NEW AND IMPROVED SIGNATURE MODELING OF GROUND VEHICLES WITH MUSES

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Abstract
Since 1986, PRISM has been the US Army's standard tool for infrared signature and thermal modeling. To meet the modeling requirements brought on by advances in LO technologies, and the pressing need for easier to use IR modeling tools with strong design capabilities, ThermoAnalytics, Inc. has developed MuSES, the Multi-Service Electro-optics Signature code, under a US Army Phase II SBIR program and other dual-use funding.

MuSES has built on the functionality of PRISM to provide a more complete and intuitive thermal and IR modeling tool. The functions performed by PRISM preprocessing utilities which calculate thermal conductance, facet to facet view factors, and multi bounce radiation exchange are now integrated into MuSES' Graphical User Interface (GUI). Boundary conditions, an expanded list of PRISM style region type assignments, sophisticated thermal conduction path rules, and applied heat sources or constant temperature assignments are all implemented through the GUI.

MuSES makes use of a more robust view factor and nodal network solver than that of PRISM. Consequently, very high resolution models, in terms of the number of surface elements and/or underlying non-homogeneous composite layers, may be processed in MuSES. This paper will describe the MuSES model building process. Meshing, thermal network generation and IR modeling issues will also be discussed.

Modeling Tools, From the Modelers Perspective
This paper will focus on MuSES from the infrared signature modeler's point of view. The MuSES code has been designed to address the needs of both commercial, thermal design analysts and infrared signature modelers. While ThermoAnalytics' earlier IR modeling code, PRISM, can be used to develop finely detailed models, these models are usually of little use to a designer because they are so time consuming to generate and edit. Consequently, in the early 1990s, ThermoAnalytics began development of a ***thermal design tool*** for Ford Motor Company which, initially, focused on radiation

exchange. This program, called RadTherm, evolved into a full first principles, comprehensive, thermal modeling package. Leveraging off the technology which makes RadTherm intuitive, fast and easy to use, MuSES was developed to address the modeling needs of the signature community. MuSES combines the comprehensive thermal modeling features of RadTherm with the signature modeling capabilities of PRISM.

Signature Modeling with MuSES

MuSES' menu driven GUI (see Figure 1) integrates the steps involved in building a signature model into a single, comprehensive modeling tool. Besides eliminating the need to step through various pre and post processing utilities, MuSES monitors the status of the model to insure that important steps are not skipped (example: failing to recalculate view factors following a geometry edit).

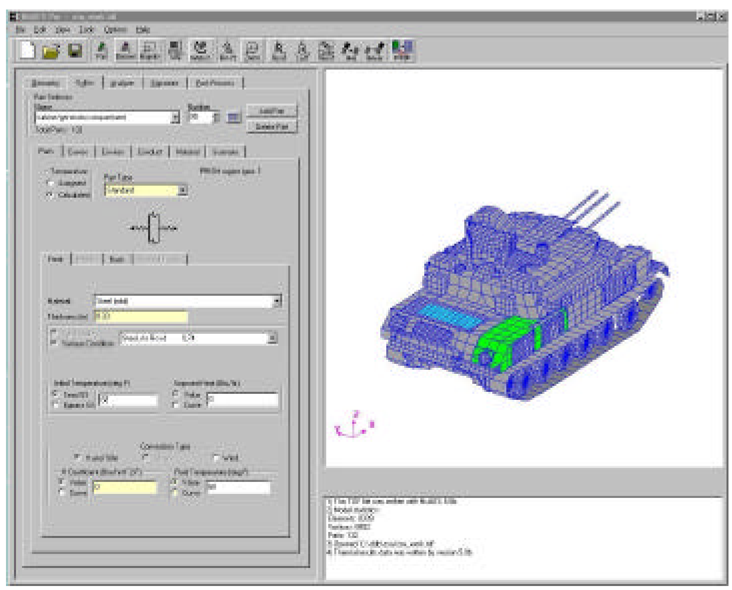

Figure 1: MuSES GUI

Typically there are four steps involved in successfully building a signature model;

- generate a surface description
- mesh the surface description
- define the thermal model, properties and boundary conditions, then engage the analysis
- post process the results

Through years of signature model building, accompanied by the evolution of PRISM, ThermoAnalytics has worked to improve the model building process. These improvements have resulted in a simplification and streamlining of each model building step; from the early stages of geometry creation through the final post processing analysis.

Surface and Mesh Editing

MuSES provides geometry and mesh creation as a preprocessing option. Currently, flat plate and cylinder primitives are available. Though the user has control over mesh resolution, scaling, translations, copying and rotation, most signature analysts will generate their geometry and mesh in separate stand alone codes and then import the finished mesh into MuSES. This process differs from that used by PRISM, where labor intensive faceted geometry was required.

Surface Mesh vs. Faceted Geometry

MuSES operates on a surface representation rather than the faceted plate geometry used by PRISM. Faceted geometry, which graphically depicts the thickness and connectivity of elements, is tedious to generate and error prone. Figure 2 shows an example of two simple models which illustrate this difference. The model on the left was generated in MuSES. The one on the right was generated for PRISM. Table 1 provides physical data for each model.

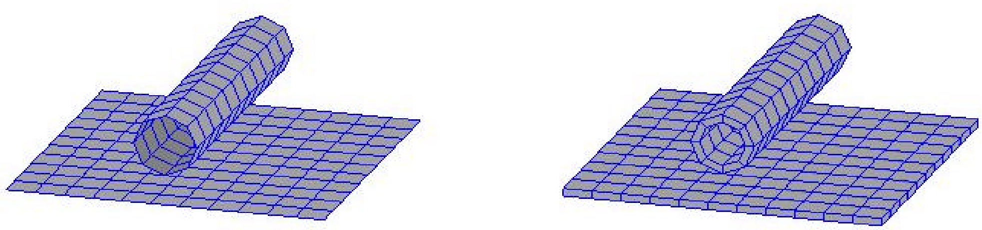

Figure 2: MuSES surface and PRISM faceted geometry examples

Model	Number of Elements	Number of Vertices	File Size (kb, *obj* format)
MuSES	209	248	25.983
PRISM	1254	479	62.109

Table 1: Physical data for geometry examples

Both models in Figure 2 would give similar results from the respective codes. But because the MuSES model only requires a surface description, the geometry is much easier to generate and assess for errors. And since the MuSES mesh file is smaller than a similar faceted geometry file, geometry manipulation within the modeling code is much more robust.

Surface Geometry and Mesh Quality

A surface description must be generated in such a way that a good, well ordered mesh will be derived from it; the geometry and the mesh are not independent entities. Figures 3 and 4 show two examples of a process which starts with a NURBS surface and ends with a MuSES temperature profile. It illustrates the effect a surface has on the mesh and the quality of the analysis. In each example, a constant temperature of 150^{o}F was applied to the bottom edge of the tapered plate and the model was allowed to reach a steady state equilibrium. From Figure 3 we see that the best results are generated by a mesh which is;

- well ordered (uniform)
- has elements which have a length to width (aspect) ratio near 1
- is orthogonal

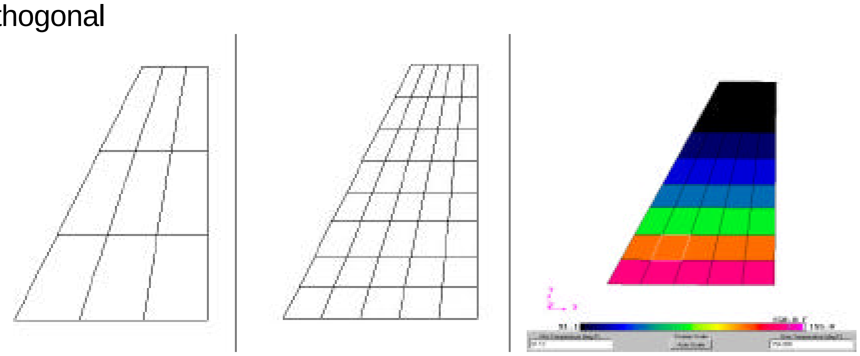

Figure 3: Surface/Mesh/Results; example of a good surface description and the results of an analysis

The unusual temperature distribution in Figure 4 suggests;

- the **mixture** of tri and quad elements arbitrarily skews thermal conduction paths
- the arrangement of “fan” elements tends to direct heat transfer according to element size and spacing

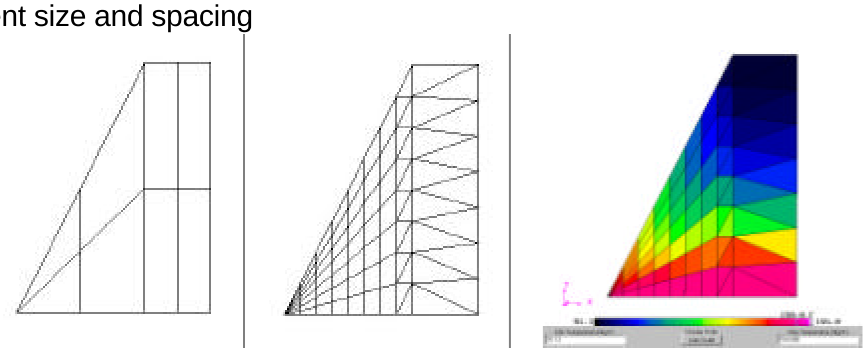

Figure 4: Surface/Mesh/Results; example of a poor surface description and the results of an analysis

Mesh Diagnostics: The MuSES Condense Feature
One meshing problem commonly experienced among modelers is disjointed geometry (see Figure 5). Disjointed geometry; a misalignment of mesh elements, breaks thermal conduction paths and can result in radiation leaks. Disjointed geometry can ruin the validity of an analysis and is hard to detect in typically complicated signature model geometry. It is not unusual for a modeler to spend several days detecting and fixing disjointed geometry, especially with faceted models.

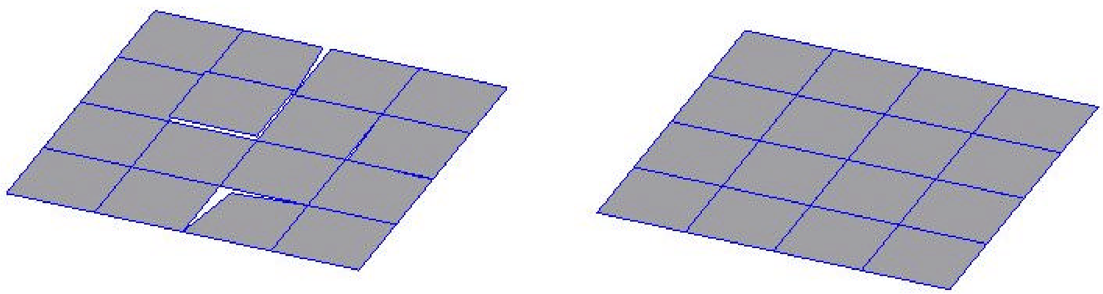

Figure 5: Disjointed mesh vs. condensed clean mesh

Since MuSES' surface geometry is not faceted, disjointed elements are relatively easy to find and fix. To eliminate small cracks which may not even be visible, MuSES' ***condense*** feature snaps together vertices separated by a user defined distance, eliminating these misalignments and, potentially, saving the modeler days of hand editing. The clean mesh seen on the right in Figure 5 was ***condensed*** in MuSES from the poor geometry on the left.

The MuSES Thermal and IR Model

Code Architecture
ThermoAnalytics has created an entirely new thermal and IR solver for MuSES, RadTherm and WinTherm (our full suite of thermal and IR modeling codes). This new solver employs an open architecture in which sub-modules exist as library routines. The library routines operate on well-defined data structures with documented inputs, outputs, and side effects. Wrappers written for existing modules allow their use within this new architecture.

Heat Transfer Physics
MuSES performs an energy balance based on calculation of convection, conduction, and radiation. The method by which elements (thermal nodes) are thermally linked together is automated under user direction. MuSES provides the user with the

automated capability to create and verify (both graphically and through debug output) thermal links between elements whenever possible. Environmental effects (solar loads, sky and earth emission, etc) are input through a weather file or calculated internally. External convection and precipitation are included via weather file inputs. All temperature and heat load data are input as constants or as functions of time at user discretion.

MuSES Model Building

The process involved in generating a signature model in MuSES from a finished mesh can be summarized in three steps; part definition, property assignment and boundary condition application.

Part Definition In MuSES, parts are groups of mesh elements which share the same;

- boundary conditions
- material, physical and surface properties
- thermal properties

Each element of a mesh must be assigned to a specific part.

Though parts are understood to be a grouping of similar elements, MuSES recognizes that radiation view factors may vary across a part, and so view factors are *always* calculated for each individual element. Some groups of adjacent elements however, may have similar view factors. Because of this, another method of element grouping can be automatically applied for view factor calculation. This grouping convention is called the ***Radiation Patch***.

The MuSES Patch Generator

MuSES assumes that each mesh element will have its own unique set of view factors (to the ground, the sky and other visible elements). By default, *each* mesh element is categorized as a radiation patch. But it is not unusual for neighboring elements to have very similar view factors. Under these circumstances, the view factors of the neighboring elements can be grouped together by implementing the MuSES ***Patch Generator*** (Figure 6).

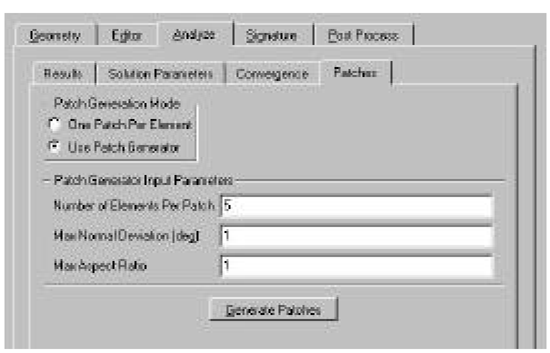

Figure 6: The MuSES Patch Generator

The patch generator allows the user to adjust the number of elements included in a radiation patch. Currently, MuSES is limited to operating on models with fewer than 65,000 radiation patches. By adjusting the parameters of the patch generator, it is possible to run models whose element count far exceeds this limit and would otherwise (with one patch per element) not run or require excessive disk storage.

Part and Property Assignment
MuSES' property assignment interface is adaptive and simple to use. The property libraries include;

- material properties
  physical and thermal, including anisotropic thermal conductivity
- surface properties
  thermal emissivity and solar absorptivity
- paint properties
  spectral surface data for band radiance calculations

MuSES allows the user to choose from a variety of **Part Types** while making property assignments. Though not yet fully implemented, MuSES part assignments will eventually include the full range of PRISM region types. Currently, MuSES functional part types include *standard, 3 layer, highly conductive* and *background*. The modeler must choose a best fit from among these options for part assignment. Discretion must be used in order to optimize the model. For example, a *three layer* part type (depicted in Figure 7) allows non homogeneous, composite layering to be accurately modeled. It would be unwise to use this type of part assignment to model thin, thermally conductive, plate material (this could result in convergence problems and would be better modeled by the *highly conductive* part type), and unnecessary to use it on a homogeneous material for steady state analysis (because the temperature gradient would be linear).

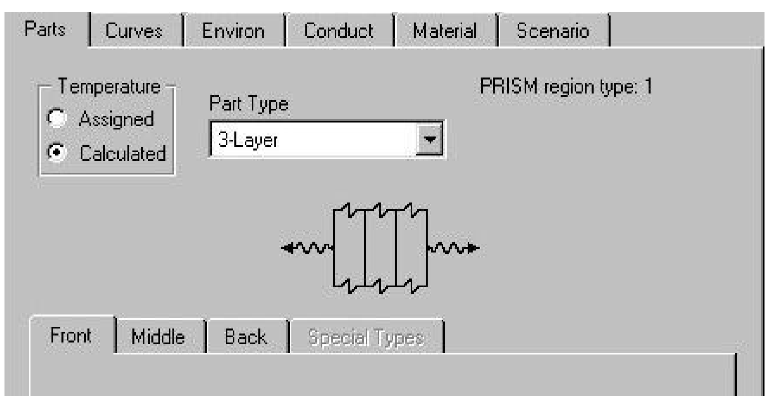

Figure 7: Part Assignment Menu

Boundary Conditions
Once all the elements of a mesh have been assigned to specific parts, boundary conditions can be applied to them. Boundary conditions, as defined here, include

environmental (weather and background) interaction, applied convection and/or applied temperature or heat assignments. MuSES allows the modeler to assign a constant or fluctuating temperature or heat profile to a part. Applied quantities (convection coefficients, heat rates and temperatures) can be defined as fluctuating values through MuSES' ***Curve Editor*** (Figure 8).

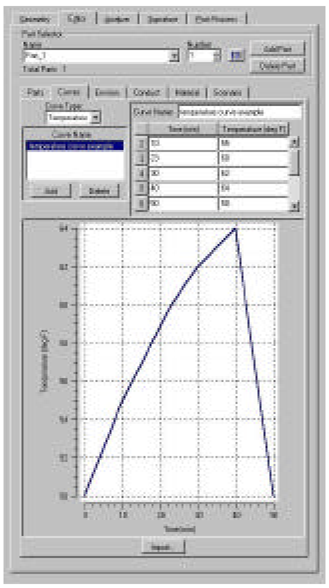

Figure 8: MuSES Curve Editor

The curve editor allows the modeler to enter *XY* data pairs which define a curve. Larger curve files, such as diurnal ambient air temperature measurements, can be imported, displayed and edited in the curve editor.

Thermal and Signature Analysis

The Thermal Analysis Editor

MuSES provides feedback from its thermal solver throughout a model run. The modeler may toggle between the following tabs (Figure 9) for diagnostics and convergence information.

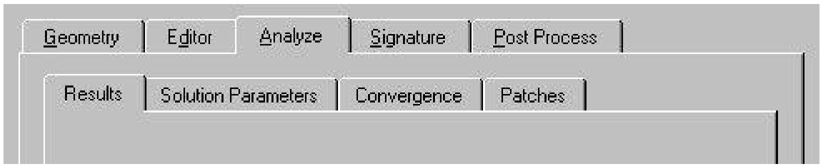

Figure 9: Analysis feedback

Results

- maximum and minimum calculated temperature at each time step
- elapsed and clock time into the run
- simulation statistics, including the current number of iterations, the steady state solution residual, transient and steady state temperature tolerance and selected element temperature

Solution Parameters

- start time, end time and date designation
- parameter settings for steady state initialization
- solution relaxation; either adaptive (MuSES adjusts the relaxation parameter to best fit the solution) or user specified (default is 1)
- view factor resolution slider; optimizes run speed or accuracy
- steady state seed temperature file import browser
- graphics update adjustments

Convergence

- graphically updates temperature tolerance and heat residual amounts at each iteration, for steady state and transient analysis

Patches

- the MuSES Patch Generator (default is one patch per element)

When the user starts a MuSES analysis, MuSES performs several consistency checks to insure that all the input parameters are synchronized. If MuSES discovers potential problems, the user is cued to provide further information. MuSES also compares the mesh geometry against the model's view factor file (if one exists). If MuSES discovers that these files are not consistent, a new view factor calculation is performed.

IR Signature Solution

MuSES does not require the user to calculate a new thermal solution each time a radiance or apparent temperature analysis is performed. If the user attempts to perform a signature analysis without having first run a temperature solution, MuSES will perform the thermal solution, followed by the specified band radiance calculations.

Prior to running a signature analysis, the user may want to verify that appropriate ***paint coatings*** have been assigned to the outer surface of the model geometry. Though MuSES will perform signature analyses on models with standard surface property assignments (example: Oxidized Steel, $\varepsilon = 0.8$, $\alpha = 0.74$), only the *thermal* emissivity will be used for radiance calculations, regardless of the specified band. In order to perform a true **band specific** signature analysis, the modeler must make paint assignments to the model.

Post Processing

MuSES' integrated post processor allows the modeler to evaluate the results of an analysis on a variety of levels.

- temperature, radiance and apparent temperatures can be plotted, viewed and exported
- heat flux breakdowns can be monitored, plotted and exported
- thermal gradients through layers can be analyzed
- steady state and transient results can be viewed in grey or color scale

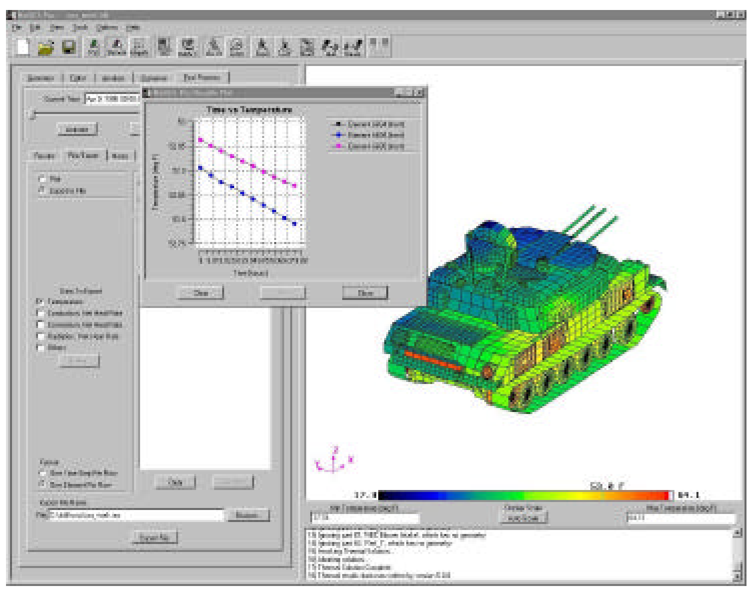

Figure 10: MuSES Post Processor

Model Evaluation

Modeling codes it seems, whether they are thermal, fluids, radar or structural modelers, are forgiving. More often than not, regardless of the quality of the model, the software will run and results can be obtained. From Figures 3 and 4, we have seen that the results of an analysis can be arbitrarily affected in ways that are not always obvious. Every step of the modeling process, even post processing, has potential pitfalls which can invalidate results or raise false confidence. The intent of this paper has been to outline an abbreviated description of signature and thermal modeling in MuSES. ThermoAnalytics has developed a high degree of modeling expertise through years of model and software development. Further examples of modeling errors, and suggestions on how they may be avoided, can be viewed at;
http://www.thermoanalytics.com/services/modeling.html

NOMENCLATURE

Symbols

ε thermal emissivity
α solar absorptivity

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