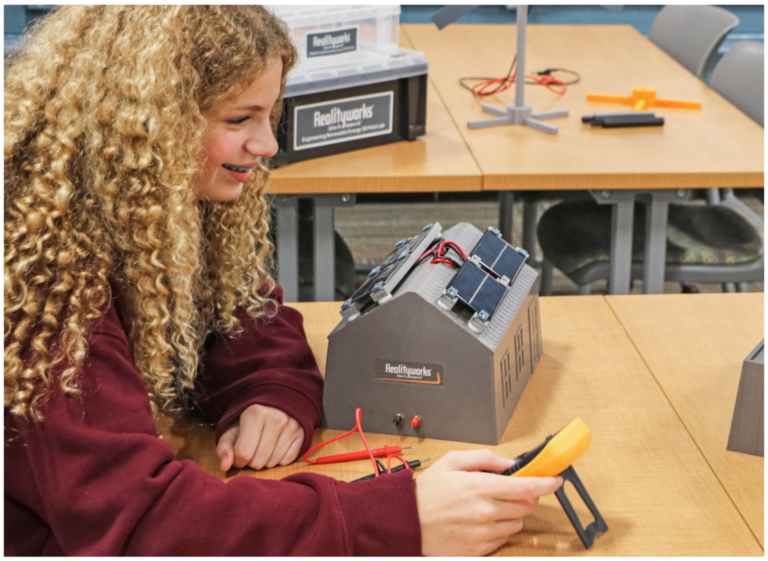
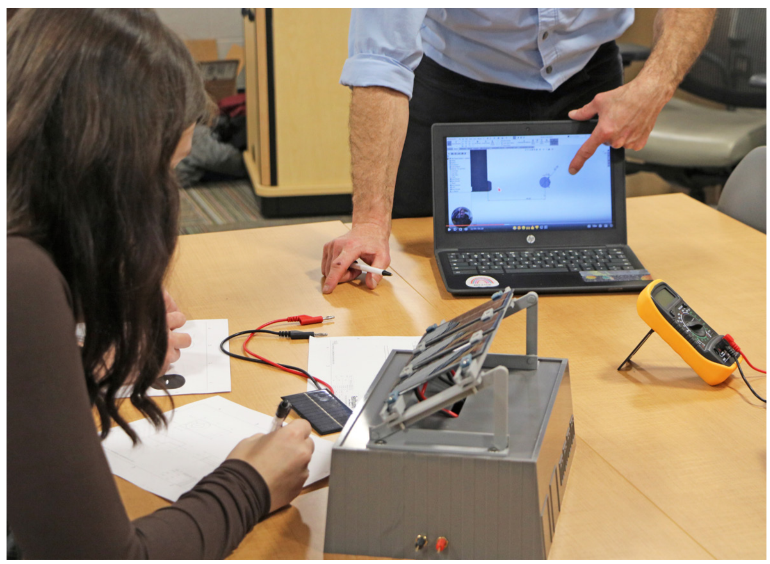
Engineering Renewable Energy 3D Print Lab

Student Engineering Workbook



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Lesson 1:

Introduction to the Solar Design Challenge

Instructions: As you follow the Lesson 1 slide presentation, complete the following questions.

Part A: Solar Energy Production

1. What does PV stand for? ___________________________

2. **Fill in the blanks:** How does a solar panel produce electricity?
   a. ___________ strike a PV cell. Some photons are _____________ by the cell's semiconductor material.
   b. When the semiconductor material absorbs enough sunlight, _________________ are freed from the material's atoms.
   c. Free __________________ naturally move to the surface of the cell.
   d. Electrical ________________________ on the cell absorb the electrons.
   e. When the conductors are connected to an external load, electricity flows in the _________________.

3. What is the typical voltage of a silicon solar cell?

4. What is the current of a typical silicon solar cell?

5. What are the two ways solar cells can be connected?

6. Why is it important to understand the voltage and current of a solar panel

7. Define these concepts related to solar power arrays:
   a. Racking:
   b. Wiring Harness:
   c. Tracking System:

8. For each of the Variables Influencing Solar Energy Production, record important concepts in the table:

Variables Influencing Solar Energy Production	
Variable	Important Concepts
Tilt	
Azimuth	
Insolation	
Global Solar Radiation	

9. How do solar panel arrays installed in Alaska need to be tilted compared to arrays installed in southern Texas?

10. Do solar panels work on cloudy days? Why?

11. What is the average PV panel efficiency percentage?

12. Use the Solar Radiation Map to assist with the following questions:
    a. What is the annual average daily total solar energy where you live?

    b. If a house in central Louisiana had 4 square meters of solar panels installed, operating at an efficiency of 23%, how many kWh could that array produce on an average day?

c. The average U.S. household consumes 30 kWh per day. How many square meters of solar panels would be necessary to meet this need in your location?

d. The average small business uses 230 kWh per day. How many square meters of solar panels would be necessary to meet this need in your location?

13. What are other factors that might affect a solar array's ability to collect energy at maximum efficiency?

Part B: Solar Design Challenge

14. What are the steps involved in the Solar Design Challenge?

Step 1:

Step 2:

Step 3:

Step 4:

Step 5:

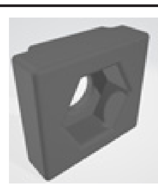
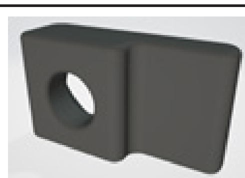
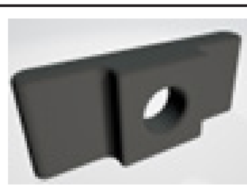
15. Ask your teacher… which 3D CAD Design software will your team use?

Lesson 2:

3D CAD Solar Components

Instructions: Use this Design Tracker to guide your team's work.

1. Which CAD software will you use to design these components?

Component	Reference Image	Who is responsible for designing this?	Status of Work: Check Once Completed
1. Solar Rack Base			☐
2. Solar Rack Upright			☐
3. Solar Rack C Channel			☐
4. Solar Angle Rail			☐
5. Solar Spacer			☐
6. Solar T Nut			☐
7. Solar L Clip			☐
8. Solar T Clip			☐

Lesson 3:

Learn the Slicer Program

Instructions: As you follow the Lesson 3 slide presentation, complete the following questions.

1. Ask your teacher which slicer program you will use:
   a. **EasyPrint**: Use Lesson 3 EasyPrint slides for this lesson.
      i. Free slicer program that can be accessed in an internet browser; offers streamlined file preparation for printing.
      ii. Access at printables.com
   b. **OrcaSlicer**: Use Lesson 3 OrcaSlicer slides for this lesson.
      i. Free, downloadable slicer program that works on Windows and Apple computers; offers a more comprehensive set of file preparation options for advanced applications.
      ii. Access at orcaslicer.com/download

2. For each concept, collect the Important to Know information in the table below:

Machine Operator Knowledge	
Concept	**Important to Know**
Print Bed	
Nozzle	
Filament	

3. What is the difference between additive and subtractive manufacturing?

1. For each 3D Printing Method, collect the requested information in the table below.

Machine Operator Knowledge			
3D Printing Method	What Does it Stand For?	How does it work?	Use?
FDM			
SLA			
SLS			

5. Summarize why gravity is a design challenge in FDM printing:

6. Summarize why placing a component in a stable position is a design challenge in FDM printing:

7. Summarize the different ways to address strength in FDM printing:
   a. Infill:

   b. Shells/Walls:

8. Supports are an important tool to guarantee successful printing of complex components. Summarize how supports can help address each design challenge.
   a. Stability:

   b. Overhangs:

   c. Bridging:

9. Filament is an expensive consumable, and engineers are always aware of how much the materials used will cost. As you practice changing print settings in the slicer for the cylinder, fill in the table below for the different infill percentages:

Machine Operator Knowledge		
Infill % of Cylinder	**Total Filament Used in Grams**	**Print Time**
2%		
10%		
75%		

10. What are the pros and cons of higher and lower infill percentages?
    a. Pros:

    b. Cons:

11. Beyond infill percentage, what are 3 other ways an engineer could reduce the material cost of a print?

Lesson 4:

Preparing Solar Files for Printing in the Slicer

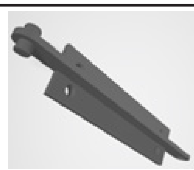
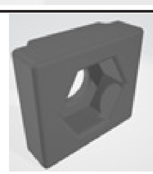
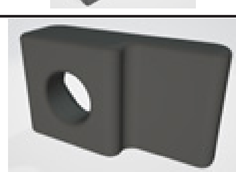
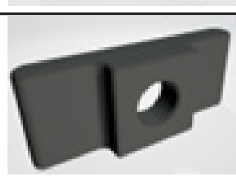
Instructions: As you follow the Lesson 4 slide presentation, complete the following questions.

1. What are the 3 steps your team needs to complete in this lesson?
   a. Part A:

   b. Part B:

   c. Part C:

2. Track your team's progress in slicing each Solar Component:

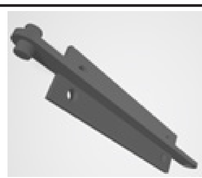
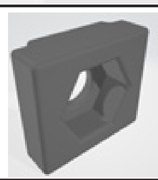
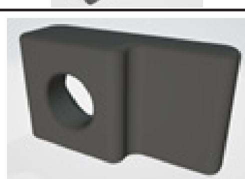
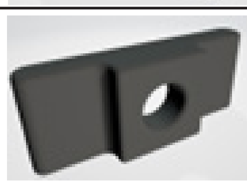
Component	Reference Image	Who is responsible for slicing this?	Status of Work: Check Once Completed
1. Solar Rack Base			☐
2. Solar Rack Upright			☐
3. Solar Rack C Channel			☐
4. Solar Angle Rail			☐
5. Solar Spacer			☐
6. Solar T Nut			☐
7. Solar L Clip			☐
8. Solar T Clip			☐

Lesson 5:

Operating the Printer and Printing Solar Components

Instructions: As you follow the Lesson 5 slide presentation, complete the following questions.

1. Use this table to track the team's printing progress through the lesson:

Component	Reference Image	Who is responsible for printing this?	1st Test Print Successfully Validated for Quality, Size, and Fit?	# Printed for Complete Build
1. Solar Rack Base			☐	___/2
2. Solar Rack Upright			☐	___/2
3. Solar Rack C Channel			☐	___/6
4. Solar Angle Rail			☐	___/2
5. Solar Spacer			☐	___/4
6. Solar T Nut			☐	___/20
7. Solar L Clip			☐	___/12
8. Solar T Clip			☐	___/8

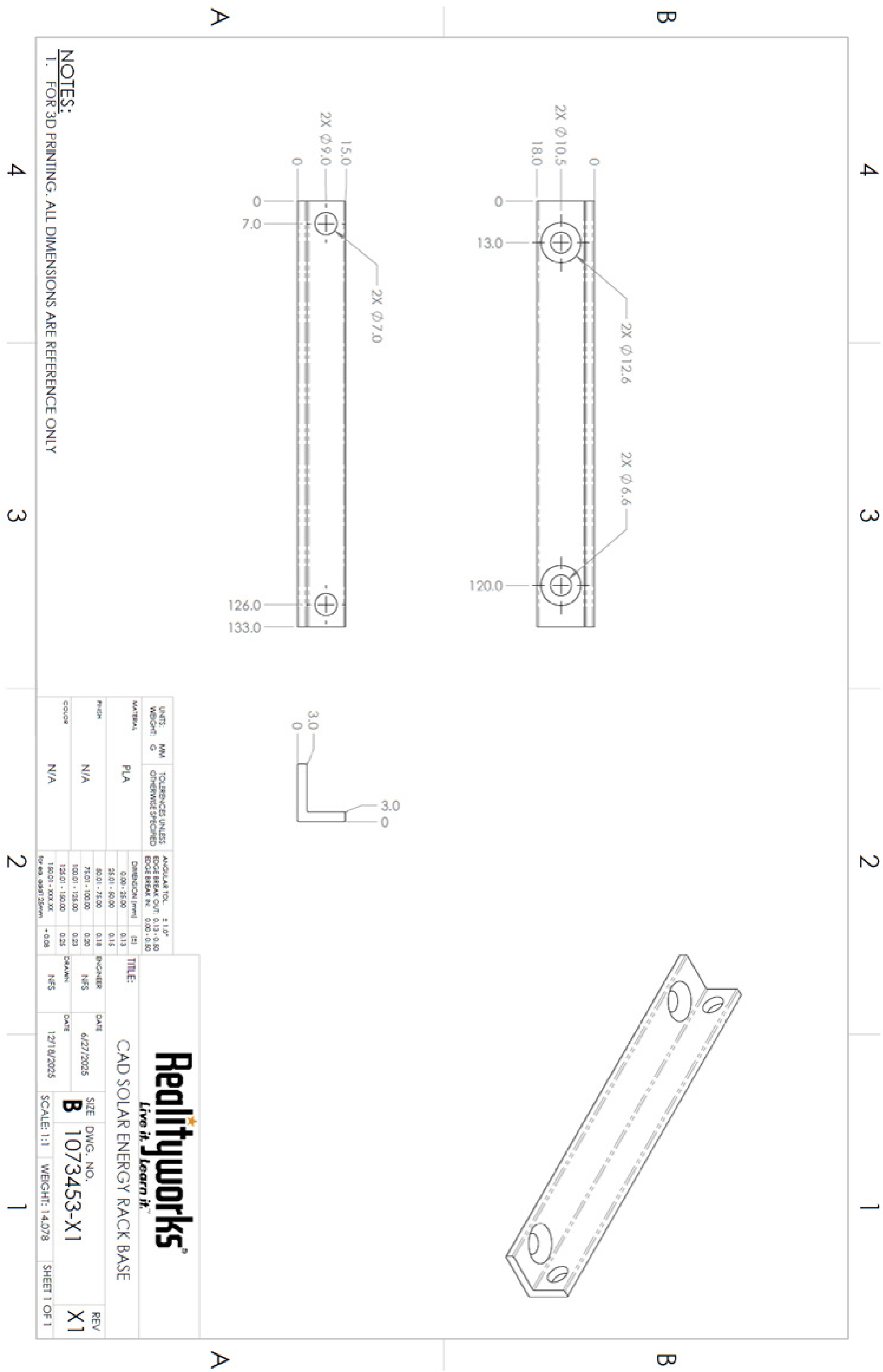
2. **As shown in the slides, check the printer's status:**
   - The printer must be on a stable, level surface
   - Confirm the printer is plugged in
   - Check the type and color of filament loaded
   - Confirm that the filament line goes from the spool to the print head with no breaks
   - Inspect the print bed; it must be clean and securely mounted in place

3. **Once you start printing your first component, confirm a successful start by checking each of the steps the printer works through:**
   - **Homing**: The print bed drops completely to establish a 0 measurement.
   - **Initial Heating:** Observe the temperatures in the upper right corner of the printer's screen increasing; the print head and bed are both heated.
   - **Leveling:** The print head precisely touches the bed in a grid pattern, measuring unevenness that might affect the printing process.
   - **Final Heating:** This brings the print head up to the right temperature for the filament to flow well.
   - **Test Bead:** The printer confirms that filament is flowing by laying a test bead along the front of the print bed. Visually check that this bead of material is smooth, straight, and flat on the bed.
   - **First Layer:** Does the outline match the expected shape and size of the component?

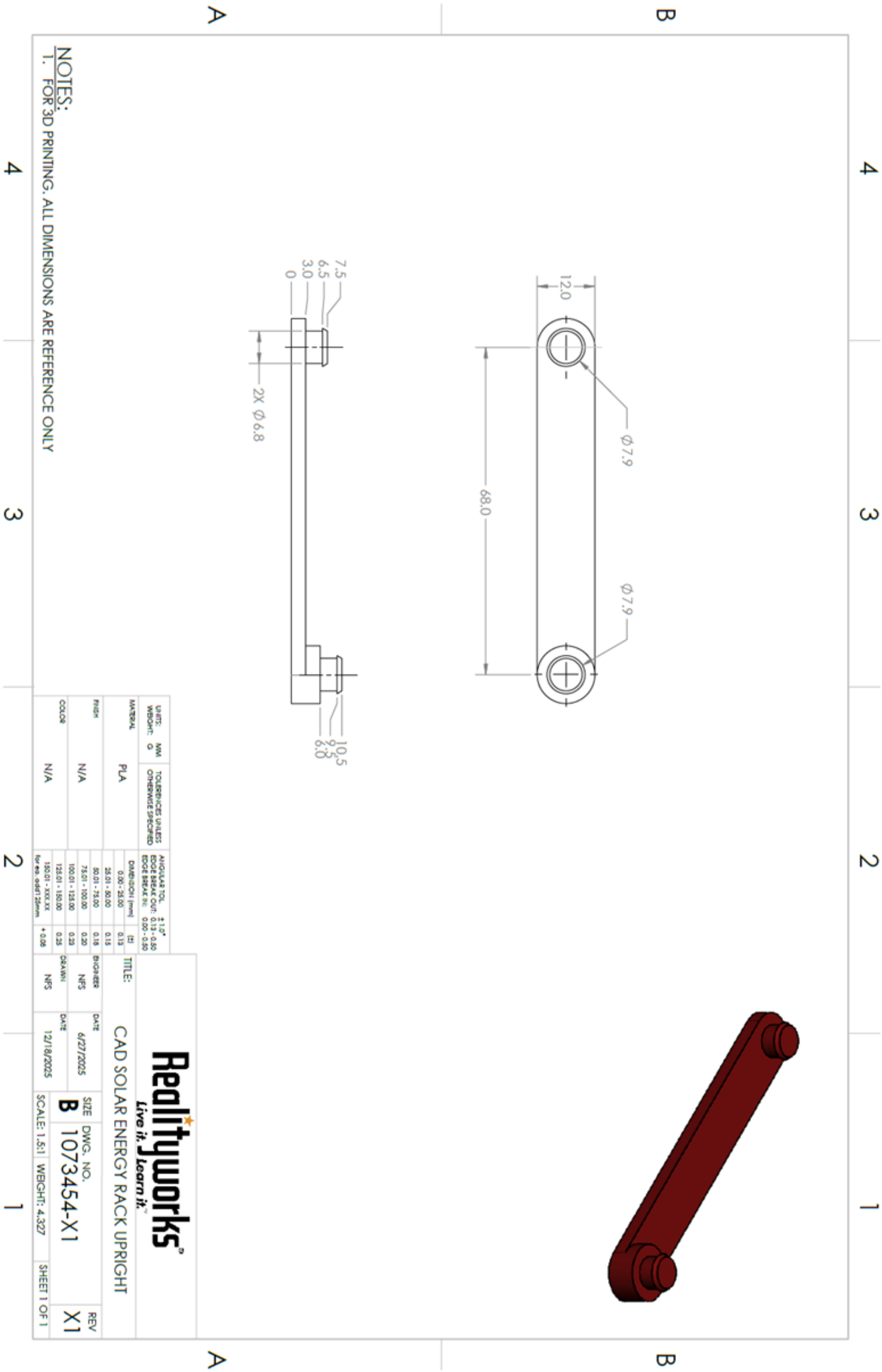
4. If a print is failing, or not printing as expected, how do you stop the print?

5. **Completed Print Validation:** As the team completes the fabrication of each component's first test print, each must be validated for quality, size, and fit. Use the provided CAD Component Drawings in the following pages to compare the designs to your 3D printed components. Check the following for each:
   - Overall Dimensions: length, width, height
   - Position of connection points and holes
   - Removal of support material where 2 components meet
   - Circled dimensions on each CAD Component Drawing

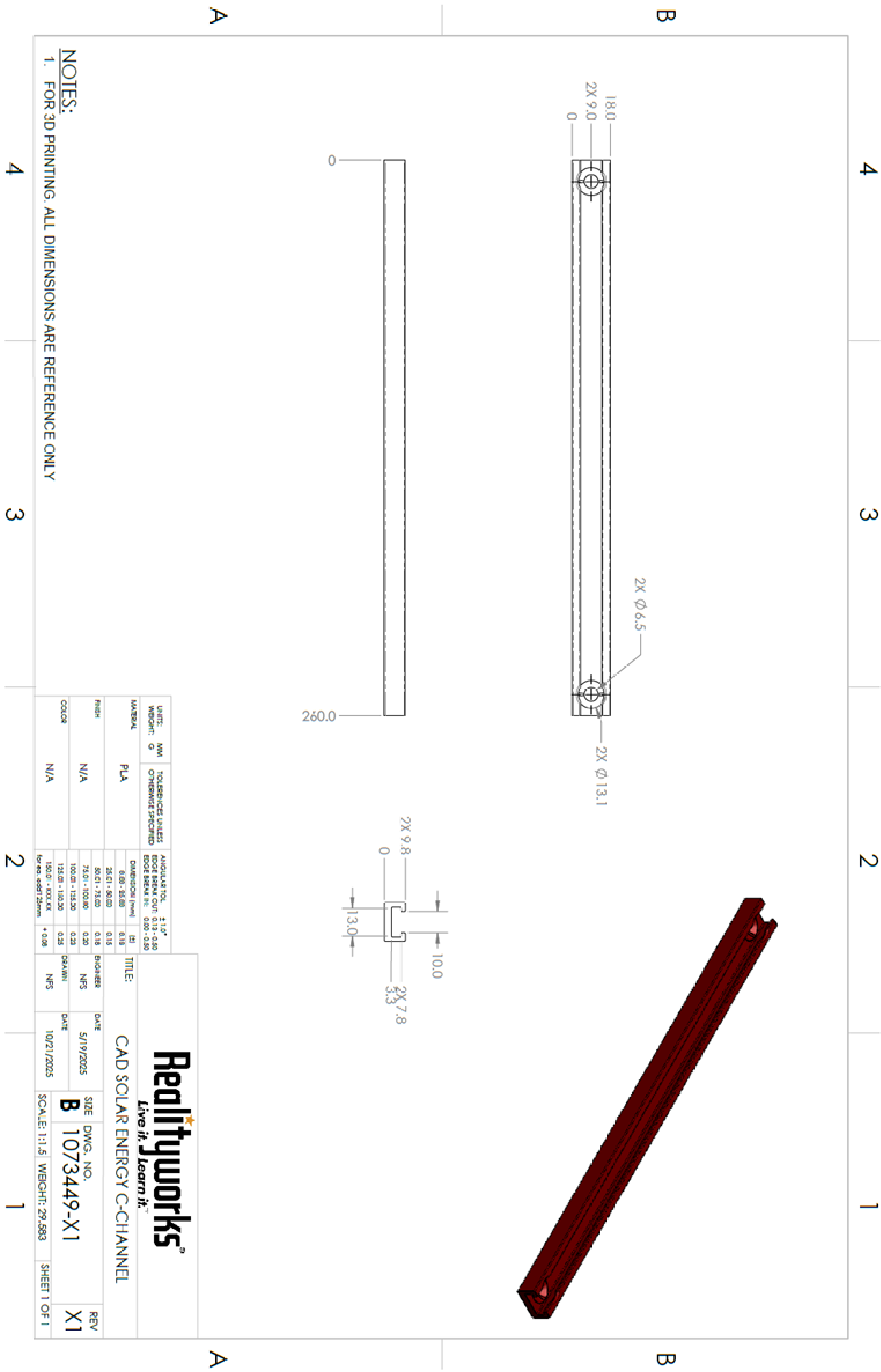
Engineering CAD Component Drawing: 1. Solar Rack Base



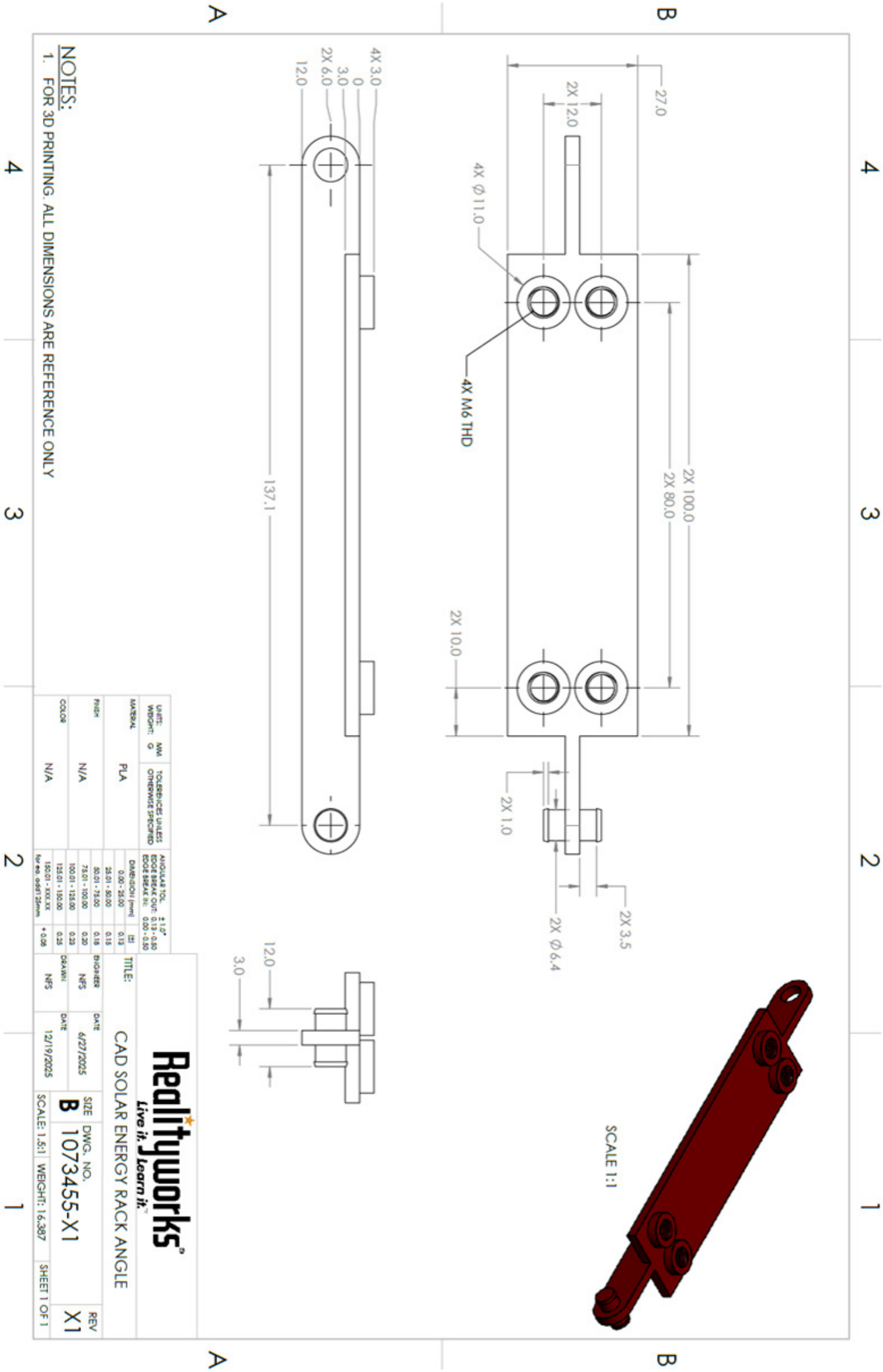
Engineering CAD Component Drawing: 2. Solar Rack Upright



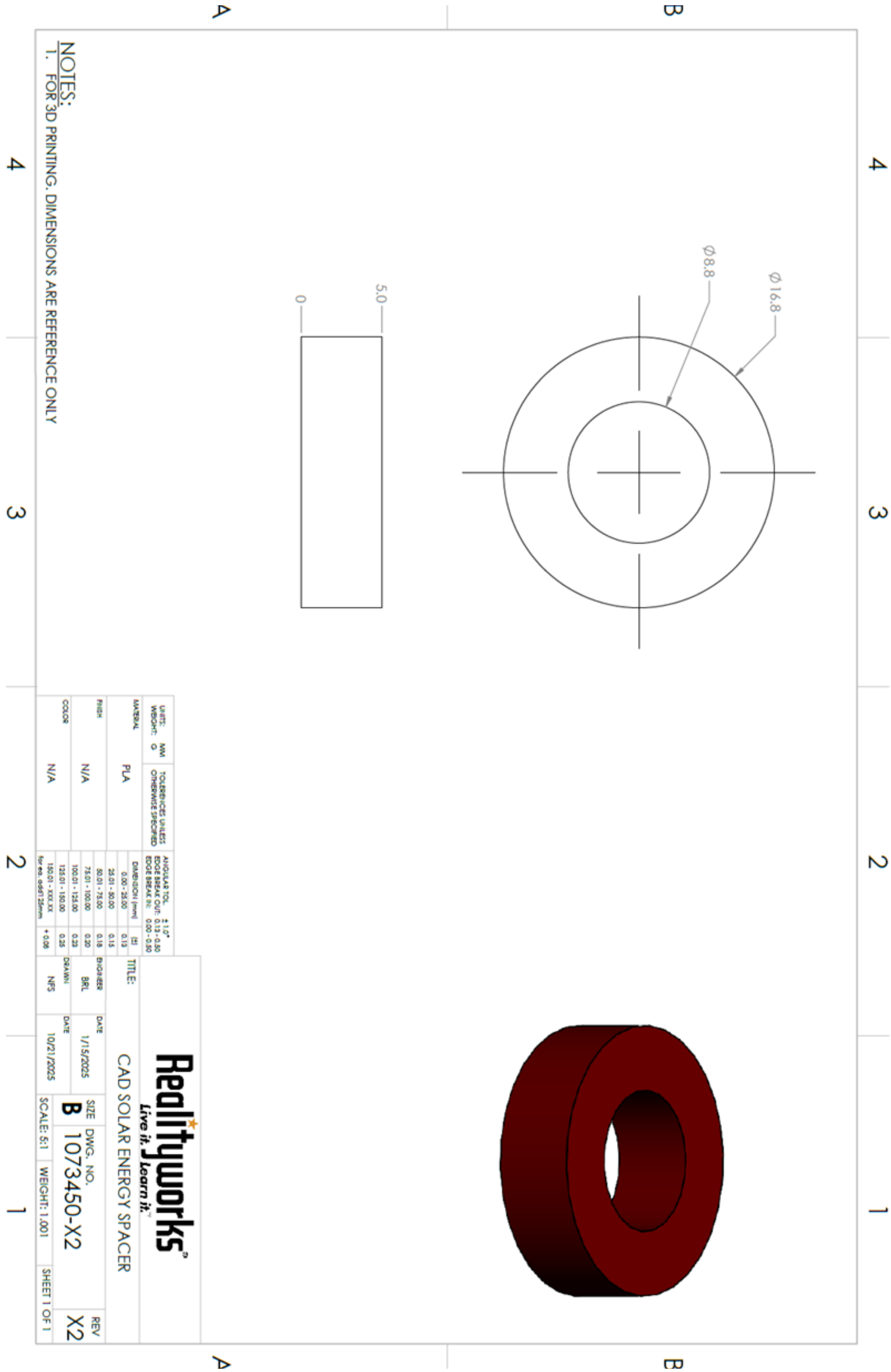
Engineering CAD Component Drawing: 3. Solar Rack C Channel



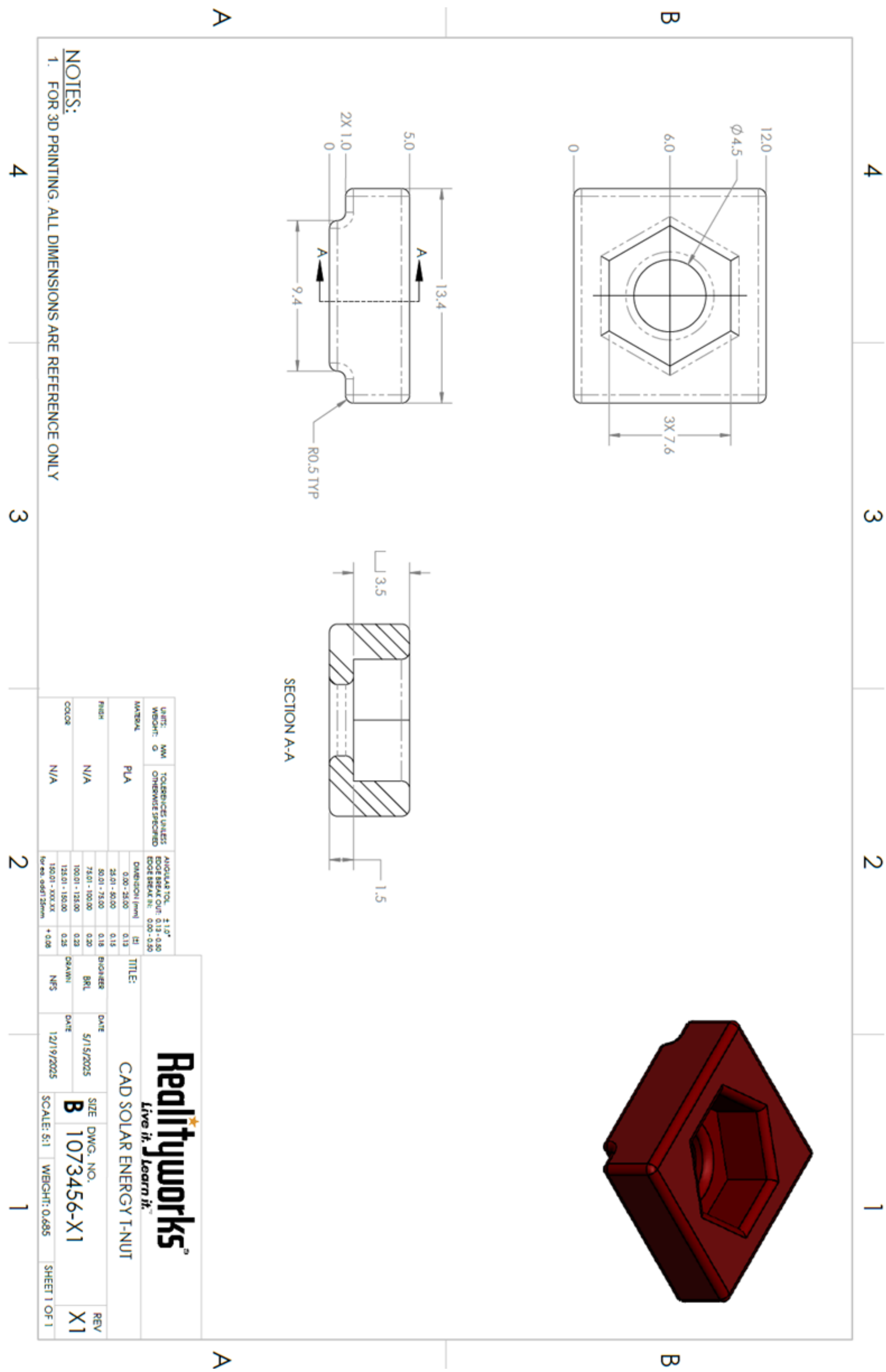
Engineering CAD Component Drawing: 4. Solar Angle Rail



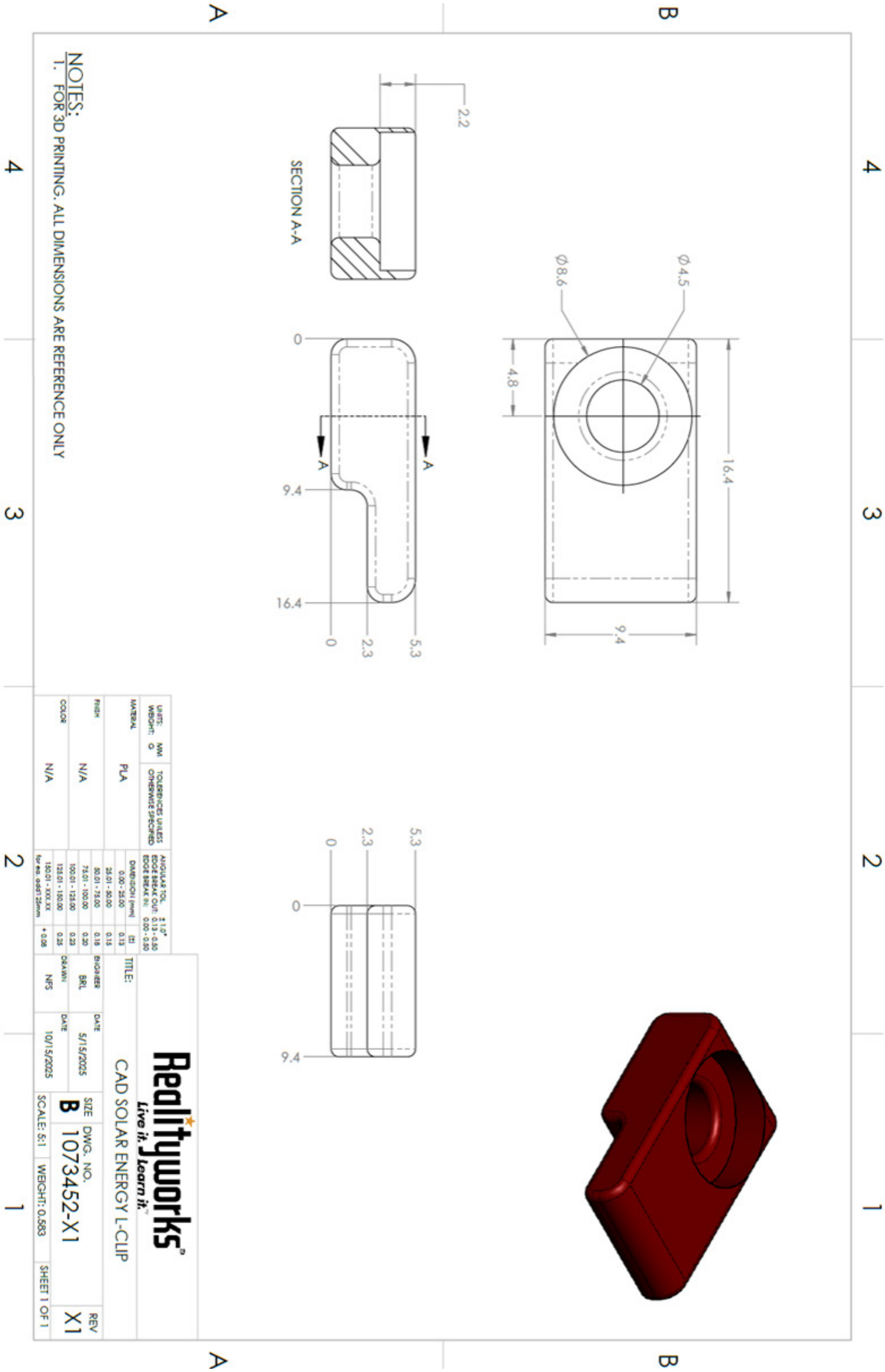
Engineering CAD Component Drawing: 5. Solar Spacer



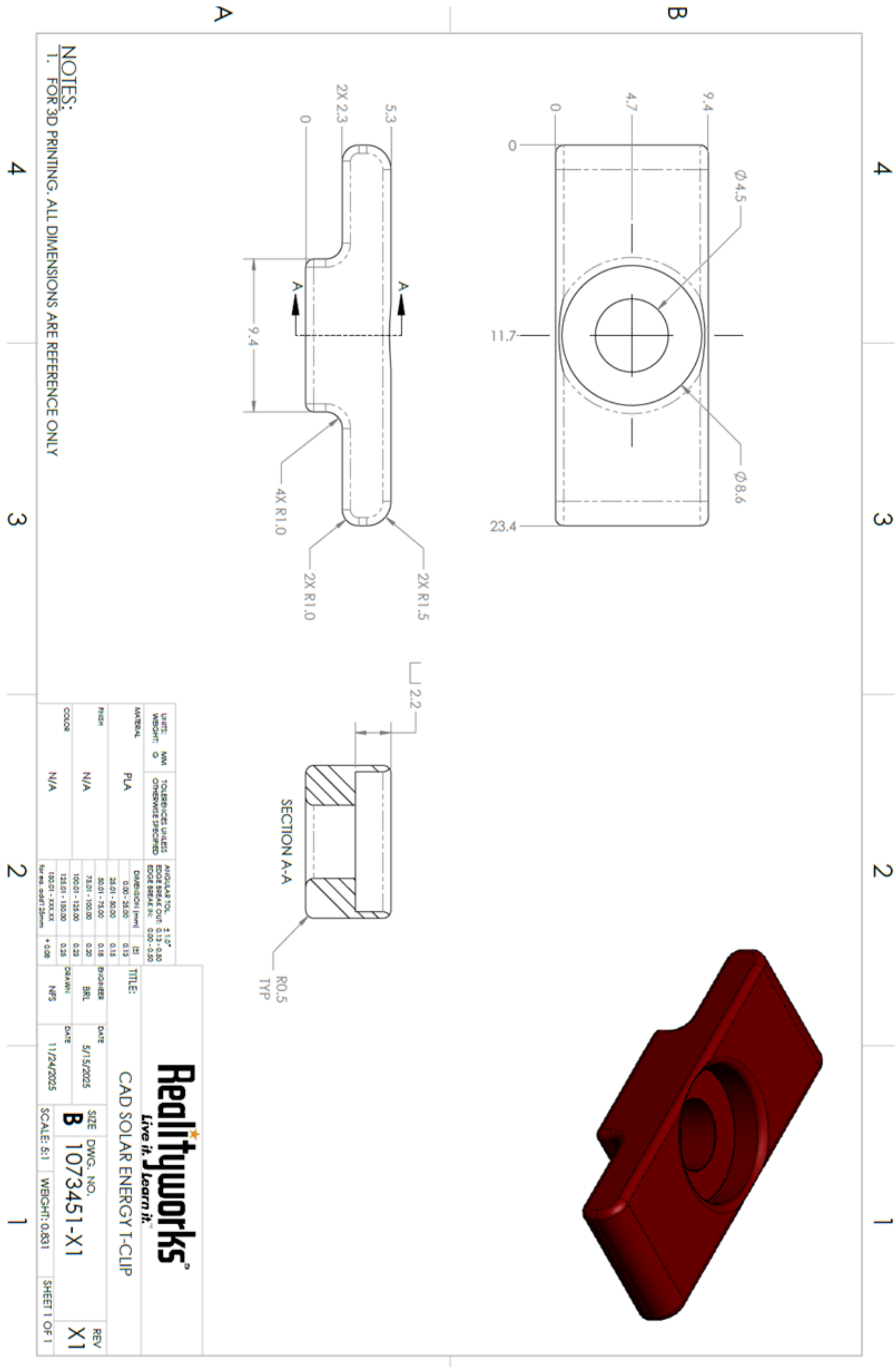
Engineering CAD Component Drawing: 6. Solar T Nut



Engineering CAD Component Drawing: 7. Solar L Clip



Engineering CAD Component Drawing: 8. Solar T Clip



Lesson 6:

Build, Test, and Improve the Solar Power Systems

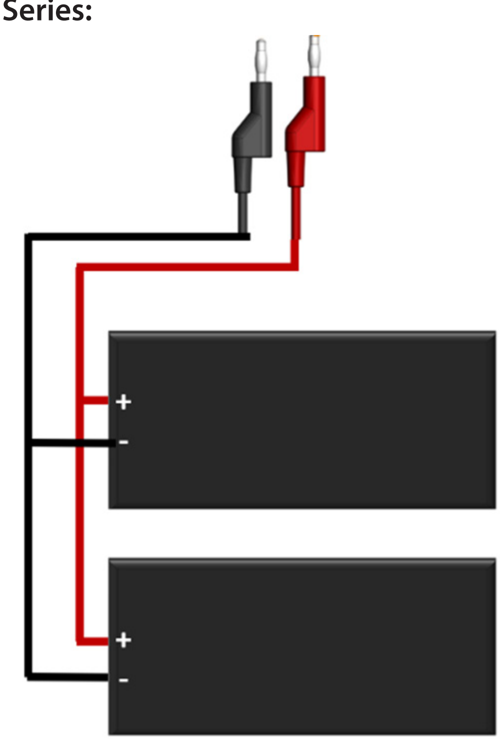
Instructions: As you follow the Lesson 6 slide presentation, complete the following questions.

1. Collect important wiring information in the table below:

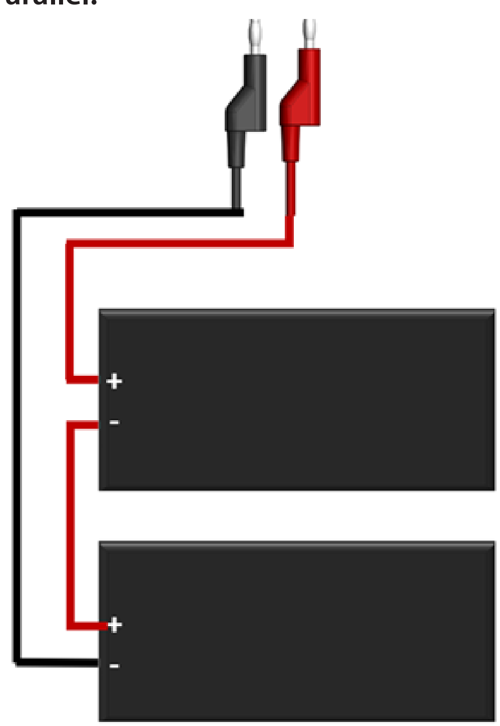
Wiring Strategy	# of Paths for Current	Pros	Cons	Impact on System Voltage and Current
Series				
Parallel				

2. For each circuit wiring example, trace the paths of current:

Series:



Parallel:



3. Testing the PV Arrays: Collext test data in the table below:

PV Array	# of Panels in Array	Light Source	Series Wiring	Parallel Wiring
Residential			**Current Measured:** _________Amps **Voltage Measured:** _________Volts	**Current Measured:** _________Amps **Voltage Measured:** _________Volts
			Current Measured: _________Amps **Voltage Measured:** _________Volts	**Current Measured:** _________Amps **Voltage Measured:** _________Volts
Commercial			**Current Measured:** _________Amps **Voltage Measured:** _________Volts	**Current Measured:** _________Amps **Voltage Measured:** _________Volts
			Current Measured: _________Amps **Voltage Measured:** _________Volts	**Current Measured:** _________Amps **Voltage Measured:** _________Volts

4. How did the voltage and current values change when placed under different light sources?

Improve The System: The data above provides a baseline for performance. Now it is time to improve the system's performance.

5. **Brainstorm** different ways to increase both the Residential and Commercial PV Arrays' voltage with your team. List at least 3 design changes for each that your team could implement:

   a. **Residential** design changes to improve voltage output:
      i.
      ii.
      iii.

   b. **Commercial** design changes to improve voltage output:
      i.
      ii.
      iii.

6. **Rank**: Which design changes will do the most to improve voltage? Rank the design changes your team identified by placing a 1, 2, and 3 next to each listed above.

7. **Divide and Conquer:** Divide the design changes among the team members. Design, print, and test these changes. Then, compare the new voltage measurements with the old baseline.

Lesson 7:

Introduction to the Wind Turbine Design Challenge

Instructions: As you follow the Lesson 7 slide presentation, complete the following questions.

1. Fill in the missing blanks: How does a wind turbine produce electricity?
   a. Most wind turbines use _____________ to collect the wind's kinetic energy.

   b. Wind flows over the blades, creating _______, which makes the _______ turn.

   c. The ________ is connected to gears that turn a _______________ to produce electricity.

2. Collect important information to build your understanding of the universal components of a wind turbine facility. Define each:

   a. Turbine:

   b. Nacelle:

   c. Generator:

   d. Tower:

   e. Cables:

   f. Transformer:

3. Complete the table below as you develop an understanding of the variables that affect the energy produced by a wind turbine's generator.

Maximizing Energy Production: Variables to Measure & Manipulate	
Variable/Tool	Important Information
Site Surveys	
Wind Rose	
Tower Height	
Swept Area	
# of Blades	

4. Wind turbine blades have different shapes, angles, weights, and characteristics that allow them to efficiently capture energy from the wind. Complete the table below as you develop an understanding of blade design concepts.

Wind Power: Blade Shape and Design	
Shape/Concept	**Important Information**
Flat Blades	
Curved Blades	
Twisted Blades	
Blade Pitch	
Angle of Attack	
Tip Speed Ratio	
Blade Life-to-Drag Ratio	

5. Fill in the missing blanks: How does a wind turbine produce electricity?
   a. Using the provided map, what is the Annual Average Wind Speed near your location in meters per second?

   b. To be economically viable on a commercial scale, the average wind speed at the hub's height must be greater than 6.5 m/s. Is commercial wind power viable in your location?

   c. Notice the windspeed values along the coastline. How does this help explain the "Global Offshore Wind Capacity 1995-2024" graph data?

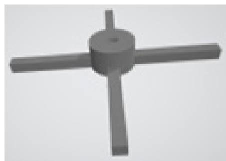
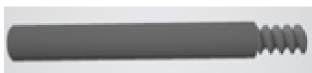
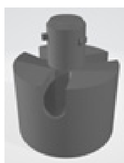
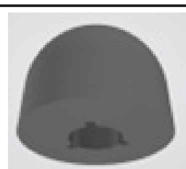
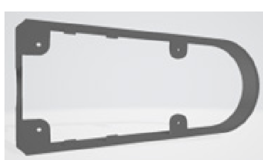
   d. What are the differences between onshore and offshore wind turbines?

Lesson 8:

3D CAD Wind Turbine Components

Instructions: As you follow the Lesson 8 slide presentation, complete the following questions.

1. Which CAD software will you use to design these components?

Component	Reference Image	Who is Responsible for Designing This?	Status of Work: Check Once Completed
1. Wind Base			☐
2. Wind Pole			☐
3. Wind Hub			☐
4. Wind Blade			☐
5. Wind Hub Cap			☐
6. Wind Nacelle Rim			☐
7. Wind Nacelle Cover			☐

Lesson 9:

Preparing Wind Turbine Files for Printing in the Slicer

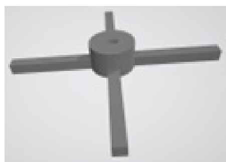
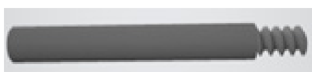
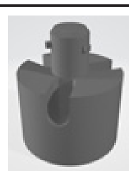
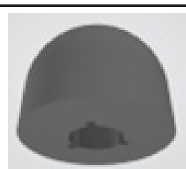
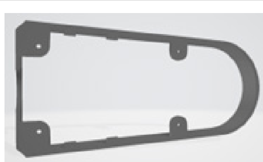
Instructions: As you follow the Lesson 4 slide presentation, complete the following questions.

1. What are the 3 steps your team must complete in this lesson?
   a. Part A:

   b. Part B:

   c. Part C:

2. Track the team's progress in slicing each Solar Component:

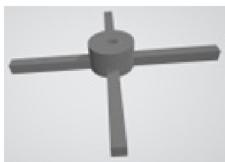
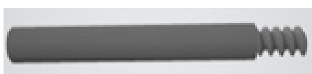
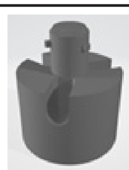
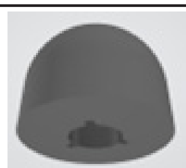
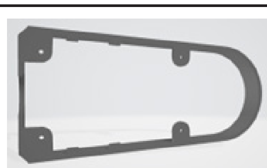
Component	Reference Image	Who is Responsible for Slicing This?	Status of Work: Check Once Completed
1. Wind Base			☐
2. Wind Pole			☐
3. Wind Hub			☐
4. Wind Blade			☐
5. Wind Hub Cap			☐
6. Wind Nacelle Rim			☐
7. Wind Nacelle Cover			☐

Lesson 10:

Operating the Printer and Printing Wind Turbine Components

Instructions: As you follow the Lesson 5 slide presentation, complete the following questions.

1. Use this table to track your team's printing progress through the lesson:

Component	Reference Image	Who is Responsible for Printing This?	1st Test Print Successfully Validated for Quality, Size, and Fit?	# Printed for Complete Build
1. Wind Base			☐	___/1
2. Wind Pole			☐	___/2
3. Wind Hub			☐	___/1
4. Wind Blade			☐	___/3
5. Wind Hub Cap			☐	___/1
6. Wind Nacelle Rim			☐	___/1
7. Wind Nacelle Cover			☐	___/1

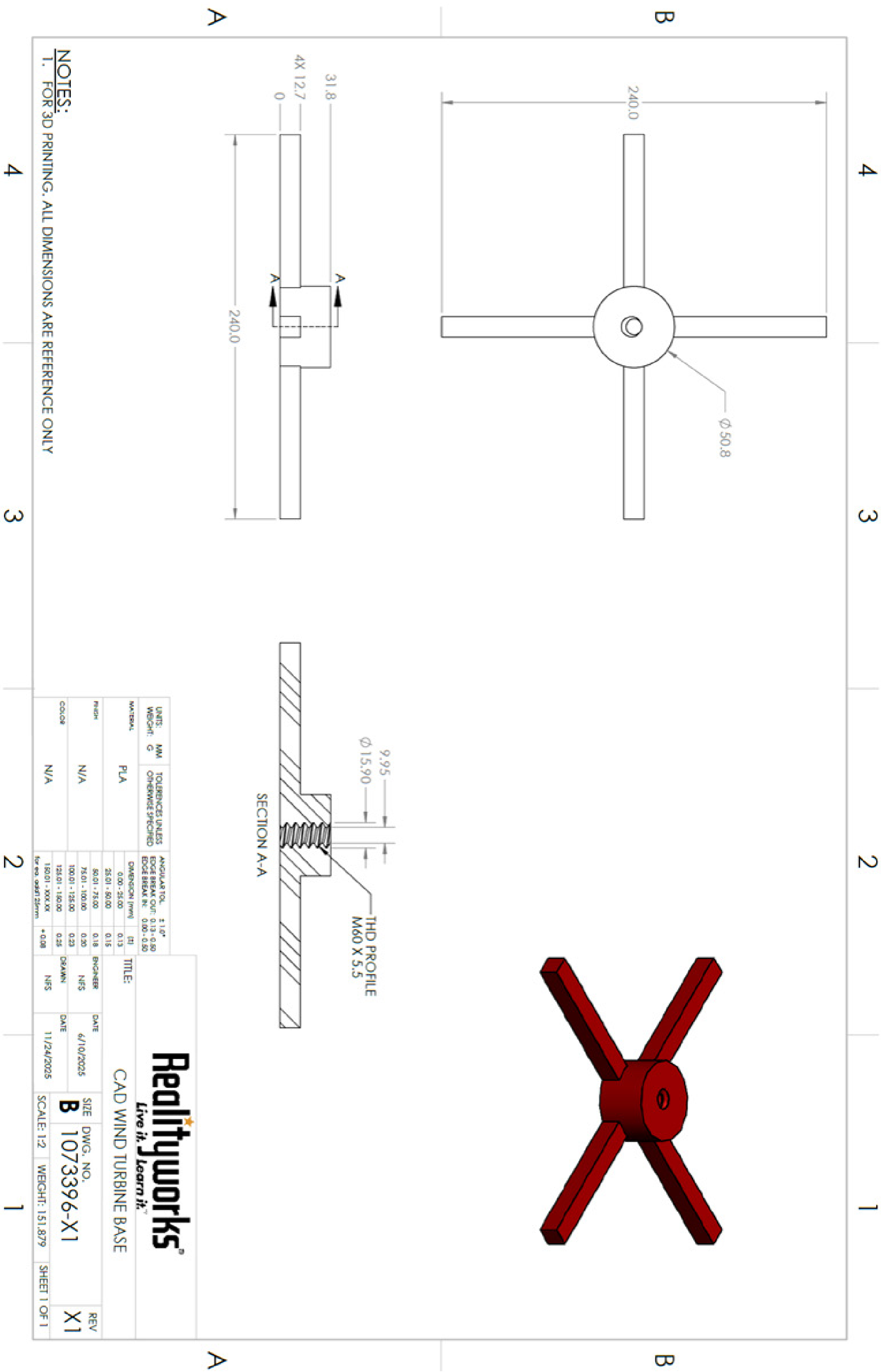
2. **As shown in the slides, check the printer's status:**
    - The printer must be on a stable, level surface
    - Confirm the printer is plugged in
    - Check the type and color of filament loaded
    - Confirm that the filament line goes from the spool to the print head with no breaks
    - Inspect the print bed; it must be clean and securely mounted in place

3. **Once you start printing your first component, confirm a successful start by checking each of the steps the printer works through:**
    - **Homing**: The print bed drops completely to establish a 0 measurement.
    - **Initial Heating:** Observe the temperatures in the upper right corner of the printer's screen increasing; the print head and bed are both heated.
    - **Leveling:** The print head precisely touches the bed in a grid pattern, measuring unevenness that might affect the printing process.
    - **Final Heating:** This brings the print head up to the right temperature for the filament to flow well.
    - **Test Bead:** The printer confirms that filament is flowing by laying a test bead along the front of the print bed. Visually check that this bead of material is smooth, straight, and flat on the bed.
    - **First Layer:** Does the outline match the expected shape and size of the component?

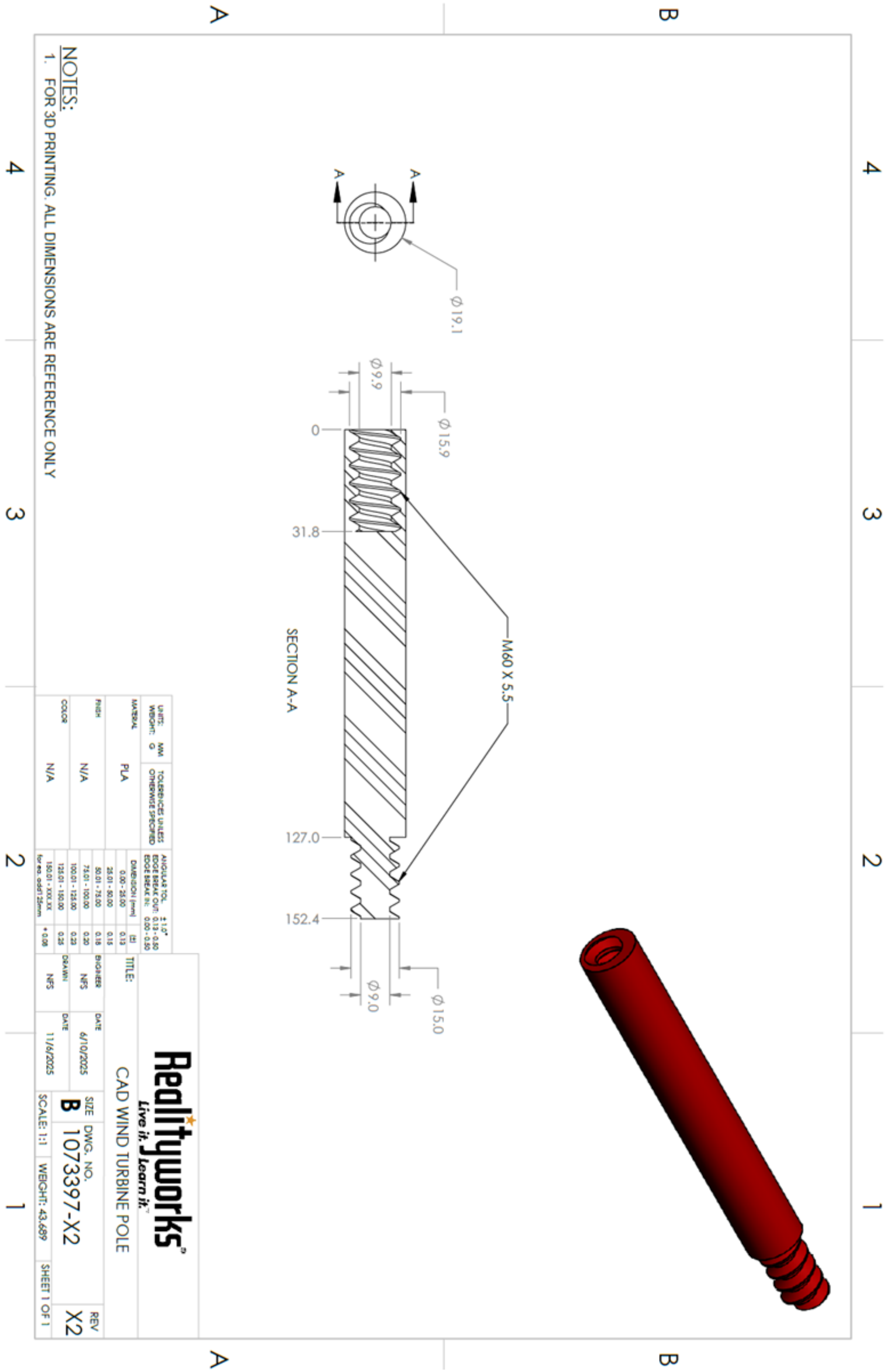
4. If a print is failing, or not printing as expected, how do you stop the print?

5. **Completed Print Validation:** As the team completes the fabrication of each component's first test print, each must be validated for quality, size, and fit. Use the provided CAD Component Drawings in the following pages to compare the designs to your 3D printed components. Check the following for each:
    - Overall Dimensions: length, width, height
    - Position of connection points and holes
    - Removal of support material where 2 components meet
    - Circled dimensions on each CAD Component Drawing

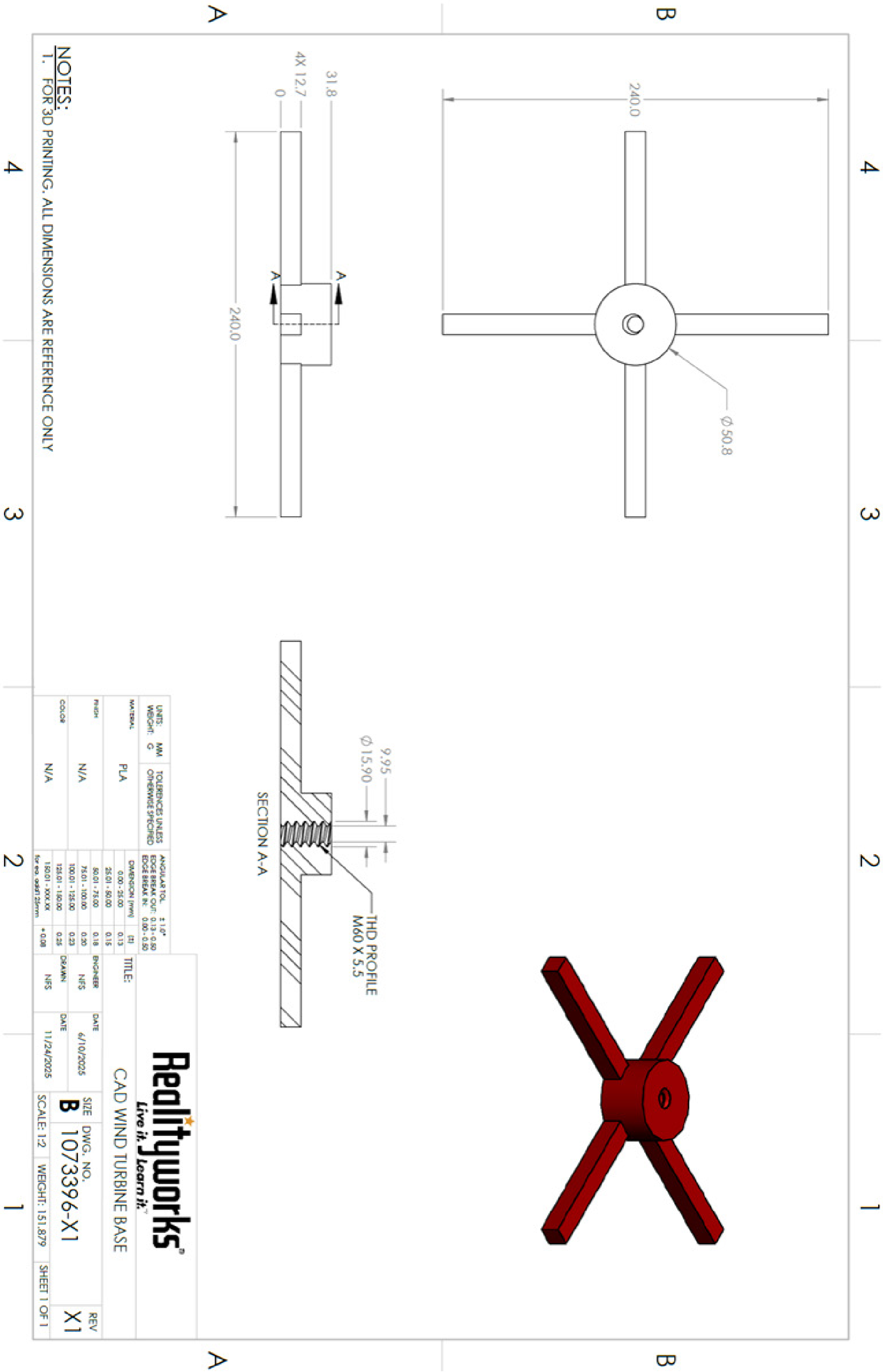
Engineering CAD Component Drawing: 3. Wind Base



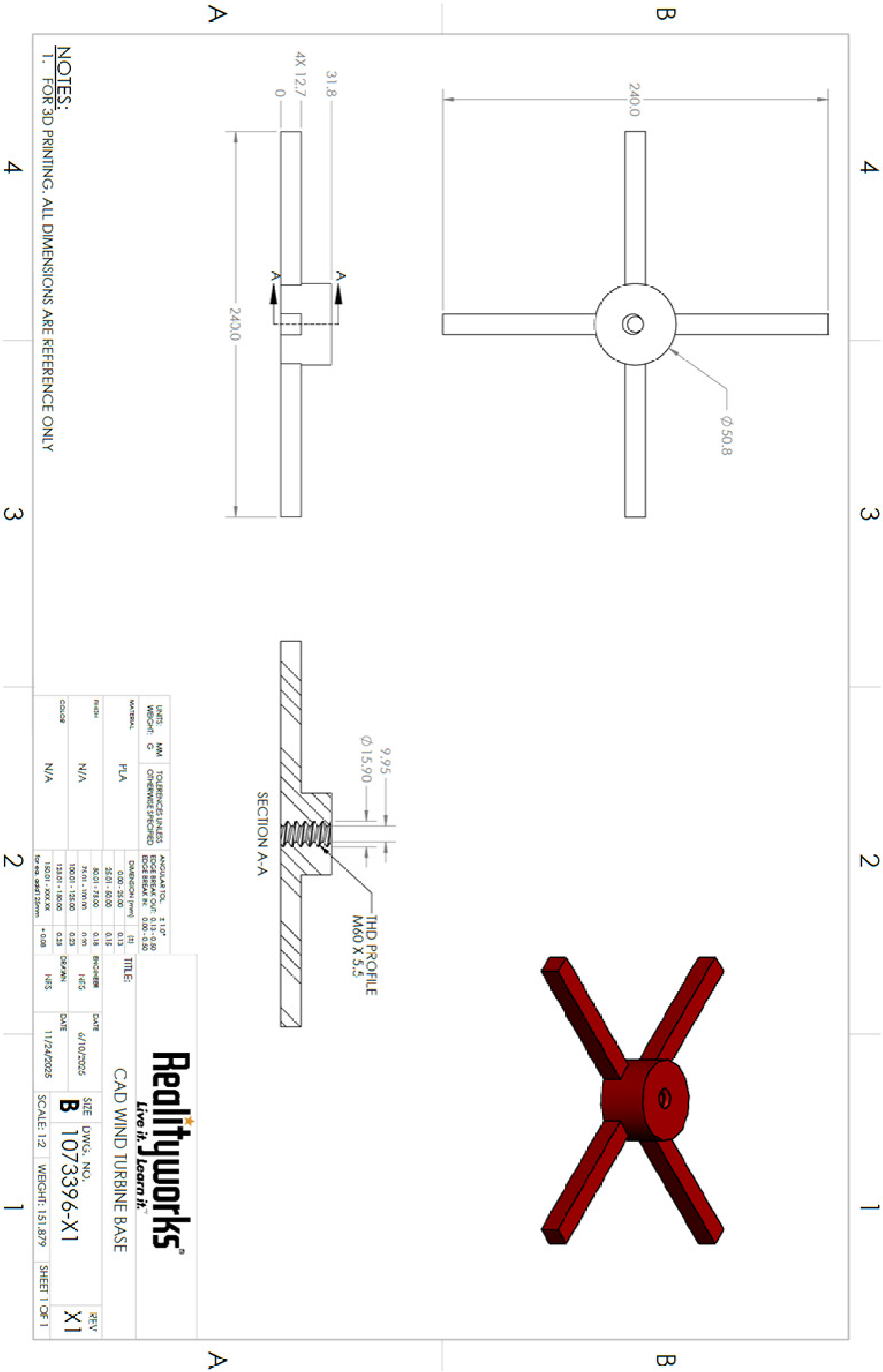
Engineering CAD Component Drawing: 4. Wind Pole



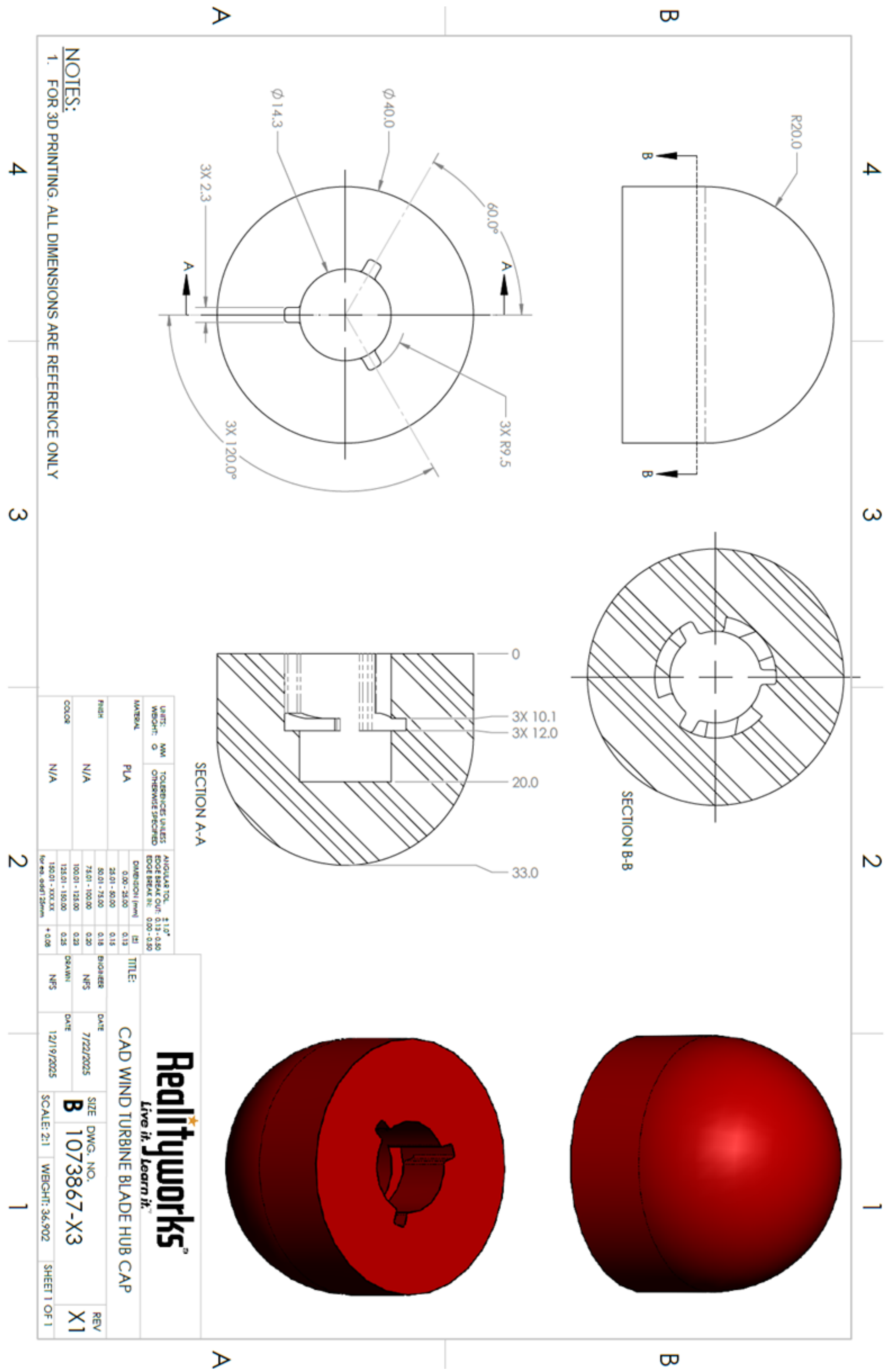
Engineering CAD Component Drawing: 5. Wind Hub Cap



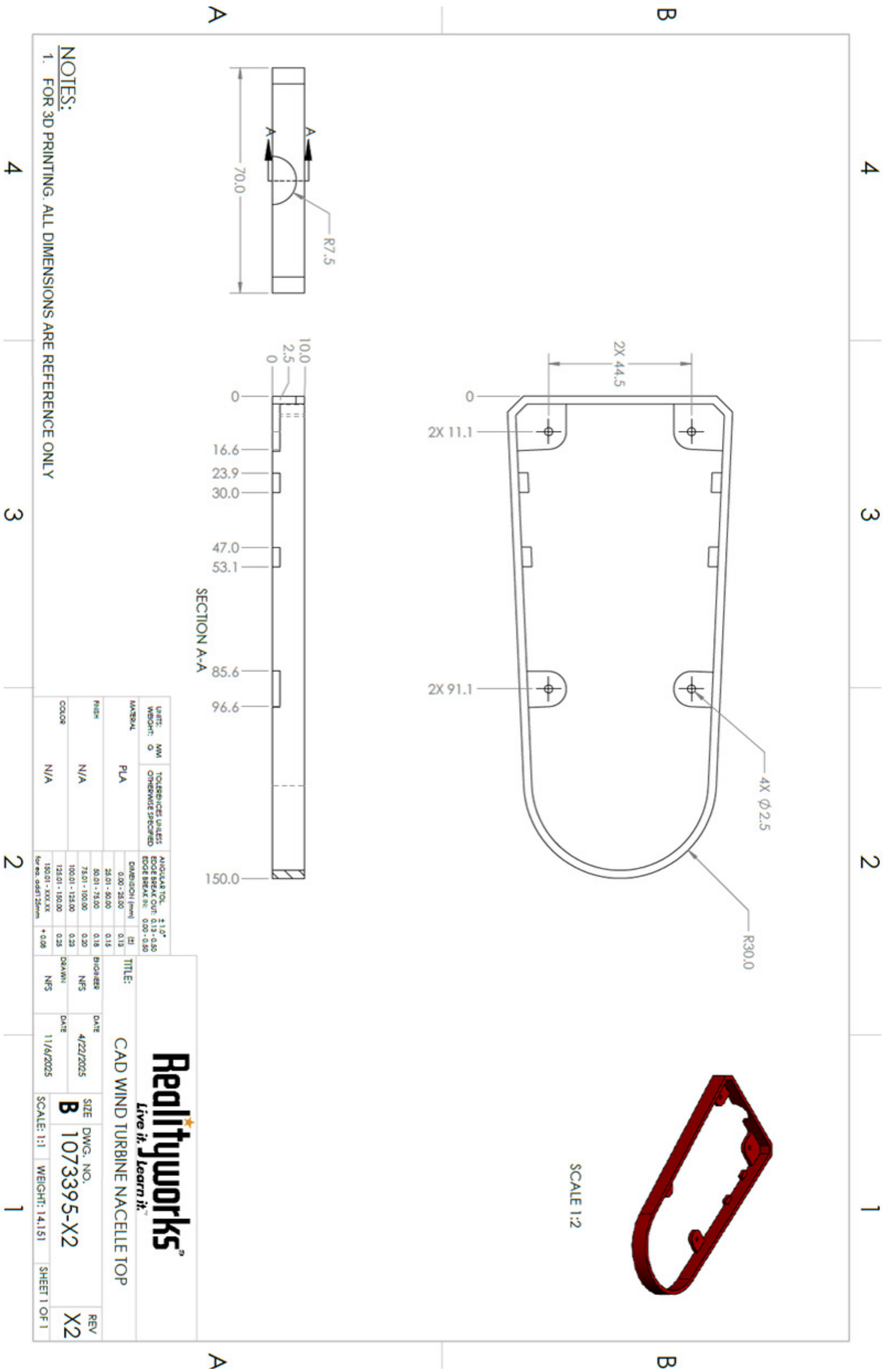
Engineering CAD Component Drawing: 6. Wind Nacelle Rim



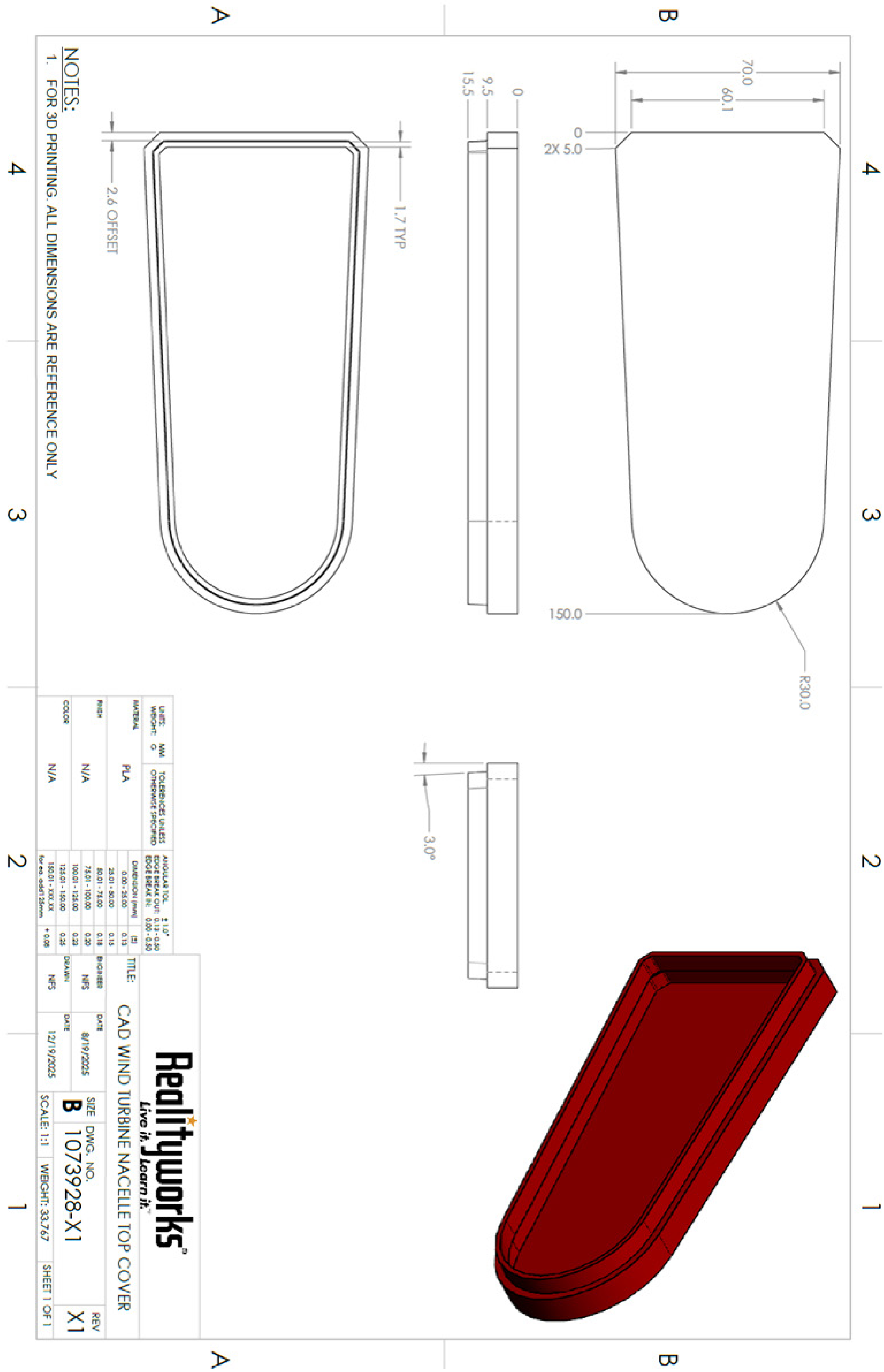
Engineering CAD Component Drawing: 3. Wind Hub



Engineering CAD Component Drawing: 1. Wind Blade



Engineering CAD Component Drawing: 7. Wind Nacelle Cover



Lesson 11:

Build, Test, and Improve the Wind Turbine

Instructions: As you follow the Lesson 6 slide presentation, complete the following questions.

1. **Testing the Wind Turbine: Collect test data in the table below.**

Turbine Test Position	Fan Speed	Voltage Measured	Current Measured
8″ Distance Between Fan and Turbine	**1**	**_____ Volts**	**_____mAmps**
	2	**_____ Volts**	**_____mAmps**
	3	**_____ Volts**	**_____mAmps**

2. How did the voltage and current values change as the fan's speed increased?

Improve the System: The data above provides a baseline for performance. Now, it is time to improve the system's performance.

3. **Brainstorm** with your team different ways to increase turbine's voltage. List at least 3 design changes for each that your team could implement:
   - **i.**
   - **ii.**
   - **iii.**

4. **Rank**: Which design changes will do the most to improve voltage? Rank the design changes your team identified by placing a 1, 2, and 3 next to each listed above.

5. **Divide and Conquer:** Divide the design changes among the team members. Design, print, and test these changes. Then, compare new voltage measurements with the old baseline.

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