Residual Stress and Distortion Prediction for Large Scale Metal Additive Parts: Challenge Information Packet

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Introduction

Thank you for participating in the 2022 Sandia Fracture Challenge on Residual Stress and Distortion Prediction for Large Scale Metal Additive Parts! The purpose of this exercise is to: (a) compare methodologies for predicting transient temperature, residual stress and distortion of large metallic additively manufactured structures, and (b) identify methodologies that appear to be most predictive. This exercise intends to evaluate the state-of-health in computational mechanics prediction, identify areas of weakness for further development, and foster relationships in the mechanics community, with a specific focus on additive manufacturing.

In this exercise, participants are asked to predict the temperature history, residual stress and distortion of an additively manufactured metal part with relatively simple geometry. A calibration problem with the same as-built geometry is provided with measured quantities of interest (QOI); including temperature histories at selective locations, post-built residual stress at selective locations, and overall distortion measurements. A challenge problem is then presented with a different built sequence, i.e., thermal history. The participants are asked to make blind predictions for the same QOI's for the challenge problem. Comparisons between the submitted predictions and the actual measurements will be published in a archivable journal. For all challenge problems, the participants are allowed to bound their predictions as they see fit.

Details are provided in this packet regarding the calibration problem and challenge problems with nominal material properties.

Throughout this packet and in the corresponding data, temperature is measured with in-situ thermocouple measurements. Residual stresses are measured with two techniques: neutron diffraction at ORNL and mechanical methods by UC Davis.

Important Deadlines

The following dates and deadlines are in effect:

1. Challenge Release: July 1, 2022
2. Submission of all challenge concerns or questions about data: September 31, 2022
3. Predictions Due: November 1, 2022 (4 months after challenge was issued)
4. Experimental "true" results available to all participants: February 31, 2023

Ethics

Detailed material property data has been included in the challenge; including chemistry certifications, hardness measurements, and tensile behavior (shear behavior will be forthcoming). By participating in the Sandia Fracture Challenge, all participants agree that they will not perform any mechanical experiments for the purpose of calibrating or validating their models. IN ADDITION TO THE MATERIAL PROPERTY DATA PROVIDED, YOU ARE WELCOME TO USE ANY EXISTING PUBLISHED INFORMATION. PLEASE KEEP TRACK OF WHICH ADDITIONAL DATA YOU DRAW FROM, IF ANY.

Funding Statements

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Chapter 1

Calibration Problem

Problem Statement 1. *Given all the input and output data, create a model/simulation that would match the provided results. Data to be matched are:*

1. *Temperature histories*
2. *Displacements and deformations*
3. *Residual Stress*

This will serve as a calibration for the challenge problem (see Chapter 3).

1.1 Geometry

1.1.1 Calibration Geometry

The calibration problem geometry is known as a *curl bar*. It consists of a long sheet of material with one axis significantly longer than the others. The purpose of this shape is to magnify the distortion in one direction and allow for direct measurements with classic shop tools. The shape printed on a base plate is shown in figure 1.1 The location of this

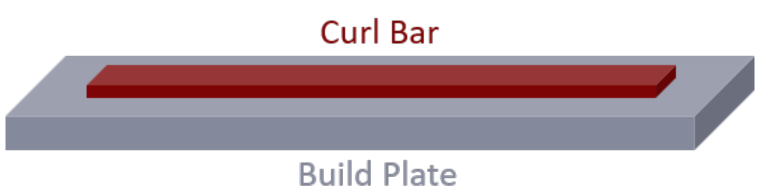

Figure 1.1: Basic curl bar shape

printed zone is symmetric with respect to the build plate. The entire measurement data set is provided for the computational model calibration.

Approximate dimensions are shown in figure 1.2 The printed zone (red) size is approximately $10 \times 48 \times 503$ mm. The base plate is approximately $12.70 \times 101.60 \times 600.00$ mm.

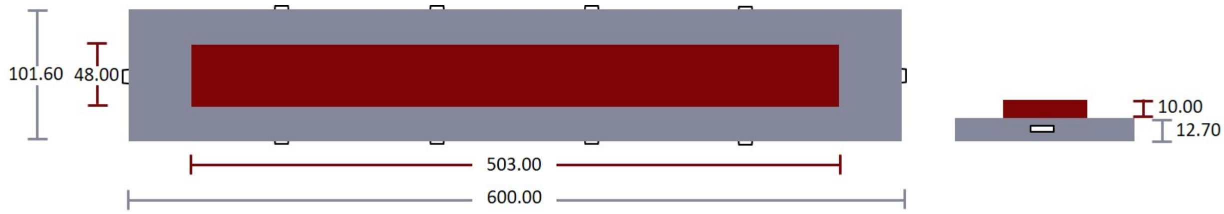

Figure 1.2: Basic curl bar dimensions (mm)

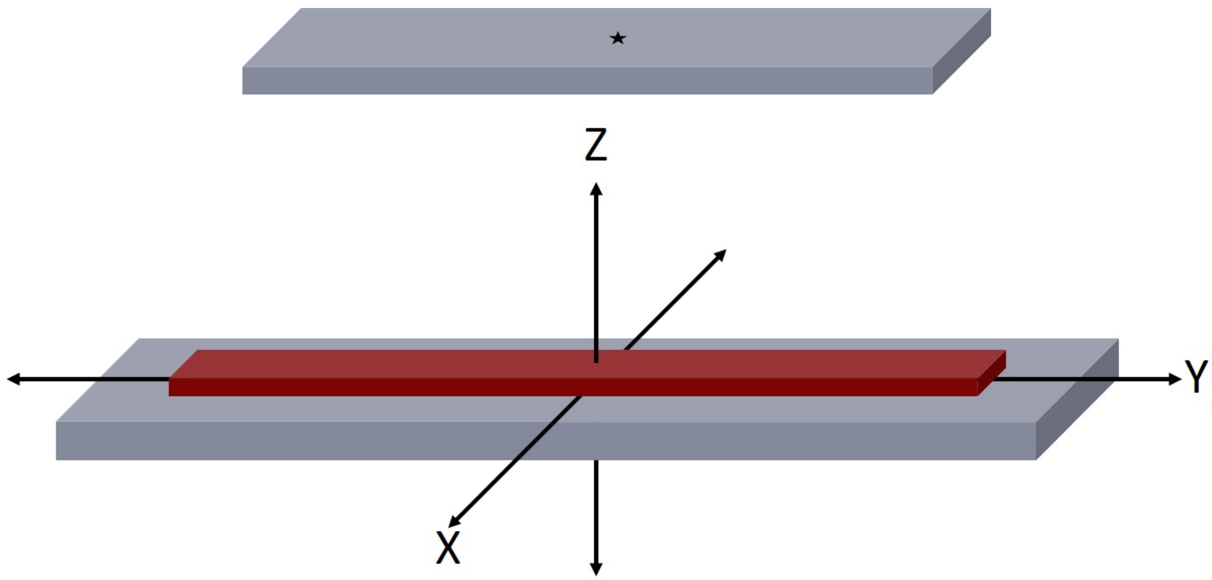

Figure 1.3: Visualization of the origin point and coordinate system

The origin for the system geometry is located on the top center of the base plate. This coordinate system is visualized in figure 1.3

Figure 1.4 presents an overview of the system geometry. Note that more detailed geometry information is provided in the CAD models repository (for example, the number of clamps is different).

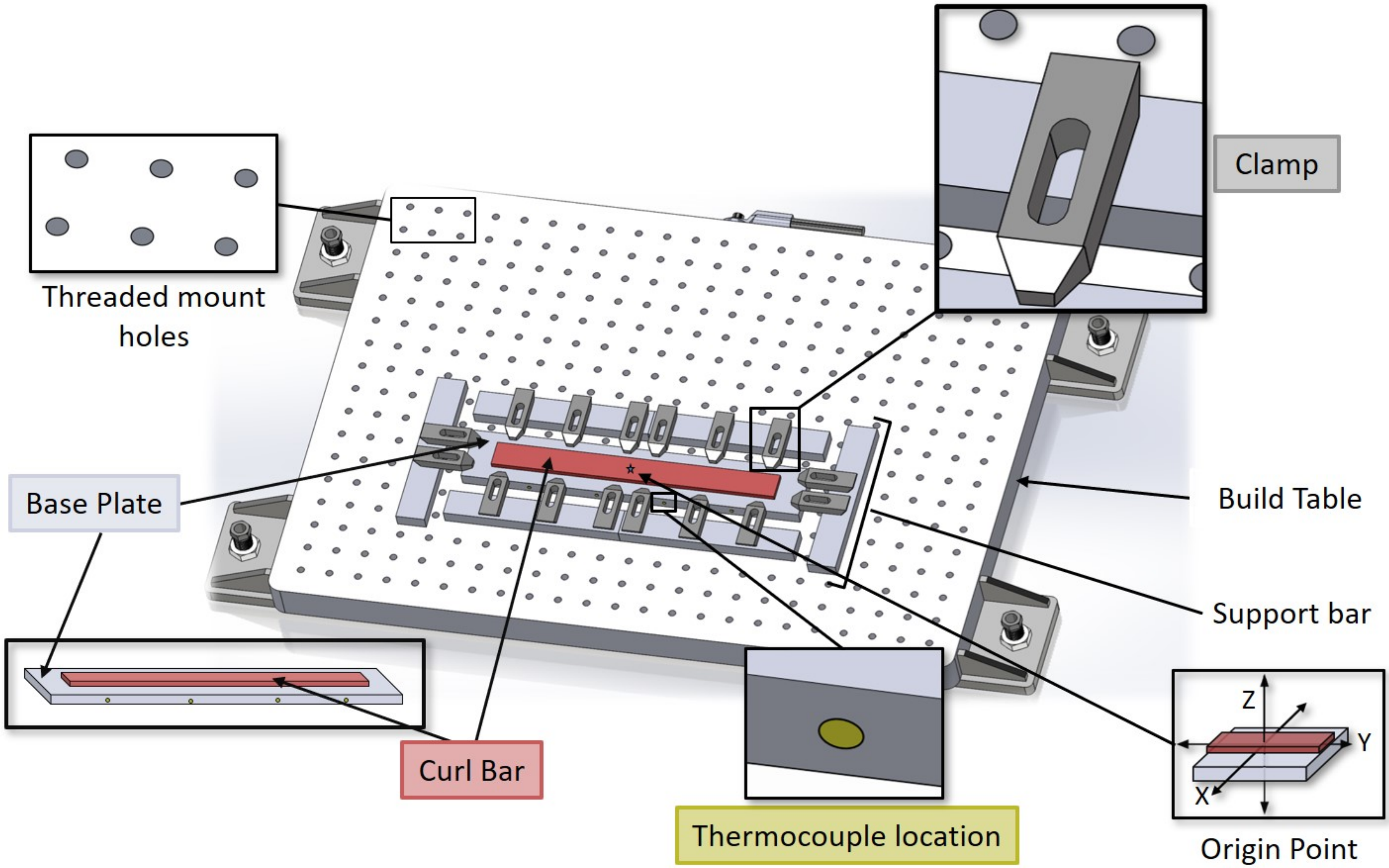

Figure 1.4: Overview of system geometry

1.2 Materials

1.2.1 Overview

Feedstock Material:

- Material: ER70S6 Lincoln electric wire (specifically - L59 by Lincoln nomenclature).
- Diameter: 0.045”.

The corresponding document is in the repository or available here.

Base Plate Material: ASTM A108, note that additional tensile test data is available in the repository.

Table Material: ASTM A36

Support Bars Material: ASTM A108

Toe Clamping Material: Steel

Welding Blanket Material: Carbon fiber. Specific material files in the repository.

1.2.2 Literature

Participants are encouraged to select the material properties best suited to their analysis method. Here we include a non-exhaustive list of potential resources. The first and second resources provide data for the machine used for challenge builds.

1. “Towards an integrated experimental and computational framework for large-scale metal additive manufacturing” by Hu, et. al. [5]
2. “Correlation of microstructure and mechanical properties of Metal Big Area Additive Manufacturing” by Shassere et. al. [10]
3. ”Simulation of tack welding procedures in butt joint welding of plates” by Jonsson, Karlsson and Lindgren. [6]
4. ”Numerical simulation to study the effect of tack welds and root gap on welding deformations and residual stresses of a pipe-flange joint”, by Abid and Siddique. [3]
5. ”Three-Dimensional finite element analysis of temperatures and stresses in a single-pass butt-welded pipe” by Karlsson and Josefson [7]
6. ”Investigation on welding distortion of combined butt and T-joints with 9-mm thickness using FEM and experiment” by Manurun et. al. [8]
7. ”Metal big area additive manufacturing: Process modeling and validation.” by Simunovic et. al. [11]

8. "Scaling Up Metal Additive Manufacturing Process to Fabricate Molds for Composite Manufacturing." by Hassen, et al. [4]

9. "Effective residual stress prediction validated with neutron diffraction method for metal large-scale additive manufacturing" by Nycz et. al. [9]

1.2.3 Wire and as deposited properties essentials

Table 1.1 gives an overview of the wire and as-deposited properties. Here we consider the following specific setting: SUPERARC® L-59® and AWS A5.18/A5.18M.

Property	Values	Notes
Yield Strength MPa (ksi)	460(67)	90% Ar/10% C02
Tensile Strength	570(83)	90% Ar/10% C02
Elongation %	25	
Composition	0.06-0.15% C, 1.40-1.85% Mn, 0.80-1.15% Si, 0.035% S max, 0.025% P max, 0.50% Cu max, 0.15% Mo max, 0.03% V max	
Density lb/in3	0.283	
As printed properties		
Yield Strength MPa	360 ± 7 MPa	Steady state, isotropic
Tensile Strength	475 ± 4 MPa	Steady state, isotropic

Table 1.1: Wire and As Deposited Properties and Notes

Note that more details on "as printed" properties can be found in "Correlation of Microstructure and Mechanical Properties of Metal Big Area Additive Manufacturing" [10].

1.2.4 Temperature-dependent mechanical properties

Temperature dependent true-stress/true-strain constitutive data was reported in a previously published simulation study on the same ORNL Big Area Additive Manufacturing process using the same L59 Lincoln Feed wire (ER70S7 by AWS) [9]. However, in that sudy, the same temperature-dependent properties appear to have been used for the printed wall, the base plate, and the table.

For the current challenge, a limited number of tensile tests were performed at three temperatures on tensile bars extracted from the as-printed material. The tensile axis of the specimens was aligned along the long-axis of the printed calibration structure, perpendicular to the build direction. Here we provide limited data for tensile bars extracted from both the Calibration weldment and from the Challenge weldment. Since the deposition conditions (specifically the scan path) were different for the two geometries, we note in table 1.2 the differences in tensile behavior.

Corresponding strain-stress curves are visualized in figure 1.5, and the original data is included in `WAAM Results revBLB.xlsx`.

Sample name	**Area** (mm^2)	**Temp (C)**	**UTS (MPa)**	**Gauge Width (mm)**	**Gauge Thickness (mm)**	**Extensometer Length (mm)**
Calibration RT	11.83	27	636.58	5.97	1.98	30.22
Challenge RT	11.83	27	532.47	5.95	1.99	30.97
Calibration 200C	11.78	200	604.32	5.94	1.98	31.68
Challenge 200C	11.83	200	527.32	5.97	1.98	31.81
Calibration 400C	11.99	400	520.38	5.96	2.01	26.94
Challenge 400C	11.63	400	463.68	5.97	1.95	32.30
Challenge 550C	11.77	550	257.26	5.99	1.96	32.02

Table 1.2: Limited Tensile Bar Data

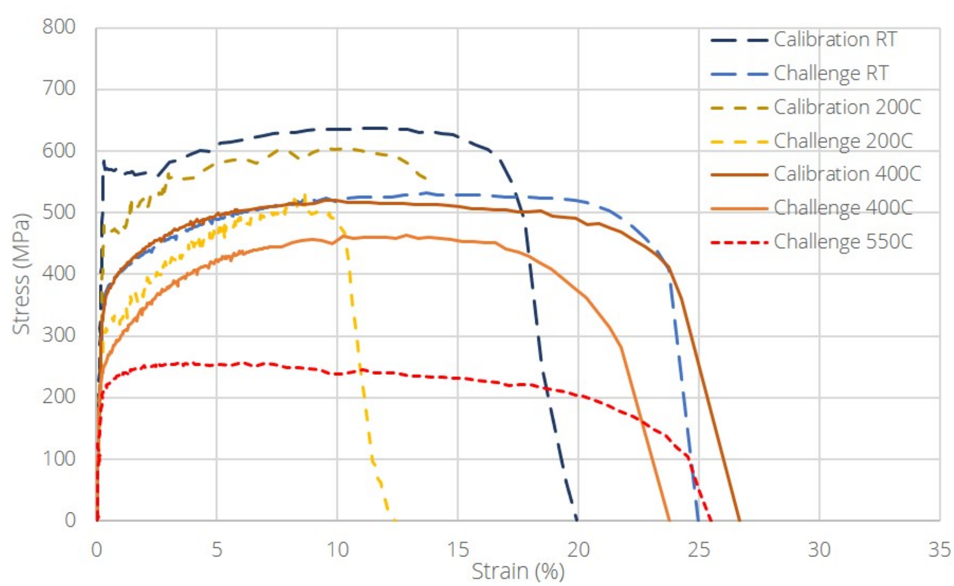

Figure 1.5: Visualization of the stress/strain curves for the extracted tensile bars.

The team thanks Dr. Jay Caroll and Todd Huber for providing this experimental data.

1.3 Printing System MBAAM

1.3.1 Overview:

Equipment: The samples were printed using ORNL's MBAAM (Metal Big Area Additive Manufacturing) prototype machine. MBAAM is a GMAW (MIG) based deposition process using a 6 degree of freedom robotic arm, a modified welder, and advanced software to create parts.

Linear Deposition Rate (arm speed): 16"/min

Wire feed speed: 200"/min

Shielding gas: Ar/CO2 (98/2%)

Welding mode: STT (Surface Tension Transfer) synergic. Exact settings in the repository.

Slicing Software: MBAAM uses in house created software for path creation (ORNL Slicer). It accepts STL geometry and outputs G-Code–based deposition path.

Units: This project uses units native to the hardware/software. Any conversions should be done by the participants on their own.

1.3.2 System control modes:

The system can operate in **constant deposition rate** (open loop) or **compensation mode** (closed loop). For the latter, it adjusts its deposition rate in real time to compensate for material flow, slicing inaccuracies, temperature expansion or deformations to deliver the required geometry. During this project the *open loop* mode was used.

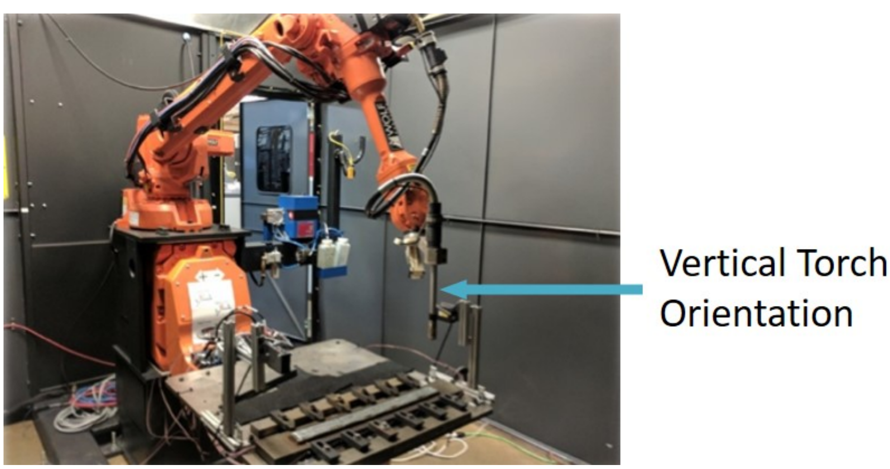

Figure 1.6: Visualization of the torch orientation

1.3.3 Hardware:

Power Source: Lincoln Electric Power Wave R450

Torch: Swanneck WH652T STD 22D S22645 523

Torch orientation: Vertical (see figure 1.6).

Wire stickout: 12mm (distance from the torch tip to the end of the wire). This value is maintained constant throughout the process.

Robot: ABB 2600

DAQ system: NI CRIO 9035

1.4 Clamping and base plate

A visual of the clamping and base plate set up is included in Figure 1.7. Note that this figure is not exact, and precise clamping geometry is provided in the CAD repository.

Here, the base plate dimensions are: 0.5" thick, 24" long, 4" wide. Recall figure 1.2 visualizes the dimensions of the base plate and curl bar (in mm). A blanket was used to insulate the plate from the table, with specifications provided. The clamping was done all around the base plate, with the bolts tightened to 30ft*lb of torque. The repository includes the following relevant files: the models for the clamps ("CLAMP.SLDPRT"), a model of the underlying table, and camera pictures of the actual setup.

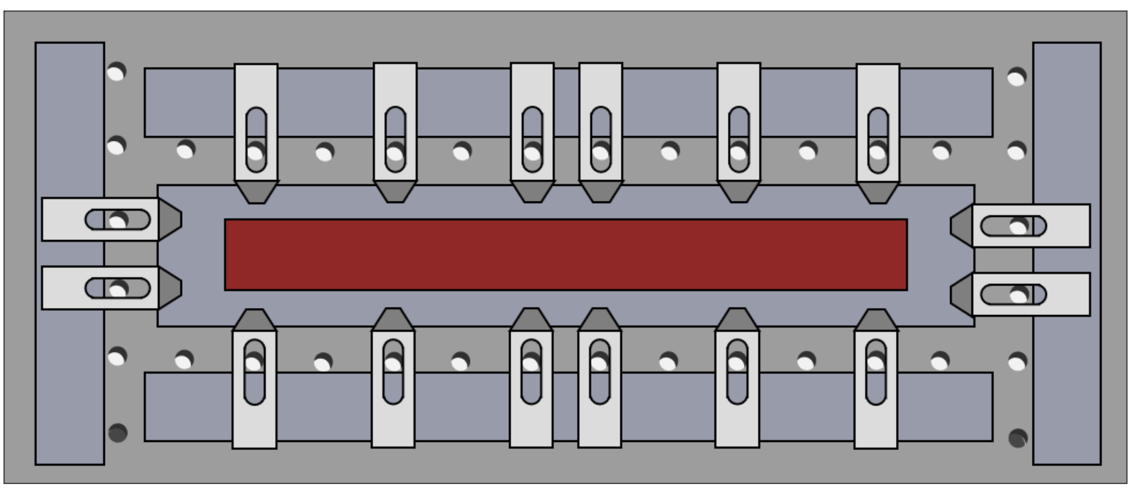

Figure 1.7: Visual of the base plate and clamping

1.5 Instrumentation

1.5.1 Temperature

For temperature data, the setup had 10 thermocouples: 4 thermocouples on each long side and 1 on each short side as pictured in figure 1.8.

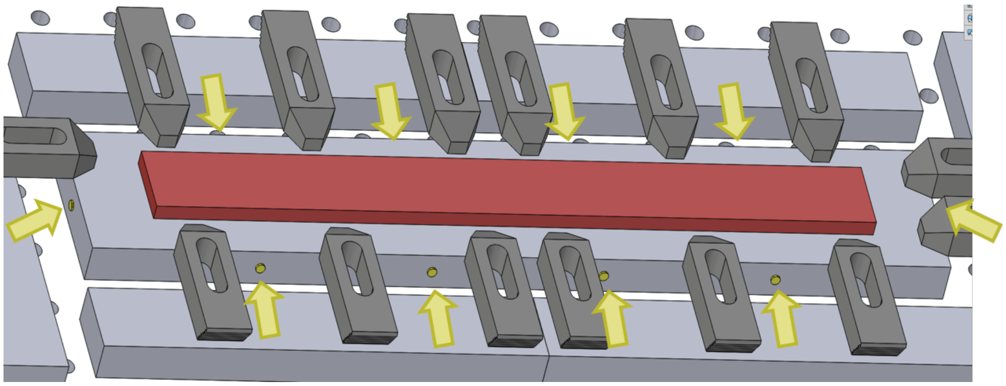

Figure 1.8: Thermocouple locations

Two additional thermocouples were included: one for the table and one for the ambient air. This results in a total of 12 thermocouples, numbered as in figure 1.9. These thermocouples were firmly mounted with a screw, again as depicted in 1.9. A CAD file with the exact thermocouple locations is included in the repository.

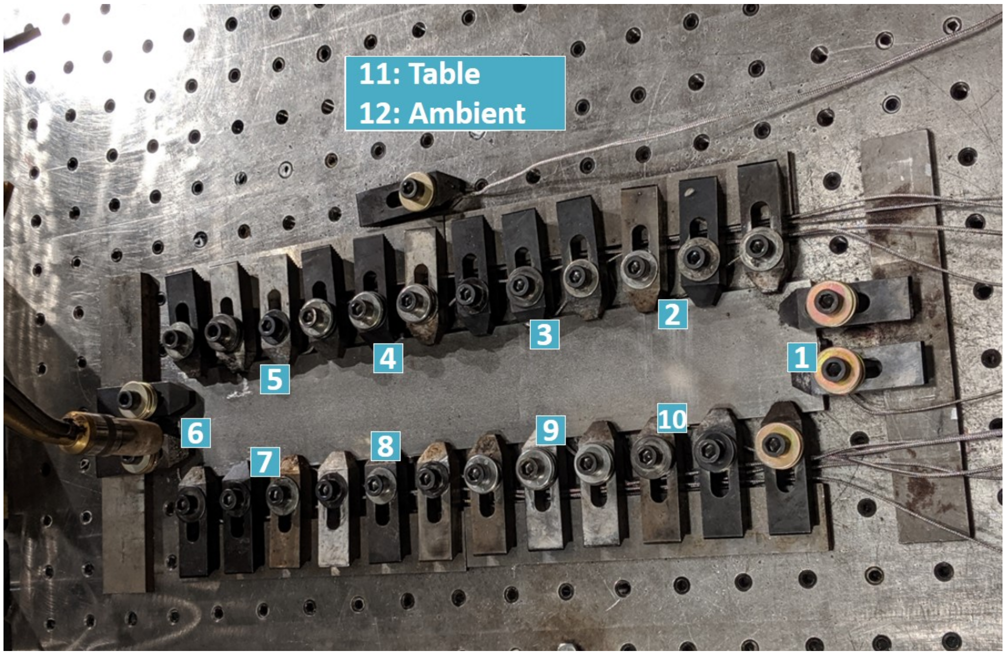

Figure 1.9: Thermocouple Numbering

The temperatures, deposition starts, and stops were recorded at 1s resolution. Thermal blankets cover the wires and the support plates and extend to the edge of the build plate;

see figure 1.10 for reference.

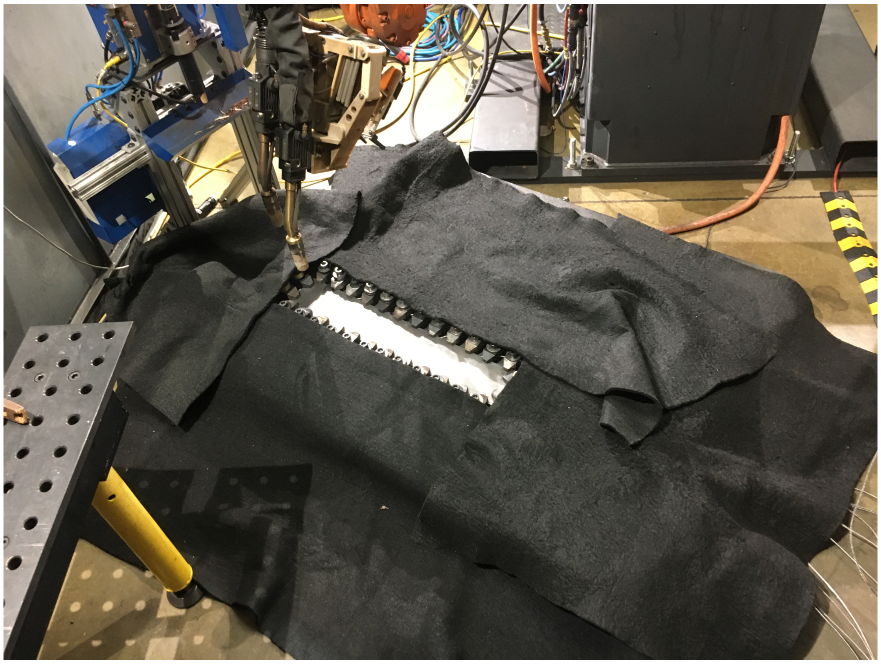

Figure 1.10: Print Bed Coverage with Welding Blankets

1.5.2 Power

For this setup, one can assume constant power as it does not fluctuate significantly. For the temperature data, power was logged indirectly (via the current and voltage) at one second intervals.

1.5.3 Deformation

Deformations/warping were recorded after clamp release. A graph of the resulting curvature is provided in the repository. Figure 1.11 provides an example of a deformed plate.

1.6 Slicing/Toolpath

For the calibration problem, the printed curl bar has four layers of even thickness. Each layer is approximately 2.3mm of nominal thickness (recall the approximate dimensions of the completed curl bar in figure 1.1). Each layer has 1 path of continuous deposition, called a *bead*. Here, the distance from bead center to bead center is 4.5mm, as in figure 1.13. Figure 1.12 gives the approximate bead dimensions on a cold plate.

Figure 1.14 outlines the planned material deposition patterns, or bead patterns, for each layer. The yellow bead indicates the starting bead for the layer. Note that the path direction changes from layer to layer. The bead deposition pattern is called *infill*–this term is used in the remaining discussion. For the calibration case, each layer has 10 *long* segments (the

Figure 1.11: Example of warping after clamp release

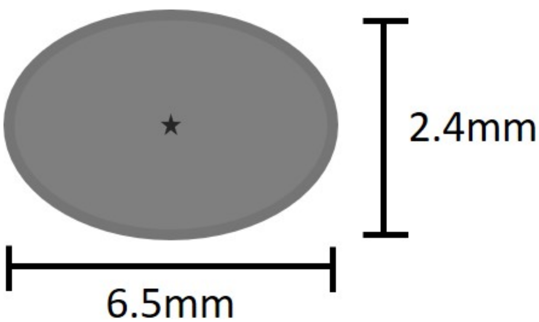

Figure 1.12: Typical single bead dimensions (cold plate)

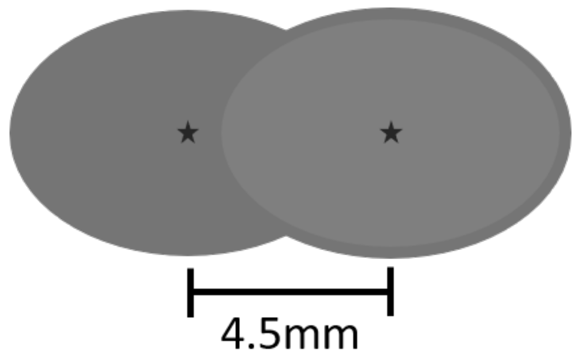

Figure 1.13: Center to center bead distance

deposition pattern fills the length of the curl bar). This is an important distinction between the calibration problem and the challenge problem, since the challenge problem deposition pattern fills the width of the curl bar in short segments (see section 3.1.1). The G-code (XYZ coordinate description) is included in the repository.

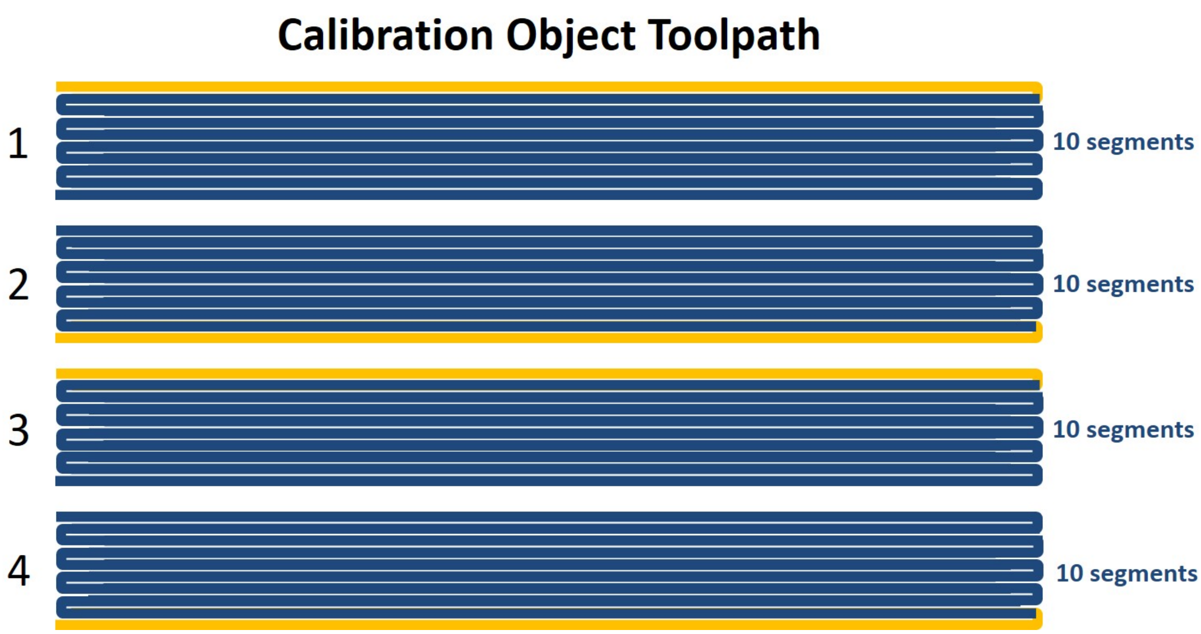

Figure 1.14: Four layers of print geometry. Layer 1 is the top, layer 4 is the bottom.

Chapter 2

Calibration Data

2.1 What calibration data are provided?

The following types of calibration data are provided. Appendix A gives a complete index of files in the repository.

1. Geometry
   - CAD files for: print object, base palte, mounting, build table, and locations of the thermocouples.
   - Common origin location for the parts (center of the build plate)
2. Printing log file
   - Temperature from the thermocouples
   - Current and voltage (arc deposition).
3. Wire specifications
4. Process parameters: welding mode (MIG)
5. Deformation of the plate after the cooldown and release of the clamps.
6. Format of the challenge information to be produced.

In this section, we examine the data formats provided for temperature, deformation, and residual stress.

2.2 What are we looking to match in the calibration problem?

We first consider what we are looking to match in the calibration problem, recalling problem statement 1. The calibration task seeks to find the following data:

1. **Temperature histories at the first 10 thermocouple locations at 1s resolution**.

    - In addition to the thermocouple temperature history, participants may also simulate specific additional locations in the build that are typically reported in literature (recall section 1.2.2). This is recommended, but optional .

2. **Overall edge displacements and curvature of the curl bar after clamp release**

3. **Residual Stress**

Use the provided spreadsheets to report the results for the specific times and locations. Returning the matched calibration data package is recommended but not required; we plan to use this matched data in the final publication of the results. If returning this matched calibration data, please use *exactly the same* data format as provided. Returned data in a different format will not be considered.

2.3 Data Formats

2.3.1 Temperature Data Format

Temperature data is provided as a .xlsx file. The first 5 rows provide background statistics for the experiment data (operator, wire, gas, etc.) Columns are then delineated as follows:

- **Column 1, Timestamp:** Timestamp data formatted as `<hour>:<minute>:<second>`

- **Columns 2-13, Thermocouple `<number>`:**. Continuous data, temperature measurements in celsius for each thermocouple (total of 12). A line graph for the thermocouple readings over time is visualized in Figure 2.1 Recall the thermocouple numbers are visualized in figure 1.9.

- **Column 14, Weld Voltage:** Continuous data, measured in V

- **Column 15, Weld Current:** Continuous data, Measured in A

- **Column 16, Weld on;** Binary data, indicates whether the power is on or off, 1 for on and 0 for off. The off periods are modelled in figure 2.2

- **Column 17-19, `<axis>` Position:** Continuous data, print head locations (X, Y, Z) in mm. Origin located in the center of the part, recall the visualization in figure 1.4.

This data is easily downloaded and manipulated in Python [12] via the `pandas` package [13]:

```
import pandas as pd

Cal_temp = pd.read_excel('<filepath to data>\SRP-4_nospike_Temperature&SysData.xlsx',
    ↪ skiprows=5)
```

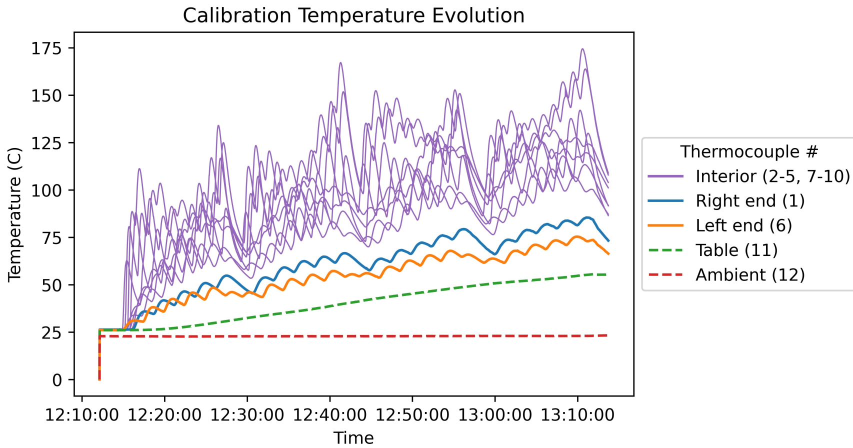

Figure 2.1: Thermocouple temperature measurements over time

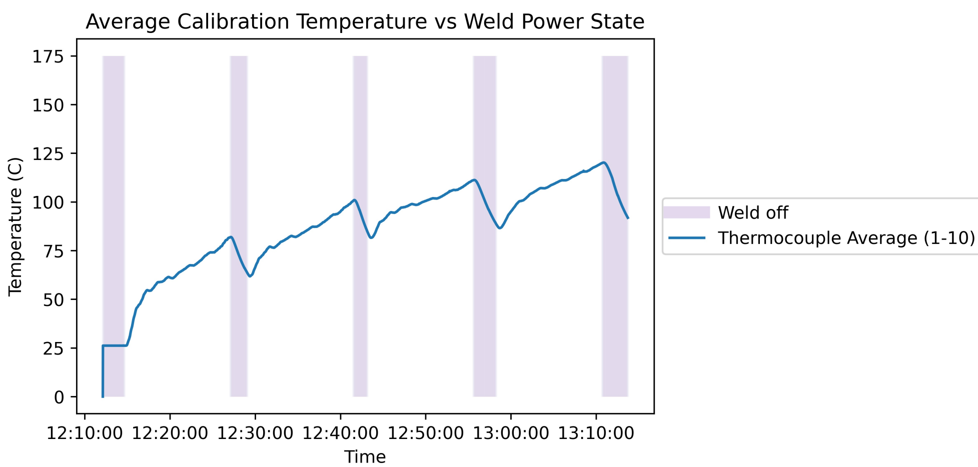

Figure 2.2: Average build plate thermocouple temperature measurements over time against compared to weld off periods.

Optional/Additional Temperature Data Point Request Calibration Sample

Participants are not required—but are strongly encouraged—to submit predicted temperature history corresponding to the approximate center of the weld passes, through the sample thickness. These predictions should be reported at one second intervals at the locations and times given in the spreadsheet provided: `\Temperature\CalTask\Temperature_Calibration_Sample_Model_Locations.xlsx`. A visualization of these prediction point locations is given in figure 2.3.

These calibration predictions are extremely useful for cross-model behavior comparison. Temperatures tend to be considerably higher at the center of the weld pass, as opposed to the exterior thermocouple locations. This means that temperature changes are also wider, which is informative for comparing models with different residual stress predictions. Though these additional samples will not be evaluated against a ground truth, they will be used in this final cross-model comparison and evaluation.

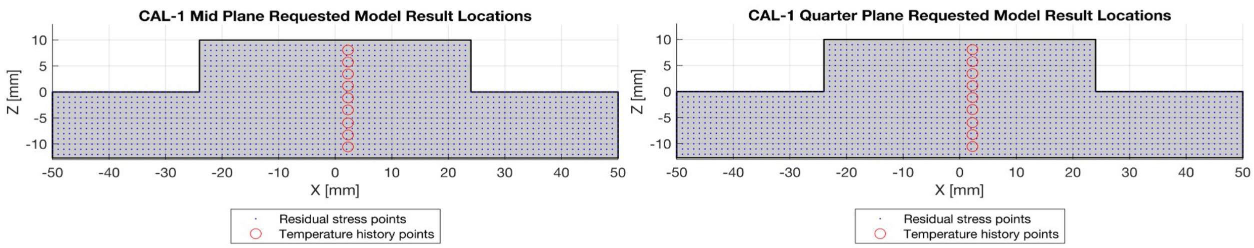

Figure 2.3: Weld pass locations for optional predictions.

2.3.2 Deformation Data Format

For the deformation data, we measure the deformation of the build plate measurement scheme. Measurements were taken from the flat surface to the bottom of the (deformed) build plate, as in figure 2.4

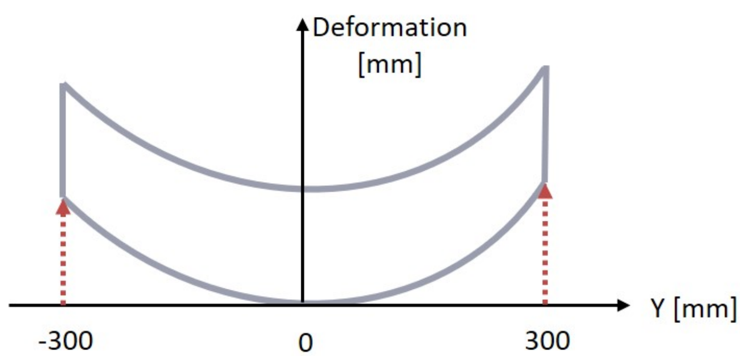

Figure 2.4: Deformation measurement (taken from the flat surface to the bottom of the plate

The calibration deformation data is included in DeformationMapsCal.xlsx. Column 1 gives the X value, and Column 2 gives the deformation value. An example of the line tracing used to calculate these deformations is included in figure 2.5

When reporting your deformation calibration results, please use the original file and add a column with simulated results (Column 3 of the DeformationMapsCal.xlsx file).

2.3.3 Residual Stress Data

Methods

Residual stress data were obtained using two key methods: Neutron diffraction (SNS, Vulcan beam) [1] and the Contour method [2].

For neutron diffraction, data were taken over three $X - Z$ planes, located at $Y = -125, 0, 125$ in mm. Figure 2.6 illustrates these data locations.

The neutron diffraction method covers data in all three directions, but the measurements were taken through the build *and* 2mm below (Z=-2). SNS data was obtained using 2mm collimator with Sigma XX and ZZ measurement cube of $2 \times 5 \times 2$ mm and Sigma YY $2 \times 3 \times 2$ mm. The stresses are volume averaged over this volume. Figure 2.7 shows the

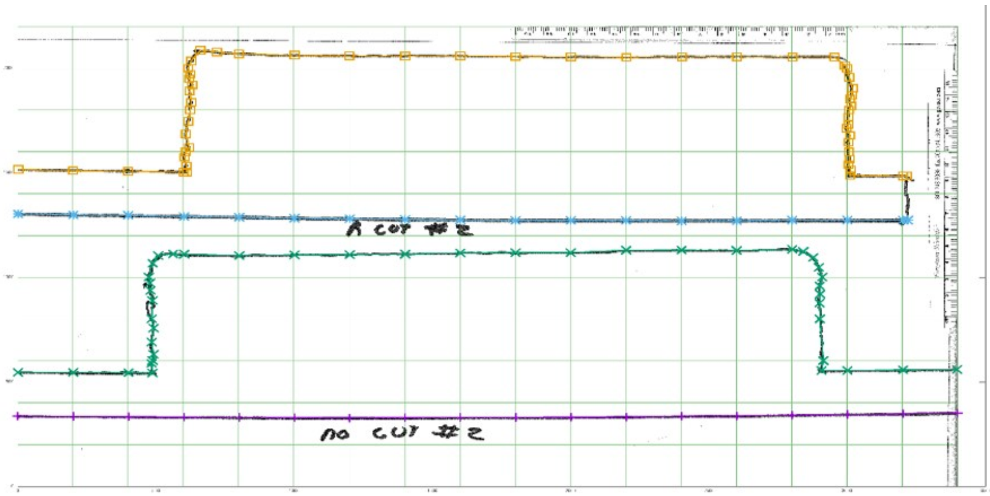

Figure 2.5: Printed part outline (plate included)

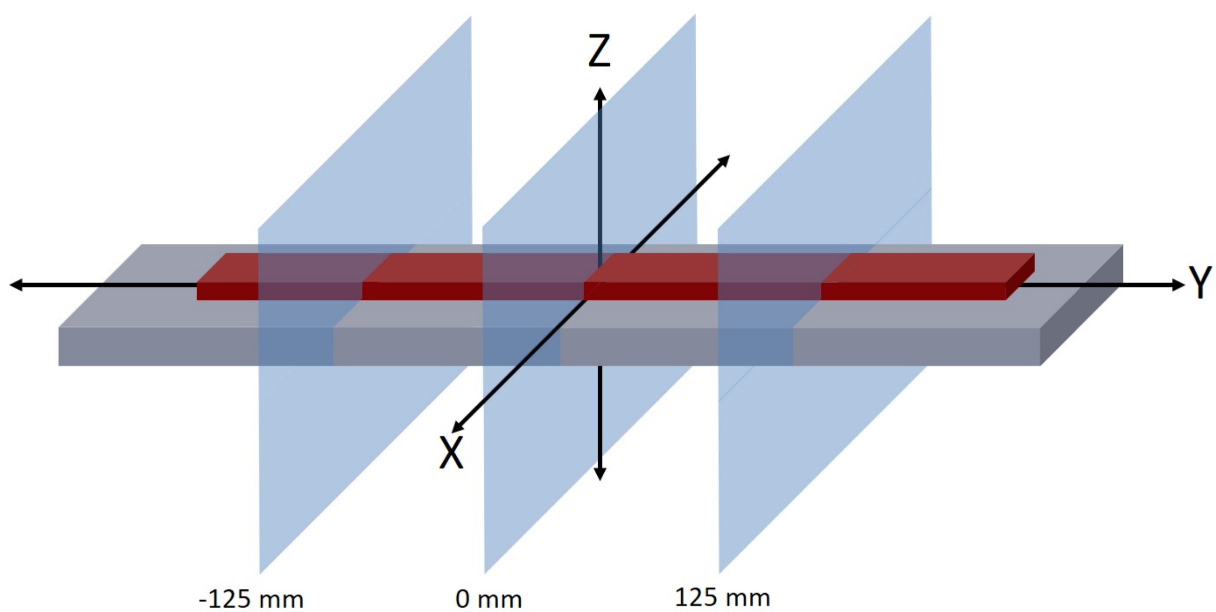

Figure 2.6: Neutron diffraction data locations

Neutron Diffraction derived residual stresses in the $Y = 0$ plane. This highlights the grid measurements and rigid structure of the neutron diffraction derived data, and gives a clear comparison between the stresses in each direction.

The contour method covers data through the entire thickness of the plate and provides stress measurement in the YY direction (see figure 2.8)

This type of data is visualized in figure 2.9

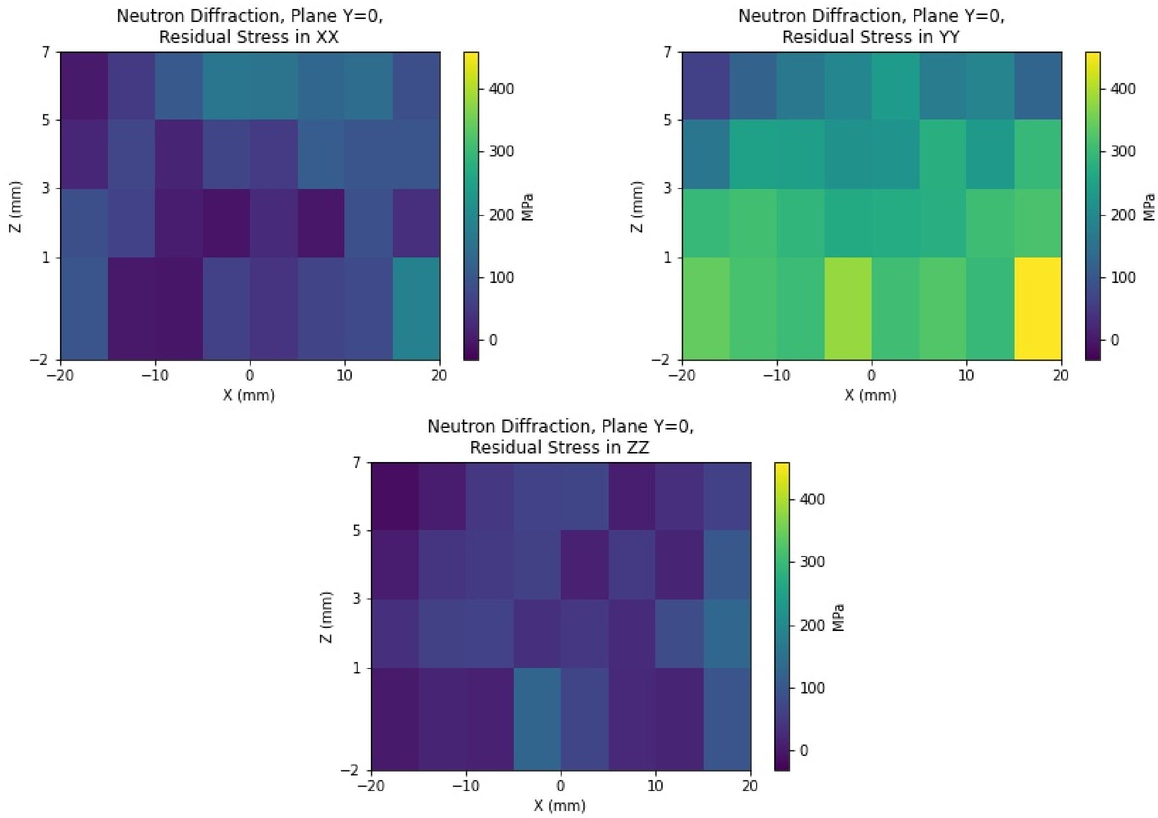

Figure 2.7: Visualization of Neutron Diffraction Residual Stress data in the Y=0 plane

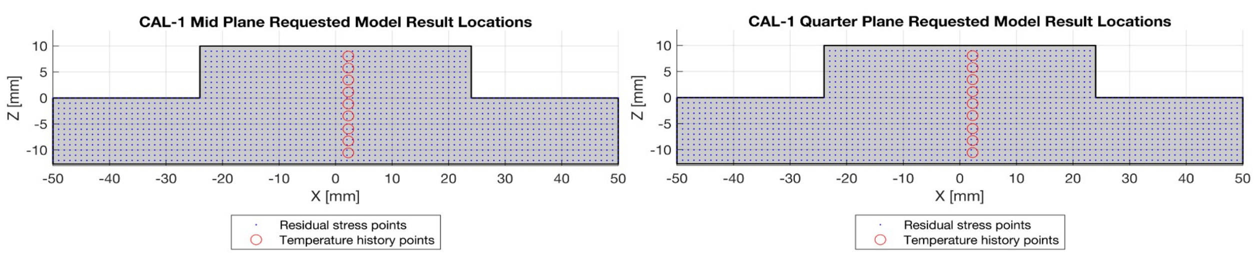

Figure 2.8: Contour method data location

Format

The residual stress data for the calibration task is contained in Residual Stress _calibration sample.xlsx.

This dataset is split into multiple spreadsheet tabs as follows:

- `CalibrationCentral(Y=0)_ND`
- `CalibrationCentral(Y=0)_Cont`
- `Calibrationleft(Y=-125)_ND`
- `Calibrationleft(Y=-125)_Cont`

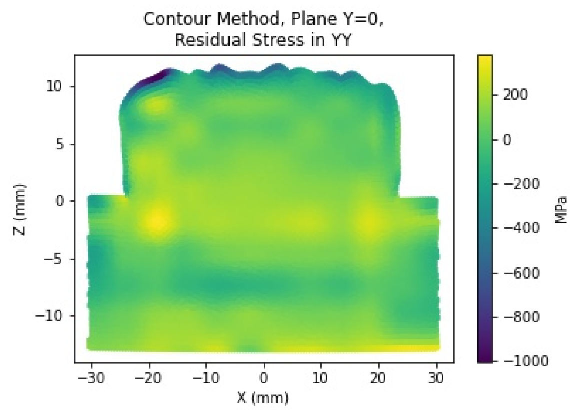

Figure 2.9: Visualization of Contour Method Residual Stress data in the Y=0 plane

- `Calibrationright(Y=125)_ND`
- `CalibrationRSLocations`

Here `ND` indicates data extracted via neutron diffraction and `Cont` indicates data extracted via the contour method. For the neutron diffraction data, we have the following column structure:

- **Column 1, X(mm)**: Integer data, the X position in mm. Measurements were taken in intervals of 5 mm between -20 and 20mm.
- **Column 2, Y(mm)**: Integer data, the Y position in mm. This value is constant, since each page in the document corresponds to a single Y plane.
- **Column 3, Z(mm)**: Integer data, the Z position in mm. Measurements were taken at the following points: $Z \in \{-2, 1, 3, 5, 7\}$.
- **Column 4, Sigma XX (MPA)**: Continuous data, the measured residual stress in the X direction, taken in megapascals.
- **Column 5, Sigma YY (MPA)**: Continuous data, the measured residual stress in the Y direction, taken in megapascals.
- **Column 6, Sigma ZZ (MPA)**: Continuous data, the measured residual stress in the Z direction, taken in megapascals.

For the contour method data, we have the following column structure:

- **Column 1, X(mm)**: Continuous data, the X position in mm. Not limited to a few integer measurements, taken through the entire thickness of the plate.
- **Column 2, Y(mm)**: Continuous data, the Y position in mm. This value is constant, as in the neutron diffraction data.
- **Column 3, Z(mm)**: Continuous data, the Z position in mm. Not limited to a few integer measurements, taken through the entire thickness of the plate.

- **Column 4, Sigma YY (MPA)**: Continuous data, the measured residual stress in the Y direction, taken in megapascals.

The final tab in the file–`CalibrationRSLocations`–provides a template for reporting the calculated residual stress problem for the calibration problem.

2.3.4 Simulation Support (Optional)

File line format

The format of the file line is as follows:

1. Time (sec) of the event.
2. X-coordinate (mm) of the event
3. Y-coordinate (mm) of the event
4. Z-coordinate (mm) of the event
5. Power (currently, the value is given as _POWER_). This value has to be replaced by the actual value used in the simulation.

For the time between the events, the location is linearly interpolated. The Power field is not interpolated and presents the value at the specified time. Value from the previous time event is assumed until is changed by a new event. The file can be used to simplify the simulation process. Power greater than zero indicates deposition and heat source, while power equal to zero indicates printing pause and tool re-position.

The following files are available for visualization of the wire deposition.

- Curlbar500Final_speed_nowipe_withpause_AB.obj: Wavefront OBJ format
- Curlbar500Final_speed_nowipe_withpause_AB.mesh: Medit mesh format

The path from the GCODE files is extruded using ellipsoidal cross section. These files *are not* supposed to be used for the modeling.

The repository also includes visualizations of the above files in PNG format.

- Curlbar500Final_speed_nowipe_withpause_AB.000.png
- Curlbar500Final_speed_nowipe_withpause_AB.001.png
- Curlbar500Final_speed_nowipe_withpause_AB.002.png

Chapter 3

Challenge Problem

3.1 Data

3.1.1 Overview

The setup for the challenge problem is *almost* identical to the calibration problem, with two key differences. First, the shape for the challenge problem includes a center channel (a hole) in the curl bar (see Figure 3.1).

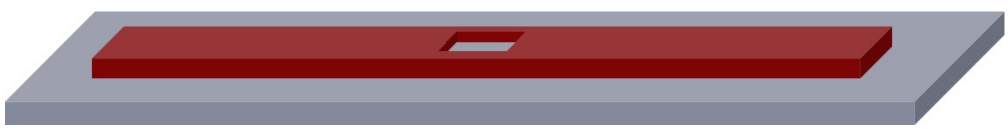

Figure 3.1: Shape of the challenge geometry. Key shape difference is middle hole

Second, the deposition pattern/toolpath for the challenge problem differs from the calibration problem. Here, the direction changes from layer to layer and the deposition has more than one bead. Note also that the deposition pattern fills along the width rather than the length of the shape, shown in Figure 3.2.

The external dimensions, origin, welding parameters are all exactly the same as in the calibration setting. The exact details for the challenge problem setup are provided in the CAD files in the repository.

3.1.2 Data Provided

The following data are provided for the challenge problem:

- Geometry: This includes CAD files for the print object, base plate, mounting, build table, and locations of the thermocouples.
- Time log for power torch locations
- Temperature of the table and ambient air
- Wire specifications

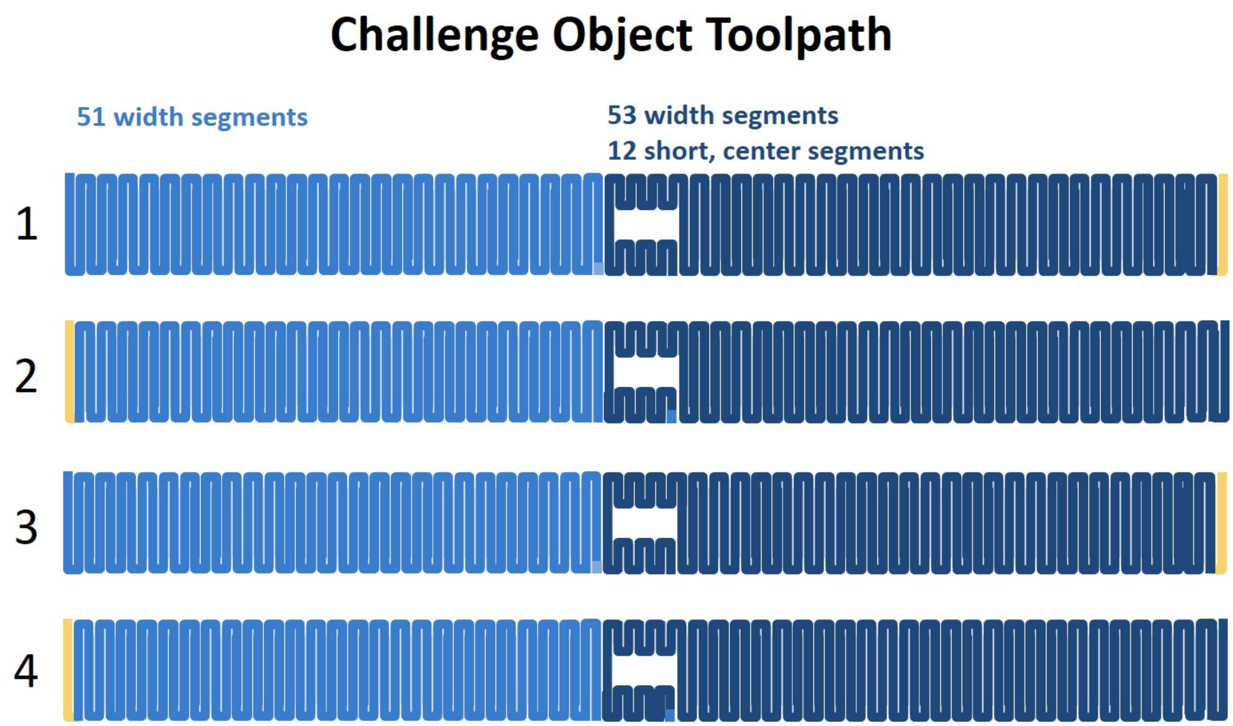

Figure 3.2: The four layers of the print geometry for the challenge problem, with the toolpath for each layer. Layer 1 is the top, layer 4 is the bottom. Yellow indicates the starting point of the toolpath for each layer.

- Process parameters: welding mode (MIG)

3.1.3 Data not provided

The following data will *not* be provided before the end of the challenge. Recall that after all predictions are submitted, they will then be compiled and compared against the true measurements for an archivable journal.

- Temperature histories at the 10 thermocouple locations. Use the template file.
  - Additional/optional different 10 locations through the thickness (will not be evaluated but compared).
- Overall edge displacements and curvature of the curl bar after clamp release at given resolution.
- Residual stress.

Use the template files for all predictions for these data points.

3.2 Challenge Tasks

3.2.1 Temperature Request

As with the calibration problem, challenge participants will compute temperature histories at the 10 thermocouple locations. Again, the optional temperature request is to calculate the temperature history (at 1 second intervals) corresponding to the approximate center of the weld pass through the sample thickness. Figure 3.3 serves as a visual for this additional request for the challenge problem. As always, use the provided template files to submit your predictions.

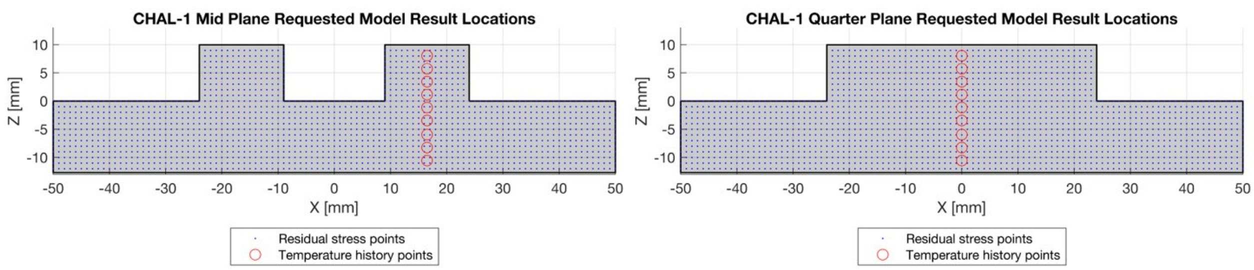

Figure 3.3: Visualization of the model result locations for the optional temperature task

3.2.2 Residual Stress Modelling

The measurements for the challenge problems were taken in three planes of interest as in the calibration problem. Residual stress points lay on mid (Y= 0mm) and quarter (Y=-125mm and Y=+125mm) planes. For the challenge task evaluation, only certain points will be compared and evaluated. Participants should use the provided spreadsheet template to submit their results.

Locations of residual stress for evaluation

For the residual stress task, the goal is to compare measurements along seven section lines in the measured Y-planes (Y=0, Y=125). The vertical lines in the Y-plane are given at $X = 0, X = 10, X = 20$ and the horizontal lines in the Y-plane are given at $Z = 7, Z = 1, Z = -2, Z = -12$. These lines go through the entire width and thickness, as in figure 3.4. For this challenge task, the resolution (number of reported points through the width or thickness) is up to the participant. A complete data matrix may be submitted, however, only these specific lines in the $Y = 0, Y = 125$ planes, in three stress directions (XX, YY, ZZ) will be evaluated.

A template is provided in the repository, please return your data in the requested format.

3.3 What to turn in?

The following files need to be turned in:

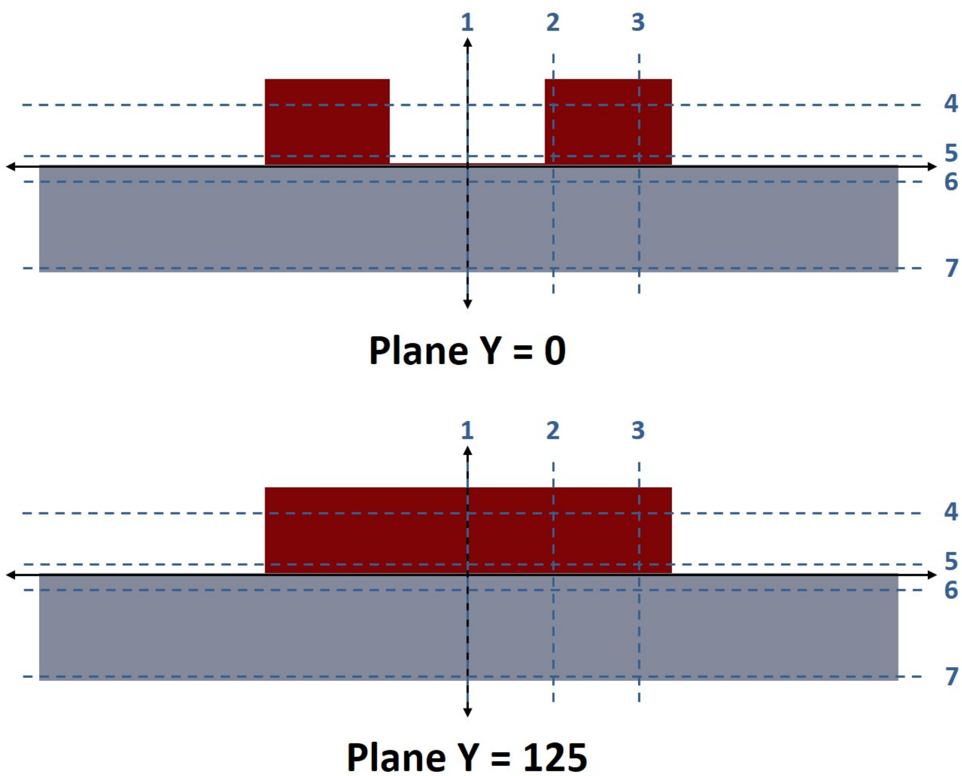

Figure 3.4: Locations of the seven section lines for evaluating residual stress. Line 1: X=0, Line 2: X=10, Line 3: X=20, Line 4: Z=7, Line 5: Z=1, Line 6: Z=-2, Line 7: Z=-12.

1. Questionaire document for basic information about the approach used.
2. Spreadsheet file with temperatures T1-T10 in the Main data format structure using the template provided for all the time rows.
    - Optional additional 10 locations (separate spreadsheet).
3. Predicted deformation data file in deformation data format using the template file (DeformationMapsChallDataRemoved.xlsx).
4. Predicted residual stress data file in residual stress format.

The template files for each of these tasks have been compiled in the "File Return Folder" for convenience. Submissions should be returned in a .zip folder titled "`<principalcontactlastname>_srpam_challenge.zip`". This should be emailed to `nycza@ornl.gov` with the subject line "SRP AM Challenge."

3.3.1 Frequently asked questions

Are there tolerances on the dimensions?

No.

Where is the origin located?

> In the middle of the base plate.

Does the printing process modify the settings dynamically?

> Not during this exercise.

Do modelers need more information, such as flow curves, hardening rule, thermophysical data all vs temperature and over a useful range of temperature?

> Participants need to model this themselves. The way such factors are incorporated should be reported in the Challenge Questionaire from the "File Return Folder"

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Appendix A

File Descriptions

File Return Folder	
File Name	**Description**
CHAL-4_TempRemoved_nodate_nospikeTemperature&SysData.xlsx	Required template for challenge temperature predictions.
DeformationMapsChallDataRemoved.xlsx	Required template for challenge deformation predictions
ResidualStress_challengesample_template.xlsx	Required template for challenge residual stress predictions
Temperature_Calibration_Sample_Model_Locations.xlsx	Optional template for mid-sample calibration temperature predictions.
Temperature_Challenge_Sample_Model_Locations.xlsx	Optional template for mid-sample challenge temperature predictions.

Table A.1: Picture file locations and descriptions.

Pictures	
File Name	**Description**
BeforeDepositionJul 31, 10 49 29 AM.jpg	System setup before deposition
CalPartJul 31, 2 57 02 PM.jpg	Calibration part printed
ChalPartAug 02, 9 38 35 AM.jpg	Challenge part printed
ClampSetupJul 31, 5 43 48 PM.jpg	Clamp and thermocouple assembly picture
RoomTCJul 31, 9 57 12 AM.jpg	Room temperature thermocouple location
TableTCJul 31, 9 57 17 AM.jpg	Table thermocouple setup picture
TCNumbering.png	Thermocouple numbering

Table A.2: Picture file locations and descriptions.

Temperature		
Directory	**File Name**	**Description**
`SRPCALLPackage/Temperature/CalTask/`	`SRP-4_nospike_Temperature&SysData.xlsx`	Calibration task temperature and location, current voltage, and time data.
	`Temperature_Calibration_Sample_Model_Locations.xlsx`	Template to input optional additional temperature simulated results–calibration.
`SRPCALLPackage/Temperature/ChalTask/`	`CHAL-4_TempRemoved_nodate_nospikeTemperature&SysData.xlsx`	Challenge data file with temperatures removed–insert challenge results here.
	`Temperature_Challenge_Sample_Model_Locations.xlsx`	Template to input optional additional temperature simulated results–challenge.

Table A.3: Temperature file locations and descriptions.

Deformation		
Directory	**File Name**	**Description**
SRPCALLPackage/ Deformation/CalTask/	DeformationMapsCal.xlsx	Deformation map for the calibration task
SRPCALLPackage/ Deformation/ChallTask/	DeformationMapsChallDataRemov xlsx	Deformation map for the challenge task. Empty file to be filled and returned.

Table A.4: Deformation file locations and descriptions.

Wire Data		
Directory	**File Name**	**Description**
SRPCALLPackage/ WireData/	WireL59.pdf	Wire information
SRPCALLPackage/ WireData/	ZLE_SDS_NA-EN-200000000296. PDF	Safety data sheet for SuperArc L-59

Table A.5: Wire data file locations and descriptions.

Residual Stress		
Directory	**File Name**	**Description**
SRPCALLPackage/ ResidualStress/	ORNL_MBAAM_Challenge_ Residual_Stress_Results_ VF.pptx	Document explaining how residual stress was measured
SRPCALLPackage/ ResidualStress/CalTask/	ResidualStress_ calibrationsample.xlsx	Residual stress data for the calibration task.
SRPCALLPackage/ ResidualStress/ ChallTask/	ResidualStress_ challengesample_template. xlsx	Challenge task spreadsheet residual stress template to be filled–locations only.

Table A.6: Residual stress file locations and descriptions.

Calibration CAD: Modelled After Printing		
Directory	**File Name**	**Description**
SRPCALLPackage/CAD/ CalTask/ ModelledAfterPrinting/	Base600_05inch.SLDPRT	Base plate model for both tasks
	Curlbar500AsPrinted.SLDPRT	The model of the printed object for the calibration task.
	ExpASSEM_cal.SLDASM	Main experiment assembly for calibration task. Shows thermocouple locations.
	SRP_CalAfterPrinting.SLDDRW	Drawing of the base-object assembly
	SRPCalAsPrinted.SLDASM	Base plate and object assembly
SRPCALLPackage/CAD/ CalTask/ ModelledAfterPrinting/ Accessories/	12.25x2x05inclampblock.SLDPRT	Clamp support model
	CLAMP.SLDPRT	Clamp model
	Thermocouple.SLDPRT	Thermocouple model
SRPCALLPackage/CAD/ CalTask/ ModelledAfterPrinting/ TableAssembly/	<#>.sldprt	Table assembly files, 1-27
	ORNLPrintTable-403151.SLDASM	Table Assembly

Table A.7: Calibration CAD files and descriptions (modeled after printing).

Calibration CAD: Modelled for Slicing		
Directory	**File Name**	**Description**
SRPCALLPackage/CAD/ CalTask/ ModelledForSlicing/	Base600_05inch.SLDPRT	Base plate model for both tasks.
	Curlbar500Slicing.SLDPRT	
	SRPCalForSlicing.SLDASM	
SRPCALLPackage/CAD/ CalTask/ ModelledForSlicing/STL_GCode/	Curlbar500Final_speed_nowipe_withpause.gcode	Calibration part object G-code file
	Curlbar500.STL	

Table A.8: Calibration CAD files and descriptions (modeled for slicing).

Challenge CAD: Modeled After Printing		
Directory	**File Name**	**Description**
SRPCALLPackage/CAD/ChallTask/ModelledAfterPrinting/	Base600_05inch.SLDPRT	Base plate model for both tasks
	Curlbar500HolesFixed_AfterPrinting.SLDPRT	Challenge part model
	ExpASSEM_Chall.SLDASM	Main experiment assembly for challenge task. Shows thermocouple locations
	SRPChallAfterPrinting.SLDASM	Challenge part and base plate assembly
SRPCALLPackage/CAD/ChallTask/ModelledAfterPrinting/Accessories/	12.25x2x05inclampblock.SLDPRT	Clamp support model
	CLAMP.SLDPRT	Clamp model
	Thermocouple.SLDPRT	Thermocouple model
SRPCALLPackage/CAD/ChallTask/ModelledAfterPrinting/	<#>.sldprt	Table assembly files
	ORNLPrintTable-403151.SLDASM	Table Assembly

Table A.9: Challenge CAD files and descriptions (modeled after printing).

Challenge CAD: Modelled for Slicing		
Directory	**File Name**	**Description**
SRPCALLPackage/CAD/ChallTask/ModelledForSlicing/	Base600_05inch.SLDPRT	Base plate model for both tasks
	Curlbar500HolesFixed.SLDPRT	
	SRPChall.SLDASM	
SRPCALLPackage/CAD/ChallTask/ModelledForSlicing/STL_GCode/	Curlbar500HolesFixed.gcode	Challenge task G-code toolpath
	Curlbar500HolesFixed.STL	

Table A.10: Challenge CAD files and descriptions (modeled for slicing).