analysis of Newton's Laws in Automobile Racing

Question for Analysis

What are Newton's laws of motion, and how are they applied 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 the air as the air pushes back against an object's motion.

Force

Any push or pull.

Friction

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

Inertia

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

Mass

The amount of matter in an object.

Momentum

The combined mass and velocity of an object, or mass times velocity.

Safety features

In an automobile, things that make the car safer or that make racing safer.

Speed

The distance an object travels divided by the time it takes to travel the distance.

Velocity

The speed of an object, including its direction.

Newton's 1st Law – The Law of Inertia

Newton's first law is called the law of inertia. Inertia is the resistance to change in motion. The first law states that a body at rest remains at rest and a body in motion remains in motion, unless the body is acted upon by an outside force. In everyday life, we have inertia because we tend to keep doing what we are already doing. When we are up, we like to stay up. But if we are sitting or sleeping, we like to stay sitting or sleeping.

In sports, we hear the term "momentum" used when one team gets going and just keeps on going. If a team has momentum, the team is difficult to stop.

If a car is standing still without the motor running, the car will remain there. Look at the digitized image of the Willys Gasser, 1958 (side view ID# THF69391).

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Newton's 1st Law – The Law of Inertia Continued

The Gasser will remain motionless until it is pushed by a force that accelerates it. The force could be provided by people [Three Men Pushing a Barber-Warnock Special Race Car Off the Track at Indianapolis Motor Speedway, probably 1924 ID# THF68328] or by the car's engine.

Once a car is moving, it will remain moving. Look at the digitized image of a car that kept going straight instead of making the left-hand turn [Damaged Race Car After a Racing Accident, 1905-1915 ID#THF12446].

When the driver starts the engine and pushes the accelerator, the motor produces a force that moves the car forward [Official Start of First NHRA Drag Racing Meet, Great Bend, Kansas, 1955 ID# THF34472]. When the car accelerates forward, the driver and passengers feel as though they are thrown or pushed backwards, but actually the car goes forward while the driver and passengers remain where they are. They feel as though they are thrown backwards when the car seat hits them in the back.

Similarly, if a car is stationary and gets hit from the rear, the driver feels as if he or she is flying backwards. Actually, the car is pushed forward, leaving the driver behind.

Race car drivers have high-backed seats so that when they accelerate forward, their entire body goes forward with the car [Lyn St. James Suited Up in Racecar, Giving a Thumbs-Up, 2008 ID# THF58671]. Their heads do not snap back because they remain against the seat. In your family car, you have head rests and seats to keep you from feeling as though you are thrown backwards.

If a car is stopped by an outside force – for example, by crashing into another car or into a wall – its driver keeps on going. Safety belts help slow the driver to prevent him or her from flying out of the car or hitting the front windshield. The safety belts in race cars are called 5-point belts; they go around both the wearer's shoulders as well as his or her waist and attach at 5 points. In a passenger car, both safety belts and air bags are used to slow the driver and passenger.

Modern race drivers also use a device called a HANS device. The HANS device is a well-padded bar wrapped around the driver's neck to help protect the neck from flying side to side. During an accident, everything tends to fly around, staying in motion in whatever direction it was already headed. Some race drivers even have attachments to keep their hands attached to the steering wheel so that their hands and arms do not fly around during an accident.

Every car accident involves the concepts of Newton's first law. Safety features are devised to keep the driver (and the passengers, in passenger cars) from continuing forward against hard objects. To consider the great improvements in safety devices over the history of automobile racing, look at the picture of one of Henry Ford's early automobile races [Henry Ford Driving the 999 Race Car Against Harkness at Grosse Pointe Racetrack, 1903 ID# THF23024].

Compare the safety features in Ford's car with those in Lyn St. James's race car [Lyn St. James Suited Up in Racecar, Giving a Thumbs-Up, 2008 ID# THF58671]. Notice the safety features that help restrain the driver during an accident.

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Newton's 2nd Law – F = m a

Newton's second law can be stated as force equals mass times acceleration (F = m a). An unbalanced force will cause an acceleration, and the greater is the force, the greater will be the acceleration; conversely, the greater the mass, the less the acceleration. Thus a car with larger mass will accelerate more slowly.

What do car builders and engineers do to increase acceleration and speed? Innovative race car designers want the most powerful engine possible in order to increase force and acceleration. At the same time, designers want the car to be lightweight in order to achieve better acceleration and speed. Look at the engine of the Ford Thunderbird NASCAR race car [Ford Thunderbird NASCAR Winston Cup Race Car Driven by Bill Elliott, 1987 (engine view ID# THF69265)]. Engine size is regulated in most races, so designers or car builders cannot put too large an engine in their cars. Race car builders try to make cars lighter by using aluminum or plastic rather than heavier steel, where possible. The mass of race cars has been a design problem that designers, engineers and race car drivers have struggled with throughout the history of racing.

Notice the early race car built by Henry Ford [Henry Ford Driving the 999 Race Car Against Harkness at Grosse Pointe Racetrack, 1903 ID# THF23024]. The 999 car had a large 1,150-cubic-inch engine to provide a large force for acceleration and speed.

Look at the picture of a race car built for drag racing on a quarter-mile straight track [Buck & Thompson Class D Slingshot Dragster, 1960 ID# THF36041]. The Slingshot car is very light. The formula used to calculate acceleration, a = F/m, shows that for a given force, a smaller mass means greater acceleration.

Working Problems Involving Newton's Laws

When working math problems involving Newton's second law, we always use kilograms (kg) for mass and meters per second^2 (m/sec^2) for acceleration. The metric unit of force is called a Newton (N), equal to 1 kilogram-meter/second^2.

Thus, a race car with a mass of 900 kilograms accelerating at 10 meters/second every second (10 meters/second^2) requires a force of:

F = m a = 900 kg * 10m/sec2 = 9,000 Newtons

A force of 12,000 N will cause a car of mass 800 kilogram to accelerate at 15 meters/second^2:

A = F/m = 12,000 N / 800 kilogram = 15 m/sec^2

Net Force

When working F = m a problems, remember that it is net force that causes acceleration. A net force is the resultant force of two or more forces. A push of 200 Newtons to the left and a force of 80 Newtons to the right on a mass of 10.0 kilograms will result in a net force of 120 Newtons to the left. The net force is what is applied to an F = m a problem.

In this case, if the forces above are applied to a mass of 10 kilograms, the acceleration will be:

a = F/m = 120 N /10 kilogram = 12 meters/second^2

Newton's 3rd Law – Action and Reaction

Newton's third law states that for every action in one direction, there is an equal and opposite reaction. Another way to state the third law is that for every force in one direction, there is an equal and opposite force in the other direction. During acceleration of a car, the motor and engine transfer force to the tires, which push against the pavement. The pavement pushes back on the race car [Henry Ford Driving the 999 Race Car Against Harkness at Grosse Pointe Racetrack, 1903 ID# THF23024]. Forces cause objects to accelerate, so the car goes forward. Whenever two objects apply forces against each other, the lighter object moves faster and farther than does the heavier object. Thus the car moves rather than the track. If there is gravel or dirt on the track, then you see the gravel or dirt fly back as the car goes forward, because the gravel is lighter than the car.

To mathematically describe action and reaction, we use the formula m*v (left) = m*v (right). A 60 kilogram girl jumps to the left off a skateboard having a mass of 2 kilograms. If the girl goes left at 1 meter/second, how fast will the board fly?

60 kilograms * 1 meter/second (left) = 2 kilograms * v (right)

v(right) = 60 kg * 1 m/sec / 2 kg = 30 m/sec (right).

Another example of action and reaction is a jet plane in flight. The jet engines expel hot gases to the rear, and the jet is propelled forward. Another example is a runner pushing against the ground to run and the ground pushing back on the runner.