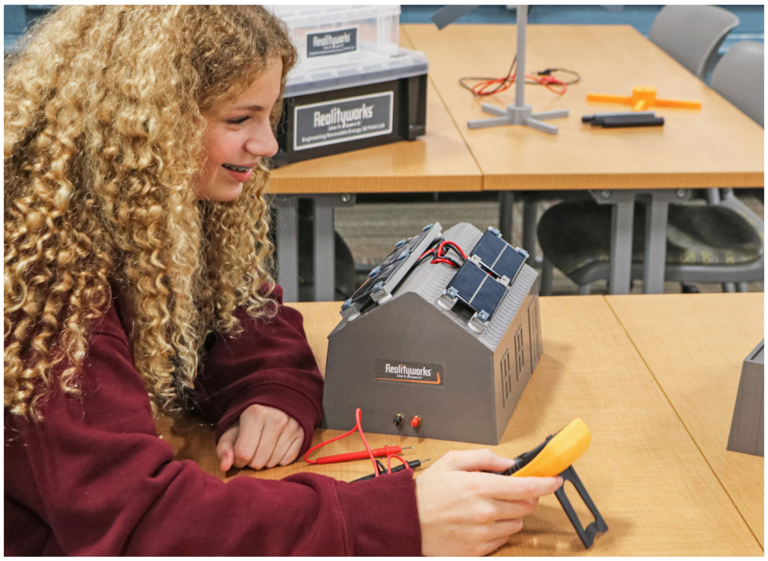
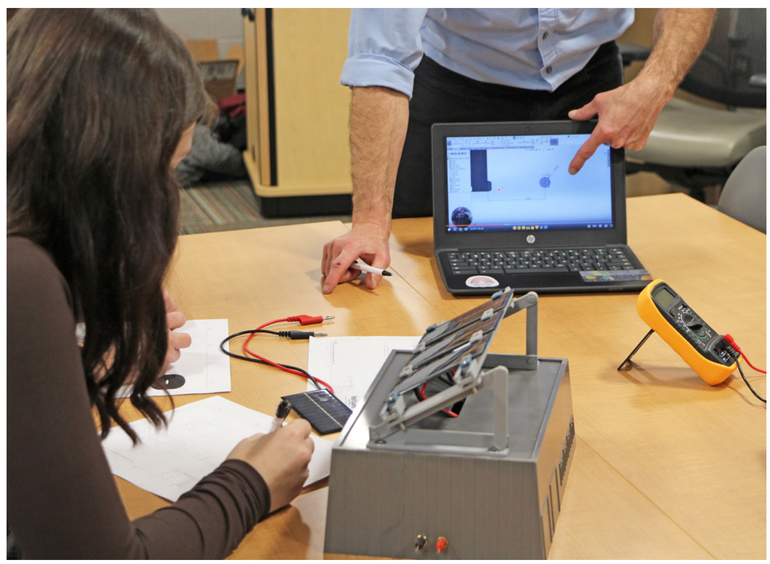
Engineering Renewable Energy 3D Print Lab

Student Engineering Workbook Answer Key





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2709 Mondovi Road
Eau Claire, WI 54701 USA
800.830.1416
+1.715.830.2040
www.realityworks.com

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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? **photovoltaic**

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

3. What is the typical voltage of a silicon solar cell? **0.5-0.6 Volts**

4. What is the current of a typical silicon solar cell? **5 to 10 mA/cm2**

5. What are the two ways solar cells can be connected? **Series or parallel**

6. Why is it important to understand the voltage and current of a solar panel? **They influence the efficiency of the solar system**

7. Define these concepts related to solar power arrays:
   a. Racking: **mounting system that holds the panels**
   b. Wiring Harness: **carries the electricity**
   c. Tracking System: **rotates on a single or dual axis to maximize solar angle efficiency**

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	**angle from horizontal ground**
Azimuth	**compass direction a tilted panel is facing**
Insolation	**the amount of solar radiation received on a given surface area during a specific amount of time** ***Latitude, climate, and weather patterns affect insolation**
Global Solar Radiation	**PV panels are able to use all sunlight, including direct and diffuse (scattered: imagine sunlight on a cloudy day)**

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

   The angle of the sun's rays is much smaller in Alaska (sun stays lower, closer to the horizon) than in Texas, so panels in Alaska must be mounted with a much greater tilt.

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

    Yes, photons are still traveling through the clouds and are able to transfer energy to the solar panels.

11. What is the average PV panel efficiency percentage? **23%**

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?

       Example: Eastern Minnesota is at less than 4.00 kWh/m2/day

    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?

       Louisiana's annual average daily total solar energy is 4.75-5.00 kWh/m2/day. Multiply this by 4 square meters and this array could produce 19-20 kWh each 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?

Example: For eastern Minnesota, if we use 4.00 kWh/m2/day, 30 kWh divided by 4.00 equals 7.5… so a house there would need 7.5 square meters of panels to produce an average of 30 kWh per day.

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?

Example: 230 kWh divided by 4.00 is 57.5 square meters of panels.

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

Shadows from trees, buildings, structures; weather; temperature; dust; snow

Part B: Solar Design Challenge

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

Step 1: **3D design basic components**

Step 2: **3D print components**

Step 3: **Assembly of residential and commercial solar arrays**

Step 4: **Test and evaluate**

Step 5: **Improve designs and repeat**

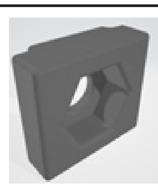
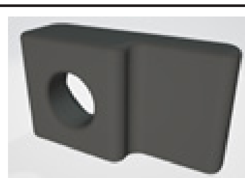
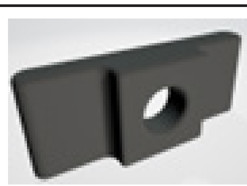
15. Ask your teacher… which 3D CAD Design software will your team use?

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	**The flat layer in the 3D printer that the component will be built upon**
Nozzle	**This is the metal piece with a tiny hole where melted filament comes out of the printer's print head. These pieces come in different sizes, and their diameter is measured in millimeters (e.g., 0.40 mm).**
Filament	**This is the roll of material that will be melted and used to build the design. There are many types of filament, each with different properties and required settings. For this lesson, we will use PLA, which is considered the most universal and easy to work with.**

3. What is the difference between additive and subtractive manufacturing?
   Additive Manufacturing: Building a physical object by adding material
   Subtractive Manufacturing: Building a physical object by removing material from a larger shape

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	Fused Deposition Modeling	Melts plastic filament and squeezes it out layer by layer	Most common type of 3D printing
SLA	Stereolithography (also known as Resin)	Uses UV laser beam to harden liquid resin into the object's form	Used for high-detail modeling
SLS	Selective Laser Sintering	Uses a laser to fuse powdered material	Used for strong industrial applications

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

   The molten filament squeezed out by the printer needs a layer beneath it to lay on top of. If there is no layer beneath, such as on an overhang, the molten filament will fall to the print bed.

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

   If the print falls over, the remaining layers will not be placed in the correct position, and the print will fail.

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

   a. Infill: **Increasing the infill percent, increases the strength of the print by adding more material to the inner volume of the component**

   b. Shells/Walls: **Adding additional shells/walls increases the strength of the outer edge of the print**

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

   a. Stability: **Supports add stability and prevent tipping**

   b. Overhangs: **Supports add a layer to build overhangs onto, preventing molten material from dropping into an unwanted position**

   c. Bridging: **Supports add a layer to build bridges onto, preventing molten material from dropping into an unwanted position**

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: **Higher Infill = Stronger, more mass, more rigid, allows for easier customization with additional shaping and threaded inserts/bolts**
Lower Infill = Less massive, faster print time, cheaper cost by using less material

b. Cons: **Higher Infill = More expensive, longer print time, heavier**
Lower Infill = Weaker, less rigid/more flimsy

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

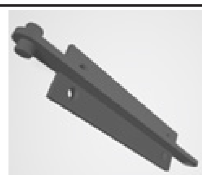
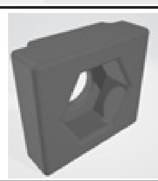
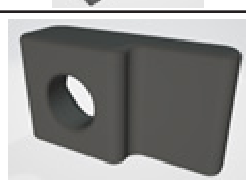
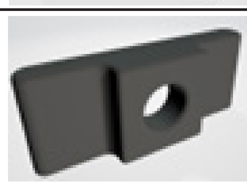
a. Try a different infill pattern
b. Make the design smaller
c. Reduce the amount of support material needed
d. Change design to contain more empty space and less volume that must be infilled with material

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: **Export Solar .STL files out of Tinkercad, SolidWorks, or Fusion360**
   b. Part B: **Load .STL into Slicer and prepare files for printing**
   c. Part C: **Save and download sliced files onto USB**
2. Track your team's progress in slicing each Solar Component:

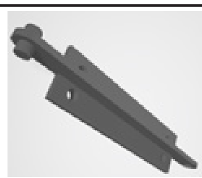
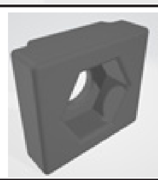
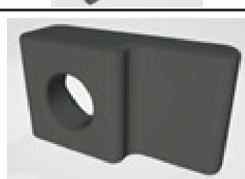
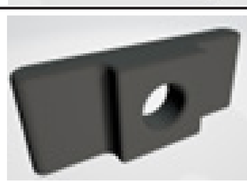
Component	Reference Image	Who is responsible for slicing this?	Status of Work: Check Once Completed
1. Solar Rack Base			☐
2. Solar Rack Upright			☐
3. Solar Rack C Channel			☐
4. Solar Angle Rail			☐
5. Solar Spacer			☐
6. Solar T Nut			☐
7. Solar L Clip			☐
8. Solar T Clip			☐

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

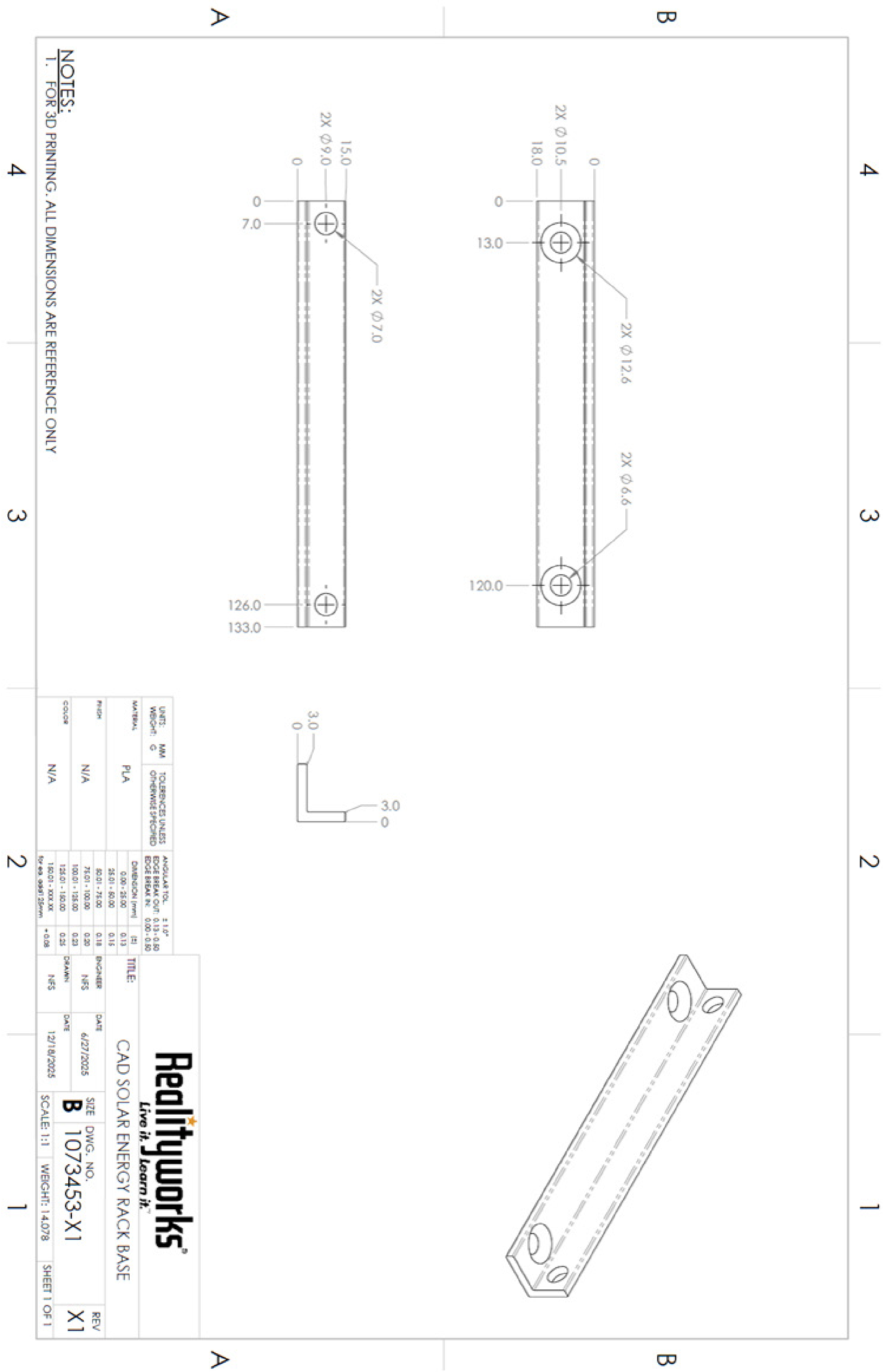
2. **As shown in the slides, check the printer's status:**
    - The printer must be on a stable, level surface
    - Confirm the printer is plugged in
    - Check the type and color of filament loaded
    - Confirm that the filament line goes from the spool to the print head with no breaks
    - Inspect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

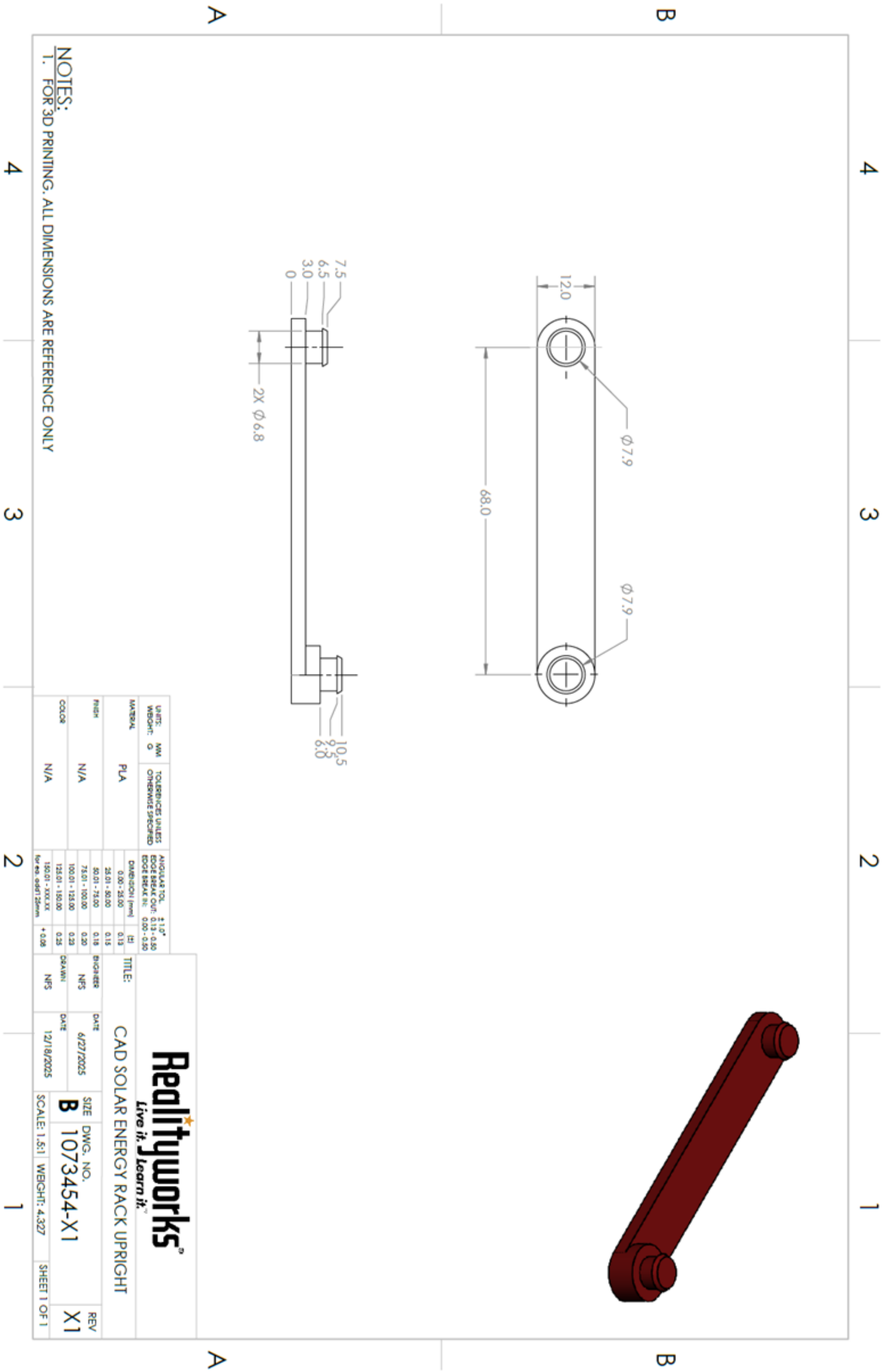
4. If a print is failing, or not printing as expected, how do you stop the print?

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

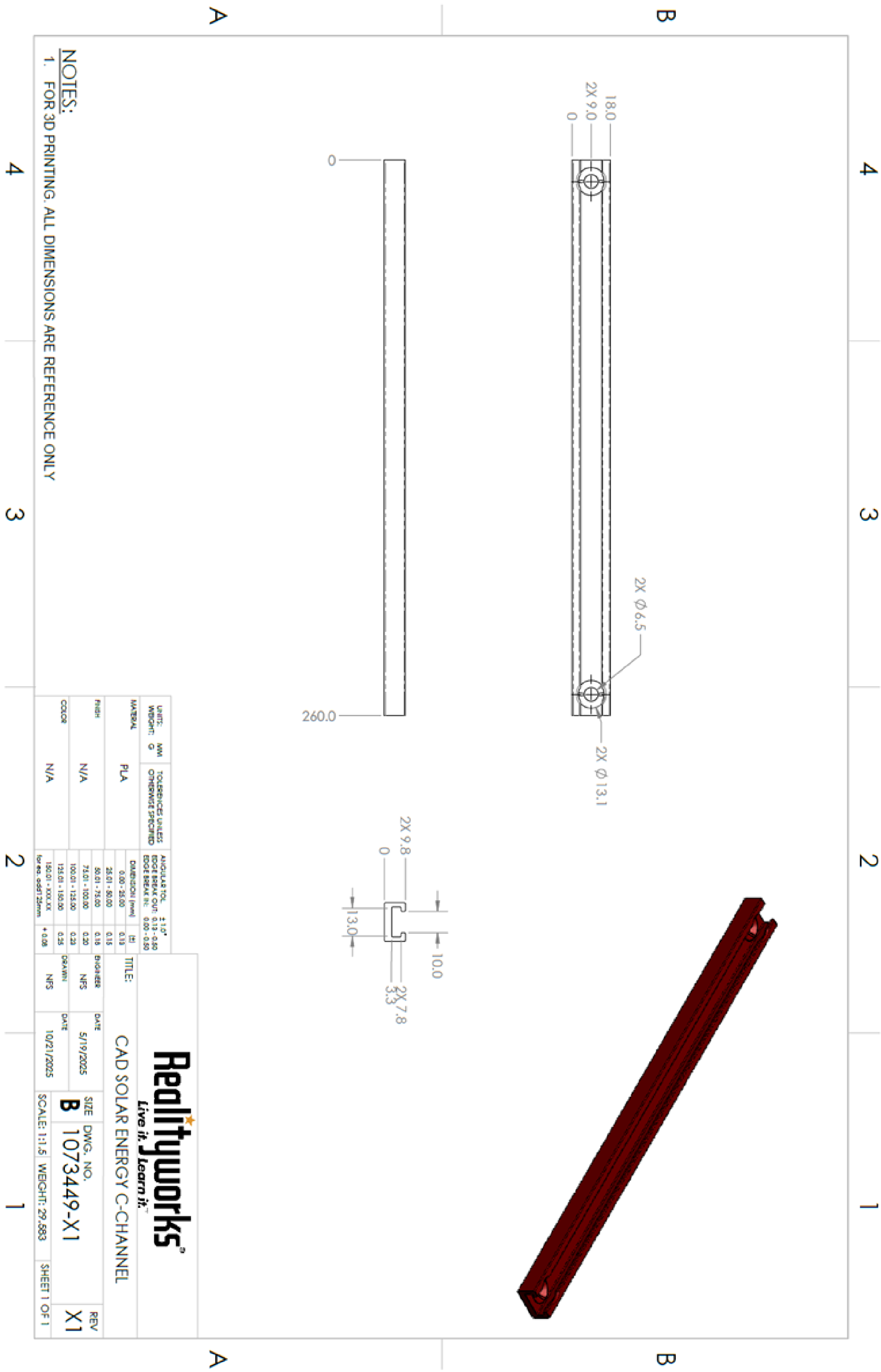
Engineering CAD Component Drawing: 1. Solar Rack Base



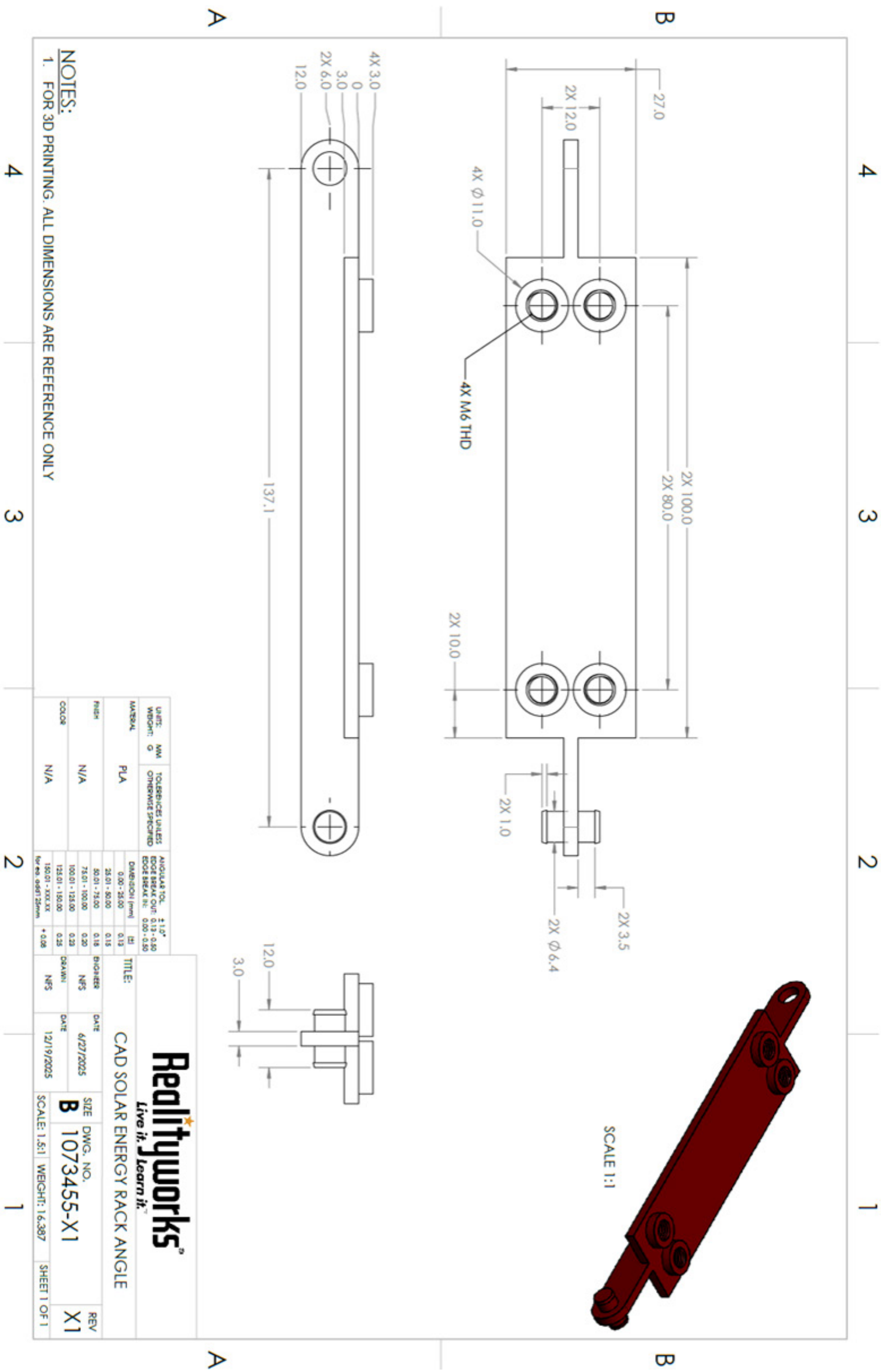
Engineering CAD Component Drawing: 2. Solar Rack Upright



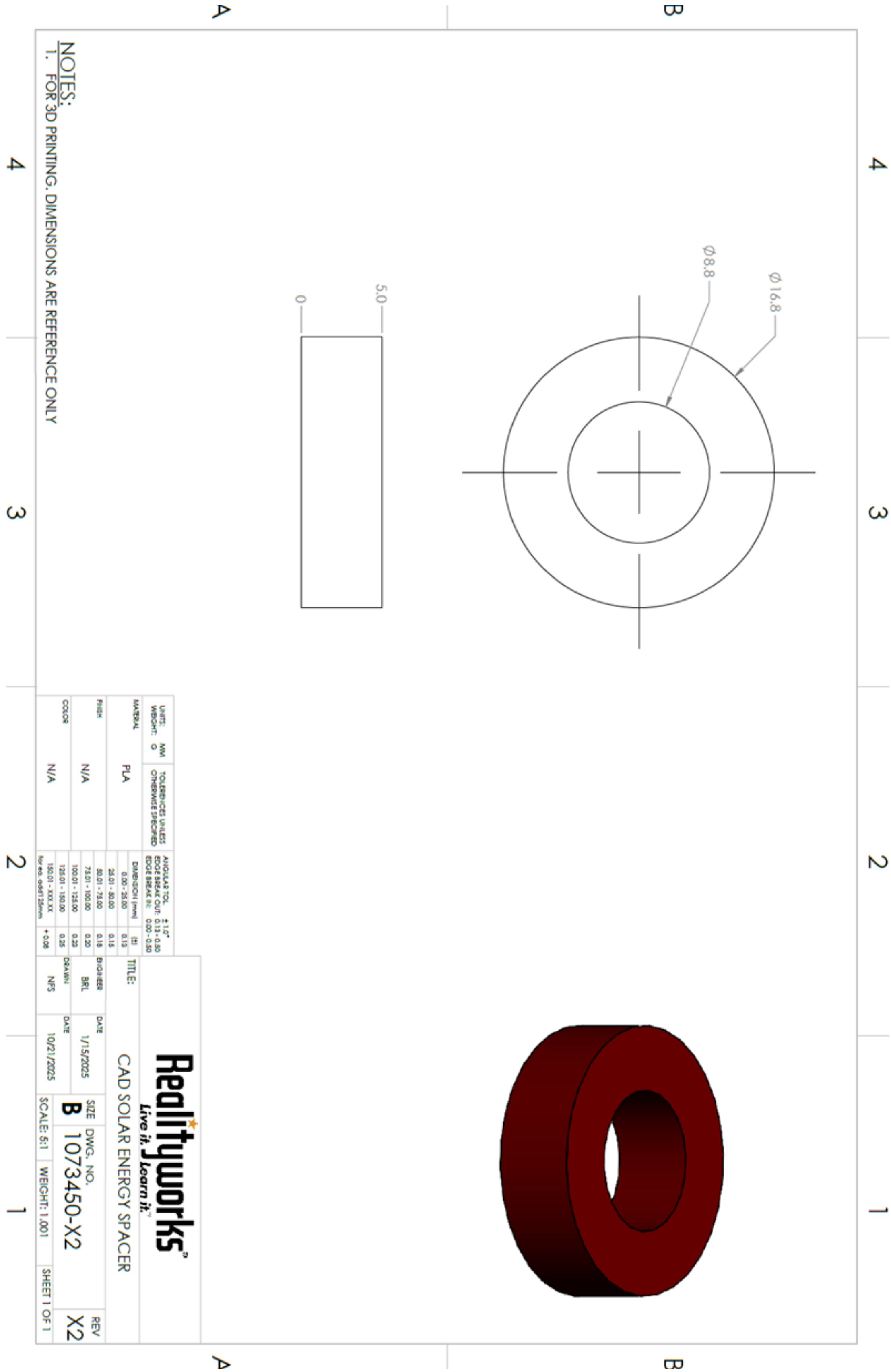
Engineering CAD Component Drawing: 3. Solar Rack C Channel



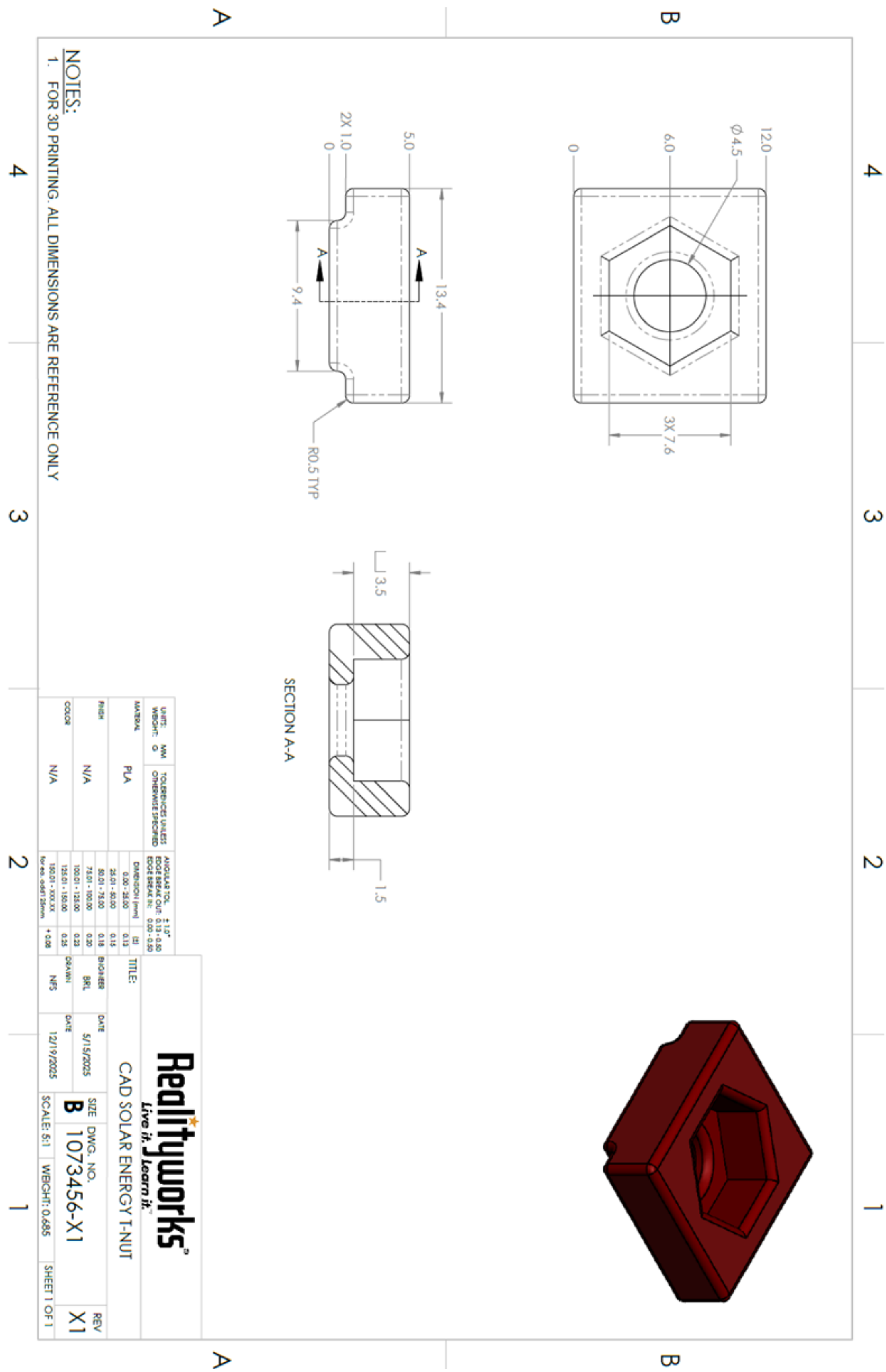
Engineering CAD Component Drawing: 4. Solar Angle Rail



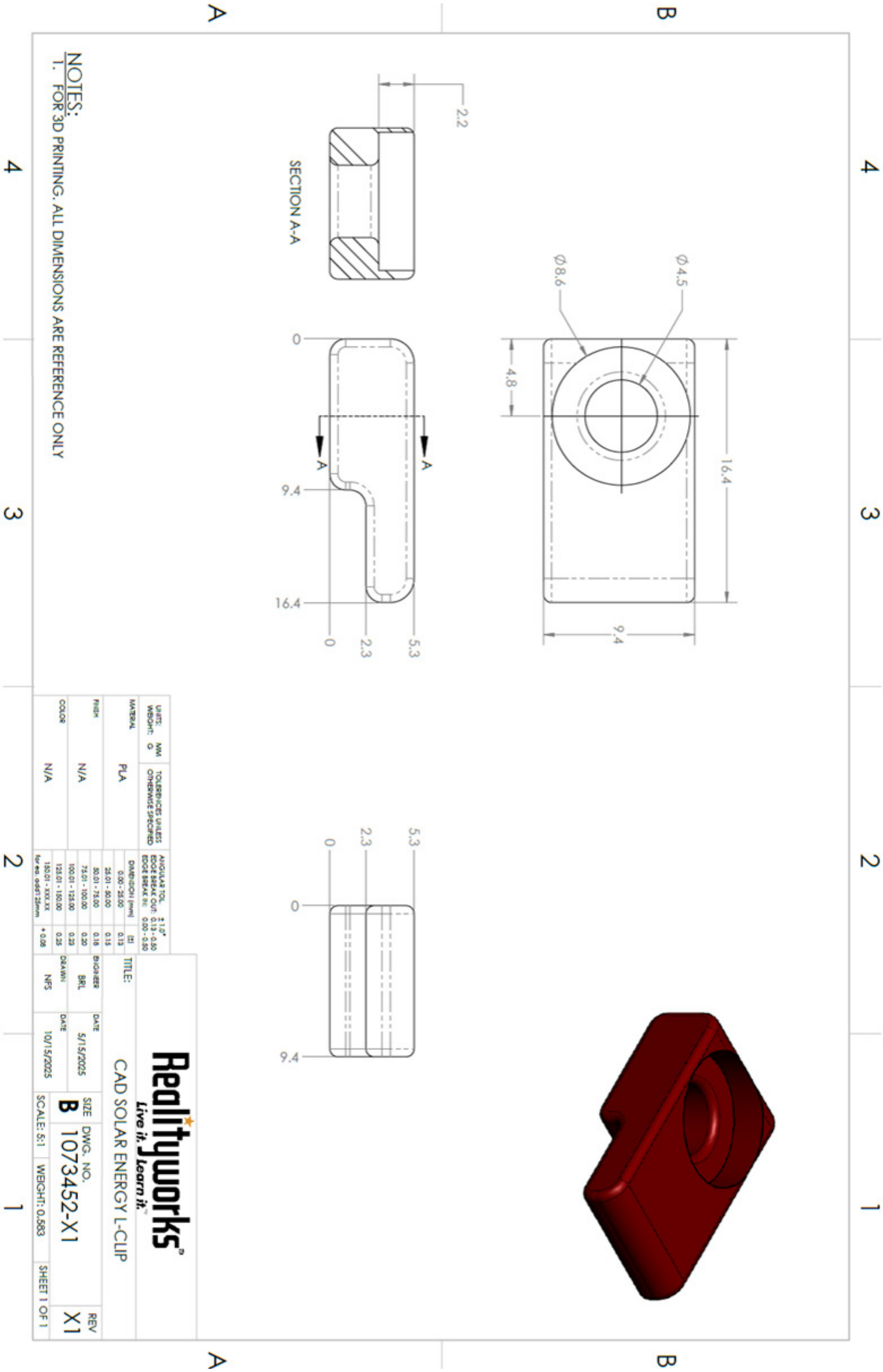
Engineering CAD Component Drawing: 5. Solar Spacer



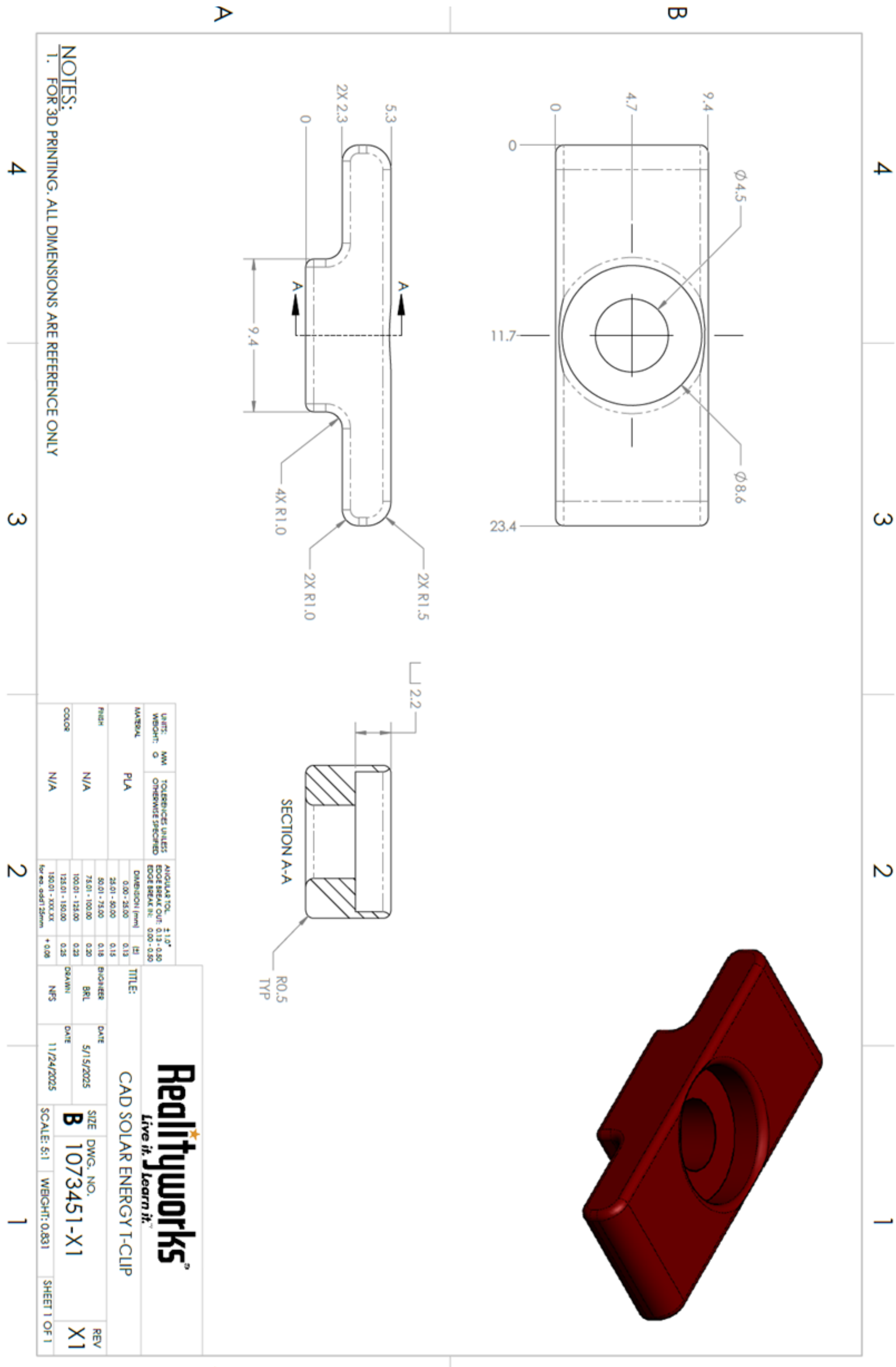
Engineering CAD Component Drawing: 6. Solar T Nut



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

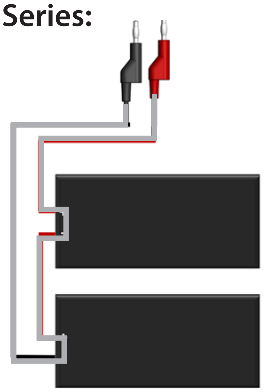
Instructions: As you follow the Lesson 6 slide presentation, complete the following questions.

1. Collect important wiring information in the table below:

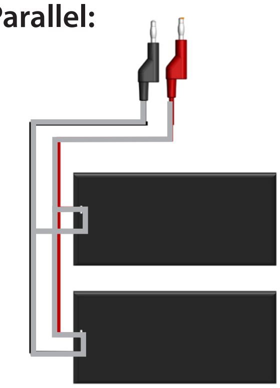
Wiring Strategy	# of Paths for Current	Pros	Cons	Impact on System Voltage and Current
Series	1	Like turning many smaller solar panels into one large panel Voltages add together: 6V panel + 6V panel = 12V PV System Good for high-voltage needs	Current is limited by the weakest panel If one panel fails, the whole system is broken, and no electricity is produced	Voltage adds up with each panel added Current is limited by the weakest panel
Parallel	2+	Each panel feeds current into the system Current add together: 2 Amp panel + 2 Amp panel = 4 Amps total current in PV System Good for low-voltage systems and shaded areas Keeps operating even if a panel fails	Requires larger gauge wiring Loses efficiency if power must travel long distance through wires	Current adds up with each panel Voltage does not add up

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

Series:



Parallel:



3. Testing the PV Arrays: Collect 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 **blades** to collect the wind's kinetic energy.
   b. Wind flows over the blades, creating **lift**, which makes the **rotor** turn.
   c. The **rotor** is connected to gears that turn a **generator** to produce electricity.

2. Collect important information to build your understanding of the universal components of a wind turbine facility. Define each:
   a. Turbine: **collects the wind's energy**
   b. Nacelle: **protects mechanical hardware from weather**
   c. Generator: **converts spin to electricity**
   d. Tower: **holds turbine in stronger wind**
   e. Cables: **carries electricity to transformer**
   f. Transformer: **matches power to grid**

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	**Identify obstructions that cause turbulence**
Wind Rose	**Shows recorded wind direction and speed distributions around a likely wind turbine installation**
Tower Height	**Taller means more power**
Swept Area	**Swept area or rotor disc is the area of wind harvested** **The larger the swept area, the greater the wind energy collected**
# of Blades	**By understanding the forces acting on turbines, engineers favor three-blade designs because they offer the best compromise between high energy yield, stability, and durability.**

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	**These blades push against the wind and were common in older windmills. However, their rotation is slow because the blades moving back up are pushing against the wind. Flat blades are easy to make but have high drag forces, making them inefficient.**
Curved Blades	**Similar to an airplane wing, curved blades have a curved surface on top, allowing air to flow faster over the top than underneath. This creates a low-pressure area on top, resulting in lift. Curved blades can move faster than the wind, producing more power and higher efficiencies.**
Twisted Blades	**Modern wind turbine rotor blades are designed with a twist along their length, transitioning from a steep pitch at their root to a shallow pitch at their tip. This twist optimizes the angle of attack along the blade, improving lift and rotation.**
Blade Pitch	**The angle of the blade's windward edge** **Modern turbines can turn blades to optimize this**
Angle of Attack	**Is between the oncoming wind and the pitch of the blade** **Turning the turbine nacelle changes this**
Tip Speed Ratio	**Describes the relationship between the blades' speed and the wind speed** **Indicates the system's efficiency** **High-efficiency 3-blade turbines have a ratio of 6-7**
Blade Life-to-Drag Ratio	**Describes aerodynamic performance** **Goal is to have a high ratio with maximum lift and minimal drag** **An airline's ratio is around 15, while a blade can be as high as 120**

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? **High wind speeds typically occur in mountainous or offshore areas; this is where the most commercial potential exists.**

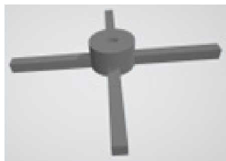
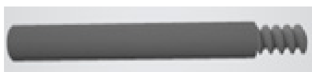
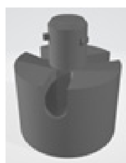
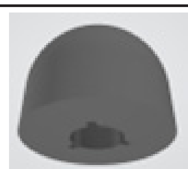
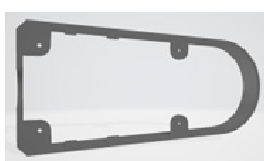
   d. What are the differences between onshore and offshore wind turbines?
   Onshore are smaller and produce much less power than offshore turbines.

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?

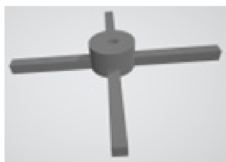
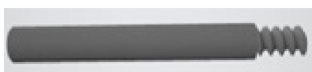
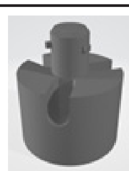
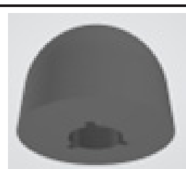
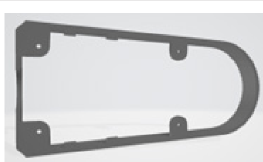
Component	Reference Image	Who is Responsible for Designing This?	Status of Work: Check Once Completed
1. Wind Base			☐
2. Wind Pole			☐
3. Wind Hub			☐
4. Wind Blade			☐
5. Wind Hub Cap			☐
6. Wind Nacelle Rim			☐
7. Wind Nacelle Cover			☐

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:

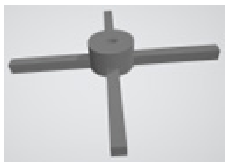
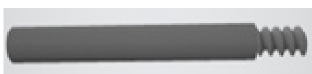
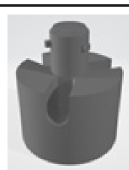
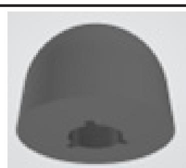
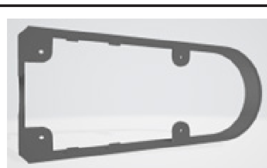
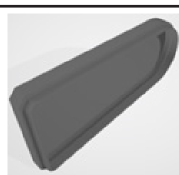
Component	Reference Image	Who is Responsible for Slicing This?	Status of Work: Check Once Completed
1. Wind Base			☐
2. Wind Pole			☐
3. Wind Hub			☐
4. Wind Blade			☐
5. Wind Hub Cap			☐
6. Wind Nacelle Rim			☐
7. Wind Nacelle Cover			☐

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

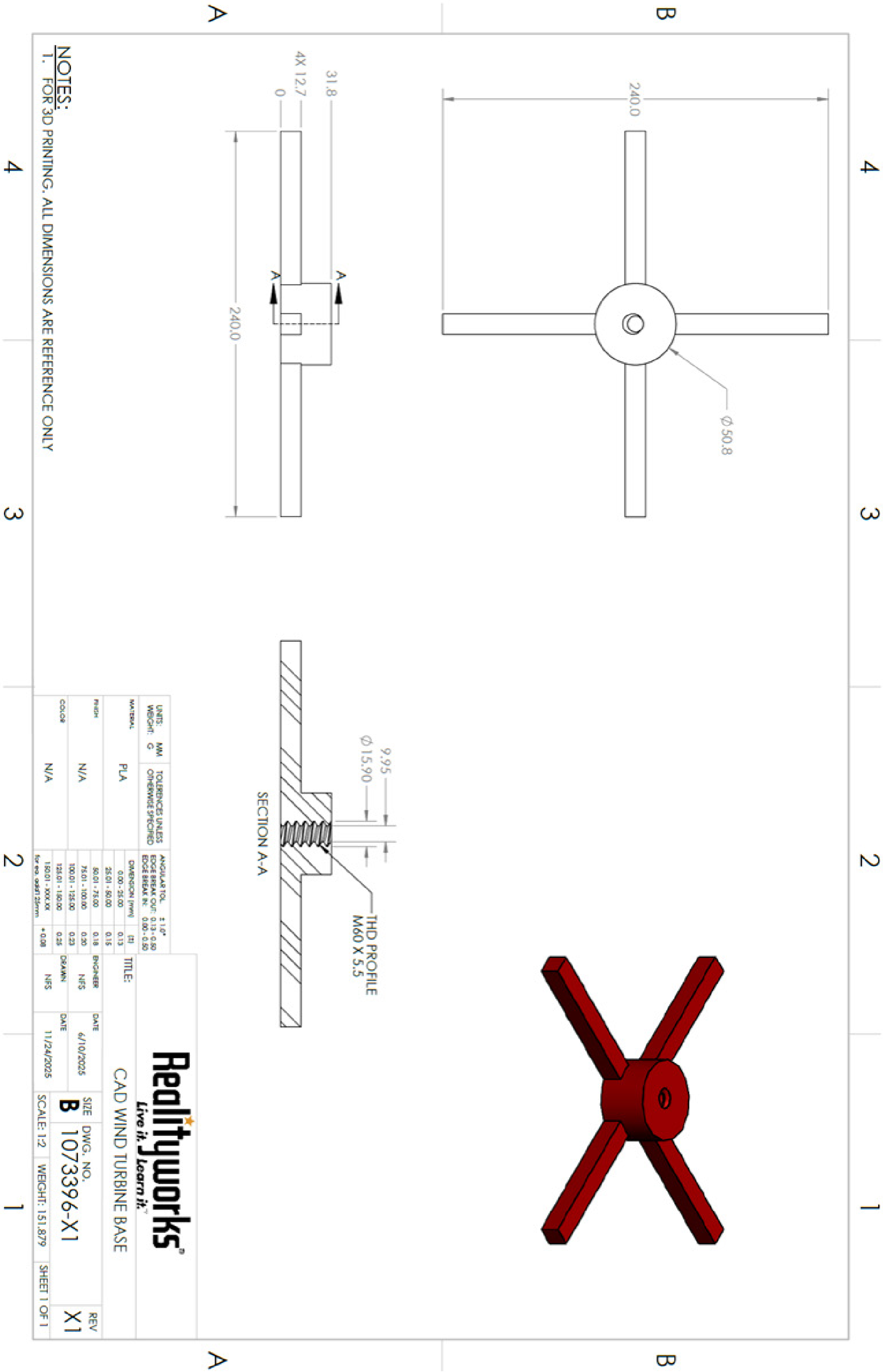
2. **As shown in the slides, check the printer's status:**
    - The printer must be on a stable, level surface
    - Confirm the printer is plugged in
    - Check the type and color of filament loaded
    - Confirm that the filament line goes from the spool to the print head with no breaks
    - Inspect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

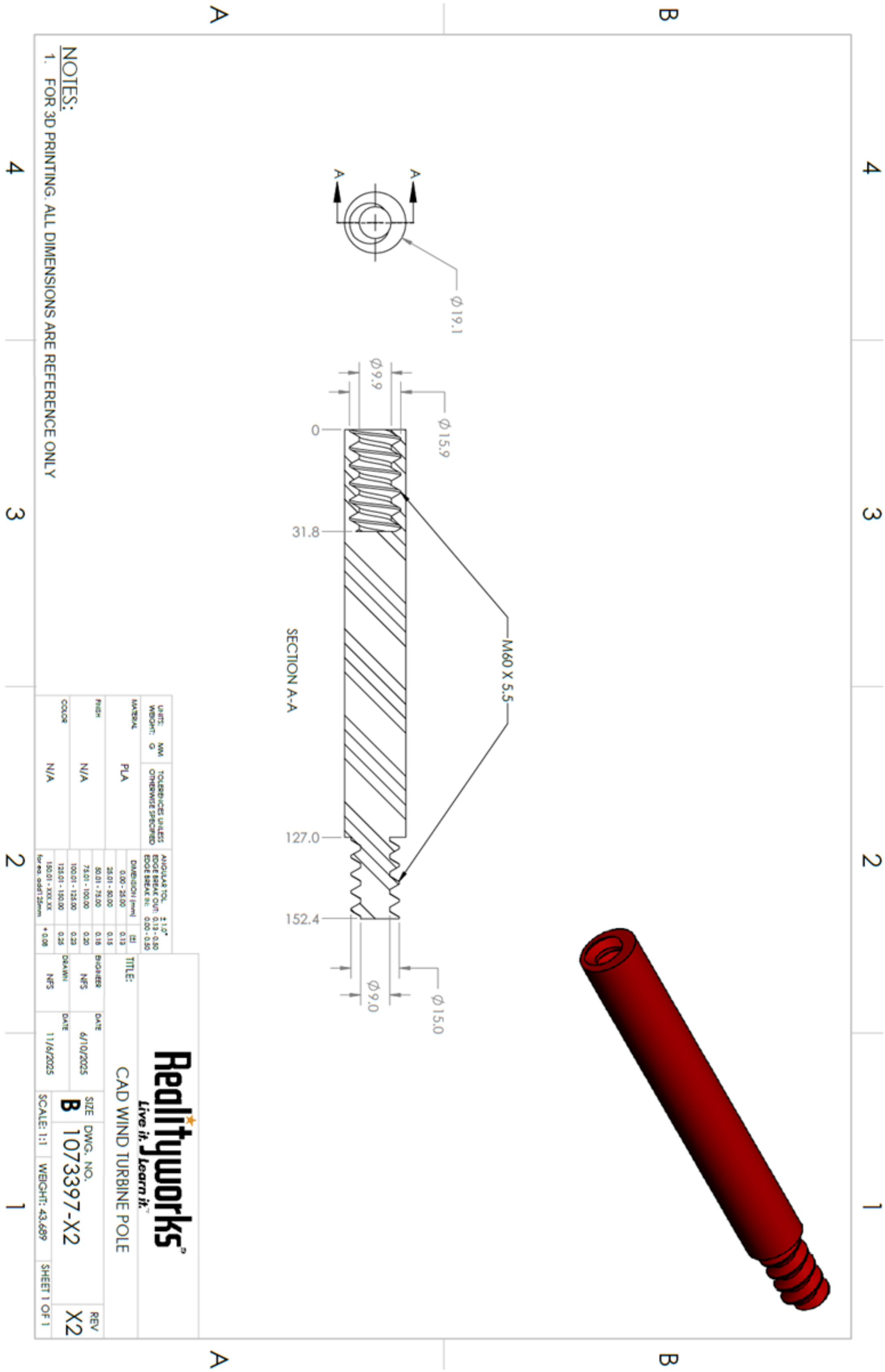
4. If a print is failing, or not printing as expected, how do you stop the print?

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

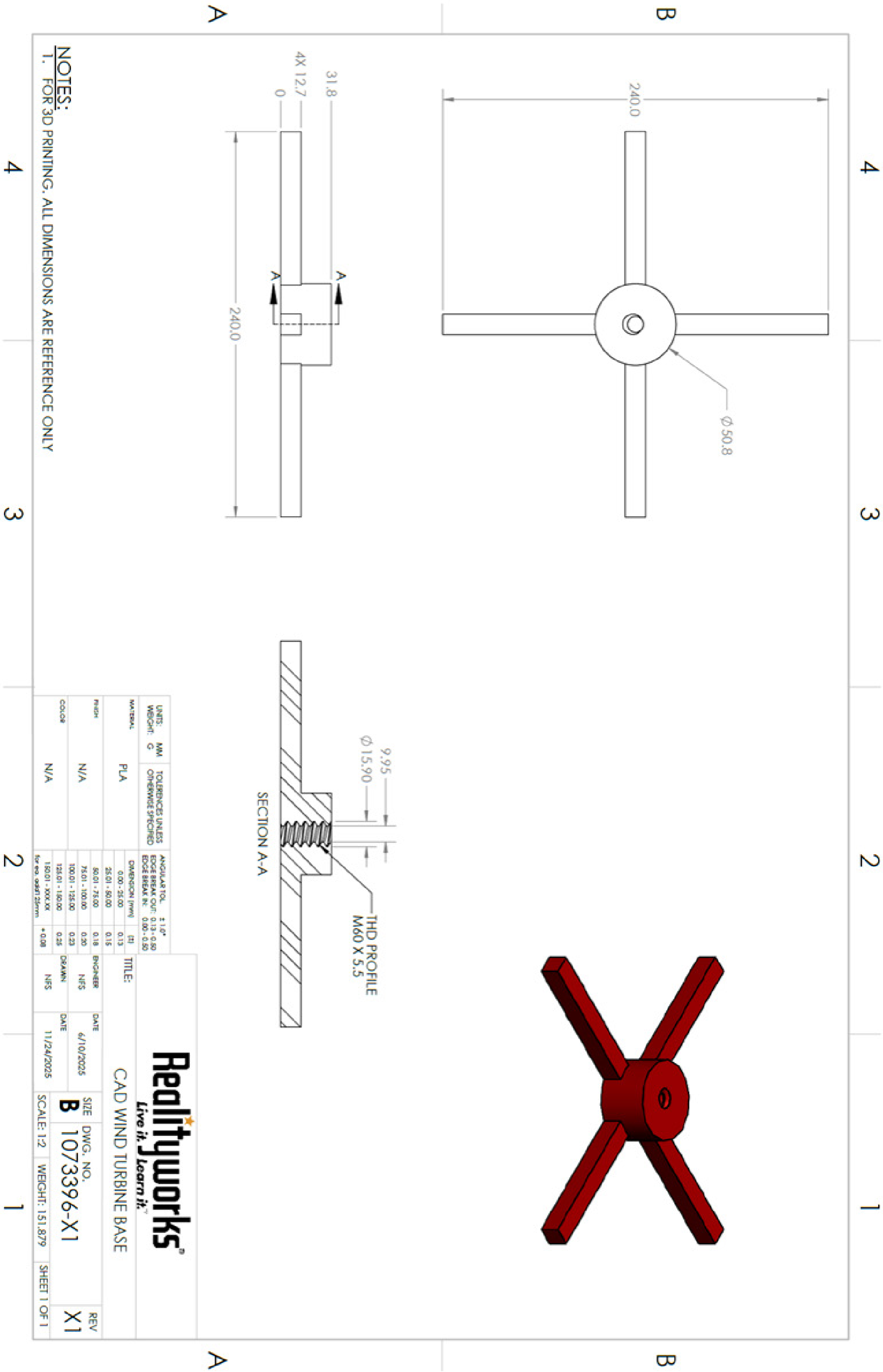
Engineering CAD Component Drawing: 3. Wind Base



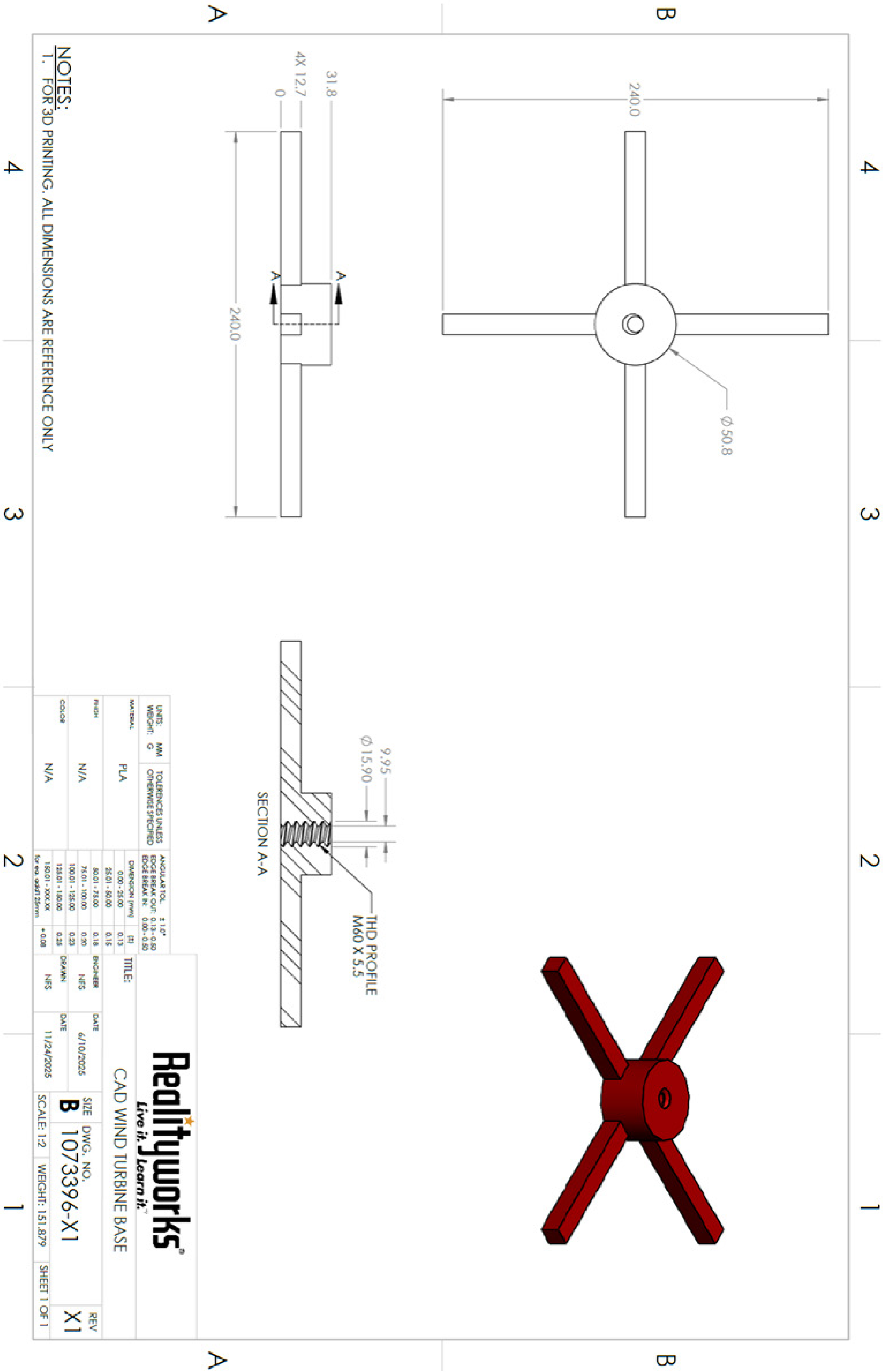
Engineering CAD Component Drawing: 4. Wind Pole



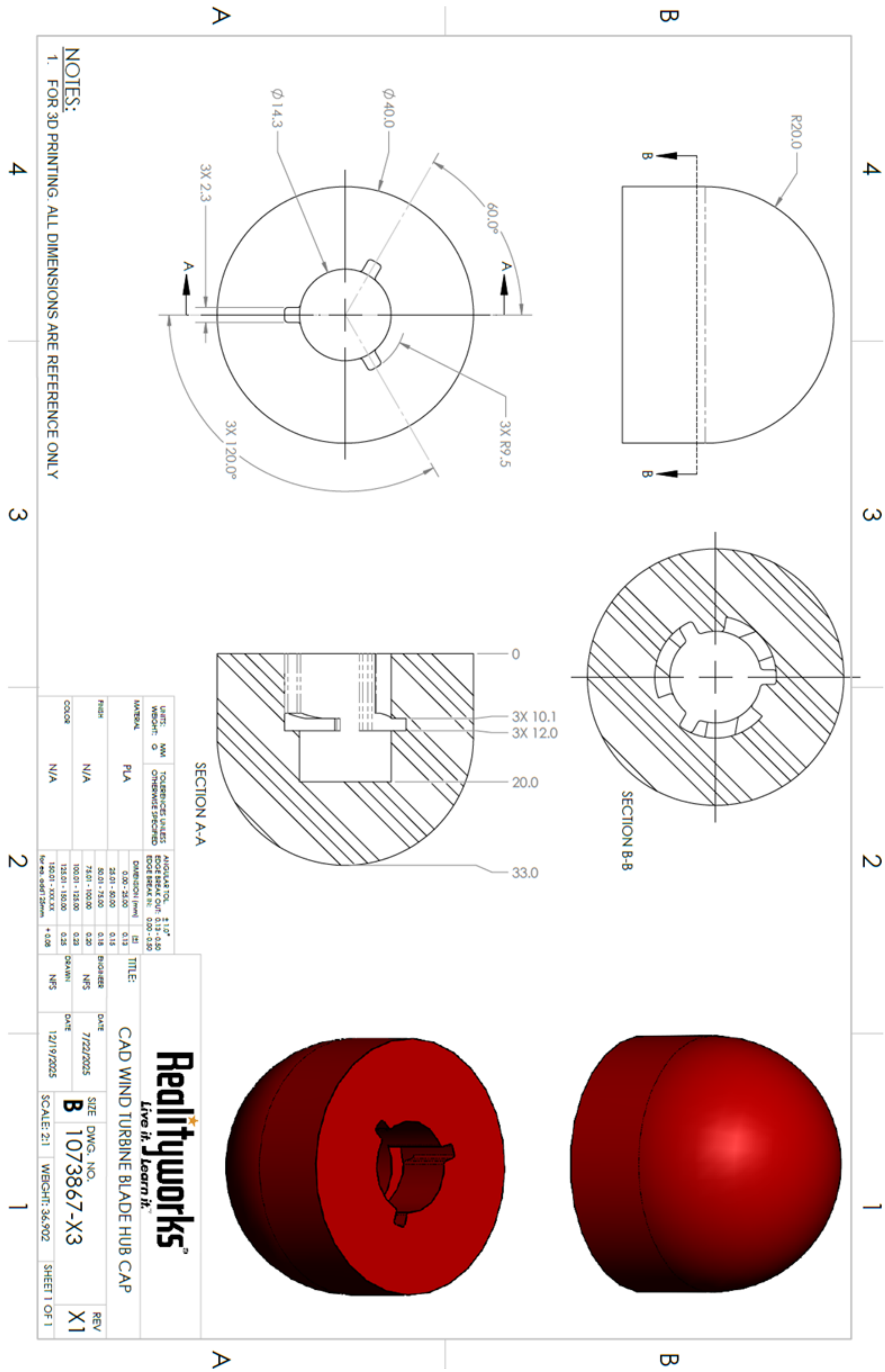
Engineering CAD Component Drawing: 5. Wind Hub Cap



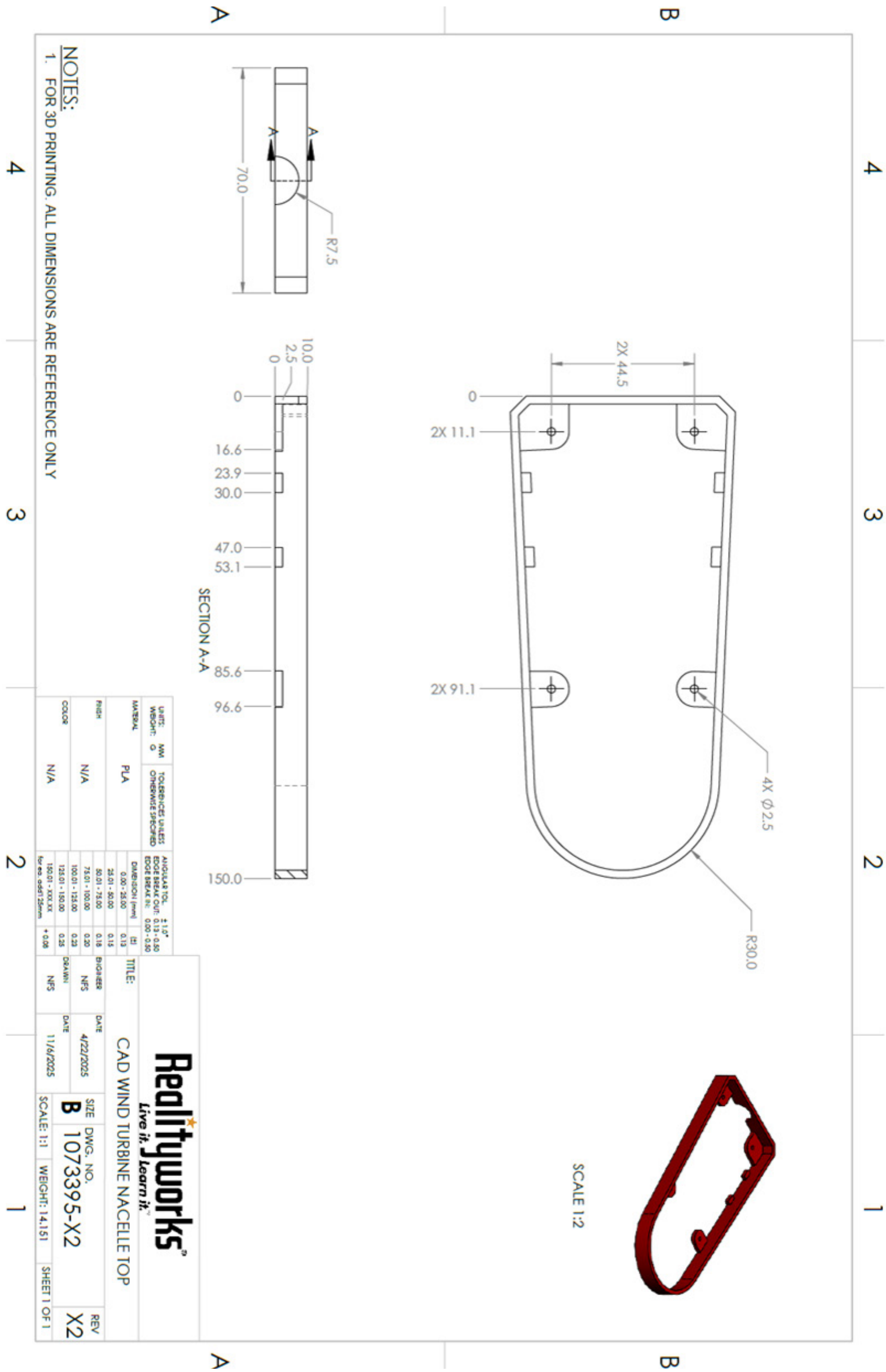
Engineering CAD Component Drawing: 6. Wind Nacelle Rim



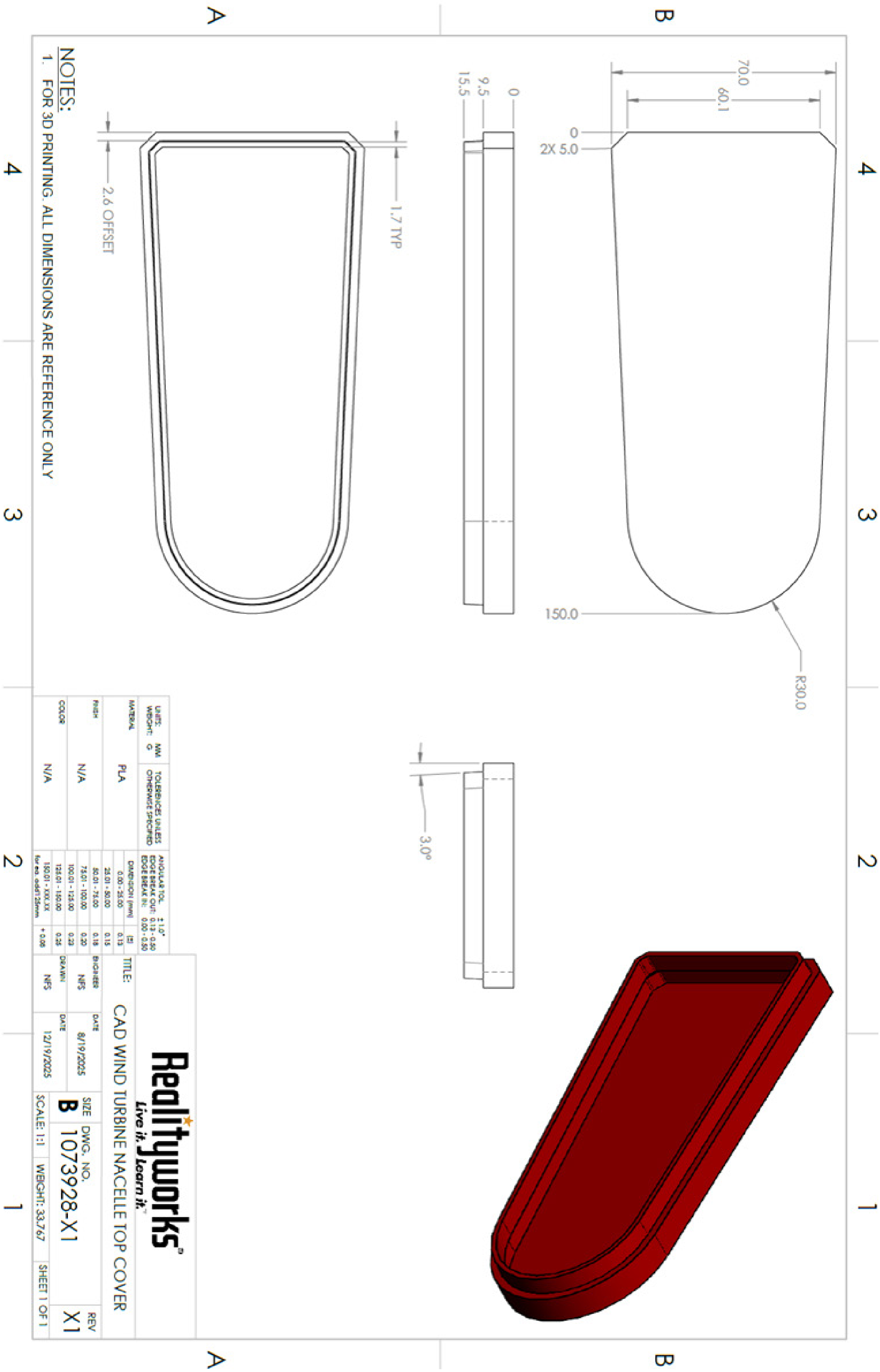
Engineering CAD Component Drawing: 3. Wind Hub



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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