# Fluid Mechanics Laboratory Experiment: Measurement of Drag on Model Vehicles

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**Abstract -** A well structured fluid mechanics laboratory that compliments the lecture course is vital to an effective presentation of the material. It is therefore prudent to provide meaningful experiments that stimulate student interest in the fluid mechanics laboratory. Such experiments are an important part of the laboratory experience.

This study shows how drag force measurements on model automobiles can be obtained experimentally, and how the data can be used to calculate a drag coefficient. Frontal area of the vehicle may be determined with internet resources, and used to find the drag coefficient.

In this study, data on drag versus velocity have been obtained for three different model vehicles. Frontal area for each of these vehicles was obtained and drag coefficient versus Reynolds number was determined. An experiment involving these measurements is a valuable addition to the fluid mechanics laboratory, and very effective in generating student interest.

*Keywords*: Drag, drag coefficient, automobile, laboratory

## Introduction

Drag force measurements on various bodies can be obtained using a subsonic wind tunnel, which can be found in most laboratories. Making measurements of drag force versus velocity using spheres, hemispheres, disks, and flat plates are classical experiments. Although important, these wind tunnel objects tend to leave a little to be desired. Alternatively, drag force versus velocity measurements on ground vehicles, such as bicycles, trucks and automobiles, can be obtained using models. Student interest is readily apparent when students work with such objects in the wind tunnel.

Traditionally, the difficulty with using automobile models is in finding the frontal area needed in the equation for drag coefficient. Several methods for estimating the area have been suggested in the literature. Previous studies indicate that a frontal area for a vehicle of interest is not easily obtained, and so published data often show the drag coefficient-area product rather than just the drag coefficient. Current data on drag force or drag coefficient is widely available on the internet. Moreover, students prefer to use the internet to obtain information, and so the references listed and described here are primarily from the internet.

Wikipedia [1] has a description of drag force and drag coefficient, and provides over 115 recent

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internet publications on this topic. One of the difficulties with converting drag force to drag coefficient is in finding the frontal area of the vehicle. Ecomodder [2] suggests using the product of height and width of the vehicle, and multiplying by 0.84 to obtain the frontal area. Instructables [3] provides a description of how to calculate the drag coefficient of a vehicle by using the coast down procedure. This procedure provides a drag coefficient which is an average. Results of the present study indicates that the drag (and drag coefficient) vary with speed. Thus the Instructables [3] result appears to be an overall average. Truth [4] provides an illustrated history of automobile aerodynamics, while Ask [5] gives a list of the most aerodynamic production cars. Mayfo [6] supplies an exhaustive index of coefficient of drag for many vehicles, but not for either of those used in this study. Mayfo also gives an index to for horsepower vs speed curves.

In this study, data on drag versus velocity have been obtained for three different model vehicles. Frontal area for each of these vehicles was obtained from an internet resource and drag coefficient versus Reynolds number was determined. An experiment involving these measurements is a valuable addition to the fluid mechanics laboratory, and very effective in generating student interest.

## Apparatus

Figure 1 is a sketch of the subsonic wind tunnel used in this study; manufactured by West Coast Research. An automobile model is placed in the test section as indicated in Figure 2. There is no provision for measuring drag on an automobile in this tunnel, so a system was set up to do so. The automobile model is secured with a fishing line that extends outward from the front of the tunnel. The line then goes over three pulleys, and is attached to a spring scale mounted on top of the test section. Air moving past the model exerts a drag force which is measured directly with the spring scale. A differential pressure meter is attached to a static pressure tap located in the top of the test section. The meter provides a reading of pressure difference bettween that in the test section and atmospheric pressure. Alternatively, an inclined manometer can be used to find the pressure difference.

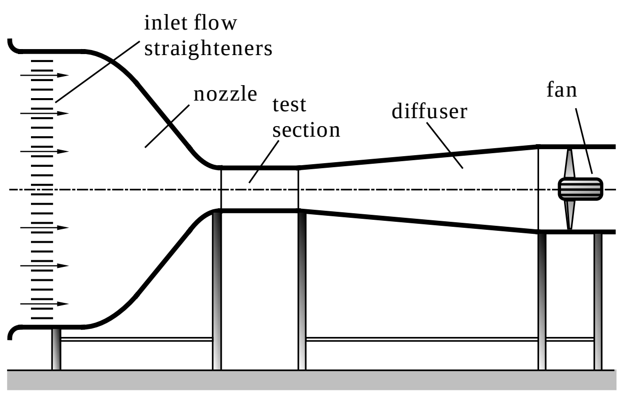


**FIGURE 1.** Subsonic wind tunnel used in this study.

## Analysis

A reading on the differential pressure meter is used to calculate the air speed in the test section using the Bernoulli equation. We identify section 1 as being far upstream of the tunnel inlet. Section 2 is at the test section where the manometer is attached. We apply Bernoulli's equation to these sections:

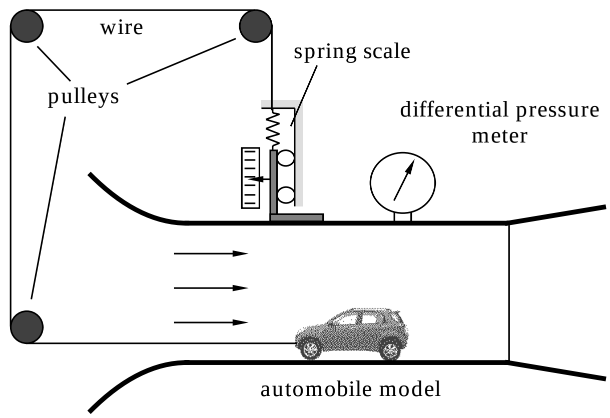


**FIGURE 2.** Sketch of the wind tunnnel test section with instrumentation.

$$\frac{p_1 g_c}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{p_2 g_c}{\rho g} + \frac{V_2^2}{2g} + z_2 \qquad (1)$$

where $p_1$ is the pressure far upstream (= $p_{atm}$), $V_1$ is the velocity upstream (= 0), $p_2$ is pressure and $V_2$ is velocity, respectively, at the test section. Changes in potential energy are neglected. Equation 1 reduces to

$$\frac{p_1 g_c}{\rho g} - \frac{p_2 g_c}{\rho g} = \Delta h = \frac{V_2^2}{2g}$$

The preceding equation may be rewritten as

$$V_2 = \sqrt{2g\Delta h} \qquad (2)$$

The drag force $D_f$ is measured directly with the spring scale. The drag coefficient is defined as

$$C_d = \frac{2D_f}{\rho V_2^2 A} \qquad (3)$$

The difficulty encountered in automobile vehicle tests is in finding the frontal area to use in Equation 3. Often what is reported in the literature is the product of drag coefficient and area:

$$C_d A = \frac{2D_f}{\rho V_2^2}$$

To determine area in this study, however, the models used were photographed from the front in a well lit setting. Photographs were uploaded into photo editing software, ImageJ [7], in which the outline of the vehicle was carefully traced and the background removed. The software measured the pixel count of the outlined area. A line was then drawn along the widest point of the outline. The number of pixels that make up the line in the photograph was counted by the software program. The pixel count divided by the actual measured length of the line was used to scale the picture and obtain the frontal area.

The Reynolds number is given by

$$Re = \frac{VD}{\nu} \quad (4)$$

In this study, the characteristic length $D$ is taken to be the bumper to bumper length of the vehicle.

## Results

Three model vehicles were used in this study, and these are listed in Table 1, along with the physical dimensions of width and length. The frontal area is also shown.

The raw data were obtained using instruments calibrated in US customary (or Engineering) units, and the results are provided in Table 2. Equation 2 was used to convert the pressure change reading to a velocity in m/s. The force readings in ounces were converted to Newtons, and the results are displayed in Table 3. Equations 3 and 4 were used to calculate drag coefficient and Reynolds number, respectively, and the results are given in Table 4. Figures 3 and 4 show frontal views of the vehicles.

**TABLE 1**. *Model vehicles used in this study.*

| Model | Chevrolet | Dodge | Ford |
|---|---|---|---|
| Vehicle | 1957 Chevrolet Bel Air | 1970 Dodge Challenger R/T | Ford F-350 pickup |
| Scale | 1:24 | 1:24 | 1:31 |
| Manufacturer | Jada Big Time Muscle | Castline M2 Machines | Maisto Adventure Wheels |
| Material | Die cast metal | Die cast metal | Die cast metal |
| Frontal Area | 5.73 $in^2$<br>0.003 7 $m^2$ | 4.35 $in^2$<br>0.002 8 $m^2$ | 5.23 $in^2$<br>0.003 4 $m^2$ |
| Width | 3.15 in<br>0.08 m | 3.18 in<br>0.08 m | 2.79 in<br>0.071 m |
| Length | 10.75 in<br>0.273 m | 11.25 in<br>0.286 m | 9.75 in<br>0.248 m |

**FIGURE 3**. Frontal view of the models tested.

**FIGURE 4.** Screen shot of ImageJ [7] software used to compute frontal area.

**TABLE 2**. Raw data of pressure difference in the test section versus drag force for each vehicle.

| $p_t - p$ | Chevrolet | Dodge | Ford |
|---|---|---|---|
| psi | oz | oz | oz |
| 0.032 | 0.750 | 0.250 | 0.250 |
| 0.042 | 1.125 | 0.250 | 0.375 |
| 0.051 | 1.500 | 0.375 | 0.500 |
| 0.063 | 1.750 | 0.750 | 1.250 |
| 0.072 | 2.375 | 1.000 | 1.500 |
| 0.089 | 3.000 | 2.250 | 2.375 |
| 0.101 | 3.875 | 3.000 | 3.125 |
| 0.117 | 4.500 | 3.500 | 4.000 |
| 0.134 | 5.250 | 4.000 | 4.875 |

**TABLE 3**. Reduced data.

| $\Delta h$ m | $V$ m/s (mph) | Chevrolet N | Dodge N | Ford N |
|---|---|---|---|---|
| 19.1 | 19.4 (43.4) | 0.209 | 0.070 | 0.070 |
| 25.1 | 22.2 (49.7) | 0.313 | 0.070 | 0.104 |
| 30.5 | 24.5 (54.8) | 0.417 | 0.104 | 0.139 |
| 37.7 | 27.2 (60.8) | 0.487 | 0.209 | 0.348 |
| 43.0 | 29.1 (65.1) | 0.660 | 0.278 | 0.417 |
| 53.2 | 32.3 (72.0) | 0.834 | 0.626 | 0.660 |
| 60.4 | 34.4 (77.0) | 1.077 | 0.834 | 0.869 |
| 69.9 | 37.1 (83.0) | 1.251 | 0.973 | 1.112 |
| 80.1 | 39.7 (88.8) | 1.460 | 1.112 | 1.355 |

**TABLE 4**. Drag coefficient and Reynolds numbers for the vehicles in this study.

| Chevrolet | | Dodge | | Ford | |
|---|---|---|---|---|---|
| $C_d$ | Re | $C_d$ | Re | $C_d$ | Re |
| 0.26 | 3.38 x $10^5$ | 0.11 | 3.53 x $10^5$ | 0.09 | 3.06 x $10^5$ |
| 0.29 | 3.87 x $10^5$ | 0.09 | 4.05 x $10^5$ | 0.11 | 3.51 x $10^5$ |
| 0.32 | 4.26 x $10^5$ | 0.11 | 4.46 x $10^5$ | 0.12 | 3.87 x $10^5$ |
| 0.30 | 4.74 x $10^5$ | 0.17 | 4.96 x $10^5$ | 0.24 | 4.30 x $10^5$ |
| 0.36 | 5.06 x $10^5$ | 0.20 | 5.30 x $10^5$ | 0.25 | 4.60 x $10^5$ |
| 0.37 | 5.63 x $10^5$ | 0.36 | 5.89 x $10^5$ | 0.32 | 5.11 x $10^5$ |
| 0.42 | 6.00 x $10^5$ | 0.43 | 6.28 x $10^5$ | 0.37 | 5.44 x $10^5$ |
| 0.42 | 6.46 x $10^5$ | 0.43 | 6.76 x $10^5$ | 0.41 | 5.86 x $10^5$ |
| 0.43 | 6.91 x $10^5$ | 0.43 | 7.23 x $10^5$ | 0.43 | 6.27 x $10^5$ |

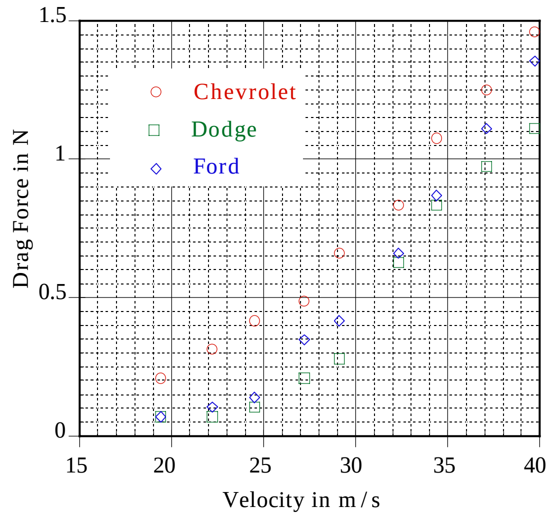


**FIGURE 5.** Drag variation with velocity for the three vehicles in this study

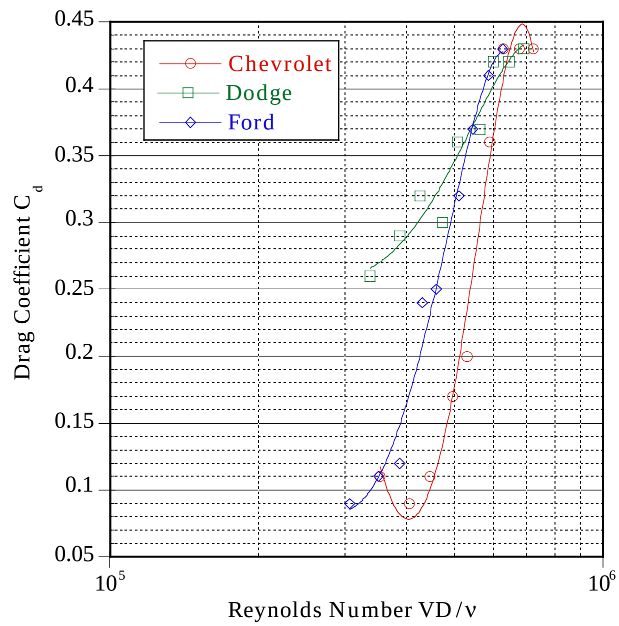


**FIGURE 5.** Drag coefficient variation with Reynolds number.

## Conclusions

Much student interest in this experiment has been experienced. Students in the fluid mechanics laboratory are to perform a "Design of Experiments" exercise. When given a choice, students have opted to measure drag on a vehicle. Students have obtained drag data on models of trucks with trailers, trucks with and without various aerodynamic devices, and much more. Furthermore, results obtained here agree very well with published data (found on the internet) on drag coefficient versus velocity. An experiment of this type is highly recommended as a significant and popular addition to the fluid mechanics laboratory.

## References

[1] http://en.wikipedia.org/wiki/Automobile_drag_coefficient
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[7] http://en.wikipedia.org/wiki/ImageJ

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William S. Janna is a Professor of Mechanical Engineering at the University of Memphis. He teaches courses in the energy systems area including fluid mechanics, heat transfer and thermodynamics. His research interests include the fluid mechanics of sprays, mass transfer from sublimating bodies and accelerating sphere problems. He has written three textbooks and is a reviewer for several technical journals.

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