PROJECT LEAD THE WAY

PLTW

Igniting imagination and innovation through learning.

Mechanisms
Simple Machines

Lever, Wheel and Axle, & Pulley

Simple Machines

Mechanisms that manipulate magnitude of force and distance.

The Six Simple Machines

Lever

Wheel and Axle

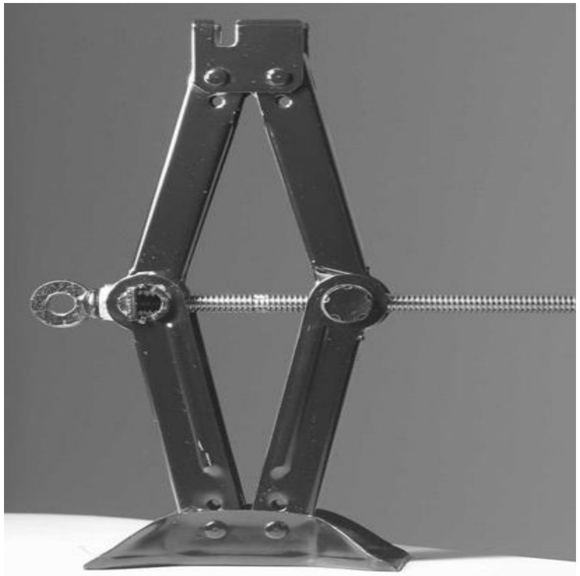
Pulley

The Six Simple Machines

Inclined Plane

Wedge

Screw



Mechanical Advantage

Ratio of the magnitude of the resistance and effort forces

Ratio of distance traveled by the effort and the resistance force

Calculated ratios allow designers to manipulate speed, distance, force, and function

Mechanical Advantage Example

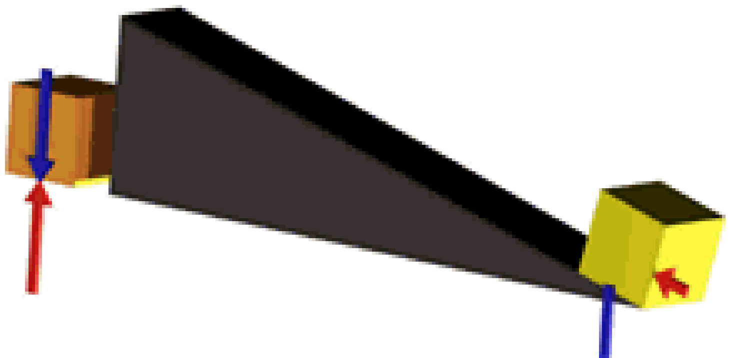
A mechanical advantage of 4:1 tells us what about a mechanism?

Magnitude of Force:

Effort force magnitude is 4 times **less** than the magnitude of the resistance force.

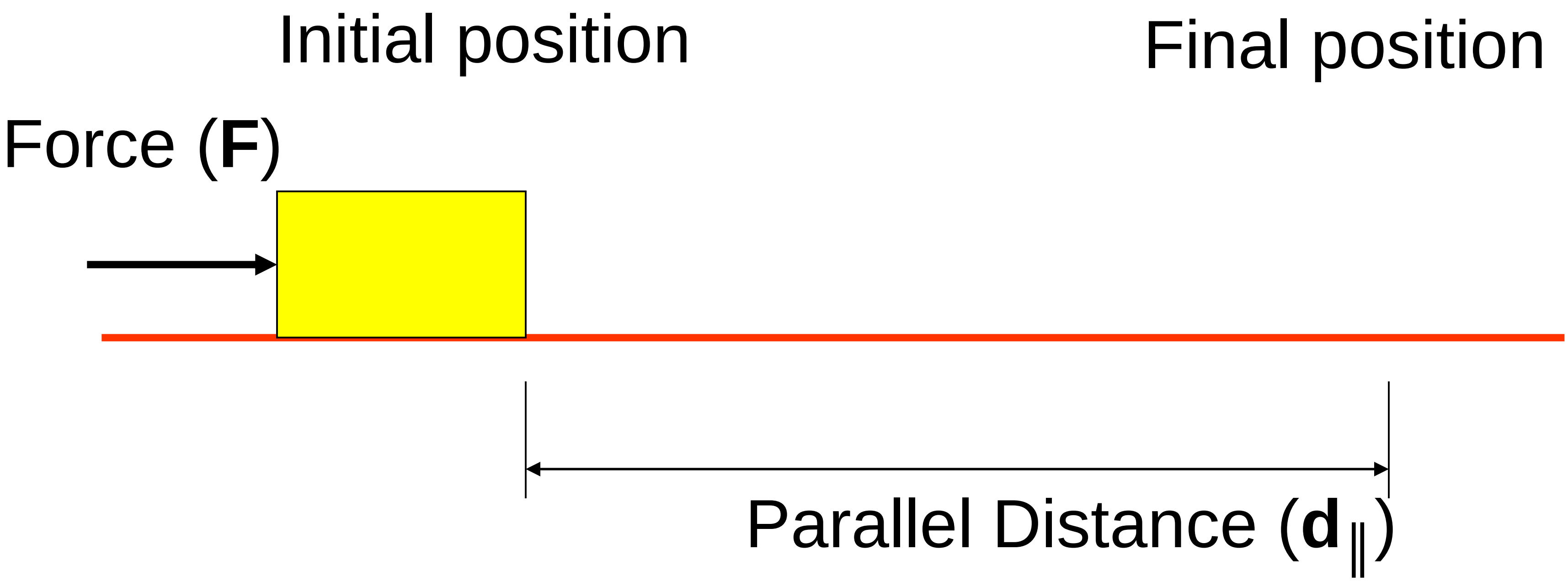
Distance Traveled by Forces:

Effort force travels 4 times greater distance than the resistance force.



Work

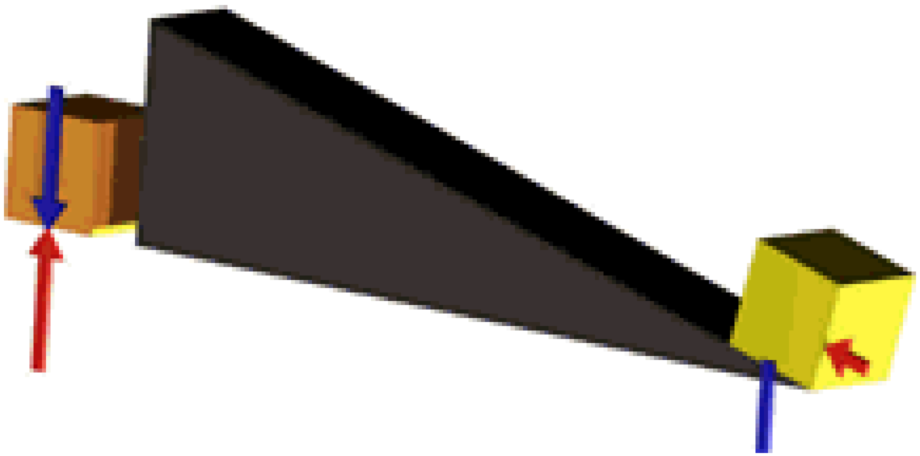
The force applied on an object times the distance traveled by the object parallel to the force



$$\text{Work} = \text{Force} \cdot \text{Distance} = F \cdot d_{\parallel}$$

Work

The product of the effort times the distance traveled will be the same regardless of the system mechanical advantage



Mechanical Advantage Ratios

One is the magic number

If MA is **greater** than 1:

Proportionally **less** effort **force** is required to overcome the resistance force

Proportionally **greater** effort **distance** is required to overcome the resistance force

If MA is **less** than 1:

Proportionally **greater** effort **force** is required to overcome the resistance force

Proportionally **less** effort **distance** is required to overcome the resistance force

MA can never be less than or equal to zero.

Ideal Mechanical Advantage (IMA)

- Theory-based calculation
- Friction loss is **not** taken into consideration
- Ratio of **distance traveled** by effort and resistance force
- Used in efficiency and safety factor design calculations

$$IMA = \frac{D_E}{D_R}$$

D_E = Distance traveled by effort force

D_R = Distance traveled by resistance force

Actual Mechanical Advantage (AMA)

Inquiry-based calculation

Frictional losses **are** taken into consideration

Used in efficiency calculations

Ratio of **force magnitudes**

$$AMA = \frac{F_R}{F_E}$$

F_R = Magnitude of resistance force

F_E = Magnitude of effort force

Real World Mechanical Advantage

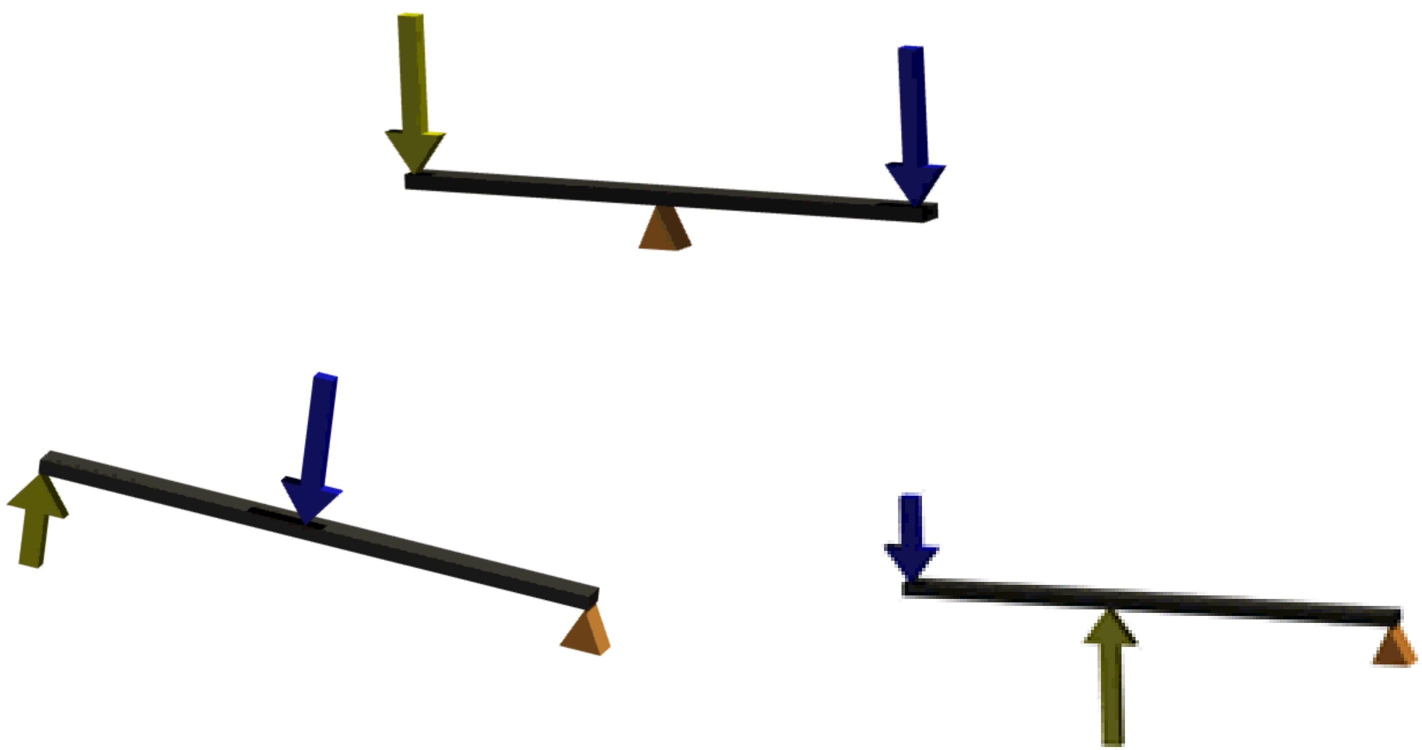
Can you think of a machine that has a mechanical advantage greater than 1?

Real World Mechanical Advantage

Can you think of a machine that has a mechanical advantage less than 1?

Lever

A rigid bar used to exert a pressure or sustain a weight at one point of its length by the application of a force at a second and turning at a third on a fulcrum.

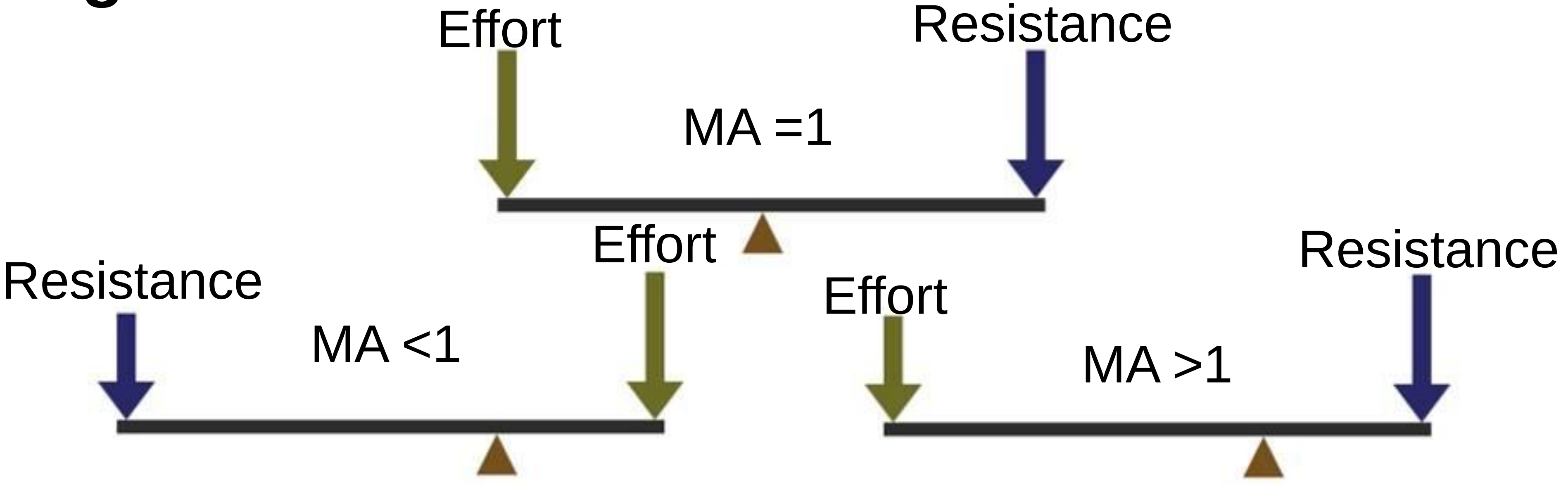


1st Class Lever

Fulcrum is located **between** the **effort** and the **resistance** force

Effort and **resistance** forces are applied to the lever arm in the **same** direction

Only class of lever that can have a MA **greater** than or **less** than **1**



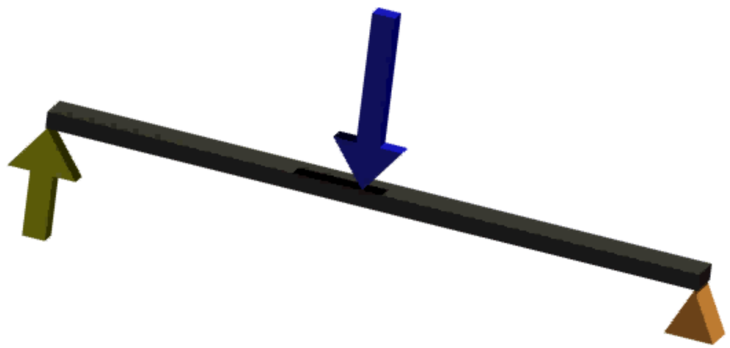
2nd Class Lever

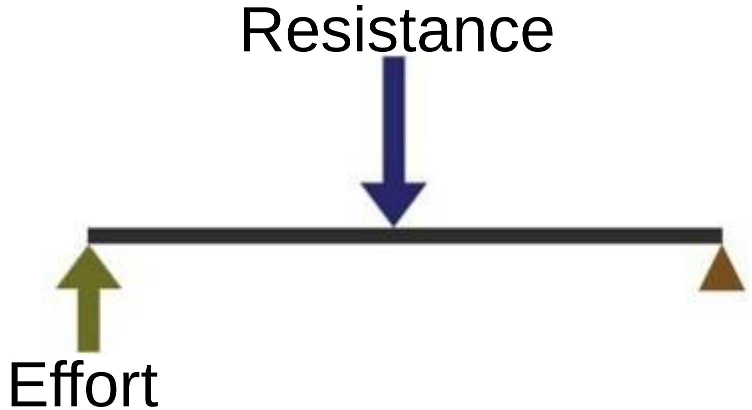
Fulcrum is located at one end of the lever

Resistance force is located between the **fulcrum** and the **effort** force

Resistance force and **effort** force are in opposing directions

Always has a mechanical advantage **>1**





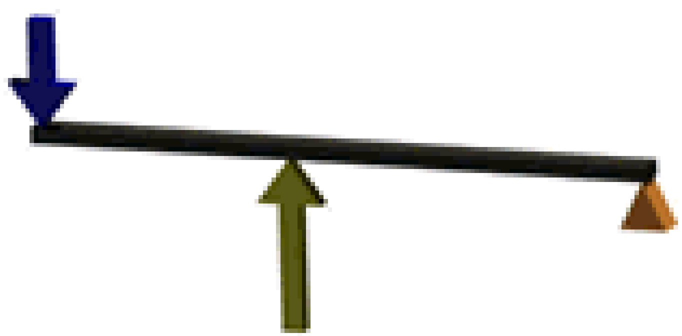
3rd Class Lever

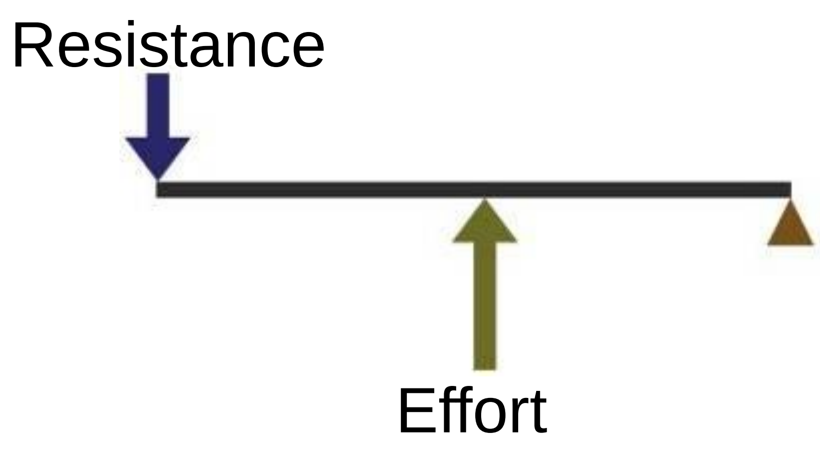
Fulcrum is located at one end of the lever

Effort force is located between the **fulcrum** and the **resistance**

Resistance force and **effort** force are in opposing directions

Always has a mechanical advantage **< 1**





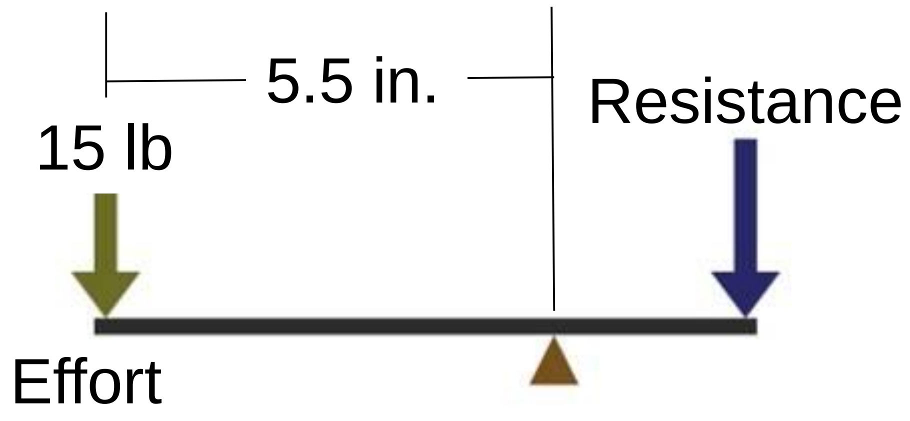
Moment

The turning effect of a force about a point equal to the magnitude of the force times the ***perpendicular*** distance from the point to the line of action from the force.

$$M = d \times F$$

Torque: A force that produces or tends to produce rotation or torsion.

Lever Moment Calculation



Calculate the **effort moment** acting on the lever above.

$$M = d \times F$$

Effort Moment = 5.5 in. x 15 lb

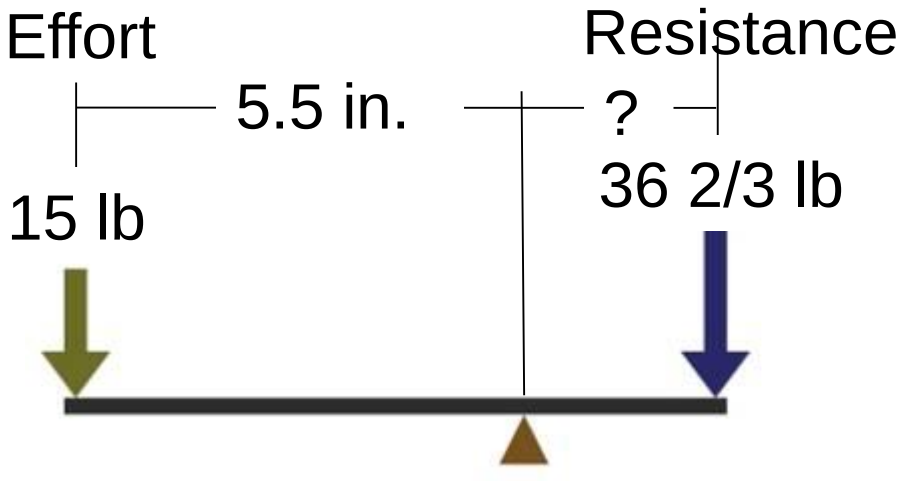
Effort Moment = 82.5 in. lb

Lever Moment Calculation

When the **effort** and **resistance** moments are **equal,** the lever is in **static equilibrium.**

Static equilibrium:
A condition where there are no net external forces acting upon a particle or rigid body and the body remains at rest or continues at a constant velocity.

Lever Moment Calculation



Using what you know regarding static equilibrium, calculate the unknown distance from the fulcrum to the resistance force.

Static equilibrium:

Effort Moment = Resistance Moment

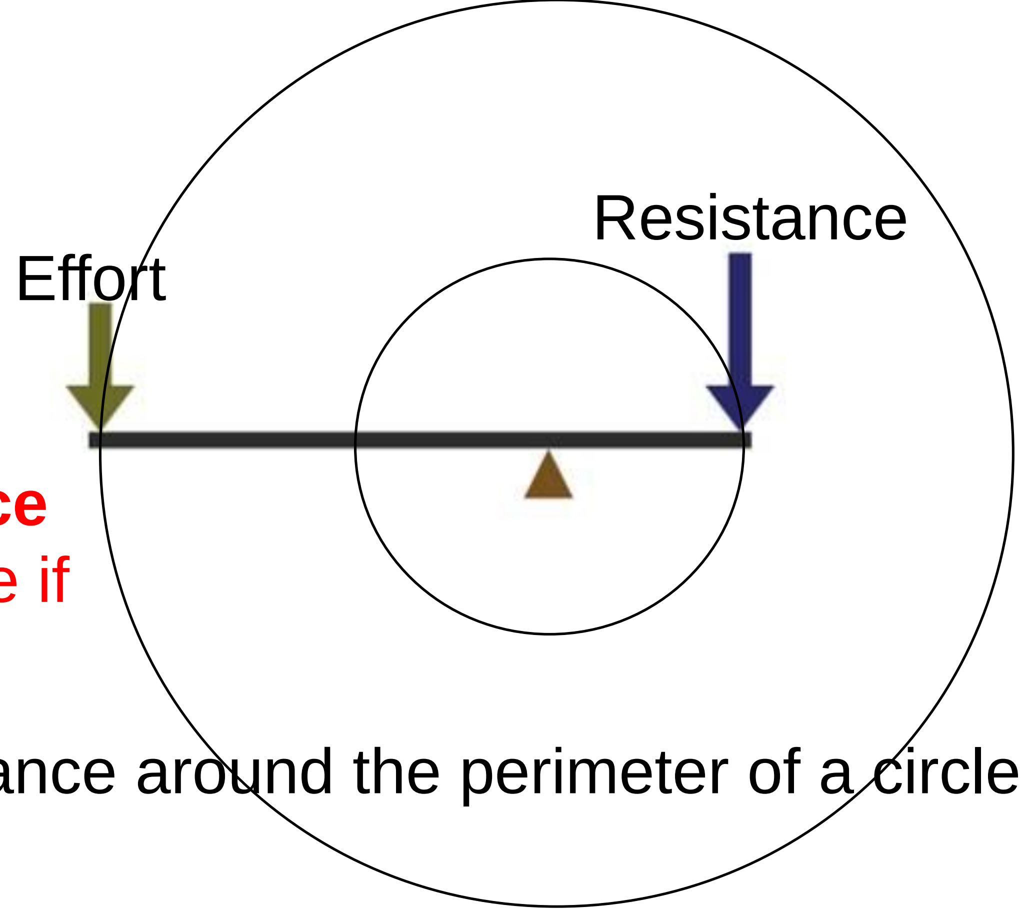
$$82.5 \text{ in.-lb} = 36\ 2/3 \text{ lb} \times D_R$$

$$82.5 \text{ in.-lb} / 36.66 \text{ lb} = D_R$$

$$D_R = 2.25 \text{ in.}$$

Lever IMA

$$IMA = \frac{D_E}{D_R}$$



Both **effort** and **resistance** forces will travel in a circle if unopposed.

Circumference is the distance around the perimeter of a circle.

Circumference = $2\pi r$

$D_E = 2\pi$ (effort arm length)

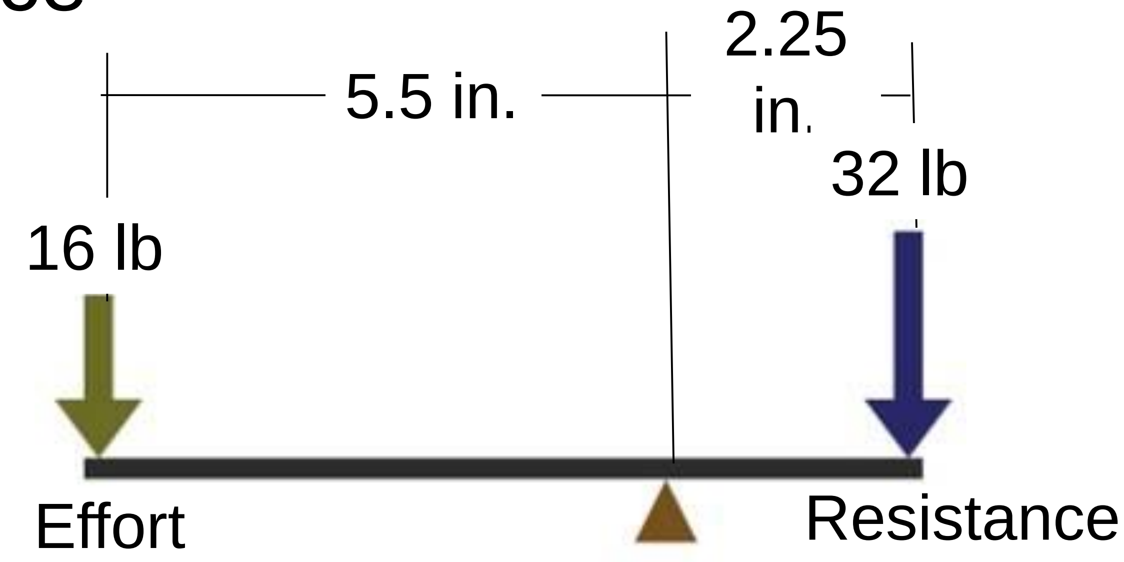
$D_R = 2\pi$ (resistance arm length)

$$IMA = \frac{\cancel{2}\,\cancel{\pi}\text{ (effort arm length)}}{\cancel{2}\,\cancel{\pi}\text{ (resistance arm length)}}$$

Lever AMA

The ratio of applied resistance force to applied effort force

$$AMA = \frac{F_R}{F_E}$$



What is the AMA of the lever above? AMA = 2:1

$$AMA = \frac{32\cancel{lb}}{16\cancel{lb}}$$

Why is the IMA larger than the AMA?

What is the IMA of the lever above? IMA = 2.44:1

$$IMA = \frac{D_E}{D_R}$$

$$IMA = \frac{5.5\cancel{in.}}{2.25\cancel{in.}}$$

Efficiency

In a machine, the ratio of useful energy output to the total energy input, or the percentage of the work input that is converted to work output

The ratio of AMA to IMA

$$\%\,\text{Efficiency} = \left(\frac{\text{AMA}}{\text{IMA}}\right)100$$

What is the efficiency of the lever on the previous slide? Click to return to previous slide

AMA = 2:1

IMA = 2.44:1

$$\%\,\text{Efficiency} = \left(\frac{2.00}{2.44}\right)100 = 82.0\%$$

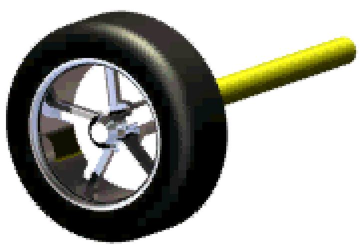
No machine is 100% efficient.

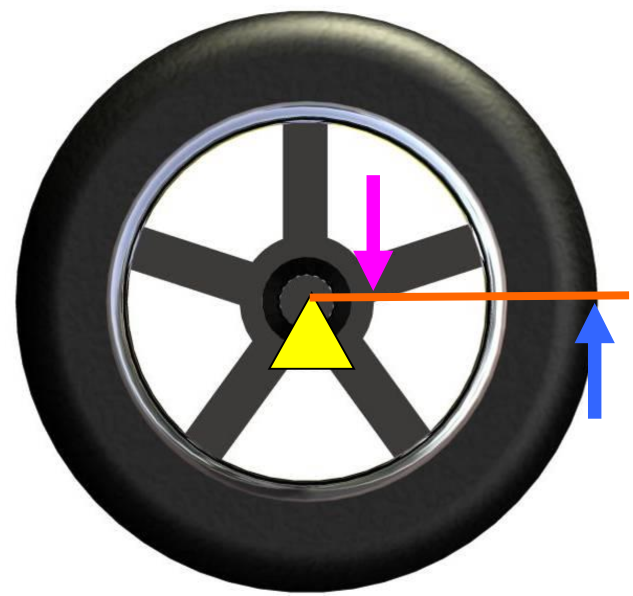
Wheel & Axle

A wheel is a lever arm that is fixed to a shaft, which is called an axle.

The wheel and axle move together as a simple lever to lift or to move an item by rolling.

It is important to know within the wheel and axle system which is applying the effort and resistance force – the wheel or the axle.



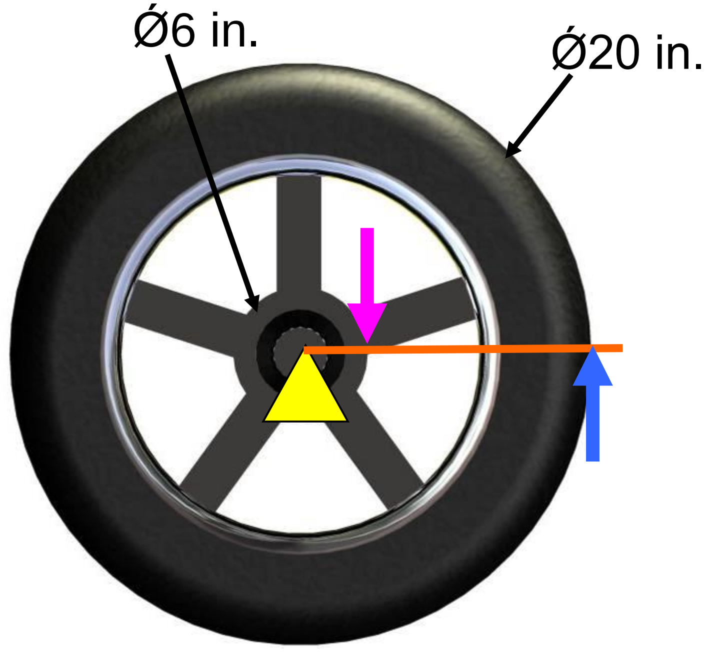


Can you think of an example of a wheel driving an axle?

Wheel & Axle IMA

$$IMA = \frac{D_E}{D_R}$$

Both **effort** and **resistance** forces will travel in a circle if unopposed.



Circumference = 2πr **or** πd

$D_E = \pi$ [Diameter of effort (wheel or axle)]

$D_R = \pi$ [Diameter resistance (wheel or axle)]

$$IMA = \frac{\cancel{\pi}\text{ (effort diameter)}}{\cancel{\pi}\text{ (resistance diameter)}}$$

What is the IMA of the wheel above if the **axle** is driving the **wheel**?

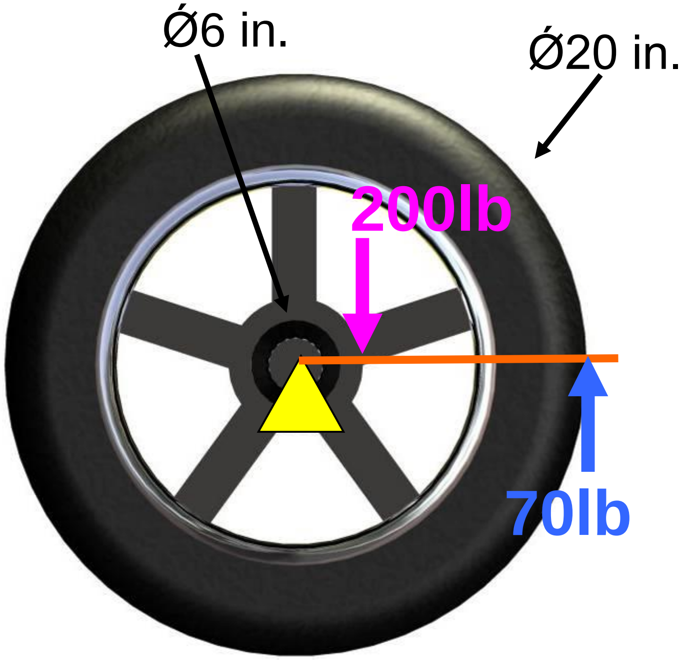
6 in. / 20 in. = .3 = .3:1 = 3:10

What is the IMA of the wheel above if the **wheel** is driving the **axle**?

20 in. / 6 in. = 3.33 = 3.33:1

Wheel & Axle AMA

$$AMA = \frac{F_R}{F_E}$$



Use the wheel and axle assembly illustration to the right to solve the following.

What is the AMA if the wheel is driving the axle?

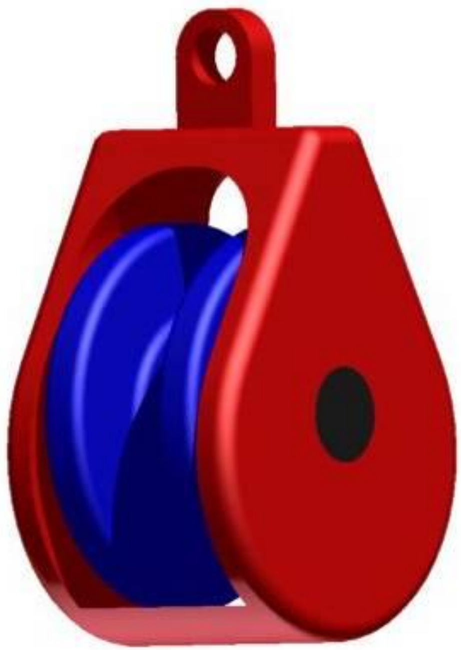
200lb/70lb = 2.86 = 2.86:1

What is the efficiency of the wheel and axle assembly?

$$\%\,\text{Efficiency} = \left(\frac{AMA}{IMA}\right)100 = \left(\frac{2.86}{3.33}\right)100 \;= 85.9\%$$

Pulley

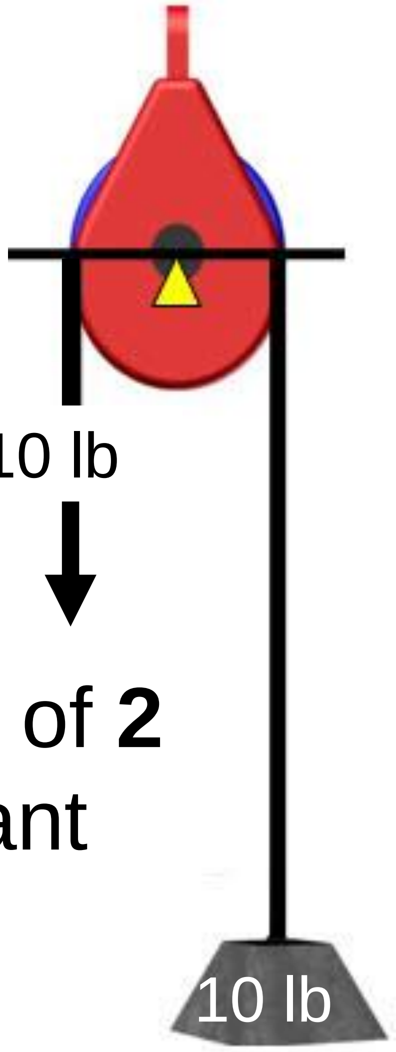
A pulley is a lever consisting of a wheel with a groove in its rim which is used to change the direction and magnitude of a force exerted by a rope or cable.



Pulley IMA

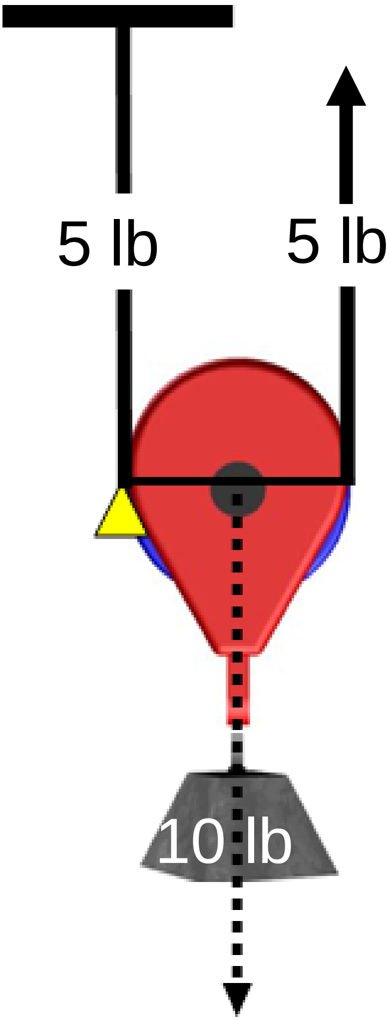
Fixed Pulley

- 1st class lever with an **IMA** of **1**
- Changes the direction of force



Movable Pulley

- 2nd class lever with an **IMA** of **2**
- Force directions stay constant



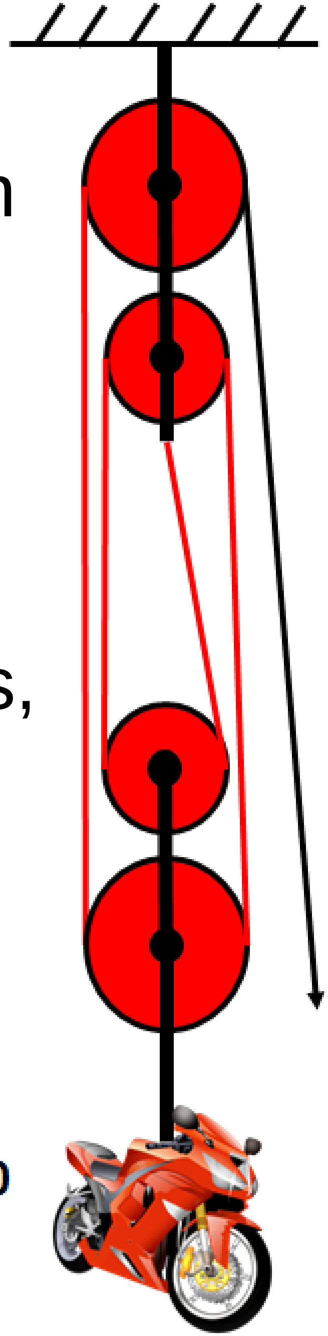
Pulleys In Combination

Fixed and movable pulleys in combination (called a block and tackle) provide mechanical advantage and a change of direction for effort force.

If a **single** rope or cable is threaded multiple times through a system of pulleys,

Pulley IMA = # strands opposing the force of the load and movable pulleys

What is the IMA of the pulley system on the right? 4



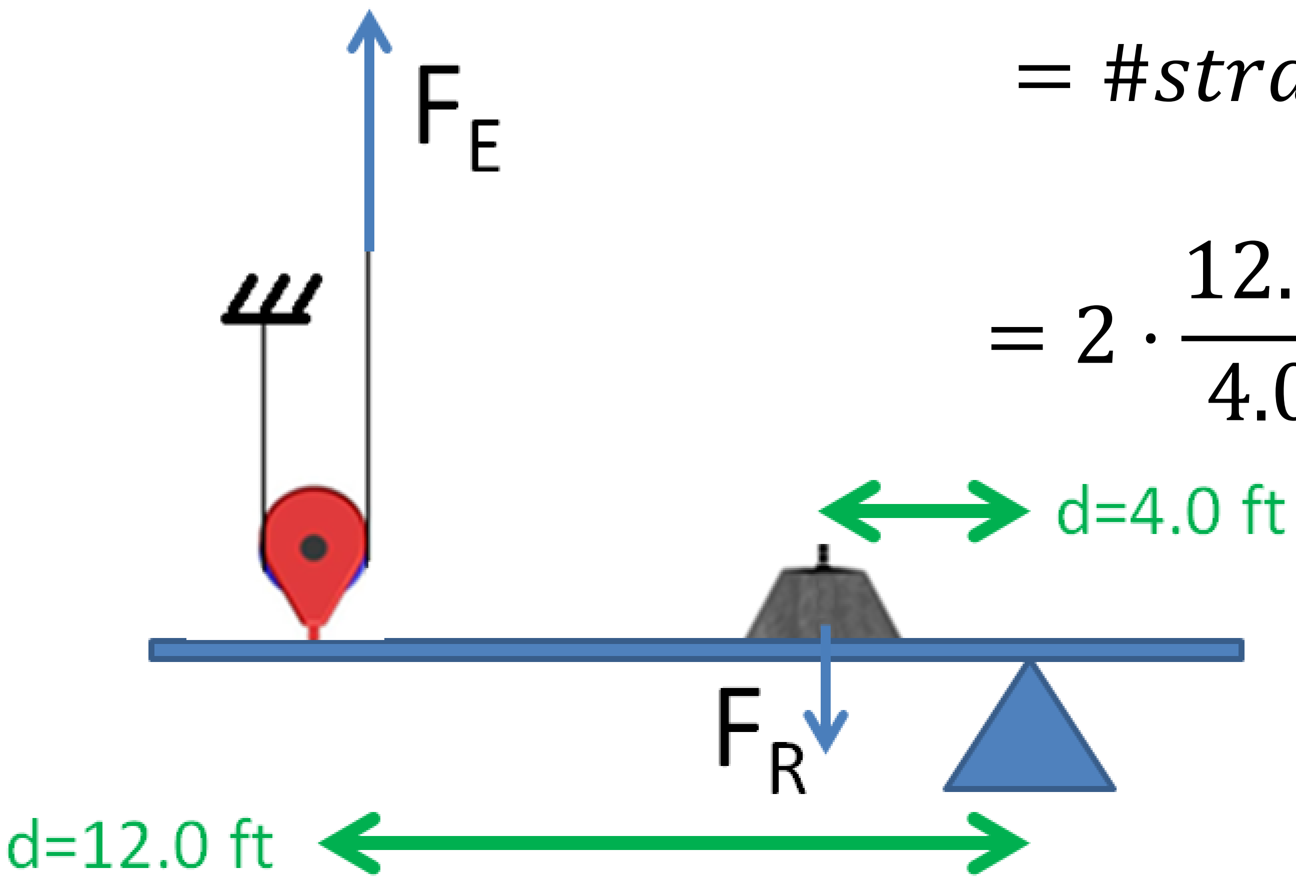
Compound Machines

If one simple machine is used after another, the mechanical advantages multiply.

$$IMA_{total} = IMA_{pulley} \cdot IMA_{lever}$$

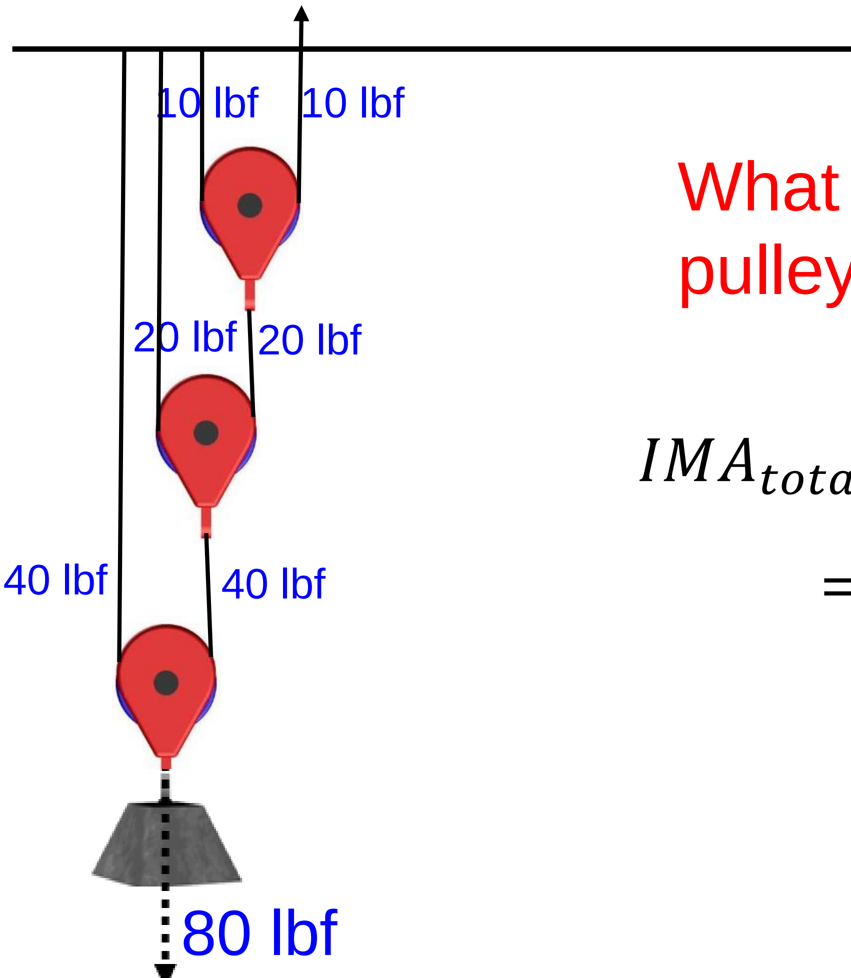
$$= \#strands \cdot \frac{D_E}{D_R}$$

$$= 2 \cdot \frac{12.0\ ft}{4.0\ ft} = 2 \cdot 3 = 6$$



Pulleys In Combination

With separate ropes or cables, the output of one pulley system can become the input of another pulley system. This is a compound machine.



What is the IMA of the pulley system on the left?

$$IMA_{total} = IMA_1 \cdot IMA_2 \cdot IMA_3$$

$$= 2 \cdot \ 2 \cdot \ 2 = 8$$

Pulley AMA

$$AMA = \frac{F_R}{F_E}$$

What is the AMA of the pulley system on the right?

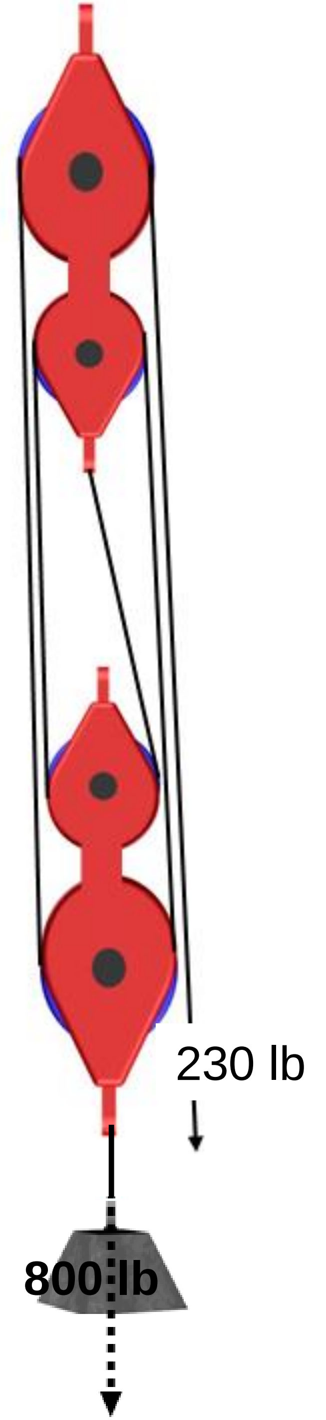
$$AMA = \frac{800\cancel{lb}}{230\cancel{lb}}$$

AMA = 3.48 = 3.48:1

What is the efficiency of the pulley system on the right?

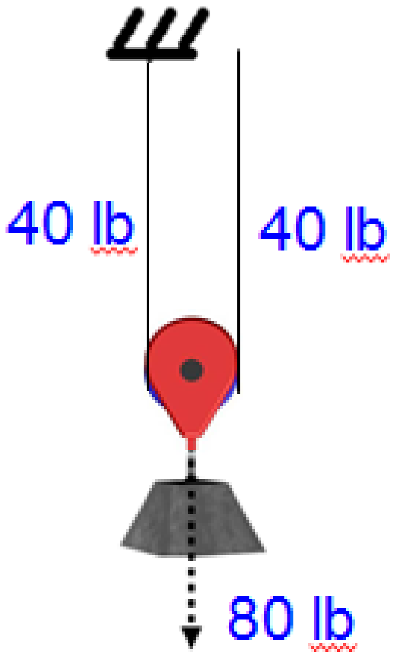
$$\% \text{ Efficiency} = \left(\frac{AMA}{IMA}\right)100 = \left(\frac{3.48}{4}\right)100$$

= 87%

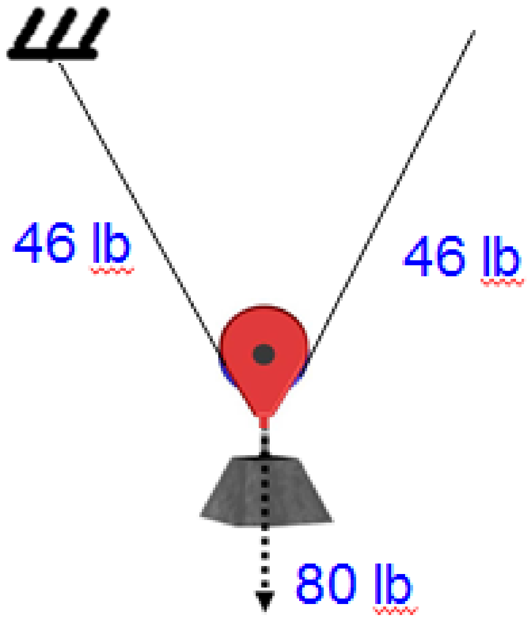


Common misconception: ~~Angles don't matter~~

Pulley IMA = # strands opposing load **only** if strands are opposite/parallel to the resistance force.



IMA=2



Calculating IMA requires trigonometry

Common misconception:
"Count the effort strand ~~if it pulls up~~"
sometimes

Pulley IMA = # strands opposing the load.

Count a strand if it opposes the load or the load's movable pulley.
It might pull up or down.

IMA=2

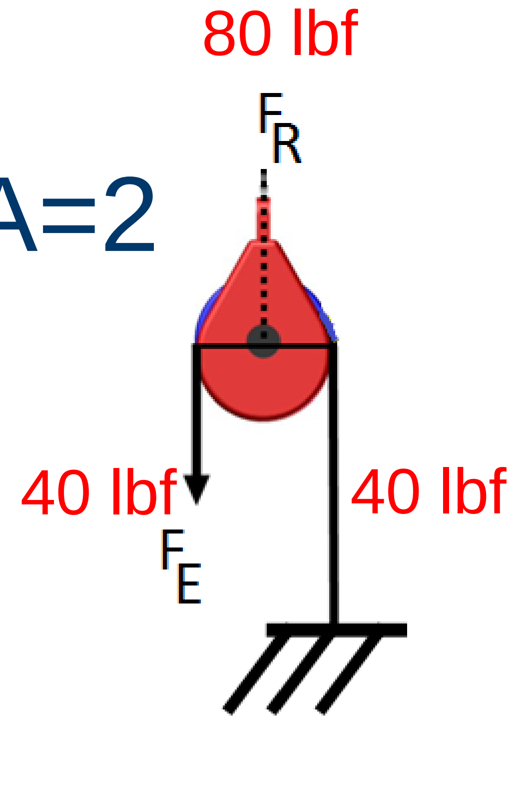


Image Resources

Microsoft, Inc. (2008). *Clip art*. Retrieved January 10, 2008, from http://office.microsoft.com/en-us/clipart/default.aspx