Optimizing Composite Repair by Tailored Heat Sources

The Joint Advanced Materials and Structures Center of Excellence

Inverse/Optimal Repair of Composites

- Goal: To minimize set up time and assure temperature control of repair site
- Objective: To design heat sources that achieve an isothermal state in the repair zone
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- Approach: An Inverse Analysis using Finite Elements, Proper Orthogonal Decomposition, Sparse Grids and Bayesian Inference
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FAA Sponsored Project Information

- A. Emery, J. Eppler, J. Knuth, J. Smith and K. Johnson, UW
- E. Casterline, C. Mays, J. Lombard, Heatcon
  –
- Curtis Davies, David Westlund, FAA Technical Monitors
  –
- Heatcon and Boeing
  –

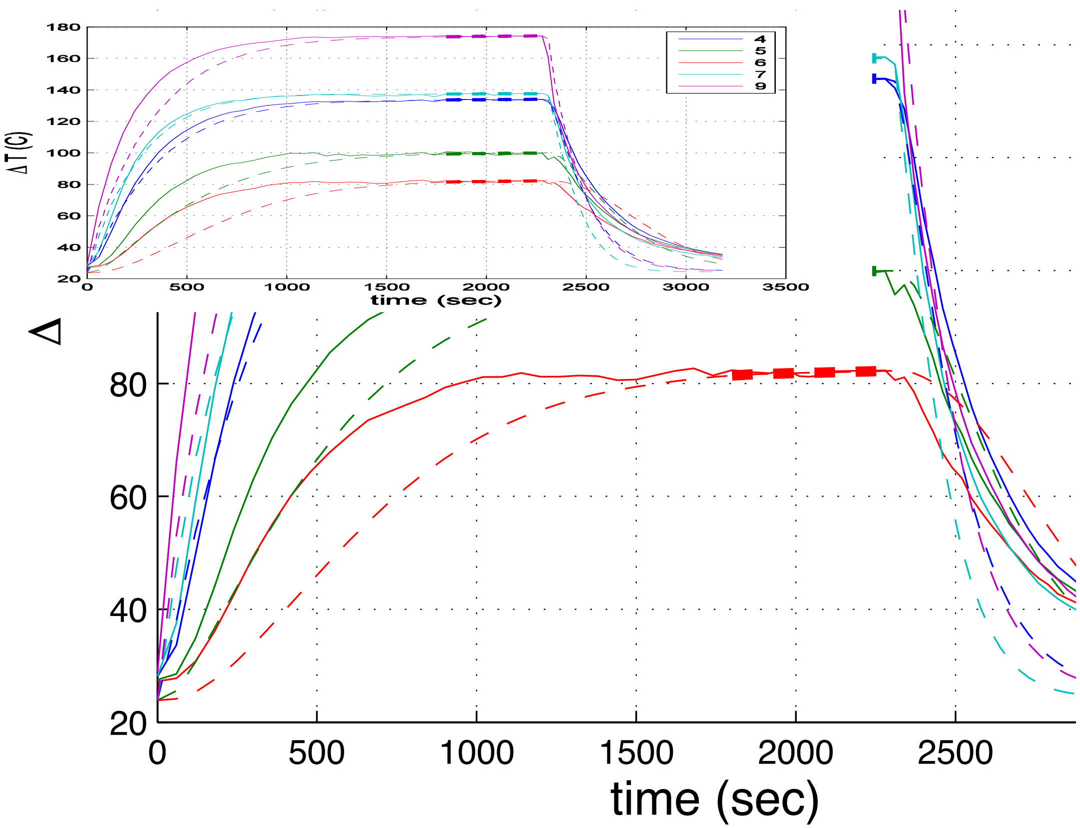
Goal

To specify the spatial distribution of heat flux
from a heating source (blanket)
to produce
a specified and constant temperature
throughout the cure zone

with a minimum of pre-repair testing

Model Simulation

Could the lack of agreement be caused by the surface TCs creating bridging (air layers) that affected the heat flow?



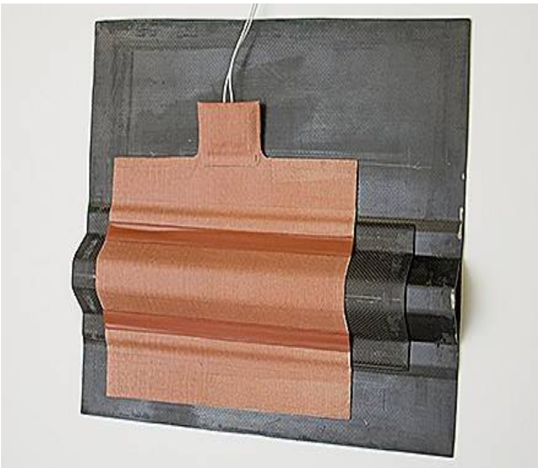
Notice that the model response is slower during heating and faster during cooling than the experiment but correct at steady state.

During the collection of additional data in run 7 the thermograms (IR camera pictures) suggested that the surface TCs were causing elevated blanket temperatures.

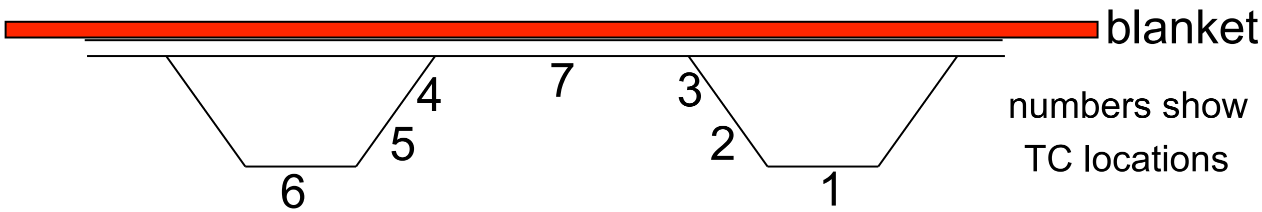
Questions about the temperatures needed to accurately simulate the experiment

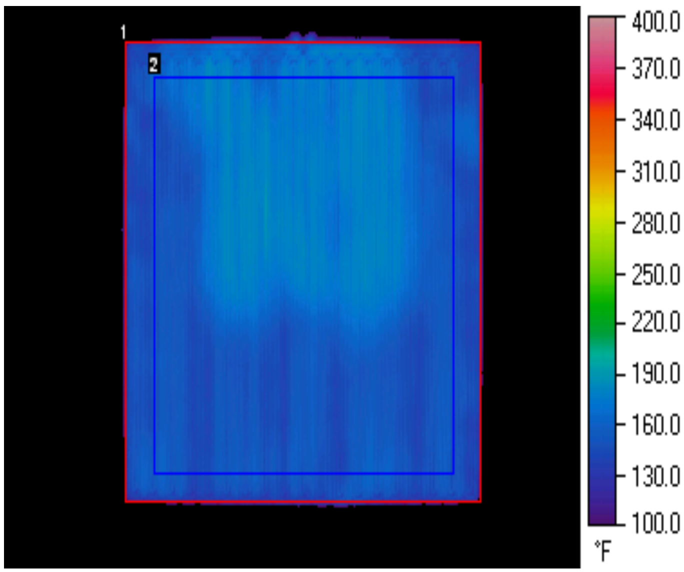
1. Are thermogram data (IR camera images) sufficient to estimate the heating required in a repair
2. Are surface mounted thermocouples of value
3. If surface TCs are used, how can the effect of the induced air gaps. be eliminated
4. Are transient measurements sufficient or must steady state data be gathered

A typical configuration is

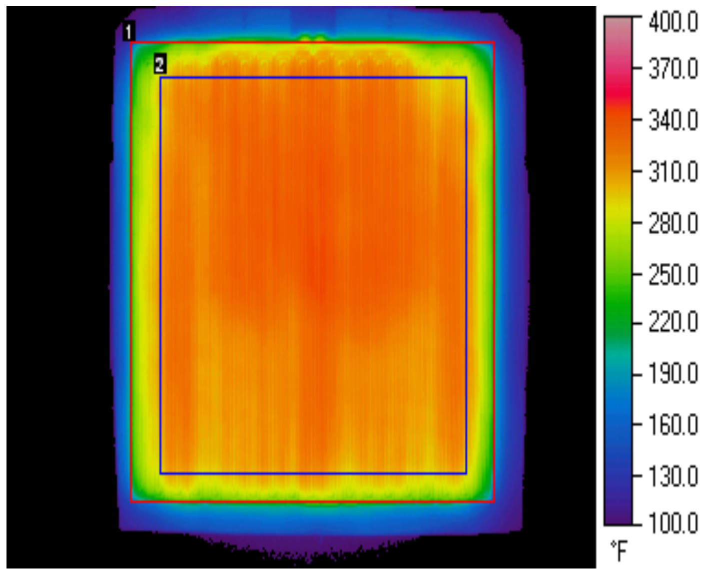


Previous Results



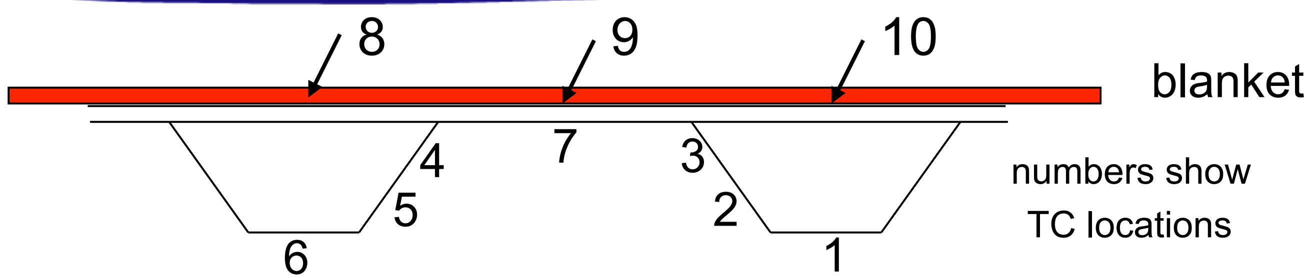


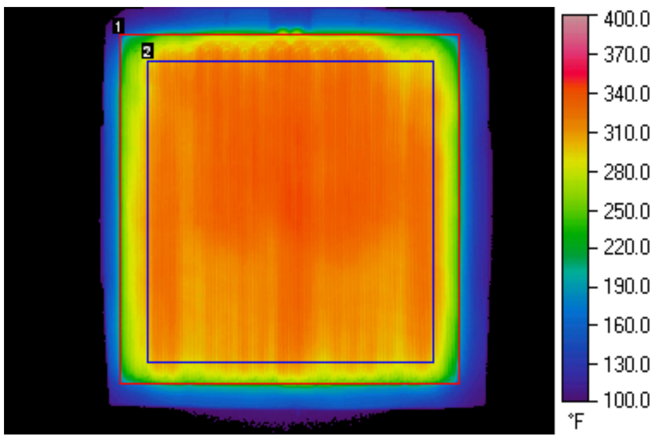
start of heating

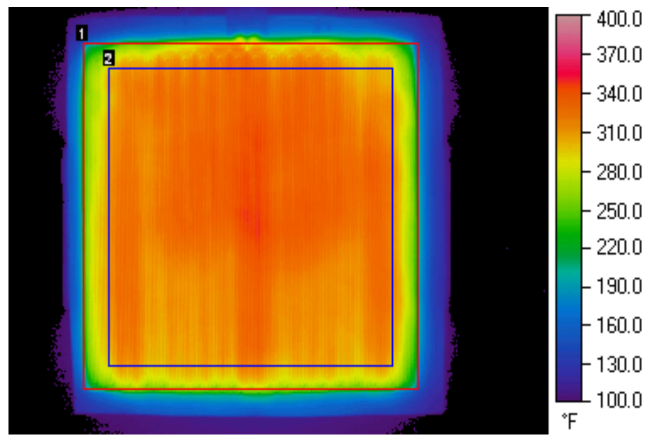


steady state

Previous Results





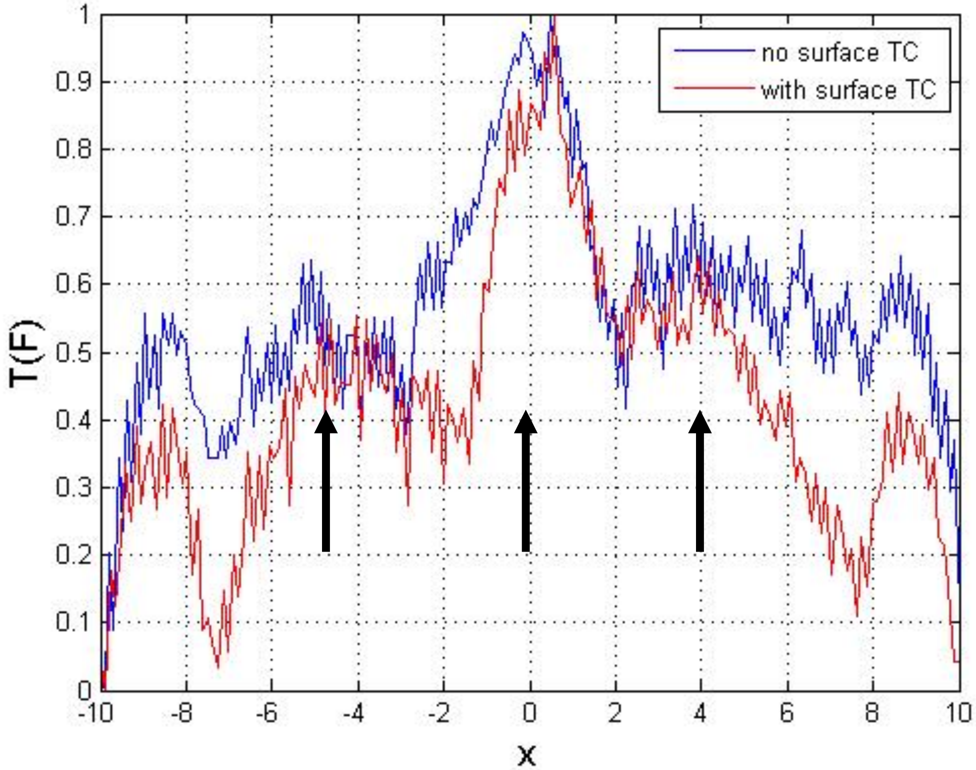


No significant difference to the eye

No surface TC

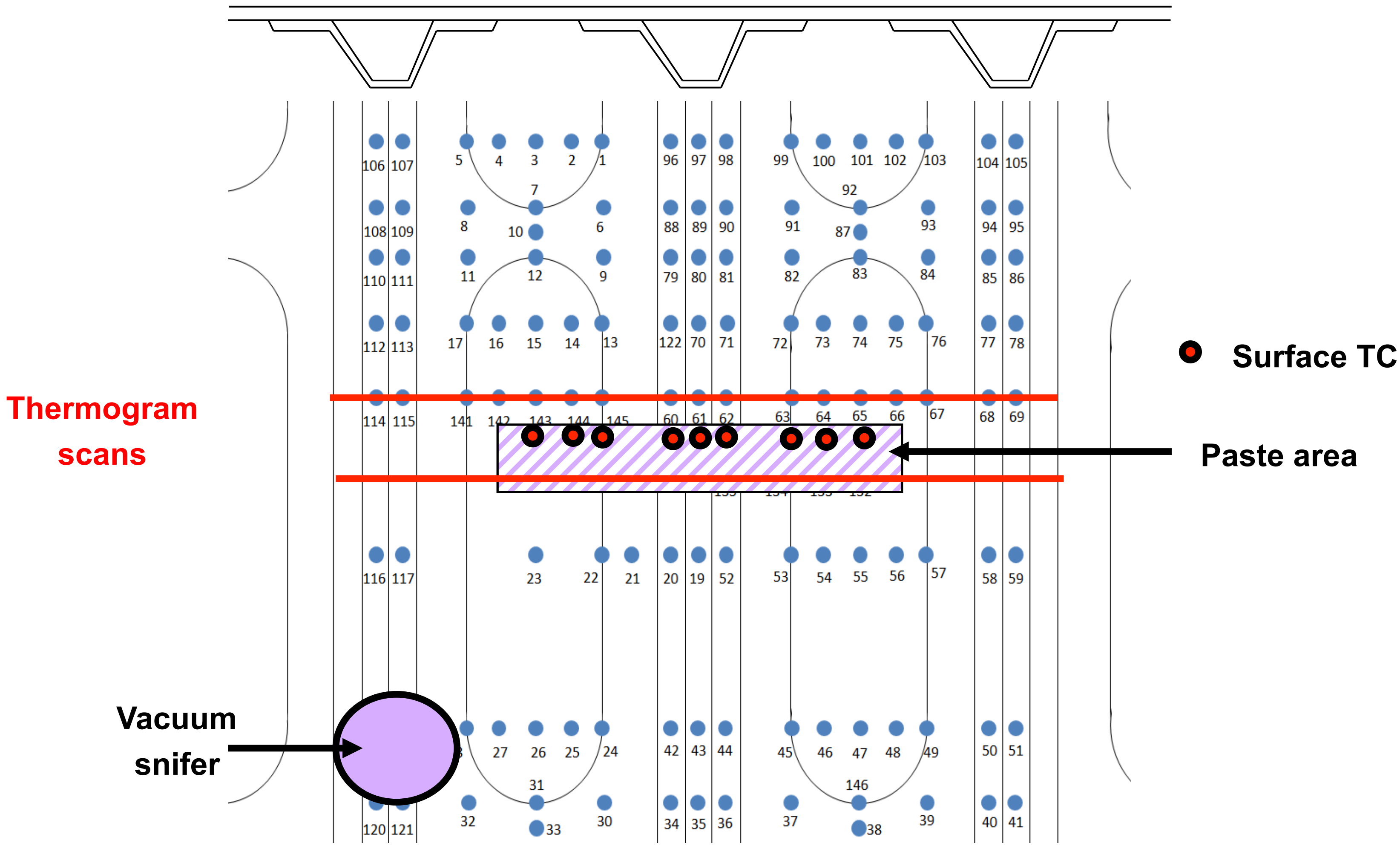
Surface TCs

Previous Results
Effect of Surface TCs



Normalized to 0 to 1

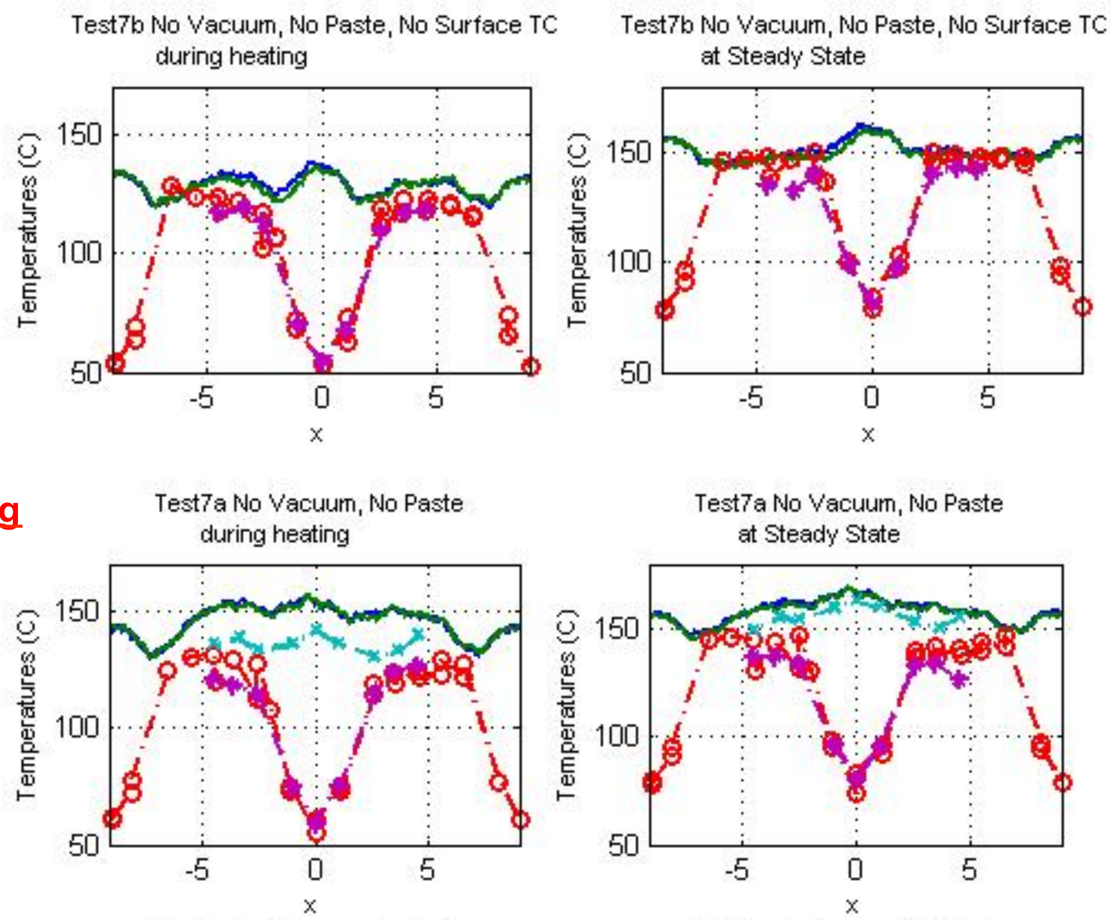
New Thermocouples embedded in the panel



Effect of Surface TCs

in Transients

Large and <u>dominating</u> effect on simulation

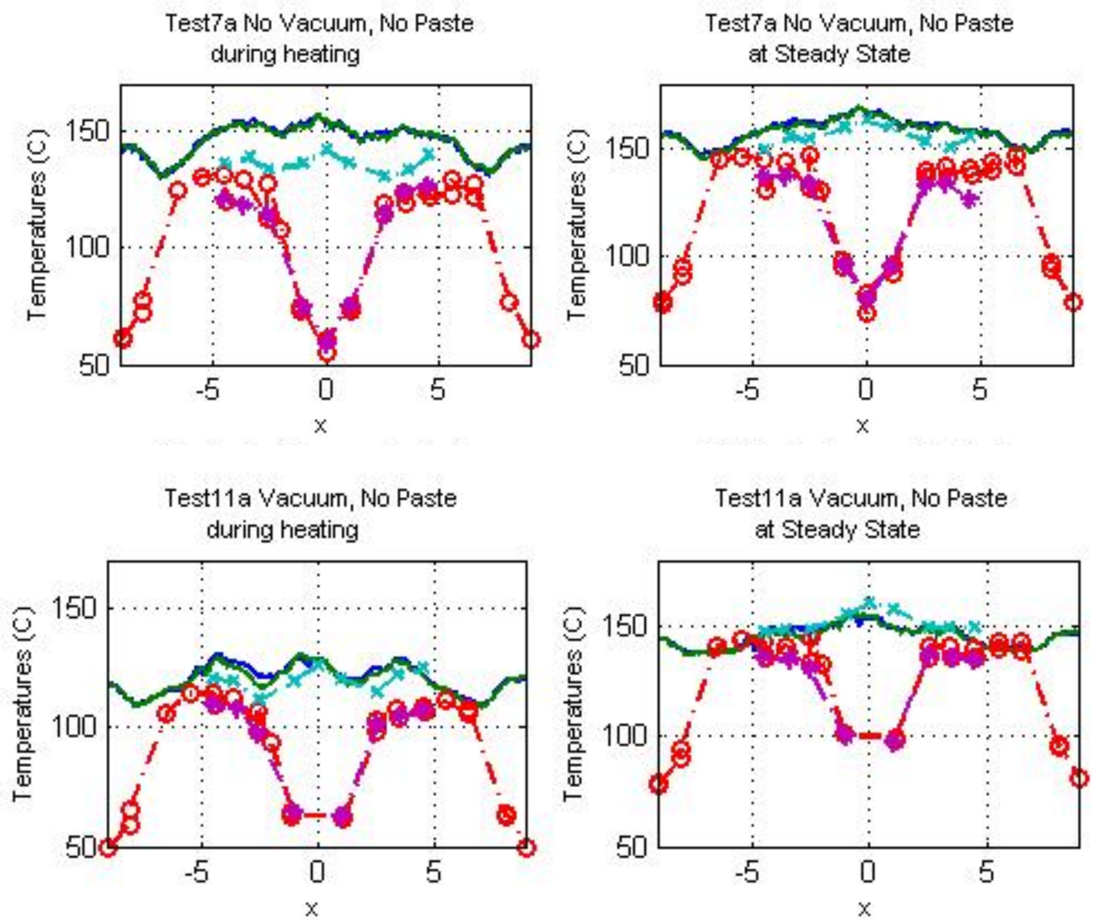


at Steady State

Small but important effect on simulation

Effect of Vacuum with Surface TCs

Vacuum bagging will press the blanket down and should squeeze the air film and minimize the insulating effect

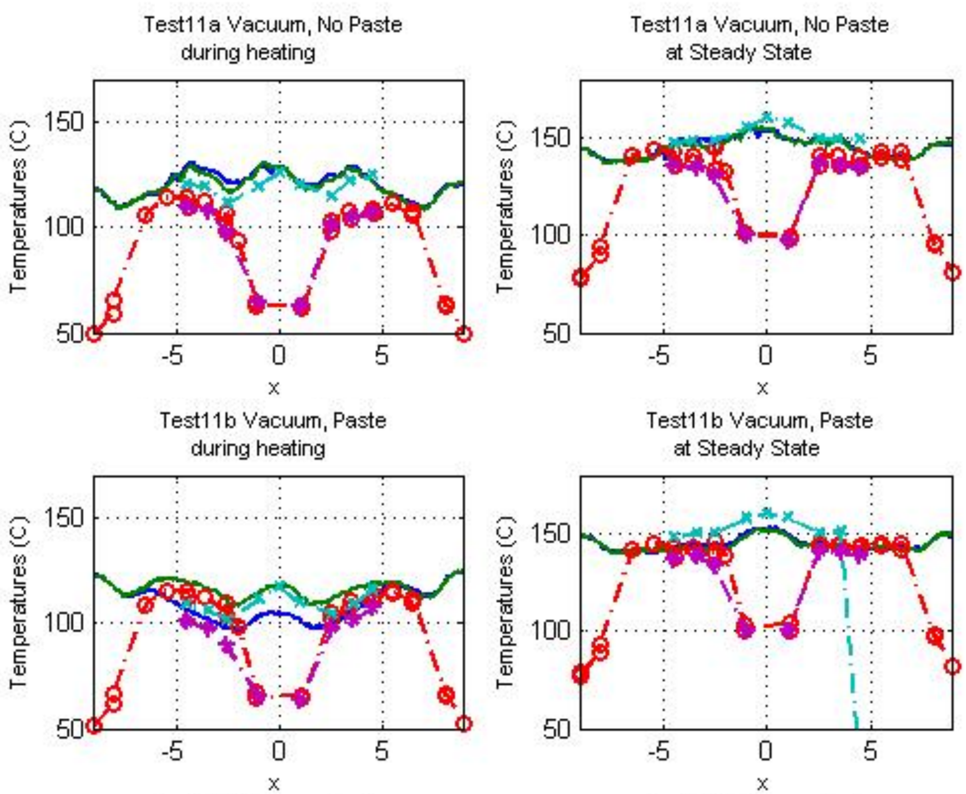


Blanket surface temperatures are elevated

Blanket surface temperatures approach the panel surface temperature

Effect of Thermal Paste.

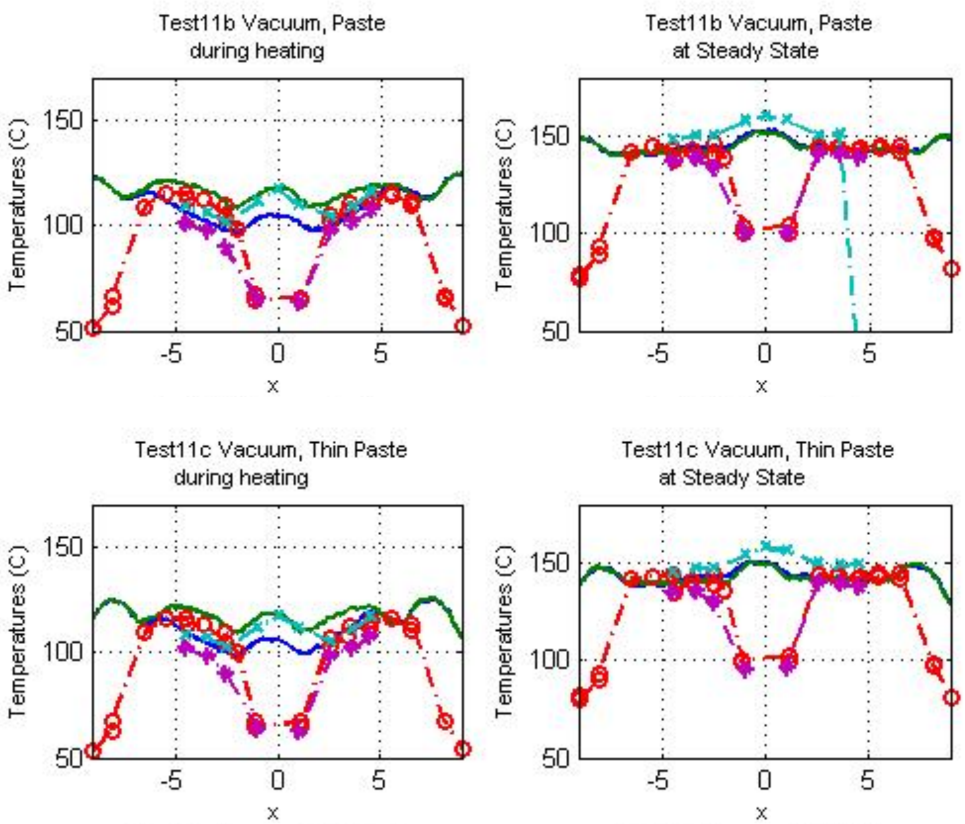
Thermal paste was applied over the TC wires for a distance of ~ 2 inches



Note that the thermogram over the pasted area {green curve) matches the TC data and is substantially hotter than that over the non pasted area (blur curve)

Effect of Paste Thinning

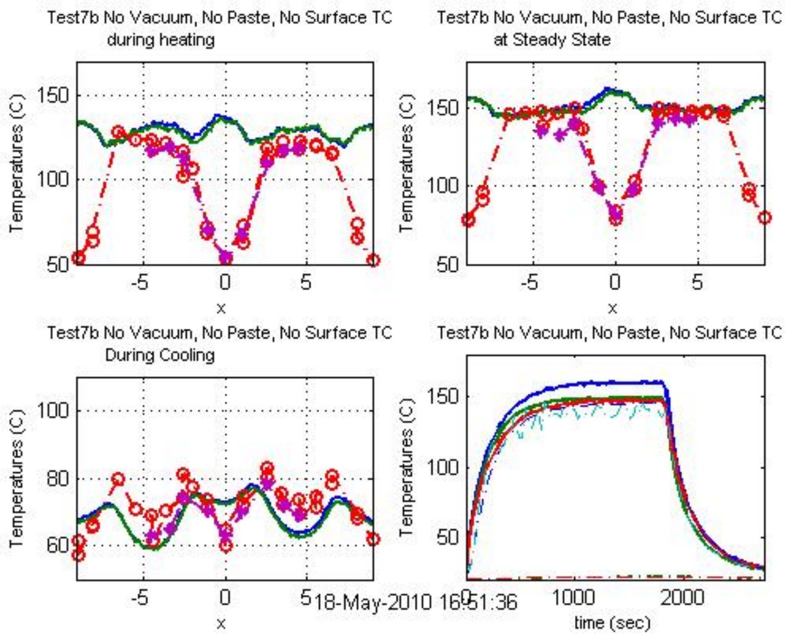
Is there any thinning of the paste due to heating as compared to that caused by the vacuum

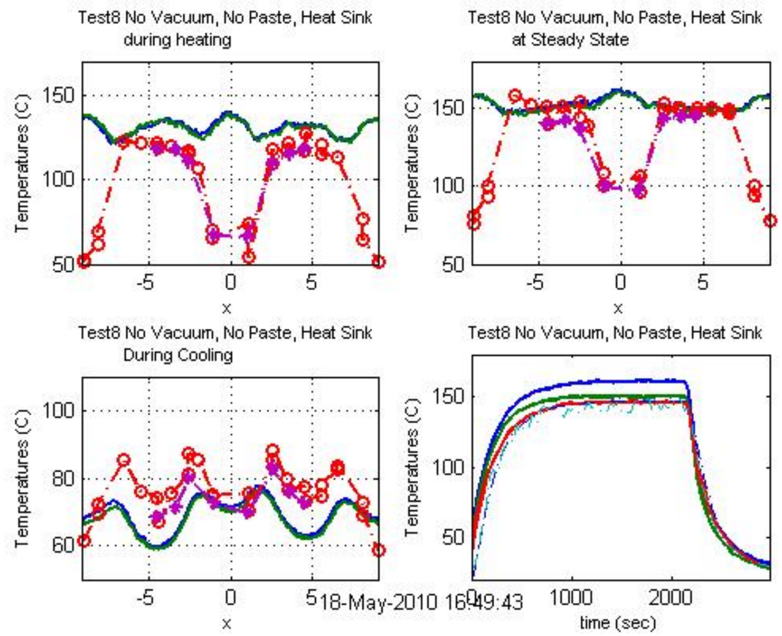


No effect observed

Adding a Heat Sink

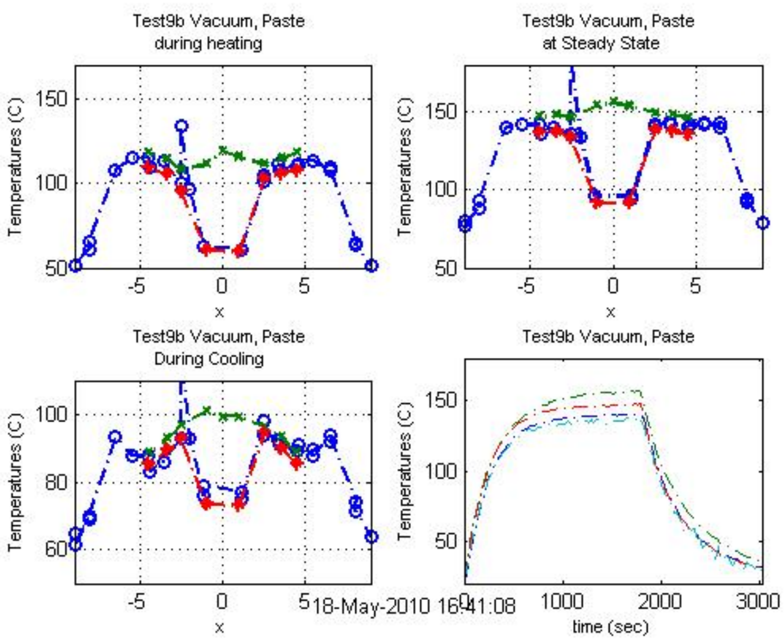
Sink attached with a modest layer of thermal paste between it and the composite

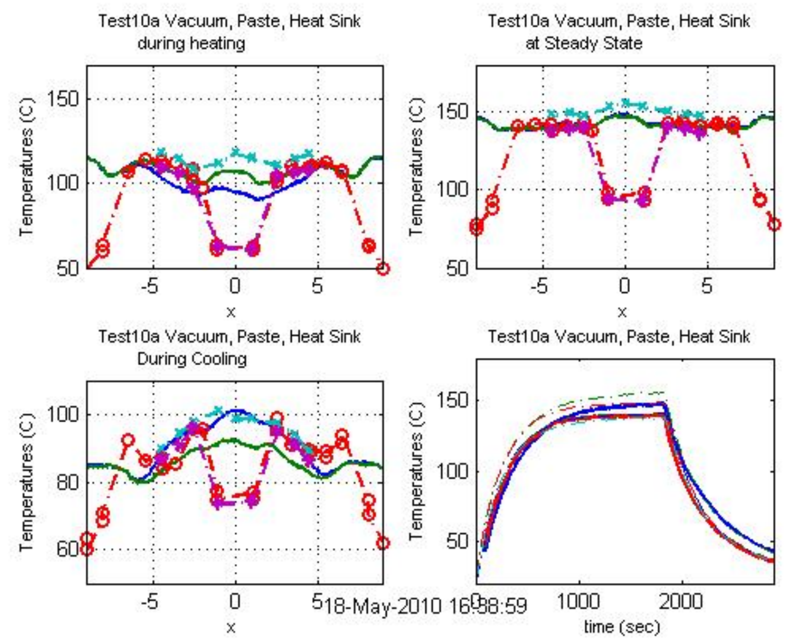




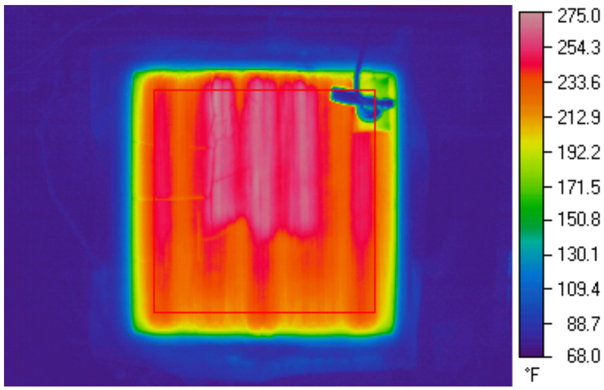
Paste over TC and Heat Sink

Sink attached with a heavy layer of thermal paste between it and the composite

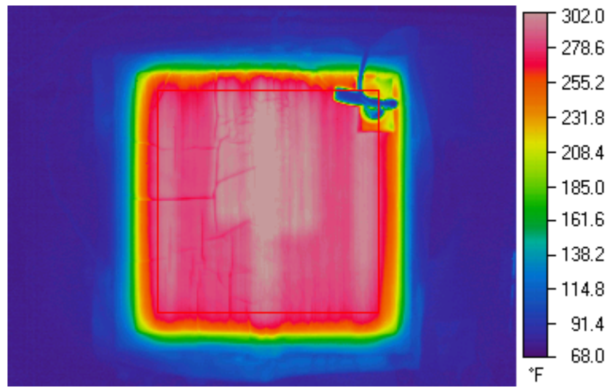




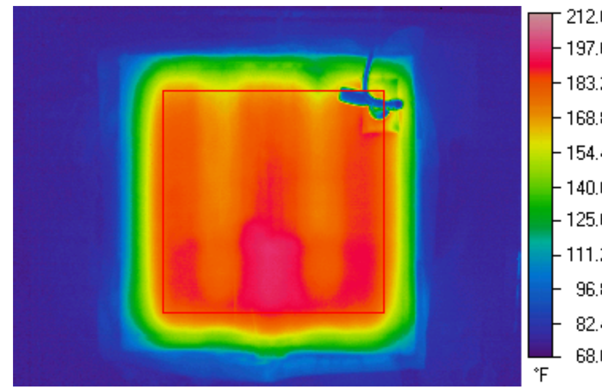
Effect of Paste over TCs



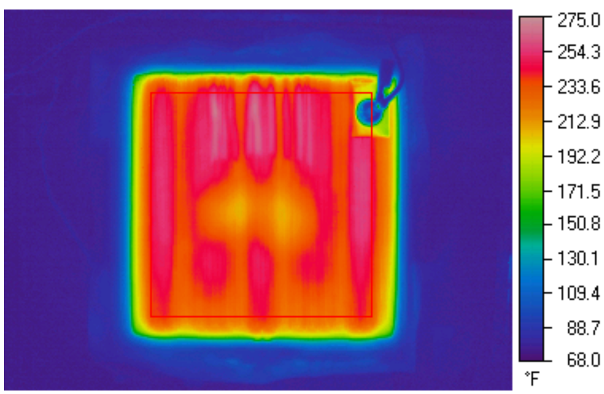
11a #13 271F



11a #60 315F



11a #69 196F



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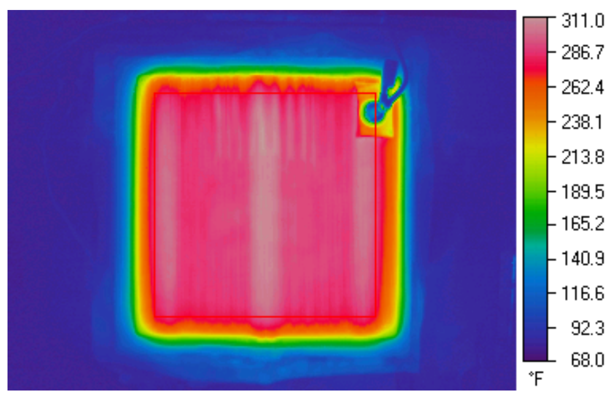
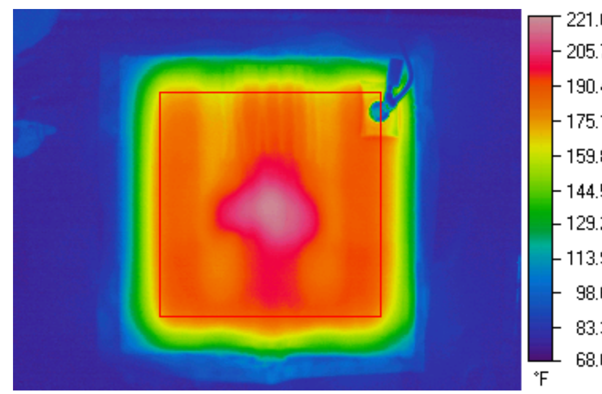
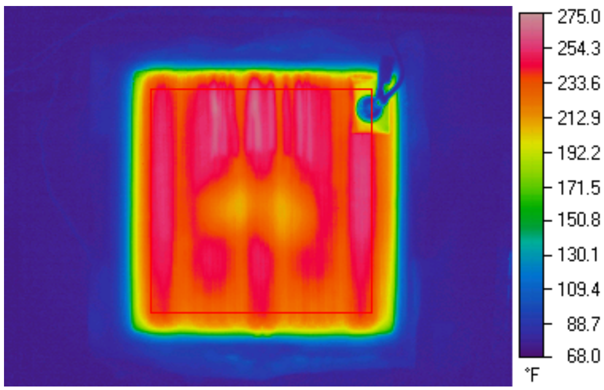


11b #60 311F



11b #69 218F

Effect of Paste on a test after an initial test with paste



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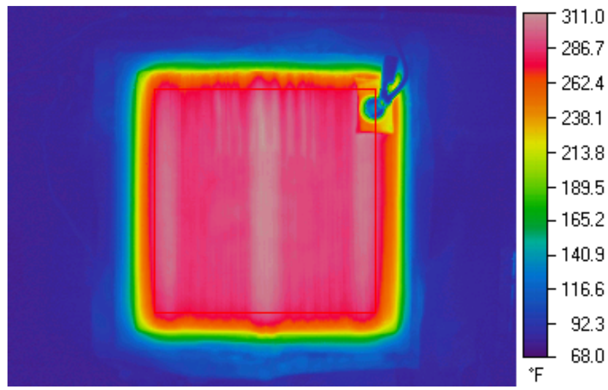

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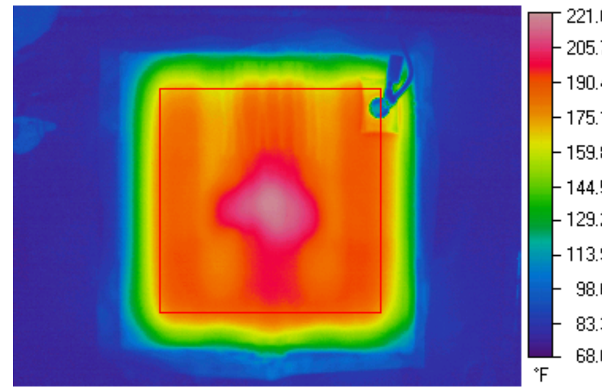

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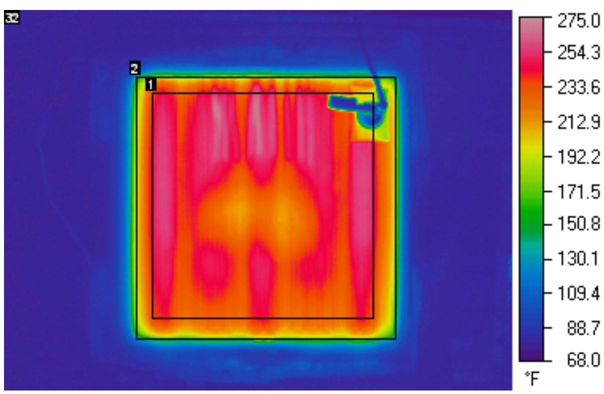
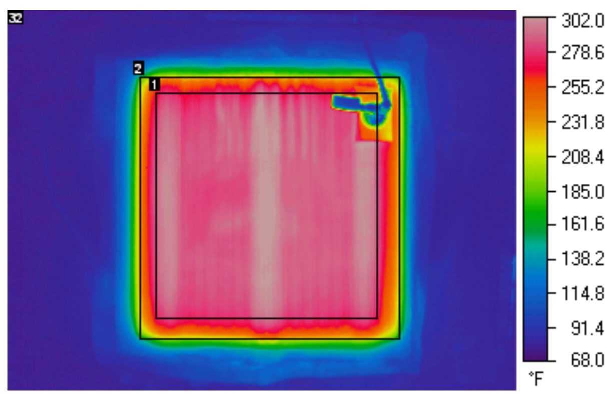
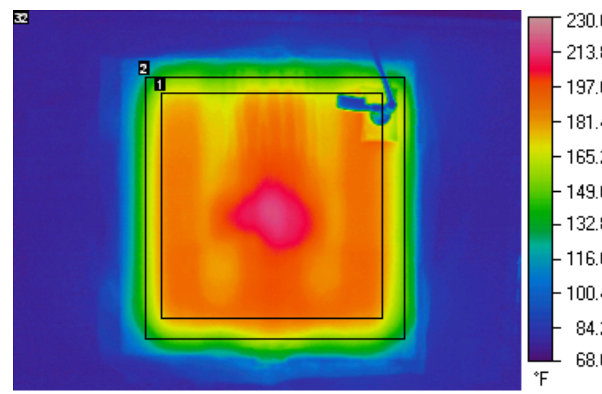


11c #13 268F

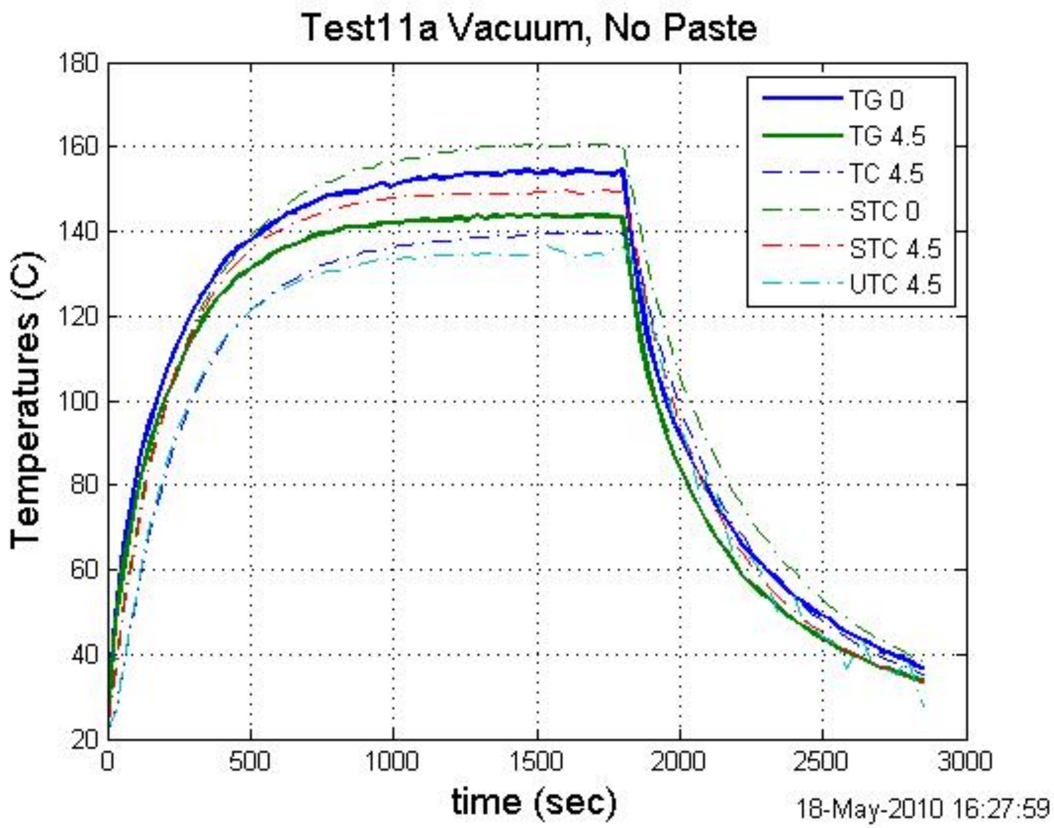


11c #60 304F



11c #69 217F

Short Time Heating



Conclusions

A) Thermograms are in reasonable agreement with panel temperatures at steady state

B) Thermograms are not representative during heating or cooling

C) Thermograms and blanket temperatures of short term heating are of little value in characterizing the thermal behavior

D) Thermal paste over surface TCs is not recommended

E) Simulation using thermograms and surface match measured behavior during transients and steady state thus even *short time transient data may be sufficient* if combined with simulation to predict heat losses

Current Status

1) Completing the validation of the model
2) Fabricating a more effective heat sink
3) Development of a generic geometry*
4) Formulating the optimization program for defining the spatial heating pattern

* Specific geometrical data may not be available to model the actual structure. It may be possible to develop a geometry independent model of panels similar to the one tested

A Look Forward

- Benefit to Aviation:
  Repair/Repair design can take days through weeks. Using this method the temperature measurements from one pre-repair blanket test can be used to design and construct a blanket overnight that we are confident will produce the desired repair site temperature distribution without further testing and with a high degree of confidence.

A Look Forward

- Needed:

  Once the procedure for determining the heat losses has been validated, an algorithm for optimizing the spatial distribution of heat will be developed

  Experimental validation of the entire process will then be done using typical repair configurations chosen by Heatcon, Boeing, and other aviation sources.