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THERMAL SIMULATION OF THE COMPONENT REWORK PROFILE TEMPERATURE

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ABSTRACT

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The aim of this study was to clarify the possibilities and feasibility of the thermal simulation for the modeling of the rework process.

The rework process modeling could enable an easy and fast access to the component and PWB level thermally critical effects like over and under heating of the component during the rework process. The modeling could also be used as a help of the real rework profile definition at an early phase of the electrical device development.

The work includes a thermal modeling of the rework station, a rework profile, a test board and the test component. This leads to the millimeter scale forced convection integration to the transient simulations. Finally, the simulation results were verified against to the real measurements of the rework process. This will ensure the feasibility of the simulations for the rework process and the correctness of modeling methods.

As a result of the study the millimeter scale forced convection model of the rework station was created and verified against to the measurement results. The results show a good correlation with the measurement and the simulated results. This also indicates the feasibility of the selected modeling method for the rework simulations. The most suitable simulation parameters for the rework simulation profile control were also defined.

Keywords:

Thermal simulation, Rework, Rework profile, Transient simulation.

CONTENTS

1 INTRODUCTION

The most used temperature measurement method uses thermocouples to measure rework and reflow temperatures in electronics production. This method is well known and widely used but the drawback of the method is the repeatability and sensitivity of the thermocouple placement which are effecting to the measurement results [2].

The newer temperature measurement method is based on a diode measurement, where a diode's forward biasing voltage is measured and converted to temperature readings. When the diode is integrated inside of a component package, the temperature measurement is done in a systematic way and it will also take care of the thermal mass effect of the used printed wiring board and the package type [2].

The component and the profile temperatures can also be estimated with the help of the thermal simulator software. This approach makes temperature estimations possible without building the actual device. The advantages of the simulations are that they cost less and save time during the product development. The thermal simulation can also be used to clarify detailed temperature effects during the heat up and cool down phases which can be difficult to measure from the real device, like component internal temperature effects or the structural and material analyses of the different design options.

With the thermal simulation of the rework profile it is possible to estimate the temperature effects of the electrical component and the printed wire board during the rework process. With the detailed model of the electrical component it is possible to see temperature differences of the package internal structures and materials which might affect the long time reliability issues of the electrical devices. These reliability issues are many times related to maximum temperature specifications of the component die, thermal stress of the different materials caused by

the miss match of the different thermal expansion coefficients or solder joint temperatures. With the thermal simulations, it is also possible to estimate the temperature profiles of the adjacent component temperatures during the rework process. The adjacent component temperature could be interesting in the case when this adjacent component is thermally critical one, like a memory device, a crystal oscillator or some other type of temperature critical mechanical part.

In this study, the thermal simulator was tested for electrical component rework profile simulations. The transient simulation model of the electrical component and printed wire board was built and also the millimeter scale forced convection thermal simulation model of the rework station was created. Also, the rework temperature profile was created for this purpose.

The simulation model of the rework station and the component level simulation results were compared against to the real rework station measurement results targeting to verify the usability and the modeling method of the thermal simulator in rework purpose.

2 SOLDERING OF THE COMPONENT

The most typical component attachment method in electronics production is soldering where components are first time soldered to the printed wired board (PWB) with the help of a reflow oven. On the other hand, if the component needs to be replaced because of the malfunction effect or other reason, the component is typically replaced with the help of the rework station. The description and the main principles of the reflow and rework processes are described below.

2.1 Reflow soldering

The typical reflow oven is divided into temperature zones where all zone temperatures can be controlled separately. The chain of the temperature zones are forming the temperature profile of how the component and printed wiring board are heated up. Typically, the temperature zones are formed by several hot air nozzles which are blowing the heated air to the component and the PWB. The component and the PWB are placed on the transportation belt, which is leading the PWB through the different temperature zones and the oven. The PWB and the component are heated up according to the pre-defined temperature profile so that the entirely PWB and all components are heated to the solder temperature and then cooled down in the controlled way [1]. The schematic view of the reflow oven is described in the figure 1.

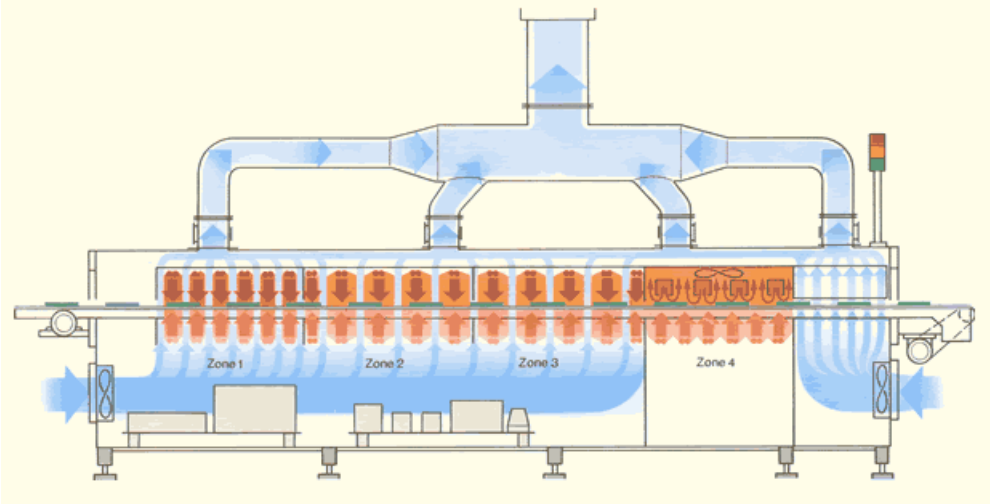

FIGURE 1. Schematic view of the reflow oven [1].

During the way through the oven, the solder paste will melt to a liquid form and finally the solder will cool down to a solid form again and it forms a solder joint between the component and the PWB [1].

The reflow oven temperature profile is selected to match the component and PWB manufacturer specifications to avoid over or under heating the components and to make a reliable solder joint. The solder joint temperature is also related to the used solder material and its specification [2].

2.2 Rework soldering

The rework soldering is usually used when a non-working component is replaced with a new one or when only a single component is soldered to the PWB.

In the typical rework solder process, the single component, solder and the PWB are heated up locally from the top side by an air nozzle and hot air and from the bottom side by an infrared heater [2]. The main difference compared to the reflow soldering is that only the replaced or soldered component is locally heated up to the soldering temperature according to the pre-defined temperature profile. The schematic of the rework process is described in figure 2.

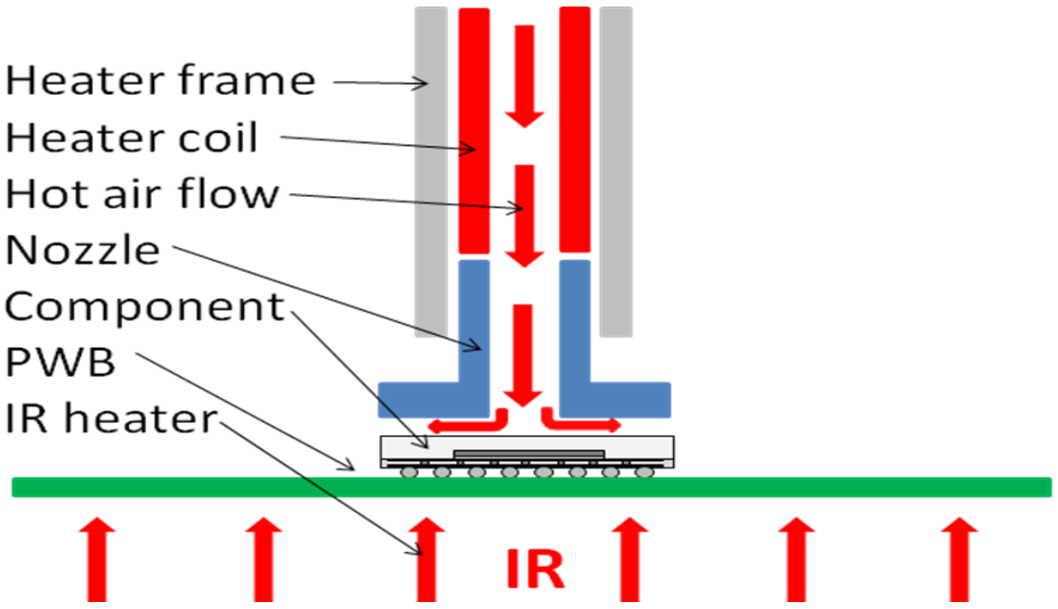

FIGURE 2. Schematic view of the rework process [2].

In the typical rework process the PWB is preheated by the help of the infrared (IR) heater from the down side of the PWB. The whole PWB is evenly preheated up well below of the solder melting point and with the good margin to the critical temperatures of the all components. After the bottom side preheating phase, the air starts to flow through the heater coil where the air temperature is heated up. The hot air is locally spread over the component top side and side areas with the help of the nozzle. Finally, the component and PWB are locally heated up according to the selected temperature profile. The temperature profile can now be controlled during the rework process by changing the IR power, hot air temperature and the air flow rate [2]. The typical rework profile consists of several phases: preheating, ramp-up, soldering, ramp-down and cooling phases [4]. The typical temperature profile phases are presented in the section 2.3.

The most effecting parameters to the soldering temperature control in the case of the rework are:

- Hot air temperature from the nozzle
- Hot air flow rate from the nozzle
- Infrared controlled bottom side temperature of the PWB
- Nozzle size and type
- PWB structure and the used materials
- Component structure and the used materials

The selection of the nozzle size and type is made according to the replaced component physical size. The IR heater power selection is based on the PWB and component structure and size [2]. For example, the bigger and thicker the PWB is, the more IR power is needed for the preheating phase.

Typically, all repair station functions are integrated to one configuration like in Martin Expert 10.6 repair station in figure 3.

FIGURE 3. Martin Expert 10.6 semi-automated rework station [3].

2.3 Temperature profile

The soldering temperature profile of the component and the PWB are defined by the component and PWB manufacturers. The JEDEC standard JSTD020D-01 can be used as a guide line to define critical parameters of the temperature profile. The typical soldering temperature profile is presented in the figure 4.

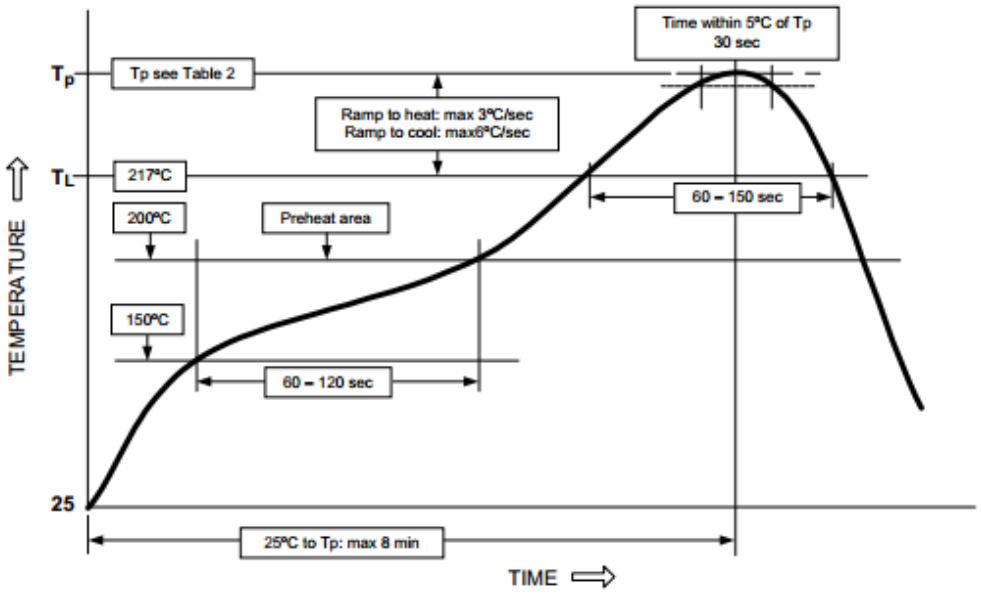

FIGURE 4. Typical soldering temperature profile [4].

The target of the solder profile definition is to avoid too high or low temperatures of the PWB and the components. Typical component maximum temperatures are approximately 250 °C depending on the component type. On the other hand, the good soldering temperature requires the minimum soldering temperature above the solder melting point (217 °C for SAC305 solder). Intel recommendation for solder temperature is 230°C [5].

The wrong solder temperature profile can affect seriously to the component and PWB reliability. The long time reliability decrease can be caused by:

- Overheating of the PWB or component
- Too low soldering temperature
- Thermal stress and mismatch in coefficient of thermal expansion (CTE)
- High temperature package warpage
- The vapor pressure of moisture inside a package -> delamination

3 TEMPERATURE MEASUREMENT

The accurate soldering profile temperature setting and fine tuning is the key to the reliable component soldering. To make this happen, the accurate temperature measurement methods are needed.

3.1 Thermocouple measurement

The mostly used temperature measurement method is the thermocouple (TC) measurement, which is well known in the electronics industry because the TC is small, durable and cheap to use. Also, the temperature range is very wide when the TC type is correctly selected. Even the TC measurement system needs an accurate voltage measurement device due to the voltage change of 60uV/°C and typically 1 mV signal level. There are a lot of commercial measurement devices available to contribute the TC measurement method [2].

The measurement method is based on the two thin wires of different materials which are coupled to each other on the other end (figure 5).

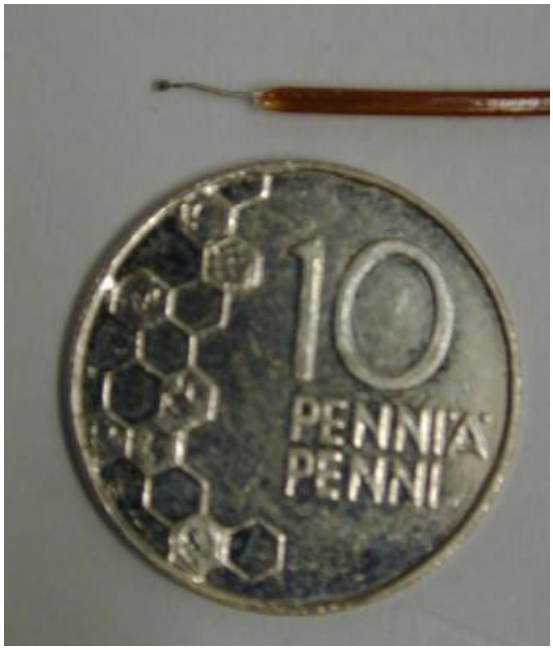

FIGURE 5. Thermocouple wires and the connection bead.

The bead produces a small measurable thermoelectric voltage, corresponding to a temperature, when the junction is heated up (Seebeck phenomenon). The schematic picture of the thermocouple measurement is presented in the figure 6 [2].

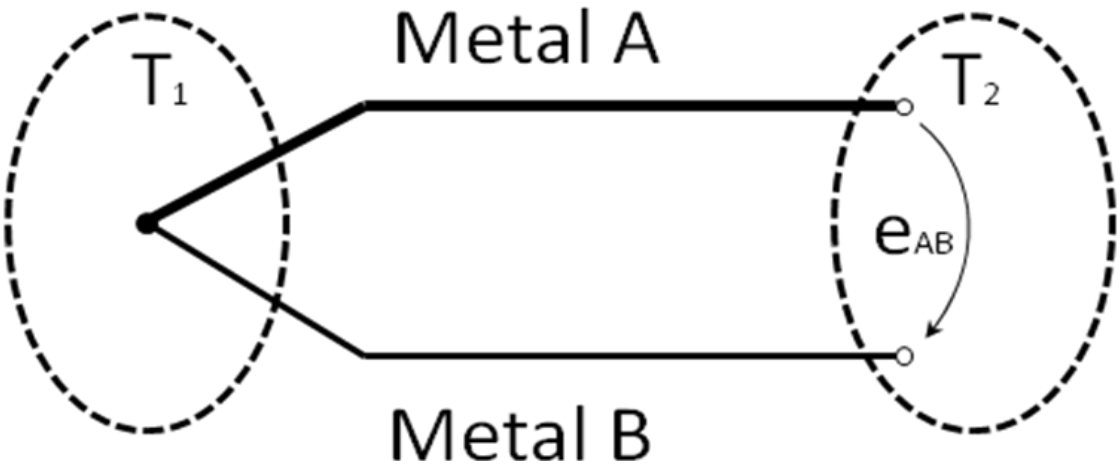

FIGURE 6. Schematic of the thermocouple measurement [2].

The typical TC attachment to the component is made by the tape or glue. The TC is attached to the top of the component surface or signal pin as presented in the figure 7. The other rather common TC attach method is a measurement thru the PWB, where the TC is placed in a small drilled hole in the solder joint area (figure 7) [6].

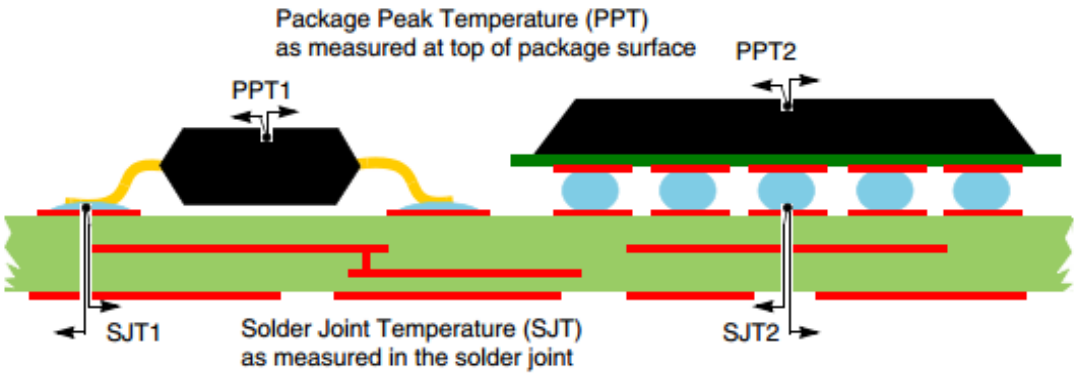

FIGURE 7. Typical thermocouple placement [6].

The advantage of the TC measurement method is that it is a simple, well known and cheap method to measure temperatures. The drawback of the method is its bad repeatability and sensitivity to the TC placement, which affect to the measurement results and accuracy [2].

The TC measurement accuracy highly depends on the TC placement method as shown in the measurement table 1. The thin TC wire pair is very sensitive to the hot air flow due to the fact that it has a very small thermal mass. Even a small error in the TC attachment causes a situation where the TC is measuring the hot air flow temperature rather than the real component surface temperature [2].

TABLE 1. Thermocouple placement effect on the temperature [2].

TC attaching method	Max. temp [°C]	Description
1. TC + tape	250	
2. Free TC bead + tape	265	
3. Free TC bead	280	
4. TC + paste	217	
5. Integrated diode	193-198	

3.2 Diode measurement

The other approach to measure the temperature is the use of a diode as a temperature sensor. This basic method is also well known in electronics industry. Typically, the diode sensor is a stand-alone diode component which is placed on the PWB or on the end of the wires.

The newer approach of diode based temperature measurement is to integrate a temperature sensor diode directly on the silicon die inside of the component package (figure 8). The die integrated sensor method measurement is typically used in high power components like processors or other types of thermally sensitive components, like memory components. For example, Intel is using internal temperature sensors to reduce the processor core power dissipation by modulating the duty cycle of a processor clock, thus reducing the operating frequency or reducing the voltage of the processor according to the core temperature [7][8].

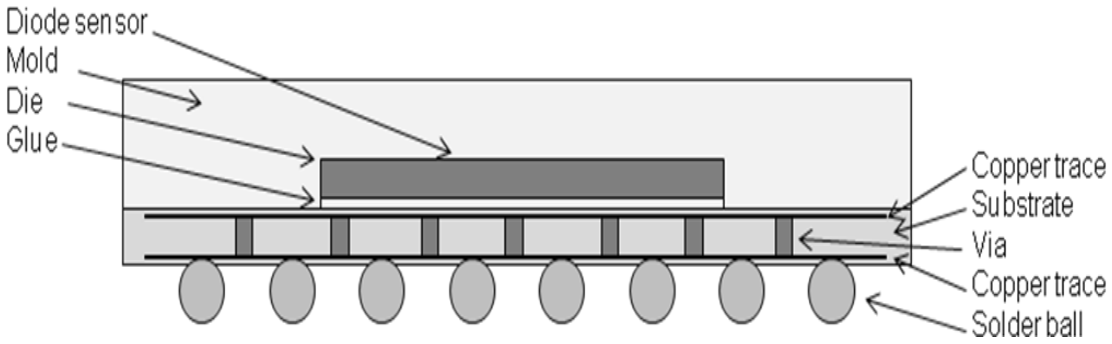

FIGURE 8. Integrated diode sensor inside of the component [2].

The advantage of the die integrated diode method is the easy repeatability and accurate temperature measurement of the die. The method also takes automatically care of the thermal mass effect of the component body as the sensor is always located away from the direct hot air flow [2] (compare to the TC measurement) as described in the table 1.

4 THERMAL SIMULATION MODEL

The simulation model was created for the FloTHERM V10 thermal simulation software which is currently the most commonly used thermal simulation CFD tool in the electronics engineering.

The simulation model development was started from the component, the PWB and the hot air nozzle modeling and the corresponding environmental settings of the true measurement situation.

4.1 Component simulation model

The first component simulation model information was based on the real component structure, materials and dimensions which were delivered by the component supplier. The supplier test component design of 10 mm * 10 mm TFBGA244 follows the JEDEC standard JESD51-4 [9] requirements. The simulation model was a detailed level model including all solder balls, interposer layers like, top and bottom copper layers, core and signal vias. Also, the die and die glue were modeled with the covering epoxy mold. The cross section view of the component model is presented in the figure 9.

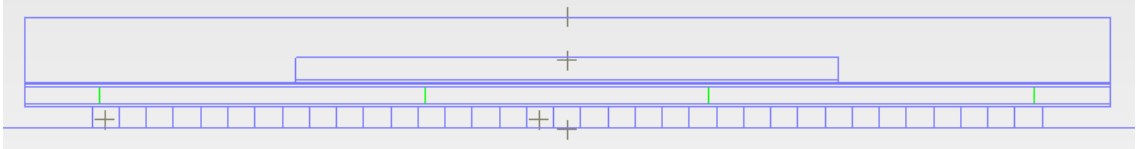

FIGURE 9. Detailed cross section view of the thermal simulation model of the TFBGA244 component.

For the transient reference simulation and parametrical simulation tests the detailed component model was simplified. The model simplification was done by averaging the solder ball and component substrate structures and the corresponding thermal conductivity. The simplified component mode structure is presented in the figure 10.

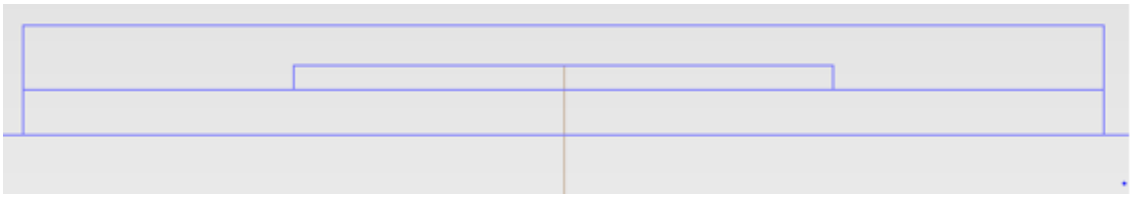

FIGURE 10. Cross section view of the simplified thermal simulation model of the TFBGA244 component.

4.2 PWB simulation model

The PWB simulation model was based on the real PWB structure, materials and dimensions of the measurement board. The true measurement board and the PWB model follows the JEDEC standard JESD51-9 [10] including the practical changes of mobile device requirements where the thickness was changed from the standard 1.6 mm to 1 mm and also the PWB build-up structure was changed from standard 4 layer structure to 8 layers and the copper thickness from 70/53 um to 17 um. The FR-4 material was changed to correspond more mobile device compatible.

The PWB model was simplified as a block model where the copper layers and signal via insulation layers and core layer thermal parameters were averaged to correspond to the actual PWB design and structure and thermal conductivity. The cross section view of the PWB and component model is presented in the figure 11.

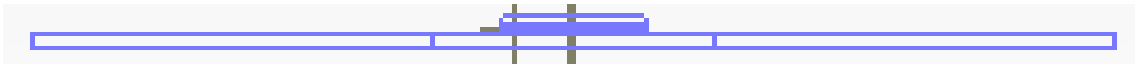

FIGURE 11. Cross section view of the thermal simulation model of the PWB and the component.

4.3 Rework station model

The rework station model was developed from the steady state model of the measurement system. The model consists of the open boundary conditions for

the free air convection set up, IR radiation for the PWB and the settings for the forced convection hot air flow from the nozzle and the heater frame and coil mechanics. The simulation results of the steady state simulations were checked to ensure the rough correctness and the gridding of the model.

The transient simulation was carried out based on the steady state simulations. The transient simulation parameters for the all model details were checked according to the supplier material information, calculations and best guess estimations. This was done for the component, PWB, rework station mechanics and environment settings. The schematic view of the thermal simulation model is presented in the figure 12.

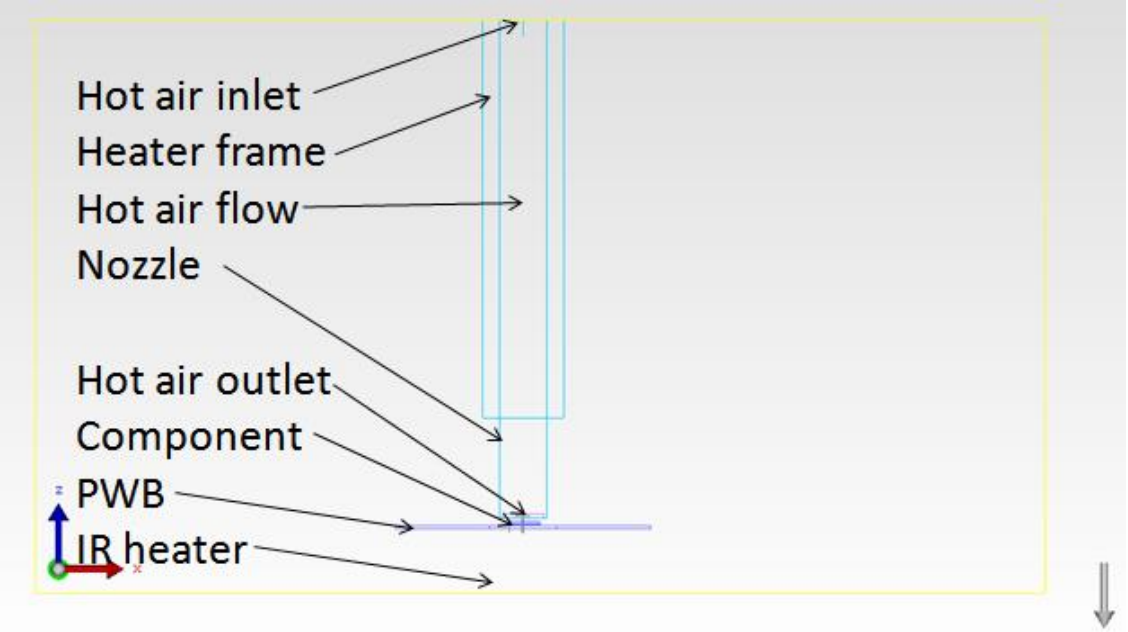

FIGURE 12. Thermal simulation model of the rework station.

5 REFERENCE TEMPERATURE MEASUREMENT

The profile temperature measurement was done by the integrated diode method and the result was used as a reference for the thermal simulation. The rework profiler was Martin Expert rework station [3].

The test board was designed according to the JEDEC standard JESD51-9 [10] as described in chapter 4.2. The used test component was 10 mm * 10 mm TFBGA244 thermal test component with the integrated diode sensor (figure 13).

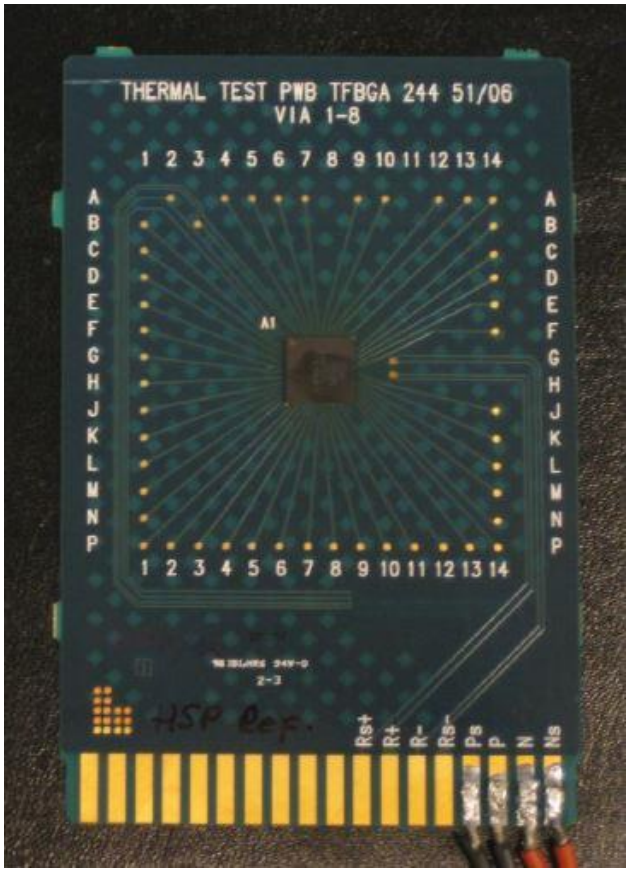

FIGURE 13. Test board and the TFBGA244 component.

The integrated diode sensor was used to measure the temperature profile which was created with the Martin rework station. Also, the TC measurement result was recorded from the component top side and from the bottom side of the test boards for the guiding purpose. The hot air temperature was measured from inside of

the heater frame of the rework station. The results of the reference measurement are presented in the figure 14 [2].

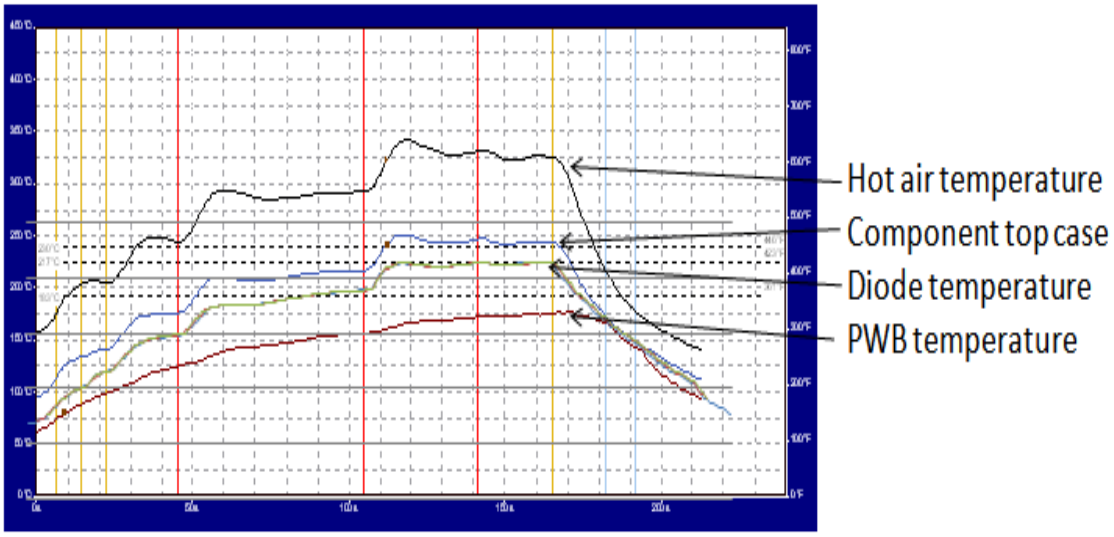

FIGURE 14. Measurement results of the rework profile

As shown in the measurement results, the hot air temperature generated by the Martin rework station was higher than that of the PWB and the component as expected. The hot air temperature measurement position was inside the heater frame and the TC sensor is measuring directly the hot air temperature. The component top case temperature is measured by the glued TC as defined in the table 1 and case 4. The diode temperature is measured by the use of the integrated diode inside of the component and the PWB temperature is from the bottom side of the PWB, measured by the TC. The most interesting temperatures from the reference measurement are presented in the table 2.

TABLE 2. Reference measurement results.

Measurement point	Soldering phase temperature [°C]
Hot air temperature	342 - 325
Component diode (junction temperature)	220 - 219

6 SIMULATION RESULTS

6.1 Reference simulation results

The reference measurement case was repeated with the simulator by using the simulation model described in the chapter 4.

The reference simulations were made with the same profile tuning parameters that were used to create the measured reference rework profile (figure 14). The matching of the fast ramp up rise of the component junction temperature was defined by the use of the higher hot air peak temperature phase to ensure a higher heat transfer from hot air to the component and the PWB. The other possibility to increase the heat transfer from the hot air to the component and the PWB is the use of a higher hot air flow rate, but this version of the simulator did not support the simultaneous change of the hot air temperature and air flow rate in the same transient simulation run.

The simulation result gives a good enough correlation against the measured results even if the absolute results are lower than the measured values. The main thermal effects can be seen from the simulation results (table 3). As in a typical simulation case, the absolute accuracy of the simulation is not the most interesting part of the results. The best performance benefits of the simulations compared to measurements can be achieved many times by looking the relative accuracy in the case of material or structural analyses. In other words: what happens if something is changed in the simulation model.

TABLE 3. Reference measurement results compared to simulation results.

Measurement point	Measured values [°C]	Simulated values [°C]
Hot air temperature	342 - 325	340 - 320
Component diode	220 - 219	200 - 213

Even if the control of the temperature profile is easy to do and the relative accuracy is in the good level compared to the measured reference temperature, the simulation model and set-up can be fixed at this point for the further parametrical analyses.

In the figure 15 the blue graph presents a hot air temperature profile from the nozzle and the black line is the component junction temperature profile, measured from the die surface inside of the component. This simulated profile picture is corresponding to the measured profile temperatures presented earlier in the figure 9.

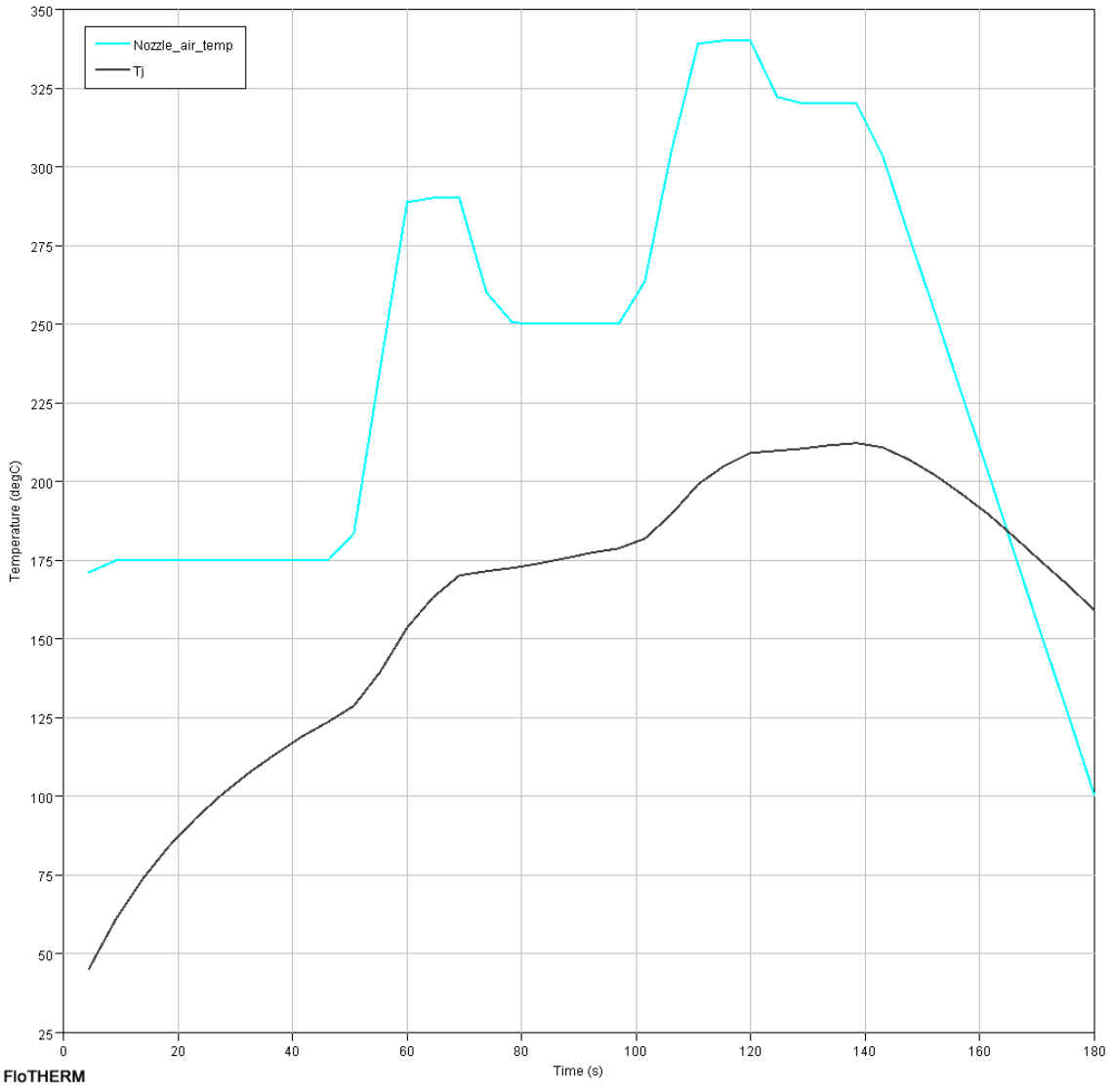

FIGURE 15. Simulation results of the diode and the hot air temperatures.

The temperature gradients of the reference simulation were captured to clarify the temperature distribution over on open surface solution domain and the component and the PWB. The temperature distribution of the PWB and the component is presented in the figure 16. Detailed simulation results are presented in the appendix 1.

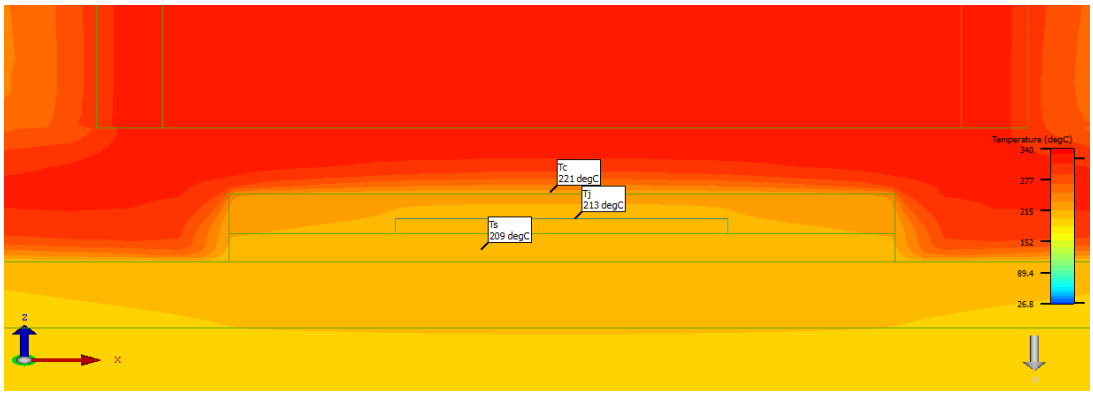

FIGURE 16. Close up cross section view of the component temperature distribution.

The temperature distribution of the solution domain, the PWB and the component cross section is presented in the figure 17.

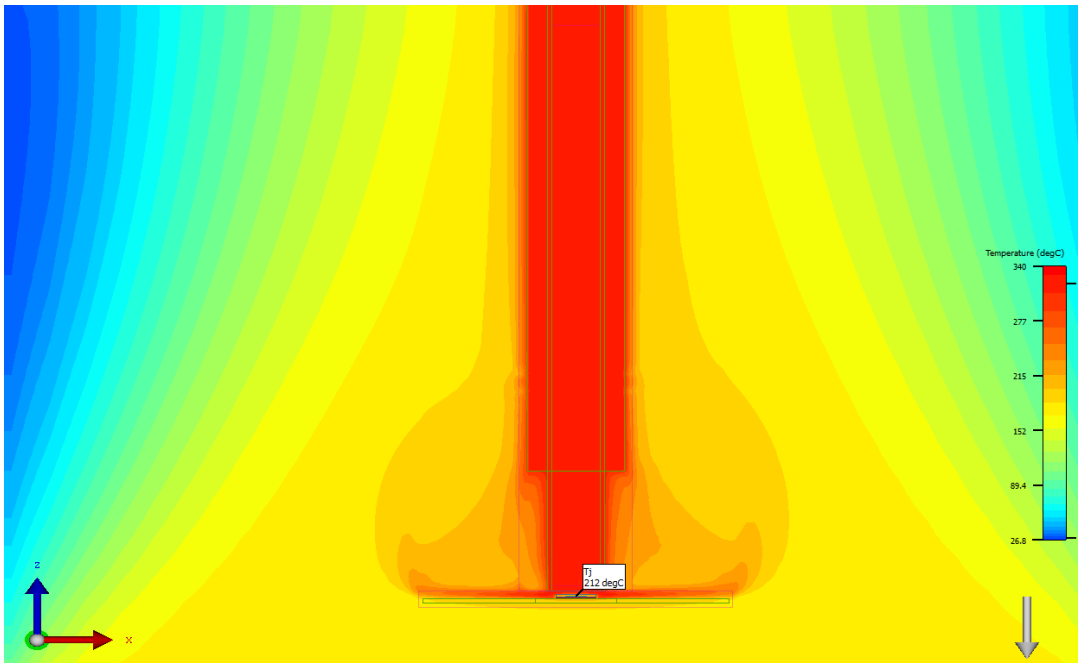

FIGURE 17. Overall solution domain temperature distribution.

6.2 Sensitivity analyze of the simulation parameters

6.2.1 Effect of the nozzle hot air flow temperature

The first parametrical simulation study was made with the nozzle hot air parameter. The target of the simulation was to clarify the effect of the response of the inlet rework hot air flow from the nozzle temperature change on the component die temperature (Tj) and to compare the simulated results with the corresponding measured values of the Martin rework station.

The profile parametrical study was done by changing the reference rework air temperature from 320 °C to 330 °C and 340 °C (soldering phase temperature). The simulated nozzle hot air temperature of 330 °C profile and the simulated component die temperature profile are presented in the figure 18.

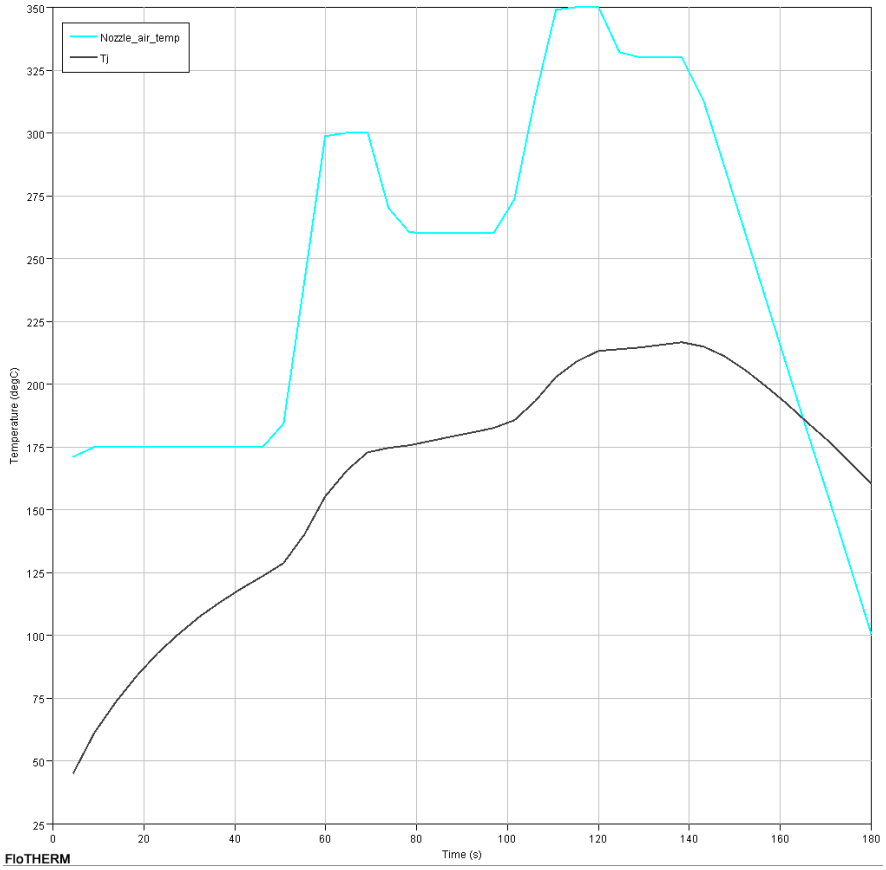

FIGURE 18. Simulation results of the 330 °C nozzle hot air and the component die temperatures.

The average simulation response of the component die temperature was 3.93 °C when the nozzle hot air temperature was increased by 10 °C. The corresponding measured value from the Martin rework station was 4.6 °C [2]. The measured value and the simulated value of the die temperature change are presented in the table 4.

TABLE 4. 10 °C rework temperature change response of the measured results compared to the simulation results.

Measurement point	Measured change [°C]	Simulated change [°C]
Component die	4.6	3.93

The temperature distribution in the highest point of the temperature profile was also checked by the simulation. The average temperature difference between the component top case (Tc) and the die (Tj) was 5.0 °C and the temperature difference between the die and solder joint (Ts) was 5.26 °C. The key temperatures of the nozzle hot air simulations are listed in the table 5. Detailed results of the simulations are presented in the appendix 2 and 3.

TABLE 5. Component key temperatures of the nozzle hot air simulations.

Simulation case	Tj [°C]	Ts [°C]	Tc [°C]	Tj-Ts	Tc-Tj
Reference 320 °C	212.25	207.32	216.92	4.93	4.67
330 °C	216.46	211.20	221.45	5.26	4.99
340 °C	220.10	214.49	225.43	5.61	5.34
Average change [°C/10 °C]	3.93	3.59	4.26	5.26	5.00

The relative simulation results are well in line with the measured values. This gives a good confidence for the usage of the nozzle hot air as a profile tuning parameter and this also supports the correctness of the selected modeling method for the component, the PWB and the hot air nozzle modeling and the corresponding environmental settings.

6.2.2 Effect of the hot air flow volume

The second parametrical simulation study was made with the hot air flow volume parameter. The target of the simulation was to clarify the effect of the response of the rework hot air flow volume change from the nozzle to the component die temperature (Tj) and to compare the simulated results with the corresponding measured values of the Martin rework station.

The profile parametrical study was simulated by changing the reference rework air volume from 10 l/min to 8 l/min and 13 l/min. The simulation result of the nozzle hot air volume 8l/min is presented in the figure 19. The simulated component die temperature Tj is presented in black color and the nozzle air temperature is presented in blue color.

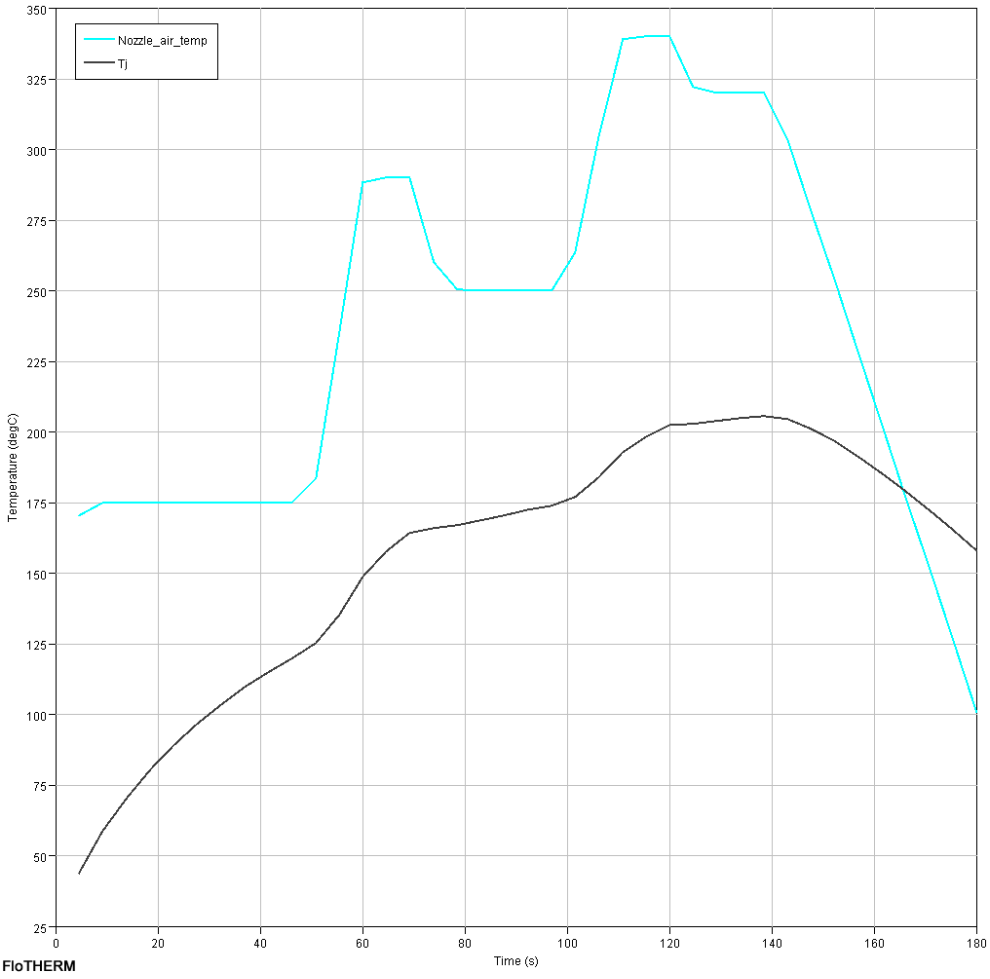

FIGURE 19. Simulation results of the nozzle hot air and the component die temperatures in the case of air flow volume 8 l/min.

The relative simulation response of the component die temperature was 2.69 °C when the nozzle hot air flow volume was increased by 1 l/min. The corresponding measured average value increase from the Martin rework station was 2.8 °C for air flow increase of 1 l/min [2]. The measured temperature value and the simulated value of the die temperature change are presented in the table 6.

TABLE 6. 1 l/min rework air flow volume response of the measured results compared to simulation results.

Measurement point	Measured change [°C]	Simulated change [°C]
Component die	2.8	2.69

The temperature distribution in the highest point of the temperature profile was also checked by the simulations. The average temperature difference between the component top case (Tc) and the die (Tj) was 4.67 °C and the temperature difference between the die and solder joint (Ts) was 4.92 °C. The key temperatures of the air flow volume are listed in the table 7. Detailed results of the simulations are presented in the appendix 4 and 5.

TABLE 7. Component key temperatures of the air flow volume simulations.

Simulation case	Tj [°C]	Ts [°C]	Tc [°C]	Tj-Ts	Tc-Tj
Reference 10l/min	212.25	207.32	216.92	4.93	4.67
8l/min	205.76	200.92	210.40	4.84	4.65
13l/min	219.20	214.21	223.90	4.99	4.70
Average change °C/l	2.69	2.66	2.70	4.92	4.67

The relative simulation results are well in line with the measured values. This indicates a good suitability for the usage of the nozzle hot air volume as a profile tuning parameter.

6.2.3 Effect of the soldering phase time

The third parametrical simulation study was made with the soldering phase time. The target of the simulation was to clarify the effect of the response of the soldering phase time change to the component die temperature (Tj). The simulated results are compared with the corresponding measured values of the Martin rework station.

The profile parametrical study was done by changing the reference soldering time from 30 s to 40 s and 50 s. The simulation of 40 s solder phase time profile and the simulated component die temperature profile are presented in the figure 20.

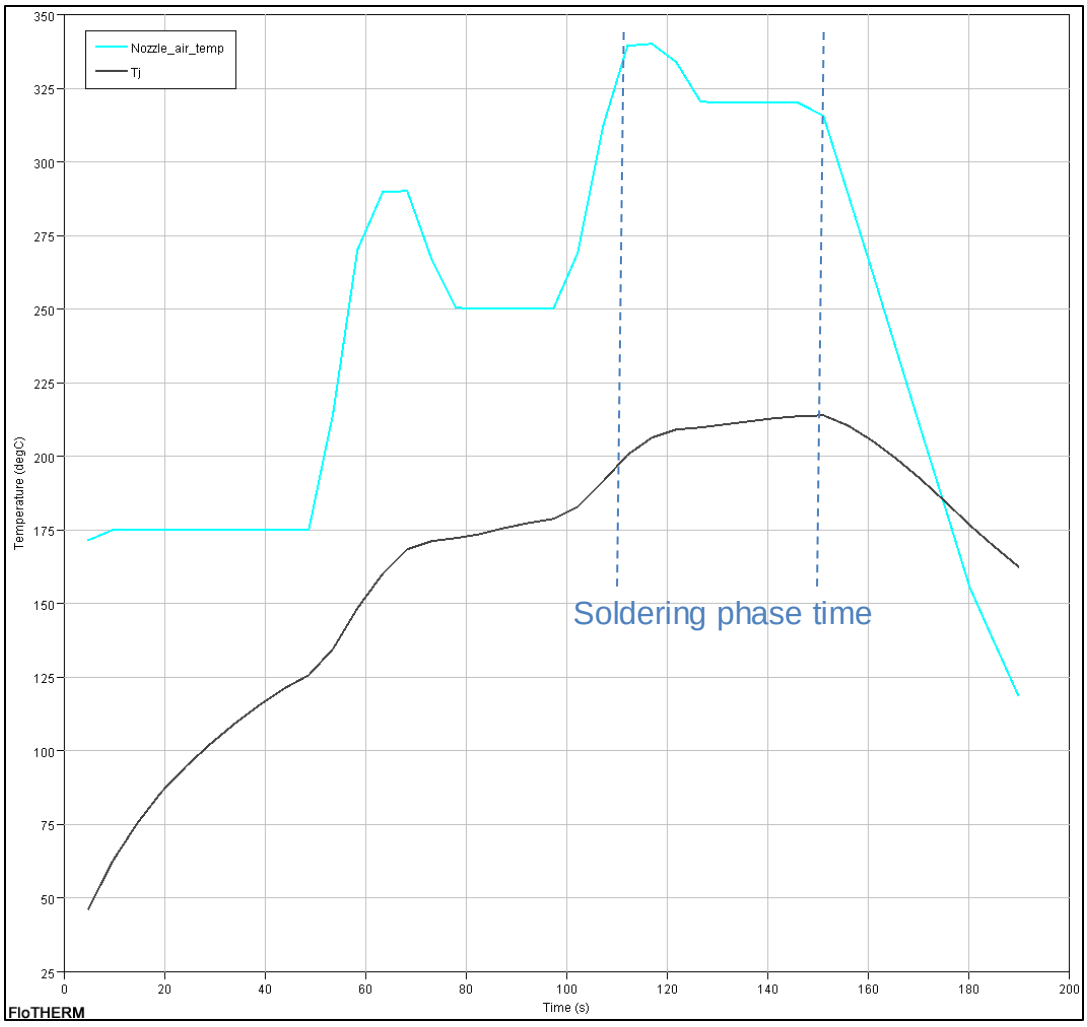

FIGURE 20. Simulation results of the 40 s solder phase to the nozzle hot air and the component die temperatures.

The average simulation response of the component die temperature was 1.69 °C when the soldering phase simulation time was increased by 10 s. The corresponding measured value from the Martin rework station was 4.4 °C [2]. The measured value and the simulated value of the die temperature change is presented in the table 8.

TABLE 8. Measured 10 s rework soldering phase time response compared to simulation results.

Measurement point	Measured change [°C]	Simulated change [°C]
Component die	4.4	1.69

The temperature distribution in the highest point of the temperature profile was checked by the simulation. The average temperature difference between the component top case (Tc) and the die (Tj) was 4.56 °C and the temperature difference between the die and solder joint (Ts) was 4.84 °C. The key temperatures of the soldering phase simulations are listed in the table 9. The detailed results of the simulation are presented in the appendix 6 and 7.

TABLE 9. Component key temperatures of the soldering phase time simulations.

Simulation case	Tj [°C]	Ts [°C]	Tc [°C]	Tj-Ts	Tc-Tj
Reference 30 s	212.25	207.32	216.92	4.93	4.67
40 s	213.73	208.99	218.17	4.75	4.44
50 s	215.63	210.80	220.18	4.83	4.55
Average change [°C/10s]	1.69	1.74	1.63	4.84	4.56

The soldering phase time in the component die follows the simulation control phase time as expected. The relative difference of the simulation results compared to the measured results are differing over 61 %. The potential reason for the different results are in the transient parameter definitions and modeling simplifications of the used modeling method. This parameter can be used as a secondary parameter for the profile tuning because the difference seems to occur in a systematic way.

6.2.4 Effect of the nozzle size

The forth parametrical simulation study was made with the hot air nozzle size. The target of the simulation was to clarify the effect of the response of the nozzle size to the component die temperature (Tj). The simulated results are compared with the corresponding measured values of the Martin rework station.

The profile parametrical study was done by changing the reference nozzle size of 11 mm * 11 mm to 13 mm * 13 mm. The simulation profiles with the 13 mm * 13 mm nozzle are presented in the figure 21. The nozzle size results are made with the different gridding set up because of the convergence problems of the simulations. For that reason, the temperature values are not comparable with the other parametrical simulation results.

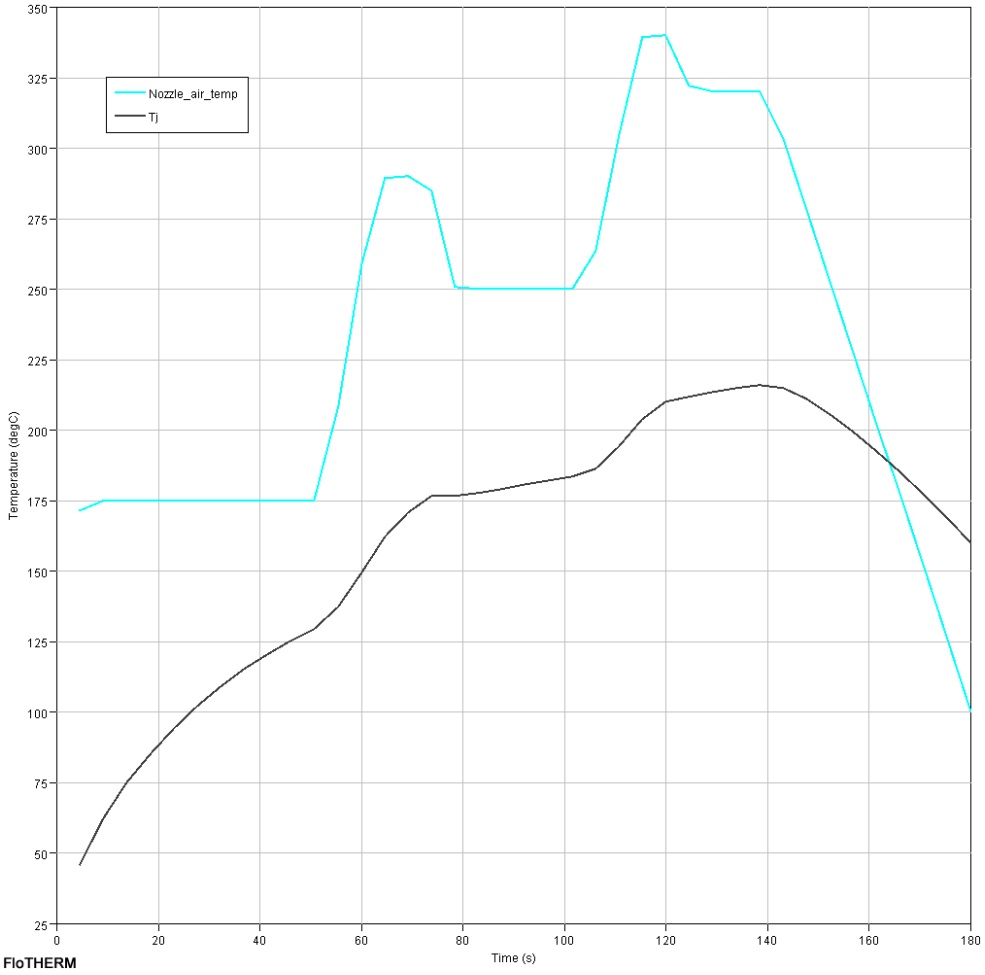

*FIGURE 21. Simulation results of the 13 mm *13 mm nozzle size.*

The simulation response of the component die temperature was -3.52 °C when the nozzle size was changed from 11 mm * 11 mm to 13 mm * 13 mm. The corresponding measured value from the Martin rework station was 4.3 °C [2]. The measured value and the simulated value of the die temperature change is presented in the table 8.

TABLE 8. Nozzle size effect response compared to simulation results.

Measurement point	Measured change [°C]	Simulated change [°C]
Component die	4.3	-3.52

The key temperatures of the nozzle size simulations are listed in the table 9. Detailed results of the simulation are presented in the appendix 8 and 9.

TABLE 9. Nozzle size simulations.

Simulation case	Tj [°C]	Ts [°C]	Tc [°C]	Tj-Ts	Tc-Tj
11*11 mm	219.59	214.14	224.78	5.45	5.19
13*13 mm	216.08	211.36	220.63	4.72	4.56
Difference [°C]	-3.52	-2.79	-4.15	-0.73	-0.63

The parametrical study of the nozzle size does not give a good and comparable results due to the convergence problems of the simulations. Even if the problem was corrected by the new gridding of the project the relative temperature results are not in line with the measurements.

6.2.5 Effect of the nozzle height

The fifth parametrical simulation study was made with the nozzle height. The target of the simulation was to clarify the effect of the nozzle height response to the component die temperature (Tj) and to compare the simulated results with the corresponding measured values of the Martin rework station.

The profile parametrical study was simulated by changing the reference nozzle distance from the component top side 1 mm to 0.5 mm and 0 mm. The simulation result of the nozzle height 0.5 mm is presented in the figure 22. The simulated component die temperature Tj is presented in black color and the nozzle air temperature is presented in blue color.

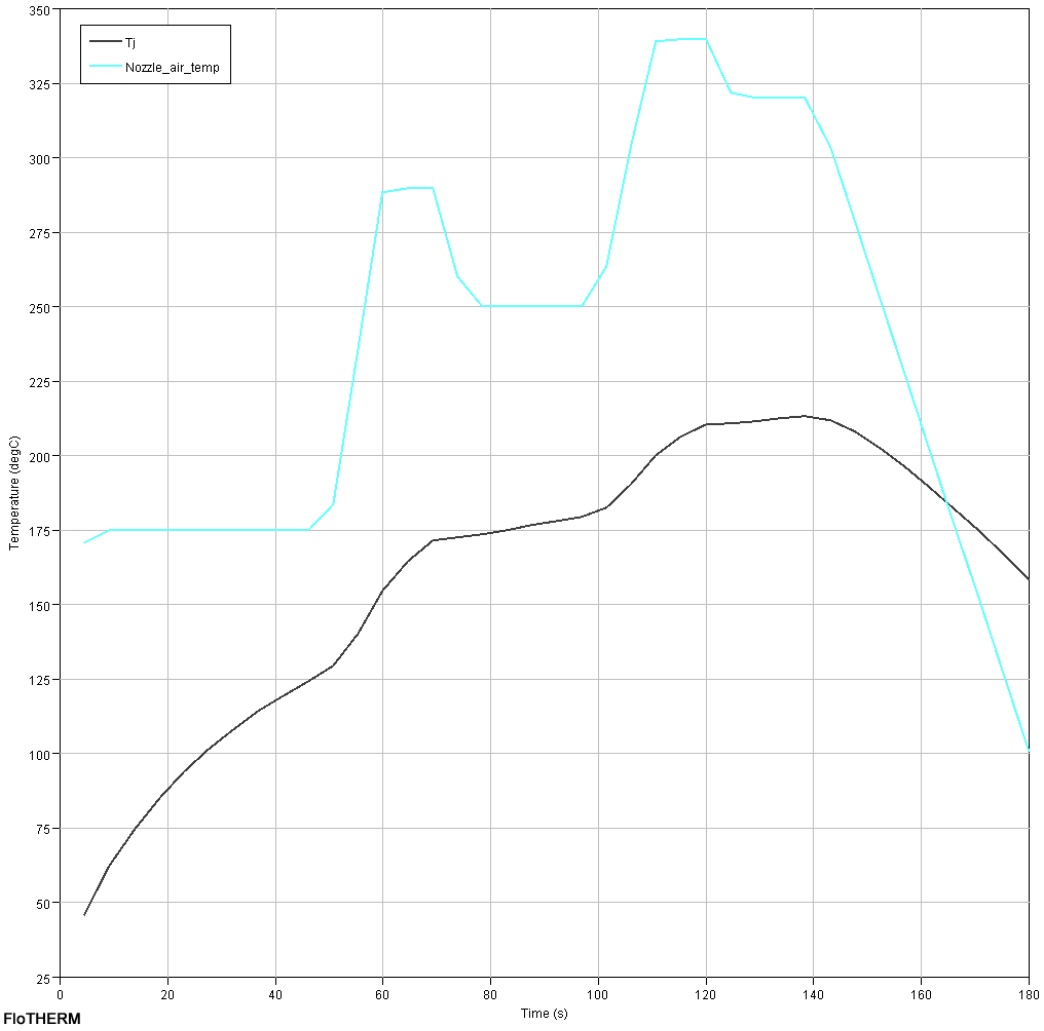

FIGURE 22. Simulation results of the nozzle height of 0.5 mm.

The relative simulation response of the component die temperature was 1.38 °C when the nozzle height was decreased by 0.5 mm. The corresponding measured average value decrease from the Martin rework station was 1.25 °C [2]. The measured temperature value and the simulated value of the die temperature change are presented in the table 10.

TABLE 10. Temperature effect of the 0.5 mm change in nozzle height.

Measurement point	Measured change [°C]	Simulated change [°C]
Component die	1.25	1.38

The temperature distribution in the highest point of the temperature profile was also checked by the simulations. The average temperature difference between the component top case (Tc) and the die (Tj) was 4.71 °C and the temperature difference between the die and solder joint (Ts) was 5.04 °C. The key temperatures of the nozzle height changes are listed in the table 11. The detailed results of the simulations are presented in the appendix 10 and 11.

TABLE 11. Component key temperatures of the nozzle height changes.

Simulation case	Tj [°C]	Ts [°C]	Tc [°C]	Tj-Ts	Tc-Tj
Reference 1 mm	212.25	207.32	216.92	4.93	4.67
0.5 mm	213.26	208.34	217.91	4.92	4.64
0 mm	215.01	209.75	219.82	5.26	4.81
Average change [°C/0.5 mm]	1.38	1.22	1.45	5.04	4.71

The relative simulation results are well in line with the measured values. The modeling of the nozzle height is not sensitive for the nozzle height and the simulation model building will be easier. Even if the simulation results are well in line with the measured values, the use of the nozzle height is not recommended to be used as a profile tuning parameter due to the small effect on temperatures.

6.3 Rework profile tuning

The target of the rework profile tuning is to match the current reference profile to the component manufacturer specifications. In this test case the component rework solder temperature target 230 °C was defined according to Intel's recommendation for the leadless solders SAC305 and SAC405 [5].

The first simulation profile tuning round was done by the use of the relative nozzle hot air information. The temperature gap of the reference simulation solder joint temperature 207.3 °C compared to the Intel's recommendation of absolute temperature 230 °C is 22.7°C. According to the nozzle hot air temperature simulations the relative average solder joint temperature rise for the 10 °C air temperature rise was 5.26 °C. The computational solder joint temperature rise of 22.7 °C should be achieved by increasing the absolute nozzle air temperature by 43.2 °C.

The first profile tuning simulation was done by increasing the reference simulation nozzle hot air temperature by 45 °C (365 °C). As a result, the simulated solder joint temperature was 225.0 °C. The first tuning test profile results are presented in the figure 23. In this picture the most interesting solder temperature profile is presented in red color. The detailed information of this simulation is in the appendix 12.

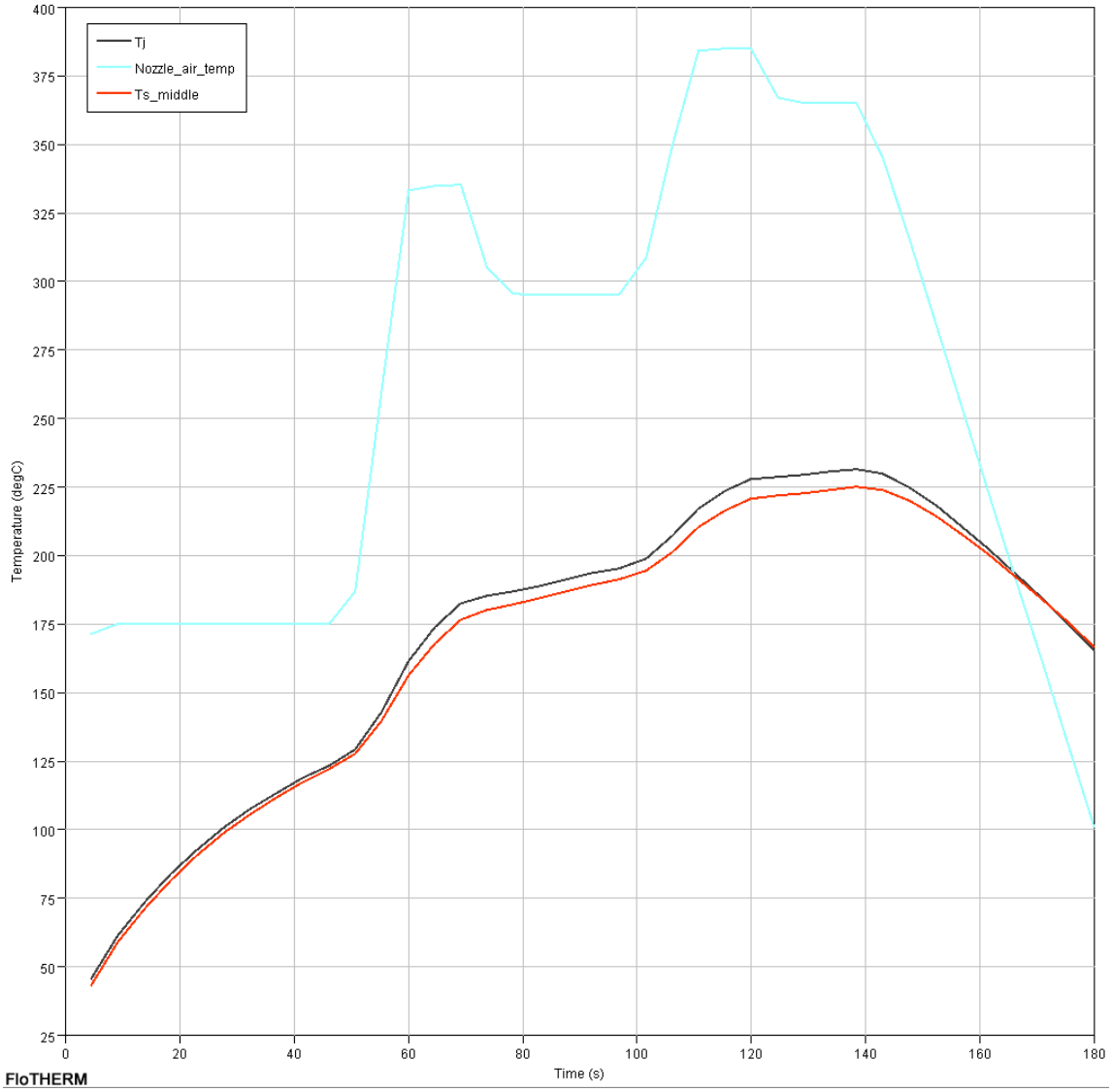

FIGURE 23. Simulation results of the 365 °C nozzle air temperature.

The final profile tuning was done by further increasing the absolute nozzle hot air temperature by 10 °C (375 °C) to achieve needed 5 °C gap to the targeted 230 °C solder joint temperature.

As a result, the final profile tuning simulated solder joint temperature was 229.03 °C which is close enough compared with the target 230 °C. The first tuning test profile results are presented in the figure 24 and the detailed information is in the appendix 13.

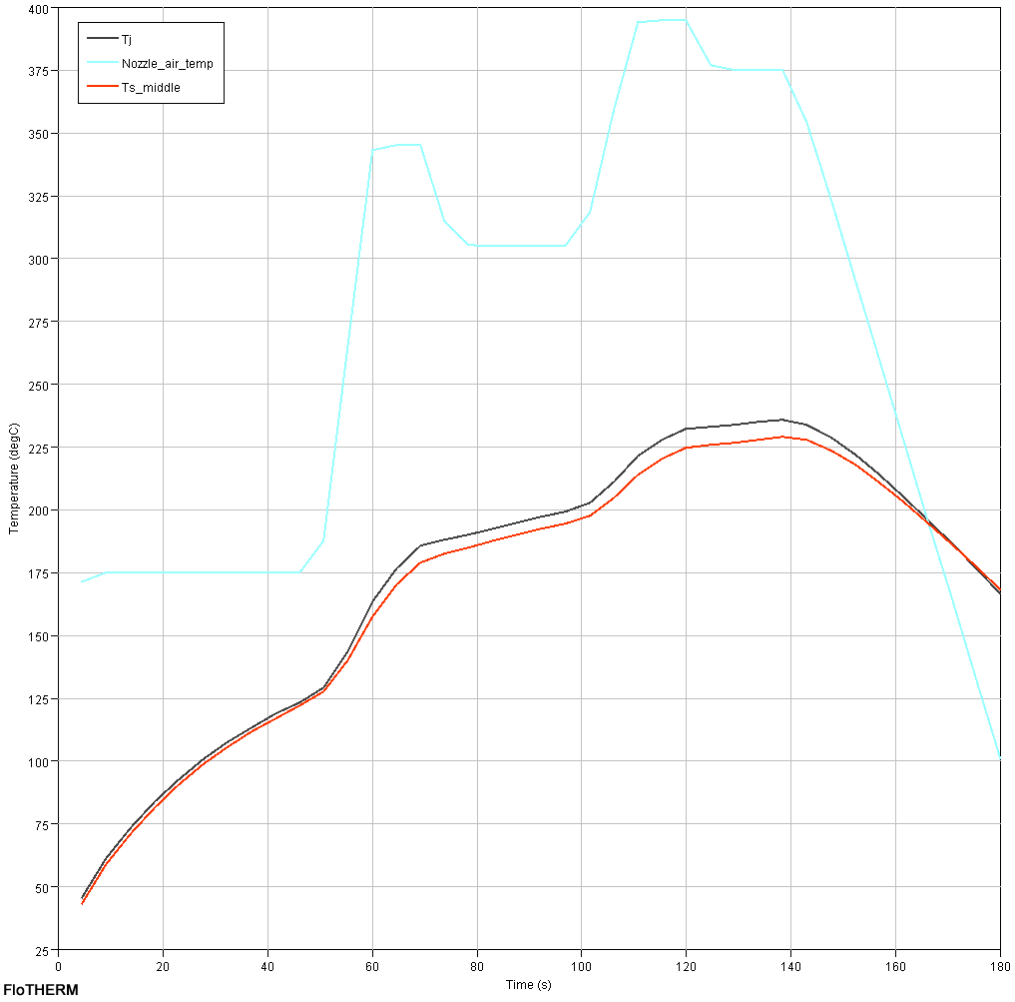

FIGURE 24. Simulation results of the 375 °C nozzle air temperature.

All of the profile tuning simulation key results are presented in the figure 25. The simulation results are well in line compared with the computational results. The computational temperature rise of the solder temperature was 5.26 °C and the simulated temperature rise average was 4.34 °C when the nozzle hot air temperature was increased by 10 °C.

Simulation case	Tj [°C]	Ts [°C]	Tc [°C]	Tj-Ts	Tc-Tj
Target profile		**230.00**			
Reference profile	212.25	207.32	216.92	4.93	4.67
Hot air 365 °C	231.15	225.04	237.64	6.11	6.49
Hot air 375 °C	235.87	229.03	242.37	6.84	6.50

FIGURE 25. Profile tuning results.

7 CONCLUSIONS

Typically the forced convection and transient simulations are made for the cooling of the desk top, cabin or rack scale electrical systems or for simulations of reflow oven soldering process. In this study the millimeter scale forced convection and transient model of the rework process was created and locally heated component rework profile simulation tuning parameters were tested and verified against to the real measurement results.

The target of the feasibility study of the thermal simulation usage for rework process simulations looks suitable also for the rework simulation purpose. According to the parametrical simulation results, the simulations relative difference between the measured and the simulated temperature values are well in line compared with each other. In most of the parametrical simulation cases the relative difference of the component junction temperature effects are comparable to the measured ones.

The relative temperature difference between the component die and the solder joint temperature are systematically at the same level regardless of the simulation cases or the used simulation parameters. Based on that information the junction temperature can be used as a reference temperature for the solder joint temperature estimations. This information can be used specially in the definition of the solder joint temperature estimations when the junction temperature is measured by the internal diode and the real solder joint temperature definition is based on the junction temperature measurement.

Even if the simulated component top side temperature differences are systematically at the same level with the junction temperature and solder joint temperature, the use of the top side temperature measurement is not recommended to the real solder joint temperature estimations of the real rework process without special attention been taken to the measurement method. In the simulator the measurement point of top side can be defined quite well and the simulated results are

systematic and repeatable. In the real rework profile measurements the top side measurement is highly sensitive of the measurement sensor attachment method to the component top surface, which can lead to a critical error in the solder joint temperature definition. In the case of true thermocouple measurement, the thermocouple positioning and attachment on the component top side surface is the key issue of the measurement result correctness and the solder joint estimation.

To make the rework profile tuning to match the component supplier target temperature values can easily be done by the information based on the parametrical results. In this case the reference profile was tuned to correspond to the Intel's recommended absolute solder joint temperature. The tuning was made by the use of the relative nozzle hot air temperature results. The parametrical simulations are quite systematically depending on the nozzle air temperature and the needed temperature change of the solder joint can easily be calculated based on the function of the hot air temperature.

8 FUTURE WORK

Even if the simulation results and the process for rework modeling were clarified and verified, there are a lot of interesting further development possibilities which have been noted during the thesis work.

One of the key issue of the simulation work in general is the simulation solving time and how fast we are able to see the results of the simulation. The solving time might be critical at some product development phases to enable the fast product development cycles, like in this study the transient simulations are typically the most time and processor power consuming simulations. In this study the typical simulation time was 6-10 hours meaning that the simulation needs to run overnight to get the results available. The simulation time optimization without reducing the simulation accuracy is the most interesting development direction.

In this study only one component type and size were tested for the feasibility of the rework modeling. In the future it could be interesting to test other types and sizes of the components to clarify the potential challenges of size and mass effect of the different component and PWB combinations.

Because this study focused only on the single stand-alone component thermal effects, there is a need to analyze the adjacent component effects near by the reworked component. In real applications the PWB can include highly thermally sensitive components which can be damaged in high temperatures caused by the reworking of the adjacent components. By doing the studies for the adjacent component effects, the risk zone around the reworked component can be defined and the possible component damages can be minimized by taking safety zones in use at an early product development phase.

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APPENDICES

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	159.555	159.557	159.538	159.602	160.467	158.932	160.276	159.397	157.146	159.555	159.557	159.538	159.602	100.642
175.385	166.672	166.656	166.637	166.656	167.705	166.927	167.632	166.839	165.728	166.672	166.656	166.637	166.656	126.026
170.769	173.501	173.466	173.447	173.423	174.664	174.673	174.714	174.004	174.092	173.501	173.466	173.447	173.423	151.411
166.154	179.997	179.943	179.923	179.859	181.299	182.13	181.477	180.847	182.201	179.997	179.943	179.923	179.859	176.796
161.538	186.097	186.026	186.005	185.904	187.546	189.235	187.857	187.307	189.999	186.097	186.026	186.005	185.904	202.181
156.923	191.715	191.628	191.607	191.471	193.312	195.895	193.76	193.292	197.397	191.715	191.628	191.607	191.471	227.566
152.308	196.716	196.614	196.593	196.423	198.444	201.952	199.032	198.66	204.245	196.716	196.614	196.593	196.423	252.951
147.692	200.88	200.766	200.746	200.544	202.685	207.128	203.412	203.164	210.271	200.88	200.766	200.746	200.544	278.332
143.077	203.828	203.708	203.69	203.458	205.58	210.898	206.431	206.357	214.941	203.828	203.708	203.69	203.458	303.497
138.462	204.768	204.647	204.629	204.378	206.396	212.246	207.316	207.385	216.921	204.768	204.647	204.629	204.378	319.992
133.846	203.748	203.627	203.608	203.355	205.39	211.292	206.319	206.39	216.006	203.748	203.627	203.608	203.355	319.992
129.231	202.655	202.532	202.515	202.26	204.347	210.34	205.291	205.357	215.103	202.655	202.532	202.515	202.26	320.037
124.615	201.606	201.479	201.465	201.207	203.378	209.593	204.357	204.442	214.499	201.606	201.479	201.465	201.207	321.996
120	200.75	200.627	200.617	200.342	202.256	209.034	203.302	203.621	214.703	200.75	200.627	200.617	200.342	339.99
115.385	196.999	196.885	196.877	196.606	198.233	204.926	199.254	199.724	210.685	196.999	196.885	196.877	196.606	339.977
110.769	191.884	191.789	191.782	191.517	192.581	198.924	193.527	194.21	204.725	191.884	191.789	191.782	191.517	339.097
106.154	183.946	183.868	183.857	183.631	184.458	189.446	185.202	185.76	194.005	183.946	183.868	183.857	183.631	304.322
101.538	177.417	177.345	177.33	177.145	178.132	181.896	178.709	178.97	185.09	177.417	177.345	177.33	177.145	263.491
96.9231	174.552	174.48	174.463	174.287	175.375	178.816	175.91	176.069	181.614	174.552	174.48	174.463	174.287	249.995
92.3077	172.986	172.914	172.894	172.715	173.805	177.302	174.348	174.521	180.154	172.986	172.914	172.894	172.715	249.995
87.6923	171.255	171.182	171.161	170.976	172.086	175.658	172.64	172.823	178.571	171.255	171.182	171.161	170.976	249.994
83.0769	169.394	169.32	169.297	169.107	170.276	173.961	170.849	171.026	176.946	169.394	169.32	169.297	169.107	249.997
78.4615	167.512	167.432	167.41	167.214	168.53	172.426	169.139	169.297	175.511	167.512	167.432	167.41	167.214	250.237
73.8462	165.998	165.91	165.893	165.682	167.083	171.519	167.772	168.028	175.05	165.998	165.91	165.893	165.682	259.998
69.2308	164.104	164.021	164.01	163.768	164.74	170.053	165.534	166.188	174.745	164.104	164.021	164.01	163.768	289.991
64.6154	157.646	157.575	157.566	157.328	157.904	163.139	158.668	159.54	167.987	157.646	157.575	157.566	157.328	289.972
60	149.216	149.169	149.16	148.929	148.753	153.561	149.423	150.579	158.497	149.216	149.169	149.16	148.929	288.633
55.3846	136.784	136.757	136.742	136.568	136.266	139.351	136.687	137.565	142.636	136.784	136.757	136.742	136.568	235.581
50.7692	126.969	126.947	126.926	126.8	126.835	128.661	127.089	127.555	130.492	126.969	126.947	126.926	126.8	183.621
46.1538	121.779	121.757	121.733	121.608	121.685	123.422	121.927	122.369	125.135	121.779	121.757	121.733	121.608	174.996
41.5385	116.952	116.931	116.904	116.77	116.806	118.675	117.065	117.572	120.534	116.952	116.931	116.904	116.77	174.996
36.9231	111.512	111.491	111.462	111.32	111.306	113.322	111.583	112.164	115.345	111.512	111.491	111.462	111.32	174.995
32.3077	105.38	105.361	105.33	105.18	105.104	107.284	105.401	106.066	109.49	105.38	105.361	105.33	105.18	174.995
27.6923	98.4597	98.4484	98.4177	98.2603	98.0999	100.463	98.4197	99.1818	102.874	98.4597	98.4484	98.4177	98.2603	174.995
23.0769	90.6573	90.6565	90.6253	90.4619	90.1934	92.7468	90.5359	91.4113	95.385	90.6573	90.6565	90.6253	90.4619	174.994
18.4615	81.8093	81.8199	81.7904	81.623	81.1943	83.9318	81.5559	82.5756	86.8182	81.8093	81.8199	81.7904	81.623	174.993
13.8462	71.6571	71.6788	71.6556	71.4875	70.7876	73.6671	71.1575	72.3771	76.8224	71.6571	71.6788	71.6556	71.4875	174.992
9.23077	59.7686	59.7924	59.7807	59.617	58.4132	61.2909	58.761	60.2636	64.7247	59.7686	59.7924	59.7807	59.617	174.941
4.61538	45.2817	45.2861	45.2846	45.138	43.1004	45.4979	43.3489	45.041	49.0493	45.2817	45.2861	45.2846	45.138	171.241

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	**Nozzle_air_temp (degC)**
180	160.912	160.912	160.893	160.956	161.873	160.331	161.683	160.772	158.509	160.912	160.912	160.893	160.956	100.671
175.385	168.362	168.344	168.325	168.341	169.451	168.7	169.385	168.563	167.492	168.362	168.344	168.325	168.341	127.209
170.769	175.517	175.479	175.459	175.431	176.743	176.818	176.806	176.07	176.255	175.517	175.479	175.459	175.431	153.748
166.154	182.329	182.271	182.251	182.181	183.704	184.641	183.901	183.248	184.763	182.329	182.271	182.251	182.181	180.287
161.538	188.736	188.66	188.639	188.531	190.269	192.107	190.605	190.033	192.957	188.736	188.66	188.639	188.531	206.826
156.923	194.646	194.553	194.532	194.387	196.339	199.119	196.82	196.331	200.747	194.646	194.553	194.532	194.387	233.364
152.308	199.918	199.809	199.788	199.608	201.754	205.51	202.383	201.99	207.974	199.918	199.809	199.788	199.608	259.903
147.692	204.319	204.198	204.178	203.964	206.243	210.99	207.02	206.752	214.352	204.319	204.198	204.178	203.964	286.438
143.077	207.45	207.322	207.304	207.059	209.325	215	210.233	210.143	219.318	207.45	207.322	207.304	207.059	312.748
138.462	208.471	208.343	208.324	208.06	210.22	216.46	211.203	211.26	221.451	208.471	208.343	208.324	208.06	329.991
133.846	207.431	207.303	207.284	207.017	209.195	215.487	210.185	210.245	220.518	207.431	207.303	207.284	207.017	329.992
129.231	206.315	206.184	206.167	205.898	208.129	214.514	209.135	209.189	219.595	206.315	206.184	206.167	205.898	330.036
124.615	205.238	205.104	205.089	204.817	207.134	213.745	208.176	208.249	218.972	205.238	205.104	205.089	204.817	331.996
120	204.352	204.222	204.211	203.922	205.985	213.172	207.096	207.401	219.178	204.352	204.222	204.211	203.922	349.989
115.385	200.541	200.42	200.411	200.125	201.899	209.002	202.984	203.443	215.101	200.541	200.42	200.411	200.125	349.977
110.769	195.348	195.246	195.238	194.958	196.163	202.912	197.172	197.848	209.055	195.348	195.246	195.238	194.958	349.096
106.154	187.302	187.217	187.206	186.966	187.919	193.289	188.722	189.281	198.165	187.302	187.217	187.206	186.966	314.321
101.538	180.672	180.593	180.577	180.378	181.48	185.605	182.113	182.382	189.091	180.672	180.593	180.577	180.378	273.491
96.9231	177.722	177.643	177.624	177.435	178.633	182.43	179.224	179.393	185.516	177.722	177.643	177.624	177.435	259.994
92.3077	176.065	175.986	175.965	175.772	176.971	180.827	177.57	177.755	183.969	176.065	175.986	175.965	175.772	259.994
87.6923	174.227	174.148	174.125	173.927	175.144	179.077	175.754	175.95	182.284	174.227	174.148	174.125	173.927	259.994
83.0769	172.239	172.158	172.134	171.931	173.205	177.254	173.834	174.027	180.537	172.239	172.158	172.134	171.931	259.997
78.4615	170.206	170.119	170.096	169.887	171.304	175.568	171.97	172.146	178.956	170.206	170.119	170.096	169.887	260.236
73.8462	168.507	168.413	168.396	168.171	169.669	174.482	170.416	170.693	178.329	168.507	168.413	168.396	168.171	269.998
69.2308	166.376	166.287	166.276	166.021	167.08	172.783	167.933	168.614	177.817	166.376	166.287	166.276	166.021	299.99
64.6154	159.57	159.494	159.486	159.235	159.863	165.474	160.683	161.6	170.672	159.57	159.494	159.486	159.235	299.97
60	150.641	150.592	150.584	150.342	150.149	155.284	150.865	152.09	160.57	150.641	150.592	150.584	150.342	298.513
55.3846	137.383	137.354	137.341	137.161	136.824	140.053	137.263	138.187	143.506	137.383	137.354	137.341	137.161	240.849
50.7692	127.034	127.011	126.99	126.863	126.892	128.736	127.148	127.622	130.589	127.034	127.011	126.99	126.863	184.371
46.1538	121.764	121.741	121.717	121.592	121.67	123.407	121.912	122.354	125.12	121.764	121.741	121.717	121.592	174.996
41.5385	116.937	116.913	116.887	116.753	116.79	118.66	117.049	117.557	120.52	116.937	116.913	116.887	116.753	174.996
36.9231	111.499	111.474	111.445	111.303	111.292	113.31	111.569	112.151	115.334	111.499	111.474	111.445	111.303	174.995
32.3077	105.375	105.349	105.318	105.168	105.098	107.28	105.396	106.062	109.487	105.375	105.349	105.318	105.168	174.995
27.6923	98.4728	98.4447	98.4122	98.2549	98.111	100.471	98.4305	99.1953	102.882	98.4728	98.4447	98.4122	98.2549	174.995
23.0769	90.6773	90.6473	90.6149	90.4514	90.2055	92.754	90.5471	91.4298	95.3917	90.6773	90.6473	90.6149	90.4514	174.994
18.4615	81.8293	81.7979	81.7679	81.6005	81.1993	83.932	81.5602	82.5922	86.8182	81.8293	81.7979	81.7679	81.6005	174.993
13.8462	71.6779	71.6472	71.6231	71.4551	70.7873	73.663	71.1567	72.3929	76.8184	71.6779	71.6472	71.6231	71.4551	174.992
9.23077	59.7906	59.768	59.7539	59.5906	58.4148	61.2888	58.7621	60.2797	64.7224	59.7906	59.768	59.7539	59.5906	174.941
4.61538	45.2787	45.2831	45.2807	45.1356	43.0973	45.4954	43.346	45.0381	49.0468	45.2787	45.2831	45.2807	45.1356	171.241

NOZZLE AIR FLOW 340 °C SIMULATION RESULTS

APPENDIX 3

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	162.1	162.098	162.078	162.14	163.108	161.562	162.92	161.98	159.71	162.1	162.098	162.078	162.14	100.7
175.385	169.859	169.839	169.819	169.832	171.001	170.284	170.943	170.096	169.071	169.859	169.839	169.819	169.832	128.392
170.769	177.312	177.271	177.251	177.217	178.6	178.745	178.676	177.917	178.209	177.312	177.271	177.251	177.217	156.085
166.154	184.41	184.348	184.327	184.251	185.855	186.905	186.072	185.398	187.086	184.41	184.348	184.327	184.251	183.778
161.538	191.087	191.006	190.984	190.868	192.701	194.698	193.064	192.473	195.644	191.087	191.006	190.984	190.868	211.47
156.923	197.247	197.148	197.126	196.972	199.032	202.021	199.548	199.041	203.787	197.247	197.148	197.126	196.972	239.163
152.308	202.74	202.625	202.603	202.413	204.681	208.7	205.354	204.944	211.35	202.74	202.625	202.603	202.413	266.856
147.692	207.32	207.193	207.172	206.946	209.36	214.427	210.189	209.907	218.028	207.32	207.193	207.172	206.946	294.545
143.077	210.563	210.429	210.409	210.151	212.559	218.609	213.526	213.426	223.226	210.563	210.429	210.409	210.151	321.997
138.462	211.58	211.445	211.426	211.148	213.446	220.099	214.493	214.546	225.434	211.58	211.445	211.426	211.148	339.991
133.846	210.416	210.28	210.261	209.98	212.293	219.001	213.349	213.407	224.38	210.416	210.28	210.261	209.98	339.991
129.231	209.148	209.011	208.993	208.711	211.072	217.876	212.143	212.199	223.311	209.148	209.011	208.993	208.711	340.036
124.615	207.885	207.745	207.73	207.444	209.886	216.92	210.993	211.072	222.506	207.885	207.745	207.73	207.444	341.996
120	206.762	206.626	206.615	206.313	208.489	216.109	209.666	209.984	222.498	206.762	206.626	206.615	206.313	359.988
115.385	202.609	202.483	202.475	202.177	204.031	211.554	205.178	205.667	218.044	202.609	202.483	202.475	202.177	359.975
110.769	196.926	196.822	196.814	196.524	197.741	204.863	198.803	199.533	211.398	196.926	196.822	196.814	196.524	358.995
106.154	188.075	187.989	187.978	187.731	188.66	194.226	189.49	190.094	199.324	188.075	187.989	187.978	187.731	320.356
101.538	180.838	180.758	180.743	180.542	181.633	185.799	182.271	182.553	189.336	180.838	180.758	180.743	180.542	274.991
96.9231	177.722	177.643	177.624	177.435	178.633	182.431	179.224	179.393	185.516	177.722	177.643	177.624	177.435	259.994
92.3077	176.065	175.986	175.965	175.772	176.971	180.827	177.57	177.755	183.969	176.065	175.986	175.965	175.772	259.994
87.6923	174.227	174.148	174.125	173.927	175.144	179.077	175.754	175.95	182.284	174.227	174.148	174.125	173.927	259.994
83.0769	172.239	172.158	172.134	171.931	173.205	177.254	173.834	174.027	180.537	172.239	172.158	172.134	171.931	259.997
78.4615	170.205	170.119	170.096	169.887	171.304	175.568	171.97	172.146	178.958	170.205	170.119	170.096	169.887	260.236
73.8462	168.507	168.413	168.396	168.171	169.669	174.482	170.416	170.693	178.329	168.507	168.413	168.396	168.171	269.998
69.2308	166.376	166.287	166.276	166.021	167.079	172.782	167.933	168.614	177.816	166.376	166.287	166.276	166.021	299.99
64.6154	159.57	159.493	159.486	159.235	159.863	165.474	160.683	161.6	170.672	159.57	159.493	159.486	159.235	299.97
60	150.641	150.591	150.584	150.342	150.149	155.284	150.865	152.089	160.57	150.641	150.591	150.584	150.342	298.513
55.3846	137.383	137.354	137.341	137.16	136.823	140.053	137.263	138.187	143.506	137.383	137.354	137.341	137.16	240.849
50.7692	127.033	127.011	126.99	126.863	126.892	128.736	127.147	127.622	130.587	127.033	127.011	126.99	126.863	184.371
46.1538	121.763	121.741	121.717	121.591	121.669	123.407	121.911	122.354	125.12	121.763	121.741	121.717	121.591	174.996
41.5385	116.937	116.913	116.887	116.753	116.79	118.66	117.049	117.557	120.52	116.937	116.913	116.887	116.753	174.996
36.9231	111.5	111.475	111.446	111.304	111.293	113.311	111.57	112.152	115.334	111.5	111.475	111.446	111.304	174.995
32.3077	105.375	105.349	105.318	105.167	105.098	107.279	105.395	106.062	109.486	105.375	105.349	105.318	105.167	174.995
27.6923	98.4711	98.4431	98.4108	98.2529	98.1094	100.47	98.4289	99.1937	102.881	98.4711	98.4431	98.4108	98.2529	174.995
23.0769	90.6769	90.6469	90.6148	90.4507	90.205	92.7535	90.5466	91.4293	95.3912	90.6769	90.6469	90.6148	90.4507	174.994
18.4615	81.8284	81.7971	81.7674	81.5991	81.1984	83.9315	81.5594	82.5914	86.8179	81.8284	81.7971	81.7674	81.5991	174.993
13.8462	71.6791	71.6485	71.625	71.4556	70.7887	73.6642	71.158	72.3941	76.8197	71.6791	71.6485	71.625	71.4556	174.992
9.23077	59.7921	59.7697	59.7565	59.5909	58.4164	61.2899	58.7636	60.2811	64.7238	59.7921	59.7697	59.7565	59.5909	174.941
4.61538	45.2771	45.281	45.2806	45.1314	43.0955	45.4939	43.3442	45.0364	49.0459	45.2771	45.281	45.2806	45.1314	171.241

NOZZLE AIR FLOW VOLUME 8L/MIN RESULTS

APPENDIX 4

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	158.802	158.802	158.787	158.832	159.544	158.14	159.368	158.609	156.498	158.802	158.802	158.787	158.832	100.785
175.385	165.098	165.081	165.067	165.071	165.988	165.316	165.926	165.236	164.248	165.098	165.081	165.067	165.071	126.169
170.769	171.123	171.085	171.072	171.037	172.169	172.26	172.227	171.603	171.796	171.123	171.085	171.072	171.037	151.554
166.154	176.834	176.777	176.764	176.694	178.05	178.937	178.232	177.669	179.111	176.834	176.777	176.764	176.694	176.938
161.538	182.181	182.106	182.091	181.989	183.576	185.295	183.887	183.383	186.146	182.181	182.106	182.091	181.989	202.322
156.923	187.086	186.995	186.979	186.847	188.666	191.25	189.109	188.666	192.823	187.086	186.995	186.979	186.847	227.706
152.308	191.431	191.326	191.309	191.148	193.183	196.663	193.763	193.388	199.007	191.431	191.326	191.309	191.148	253.09
147.692	195.018	194.901	194.885	194.696	196.896	201.282	197.611	197.33	204.451	195.018	194.901	194.885	194.696	278.468
143.077	197.509	197.385	197.368	197.155	199.394	204.624	200.229	200.085	208.663	197.509	197.385	197.368	197.155	303.581
138.462	198.203	198.079	198.06	197.832	200.013	205.756	200.916	200.887	210.401	198.203	198.079	198.06	197.832	319.978
133.846	197.159	197.036	197.017	196.787	198.984	204.774	199.894	199.867	209.457	197.159	197.036	197.017	196.787	319.978
129.231	196.039	195.915	195.896	195.665	197.911	203.787	198.836	198.804	208.518	196.039	195.915	195.896	195.665	320.034
124.615	194.943	194.815	194.799	194.566	196.896	202.982	197.854	197.836	207.85	194.943	194.815	194.799	194.566	322.087
120	193.977	193.853	193.838	193.592	195.73	202.355	196.754	196.93	207.949	193.977	193.853	193.838	193.592	339.972
115.385	190.435	190.321	190.307	190.066	191.942	198.477	192.94	193.251	204.147	190.435	190.321	190.307	190.066	339.953
110.769	185.663	185.568	185.554	185.319	186.676	192.861	187.6	188.103	198.549	185.663	185.568	185.554	185.319	338.873
106.154	178.416	178.339	178.324	178.122	179.18	184.049	179.907	180.325	188.525	178.416	178.339	178.324	178.122	304.069
101.538	172.438	172.368	172.352	172.183	173.297	176.985	173.862	174.046	180.15	172.438	172.368	172.352	172.183	263.404
96.9231	169.666	169.598	169.579	169.418	170.596	173.973	171.12	171.222	176.762	169.666	169.598	169.579	169.418	249.986
92.3077	168.006	167.938	167.918	167.753	168.933	172.363	169.464	169.58	175.203	168.006	167.938	167.918	167.753	249.985
87.6923	166.173	166.106	166.083	165.914	167.112	170.612	167.654	167.778	173.513	166.173	166.106	166.083	165.914	249.985
83.0769	164.197	164.129	164.105	163.931	165.184	168.79	165.743	165.863	171.76	164.197	164.129	164.105	163.931	249.99
78.4615	162.173	162.102	162.077	161.899	163.288	167.095	163.881	163.984	170.168	162.173	162.102	162.077	161.899	250.283
73.8462	160.433	160.356	160.334	160.144	161.634	165.956	162.304	162.487	169.456	160.433	160.356	160.334	160.144	260.159
69.2308	158.288	158.216	158.196	157.983	159.148	164.304	159.919	160.434	168.905	158.288	158.216	158.196	157.983	289.975
64.6154	152.094	152.035	152.017	151.808	152.614	157.682	153.355	154.064	162.417	152.094	152.035	152.017	151.808	289.947
60	144.115	144.082	144.061	143.861	143.977	148.618	144.627	145.589	153.41	144.115	144.082	144.061	143.861	288.307
55.3846	132.635	132.622	132.599	132.444	132.336	135.31	132.742	133.492	138.504	132.635	132.622	132.599	132.444	235.274
50.7692	123.451	123.446	123.418	123.303	123.401	125.166	123.644	124.061	126.973	123.451	123.446	123.418	123.303	183.566
46.1538	118.261	118.258	118.227	118.112	118.234	119.91	118.465	118.866	121.606	118.261	118.258	118.227	118.112	174.99
41.5385	113.335	113.331	113.297	113.175	113.262	115.06	113.508	113.969	116.894	113.335	113.331	113.297	113.175	174.989
36.9231	107.819	107.815	107.779	107.65	107.696	109.628	107.959	108.486	111.616	107.819	107.815	107.779	107.65	174.988
32.3077	101.648	101.643	101.605	101.468	101.466	103.547	101.748	102.35	105.705	101.648	101.643	101.605	101.468	174.987
27.6923	94.7428	94.7353	94.6967	94.5527	94.4903	96.7319	94.7914	95.4804	99.0785	94.7428	94.7353	94.6967	94.5527	174.986
23.0769	87.0045	86.9939	86.9566	86.8056	86.6611	89.0724	86.9821	87.774	91.6265	87.0045	86.9939	86.9566	86.8056	174.984
18.4615	78.3014	78.2867	78.2548	78.0959	77.8273	80.4038	78.1655	79.0866	83.1839	78.3014	78.2867	78.2548	78.0959	174.983
13.8462	68.4297	68.4105	68.392	68.2201	67.7371	70.4394	68.0828	69.179	73.4613	68.4297	68.4105	68.392	68.2201	174.98
9.23077	57.029	57.008	57.0182	56.8148	55.9216	58.6145	56.2468	57.5819	61.8807	57.029	57.008	57.0182	56.8148	174.904
4.61538	43.3589	43.3483	43.4061	43.1431	41.5582	43.7955	41.7924	43.2613	47.1324	43.3589	43.3483	43.4061	43.1431	170.41

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	160.129	160.132	160.108	160.196	161.233	159.553	161.025	160.008	157.598	160.129	160.132	160.108	160.196	100.522
175.503	167.941	167.927	167.904	167.94	169.135	168.214	169.045	168.13	166.844	167.941	167.927	167.904	167.94	125.256
171.006	175.464	175.433	175.41	175.397	176.756	176.623	176.789	175.973	175.868	175.464	175.433	175.41	175.397	149.991
166.509	182.652	182.605	182.581	182.522	184.049	184.737	184.209	183.491	184.631	182.652	182.605	182.581	182.522	174.724
162.012	189.442	189.379	189.356	189.253	190.949	192.493	191.242	190.622	193.076	189.442	189.379	189.356	189.253	199.458
157.515	195.747	195.669	195.645	195.501	197.361	199.798	197.791	197.275	201.115	195.747	195.669	195.645	195.501	224.193
153.018	201.434	201.342	201.319	201.136	203.139	206.503	203.71	203.31	208.604	201.434	201.342	201.319	201.136	248.927
148.521	206.296	206.193	206.172	205.95	208.045	212.354	208.757	208.501	215.299	206.296	206.193	206.172	205.95	273.66
144.024	209.988	209.876	209.859	209.601	211.663	216.885	212.504	212.446	220.737	209.988	209.876	209.859	209.601	298.334
139.527	211.844	211.733	211.717	211.429	213.277	219.198	214.209	214.379	223.897	211.844	211.733	211.717	211.429	319.997
135.03	210.89	210.778	210.762	210.473	212.331	218.301	213.271	213.446	223.038	210.89	210.778	210.762	210.473	319.997
130.533	209.854	209.741	209.726	209.433	211.332	217.379	212.285	212.456	222.162	209.854	209.741	209.726	209.433	320
126.035	208.812	208.694	208.682	208.387	210.381	216.592	211.361	211.534	221.451	208.812	208.694	208.682	208.387	320.291
121.538	208.161	208.045	208.038	207.725	209.519	216.229	210.562	210.938	221.707	208.161	208.045	208.038	207.725	333.973
117.041	205.368	205.258	205.257	204.938	206.425	213.288	207.475	208.052	219.112	205.368	205.258	205.257	204.938	339.992
112.544	200.575	200.479	200.48	200.166	201.167	207.8	202.162	202.952	213.712	200.575	200.479	200.48	200.166	339.616
108.047	193.393	193.316	193.314	193.028	193.611	199.33	194.458	195.285	204.61	193.393	193.316	193.314	193.028	321.561
103.55	185.319	185.251	185.243	185.009	185.674	189.984	186.322	186.845	193.814	185.319	185.251	185.243	185.009	281.277
99.0532	180.295	180.227	180.214	180.015	181.011	184.473	181.55	181.759	187.258	180.295	180.227	180.214	180.015	249.998
94.5562	178.938	178.869	178.854	178.651	179.645	183.159	180.192	180.417	185.993	178.938	178.869	178.854	178.651	249.998
90.0592	177.424	177.354	177.337	177.129	178.132	181.71	178.688	178.926	184.602	177.424	177.354	177.337	177.129	249.998
85.5621	175.769	175.698	175.679	175.465	176.502	180.17	177.073	177.314	183.128	175.769	175.698	175.679	175.465	249.998
81.0651	174.035	173.961	173.941	173.721	174.851	178.664	175.446	175.672	181.7	174.035	173.961	173.941	173.721	250.004
76.568	172.397	172.313	172.297	172.069	173.405	177.512	174.051	174.262	180.672	172.397	172.313	172.297	172.069	250.494
72.071	171.616	171.529	171.521	171.259	172.338	177.284	173.093	173.627	181.392	171.616	171.529	171.521	171.259	273.778
67.574	167.874	167.794	167.793	167.511	168.116	173.542	168.919	169.81	178.403	167.874	167.794	167.793	167.511	289.993
63.0769	160.524	160.458	160.462	160.183	160.221	165.459	160.972	162.135	170.478	160.524	160.458	160.462	160.183	289.641
58.5799	150.302	150.258	150.26	150.008	149.46	153.834	150.062	151.342	158.394	150.302	150.258	150.26	150.008	272.567
54.0828	137.916	137.885	137.879	137.693	137.246	139.991	137.617	138.509	142.926	137.916	137.885	137.879	137.693	220.967
49.5858	128.768	128.739	128.723	128.588	128.653	130.336	128.89	129.32	131.957	128.768	128.739	128.723	128.588	174.999
45.0888	124.602	124.572	124.554	124.409	124.433	126.244	124.686	125.18	128.004	124.602	124.572	124.554	124.409	174.999
40.5917	119.889	119.857	119.837	119.682	119.658	121.614	119.93	120.496	123.529	119.889	119.857	119.837	119.682	174.999
36.0947	114.558	114.524	114.502	114.337	114.257	116.373	114.549	115.198	118.464	114.558	114.524	114.502	114.337	174.998
31.5976	108.526	108.491	108.467	108.292	108.142	110.436	108.456	109.2	112.724	108.526	108.491	108.467	108.292	174.998
27.1006	101.692	101.655	101.631	101.446	101.205	103.694	101.544	102.399	106.203	101.692	101.655	101.631	101.446	174.998
22.6035	93.9214	93.8827	93.8597	93.6662	93.301	95.9953	93.6637	94.6539	98.7503	93.9214	93.8827	93.8597	93.6662	174.998
18.1065	85.0301	84.9907	84.9713	84.7714	84.2181	87.1143	84.6017	85.7651	90.1421	85.0301	84.9907	84.9713	84.7714	174.998
13.6095	74.7335	74.6965	74.6837	74.4811	73.61	76.6632	74.0025	75.4043	79.9893	74.7335	74.6965	74.6837	74.4811	174.997
9.11243	62.5328	62.5067	62.5026	62.3042	60.8419	63.8982	61.21	62.9428	67.5399	62.5328	62.5067	62.5026	62.3042	174.963
4.61538	47.4129	47.4178	47.4206	47.2442	44.7965	47.3638	45.0599	47.0145	51.1764	47.4129	47.4178	47.4206	47.2442	171.937

SOLDERING PAHASE TIME 40s SIMULATION RESULTS APPENDIX 6

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
190	162.669	162.666	162.649	162.691	163.475	162.383	163.346	162.615	161.045	162.669	162.666	162.649	162.691	118.773
185.128	168.888	168.869	168.851	168.858	169.854	169.333	169.817	169.106	168.403	168.888	168.869	168.851	168.858	137.109
180.256	175.264	175.226	175.208	175.179	176.457	176.582	176.525	175.82	176.085	175.264	175.226	175.208	175.179	155.641
175.385	182.152	182.094	182.075	182.005	183.495	184.489	183.698	183.076	184.684	182.152	182.094	182.075	182.005	182.398
170.513	188.602	188.526	188.506	188.398	190.102	192.006	190.446	189.906	192.937	188.602	188.526	188.506	188.398	209.155
165.641	194.505	194.412	194.392	194.248	196.159	199.011	196.649	196.196	200.732	194.505	194.412	194.392	194.248	235.912
160.769	199.684	199.577	199.558	199.379	201.465	205.295	202.102	201.756	207.863	199.684	199.577	199.558	199.379	262.669
155.897	203.84	203.722	203.705	203.492	205.663	210.465	206.443	206.245	213.947	203.84	203.722	203.705	203.492	289.418
151.026	206.429	206.308	206.292	206.05	208.095	213.734	208.987	208.999	218.173	206.429	206.308	206.292	206.05	315.639
146.154	206.142	206.021	206.005	205.756	207.772	213.571	208.685	208.741	218.197	206.142	206.021	206.005	205.756	319.992
141.282	205.233	205.112	205.095	204.845	206.859	212.69	207.777	207.842	217.348	205.233	205.112	205.095	204.845	319.992
136.41	204.203	204.082	204.065	203.812	205.834	211.709	206.759	206.831	216.405	204.203	204.082	204.065	203.812	319.992
131.538	203.067	202.944	202.927	202.673	204.728	210.673	205.663	205.735	215.415	203.067	202.944	202.927	202.673	319.996
126.667	201.886	201.76	201.745	201.489	203.63	209.728	204.591	204.663	214.545	201.886	201.76	201.745	201.489	320.318
121.795	200.999	200.874	200.863	200.594	202.593	209.167	203.614	203.853	214.564	200.999	200.874	200.863	200.594	333.659
116.923	198.091	197.974	197.966	197.693	199.407	206.128	200.436	200.86	211.86	198.091	197.974	197.966	197.693	339.981
112.051	193.121	193.022	193.014	192.747	193.955	200.391	194.92	195.55	206.184	193.121	193.022	193.014	192.747	339.333
107.179	185.5	185.418	185.409	185.174	186.032	191.31	186.818	187.414	196.146	185.5	185.418	185.409	185.174	312.178
102.308	178.164	178.09	178.076	177.886	178.841	182.761	179.438	179.744	186.134	178.164	178.09	178.076	177.886	268.989
97.4359	174.569	174.497	174.48	174.305	175.391	178.831	175.925	176.085	181.629	174.569	174.497	174.48	174.305	249.995
92.5641	172.913	172.842	172.822	172.643	173.731	177.23	174.274	174.449	180.084	172.913	172.842	172.822	172.643	249.995
87.6923	171.071	170.999	170.977	170.793	171.901	175.479	172.456	172.641	178.399	171.071	170.999	170.977	170.793	249.994
82.8205	169.08	169.005	168.983	168.792	169.966	173.667	170.541	170.721	176.663	169.08	169.005	168.983	168.792	249.999
77.9487	167.068	166.986	166.965	166.768	168.103	172.047	168.719	168.885	175.158	167.068	166.986	166.965	166.768	250.388
73.0769	165.561	165.475	165.459	165.241	166.528	171.144	167.238	167.589	174.929	165.561	165.475	165.459	165.241	266.776
68.2051	162.408	162.329	162.318	162.077	162.936	168.222	163.722	164.435	172.954	162.408	162.329	162.318	162.077	289.985
63.3333	155.016	154.953	154.944	154.708	155.041	160.134	155.775	156.737	165.007	155.016	154.953	154.944	154.708	289.527
58.4615	144.762	144.721	144.711	144.5	144.266	148.449	144.845	145.911	152.787	144.762	144.721	144.711	144.5	269.994
53.5897	132.604	132.58	132.563	132.408	132.212	134.753	132.559	133.28	137.429	132.604	132.58	132.563	132.408	214.44
48.718	124.089	124.068	124.045	123.924	124.021	125.694	124.254	124.665	127.336	124.089	124.068	124.045	123.924	174.996
43.8462	119.303	119.282	119.256	119.127	119.183	120.987	119.433	119.909	122.775	119.303	119.282	119.256	119.127	174.996
38.9744	113.875	113.854	113.825	113.687	113.695	115.647	113.963	114.513	117.598	113.875	113.854	113.825	113.687	174.996
34.1026	107.717	107.698	107.667	107.52	107.467	109.584	107.756	108.39	111.721	107.717	107.698	107.667	107.52	174.995
29.2308	100.725	100.711	100.681	100.525	100.392	102.694	100.704	101.435	105.039	100.725	100.711	100.681	100.525	174.995
24.359	92.7887	92.7854	92.7545	92.5926	92.3524	94.8532	92.6885	93.5334	97.4295	92.7887	92.7854	92.7545	92.5926	174.994
19.4872	83.7461	83.7551	83.725	83.5584	83.1631	85.8597	83.5204	84.5089	88.6918	83.7461	83.7551	83.725	83.5584	174.993
14.6154	73.3256	73.3466	73.3221	73.1542	72.4966	75.3521	72.8651	74.0523	78.4632	73.3256	73.3466	73.3221	73.1542	174.992
9.74359	61.074	61.0974	61.0839	60.9202	59.77	62.6469	60.1201	61.5923	66.0501	61.074	61.0974	61.0839	60.9202	174.947
4.87179	46.0788	46.0816	46.079	45.9327	43.9411	46.3643	44.195	45.8772	49.9091	46.0788	46.0816	46.079	45.9327	171.436

SOLDERING PAHASE TIME 50s SIMULATION RESULTS APPENDIX 7

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
200	164.029	164.023	164.006	164.047	164.899	163.814	164.774	164.007	162.444	164.029	164.023	164.006	164.047	118.826
195.652	169.956	169.935	169.918	169.924	170.968	170.45	170.934	170.198	169.494	169.956	169.935	169.918	169.924	137.162
191.304	175.933	175.895	175.877	175.85	177.132	177.236	177.198	176.483	176.717	175.933	175.895	175.877	175.85	155.638
186.956	182.163	182.107	182.088	182.025	183.496	184.368	183.681	183.039	184.457	182.163	182.107	182.088	182.025	179.388
182.609	188.068	187.995	187.976	187.878	189.543	191.213	189.852	189.28	191.946	188.068	187.995	187.976	187.878	203.138
178.261	193.578	193.49	193.471	193.341	195.196	197.697	195.633	195.134	199.112	193.578	193.49	193.471	193.341	226.889
173.913	198.588	198.487	198.468	198.307	200.337	203.697	200.905	200.488	205.84	198.588	198.487	198.468	198.307	250.639
169.565	202.929	202.816	202.799	202.608	204.771	209.003	205.469	205.158	211.922	202.929	202.816	202.799	202.608	274.388
165.217	206.321	206.2	206.184	205.965	208.155	213.23	208.975	208.813	216.977	206.321	206.2	206.184	205.965	298.096
160.87	208.243	208.122	208.107	207.865	209.894	215.628	210.799	210.827	220.181	208.243	208.122	208.107	207.865	319.992
156.522	207.717	207.596	207.581	207.337	209.361	215.112	210.269	210.304	219.683	207.717	207.596	207.581	207.337	319.992
152.174	207.117	206.996	206.98	206.735	208.755	214.523	209.664	209.708	219.115	207.117	206.996	206.98	206.735	319.992
147.826	206.434	206.313	206.296	206.049	208.066	213.855	208.978	209.03	218.471	206.434	206.313	206.296	206.049	319.992
143.478	205.66	205.539	205.522	205.273	207.287	213.102	208.202	208.264	217.745	205.66	205.539	205.522	205.273	319.992
139.13	204.79	204.669	204.651	204.401	206.416	212.264	207.336	207.405	216.938	204.79	204.669	204.651	204.401	319.992
134.783	203.826	203.705	203.687	203.434	205.464	211.358	206.391	206.463	216.068	203.826	203.705	203.687	203.434	319.992
130.435	202.791	202.668	202.651	202.397	204.47	210.442	205.41	205.477	215.196	202.791	202.668	202.651	202.397	319.998
126.087	201.758	201.632	201.617	201.361	203.534	209.676	204.503	204.571	214.508	201.758	201.632	201.617	201.361	320.432
121.739	201.098	200.974	200.963	200.692	202.665	209.333	203.699	203.966	214.845	201.098	200.974	200.963	200.692	336.451
117.391	198.154	198.037	198.029	197.757	199.472	206.192	200.5	200.925	211.923	198.154	198.037	198.029	197.757	339.982
113.043	193.725	193.624	193.617	193.35	194.613	201.086	195.585	196.199	206.875	193.725	193.624	193.617	193.35	339.479
108.696	187.222	187.139	187.13	186.888	187.746	193.307	188.572	189.219	198.434	187.222	187.139	187.13	186.888	320.526
104.348	180.155	180.082	180.07	179.868	180.707	184.948	181.345	181.76	188.732	180.155	180.082	180.07	179.868	281.846
100	175.563	175.491	175.474	175.302	176.392	179.801	176.923	177.07	182.566	175.563	175.491	175.474	175.302	249.995
95.6521	174.204	174.132	174.114	173.938	175.027	178.481	175.563	175.725	181.291	174.204	174.132	174.114	173.938	249.995
91.3043	172.698	172.626	172.605	172.425	173.521	177.032	174.066	174.24	179.894	172.698	172.626	172.605	172.425	249.994
86.9565	171.056	170.982	170.96	170.775	171.897	175.486	172.454	172.634	178.408	171.056	170.982	170.96	170.775	249.994
82.6087	169.321	169.245	169.222	169.032	170.227	173.935	170.804	170.972	176.926	169.321	169.245	169.222	169.032	249.999
78.2608	167.617	167.534	167.513	167.317	168.676	172.615	169.293	169.441	175.708	167.617	167.534	167.513	167.317	250.344
73.913	166.385	166.297	166.28	166.066	167.448	171.988	168.151	168.437	175.635	166.385	166.297	166.28	166.066	263.448
69.5652	164.293	164.209	164.198	163.958	164.928	170.233	165.721	166.373	174.919	164.293	164.209	164.198	163.958	289.991
65.2174	158.223	158.15	158.142	157.905	158.499	163.728	159.264	160.123	168.56	158.223	158.15	158.142	157.905	289.973
60.8696	150.395	150.345	150.337	150.106	150.005	154.844	150.683	151.809	159.762	150.395	150.345	150.337	150.106	288.782
56.5217	139.103	139.072	139.059	138.877	138.579	141.915	139.036	139.964	145.447	139.103	139.072	139.059	138.877	244.23
52.1739	129.467	129.443	129.425	129.289	129.22	131.288	129.504	130.068	133.419	129.467	129.443	129.425	129.289	195.35
47.8261	123.513	123.49	123.467	123.345	123.438	125.128	123.674	124.093	126.787	123.513	123.49	123.467	123.345	174.996
43.4783	119.176	119.153	119.127	118.997	119.054	120.863	119.305	119.783	122.655	119.176	119.153	119.127	118.997	174.996
39.1304	114.322	114.298	114.27	114.132	114.148	116.089	114.415	114.958	118.028	114.322	114.298	114.27	114.132	174.996
34.7826	108.891	108.865	108.835	108.69	108.656	110.744	108.942	109.559	112.846	108.891	108.865	108.835	108.69	174.995
30.4348	102.814	102.787	102.755	102.602	102.508	104.758	102.814	103.516	107.041	102.814	102.787	102.755	102.602	174.995
26.087	96.0082	95.9792	95.9464	95.7866	95.6158	98.0388	95.9429	96.7431	100.523	96.0082	95.9792	95.9464	95.7866	174.994
21.7391	88.3646	88.3337	88.3015	88.1364	87.8596	90.4634	88.2077	89.1256	93.1676	88.3646	88.3337	88.3015	88.1364	174.994
17.3913	79.7354	79.7034	79.674	79.5059	79.0671	81.8429	79.4324	80.5002	84.7875	79.7354	79.7034	79.674	79.5059	174.993
13.0435	69.8828	69.8521	69.829	69.6611	68.9451	71.845	69.3158	70.5884	75.0476	69.8828	69.8521	69.829	69.6611	174.992
8.69565	58.3958	58.3743	58.3608	58.1984	56.9616	59.8334	57.3059	58.8567	63.2995	58.3958	58.3743	58.3608	58.1984	174.935
4.34783	44.4295	44.435	44.4329	44.2893	42.2001	44.5686	42.4427	44.1446	48.1259	44.4295	44.435	44.4329	44.2893	171.013

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	159.614	159.614	159.622	159.619	160.566	158.614	160.316	159.454	156.413	159.614	159.614	159.622	159.619	100.417
175.385	167.626	167.625	167.612	167.607	168.72	167.634	168.605	167.82	166.109	167.626	167.625	167.612	167.607	125.801
170.769	175.333	175.33	175.296	175.291	176.577	176.391	176.602	175.891	175.574	175.333	175.33	175.296	175.291	151.186
166.154	182.685	182.68	182.628	182.621	184.087	184.838	184.258	183.619	184.767	182.685	182.68	182.628	182.621	176.571
161.538	189.613	189.609	189.54	189.532	191.181	192.908	191.503	190.934	193.628	189.613	189.609	189.54	189.532	201.955
156.923	196.02	196.02	195.936	195.928	197.753	200.498	198.232	197.737	202.059	196.02	196.02	195.936	195.928	227.34
152.308	201.757	201.763	201.667	201.658	203.638	207.437	204.277	203.868	209.898	201.757	201.763	201.667	201.658	252.725
147.692	206.586	206.598	206.492	206.483	208.553	213.422	209.351	209.059	216.85	206.586	206.598	206.492	206.483	278.107
143.077	210.089	210.104	209.993	209.983	211.99	217.866	212.93	212.808	222.324	210.089	210.104	209.993	209.983	303.352
138.462	211.346	211.365	211.25	211.24	213.101	219.594	214.123	214.143	224.78	211.346	211.365	211.25	211.24	319.999
133.846	210.38	210.398	210.283	210.273	212.153	218.707	213.185	213.205	223.937	210.38	210.398	210.283	210.273	320
129.231	209.351	209.37	209.255	209.245	211.184	217.846	212.234	212.246	223.132	209.351	209.37	209.255	209.245	320.027
124.615	208.4	208.42	208.308	208.296	210.333	217.252	211.424	211.451	222.698	208.4	208.42	208.308	208.296	321.838
120	207.752	207.774	207.665	207.653	209.382	216.974	210.555	210.816	223.308	207.752	207.774	207.665	207.653	339.999
115.385	203.831	203.851	203.75	203.738	205.167	212.698	206.317	206.731	219.158	203.831	203.851	203.75	203.738	339.994
110.769	198.395	198.412	198.319	198.308	199.127	206.305	200.198	200.834	212.856	198.395	198.412	198.319	198.308	339.43
106.154	189.676	189.687	189.602	189.591	190.217	195.867	191.06	191.576	201.024	189.676	189.687	189.602	189.591	304.706
101.538	182.497	182.503	182.421	182.411	183.284	187.515	183.934	184.152	191.096	182.497	182.503	182.421	182.411	263.62
96.9231	179.523	179.528	179.444	179.434	180.441	184.293	181.041	181.154	187.411	179.523	179.528	179.444	179.434	250
92.3077	178.079	178.085	177.997	177.987	178.998	182.917	179.608	179.732	186.095	178.079	178.085	177.997	177.987	250
87.6923	176.483	176.49	176.397	176.388	177.42	181.426	178.044	178.173	184.674	176.483	176.49	176.397	176.388	250
83.0769	174.776	174.786	174.689	174.679	175.778	179.914	176.423	176.542	183.242	174.776	174.786	174.689	174.679	250.001
78.4615	173.089	173.101	173.001	172.991	174.255	178.635	174.943	175.033	182.071	173.089	173.101	173.001	172.991	250.154
73.8462	171.898	171.913	171.814	171.803	173.158	178.173	173.941	174.12	182.122	171.898	171.913	171.814	171.803	259.732
69.2308	170.407	170.426	170.33	170.319	171.164	177.242	172.077	172.653	182.563	170.407	170.426	170.33	170.319	289.999
64.6154	163.737	163.754	163.669	163.658	164.084	170.124	164.972	165.769	175.658	163.737	163.754	163.669	163.658	289.992
60	154.876	154.889	154.813	154.803	154.407	160.021	155.196	156.291	165.717	154.876	154.889	154.813	154.803	289.127
55.3846	141.347	141.35	141.285	141.276	140.829	144.464	141.33	142.153	148.27	141.347	141.35	141.285	141.276	236.057
50.7692	130.769	130.769	130.708	130.7	130.705	132.852	131.009	131.414	134.939	130.769	130.769	130.708	130.7	183.702
46.1538	125.598	125.598	125.534	125.525	125.593	127.641	125.885	126.259	129.589	125.598	125.598	125.534	125.525	175
41.5385	120.924	120.925	120.855	120.847	120.873	123.09	121.187	121.621	125.214	120.924	120.925	120.855	120.847	175
36.9231	115.621	115.623	115.547	115.539	115.516	117.923	115.856	116.358	120.247	115.621	115.623	115.547	115.539	175
32.3077	109.603	109.605	109.524	109.516	109.433	112.052	109.8	110.382	114.601	109.603	109.605	109.524	109.516	175
27.6923	102.762	102.764	102.681	102.672	102.512	105.364	102.909	103.583	108.166	102.762	102.764	102.681	102.672	175
23.0769	94.9613	94.9636	94.8793	94.8712	94.6017	97.7052	95.0303	95.8188	100.791	94.9613	94.9636	94.8793	94.8712	174.999
18.4615	86.0063	86.0089	85.9274	85.9197	85.4817	88.8393	85.9394	86.8762	92.2424	86.0063	86.0089	85.9274	85.9197	174.999
13.8462	75.5934	75.5963	75.5231	75.5164	74.7834	78.3557	75.2588	76.4047	82.1102	75.5934	75.5963	75.5231	75.5164	174.999
9.23077	63.1882	63.1913	63.1338	63.1289	61.82	65.446	62.2777	63.7251	69.5783	63.1882	63.1913	63.1338	63.1289	174.978
4.61538	47.7064	47.7095	47.6758	47.6742	45.3247	48.4247	45.6671	47.3404	52.7871	47.7064	47.7095	47.6758	47.6742	172.556

NOZZLE SIZE 13MM*13MM SIMULATION RESULTS

APPENDIX 9

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	160.516	160.536	160.543	160.571	161.719	160.236	161.54	160.708	158.411	160.516	160.536	160.543	160.571	100.595
175.385	168.24	168.256	168.237	168.258	169.492	168.725	169.424	168.653	167.467	168.24	168.256	168.237	168.258	125.978
170.769	175.656	175.667	175.624	175.637	176.963	176.945	177.012	176.3	176.287	175.656	175.667	175.624	175.637	151.361
166.154	182.712	182.722	182.653	182.66	184.083	184.848	184.253	183.598	184.827	182.712	182.722	182.653	182.66	176.745
161.538	189.34	189.352	189.257	189.257	190.778	192.363	191.074	190.476	193.021	189.34	189.352	189.257	189.257	202.128
156.923	195.439	195.453	195.333	195.327	196.937	199.381	197.365	196.83	200.766	195.439	195.453	195.333	195.327	227.512
152.308	200.853	200.87	200.728	200.715	202.388	205.721	202.949	202.493	207.889	200.853	200.87	200.728	200.715	252.895
147.692	205.336	205.355	205.193	205.172	206.842	211.078	207.536	207.191	214.091	205.336	205.355	205.193	205.172	278.275
143.077	208.466	208.487	208.307	208.278	209.801	214.881	210.612	210.434	218.798	208.466	208.487	208.307	208.278	303.46
138.462	209.357	209.379	209.189	209.153	210.478	216.076	211.356	211.321	220.633	209.357	209.379	209.189	209.153	319.993
133.846	208.032	208.054	207.864	207.827	209.145	214.791	210.03	210.007	219.397	208.032	208.054	207.864	207.827	319.993
129.231	206.531	206.552	206.364	206.326	207.654	213.38	208.551	208.539	218.045	206.531	206.552	206.364	206.326	320.033
124.615	204.913	204.934	204.749	204.709	206.029	211.937	206.951	206.991	216.756	204.913	204.934	204.749	204.709	321.954
120	203.237	203.258	203.07	203.021	203.843	210.214	204.809	205.142	215.814	203.237	203.258	203.07	203.021	339.981
115.385	197.83	197.851	197.669	197.618	197.877	203.91	198.77	199.318	209.569	197.83	197.851	197.669	197.618	339.183
110.769	189.354	189.373	189.215	189.174	189.362	194.087	190.062	190.493	198.51	189.354	189.373	189.215	189.174	304.419
106.154	182.473	182.491	182.355	182.326	182.858	186.399	183.4	183.547	189.452	182.473	182.491	182.355	182.326	263.522
101.538	179.648	179.665	179.534	179.508	180.194	183.419	180.696	180.743	186.071	179.648	179.665	179.534	179.508	249.995
96.9231	178.275	178.292	178.157	178.13	178.81	182.082	179.318	179.378	184.781	178.275	178.292	178.157	178.13	249.995
92.3077	176.746	176.764	176.624	176.597	177.282	180.614	177.798	177.866	183.368	176.746	176.764	176.624	176.597	249.995
87.6923	175.085	175.103	174.959	174.931	175.647	179.067	176.178	176.242	181.884	175.085	175.103	174.959	174.931	249.995
83.0769	173.364	173.382	173.235	173.206	174.016	177.585	174.573	174.614	180.478	173.364	173.382	173.235	173.206	250.005
78.4615	171.789	171.808	171.66	171.63	172.641	176.529	173.252	173.275	179.56	171.789	171.808	171.66	171.63	250.799
73.8462	171.336	171.356	171.193	171.149	171.601	176.48	172.334	172.742	180.795	171.336	171.356	171.193	171.149	285.025
69.2308	165.9	165.92	165.761	165.712	165.766	170.748	166.495	167.126	175.395	165.9	165.92	165.761	165.712	289.983
64.6154	158.101	158.121	157.97	157.916	157.361	162.074	158.025	158.911	166.853	158.101	158.121	157.97	157.916	289.287
60	146.959	146.977	146.848	146.799	145.979	149.564	146.467	147.335	153.438	146.959	146.977	146.848	146.799	258.816
55.3846	135.695	135.708	135.608	135.572	135.056	137.26	135.354	135.913	139.655	135.695	135.708	135.608	135.572	208.439
50.7692	128.116	128.128	128.041	128.014	127.885	129.405	128.096	128.407	130.936	128.116	128.128	128.041	128.014	174.997
46.1538	123.888	123.9	123.806	123.777	123.593	125.225	123.818	124.181	126.887	123.888	123.9	123.806	123.777	174.996
41.5385	119.106	119.118	119.017	118.986	118.738	120.496	118.978	119.4	122.305	119.106	119.118	119.017	118.986	174.996
36.9231	113.699	113.711	113.604	113.569	113.247	115.147	113.505	113.994	117.12	113.699	113.711	113.604	113.569	174.996
32.3077	107.585	107.596	107.483	107.445	107.036	109.091	107.312	107.879	111.25	107.585	107.596	107.483	107.445	174.995
27.6923	100.664	100.675	100.556	100.515	99.9975	102.224	100.294	100.951	104.588	100.664	100.675	100.556	100.515	174.995
23.0769	92.8097	92.8184	92.6971	92.6529	91.994	94.3992	92.3112	93.0786	96.9937	92.8097	92.8184	92.6971	92.6529	174.994
18.4615	83.8448	83.8513	83.7307	83.6831	82.8243	85.4037	83.1586	84.0681	88.2523	83.8448	83.8513	83.7307	83.6831	174.994
13.8462	73.4994	73.5029	73.3881	73.3373	72.1631	74.8757	72.5035	73.6099	78.0015	73.4994	73.5029	73.3881	73.3373	174.992
9.23077	61.3079	61.3081	61.2059	61.152	59.4278	62.1393	59.7453	61.1262	65.5571	61.3079	61.3081	61.2059	61.152	174.95
4.61538	46.3318	46.3303	46.2474	46.1914	43.6245	45.9061	43.8507	45.4167	49.4706	46.3318	46.3303	46.2474	46.1914	171.541

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	158.846	158.851	158.83	158.883	159.981	158.514	159.802	158.781	156.773	158.846	158.851	158.83	158.883	100.757
175.385	166.161	166.146	166.126	166.136	167.361	166.644	167.299	166.408	165.48	166.161	166.146	166.126	166.136	126.119
170.769	173.201	173.163	173.145	173.115	174.473	174.536	174.533	173.77	173.981	173.201	173.163	173.145	173.115	151.482
166.154	179.919	179.858	179.843	179.775	181.274	182.151	181.46	180.823	182.24	179.919	179.858	179.843	179.775	176.845
161.538	186.256	186.174	186.159	186.058	187.699	189.427	188.017	187.506	190.2	186.256	186.174	186.159	186.058	202.206
156.923	192.124	192.022	192.009	191.878	193.654	196.27	194.108	193.73	197.773	192.124	192.022	192.009	191.878	227.566
152.308	197.388	197.268	197.257	197.096	198.985	202.519	199.579	199.347	204.804	197.388	197.268	197.257	197.096	252.926
147.692	201.822	201.687	201.679	201.491	203.426	207.886	204.157	204.106	211.011	201.822	201.687	201.679	201.491	278.28
143.077	205.031	204.885	204.882	204.667	206.499	211.819	207.35	207.534	215.835	205.031	204.885	204.882	204.667	303.403
138.462	206.139	205.991	205.99	205.758	207.421	213.262	208.341	208.709	217.905	206.139	205.991	205.99	205.758	319.852
133.846	205.157	205.007	205.006	204.774	206.453	212.345	207.381	207.752	217.026	205.157	205.007	205.006	204.774	319.852
129.231	204.116	203.964	203.964	203.73	205.465	211.451	206.409	206.775	216.18	204.116	203.964	203.964	203.73	319.898
124.615	203.155	202.999	203.003	202.766	204.579	210.786	205.558	205.953	215.654	203.155	202.999	203.003	202.766	321.879
120	202.493	202.339	202.349	202.098	203.57	210.32	204.611	205.296	215.944	202.493	202.339	202.349	202.098	339.819
115.385	198.763	198.617	198.63	198.383	199.539	206.191	200.552	201.405	211.902	198.763	198.617	198.63	198.383	339.8
110.769	193.603	193.477	193.49	193.25	193.799	200.082	194.734	195.813	205.835	193.603	193.477	193.49	193.25	338.861
106.154	185.33	185.226	185.231	185.026	185.432	190.371	186.167	187.044	194.888	185.33	185.226	185.231	185.026	304.11
101.538	178.468	178.375	178.372	178.202	178.91	182.65	179.483	179.968	185.814	178.468	178.375	178.372	178.202	263.366
96.9231	175.525	175.435	175.427	175.266	176.12	179.548	176.653	177.006	182.32	175.525	175.435	175.427	175.266	249.904
92.3077	173.998	173.907	173.897	173.732	174.587	178.07	175.128	175.498	180.894	173.998	173.907	173.897	173.732	249.902
87.6923	172.316	172.224	172.212	172.043	172.914	176.473	173.467	173.848	179.356	172.316	172.224	172.212	172.043	249.9
83.0769	170.519	170.425	170.412	170.238	171.169	174.843	171.741	172.118	177.797	170.519	170.425	170.412	170.238	249.901
78.4615	168.733	168.632	168.621	168.443	169.525	173.416	170.135	170.494	176.471	168.733	168.632	168.621	168.443	250.153
73.8462	167.42	167.31	167.304	167.114	168.246	172.67	168.935	169.425	176.161	167.42	167.31	167.304	167.114	259.932
69.2308	165.849	165.739	165.743	165.527	166.091	171.359	166.878	167.856	175.997	165.849	165.739	165.743	165.527	289.836
64.6154	159.436	159.337	159.344	159.132	159.256	164.427	160.01	161.231	169.216	159.436	159.337	159.344	159.132	289.806
60	150.959	150.885	150.892	150.688	149.996	154.714	150.65	152.176	159.588	150.959	150.885	150.892	150.688	288.375
55.3846	138.064	138.017	138.013	137.858	137.194	140.212	137.602	138.737	143.448	138.064	138.017	138.013	137.858	235.375
50.7692	127.87	127.835	127.82	127.706	127.558	129.356	127.807	128.416	131.155	127.87	127.835	127.82	127.706	183.538
46.1538	122.673	122.639	122.62	122.507	122.42	124.134	122.659	123.232	125.817	122.673	122.639	122.62	122.507	174.931
41.5385	117.917	117.881	117.86	117.74	117.597	119.441	117.852	118.502	121.267	117.917	117.881	117.86	117.74	174.925
36.9231	112.561	112.523	112.5	112.372	112.164	114.152	112.437	113.173	116.139	112.561	112.523	112.5	112.372	174.918
32.3077	106.525	106.486	106.461	106.326	106.038	108.184	106.331	107.166	110.351	106.525	106.486	106.461	106.326	174.91
27.6923	99.707	99.6653	99.6401	99.4983	99.1122	101.432	99.4256	100.376	103.798	99.707	99.6653	99.6401	99.4983	174.901
23.0769	91.9965	91.9525	91.9276	91.7824	91.2635	93.7643	91.5978	92.6865	96.3521	91.9965	91.9525	91.9276	91.7824	174.89
18.4615	83.2254	83.1791	83.1574	83.0107	82.297	84.9706	82.6484	83.9124	87.8014	83.2254	83.1791	83.1574	83.0107	174.878
13.8462	73.1193	73.0731	73.0592	72.9135	71.8779	74.6753	72.234	73.7366	77.7688	73.1193	73.0731	73.0592	72.9135	174.864
9.23077	61.202	61.1635	61.163	61.0259	59.3956	62.1601	59.7231	61.5516	65.525	61.202	61.1635	61.163	61.0259	174.79
4.61538	46.4541	46.4424	46.4644	46.3406	43.7503	46.0115	43.973	45.9924	49.4931	46.4541	46.4424	46.4644	46.3406	170.842

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	158.161	158.184	158.11	158.137	159.267	157.636	159.059	157.892	155.811	158.161	158.184	158.11	158.137	102.585
175.385	165.662	165.666	165.619	165.58	166.858	166.046	166.782	165.785	164.829	165.662	165.666	165.619	165.58	127.407
170.769	172.897	172.879	172.86	172.759	174.191	174.23	174.251	173.424	173.65	172.897	172.879	172.86	172.759	152.22
166.154	179.823	179.78	179.79	179.631	181.222	182.146	181.423	180.767	182.239	179.823	179.78	179.79	179.631	177.021
161.538	186.378	186.312	186.35	186.139	187.89	189.736	188.237	187.753	190.542	186.378	186.312	186.35	186.139	201.808
156.923	192.477	192.389	192.456	192.196	194.099	196.903	194.596	194.291	198.468	192.477	192.389	192.456	192.196	226.58
152.308	197.98	197.871	197.967	197.664	199.691	203.484	200.341	200.234	205.861	197.98	197.871	197.967	197.664	251.329
147.692	202.657	202.529	202.654	202.313	204.391	209.179	205.192	205.322	212.425	202.657	202.529	202.654	202.313	276.04
143.077	206.092	205.948	206.103	205.732	207.691	213.399	208.624	209.054	217.567	206.092	205.948	206.103	205.732	300.478
138.462	207.34	207.189	207.362	206.976	208.745	215.007	209.751	210.412	219.82	207.34	207.189	207.362	206.976	316.441
133.846	206.381	206.231	206.405	206.015	207.806	214.127	208.822	209.486	218.98	206.381	206.231	206.405	206.015	316.412
129.231	205.378	205.226	205.404	205.01	206.867	213.292	207.901	208.559	218.196	205.378	205.226	205.404	205.01	316.43
124.615	204.494	204.335	204.522	204.123	206.074	212.743	207.148	207.842	217.79	204.494	204.335	204.522	204.123	318.325
120	203.99	203.828	204.038	203.633	205.21	212.459	206.352	207.397	218.286	203.99	203.828	204.038	203.633	335.664
115.385	200.264	200.11	200.321	199.932	201.17	208.32	202.283	203.515	214.238	200.264	200.11	200.321	199.932	335.507
110.769	195.036	194.903	195.109	194.746	195.318	202.072	196.345	197.827	208.034	195.036	194.903	195.109	194.746	334.395
106.154	186.439	186.337	186.503	186.182	186.612	191.936	187.423	188.624	196.629	186.439	186.337	186.503	186.182	300.456
101.538	179.268	179.187	179.31	179.02	179.797	183.844	180.433	181.136	187.139	179.268	179.187	179.31	179.02	260.784
96.9231	176.244	176.168	176.279	175.991	176.938	180.653	177.531	178.068	183.544	176.244	176.168	176.279	175.991	247.658
92.3077	174.738	174.664	174.775	174.479	175.431	179.209	176.033	176.59	182.154	174.738	174.664	174.775	174.479	247.609
87.6923	173.086	173.013	173.126	172.82	173.796	177.658	174.412	174.98	180.666	173.086	173.013	173.126	172.82	247.557
83.0769	171.336	171.261	171.378	171.06	172.11	176.101	172.748	173.311	179.183	171.336	171.261	171.378	171.06	247.508
78.4615	169.631	169.552	169.675	169.343	170.573	174.806	171.254	171.796	177.99	169.631	169.552	169.675	169.343	247.709
73.8462	168.498	168.407	168.551	168.201	169.501	174.32	170.272	170.974	177.96	168.498	168.407	168.551	168.201	257.151
69.2308	167.198	167.101	167.282	166.918	167.6	173.33	168.481	169.768	178.16	167.198	167.101	167.282	166.918	286.04
64.6154	160.81	160.722	160.908	160.562	160.773	166.407	161.619	163.18	171.396	160.81	160.722	160.908	160.562	285.781
60	152.257	152.195	152.374	152.063	151.375	156.523	152.113	154.013	161.605	152.257	152.195	152.374	152.063	284.077
55.3846	138.925	138.9	139.021	138.768	138.122	141.449	138.592	139.98	144.838	138.925	138.9	139.021	138.768	232.325
50.7692	128.393	128.39	128.46	128.242	128.175	130.191	128.47	129.206	132.084	128.393	128.39	128.46	128.242	181.811
46.1538	123.195	123.195	123.26	123.037	123.049	124.982	123.334	124.021	126.755	123.195	123.195	123.26	123.037	173.314
41.5385	118.509	118.508	118.578	118.342	118.306	120.388	118.612	119.384	122.311	118.509	118.508	118.578	118.342	173.159
36.9231	113.23	113.228	113.302	113.057	112.962	115.209	113.29	114.16	117.303	113.23	113.228	113.302	113.057	172.984
32.3077	107.284	107.279	107.358	107.104	106.938	109.368	107.29	108.271	111.651	107.284	107.279	107.358	107.104	172.787
27.6923	100.577	100.568	100.653	100.395	100.135	102.764	100.513	101.625	105.257	100.577	100.568	100.653	100.395	172.563
23.0769	92.9874	92.9713	93.0642	92.8071	92.417	95.2548	92.8201	94.0902	97.9811	92.9874	92.9713	93.0642	92.8071	172.309
18.4615	84.3354	84.3101	84.4123	84.1651	83.5744	86.6123	83.9988	85.4711	89.5954	84.3354	84.3101	84.4123	84.1651	172.016
13.8462	74.3335	74.2976	74.4106	74.187	73.2475	76.4274	73.6783	75.4301	79.6873	74.3335	74.2976	74.4106	74.187	171.669
9.23077	62.4415	62.3989	62.5224	62.344	60.7332	63.8688	61.13	63.2719	67.4145	62.4415	62.3989	62.5224	62.344	171.187
4.61538	47.4769	47.4508	47.5723	47.4691	44.7204	47.263	44.9906	47.3713	50.9341	47.4769	47.4508	47.5723	47.4691	166.822

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	165.66	165.655	165.634	165.694	166.794	165.226	166.609	165.588	163.278	165.66	165.655	165.634	165.694	100.772
175.385	174.284	174.257	174.236	174.243	175.569	174.915	175.527	174.606	173.672	174.284	174.257	174.236	174.243	131.35
170.769	182.588	182.538	182.517	182.474	184.04	184.344	184.147	183.32	183.849	182.588	182.538	182.517	182.474	161.928
166.154	190.524	190.451	190.429	190.34	192.16	193.47	192.424	191.685	193.773	190.524	190.451	190.429	190.34	192.506
161.538	198.022	197.929	197.906	197.774	199.858	202.229	200.287	199.63	203.386	198.022	197.929	197.906	197.774	223.082
156.923	204.981	204.868	204.845	204.671	207.022	210.508	207.623	207.05	212.586	204.981	204.868	204.845	204.671	253.66
152.308	211.23	211.1	211.077	210.863	213.464	218.115	214.242	213.764	221.191	211.23	211.1	211.077	210.863	284.237
147.692	216.494	216.349	216.327	216.074	218.861	224.704	219.816	219.465	228.866	216.494	216.349	216.327	216.074	314.811
143.077	220.293	220.14	220.12	219.831	222.633	229.603	223.748	223.585	234.928	220.293	220.14	220.12	219.831	345.123
138.462	221.618	221.465	221.444	221.133	223.828	231.49	225.036	225.033	237.642	221.618	221.465	221.444	221.133	364.989
133.846	220.511	220.358	220.337	220.024	222.736	230.454	223.952	223.953	236.648	220.511	220.358	220.337	220.024	364.99
129.231	219.316	219.161	219.141	218.825	221.593	229.409	222.826	222.821	235.66	219.316	219.161	219.141	218.825	365.035
124.615	218.15	217.991	217.973	217.654	220.516	228.573	221.786	221.797	234.977	218.15	217.991	217.973	217.654	366.996
120	217.16	217.006	216.991	216.655	219.275	227.956	220.621	220.859	235.203	217.16	217.006	216.991	216.655	384.987
115.385	213.135	212.991	212.978	212.644	214.966	223.565	216.286	216.685	230.914	213.135	212.991	212.978	212.644	384.975
110.769	207.661	207.537	207.524	207.196	208.924	217.156	210.165	210.796	224.558	207.661	207.537	207.524	207.196	384.091
106.154	199.227	199.119	199.103	198.814	200.24	207.003	201.261	201.803	213.047	199.227	199.119	199.103	198.814	349.315
101.538	192.232	192.13	192.111	191.862	193.396	198.832	194.235	194.511	203.392	192.232	192.13	192.111	191.862	308.488
96.9231	188.983	188.882	188.86	188.621	190.236	195.326	191.03	191.216	199.461	188.983	188.882	188.86	188.621	294.992
92.3077	187.015	186.913	186.889	186.646	188.258	193.414	189.061	189.268	197.617	187.015	186.913	186.889	186.646	294.992
87.6923	184.808	184.706	184.68	184.432	186.055	191.297	186.87	187.094	195.577	184.808	184.706	184.68	184.432	294.992
83.0769	182.379	182.276	182.249	181.996	183.667	189.035	184.501	184.731	193.407	182.379	182.276	182.249	181.996	294.995
78.4615	179.816	179.707	179.683	179.425	181.227	186.825	182.1	182.321	191.319	179.816	179.707	179.683	179.425	295.235
73.8462	177.475	177.361	177.342	177.07	178.939	185.12	179.897	180.231	190.118	177.475	177.361	177.342	177.07	304.999
69.2308	174.509	174.401	174.391	174.09	175.483	182.604	176.551	177.311	188.891	174.509	174.401	174.391	174.09	334.988
64.6154	166.465	166.374	166.368	166.073	166.913	173.893	167.936	168.992	180.37	166.465	166.374	166.368	166.073	334.962
60	155.761	155.704	155.699	155.417	155.189	161.514	156.071	157.523	168.076	155.761	155.704	155.699	155.417	333.091
55.3846	139.551	139.521	139.509	139.31	138.853	142.598	139.36	140.442	146.651	139.551	139.521	139.509	139.31	259.284
50.7692	127.324	127.302	127.282	127.152	127.157	129.064	127.421	127.92	130.993	127.324	127.302	127.282	127.152	186.996
46.1538	121.778	121.757	121.732	121.607	121.685	123.422	121.926	122.368	125.134	121.778	121.757	121.732	121.607	174.996
41.5385	116.951	116.93	116.903	116.769	116.805	118.674	117.064	117.571	120.533	116.951	116.93	116.903	116.769	174.996
36.9231	111.512	111.491	111.461	111.319	111.305	113.322	111.582	112.164	115.345	111.512	111.491	111.461	111.319	174.995
32.3077	105.379	105.361	105.329	105.179	105.103	107.283	105.4	106.066	109.49	105.379	105.361	105.329	105.179	174.995
27.6923	98.46	98.4485	98.4179	98.2602	98.1001	100.463	98.42	99.1821	102.875	98.46	98.4485	98.4179	98.2602	174.995
23.0769	90.6574	90.6564	90.6253	90.4616	90.1935	92.7467	90.5359	91.4114	95.3848	90.6574	90.6564	90.6253	90.4616	174.994
18.4615	81.809	81.8195	81.7902	81.6224	81.1938	83.9311	81.5554	82.5751	86.8174	81.809	81.8195	81.7902	81.6224	174.993
13.8462	71.6547	71.6764	71.6535	71.4847	70.785	73.6645	71.155	72.3747	76.8199	71.6547	71.6764	71.6535	71.4847	174.992
9.23077	59.7652	59.7891	59.778	59.6131	58.4096	61.2875	58.7575	60.2602	64.7216	59.7652	59.7891	59.778	59.6131	174.941
4.61538	45.2769	45.2811	45.2806	45.1321	43.0956	45.494	43.3443	45.0365	49.0456	45.2769	45.2811	45.2806	45.1321	171.241

Pressure | XVelocity | YVelocity | ZVelocity | Temperature | Density | Viscosity | TurbVis

	Tpwb X-low (degC)	Tpwb X-high (degC)	Tpwb Y-high (degC)	Tpwb Y-low (degC)	PWB Center Point (degC)	Tj (degC)	Ts_middle (degC)	Ts_edge (degC)	Tc (degC)	L2_Component_Tb1 (degC)	L2_Component_Tb2 (degC)	L2_Component_Tb3 (degC)	L2_Component_Tb4 (degC)	Nozzle_air_temp (degC)
180	167.017	167.01	166.989	167.048	168.201	166.626	168.017	166.964	164.641	167.017	167.01	166.989	167.048	100.801
175.385	175.978	175.948	175.927	175.931	177.319	176.694	177.284	176.335	175.441	175.978	175.948	175.927	175.931	132.532
170.769	184.613	184.559	184.538	184.491	186.13	186.501	186.251	185.397	186.025	184.613	184.559	184.538	184.491	164.264
166.154	192.874	192.797	192.775	192.681	194.587	196.006	194.871	194.106	196.36	192.874	192.797	192.775	192.681	195.996
161.538	200.692	200.593	200.57	200.431	202.616	205.141	203.072	202.39	206.388	200.692	200.593	200.57	200.431	227.728
156.923	207.957	207.838	207.814	207.633	210.102	213.794	210.738	210.138	216.004	207.957	207.838	207.814	207.633	259.46
152.308	214.495	214.358	214.334	214.111	216.848	221.762	217.67	217.164	225.018	214.495	214.358	214.334	214.111	291.19
147.692	220.015	219.862	219.84	219.577	222.515	228.682	223.524	223.145	233.081	220.015	219.862	219.84	219.577	322.918
143.077	224.013	223.853	223.831	223.531	226.494	233.85	227.671	227.483	239.476	224.013	223.853	223.831	223.531	354.373
138.462	225.43	225.27	225.249	224.925	227.783	235.869	229.057	229.031	242.369	225.43	225.27	225.249	224.925	374.989
133.846	224.305	224.145	224.123	223.797	226.672	234.815	227.955	227.933	241.358	224.305	224.145	224.123	223.797	374.989
129.231	223.089	222.926	222.904	222.576	225.508	233.751	226.808	226.78	240.352	223.089	222.926	222.904	222.576	375.034
124.615	221.897	221.731	221.712	221.38	224.408	232.897	225.746	225.734	239.654	221.897	221.731	221.712	221.38	376.996
120	220.879	220.717	220.701	220.351	223.142	232.269	224.558	224.771	239.888	220.879	220.717	220.701	220.351	394.987
115.385	216.791	216.64	216.626	216.279	218.768	227.813	220.158	220.534	235.538	216.791	216.64	216.626	216.279	394.974
110.769	211.235	211.103	211.089	210.747	212.636	221.309	213.945	214.557	229.089	211.235	211.103	211.089	210.747	394.09
106.154	202.683	202.569	202.552	202.249	203.819	210.997	204.905	205.437	217.39	202.683	202.569	202.552	202.249	359.314
101.538	195.581	195.473	195.452	195.19	196.855	202.68	197.755	198.028	207.557	195.581	195.473	195.452	195.19	318.487
96.9231	192.245	192.137	192.114	191.861	193.605	199.078	194.458	194.644	203.526	192.245	192.137	192.114	191.861	304.992
92.3077	190.188	190.079	190.055	189.797	191.536	197.078	192.399	192.608	201.597	190.188	190.079	190.055	189.797	304.992
87.6923	187.874	187.766	187.739	187.477	189.224	194.855	190.1	190.328	199.456	187.874	187.766	187.739	187.477	304.992
83.0769	185.319	185.209	185.182	184.915	186.707	192.467	187.602	187.838	197.164	185.319	185.209	185.182	184.915	304.995
78.4615	182.603	182.487	182.463	182.191	184.111	190.104	185.045	185.276	194.928	182.603	182.487	182.463	182.191	305.235
73.8462	180.075	179.954	179.936	179.65	181.634	188.221	182.655	183	193.563	180.075	179.954	179.936	179.65	314.999
69.2308	176.866	176.752	176.742	176.428	177.925	185.47	179.058	179.835	192.132	176.866	176.752	176.742	176.428	344.987
64.6154	168.458	168.362	168.357	168.05	168.959	176.347	170.042	171.134	183.208	168.458	168.362	168.357	168.05	344.959
60	157.234	157.174	157.17	156.877	156.644	163.324	157.575	159.089	170.269	157.234	157.174	157.17	156.877	342.969
55.3846	140.16	140.129	140.117	139.912	139.422	143.318	139.95	141.076	147.547	140.16	140.129	140.117	139.912	264.55
50.7692	127.39	127.367	127.347	127.216	127.215	129.141	127.481	127.988	131.091	127.39	127.367	127.347	127.216	187.746
46.1538	121.764	121.742	121.718	121.592	121.67	123.408	121.912	122.354	125.121	121.764	121.742	121.718	121.592	174.996
41.5385	116.938	116.914	116.888	116.754	116.791	118.661	117.05	117.558	120.521	116.938	116.914	116.888	116.754	174.996
36.9231	111.5	111.476	111.447	111.304	111.294	113.311	111.571	112.153	115.335	111.5	111.476	111.447	111.304	174.995
32.3077	105.376	105.35	105.319	105.168	105.099	107.281	105.397	106.063	109.488	105.376	105.35	105.319	105.168	174.995
27.6923	98.4733	98.4453	98.4129	98.2552	98.1116	100.472	98.4311	99.1959	102.883	98.4733	98.4453	98.4129	98.2552	174.995
23.0769	90.6783	90.6484	90.6161	90.4523	90.2066	92.7552	90.5483	91.4309	95.3928	90.6783	90.6484	90.6161	90.4523	174.994
18.4615	81.831	81.7997	81.7699	81.602	81.2011	83.9338	81.562	82.594	86.82	81.831	81.7997	81.7699	81.602	174.993
13.8462	71.6801	71.6495	71.6257	71.457	70.7898	73.6653	71.1591	72.3951	76.8207	71.6801	71.6495	71.6257	71.457	174.992
9.23077	59.7932	59.7707	59.7569	59.5927	58.4177	61.2916	58.7649	60.2823	64.7253	59.7932	59.7707	59.7569	59.5927	174.941
4.61538	45.2819	45.2863	45.2847	45.138	43.1006	45.4981	43.3491	45.0412	49.0492	45.2819	45.2863	45.2847	45.138	171.241