TABLE OF CONTENTS

1 INTRODUCTION TO EES 1
1.1 Acquiring and Installing EES 1
Acquiring EES 1
Installing EES 2
Silent Installation 3
Online Help 4
AI Librarian 7
1.2 Entering and Solving Equations 7
Entering Equations 8
The Solution Window 10
Decimal vs Comma Separator 11
The Variable Palette and Information dialog 11
Guess Values 13
Limits 13
Display Format 14
Rules for Entering Equations 16
Comments 16
Hyperlinks in the Equations Window 17
Visible Hyperlinks 17
Hidden Hyperlinks 18
Built-In Math and String Functions 19
External Functions and Procedures 19
String Variables 20
The $TabStops Directive 21
Showing Variable Values and Units in the Equations Window 21
The Status Bar and Screen Background Color 21
Equations and Display Preferences 23
The Formatted Equations Window 27
Password Protection 29
Key Variables 29
1.3 Parametric Tables 31
Creating a Parametric Table 32
Alter Values 33
Solving a Parametric Table 34
Formatting Columns 37
The $If, $IfNot, $Else, and $EndIf Directives 38
Naming and Documenting Parametric Tables 39
Saving and Loading Parametric Tables 39
1.4 Basic Plotting 42
Generating a Plot 42
Modifying Axes 43
Overlaying Plots 45

Modifying Plots *46*
Automatic Update *47*
Plotting Uncertainty Information *48*
The Plot Tool Bar *49*
the Cross-Hairs, Move, and Zoom Tools *52*
1.5 Units *54*
Unit System *54*
Entering Units *54*
Dual Units *56*
Units Lists *57*
Units Recognized by EES *59*
Checking Units *60*
Automatically Setting Units *63*
The Convert Function *63*
Suggested Method for Working with Units *64*
The ConvertTemp Function *66*
Adding Units *67*
Using String Variables for Units *68*
EXAMPLE 1.1 Oxygen Dewar *69*
1.6 Printing *69*
Printing a Hard Copy *69*
Copying Equations *70*
LaTeX/PDF Print *71*
1.7 Arrays *73*
Assigning Array Variables *73*
Array Range Notation *74*
Two-Dimensional Arrays *74*
Hiding and Showing Array Variables *75*
The Array Editor *75*
The Duplicate Statement *77*
Arrays in the Variable Information Dialog *78*
Using the Variable Information Dialog with Large Arrays *79*
Purge Unused Variables *79*
EXAMPLE 1.2 Extended Surface Problem *81*
1.8 Lookup Tables and Lookup Files *81*
Creating a Lookup Table *81*
Entering Data *81*
Deleting Rows *82*
Using Strings in Lookup Tables *83*
Using Equations in a Lookup Table *83*
Saving and Loading Lookup Files *85*
Deleting Lookup Tables from the Lookup Table Window *85*
Lookup Table/File Commands *86*
Lookup File Formats *87*
EXAMPLE 1.3 Pump Performance Model *89*
1.9 Other Features *89*

Built-In Constants ... *89*
Adding Constants ... *90*
The Calculator Window ... *91*
Preferences and Syntax Highlighting ... *93*
Auto Complete Window ... *96*
References ... *98*

2 CURVE FITTING & INTERPOLATION ... **99**
2.1 Curve Fitting ... *99*
Curve Fitting Plotted Data ... *99*
EXAMPLE 2.1 Fitting Compact Heat Exchanger Data ... *104*
Curve Fitting Data in a Table ... *105*
Curve Fitting Data in an Array Table with the CurveFit1DT Procedure ... *115*
Curve Fitting Data in a Lookup Table using the CurveFit1DT Procedure ... *117*
EXAMPLE 2.2 Fitting the Saturation Pressure of Water ... *118*
2.2 Linear Regression ... *119*
The Linear Regression Menu command ... *119*
The LinearRegression Procedure ... *123*
EXAMPLE 2.3 Fitting Compressor Data ... *123*
EXAMPLE 2.4 Fitting Compressor Data (revisited) ... *127*
2.3 One Dimensional Interpolation ... *127*
2.4 Two Dimensional Interpolation ... *128*
The Interpolate2D Function ... *129*
The Interpolate2DM Function ... *130*
References ... *130*

3 FUNCTIONS AND PROCEDURES ... **131**
3.1 Equations and Assignment Statements ... *131*
The Assignment Operator ... *132*
3.2 Functions ... *132*
Format of Functions ... *132*
First Example of a Function ... *133*
Second Example of a Function ... *135*
Setting and Checking Units for Function Variables ... *135*
Variable Information Page for Functions and Procedures ... *136*
3.3 Procedures ... *137*
Format of Procedures ... *137*
Example of a Procedure ... *138*
3.4 Logic Statements ... *140*
If-Then-Else Statements ... *140*
EXAMPLE 3.1 Wind Turbine ... *141*
Return Statements ... *141*
GoTo Statements and Statement Labels ... *143*
Repeat-Until Construct ... *144*
Case Statements ... *144*
EXAMPLE 3.2 Compressor Refrigeration Capacity ... *145*
3.5 Units in Functions and Procedures ... *147*
3.6 Arrays in Functions and Procedures ... *150*

Arrays as Arguments *150*
Using the $Common Directive to Access Arrays *152*
Using the $Constant Directive to Set Array Limits *152*
Arrays Table Window for Functions and Procedures *153*
EXAMPLE 3.3 Lumped Capacitance Problem *153*
3.7 Using Lookup Tables *156*
3.8 The Beep and Print Commands *157*
3.9 The Warning and Error Procedures *159*
The Warning Procedure *159*
The Error Procedure *161*
References *162*

4 PROPERTY DATA 163
4.1 Unit System *163*
Unit System Dialog *163*
Specific Properties on a Molar vs Mass Basis *163*
The $UnitSystem Directive *164*
Unit Settings in the Status Bar *165*
Importance of Unit System Selection *165*
4.2 Function Information and Substance Information *165*
4.3 Property Functions for Real Fluids and Mixtures *167*
Calling Protocol for Property Function *167*
List of Property Functions *168*
The RealThermoProps Procedure *170*
Built-in Real Fluids *172*
Property Indicators *174*
Fixing the State *174*
Two-Phase States *175*
The Example Box *176*
EXAMPLE 4.1 Vapor Compression Cycle *177*
Equations of State *180*
Properties of Water *180*
The Reference State *182*
The $Reference Directive *183*
4.4 Property Functions for Ideal Gases *184*
The Ideal Gas Model *184*
List of Ideal Gas Fluids *184*
Ideal Gas vs Real Gas Fluids *185*
The IdealGasThermoProps Procedure *186*
EXAMPLE 4.2 Gas Turbine Engine *188*
The NASA Ideal Gas Database *191*
The FluidType$ Function *193*
EXAMPLE 4.3 Turbine Function *193*
The Ideal Gas Reference State & Chemical Reactions *194*
EXAMPLE 4.4 Chemical Reaction between Methane and Oxygen *194*
EXAMPLE 4.5 Adiabatic Combustion with Chemical Equilibrium *196*
4.5 Psychrometric Properties *201*

The Fluid AirH2O *201*
Properties Specific to Psychrometrics *201*
List of Psychrometric Properties *202*
List of Indicators for Psychrometric Properties *203*
Psychrometrics Example *203*
The PsychProps Procedure *204*
EXAMPLE 4.6 Humidification System *205*
4.6 Solution Properties *206*
Solution Property Functions *206*
Using the Solution Property Functions *207*
4.7 Incompressible Substances *208*
Incompressible Property Library Functions *209*
Using the Incompressible Property Functions *211*
Incompressible Property Tables *211*
Adding Incompressible Property Data *215*
4.8 More Libraries *219*
4.9 Property Plots *220*
The Property Plot Dialog *220*
Property Plots for Real Fluids *221*
Property Plots for Ideal Gases *224*
Psychrometric Plots *224*
Property Plots for Solutions *226*
Property Plots Using the EES_REFPROP Interface *227*
Property Plots for Incompressible Substances *227*
Overlaying States onto Property Plots *229*
4.10 NH3H2O (Ammonia-Water) *232*
EXAMPLE 4.7 Absorption Refrigeration Cycle *234*
4.11 Property Data in External Procedures *237*
The IdealGasMixtureProps Library Procedure *238*
The NASA Library *240*
Ammonia-Water Properties *242*
Sea Water Properties *244*
Lithium Bromide-Water and Lithium Chloride-Water Properties *244*
The GENEOS Library *246*
The Peng-Robinson Library *247*
The EES_REFPROP Interface *247*
EXAMPLE 4.8 Using EES Property Functions to Access REFPROP data *247*
EXAMPLE 4.9 Using the EES_REFPROP Procedure *258*
Metal (Solid, Liquid, Vapor) Properties *259*
The Rocket Propellants Library *260*
4.12 Adding Property Information *262*
Providing Data in Lookup Tables *263*
Providing Ideal Gas Property Data *263*
Providing Real Fluid Property Data represented by the Martin-Hou Equation of State *266*
Using REFPROP .fld Files *271*
References *273*

5 CONVERGENCE AND DEBUGGING 275
5.1 Solution Methodology Used in EES 275
Numerical Solution of One Non-Linear Equation 275
Stopping Criteria 278
EXAMPLE 5.1 Setting Guess Values and Limits 279
Numerical Solution of Simultaneous Non-Linear Equations 280
Blocking and Reordering Equation Sets 284
5.2 The Residuals Window 286
Blocks 286
Residuals 287
Units 287
Calls and Time 288
Procedures in the Residuals Window 289
EXAMPLE 5.2 Blocking Equations 290
5.3 The Computational Flow Window 290
5.4 Setting Guess Values and Limits 296
The Variable Information dialog 296
Setting Guess Values and Limits using Variables 297
Arrays in the Variable Information dialog 298
Changing Variable Names 299
Variable Information Files 299
EXAMPLE 5.3 Using Arrays as Guess Values and Limits 300
Default Variable Information 303
5.5 Using the Debug Window 303
Incorrect Degrees of Freedom 303
Constrained Solution 305
5.6 Debugging Techniques 305
Effective Use of EES 306
The Update Guesses Command and Directive 306
EXAMPLE 5.4 Using the Update Guesses Command 307
The Residuals or Computational Flow Window as a Debugging Tool 310
Common Problems 312
The $Trace Directive 314
References 315

6 OPTIMIZATION 316
6.1 One-Dimensional Optimization 316
Implementing an Optimization Problem 317
Objective Function 319
Degrees of Freedom 319
The Min/Max Dialog 319
Stopping Criteria 320
Guess Value and Bounds 321
The Golden Section Search 321
The Quadratic Approximations Optimization Method 323
Min/Max Table 325
EXAMPLE 6.1 Maximum Power of a Heat Transfer-Limited Power Cycle 327

6.2 Multi-Dimensional Optimization *330*
The Conjugate Directions Method *332*
The Variable Metric Method *333*
The Nelder-Mead Simplex Method *333*
The DIRECT Algorithm *334*
The Genetic Method *335*
EXAMPLE 6.2 Non-linear Regression using Optimization *338*
6.3 Constrained Optimization *341*
Implementing Constraints using Bounds *341*
Parameterizing Variables *342*
Penalty Function *344*

7 INTEGRATION 347
7.1 Numerical Integration of Ordinary Differential Equation *347*
Example ODE *347*
Analytical Solution *348*
Discretizing Time *349*
Euler's Technique (First Order Explicit) *349*
Heun's Method (Second Order Explicit) *353*
The Fully Implicit Method (First Order Implicit) *356*
The Crank-Nicolson Method (Second Order Implicit) *357*
7.2 Equation-Based Integral Function *358*
Calling Protocol for the Integral Command *358*
Entering the State Equations *358*
Carrying out the Integration *359*
The Integral Table *360*
Adaptive Step Size *361*
The $IntegralStop Directive *363*
Integrating Simultaneous ODEs *364*
EXAMPLE 7-1 Simultaneous ODEs *364*
The IntegralValue Function *367*
EXAMPLE 7-2 The IntegralValue Function *367*
Double Integration *371*
Multiple Integral Tables *373*
7.3 Table-Based Integral Function *375*
EXAMPLE 7.3 Use of the Table-Based Integral Function *375*
7.4 Solving Partial Differential Equations *376*
EXAMPLE 7.4 Solving Partial Differential Equations *376*

8 UNCERTAINTY PROPAGATION 382
8.1 Uncertainty Propagation using the RSS Method *382*
The Root Sum Square Method *382*
Example of the RSS Method *383*
8.2 Uncertainty Propagation in EES *385*
Assigning Uncertainties to Measured Variables *385*
Determining the Uncertainties of Calculated Variables *387*
UncertaintyOf Function *388*
Uncer.Pardif and Uncert.Percent Functions *389*

8.3 Uncertainty Propagation in Tables *389*
Uncertainty Propagation Table *389*
Plotting Data with Uncertainties *390*
Uncertainty Propagation with Lookup Tables *391*
EXAMPLE 8-1 Uncertainty Calculations using Data in a Lookup Table *391*
8.4 Uncertainty Propagation in Integrals *395*
EXAMPLE 8-2 Uncertainty in the Calculation of Work to Compress Ammonia *395*

9 ADVANCED PLOTTING 399
9.1 General Plot Window Options *399*
Naming and Documenting Plots *399*
Duplicating a Plot *400*
Saving a Plot to a File *400*
Copying a Plot to a Different Application *400*
Storing and Retrieving Plots *402*
Deleting Plot Windows *402*
Setting the Default Plot Appearance *403*
Plot Templates *403*
Plot Thumbnails Window *403*
9.2 Advanced Capabilities of X-Y Plots *405*
The Cross-Hairs Tool *406*
Point Labels *407*
EXAMPLE 9-1 Analysis of a Refrigeration Cycle *408*
Dual Axis Scales for Two-Dimensional Plots *411*
EXAMPLE 9-2 Plots with Dual Axes *411*
Plotting Date and DateTime Information *414*
Using Variables as Axis Limits *417*
9.3 Other Types of 2-D Plots *419*
Bar Plots *419*
Overlays on Bar Plots *422*
Bar Plots using String Values *425*
Side-by-Side Bar Plots *425*
Area Plots *427*
Polar Plots *430*
Time Sequence Plots *432*
9.4 Three-Dimensional Plots *440*
Three Column Data *441*
Contour-Lines Contour Plot *442*
Contour-Bands Plot *443*
Contour-Gradient Plot *445*
3D Surface Plots Using 3-Column Data *445*
3D Surface Plots Using 2-D Tabular Data *449*
3D Polygon/Points Plots *451*
Symbol Color Plots *453*
References *454*

10 SUBPROGRAMS and MODULES 455
10.1 Subprograms *455*

Format of a Subprogram *455*
Solution and Residuals Windows *457*
Guess Values and Limits of Inputs and Outputs *459*
Subprograms with the Integral Command *460*
Subprograms to Determine the Limit of an Integral *465*
10.2 Modules *467*
Module Execution *467*
The Solution Window *468*
The Residuals Window *469*
Guess Values and Limits of Inputs and Outputs *470*
10.3 Should you use Subprograms or Modules? *470*
References *471*

11 INTERNAL LIBRARY FILES 472
11.1 Writing and Saving Library (.lib) Files *472*
An Example Library File Function *473*
Units in Library File Functions *473*
Testing a Library File Function *476*
Saving Functions as a Library File *476*
11.2 Loading and Using Library Files *477*
EES Library Routines in the Function Information Dialog *477*
Libraries in the Userlib (Userlib64) Folder *478*
Manually Loading Library Files *479*
11.3 Help for Library Files *480*
Using a Dedicated Help File *481*
11.4 Application Library Files *483*
11.5 The Textbook Menu *483*
11.6 The Library Manager *486*
References *487*

12 THE HEAT TRANSFER AND MECHANICAL DESIGN LIBRARIES 488
12.1 Boiling and Condensation *488*
EXAMPLE 12.1 Steam flow in a pipe *492*
12.2 Compact Heat Exchangers *496*
Compact Heat Exchanger Data *496*
Organization of the Compact Heat Exchanger Library *497*
Non-Dimensional Functions *498*
Geometry Functions *498*
Coefficient of Heat Transfer Functions *499*
Pressure Drop Functions *499*
12.3 Steady State Conduction *500*
Conduction Shape Factors *500*
Spreading Resistances *502*
EXAMPLE 12.2 Spreading Resistance *503*
12.4 Convection *504*
Internal Forced Convection *504*
EXAMPLE 12.3 Designing a Water Heater *507*
External Forced Convection *509*

Free Convection ... *511*
Impinging Jets ... *512*
Regenerator Packings ... *513*
12.5 Fin Efficiency ... *514*
12.6 Flow Maps ... *516*
EXAMPLE 12.4 Flow Maps ... *516*
12.7 Fouling Factors ... *518*
12.8 Heat Exchangers ... *519*
Log Mean Temperature Difference Solutions ... *519*
Effectiveness-NTU Solutions ... *521*
Axial Conduction and Regenerator Models ... *523*
12.9 Radiation View Factors ... *523*
12.10 Total Hemispherical Emissivity ... *524*
12.11 Transient Conduction ... *525*
12.12 Pipe Dimensions ... *527*
12.13 Minor Losses and Flow Measurement ... *528*
12.14 The Mechanical Design Library ... *531*
Moment of Inertia ... *531*
Stress Concentration Factors ... *532*
Gear Design Library ... *532*
Endurance Limits Library ... *532*
References ... *533*

13 COMPLEX ALGEBRA & VECTORS ... **534**
13.1 Introduction to Complex Algebra in EES ... *534*
Assigning Complex Variables in Rectangular Form ... *535*
Assigning Complex Variables in Polar Form ... *536*
Units of Complex Variables ... *537*
The Variable Information dialog ... *538*
Complex Algebra ... *538*
Functions Specific to Complex Variables ... *539*
Built-In Functions and Complex Variables ... *539*
EXAMPLE 13.1 Analysis of an AC Circuit ... *540*
Parametric Table ... *542*
The $Real Directive ... *544*
Subprograms ... *545*
13.2 Vectors in EES ... *545*
Assigning and Using Vector Variables ... *545*
Vector Dot and Cross Products ... *548*
EXAMPLE 13.2 Force Components Relative to a Plane ... *550*
13.3 Vector Plots ... *551*
2D Vector Plots ... *551*
3D Vector Plots ... *553*
The $VectorPlot Directive ... *555*

14 DIRECTIVES ... **557**
14.1 Directives related to Display & Formatting Options ... *558*
$Allow '//' On/Off ... *558*

$Arrays On/Off ... 558
$Bookmark ... 559
$CheckUnits On/Off/AutoOn/AutoOff ... 560
$DiagramUpdate On/Off ... 561
$Font ... 561
$HideWindow ... 561
$Private ... 562
$ShowWindow ... 563
$SumRow On/Off ... 564
$Syntax ... 565
$TabStops ... 565
$Warnings On or Off /All or /Last ... 566
14.2 Directives related to Units ... 566
$AutoSetArrayUnits On/Off ... 566
$CheckUnits On/Off/AutoOn/AutoOff ... 567
$ConvertEESREFPROPUnits On/Off /mass ... 567
$UnitSystem ... 568
14.3 Directives for Code Segments ... 569
$Common ... 569
$Constant ... 570
$InsertTab TabName ... 570
EXAMPLE 14.1 Using Tabbed Equation Windows in the Analysis of a Rankine Cycle ... 571
14.4 Directives related to Property Data ... 573
$IGMixture ... 573
$Natural_Gas2 ... 573
14.5 Directives related to Complex Algebra ... 573
$Complex On/Off ... 573
$Real ... 574
14.6 Directives related to Saving & Copying Data ... 574
$CopyToLookup ... 574
$Export ... 575
$ExportPlot ... 577
$ExportText ... 577
$Import ... 578
$ImportText ... 580
$OpenLookup ... 581
$SaveLookup ... 582
$SaveTable ... 582
$SaveVarInfo /A ... 583
14.7 Directives related to Program Execution & Debugging ... 584
$ClearLookup 'LookupTableName' /C1..3 /R2..5 ... 584
$ClearParametric 'ParametricTableName' /A /R220..500 ... 584
$DefaultArraySize=100 ... 584
$DefaultDirectory DirName ... 584
$DefaultVarInfo ... 585
$DoLast & $EndDoLast ... 586

$If, $IfNot, $Else & $EndIf ... *587*
EXAMPLE 14.2 Use of $IF and other Directives ... *588*
$Include FileName /R ... *592*
$Input V ... *592*
$IntegralAutoStep ... *593*
$IntegralStop ... *593*
$IntegralTable ... *594*
$Keyboard US/EU ... *594*
$Load ... *595*
$MaxCalls N ... *595*
$Python Python_Directory ... *595*
$Recompile ... *595*
$Reference ... *596*
$RunMacroAfter ... *597*
$RunMacroBefore ... *598*
StopCriteria ... *598*
$Trace ... *599*
$Unload LibName ... *599*
$UpdateGuesses /A ... *599*
$VarInfo ... *600*
14.8 Directives related to Plotting ... *602*
$NewPlot ... *602*
$OverlayPlot ... *604*
$PropertyPlot ... *605*
EXAMPLE 14.3 Performance of Refrigeration Cycle ... *606*
$VectorPlot2D and $VectorPlot3D ... *607*
EXAMPLE 14.4 Socket and Cable supports ... *608*

15 THE DIAGRAM WINDOW ... **609**
15.1 Placing Graphic Objects in the Diagram Window ... *609*
Development and Application Modes ... *609*
Graphical Objects from a Drawing Program ... *610*
Graphical Objects Drawn in the Diagram Window ... *612*
Drawing and Modifying Lines and Arrows ... *612*
Drawing and Modifying Rectangles ... *615*
Drawing and Modifying Ellipses or Circles ... *617*
Drawing and Modifying Polylines and Polygons ... *617*
Accessing the Diagram Window Palette ... *620*
The Add Picture from File Capability ... *622*
15.2 Placing Text Items in the Diagram Window ... *624*
Entering Plain Text ... *624*
Entering Formatted Text ... *626*
EXAMPLE 15.1 Performance of an IC Engine ... *629*
15.3 Entering Input and Output Variables ... *631*
EXAMPLE 15.2 Setting up a Graphical User Interface ... *631*
Entering Input Numerical Variables from the Diagram Window ... *632*
Displaying Output Variables on the Diagram Window ... *633*

Limits on Input Variables ... *635*
Entering Input String Variables from the Diagram Window ... *636*
Mapping String Variables in a Drop-Down List to Equations ... *638*
The Find Command ... *640*
15.4 Copying and Resizing the Diagram Window ... *641*
The Copy Command in Application Mode ... *641*
The Copy Command in Development Mode ... *641*
Change Window Size Dialog ... *642*
Clearing the Diagram Window ... *643*
15.5 Adding Calculate, Print, Plot Access, and Help buttons ... *643*
Adding a Calculate Button ... *643*
Moving and Resizing the Calculate Button ... *643*
Calculate Button Characteristics Dialog ... *644*
Adding a Print Button ... *645*
Adding a Plot Access Button ... *646*
Showing a Plot on the Diagram Window ... *649*
EXAMPLE 15.3 Using a Macro to Create the Plot ... *651*
Adding a Help Button ... *651*
15.6 Child Diagram Windows ... *652*
Creating a Child Diagram Window ... *652*
How to Modify Child Diagram Property Information ... *653*
How to Access a Diagram Window from another Diagram Window ... *654*
15.7 Other Professional License Enhancements ... *655*
Group and Ungroup Selected Items Buttons ... *655*
Align Selected Items Button ... *657*
Showing a Grid on the Diagram Window ... *657*
Creating Links ... *657*
Adding an Audio-Visual Item ... *660*
Saving and Loading User Inputs ... *661*
Add Check Box Item ... *663*
Creating and Using Radio Button Groups ... *665*
Using Sliders for Inputting Values ... *668*
EXAMPLE 15.4 Creating a Quiz Using Equations in Diagram Input fields ... *670*
Entering a Filename into a String Variable ... *674*
EXAMPLE 15.5 Converting Units for Inputs and Outputs in the Diagram Window ... *674*
Adding and Using Tables in the Diagram Window ... *679*
Saving and Using Diagram (.DGM) Files ... *682*

16 DIAGRAM WINDOW ANIMATION ... **684**
16.1 Controlling the Attributes of Diagram Window Objects ... *684*
Attributes of Rectangle and Ellipse/Circle Objects ... *684*
The GetAttribute function ... *687*
Attributes of Line Objects ... *688*
Attributes of Polyline and Polygon Objects ... *688*
Attributes of Text Objects ... *689*
Attributes of Diagram Window Plot Objects ... *690*
EXAMPLE 16.1 Selecting a Plot to Display in the Diagram Window ... *691*

Attributes of Button, Radio Group and Check box Objects *694*
Showing and Hiding Diagram Window Objects *694*
16.2 Setting Attributes within the Diagram Window *695*
Setting Attributes with Text Drop Down Lists *695*
Setting Attributes with a Check Box Object *699*
Setting Attributes with a Radio Button Group *700*
Controlling the Equations Window with Check Boxes and Radio Button Groups *701*
Using Attributes to Select a Picture in the Diagram Window *703*
EXAMPLE 16.2 Selecting a Heat Exchanger Core in the Diagram Window *704*
Improving the Response Time of Diagram Window Controls *706*
16.3 Exchanging Inputs and Outputs *706*
16.4 Using Parametric and Integral Tables for Animations *711*
EXAMPLE 16.3: Setting up an Animation Using the Parametric Table *712*
Saving Animation Files for the Generation of a Movie *713*
EXAMPLE 16.4: Setting up an Animation Using the Integral Table *714*

17 DISTRIBUTABLE PROGRAMS **720**
17.1 Distributable Program Setup and Startup Dialog *720*
17.2 Setting Distributable File Information *725*
17.3 Completing the Distributable File *729*

18 MACROS **731**
18.1 The EES Macro Window *731*
The Macro Window Toolbar *733*
Creating a Macro in the Macro Window *735*
EXAMPLE 18.1 Repeated Solving Using a Macro *737*
The EES Log File *740*
18.2 EES Macro Commands *742*
18.3 Interacting with External Programs using Macros *786*
EXAMPLE 18.2 Interacting with Microsoft Excel *786*
EXAMPLE 18.3 Interacting with MATLAB *789*
18.4 Using a Macro for Serial Port Communications *793*
Basic Communication with the Arduino UNO *793*
Logging Data to a Lookup Table and Plotting *795*
18.5 Executing EES Macros from External Programs *801*
Executing an EES Macro File from the Windows Run dialog *801*
Executing an EES Macro File from MATLAB *802*
Executing an EES Macro File from Excel *804*
Executing an EES Macro File from LabView *807*
18.6 Interacting with EES using Dynamic Data Exchange *811*
Dynamic Data Exchange with Excel *811*
Dynamic Data Exchange with MATLAB *813*
18.7 Alternative Ways to Run a Macro from EES *814*
The CallMacro Statement *814*
The $RunMacroAfter and $RunMacroBefore Directives *817*
18.8 Useful Macro Examples *818*
EXAMPLE 18.4 Set up a Lookup Table for a Factorial Design *818*
EXAMPLE 18.5 Select all Files of a Particular Type from a Directory *819*

EXAMPLE 18.6 Create a Property Plot and Superimpose State Data *820*
EXAMPLE 18.7 Open all .EES files in a directory and copy the equations to .docx files . *821*
EXAMPLE 18.8 Repeatedly call EES from MATLAB *822*
EXAMPLE 18.9 Use of the Input dialog with Radiation View Factors *824*
EXAMPLE 18.10 Automatically Creating 3-D Polygon Plots *827*

19 EXTERNAL FUNCTIONS AND PROCEDURES **829**
19.1 EES External Functions (.dlf files) *829*
External Functions written in DELPHI Pascal *830*
External Functions written in C++ *834*
19.2 EES External Procedures - Type 1 (.dlp files) *836*
Type 1 External Procedures written in Pascal *837*
Type 2 External Procedures written in C++ *841*
19.3 EES External Procedures - Type 2 (.fdl files) *844*
Type 2 (.fdl procedure) with the MinGW Open Source GCC Fortran Compiler *848*
19.4 Multiple Files in a Single Library File (.dll or .dll64) *852*
19.5 Managing External Library Files *855*
Loading External Library Files *855*
Providing Help for External Library Files *855*
19.6 External Python Procedures *856*

20 THE COMPONENT LIBRARY **865**
20.1 Overview of the Component Library *865*
20.2 Examples using the Component Library *869*
EXAMPLE 20.1 Heat Pump Design *869*
EXAMPLE 20.2 Heat Pump Simulation *874*
EXAMPLE 20.3 Analysis of a Pump and Piping System *878*
EXAMPLE 20.4 Adiabatic Combustion with Chemical Equilibrium *883*
EXAMPLE 20.5 Humidification System Simulation *885*
20.3 Summary of the Component Library *889*

21 THE REPORT WINDOW **894**
21.1 Creating the Report *894*
EXAMPLE 21.1 Analysys of a Refrigeration Cycle *894*
21.2 Inserting EES Variables *899*
21.3 Inserting EES Plots *900*

22 CALLING EES FROM OTHER PROGRAMS **902**
22.1 Sending Messages to EES *902*
22.2 Example 22.1 Calling EES from EXCEL *903*

23 EESyGrader **912**
23.1 Acquiring and Installing EESyGrader *912*
23.2 EESyGrader Starter Code and Rubric *915*
Problem Statement *915*
Problem Solution *916*
Create an EESyGrader Rubric *917*
Create an EESyGrader Starter Code *919*
Checking Program for EESyGrader Outputs *923*

Saving the Rubric *925*
23.3. Grading with EESyGrader *926*
Starting EESyGrader *926*
Specifying the EES Program *927*
Loading a Rubric *928*
Building a Grade Report *931*
Building Text Files *931*
23.4 Using EESyGrader with Canvas *933*
Using a Canvas Gradebook *933*
List of Students with no Submissions *934*
Canvas Grade Report File *934*
Canvas Re-Upload Files *936*
23.5 Troubleshooting EESyGrader *938*

Appendix A: Built-In Mathematical Functions 939

Appendix B: Built-In String Functions 950

Appendix C: Directives 953

Appendix D: Macro Commands 957

Appendix E: Overriding Default Behavior 970

Appendix F: EES File Types 974

Appendix G: The 64-bit Professional license 979

Appendix H: Startup Options 980

Index 981