Engaging Manufacturing's Next Generation

NRL TEAM RESOURCE GUIDE

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FULL CONTACT INNOVATION

www.gonrl.org

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PREFACE

Teacher Advisors for NRL teams come to their positions in different ways. Some willingly or coercively volunteer for the task. It is important to immediately understand the benefits that the NRL program offers to your students. When speaking with the vast array of professionals that offer their time, info, and expertise to this program, we have found a variety of different perspectives as to exactly what "NRL" is. It was started by the NTMA (National Tooling and Machining Association) and sponsored by local companies, it is manufacturing workforce development, it is pre-engineering, and additionally it is exploratory robotics. No matter, from what perspective it is viewed, NRL can be both a direct track into a highly-skilled, well paying job or a step along the path to higher education. We as educators and instructors who have called NRL our own for more than a handful of years, have come to realize that this program is a dynamic, real-world experience that prepares and engages the students of today to become passionate, driven leaders for the technical fields of manufacturing and engineering tomorrow.

When tasked with the assignment of creating a resource center, Craig and I felt it was important to first give you and your teams a reaffirming statement as to why us? Who are we to tell you in detail what is the best way to design and build a robot. We don't claim to be experts on every aspect of building a robot but after a combined 16 years and 18 robots we are becoming experts on what not to do. However, we have picked up a few good ideas along the way and wouldn't have our knowledge base without the input of all of the other advisors and teams. This guide is our opportunity to help pass that information along to you. Bill Fiedler is a Technology and Engineering Education teacher at Central Valley High School in Beaver County. He has been teaching for 13 years and as the founder of the BotsIQ team at Central Valley has advised the team for its 9 years. Craig Siniawski is a Technology and Engineering Education Teacher at Hempfield Area High School, located in Greensburg PA. In addition to teaching for the past 11 years in secondary education, Craig has spent the last seven as the sole sponsor of the Hempfield RoboSpartans. Under his advisement, Hempfield's team has seen success and failure in the areas of design, documentation, and competition with their robots at both BotsIQ of Western PA and the National Robotics League's competitions.

The following pages outline the project timeline, engineering design process, and systematic breakdown of what it takes to successfully build a battling robot. Each step is identified and explained with examples from both our teams, and others who have influenced us along our way. Although there is certainly more than one way to approach this problem, we hope that this document truly becomes a resource for you and your team. Also, we hope that by the end, you realize that in the world of engineering, manufacturing and robotics, "building a successful robot," really doesn't have to mean at the end of the day you walk away with any awards or trophies. Rather, being successful means you have gained a strong knowledge and confidence in the fields of technology through successfully designing, collaborating on, and ultimately seeing a complex problem through to completion. Our greatest successes over the past combined 16 years, is not that of our teams but rather the individual students that have taken huge strides in the areas and careers of manufacturing and engineering though the passion they have fostered through this program.

WARNING... READ BEFORE PROCEEDING ON THE PATH TO SUCCEEDING!

- Initial meetings with sponsors should occur early in the design process. Many sponsors encourage students to visit their facilities for meetings and are willing to have representatives visit schools. Contact throughout the process is important, sponsors can help with suggestions for materials and with manufacturability of parts. In addition many companies can help with analysis of parts and material for strength and durability. It is important that decisions about the robots be made by the student team however interaction with machinists, engineers, and designers is important.

- Fundraising or requests for sponsorship should be made early. Many teams send out letters to local businesses and industry leaders within their area describing the project, how it relates to industry, and what the team needs in terms of materials and monetary donations if not already being provided by t eir school or sponsor.

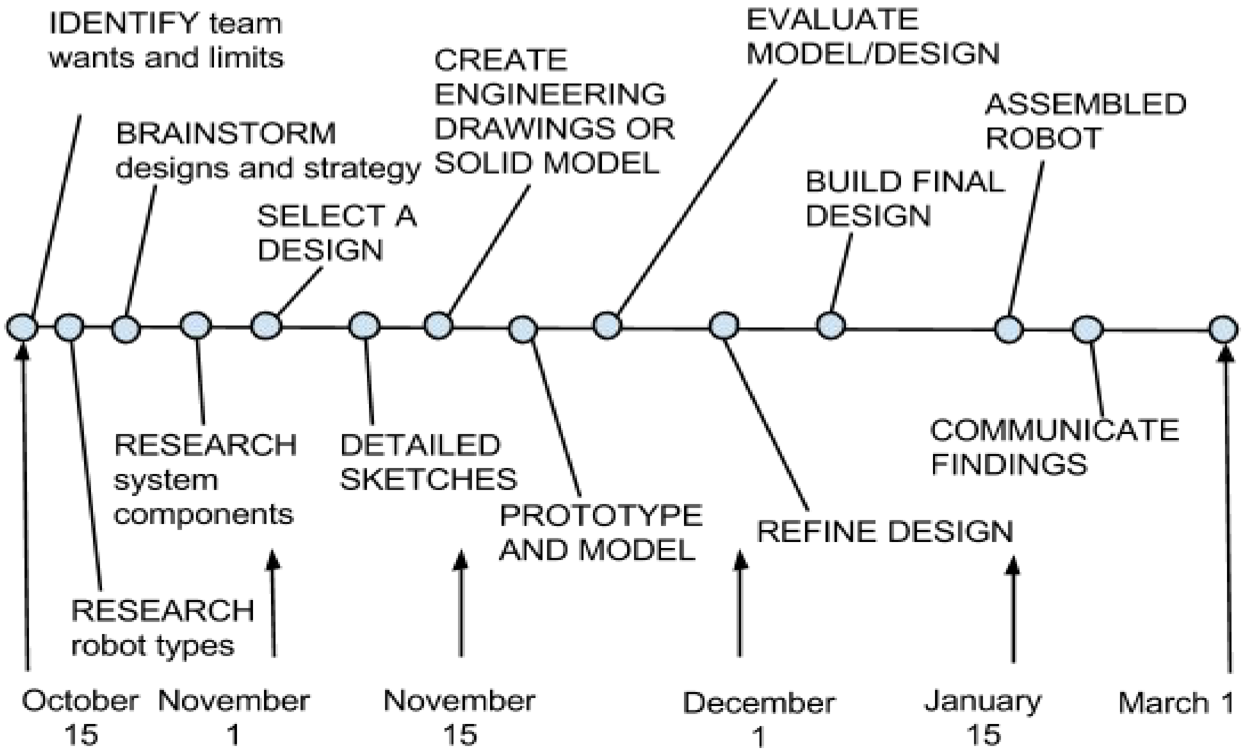
- With the understanding that funding has to come first, it is critical to understand that parts like gear boxes, drive motors, wheels, and speed controllers are known for becoming back ordered quickly. It is recommended that you try to decide on these parts and find a way to have them ordered before winter recess.

- Documentation must be ongoing. Read and understand the documentation rubric which is provided early so that as the trail of paperwork begins to form, everything can automatically find its place. Google docs has become a wonderful tool for collaborating and managing these types of files so that when the time comes to construct the engineering portfolio, the work is already well on the path to completion.

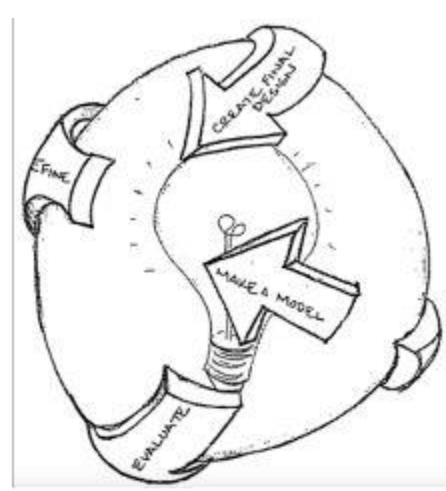
- Safety is priority one! Not only is safety a priority when working in the lab and with your industry partners during production, but it is also important in the handling and powering up of the actual completed robot. All edges, pinch points, spinning/swinging weapons must have guards and pins in place to safeguard the operators. Like with any mechanical/electrical system, if something can go wrong, it eventually will when you least expect it. Safety guards and weapon pins cannot, and should not be an afterthought. When designing, students must be directed to make points of contact and connection for safety features (pin alignment holes for weapons, latching points for covers and shields, etc) integral to the design. Even wedge style robots pose safety hazards as their edges become damaged and torn through multiple rounds of competition. These elements must be considered and addressed prior to competition to keep everyone's well-being in mind.

READ AND MAINTAIN ALL DOCUMENTATION ON YOUR TRANSMITTER AND RECEIVER. PRACTICE AND VERIFY POWER-UP AND POWER-DOWN PROCEDURES ALONG WITH BINDING AND FAILSAFES, AS DESCRIBED LATER IN THE CONTROL SYSTEMS SECTION.

TIME LINE



The time line follows a 10 step design process. The process is shown in a linear fashion however it can be addressed using a dynamic approach. Steps can be skipped and returned to as needed. The design process can be recycled for smaller problems and design topics throughout the larger design of the robot. The design process is used in engineering as a systematic process to create something new and to solve problems. Everything we interact with in our modern technological world has been created by us. Someone identified a need and proceeded to create a solution. In some cases solutions are better than others but the general idea of how the solution came about is the same. The design process is used to create both things we need and things we want. In the case of your robot, it's a want. The robot is being created for education and entertainment. As you work through the design of the robot you will begin to face small problems, an area you don't know much about or a robot part that isn't tough enough to handle the stresses it's under. By applying the design process you can solve these small problems and continue with the design of the robot.



A dynamic model to the design process

If a video of the process is desired the “Deep Dive” an ABC news special can be found on YouTube. Dave Kelly and designers from industrial design firm, IDEO are shown going through the design process. Dave Kelly has also given several TED talks.

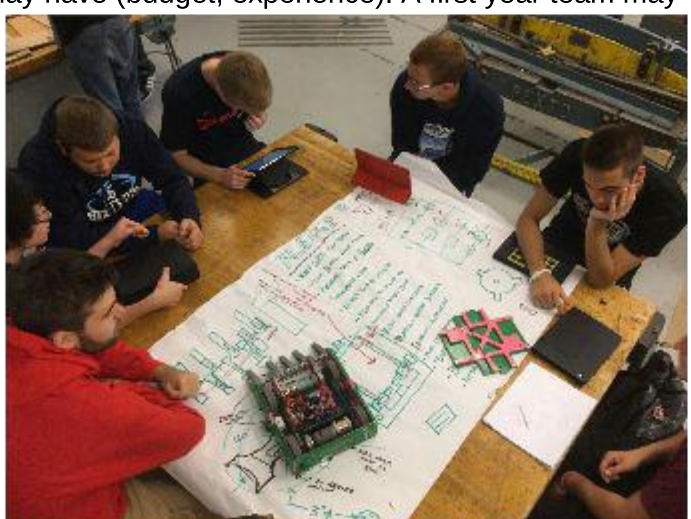
The steps of the engineering design process are:

Identify a Problem
Research
Brainstorm
Select a Design
Create Engineering Drawings/Solid Models
Prototype and Model
Evaluate Model and Design
Refine the Design
Build the Final Design
Communicate the Findings

The engineering design process steps are defined below.

One aspect that will help organize the team is to assign jobs to each of the team members. The students will be responsible for sharing all of the duties of team management, design, and fulfilling the documentation requirements. It should be pointed out that the components of the documentation binder should be created throughout the design process and development of the robot as opposed to an afterthought. The documentation binder components each fit into the various stages of the design process explained below.

Identify the Problem (identify team wants and limitations)
It is important to come to a decision quickly as to the type of robot your team wants to design so that more time can be devoted to the direct development of your robot. Your goal during this first stage is to identify the criteria that will define your robot (strategy, components). It is also important to identify limitations your team may have (budget, experience). A first year team may be very concerned with having a basic robot design which power on and can manage basic functions. An experienced team may want to challenge themselves with complex weapon development. Some robot concepts and descriptions are listed below. If you have built before it is important to identify issues of previous robot designs and key points to include in a new design. Bulleted lists work well for this step. It is important that the criteria you establish for your robot is specific so that it is easier to focus your research later on.



Students work together brainstorming new ideas for a robot design. Notice the old design, they're identifying problems to correct.

In addition, this step, Identifying the problem, will be the first step of solving any problems you encounter through the development of your robot. For example...when you find yourself questioning what the numbers mean when looking at screws Ex: ¼”-20 x 1”, begin by identifying this as a problem then continue with research etc. You may find that in some cases such as this you won’t need to brainstorm or create drawings, just get an answer and communicate it with your team.

It is important to identify that this step is the beginning for your documentation, in particular the basis for these sections:

1. Data Management
2. Competition Strategies
3. Research and refinement

<u>Robot Types</u>

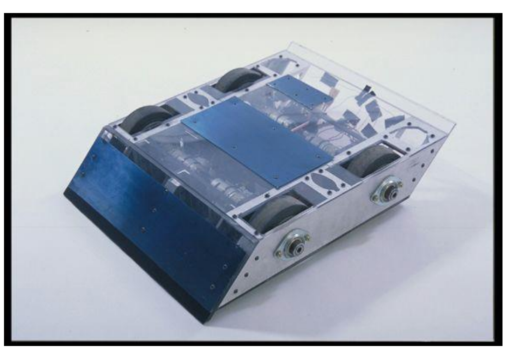
Note: One thing to keep in mind when designing a robot for the first time is to remember that it is a competition and scoring well when competing should be a concern. The judges will be scoring you on four (4) criteria:

Aggression - Is your team, driver, robot making an attempt to attack and act as a fighting robot?
Damage - Is your robot inflicting on the opponent?
Control - Does the driver have visible mastery of the robot.
Strategy - Does the team, driver, robot meet the obvious strategic plan of the robot design?

- does a bladed robot use its blade to inflict damage?
- does a flipper robot use its flipper arm to incapacitate the opponent?
- does a wedge push, trap, or otherwise use it’s wedge to attack their opponent?

Optimizing these points with your design will increase your competitive edge. All of the robot types identified have been used by someone and have been successful in the arena.

Wedge- A wedge bot has the shape of a wedge on at least one side of it’s body. What defines the wedge bot as a wedge is that it’s strategy is solely based on the wedge as a weapon to get under the opponent and flip them, incapacitate them or restrict them. For inexperienced teams a design such as the wedge bot is fairly simple to construct due to its basic design and few components.



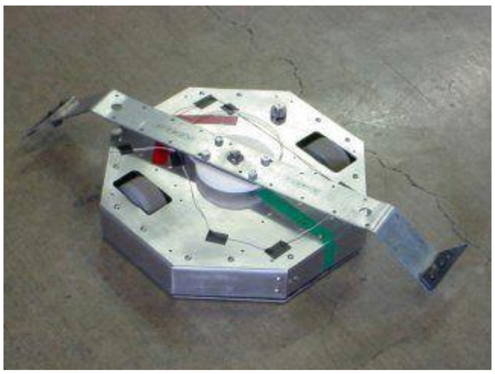

Rammer- A ramming robot uses its body to push and smash into other robots either inflicting direct damage, trapping, or causing the opponent to self-inflict damage (a blade consequently hitting into a wall causing damage). For inexperienced teams a design such as the rammer bot is fairly simple to construct due to its basic design and few components.

Flipper/ launcher- A flipper robot may use a spatula type lifter or other to intentionally lift their opponent from the arena floor to incapacitate them.

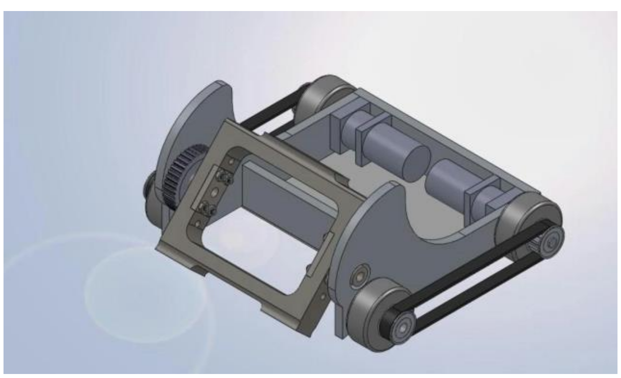
Hammer/ Thwackbot- A thwackbot may use a hammer, ax, pick or whiplike hammer to strike their opponent. There are variations of this type where the striker is either on a horizontal plane or vertical. The striker may be activated using an actuator or simply by spinning the robot.

Spinner/ Salad bowl- The spinner uses an outer shell often referred to as a "salad bowl" because many times a salad bowl is actually used as the shell. The outer shell spins on a vertical axis with the intent to inflict damage to the opponent when contact is made. The shell often has hammers or teeth attached to cause optimal damage.

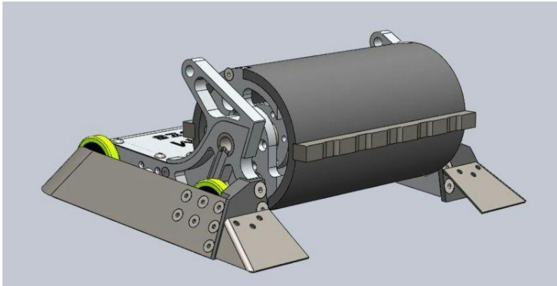
Horizontal-blade- Robots using a horizontal blades have a blade traveling on a horizontal plane, they function similarly to the spinner except that only a blade spins on a vertical axis under, over, or around the robot body. Blades vary from saw blades to bars of metal similar to a lawn mower.

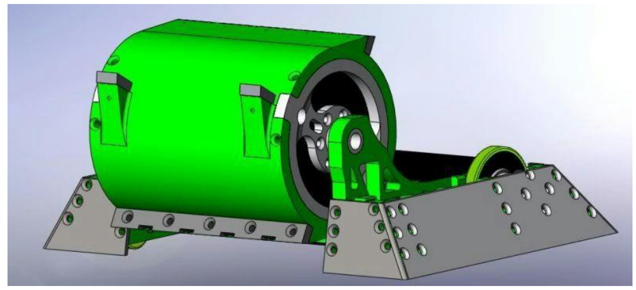


Eggbeater- The eggbeater is a bladed robot with a flat blade spinning on a horizontal axis. The blade is commonly a rectangle but many other shapes have been used.



Drum-The drum is a bladed robot with a cylindrical blade spinning on a horizontal axis. The blade is commonly a tube or pipe with several “teeth” installed to cut at the opponent.

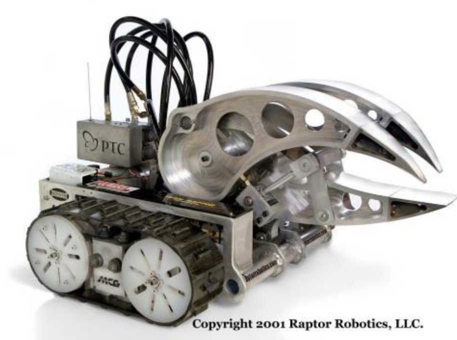




Multi-bot- Multi-bots are somewhat self explanatory, where two or more robots fight as a team against an opponent. The catch with using multi-bots is that the combined weight of the robots must be less than the weight limit of the competition (15 lbs) in the case of SWPA BotsIQ. Two controllers/ drivers can be utilized. The types of dual robots can be different, they don’t need to be two wedges or two replica bladed bots. They can be different weights and types.

Sawblade-The sawblade is a bladed robot with a flat blade spinning in a vertical plane on a horizontal axis. The blade is commonly a circular saw blade 10”or 12” but other sizes are used including flywheels which is a large flat plate with teeth or weights attached on its outer edge.

Crusher/Shear- A crusher or shear-bot uses rams, shears, or pincers to either trap, cut, or crush their opponent.



Walker- A walking robot uses legs for locomotion instead of treads of wheels.

The Basic Parts List of a Robot

Note: Robot body parts have been omitted from the list. Only the basic mechanical and electrical components have been included due to the significant variation in body designs and robot styles. It should also be pointed out that the parts list is, in this case, intended to be a general listing. Things such as motors, speed controllers, switches, etc. can vary greatly in type, size, and capacity. This parts list is intended to give a novice team the basic idea of what general components make up a basic robot and general idea of descriptions.

Robot type: 2 wheeled wedge

Part Name	**Notes/description**
Drive motor 1	Left side, 700 series motor, 5mm shaft, brushless
Drive motor 2	Right side, 700 series motor, 5mm shaft, brushless
Planetary gearbox 1	16:1, compatible with motors, with ½” dia. x 1-½” hexagonal shaft
Planetary gearbox 2	16:1, compatible with motors, with ½” dia. x 1-½” hexagonal shaft
Switch	Screw actuated, 40A+
Battery	NRL approved battery, 12V + NiMH
Indicator light (LED)	Power identification light
Transmitter	compatible transmitter with receiver (the RC controller, usually a spektrum DX6i)
Receiver	4 channel minimum, with Fail safe capability
Wheel 1	3-½” Dia. with ½” hex hub
Wheel 2	3-½” Dia. with ½” hex hub
Electronic Speed Controller	Scorpion XXL dual motor ESC with BEC
(32) #10-32 screws	All screws 1” length
13” 14 AWG red wire	copper noodle wire
16” 14 AWG black wire	copper noodle wire
9 sets of wire connectors	9 male and 9 female connectors
1, 8” RC wire	to power LED from receiver

Research

During the research stage, depending on team structure, several methods can be used nd are outlined below. It is very important that during the research stage specific attention to established criteria is researched as opposed to just having the students researching anything. As in the example used below brushed 12V motors are specified as opposed to any brushed motor or any motor of any type. Some areas of research which are important are but not limited to:

- Motors to act as drive motors, usually brushed 500 series but can be larger or brushless
- Gear boxes compatible with drive motors to increase/decrease speed or torque
- Wheels that have a compatible hole/shape/keyway etc. for gearbox or motor shaft
- Electronic Speed Controller to control motors, capable of handling voltage and current draw of motors. Two single ESC's or one dual ESC?
- Battery to supply voltage and current required by motors
- Material to construct frame/structure of robot (metal, plastic, composite and type/alloy?) 6061 Aluminum is most common.
- Material to cover the robot...armor/ skin/ plating (metal, plastic, composite and type/alloy?)

One method is that individual research tasks be assigned to individual students where one team member is responsible for one topical area.
Example: 12V brushed motor options, assigned to Jimmy e is to find 10 different 12V brushed motors that could be used for drive motors. The motors must be 1/10th scale motors with an ⅛" shaft nd compatible with the gearbox the team has chosen. Other criteria may be specific size (length, diameter, etc.), weight, or torque/power. In this example Jimmy is the only team member researching brushed drive motors. He would at this point turn his information into the team Research/ Data manager.

Another method is that every team member is given the same research topics, the information is then collected, compiled, and recorded by the team research manager. In this method everyone on the team researches all components of the bot.
Example: All team members research 12 Volt brushed motor options. They are to find 1, 12V brushed motor that could be used for drive motors. The other optional criteria listed earlier may apply. The team would continue this method for each material, motor, component, etc. of the robot.

A third method which can be used is to re k down t e rese rc into several major robot subsystems in which team members can choose their place of interest. An example break down would be…

Chassis/Structure
Weapon System
Drive System
Power System

In this example, students could then work in these focused areas to research information pertaining to components of the one sub-system, possible components, and parts choices, costs, etc. All data should be saved in a folder (digital or hard copy) relative to these sections of the documentation and submitted to the team Research/ Data manager.

RESEARCH BINDER

MOTORS									
	Banebots 550	Banebots 555	Castle- Sidewinder 3	Trinity maxi	THUNDER POWER	Tacon 3650-8T	Leopard 4370 KV	Novak GTB 3	Marine Motor 1500kv
Type	Brushed	Brushed	Brushed	Brushless	Brushless	Brushless	Brushless	Brushless	Brushless
Nominal Voltage	12V	12V	18.4V		12V	8.4V	7.2V	6	22.2V max
RPM no load	19300	7760	12600		12000	4420	4600	1.65	5000
Stall Current	85A	15A	40A		40A	45A	30A	30A	65A max
Stall Torque	66.86 oz in	29.16 oz in	46.18 oz in		45 oz in	42.66 oz in	50 oz in	50 oz in	50 oz in
Current- Peak Eff.	10.9A	2.5A	8A		40A	81A	40A	60A	60A
Cost	$7.25	$6.25	$110.50		$69.99	$24.09	$69.50	199.99	$69.99
Shaft Diameter	3.2mm	3.2mm	3.18mm		3.18mm	3.175mm	3.165mm	3.175mm	0.20in (5mm)
Weight	218g	213g	56.5g		176g	223g	178g	175.8g	222g
KV Rating	1608	646	5700		4000	4420	4370	1560	1500

motors · materials · ESC's · gearboxes · R/C controller · wheels · belts · pulleys · Batteries

An example research "book", a shared spreadsheet in which all team members can add items. Notice 9 topical tabs, sheets, make up this workbook. Criteria is listed on the left column, models are listed along the top row, they're also links to the webpages where the items can be purchased.

Brainstorming

The brainstorming process is vital to the development of a productive idea. A team will develop great ideas if they are left to come up with wild ones too. Some of the “crazy” ideas help to develop better “rational” ones. It is a good idea to work under time constraints due to the nature of the process. Brainstorming, if left unchecked, could continue on for a long time and not become focused enough on any one idea to be helpful.

The brainstorming phase should be driven by information found through the research phase. This is why the research must be compiled in a way that it can be shared and seen by all team members. Criteria established by the team should be the focal points for brainstorming. Brainstorming can done using varying methods, however, it has been found helpful to assign individual team members a brainstorming assignment. Each member is to create:

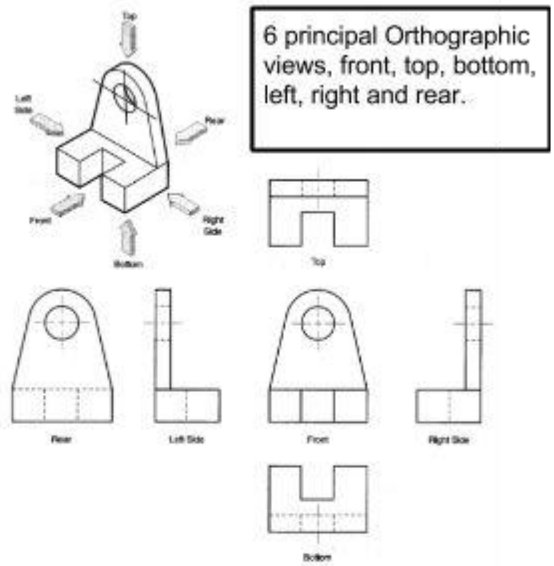
- Sketches
- CAD drawings
- Lists
- Mindwebs
- Diagrams

Whichever method the student feels most comfortable with to convey their ideas.

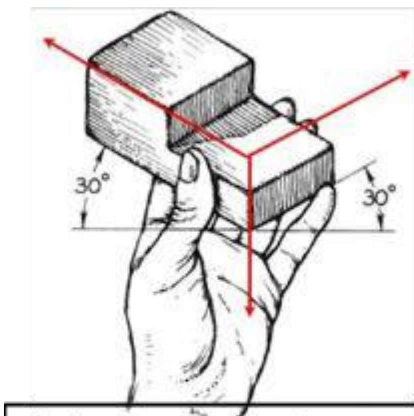
Once the team members have created their own ideas they must meet and share their brainstorming work with their team. This can be done using a formal presentation format or through a collaborative team brainstorming session. It is again important, if using a group activity that the activity be timed and a goal given to keep the students focused on developing an idea. It should also be mentioned that during the individual and group brainstorming periods anything beyond “rational” limits should be ignored like cost, machinability, size, shape, weight, etc. In the next phase limits can be applied. A team should be split into design groups of three to five, their ideas shared and developed. The design groups can be given a focus area or let to work on their own interest areas again. The design groups will present their best idea to the entire team next. Again, brainstorming could also be broken down into major subsystems as described in the last example under RESEARCH.

<u>Selecting and Establishing a Design</u>

Selecting a design should and will create debate within the team. Students need to be able to clearly and confidently provide good rationale as to why the team will choose a design which to move forward with. Due to time constraints it is important that the selection period not be too long and that the students understand that finalizing an idea quickly is important. The team should create detailed design sketches (more detailed and defined than brainstorming sketches) to fully define their concept. This will help to set the base for the engineering drawings or solid models. Formal drawings are difficult to create if there are no hard numbers to start with. Detailed sketches are quicker to draw and don’t necessarily need to be to scale. Sketches can be pictorial or orthographic (see picture for reference).



6 principal Orthographic views, front, top, bottom, left, right and rear.



This is an isometric example, a type of pictorial part drawing, all horizontal lines are at 30 degrees. Perspective is another method, no specific angles are used (not pictured).

It is important to realize that once solid models and engineering drawings begin, the team should be unified on the solution or else valuable resources, primarily time, will be wasted. Students should rely on their research and brainstorming to promote the foundation of their design choices. There needs to be an order to the decision making process for the design. Again, several options could be used to organize the team members. One option is that the team work as a unified unit on the development of each subsystem. This is usually done as a group one section at a time. Another option is that the team divide the subsystems up and work on them individually. The advantage of this method is that all of the subsystems can be worked on simultaneously. The subsystems are listed below in order, the rationale is included in each section.It is best that within each section of design, there is one liaison who reports back to a leadership design group or individual project manager.

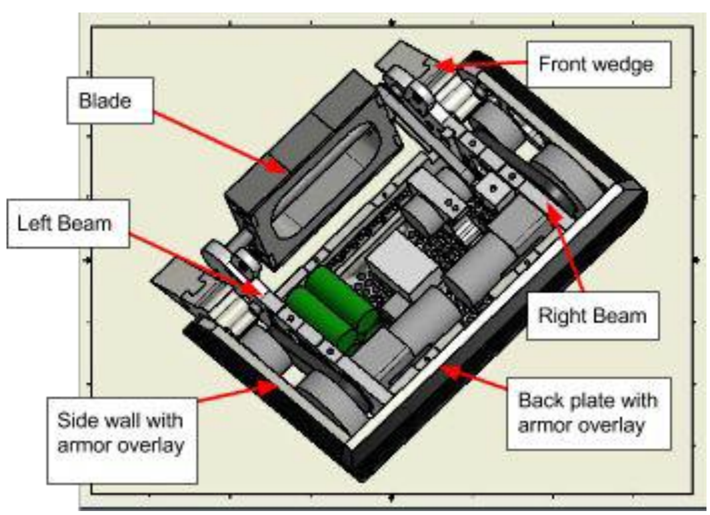
<u>Drive System Development</u> – The drive system motors are important in particular because their voltage and current specifications should be used when selecting the power system. If a pulley and belt or sprocket and chain system will be used it will be important to identify the specific combination of components so the proper spacing of axles, center of one axle to the center of the next (known as on center, see pulley calculations) can be identified, this will affect the structure of the robot.

Students who will be designing the drive system are responsible for identifying whether they wish to further develope a 2 wheel drive (2wd) or four wheel drive (4wd) system that will dictate the parameters of the chassis and be buildable with readily available motors, belts, pulleys, wheels, and axles from known suppliers.

Weapon System Development – If applicable… These students are responsible for creating an effective and powerful weapon relative to its overall size and mass (see section on rotational inertia). This could also be the team in charge of wedge designs, ram designs, or even offensive/defensive armor. If the weapon will be utilizing motors, whether the motor is being used in an air compressor, to drive a rotating weapon, or used to drive an actuator, the motor needs must be taken into account and added to the drive system demands (see electrical system design section). The motor driving the weapon whether brushed or brushless will need an ESC, an Electronic Speed Controller, compatible with the motor. Other components which would need to be considered are pulleys and belts, linkages, air tanks (must be certified), chains and sprockets, motor mounts, bearings/bushings, airlines and fittings, etc.

Electrical System Development– This group or individual is responsible for researching, purchasing, wiring, and the programming of the electronic components for the robot's drive systems, weapon systems, and transmitter/receivers units. Also responsible for battery pack/cell selection and/or possible design and production. Teams have had success with store bought drill batteries, model R/C batteries, and custom packs from individual cells they've assembled. Refer to electrical system details in regards to legal cell types (NiCad, LiFEPO4, etc). The demands on this system are defined by the motors and electrical loads of the drive and weapon systems. Wire, for example, can add a lot of extra weight to a robot. If 14 AWG (American Wire Gauge) wire can be used in place of 12 AWG wire some weight could be saved, however if the demands of the system dictate 12 AWG then weight may have to negotiated from other areas. The members of this system design team must consider these types of topics. A test bed should be built too to verify function of the system (see model and prototyping section).

Chassis/ Structure Development – Once the above three sections have been selected and modeled (jumping ahead to the next step of the process just a little bit) the chassis or frame/body of the robot can be considered. The models should be simple, such as paper and tape or cardboard, knowing that more extensive 3D modeling will be done in the prototyping/modeling section.



Rationale for this sequential order is that the robot is a box in a sense and if the box size is decided on prior to knowing what goes inside, enlarging the robot will be a challenge. Having all of the components known first will help in deciding where parts will fit and having proper space for each item. One option proven to be successful is to make the individual who is in charge of chassis design the project manager, team president, or captain. If there are a group of students there should be a leader responsible for looking over the work of the design group. This individual is naturally tasked with making sure everything fits and functions together as a whole. There will need to be communication between groups, each group leader should have regular meetings and discussions with the other group leaders to discuss issues with compatibility, see examples...

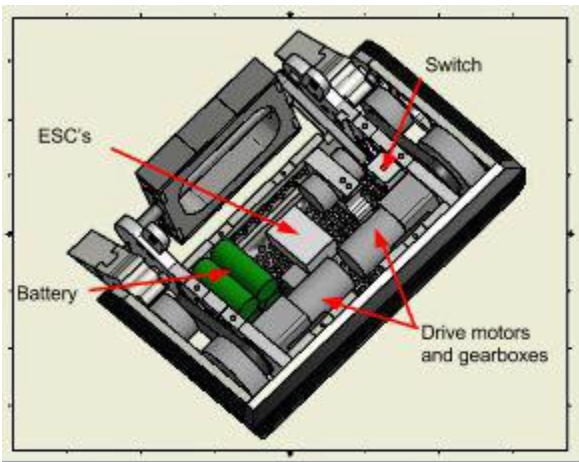
Example: if what the chassis team has allotted as on-center spacingfor a 4wd system and the drive system team can't acquire pulleys, belts, and wheels that meet that spacing and ratio requirements, there will be a problem. Therefore the chassis team should provide dimensional constraints for the drive system team to center their design around and the chassis team needs to be flexible in relation to what is available for purchase.

Example: the chassis team should coordinate with the weapon team to verify ground clearance and chassis needs with the weapon system according to the center point of rotation and loads on the frame and components such as bearings. If issues exist, either the weapon center (to raise or lower the weapon in relation to the floor) or drive wheel axle centers (to raise or lower the robot body and therefore the weapon too) must be adjusted accordingly.

Note: It is imperative that you order parts such as gearboxes, motors, and electronics as soon as possible. Alot of the parts desired are in short supply and can become backordered fairly quickly. Once components, materials, etc. are verified by both the team and you as the adviser it is highly recommended you review the resources page or find/contact your own known vendors and purchase these items as funds become available.

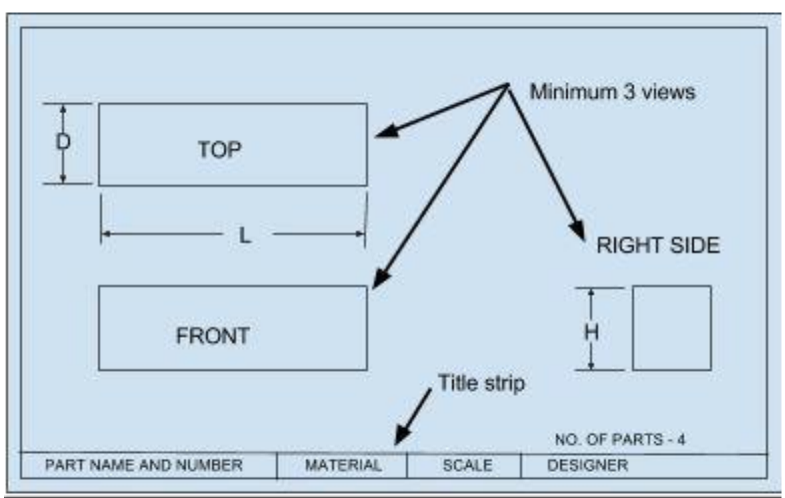
Create Solid Models and Engineering Drawings

Overall Chassis Assembly	Overall Weapon Assembly	Overall Drive Assembly
1. left rail 2. right rail 3. front rail 4. back rail 5. bottom plate 6. etc.	6. weapon axle 7. weapon body 8. weapon pulley 9. etc.	otor mount wheel ub shaft extension wheel odif. wheel spacers etc.



Once a design is chosen and design groups are established within the different areas of focus, students should immediately begin creating a set of solid models. If your school does not provide a software, Solidworks is made available to your entire team through the BotsIQ program and should be highly considered as a valuable and essential tool. It is helpful to keep the students organized into their design groups, chassis/structure, weapon, drive system, etc. for the creation of the part drawings. Models and parts can be drawn using conventional methods too, on a drafting board with paper and drafting tools. Regardless of the method the important thing to remember is that standard engineering drawing conventions should be followed, such as:

- View orientation (3 standard views Top, Front, and Right side, out of 6 potential not considering auxiliary views)
- Scale (1:1, or is the part scaled down to ½ or ¼ scale)
- Identifying units (imperial or metric)
- Dimensions
- Notes (special instructions for the manufacturer)



Example Engineering Drawing sheet showing the standard 3 views of a part with a title strip.

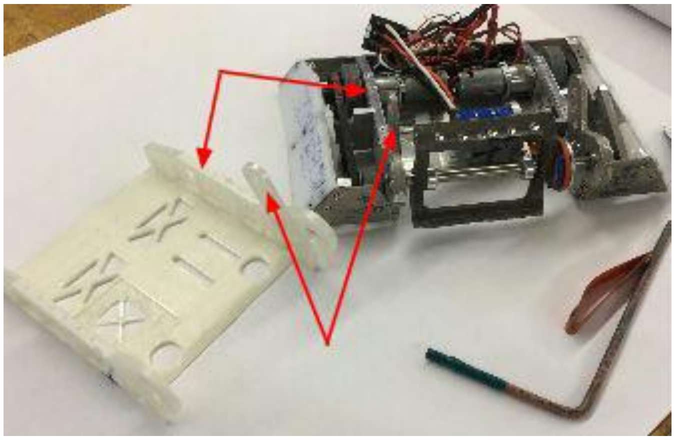
When creating solid models and engineering drawings it is smart to establish a project manager. This project manager does not have to be the same person responsible for the actual design of the robot, but rather someone able to organize and manage the extensive number of parts, assemblies and drawings that are going to be generated through this process. Students should establish clear file names for each part so that they can relate easily to the overall assembly. Something as simple as determining whether the team views the robot's left and right sides from the front perspective or rear is essential to the team's ability to communicate through this extensive process. The project manager should also be in charge of the complete set of engineering drawings and title block template containing all required data. (i.e. part name, number, material type, quantity, units, etc.) This sheet set should correlate with the ***Bill of Materials,*** while working in a sequential order relative to the assembly of your robot. An example order is as follows:

TIP: Many part drawings are available online from vendors, manufacturers or from online libraries such as

McMaster.com (Mcmater Carr)
SDP-SI.com (Stock Drive Products - Sterling Instrument)
3dcontentcentral.com
Grainger.com

Prototype and Model

In this phase constructing a model of the robot is expected. The model does not have to be the exact, final robot, meaning the robot does not need to be made from the materials that the



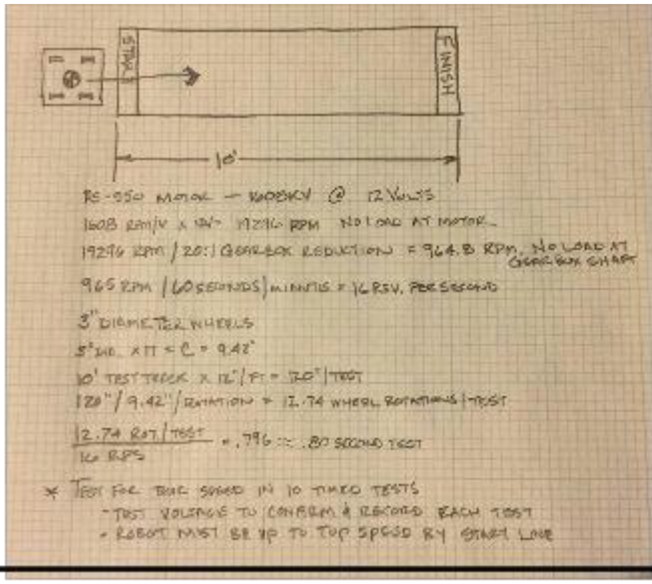
arena ready robot will be made of. The model can be constructed from wood, foam core, cardboard, sheet metal, plastic, etc. However, the size and shapes of the robot are important at this point. Having the motors, RC receiver, ESC's, batteries, pulleys, belts, etc. is important so that sizing and spacing can be seen and tested. The model or prototype should be a drivable version so that the team can see that the components fit into the spaces they've planned for and that the robot functions as expected. See the Evaluating section below for some tips on testing.

In manufacturing a prototype is often made from inexpensive materials for evaluation purposes. Modern methods include 3d printing prototypes and machine cutting inexpensive materials to test CNC programs, tools paths and parts. Prototyping and evaluating your design should be discussed with your sponsor. Relationships with neighboring schools may also be helpful in establishing partnerships for prototyping and machining.

Evaluating independent systems of the robot can be done early in the process usually prior to finalizing structural designs and prototyping. Do not overlook the space needed for wiring. If possible have your power systems team create a test bed and build all necessary wiring harnesses and test all components as soon as possible. One option for this is to use a piece of pegboard sized the same as the available internal space of your robot's design and zip ties to safely test motors and electronics with your controller and receiver. Having the "guts" of the robot available and operational early will save you time and stress later in the process with things like fit, routing of wiring, and even failsafe and programming.

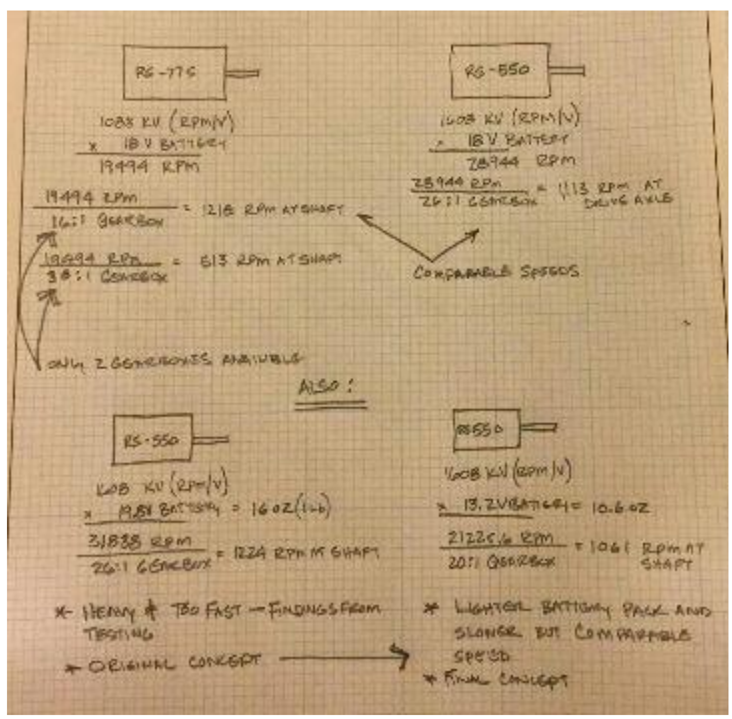
Evaluate the Model/Design

During the evaluation phase the team should have thorough testing of each system of the robot. The prototype and all parts should be looked at. It is important to have debriefing meetings with the various design groups of the team so that identified problems can be addressed. Problems found should be listed and recorded to the team documentation. In cases where a team's design groups have limited involvement with each other, short presentations of findings to the team's other design groups are helpful.



Calculations and diagram for a speed comparison test.

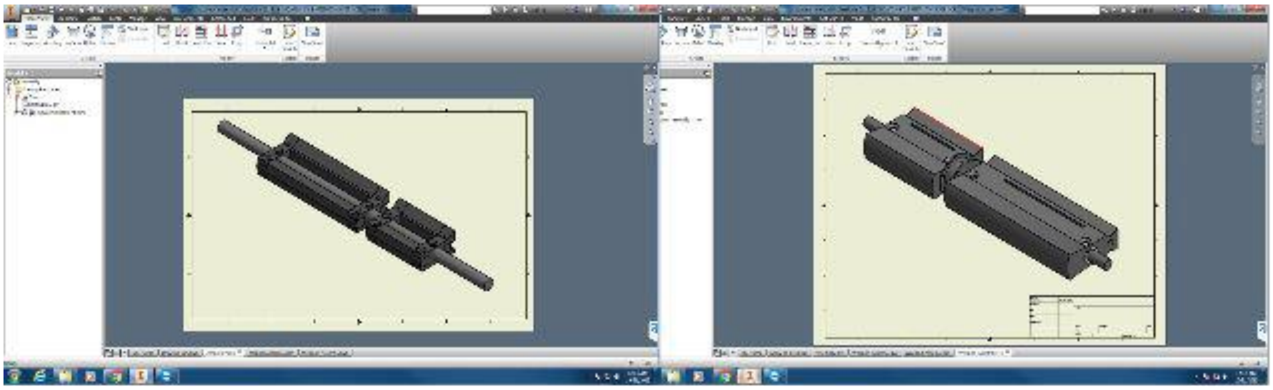
Some examples of tests that can be done with a model to verify design theory are for speed and drivability. The specifications for the motors and gearboxes allow you to calculate speeds and then test to see how closely the speeds actually are to the real components. A test like this may be important for your team to refine the design. You may find the robot is too quick and uncontrollable or that it is slow and lumbering. By testing and proving true speeds you'll be able to make better choices in the future. This also helps with comparing various motors for an application. Take into consideration a higher RPM/V motor and a lower voltage battery combination, you can reduce some battery weight by keeping the motor weight the same. Additionally, perhaps you choose a larger high torque motor which has slower RPM/V you may choose a gearbox with less of a reduction to maintain driving speed with a faster less powerful motor.



Also see material testing.

<u>Refine the Design</u>

Problems identified in the evaluation stage must be discussed as a team. Part drawings must be changed to correct the design flaws identified. This includes in assembly models and instructions. The refinements themselves need to be tested and approved by the team before final production. At this point the final robot design should be ready to be produced.



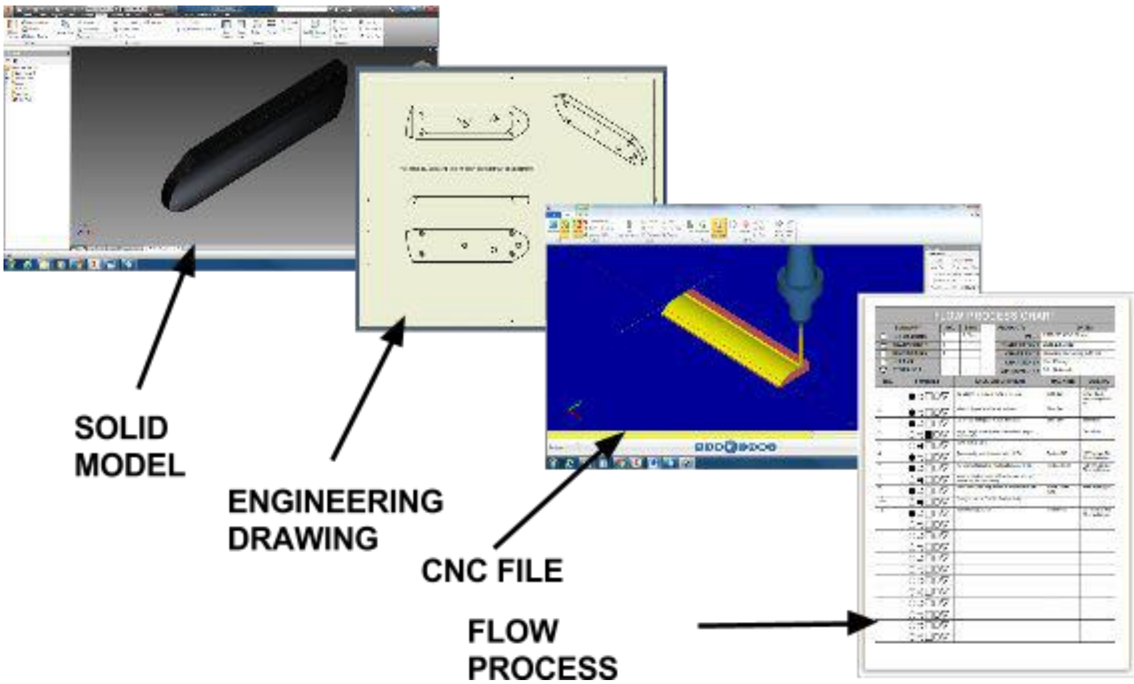
Example of Blade Refinement. Initial design was a bolt together tool steel assembly which fractured in competition. This design was then redesigned as solid one piece alloy metal part.

Documentation Connection:

- Research and Refinement

Build the Final Design

This step will require you to take the raw material and begin to make parts. Many teams will send their final design engineering drawings to their machine shop, in many cases this is your sponsor. It is very important that meetings between the team and the team's sponsor occur prior to and during the final production of the robot. The bill of materials and part drawings (sheet set) need to be complete and submitted so that the machinists know what material to order and make parts from. See machine processes in glossary for some explanation of some machines and their uses.



Documentation connection:

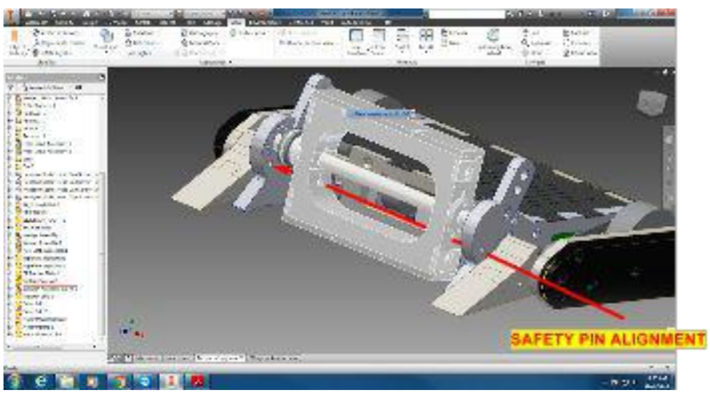
- **Assembly instructions**
- **manufacturing plans**
- **Safety plan**

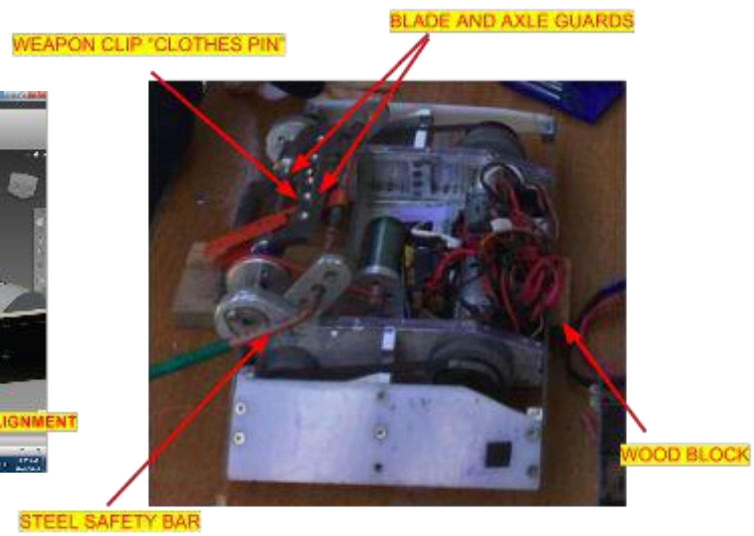
SYSTEMS DESIGN: (Old Tricks for New Dogs))

Safety Design:

As discussed in the beginning of this document, safety is priority one. The processes of producing such a robot, and ultimately the handling and operating of a functional one can bring about a number of safety concerns, that if overlooked can lead lead to injury. There this focus on safety can be broken into two main categories:

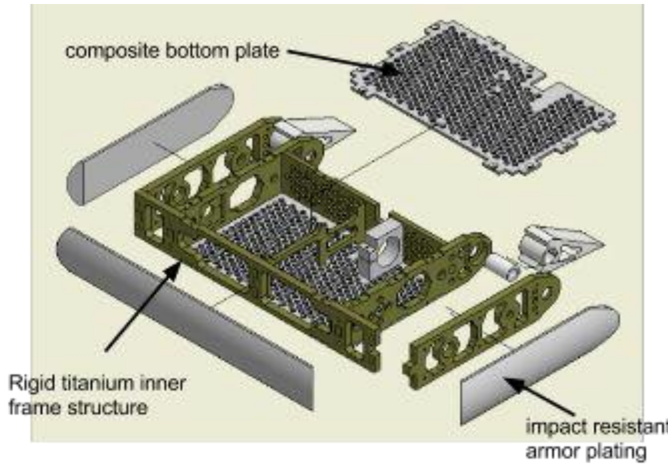
- Safety in the Manufacturing Environment
- Robot Safety Guards/ Restraints & Handling Procedures.





Structural System

When designing the structural system of your robot it is important to keep in mind the extreme stresses that the robot will be under. If your design is basic and your goal is to just have a robot capable of driving around the arena as a wedge or rammer, you'll want to be able to withstand impacts well.The frame or structure of your bot will need to be rigid. If your intent is to incorporate a weapon of some type, having a rigid frame is mandatory for your robot to withstand its own dynamic forces when a blade or actuator is activated in addition to your opponent's attack.



Many aspects need to be considered when choosing materials for your frame. Teams have used, plastics such as UHMW (ultra high molecular weight plastic), Alum inum, Titanium, and Steel. See the basic table below for some basic comparisons of materials that could be used for your robot's structural system or frame. See the resource section for websites and stores where these materials can be found.

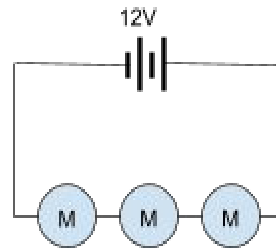
MATERIAL COMPARISON CHART:

	COST	WEIGHT	MACHINING	FASTENER INTERACTION
Aluminum, Al	$$	##	Easy	easy to tap, holds screws well
Titanium, Ti	$$$$	##	difficult, requires carbide tooling	difficult to tap, holds screws extremely well
Steel	$	###	Moderate	holds screws well
Ultra High Molecular Weight Plastic, UHMW	$$	#	Easy	requires long screw or back nut
Fiberglass	$$	#	Easy, requires dust precautions, hazardous	requires back nut
Carbon Fiber	$$$	#	Easy, requires dust precautions, hazardous	requires back nut

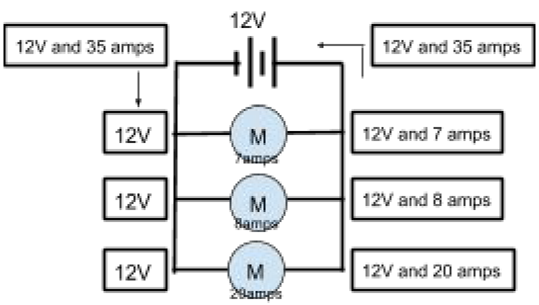
Sometimes material tests are mentioned in the data sheets of materials as you are searching, several are mentioned in the glossary.

Electrical System:

When designing the robot's electrical system several things must be considered. First the components which will be electronically driven need to be identified. It should be noted that the robot's electrical system will be a battery powered DC (direct current) circuit as opposed to common AC (alternating current) M ost designs use a parallel circuit however a series circuit is an option. The difference can be seen in the images below. A good example of the difference is with a strand of Christmas lights. A strand wired in series will not work if one light in the strand is broken, the electrical flow is dependant on all of the lights working to carry the flow through the entire circuit. In a parallel circuit, one light or more could out and the flow of electricity would still have routes through the circuit.



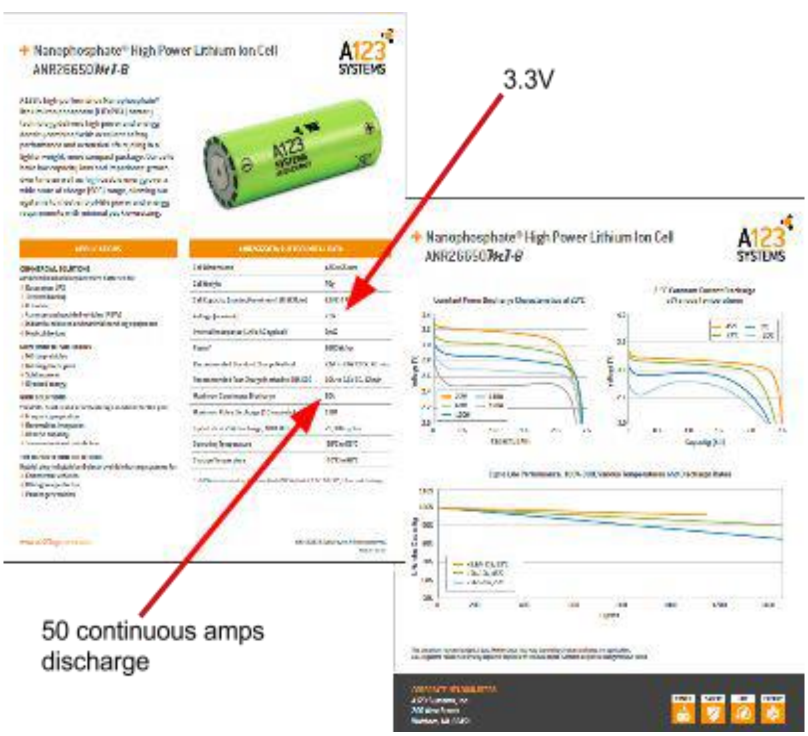
Example 1: A series circuit



Example 2: A parallel circuit

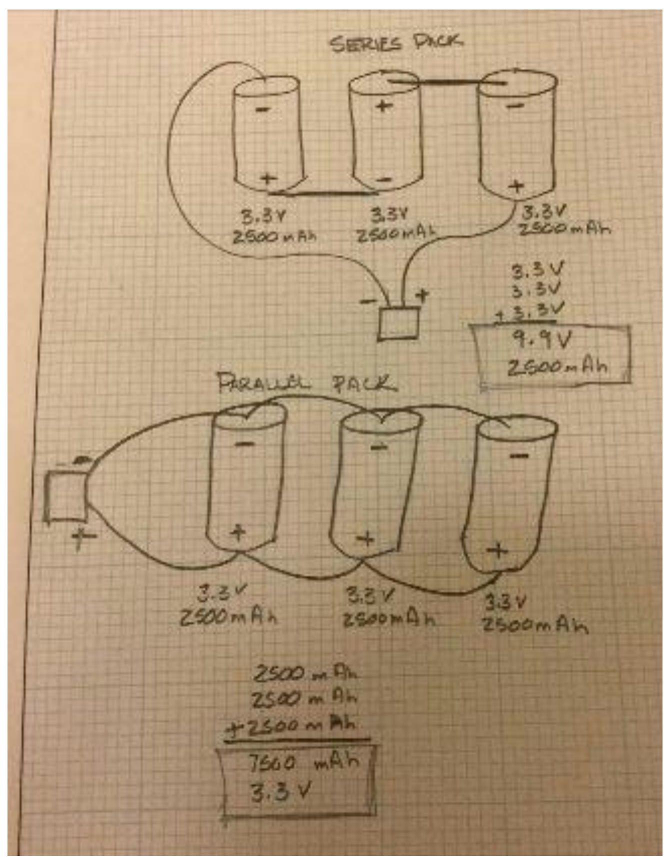
It would be recommended to use a parallel circuit for your electrical design. In a parallel circuit the voltage will remain constant to each component. The current can and will vary through each component, dependant on that components demand. In Example 2 the voltage appears to be the same on the output side of the motor as on the input side, but there will be a voltage drop, the motor has some resistance and this will vary from motor to motor. Also, in Example 2 the schematic shows 35 Amps traveling to the battery, in fact it would be drawn from the battery (the diagram shows the individual amperages added up).

When you begin the design of your electrical system you must first identify the demands that will make it up. You must identify the components that will draw on the battery, the power supply of the system. Identify the drive motors and find the motors operating amperage draw, usually listed in the motors specification sheet. The motor should also have a operating voltage rating and range, ex: 12V motor, 7V-14V range. Motors can run at voltages higher than their range however the life of the motor will be compromised. Robots usually have two drive motors, some use four. In a parallel circuit, regardless if you're using two motors or four the battery will need to be rated for the operating voltage of the motors.



If you’re using a weapon system that requires a motor, unless you’re using a two battery system your battery will need to support the weapon motor too. As depicted in example 2 in a parallel circuit with a 12V battery 12 volts will be supplied to all of the motors in the system.
The amperage needed by the motors must be determined prior to choosing your battery. You’ll need to add-up the amperage demands of the motors as in example 2, which equated to 35 amps, in a parallel circuit the amperage compounds. You’ll need to identify the discharge rate of the battery to match the demand of the circuit, you can find this in the battery specification sheet, as pictured to the left. A data sheet for a A123 lithium ion battery cell is shown above, one 3.3V cell, with a discharge of 50 continuous amps. The continuous discharge is what must be identified, a burst may be listed as well, this particular cell has a burst discharge of 120 amps for 10 seconds. If the demand for energy is higher than 50 amps and lasts longer than 10 seconds damage to the battery may occur including dead cells, weakened life inability to recharge, etc.

You may find it difficult to find ready made battery packs (see battery types in glossary) although many are available online, robotmarketplace.com has several type to choose from as well as batteryspace.com. Many teams use model car, boat or aero batteries, however many of these batteries are changing to li-po (lithium polymer) which are illegal due to their tendency to explode or catch on fire. Many other teams have been using cordless tool batteries due to their durability for daily use in tools. You may decide that building your own battery pack is an option or using ready made packs but combining them together for more Voltage or life mAh (milli Amp hour, how long it will last, ex: 2500 mAh battery should last 2.5 hours if it is used within its specified discharge capacity).



When dealing with cells or batteries you must identify what your needs are. Once that is done you can start building. When designing for voltage you must:

- Note that when wired in series, add the battery voltages together for a compounded voltage, the amperage, Amp hour of the battery remains the same.

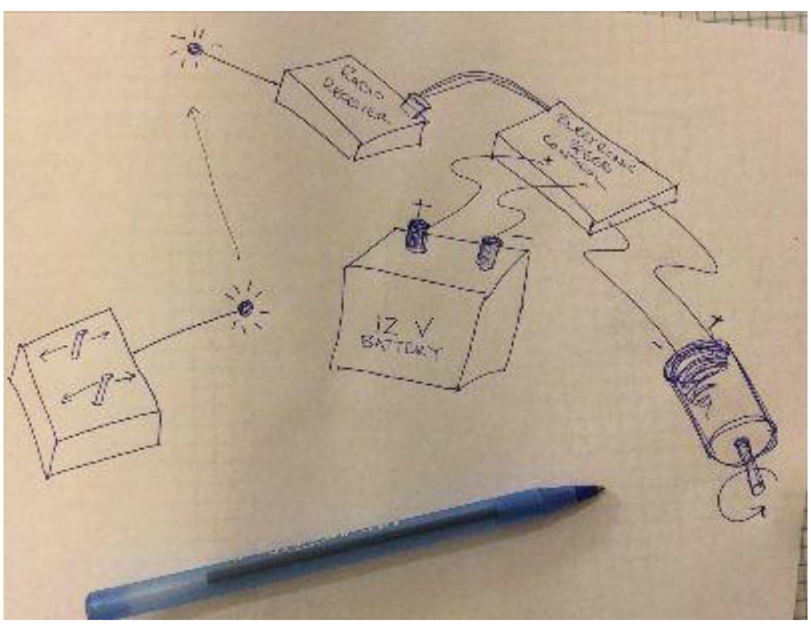
- Note that when wired in parallel the voltages stay the same but the amperage, amp hour, is added. This is depicted in the picture above

Many battery packs exploit the best of both options where cells are wired in parallel then joined to more cells to increase the pack's voltage. Some important things to note are:

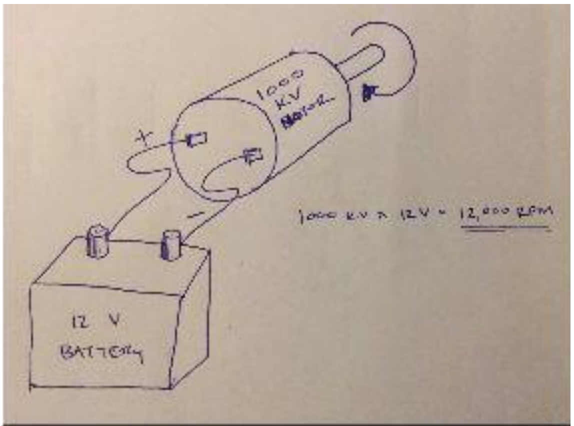
- Identify a charger for your battery cells prior to buying the battery (some chargers may be very expensive or difficult to use)
- A balancer is important to have on a battery pack and charger, this will ensure that each cell of the pack is charged at the same rate as the other cells in the pack. If the pack is not balanced then one cell may charge faster than the other cells, over burdening the undercharged cells during use, resulting in battery failure.

- when building your own pack each cell must be fully charged prior to building the pack (failure to do so can cause premature battery failure). Batteries coming from a manufacturer usually come fully charged however it should be good practice to check the voltage prior to assembly.

The last major component of the electrical system is the ESC (Electronic Speed Controler). In Robotics they are used to regulate the electricity that is allowed to flow to a motor. It doesn't matter if the motor is brushed or brushless, the motor will need to be regulated by an ESC. There are, however, specific speed controllers for brushed and brushless motors. The ESC can be thought of as an electric valve which is allowed to open and shut by the signal received through the radio receiver. If the ESC is removed from the circuit and the motor were to be directly connected to the battery the motor would receive the total voltage supplied by the battery and rotate at full speed and in one direction. To reverse the direction of the motor the polarity to the motor terminals would need to be reversed but the motor would again rotate at full speed. The ESC regulates the electricity as it is needed by the motor so that the motor has the ability to rotate slowly or quickly or to rotate forward or in reverse. This is all dependant on what signal the driver is sending to the robot through the transmitter to the radio receiver.



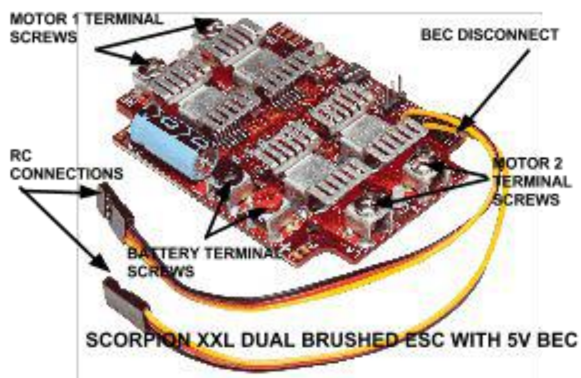
Some examples of Electronic Speed Controllers are pictured in the glossary and a resource list is attached as well as to where ESC's could be purchased. Brushed motor ESC's can be found



A motor connected directly to a battery will spin at full speed.

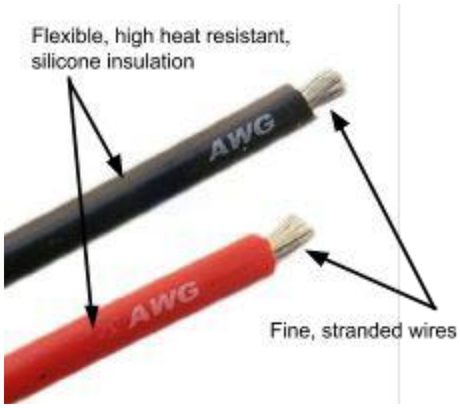
as single control or dual control, meaning they can either control one single motor or can control two motors. Brushless motor ESC's usually control only one motor. One point to be careful of is that many brushless motors and therefore their ESC's are used by airplanes, helicopters, quad and hexcopters, etc. (aero) many of these allow the motor to only spin in one direction due to their use. Be sure that you find ESC's which are reversible if they are to be used for drive and for your weapon motor if your weapon has a need to be rotated or operated in two directions .

Electronic Speed Controllers must be matched to the voltage and amperage demands of the circuit, motors, and battery. An undersized ESC will burn, fail, and can be the weak link in an otherwise great robot design. When designing the system and selecting your ESC pay attention not only to the motor's operating voltage and current but to the capabilities of the battery. The continuous discharge rate of the battery should be paid attention too but also the burst ability. Although it may be brief, the battery's burst discharge current, may be enough to overload the ESC's limit.

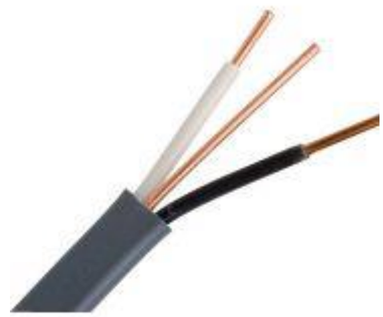


Some ESC's have a 5V BEC (Battery Eliminating Circuit). It is common for ESC's to have these built in. A Battery Eliminating Circuit is useful as a power supply for the receiver, LED indicator light, etc. External BECs can be purchased too, several are pictured in the glossary as well to illustrate an external BEC. The ESC may need minor modifications if an external BEC is used because there could be some electrical feedback otherwise. The modifications are unique to the ESC some can be as simple as clipping a wire or some have a BEC disconnect which is clipped or removed from the circuit board. An advantage of the external BEC is that if more than one ESC is used and one supplying the receiver voltage is damaged the independant BEC will still supply the receiver and the robot will still be "live". Likewise, disadvantages include weight, although minimal usually, additional electronics, and the potential for the BEC to be the component which gets damaged in a fight, however to replace a BEC is relatively cheap.

The last two components of the electrical system which need to be addressed are the wire and the connectors that the team will use to connect their components. Wire and connectors can add quite a bit of weight to the robot's design, sometimes upwards of 4 pounds. The type of wire you choose is important, pictured is stranded 14AWG wire. This type of wire is one common

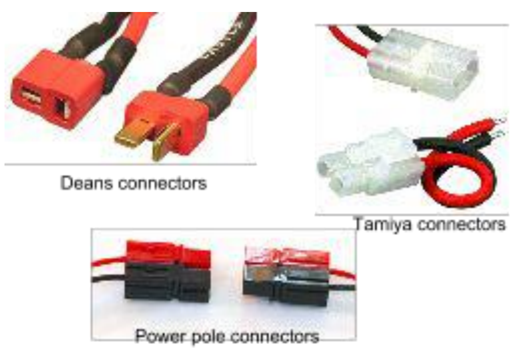


type used. The advantages are that it can handle higher amperages, it's flexible, and the silicone insulation can handle higher heat than other types of wire. A comparable wire commonly seen is called Romex, it's used in residential wiring. Romex wire is rated for high voltages (600V printed on insulation) but is limited in current, for example 14 AWG Romex wire is usually fused in your home at 15 amps, fighting robots can reach much higher current. The copper wire itself can support the electricity, however the insulation very likely will melt and burn off causing a short circuit or fire. The Romex wire is also relatively stiff, it is difficult to bend in tight spaces, which are plentiful in a battle bot. It's important to identify the limitations of the wire you plan on buying and using in your design, voltage, current (how many amps), and temperatures.



14 AWG Romex wire

The type of connector you use can be a personal preference, including soldering all joints. Solder is great for many reasons and many applications, however in the pit when repairs need to be made quickly and if parts need to be removed and replaced connectors are much faster. There are many types on the market and are very reliable. RC car, boat , and aero connectors are most commonly used. Pictured are several common types used by robot teams. Some teams use crimp-on style connectors too, however these aren't polarized. An important aspect of the connector you choose should include whether the connector has a positive and negative pole. If the connector can accidentally be plugged in backwards, negative to the positive and vice versa, you will short out your circuit and potentially damage components.



Several common connector types

Drive System:

Motor choice:
There are basically two types of DC motors you can choose to use as drive motors, brushed and brushless (see glossary for pictures of each). T here are advantages and disadvantages to both. The type of motor chosen for the drive system can be based on some of the following criteria found in the table:

MOTOR INFO TABLE 1

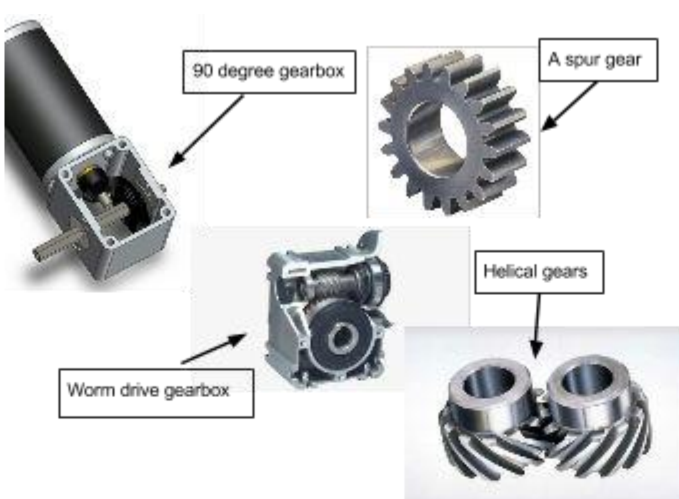
	BRUSHED	BRUSHLESS
TORQUE	usually measured in oz. in. usually has lower torque than brushless motors	usually measured in oz. in. usually has higher torque than brushed motors
ELECTRONIC SPEED CONTROLLER	can be dual or single control. average cost $150.00 for usable dual controller with built in BEC	most often found as single controller only. These controllers are far more complex than brushed controllers and average $150.00 for a single controller with a BEC
AMPERAGE DEMAND	Variable, comparable to brushless, often lower	Variable, comparable to brushed, often higher
VOLTAGE	Variable, comparable to brushless	Variable, comparable to brushed
AXLE SIZE	varies, see table below	varies, see table below
GEARBOX COMPATIBILITY	can be purchased with a matching gearbox designed for the motor. see below.	usually not sold with match. Their higher torque can damage some gearboxes. see below.
COST	$ cheap, starting at around $7.00	$$$ expensive, cheaper ones start around $65 and can range up to and more than $300

MOTOR INFO TABLE 2

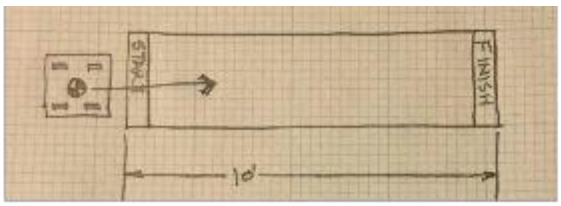
	Axle size fraction	Axle size decimal	Axle size mm
1/5th scale motors	5/16” closest equivalent (= to 7.9375 mm)	.3125” actual .3150”	8.00mm
1/8th scale motors	13/64” closest equivalent (= to 5.1595 mm)	.2031” actual .1969	5.00mm
1/10th scale motors	1/8”	.125”	3.175mm

Gear boxes:
The motors you choose regardless of type will spin at speed too high to be usable as a drive system. To determine the speed of your motor it will have a (kv) or rpm/v rating. The kv rating stands for revolutions per minute per volt i.e. if you have a 1,000kv motor and you are running it on an 18v battery the motor will run at 18,000 rpm (1,000kv x 18v battery = 18,000 rpm). The motor, more than likely, would stall from having a low torque when you get into a pushing match. The solution is to attach a gearbox unit to your motor to reduce speed and increase your pushing power, or torque. It may be important to mention that as voltage increases the rpm of a motor, the amperage of a circuit will increase the torque of a motor. A common gearbox option is to use a planetary gearbox. Planetary gearboxes are commonly purchased as sets with brushed motors from several websites (these can be seen in the resource guide).

There are other types of gearboxes too. There are also different types of gears. The specific types may be dependant on your specific need or simply what is affordable or available. If space, for example, is an issue there are 90° gearboxes where the motor is 90° to the output shaft of the gearbox. Spur gears are common but they are noisy because the teeth engage one at a time and tend to “slap” together. This could result in teeth breaking off of the gear. Comparatively, helical gears engage multiple teeth as they turn reducing chances of teeth breaking. If high torque is necessary a worm drive gear system may be ideal. The worm screw turns a worm gear, the result is a great



mechanical advantage. The worm drive system also acts as a 90° gearbox due to its natural orientation.
When researching gearboxes you'll see there are a relatively wide range of gear ratios to choose from, therefore, it is important to keep in mind several aspects when selecting your gearbox. As mentioned in the robot types section, two components of scoring in the arena by the judges will be your team's ability to demonstrate control and show aggression. That translates to your need to be slow enough to be controllable but to be fast enough to maneuver around your opponent to attack them. A good question to ask is, "how fast should we go?". When comparing various gearing options the range of functional operation is between 85"/second - 120"/second. Refer to the "Evaluation section" above for an example of the calculations.



RS-550 motor 1608 kv x 12 volts = 19,296 rpm motor speed

----------------------------------OPTION 1--
19,296 rpm / 64:1 gearbox = 301 rpm / 60 seconds / minute = 5 rotations/second

(assume a 3" dia. wheel) 9.42" / rotation x 5 rotations / second = 47.1"/ second
3" x 3.14 = 9.42"

Too slow...

----------------------------------OPTION 2--
19,296 rpm / 16:1 gearbox = 1,206 rpm / 60 seconds / minute = 20.1 rot./sec.

(assume a 3" dia. wheel) 9.42" / rotation x 20 rotations / second = 188.4"/ sec.
3" x 3.14 = 9.42"

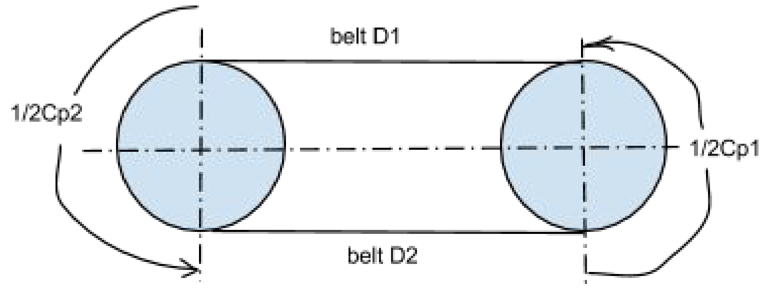
Too fast...

Calculating Pulleys and Belts

1. from your sketches you'll need to identify an approximate location of your axles
2. do a rough calculation of some pulleys and belts with your axle distances
3. be sure to identify a list of pulleys and belts that you may be choosing. See the attached list of resources. Although there are many sources, SDP-SI.com and McMaster.com have many options.
4. compare the list of mass produced components with your rough calculations, adjust your axle distance to accommodate the components available and, very important, adjust any engineering drawings and solid models.

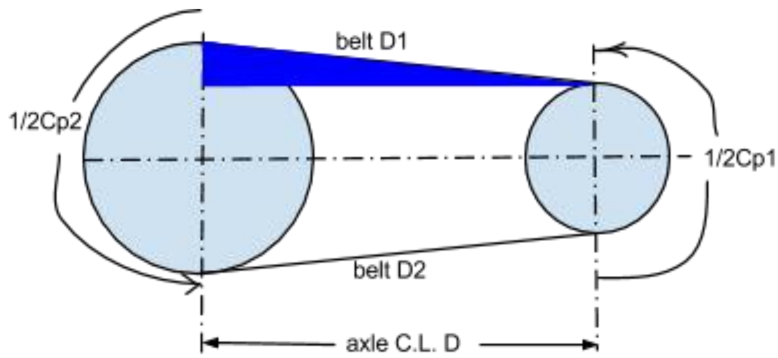
Pulleys of equal size

1. use the distance from centerline of one axle or pulley to the centerline of the second axle or pulley to determine D1 and D2.
2. use the pitch diameter of the pulley to calculate its circumference (C=2œ·R or C=œ·D)
3. add the D1+D2+Pulley Circumference= belt length

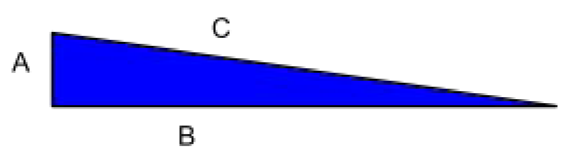


Pulleys of issimilar Size

1. Notice the blue triangle formed at the top of the diagram below. It will be important to find the hypotenuse of the triangle in order to calculate the belt length.



2. To determine “A” subtract the diameter of the smaller pulley from the larger one. The difference is “A”.



3. To determine “B” use the distance from centerline of one axle or pulley to the centerline of the second axle or pulley to determine “B”.
4. Solve for “C” using the pythagorean theorem, $A^2+B^2=C^2$
5. You will then need to solve for half the circumference of both pulleys. Use the pitch diameter of the pulleys to calculate ½ their circumference (½ C=ue·R or ½ C=½*ue·D)
6. Use the following formula to calculate the belt length

½ Circumference Pulley 1 + ½ Circumference Pulley 2+D1+D2 = Belt Length

See Glossary for information on:

- timing pulley
- timing belt
- sprocket
- chain drive
- v-belt
- o-ring

Control System:

BINDING- the process of linking the transmitter and receiver together on the same digital signal so that no outside device or signal can interfere with their operation. Always follow manufacturer's instructions and verify that both components are compatible before purchasing.

RADIO CONTROL TRANSMITTER- (simply referred to as a RC Remote Controller) is the control device by which the robot operator/driver steers and manipulates the robot. The Bots IQ program requires teams to use a 2.4GHz spread spectrum type system. Simply put, this is the type of signal used by the system to communicate. This is considered the safest and most secure system available on the market, and is readily available. Controllers come in a variety of configurations, types, and price ranges, and offer a range of available channels. Two main types of controllers are surface and air controllers.

SURFACE CONTROLLER- used for a variety of RC-style cars and trucks. Range from 2 to 4 channels. Have a steering wheel and throttle trigger along with a range of additional control buttons (trim switches). More difficult to program for battle bots and typically require and additional electronic device known as a v-tail mixer to link the two drive motors together for throttle and steering. Easier than air controllers for maintaining failsafe. Some drivers prefer the responsiveness of the steering wheel over the joystick controllers used for aircraft.

<table>
<tr>
<td>High End Surface Transmitter

Spectrum DX4S MSRP $249.00

Compatible Receiver

SR410 4-Channel DSMR Sport Surface Receiver
MSRP $59.99</td>
<td></td>
</tr>
</table>

AIR CONTROLLERS- used for a variety of RC-style planes and helicopters. Range from 4 to 18 channels. Have two joysticks which can be set up to control each motor independently like a tank, along with a variety of other switches and control buttons. Easier to program than surface controllers for battlebots due to the dual control sticks working independently for steering and throttle. Can be configured multiple ways.

<table>
<tr>
<td>

<u>High End Air Transmitter</u>

Spektrum DX6i 2.4GHz DSM2 6CH Transmitter
MSRP $159.99

<u>Compatible Receiver</u>

AR6210 DSMX® 6-channel receiver
MSRP $69.99

</td>
<td>

<u>Low End Air Transmitter</u>

OrangeRx T-SIX 2.4GHz DSM2 Compatible 6CH Programmable Transmitter
MSRP $64.99

<u>Compatible Receiver</u>

OrangeRx R615X DSM2/DSMX 2.4GHz compatible receiver
MSRP $11.30

</td>
</tr>
</table>

<u>RADIO CONTROL RECEIVER</u>- is the device with which the transmitter communicates to manipulate the robot. The receiver is placed inside the robot and all esc's and/or besc's are connected through a different channel to the receiver. The channel denotes what control on the transmitter will operate a given motor. For example: if the left motor's esc of the robot is connected to the throttle channel of a receiver, than the throttle joystick will control whether the motor goes, forward, reverse, or stops according to to the joystick's position.

<u>FAIL SAFE-</u> the feature found in all receivers to determine motor output when accidental loss of transmitter power occurs. This feature is set during initial binding of the transmitter and receiver. **Always read the instruction manuals for your transmitter and more specifically your receiver for proper set up during the binding process.** Some air systems can not be used because the throttle channel is automatically set to provide power so that a RC plane will not crash. In battlebots terms, it is the necessary setting of the robot to go all-systems dead if the transmitter loses power. An example problem that regularly occurs in competition is when the driver does the initial binding of the robot, he/she accidently bumps the throttle upward from the neutral state. This essentially tells the receiver when power to the transmitter is lossed, engage the throttle to that previously “trained” position, causing the robot to move.

Important: Failsafe is the final safety check before any robot is allowed to compete in a match.

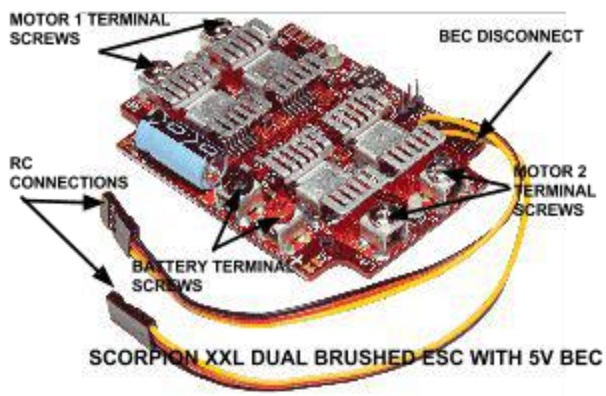
GLOSSARY:

ELECTRICAL SYSTEM:

A/C Alternating Current: Alternating current (AC), is an electric current in which the flow of electric charge periodically reverses direction

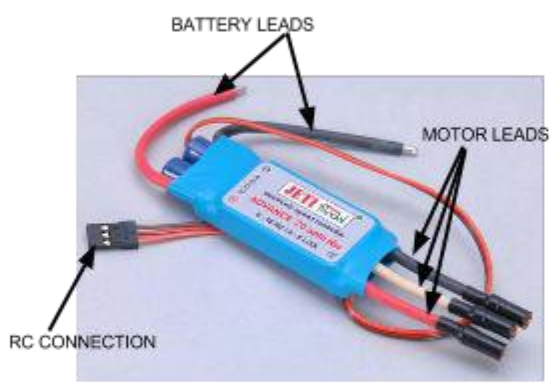
D/C Direct Current - The flow of electric charge is only in one direction.

ESC - ELECTRONIC SPEED CONTROLLER(FOR BRUSHED MOTORS).



SCORPION XXL DUAL BRUSHED ESC WITH 5V BEC

BESC - BRUSHLESS ELECTRONIC SPEED CONTROLLER.

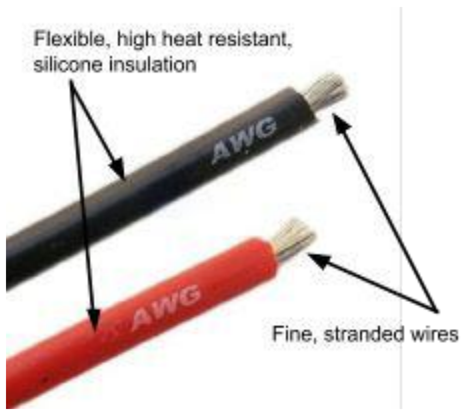


JETI SINGLE BRUSHLESS MOTOR ESC WITH 5V BEC

BEC - (Battery Elimination Circuit), an electronic circuit designed to deliver electrical power to other circuitry without the need for multiple batteries.

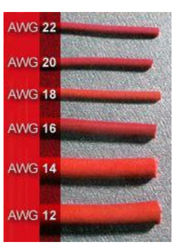
BALANCER - A battery balancer or battery regulator is a device in a battery pack that performs battery balancing, they regulate the rate that each cell in a pack is charged. A balancer may be added to a battery pack when charging. They come in different forms a “blinky” is pictured

STRANDED WIRE - small wires contained in an insulated coating, usually very flexible, such as [Noodle Wire](#)stranded wire can usually allow for better flow as the electrons flow on the outer surface of the wire and there are by definition more wires.



SOLID WIRE - one single solid piece of copper in an insulated coating, usually relatively inflexible, used commonly in residential wiring applications

AWG - (AMERICAN WIRE GAUGE) The standardized diameter of wire



Total System Amperage Draw	Up To 4'	Up To 7'	Up To 10'	Up To 13'	Up To 16'	Up To 19'	Up To 22'	Up To 28'
0-20A	14 ga.	12 ga.	12 ga.	10 ga.	10 ga.	8 ga.	8 ga.	8 ga.
20-35A	12 ga.	10 ga.	8 ga.	8 ga.	6 ga.	6 ga.	6 ga.	4 ga.
35-50A	10 ga.	8 ga.	8 ga.	6 ga.	4 ga.	4 ga.	4 ga.	4 ga.
50-65A	8 ga.	8 ga.	6 ga.	4 ga.	4 ga.	4 ga.	4 ga.	2 ga.
65-85A	6 ga.	6 ga.	4 ga.	4 ga.	2 ga.	2 ga.	2 ga.	0 ga.
85-105A	6 ga.	6 ga.	4 ga.	2 ga.	2 ga.	2 ga.	2 ga.	0 ga.
105-125A	4 ga.	4 ga.	4 ga.	2 ga.	0 ga.	0 ga.	0 ga.	0 ga.
125-150A	2 ga.	2 ga.	2 ga.	0 ga.	0 ga.	0 ga.	0 ga.	00 ga.

BATTERY TYPES:
LITHIUM ION - is a member of a family of rechargeable battery types in which lithium ions move from the negative electrode to the positive electrode during discharge

LITHIUM POLYMER (Li-Po) - (**ILLEGAL** for use in Bots IQ), a lithium form battery which come in a soft package or pouch, which makes them lighter but also less rigid. Their particular chemistry allow them to discharge at high rates but they can get hot quickly and catch on fire or explode.

NICKEL METAL HYDRIDE (Ni-MH) - A type of rechargeable battery. The chemical reaction at the positive electrode is similar to that of the nickel–cadmium cell (NiCad), with both using nickel oxyhydroxide (NiOOH). However, the negative electrodes use a hydrogen-absorbing alloy instead of cadmium. A NiMH battery can have two to three times the capacity of an equivalent size NiCd

NICKEL CADMIUM (NiCad) - A type of rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes

LITHIUM IRON PHOSPHATE (LiFePo) - A type of lithium-ion rechargeable battery which uses LiFePO4 as a cathode material and offers longer life and better power density (the rate that energy can be drawn from them).

LEAD ACID (Pb) - (**ILLEGAL** for use in Bots IQ), the oldest type of rechargable battery which can provide high current discharges. The charge is produced from the reaction of lead(II) sulfate (PbSO4) and sulfuric acid contained in the battery casing.

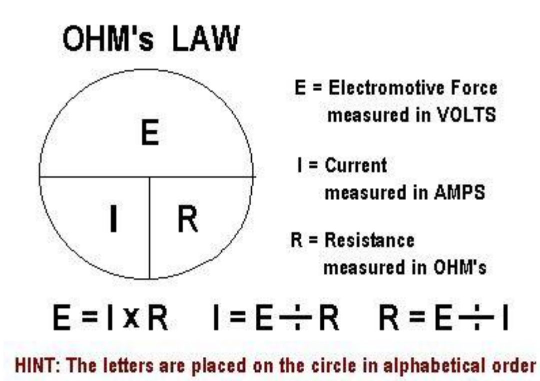
SWITCH - A device for making and breaking the connection in an electric circuit.

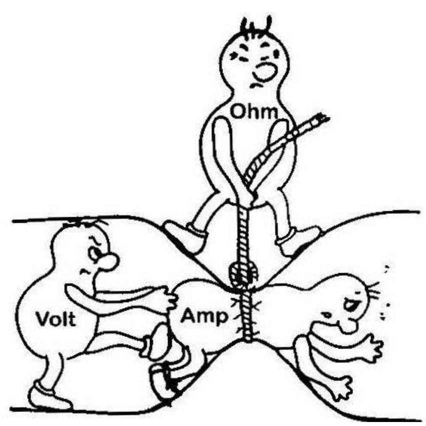
toggle switch

screw actuated switch

push button

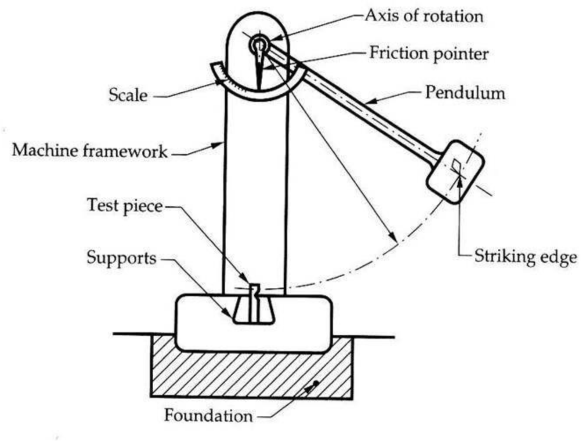
OHMS LAW- calculation used to calculate the relationship between electrical Voltage, Current and Resistance.



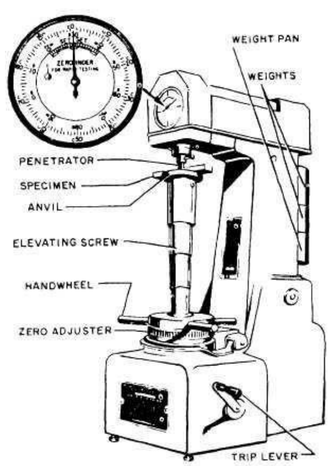


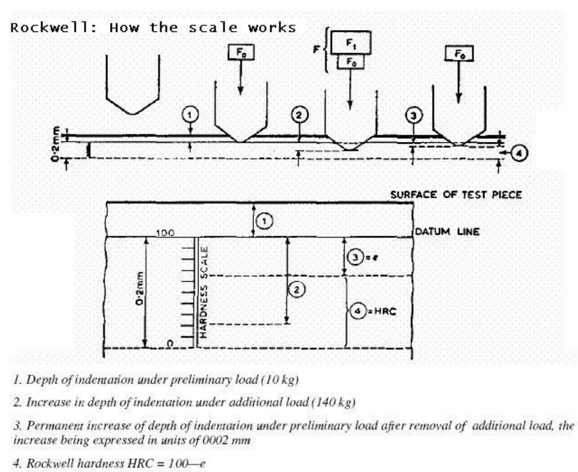
TESTING METHODS:

The Izod impact test - a hammer/ pendulum is dropped from a fixed position and impacts a material sample. The sample can be inspected

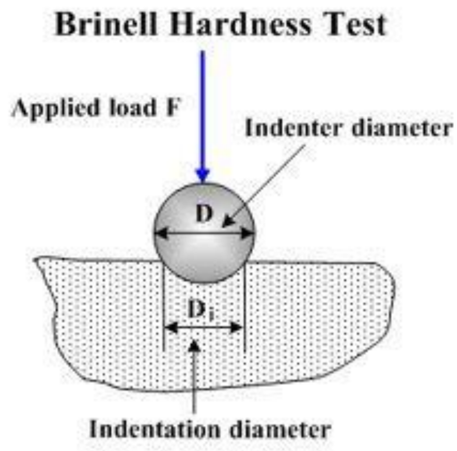


The Rockwell hardness test - There are several type of rockwell tests the A, B, and C. The A is for softer materials the C the hardest. The testing device measures the pressure it takes to press into a sample of a material.

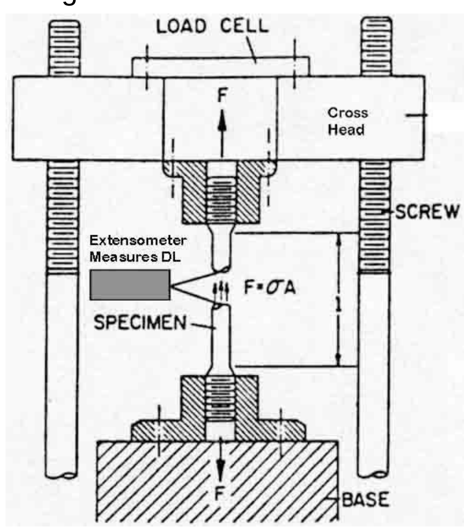




The Brinell hardness test - is similar to the rockwell however the penetrator pressed into the sample is rounded as opposed to the pointed penetrator of the rockwell.



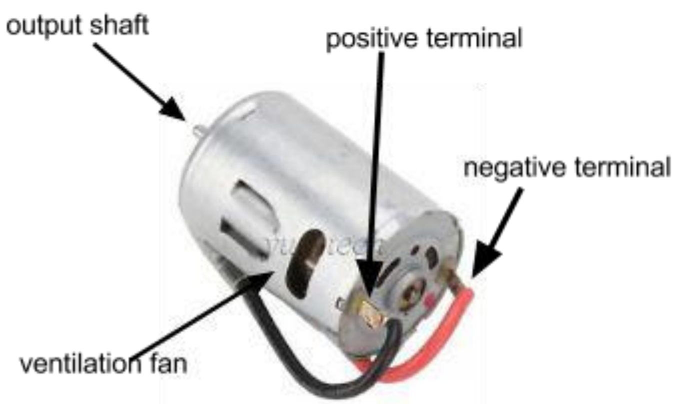
Tensile testing (yield strength) - A specimen is loaded into the tensile tester and pulled until it snaps apart. The specimen must have certain size requirements to fit into the tester for accurate measurements and due to the design of the machine.



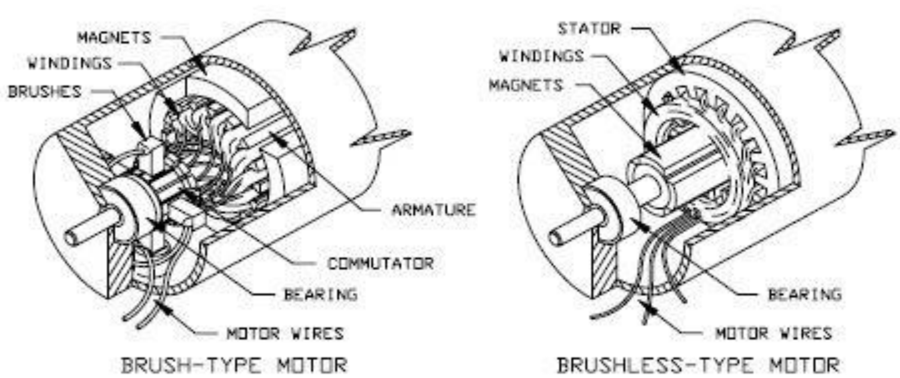
Durometer tests - usually for rubber (your wheels may have a rating related to this). The material is pressed by the testing device and the value of its give can be seen on a dial. A tire is being tested below.

MECHANICAL SYSTEM:

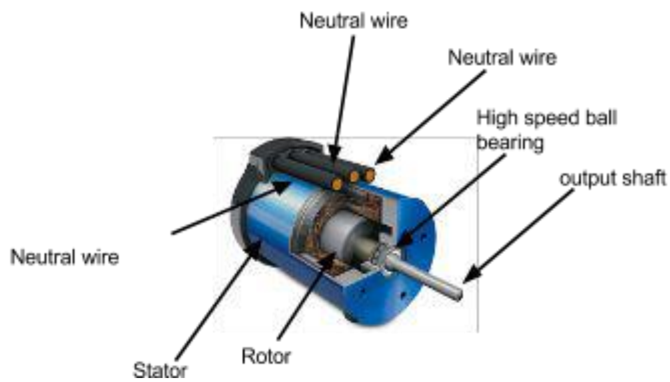
BRUSHED MOTOR:



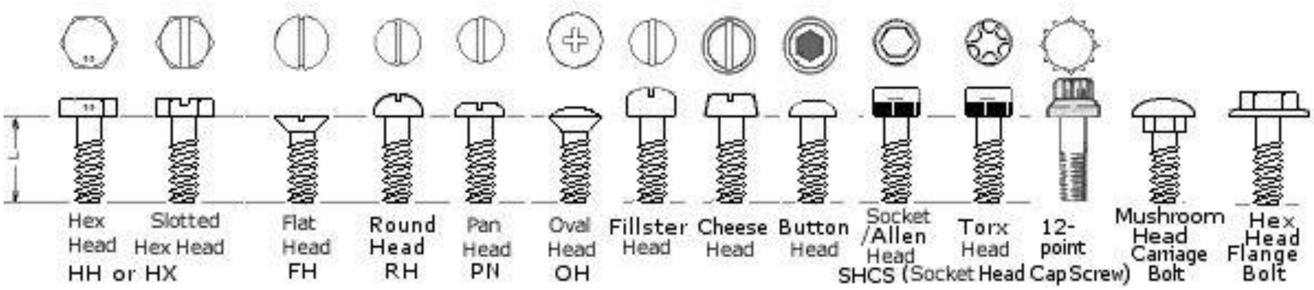
Brushed/ Brushless comparison (http://www.fadalvmcparts.com/about_servos.html)

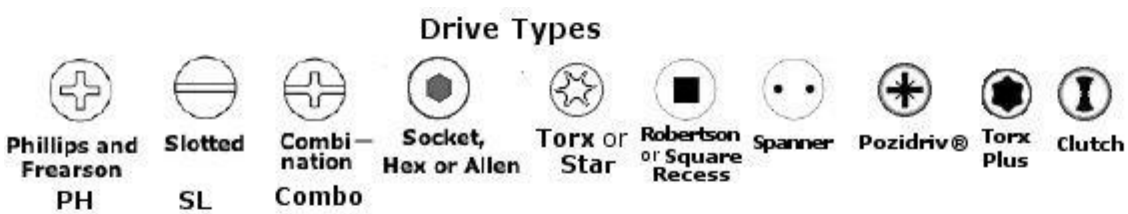


BRUSHLESS MOTOR - Brushless motors usually have more torque than brushed motors of the same size. They will have 3 wires.

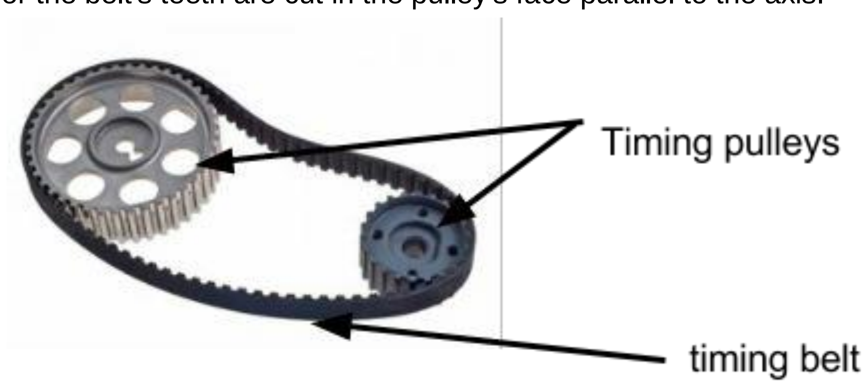


SCREW TYPES:



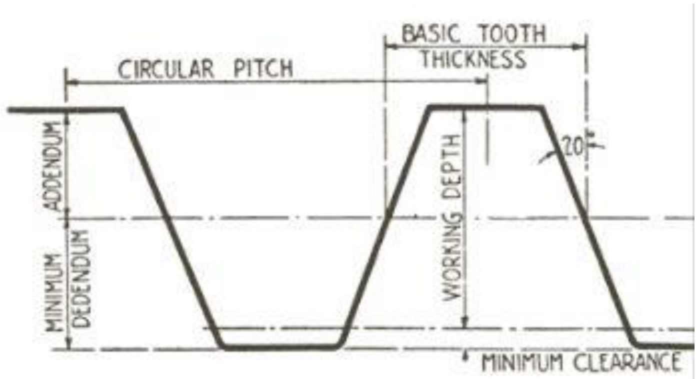


TIMING PULLEY - A pulley that is similar to an uncrowned flat-belt pulley, except that the grooves for the belt's teeth are cut in the pulley's face parallel to the axis.

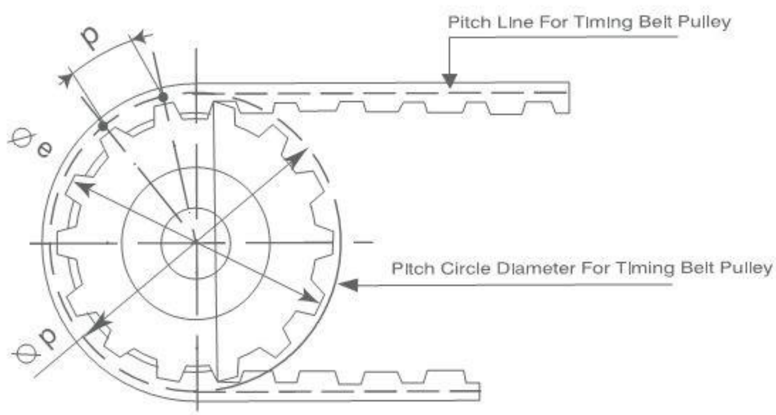


TIMING BELT - A timing belt is a belt that has teeth to prevent slippage and is used to synchronize the rotation of several pulleys or shafts.

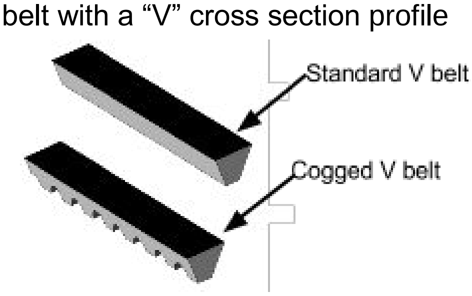
PITCH - The distance from the centerline of one tooth to the next, in the diagram it is labeled as circular pitch



PITCH LINE / DIAMETER - The diameter of a gear or pulley measured at the centerline of the tooth of the gear or timing pulley. the pitch line is similar on the belt as depicted in the diagram.



V-BELT - A fiber reinforced belt with a “V” cross section profile

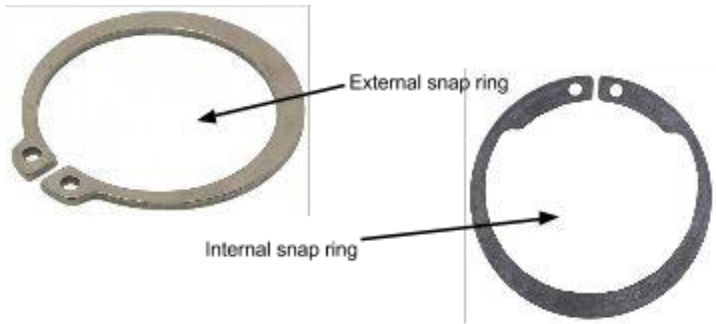


O-RING - A “rubber”, can be various materials, urethane, silicone, etc., ring used as gasket or seal. Can be used in a belt drive system too.

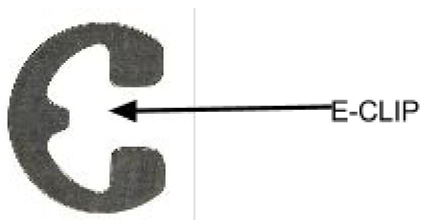
SPROCKET - A profiled wheel with teeth that mesh with a chain, commonly seen is use on bicycles

CHAIN DRIVE - is a way of transmitting mechanical power from one place to another. It is often used to convey power to the wheels of a vehicle, particularly bicycles and motorcycles. It is also used in a wide variety of machines besides vehicles.

SNAP or RETAINING RING - is a fastener that holds components or assemblies onto a shaft or in a housing/bore when installed in a groove. Once installed, the exposed portion acts as a shoulder which retains the specific component or assembly.

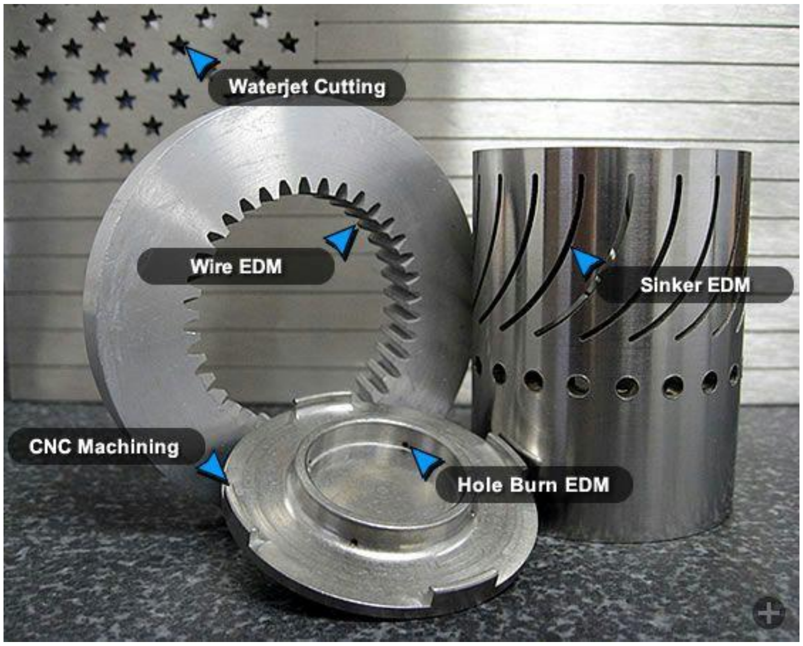


E-CLIP - An E-clip is an "E" shaped fastener that holds components or assemblies onto a shaft when installed in a groove. Once installed, the exposed portion acts as a shoulder which retains the specific component or assembly.



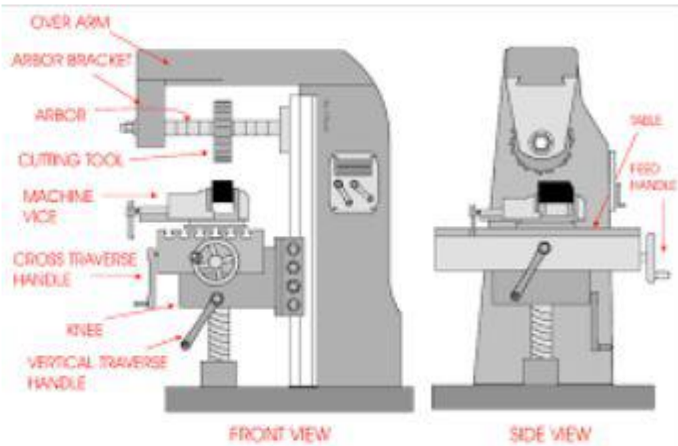
SHAFT COLLAR - Shaft collars are used as mechanical stops, locating components, and bearing faces on shafts, they usually have a screw of some type to compress the shaft to eliminate movement.

MACHINING: Many types of various machines can be employed in the development of a robot. Each machine has its particular specialty and purpose. Pictured are some cuts made by various machining processes.

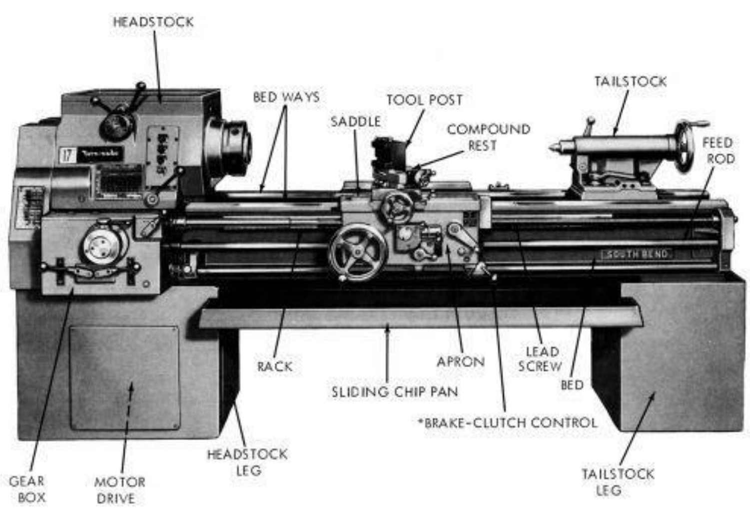


VERTICAL MILL - Pictured below is a manual Vertical Mill. The tool is held in a vertical axis in a vertical milling machine. The workpiece is clamped to the movable table top or in a vise or fixture on the table top. The table can move in an X, Y, and Z axis.

HORIZONTAL MILL - Pictured below is a manual Horizontal Mill. The tool is held in an horizontal axis in a horizontal milling machine. The workpiece is clamped to the movable table top or in a vise or fixture on the table top. The table can move in an X, Y, and Z axis.

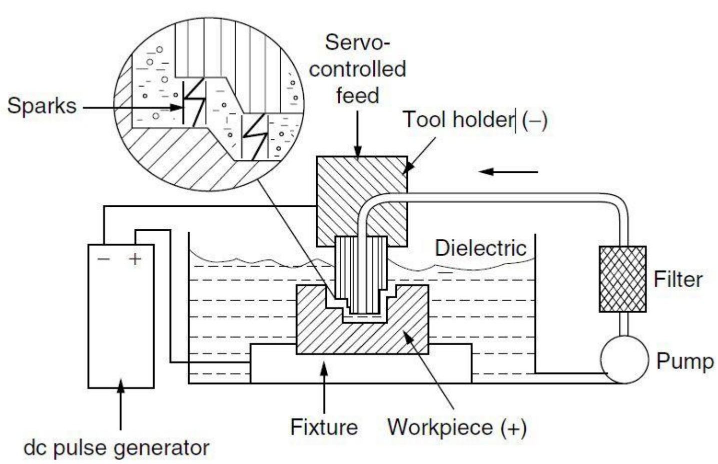


LATHE or TURNING - The machine holds round material between centers of the headstock and tailstock or in the chuck of the headstock. Round or cylindrical profiles can be cut into the face of material or into the side.

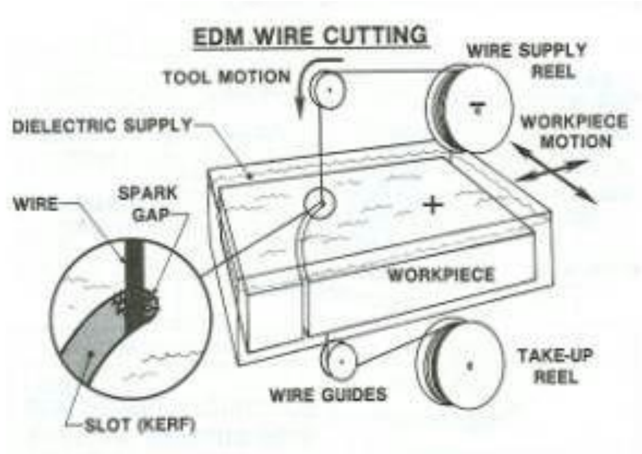


WATER JETTING - High pressure water (25,000- 75,000 PSI) mixed with fine garnet is used to cut through metal and other materials. In some cases hard materials up to 10” thick can be cut using a water jet.

EDM, ELECTRICAL DISCHARGE MACHINING - A graphite or other conductive material is used to “burn” material from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. Any material hardness can be burned away with the EDM process to a close tolerance.



WIRE EDM - Similar to conventional EDM machining however a thin wire is used in place of an electrode. Wire cutting allows for more degrees of freedom to cut irregular shapes in any hardness material to a close tolerance.

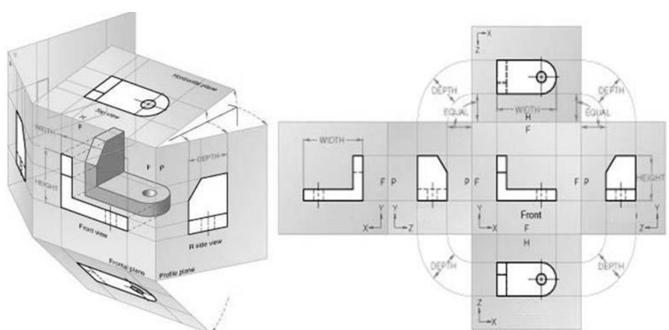


GRINDING and JIG GRINDING - is a machine tool used for grinding complex shapes and holes where the highest degrees of accuracy and finish are required.

3D PRINTING - A process in which plastic, ceramics or metals can be extruded or printed onto a build plate through a printer nozzle.

DESIGN:

<u>ORTHOGRAPHIC MULTIVIEW DRAWINGS (2D)</u>- A 2 dimensional drawing of an object that provides a specific number of views to accurately convey all details and dimensions. In most cases, objects can be broken down into 6 views, but only 2-3 views are typically necessary. Each view is drawn at a right angle (90°) to the last.



LINE TYPES

VISIBLE/OBJECT - solid lines that represent the edges and features of a given part.

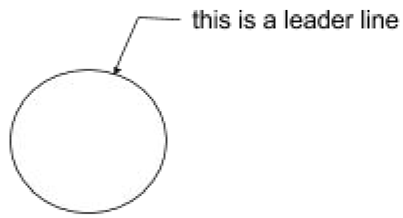
HIDDEN - short dashed lines that represent hidden feature that are not visible on a given view of a part.

CENTER - alternating long and short dashed lines that represent the center of holes, slots, paths of rotation, and symmetrical objects.

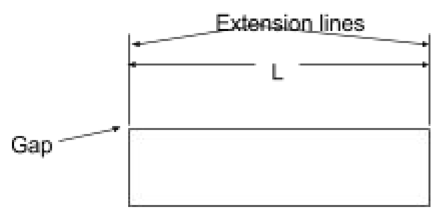
CONSTRUCTION - A very thin, light line or in CAD a layer used to layout dimensions and points that will be used to construct the view, object, or shape.

DIMENSION - A line containing the dimension of a feature which ends with arrows.

LEADER - A line which is used to dimension a curved surface such as a circle, hole, fillet or round. The leader terminates with an arrow and points to the center point of the feature.



EXTENSION - A line which extends from an object or feature into space so that the feature or object can be dimensioned in the drawings “white space”. They do not touch the object and contain the dimension lines.



ENGINEERING DRAWING SET
- SHEET SIZE
- TITLE BLOCK
- EXPLODED VIEWS W/ B.O.M.
- BASELINE DIMENSIONS
- ORDINATE DIMENSIONS
- PRECISION AND TOLERANCING

<u>PARAMETRIC MODELING (3D)</u>- A 3-Dimensional form of CADD that utilizes dimensions and relationships to drive model geometry. A major advantage over traditional AutoCAD lies in the software's ability to modify an object by adjusting dimensions and not by redrawing the object. Solidworks is available to all teams for free through the Bots IQ Program.

<u>SKETCH-</u> The fundamental starting point for drawing in Solidworks. Similar to traditional AutoCad in that the user will draw basic 2 dimensional geometric shapes based off of lines, arcs, etc. The shape is given a set of dimensions before being completed. Sketches differ from drawings in that sketches are used to create features, features are used to create parts, and parts are eventually turned into drawings used in actual part production.

<u>PART</u>- Once a sketch is complete, the user can utilize tools to transform the 2D object into a 3D object (extruding). Additional sketches can be created on this 3D shape to further develop the

part. Additional features can be both added and removed from the shape through this method of additive/subtractive modeling. The model can always be adjusted or changed by going back into the sketches of the part and altering dimensions.

ASSEMBLY- a group of parts locked together through dimensions and relationships called constraints.

EXPLODED VIEW- A view that shows the breakdown of an assembly into its parts. Similar to a set of instructions for assembling a toy. The user is able to see the relationship of parts and correlate how all the parts ultimately align.

RESOURCES

SYSTEM AREA	WEBSITE	NOTES/DESCRIPTIONS
GENERAL		
	engineeringtoolbox.com	genral informationa on all things engineering
	howstuffworks.com	how stuff works, articles, videos and more
	http://letsmakerobots.com/	blog, Q/A, on how to do many things with robots
	https://www.physicsforums.com	
ELECTRICAL		
	radioshack.com	heatshrink, soldering stations/material, resistors, wires, LEDs, Volt meters
	mcmaster.com	wire, motors, heat shrink...NOTE: dc gearhead motors are expensive
	banebots.com	brushed motors, gearboxes NOTE: their 45A ESC is not available, but really good:(***almost everything is out of stock***
	robotmarketplace.com	wire, connectors, battery chargers/balancers, bateries and custom battery packs
	holmeshobbies.com	quality brushed/brushless speed controllers, and new brushless motors (excellent customer support)
	towerhobbies.com	extensive rc supplier (high end speed controllers and motors)
	robotshop.com	speed controllers, brushed and brushless. Connectors, wires, lights, etc. LOTS! some on the hobbyist/lighter duty side
	maxamps.com	Really good LiFePo batteries, expensive
	onlybatterypacks.com	battery packs...
	amazon.com	connectors, etc. lots...
	servocity.com	ESC's , motors, connectors, wire
	teamtekin.com	Brushed and Brushless motors and ESC's, software, forums, etc.
	castlecreations.com	Brushless motors and ESC's, documentation, forums, info on programming etc.
	batteryspace.com	A123 Systems 3.3v cells, tabbing material
	amain.com	
	buddyrc.com	chargers, stranded wire, balance tabs and boards
STRUCTURAL		
	Mcmaster.com	various metals, plastics, composites, and hardware...Usually receive next day
	dragonplate.com	carbon fiber manufacturer

	grainger.com	material...UHMW
	metalsupermarkets.com	metal...can get almost any type, size or shape...Campbells run road, Robinson twp. and online
	amazon.com	various materials
	ebay.com	titanium and other various materials
	onlinemetals.com	lots of metal types, sizes, and shapes
	metalsdepot.com	lots of metal types, sizes, and shapes
	servocity.com	various robot specific material...Ex: carbon fiber tubing, brackets, etc
MECHANICAL		
	sdp-si.com	Stock Drive Products-Sterling instrument, belts, gears, pulleys, etc.
	Mcmaster.com	belts, pulleys, motors, gears, screws, bolts, keyed axle stock, key stock etc.
	banebots.com	wheels, hubs, keystock, etc...***almost everything is out of stock***
	robotshop.com	motors
	robotmarketplace.com	everything...wheels, hubs, axle stock and keystock, etc.
	bbman.com	B&B Manufacturing- belts, gears, pulleys, etc. Call and mention Bots IQ for discount
	colsoncaster.com	wheels of all sizes...NOTE: alot are not keyed and may need to modified, good otherwise
	servocity.com	wheels, pulleys, bearings, belts, etc.
	pittman-motors.com	motors, both brushed and brushless, A bunch of good articles on how to size/pick a motor and other... on site
	gaussboys.com	magnets
CONTROL	robotmarketplace.com	ESC's, transmitters, receivers, etc.
	banebots.com	***almost everything is out of stock***
	https://www.spektrumrc.com/default.asp	spectrum dx61 and other RC controllers, receivers and resources
	http://www.futaba-rc.com/	spectrum dx61 and other RC controllers, receivers and resources
	trossenrobotics.com	arduino and a bunch of other robot specific items including kits, more towards autonomous bots or hobbyists
	servocity.com	ESC's, transmitters, receivers, etc.

MACHINING	protolabs.com	any part cnc cut and shipped in mail in 48 hours
	bigbluesaw.com	mail order water jetting
	tormach.com	small affordable cnc mills/lathes
	Fenton Heat treating Inc.	3605 Homestead Duquesne Rd West Mifflin, PA 15122 (412) 466-3960...Really nice guys
	pghanodizing.com	Anodizing services, ...cause it's important to look good too. Also offer hard coat, harder than tool steel
	eastlibertyelectroplating.com	Anodizing services and offer hard coat in addition to other coatings, plating etc. good definitions/explanations of the different coatings on their site
DESIGN	http://www.riobotz.com.br/riobotz_comb	robot building handbook-

NRL TECHNICAL REGULATIONS

Revision Date: August 2018

1. General

1.1. All participants build and operate robots at their own risk. Combat robotics is inherently dangerous. There is no amount of regulation that can encompass all the dangers involved. Please take care to not hurt yourself or others when building, testing and competing. Robots must be free of words, logos or graphics that are offensive in any way.

1.2. If you have a robot or weapon design that does not fit within the categories set forth in these rules or is in some way ambiguous or borderline, please contact the Event Organizer. Safe innovation is always encouraged, but surprising the event staff with your brilliant exploitation of a loophole may cause your robot to be disqualified before it ever competes.

1.3. Compliance with all event rules is mandatory. It is expected that competitors stay within the rules and procedures of their own accord and do not require constant policing.

1.4. Each event has safety inspectors. It is at their sole discretion that your robot is allowed to compete. As a builder you are obligated to disclose all operating principles and potential dangers to the inspection staff.

1.5. Cardinal Safety Rules: Failure to comply with any of the following rules could result in expulsion or worse, injury and death.

1.5.1. Radios may not be turned on, at or near events for any purpose without obtaining permission from the event personnel.

1.5.2. Proper activation and deactivation of robots is critical. Robots must only be activated in the arena, testing areas, or with expressed consent of the event personnel or its safety officials.

1.5.3. All robots must be able to be FULLY deactivated, which includes power to the drive and the weaponry, **within 60 seconds by a manual disconnect**. (Removable link or Main Power Switch) The operator must be able to perform the deactivation without handling the robot.

1.5.4. All robots must be able to be fully activated within 30 seconds.

1.5.5. All robots not in an arena or official testing area must be raised or blocked up in a manner so that their wheels or legs cannot cause movement if the robot were accidentally turned on. Runaway bots are VERY dangerous. (We strongly suggest a custom designed block that ensures the robot will not be inadvertently dislodged from the block.)

1.5.6. Locking devices: Moving weapons that can cause damage or injury must have a **clearly visible** locking pin in place **at all times** when not in the arena. Locking pins must be painted in neon orange or another high-visibility color. Locking pins must be clearly capable of stopping, arresting or otherwise preventing harmful motion of the weapon.

1.5.7. Weapon locking pins **must be in place** when weapon switch is turned on during a robot's power-on procedure (the weapon switch will be on, but no power will be applied to the weapon). The locking pin will be removed just prior to closing the arena door. This includes **all** powered weapons regardless of the power source..

1.5.8. It is expected that all builders will follow basic safety practices during work on the robot at their pit station. Please be alert and aware of your pit neighbors and people passing by. Continued failure to follow safety directions could result in an individual's or the entire team's disqualification for the event. This includes and is not limited to wearing SAFETY GLASSES at ALL times while in the pit area and in the arena area while handling or controlling your bot.

1.5.9. Safety offenses will be handled as follows:

(1) The first safety offense from any member of the team will result in a warning.

(2) The second offense from any member of that same team will result in a 10 second controller impoundment at the beginning of your next match. This means your opponent will be able to attack your immobile robot.

(3) Violations stack so if a team has 3 infractions between matches the impoundment period would be 20 seconds.

(4) After the penalty is assessed, the team starts over meaning the next offence results in a 10 second impoundment during the next match. No additional warnings will be given.

2. **Weight Classes & Size.** This event offers 15 pound robots. (There is no weight bonus for shufflers or other forms of locomotion which are predicated on rolling - see 3.1.2 for a definition of a non-wheeled robot.)

2.1. Wheeled weight = 15 pounds

2.2. Non-wheeled weight = 20 pounds

2.3. Your Bot must be no wider than 3 feet and no taller than 3 feet to ensure that your robot fits in the arena door.

2.4. Your Bot must be able to clear the arena floor during normal driving operations. Consideration must be made by teams to ensure that their Bot will not damage the arena structure.

2.5. Multi-Bots are allowed as long as the combined weight is 15 pounds or less.

If both bots are exactly the same weight, the team will need to decide which robot is the “primary” robot. If one of the bots weighs more than the other, the heavier bot is automatically the “primary” bot. The primary bot must be clearly marked with a piece of yellow tape. The “primary” bot is identified for the purpose of a countdown or knockout. As long as the “primary” bot is functioning, the match continues. If the “primary” bot is knocked out or it is counted out, the match is over. The other bot cannot compete without the “primary” bot.

3. Mobility

3.1. All robots must have easily visible and controlled mobility in order to compete*. Methods of mobility include:

3.1.1. Rolling (wheels, tracks or the whole robot)

3.1.2. Non-wheeled: non-wheeled robots have no rolling elements in contact with the floor and no continuous rolling or cam operated motion in contact with the floor, either directly or via a linkage. Motion is “continuous” if continuous operation of the drive motor(s) produces continuous motion of the robot. Linear-actuated legs and novel non-wheeled drive systems may qualify for this bonus. []

3.1.3. Shuffling (rotational cam operated legs)

3.1.4. Ground effect air cushions (hovercrafts)

3.1.5. *In the case of a Multi-bot, only the “primary” bot must have easily visible and controlled mobility in order to compete.

4. Robot Control Requirements:

4.1. Primary control and fail-safe communications to a Bot have to be via a remote radio link. Tethered control is specifically not allowed.

4.1.1. A Bot may be controlled by a maximum of three Operators/Drivers

4.1.2. A Bot must have a robust radio fail-safe that shuts off all motion-system and weapons power within one second after the remote-control transmitter is switched off, or otherwise stops transmitting. This fail-safe is required in addition to the Master Switch requirements

4.1.3. Binary (on/off) movement speed control is not allowed. Any control of the Bot speed along the ground has to be continuously variable in both forward and reverse directions.

4.2. The NRL recommends using the Spektrum Transmitter DX6, due to the corresponding receivers having SmartFail Technology. If a team is utilizing a different transmitter system for the competition, the system must meet the fail-safe protection requirements.

4.3. Bluetooth systems must be approved by the NRL safety committee prior to the competition. Operating plans, schematics, and a clear explanation of controls must be presented for review.

The NRL should get this information at least one week before the competition so that the safety committee can verify it at the start of competition. The Bot must comply with all other regulations, meaning the Bot should be in zero energy state when not in the test box or arena (cage). All power must be off and dissipated. The students should not need to handle the Bot in order to bring the robot to a zero energy state. The battery must be disengaged by the master switch and any energy storing devices must automatically drain when the master switch is shut off. The energy storing should only take place when the Bot is on.

Any capacitors or electrical storage devices used in the system must be capable of being safely discharged without putting the students at risk.

5. **Autonomous/Semi-Autonomous Robots:** Any robot that moves, seeks a target, or activates weapons without human control is considered autonomous. If your robot is autonomous contact the event organizer.

5.1. Autonomous robots must have a clearly visible light for each autonomous subsystem that indicates whether or not it is in autonomous mode, e.g. if your robot has two autonomous weapons it should have two “autonomous mode” lights (this is separate from any power or radio indicator lights used).

5.2. The autonomous functionality of a robot must have the capability of being remotely armed and disarmed. (This does not include internal sensors, drive gyros, or closed loop motor controls.)

5.2.1. While disarmed, all autonomous functions must be disabled.

5.2.2. When activated the robot must have no autonomous functions enabled, and all autonomous functions must failsafe to off if there is loss of power or radio signal.

5.2.3. In case of damage to components that remotely disarm the robot, the robots autonomous functions are required to automatically disarm within one minute of the match length time after being armed.

6. Batteries and Power

6.1. The only permitted batteries are ones that cannot spill or spray any of their contents when damaged or inverted. This means that standard automotive and motorcycle wet cell batteries are prohibited. Examples of batteries that are permitted: gel cells, Hawkers, NiCads, NiMh, dry cells, LiFePO4, AGM, and LiIon. . **(NO LiPoly batteries will be allowed.)**

[If your design uses a new type of battery, or one you are not sure about, please contact the Event Organizer.]

6.2. All nominal onboard maximum voltages are limited to: **28 Volts for 15# class robots** for this league. (It is understood that a charged battery's initial voltage state is above their nominal rated value.)

6.3. All electrical power to weapons and drive systems (systems that could cause potential human bodily injury) must have a manual disconnect that can be activated within **15 seconds** without endangering the person turning it off. (E.g. No body parts in the way of weapons or pinch points.) Shut down must include a **manually** operated mechanical method of disconnecting the main battery power, such as a switch (Hella, Whyachi, etc.) or removable link. Relays may be used to control power, but there must also be a mechanical disconnect. Please note that complete shut down time is specified in section 1.5.

6.4. All efforts must be made to protect battery terminals from a direct short and causing a battery fire. All charging of batteries must be done outside of the Bot.

6.5. All robots must have a separate light per switch that is easily visible from the outside of the robot that shows its main power is activated.

6.6. Batteries must be visible for inspection and must have marking from the manufacturer that clearly identifies the type of battery. If such markings are not possible, be prepared to show another form of proof that your battery is allowed (vendor receipt, etc).

7. Pneumatics

Pneumatic systems on board the robot must employ non-flammable, nonreactive gases. Only LPA (low pressure air [150 PSI max]) or single use CO2 cartridges are permissible. LPA systems may use certified refillable tanks; CO2 systems may NOT use refillable tanks. (The terms 'pressure vessel, bottle, and source tank' are used interchangeably.)

7.1. All components must be used within the specifications provided by the manufacturer or supplier.

7.2. All pneumatic components on board a robot must be securely mounted. Particular attention must be made to pressure vessel mounting and armor to ensure that if ruptured it will not escape the robot.

7.3. All pneumatic components within the robot must be rated or certified for AT LEAST the maximum pressure in that part of the system. You are required to have rating or certification documentation on all components in the pneumatic system. This includes the following:

- Onboard air compressors
- Air Tanks/Air Storage Devices
- All Valves (Solenoid, Purge, Shut-off, Pressure Relief, Check & Shraeder)
- Pressure Switch
- Manifolds
- Tubing/Hose

7.4. All pressure vessels must be rated for at least **120%** of the pressure at which they are used. (This is to give them a margin of safety if damaged during a fight.)

7.5. If regulators are used anywhere in the pneumatic system there must be an (additional) over pressure safety valve downstream of the regulator set for no more than **100%** of the lowest rated component in that part of the pneumatic system and there must be a gauge easily visible from outside the robot not on the bottom.

7.6. All pneumatic systems must have a manual main shut off valve to isolate the rest of the system from the source tank. This valve must be easily accessed for robot deactivation and refilling. It must also be out of any danger areas. It must be clearly marked.

7.7. All pneumatic systems must have a manual bleed valve downstream of the main shut off valve to depressurize the system. This bleed valve must be easily accessed for deactivation. This valve must be left OPEN whenever the robot is not in the arena to ensure the system cannot operate accidentally.

7.7.1. You **MUST** be able to be able to easily bleed all pressure in the robot before exiting the arena. (You may be required to bleed the entire system, including the source tank, if it is believed that you have any damaged components.)

7.8. If back check valves are used anywhere in the system you must ensure that any part of the system they isolate can be bled and has an over pressure safety valve..

7.9. All pneumatic systems must have an appropriate gauge on the low side of the regulator to show maximum resolution of the pressure in that part of the system. The gauge should be easily readable from outside the bot, not on the bottom.

7.10. Source Specifications for Pneumatic Systems:

7.10.1. Source Specifications for CO2 Based System

The max pressure that may be stored on board when using CO2 is relative to ambient temperature. The pressure at the liquid to vapor phase of CO2 at 70 degrees F ambient temperature is 853 PSI. No form of tank heater is allowed, including mounting of tanks near components that heat up during use. The max total volume of pressurized gas stored on board is 8 cubic ft at standard temperature (70 degrees).and pressure (14.7 PSI or 1 atmosphere).

7.10.1.1. No refillable tanks may be used for CO2.

7.10.1.2. Source system must be hard plumbed down to 150 PSI (no flexible tubing).

7.10.1.3. Minimum requirement for component stream:

Single use CO2->Puncture Valve->Burst disc->Regulator->Pop-off valve-> Gauge->150 PSI (max)

7.10.1.4. Burst disc must be rated at 1.8k (1800 PSI standard CO2 Safety Burst Disc or less)

7.10.1.5. Over pressure safety valve must be rated at 175 PSI or less

7.10.1.6. Gauge must show maximum resolution for 150 PSI max and must be readable from outside the robot.

7.10.2. LPA Based Systems

The maximum pressure that may be stored on board when using LPA is 150 PSI.

On-Board Compressor LPA System:

7.10.2.1. Minimum requirement component stream for On-Board Compressor System:

On Board LPA Compressor->Pressure Switch->Over pressure safety valve->pressure gauge->150 PSI (max)

7.10.2.2. Pressure Switch must be set at 150 PSI (max)

7.10.2.3. Over pressure safety valve must be rated at 175 PSI or less

7.10.2.4. Gauge must show maximum resolution for 150 PSI max and must be readable from outside the robot.

Refillable LPA System:

7.10.2.5. Minimum requirement component stream for refillable LPA System: Fill valve-> LPA tank-> Pop-off Valve->Gauge

7.10.2.6. Over pressure safety valve must be rated at 175 PSI or less

7.10.2.7. Gauge must show maximum resolution for 150 PSI max and must be readable from outside the robot.

7.10.2.8. You must have a safe and secure method of refilling your pneumatic system.

8. Hydraulics

8.1. Robots in the 15# class are **NOT** allowed to use hydraulics.

9. Internal Combustion Engines (ICE) and liquid fuels.

9.1. Robots in the 15# class are **NOT** allowed to use ICE.

10. Rotational weapons or full body spinning robots:

10.1. Spinning weapons cannot contact the outer arena walls during normal operation. (Contact with an inner arena curb, or containment wall is allowed).

10.2. Spinning weapons must come to a full stop within **30 seconds** of the power being removed.

11. Springs and Flywheels

11.1. Springs used in robots will use the remaining rules in this section. Safe operation, good engineering and best practices must be used in all systems.

11.2. Any springs used for drive or weapon power must have a way of loading and actuating the spring remotely under the robots power.

11.2.1. Springs used for active weapons must not be loaded when the robot is out of the arena or testing area.

11.2.2. Springs used within switches or other internal operations are exempt from this rule.

11.3. Any flywheel or similar kinetic energy storing device must not be spinning or storing energy in any way unless inside the arena or testing area.

11.3.1. There must be a way of generating and dissipating the energy from the device remotely under the robots power.

11.4. All springs, flywheels, and similar kinetic energy storing devices must fail to a safe position on loss of radio contact or power.

12. **Forbidden Weapons and Materials.** The following weapons and materials are absolutely forbidden from use:

12.1. Weapons designed to cause invisible damage to the other robot. This includes but is not limited to:

12.1.1. Electrical weapons

12.1.2. RF jamming equipment, etc.

12.1.3. EMF fields from permanent or electro-magnets that affect another robot's electronics.

12.1.4. Weapons or defenses that stop combat completely of both (or more) robots. This includes nets, tapes, strings, and other entanglement devices.

12.2. Weapons that require significant cleanup, or in some way damages the arena to require repair for further matches. This includes but is not limited to:

12.2.1. Liquid weapons. Additionally a bot may not have liquid that can spill out when the robot is superficially damaged.

12.2.2. Foams and liquefied gasses

12.2.3. Powders, sand, ball bearings and other dry chaff weapons

12.3. Un-tethered Projectiles (see tethered projectile description in Special Weapons section 13.1)

12.4. Heat and fire are forbidden as weapons. This includes, but is not limited to the following:

12.4.1. Heat or fire weapons not specifically allowed in the Special Weapons section

12.4.2. Flammable liquids or gases

12.4.3. Explosives or flammable solids such as: DOT Class C devices

Gunpowder / Cartridge Primers Military Explosives, etc.

12.5. Light and smoke based weapons that impair the viewing of robots by an Entrant, Judge, Official or Viewer. (You are allowed to physically engulf your opponent with your robot however.) This includes, but is not limited to the following:

12.5.1. Smoke weapons not specifically allowed in the Special Weapons section

12.5.2. Lights such as external lasers above 'class I' and bright strobe lights which may blind the opponent.

12.6. Hazardous or dangerous materials are forbidden from use anywhere on a robot where they may contact humans, or by way of the robot being damaged (within reason) contact humans.

13. Special Weapon descriptions allowed:

Tethered Projectiles are allowed, but must be no longer than 3 feet and my not entangle the opponent.