Lesson 2 Forces in Automobile Racing

Questions for Analysis

- What forces are involved in automobile racing?
- How do air resistance and downforces from air movement create forces that affect race cars?
- What accounts for centripetal forces in automobile racing?

Key Concepts

- Acceleration
- Air resistance
- Centripetal force
- Downforce
- Friction
- Force
- Inertia
- Gravity
- Mass
- Trade-off

Digitized Artifacts

From the Collections of **The Henry Ford**

Lesson 2

Forces in Automobile Racing

- Soap Box Derby Car, 1939 ID# THF69252
- Official Start of First NHRA Drag Racing Meet, Great Bend, Kansas, 1955 ID# THF34472
- Three Men Pushing a Barber-Warnock Special Race Car Off the Track at Indianapolis Motor Speedway, probably 1924 ID# THF68328
- Ford Race Car “666,” 1906-1907, Driven by Frank Kulick ID# THF69468
- Buck & Thompson Class D Slingshot Dragster, 1960 ID# THF36041
- Damaged Race Car After a Racing Accident, 1905-1915 ID# THF12446
- Henry Ford Driving the 999 Race Car Against Harkness at Grosse Pointe Racetrack, 1903 ID# THF23024
- Dave Lewis’s Race Car Stopped on the Board Track at Altoona Speedway, Tipton, Pennsylvania, 1925 ID# THF73131
- March 84C Race Car, 1984 (cockpit view ID# THF69363)
- Leon Duray Being Timed at Culver City Speedway, California, 1927 ID# THF73132
- Willys Gasser, 1958 (front view ID# THF69394)
- Ford Thunderbird, NASCAR Winston Cup Race Car Driven by Bill Elliott, 1987 (overhead view ID# THF69264)
- Race Car “999” Built by Henry Ford, 1902 ID# THF70568

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Lesson 2 Forces in Automobile Racing Continued

Materials

- Computers with access to the Internet; digital projector and screen (preferred) OR printed handouts of Background Information Sheet, Student Activity Sheet and digitized artifacts' images and descriptions
- Background Information Sheet for Students 2A: Forces in Automobile Racing
- Student Activity Sheet 2B: Forces
- Answer Key 2B: Forces

Instructional Sequence

1. Distribute copies of Background Information Sheet for Students #2A: Forces in Automobile Racing to read and study. If possible, access this online so that students can view the digitized artifacts embedded and hyperlinked in the Background Information Sheet.
2. Use the Background Information Sheet to review, read and discuss with students the questions for analysis, key concepts and information about forces as they apply to automobile racing.
3. Encourage students to make their own observations, ask questions and offer other examples from life that illustrate the concept of forces in everyday life

Assessment

Have the students complete Student Activity Sheet 2B: Forces to assess their learning and understanding.

forces in Automobile Racing

Questions for Analysis

- What forces are involved in automobile racing?
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- What accounts for centripetal forces in automobile racing?

Key Concepts

Acceleration
The rate at which an object's velocity changes; $a = \Delta v / \Delta t$.

Air resistance
The force created by air when it pushes back against an object's motion; also referred as drag on a car.

Centripetal force
The force toward the center that makes an object go in a circle rather than in a straight line.

Downforce
The force on a car that pushes it downward, resulting in better traction.

Force
Any push or pull.

Friction
The opposing force between two objects that are in contact with and moving against each other.

Gravity
The natural pull of the Earth on an object.

Inertia
An object's tendency to resist any changes in motion.

Mass
The amount of matter in an object.

Trade-off
A term that describes how an improvement in one area might decrease effectiveness in another area.

The Concept of Force

In simple terms, a force is any push or pull. We encounter numerous types of forces every day. Many of these forces can be analyzed using examples from automobile racing.

An unbalanced force will make an object increase or decrease its speed, while forces that are balanced do not cause acceleration. A race car sitting on the track is subject to forces, but they are balanced [Soap Box Derby Car, 1939 ID# THF69252]. The force of gravity pulls down on the car while an equal force from the track pushes back up so that the forces are balanced and the car remains stationary. When the soapbox derby car is on a hill, the downward force is greater than the upward force, and the car accelerates down the hill.

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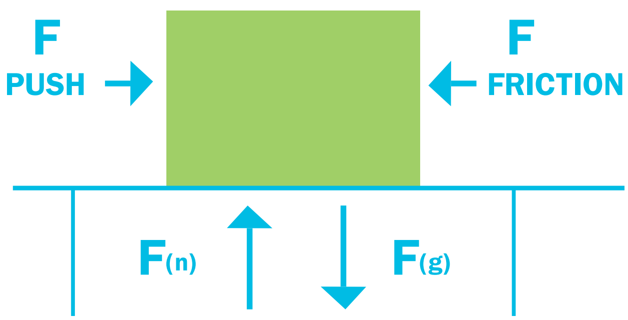
Free-Body Diagrams

When analyzing forces, a useful concept is a free-body diagram. A free-body diagram is a simple sketch with arrows that show the direction of all the forces. Longer arrows represent larger forces and shorter arrows represent smaller forces. Using free-body diagrams helps scientists visualize all the forces.

Below is a simple free-body diagram for a block on a table; the block is being pushed to the right. F(n), which is the upward force from the table, is called a normal force. F(g) is the force of gravity.



There are many forces involved in an automobile race, and free-body diagrams can help to show them.

Accelerating Forces

Before a race, when a race car's engine hasn't been started to provide a forward force for acceleration, the car is sitting still at the starting line [Official Start of First NHRA Drag Racing Meet, Great Bend, Kansas, 1955 ID# THF34472].

In order to move an object, there must be an unbalanced force. Notice that it takes several people to push a car and overcome friction (a backwards force opposing motion) to get the car to accelerate [Three Men Pushing a Barber-Warnock Special Race Car Off the Track at Indianapolis Motor Speedway, probably 1924 ID# THF68328]. For safety reasons, people in the pit areas usually push race cars by hand before races, as the pit areas are crowded with workers and spectators.

It takes a lot of force to accelerate a large race car. In one of the earliest race cars built by Henry Ford, the motor was extremely large to provide a lot of force. Because the motor and the rest of the car were so massive, this early car could only race at about 90 miles per hour [Ford Race Car "666," 1906-1907, Driven by Frank Kulick ID# THF69468]. The car was effective for its day because other cars were also very heavy. Compare Ford's car to the 1960 Slingshot dragster, which has a smaller engine but is much lighter, enabling it to go faster than the 666 [Buck & Thompson Class D Slingshot Dragster, 1960 ID# THF36041].

In math terms, the formula that describes accelerating forces is F = m a. For a given mass, a larger value for force will create more acceleration. A smaller mass would also create more acceleration. If the force on a car is tripled and the mass is cut in half, the acceleration would be 3 * 2 times the acceleration, or 6 times the acceleration. Doubling the force but also doubling the mass will keep the acceleration the same. (2 * F gives 2 times the acceleration and 2 * m gives ½ the acceleration, so overall the acceleration would be the same.)

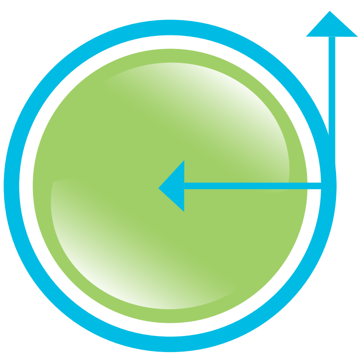
Centripetal Force

Another force involved in racing is centripetal force. Newton's first law states that a body in motion remains in motion unless acted upon by an outside force. A centripetal force is any force that pulls the car back toward the center of the circle or curve that the car is traveling in. Some racetracks are banked to "push" the car back toward the center with an inward force.

Continued…

Most people think that when a car is traveling around a curve, the car is forced out of the circle. Actually, a car's natural motion will keep it going straight, but there has to be an inward force toward the center to keep the car on the track [Damaged Race Car After a Racing Accident, 1905-1915 ID# THF12446]. In this digital image, the car has crashed through the fence. If you look back at the track in the upper left, you can see that the car was coming into a left-hand curve but didn't make the curve. In order to stay on the track around the curve, the car needed an inward force. The tires against the road or pavement normally provide the inward force in a circle, but in this case, for some unknown reason, the tires did not force the car back inward.

A helpful diagram shows the directions of force, acceleration and velocity for an object traveling in a circle or curve:



Look at the digital image of the driver in the driver's seat and a man sitting on the running board on the left side of the car [Henry Ford Driving the 999 Race Car Against Harkness at Grosse Pointe Racetrack, 1903 ID# THF23024]. What do you think the man on the running board is doing?

This is actually Henry Ford driving, with his friend Spider Huff riding on the side. Imagine sitting on the small running board, racing and bouncing down the road at 60 to 90 miles per hour.

Newton's first law states that an object (in this image, a car) in motion will continue in motion (straight ahead) unless acted upon by a force to change either the speed or direction of motion). When a driver makes a left-hand turn, his race car keeps trying to go straight. The car's tires grip the road to provide a force to turn the car around the corner or circle. In early race cars, the bottom of the car where the tires are located turned with the tires, but the heavy top of the car tried to keep on going straight. Early cars were unstable, so when they rounded a left-hand turn, they tended to roll over to the right if they were going very fast.

So why did the rider ride on the left side? Most races are on oval tracks where the drivers are almost constantly turning left around curves. Since early race cars on these tracks could not corner very fast without rolling over to the right, the weight of the running-board rider on the left provided a downforce on the left side of the car to keep it balanced.

Notice the similarity to sailboat racers who lean over the edge of their sailboat to keep it from tipping over.

Many racetracks are banked to provide more centripetal force. The larger the angle of the banked turns, the faster the race car can travel around the curve. The banked turn allows the tires to grip better and gain more traction [Leon Duray Being Timed at Culver City Speedway, California, 1927 ID# THF73132].

The formula for centripetal force is $F = m\ v^2/r$. The m is mass, the v is velocity and r is the radius of the curve (if you continue the curve to make it a complete circle, r is the imaginary radius of that imaginary circle).

Continued…

Example Problem

A car with a mass of 800 kilograms is traveling at a speed of 160 miles/hour (about 72 meters/second) around a curve with an imaginary radius of 100 meters. Find the force needed by the tires or track to keep the car in a circle.

$F = m * v^2 / r$ = 800 kilograms * (72 meters/second)^2 / 100 meters = 41,470 Newtons (N) of force.

Center of Gravity

Lowering the center of gravity or center of weight of a car also helps keep it from rolling over. Most of the weight in modern race cars is very low to the ground, giving them what is called a low center of gravity. The center of gravity of an object is the average center of all its weight. If a car's center of gravity is too high, it can tip over while going around sharp turns.

Maintaining Race Cars

The running-board rider on early race cars also provided another service. Can you guess what that might be? The rider watched the engine to make certain that it was running properly and could warn the driver to slow down if there was an engine or gear problem. If needed, he could actually oil the motor during the race. He was also looking around, especially behind the driver, to help avoid accidents. The running-board rider is certainly an example of an early innovation in racing.

In modern race cars, onboard computers monitor the car's entire system and send information back to the engineers in the pits so that necessary adjustments and repairs can be made to the car during pit stops. Look at the image of an older pit stop during a car race and compare it with what you've seen in modern NASCAR races [Dave Lewis's Race Car Stopped on the Board Track at Altoona Speedway, Tipton, Pennsylvania, 1925 ID# THF73131].

G-Forces

Sometimes, scientists refer to large forces as g-forces. One g-force is the normal force of gravity on a person or object, which is the same as the weight of the person or object. Thus, one g-force is equal to mass times gravity. To find a person's weight, or the force of gravity on that person, multiply the person's mass by the acceleration due to the earth's gravity, a value of 9.8 meters/second^2. If a force measures 4 times the calculated force of gravity, this force would be called four gs. In the example problem above, the 800-kilogram car would have a weight, or one g, of 800 kg * 9.8 m^2 = 7,840 N.

In this case, the calculated force going around the curve would be 41,470 Newtons. The 41,470 N would be 41,470 N/7,840 N or about 5.3 gs, and the race car driver would feel about 5 times his normal body weight while going around the curve. Because race car drivers constantly feel the sensation of several gs, they need to be in very good physical condition.

Forces on Tires and Tire Design

Because the force between the tires and the road needs to be so large, tires wear out rapidly. Look at the width of the tires on a newer race car [March 84C Race Car, 1984 (cockpit view ID# THF69363)] and compare them with the tires on an early racecar [Race Car "999" Built by Henry Ford, 1902 ID# THF70568]. Physicists usually say that the width of the tire shouldn't provide for friction force, but engineers have found that the wide tires work best, gripping better and lasting longer.

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Drag Force, or Air Resistance Force

Innovators are constantly redesigning cars to cut down on wind resistance by reshaping the front of the car. Look at Willys Gasser, 1958 (front view ID# THF69394). This car certainly fights the force of air resistance; it has to push through the air. The force of the air slows the acceleration and speed of the car, so to decrease the air resistance from its large, flat front, the top of the Gasser was chopped off and lowered.

Notice the difference between the shape of the Gasser and the shape of the Ford Thunderbird [Ford Thunderbird, NASCAR Winston Cup Race Car Driven by Bill Elliott, 1987 (overhead view ID# THF69264)]. The front of the Gasser pushed a lot of air, but the Thunderbird has a sloped front, allowing air to pass over the top of the car with less back force.

When the Gasser's owner, George Montgomery, finally retired the Willys, he replaced it with a modified Mustang that was much lower and had better aerodynamics.

Engineers do everything they can to cut down on air drag, or the force of air resistance, in order to gain more speed. In a passenger car, the shape of the car is aerodynamically designed with a sloping front to allow the car to pass through the air with less force and therefore get better gas mileage. Modern passenger cars are wind-tunnel tested to make certain that they will not encounter too much air resistance, or drag.

Name

Forces

1. Draw a free-body diagram for a race car rounding a curve during a race.

2. Explain the physics of force, mass and acceleration for a NASCAR race car coming out of the pits.

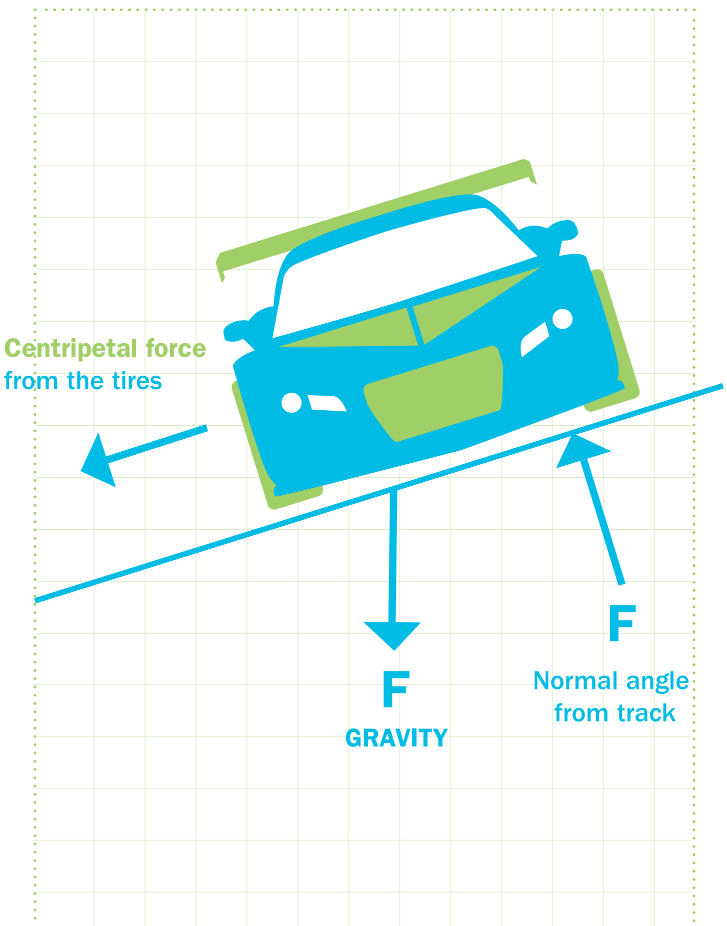
3. How much force would be needed to for a 900-kilogram race car to accelerate from 0 meters/second to 65 meters/second in 10 seconds?

4. A small, fairly light drag race car accelerates from the starting line at a high rate of speed. Later, a different car, having 3 times as much mass but with an engine that delivers 4 times the force, takes its turn. What is the acceleration of the second car compared to the first car?

5. A force of 100 N (Newtons) is applied toward the left on a 6-kilogram block on a rough floor having a friction force of 30 N. A second force is applied to the brick toward the right at 50 N. What is the magnitude and direction of the net force on the block?

Forces

1. Draw a free-body diagram for a race car rounding a curve during a race.



2. Explain the physics of force, mass and acceleration for a NASCAR race car coming out of the pits.

As a NASCAR car comes out of the pits, the pit crew exerts a quick small force as they push the car. The engine provides a large force that is transferred to the tires. The car begins to accelerate according to a = F / m, (the larger the mass, the less the acceleration, the larger the force the more the acceleration). The driver turns the steering wheel, causing a force to change the direction of the car through the tires.

3. How much force would be needed for a 900-kilogram race car to accelerate from 0 meters/second to 65 meters/second in 10 seconds?

*F = ma = m * Δ v/ Δ t*

*F = ma = 900 kilograms * (65 meters/second - 0 meters/second)/10 seconds = 5850 N.*

Continued…

4. A small, fairly light drag race car accelerates from the starting line at a high rate of speed. Later, a different car, having 3 times as much mass but with an engine that delivers 4 times the force, takes its turn. What is the acceleration of the second car compared to the first car?

3 times as much mass means 1/3 as much acceleration, and 4 times the force means 4 times the acceleration. Therefore the ratio of acceleration of Car 2 to Car 1 is 4:3.

5. A force of 100 N (Newtons) is applied toward the left on a 6-kilogram block on a rough floor having a friction force of 30 N. A second force is applied to the brick toward the right at 50 N. What is the magnitude and direction of the net force on the block?

Net force =
100 N left – 50 N right – 30 N friction = 20 N net

F = ma

a = F(net) / m = 20 Newtons /6 kilogram = 3.33 Newtons