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August 2018 • Vol 28 No 8 • www.racecar-engineering.com • UK £5.95 • US $14.50

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The real story behind Toyota's victory at the 24 hour race

Peak performance

There's much more to aero development for the Pikes Peak Hillclimb than merely bolting on a massive wing, as the first part in our new Chevrolet Corvette CFD study clearly shows

By SIMON McBEATH

The Rotek Racing Chevrolet Corvette Z06 takes the flag at the top of the Pikes Peak Hillclimb course last year. It finished in 17th overall and was fourth in its class (*Larry Chen*)

Table 1: The aerodynamic coefficients on our Corvette Z06 road model, derived in ANSYS CFD-Flo

	CD	-CL	-CLfront	-CLrear	%front	-L/D
Road model	0.372	0.010	-0.026	0.035	-263.8%*	0.026

**The value for %front seems anomalous because it is large and negative*

Rotek Racing's managing partner Robb Holland took his Chevrolet Corvette Z06 to Pikes Peak in 2017 and, according to the official results, netted 17th place overall for cars with a very creditable fourth in the Time Attack 1 class. Holland says: 'We did a last minute build of the car for the 2017 event with a wing and splitter thrown on to give it whatever downforce we could get. This year we are looking to do a chassis-up build that is more of a racecar than a street car with some aero thrown at it.'

The objective for 2018, then, was to improve in all areas, including aerodynamics. And so *Racecar Engineering* took on the task of developing the aerodynamics of the Rotek Racing Chevrolet Corvette Z06 for the world-famous Pikes Peak International Hillclimb (PPIHC).

The project came about following a conversation between owner/driver Holland and *Racecar's* editor at PRI late in 2017, with the original idea being simply to apply some lessons learned from CFD projects on our generic digital GT project car, as showcased in previous issues.

However, your writer had been working with occasional wind tunnel test colleague James Kmieciak ('JK') of Black Art Customs, a specialist in the application of contemporary 3D processes including CAD and CFD, on the creation of improved CAD models for CFD projects for this journal. JK's ability to produce CAD models with a representative level of accuracy and fidelity – yet which did not contain superfluous detail that would needlessly consume computing resources and which would mesh with minimal issues – was going to be invaluable. Such models are incredibly useful for analysing and developing aerodynamic packages at what might be called the macro and meso levels, and the micro level was neither attainable on the available computational resources, nor essential in this, the early stages of development. In short, aerodynamics can be driven into the right ballpark using this approach.

Project strategy

The first stage, then, was for JK to generate a model of the Corvette Z06 body using (validated) online resources plus measurements and photographs supplied by the team, to which your writer subsequently added simple wheel and tyre models using the sizes specified for the road car, along with simplified suspension. This was then used to ascertain satisfactory CFD conditions and to produce comparison data on the road version of the model using ANSYS CFD-Flo. Given that our models were necessarily simplified compared to reality, the actual forces and coefficients we obtained were of less interest than the delta values, that is, the changes brought about by modifications, and these are what drove the development through its various stages. Nevertheless, the comparison between our road model and real data was irresistible, as we shall see shortly.

One further simplification is that with no apparent facility to alter the density of the air in CFD-Flo simulations to reflect the reduced density found at PPIHC altitudes, all runs were carried out at mean sea level pressure and 25degC. This was not felt to be an issue, having no appreciable effect on the proportionate delta values and trends observed. However, the simulated air speed was reduced from our usual 100mph to 80mph, so that the Reynolds Number was akin to that at 100mph at the average altitude (and reduced air density) of Pikes Peak International Hillclimb, giving flow similarity.

Once satisfactory CFD parameters had been derived on the road model, including rotating wheels and moving ground, and baseline data had been obtained, the model was then modified in line with the 2017 racecar, the starting point for the subsequent incremental development approach.

Front first

The focus was initially directed at the front end of the car, for two reasons. First, it was going to be straightforward obtaining enough rear downforce by either increasing the rear wing angle above the shallow angles used in 2017, or by fitting a more aggressive rear wing; and second, consideration had to be given to the manufacturing times on the front end components, and with the project not starting until Spring 2018 the schedule was tight.

The data obtained on the road model are given in **Table 1** as coefficients for easy run-to-run comparisons. In short, the model showed modest drag and a very small amount of total downforce, amounting to some 19N (2kg or 4.4lb) at test speed. The aerodynamic balance actually showed a small amount of front lift (a negative –CLfront value) and a not quite so small amount of rear downforce. Brief internet research revealed quoted values of 0.34 to 0.37 for the drag coefficient of the Z06, so the value of 0.372 on our simplified model was of the right order. No published values were found for the vertical coefficient of the real car, but our first run showed an essentially neutral car that would not change its vertical forces, aerodynamically anyway, across its speed range, which would seem like a reasonable premise for a road car.

Pausing briefly to examine the pressure plots on the road model reveals some pointers to where developments needed to be focussed **(Figures 1-6)**. As ever, yellows and reds indicate where surface pressure was raised, greens and blues where it was reduced, and the sources of

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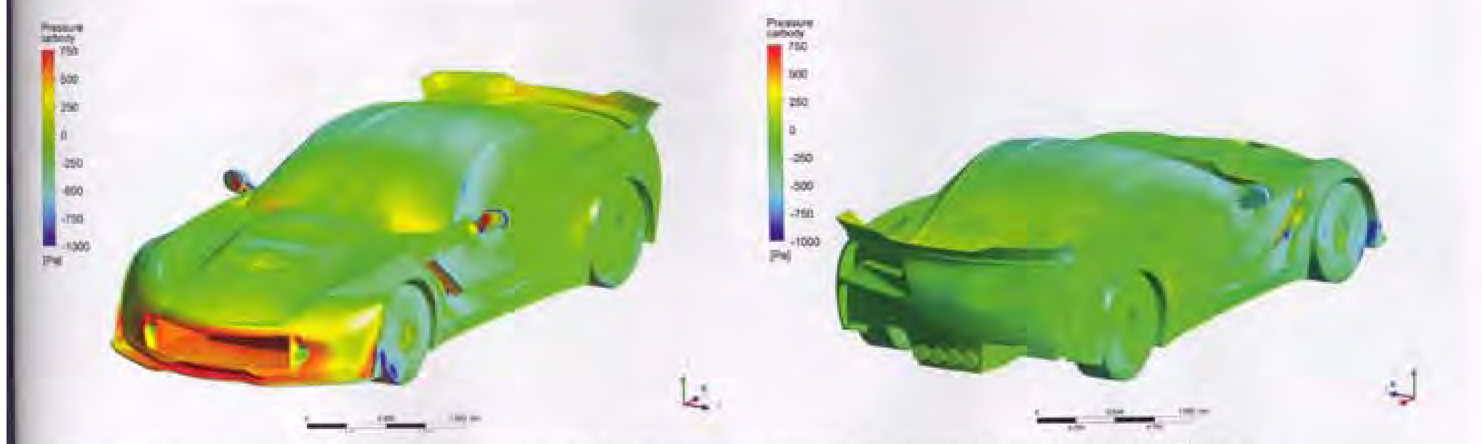
Aerodynamics can be driven into the right ballpark using this approach



Figures 1 and 2: The pressure highs and lows on the road model of the Corvette go some way to revealing the sources of drag, lift and downforce in the car

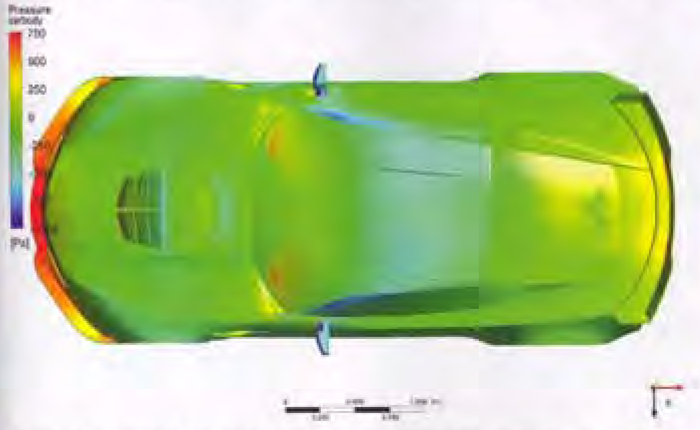


Figure 3: Suction over bonnet and roof is offset by pressure on splitter and rear deck

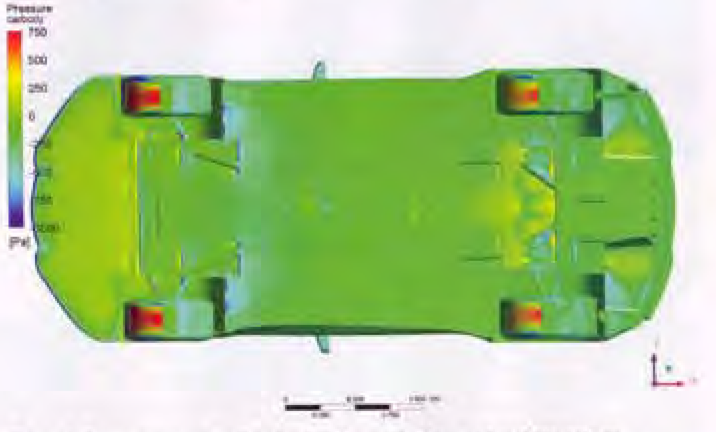


Figure 4: Pressure was actually raised under most of the road model's splitter

Figure 5: Pressure readings on the symmetry plane show pockets of high pressure

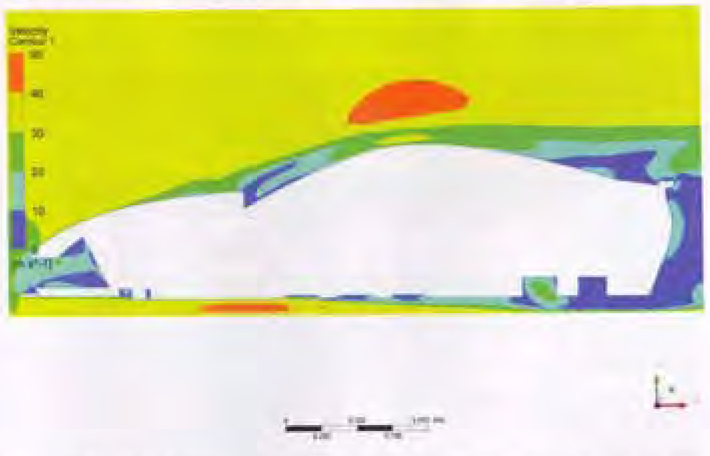


Figure 6: Rough underside created a thickening boundary layer under the rear of car

The Corvette Z06 road car CAD model

Figure 7: The 2017 racecar's more effective splitter produced some useful downforce

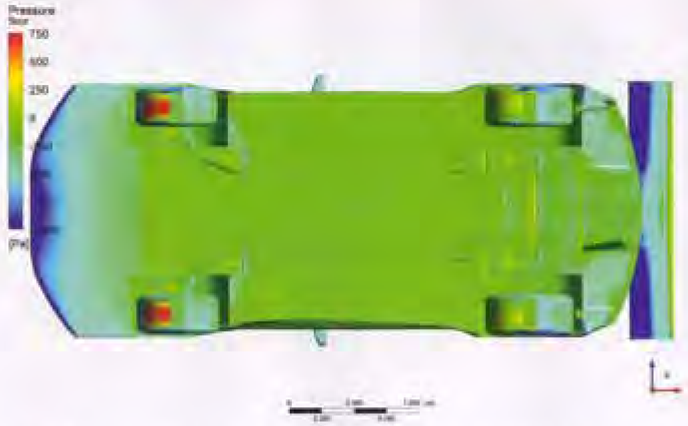


Figure 8: The pressure was negative under the 2017 baseline racecar's splitter

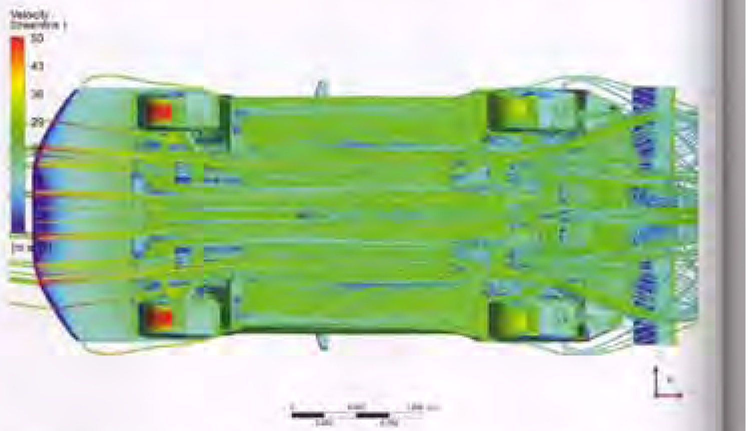


Figure 9: It was evident that the rough underside of the racecar disrupted the flow

Table 2: The 2017 baseline racecar aerodynamic data

	CD	-CL	-CLfront	-CLrear	%front	-L/D
2017 car	0.457	0.650	0.370	0.280	56.9%	1.421

drag and lift/downforce, become evident. The road model was given a rough underside to make it more representative of the real car which, although relatively tidy for a production car, still featured bumps and cavities. And these can be seen to create pockets of raised pressure on the underside as well as contributing to the thickening of the boundary layer of slow-moving air under the rear of the car, as shown in **Figure 6**.

Another key aspect is that most of the underside of the splitter was at slightly raised pressure, and this was because it was slightly higher than the main floor of the car. This reflected that on the real car the cross members carrying the bottom suspension arms, and the rest of the underside, were lower than the splitter's underside. This created blockage, leading to the raised pressure under the splitter.

On the other hand there was reduced pressure under much of the floor, especially just behind and inboard of the car's front wheels. And there was raised pressure on top of the splitter and ahead of the rear spoiler, which collectively just about redressed the reduced pressure over the roof and the forward regions of the car's upper surface.

Racecar 2017

Next, the road model was modified to represent the car as it was run at PPIHC in 2017. This included slightly altering the wheel and tyre sizes, along with the ride height and rake to dimensions supplied by the team.

The primary downforce inducing devices, comprising a simple but quite substantial, inclined, flat splitter with large end fences and a modestly cambered, shallow angle dual-element rear wing, were also added, again based on CAD data and information from the team.

The rough floor of the road car was retained, as it was on the 2017 racecar. The splitter was now lower than the main floor, even at its trailing edge, so there was no forward facing blockage, as seen on the road car. The set-up of the splitter, tilted 25mm overall with the leading edge down at 50mm ground clearance, and shallow rear wing angle, had been derived at the 2017 event and produced a balance with which the driver was happy: 'We were aiming for a somewhat front biased aero balance last year as with the steepness of the hill we tended towards understeer,' Holland tells us. So it was going to be interesting to see what the first CFD run on the racecar specification produced. The data are shown in **Table 2**.

These results were not unreasonable for a car with no aerodynamic development, and the %front figure tallied nicely with the driver's view that the car's aerodynamic balance had been slightly forward biased. However, total downforce could undoubtedly be increased from this starting level.

Analysis

Pausing briefly to study three visualisations, **Figure 7** shows how the bigger splitter produced a larger area of raised pressure on its upper surface, aided by the end fences; and the rear wing and part-width body Gurney that replaced the rear spoiler of the road car. **Figure 8** shows much reduced pressure under the 2017 racecar's splitter, and the low pressure on the wing underside. The rear underside of the car was also at lower pressure than the road car's, as shown in **Figure 4**. And **Figure 9** shows streamlines projected upstream and downstream from the floor, and

'We were aiming for a somewhat front biased aerodynamic balance last year as with the steepness of the hill we tended towards understeer'

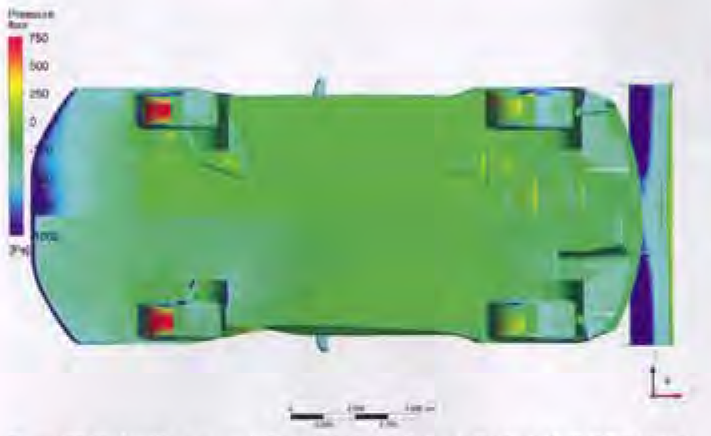


Figure 10: Underside pressures changed to those shown in the lower half of this image

Figure 11: Here the wheel arch extractor can be seen aft of the front wheel

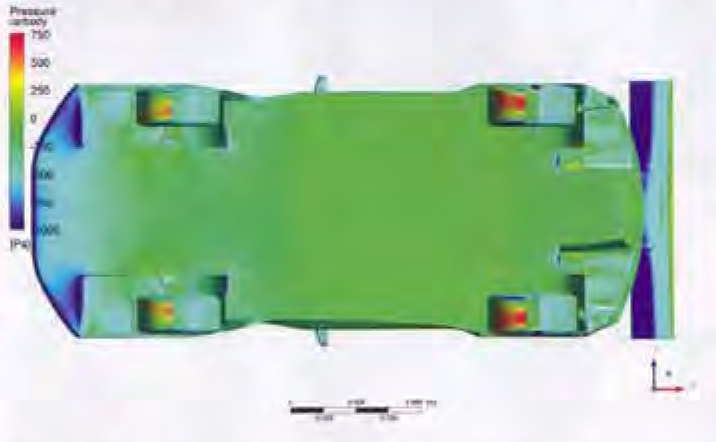


Figure 12. The first front diffuser increased splitter downforce but needed optimising

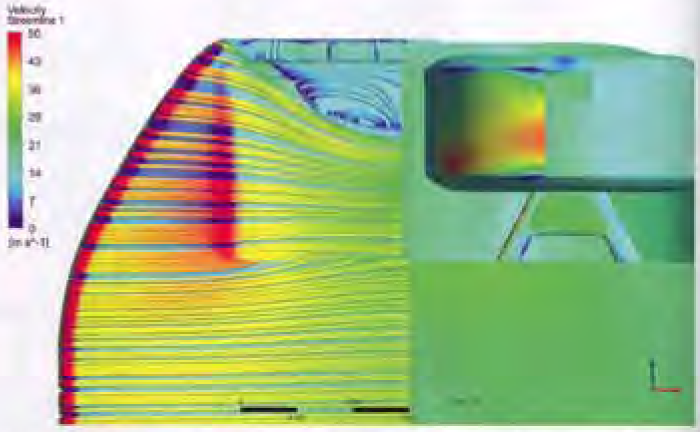


Figure 13: Stall could be seen in the outer section of the first front diffusers we tried

Removing the tilt in the splitter enabled overall downforce to increase by over five per cent

illustrates well the disruption caused by the roughness here.

In keeping with the strategy, the first part of the project focussed on essentially front end modifications, and this included integrating the front underside with the rest of the racecar's floor. The rationale behind these first steps was to improve the overall performance of the floor with a view to then adding front diffusers on the way to maximising front end downforce.

The first step involved removing the tilt from the splitter by raising its leading edge, mainly because it was already grounding too frequently, causing damage as well as restricting mass flow under the car. Thus the splitter underside was now parallel to the floor but 25mm lower.

Removing the tilt enabled overall downforce to increase by over five per cent and the main beneficiary was the floor thanks to that increased mass flow. Balance shifted rearwards to just under 51 per cent front, the splitter obviously losing some downforce at this stage simply because of its increased ground clearance.

Next, the simulated roughness in the floor was removed to create an entirely smooth floor (at the same height as the original floor); rake was 20mm, as run in 2017, measured at the front and rear of the side sill. This added nine per cent more total downforce for no change in drag, and once again the floor was the principle contributor here, with the pockets of raised pressure having been eradicated. Aero balance again migrated rearwards to just under 48 per cent front.

False bottom

Wheel sizes and geometry meant that it wasn't going to be possible to lower the car on its suspension, yet the floor of the car was well clear of the ground. So a 25mm lower false flat floor was incorporated, such as might be achieved with 25mm thick honeycomb panel, and the splitter underside was aligned with this lower floor plane with the same 20mm rake along the side sill. This boosted floor downforce by a further five per cent, but splitter downforce reduced so that overall downforce was the same as the previous run, and balance shifted slightly further rearwards.

Lastly in this initial phase the lower part of the wheel arch and forward sill behind the front wheels was sculpted away (hopefully compatibly with the chassis structure within) to provide improved egress for air flowing from under the splitter and within the wheel arch. A floor panel extension was also inserted behind the front wheel.

This wheel arch modification was really in preparation for the next phase. However, even at this stage it produced a 3.8 per cent increase in total downforce, with both the splitter and floor seeing downforce increases. The predominant gain was once more from the flat floor, so balance again shifted slightly rearwards to finish this first stage at 45.5 per cent front, ordinarily an acceptable figure but our target figure was in the mid-50s.

The car runs in the Time Attack 1 class which has refreshingly open regs (*Larry Chen*)

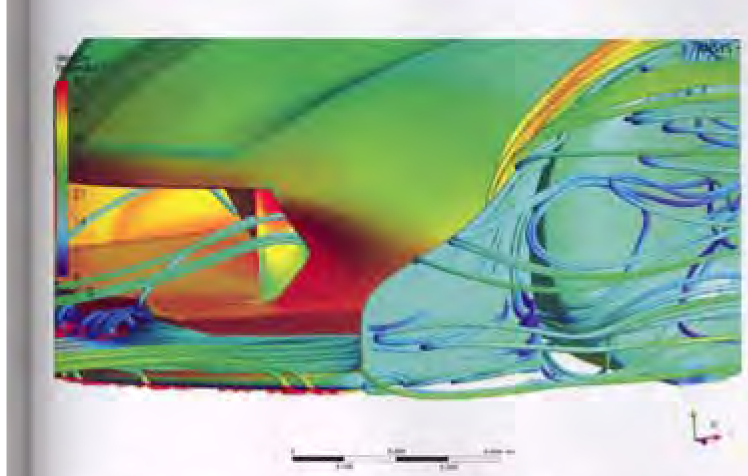


Figure 14: Flow separation on outer faces adversely affected the flow under outer ends

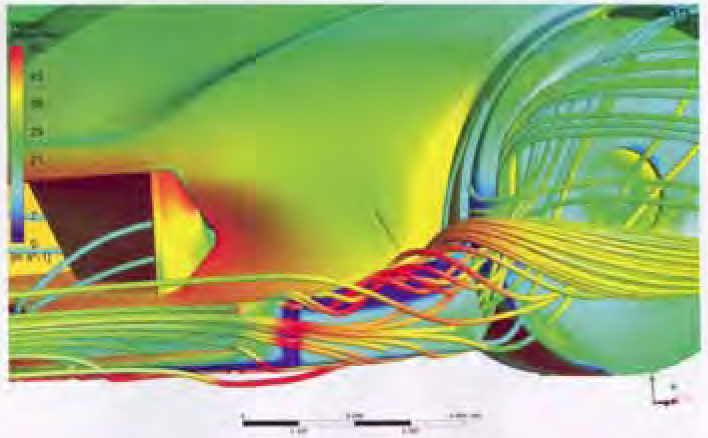


Figure 15: Longer and not so high fence allowed energetic air under the splitter ends

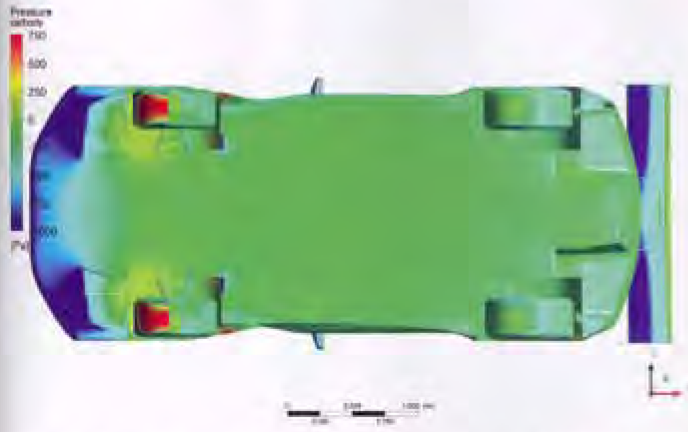


Figure 16: The modified end fences and angled walls improved the dual-height diffuser

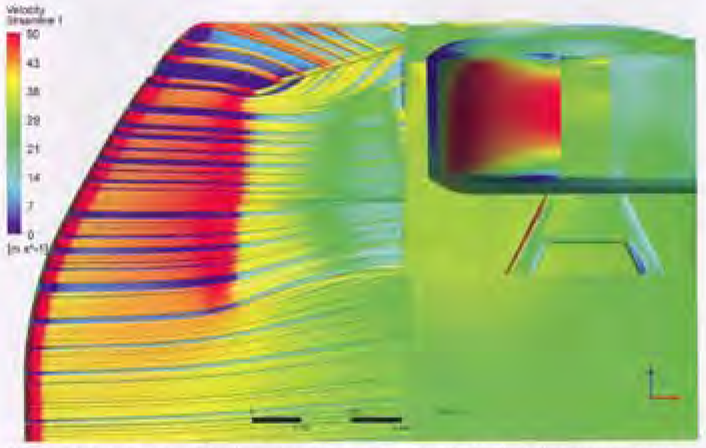


Figure 17: Instead of stall there was an energetic vortex that helped increase suction

Last year the aero package on the Rotek Racing Corvette was rudimentary (*Larry Chen*)

Nevertheless, so far we had reduced drag by 4.4 per cent and increased downforce by 18.8 per cent.

Figure 10 compares underside pressures between the start and end of this first phase, **Figure 11** shows the front wheel arch extractor.

Front diffusers

The first steps had usefully improved the performance of the floor, so next some front diffuser options were evaluated in order to shift the balance forwards while adding more total downforce. A simple parallel sided diffuser **(Figure 12)** increased splitter downforce by over 21 per cent compared to the previous run, with balance shifting forwards to exactly the same value as the 2017 baseline at 56.9 per cent, total downforce now being 24 per cent more than that first run. JK then implemented a dual-angle front diffuser he had applied to the RCM Gobstopper 2 Time Attack Subaru we featured in Aerobytes in 2013. The angle of the diffuser ahead of the front tyre was shallower than the angle ahead of the chassis-tyre gap (where greater mass flow can be channelled). This added another 7.5 per cent splitter downforce and 1.7 per cent total downforce, with the balance now at 60.2 per cent.

However, inspection of the pressures and streamlines in both front diffusers showed that stall was occurring **(Figure 13)** in the outer sections, so the angle of the outer wall was changed from parallel to the car's centreline to divergent, a feature that had helped on previous projects by creating a vortex inside the outer wall that increased suction and helped maintain flow attachment.

Unexpectedly this did not help, and attention switched to the flow separation on the outside faces of the tall splitter end fences that appeared to be related to the flow passing under the outer ends of the splitter **(Figure 14)**. So a further measure known to be beneficial from previous projects (and shown to work in Aerobytes sessions) was to cut down the height of the end fences and also to extend them forwards and around the splitter's curved corner for a short distance **(Figure 15)**. Satisfyingly, this enabled a significant increase in the performance of the single height front diffuser and the dual height diffuser, which now also incorporated the divergent outer wall **(Figures 16** and **17)**. At this stage we had achieved 35.5 per cent more total downforce with a 4.2 per cent drag reduction, and balance was close to target at 55.2 per cent front.

Ducting

As configured in 2017 there was no ducting leading to the coolers in the front aperture of the car, and our starting CAD model was configured in a similar way. This meant that air was able to bypass the coolers and enter the front compartment, which would have contributed to reduced cooling efficiency as well as reduced aerodynamic efficiency. There were 'gill' exits on either side of the front wheel arches to vent some air from the engine bay. So the next phase of the CAD/CFD project looked at adding a duct on the inlet side of the radiator (just one in our simulations), a full exhaust duct (a partial one was installed from the outset), and also at blanking off the apertures either side of the radiator duct, previously open into the engine bay.

Finally louvred apertures were installed in the bonnet, but constraints on the CAD model in this area meant that only a part of

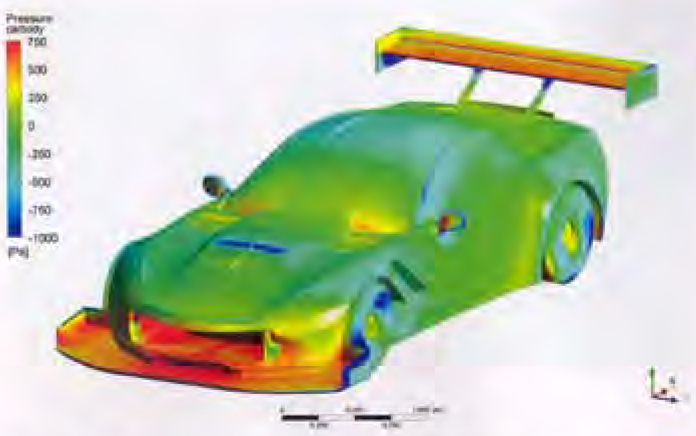


Figure 18: With wide splitter a near maximum wing angle was needed for aero balance

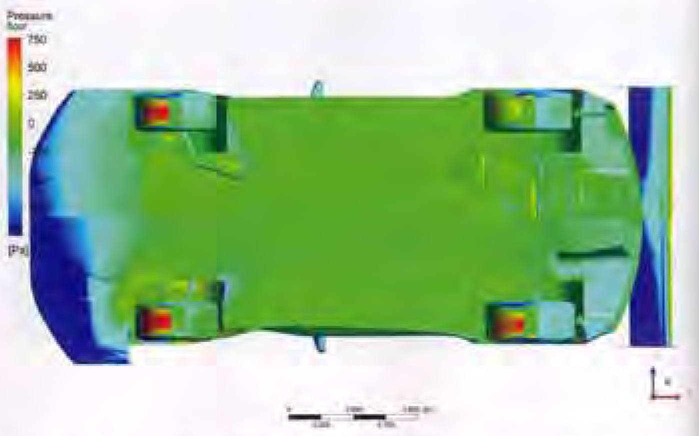


Figure 19: Baseline car's underside (upper half) is compared to the final variant

The phase 1 2018 aero CAD model. We will be developing this further in a future issue

Table 3: Data following the balancing wing adjustment, with changes shown in percentages

	CD	-CL	-CLfront	-CLrear	%front	-L/D
2017 PPIHC	0.457	0.650	0.370	0.280	56.9%	1.421
Run 21	0.588	1.335	0.758	0.577	56.8%	2.272
Change, %	+28.7%	+105.4%	+104.9%	+79.6%	-0.01%*	+59.9%

** Absolute rather than relative difference in percentage front*

Rotek Corvette in the Top Paddock at the Pikes Peak Hillclimb last year (*Robb Holland*)

the desired region could be opened up on the model. With the most successful combination of ducting and blanking panels employed, plus the bonnet louvres, drag reduced by 9.4 per cent, total downforce increased by 1.2 per cent, leading to an 11.7 per cent increase in –L/D, and balance moved forwards to 58 per cent front. In terms of the effects on component groups, body lift and splitter downforce both increased, these responses probably the result of more mass flow going over and under the racecar, the latter outweighing the former and being responsible for the overall downforce increase and forwards balance shift.

With the rules essentially open in the Time Attack 1 category, the owner/driver was asked if a sideways splitter extension could be used in this class. The response was 'yes, but by a maximum of 150mm each side, mainly for aesthetic reasons.'

So JK extended the splitter and the front diffuser on the CAD model by 150mm sideways. The ensuing increase in total and front downforce was much bigger than expected, although there was also a drag penalty, probably much of this from the detail of this first iteration. Drag increased by over 23 per cent and total downforce by about 15 per cent, so the efficiency of the modification was not good. However, thanks largely to a 47 per cent increase in splitter downforce the balance changed to 82.6 per cent front.

Now, this level of front end downforce raised the question of whether the current rear wing was going to be capable of balancing the front. For the next run, which happened to be Run 21, the wing was set at what was expected to be close to the maximum possible main element and flap angles. Perhaps fortuitously with this first wing angle adjustment, balance was almost exactly the same as the Run 1 target value at 56.8 per cent front. The full set of coefficients is shown in **Table 3**, with the Run 1 data for comparison. **Figures 18** and **19** illustrate.

Double downforce

Over this whole sequence of modifications drag increased by less than a third while total downforce more than doubled, efficiency increased by nearly 60 per cent and balance remained exactly the same.

In force terms at the 80mph test speed (at sea level), downforce went from around 2kg (4.4lb) on the road model, to 132kg (290.4lb) on the 2017 baseline model, to 272kg (598.4lb) in this last reported run. That force would scale up by the square law to around 425kg (935lb) at 100mph, and 612kg (1346.4lb) at 120mph.

The next step

Further modifications have been done on rear diffusers along with some rear wing and rake mapping, but at this point a line was drawn, partly because of available space in these pages, but also to enable the major body parts that were defined in this short project to be manufactured (hopefully) in time for the 2018 event, which will have just taken place by the time this issue is published.

At the time of writing in early June, ECU issues may have precluded the car running at all. But if it does not make PPIHC in 2018, it certainly will in 2019. Meanwhile, the next challenge in 2018 could be tackling the Nurburgring Nordschleife, which will surely require a re-think on the car's aero balance. *Racecar* will return to this project in a future issue.

Over this whole sequence of modifications to the Corvette model, drag increased by less than a third while total downforce more than doubled