

## Speed on Land

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Travel over land has been a necessity of people and animals since the beginning of time. Traveling faster and further gives both people and animals advantages.

For animals, predators need speed to run down prey for food. For people, travel allows us to transport food and supplies to support life. And, travel keeps us connected with family and friends. Unfortunately, people are not physically the best at land travel. The table shows that we are not the fastest animals on earth. Our rank is not very impressive with a Cheetah 55 miles per hour (mph) faster than the average human.

So, humans are not very fast. But, they are when you factor in technology. ***Throughout history people have used technology to overcome limits on their physical abilities.*** We do not need to run faster and further because people have created vehicles and transportation systems to move people and cargo beyond our physical abilities and those of every species on earth.

Animal	Speed (mph)
Cheetah	70.0
Antelope	61.0
Lion	50.0
Horse	47.5
Fox (Gray)	42.0
Dog (Greyhound)	39.0
Deer (White-Tailed)	30.0
Bear (Grizzly)	30.0
Cat (domestic)	30.0
Human (Olympic Class)	27.9
Elephant	25.0
Human (average)	15.0
Squirrel	12.0
Pig (domestic)	11.0
Chicken	9.0



How fast have humans traveled on land? In, 1997, the Thrust SSC land speed vehicle reached a speed of 766 mph. This is faster than the speed of sound.

This first land vehicle to break the sound barrier was 696 mph faster than a Cheetah! Vehicles designed to break the land speed record are not your typical cars. The vehicle was shaped like a fighter jet and was powered by two turbojet engines.

We don't see jet powered cars on the road. Internal combustion engines power cars and trucks. Top fuel dragsters, the top land speed vehicles with internal combustion engines, have reached speeds of 336 mph in  $\frac{1}{4}$  mile. Going from 0 mph to 336 mph in such a short distance would surely be an exciting ride.

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## Systems Thinking

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Systems are a collection of components that work together to get a job done. Transportation is a system designed to move people and cargo. The system includes: land, water and space vehicles. Land transportation vehicles are also a system. To understand a system you need to understand the components of the system. The components of a land transportation vehicle include: power, suspension, guidance, control, structure and support

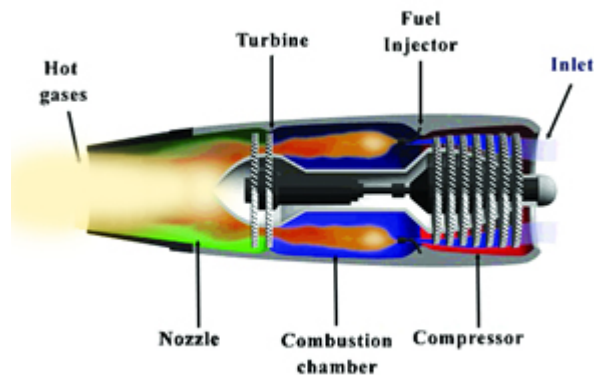
All designs require careful consideration of the purpose or function of the product. Is the product designed to solve a problem, break a record, or sell to make profit? The purpose of the North American Eagle team is to design a vehicle to break the land speed record. There is not a market for this vehicle but it does contribute to our knowledge base. In contrast, your family automobile will not break the sound barrier but it does dependably move people and cargo over land. You may think these vehicles have nothing in common but they do. **All land vehicles are systems made from power, suspension, guidance, control and structure subsystems.**

## Power

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Turbojet engines were used to power the land speed record vehicles. Jet engines create force or thrust by heating air that quickly expands and escapes from a nozzle. The process involves:

1. Air enters the inlet and a compressor is used to increase the pressure and temperature of the air;
2. In the combustion chamber, fuel is sprayed into the compressed air and burned. The heat generated from the burning fuel expands the air;
3. This expanding air moves past the turbine that powers the compressor; finally,
4. Exhaust nozzle accelerates the air resulting in thrust.



The turbojet powering the North American Eagle produces 42,500 horsepower. The engine is 17ft long and little over 3ft in diameter. It weighs 3600 pounds. Fuel consumption is about 40 gallons per minute.

## Power-Continued

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Your dragster uses a CO<sub>2</sub> cartridge for power. The cartridge contains CO<sub>2</sub> gas under pressure. The end is punctured so the gas escapes creating thrust or force that powers your dragster down the track.



## Suspension

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Suspension supports the vehicle on the road. For cars, it helps keep the rubber on the road. Control arms and spring support the vehicle. Wheels and axles connect the vehicle to the road.



Working together traction is optimized while keeping the ride comfortable.

The suspension on your dragster is not as complicated. It consists of wheels, axles and a bearing surface to reduce friction. There are many combinations of wheels, axles and bearings that can be used. As you will learn, each combination will have its own performance characteristics.

## Guidance

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The guidance system provides information to the operator to help guide him or her to their destination. Speedometers in cars provide information about vehicle speed. Road sign help guide the driver by providing information about location and direction. Modern guidance systems are getting more sophisticated. GPS systems can pinpoint a vehicle's location on earth. With a map overlay, they can tell the driver when to turn and calculate alternate routes to avoid traffic jams.

A guidance system is not needed to race down the drag strip. But, a control system is needed to keep it going straight down the track.

## Control

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Accelerate, turn, stop-- vehicles need subsystems to control motion. Throttle, steering and braking subsystems control the motion of most land transportation vehicles. The **throttle** subsystem controls vehicle speed. For cars and



## Control - Continued

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trucks, the gas peddle provides this control.

**Steering** systems provides drivers with a means to turn the vehicle left or right. To stop, brakes are attached to wheels. Braking systems use friction to slow a vehicle.

Your dragster will not have steering or braking systems. Direction will be controlled by a line stretched from the start line to the finish line.

Eye screws will be used to guide the vehicle along the guide line.



## Structure

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The vehicle's chassis provides the structure that joins together the power, suspension, guidance and control subsystems. The chassis is designed to hold all of these subsystems while overcoming forces that could cause failure. Some of these forces include:

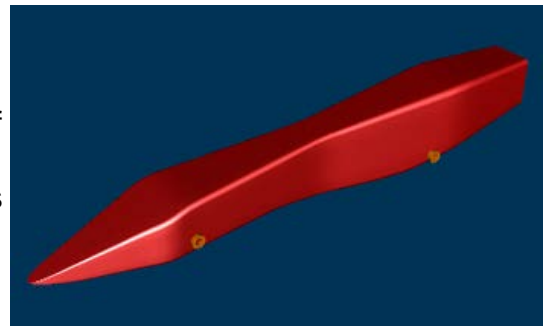
1. Weight of the engine, suspension, people and cargo.
2. Forces created by driving and road conditions (i.e. acceleration, deceleration, turns, bumps, potholes, etc.).
3. Impact from accidents that could injure passengers.



Chassis designs vary depending on the purpose of the vehicle. There are three basic vehicle chassis designs-- Ladder, Tubular Space Frame and Unibody. The **Ladder Chassis** is made from two or more rails connected by a cross brace.

It's like a ladder. this design is still used in trucks and SUVs to isolate passengers from road conditions. This isolation is possible because the body is bolted to the frame. When you are driving off road or hauling heavy loads in your truck, a separate frame and body construction is better.

Race cars use a **Tubular Space Frame** design. It is a light, stiff and safe chassis design. The frame uses steel tubes welded together with diagonal braces. The design takes advantage of the structural characteristic of the material and the best concepts of structural engineering. This chassis is used in race cars and some low production vehicles. Easy custom fabrication allows designers to be creative.





## Structure - Continued

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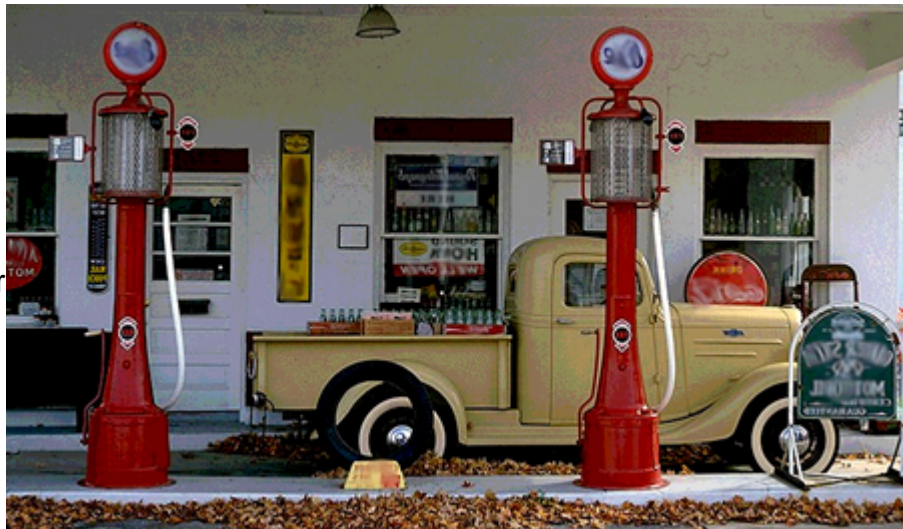
Your dragster will be like a unibody chassis. This design integrates the body and frame. The **Unibody Chassis** is made of sheet metal integrated into the design of the car. Sheet metal welded together forms tubes, beams, braces and other structural elements to make a system that is light and stiff while protecting passengers. A unibody chassis requires specialized tools for fabrication. They are mostly used on high production vehicles. The majority of the vehicles, Ford, Chevy, Dodge, Honda, Toyota, Nissan, etc. are unibody construction. In the future, you will see composite materials such as fiberglass, carbon fiber and Kevlar being incorporated in the design. These materials will make the structure stronger and lighter.

## Support

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The support subsystem is not part of a land transportation vehicle. Rather it is the components that provide the energy and infrastructure that keep vehicles operating. Cars need roads and maintenance for continued safe driving. They also need gasoline. As cars developed and improved, the infrastructure needed to support travel had to develop and improve as well. Road systems began to connect communities. Gas stations became frequent enough that great distances could be traveled.

Improved transportation systems affect American life in many ways. People no longer need to live close to their work. Families can stay connected without living in the same town. Food can be transported over



great distances. The automobile and its support systems enable the highly mobile society that we enjoy today. A car is driven an average 12,000 miles per year or 33 miles per day. We live miles from work, school and stores. We travel miles for vacation and other leisure activities.

Like all technologies, with the good there is also bad. The fuel that powers our transportation systems is made from oil. Oil is a nonrenewable resource - a resource that cannot be replaced. We will eventually run out of oil. In addition,

burning oil creates pollution that affects our environment. There are always tradeoffs.

Given oil dependency and environmental problems, scientists and engineers have been exploring alternative fuel vehicles. Electric powered vehicles have shown promise as a viable option. However, batteries are heavy, contain caustic chemicals and take a long time to charge. Fuel cells show some promise in overcoming these problems. Fuel cells produce electricity from hydrogen and oxygen. The byproduct is water so they are pollution free. At this time they are too expensive for mass production, but the future is promising.

Hybrid vehicles have been seeing a commercial success. These vehicles are gas and electric powered vehicles. An internal combustion engine is used to power the vehicle and charge batteries for the electric motor. The electric motor is used to help power the vehicle to save gas. Since the vehicle is primarily powered by gas, the infrastructure to support hybrids exists. Drivers simply need to stop at a gas station. Development of hybrids overcame a design limitation of electric vehicles because they fit the existing fuel support system.

### **Think about it...**

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The land speed record is a challenge that attracts engineers and technicians. Humans will continue to design vehicles to travel faster on land. To do so, they will improve the subsystems of the vehicle to maximize performance. An improvement in a subsystem (power, suspension, guidance, control or structure) improves the overall system.

Remember though, ***all decisions have tradeoffs***. A decision to improve one subsystem may adversely affect another. A change in a technological system has an impact on other systems and the environment. In our highly mobile society, we are enjoying our vehicles but we are experiencing problems. Solving these technical problems is what leads to innovation and invention.

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## Designing to Specifications

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How fast can you make a model car travel down a 20 meter track powered by a CO<sub>2</sub> cartridge? That is the design challenge you are facing. Like every design challenge that scientist and engineers face, there are rules that must be followed. The rules are the specifications and tolerances that must be followed to insure that the design works properly. Specifications are written description of the size, shape, materials and other details of a design. Tolerances define the allowable difference, minimum and maximum, in the size of a part. Your design must meet the following specifications and tolerances. Just review these for now. You will get into the specifics during the design process.

## Dragster Design Specification and Tolerances

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### Structure

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CO<sub>2</sub> dragsters are fabricated from a wood block. The blank must be one-piece all wood material. Two or more pieces cannot be glued together or laminated to create a blank. The use of additional material such as fiberglass or epoxy to increase the strength of the material cannot be used.

The size of the dragster you design must comply with the following specifications.

Body	Tolerance	
	Minimum	Maximum
Length	205mm	305mm
Height with wheels		73mm
Width at axles	37mm	42mm
Total width including wheels		85mm
Mass (without CO <sub>2</sub> cartridge): Middle School	43g	
Mass (without CO <sub>2</sub> cartridge): High School	48g	

### Suspension

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Suspension includes the components that connect the vehicle to the road (or track). For the dragster design challenge, these components include wheels, wheelbase, bearing surface and assembly.

Axles and Wheelbase	Tolerance	
	Minimum	Maximum
Number of axles	2	2
Bottom of axle hole above car bottom	5mm	8mm
Rear axle hole from car rear	10mm	95mm
Wheelbase (measured at farthest point)	110mm	265mm
Space Washers		8
Axle Clips		4

Wheels	Tolerance	
	Minimum	Maximum
<b>Middle School</b>		
Diameter	32mm	40mm
Width	2mm	18mm

- Technical Notes:
1. Bearing, bushings and lubricants may be used
  2. Glue may not be used to hold wheels and axles in place
  3. Dragster must have 4 wheels

## Power

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The power plant provides the force needed to move your dragster down the track. Your dragster will be powered by a CO2 cartridge mounted in hole at the rear of the car.

Power	Tolerance	
	Minimum	Maximum
Hole Depth	50mm	52mm
Wall Thickness	4mm	
Chamber Diameter	19mm	20mm
Lowest Point of Hole to Race Surface	28mm	38mm

- Technical Notes:
1. The hole must be drilled so it is parallel to the track surface.
  2. The 4mm minimum wall thickness is required for safety.
  3. Only cartridges provided by your teacher may be used.

## Control

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Your car will not have a steering wheel but it will have a guidance system. The car will be guided down the track by a string tethered to the start and finish gate. Two eye screws attached to the bottom of the body will steer the car to the finish line.

Eye Screws	Tolerance	
	Minimum	Maximum
Inside Diameter	3mm	5mm
Distance Apart	155mm	265mm

- Technical Notes:
1. Screw eyes must not contact the race track.
  2. Glue may be used to reinforce the screw eyes.
  3. Screw eyes must be tightly closed to prevent string from slipping out.

Be creative when you begin designing your car and be sure to check these specifications and tolerances when you finalize your design.



## Study Quiz: Speed on Land

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### Question 1

The desire to improve existing technologies or solve technological problems drives \_\_\_\_\_.

- market and cost
  - innovation and invention
  - function and design
  - mass production
- 

### Question 2

Gasoline is a \_\_\_\_\_ resource so supply is limited.

- Expensive
  - Renewable
  - Limitless
  - Nonrenewable
- 

### Question 3

Looking forward, what transportation vehicle subsystem will you need to consider in your dragster engineering design challenge.

#### Check all that apply...

- Power
  - Suspension
  - Guidance
  - Control
  - Structure
  - Support
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## Newton's Second Law of Motion

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What makes a CO<sub>2</sub> dragster go fast? If you want to design the best dragster, you need to know what design factors make CO<sub>2</sub> cars perform. Knowing how these factors or system components improve or hinder performance leads to good design decisions.

Given a design problem, there are things that can be changed and some things that cannot be changed. The things that can be changed are called **variables**. Those factors that cannot be change are called **constants**. Mathematical equations define the relationship between variables and constants. Understanding these relationships, and recognizing when they apply to real world design problems, is the key to good design decisions.

### Get Moving Fast!

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The goal is to move your dragster down the track as quickly as possible. Sir Isaac Newton (the chap on the right) defines the problem. His second law of motion states:



**The acceleration of an object of constant mass is proportional to the force acting upon it.**

In mathematical form, the relationship of force, mass and acceleration is defined as:

$$\text{Force } (F) = \text{mass } (m) \times \text{acceleration } (a)$$

To go fast, acceleration is the key. The faster the car accelerates the greater the speed. What does Newton's law tell us about acceleration? We can use algebra to change the force equation to solve for acceleration.

Given  $F = m a$

To solve for acceleration (a) divide both sides by mass (m)

$$\frac{F}{m} = \frac{m}{m} \times a$$

Therefore  $a = \frac{F}{m}$

This equation shows how to increase acceleration. An increase in force ( $F$ ) will increase acceleration. Acceleration will also increase by decreasing mass ( $m$ ).

To better understand Newton's law and how it applies to improving your design, you need to understand the variables—acceleration, mass and force.

## Acceleration

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Acceleration is related to velocity, but they are not the same. First, let's take a look at velocity.

Velocity is equal to distance traveled over time.

$$\text{velocity } (v) = \frac{\text{distance } (d)}{\text{time } (t)}$$

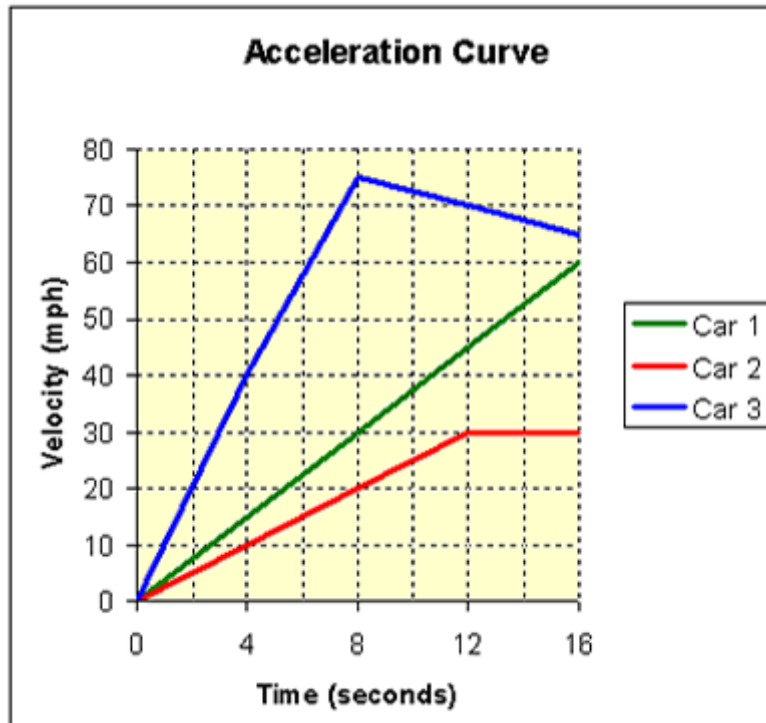
Miles per hour (mph) is a common measure of velocity. It is the distance traveled (miles) over time (hours). If you were driving at a constant velocity of 60 miles per hour (mph), in one hour you would have traveled 60 miles.

Acceleration is a change in velocity ( $v$ ) over time ( $t$ ).

$$a = \frac{(v_2 - v_1)}{(t_2 - t_1)}$$

A typical sedan can accelerate from 0 to 60 mph in 16 seconds. Therefore

$$a = \frac{(60 - 0)}{(16 - 0)} = 3.75 \text{ mi/hr/s}$$



An acceleration curve is a graph of velocity versus time. In the graph on the left, we see that "Car 1" represents our typical sedan. Since acceleration is the change in velocity over the change in time, the slope of the line represents acceleration. In the case of our typical sedan, we have a straight line from  $t = 0$  seconds to  $t = 16$  seconds, so we can pick any two data points from the graph and find that acceleration is 3.75 mph every second. For "Car 2" we can see that there is constant acceleration between  $t = 0$  seconds and  $t = 12$  seconds. At 12 seconds, acceleration is 0 mph per second. Can you see why? Use the graph to answer the questions that follow...

### Question 1

Which of the three cars in the graph above accelerates most rapidly between 0 and 8 seconds?

- Car 1
- Car 2
- Car 3
- Car 1 and 2

### Question 2

Which of the following statements best describes Car 3's motion between  $t=8$  seconds and  $t=16$  seconds?

- The car is accelerating.
- The car's acceleration is zero.
- The car is slowing down.
- The car is stopped.

Question 3

3) If car 1 continues to accelerate at 3.75 mph/s, how fast would it be going at t=20s?

- 60 mph
  - 15 mph
  - 70 mph
  - 75 mph
- 

*Worksheet...*

Now that you know  $a = \frac{v}{t}$ , using algebra to solve for velocity we find that  $v = a \times t$

Calculate it:

	mph/s	x		s
	mph			

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## Mass

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Mass is the weight of the vehicle. There is a difference between the mass of an object and how much it weighs. Mass is a measure of the amount of matter or material an object contains. Weight takes in to account the gravitational pull. For example, the moon's gravitational pull is much less than the earth's. Your car would weigh less on the moon but the mass would be the same. Since all races occur on earth, the difference between mass and weight factors out. If your car weighs less than your classmate's car, it has less mass.

So how do we go about changing the mass of a car? To answer this, let's take a closer look at what mass really is.

$$\text{mass } (m) = \text{density } (p) \times \text{volume } (v)$$

This equation shows that the mass of an object depends on a variable called **density**, and the **volume** of an object. All materials have a unique density, and as the following table shows, they vary a lot. The density of steel, for example, is approximately 7.84 grams per cubic centimeter. In other words, one cubic centimeter of steel would have a mass of 7.84 grams. Balsa wood has a density of 0.17 grams per cubic centimeter. To put things into perspective, if you designed a dragster made of steel, it would have to be about the size of your thumb to have the same mass as the other balsa wood cars.

	Density (g/mm <sup>3</sup> )	Tensile Strength (MPa)
Brass	.00855	45,700
Steel	.00784	4,800
Aluminum	.00264	3,800
Kevlar	.00144	43,500
Plastic	.0010	4,000
Oak	.00063	750
Pine (Ponderosa)	.00054	406
Basswood	.00041	384
Balsa	.00017	150

### Apply it...

<p><b>Question:</b> What is the mass of a brass axle that has a volume of 318mm<sup>3</sup>?</p> <p><b>Step through the solution...</b></p>	<h2>Worksheet...</h2>
<p><b>Step 1:</b> The density of the axle is given in the data table above. Now you can calculate the mass of the axle using the mass equation.</p>	$\text{mass} = \text{density}(\rho) \times \text{volume}(v) =$ <div style="display: flex; justify-content: center; align-items: center; gap: 10px;"> <div style="border: 1px solid black; width: 80px; height: 20px; display: inline-block;"></div> <span>g/mm<sup>3</sup> x</span> <div style="border: 1px solid black; width: 60px; text-align: center;">318</div> <span>mm<sup>3</sup></span> <span style="margin-left: 10px;">=</span> <div style="border: 1px solid black; width: 60px; height: 20px; display: inline-block;"></div> <span>g</span> </div>
<p><b>Answer:</b> So, what is the mass of a brass axle if its radius (<i>R</i>) is 1.5mm and length (<i>L</i>) is 45mm?</p> <ul style="list-style-type: none"> <li><input type="radio"/> 3.0g</li> <li><input type="radio"/> 4.2g</li> <li><input type="radio"/> 2.7g</li> <li><input type="radio"/> 1.3g</li> </ul>	



**Engineering Solution:** One of the objectives of the design problem is to reduce mass. If the length of the axle was cut 5mm shorter, the volume would be reduced to 280.7mm<sup>3</sup>. How much would axle mass be reduced?

- 1.1g
- 0.3g
- 0.1g
- 0.7g

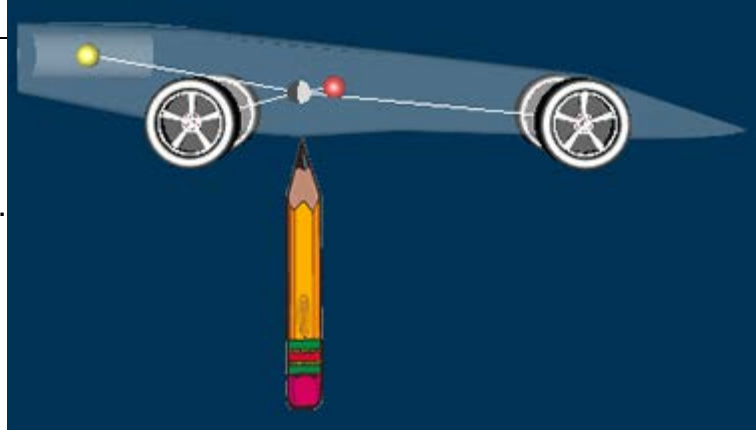
Kevlar is a material used in products from bike frames to bulletproof vests. You can see from the table that its tensile strength is extremely high for a material with a density of 1.44 g/cm<sup>3</sup>. Kevlar is used in race cars to reduce the mass of structural components. Mass vs. strength is a classic engineering trade off.

Since Newton's second law tells us that decreasing mass will increase acceleration, then the lightest possible materials and minimum volumes must be the right way to go, right? Well, not necessarily. Generally, lighter materials are not as strong as heavier materials. From our table, we can see that basswood is more than twice as heavy as balsa wood, but it is also more than twice as strong. So, if you want your car to make several runs, you may want to consider using basswood.

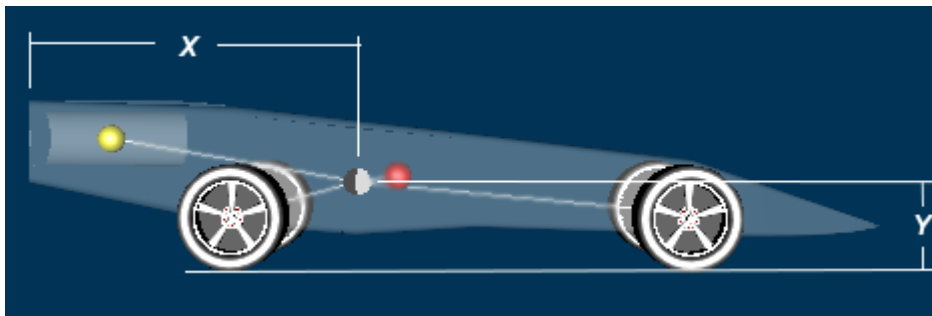
Body design is not the only thing to consider when it comes to mass. The total mass of your car includes the mass of the wheels, axles, bearings, and the CO<sub>2</sub> cartridge. When considering axle selection, for example, can we say that aluminum is always a better choice than brass because it is lighter? Not necessarily. As we'll see later, a brass axle may produce less surface friction than aluminum. So, it's possible that a heavier axle will result in a faster car. Once again, we have an interesting **trade off** to consider.

## Center of Mass

As you have learned, the total mass of the vehicle is important. How this mass is distributed is also important. Your car's behavior as it runs down the track depends on its center of mass (CM).



The center of mass is an object's "balance point". For example, if you could balance a CO<sub>2</sub> car on the tip of a pencil, the pencil would be just below the center of mass. This literally means that half of the car's mass is on either side of your finger.



The center of mass is a point. It has an x-coordinate and a y-coordinate, and both are

important for different reasons. Its position from the ground (y-coordinate) affects the stability of the vehicle. Its position from the rear (x-coordinate) determines the distribution of mass between the front and rear axle assemblies. Both of these factors are important in the design of a CO<sub>2</sub> car dragster. We'll address stability now. The importance of the distribution of mass will be more clear when you learn about surface friction.

## Stability

The center of mass helps us understand how an object will behave when external forces are applied. In an automobile, if the center of mass is high, the vehicle will tend to flip when going around a corner. SUVs and vans have a

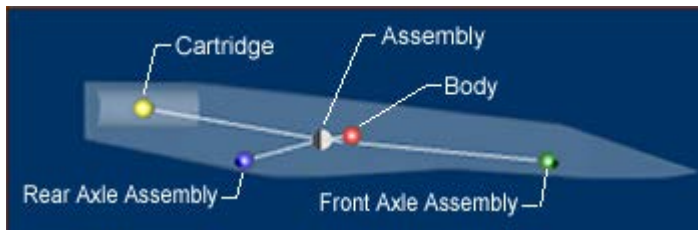


higher center of mass than sedans, which is why we sometimes hear about "rollover" problems with these vehicles.

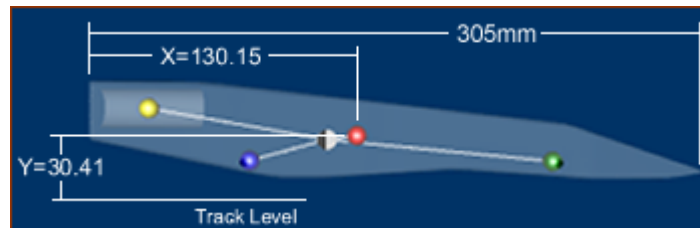
Race car designers try to keep the center of mass low and as close to the middle of the wheel base as possible. If the center of mass is

located in the middle of the wheelbase, the car's mass will be evenly split between the front and rear axles, resulting in better cornering.

Likewise, the stability of a CO<sub>2</sub> depends on the location of the center of mass. Also important is the contact width of the car. A wider car is less likely to flip when raced. Again, there are tradeoffs. As you will learn in the next section, the width of the car may affect forces that slow your vehicle. But, nothing will slow your car more than it flipping and sliding down the track on its side.



The **Center of Mass** data table in the Work Area to the left specifies the location of the center of mass for these components. For example the location of the Body center of mass for the default design is  $Y = 30.41$  and  $X = 130.15$ . This puts it closer to the rear and top of the design.



## Mass: Design Considerations

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You can use the analysis capabilities of the application to help make design decisions. How do the wheel assemblies affect mass and center of mass?

## Cartridge Force

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There are two types of force that will affect your design – positive forces and negative forces. Positive forces accelerate (or push) the dragster off the starting line. Negative forces decelerate (or pull) the dragster away from the finish line. The cartridge force is a positive force, while surface friction and drag are negative forces.

If you push your dragster forward, you are applying a positive force to the vehicle. Likewise, when cartridge force acts on a dragster, it causes it to move.

The force causes the car to increase velocity or accelerate. Remember Newton's law:

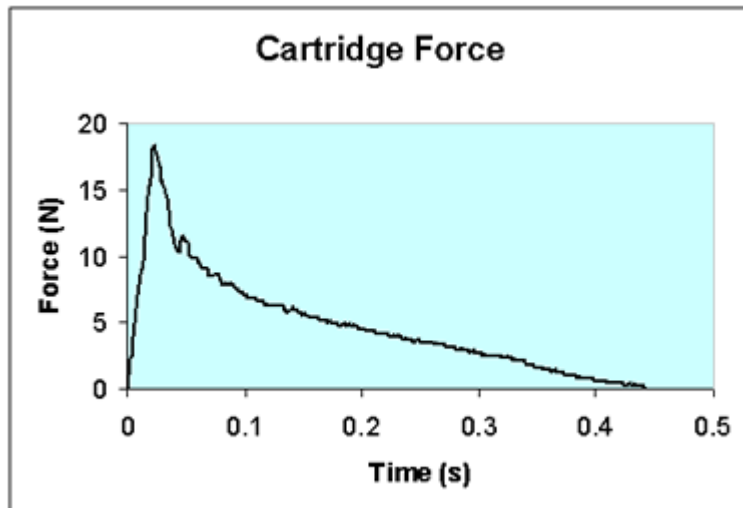
$$F = m a$$

Math shows the relationship of variables. This equation tells us that there is a direct relationship between the variables force ( $F$ ) and acceleration ( $a$ ). Assuming mass does not change, if the force ( $F$ ) applied to an object increases, then the object will accelerate ( $a$ ). Conversely, if the applied force is negative, then the object will decelerate.



For all the dragsters in the challenge, a CO<sub>2</sub> cartridge provides the force to move the vehicle forward. The cartridges contain a large volume of carbon dioxide gas under extreme pressure. The firing pin on the start gate makes a hole in the nozzle so the pressurized CO<sub>2</sub> gas escapes producing thrust or force.

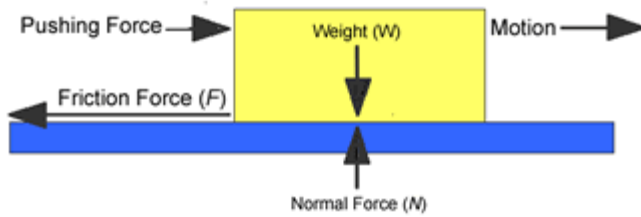
How much force does the CO<sub>2</sub> cartridge produce when fired? The Cartridge Force graph below shows the typical force of a Pitsco 8-gram cartridge. The data was collected by firing a cartridge against a force sensor connected to a computer. Data was sampled every .001 seconds. As you can see from the graph, the escaping gas produces the maximum force in less than 0.05 seconds. Force then ramps off gradually until the cartridge is empty in about 0.45 seconds. The maximum force is 18.3 N (Newtons), with an average of 4.67 N.



Dragsters will accelerate until force stops. So we can assume from the test that a typical dragster will accelerate for about 0.45 seconds. At this point, maximum velocity is reached. How fast would the dragster be going at this point? If we assume an average force of 4.67N, we can use Newton's law to calculate maximum speed. This can be done by replacing acceleration with velocity divided by time,  $a = v / t$ .

$$F = m a = m \left( \frac{v}{t} \right)$$

We can use rules of algebra to solving for velocity,



$$V = \frac{F t}{m}$$

The average mass of a CO<sub>2</sub> dragster is about 50 grams, but we also need to include the mass of the cartridge - about 25 grams empty. So our total mass is 75 grams, or 0.075 kilograms. If force (F) equals 4.67 Newtons and time (t) equals 0.45 seconds, then the maximum velocity in meters per second is calculated as follows.

$$V_{\max} = \frac{4.47 \times 0.45}{0.075} = 28.02 \text{ m/s}$$

If we convert 28 meters per second to miles per hour, the top speed is 62.6 mph. This equates to an average acceleration of 139 mi/hr/s! Unfortunately, dragsters do not cross the finish line at 62.6 mph. There are resistive forces working to slow the vehicle.

## Resistive Force

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Resistive forces are the forces working against or resisting the forward motion of your dragster. If there were no resistive forces, your dragster would continue to travel at its maximum velocity forever. If you take your foot off the accelerator in a car, the car slows down. Likewise, when the power from the Co2 cartridge stops, the dragster slows down. The forces that slow the vehicle include friction and drag.

## Sliding Friction

---

Friction occurs when two surfaces are in contact and a force is moving one surface over the other. For example, if you push a wood block across your desk, friction will resist the motion of the block and bring it to a stop. Friction is caused by the roughness of the two objects in contact. Even two materials that seem very smooth have some degree of roughness. Viewing surfaces under a microscope can be revealing.

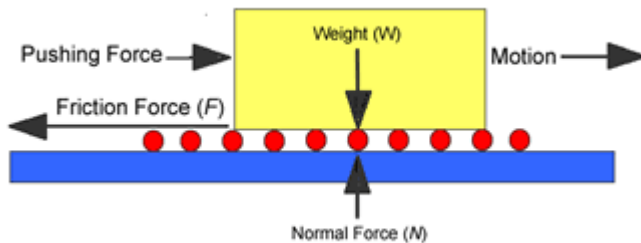
We can measure the force of friction between two surfaces if we know the normal force between them (N) and a number called the coefficient of friction ( $\mu$ ). Here's the formula.

$$F_f = \mu N$$

In the case of our block sliding over the desktop, the normal force is simply the weight of the block, which is the mass of the block multiplied by the acceleration

of gravity (weight = mass x gravity). The coefficient of friction is a number showing the friction between two surfaces in contact.

In our simple example, let's assume that our block is wood and the desktop is metal. The table below shows that the friction coefficient is 0.60. So if the mass



of our block were .05 kilograms, then we could calculate the force of friction. First let's calculate the normal force (N). N is equal to mass times the acceleration of gravity. The force of gravity is equal to  $9.8\text{ m/s/s}$ . Therefore,

$$N = .05\text{ kg} \times 9.81\text{ m/s/s} = .49$$

Back to our friction equation, given a coefficient of friction of 0.60, the friction force is:

$$F = 0.60 \times 0.49 = .294\text{ N}$$

Let's say that our block is now made of steel and the desktop is covered with plastic (polystyrene). Our friction table shows us that the coefficient of friction is now 0.35 – much lower than our previous example of wood and metal. If we assume that the mass of the steel block is also .05 kilograms, what would the force of friction be? Would you expect the steel block to slide further?

Remember, if the force of friction is low, then the resistance to forward motion is low.

## Rolling Friction

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Rolling friction is a force that resists the motion of wheels or balls. Rolling friction will slow your dragster but it is much less than sliding friction. Think about it. Place a wheel, marble and wood block on a board. Slowly raise one end of the board. What object will move first? Rolling force is very small in comparison to sliding force.

## Friction Forces on Your Dragster

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On a Co2 dragster, surface friction occurs between the wheels and track surface and between each axle and bearing surface. The axle is typically a 3.18 mm diameter rod made of steel, brass, aluminum or plastic. The bearing is whatever surface the axle is in contact with. This may be the car's body if no explicit bearing is selected or, any number of other options from a plastic straw to premium bushings. The friction force at each of these locations is a function of a unique coefficient of friction between the contact materials and the normal force at each location. On a dragster, the four locations producing friction force:

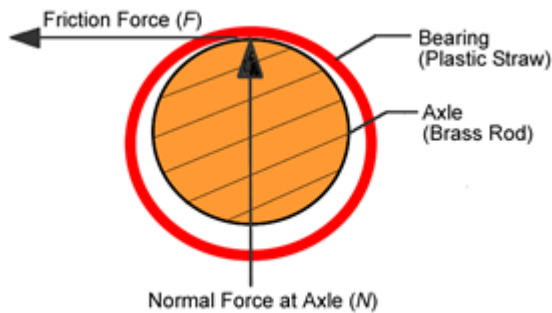


1. Front wheel and track ( $F_{fw}$ )
2. Rear wheel and track ( $F_{rw}$ )
3. Front Axle and Bearing ( $F_{fa}$ )
4. Rear Axle and Bearing ( $F_{ra}$ )

Thus, the total friction force is:

$$F_{tot} = F_{fw} + F_{rw} + F_{fa} + F_{ra}$$

This equation is long but not complicated. It simply adds the force at each point to get total force. As the friction formula shows, to calculate friction force we need to know the coefficient of friction ( $\mu$ ) and the normal force ( $N$ ) for each of the four sources of friction.

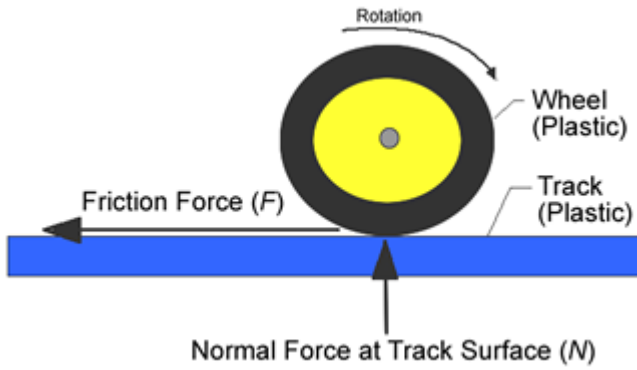


The friction on the axle is caused by the axle material (brass in the illustration) and bearing (a plastic straw in the illustration) rubbing together. There are many different kinds of material that can be used for axles and bearings. The coefficient of friction for axles and bearings depends on the materials used for

each of these parts. The coefficients of friction for all axle assembly components available from Pitsco are listed in the following table.

	Coefficient for Axle Type				
Bearing Type	Steel	Brass	Delrin	Aluminum	Chrome/Molly
No Bearing (Wood)	0.0618	0.0408	0.0392	0.0534	0.0484
Plastic Straw	0.0554	0.0238	0.0282	0.0325	0.0317
Laminated Bushing	0.0184	0.0140	0.0132	0.0180	0.0174
Brass Busing	0.0205	0.0187	0.0142	0.0232	0.0182
Ultimate Bushing	0.0157	0.0092	0.0139	0.0185	0.0168

The wheel rolling on the track also produces a friction force. The table below shows the coefficient of friction for manufactured wheels available from Pitsco rolling on a common track surface, plastic.



Type	Wheel	Coefficient
Outside Front	L Wheel	0.0072
	Super C Wheel	0.0082
	X Wheel	0.0077
	LX Wheel	0.0080
	Premium Outside Front	0.0042
Outside Rear	P Wheel	0.0083
	Fusion Wheel	0.0072
	Nitro Wheel	0.0087
	PX Wheel	0.0072
	Premium Outside Rear	0.0044
	Premium Hollow Rear	0.0041
Inside Front	GT-F Wheel	0.0078

	Premium Inside Front	0.0041
Inside Rear	GT-R Wheel	0.0073
	Premium Inside Rear	0.0054

The wheel coefficients are low compared to axle and bearing coefficients. This should not be surprising. Wheels roll over the track surface (*rolling friction*), while axles turn or slide inside the bearing (*sliding friction*). But, the friction force of the wheel does add to the total force.

Let's look at the total friction force of a typical dragster. The application will help you with the calculations but you do need to know how the forces on the front and rear assembly contribute to total force. The table to the right shows the friction forces on the front axle assembly of a dragster. The reaction force is the force of the weight on the surfaces. As the equation above shows, this reaction force times the coefficient of friction gives us the friction force.

Front Axle Assembly	
<b>Wheel Friction:</b>	
Reaction Force	0.2679
Coefficient of Friction	0.0087
Friction Force	0.0023
<b>Bearing Friction:</b>	
Reaction Force	0.0550
Coefficient of Friction	0.0618
Friction Force	0.0034
<b>Assembly:</b>	
Mass Distribution	25.4 %
Total Friction Force (N)	0.0057

The table to the right shows front axle friction force for a dragster. For this example, reaction force on the front wheel is .2679N and the coefficient of friction is .0087. The wheel friction is equal to reaction force times the coefficient of friction,  $.2679\text{N} \times .0087 = .0023$ . Likewise, using the same formula we find that bearing friction is .0034N. Add these together and we find total friction is .0057N.

Rear Axle Assembly	
<b>Wheel Friction:</b>	
Reaction Force	0.7884
Coefficient of Friction	0.0087
Friction Force	0.0069
<b>Bearing Friction:</b>	
Reaction Force	0.5755
Coefficient of Friction	0.0618
Friction Force	0.0356
<b>Assembly:</b>	
Mass Distribution	74.6 %
Total Friction Force (N)	0.0424

As you can see in the table to the left. The rear wheel assembly has a higher total friction. Notice that the coefficient of friction is the same but the reaction force is greater. Remember your readings on center of mass? Distribution of mass comes to play for friction force. 76.6 percent of the mass is on the rear assembly. Thus increasing reaction force and total friction.

The car in this example was designed with steel axles, plastic straw bearings and Pitsco's Nitro wheels. As you can see in the friction coefficient tables above, there are 25 axle and bearing combinations and 17 wheels to choose from.

What is the best combination? Working with those that have the lowest friction coefficient would be the first choice. But, engineers must always design with constraints. You have to work with what is available (the parts you teacher gives you) and cost limitations.

## Total Friction Force

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So what is the total force of friction working to slow the dragster? Just add them up. With a friction force of .0057N on the front and .0424N on the rear, .0482N of force is working to slow your car.

Not a big number given a cartridge force of 5N. But remember, this force is working against you. With a cartridge force of 5N the net force is now 4.957. When the cartridge expires around mid track, this force takes over to slow the vehicle. Careful consideration of friction forces can mean the difference between first and second place.

SURFACE FRICTION	
<b>Suspension Calculations:</b>	
Mass Distribution - Front	25.4 %
Mass Distribution - Rear	74.6 %
Friction Force - Front (N)	0.0057
Friction Force - Rear (N)	0.0424
Total Friction Force (N)	0.0482

There can actually be a difference between the car's weight distribution when the cartridge fires and when the cartridge is empty. If the center line of the cartridge lies above the y-coordinate of the center of mass, this will shift more weight to the front wheels while the cartridge is firing. The opposite is also true. The effect could be that the front and rear wheels lift up from the ground. This force will effect friction calculations. In fact, if either the front or rear wheels lift off the track, a significant amount of your car's energy could be wasted on friction between the eye screws and line.

## Drag

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Drag occurs when a solid object moves through a gas or liquid. When your dragster is streaking down the track, air flow creates pressures and friction on the vehicle. Like surface friction force, drag force is a negative force working to slow your dragster.



To understand drag force you need to understand the variables involved. Drag force is caused by air friction on the body and the difference in air pressure on the front and rear of the body. The size and shape of the object determines the amount of friction and pressure force. The main design factors that affect drag are:

1. Air density which is a function of temperature and altitude;
2. velocity of the vehicle, as the dragster accelerated drag increases;
3. coefficient of drag which depends on body shape; and
4. frontal area of the body.

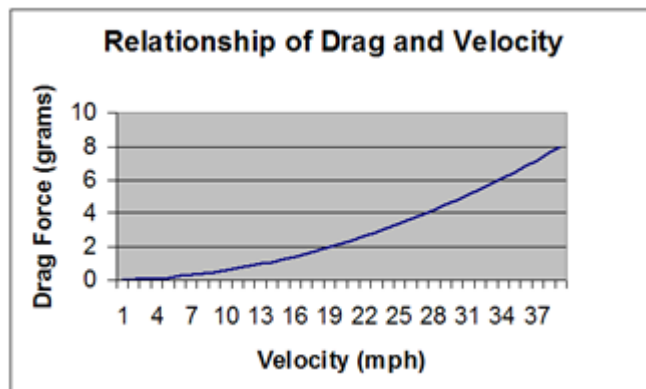
Let's look at each of these factors in more detail.

### Air Density

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When you are standing in high winds, you can feel the pressure of the wind on your body. When wind speed increases, the pressure increases. A vehicle moving through the air is like the wind pushing on your body. As a vehicle speed increases, pressure increases thus increasing drag force. Unlike the other variables that are

proportional, drag increases with the square of velocity. This means that if you double the vehicle's speed you will quadruple the drag. The graph at the right shows the exponential relationship of drag and velocity. At 16 mph the drag force is 1.28 grams. At 32 mph the drag force 5.12 (quadrupled).



Drag force is also related to air density. Cold air is denser than hot air. Air at sea level is denser than air at high altitudes. The denser the air the greater the drag. As stated earlier, drag occurs when an object moves through a gas or a liquid. The same principles of drag apply with objects moving through water. The density of water is much greater than air so drag is significantly increased on water vehicles.

Decreasing velocity or air density will decrease drag force. But, as you learned, the key to speed is increasing velocity. And, you cannot control air density on race day. Thus, to decrease drag, engineers must look at the other variables, the drag coefficient and frontal area.

## Coefficient of Drag

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The total coefficient of drag is equal to

$$C_D = C_{D(\text{Pressure})} + C_{D(\text{Friction})}$$

The sources of drag are pressure and friction. Pressure drag ( $C_{D(\text{Pressure})}$ ) is the difference in the high pressure pushing on the front and low pressure in the rear of a vehicle. Friction drag ( $C_{D(\text{Friction})}$ ) results from air molecules colliding with the vehicles surface. Total drag ( $C_D$ ) is equal to the sum of both sources for drag.

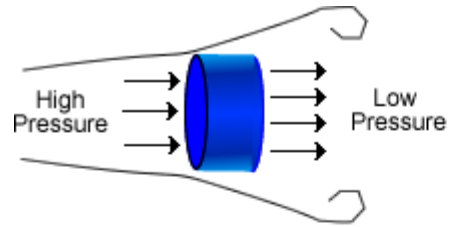
The amount of pressure and friction drag depends on the body shape. Let's examine the coefficient of drag on a cylinder. For this experiment, four 22mm diameter dowel rods were cut to different lengths and tested in a wind tunnel. The table below shows the drag force in grams for each of the samples. Drag Force (g) equals the sum of both sources for drag.

Sample	Length (mm)	Drag Force (g)
1	11	4
2	22	3
3	44	2
4	88	3

These results may not be what you would expect. The shortest rod has the greatest drag (11mm length with a drag force of 4 grams). As length increases, drag decreases, sample 2 and 3. Then, in sample four, drag begins to increase. To understand these results, you need to understand the causes of drag.



One source of drag is the pressures caused by air flow. As stated earlier, it is the pressure difference on the front and back of the cylinder. When air hits the front surface it creates pressure. As air passes over the surface and side, it separates from the surface. This flow separation creates a low pressure area on the rear surface. Pressure drag is the difference in these high and low pressure areas.



Sample 1: Wind tunnel test = 4g



Sample 3: Wind tunnel test = 2g



Sample 4: Wind tunnel test = 3g

As length increases, Sample 2, flow separation is reduced. Essentially, the increase in length makes the object more slender aerodynamically. Air flows parallel to the body surface. With less flow separation, the low pressure area on the rear surface is reduced. The difference in the front pressure and rear pressure is less.

However, as length increases, surface friction increases. Illustrated by data from sample four, there is a point when surface friction begins to overcome the advantages of increasing length to decrease flow separation.

Some key points to remember when designing and fabricating your dragster. Surface friction is caused by air molecules colliding with the surface. Rough surfaces have higher coefficient of friction than smooth surface. Surfaces in contact with the air steam as well as surface quality are factors to consider. Also, flow separation creates low pressure areas. Reducing the low pressure area on the rear of the vehicle reduces drag. Keep in mind, if there is flow separation on any area of the body a low pressure area is created. Flow separation on the top of the car will create lift.

## Frontal Area

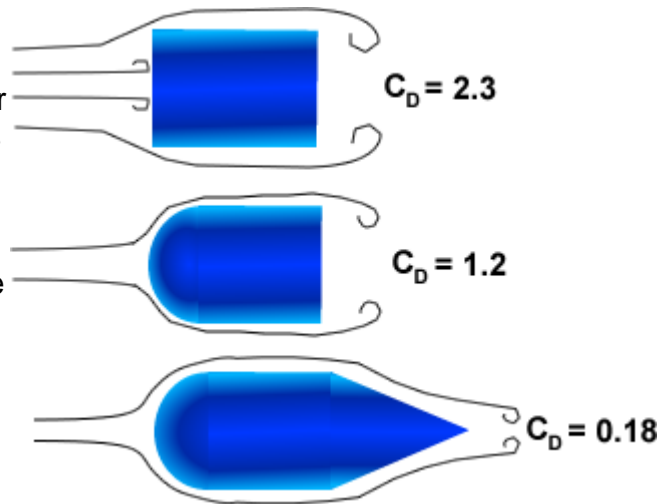
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Frontal area is what the air stream sees or what you see looking at the front of a car. As you would expect the larger the area the greater the drag because of the increase in frontal pressure. Drag force is proportional to area so if frontal area doubles drag force doubles. Keeping frontal area to a minimum will reduce drag. Note the frontal area of your designs when engineering your dragster. The application will provide you with this data the engineering phase.

## Streamlining

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Streamlining involves changing the shape of an object to reduce pressure and friction caused by air flow. Look at the three illustrations below with associated drag coefficients. The first object has a drag coefficient of 2.3. The flat front creates a large high pressure area and the sharp edges cause air separation increasing drag. Rounding the front to reduce air separation reduces the drag coefficient to 1.2. Streamlining the rear to a point reduces the low pressure area in the rear reducing the drag coefficient to 0.18. Dips in body shape can reduce surface friction reducing the drag coefficient.



The value of streamlining cannot be overstressed. When designing your dragster, think about sources of friction and pressure drag. How can these sources of drag be reduced by streamlining? Can frontal area be reduced with good design decisions? What effect do dips in the body shape have on surface friction and flow separation?



Computer simulations can help with some of these design decisions. Aerodynamic analysis software can calculate pressure and air flow on 3-D objects. Even with the most sophisticated software, aerodynamic performance is difficult to predict. State-of-the-art designs (including automobile, air craft and space craft) undergo wind tunnel and field test before designs are finalized. Experimenting with several different

designs may lead to the best solution.

## Putting it all together

### **Net Force**

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The net or total force acting on the vehicle is equal to

$$F_{\text{net}} = F_C - (F_D + F_F)$$

Where:

$F_C$ : Cartridge Force

$F_D$ : Drag Force

$F_F$ : Friction Force

The force from the cartridge ( $F_C$ ) is working to move the car forward. Drag ( $F_D$ ) and friction ( $F_F$ ) forces are working against this force. To maximize the net force, the equation tells us to increase the cartridge force and/or reduce the forces of drag and friction. Since we can't change the cartridge force, net force can only be increased by reducing all forms of drag and friction.

So, the key to building faster CO2 cars is to focus on the design factors that increase acceleration. Let's review Newton's Second Law of Motion.

$$a = \frac{F}{m}$$

This equation tells us that we can increase acceleration by increasing the net force acting on the car or decreasing its mass. Now that we have a better understanding of the forces acting on the car, we can expand our equation for acceleration to :

$$a = \frac{F_{\text{net}}}{m} = \frac{F_C - (F_D + F_F)}{m}$$

Since we can't change cartridge force, we must focus on:

- Reducing drag (force)
- Reducing surface friction (force)
- Reducing mass

But given that we have limited resources (time and money), how should we focus our efforts? In theory, we should be able to establish priorities by simply

plugging realistic numbers into our equation for acceleration and performing a series of calculations. If we know acceleration at a given time, it is possible to predict the amount of time it will take for a given design to travel 20 meters (this is what we'd really like to know). But this prediction is a real challenge for a number of reasons:

- Drag force depends on velocity, and velocity changes throughout the race. In fact, since drag increases with the square of velocity, drag can change quite a lot.
- The existence (or lack of) cartridge force affects the distribution of the car's mass about the front and rear axle assemblies. This means that surface friction is not a constant.
- The CO<sub>2</sub> cartridge will lose 8 grams of mass in the process of firing. Since we have to include the mass of the cartridge in our acceleration calculations, the total vehicle mass is not constant.

So there you have it. Everything - a cartridge force, drag force, friction forces, and mass-changes from one instant to the next. This means that the process of predicting performance and assessing trade-offs is much more tedious and time consuming, but the good news is that the underlying math is the same. For this reason, we've developed a tool to help you analyze the performance of your design, and therefore provide a solid framework to evaluate the many trade-offs that exist in the C2 dragster challenge.

You now have a solid understanding of the fundamental science and engineering principles that determine performance. You also have the tools to design and analyze an infinite number of concepts. Have fun, and good luck.

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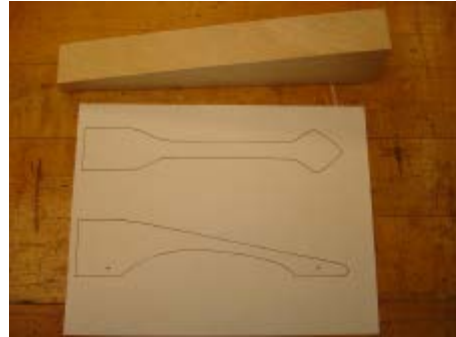
## Fabrication: Rail Dragster

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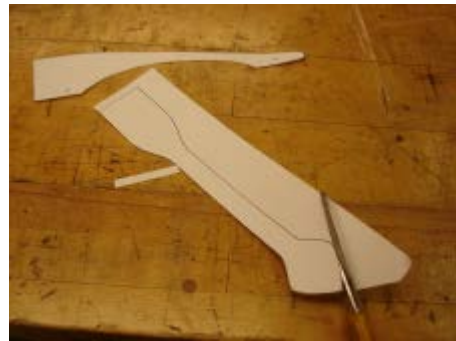
### Layout

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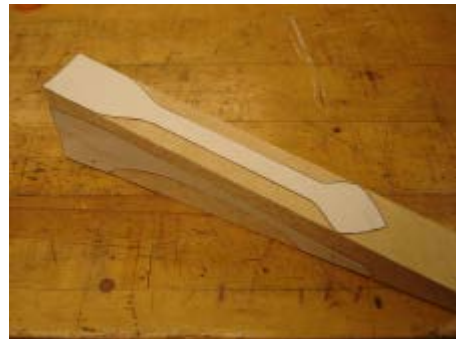
1. If you have not done so yet, print the templates for your design. Refer to the Print Template Tutorial for instructions.



2. Using scissors cut the templates out for the top view and side view of your design.



3. Attach the templates to the top and side of a dragster blank with tape, glue stick or spray glue.



### Drill

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4. Drill 3/16" axle holes using a drill press.

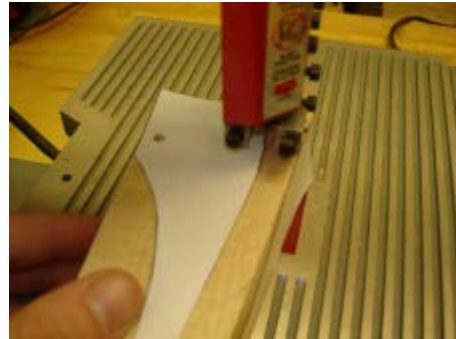
It is very important that the axle holes are drilled parallel to each other. Take your time and make sure the set up is right.



## **Cut Profiles**

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5. Cut the side profile along the template with a coping or band saw.



6. Tape the waste pieces back on the blank so the blank is back to its original shape.



7. Cut the top profile along the template with a coping or band saw.



## **Shape**

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8. Shape the body using files, sandpaper, belt sander or high speed rotary tools. Cross section templates can be used to make sure your body is symmetrical.

Periodically measure and weigh your body to make sure it is within specs. Don't forget to add the weight of the wheels, axles, bearings and eye screws to your body weight.





## **Quality Control Inspection**

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9. Assemble your dragster fitting the bearings, wheels and axles on your car body. Make adjustments in axle length and bearings if needed.

10. Roll test your dragster to be sure it rolls straight and there is no interference with components. Make adjustments if needed.

11. Now that you have tested and optimized your design, disassemble your dragster to prepare for finishing.



## **Finish**

---

12. Prepare the surface for finish by sanding with medium grit sand paper (120 grit) then fine grit sand paper (220 grit).



13. Spray several coats of primer on the car body. Sand between coats with 220 grit sandpaper.



14. Spray top coat of paint on your car body. It is better to spray several light coats than one heavy coat. Wait a few minutes for the paint to dry between coats.

There are several things that can be done to improve your car's finish. Sanding between coats removes defects and smooths the surface for the next coat. Be sure the finish is dry before sanding. Detail work like decals and pinstripes can be added to customize the look. In addition, a clear coat can be sprayed over the top coat to add luster and protect details. Remember, some clear coats, paints and decals are not compatible. Test the effect of spraying one finish over another before spraying your car body.



### **Assembly**

15. Layout eye screws along the bottom centerline of the car body. Be sure to follow specifications. Screw the eye screws into the body. A pilot hole may need to be drilled.



16. Insert bearing into the axle holes.

17. Assemble wheel and axles.



## Quality Control Inspection

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18. Measure and weigh your finished car to be sure it meets specs.

19. Again, conduct roll tests to be sure the car rolls straight and there is no interference with components. Make adjustments if needed.



## Let's Go Racing...

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### Evaluation

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Collecting data and evaluating your dragsters performance can lead to design improvements. Evaluation allows you to identify those areas that can be improved. It is a method used to benchmark performance and optimize designs.

Evaluation involves setting up a test bed, collecting data, analyzing data and then evaluating results. There are tests that can be conducted with you dragster to analyze performance factors. Let's take a look at a series of test that can be done and how these tests can help you predict and/or improve the performance of you vehicle.

### Working within Constraints: Does it meet specs?

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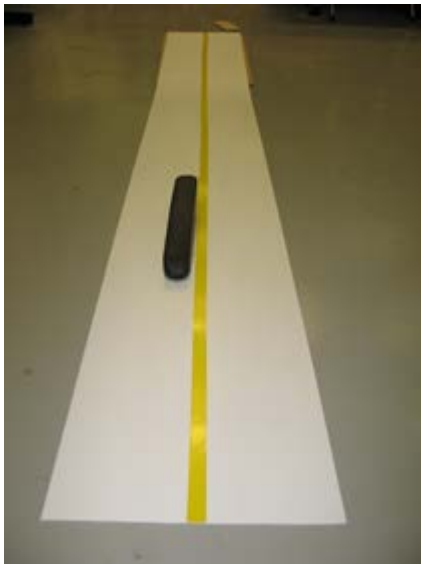
If you are entering a competition, you car will be disqualified if it does not meet specifications. Carefully measure each of the requirements and check them against

the specification and tolerance for that component. Rules and specifications are design constraints but the key is to work within these constraints to maximize performance. For example, you have learned the effect of mass on acceleration. Reducing mass while staying within specifications will increase performance. How about wheelbase or axle height? Take measurements of critical components and evaluate how you can work within the constraints to design for performance.



## Roll Test

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As you learned, friction is a force that is working to slow your vehicle. If the car you built does not roll straight, friction will increase. Why? Think about what you have learned. You should be able to answer that question yourself. There are several sources of friction that will be added to net forces as the vehicle tries to turn.

A roll test can be done to see how straight your vehicle rolls. Set up a ramp with a height of 2 or 3 inches. Draw or tape a centerline on the ramp and floor so deviation from a straight line can be measured. Roll your car down test ramp five times and record the distance and deviation from center. Calculate an average distance and deviation for comparison. If the deviation from the centerline is significant, analyze your dragster to determine if modifications can be made to improve its roll. Make the modifications and test it again. Compare your results to see if roll performance improved.

## Wind Tunnel Test

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Wind tunnel testing provides you with the drag force of your vehicle. As you have learned drag force is related to frontal area and streamlining of the body shape can have a significant effect on drag.

To get an accurate comparison of different body styles, it is essential that the test conditions be the same. Air speed is very important. Remember, drag force increase exponentially with velocity ( $d$ ). Therefore, it is important that air speed in the wind tunnel be kept to a constant. Also, the car must be parallel to the air stream. Keeping these variables constant will provide data that you can use analyze the effects of body shape on drag. Compare the wind tunnel results with the frontal area and body shape. What is the relationship?

## Pilot Run

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There are not many products that are introduced into the market without proper pilot testing. Pilot tests involve conducting experiments in the environment that product will be operating. For an air or space plane, it



involves actual test flights. For a new beverage, it involves, introducing the product in sample markets. For your dragster, it involves giving it the first run down the track. Is it fast? Is it stable? It is structurally sound? Put in a cartridge and give it a pilot run. Be sure to record your time. When you conduct a comparative analysis, track time is the performance measure used to benchmark design factors.

## Comparative analysis

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Now that you have collected data on your car, comparing that data to other dragster designs can lead to new ideas and solutions. What are the specifications of your classmate's dragsters? How well did they perform? What factors do you think affect performance? By conducting a comparative analysis, comparing your design to others, you can learn about what works and why.

Comparative analysis can be complicated involving large databases and statistical analysis but, for your dragster design activity, it can be done with a little help from your classmates. Working together, Identify the factor you think will affect performance. For example: mass, wheelbase, axle height, shell/rail design. Set up a spread sheet with the factors in the columns and be sure to include performance (track time) in the last column.

With the spreadsheet set up, enter data from all the dragsters in your class. Sort the spreadsheet by performance.

Teacher: Mrs. Angela Thompson		Period: 3rd								
Class: Technology Education										
Racer	Mass	Center of Mass		Stability	Mass Distribution		Friction Force	Frontal Area(m <sup>2</sup> )	Drag	Track Speed
		Y(cm)	X(cm)		Front(%)	Rear(%)				
Nick	49.5	31.8	86.6	1.98	28.2	71.8	0.038	0.00224	7.6	0.97
Cindy	50.3	32.1	79.7	1.95	27.2	72.8	0.033	0.00229	7.7	0.98
Angi	50.4	32.1	80.4	1.96	6.5	93.5	0.033	0.00234	7.6	0.98
Bill	50.1	32.5	90.2	1.94	20.2	79.8	0.039	0.00226	8	1.01
John	66	30.1	77.6	2.09	25.6	74.4	0.04	0.00239	8.3	1.05
Sally	53.4	34.5	77.9	1.83	10.5	89.5	0.045	0.00244	6.1	1.11
Lisa	53.9	32.6	77.6	1.93	11.6	88.4	0.045	0.00319	7.9	1.12
Shara	57.2	36.5	85.6	1.73	7.3	92.7	0.049	0.00299	8.6	1.12
Joe	5	32.2	77.7	1.96	9.8	90.2	0.038	0.00445	8.5	1.32
Jim	52	36	76	1.75	8.6	91.4	0.051	0.00224	8.3	1.36

Look at the factors in each column. Is there a pattern in the data that may indicate a relationship to performance? Are shell cars faster? Does axle material make a difference? Observing patterns in data can answer these types of questions. Sorting the data in different way, calculating averages, color coding factors by type are some ways to help analyze the results. There are many techniques that can be used to help benchmark design factors. Be creative...

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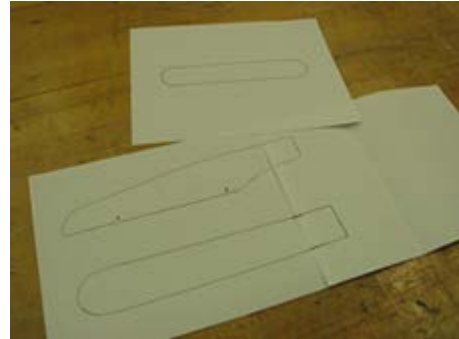
## Fabrication: Shell Car

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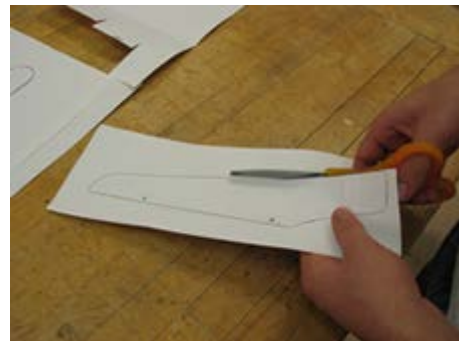
### Layout

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1. If you have not done so yet, print the templates for your design. Refer to the Print Template Tutorial for instructions.



2. Using scissors cut the templates out for the top, side and internal cavity view of your design.



3. Attach the templates to the top, side and bottom of a dragster blank with tape, glue stick or spray glue.



### Drill Axles

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4. Drill 3/16" axle holes using a drill press.

It is very important that the axle holes are drilled parallel to each other. Take your time and make sure the set up is right.



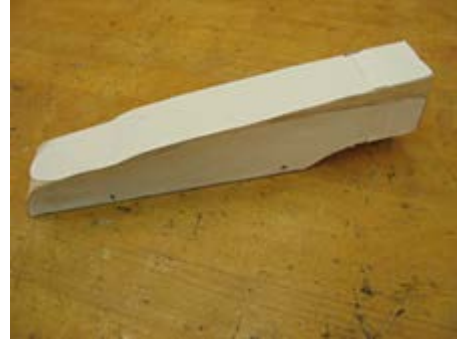
### Cut Profiles

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6. Tape the waste pieces back on the blank so the blank is back to its original shape.

7. Cut the top profile along the template with a coping or band saw.



8. Remove material from the body cavity using hand tools or high-speed rotary tool. Talk with your teacher to determine the best method to remove material from the body cavity.



9. Shape the body using files, sandpaper, belt sander or high-speed rotary tool. Cross section templates can be used to make sure your body is symmetrical.

Periodically measure and weigh your body to make sure it is within specs. Don't forget to add the weight of the wheels, axles, bearings and eyescrews to your body weight.



### **Fit the Wheel and Axle Assembly**

10. Cut the axle to proper length taking into account the space needed for the axle clips.

11. Fit wheels on the axles. If the wheels require modification, complete the modification and test the fit. Add washers and spacers if needed.



### **Quality Control Inspection**

12. Assemble your dragster fitting the bearings, wheels and axles on your car body. Make adjustments in axle length and bearings if needed.

13. Roll test your dragster to be sure it rolls straight and there is no interference with components. Make adjustments if needed.

14. Now that you have tested and optimized your design, disassemble your dragster to prepare for finishing.



## **Finish**

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15. Prepare the surface for finish by sanding with medium grit sand paper (120 grit) then fine grit sand paper (220 grit).



16. Spray several coats of primer on the car body. Sand between coats with 220 grit sandpaper.



17. Spray top coat of paint on your car body. It is better to spray several light coats than one heavy coat. Wait a few minutes for the paint to dry between coats.

There are several things that can be done to improve your cars finish. Sanding between coats removes defects and smoothes the surface for the next coat. Be sure the finish is dry before sanding. Detail work like decals and pinstripes can be added to customize the look. In addition, a clear coat can be sprayed over the top coat to add luster and protect details. Remember, some clear coats, paints and decals are not compatible. Test the effect of spraying one finish over another before spraying your car body.



## **Assembly**

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18. Layout eye screws along the bottom centerline of the car body. Be sure to follow specifications. Screw the eye screws into the body. A pilot hole may need to be drilled.



19. Assemble wheel and axles.



### **Quality Control Inspection**

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20. Measure and weigh your finished car to be sure it meets specs.

21. Again, conduct roll tests to be sure the car rolls straight and there is no interference with components. Make adjustments if needed.



### **Let's Go Racing...**

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