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MuSES: A New Heat and Signature Management Design Tool for Virtual Prototyping

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ABSTRACT

The current Army infrared signature code, PRISM, does not fully meet the needs of vehicle designers. In this age of rapid prototyping and advanced signature and heat management designs, an overhaul of the infrared modeling process is required.

The Army awarded a SBIR Phase II program at the end of 1997 to create a new design tool called MuSES (Multi-Service Electro-optics Signature) code capable of meeting these arising requirements. MuSES will provide a virtual prototyping platform for both concept and retrofit design efforts. Because of the strong connections between signature management for military ground vehicles and heat management for commercial automobiles, there is considerable dual-use collaboration and commercial commitments from the automobile industry. This SBIR program will create an innovative design tool for the Army, provide considerable technology transfer to other tri-service defense organizations, and be positioned for Phase III follow-on commercialization with the automobile industry. A description of the MuSES code is detailed in this paper.

In addition, TACOM engineers are developing a software package to convert solid CAD geometry into a faceted mesh to feed the MuSES 3-D Model Editor. This package, currently in alpha form, is named Eclectic.

TAI THERMAL PRODUCTS

In developing MuSES, ThermoAnalytics is leveraging on experience gained from past and on-going thermal model development programs. The complementary attributes of these products are illustrated in Figure 1. Primarily, MuSES is patterned after Ford Motor Company’s RadTherm, a rapid prototyping thermal design tool. Thermal models can be rapidly constructed in RadTherm from commonly available geometric and material descriptions. This work has been accomplished in part under a Cooperative Research and Development Agreements (CRADA) between TACOM and Ford with ThermoAnalytics as the primary developer.

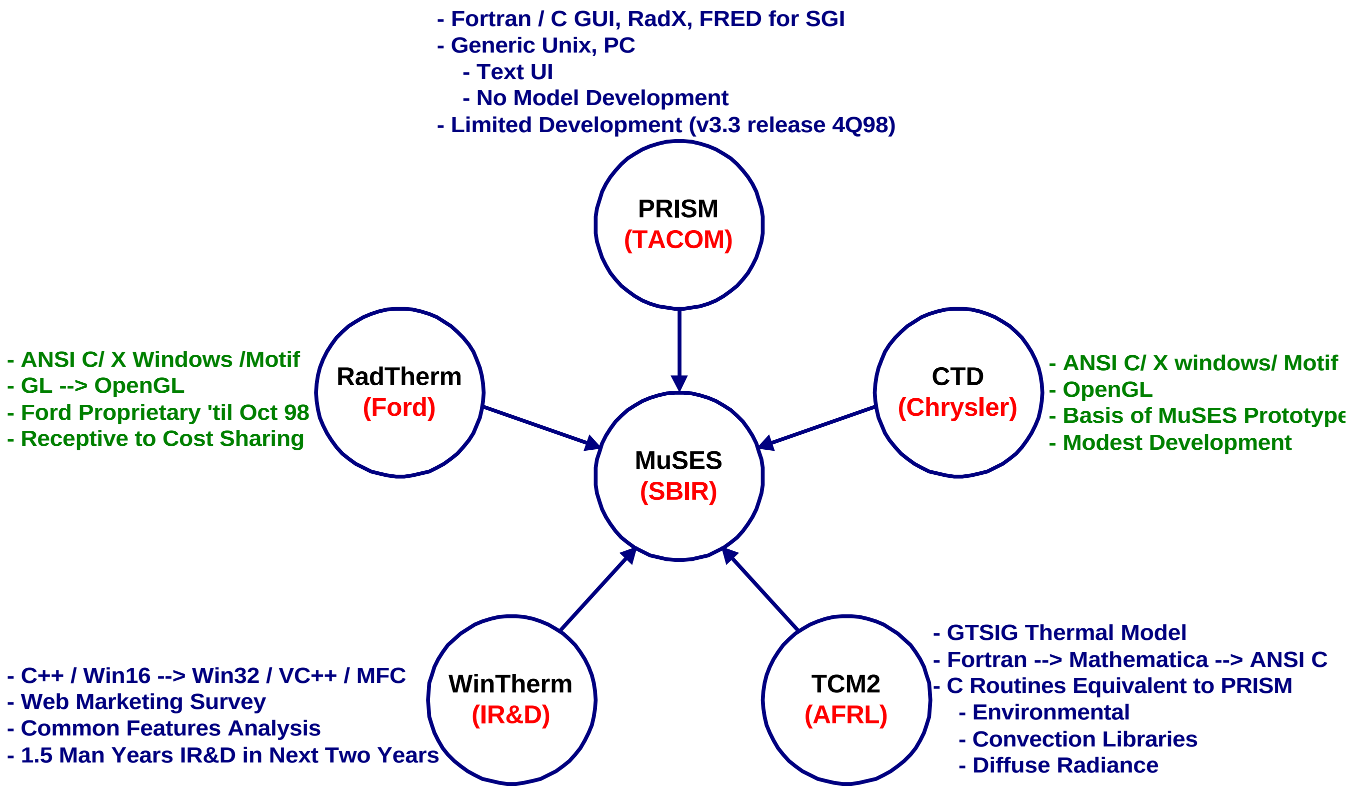

Figure 1. ThermoAnalytics Complementary Programs Provide a Leveraged Advantage for MuSES.

MuSES OVERVIEW

The motivation for developing MuSES is three fold:

1. PRISM does not meet vehicle designers needs as a **fast prototyping design tool**.
2. Major modifications to the PRISM code are not **cost effective** due to the years of incremental development.
3. Cost sharing partnerships through **SBIR's**, **CRADA's** and **commercial investments** provide key opportunities for a "leveraged" signature and heat management design tool.

The MuSES interface is optimized for engineers who need to incorporate signature management treatments or heat management solutions into vehicle designs. Since its development is based on dual-use programs and tri-service participation, the MuSES code is aimed at serving a broad spectrum of vehicle design and analysis issues. The cost sharing inherent in the MuSES development enhances the depth and breadth of the engineering design tool.

MuSES departs from PRISM in several important ways:

- MuSES native geometry representation is consistent with **current CAD tools** (e.g., Pro-E, PATRAN, AutoCAD);
- MuSES incorporates **rapid prototyping techniques** developed for commercial automotive applications;
- MuSES **integrates IR model preparation, simulation, and post-processing** operations thus ensuring a good match of the technology used to predict the signature with the source of input and the end-use.

The MuSES project is organized into six task groups. These tasks consist of a 3-D Model Editor, Thermal Solver, Radiosity Solver, Plume Model, Internal Flow Model, and Generic Engine Model

Specifications used in the development of the MuSES design tool are:

- The software is developed with cross-platform tools for both **UNIX** and **Windows** operating systems.
- The meshed geometry file formats include **PRISM FAC** files, **SPIRITS** wireframe files, **GTSIG FAC** files, **PATRAN** neutral files, **DXF**, **Wavefront OBJ** and others.
- The mesh features include **wireframe**, **wireframe with hidden lines**, **solid model**, and **solid model with facet outline** displays. The facet geometric attributes can be displayed with mouse-clicks.
- Geometry editing features include **scale, translate, rotate, delete, copy, and append.** Additional capabilities include **radiation patch generation, attribute assignment**, and **facet normal reversal**.
- The radiation view factor module uses state-of-the-art high-speed algorithms such as the hardware graphical **hemi-cube** technique and a brand new software **ray casting** solution.
- The thermal radiation exchange is based on **diffuse multiple bounce** (reflection) for both the thermal radiosity solution and the infrared signature output. Additional directionality using the **BRDF module** will be available for the signature output only.
- The surface temperatures are optionally initialized with a **steady state solution** and then the simulation proceeds through time with a **transient solution** over the designated prediction time. The energy balance is based on linkages of **radiation**, **convection**, and **conduction**. MuSES will employ **automatic link generation** to create many of these linkages. The effects of **aerodynamic heating** will be included. Imposed **heating** is added as a function of time as well as time dependent temperatures for boundary conditions. **Environmental effects** are also included as boundary conditions.
- The user inputs include **temperature**, **heat rate**, **convection coefficient, thickness**, and **surface/material** assigned at the part level. A **customized thermal node menu** provides the user with the options for specifying part (or node) types (e.g., assigned temperature, computed, and others). All of these model attributes can be entered interactively through **the Graphical User Interface (GUI)**. The user can toggle MuSES to operate with either SI or English units
- To include the thermal effects of internal components, the user can insert simple **isothermal solids** (rectangular or cylindrical), **engine solids** with temperature/heat distributions, **ducts** with fluid flow, and simple **heat exchangers**.
- MuSES displays the physical temperature of the model's surface as a **thermal image** during the solution process. The image can be **rotated** and **viewed** at any direction throughout the thermal prediction simulation. Temperature and radiance output files are automatically created during the simulation thus providing the **time-history results** for post-processing of the dynamic simulation.

The current state of the PRISM design modeling process is outlined in Figure 2. This flow chart illustrates the large amount of user intervention required to achieve a completed model. When additional complex modeling capabilities are added such as plume and fluid flow modeling, the burden on the user can become overwhelming. The integrated architecture of MuSES greatly reduces the burden. The flow of the MuSES modeling process is illustrated in Figure 3. This diagram emphasizes the automation of many of these steps that were once undertaken by the user in a slow and often error prone fashion.

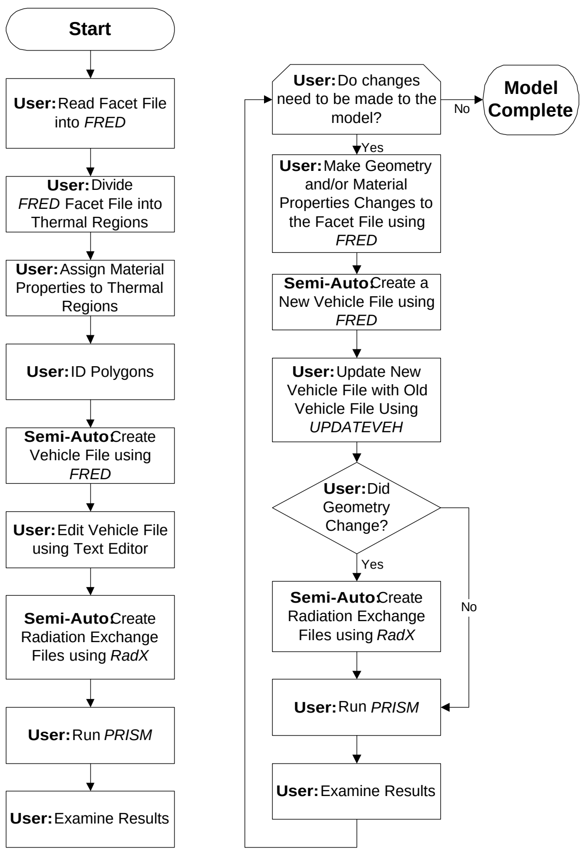

Figure 2. The Current PRISM Modeling Procedure is Very Labor Oriented.

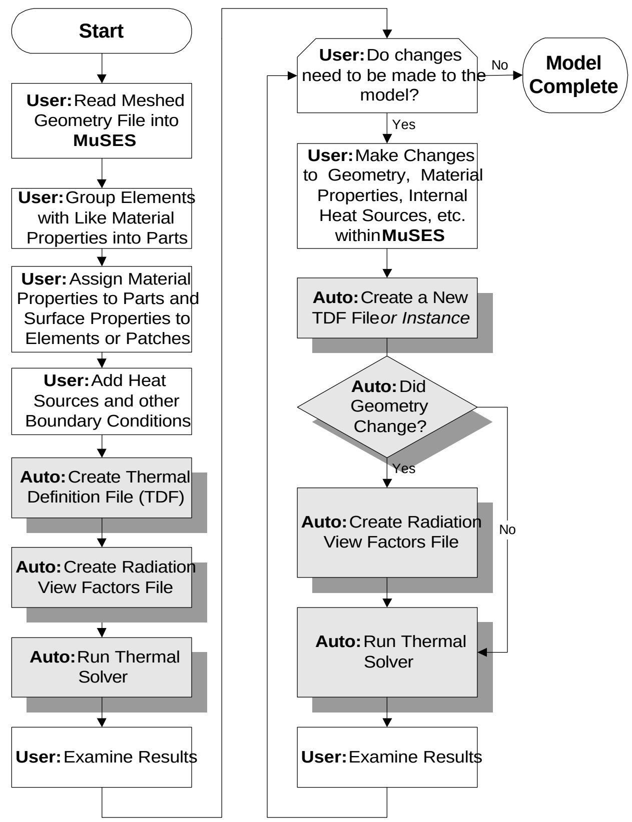

Figure 3. MuSES will Automate Most of the Design and Modeling Processes.

MuSES NODAL NETWORK SOLVER FEATURES

To restore modularity lost over ten years of PRISM evolution, ThermoAnalytics created a new thermal solver from scratch. The 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. The new thermal solver incorporates numerous advanced features including an adaptive time step, restart capability, batch mode, and alternate solution strategies (such as the “partial direct” solution method). Figure 4 outlines the data flow between the thermal solver, library routines, and user interface.

Heat Transfer

MuSES calculates convection, conduction, and radiation. The method by which elements (thermal nodes) are thermally linked together is

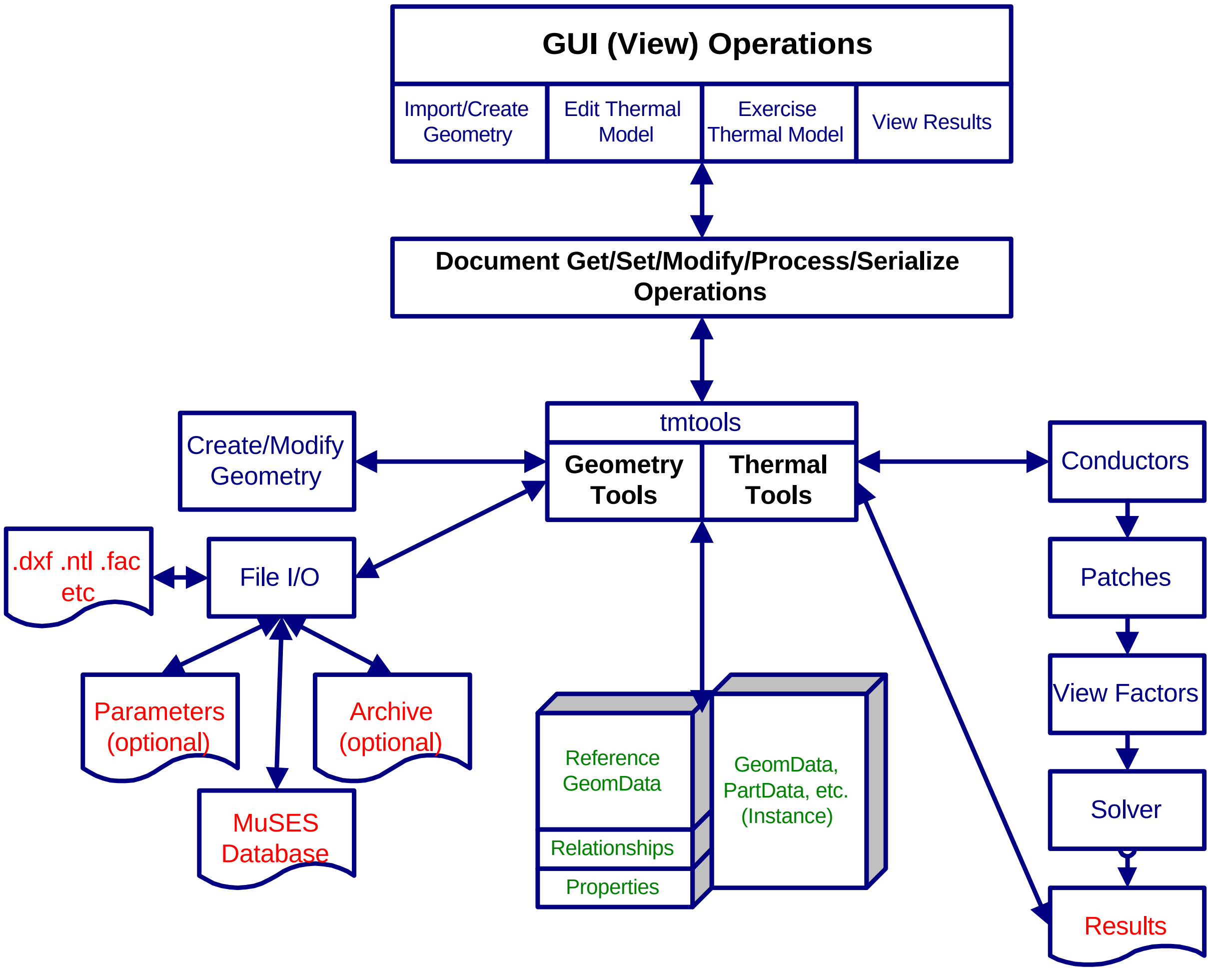

Figure 4. MuSES Dataflow Architecture

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. Through menu options the user applies complex linkages.

Environmental effects (solar loads, skyshine, earthshine, etc) will be input through a weather file or calculated internally. External convection, precipitation, condensation and evaporation will be included via weather file inputs.

All temperature and heat load data are input as constants, as a function of time, or as a function of a single generic engine setting (throttle, RPM, etc.).

The new thermal model in MuSES is general enough to be used in many applications since it includes aerodynamics, high altitude boundary conditions, and a CFD interface.

File I/O Uses HDF (Hierarchical Data Format)

Files created by MuSES are in the HDF File Format. This format is:

- **Machine and language independent**.
- **Versatile and flexible.** A HDF file can contain several different data models, including multi-dimensional arrays, raster images, and tables.
- **Self-describing.** A HDF file contains information about the data that it contains.

- **Extensible and appendable.** A HDF file can easily accommodate new data models, regardless of who adds them.
- **Direct-access.** A small subset of a large data set may be accessed efficiently, without first reading through all the preceding data.

MUSES 3-D MODEL EDITOR AND GRAPHICAL USER INTERFACE

The MuSES GUI includes full modeling support for finite element surface meshes. This includes the capability to store and process user defined conduction rules as well as linkages to arbitrary thermal nodes. Special part types will be used to provide easy access to internal structure and common thermal linkages.

The GUI window adjusts to the current needs of the user. When creating geometries, illustrated in Figure 5, dialog boxes appear to specify the shape, dimensions, and mesh resolution. After geometry creation, the user moves to the Editor by selecting the proper tab as shown in Figure 6. Through this display, elements can be arranged into parts, names assigned to the parts, part types selected, and material properties and boundary conditions assigned. Run time parameters are set under the next tab, Analysis, depicted in Figure 7.

Examples of the on-line help built into MuSES, as diagrammed in Figure 8, can be viewed at http://www.thermoanalytics.com under the Help menu of the MuSES/WinTherm page.

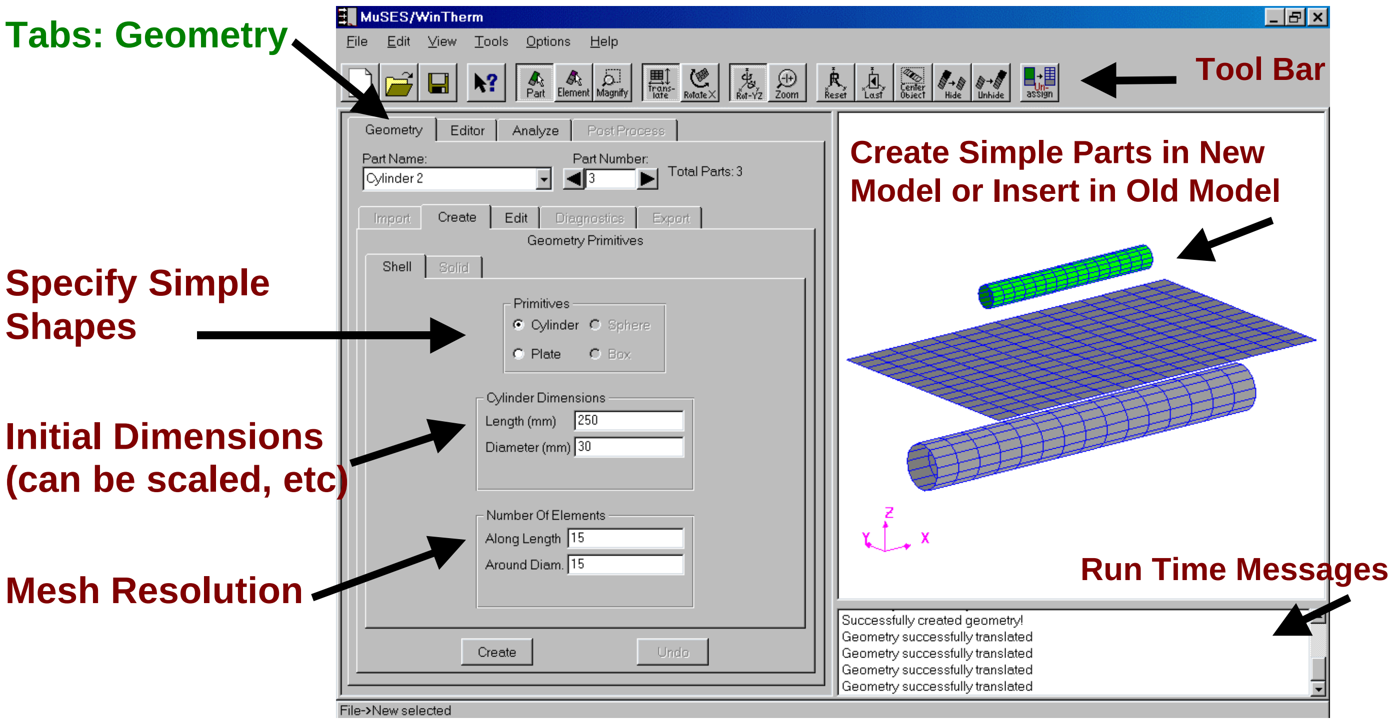

Figure 5. MuSES in Create Geometry Mode

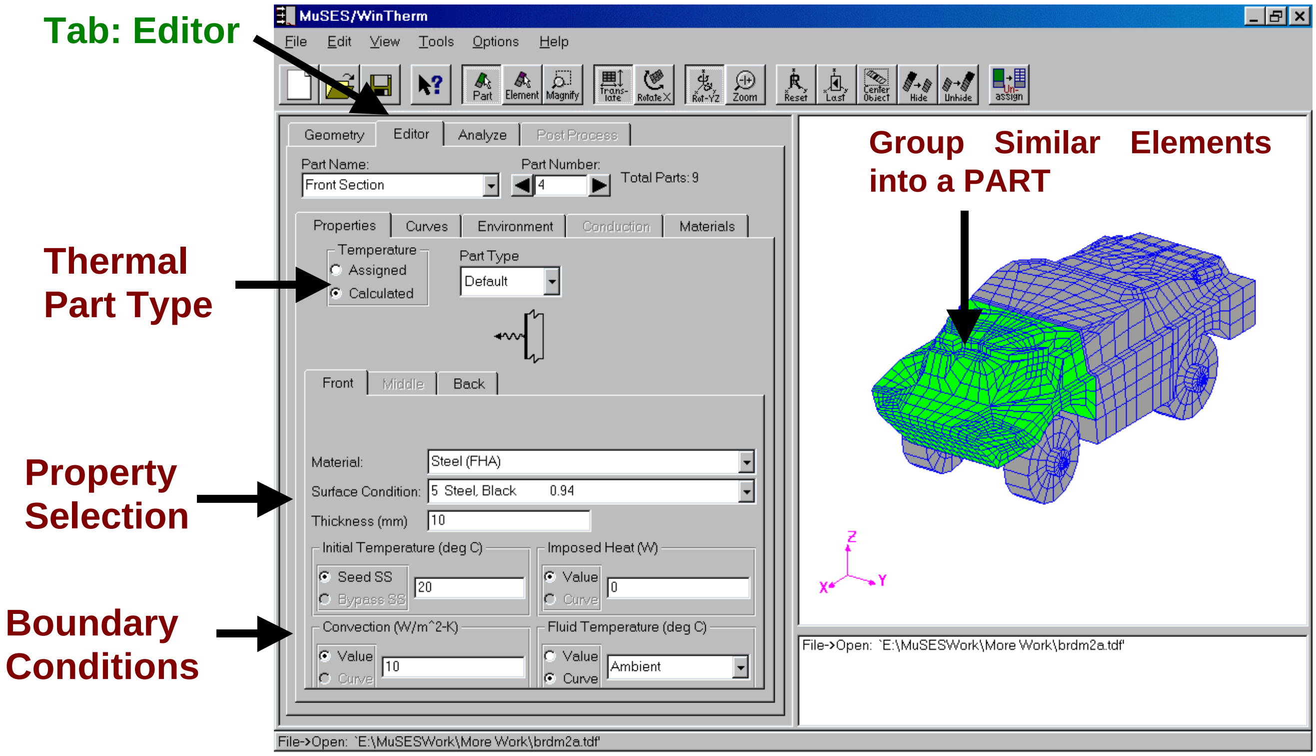

Figure 6. MuSES in Editor Mode (Build Model)

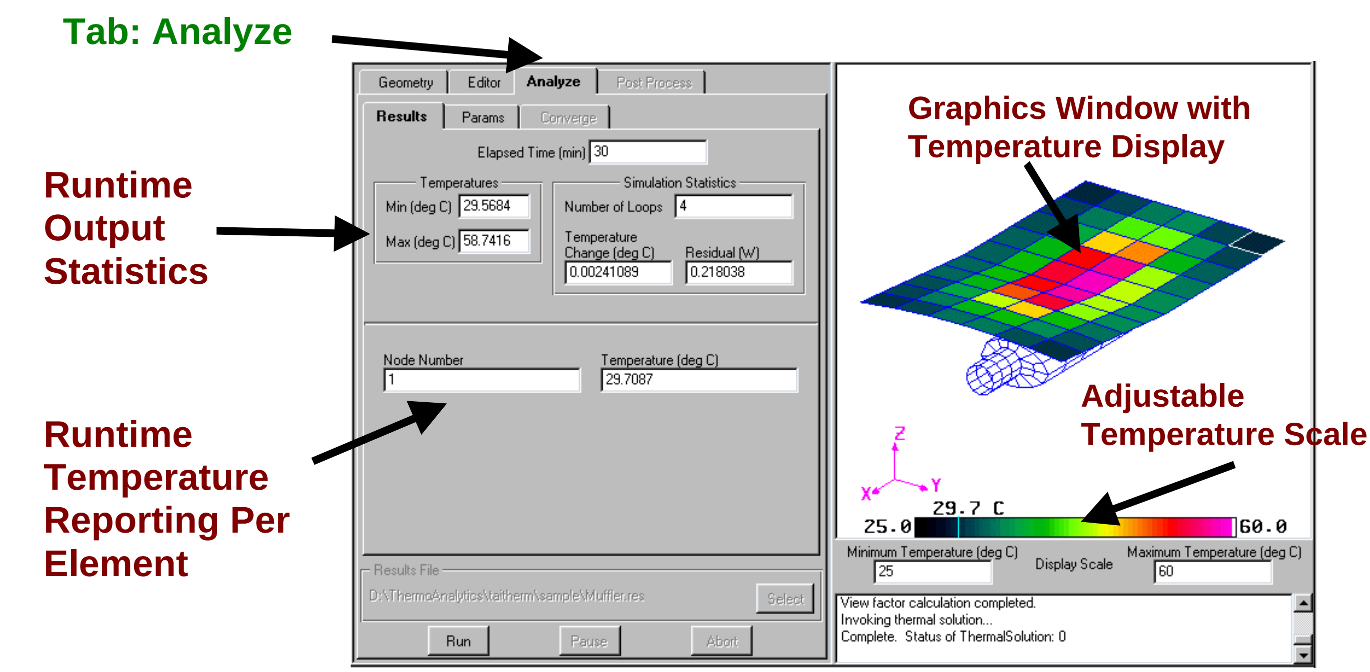

Figure 7. MuSES in Analyze Mode (Create Output):

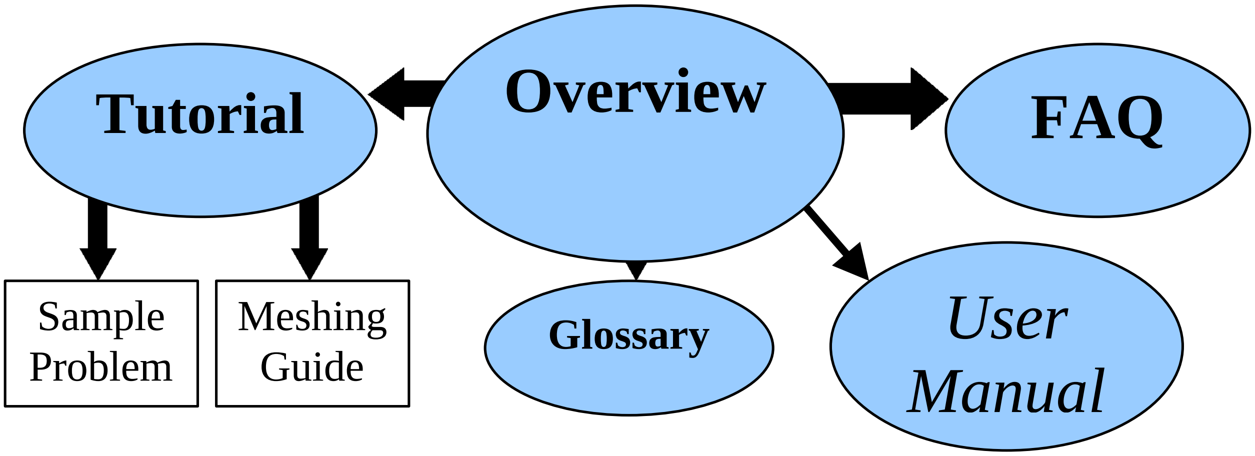

Figure 8. On-line Help within MuSES

MESHING GUIDELINES FOR THERMAL ANALYSIS IN MuSES

MuSES operates from a surface mesh. The thicknesses of the hull, track, etc are assigned as attributes to the surface mesh. MuSES requires that the surface mesh be of high quality. Because of the code's innovative ability to create a thermal mesh from surface geometry, to handle tee and plus junctions and, in the future, conduction through faces, its ability to perform error checking on the mesh is limited. Since MuSES cannot automatically discriminate bad geometry from good, the code will offer an interactive diagnostic mode in future releases to deal with questionable geometry.

The characteristics of a good quality mesh for import into MuSES are:

- All adjacent polygons share common vertices (equivalenced mesh);
- All polygons are 3 or 4-sided (triangles or quads);
- All polygons are convex;
- All polygons have an aspect ratio near unity (e.g. no long and skinny polygons);
- Polygons are spread uniformly across the surface (e.g. avoid fans of polygons);
- No overlapping or repeated facets;
- Surface mesh only (e.g. thin plates represented by their exterior surface only);
- Mesh is broken into meaningful parts.

Figures 9 shows a mesh that does not meet these requirements. The mesh depicted in Figure 10 is suited for thermal analysis.

An equivalenced mesh defines each coordinate point once. If multiple polygons use the same coordinate then they will refer to the same definition (i.e. same vertex index). By default MuSES will treat two facets that refer to two different – but identical – vertex coordinates as being disconnected. When reading in geometry file formats that do not support equivalence meshes (e.g. STL, DXF) the code will "crunch" the geometry by replacing identical and nearly identical vertices with a single vertex. If the user intends a discontinuity between two elements, the user must specify such after the geometry has been read in.

The last characteristic is driven by the assignment of attributes (material, boundary conditions, coatings, etc.) at the part level. If two adjacent polygons have a different materials or coatings or are linked to different heat sources then they should be in different parts. Usually one would want all adjoining polygons that have similar attributes to be grouped into the same part.

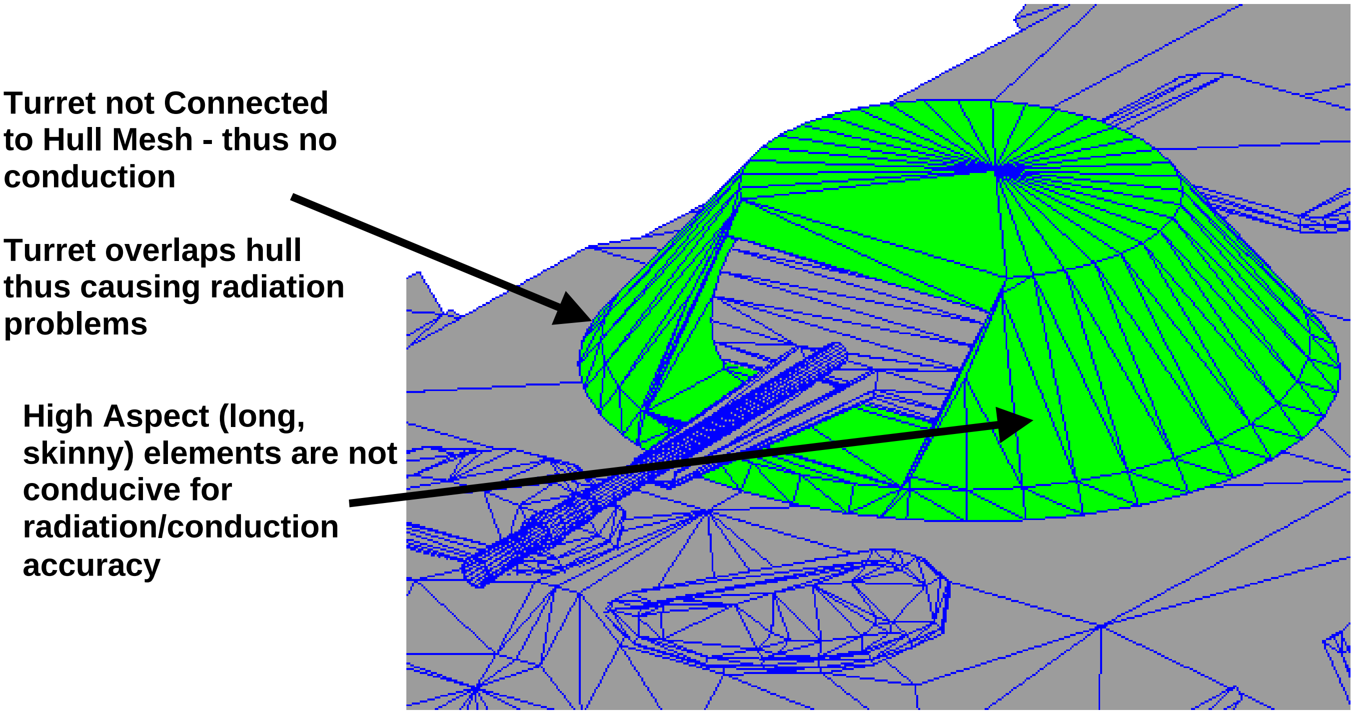

Figure 9. Example of a Poor Quality Mesh

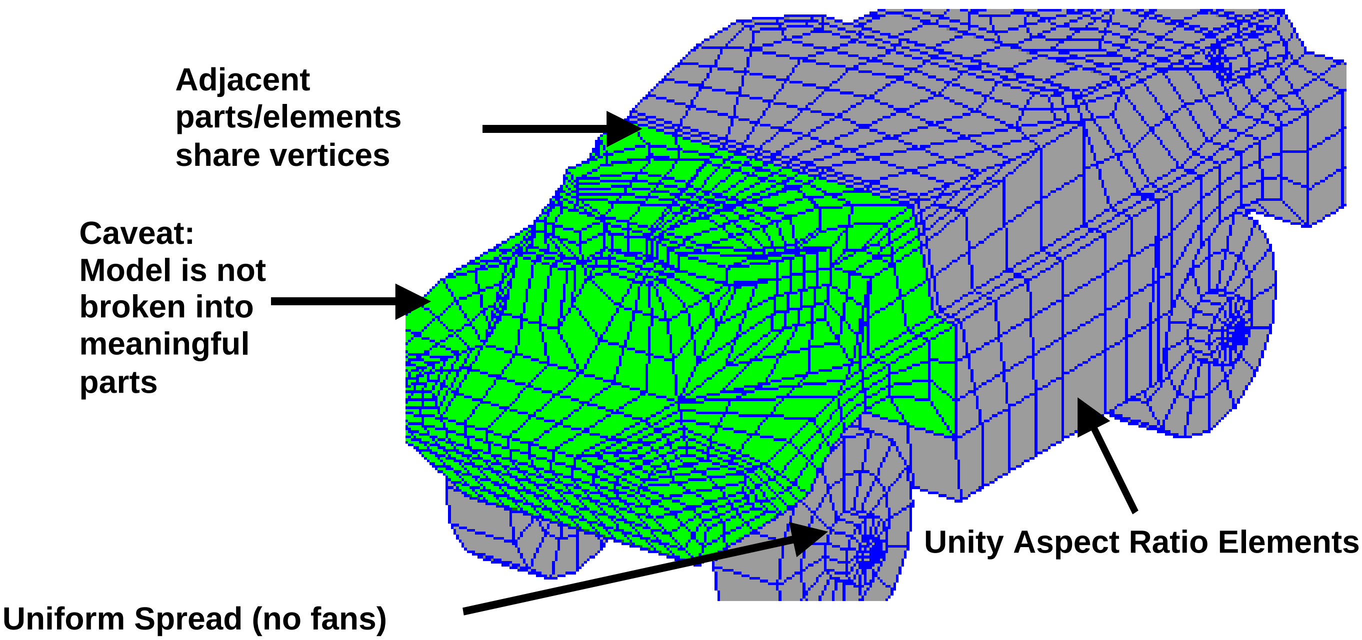

Figure 10. Example of a Good Quality Mesh

SOLID GEOMETRY SUPPORT

Eclectic is being developed to manipulate various forms of CAD geometry for export to analytical models that require polygons. It features a BRL-CAD converter that is superior to the one in FRED in a number of ways. It is written in ‘C’ with dynamic memory allocation; thus it is able to convert the entire binary CAD file, as opposed to having to create numerous ASCII files containing the vehicle components. It uses double precision which decreases the number of errors resulting from round off error and numerical instability. The polygonal data structure retains additional information, such as vertex normals, for export to visual and other signature models. Finally, Eclectic is designed to be machine independent and command line driven, which will make possible its direct integration into the analytical codes.

The goal for Eclectic is to transform the CAD geometry into an ‘ideal’ faceted geometry for analysis. For example Eclectic currently is able to simplify the BRL-CAD geometry to reduce the number of polygons necessary to produce a visually correct surface description. It does so by eliminating certain cutouts. An example would be where the hull of a tank had a number of holes cut in its side to let the torsion bars pass through. This would produce dozens of polygons where one would suffice visually.

Other analytical models, including MuSES, may require an ‘ideal’ geometry that contains more, rather than less, spatial resolution. Thus, work is in progress to develop a mesher and a voxelator as illustrated in Figure 11. The current approach is to produce the individual thermal elements by taking the intersection with a regular array of cubes. This approach, although fairly easy to implement, produces thermal nodes that are somewhat less than ‘ideal’. An object can occupy one of the cubes completely and only a fraction of the next cube, which produces a highly non-uniform type of thermal mesh. Thus, another approach is being considered where the mesh will radiate away from the areas of contact between the regions.

Given the experimental nature of the code and the early stage of its development cycle, the plans for a beta release of Eclectic have not been established. However, it may be possible to obtain an alpha version, which contains the BRL-CAD translator and output to a number of faceted geometry formats (.facet, .obj, .fac). Please direct inquiries to Jack Jones, TACOM, jonesja@cc.TACOM.Army.mil.

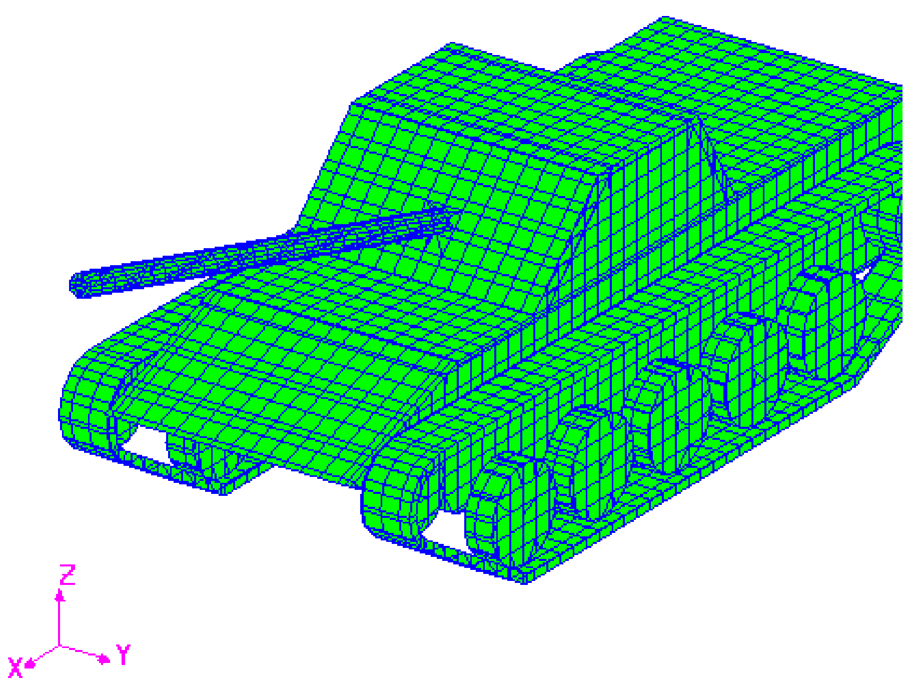

Figure 11. Example of a Meshed Model from Eclectic for use in MuSES