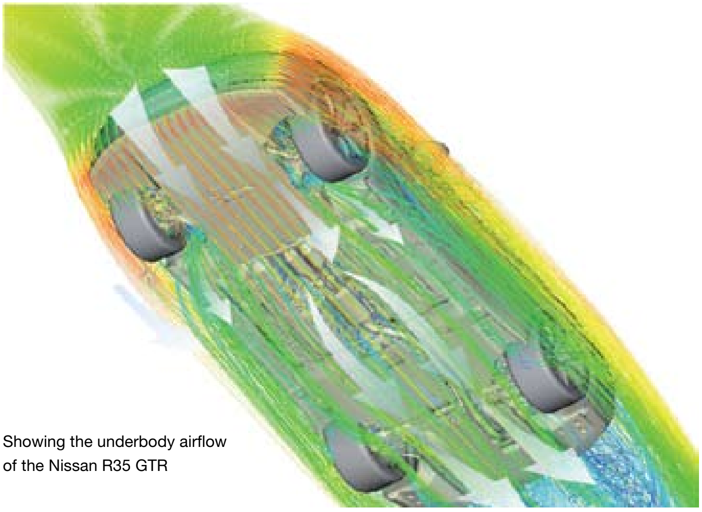
Flying like the wind

The challenge for the designers of the Nissan R35 GTR was to create a car that drew on lessons learned from the development of the successful Nissan Le Mans prototypes, and to apply this to the new GTR. **Yoshi Suzuka** was on the design team and explains how this was achieved



Showing the underbody airflow of the Nissan R35 GTR

Having designed cars for IMSA GTP, Le Mans, Indy and GT classes, Yoshi Suzuka was the ideal candidate to head up the design team responsible for the R35 GTR, as amongst other accomplishments, Suzuka's Group C Nissan R90CP qualified third on the grid at Le Mans in 1990. His experience in developing cars which tend to generate large downforce levels was invaluable to this project as most automakers generally do not have this expertise readily available within their organisations. The aerodynamic development of the Nissan R35 GTR (which took place between 2004-2006) represented groundbreaking advances for Nissan as well as the whole Japanese car industry. This is his story…

A Black Art?

The Science of Aerodynamics, particularly the generation of downforce is not well understood in road car automotive circles, writes Suzuka. It is understood that most road cars generate lift, but how much lift? Even armed with this knowledge, how much downforce is adequate for a road car when they primarily generate lift? More importantly, how do you create downforce when you are normally generating unintentional lift? Suffice it to say that these topics are not often discussed, or even less, published.

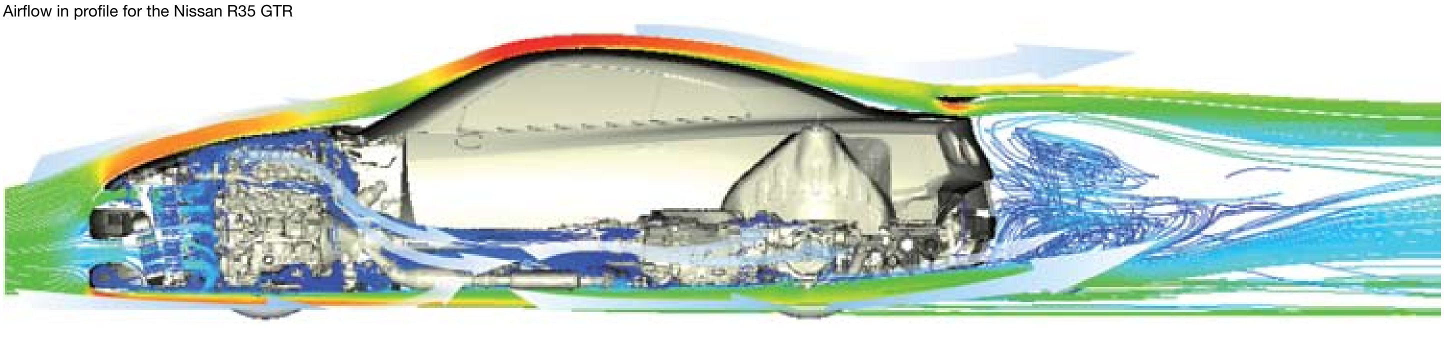
Some Realities

Only a handful of the hundreds of road cars manufactured in the world generate front end downforce, all other cars typically generate front lift or close to zero lift. Some cars create rear downforce when fitted with a spoiler, but with this rear device removed, the downforce is likewise lost which means that the car's shape still tends to generate lift. For the last 25 years I have worked on various race cars, but in many cases even these would generate lift without a rear wing. It is correct to say that rear downforce is created by the rear wing, but more fundamentally the rear wing complements the underfloor diffuser and therefore the diffuser doesn't work particularly well without the rear wing. What this means is that the basic shape of the car (any car) is the primary source of lift, so in general, all cars are subject to creating aerodynamic lift force, and it takes concerted effort to correct this.

On a Wing and a Prayer…

Aerodynamic lift isn't necessarily dangerous as long as the car is running at low speeds, so in most cases this really isn't an issue because a driver seldom exceeds 100 mph in their road car? However, as the car's velocity increases the aerodynamic situation certainly changes as I experienced in the '70s with a Ford Mach 1. Well aware that the car generated significant front lift, this was revealed in an

Airflow in profile for the Nissan R35 GTR



								Lift force at 245kph	
Year	Model	Cd	S sq.m	S	CLTotal	CLf	CLr	FDF kg	RDF kg
2004	Ferrari 360 Modena F1	0.34	1.906	calculate back	-0.58	-0.25	-0.33	-138	-182
2006	Pininfarina Ferrari P4/5	0.34	1.90	calculate back	-0.15	-0.12	-0.03	-68	-14
2004	Porsche Carrera GT	0.39	1.90	calculate back	-0.29	-0.09	-0.20	-48	-112
2007	Nissan GTR	0.27	2.09	estimated	-0.08	-0.04	-0.04	-24	-24
2008	Porsche GT2	0.32	1.90	estimated	-0.10	-0.03	-0.08	-14	-43
2002	Honda NSX Type R	0.32	1.78	announced	-0.1	-0.04	-0.06	-21	-31
2000	Audi TT(Original model)	0.34	2.00	fixed number	0.31	0.14	0.17	81	98
2000	VW Beatle		2.00	fixed number	0.88	0.39	0.49	226	284

Fig. 1: Forces are in Kg. Sign (-) indicating downforce, positive indicates lift.
Note: Measurement conditions of aerodynamic values are not well standardised in the same way that engine performance indicators are. Often, each windtunnel shows different values even for the same car. The amount of downforce or lift is proportional to the square of the velocity, accordingly the ride-height and pitch angle of the vehicle changes. When the attitude of the vehicle changes, the aerodynamic values also change accordingly. If the ride height of the GTR is lowered by 10-30mm, like other exotic cars, one can assume the Cd value will be lower and the downforce will increase substantially. Thus the aerodynamic values must be compared at set ride height and set speeds in order to be consistent.

all too real manner when I noticed that as the speed increased, my headlights started shining further and further ahead up the road until they were aiming skywards. At 120 mph, the steering became dull and mushy and the car needed more than its fair share of attention on entry into corners. It went without saying that this car produced front lift (the headlights pointing to the sky at speed was an indication as the front cantilevered and rotated up) but more than likely the rear end produced its fair share of lift as well.

Car manufacturers publish precious little aero data, though some of what they do reveal ends up in car magazines and ultimately that is one of our best sources. According to data published in the July 2000 issue of Road & Track magazine, the new Volkswagen Beetle (2000 model year) created 79 kg lift at the front and 99 kg lift at the rear at 145 km/h (90 mph). These forces on their own wouldn't be considered too much of an issue for the 1400 kg car, but the problem is certainly compounded if you entertain the idea of a 110 km/h (70 mph) head wind as you're suddenly faced with a 245 km/h relative wind speed. Lift forces then rise to 226 kg at the front and 284 kg at the rear, totalling 510 kg of lift. So the lift forces are beginning to nip at the heels of the car's overall weight of 1400 kg when you run into a gusty cross or head wind. Granted this situation is perhaps not particularly likely, but it also certainly wouldn't be unheard of or outside the realms of possibility. At the very least, if you're a VW Beetle owner and these figures are correct, you might reconsider high speed cornering, especially in blustery conditions!

One thing that manufacturers need to consider are the potential liability issues if aerodynamics are ever cited as the primary cause of an accident. With this in mind, some are looking at the issue and trying to reduce the amount of aerodynamic lift when considering that downforce makes a significant difference in high speed stability.

All work and no play...

The question begs asking then, why is it that car manufacturers do not appear to put much effort into aerodynamic research and development? Furthermore, why is it so difficult to design a road car that makes downforce or, at the very least, approaching zero lift? There are potentially several reasons:

1. There has never been a tendency to be concerned about lift, and there is a reluctance to start now, as it simply adds time and cost.
2. Simple lack of knowledge; as lift was reduced drag increased and manufacturers lack the knowledge to manage drag versus downforce.
3. With fuel economy the number one priority, manufacturers are concentrating solely on reducing drag as it is more profitable to be able to promote this for marketing reasons. This was confirmed by industry personnel who agreed with these likely answers.

Moving target

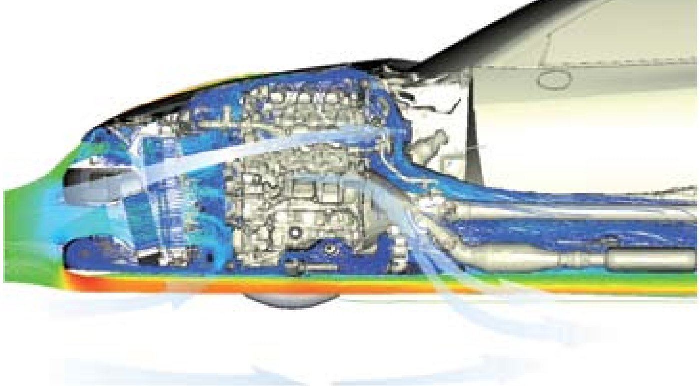
Looking back at Fig 1, we can see that the Ferrari 360 Modena indeed generates very respectable front and rear downforce (not merely reduced lift), but for a relatively high drag penalty of Cd 0.34. But the 360 Modena had different aerodynamic priorities than the Nissan GTR, which is where the ability to manage drag and downforce while achieving the desired results becomes paramount. Drag is an inevitable by-product of downforce, all one has to do for proof of that is to look at Formula One cars with their drag coefficients of between 0.7 and 1.1, depending on circuit and configuration. Generally speaking, downforce naturally takes precedence over drag when designing a race car, but for a road car then how much is too much downforce when drag creeps back into the equation?

Nissan GTR R35: The first road car in the world to combine downforce with low drag, with a twist...

Referring to Fig 1, we see that the GTR has Cd=0.27, and more interestingly CLf=0.04 and CLr=0.04, therefore it is balanced fore and aft. While the GTR's total downforce is much less than the Ferrari Modena, this was planned for, as the level of downforce required depends on the purpose to which the vehicle will be put. The GTR is not a race car, it is a grand touring car which is able to run on the ►

				All downforce			At 150mph	Frontal area
Year				Cd	Cl	L/D	Downforce Kg	m²
2000	F-1	Monza	Speed course spec.	0.83	2.74	3.3	1100	1.42
		Monaco	Hi downforce spec.	1.06	3.39	3.2	1300	1.43
1992	Nissan GP-C		LeMans spec.	0.5	2.3	4.6	1100	1.7
1993	Nissan IMSA GTP		Hi downforce spec.	0.79	3.84	4.8	1879	1.74
1997	McLaren GTR	Street car		0.5	1.1	2.2		
1998	Nissan LMP		LeMans open prototype	0.5	1.5	3	706	1.67
2000	Nissan R34	GT race	Speed course spec.	0.43	1.01	2.35		
			Hi downforce spec.	0.45	0.99	2.2		
2003	NASCAR		Speed course spec.	0.35	0.42	1.21		
			Hi downforce spec.	0.47	0.67	1.43		
2001	INDY Car		Speed course spec.	0.76	0.91	1.2		1.2
			Hi downforce spec.	1.18	3.44	2.92		

Fig. 2: All Cl number on this list are downforce.



Profile of frontal airflow ‘through’ the engine compartment of the Nissan R35 GTR

Rear underbody layout of the Nissan R35 GTR

highway and in the snow. High downforce will unavoidably increase drag and consequently fuel consumption, therefore we targeted a total Cl of 0.08 as we considered this level of downforce to be adequate.

Our intention with the GTR was not only to create a company icon, but to also create a benchmark for the Japanese car industry. Our primary concern was not only drag, which can be translated as a car’s CO^2 footprint, but also high speed stability. Drag values of between Cd=0.36 and 0.27 make a significant difference in fuel consumption and CO^2 footprint throughout the life of the car, so we were not content with designing a car that was aesthetically pleasing yet lacking in substance. We were aiming to create a new standard bearer in the GT class.

Life’s a drag

There have been many ultra low drag prototype cars in the past, but many factors make this a difficult objective. A road car’s high road clearance creates strong turbulence under the car which also exposes more of the tyre’s frontal area to the air flow, while low road clearance just isn’t practical for a road car when taking into account road quality and climate, especially snow, and the GTR clearly has a higher clearance compared with other exotic cars.

Wide tyres are a draw back with regard to aerodynamic drag but they do ensure greater road handling stability. The R35 GTR has 285 mm wide rear tyres and fitting narrower tyres would have certainly reduced the Cd value, but it became a trade off between drag versus the desired chassis stability.

But there are many other factors that prevent a low target drag, such as; safety regulations, visibility standards, passenger ingress and egress, headlight set back as mandated by insurance standards, the minimum bending radius of aluminium panels, material cost restrictions, and numerous other issues. Of course, I did not have to deal with any of these factors when developing Le Mans race cars.

Styling driven

A few years ago when Nissan was facing bankruptcy, Mr. Carlos Ghosn was dispatched from Renault to rejuvenate the ailing company and in a surprisingly short period of time, the company was completely revived. During this reformation, the design department was reorganised and gained independence from the engineering department as Ghosn wanted to emphasise styling in order to increase car sales. While the Styling department drove the GTR’s overall design, the target drag of Cd= 0.28 was non negotiable and more significantly, there was a call for downforce both fore and aft.

An internal design competition was established between the various Nissan design studios worldwide (Atsugi and Tokyo, Japan, London, UK and La Jolla, USA) which narrowed the GTR styling concepts from approximately 80 design studies down to a more manageable twelve. These twelve were then whittled down to three models which the aero team then made into windtunnel models.

Given the predetermined drag and downforce targets, the design concept’s shape would need to be altered from the initial model, but since so much effort had already been poured into these concepts, this would only be done reluctantly. This would have been much easier if either active suspension or adjustable aerodynamics could have been adopted, but neither of these was considered given the target car price. This was unlike a race car design where cost is usually a secondary concern.

Getting down to business

It was August 2004 when Ken Nambo and I started work together on the car at Nissan Technical Centre in Atsugi, Japan, and over a three month period we tested the three selected ¼ scale designs, subjecting them to nearly 300 windtunnel runs. The Nissan GTR began to emerge from this study and the program then moved on to 40% scale models. At this point we decided to build two 40% scale windtunnel models; one was the development Nissan GTR and the other was a replica of the actual full-size prototype car that had been track testing with an Infiniti G37 coupe body at the Nürburgring. The reason for this was to use this model as a datum against which the Nissan GTR could be compared as the team had collected full size aerodynamic data during track testing.

We were very sensitive to maintaining the external shape of the Nissan GTR considering this was the fruit of the stylist’s labour and while you’d never suggest the colour of Van Gogh’s sunflower wasn’t right, in our case we had to be prepared to alter the stylist’s agenda if the first tests came in outside the set targets. And as our first runs came in, they showed values of around Cd= 0.32 which were quite a long way out, and based on that evidence we began to accept the possibility of modifying the external shape if we were to achieve our goals.

The methodology in developing either a road car or a race car is the same, as in both cases it is generally more productive to accumulate many smaller improvements and to continue to chip away at your goal. If you add a 0.001 gain (we call this one count) 20 times you end up with an improvement of 0.02. There are no short cuts to this approach, and every panel or surface of the model needs to be considered, such as, underfloor, wheel wells, wing, internal flow, tunnels, and many more.

Around this time, styling designer Masato Taguchi and Hiroo Ono, who were responsible for one of the three original concepts, joined the windtunnel team. We made progress early on by looking at changes to the car's general exterior shape and specifically the nose height, all within 20-30mm of the original concept, though I began to think that in order to achieve Cd .28, we would have to look beyond the car's shape and investigate the internal airflow.

A lot of work goes into designing the cooling system on a race car, but conversely, on a road car, the radiator is simply located within the engine bay and is usually without any proper inlet or outlet ducting; on a road car the airflow management into and exiting the radiator is an afterthought at best. The cooling airflow blows through the radiator core and then exits straight into the engine bay where it encounters many obstacles and protuberances, becoming turbulent. Ultimately the air migrates underneath the car, blocking the underfloor airflow coming in from the front of the car resulting in more front lift. Considering the speed of the airflow through the radiator, usually in the range of 15-30% of the car's speed, managing this flow is rather important and gains can be found in this area.

Most ancillary components in a road car, such as engine mounts, transmission mounts, turbo shrouding, muffler and all the brackets, are made by independent companies such as Delco, Denso, Hitachi. As such, their shape is an execution of their mechanical function without any thoughts given to aerodynamics, and a large portion of my focus was to chip away at the numbers in these areas.

The biggest change I called for was a reconsideration of the design of the car's chassis frame. In most front engined, rear drive road cars, the front frame rails are raised and extend rearward and then down under the passenger section. Considering that the engine mounts to these frame rails, and there is nothing underneath the engine to smooth the transition between the raised front section and low passenger section, the detriment to the all important underfloor aerodynamics is obvious. I requested that the chassis department change the design so that the frame rails were on the same plane (low) as the passenger section in order to eliminate the transition, and to smooth out the underfloor.

Even a major modification like this didn't result in an instant realisation of our target aero numbers, but such is the nature of the game, and accumulation was done one small step at a time.

A CFD program was run in parallel with the windtunnel work, and while contemporary CFD showed good correlation, it obviously could not tell us what to do, but it does help us to understand and visualise general flow. Ultimately though, this was only used for reference purposes.

What we needed most was experience and intuition, and furthermore the ability to modify the windtunnel model quickly. This allowed us to create hundreds of parts in a short period of time using various materials. A good craftsman with a well equipped workshop, and an experienced 3D CAD operator helped us to achieve accurate windtunnel results using a moving ground plane windtunnel.

Yoshi Suzuka is a freelance automotive aerodynamicist who started his career in race car engineering in 1968 after obtaining an MSc degree in mechanical design. He later became a fulltime aerodynamicist. Since then, Suzuka has created many successful race cars in IMSA GTP, Indy car, Le Mans car and GT car fields and the Nissan GTR is his first production car. He is also involved in a project to develop a 500 km/h world speed record Nissan GTR. Alongside four factory Nissan R90CKs and two R89Cs, Suzuka's Group C Nissan R90CP qualified 3rd on the grid at Le Mans in 1990 finishing 5th, the highest place finisher of any of the Nissan entries that year.

Moving targets

Road cars are built in their tens of thousands and consequently the design process takes a substantial amount of time as negotiation between parts suppliers, modification of the production line and design reviews all take time. Even while we were in the midst of the R35 GTR windtunnel program, the designs of many of the components had still not been finalised.

On one occasion we changed to a new and more accurate model wiring harness located in the engine bay, and the Cd unexpectedly increased 20 counts (0.02), which represents a significant performance set back. We then had to recover 20 counts from somewhere else to make up for this increase which ended up taking a few months to resolve. This particular example was a large set back, but smaller set backs were a daily occurrence, however, rarely did we see a positive gain when switching to a new model part, it was always a step backwards. After nearly 2000 runs, and much agony, we achieved Cd= 0.27 in drag and combined front and rear downforce.

Conclusion

Styling and design used to always be a top priority when I was in the market to purchase a car. Coefficients of drag certainly didn't enter into the picture, but more recently my conscience has shifted and it seems rather sinful to drive a car with a high fuel consumption.

Low drag will continue to be the primary factor in road car aerodynamics, even for electric cars as they gain popularity in the near future. Consider that in Japan in 2005 nearly 63% of all electricity was produced from either oil or natural gas. In the United States that number is 72%; 82% in China, 51% in Germany, and 74% in England – so even if you are driving an electric car, you are indirectly emitting carbon dioxide.

Developing the GTR was a fun task, but it certainly had its challenges. Ferrari claims to have spent several thousand windtunnel hours honing the shape for the beautiful Ferrari 360 Modena. In comparison, we spent nearly a year and half in the windtunnel creating the GTR. Good numbers do not come easily! The cynics would certainly wonder what impact the windtunnel hours spent contributed to CO^2 emissions, but when you consider the importance of this work, that it is a means to an end and is for the greater good, the effort is certainly worth it. ■