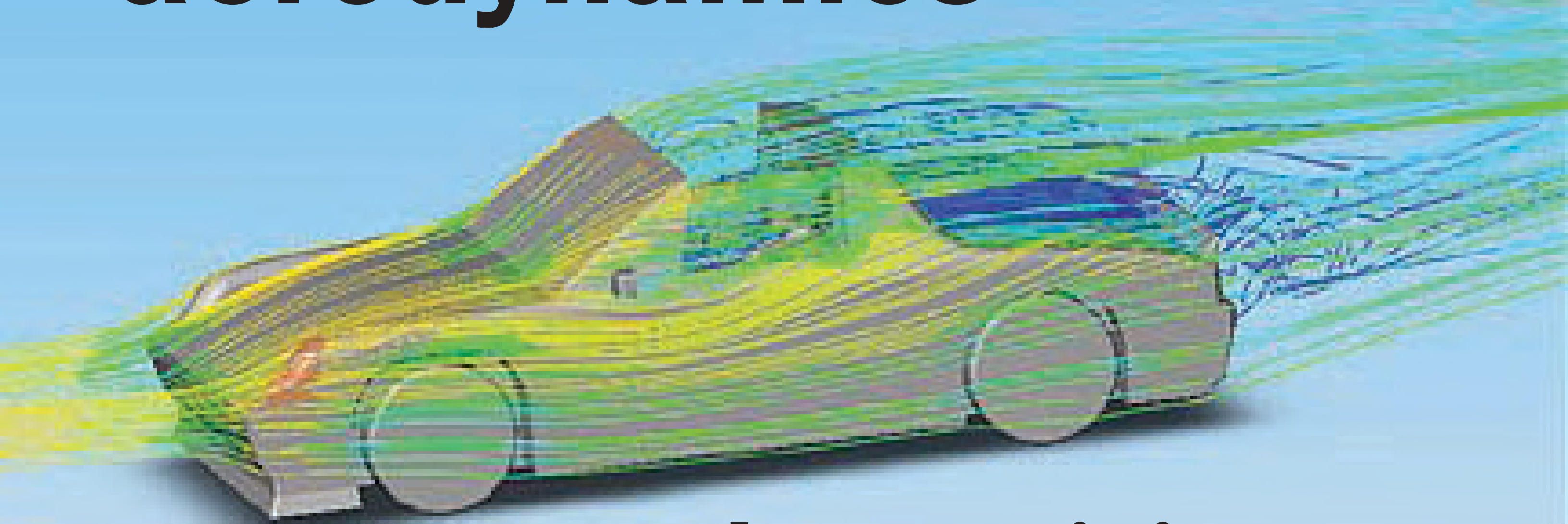
Optimizing the 914's aerodynamics



TEXT AND ILLUSTRATIONS BY CHRIS CASSIDY AND STUDENTS

When I bought my 914, it came with an aftermarket front spoiler. I kept it on the car because I liked the way it looked. It gave the car that kind of racecar look and feel. I bought the car for only one use: to have fun driving it in PCA-SDR autocross events!

I like working on my cars and driving them. When the car is not at an autocross, it is at home in the garage being worked on. So on the down side, the front spoiler adds two points to my class standing for "Non-stock Aerodynamic Aids." For me, the look of the spoiler outweighed the added points. Until I have a chance to improve the engine and suspension more and I need the points for those improvements, I will continue to use the front spoiler.

I work at UCSD in the Mechanical and Aerospace Engineering (MAE) Department. Besides classroom lectures for the students, we have laboratories where students go for hands-on learning. We have different laboratories for different engineering disciplines. I manage a laboratory where the students learn about Engineering Design.

We have a laboratory-course class in which students learn about fluid mechanics, solid mechanics, vibration, control systems, and heat exchange and pollution experiments. Each year, they ask for projects for the students in these areas. I offered to sponsor and advise a project that would look at the aerodynamic effects of my front spoiler on my 914 and some rear spoilers that I had bought on eBay. I wanted to know how the spoilers would affect the performance of my car for autocross driving.

Students in projects of this type apply what they've learned in the classroom while trying to accomplish the sponsor's goal. Over the past three years I have sponsored my 914 aerodynamics project three times with three different student groups. Each year, the project had a different emphasis. Several methods were used to measure the same effects of aerodynamic drag and air flow on my 914. This way the students could verify their results and at the same time learn different scientific and engineering techniques.

2005: Working with models

The first year's group worked on preparing two Revell scale models for wind-tunnel testing, creating a computer model for airflow and drag coefficient analysis, and purchasing a car data-acquisition system. The goal was to take three different approaches to measure the 914's drag coefficient and to compare the results.

The students' first step was to perform a litera-

Computer models created with the SolidWorks 3D CAD software.

ture search on the web, and to post requests for information on the various 914 forums. It was interesting to find that out that there was almost no aerodynamic analysis of the 914 in the Porsche community. A number of people have added spoilers and wings to their 914s, but no aerodynamic testing or analysis has been done using them.

A Stratasys Systems 3D Prototyper created the spoilers for the Revell models. 3D computer models were made of the spoilers and then scaled down to match the scale of the Revell models. Because our Stratasys Prototyper can make parts using only wax, female molds were made, and then resin was cast into them to form the spoilers.

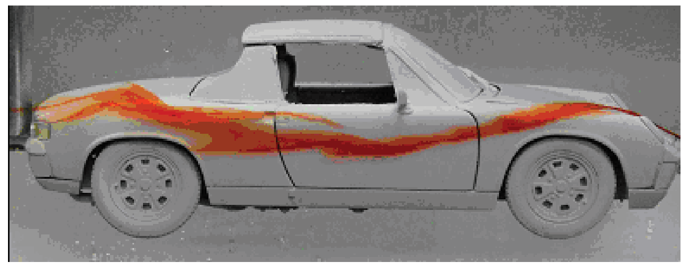
For the computer analysis, FloWorks was used to model the airflow around the 914 and calculate the drag coefficient. At the time, there were no computer models of the 914, so they had to be made from scratch.

All of the spoilers were mounted on the actual 914 to see how they affected the car's drag. The drag measurements were done using a G-Tech Meter, which calculates a car's horsepower based on its weight and acceleration. Because the spoilers affect the aerodynamics of the car, it shows up as more or less horsepower, which can be calculated into more or less drag.

Their main conclusion was that the front spoiler that came on my 914 increases its drag and should be removed for autocross driving.

2006: Verification

The second year's group worked on testing the models in a water tunnel, performing a traditional yarn test, creating a dye-flow visualization, and improving the models and methods used in the computer modeling.

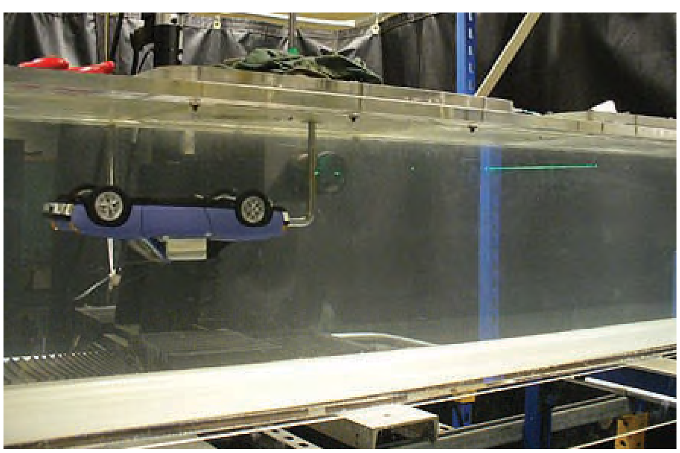


Dye visualization.

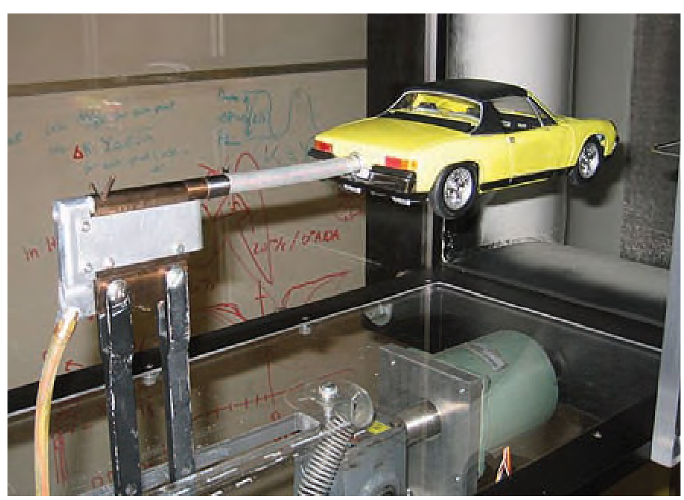
Their main conclusion was that computer models could be used to model real-world results. It was interesting to see how well the yarn test and the dye visualization matched up with the computer analysis of the airflow around the 914.

2007: Innovation

The third year's group was given the chance to be creative. Previous groups had measured the aerodynamic effects of drag on the 914 in different ways and then verified the theoretical with the real world. This year's group used everything that was previously learned to design different aerodynamic improvements for the 914.



In a water tunnel, a laser Doppler measures water velocity passing the (inverted) model.



In the wind tunnel, a drag balance measures forces on the car from surrounding air flow.

Optimization of Aerodynamic Aids for Autocross Racing

Joseph Chun, James Grover, Michael Morishita, Jason Robertson
***Course Advisor*:** Dr. V. Shevchenko, ***Project Advisor and Project Sponsor*:** Chris Cassidy

Introduction

The overall objective of this project was to study the aerodynamic effects of different car configurations for Chris Cassidy's 1972 Porsche 914. Chris wants to determine whether or not aerodynamic aids such as front and rear spoilers will decrease his lap times enough to offset penalty points given for aerodynamic modifications in autocross events.

What is Autocross?

- Car racing competition based on lap times
- Different classes separate cars based on performance, focusing on driver skill
- Speeds relatively low, ~60 mph max
- Track is narrow and outlined by cones
- Usually held in large parking lots

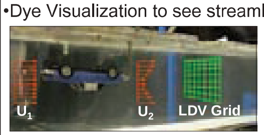
Objectives and Achievements

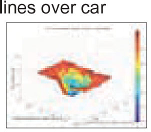
- Experimentally determining aerodynamic characteristics (drag and streamlines) of different car configurations
- Correlate experimental data to full-scale car
- Optimize car aerodynamics for best autocross score

Set up and Methods

Water Tunnel Testing

- 1:18 scale models tested at Re = 5.06?10^5
- Laser Doppler Velocimetry (LDV) to measure drag
- Dye Visualization to see streamlines over car





Yarn Testing

- Full size car tested to see flow behavior

Solid modeling

- Full size model created for CFD analysis

Computational Fluid Dynamics

- Utilize flow analysis software
- 30, 50, 60 mph (Re = 2.93?10^6, 4.88?10^6, 5.86?10^6)

Design and Analysis Tools

A variety of tools and technologies were used to analyze the aerodynamic characteristics of the car:

- Water tunnel testing / LDV testing was performed in the UCSD undergraduate laboratory
- LDV raw data was analyzed with Matlab 7.0
- 3-D modeling of the car was done in Solidworks.
- Computational Fluid Dynamics analysis was performed using Solidworks Floworks software.

Theory

Total drag on a car is due to rolling resistance, mechanical friction, and aerodynamic forces. Reducing aerodynamic drag will free up engine power to allow for higher acceleration and speeds.

Drag on an object in a fluid is the force parallel to and in the direction of the flow associated with the interaction of fluid particles with the object's surface. There are two types of drag: pressure and viscous. Viscous drag arises from the interaction of fluid particles with the surface of an object. Pressure drag depends on the pressure gradient across an object and the frontal area of the object. By knowing the drag force in the direction of the flow and the flow characteristics, the drag coefficient C_D can be solved:

$$C_D = \frac{F_D}{\frac{1}{2}\rho U_\infty^2 \cdot A_{frontal}}$$

The drag force F_D can be calculated experimentally by measuring the velocity profile of the wake behind the car with LDV and applying momentum analysis to yield:

$$F_D = \frac{1}{2}\rho U_{1\infty}^{\ 2} \cdot \int 2[\frac{U_2}{U_{1\infty}} - (\frac{U_2}{U_{1\infty}})^2]dA$$

Where U_{18} is the upstream flow velocity, U_2 is the flow velocity in the wake at a given point, and dA is an incremental area in the wake being analyzed.

To maintain a constant velocity, a certain force from the engine is required to overcome the total drag force on the car. This can be translated into a required power (equation below), which changes for different aerodynamic configurations. The difference between the engine's power output and the power required to maintain constant velocity can be used for vehicle acceleration. Minimizing the required power leaves the vehicle more power for acceleration.

$$P_d = -\frac{1}{2}\rho V^3 A_f C_d$$

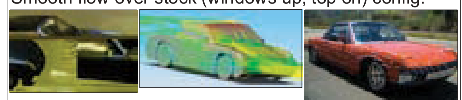
Results

Best Performance by Drag Coefficient:

1) Windows up – Top on
2) Windows down – Top on
3) Windows down – Top off
3) Windows up – Top off

		FloWorks	LDV	
#	Description	Cd (50 mph)	Cd	δCd
1	windows up, top on	0.347	0.376	0.014
2	windows up, top off	0.483	0.451	0.018
3	windows down, top on	0.432	0.404	0.016
4	windows down, top off	0.480	0.467	0.018
5	closed up, front spoiler	0.435	0.396	0.016
6	closed up, rear spoiler	0.411	0.378	0.015
7	closed up, full aero	0.414	0.429	0.017

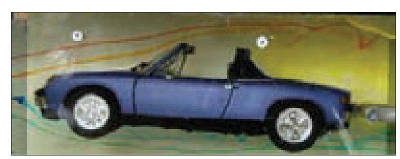
Smooth flow over stock (windows up, top on) config.

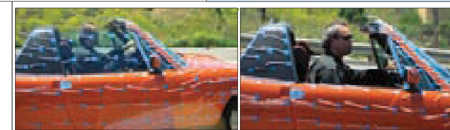


Flow into interior when windows down

Flow recirculation behind rear window in all cases

Adding sharp changes in geometry (aero modifications, windows down, top off) leads to higher drag because of flow separation causing increased pressure drag





Increases in wind noise and frayed yarn showed areas of turbulence during the real car tests. Because of the flow recirculation behind the rear window, the addition of a rear spoiler in such stagnant airflow would not be effective

Effective Horsepower Loss Results

		FloWorks	Horsepower	
#	Description	Cd (50 mph)	Hp	ΔHp
1	windows up, top on	0.347	5.5	0.000
2	windows up, top off	0.483	7.6	2.100
3	windows down, top on	0.432	6.8	1.300
4	windows down, top off	0.480	7.6	2.100
5	closed up, front lip	0.435	6.9	1.400
6	closed up, rear spoiler	0.411	6.5	1.000
7	closed up, full aero	0.414	6.5	1.000

Discussion of Results

We utilized a variety of independent testing methods to gain both quantitative and qualitative insights into the aerodynamic effects of various car configurations. Each set of results confirmed of hypothesis that introducing sharp geometry changes into the car's surface would contribute to flow separation and turbulence, thereby producing a higher drag coefficient. C_D estimates from both CFD and LDV were in close agreement with each other and the published value of 0.363 (closed up), although CFD generally estimated a slightly lower value, probably due to the lack of both body panel gaps and subtle surface roughness in the Solidworks model. Flow visualizations produced through CFD, water tunnel dye testing, and yarn tuft testing all qualitatively depicted the adverse aerodynamic effects caused by such modifications.

Conclusion and Recommendations

In conclusion, we have seen that the coefficient of drag increases greatly after rolling down the windows or removing the top. The C_D increase is directly related to the pressure drag increase. The greater pressure drag also increases the power necessary to maintain a given velocity, a 2.1 horsepower increase comparing lowest and highest drag configurations at 50 mph. This study recommends that the best configuration for a Porsche 914 during an autocross with point penalties is windows up, top on, and no aerodynamic modifications. This configuration has the lowest drag and receives no point penalties.

Presentation Poster summarizes students' project. (The equations in the second column are, of course, obvious.)

They looked at the aerodynamic designs that other people were using on their 914s and then came up with several designs of their own. Because there was so little information in the 914 communities in regard to the 914's overall aerodynamic characteristics, the students concentrated their efforts on measuring drag coefficients and airflow around the 914. Their Student Presentation Poster shows what they found. The chart also shows downward forces generated.

Their main conclusions showed that the stock car is pretty good in regard to drag. Not bad for a 37-year-old design.

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#	Description	Cd (50 mph)	Hp	ΔHp
1	windows up, top on	0.347	5.5	0.000
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Table shows effective loss of horsepower at 50 mph for various configurations.

What's next?

I'm going to have next year's group look at the downward effects of the aerodynamics of the 914 and how it performs on larger tracks. They will model what is currently being used and then try to design improvements that would make them more efficient. They will look at how much downward force the 914 needs to keep it stable at higher speeds in a straight, and how much force it needs to keep it stuck to the ground when cornering. Is there anyone out there who would be willing to have the students come take measurements of their large rear wings?

Currently my old, tired, 80-hp, 1.7L (with low compression in one cylinder) 914 is starting to make a crankshaft-knocking noise and needs to be replaced. I've replaced, rebuilt, or upgraded everything else in the car, so the motor will be next. After that, I will be looking into lightening the car and possibly using a very large rear wing that other types of cars use for lower-speed racing.

Working with the students has been very rewarding and motivating. Their energy is highly contagious.

FUEL: *Continued from page 47*

enough. This detonation can eventually lead to engine destruction.

The most important thing to remember about octane is that having an octane level too high will not harm an engine; having an octane level too low can be catastrophic. Therefore, do not try and save money by reducing the octane level of the fuel required. On a side note, putting a higher octane fuel in your car than is required *might*— but will not necessarily—improve its performance.

Here are a couple more bits of information that you may find interesting.

- Chevron has been supplying the gasoline that the Big Three Detroit auto makers use to accumulate mileage on their vehicles to demonstrate compliance with the U.S. EPA's 50,000- and 100,000-mile emissions-durability requirement. Even though the closest supply point is 350 miles away in Louisville, KY, the Big Three pay to have the fuel trucked into Detroit. The Big Three must believe that using Chevron fuels offers their best chance to keep the vehicles performing to their optimum and passing the EPA's requirements.
- A number of Porsche racers and collectors whom I personally know add Techron (Chevron's well known additive/detergent) to their race fuel. They add it to prevent their fuel injectors from clogging and to keep their fuel systems clean during prolonged periods of storage. They, as well as I, believe it is cheap insurance.

Summing up

Putting this into context: Our engines are more complex, higher performance, and more expensive to maintain than the engines from BMW, GM, Honda and Toyota. If those manufacturers specify Top Tier fuels in their cars for performance reasons, it seems only logical to me that running anything less in our cars is asking for problems.

Everyone has heard the saying, "Pay me now, or pay me later." The decision is yours to make. With the price of repairs and the cost of our car engines, I personally believe that buying a premium Top Tier fuel is money well spent.

Ken Koop is president and editor of Yellowstone Region, PCA. Reprinted with permission from Yellowstone Region's Old Faithful Porsche, *February 2007.*