EES

for Android Tablets

I. Introduction

EES is an acronym for Engineering Equation Solver. This manual provides information specific to the version designed to operate on Android tablets running the Android operating system version 4.0 or newer. The application is specifically designed for 7 inch or larger tablets, but it will operate on smaller equipment.

EES solves systems of linear and non-linear algebraic equations. A major feature of EES is the built-in high accuracy thermodynamic and transport property database that is integrated with the equation solving capability. EES also provides built-in capability to convert variables from one unit set to another and it checks the unit consistency of all equations.

The Android version of EES is limited in its capabilities compared to the much more powerful versions of EES designed for Windows operating systems (F-Chart Software, http://fchart.com/ees/). Limitations of the Android version compared to the Windows version are evident in Table 1. Nevertheless, the Android version offers a powerful and inexpensive tool for solving equations and checking units on a portable device and it is much less expensive.

Table 1. Comparison of the Windows and Android versions of EES

Feature	Windows Version	Android Version
Maximum number of variables	6000(Com), 12000 (Pro)	250
Solves non-linear equations	Yes	Yes
Property data for ideal gas and real fluids	Yes	Yes
Checks unit consistency of equations	Yes	Yes
Saves files that can be read in EES or tablet	Yes	Yes
Parametric Tables	Yes	No
Lookup Tables	Yes	No
Arrays Tables	Yes	No
Integral Tables	Yes	No
Plotting capability	Yes	No
Functions, Procedures	Yes	No
Modules, Subprograms	Yes	No
Optimization	Yes	No
Graphical Input/Output	Yes	No

II. Installation

EES is obtained from the Play Store. along with support and example files in a single file named EES_Android.apk. The Android operating system will install this file as an application when it is selected. The application requires the usual permissions including WiFi and reading/writing to storage. EES requires approximately 32 MB of memory and it installs in the tablet memory. An installed version of EES can be removed, if desired, using the Android Task Manager.

III. Starting EES

The EES application is associated with the icon shown in Figure 1, which will appear on the desktop after installation. Clicking or touching this icon will start EES and show its main screen, as seen in Figure 2 in the landscape orientation.

EES_Android

Figure 1. The EES application icon.

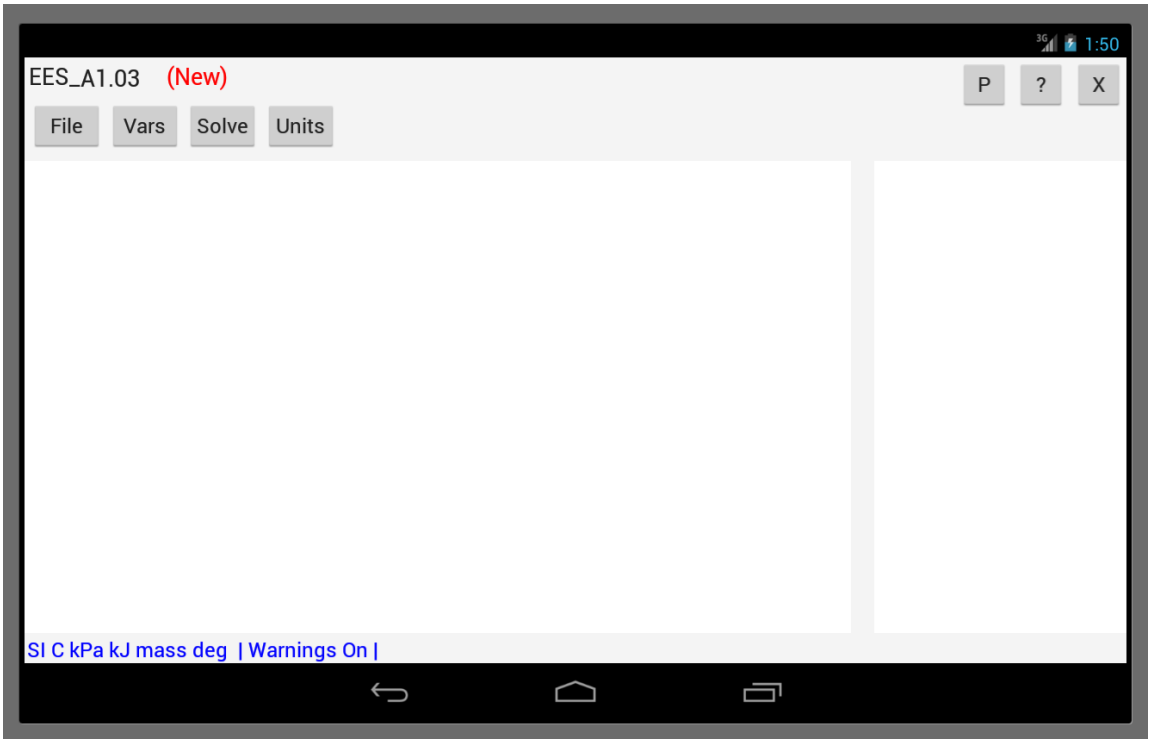

Figure 2. EES main screen in landscape orientation.

The main screen is divided into two sections. The section on the left in landscape mode and on top in portrait mode is the Equations window. The other section is the Solution window where the values of the variables will be displayed after the calculations are completed. Note that the divider separating the Equations and Solution can be 'dragged' left or right (landscape mode) or up or down (portrait) mode by holding your finger on the divider while sliding it in the desired direction.

If you are new to EES, the best place to get started is the Mastering EES ebook. Chapter 1, which convers most of what you need to know to use the EES Android App can be downloaded at no cost. Alternatively, there are YouTube videos on http://fchart.com. A .pdf copy of this manual can also be downloaded from this site.

The equations window operates in a manner similar to a word processor application in which equations can be entered, modified or deleted. EES variables consist of up to 30 alphanumeric characters with a letter as the first character. Upper and lower case letters are not distinguished. Generally, each equation appears on a separate line, but multiple equations may be placed on one line if they are separated by semicolons. Comments are enclosed within curly braces { } or quotes and they can span multiple lines. Some keyboards (notably the virtual keyboard on the Samsung Galaxy Tab Pro) do not provide keys for curly braces. However, they can be entered using the Ctrl+(and Ctrl+) keyboard combinations. Operators such as +, -, * and / are used as in any computer language. The ^ operator is used to raise a quantity to a power.

Touch the Equations window to enter the edit mode. A virtual keyboard will appear on bottom half of the screen (unless you have a Blue Tooth keyboard installed). Enter the equations shown in Figure 3 and then click the  button on the tablet to dismiss the virtual keyword[1]. The equations window will scroll as needed so that the selected location is within view. The virtual keyboard works, but it is somewhat awkward to use with EES. If you expect to use the program often for entering equations, consider using a Blue Tooth external keyboard.

The simple program shown in Figure 3 demonstrates the equation-solving capability of EES. The equations are non-linear and interdependent. The equations can be entered in any order. It is not necessary to isolate the unknown variable, e.g., X, on the left side of an equation, as required in formal programming languages such as FORTRAN or C. It is necessary to have the same number of equations and variables. In this example, there are three equations and three variables (X,Y, and alpha).

Touch the Solve button to solve the equations. EES will first compile the equations and check for proper syntax. If no problems are found, EES will attempt to solve the

[1] Some virtual keyboards have a hide keyboard key. EES will not respond properly when this key is pressed. Use the back button.

equation set numerically. If the process is successful, the solution will be displayed in alphabetical scrollable list in the Solution window, as shown in Figure 4.

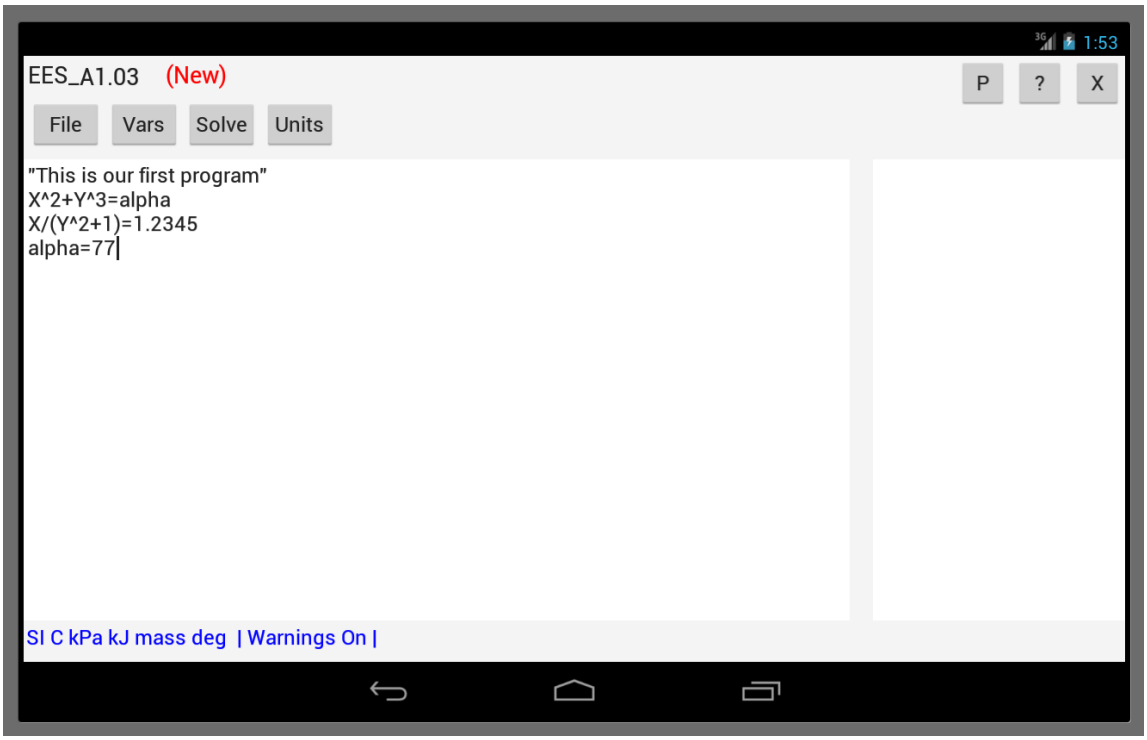

Figure 3. Equations window showing a simple test program.

Figure 4. Solution to test program.

Congratulations! You have solved the first test program. There's more to learn. These equations are non-linear and perhaps provide more than one real solution. EES allows you to set guess values and bounds for each variable, which determines which solution will result, as discussed in Section V. EES provides an extensive library of built-in mathematical and property functions. Use of the property functions is described in the online help that is provided with the application. Touch the ? button to access the help. Detailed information is also provided in the Mastering EES book and YouTube tutorials. Units can be assigned to each variable and EES will check unit consistency, as described in Sections V and VI.

IV. Opening, Saving and Managing EES Files

The File button in the main screen provides access to the File window, shown in Figure 5. As indicated by the buttons, this window allows you to start a new EES session, and open, save and delete EES files.

Figure 5. EES File window.

Click the Save button to save the test file. A dialog will appear in which you can enter the name of the saved file, as seen in Figure 6. EES Android files are identified by an .EES_ file name extension. However, it is not necessary to enter .EES_ following the file name as EES will automatically supply the extension. An .EES_ file is an ASCII text file that includes the equations and variable information. The Windows version of EES can

read and write .EES_ files so it is possible to exchange files between the tablet and Windows versions.

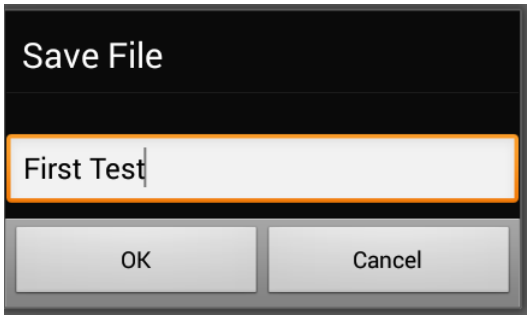

Figure 6: Save File dialog

After saving the file, the control will return to the main window. Click the File button again. Now you will see the file that was just saved listed in the directory.

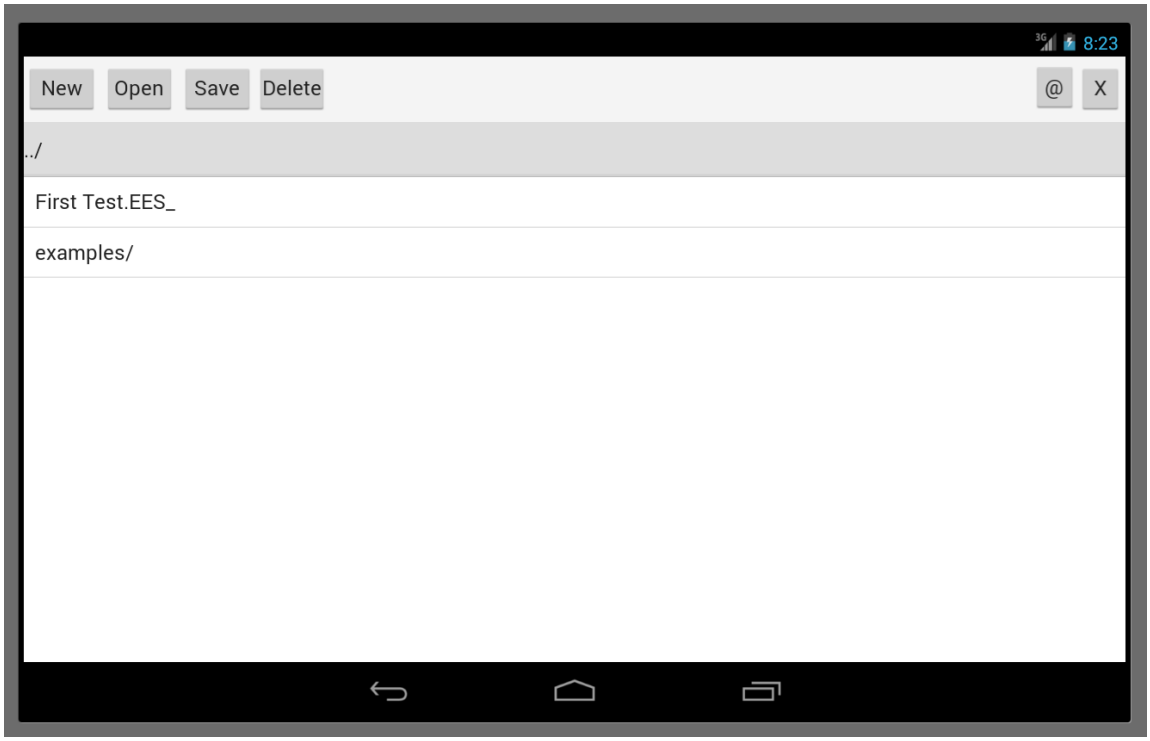

Figure 7: File listing after saving First Test

We will next open one of the examples provided with EES. Touch the examples/ entry in the file list. The first touch will highlight the item with a gray background. Now either touch the Open button or touch the selected item a second time. The files in the examples subdirectory will be displayed (Figure 8). The Throttle example will be used to demonstrate the additional capabilities of EES. Touch Throttle.EES_ and then touch the Open button (or touch Throttle.EES_ a second time). The file will open to display the equations, as shown in Figure 9.

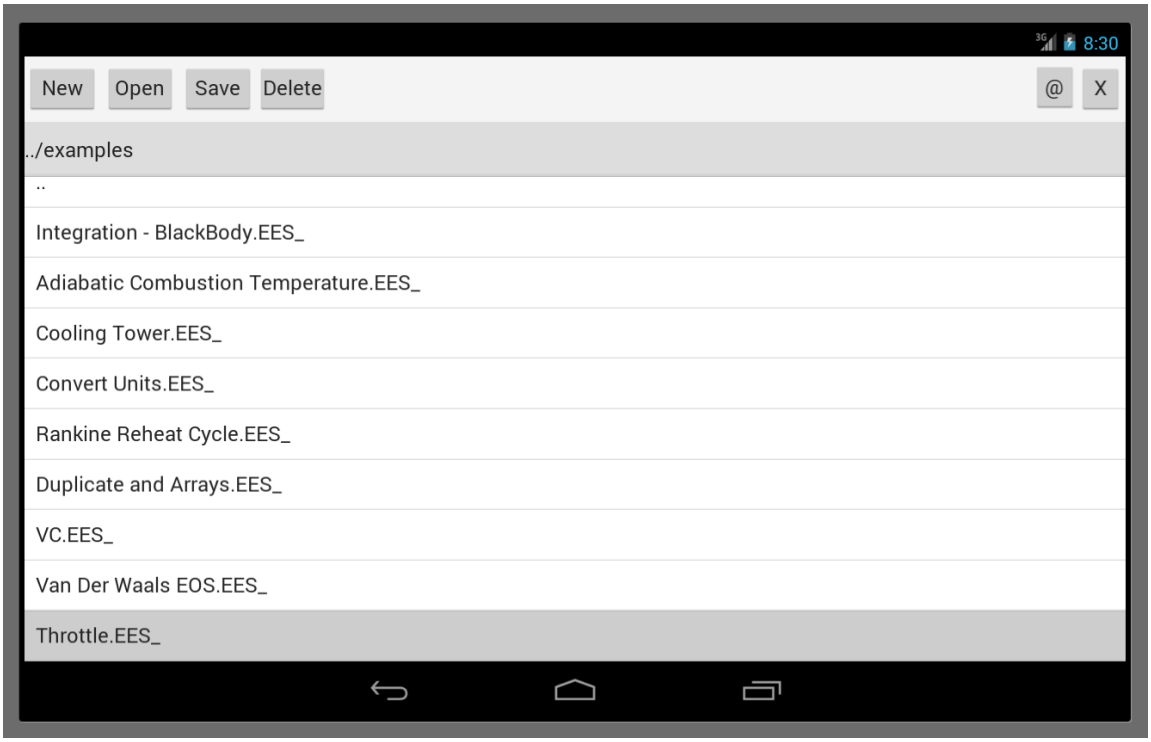

Figure 8. Examples provided with the application with Throttle.EES_ selected.

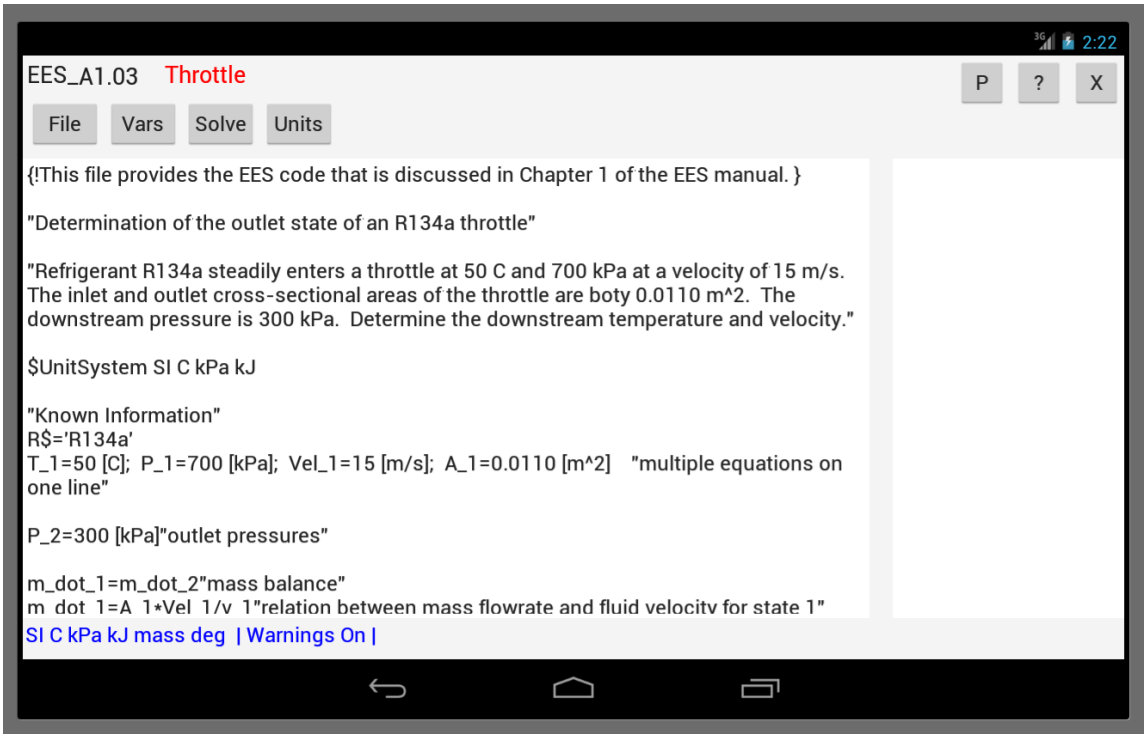

Figure 9: Equations for the Throttle example.

Other controls in the Files window need little explanation. The New button will, after a confirmation to save the current file, clear the Equations window and variable space to start a new EES program. The Delete button will, after confirmation, delete the selected file. The @ button provides a way to send the EES file to another person or to another computer. After touching this button, an email application (or a choice of applications) will appear. Enter your destination email address to send the selected file as an email attachment. If no file is selected, the currently opened file will be sent. You can also send files to your Google drive in this way. The X button will return control back to the main window.

NOTE: If you are updating your current version, use the @ button to save all .EES_ files that you wish to keep as the update will completely erases all files in the EES_Android directory.

V. Using the Controls in the Main Window

Figure 9 shows the equations for the Throttle example. The name of the file (excluding the directory and the .EES_ file name extension) are displayed in red type at the top of the main window. This example uses the built-in property data for refrigerant R134a. The refrigerant is specified using string variable, R$. String variables, which end with the $ character, hold string data rather than numerical values. Using a string variable makes it easy to change this example for other fluids. A list of the currently-implemented fluids that EES will recognize is available in the online help file, which can be accessed by touching the ? button at the upper right of the window.

The unit system that EES is configured for is shown in the status line in blue at the bottom of the equations window. The unit system is needed only if the equations use the built-in thermodynamic and transport property database, as in this example. In this case, all inputs and outputs to the property functions must be in the specified unit system. Note that the unit system can be changed with the $UnitSystem directive, as described in Section VII. It is good EES programming practice to include the $UnitSystem directive at the top of the file.

Take a moment to review the equations in this example. Comments appear both within curly braces and quotes. The file contains several directives. Directives which begin with a $ character, are instructions to EES. Not all of the directives function on the tablet version. However, there are several important directives, such as $UnitSystem, which are discussed in Section VII. Equations are generally entered one per line, but in this example, several appear on the same line, separated with a semicolon. Finally, note that the units of numerical constants can be specified by entering the units after the numerical value within square braces, as seen for variables T_1, P_1, Vel_1, A_1, and P_2.

Touch the Solve button to solve the equations. Note that an animated control will be displayed at the top right of the window just below the X (quit) button to indicate that calculations are in progress. The animation control will disappear when the calculations are completed. EES will first check the syntax of the equations. If an error is found, the offending equation will be highlighted and an appropriate error message will be displayed. Assuming that there are no syntax errors, the variables in the Equations window will be displayed in a scrollable list the right (landscape mode) or below (portrait mode) of the equations, as shown in Figure 10.

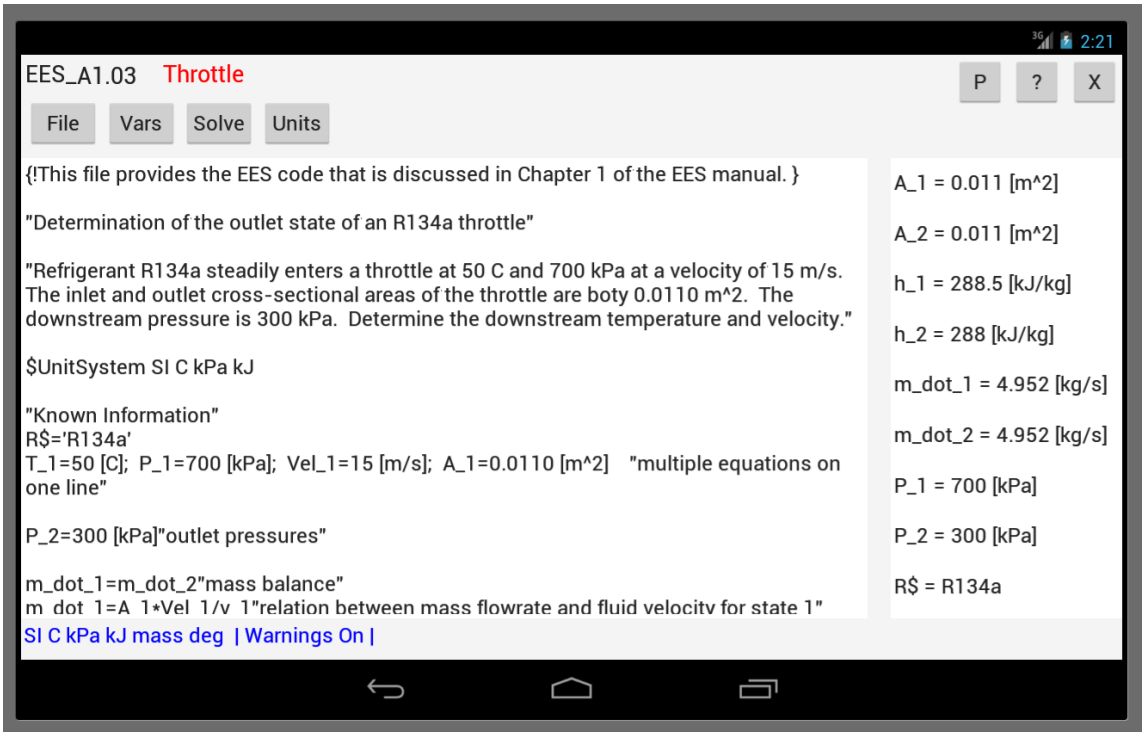

Figure 10. After solving the solution window will be displayed.

At this point, you may want to print your results. This is not directly possible, but instead, you can prepare a text file with the equations, the solution and a summary of the unit checking and email it to yourself or another person or put it on Google Drive. To prepare the report, touch the P button at the upper right of the window. Depending on how your system is configured, you may next see a dialog offering a selection of programs. If you select an email application[2], enter a recipient and click the send button. The report will be produced in the body of the email and sent to the specified recipient.

Note that the Solution window shows variables in a specified numerical format with their units. By default, all new variables use the Auto format display in which EES determines the format and no units are assigned. Each variable has an associated guess value and

[2] The GMail program appears to have a bug that causes the EES Android App to stop after the email is sent. Use an alternative if available or save your file before you use the P button.

lower and upper bounds. By default, the guess value is 1.0 and the bounds are negative and positive infinity. All of this information can be changed in the Variable Information window. One way to use this window is to touch one or more variables in the Solution window for which you want to change variable information. Then touch the Vars button to bring up the Variable Information window, as shown in Figure 11.

Figure 11: The Variable Information window.

The appearance of the Variable Information window will depend on the tablet orientation (landscape or portrait) and on the window size. If sufficient width is available, the variables will be displayed in several columns. The selected variable(s) will be highlighted and the information for the selected variables is displayed in the left panel. The format, units, guess value, and lower and upper bounds for the selected variable(s) can be modified. Note that a dash (-) should be used to specifically indicate that a variable is dimensionless. Clicking the Apply button will register the changes and keep the focus in the Variable Information window so that additional changes can be made. The Update button is enabled if the calculations were successfully completed before this window appeared. Touching the Update button will change the guess value of all variables to the calculated value for the variables. Updating can also be accomplished with the $UpdateGuesses directive. Clicking the OK button will register the changes and return to the main window. The Cancel button will return to the main window without registering the last input.

VI Checking Units

The ability to check the unit consistency of a set of equations is one of the most powerful features of EES. To use this capability, the units of each variable must be assigned by using Variable Information window, as indicated in Section V. Touch the Units button. EES will check each equation for unit consistency. If a problem is found, the offending equation will be highlighted and error message will be displayed. Consistent units for all variables has already been entered for this example, so the Units checker will simply display "No unit errors were detected" if no error issues are identified. To demonstrate the unit checking capability, we will change the units of an arbitrary variable, in this case m_dot_1, to an incorrect entry. Touch the Vars button. Select m_dot_1, as shown in Figure 11. Change its units from kg/s to kg. Touch OK to return to the main window and then touch the Units button. EES will respond with the warning shown in Figure 12. After the warning has been dismissed, the equation that produced the warning will be selected in the Equations window, as shown in Figure 13.

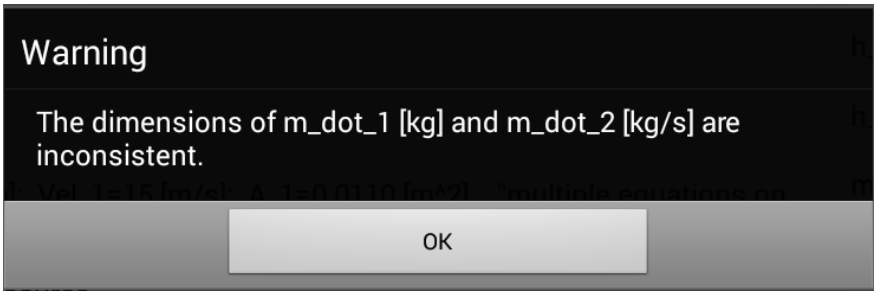

Figure 12: Warning message from the unit checker.

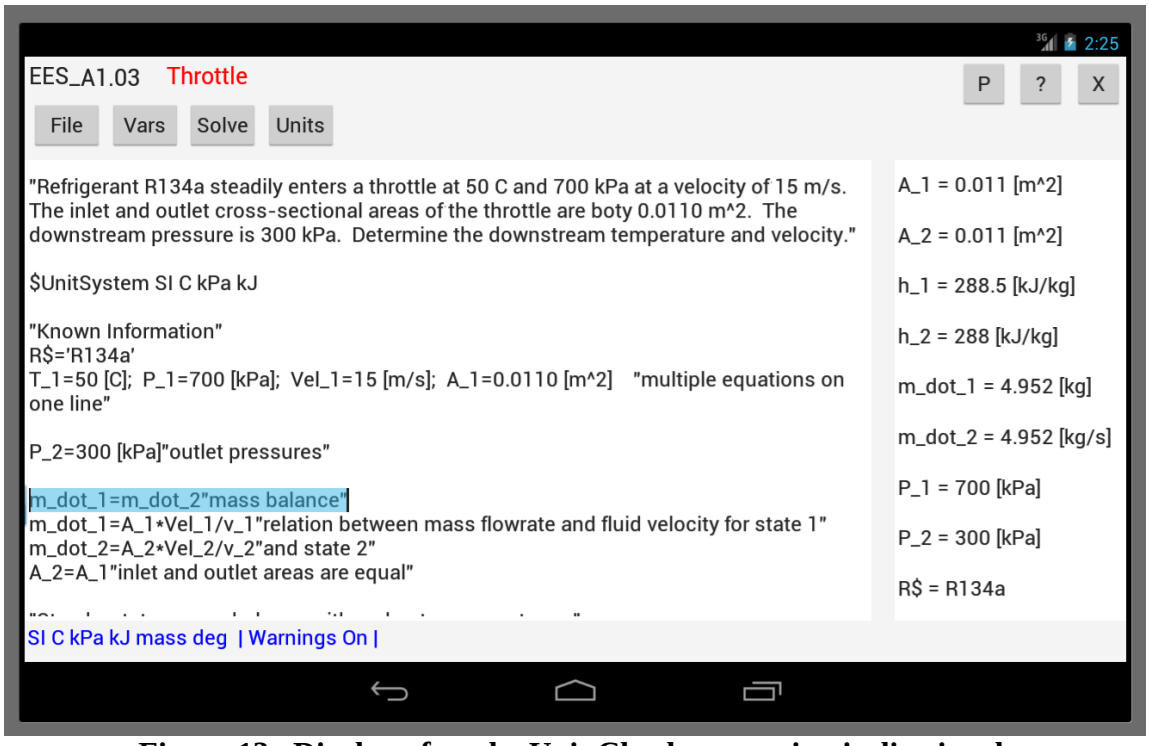

Figure 13. Display after the Unit Checker warning is dismissed.

It is good practice to enter the correct units for all variables so as to eliminate all unit warnings. In the few cases where this is not possible, the $CheckUnits On/Off directive can be applied, as described in the next section.

VII Directives

Directives are instructions to EES, rather than equations. The EES Windows application provides many directives, but only a subset of these are supported in the EES_Android version. The directives applicable to EES_Android are described below in alphabetical order.

$CheckUnits

EES will check the unit consistency of each equation when the Units button is touched. It is recommended that you set the units of each variable in your equation set using the Vars button and use the Units button to ensure that there are no unit errors. However, in some cases, such as when an empirical equation is employed, it is tedious to enter the units for all of the constants and variables. This is the situation for which the $CheckUnits directive is most useful. Unit checking can be selectively deactivated for one or more equations by enclosing them within a $CheckUnits Off directive and a $CheckUnits On directive, as shown.

```
$CheckUnits Off
{Unit checking will not occur for these equations}
m_dot_1=m_dot_2 "mass balance"
m_dot_1=A_1*Vel_1/v_1 "relation between mass flowrate and fluid velocity for state 1"
$CheckUnits on
{Unit checking resumes}
```

$Complex

EES can be configured to operate in complex mode so that each variable is assumed to have both a real and imaginary part. The $Complex directive can be used to activate or deactivate this mode and also to specify whether the variable i or j is used to represent $\sqrt{-1}$. For example,

```
$Complex On j
```

activates complex algebra and indicates that j will be used as $\sqrt{-1}$. File Complex.EES_ in the Examples folder demonstrates the complex algebra capability.

$Keyboard US/EU

This directive changes the decimal separator, list separator, and end of line indicator to be the US or EU conventions used by EES. The US setting uses a decimal point for the decimal separator whereas the EU setting uses a comma for the decimal separator. The US and EU list separators are the comma and the semicolon, respectively. The end of

line indicator (used when there is more than one equation on a single line) are semicolon for the US convention and colon for the EU convention.

$Reference

The values of specific internal energy, specific enthalpy, and specific entropy are not absolute. These values are only defined relative to reference values that are specified at a reference state. The choice of reference state is arbitrary if chemical reactions do not occur. The specification of different reference states is the primary reason that different sources of property information may appear to be providing very different property values. There are several common reference state choices, including:

1. The *International Institute of Refrigeration (IIR)* reference state sets the value of specific enthalpy to be 200 kJ/kg and the value of specific entropy to be 1.0 kJ/kg-K for saturated liquid at 0°C (273.15 K). Note that this option is not applicable to fluids for which the critical temperature is less than 0°C.
2. The *ASHRAE Standard (ASH)* reference state sets the values of specific enthalpy and specific entropy to 0 for saturated liquid at -40°C (-40°F). Note that this option is not applicable to fluids for which the critical temperature is less than -40°C.
3. The *Normal Boiling Point (NBP)* reference state sets the values of specific enthalpy and specific entropy to 0 for saturated liquid at the normal boiling point (i.e., the saturation temperature at one atmosphere). Note that this option is not applicable to fluids for which the critical pressure is less than one atmosphere.

The reference state can be changed using the $Reference directive. The format is:

```
$Reference  FluidName  ReferenceID
```

where FluidName is the name of the real fluid (e.g., R22, R134a, Ammonia, etc). The ReferenceID must be IIR, ASH, NBP, or DFT Note that the $Reference directive is not applicable to fluids that are modeled with the Martin-Hou or Ideal Gas equations of state. If the reference state choice is not applicable to the fluid then the reference state will remain at its default value. By default, the reference state for the refrigerant R134a is set to the ASHRAE Standard. The EES code below changes the reference state for the fluid to the IIR standard.

```
$Reference R134a IIR
```

$StopCriteria

The $StopCriteria allows the user to specify the stop criteria that control the iterative calculation process used by EES to solve the equations. It should not be necessary to adjust these criteria for most problems. The parameters that can be set using this directive are:

The number of iterations (default=250)
The relative residuals (default=1e-6)
The change in any variable (default=1e-9)
The calculation time (default=30 s)

The $StopCriteria directive corresponding to the default values is

$StopCriteria Iterations=250 Residuals=1e-6 Variables=1e-9 Time=30

The relative residual is the difference between the left and right sides of the equation divided by the value of the left side. The default stop criteria will cause the iteration process to stop when the number of iterations reaches 250, or the relative residual (i.e., the difference between the left and right sides of the equation normalized by the value of the left side of the equation, assuming it is not zero) of all equations is reduced below $1x10^{-6}$, or the change in all variables between iterations is reduced below $1x10^{-9}$.

The Time criteria in the Android version operates in a different manner than in the Windows version. In the Android version, EES will show a dialog allowing you to cancel the calculations when calculation time exceeds the specified time. It is not necessary to specify all of the criteria. If you just wish to specify the allowable calculation time to be 60 seconds, you would enter:

$StopCriteria Time=60

$UnitSystem

The $UnitSystem directive provides a method for specifying the unit system settings in EES which is used for inputs and outputs to all of the built-in thermodynamic and transport properties. The format for the $UnitSystem directive is:

$UnitSystem SI Mass (or Mole) Deg (or Rad) kPa (or Pa, bar, MPa) J (or kJ) C (or K)

or

$UnitSystem Eng Mass (or Mole) Deg (or Rad) psia (or atm) F (or R)

The order in which the unit specifications appear is not important and not all of them need to be specified. Note that it is not possible to specify a mixed unit system. For example, if the unit system is SI, then specifying F for the temperature units will result in temperature units of C, not F.

$UpdateGuesses

The $UpdateGuesses directive causes the guess values to be automatically updated after the calculations are successfully completed. Setting the guess values will likely result in EES converging faster or more successfully, even when some of the values are changed. The guess can also be updated by touching the Update button in the Variable Information window (accessed from the main window with the Vars button).

$VarInfo

The $VarInfo directive allows variable information (e.g., the guess value, limits, units, and display format) to be entered from the Equations window, rather than from the Variable Information dialog using the Vars button. A separate directive is needed for each variable. The format of the $VarInfo directive is as follows

$VarInfo VariableName Guess=V1 Lower=V2 Upper=V3 Units='XXXX' Display=F1

VariableName must be the first parameter. The variable name does not need to previously defined, so the location of the $VarInfo directive is not important. However, it is best to place the $VarInfo directives before the first equation in the main section of the Equations window. Following VariableName, the remaining part of the directive consists of one or more keywords followed by an equal sign and a specification. It is only necessary to provide the keyword=specification terms that you are interested in changing and they can be provided in any order. V1, V2, and V3 are the specifications for Guess, Lower, and Upper, which should be numerical values. The Units specification must be a string constant (within single quotes).

The Display specification consists of two characters. The first character can be A, F, or E. A stands for Auto format. When this format option (the default) is selected, EES will internally choose a format for displaying the value. F means Fixed Decimal format. In this case, the number in the second field indicates the number of digits to the right of the decimal separator. E indicates exponential or floating format. The number that follows the E is the number of digits to the right of the decimal separator.

The following example will calculate the specific enthalpy of steam in variable h and set its units to 'kJ/kg' and its display to show 1 digit beyond the decimal point.

```
$UnitSystem SI C kPa kJ mass
T=100 [C]
P=50 [kPa]
$VarInfo h   Units='kJ/kg'   Display=F1
h=enthalpy(Steam,T=T,P=P)
```

$Warnings

Warnings in EES are generated for a variety of reasons. Warnings are generated internally by the EES program if the equations appear to be singular. Warnings can be generated within property correlations if they are used outside of their published range of applicability. By default, warnings are automatically displayed after the calculations have been completed. You can enable or disable warnings with the $Warnings On or $Warnings Off directives. Warning messages will be disabled for all equations that follow the $Warnings Off directive. $Warnings On and Off directive can be used multiple times within a program to control which equations can or cannot issue warning message.

VIII Disclaimer

The Android operating system is used on many types of equipment. It has been tested for selected tablets running operating systems 4.0 and higher. We do not guarantee that it will work on your equipment. F-Chart Software makes no guarantee that the EES Android Tablet is free from errors or that the results produced with it will be free of errors and assumes no responsibility or liability for the accuracy of the program or for the results that may come from its use. You can report problems by email to: info@fchart.com.