study of motion
Using Artifacts from the Collections of **The Henry Ford**

Question for Analysis

How are the basic concepts of distance, velocity, acceleration and inertia applied in the study of automobile racing?

Key Concepts

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

Acceleration of gravity
The acceleration downward, due to gravitational attraction, of a falling body.

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

Conversion
Changing from one set of units to another, such as from miles per hour to meters per second.

Displacement
The distance and the direction that an object moves from the origin.

Distance
The change of position from one point to another.

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.

Power
Rate of doing work, or work divided by time.

Revolution
The motion of one object as it orbits another object.

Rotational motion
The motion of an object turning on an axis.

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

Velocity
The speed of an object, including the direction of an object.

Work
The force on an object times the distance through which the object moves as the work is converted to either potential energy or kinetic energy.

Continued…

Early Automobile Racing

Compared to races today, most early automobile races were short. Early race cars were still far from reliable and were very much in the development stage.

In the earliest races, a rider rode on the running board to constantly oil the gears and keep the motor lubricated. Pit stops were quite different; mechanics had to make many adjustments and repairs. Look at this image of a pit crew working with no particular hurry on a car during a race [Barber-Warnock Special Race Car in Pit at Indianapolis Motor Speedway, 1924 ID# THF68329].

Henry Ford became interested in developing race cars largely to showcase his talents at building cars in order to attract investors to his new Ford Motor Company. Look at the digitized composite photograph depicting Henry Ford driving the 999 race car [Henry Ford Driving the 999 Race Car Against Harkness at Grosse Pointe Racetrack, 1903 ID# THF23024]. Driving this car in practice runs, Henry Ford completed a one-mile lap of the Grosse Pointe track in one minute and eight seconds. Can you determine his average speed for this lap?

Conversions

Probably the most confusing aspect of working problems about automobile racing is that some measurements are given in the English System, which uses miles and miles per hour, and other measurements are given in the International System of Units (SI), which uses meters and joules and kilograms. When working problems using any math or physics equations, be certain that all units are from the same system, either English or SI. Units of length should be all in miles for the English system and all in kilometers or all in meters for the International system. Times must be all in hours or seconds (for either system), and mass must be in kilograms for the International system. Speed must be in meters per second (m/s) or kilometers per hour (km/hr) for the International system and miles per hour (mi/hr) for the English system.

Sample Conversion Problems

To convert all values to the same units, multiply by an appropriate factor that is equal to 1. Either of the equivalent units can be numerator or denominator to cancel units. Examples:

Convert 25 minutes to seconds

$$25 \text{ minutes} \ * \ \frac{60 \text{ seconds}}{1 \text{ minute}} = 1{,}500 \text{ seconds}$$

Convert 6 miles to meters

$$6 \text{ miles} \ * \ \frac{1{,}610 \text{ meters}}{1 \text{ mile}} = 9{,}660 \text{ meters}$$

Convert 120 miles/hour to meters/second

$$\frac{120 \text{ miles}}{\text{hour}} \ * \ \frac{1{,}610 \text{ meters}}{\text{miles}} \ * \ \frac{1 \text{ hour}}{3{,}600 \text{ seconds}} = 53.7 \text{ meters/second}$$

Referring to the early racecar above, we can now calculate the average speed for the 10-mile race that took 1 hour 10 minutes:

First convert the 10 minutes to hours

$$10 \text{ minutes} \ * \ \frac{1 \text{ hour}}{60 \text{ minutes}} = 0.17 \text{ hour}$$

speed = distance/time = 10 miles/1.17 hours = 8.55 miles/hour

Calculating Distance, Speed and Velocity

In correct physics terms, distance and displacement have different meanings. Distance is simply the difference between two points, $d = x(2) - x(1)$ where $x(2)$ is the ending or second point and $x(1)$ is the beginning or 1st point. Displacement, however, is the distance and the direction from the origin. If you walk 8.0 meters north,

Continued…

8.0 meters east and 8.0 meters south, your distance will be 24 meters, but your displacement will be 8.0 meters east of the origin.

In the same way, speed and velocity have different meanings. Speed is the distance traveled per time. Velocity is the displacement per time. A velocity calculation for 8.0 meters north, 8.0 meters east and 8.0 meters south for a trip lasting 4.0 seconds would be:

v = d / t = 8 meters/ 4 seconds = 2 meters/second east

For most physics problems, we interchange the words speed and velocity, and most people do not differentiate between the two.

There are several basic equations that are useful in physics and that can be helpful when analyzing automobile racing:

Physics Equations of Motion

1. $d = v(\text{average}) * t$
2. $v(\text{average}) = \text{total distance} / \text{total time}$
3. $a = \Delta v / \Delta t$ (where Δv means change in velocity and Δt means change in time)
4. $v(\text{average}) = \dfrac{v(\text{initial}) + v(\text{final})}{2}$

   (v(i) means initial velocity and v(f) means final velocity
5. $d = v(i) * t + ½ * a * t^2$
6. $v(f)^2 + v(i)^2 + 2 a * d$
7. Kinetic energy $KE = ½ m * v^2$
8. Potential energy of gravity $PE = m * g * h$
9. Work $W = F * d$
10. Centripetal force $F = \dfrac{m * v^2}{R}$

Sample Motion Problems

1. A car starts from rest and accelerates to a speed of 140 miles per hour over a 10-second period. What is the car's acceleration?

   $A = \Delta v / \Delta t$ = 140 miles/hour /10 seconds = 14 miles/hour per second, so the car gains 14 miles per hour each second.

   If we want the acceleration in meters/second^2, we first need to convert miles/hour to meters/second:

   $$\frac{140 \text{ miles}}{\text{hour}} * \frac{1{,}610 \text{ meters}}{\text{miles}} * \frac{1 \text{ hour}}{3{,}600 \text{ seconds}} = 62.6 \text{ meters/second}^2$$

   Acceleration =

   62.6 meters/second /10 seconds = 6.26 meters/second^2

2. Because of a refueling problem at the Daytona 500, a car took 2 seconds longer in the pits than did its competitor. At an average racing speed of 170 miles/hour, what distance, in feet, did the car lose to its competitor?

   $D = v * t =$

   $$\frac{170 \text{ miles}}{\text{hour}} * \frac{5{,}280 \text{ feet}}{\text{mile}} * \frac{1 \text{ hour}}{3{,}600 \text{ seconds}} * 2 \text{ seconds} =$$

   499 feet, or almost 166 yards

   (No wonder pit crews work with such organization so rapidly!)

Analyzing Energy

The various kinds of energy are another interesting aspect of automobile racing. In a car, the chemical energy of the fuel becomes thermal energy in the engine. Look at the digitized image of the engine in the red Thunderbird #9 [Ford Thunderbird NASCAR Winston Cup Race Car Driven by Bill Elliott, 1987 (engine view ID# THF69265) (side view ID# THF69258)]. The thermal energy in the engine then becomes kinetic energy, or energy of motion, as the car races around the track.

Continued…

To analyze a drag race, determine the kinetic energy gained by a car during a quarter mile. Look at this image of the start of a drag race [Official Start of First NHRA Drag Racing Meet, Great Bend, Kansas, 1955 ID# THF34472]. At the start of the race, the car's speed is obviously 0 mph. At the completion of a drag race, the racer is typically given a timing slip like this one from the Oswego Dragway [Timing Slip From Oswego Dragway, Used with Buck & Thompson Slingshot Dragster, 1963 ID# THF45621].

Note the top speed measured is 123.29 mph, which lasted 11.32 seconds.

While we do not have the means to calculate the chemical energy used, we can calculate the kinetic energy gained by the racecar during the 11.32 seconds. We can also calculate the average force the engine provided during the race.

We will assume the weight of the car was 1,600 pounds, or about 700 kilograms. First, convert the 123.29 miles/hour to meters/second, as kinetic energy needs to be measured in kilograms, meters and seconds to get the proper energy unit of joules.

$$\frac{123.29 \text{ miles}}{\text{hour}} * \frac{1{,}610 \text{ meters}}{\text{miles}} * \frac{1 \text{ hour}}{3{,}600 \text{ seconds}} = 55.14 \text{ meters/second}$$

Next, calculate the kinetic energy

KE = ½ m * v^2 = ½ * 700 kilogram * (55.14 meters/second)^2 = 1.06 x 106 joules

The kinetic energy gained = the work done by the engine.

In a quarter mile, the KE gained = Work = Force * distance.

Convert the quarter mile to meters

¼ mile * 1,610 meters/mile = 402.5 meters

Calculate the kinetic energy and the work

KE = 1.06 x 106 joules = Work = F * 402.5 meters

The force supplied by the engine is therefore

W / d = 1.06 x 106 joules / 402.5 meters = 2,633 Newtons of force

Rotational Motion

There are many examples of rotational motion in automobile racing. The wheels turn hundreds of revolutions through the course of a race. The motor itself rotates in what is referred to as revolutions per minute, or rpm. Each time a tire rotates through one revolution, the car moves the distance equal to the circumference of the tire. The distance a car moves with each revolution of a tire can be calculated from the equation

distance = Circumference = $2\pi r$

where r is the radius of the tire; a 15-inch tire means its radius is 15 inches. So each time the tire rotates one revolution, the car moves

C = $2\pi r$ = 2 π * 15 inches = 94.2 inches * 1 foot /12 inches = 7.85 feet

A larger tire would theoretically allow a race car to travel faster or farther in one revolution. A large tire, however, has less power, so that large tires are not practical. (In most races, to keep everything competitive, all the race cars must have the same size tires.) Tires on early race cars were fairly large, as can be seen in the old Ford # 999 car [Race Car "999" Built by Henry Ford, 1902 ID# THF70568]. Compare the tires on the 999 with the tires on a NASCAR race car [Ford Thunderbird NASCAR Winston Cup Race Car Driven by Bill Elliott, 1987 (side view ID# THF69258)].