



Thermal modelling

Thermal Modelling	1
Types of thermal models	1
Heat and mass transfer modelling	2
Selecting a Thermal Analysis Solver	2
Some commercial packages	3
References	4

THERMAL MODELLING

A model (from Latin *modulus*, measure) is a representation of a reality that retains the salient features. A model cannot be coincident with the reality it represents; all models are approximations to reality, and their goodness depends on practical usefulness and aesthetic perception. Physical modelling focuses on creating predictive mechanisms (usually mathematical constraints) to simulate the real world, commonly paying separate attention to different aspects of the problem: mechanical, thermal, electrical, chemical, biological, etc. We focus here on thermal problems.

Thermal problems may be varied, and so its modelling. We restrict the scope to mathematical modelling, leaving aside other physical modelling means (as electrical analogy, and scale experimentation). The key to mathematical modelling is knowing the equations that govern the problem, e.g. geometrical constraints, Newton's equations of Mechanics, Kirchhoff equations of Electricity, Maxwell equations of electromagnetism, heat equation and Fourier's law of Heat Transfer, Navier-Stokes equations of Fluid Mechanics, etc.

Thermal problems are mathematically stated as a set of restrictions (implicitly assumed as expertise, and explicitly given as data) that the sought solution must verify (if there were no restrictions, any answer would be valid, and there would be no problem). The restrictions are equations (algebraic, differential, integral) and bounding inequalities, both of them subjected to uncertainties coming from the assumed geometry, assumed material properties, assumed external interactions, etc.

All models are only approximate simulations, trying to reproduce some real conditions which are inherently unattainable in all the details (otherwise, a model would not be a model but the actual thing). Remember that the ultimate goodness of a physical model is dictated by its comparison with experiments, and experiments can only be accurate (from Latin *cure*, perform with care) to the practical limitations of controlling a subset of all possible interactions. Thus, there is neither an exact model, not an exact solution to a physical problem; they can just claim to be accurate enough.

TYPES OF THERMAL MODELS

According to the type of thermal problem, several traditional model-types have been developed:

- Models to simulate materials property data under different conditions, as equations of state and transport properties. The most involved problem may be the prediction of real mixture properties in terms of pure-component data. These models are usually auxiliary to the following ones. As for the rest of the models, materials modelling is not a simple equation fitting approach, but a knowledgeable setting of the physical constraints applicable. Some simple models can be found in Potentials and properties for pure substances, and in Mixtures.
- Models to simulate thermodynamic processes, particularly in control-volume elements, like compressors, expanders, heat exchangers (as black boxes), valves, mixing chambers, and so on. Some thermal problems seem deceptively simple in the statement (e.g. how much does a catenary cable sag from winter to summer?), and its mathematical solution becomes entangled, but in most cases it is the conceptual modelling what is difficult, and the mathematical solution is straightforward. The most involved models are able to simulate complete thermodynamic cycles, as complex steam turbine installations, combined power cycles, refrigeration, and air-conditioning cycles. These thermal systems may be quite complex, with many pieces of equipment interacting, but each of them is usually just a black-box model (e.g. local efficiencies are input parameters, not functions to be computed).
- Models to simulate heat transfer processes, basically grouped in two categories, those allowing internal fluid flow (which must be solved concurrently), and those where internal fluid flow does not exist, or it is modelled as a known empirical correlation without solving the fluid-dynamic problem. Sometimes special models are tailored to particular fields, e.g. thermal architectural models, specialised in solar heat-gains, heat losses by air filtration, and so on.
- Models to simulate specially-complex thermal phenomena, as combustion processes.

Because the equations of Heat Transfer are well defined and moderately complex, and the scope of application so large and varied, traditional thermal modelling (as well as commercial thermal modelling packages) usually refers exclusively to Heat Transfer modelling, and many times restricted to the partial differential equation (PDE) formulation of heat transfer by conduction inside solids, perhaps with some given convective and radiative boundary conditions, since the coupled solution of heat transfer with fluid flow renders the problem much more intricate (full Navier-Stokes PDEs), and radiative coupling even more (multi-spectral and directional properties).

This may seem a very narrow goal of thermal modelling, but it is illustrative of other modelling endeavours. To gain more generality with little extra effort, Heat and Mass Transfer can be jointly considered, as done here.

HEAT AND MASS TRANSFER MODELLING

SELECTING A THERMAL ANALYSIS SOLVER

The questions to be considered when one must face a thermal problem may be:

- Is the thermal problem just a single side-case, unrelated to our business? If so, ask for an external service (however, in most cases one wants to try ‘what-if’ possibilities to analyse several aspects of different problems).

- Can the thermal problem be modelled by a small number of isothermal lumps, or as a 1D problem? If so, do it manually or in a spreadsheet.
- Is the problem one-dimensional? Do not use full-featured packages but a tailored FDM of your own.
- Is the 2D or 3D geometry isoparametric (rectangular, circular...)? Use a FDM, preferably of your own.
- Is the thermal problem so linked to a fluid flow problem that we need a CFD package? Even in such cases, it might be wise to model the fluid influence as an assumed convective boundary condition and solve only the thermal problem in the solids, to see the possible effects.
- Is the thermal problem so linked to an elasticity problem (e.g. thermal stresses) that we need a structural package? Even in such cases, it might be wise to model the elastic influence as an assumed deformation (usually negligible) and solve only the thermal problem in the solids, to see the effects.
- Is the package prepared to import geometrical data from other CAD applications?
- Is the package prepared to deal with time and temperature dependence of boundary conditions?
- Is the package prepared to deal with time and temperature dependence of source terms?
- Is the package prepared to deal with space and temperature dependence of material properties?
- Is the package prepared to deal with radiative boundary conditions?
- Is the package prepared to compute radiative view factors?
- Is the package prepared to deal with directional and wavelength dependent radiation effects?
- Is the package prepared to export all our investment in it (e.g. meshes and temperature fields) in case we wanted to change to other thermal package (e.g. to an integrated CFD)?
- Is the package prepared to (or can it easily be integrated with) other packages to perform thermal-stress analysis, structural analysis, electrical or electromagnetic analysis?
- Do we need additional hardware (e.g. larger computers), software (e.g. additional pre- or post-processing), and other resources (e.g. special human skills and/or a prolonged training course) to make the package running?
- Is the package accessible (may we try a test-case of my interest to be convinced of its utility to us, is it worth to us, is it affordable, is it the best (to us) among the available offer)?

Some commercial packages

Name	Supplier	Type	Comments
NASTRAN	e.g. MacNeal	finite element	widely used for stress, vibration and heat transfer analysis
MSC/PATRAN THERMAL	MacNeal	finite element	built-in view factor and flow-network programs that use the same MSC/PATRAN finite element model
SINDA	NASA	lumped network	Systems Improved Numerical Differencing Analyser
ESATAN	ESA	lumped network	derived from SINDA
ESARAD	ESA	integral method	view factors
FEHT	F-Chart	finite element	2-D finite element analysis for heat transfer
ALGOR	Algor Inc.	finite element	widely used for stress and vibration analysis
ANSYS	Ansys Inc.	finite element	widely used for stress and vibration analysis
COSMOS	.	finite element	widely used for stress and vibration analysis
ABAQUS	HKS Inc.	finite element	widely used for geotechnical and structural analysis
ADINA		finite element	analysis of solids, structures and fluid flows
COOLIT	Daar		electronics thermal analysis
DYNAFLOW	Princeton	finite element	transient analysis capabilities for both parabolic and

	University		hyperbolic initial value problems in solid, structural and fluid mechanics
TAK	K&K Assoc.	finite difference	Thermal Analysis Kit
WINTHERM	Thermo-Analytics		heat transfer analysis of special configurations
I-DEAS	SDR Corp.		integrated CAD/CAM/CAE package

REFERENCES

Ketkar, S.P., "Numerical Thermal Analysis", ASME, 1999.

Pepper, D.W., Heinrich, J.C., "The Finite Element Method", Hemisphere, 1992.

Basmadjian, D., "The art of modeling in science and engineering", Chapman & Hall/CRC, 1999.

Ilegbusi O.J., Iguchi, M., Wahnsiedler W., "Mathematical and Physical Modeling of Materials Processing Operations", Chapman & Hall/CRC, 2000.