Introduction to Project Lead the Way

Topic One
Mechanical Advantage Ratios, &
Work Input vs Output

By Edward Locke

Course Overview (STEM Basics)

- **Engineering & technology systems:** Mechanical (spaceship, train, …), civil (Hoover Dam, freeway, …), electrical (nuclear power plants, solar energy, …), bio-genetic (Monsanto lab, …), …
- **Engineering processes:** Changes materials and environment into products, equipment/tools, systems for human usages, …
- **Impact of math, science, and technology:** For good (better-qualify life, improvement of health, social progress, …) or for bad (pollution, war, poisoning, …)
- **Design process:** Setting objectives/criteria, market investigation, ideation (“brainstorming,” …), initial design (sketch, CADD), prototyping/testing, optimization, communication and documentation.

Course Overview (Engineering Foundation)

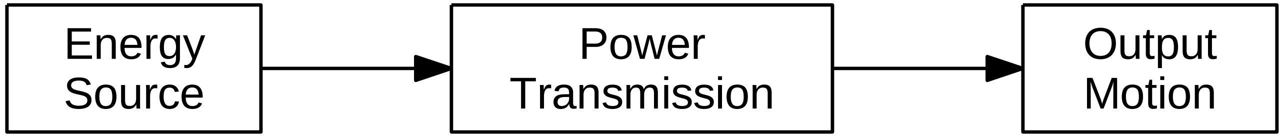
- **Statics:** The branch of mechanics concerned with the analysis of loads (force and torque, or "moment") on physical systems in static equilibrium (motionless or moving at a constant velocity). Reference: http://en.wikipedia.org/wiki/Statics
- **Properties of materials:** Physical, chemical, outlook, etc. Mostly “descriptive” information.
- **Materials testing:** Using equipment, and formulas from “mechanics of materials” (or “strength of materials”) course, to come up with conclusions supported by data or “numbers.” “Hands-on” and “pen-and-pencil.”

Course Overview (Engineering Application)

- **Control systems:** A device, or a system made of several devices, that manages, directs or regulates the behavior of other devices or systems. (Reference: http://en.wikipedia.org/wiki/Control_system)
- **Quality assurance (QA):** A way of preventing mistakes or defects in manufactured products and avoiding problems when delivering solutions or services to customers. (Reference: http://en.wikipedia.org/wiki/Quality_assurance, and http://en.wikipedia.org/wiki/ISO_9000)
- **Engineering for reliability:** Emphasizes dependability in the lifecycle management of a product, describes the ability of a system or component to function under stated conditions for a specified period of **time** (Reference: http://en.wikipedia.org/wiki/Reliability_engineering)

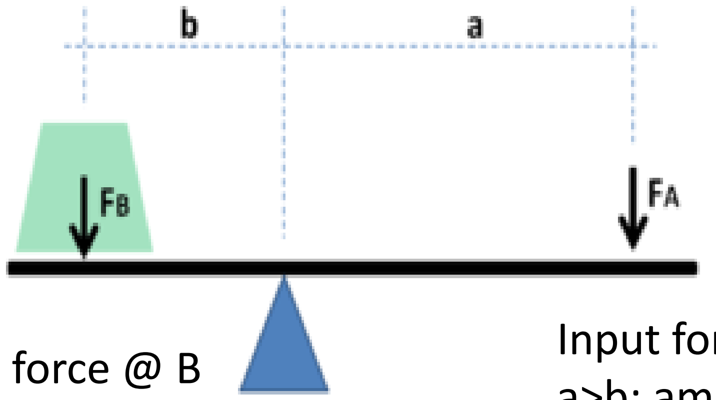
Mechanical Advantage Ratios & Work Input vs Output

- **Definition:** A measure of the force amplification achieved by using a tool, mechanical device or machine system. Ideally, the device preserves the input power (frictionless, from rigid bodies without deflect or wear), and simply trades off forces against movement to obtain a desired amplification in the output force.
- **Model: The law of the Lever.** An ideal one transmits power without adding to or subtracting from it. The actual performance of a real system is expressed in terms of efficiency factors ("ideal" minus friction, deformation and wear).



Mechanical Advantage Ratios & Work Input vs Output

- **Model:** **The law of the Lever** (a movable bar that pivots on a fulcrum on or across a fixed point, operates by applying forces at different distances from the fulcrum, or pivot).



Output force @ B

Fulcrum (pivot point)

Input force @ A
a>b: amplification

Pivoting: Points farther from this pivot move faster than points closer. Same power into and out of the lever
(Power = force x velocity).

Scissors & rench

Ratio of the output force to the input force, or **mechanical advantage (O/I)**

$$MA = \frac{F_B}{F_A} = \frac{a}{b}.$$

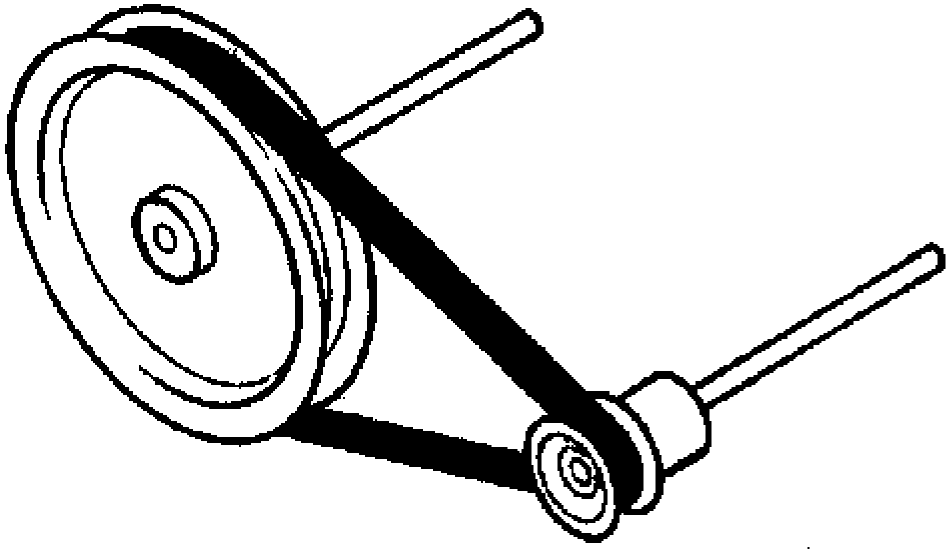
Mechanical Advantage Ratios & Work Input vs Output

Example: **Speed ratio of a gear train** (MA from the input-output speed ratio of the system)

The power input to a gear train with a torque T_A applied to the drive pulley which rotates at an angular velocity of ω_A is $P=T_A\omega_A$. The power flow is constant.

$$P = T_A\omega_A = T_B\omega_B, \quad MA = \frac{T_B}{T_A} = \frac{\omega_A}{\omega_B}.$$

For an ideal mechanism the input-output speed ratio equals the mechanical advantage of the system (from robots to linkages)



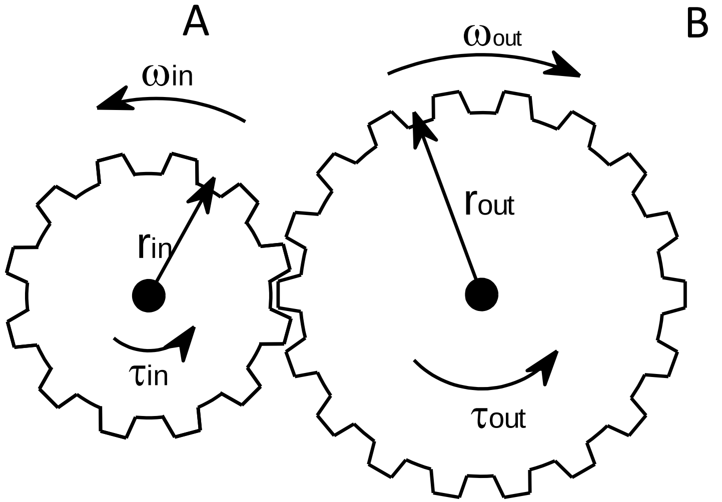
Mechanical Advantage Ratios & Work Input vs Output

Gear teeth: Number of teeth is proportional to the radius of its pitch circle, so that the pitch circles of meshing gears roll on each other without slipping.

The velocity *v* of the point of contact on the pitch circles is the same on both gears.

r: radius
N: number of teeth

$$v = r_A\omega_A = r_B\omega_B, \qquad \frac{\omega_A}{\omega_B} = \frac{r_B}{r_A} = \frac{N_B}{N_A}.$$



The MA of meshing gears (Input A vs. Output B)

$$MA = \frac{r_B}{r_A} = \frac{N_B}{N_A}.$$

If the output gear has more teeth than the input gear, he gear train *amplifies* the input torque; otherwise, the gear train *reduces* the input torque. If the output gear of a gear train rotates more slowly than the input gear, then the gear train is called a *speed reducer*; because the output gear must have more teeth, the speed reducer will amplify the input torque.

Mechanical Advantage Ratios & Work Input vs Output

Chain and belt drives: Two sprockets connected by a chain, or two pulleys connected by a belt to provide a specific MA in power transmission systems. The velocity *v* of the chain or belt is the same when in contact with the two sprockets or pulleys.

$$v = r_A\omega_A = r_B\omega_B, \quad \frac{\omega_A}{\omega_B} = \frac{r_B}{r_A} = \frac{N_B}{N_A}.$$

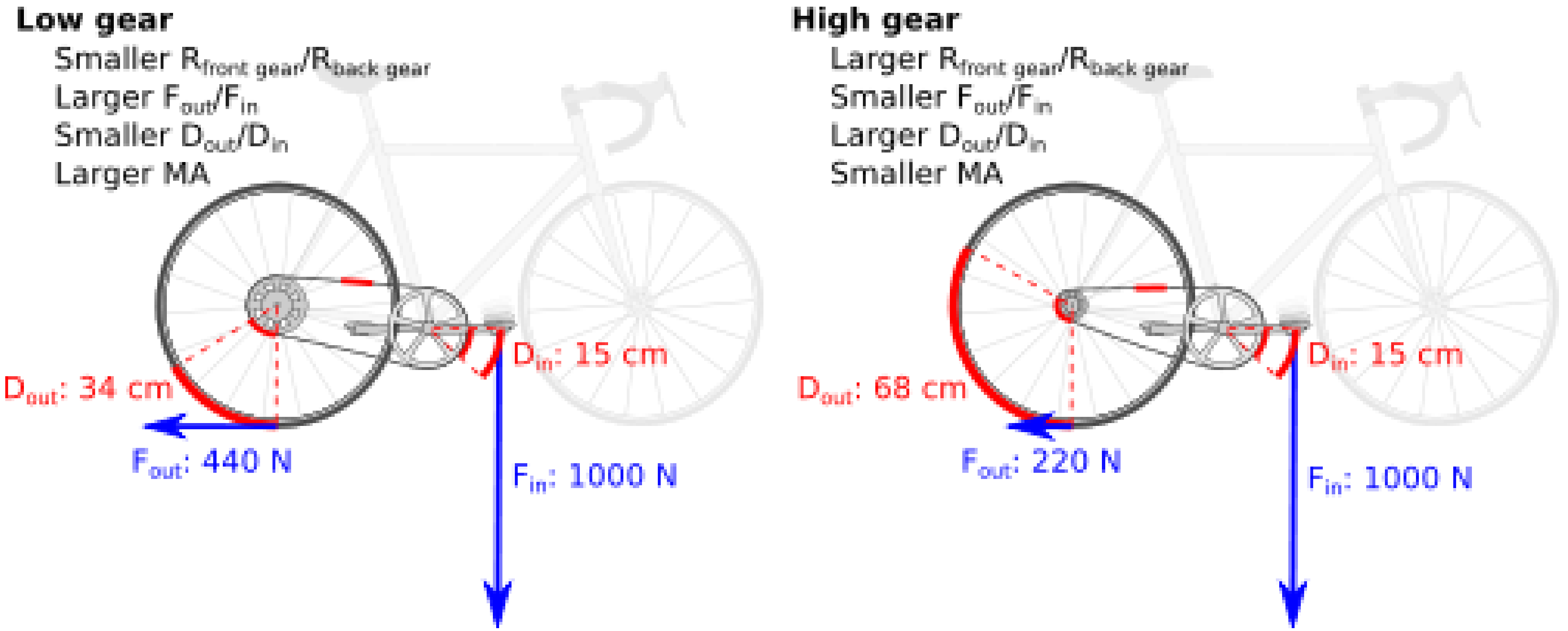
Friction, stretch and wear: Power output is actually less than the power input (5%)

The MA of a pair of a chain drive or toothed belt drive with an input sprocket A and the output sprocket B

$$MA = \frac{T_B}{T_A} = \frac{N_B}{N_A}.$$

The MA for friction belt drives

$$MA = \frac{T_B}{T_A} = \frac{r_B}{r_A}.$$



Mechanical Advantage Ratios & Work Input vs Output

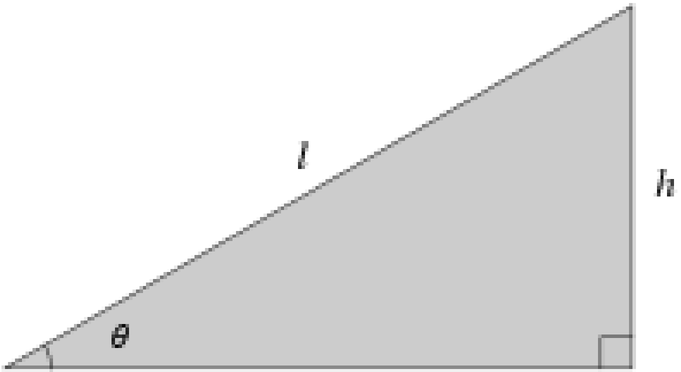
Inclined plan: MA is the length of the slope divided by the height of the inclined plane

length	100 meters
height	50 meters

mechanical advantage	2

$$\text{MA} = \frac{l}{h}$$

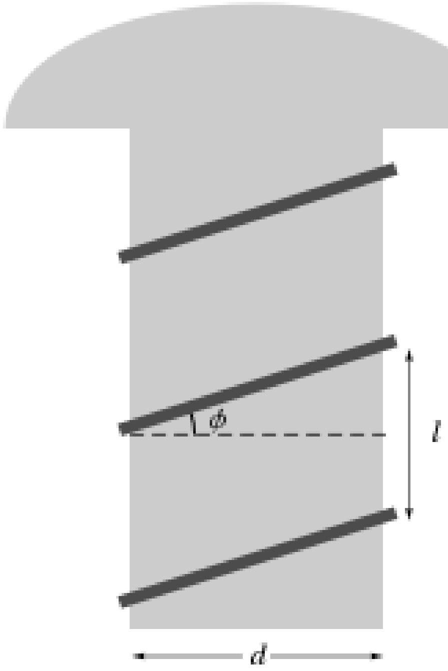
MA	mechanical advantage
l	length
h	height



Mechanical Advantage Ratios & Work Input vs Output

Screw: A modified incline plane. **Thread of the screw**: an inclined plane wrapped around the shaft of the screw. **Slope of the screw**: the distance for one complete rotation around the screw. **Height of the inclined plane:** distance between the threads (pitch). **The mechanical advantage of a screw can be found by dividing the circumference of the screw by the pitch (lead) of the screw.**

$MA = \frac{\pi d}{l}$	
MA	mechanical advantage
d	diameter of screw
l	lead of screw thread



diameter of screw	5 mm (millimeters)
lead of screw thread	1 mm (millimeter)

mechanical advantage	15.71

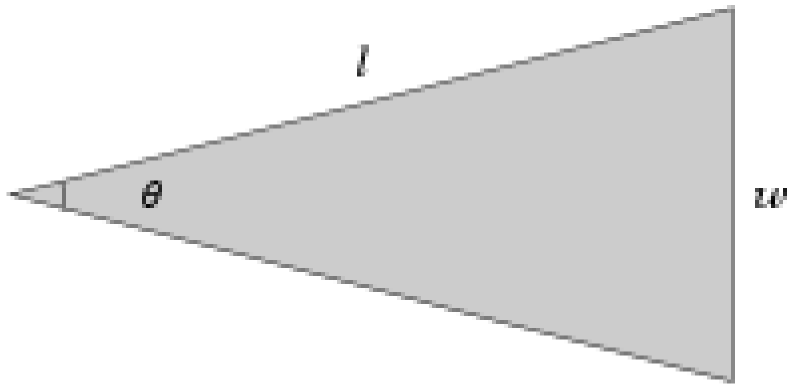
Mechanical Advantage Ratios & Work Input vs Output

Wedge:

side length	20 cm (centimeters)
thickness	10 cm (centimeters)

mechanical advantage	2

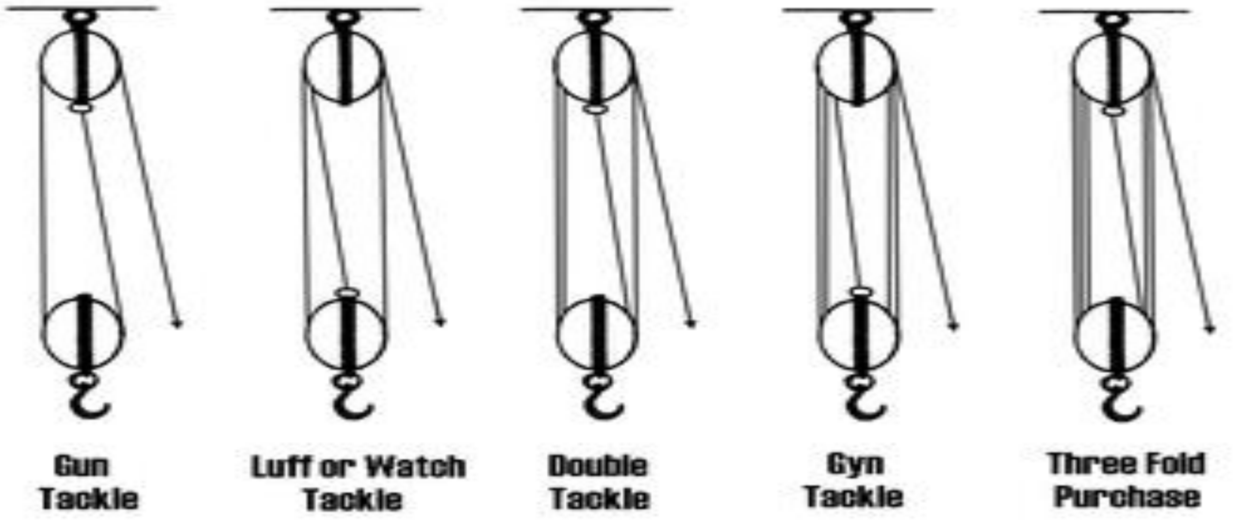
$MA = \frac{l}{w}$	
MA	mechanical advantage
l	side length
w	thickness



Mechanical Advantage Ratios & Work Input vs Output

Block and tackle: An assembly of a rope and pulleys used to lift loads. A number of pulleys are assembled together to form the blocks, one fixed and one that moves with the load. The rope is threaded through the pulleys to provide mechanical advantage that amplifies that force applied to the rope.

The mechanical advantage of a moveable pulley is equal to the number of ropes that support the moveable pulley. (When calculating the mechanical advantage of a moveable pulley, count each end of the rope as a separate rope).



http://iqa.evergreenps.org/science/phy_science/ma.html

Ideal Mechanical Advantage (IMA) or “Theoretical MA”

Definition: The mechanical advantage of a device with the assumption that its components do not flex, there is no friction, and there is no wear (maximum performance possibly, “in theory”).

Assumptions: (1) the machine does not store or dissipate energy; (2) the power into the machine thus equals the power out.

$$P = F_{in} v_{in} = F_{out} v_{out}.$$

$$IMA = \frac{F_{out}}{F_{in}} = \frac{v_{in}}{v_{out}}.$$

Actual Mechanical Advantage (AMA)

Definition: The mechanical advantage determined by physical measurement of the input and output forces. Actual mechanical advantage takes into account energy loss due to deflection, friction, and wear.

$$AMA = \frac{F_{out}}{F_{in}},$$ (Input and output forces determined by testing)

The ratio of the experimentally determined mechanical advantage to the ideal mechanical advantage is the efficiency η of the machine

$$\eta = \frac{AMA}{IMA}.$$

Internet Resource

http://en.wikipedia.org/wiki/Mechanical_advantage

http://en.wikipedia.org/wiki/Gear_ratio

http://maelabs.ucsd.edu/mae_guides/machine_design/machine_design_basics/Mech_Ad/mech_ad.htm

https://www.youtube.com/watch?v=uhWeWaIYU-M

http://hyperphysics.phy-astr.gsu.edu/hbase/mechanics/simmac.html

www.bostongear.com

http://iqa.evergreenps.org/science/phy_science/ma.html