Modeling for Best Results

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Introduction

Packaging of electronics often requires modeling of the thermal and mechanical characteristics to verify the design will meet various requirements. In the area of thermal modeling, ensuring components will not be stressed above (or sometimes below) their limits is critical for meeting lifetime goals of the product. Other critical goals can be surface temperatures for wearable items. Mechanical packaging involves taking various loads (structural, thermal, etc.) and examining how the product reacts to those and verifying no limits are exceeded (commonly stresses, strains, and forces).

With that background, modeling of thermal and mechanical loads is now a regular part of the product development process. To obtain the best results, there is more to modeling than simply throwing loads on a CAD model and solving a detailed model. A good model achieves four key results and these should be considered before pushing the "solve" button in any analysis.

A good model answers the right questions

Sometimes modeling is thought of as a push button approach and the analysis is thought of as something to get done. "Will the product work? Run a model and make sure we have no problems." These are good overall questions, but other questions need to be asked in conjunction – the right questions – so the model will provide the results for the project.

These questions start with rephrasing the requirements the project team has defined, and also importantly, the requirements the customer is seeking. They might be quite broad, such as "product X needs to last operationally for Y hours." This question should lead to a number of more specific questions and goals. For example, the overall product may have a lifetime reliability goal. If the product contains die and SiPs with solder bumps and balls, these will likely require a nonlinear thermal cycling analysis to show solder strains within a certain range to achieve the product goal.

Once the specific goal is determined, it is also important to know how accurate the solution must be for the goal. Usually this is determined by how close the product is to the performance edge. If some initial back of the envelope calculations show a component or surface is 5°C below the maximum temperature, trying to achieve 0.5°C accuracy instead of 2°C accuracy with a solution may not be warranted. That allows for a more coarse and likely less expensive solution to be found. "How accurately do you need to know this?" is a companion question to "What do you need to know?"

Thus a broad product goal or goals should lead to a more detailed and defined set of questions the model must answer. In the thermal and mechanical field, specific questions will need to know what stresses, strains, temperatures, forces, and displacements need to be examined and at what points in the model those must be answered. This gives the analyst the scope of what the model must cover.

When this process of defining the right questions isn't followed, it can easily lead to delays in the desired answers – and sometimes items will be missed, perhaps not found until after the product is launched. If a model must be remeshed for refinement of key regions or must use a different material condition (nonlinear vs. linear) then it must be re-solved. For a small model this is a minor issue, but larger models that may take several hours or a number of days to solve can cause project delays. Defining the problem and questions completely can save large amounts of project time and frequently avoids delays because one avoids this "model creep."

As a consultant, I spend a significant amount of time up front trying to determine what my clients want the model to do, and also what they need the model to do (in some cases those two don't initially overlap well). Those are often different, and a person outside the organization can often clarify these issues. Spending this time up front in project definition and quoting leads to faster simulation results – and less cost.

A good model meets time and budget goals

This is an area not unique to the simulation models, as all parts of a project are subject to time and budget limitations. It is important to the simulation side to understand these limitations. The best practice for this area is to tailor the model so it matches the scope of the right questions to what can be achieved given time and budget constraints.

The best case scenario is when these two areas overlap with room to spare, as then the scope of the model can be adapted so all constraints and model requirements are met. In most of my consulting work, this is the case and the simulation goals can meet everything the client requires.

There are cases where the project needs conflict between the model scope and the time allotted or budget (or sometimes both). Some important compromises need to be worked out in this case. A highly experienced analyst is invaluable in cases such as these because the analyst can recommend tradeoffs to make. The discussion of solution accuracy in the previous section is an example of a tradeoff. Descoping the simulation the least amount while reducing the time or budget of the simulation is a skill experienced analysts possess. This often involves simplifying a model using methods commonly found in engineering practice a few decades ago, but largely untaught in universities today.

As a consultant, when the project has a conflict between the model scope and the time/budget requirements, the client discussions become much more important and detailed to find the best project compromise.

A good model is built to the requirements of questions and project goals

At this point, with the previous two sections completed, the right model can be built. It's now planned to meet the project requirements, and the various specifics of modeling all focus on meeting those requirements. This means meshing, types of physics utilized in the simulation, boundary conditions, process flow steps, and the specifics to examine in the simulation post processing are all incorporated.

This step is one of execution, and not planning. It is a step where one might ask, "how do I do this in the software?", but is not one where one asks "what" or "why" – those should be answered in the previous two steps of planning.

A good model is verifiable

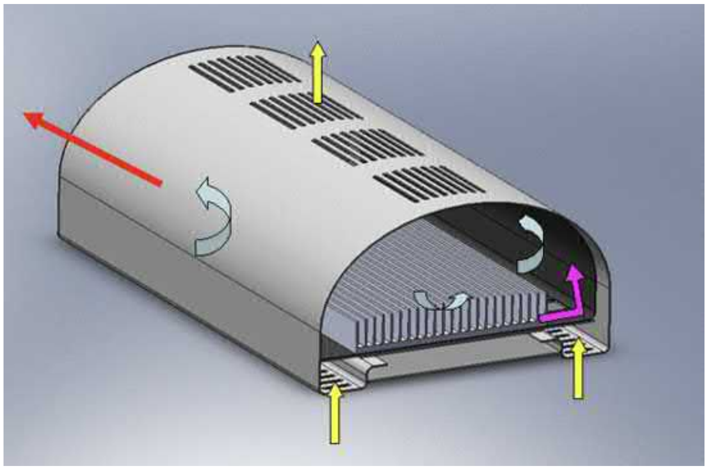
The first two topics generally occur before the simulation is made, and the third one is making (and solving) the simulation. At this point, one now has generated answers. Are we done? No, at this point one now goes back and examines results carefully – against some type of other method/calculation.

There has been a trend in engineering to trust the computer output implicitly, and while much of the time the answers are correct for the physics modeled – something can be missed if a small verification step is not taken. This has become more true as models have become more complex to the point where they cannot be easily verified in some manner. In his book *To Engineer is Human*, Henry Petroski (no relation to the author) wrote:

> "The computer is both blessing and curse for it makes possible calculations once beyond the reach of human experience while at the same time also making them virtually beyond the hope of human verification." (p 197)

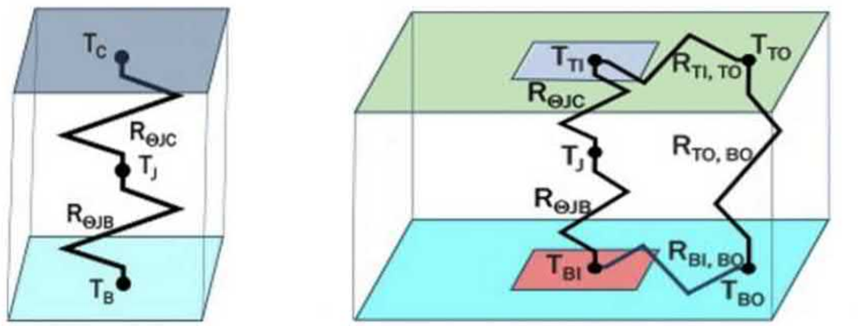
So the difficulty that falls in the analyst's lap is asking, "how can I verify this result to a reasonable degree?" An analyst will need some skills at this point to verify a complicated model. If a complicated FEA (finite element analysis) or CFD (computational fluid dynamics) model was solved, there are a number of methods for some simple calculations. In some cases, a simple equation can be solved to see if the solution is the right magnitude. These can be simple fundamental equations for the relevant field, or they might be one of a number of correlations derived and catalogued in textbooks or formula books. Heat transfer of flowing fluid fields can be solved with natural and forced convection correlations. Structural problems can be simplified and examined with solved equations found in books such as *Roark's Formulas for Stress and Strain*.

If one equation/correlation is not adequate, it is not too difficult to create a model of several equations and solve them simultaneously in a spreadsheet or in a dedicated equation solver. A dedicated equation solver has been an invaluable tool in my consulting practice. Using this type of model first in the early project stages is helpful, as various architectures can be examined with simple parameter changes. A somewhat more complex type of this method is to use a numerical analysis solved by finite difference methods – again, keeping this model simple but faithful to the problem geometry and physics. More details of this type of approach is found in the Electronics Cooling article Strategies for Using Thermal Calculation Methods published originally in 2011 (https://www.electronics-cooling.com/2018/03/strategies-using-thermal-calculation-methods/).



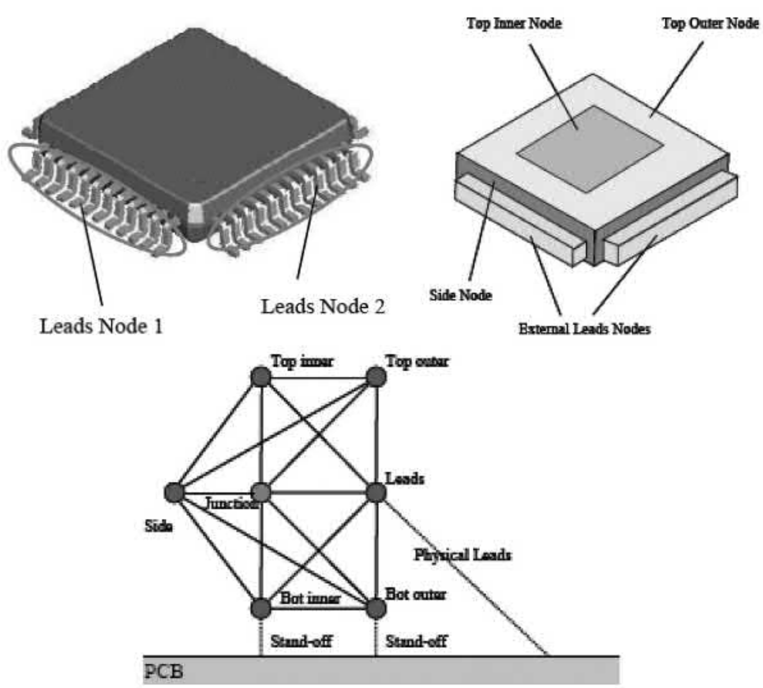
A sample of geometry that can be modeled with 1D correlation equations is shown below. The various arrows represent heat transfer equations such as convection, conduction, air flow, and radiation. Less than ten equations are used to model this system.

Samples of finite difference thermal models are shown with various boundary conditions (https://www.electronics-cooling.com/2019/11/jedec-thermal-standards-developing-a-common-understanding/, and JEDEC JC15.1 figure). The nodes and physics-based connecting links create the model. Some, such as the Delphi model has been commonly used to model more complex semiconductor packages, while other more complex models are created by the analyst as a larger number of nodes and links.

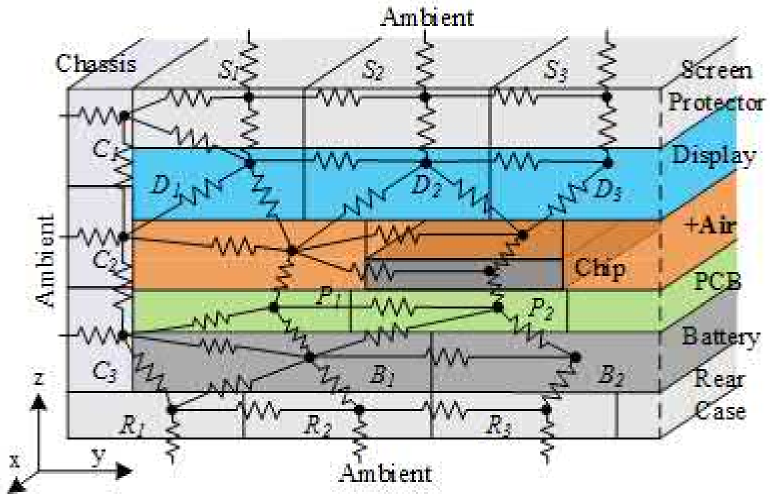


4(a) Two-resistor compact model

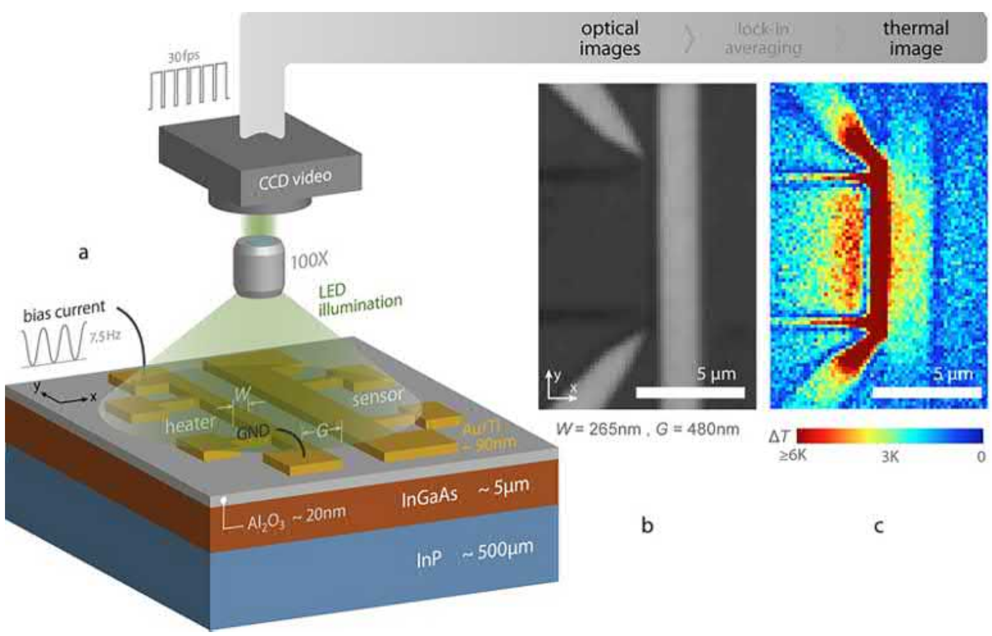
4(b) Delphi compact thermal model



An entire assembly can also be modeled with this thermal network approach as shown below (https://sportlab.usc.edu/download/therminator/therminator.pdf)



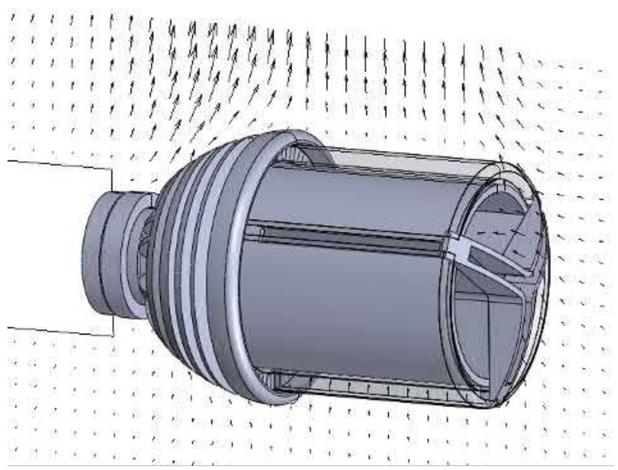
Last, verification can be made by some form of testing. A test of a simplified physical system is best but may not be possible if the product isn't available or if it resides in an unusual location (e.g., a satellite in space). In some cases a simple portion of the product might be testable and provide some degree of verification. One example of a test method was a study conducted by Purdue University of heat flows in semiconductors (https://www.purdue.edu/newsroom/releases/2018/Q1/study-reveals-secrets-of-fluid-like-heat-flow-in-solid-semiconductor-at-nanoscale-findings-important-for-design-of-new-devices.html) which showed phonon level heat flows. A good model will follow the physics of heat transfer needed for the model solution.



A good model will understand and improve the product

Finally, if a company seeks to maximize what a simulation model can do for it, a good model will be useful in pointing toward improvements in the product and possibly new innovations. A thorough examination of the model may show weak points in a design, or show areas where marginal performance can be improved with minor changes. A product which met specifications originally may have improved performance with these changes – or as an alternative, perhaps enact cost reductions while meeting original goals. At this point a model becomes much more than a report. It now actively assists in achieving the goals the product must meet and optimizing it at the same time.

In more advanced cases, the models can point toward new innovations that were not seen before. A behavior in the model may point toward a method of meeting a goal in a new manner. In the image below, a chimney based LED light bulb was built with an unusual cooling channel system to aid in vertical cooling. However, in the CFD simulations the channel system was also found to aid cooling the horizontal chimney – something not expected. Airflow was pulled into the chimney from the front of the bulb. This behavior was developed in subsequent simulations and early prototypes to verify the effect, and then patented.



This overall process is one I have incorporated in my consulting business to benefit my clients over the years. The process of using models to best improve client's needs is illustrated by the circle of Analyze/Understand/Improve & Innovate® so the best model practices are used for every project.