ENGINEERING MECHANICS

Purpose:

- Introduce students to the theory of some simple machines.

- Apply the theory of simple machines to robotics design.

WHAT IS A MACHINE?

- A device that transmits, or changes, the application of energy.

- Allows for the multiplication of force at the expense of distance. A machine does work.

- Work is force applied through a distance.

NEWTON'S LAWS OF MOTION

First Law: (Inertia)

- An object at rest remains at rest unless acted upon by a force.

- An object in motion continues moving in a straight line at a constant velocity until acted upon by a force

Second Law:

- Acceleration of an object is directly proportional to the net force acting on the object and inversely proportional to its mass or:

$$\boxed{F = ma}$$

Third Law:

- Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first or:

For every action, there is an equal an opposite reaction

SIMPLE MACHINES:

- Simple machines have existed and have been used for centuries.
- Each one makes work easier to do by providing some trade-off between the force applied and the distance over which the force is applied.
- We will discuss the following simple machines and relate them to robotics design:
    - LEVERS
    - PULLEYS
    - GEARS

- We will also discuss the concepts of torque as related to robotics design

LEVERS

A lever is a stiff bar that rotates about a pivot point called the fulcrum. Depending on where the pivot point is located, a lever can multiply either the force applied or the distance over which the force is applied.

There are three classes of levers:

First Class Levers

The fulcrum is between the effort and the load. A seesaw is an example of a simple first class lever. A pair of scissors is an example of two connected first class levers.

Second Class Levers

The load is between the fulcrum and the effort. A wheelbarrow is an example of a simple second class lever. A nutcracker is an example of two connected second class levers.

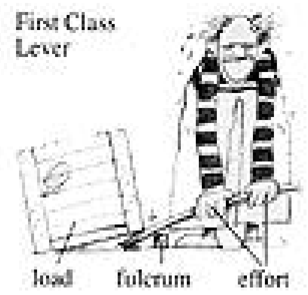
Third Class Levers

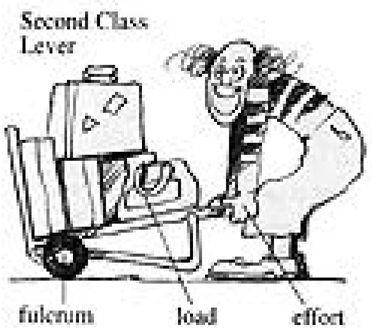
The effort is between the fulcrum and the load. A stapler or a fishing rod is an example of a simple third class lever. A pair of tweezers is an example of two connected third class levers.

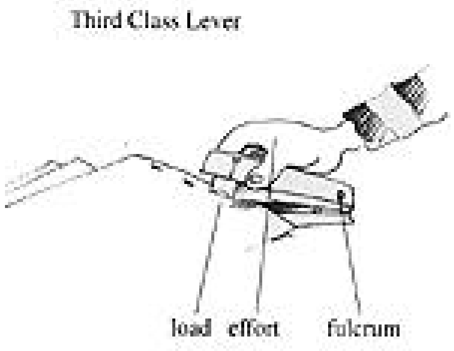
Force and Effort

To lift a load with the least effort:

- Place the load as close to the fulcrum as possible.
- Apply the effort as far from the fulcrum as possible.

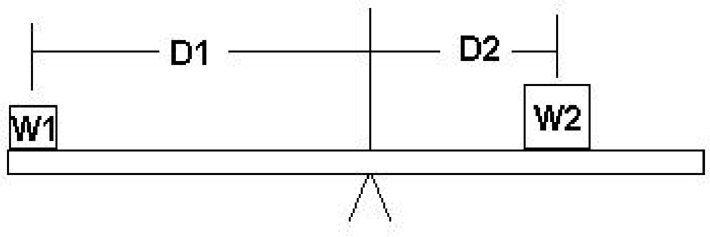






THE LEVER BALANCE EQUATION FOR A FIRST CLASS LEVER IS :

$$\boxed{W1\ D1 = W2\ D2}$$

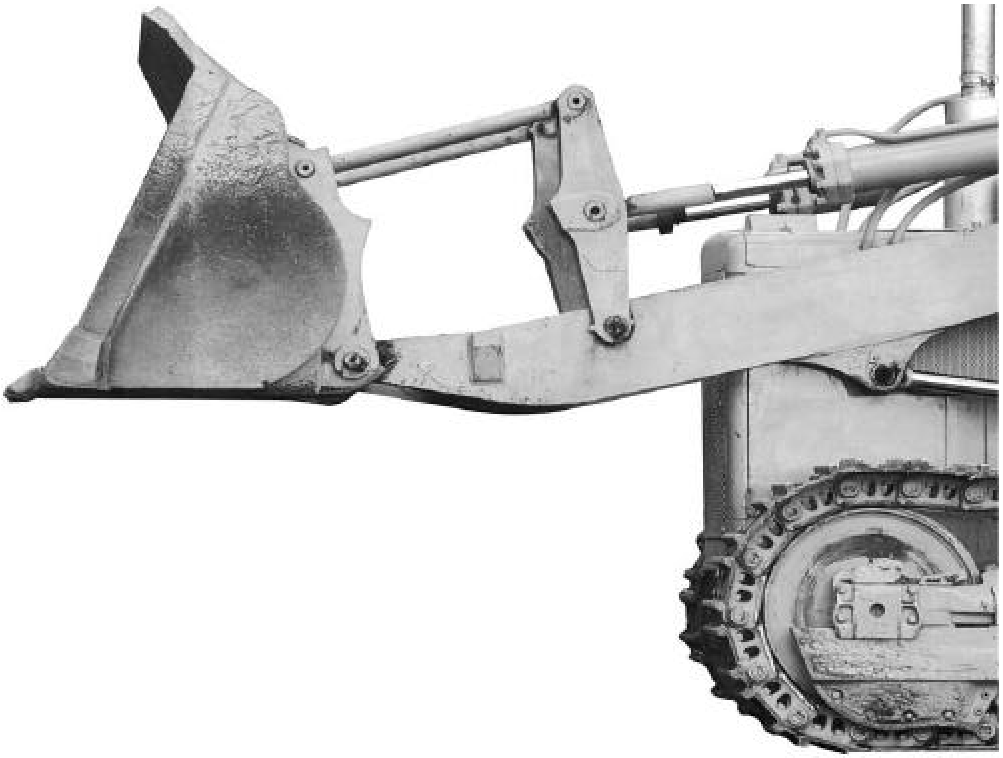


THIS CAN BE DEMONSTRATED USING A RULER AS A LEVER AND COINS AS WEIGHTS.

If more weights are to be added, simply add them to the required side of the equation. For example, to add an additional weight (W3), a distance (D3) to the right of the fulcrum makes the equation :

$$\boxed{W1\ D1 = W2\ D2 + W3\ D3}$$

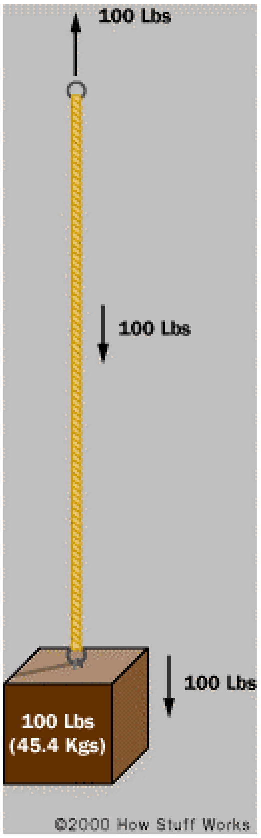
HOW MANY LEVERS CAN YOU FIND IN THE LOADER?



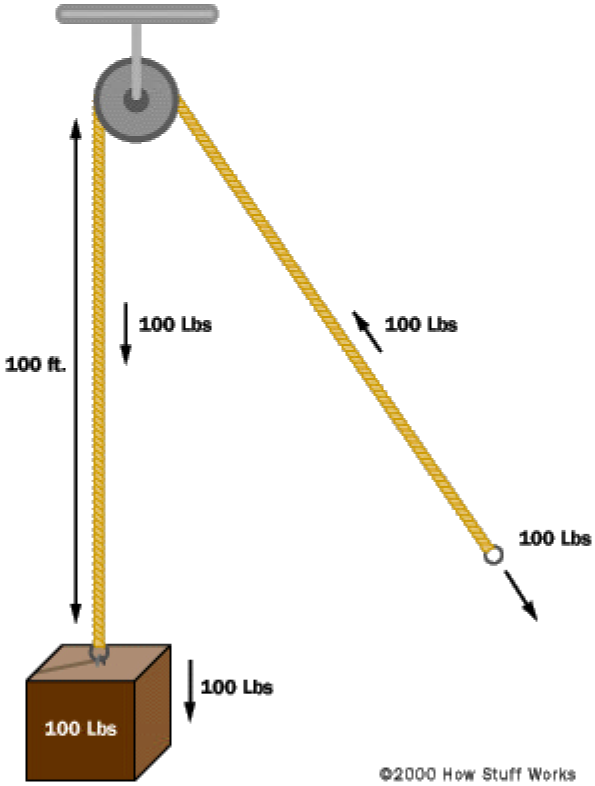
PULLEYS / BLOCK AND TACKLE

- A block and tackle is an arrangement of rope and pulleys that allows you to trade force for distance.

Imagine that you have the arrangement of a 100 pound weight suspended from a rope, as shown. If you are going to suspend the weight in the air then you have to apply an upward force of 100 pounds to the rope. If the rope is 100 feet long and you want to lift the weight up 100 feet, you have to pull in 100 feet of rope to do it.



Now imagine that you add a pulley. Does this change anything? **Not really**. The only thing that changes is the direction of the force you have to apply to lift the weight. You still have to apply 100 pounds of force to keep the weight suspended, and you still have to reel in 100 feet of rope in order to lift the weight 100 feet.



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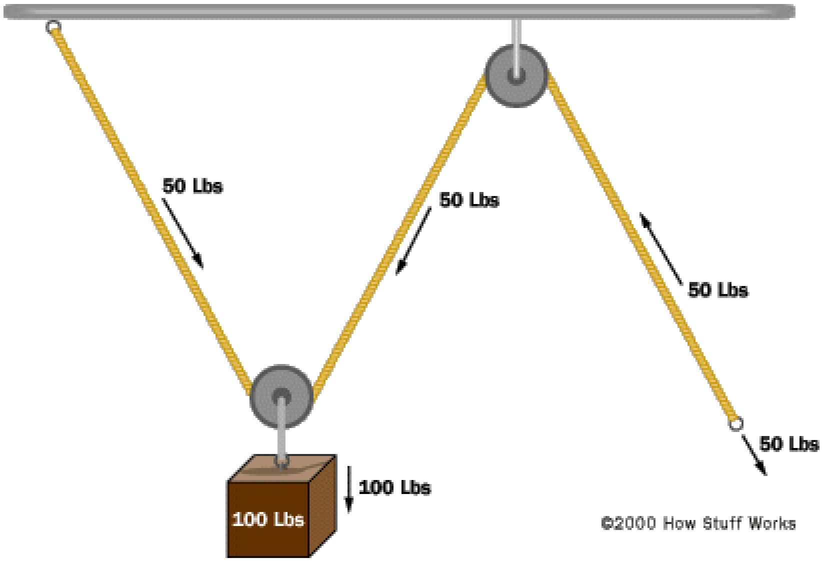
The following figure shows the arrangement after adding a second pulley.

This arrangement actually does change things in an important way. You can see that **the weight is now suspended by two ropes rather than one**. That means the weight is split equally between the two ropes, so each one holds only half the weight, or 50 pounds. That means that if you want to hold the weight suspended in the air, **you only have to apply 50 pounds of force** (the ceiling exerts the other 50 pounds of force on the other end of the rope). If you want to lift the weight 100 feet higher, then you have to **reel in twice as much rope** - 200 feet of rope must be pulled in. This demonstrates a force-distance tradeoff. **The force has been cut in half but the distance the rope must be pulled has doubled.**



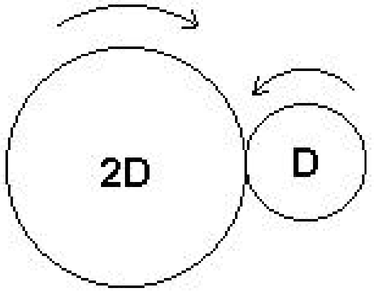
GEARS

Gears are generally used for one of four different reasons:

1. To reverse the direction of rotation
2. To increase or decrease the speed of rotation
3. To move rotational motion to a different axis
4. To keep the rotation of two axis synchronized

You can see effects 1, 2 and 3 in the figure

- The two gears are rotating in opposite directions.
- The smaller gear spins twice as fast as the larger gear because the diameter of the gear on the left is twice that of the gear on the right. The gear ratio is therefore 2:1 pronounced, "Two to one").
- The axis of rotation of the smaller gear is to the right of the axis of rotation for the larger gear.
- If D is the motor and 2D is being driven, 2D has twice the torque. (Same effect can be accomplished with a belt).



TORQUE

A force applied to a body that causes it to rotate creates torque.

The motors supplied in your kits are designed for a specific torque and are listed as:

Large motors - 216 in-oz at 56 rpm (a little less than 1 revolution per second)

Small motors – 34 in –oz at 113 rpm (a little less than 2 revolutions per second)

The equation for torque for the motors is:

$$\boxed{T = r\,F}$$

Where:

T = torque of the motor

r = radius of the motor shaft, pulley or whatever is attached to the motor shaft

F = the force created by the motor

Since the torque is pretty much a constant (you are stuck with the motors provided in the kit), and you probably want to know the force your motor can produce, the equation can be written as:

$$\boxed{F = T/r}$$

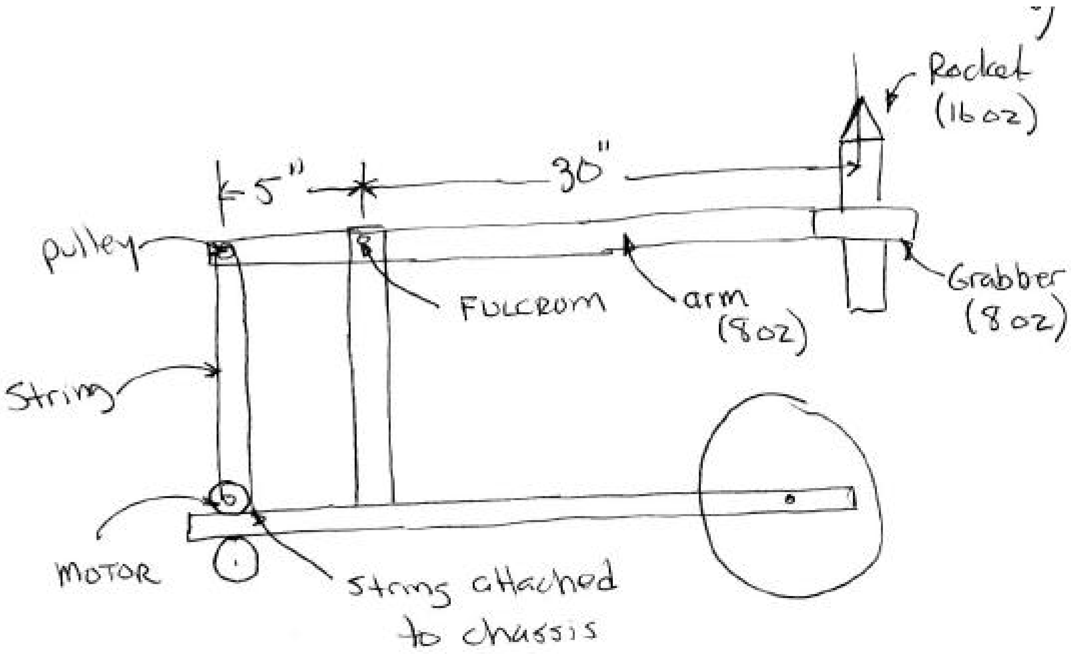
If you want to know the radius needed for your motor shaft, the equation becomes:

$$\boxed{r = T/F}$$

EXAMPLE:

Let’s take the concepts we have learned and design an arm that will lift a 1 lb game piece.

Let’s assume that our mockup resulted in the following:



Since the arm is a lever, let’s use the lever equation to figure out how much force is on the string. The weights and distances from the fulcrum for everything on the right is :

Item	**Weight (oz)**	**Distance from fulcrum (in)**	**W D (in-oz)**
Rocket	16	30	480
Grabber	8	30	240
Arm	8	10	80

If we add 480+240+80 we get 800 in-oz. This is the right side of the lever equation. The equation becomes:

W1 x 5 inches = 800 in-oz

Or W1 = 160 oz

This means that the force in the string is 160 oz **except,** we have two strings sharing the load because of the pulley arrangement so therefore the force in the string is only 80 oz.

Let's put in a safety factor of 1.5 so that the force in the string is now 80 * 1.5 = 120 oz. This will ensure that the motor will lift the required weight even on low batteries etc.

Now we need to calculate the motor shaft size that will create a 120 oz force. The equation for the shaft radius is

r = T/F or r = 34 / 120 = .283 inches.

This means our shaft needs to have a radius of .283 inches or a diameter of **.566 inches.**

<u>What else could you do to improve things?</u>

A counterweight , but not too much or the arm will not lower.