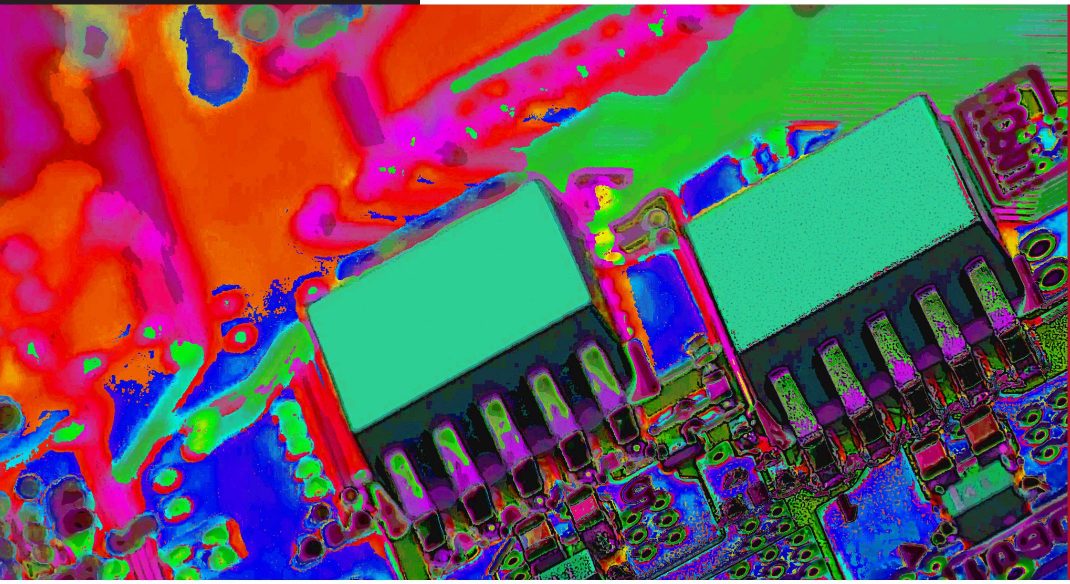
ENGINEERING BRIEF



The Heat is On

Using Three-Stage Thermal Analysis to Design Cool Products

Thermal Analysis Pays Off

More power, smaller form factors, shorter development cycles, lower manufacturing costs—all factors that, when combined, demand engineering processes that are as forward-thinking and efficient as the products you're developing. A powerful tool in your arsenal is thermal analysis—introduce it early in the development process and you'll significantly impact both the speed and effectiveness of your work.

The bar for efficient performance continues to rise

Tackling heat dissipation with brute force—such as a bigger fan—only works if restrictions on size, noise, efficiency, or power consumption are minimal. The bar for robust performance, quiet operation, minimal energy consumption, and affordable manufacturing continues to rise. As a result, innovative thermal engineering is increasingly key to a product's success.

"Prototype and pray" is no longer an option

Often, product development moves through the design and prototype stages without conducting extensive, software-based thermal analysis upfront. As a result, the development team hopes—and prays—that its assumptions pan out when the prototype is tested. If thermal issues do arise, then either a fix or redesign will be required, and development time and costs will rise. Depending on when the issue is discovered—and how it's resolved—manufacturing delays and extra expenses may also be incurred.

Take charge of thermodynamics from the beginning

When it comes to complex, high-stakes projects, thermal analysis can make a big difference, both functionally and fiscally. The earlier you can identify, model, and refine the thermal aspects of your product, the better your prototype will perform. Thermal analysis should begin with product conceptualization, and continue as the product is designed. The process is iterative—potential solutions are analyzed, refined, or eliminated as product development progresses. By conducting thermal analysis throughout the design cycle—beginning with quick thermal calculations and progressing to granular, analytical models—your initial prototype is more likely to meet its performance, manufacturing, and cost goals without requiring numerous costly and time-consuming iterations.

Innovative product designs pack more power into smaller spaces, making upfront thermal analysis increasingly critical.

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Analyzing a chassis with strategically simplified geometry

Acorn was called into the early stages of chassis design with a client who had failures with a similar design in the past. In evaluating the previous chassis design, the team identified an issue pertaining to two separate airflow paths. There was a very packed channel with strong fans that pulled air through, and a second channel that wasn't as packed but had fans that weren't as capable. Small leaks between the channels could cause a big difference in pressure that would flow back through the weak fan.

For the new design, Acorn ran simulations and analyzed the paths together, looking for potential leak locations and how to seal them. Some locations would be cost-prohibitive to seal completely or would restrict serviceability—in these locations, small leaks were placed in the simulation to show what would happen. Running the main fans at a lower power was also simulated—the pressure difference was decreased and allowed the weaker fans to pull enough flow through its smaller channel. A different layout—in which the stronger fan would help pull air through the weaker path instead of fighting it—was also analyzed.

This issue wouldn't show up in an analysis if the model was simplified incorrectly and the paths were looked at separately. Often you can run two separate, smaller models and the design will look feasible. In this case, the team was able to simplify the model without oversimplifying it, and identify the risk early.

Iterative thermal analysis delivers measurable results

Capitalize on advanced thermal analysis to streamline development

The science of thermal analysis, including state-of-the-art software-based tools, allows predictive behavior to be validated during design development, and prior to prototyping. While physical prototypes will always be needed, advanced thermal modeling techniques bring performance data to the development process much earlier, increasing the probability that the prototype will perform successfully.

Increase the odds of achieving a successful prototype sooner

In the time it takes to build and test one prototype, a number of thermal models will produce findings that optimize product design well before prototyping begins. The likelihood of building a successful prototype increases, minimizing or even eliminating the need to build additional—often costly—prototypes.

For example, Acorn engineers reduced a client's development schedule by six months by using iterative thermal analysis. Not only were results achieved more quickly, but also more economically—a computational fluid dynamics (CFD) license costs much less than prototype production costs.

Incorporate thermal analysis into early development phases

Thermal analysis—conducted during concept development, refinement, and design—yields actionable, beneficial results (Figure 1). Because the process is iterative, the point when thermal risks have been mitigated and analysis is complete varies by product type.

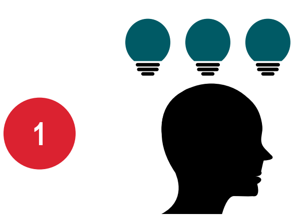
Pre-prototype performance testing reduces time to market

Concept development

During initial concept development, rough order of magnitude (ROM) thermal calculations are used. By conducting macro-level power and heat assessments, approximate calculations can be rapidly generated. Resulting concepts include those that have no risk and those with an acceptable level of risk with roughly defined trade-offs.

At this stage, concepts with unacceptable levels of risk are eliminated. If design directions with no risk are chosen, then it is likely that thermal issues won't be a factor in later phases, allowing more focus to be placed on other aspects of the design. If a direction

Figure 1: Integrating Thermal Analysis into Early Development Stages

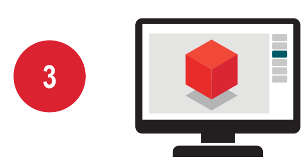


Concept Development

During the brainstorming phase, initial calculations are run to determine the thermal impact of each concept. This initial analysis eliminates concepts that stand little—if any—chance of working.

Concept Refinement

The remaining concepts undergo increasingly rigorous thermal analysis in order to assist the team in determining which of the remaining concepts should advance to the detailed design phase.



Detailed Design

During the design phase, sophisticated simulation modeling techniques yield accurate predictors of thermal performance.

with some level of risk is chosen, then the risks need to be outlined and mapped to the expected steps for mitigation of those risks. More attention to thermal design and refinement will be required in subsequent design phases.

For example, if you're developing a device that's relatively small and has one or more components that generate a lot of heat, thermal concerns should be addressed, but not at a granular level. During concept development, you don't need to determine how heat from specific chips will be dissipated, but focus on high-level concerns instead: Can the heat be moved? Is the exterior surface area large enough? What is the power density of the heat source? What temperature does the device need to maintain, and is that possible given the size and the answers to the previous questions?

The total duration of the concept development phase varies depending on the complexity of the product, the processes required, and the remaining questions to be answered. Once the design engineering team decides most open issues have been resolved and that the remaining issues appear minor, concept refinement can begin with all of the remaining vetted concepts.

Concept refinement

During the second stage of concept development—concept refinement—a wide range of previously vetted concepts are evaluated and compared. Thermal analysis at this stage typically begins with spreadsheets, engineering calculations, resistance diagrams, and network flow models. Thermal models of the product running very targeted, simplified, computational fluid dynamics on particular risk areas are run.

These methods assist with the calculation of basic thermal details, such as total system flow and specific air channel flows, air temperatures, rough component or outer surface temperatures, and the largest pressure drops in the system. Other factors under evaluation may include product size and shape, electrical requirements, environmental factors, parts costs, and development budget, and expected time to market.

At this point, engineers are working with block elements and typical output is still rough. Block sketches, block diagrams, and rough CAD models indicate if components are within acceptable temperature sensitivity margins. Information gleaned at this stage enables team members to make educated decisions about design direction and trade offs. For example, one concept may guide air to the hottest areas and another may treat hot spots and general cooling needs differently. By simulating the concepts, you can not only determine viability, but also assess trade-offs pertaining to performance, space, and costs. When the concept refinement concludes, ideally only one or two concepts advance to the detailed design phase.

In some cases, the best direction may still present thermal design challenges. When choosing a design with narrow thermal margins, performance has to be watched carefully—more analysis may well be needed in subsequent phases. Besides potential effects on schedule and development costs, choosing a direction with narrow thermal margins may lead to constraints that impact other aspects of design, such as component layouts, ease of assembly, and/or cost.

Detailed design

In the detailed design phase, thermal analysis produces the most precise data using a very specific, targeted process. In this phase, the primary concept is designed in detail, with small variations and minimal iterations or changes. Actual part dimensions, thickness, shape, and venting locations are made. At the same time, decisions—such as material selections—are completed.

Developing a cooling solution for Apple Power Mac G4

Acorn has been integrating thermal analysis into concept development and design for a number of years. In fact Acorn engineers worked with Apple to develop a cooling system for its Power Mac G4 (tower). With the Power Mac G3 shape as a requirement, a thermal management solution was needed to support components that generated significantly more power, including two G4 processors and two DVD drives.

The brainstorming process produced 25 concepts for cooling the product. Using one of its rapid thermal analysis tools, Acorn was able to quickly evaluate the performance of each concept to within +/-20% accuracy. Next, a deep, detailed computational fluid dynamics (CFD) analysis was conducted on the top two concepts and a solution was chosen. The end result was a parallel cooling scheme that provided cool fresh air for the sensitive hard drive, and high-volume airflow for the massive G4 heat sinks.

Analyzing chip heat with resistance diagrams

Even chip designers nowadays talk about how to get more heat out of the chip. Chips can be fabricated for faster speeds in a smaller size, but can generate more heat per unit volume than ever before.

Acorn designed a consumer product with a high-power chip in a very small space. The client wanted the product to be very small but the chip put out more power than could be dissipated in the required amount of space. Temperature had to be kept at safe levels for both the chip and the outside temperature of the case.

Doing an effective analysis came down to the development of resistance diagrams. We looked at conduction paths within the system to get heat to the outside of the case, and convection paths from the outside of the case into the air. As with most small hand-held devices, the product wasn't designed with air movers, so we considered how to move the heat with as little material as possible, like with a fluid cooler or heat pipe.

Early analysis clears the path to success for portable robotic rovers

Robotex, a startup company that provides portable robotic rovers for first responders and other paramilitary customers, needed to redesign their prototype design to reduce weight, lower costs, and improve performance. Because weight, battery life, vehicle speed, and package size had to be balanced optimally, thermal performance was critical.

Acorn used progressive design and analysis to thoroughly vet the design. Starting at the concept level, hand-calculated first-order models were developed to quickly evaluate different layouts and component selections. The solution required 250W of power dissipation inside the IP65-rated enclosure while balancing heatsink size and air movers for the rugged environment. By developing several thermal models in parallel, expedient decisions were made on vehicle layout, safe plastic touch temperatures of below 60C, and methods to minimize the 600W/m^2 effects of the sun from the target desert environment.

For some critical components such as motors and heatpipes, simplified CFD models were analyzed at the sub-assembly level to more accurately input their performance into the overall system model. A matrix of results enabled Robotex to view trade-offs and finalize decisions on architecture.

In the detailed design phase, thermal refinement continued and led to a simplified system-level CFD model. From the vetted high-level architecture, component level temperatures were fine-tuned—no significant changes were required. Finally, a prototype was fabricated and assembled. Empirical test data taken from the physical system validated the earlier analytical models to within 15% of the measured data.

Through a layered strategy of thermal analysis, Robotex achieved an optimized production design within its accelerated development schedule.

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During this phase, the system performance of the device and its components are analyzed using computational fluid dynamics (CFD) simulations running on a 3D CAD model. For each detailed CFD, several days are scheduled to input all of the required data and run the analyses. The model is complex and the accuracy of a simulation run depends on the quality of the model and the simulation inputs. Often, the model is run a number of times with different use cases and results to evaluate.

Whether you're determining worst case scenarios or the level of detail to include in a complex model, simplifying the model can reduce the amount of time required to understand product performance. The results from a CFD run can be very precise, with analysis outputs that include chip-level temperature, velocity vectors, pressure plots, and transient analysis. Once concluded, the detailed design phase yields a fully-realized design that is ready to advance to the prototype and test phases.

Conclusion

Thermal engineering is a winning approach from start to finish. As companies continue to put more computational power and complexity into increasingly smaller packages—from hand-held devices and desktop boxes to chassis—innovative solutions for heat dissipation are crucial.

A thermal engineering methodology that begins at the earliest stages of design—and increases in detail with each stage—can be key to developing a product that meets operating temperature, safety, and other requirements. By incorporating thermal analysis into the concept development, concept refinement, and detailed design phases of your development cycle, you'll obtain the data you need to make informed decisions and avoid thermal-related problems during prototyping or manufacturing, when fixes are expensive and impact time to market.

About the Author, Gwynn Masada

An Acorn veteran of over 10 years, Gwynn has deep expertise in designing successful products and bringing them to market quickly. Her extensive knowledge of rapid prototyping, high volume manufacturing, and assembly technologies helps fast track client visions into production. She regularly employs structural, tolerance and thermal analyses to vet concepts, identify risk areas and evaluate detailed designs. Gwynn earned her bachelor's and master's degrees in engineering from Stanford.

About Acorn

Founded in 1993, Acorn Product Development is based in Silicon Valley with design centers in Texas, Boston, and China. We provide comprehensive product engineering services—from turnkey product development, subassembly development, and engineering analysis to materials cost analysis and manufacturing cost reduction—for leading companies around the globe.

Questions or suggestions?

If you'd like to learn more about thermal analysis, share your ideas, or discuss this brief, please contact us—we'd welcome the opportunity to talk with you.

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