Things You Should Know About

Interactive Thermodynamics (*IT*)
and
Interactive Heat Transfer (*IHT*)

What is the software all about?

IT and *IHT* provided on your CD-ROM are Windows-based, general-purpose, nonlinear equation solvers with built-in functions for solving thermodynamics and heat transfer problems. The packages were designed for use with the texts *Fundamentals of Engineering Thermodynamics* (Moran & Shapiro, 4th Ed., 2000, Wiley) and *Introduction to Heat Transfer* (Incropera & DeWitt, 4th Ed., 2002, Wiley), respectively. The equation numbering, text section/topic identification, and content, are specific to those texts. However, the software is also well suited for use with *Introduction to Thermal Systems Engineering (ITSE)*. It is our purpose here to identify features of *IT* and *IHT* that will help you make good use of the software in solving thermodynamics and heat transfer problems.

Why use *IT* and *IHT*?

You should consider *IT* and *IHT* as productivity tools to reduce the tediousness of calculations, and as learning tools to permit building models and exploring influences of system parameters. Use the software as you would a hand calculator to check solutions. Solve systems of equations that otherwise would require iterative hand calculations. Sweep across the value of a parameter to generate a graph. But, best of all, use the special features of the packages identified below that will greatly facilitate your problem solving assignments.

For thermodynamics applications, you will find *IT* especially helpful for retrieving thermodynamic property data while solving a problem that requires one numerical solution, or for varying parameters to investigate their effects.

For heat transfer applications, you will find *IHT* especially helpful for solving problems associated with these topics: transient conduction using the lumped capacitance method and one-term series analytical solutions; estimating convection coefficients using correlations requiring thermophysical properties of fluids as a function of temperature; and blackbody radiation functions.

Getting Started with *IT* and *IHT*

When you first start up *IT* and *IHT*, you will be asked whether you want to run the *Tutorial*. If you are new to the software, you should go through the *Tutorial* so that you can build these basic skills:

- enter equations from the keyboard,
- solve equation sets with an understanding of *Initial Guesses* and solver behavior,
- perform *Explore* and *Graph* operations, and
- understand general features of the solver *Intrinsic Functions* .

For *IT*, the *Tutorial*, is self-contained and provides you with all that you need to learn the basic features of the software. After working through the tutorial you will be able to solve basic thermodynamic problems, vary parameters, and make graphs. Your skills with *IT* will serve you as well with *IHT* since their architecture, solver engine and other key features are similar.

For *IHT*, the *Tutorial,* while labeled as Example 1.6*,* is based on *ITSE* Example 15.3, Curing a Coating with a Radiant Source. Step-by-step instructions will lead you through the construction of the model, solution for the unknown variables, and graphical representation of a parametric study.

You should become familiar with the *Help Index,* which serves as the User's Manual for the software. You should read the first section, *IHT Environment*, so that you understand the structure of the software. Later we'll introduce you to some special *Intrinsic Functions.*

To find out more about using the software, you should go to the sections that follow entitled, *IT: Some Special Tips* or *IHT: Some Special Tips.*

IT: Some Special Tips

IT was designed to accompany the text *Fundamentals of Engineering Thermodynamics (Fundamentals)*, and it includes a number of features that enhance your study of thermodynamics. Some of the features, however, are tied to topics that are beyond the scope of *Introduction to Thermal Systems Engineering (ITSE)*. Also, *IT* has a folder with a large number of examples from *Fundamentals*. Most of these examples are in *ITSE* as well, and the table below shows the correspondence. Some of the *IT* examples are not relevant to the thermal systems text, as noted in the table. The entire selection of examples, though, provides a complete set of illustrations of the capabilities of *IT*.

IT capabilities tied to topics beyond the scope of *ITSE*

- Exergy analysis
- Reacting mixtures and combustion
- Chemical and phase equilibrium

IT Examples – *Fundamentals* and *ITSE* equivalence guide

Fundamentals	*ITSE*	*Description*
2.1	3.1	Evaluating expansion work
3.3	4.3	Stirring water at constant volume
3.5	4.5	Plotting thermodynamic data using software
4.5	5.5	Calculating compressor power
6.14	7.12 (CD-ROM)	Evaluating the isentropic compressor efficiency
8.5	8.4	Regenerative cycle with open feedwater heater
9.6	9.4	Brayton cycle with irreversibilities
9.14	12.8 (CD-ROM)	Effect of back pressure: converging nozzle
12.14	10.4	Spray-steam humidifier
13.8	Not included	Determining the adiabatic flame temperature
14.6	Not included	Determining the equilibrium flame temperature
14.7	Not included	Determining the equilibrium flame temperature using software

IHT: Some Special Tips

IHT was designed to accompany the text *Fundamentals of Heat and Mass Transfer (4ed, 2002)* and *Introduction to Heat Transfer (5ed, Wiley, 2002),* and includes a number of features that will enhance your study of heat transfer. However, many other features are beyond the scope of coverage in *ITSE,* so it is not useful to track any equivalence between the two texts with respect to topics and examples for use of the software.

It is the purpose of this section to identify specific features of *IHT* that will increase your productivity in problem solving. In addition to having basic solver literacy, and good skills in using *IT* as earlier described, you will find the following topics useful in solving the heat transfer problems of *ITSE*.

Entering Equations from Text Reference Tables and Figures

It has been our practice in the *ITSE* heat transfer chapters to summarize key concepts and equations in table or figures to facilitate convenient reference during your problem solving sessions. You should be able to enter the relevant equations into the *IHT Workspace* and affect solutions.

Table/Figure	*Content*
T-15.5	Rate equations for conduction, convection, radiation
T-16.3	One-dimensional conduction: HE solutions, resistances
T-16.4	Fin equations: distribution, heat rates
F-16.27	Semi-infinite media: temperature distribution, heat rate
T-17.3	Correlations: external flow
T-17.5	Correlations: internal flow; also with Eq. 17.56
T-17.6	Correlations: free convection

Understanding How to Handle Stiff-Equation Sets

The solver engine affects solutions to the equation set comprising your model by using initial guesses to converge on the values for the unknown variables. With highly non-linear equations, the engine might not converge within the required limits for the allowed iterations. Examples of such equations include the convection correlations, property functions, the radiation rate equation, and the LMTD heat exchanger method.

The strategy for dealing with stiff-equations sets involves making good initial guesses and specifying upper and lower bounds. Also, consider developing models of more complex systems by building on simplified models. For more advice see the *IHT Help, Solution Strategies and Hints*.

Using Functions that Provide Unique Computational Capability

There are four heat- transfer-specific *intrinsic functions* that provide unique computation capability for the problems of *ITSE* . A *function* is a subroutine that performs a calculation based upon values of the argument provided by the user. Descriptions of the function and *IHT Help* references follow. See the final section, IHT Codes for Text Examples, for the identity of the *IHT* files that illustrate use of these functions.

Function / Description

DER(T,t)

Used to solve differential equations, in this case, the derivative of temperature T with respect to time t. Useful for solving the transient energy balance of the for the lumped capacitance method, Eq. 16.81. See Example 16.9, Comment 4. *IHT Help* reference: *Solver, Intrinsic Functions, DER Function.*

Properties

Provides functions for the thermophysical properties of selected materials, liquids and gases. Click on the *Properties* button on the *Tool Bar* for the substance of choice, highlight window contents, and drag the functions into the *Workspace*. Properties are based on values from *ITSE* Appendices HT-1 to 5. For example, the function for the thermal conductivity of air at one atmosphere is "k = k_T("Air",T) // Thermal conductivity, W/m-K". Note, the temperature T must be specified in kelvin units. *IHT Help* reference: *Tools, Properties.*

Tfluid_avg(x,y)

Calculates the film temperature or average mean temperature for internal flow, written as

Tf = Tfluid_avg(Ts,Tinf) or Tmbar = Tfluid_avg(Tmi,Tmo)

This function is preferred to "Tf = (Ts + Tinf)/2" when working with stiff-equation sets. *IHT Help* reference: *Solver, Intrinsic Functions, Tfluid_avg Function.*

F_lambda_T(lambda,T)

Calculates the blackbody band emission factor according to Eq. 18.10a and Table 18.2. This function is especially useful for calculating total or band properties from their spectral distributions. See Example 18.4, Comment 2, for an illustration of its use. *IHT* reference: *Tools, Radiation Exchange, Radiation Functions*; see also from the tool bar menu, *Tools, Radiation, Band Emission Factor.*

Transient Conduction with Spatial Effects

IHT models have been developed for solving the transient conduction problem for a Plane Wall with Convection, Sec. 16.5.2, and Radial Systems, Sec. 16.5.3. Evaluating the one-term series analytical solution for these geometries is tedious work, requiring use of tables for the coefficients C and ζ or Bessel functions.

The following table presents the functions that will allow you to calculate the temperature distribution T(x,t) or T(r,t) and energy transfer relation Q/Qo for the plane wall and radial system geometries. The functions are keyed to equations in your text. You must provide appropriate equations for the function arguments: xstar (x/L) or rstar (r/ro), Bi, Fo, and Qo. The initial internal energy, Qo, follows from Eq. 16.108. See the final section, IHT Codes for Text Examples, for the identity of the *IHT* files that illustrate use of these functions.

The Plane Wall

```
T_xt = T_xt_trans("Plane Wall",xstar,Fo,Bi,Ti,Tinf)     // Eq 16.104
QoverQo = Q_over_Qo_trans("Plane Wall",Fo,Bi)      // Eq 16.110
```

Plane wall with an initial uniform temperature, Ti, subjected to sudden convection conditions (Tinf, h) as represented in Fig. 16.25. These functions represent the multiple-term series analytical solution, and hence will return more accurate results than the one-term solutions of the text. These functions are used to solve the plane wall transient conduction problem of Example 16.10. See the next section for the identity of the *IHT* file.

The Infinite Cylinder

```
T_xt = T_xt_trans("Cylinder",rstar,Fo,Bi,Ti,Tinf)     // Eq 16.111
QoverQo = Q_over_Qo_trans("Cylinder",Fo,Bi)     // Eq 16.113
```

Infinite cylinder with an initial uniform temperature, Ti, subjected to sudden convection conditions (Tinf, h) as represented in Fig. 16.26. These functions represent the multiple-term series analytical solution, and hence will return more accurate results than the one-term solutions of the text.

The Sphere

```
T_xt = T_xt_trans("Sphere",rstar,Fo,Bi,Ti,Tinf)     // Eq 16.112
QoverQo = Q_over_Qo_trans("Sphere",Fo,Bi)     // Eq  16.114
```

Sphere with an initial uniform temperature, Ti, subjected to sudden convection conditions (Tinf, h) as represented in Fig. 16.26. These functions represent the multiple-term series analytical solution, and hence will return more accurate results than the one-term solutions of the text. These functions are used to solve the sphere transient conduction problem of Example 16.11.

IHT Codes for *ITSE* Text Examples

Six examples from *ITSE* have been solved using *IHT.* The examples were chosen to illustrate the use of the functions described in the previous sections. The following table identifies the features illustrated in the example, and the identity of the *IHT* file that is located in the directory on your CD-ROM labeled IHT Text Example Codes. You can open one of these files while in *IHT*, press the *Solve* button, and examine the results in the *Data Browser*.

Text Example	Content	File name*
16.9	Workpiece temperature-time history during heat treatment. Use of the derivative function DER(T,t) for solving the transient energy balance including radiation exchange as treated in Comment 4.	E16_09.msm
16.10	Plane wall experiencing sudden convective conditions. Use of transient conduction functions T_xt_trans("Plane Wall",…) and Q_over_Qo_trans("Plane Wall",….). The files –A and –B correspond to solutions for parts a-d and Comment 2, respectively.	E16_10A.msm E16_10B.msm
16.11	Quenching a spherical workpiece in an oil bath. Use of transient conduction functions T_xt_trans("Cylinder",…) and Q_over_Qo_trans("Cylinder",….) to calculate quench time.	E16_11.msm
17.11	Turbulent flow: Steam-heated water supply line. Use of Tfluid_avg and Properties functions with an internal flow convection correlation to determine outlet temperature for constant temperature surface condition.	E17_10.msm
17.12	Free convection: Cooling an electronic equipment enclosure. Use of Tfluid_avg and Properties functions with a free convection correlation to estimate heat flux by convection and radiation	E17_12.msm
18.4	Total emissivity from the spectral emissivity distribution. Use of the blackbody band emission function F_lambda_T(lambda,T) to evaluate total emissivity as a function of temperature	E18_04.msm

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* These files are located in the directory IHT Text Example Codes on your CD-ROM. When opened from *IHT*, the files appear with the ".msm" extension. *IHT* searches for files based on this extension, but the saved session includes three other files with the same name (up to eight characters), but different extensions (.dsk, .eqd, and .eqs). Remember to include all four files if you perform a copy-and-paste sequence to relocate the files from your CD-ROM to another drive on your computer.