ENPH 253 – Design week 4 topics

Design and Fabrication Planning
Proposal Document
Project Management and Teamwork

Motors and Solenoids

Software and Algorithms
Electronics Planning
Sensors and Feedback

General Mech Design Advice
Design Elements (structures/materials/mechanisms)

Motors

Gear Ratios

Solenoids

DC electric motors

•Sometimes you are given a graph for motor specifications, but usually you are only given a few operating parameters

•Example Motor https://solarbotics.com/product/rm4a/ (used in Week4 Bootcamp)

Model	Voltage		Free load		At Max. Efficiency				Stall
	Operating range	Norminal Voltage (V)	Speed (r.p.m.)	Current (A)	Speed (r.p.m.)	Current (A)	Torque (g.cm)	Output (W)	Torque (g.cm)
QX-RF-500TB-14415	1.5~6.0	3.0	1800	0.022	1400	0.085	8.0	0.11	41
QX-RF-500TB-14415	1.5~6.0	6.0	3700	0.028	3000	0.13	14	0.43	84

•Often you are only given 3 parameters: Nominal Voltage, Max Speed, and Stall Torque. This is sufficient for first-order analysis.

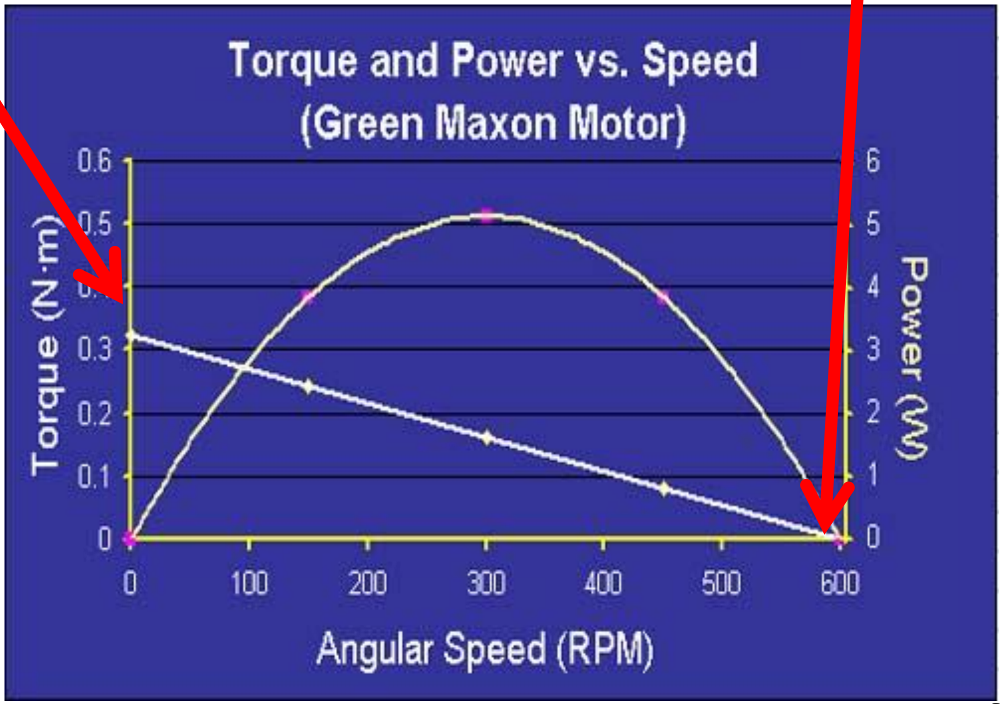
DC electric motors: torque-speed curves

- There is a linear relationship torque & speed for most small DC motors (both geared and ungeared motors).
- You can estimate a torque-speed curve using only 2 parameters: <u>stall torque</u> (maximum torque) and <u>no-load speed</u> (max speed):

<u>For Motor Power :</u>

$P = T * \omega$
$= (\text{torque}) * (\text{ang velocity})$
$= 0$ when $T=0$ or
$= 0$ when $\omega = 0$

Pmax ~ maximum power delivered when at mid-point
~ ½ Tmax * ½ ω max)



Gear Ratio

Question: Where is the best place to put the operating point?

Remember, there is still one degree of freedom available, sliding the operating point up and down the torque speed curves.

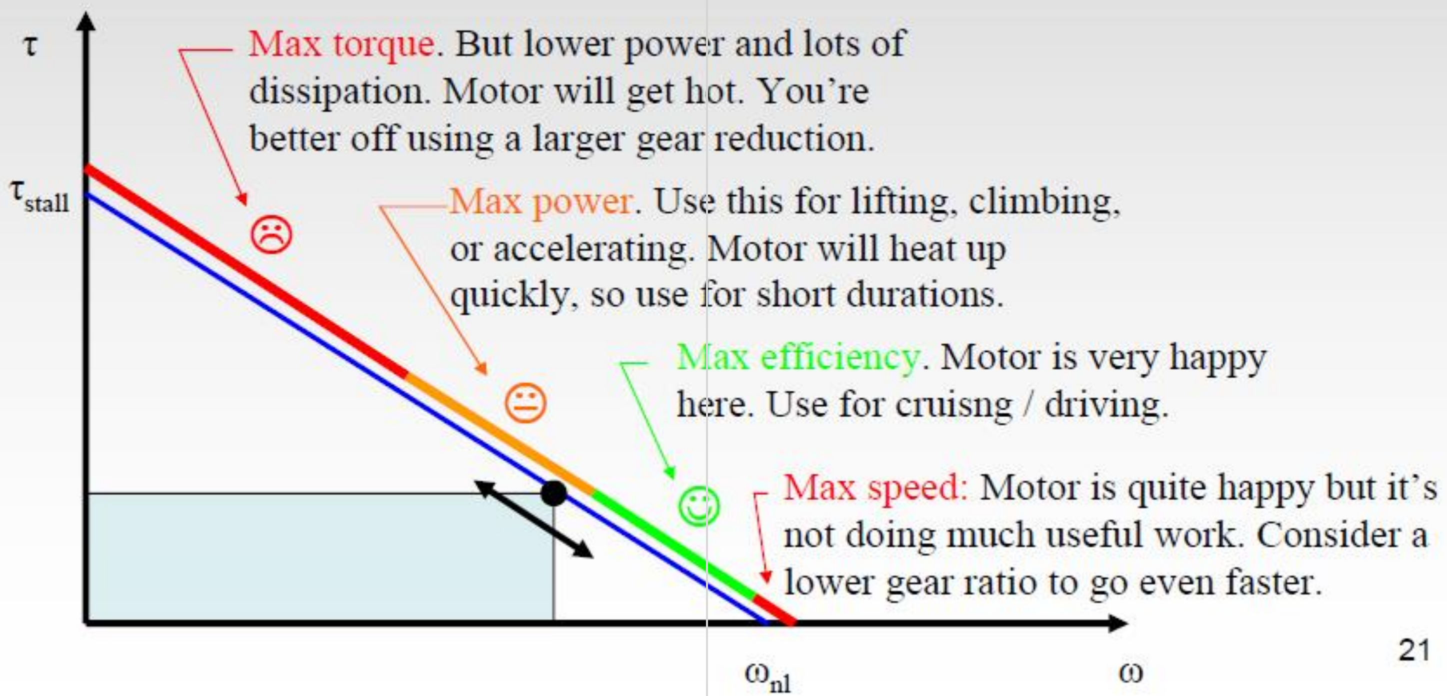
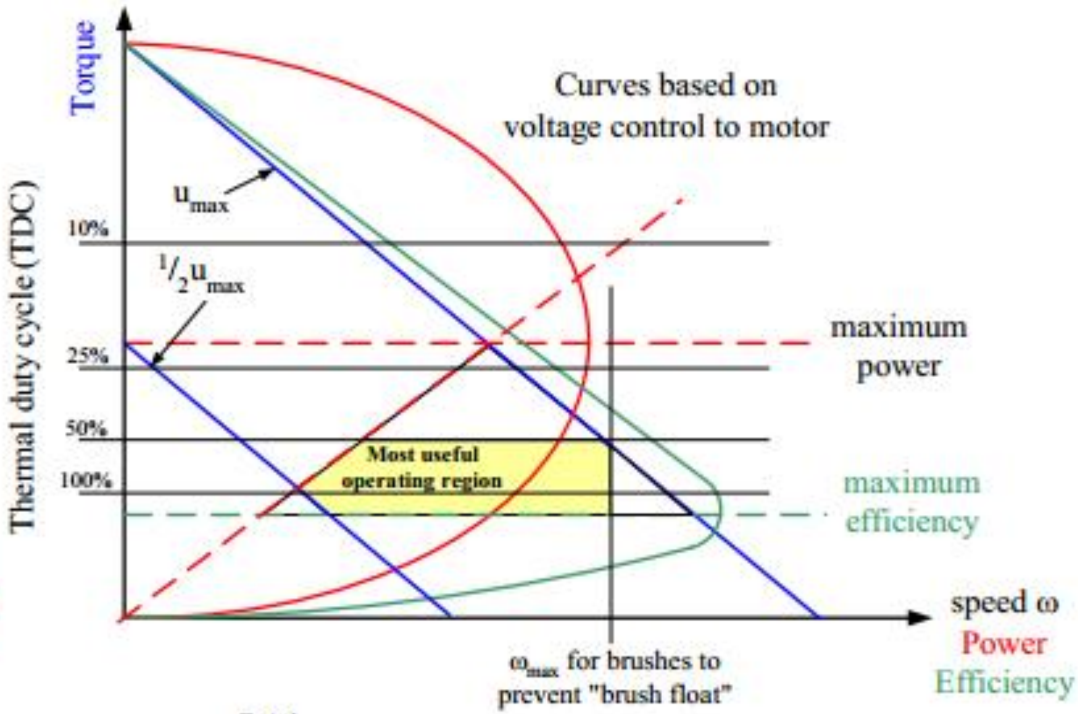


Image – MIT 2.007 course (formerly taught by Slocum)

For a good derivation of DC Motor efficiency:
http://mplab.ucsd.edu/tutorials/dc.pdf

DC Brushed Motors: *Best Operating Region*

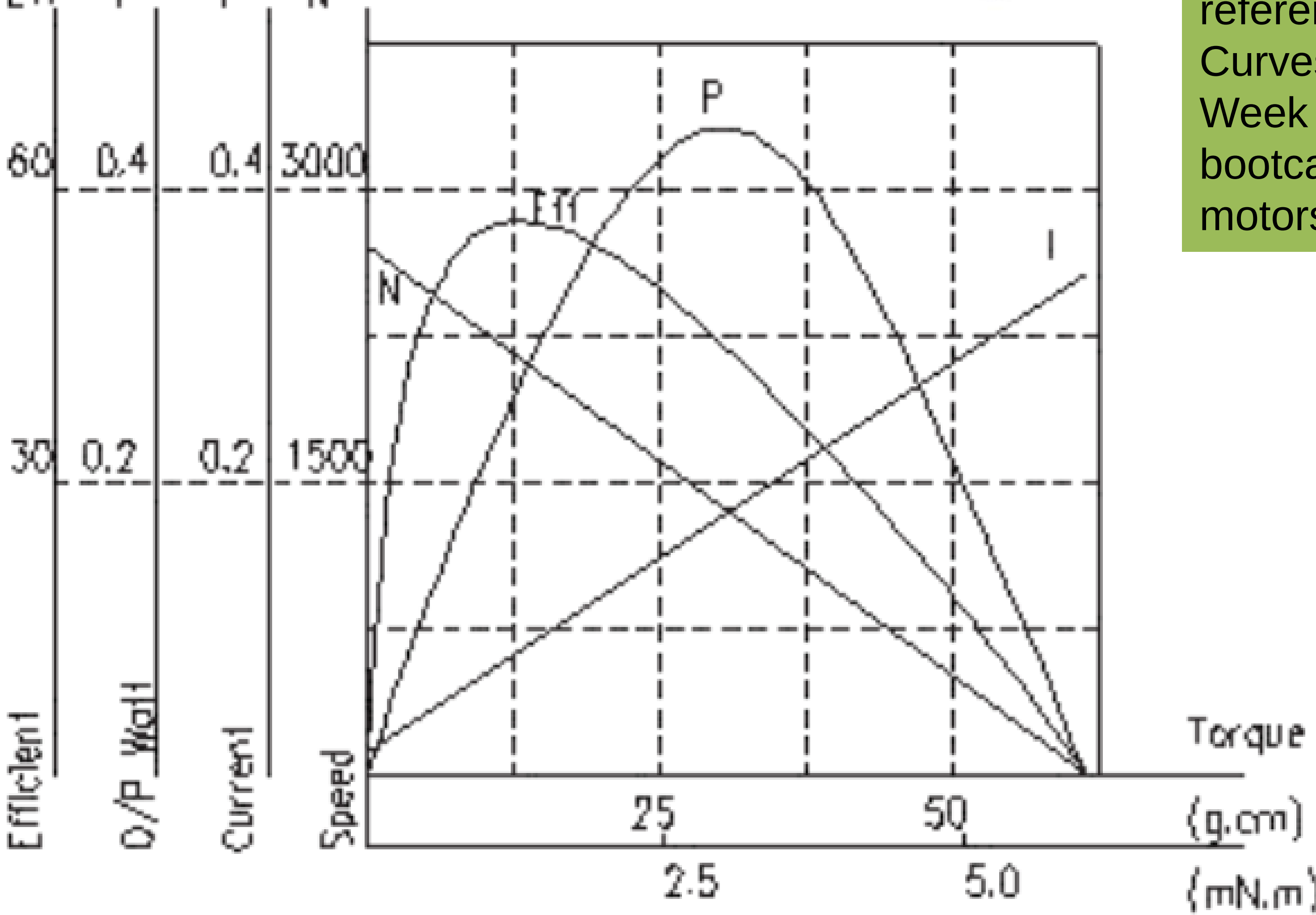
- When selecting a motor and transmission, the motor must not be too big nor too small:
  - The maximum operating voltage u_{max} (and hence maximum current) is set to prevent motor magnet demagnetization
    - To continually use a motor at less than ½ u_{max} is not cost effective
- ***HEAT*** (thermal overload) is one of the greatest causes of motor damage
  - Time must be allowed between on-cycles for the motor to cool down



7-16

Similar analysis - Text and images - FUNdaMENTALS of Design, ch.7 (Slocum)

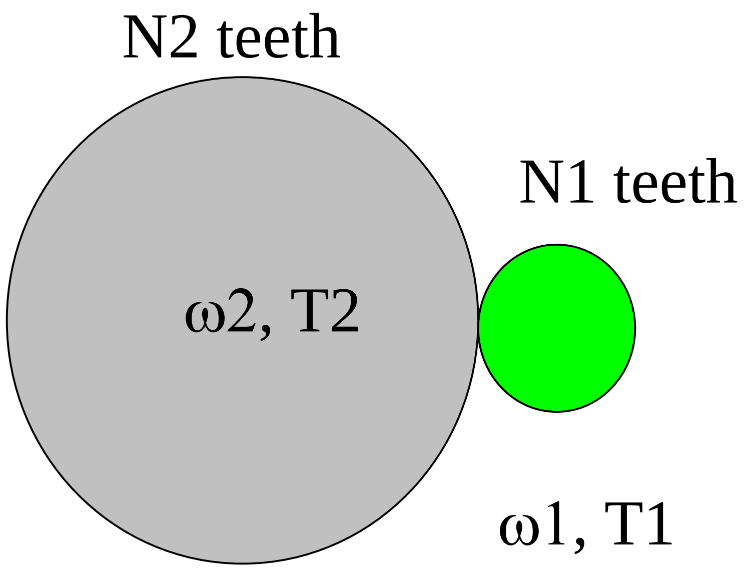
Characteristic Curve



For reference - Curves for Week 4 bootcamp motors

Gear Train / Drive Train Ratios

- Power in = Power out
- $T1\ \omega 1 = T2\ \omega 2$
- Torque and speed both scale WRT the number of teeth on the input and output shafts.
- Output slower = more torque.
- Output faster = less torque



Angular velocity:

$N1\ \omega 1 = N2\ \omega 2$

Torque:

$(T1\ / N1) = (T2\ / N2)$

Drops in efficiency at each drive train stage are hard to estimate, and will depend on how well things are assembled, frictional losses, etc.

DC Electric Motor: Select based on Desired Mechanical Power

How Much Power Do you Need?

1. Estimate desired power for the final application of the motor

$$P_{requried} = Fv \quad \text{(How much force and how fast?)}$$

$$= T\omega \quad \text{(How much torque and how fast?)}$$

2. Check that motor can provide adequate mechanical power (from torque and speed specs)

3. Design a drive train to go from the motor torque/speed of the motor to the desired torque/speed.

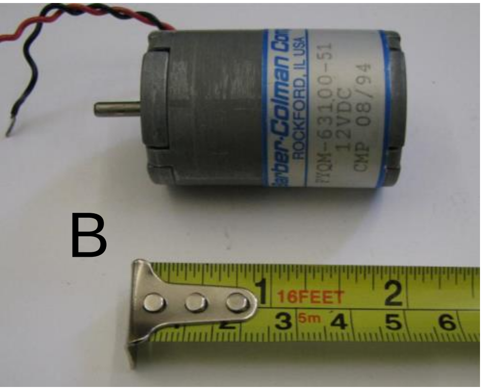
253 Stock Motors – DC Motors (3 types)

A. Geared Barber Coleman motor (FYQF 63310-9) (at 12V)

no-load speed: 470 rpm max torque: 28 oz-in (20 N-cm)

no-load current: 0.1A stall current: 1.3 A

P_{max} ~ 2.4 Watts



B. Un-geared Barber Coleman motor (FYQM 63100-51) (at 12V):

no-load speed: 2300 rpm max torque: 5.2 oz-in (3.7 N-cm)

no-load current: 0.13A stall current: 2.75 A

P_{max} ~ 2.2 Watts

C

C. GM7 (BabyGM3) (at 6V)

no-load speed: 146 rpm max torque 23.78 oz-in (17 N-cm)

no-load current 0.092A stall current 0.524 A

P_{max} ~ 0.64 Watts

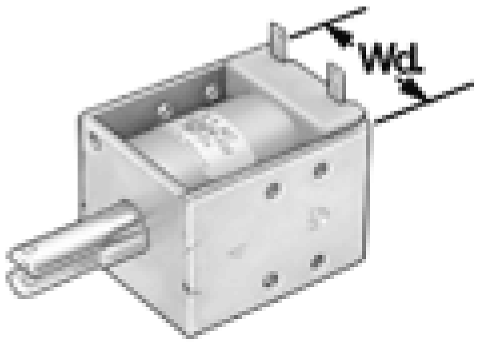
253 Stock Motors – RC Servo Motors (2 types)

Torque ~ 42 N cm
40x20 mm body
(same body as existing black futaba-style motors, slightly more torque)

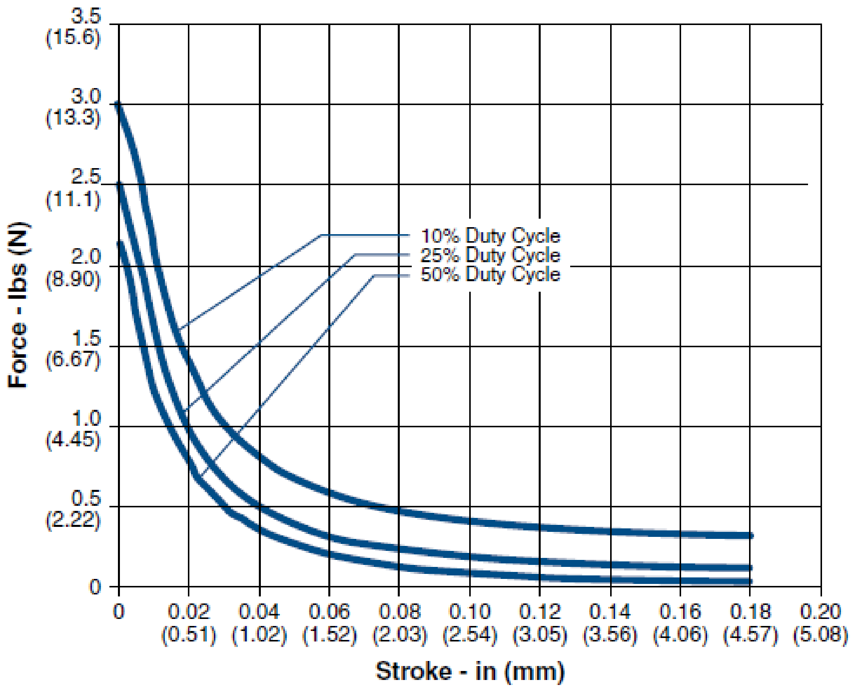
Stall torque: 15 N cm
Size: 22mm x 12.5mm x 29.5mm
Weight: 9g

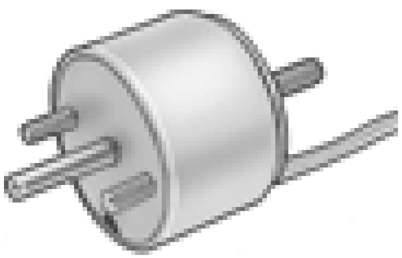
Solenoids

- Strong at short distances (very short!), with relatively heavy coils
- **<u>Solenoids only pull</u>** objects into the field. "Push" solenoids are really normal solenoids with small pins reaching through the body.
- Typical force-stroke distance curve has a very sharp dropoff:



•Open-frame (we stock 1 type)

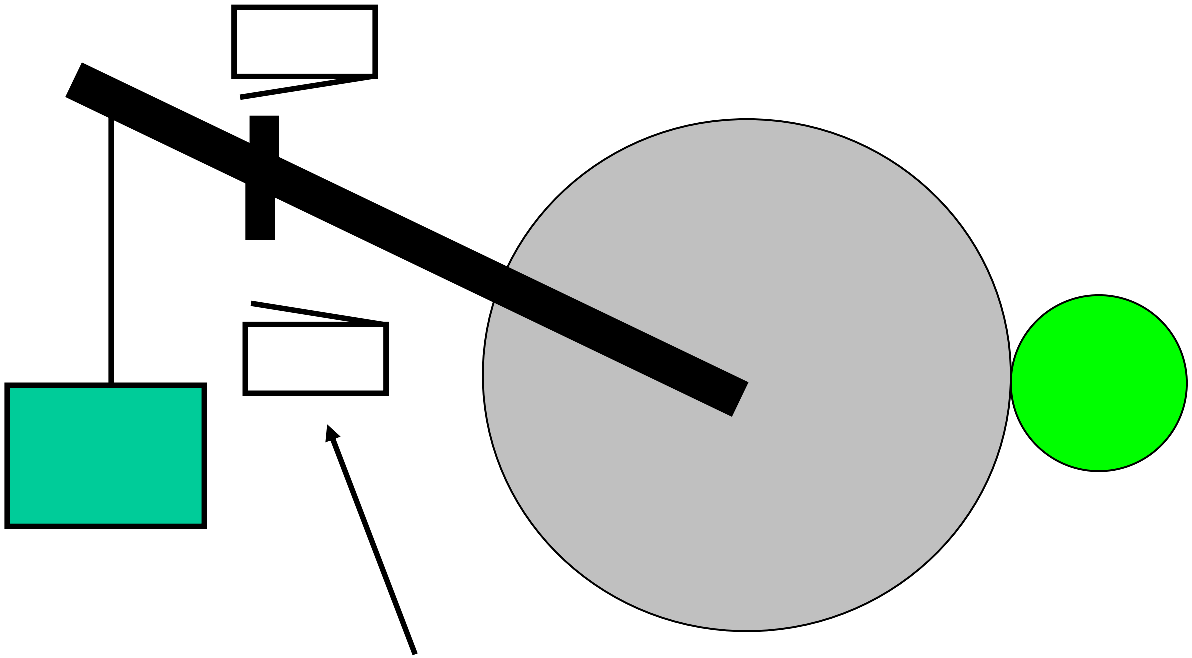




•Combination push/pull (we do not stock)

Sensors and Feedback

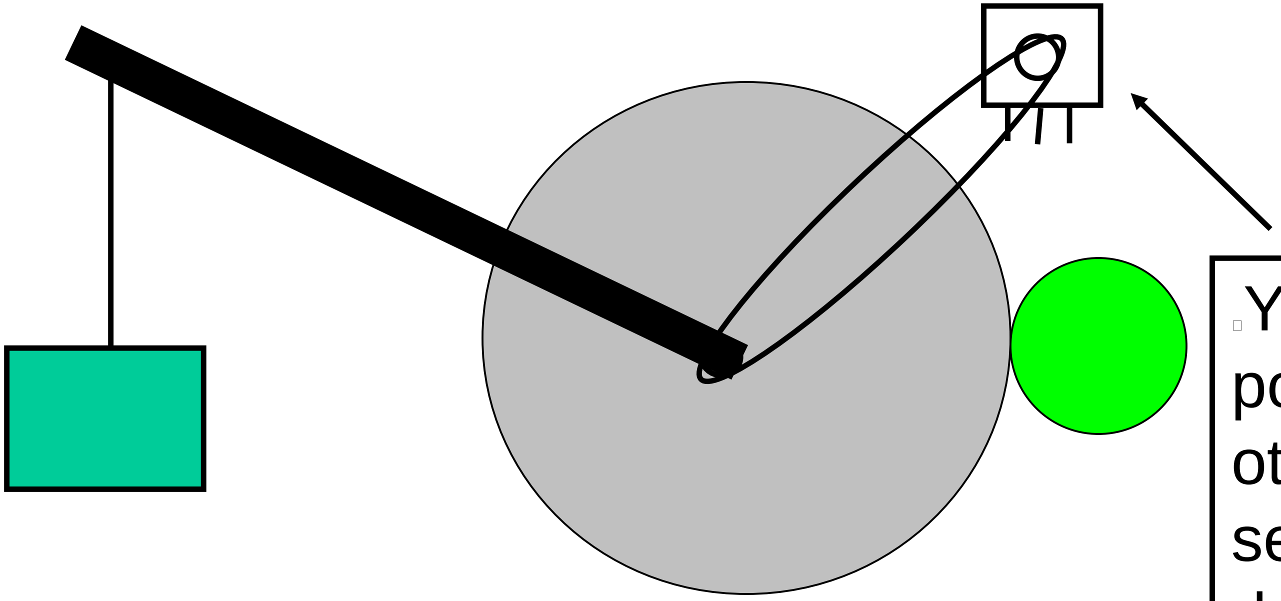
Limit switches to determine end-of-travel



Use limit switches to determine end points of motion when using a DC motor.   Can be combined with mechanical stops/limits at each end point to make two very stable positions.

Can also use same switch to help indicate a mid-point position too, if switch can be activated as arm goes past switch mechanism

Rotary position sensors for more accurate position info



You can also use a potentiometer or other type of rotary sensor or encoder to determine the gear or arm position exactly. This can also be turned into a servo system.

Pros: More possible positions, one analog input vs. at least 2 digital inputs.

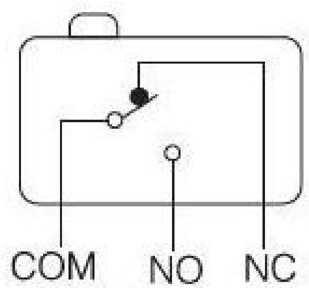
Cons: May oscillate, may require different tuning parameters with and without weight, gravity a problem.

253 – Touch Switches and Rotation Sensors

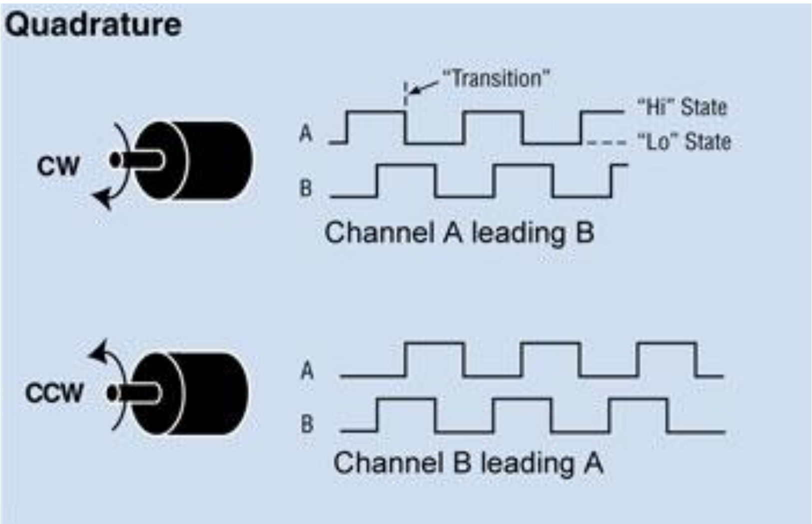
Microswitch and sub-microswitch are Single-pole Double Throw (SPDT)

1-turn 10kohm potentiometer (meccano- compatible shaft)

Rotary potentiometer (10k, but continuous rotation. “Dead-Zone” during part of the rotation)

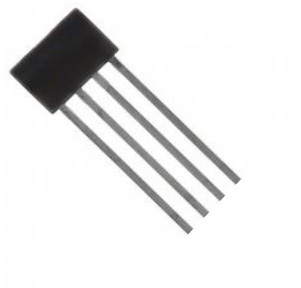


COM common
NO Normally Open
NC Normally Closed



Rotary encoder (continuous rotation, produces 24 pulse per revolution in quadrature outputs)

253 – other sensors



MAGNETIC - Hall Effect Sensors (Allegro A1362)
- small, moderately expensive. Kept in front of lab.
- Analog signal. But can only measure relatively short distances.

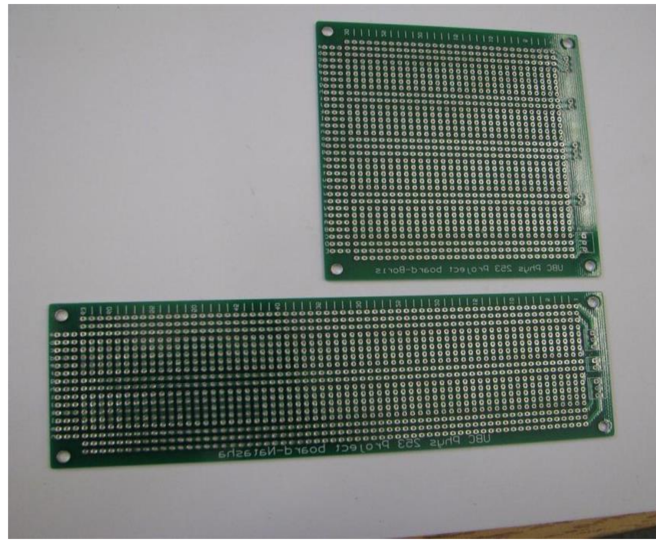
Ultrasonic – HC-SR04
- Can detect flat objects upto 50cm away.
- Problems with small objects, objects at an angle, and “soft” objects (absorbs ultrasound signals)
- Requires using digital outputs from TINAH board

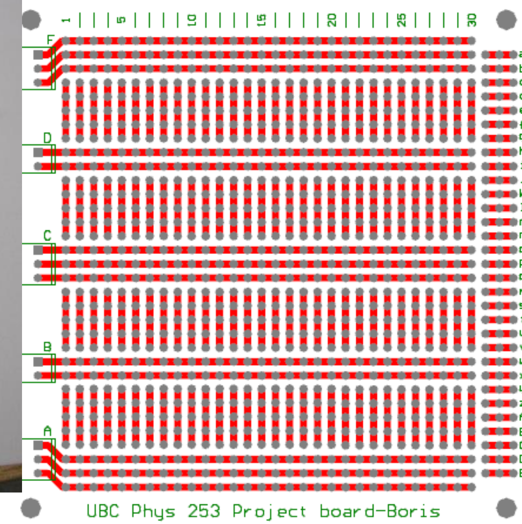
Along with the IR sensors (QSD124, QRD1114), these sensors represent most of the methods used in ENPH 253 to detect the environment.

Electronics Planning

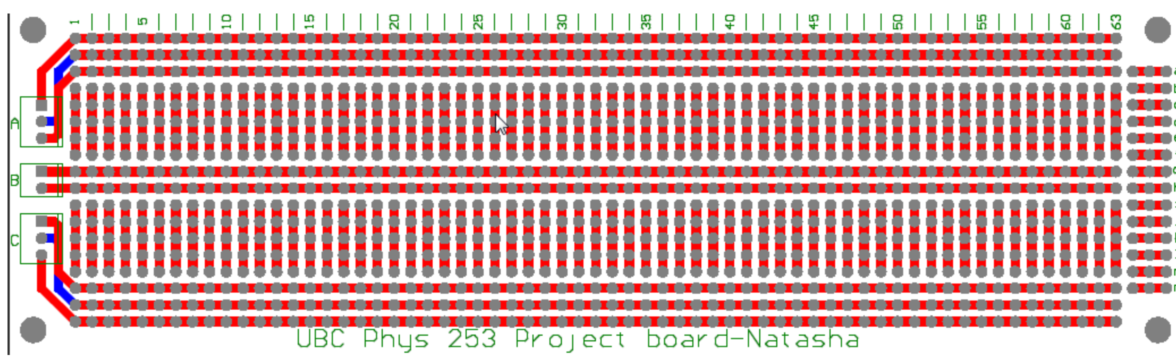
Printed Circuit Boards – Boris & Natasha

- Layouts similar to the solderless breadboards, useful for planning.
- You can plan/debug your circuits on your breadboards and transfer directly to PCB.





- PDF drawings of boards available on lab “Downloads” page.

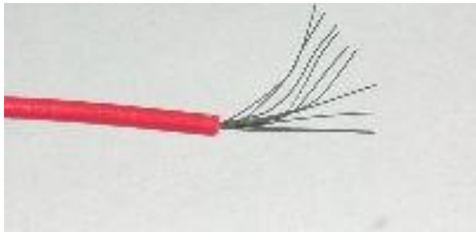


Printed Circuit Boards – other styles

- Veroboard (aka strip-board) have continuous rows of copper which can be cut with a knife
- Useful for power distribution or similar requirements.
- There is also board with NO rows, only holes to solder in. Maximum flexibility, but painful for rapid prototyping.

http://www.zen22142.zen.co.uk/Prac/vero_circ/vero.htm

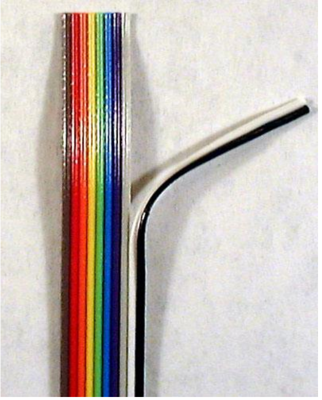
Wire



Stranded wire 4 colours: Black, White, Red, Green
Use for all flexible wires Take care with frayed wire ends when pushing into holes!

Solid core wire 4 colours: Blue, Yellow, Grey, Orange
Use for PCBs and other non-flexing areas

Multi-conductor shielded wire for noise isolation and organization (we stock 4-wire, 6-wire)



Ribbon cable to group several wires together.
Use IDC connectors for ribbon cable (6-wire, 8-wire, etc…)

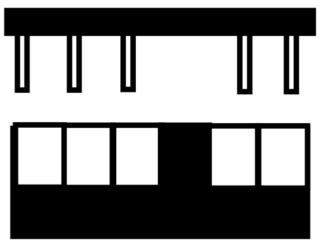
Connectors

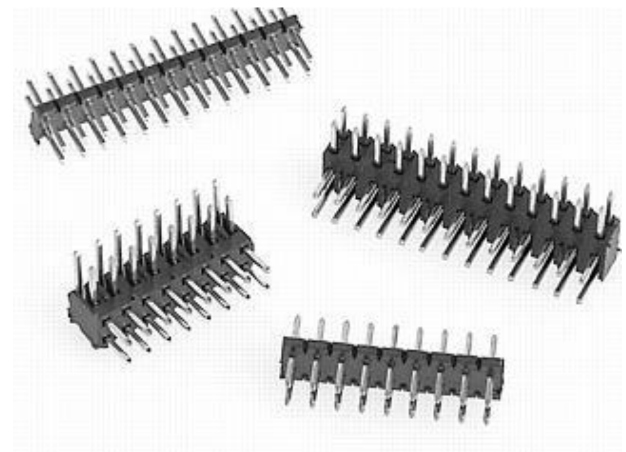
Male/Female Header pins

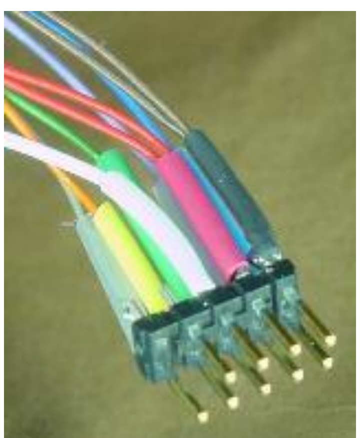
- Normally used to connect PCBs to other PCBs. (“ board-to-board connectors”)

- We often use header pins in ENPH 253 to connect wires to PCBs because they are much cheaper than most proper wire-to-board connectors.

- “polarize” your connections to prevent putting them in backwards or off by one position.



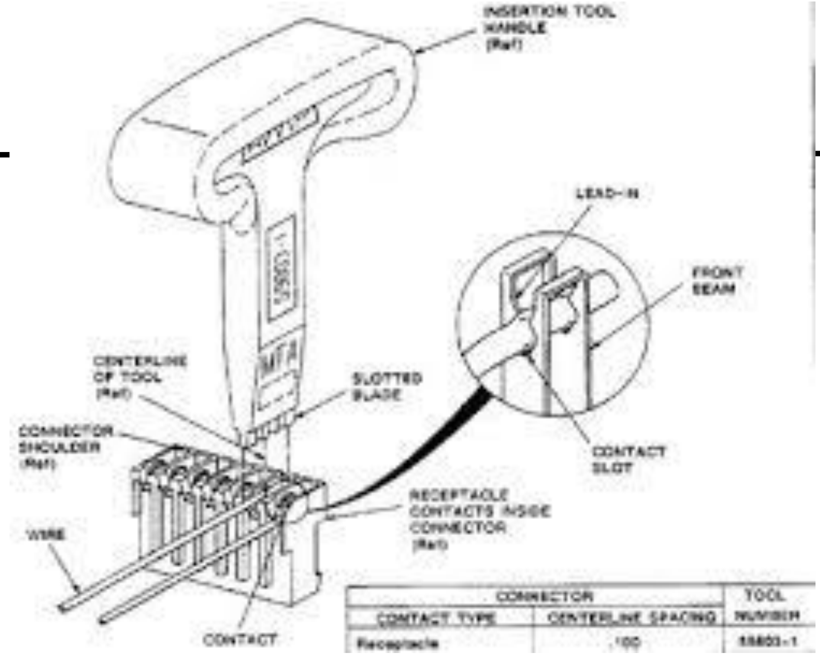


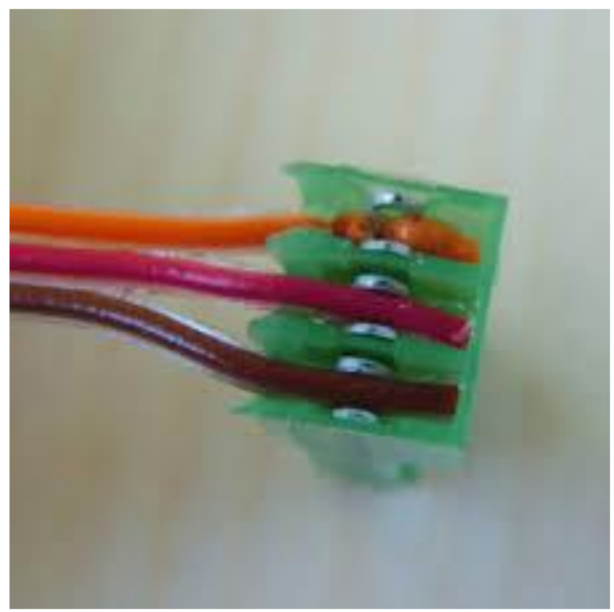


Strain relief -   Use shrink tubing around each solder joint from wire to pin/connector

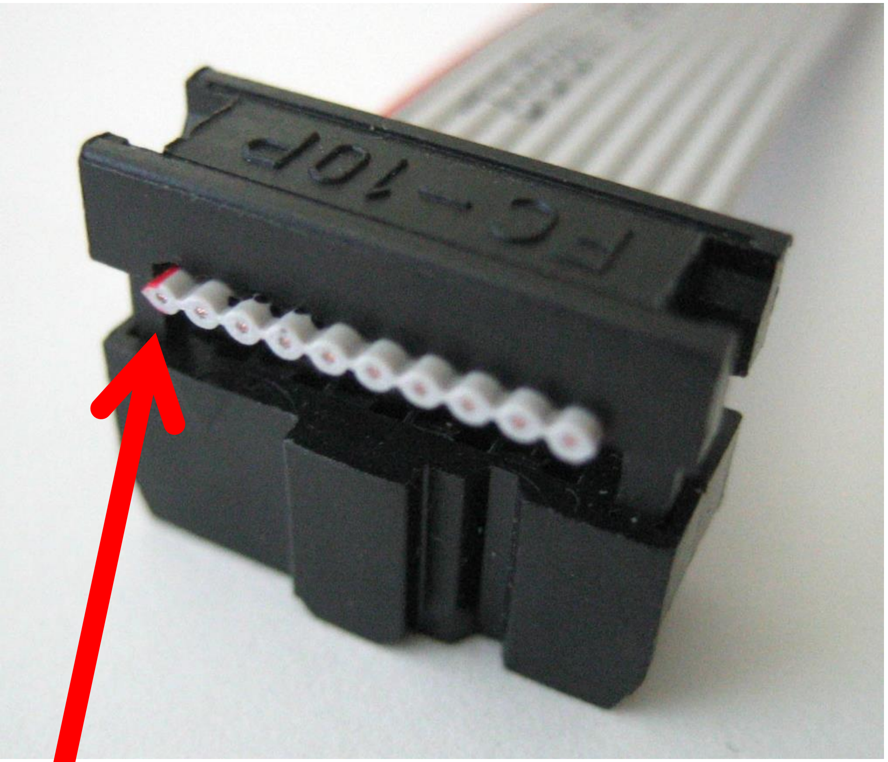
MTA-100 headers

Actual wire-to-board connections. No soldering required. Integrated strain relief. Costs ~$0.20 / header

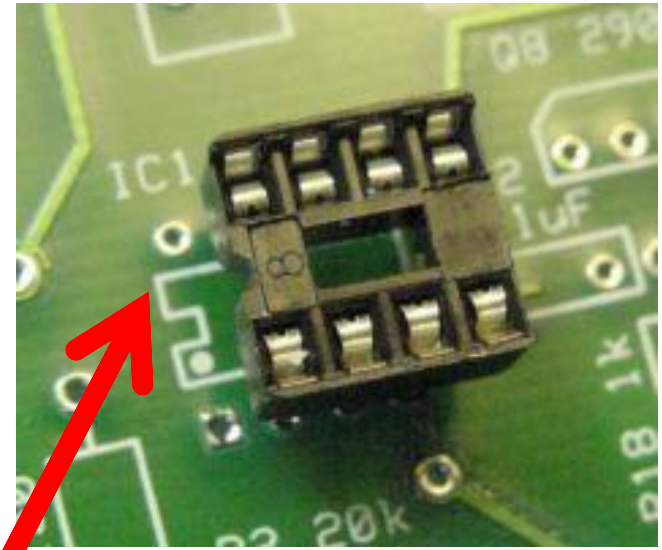




Polarized Connectors, Sockets and Wires



Ribbon cable is marked – red is wire #1



DIP sockets are polarized (the notch indicates where Pin #1 goes)

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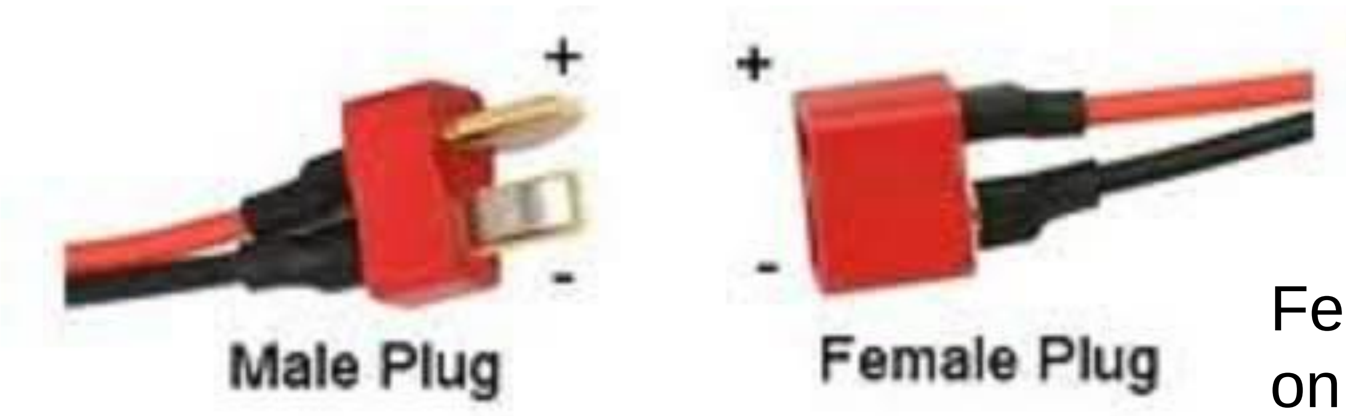
Deans Connectors (new for 2016)

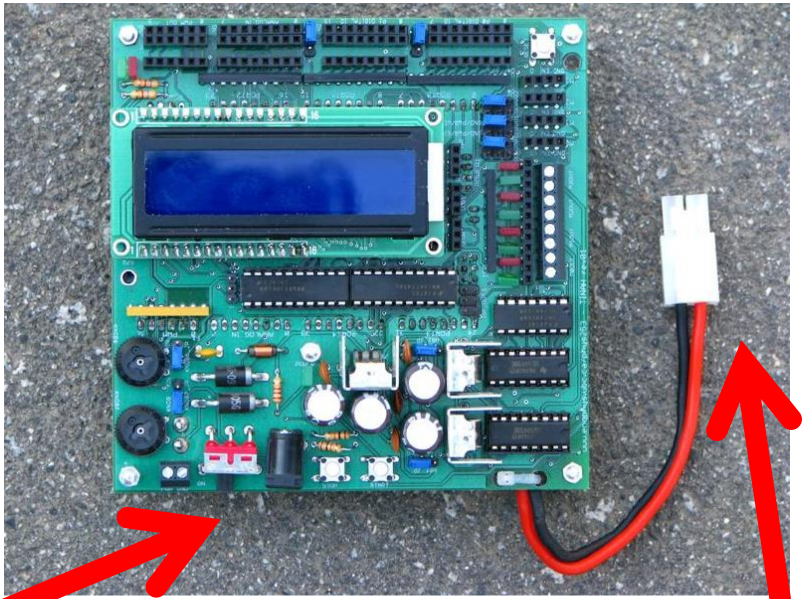


Female side - use on battery side and side with live power (to avoid shorting on other electronics)

Male side - use on unpowered side

Connectors for Power

TINAH now has male Deans Connector (2016).



When the TINAH is connected to 1 battery, you have two choices for connecting power to external circuits, H-bridges, etc:

(A) Screw-down terminal is directly connected to battery input (it doesn't go through the power switch). Very useful, but you need to screw in/out to swap TINAHs.

(B) You may want to make a T-connection so that external circuits connect directly to the battery pack.

Plan for each Printed Circuit Board

- Plan each board you need for the setup
  - Inputs/outputs/power connections?
  - Minimize number of connectors? (avoid single-wires!)
  - Can you put all connectors on the same edge of the board?
  - How to mount board to chassis? (standoffs/clips/etc)
  - Making boards too small means making them too hard to mount.

Plan for Every Bundle of Wires

- Very likely the most overlooked portion of robot planning!
- Wires take up lots of room (Look at old robots)
- Bad wiring means loose connections. Nothing fails more than loose connections.
- Make wire bundles using cable ties.   Label wires and bundles to keep organized.
- Can use **board-to-board connections** rather than board-to-wire connections.

Drawing Circuit Schematics

- Can do it by hand
  - make photocopies for editing.

- Can do it in software
  - Eagle (CadSoft) installed in Hebb 42, and can download and use student version for free.
  - Other popular free options:
    - Altium Circutmaker
    - KiCad EDA
  - Useful for circuit schematics, and possibly easier to update later.

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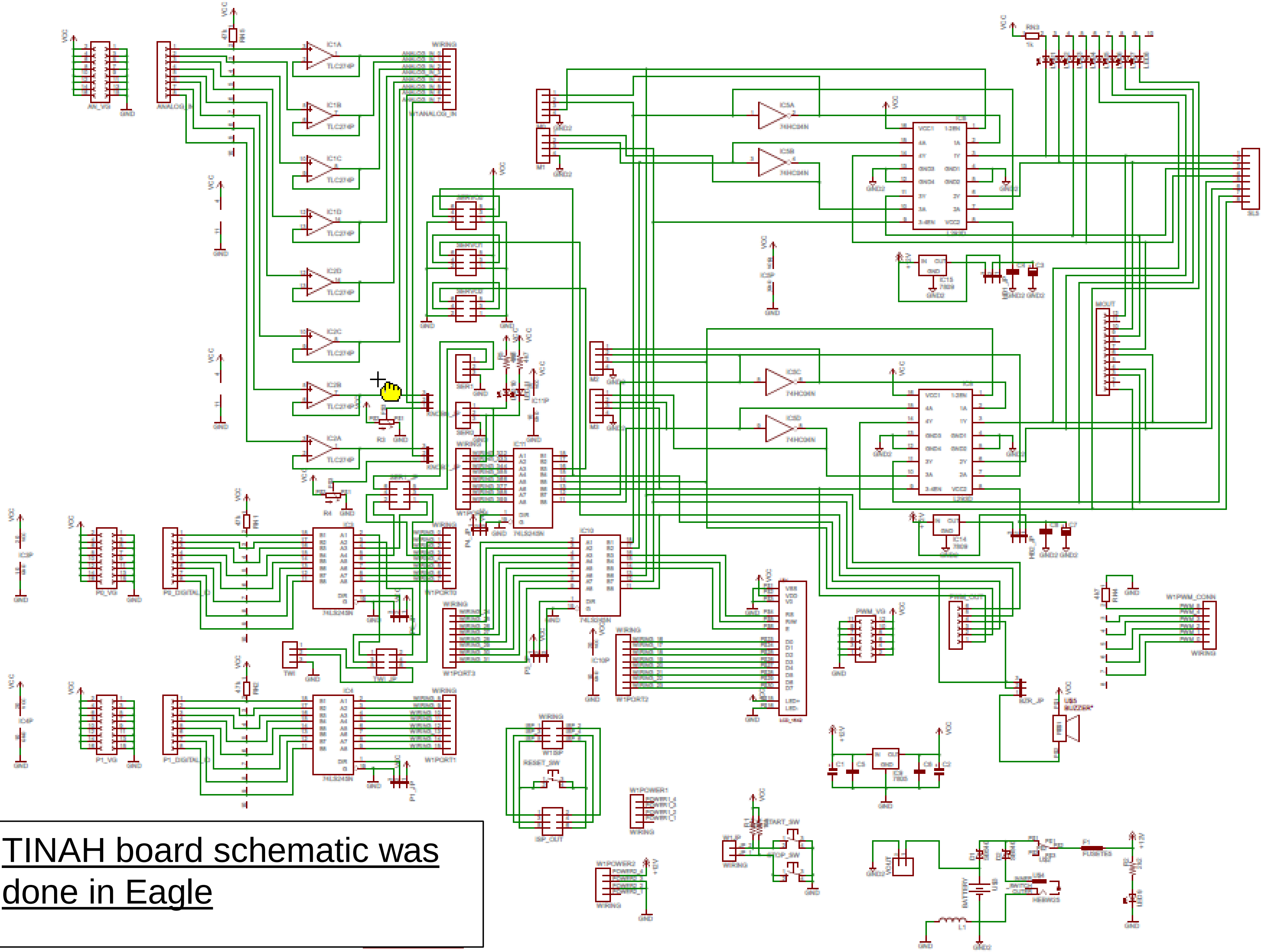
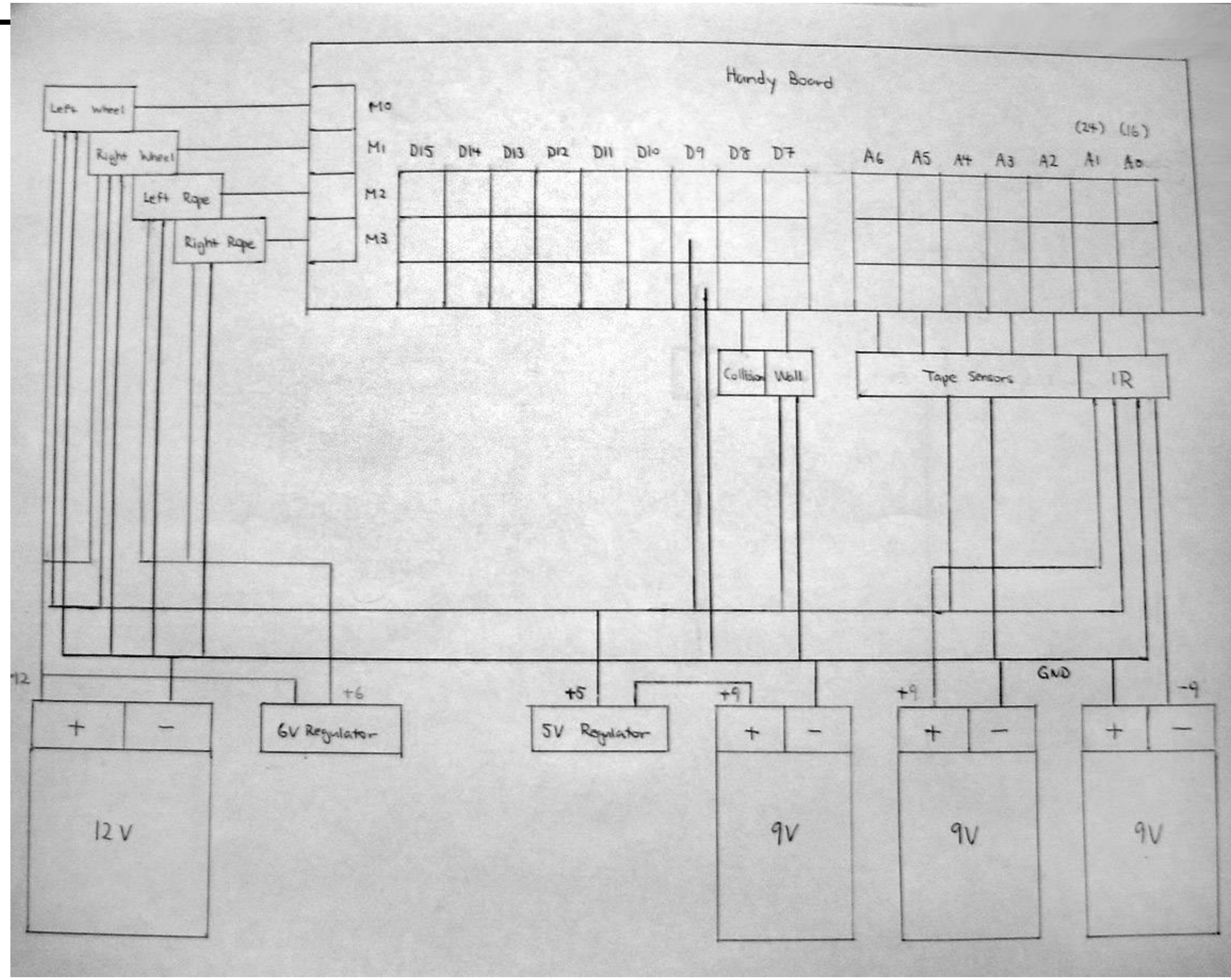


TINAH board schematic was done in Eagle

Wiring Diagram Layout

You not only need to plan out each circuit, but how different circuits will be wired to each other.



From a previous group's Design Document – a reasonable start, but needs to show specific PCBs being made, and how many wires are required to interconnect every different PCB, sensor, etc.…

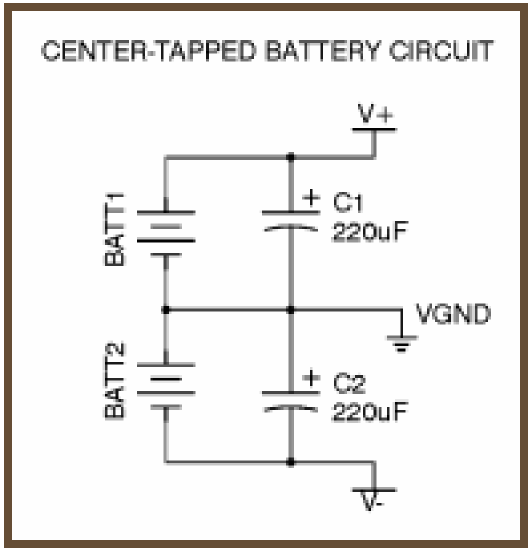
Other Electronics Components - Power

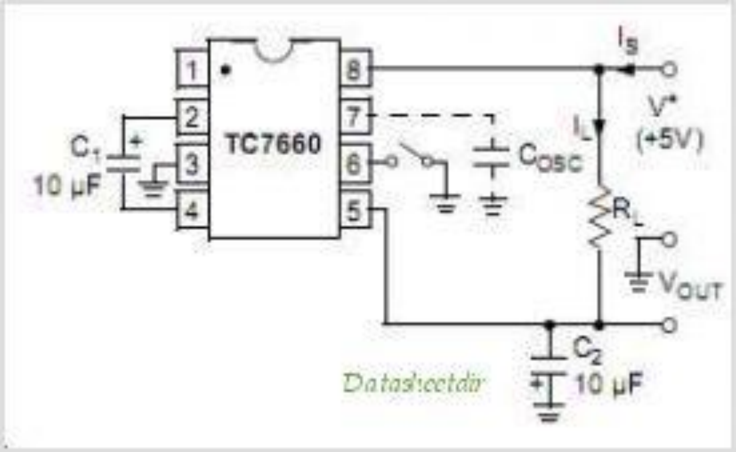
TINAH board 5V line should only output ~500 mA in total (TINAH is also using its own 7805)

5V voltage regulator (7805)
- Easy to use, only 3 pins: input (6V-30V),   ground,   output (5V)
- can supply up to 0.5amps, upto 1Amp with a heat-sink

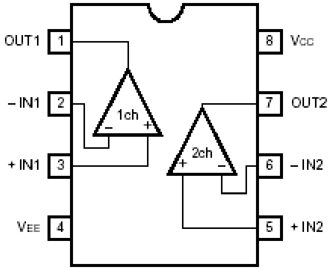
5V Switching Regulator – LM2596 Board
- Can produce 2Amp+ output 5v.

Negative Voltage Supply
- In 253, we normally use 2 small batteries connected in series to produce positive and negative voltage rails (Center-tapped battery cct).
- For small amounts of power on the negative rail (< 5 mA), can use TC7660 chip (negative charge pump)





Other Electronics Components



<u>Dual comparator (LM393)</u>

• 2 comparators on one 8-pin chip

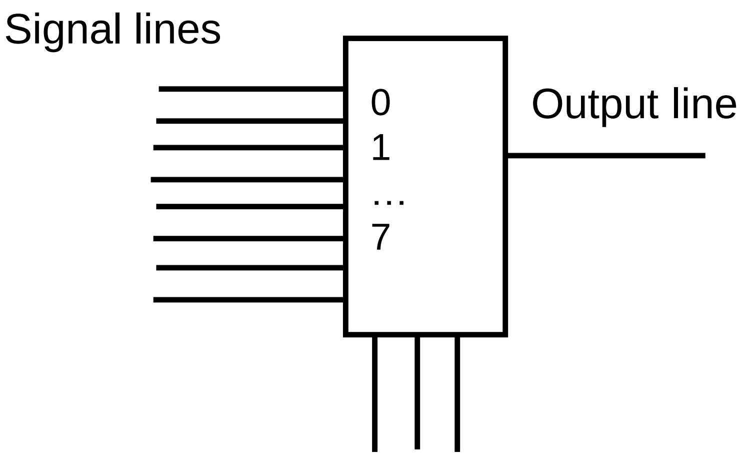
• Ground and negative power combined into one pin (they are separate on the LM311), so may not function as desired.

• Input voltages (Vin+ and Vin-) can operate to ground, same as LM311.

Analog Multiplexers

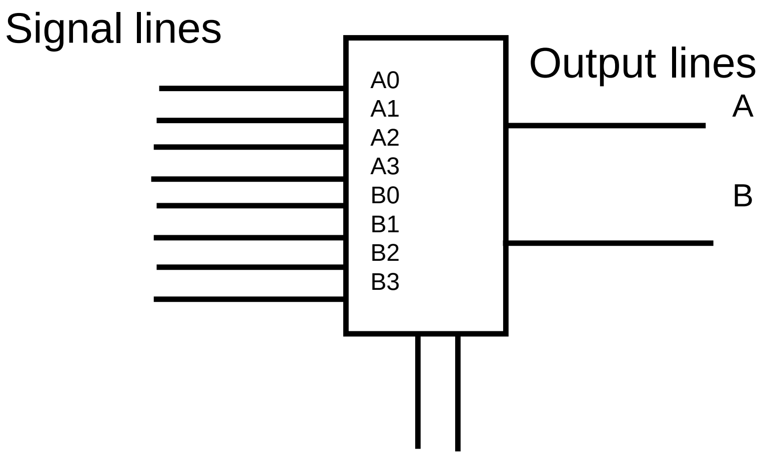
Multiple inputs can be combined into a single input, selected by digital control lines (useful if you want more analog inputs than you have on your microcontroller)

8-to-1 multiplexer (CD4051)



Input control lines
(digital value from 000 to 111)

Dual 4-to-1 multiplexer (CD4052)



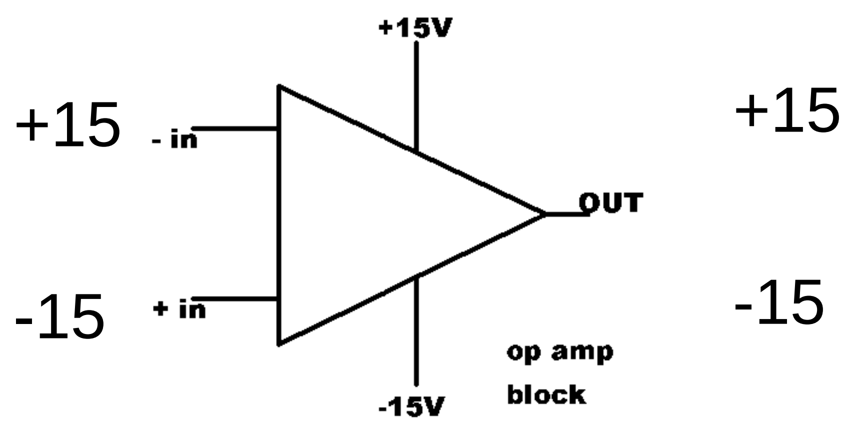
Input control lines
(digital value from 00 to 11)

We also have triple 2-to-1 multiplexer (CD4053)

Useful to know…

Rail-to-Rail Op-Am/Comparators

- Can handle input and output voltages all the way to the supply lines
- Cost more (3-5x) than standard op-amps, so not found in high-volume commercial products… (or ENPH 253 robots)



Algorithm Planning

Flowcharts
and State Diagrams

Algorithm Planning for 253

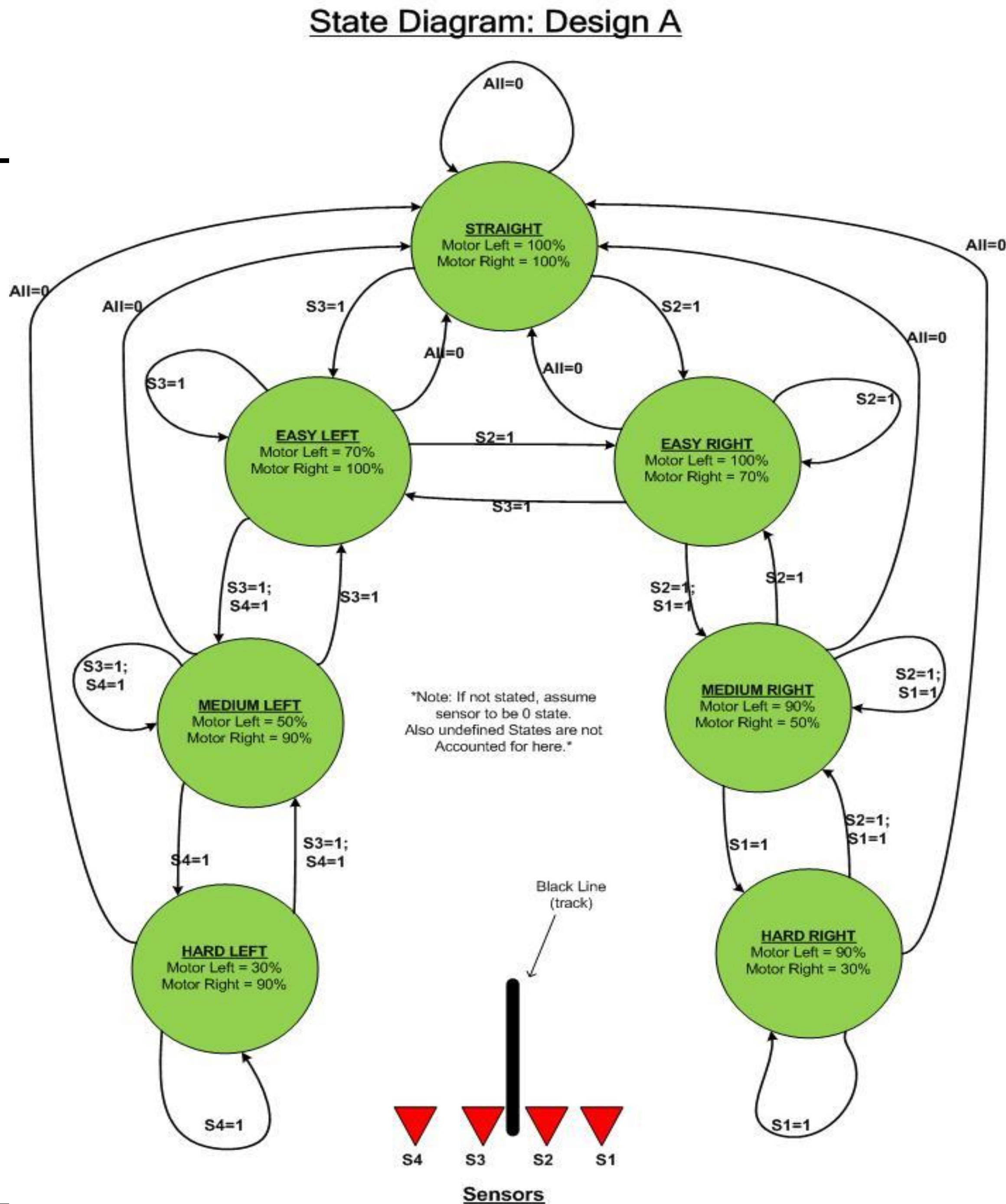
When used as an planning tool for system operation

State Diagrams > Pseudocode > Flowchart

* Flowcharts are good as a documentation tool to explain an existing process, not so useful for planning.

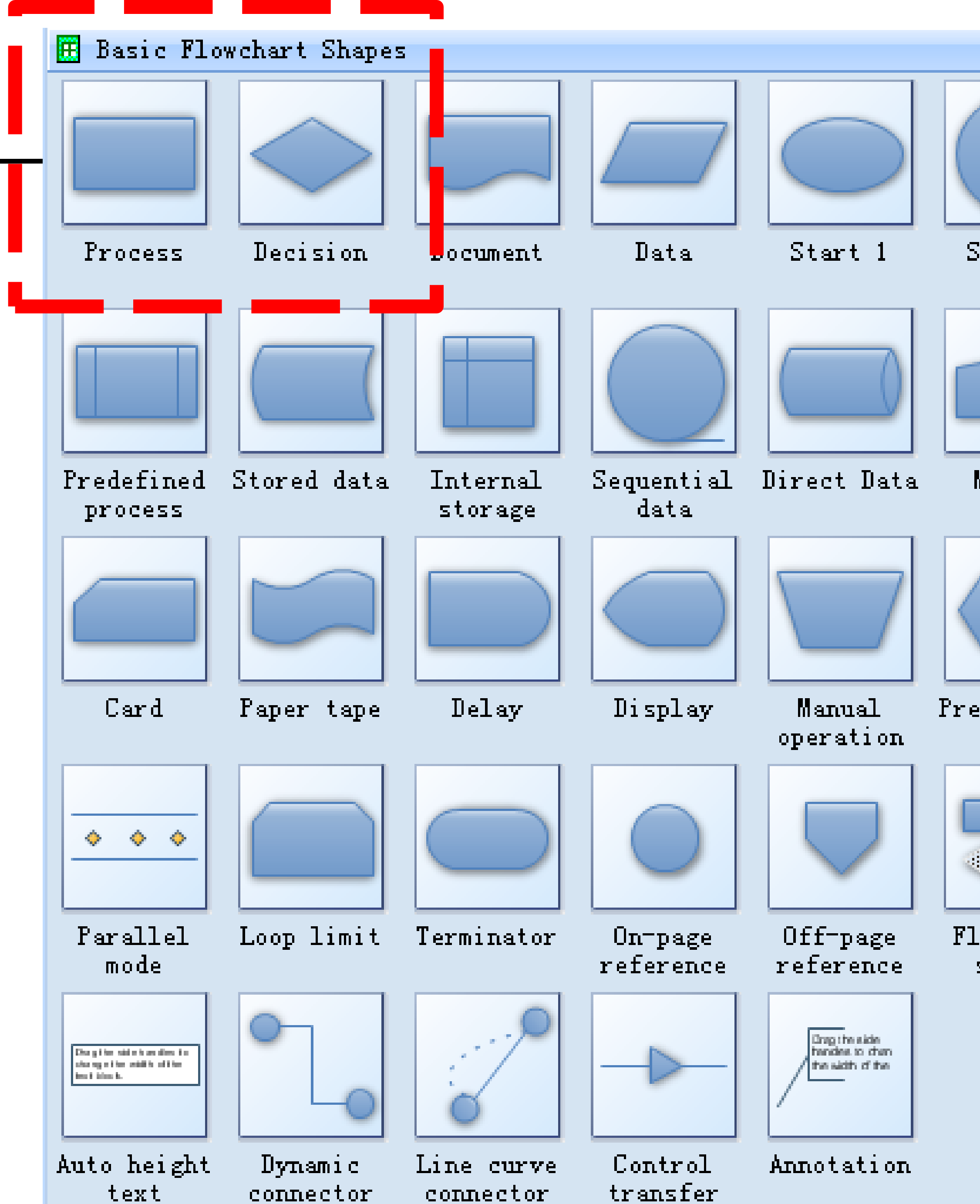
State Diagram

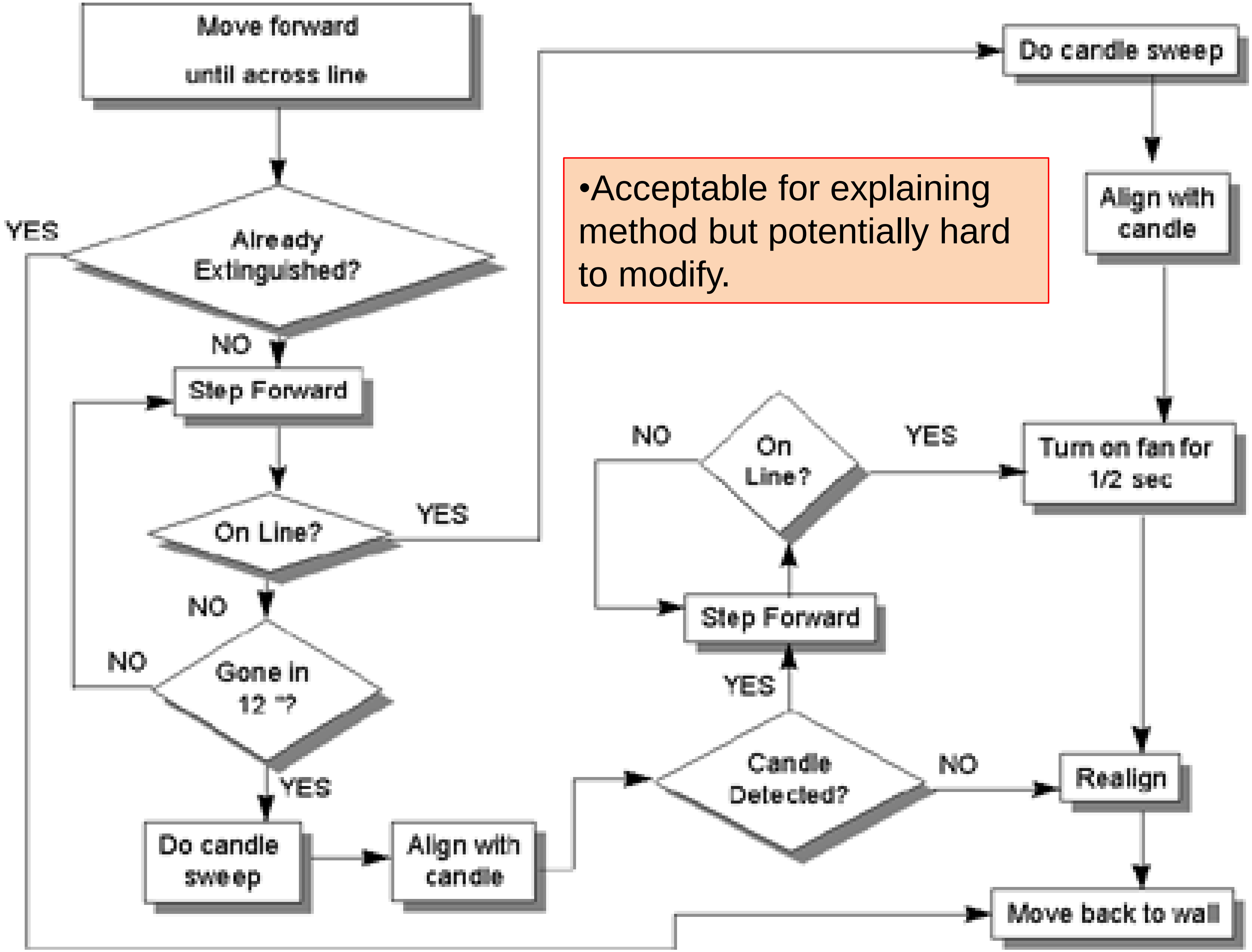
- Each circle represents one "state"
- Arrows indicate the ONLY ways to transition from one state to another state.
- Description on each arrow describes the only conditions that are allowed to change from 1 state to another state
- You can create a "state variable" to keep track of which state your robot is in.
- *NB – this particular example is not very good for tape following! Use PID.*



Flowcharts

- Often done very poorly by 253 students.
- Process sections (rectangles) describes one single step
- Decision points (diamonds) are the ONLY place to have branches leaving the path





•Acceptable for explaining method but potentially hard to modify.

Minor Software Tips

- **<u>EEPROM</u>**
  - Useful for storing variable values, even when TINAH turned off.
  - https://www.arduino.cc/en/Reference/EEPROM
  - However, info is lost if you have to swap TINAH boards!

- **<u>Reading input values at the same time.</u>** What's wrong with this code?

```
value = -99 ;
if (digitalRead(1) && digitalRead(2))    value = 0 ;
if (digitalRead(1) && !digitalRead(2))   value = 2 ;
if (!digitalRead(1) && digitalRead(2))   value = -2 ;
if (!digitalRead(1) && !digitalRead(2))   value = 10 ;
```

General Mech Design Advice

Jon's Checklist of Generic 253 Mech Design Questions

1. **Reduce operating accuracy** - Does it need to have super-precise operation or high accuracy in any movements to work properly? can you eliminate that?

2. **Less Machining** Can you make an equivalent component with fewer machining steps? (and can you use less material?)

3. **Less Machining Accuracy** Can you reduce or eliminate the need for highly precise fabricated parts to have it work properly?

4. **Modular Development** - Can you make it in different sections that can be shared among teammates, and that can be tested separately?

5. **Separable** - Can you easily modify any critical parts without requiring a full redesign?

6. **Access** Can you use the oscilloscope probe to access the TINAH, battery and all PCBs in less than 15 seconds?

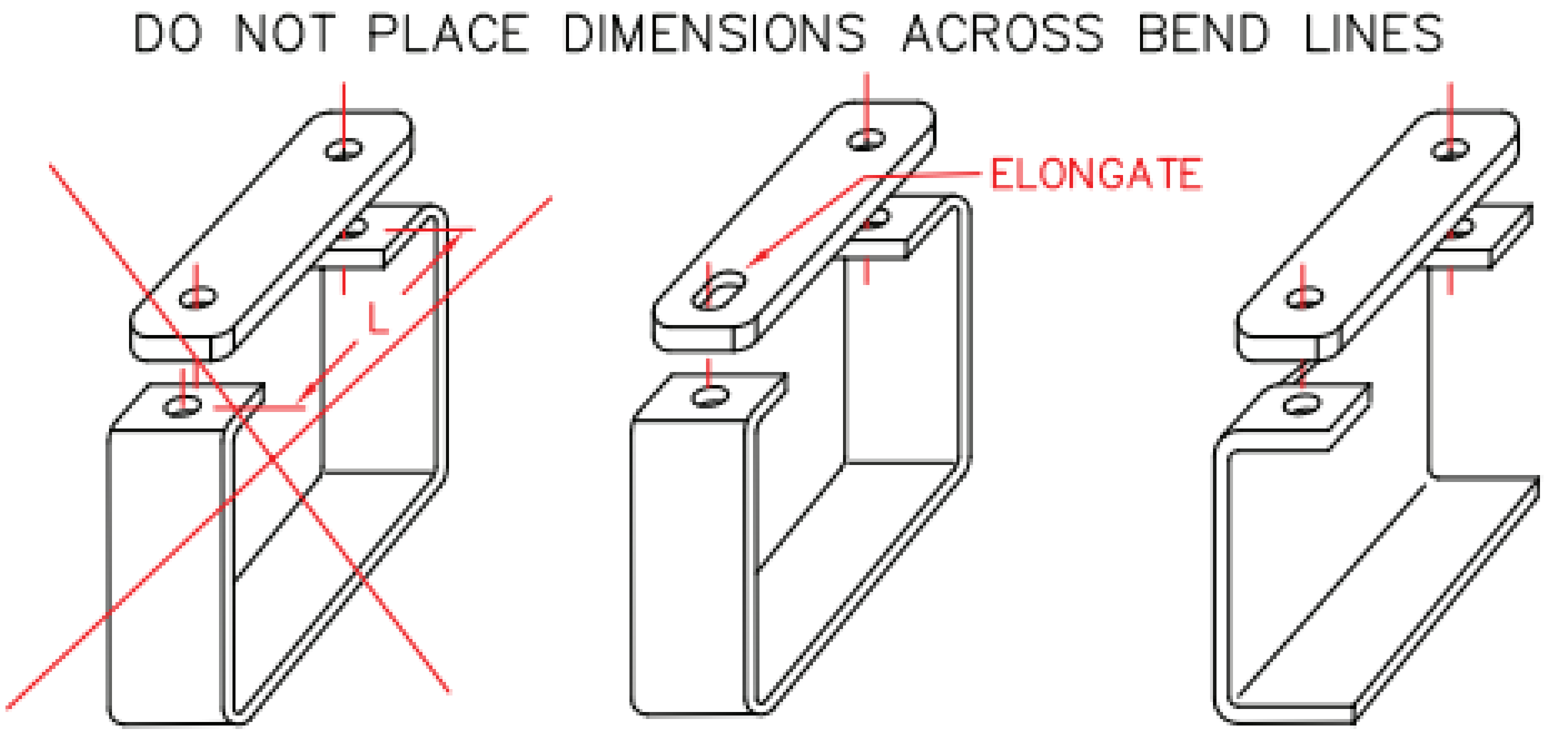
7. **Replacement** Can you replace a motor in less than 3 minutes?

Jon's Checklist of Generic 253 Mech Design Questions

1. **Reduce operating accuracy** - Does it need to have super-precise operation or high accuracy in any movements to work properly? can you eliminate that?
2. **Less Machining** Can you make an equivalent component with fewer machining steps? (and can you use less material?)
3. **Less Machining Accuracy** Can you reduce or eliminate the need for highly precise fabricated parts to have it work properly?
4. **Modular Development** - Can you make it in different sections that can be shared among teammates, and that can be tested separately?
5. **Separable** - Can you easily modify any critical parts without requiring a full redesign?
6. **Access** Can you use the oscilloscope probe to access the TINAH, battery and all PCBs in less than 15 seconds?
7. **Replacement** Can you replace a motor in less than 3 minutes?

I will print out and use this list as a guide for commenting your proposal documents.

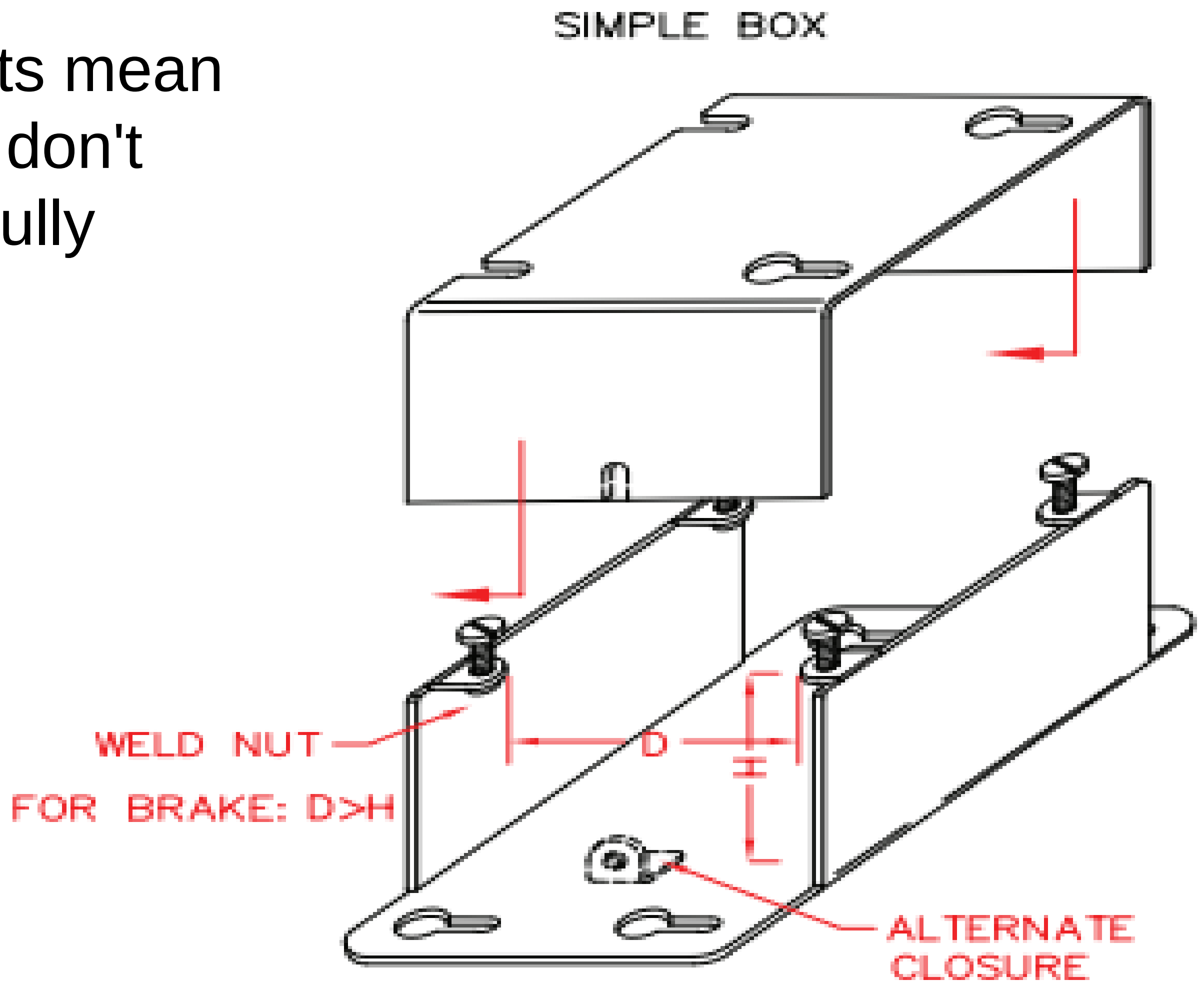
Design Choices can change required tolerances



(Image: Dan Gelbart Part 1)

Thoughtful design makes items easier to use

Keyhole slots mean that screws don't have to be fully removed.



(Image: Dan Gelbart Part 1)

Other

Better

Resources

Other Better Resources

- FUNdaMentals of Design Alex Slocum, MIT
- Design and How to Make Things   Robin Coope, BC Genome Science Centre
- Prototyping and Low Volume Production (Part1 Part2 Ppt Talk) Dan Gelbart (founder, CREO)
- Engineering Design – Larry Leifer, Stanford

Red = highly recommended

Vendors

Newark Electronics – Electronics distributor and Sponsor

McMaster-Carr – Mech component distributor

Red = highly recommended

An introduction to (some) Mechanical Design Elements

Materials

and

Structures

Stock Materials - Metals

All metals can be recycled (we like this)

Steel

Can be harder to machine, needs surface finishing (will rust)
Can be spot-welded
$3/kg ($12/kg for stainless)
Density = 7.9 g/cm3, Young's Modulus = 200 Gpa

Aluminum

Easier to machine, much lower density, not as stiff as steel.
Cannot be spot welded (too good a conductor)
$12/kg
Density = 2.7 g/cm3, Young's Modulus = 70 GPa

Brass

Heavy, ductile. Low surface friction, good for bushings
Density ~ 8.5 g/cm3, Young's Modulus ~ 100 MPa

Stock Materials - Plastics

All our stock plastics can only be downcycled, not fully recycled. (we don't love this)

Polycarbonate (aka Lexan)

- Bendable, and strong (it is a component of bulletproof glass)
- Waterjet cut only. Do not lasercut! (fumes)

Acrylic (aka plexiglass, PMMA, Poly(methyl methacrylate))

- Looks like polycarboate, but can be brittle during machining
- Laser-cut only! Shatters on waterjet without proper care.

Delrin (aka Acetal)

- Nice to machine, won't deform like softer plastics.
- 2x more expensive than other plastics
- Can laser-cut, but sometimes melts a bit.

Softer Plastics (Polyethylene, Nylon, Teflon)

- Most can be lasercut as well as waterjet cut.
- Useful for making pivots and bushings.
- PE and nylon are cheap, Teflon expensive (10x more than Polycarbonate, Acrylic)

Material Sampler

Link to [material sampler info page]

	253 MATERIAL SAMPLER				yellow	> primary materials	
Sample Number	Material	Sample Weight [g]	Also Known As	Brand name(s)	nominal thickness [mm]	nominal thickness [inches]	(na gauge
1	Mild Steel	45.0	Steel	-	0.600	0.024	
2	Mild Steel	58.5	Steel	-	0.760	0.030	
3	Mild Steel	72.0	Steel	-	0.910	0.036	
4	Mild Steel	95.5	Steel	-	1.210	0.048	
5	Polycarbonate	9.0	-	Lexan, Makrolon	0.794	0.03125 (1/32")	1
6	Polycarbonate	19.5	-	Lexan, Makrolon	1.587	0.0625 (1/16")	1
7	Polycarbonate	36.5	-	Lexan, Makrolon	3.175	0.125 (1/8")	
8	Polycarbonate	76.5	-	Lexan, Makrolon	6.350	0.250 (1/4")	
9	PMMA (PolyMethylMethAcrylate)	76.0	Acrylic	Plexiglas, Acrylite, Lucite	6.350	0.250 (1/4")	
10	PMMA (PolyMethylMethAcrylate)	68.0	Acrylic	Plexiglas, Acrylite, Lucite	6.350	0.250 (1/4")	
11	SBR (Styrene Butadiene Rubber)	54.0	Rubber	-	3.175	0.125 (1/8")	

Price per square foot

• Mild steel, 30 gauge	?
• Aluminum, 2mm	?
• Acrylic, 1/8”	?
• Polycarbonate, 1/8”	?
• Hardboard, 1/8”	?

Price per square foot

• Mild steel, 30 gauge	$1.25
• Aluminum, 2mm	$1.35
• Acrylic, 1/8”	$4.25
• Polycarbonate, 1/8”	$4.50
• Hardboard, 1/8”	$0.32

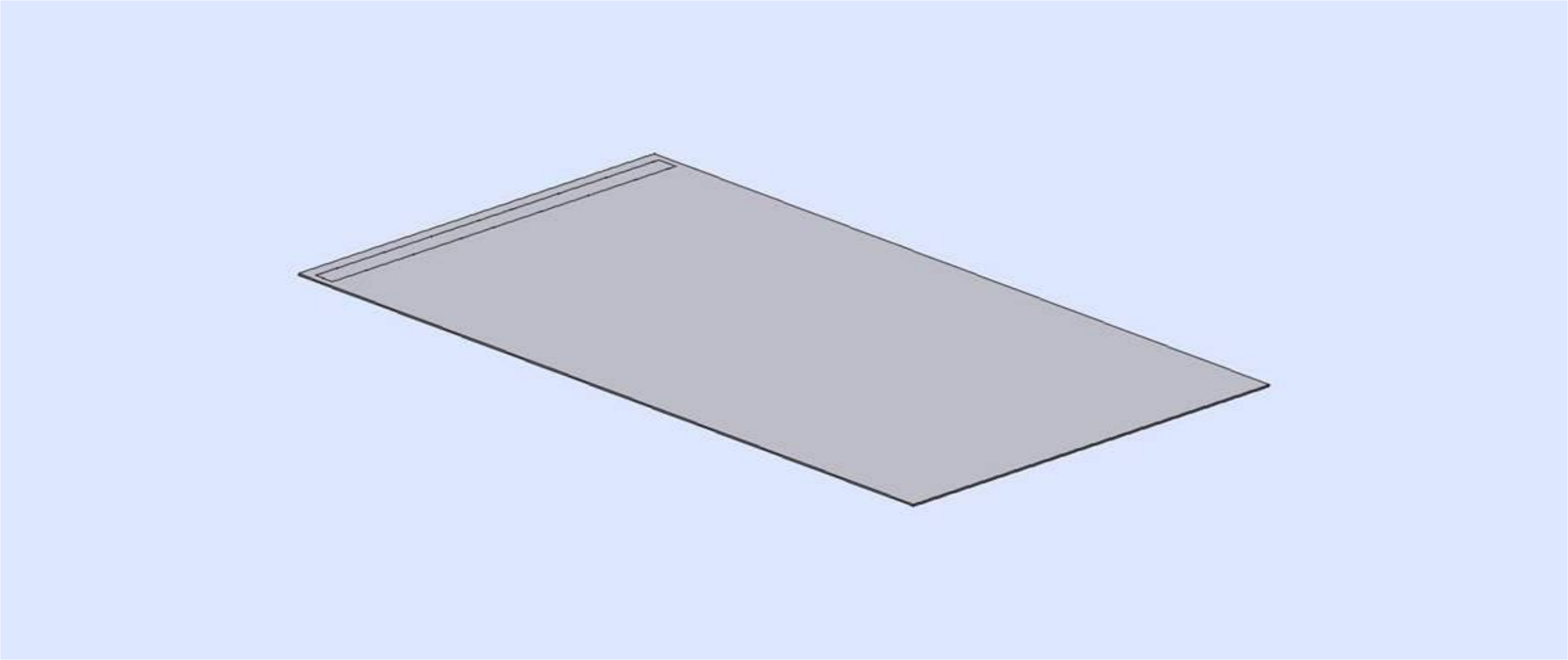
Chassis

- **Sheet Metal is Useful** - majority of 253 robots have a sheet metal chassis, stiffened by bending or other parts spot-welded together.
- **Minimize required machining processes.** Make use of waterjet/laser cutter and hand tools. Design for lathe/mill only when necessary for function.
- **Practice with hardboard / cardboard!** Plan your design for ease of access and fabrication. Can laser-cut cardstock and try multiple versions out very fast.

Making Things Stiff

100mm x 200mm piece of 24gauge (0.6mm) mild steel.

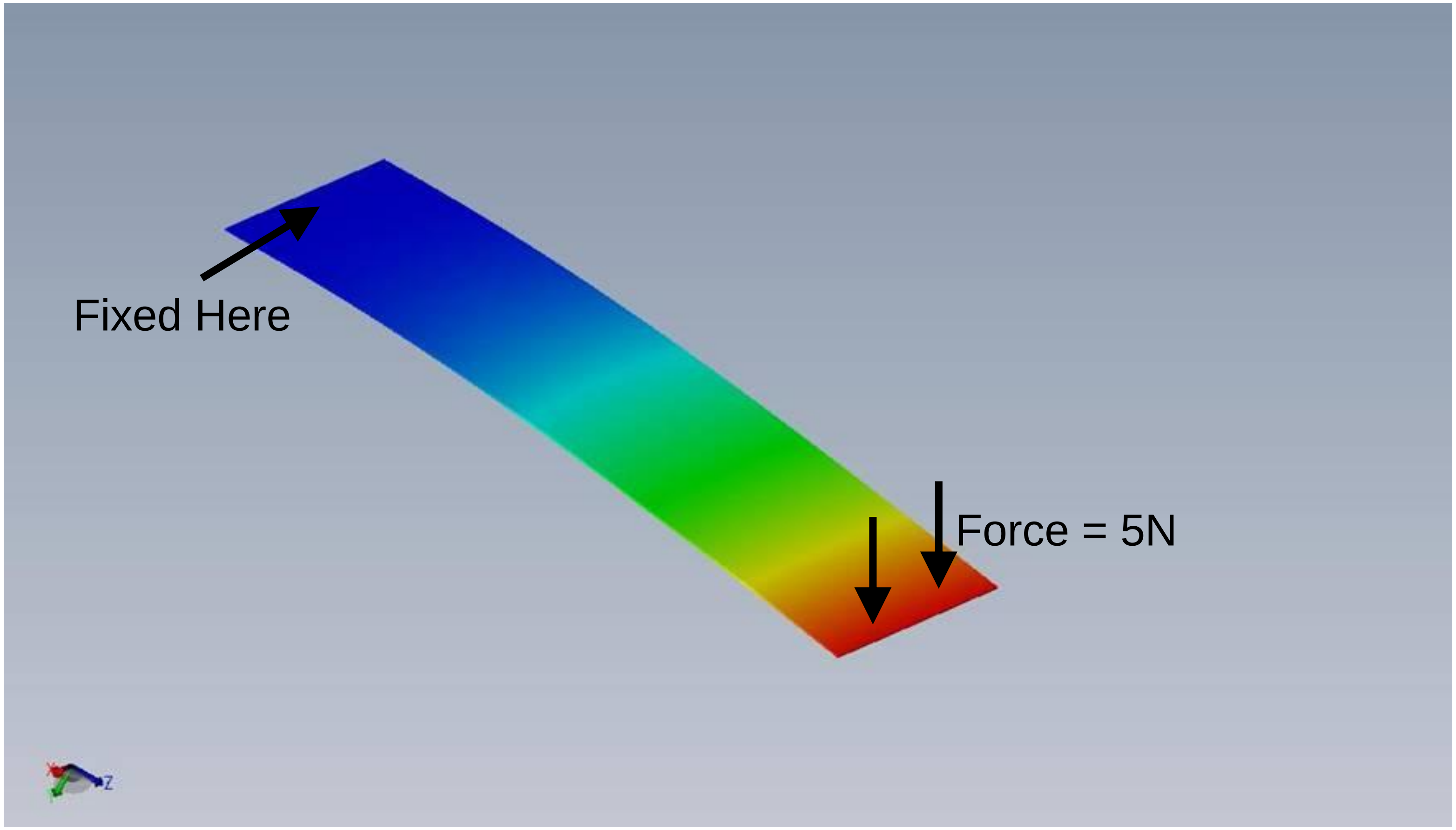
Fix one end, then apply 5N of vertical force in a Solidworks simulation.



Images and Calculations – Robin Coope, Design

Making Things Stiff, pg2

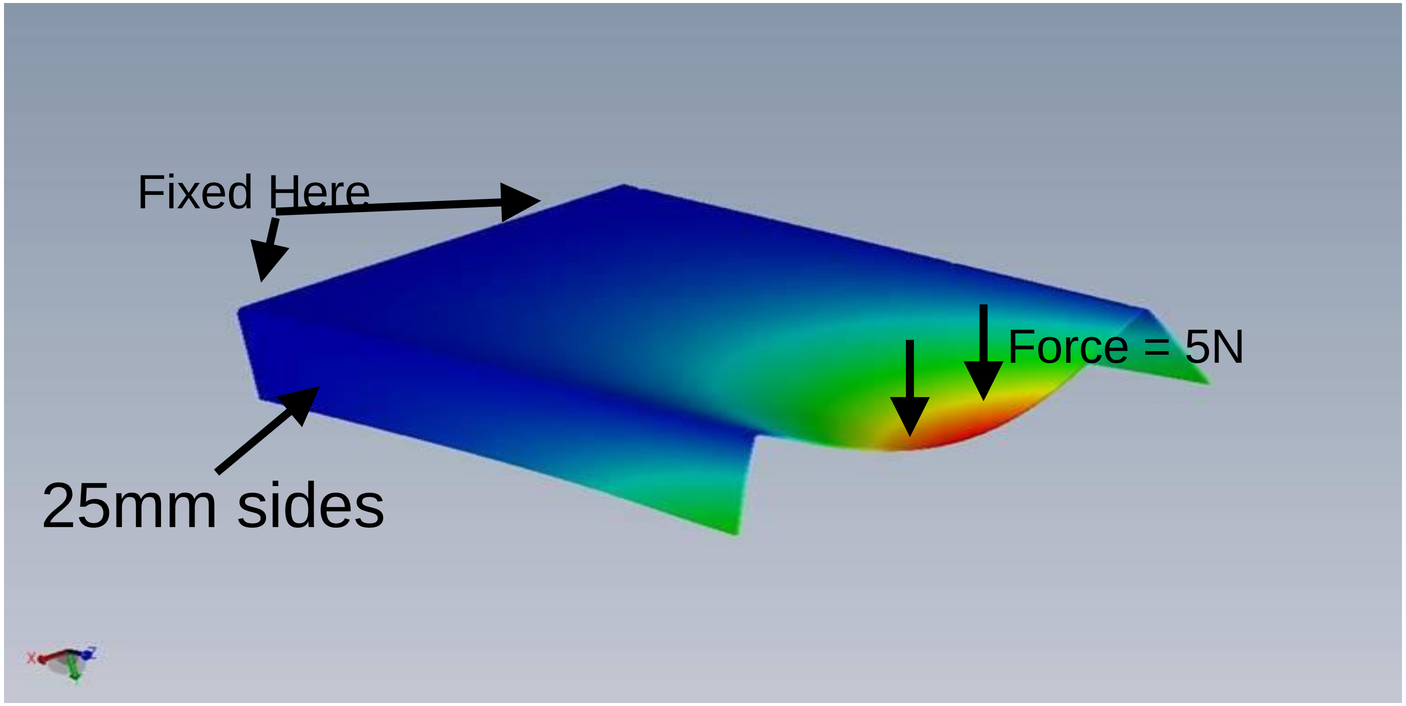
- Deflects 27mm @ 5 Newtons



Images and Calculations – Robin Coope, Design

Making Things Stiff,   pg3

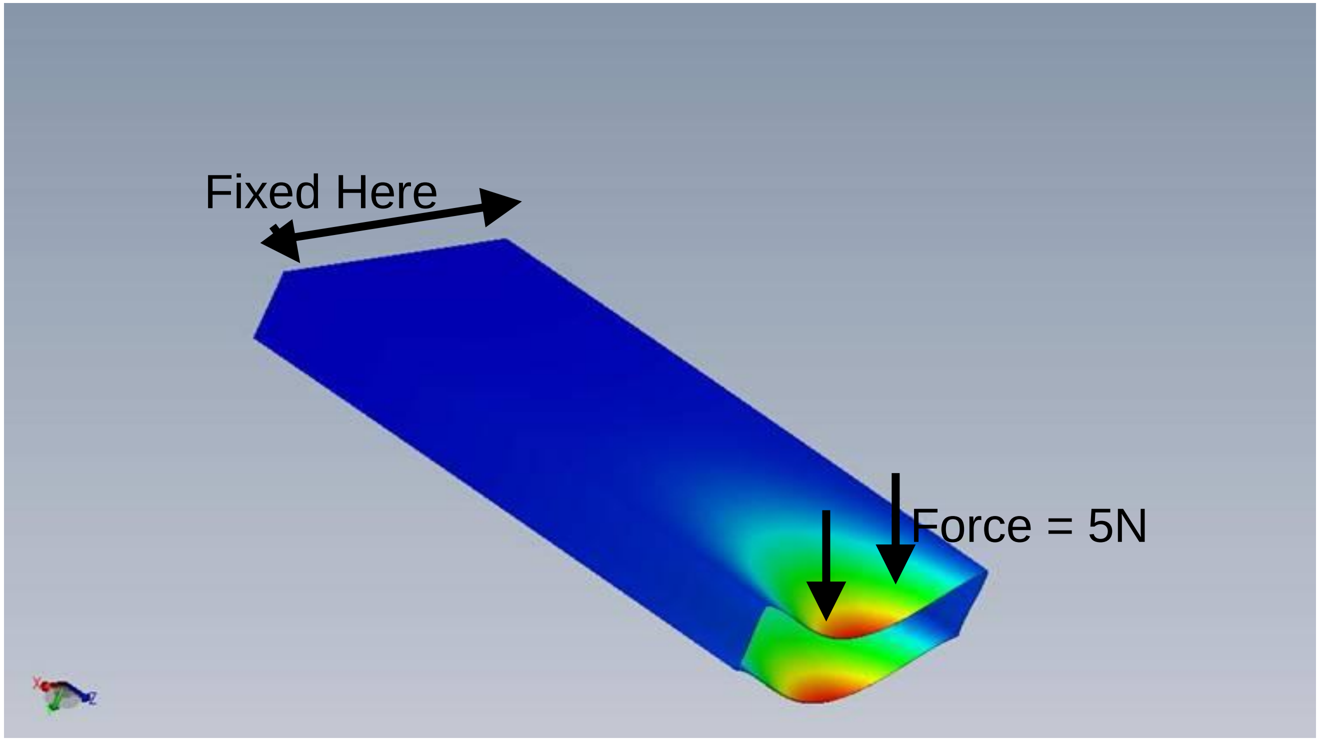
- Adding bends can make things stiffer
- With two 25mm edges, deflects 0.34mm @ 5N (80x stiffer!)



Images and Calculations – Robin Coope, Design

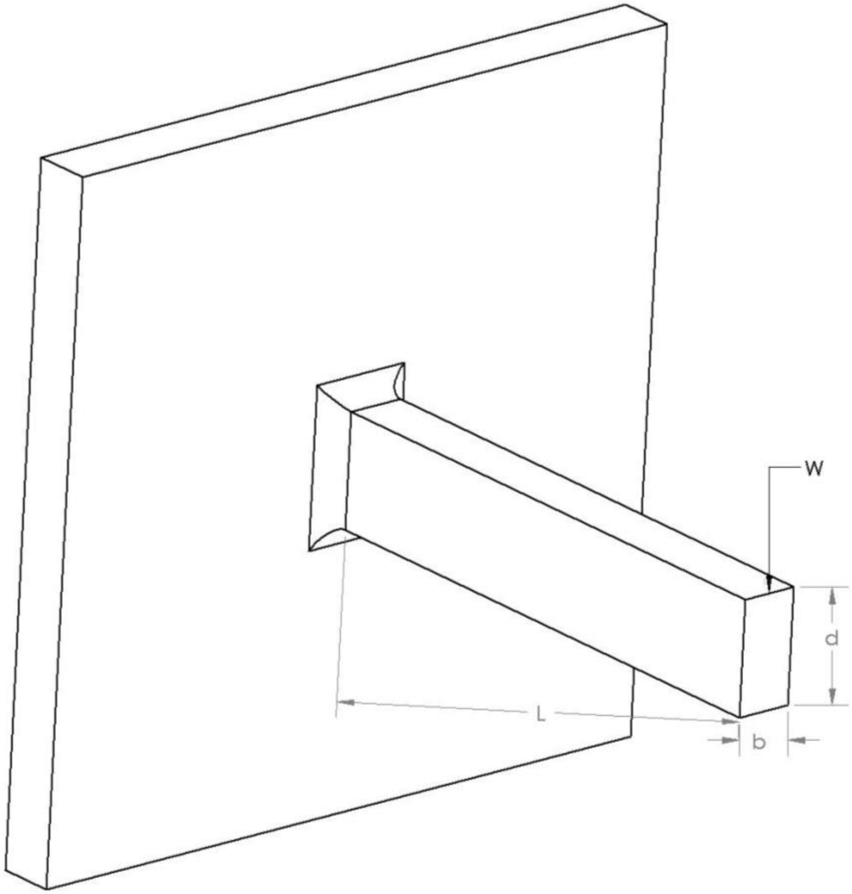
Making Things Stiff, pg4

- Closed boxes are even stronger
- Deflects 0.013mm @ 5N (2000x stronger!)



Images and Calculations – Robin Coope, Design

Deflection Theory

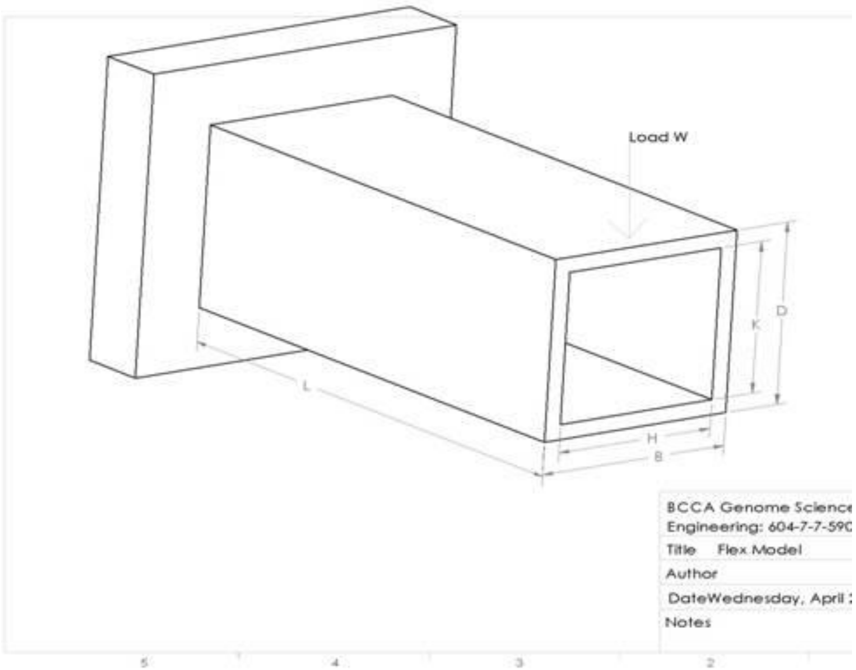


$$y_{max} = \frac{4WL^3}{Ebd^3}$$

Stiffness ∝ thickness3

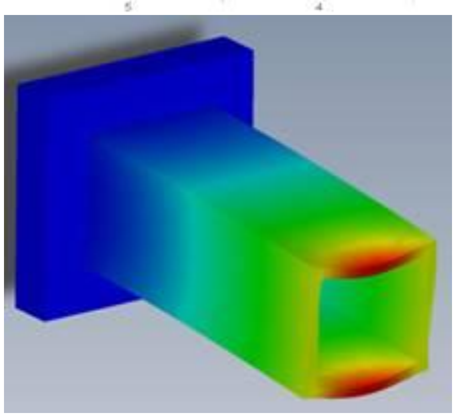
Images and Calculations – Robin Coope, Design

Deflection Theory,   pg2



$$y_{\max} = \frac{WL^3}{3EI}$$

$$I = \frac{BD^3 - HK^3}{12}$$



The strength-to-weight ratio depends on getting material farther from the neutral axis, without introducing other bending modes

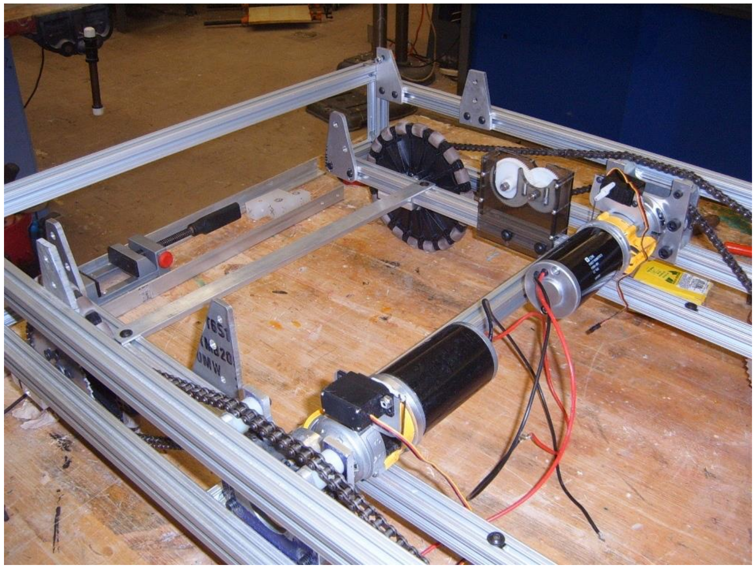
Images and Calculations – Robin Coope, Design

Stock Material Shapes

(red is most useful for 253)

Other stock materials

Shim Stock – very thin (0.001”)
Insert between other pieces of material to make small alignment adjustments.

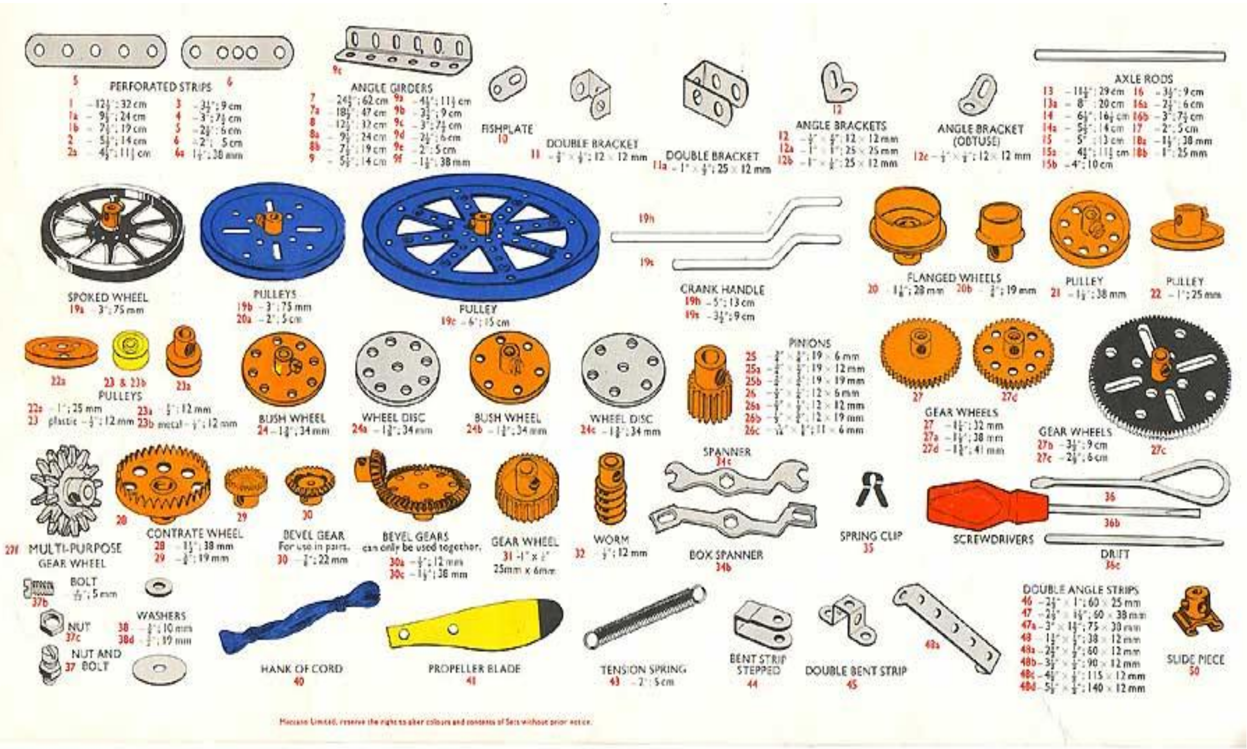


Aluminum Structural Extrusion (“80/20” OpenBeam)

Slots have room for sliding mounts. Useful but very expensive ($10/meter). In 253, small pieces may be used for precise alignment, not for entire chassis.

Other stock materials - Meccano

Hebb 42 has a selection of gears, pulleys, structural elements and shafts to quickly prototype ideas and verify calculations.



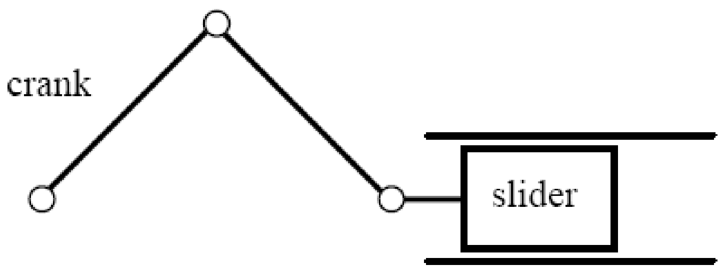
e.g. working mechanical differential drive mechanism

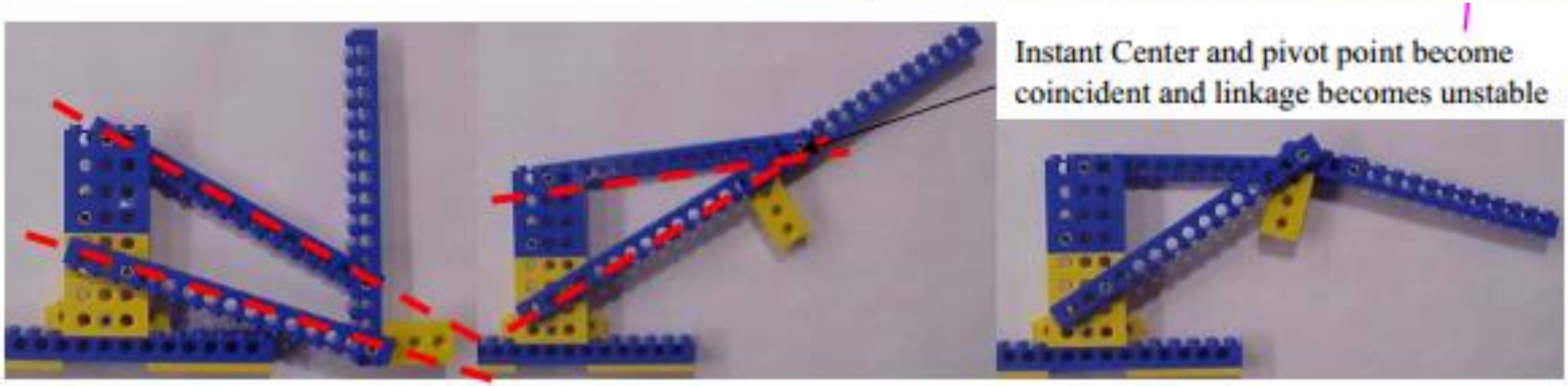
Moving Parts

(joints, flexures, springs)

Linkages

Linkages translate rotational motion into other useful curves or linear motions. Explore references to see lots of potentially useful examples.

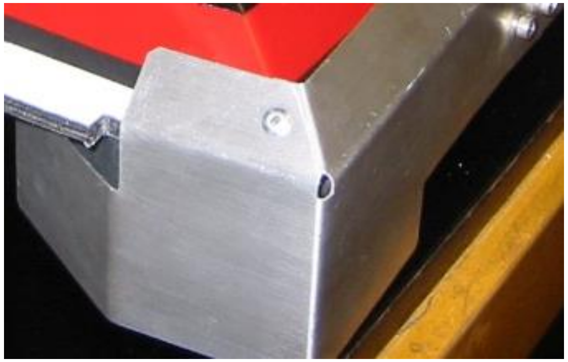


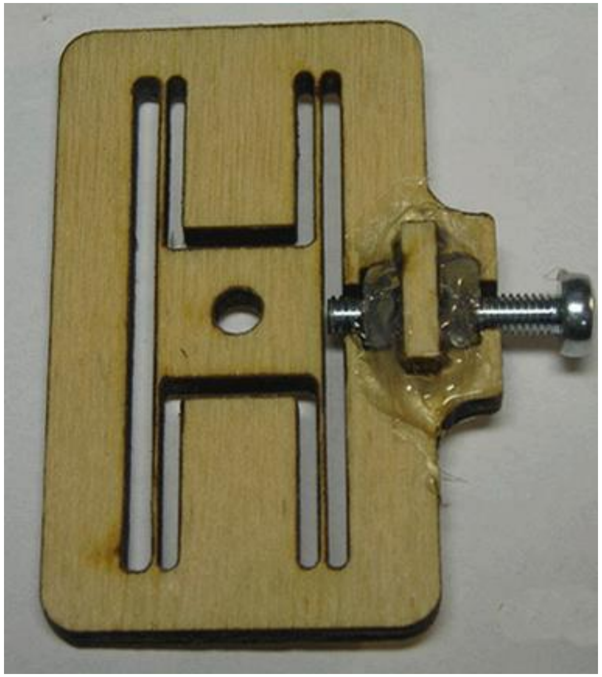


(Images – FUNdaMENTALS of Design, Slocum)

Flexure Hinge

- Instead of using a hinge with separate mechanical parts, it is sometimes better to rely on the flexibility of the material itself.
- Flexures instead of hinges mean fewer parts, possibly more accurate and repeatable motions, and likely a stronger structure.



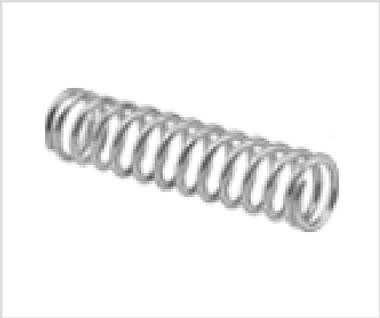


Flexure used for bumpers
(microswitch underneath)

(Left – FUNdaMENTALS of Design (slocum)
Right - imajeenyus.com)

Springs

- Safety!   Springs should always be mechanically constrained.



Compression and Die Springs

Extension Springs

Torsion Springs

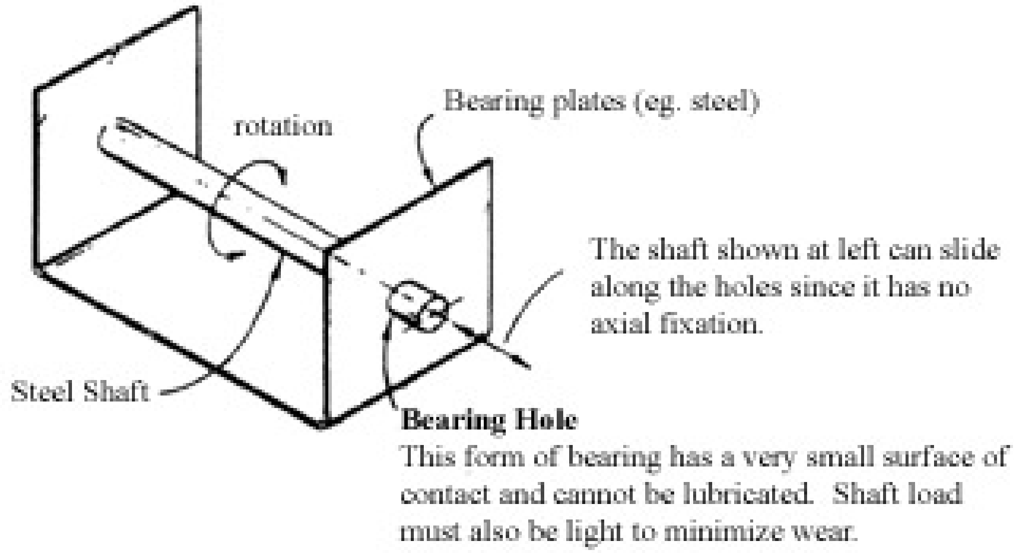
- Can use flat pieces of spring steel to make custom springs

(Images from mcmaster.com, www.aps-ct.com/flat-springs/flat-leaf-springs.php)

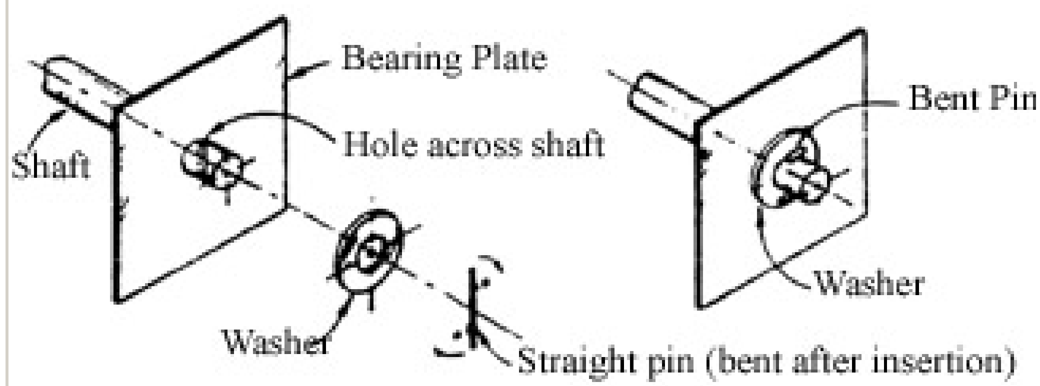
Pivots

- Whenever possible, **<u>rotation should be used instead of sliding joints</u>**.

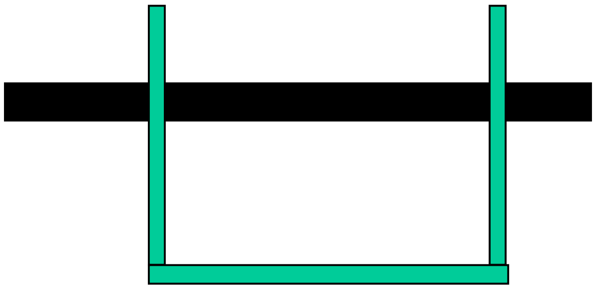
- To minimize friction forces, shafts should be made of hard materials (preferably steel, not aluminum), should be of a small diameter, and ideally running on a low-friction surface (although thin sheet metal can often be ok as well).



Axial Fixation of Shaft by Simple Pin and Washer

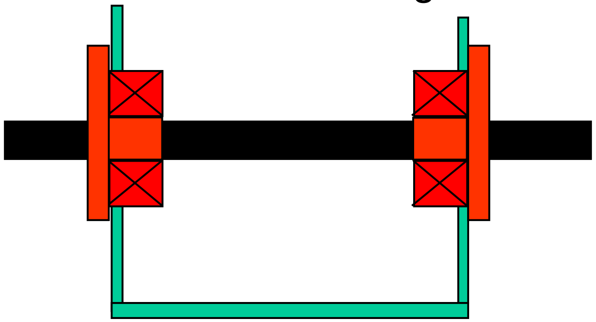


Bearings

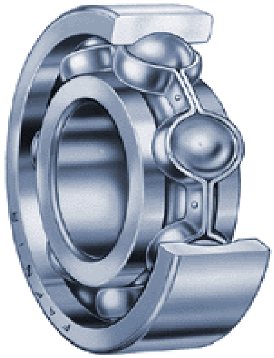


Not great (bracket can flex and bind up the shaft)

Better (bushings in thin sheet metal can prevent structure from flexing.



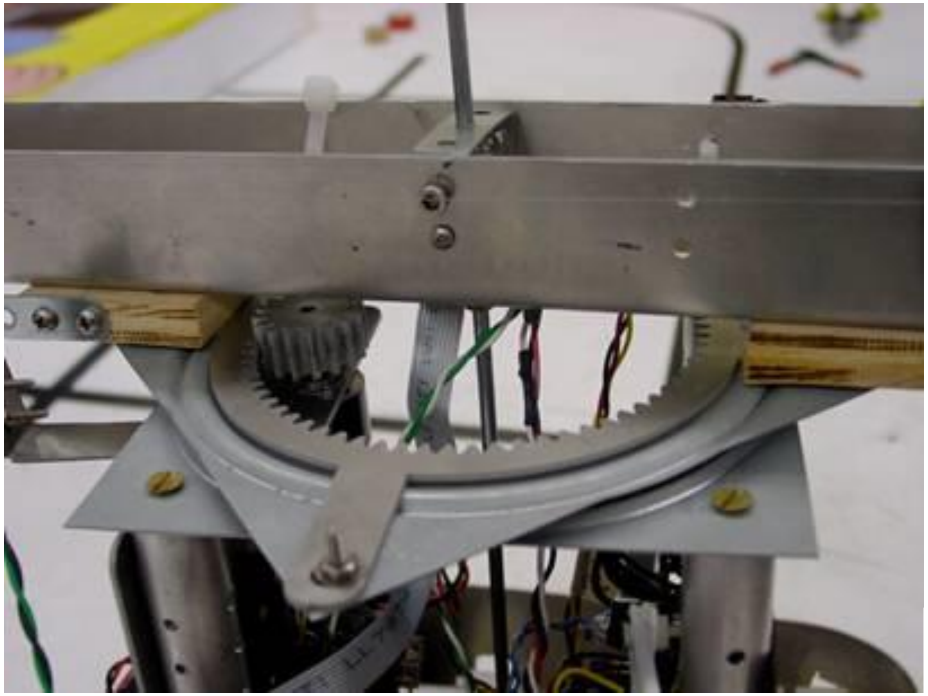
Thin Sheet Metal – easy, quick, but beware of binding!



<u>Plastic and brass bushings (left)</u>: much more tolerant of misalignment and good up to fairly high speeds.

<u>Ball bearings (right)</u> good for high-speed high-load applications, but require a great deal of precision (steel bearing housing tolerances are ~0.0001” to 0.0005”). Rarely useful for ENPH 253.

Lazy Susan Bearing and Thrust Bearings



•Thrust Bearing – rollers allow for rotation under load along the vertical axis

•Lazy Susan Bearing – useful for distributing weight and still allowing for rotation for a large load.

Clamping to Shafts

Splines. Great torque resistance. Can be end-bolted if the spline is tapered or split bolted (e.g. RC servo output shaft). A loose fit will "nag" the splines and wreck the shaft.

Key and keystock: A single spline for a steel shaft and hub. Material of the key (e.g. brass) is chosen so it can break under a specified load, as a safety mechanism.

Clamping to Shafts pg2

Shaft Collars and Set Screws

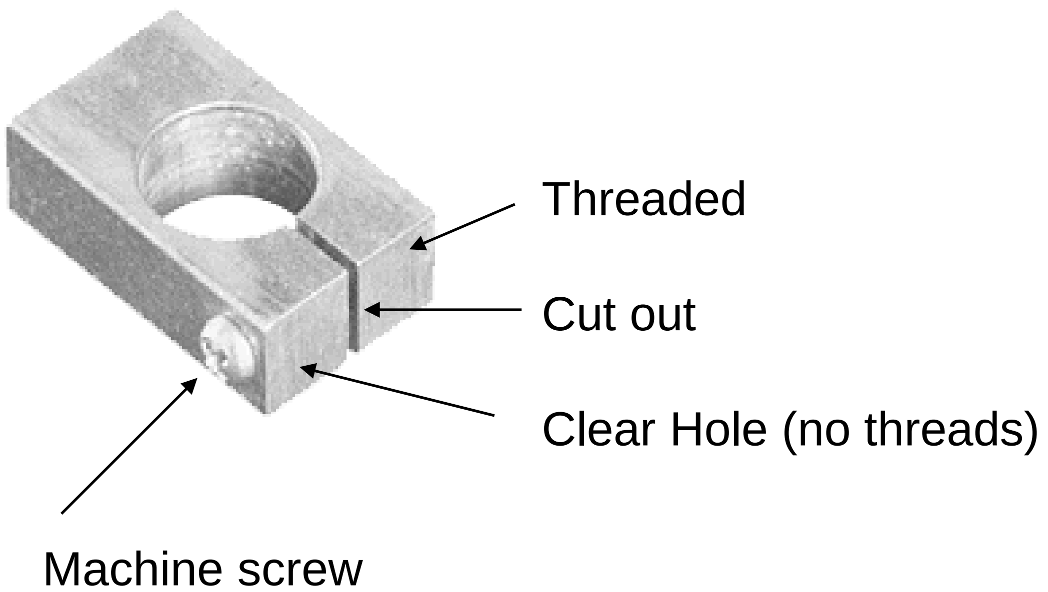
Positives: Easy to make, can use on any shaft.

Negatives: Can damage the shaft, not much torque resistance, easy to strip set screws, need to use shaft flats for better grip larger shafts.

Best used with smaller shafts with small torques

Clamping to Shafts   pg3

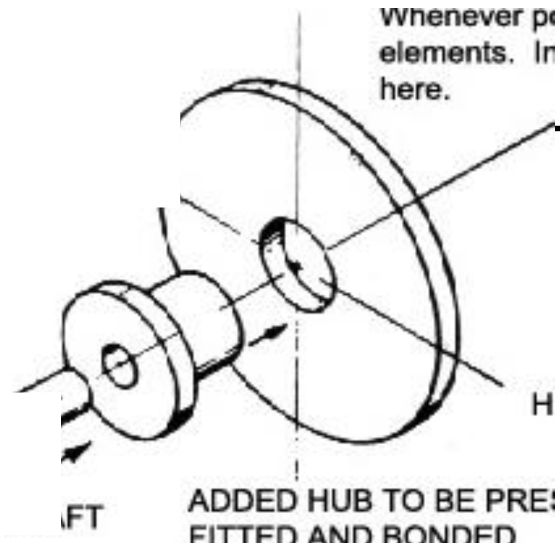
- The best general method for clamping without spines is a split clamp.
- MUST have an accurate fit to the shaft before the screw is tightened.

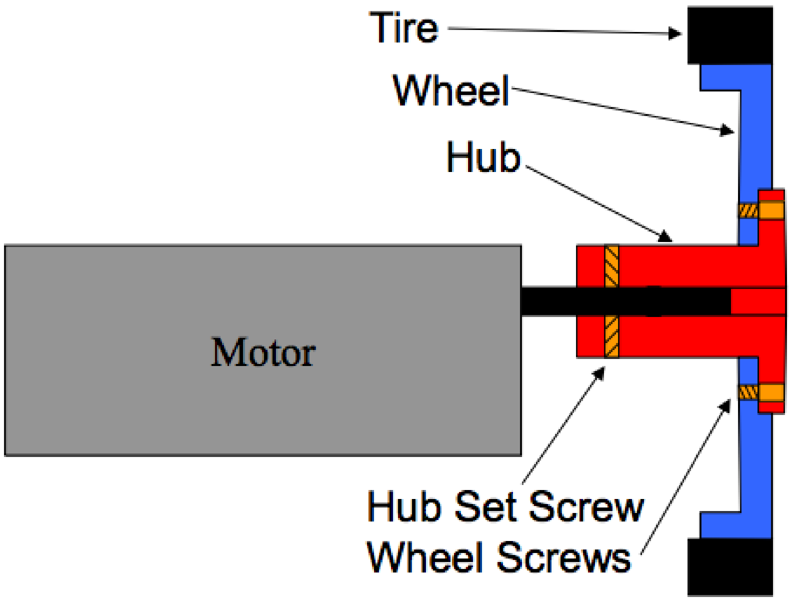


•**<u>Also:</u>** Check out the split-clamp shaft adapters for geared Barber Colman motors (from 3d Printer)

Wheels and Hubs

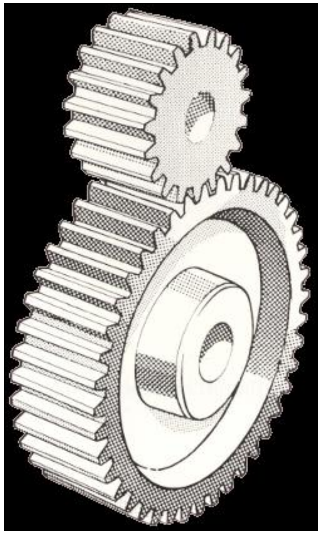
- The key to good hubs for gears and wheels is concentricity and good grip.
- Make hubs long enough to allow access to set screws
- Good hub/shaft overlap (eg ~20mm for our motors), increases stiffness which helps keep wheels tight to the motor





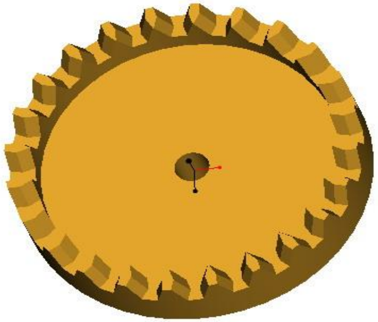
Power Transmission (aka Drive Train)

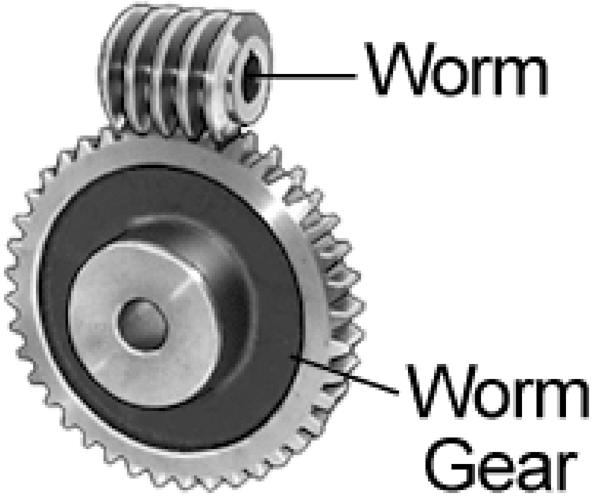
Gears



Spur Gears – common for 253. We waterjet/ laser/3D print gears which are functional but are not very good at high speed (good for increasing torque, not great for speed)

Right-angle gears with **bevel gears** (above) or **crown gears** (below)

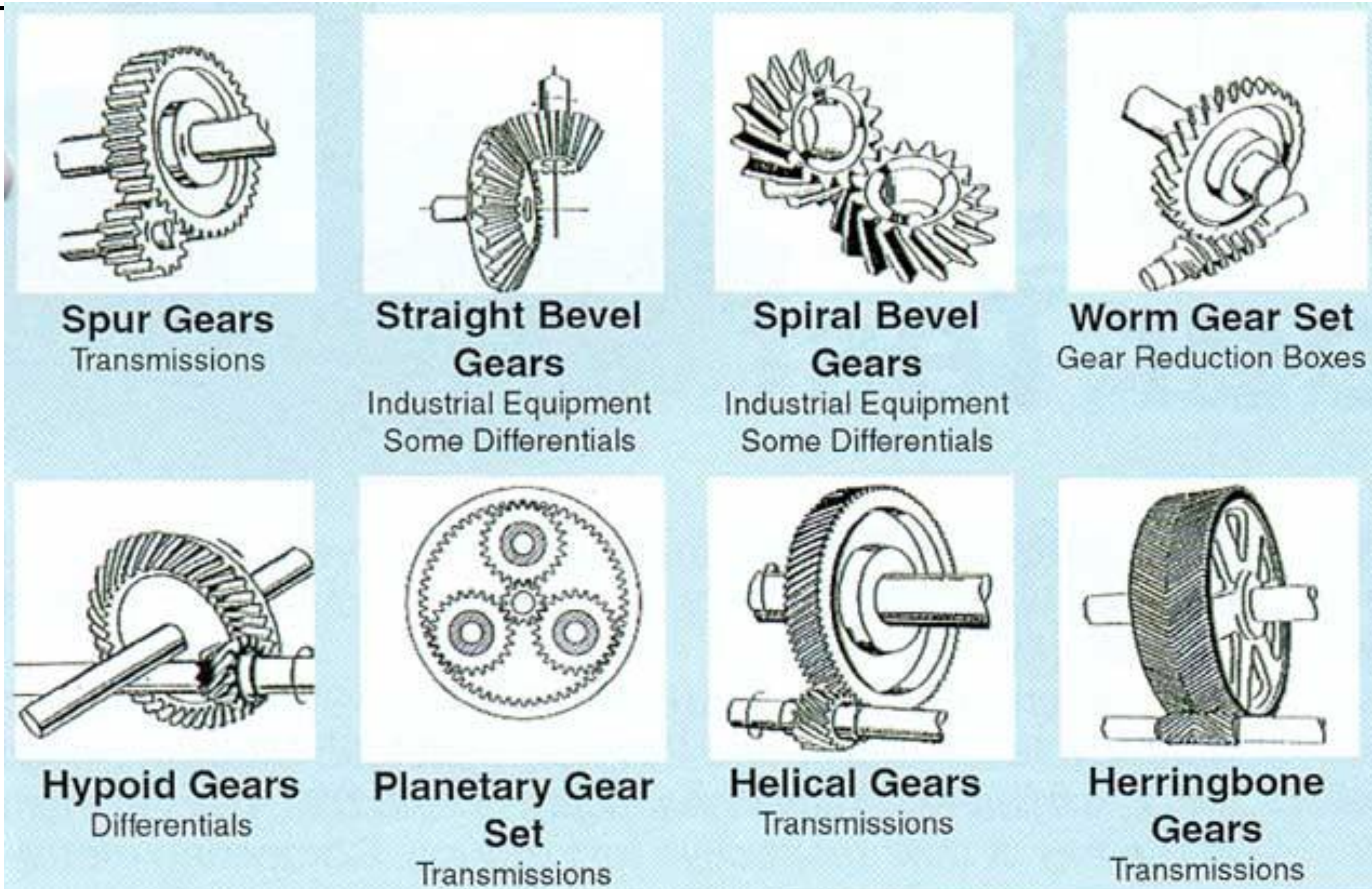




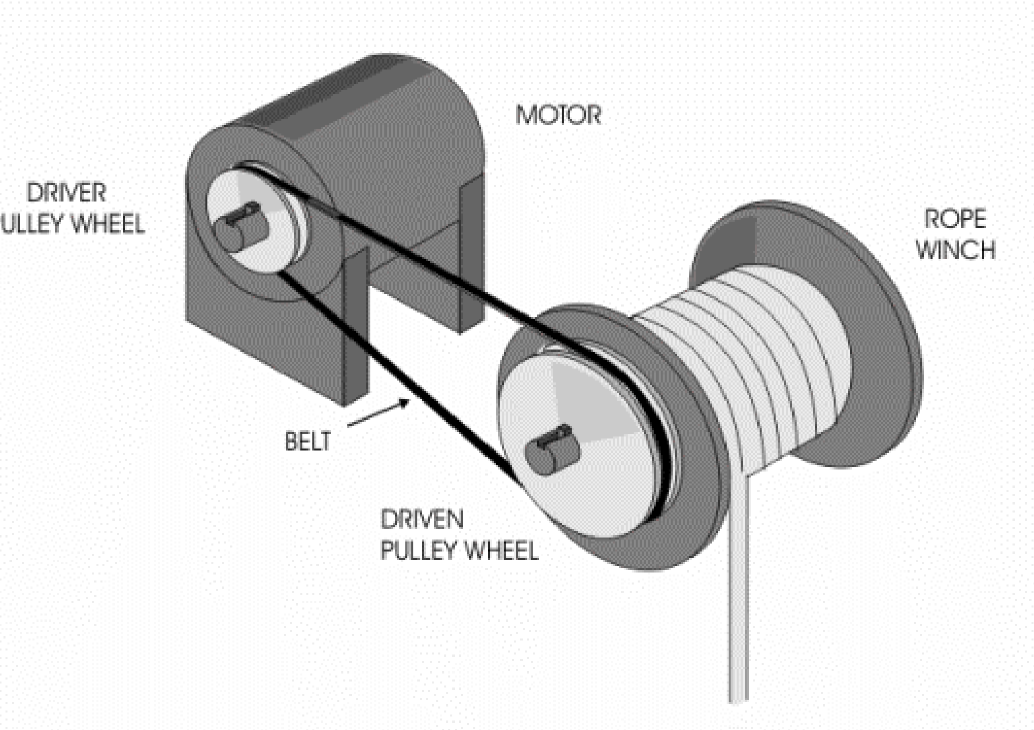
Worm and worm gear - lots of torque but slow N:1 ratio (worm gear only moves 1 tooth for every 1 rotation of the worm)

Cannot back-drive system, useful to hold a position with no power input.

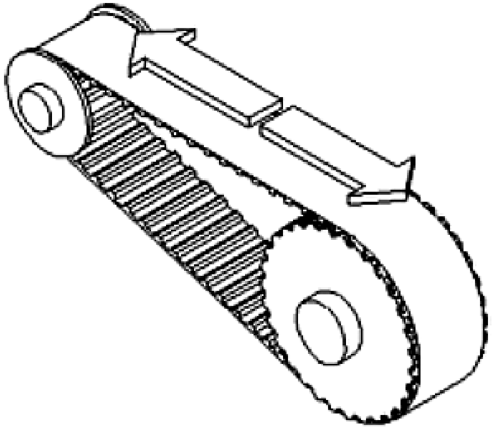
Gears pg2


Spur Gears
Transmissions
Straight Bevel Gears
Industrial Equipment
Some Differentials
Spiral Bevel Gears
Industrial Equipment
Some Differentials
Worm Gear Set
Gear Reduction Boxes
Hypoid Gears
Differentials
Planetary Gear Set
Transmissions
Helical Gears
Transmissions
Herringbone Gears
Transmissions

Pulley drives

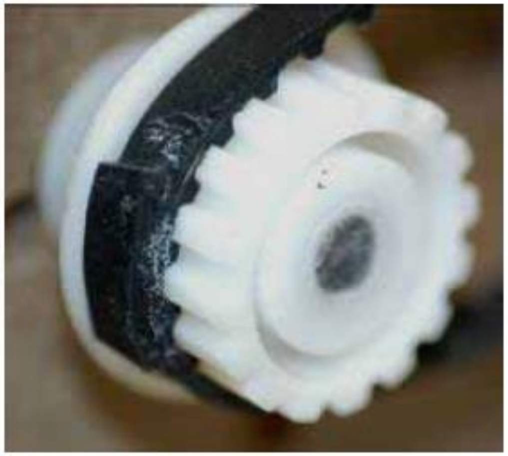


•**<u>Timing belts</u>** have beads or rubber teeth to minimize the chance of slipping



•For pulleys, use **<u>same ratio calculations as with gears</u>**, except use diameters instead of teeth

•Pulleys may slip, which may or may not be a good thing (bad for accuracy, good for protecting fragile mechanical pieces)

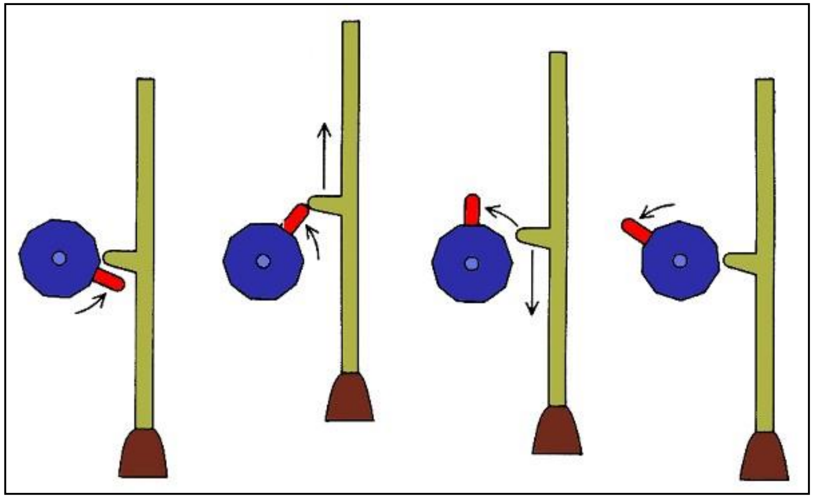


Linear Motion

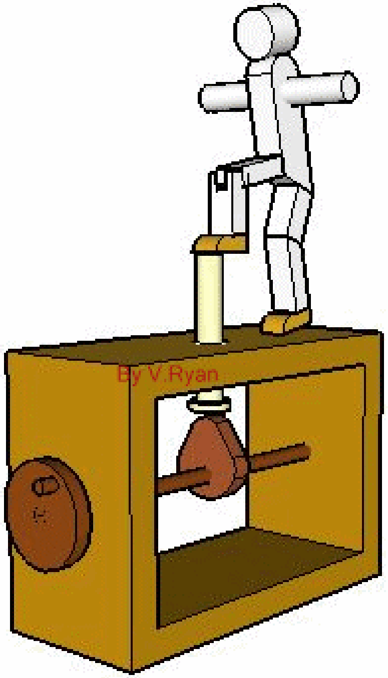
- **Rotation is always easier than linear motion.** Can you redesign the mechanism or method to rotate instead of move linearly
- **Binding can be tricky to avoid**
- **Look at commercial linear stages** for design attributes to help avoid binding (drawer slides, electric forklift just outside Hennings student shop)

Lead screw. Make nut out of low-friction plastic and can run on standard thread reasonably well.

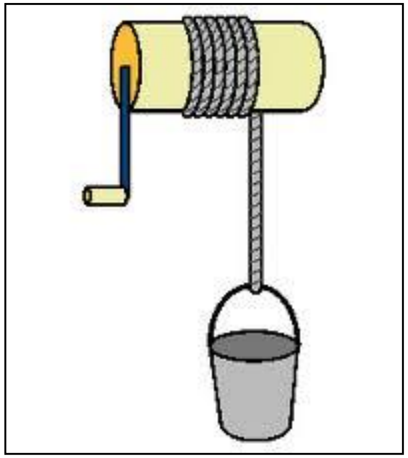
Linear displacement and force from rotary motion



<u>Cam</u> forcing an arm to oscillate vertically



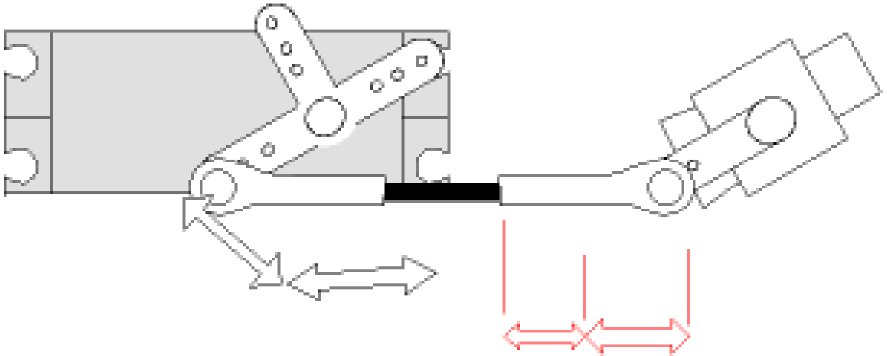
http://www.technologystudent.com/images7/pear1.gif



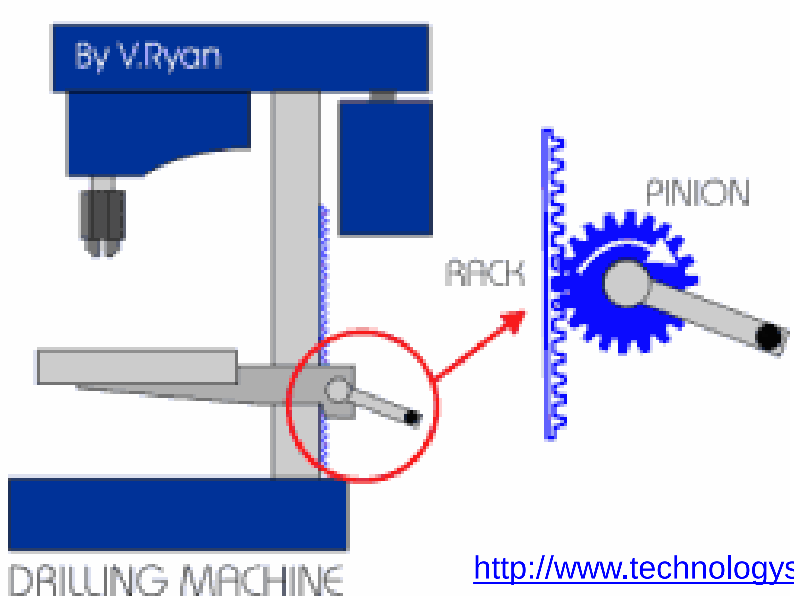
Cable on winch (good way to create linear force from rotary motion)

Linear motion from rotary motion - other eg's

RC Servo Motor with wire linkage connecting horn to mechanism (this is how RC servo motors are normally used in RC planes)



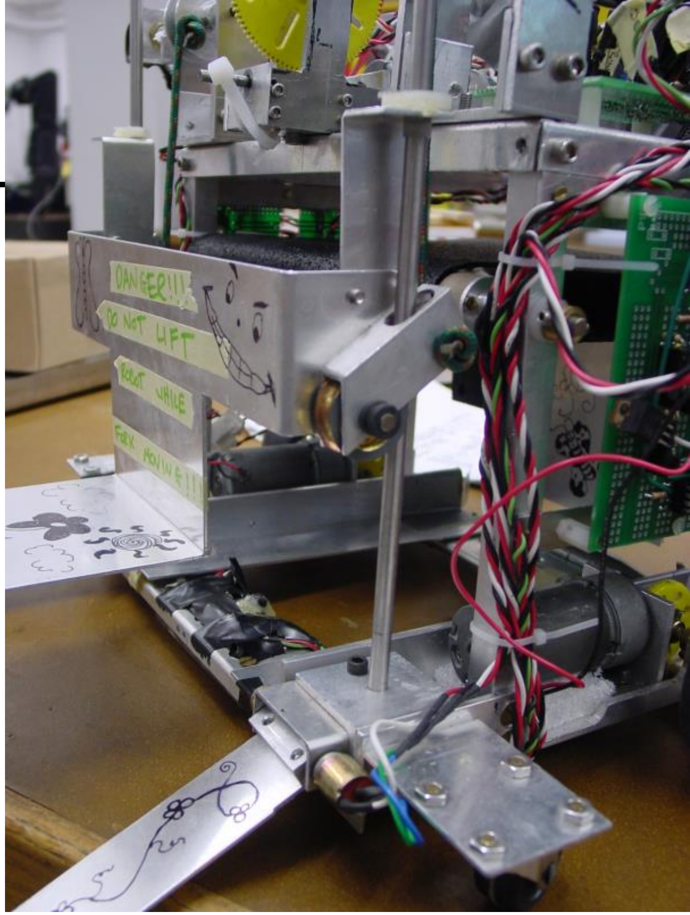
http://www.vueloinvertido.com/imagenes/web/ajustes-varillaje-gaz/thservoanim.gif



Rack and pinion Requires good constraint between rack and gear at all times. Sliding can result in binding.

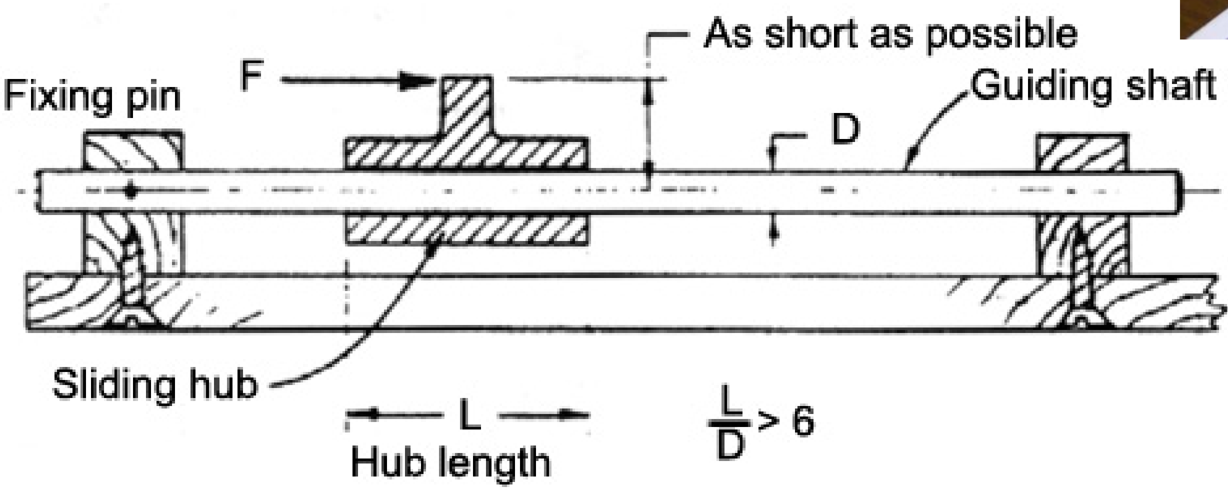
http://www.technologystudent.com/images2/rck2.gif

Sliding Bearings



•"Linear bearings are ~10x more expensive that rotating bearings although they work really well. Linear systems have been used successfully in 253 but ~50% of such devices have had major sticking problems. "

•"Homemade linear bearings systems are particularly problematic under heavy load." (Robin Coope)

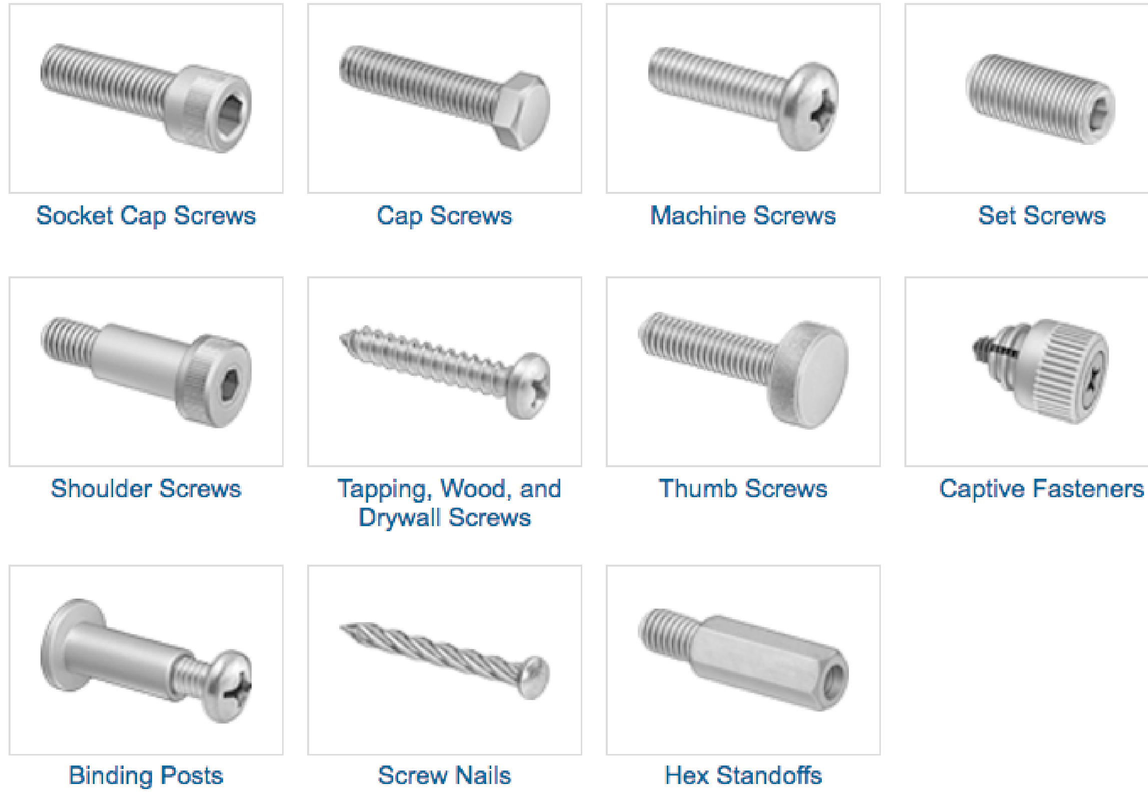


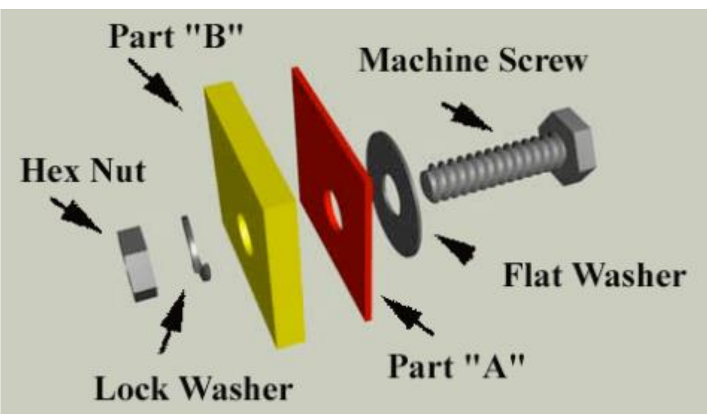
Linear stage using pulleys on 2005-winning robot

Fasteners and Adhesives

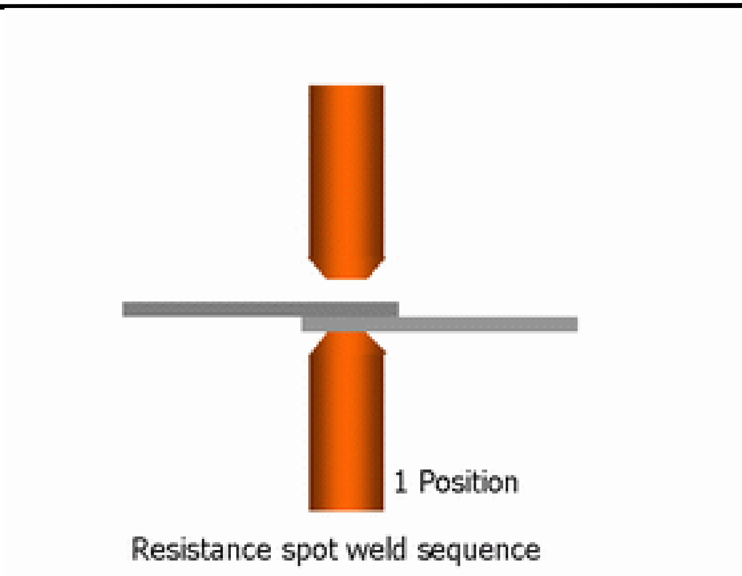
Screws, Nuts and Bolts

- Metric (M3, M4 etc)
- Imperial (6/32, 8/32, etc)
- Can use Loctite adhesive or lock washers to prevent bolt from coming out due to vibrations.





Permanent Fastening



http://www.davidpageassociates.co.uk/images/spotweld.gif

<u>Spot-Welding</u> – for steel only. In waterjet room.

<u>Epoxy</u> – Can be as strong as welding. Clean/sandblast surfaces. Mix thoroughly ~30sec, or it doesn't harden.

<u>Solvents</u> – dissolves and reforms the material. We have solvents for plastics.

Temporary Fastening

Velcro (hook and loop) **-** do not use on TINAH or batteries.

Tie straps and rubber bands – very useful in keeping wiring organized, items held in place against vibration, ease of access for parts.

End.