2.0 – An understanding of mechanical advantage and work helps in determining the efficiency of machines

2.1 –Machines Make Work Easier

Machines help people do things that they normally couldn't do on their own.

Mechanical Advantage
A machine makes work easier for you by increasing the amount of force that you exert on an object. This produces a **mechanical advantage**, which is the amount of force that is multiplied by the machine. The force applied to the machine (by you) is the ***input force***. The force that is applied to the object (by the machine) is the ***output force***.

Calculating Mechanical Advantage
The mechanical advantage of a machine is the output force divided by the input force.

$$\text{MA} = \frac{\text{Output Force}}{\text{Input Force}}$$

The mechanical advantage is the *force ratio* of a machine.

$$\text{MA} = \frac{F_{output}}{F_{input}}$$

F = Force in Newtons (**N**)

The more a machine multiplies the force, the greater is the mechanical advantage of the machine.

Speed Ratio
Speed measures the distance an object travels in a given amount of time. The measure of how a machine affects speed is called the **speed ratio**. It is calculated by dividing the ***input distance*** by the ***output distance***.

$$\text{SR} = \frac{\text{Input distance}}{\text{Output distance}}$$

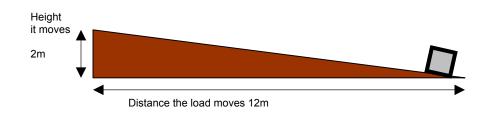$$\text{SR} = \frac{d_{input}}{d_{output}}$$

d = distance (**m**)

Using the formula provided, you can calculate the speed ratio of any device.
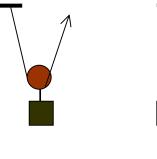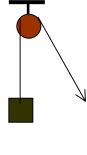
Less Force But Greater Distance
You do not get something for nothing when using a machine. The *advantage* to **gaining force** is offset by the *disadvantage* of **losing distance**.
An inclined plane makes it possible to lift heavy objects using a smaller force (examples: loading ramp, wheelchair access ramp), but you have to move the object over a much longer distance.

Height it moves
2m

Distance the load moves 12m

A **Pulley system** consists of one or more combinations of wheels and ropes, which can be fixed in place or movable. Pulleys help you lift larger loads. To calculate the **MA** of a pulley, count the number of ropes/cables **supporting the load**.

A single movable pulley
MA = **2**

A single fixed pulley
MA = **1**

Pulley System
MA = **4**

Pulley System
MA = **3**

A Mechanical Advantage Less Than 1
In the case of machines where the mechanical advantage is greater than 1 the machine is multiplying the input force to create a larger output force. If a machine has a mechanical advantage that is **less than 1**, it is useful for tasks that don't require a large output force. A bicycle is a machine with a mechanical advantage of less than 1. Even though it has a mechanical advantage of less than 1, the output force causes the bicycle to move faster than the rider could walk, so it is a very useful machine.

Comparing Real Mechanical Advantage With Speed Ratio
When people calculate mechanical advantage and speed ratio they may find that they are the same. In real situations however, when they are calculated, they can be very different. This is because of friction.

The Effect of Friction
The difference between the calculated value and the real (actual) value of mechanical advantage is friction, which is **a force that opposes motion**. Friction is caused by the roughness of materials. Because friction is a force in any device, additional force must be applied to overcome the force of friction. The mechanical advantage of the device will be less because of this added force that must be overcome. The speed ratio will not be affected. In fact, the speed ratio represents the *ideal mechanical advantage* of a machine – as if friction didn't exist. Friction in a system also causes heat, which can cause additional concerns.

Efficiency
Efficiency is a measure of how well a machine or a device uses energy. The more energy that is lost, the less efficient a machine is. Efficiency is represent in %.

Efficiency = Mechanical Advantage X 100
Speed Ratio

In complex machines, there are many subsystems that are affected by friction and other factors. Because of this, most complex machines are not very efficient.

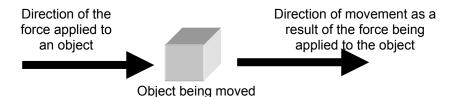**NO MACHINE CAN BE 100% EFFICIENT !!!!**

2.2 The Science of Work

The Meaning of Work

Scientifically, work is done when **a force** acts on an object to make that object **move**.

In order to say that work is being done, there must be movement. If there is no movement, no matter how much force is used, no work is done.

Direction of the
force applied to
an object

Direction of movement as a
result of the force being
applied to the object

Object being moved

For example; a worker uses force to move a large carton up a ramp. Energy (pushing) is transferred to the carton from the worker. Thus, we say that the worker did work on the carton as long as the carton moved up the ramp as a result of the worker's pushing action (force).

Calculating Work

The amount of work is calculated by multiplying the force times the distance the object moves.

The formula looks like this: $W = F \times d$

Force is measured in Newtons and distance is measured in meters. The resulting work unit is called a **joule**, named after the English scientist James Joule.

Energy and Work

Energy and work are closely related, because without energy there would be no work. Work is done when there is a transfer of energy and movement occurs. Energy provides the force needed to make an object move. The energy can be in the form of human energy (muscle power – chemical reactions in the body producing energy) or it can be in the form of another energy source, such as gasoline (for a car). A machine transfers energy from its source to the object, causing the object to move. There is a very complicated chain of events that make a car move - beginning with it being fueled up with gasoline - all the way through its many subsystems (each doing work) - to eventually the tires rotating to make the car move forward or backward.

Work and Machines

There are different types of simple machines that can help us do work. The work done with a machine is the same as the work done without it. This can be shown by calculating work input and work output.

Work input is the work needed to use, or operate the machine

$$\text{Work}_{input} = \text{Force}_{input} \times d_{input}$$

Work output is the work done by the machine.

$$\text{Work}_{output} = \text{Force}_{output} \times d_{output}$$

Work and Friction

Friction is the reason that work input does not equal work output in real situations. Friction affects the machine's efficiency. Efficiency can be calculated using work input and work output.
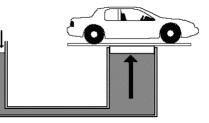
$$\text{Efficiency} = \frac{\text{Work}_{output}}{\text{Work}_{input}} \times 100$$

2.3 The Big Movers – Hydraulics

Most machines that move very large, very heavy objects use a hydraulic system that applies force to levers, gears or pulleys. A **hydraulic system** uses a liquid under pressure to move loads. It is able to increase the mechanical advantage of the levers in the machine.

Modern construction projects use hydraulic equipment because the work can be done quicker and safer. There are many practical applications of hydraulic systems that perform tasks, which makes work much easier.

A **hydraulic lift** is used to move a car above the ground,
so a mechanic can work underneath it.

Pressure in Fluids

Pressure is a measure of the amount of force applied to a given area.

$$p = F / A$$

p is pressure **F** is Force and **A** is Area

The unit of measurement for pressure is a pascal (Pa), named after Blaise Pascal who did important research on fluids.

1 **Pa**scal is equal to the force of 1 **N**ewton over an area of 1 m^2

Pascal discovered that pressure applied to an enclosed fluid is transmitted equally in all directions throughout the fluid. This is known as **Pascal's Law** and it makes **hydraulic** (liquid) and **pneumatic** (air) systems possible. A common application of Pascal's law is illustrated above, with the hydraulic jack.

A Piston Creates Pressure

In hydraulic systems, the pressure is created using a piston. Pistons can be different sizes and hydraulic devices use pistons that are different sizes attached to each other with a flexible pipe. The Input piston is used to apply force to the fluid, which creates pressure in the fluid. The fluid transfers this pressure to the output piston. This pressure exerts a force on the output piston and the result is a mechanical advantage that makes the hydraulic system very useful.

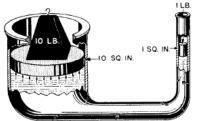### Mechanical Advantage In Hydraulic Systems

The mechanical advantage in a hydraulic system comes from the fluid pressure in the system.

Calculating the input force and the output force
will give you the Mechanical advantage of the
system.

MA = Output force / Input force

$$MA = F_o x d_o / F_i x d_i$$

MA = 10 / 1 = 10

This hydraulic system has
a mechanical advantage of 10

Mechanical advantages in hydraulic systems are usually quite high, showing how useful they are.

Pressure and Mechanical Advantage

The reason for the large mechanical advantage in a hydraulic system is the ability of the fluid to transmit pressure equally. It allows you to use a small force on the small piston to produce a larger force on the large piston.

$$p = F / A$$

From Pascal's law, we know that the pressure the small piston creates is the same everywhere in the fluid. So the large piston has a larger area and is able to multiply the pressure because of its larger area. The force and area at each piston act as ratios that have to be equal.

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Force of the small piston   =   Force of the large piston
Area of the small piston   Area of the large piston

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$$\frac{F_{small}}{A_{small}} = \frac{F_{large}}{A_{large}}$$

By solving this ratio you will find that the forces created within a hydraulic system provides very large mechanical advantages - making them useful in many applications.

Larger Force – Greater Distance To Move

Mechanical advantage in hydraulic systems has a cost. That cost is the increased distance the smaller force must go through to make the large force move a small distance.

*To increase the force on the output piston ,
the input piston must move through a greater distance.*

Amusement park rides make extensive use of hydraulic systems