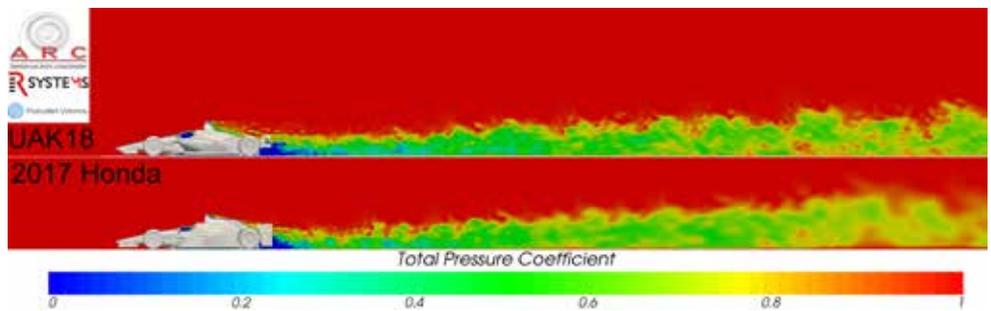


Figure 2: Comparison of total pressure coefficient for the single-car case along the centreline of each car, seen in profile. The Honda wake grew taller as it travelled downstream whereas the UAK18 wake maintained a relatively consistent height

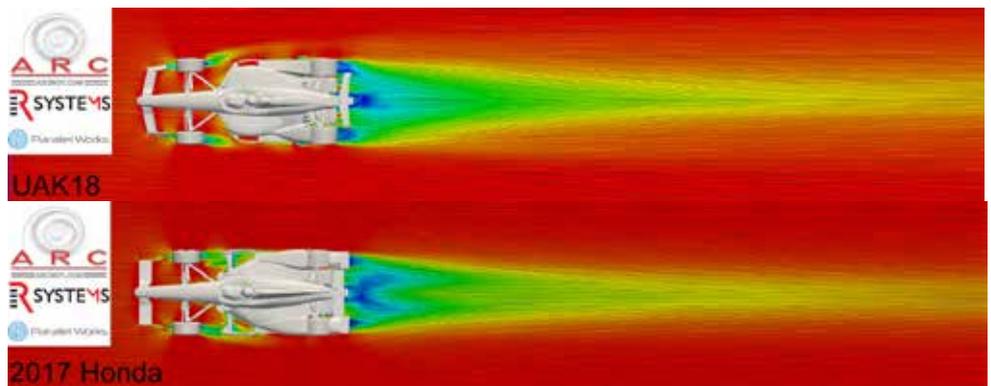


Figure 3: Comparison of streamlines (colour-coded by velocity) for the single-car case at the height of the front wing airfoil, seen from above. These streamlines illustrate that the rear tyres were influential in determining the shape of the car's wake

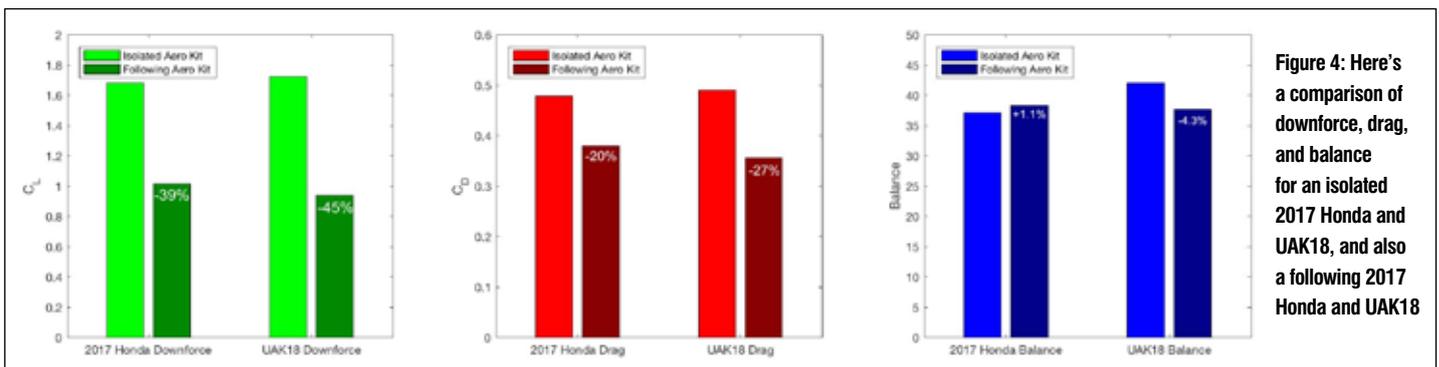


Figure 4: Here's a comparison of downforce, drag, and balance for an isolated 2017 Honda and UAK18, and also a following 2017 Honda and UAK18

‘When you get close to other racecars the front goes, and that was the problem’

more than four per cent while the 2017 Honda’s aero balance moved forward approximately one per cent. Note how the balance of the following car was set by the drivers to be similar to 2017 in UAK18, but as a consequence the UAK18 has more oversteer when leading. While the loss in downforce and drag were somewhat similar between the two aero kits, the discrepancy in balance shift was large. Drivers and engineers across the paddock agreed, the balance shift in the UAK18 was greater than the 2017, and that this made it difficult to set up an overtake.

‘On my own I was loose. But I had to run like that because otherwise I would push in traffic,’ says Team Penske driver Simon Pagenaud.

Chip Ganassi Racing engineering manager Julian Robertson echoed this sentiment. ‘When you get close to other people, the front goes, that was the problem,’ he says. ‘It always has done, but you live with it. But this year your tools had to be all one way to even stand a chance in traffic. You had to be loose on your own to be half decent in traffic; it was a big disparity.’

Balancing act

The change in balance was identified as one of the principal causes for overtaking being more difficult at the 2018 Indy 500. Therefore, further investigation was conducted in CFD to understand why there was such a large difference in balance shift between the two aero kits. Surface pressure across the entire car was plotted for both aero kits in order to visually demonstrate where downforce was being lost on the following car. This was then validated numerically by breaking down the

per cent downforce loss suffered by the main aerodynamic devices on the racecar between the isolated case and when following behind another racecar at a distance of one car length, as is illustrated below in **Table 1**.

As is evident both visually and numerically, the biggest discrepancy between the two aero kits was the loss of performance experienced by the front wing. The UAK18 front wing appeared to suffer more than the 2017 Honda when operating in the wake. Yet, no evidence of airfoil stall or massive separation was found on either following car’s front wing.

So, the effect of the wake of the leading car on the following car’s front wing was thought to be the main culprit, given the differences between the two wakes found previously. The effect of the leading car on the following car front wing was investigated to understand just how influential the wake is in determining the front wing performance of the following car.

From **Figure 9** it was evident that the available total pressure in the wake for the front wing to utilise was significantly less for the following UAK18 than the following 2017 Honda, due primarily to the difference in wake characteristics. With this loss of total pressure, the ability of the UAK18 front wing to generate downforce when following closely suffered greatly compared to the 2017 Honda, all due to the wake of the leading car.

Not only did this explain the discrepancy in front wing performance in traffic, but also the disparity in balance shift between the two aero kits. This was seen as the main cause for overtaking being more difficult in 2018

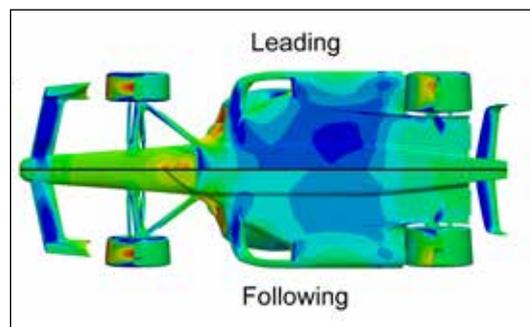


Figure 5: A comparison of the surface pressure distribution for UAK18 when running in front and then behind, viewed from below

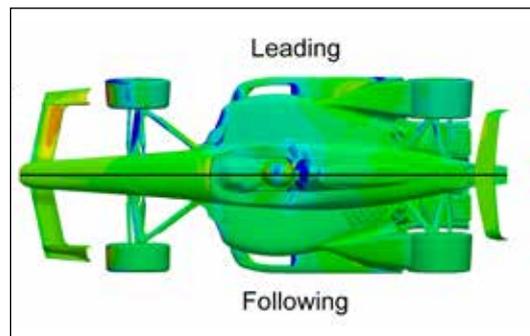


Figure 6: This shows the same comparison of the surface pressures acting on the UAK18, this time viewed from above

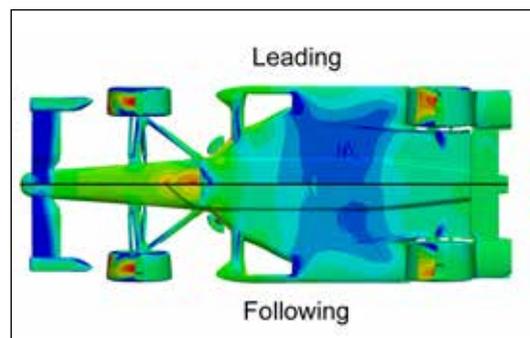


Figure 7: A comparison of the surface pressure distribution for the Honda when running in front and behind, viewed from below

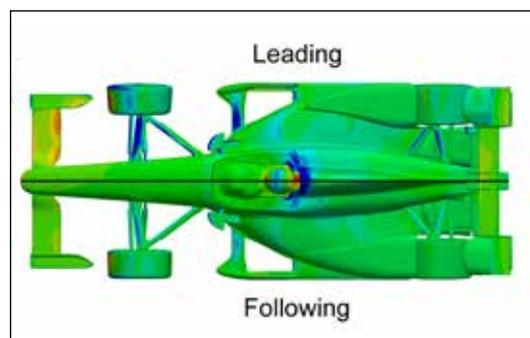


Figure 8: This is the same comparison of the surface pressures acting on the 2017 Honda bodykit, viewed from above the car

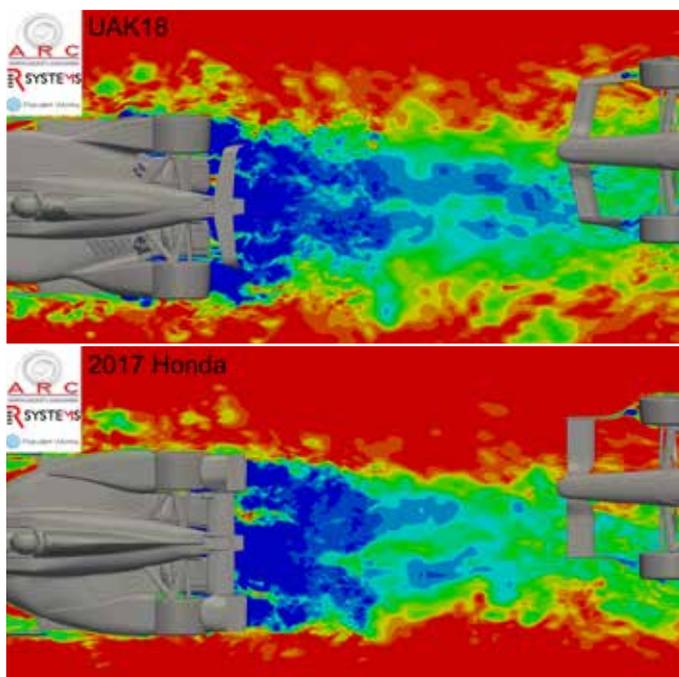


Figure 9: This shows a comparison of total pressure coefficient for the two-car case at the height of the front wing airfoil, viewed from above

Component	CL % change	UAK18	2017 Honda
Front wing		-44.684	-16.529
Cockpit and floor		-40.615	-39.571
Rear wing		-4.802	-19.695
Wheel guard		–	-53.794

Table 1: A comparison of per cent change in downforce relative to the single-car case; as experienced by various components on a following UAK18 and also on a following Honda 2017 kit

The UAK18 front wing appeared to suffer more when operating in the wake

compared to the 2017 season, and the solutions to this are already in the works.

These include front wing extensions, which were made available to the teams at Pocono. They will be allowed to use these for the 2019 Indy 500. This allows them to have more front downforce by extending the chord of the airfoil.

Together with Firestone, new tyre compounds and constructions have also been tested on several occasions at Indianapolis in order to give additional mechanical front grip. With the reasons as to why overtaking was more difficult in 2018 identified and remedies already in place for next year, the 2019 Indy 500 is expected to feature more close racing and overtaking, though not without the requisite bravery and skill from the drivers.

Mapping an overtake

Simulations were conducted where the position of the following car relative to the leading car was varied by up to 50 metres in distance and six metres in offset. With these results, a predictive model was developed in order to create a map of aerodynamic performance as a function of following position. With this, the behaviour of both the leading and following cars was calculated at each and every moment during an overtake, as shown in **Figure 10**.

Another vital use of this mapping is its integration with the driver-in-the-loop (DIL) simulator. DIL has become an essential training tool for race drivers, as track time is not always feasible. By simulating two-car situations in CFD and integrating the results in DIL, drivers would be able to experience traffic situations in the simulator, with all the aerodynamic consequences that come with following and overtaking another racecar.

Beyond helping drivers practise following and overtaking, the DIL could also be used to get driver feedback on how an aero kit performs in race traffic. This could be extremely useful for understanding how potential changes to an aero kit will impact the racing on track. Just like CFD, the DIL could be an important tool in developing future aero kits.

Conclusion

Overtaking should always require skill and bravery from the drivers, but it can't be so difficult that it leads to a high-speed parade. However, finding that balance is a very difficult



The biggest discrepancy between the two aero kits was the loss in performance experienced by the UAK18's front wing



Front wing extensions were made available to the teams at Pocono in 2018 and will now also be used in the 2019 Indy 500

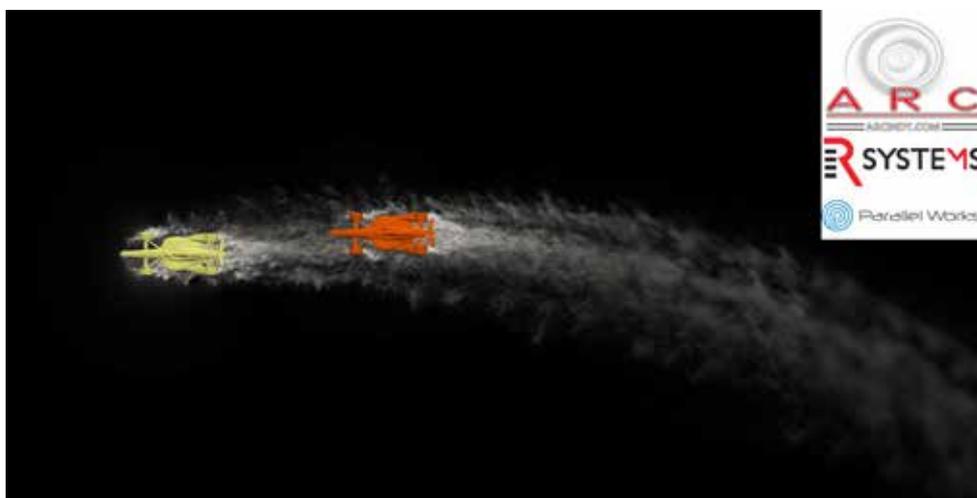


Figure 10: Velocity contours for two UAK18 kits. The predictive map for following-car aero will be used in DIL simulators

task, as it exists on a knife-edge. With the help of ARC, R-Systems and Parallel Works, a foundation has been laid using CFD to quantify the difficulty of overtaking due to aerodynamics. With this knowledge, future iterations of IndyCar aero kits can be designed with overtaking performance in mind. It can become another design parameter just like a target downforce or spin stability.

In doing this, racing at Indy can be engineered to make it challenging for the drivers and entertaining for fans. Once again, overtaking can become a work of art.



 The Honda Performance Development DIL simulator (Honda)