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Racecar engineering

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Draft dodging

Lots of (frequently hot) air is expended on the topic of aerodynamics influencing racing. CFD puts some real numbers on it…

Words	Simon McBeath
Images	Advantage CFD; Sutton

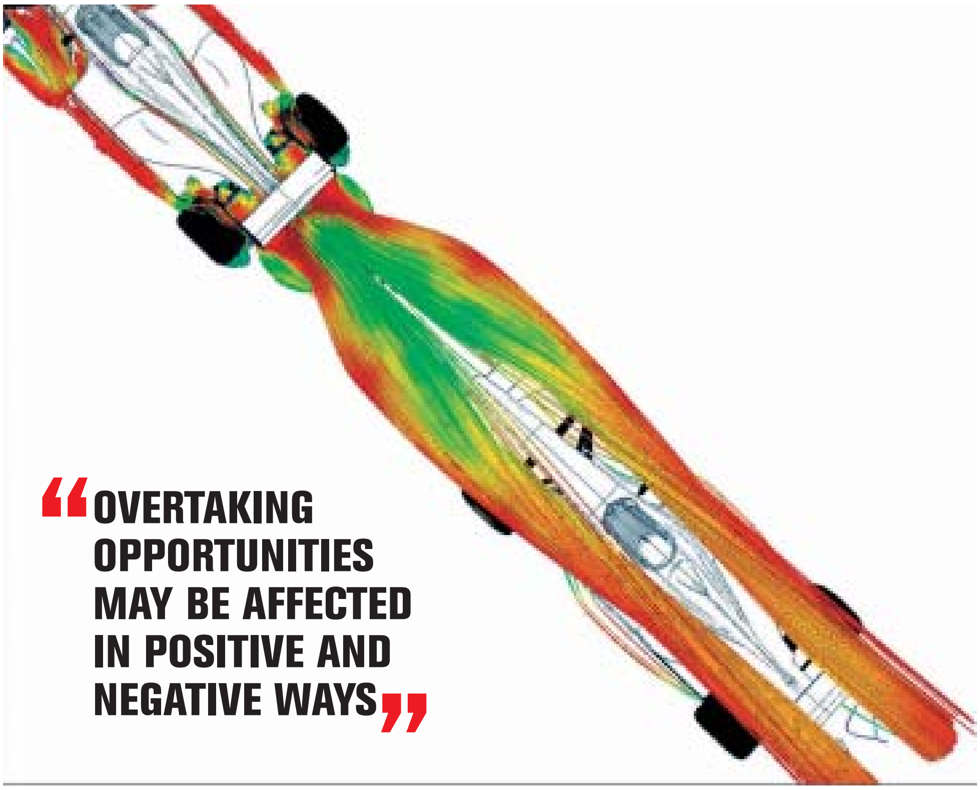
Long before downforce was 'invented' racers already knew about the drag reductions in the wake of the car in front that enabled 'slip streaming' or 'drafting'. Later, when wing-generated downforce and then underbody downforce became exploited, the loss of downforce on the following car became clear. Whether these effects are perceived as beneficial or detrimental depends, at the most basic level, on whether you're in the car in front or the one behind.

Some think the effects are crucial. There is a commonly held perception that downforce ruins racing because it lessens the opportunities for overtaking. This is a debatable view, and examples could be cited of poor racing in categories where downforce is outlawed, and excellent racing where downforce plays a big part in racecar performance. And let us not forget that overtaking frequency is also influenced by other factors such as track design, driver ability and, seemingly in the case of Formula 1 these days, car colour…

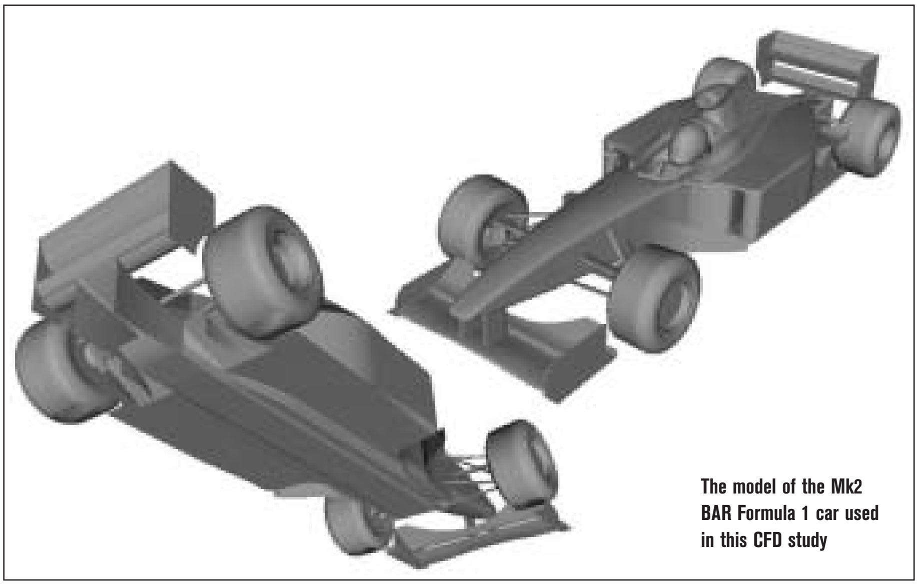
However, what is not arguable is that racecars interact aerodynamically in ways that can both improve and worsen performance. Overtaking opportunities may be affected in positive and negative ways. So just what are the aerodynamic effects, and how big are they? Front-running F1 team BAR commissioned Advantage CFD (now owned by BAR) to carry out a computational fluid dynamics study on the interaction between two cars running line astern using the virtual model of one of its earlier cars (figures 1 and 2), and has now revealed the results to Racecar Engineering. Though current cars are very different in detail to those of a few years ago, it is realistic to expect that the trends shown will be very similar today.

Balance shift

Cases of two cars running at separation distances ranging from a half car's length to eight car lengths were evaluated against a baseline single car, all at the equivalent of 200mph (320km/h). The graph in figure 3 summarises the percentage changes to the overall forces felt by the following car, and the results are plain to see. There is a reduction in drag and a reduction in overall downforce, and the magnitude of these reductions increases



“OVERTAKING OPPORTUNITIES MAY BE AFFECTED IN POSITIVE AND NEGATIVE WAYS”



The model of the Mk2 BAR Formula 1 car used in this CFD study

with decreasing car separation, the more so at closer separations. Thus, even at eight car lengths separation, the following car senses a 13 per cent reduction in drag, but also experiences nearly 18 per cent reduction on downforce. These values rise to 28 and 45 per cent respectively at a half car's length separation.

Looking a little more closely at this graph, the relative changes to the front and the rear of the following car are also shown. Clearly both ends of the car see a drop in downforce, but the reduction at the front is considerably bigger, resulting in a rearward shift of the aerodynamic balance. Interestingly this rearward balance shift is actually pretty consistent across the range of separations investigated, averaging around 6 per cent shift to the rear. The magnitude of the reduction at the front is as high as 29 per cent even at eight car lengths, rising to over 53 per cent loss of downforce at half a car's separation, while at the rear the reduction is just 10 per cent at eight car lengths, rising to nearly 39 per cent at half a car's separation.

It doesn't take a huge mental leap to connect these substantial aerodynamic changes felt by the following car to the real world ability to close the gap to the car in front along fast straights, or to the understeer experienced by the following car in corners where aerodynamic loads are significant. But CFD permits us to look more deeply at exactly what's going on, why, and perhaps to formulate plans to counter or exploit the effects.

Figure 4 isolates the effects felt by the following car's front wing and its two main components, the mainplane (designated mp) and the flap. Again the overall downforce reduction with decreasing car separation is evident, but this plot shows it is the mainplane that loses the larger proportion, whereas the flap seems not to suffer as much at closer car separations.

Figure 5 shows the effects on the following car's various rear wing components, and once more the relationship with decreasing separation is consistent except that the rear wing loses less downforce than the front. The rear wing components seem to lose downforce in similar patterns to each other, although one interesting detail is that the upper tier loses a bigger proportion of its downforce than the lower tier, perhaps because the lower tier is →

Figure 3: percentage changes to the forces felt by the following car, relative to the single car case

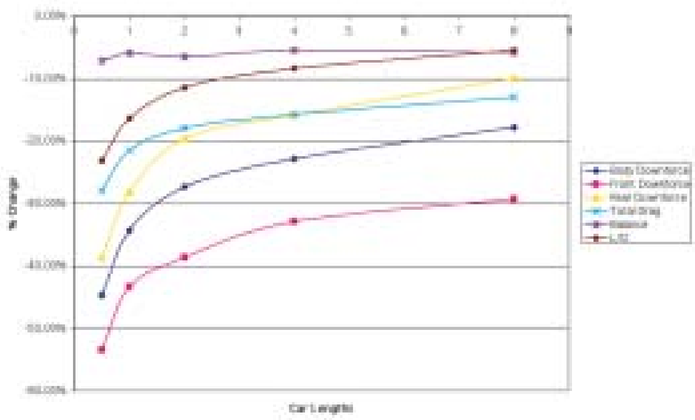


Figure 4: percentage changes to the front wing of the car following behind

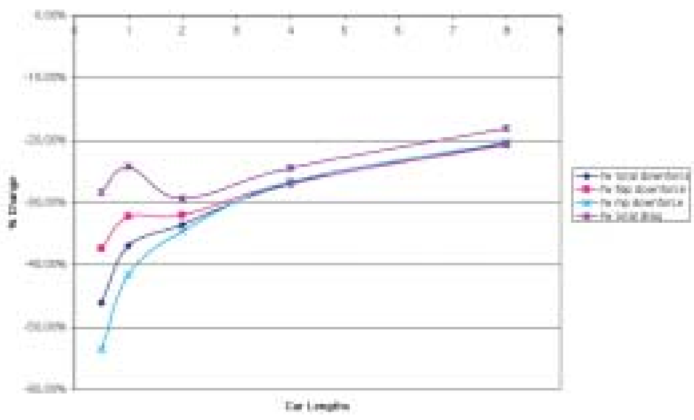


Figure 5: changes to the rear wing forces of the following car

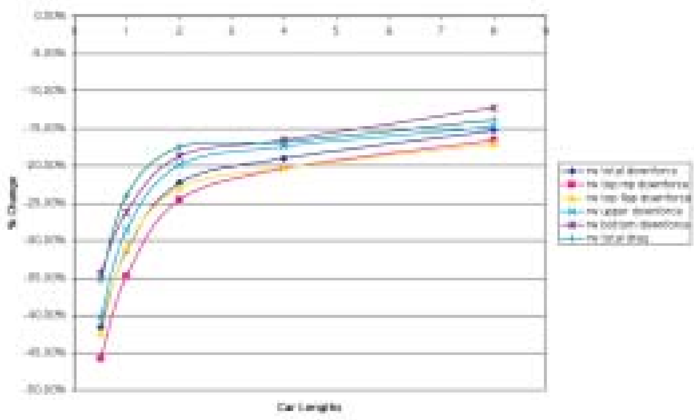
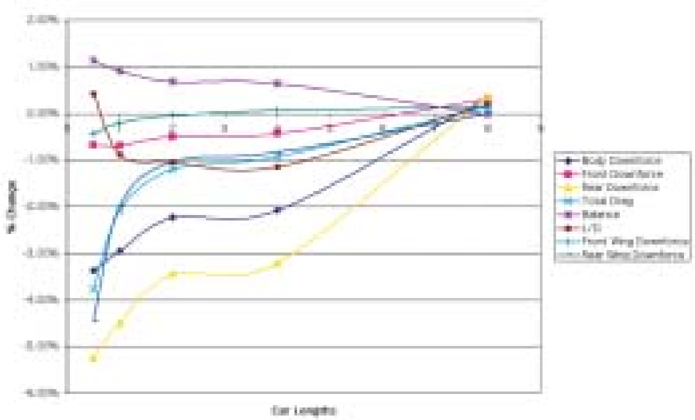


Figure 6: changes to the forces felt by the leading car relative to the single car case



"AS LONG AS RACECARS RUN IN CLOSE PROXIMITY THERE WILL BE AERODYNAMIC INTERACTIONS"

already partly shrouded behind the car. The greatest loss is felt by the upper mainplane, especially at closer car separations.

Now look at figure 6, which shows what the leading car experiences. First, it is apparent that the lead car does experience the effects of interactions, but they produce much smaller percentage changes than those felt by the following car. But second, the effects are potentially significant, the change which is most likely to affect handling being the loss of rear downforce that increases with decreasing car separation, with a five per cent loss at half a car's separation. There is also a loss of front downforce but this is very much smaller, and the overall balance shifts slightly to the front in line with the greater loss at the rear. Total drag decreases slightly too, by up to almost four per cent at the closest separation, this being an effect reportedly sometimes exploited by team mates (not necessarily in single-seat categories) to extract better lap times from each other.

So far the interactions can be summarised as follows: reductions in drag for the leading and, more significantly, the following car; a big reduction in downforce on the following car, especially at its front end; a small but significant reduction in rear downforce for the leading car.

Visualising the changes

CFD offers a range of visualisation techniques that help to show what's going on at a detailed level, as well as overall. Figure 7 gives a clearer idea of the 'big picture' along the car centrelines at one car's length separation. Here the colours represent air velocity – red showing the unimpeded 'freestream' airflow, while greens and blues show areas of reduced velocity. It is immediately evident that the airflow has slowed down greatly in the leading car's wake (no surprise there), and it will be obvious too that this reduction of the flow velocity onto the following car will contribute to the reduction in both drag and downforce it feels, since both forces are proportional to velocity squared.

On a more detailed level, 'oil flow' images illustrate the CFD simulation of the real world technique of using oily fluid droplets to reveal the flow directions on the surfaces of racecar components. In this case the clearest change to surface flow patterns shows up in figure 8, revealing the oil flow on the front wing underside. The baseline case shows two areas of flow separation near the trailing edge, either side of the centre of the flap, and areas of recirculation near the rear of the flap tips, adjacent to the end plates. The same image on the front wing of the following car at half a car's length distance shows no flow separation on the flap and reduced re-circulation near the tips. Why is this significant?

Figures 9 and 10 provide the explanation. There is a noticeable difference in the angle at which the approaching air hits the front of the following car. This has exactly the same effect as reducing the angle of attack of the front wing, which obviously results in a reduction in downforce (and accounts for the aforementioned flow pattern changes). So, as well as a reduction in air velocity on the front of the following car, the airflow also changes direction in a way that reduces its downforce.

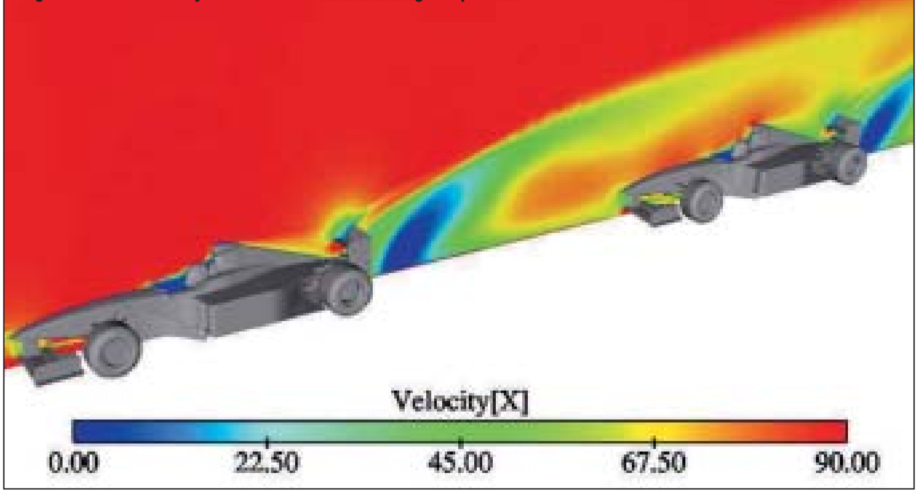
Changes to the pressure felt on the car surfaces can also be visualised using CFD techniques, and reveal further detail about the effects on the following and leading cars. Figure 11 shows how the upper surface pressures change, relative to a car running on its own. Negative colours (greens and blues) demonstrate a reduction in downward acting pressure on the upper surface corresponding to decreases in downforce. Figure 12 shows how the lower surface pressures change, with positive colours (reds and yellow) indicating upward acting changes in pressure on the underbody, also corresponding to decreases in downforce.

While there is an obvious loss of downforce from the upper wing surfaces in particular, the greatest losses would appear to accrue from increases to the pressure on the entire underside of the car, with the effects concentrated on the wing undersides and the sidepod inlet and diffuser inlet sections of the underbody. Again, the reduction in velocity of the incoming airflow to the following car would explain this. So it's not just wing downforce that is 'robbed', but underbody downforce, too.

The changes in surface pressures felt by →

> **"THE MOST OBVIOUS NEXT STEP MIGHT BE TO DEVELOP WAYS OF LESSENING THE DETRIMENTAL EFFECTS OF RUNNING IN THE WAKE OF ANOTHER CAR"**

Figure 7: airflow velocity contours for the one car length separation case



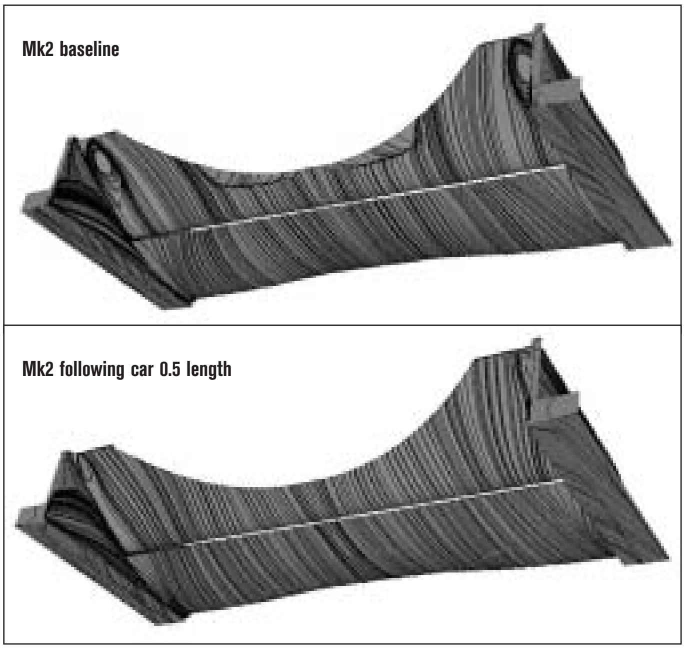


Figure 8: oil flow comparisons on the front wing underside at half a car's separation

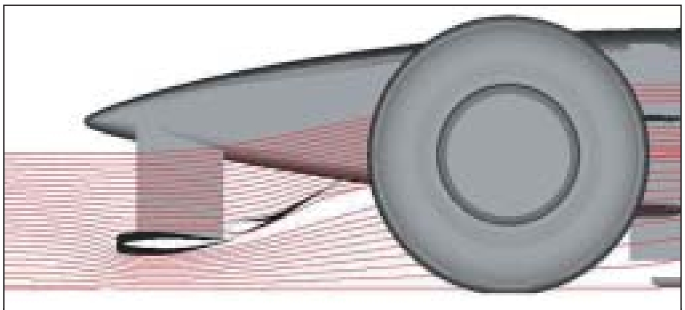


Figure 9: streamlines on the front wing of the leading car, 600mm from the centreline (end plate removed for clarity)

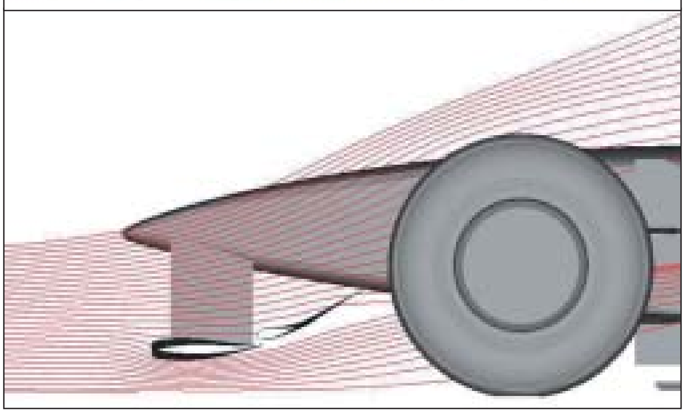


Figure 10: streamlines on the front wing of the following car, 600mm from the centreline, at half a car's length separation

Figure 11: changes to upper surface pressures on the following car at half a car's length separation

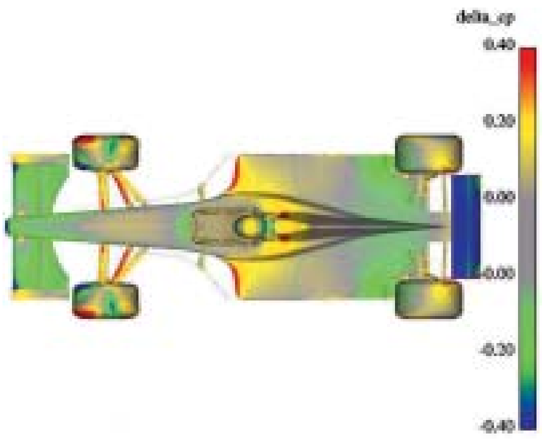


Figure 12: changes to the lower surface pressures on the following car at half a car's length separation

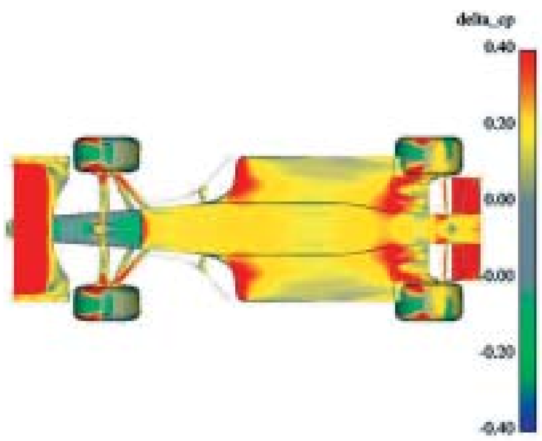


Figure 13: changes to upper surface pressures on the leading car at half a car's length separation

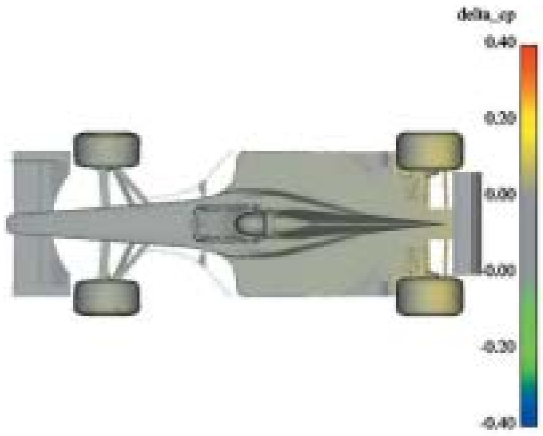
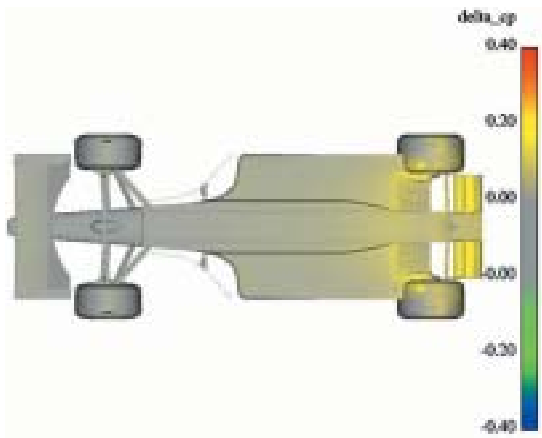


Figure 14: changes to lower surface pressures on the leading car at half a car's length separation



the leading car are subtler, as figure 13 and 14 show. Figure 13 shows very small upward acting pressure changes to the upper sidepod and rear deck surfaces only, while figure 14 shows more significant upward acting changes to the underbody, especially around the diffuser inlet area, and the rear wing undersides. Obviously these changes are concentrated at the rear end of the car, corresponding with the reduction in rear downforce. There is also a small but definite change to the front wing underside, corresponding to the small drop in front end downforce previously mentioned. Thus, the 'bow wave' effect of the following car is slightly modifying the airflow over the whole of the leading car, be that by affecting the direction and/or the velocity of the airflow.

Response time

At its simplest level this study has demonstrated the reduction in drag and changes to downforce that are well known. By putting some numbers on the effects though it is abundantly evident that the effects are highly significant. However, it is also apparent that it may be possible to use this type of information in various positive ways. For example, the most obvious next step might be to develop ways of improving the beneficial effects or lessening the detrimental effects of running in another car's wake either through the tuning or re-design of components.

For example, the illustration showing the modification to the airflow onto the front wing suggests that in a situation where a fast car is forced to run in heavy traffic (such as a car penalised by loss of grid position) it might benefit from running a steeper front wing angle to recoup some of the downforce lost when close to cars in front. The downside of this would be high speed oversteer when running in free air, unless the desired effect could be achieved using front flap flex...

> **"MIGHT IT ALSO BE POSSIBLE TO DESIGN A CAR THAT COULD EXPLOIT THE SLIPSTREAM OF A CAR IN FRONT MORE EFFECTIVELY?"**

Might it also be possible to design a car that could exploit the slipstream of a car in front more effectively? A more aggressive strategy might be to develop components that make the situation for the following car worse, if that could be done without adversely affecting your own car's performance. Or perhaps you could develop a car that made the balance of the car in front deteriorate when your car came up behind it. If you were a deviser of regulations you might take exactly the opposite approach to these aggressive ideas and use this type of study to make the situation better for the following car in the hope that this might aid overtaking.

Final thoughts

While the results shown here are illuminating, as with all studies further questions are raised. An analysis of cars running line astern necessarily only looks at the earliest phase of an overtaking manoeuvre. There would ideally be a detailed study of the interaction between two cars in all phases of the overtaking manoeuvre, with differing lateral offsets at various longitudinal separations, and at various 'alongside' phases. Proximity to walls and multi-car scenarios represent other possible fields of study.

There is one certainty though. Whatever influences the regulators may have, as long as racecars run in close proximity there will be aerodynamic interactions. The team that pays closest attention to these will have less difficulty passing its opposition, or staying in front... RE

Racecar would like to thank BAR and Advantage CFD for their help with this feature.
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