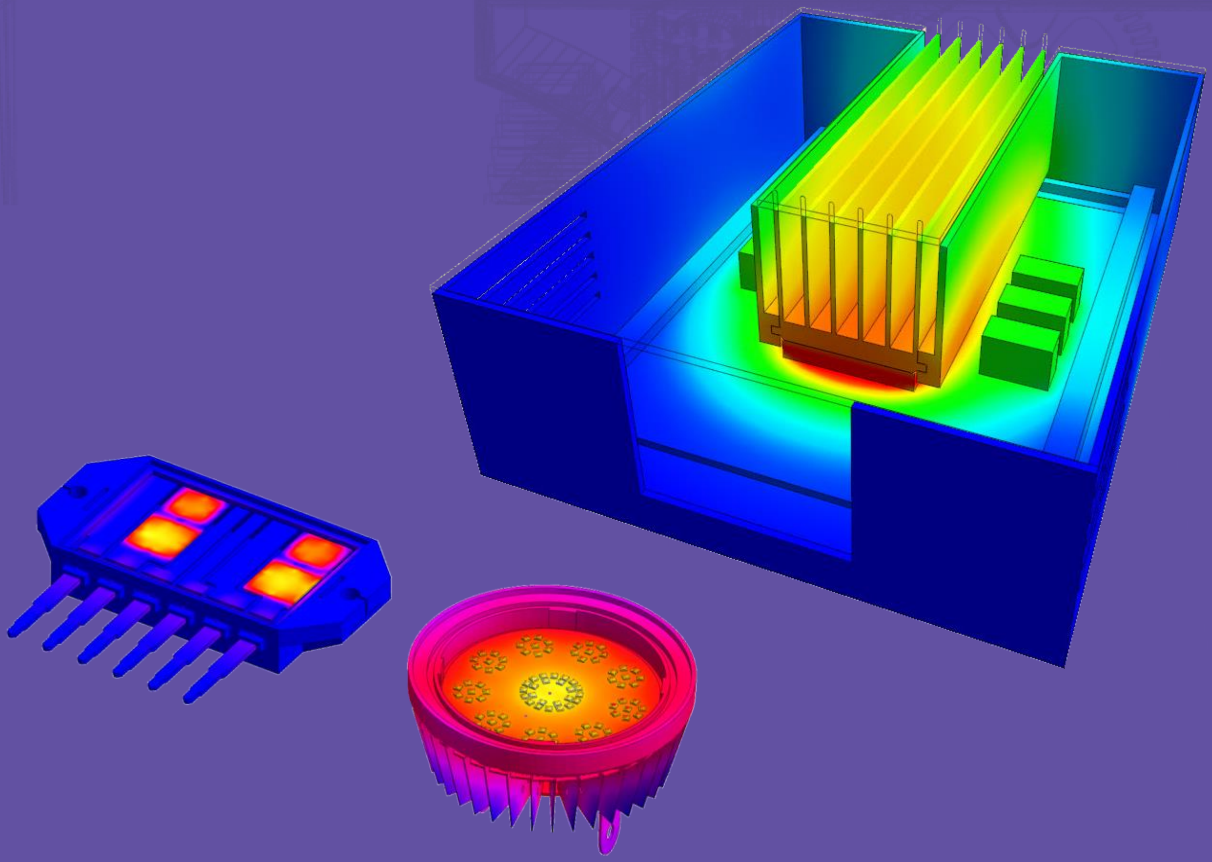
midas NFX

A Guide to
Thermal Analysis

This guide starts from applications of thermal analysis and its role in simulation driven design. Fundamental concepts and principles will be introduced such as conduction, convection, radiation, linear and nonlinear heat transfer, steady state and transient analysis, etc. Finally we will discuss how to choose appropriate finite element analysis software for thermal analysis; and introduce strength of midas NFX for solving thermal problems.



Thermal Analysis for Analysis Driven Design

Efficiency and innovation are contradictory challenges in the sector of product development, and both them must be satisfied in modern companies that strive to remain competitive. **Simulation driven design** process was introduced and has largely replaced the traditional prototyping-testing process in the last decade.

Companies can benefit from the cost and time efficiency of design verification tools based on finite element methods, and concentrate main efforts on product innovation.

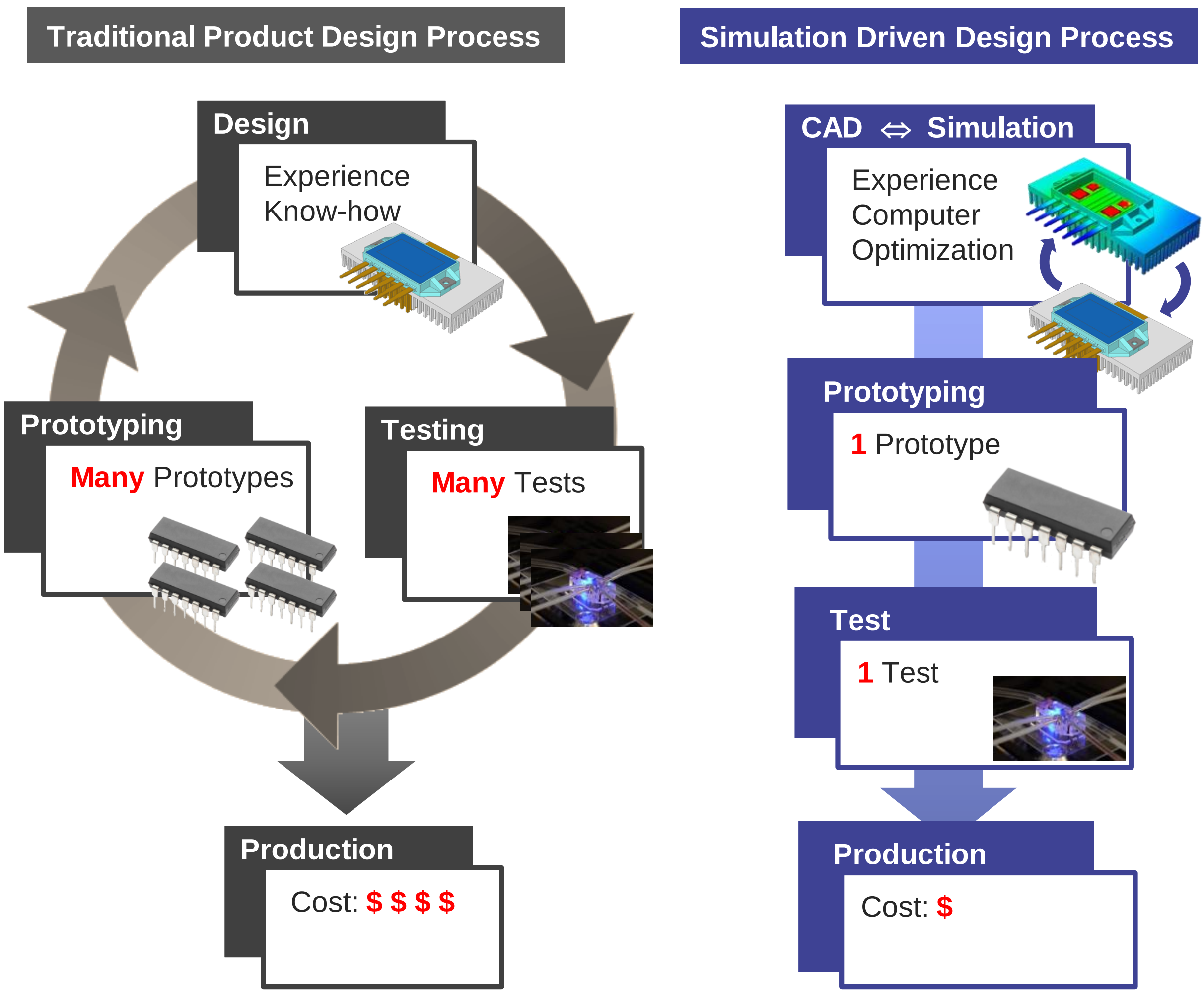


Figure 1

By introducing computer aided design verification tools in the early stage of the product design. Time and cost wasted in the “prototype - test - redesign” cycle are significantly reduced.

Thermal Analysis Application

Thermal related problems are challenges commonly faced by product design engineers. Some of the problems include overheating, excessive thermal stresses, thermal effect on dimensional stability, etc. Following are some applications in which thermal factors need to be considered.

Electronics product design

Thermal problems are commonly encountered in electronic product design. In design of conventional parts, such as heat sinks and cooling fans, adequate heat needs to be removed, as well as keeping the parts small enough.

In the heat sink application, by performing thermal analysis on the design model, engineer easily spotted overheated area on the MOSFET, and made appropriate modification to improve the cooling performance of the heat sink.

All the “verification - redesign” iterations were done in the early stage of the design without having to manufacture any costly physical prototype. Product failure was prevented, meanwhile time and cost were reduced.

NFX Application

Cooling performance improvement of MOSFET heat sink

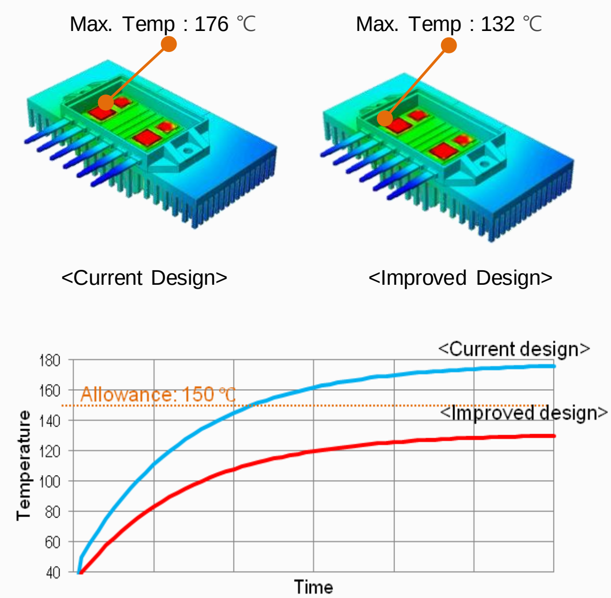


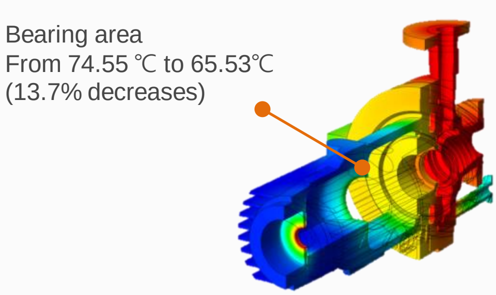
Figure 2

Traditional machine design

Thermal problems are also to be considered in traditional machine design. In design of engines, pumps, hydraulic cylinders, excessive temperature and thermal stress are to be prevented to ensure the machine performance. And for processing machines where mechanical precision is important, the effect of thermal expansion need to be considered .

NFX Application

Design of cooling fins for high temperature / high tension pump



Position	Temperature <Original>	Temperature <Improved >
7310 bearing	95.95 ℃	95.38 ℃
6309 bearing	74.55 ℃	65.53 ℃
Housing center	53.80 ℃	45.04 ℃
Lubricant	69.27 ℃	62.16 ℃

Figure 3

In the application above, cooling fins were designed to prevent overheating of a pump which operates under high temperature and high pressure environment.

Automotive parts design

Same as machines, design of automotive parts and components also need to consider overheating and excessive thermal stress problems. Thermal performances of motors, brakes, hydraulic pumps are to be evaluated during the design process.

In the right application, thermal analysis was performed to choose the appropriate type of brake fluid. The maximum temperature transferred to brake fluid was predicted using heat transfer analysis. And the boiling point of the chosen brake fluid needs to be higher to avoid the vapor lock phenomenon.

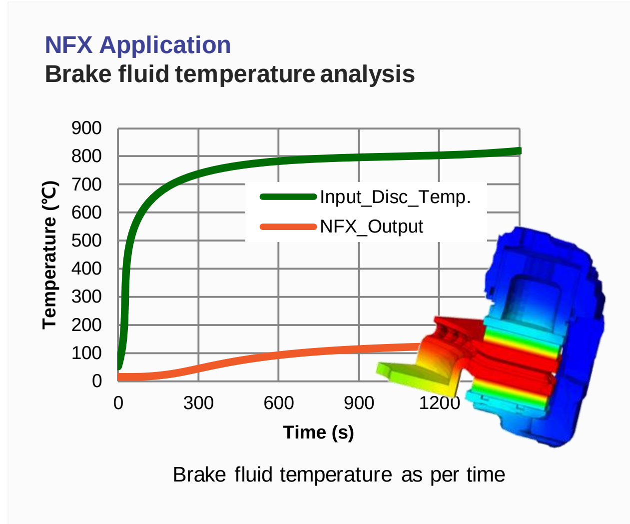


Figure 4

Thermal Analysis Fundamentals

From structural analysis to thermal analysis

Using computer aided design verification tools to validate structural design is already a common practice among design engineers. It is very easy to expand the knowledge of structural analysis to thermal analysis because they are based on the same concept and follow the same workflow.

Structural Analysis and Thermal Analysis Comparison

Structural Analysis	Thermal Analysis
Load: Axial force per unit length	Internal heat generation per unit length
Boundary: Constraint condition or forced displacement	Specified temperature
Displacement	Temperature
Strain	Temperature Gradient
Stress	Heat Flux

Figure 5

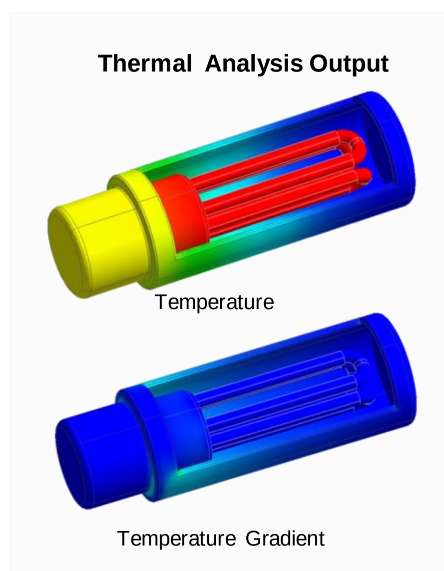


Figure 6

As illustrated in figure 5 - 6, thermal analysis are usually performed to find the temperature distribution, temperature gradient and heat flux of the target model. The simulation approach is particularly beneficial for solving thermal problems because firstly you can use the same CAD model to perform thermal analysis as well as structural analysis. Secondly measuring temperatures and temperature changes can be very difficult in a real test, especially when temperatures inside small parts and assemblies are to be decided.

Heat transfer mechanism

Heat transfer analysis is the most common thermal analysis, it analyzes the heat flow due to temperature differences and the subsequent temperature distribution and changes. 3 heat transfer methods include conduction, convection and radiation

Mechanism	Main Characteristics
Conduction	Responsible for heat flow inside a solid body
Convection	Responsible for heat entering and escaping a solid body Heat Transfer by convection requires the solid body to be surrounded by a fluid like air, water, oil etc..
Radiation	Responsible for heat entering and escaping a solid body Heat Transfer by radiation is always present but becomes noticeable only at higher temperatures

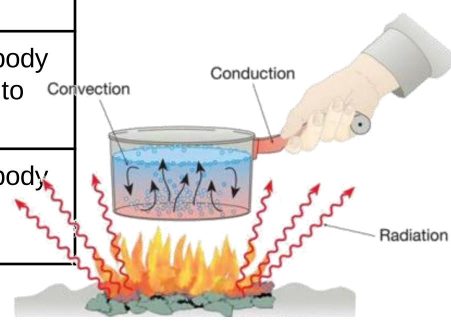
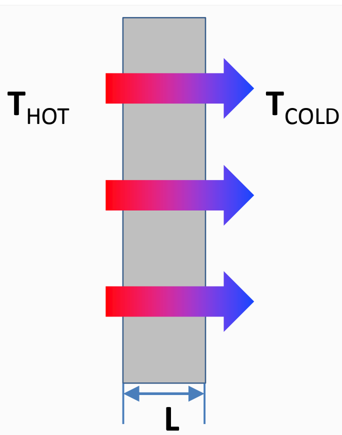


Figure 7

Heat Transfer Fundamentals

Conduction

Conduction describes heat flowing inside a body. Heat energy is transferred through the chained vibration of molecules or neutrons from high temperature region to low temperature region.



$$Q_{CONDUCTION} = K.A.(T_{HOT} - T_{COLD})/L$$

K: Thermal conductivity
A: Area of the wall
L: Wall Thickness

Metals (conductor) → K~10 - 1000 W/m.K
Foams (Insulators) → K~0.01 - 1 W/m.K

Figure 8

Regardless of the state of a material such as solid, liquid or gas, conduction always occurs if a temperature difference (temperature gradient) exists within the object.

Moreover, thermal energy moves from the high-temperature region to a low-temperature region.

The simple example in figure 9 demonstrates typical analysis result of conduction in heat transfer.

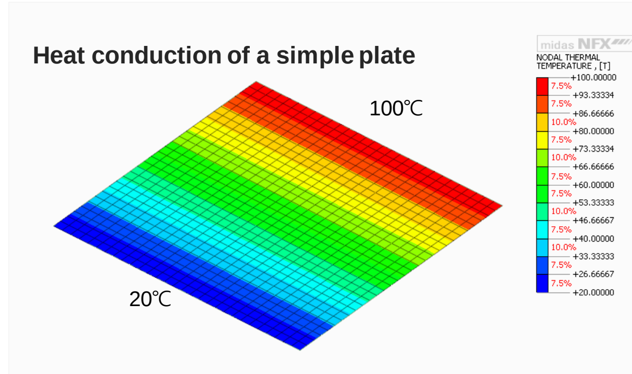
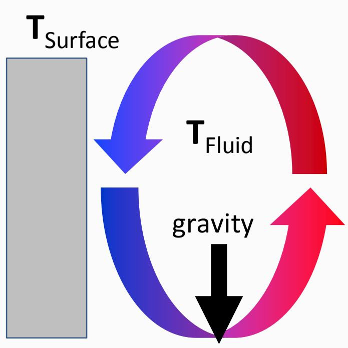


Figure 9

Convection

Convection describes the mechanism of heat exchange between an external face of a solid body and the surrounding fluid such as air, steam, water, oil, etc. The convection coefficient strongly depends on the medium (e.g. steam, water, oil).



$$Q_{CONVECTION} = h.A.(T_S - T_F)$$

h: Convection/ Film Coefficient
A: Area of the face exchanging heat

Air (natural convection) → h~5 - 25 W/m^2.K
Air (forced convection) → h~20 - 300 W/m^2.K

Figure 10

Convection can be further classified into 2 types: natural convection and forced convection. Natural convection happens because of gravity difference between cold and hot fluids. While forced convection can created by external force (cooling fan, wind, etc.).

Figure 11 is an example of natural convection. The analysis model is a LED light. Fluid flow occurs purely due to temperature difference of the air near and far from the LED light. Fluid temperature, fluid velocity distributions and air flow lines are verified through thermal analysis.

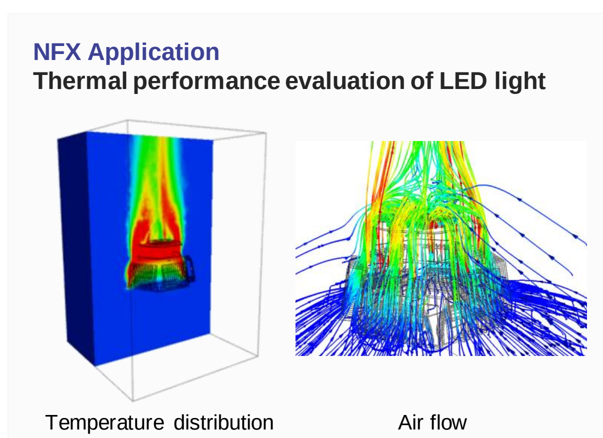


Figure 11

Figure 12 is an example of forced convection. Cooling fan is installed in the PCB system and initiates the convection. In this application temperature distribution, fluid flow velocity and fluid flow path were determined. It practically uses fluid analyses (CFD) coupled with transient heat transfer to solve such forced convection problem.

NFX Application
PCB Cooling Forced Convection

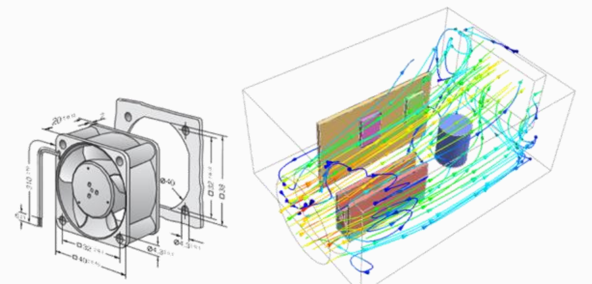
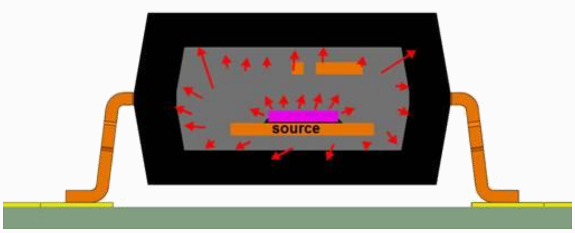


Figure 12

Radiation

Radiation is the heat transfer phenomenon in which energy is transferred in the form of electromagnetic waves between two separated objects with or without the existence of a medium in between.



$$q = \sigma F(\varepsilon T^4 - \alpha T_a^4)$$

σ: Stefan-Boltzmann constant
F: Radiation view factor
ε: Emissivity
α: Absorptivity
T, Ta: temperature of the object and ambient

Figure 13

In the automotive lamp application. Temperature distribution at the lens surface was measured 2 hours later after the bulb is turned on. Cavity radiation between bulb, reflector and lens is considered.

NFX Application
Radiation heat transfer analysis of a automotive lamp

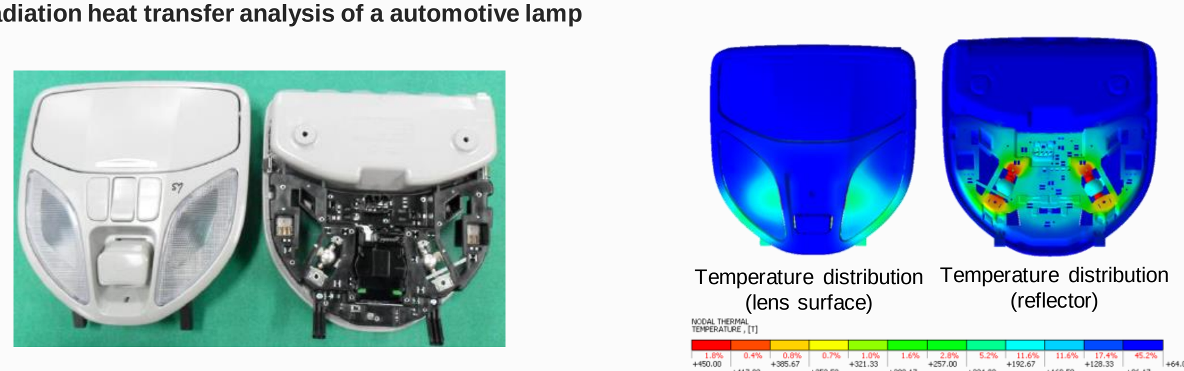


Figure 14

Linear and nonlinear heat transfer

Heat transfer analysis can also be classified as linear and nonlinear considering material properties, heat transfer mechanisms and analysis conditions.

For linear heat transfer analysis, material properties are assumed to be constant and do not vary according to temperature. However, most materials, especially metallic materials, have properties (conductivity, specific heat, and density) that are temperature-dependent. Therefore, when modeling and simulating temperature distribution for such materials, nonlinearities have to be accounted.

For conduction and convection heat transfer, heat flux has linear relationship with temperature difference. (see Figure 8, 10) However radiation heat transfer is a high order nonlinear phenomenon due to T^4 and Ta^4 terms in the governing equation. (see Figure 13) Therefore, nonlinear analysis is needed in radiation problems.

In addition, linear analysis consider loads and boundaries to be constant (constant temperature of heat source and environment). This may involve some assumptions and hypotheses.

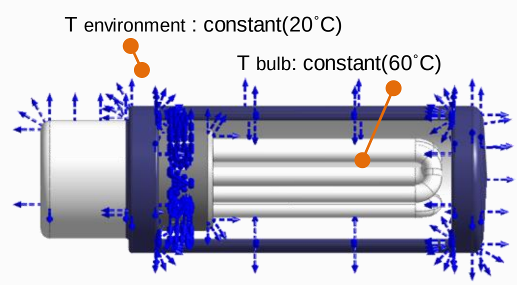
Although in real life, temperature-dependent materials and varying boundaries are more common, to simplify the problem, in most cases engineers choose to make linear assumptions and obtain acceptable analysis results.

The example in figure 15 shows a common linear heat transfer case. In this case both bulb and environment temperatures are assumed to be constant. Natural convection transfer is studied, therefore heat flux and temperature are calculated according to linear equation. And the convection. The convection coefficient doesn't depend on temperature change either.

NFX Application

Convection analysis of a LED bulb

1) Constant Boundary



2) Linear Equation:

$$Q_{CONVECTION} = h.A.(T_S - T_F)$$

3) Linear Material

Convection Coefficient: 10 W/m2 [T]

Figure 15

Steady state and transient heat transfer

Furthermore heat transfer analysis can be classified as steady state and transient analysis. Steady state analysis deals with problems in which the object and it's surroundings reach constant temperatures. At this state heat flow velocity and temperature distribution are steady and do not vary according to time. While transient analysis deals with problems in which temperatures within an object and surroundings changes as functions of time.

In normal situation, an object always passes from transient state to steady state, imagine a hot pan taken out from the oven and set aside to cool down. At first temperature continuously goes down until reaching some point, then temperature stays almost constant at this low temperature.

Therefore steady state analysis is used to determine the final state and usually the maximum temperature generated in a product during the design. While transient analysis is used to investigate the process in detail.

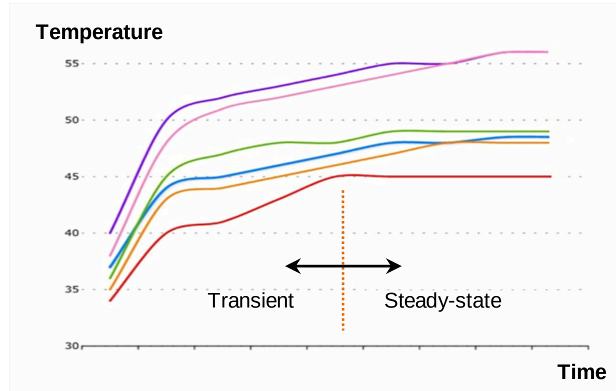


Figure 16 Temperature change in CPU

Another common application of transient analysis is to study drastic temperature changes based on time (ex. iron, break pad, LED lamp, power semiconductors, etc).

Similar as transient response analysis in structural analysis, transient heat transfer analysis also needs to set proper time intervals. If the time interval is too large, it may not capture the correct temperature change. Because the temperature changes drastically in the beginning, we can use short time intervals in the beginning and large time intervals near the steady state.

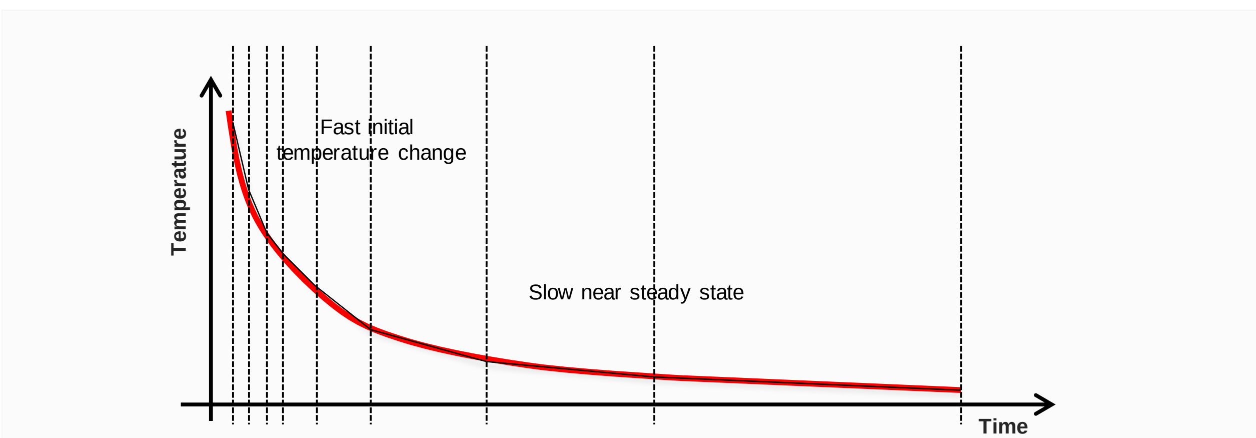


Figure 17 Time interval setting for transient heat transfer analysis

Thermal Stress Fundamentals

Heat flowing through a solid body will cause a change in temperature in this body. Consequently the body will expand or shrink. Stresses caused by this expansion or shrinkage are called thermal stresses. And the expansion and shrinkage are thermal deformations. Figure 18 explains the generation of thermal stress and thermal deformation generated from heating.

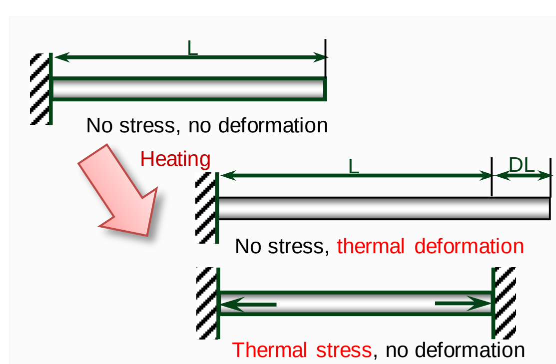


Figure 18

For a chip in electronic device, thermal stress occurs when electrical energy dissipated as heat, and the chip starts to get hot.

For this kind of problem, temperature distribution needs to be determined and further used as heat load to calculate deformation and stress.

For this, you can perform a heat transfer analysis first and followed by a structure analysis. In some software coupled analysis can be performed, from which thermal stress and deformation are obtained directly. In midas NFX you can choose both ways to perform thermal stress analysis.

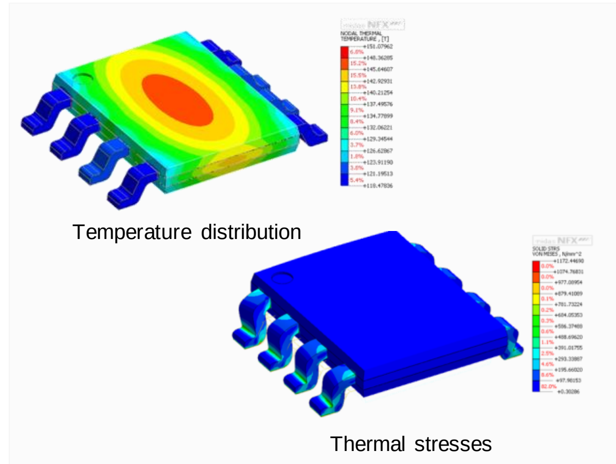


Figure 19

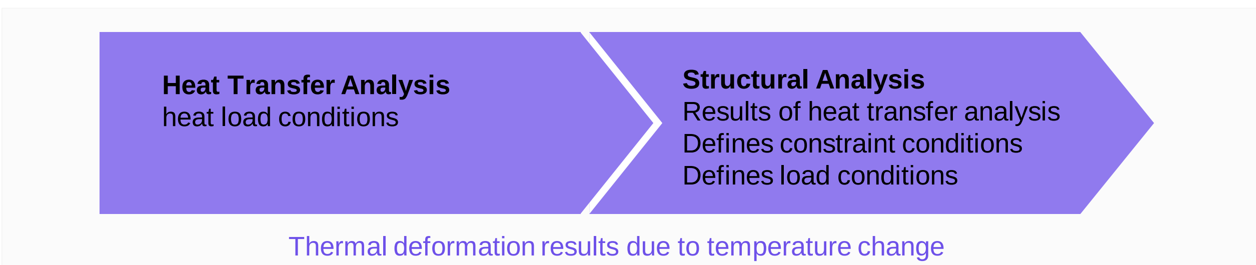


Figure 20 Connection between heat transfer analysis and structural analysis

Difference Between Structural and CFD Analysis to Study Heat Transfer

Until here, we are discussing thermal problems in structural analysis, in which behavior of structural component itself is being studied under heating. For these problems fluid temperature of the environment is considered to be constant. Common structural thermal problems are: heat generation, convection, radiation problems and thermal stress problems in which thermal deformation and stress caused by heat load are to be determined.

When temperature distribution of the surrounding fluid needs to be studied; or the impact of the structural component on the environment needs to be studied heat flow coupled analysis is necessary. One of the most common application is to natural / forced cooling of the system.

In NFX, both structural heat transfer analysis and CFD solid / fluid coupled analysis can be performed.

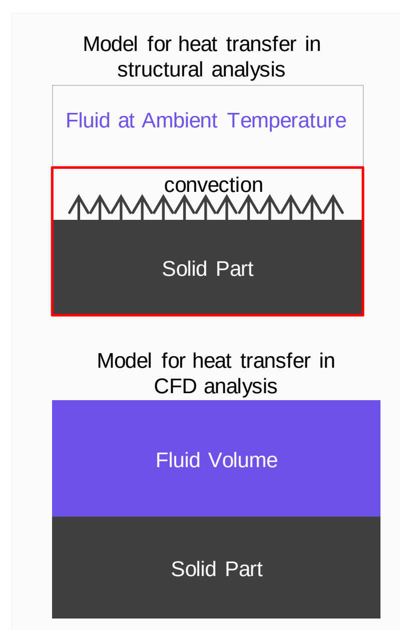


Figure 21

How to Choose Software for Thermal Analysis

We have well understood that FEA based verification tools are beneficial in many ways such as reducing prototyping cost, discovering problems in early stage of the design, gaining insights on thermal phenomenon which cannot be easily measured in physical tests, etc.

However, choosing the right software is more crucial in order to solve the exact problem as well as to secure your project schedule and budget.

To choose the right CAE software, especially to adopt the "simulation driven design" approach in a well established product design team, 4 major factors are to be considered here:

1) Solver capabilities
2) Easiness for modeling : CAD compatibility and integrated modeling tools
3) Speed and convenience of graphical output and reporting
4) Easiness to be learned and adopted in existing product design process

Solver capabilities

Considering the typical thermal problems introduced above, competent software should be able to analyze

- Conduction, convection and radiation problems
- Temperature-dependent material properties and boundary conditions (nonlinear heat transfer)
- Time-dependent thermal effects (transient thermal analysis)
- Thermal-structural coupled analysis to calculate thermal stress and deformation
- Thermal-fluid coupled analysis to calculate natural / forced convection problems

midas NFX solver has the capability to solve all the problems above and provide reliable results. Some analysis features are dedicated to thermal analysis. "Thermal sensor" for example can be put on any point or surface. It automatically detects when the system achieves steady state and tells the solver to stop further calculation. This feature can reduce significantly calculation time of transient thermal analysis.

Further more, as an all-in-one solution software, midas NFX is not only specific to thermal analysis, but able to apply to structural, fluid dynamic and topology optimization analyses. This wide range of analysis capabilities can be extremely beneficial to your product design team to check structural and fluid flow problems in the products without having to work on multiple interfaces.

Especially, powered by multi-core solver and GPU calculation, midas NFX solver is featured with its impressive analysis speed.

Easiness for modeling

New product are designed in CAD tools, many CAD tools are available on the market, and even in one team different CAD tools are usually being used. Therefore, CAD compatibility is another critical capacity to consider.

midas NFX is fully compatible with CAD, 13 most commonly used CAD formats are supported, including Parasolid, CATIA V4/V5, UG, Pro/E, SolidWorks, Soild Edge, Inventor, STEP, IGES, ACIS. Nastran format (.nas; .bdf) can also be import for analysis.

Models directly taken from CAD designs are usually with excessive detailing. Especially electronic components, machine parts include many small holes, fillets, lines, faces which are not only unnecessary but also will lead to inefficient analysis. Common practice is to clean up the geometry model first before meshing and analyzing it.

midas NFX is equipped with automatic and manual simplification tools to handle effectively the clean up work. With several clicks such detailing can be automatically detected, selected and removed. This will save you considerably amount of time.

Furthermore, midas NFX is equipped with geometry creation and editing tools. Simple modifications to the model can be directly done in midas NFX without going back to CAD tools.

Convenient graphical output and reporting

Thermal analysis calculates the temperature distribution and related thermal quantities in a system or component. Typical thermal quantities of interest are:

- temperature distribution
- amount of heat lost or gained
- thermal gradient
- thermal flux

A good software provides result visualization in the most appropriate manner, as well provides tools to extract flexibly any result at any location of interest. Advanced requirements such as drawing value tables and graphs should also be satisfied.

Result visualization is one of the biggest strengths of midas NFX. The software provides different kinds of contour maps. With “ISO Surface”, overheated locations can be easily discovered. With the temperature extraction tools, result at any location inside or outside the model can be easily obtained. Graph such as temperature change according to time can be easily drawn in the software.

midas NFX has the provision for automatic report generation. The reports include all the information related to the model, right from the geometry to the result graphs and tables. The automatic reports can be generated in MS-Word or 3D PDF format. The former can use default or custom templates whereas the latter is an interactive report with animated illustrations of the model in a 3D view.

Easiness to be learned and adopted

Despite all the benefits that simulation can bring to product design, adopting "simulation driven design" approach in a well established team can be sometimes challenging.

To fully leverage the capabilities of FEA simulation and create maximum values, design engineers need to learn FEA software as well as some specialized engineering knowledge. Sometime design engineers need to work together with analysis specialist in the team to complete a more complex analysis.

midas NFX is well-known for its fast learning curve to both analysis specialists and product designers. midas NFX divides its interface into **Designer Mode** and **Analyst Mode** to fit the needs of simple and powerful analysis in one software.

Designer mode aims to help design engineers who aspire to take that intellectual leap from CAD design to FEA simulation. It is equipped with automation tools such as automatic simplification, auto-meshing, analysis wizards, etc., as well as powerful meshing algorithms and high-performance solvers.

Analyst mode provides experienced analyst full flexibility to build and analyze finite element models in the way you want. One can use different types of elements for modeling, and also generate mesh manually. There are also tools to create and edit geometry that can help the user tweak with the geometry without the inconvenience of returning to the CAD platform.

With the "auto-update" function, user can create " analysis template" with which when model is redesigned, analysis can be directly performed on the model without having to assign all the analysis condition again and again. Besides time saving, you can also extend knowledge of the analysis specialist by asking a specialist to create the template so that the design engineers can use it later in the "design – simulation" iterations.

midas NFX

Contact Us at

Website: www.midasNFX.com

Email: Info@MidasUser.com

Telephone: +82-31-789-4040

You Tube f blog

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