

## Mechanical Advantage of Pulleys

### OBJECTIVE:

The objective of this experiment is to study different pulley arrangements and determine their advantage and efficiency.

### THEORY:

In general, people use **machines** to make work easier. Machines make tasks easier because they either decrease the force that the operator has to apply or because they increase the speed with which the task is performed.

Essentially, a **machine** is any device used to change the magnitude or direction of a force. However, work or energy is never multiplied by a machine, i.e. “we can’t get something for nothing”.

A simple machine is used to exert an output force (or torque) greater than the input force (or torque). The magnitude of the force multiplication is called the **Mechanical Advantage**. The **Theoretical Mechanical Advantage** or TMA for short, is simply the ratio of the output force (load) by the **ideal** input force (ideal effort):

$$TMA = \frac{F_o}{F_i^{ideal}}$$

But in **real** situations frictional losses always occur. That is, the input force (real effort) is always greater than the effort that would be required in an ideal frictionless case. We define then the **Actual Mechanical Advantage** or AMA for short, as

$$AMA = \frac{F_o}{F_i^{real}}$$

As far as work is concerned, in the ideal case, the input work equals the output work, i.e.

$$F_o d_o = F_i^{ideal} d_i$$

(assuming, for simplicity, that in the definition of work the force and displacement have the same direction). Clearly,

$$TMA = \frac{F_o}{F_i^{ideal}} = \frac{d_i}{d_o}$$

In the real case, the input work equals the output work plus lost energy. Thus,

$$W_{fr} + F_o d_o = F_i^{ideal} d_i$$

Where,  $W_{fr}$  is the work due to friction, the most common cause of energy loss.

Machines and motors are quite common and we often talk about their **efficiency**. Simple or complex machines have mechanical parts that move, so some energy is always lost due to some friction or some other causes. That is, not all the input energy goes into doing work.

Mechanical efficiency is essentially a measure of how much we get from the machine as compared to how much we put in. It is given as a percentage. For example, if a machine requires 100 J energy input and only produces 50 J of work we say that its efficiency is 50%.

One can define **efficiency**,  $\varepsilon$ , in terms of work (W), energy (E) or power (P). Thus, the following definitions:

$$\varepsilon = \frac{W_{out}}{W_{in}} = \frac{E_{out}}{E_{in}} = \frac{P_{out}}{P_{in}} = \frac{AMA}{TMA}$$

Note that in order to have an efficiency of 100% the AMA would have to equal the TMA. If 100% efficiency could be attained, a so-called perpetual motion machine could be devised. Using the machine's output as input, would cause the machine to run for ever.

Let's now apply these concepts to pulley systems.

Pulleys are said to be continuous levers. Figure 1 depicts a fixed (a) and a moving (b) pulley.

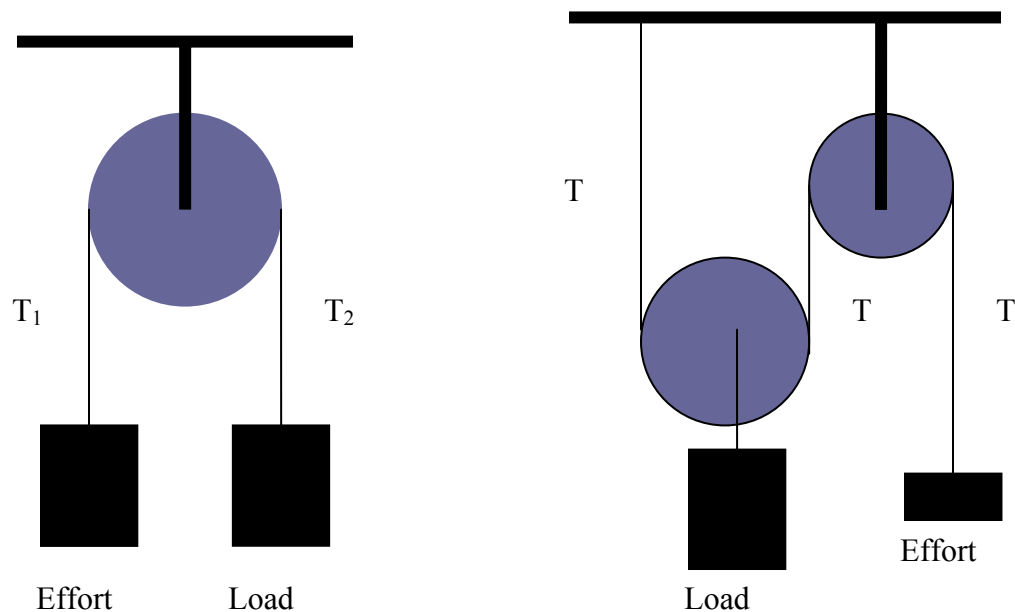


Figure 1 – (a) Fixed and (b) Moving Pulley

In a fixed pulley the TMA equals one. Assuming the pulley to be frictionless (ideal case) the tension throughout the rope is the same. That is,  $T_1 = T_2$  and since the effort =  $T_1$  and load =  $T_2$  we immediately conclude that effort = load or  $F_0 = F_i^{ideal}$  implying then that  $TMA = 1$ . In fact a fixed pulley only acts as a direction changer.

On the other hand, for the moving pulley of figure 1 (b):

$$\begin{aligned}\text{Effort} &= T_1 = T \\ \text{Load} &= T_1 + T_2 = 2T\end{aligned}$$

and clearly then  $TMA = 2$ .

Of course, the input force will have to move twice as far as the load itself, moves. For example, to raise a load a distance of 1 metre, one would have to pull up a length of rope of two metres.

In order to obtain a greater TMA one can use a system of several pulleys. There are several ways of arranging pulleys. Two particular types of pulley arrangements are known by the names of *block* and *tackle*.

Using equilibrium conditions it is easy to determine the TMA of an arbitrary system of pulleys. Consider, for example, the system represented in Figure 2.

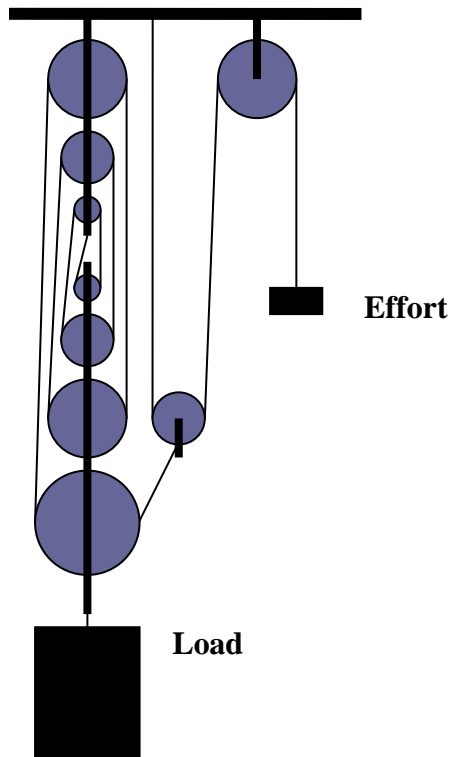


Figure 2 – Pulley arrangement

The force that the load exerts on the pulley system is balanced by  $8T$  where  $T$  is the tension in each cord of the 7 pulley arrangement. Since there is a separate moving pulley we have then that the effort =  $T/2$  and  $TMA = 16$ .

As a general rule one can say that, for each pulley arrangement,  $TMA = n$  where  $n$  is the number of ropes that directly or indirectly support the load. Since in figure 2 there are two pulley arrangements one with a  $TMA = 8$  and the other with a  $TMA = 2$  the resulting  $TMA$  is 8 times 2 or 16.

#### MATERIAL:

Support frame; pulleys: single, double and triple; weights.

#### PROCEDURE:

1. Determine the mass of each pulley type.
2. Set-up two single pulleys as shown in figure 1(b).
3. Use as load a mass of 250 g and determine the mass you have to place at the other end of the string to balance the pulley arrangement.
4. Repeat step 2. for loads up to 500g in intervals of 50 g.
5. Plot the graph of “load” (include in the value of the load the mass of the hanging pulley) versus “effort” and determine the slope of the best fit line. The value obtained is the  $AMA$  of the pulley arrangement.
6. Determine the efficiency of the pulley arrangement given by:

$$Efficiency = \frac{AMA}{TMA}$$

7. Repeat steps 3 – 6 for other pulley arrangements as shown in figure 3.

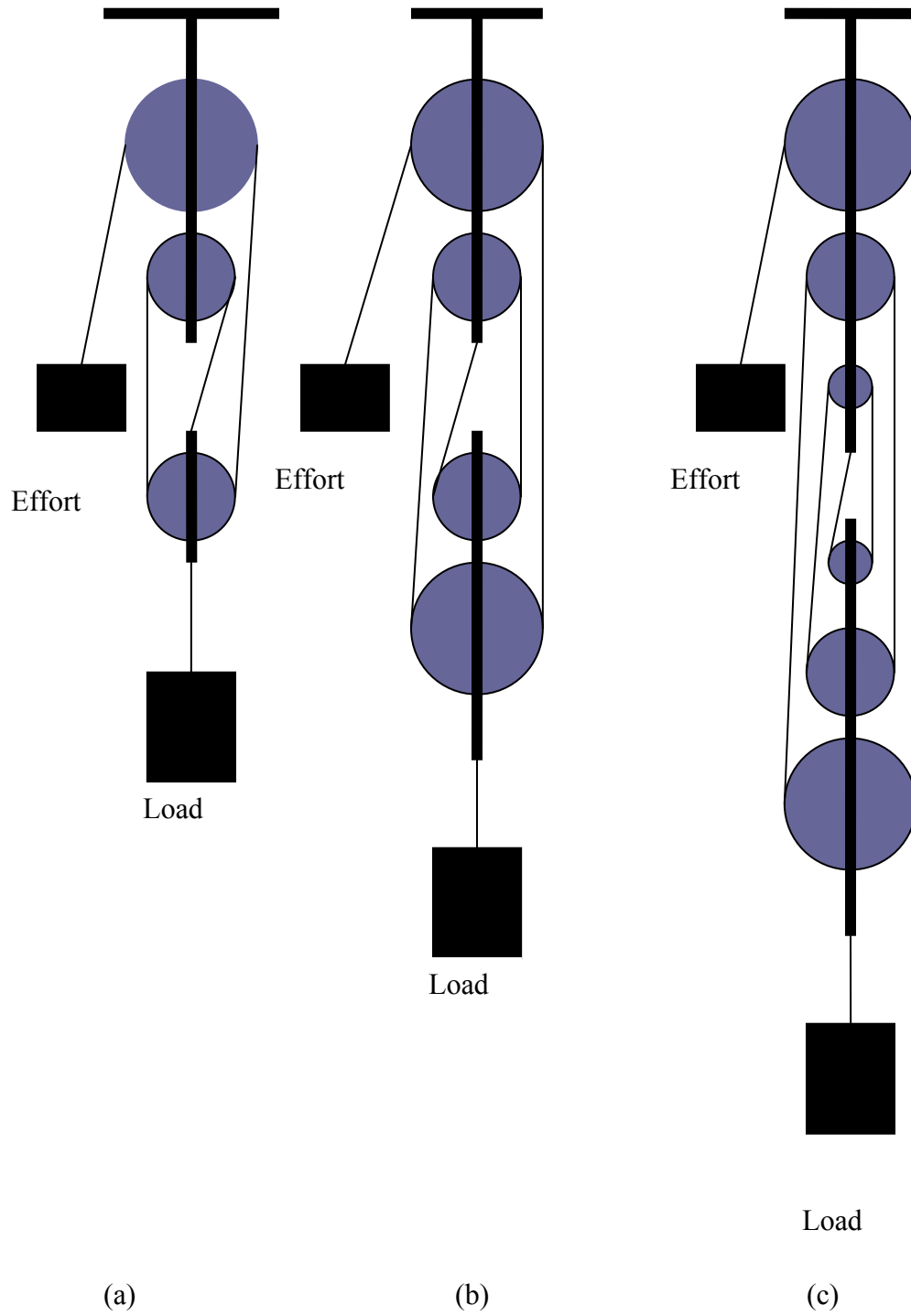


Figure 3 – Pulley Arrangements

## MECHANICAL ADVANTAGE

### I – Theory

1. [1] Why is a pulley a machine?
2. [1.5] Explain in your own words the difference between the TMA (Theoretical Mechanical Advantage) and AMA (Actual Mechanical Advantage).
3. [1] If a pulley is frictionless what can you say about the values of tension in a cord wrapped around it?
4. [1.5] What is the efficiency of the pulley? How can you determine its value experimentally.

**Read the procedure in the lab manual and prepare tables to record the required data.**

### II – Procedure

1. Describe briefly and in your own words the pulley systems you are to study.
2. Record the required values of the *load* and *effort*.
3. Draw the required graphs.

### III – Conclusions

1. Discuss the values obtained for AMA for different pulley arrangements.
2. Discuss the values obtained for the efficiency.
3. What in your opinion could improve the efficiency of the systems studied?