MACHINES

A machine is a device that makes work easier by transmitting or transforming energy. They have been used since ancient times to help people move heavy objects, bring substances like water from one place to another and fasten materials to one another in construction. Today, machines are used for a huge number of tasks, including transportation, communication and entertainment.

Machines can make work easier by decreasing the force necessary to move an object or increasing the speed of an object. They can also make work easier by changing the direction in which force must be applied to do work. Different types of machines accomplish this in different ways. Examples of machines are levers, inclined planes, wedges, wheels and axles, gears and pulleys. These different types of machines will be discussed in depth in later chapters.

Force multipliers and speed multipliers

Machines can make work easier by reducing the amount of force necessary to move an object or increasing the speed of an object relative to the force applied to it.

Force multipliers are devices that reduce the amount of force necessary to move an object. Force multipliers are useful for lifting heavy objects or doing other things that require large amounts of force. Some examples of force multipliers are inclined planes and most levers.

Speed multipliers are devices that increase the speed of, or distance travelled by, an object. Although more force than usual is required to move the object in these cases, the extra force is changed into more kinetic energy. Speed multipliers are useful when an object needs to move a further distance or at a higher speed. Some examples are wheels and axles and third class levers.

Simple and complex machines

Machines can be either simple or complex. Simple machines are machines that only use one type of machine, such as a lever or an inclined plane. Complex machines are machines that use multiple types of machines together. A door, for example, uses both a wheel and axle (the doorknob) and a lever (the door itself).

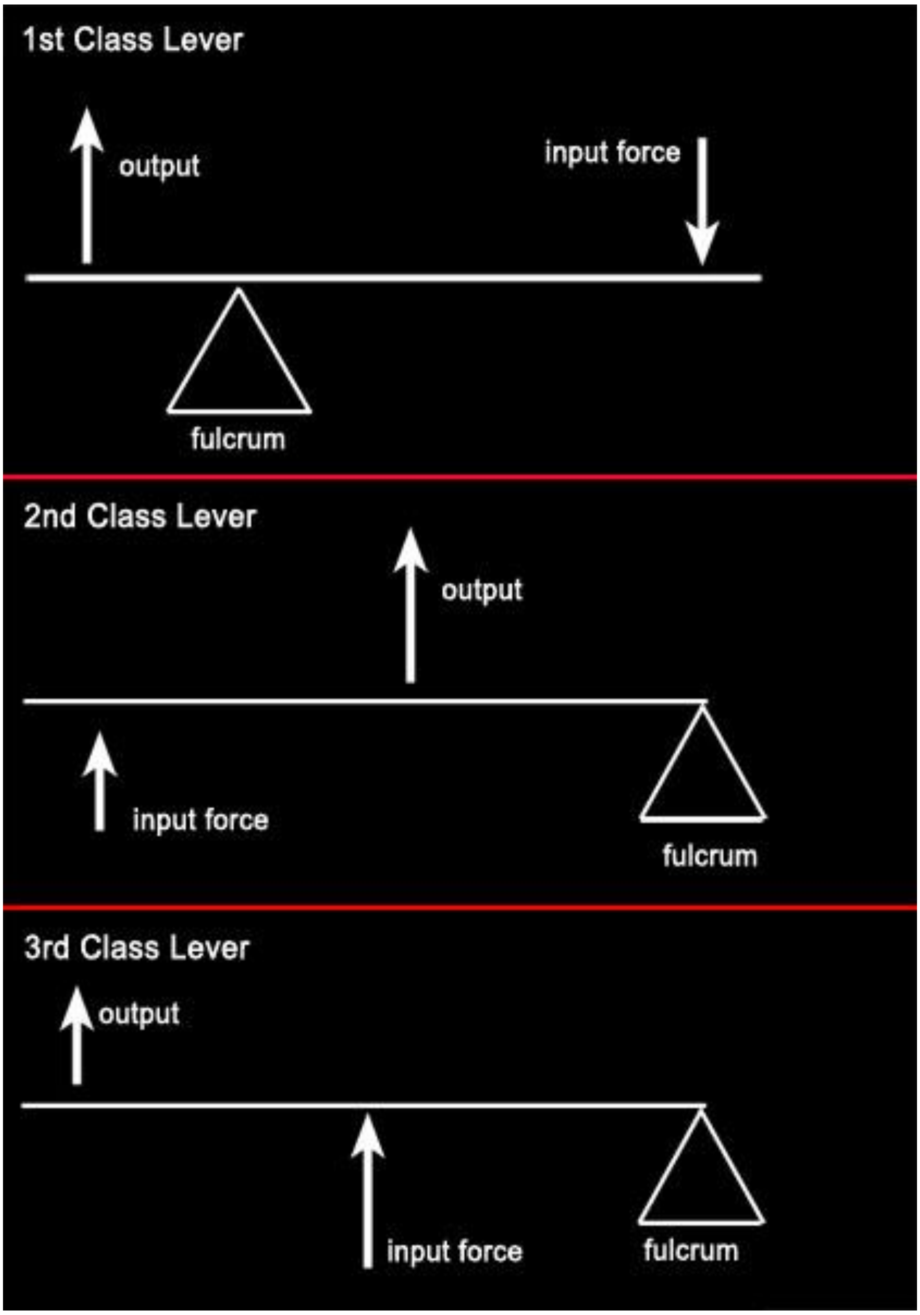
Early machines

The first machines were made by early humans. They included weapons for hunting food, knives for cutting meat and skins, and shovels for digging in the earth for roots. As technology used by humans progressed, tools became more sophisticated. Agriculture was made possible by tools such as the plough and irrigation devices.

The earliest machines were simple machines. As human society became more complex, however, more complex machines were built.

LEVERS

A lever is a machine that consists of a bar or plane pivoting on a fulcrum. Levers have three main parts: The load, the fulcrum and the effort. The load is the object that is to be moved. The fulcrum is the point at which the lever pivots. The effort is the force that is used to move the lever.



Levers work under the principle of conservation of energy. Remember that a joule of energy or work is equivalent to a newton times a metre. Since the amount of energy is the same for all forces on the lever, if the distance the object is required to move is greater, the force required to move it is smaller.

First and second class levers

In a first class lever, the fulcrum is located between the load and the effort. Some examples of first class levers are pliers, scissors and see-saws. In first class levers, the direction of the effort is opposite the direction of the load. In other words, the effort must push down on the lever to move the load upwards.

In a second class lever, the load is located between the effort and the fulcrum. Some examples of second class levers are wheelbarrows, nutcrackers and bottle openers. In second class levers, the direction of the effort and the load are the same. In order to move the load upwards, the effort must be applied upwards as well.

First and second class levers are both force multipliers. Force multipliers reduce the force required to move an object. Force multipliers are said to provide mechanical advantage because they decrease the force that needs to be exerted. In a first or second class lever, the mechanical advantage can be increased by moving the load closer to the fulcrum and the effort farther away from the fulcrum.

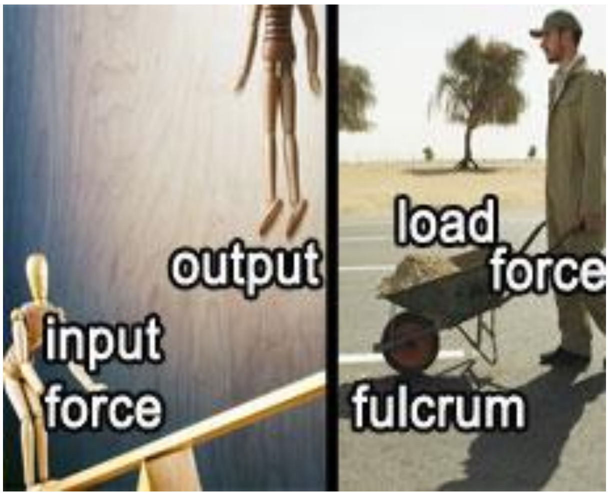
The mechanical advantage of a first or second class lever can be measured in two ways:

$$\text{mechanical advantage} = \frac{\text{load}}{\text{effort}}$$

or

$$\text{mechanical advantage} = \frac{\text{distance of effort from fulcrum}}{\text{distance of load from fulcrum}}$$

Levers provide mechanical advantage by changing the distance over which force must be applied to move an object. If the distance between the fulcrum and the effort is increased, the distance that the effort must move the lever increases as well. Conversely, if the distance between the fulcrum and the load is decreased, the distance that the lever must move also decreases. Since work is directly proportional to force and distance, the greater the distance needed to move the lever, the smaller the force necessary to move the load.



Third class levers

In a third class lever, the effort is between the load and the fulcrum. Some examples of third class levers include fishing rods, cricket bats and chopsticks. Third class levers are different from first and second class levers because instead of force multipliers, they are speed multipliers. This means they do not provide a mechanical advantage. In fact, more force is required in a third class lever to move an object.

Third class levers are used in applications where speed is important. Because a larger force is applied by the effort, the load travels a further distance. Since the load travels a further distance, its speed is also multiplied.

INCLINED PLANES, WEDGES AND SCREWS

Inclined planes, wedges and screws are related types of force multipliers. They all reduce the force necessary to move an object by increasing the distance the object is transported.

Inclined planes

An inclined plane, commonly referred to as a ramp, is an even surface that is tilted at an angle. It helps reduce the force necessary to move an object by increasing the distance it must be moved. Picture a vertical wall two metres (m) tall. You would have to apply a lot of force to lift a 10 kilogram (kg) object over the wall. Now picture a 5 m ramp leading up to the top of the wall. It would be far easier to move the 10 kg object up the ramp than it would be to lift the object straight up. Ramps are used this way in many applications. They allow people with physical disabilities to move up to another floor in a building, for example, and they help to move objects into a truck.

Inclined planes work because energy is always conserved. Since work is equal to force times distance, if the distance the object travels is increased, the force necessary to move it decreases. The same amount of work is being done in both cases, but the force necessary to do that work decreases when using a ramp.

Inclined planes have been used for thousands of years by human beings. The Egyptian pyramids, for example, are believed to have been built using inclined planes. When large, heavy slabs of rock had to be moved up the side of a pyramid, it is believed that the Egyptians used ramps to help move the rocks to a higher level.

Inclined planes are also used in road building. On roads travelling down the sides of steep mountains, for example, roads tend to wind up the mountain instead of going straight up. These are called hairpin turns. This way, cars do not have to exert as much force to move up the mountain.

Wedges

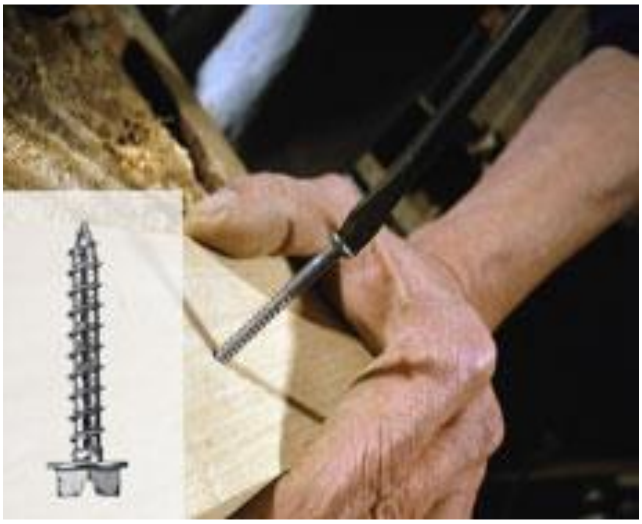
Wedges are a type of inclined plane. Instead of being stationary and having work done upon it, however, the wedge is an inclined plane that is moved through something else. As a wedge is forced into a space in an object, it exerts force to widen the space.

An example of a wedge is an axe. Axes are used to split logs. As the axe is forced into a space in the wood, it pushes the two parts of the log apart. Many other types of cutting implements are also wedges, including knives, scissors, and teeth.

Another example of a wedge is a nail. As the nail is pounded into a piece of wood, the bottom part of the nail opens up a large enough hole for the shaft of the nail to move through.

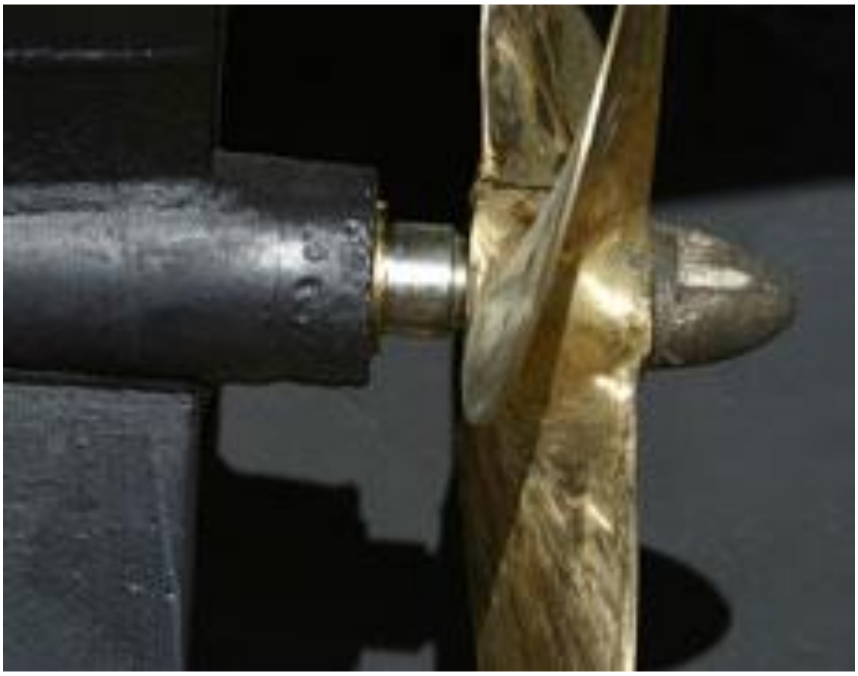
Screws

Screws are inclined planes that travel in a circle around a central point. Screws reduce the force necessary to move an object through another object or substance by extending the distance necessary to move the object. In addition, the motion is rotational, which means it spins around a central point.



An example of a screw is a woodscrew. Woodscrews are used to fasten pieces of wood together. A woodscrew is an inclined plane wrapped around a central shaft. To demonstrate the power of a screw, try to use a hammer to pound a woodscrew into a piece of wood. The wood will resist the screw, and it would take a lot of force to push the screw into the wood. If you turn the screw with a screwdriver, however, it will be a lot easier to push the screw into the wood. Screws like this are used in many applications. A wrench, for example, uses a screw to adjust its size. Screws are also used in water taps. When you turn the tap, it pulls a screw up, allowing water through the faucet.

Another type of screw is a propeller. These screws consist of multiple inclined planes around a central point. Propellers are used to move objects like aeroplanes, submarines and boats through air or water.

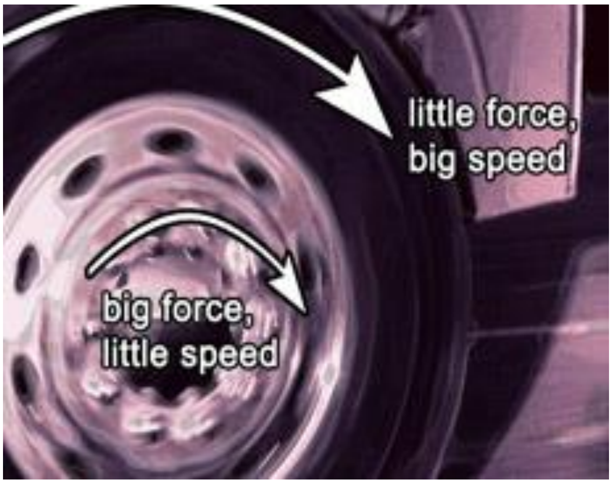


Uses of Screws

- Screws are used to fasten two pieces of wood or metal. As screw is a winding inclined plane, therefore it cannot be pulled out easily from the fasten pieces, as is in case of a nail.
- In case of nut and bolt arrangement, two winding inclined planes are made. One inclined plane is on the external side of a solid cylinder and is called the bolt. The other inclined plane is on the inner side of a hollow cylinder and is called the nut. When the nut is given a circular motion over the bolt, it moves up or down, without slipping and can withstand a lot of load.
- A cork screw is used for pulling out cork from the bottles of ketchup or wine.
- Screw jack is basically a nut and bolt arrangement used for lifting one side of a car or a truck, in order to change the punctured wheel.

WHEELS AND AXLE

Wheels are circular objects that spin around a central shaft, called an axle. Unlike levers or inclined planes, wheels and axles use spinning or rotary motion. Wheels and axles can work as either speed or force multipliers.



Wheels as speed multipliers

In some cases, wheels are speed multipliers. If a large force is applied to the axle of the wheel, the edge (or rim) of the wheel will move very quickly as it covers a greater distance with less force.

An example of a wheel that is a speed multiplier is a wheel on a car. A great amount of turning force is applied to the axle by the car's engine, which is transferred into high speed at the rim of the wheel. This causes the car to move forward very quickly.

A fan is another example of a wheel that is a speed multiplier. A motor turns the axle with great force at the centre of the fan. The edges of the fan blades, however, are moving very quickly.

Wheels as force multipliers

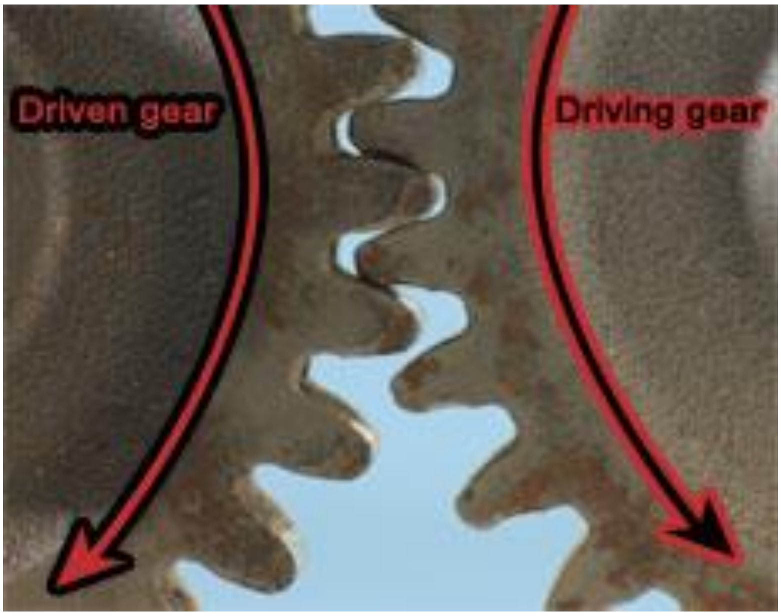
Wheels can also be force multipliers. If a small force is applied to the rim of a wheel to make it move a great distance, it is transformed into a larger force at the axle to move a smaller distance.

An example of a wheel used as a force multiplier is a windmill. Windmills are turned by the force of the wind. This force is multiplied at the axle. The force is then used to Windmills use wheels as force multipliers.

Another example of a wheel that is a force multiplier is a doorknob. When you turn a doorknob, it turns a shaft called the spindle. It would require a great force to turn the spindle with your bare hands. When you use a doorknob, however, you can apply a smaller force to turn the spindle.

Gears

Another type of wheel is called a gear. Gears are special wheels that have teeth, or pieces that stick out, on them. These teeth can interlock. When the teeth are interlocked, if one gear turns, the other turns as well. A gear that is turned by an axle is called the driving gear, while the gear that is turned by the other gear is called the driven gear. The driven gear moves in the opposite direction as the driving gear.



Gears are used to transfer motion from one wheel to another. This can transfer motion from one part of a complex machine to another. In addition, gears can be speed or force multipliers. When a larger driving gear is engaged with a smaller driven one, for example, the driven gear moves more quickly than the driving gear. This is called gearing up. When a smaller driving gear is engaged with a larger one, however, the larger (driven) gear moves more slowly. This is called gearing down. When gearing down, the driven gear moves with more force than when gearing up.

Gears are used in many complex machines such as clocks, drills, kitchen mixers, bicycles and cars. Gearing up is common in machines where speed is important, like drills and mixers. Gearing down is helpful for machines that need a lot of force, such as cars and bicycles.

If N_A and N_B denote the number of teeth in the driven wheel and driven wheel respectively, then gain in torque = N_B N_A , gain in speed = N_A N_B .

The number of rotations completed by wheels are in the inverse ratio of the number of teeth.

Maintenance and Care of Machines

The following points should be remembered about the maintenance of machines

- The machines should be protected from dust which increases the wear and tear of the machines.
- When any machine is not in use, it should be kept covered.
- The non-movable parts of a machine are generally made of iron, which easily gets rusted in moist air. To avoid rusting, such parts should be painted.
- Some parts in a machine rub against each other due to which the parts wear and become loose. They also produce harsh sounds.

A large amount of energy is lost in the form of fiction . To avoid these problems, the moving parts of a machine should be regularly lubricated.

PULLEY

A pulley is a wheel with a grooved edge where a long, thin object such as a rope, cable, string or chain can be held. Pulleys can be used to change the direction or magnitude of effort. They are often used to lift objects from the ground.

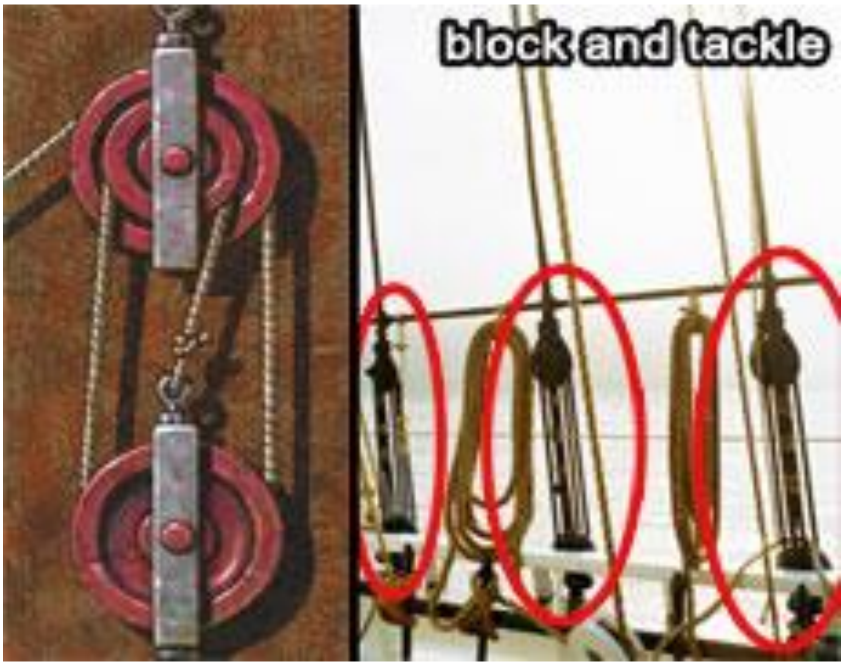
Single pulleys

A single pulley attached to a fixed, or stationary, point changes the direction of the effort, but it does not change the magnitude of the effort. Let's say we have an object with a mass of 10 kilograms (kg). The Earth pulls down on the object with a force of 98 newtons (N). In order to simply lift the object, you would have to exert a force of more than 98 N upwards. If you were to attach it to a single fixed pulley, however, you would have to exert a force of more than 98 N downwards on the rope. In fact, you might have to exert more than 98 N to overcome the force of friction within the pulley.

Since the effort to lift the object is not increased, it may seem that single fixed pulleys are not very helpful. They can help, however, by simply changing the direction of the effort. Pulling down on a rope is easier than pulling up on an object because you can use the force of gravity and weight of your body to pull the rope.

Multiple pulleys

If a fixed pulley is combined with a movable pulley, or a pulley that is attached to the load and allowed to move freely along with it, the effort is reduced by half. This happens because the distance the rope must be pulled is doubled. As has been discussed in earlier chapters, when distance is increased, force is decreased. To lift our 10 kg mass with one fixed pulley and one movable pulley, you would have to apply more than 49 N of force, but you would have to move the rope twice as far. For each pulley added to the system, the effort is decreased. Each pulley added, however, also causes additional friction, making the system less efficient.



A system in which two or more pulleys are connected is called a block and tackle or chain hoist. These systems are often used in garages, factories and on cranes to lift heavy loads.

Formulae

1. For an ideal machines ; Output = Input.
   Input = Effort x Distance travelled by effort.
   Output = Load x Distance travelled by load.

2. $\eta = \frac{\text{Work output}}{\text{Work input}}$, where η is the efficiency.

3. M.A. = $\frac{\text{Load}}{\text{Effort}}$, Where M.A. is mechanical advantage.

4. V.R. = $\frac{v_E}{v_L} = \frac{d_E}{d_L}$, where V.R. is the velocity ratio.

5. $\eta = \frac{\text{M.A.}}{\text{V.R.}}$

6. For levers: Load x Load arm = Effort x Effort arm.

7. M.A. for levers : M.A. = $\frac{\text{Effort arm}}{\text{Load arm}}$.

8. M.A. = V.R. x η (efficiency) and if η = 100 % , M.A. = V.R.

9. For a single fixed pulley; M.A. = Load Effort = 1

10. For a single movable pulley; M.A. = Load Effort = 2

11. For a block and tackle arrangement in which the weight of the movable block is negligible, we have M.A. = V.R. = n , where n is the total number of pulleys.

12. For a block and tackle arrangement in which the weight of the movable block is W, we have
M.A. = n - Weight of the lower block E ,
V.R. = n , and
n = 1 - Weight of the lower block nE , where n is the total number of pulleys , L is load and E is Effort.

13. For an inclined plane
M.A. = Load (w) Effort (E) = W W
Sin θ = 1 Sin θ = S h and V.R. = d_E d_L = S h .

14. V.R. = M.A. + x E . where x is weight due to movable parts of machine and E is effort required.

15. For gear sytem
N_A N_B = r_A r_B = n_B n_A .