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

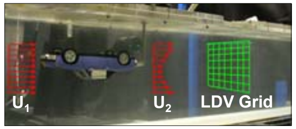
Objectives and Achievements

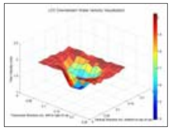
•Experimentally determining aerodynamic characteristics (drag and streamlines) of different car configurations
•Correlate experimental data to full-scale car
•Optimize car aerodynamics for best autocross score

Set up and Methods

Water Tunnel Testing

•1:18 scale models tested at Re = $5.06 \cdot 10^5$
•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 = $2.93 \cdot 10^6$, $4.88 \cdot 10^6$, $5.86 \cdot 10^6$)

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:

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

Where $U_{1\infty}$ 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.

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

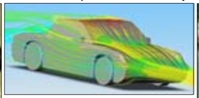
Results

Best Performance by Drag Coefficient:

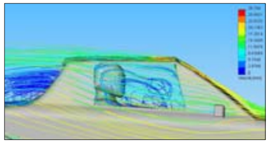
1) Windows up – Top on
2) Windows down – Top on
3) Windows down – Top off
3) Windows up – Top off

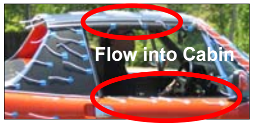
		FloWorks	LDV	
#	Description	Cd (50 mph)	Cd	δCd
1	windows up, top on	0.347	0.376	0.014
2	windows up, top off	0.483	0.451	0.018
3	windows down, top on	0.432	0.404	0.016
4	windows down, top off	0.480	0.467	0.018
5	closed up, front spoiler	0.435	0.396	0.016
6	closed up, rear spoiler	0.411	0.378	0.015
7	closed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

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



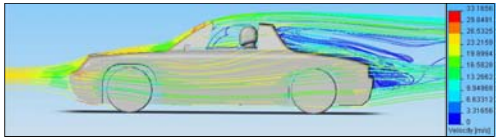
Flow into interior when windows down





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.