The Compass Alliance Pathways: Design

Before you begin learning about design, first make sure you're in the right place: this pathway is specifically for FRC *design*, while there is another pathway (CAD Pathway) that provides resources about software-specific *CAD.* If you are hoping to learn strategies for coming up with a successful robot, you're in the right place. If you want to learn specific software that might help with design, check out the other pathway.

Design is the starting place for every robot. Whether it's done in solidworks, a whiteboard, or the back of napkin, the process will always be the same. Mechanical design is an enormous topic, and it would be impossible to record every necessary aspect of it in a single place. Instead, this pathway is intended to give you a starting place for learning design in an FRC context.

Robot design is a tricky topic to teach. There is no science to coming up with the perfect mechanism - it takes a lot of experience, a good guess, and a lot of trial and error. This guide is designed to provide the resources that can *help* in this process: but it cannot tell you exactly how to design a winning robot. That is up to you and the creativity of your team.

For some other great overviews of FRC design, check out 1114's page: http://www.simbotics.org/resources/robot-design, and 3847's in depth presentation: http://design.spectrum3847.org/

Overview of pathway:

- Level 0 - initial robot planning. This is where you consider the goals of the robot, and begin the process of laying out the mechanisms. It is common to complete all these steps at the very beginning of build season.
- Level 1 - mechanism design. It provides a workflow that will help refine the process of moving from a mechanism idea to a functional product.
- Level 2 - advanced design topics. The topics included here are not meant to be necessary to design a basic robot.

Level 0: Initial Plan

In almost every case within FRC, the largest constraining factor on design is time. 6 weeks is never enough. For this same reason, the first couple steps of robot design are often the most important. If we had infinite time, we could come up with a list of every robot that *might* work, build them all, and test to see which works best. Instead, we have to pick one (with some room for iteration, of course). You will need to come up with an honest evaluation of your team's ability. If you attempt to take on too many challenges on the field, your robot will inevitably underperform in all of them. If you take on too few, you may not be reaching your maximum potential. Making this evaluation to determine what is *most likely* to be effective is not an easy task. The resources below will help you along these first steps:

- Game Strategy
    - The first, and arguably most important, things you will need to know about any design project are the goals. *What* should the robot do. Strategic design is a process that will help a team answer this question.
        - 1114 gives the following presentation on game analysis: http://www.simbotics.org/files/pdf/effective_first_strategies.pdf
        - The majority of FRC strategy is beyond the scope of this pathway. For more information, visit the strategy pathway: https://docs.wixstatic.com/ugd/c6b003_bd1e1ff44e9643398f6e96e5a6a281e0.pdf
- Strategic Design
    - After it is decided what your robot should do, the next question is how it should do it. Sometimes the answer is obvious, and little/no design discussion or prototyping is necessary. Other times there are multiple possible solutions, and you have to make a call on which is *most likely* to work.
    - The logical first step is grouping the required tasks into mechanisms. Sometimes one mechanism can solve several tasks, such as intaking and shooting, but often the added complexity of attempting to join mechanisms is not worth the gain.
    - Next comes brainstorming ideas for mechanisms. Often, the best starting place is looking for inspiration in previous people who have solved a similar problem before you:
        - Robot in 3 Days (RI3D) is a great resource for year-specific mechanisms, since they are playing the same game:
            - https://www.youtube.com/watch?v=IQXbA9EmmC4&list=PLpJRpRT0xvIh4RgO0zm9b6JvMHzuYMYTC
        - When it comes to common mechanisms - drivetrains, elevators, ball intake/shooters, etc - previous FRC teams have solved many of the hardest problems:
            - A collection of well-known, successful FRC robot models from previous years has been imported into OnShape. To access, search the phrase ‘TCA FRC’ into the public search bar.
            - 3847 keeps a well organized photo gallery of robot mechanisms: https://photos.spectrum3847.org/Robot-Mechanisms
            - Team 254’s technical binders contains great information: https://www.team254.com/blog/
            - As well as team 971’s page on robot design: http://frc971.org/content/team-documents

- Sometimes, the best inspiration is from a commercial product. Inspiration might come from airplanes, automobiles, buildings, or industrial robots.
  - Ex: Team 1678's 2018 buddy lift system was modeled after an airplane wing for strength and durability, while remaining incredibly light
- Some of the most effective designs combine simplicity, repeatability, and accuracy. 1678 strategic design presentation gives guidelines to help teams approach these designs:
  - http://www.citruscircuits.org/uploads/6/9/3/4/6934550/strategic_design.pdf
  - https://www.youtube.com/watch?v=SVacrE4sKig
- When discussing design as a large group with conflicting ideas, in can often be difficult to arrive at a single solution. Sometimes, this just takes enough time and logical arguments before everyone agrees. To help with this, creating a trade-off matrix of all the proposed design ideas can help define the pros/cons of every option, and illuminate a ideal solution. If the group is still unable to agree, your team will have two options: either leave the decision to the lead designer, or hold a popular vote.

- Overall Robot Layout
  - It is very easy with initial, conceptual design to lose touch from reality. Every robot has size constraints, and they need to be kept in mind throughout the entire design process. Drawing the robot to scale from the front, side, and top is an effective way to make sure your ideas are feasible in the real world.
  - In addition, it is easy to blow off the essential robot components such as electronics, battery, bumpers, etc during this initial design phase. It is important to make sure that every component/mechanism not only has space, but is also accessible for repairs if needed. This is the ideal time to nail down locations for important components and make sure nothing is going to interfere.
  - Often, using 3D design software is the most effective way to do this, since it is very easy to keep an accurate scale.
    - 973 provides a video on this topic: https://youtu.be/_XzdzE0L3HY

Level 1: Mechanism Design

At this point in the design process, you should have a concrete list of what the robot should do, a general idea of what the robot is going to look like, and a series of concepts for mechanisms that you believe are likely to work.

Although every mechanism is different, the following is a design workflow that will help streamline the process of designing a mechanism. The steps are not intended to be strict: some mechanisms will require no prototyping, some will never stop prototyping. However, the general flow is applicable to almost all situations.

- Prototyping
    - Prototyping is the first opportunity to test the concepts for mechanisms that you have created. The more you can get a prototype to fail, the more information you can collect, and the less failure you will experience later.
    - The key with prototyping is always the ability to iterate quickly. Spending your time fully developing the model is often not worth it. Instead, build using cheap construction materials such as wood and screws, and consider powering wheeled shooters with hand drills. To test robot movement, mount the prototype on a previous robot or an unpowered rolling chassis. Be sure to keep iteration in mind: adding a small amount of complexity in order to make the prototype easy to adjust is often worth it.
    - Unfortunately, the majority of prototyping and its techniques is beyond the scope of this pathway. However, for an overview of prototyping in FRC check out the video by Behind the Lines: https://www.youtube.com/watch?v=ToZ819hR2mQ
- Mechanism Details
    - Even after a functional prototype is built, it is frequently a challenge to take the lessons learned from the prototype and turn it into a robust, manufacturable mechanism. Every mechanism is different, so unfortunately there is no 'correct' way to do it that will always work.
    - Understanding common construction methods in FRC is a great starting place for this step. While not always applicable, they often point in the right direction:
        - In 90% of mechanisms, the frame can be made out of simple aluminum tube, gussets, and hex shafts. Aluminum tube, combined with a standard hole pattern such as placing holes every .5" along the tube, is light, strong, and easily expanded on.
        - In some cases, it's preferable to have a mechanism bend, as opposed to breaking. The most common case is with the intake that extends far outside the robot. It it likely going to get abused throughout the average match, and flexibility will ensure that it remains functional after a hard hit. For these applications, polycarbonate is usually the answer.
        - Finally, never overlook the simplest construction material: plywood. It is easy to work with, light, and often strong enough. In some applications, match-drilled plywood can sufficiently replace the entire process of modelling, pocketing, and machining that is often involved with aluminum.
        - For more examples of common construction, check out the robot library linked in the previous section
        - FRC COTS parts
            - The term COTS parts, or commercial off the shelf parts, is used in FRC to describe any purchased component on the robot. Having

knowledge of the most common fasteners, wheels, power transmission parts, and other construction materials will provide more options when deciding how to construct a mechanism.
        - VexPro, Automation Direct, and McMaster Carr have 3D models for the majority of the parts you will need. Becoming familiar with their available components can help you quickly arrive at the best solution for a problem:
            - https://www.vexrobotics.com/vexpro,
            - https://www.automationdirect.com/adc/Home/Home,
            - https://www.mcmaster.com/
- Power
    - Almost every mechanism is going to have some piece that moves. All of this movement has to come from one of four power sources: a battery, compressed air, a spring, or gravity. Converting the stored energy into the movement that you want can be one of the more challenging aspects of mechanism design.
    - For a basic overview of power transmission as a whole, check out 1678's presentation: https://docs.google.com/presentation/d/1FNW_4hSq6DLU12VpKY5lI2R4Y-ZLLslgObVoORkG5gc/edit?usp=sharing
    - For short, linear movements with 2 distinct positions, pneumatics are often the ideal solution. 1114's presentation gives a great guide: https://www.simbotics.org/files/pdf/pneumatics.pdf
    - When it comes to rotary motion, the challenge always lies in getting the rotation at the right speed. It often requires significant reductions to make it happen. Some teams choose to design their own gearboxes to achieve this goal. While custom gearboxes have their benefits, many teams spend a lot of time on them, time that could be spent on other, more important things. COTS gearboxes provide a great alternative. Some examples can be found at:
        - https://www.vexrobotics.com/vexpro/motion/gearboxes
        - For more info on custom gearboxes, check out level 2 of this pathway.
    - Lastly, there are several options available when it comes to spring power. Standard coiled springs can provide force in compression or tension. They can also be used in combination with pneumatics, if installed around the shaft, in order to provide extra force in one direction. Surgical tubing only provides force in tension, but it is easy to work with and can be combined with cables and pulleys to 'reroute' a spring force. This can help if you need a large force but are constrained with space. Lastly, gas shocks are available at incredibly high forces. Since they are sealed off, they are not limited by the 60 psi working pressure rule, so

they can reach the hundreds of pounds of force range easily, while taking up a relatively small space.

- Sensors
  - Understanding what sensors are, how they work, or how to use them for control is a bit out of the scope of this pathway. However, there are a few key design notes when it comes to sensors that are worth mentioning.
  - The most common kind of sensor is the encoder, for measuring changes in angular position. Wherever possible, it is best to place encoders on shafts that spin as fast as possible - in other words, shafts that haven't had a significant reduction from the motor. This way, they will experience a higher resolution.
    - When it comes to mounting encoders, the ideal method depends on the type of encoder. For optical encoders, the encoder will physically interface with the shaft, and therefore will constrain itself to be concentric. The only job of the mount is to prevent rotation. Therefore, your mount should be flexible, and not overconstrain it and introduce the possibility of snapping the shaft. A good example is the polycarb z-bends used frequently by team 971 (see OnShape robot collection for model)
    - For magnetic encoders, the encoder will not interface with the shaft, and therefore has to be fully constrained elsewhere to ensure a constant distance from the magnet. There should be at least two points of contact for the mount to be sure there is no flexing in the encoder.
  - With all kinds of sensors, make sure the sensor is easily accessible if something goes wrong or you need to swap a sensor out.

- Iteration
  - The third, and by far most important step in mechanism design is iteration. A mechanism is *never* done. Even after it works, there are always things that could be improved on it. The design process constantly repeats itself. After testing the mechanism, identify areas of improvement, develop more concepts for how to solve the challenges, and start the process again from the beginning.

Level 2: Additional Design Tools

- Design calculations / custom gearboxes
  - The ability to design custom gearboxes opens up huge opportunities for mechanisms within a team. You can pick specific ratios, or optimize its strength, weight, size, and efficiency. That being said, they are by no means necessary: COTS gearboxes are often sufficient, and spending the resources needed to develop a custom gearbox can sometimes take time away from other goals.

- The first and most important resource will always be JVN's calculator, found here:
  - https://www.chiefdelphi.com/media/papers/3188
- All the critical motor information for gearbox design can be found at
  - http://motors.vex.com/
- 973's videos on google spreadsheets, motor curves, and motor selection can help you understand and apply the previous two links. In addition, he touches on gearbox sketching itself in his West Coast Drive videos
  - https://www.greybots.com/videos.html.

- 3D printing
  - 3D printing within FRC has only recently become viable for most applications. Every printer is different, and it's critical to know it's limits and what it can achieve. When done right, a 3D print can be a quick, lightweight, and effective solution to a challenging mechanical problem.
  - The Markforged blog provides a lot of great printing information, regardless what printer you have:
    - https://markforged.com/blog/
    - Some additional notable links:
      - Design for 3D printing part 1, unit test: https://markforged.com/blog/3d-printed-unit-tests/
      - Design for 3D printing part 2, warping: https://markforged.com/blog/3d-printed-part-warping/
      - Design for 3D printing part 3, print time: https://markforged.com/blog/design-for-3d-printing-part-3-decreasing-print-time/
      - Embedded fasteners: https://markforged.com/blog/embedding-nuts-3d-printing/
  - 3D Hubs is another great source of printing information. Particularly, the 6th step provides an overview of some notable tricks with printed parts and common printed design features:
    - https://www.3dhubs.com/knowledge-base/enclosure-design-3d-printing-step-step-guide
- Design for controllability
  - As your team progresses toward solving more complicated software problems, it becomes necessary to be more precise in your mechanisms to allow better control. Travis Schuh provides an excellent presentation on design for controllability, found here:
    - http://frc971.org/testing/workshops_download.html#

Appendix A - Revision History

Revision #	Revision Date	Revision Notes
1.0	Sept. 2018	Initial Release