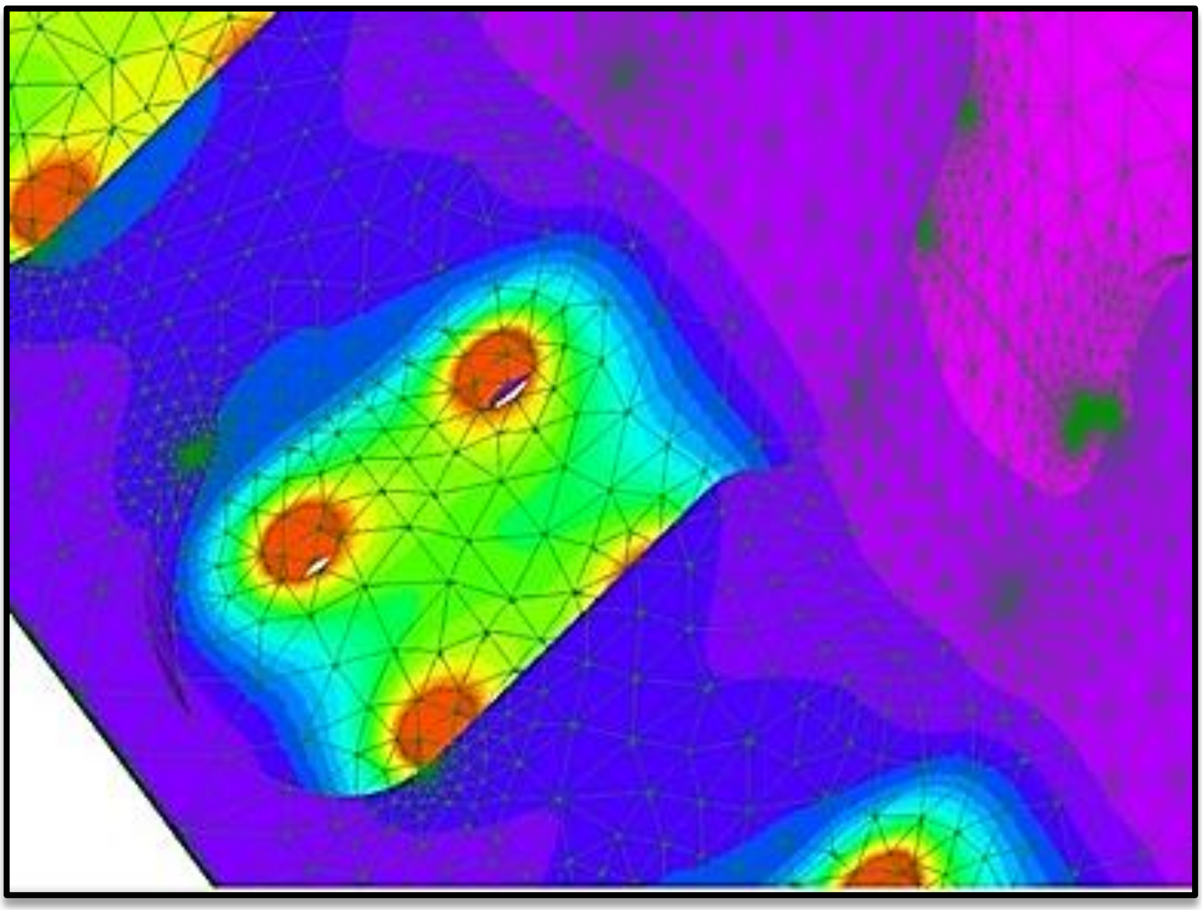
Semi-automatic

(8-Station) Polymer Welding System

FEA Report

(3D Thermal Transient Analysis)



Submitted by:

Ray M. Frey

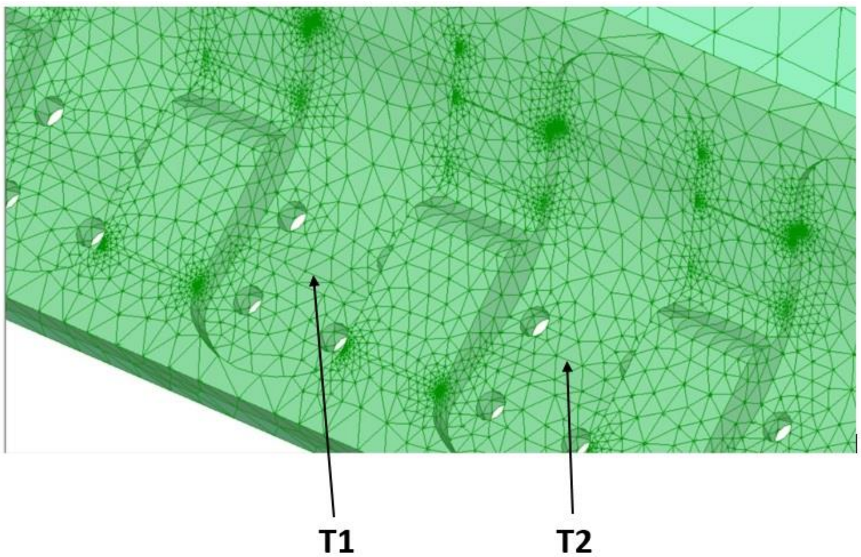
R.J. Frey Technologies

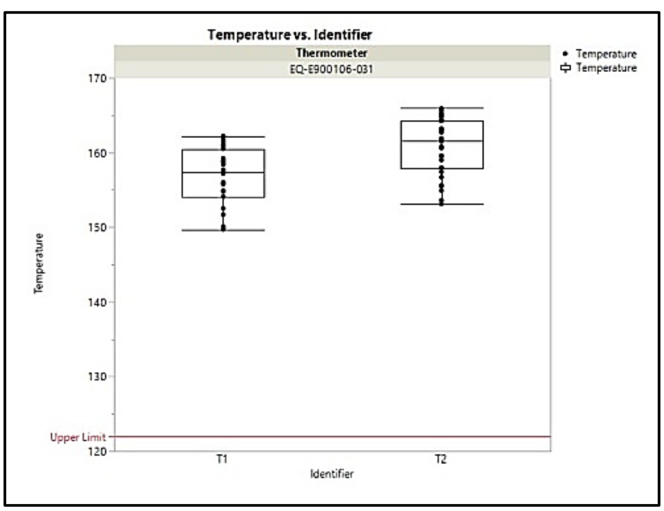
Date: 12/17/2018

1.0 **Statement of the Problem**:

A semi-automated (8-station) polymer thermal welding process operates at an average temperature of (456°F). This average welding temperature is based on empirical field test measurements of the system's welding element tips.

During operator removal of the product after thermal welding, the product's lower holding platen is reaching a temperature range of (150-168°F) (See images below). This high temperature is a safety hazard for the operator and exceeds the operator handling threshold limits of (111-122°F) outlined in OSHA referenced document (ASTM C-1055 "Standard Guide for Heated System Surface Conditions that Produce Contact Burn Injuries").





Design steps must be implemented to reduce this temperature in the product lower holding platen to be within OSHA-ASTM specified limits. The duty cycle of the process is continuous with the thermal welding tips remaining at the controlled operating temperature for an entire work shift.

Thermal Welding Process Defined:
There are (4) heat staking welding tips per product (8 products per dual platens) for a total of (32) tips. The engagement of the heat staking welding tips with the product is intermittent (15-17 secs) during the overall (36 sec approx.) process cycle time. There is a (5 sec) compressed air cooling cycle at the end of the (17 sec) welding tip engagement to help solidify the thermal welds in the product.

There are (2) separate (8-station) product holding platen assemblies mounted on a linear slide system. Only (1) (8-station) product platen assembly at a time is being thermally welded while the operator is unloading the other product platen assembly.

The (8-station) polymer thermal welding subassembly is located in "dead" air space within the machine, confined on all sides by metal structural components and Lexan® shielding. There are some areas around the shielding where the internal air can vent to atmosphere during the process cycle, but there is no fan induced forced air convection movement to cool the air space at this time.

There is ambient air temperature mixing that take place every (36 sec) during a welding cycle completion, when ambient air is pulled into the machine from the side sheet metal guards as the machine indexes into the load/unload positions.

2.0 Purpose of this FEA Simulation:
The purpose of this FEA simulation is to build an analytical model that closely simulates the existing temperature conditions within the thermal welding process and to begin implementing design changes to reduce high thermal load regions that are a safety hazard to the operator.

FEA Solution Strategy: (Using LISA v8.0 FEA Software)

2.1 FEA Solution Step 1: This type of thermal process problem requires a "real-time" 3D transient FEA thermal analysis over the critical heating and cooling periods within the process cycle. It is not a thermal steady state model because the thermal loads change over time, but an initial "thumbnail" thermal steady state FEA will be run during the heater engagement time to get a quick "snap shot" at the "puedo worse case" thermal pathways and critical thermal load areas. This "snap shot" will be helpful in defining a potential corrective action prior to building a more complex and accurate thermal transient FEA model.

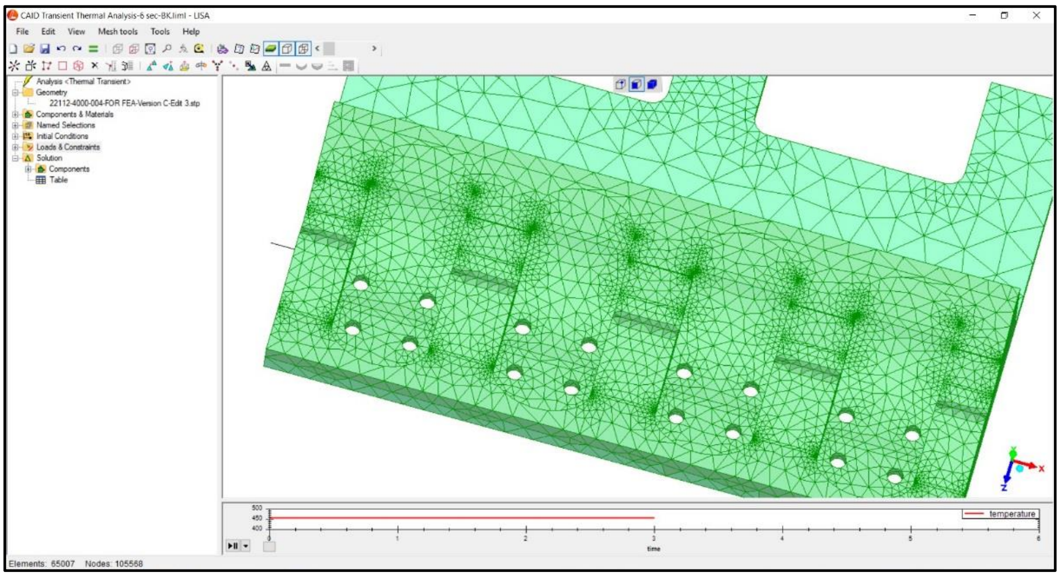
2.2 FEA Solution Step 2: A second comprehensive 3D transient FEA thermal analysis will be run to define the more accurate "real-time" thermal conditions over the critical heating/cooling periods of the process cycle. The overall process cycle time is approximately (36 sec), but only the last (28 seconds) of the cycle will be evaluated as they contain the critical heating/cooling times.

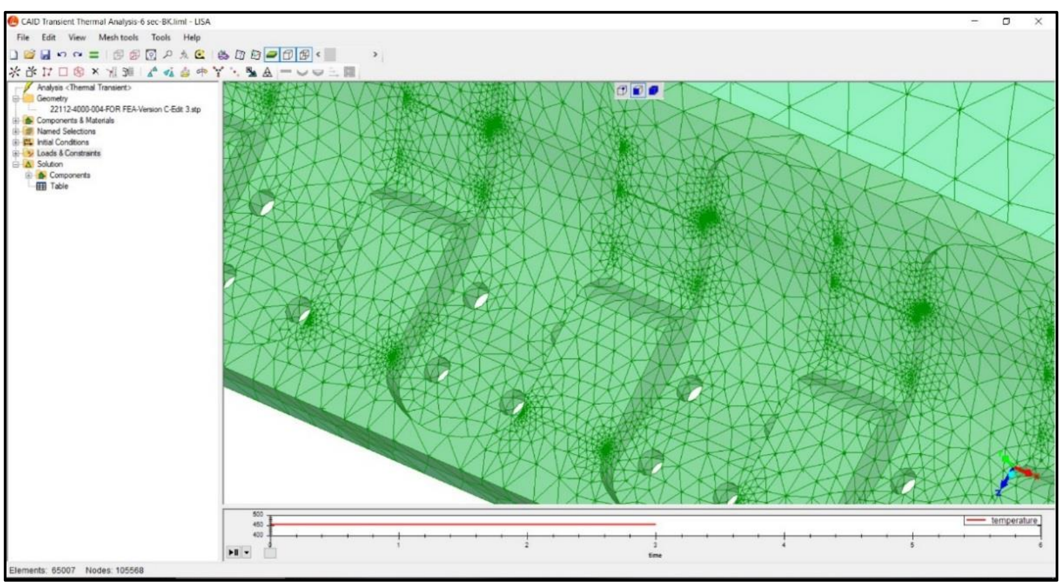
2.3 **<u>FEA Solution Step 3</u>:** A third 3D transient FEA thermal analysis will be run implementing one potential design corrective action.

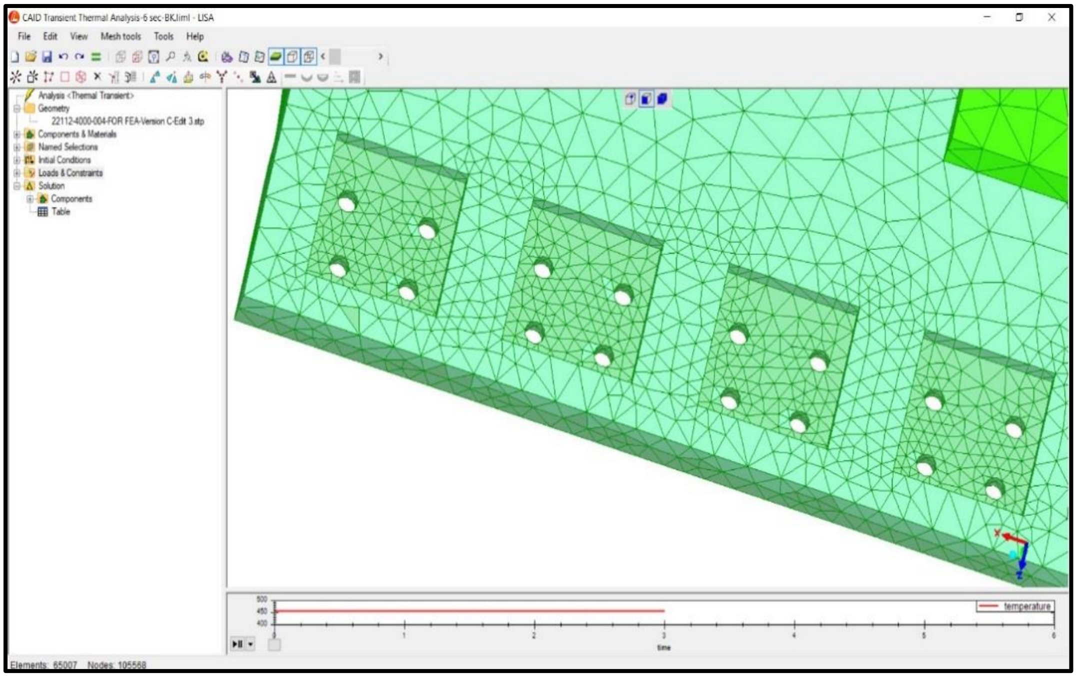
3.0 <u>FEA Model Mesh Data and Analysis Parameters</u>:

(Note: Non-essential small part features were eliminated in the model to improve FEA meshing)

<u>Model Mesh Data</u>: Nodes: (105,568) Elements: (65,007) DOF (N/A)







FEA Analysis Types Used: 3D Steady State and 3D Transient Thermal

Composite Materials Used: Yes

Material Properties Used:

>Upper/Lower Platen:
Mat'l: (Delrin® (Acetal homopolymer))
Thermal Conductivity: (4.533 E-06 BTU-in/sec-in^2 °F)
Specific Heat Capacity: (0.350 BTU/Lb-°F)
Weight Density: (0.0513 lbs/in^3)

>Customer Product:
Mat'l: Makrolon® (Polycarbonate)
Thermal Conductivity: (2.7064 E-06 BTU-in/sec-in^2 °F)
Specific Heat Capacity: (0.299 BTU/Lb-°F)
Weight Density: (0.0434 lbs/in^3)

>Base Mounting Plate:
Mat'l: Aluminum 6061
Thermal Conductivity: (2.239 E-03 BTU-in/sec-in^2 °F)
Specific Heat Capacity: (0.214 BTU/Lb-°F)

Weight Density: (0.0975 lbs/in^3)

>Linear Slide Bearings: Mat'l: Aluminum 6061
Thermal Conductivity: (2.239 E-03 BTU-in/sec-in^2 °F)
Specific Heat Capacity: (0.214 BTU/Lb-°F)
Weight Density: (0.0975 lbs/in^3)

<u>and</u>

Mat'l: Carbon Steel
Thermal Conductivity: (6.464 E-04 BTU-in/sec-in^2 °F)
Specific Heat Capacity: (0.118 BTU/Lb-°F)
Weight Density: (0.283 lbs/in^3)

Heat Transfer Data:

>Heating Element Tip Data: Average Process Temperature: (456°F) (Continuous duty)

>Heating Element Engagement: Intermittent welding cycle (17 sec) engagement with product. (5 sec) of this engagement is with compressed air cooling at weld contact zone.

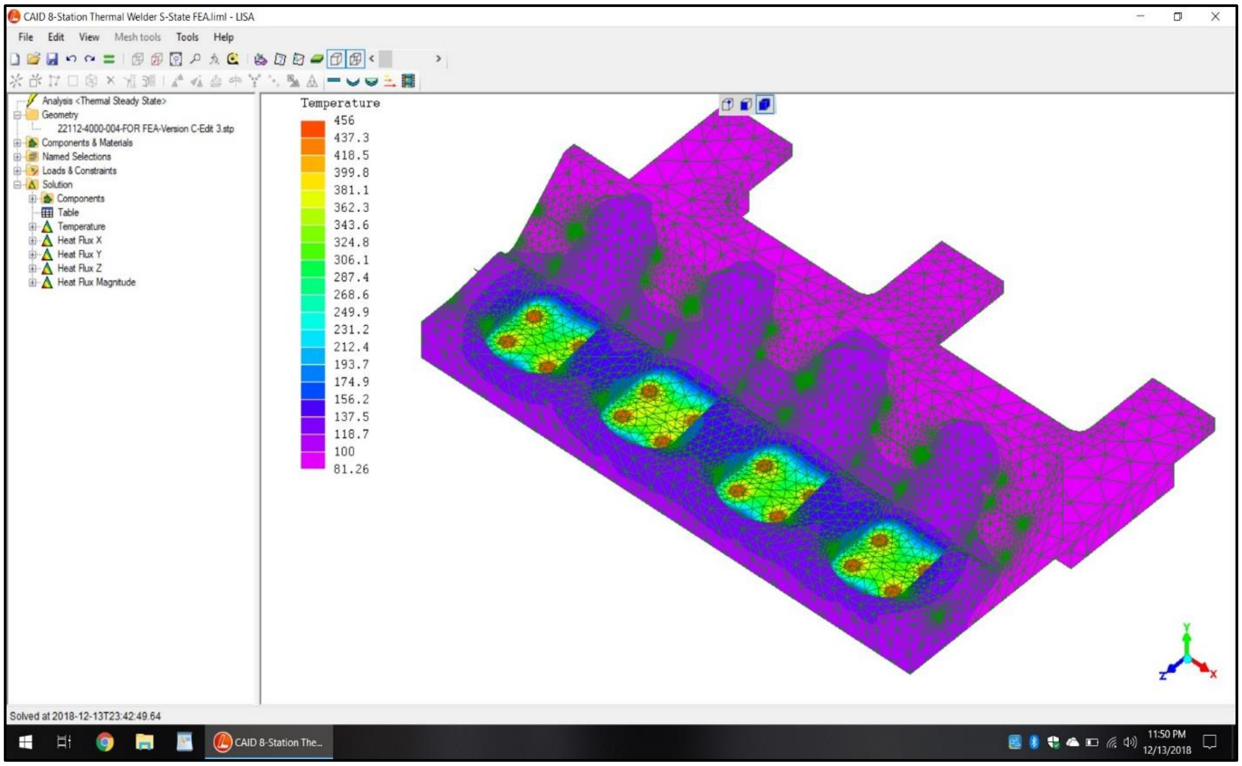
>System Thermal Losses: >Lower Mtg Plate "heat transfer"
>Linear Bearing Assembly "heat transfer"
>Product "heat transfer"
>Air "heat transfer" around subassembly

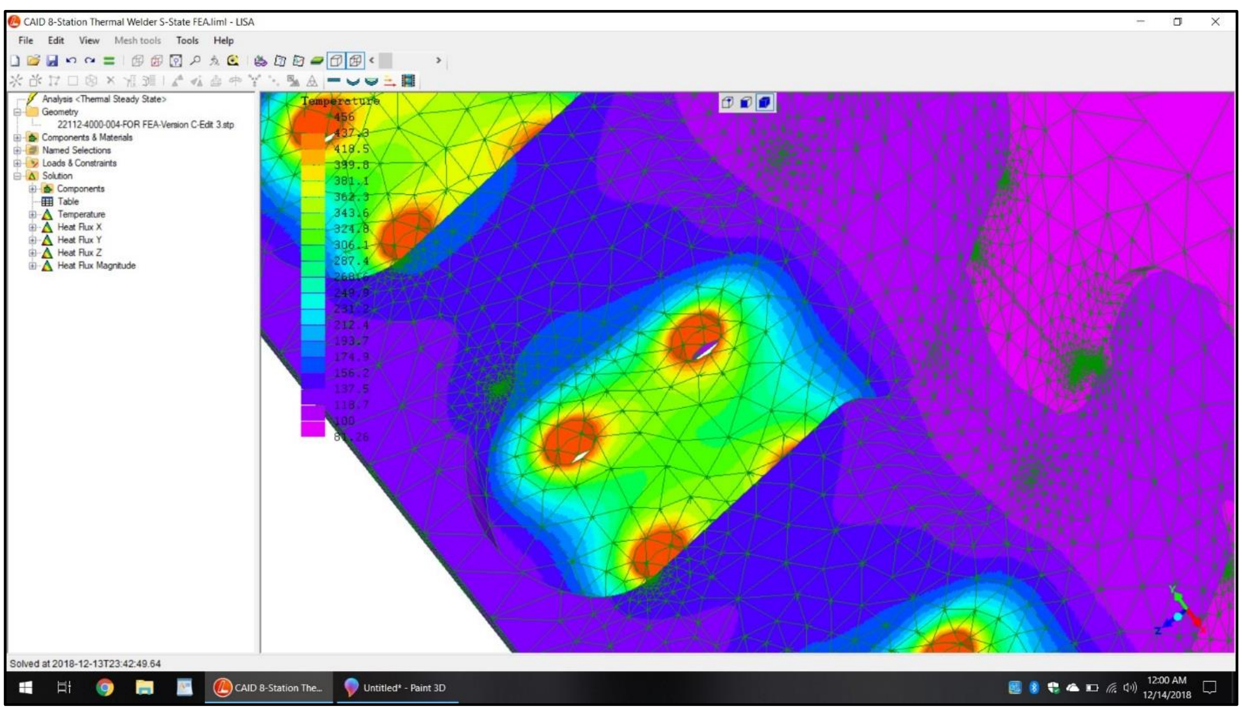
>Dead Air Thermal Conductivity: (3.463 E-07 BTU-in/sec-in^2 °F)

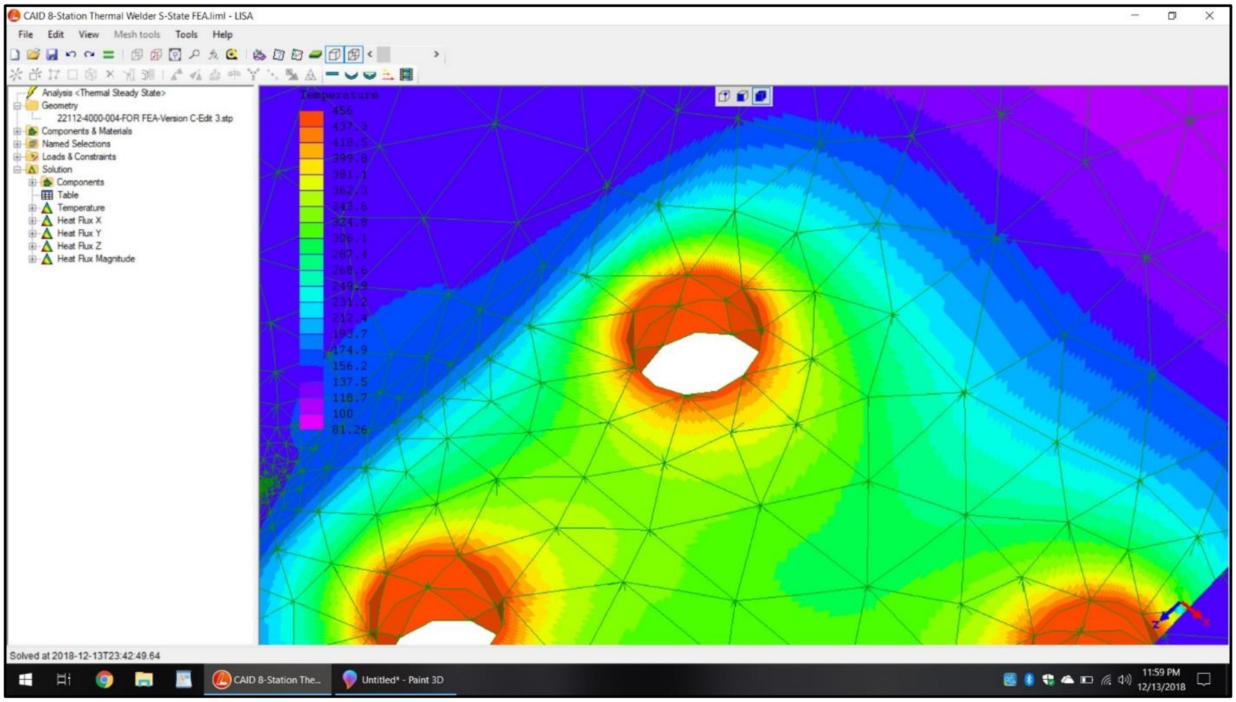
4.0 FEA Solution Step 1A- Analysis Results:

This is an initial "thumbnail" thermal steady state FEA model during the heater element tip engagement to get a quick "snap shot" at the "puedo worse case" thermal pathways and critical thermal load areas.

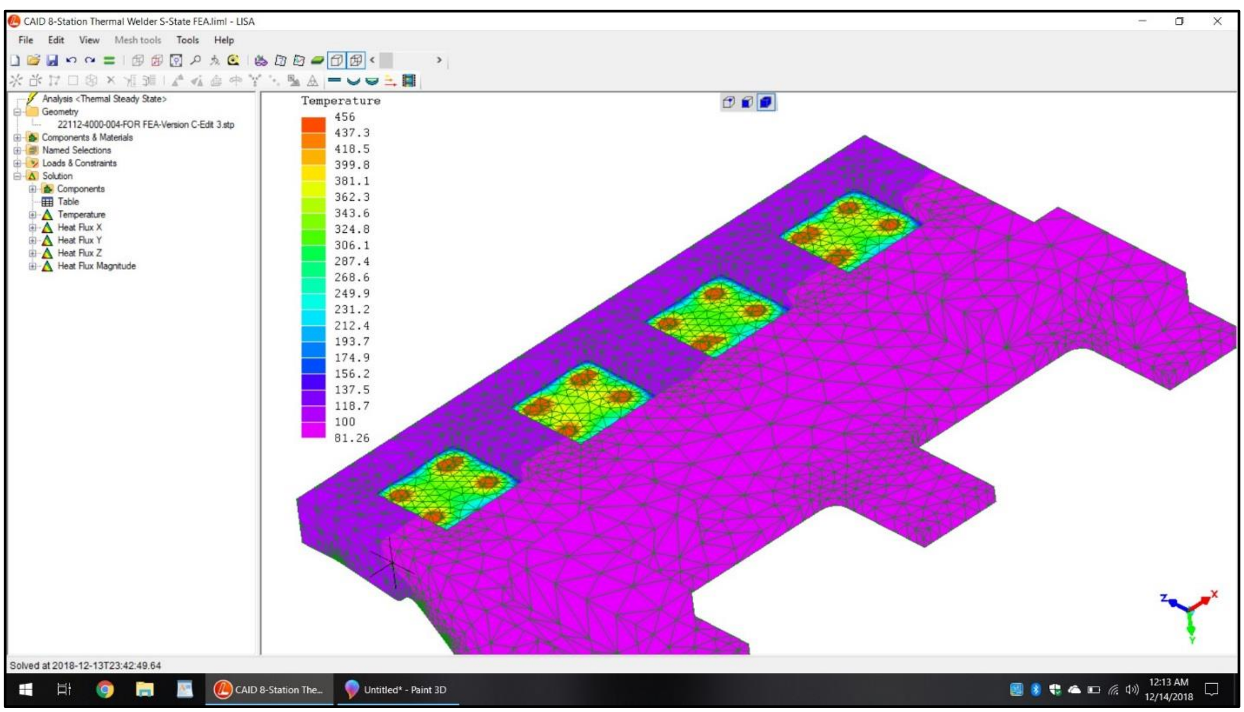
Top View Images: (showing product holding pockets)







Bottom View Image: (showing heater element tip entry points)

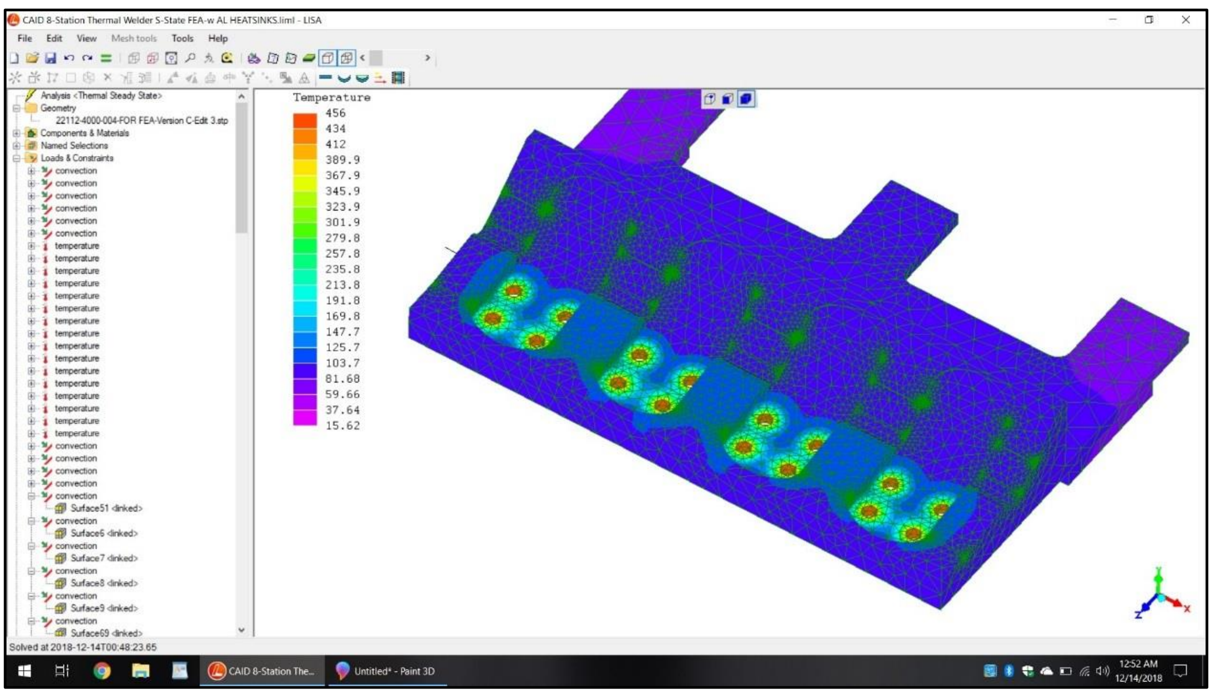


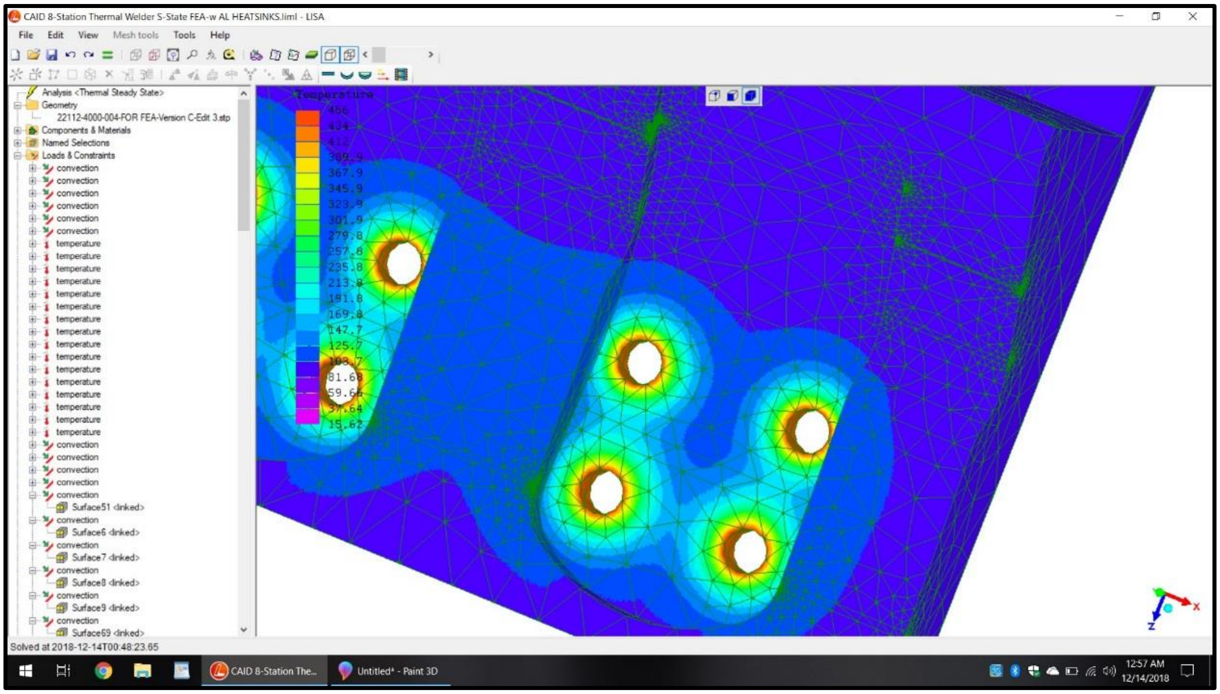
5.0 **<u>FEA Solution Step 1B- Analysis Results</u>:**

Based on evaluating the initial FEA Solution Step 1A results, it appears that if heatsinks were mounted into the machined underside pockets in the Delrin® Lower Platens, that you could affectively remove heat energy from that Lower Platen zone without adversely impacting the thermal welding process (which is located higher up in the product assembly). You would need large enough clearance holes (in the added heat sink components) around the heating tip entry points to minimize heating tip thermal losses. Thermal losses in the heating tips could adversely affect the welding process.

To simulate aluminum heatsinks in the underside pockets, the thermal transfer loss conductivity from the pocket surfaces were changed to match that of aluminum's thermal properties.

Top View Images: (showing product holding pockets)

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Geometry
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Loads & Constraints
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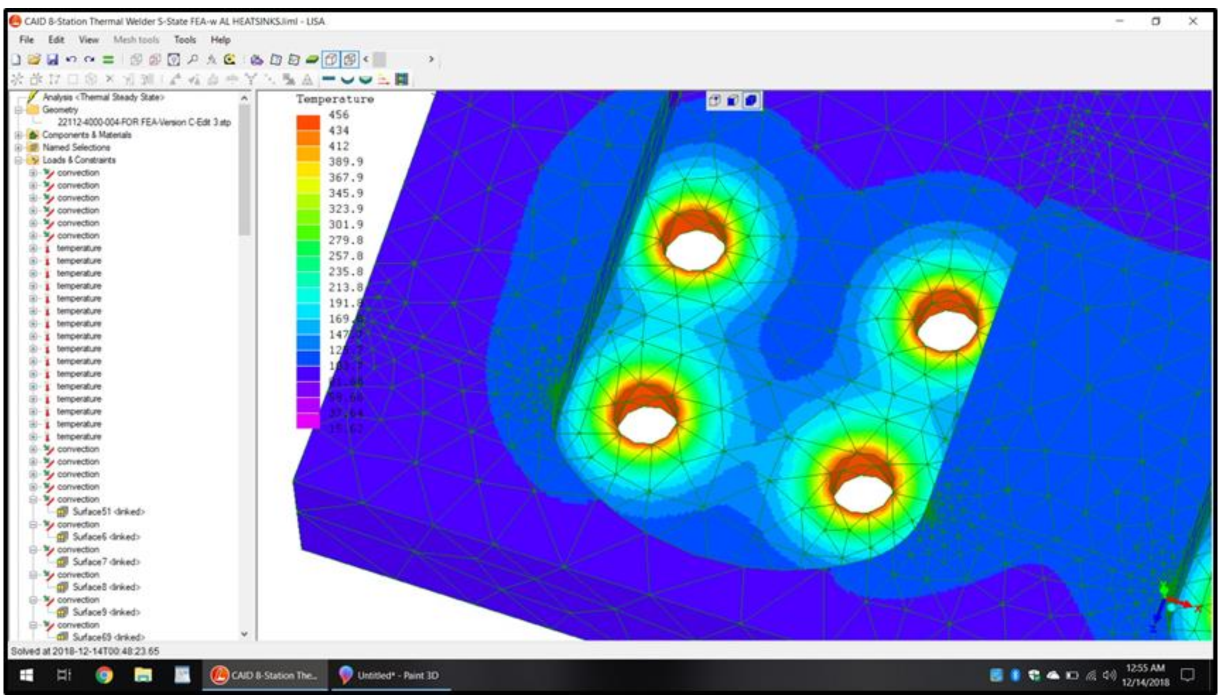
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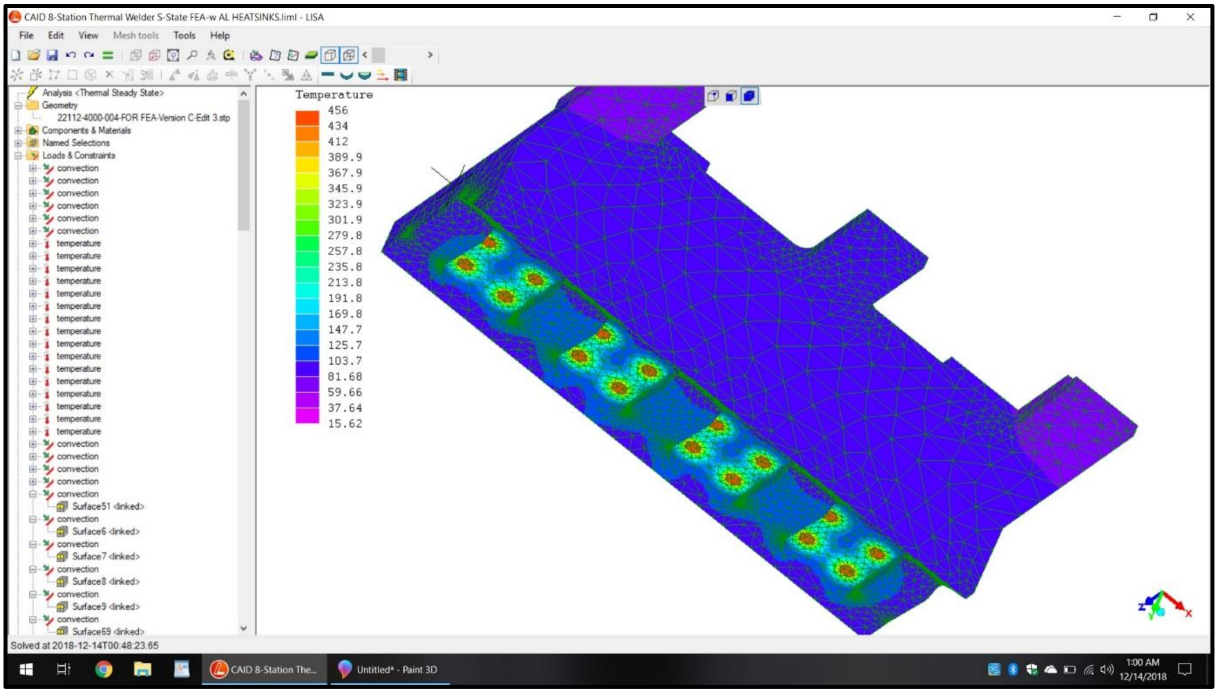


Conclusions: The FEA heat transfer and temperature distribution gradient in FEA Results (1A and 1B) appear to be valid for a steady state thermal condition. The thermal conductivity properties of each composite material were included in the analysis. There were no errors in the mesh generation and in the FEA solver processing.

Even though this thermal steady state analysis is not the "real" thermal condition for the process cycle, it is a quick "snap shot" (an indicator) of the "puedo worse case" thermal pathways and critical thermal load areas. This FEA gives a clear indication that by placing aluminum heatsinks in the underside Delrin pockets, a considerable amount of thermal energy can get transferred out of the central platen zone between the holes.

Based on these FEA results, aluminum heatsinks will be placed into the (Solution Step 3) FEA model in the machined underside Delrin platen pockets as a potential corrective action for the "real-time" transient thermal analysis.

6.0 **FEA Solution Step 2 Parameters:** (3D Transient Thermal w/o Heatsinks)

Model Mesh Data: Nodes: (105,568) Elements: (65,007) DOF (N/A)

FEA Analysis Type: 3D Transient Thermal

Decimation Used: Yes (5 sample times)

Composite Materials Used: Yes

Thermal Welding Process Cycle Time Data: (Times are approx. based on empirical observation time studies)

>Total Cycle Time: (36 sec approx.)

>Critical Cycle Time for FEA: (Last 28 seconds of the cycle)

Transient Thermal FEA- Sample Time 1: (1 sec)

- Prior cooled Lower Product Platens inside the thermal welding machine immediately before heater element tip engagement.

Transient Thermal FEA- Sample Time 2: (12 sec)

- Heater element tips are engaged contacting the product for the thermal welding process. Compressed cooling air is OFF.

Transient Thermal FEA- Sample Time 3: (5 sec)

- Heater element tips are engaged contacting the product for the thermal welding process. Compressed cooling air is ON.

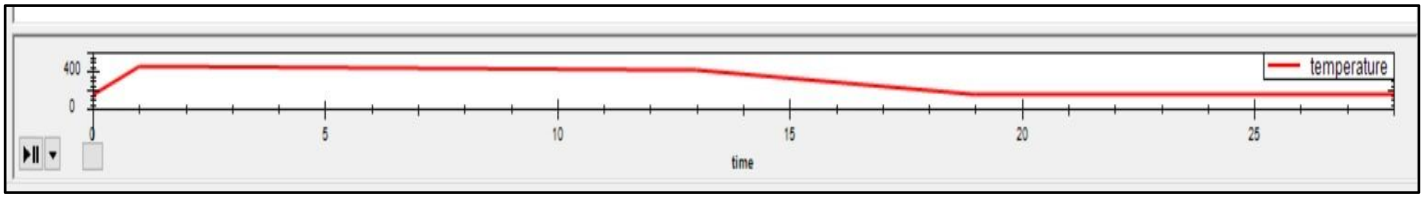
Transient Thermal FEA- Sample Time 4: (8 sec)

- Heater element tips disengage the Lower Product Platens. Cooling thermal losses begin with Lower Platen and product. Both Lower Product Platens retract exposing the product to heated air inside the machine.

Transient Thermal FEA- Sample Time 5: (2 sec)

- Heaters still disengaged. Additional ambient cooling thermal losses occur with Lower Platens and product exposed to the air exiting the system. Cycle ended.

>Transient Temperature/Time Cycle- (Heat Load) Profile:



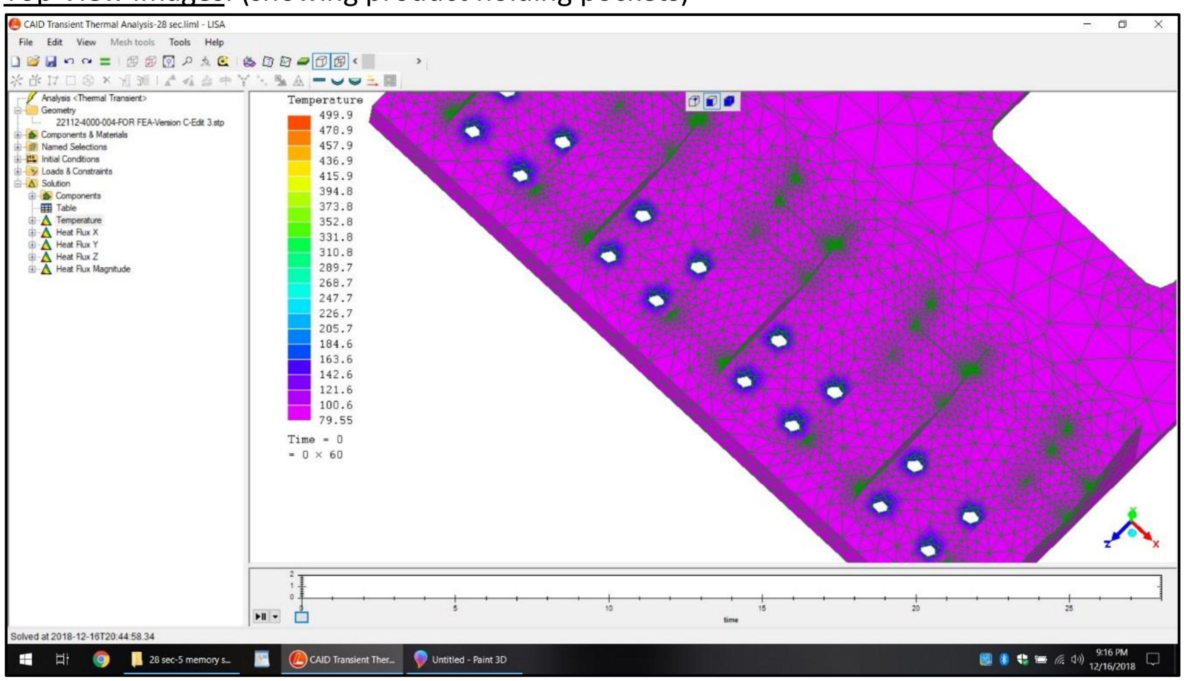
7.0 <u>FEA Solution Step 2-Analysis Results</u>: (3D Transient Thermal w/o Heatsinks)

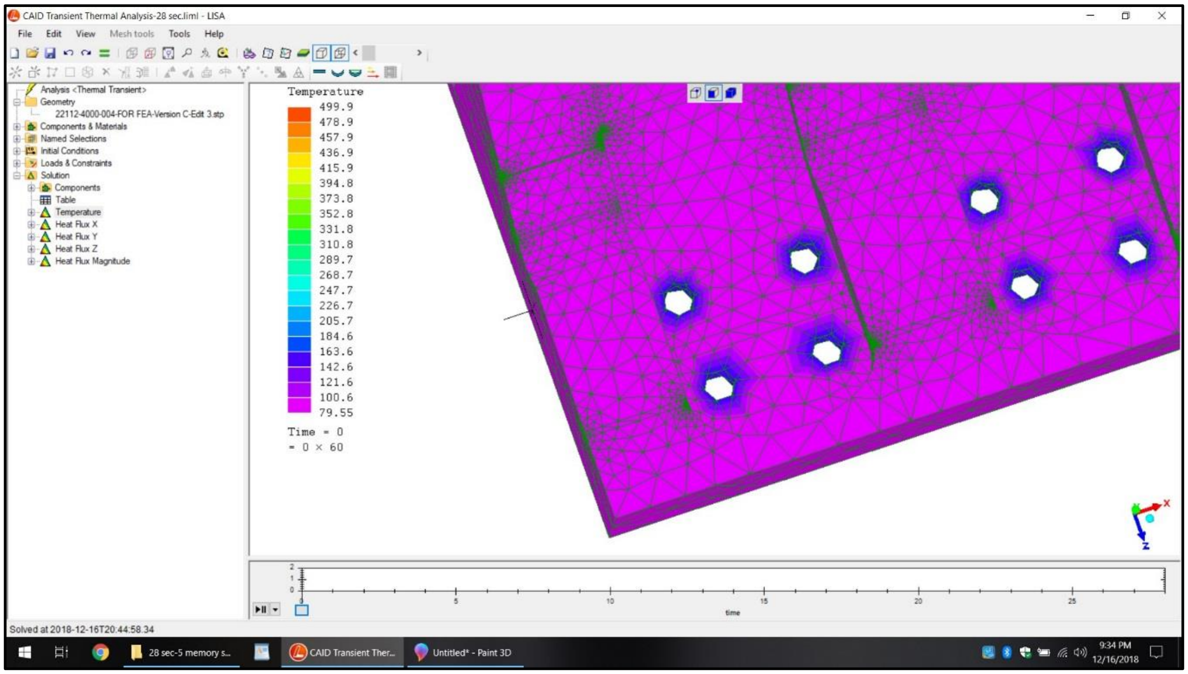
This FEA is for the current system process with the Lower Product Platen at a 159°F (average) at operator product removal station.

<u>**FEA Transient Sample 1**</u>: (No heatsinks added)

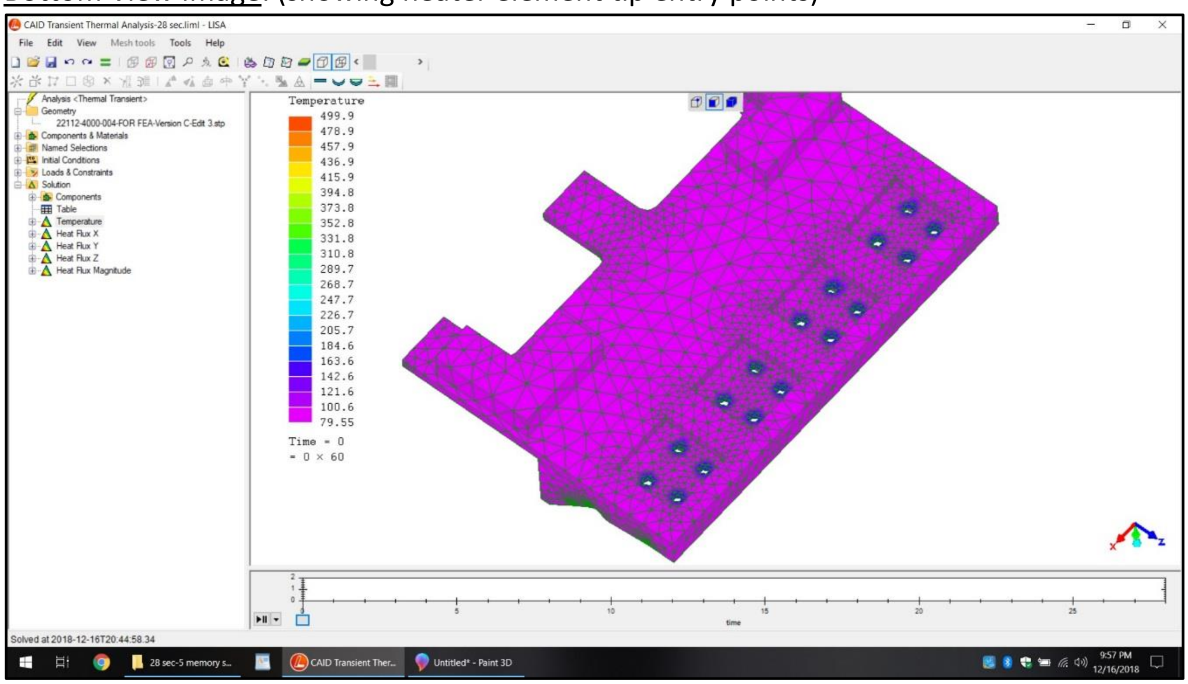
- (1 second) Start of cycle with prior cooled product platens immediately before heaters engage. Some residual thermal energy (from the previous cycle) still exists around holes:

<u>Top View Images</u>: (showing product holding pockets)





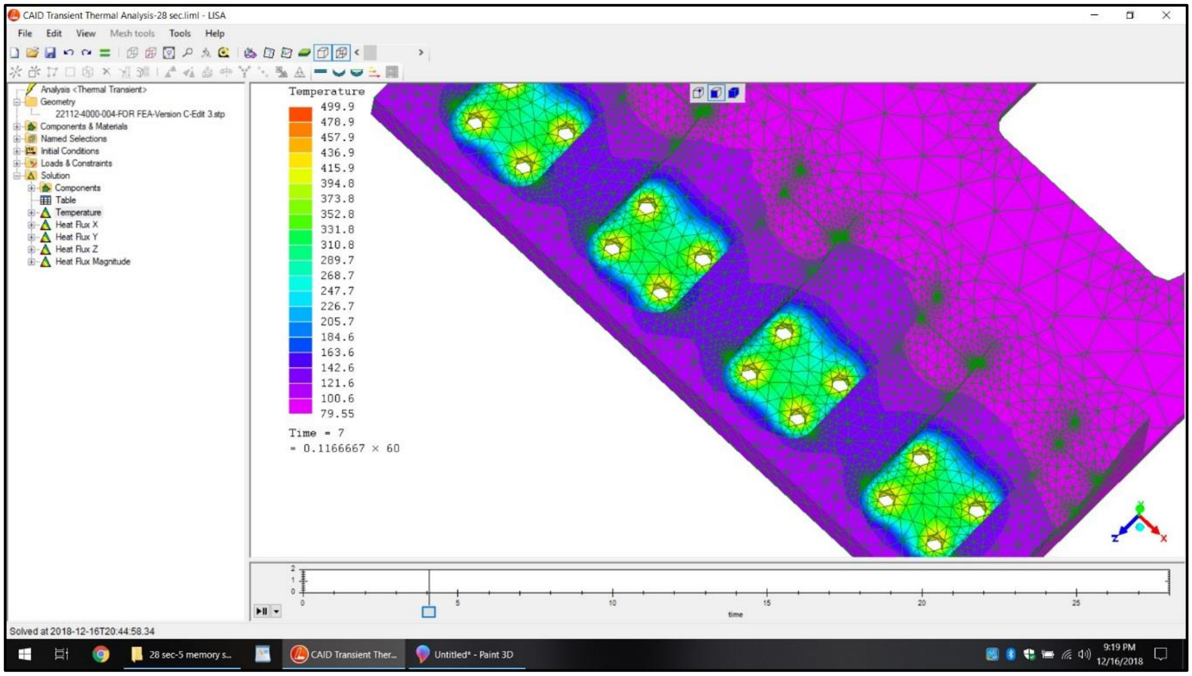
Bottom View Image: (showing heater element tip entry points)

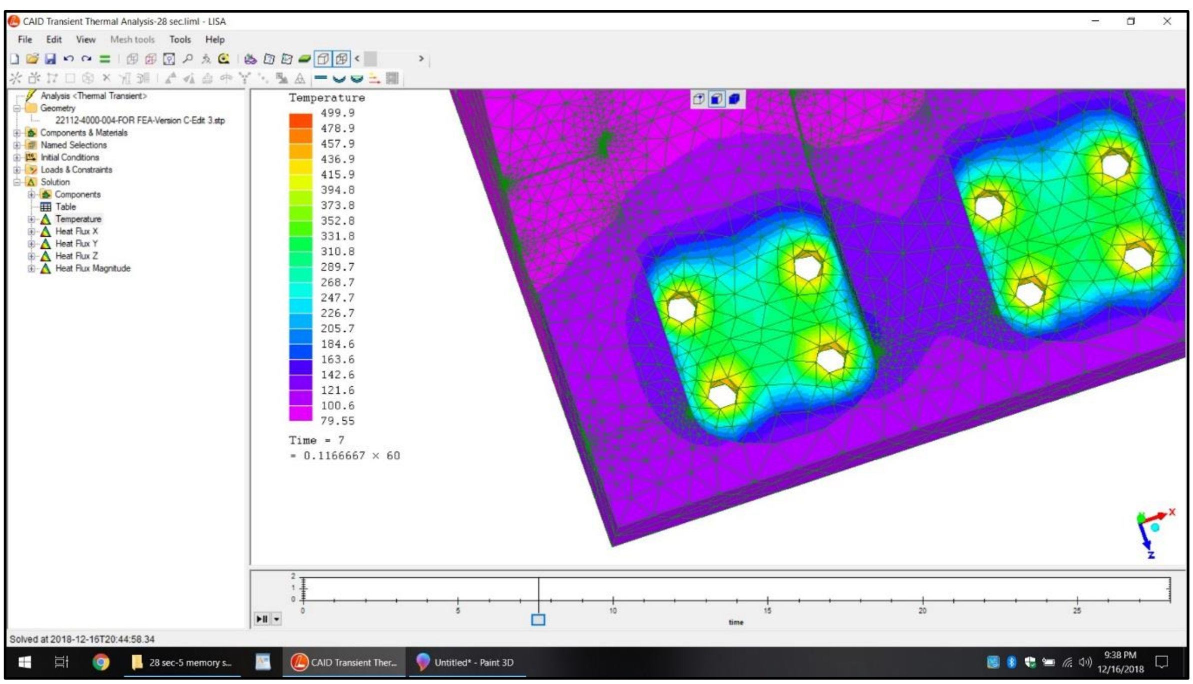


<u>FEA Transient Sample 2</u>:

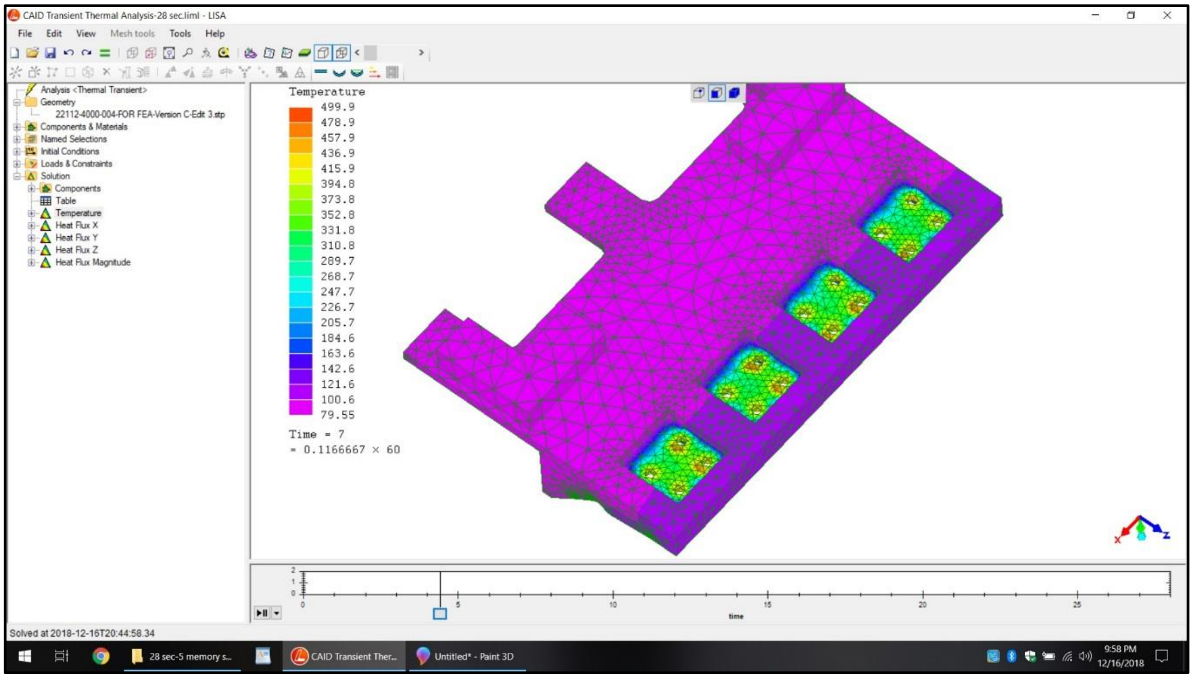
- (12 seconds) Heater platens engaged for thermal welding. Cooling air OFF:

<u>Top View Images</u>: (showing product holding pockets)





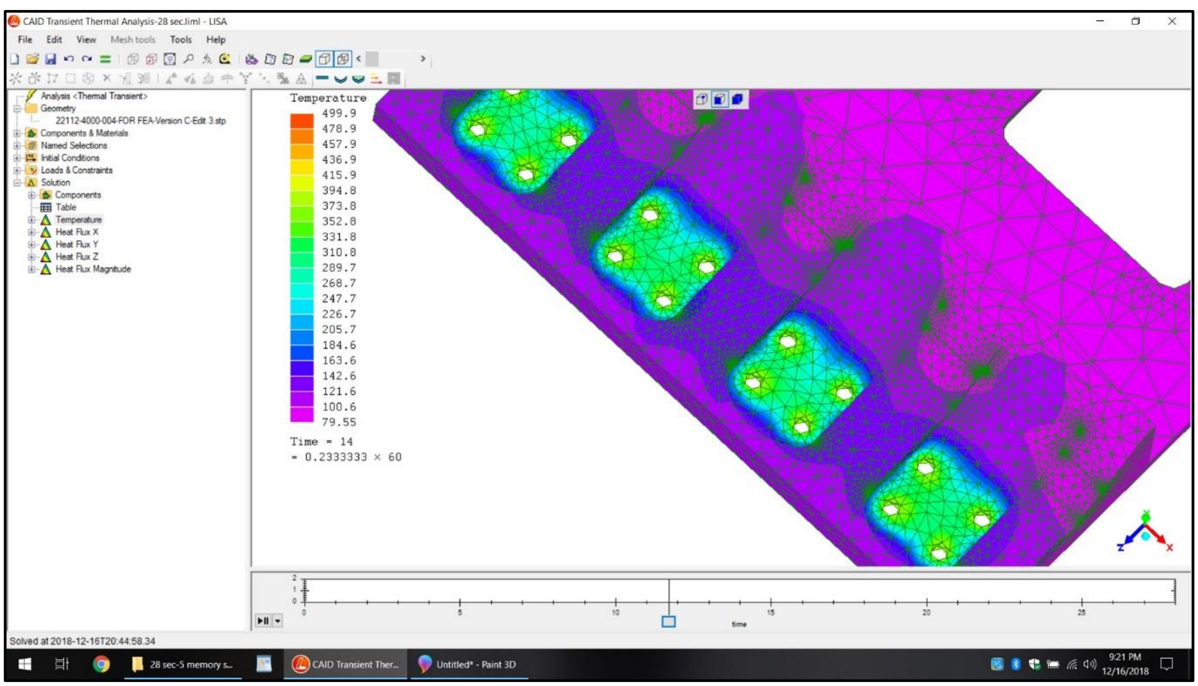
Bottom View Image: (showing heater element tip entry points)

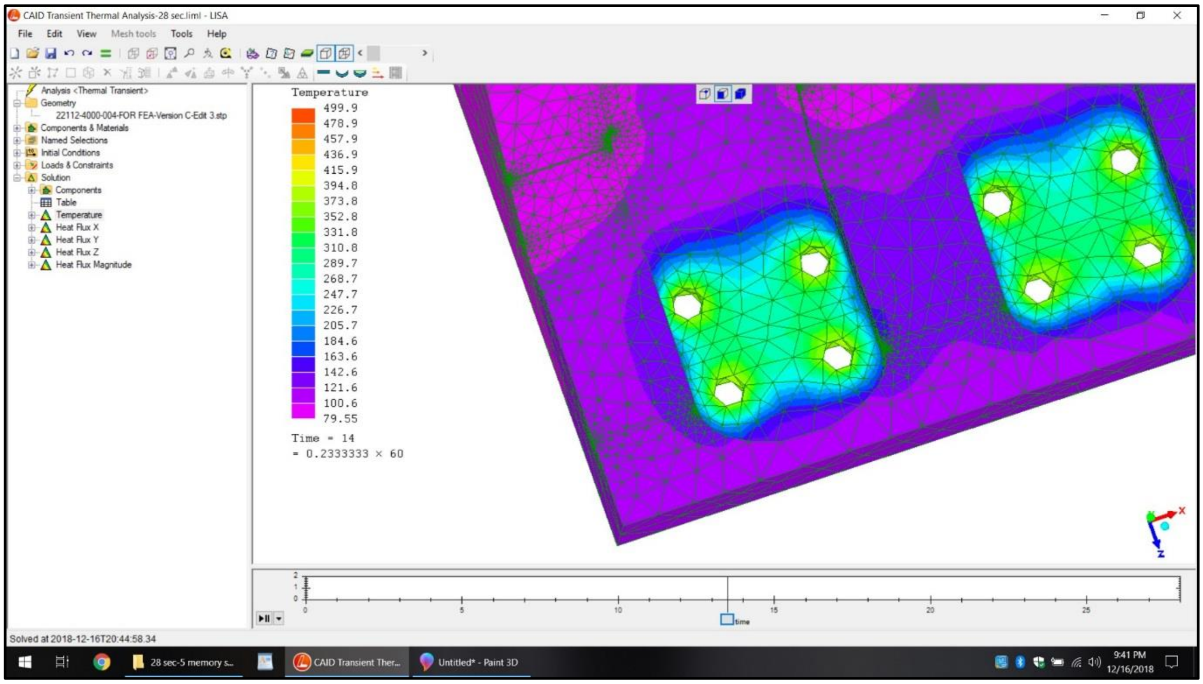


FEA Transient Sample 3:

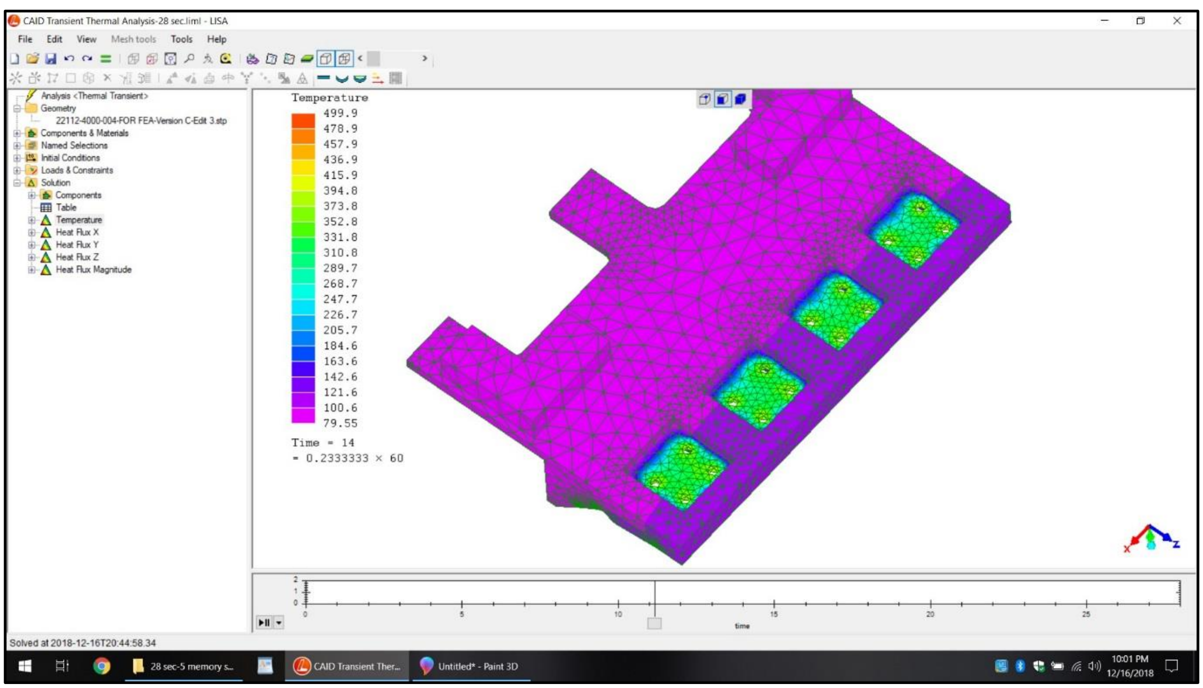
■ (5 seconds) Heater platens engaged for thermal welding. Cooling air ON:

Top View Images: (showing product holding pockets)





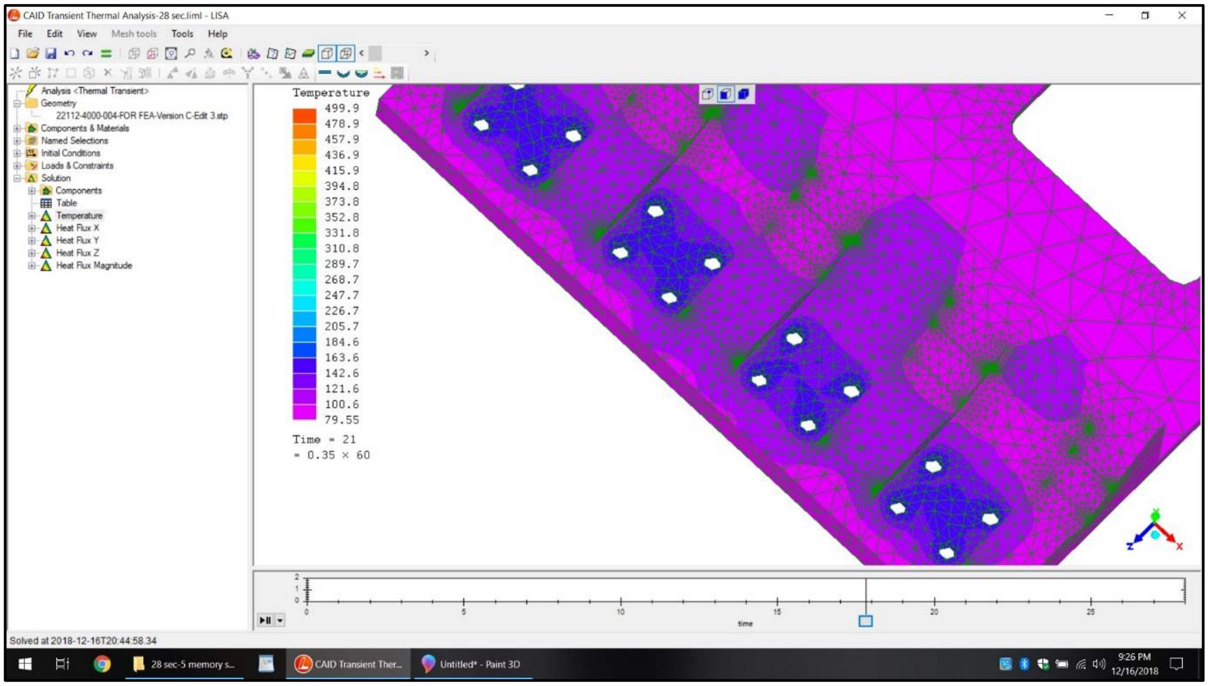
<u>Bottom View Image</u>: (showing heater element tip entry points)

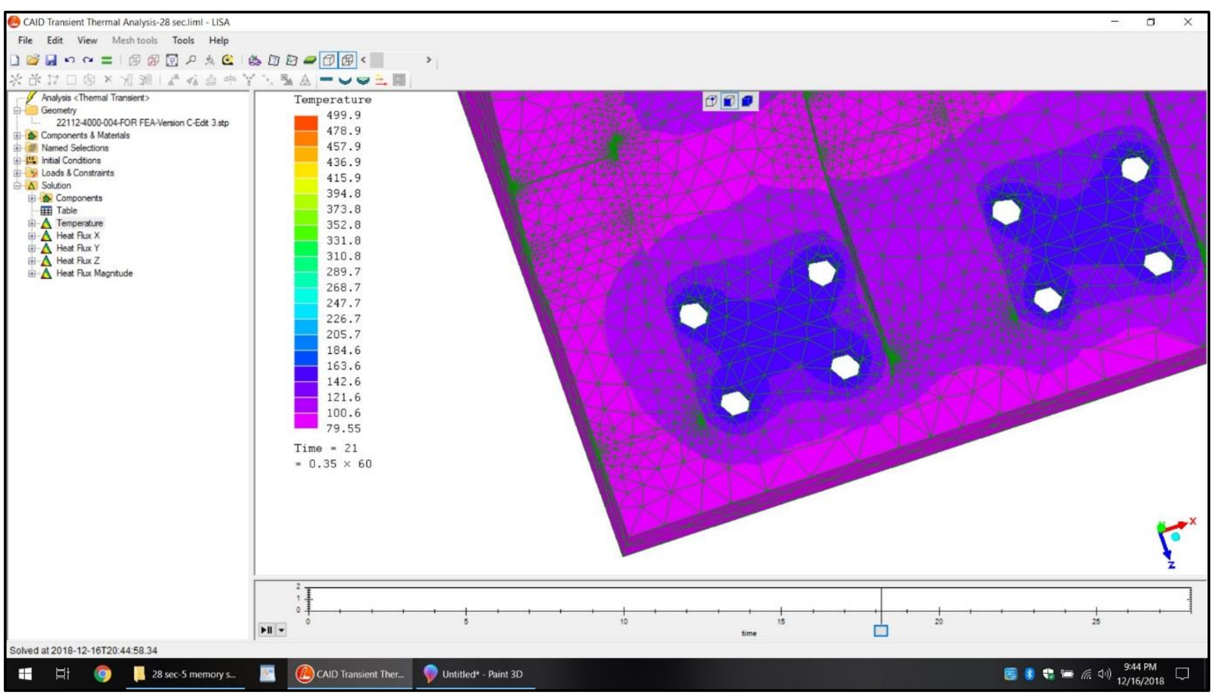


<u>FEA Transient Sample 4</u>:

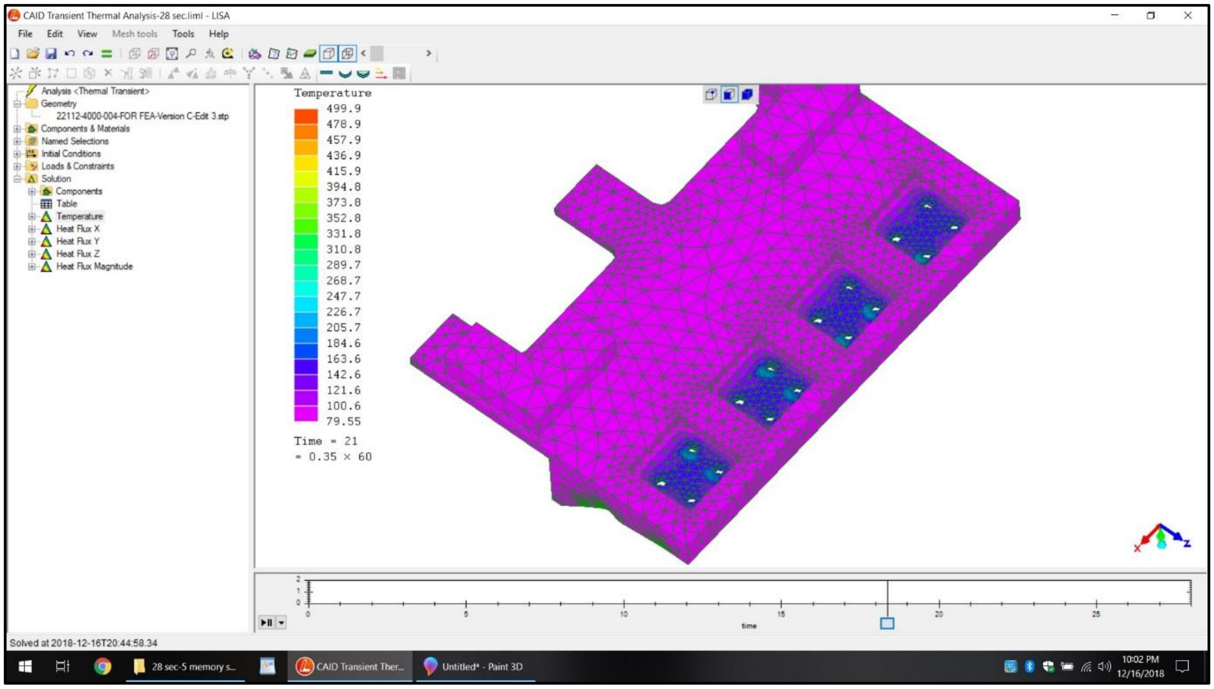
■ (8 seconds) Heaters disengage. Cooling thermal losses begin with Lower Platen and product. Both Lower Product Platens retract.

<u>Top View Images</u>: (showing product holding pockets)





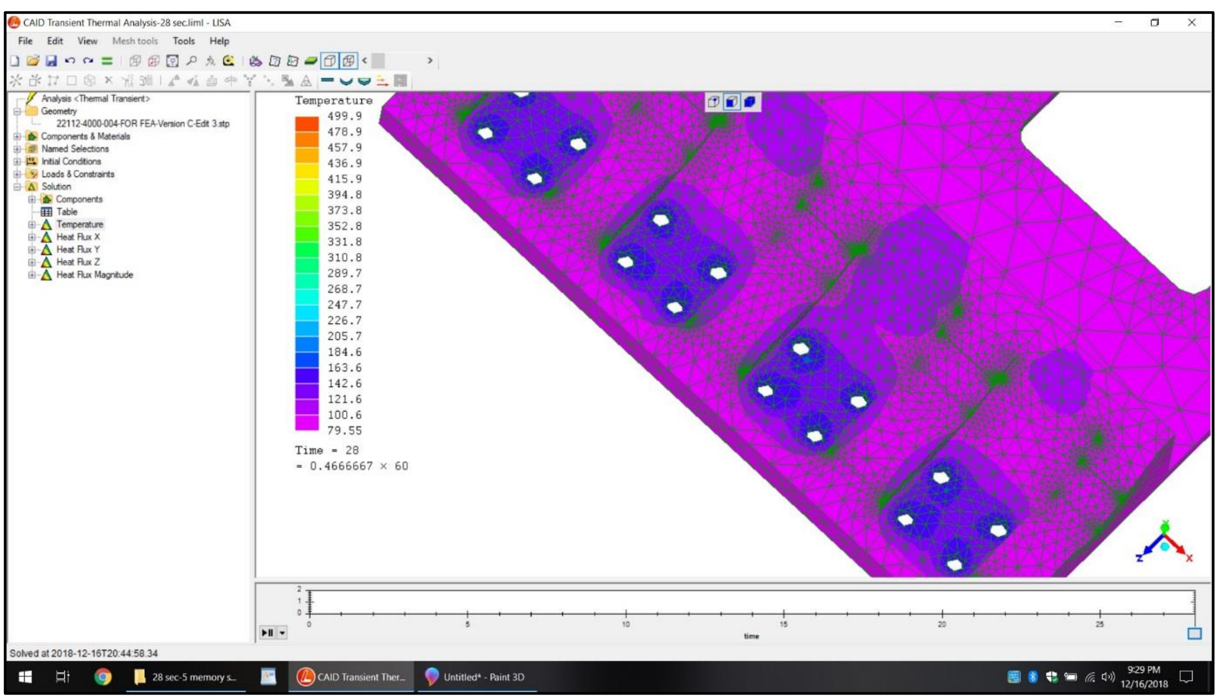
Bottom View Image: (showing heater element tip entry points)

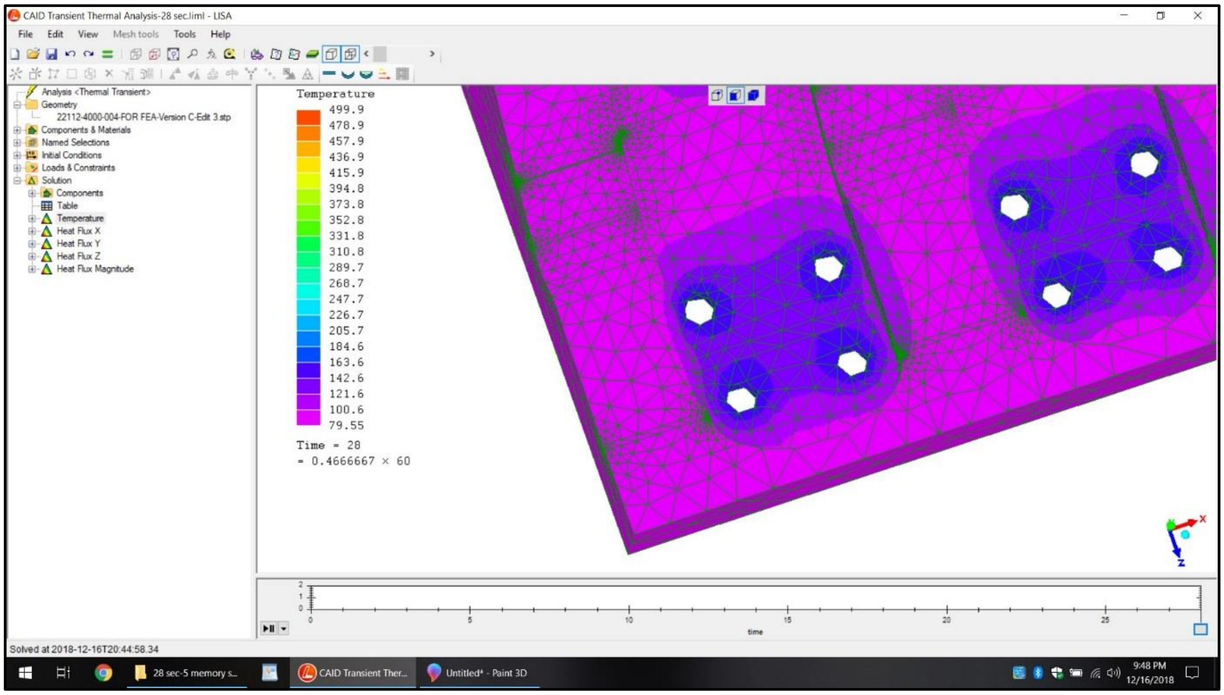


FEA Transient Sample 5:

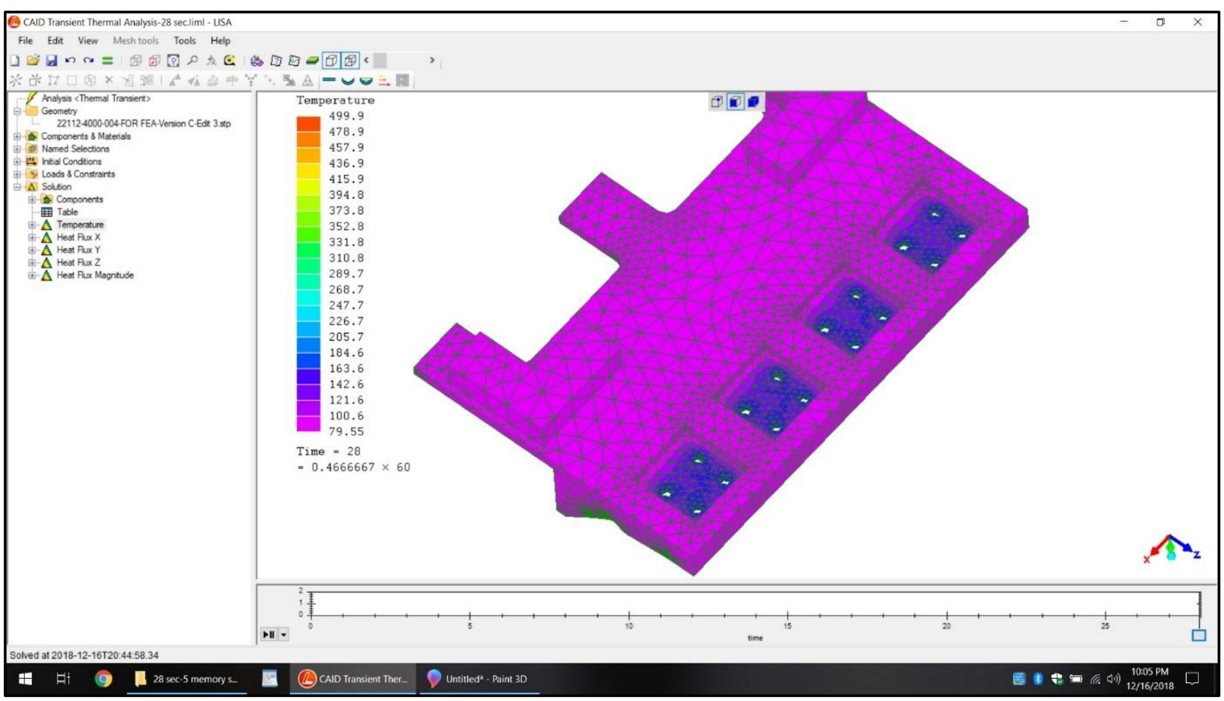
■ (2 seconds) Heaters disengaged. Additional ambient cooling thermal losses occur with Lower Platens and product exiting the system. Cycle ends.

Top View Images: (showing product holding pockets)



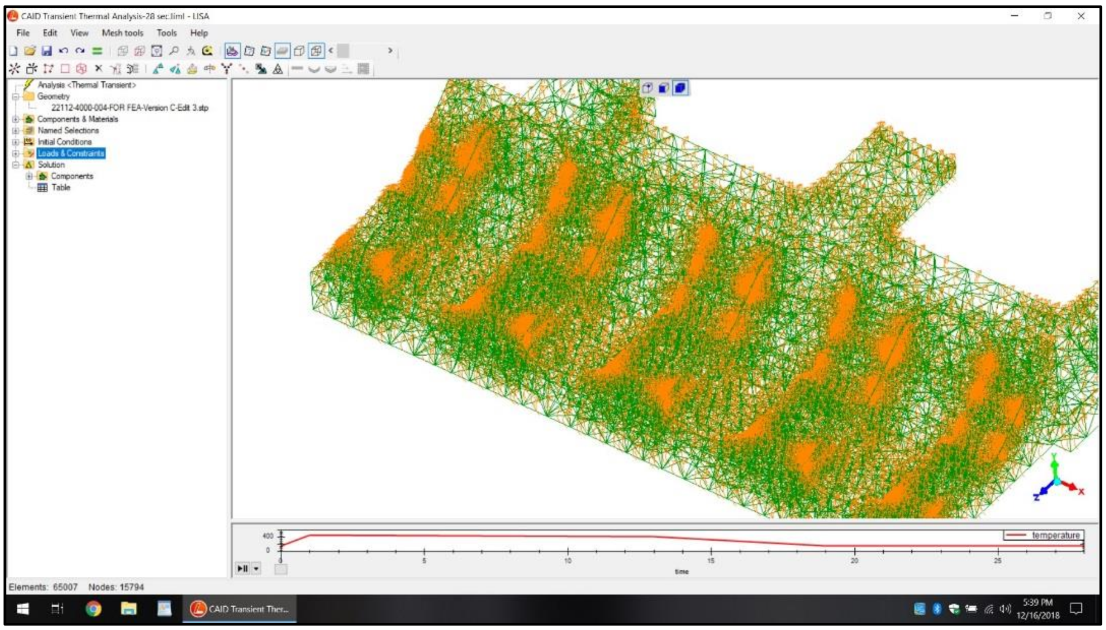


Bottom View Image: (showing heater element tip entry points)



Conclusions: The FEA heat transfer and temperature distribution gradient appear to be valid based on the available data and is very close to the empirical temperature readings shown earlier in this report. The thermal conductivity properties of each composite material were included in the analysis. Based on these FEA results, this analysis model can be used as a baseline to make corrective design decisions.

All heat transfer external boundary conditions and heat sinks were carefully defined (See image below showing each boundary condition (orange vectors)). There were no errors in the mesh generation and the FEA solver processing.



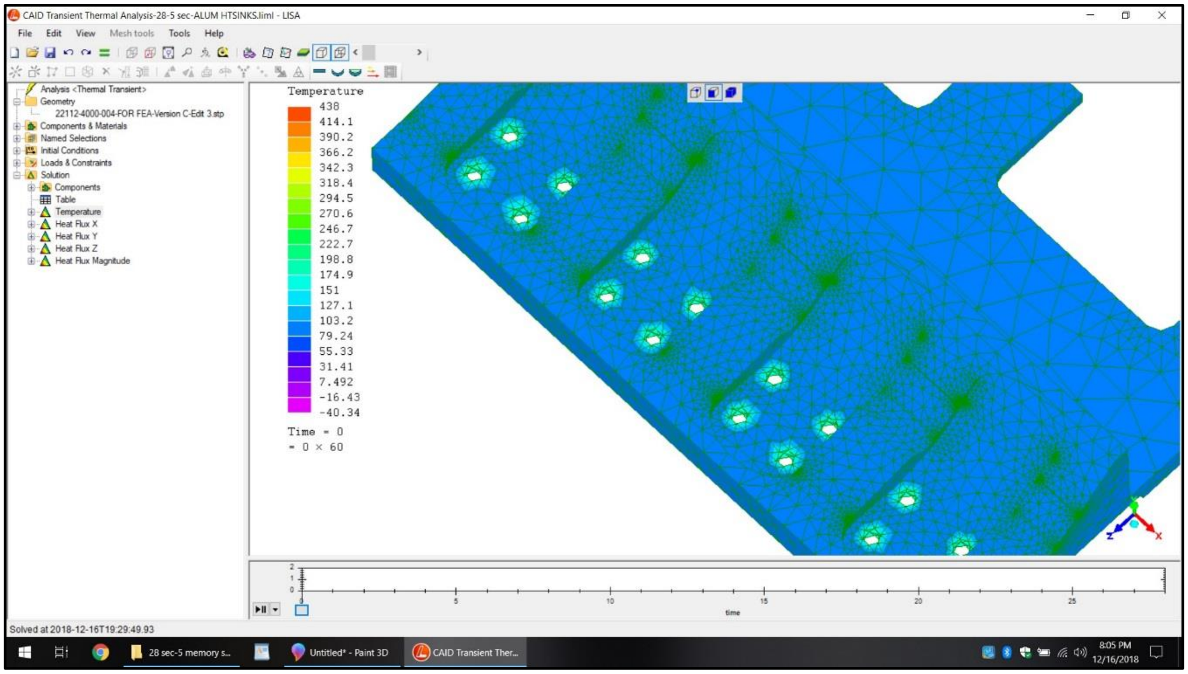
8.0 FEA Solution Step 3-Analysis Results: (3D Transient Thermal)

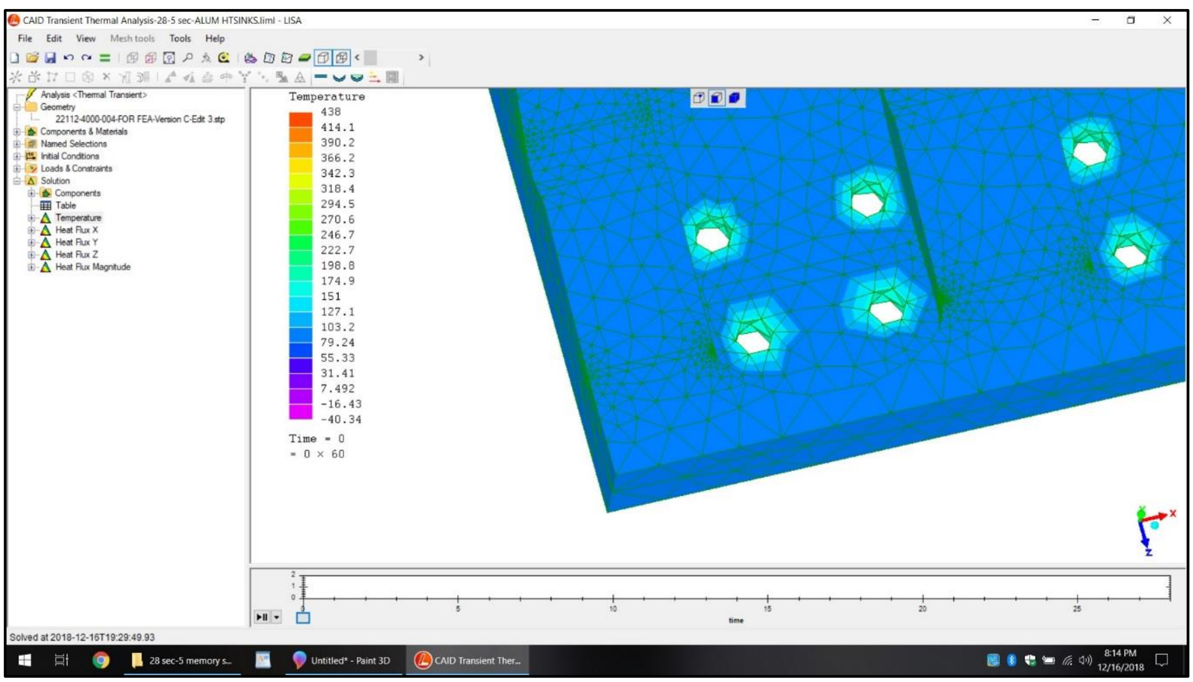
This FEA is for the current system process with aluminum heatsinks added to the underside machined pockets in the Lower Product Platens.

FEA Transient Sample 1: (with aluminum heatsinks)

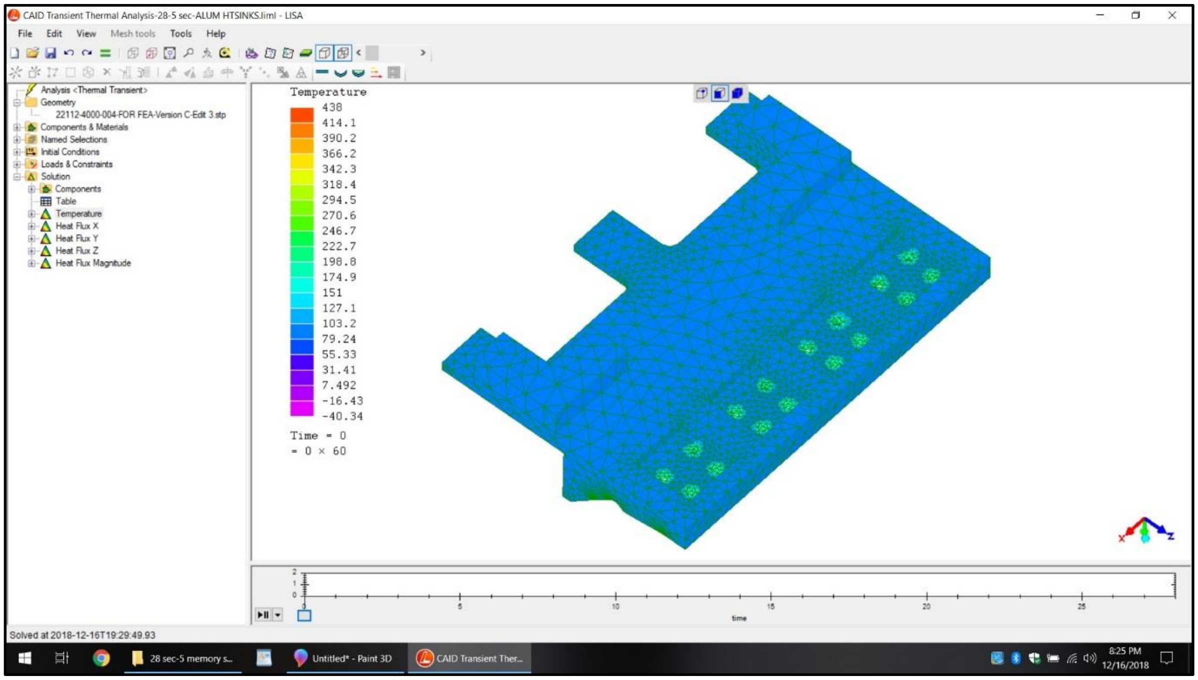
■ (1 second) Start of cycle with prior cooled product platens immediately before heaters engage. Some residual thermal energy (from the previous cycle) still exists around the holes:

<u>Top View Images</u>: (showing product holding pockets)





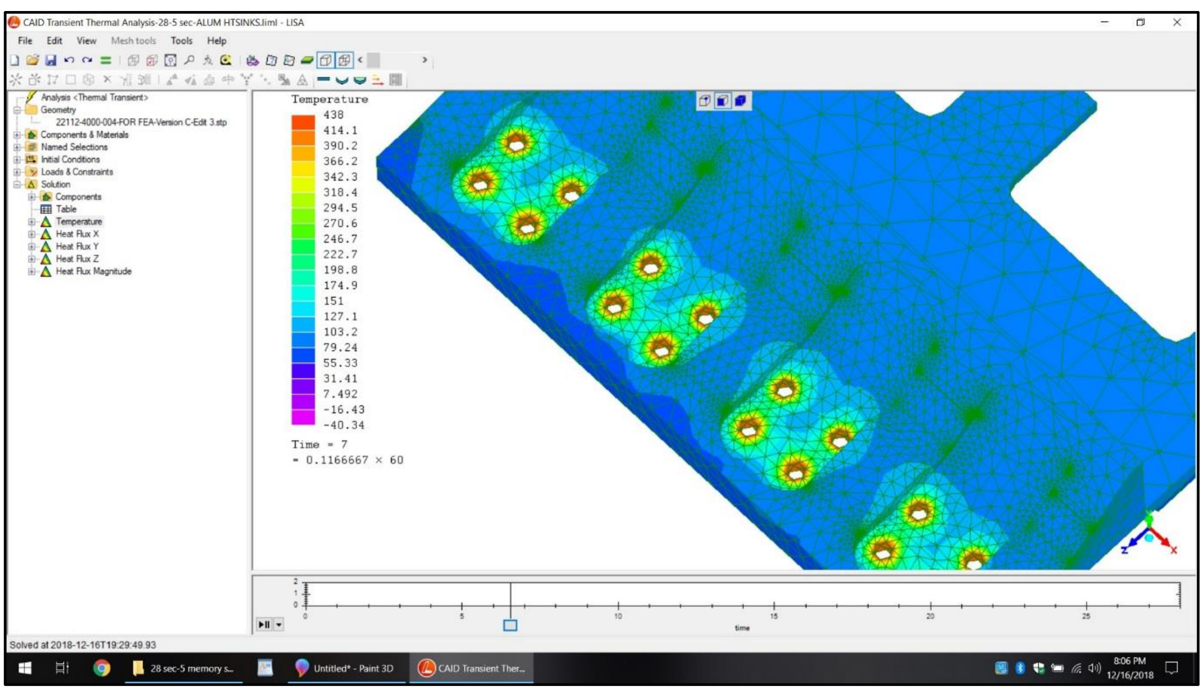
Bottom View Image: (showing heater element tip entry points)

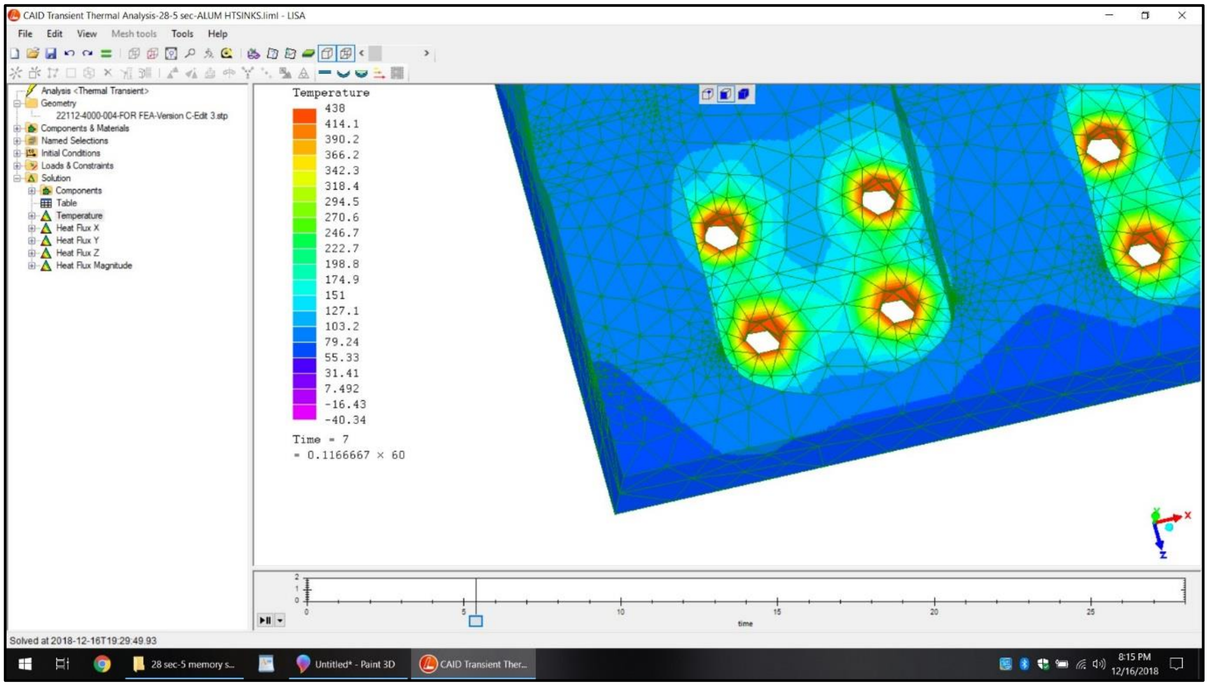


FEA Transient Sample 2:

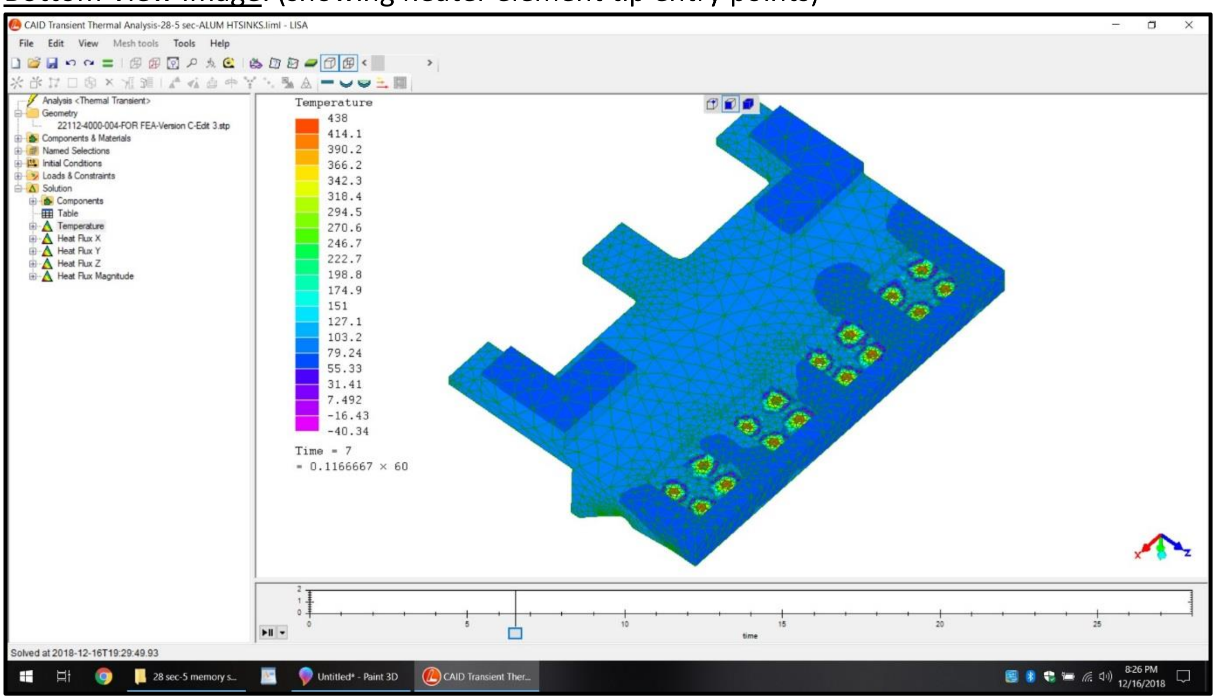
- (12 seconds) Heater platens engaged for thermal welding. Cooling air OFF:

Top View Images: (showing product holding pockets)





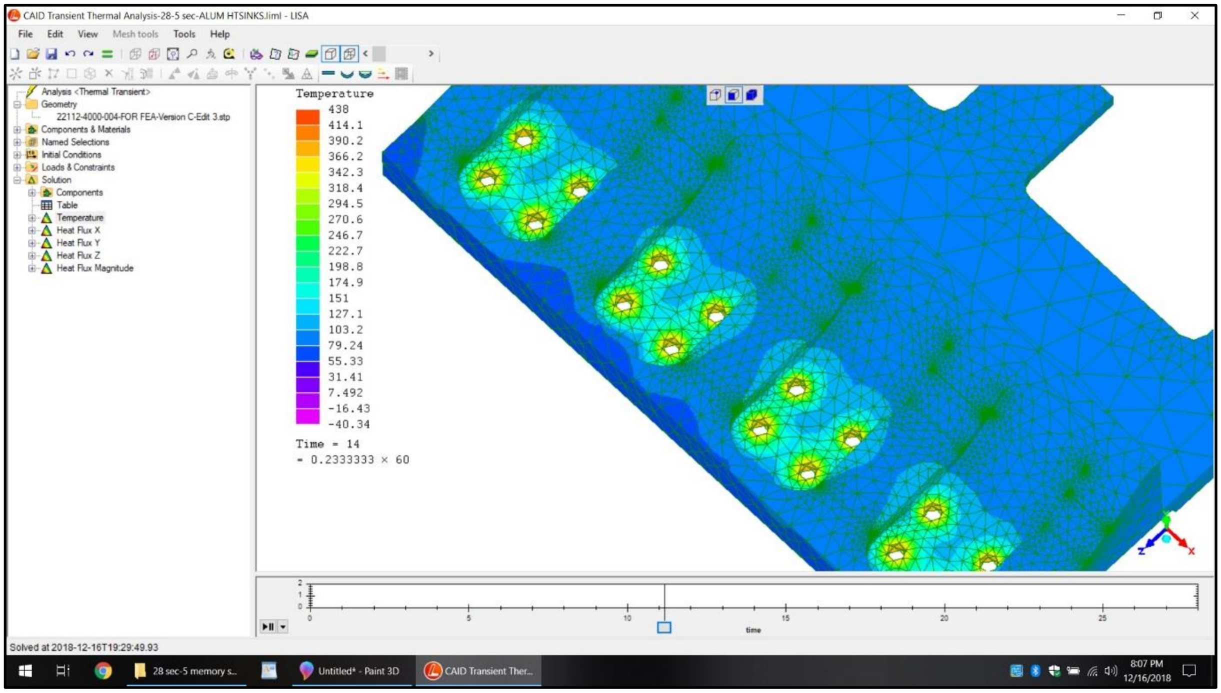
<u>Bottom View Image</u>: (showing heater element tip entry points)

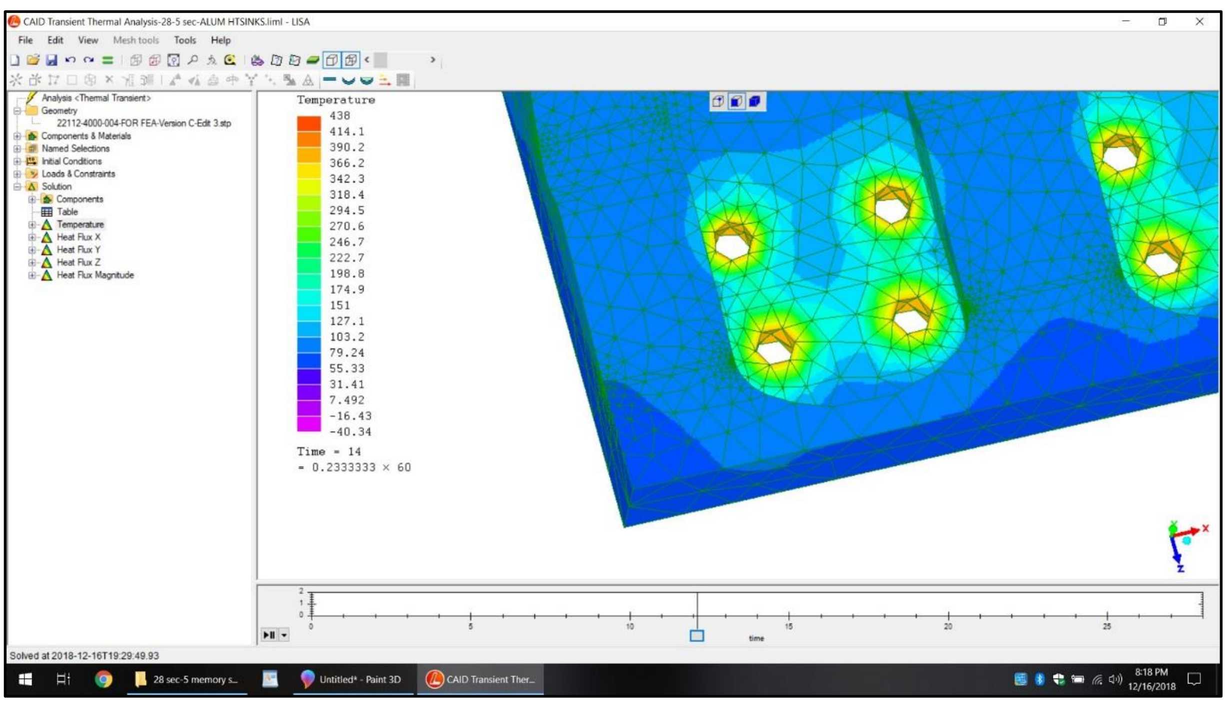


FEA Transient Sample 3:

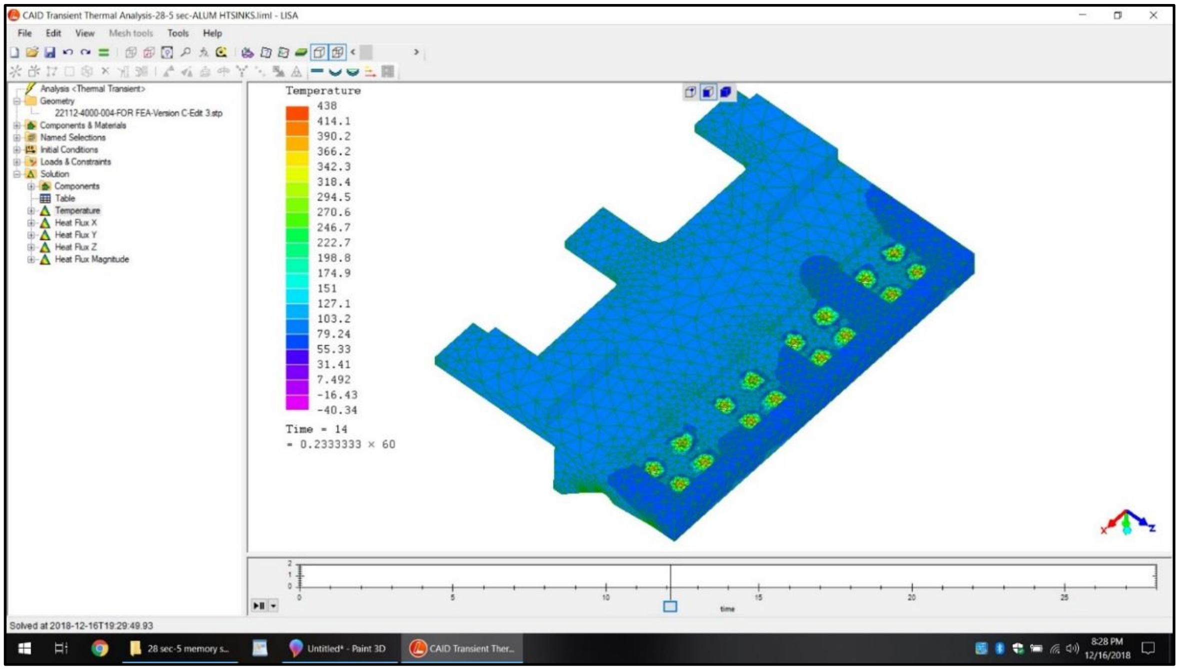
- (5 seconds) Heater platens engaged for thermal welding. Cooling air ON:

Top View Images: (showing product holding pockets)





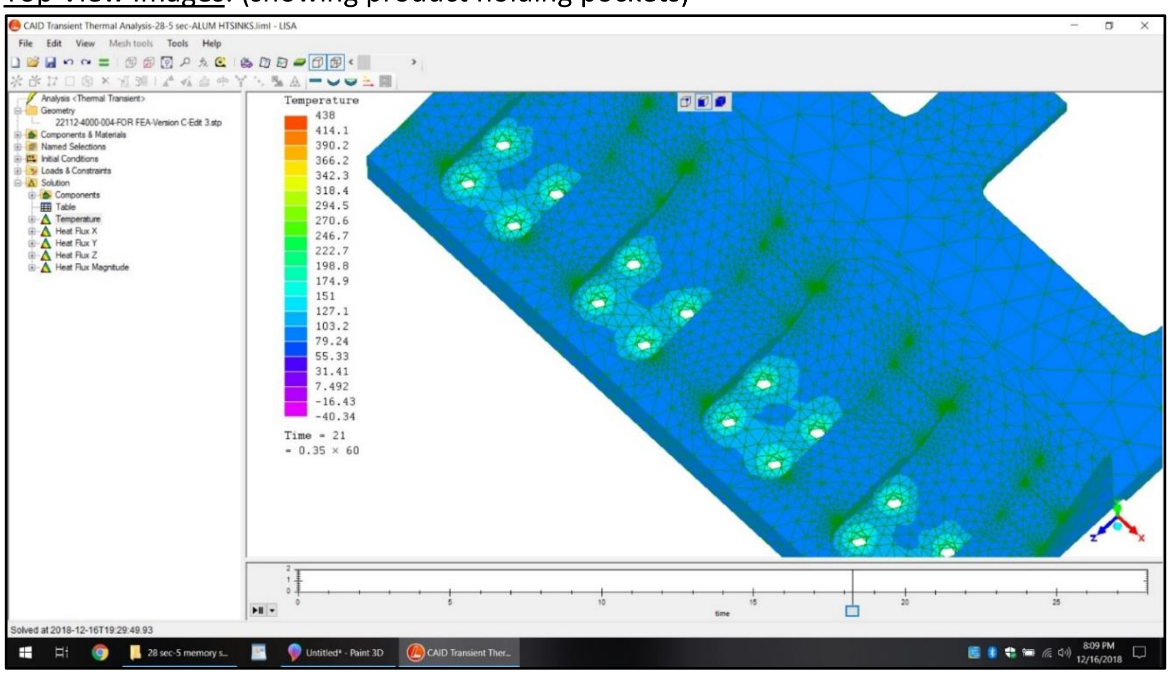
Bottom View Image: (showing heater element tip entry points)

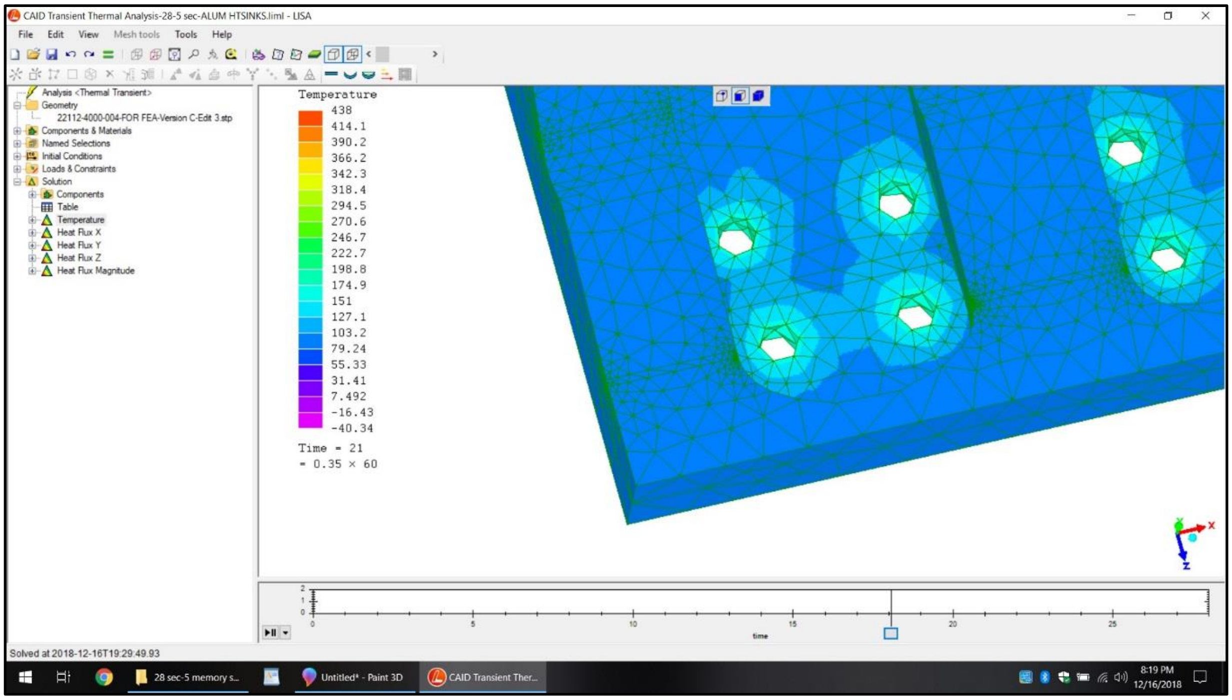


FEA Transient Sample 4:

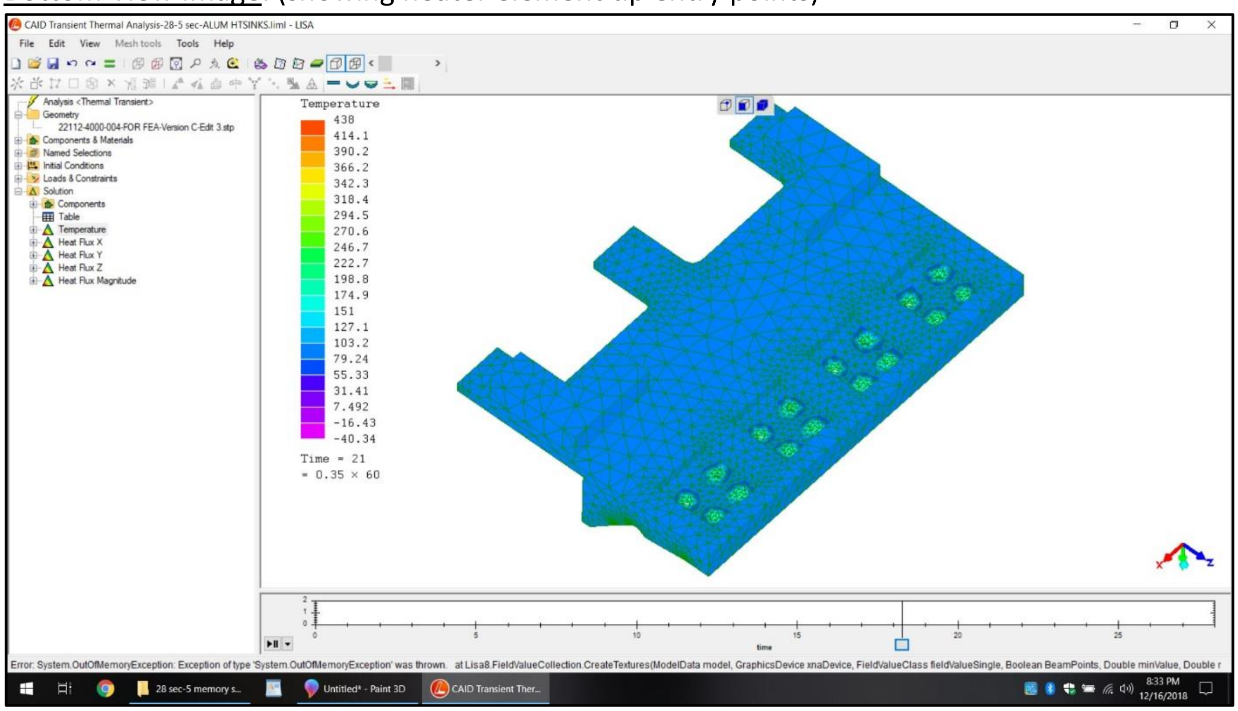
■ (8 seconds) Heaters disengage. Cooling thermal losses begin with Lower Platen and product. Both Lower Product Platens retract.

Top View Images: (showing product holding pockets)





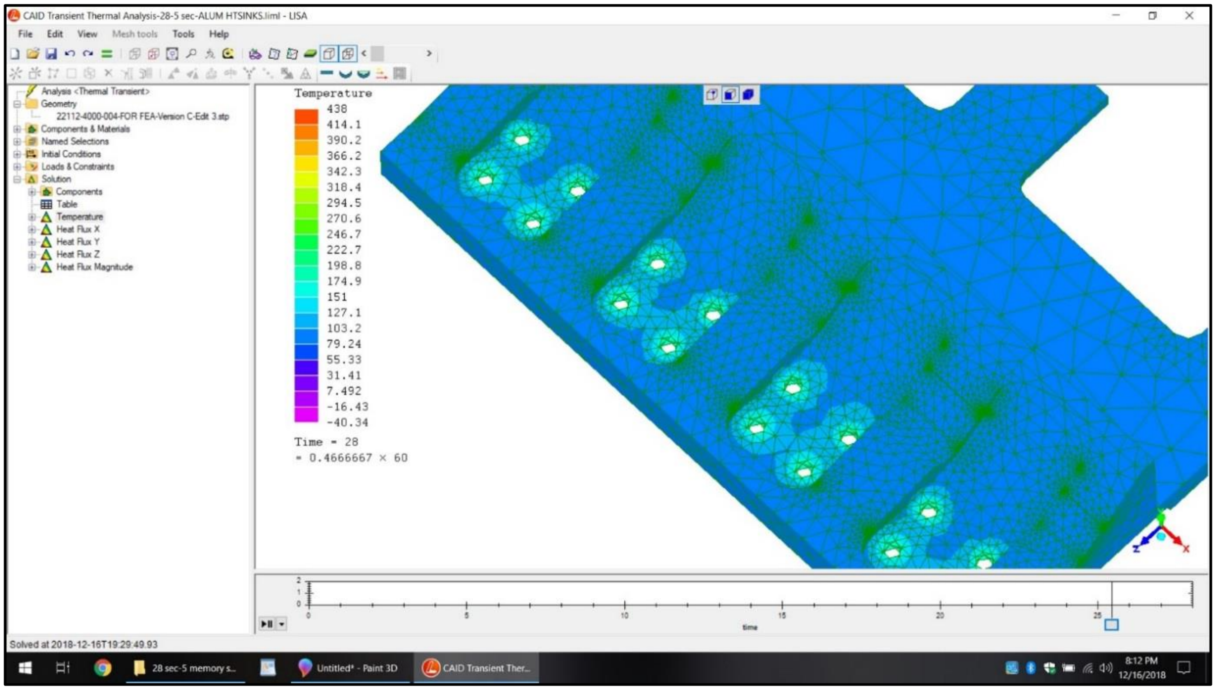
<u>Bottom View Image</u>: (showing heater element tip entry points)

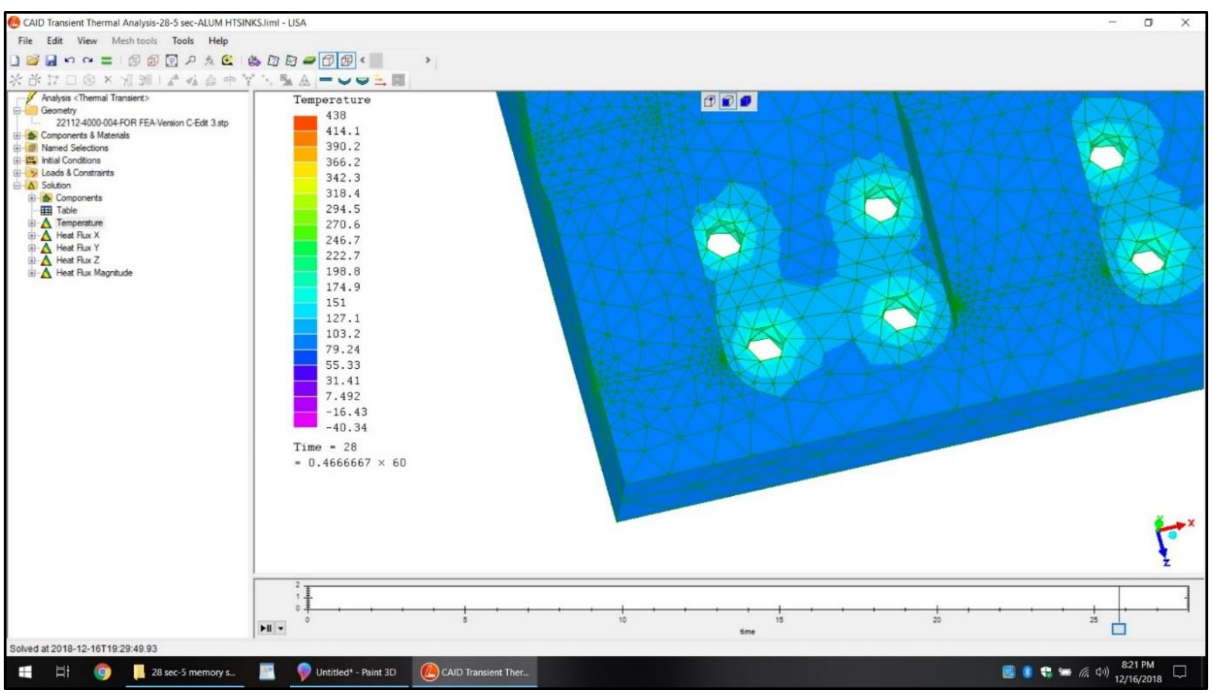


<u>FEA Transient Sample 5</u>:

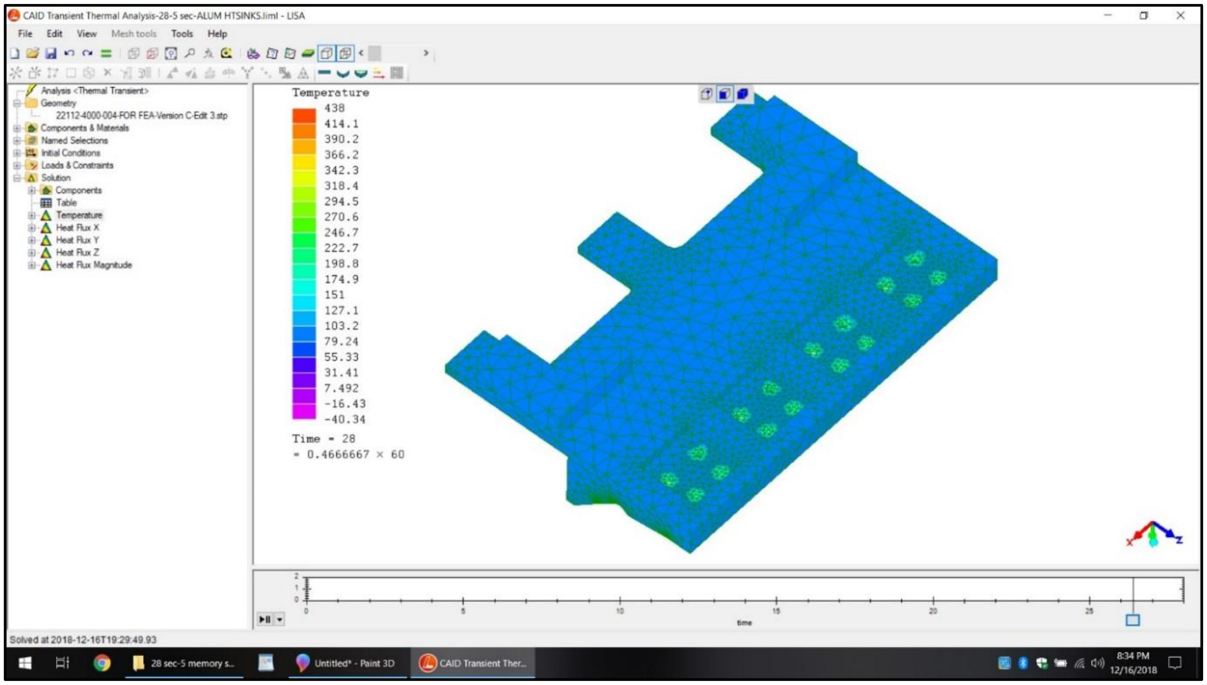
■ (2 seconds) Heaters disengaged. Additional ambient cooling thermal losses occur with Lower Platens and product exiting the system. Cycle ends.

<u>Top View Images</u>: (showing product holding pockets)



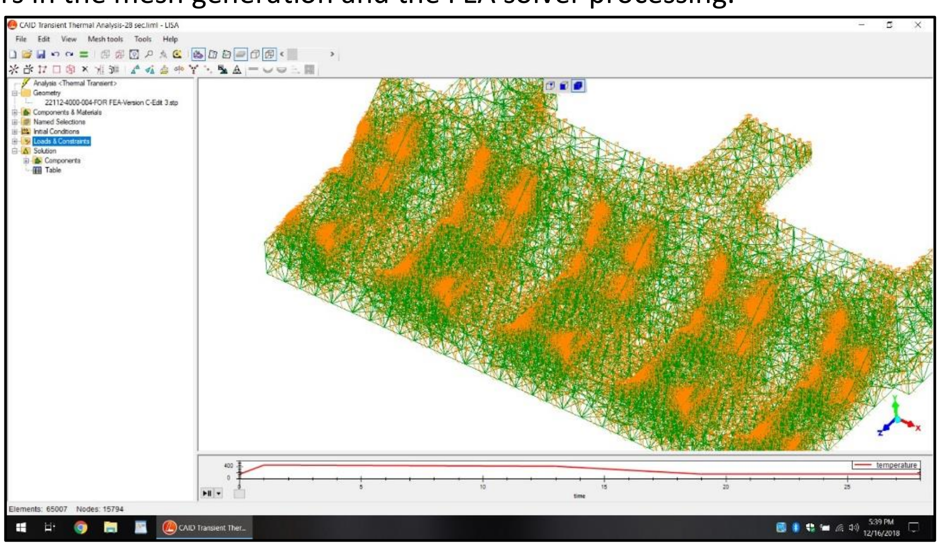


Bottom View Image: (showing heater element tip entry points)



Conclusions: The FEA heat transfer and temperature distribution gradient in the Lower Product Platen with the added aluminum heatsinks appear to be valid as they are within expected ranges. The thermal conductivity properties of each composite material were included in the analysis. Based on the FEA results of this analysis model the aluminum heatsinks appear to be reducing the thermal energy in the Lower Platen zone between the holes sufficiently to meet OSHA-ASTM safety guidelines for operator handling.

All heat transfer external boundary conditions and heat sinks were carefully defined (See image below showing each boundary condition (orange vectors)). There were no errors in the mesh generation and the FEA solver processing.



If the aluminum heatsinks do not create any process welding issues with the product, then they should be tested as a first pass corrective action. This FEA has demonstrated that the Lower Product Platen temperature distribution gradient can be redirected using aluminum heatsinks creating safe operator handling conditions.

9.0 FEA Model Solution Disclaimer:

This FEA Model Solution is meant to be a design tool to help guide the final design of the overall system. At best, this FEA Model Solution is a close approximation of the actual physical conditions occurring in the mechanical or process system. The accuracy of this analysis is only as accurate as the available data. It is impossible to include and accurately simulate in an FEA Model every physical factor or variable affecting the process. A liberal safety factor allowance must be incorporated in the application to minimize the adverse effects of these unknown variables and inaccuracies. Verification of the results must be validated by empirical testing

Therefore, R.J. Frey Technologies, nor their employees thereof, make any claim to the accuracy, warranty, nor assumes legal liability or responsibility for the usefulness of the information contained in this report. As stated previously, verification of the results must be validated by empirical testing.