Preview of Period 8: Work, Efficiency, and Complex Machines

8.1 Work and Efficiency of Machines

How efficient are block and tackle systems, winches, and wheels and axles?

8.3 More Simple Machines

How do hydraulic systems and gears work?

8.4 Complex Machines

How are simple machines combined into complex machines?

How are the efficiency and mechanical advantage of complex machines defined?

Efficiency of Machines

$$Efficiency = \frac{W_{out}}{W_{in}} = \frac{F_{out}\ D_{out}}{F_{in}\ D_{in}}$$

W_{in} = work put into the machine (joules or foot-pounds)

W_{out} = work done by the machine (joules or foot-pounds)

Machines do not reduce the amount of work needed. Since some energy is wasted overcoming frictional forces, the amount of work required using a machine is greater than the amount of work required without a machine.

(Example)

A machine requires 2,000 joules of energy to raise a 20 kilogram block a distance of 6.0 meters. What is the machine's efficiency?

First, find the work done to raise the block:

$W = M\,g\,h$ = 20 kg x 9.8 m/s^2 x 6.0 m = 1,176 J

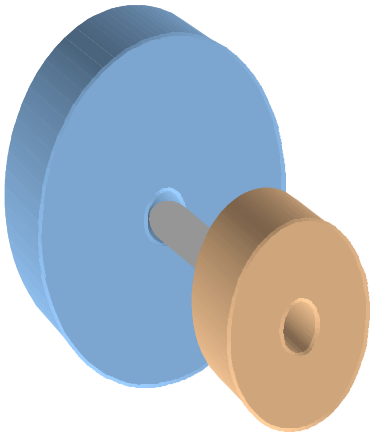
Next, use the efficiency equation. The work in equals 2,000 joules.

$$Eff = \frac{Work_{out}}{Work_{in}} = \frac{1{,}176\ \text{joules}}{2{,}000\ \text{joules}} = 0.59 = 59\%$$

Wheels and Axles

- When wheels of different diameters are attached to an axle, they trade force for distance.
- With each turn of the axle both wheels rotate one turn.
- If the wheels have different diameters, the edge of each wheel turns a different distance and speed.

The large wheel turns a longer distance at a faster speed.



The small wheel turns a shorter distance at a slower speed.

- The force that the rim of the small wheel can exert is greater than the force applied to the rim of the large wheel.

Efficiency from Mechanical Advantage

$$Eff = \frac{W_{out}}{W_{in}} = \frac{F_{out}\ D_{out}}{F_{in}\ D_{in}} = \frac{F_{out}}{F_{in}} \times \frac{D_{out}}{D_{in}}$$

Efficiency is the product of two familiar ratios:

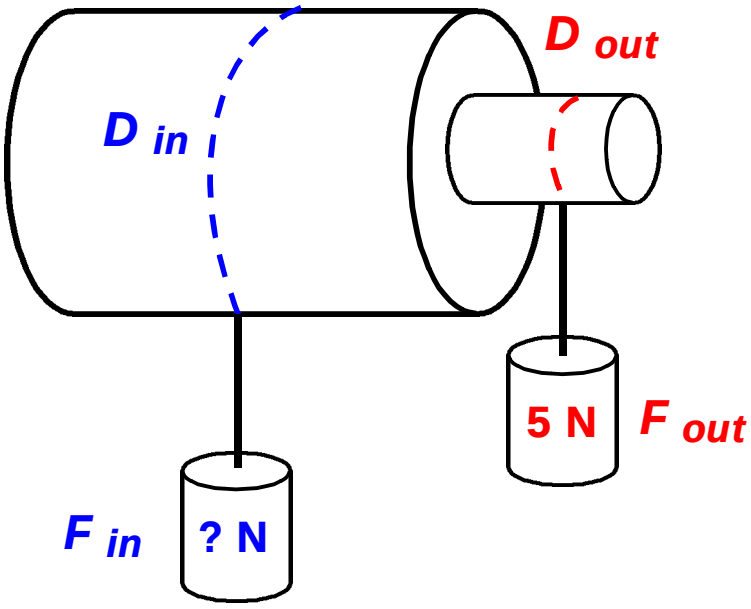
$$MA_{actual} = \frac{F_{out}}{F_{in}}$$

$$MA_{theoretical} = \frac{D_{in}}{D_{out}}$$

Substituting these ratios into the efficiency equation gives:

$$Eff = MA_{actual} \times \frac{1}{MA_{theoretical}} = \frac{MA_{actual}}{MA_{theoretical}}$$

Act. 8.1.c: Wheels and Axles



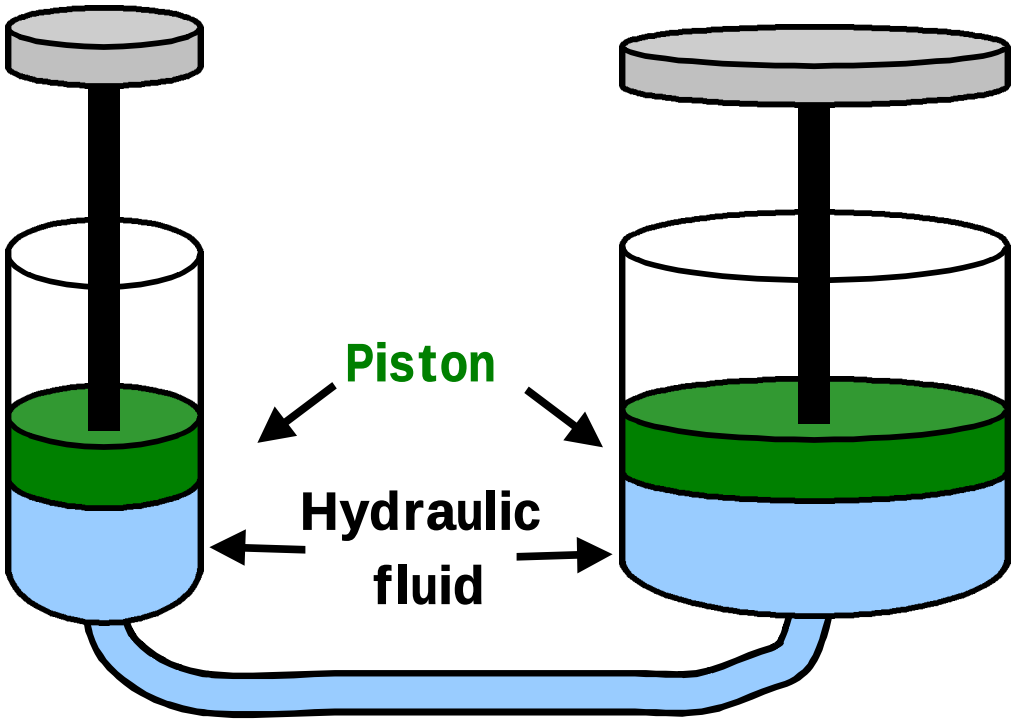
- Assuming the system is frictionless, the work in = the work out: $W_{in} = W_{out}$
- Since $W = F \times D$, $F_{in} \times D_{in} = F_{out} \ D_{out}$
- Use this equation to find the force in needed to balance the bottle.

Hydraulic Machines

Hydraulic pistons trade force for distance

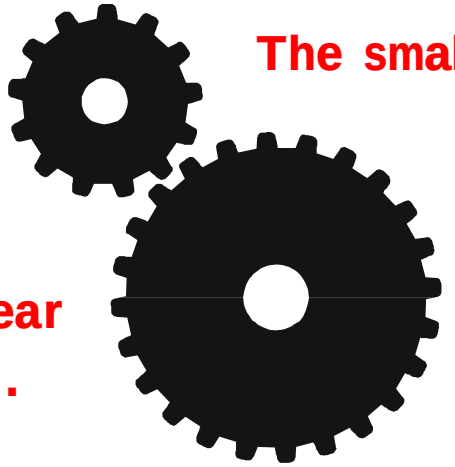
Less force is required to push the narrow piston in because the piston exerts force over a smaller area of fluid. The narrow piston is moved over a longer distance in.

The hydraulic fluid exerts force over the greater area of the wide piston, so a greater force results. The wide piston moves a shorter distance out.



Gears

- The edges of meshed gears move the same distance during every turn regardless of the diameter of the gear.
- However, gears of different diameters differ in their speed of rotation and number of turns.
- If a large gear has twice the diameter of a small gear, the small gear turns two times for every one turn of the large gear.



- To start a car from rest, force from the engine is applied by a small diameter gear, which turns a larger diameter gear attached to the wheels. This gear ratio maximizes the car's acceleration.

The Mechanical Advantage of Complex Machines

Complex machines are combinations of simple machines.

$$MA_{complex} = MA_1 \times MA_2 \times MA_3$$

$MA_{complex}$ = mech. adv. of the complex machine

MA_1 = mech. adv. of the first simple machine

MA_2 = mech. adv. of the second simple machine

MA_3 = mech. adv. of the third simple machine

(Ex. 8.8)

A complex machine has a pulley system with 4 rope segments supporting the load and a lever. The lever arm must move a distance of 1.5 feet to raise the load 6 inches. What is the theoretical mechanical advantage of the complex machine?

$MA_{theoretical}$ of 4 supporting rope segments = 4

$$MA_{theoretical} \text{ of lever} = \frac{D_{in}}{D_{out}} = \frac{1.5 \text{ ft}}{0.5 \text{ ft}} = 3$$

$$MA_{complex} = MA_{pulley} \times MA_{lever} = 4 \times 3 = 12$$

Efficiency of Complex Machines

$$Eff_{complex} = Eff_1 \times Eff_2 \times Eff_3 \ldots$$

$Eff_{complex}$ = efficiency of the complex machine

Eff_1 = efficiency of the first simple machine

Eff_2 = efficiency of the second simple machine

Eff_3 = efficiency of the third simple machine

(Ex. 8.7)

A complex machine consists of a pulley system and a lever. The efficiency of the pulley is 40% and the efficiency of the lever is 60%. What is the efficiency of the complex machine?

$$Eff_{complex} = Eff_{pulley} \times Eff_{lever} =$$

$$0.40 \times 0.60 = 0.24 = 24\%$$

Period 8 Summary

8.1: **Ignoring the energy wasted by friction, the work put into a machine equals the work out.**

The work done to lift a load is $W = M g h$

The efficiency of a machine is

$$Eff = Work_{out} / Work_{in}$$

The efficiency of machines is always less than 100%, since energy is wasted in every energy conversion.

8.2: **Wheels and axles maximize the speed and distance of a large wheel when force is applied to a small wheel. Force out is maximized when the force in is applied to a large wheel.**

Gears: Gears are meshed wheels with teeth. Force applied to a large gear, which is meshed with a small gear, results in greater speed out.

Winches trade force for distance. Force is applied to a large diameter crank to wind a rope attached to a small diameter axle.

Period 8 Summary, Continued

Hydraulic pistons filled with fluid trade force for distance in elevators, automobile lifts, and construction machinery.

8.4: Complex machines are combinations of two or more simple machines.

$$Eff_{complex} = Eff_1 \times Eff_2 \times Eff_3 \ldots$$

$$MA_{complex} = MA_1 \times MA_2 \times MA_3 \ldots$$

8.5: The efficiency of a machine can also be calculated using the equation

$$Eff = MA_{actual} / MA_{theoretical}$$

Period 8 Review Questions

R.1 How does a lever reduce the amount of force needed to raise an object? Can a lever reduce the amount of work required? Why or why not?

R.2 Explain how to calculate the efficiency of a simple machine. How do you find the efficiency of a complex machine?

R.3 Two gears turn together. If the larger gear has a diameter twice that of the smaller gear, how many times will the larger gear turn when the smaller gear turns 50 times?

R.4 Can you combine simple machines to form a complex machine with a greater overall efficiency than its component machines? Why or why not?

R.5 Can you combine simple machines to form a complex machine with a greater overall mechanical advantage than its component machines? Why or why not?