Race Car Aerodynamics Project

Purpose:

The purpose of this project is to learn about the aerodynamic design of race cars and how it relates to lift and drag forces. In addition you will be introduced to techniques for measuring pressure, lift and drag forces and velocity.

Background:

"Why all the fuss about aerodynamics when racing engines are the reason the cars go so fast?"[1]

In the world of modern automobile racing the difference between winning and losing can be measured in fractions of a second. One of the major factors that racecar manufacturers focus on to decrease lap times, and gain a competitive edge is the aerodynamic performance of the vehicle. The lift and drag forces that act on a race vehicle impact the performance and the body shape of each car is formed in an attempt to control these forces to maximize vehicle performance. (see Figure 1)

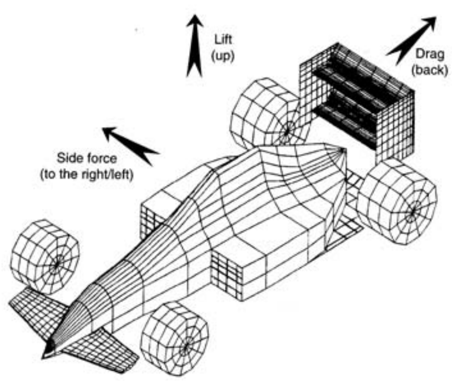

Figure 1. The directions used to identify the three component of aerodynamic force. (from Katz, 1995)

Drag is the force that acts opposite to the path of the vehicles motion. Drag is detrimental to vehicle performance as it can limit the top speed of a vehicle and increase the fuel consumption, both of which are negative consequences for race vehicles. Low drag vehicles usually have one or some combination of the following characteristics: streamlined shape, low frontal area, and minimal openings in the bodywork for windows or cooling ducts. The drag performance of vehicles is characterized by the drag coefficient (C_D) which is defined as:

$$C_D = \frac{F_D}{{}^1/_2 \rho V^2 A} \qquad (1)$$

Where F_D is the drag force, ρ is the air density, V is the free stream velocity, and A is the frontal area of the vehicle. This non-dimensional coeff-icient allows the drag performance between diff-erent vehicles and different setups of the same vehicle to be compared directly.

Lift is the other of the two main aerodynamic forces imposed on a race vehicle, but unlike drag, lift can be manipulated to enhance the performance of a racecar and decrease lap times. Lift is the force that acts on a vehicle normal to the road surface that the vehicle rides on. As its definition implies, lift usually has the effect of "pulling" the vehicle away from the surface it drives on. However, by manipulating the racecar geometry it is possible to create negative lift, or down-force. Down-force enhances vehicle performance by increasing the normal load on the tires. This increases the potential cornering force which results in the ability of the vehicle to corner faster and reduce lap times. The lift of the vehicle is characterized by the lift coefficient (C_L) and is defined as:

$$C_L = \frac{F_L}{{}^1/_2 \rho V^2 A} \qquad (2)$$

Where F_L is the lift force, A is the area of the upper surface of the vehicle, and the other variables are as defined above. A negative lift coefficient means that a vehicle is experiencing down force.

The pressure over the vehicle varies across the surface and is dependent on the geometry of the vehicle. The pressure on the vehicle acts normal to the surface and contributes to the lift and drag forces accordingly. The pressure at each point on the surface of the vehicle can be characterized by the pressure coefficient (C_P) which is defined as:

$$C_P = \frac{P - P_\infty}{{}^1/_2 \rho V^2} \qquad (3)$$

Where p is the static pressure at the vehicle surface, p_∞ is the free-stream static pressure, and the other variables are as defined above. The value of C_P is one at a stagnation point and is zero when the local and free-stream velocities are the same such as over flat sections of the vehicle. In regions of accelerated flow the pressure coefficient is negative.

In this project you will measure the lift, drag and surface pressure characteristics of 1/8 scale model size radio control vehicles and compare them to the velocity distribution around the vehicle.

The Vehicles:

Each lab group will be assigned a model car for all of their tests (see Figure 2).

(a) NASCAR racer
(b) Mercedes CLK
(c) Audi TT
(d) Baja Pickup truck

Schedule:

Week of 2/18 : Surface Pressure Measurements
Week of 2/25: Lift and Drag
Week of 3/4: Computational Fluid Dynamics (CFD) & Particle Image Velocimetry (PIV)
Week of 3/7: Oral Presentations - time TBA

Writing/Presentation Requirements:

Each group will submit 1 memo report per week. One student in each group will be responsible for submitting the memo but the grade will apply to all 3 group members. For week 1 you will write a memo report to present the surface pressure results. For week 2 you will write a report on the lift/drag results and in week 3 you will submit a report on the CFD modeling results.

In addition, as a group you will make a group oral presentation during the last week of the term.

Acknowledgements/References

1. Jeremy Losaw, Aerodynamic Characterization of a 1/12 Scale Radio Controlled Car with NASCAR and LeMans Style Bodies, Senior Project Report, (ME Class of 2002)
2. Katz, J., <u>Race Car Aerodynamics</u>, Robert Bentley Publishing, 1995

Fig 2a. Nascar Racer


Fig 2b. Mercedes CLK

Fig 2c. Audi TT

Fig 2d. Baja Pickup

Week 1: Surface Pressure Measurements:

The first lab exercise is to measure the surface pressure distribution around the vehicle using the pressure-tapped models. Each model has 13-14 pressure taps. The pressure taps were made by drilling small holes in the surface of each car and connecting tygon tubing to the underside of each hole. Figure 3 is a schematic of the pressure tap and Figure 4 shows a pressure tapped model. More information on each model car can be found at the end of this package.

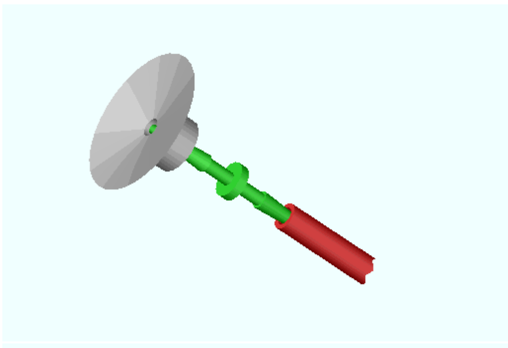

Fig 3. Schematic of Pressure Tap system.

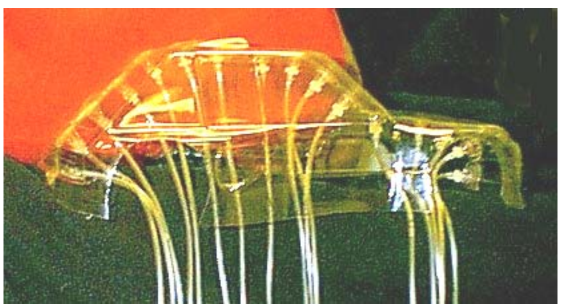

Fig 4. Picture of instrumented car.

Procedure: The pressure-tapped car body will be pre-mounted in the wind tunnel for you. The tygon tubes which are each numbered indicating the pressure tap number are passed through a hole in the bottom of the wind tunnel and the mounting beam is attached to the dynamometer (for support only). **Remember to record all important information in your lab notebook! I will be asking questions during your oral presentation that may require you to refer to the lab notebook!**

Note: If you have problems activating the data acquisition system reboot the computer.

1. Make sure that the pressure transducer output is connected to the channel one on the DAQ system and that the USB cord attaches the DAQ to the computer.
2. Check the connections on the wind tunnel pitot probe. The stagnation pressure (vertical tap) should be connected to the "total" connection on the back of the pressure transducer box and the static pressure (horizontal tap) should be connected to the "static" tap on the back of the pressure transducer box.
3. Connect the tygon tubes from ports 1-9 (coming out of the tunnel) to the multicolored numbered tubes coming from the pressure transducer box (connect Port 1 to tube 1, Port 2 to tube 2 etc…)
4. Load the DAQ software. Check to see that the software is configured to read Channel 1 and make 100 readings.
5. Turn on the wind tunnel to 20 hz and wait 1-2 minutes for the motor to stabilize before taking data.
6. Turn the selector switch on the pressure transducer box to channel 0 (this connects the pitot probe output to the pressure transducer and will allow you to determine velocity). Trigger the data acquisition system to start taking data. Save the Data in Excel.
7. When the data acquisition is complete calculate the average and standard deviation numbers at the top of the column. The percent standard deviation should be less than about 10% (unless the number is really small).
8. Now turn the selector switch on the pressure transducer box to channel 1 and acquire another set of 100 readings. You are now reading the difference between the local static pressure and the free stream static pressure at port 1. When the data acquisition is complete you need to check the standard deviation which should be less than about 10% (although if ΔP is near zero this number can be much higher).
9. Repeat step 8 and cycle through channels 2-9 to read ports 2-9 ΔP values. Make sure to acquire data in the next column over.
10. **Save your data file so that you do not lose your data.**
11. Set the wind tunnel speed to 35 hz, and repeat steps 6-9 (except you probably want to save this information in a separate work sheet).
12. Set the wind tunnel speed to 50 hz, and repeat steps 6-9 (except you probably want to save this information in a separate work sheet).
13. Disconnect ports 1-9 tygon tubing and connect ports 10-14 to channels 1-9 on the selector switch. Repeat step 8 until you have read all of the ports.
14. Repeat step 8 for channels 10-14 for the 35 hz

motor frequency setting.

15. Repeat step 8 for channels 10-14 for the 50 hz motor frequency setting.
16. **Save your file and move to another computer for data analysis.**

Data Analysis:

- Convert all transducer output voltages to pressures using the information in Figure 4. (Note this is a calibration curve for the wind tunnel pressure transducer that I recently calibrated).
- Convert the pitot probe pressures to velocity (it would probably be a good idea to compare these numbers to what you got last week).
- Calculate Cp at each pressure port location for both speeds. Make a plot of ΔP versus x location and one of Cp versus x location for both velocities tested (see attached information for x location information). ***Your plots MUST have error bars on the data points!*** The uncertainty in ΔP due to the calibration is given in Figure 4 below. When you estimate your uncertainty in ΔP you need to account for the variation in the measurements plus the calibration uncertainty.

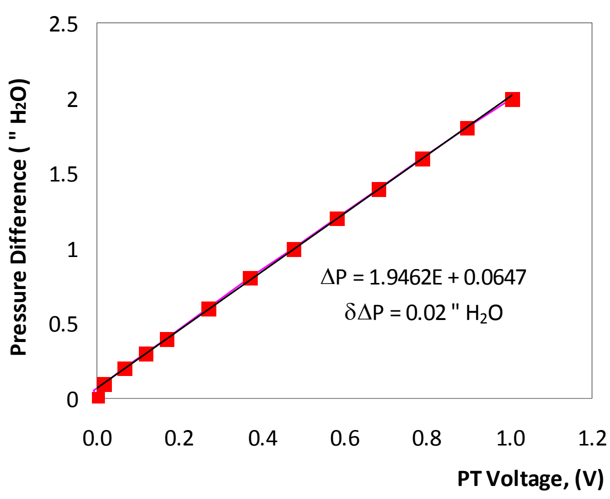

Figure 4. Wind tunnel pressure transducer calibration results. The uncertainty in the pressure measurement is 0.02" water and accounts for the micro-manometer accuracy and calibration fit.

Lab Reports:

Each group member is to prepare a draft lab report due in one week (at next lab period). Bring two copies (one for me, one to discuss with the group). During the lab period you will review each others memos and discuss and designate one lab member to be responsible for submitting a final draft to me on Friday 3/1.

The memo report should be on the results (including the uncertainty estimates) of your surface pressure tests. The intent of the memo is to relay your results to me and the other lab groups. Include a description of the experiment, your results and a short discussion. Include tables of data as an attachment.

Note: I will be posting electronic versions of your report to the course webpage.

Model Car Information

NASCAR

L = 260mm **W** = 110mm **H** = 70mm

Top Area = 286 cm^2
Front Area = 77 cm^2

Position of Pressure Taps (distance from front in mm)

1	0
2	16
3	30
4	52
5	70
6	92
7	114
8	134
9	154
10	174
11	193
12	215
13	235
14	260

AUDI TT

L = 250mm **W** = 100mm **H** = 70mm

Top Area = 250 cm^2
Front Area = 70 cm^2

Position of Pressure Taps (distance from front in mm)

1	0
2	10
3	28
4	48
5	70
6	85
7	108
8	125
9	145
10	164
11	183
12	200
13	225
14	240

MERCEDES CLK

L = 250mm **W** = 100mm **H** = 70mm

Top Area = 250 cm^2
Front Area = 70 cm^2

Position of Pressure Taps (distance from front in mm)

1	5
2	20
3	42
4	62
5	80
6	100
7	122
8	145
9	165
10	185
11	205
12	225
13	250

BAJA PICKUP

L = 235mm **W** = 90mm **H** = 80mm

Top Area = 211.5 cm^2
Front Area = 72 cm^2

Position of Pressure Taps (distance from front in mm)

1	0
2	30
3	50
4	70
5	85
6	100
7	120
8	140
9	153
10	170
11	190
12	210
13	240