

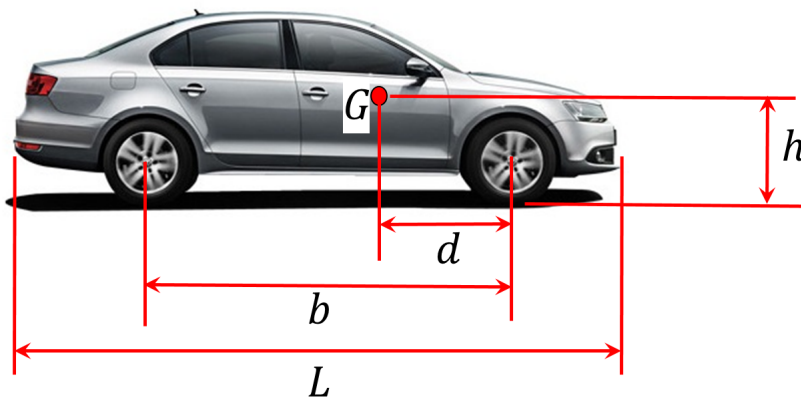
Name: _____

Group members: _____

TAM 210/211 - Worksheet 11

Today we will analyze how vehicles perform on slopes in a variety of conditions. We will consider upward and downward slopes and vehicles that are braked or have slipping wheels. We want to consider design options to improve performance, so as you work the problems, solve everything analytically, and only use numbers at the very end.

A vehicle makes contact with the road at both the front and rear tires; those tires experience static friction when not slipping, and kinetic friction if the wheels are slipping. We'll consider the 2013 Volkswagen Jetta TDI: wheelbase $b = 104.4$ in, center of gravity defined by $h = 22.5$ in and $d = 40.5$ in, total weight $W = 3255$ lb and front-wheel drivetrain.



We want to consider what the largest slopes – pointing uphill and downhill – that this vehicle can handle when placed on (a) dry pavement, and (b) icy pavement. For everything ahead, we will simplify the problem by considering it in 2D: so the front wheels act together and the rear wheels act together.

Ice Breaker: What are your teammates' favorite candies?

1. Draw the free-body diagram for the vehicle uphill on an incline of angle θ . Include and label all the relevant forces.

2. Write equations of equilibrium for this 2D problem, **use symbols only**. Consider using a coordinate system aligned with the inclined plane. For example, x' parallel to the inclined plane and y' perpendicular to the inclined plane, and perform $\sum F_{x'} = 0$ and $\sum F_{y'} = 0$.

3. Obtain symbolic expressions for the normal forces on the front and rear tires as a function of θ and the given variables.

4. Assume that brakes are engaged: all tires experience static friction. Obtain an expression for the maximum angle for equilibrium.

5. What is the value of the maximum angle for equilibrium if the Jetta is on dry pavement ($\mu_s = 0.75$)? Or in icy pavement ($\mu_s = 0.24$)?

6. Next, consider only the hand brake is engaged, so the front wheels experience static friction, but the rear tires can freely rotate (i.e. no contribution from static friction). Obtain the symbolic expression for the maximum angle for equilibrium.

7. What is the value of the maximum angle for equilibrium if the Jetta is on dry pavement ($\mu_s = 0.75$)? Or in icy pavement ($\mu_s = 0.24$)?

8. What changes would you make to the car to increase the possible incline angle?

9. What is the maximum incline so that the car does not flip backwards?

10. *Challenge.* Does your analysis change if the vehicle is pointed downhill instead? Explain.