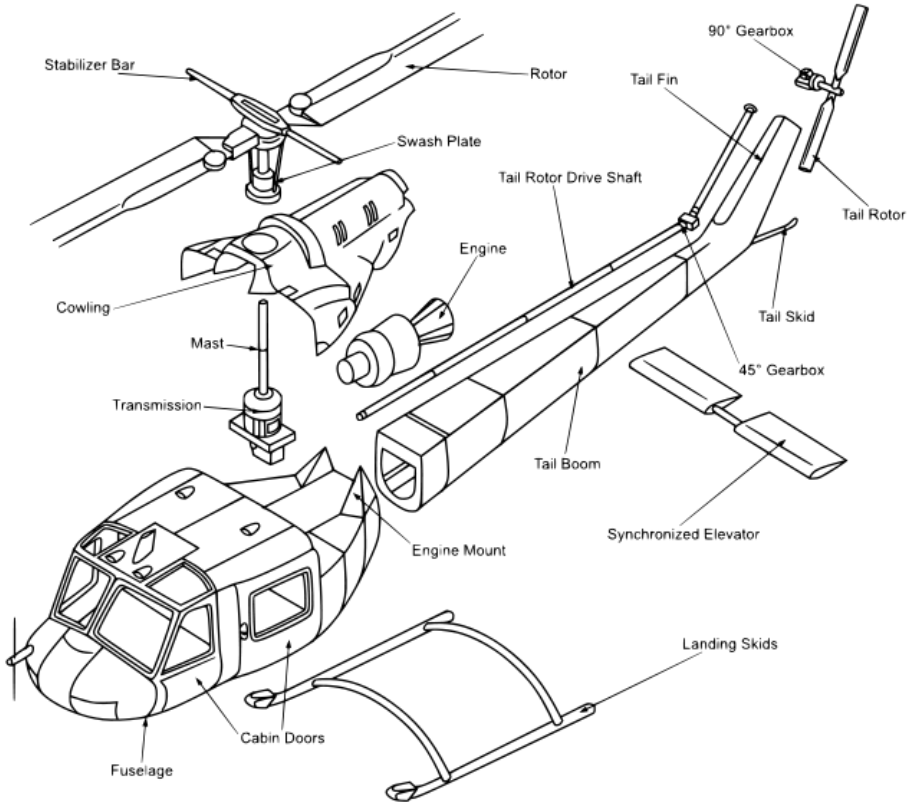
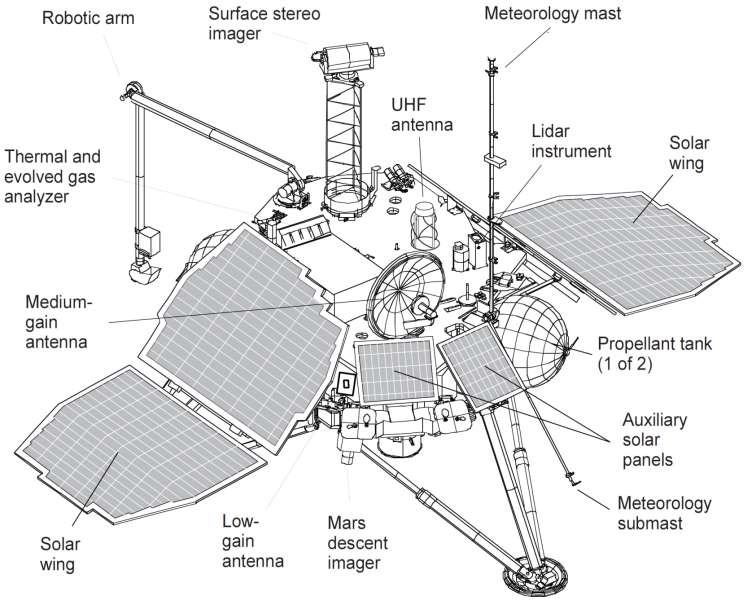
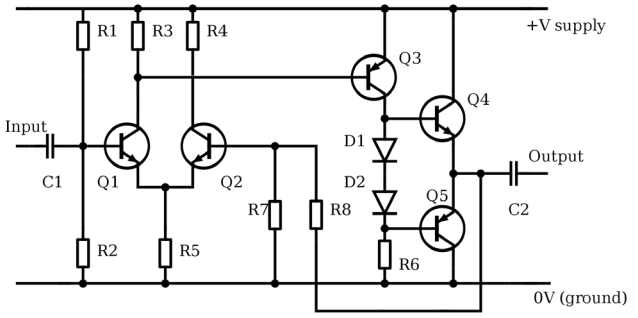




Lecture 4 – Machine elements

Andrés Faíña (anfv@itu.dk)



From parts to machines

What you have learnt:

- Part modelling
- 3D printing
- Laser cutting

How do you build a machine?

Overview

Forces and Moments (Physics 101)
Mechanisms
Bearings and guides
Power transmission
Fasteners

Forces and Moments

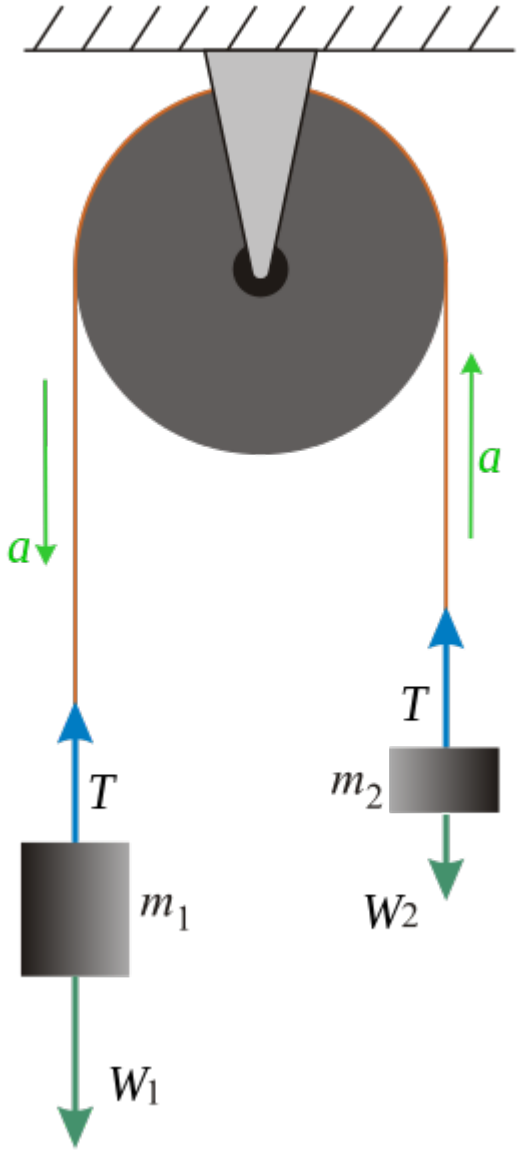
Forces

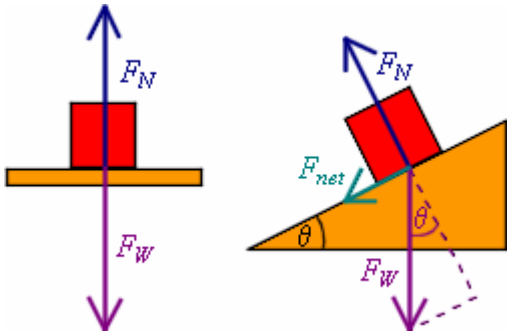
A quantitative description of an interaction that causes a change in an object's motion

$$\sum \mathbf{F} = m \cdot \mathbf{a}$$

Force and acc are vectors:

- Magnitude
- Direction



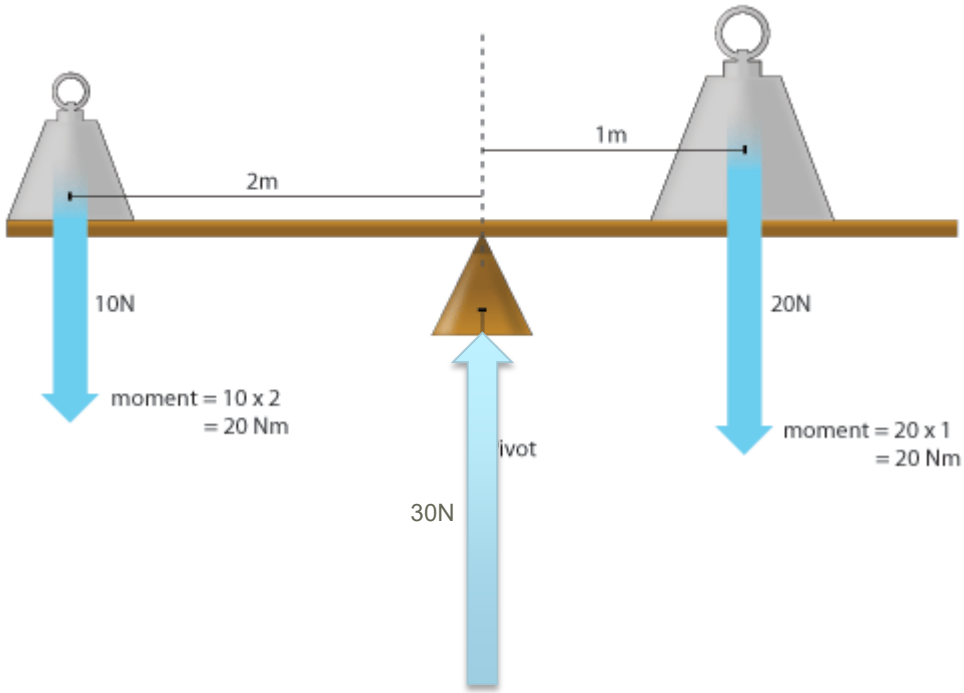


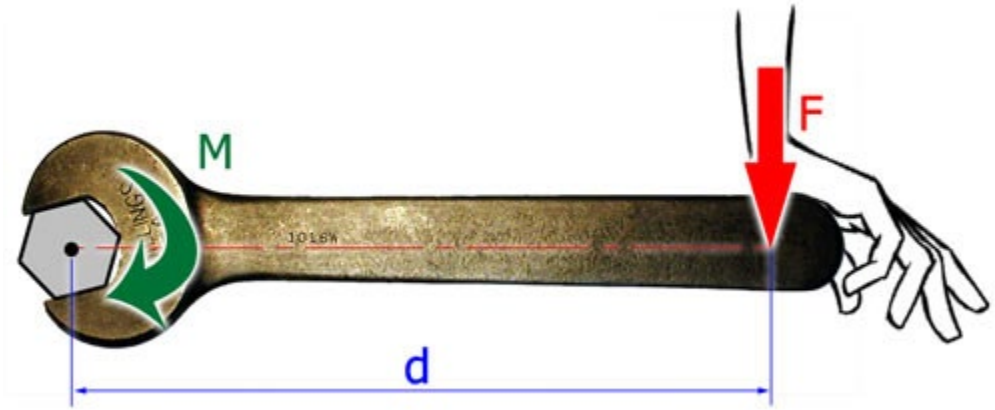
Moments or torque

Turning effect of a force

$M = F \cdot d$

$\sum \mathbf{M} = I \cdot \boldsymbol{\alpha}$





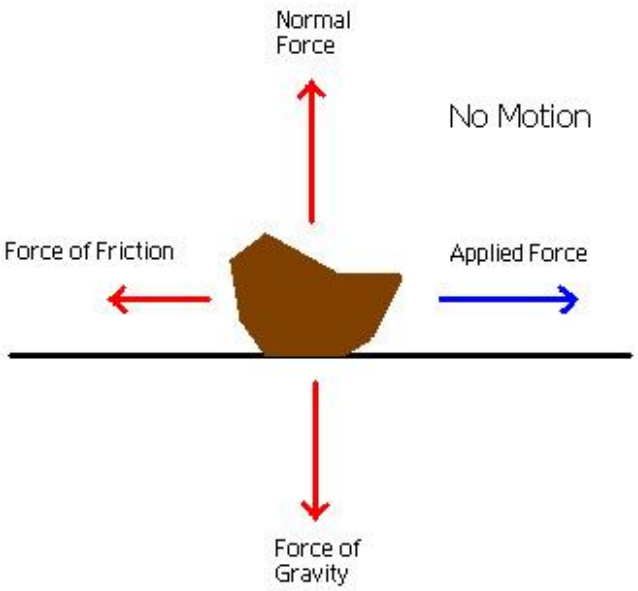
Static equilibrium

$$\sum \mathbf{F} = m\,\mathbf{a}$$

$$\mathbf{a} = \mathbf{0}$$

Therefore...

$$\sum \mathbf{F} = \mathbf{0}$$

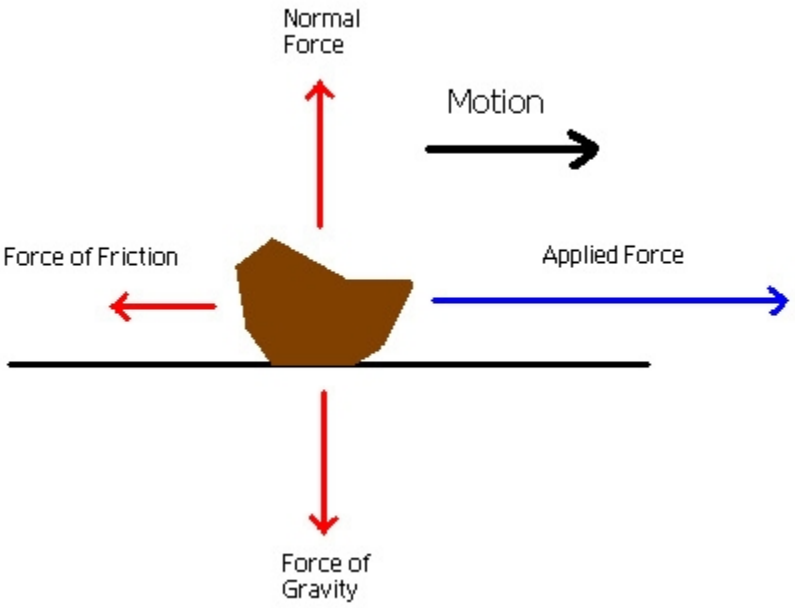


$$\sum \mathbf{M} = I\,\boldsymbol{\alpha}$$

$$\boldsymbol{\alpha} = \mathbf{0}$$

Therefore...

$$\sum \mathbf{M} = \mathbf{0}$$



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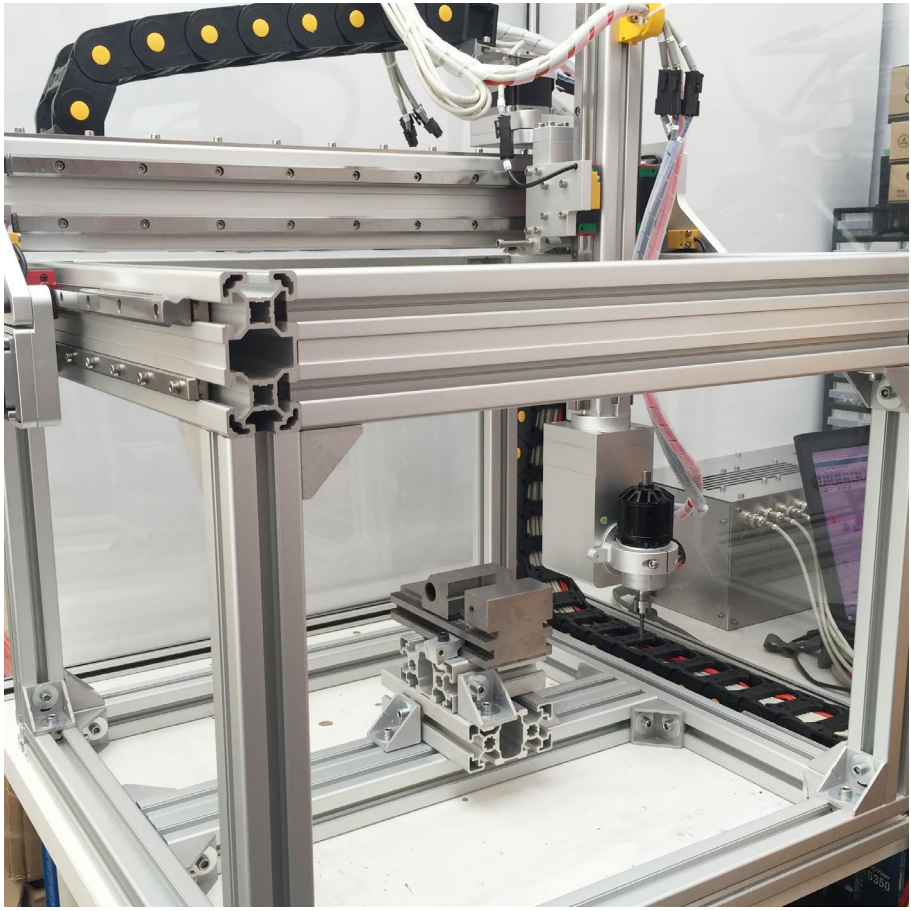
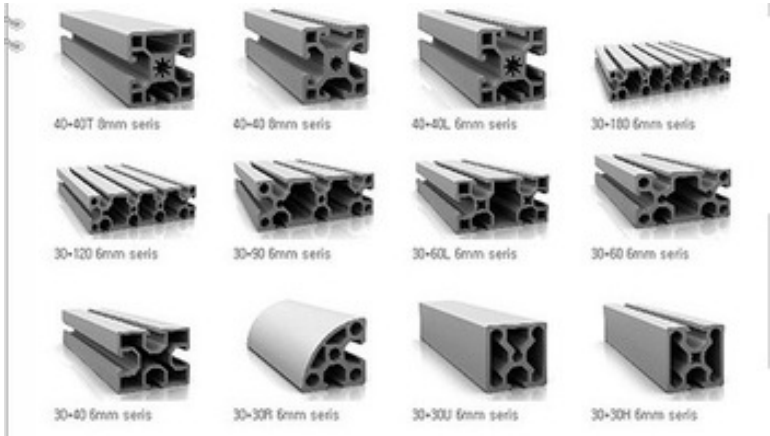
Structural elements





Mechanisms

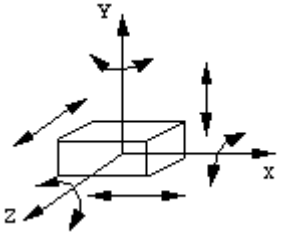
Degrees of freedom

number of independent parameters that define its configuration

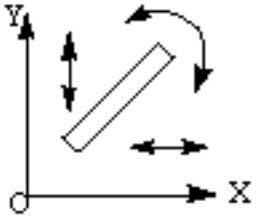
In a machine:

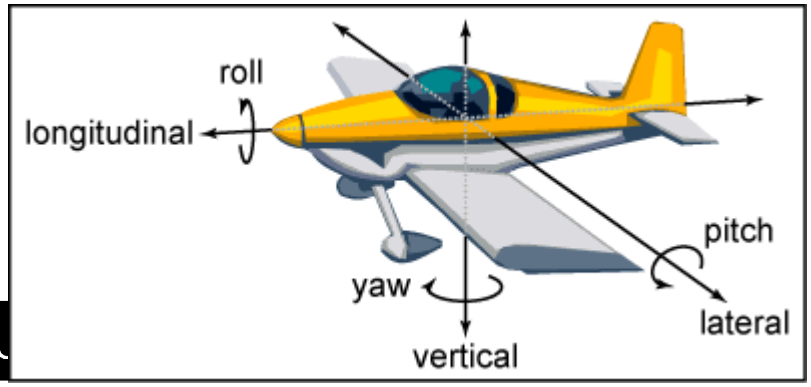
dof = motors or actuators

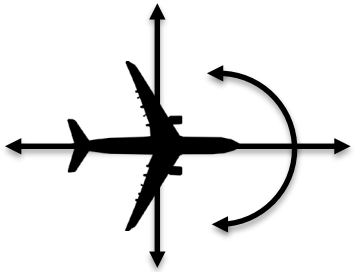
A rigid object in space has 6 *dof*



A rigid object in a plane has 3 *dof*

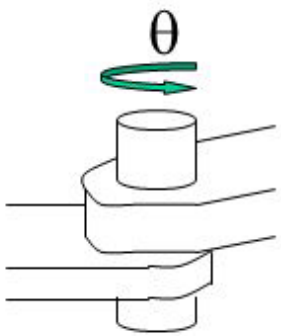




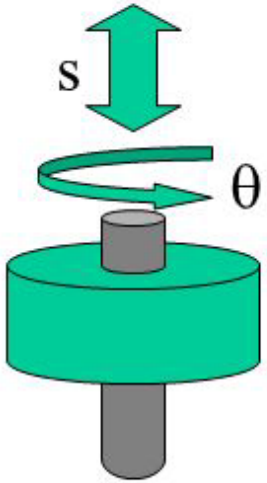


Kinematic pairs

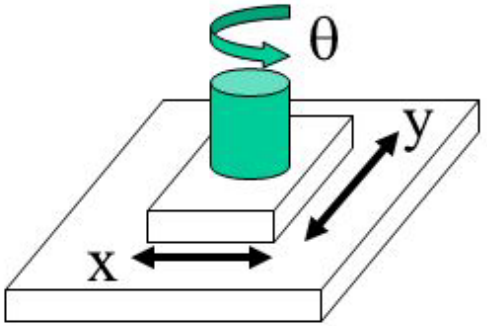
connection between two bodies that imposes constraints on their relative movement



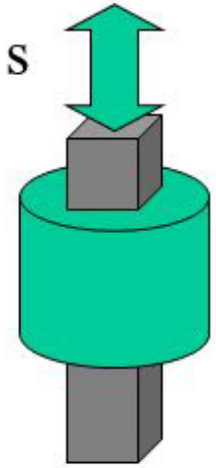
Revolute/pin joint



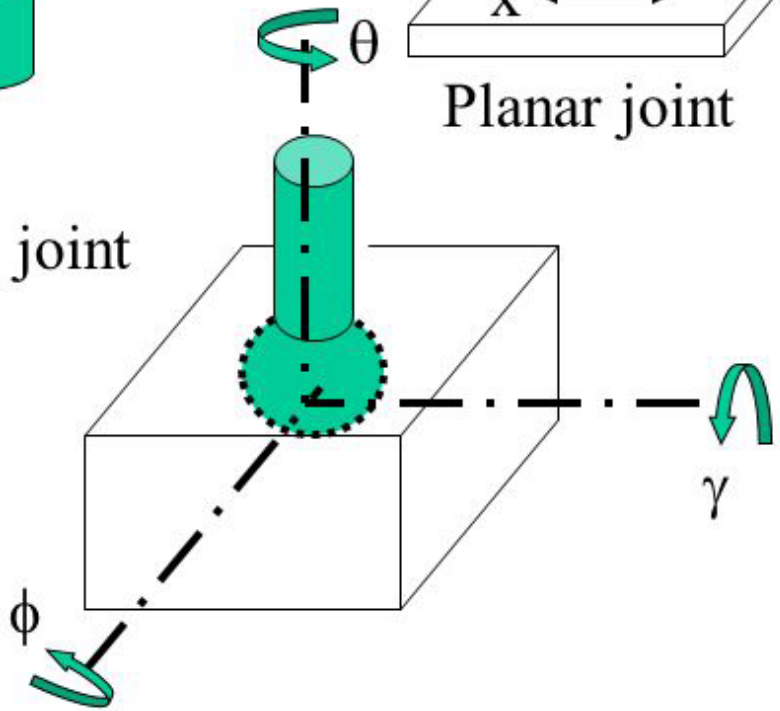
Cylindrical joint



Planar joint



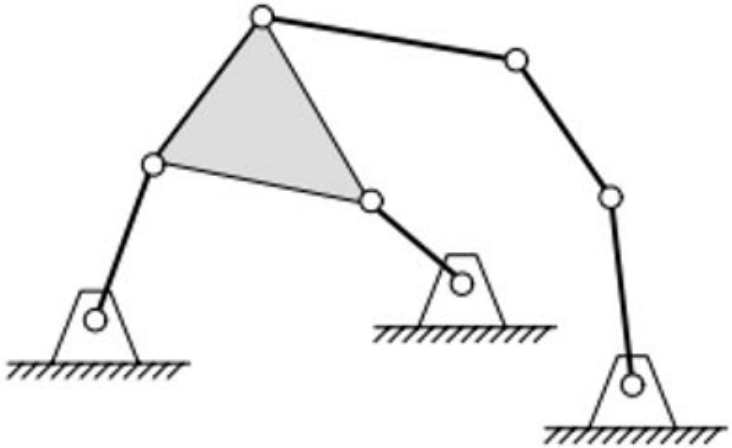
Prismatic joint

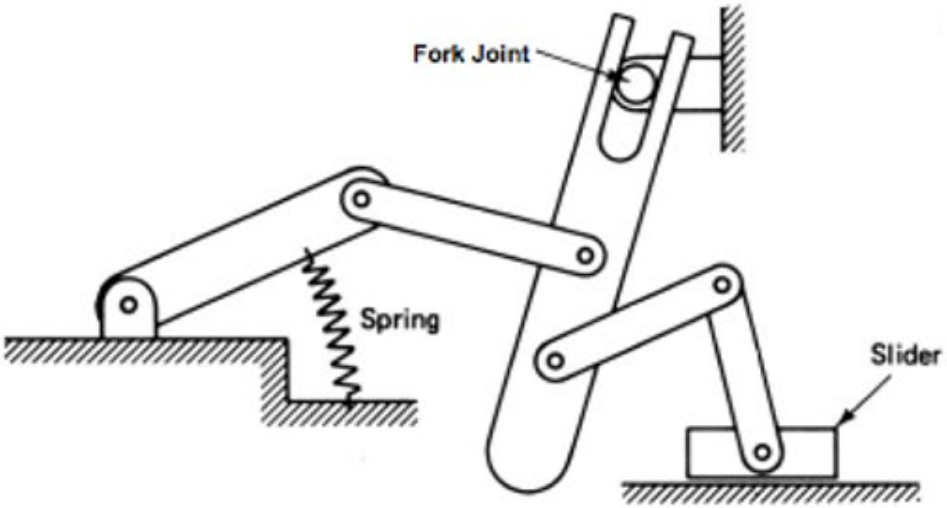


Spherical joint

dof can be difficult to calculate…

Determine the degree of freedom of the following mechanisms



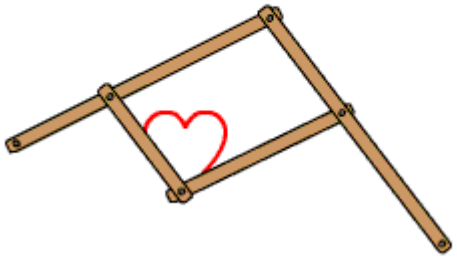


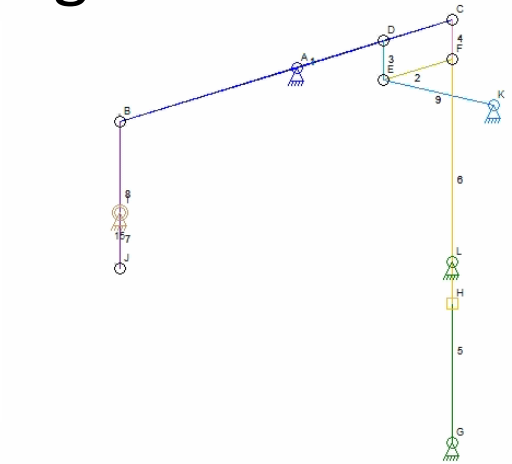
Gruebler's Equation:

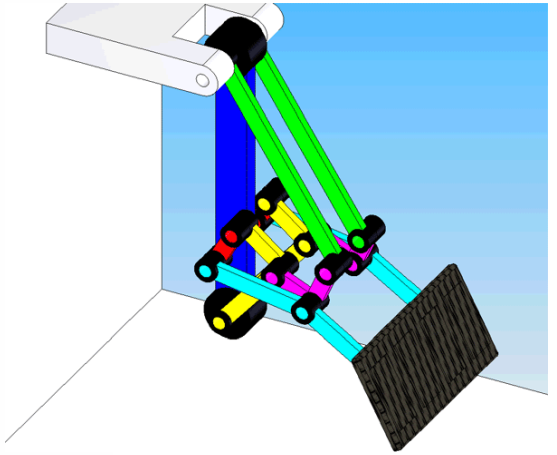
$$M = \text{degrees of freedom} = 3(n-1) - 2j_p - j_h$$

4 bar linkage

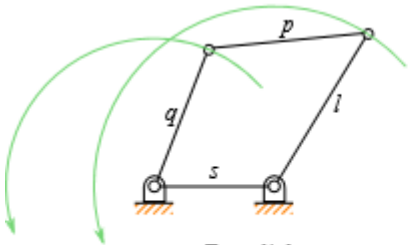
A **mechanical linkage** is an assembly of bodies connected to manage forces and movement.





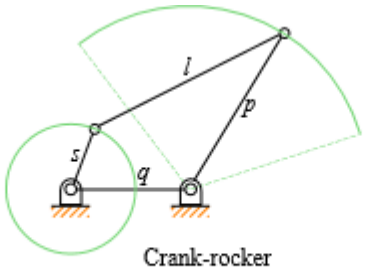


A 4 bar linkage is the simplest movable closed chain linkage

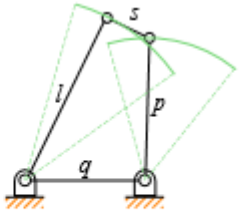


full revolution both links

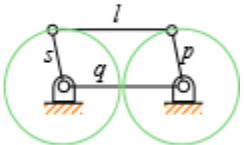
Drag-link
$s+l < p+q$
(continuous motion)



Crank-rocker
$s+l < p+q$
(continuous motion)



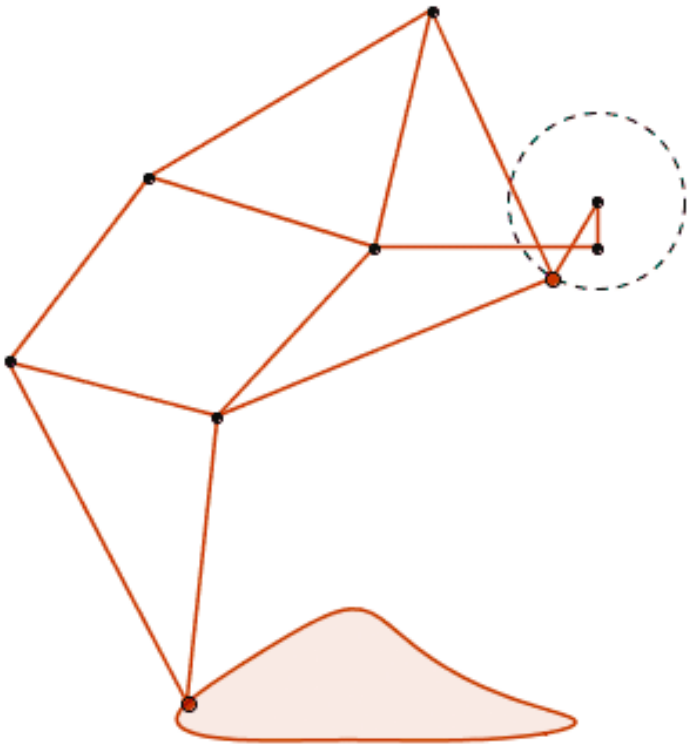
Double-rocker
$s+l > p+q$
(no continuous motion)



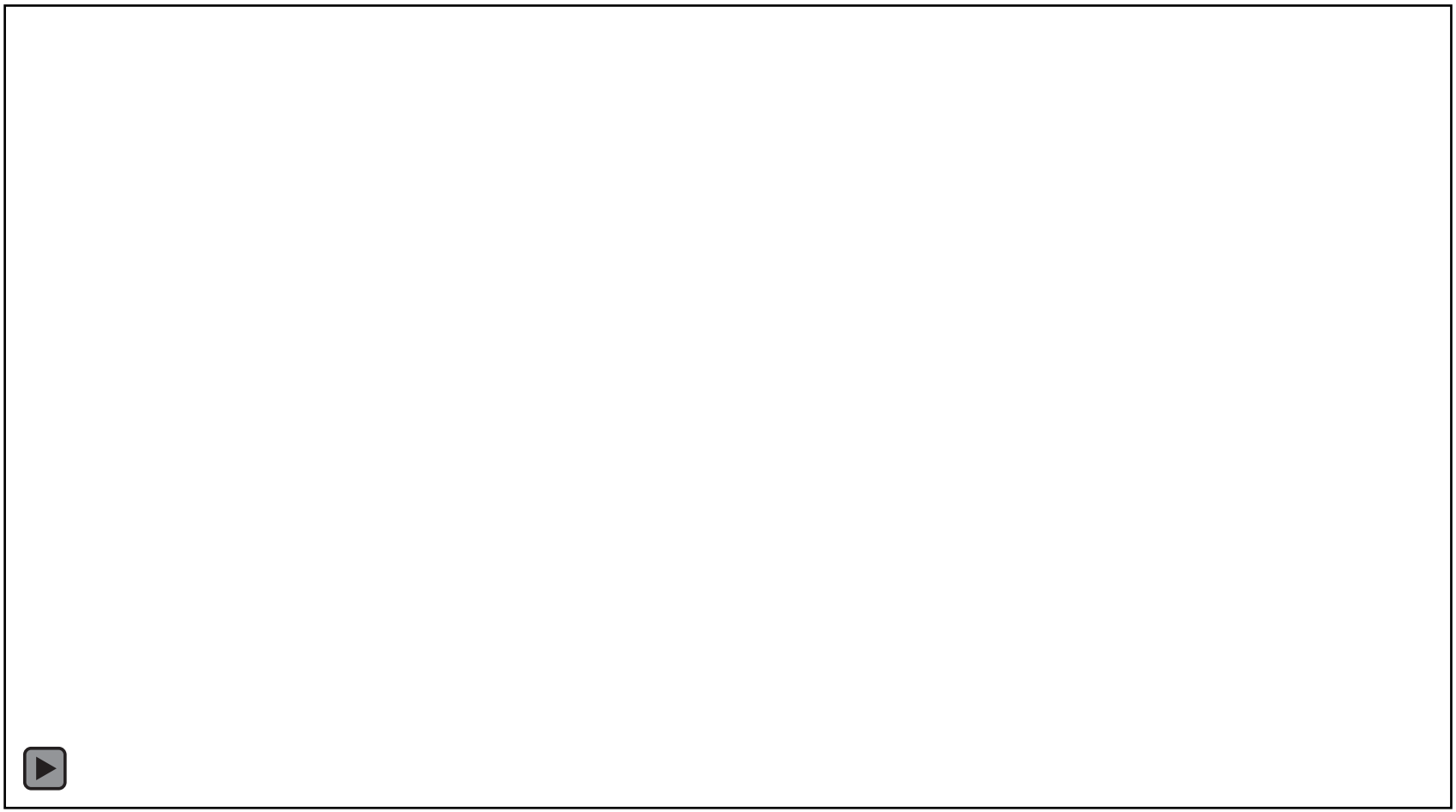
Parallelogram linkage
$s+l = p+q$
(continuous motion)

Some 4 bar linkages

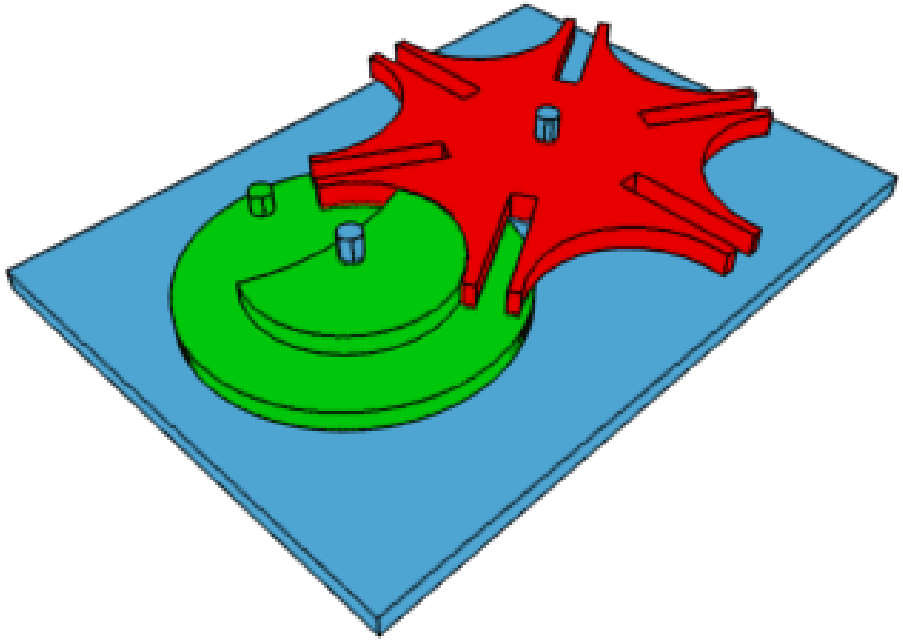
Theo Jansen Linkage

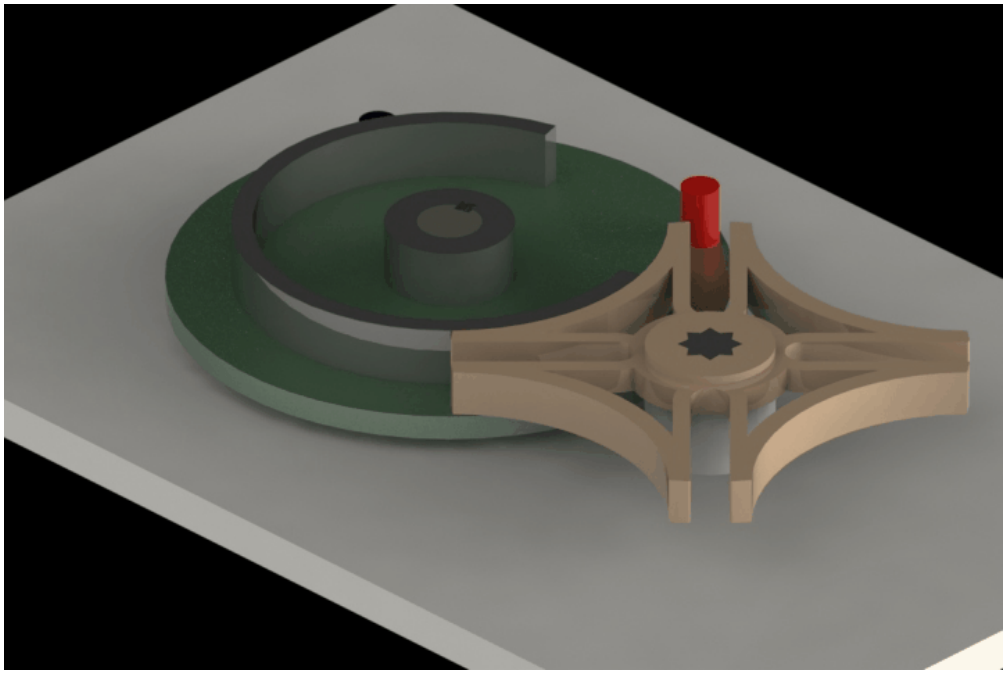


Theo Jansen Linkage made at ITU

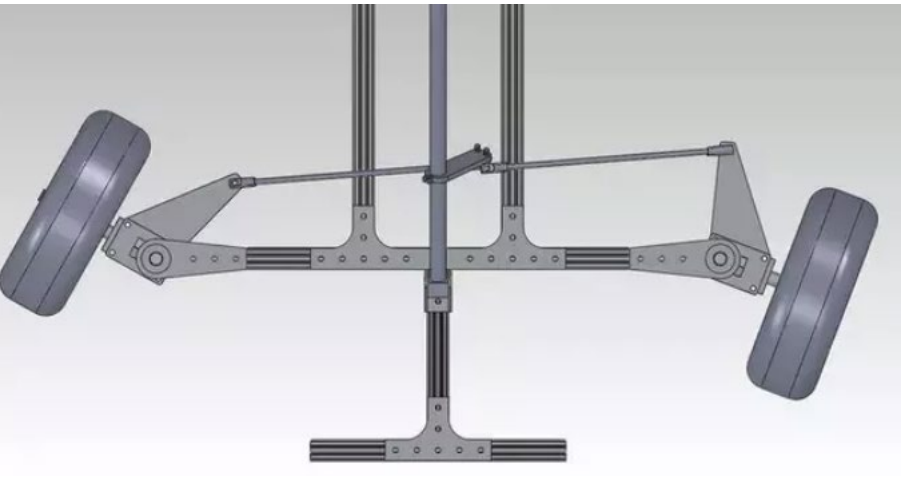


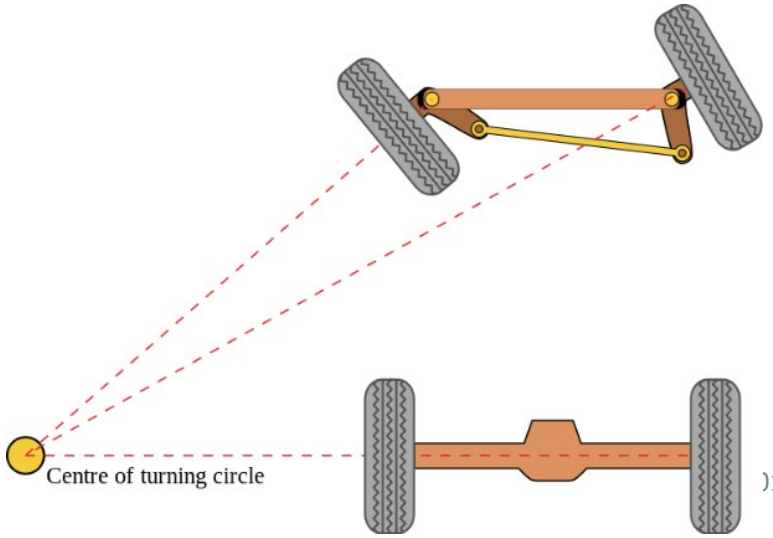
Geneva drive





And many more…





Task I: Test some linkages

Option 1:

Build some 4 bar linkages with Lego parts

Option2:

Check the behaviour of a 4 bar linkage

http://dynref.engr.illinois.edu/aml.html#aml-sj

Option 3:

Check Theo Jansen linkage

http://www.mekanizmalar.com/theo-jansen.html

Option 4:

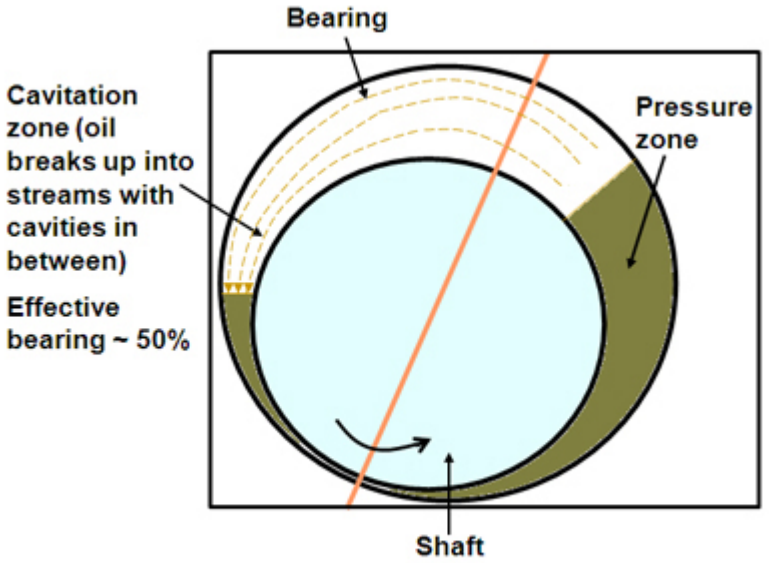
Look “linkage” up in Thingiverse

Bearings and guides

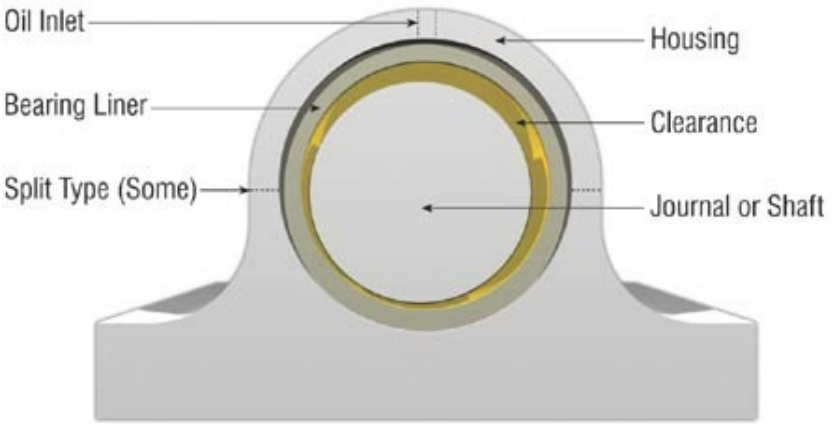
Plain bearings

Simplest bearing
No rolling elements
Low friction
    Plastic
    Bronze

Compact
Lightweight
Support high loads
Cheap



NOTE: Oil cannot be stretched in tension, the film breaks up into streams of droplets with cavities in between.

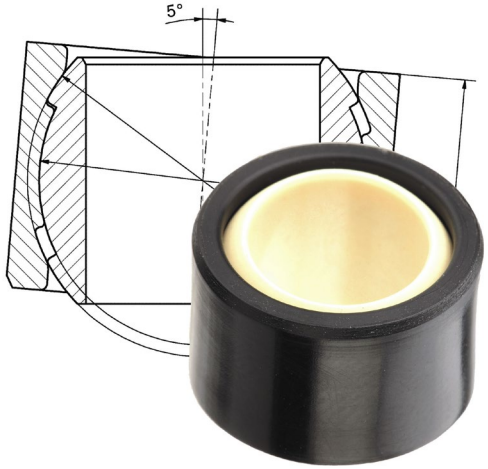


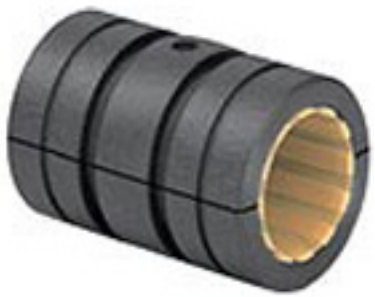
Common Journal Bearing Components

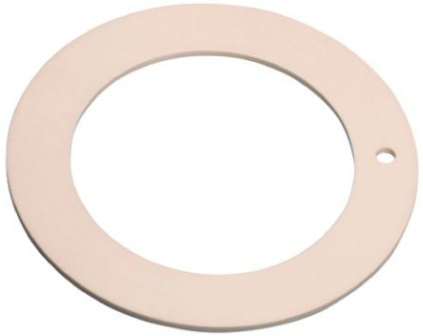
- Housing
- Bearing liner
- Segment (split type)
- Oil inlet
- Drain
- Journal

Figure 2. Plain Bearings (Journal Bearings)

Plain bearings

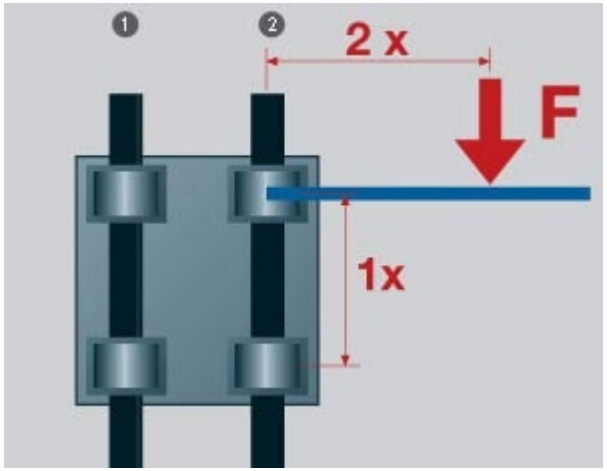


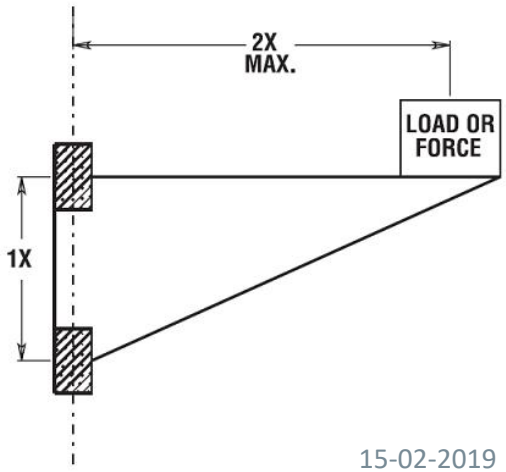




Plain bearings- Rule 1:2

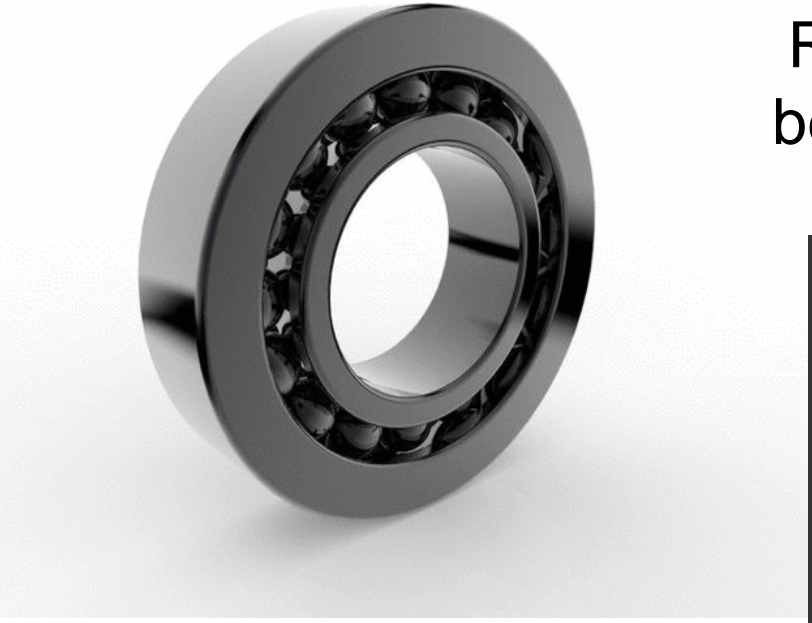
if either the drive force or applied load force are a greater distance than twice the bearing length, then a binding or chattering of the system can occur.

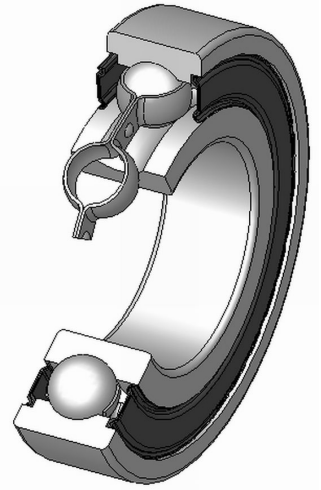




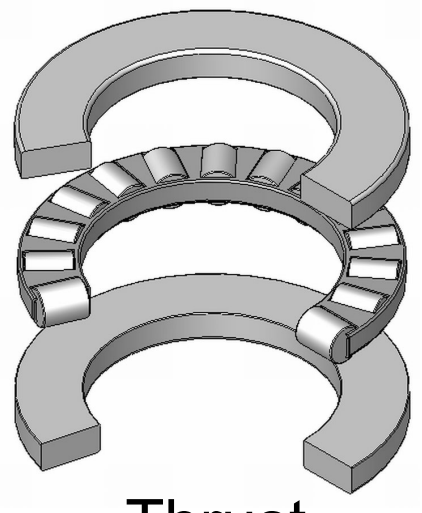
Rolling bearings

Almost no friction
High loads
Require lubrication
More expensive



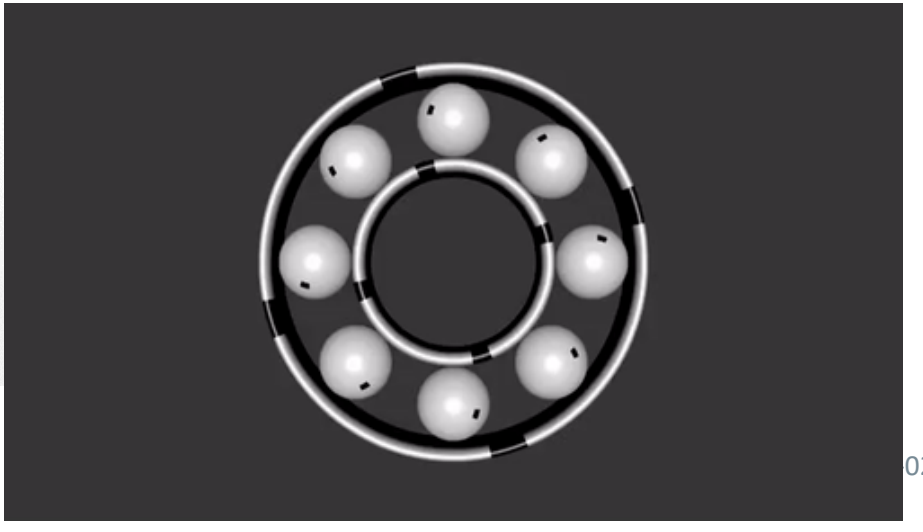


Radial bearing



Thrust bearing

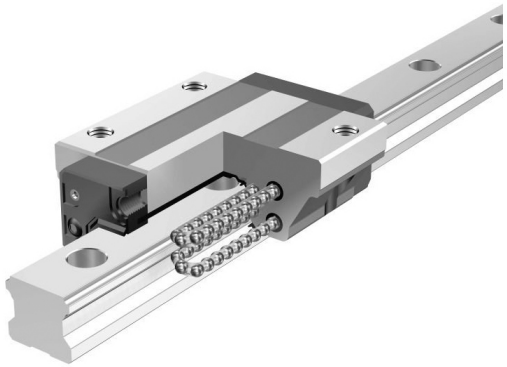
Linear bearing



Linear guides

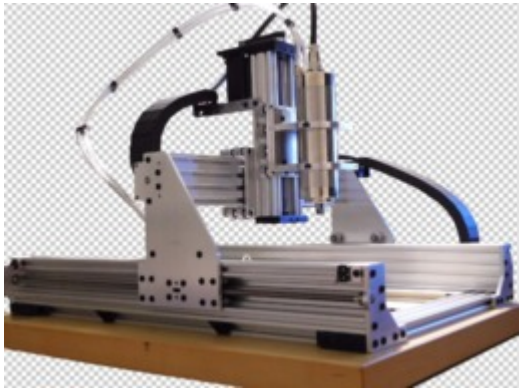
Using plain bearings:

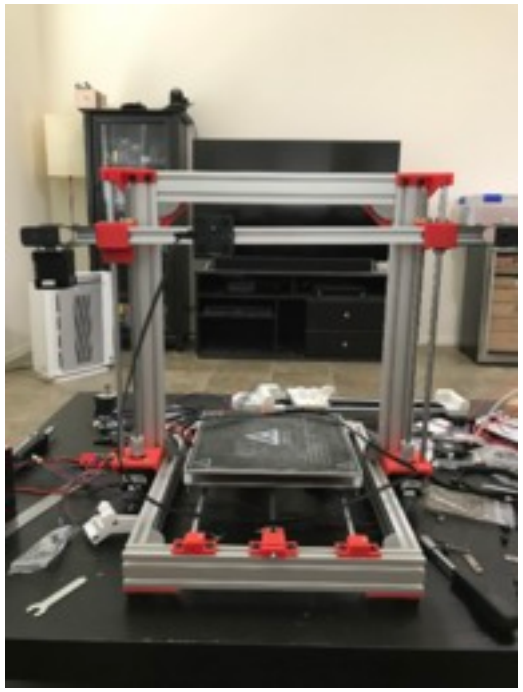
Using rolling bearings:

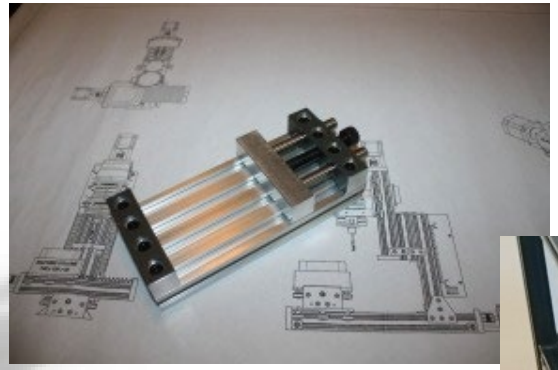


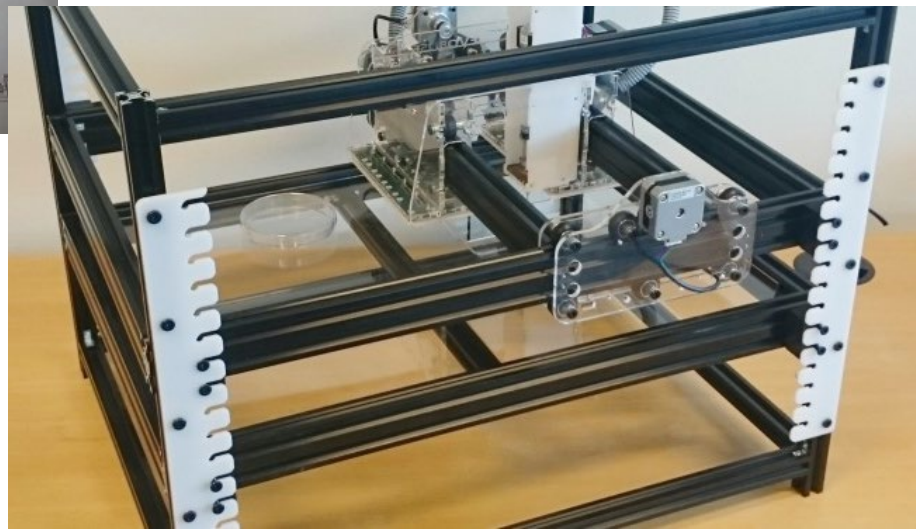
Linear guides: V-slot

Linear guides: V- slot



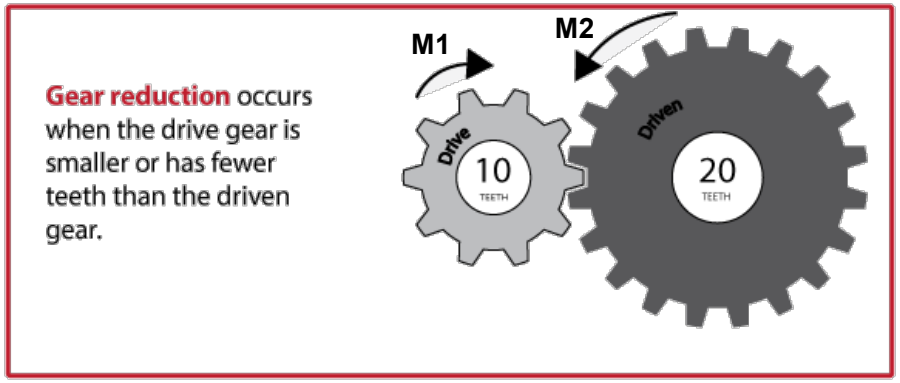


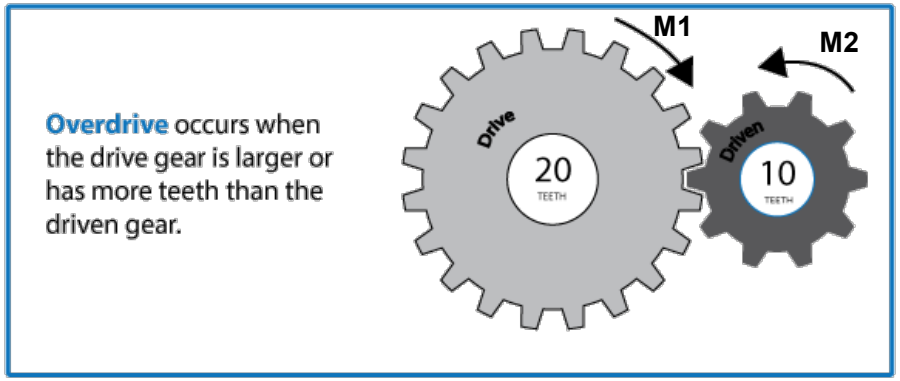


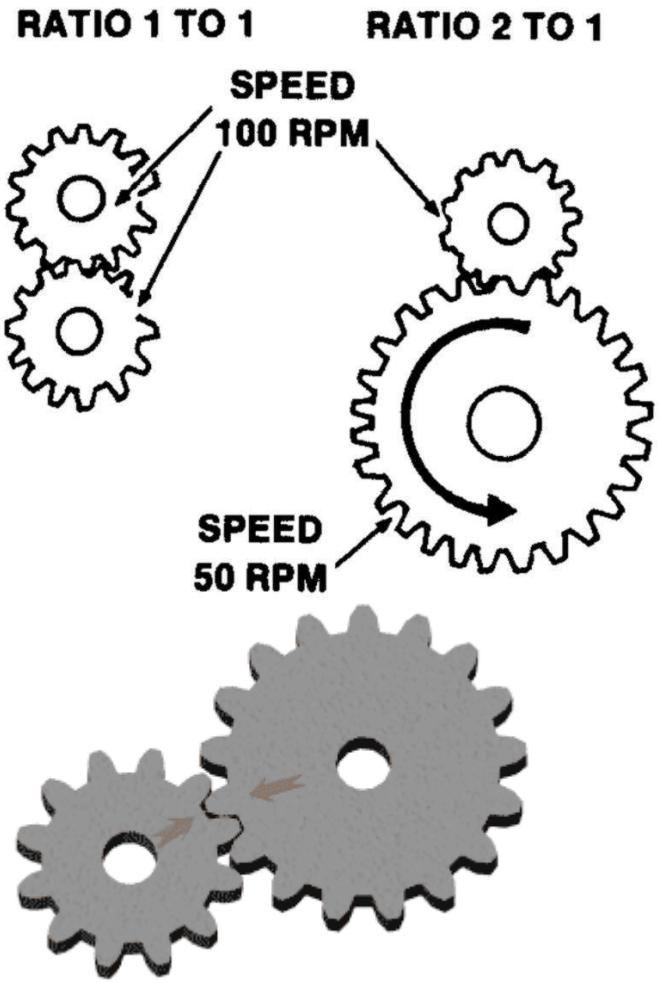


Power Transmission (forces)

Gears





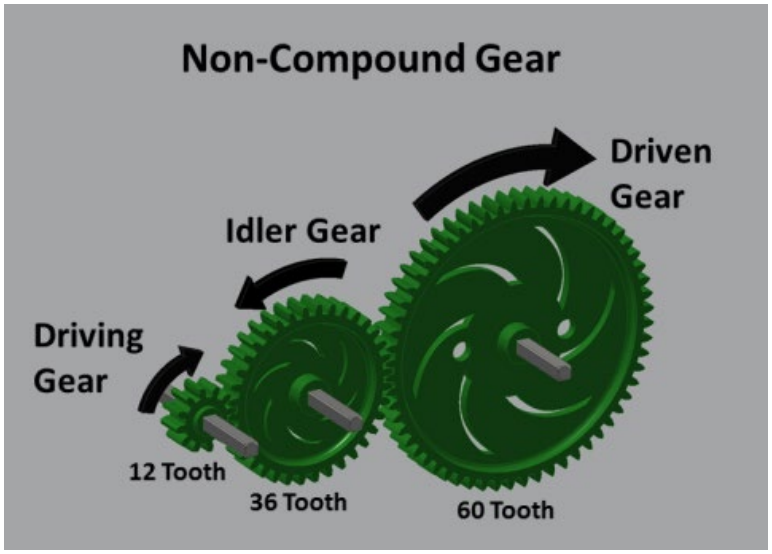


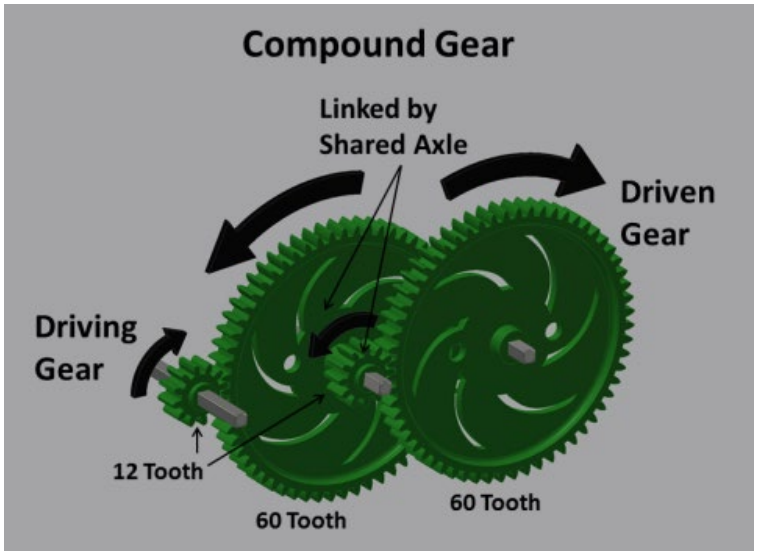
$$\text{Gear ratio} = \frac{Teeth\ output\ gear}{Teeth\ input\ gear}$$

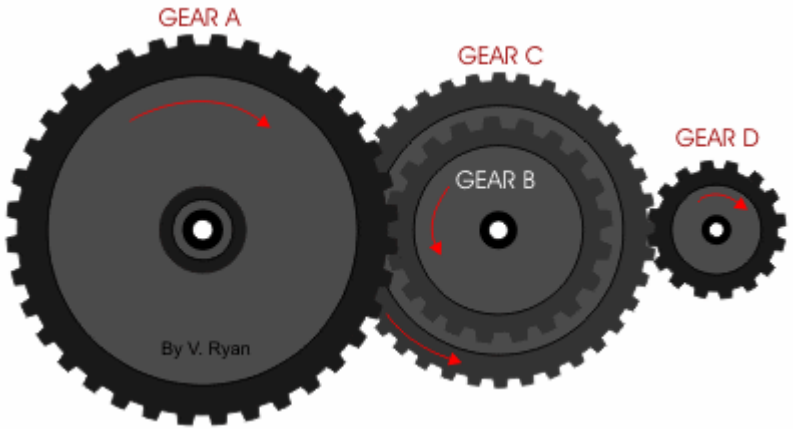
$$\text{M2} = Gear\ ratio\ * \text{M1}$$

$$\text{Speed2} = \frac{1}{Gear\ ratio}\ * \text{Speed1}$$

Compound Gears



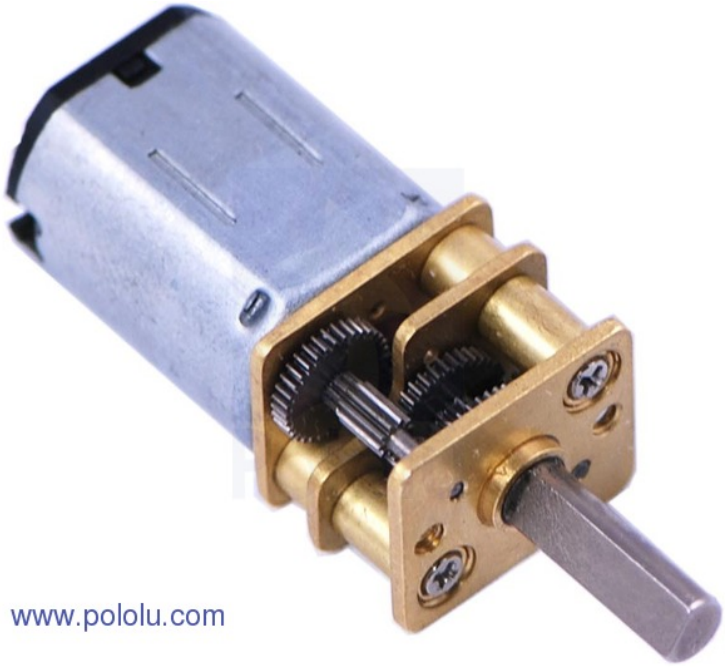




Compound Gear Ratio = Reduction 1 x Reduction 2

Compound Gear Ratio =(60 / 12) x (60 / 12) = (5/1) x (5/1) = 25/1

DC motor + reduction



Motor Type	Stall Current @ 6 V	No-Load Speed @ 6 V	Approximate Stall Torque @ 6 V	 Single-Shaft (Gearbox Only)
high-power, carbon brushes **(HPCB)**	1600 mA	3000 RPM	4 oz-in	10:1 HPCB
		1000 RPM	9 oz-in	30:1 HPCB
		625 RPM	15 oz-in	50:1 HPCB
		400 RPM	22 oz-in	75:1 HPCB
		320 RPM	30 oz-in	100:1 HPCB
		200 RPM	40 oz-in	150:1 HPCB
		140 RPM	50 oz-in	210:1 HPCB
		120 RPM	60 oz-in	250:1 HPCB
		100 RPM	70 oz-in	298:1 HPCB
		32 RPM	125 oz-in	1000:1 HPCB

Types of Gears

Spur Gear

Helical Gear

Double Helical Gear
(Herringbone Gear)

Spiral Bevel Gear

Miter Gear

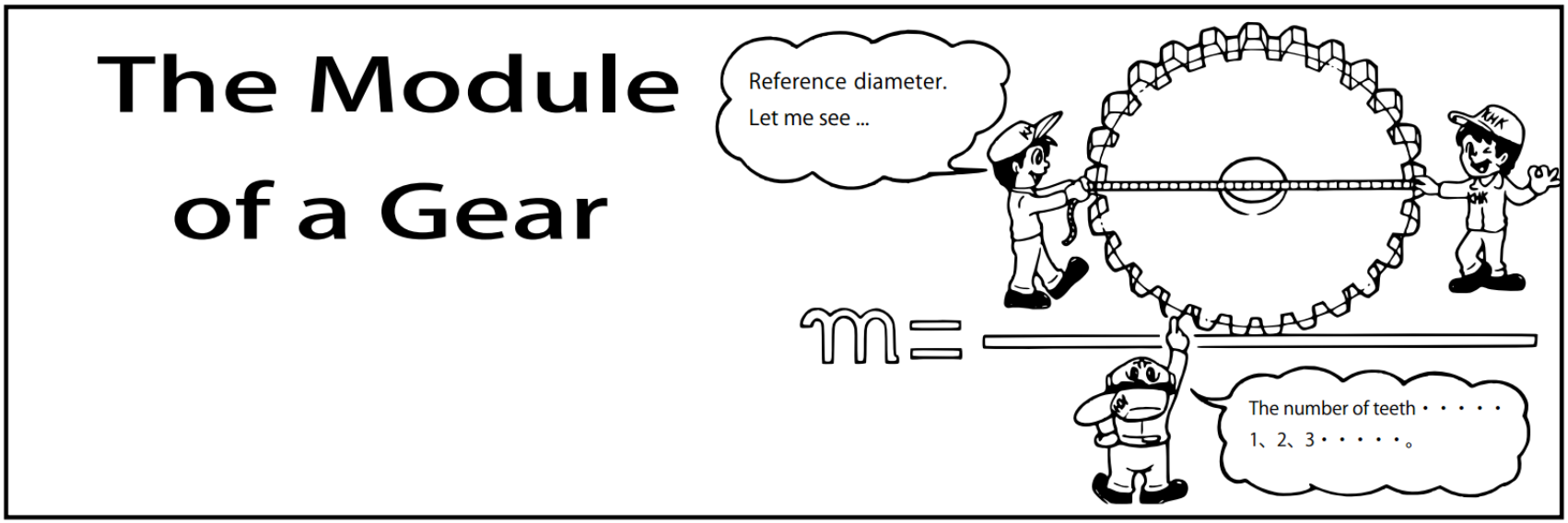
Straight Bevel Gear

Internal Gear

Worm Gear

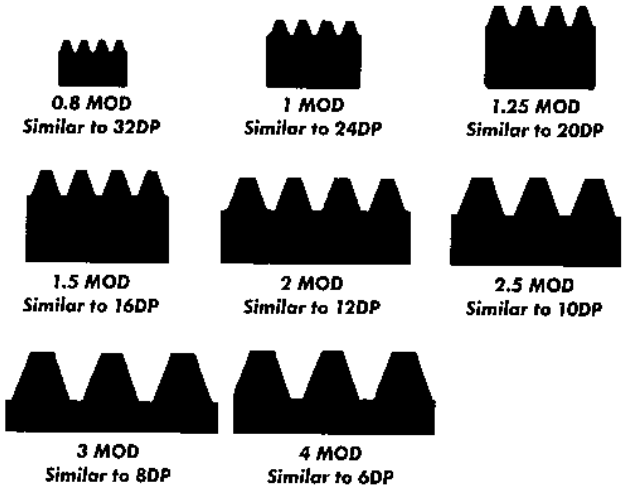
Rack and Pinion

Gears – Module



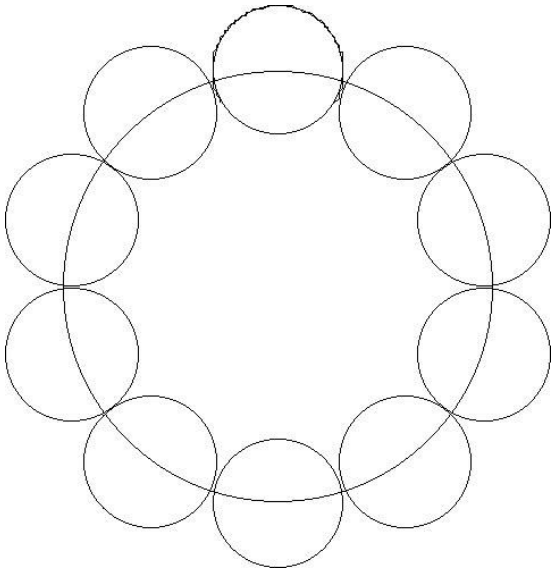
Gears only work with gears of the same module!

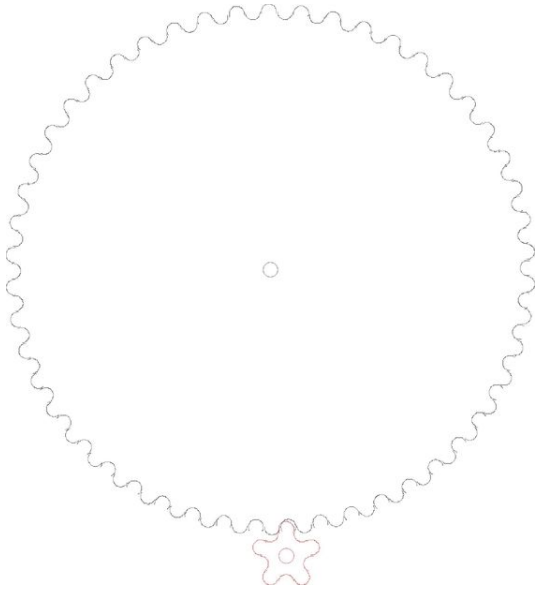
Gear of module < 1 are difficult to laser cut / 3d print!

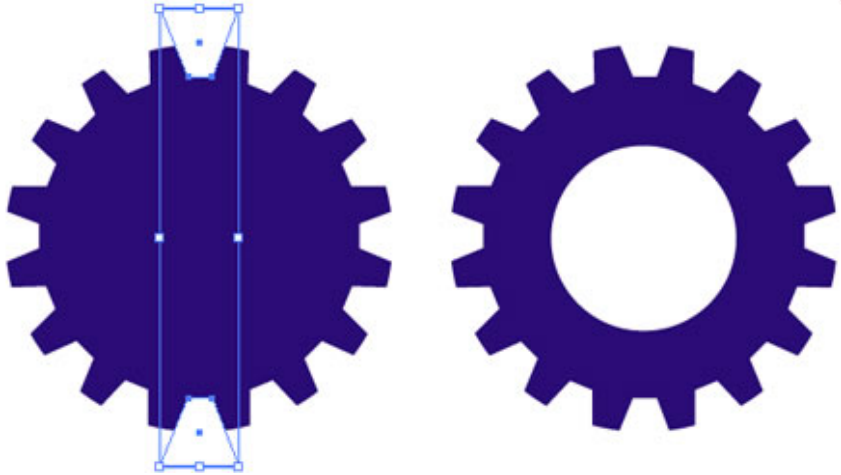


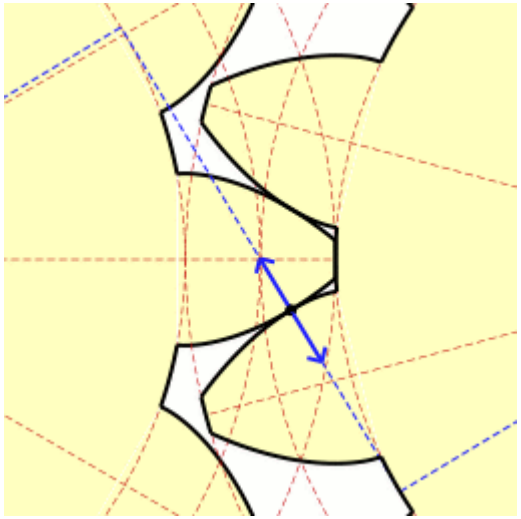
Gears – Tooth profile

There is a plugin to create gears in Fusion 360!









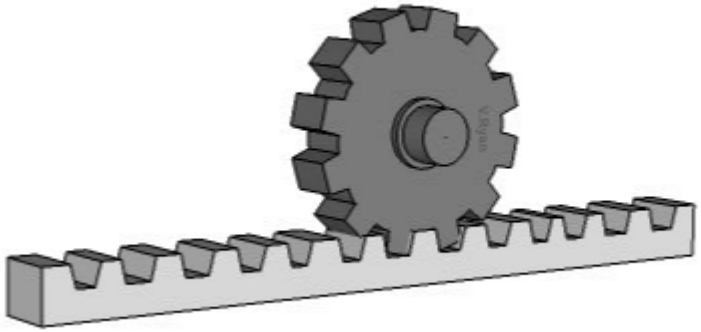
"Real" gears

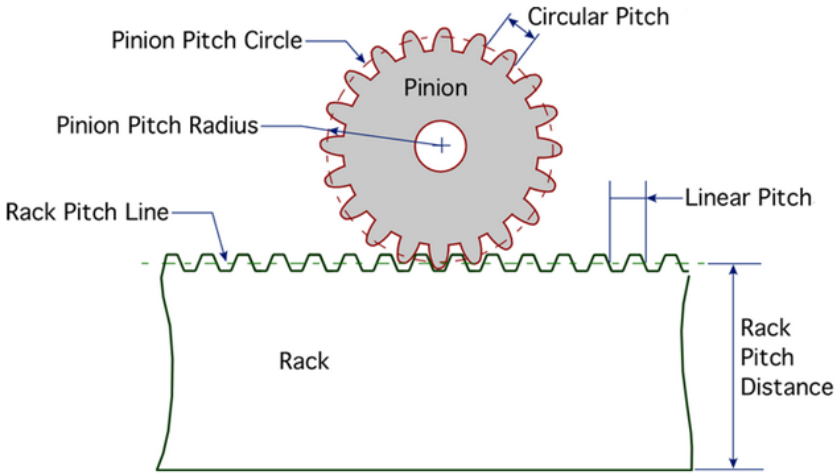
Pinion and Racks

Translate

turning motion into linear motion

linear motion into rotational motion

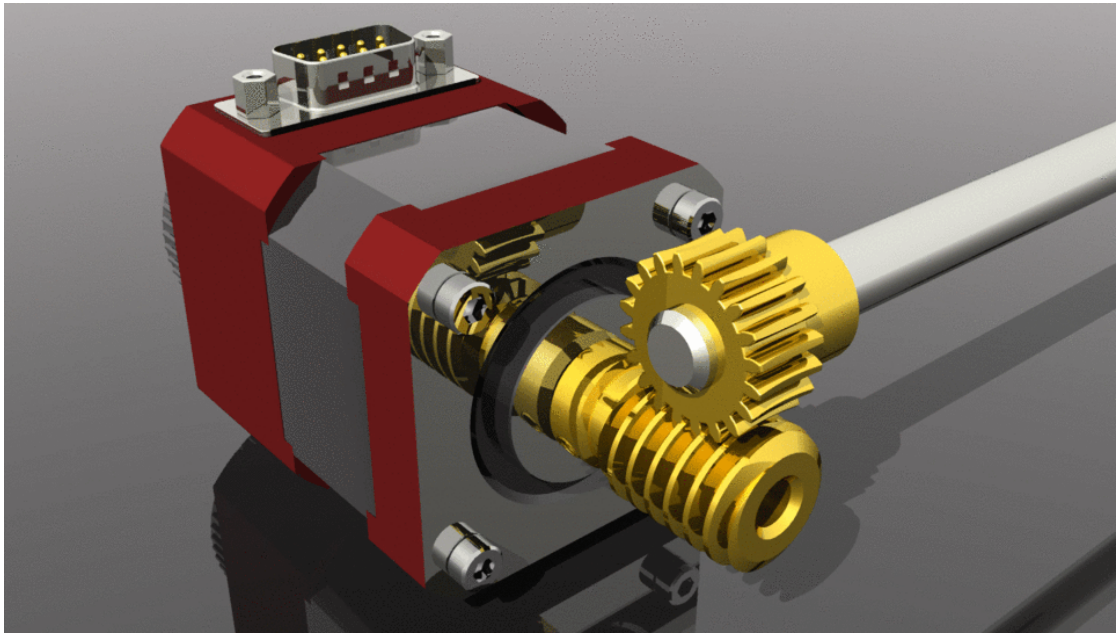




Endless gear or Worm gear

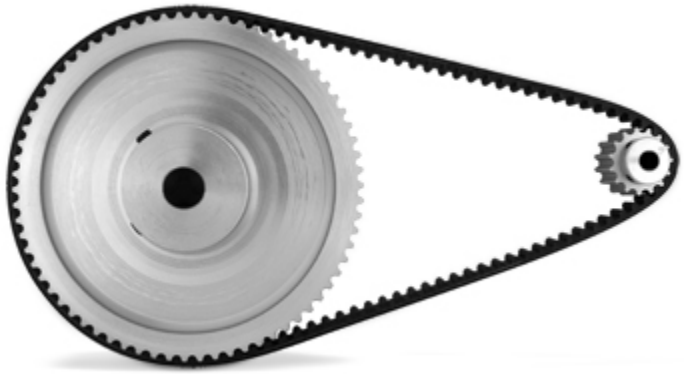
Translate turning motion into linear motion

Precise and accurate linear motion
High reduction (slow)
Self-locking
Not very efficient



Power transmission – Belts

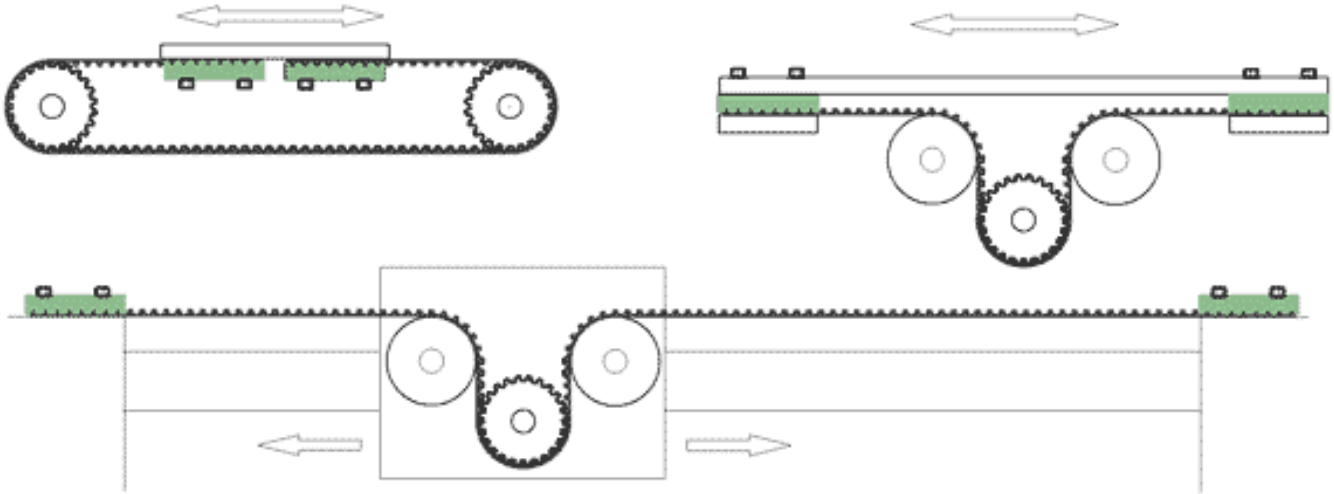
Loop of flexible material
Links 2 o more pulleys



Rotational movement

Lightweight
Cheap
Easy

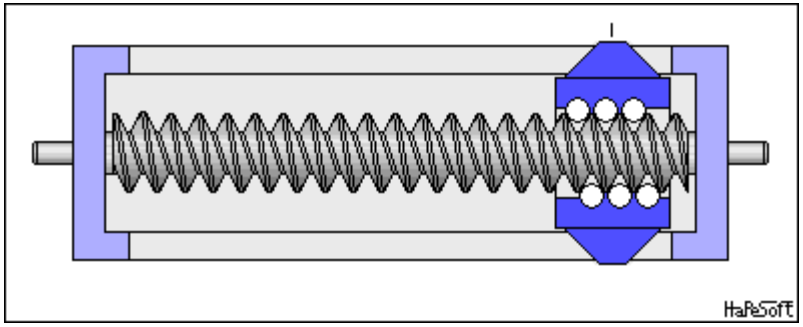
Linear movement



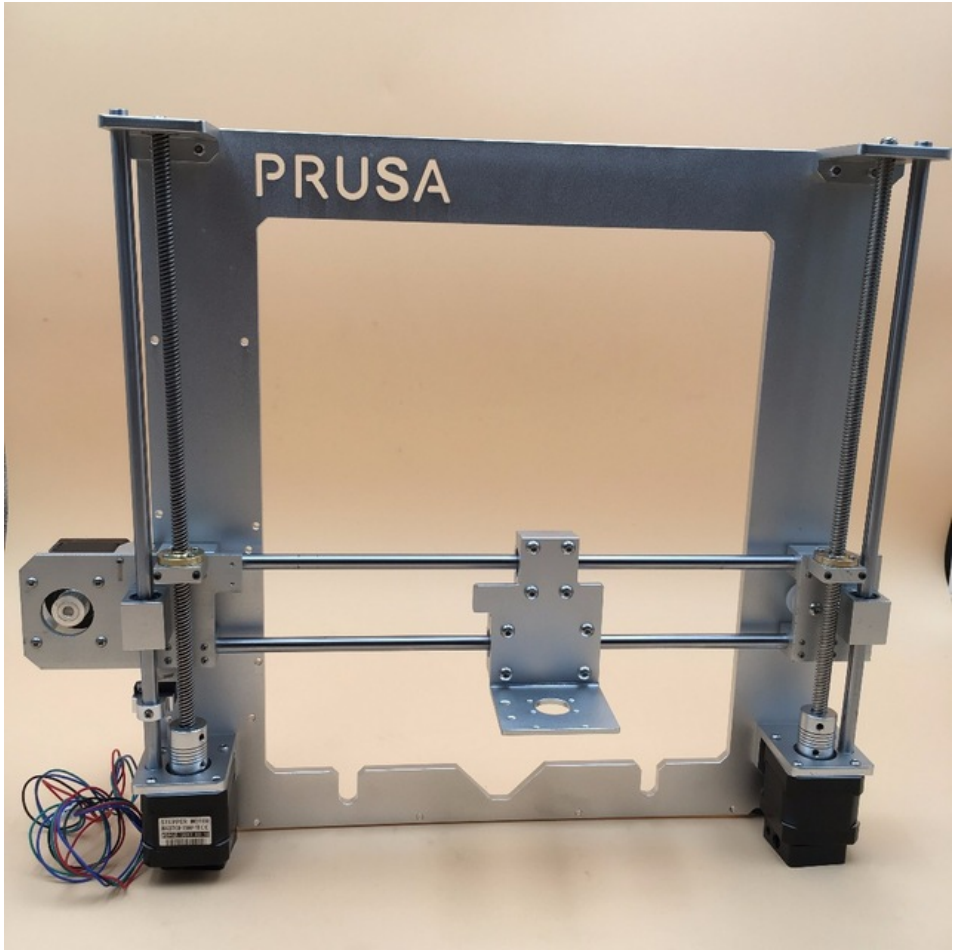
Power transmission – Lead screw

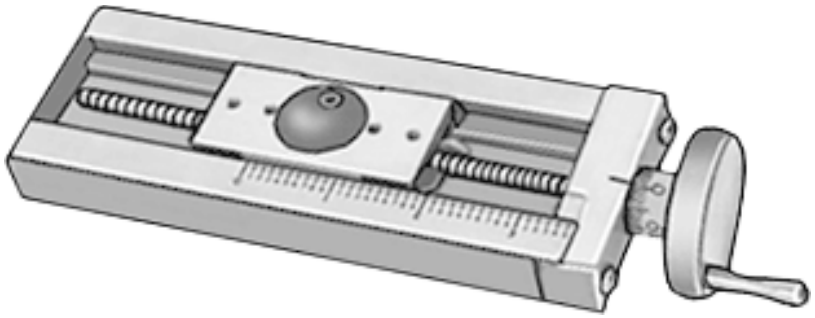
Translate turning motion into linear motion
Same principle as screws and nut (but larger pith)

Precise and accurate linear motion
Self-locking
Not very efficient



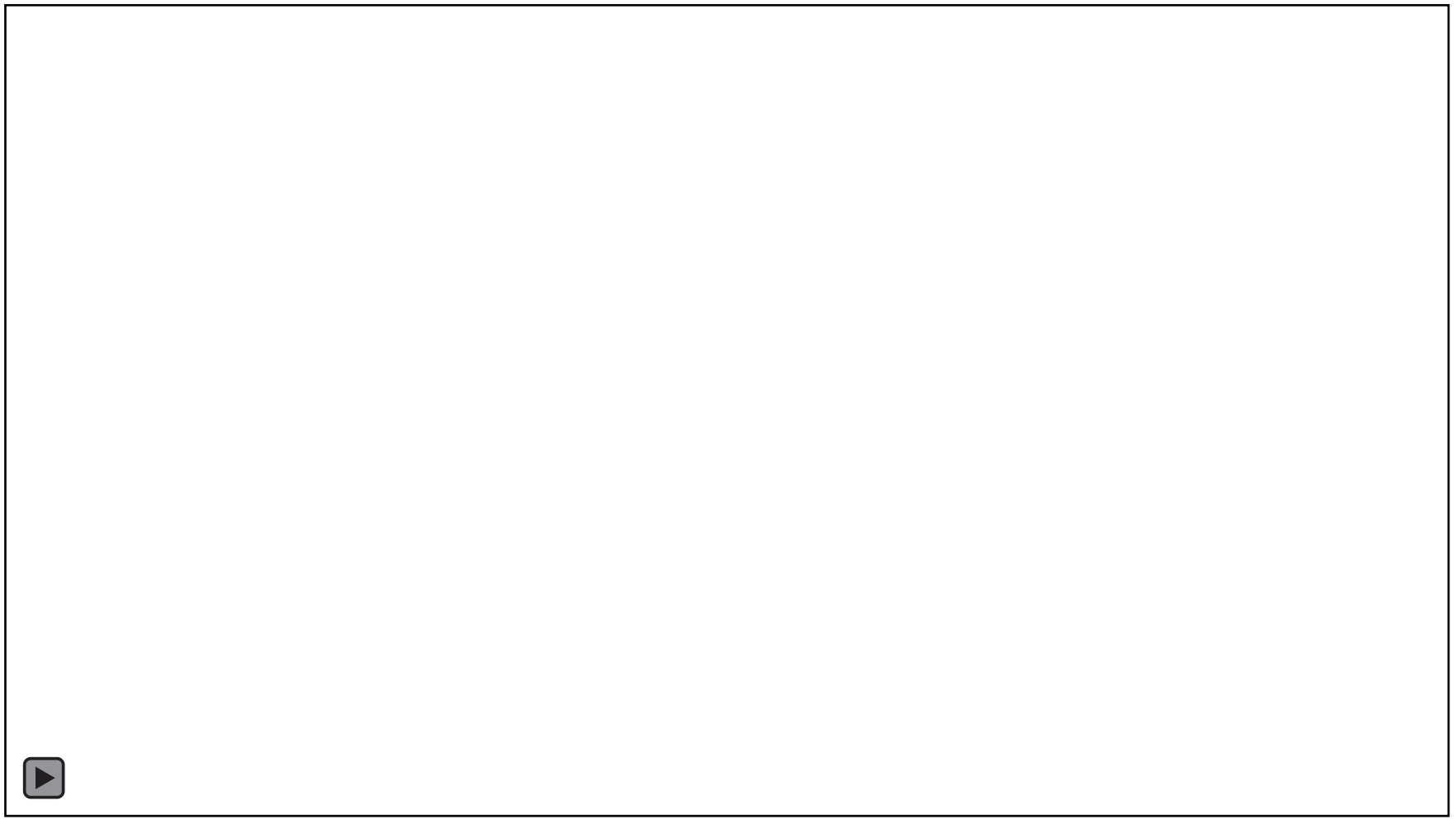
Lead screw – Applications





Some mechanisms in action

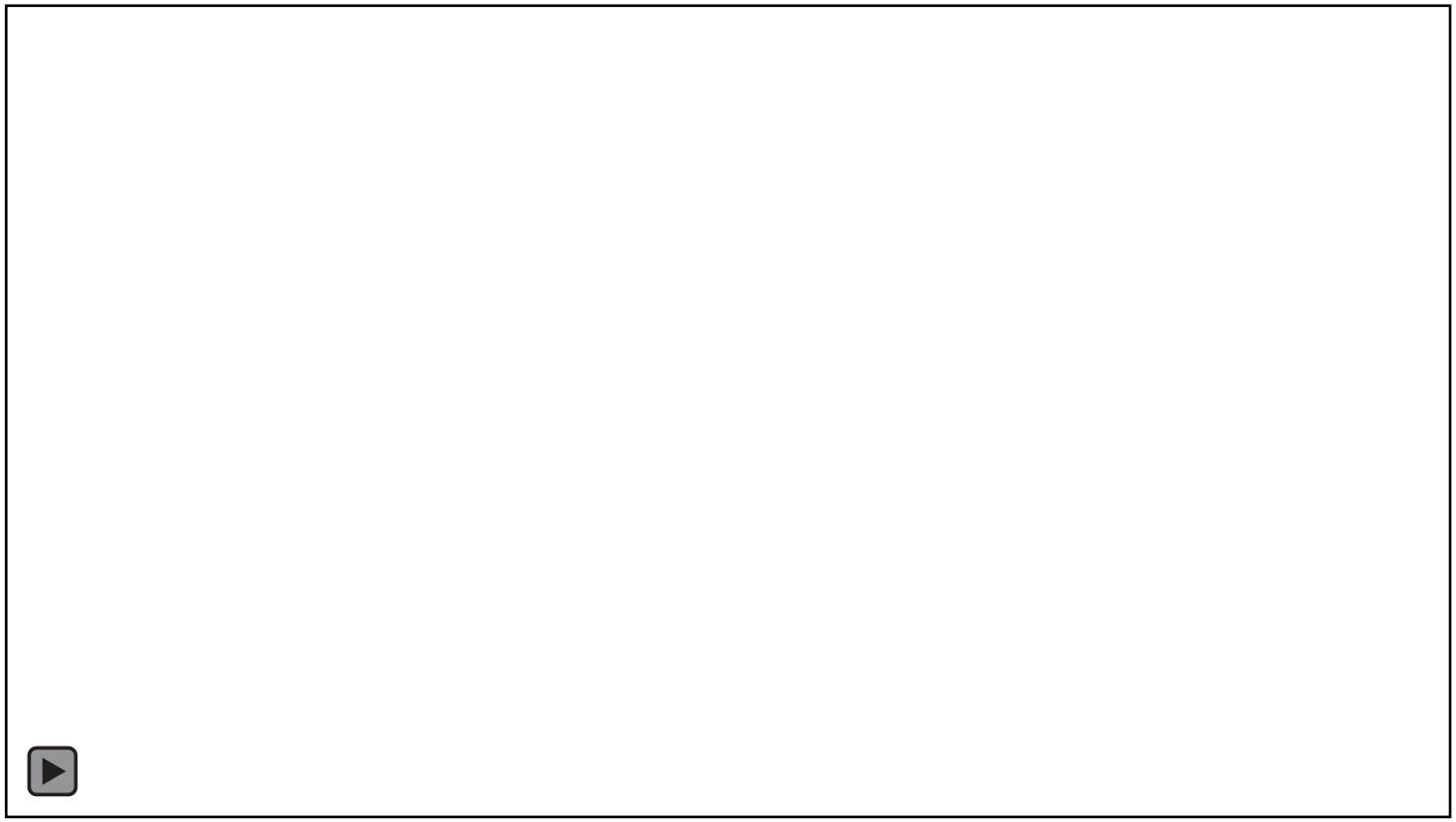
Some mechanisms in action II



Task 2:

Test some power transmission devices with Lego:

- Gears
- Endless screw + gear
- Pinion and rack

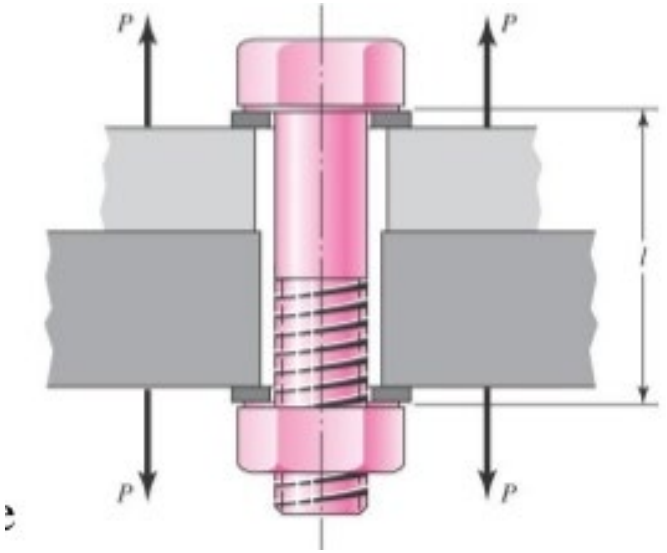


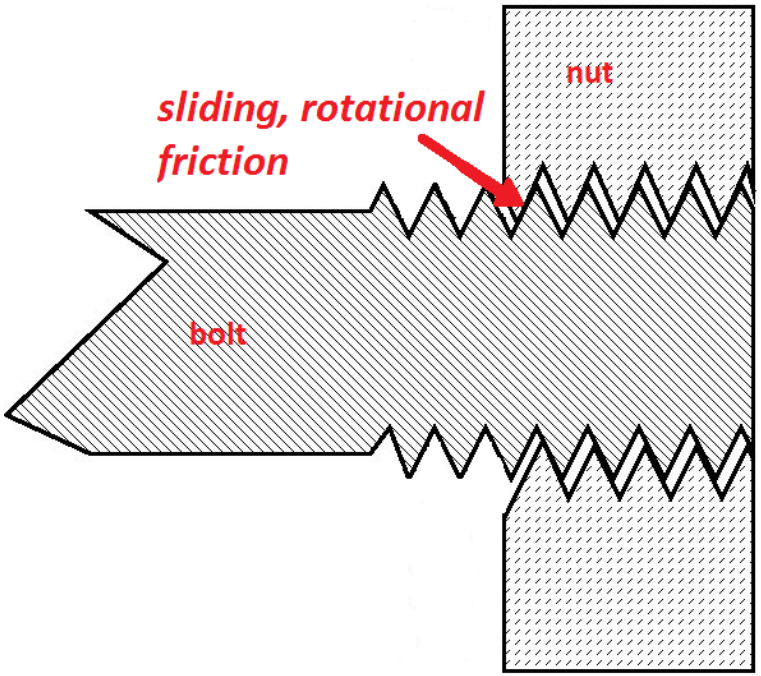
https://www.youtube.com/watch?v=BZIkTLrnLKw

Fasteners

Screws

a solid profile wrapped around a rod or nail

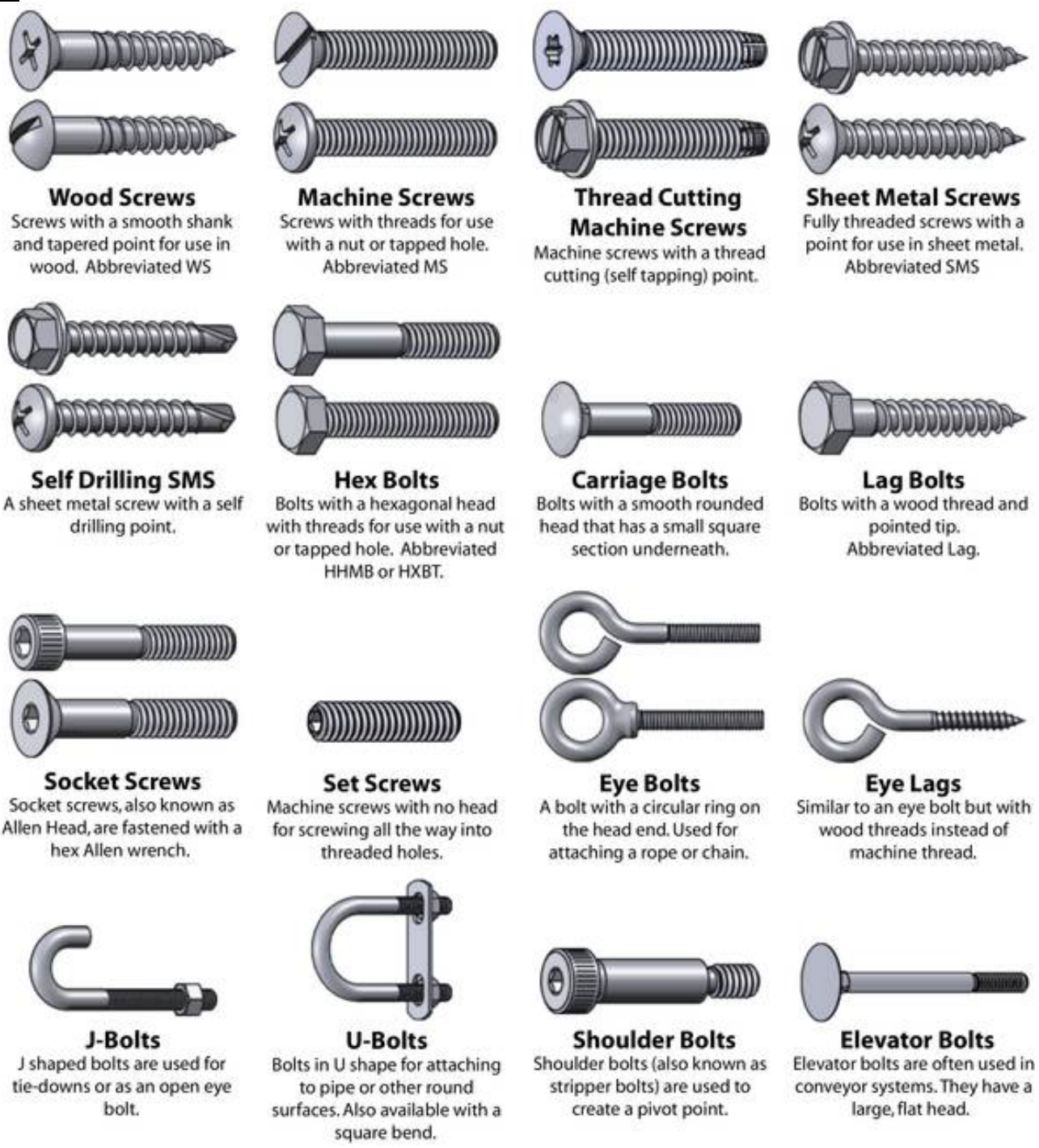




Types of screws

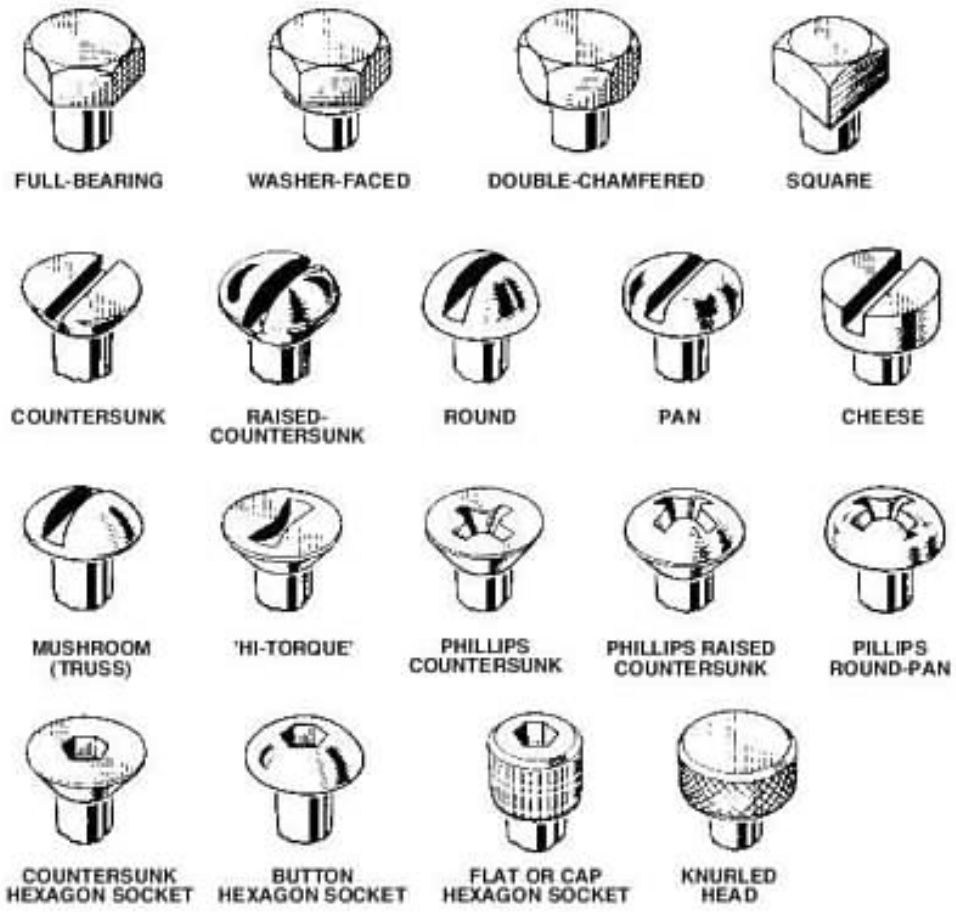
Most common types in our labs:

- Wood Screws
- Machine Screws
- Socket Screws
- Set Screws

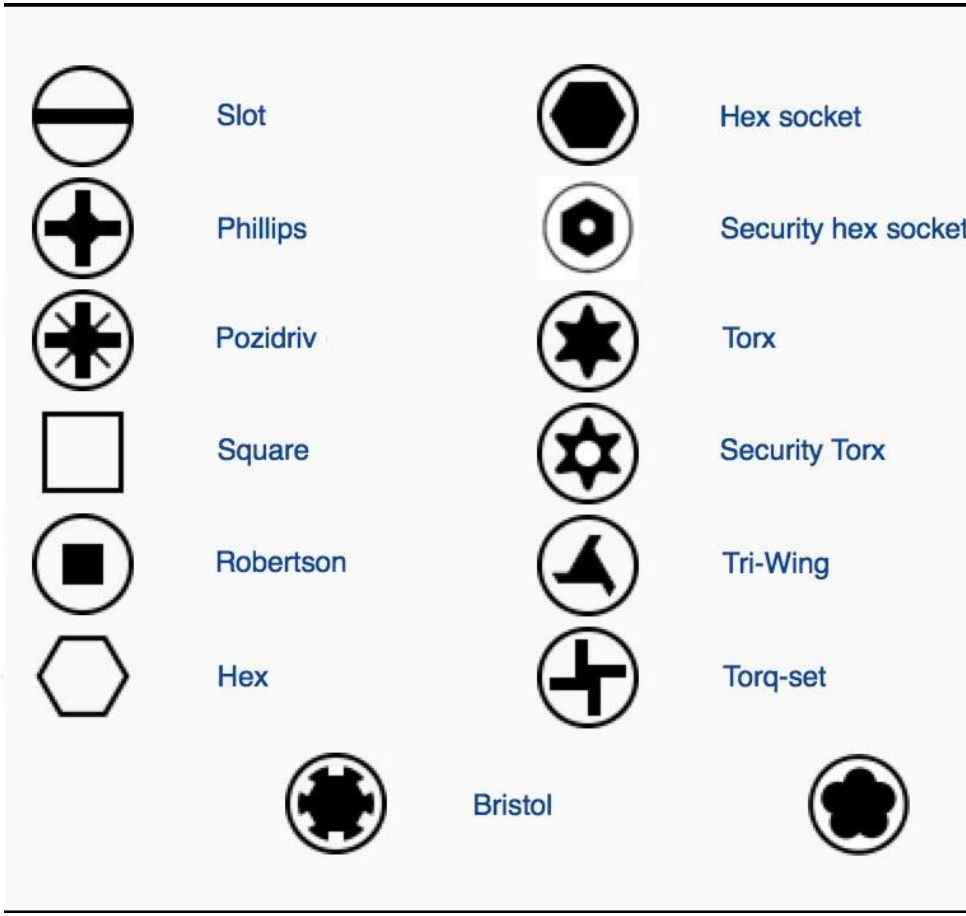


Screws- Heads and Screw drives

Heads



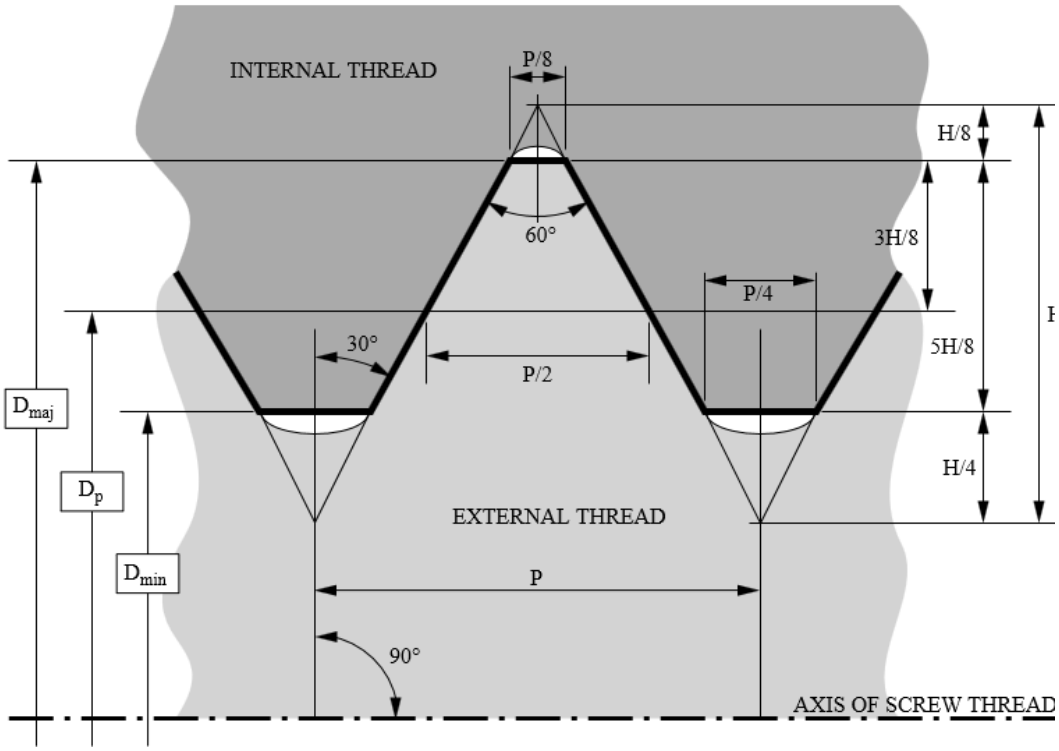
Screw drives



Machine Screws

Standards:

- Metric
- UNC (Imperial)

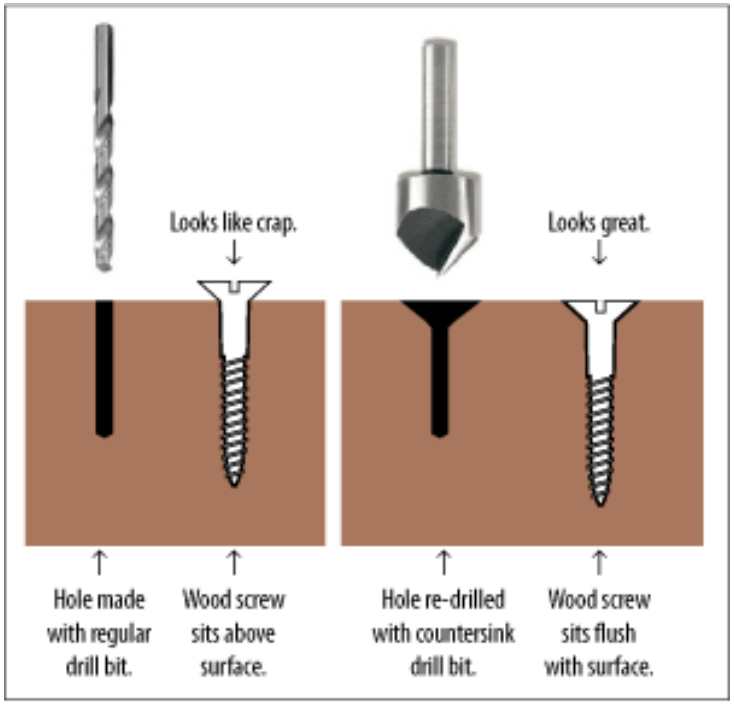


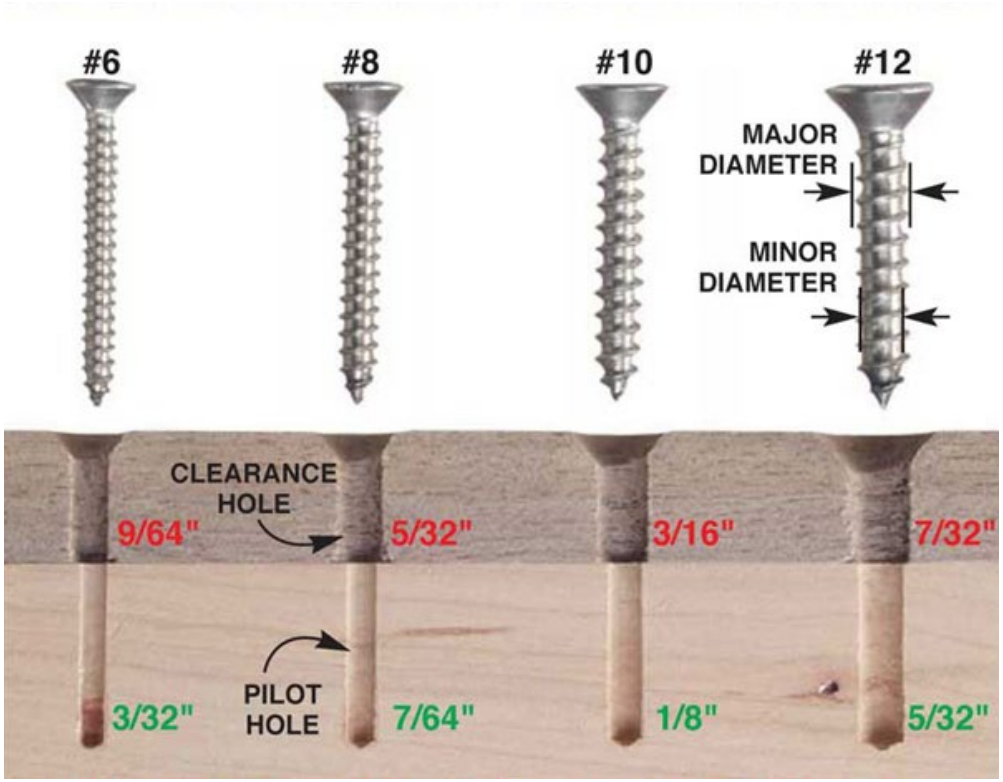
ISO 262 selected sizes for screws, bolts and nuts

Nominal diameter *D* (mm)		Pitch *P* (mm)		Nominal diameter *D* (mm)		Pitch *P* (mm)	
1st choice	2nd choice	Coarse	Fine	1st choice	2nd choice	Coarse	Fine
1		0.25	0.2	16		2	1.5
1.2		0.25	0.2		18	2.5	2 or 1.5
	1.4	0.3	0.2	20		2.5	2 or 1.5
1.6		0.35	0.2		22	2.5	2 or 1.5
	1.8	0.35	0.2	24		3	2
2		0.4	0.25		27	3	2
2.5		0.45	0.35	30		3.5	2
3		0.5	0.35		33	3.5	2
	3.5	0.6	0.35	36		4	3
4		0.7	0.5		39	4	3
5		0.8	0.5	42		4.5	3
6		1	0.75		45	4.5	3
	7	1	0.75	48		5	3
8		1.25	1 or 0.75		52	5	4
10		1.5	1.25 or 1	56		5.5	4
12		1.75	1.5 or 1.25		60	5.5	4
	14	2	1.5	64		6	4

Wood Screws

Self-tapping
Bigger pitch than Metric screws





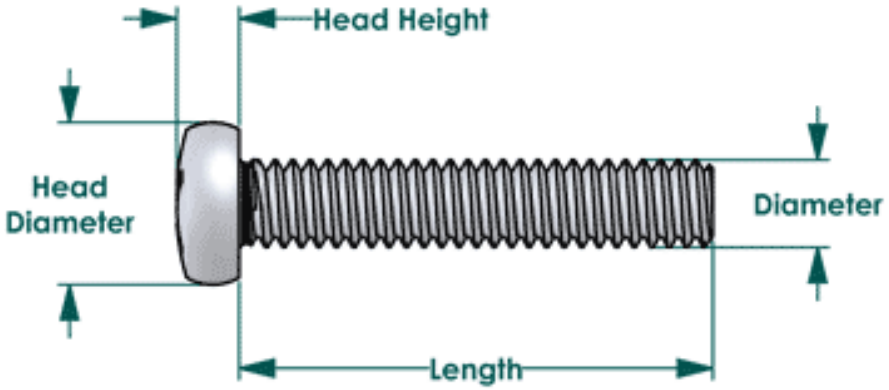
Defining Screws

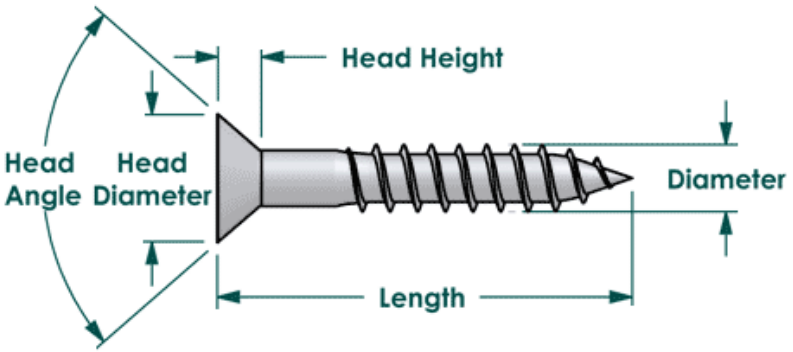
Minimum: Type of thread and length

Examples:

- M5x30
- M3x20
- #8-32x1´´ (Imperial screw, avoid them)

Optional: Type of head, screw drive





Thread rods

"Infinite" screws

Cut them to appropriate lengths

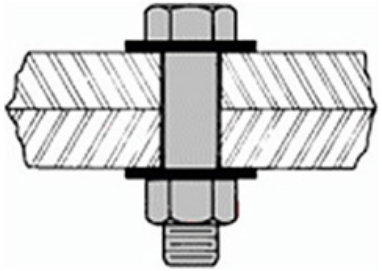
Can be used as a cheap lead screw

Very small pitch (slow but accurate movements)

Nuts, inserts and tapping

Nuts

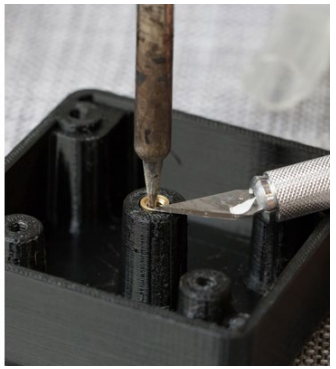
- Nyloc nuts to avoid loosening



Nyloc

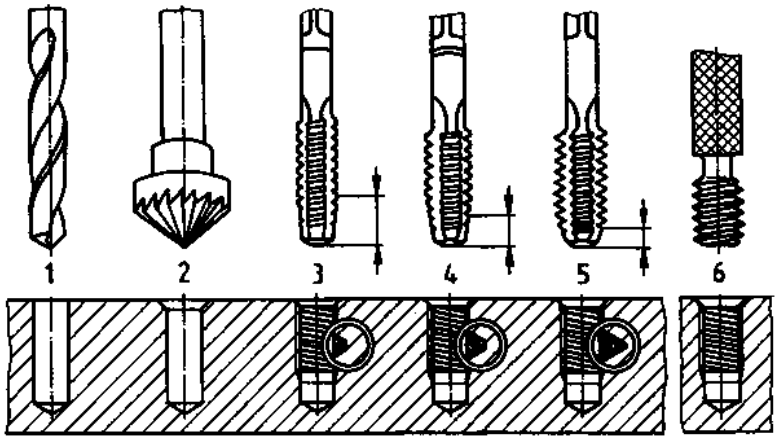
Inserts

- Premade thread
- Attached them to a part



Tapping

- Create a thread on a hole



Fasteners – Adhesives

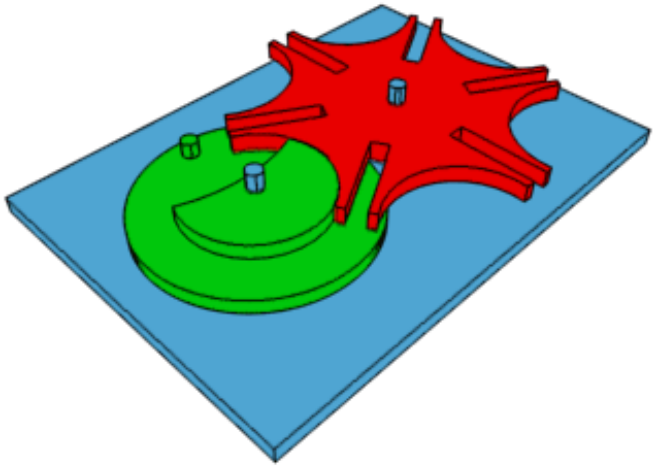
Hot glue
Glue
Glue stick
Tape
Double sided tape

Fasteners – Cable ties

Mandatory activity

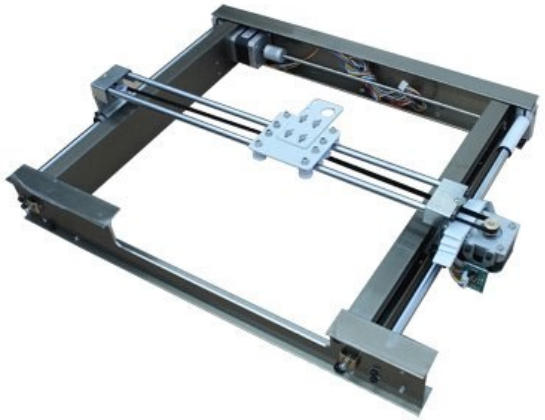
Finish the two proposed tasks:

- Check different linkages
- Test power transmission with LEGO



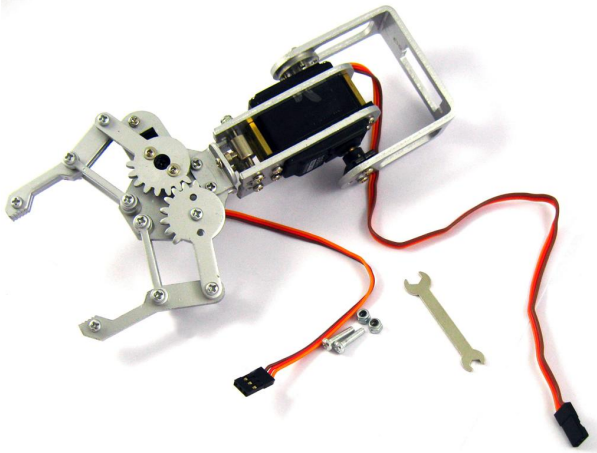
Design a mechanism in Fusion 360:

- Add joints to simulate the movement
- Add contact sets if needed
- **Groups of 3 members**:
  - 3D print/laser cut it (gripper for robot)



Ideas:

- Gripper in front of the robot
- Theo Jansen mechanism
- Gear reduction
- Geneva drive
- XY platform



What do we have in stock?

V-slot system (aluminium profiles, wheels, etc.)
8 and 3mm rods
3mm plain bearings
5 and 8mm rolling bearings
Pulleys and belts (GT2)
Thread rod (3, 4, 5, 8)
8mm lead screw

And gears, racks?

A few, but try to laser cut/3D print them

Other elements:

If cheap, we can buy them. Ask first!

Resources - Design

Designing gears:

http://www.learningfusion360.com/lesson-4-modelling-a-gear/

https://www.desktopmakes.com/single-post/2017/05/04/The-Easy-Way-to-Design-Gears-in-Fusion-360

http://www.instructables.com/id/How-To-3D-Printable-Bevel-Gears-Fusion-360/

http://www.instructables.com/id/How-to-make-gears-easily/

V-Slot:

http://openbuilds.org/

Models of parts:

https://www.tracepartsonline.net

Resources – Shops (with 3d models too)

RS (Distributor):
http://uk.rs-online.com/web/
TME (Distributor): :
www.tme.eu/
V-Slot (V-Slot system and mechanics):
http://openbuildspartstore.com/
Igus (Bearings and guides):
www.igus.com
SKF (Bearings and guides): *:*
www.skf.com
Ebay (cheap parts):
www.ebay.com

Ready?

Let´s design!

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