Introduction to EES (Engineering Equation Solver)

- Solves linear and nonlinear algebraic and differential equations
- Provides property data for many fluids, including refrigerants
- Checks equations for unit consistency
- Includes spreadsheet-like Parametric table for repeated calculations
- Features high quality plotting package with exportable graphics
- Provides a Diagram window to couple equations to figures

EES Solves Non-linear Algebraic Equations

- Equations can be entered in any order
- Equations need not be rearranged
- EES is NOT case sensitive
- Variable names start with a letter and consist of up to 30 characters
- Enter one equation per line or use ;
- Use * to signify multiplication

EES also solves systems of combined algebraic-differential equations
Comments and Formatted Equations

- Comments are entered between {} or between " "
- Comments in braces do not appear in the Formatted Equations window
- Greek variable names are displayed in symbol

\[ x^2 + y^3 = 77 \]
\[ \sqrt{\frac{x}{y^2 + 1}} = \alpha \]
\[ \alpha = 1.23456 \] Greek names appear in symbol font
\[ \Delta T = 25 \] Use upper case letters for upper case symbol
\[ m = x + y \]
\[ V_1 = \alpha^2 \] note that underscores signify subscripts

Equations can also be output in Latex and .PDF files

Variable Information

- Each variable has an associated
  - Guess value
  - Lower and upper bounds
  - Display format and highlighting
  - Units
**Residuals Window - Example**

There are 6 equations in 4 blocks in the Main program.

- **Equation:** \( G = \sqrt{13} \cdot \text{Temperature} \cdot \text{Steam,} \ P = 101.3, X = 1 \)

<table>
<thead>
<tr>
<th>Block</th>
<th>Rel.</th>
<th>Res.</th>
<th>Abs.</th>
<th>Res.</th>
<th>Units</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.000E+00</td>
<td>0.000E+00</td>
<td>?</td>
<td>G = \sqrt{13} \cdot \text{Temperature} \cdot \text{Steam,} \ P = 101.3, X = 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.961E-10</td>
<td>3.966E-08</td>
<td>OK</td>
<td>X = \sqrt{2} \cdot Y = 77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.77E-16</td>
<td>8.892E-16</td>
<td>OK</td>
<td>X = Y = 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.441E-11</td>
<td>9.770E-10</td>
<td>OK</td>
<td>A+B = 22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.02E-10</td>
<td>1.75E-08</td>
<td>OK</td>
<td>A+B = X = 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.06E-10</td>
<td>1.942E-08</td>
<td>OK</td>
<td>Z = X+Y+A+B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Variables shown in bold font are determined by the equation(s) in each block.

---

**Unit Consistency Checking**

- EES will check each equation for unit consistency
- The CONVERT function provides unit conversions

```
Re = \frac{4 \cdot \text{m} \cdot \text{dot} \cdot \text{p} \cdot \text{D}^2 \cdot \text{mu}}{\text{[kg/m-s]}}
```

The units of \( h[1] \) [kJ/kg] and \( v[1] \cdot 2/2 \) [(m/s)^2] differ by a factor of 1000.

The dimensions of \( \text{Re} \) [dimensionless] and \( 4 \cdot \text{m} \cdot \text{dot} / (\text{p} \cdot \text{D}^2 \cdot \text{mu}) \) [kg/m-s] are inconsistent.

Click the left or right mouse button on an equation to access options.
Parametric Tables

- Use Parametric tables to vary one or more variables
- The New Table command creates a Parametric Table

3 equations, 4 variables

\[ X^2 + Y^3 = Z \]
\[ \sqrt{X/(Y^2+1)} = \alpha \]
\[ \alpha = 1.2345 \]

Plotting

- Any data in a table can be plotted using the New Plot Window command
- Plots can be X-Y, bar, contour, or 3D
- Multiple plots can be overlayed on the same axes
Plotting Enhancements

- Use the plot window toolbar to add text, legend or graphics
- Right click on text, axes, or the plot window to change characteristics

Built-in Functions

- EES provides many built-in functions
- Use the Function Information command (Options menu) to review
- Click the Function Info button for specific help
Thermodynamic and Transport Functions

- EES provides thermodynamic and transport properties for many fluids
- Any independent set of properties can be provided
- SI and English Units

Automatic Property Plots

Calculated state points can be superimposed on plots.
Internal Property Data Base

• Ideal gases
  – air, CO₂, N₂, O₂, psychrometrics, CH₄, C₂H₆, C₃H₈, etc.
• Real Fluids
  – Refrigerants, steam, cryogens
  – 2 equations of state
    Martin-Hou (1949)
    Fundamental Equation of State (e.g., Tillner-Roth, 1998)
• Mixtures
  – Azeotropes (R500 series)
  – Blends (R400 series)
  – Ammonia-water mixtures
  – LiBr-water mixtures
• Transport (Viscosity and Thermal Conductivity)

Internal Functions and Procedures

• Functions return one value
  Function Test(X,Y)
    If (X<Y) then Test=Y-X else Test=X-Y
  End
  G=Text(a,b)

• Procedures return one or more values
  Procedure ABC(X,Y:A,B)
    A=X+Y
    B=X-Y
  End
  Call ABC(xx, yy: aa, bb)

• Functions and Procedures can be stored as Library files
**Modules and Subprograms**

- Modules and Subprograms are EES subroutines
- Format and use similar to EES Procedures
- Major differences
  - Equation order and variable location is irrelevant
  - Logic (If-Then-Else) is not possible
- The equations in a Module are intermingled with those in the main program.
- A Subprogram is a stand-alone EES program, callable from EES.

**External Procedures**

EES can link to any external program that is written as a dynamic link library (DLL)

External programs can be written in C, C++, FORTRAN, Pascal, etc.

External Procedures are accessed with a CALL statement

```plaintext
Call Name('String', In1, In2, ... : Out1, Out2, ..)
```
Existing External Procedures

EESREFP6 links to NIST REFPROP returning accurate property data for 33 pure refrigerants and refrigerant mixtures.

CALL EESREFP6('R123+R152a',BUBP,P,X_123:T_L,rho_L,T_V,rho_V,y_123,y_152a)

EESNIST4 links to NIST SuperTrapp returning property data for mixtures of up to 20 components from an available library of 200 pure species (hydrocarbons, common gases)

CALL EESNIST4('Methane+N2',CODE,T,P,FEED[1]:T,P,z_l,z_v,rho_L,rho_V,h_l,h_v,s_L,s_v,cp_l,cp_v,ru_l,ru_v,k_l,k_v,MW_L,MW_V,Q,X[1],Y[1],X[2],Y[2])

CHEM_EQUIL calculates the equilibrium composition for an ideal gas mixture containing elements C, H, O, N, and A.

CALL CHEM_EQUIL(P,T,AO,CO,HO,NO:x_H2,x_O2,x_H2O,x_CO,x_CO2,x_OH,x_H,x_O,x_N2,x_N,x_NO,x_NO2,x_CH4,x_A)

Diagram Window

Eff=0.3631
Conclusions

- EES contains a large data base of fluid property data
- The coupling of the property data, equation solving, and other capabilities (tables, plotting, unit checking, regression, uncertainty analyses) provides powerful analysis tools.
- EES is continuously being improved