

Cars on Flooded Streets

Effect of Water Depth and Car Velocity on Drag Force

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Abstract

A model car was pushed and then allowed to freely decelerate through water with depths ranging from 0.0 to 4.0 cm. Water depths that submerged only the wheels, not reaching the body of the car, were tested. It was shown that the rate of increase of drag force decreases as depth of water increases, and the drag force is proportional to the velocity of the car. The drag force was almost constant for water depths above 75% of the wheel's radius, for a given velocity.

Keywords: car, flood, drag, water depth, speed

I. INTRODUCTION

In Bangkok, Thailand, flooding is a common problem, making it difficult to drive on the roads in the rainy season. When a car travels through a flooded street, there is a significant drag force from the water. While studies have been conducted investigating the forces acting on cars on heavily flooded roads with flowing water^{1,2}, no studies on cars driving through low-level floods were found. Often, when the flood level is not enough to stall the engine, only the wheels are submerged in the water and the body of the car does not come in contact with the water, so here only the situation where the



Figure 1. A car driving through a flood.
AAA Image, AAA Automotive, 2017

floodwater does not reach the body of the car is investigated, as shown in figure 1. The effects of the depth of the water and the velocity of the car on the drag force are studied.

The dominant factor affecting the drag force from the water is expected to be the displacement of the water in front of the wheels. Energy from the motion of the car is transferred to the water as it is pushed away from the front of the rolling wheels. The volume of water being displaced increases with increasing depth, causing a corresponding increase in the drag force (figure 2). Due to the shape of the wheel, the volume of water displaced does not increase proportionally to depth. The rate of change in

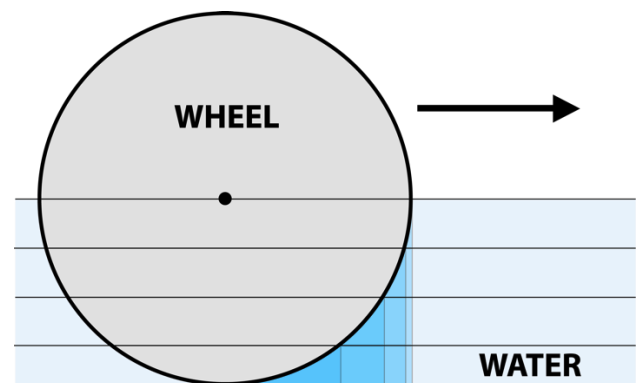


Figure 2. Volume of water being displaced at the front of a wheel at different water depths.

volume with depth in shallow water is larger than the rate of change in deeper water. It is predicted that the rate of increase of the drag force will decrease with increasing depths.

Other factors that contribute to the total drag force include surface drag of the water as it passes along the sides of the wheels and the turbulence behind the wheels of the car. The waves formed and the water thrown out from the sides and back of wheels, shown in figure 1, are also expected to contribute to the total drag force. Determining the contribution of each of these factors in the total drag force is beyond the scope of this paper.

II. METHODS

A Vernier Motion Detector with a sample rate of 40 Hz was placed at the end of an aquarium with length 150 cm and width 31 cm, as shown in figure 3. A model car with a mass of 0.59 ± 0.01 kg, a length of 27.0 ± 0.1 cm, a width of 18.5 ± 0.1 cm, and a total height of 9.0 ± 0.1 cm was used. The radius of each wheel was 4.0 ± 0.1 cm and the height between the ground and the car was 4.5 ± 0.1 cm.

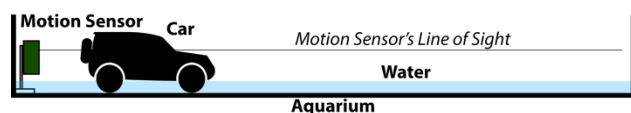


Figure 3. Setup of apparatus.

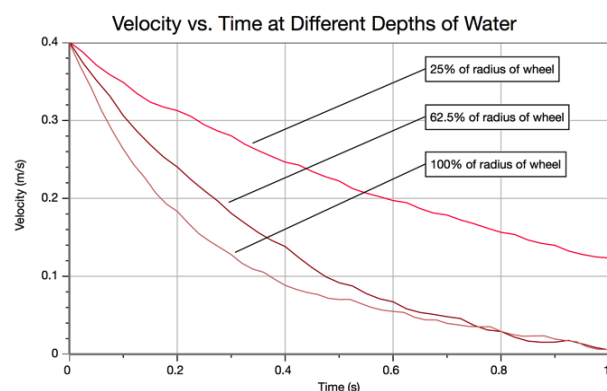


Figure 4. Graph of velocity of the car as it decelerates at different depths of water.

The car was given a quick push by hand so that it reached a velocity greater than 0.4 m/s, and then allowed to decelerate until it stopped. The motion of the car was recorded with the Motion Detector. The depth of water tested ranged from 0.0 cm to 4.0 cm.

Figure 4 shows typical samples of velocity-time graphs for three different water depths. The deceleration of the car was determined by finding the gradient of the velocity-time graph at velocities of 0.3 ms^{-1} , 0.2 ms^{-1} , and 0.1 ms^{-1} . These values were multiplied by the mass of the car to determine the drag force on the car at each velocity.

III. RESULTS AND DISCUSSION

Figure 5 shows that for a given velocity, the force increases as the depth of water relative to the radius of the wheel increases. As predicted, as the depth of the water increases, the rate of increase of the drag force decreases. Above a relative depth of 75% of the wheel's radius, the drag force remains fairly constant. This relationship between force and depth of water is similar for all velocities tested, but at higher velocities, the values of the drag are greater.

In figure 6, the relationship between velocity and drag force is shown. For all tested depths, the force increases proportionally with velocity.

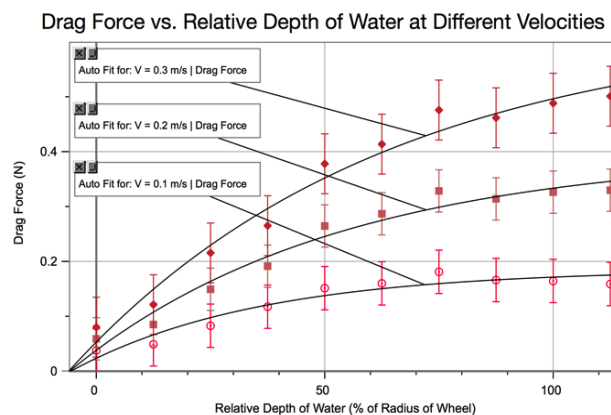


Figure 5. Relationship between the force of friction and the depth of water at three different velocities.

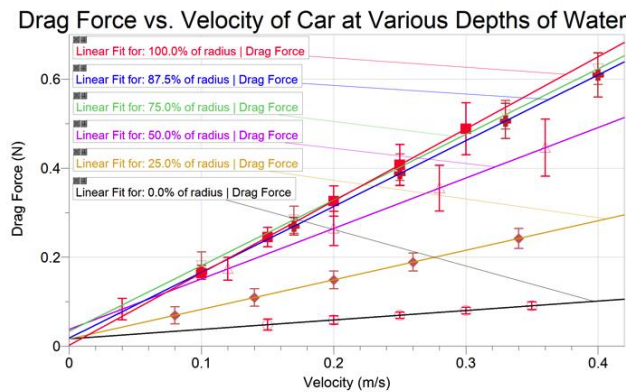


Figure 6. Linear relationship between drag force from water and velocity of car at different depths of water.

Looking at figure 6, it can be seen that the y-intercepts for the linear fits are spread in a small range above zero. This likely indicates that there is constant internal friction between the wheels and the axles as well as the rolling resistance between the wheels and the surface.

These findings might not be fully applicable to real cars driving in flooded conditions. Here a model car was used, and it was tested only at low speeds. One of the major differences between the model car and real cars was that the model car had hollow wheels, as shown in figure 7. This allowed water to enter the insides of the wheels as the car rolled, unlike a real car tire. Further research using real cars driving in controlled flood conditions at normal speeds is recommended. The effect of wheel diameter and radius could be studied, along with the drag force for flood depths that reach the body of the car. Finally, the relative contributions of the various factors involved in the total drag force should also be studied.



Figure 7. The hollow inside of the wheel.

IV. CONCLUSION

It has been shown that increasing the depth of water increases the drag force on the car. The rate of increase of the drag force is greater in shallower depths, with the magnitude of the drag force becoming constant for depths greater than 75% of the wheel's radius. A proportional relationship is shown between the drag force and the car's velocity at a given depth, with depths above 75% of wheel radius having a constant rate of increase of drag force.

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