USE OF THERMPLOT SOFTWARE FOR QUICK EVALUATION OF THERMAL MODEL RESULTS

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Abstract

Recently, advances have been made in graphical displays of thermal modelers, allowing color contour temperature plots and animations. While these are useful for presentations, they do little to help debug or identify areas of a model that may be out of design limits. Often, a thermal engineer needs hard data for analysis or debugging.

Swales Aerospace has developed a tool called ThermPlot that runs in the familiar Windows environment. ThermPlot reads output files from many of the popular thermal analysis packages (SindaFluint, Sinda/G®, ESATAN, TMG) and stores the data in a Microsoft Excel® workbook. This allows the user access to ***all*** time dependent thermal data for post processing, rather than a simple plot or image.

Features included in ThermPlot are: inclusion of node descriptions from thermal model file, multiple file capabilities for trend studies and comparisons, creation of tables and plots of selected data, grouping of nodes, and generation of post run-time calculated heatmaps. Once the desired options have been selected, the data is read from the thermal model output files and written directly into an Excel® workbook. Tables and plots are also created in the workbook as defined by the user. The user is also free to perform any additional analysis using the wide range of functions offered in Microsoft Excel®.

This paper describes the features of ThermPlot in greater detail. It also provides some examples of real-world applications where use of ThermPlot resulted in quicker data reduction and analysis of model conversions, parametric studies, and heat flow analysis.

1 INTRODUCTION

In this age of faster computers and quick information transfer, the trends have been towards larger, more detailed models and shorter project timelines. With many thermal solvers actually creating models, including conduction and radiation effects, it becomes more difficult for the thermal analyst to fully understand a model's behavior. Combined with a customers desire for results in a shorter amount of time, it can be a quite daunting task to process vast quantities of data to isolate the relevant data subset. Unfortunately, as the thermal solvers have gotten more advanced, the same cannot be said for the post-processing tools.

ThermPlot is a post-processing tool developed by Swales Aerospace to allow a thermal analyst to quickly take output and select the most crucial pieces of data for evaluation. While each company may have particular scripts and utilities to process data, none offer the power and simplicity of ThermPlot. It creates an interface between many popular thermal analysis solvers and Microsoft Excel® by reading data from the standard output routines from the thermal solver output and storing it on a worksheet in an Excel® file. It also has the capabilities to create customizable tables and plots of pertinent data. Combined with its abilities to process multiple files, it is an ideal tool for analyzing results from parametric studies. But perhaps its most powerful option is the ability to create interactive heatmaps within Excel® which allow the analyst to evaluate not only the temperature of critical nodes, but also the heat paths connected to them. ThermPlot can greatly reduce the time required to evaluate thermal model results thereby, allowing the thermal analysts to quickly respond to a customer's needs or questions. Figure 1 shows the main screen from ThermPlot.

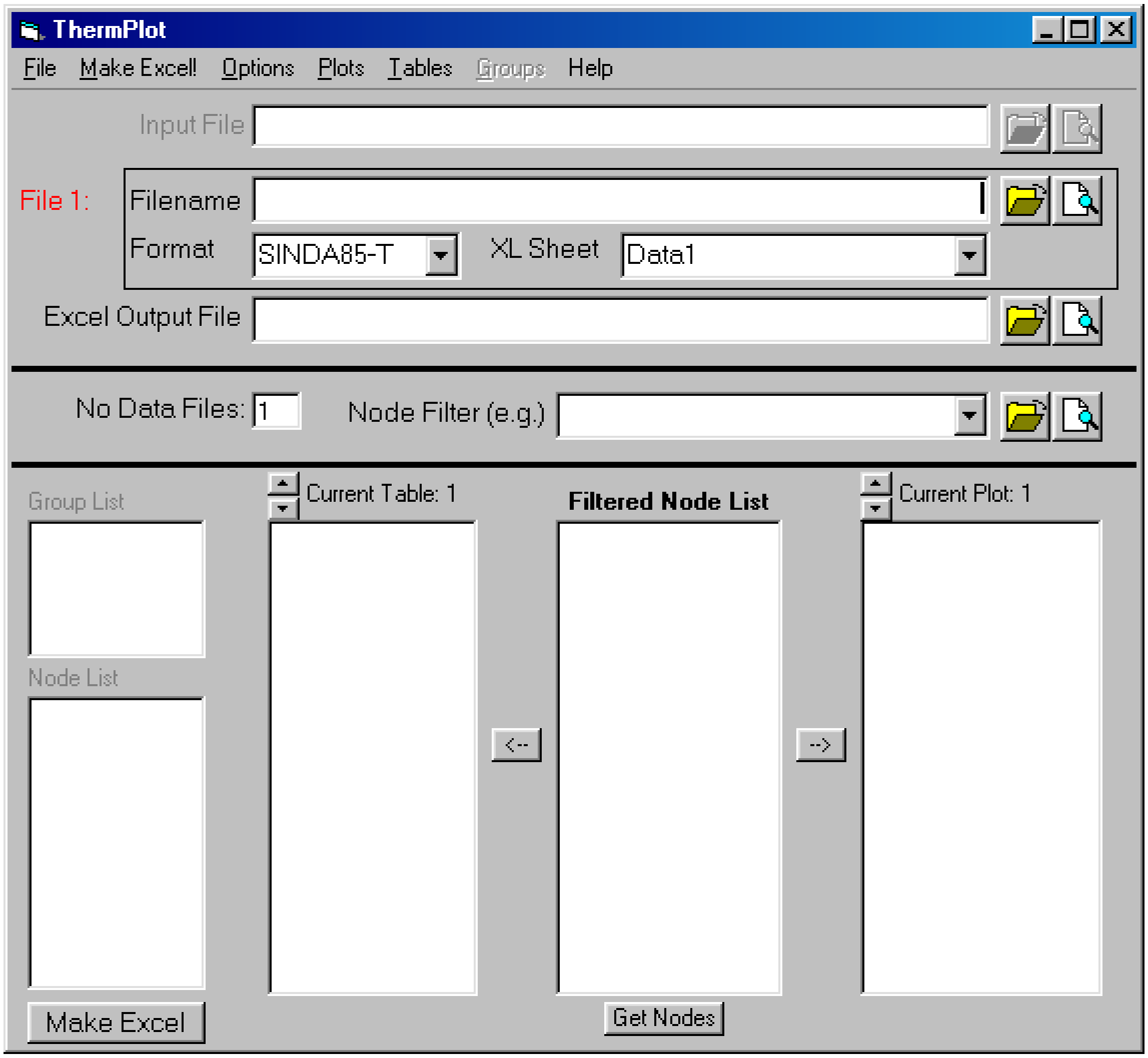

Figure 1 – ThermPlot Main Screen

2 FEATURES

2.1 Formats

ThermPlot supports the following thermal solver packages: SINDA85 (or SINDA/Fluint), SINDA/G®, TMG, and ESATAN. Additional thermal solver formats may be added in the future if demand warrants. Table 1 shows the supported outputs for each solver as well as the required output call within the solver.

Table 1 - Supported Thermal Solvers

Solver	Parameter	Calling Command	Format Selection	Comment
SINDA-85	T	TPRINT	SINDA85-T	
	Q	QPRINT	SINDA85-Q	No Time header is printed*
	G	GPRINT	SINDA85-G	No Time header is printed*
SINDA/G®	T	TPRINT	SINDA/G-T	
	Q	QIPRNT	SINDA/G-Q	No Time header is printed*
	G	GPRINT	SINDA/G-G	No Time header is printed*
	C	CPRINT	SINDA/G-C	No Time header is printed*
	C(Q)	QFPRNT	SINDA/G-C(Q)	Heat flow through conductor
ESATAN	T	PRNDTB	ESABLK-T	
	Q	PRNDTB	ESABLK-Q	Sum of QS, QA, QE, QI, QR
	QS	PRNDTB	ESABLK-QS	
	QA	PRNDTB	ESABLK-QA	
	QE	PRNDTB	ESABLK-QE	
	QI	PRNDTB	ESABLK-QI	
	QR	PRNDTB	ESABLK-QR	
ESATAN	T	PRNDBL	ESATBL-T	
	Q	PRNDBL	ESATBL-Q	Sum of QS, QA, QE, QI, QR
	QS	PRNDBL	ESATBL-QS	
	QA	PRNDBL	ESATBL-QA	
	QE	PRNDBL	ESATBL-QE	
	QI	PRNDBL	ESATBL-QI	
	QR	PRNDBL	ESATBL-QR	
TSS	Heat Load/Flux	HeatRate	TSS-HRT	
TMG	T		TMG-T	Tempf file
	Q		TMG-Q	Qnodef file
Generic CSV			GEN. CSV	Comma Delimited
Generic SDF			SPC DELIM	Space Delimited

** ThermPlot requires that the time header be printed for each timestep. This is not done for the highlighted commands. Therefore, if **only** a GPRINT is called, the data may not be processed correctly.*

2.1.1 Multiple Files

One useful feature of ThermPlot is the ability to post process multiple output files for comparison. Multiple output files may be compared using Tables in various ways. Two common comparison styles are: (1) compare the same parameter (e.g. Min, Max, etc) for multiple cases (Compare Results) or (2) compare cases based on the specified parameters (Multiple Cases). This is discussed in greater detail in Section 2.4.1. Multiple files also allows the user to plot data from different sources (e.g. thermal vacuum data versus model data).

2.2 Options

2.2.1 Node descriptions

Often in large spacecraft models, it is difficult to remember which nodes represent which components. As such, thermal analysts often include a comment after the node definition or around a block of nodes. Thermplot allows these values to be read from the thermal model and associated with the corresponding node in Excel®. Two types of node descriptions are included: Block Description and Node Description. The block description refers to the comments before a node definition (e.g. "C MLI Nodes"). The node description is anything after the line comment character ('$' for SINDA and '#' for ESATAN). If no node description is given, the block description is used. The node descriptions are used exclusively in tables.

2.2.2 Filtering of output

At times, the user may wish to output only a subset of the complete data set. This may be accomplished in two ways: only selected nodes may be output or only nodes that meet specified criteria may be output. "Selected Nodes Only" will only output nodes that are (1) Included in a table or Plot, (2) Included in a group (discussed in Section 2.3), or (3) Selected in the Filtered Node List. This is a much quicker algorithm since the search parameters are already known. Conversely, the user may also specify a range of nodes to output. This method requires as much processing time as the default of reading the entire file, since each line must be evaluated to determine if it satisfies the criteria. However, it does provide an easy way to output particular nodes within a specified range. It supports single nodes, ranges of nodes, or any combination thereof. Each criterion should be separated by commas; range start values and end values should be separated by a dash. (e.g. MOTOR.1-MOTOR.15, PANEL.1-15, ELEC.32, 15). If only a node number is specified, the submodel is ignored and any thermal node with the specified node number is included regardless of its submodel.

2.2.3 Update Existing Data

A user may have defined a particular format or style for an existing spreadsheet and wish to retain it (e.g. plot style, table formats, etc). Assuming the data on the data sheets remains in ***exactly*** the same format, it is possible to update only the data and bypass the Table and Plot creation phases. This requires the new data to have the identical order of nodes and timesteps to assure that formulas apply to the correct cells. If a node type in SINDA is changed (e.g. from diffusion to boundary or arithmetic), this may change the output order of the nodes. If the data location has been modified (i.e. column or row inserted, etc) the formulas may no longer apply to the correct cells.

2.2.4 Transpose Output

At times, a user may have output for more than 250 timesteps. Due to the 256 column limitation in Excel®, it is impossible to have more than 256 timesteps **and** nodes. If the user requires more than 250 timesteps (or 247 if using groups) to be output, the data may be transposed such that each row represents a timestep rather than the default of each column. However, unless the model contains less than 255 nodes, a subset of less than 256 nodes must be selected using the filtering options (discussed in Section 2.3.2) or nodes beyond the 255th will be truncated.

2.2.5 Unit Conversion

Data from different models may not be in units compatible for direct comparison. ThermPlot provides the capability to convert the data from one unit system to another so that direct comparisons may be made. Time, Temperature, Heat and Flux conversions are provided for the most commonly used systems of units. Table 2 lists the units that are supported; any one of these may be converted to another for a given parameter. The conversion is done through a formula for each cell so that the original output value is preserved.

Table 2 – Supported Units for Conversion

Parameter	Units Supported
Time	s, min, hr
Temperature	°C, °F, K, R
Heat	W, J/min, BTU/min, BTU/hr
Flux*	/cm^2, /m^2, /in^2, /ft^2

** To convert a heat flux, both the heat conversion and flux conversion must be selected*

2.3 Groups

Detailed models typically have many more nodes to represent components that may be more simply modeled in a reduced model. It can be difficult to directly compare results from the two models. To simplify this comparison, the average temperature (or total heat load) may be calculated for a selection of nodes. These are referred to as Groups in ThermPlot.

Groups can be very useful when comparing a bulk temperature or total heat applied for a region or component in a detailed model to the equivalent section in a reduced model. Groups are also very useful when combined with the heatmap option as they allow the user to quickly see what areas have an effect on the node or group of interest. Heatmaps are discussed in detail in Section 2.7.

2.4 Tables

Commonly, tabular form is the best way to present a concise summary of thermal data. A table of relevant nodes would represent each instrument or major component of a spacecraft. Often the maximum and minimum are of the most interest to determine if the design is within limits. However, sometimes it is also desirable to know the orbit average (from a transient run) or the steady state temperatures as well. The Table Builder allows the user to create tables customized to each analysis. The Table Builder screen is shown in Figure 2.

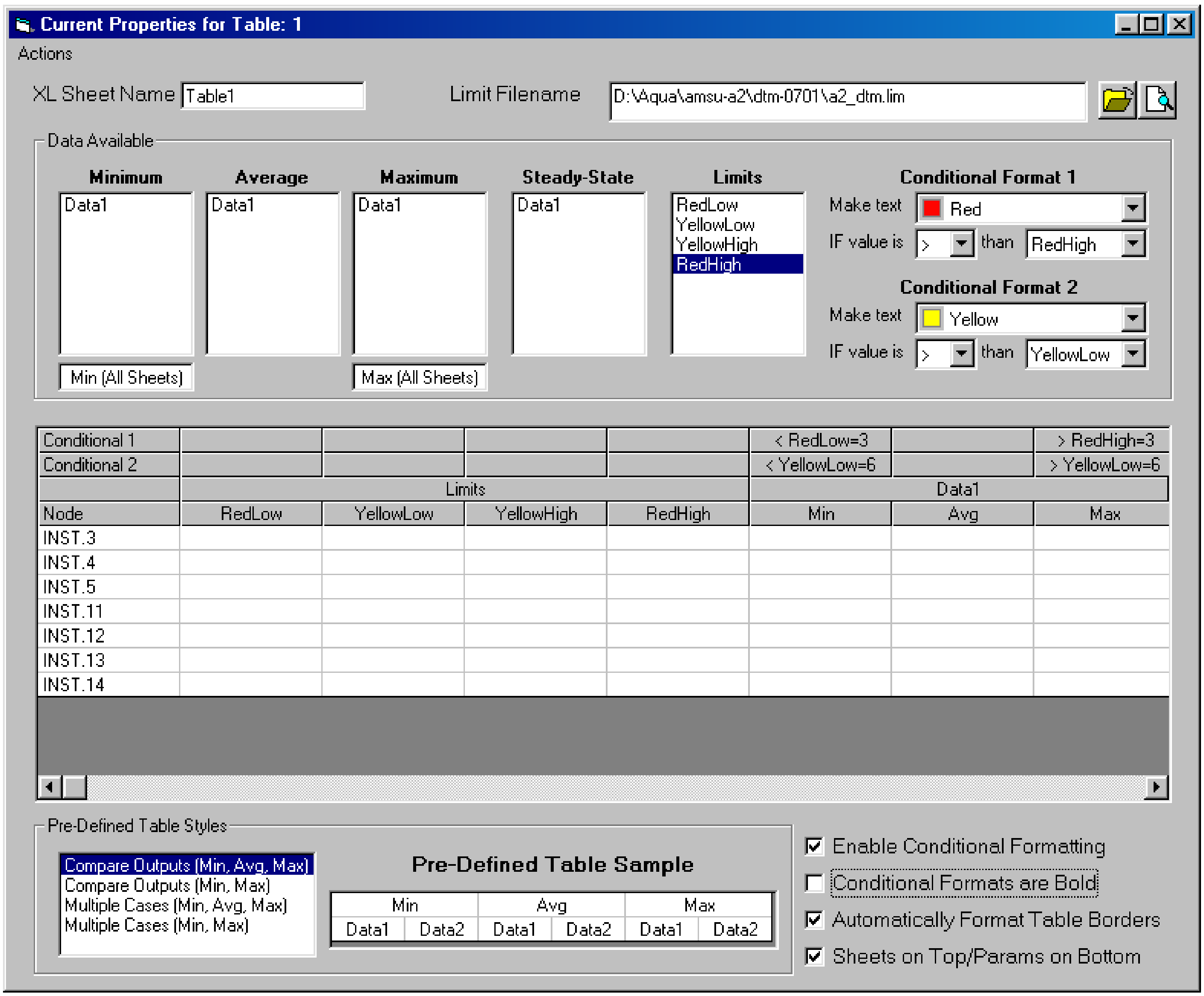

Figure 2 – Table Builder Form

2.4.1 Table Properties

Tables may include any of the following information for any group or node from any dataset (i.e. sheet): minimum, average, maximum, or steady-state value. The minimum, maximum, and average values are calculated over the last orbit defined as follows: the range over which the timesteps are continuously increasing. For example, a model run for ten, 6000 second orbit periods starting at TIMEO=0 and TIMEND=60000 would calculate the values over the entire 60000 seconds. Conversely, a model run for ten, 6000 second orbits with each orbit starting at TIMEO=0.0 and ending at TIMEND=6000, would calculate the value over the last 6000 seconds only. The user may define any combination of parameters (e.g. Min, Max, etc.) and datasets (i.e. sheets) for each table by simply double clicking a single selection from the appropriate list box or by Alt-Dragging a selection to the table Preview.

Some predefined table styles may also be quickly created. The “Compare Results” style is most applicable for thermal model verification after conversion from one format to another, providing quick confirmation that the thermal model in the “new” format provides the same behavior as the thermal model in the “old” format. The “Multiple Cases” is best suited for determining the effects of changing parameters within the model (i.e. heater power, conductance, etc.) This style provides a quick look at specified parameters on a case by case basis. A sample of the “Compare Outputs” and “Multiple Cases” style headings are shown in **Table 3** and **Table 4** respectively.

Table 3 – Sample of Compare Results Table Headings

Min		Avg		Max	
Case1	Case2	Case1	Case2	Case1	Case2

Table 4 – Sample of Multiple Cases Table Headings

Case1			Case2		
Min	Avg	Max	Min	Avg	Max

2.4.2 Table Formats

Limits may also be defined for each node. These should be in an external, comma-separated value file, which is loaded onto a new sheet within the workbook. The user can then add any of the defined limits in the same manner as adding any other parameter. Once a limit has been added to a table, the user may define a highlight format (i.e. color and bolding) based on the value compared to the limit (Conditional Format). For example, values for the Min on sheet 1 may be colored red if they are less than the “RedLow” limit. The borders for the table may also be automatically formatted, with heavier lines dividing similar sheets or parameters.

2.5 Plots

Transient results are often presented in a graphical plot format. Many existing packages provide for this already, ThermPlot included. The user may plot data from various sources (i.e. different files) onto any plot and even mix formats (i.e. T and Q). This may be useful for plotting a heater's behavior and the transient temperature behavior of the sensing node to ensure it is cycling properly. Each data set may be plotted on the primary or secondary axis as desired. Groups and/or nodes may also be plotted together. Excel® supports up to 256 data series of up to 4096 data points each. Each individual plot is stored on a separate Excel® worksheet which can be named by the user. The Plot Properties screen is shown in Figure 3.

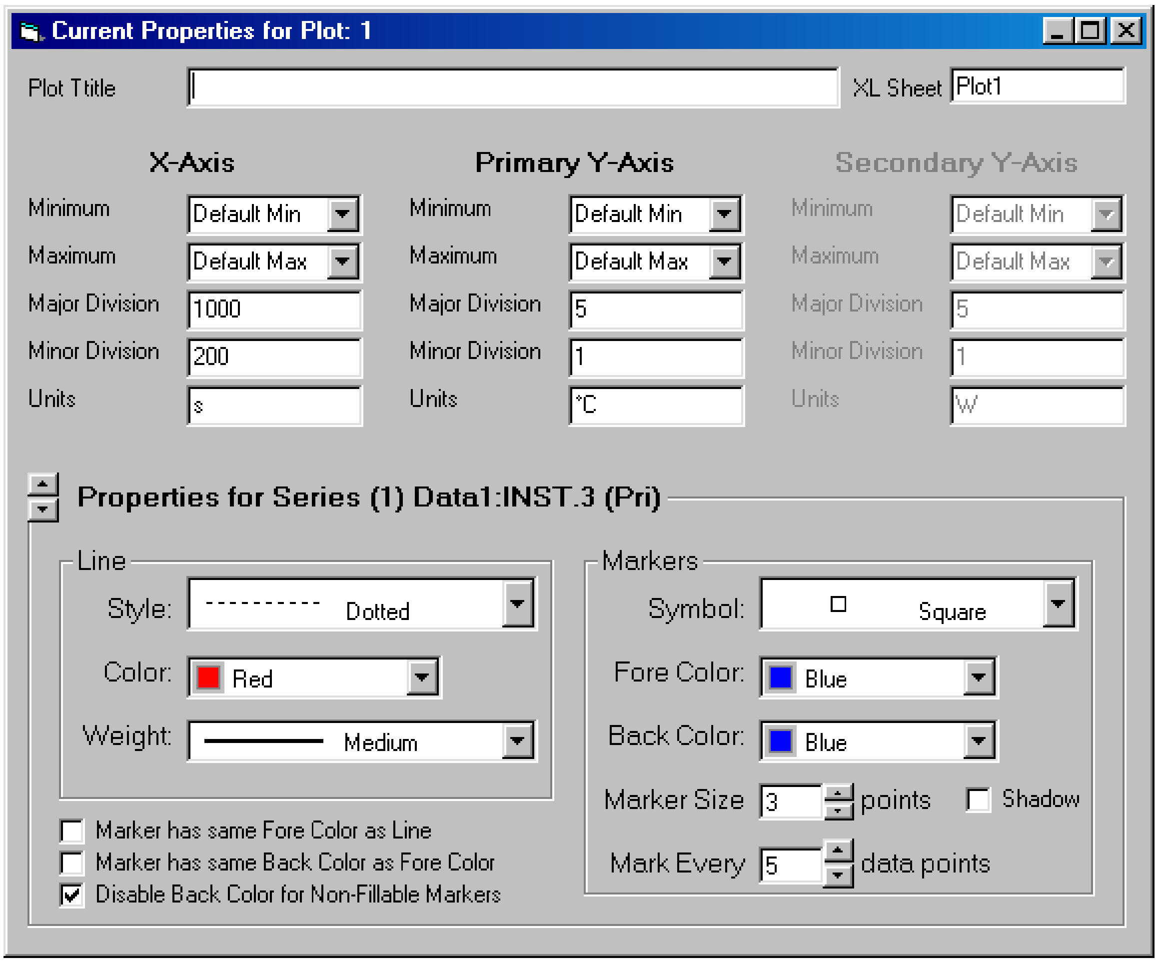

Figure 3 – Plot Properties Form

2.5.1 Plot Properties

The user may define the maximum and minimum values for each axis, as well as the spacing of major and minor gridlines. The Plot Title and axis units may also be specified. If any data series is to be plotted on a secondary axis, the properties for the secondary axis are enabled.

2.5.2 Plot Formats

The user has full control over the line for each data series including both line style and marker style. For the line style, the user may change the color, line type, and weight. For the marker, the user may change the symbol, symbol foreground color, symbol background color (if a fillable marker, e.g. square, circle, but not X or dash), and marker size and shadowing. The user may also determine the data point spacing between markers for dense marker patterns.

2.6 Heatmaps

Perhaps the most powerful feature of ThermPlot is the ability to create heatmaps for an entire thermal model. These heatmaps are calculated at the time of request rather than simply loading in data output from the thermal solver. As such, they require the following information at each output timestep: temperatures, applied heat loads, and conductance values. For SINDA, the conductor node pairs are determined by reading the input file; for ESATAN conductor values are currently read from the ESATAN model input file (i.e. time varying conductances are not yet supported). All of the data is stored on appropriate sheets within an Excel® template, which is then saved as an Excel® workbook. Once this workbook is opened, the user may set appropriate parameters (e.g. Stefan-Boltzman constant, Timestep, etc) for calculation of heatflows. Table 5 shows a sample of the heatmap worksheet along with letters denoting particular sections referenced later.

Table 5 - Sample of Heatmap Table

	Description	OCCULTER TIP			
(A)	**Node i**	COR1.500		**Temp**	143.88
(B)	**Time**	SS		**Time Col**	C
(C)	**Sigma**	5.67E-12	*(E)*	**Min Heat**	0.0005
(D)	**Toffset**	273.15	*(F)*	**Heat to**	Node

(G)	**SUMMARY:**	**In**	**Out**
	Conduction	0.000	0.234
	Radiation	0.000	0.017
	Source	0.252	-
	Sum	0.252	0.251

High (In) to Low (Out):						***Low (Out) to High (In):***					
Description j	**Node j**	**Type**	**Cond**	**Temp j**	**Heat j**	**Description j**	**Node j**	**Type**	**Cond**	**Temp j**	**Heat j**
OCCULTER TOP	COR1.501	Lin	3.86E-02	137.82	-0.23	OCCULTER TOP	COR1.501	Lin	3.86E-02	137.82	-0.23
	COR1.35	Rad	5.67E-02	30.59	-0.01		COR1.15	Rad	6.49E-03	30.57	0.00
	COR1.5	Rad	2.51E-02	30.53	0.00	OCCULTER BAFFLE (LIGHT TRAP)	COR1.600	Rad	2.40E-02	43.44	0.00
	COR1.25	Rad	2.46E-02	30.65	0.00		COR1.25	Rad	2.46E-02	30.65	0.00
OCCULTER BAFFLE (LIGHT TRAP)	COR1.600	Rad	2.40E-02	43.44	0.00		COR1.5	Rad	2.51E-02	30.53	0.00
	COR1.15	Rad	6.49E-03	30.57	0.00		COR1.35	Rad	5.67E-02	30.59	-0.01

2.6.1 Post Run-Time Calculated Heatmaps

Because the heatflows are calculated for a user specified (variable) timestep, massive amounts of heatflow data need not be stored in the thermal model output file (i.e. QMAP, QDUMP,etc). Upon changing the timestep *(B)*, the worksheet will calculate the entire set of heat flows for all node/group interactions for the selected timestep, Stefan-boltzman constant *(C)*, and absolute temperature offset *(D)*. Models with hundreds of thousands of conductor can quickly create workbooks that may exceed limitations in Excel®. The heatmap option currently supports 131066 [(65536 rows – 3 header rows) x 2 worksheets] conductors. If demand warrants, additional conductor capability may be added.

2.6.2 Heatflows between Nodes and/or Groups

Heat flow between nodes and groups may be displayed for any of the following combinations: node-to-node, node-to-group, group-to-node, and group-to-group. The option is determined by combining the "Heat to" selection *(F)* with the Node/Group entered by the user *(A)*. Once the user has entered a node or group name for "Node i", the worksheet will output all nodes/groups connected to the specified node/group, the description for the node, the conductance value, the temperature of the adjoining node, and the heat flow through the conductor. The data will then be sorted from High to Low (i.e. In to Out where heat in is defined as positive). The data will be repeated on the right side of the spreadsheet and sorted from Low to High. The temperature and description of the specified node/group will also be calculated. A summary of the node/group heat balance is provided in the upper right including total heat flow in and out by conduction and radiation, the heat applied to the node and the overall balance *(G)*.

2.6.3 Show only relevant heatflows

For large models with thousands of nodes, many heat paths to a single node can exist. However, many of these may contribute negligible amounts of heat to the node. A "Min Heat" setting *(E)* allows the user to specify a minimum threshold value to be output; anything less than the threshold will not be displayed. This eliminates negligible heat paths from being displayed.

3 APPLICATIONS

3.1 File conversion

3.1.1 Quick comparison of converted file format results

Many projects receive models in formats used by instrument suppliers, which may not be compatible with the software used by the spacecraft contractor. The provided instrument models must therefore be converted to the format used by the spacecraft contractor for incorporation into the spacecraft model. This is an arduous task unto itself, but once converted, it must be assured that the converted model behaves the same as the original model.

The "Compare Outputs" option provides a quick look at the minimum, maximum, and average between various stages of the model conversion. Assuming that each of these parameters is within acceptable errors, it can be concluded that the model conversion is a success.

Table 6 - Sample Table For Model Conversion Comparison

	Min				Avg				Max			
Node #	**TMG**	**SINDA**	**ESA**	**RAD**	**TMG**	**SINDA**	**ESA**	**RAD**	**TMG**	**SINDA**	**ESA**	**RAD**
1	13.1	12.7	13.1	13.5	13.3	12.9	13.3	13.8	13.6	13.4	13.7	14.1
2	13.7	13.3	13.7	14.2	14.0	13.7	14.1	14.6	14.8	14.6	14.9	15.3
3	13.6	13.1	13.6	14.1	13.7	13.3	13.7	14.4	13.9	13.6	14.0	14.7
4	13.6	13.3	13.6	14.1	13.6	13.4	13.6	14.1	13.7	13.4	13.7	14.1
5	13.1	12.9	13.1	13.6	13.1	12.9	13.1	13.7	13.2	13.0	13.2	13.7
6	12.2	11.9	12.2	12.7	12.3	12.0	12.3	12.8	12.3	12.1	12.4	12.9
7	14.9	14.3	14.8	15.6	15.1	14.6	15.1	16.0	15.4	15.1	15.6	16.4
8	15.1	14.4	15.0	15.8	15.3	14.8	15.4	16.3	15.8	15.5	16.0	16.8

3.2 Parametrics

3.2.1 Comparison of effects of changing parameters compared to baseline

Parametric studies are another common task of a thermal analyst. Often exact values are unknown for particular parameters in a model (conductance, heater power, dissipation, MLI effective emissivity). Varying these parameters can create many output files that may be tedious to compare. By using the Multiple Files or Compare Outputs options, the effects of varying these parameters can be quickly established.

For a small satellite, the batteries were predicted to run warmer than allowed. By varying the conductance to the top of the battery box and the emissivity of the top, it was possible to quickly determine the overall effect of each change.

Table 7 - Sample Table for Parametric Case Study

		Min				Max			
Desc	**Node #**	**Case1**	**Case2**	**Case3**	**Case4**	**Case1**	**Case2**	**Case3**	**Case4**
BATTERY 1	HOKIES.1001	38.8	35.7	35.1	35.0	45.1	42.2	41.8	42.4
BATTERY 2	HOKIES.1002	39.0	35.9	35.2	35.2	45.3	42.4	41.9	42.6
BATTERY 3	HOKIES.1003	39.1	35.9	35.3	35.2	45.5	42.4	42.0	42.6
BATTERY 4	HOKIES.1004	39.2	35.9	35.3	35.2	45.5	42.4	42.0	42.7
BATTERY 5	HOKIES.1005	39.2	35.9	35.2	35.2	45.5	42.4	42.0	42.7
BATTERY 6	HOKIES.1006	38.9	35.7	35.1	35.0	45.2	42.1	41.8	42.4
BATTERY 7	HOKIES.1007	39.0	35.7	35.1	35.1	45.3	42.2	41.8	42.5
BATTERY 8	HOKIES.1008	39.1	35.8	35.2	35.1	45.4	42.2	41.9	42.5

3.3 Heatmaps

3.3.1 Analyze heat flow instead of just temperature

For a thermal balance test, a particular instrument component was predicting colder that the instrument provider would allow. This component was a bonded composite/metal junction that was required to remain above –30°C; it was predicted at –50°C. To provide for the safety of the instrument, it was proposed to use the flight cover (instrumented with a heater) to provide a warm view for the component. Thermal analysis revealed that even with 50W of heater power on the cover, the temperature still did not reach an acceptable value.

By using the heatmap option of ThermPlot, it was discovered that much of the heat being added to the cover was simply conducting through the shaft to a nearby radiator for the motor! This path was certainly not evident from the temperatures. This new information led to the introduction of a second heater plate in view of the radiator and resulted in an acceptable temperature for the composite bond. Without knowledge of how the heat was flowing through the model, it would have been difficult to analyze this particular problem.

4 CONCLUSIONS

As models continue to grow in size and complexity, it is a difficult task to understand how a model will behave in a particular set of circumstances. Understanding and identifying the major contributing heat paths is crucial to debugging and understanding the physical behavior of the system. ThermPlot allows the thermal analyst to spend more time analyzing critical areas of a design rather instead of reducing massive amount of data to a subset of importance.