Recent Advances in MSC/PATRAN Pre-Processing Software Allows Modeling of Complex Automotive Lamp Designs

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ABSTRACT

Advances in automotive lamp designs have resulted in a more compact, aerodynamic packaging and the use of less expensive plastic materials for the lens and housing. The smaller packaging and lower melting point of plastics have increased the need for a predictive tool for simulating the lamp temperature rise under operating conditions. The modeling of lamps requires sophisticated analysis tools incorporating computational fluid dynamics and specular radiation. These tools use a finite element method to solve a system of non-linear equations for velocity, pressure and temperature. In addition to the non-linearity, the complex parabolic shape of the lamp reflector and lens requires very powerful mesh generation capability in order to produce an adequately refined mesh. The lamp modeling is performed in two stages. First the model is generated by importing CAD data from Pro/ENGINEER or Unigraphics into the MSC/PATRAN pre-processor. The surfaces are then meshed with triangular elements which are used as a seed for creating the air volume and lamp solid wall tetrahedral element meshes. The use of the new MSC/PATRAN hybrid tetrahedral mesher has enabled the creation of very complex 3D element meshes to represent fluid volumes with several hundred thousand elements. MSC/PATRAN has become a common pre/post-processor for many analysis codes because of the open CAE environment, advanced meshing capability, ease of applying loads and boundary conditions and effective post-processing capability for displaying results.

1. INTRODUCTION

The introduction of plastic materials in automotive lamp design, which have low melt temperatures relative to glass, and the requirement of a more aerodynamic shape to the lamp body have increased the need for accurately predicting lamp operating temperatures. Predicting lamp temperatures requires a sophisticated computational fluid dynamic (CFD) code with the capability to model combined surface radiation and natural convection effects.

The Adina-F CFD code was chosen for the lamp thermal analysis program because of the coupled specular surface radiation and fluid flow analysis capabilities [1]. Since the CFD code is not typically designed to specialize in importing and meshing geometry, a dedicated pre-processor code for these tasks is highly desirable. Because many lamps are designed using Unigraphics [2] and Pro/ENGINEER [3] the pre-processor must have a strong interface with these computer aided design (CAD) programs and to be able to import the math data geometry in a highly reliable and clean manner. Powerful three dimensional (3D) mesh generation capability is also required due to the complex parabolic shape of the lamp reflector and the need to model details such as the bulb, shield, lens and lamp internal air volume -- as well as other internal lamp features as required. Because of the difficulties involved in creating a structured "brick" mesh for the lamp geometry, an unstructured mesh is used with 4 node tetrahedral elements to represent the 3D regions of the model. Another reason for using an unstructured mesh is the improved performance of the Adina-F code under rapid flow conditions with the tetrahedral elements. Using an unstructured mesh requires much less time for geometry preparation and meshing, so that design alternatives can be analyzed faster with more emphasis on evaluating results and making recommendations to the designer. In addition to the advanced geometry importation and meshing capability available in the pre-processor, the ability to analyze results using the post-processor is also desirable. MSC/PATRAN [4] was used due to its CAD and CFD analysis software interface and due to the pre- and post-processing requirements of the lamp thermal analysis program.

The following sections describe the lamp thermal analysis process in detail. Section 2 discusses the importation of geometry into the MSC/PATRAN database and the meshing technique. A triangular surface mesh is applied to the surfaces from which the 3D tetrahedral mesh is generated to represent the lamp air volume and solid wall. Separate lamp components such as bulbs are imported from an existing database file using the database import feature. Finally, loads and boundary conditions are applied, and the model is translated into an Adina-F analysis input file.

Section 3 presents the results of a thermal analysis of a production headlamp using the MSC/PATRAN post-processor. The predicted lamp temperatures are compared with measurements obtained using an infrared thermal imaging camera.

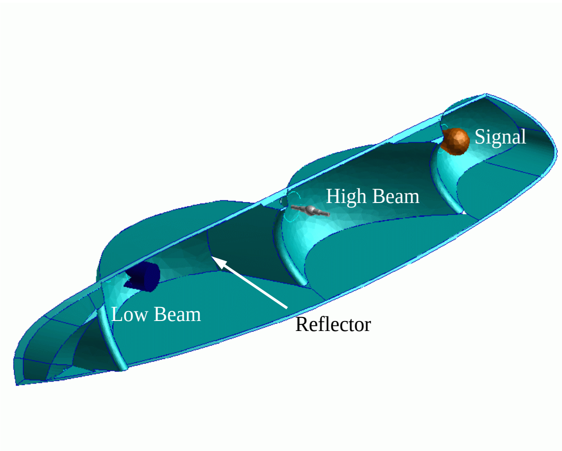


Figure 1. Headlamp Geometry for FEA Model

Section 4 demonstrates the successful benchmarking of the lamp thermal analysis method using enhancements in MSC/PATRAN.

2. PROBLEM DEFINITION

As the automotive industry looks to build sleeker and more attractive cars, automotive engineers are faced with larger and more complex problems to solve. A trend in automotive styling is to update the exterior lighting components on a car line in the years between major body styling updates. The updated design is typically more complex than the original. Given this design complexity, the analyst must determine the level of detail to be incorporated into the finite element model.

A typical automotive headlamp consists of a lens adhesively bonded to a reflector, one or more bulbs, and a bulb shield (see Fig. 1). The lens and reflector are generally made of plastic or composite materials. Bulb shields are stamped metal, and the bulbs are gas-filled glass envelopes. Depending on the complexity, lamps may include inner lens, bezels, internal moveable reflectors, etc.

· **Math Data Preparation**

Initially the analyst simplifies the geometry for meshing. When performing a thermal analysis, features that are unnecessary or irrelevant to temperature profiles are discarded (e.g., vent holes, screw bosses, attachment mechanisms, lock towers, etc.). Once these features are removed, the major task of mating the lens and housing surfaces is addressed (see Fig. 2). The inherent problem is that the data is designed with a gap between the housing and lens to account for the adhesive; however, for meshing purposes enclosed volumes must be created to represent the inside and outside surfaces of the lamp. Therefore, the inner surfaces of the housing are matched with the inner surfaces of the lens. The same methodology

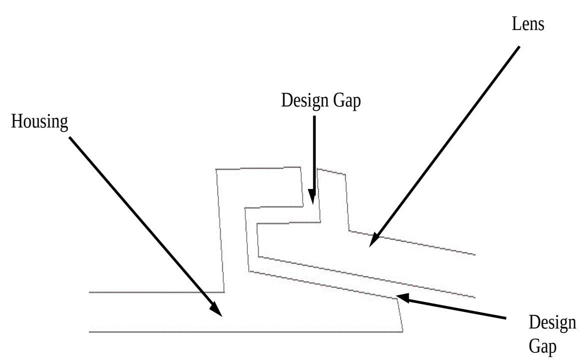
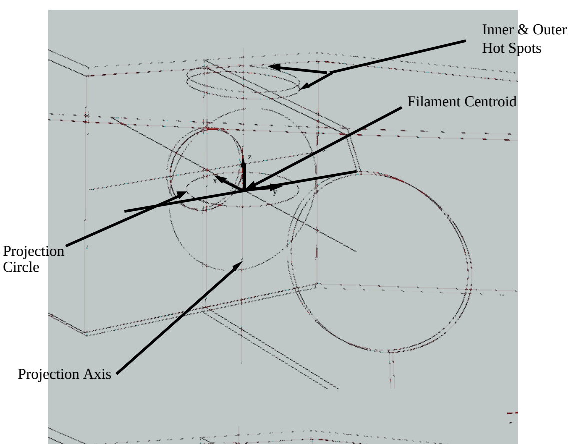


Figure 2. Lens and Housing Seal Channel

applies to the lamp's outer surfaces as well (see Fig. 3).

The next task is to break out sections that represent probable high temperature regions (hot spots). These are typically the areas directly above (+z) and in front (-x) of the bulbs. The hot spot of the housing is defined by generating a circle in xy-plane with its center at the filament centroid and then projecting the circle in the +z direction to the inner and outer surfaces of the housing. The hot spot of the lens is defined by generating a circle in yz-plane with its center at the filament centroid and then projecting the circle in the -x direction to the inner and outer surfaces of the lens. Figures 4 and 5 show examples of the housing and lens respectively. Lens and housing surfaces are broken or recreated around this projected circle to allow for a fine mesh in the hot spot locations. The data is then separated into groups prior to importing the geometry into MSC/PATRAN.



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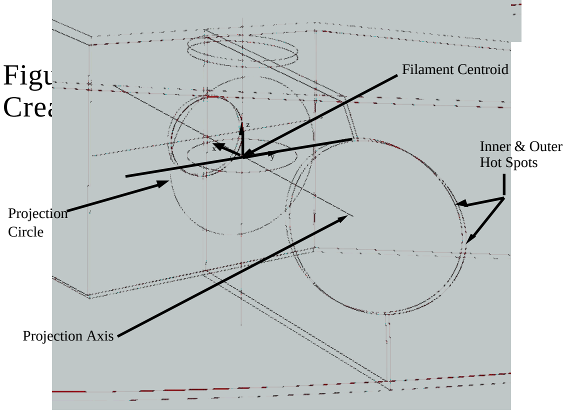

Figure 5. Lens Hot Spot Geometry Creation

The method used to import the data into MSC/PATRAN depends upon the CAD system of origin. Due to issues with solid modeling, math data created in Pro/ENGINEER is exported in an IGES[6] format then imported into MSC/PATRAN using the IGES translator. However, Unigraphics data is brought directly into MSC/PATRAN.

After the CAD data has been imported, an Edit/Surface/EdgeMatch is performed on the geometry in order to prepare the surfaces for meshing.

· **Meshing**

The geometric surfaces including the high and low beam bulbs, bulb shield, reflector, and lens are meshed using triangular elements in preparation for generating solid tetrahedral elements for the lamp inner air volume. A fine mesh is first applied to regions where high temperature gradients are expected. Then a relatively coarse mesh is applied to the remaining surfaces using smooth transitioning from smaller to larger elements. Typically, an element edge length of 2 mm is

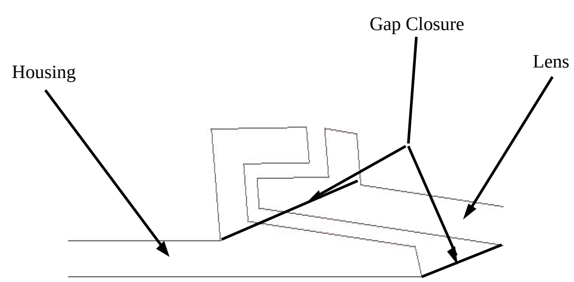

Figure 3. Matching Lens and Housing Inner and Outer Surfaces

used in the hot spots and lengths of 7 to 15 mm are used for the remaining portions of the ... ature predi...

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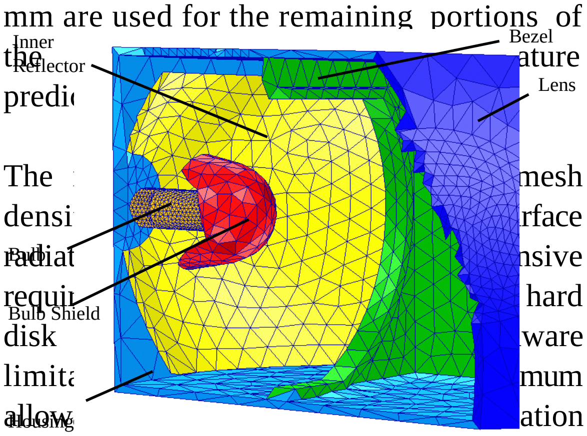

Figure 6. Solid Mesh Showing Components of Complex Headlamp System in Low Beam Cavity

The next step involves equivalencing all nodes. Because the outer lamp shell must be completely enclose the lamp air volume, all nodes must be equivalenced and any gaps closed. This process is repeated for all surface meshes in the model, both inner and outer. After all surfaces have been meshed the element normals are oriented in the outward direction from the volume to meshed.

MSC/PATRAN's Hybrid mesher is used to generate the tetrahedral mesh while the State Machine mesher is used for diagnostic work. The lamp 3D air volume mesh poses the most difficult meshing problem due to the number of entities inside the enclosed air volume (e.g., bulbs, bulb shield, reflectors, etc.). Figure 6 is a cutaway section through the low beam cavity which shows the reflector, bulb, and bulb shield.

The State Machine, MSC/PATRAN r1.4 algorithm, has diagnostics for determining the causes of mesh failure such as self intersections, problems with element normals, or duplicate elements. Several attempts are often required to resolve the surface element problems before the volume can be successfully meshed. The new Hybrid tetrahedral mesher, available with MSC/PATRAN version 7.5, is used to create the solid tetrahedral mesh representing air inside the lamp. Figure 7 is a cross-section of a simple headlamp to be analyzed showing the air volume mesh in the low beam cavity with a 2 mm global element edge length for the high beam bulb and a 7 mm edge length for the lamp air volume.

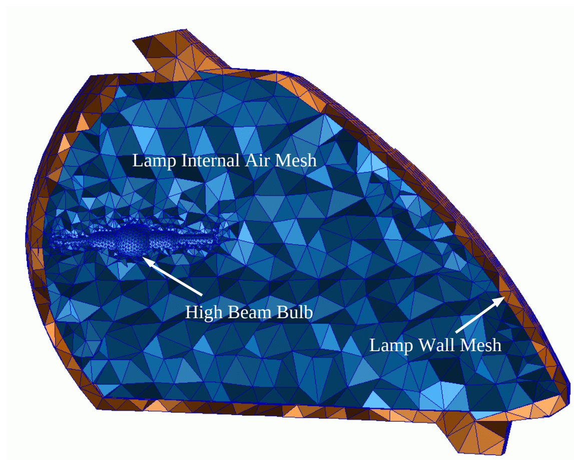

Figure 7. Lamp Air Volume Solid Mesh Showing Section Through Low Beam Cavity

The hybrid mesher produces a smooth element transition from the fine 2 mm bulb elements to the larger 7 to 15 mm lamp surface elements. Smooth transitioning and high quality tetrahedral elements are extremely important for CFD analysis.

- **Material Properties**

Material properties are assigned to all 3D element groups. A viscous incompressible flow model with temperature dependent properties is assigned to the air element group while thermal conductivities are assigned to the lamp wall, lens, and shield groups.

- **Loads & Boundary Conditions**

As in any problem involving heat transfer, many loads and boundary conditions must be specified, including:

- Temperature Dependent Air Properties - Density, Viscosity, Thermal Conductivity
- Solid Lamp Wall Conductivity
- Bulb and Lamp Outer Surface Emissivity
- Aluminized Surface Reflectivity
- Lens Transmissivity
- Boundary Convection and Radiation to Environment
- Fixed Velocity and Initial Temperature
- Bulb Heat Loads

3.0 ANALYSIS RESULTS

In order to test the accuracy of the lamp thermal model, an actual headlamp design was selected and modeled. The purpose of the analysis was to verify the accuracy of the lamp thermal model temperature predictions by comparing them to actual test data. The first step in the analysis process

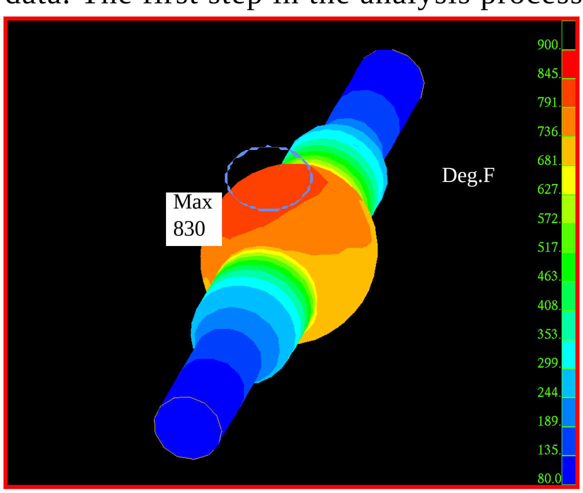

Figure 8. Predicted Bulb Temperature

was to run a thermal analysis of the bulb to verify the accuracy of the bulb model. The results for the predicted and measured high beam bulb temperatures are shown in Figure 8 and Figure 9 respectively. The predicted temperature was 830°F while the thermal camera temperature measurement was 777°F. Successfully correlating the bulb thermal model was a very important step in accurately modeling the headlamp temperature.

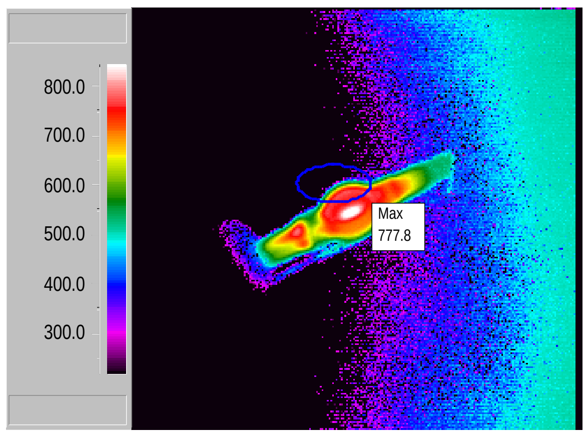

Figure 9. Bulb Temperature Measurement

Next, a thermal model of the full headlamp was run. The headlamp thermal analysis temperature prediction is shown below in Figure 10. The maximum predicted lens outer surface temperature of 198°F for the high beam compartment showed outstanding agreement with the thermal camera temperature measurement of 195°F (see Fig. 11).

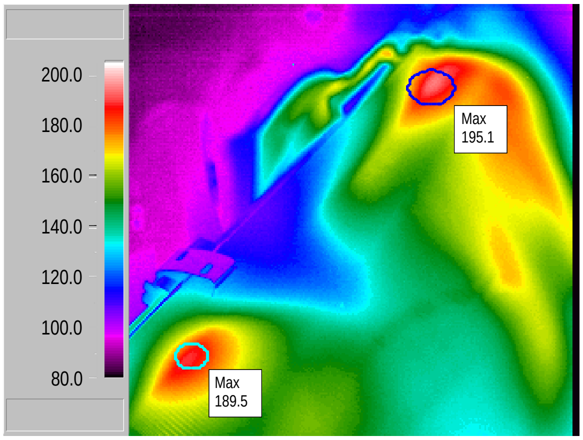

Figure 11. Measured Lens Temperature

The temperature distribution also exhibits nearly complete agreement with the thermal camera image (compare Figures 10 and 11). The predicted maximum temperature of 175°F for the signal compartment was slightly below the measured value of 189°F. The lamp internal air flow pattern is shown in Figure 12 exhibiting the phenomenon of a counter rotating vortex with high velocity air above the bulb and a relatively stagnant layer of air below.

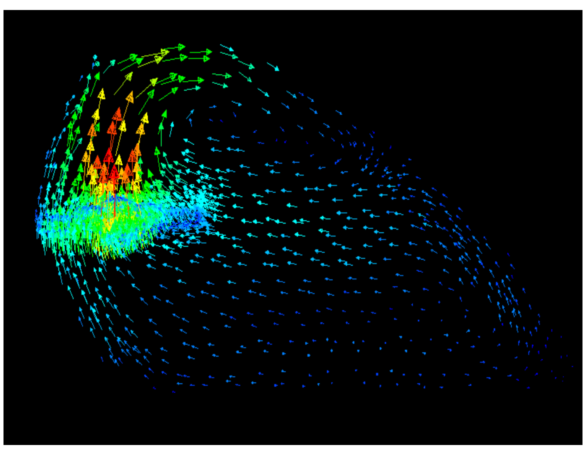

Figure 12. Lamp Internal Air Velocity

4.0 DISCUSSION

A comparison between the predicted and measured temperatures is summarized in

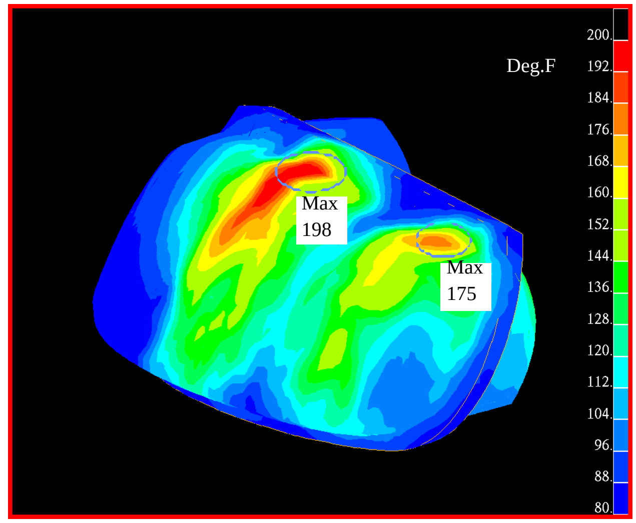

Figure 10. Predicted Lens Temperature

Table 1 which shows a very satisfactory correlation.

Table 1

Location	Predicted (°F)	Measured (°F)
Bulb	830	777
High Beam Lens	198	195
Signal Lens	175	189

The high accuracy of the lamp temperature predictions indicates that the mesh refinement was sufficient to accurately capture the primary effects of radiation and natural convection. Using high quality elements improved the stability and convergence of the analysis as well as the accuracy.

In the surface radiation model, very large amounts of memory were required to obtain a solution. The memory requirements increased as the square of the number of surface radiation elements and could have easily exceeded the available computer memory. Therefore, in order to reduce the number of surface radiation elements and reduce the required memory, a somewhat coarse global element edge length was used in low temperature gradient regions while a finer element edge length was used in regions where high thermal and velocity gradients exist.

Advances in the MSC/PATRAN hybrid mesher capability have reduced the time required to generate large, complex 3D meshes. Using an HPJ210 workstation with 512 Mbytes of RAM, the tetrahedral mesher generated 200,000 elements in less than fifteen minutes which is an improvement over the hybrid mesher performance in previous versions.

5.0 CONCLUSIONS

The results of the headlamp thermal analysis have demonstrated that complex geometries with coupled fluid flow and surface radiation can be accurately modeled using state of the art CFD codes and pre-processing software with powerful meshing capability. Using MSC/PATRAN with the Adina-F analysis preference provides the necessary flexibility in meshing, in applying loads and boundary conditions, and in analyzing the results. The ability to import lamp design geometry from Unigraphics and other standard CAD formats and to create high quality triangular surface and 3D tetrahedral meshes makes MSC/PATRAN an acceptable tool for pre-processing. These meshing capabilities result in a significant reduction in the analysis cycle time. Enhancements to MSC/PATRAN, such as importing one database into another database while not losing material properties and loads and boundary conditions, have also resulted in time savings. Now, less effort is spent in meshing and building the model, and more time is available for evaluating new conceptual designs and solving existing design problems.

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