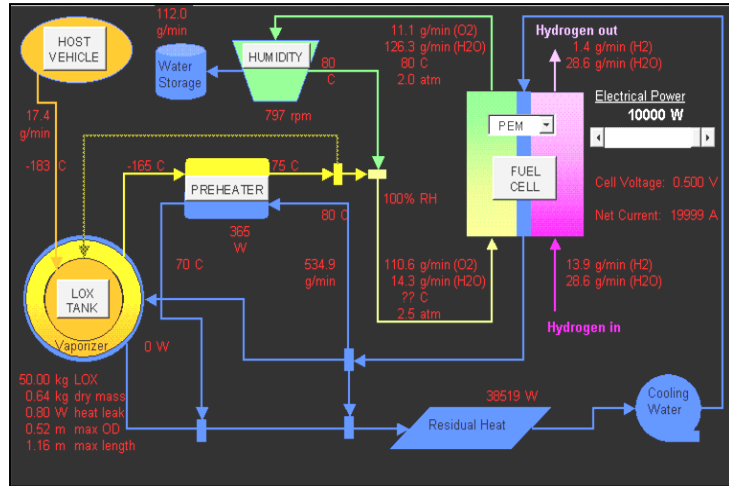


# Test Your Excel VBA Skills: 8 Engineering Exercises



These course exercises and application examples are from the 2-day short course “Engineering Analysis & Modeling with Excel-VBA”. The complete set of notes are available in [paperback](#) and [kindle](#) formats on Amazon. In-depth details are presented on principles, practices, and implementation of Excel and its integrated programming environment, Visual Basic for Applications (VBA), for analysis and creating engineering models.

Units	Sink temperature:	%Tot area:	Isofoam	Section	MLI Layers	Misc. factors:
English	Area 1: 300.0 K	100%	0.000 m	all	300	MLI factor: 174%
SI (metric)	Area 2: 300.0 K	0%	0.000 m	none	0	Design Cond factor: 14.6%
	Area 3: 300 K	0%	0.000 m	none	0	Mass factor: 10%

Hydrogen (bara)	Fluid mass:	Fluid temp:	Tank press:	Ullage:	Material	MEOP:	Safety Factor:	Stiffening rings:	Thickness:	Crosssect area:	Length btwn:
500.0 kg	500.0 kg	16.0 K	345.0 kPa	2%	Aluminum (6061-T6)	551.6 kPa	1.50	10	0.25 cm	0.012 cm <sup>2</sup>	4.967 m

Geometry	Dimensions	Area	%Area
Cylinder	cylinder length: 7.9 m inside length: 8.9 m inside diam: 1.00 m	internal area: 28.1 m <sup>2</sup>	%area cylinder: 88.8%
Spherical	inside diameter: 2.35 m	internal area: 17.3 m <sup>2</sup>	
Annular	inside length: 11.5 m end diam: 0.25 m outer diam: 1.00 m inner diam: 0.50 m	internal area: 55.1 m <sup>2</sup>	%area ends: 3.36% %area outer cyl: 64.4% %area inner cyl: 32.2%


C-C Overwrap (outer diam only)	
<b>CALCULATED TANK PARAMETERS</b>	
Fluid density:	75.410 kg/m <sup>3</sup>
Internal volume:	6.77 m <sup>3</sup>
Wall thickness:	0.1500 cm
Dry mass:	114.34 kg
Misc mass:	11.43 kg
MLI mass:	144.21 kg
Heat leak:	2.34 W
Conduction:	0.34 W
Max outer diam:	1.296 m
Max outer length:	9.24 m
Min inner diam:	N/A m
% Fluid mass:	79.90%
Optimiz Target:	2.34
Active Cooling:	
system mass	521.4 kg
power in @20K	608.2 W

The exercise problems in each section build upon the previous exercises to demonstrate new techniques. To obtain completed exercises and other helpful Excel-VBA resources, visit: [www.isothermtech.com](http://www.isothermtech.com)

# Exercise 1: Convection Sheet

(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))

E10    `=IF(Reynolds_number<2300,"Laminar","Turbulent")`



**DESCRIPTION:**  
Forced convection heat transfer for internal fully developed turbulent flow

**ASSUMPTIONS:**  
1. Fully developed turbulent flow  
2. Smooth pipe walls  
3. Constant properties at the bulk temp.

**REFERENCE:**  
Lienhard, A Heat Transfer Text, 3rd ed., 2006, p360

**EQUATIONS:**

$$Nu = \frac{hD}{k} = \frac{(f/8)(Re - 1000) Pr}{1 + 12.7 \sqrt{f/8} (Pr^{2\beta} - 1)}$$

for

$$2300 \leq Re \leq 5 \times 10^6$$

$$f = \frac{1}{(1.82 \log_{10} Re - 1.64)^2}$$

$$Re = \frac{uD}{\nu}$$

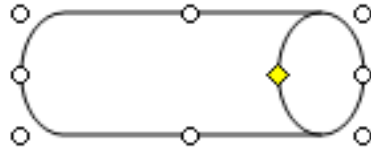
INPUTS			
D	Pipe diameter	0.05	m
T <sub>b</sub>	Bulk temp	40	C
k	Fluid conductivity	0.633	W/m-C
Pr	Prandtl number	4.3	
u	Fluid velocity	1	m/s
ν	Kinematic viscosity	6.58E-07	m <sup>2</sup> /s

OUTPUTS			
Re	Reynolds number	7.60E+04	Turbulent
Nu	Nusselt number		
h	Heat transfer coeff		W/m <sup>2</sup> -C

Pipe Heat Transfer

1. Draw the graphics
2. Add the sheet name, description, assumptions, & reference
3. Set up the inputs & outputs (I/O) as shown and define the cell names
4. Use standard cell equation and the built-in "IF" function to check flow regime
5. Format the cells (fill, border, etc.)
6. Start documenting the equations

# Exercise 1: Convection Sheet - Hints



• Resize the “A” column by dragging the separator line to make room for the graphics

• Use the cylinder (“can”) from the menu and use the green edit circle to rotate it (optional: add black “hole” at pipe end)

• Use the arrow icon to add flow arrows

• Experiment with the Equation Editor:

**EQUATIONS:**

$$Nu = \frac{hD}{k} = \frac{(f/8)(Re-1000)Pr}{1+12.7\sqrt{f/8}(Pr^{2/3}-1)}$$

for

$$2300 \leq Re \leq 5 \times 10^6$$

where

$$f = \frac{1}{(1.82 \log_{10} Re - 1.64)^2}$$

$$Re = \frac{uD}{\nu}$$

– Fraction notation

– Subscript & superscripts

# Exercise 2: Convection VBA

```
Dim Veloc As Single 'Fluid velocity
Dim Diam As Single 'Pipe diameter
Dim Kvisc As Single 'Kinematic viscosity
Dim Prandtl As Double 'Prandtl number
Dim Cond As Double 'Thermal conductivity
Dim FFactor As Double 'Friction factor

'CALCULATE REYNOLDS NUMBER
Function Reynolds(Veloc, Diam, Kvisc)
    Reynolds = Veloc * Diam / Kvisc
End Function

'CALCULATE FRICTION FACTOR
Function Friction(Reynolds)
    Friction = 1 / ((1.82 * Application. _
        WorksheetFunction.Log10(Reynolds)) _
        - 1.64) ^ 2
End Function

'CALCULATE NUSSELT NUMBER
Function Nusselt(Reynolds, Prandtl)
    FFactor = Friction(Reynolds) 'Call to a function
    Nusselt = FFactor / 8 * (Reynolds - 1000) * _
        Prandtl / (1 + 12.7 * Sqr(FFactor / 8) * _
        (Prandtl ^ (2 / 3) - 1))
End Function

'CALCULATE HEAT TRANSFER COEFFICIENT
Function HTcoeff(Nusselt, Diam, Cond)
    HTcoeff = Nusselt * Cond / Diam
End Function
```

1. Insert a module
2. Declare the variables using “Dim”
3. Add the functions shown to calculate the outputs, and call them from the worksheet
4. Include a friction factor function called by the Nusselt function
5. Use the debugger and locals window to try out the procedures
6. Optional: Use the macro recorder to change the fill color of a cell, then edit the macro & interpret it using VBA Help

# Exercise 2: Convection VBA - Hints

(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))

Reynolds\_nu...  $\text{=Reynolds(Fluid\_velocity, Pipe\_diameter, Kinematic\_viscosity)}$

INPUTS			
D	Pipe diameter	0.05	m
$T_b$	Bulk temp	40	C
k	Fluid conductivity	0.633	W/m-C
Pr	Prandtl number	4.3	
u	Fluid velocity	1	m/s
$\nu$	Kinematic viscosity	6.58E-07	m <sup>2</sup> /s

OUTPUTS			
Re	Reynolds number	7.60E+04	Turbulent
$Nu_x$	Nusselt number	380.47	
h	Heat transfer coeff	4817	W/m <sup>2</sup> -C

**DESCRIPTION:**  
Forced convection heat transfer for internal fully developed turbulent flow

**ASSUMPTIONS:**  
1. Fully developed turbulent flow  
2. Smooth pipe walls  
3. Constant properties at the bulk temp.

- Select the target cell, and use the “fx” icon and the “user defined” category to find your created functions
- Click in front of any line of code to create a toggle breakpoint for debugging
- Open the locals window to watch variables
- Step into the code to observe execution

Microsoft Visual Basic - Ex2-Internal Flow II.xls - [Module1 (Code)]

File Edit View Insert Format Debug Run Tools Add-Ins Window Help

Project - VBAPROJECT

(General) Reynolds

```

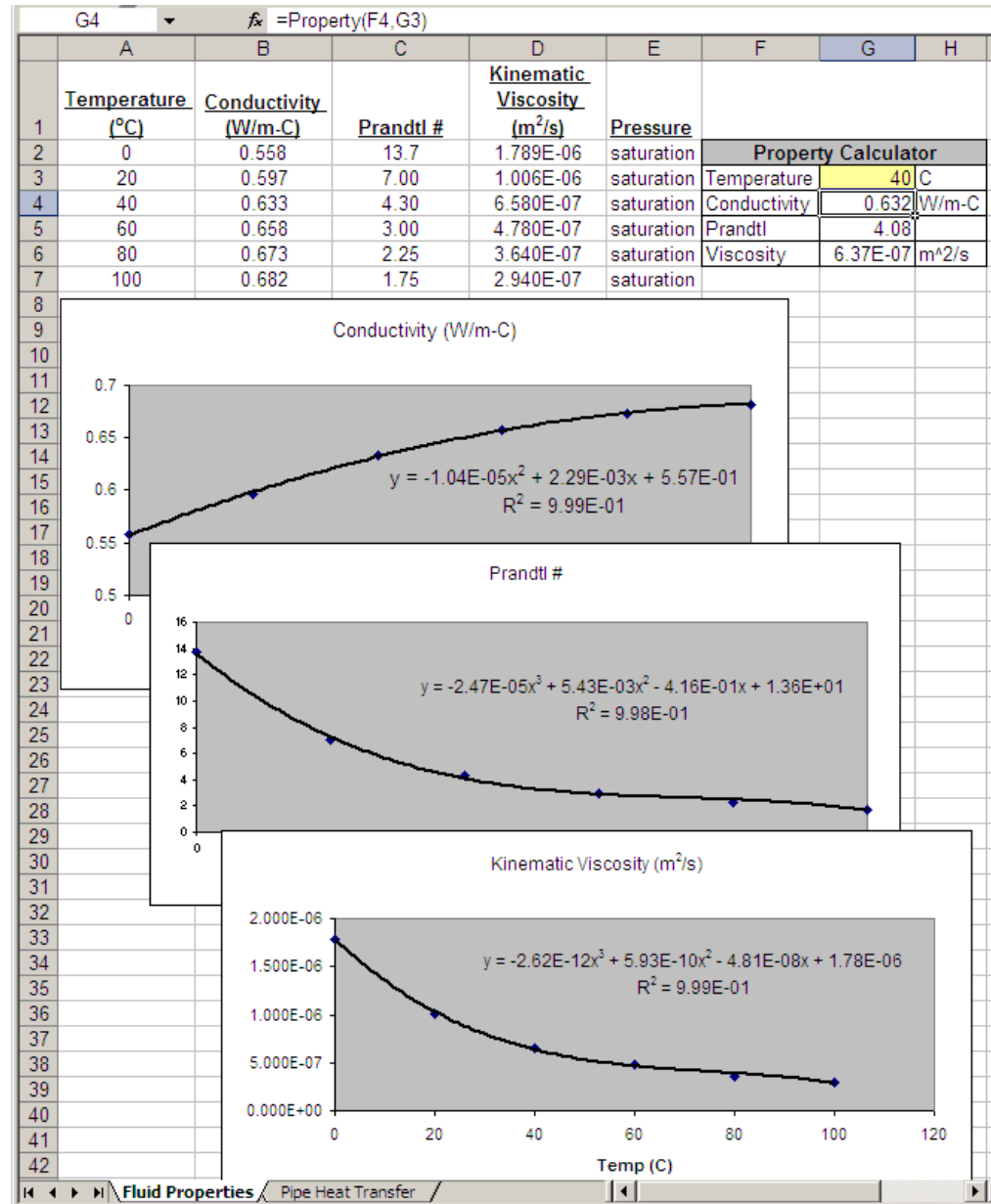
Dim Veloc As Single 'Fluid velocity
Dim Diam As Single 'Pipe diameter
Dim Kvisc As Single 'Kinematic viscosity
Dim Prandtl As Double 'Prandtl number
Dim Cond As Double 'Thermal conductivity
Dim FFactor As Double 'Friction factor

'CALCULATE REYNOLDS NUMBER
Function Reynolds(Veloc, Diam, Kvisc)
    Reynolds = Veloc * Diam / Kvisc
End Function
    
```

# Exercise 3: Fluid Properties

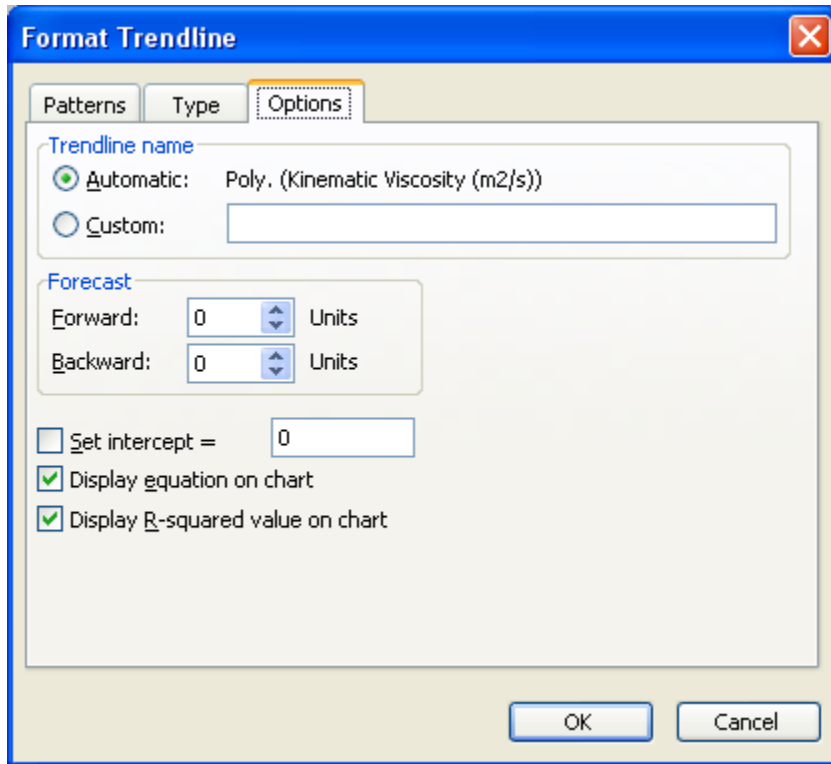
1. Add a new sheet called "Fluid Properties"
2. Fill in the property data shown
3. Create plots for all the properties vs temperature
4. Add trendlines (curve fits) for each property
5. Create a function that calculates the properties using the curve fit equations & try it out from the worksheet

```
'DETERMINE FLUID PROPERTIES FROM CURVE FITS
Function Property(Prop As String, Temp As Single)
Select Case Prop
Case "Conductivity"
Property = -1.04 * 10 ^ -5 * Temp ^ 2 + _
0.00229 * Temp + 0.557
Case "Prandtl"
Property = -2.47 * 10 ^ -5 * Temp ^ 3 + _
0.00543 * Temp ^ 2 - 0.4159 * Temp + 13.
Case "Viscosity"
Property = -2.62 * 10 ^ -12 * Temp ^ 3 + _
5.93 * 10 ^ -10 * Temp ^ 2 - 4.81 * _
10 ^ -8 * Temp + 1.78 * 10 ^ -6
End Select
End Function
```



# Exercise 3: Fluid Properties - Hints

*(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))*



- Right click any cell to access formatting options (or use menu/ribbon)
  - Select wrap text to auto-size the cell to fit the text
  - The font of individual characters can be made superscripts
- Make a scatter plot of the data
  - For noncontiguous data, use the “ctrl” key while selecting the cells
  - Right click on chart axis to change the scale
- Add a trendline by right clicking on a data point & choosing settings
  - Right click the curve fit equation to format as scientific with 2 digits after the decimal (in  $\leq 2003$ , double click curve fit equation to set format)

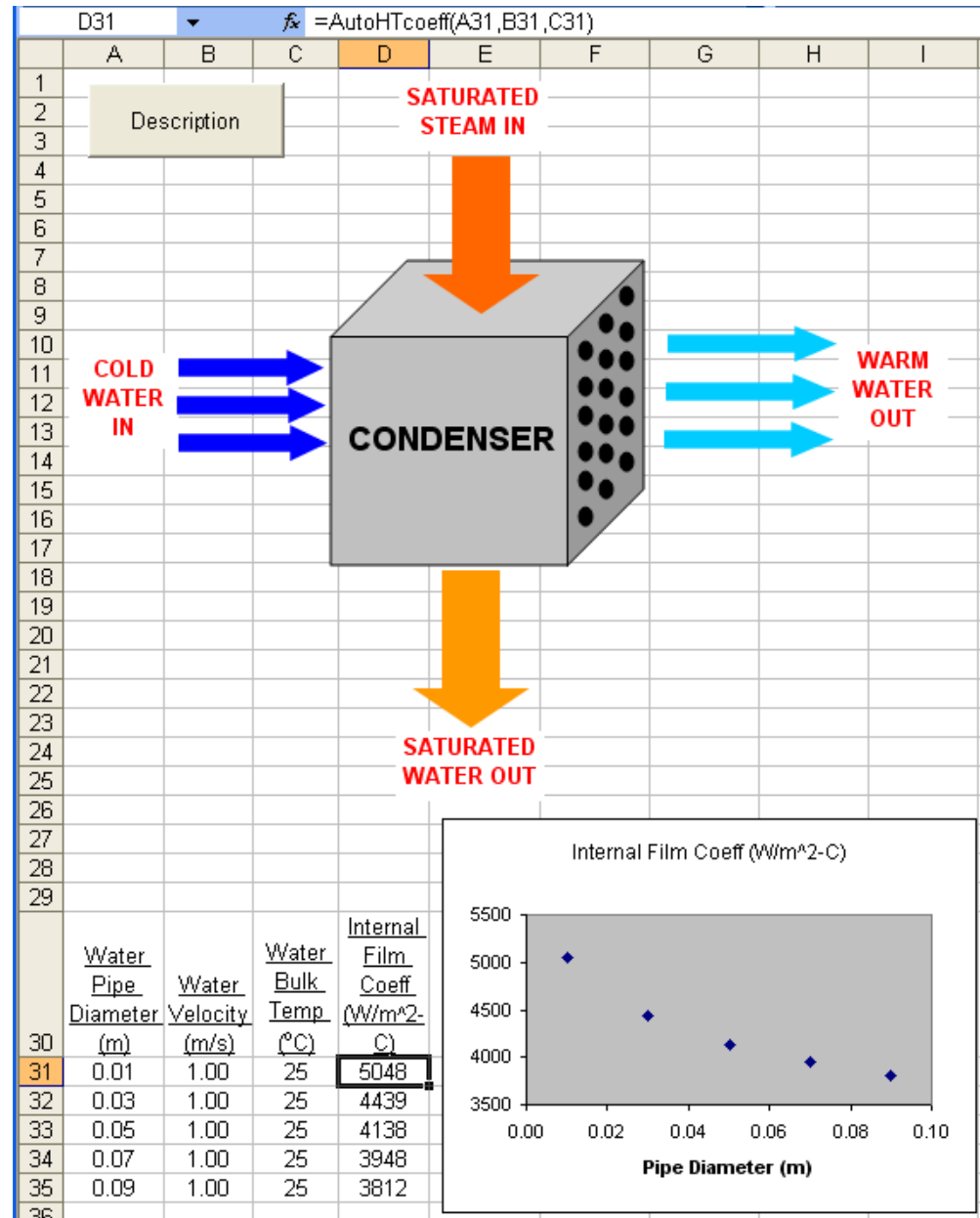
**Note: Curve fitting of properties in this exercise is for illustrative purposes only. Better approaches include: NIST Refprop (or online webbook), equations of state, or interpolation of high fidelity tabular data**

# Exercise 4: Condenser

1. Add a "Condenser" sheet & create a condenser sketch as shown
2. Make a button to open a message
3. Add the data for pipe diameter, water velocity, and water bulk temp
4. Create a new function in "Module 1" that calls the existing functions to calculate film heat transfer coeff's
5. Call the new function from the sheet
6. Create a scatter plot of film coeff vs pipe diameter (change temperature to 30... what happens to the plot?)

```
Private Sub CommandButton1_Click()
    MsgBox ("This is a steam condenser")
End Sub
```

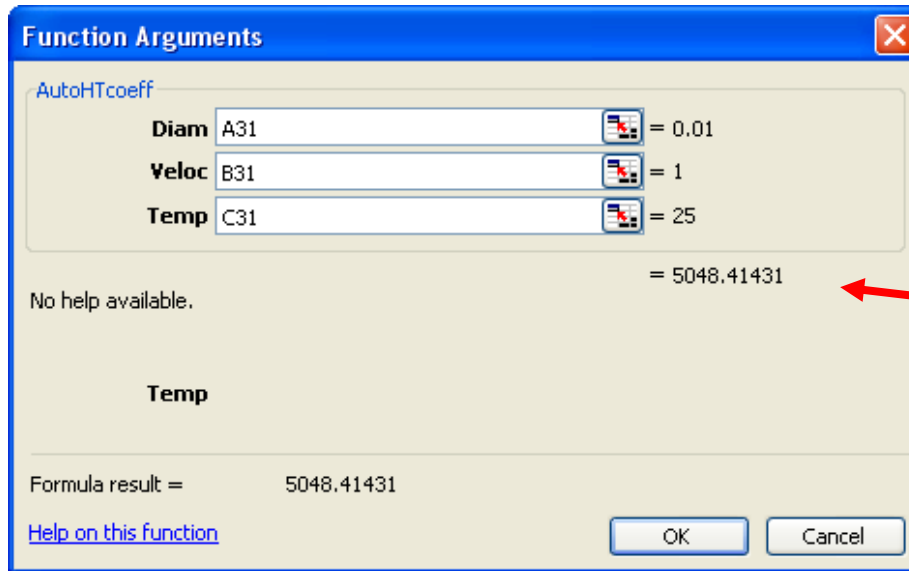
```
'CALCULATION OF HT COEFF DIRECTLY FOR DATA TABLE
Function AutoHTcoeff(Diam As Single, Veloc As _
    Single, Temp As Single)
'Multiple function calls set equal to variables
    Cond = Property("Conductivity", Temp)
    Kvisc = Property("Viscosity", Temp)
    Pr = Property("Prandtl", Temp)
    Re = Reynolds(Veloc, Diam, Kvisc)
    Nu = Nusselt(Re, Pr)
    AutoHTcoeff = Nu * Cond / Diam
End Function
```





# Exercise 4: Condenser - Hints

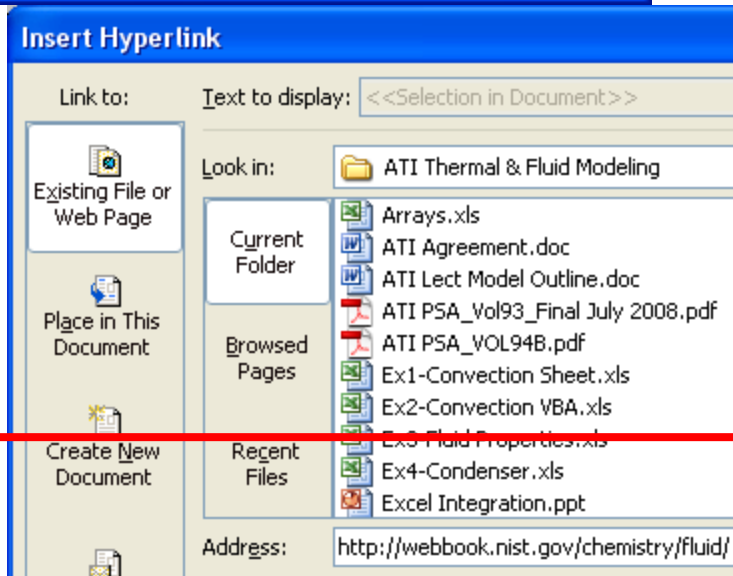
(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))



- Use the “ctrl-D” keys together to duplicate selected graphics
- Right click the button to add code
- Call the new “AutoHTcoeff” function from the first cell in the film coeff column
  - Use the “knuckle” to drag the first cell down to the remaining cells
  - Since this equation uses the default relative cell reference, the function call is updated with the appropriate inputs
- Optional: add link to the “Fluid Properties” sheet for NIST data source

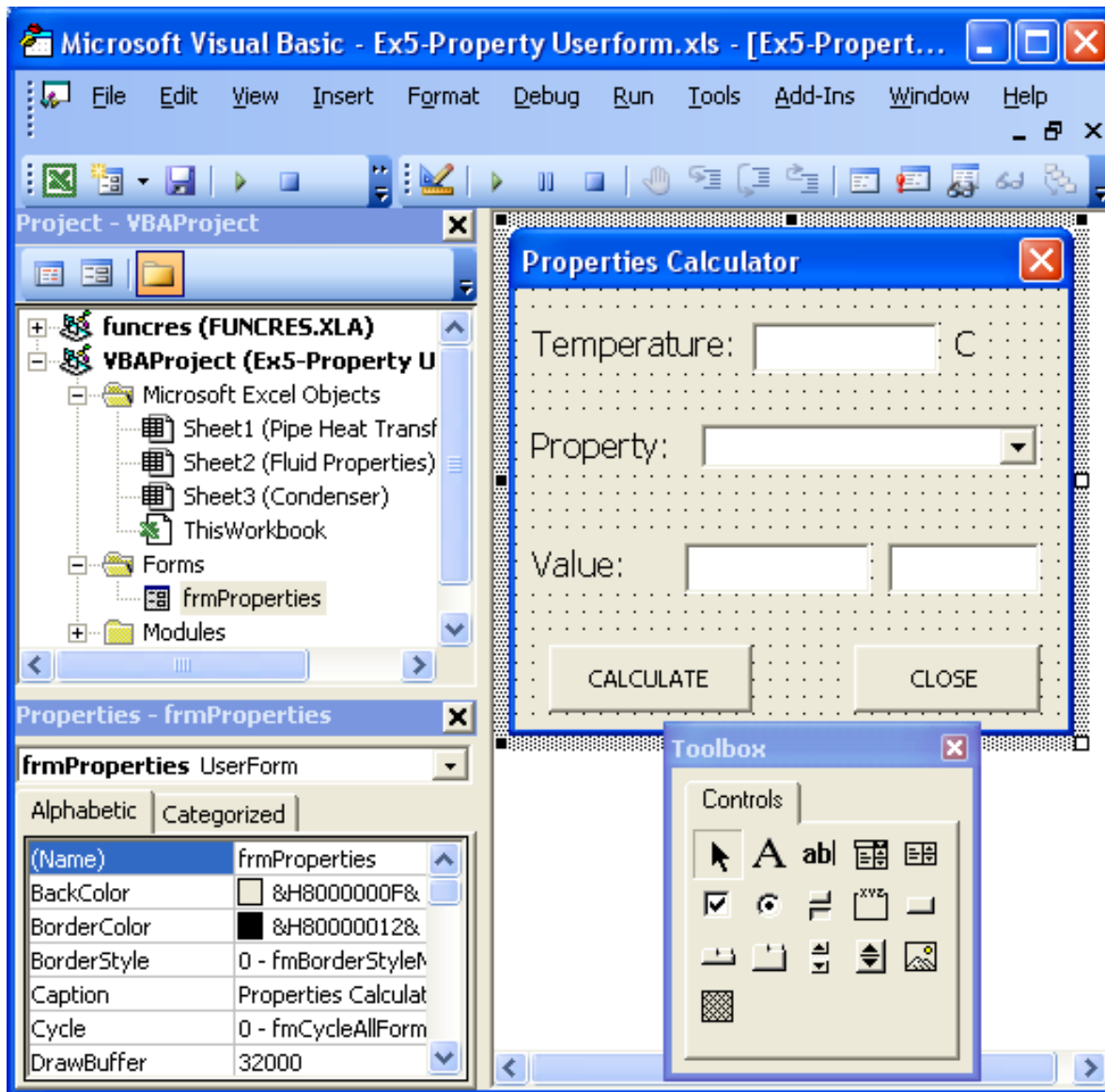
ty Calculator	
25	C
0.608	W/m-C
6.22	
9.07E-07	m <sup>2</sup> /s

**COMPARE TO NIST**



# Exercise 5: Properties Userform

(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))



1. Insert a userform in the VBA Editor
2. Name the form "frmProperties" and change the caption to "Properties Calculator"
3. Use Label, TextBox, ComboBox and CommandButton controls to build the userform shown
4. Name the controls using the prefix nomenclature:
  - lblTemp
  - txtTemp
  - lblProp
  - cboProp
  - lblValue
  - txtValue
  - txtUnits
  - cmdCalculate
  - cmdClose

# Exercise 5: Properties Userform (cont)

```
Dim Temp As Single
Dim PropType As String
Dim Result As String
Dim Units As String

Private Sub cmdCalculate_Click()
'Collect input data from the userform
Temp = frmProperties.txtTemp.Value
PropType = frmProperties.cboProp.Value

'Call property function
Result = Property(PropType, Temp)

'Display result in value textbox
frmProperties.txtValue.Value = Result

'Display correct units in units textbox
Select Case PropType
Case "Conductivity"
    frmProperties.txtUnits.Value = "W/m-C"
Case "Prandtl"
    frmProperties.txtUnits.Value = "#"
Case "Viscosity"
    frmProperties.txtUnits.Value = "m^2/s"
End Select
End Sub

Private Sub cmdClose_Click()
'Unload & hide the form
Unload frmProperties
frmProperties.Hide
End Sub
```

5. Right click on the cmdCalculate userform button and add the code shown
6. Right click on the cmdClose userform button and add the code shown
7. Go to the "Fluid Properties" sheet, add a button, change the caption to "Property Userform", right click on the button and add the code shown

Property Calculator		
Temperature	25	C
Conductivity	0.608	W/m-C
Prandtl	6.22	
Viscosity	9.07E-07	m^2/s

```
Private Sub CommandButton1_Click()
'Load userform into memory
Load frmProperties
'Populate the userform's combobox
frmProperties.cboProp.AddItem "Conductivity"
frmProperties.cboProp.AddItem "Prandtl"
frmProperties.cboProp.AddItem "Viscosity"
'Make the userform visible
frmProperties.Show
End Sub
```

# Exercise 5: Properties Userform - Hints

F	G	H	
<b>Property Userform</b>			
<b>Property Calculator</b>			
Temperature	25	Celsius	▼
Conductivity	0.608	Centigrade	
Prandtl	6.22	Celsius	
Viscosity	9.07E-07	m <sup>2</sup> /s	

- To name controls, make sure the properties window is open, select the control, and edit the “(Name)” property (the “Caption” property is accessed the same way)
- Optional: try setting up validation for the temperature cell of the worksheet property calculator, and drop down selection for the units cell, using data validation

**Data Validation**

Settings | Input Message | Error Alert

Validation criteria

Allow: Decimal [v]  Ignore blank

Data: between [v]

Minimum: 0 [icon]

Maximum: 100 [icon]

Apply these changes to all other cells with the same settings

Clear All | OK | Cancel

**Data Validation**

Settings | Input Message | Error Alert

Validation criteria

Allow: List [v]  Ignore blank

Data: between [v]  In-cell dropdown

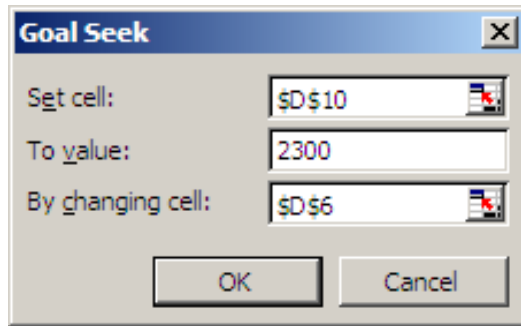
Source: Centigrade, Celsius [icon]

Apply these changes to all other cells with the same settings

Clear All | OK | Cancel

# Exercise 6: Pipe Design

*(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))*



INPUTS			
$D$	Pipe diameter	0.01	m
$T_b$	Bulk temp	25	C
$k$	Fluid conductivity	0.608	W/m-C
$Pr$	Prandtl number	6.22	
$u$	Fluid velocity	0.20861	m/s
$\nu$	Kinematic viscosity	9.07E-07	m <sup>2</sup> /s

OUTPUTS			
$Re$	Reynolds number	2.30E+03	Turbulent

1. Use Goal Seek to find out what velocity gives a Reynolds number of 2300 for a pipe diameter of 0.01 m and bulk temp of 25 C

2. Create a Diameter Trade button on the Pipe HT sheet, and add the code shown on the next slide

3. Create an Echo Data button & add the code shown on the next slide

4. Try changing the velocity value to 1 in the input cell, then run the Diameter Trade again

	B	C	D	E	F	G	H	I	J
1	INPUTS					D (m)	u (m/s)	Tb (C)	h (W/m-C)
2	$D$	Pipe diameter	0.01	m		0.01	1	25	5048
3	$T_b$	Bulk temp	25	C		0.02	1	25	4681
4	$k$	Fluid conductivity	0.608	W/m-C		0.03	1	25	4439
5	$Pr$	Prandtl number	6.22			0.04	1	25	4269
6	$u$	Fluid velocity	1	m/s		0.05	1	25	4138
7	$\nu$	Kinematic viscosity	9.07E-07	m <sup>2</sup> /s		0.06	1	25	4034
8						0.07	1	25	3948
9	OUTPUTS					0.08	1	25	3875
10	$Re$	Reynolds number	1.10E+04	Turbulent		0.09	1	25	3812
11	$Nu$	Nusselt number	83.07						
12	$h$	Heat transfer coeff	5048	W/m <sup>2</sup> -C		D (m)	u (m/s)	Tb (C)	h (W/m-C)
13						0.01	0.21	25	904
14						0.02	0.21	25	1076
15	Diameter Trade		Echo Data			0.03	0.21	25	1083
16						0.04	0.21	25	1068

# Exercise 6: Pipe Design - Hints

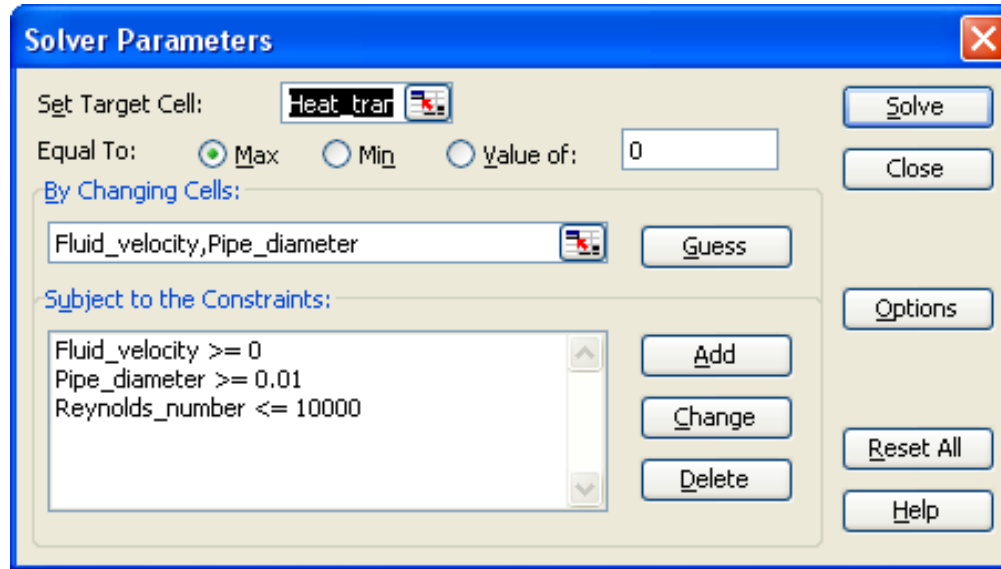
```
Dim Velocity As Single
Dim Temp As Single
Dim Diam As Single
Dim HTcoeff As Single
Dim i As Integer

Private Sub CommandButton1_Click()
'Read in velocity & temp data from sheet
Velocity = Cells(6, 4).Value
Temp = Cells(3, 4).Value
'Write out headers to sheet
Cells(1, 7).Value = "D (m)"
Cells(1, 8).Value = "u (m/s)"
Cells(1, 9).Value = "Tb (C)"
Cells(1, 10).Value = "h (W/m-C)"
For i = 1 To 9
    'Call the HT function & set equal to coeff variable
    Diam = i / 100
    HTcoeff = AutoHTcoeff(Diam, Velocity, Temp)
    'Write out results to sheet one cell at a time
    Cells(1 + i, 7).Value = Format(Diam, "0.00")
    Cells(1 + i, 8).Value = Format(Velocity, "0.00")
    Cells(1 + i, 9).Value = Format(Temp, "###")
    Cells(1 + i, 10).Value = Format(HTcoeff, "####")
Next i
End Sub

Private Sub CommandButton2_Click()
'Read pipe diameter trade data & echo back to sheet
Echo = Range("G1", "J10").Value
Range("G12", "J21") = Echo
End Sub
```

- Right click on the buttons to change the captions & create the associated code
- Remember the syntax is “Cells(Row#,Col#)”, not the other way around as is typical in cell references on the worksheet side (i.e. cell “D2” would be referenced as “Cell(2,4)” in VBA)
- In this exercise, the Cells and Range objects can be accessed without specifying parent objects (e.g. Worksheet) since all the “action” is occurring on one active sheet

# Exercise 7: Optimize Pipe



1. Use Solver on the Pipe HT sheet to find the maximum heat transfer coeff given the constraints shown

2. Select the Answer report and diagnose which variables the solution “bumped up against”

3. Save the Solver model on the Pipe HT sheet

4. Add code to the Property function that returns an “Out of Range” message if the temp is not 0-100 C

Target Cell (Max)			
Cell	Name	Original Value	Final Value
\$D\$12	Heat_transfer_coeff	904	4616

Adjustable Cells			
Cell	Name	Original Value	Final Value
\$D\$6	Fluid_velocity	0.20861	0.907
\$D\$2	Pipe_diameter	0.01	0.01

Constraints					
Cell	Name	Cell Value	Formula	Status	Slack
\$D\$10	Reynolds_number	1.00E+04	\$D\$10<=10000	Binding	0
\$D\$2	Pipe_diameter	0.01	\$D\$2>=0.01	Binding	0
\$D\$6	Fluid_velocity	0.907	\$D\$6>=0	Not Binding	0.907

SOLVER MODEL	
4616	
2	
TRUE	
TRUE	
FALSE	
100	

# Exercise 7: Optimize Pipe - Hints

*(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))*

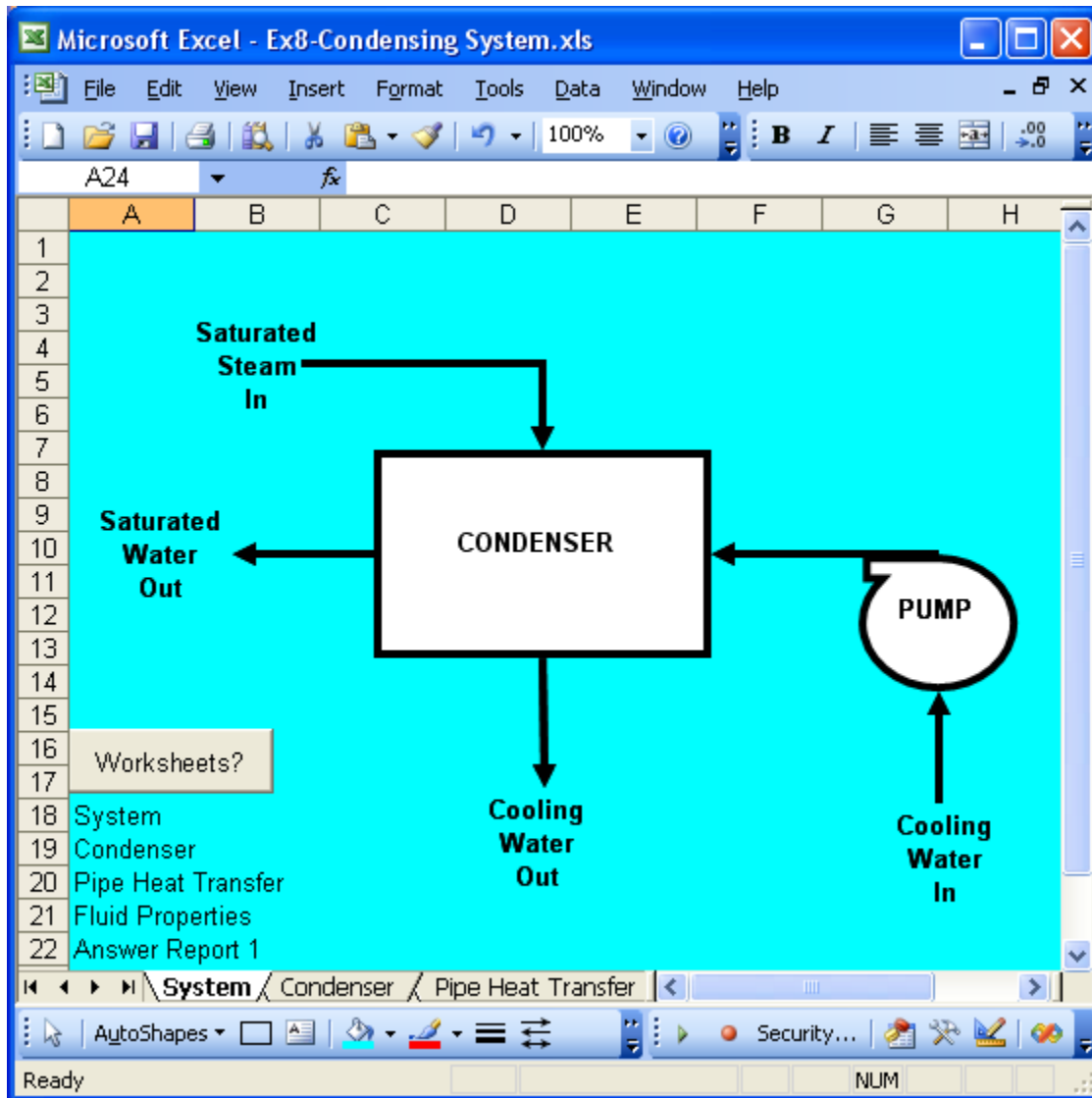
```
'DETERMINE FLUID PROPERTIES FROM CURVE FITS
Function Property(Prop As String, Temp As Single)
  If Temp < 0 Then
    Property = "Out of Range"
  ElseIf Temp > 100 Then
    Property = "Out of Range"
  Else
    Select Case Prop
    Case "Conductivity"
      Property = -1.04 * 10 ^ -5 * Temp ^ 2 + _
        0.00229 * Temp + 0.557
    Case "Prandtl"
      Property = -2.47 * 10 ^ -5 * Temp ^ 3 + _
        0.00543 * Temp ^ 2 - 0.4159 * Temp + 13.613
    Case "Viscosity"
      Property = -2.62 * 10 ^ -12 * Temp ^ 3 + _
        5.93 * 10 ^ -10 * Temp ^ 2 - 4.81 * _
        10 ^ -8 * Temp + 1.78 * 10 ^ -6
    End Select
  End If
End Function
```

- You can select cells for Solver by clicking on them
- Solver may initially show cell references instead of defined names when setting it up for the first run
- Use the “Options” button in the Solver window to save the model, and select a location on the sheet with empty vertical cells



# Exercise 8: System Sheet

*(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))*



1. Add a system sheet and create the graphics shown
2. Make a hyperlink from the Condenser box that goes to the Condenser sheet
3. Select the input cells on the Pipe HT sheet change the format protection to unlock the cells (do the same with columns G - J)
4. Protect the sheet with a blank (null) password (now try modifying cells)
5. Hide the Answer sheet
6. Add a "Worksheets?" button on the System sheet and create the code shown on the next slide to count and list names of the sheets (how does it handle the hidden sheet?)

# Exercise 8: System Sheet - Hints

*(To obtain completed exercises, an electronic version of the notes, and other helpful Excel-VBA resources, visit: [isothermtech.com](http://isothermtech.com))*

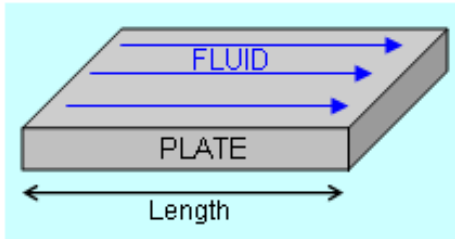
```
Dim TotalSheets As String
Dim i As Integer
Dim SheetArray()

Private Sub CommandButton1_Click()
'Count the sheets & put in a message
TotalSheets = Worksheets.Count
MsgBox ("This Workbook has " & TotalSheets & " Sheets")
'Create an array of the sheet names
ReDim SheetArray(1 To TotalSheets)
Do While i < TotalSheets
    i = i + 1
    SheetArray(i) = Worksheets.Item(i).Name
Loop
'Place the sheet names on the System sheet
For i = 1 To TotalSheets
    Cells(i + 17, 1).Value = SheetArray(i)
Next i
End Sub
```

- Hyperlink the condenser by right clicking on the object and choosing the Condenser sheet
- Be sure to unlock input cells before protecting the sheet
- Optional: Try getting rid of the column & row headings and the gridlines on the Condenser sheet

# Application: Simple Calc Sheet

## FORCED CONVECTION: FLAT PLATE



### Description:

Forced convection over a flat plate where bulk fluid is flowing parallel to the plate.

### Assumptions:

Fluid properties evaluated at film temp (avg of plate & fluid temps)

### Equations:

$$Nu = \frac{hL}{k} = 0.664 Re^{1/2} Pr^{1/3} \text{ for } Re < 5 \times 10^5$$

$$Nu = \frac{hL}{k} = 0.036 Pr^{1/3} (Re^{0.8} - 23,200) \text{ for } Re > 5 \times 10^5$$

$$Re = \frac{VL}{\nu}$$

$$q = h(T_p - T_f)$$

**References:** Kreith & Black, Basic Heat Transfer, 1980, pp248-249

### INPUTS

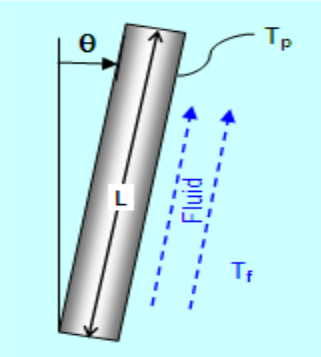
L	Plate Length	10	ft
T <sub>p</sub>	Plate Temp	97	F
V	Fluid velocity	0.6	ft/s
T <sub>f</sub>	Fluid Temp	72	F
Pr	Fluid Prandtl Number	0.71	
ν	Fluid Kinematic Viscosity	1.60E-05	m <sup>2</sup> /s
k	Fluid Thermal Conductivity	0.025	W/m-C

### OUTPUTS

T <sub>m</sub>	Film Temp	29.16666667	C
Re	Reynolds Number	34838.64	(Laminar)
Nu	Nusselt Number	110.5651159	
h	Heat Transfer Coeff	0.159715764	Btu/hr-ft <sup>2</sup> -F
q	Heat Flux	3.995356895	Btu/hr-ft <sup>2</sup>

# Application: Another Calc Sheet

## NATURAL (FREE) CONVECTION: VERTICAL PLANE



INPUTS			
L	Plate Length	0.0254	m
θ	Plate Angle from Vertical	0	degrees
T <sub>p</sub>	Plate/Cylinder Temp	80	C
T <sub>f</sub>	Fluid Temp	25	C
Pr	Fluid Prandtl Number	0.71	
βg/ν <sup>2</sup>	Buoyancy Factor	1.17E+08	1/C-m <sup>3</sup>
ν	Fluid Kinematic Viscosity	1.67E-05	m <sup>2</sup> /s
k	Fluid Thermal Conductivity	0.026	W/m-C

OUTPUTS			
T <sub>m</sub>	Film Temp	52.5	C
Gr	Grashof Number	1.05E+05	
Nu	Nusselt Number	9	
h	Heat Transfer Coeff	9.4	W/m <sup>2</sup> -C
q	Heat Flux	516.9	W/m <sup>2</sup>

**Description:**  
Natural (free) convection along a vertical cylinder or plate (small inclination allowed)

**Assumptions:**

- Fluid properties evaluated at film temp (avg of plane & fluid temps)
- Isothermal surface temp, or uniform heat flux with temp taken at plate midpoint

**Equations:**

$$Nu = \frac{hL}{k} = C (Gr Pr)^n$$

$$Gr = \frac{\beta g}{\nu^2} (T_p - T_f) L^3$$

$$\beta = \frac{\rho_f - \rho_p}{\rho_p (T_p - T_f)}$$

$$q = h(T_p - T_f)$$

**References:**

- Kreith & Black, Basic Heat Transfer, 1980, pp257-261
- McAdams, Heat Transmission, 3rd ed., 1954
- Gebhart, Heat Transfer, 2nd ed., 1970
- Eckert & Jackson, "Analysis of Turbulent Free Convection Boundary Layer on a Flat Plate", NACA Rept. 1015, 1951

Ref	GrPr	C	n
3*	< 10 <sup>4</sup>	0.555	0.25
2	10 <sup>4</sup> - 10 <sup>9</sup>	0.59	0.25
4	10 <sup>9</sup> - 10 <sup>13</sup>	0.021	0.4
3*	> 10 <sup>13</sup>	0.021	0.4

\* Out of range of experimental data; values extrapolated from reference 3 (Gebhart) figure.

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# Application: Multilayer Insulation (cont)

The diagram illustrates a cross-section of a Multilayer Insulation (MLI) system. It consists of several layers: a top layer with a **SEAM** and a **PENETRATION** (a pipe passing through the layers), followed by a **SHIELD (Aluminized Mylar)** layer, and a **SPACER/SEPARATOR** layer. A vertical arrow labeled **HEAT LEAK** points downwards from  $T_{\text{ambient}}$  at the top to  $T_{\text{cryo}}$  at the bottom.

INPUTS	
MLI coverage	0.4536 m <sup>2</sup>
# of Layers	300
Layers/cm	39.4
Pressure	5.00E-05 Pa
Ambient temp	317 K
Cryo temp	21 K
Spacer type	Dacron
thickness	2.03E-04 m
exp. const	0.0080
solid ratio	0.0450
Seam type	Butt Joint
length	1 m
width/gap	0.001 m
hot temp	300 K
cold temp	25 K
Penetration	Pipe
diameter	0.05 m

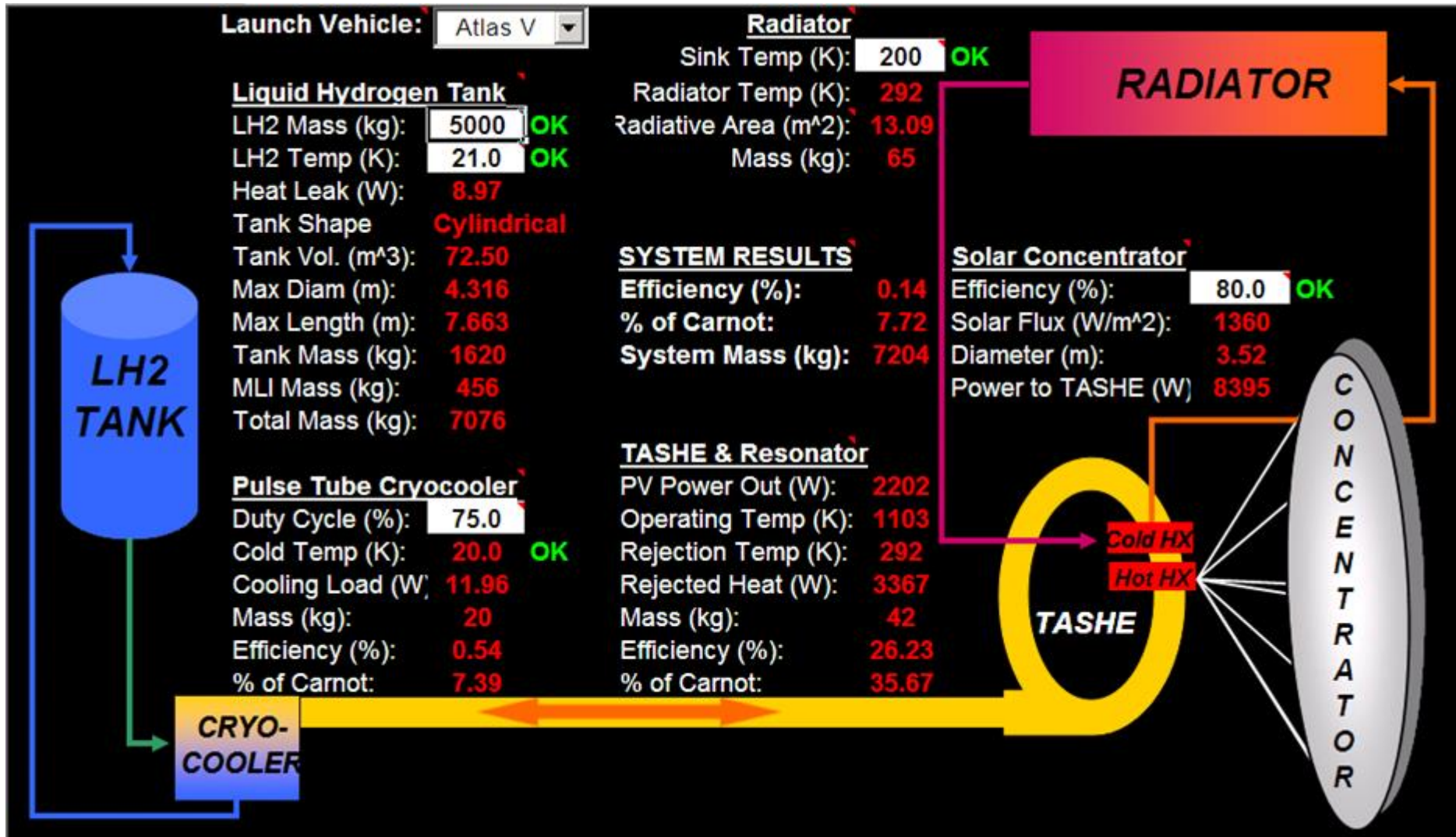
Effective Conductivity	
Blanket:	6.50E-05 W/m-K
Overall:	5.21E-04 W/m-K

Heat Leak	Watts	of Tot
MLI blanket:	0.115	12%
Seams:	0.459	50%
Penetration		
Degradation:	0.345	38%
<b>TOTAL:</b>	<b>0.92</b>	<b>100%</b>

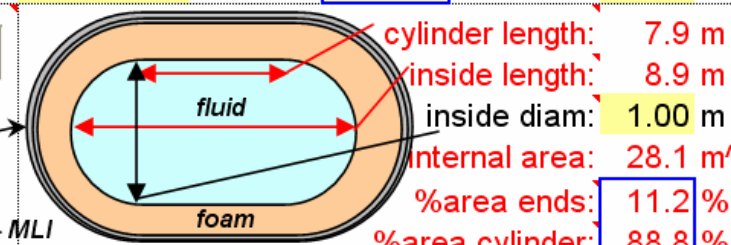
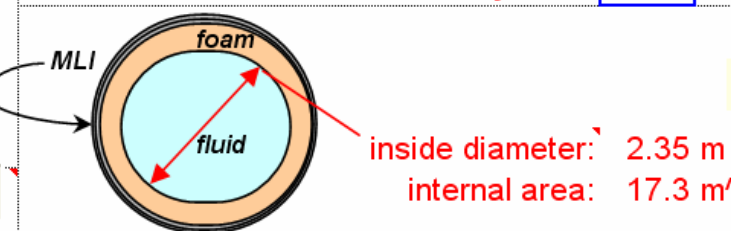
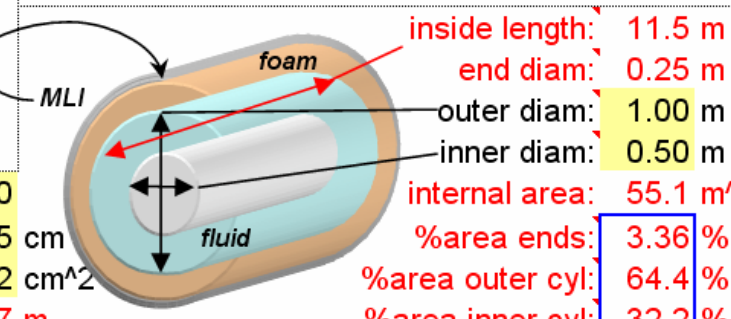
**OK**

Buttons: Show Plots, Detailed Results, **CLICK HERE TO CALCULATE**

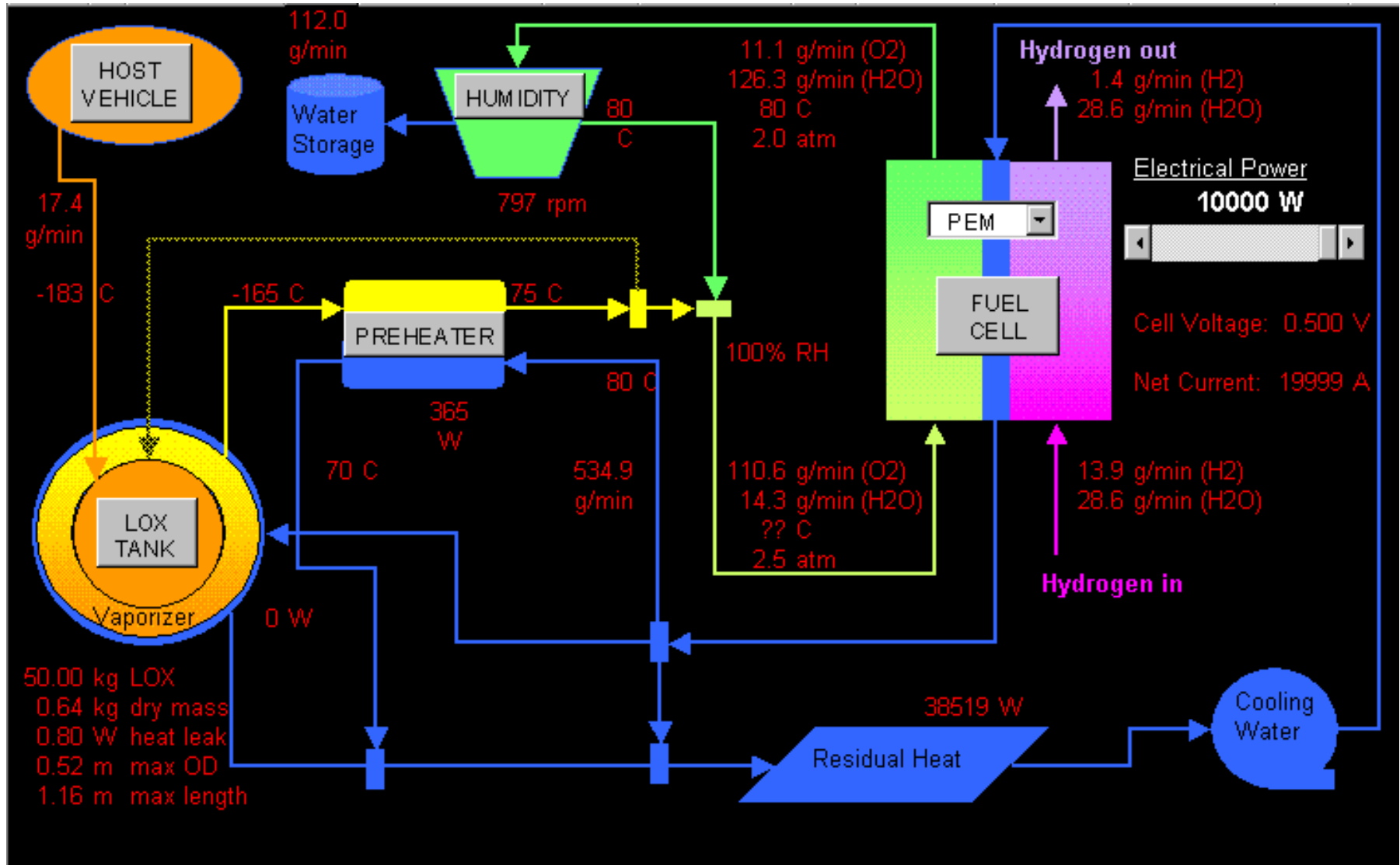
# Application: SOTV Spacecraft (cont)



# Application: Cryo Tank Design

Units	Sink temperature:	%Tot area:	Isofoam	Section	MLI Layers	Misc. factors:
<input type="radio"/> English	Area 1: 300.0 K	100 %	0.000 m	all	300	MLI factor: 174 %
<input checked="" type="radio"/> SI (metric)	Area 2: 300.0 K	0 %	0.000 m	none	0	Cond factor: 14.6 %
	Area 3: 300 K	0 %	0.000 m	none	0	Mass factor: 10 %
Hydrogen (para)					<input type="checkbox"/> C-C Overwrap (outer diam only)	
<b>Fluid mass:</b> 500.0 kg				<input checked="" type="radio"/> Cylinder	<b>CALCULATED TANK PARAMETERS</b>	
<b>Fluid temp:</b> 16.0 K					Fluid density: 75.410 kg/m <sup>3</sup>	
<b>Tank press:</b> 345.0 kPa				<input type="radio"/> Spherical	Internal volume: 6.77 m <sup>3</sup>	
<b>Ullage:</b> 2 %					Wall thickness: 0.1500 cm	
Aluminum (6061-T6)					Dry mass: 114.34 kg	
<b>MEOP:</b> 551.6 kPa				<input type="radio"/> Annular	Misc mass: 11.43 kg	
<b>Safety Factor:</b> 1.50					MLI mass: 144.21 kg	
<b>Stiffening rings</b> thickness: 0.25 cm crosssect area: 0.012 cm <sup>2</sup> length btwn: 4.967 m					Heat leak: 2.34 W	
					Conduction: 0.34 W	
					Max outer diam: 1.296 m	
					Max outer length: 9.24 m	
					Min inner diam: N/A m	
					% Fluid mass: 79.90%	
					<b>Optimiz. Target: 2.34</b>	
					<b>Active Cooling:</b>	
					system mass: 521.4 kg	
					power in @20K: 608.2 W	
					<input type="button" value="Add to Summary"/>	<input type="button" value="Density Calculator"/>

# Application: Fuel Cell (cont)





# Engineering Analysis & Modeling with Excel-VBA

## Version 8.0

**Launch Vehicle:** Atlas V

**Radiator**  
Sink Temp (K): 200 OK  
Radiator Temp (K): 292  
Radiative Area (m<sup>2</sup>): 13.09  
Mass (kg): 65

**Liquid Hydrogen Tank**  
LH2 Mass (kg): 5000 OK  
LH2 Temp (K): 21.0 OK  
Heat Leak (W): 8.97  
Tank Shape: Cylindrical  
Tank Vol. (m<sup>3</sup>): 72.50  
Max Diam (m): 4.316  
Max Length (m): 7.663  
Tank Mass (kg): 1620  
MLI Mass (kg): 456  
Total Mass (kg): 7076

**SYSTEM RESULTS**  
Efficiency (%): 0.14  
% of Carnot: 7.72  
System Mass (kg): 7204

**Solar Concentrator**  
Efficiency (%): 80.0 OK  
Solar Flux (W/m<sup>2</sup>): 1360  
Diameter (m): 3.52  
Power to TASHE (W): 8395

**TASHE & Resonator**  
PV Power Out (W): 2202  
Operating Temp (K): 4103  
Rejection Temp (K): 292  
Rejected Heat (W): 3367  
Mass (kg): 42  
Efficiency (%): 26.23  
% of Carnot: 35.67

**Pulse Tube Cryocooler**  
Duty Cycle (%): 75.0  
Cold Temp (K): 20.0 OK  
Cooling Load (W): 11.96  
Mass (kg): 20  
Efficiency (%): 0.54  
% of Carnot: 7.39

**CRYO-COOLER**

**RADIATOR**

**TASHE**

**CONCENTRATOR**

**HEAT LEAK: TRANSFER LINE**

**INPUTS**

D <sub>o</sub> Outside diam. of insulator	1.208	m
D <sub>i</sub> Inside diam. Of insulation	0.208	m
T <sub>a</sub> Ambient temperature	100	F
T <sub>f</sub> Fluid Temp	-320	F
V Ambient air velocity	60	m/s
Pr Ambient Prandtl Number	0.71	
ν Ambient Kinematic Visc.	1.00E-04	m <sup>2</sup> /s
k <sub>i</sub> Insulation Thermal Cond.	0.019	Btu/hr-ft <sup>2</sup> -F

**OUTPUTS**

T <sub>o</sub> Film Temp	-110	F
Re Reynolds Number	7.25E+05	
Nu <sub>o</sub> Nusselt Number	1238.47	
h Heat Transfer Coeff	11.3	Btu/hr-ft <sup>2</sup> -F
Q Heat Leak per lineal foot	28.5	Btu/hr-ft

**Equations:**  

$$Q = \frac{A_s (T_a - T_f)}{D_o \ln(D_o / D_i) + \frac{1}{h_o}}$$

$$Nu = \frac{h D_o}{k_i} = C Re^n Pr^m$$

$$Re = \frac{VD_o}{\nu}$$

**References:**  
 1 Barron, Cryogenic Systems, 2nd ed., 1985, pp385,404-405  
 2 Kreith & Black, Basic Heat Transfer, 1980, pp249-251

**INPUTS**

MLI coverage	0.4536	m <sup>2</sup>
# of Layers/cm	300	
Pressure	5.00E-05	Pa
Ambient temp	317	K
Cryo temp	21	K
Spacer type	Dacron	
thickness	2.03E-04	m
exp. const	0.0080	
solid ratio	0.0450	
Seam type	Butt Joint	
length	1	m
width/gap	0.001	m
hot temp	300	K
cold temp	25	K
Penetration	Pipe	
diameter	0.05	m

**Effective Conductivity**  
 Blanket: 6.60E-05 W/m-K  
 Overall: 6.21E-04 W/m-K

**Heat Leak: Watts of Tot**  
 MLI blanket: 0.115 12%  
 Seams: 0.459 50%  
 Penetration: 0.345 38%  
**TOTAL: 0.92 100%**

**CLICK HERE TO CALCULATE**

**Units**  
 English  
 SI (metric)

**Sink temperature:** 300.0 K  
**%Tot area:** 100%  
**Isofoam:** 0.000 m  
**Section:** all  
**MLI Layers:** 300  
**Misc. factors:** 174%  
**MLI factor:** 14.6%  
**Cond factor:** 10%  
**Mass factor:** 10%

**C-C Overlap (outer diam only)**  
**CALCULATED TANK PARAMETERS**  
 Fluid density: 75.410 kg/m<sup>3</sup>  
 Internal volume: 6.77 m<sup>3</sup>  
 Wall thickness: 0.1500 cm  
 Dry mass: 114.34 kg  
 Misc mass: 11.43 kg  
 MLI mass: 144.21 kg  
 Heat leak: 2.34 W  
 Conduction: 0.34 W  
 Max outer diam: 1.296 m  
 Max outer length: 9.24 m  
 Min inner diam: N/A m  
 % Fluid mass: 79.90%  
 Optimiz. Target: 2.34  
 Active Cooling: system mass 521.4 kg, power in @20K 608.2 W

**MEOP:** 551.6 kPa  
**Safety Factor:** 1.50  
**Stiffening rings:** 10  
 thickness: 0.25 cm  
 crosssect area: 0.012 cm<sup>2</sup>  
 length btwn: 4.967 m

**FORCED CONVECTION: FLAT PLATE**

**INPUTS**

L Plate Length	10	m
T <sub>p</sub> Plate Temp	97	F
V Fluid velocity	0.6	m/s
T <sub>f</sub> Fluid Temp	72	F
Pr Fluid Prandtl Number	0.71	
ν Fluid Kinematic Viscosity	1.60E-05	m <sup>2</sup> /s
k Fluid Thermal Conductivity	0.025	W/m-C

**OUTPUTS**

T <sub>m</sub> Film Temp	29.16666667	C
Re Reynolds Number	34838.64	(Laminar)
Nu <sub>o</sub> Nusselt Number	110.5651159	
h Heat Transfer Coeff	0.159715764	Btu/hr-ft <sup>2</sup> -F
q Heat Flux	3.995356895	Btu/hr-ft <sup>2</sup>

**Equations:**  

$$Nu = \frac{hL}{k} = 0.664 Re^{1/2} Pr^{1/3}$$
 for Re < 5 × 10<sup>5</sup>  

$$Nu = \frac{hL}{k} = 0.036 Re^{4/5} Pr^{1/3} (Re^{0.8} - 28,200)$$
 for Re > 5 × 10<sup>5</sup>  

$$Re = \frac{VL}{\nu}$$
  

$$q = h(T_p - T_f)$$

**References:** Kreith & Black, Basic Heat Transfer, 1980, pp248-249

**HOST VEHICLE**  
 17.4 g/min  
 -183 C

**Water Storage**  
 112.0 g/min  
 HUMIDITY: 80  
 797 rpm

**PREHEATER**  
 75 C  
 365 W

**LOX TANK**  
 50.00 kg LOX  
 0.64 kg dry mass  
 0.80 W heat leak  
 0.52 m max OD  
 1.16 m max length

**FUEL CELL**  
 100% RH  
 11.1 g/min (O<sub>2</sub>)  
 126.3 g/min (H<sub>2</sub>O)  
 80 C  
 2.0 atm  
 11.0 g/min (O<sub>2</sub>)  
 14.3 g/min (H<sub>2</sub>O)  
 ?? C  
 2.5 atm

**Hydrogen out**  
 1.4 g/min (H<sub>2</sub>)  
 28.6 g/min (H<sub>2</sub>O)

**Electrical Power**  
 10000 W  
 Cell Voltage: 0.500 V  
 Net Current: 19999 A

**Hydrogen in**  
 13.9 g/min (H<sub>2</sub>)  
 28.6 g/min (H<sub>2</sub>O)

**Residual Heat**  
 36519 W

**Cooling Water**

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# Course Description

These course notes (available in [paperback](#) and [kindle](#) formats) are from the 2-day short course entitled “Engineering Analysis & Modeling with Excel-VBA”. In-depth details are presented on principles, practices, and implementation of Excel and its integrated programming language – Visual Basic for Applications (VBA) – for analysis and engineering model creation.

The exercise problems in each section build upon the previous exercises to demonstrate new techniques. To obtain completed exercises and other helpful Excel VBA resources, visit: [www.isothermtech.com](http://www.isothermtech.com).

## FEEDBACK ON SELF-STUDY USING THE COURSE NOTES

***"I worked through the course materials of 'Engineering Analysis & Modeling w/Excel/VBA' and would highly recommend it to other engineers."***, Maury DuPont, University of Cincinnati

***"...the exercises were very easy to understand... followed extremely well after the learning slides that came before them. The instructions were detailed enough to understand, but still left enough leeway for individual learning"***, Monica Guzik, Rose-Hulman Institute of Technology

# Course Feedback

**“Great material, great presentation”**, William J. Armiger, Naval Research Laboratory

**“Lots of useful information, and a good combination of lecture and hands-on”**, Brent Warner, Goddard Space Flight Center

**“Excellent course documentation... excellent communicator”**, Linda Hornsby, Jacobs ESTS Group

**“Very knowledgeable... presented clearly and answered all questions”**, Marc Wilson, Johns Hopkins University Applied Physics Laboratory

**“Great detail... informative and responsive to questions. Offered lots of useful info to use beyond the class”**, Sheleen Spencer, Naval Research Laboratory

**“Excellent... Good overview of VBA programming...”**, John Yocom, General Dynamics

**“Really enjoyed how much info was passed along in such a short and easily understandable method”**, Will Rehlich, Noren Products

**“Good introduction and quick functioning using VBA was enabled by this course”**, Michael R. Palis, Hybricon Corp.

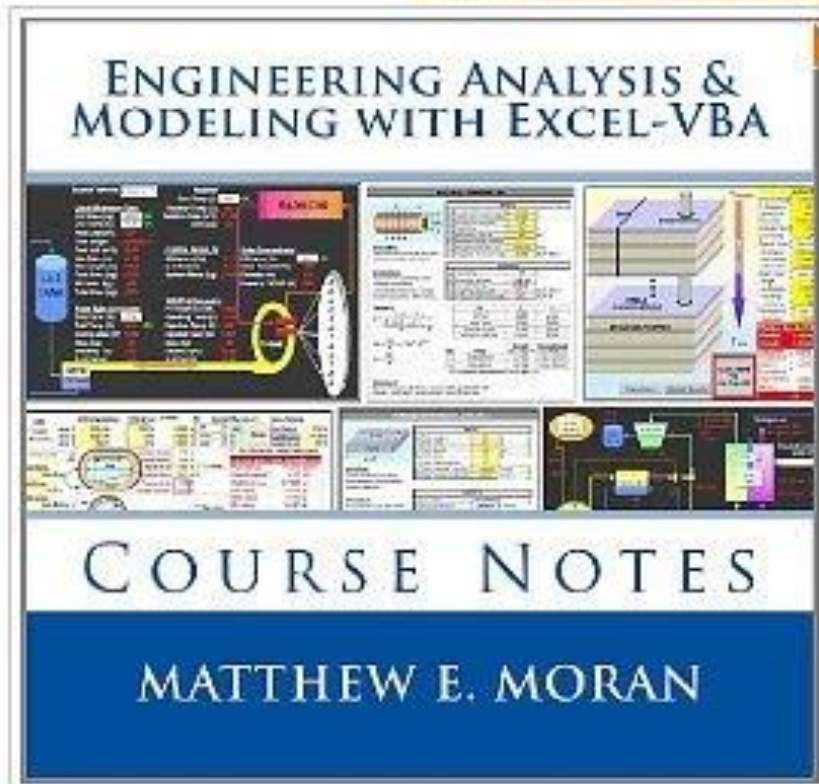
**“I’ve been looking for a course like this for years! Matt was very knowledgeable and personable and walked his talk”**, James McDonald, Crown Solutions

**“Gave me a lot to work with. Very helpful and hands on. [My favorite parts?]... It was all good”**, Dale Folsom, Battelle

**“Matt was extremely knowledgeable and a great instructor”**, Jennifer Snelling, Barrios Technology

# Course Materials

Click to **LOOK INSIDE!**



Visit [www.isothermtech.com](http://www.isothermtech.com) to get a variety of course materials and resources:

- **Course notes in paperback and kindle formats**
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# Intended Audience & Usage

These course notes are intended for practicing engineers, scientists and others with an interest in analysis and modeling. It is targeted toward intermediate to advanced Excel users, although no prior experience with VBA is assumed. If you are new to Excel, you should consider supplementing these notes with an introductory course or book.

You may occasionally hear or read the opinion that Excel is not an appropriate tool for engineers. This is nonsense. The instructor has used many engineering software tools for more than three decades (e.g. general math, finite difference, FEA, CFD, CAE, DAQ, system simulation, custom codes, etc.), and they all have their place. Excel has a rich set of features for calculation, visual display and user interaction that makes it a very good general tool for many engineering and other technical computations. With its built-in VBA programming environment, and the associated techniques taught in these course notes, it becomes a highly versatile platform. Nonetheless, there is no substitute for good professional judgment in choosing the right tool for the job. There are certainly applications where Excel isn't the best choice - or even a viable option in some cases.

It's important to remember that the quality of all analytical results are dependent on a user's skills, knowledge, experience, discipline, and work quality. Any software tool will provide poor results if used improperly, although some tools hide it better with a polished display! In addition, verification and validation are always critical, and should be part of any analysis or model regardless of the tools and methods used. With that in mind, this course teaches principles and practices with Excel VBA that facilitate quality results.

# How to Use These Course Notes

## Ways to use the course notes: \*

- Self study (paperback or kindle versions)
- Video training (with paperback or kindle version) \*\*
- Course offering (public or hosted) \*\*

## Each section uses a sequential teaching methodology:

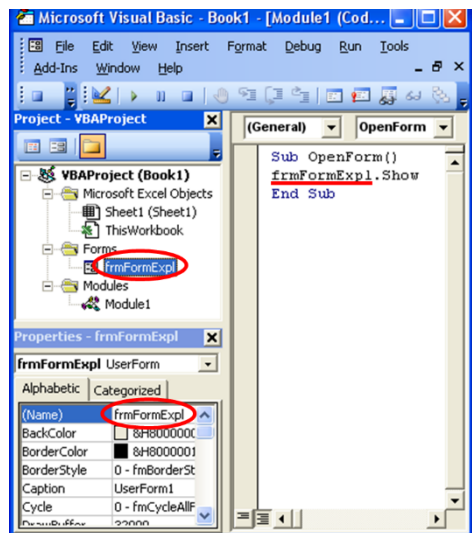
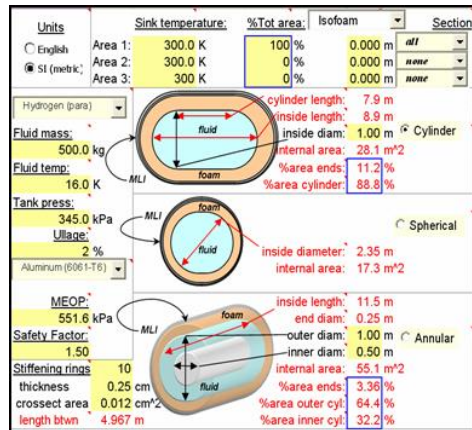
- 1) Real world application to illustrate the topics to be covered
- 2) Introduction to the learning topics and step-by-step details on how to implement them in Excel VBA
- 3) Integrated hands on exercise to solidify the topics learned

## General format & conventions:

- Screen shots are predominantly used to facilitate immediate experimentation and rapid learning
- Notes, tips, and step-by-step instructions throughout
- Detailed text limited to topics needing more explanation
- Valuable supplemental info included in the appendices

\* Visit [www.isothermtech.com](http://www.isothermtech.com) for information on video training and upcoming courses

\*\* Video & course offerings can be applied toward PE continuing education requirements (check with your state or other licensing entity to confirm what types of training qualify)



# Instructor Bio



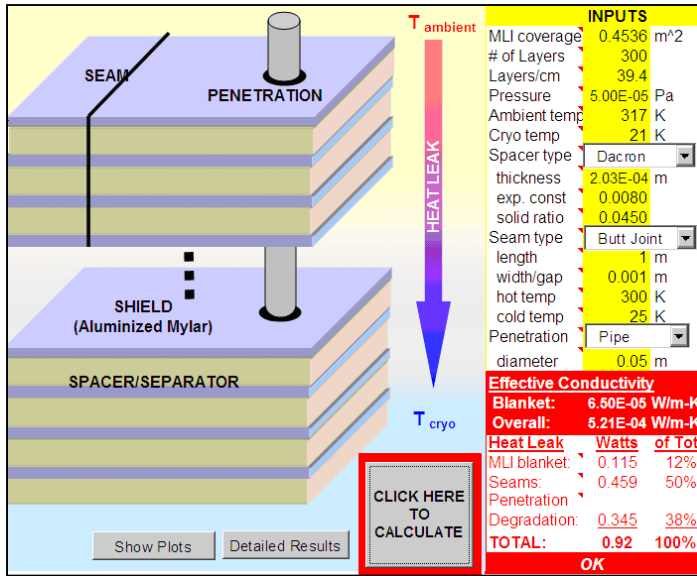
(Dec, 2013)

Matt Moran is the owner of Isotherm Technologies LLC. He is also a sector manager and senior engineer at NASA. Matt teaches engineering analysis seminars throughout the U.S., and has been adjunct faculty at the graduate school at Walsh University and other colleges. He has been a co-founder or key contributor to the start up of five high tech businesses, and has worked with hundreds of organizations of varying size, type and industry sector.

Matt has 32 years experience developing products and systems for aerospace, electronics, military, and power generation applications. He has used many software tools for analysis and modeling. Matt has created Excel VBA engineering system models for DARPA, Air Force, Office of Naval Research, Missile Defense Agency, NASA and various commercial organizations.

Matt is a Professional Engineer (Ohio), with a B.S. & graduate work in Mechanical Engineering, and an MBA in Systems Management. He has published 44 papers and a book; and has 3 US patents.

# Course Summary

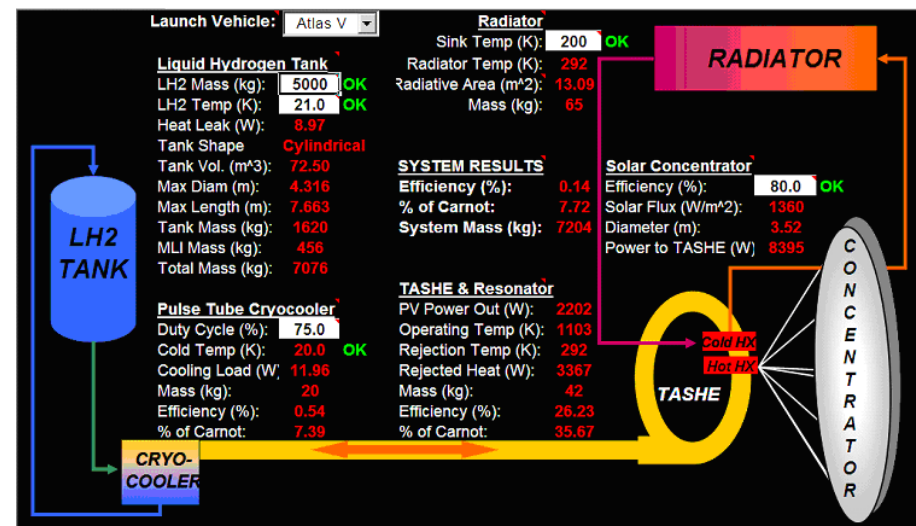


*This course will provide the knowledge and methods to create custom engineering models for...*

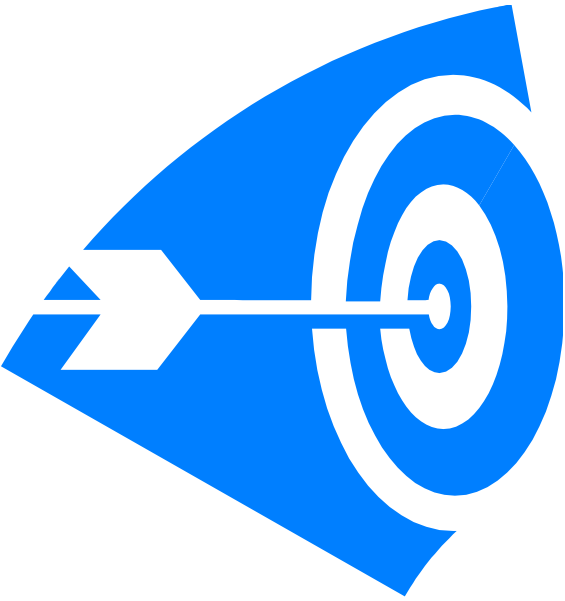
- *Analyzing conceptual designs*
- *Creating system trades*
- *Simulating operation*
- *Optimizing performance*

*...with Excel VBA.*

*The instructor has been using spreadsheets for engineering computations since the early 1980s; and VBA since 1996 (shortly after its integration with Excel). He has taught these methods to hundreds of course participants since 2007.*

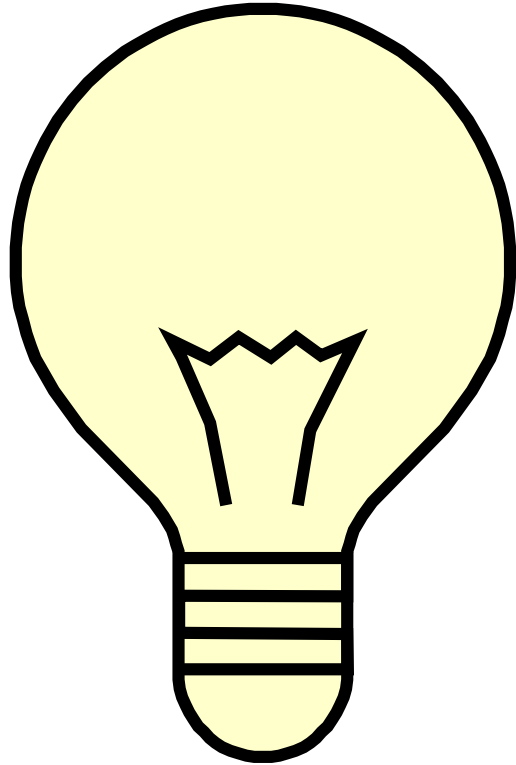


# Learning Objectives



- Exploit the full power of Excel for building engineering models
- Master the built-in VBA programming language
- Implement advanced data I/O, manipulation, analysis, and display
- Create full featured graphical interfaces and interactive content
- Optimize performance for multi-parameter systems and designs
- Integrate interdisciplinary capabilities into engineering models

# Topics: Design & Build



1. Excel VBA Review
2. Identifying Scope & Capabilities
3. Quick Prototyping
4. Defining Model Structure
5. Designing Graphical User Interfaces
6. Building & Tuning the VBA Engine
7. Customizing Output Results
8. Exploiting Built-in Excel Functions

# Topics: Refine & Optimize

9. Integrating External Data
10. Adding Interdisciplinary Capabilities
11. Unleashing GoalSeek & Solver
12. Incorporating Scenarios
13. Documentation, References, & Links
14. Formatting & Protection
15. Flexibility, Standardization, & Configuration Control
16. Other Useful Tips & Tricks
17. Application Topics

