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
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.

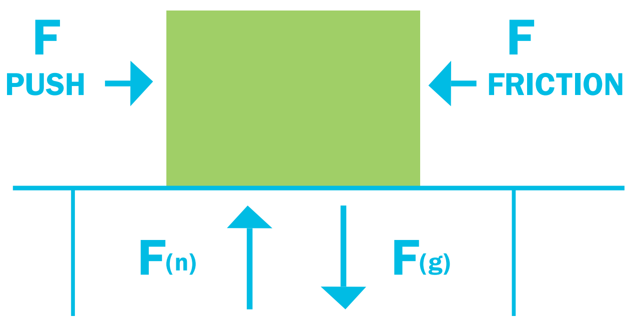
An unbalanced force will make an object increase or decrease its speed, while forces that are balanced do not cause acceleration. A race car sitting on the track is subject to forces, but they are balanced [Soap Box Derby Car, 1939 ID# THF69252]. The force of gravity pulls down on the car while an equal 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.

Continued...

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.)

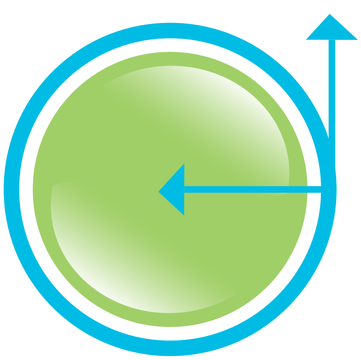
Centripetal Force

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.

Continued…

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.