Updated for 2104 These notes are a preview to what is on the wiki. Use the wiki for best quick links to materials and suppliers.

- http://bdml.stanford.edu/Main/FinalProjectMaterials
- http://bdml.stanford.edu/Main/FinalProjectConstructionTips

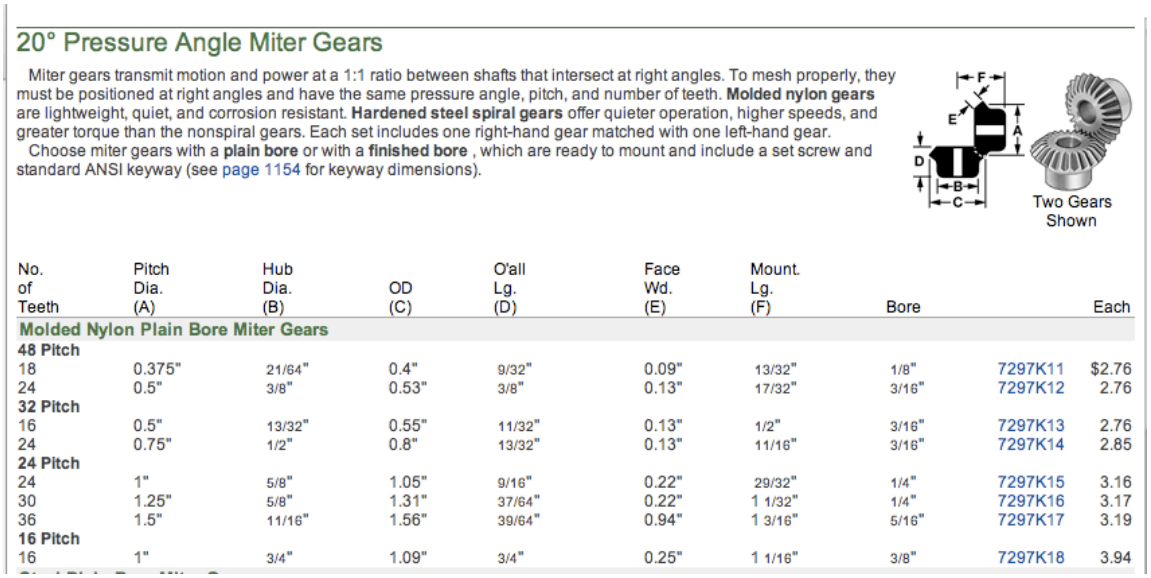
Motors, Gears, Etc.

Tamiya motors & gearboxes, one-way wheels, useful hardware from RC car and airpline suspensions:
D&J Hobby, San Jose (off route 85) http://www.djhobby.com/
J&M Hobby House, San Carlos -- tiny but suprisingly good selection of Tamiya stuff.
Jameco (including Jameco Robotics), Belmont CA will-call pickup.
http://www.jameco.com and http://www.robotstore.com/

Mailorder
There are many on-line places. For example http://www.hobbylinc.com has the Tamiya stuff.
Stock Drive Products (http://www.sdp-si.com/) has relatively inexpensive plastic gears, timing belts and pulleys and plastic chain drives.
Misumi rotary transmission components – good selection of bearings, shafts, etc. (http://us.misumi-ec.com/vona2/mech/M1000000000/) higher quality and more expensive.

Hardware

- Orchard Supply - pretty good selection. Not particularly cheap. Can sometimes find cabinet, shower door, etc. hardware and rollers that are cheap, have good bearings and can easily be retrofitted to your purpose. (For example the “low friction pulley” for Crawler tests...)
- Home Depot - cheap, especially for items in bulk boxes, if you can find what you are looking for…
- ACE Hardware on Alma St. - easy bike ride from campus. Not particularly cheap but decent selection and knowledgeable staff.
- Peninsula Hardware, Middlefield Rd. near Oregon Expwy - last of the old-fashioned hardware stores. Average prices, very knowledgeable staff.
- Office supply places may have bulk (much cheaper than buying small quantities) of screw posts, also called binding posts (http://www.screwpost.com).



20° Pressure Angle Miter Gears

Miter gears transmit motion and power at a 1:1 ratio between shafts that intersect at right angles. To mesh properly, they must be positioned at right angles and have the same pressure angle, pitch, and number of teeth. **Molded nylon gears** are lightweight, quiet, and corrosion resistant. **Hardened steel spiral gears** offer quieter operation, higher speeds, and greater torque than the nonspiral gears. Each set includes one right-hand gear matched with one left-hand gear.

Choose miter gears with a **plain bore** or with a **finished bore** , which are ready to mount and include a set screw and standard ANSI keyway (see page 1154 for keyway dimensions).

No. of Teeth	Pitch Dia. (A)	Hub Dia. (B)	OD (C)	O'all Lg. (D)	Face Wd. (E)	Mount. Lg. (F)	Bore		Each
Molded Nylon Plain Bore Miter Gears									
48 Pitch									
18	0.375"	21/64"	0.4"	9/32"	0.09"	13/32"	1/8"	7297K11	$2.76
24	0.5"	3/8"	0.53"	3/8"	0.13"	17/32"	3/16"	7297K12	2.76
32 Pitch									
16	0.5"	13/32"	0.55"	11/32"	0.13"	1/2"	3/16"	7297K13	2.76
24	0.75"	1/2"	0.8"	13/32"	0.13"	11/16"	3/16"	7297K14	2.85
24 Pitch									
24	1"	5/8"	1.05"	9/16"	0.22"	29/32"	1/4"	7297K15	3.16
30	1.25"	5/8"	1.31"	37/64"	0.22"	1 1/32"	1/4"	7297K16	3.17
36	1.5"	11/16"	1.56"	39/64"	0.94"	1 3/16"	5/16"	7297K17	3.19
16 Pitch									
16	1"	3/4"	1.09"	3/4"	0.25"	1 1/16"	3/8"	7297K18	3.94

Figure 1: From McMaster Carr. You want plastic gears with the biggest teeth (coarse pitch) that you can find in the diameter range that works. Remember that bevel gears need precise mounting in both radial and axial directions.

Figure 2 Gears and sprocket/chain sets from Jameco/Robot Store. Note that some gears have no hub, which makes mounting on shafts a bit trickier (lasercut you own hub). Also watch for different pitch and pressure angle. For sprockets, use big ones to reduce chain tension for given torque. Couplings (see below) can also be useful for connecting shafts.

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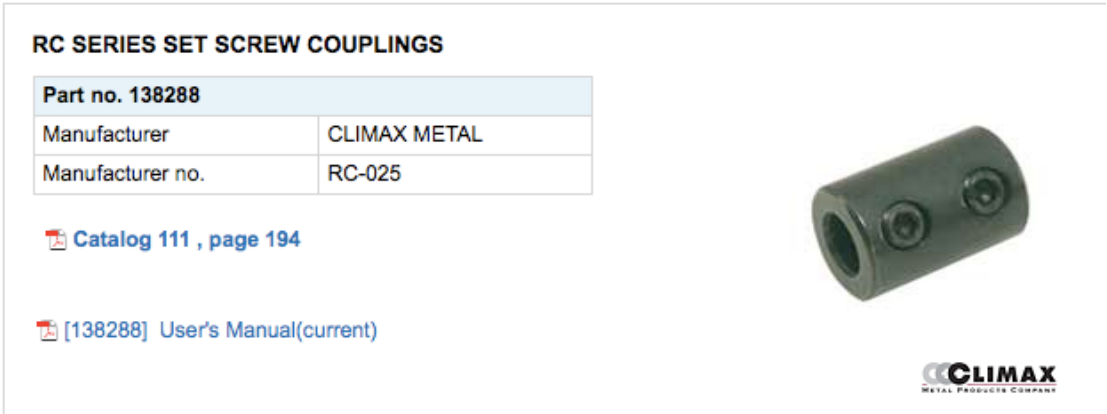


Description
Twin core Posi-Drive belt, 0.1475" (C.P.) Pitch, 11.8"Pitch Length 080 Pins

SINGLE CORE

TWIN CORE

Product Details	
Part Number	S7915Y-CPAFT080
Unit	Inch
Pitch	0.1475(C.P.)
Working Tension	10 - 12 lbs
Pitch Length	11.8000"
Max. Speed- Loaded	550 ft/min
Max. Speed-no Load	1300 ft/min
Belt Type	Twin Core
Min.teeth In Mesh	6
Min. Pulley Dia.	0.750"

Price Information	
Quantity	**Price**
1 to 9	$13.35
10 to 49	$11.54
50 to 99	$9.86
100 to 249	$9.12
250 to 499	$8.56
500 and up	$8.01

Availability Out of Stock

Sell Unit Each

Quantity

ADD TO CART

ADD TO RFQ

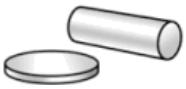
Figure 3. belt and plastic belt/chain hybrid from Stock Drive Products

Aluminum Shaft Stock

Aluminum

712 products match your selections

View catalog pages (7)



Shape Rods and Discs

Diameter

1/8" | 3/16" | 1/4" | 5/16" | 3/8" | 7/16" | 1/2" | 5/8" | 3/4" | 7/8" | 1" | 1-1/8" | 1-1/4" | 1-3/8" | 1-1/2" | 1-5/8" | 1-3/4" | 1-7/8" | 2" | 2-1/8" | 2-1/4" | 2-3/8" | 2-1/2" | 2-5/8" | 2-3/4" | 2-7/8" | 3" | 3-1/8" | 3-1/4" | 3-3/8" | 3-1/2" | 3-3/4" | 4" | 4-1/2" | 5" | 6" | 6-1/2" | 7" | 7-1/2" | 8" | 3 mm | 4 mm | 5 mm | 6 mm | 7 mm | 8 mm | 9 mm | 10 mm | 12 mm | 14 mm | 15 mm | 16 mm | 20 mm | 25 mm | 30 mm

Length

1/4" | 1/2" | 3/4" | 1" | 3" | 6" | 12" | 36" | 6' | 8' | 1 m

Alloy

2007 | 2011 | 2017 | 2024 | 4032 | 6013 | 6020 | 6060 | 6061 | 6063 | 7068 | 7075

Material — About Aluminum Alloys

Figure 4 Shafting (McMaster Carr). Aluminum is much easier to drill holes into, cut slots into the end of, or file a flat on. You will probably need one of these mechanical fastening methods in addition to any glue you use.

Tubing

2 products match your selections

View catalog page
Compare products (2)

Type	Nylon Vacuum Tubing
Plastic	Nylon
Nylon Material	Nylon 6
Material	Nylon 6
Shape	Single Line
System of Measurement	Inch
Outside Dia.	5/16" (.3125")
Inside Dia.	.188"
Wall Thickness	.062"
Reinforcement	Unreinforced
Maximum Pressure Range, psi	751-1,000
Maximum Pressure	913 psi @ 70° F
Low Temperature Range	-99° to -1° F
High Temperature Range	+201° to +300° F
Operating Temperature Range	-40° to +225° F
Performance Characteristics	Vacuum Rated
Bend Radius	2-3/4" (2.75")
Rockwell R	112
For Use With	Air and Food and Fuel and Water
Fittings Used	Compression
Specifications Met	United States Food and Drug Administration (FDA)
FDA Specification	CFR21 177.1500

Figure 5. Plastic tubing can be cut into sections for cheap bushings. Teflon tubing (available from McMaster Carr, etc.) is ideal for this purpose.

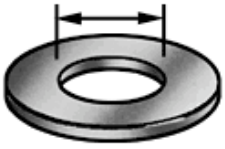
Plastic Type > For Screw Size

Washers

3 products match your selections

Shape	Round Hole
For Screw Size	8
Material Type	Plastic
Finish	Plain
Plastic Type	Nylon 6/6
Color	White
System of Measurement	Inch
Inside Diameter Range	.15" (5/32") to .249" (15/64")
Application	Insulating Washer
Durometer Hardness	Not Rated

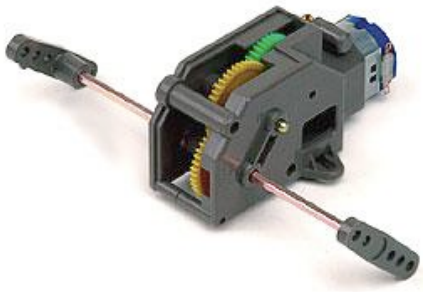
Inside Diameter .15" (5/32") to .249" (15/64")



.173" | .177" | .188" (3/16")

Figure 6. Plastic washers are especially useful to reduce friction where you have axial loads, or between links. These are *much* cheaper if bought in bulk. So pool orders across several teams. How about a gross of 3/16 or ¼ inch diameter plastic washers – they are much cheaper in boxes of 100 than in little plastic bags of 5 or 6.

Figure 7. Hobby stores have interesting linkage parts (e.g. for helicopters, RC cars) – it is always worth taking a field trip to a local hobby shop to browse what's available.



Add to Cart

4-Speed Crank Axle Gearbox

Figure 8. Tamiya gearboxes often have adjustable speed ranges by switching the order of gears. The ones with good shaft connections are best because the shafts are small, hardened steel and otherwise hard to modify.

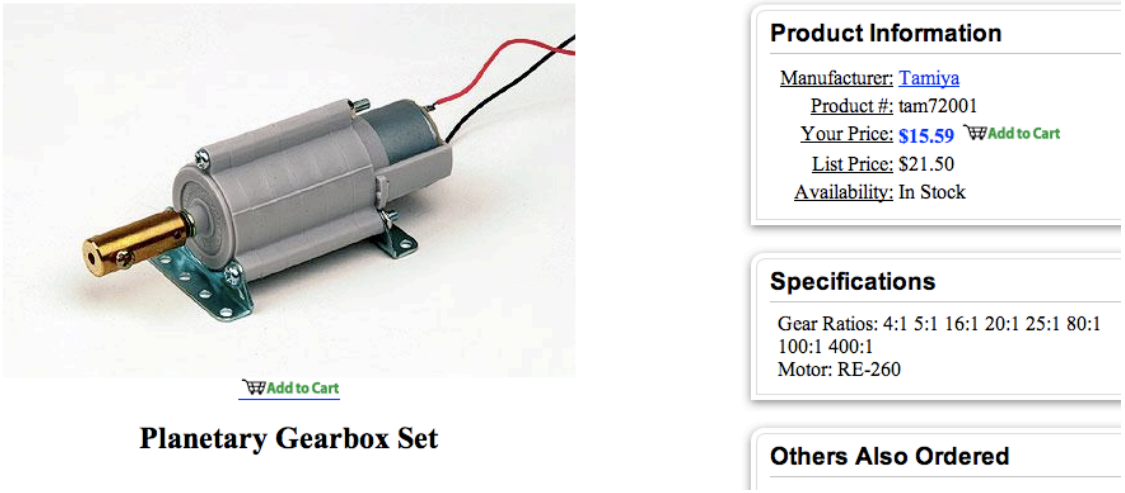


Figure 9 Tamiya planetary gearbox kit is another popular option with a huge range of possible speeds and convenient shaft connection. Friction gets high with many stages; lubricate for best results.

Figure 10. Tamiya one-way wheels provide a cheap way to get a ratchet effect.

Figure 11. Plastic screw posts are great for making joints in linkages. You can glue one side to the link for increased stability and, eventually, glue the screw into the outer sleeve to prevent loosening. You can also cut the other sleeves slightly shorter if they are too long. Note that these are much cheaper if you buy a box of 100 – so get together with a couple other teams and order in bulk.

More	91836	#10 (1024-1032) Screw .062 Thickness Nylon Washer Qty 75: 5% off; Qty 150: 10% off; Qty 450: 15% off;	Package of 100	Yes	$1.29	Add To Cart
More	91837	1/4-20 Screw .032 Thickness Nylon Washer Qty 75: 5% off; Qty 150: 10% off; Qty 450: 15% off;	Package of 100	Yes	$1.17	Add To Cart
More	91838	1/4-20 Screw .062 Thickness Nylon Washer Qty 75: 5% off; Qty 150: 10% off; Qty 450: 15% off;	Package of 100	Yes	$1.40	Add To Cart

Figure 12. Nylon washers are another handy item that is much cheaper if you buy in packages of 100, like these from http://www.usplastic.com

Materials

- Masonite and aircraft plywood are often ideal materials for dry construction – easy to cut with laser or saw, easy to drill, sturdy and easy to glue with water-based glues.
- For 2104 we will need different materials below the water line. The main options are:
  - Acrylic – cuts beautifully on laser cutter, easy to glue, but brittle. Tends to crack at joint holes.
  - Polystyrene (what plastic models are made of) – cut on laser in PRL, easy to glue, less brittle than acrylic but also a bit more flexible. We are providing a couple sheets of 1/8 polystyrene to each team that could be used for reinforcing crack-prone areas, etc.
  - Polypropylene, polyethylene and acetal (Delrin) – soft, non-brittle, low friction. Can cut on laser cutter or with saw. In general these cannot be glued. Could be useful for stand-alone links or parts that will be bolted without gluing.
- Aluminum bar stock could be useful for crank links or other parts needing high strength.
- For shafts, solid aluminum or hollow steel (e.g. brake line tubing from auto parts store) is often easier to work with than steel shafting which tends to be case-hardened. See notes below about attaching gears or links to shafts.

Construction tips

- **Hot melt glue** is only good for tacking stuff in place temporarily. It will fail with a few fatigue cycles. But you can use it while your wood glue dries.
- Epoxy and superglue are OK, but they often only glue the outermost layer of the material (e.g. masonite or plywood) so the joint is not as strong as you might expect. Both will also glue polystyrene and acrylic.
- Gorilla glue (polyurethane) is another option but beware that (i) it tends to foam and (ii) nothing will remove it from your fingers until you shed some skin
- Wood glue will penetrate if you first scuff the surfaces with sandpaper to help it soak in.

- Masonite glues well with corner blocks if you scuff it with sandpaper (see in-class demo) and then use surface tension to hold it in place.
- When lasercamming, you can also do the "tooth" (quasi-dovetail) connections at corners.

Link joints

- Link-link connections are a common problem. If they are loose, the friction forces and binding will rapidly cause much higher forces and torques in your mechanism, with leads to a vicious cycle of friction/binding/slop/poor functioning/more friction…
- Whenever you have 2 links together, think about rigidly gluing and/or pinning the shaft to one of the links. The pin only needs to rotate with respect to one of them! Your pin joint should have only 1 DOF, but if you have multiple loose pieces, you have multiple DOF.
- Screw posts (see Fig. 11) are one useful way to get a smooth pin joint. They can be glued if they tend to unscrew.
- For best results make "fat joints" as shown below in Fig. 13 and/or put a "hub" or "boss" on one of the links. These will have much less slop and will take unavoidable out-of-plane loads.

Crank arm clearance

You may run into interference problems with your crank arm preventing it from making a full circle. Solutions include (i) countersinking the head of a screw so it is flush with link surface and (ii) adding offsets to other links so they clear the crank shaft. If using 1/8'' masonite or plastic and you need more strength then it's easy to get a countersink effect by laminating two 1/8 pieces together, where one piece has a larger hole (see discussion in class).

Crank-shaft and Gear-shaft connections

These are a major source of difficulty. Torques are high and there are occasional dynamic loads. Gluing gears and cranks onto shafts almost never works – you need a mechanical connection. This can be (i) drill through hub and the shaft and insert a wire or pin (ii) make a slot at end of shaft and use a wire (iii) use a clamping shaft collar (good but more expensive) (iv) screw the face of gear or link to something else that has a hub and a pin or set screw. (See discussion in class.)
Concerning the shafts – aluminum 3/16 or ¼ inch shafts are much easier to work with than steel, which tends to be case-hardened and smaller diameter.

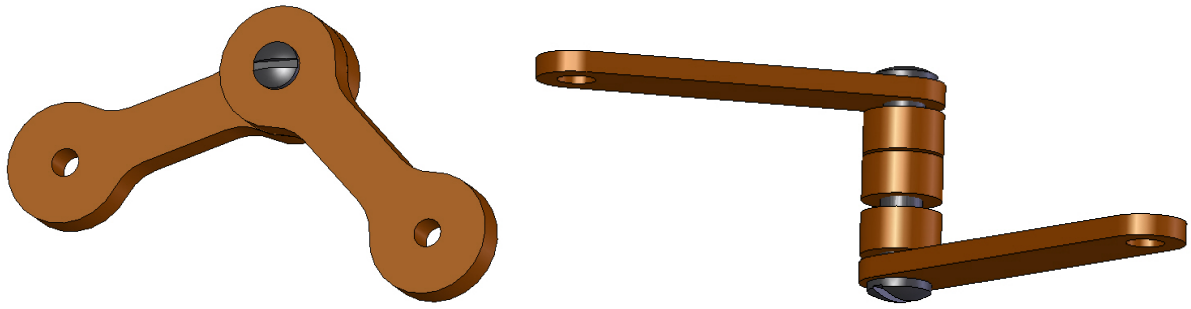


Figure 13. (left) joint using plastic screw post and "fat knuckle" for stability. (right) this joint will be very wobbly unless you glue all spacers + the pin to one of the 2 links.