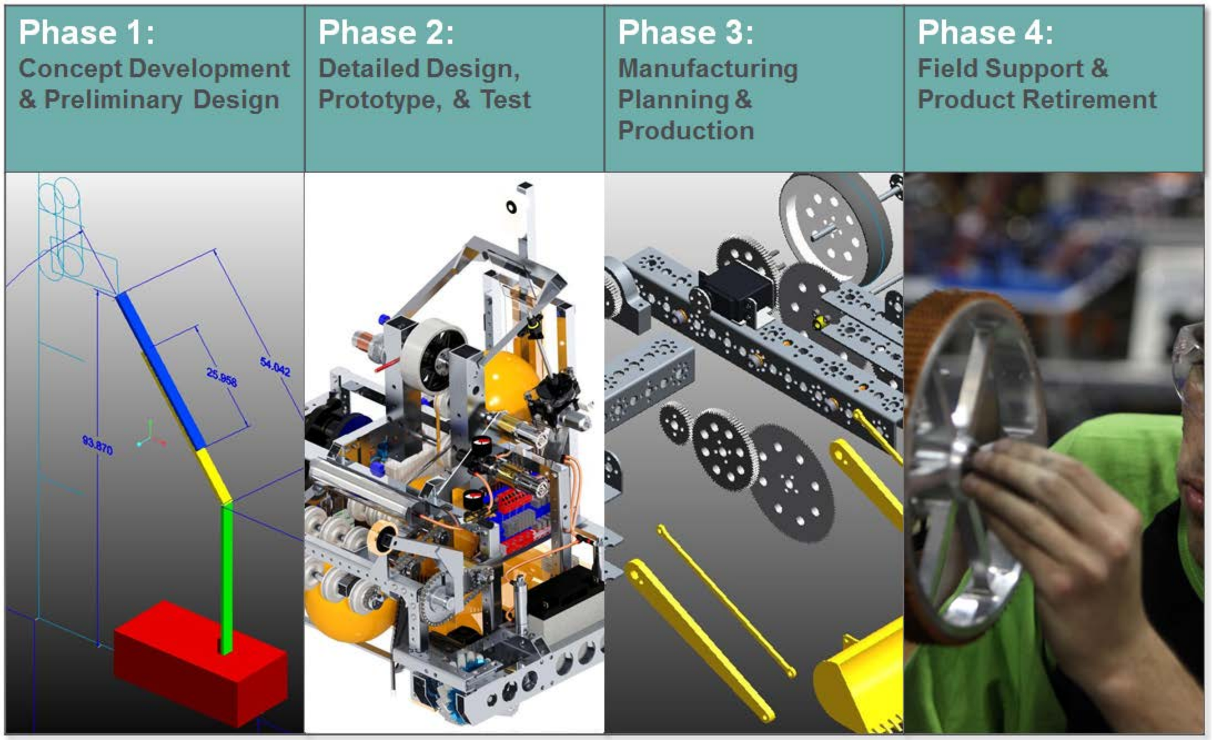
PTC® | ACADEMIC PROGRAM



FIRST®

Robotics Curriculum

The Product Development Process

Written by Jordan Cox

Acknowledgements

Tim Brotherhood, Christopher Hartmann, and Scott Morris

Introduction

What products do you use every day? There are cars, airplanes, toothbrushes, computers, palm devices, pliers, refrigerators, televisions, bookcases, and many more products that you use every day. Have you ever stopped to think about how these products came to be? How did the ideas for a product get transformed into the actual product? Is it easy to create a new product? Is there a process for transforming your creative ideas into useful products? The answer is "YES, there is a process for transforming creative ideas into products. It is called: THE PRODUCT DEVELOPMENT PROCESS".

Many companies engage in the product development process to create useful products. This curriculum has been designed using these companies' expertise to give you a working knowledge of how to follow the product development process in designing and building useful products like robots. It is designed to explain the "whys" and some of the "hows". The curriculum introduces the product development process in four parts that match the four phases of the product development process. Exercises and explanations are provided for the major activities of each phase.

Table of Contents

The Product Development Process

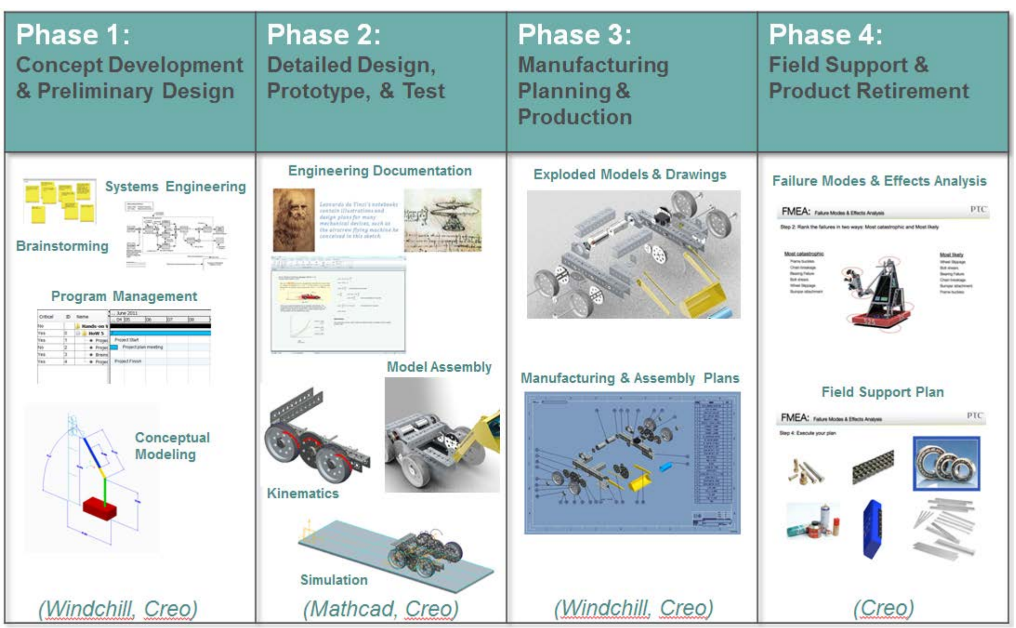
Objective: To introduce you to what the product development process is and why it is important in the development of a new product.

What is the Product Development Process?

Throughout history, people have created new things to help improve their lives, like the wagon for moving things or the plow for cultivating fields. As the things have become more sophisticated, it has required more planning and careful management of the creative activities to accomplish the design of these things. Take for example the development of the airplane by Wilbur and Orville Wright. They were not able to build the airplane in a single day with wood and canvas. It required that they carefully plan, prototype, test, manufacture, and reinvent over a long period of time.

This careful planning and reinvention process has become formalized into what is called: "The Product Development Process." People and organizations like businesses have learned that by formalizing this process and then managing their organizations so that they follow this process, they are more successful in creating new sophisticated things that dramatically improve people's lives. The commercial airplane industry is a great example where the careful management of the product development process has created very sophisticated things that allow people to travel throughout the world in a fraction of the time it used to take. Most businesses have their own version of the formal product development process that best suits their creative activities.

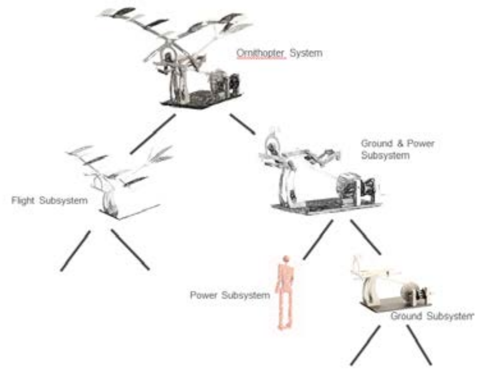
The FIRST Robotics program provides students with the opportunity to experience the creative process. The product development process can be formulated to address the needs of this program as follows:



Phase 1: Concept Development & Preliminary Design

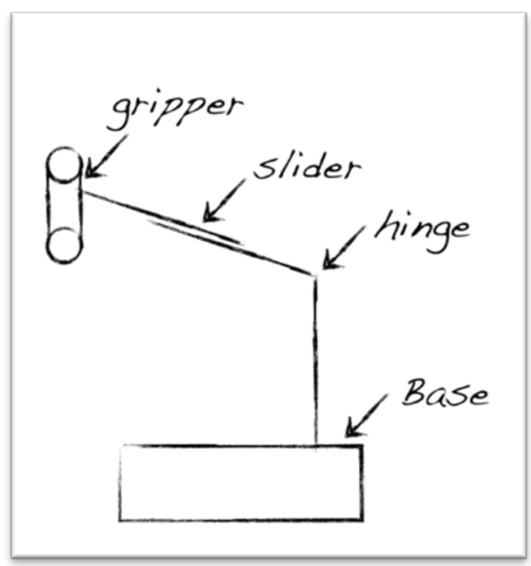
The purpose of this phase is to generate as many creative ideas and concepts as possible and then to study them for feasibility before choosing the candidate concepts that will be developed into detailed designs. In this part of the curriculum, three specific activities are presented for this phase. They are as follows:

1. **Systems Engineering** (Develop a conceptual idea of the parts and function of the proposed product)



2. **Brainstorming** (Learn how to conduct a formal brainstorming session and how to use these sessions throughout the product development process)

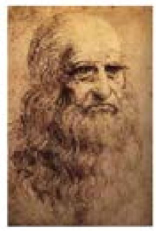
3. **Conceptual Design** (Learn how to create conceptual models to study feasibility and plausibility before selecting the candidate concepts)



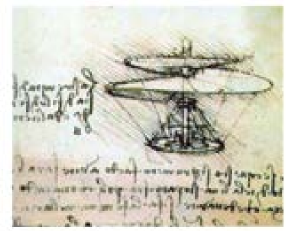
Phase 2: Detailed Design, Prototype & Test

The purpose of this phase is to develop detailed designs of the candidate concepts to determine how to deliver them as working products. A very important part of these activities is the documentation of decisions, assumptions, and calculations in an engineering notebook. The other activities associated with design involve creating models of the proposed design and testing them to make sure they work as intended. This phase involves many activities. In this workshop, there are three activities that will be presented. They are as follows:

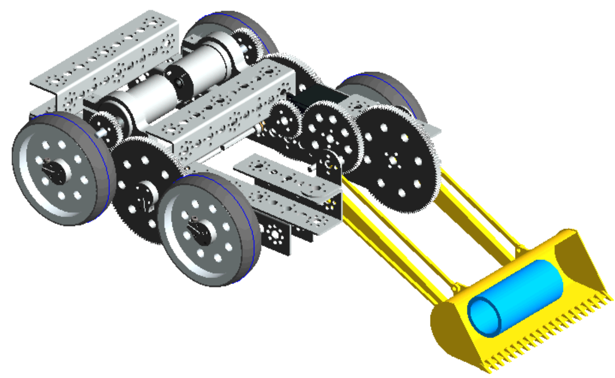
1. **Engineering Documentation & Calculations** (Learn how to create an effective engineering notebook and how to use engineering computer tools to do it.)



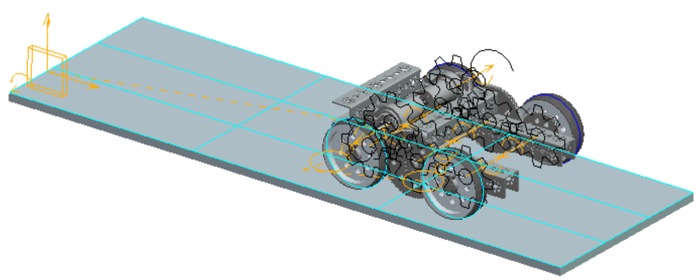
Leonardo da Vinci's notebooks contain illustrations and design plans for many mechanical devices, such as the airscrew flying machine he conceived in this sketch.



2. **3D-Assemly** Assembling a working model of the design (Create a 3D Computer-Aided Design model that functions and moves as the product will once its produced)



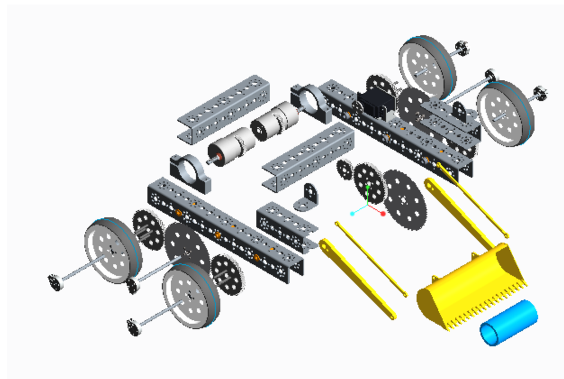
3. **Simulation** (Create simulations that validate the design using the 3D CAD model prototype)



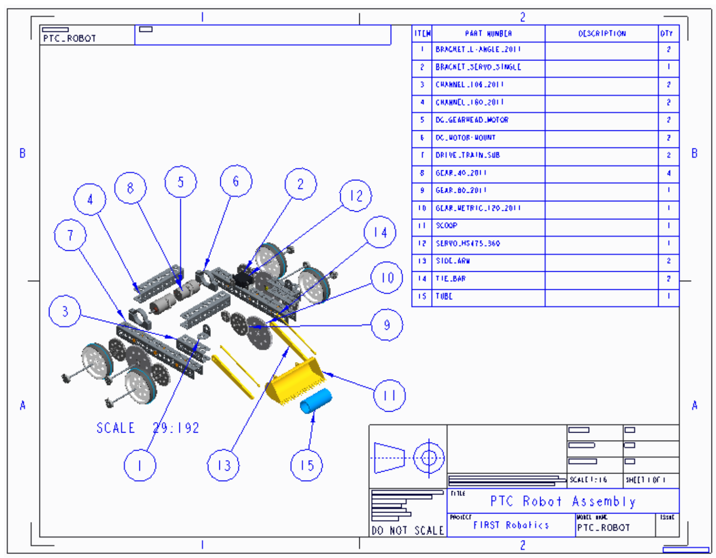
Phase 3: Manufacturing Planning & Production

The purpose of this phase is to prepare plans for manufacturing and assembling the product as well as any plans to produce the product in large quantities. Since the *FIRST* Robotics competition relies on a single product, the activities in this phase are focused on preparing a plan for assembly and manufacture. The exercises and activities include:

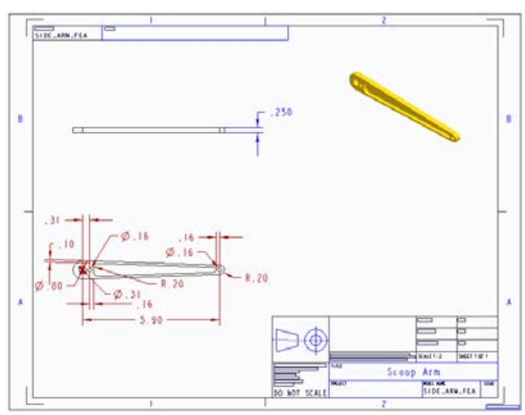
1. **Exploded Models** (Create an exploded version of the 3D model of the design to show all the parts and how they assemble together)



2. **Exploded drawings and bill of materials** (Create an exploded drawing with a bill of materials and assembly instructions)



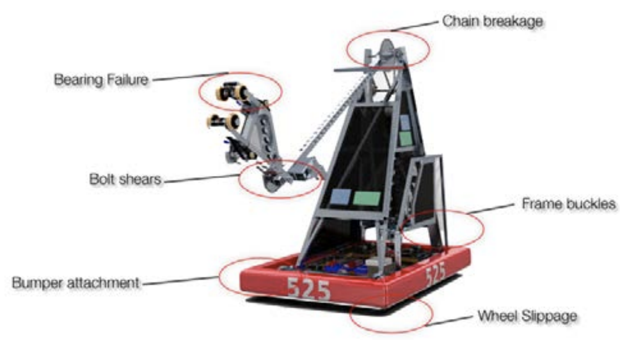
3. **Part Drawings** (Create a drawing for a custom part that must be manufactured)



Phase 4: Field Support & Product Retirement

The purpose of this phase is to anticipate possible problems that might affect the performance of the product in the field and then prepare a plan to support the product while it is operating in the field. This can involve warranties, replacement parts, etc. For the *FIRST* Robotics program, the most important part of this phase is to prepare a field support plan for supporting the robot in competition. The final aspect of this phase is to plan for the retirement of the product in an environmentally sound manner. The activities and exercises in this part of the workshop include:

1. **Failure Modes and Effects Analysis** (Analyze the product for possible methods of failure in the field and determine how likely they are to happen and how significant they would be)



2. **Field Support Plan** (Create a field support plan)

3. **Product Retirement** (Create a plan for an environmentally sound product retirement)

Getting Started – Team Organization

One of the most important aspects of being successful in the product development process is to create a well-organized team with clear roles and responsibilities. This team then can prepare a business plan for the operation of the company, robotics team, or organization as well as a project plan for this season's competition or a product creation project.

The team organization should consist of several key roles:

1. **Coach**
2. **Mentors**
3. **Members**
4. **Program Manager**
5. **Public Relations Manager**
6. **Chief Engineer**

Responsibilities	**Role**
I am responsible for the technical aspects of the product development project. I make sure that team members follow best practices in designing and documenting the product.	
I am responsible for the business plan and the general operations of the team.	
I am responsible for all the communications with stakeholders and managing all the strategic relationships with people outside the team.	
I am responsible for defining the project plan and making sure that every team member sticks to the schedule.	
I am responsible to know the project plan and business plan and to actively participate in all activities and assignments that will make the team successful.	
I am responsible for guiding the team and reviewing the project plan and product design to ensure that the team is successful.	

Business Plan – (Coach and team members)

It is important to create and maintain an effective business plan for your team or organization. The business plan defines the goals and objectives of the team and the basic operating rules and guidelines that the team will follow. It is a plan that is broader than just one season.

Typically, the entire team creates the plan but it is the responsibility of the coach since the coach remains a part of the team for more than one season and is responsible for the existence and continuance of the team. However, every member of the team should be familiar with the plan.

Here is an outline to help you get started building a business plan:

Sample Business Plan Outline

1. Cover sheet
2. Executive summary (statement of the business purpose)
3. Table of contents
4. Body of the document
    - A. Business
        1. Description of business
        2. Marketing
        3. Competition
        4. Operating procedures & team rules
        5. Personnel (Key Officers)
    - B. Financial data
        1. Capital equipment and supply list
        2. Budget Balance sheet
        3. Three-year summary Budget
        4. Detail by quarters, Academic Year
        5. Detail by month, *FIRST* Season
    - C. Supporting documents
        1. Copy of team charter or application
        2. Copy of agreement for building space (meeting space)
        3. Copies of letters of intent from suppliers and sponsors.

For more information see:

http://www.sba.gov/content/templates-writing-business-plan

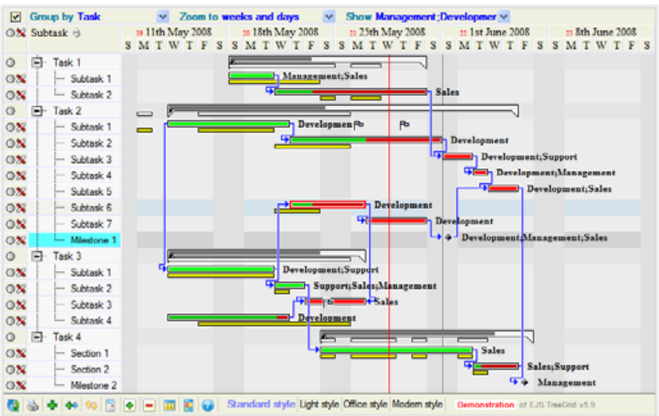
Program Management – (Program Manager)

Each season, the FRC or FTC launch introduces your team to a new game. Afterward, your team races against a tight schedule to design and build a robot to compete in that year's game. Many goals must be accomplished in order for your *FIRST* team to be successful.

This requires a successful **PROJECT PLAN**.

There are two types of project plans that your team can choose to implement:

<u>Type 1: Structured</u>



The first type of project plan involves detailed tasks and program phases with defined due dates, responsibilities, and project milestones. Every part of the project is defined and everyone knows who is responsible. Nothing is left to chance.

<u>Type 2: Flexible</u>

Milestones

Task 1

Task 2

…

The second type of project plan involves creating general milestones and then activity lists indicating who is working on what between the milestones. The plan is loose because nobody knows exactly what technology will be used and therefore what tasks will need to be done and when those tasks will need to be accomplished.

Using Windchill to manage your Project Plan and your Data and Documents

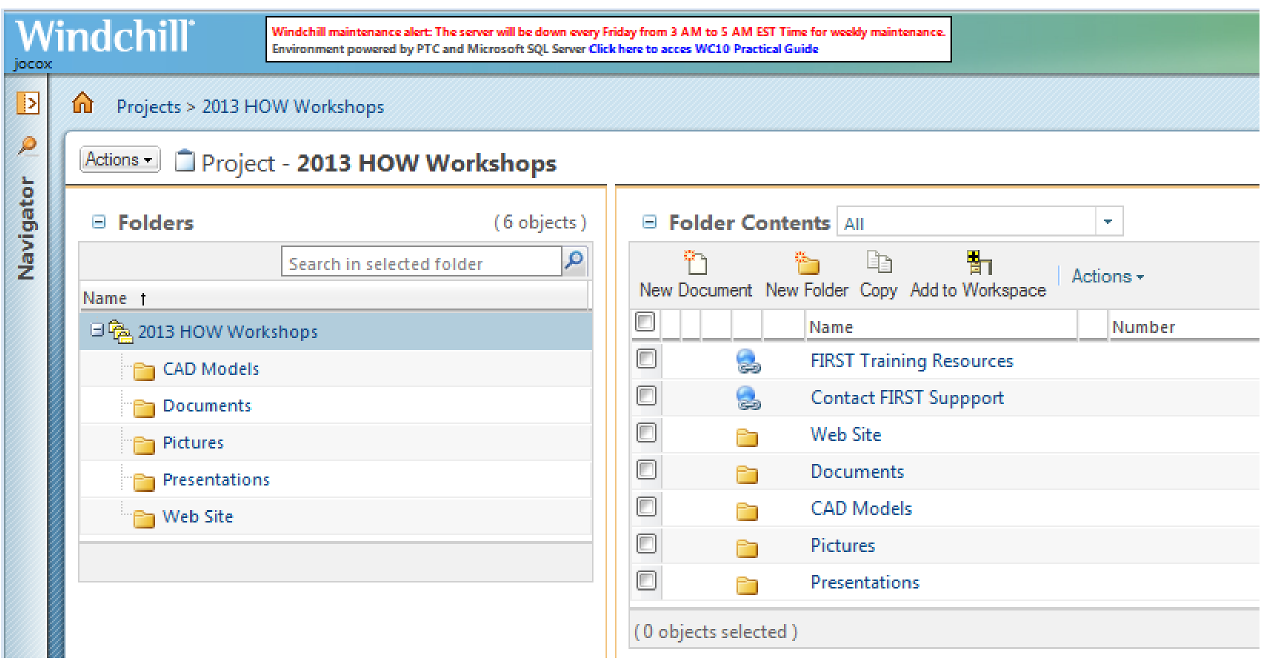
Windchill is a **Product Lifecycle Management (PLM)** tool used by engineering companies to manage their product development processes from start to finish. It has many capabilities beyond what you will need for your *FIRST* robotics team projects. However, it can be used to manage a task-list project plan and provide cloud-based storage capabilities for your team's design data and project documents.

Windchill opens up to the “Folders” portion of your project. This is where all your data and documents are stored. You can create folders and manage the content in much the same way you manage folders and data on your computer.

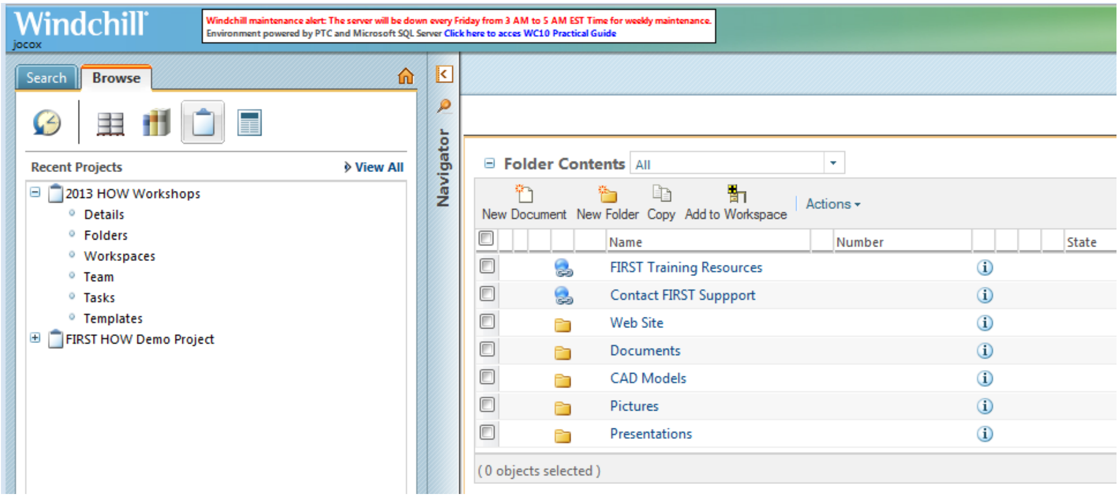
There is a subtle difference that is important. Windchill keeps track of all the data you “Check-in” to your folders. This means that Windchill automatically assigns version numbers to the documents you check-in. If you revise a document and check it in, a new version number will be added to the document rather than deleting the former version of the document. This means Windchill maintains a history of all the documents you store in Windchill. This can be very helpful for managing software, CAD models, etc.

To upload a document, simply click on **New Document**, fill out the dialog box, including browsing for the file you want to upload, and then clicking **Finish**. The file will be uploaded into Windchill. If you want to check a document out from Windchill, simply click on the **Actions** pull-down menu and select **Check Out and Download**. This will check out the document to you and allow you to download the document. When you have made your changes and are ready to check the document back in, use the **Actions** pull-down menu again and select **Check in Document**. It will ask you to browse to the file and then it will add the file to the vault, not overwriting the previous document but creating a new version.

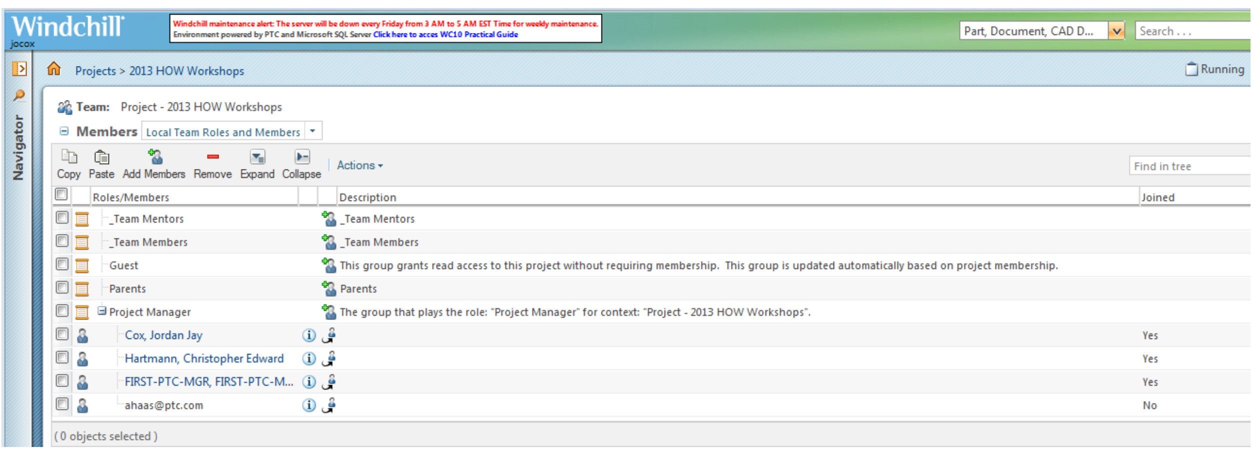
Notice that there are also two links in the folders; one for *FIRST* Training Resources which is a link to a PTC library project that contains materials helpful for training. The second link allows you to contact *FIRST* support when you have questions.



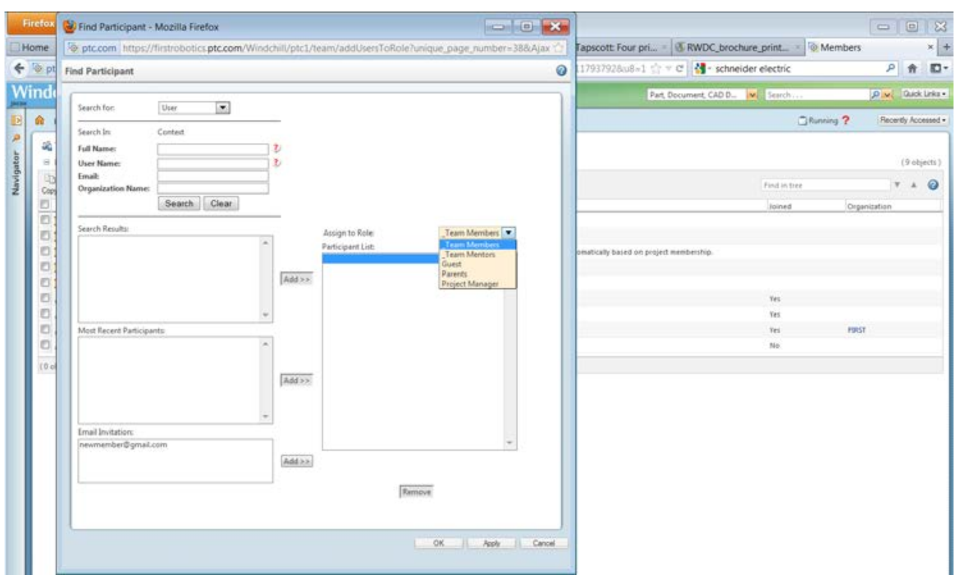
Clicking on the **Navigator** bar on the left allows you to toggle to the other contents of your project.



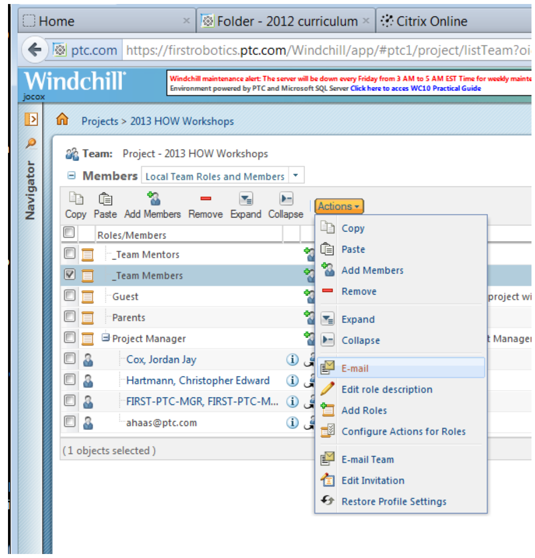
The first area in your project you should become familiar with is the **Team** link. It allows you to create your team and maintain communications with all the members of the team. There is a tool to add members and actions like emailing to groups within the team.



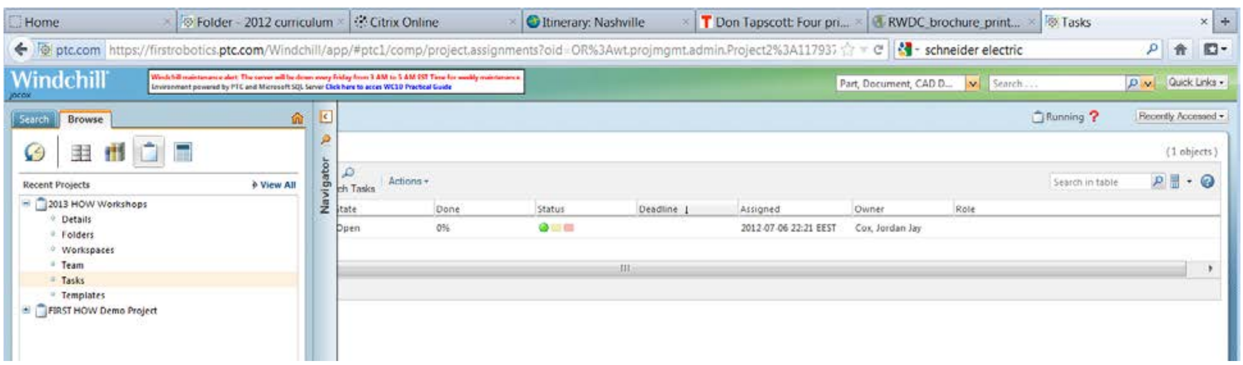
Adding a new member to the team is simple. Click on the **Add Members** button and then type the new member's email address (the one they used to create their PTC account), click **Add**, select the role and then click **OK**.



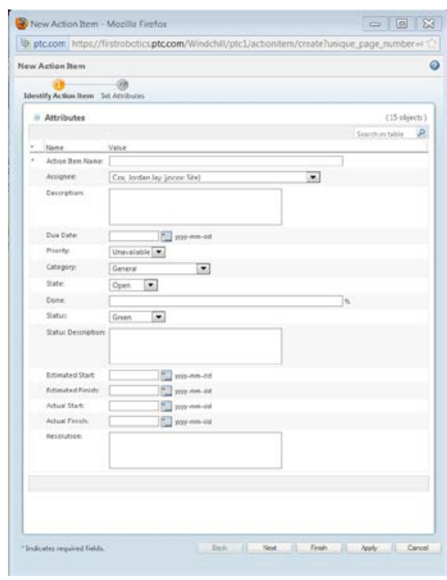
If you want to email a group within the team, simply select the group by checking the box in front of the group name and then select **Actions** and **Email**.



Now go back to the **Navigator** bar and toggle it to see the elements of your project, and then select **Tasks**. This is where you can manage your project one task at a time.



You will see a list of tasks. To create a task click on **Actions** and then select **New Action Item**. A dialog box will appear that will allow you to specify enough information to create a task. To assign an owner of the task, simply use the pull-down menu to select a member of your team.



This task management area in your Windchill project will allow you to keep track of the tasks that each member of you team is working on from week to week. You can simply open your project at each of your team meetings and check on the status of each of the tasks.

Public Relations – (PR Manager)

What is Public Relations?

Public Relations (PR) is a strategic communication process that uses communication skills and technology to foster relationships that are conducive to the success of your *FIRST* team.

An FRC Team with poor PR

FRC team #543210 was established three years ago. The team successfully recruited 6 sponsors: four Fortune 500 Companies and two local food service providers. The team ran smoothly the first two years, but during the third season organizational difficulties led to poor planning and follow through on many important tasks.

The first visible sign of difficulty was that students stopped showing up to the team's weekly meetings. In addition, the students who did show up did not seem interested in getting help from their mentors (application engineers from a nearby corporate sponsor). Feeling slighted, the mentors stopped showing up regularly at team meetings.

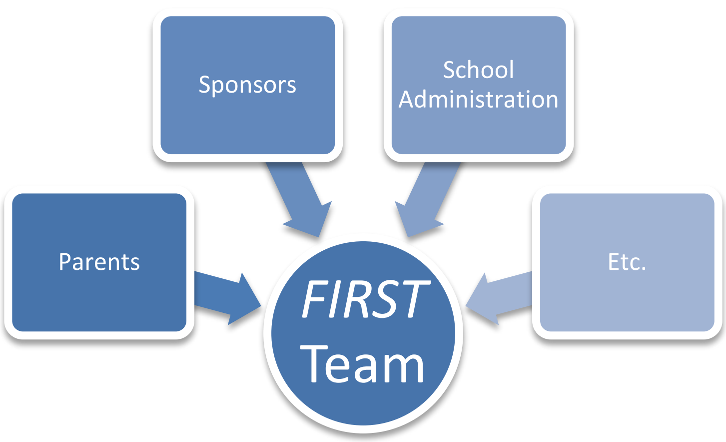
As the team continued to struggle, communications with team sponsors was overlooked. When the team's largest corporate sponsor didn't hear from the team, they decided to allocate the grant money to another team who had submitted an informative proposal and invited the company's philanthropic program manager to come for a tour of the team's shop. Lacking adequate sponsorship money, the team couldn't travel to regional events or even purchase new t-shirts for the season. Even the most devoted members of the team began to get frustrated.

Finally, the school's principal, sensing an unhealthy climate in the shop and finding herself unable to contact a student leader to get an explain of the situation, informed the students that they would need to reapply for space in the school for the following season.

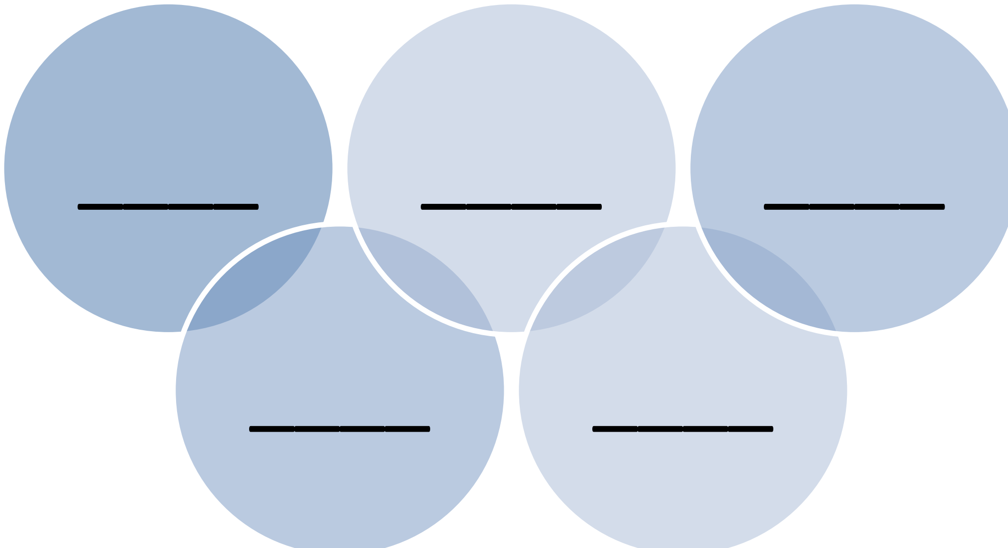
Don't Let this Happen to You!

Take a Systems Perspective

Public Relations is a System connecting *FIRST* Teams to other groups in their community



Activity 1: Who are the stakeholders for your team?

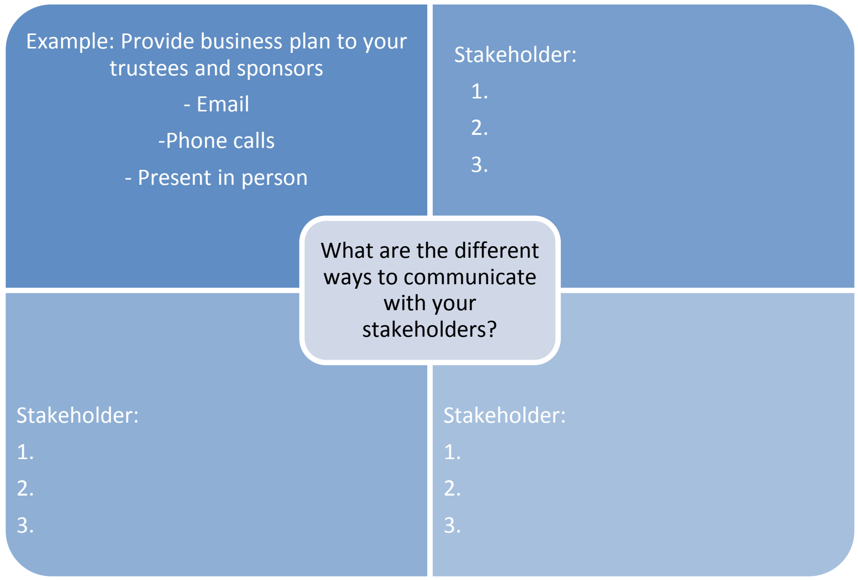


Activity 2: List all the methods of communicating that could be used in interacting with stake holders:

Methods

- Phone
- Email

Activity 3: For each of the stakeholders you listed above, identify the strategies that would be the most appropriate for communicating with the stakeholders at appropriate stages of the *FIRST* season.



Activity 4: How will your team ensure that the strategies above are put into place?

(Select a PR Manager and Create a Public Relations Plan)

What do you expect to gain from implementing these strategies?

Summary & Conclusion

This overview has presented the four phases of the product development process and the exercises and activities that will introduce this process during the workshop. It has also discussed the necessary activities for organizing your team for the robotics season.

Congratulations! You are ready to start the first phase of the product development process.

Phase 1: Concept Development & Preliminary Design

Introduction

The primary purpose for Phase 1 of the product development process is to generate the ideas, concepts and preliminary designs that will be turned into the final product. It is also the time to define the project goals, schedule, and criteria for completion. This part of the workshop will focus on several exercises to help you as a team to understand and become proficient in the necessary skills required to be successful in this phase.

Systems Engineering

A system is a group of interacting, interrelated, or interdependent elements that forms a complex whole. You are familiar with many types of systems. The **solar system** is a group of planetary bodies that are interrelated by their mutual gravitational attractions. The **human body** is a group of interdependent organs that function as a whole. An **automobile** is made up of many interrelated subsystems to accomplish the goal of protecting, entertaining, and ultimately transporting you where you want to go. Even a **robot arm** is made up of subsystems that work together to accomplish the overall goal.

A different definition of a system is an assembly of things arranged in a way that conforms to a plan. Under this definition a system doesn't exist until a plan is created that brings all the elements together in ways that accomplish a predefined goal. Creating the plan for a system is called system design and it is done by system engineers.

System Design

System Design is the process of defining the architecture, components, modules, interfaces, and data for a system in order to satisfy specified requirements. *So how do you design a system?* There are several steps for creating the plan or design of a system. These steps involve writing a system definition, drawing a schematic identifying each of the subsystems and the other subsystems that they will interact with, writing system and subsystem requirements, etc.

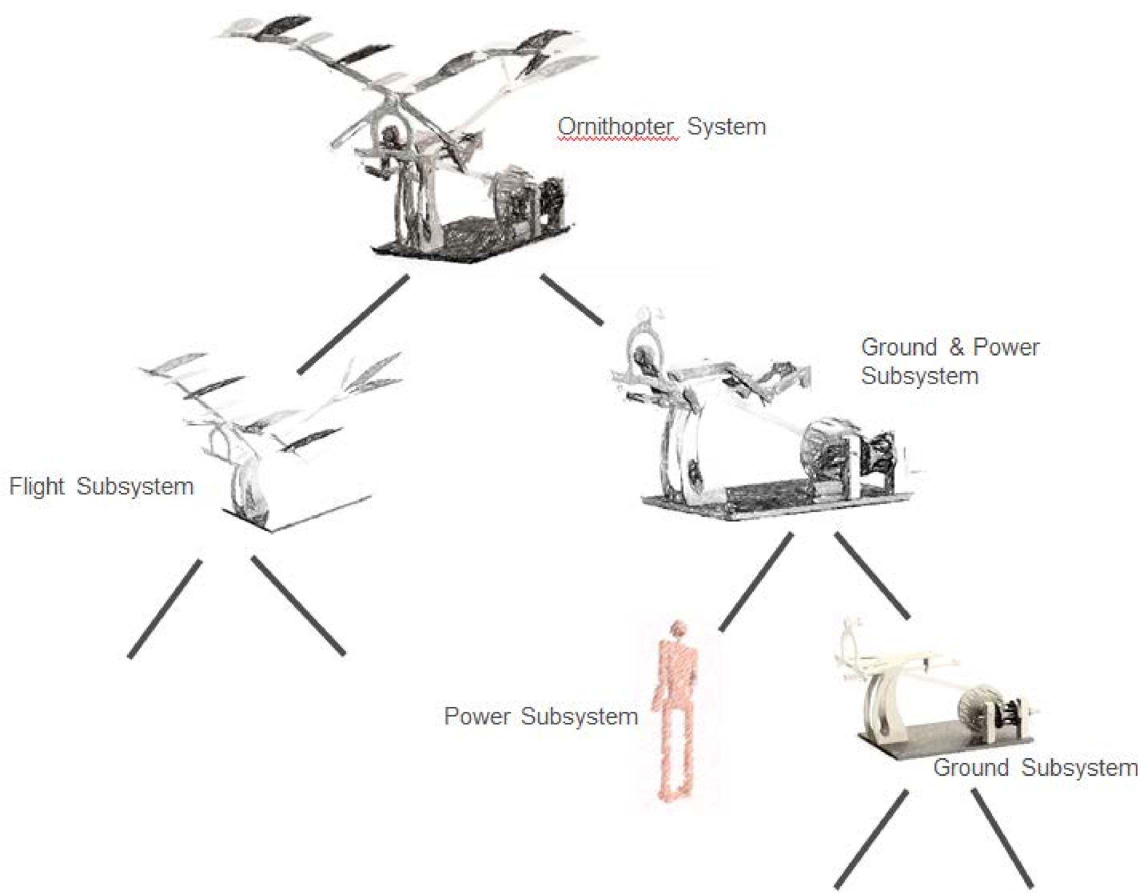
Systems engineers have developed many tools and languages to help accomplish these steps. In this workshop you will become familiar with several of them. Designing a system can be difficult. Oftentimes the desired system doesn't usually exist. This makes the processes of subsystem decomposition and requirements definition tricky. The tools and languages provide a structure for imagining and defining all the aspects of the system before it ever exists. There are three different representational languages that will be covered in this workshop: **Tree Diagrams**, **Zachman Diagrams**, and **Use Case Diagrams**. These languages are used by engineers today as they design systems in a product development process.

Systems Design Exercise 1

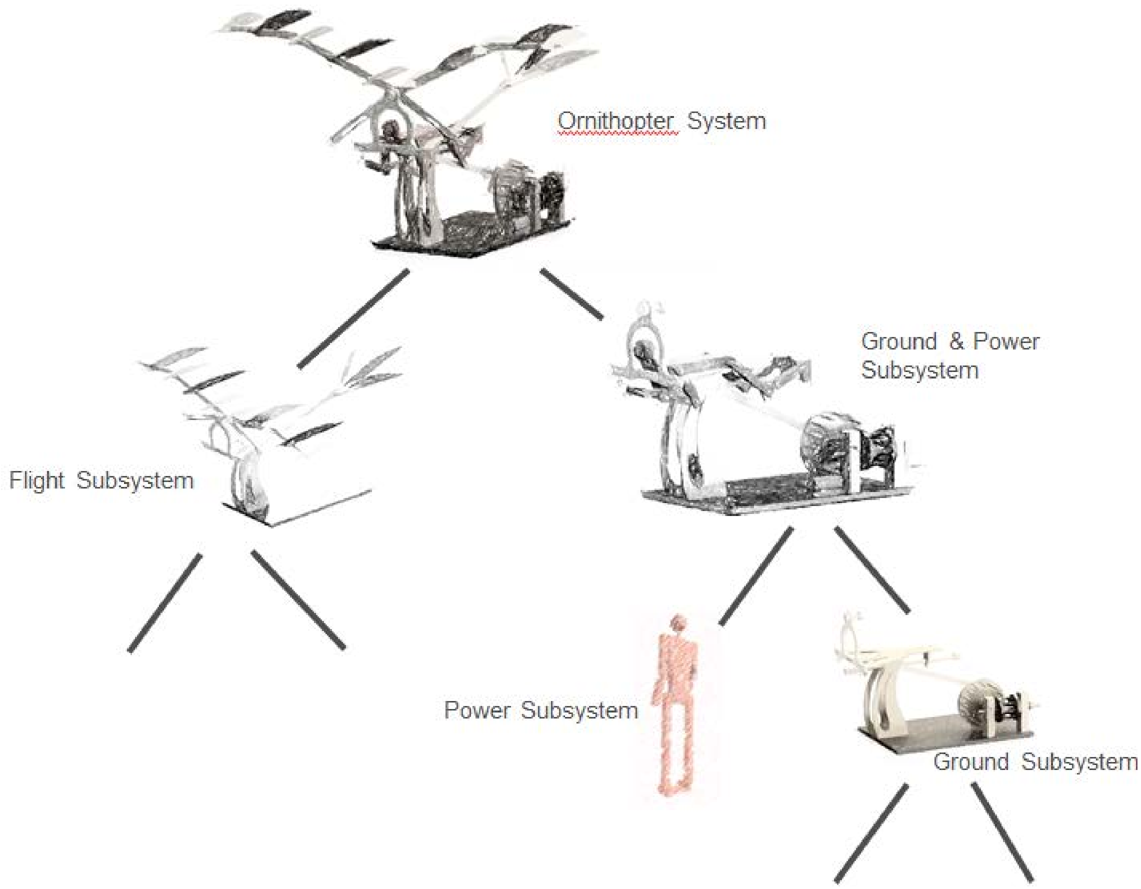
Systems design is exciting. It requires creativity and thoughtful decision making because there is no one-way to do it. This exercise will familiarize you with decomposing a system. We will decompose a model of the Da Vinci Ornithopter into its subsystems.

Objectives: To understand how to visually represent a system decomposition. To better understand the purpose for decomposing systems into their subsystems.

1. Here is the Da Vinci Ornithopter System broken into three subsystems: Ground Subsystem, Ground & Power Subsystem, and Flight Subsystem.



2. On the next page continue the tree diagram showing these three subsystems and further decomposing the Ornithopter System into subsystems.


Ornithopter System
Ground & Power
Subsystem
Flight Subsystem
Power Subsystem
Ground Subsystem

Systems Design Exercise 2

1. There are several different visual representation languages that engineers use to design systems. In this exercise, you will get a chance to represent your robot system using a Zachman Framework Diagram (ZFD).

The basic idea behind the Zachman Framework is that a complex system can be differently depending on the perspective that is taken. The Zachman Diagram contains thirty-six discrete categories for describing objects and systems comprehensively. Complex systems like an automatic dishwasher, a school building, or your FIRST team can be characterized in detail using this diagram. The goal is to identify all of the information necessary to construct a holistic view of the system.[1]

2. Complete the ZFD below by specifying the why, how, what, where, when of the Ornithopter as a System

Ornithopter	*Why*	*How*	*What*	*Who*	*Where*	*When*
Customers	*Entertainment*	*Working historical model*	*Da Vinci Ornithopter*		*Table top*	*Daylight hours*
Company mgmt.		*High Margins*	*Cheap wood product*		*Global Sales*	*Christmas*
Manufacturing	*Cheap*		*Simple wood cut parts*		*Asia/pacific*	*Fall*
Sales	*Holiday sales*		*Historical working models*	*Youth and adult males*		*Holiday*
Field Support/ Warranty	*Customer satisfaction*	*Spare parts*		*failures*	*Regional centers*	*Within 30 days*

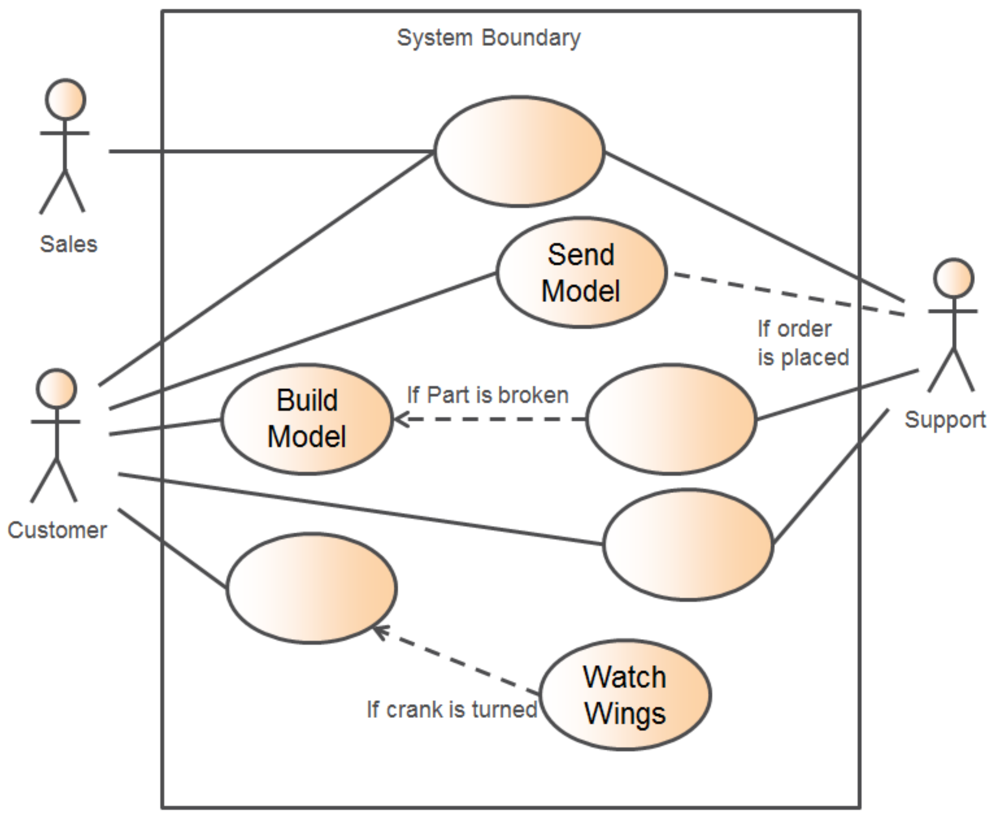
[1] For more information see Systems Engineering, Wikipedia 2011: http://en.wikipedia.org/wiki/Systems_engineering

Systems Design Exercise 3

Objective: To employ a Use Case Diagram to further refine the definition of a system so that the relationships between the individual functions and behaviors within the system are identified.

1. Complete the Use Case Diagram for the Da Vinci Ornithopter by identifying all of the actions that must be completed during the process of buying and selling the Ornithopter Model.

A Use Case Diagram represents the behaviors within a system as well as the relationships between the agents. The purpose of a Use Case Analysis is to present a graphical overview of the actors, their goals (represented as use cases), and the dependencies between use cases. This diagram will be helpful in depicting all the roles that your system must perform. It can also depict the interaction between external people and the system.[2]



[2] For more information see Systems Engineering, Wikipedia: http://en.wikipedia.org/wiki/Systems_engineering

Brainstorming

Brainstorming is a fundamental skill that is used throughout the product development process. This exercise will review good brainstorming practices and offer suggestions for maximizing your brainstorming sessions.

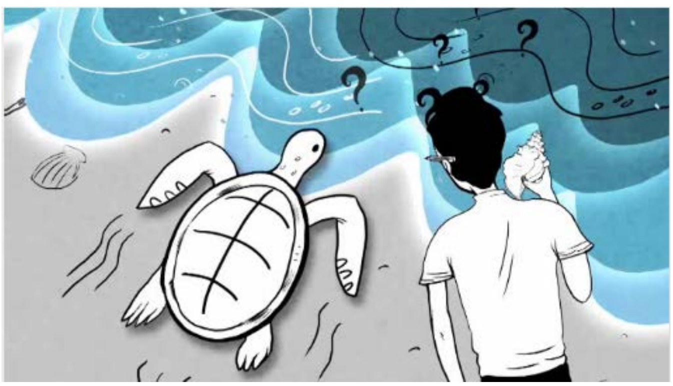
There are three parts in a good brainstorming session:

Part 1: Establishing the Problem

Part 2: Generating Ideas

Part 3: Selecting Candidate Solutions

What if…



Part 1: Establishing the Problem

Select one person to read or describe the problem, game, or competition. Discuss as a group until everyone understands each aspect of the problem. The better the problem is defined the more effective the brainstorming will be.

Part 2: Generating Ideas

Establish a set of rules that will be followed during this part. Here is a set of rules to follow for today's exercise:

1. No idea is a bad idea -- identify as many candidate solutions as possible
2. Respect the feelings of others –- practice gracious professionalism
3. Be creative, take risks when offering ideas
4. No criticism, judgment, or evaluation

5. Avoid dismissive comments

It will never work

We tried that before

We can't afford that

That's a crazy idea

There you go again

6. Avoid self-censorship; crazy ideas may lead to great solutions.

Once the rules are agreed to select a **facilitator**. The facilitator should provide everyone in the group with a set of sticky notes. Once the notes are distributed each individual should start writing ideas on sticky notes (1 idea per note) and calling out each idea after it is written down (e.g., "Design the phone to have a protective shell"). The facilitator should collect the notes and display them on a common whiteboard. Continue idea generation until the supply of potential ideas is exhausted.

Part 3: Selecting Candidate Solutions

Group the ideas into general categories and then carefully consider the ideas and down select to one or two that have the greatest potential for success. Start by gathering the group together at the whiteboard and classify the ideas into common groups. Usually there will be 3-4 groups that the ideas fall under.

Once this is done, give everyone a colored sticker and let each one vote for one solution by placing the sticker on the sticky note containing the idea. Once the voting is completed, the top two candidates can be selected as the concepts to take into preliminary design. These concepts now must be modeled to determine whether they will work and what the specifics of their designs will be. Problem statements for example Brainstorming Problems follow. These example problems can be used for the brainstorming exercises.

Brainstorming Exercise 1

Objective: To practice brainstorming with a business case study involving aircraft brakes.

1. Conduct a brainstorming exercise with your group.
2. Choose a spokesperson to read the problem statement

Problem Statement

Discount Airlines is experiencing problems with their aircraft brakes. The brakes heat up during landing. Since the plane makes frequent stops, the brakes are used a lot, which causes a residual heat to build up in the plane. When it is too hot the plane is grounded so the brakes can cool. This cooling period limits the flying time and turnaround of the plane. The problem is costing millions of dollars in delayed and cancelled flights. Your company has been contracted to fix the problem. The current braking system consists of a set of disk brakes that fit inside the wheels as shown in the pictures.

3. Conduct the brainstorming portion of the exercise. Make sure to remind everyone of the rules for this part of the session
4. Refine the concepts into groups and then ask each member of the group to vote for one of the concepts. Once completed identify which concepts were selected.

Brainstorming Exercise 2

Objective: To practice brainstorming with a business case study involving a Bradley fighting vehicle.

1. Conduct a brainstorming exercise with your group.
2. Choose a spokesperson to read the problem statement

Problem Statement

When armored personnel carriers arrive at the deployment site, there is currently no way to know what conditions exist when the large tailgate is opened. The soldiers therefore do not know whether they will be facing enemy fire or friends. Your company has been hired to find a solution to this problem. The Bradley armored vehicle is heavily armored and has a large armored tailgate that must be lowered to deploy the troops as shown in the photo.

3. Conduct the brainstorming portion of the exercise. Make sure to remind everyone of the rules for this part of the session
4. Refine the concepts into groups and then ask each member of the group to vote for one of the concepts. Once completed identify which concepts were selected.

Conceptual Design

Conceptual design is a process of exploring whether design ideas that were identified during the brainstorming process will work. The conceptual design phase of a project involves creating simple mathematical and geometric models that allow the size, shape, movement, efficiency, and strength of proposed concepts to be judged.

Conceptual models are not complete models of all the parts or pieces of a design. They are as simple as possible and as complete as necessary to be able to determine whether the concept will work.

Conceptual models can often be explored using 2D sketches or mathematical calculations. Force and energy balances can be used to determine the effectiveness or efficiency of a specific concept.

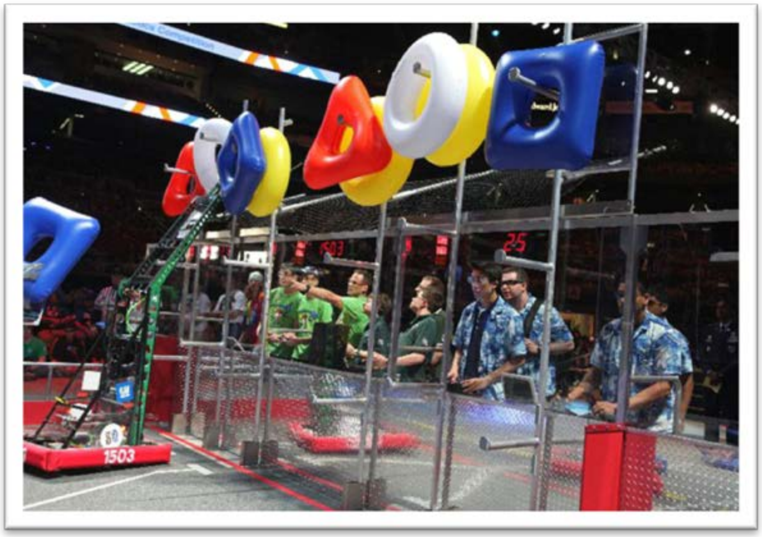
Geometric configurations can be explored with simple models combining 2D and 3D geometry. Other factors to consider include the suitability of the concept in terms of cost, environmental impact, manufacturability, or serviceability. It is efficient to keep conceptual models as simple as possible so that many (more than one) can be explored before committing to building a design into a detailed model.

There are four simple steps in developing a conceptual model.

1. Start by creating sketches of the concept so that you can identify individual parts and basic shapes and size. These sketches also help with the second step.
2. Identify criteria you will use to determine if the concept will succeed. This can include forces, speed, movement, availability of parts, etc.
3. Decide upon the type of model you will need to assess the concept successfully. For example you might need to create a conceptual model in Creo to determine if a mechanism will work. Other times, you may need to create a Mathcad worksheet so that you can calculate forces or costs.
4. Review the plan to make sure that the conceptual model is as simple as possible. You want to try as many concepts as possible in a short amount of time. That requires that the models are easy to build. Also, remember to document each of the models in your engineering notebook. You don’t want to have to rediscover what you already knew.

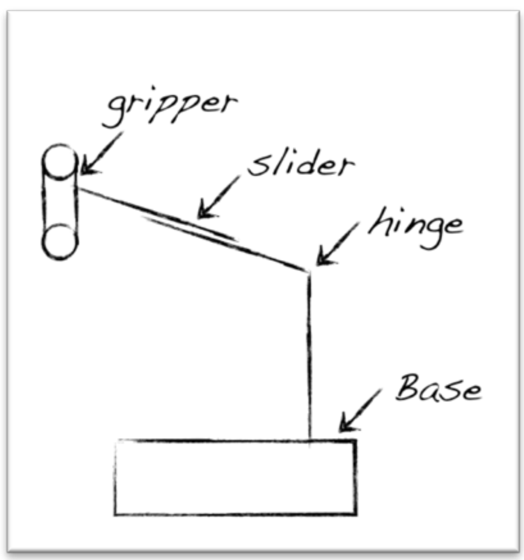
Conceptual Design Exercise

Objective: Create a conceptual model of an FRC robot to explore the feasibility of an arm mechanism configuration for a game similar to the 2011 FRC game.



Assume that you have made a sketch, as shown below, of an arm mechanism and you now want to determine whether the motion of the arm will be adequate. A simple Creo Parametric model can show the kinematic motion and allow efficient exploration of variants of the design. First we will create the basic geometry using a simple but powerful CAD tool called Creo Parametric.

It is important to understand that there are several different levels of capability in modern CAD modeling tools: **Geometry**, **Kinematics**, and **Forces**. PTC has developed a suite of CAD tools that enable concept (and detailed) design using all three levels of capability. In this exercise, we will be using PTC's **Creo Parametric** to model geometry and kinematics for potential robotic arm. Then, we will use PTC's **Mathcad Prime** to quickly assess the design of a gear box to lift the arm.

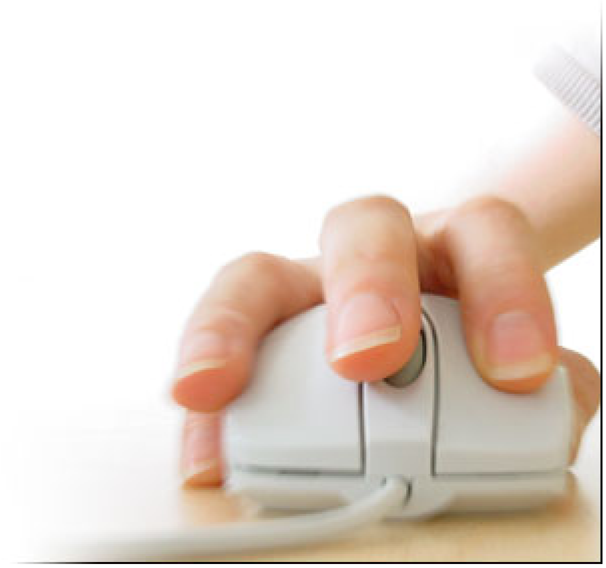


Creo Parametric – An Introduction

Creo parametric is a powerful software tool that allows engineers to design and analyze their concepts. It represents many years of development and can be very sophisticated. The best way to think of Creo Parametric is to imagine that it is a virtual studio or workshop where you can build things. There are many different modes where different functions can be completed. Within each of the modes the tool sets are different. Moving from one mode to another is important to recognize.

For this conceptual modeling exercise, we will use the 3D Part Modeling mode and the 3D Assembly mode. But we will also use a 2D Sketch mode in order to create the sketches needed in building the conceptual model.

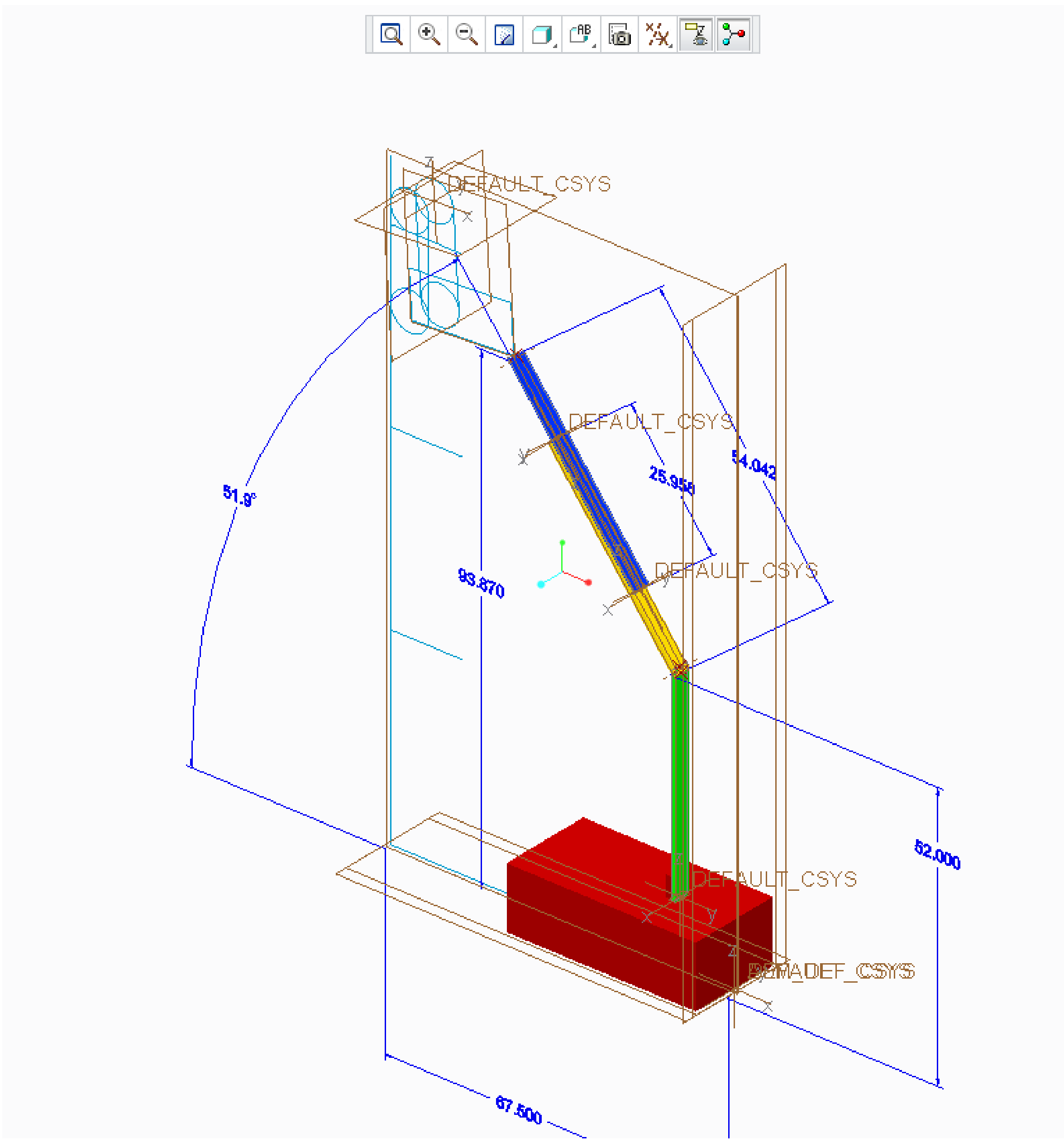
The other aspect of Creo Parametric that is unique is the amount of user interaction that is required in creating geometry. When you think about how you would use your hands, fingers, and all types of tools if you were creating or sculpting in an art studio, you can understand why it requires so much user interaction in creating geometry. Because Creo Parametric is software, the only means of user interaction is through the buttons and motion of the mouse and keyboard. You will find that you will use more buttons and button combinations in interacting with Creo Parametric than any other program you have used.



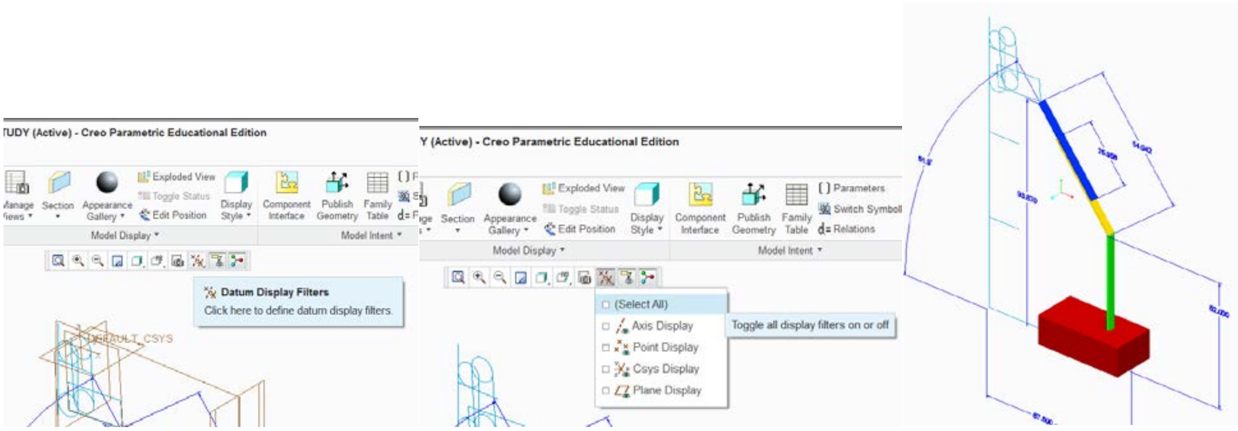
The conceptual robot arm model has been created and assembled previously and is available in the HOWS FOLDER 2012 Folder. You will be able to navigate to the conceptual robot model and open it to explore it before you build it.

When you open the model, you will be in the 3D Assembly mode because the model is an assembly of 5 parts. In the 3D Assembly mode, you can zoom, rotate, and pan to explore and view the model.

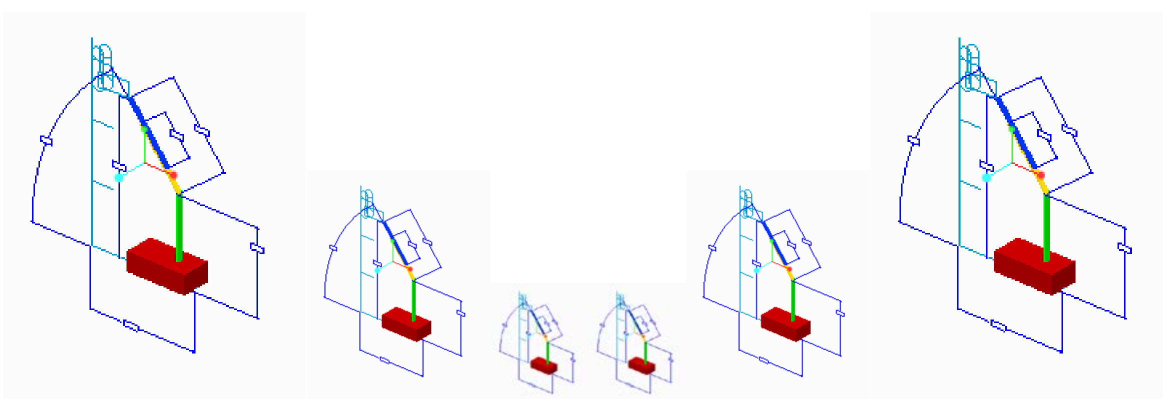
The first thing that you will notice when you open the conceptual robot model is that there are datum planes all over the model. They are the brown planes and coordinate systems. They are very useful when we are building the model, but when we are just exploring the model, they clutter up the view.



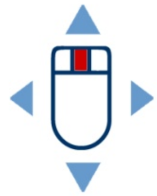
You can hide them by selecting the datum filter tool right above the model, selecting **all** and then making sure all the boxes are empty and then clicking in the viewing area again.

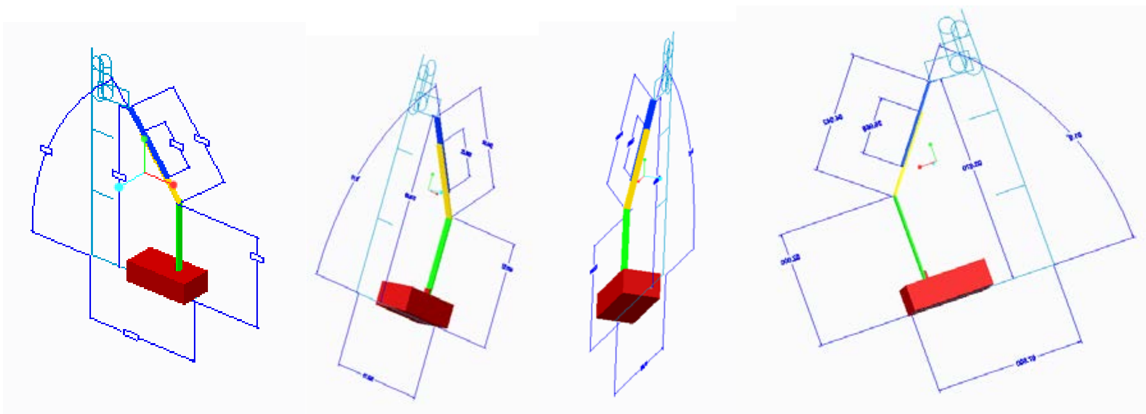


ZOOM: to zoom in and out from your model, simply roll the scroll wheel on the mouse. Notice that Creo Parametric zooms in and out based upon where you position the cursor. This can be very helpful since you can zoom out with the cursor in one location and then move the cursor into another location and zoom back in. This will actual reposition the model.

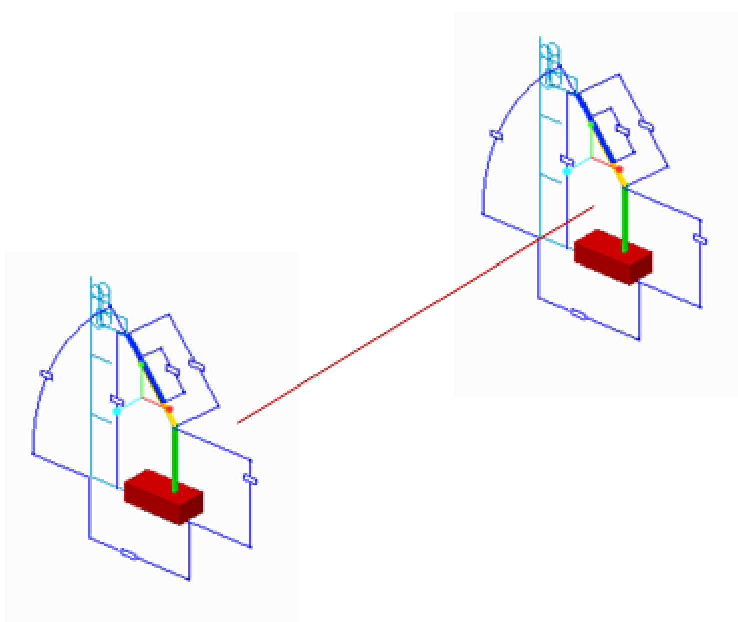


ROTATE: To rotate simply press and hold the scroll wheel down and then move the mouse. You can do this at almost any time you are in any of the modes.

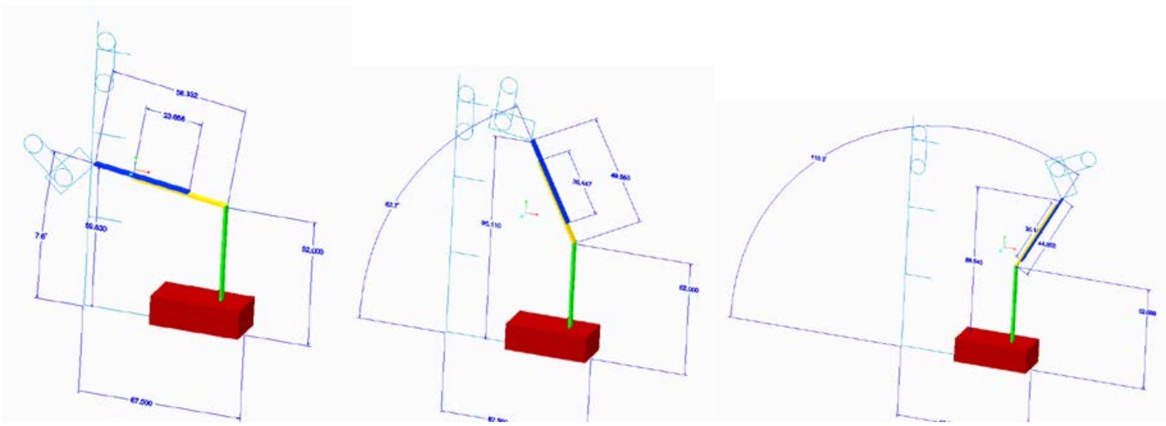




PAN: To pan, press and hold the middle scroll wheel and also hold the SHIFT key down on the keyboard. You can then move the mouse to pan the model.

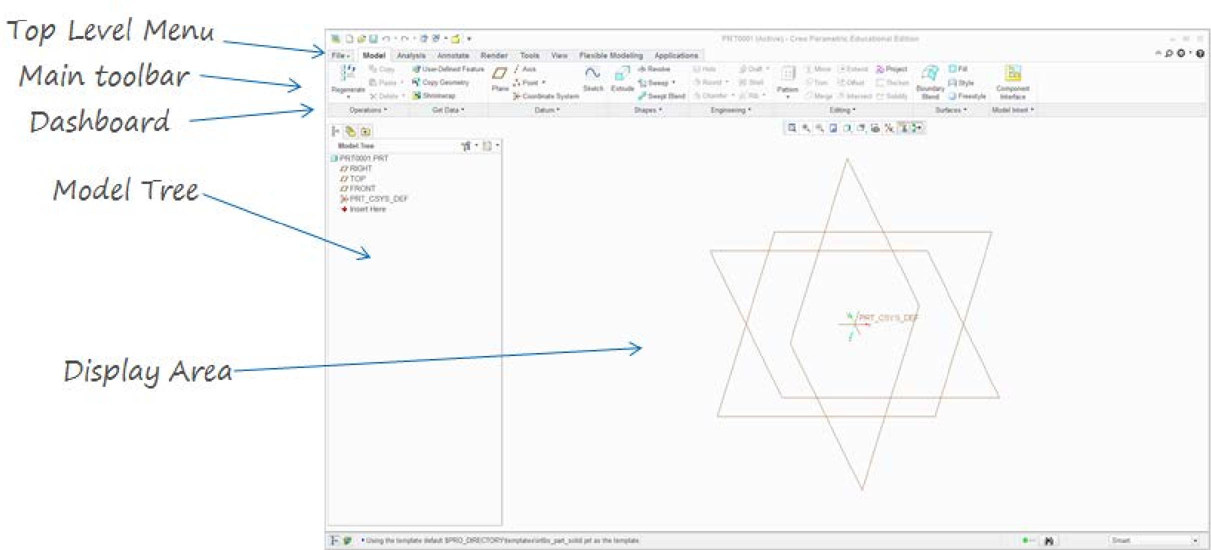


Another way to explore the conceptual robot model is to explore the **KINEMATIC** aspects of the model. This means the moving parts of the model. This is done by pressing and holding the **CTRL** and **ALT** buttons on the keyboard and then left clicking on the arm of the robot and moving your mouse.



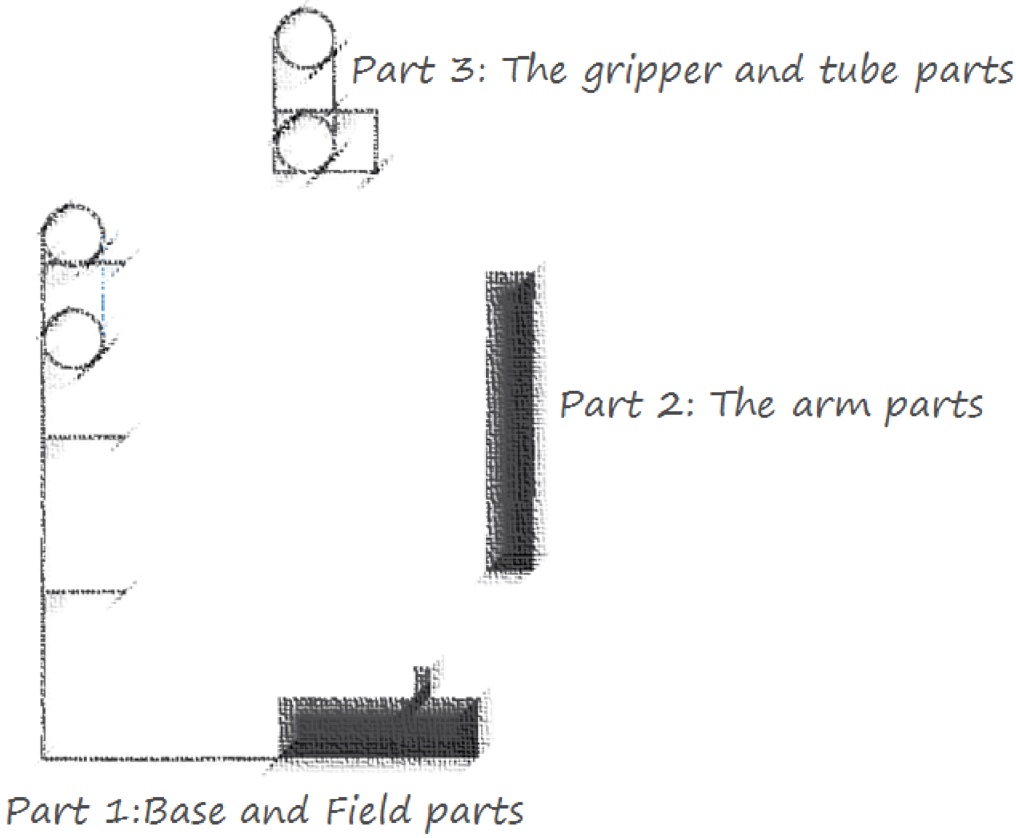
OK let’s close this model and get started building it. Exit **Creo Parametric**.

To enter the **3D Part Modeling** mode, and start building the conceptual robot model, one needs to open **Creo Parametric** and then create a New Part. The part modeling mode will look like this:



There are tools all along the top, a model tree representation on the left, and a 3D viewing area in the middle with 3-datum planes represented and the origin coordinate system. You will use many of the tools in the upper toolbar to create solid geometry.

The conceptual model of the robot arm can be decomposed into 3 different parts.

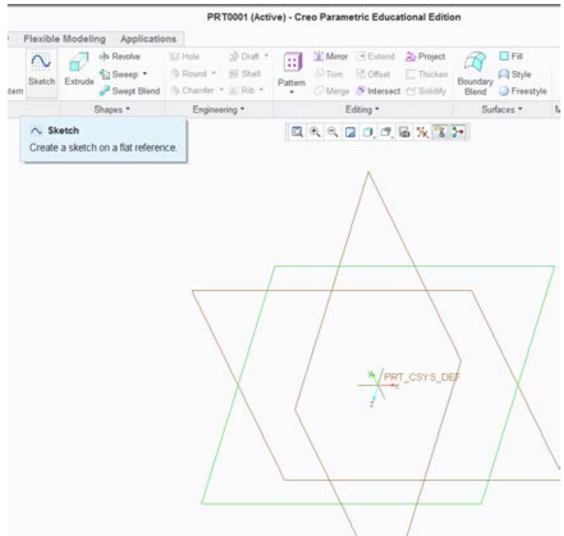


Model planning is important to be successful in creating geometry in Creo Parametric. Notice that the parts we will create are a combination of 3D and 2D geometry. We will need to use the 2D sketch mode several times in the creation of these parts.

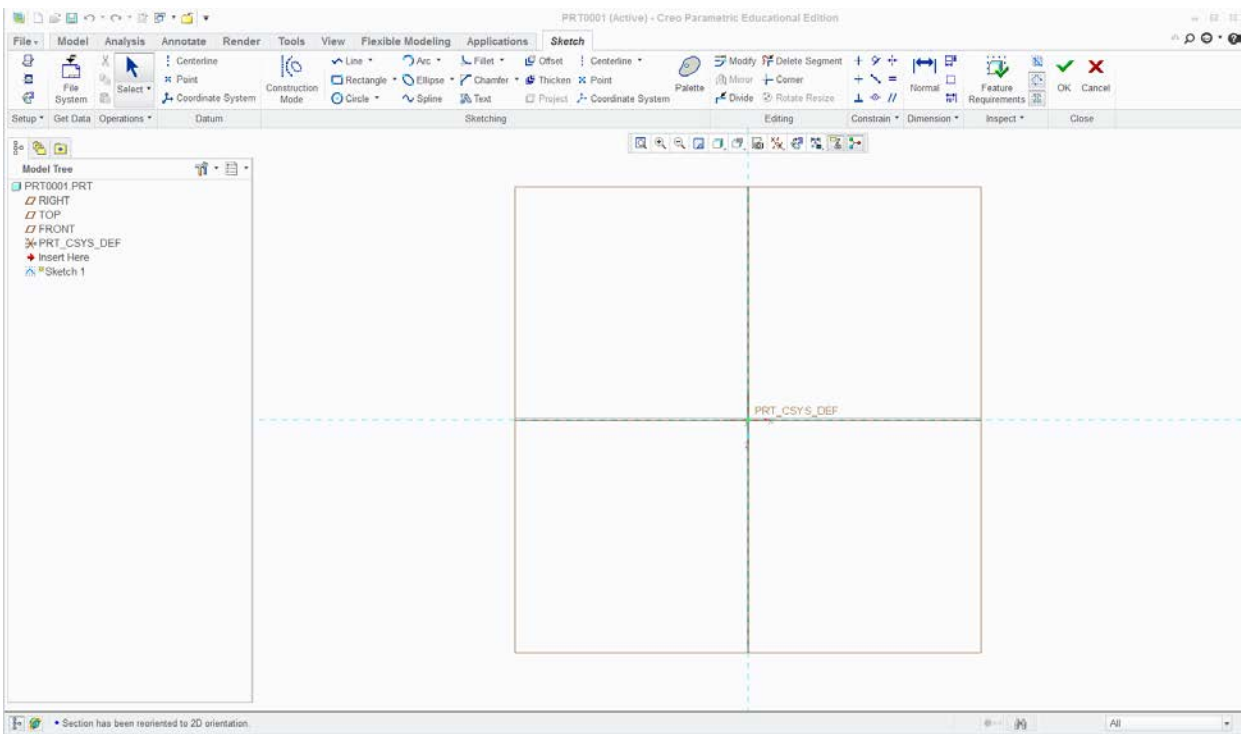
Solid parts are created in the 3D Part Modeling mode by extruding (pulling in a straight line) a 2D sketch. So a rectangular box is created by making a 2D sketch of a rectangle in the 2D Sketch mode and then bringing that sketch into the 3D Part Modeling mode and pulling the sketch into the 3rd dimension by extruding it.

The steps in this process are shown below. Let's review them before we actually do them:

Step 1: Go into the 2D Sketch mode by selecting a flat plane and then clicking on the sketch tool in the upper toolbar.

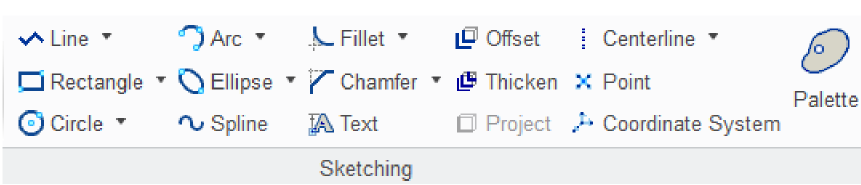


This is what the **2D Sketch** mode looks like:

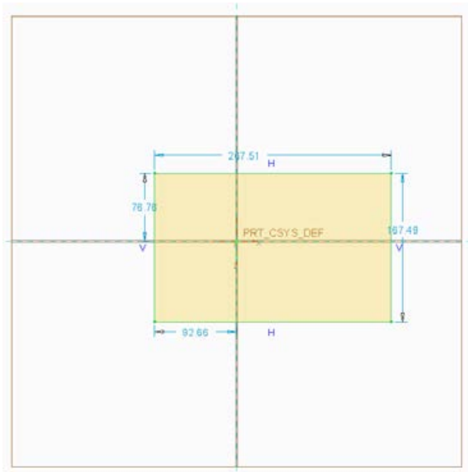


There are new tools in the upper toolbar, sort of like having tools set out on tables in each mode.

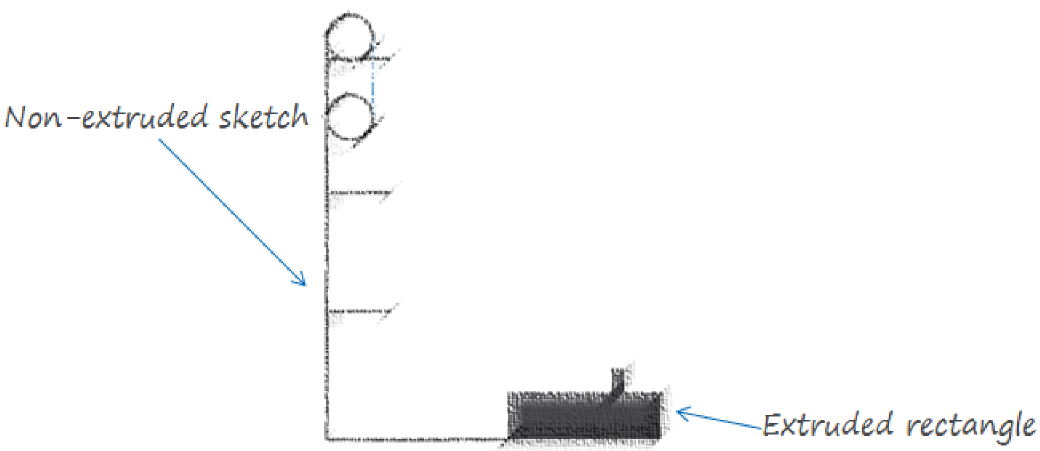
Step 2: Create the outline of the desired part using sketch tools like the **Line** tool, the **Rectangle** tool, or **Circle** tool.



The 2D sketch will need to be placed in the right location and set to the right size and shape. However, a parametric sketcher allows you to sketch the basic shape first and then set the correct lengths later.

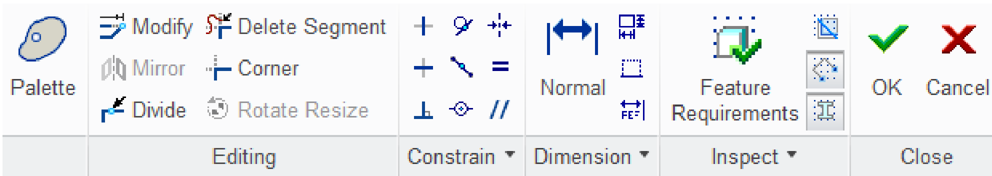


NOTE: An important note here is that 2D sketches must be closed and without any redundant lines or arcs if you want to extrude them in the 3D Part Modeling mode. However, they don't need to be closed if you won't be extruding them.

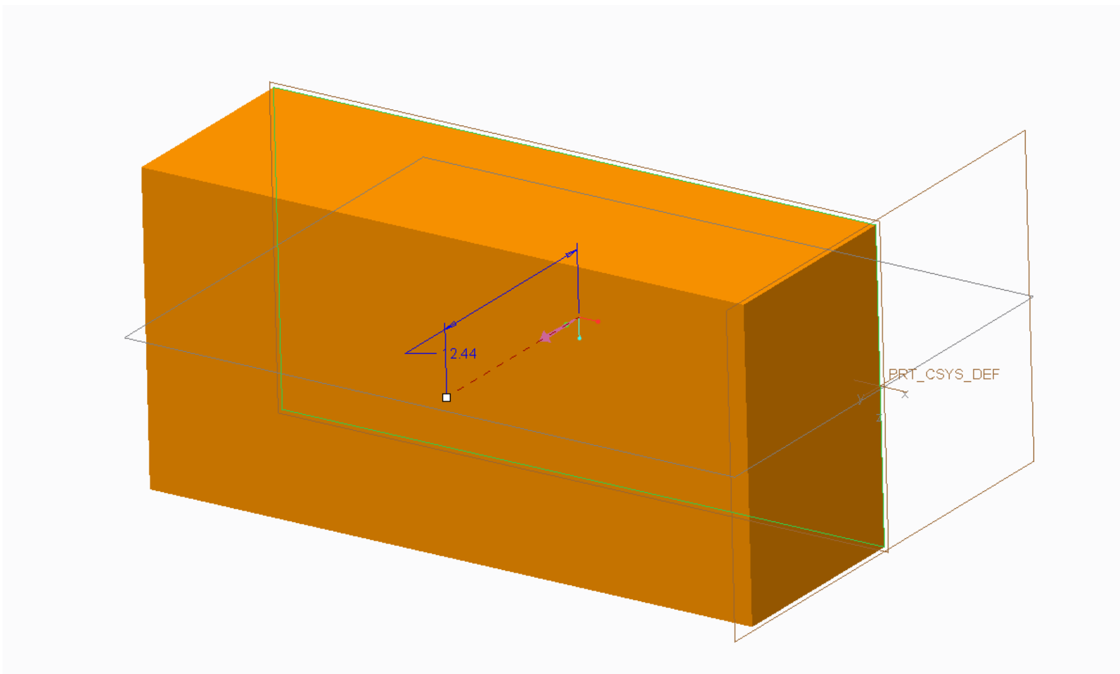


Part 1:Base and Field parts

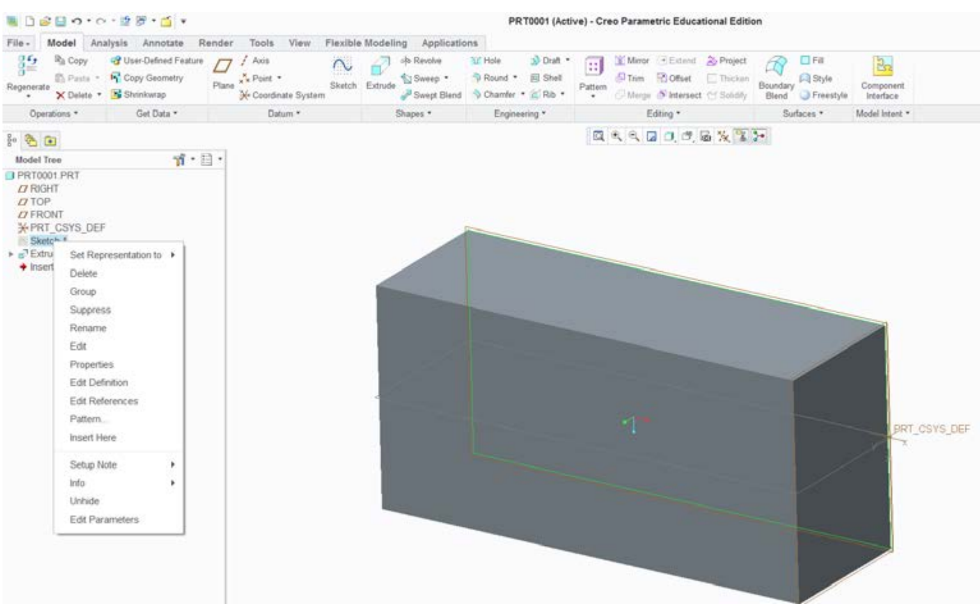
Step 3: Once the 2D sketch has been created, then we have to exit the **2D Sketch** mode and go back into the **3D Part Modeling** mode. This is done by clicking on the green checkmark in the upper toolbar. The red **X** cancel will also take you out of the **2D Sketch** mode but won't bring your sketch with you.



Step 4: Now that you are back in the **3D Part Modeling** mode, you can pull your sketch into 3 dimensions using the extrude tool.



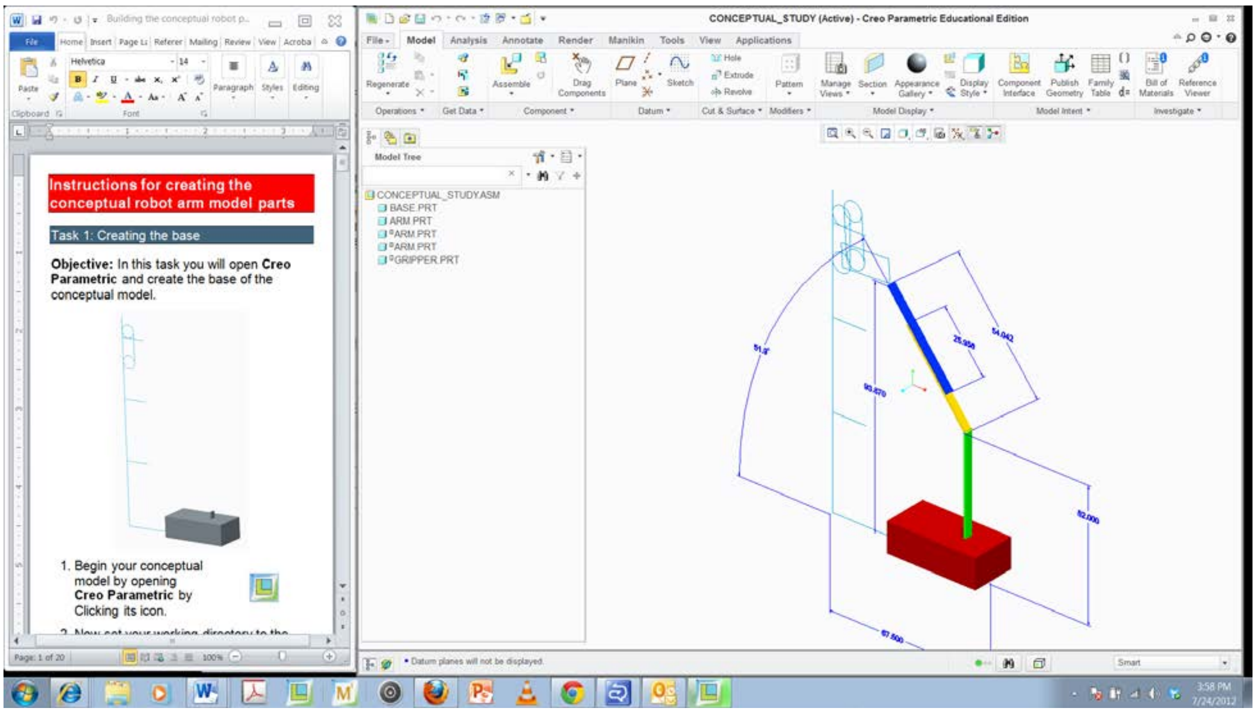
If you want to go back into the **2D Sketch** mode to re-work one of your sketches, find the sketch in the model tree on the left and then right click on it and select **Edit Definition**. This will bring you back into the **2D Sketch** mode with that specific sketch.



OK, you are ready to start building the 3 parts needed for the conceptual model of the robot arm. Let's get these parts built and then we will talk about the **3D Assembly** mode.

Conceptual Design Exercise 1. Building the Conceptual Robot Parts

Navigate to the **HOWS FOLDER 2012**. There you will find a file called: "**Building the conceptual robot parts**". Open this file. You will notice that it is in a narrow format. Position it to the right or left of your computer screen so that you can open **CREO Parametric** and work from the instructions simultaneously as shown:



Follow the instructions and build the parts for the conceptual robot.

Assembly Modeling – An Introduction

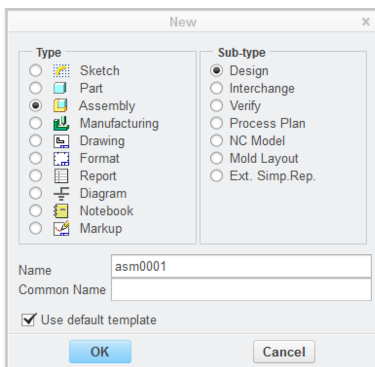
You have now experienced **Creo Parametric** as you have created the parts for the conceptual robot. Assembling these parts is done in the **3D Assembly** mode. In order to assemble these parts, we need to use a new type of language that tells **Creo Parametric** how each part should be positioned with respect to the other parts. This new language involves ***constraints***.

Each part that is assembled into an assembly model can move in 6 ways: it can translate in three directions; the X-direction, the Y-direction, and the Z-direction. It can also rotate about each of those axes. Constraints limit the part from moving in each of these possible motions. Constraints are applied to parts by specifying relationships between two surfaces, two lines, or two points. For example, I could specify that I want the faces of two rectangular parts to always be on the same plane, or always be normal to each other.

The most common constraints will be **Coincident** and **Distance**. Coincident means that two flat faces will always be on the same plane or that two axes (the center of spheres or cylinders) will always be along the same line. Distance means that faces will be parallel but at a specified distance.

Creo Parametric guesses from what surfaces you select, what type of constraint you want. The general process for creating an assembly is as follows:

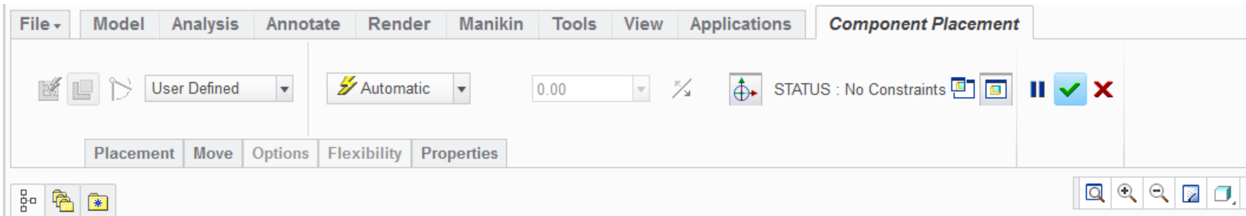
Step 1. Open a new file and make sure you select Assembly.

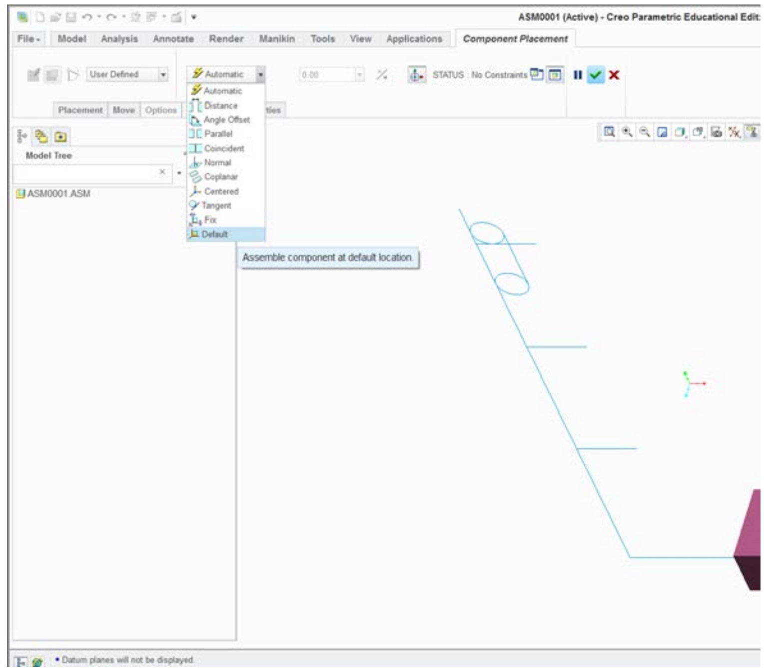


Step 2. Bring a part into the 3D Assembly mode by clicking on **Assemble** in the upper menu.

Note: *When a part is being brought into the 3D Assembly mode, a new set of assembly tools opens up in the dashboard. These tools allow the user to specify the constraints that will relate the new part to the existing parts.*

There are two types of constraint menus; rigid constraints that rigidly fix parts with respect to each other, and kinematic constraints that allow parts to move with respect to each other.



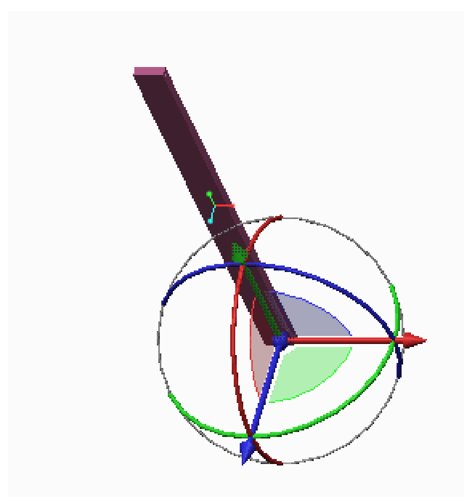


Step 3. If it is the first part in an assembly, choose **Default** from the **Automatic** constraint menu to fix it to the ground. Then click the green check mark to exit the assembly dashboard tools.

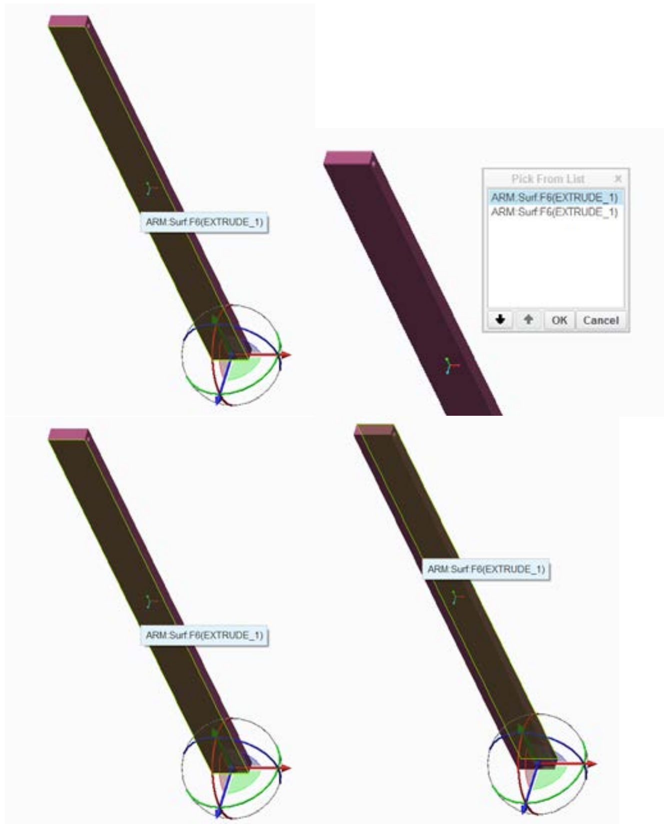
Step 4. Bring another part into the assembly by selecting the **Assemble** icon again.

Step 5. Use the orientation sphere to position the new part in the approximate orientation and position you desire it to be in. This helps **Creo Parametric** accurately guess what constraints you want when you select the surfaces.

You can move the part using the orientation sphere by left mouse clicking on the red, blue, and green axes for translation or the colored circles for rotation (You can see the 6-degrees of freedom here).

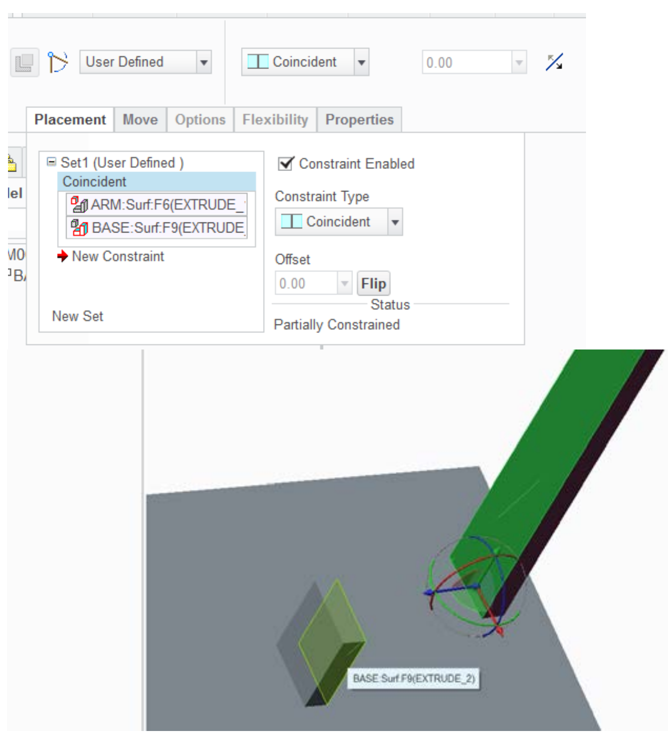


Step 6. Begin applying constraints to position the new part with the existing part in the assembly. This is done by selecting one surface on the new part and the mating surface on the existing part.



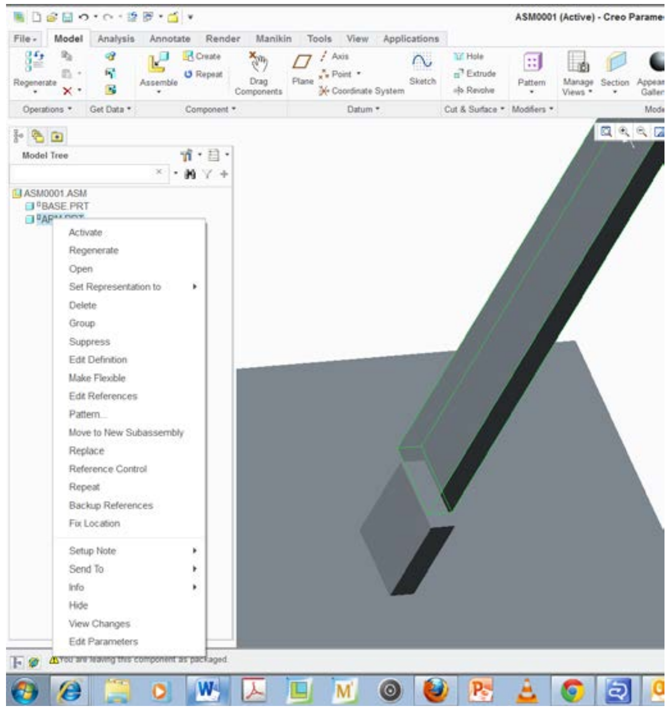
***Note**: **Creo Parametric** has 3 ways to select surfaces; first by hovering over a surface until it turns green and then left clicking on it. Second by positioning the mouse over a set of surfaces and right mouse clicking and holding, you can pick to select from a list of surfaces and a dialog box appears and you can select the appropriate surface from the list. Finally, if you right mouse click and continue to click it will cycle through the list.*

Step 7. Begin applying constraints by selecting appropriate surfaces. **Creo Parametric** keeps track of the constraints you choose under the **Placement** tab in the dashboard. You will notice a list of constraints and under each constraint the two selected surfaces. If you want to change the surfaces or the constraints, just right click and remove or delete them and then re-select.



Step 8. Once you have applied enough constraints to fully constrain the part, finish the assembly by clicking the green checkmark in the dashboard. You can also finish by middle clicking the scroll wheel. The dashboard will disappear.

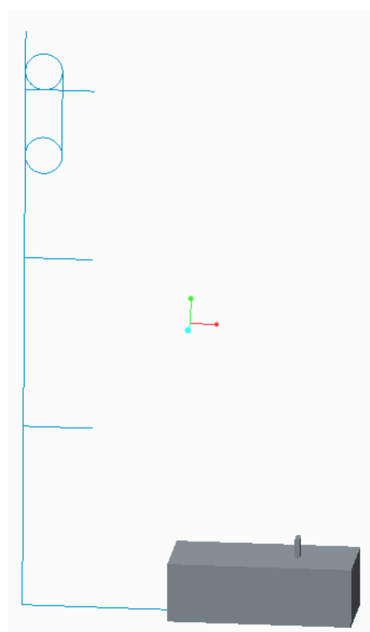
Note: If for some reason you accidentally exit the assembly dashboard, you can re-enter it by finding the new part in the Model Tree, right clicking on it and then selecting ***Edit Definition****.*

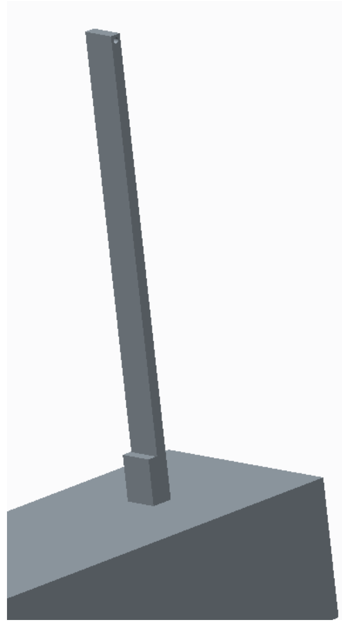


Note*: When you are building an assembly in* ***Creo Parametric****, it is important to be aware that every click of the mouse is significant. Since* ***Creo Parametric*** *is trying to interpret what you are trying to do, any click of the mouse changes the result. You can't break* ***Creo Parametric****, so don't worry about that, but remember that just clicking away isn't going to help. You need to be aware of what clicks you are making and correct them if necessary.*

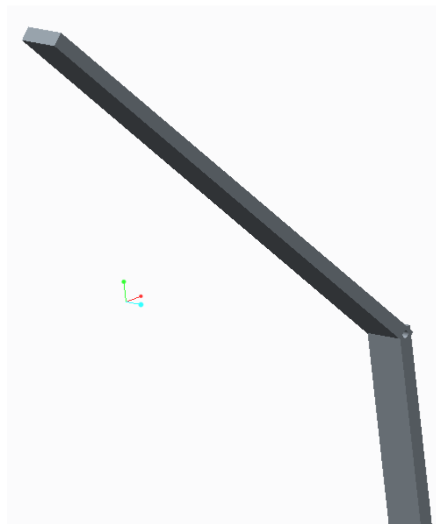
So let's do a quick plan for the conceptual robot arm model so that you know what you will be doing.

1. Bring the base part in and fix it to the ground using the Default constraint.

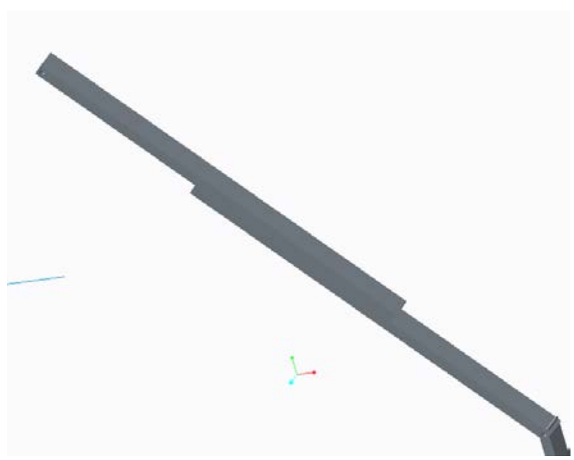




2. Bring in the arm part and fix it to the base as shown using 3 coincident constraints.

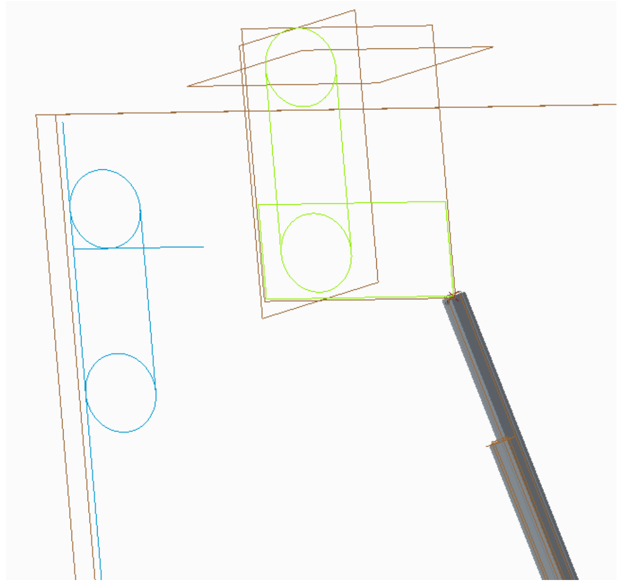


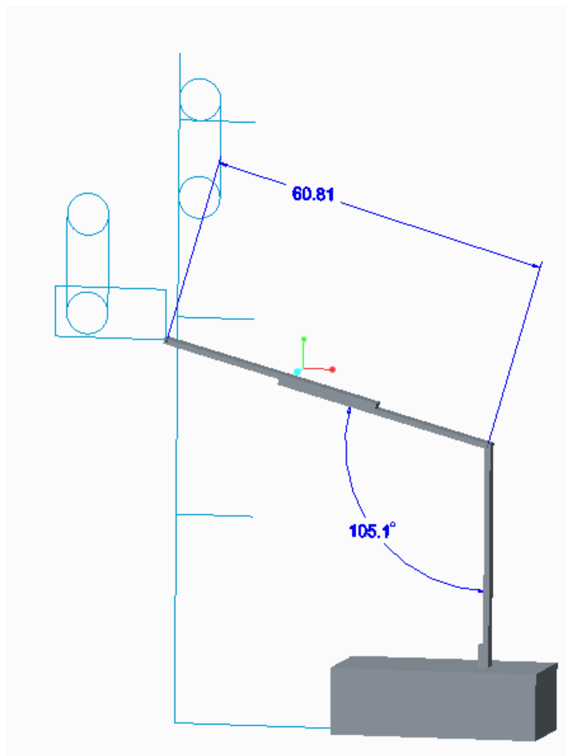
3. Bring the arm part in again and assemble it to the first arm part using a **Pin** constraint from the kinematic (**User Defined**) constraint menu. You will align the axes of the holes and the sides of the arms and then set limits to how far the arm can rotate.



4. Bring the arm part in again and assemble it to the rotating arm part using a **Slider** constraint from the kinematic constraint menu. You will select the edges of the two arms and then the two faces that will slide on each other. Finally you will limit how far the sliding arm can move.

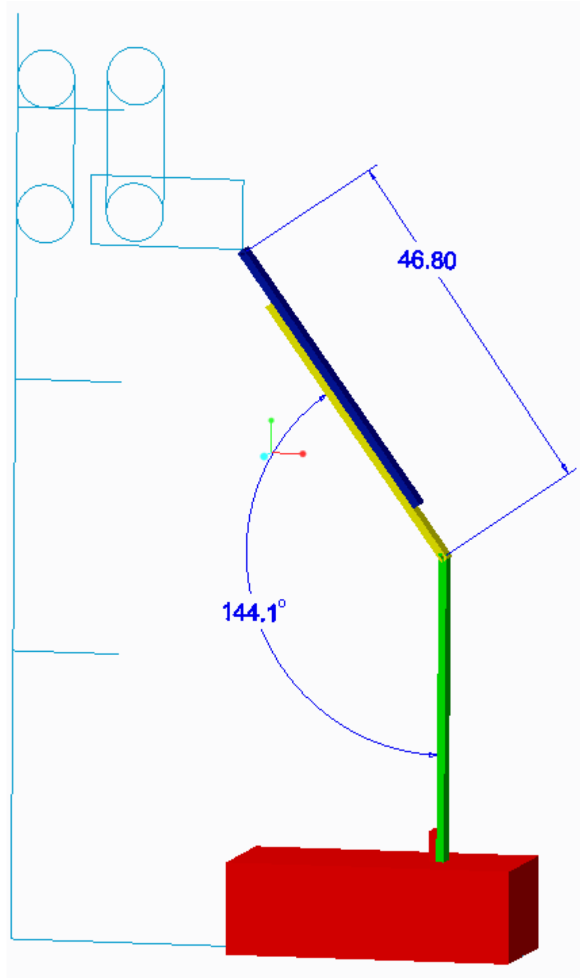
5. Bring in the gripper and assemble it to the sliding arm part. You will use **coincident** constraints and pick the defining datum planes as reference surfaces.



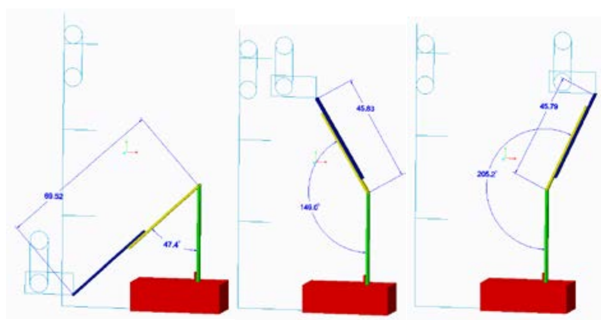


6. You will add annotations that change as you move the kinematic parts.

7. You will add color to your assembly to make it more clearly defined.

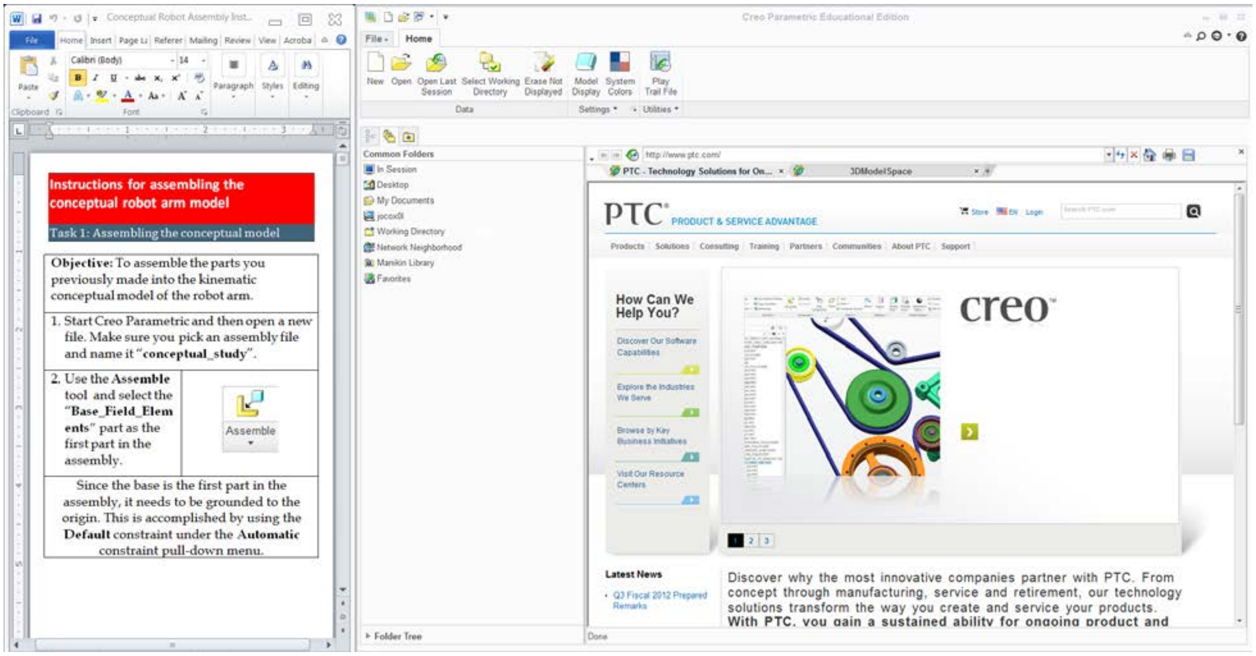


8. You will finish your assembly and test it using the **CTRL-ALT** keys on the keyboard and left mouse select the moving arm parts to show the kinematic motion.



Conceptual Design Exercise 2. Assembling the Conceptual Robot Parts

Navigate to the **HOWS FOLDER 2012**. There you will find a file called: "**Assembling the conceptual robot parts**". Open this file. You will notice that it is in a narrow format. Position it to the right or left of your computer screen so that you can open **CREO Parametric** and work from the instructions simultaneously as shown:



Follow the instructions and assemble the parts to build the conceptual robot model.

Mathcad Conceptual Design Worksheet

PTC | ACADEMIC PROGRAM

Concept Design Validation using Mathcad Prime

As an illustration of engineering calculations in conceptual design, this worksheet will help you to assess the viability of the concept design for the robot arm based on the torque requirements during the lift.

Design Specifications

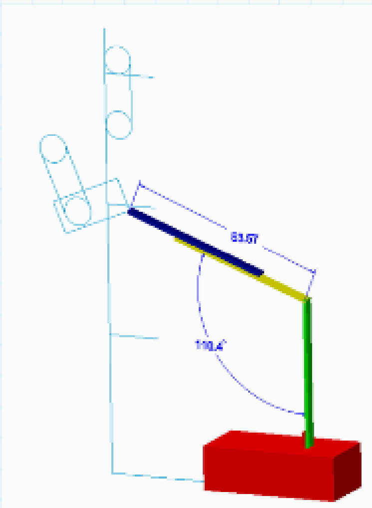
Using Creo, you built a working concept model for a lifting mechanism. In this worksheet we will consider the feasibility of the design in relation to the motors and gears that we have available in the kit of parts. Our engineering task is to ensure that we can provide sufficient torque to lift the load.

Important Considerations

1. Engineering best practice requires us to identify and consider the scenario where the torque required is greatest.The greatest amount of torque is required when the arm is in a horizontal position. At this stage of the product development process we will calculate the torque required to lift the arm at maximum torque.

2. We need to account for the fact that the arm is extendable. The worksheet will perform calculations at the minimum and maximum length of the arm.

3. Since we may want to perform these calculations again on a different design, we will use parameters (variables) to make the worksheet reusable. Creating a resuable worksheet requires careful documentation. The given information and input parameters are specificed on page 2 of the worksheet.



Model Identification

Filename:

Version Date:

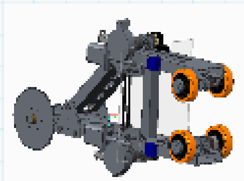
PTC | ACADEMIC PROGRAM

Input Parameters

Arm Measurements

Properties of arm.prt $length_{prt} := 40\ in$

Old Gripper Assembly $m_{gripper} := 11\ lb$ Estimated



Source: Team 525 2011 Robot
We will need a mechanical gripping device attached to the end of our arm. We can use an old gripper to estimate the mass we might attach to the arm.

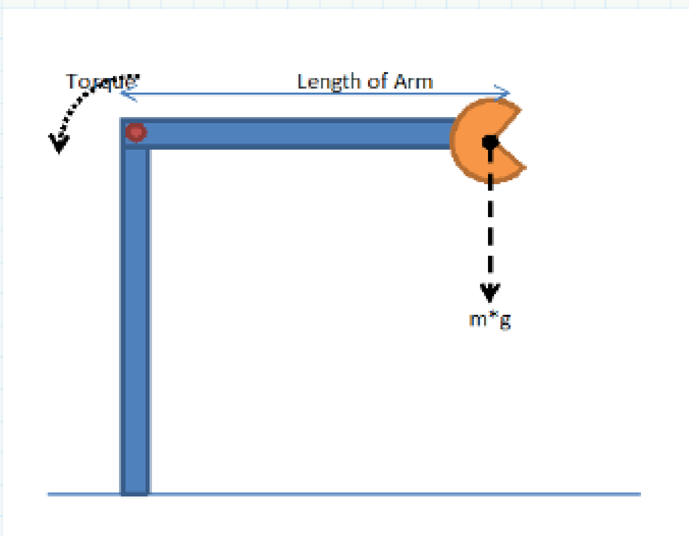
Gravitational Acceleration Constant
(Mathcad built-in constant) $g = 9.807\ \frac{m}{s^2}$

Maximum Force Applied to the Load $F_{load} := m_{gripper} \cdot g = 48.93\ N$

Robotic Arm Length

Retracted $l_{min} := 40 \cdot in$ Estimated
Extended $l_{max} := 60 \cdot in$

Step 2: Draw a **free body diagram** for the concept model. For the present assume that the mass of the arm is inconsequential.



Description:
We will calculate the torque required to lift the gripper at the end of the arm in order to establish initial criteria for the design of a motor and gearbox.

We will calculate two different torque values to set a range based on the concept of using an extendable arm.

PTC | ACADEMIC PROGRAM

Torque Calculations

Torque is defined as the cross product of the radius vector with the force vector. In our case, because the two vectors are perpendicular, the equation reduces to a normal (multiplicative) product. We can calculate the torque as the arm length times the weight of the load.

$$r_{arm} := \begin{bmatrix} l_{min} \\ l_{max} \end{bmatrix}$$

$$\tau_{req} := r_{arm} \cdot F_{load} = \begin{bmatrix} 49.713 \\ 74.57 \end{bmatrix} \boldsymbol{N \cdot m}$$

$\tau_{req_0} = 49.713\ \boldsymbol{N \cdot m}$ is the torque required at 40 in extension

$\tau_{req_1} = 74.57\ \boldsymbol{N \cdot m}$ is the torque required at 60 in extension

Motor Candidate: AndyMark (am-0914)

$\tau_{motor} := g \cdot 3101\ \boldsymbol{oz \cdot in} = 21.898\ \boldsymbol{N \cdot m}$ from the FIRST 2012 kit-of-parts

$Motor_{fs} := 84\ \boldsymbol{rpm}$ from the FIRST 2012 kit-of-parts

$P_{max} := 48.50\ \boldsymbol{W}$ from the FIRST 2012 kit-of-parts

We can increase the torque from the motor by utilizing a gearbox. A gearbox employs a set of gears with different numbers of teeth to increase/decrease the speed, which in turn decreases/ increases the torque.

The gear ratio is typically defined as the ratio of the number of teeth on the driven gear to the number of teeth on the driving gear. In our case, we have the the torque required to lift the load and the motor torque. We re-define the gear ratio as the torque on the driving gear (gear attached to the motor) to the driven gear (gear attached to the arm).

$$GR_{req} := \frac{\tau_{motor}}{\tau_{req}} = \begin{bmatrix} 0.44 \\ 0.294 \end{bmatrix}$$

$$\frac{1}{GR_{req}} = \begin{bmatrix} 2.27 \\ 3.405 \end{bmatrix}$$

We need to increase the torque by a factor of 3.5 or more to be able to lift the arm when fully extended with our current estimates.

Since we have gears of three different sizes, we can generate three gear ratios from the following three base ratios. From these three base ratios, we can generate more ratios by multiplying any of the base ratios.

$$gr_1 := \frac{40}{80} = 0.5 \qquad gr_2 := \frac{40}{120} = 0.333 \qquad gr_3 := \frac{80}{120} = 0.667$$

Consider the following gear box: $gr_{lift} := gr_2 \cdot gr_3 = 0.222$

If we use this ratio in the design of a gear box, the motor can now provide more torque on the end of the arm, but at a slower speed.

$$\tau_{effective} = \frac{1}{gr_{lift}} \cdot \tau_{motor} \qquad speed_{effective} = gr_{lift} \cdot speed_{motor}$$

$\tau_{motor} = 21.898\ \boldsymbol{N \cdot m}$ Amount of Torque provided by the motor

$$\tau_{effective} := \frac{1}{gr_{lift}} \cdot \tau_{motor} = 98.54\ \boldsymbol{N \cdot m}$$

$\tau_{req} = \begin{bmatrix} 49.713 \\ 74.57 \end{bmatrix} \boldsymbol{N \cdot m}$ Estimated range of torque required to lift the load

$\tau_{effective} > \tau_{req_1} = 1$ Is the torque provided by the motor with the gearbox in place larger than the required torque?

We now know that the motor can provide enough torque to lift the scoop in the worst case scenario, i.e. the horizontal position. Next we should see if the speed is acceptable.

$$v_g := Motor_{fs} = 84\ \boldsymbol{rpm}$$

$v_{calc} := v_g \cdot gr_{lift} = 18.667\ \boldsymbol{rpm}$ $radius := 60\ \boldsymbol{in}$

$v_{arm} := v_{calc} \cdot radius = 2.979\ \frac{\boldsymbol{m}}{\boldsymbol{s}}$ at full extension

If the speed is acceptable, then we can move on with the modelling. Keep in mind that this is an estimate. We have not accounted for mass of the arm and scoop, losses in the gears, motor efficiency, etc. It does, however, give us a good approximation of what gear ratio(s) to employ instead of trial and error.

Congratulations Phase 1 exercises are completed!

Phase 2: Detailed Design, Prototype, & Test

Introduction

Once a design concept has been selected as a candidate solution, it must be developed into a full design. This requires that all aspects of the design be explored and specified in detail. Modern computer technology provides methods for taking this next step using virtual prototypes. Rather than undertake a **build & break** approach (build the parts of the design and test the model to see how it performs), the entire design can be modeled and tested on the computer before any physical assembly takes place. This process is called **engineering simulation**.

Engineering simulation is the work of building **virtual prototypes** of your design and testing them in a virtual environment. Although it is not always possible to simulate a model completely, robots are very well suited for simulation and testing using virtual prototypes.

Virtual prototyping is a predictive method where equations that predict parts-behavior are programmed into the computer. Virtual prototyping enables sketches of new parts to be turned into models. Advanced tools like PTC's Creo allow virtual forces to be applied to those models. In most cases, observing the simulated behavior of a model makes it possible to predict how a prototype will bend and move in the real world.

Why use engineering simulation and virtual prototyping?
When the Wright brothers were designing their Wright Flyer, there were no equations to predict the aerodynamics of wings. They had to use a build & break strategy, testing over 200 wings in their wind tunnel. However, when NASA was preparing to send a man to the moon, they could not afford to use a build and break strategy. They had to develop and use predictive methods. You are fortunate to live in an age when modeling and simulation are standard engineering tools – so much is possible!

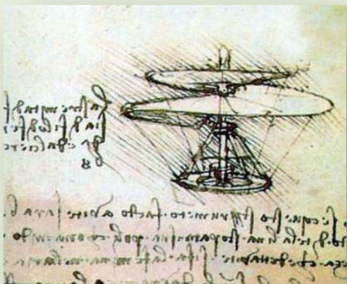
Engineering Calculation & Communication

Engineers use calculations to predict, model, and communicate. In this activity you will learn about how to perform engineering calculations and documentation using electronic tools and techniques that make your calculations as re-usable as possible.

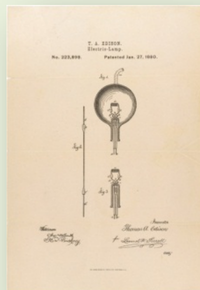
Task 2: Learn about engineering calculation

Throughout history great artists and engineers have employed notebooks to record the design and engineering decisions behind their designs. Leonardo da Vinci, Thomas Edison, and Alexander G. Bell are all famous for their creativity and inventiveness. Each carefully and meticulously documented the thinking, calculations, and problem solving behind their best known works.

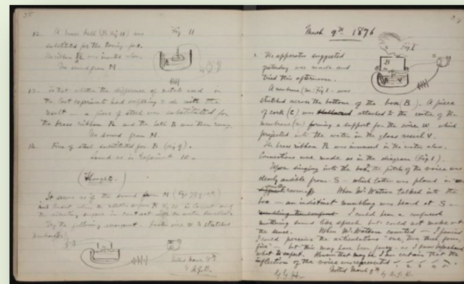
Da Vinci's Airscrew



Edison's Light Bulb Patent



Alexander Graham Bell's Engineering Notebook



In the world that you live-in engineering research and product design are fast-paced, team-oriented, high technology environments. In innovative workspaces such as Lockheed Martin's Skunk Works or your FIRST Robotics shop, the engineering notebook remains a critical resource.

In modern product development, engineering notebooks fulfill the following mission critical objectives (amongst others):

- Capture design requirements
- Document assumptions and decisions
- Store design history
- Communicate vital information to colleagues and other stakeholders
- Identify design or engineering problems encountered
- Establish action items and responsibilities
- Record mathematical and scientific calculations
- Reduce project risks
- Establish ownership of intellectual property

Your engineering notebook is a necessary legal document! It protects you and your team from the problems that occur when vital information is lost, misplaced, forgotten (or stolen)!

Task 3: Learn about Mathcad Prime 2.0

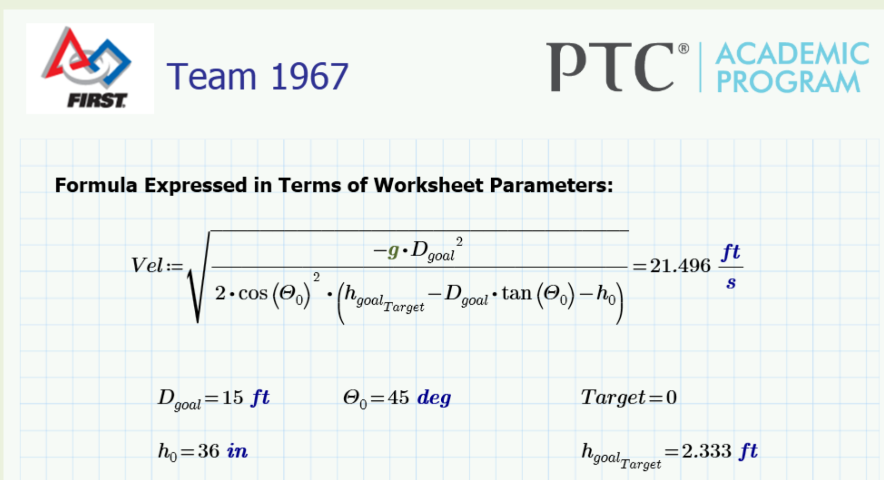
During the Detailed Design, Prototype and Test phase of the Product Development Process your team will want to capture all of the design information that is considered and implemented. While this seems obvious, in the real world critical information is often lost, leading to situations where companies end up reverse engineering a part or a product that they have already built. Mathcad was developed to make it easier for engineers to capture and reuse engineering calculations, requirements definitionss, and other important documents created during the Product Development Process.

In order to fully understand Mathcad Prime's potential value to your *FIRST* team's work we will look at a few brief examples of how Mathcad Prime enhances the traditional engineering notebook.

- **Engineering notebooks are important records of your teams accomplishments**

Mathcad is a WYSIWIG ("what you see is what you get") environment for clear and concise recording of engineering calculations and design intent. Below is a screen shot from a Mathcad Worksheet created by Team 1967 for the Rebound Rumble.

Design Review Question: **How did we calculate the desired velocity from our ball launcher?**



- **Engineers write reports to communicate**

Mathcad's document interface is a whiteboard for reporting engineering content using type-specific regions

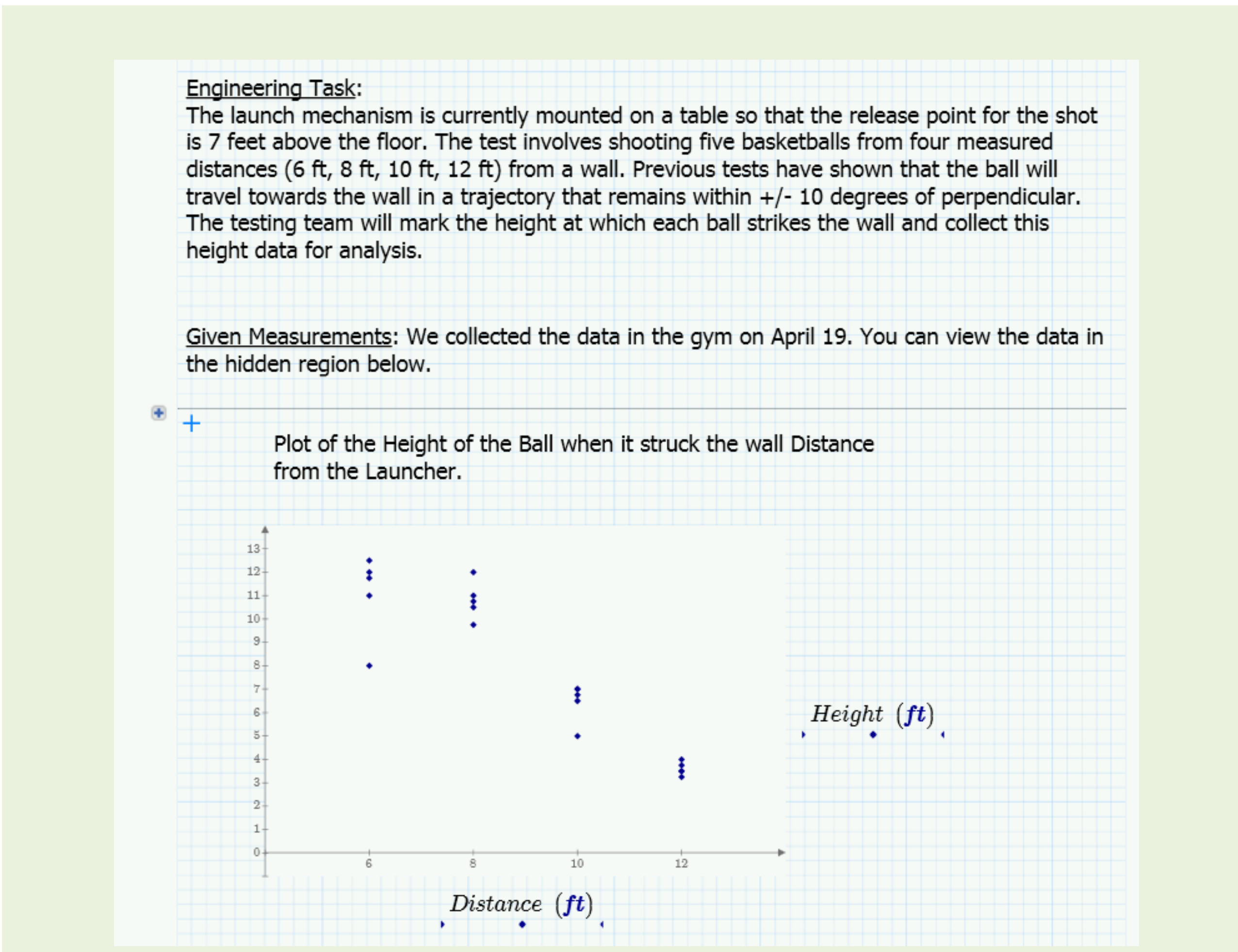
Text Regions contain headings, introductions, questions, and explanations

Math Regions express numerical calculations, symbolic expressions, variable & function definitions, matrices, and conditional statements

Graphics Regions represent data or relationships using 2-D or 3-D plots, contour plots, or polar plots

Below is a screen shot of a simulated Mathcad worksheet. I created this worksheet after watching a number of *FIRST* team ball launcher tests on YouTube. The worksheet is a template for reporting the results of a performance test using data analysis.

Design Review Question: **How did we test the performance of our basketball launcher?**



❖ **Unit conversion is one of the greatest sources of error in engineering**

Mathcad has full unit handling capability that enables users to perform most calculations using standard units of measure. Many engineers point this out as Mathcad's most valuable capability. In each of the screen shots so far, Mathcad has reported results using units (***blue italic text***). These units are actually mathematical quantities used by Mathcad to perform data analysis and engineering calculations.

Design Review Question: **What units did we use when we made those calculations?**

<u>Motor Specifications</u>

Torque Output at 10000 rpm $torque_G := 3\ lb \cdot in$

$v_G := 10000\ rpm$

Calculate the torque at v = 400 rpm

Target Velocity $v_T := 400\ rpm$

$$torque_G \cdot v_G = torque_T \cdot v_T$$

$$torque_T := torque_G \cdot v_G = torque_T \cdot v_T \xrightarrow{solve,\, torque_T,\, explicit} \frac{v_G \cdot torque_G}{v_T}$$

$$torque_T = 75\ lb \cdot in$$

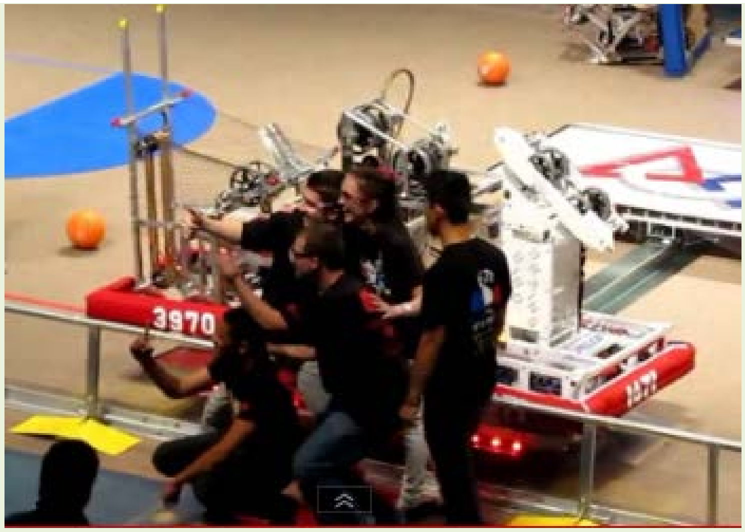
- **Following established conventions for mathematical and symbolic notation are critical to the successful practice of engineering**

Mathcad Prime's patented technologies enable users to type **<u>AND</u>** evaluate numerical and symbolic mathematical expressions using standard notations and conventions. Mathematical regions on a Mathcad Prime worksheet are live and dynamically linked. When values are assigned to variables in a Mathcad worksheet, those values are available to be used in expressions, functions, and plots everywhere after the variable definition occurs in the worksheet.

Mathcad Prime is the only tool that enables engineers to type mathematical equations exactly as they would write them by hand, and then, evaluate them numerically or symbolically. This capability is powerful for both easy applications (define variables, define a function, make a plot) and complicated analyses (use differential equations to model an automobile suspension).

Design Review Question:

If we lengthen the arm will we still be able to successfully lower the ramp?



Modeling the Force Required to Lower the Ramp

$D := 25\ in, 31\ in .. 44\ in$

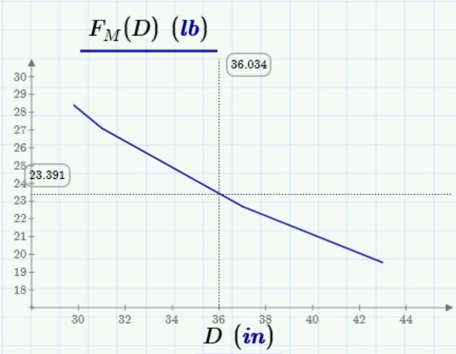
The ramp is 88 inches in length, the force can be applied up to 44 inches from the midline. D is a range variable that allows us to model distances from 30 in to 44 in.

$F_M(D) := \frac{Moment}{D}$ where $Moment = 840\ lb \cdot in$ based on prior analysis

Enter the distance from the midline of the ramp that your robot will apply the downforce:

$D_C := 42\ in$ $F_M(D_C) = 20\ lb$

Plot of Force Required vs. Distance from the Midline of the Ramp



Using the Plot:
Changing the value assigned to Dc above will calculate a new value for Fm.

The horizontal and vertical markers on the plot adjust automatically.

- **Creating standardized and reusable worksheets enables engineering teams to increase the accuracy of their engineering calculations and the efficiency of their workflow**

Mathcad Prime worksheets are often organized with sections for: (i) Given Values, (ii) Input Parameters, (iii) Engineering Analysis, and (iv) Design Recommendations. Using this document structure enables worksheets to be easily reused when design requirements change or when conducting what-if analyses during conceptual design or problem resolution.

Design Review Question:

Can someone quickly check to see if we can make that change to the design?

Goal Heights: Defining the height of the game baskets

$$h_{goal} := \begin{bmatrix} 28 \\ 61 \\ 98 \end{bmatrix} \cdot in$$

$low := 0$

$mid := 1$

$high := 2$

Shot Parameters

Launch Height: $h_0 :=$ Enter Launch Height with units

Launch Angle: $\Theta_0 :=$ Enter Launch Angle with units

Shot Distance: $D_{goal} :=$ Enter Distance to the Basket with units

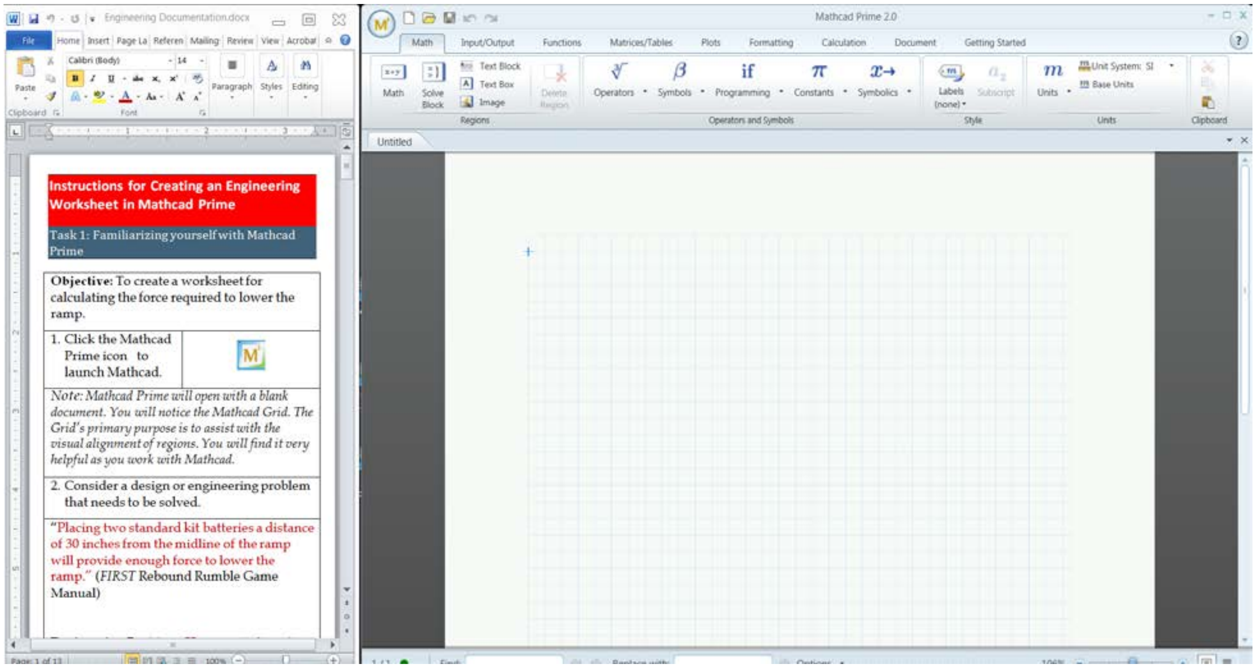
Target Selection: $Target := 0$ Enter 0, 1, 2 for the selected target
Low = 0, Middle = 1, High = 2

$$h_{goal_{Target}} = 2.333 \; ft$$

Desired initial velocity for the basketball is calculated on Page 3.

Detailed Design Exercise 1. Building a Mathcad Engineering Notebook

Navigate to the **HOWS FOLDER 2012**. There you will find a file called: "**Engineering Documentation**". Open this file. You will notice that it is in a narrow format. Position it to the right or left of your computer screen so that you can open **Mathcad** and work from the instructions simultaneously as shown:



Follow the instructions and build an engineering notebook.

Engineering Simulation

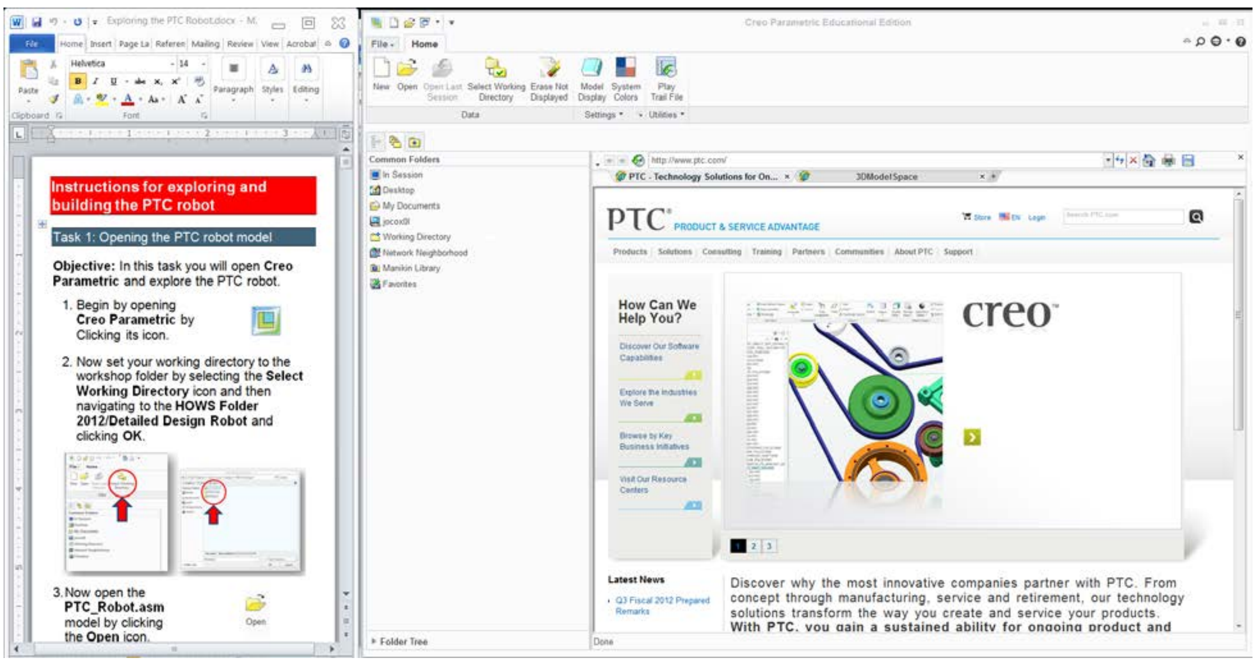
Engineers build virtual prototypes of their designs and then test them using simulations of the real world. In this activity you will learn how to build a model of a robot and then how to take measurements and do simulations of the real world.

The process for virtual prototyping that you will follow in modeling your robot involves building a model of your robot using a library of pre-modeled parts.

This library of parts is like a virtual kit of parts that you will use to assemble your virtual robot. You will use Creo Parametric to assemble your robot model. Once the model is ready, you can test it to see how it will react to static forces and how it will move dynamically.

Detailed Design Exercise 2. Exploring an existing detailed model of a robot

Navigate to the **HOWS FOLDER 2012** and open the instruction file called: “**Exploring and Building the PTC Robot**.” Once again position it on the right or left hand of your screen so that you can work in **Creo Parametric** simultaneously as shown.



Congratulations you have completed the Phase 2 Exercises!

Phase 3: Manufacturing Planning and Production

Introduction

A manufacturing plan involves full documentation of the product design, assembly, and parts. It also includes a plan for how all the parts will be procured or manufactured, how the assembly will occur and final inspection to insure the quality standards are met. An effective plan for your robot design should involve all of these things. The first step is therefore to create complete documentation for your product.

The first set of documentation you will need for your manufacturing plan involves documenting the assembly of your robot. This involves identifying all the parts in your product and how they all fit together. An exploded drawing of your product where all the parts are identified in relation to each other with a bill of materials list is the best way to document your assembly.

Exploded drawings are visual representations of the assembly process for your product and also provide a visual index to each of the parts in the assembly.

There are four simple steps in developing an effective manufacturing plan for your robot.

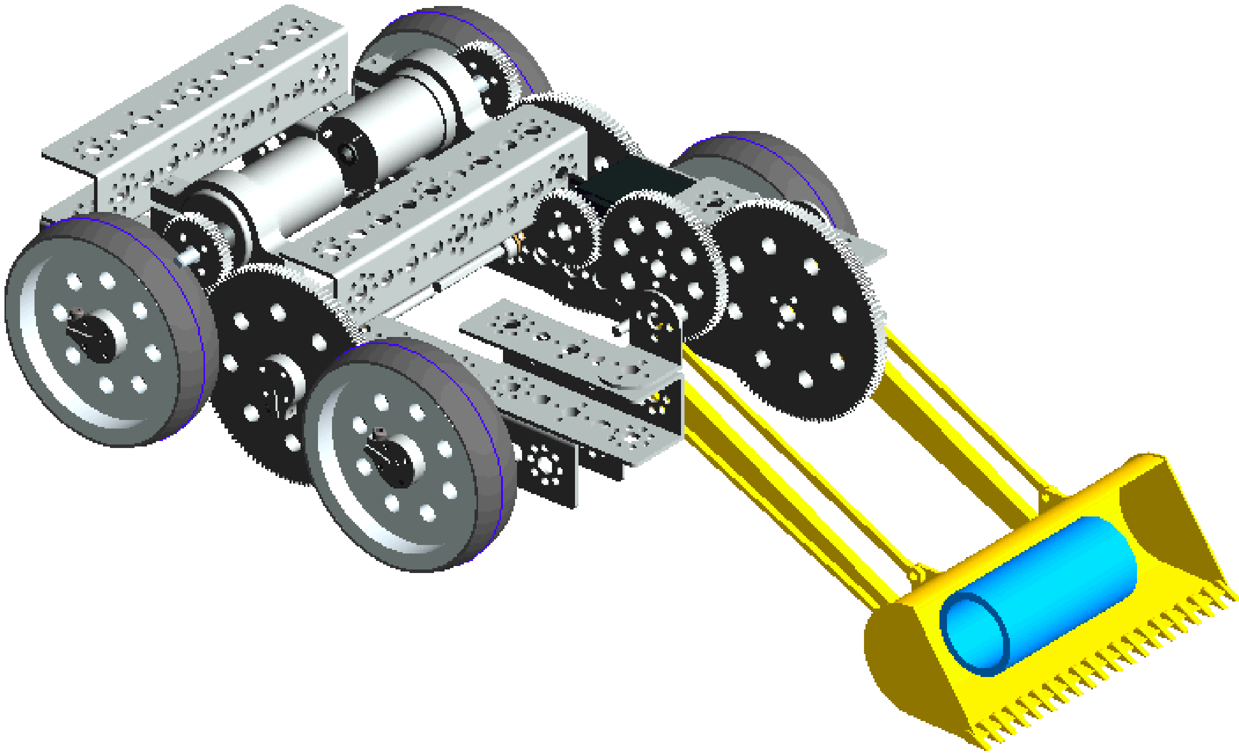
1. Start by creating an exploded drawing of your robot. This exploded drawing should show every part distinctly and should include lines indicating how the parts fit together.
2. Create a bill of materials. A bill of materials is a list that should be included on the exploded drawing to provide a textual representation of all the parts needed and their quantities to build your robot.
3. Write any additional assembly instructions that will be needed to fully assemble your robot. These instructions can include special fixturing needed in the assembly process or any other special instructions.
4. Creating full documentation for any custom parts that may be needed for your robot. This documentation comes in the form of drawings with dimensions so that the parts can be made.

A good manufacturing plan is essential for insuring that the robot is made according to the design and that it can be assembly appropriately and reassembled when being serviced during competition.

Activity One – Creating an Exploded Model

In this activity you are going to learn how to explode an existing model.

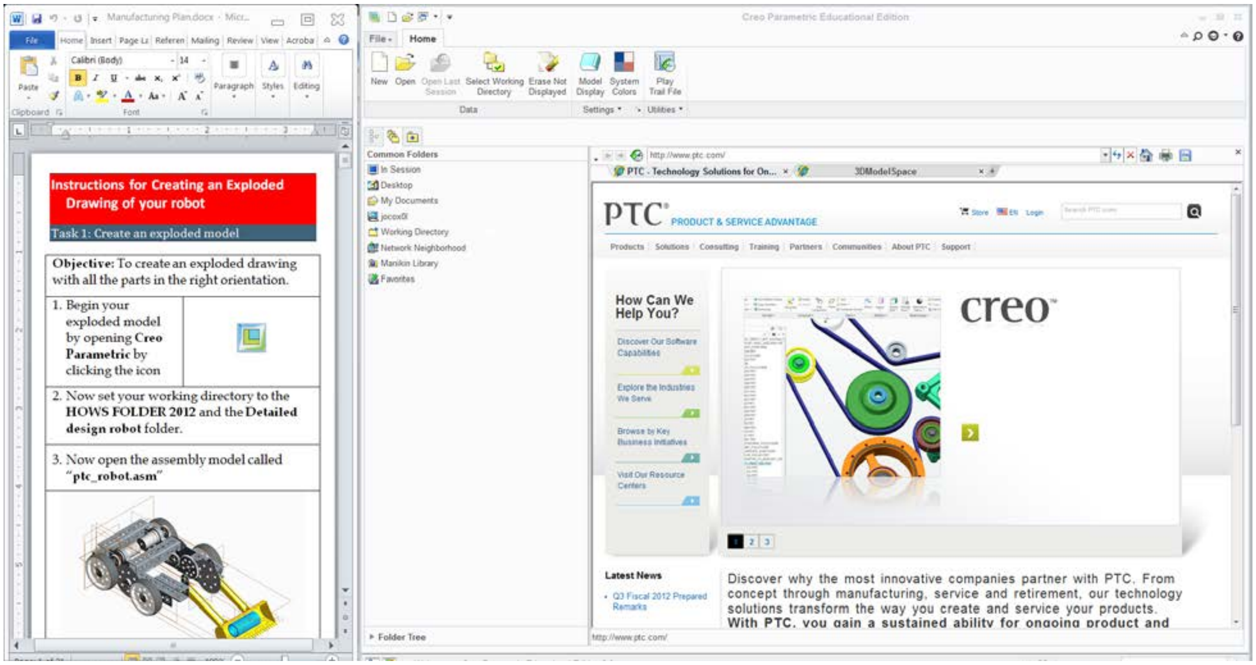
During this activity, you are going to learn how to use automatic explosion as well as manual positioning of exploded parts.



Most manufacturing plans involve drawings of all the parts and instructions about how they will all be made. They also have assembly instructions for the final product. Since most of the parts for your robot have already been made, we will focus in this workshop on creating assembly instructions. This can be done by creating an exploded drawing of the robot with labels on each part that link to a bill of materials or list of all the parts. The exploded drawing provides a visual representation of how all the parts will be assembled to create the final product. The bill of materials provides a list of all the parts in the assembly and the quantities of each.

Manufacturing Planning Exercise 1: Create an exploded drawing of the robot model

Navigate to the **HOWS FOLDER 2012**. There you will find a file called: "**Manufacturing Plan**". Open this file. You will notice that it is in a narrow format. Position it to the right or left of your computer screen so that you can open **Creo Parametric** and work from the instructions simultaneously as shown:



Follow the instructions and build a manufacturing plan.

Congratulations you have completed the Phase 3 Exercises!

PTC® | ACADEMIC PROGRAM

Phase 4: Field Support and Product Retirement

Introduction

It is important to anticipate the problems you may experience with your product when it is in its field of operation. For your robot, this means on the field of competition or in transit. All products fail and experience less than perfect behavior while operating in whatever field they were designed to operate in. Sometimes, products end up being used in ways they weren't designed to operate. However it happens, products need support in the field.

Field Support and Product Retirement

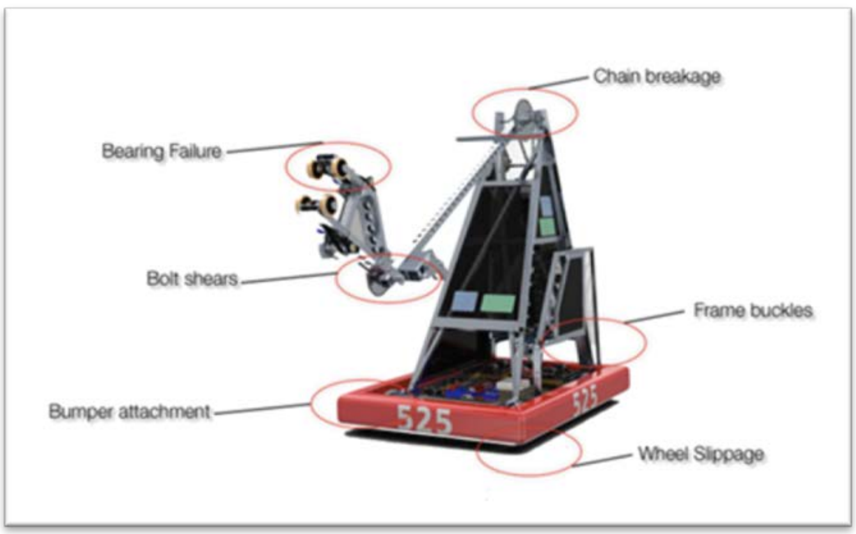
Failure Modes and Effects Analysis

An effective way to anticipate these needs in the field is to perform a failure modes and effects analysis (FMEA). This analysis is a way of predicting how parts might fail in the field.

The analysis involves determining why things might fail (Failure Mechanisms), How things fail (Failure Modes), as well as what probability there will be that they will fail.

Failure modes are defects in the design, the process of making the parts, the inspection process or how the parts are being used. These defects end up causing the failure of the product or system.

The first step in performing a FMEA is to identify all the ways that your robot could fail. This involves a brainstorming session where you and your team members brainstorm all the ways that your robot could possibly fail during competition or transit.



Step 2 is to rank each of these failures in terms of how likely they are to occur and what effect the failure would have on the overall robot system.

Some engineering companies have created worksheets to help them document this brainstorming session.

FFF

FMEA WORKSHEET

Title:__________________________________
System:_______________________________ **Page** ___ **of** ____
Analyst:______________ **Date:**__________

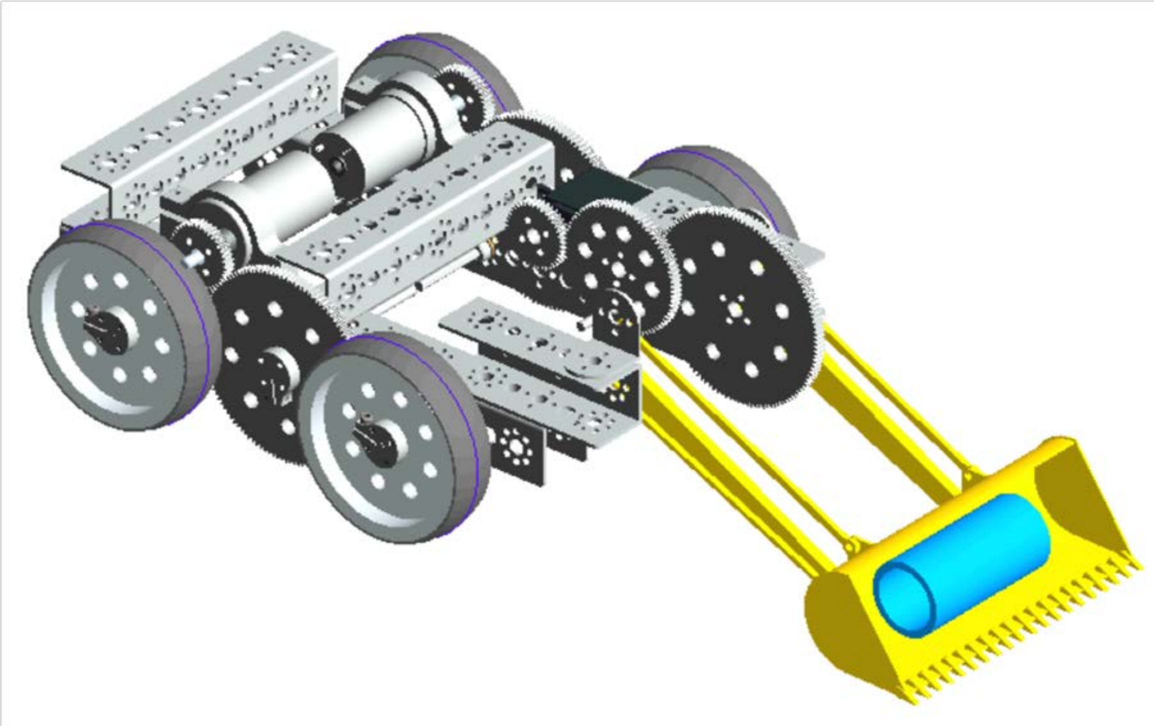
Description	Function	Failure Mode	Cause of Failure	Effect of Failure	Corrective Action Detection	Crit

Step 3 is to discuss a plan for addressing all of the failure modes that you and your team feel have the potential to happen and will be catastrophic to the robot during competition.

Let's review. A field support plan begins with performing a failure modes and effects analysis where all possible failure modes are identified and are classified as to their severity and potential to happen. Once this is completed, a plan is made to procure spare parts or redesign subsystems so that failures won't happen or if they do, there will be back up parts and systems available during competition.

Once your plan is in place, execute it. Procure the parts and be prepared so that your robot can perform at its finest.

Field Support Exercise 1: Failure Modes and Effects Analysis



Do a brainstorming session to execute a failure modes and effects analysis. Use the table below to document each of the possible failure modes and what you would do to resolve them.

Failure Mode	Description	Solution

Congratulations, you have completed the Phase 4 Exercises!

FIRST Team Awards Activity: Matching (Match the Awards to the appropriate description)

1. ____ This Award helps keeps the central focus of the FIRST Robotics Competition on the goal of inspiring greater levels of respect and honor for science and technology
2. ____ This Award celebrates outstanding student leaders whose passion for and effectiveness at attaining, FIRST ideals is exemplary.
3. ____ This Award celebrates outstanding success in advancing respect and appreciation for engineering and engineers, both within their school, as well as their community.
4. ____ This Award is presented each year to one organization or individual for exceptional service in advancing the ideals and mission of FIRST
5. ____ This Award is presented to an outstanding engineer or teacher participating in the robotics competition who best demonstrates excellence in teaching science, math, and creative design.
6. ____ Celebrates the team that best demonstrates the greatest level of Co-opertition during the event, based on their performance on the field.
7. ____ Celebrates creative design, in process, execution, or via a creative or unique strategy of play. It is focused on a feature or features of the machine or development process.
8. ____ Celebrates the entrepreneurial spirit and recognizes a team which has developed a comprehensive business plan in order to define, manage, and achieve team objectives.
9. ____ This Award honors clear and compelling evidence of excellence in design development, documentation, communication, and presentation. The intention of the Award is to inspire, recognize and celebrate design as one way in which you can change your world.
10. ____ This Award celebrates outstanding sportsmanship and continuous Gracious Professionalism™ in the heat of competition, both on and off the playing field.
11. ____ This Award celebrates attractiveness in engineering and outstanding visual aesthetic integration from the machine to the team appearance.
12. ____ This Award celebrates form and function in an efficiently designed machine.

A. Entrepreneurship Award
B. Quality Award
C. Industrial Safety Award
D. FIRST Dean's List Award
E. Engineering Inspiration Award
F. Coopertition™ Award
G. Imagery Award
H. Founder's Award
I. Woodie Flowers Award
J. Creativity Award
K. Engineering Excellence Award
L. Gracious Professionalism
M. Industrial Design Award
N. Chairman's Award
O. Excellence in Design Award

Congratulations for completing the Hands-on Workshop!