Phase

1

HOW TO DEVELOP A

PRODUCT

Concept Development

PRODUCT DEVELOPMENT MANUAL

How to Develop a Product

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TRADEMARKS

ACKNOWLEDGEMENTS

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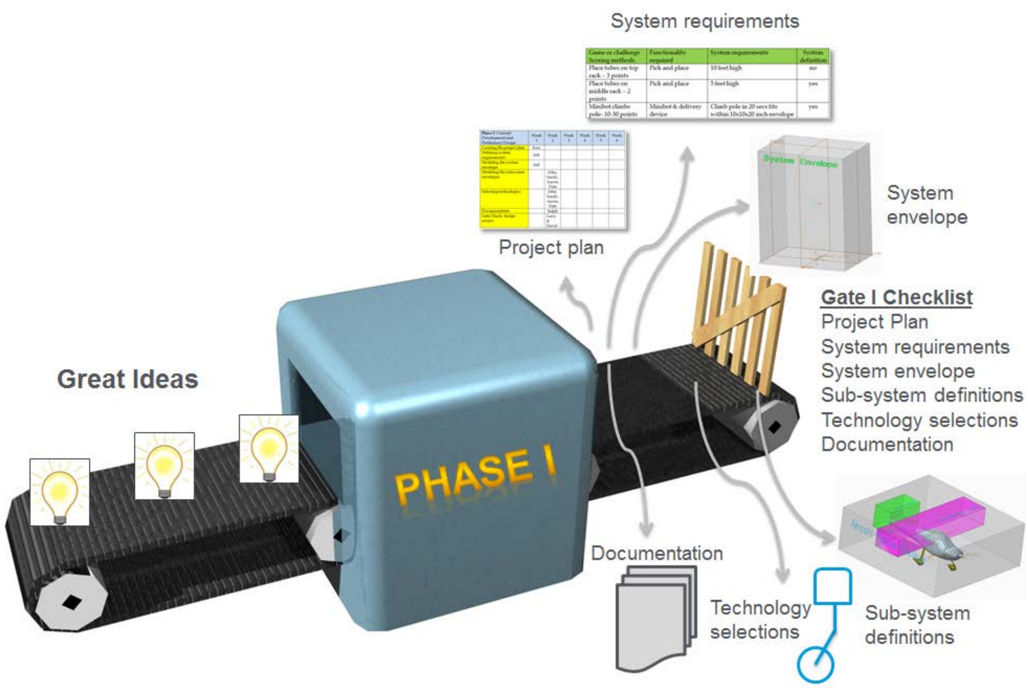
Phase

1

Converting Great Ideas into a Preliminary Design

Phase I: Concept Development & Preliminary Design



Let's get started! Everybody has great ideas. Let's begin by learning how to convert them into a project plan, a set of system requirements, a system envelope, subsystem envelopes, technology selections, and documentation.

Phase 1 of the product development process focuses on converting great ideas into a preliminary system design. This requires that many different tasks be completed. It is important to identify and execute each of these tasks to insure that all of the deliverables are completed. There are many artifacts that are produced during this phase. We will focus on six:

1. A project plan
2. Systems requirements
3. System envelope
4. Subsystem definitions
5. Technology selections
6. Documentation

This chapter presents what each of these artifacts are and how they are created. Exercises are recommended which will help with understanding the concepts. At the end of this phase, there will be a design review or gate check where each of the artifacts will be reviewed.

DEVELOPING A PROJECT PLAN

A project plan is an important part of being successful as a team. Your project plan can be created very quickly simply by gathering all of the tasks from the four gate checks and assigning due dates and owners to each of them. This provides a quick outline for your overall project that can be updated as you manage your program. Here is an example.

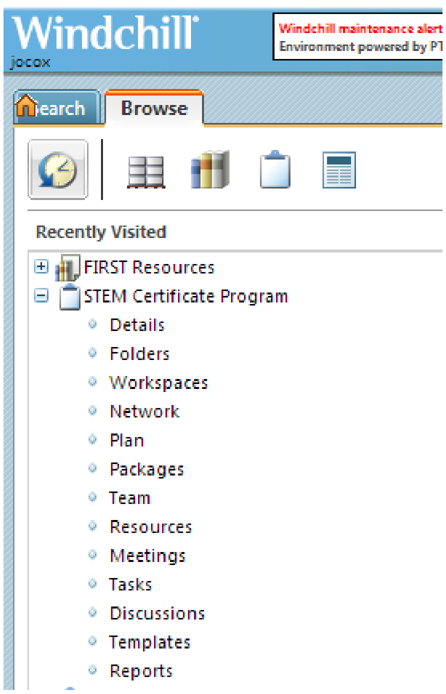
Phase I: Concept Development and Preliminary Design	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Creating the project plan	Keri					
Defining system requirements	Jeff					
Modeling the system envelope	Jeff					
Modeling the subsystem envelopes		John, Sandy, Aaron, Dale				
Selecting technologies		John, Sandy, Aaron, Dale				
Documentation		Ralph				
Gate Check: design review		Larry & David				

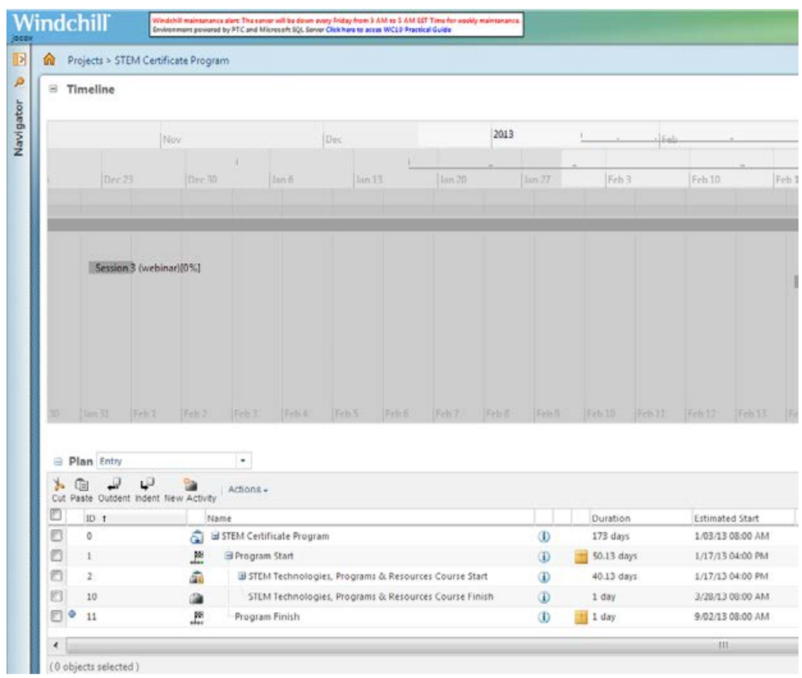
A project plan can be created simply by listing all of the deliverables from each of the phases and then assigning owners and due dates.

Exercise 1: Refer to the Appendix for Exercise 1.0 *Project plan Exercise* and work together as a team to complete an initial project plan

You can use tools such as **PTC Windchill** to automate your project plan. Once you have a **Windchill** project created, you can navigate to the **PLAN** folder and set up your entire plan within **Windchill** so that automatic emails can be sent to remind team members of the due dates and so that the plan is in a central location for the entire team to reference.

Windchill is a web-based tool that engineering companies use to manage all of their data, schedules, and deliverables during the Product Development Process.





*Using the menus in Windchill you can create your **Team**, set up your project **Plan**, schedule **Meetings**, have **Discussions**, and store data and documents in your own **Folders**, just to name a few. A project plan can be created in Windchill that has all of the actions with due dates and owners. Once these are set up inside of Windchill, automatic reminders can be sent through email to help your team stay on schedule.*

Defining the System Requirements

Great ideas need a context and a purpose. In the case of design competitions this context will be provided by the game or challenge definition. In the real world the context comes in the form of a market analysis or request for proposal which identifies a need for a product or service. Regardless of where the context comes from, they must be converted into system requirements. This section will walk you through a simple method for converting your game definitions into an intital set of system requirements.

IN A GAME OR COMPETITION IDENTIFY HOW YOUR SYSTEM IS GOING TO SCORE POINTS

The first step in identifying your system requirements is to identify what your system is going to do. In the case of a robotics competition it means determining how your robot is going to score points. In the case of an aerospace or ground transportation system it means identifying how you are going to complete the challenge. Let's start by listing what your system is going to do.

Review the game definition or competition challenge and then list what your system is going to do. Normally you would do this as a brainstorming session with your team. So let's begin by reviewing some good brainstorming techniques.

Define the problem	Generate ideas	Select the best
Select one person to read aloud the problem statement and make sure everyone understands.	• Be creative • Call out the ideas • Write them on sticky notes • Collect them on the board • (Make sure there is no criticism or judgement during this part of the brainstorming)	Group the ideas Everyone votes for one idea Keep the top 2 or 3

Organize yourselves into groups and select the game or challenge statement and familiarize yourselves with it. Then brainstorm and determine the list of functions your system will have. Here is an example of how to create a list of functions your system will perform.

Game: LOGOMOTION

System Functions:

1. Standard driving
2. Arm to pick up tubes
3. Arm to place tubes on lowest racks
4. Play defense
5. Send small robot to score points at end of competition

Let's start with the FRC game of 2011-2012 Logomotion. It consisted of designing a robot to pick up inner tubes and place them on racks. Also at the end of the match small minibots were deployed to climb a pole. There were many ways to score points. You have to decide which ways your robot will score. Remember it doesn't have to do all of them.

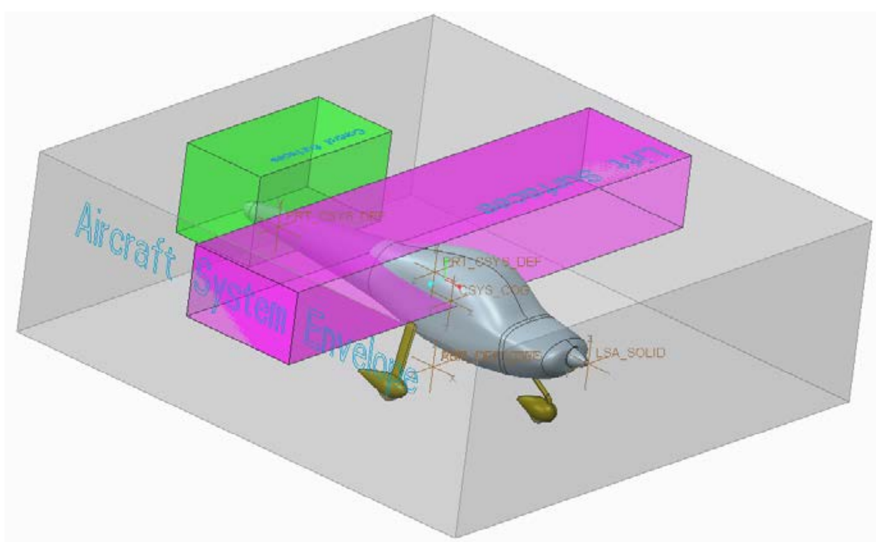
While listing the scoring methods identify what functionality is required and how high or fast it must be done.

Game or challenge Scoring methods	Functionality required	System requirements	System definition
Place tubes on top rack – 3 points	Pick and place	10 feet high	no
Place tubes on middle rack – 2 points	Pick and place	5 feet high	yes
Minibot climbs pole- 10-30 points	Minibot & delivery device	Climb pole in 20 secs fits within 10x10x20 inch envelope	yes

Exercise 2: Refer to the Appendix for Exercise 2.0 *System Requirements Exercise* and select as a group one of the example challenge definitions found there. Complete the System Requirements table at the end of the document by brainstorming as a group.

Defining the System Envelope

The next step in creating a system design is to specify the overall system envelope. This involves determining the physical limits to your system. These limitations are usually specified by the person or company requesting you to design the system. In the case of a game or competition, these limitations are specified in the description.



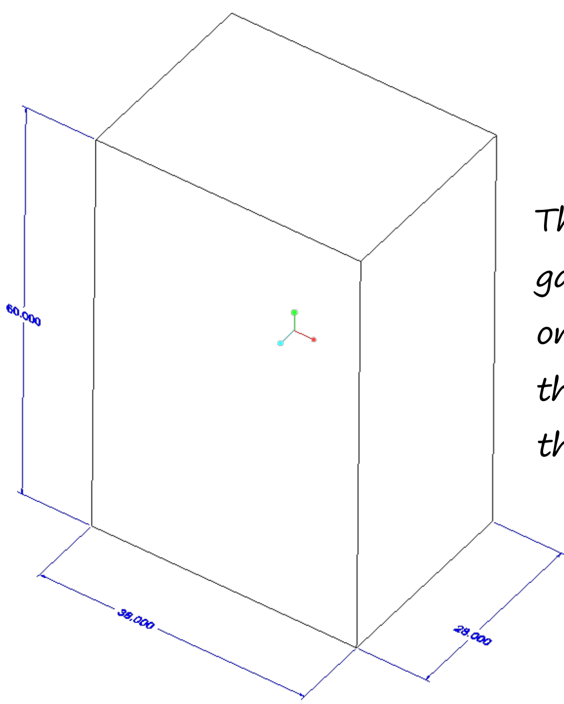
A system envelope is like a see-through box surrounding your system that defines how big it can be. Usually you won't have any idea what your product is going to look like, but sometimes your product will be part of a bigger system. For example you might be asked to design the wings and control surfaces for an airplane. The fuselage may already be designed and you just need to add the wings and control surfaces.

The purpose of defining the system envelope is to begin to define how big your product will be and to insure that it will be within the required limits. Here are several examples using game definitions.

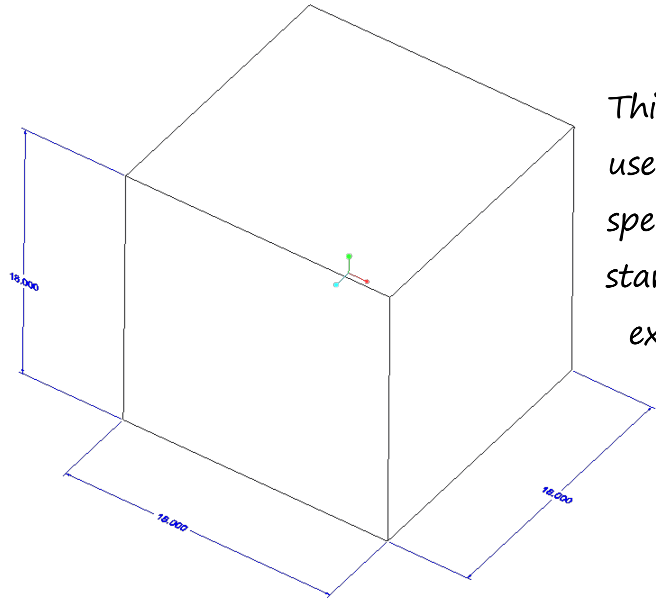
During the MATCH, the ROBOT may not exceed the volume constraints of either STARTING or PLAYING CONFIGURATIONS (note: these limits are defined in reference to the ROBOT, not the FIELD).

	Maximum Horizontal Dimensions	Maximum Height	Maximum Weight
STARTING CONFIGURATION	28" x 38" (71.12cm x 96.52cm) rectangular space	60" (152.40cm)	120 pounds (54.43Kg)
PLAYING CONFIGURATION	84" (213.4cm) diameter vertical right cylindrical volume	N/A	

When determining weight, the basic ROBOT structure and all elements of all additional mechanisms that might be used in different configurations of the ROBOT shall be weighed together. Included in the weight limit are the robot control system, decorations, and all other attached parts.



These were the limits for one of the FRC games. Notice that the definition not only specifies the size of the envelope but the weight as well. We will need to know the cost limits too.



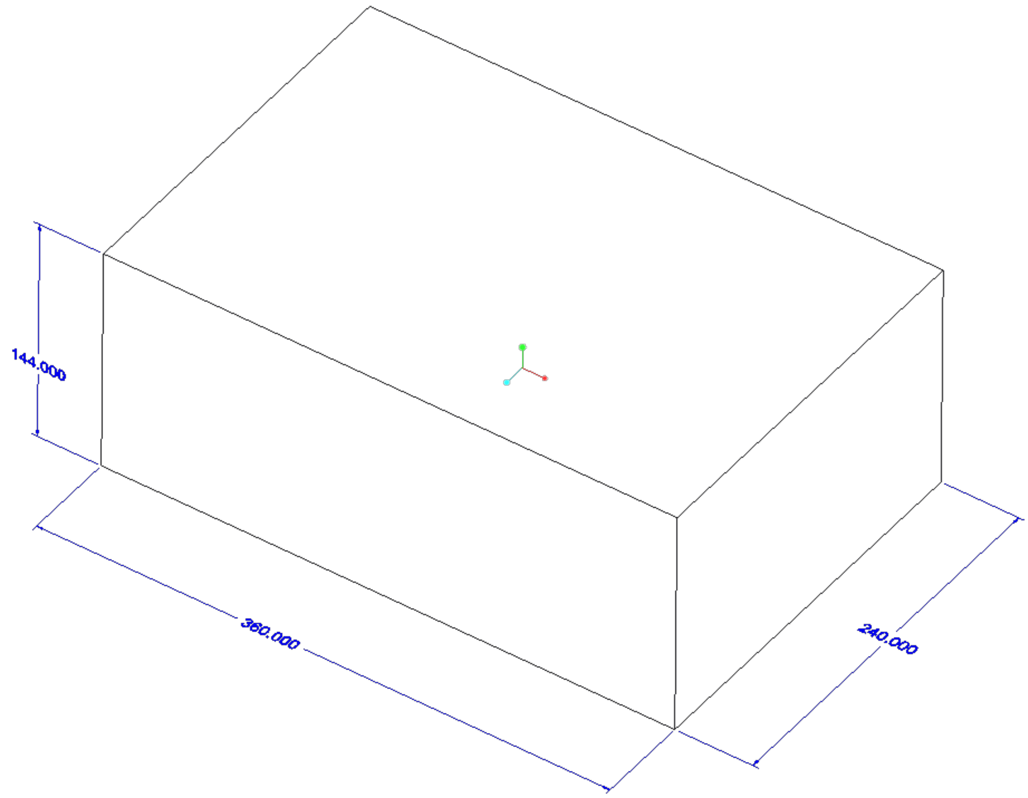
This was a system envelope definition used in an FTC game. Notice how specific the definition is about starting size but how the robot could expand outside these limits once the game began.

At the beginning of any match, the maximum allowed size of a Robot is 18" x 18" x 18" (45.72cm x 45.72cm x 45.72cm).

a. During inspection, the Robot will be placed into a "sizing box" which has interior dimensions matching the above size constraints. To pass inspection, a Robot must fit within the box as defined in the Robot Inspection Section.

b. Robots may expand beyond their starting size constraints after the start of a match.

c. Any restraints used to maintain starting size (i.e. zip ties, rubber bands, string, etc.) MUST remain attached to the Robot for the duration of the match.



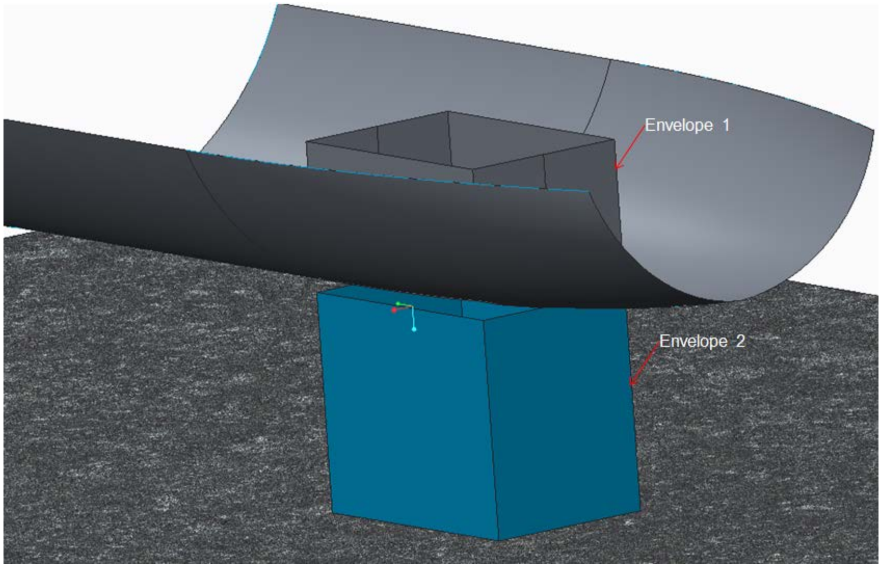
A light-sport aircraft, also known as light sport aircraft or LSA, is a small aircraft that is simple to fly and which meets certain regulations set by a National aviation authority restricting weight and performance. For example, in Australia the Civil Aviation Safety Authority defines a light-sport aircraft as a heavier-than-air or lighter-than-air craft, other than a helicopter, with a maximum gross takeoff weight of not more than 560 kilograms (1,200 lb) for lighter-than-air craft; 600 kilograms (1,300 lb) for heavier-than-air craft not intended for operation on water; or 650 kilograms (1,400 lb) for aircraft intended for operation on water. It must have a maximum stall speed of 45 knots (83 km/h; 52 mph) in landing configuration; a maximum of two seats; a maximum speed in level flight with maximum continuous power (Vh)—138 mph (120 knots) CAS; fixed undercarriage (except for amphibious aircraft which may have repositionable gear, and gliders which may have retractable gear); an unpressurized cabin; and a single non-turbine engine driving a propeller if it is a powered aircraft.

In the RWDC 2011 challenge, the overall system envelope had to be calculated. In fact it was part of the challenge to determine what the overall envelope would be. Notice though that the weight is specified.

For this challenge it was sufficient to identify a beginning envelope which would change as the design progresses. Something like: 20'x30'x12' (width x length x height)

Once the envelope has been determined, the overall weight and allowable cost must also be defined. The FRC LOGOMOTION system weight was: 120 lbs. The FTC overall weight was not constrained and the RWDC overall weight was: 1,200 lbs. Cost may or may not be defined and once again a starting guess is sufficient since it will be refined as the design progresses.

It is important to note that depending on the game or competition the system envelope could have multiple parts. For example, if a RWDC challenge was focused on designing landing gear for an aircraft, it might define two envelopes one for the gear deployed and one for the gear retracted as shown.



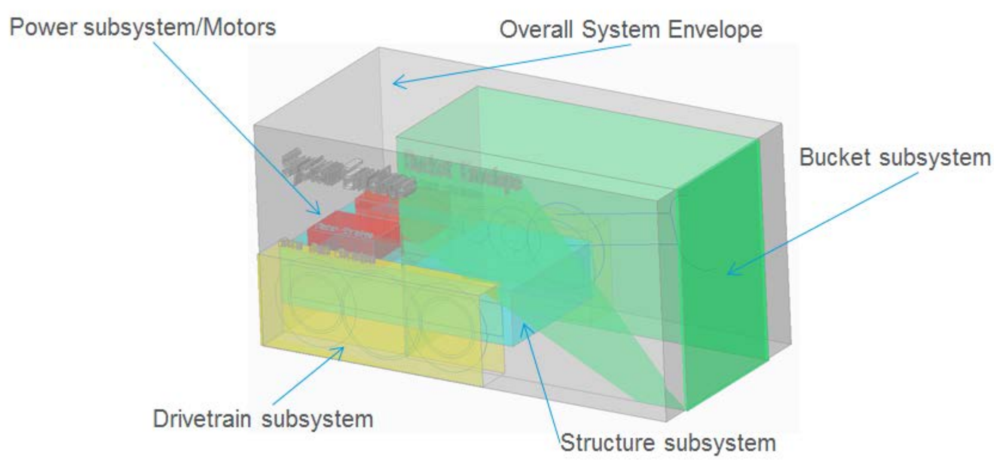
It is not uncommon for a system envelope to be a combination of several smaller envelopes depending on the function of the system.

The final step in the system envelope design is to create an actual model of the system envelop. This can be done using a CAD system like Creo Parametric. The best practice is to create the envelope model as an assembly of envelopes that will be the model of the system and all of the subsystems that will be defined later on in the preliminary design.

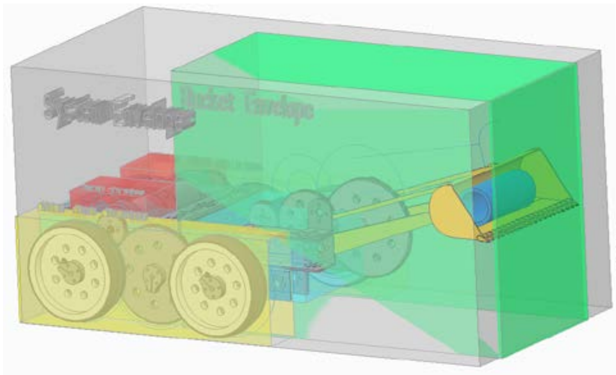
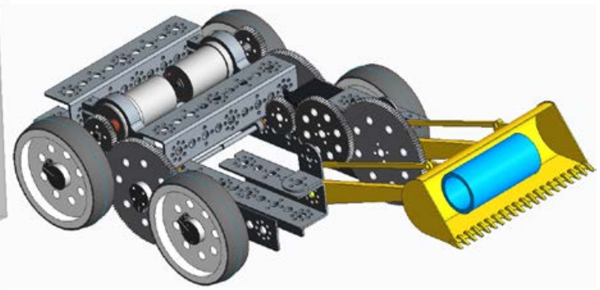
Exercise 3: Refer to the Appendix for Exercise 3.0 *System Envelope Exercise* and create a system envelop assembly file in PTC Creo Parametric. Then create a skeleton file and define an envelope that represents the overall system envelope. Save the file.

DEFINING THE SUB-SYSTEMS AND THEIR ENVELOPES

After the system envelop has been defined, you can begin to design your system at a very preliminary or conceptual level by identifying the subsystems and creating subsystem envelopes for each one. In this way, you are dividing the overall size, weight and cost of the system into the definitions of the subsystems.

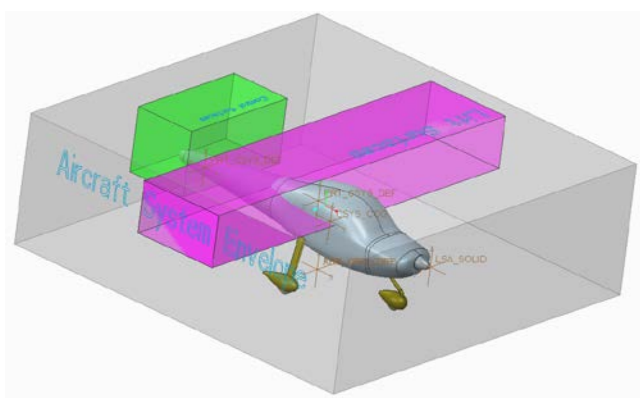


This is the first step in designing your system. You get to decide what subsystems you will have, what size they will be and where they will be positioned as well as how much they will weigh and cost. Eventually these subsystems will become the designs of the parts that will create your final design.

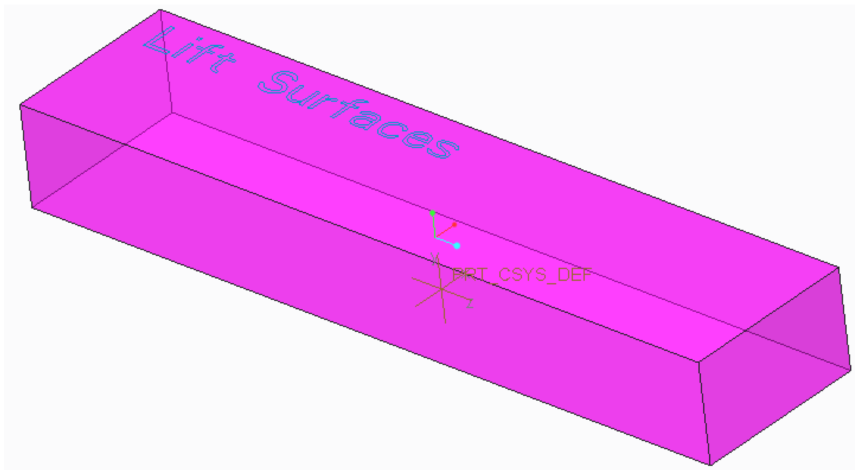
Now that the system requirements are known, and the envelope defined, the next step in designing your system is to identify the subsystems you will need and then to distribute the system weight and cost to these subsystems. For example, if you are designing an aircraft system you might define the lift surfaces and the control surfaces and the fuselage as the subsystems as shown in the figure below. The lift surfaces and the control surfaces are yet to be designed. All that is known is the rough size and location of these systems. You can create a virtual model of this by creating envelopes for the subsystems. This can be useful for developing size, weight, center of gravity and other preliminary calculations.

The subsystems can be defined as simple envelopes and positioned in the overall system envelope according to their function. This airplane system and subsystem model shows the wings and control surfaces as simple envelopes, but their size and position are defined.



So to begin, you must identify all the subsystems that you will have in your design. At this point you may not know every subsystem, but you need to identify all of the subsystems you do know. Group the system functions into logical sub groups. You will once again need to brainstorm as a group to identify the subsystems. For an aircraft they might be the lift surfaces, the control surfaces, the fuselage, the thrust, and the landing gear. For a robot they might be the drive train, the electronics, the structure, the arm, and the gripper. You will need to define them based upon your system needs.

Now for each subsystem you need to define an envelope just like you did with the system. This is part of the design process for you. You are now the designer and you must decide how much of the overall system envelope each subsystem will occupy. You also must allocate a weight and a cost for each subsystem.



Here is the envelope for the lift surfaces subsystem for an airplane.

This is an important part of a top-down design strategy to allocate the overall system envelope, weight and cost to the sub-systems. The easiest way to do this is by dividing the system envelope , weight and cost by percentages. So you might identify a subsystem to be the drive train and allocate 25% of the envelope, 35% of the system weight and 15% of the cost to it. You will need to allocate some percentage of the system envelope, weight and cost to each subsystem. One strategy is to keep some of the weight and cost as a reserve for any new subsystem that you discover you need later on.

A good way to keep track of all of this is to use a table as shown:

List each of the subsystems and then allocate the percentage of the overall system weight, cost and size.

Subsystem	Function	Envelope	Weight	Cost
Drive train	Robot motion	25%	35%	15%
Gripper	Hold tubes	5% (5x5x9)	1%	10%
Arm	Pick and place	10%	20%	25%
Electronics	Control	10%	15%	30%

Remember that each column must sum to 100% or less. This is the first real design activity that you will do as you allocate volume, weight, and cost to the various subsystems. Remember that these are targets. Your final designs will not be exactly these numbers but these are the targets you will try to meet as you design the subsystems.

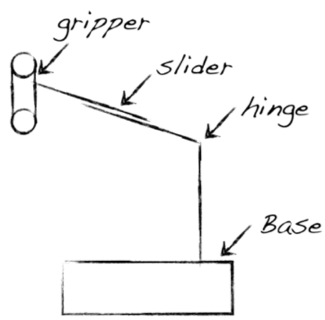
In the next exercise, you will identify the subsystems for a robot and then create envelope models for each of the subsystems with their relative size and then assign them their weight allocation. You will assemble them into the system model so that you can determine their position with respect to the system and calculate an initial center of gravity.

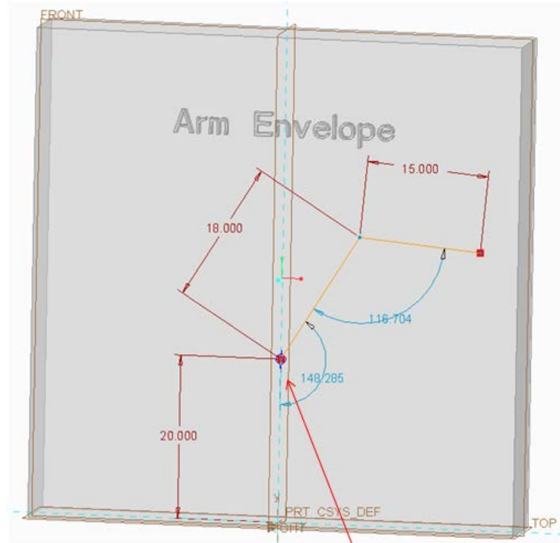
You will create the sub-system envelopes in a similar manner as you did the system envelope and then assemble them into the system envelope assembly model. Move them around and rearrange them to improve the system center of gravity. This is the first part of designing your system.

Exercise 4: Refer to the Appendix for Exercise 4.0 *Subsystem Definition Exercise* for detailed instructions for completing this exercise.

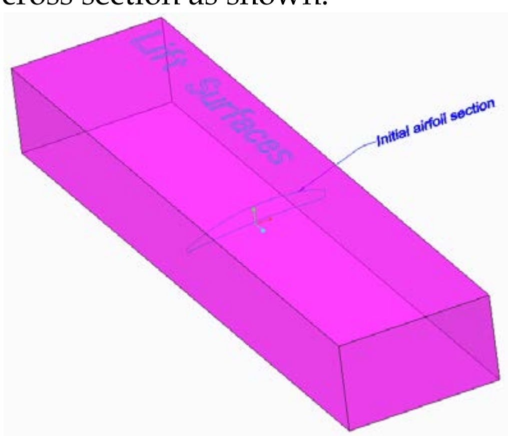
Selecting the Technology Solutions

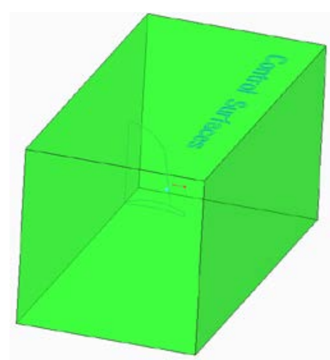
The specific technologies that you will use in each subsystem must be selected. At this point you will only be able to identify conceptual models of these technologies. This can be done using simple 2D sketches that can animate to show kinematics or other functions.





Once your system model is tuned to provide the best weight, cost, center of gravity and positioning for the subsystems, it is time to begin to select the technologies that you will use in your subsystems. Since this is still in the conceptual modeling and preliminary design phase, the models of the technologies you are going to use will be conceptual. For example, let's assume we are working on the aircraft system and want to select a technology for the lift surfaces. At this point it may be sufficient to identify an initial airfoil cross section as shown.

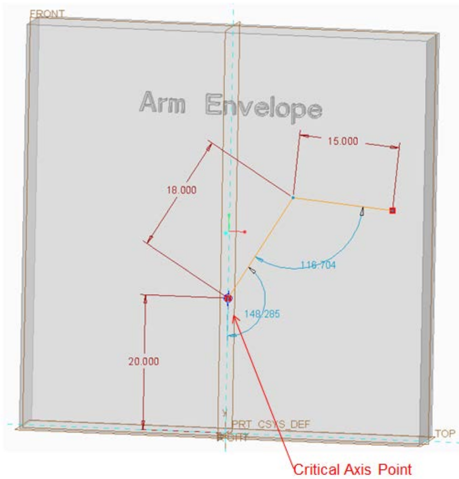


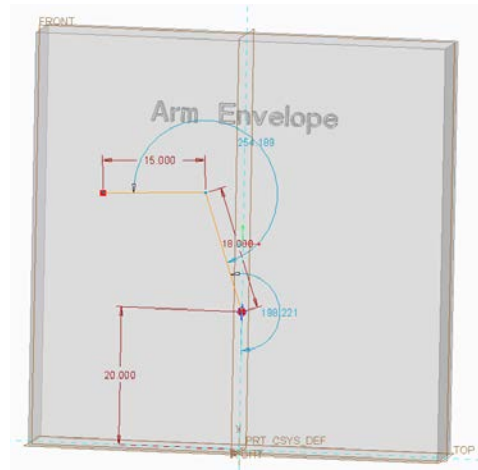


Simple 2D sketches can represent the conceptual design concepts you will use later on in creating the detailed designs of each subsystem.

For a robot subsystem, the technology may be a kinematic mechanism. For example, the arm subsystem could be a set of linkages as shown. In Creo Parametric you can create a 2D sketch of these linkages and the sketch can be animated to determine how the arm would work.

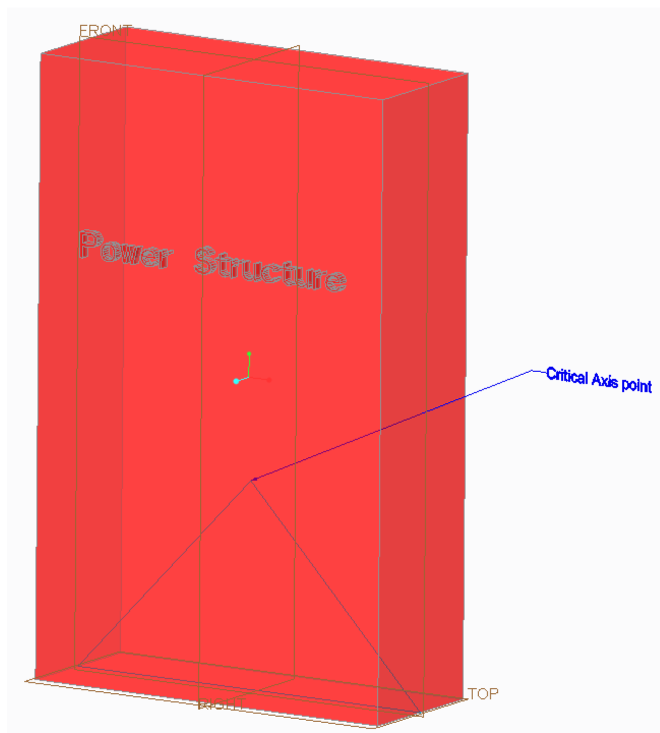
A 2D sketch can be animated so that the concept can be validated.





This allows you to create conceptual models of your subsystems quickly that can help you to see if the concepts will work and will identify the critical points such as axes for arm connections, etc.

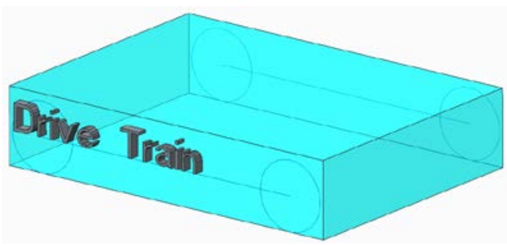
These critical points are important as well because they tend to be the interaction points between subsystems. For example the critical axis point in the robot linkage model must be supported by the Power Structure subsystem. So the Power Structure subsystem model must also have this critical axis point identified.

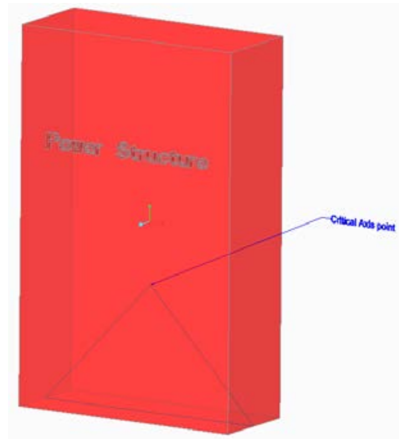


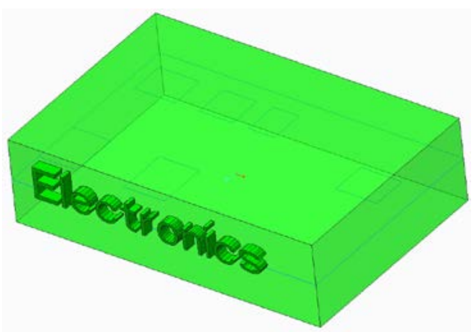
Critical axes and connection points can be identified so that the subsystems can be integrated into the system model.

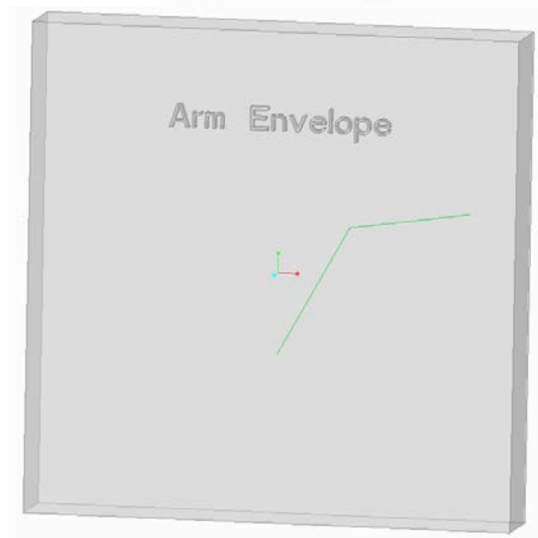
Brainstorm as a team to identify the initial starting technologies for each of the subsystems and then create 2D sketches of them within the subsystem envelopes you created. Once these modesl are complete, you are ready to document your system design and conduct a design review.

Now let's review, In identifying potential technologies, consider the libraries of technologies available on the internet or in books. Spend some time researching what the possibilities might be. There are kinematic mechanisms, airfoils, aerodynamic profiles, etc. Create 2D sketches of these technology selections that can be "live" in the case of kinematic mechanisms so that you can move them and determine if they will provide the functions needed.





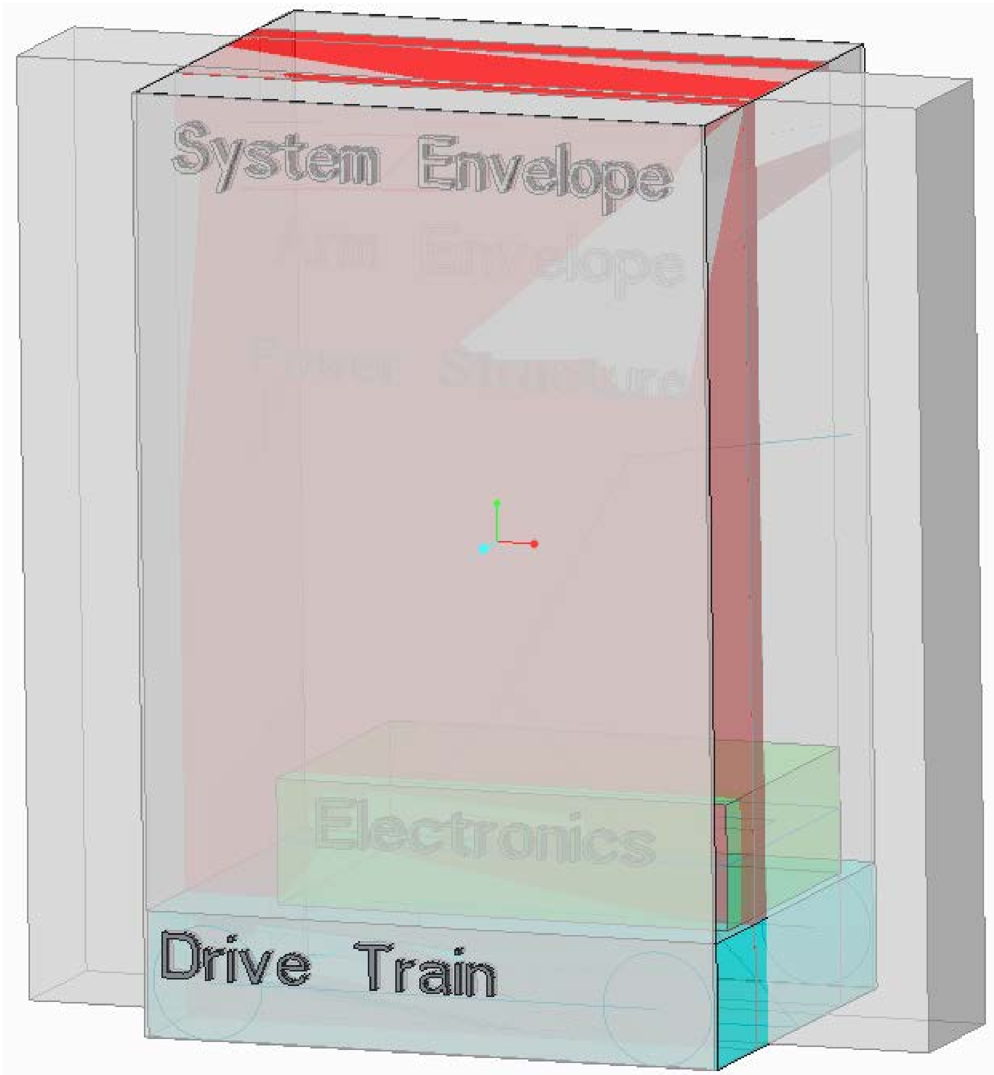




Create each of your subsystem envelope models with the associated technology sketches.

Choose the best technologies for each subsystem and then create the 2D sketches of them in your subsystem models customizing them for the right size, shape and location. Then identify important datums and references from these sketches that will be used for your detailed design of the sub-systems.

The final system model combines all of the subsystem envelopes and technology sketches into the system envelope model.



Finally, consider the interfaces between the subsystems. What technologies will be needed to transfer power or motion or forces between the subsystems? Identify these technologies and place them in the subsystem models as well. Remember that this is the point where you can explore many different types of technology solutions quickly and cheaply.

Exercise 5: Refer to the Appendix for Exercise 5.0 *Technology Selection Exercise* for instructions on completing this exercise.

Develop these conceptual models until you are ready to move on to the detailed design phase.

Documenting

One of the most important parts of your product development is documenting the decisions that are made. Keep a notebook and document each of the system and subsystem design decisions that you make. You can certainly print the tables and pictures of the envelopes and paste them into your notebook. You should also be using PTC Windchill to store all of your models. This repository is part of your documentation.

Conducting a Design Review – Phase I Gate Check

Congratulations, you have completed the first phase of the product development process. Now you need to do a gate check to make sure everything is ready to move on to the next phase in the product development process. A gate check is best conducted as a design review. Assemble a group of mentors and then go through each of the aspects of your design to date. This is your chance to present the preliminary design of your system. Use all the artifacts you created like the system requirements table and envelope models. Review the overall system envelope design and then each of the subsystem envelopes and finally the integrated system. Review each of the technologies and do a final review on your documentation. Record the design review in your notebook along with recommended changes and have the mentors sign and date it.

Phase

1

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APPENDIX

EXERCISE 1.0: A PROJECT PLAN

Step 1: Complete this table by writing the names of the team members who will be responsible for the given artifact in the table cell which is the due date for that artifact as shown in the figure below. Complete this for all of the phases.

Phase I: Concept Development and Preliminary Design	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
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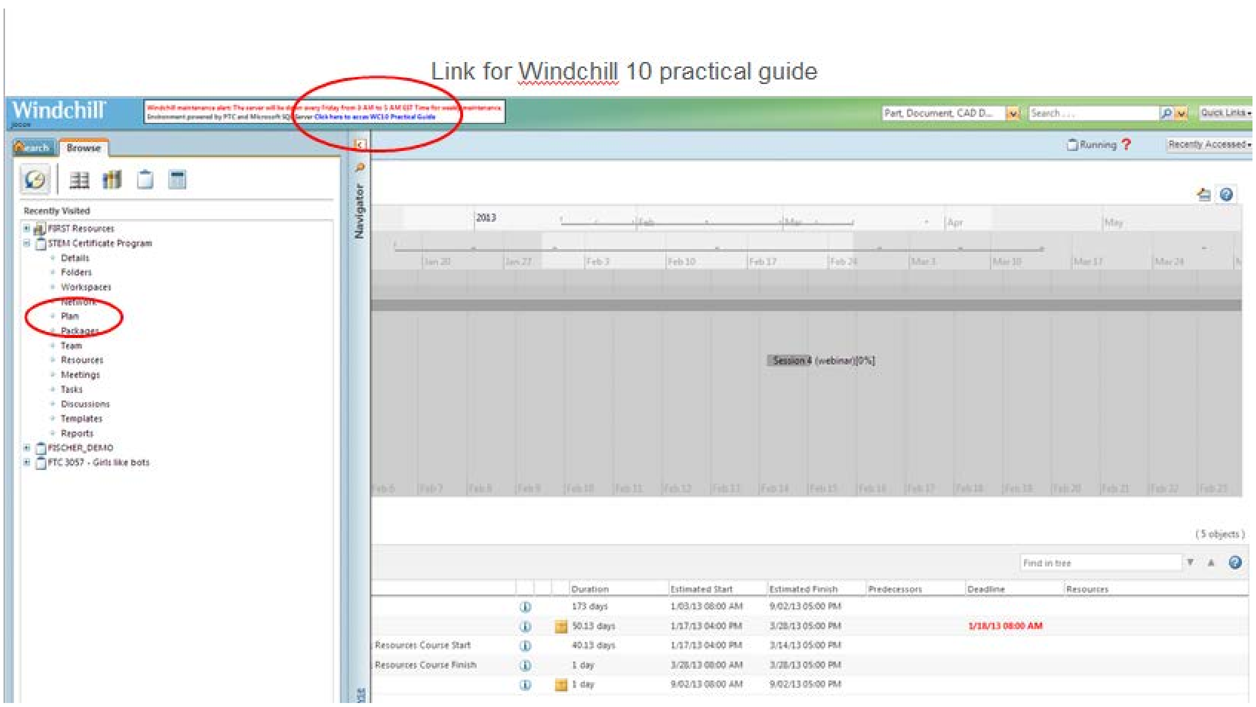
Selecting technologies		John, Sandy, Aaron, Dale				
Documentation		Ralph				
Gate Check: design review		Larry & David				

Project Plan Table

Phase I: Concept Development and Preliminary Design						
Creating the project plan						
Defining system requirements						
Modeling the system envelope						
Modeling the subsystem envelopes						
Selecting technologies						
Documentation						
Gate Check: design review						
Phase II: Detailed Design, Prototype & Test						
Susbsystem detailed designs						
System integration						
Simulation						
Testing						
Documentation						
Gate Check: design review						
Phase III: Manufacturing Planning & Production						
Assembly Plan						
Manufacturing Plan						
Supply Chain						

Documentation						
Gate Check: design review						
Phase IV: Field Support & Product Retirement						
Product						
Field support plan						
Product retirement plan						
Documentation						
Gate Check: design review						

Step 2: Create your plan in PTC Windchill. You can refer to the Windchill 10 practical guide to set up your project plan within Windchill. This will allow you to automate reminders and provide a central location for the plan.



Exercise 2.0: System Requirements

Select one of the game/challenge descriptions below and complete the table at the end of this document.

1.5 LOGO MOTION™ SUMMARY

LOGO MOTION is played by two competing alliances on a flat 27' x 54' foot field. Each alliance consists of three robots. They compete to hang as many inflated plastic shapes (triangles, circles, and squares) on their grids as they can during a 2 minute and 15 second match. The higher the teams hang their game pieces on their scoring grid, the more points their alliance receives.

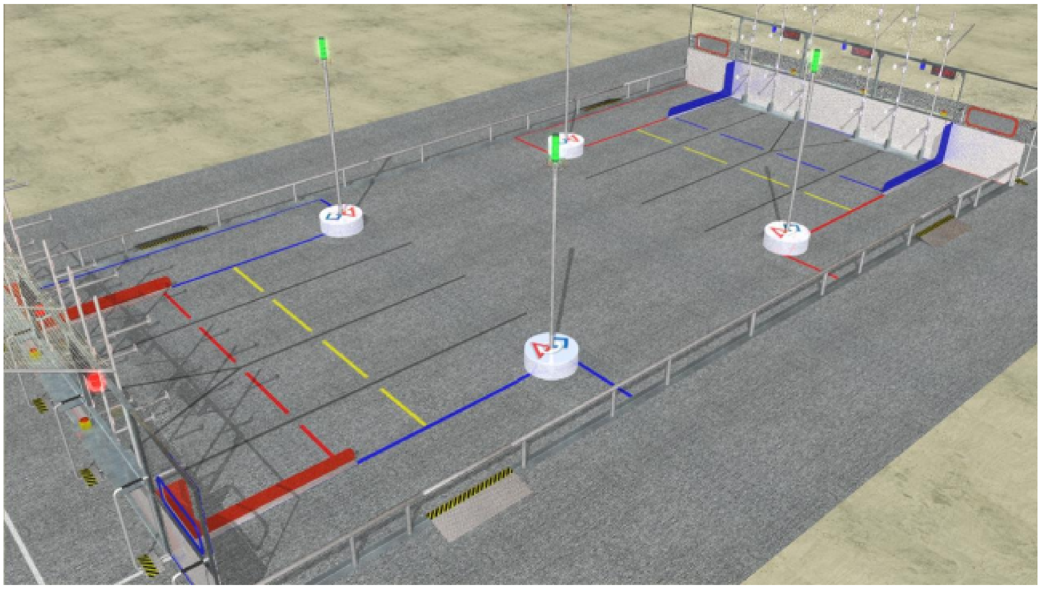
The match begins with one 15-second Autonomous Period in which robots operate independently of driver inputs and must hang Ubertubes to score extra points. For the rest of the match, drivers control robots and try to maximize their alliance score by hanging as many logo pieces as possible. Any logo piece hung on the same peg as an Ubertube receives double points. If teams assemble the logo pieces on their scoring grids to form the *FIRST* logo (triangle, circle, square, in a horizontal row in that order), the points for the entire row are doubled.

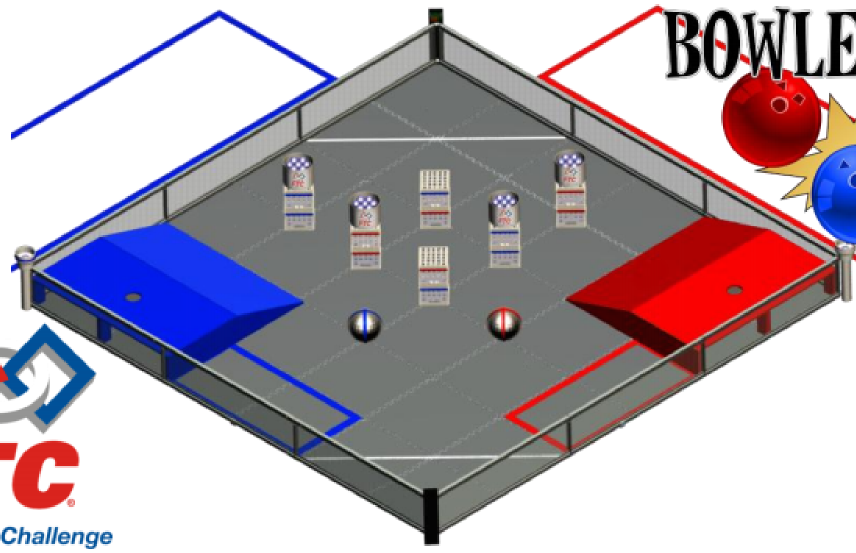
The match ends with robots deploying minibots, small electro-mechanical assemblies that are independent of the host robot, onto vertical poles. The minibots race to the top of the pole to trigger a sensor and earn additional bonus points. Scoring is summarized below:

Ubertubes hung during Autonomous	
On bottom row	2 points
On middle row	4 points
On top row	6 points

Logo pieces	*Alone*	*Over Ubertube*
On bottom ROW	1 point	2 points
On middle ROW	2 points	4 points
On top ROW	3 points	6 points

Minibot race bonus	
1st MINIBOT	30 points
2nd MINIBOT	20 points
3rd MINIBOT	15 points
4th MINIBOT	10 points





Use your Smart Phone to scan this!

The Game:

Bowled Over! is played on a 12'x12' diamond shaped field as shown on the diagram above. Two alliances – one "red" and one "blue" – composed of two teams each compete in matches consisting of a 30 second autonomous period followed by a two-minute driver controlled period.

The object of the game is to score more points than your opponent's alliance by placing racquet balls into crates and then stacking the crates. Teams will be challenged to complete tasks during autonomous and driver controlled periods and will score special racquetballs and six pound bowling balls for additional points.

The Details:

There are a total of 100 racquetballs available to both teams as scoring objects in the game. The field also holds 12 stackable Ball Crates that teams can fill with racquetballs and stack for additional points, and two bowling balls that can be scored during the autonomous or end game period for additional points.

The field includes two home zones comprised of a platform and a ramp, and two protected zones where a team may stack their crates without fear of having them toppled by their opponents.

End Game:

The final thirty (30) seconds of the Driver Controlled Period is called the End Game. Each Alliance is challenged to push their Bowling Ball onto their Home Zone or to elevate stacks of Ball Crates to score additional points based on the height of the Ball Crates.

Autonomous Period Scoring:

Upright Ball Crate	5 points each
Parking a Robot	
In Back parking zone	5 points
Parking a Bowling Ball	
In Back Parking Zone	20 points
Parking a Robot	
In Front Parking Zone	10 points
Parking a Bowling Ball	
in Front Parking Zone	10 points

Match Scoring:

Regular or Magnet Ball in Low Goal	1 point each
Regular or Magnet Ball in Ball Crate	2 points each
Magnet Ball in Off Field Goal	25 points each
Crates Stacked are awarded Based on the highest point of each crate in the stack (for a crate to count it must contain at least one ball)	10 points above 10.5", then 10 more points for each 6" above that

FY12 RWDC State Challenge Statement

Background:

In September of 2004, the FAA approved a new category of aircraft called Light Sport Aircraft (LSA). This category is a new classification of simple-to-operate aircraft with less demanding pilot and aircraft certification requirements. The LSA movement is opening the world of flight to more people through lower cost of ownership and operation.

In addition, with the political, environmental, and economic consequences of fossil fuel consumption, the transportation industry at large is compelled to "go green" in order to reduce dependency on these increasingly costly energy resources.

The Challenge:

The challenge is to design an efficient, low-carbon-emission and environmentally friendly personal light sport aircraft. The aircraft must accommodate two team members and fly 200 miles in less than two hours at a cruise altitude of 1000 feet above ground level (AGL) minimum.

For the State Challenge, teams will perform aerodynamic, propulsion, sizing, and weight estimation analyses to optimize wing geometry and minimize fuel consumption. Teams are to write a 2000 word essay on what they would see and do given the opportunity to fly their design across the country.

The Final Design Must:

1. Follow FAA design criteria for Light Sport Aircraft:
http://www.faa.gov/aircraft/gen_av/light_sport/.

2. Document design details including:

a. Aerodynamics Analysis (C_L, C_D, C_M versus angle of attack, AOA).

C_L is the aircraft coefficient of lift, C_D is the aircraft coefficient of drag, CM is the aircraft coefficient of moment.

b. Power Loading

c. Wing Loading

d. Airplane Sizing

e. Engine Sizing and Selection

f. Wing Geometry

g. Airfoil Selection

h. Tail Geometry

i. Fuselage Geometry

j. Weight Estimation

k. Material Selection for Wing

Objective Function:

Minimize the objective function (OF), which is the aircraft cruise efficiency, for the flight mission to fly two team members 200 miles in less than two hours by varying specified design variables without violating constraints:

$$OF = 0.57K(A^3B)^{-\frac{1}{4}}$$

Where

$$K = \frac{C_D/C_L}{V}, \quad A = \frac{\rho C_D S}{2W}, \qquad B = \frac{2W}{\rho b^2 \pi e}$$

V is the aircraft cruise velocity, **ρ** is the density of air, **S** is the wing planform reference area, **W** is the aircraft weight, and **b** is the wing span. **e** is the Oswald's efficiency factor which can be estimated from the empirical equation, $e = 1.78(1 - 0.045AR^{0.68}) - .64$, for straight wing aircraft with normal aspect ratios, or with computational fluid dynamics (CFD) software. **AR** is the wing planform aspect ratio. Weight will be estimated with Mathcad and Mechanica methods. See reference on flight efficiency listed below for background on equations.

Design Variables:

- Wing area
- Wing aspect ratio
- Wing taper
- Wing sweep
- Wing twist
- Root and tip airfoil shapes
- Wing placement
- Power plant selection
- Fuselage selection
- Wing material selection

Constraints:

- A maximum takeoff weight of not more than 1,320 pounds.
- A maximum airspeed in level flight with of not more than 120 knots under standard sea level atmospheric
- conditions.
- A maximum stalling speed (or minimum steady flight speed without the use of lift-enhancing devices) of
- not more than 45 knots at the aircraft's maximum takeoff weight and most critical center of gravity.
- A maximum seating capacity of no more than two persons, including the pilot.
- A single reciprocating engine or electric motor.
- A fixed or ground-adjustable propeller.
- A non-pressurized cabin.
- Fixed landing gear.
- Not to exceed material allowables for ultimate load condition (6g's) at maximum cruise speed at sea level.
- A minimum skin gage of 0.032 inches.

Assumptions:

- U.S. Standard Atmosphere and Standard Day conditions with no winds aloft.
- Other active design elements (i.e. propeller sizing) will be managed by supporting worksheets and Mathcad methods.

Resources:

- UIUC Airfoil Coordinates Database: http://www.ae.illinois.edu/m-selig/ads/coord_database.html
- CAFÉ Foundation Green Flight Challenge and Resource Library:
- http://cafefoundation.org/v2/gfc_main.php
- http://cafefoundation.org/v2/tech_lib.php
- Landmark paper in flight efficiency:
- http://cafefoundation.org/v2/pdf_tech/MPG.engines/AIAA.1980.1847.B.H.Carson.pdf
- NASA – Green Aviation: http://www.nasa.gov/centers/ames/greenspace/green-aviation.html □ The RWDC Support Site with FAQs, tutorials, Mathcad modules, material allowables, library of available
- propulsion systems and fuselages, and other supporting materials:
- www.ptc.com/go/rwdcgettingstarted
- http://www.ptc.com/appserver/wcms/standards/fileothumbredirect.jsp?&im_dbkey=132074&im_la

- nguage=en
- Mentors from the aviation industry.
- Tools:
- Creo Elements/Pro Student Edition, Creo Elements/Pro Mechanica, Mathcad Prime 1.0 Student Edition,
- and the Windchill collaboration site provided by PTC.
- FloEFD.Pro aerodynamic analysis software provided by Mentor Graphics.
- Sizing and performance worksheets in Mathcad and Excel provided by NASA and PTC.
- Scoring:
- Technical scoring will be based on deliverables to be incorporated in the Design Notebook.
- Design Notebooks should follow the paragraph order of the Scoring Rubric.
- Judges will be looking for ability to express comprehension, and linkage between the design solutions
- with what students have learned. Specific merit will be given for design viability, innovation, and design
- considerations that minimize carbon, noise, and infrastructure footprints

System Requirements Table

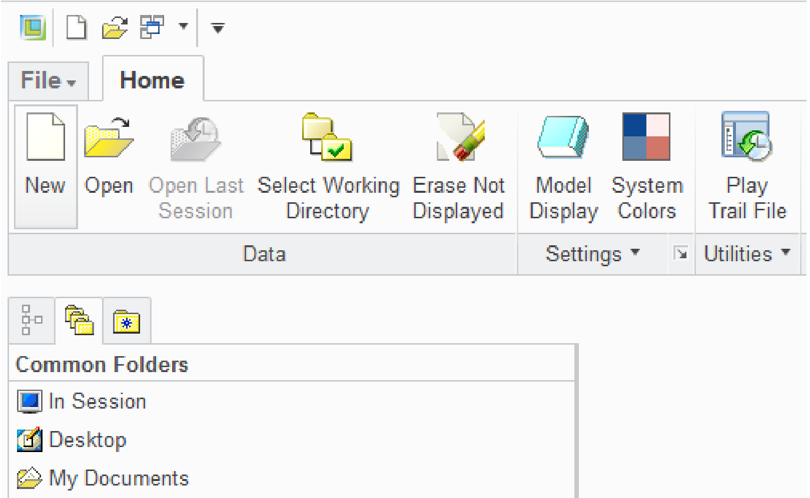
Complete the table by identifying the scoring options, the functionality required and then the system requirements. Be as specific as you can be in providing numbers or measures for the system requirements. Then indicate whether you will be including each option in your system design as shown below:

Game or challenge Scoring methods	Functionality required	System requirements	System definition
Place tubes on top rack – 3 points	Pick and place	10 feet high	no
Place tubes on middle rack – 2 points	Pick and place	5 feet high	yes
Minibot climbs pole- 10-30 points	Minibot & delivery device	Climb pole in 20 secs fits within 10x10x20 inch envelope	yes

Game or challenge Scoring methods	Functionality required	System requirements	System definition

EXERCISE 3.0: SYSTEM ENVELOPE

This document provides detailed instructions for building a system envelope model in PTC Creo Parametric.

<table>
<tr>
<td>Begin by opening PTC Creo Parametric</td>
<td>
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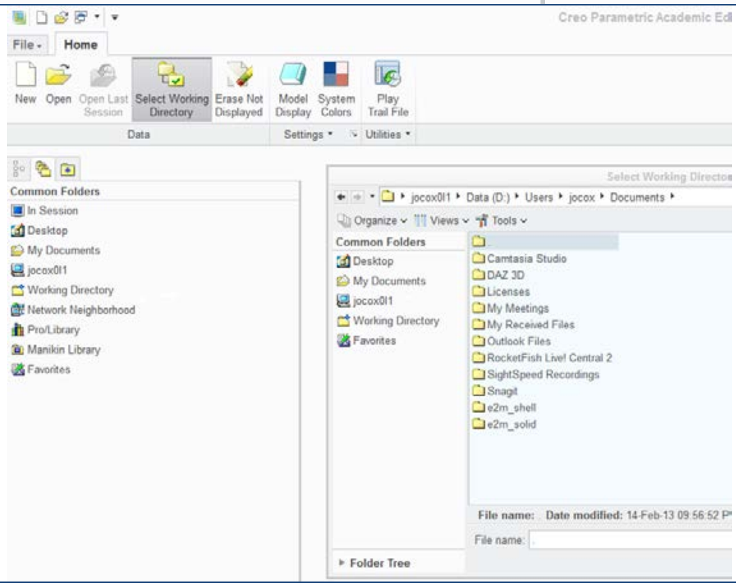
<tr>
<td>Select your working directory (make sure to remember what folder you choose)</td>
<td>
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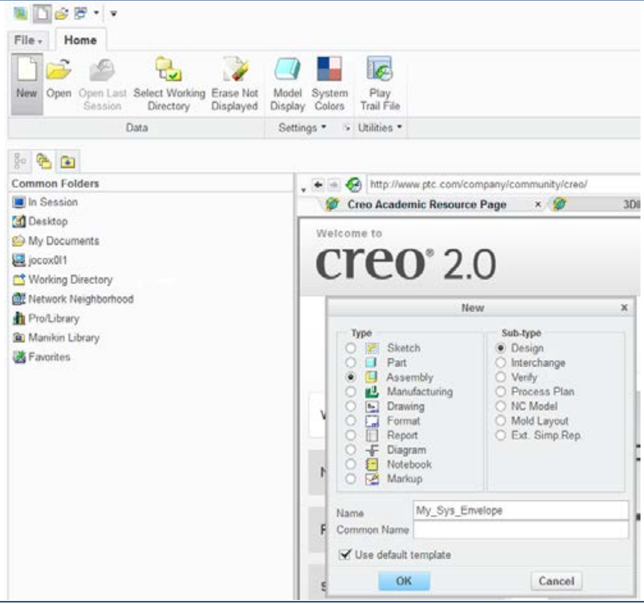
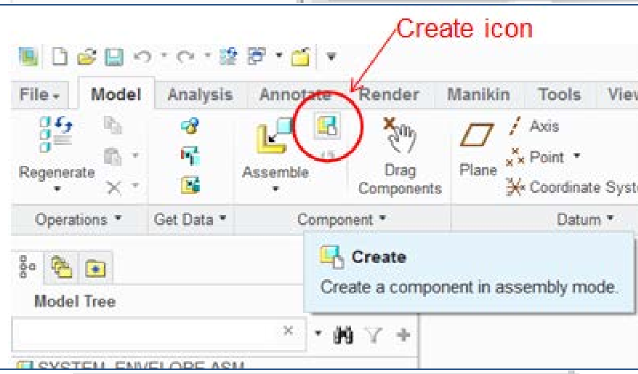
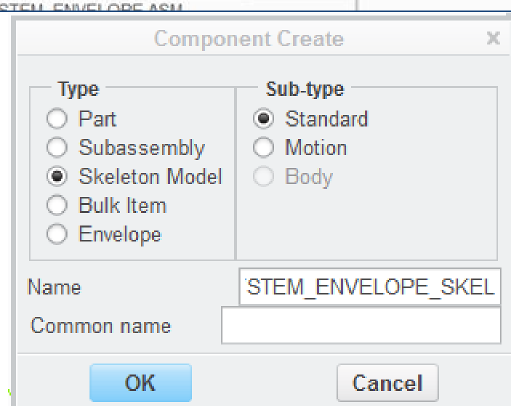
Now create a new assembly file by clicking on the **NEW** icon and selecting an assembly file. Name the file **MY_SYS_ENVELOPE**

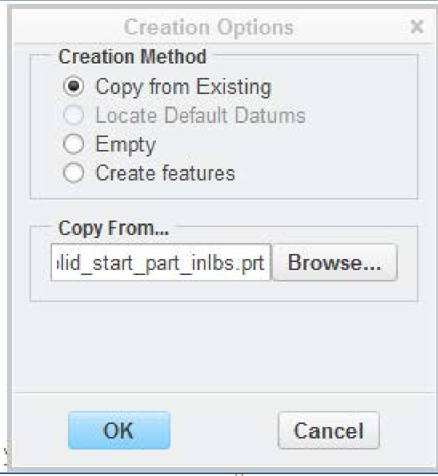


Create a skeleton model *(this is a reference model. You will create the system envelope so that it can be referenced by the subsystem models)*, by selecting the **CREATE** icon.



Select a skeleton Model, then click **OK**



<table>
<tr>
<td>Use Copy from Existing and click OK again.</td>
<td>
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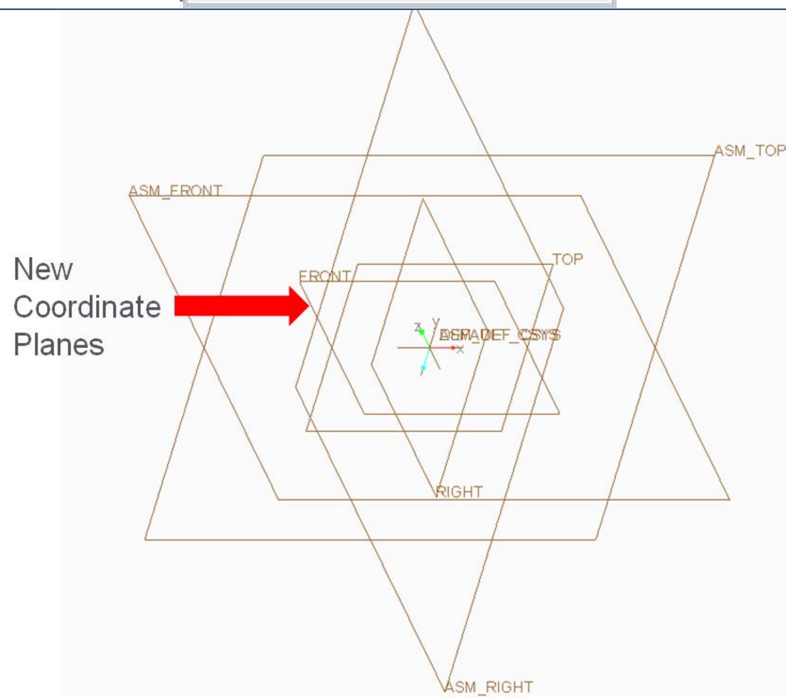
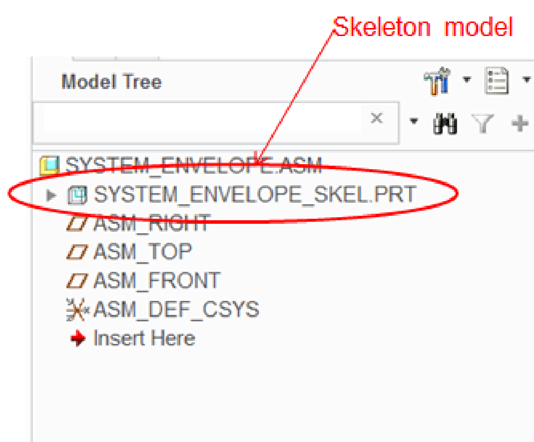
<tr>
<td>You will notice that a new set of coordinate planes have been assembled at the origin.

The skeleton model is blank except for its own coordinate planes</td>
<td>
</td>
</tr>
<tr>
<td>Notice in the Model Tree that there is an entry for the SYSTEM_ENVELOPE_SKEL.PRT. This is the skeleton model. Right click on it and OPEN it.

This will open a new window of Creo with only the skeleton model's coordinate planes visible.</td>
<td>
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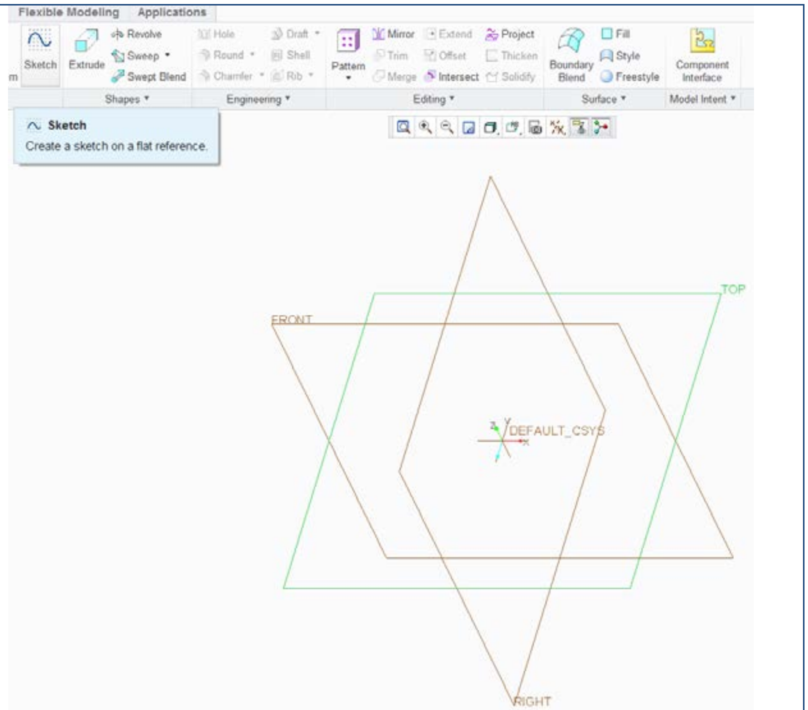
<table>
<tr>
<td>Left click on the TOP plane as shown (it will turn green) to select it. Then select SKETCH in the top level menu.

You are going to create an envelope that will represent the system envelope.</td>
<td>
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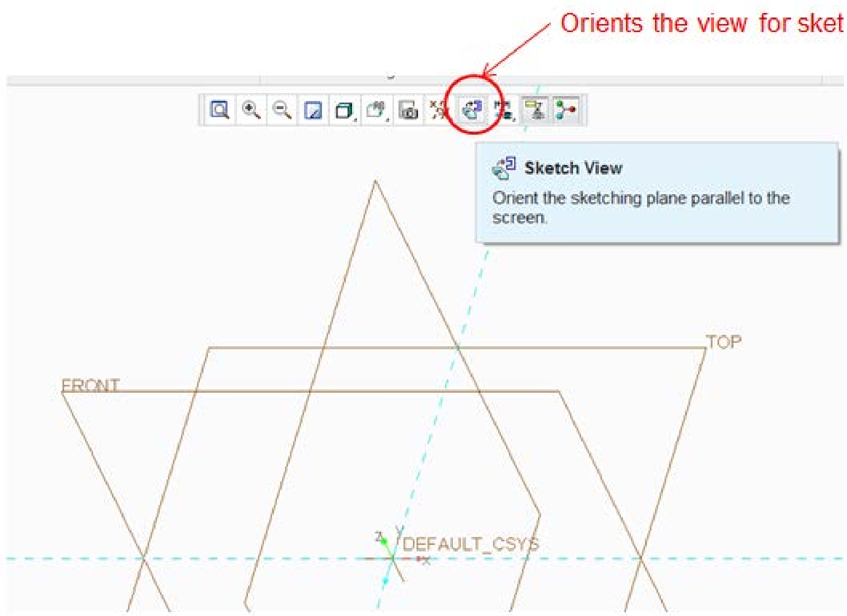
<tr>
<td>Now select the SKETCH VIEW icon in the display menu to orient your TOP plane for sketching.</td>
<td>
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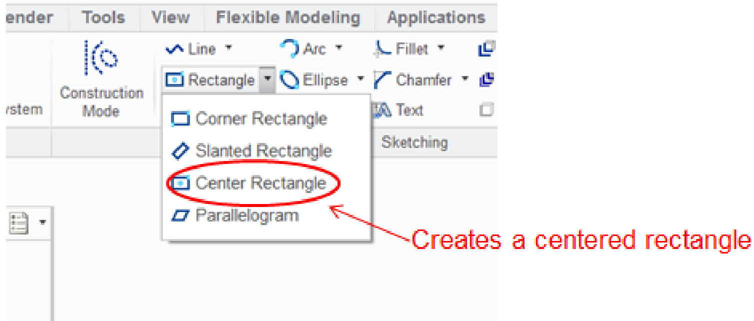
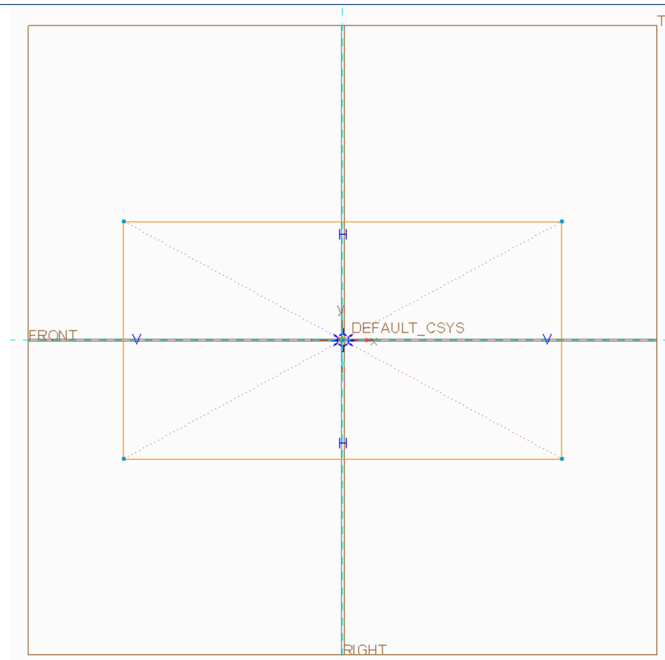
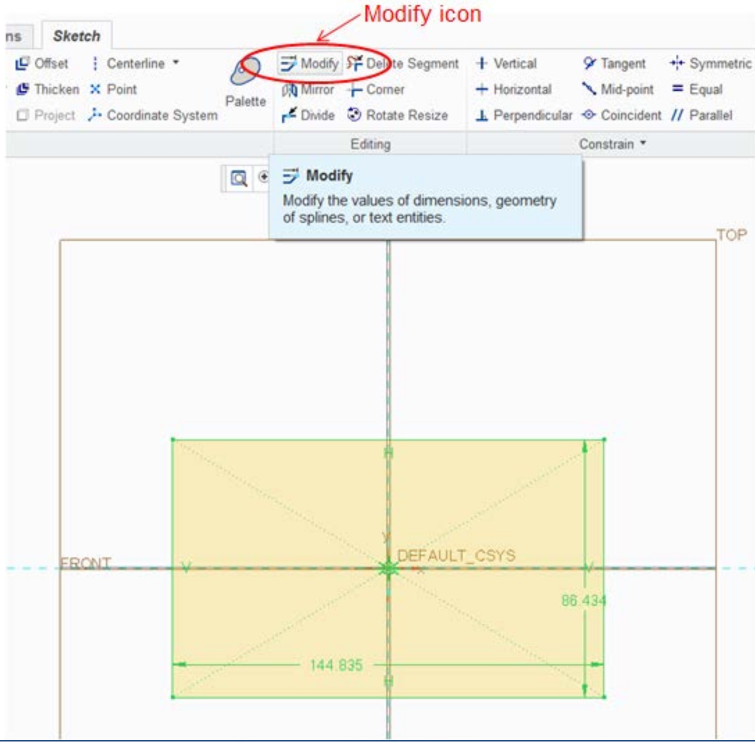
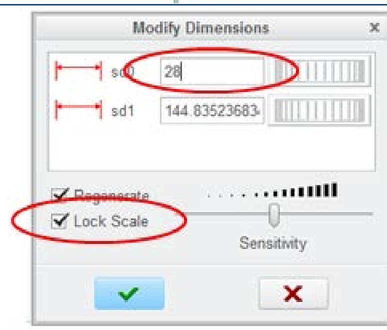
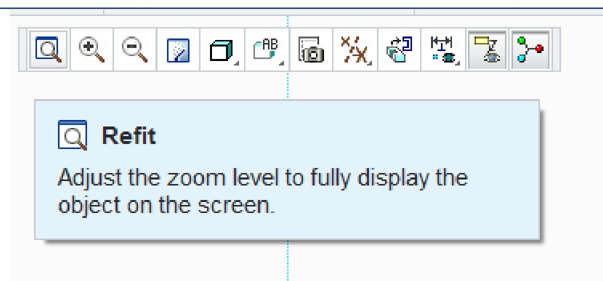
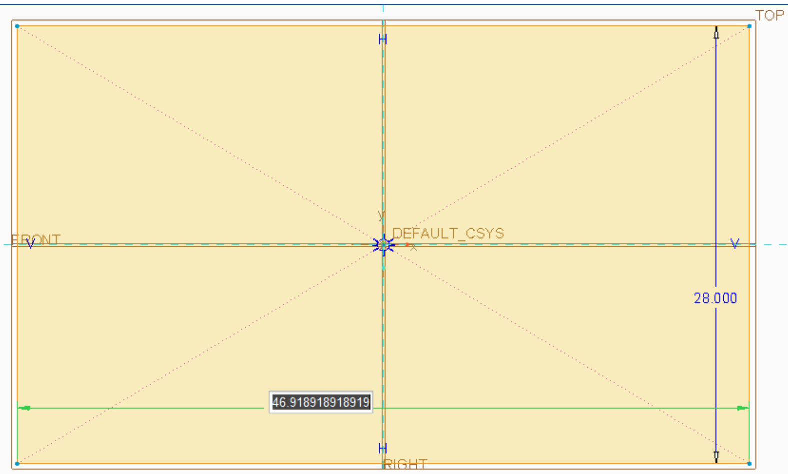
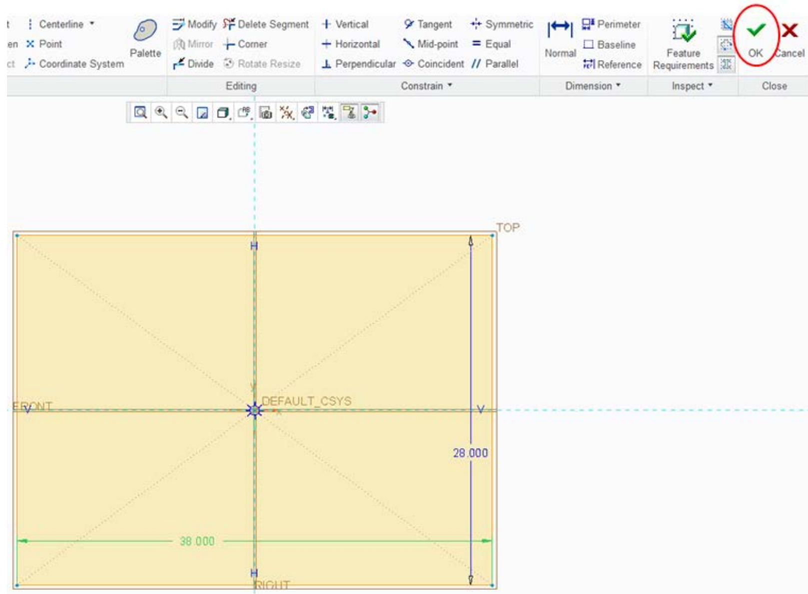
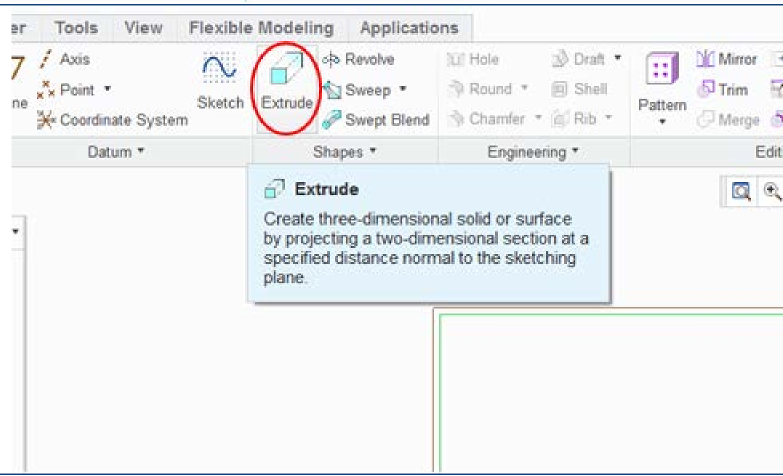
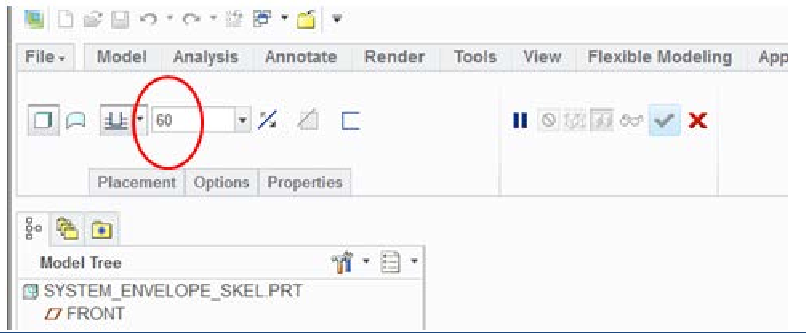
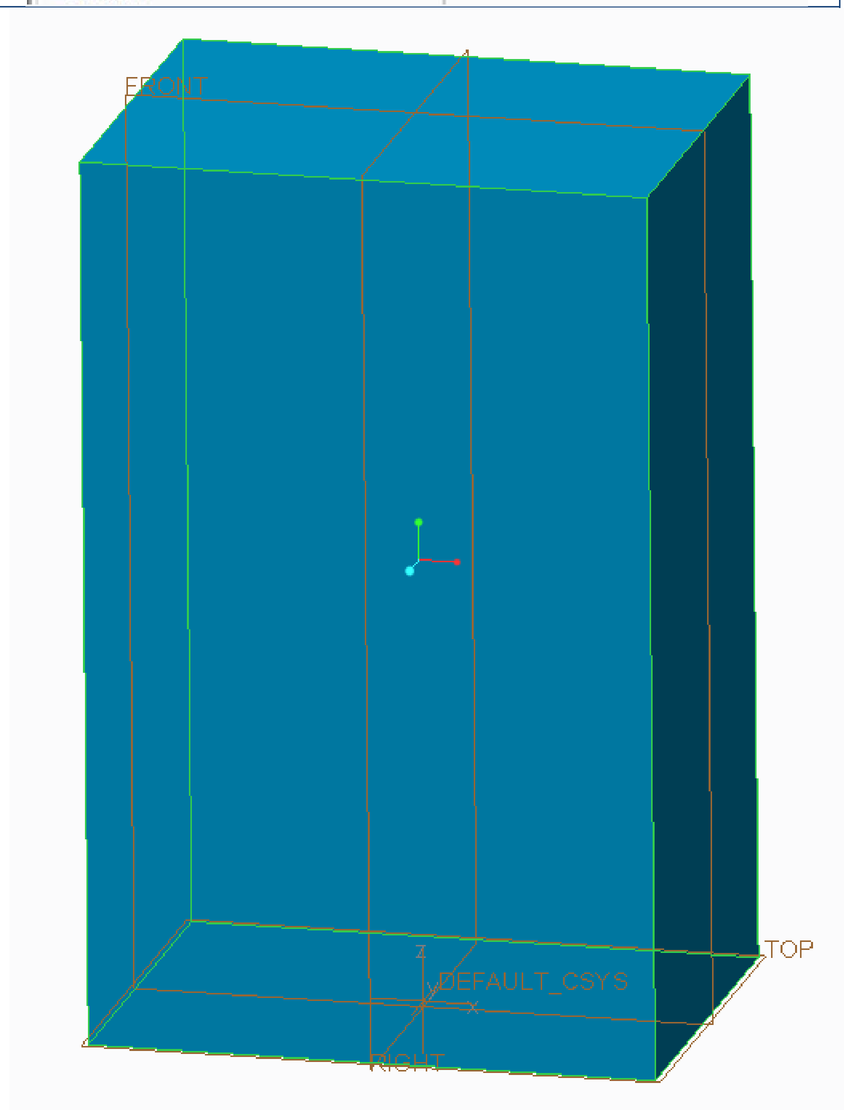
Select a **Center Rectangle** from the **Rectangle** pull-down menu as shown. This will allow you to create a rectangle by selecting a center point first and then stretching it to define its length and width.	
Left click at the center of the coordinate planes and then move your mouse until you have a rectangle as shown. Then left click to place it and middle click to end the rectangle tool. Don't worry about the dimensions; you'll change them to the right values in a minute.	

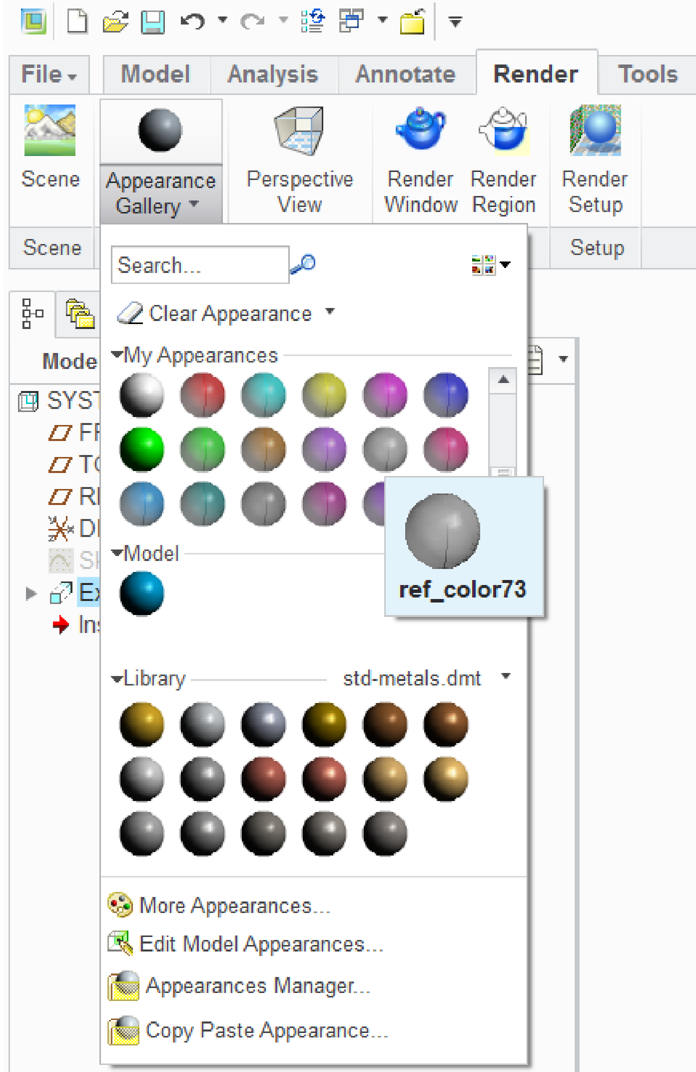
Drag select the entire rectangle. *(place your cursor below and to the left of the rectangle then left click and hold down while you drag the selection box to the top right corner of the rectangle and then let up on the left mouse button)* Then select **Modify** in the upper menu.	
Select **Lock Scale** and then set one of the dimensions to the right value. *(this is the value of the system envelope you determined earlier from the game or challenge definition)* For this exercise make it **28** units.	
Click the refit button in the display menu to resize your rectangle. *(your computer might do it automatically)*	

Change the other dimension of the rectangle to the right value by double clicking on it and typing in the correct value. Again, for this exercise, make it **38** units.	
The base of the rectangle is now finished so left click the green check mark in the upper right corner of the menu to exit **Sketch Mode**.	
Select the **Extrude** icon to extrude the rectangle in the third dimension. This will make it into an envelope.	

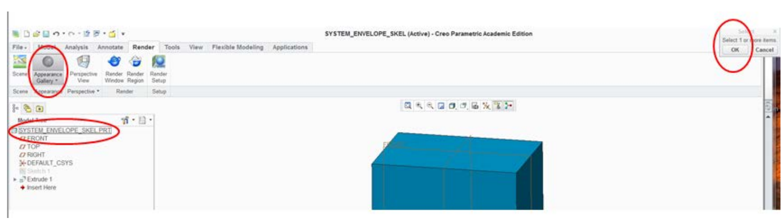
Set the value of the extrude to the correct height for the system envelope, **60** units, and then click on the green checkmark to finish the extrude.	
You can rotate this envelope by holding the middle mouse button down while moving the mouse.	

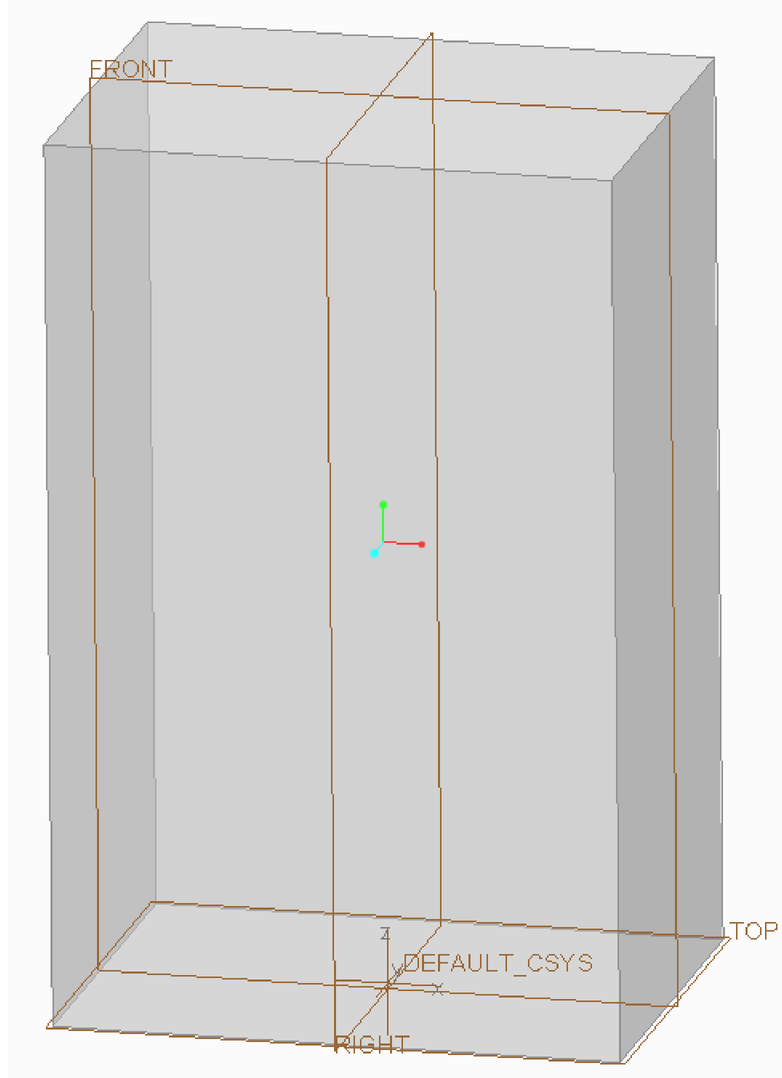
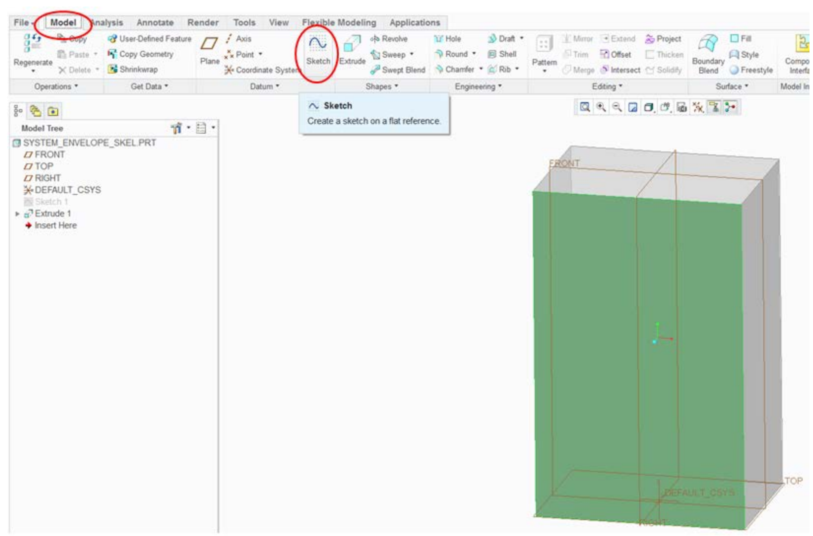
The final step in creating the system envelope model is to change its color and appearance to a transparent color. This will facilitate viewing the subsystem envelopes when they are added.

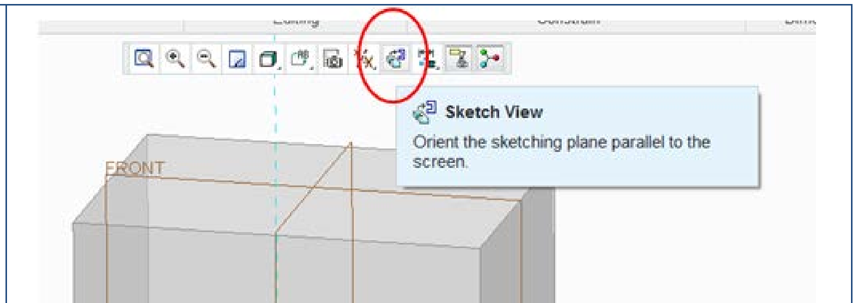
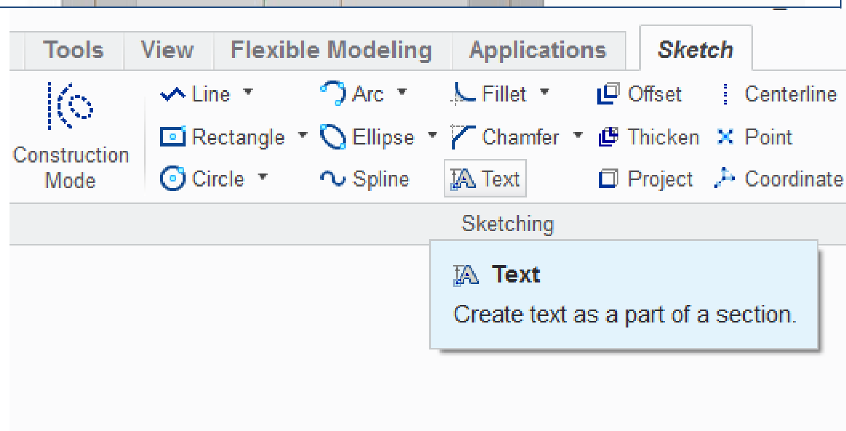
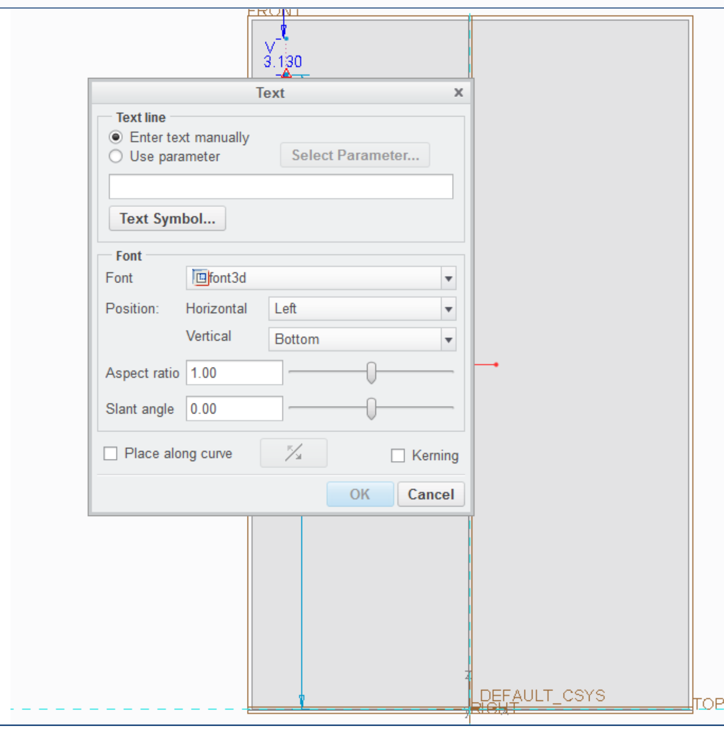
Select the **Render** tab in the upper menu and navigate through the colors to find a transparent color.



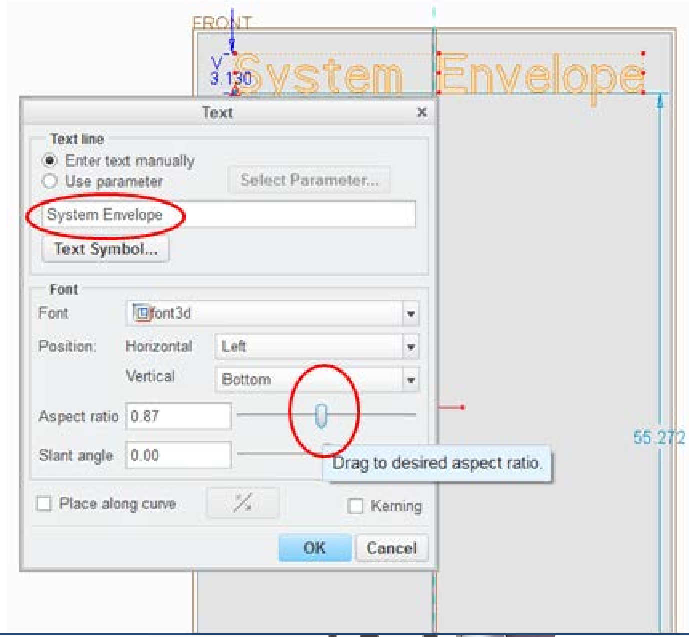
Now left click on the new transparent color icon in the render menu, then left click on the skeleton file name in the **Model Tree** and finally click **OK** to finish applying the color.



Your envelope should now be transparent.	
Click on the **Model** menu tab in the upper menu to return to the modeling palette. Then left click on the front surface of the rectangle. (It might take a couple of clicks to get it to select and turn green). Then click **Sketch**. You are going to put some text on the envelope to distinguish it as the System Envelope.	

Orient the view again so that you can sketch on the front face by left clicking on the **Sketch View** icon in the display menu.	
Select the **Text** icon in the upper menu by left clicking on it.	
Make a vertical line by left clicking to start the line and left clicking to stop the line near the top of your rectangle. This defines the placement of the text and the height.	

<table>
<tr>
<td>Type in the words: System Envelope and then drag the Aspect ratio slider until the text fits on the rectangle.

Then click OK.</td>
<td>
</td>
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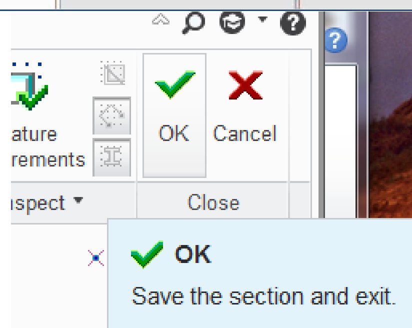
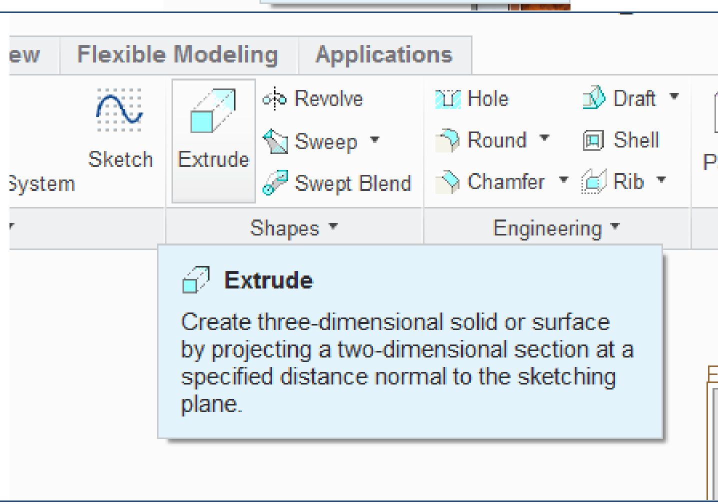
<tr>
<td>Now click the OK green checkmark to exit sketch mode.</td>
<td>
</td>
</tr>
<tr>
<td>Click the Extrude icon to extrude the text and set the value of the extrude to 1 unit. Click the green check mark to finish the extrude.</td>
<td>
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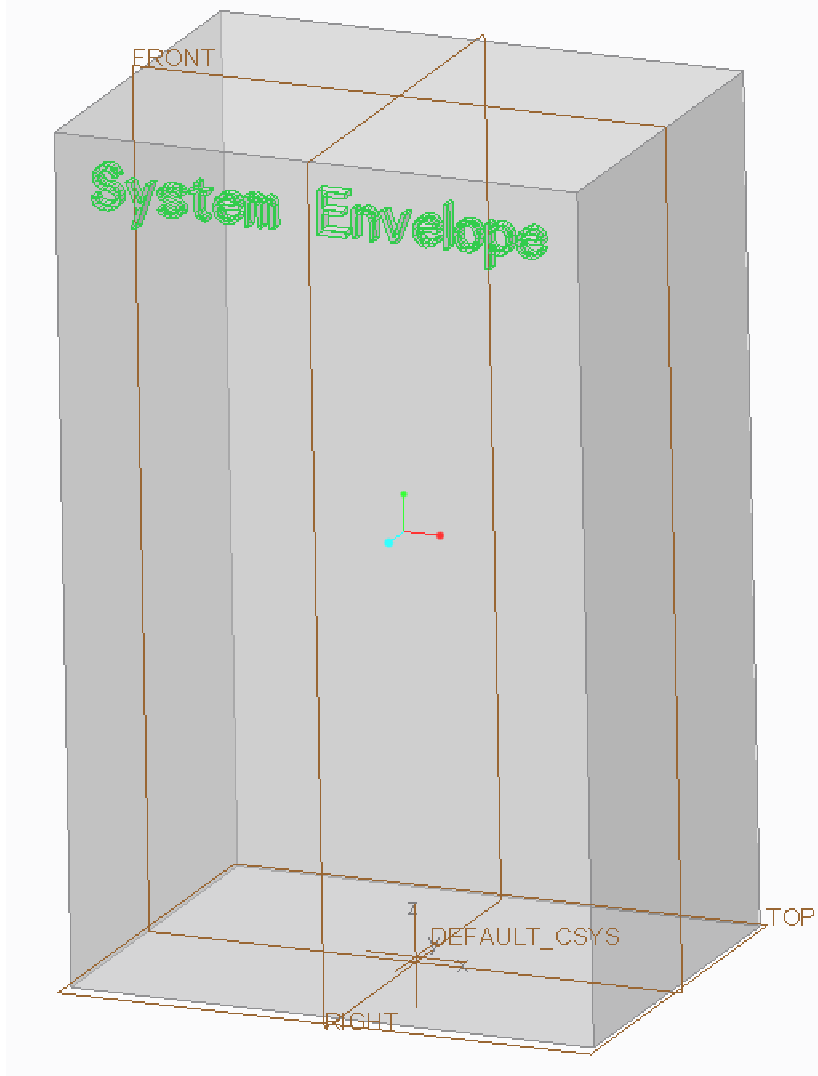
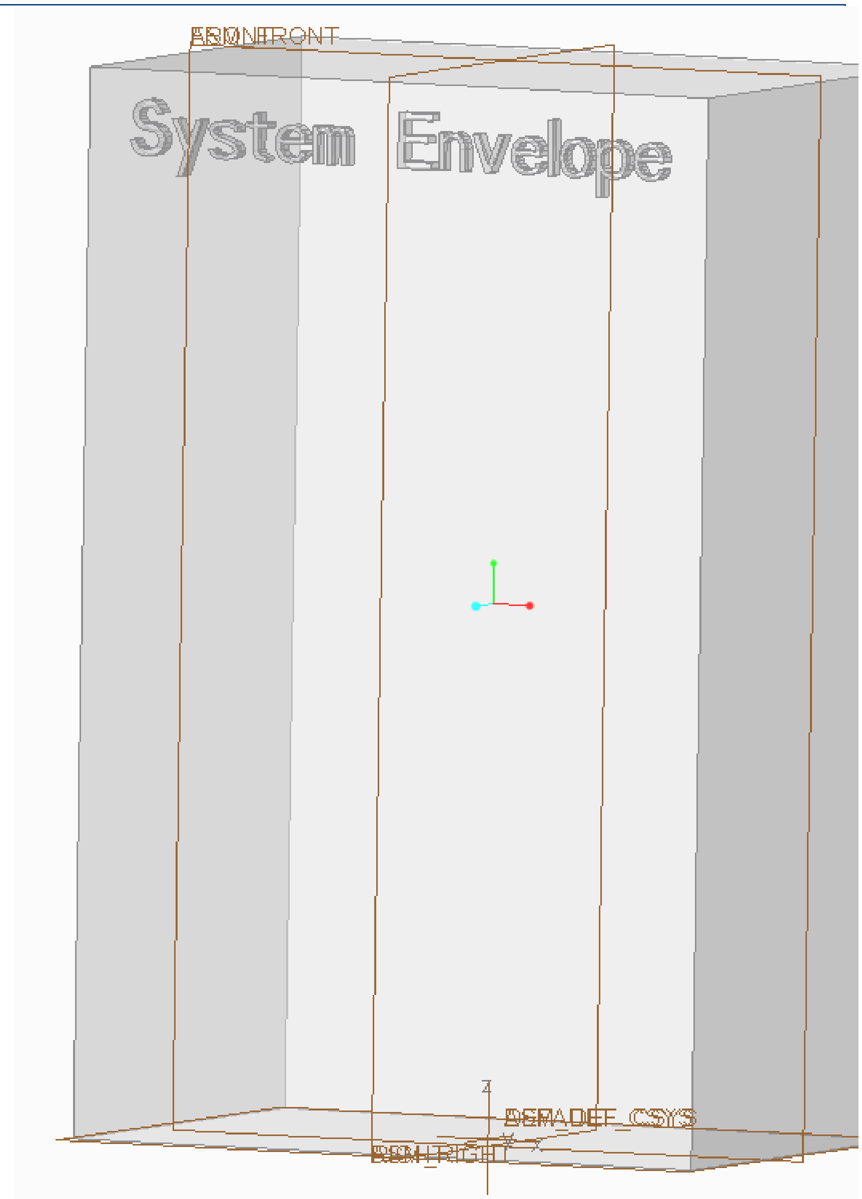
You are now finished with your system envelope skeleton file. Save it by clicking on the **Save** icon under the **File** tab in the upper menu and click **OK**. (You don't need to provide a new name, just click **OK** to save your file) Then pick the **Close** icon under the **File** tab to close the skeleton file.	

You will notice that your system envelope is now part of the original assembly file. Save this file by clicking on the **Save** icon under the **File** tab and then exit **Creo**.

You have completed the exercise for creating a system envelope model.



You can create several system envelopes if the challenge you are working on requires it, by simply following the methods presented in these instructions. You should probably name the envelopes based upon their purpose; possibly System Envelope1 (retracted), and System Envelope 2 (deployed). The purpose of this exercise is to create a reference model of your entire system envelope.

Exercise 4.0: Sub-System Definition

The first activity you need to complete is identifying all of the subsystems in your overall system. You can use a table like this to identify all the subsystems and distribute the weight and cost.

Subsystem	Function	Envelope	Weight	Cost
Drive train	Robot motion	25%	35%	15%
Gripper	Hold tubes	5% (5x5x9)	1%	10%
Arm	Pick and place	10%	20%	25%
Electronics	Control	10%	15%	30%

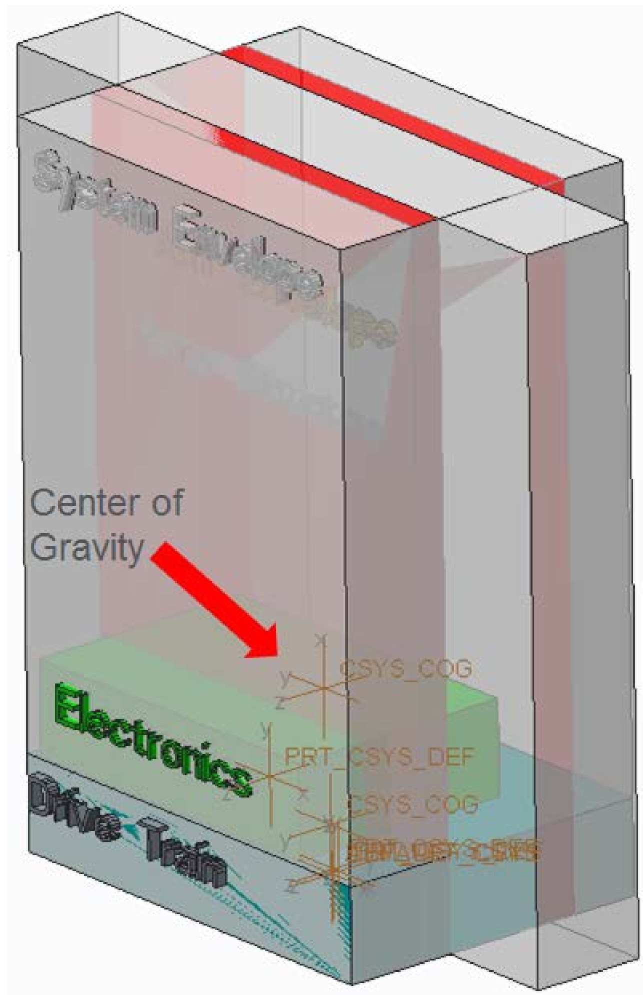
Then you can create the envelopes for each of the subsystems. However, before doing all of this, let's look at what we are trying to create; a preliminary system model that defines all of the subsystems and provides size, weight, and cost estimates. This will be the first model of your system design.

Start **Creo Parametric** and open the **ROBOT_SYSTEM_ENVELOPE** model in the Robot Systems folder within the System Envelopes folder.

Here you will see a system model of a robot. It is a collection of several envelopes. Notice the system envelope in gray and inside that there are the Drive Train, Electronics, Power Structure, and Arm envelopes. In this case, the arm envelope extends outside the overall system envelope because in the game description it allows the arm to extend beyond the initial system envelope.

Each of these envelopes has a size, a weight and a cost associated to it. The position of these envelopes with respect to each other allows an initial calculation of the system center of gravity which you can see as a coordinate system labeled as CSYS_COG.

So even though you know very little about what your Robot System is going to look like, you have an initial idea of what subsystems will be in it and what it will weigh and where it's center of gravity will be.

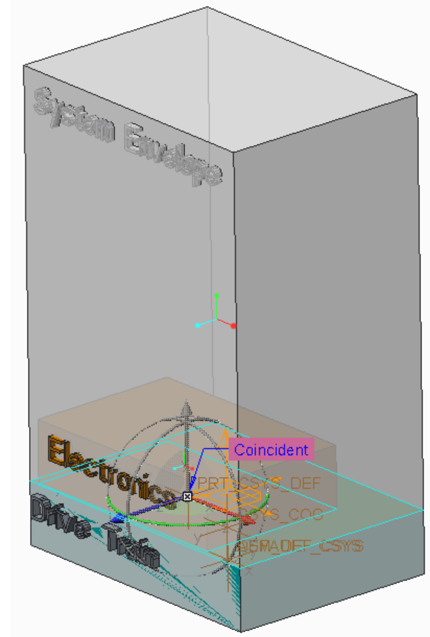


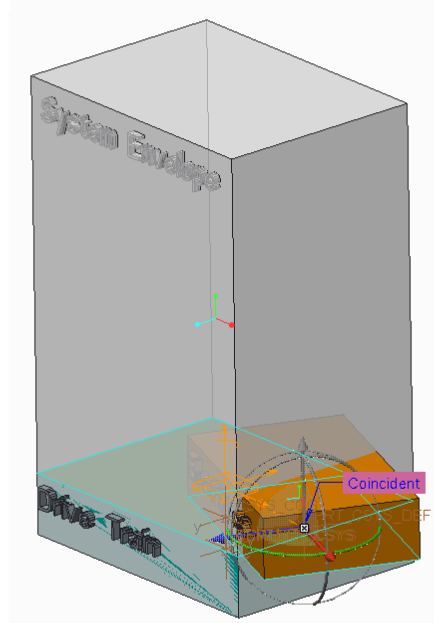
You can change the position of each of the subsystem envelopes by right clicking on their names in the **Model Tree** and selecting **Edit Definition**.

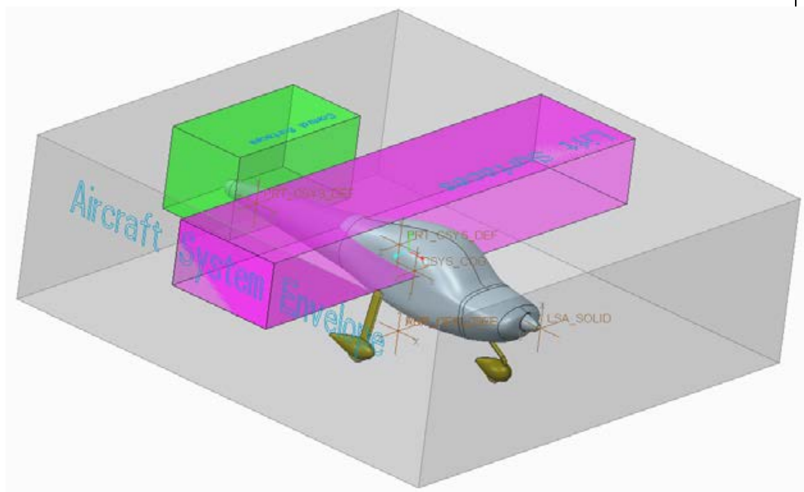
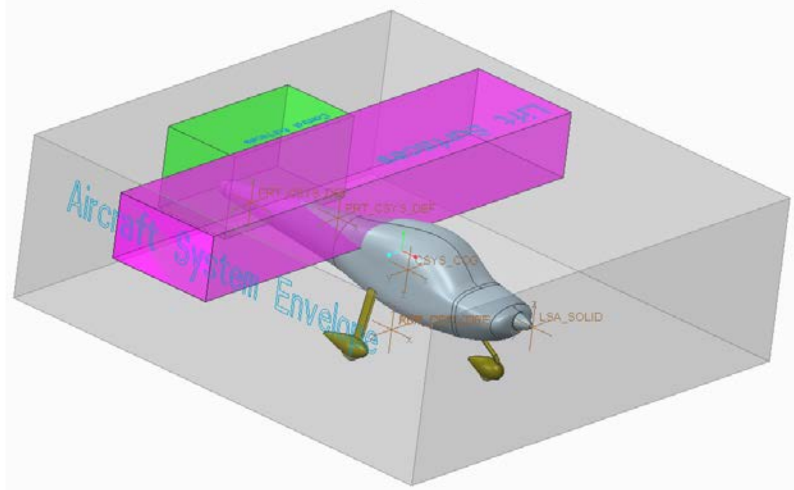
The envelopes are assembled using a planar constraint to define what surface they will rest upon. The orientation sphere can now be used to rotate or drag the subsystem envelope to a new orientation or position. This allows you to explore new configurations as you design your system.

The purpose of this model is to explore the relative sizes and locations of all of the subsystems within your system before you begin the detailed design of these subsystems.

Now close the **Robot_System_Envelope** file and click **Erase not Displayed**.





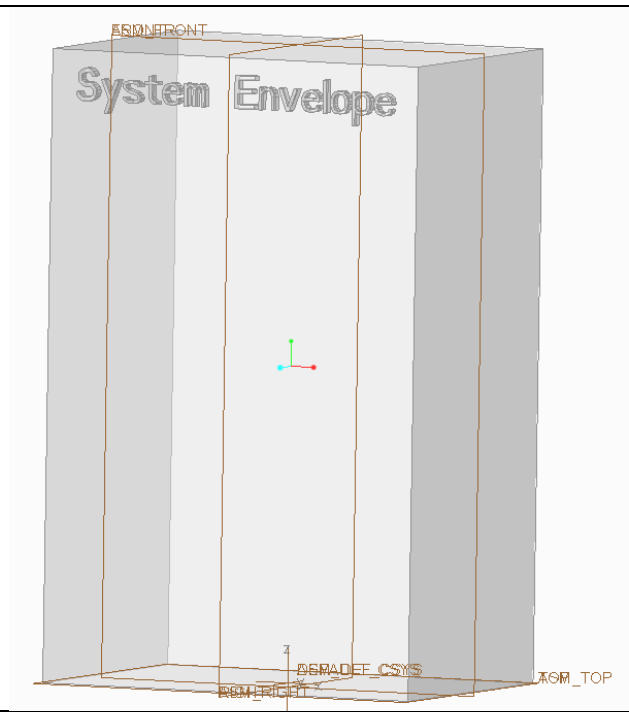
Here is another example of a system envelope model. **Open** the model called: **Aero_System.asm** in the folder **Aircraft System** within the **System Envelopes** folder. In this model you will see that the fuselage is fixed and is provided as reference. The lift surfaces (wings) and control surfaces (tail) are indicated by envelopes since they must be designed. Again the center of gravity can be seen. Shifting the location of the lift surface envelope affects the overall center of gravity as well as the center of lift. You can explore the positioning of the subsystem by selecting the subsystem in the model tree and right clicking and selecting **Edit Definition**. Then use the orientation sphere to reposition the subsystem.	 
Close the file **Aero_System.asm** and click **Erase not Displayed**.	

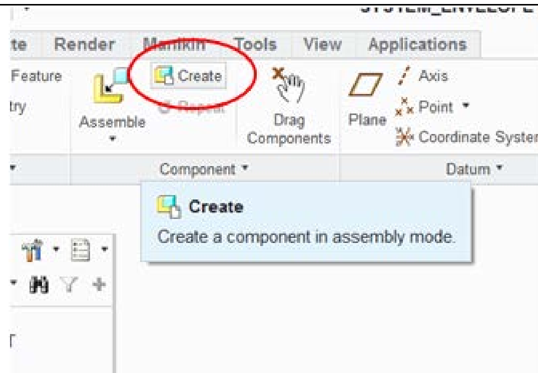
Now let's build our own subsystem models. You will begin by creating the envelope model for one of your subsystems. You will need to continue creating envelope models for all of your subsystems to complete an overall system assembly model. We are going to create a system envelope model for the robot system we explored above.

Remember that in your own system design you would begin by identifying all of the subsystems and defining their percentages in terms of weight, size and cost. So here is a table with that information for the robot system. These are targets so they won't be exactly right, but sort of like "suggestions" for your system model.

Subsystem	Function	Envelope	Weight	Cost
Drive train	Robot motion	15%	40%	15%
Electronics	Control	10%	10%	10%
Structure	Framework	50%	20%	25%
Arm	Pick and place	50%	25%	30%

Now we can get started creating the envelopes. We will build two of the envelopes and you can continue to finish creating the entire system.

Begin by opening **Creo** and setting the **Working Directory** to the same folder in which you created the system assembly model. Then open the **My_Sys_Envelope.asm** file you created earlier.	

<table>
<tr>
<td>Click on the Create icon again to create a new part file in this assembly.</td>
<td>
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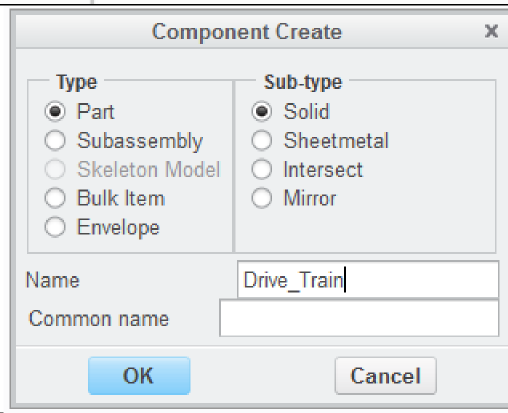
<tr>
<td>Select a part and give it the name of your first subsystem, in this case “Drive_Train” and then click OK.</td>
<td>
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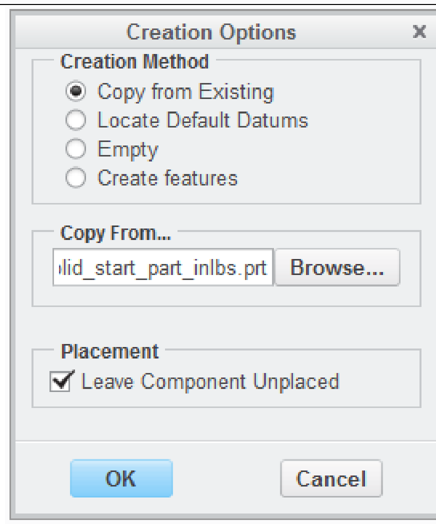
<tr>
<td>Select Copy from Existing so that it uses the same settings as your system model and then check Leave Component Unplaced. This will place the part in the model tree and once its envelope is created, you can edit its definition to place it correctly in the assembly. Then click OK.</td>
<td>
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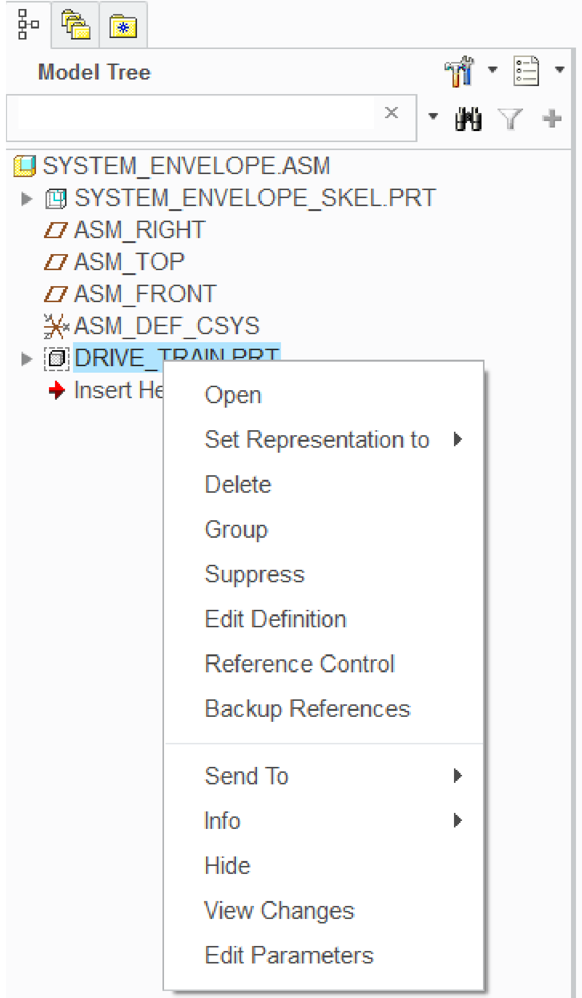
<tr>
<td>You will notice that the subsystem part is now entered in your model tree. Right click on it and select Open. This will open the part model so that you can create the envelope and set its weight.</td>
<td>
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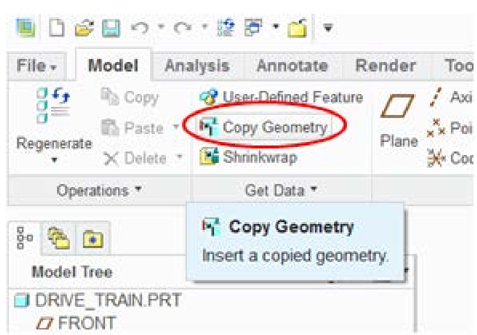
<tr>
<td>Now the drive train envelope will usually always be the same size in width and length as the system envelope. So we can reference the original system envelope by using Copy Geometry. Click on the Copy Geometry icon.</td>
<td>
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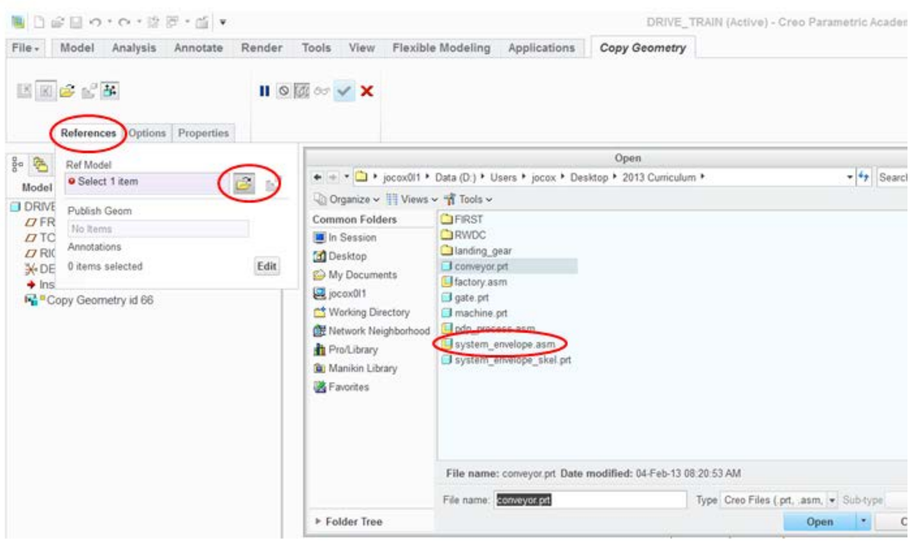
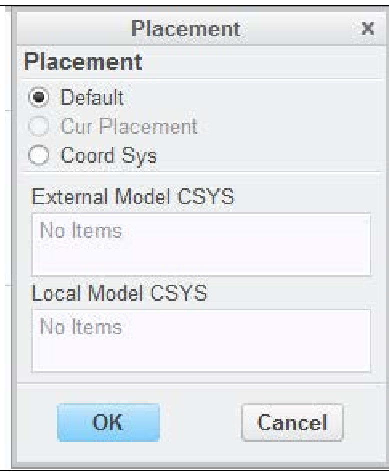
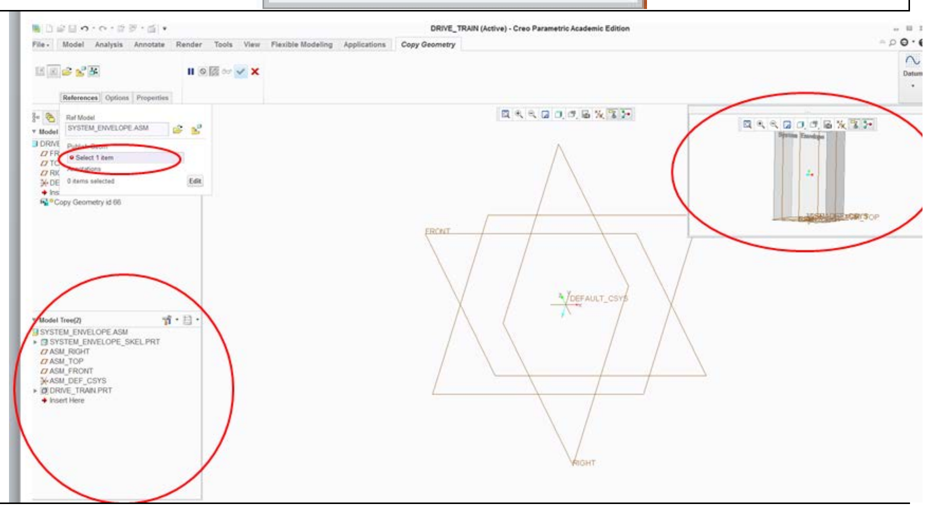
Now select the **References** tab (it may be red). Then click on the folder icon next to the **Ref Model** selection. This allows you to open the **System_Envelope** model as a reference. Select the **System_Envelope.asm** file.	
You can allow the **Default** placement so just click **OK**.	
Now click on the **Select Item** tab under **Publish Geometry**. You will see the **System_Envelope** model appear to the right and its tree in the bottom left of your screen.	

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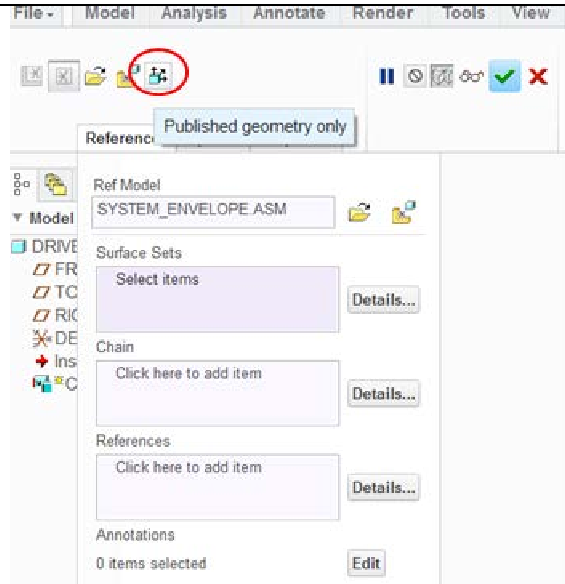
<td>Click on the Published geometry icon in the top menu to turn it off. This will allow you to select surfaces and other reference geometry you want to reference in your model.</td>
<td>
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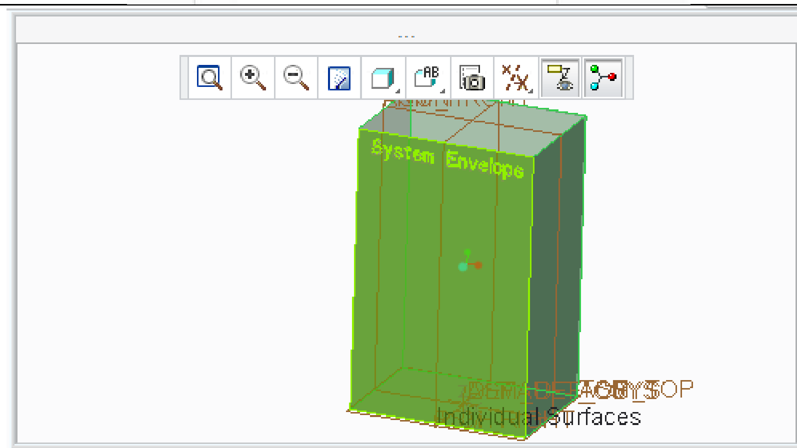
<tr>
<td>Now select the four faces of the system envelope using the left mouse button and using the Ctrl key (like the shift key) to make multiple selections. Also select the bottom surface.

Then click OK.</td>
<td>
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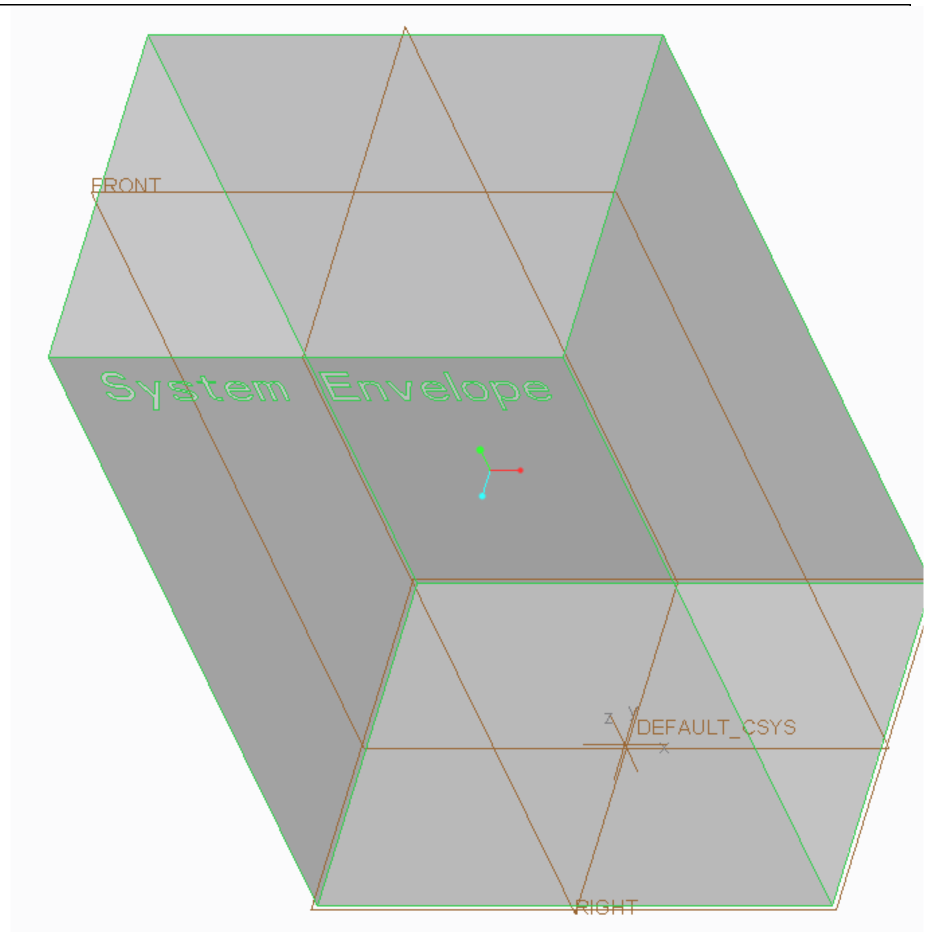
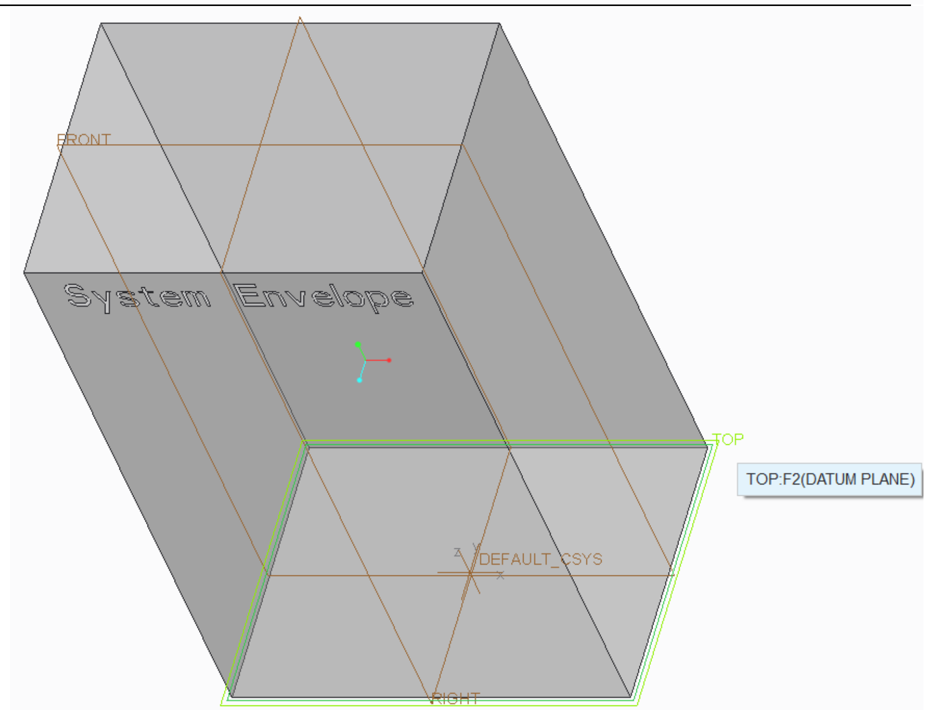
You will notice that you now have the System Envelope surfaces in your Drive Train model. This will allow you to reference them in building your Drive train envelope. That way if you change the overall system envelope, your drive train subsystem envelope will change with it.

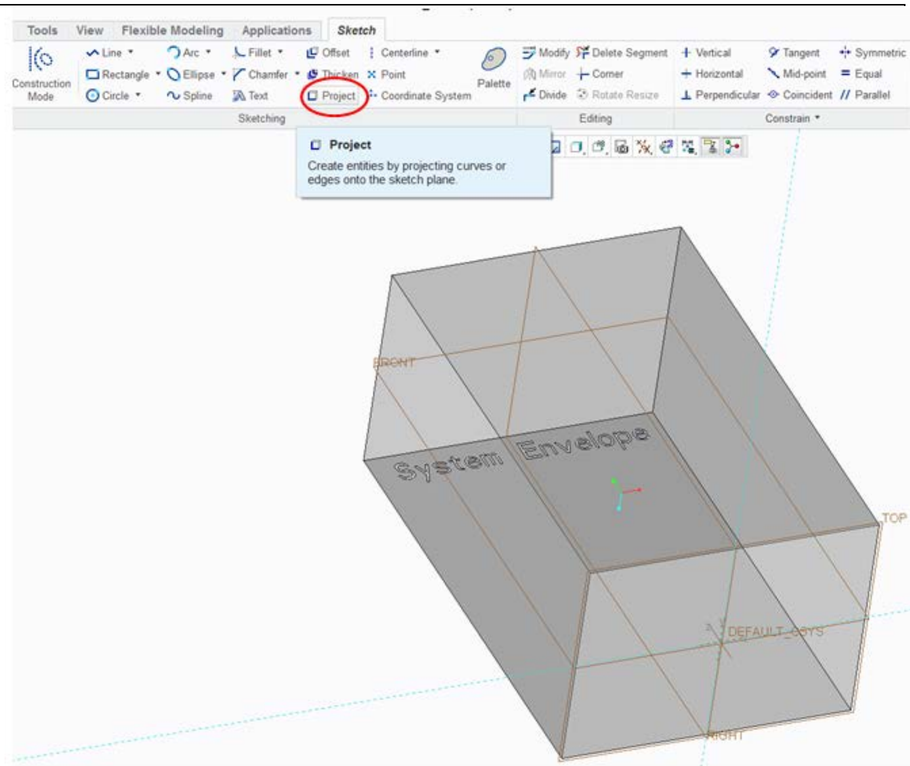


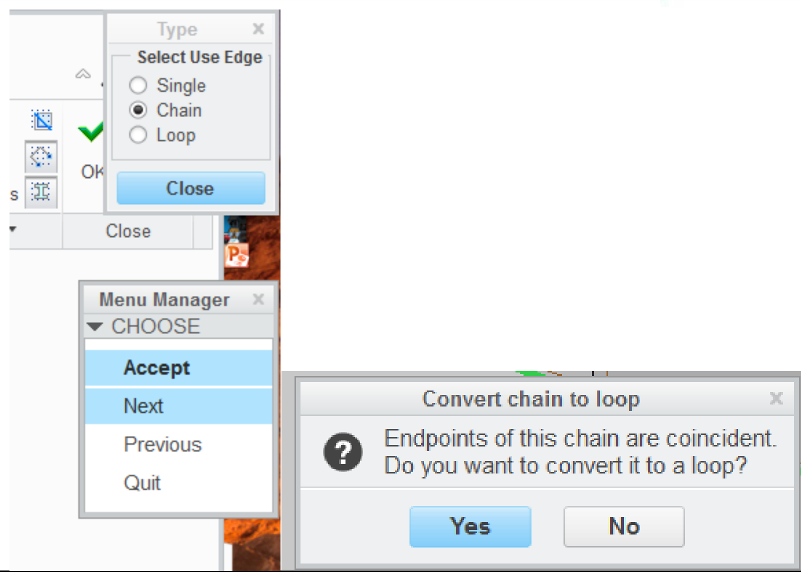
Select the **Top** datum plane. You will find it at the bottom of the System Envelope. You will use it to sketch your drive train envelope on. So now click on the **Sketch** icon to go into the Sketcher.

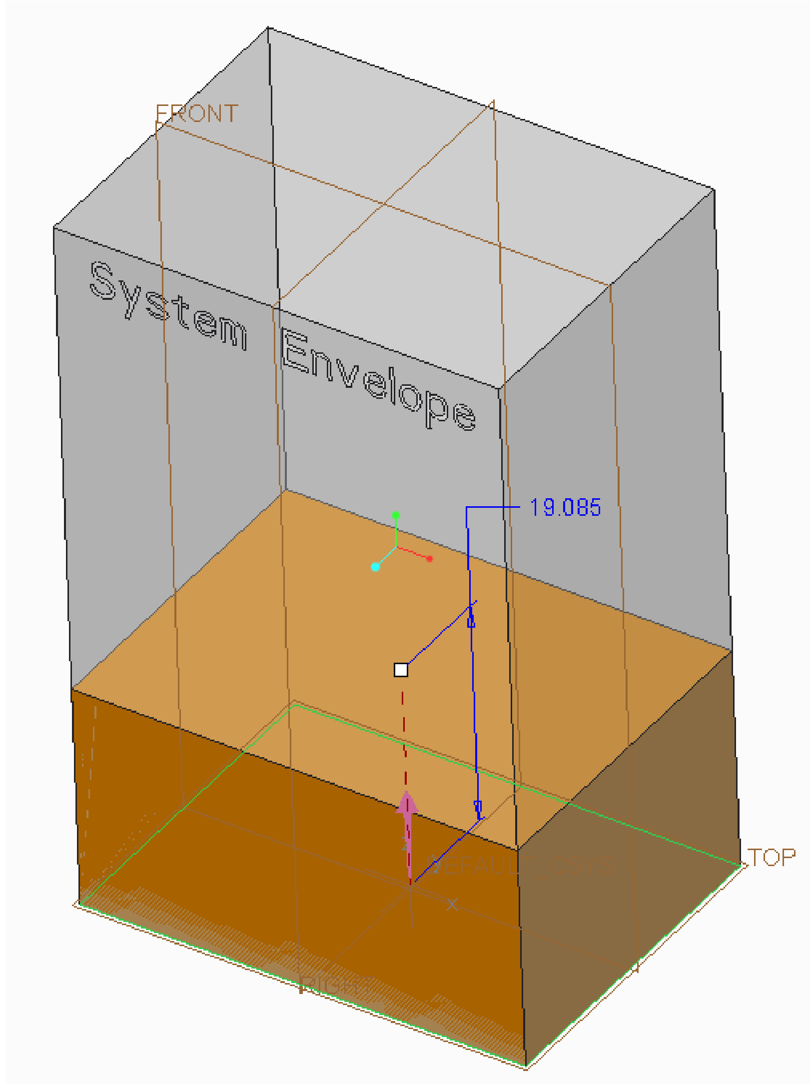


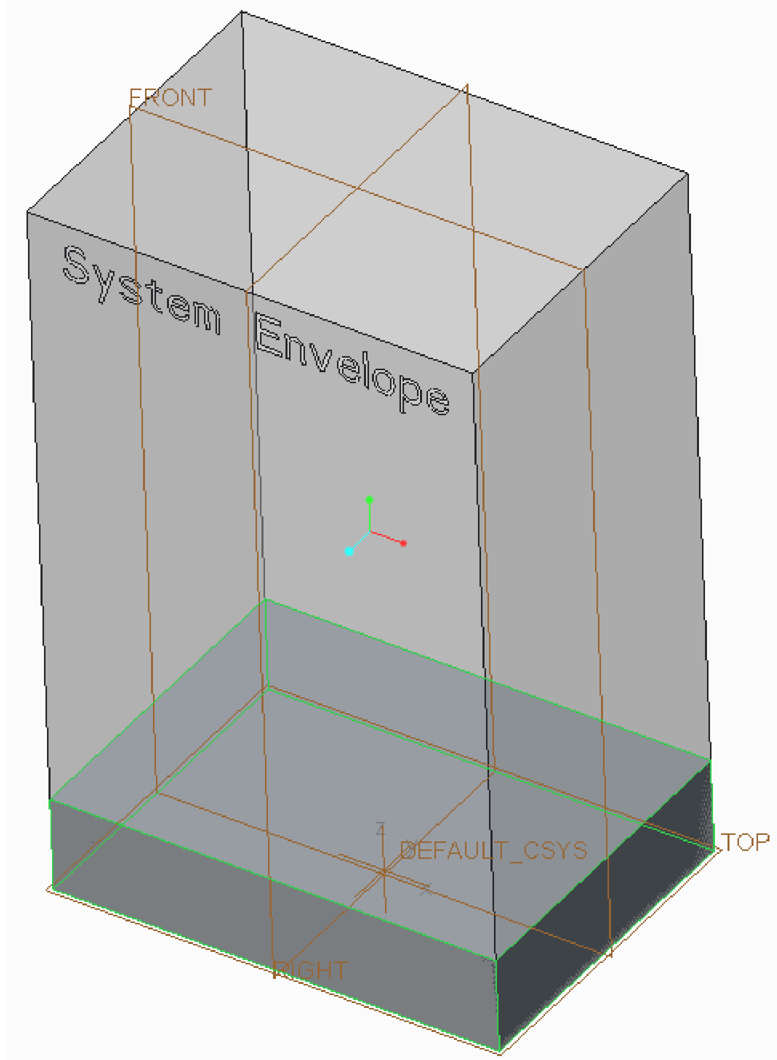
You don’t need to orient your model this time. You will use the Project tool to project the edges of the **System_Envelope** onto the sketch plane. Click on the **Project** icon. Then select **Chain** and left click to select the first edge of the envelope and then select the next edge. When the menu appears click **Next**. It will select the whole loop of edges. Click **Accept**.

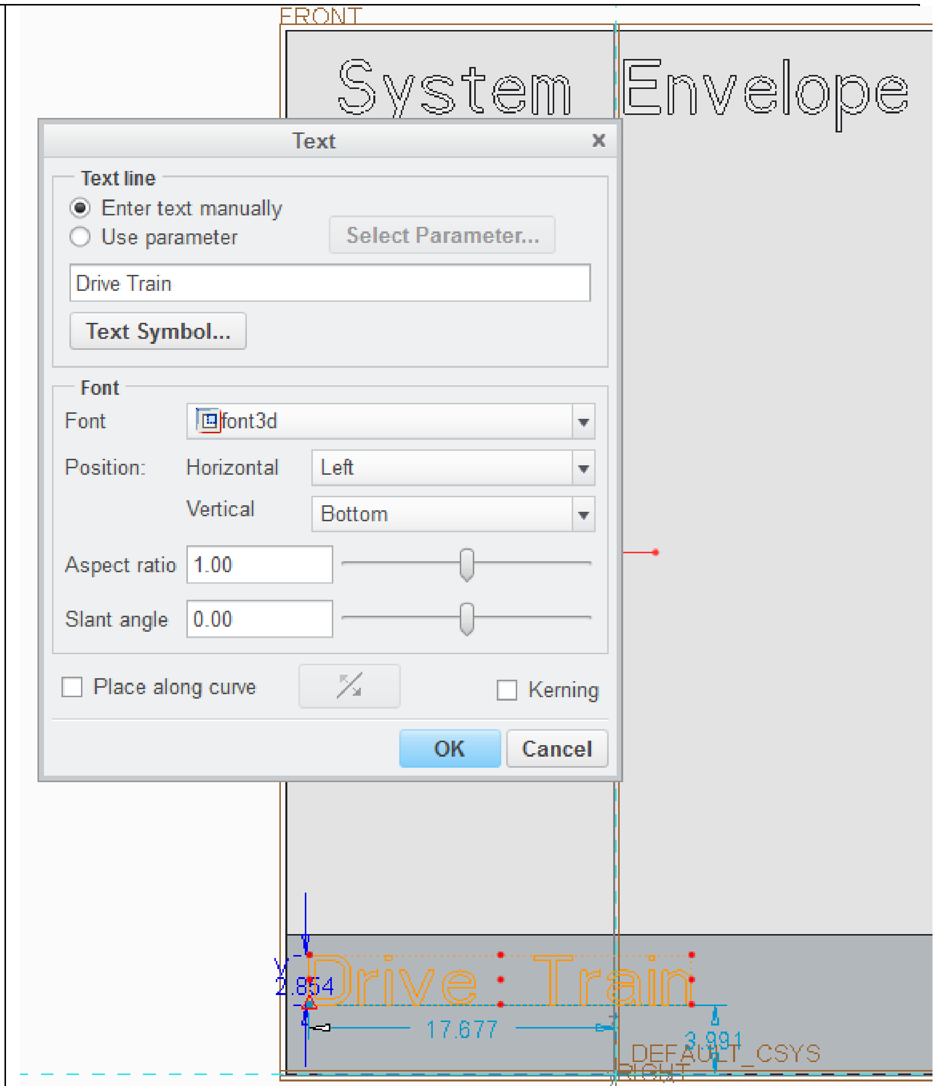
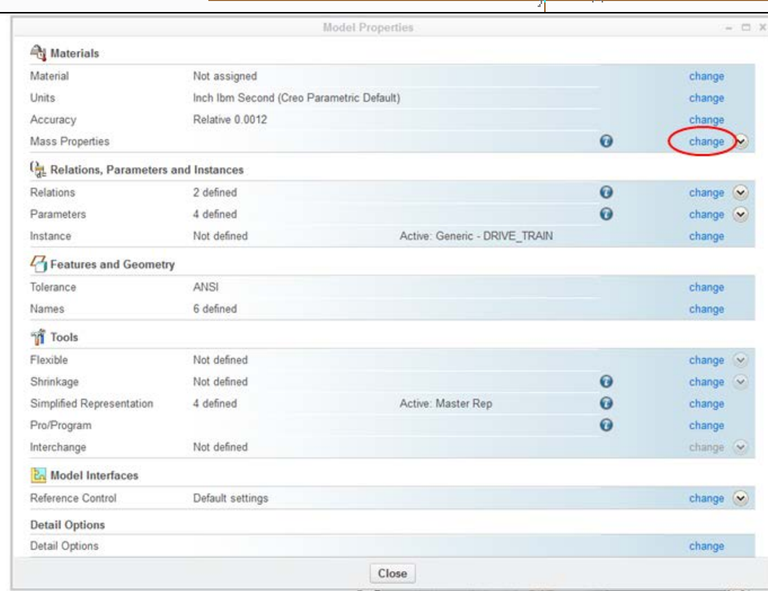
You will be asked if you want to convert the chain into a loop. Click **Yes**.





Now click **Close** in the **Project** menu and then click the green checkmark to exit the sketcher. Click on the **Extrude** icon and you will now be able to set the height of your drive train subsystem envelope. You will need to decide what that height will be based on your space allocations. Once you have set the height, click the green checkmark to finish the extrude.	

It will be helpful to place text on your drive train subsystem envelope to identify it. So left click the front surface and click on the **Sketch** icon to go into the sketcher.	

Orient your sketch and then select the **Text** icon and label your envelope. Once you have your text placed, exit the sketcher and click the **Extrude** icon to extrude the text. Set its length to **1** unit and click the green checkmark.	
Now let's set the weight of your drive train subsystem. For this exercise we will assume that you allocated 50lbs for the drive train. So let's set up your model so that it weighs 50lbs. Begin by selecting the **File** tab at the top menu and then select **Prepare**. A dialog box will appear. Select the	

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Model Properties tab. Under the **Materials** section there will be a **Mass Properties** entry. On the right of the Mass Properties entry there will be a Change link, click the blue Change link.

Now click **Calculate** at the bottom of the dialog box. And finally click **Save**. Then select **Close** to exit the mass properties dialog box.

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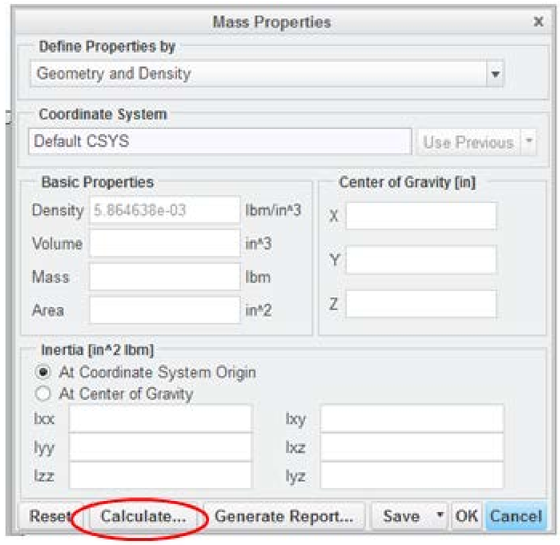

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Now let's define a feature in your model tree that indicates the center of gravity and mass. Do this by selecting **Analysis** in the top menu and then select **Mass Properties**. Calculate the properties by clicking on the eye glasses. Now, click on the Quick pull down menu and then select **Feature**.

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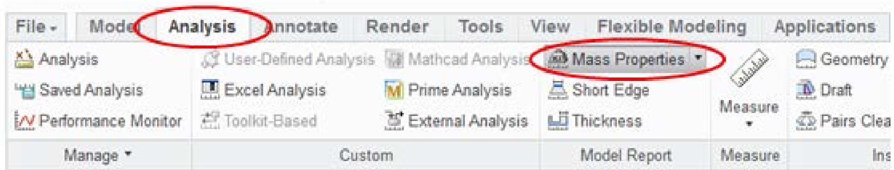

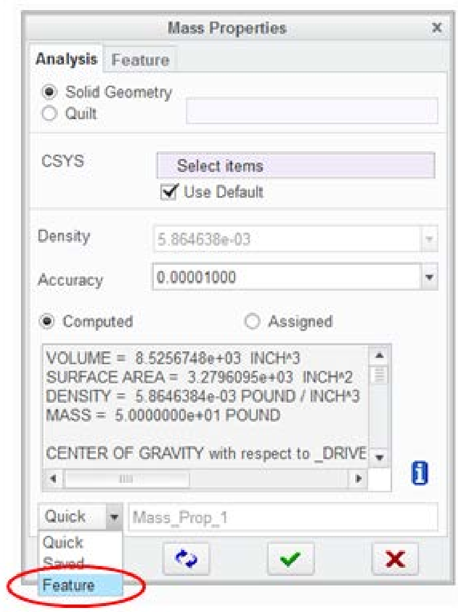

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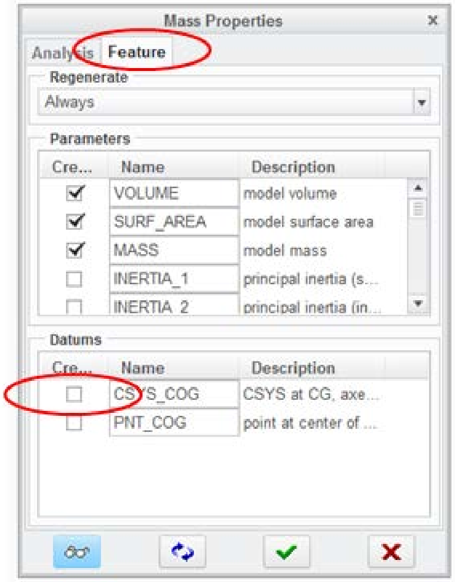
<td>Now select the Feature tab at the top of the dialog box and then check the box with CSYS_COG. This will create a center of gravity coordinate system feature in your model. Once done. Click the green check mark.</td>
<td>
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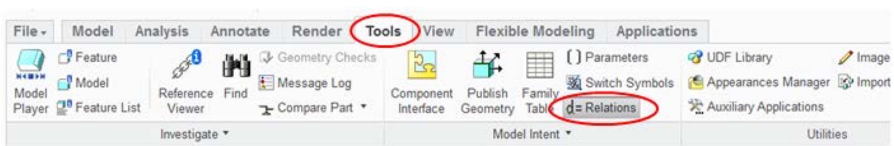
<td>The final step is to set up a relationship that insures that the drive train subsystem envelope is exactly 50 lbs. To do this, select the Tools tab at the top of the Creo menu and then select Relations.</td>
<td>
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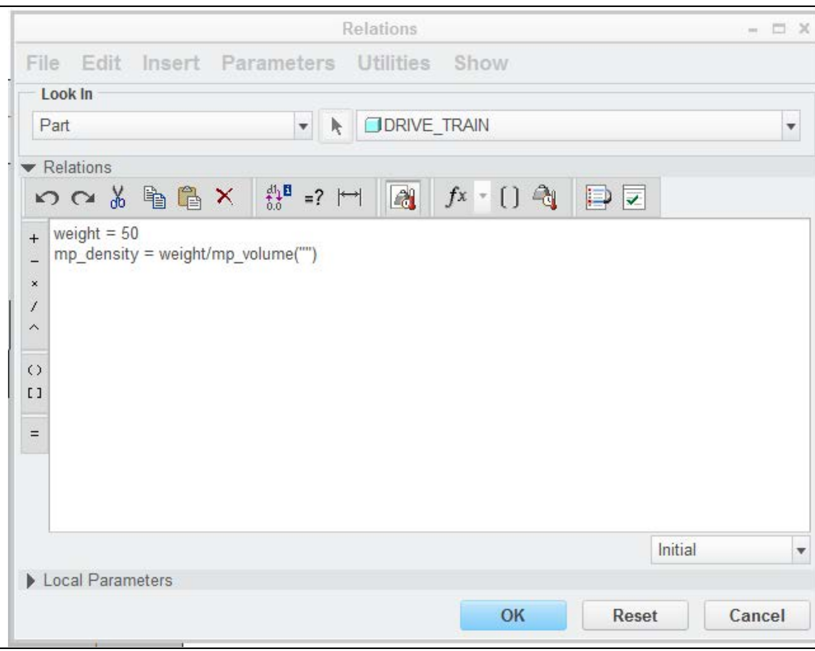
<td>Now enter these relationships exactly as they are shown in the figure. Weight is the parameter that you will be able to change going forward to set the weight of your envelope to whatever you allocate.

Click OK and then go back to the Model tab and click Regenerate to set the parameters.</td>
<td>
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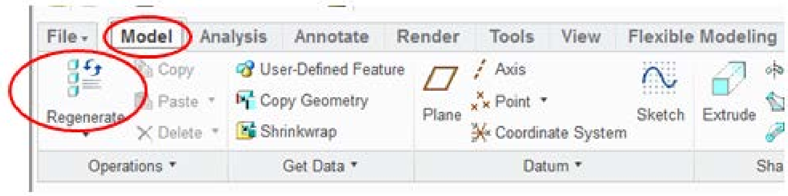
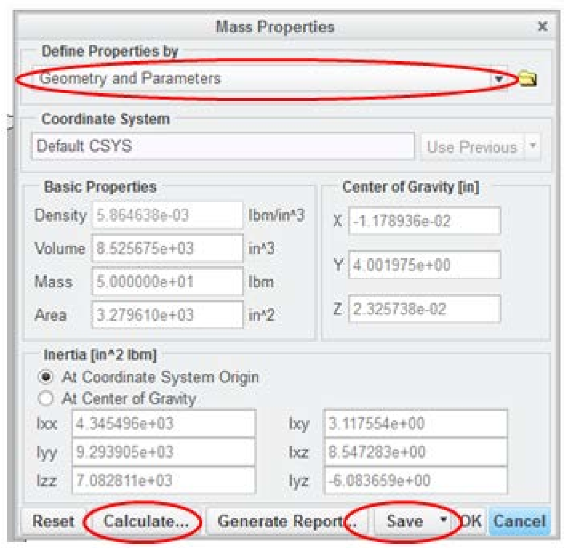
	
Now let's recalculate the mass properties to make sure that your envelope really does weigh 50lbs. Select the **File** tab in the upper menu and then click on **Prepare** and select **Model Properties**. Click on the Change link associated with **Mass Properties**. This time change the way the mass is defined to Geometry and Parameters, then click on calculate and then make sure the mass is 50lbs. Finally click **Save** and **Exit**. Examine the model tree and find the **Extern Copy Geometry** entry. Right click upon it and select **Hide.** You can now use the **Render** tab to set the color of your **Drive Train** subsystem envelope. Now save your file and close it.	

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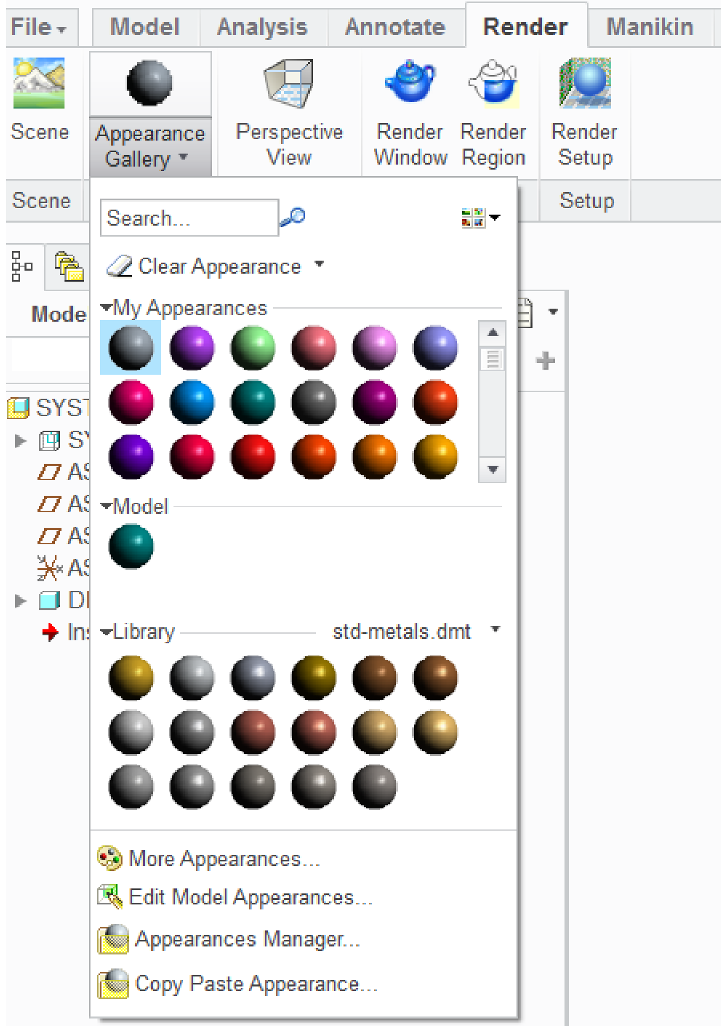
<td>
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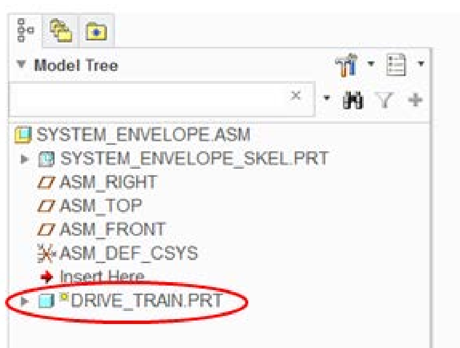
<tr>
<td>Once you close your drive train file, you will be brought back to your overall system envelope file. The drive train subsystem envelope is not visible because you need to place it in the assembly.

Right click on the DRIVE_TRAIN.PRT in the model tree and select Edit Definition.</td>
<td>
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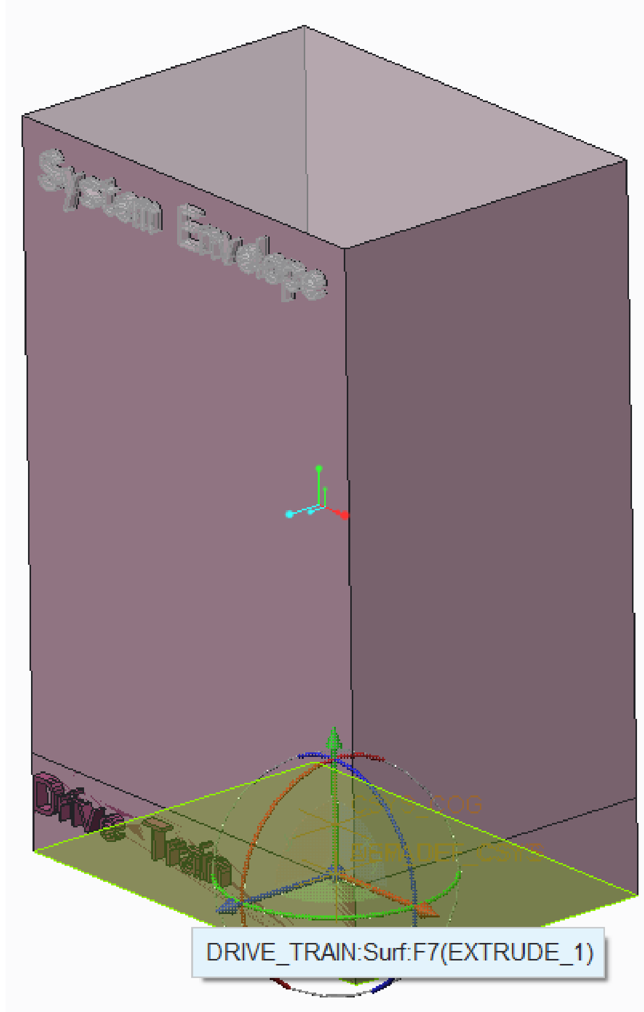
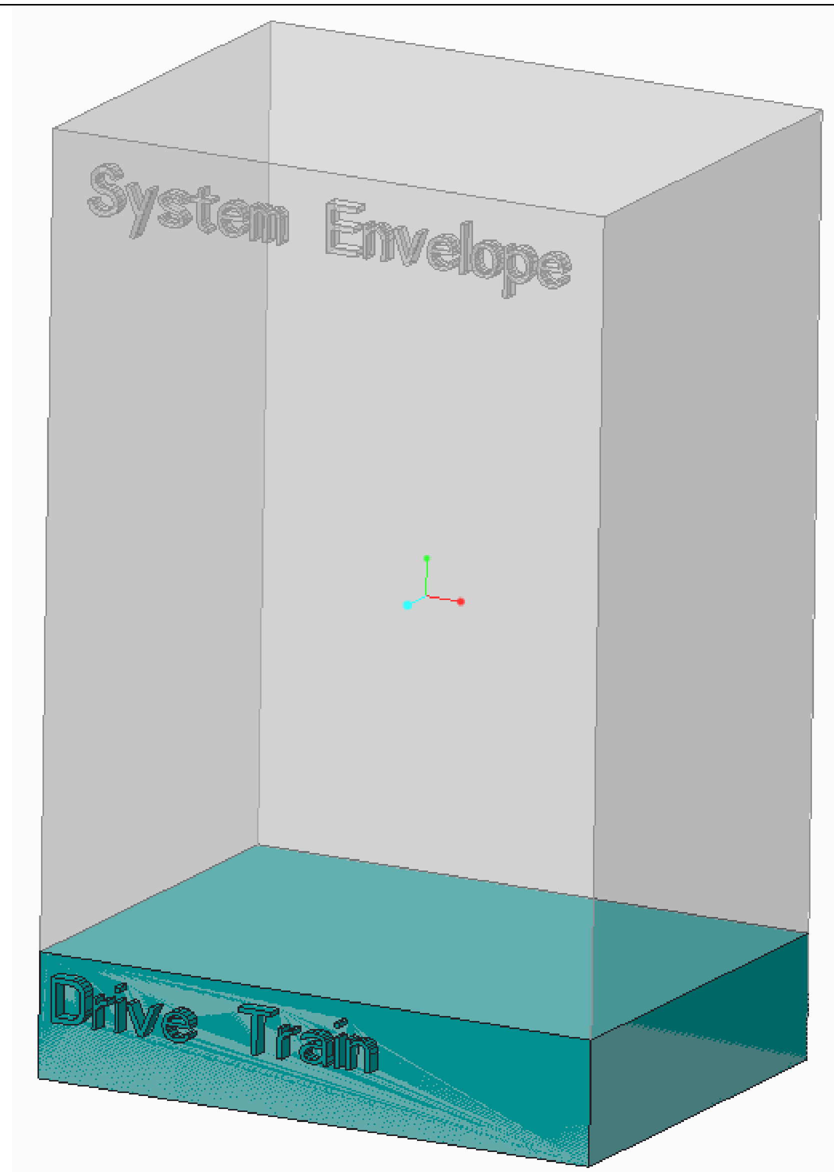
Choose **Planar** from the **User Defined** pull down menu at the top of the screen. Then left click to select the bottom face of the Drive Train and the bottom face of the System Envelope. This will place the drive train on the bottom of the system envelope but allow you to use the orientation sphere to rotate or drag it to the position you want. For now we will place it centered in the system envelope. Now click the green check mark.	

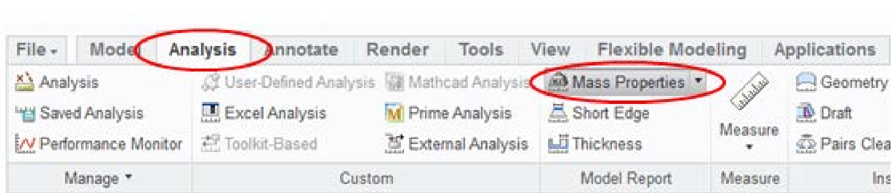
Your first subsystem is now placed in the system.

You will continue to build the subsystem envelopes and place them into the system envelope in the same way you did the Drive Train. Once all the subsystems are in place, You will want to insert the center of gravity feature in the overall system model in the same way you did it in the **Drive Train** model.

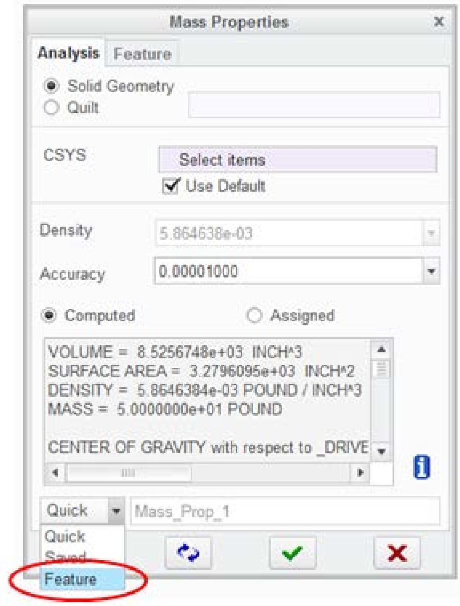


Do this by selecting **Analysis** in the top menu and then select **Mass Properties**. Calculate the mass properties by clicking on the eye glasses. Then click on the **Quick** pull down menu and select **Feature**.

Now click on the

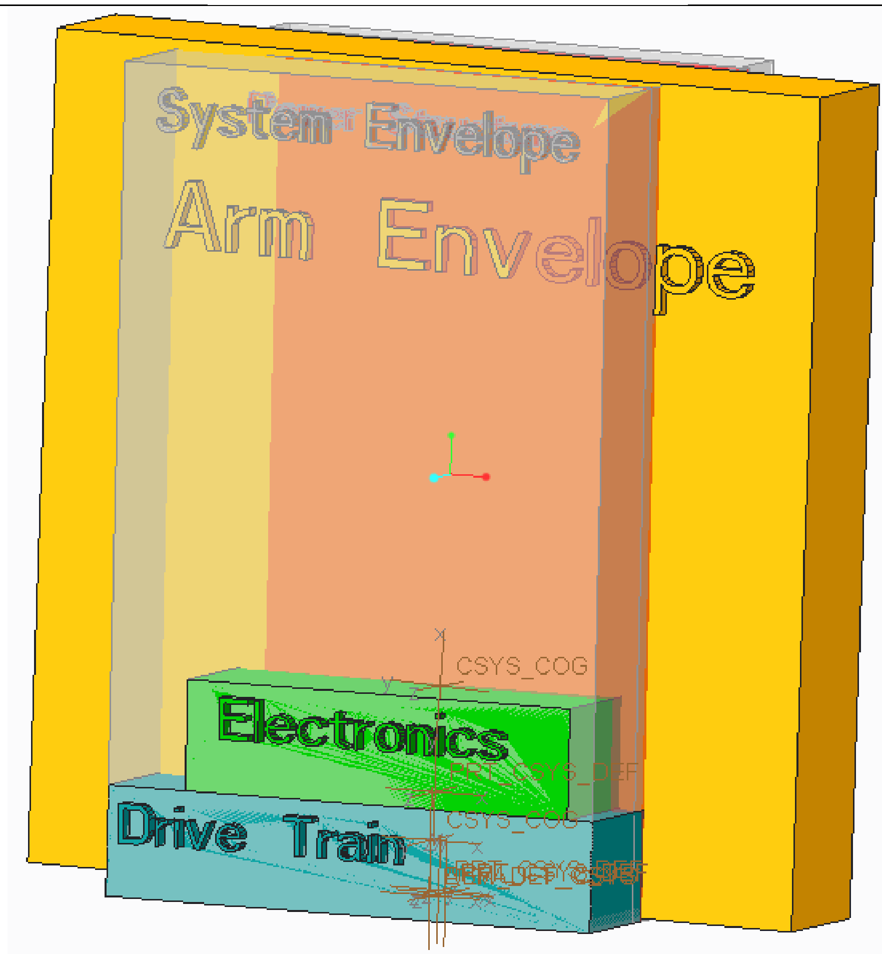


Feature tab at the top of the dialog box and then check the box next to **CSYS_COG** to create a coordinate system at the center of gravity.
Now click the green check mark to finish.



You can now explore new placement strategies as well as different weight allocations to improve your system's overall weight, cost, and center of gravity.

In the system model shown the arm envelope is bigger than the system envelope because it can extend beyond the system envelope after the robot begins moving. Notice the **CSYS_COG** that indicates the system's center of gravity.



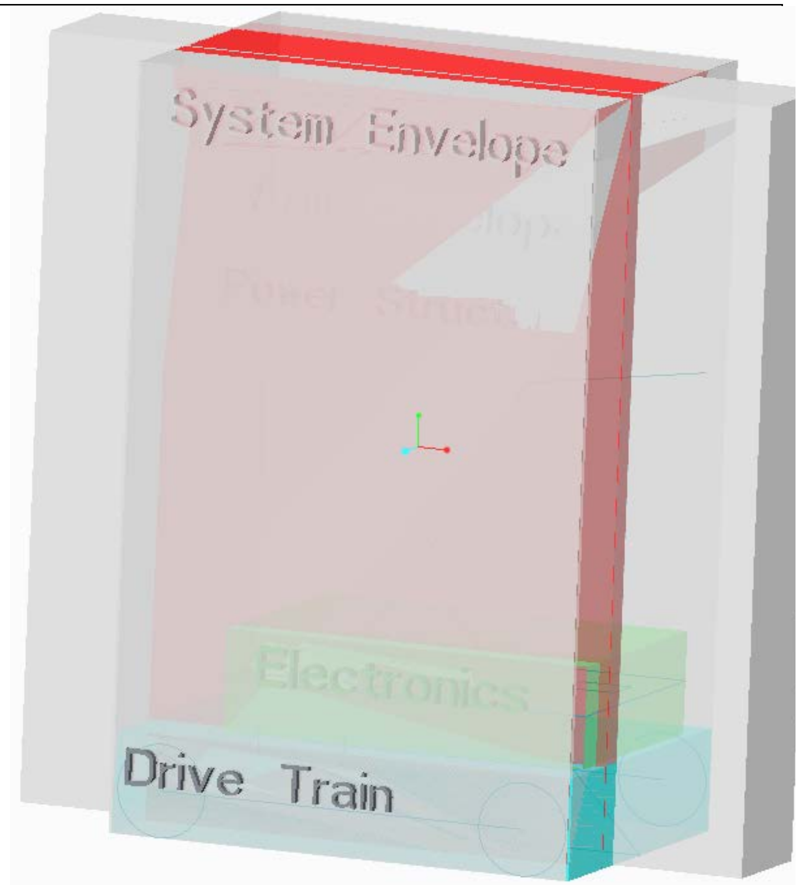
EXERCISE 5.0: TECHNOLOGY SELECTION

In this exercise, you will select technology solutions for each of the subsystems you created previously in exercise 4. Remember that these are just the beginning conceptual ideas for the different technologies.

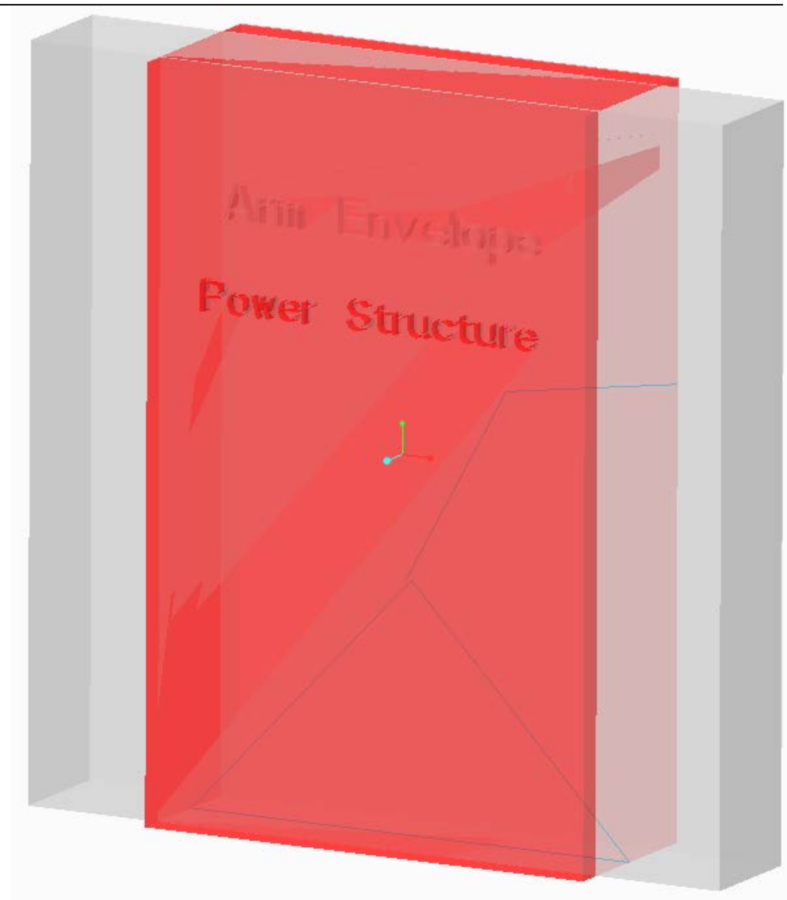
Let's examine the robot system to begin with so that you can see how simple and easy the conceptual models can be.

Start **Creo Parametric** and open the **ROBO_SYS_TECH** model that is found in the Robot_Tech folder within the System Envelopes folder.

Now let's explore how the robot arm will work. First we will want to **Hide** the envelopes that aren't necessary and are blocking our view.



<table>
<tr>
<td>Find the SYSTEM_ENVELOPE_SKEL.PRT model in the model tree and right click and select Hide. Do the same for the DRIVE_TRAIN_TECH.PRT and the ELEC_TECH.PRT models.

Now you should just see the STRUCT_TECH.PRT and the ARM_TECH.PRT envelopes. Also you should see the faint outline of the arm mechanism. Right click to select the ARM_TECH.PRT in the model tree and select Activate.</td>
<td>


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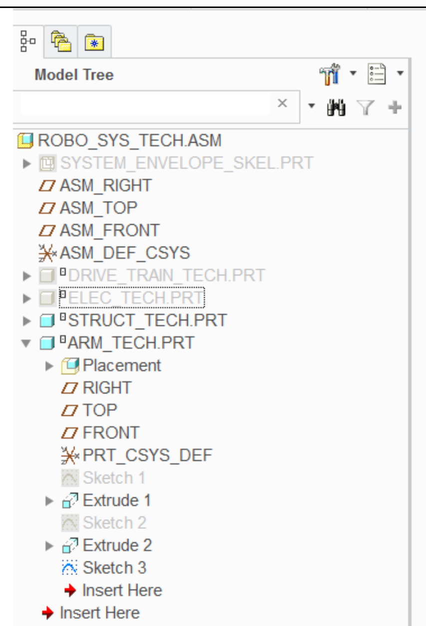
<tr>
<td>Expand the arrow on the left of the ARM_TECH part to see the details of that model. Select the last Sketch in the model tree (Sketch 3). Right click on it and select Edit.</td>
<td>


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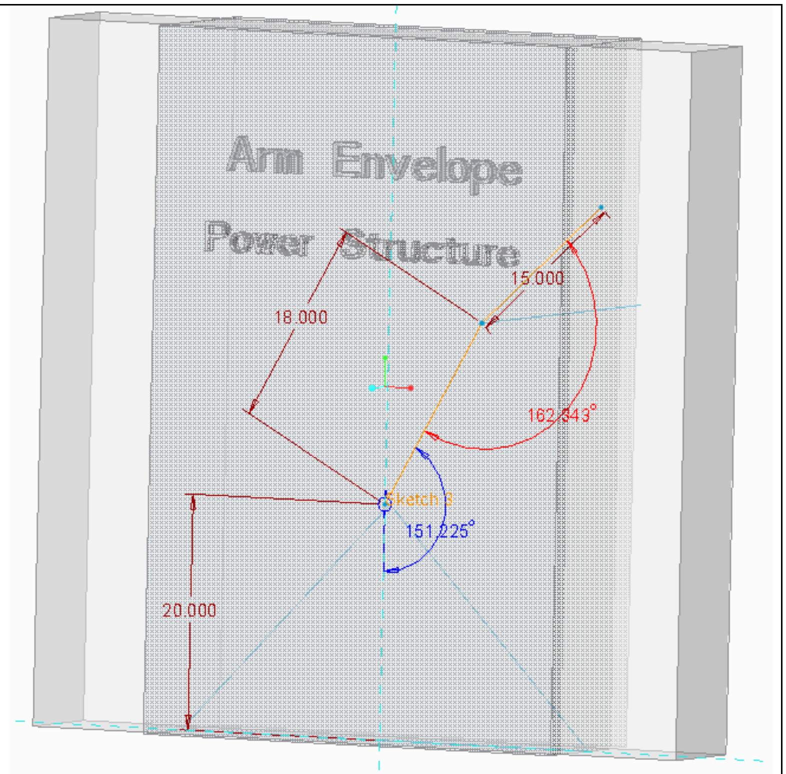
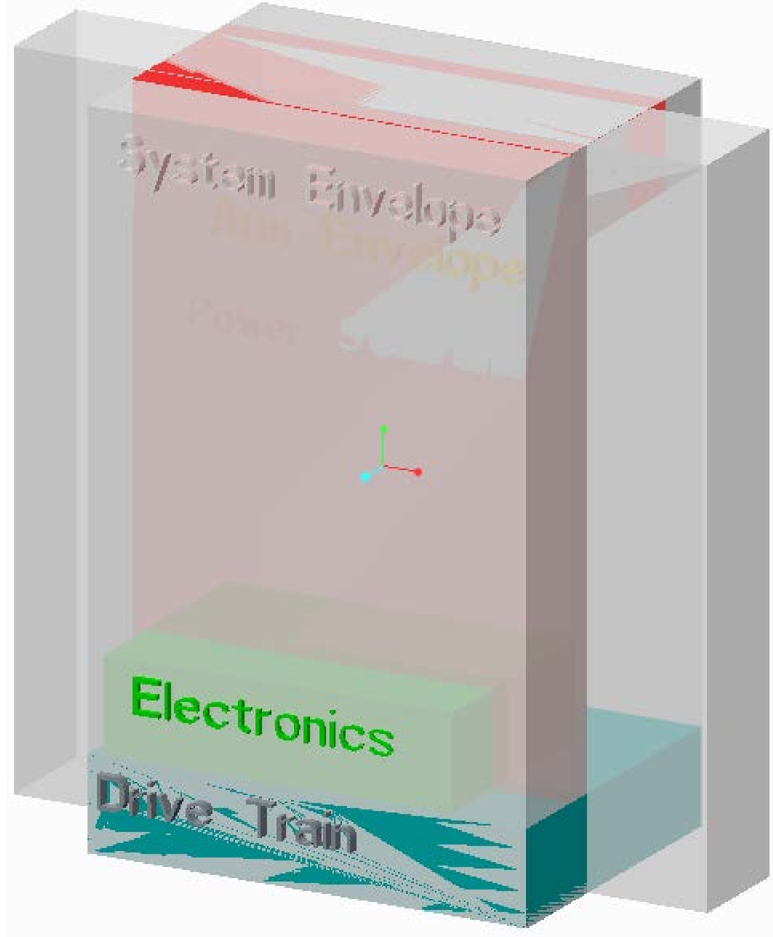
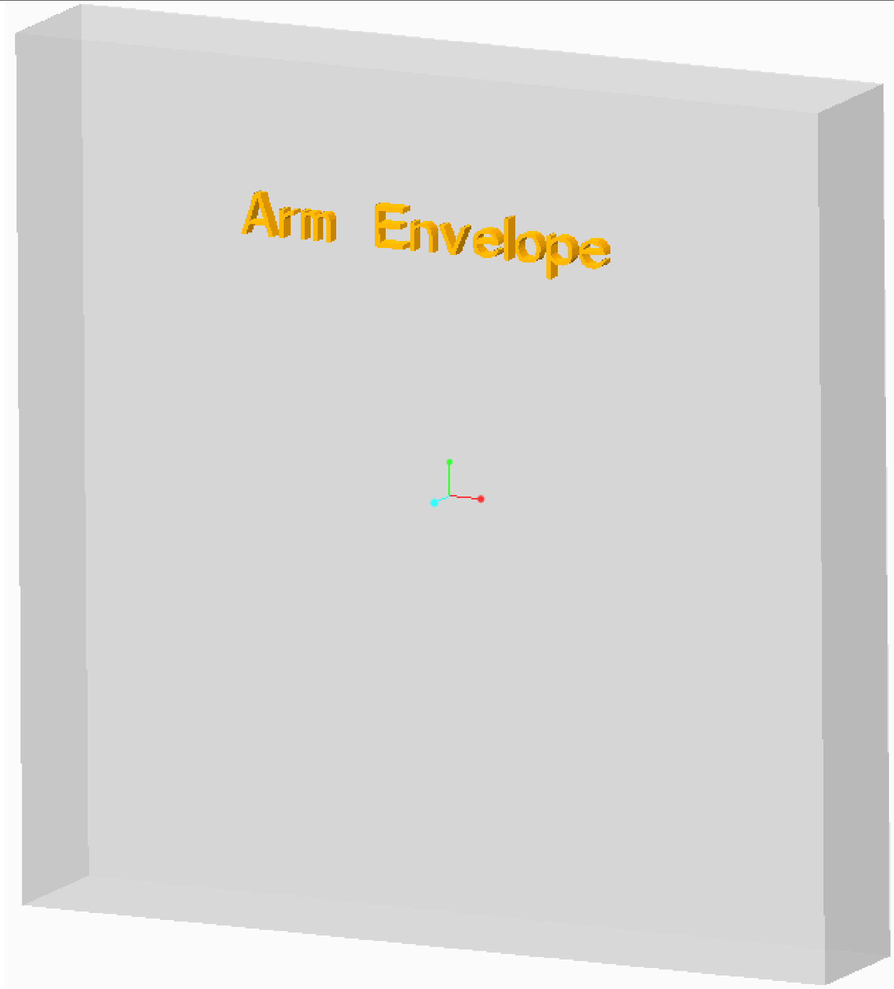
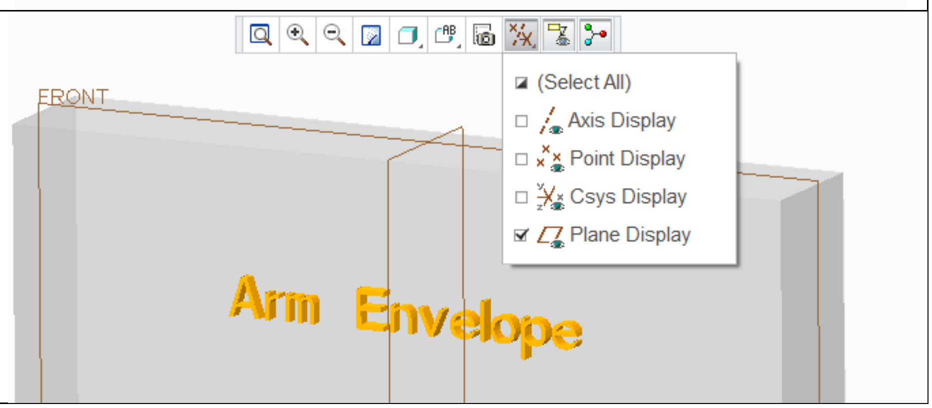
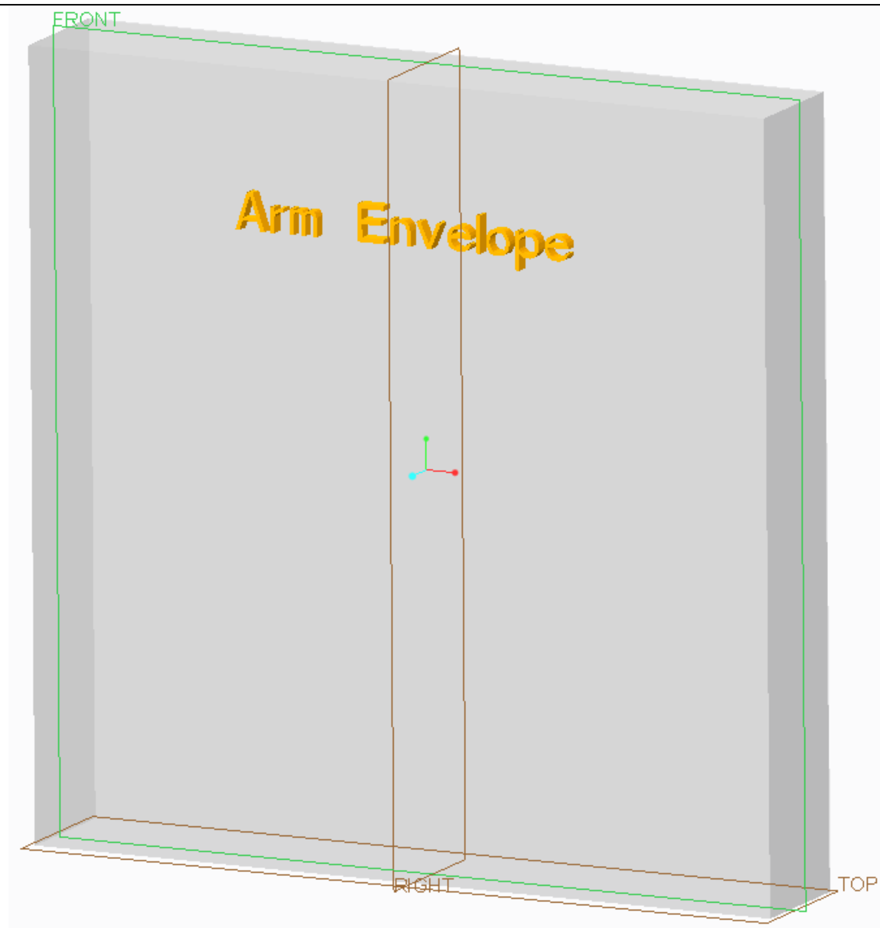
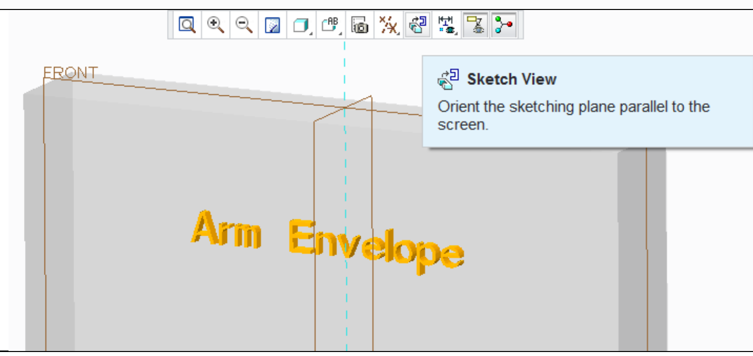
Now the dimensions for the sketch of the arm are displayed. You can left click on either of the arm segments and move the arm. Try to move the arm through its complete range of motion. Notice how just creating a sketch of two lines and dimensioning them properly has created a conceptual model that allows you to explore range of motion and kinematics.	

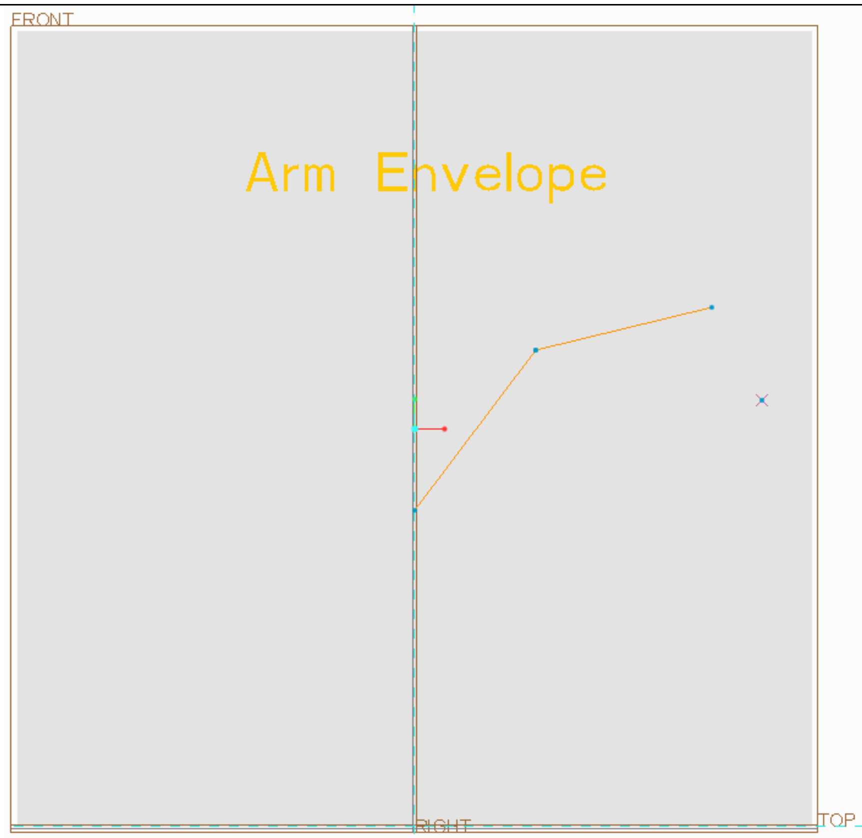
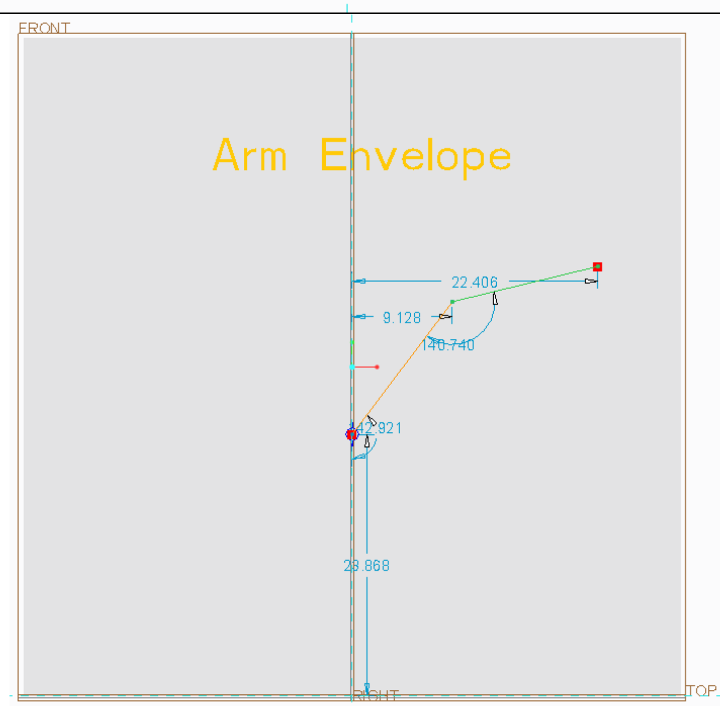
Now let's build our own subsystem technology models.

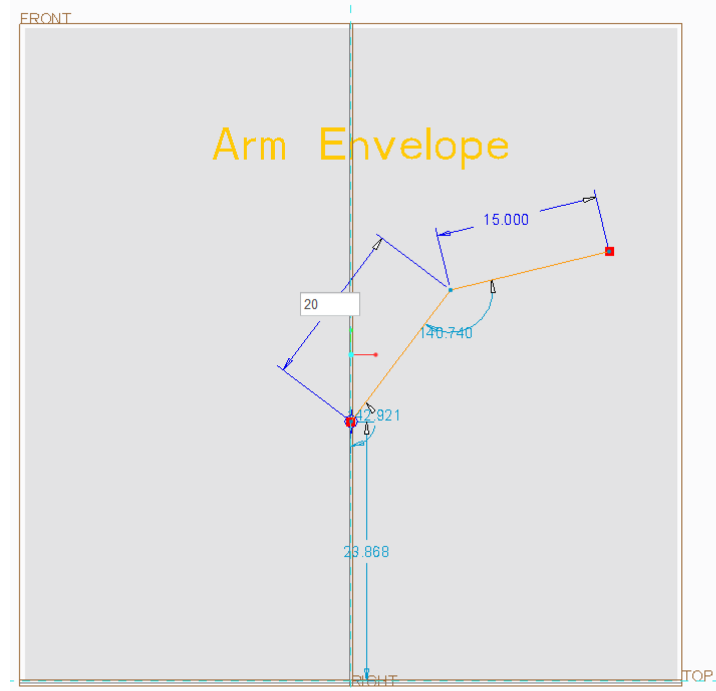
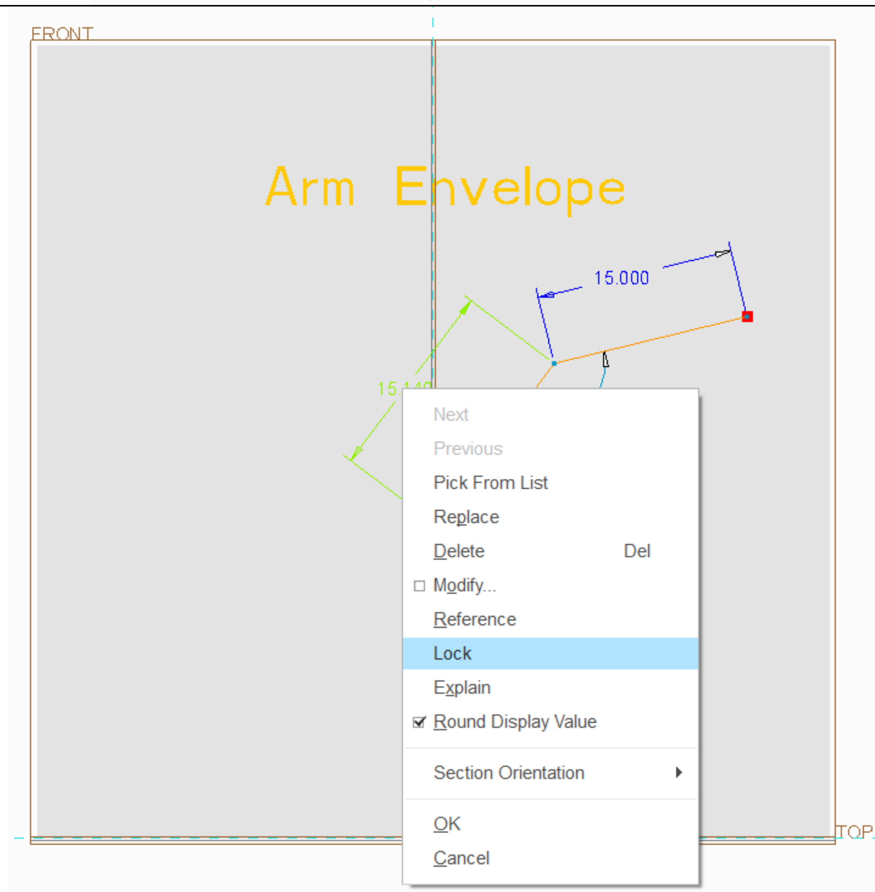
Begin by opening **Creo Parametric** and setting the working directory to the **Robot System** folder found in the System Envelopes folder in the Phase 1 folder. Then open the **Robot_System_Envelope.asm** file.	

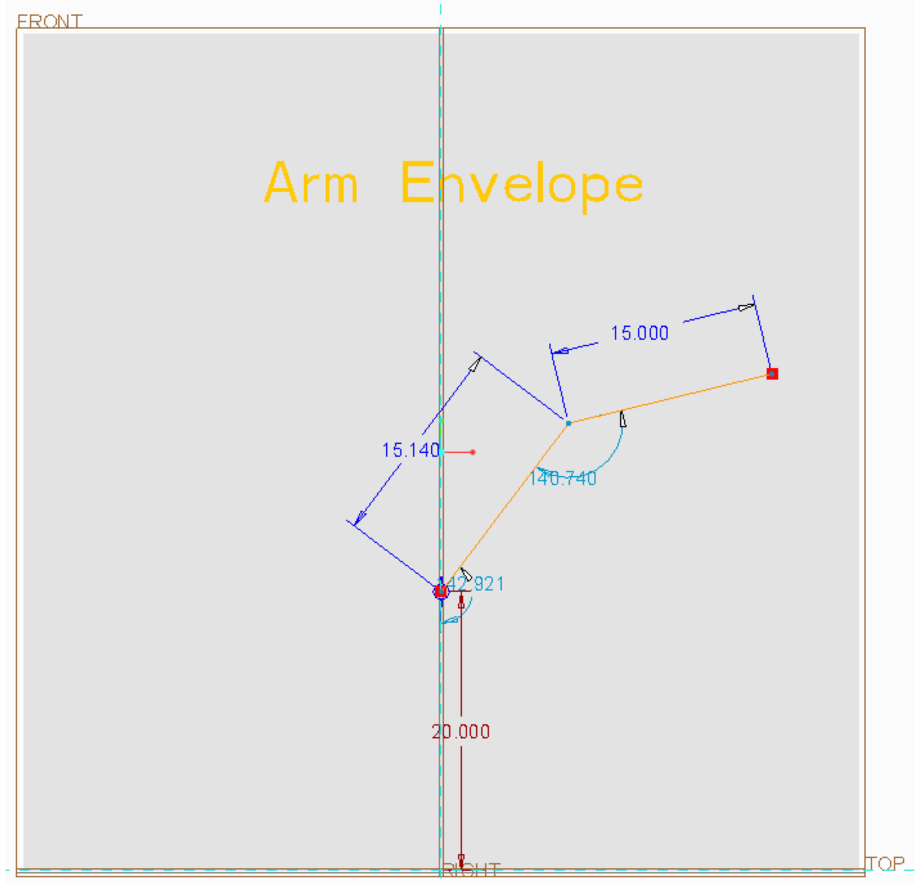
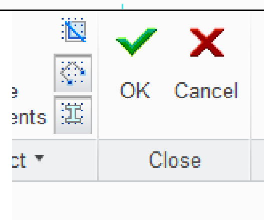
Now select the **ARM_ENVELOPE.PRT** model in the model tree and right click on it and select **Open**. The **Arm** envelope model will open.	
Now check the planes display in the display filter menu so that the datum planes are displayed.	

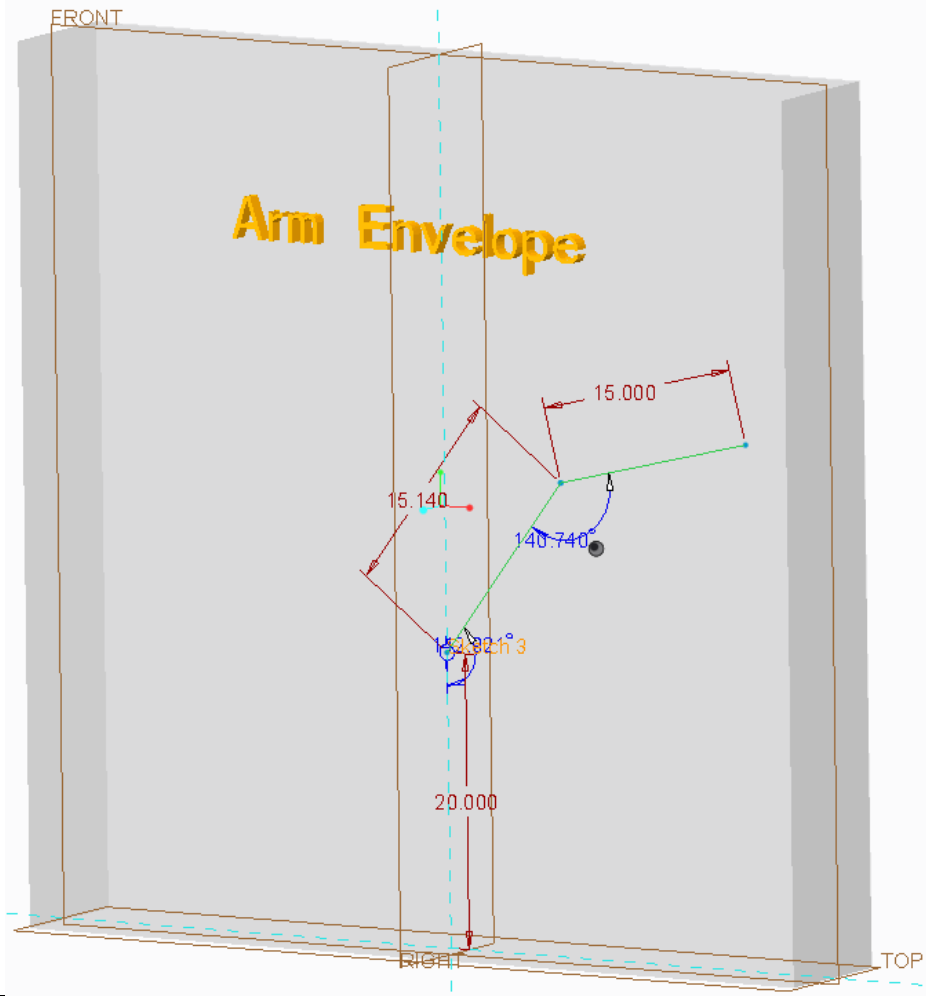
<table>
<tr>
<td>Left click to select the FRONT datum plane and select Sketch in the upper menu.

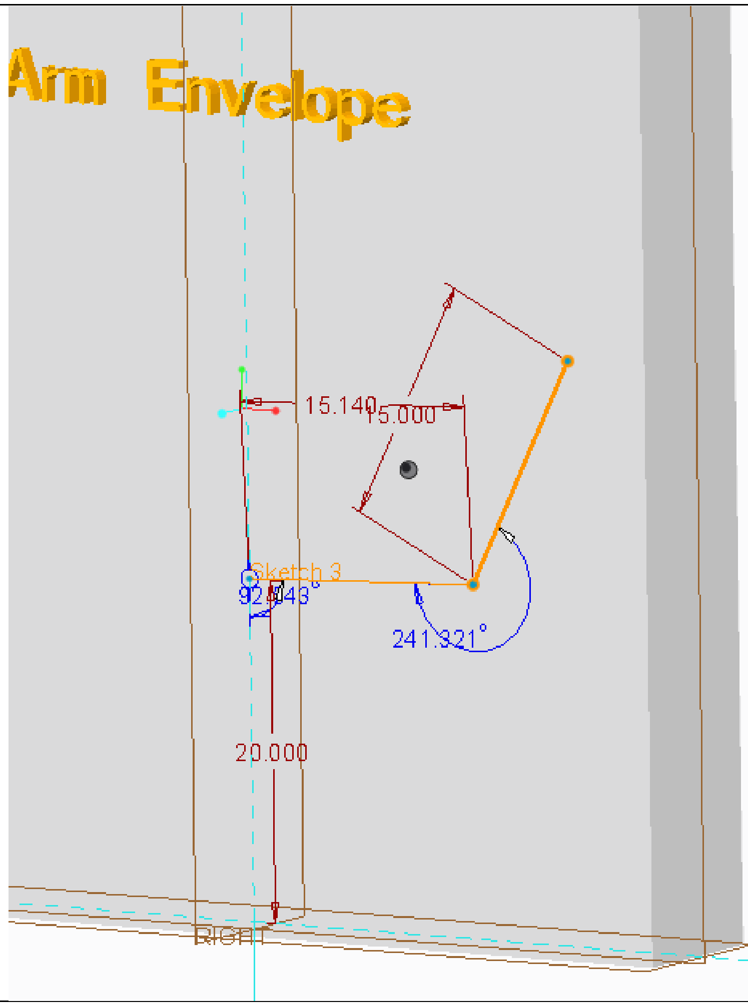

You will enter Sketch mode and the upper menu will change.</td>
<td>
</td>
</tr>
<tr>
<td>Orient your view so that you are looking directly at the Front datum plane by clicking on the Sketch View icon in the display menu.</td>
<td>
</td>
</tr>
</table>

Select the Line tool in the upper menu and  click to make two line segments as shown. Make sure that the first click you make is somewhere on the middle datum (Blue dashed line). Then click to end the first line and click again to create the second line. Don't worry about the dimensions yet, we will set them and lock them in a minute.	
Now select the Normal dimension tool in the upper right menu.  Then left click on the second line and middle click above it to place the dimension.	

<table>
<tr>
<td>Set this value to 15 and do the same for the first line segment and set its length to 20. Then middle click to exit the Normal dimension tool.</td>
<td>
</td>
</tr>
<tr>
<td>Left click on each of the dimensions to select them. When they are green, right click on them and select Lock. This will lock them at their appropriate values.</td>
<td>
</td>
</tr>
</table>

Double click the height dimension between the first point and the bottom of the envelope and set it to **20** and then **Lock** it as well.	
Finish your sketch by clicking on the green check mark in the upper right of the screen menu.	

Find **Sketch 3** in the model tree and right click on it and select **Edit**. This will now allow you to move the linkages through their range of motion.	

The selection of the lengths of the arm segments depends upon many things including the range of motion, the motion path and the mechanical advantage that is desired. *These issues can be addressed at this point or can be left to the detailed design phase to refine.*	
You can continue creating the appropriate technology sketches for each of the subsystems. This allows you to develop an overall conceptual system design.	

Optional Challenge Here is a challenge to help you improve your abilities to define technology sketches. Use the envelope files in the Landing gear folder to create a working sketch of a kinematic linkage for a landing gear system that fits up in the upper envelope when stored and lowers down to the lower envelope when deployed.