shaft. Torque is measured in units of force and distance, for example in-lbs. What does this mean? If you have a torque of 6 in-lbs, you can expect 6 lbs of force, one inch from the shaft of the motor. In our case, our drive wheels are six inches in diameter. This means that the force is applied three inches from the drive motor. We could expect 2 lbs of force to be applied by the wheel to the ground. As you will see, many of these values come in a variety of units. Some popular measurements of torque are ft-lb (foot-pounds), oz-in (ounce-inches), and Nm (Newton-meters). Some units will be in English units and some will be in metric units. Values will need to be converted to metric before plugging them into the equations. In most cases, these resulting answers will need to be converted to English units in order to determine what motor to order from most suppliers.

$$Torque = Force \ x \ Distance$$

Finally, velocity is the speed at which our robot will move up the incline and acceleration represents how fast our robot will reach the desired velocity.

How does acceleration relate to speed (velocity)?

$$Velocity = \frac{Acceleration * Time}{2} + initial\ velocity$$

Now that we understand the forces acting on our robot, we can begin the process of sizing the drive motors.

To determine what size motors we need for our robot, we will need to define the following:

Weight of the robot: $w = 25\ lbs$

Maximum Speed: 60 ft/min $v = 1\ ft/s$

Maximum incline to climbs: $\theta = 10\ degrees$

Reach maximum speed in two seconds: $a = .254\ m/s$

Drive wheels will be six inches in diameter: $r = 3\ in$

From our free body diagram, we will focus on the forces working in parallel to the inclined surface. Let's also assume that our robot will start from rest and need to accelerate up the incline to full speed.

f_w = the force pushing against the wheel

f_g = the force pulling robot down incline due to gravity

$$\text{Torque}: T = f_w * r$$

In physics, all forces must balance which gives the equation:

$$\Sigma\ Forces = 0$$

If your robot is moving at a constant speed, the sumation of all forces will equal zero.

$$\Sigma\ Forces = f_{total} = f_w - f_g = 0$$

To properly size our motor, we will focus on the situation where the robot is accelerating from rest to full speed. This is where you want to size your motors to be large enough to get the job done. The torque required to get your robot moving can be much greater than keeping it in motion. In this case, the sumation of the forces acting on our robot will equal the total mass multiplied by acceleration. I usually accelerate my robot to full speed in one second or less in the calculations.

$$\Sigma\ Forces = f_{total} = f_w - f_g = Ma$$
$$f_w = Ma + f_g$$
$$T/r = Ma + Msin\theta$$

Finally:

$$T = M(a + gsin\theta)r$$

We must convert weight to mass in metric units:

$$M = 25\ lbs * ((1\ kg)/(2.2\ lbs)) = 11.36\ \text{kg}$$

Next, we convert radius from three inches to meters.

$$r = 3\ in * \frac{2.54\ cm}{in} * \frac{100\ m}{cm} = .0762\ m$$

$$T = (11.36\ kg)\left(\frac{.254\ m}{s^2} + \left(\frac{9.8\ m}{s^2}\right) sin(10)\right) * .0762\ m = 1.69\ Nm$$

Most of the motors I have worked with define torque in in-lbs or oz-in. We will convert to in-lbs:

$$T_{ft\text{-}lbs} = 1.69\ Nm * \left(\frac{.225\ lb}{1\ N}\right) * \frac{100\ \text{cm}}{1\ m} * \left(\frac{1\ in}{2.54\ cm}\right) = 14.97\ in\text{-}lb$$

This is the total torque required to drive the robot. Since we are using two drive motors, we can divide this in half.

$$T_{per\ motor} = 6.5\ in - lb$$

Next, we will determine how fast in rpms the motor will need to turn.

$$\frac{Rev}{Min} = \left(Velocity\ \frac{ft}{min}\right) *$$

$$(2 * \pi * Drive\ wheel\ radius) * \left(\frac{1\ ft}{12\ in}\right) = 38\ Rev/Min$$

Finally, to determine how much power the motors are required to supply, the following equation should be used:

$$P = T * \omega$$
$$\omega = angular\ velocity$$

Angular velocity is measured in radians per second.

$$One\ Revolution = 2 * \pi\ radians$$

$$\omega = \frac{38\ Rev}{Min} * \frac{2\pi\ Rad}{1\ Rev} * 1\ \frac{min}{60}\ sec = 3.98\ rad/sec$$

$$P = 1.69\ Nm * 3.98\ rad\ /\ sec = 6.72\ watts$$