Aero Testing - Part 1

Welcome to our wool tuft extravaganza!

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In this series we're going to carry out some on-the-road aerodynamic testing of a variety of cars: the sort of approach that anyone with a few hours to spare can also do. This week we look at how the technique can be applied and how to interpret some of the results, while next week we launch into action with the first of five cars. Over the next weeks we'll test a 1997 Porsche 993 twin turbo 4WD, a 1991 Lexus LS400, a 1996 Mazda RX7 twin turbo, a 2001New Beetle, and a 1999 Impreza WRX. We hope that you'll be as fascinated as we are by the story writ in those fluttering bits of wool....

Airflow

As a car move forward, air passes over its body. But, unlike a boat that pushes water aside, in the case of cars, the fluid (air) is invisible. So, while an implication of the air movement can be gained by looking at the patterns of water droplets and the deposition of dust, in most cases people don't really have any idea of the paths that the air takes over, under and around their car.

But help is at hand: it is a near zero cost process to wool-tuft a car and then drive it down the road, inspecting the pattern of airflow from another moving car!

And why would you want to do that? Well, two main reasons, really.

- Because it's interesting
- Because it can help you in making aerodynamic performance mods

The Technique

The idea is deceptively simple: cut up lots of short lengths of wool, selecting a colour that contrasts well with the car's paint colour. Using good quality masking tape (good quality so that it won't lift the paint when you take it off!), stick the tufts all over the car, keeping them far enough apart that they can't touch together. (If they're too close, they tend to adhere to one another.) If you want to be neat, stick the tufts in lines.

Once you've done that, drive the car (or have someone else drive the car) down an empty, multi-lane road at about 70-80 km/h. From another car, shoot video or still pics of the tufts, including close-up details as well as overall shots.

If you are concerned that the buffeting of the chase car will upset the target's aerodynamics, get further away and use a telephoto lens.

Interpretation

Airflow over cars can be basically split into two types: attached and non-attached. The slightly less precise alternative terms are also more descriptive: laminar and turbulent.

In laminar flow, the air slides over the surface of the car in layers. Where this type of flow is present, the wool tufts will line up end to end, the ends fluttering just a little. On the other hand, where turbulence is present, the movement of the tufts is nearly random - they'll wave around in the air, sometime writhe upwards at 90 degrees to the surface that they're stuck to, and quite often angle forward **into** the direction of flow! Usually in turbulence they're doing all of this pretty well simultaneously...

At the front of a modern car, the flow across the surface of the bonnet will be almost always be characterised by laminar flow: the tufts will be lined up beautifully. The transition up the windscreen will also be laminar (ok, ok, "attached", then), but the transition from the windscreen to the roof may not be so good. If the flow detaches itself at this transitional change of angle, there will be turbulence across the leading edge of the roof. The tufts here will be whirling around, not lying flat and nearly still.

If this is the case, you can imagine that the frontal area of the car which is disturbing the air is actually larger than that indicated by the body dimensions - the turbulence on the leading edge of the roof making the car "appear" larger, resulting in more drag. (When envisaging this, pretend that turbulence colours the air green. Looking at the car from directly front-on, you'll see that the "green air" increases the apparent size of the car.) But back to the main game...

On a sedan, the airflow will generally be attached at the trailing edge of the roof - but then it has to make the transition onto the rear glass. It's the **back** of the car which is most important in determining overall lift and drag, so it's really important what happens here. If the flow remains attached and laminar right down the back window and onto the boot, the car's doing bloody well. Why? Because when the air finally leaves the trailing edge of the boot, the cross-sectional area of disturbed air being pulled along behind (called the "wake") will be small. And a small wake equals lower drag.

But if the air becomes detached, say, halfway down the rear window, then the wake is made much larger. If the flow leaves the car at the top of the rear window (eg all hatchbacks and the vast majority of old-shape sedans) you can see that the drag will be even larger again.

So a small wake is important to low drag, and this can be gained by the presence of attached flow as long as possible. A small wake is to be strived for if you want low drag - but it has a major downside. If you still want to be able to fit people in the cabin, the centre part of the car will be much higher than the rear proportions - so the airflow will have to wrap up and over curves. Hmm - an aircraft wing generates lift by having a curved upper surface and a much flatter lower surface....

and in much the same way, a car body generates lift as well. So, the more attached the flow is from the front of the car to the rear and the lower the rear surface can be made - the smaller the wake and therefore probably the drag. But shapes like this invariably generate lots of lift because of the flow wrapping itself around those upper curved surfaces....

And even worse, if the curved surface is at the very rear of the car (eg the classic Porsche 911 or the New Beetle shapes), well, that airflow will generate both lift **and** drag. Instead, you want the airflow to finally depart the car body without wrapping over any final curves - the reason for raised lips and sharp changes of angle on the trailing edge of the boots of modern aero sedans, and the roof extension spoilers of hatches. So a trade-off is necessary - keep the wake small but generate as little lift at the rear of the car as possible. (Rear lift leads to instability - again, the rear is a vital area.)

So where does all this leave us?

Well, by looking at the patterns of airflow revealed by wool tufting, you can accurately estimate:

- The size of the wake
- Where the attached flow separates from the body

Using some rules of thumb, you can then estimate:

- Where major lift is occurring
- Where spoilers and wings should be placed to be most effective
- Where minor mods might decrease turbulence

You can also clearly see airflow patterns through:

- Intake ducts (eg oil cooler intakes)
- Outlet ducts (eg ventilation exits)

Further, you can generalise as to:

- The areas of low pressures (attached airflow wrapping around upper curves and, to a lesser degree, within wakes)
- Areas of high pressure (eg the area at the very front of the car above which the flow goes over the bonnet and below which it goes under the car)

So you see those bits of wool are actually an enormously powerful tool!

Accuracy

If I had the choice between a fully equipped wind tunnel complete with expert technicians - and wool tuft testing on the road, well, I'd take the tunnel, thanks! But I don't know too many people with that choice...

So how good is on-road testing of the type described? Firstly, the point should be made that, not too many years ago, even performance manufacturers like Lamborghini used on-road wool tuft testing as a major part of their development process. Secondly, while yaw angle airflow (ie a cross-wind component) cannot be accurately and consistently simulated on the road, in most other areas, the airflow over a car being tested on the road is very accurate - cos after all, cars do drive on roads, not in wind tunnels!

While the real possibility exists of the chase car disrupting the airflow, when you actually do the testing, there usually is no discernible difference in the tuft behaviour when you're up close or the chase car is further away. (And if you want to, there's nothing stopping you doing pans with a camera from the side of the road as the tufted car drives by.)

The proof of the pudding, though, is when you compare wind tunnel woof tuft testing with the results of the same cars tested on the road. In general, the road testing is very, very close to the wind tunnel pics.

Conclusion

Over the next issues we'll show you the results gained in wool tuft testing a variety of cars, and do some interpretation of those fluffy patterns. But if you want to get out there and do it, don't wait for us! It really is one of the most interesting tests you can make of your car - and since it costs near nix, what's stopping you?

Coming Up: the Impreza WRX and Lexus LS400