ICCA AUTOMESH TASK 3.1

Mesh Generation Developments and Results at SCOREC, RPI

Rao Garimella, Mark S. Shephard

Scientific Computation Research Center,

Rensselaer Polytechnic Institute, Troy, NY 12180

I. Introduction

The Investment Casting Cooperative Arrangement (ICCA) was established to develop technologies for better understanding and controlling the design and manufacture of structural and airfoil parts by the investment casting process. An important component in the technologies for computer simulation of the casting process is the automatic generation of finite element meshes for arbitrarily complex domains. This document gives an executive summary of the automatic mesh generation efforts of the Scientific Computation Research Center in the ICCA project as part of the Task 3.1 Automesh team.

A summary list of deliverables to the project from RPI is given below:

1. Finite Octree automatic mesh generator interfaced to Parasolid (stand-alone executable)
2. Non-manifold modeling for Parasolid assemblies (as part of Finite Octree executable)
3. Program to generate multiple elements through the thickness (v1.0 to be released shortly)
4. Meshes of ICCA models to PCC Airfoils, Howmet Corp., Pratt & Whitney and GE Aircraft Engines
5. Technical documents and user manuals for Finite Octree
6. Improvements to Finite Octree including small feature removal, large dihedral angle optimization.
7. Direct help to PCC, Howmet, Pratt & Whitney and GE on automeshing
8. Program to minimize tolerances on model entities while maintaining model validity
9. Shell scripts for file transfer functions

The following is a list of supporting documents from RPI included in the final report

1. Finite Octree mesh generation guidelines and final results for ICCA models
2. Specification of mesh control functions in Finite Octree
3. Finite Octree mesh generation and output options
4. Support of non-manifold modeling using 2-manifold modelers
5. Tetrahedral mesh generation with multiple elements through the thickness
6. SCOREC mesh database operators

II. Mesh generation results summary for ICCA models

To date, 52 valid solid models were received as part of ICCA and all 52 models were meshed by Finite Octree. The teams started with models which were simplified representations of the real parts to be manufactured and as the different pieces of software were improved and enhanced, the models were made more and more complex until the latest set of models were the structural and airfoil verification parts with the gating attached. Finite Octree was used in multiple ways during the course of the project, on site as a stand alone executable, from within other commercial software and at SCOREC utilizing the latest developments to the software. A large number of enhancements were made to the mesh generator during the course of the project the most significant being a substantial improvement in the quality of meshes generated. In addition, many new functionalities were added and the overall robustness of the mesh generator improved.

Given below is a list of the models meshed by Finite Octree

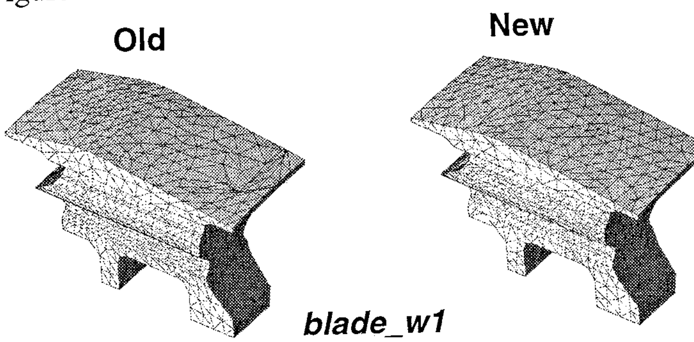
Number of valid parts	52
Number of these parts with model/modeler problem	5
Number of parts meshed	52

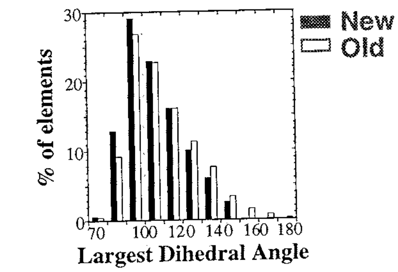
SATISFACTORIFY MESHED			
af_val_pw af_gating 11219sprue test8_blocked final_r1 1fv102 1fv1027688 airfoil 1873_g1 hcnew0595 hc0695 chicklet	laportwheel ncrsr_g1f1 ncrsr_w1n1 fuel bracket block test9 block_h1n1 blade_w1 11265sprue gate3	blade_w1r1 full_solid_c1 seal_r1 test8_blended vane_h1n1 ncrsr_g1n1 v10-pw-rsr1f ncrsr_w1f1 lpbld/1386m42_g1 chopsolid_c1 str_gating_sect1	afcore_h1n1 (howmet_h1) PW_ncsr2a1(ncrsr_w1n1_h1) sblade_h1n1 (airfoil) gegennozzle_hollow 204sprue_d1 gegenblade2 gegennozzle_g1 gegennozzle_blended 9529m89p13_ar_ver10_2 t4cast_r2 segment_h1

MESH IMPROVEMENT DESIRED			
pw22095 pw22095wg	50j780_105seg 55_5seg	so373a 50j780_120seg2	so373_h1 (so373a+so373a_core)

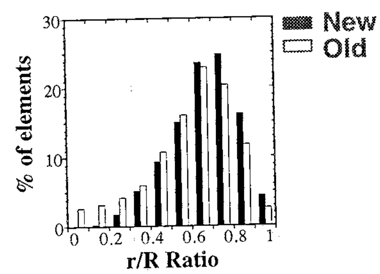
MODEL/MODELLER PROBLEM	
50j780_120seg2	Modeler missed intersection - meshed without augmentation
struct/final_c1	Defective face - meshed fixed version of model (final_r1)
seal	Unfixed blend caused missed intersection - meshed fixed model seal_r1
55h705v102	Invalid geometry
hcnew0595	Modeler returns wrong bounding box for edge - meshed

The examples below illustrate the magnitude of improvements in mesh quality obtained due to new functionality introduced into the mesh generator. From the mesh statistics for the example blade_w1 (Figure 1), improvement can be seen in all the quality measures. Most importantly, the largest dihedral angle decreased from 177 degrees to 145 degrees. Furthermore, the histograms of large dihedral angles and ratio of inscribed radius to circumscribed radius show a shift towards the optimal value. This trend can be seen in the histograms for other ICCA models shown in the figure. Shown below in Figure 2 is the mesh for an ICCA model with gating attached and shown in Figure 3 are meshes of ICCA models test9 and 1fv102.





	OLD	NEW
Max dihedral angle	177	145
Min dihedral angle	2	8
Min r/R ratio	0.0001	0.07
Max aspect ratio	308	12



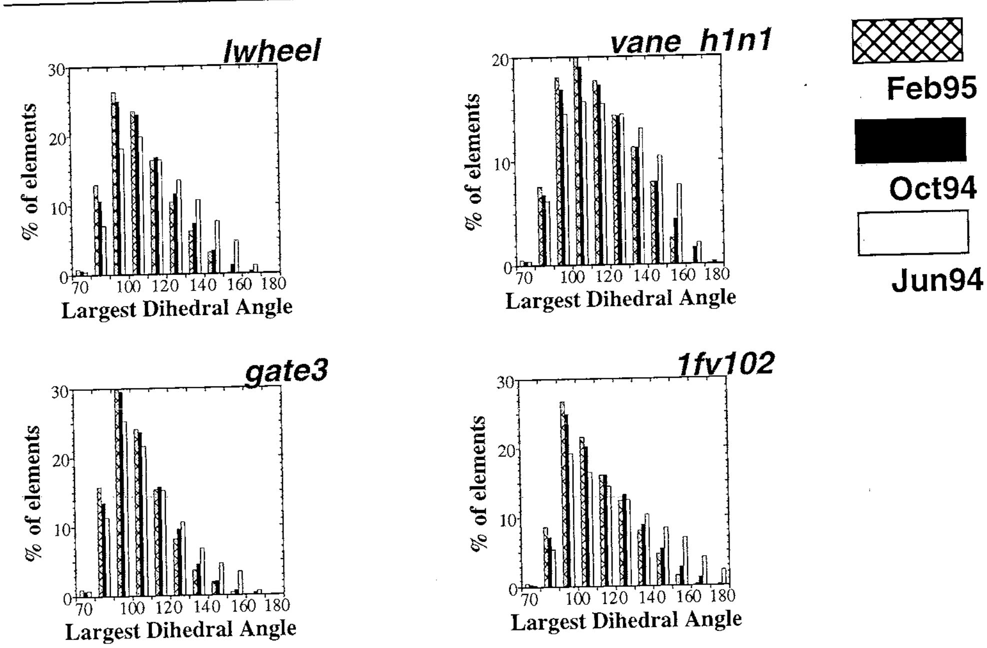


Figure 1 Improvements to large dihedral angles in meshes generated by Finite Octree from June '94 to February '95

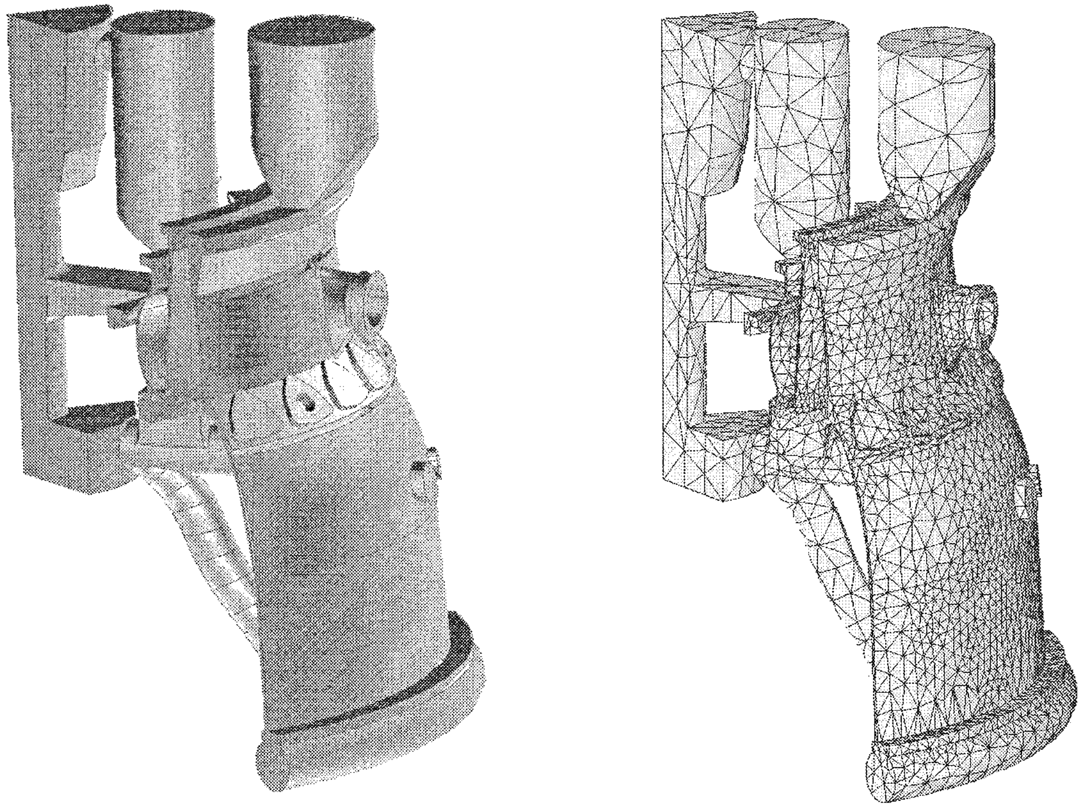


Figure 2 ICCA model final_r1 and mesh generated by Finite Octree

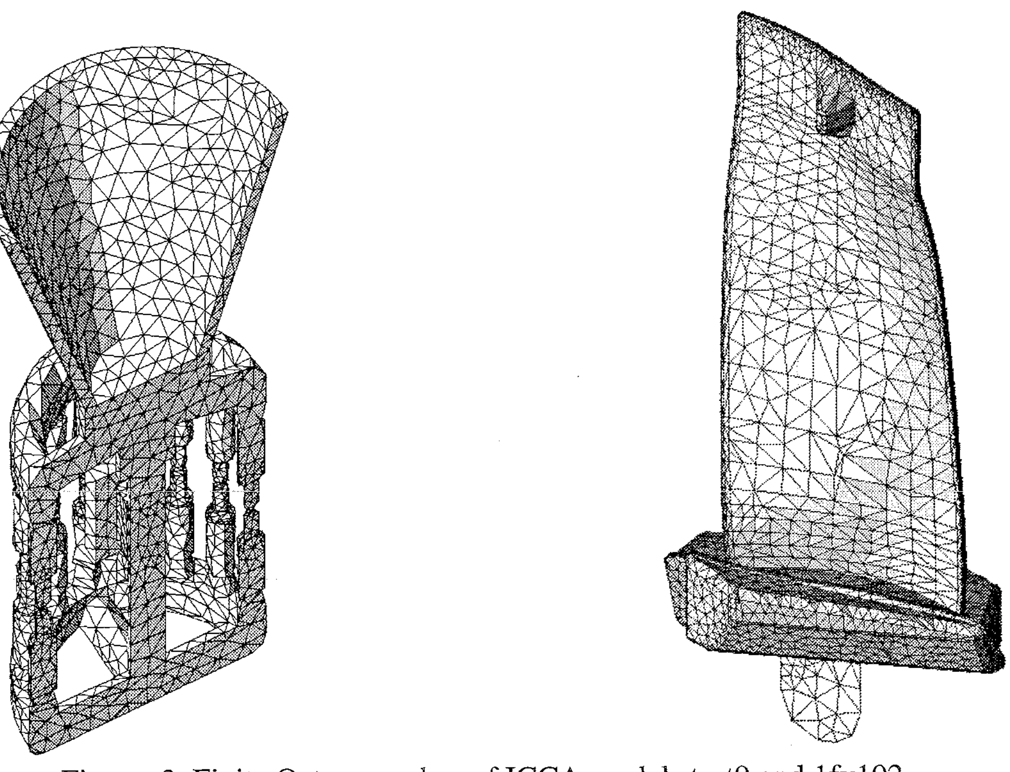


Figure 3 Finite Octree meshes of ICCA models test9 and 1fv102

III. ICCA model meshing and evaluation procedure

The typical procedure followed for meshing ICCA models was for a member of the Automesh Task to mesh the model on site either using Finite Octree in Unigraphics GFEM+ from EDS (or P3 from MSC/PDA) or using the stand-alone version of Finite Octree. If the model could not be meshed by one of these versions of Finite Octree or the mesh was unacceptable, the part was referred to SCOREC. On receiving a model from an ICCA group member, mesh generation for the part was tried at SCOREC using the latest version of Finite Octree. If the part meshed, then the reason for it not meshing in the other versions was established and communicated to the teams. The mesh quality was then examined and if it was not good enough, the reasons for this behavior carefully researched with the help of SCOREC's mesh visualization tools. Often this examination revealed features of the model which were not evident from a general inspection of the model (small features, thin sections etc.) and indicated the appropriate mesh controls to be applied. If no such features were evident, the code was debugged carefully to check for any deficiencies in the procedures to improve mesh quality. Any such shortcoming found was communicated to the appropriate developer to be fixed. The part was then meshed again to get a mesh of good quality.

If the part did not mesh for any reason, the mesh generation process was debugged to determine the cause. For some examples this led to discovery of missed curve-plane and line-surface intersections by the modeler among others. The specific entities for which the problem occurred was isolated and sent to Shape Data Ltd. for debugging. Isolation of the particular problem entities, which often required several days for a single model, served the dual purpose of maintaining confidentiality of proprietary models as well as expediting the debugging of the isolated geometric modeling problem.

In the case of some other models, much of the debugging of the modeling/modeler problem was done at SCOREC itself, employing a lisp based interface to Parasolid called Kernel Interface Driver. Such problems included unfixed blends, invalidity and self intersecting surfaces, exceptionally high tolerances on others, modeler problem in loading, mismatch of overlapping entity geometries, etc. Whenever possible, the part was mended or modified to verify that it meshed if the problem entities were eliminated. This included replacing face geometry, collapsing out faces, replacing edge geometry, changing entity tolerance to make the model valid, etc. If the modified model meshed and the modification was not going to have any impact on the analysis, it was sent to the appropriate team member. In cases of modeler problems, this provided a highly valuable interim solution before the next release of Parasolid was available.

On the other hand, if a deficiency was found in the mesh generation algorithms, the problem was fixed by Finite Octree developers and the part remeshed.

At the end of this process, the final mesh and if necessary, a modified model and an updated Finite Octree executable was sent to the appropriate team member. The specific aspects of meshing the model were communicated and also discussed at each ICCA meeting.

IV. Modeling issues

The generation of meshes for the various model raised a number of modeling issues. Among them the most important was the creation of extremely small features in the model unknown to the modeling groups. Often the features in the model were 2 to 6orders of magnitude smaller than the model size and occasionally would be very close to modeler tolerance (See Figure 2). One of

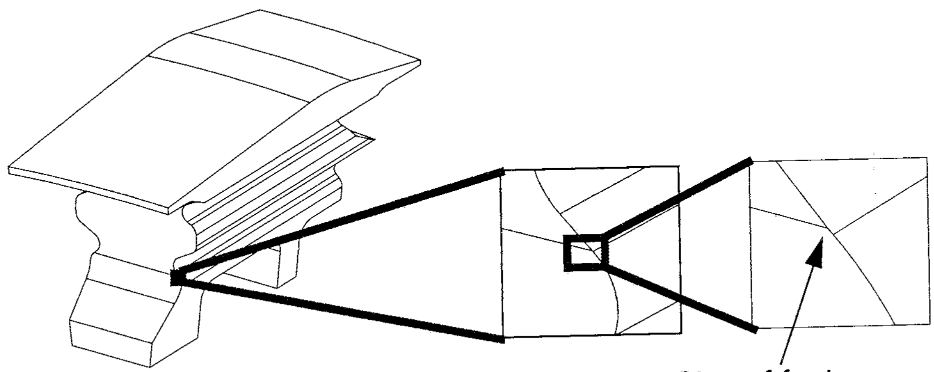


Figure 4 View of blade_w1 and the location of one of the small features in the model

the common manifestations of this problem is the presence of sliver faces in the model. Invisibility of the features on a fully displayed model made it necessary to detect these features by generating an initial mesh without advanced mesh controls and investigating parts of the model in which the mesh had poorly shaped elements, a fairly time consuming process. Although the cause for the creation of these features could not be nailed down to any particular modeling practice or software feature, the frequency with which these features occurred prompted the development of methods to automatically deal with them. Within Finite Octree the resulting procedures automatically eliminate the influence of small features without the user having to perform time consuming model editing.

Another important modeling issue was missed intersections by the modeler. In Finite Octree a missed or incorrect intersection often manifests itself as problem later in the meshing process. Whenever a missed or wrong intersection or any other modeler problem was detected, efforts were made to isolate the problem down to the specific model entities. This data was then conveyed to Shape Data allowing them to quickly address the issue and fix it in later releases of Parasolid. Every effort was made to get new releases of Parasolid as quickly as possible, so that the parts could at least be meshed at RPI allowing the teams to proceed with the following tasks.

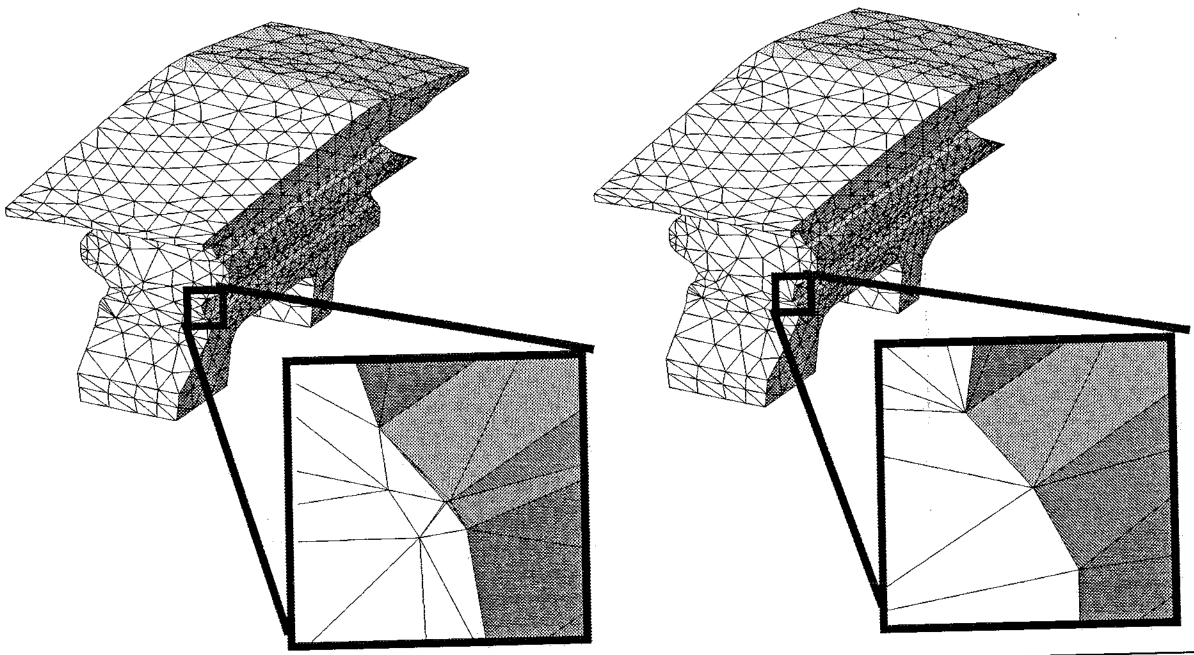
Other modeling issues and problems such as high tolerances for entities in the model, self-intersection of surfaces and validity of blends were identified during the course of the project. Solutions were devised for many these problems (such as a program to reduce tolerances on model entities iteratively while maintaining the validity of the model) while other issues were referred to Shape Data or the modeling teams (such as fixing of blends in models).

V. Mesh generation issues and developments

Many major enhancements were made to Finite Octree over the course of the project, some of the more important ones being:

1. Procedures to eliminate the representation of small model features in the mesh

   This capability was developed to deal with the presence of extremely small features in the model which caused over refinement of the mesh or elements with poor aspect ratio if the refinement was capped. Normally Finite Octree maintains strict geometric and topological compatibility of the mesh with the model. If the small feature removal option is on, it locally violates this compatibility and removes elements which represent the small features of the model. The procedure ensures that this local modification does not yield a nonphysical situation such as a hinge line. The categorization of an element as representing a small model feature is user controlled. Shown below in Figure 3 is the effect of small feature removal on mesh quality for ICCA model blade_w1 shown in Figure 2.

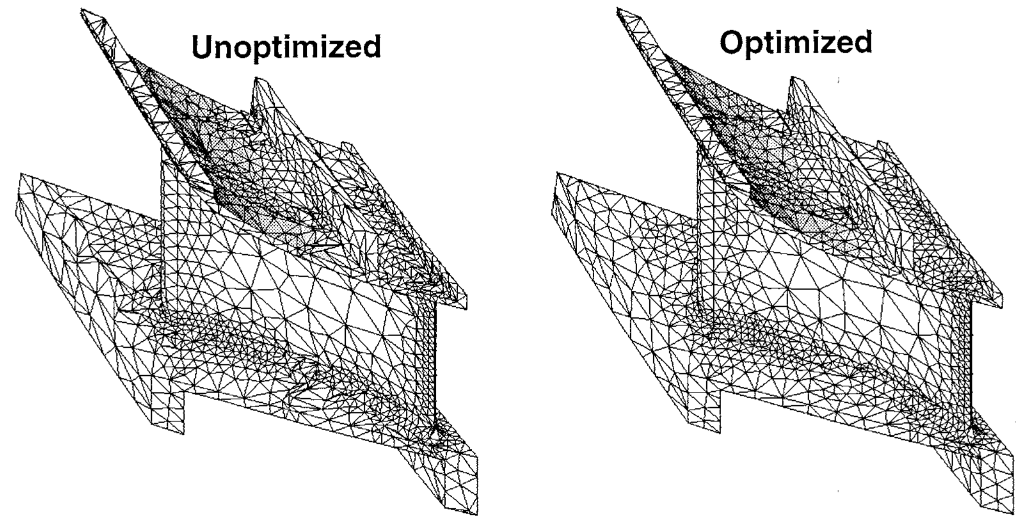


Mesh quality measure	Without small feature removal	With small feature removal
Min r/R measure	0.00009	0.02
Largest aspect ratio	128	23

Figure 5 Improvement in mesh quality by automatic elimination of small features

2. Procedures to improve large dihedral angles and thereby, overall quality of the mesh

Improvement of the overall quality of Finite Octree meshes was given in-depth consideration and large dihedral angles were identified as the most important quality measure to improve. A capability to explicitly improve the large dihedral angles of elements was introduced into Finite Octree. The large dihedral angle improvement procedures use local mesh modification tools (edge splitting, edge swapping, edge collapsing and face swapping) to optimize the mesh. Use of this capability has led to substantial improvements to the quality of meshes generated by Finite Octree. Shown in Figure 4 is a comparison of the meshes obtained with and without dihedral angle improvement.



	Initial	Optimized
Min dihedral angle	0.02	6
Max dihedral angle	179.96	151
Min r/R ratio	3e-7	0.06
Largest edge/shortest height	12825	17

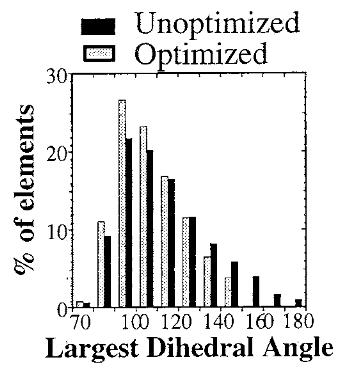


Figure 6 Effect of dihedral angle optimization on mesh quality

3. Capability to handle multi-material Parasolid models

The ability to build non-manifold models from Parasolid assemblies was introduced to meet the need for meshing multi-material Parasolid models such as structural and airfoil parts with gating attached. Multi-material models are a subset of non-manifold models. Non-manifold objects may have surfaces touching at a single point or an edge, have internal faces and be general combinations of wires, surfaces and solids.

Given a non-manifold representation, Finite Octree can mesh multi-material models. At the start of the project Parasolid only supported 2-manifold models. However, it did support modeling of individual geometric entities of non-manifold models. Therefore, procedures were developed to create a non-manifold representation using a manifold modeler (Parasolid) so that the resulting model could be meshed by Finite Octree.

The procedures developed have the capability to preprocess a Parasolid assembly of objects representing the material regions of the model and create the non-manifold representation required by Finite Octree. The various overlapping (or coincident) entities among the components are automatically identified. If matching entities do not exist at interacting boundaries of the components, they are added with the help of the modeler.

Figure 5 shows the mesh for a non-manifold ICCA model automatically built from a Parasolid assembly and then meshed by Finite Octree.

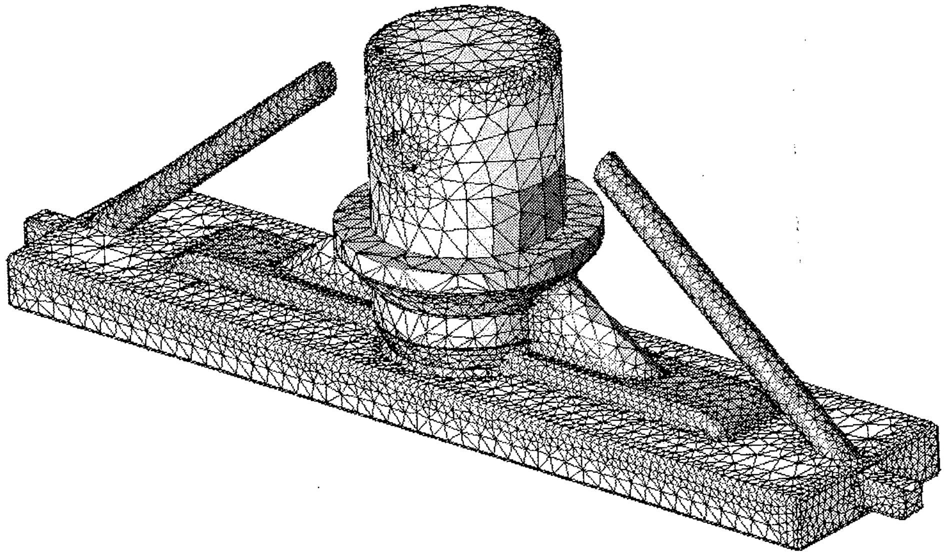


Figure 7 Mesh of non-manifold ICCA model generated by Finite Octree

4. Procedures to use local retriangulation to allow for curving of elements

   If higher order nodes on mesh edges are requested, Finite Octree tries to pull these nodes to the boundary to improve geometric approximation of the model by the mesh. Pulling a node to the boundary may make the element unacceptably distorted or cause penetration into other elements in the local neighborhood by the curved entities. Techniques were developed to detect the cause of such a situation and to modify the surrounding mesh so that the edge may be curved in most situations.

5. More robust and efficient octant level loop building procedures

   Octant level loop building procedures were modified to minimize the use of face normal information thereby resulting in increased robustness and speed.

6. Implementation of templates for interior octant meshing

   Templates were introduced for tetrahedronizing octants which are completely interior to the model and therefore, can have only a fixed number of configurations. The tetrahedronization of these different configurations is pre-evaluated and coded thereby making the process of interior octant meshing very fast and efficient.

7. Procedures to deal with subset of near tangency situations

   When two different model entities are geometrically closer than the tolerance used to tell two points apart, then a near tangency situation exists. Special techniques are required to discretize such portions of a model. The capability to deal with some of these situations was added to Finite Octree.

8. Procedures to optimize number of connections at mesh vertices

   These procedures attempt to improve mesh quality by optimizing the number of elements connected to each mesh vertex.

9. Enhancements to deal with tolerant models

   Parasolid models in which the tolerance varies from entity to entity are called tolerant models. Finite Octree's procedures were modified to allow for such situations.

10. Capability to specify non-cubical universe allowing creation of stretched elements

   Normally Finite Octree builds a discretization of the model starting from a cubical bounding box of the model (referred to as the universe). Building the discretization using a non-cubical universe results in elements which are stretched along the long direction(s) of the universe.

11. Speed improvements (40% decrease in meshing time)

   Faster computation of quality measures (e.g., dihedral angles), storing of surface parameter values, storing of large dihedral angle values, improvement in point containment checks etc. were some of changes made to Finite Octree to cut mesh generation times by an average of 40% (i.e. current meshing time is 60% of the old meshing time) during the second year of the project alone.

VI. Generation of multiple elements through the thickness

Most ICCA models are domains with thin sections and strong gradients through the thickness Therefore, their analysis requires meshes with multiple elements through the thickness. Isotropic refinement of meshes to obtain such meshes results in a large increase in the number of elements and consequently, considerably higher computational cost. An alternative solution was implemented by developing the capability to anisotropically refine the mesh such that multiple elements could be introduced through the thickness with the resulting elements stretched in directions perpendicular to the thickness direction. This capability can handle domains which are not uniformly thin and produce a user specified number of elements through any thickness.

The procedures developed generates multiple elements through the thickness by modifying the portions of an initial mesh where insufficient elements are present across the thickness. A method for detecting such portions of the mesh was developed based on identifying shortest *paths* (ordered set of mesh edges) in the mesh between mesh vertices classified on locally opposite model faces. The mesh is considered to be locally deficient in the thickness direction if the path has less than the required number of edges.

The algorithm to detect thin sections consists of three steps for each mesh vertex classified on the closure of a model face (see Figure 1). They are:

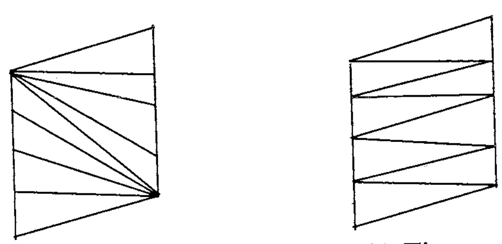
1. *Forward search* from start vertex to find another mesh vertex classified on the closure of the model face on the other side
2. *Boundary search* on opposite model face to find closest vertex to start vertex. This boundary vertex is referred to as the *opposite* vertex

3. *Reverse search* to find shortest path between opposite and start vertices

The computational complexity of finding an opposite vertex for a mesh vertex with respect to a given model face can be shown to be a constant subject to a limit on the number of boundary search iterations.

The creation of the required number of elements through the thickness is done through a series of tetrahedral mesh modification procedures, in particular, edge splitting and edge swapping. The necessary number of edges are added to paths between each pair of opposite vertices by splitting existing edges of the paths. Parts of the mesh affected by edge splitting are further processed utilizing edge swapping to improve alignment of the newly created mesh edges and the connectivity of the mesh.

Swapping of edges to get the required alignment is carried out by abstracting portions of the mesh between opposite faces as wedges that have been tetrahedronized. The lateral faces of such wedges can then be thought of as triangulated quadrilateral faces. The triangulation on a wedge face resulting from edge splitting alone is shown in Figure 3(a) while the desired triangulation is depicted in Figure 3(b). The former triangulation is called a *diagonal* triangulation while the latter a *zigzag* triangulation. The goal of the swapping procedures is to convert a wedge from a diagonal triangulation to zigzag triangulation. This process results in multiple "wedges" through the thickness.



(a) Diagonal (b) Zigzag

Figure 8 Diagonal and zigzag triangulations

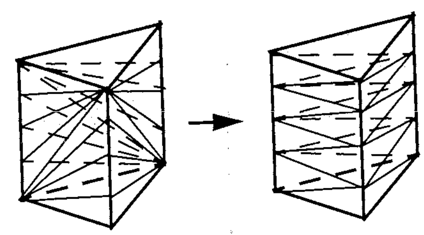


Figure 9 Transformation of a wedge from diagonal to zigzag configuration

The success of the procedures to identify wedge configurations and efficiently convert wedges to the desired form depends on the initial mesh having matching faces through the thickness. Since a mesh obtained from an unstructured mesh generator is not guaranteed to have this topology, preprocessing procedures are necessary to obtain this form. These procedures rely on the edge swapping mesh modification operator.

A post processing step to improve the quality of the mesh is applied after the generation of multiple elements. This procedure is a generalized mesh optimization procedure which relies on local mesh modification to improve large dihedral angles.

A mesh of an ICCA model with multiple elements through the thickness generated using the above procedure is presented in Figure 6. Other ICCA models successfully meshed by this procedure are af_gating, str_gating_sect1, PW_ncsr2a1, bracket, test9. Work is in-progress to eliminate the remaining "diagonal" configurations from the mesh.

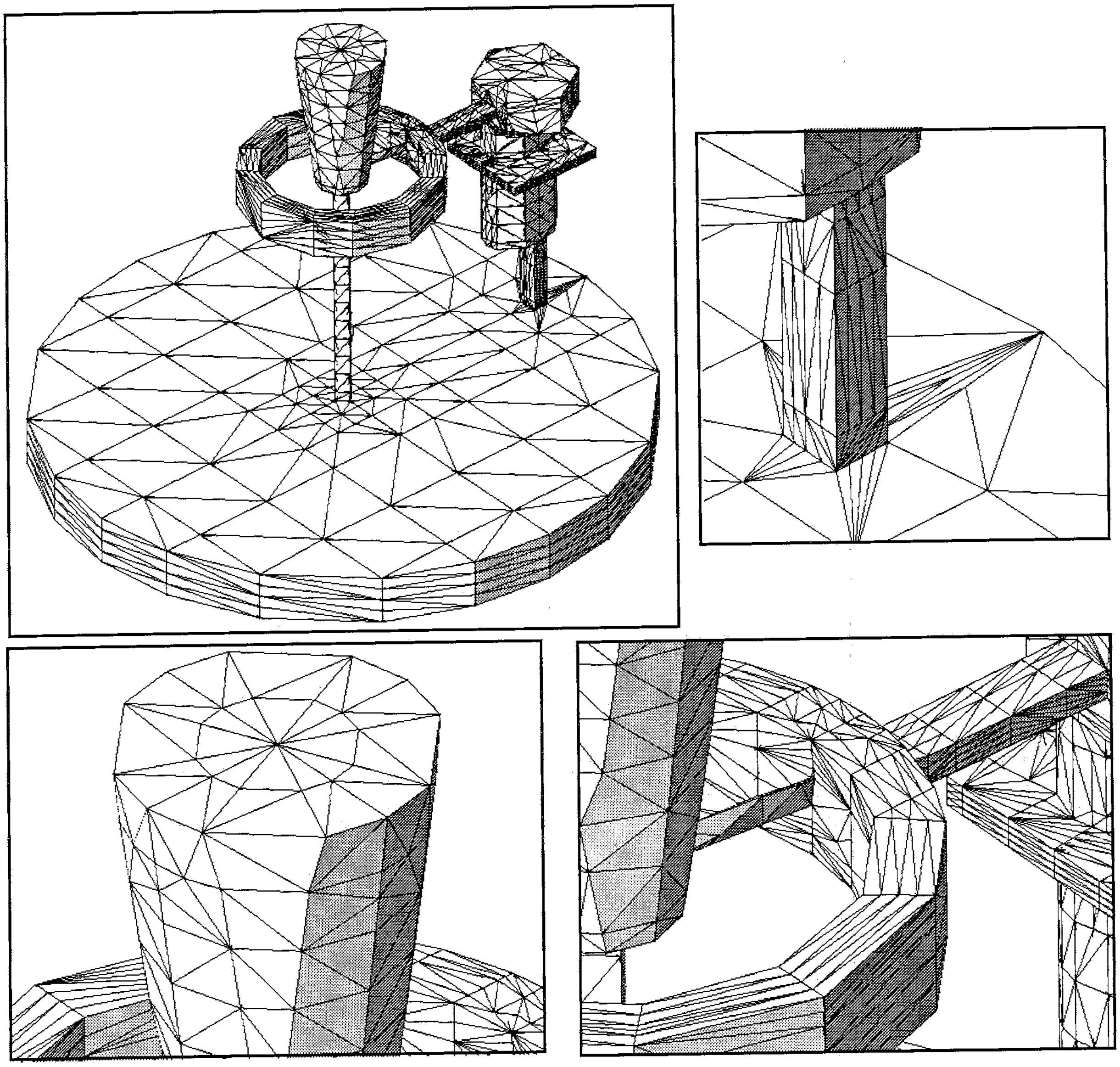


Figure 10 Mesh for ICCA model full_solid with 4 elements through the thickness

VII. Interactions with ICCA teams

The process of meshing models described earlier required coordinating between the various modeling teams, Shape Data, MSC/PDA, EDS and the various researchers at SCOREC. Wide ranging input had to be collected from all these sources, consolidated and utilized to solve the different technical issues. This was also true of the different developments and software enhancements made in this project. In particular, widespread consultation with all the analysts was used in the development of procedures for generation of meshes with multiple elements through the thickness. All means of communication were used for this purpose including mail, e-mail, FAX and telephone. In addition, ftp landing sites were provided for all teams requesting them to facilitate fast and efficient transfer of data to and from SCOREC. Shell scripts were written to allow transfer of large models and executables by fragmenting them at the SCOREC site and rejoining them at the company site.

Apart from investigating meshing and modeling issues, additional support was provided to different team members. Stand alone Finite Octree executables were provided to Howmet Corp, PCC Airfoils Inc. and Pratt & Whitney with the consent of EDS. Updates to Finite Octree (and software documentation) were provided before their appearance in the commercial software products.

Also, technical support for the use of Finite Octree executable and controlling the mesh generation process was provided to all the team members through the duration of the project. This was primarily in the form of Finite Octree documentation and trouble shooting by e-mail or telephone. Modeling help was made available to all teams, with the assistance of Shape Data Ltd., from time to time for modeler problems and difficulties.

Finally, this documentation detailing guidelines for generating good meshes using Finite Octree and various mesh controls used to mesh ICCA models is being provided to all the teams.

VIII. Closing Remarks

A number of meshing related contributions were made by SCOREC to the ICCA project. The most significant of them was a robust, reliable mesh generation capability which meshed all the models in the project.

Many of the models were very complex and required new modeling and mesh generation issues to be addressed. Developments were made to deal with undesirable model features (small features), added modeler capabilities (tolerant modeling) and multi-material models (non-manifold modeling). On the mesh generation side, enhancements were made to improve mesh quality (e.g., dihedral angle improvement, small feature removal, local retriangulation for curving of elements) and reliability of mesh generation (e.g., enhanced octant level loop building procedures, dealing with some near tangency situations). An all new algorithm was developed for the generation of meshes with multiple elements through the thickness. Technical support and documentation was provided to team members throughout the project.

APPENDIX A:

ICCA AUTOMESH TASK 3.1

MESH GENERATION OF ICCA MODELS BY FINITE OCTREE

Rao Garimella and Mark S. Shephard

Scientific Computation Research Center,

Rensselaer Polytechnic Institute,

Troy, NY 12180

September 24, 1995

Table of Contents

Introduction

The Investment Casting Cooperative Arrangement (ICCA) was established to develop technologies for better understanding and controlling the design and manufacture of structural and airfoil parts by the investment casting process. An important component in the technologies for computer simulation of the casting process is the automatic generation of finite element meshes for arbitrarily complex domains. This document contains the results of RPI efforts to generate tetrahedral meshes using SCOREC's automatic mesh generator Finite Octree for examples from various members of the ICCA Automesh team.

To date, 52 valid solid models were received as part of ICCA and all 52 models were meshed by Finite Octree. The teams started with models which were simplified representations of the real parts to be manufactured and as the different pieces of software were improved and enhanced, the models were made more and more complex until the latest set of models were the structural and airfoil verification parts with the gating attached. Finite Octree was used in multiple ways during the course of the project, on site as a stand alone executable, from within other commercial software, and at SCOREC utilizing the latest developments to the software. A large number of developments were made to the mesh generator during the course of the project to enhance its reliability and substantially improve the quality of meshes generated.

Given below is a list of the models meshed by Finite Octree

Number of valid parts	52
Number of these parts with model/modeler problem	5
Number of parts meshed	52

SATISFACTORIFY MESHED			
af_val_pw af_gating 11219sprue test8_blocked final_r1 1fv102 1fv1027688 airfoil 1873_g1 hcnew0595 hc0695 chicklet	laportwheel ncrsr_g1f1 ncrsr_w1n1 fuel bracket block test9 block_h1n1 blade_w1 11265sprue gate3	blade_w1r1 full_solid_c1 seal_r1 test8_blended vane_h1n1 ncrsr_g1n1 v10-pw-rsr1f ncrsr_w1f1 lpbld/1386m42_g1 chopsolid_c1 str_gating_sect1	afcore_h1n1 (howmet_h1) PW_ncsr2a1(ncrsr_w1n1_h1) sblade_h1n1 (airfoil) gegennozzle_hollow 204sprue_d1 gegenblade2 gegennozzle_g1 gegennozzle_blended 9529m89p13_ar_ver10_2 t4cast_r2 segment_h1

MESH IMPROVEMENT DESIRED			
pw22095 pw22095wg	50j780_105seg 55_5seg	so373a 50j780_120seg2	so373_h1 (so373a+so373a_core)

MODEL/MODELLER PROBLEM	
50j780_120seg2	Modeler missed intersection - meshed without augmentation
struct/final_c1	Defective face - meshed fixed version of model (final_r1)
seal	Unfixed blend caused missed intersection - meshed fixed model seal_r1
55h705v102	Invalid geometry
hcnew0595	Modeler returns wrong bounding box for edge - meshed

The examples below illustrate the magnitude of improvements in mesh quality obtained due to new functionality introduced into the mesh generator. From the mesh statistics for the example blade_w1 (Figure 1) improvement can be seen in all the quality measures. Most importantly, the largest dihedral angle decreased from 177 degrees to 145 degrees. Furthermore, the histograms of large dihedral angles and ratio of inscribed radius to circumscribed radius show a shift towards the optimal value. This trend can be seen in the histograms for other ICCA models shown in the figure.

The generation of meshes for the various model raised a number of modeling issues. Among them the most important was the creation of extremely small features in the model unknown to the modeling groups. Often the features in the model were 2 to 6 orders of magnitude smaller than the model size and occasionally would be very close to modeler tolerance (See Figure 2). One of the common manifestations of this problem is the presence of sliver faces in the model. Invisibility of the features on a fully displayed model made it necessary to detect these features by generating an initial mesh without advanced mesh controls and investigating parts of the model in which the mesh had poorly shaped elements, a time consuming process. Although the cause for the creation of these features could not be nailed down to any particular modeling practice or software feature, the frequency with which these features occurred prompted the development of methods to automatically deal with them. Within Finite Octree the resulting procedures automatically eliminate the influence of small features without the user having to perform time consuming model editing.

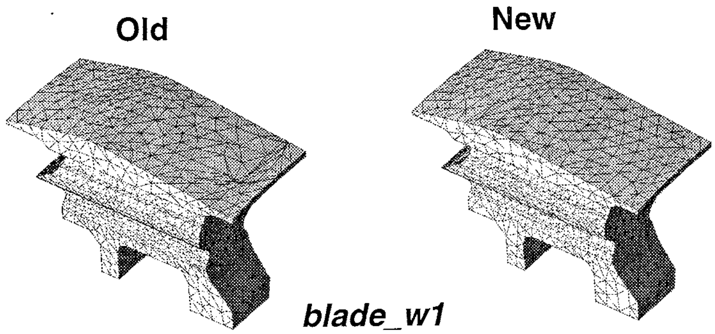
Another important modeling issue was missed intersections by the modeler. In Finite Octree a missed or incorrect intersection often manifests itself as problem later in the meshing process. Whenever a missed or wrong intersection or any other modeler problem was detected, efforts were made to isolate the problem down to the specific model entities. This data was then conveyed to Shape Data allowing them to quickly address the issue and fix it in later releases of Parasolid. Every effort was made to get new releases of Parasolid as quickly as possible, so that the parts could be meshed allowing the teams to proceed with the following tasks.

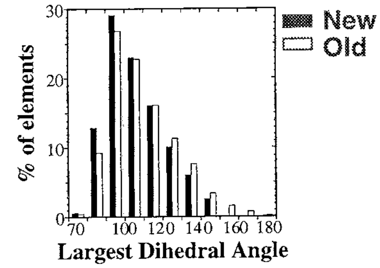
Other modeling issues and problems such as high tolerances for entities in the model, self-intersection of surfaces and validity of blends were identified during the course of the project. Solutions were devised for many these problems (such as a program to reduce tolerances on model entities iteratively while maintaining the validity of the model) while other issues were referred to Shape Data or the modeling teams (such as fixing of blends in models).

Many major enhancements were made to Finite Octree over the course of the project, some of the more important ones being:

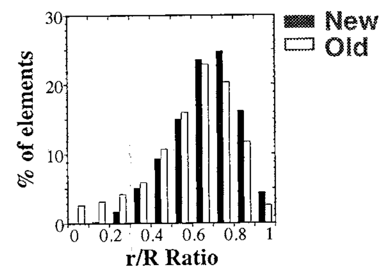
1. Procedures to eliminate the representation of small model features in the mesh

    This capability was developed to deal with the presence of extremely small features





	OLD	NEW
Max dihedral angle	177	145
Min dihedral angle	2	8
Min r/R ratio	0.0001	0.07
Max aspect ratio	308	12



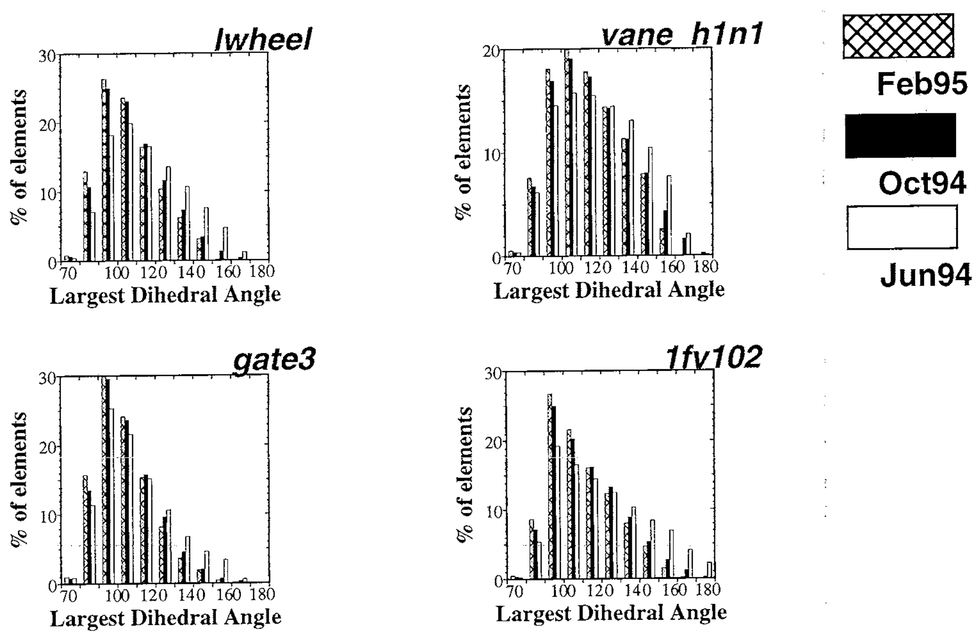


Figure 1 Improvements to large dihedral angles in meshes generated by Finite Octree from June '94 to February '95

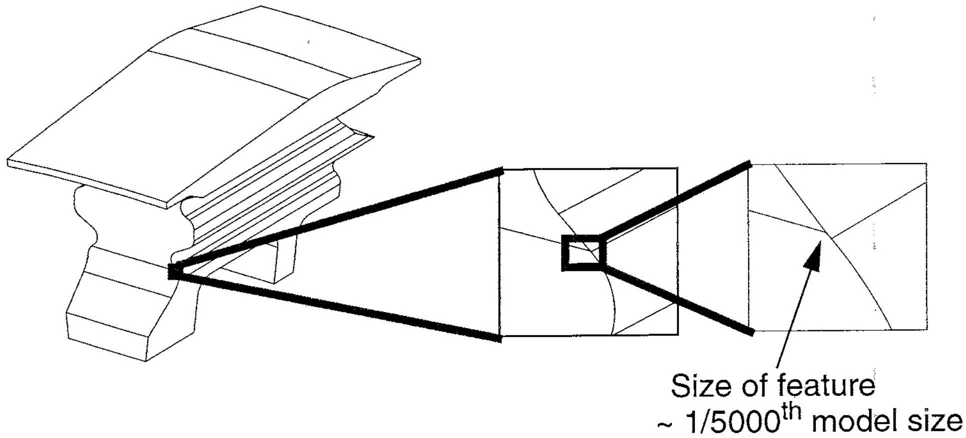


Figure 2 View of blade_w1 and the location of one of the small features in the model

in the model which caused over refinement of the mesh or elements with poor aspect ratio if the refinement was capped. Normally Finite Octree maintains strict geometric and topological compatibility of the mesh with the model. If the small feature removal option is on, it locally violates this compatibility and removes elements which represent the small features of the model. The procedure ensures that this local modification does not yield a nonphysical situation such as a hinge line. The categorization of an element as representing a small model feature is user controlled. Figure 3 demonstrates the effect of small feature removal on mesh quality for ICCA model blade_w1 shown in Figure 2.

2. Procedures to improve large dihedral angles and thereby, overall quality of the mesh

   Improvement of the overall quality of Finite Octree meshes was given in-depth consideration and large dihedral angles were identified as the most important quality measure to improve. A capability to explicitly improve the large dihedral angles of elements was introduced into Finite Octree. The large dihedral angle improvement procedures use local mesh modification tools (edge splitting, edge swapping, edge collapsing and face swapping) to optimize the mesh. Use of this capability has led to substantial improvements to the quality of meshes generated by Finite Octree. Figure 4 shows a comparison of the meshes obtained with and without dihedral angle improvement.

3. Capability to handle multi-material Parasolid models

   The ability to build non-manifold models from Parasolid assemblies was introduced to meet the need for meshing multi-material Parasolid models such as structural and airfoil parts with gating attached. Multi-material models are a subset of non-manifold models. Non-manifold objects may have surfaces touching at a single point or an edge, have internal faces and be general combinations of wires, surfaces and solids.

   Given a non-manifold representation, Finite Octree can mesh multi-material models. At the start of the project Parasolid only supported 2-manifold models. However, it did support modeling of individual geometric entities of non-manifold models. Therefore, procedures were developed to create a non-manifold representation using a manifold modeler (Parasolid) so that the resulting model could be meshed by Finite Octree.

The procedures developed have the capability to preprocess a Parasolid assembly of objects representing the material regions of the model and create the non-manifold representation required by Finite Octree. The various overlapping (or coincident) entities among the components are automatically identified. If matching entities do not exist at interacting boundaries of the components, they are added with the help of the modeler.

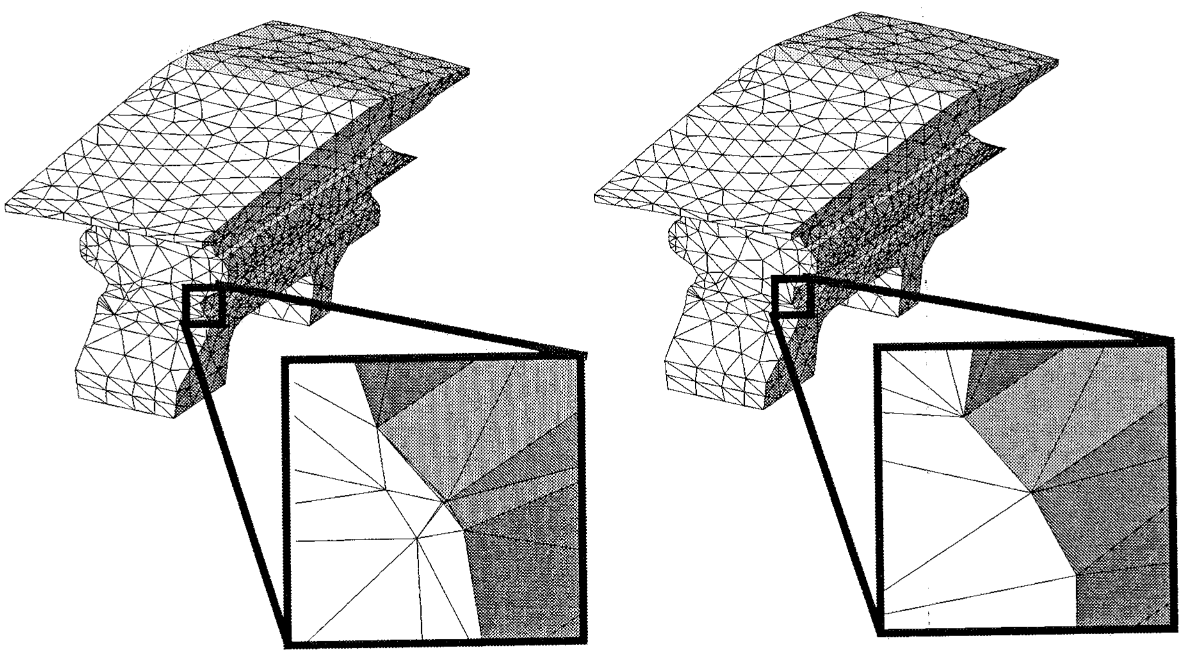
Figure 5 shows the mesh for a non-manifold ICCA model automatically built from a Parasolid assembly and then meshed by Finite Octree.

4. Procedures to use local retriangulation to allow for curving of elements

    If higher order nodes on mesh edges are requested, Finite Octree tries to pull these nodes to the boundary to improve geometric approximation of the model by the mesh. Pulling a node to the boundary may make the element unacceptably distorted or cause penetration into other elements in the local neighborhood by the curved entities. Techniques were developed to detect the cause of such a situation and to modify the surrounding mesh so that the edge may be curved in most situations.

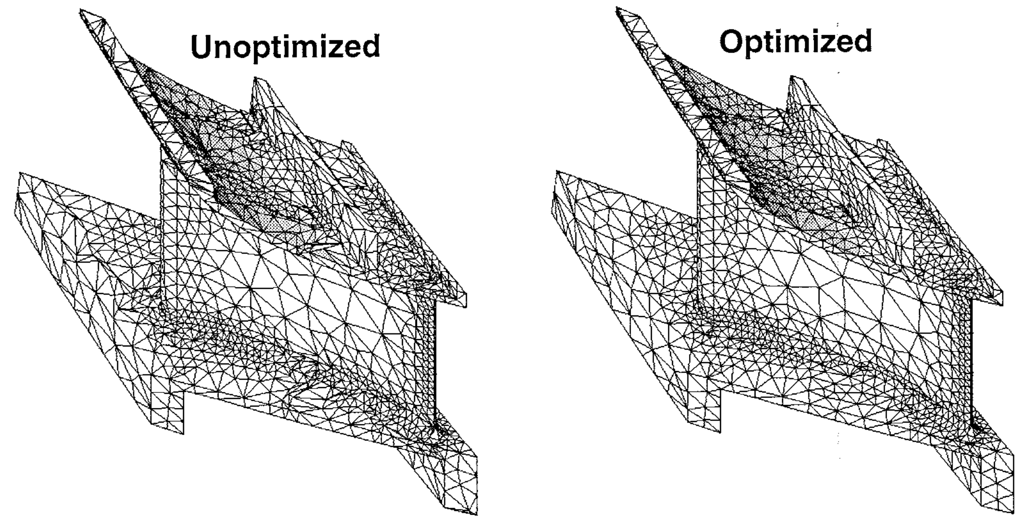
5. More robust and efficient octant level loop building procedures

    Octant level loop building procedures were modified to minimize the use of face normal information thereby resulting in increased robustness and speed.



Mesh quality measure	Without small feature removal	With small feature removal
Min r/R measure	0.00009	0.02
Largest aspect ratio	128	23

Figure 3 Improvement in mesh quality by automatic elimination of small features



	Initial	Optimized
Min dihedral angle	0.02	6
Max dihedral angle	179.96	151
Min r/R ratio	3e-7	0.06
Largest edge/shortest height	12825	17

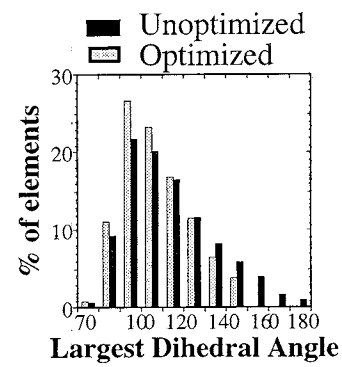


Figure 4 Effect of dihedral angle optimization on mesh quality

6. Implementation of templates for interior octant meshing

   Templates were introduced for tetrahedronizing octants which are completely interior to the model and therefore, can have only a fixed number of configurations. The tetrahedronization of these different configurations is pre-evaluated and coded thereby making the process of interior octant meshing fast and efficient.

7. Procedures to deal with subset of near tangency situations

   When two different model entities are geometrically closer than the tolerance used to tell two points apart, then a near tangency situation exists. Special techniques are required to discretize such portions of a model. The capability to deal with some of these situations was added to Finite Octree.

8. Procedures to optimize number of connections at mesh vertices

   These procedures attempt to improve mesh quality by optimizing the number of elements connected to each mesh vertex.

9. Enhancements to deal with tolerant models

   Parasolid models in which the tolerance varies from entity to entity are called tolerant models. Finite Octree's procedures were modified to allow for such situations.

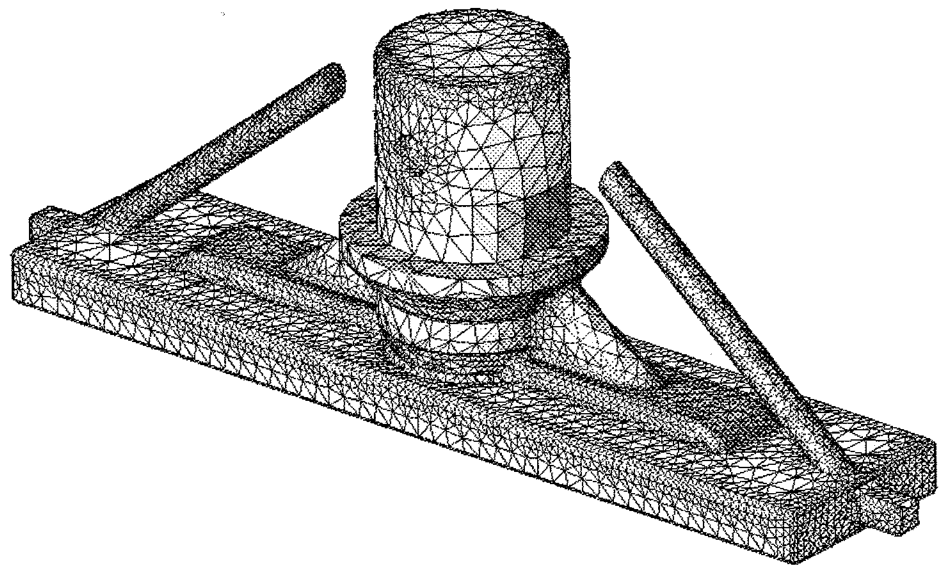


Figure 5 Mesh of non-manifold ICCA model generated by Finite Octree

10. Capability to specify non-cubical universe allowing creation of stretched elements

    Normally Finite Octree builds a discretization of the model starting from a cubical bounding box of the model (referred to as the universe). Building the discretization using a non-cubical universe results in elements which are stretched along the long direction(s) of the universe.

11. Speed improvements (40% average decrease in meshing time)

    Faster computation of quality measures (e.g., dihedral angles), storing of surface parameter values, storage of large dihedral angle values, improvement in point contain ment checks etc. were some of changes made to Finite Octree to cut mesh generation times by an average of 40% (i.e. current meshing time is 60% of the old meshing time) during the second year of the project alone.

From the experience of meshing the ICCA models, some guidelines for mesh generation for ICCA models with Finite Octree may be derived as follows:

1. Use moderately large maximum element sizes and utilize the automatic refinement features of Finite Octree to get refinement only where necessary.

    Finite Octree has automatic curvature based refinement and refinement in the presence of small segments (as in thin sections of the models) and these features can be used to generate graded meshes. This allows the meshes to approximate the model well while generating meshes smaller than those possible through uniform refinement. Initial attempts at meshing a model may use element sizes that are approximately $1/10^{th}$ to 1/

2. Cap the minimum element size so that the automatic curvature based refinement or refinement due to small segments does not result in excessive refinement.

   This guideline is particularly useful when using the specifying maximum allowable geometric approximation as a fraction of the finite element segment size, since the procedures tend to cause considerable refinement in the presence of curvature singularities. Capping the refinement also controls the size of the mesh. Typical minimum element sizes used for the ICCA models was $1/50^{th}$ to $1/500^{th}$ of the model size.

3. Turn on small feature elimination

   One technique to detect the presence of small features is to generate an initial mesh without small feature elimination and examine the parts of the mesh in which elements with large aspect ratios or small dihedral anglesare present. Corresponding portions of the geometric model can then be examined in detail to see if there are any such features not visible in the overall picture of the model. Typical sizes of features that were eliminated in the mesh ranged from $1/1000^{th}$ to $1/100^{th}$ of the model size. The actual value used for small feature elimination depends on the relative size of the smallest design feature with respect to the model size.

4. For some geometric surfaces, such as very high order free-form surfaces, curvature evaluation by the modeler may be expensive and can cause significant slow down of the mesh generation process. It may be more efficient in such a case to uniformly refine the mesh.

Further details on mesh control specification for Finite Octree are given in the document "Specification of mesh control functions in Finite Octree"[1].

The rest of the report documents the results of Finite Octree mesh generation for ICCA models. The description of each example follows a general format agreed upon by the team and subsequently augmented based on suggestions from Howmet Corp. Each example description is made up of a header (consisting of cataloging information such as example identifier, date received, etc.), issues raised by the group submitting the example and the results of the Finite Octree mesh generation of that model. Wherever necessary, example descriptions contain a discussion of the modeling and mesh generation issues addressed for meshing the model.

full_solid_c1

I. Header Information

1. Problem name/ID number: full_solid_c1
2. Communication #: 1
3. Organization sent by: PCC through PDA
4. Date sent: October 11, 1993
5. Organization received by: SCOREC, RPI
6. Date received: October 12, 1993
7. Retrieval of example: edit e-mail, uudecode and uncompress
8. Type of file: UG part file
9. Picture of model: See Figure 6 on Page 11

II. Issues and Comments on Initial Mesh:

1. Meshes do not provide good geometric approximation to model (especially airfoil, cone shaped pour cup, ring and cylindrical downpole).
2. Excessive refinement at Gate-to-Ring attachment.
3. Model needs uniformly high refinement for good geometric approximation and still has problems of high refinement at Gate-to-Ring attachment.

III. Discussion:

Straight-sided and curved-sided tetrahedral meshes were generated for this model. The issues raised about the geometric approximation of Finite Octree in PATRAN3 were addressed by applying appropriate mesh controls. The problem of excessive refinement at gate-to-ring attachment was examined carefully and was found to be caused by a small feature. The representation of this feature was eliminated from the mesh by small feature elimination procedures.

IV. Results:

Good meshes were generated with improved versions of Finite Octree.

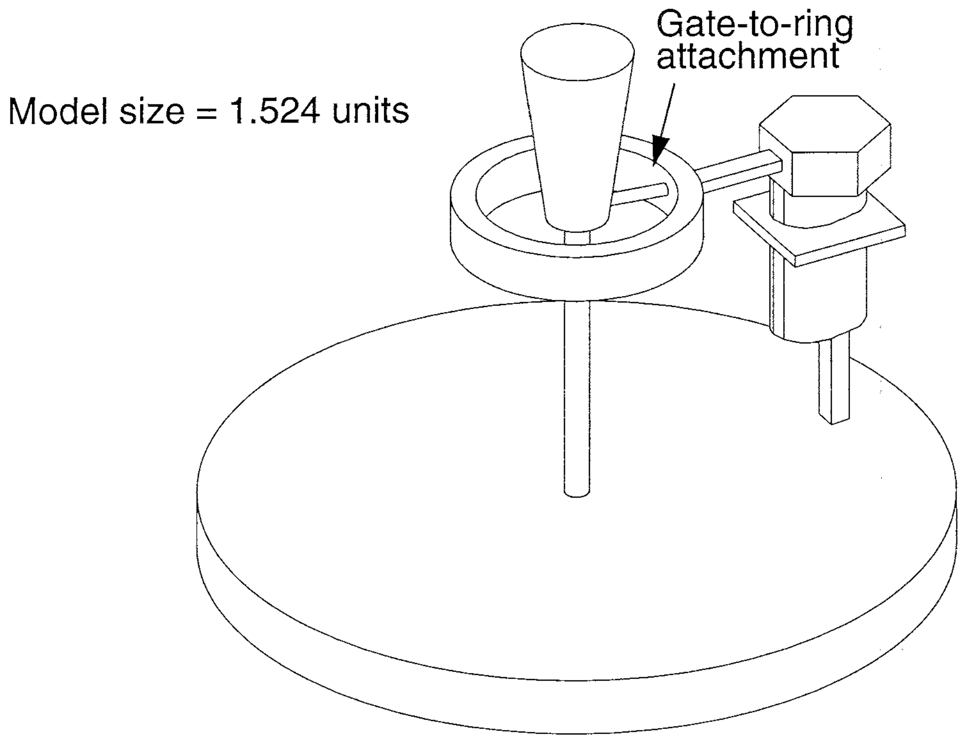


Figure 6 - Isometric view of geometric model fulll_solid_c1

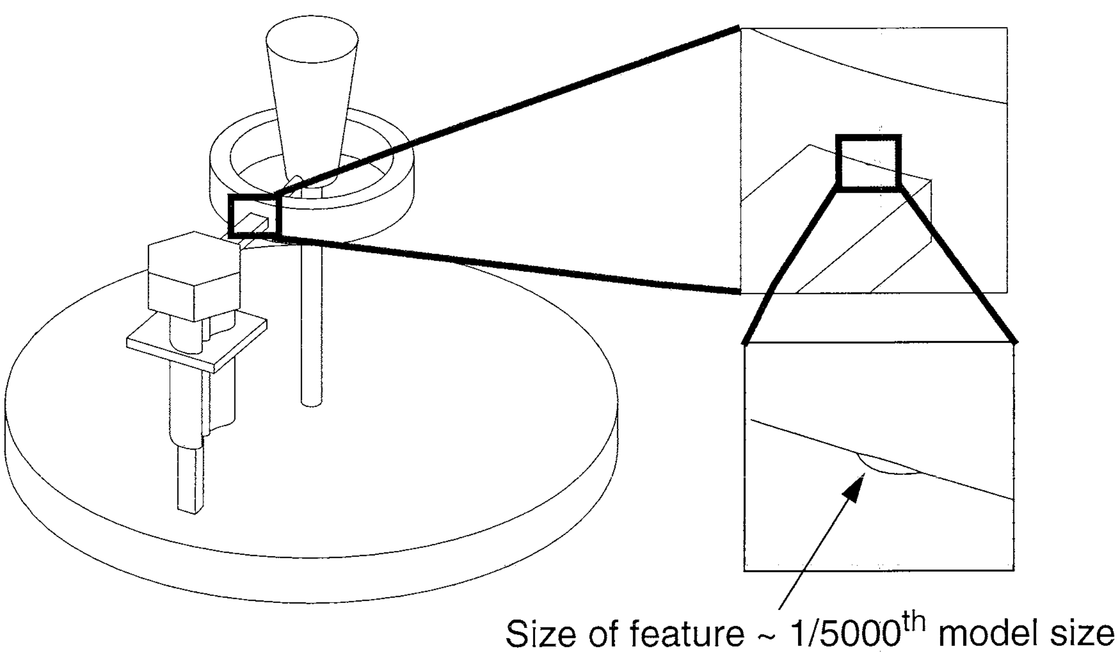


Figure 7 - Small feature in geometric model

Table 1 : Mesh control parameters (straight sided tetrahedral mesh with small features present, refinement capped and small segment checking on)

Minimum element size	0.025
Maximum element size	0.2
Curvature refinement method	2
Maximum allowable geometric approximation	0.08
Check for small segments	1 (On)
Maximum requested longest edge to smallest edge ratio	5

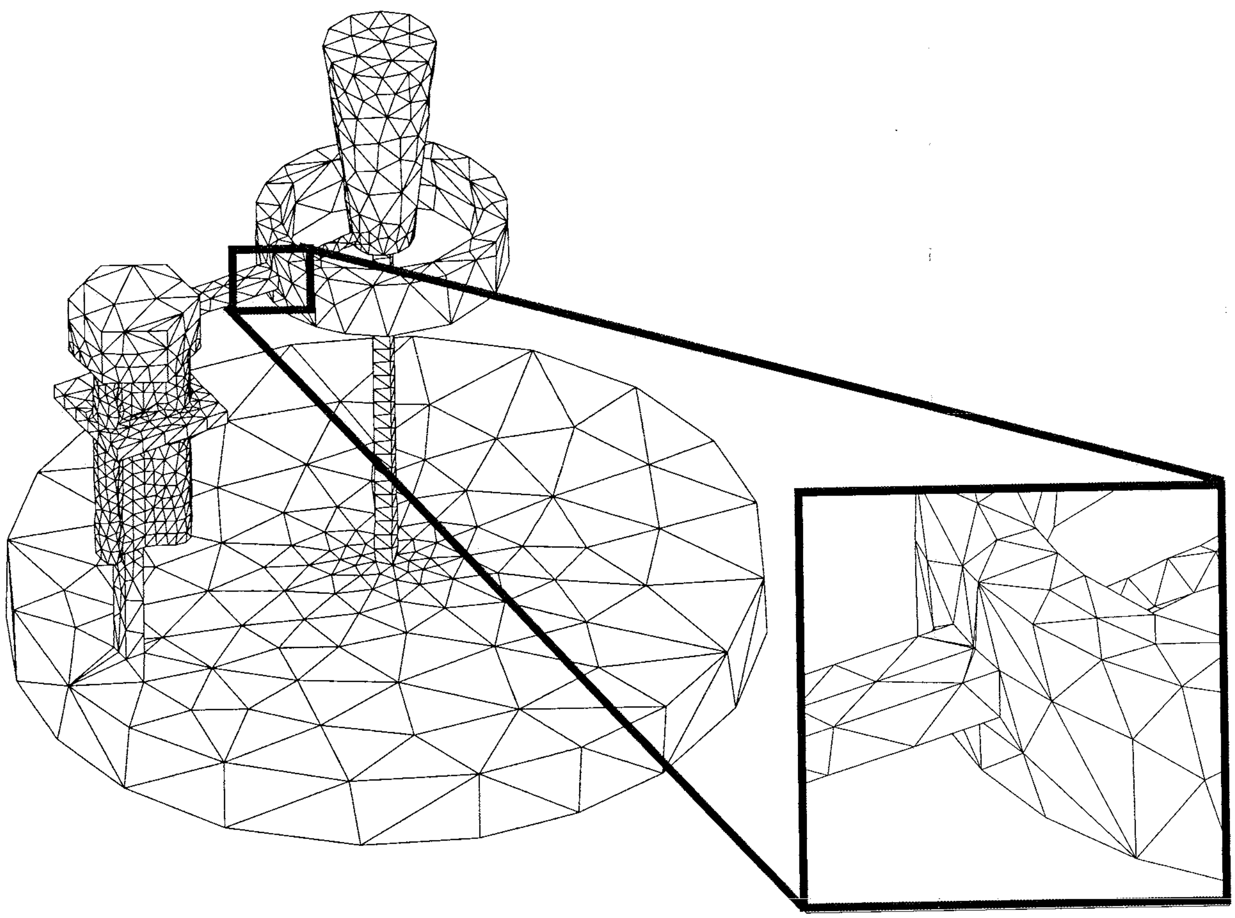
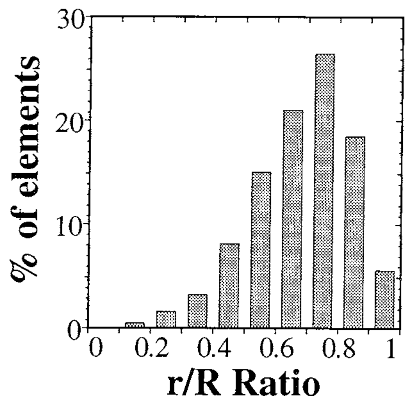


Figure 8 - Straight sided tetrahedral mesh for model generated with curvature-dependent refinement and small segment checking. Inset shows the mesh in the vicinity of the small feature



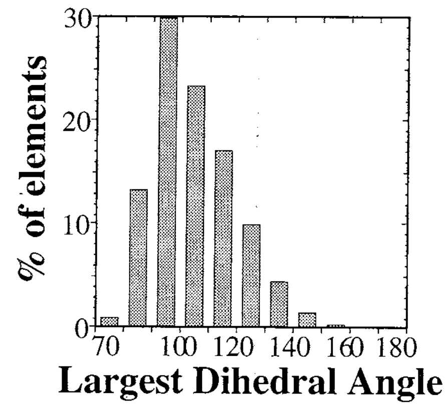


Figure 9 - Histogram of element characteristics for straight-sided mesh of full_solid_c1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 2 Mesh statistics for full_solid_c1 (straight sided tetrahedral mesh with small features present and refinement controlled)

Number of nodes	2066
Number of surface triangles	2944
Number of tetrahedrons	7425
Worst shape (**3r/R**)	0.06
Smallest dihedral angle	4
Largest dihedral angle	159
Largest edge/shortest edge	30
Largest edge/ shortest height	40

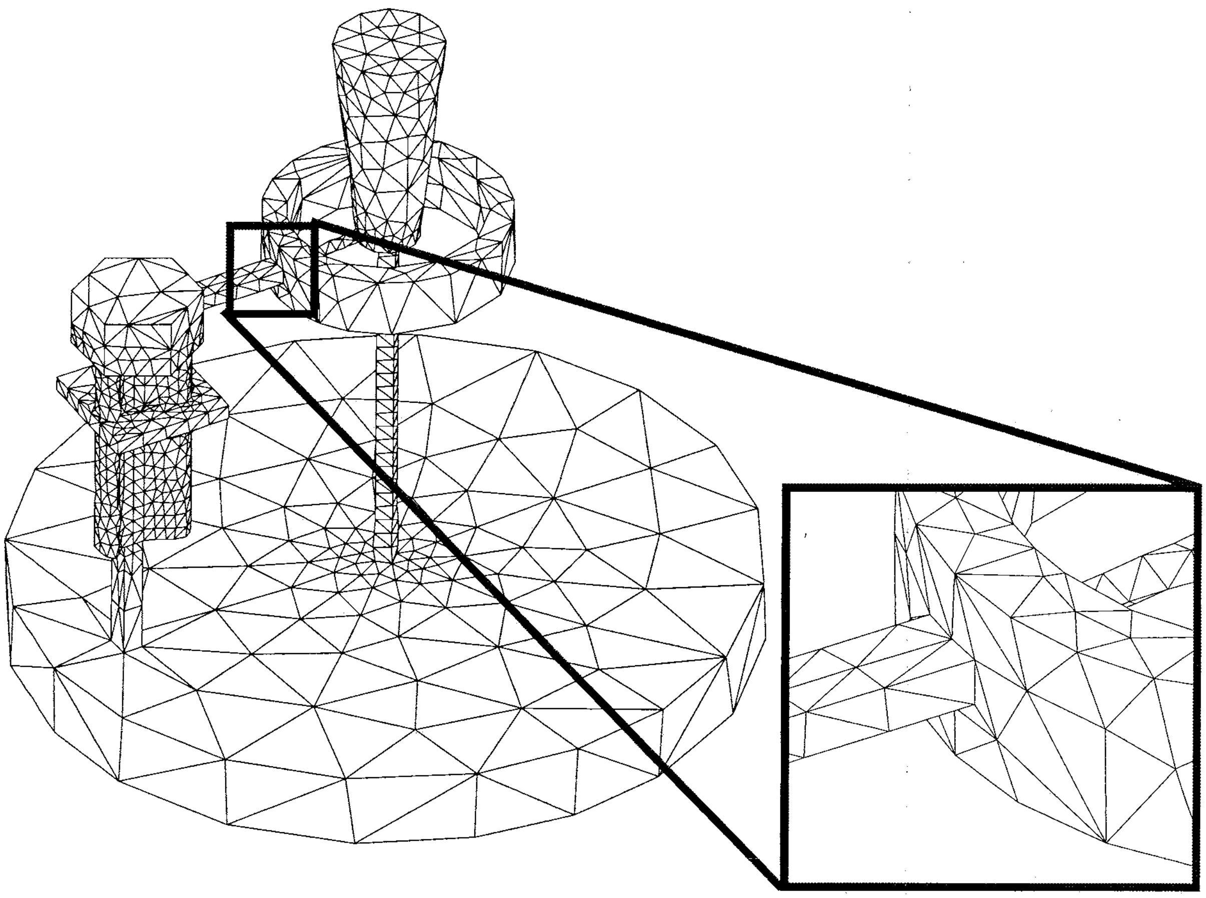


Figure 10 - Straight sided tetrahedral mesh for model generated with same mesh controls as before except that small features have been removed. Inset shows the mesh in the vicinity of the small feature

Table 3 Mesh statistics for full_solid_c1 (straight sided mesh with feature removed)

Number of nodes	2019
Number of surface triangles	2882
Number of tetrahedrons	7249
Worst shape (**3r/R**)	0.08
Smallest dihedral angle	11
Largest dihedral angle	154
Largest edge/shortest edge	8
Largest edge/ shortest height	11

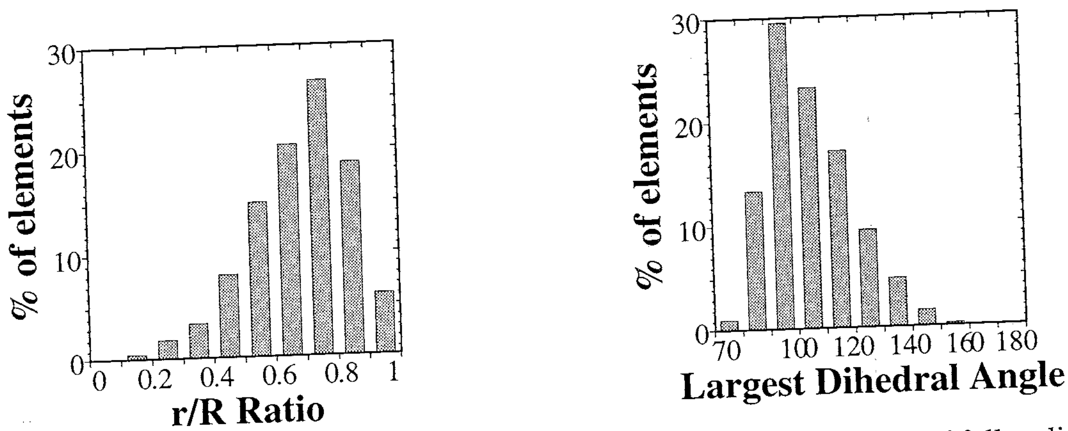


Figure 11 - Histogram of element characteristics for straight-sided mesh of full_solid_c1 with small features removed (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

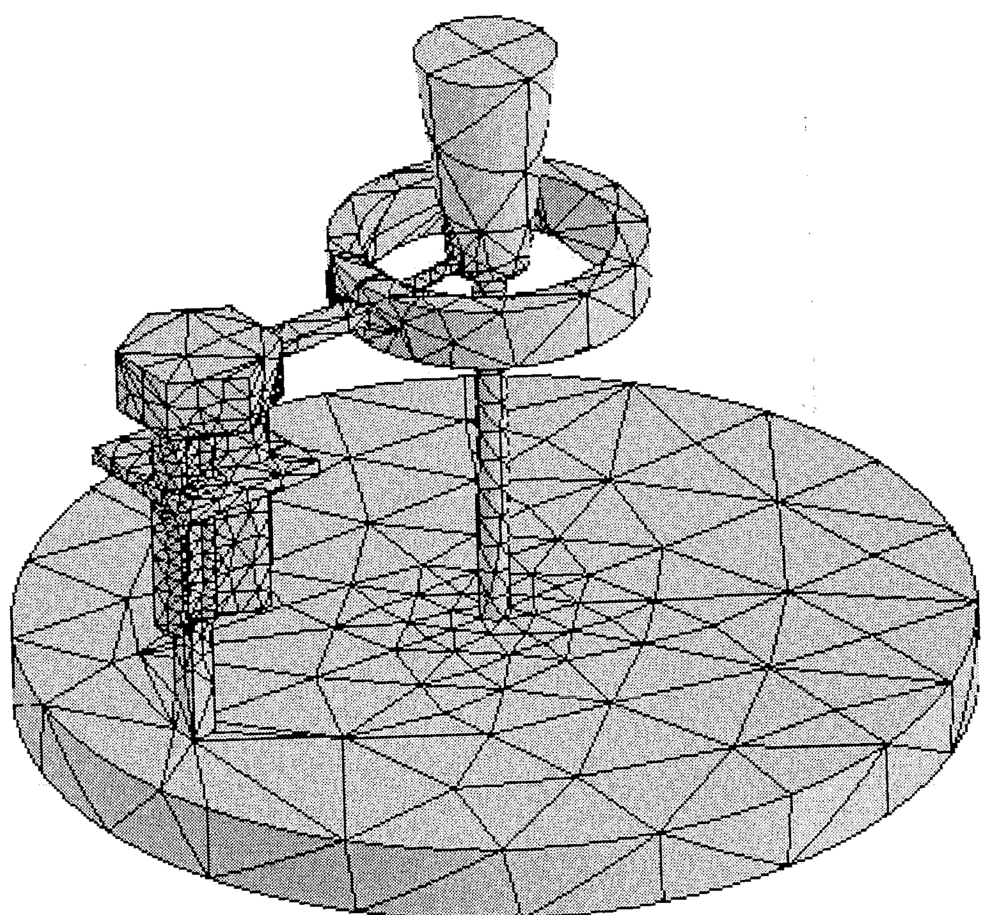
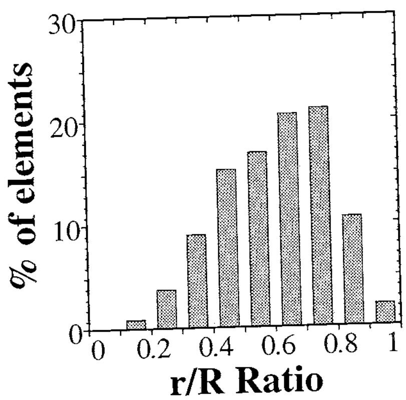


Figure 12 - Curved sided tetrahedral mesh for model, full_solid_c1



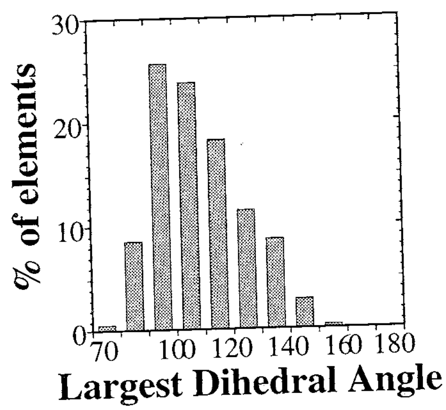


Figure 13 Histogram of element characteristics for curved-sided mesh of full_solid_c1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 4 : Mesh control parameters (curved sided tetrahedral mesh)

Minimum element size	0.045
Maximum element size	0.2
Curvature refinement method	2
Maximum allowable geometric approximation	0.5
Check for small segments	-1(Off)
Small feature removal for features smaller than 1/500th model size	1 (On)

Table 5 Mesh statistics for full_solid_c1 (curved sided tetrahedral mesh)

Number of nodes	6759
Number of surface triangles	1724
Number of tetrahedrons	3663
Worst shape for corresponding straight sided tetrahedron (**3r/R**)	0.07
Smallest dihedral angle	11
Largest dihedral angle	158
Largest edge/shortest edge	7
Largest edge/ shortest height	12

chopsolid_c1

I. Header Information

1. Problem name/ID number: chopsolid_c1
2. Communication #: 1
3. Organization sent by: PCC
4. Date sent: February 14, 94
5. Organization received by: SCOREC, RPI
6. Date received: February 21, 94
7. Retrieval of example: E-mail
8. Type of file: Parasolid v4.3 transmit file
9. Picture of model: See Figure 14 on Page 18

II. Issues and Comments

The model was meshed with an older version of Finite Octree (in PATRAN3) but produced unsatisfactory meshes and raised several issues (See FAX dated 1/6/94 from Kathy Bell)

III. Discussion and Results

Good straight sided and curved sided tetrahedral meshes were generated by Finite Octree interfaced to Parasolid v4.3 and v6.0 with suitable mesh controls. Meshing trouble encountered with Finite Octree interfaced to Parasolid v5.3 examined and missed intersection problem in Parasolid reported to Shape Data.

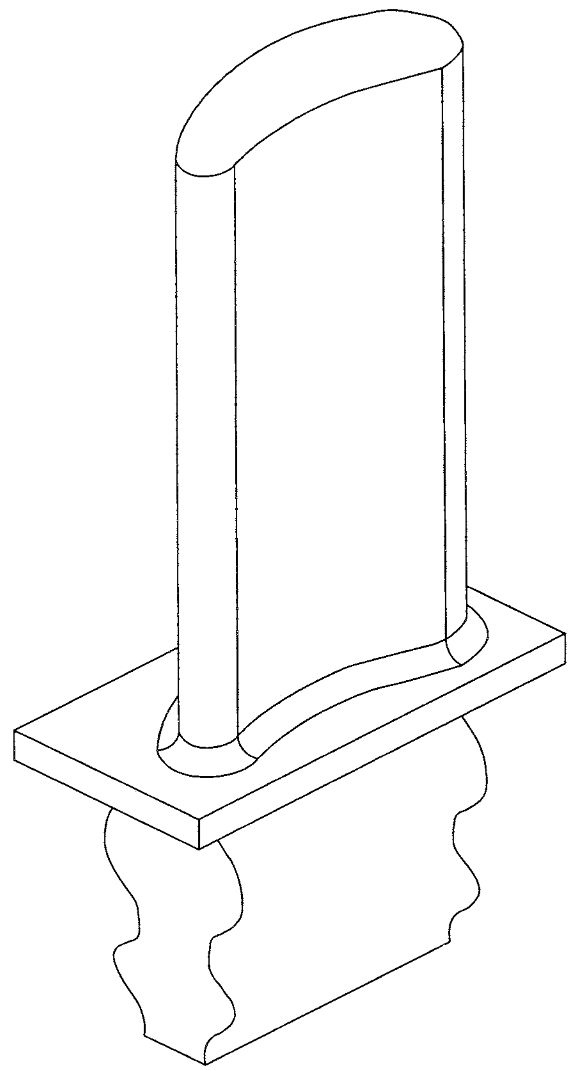
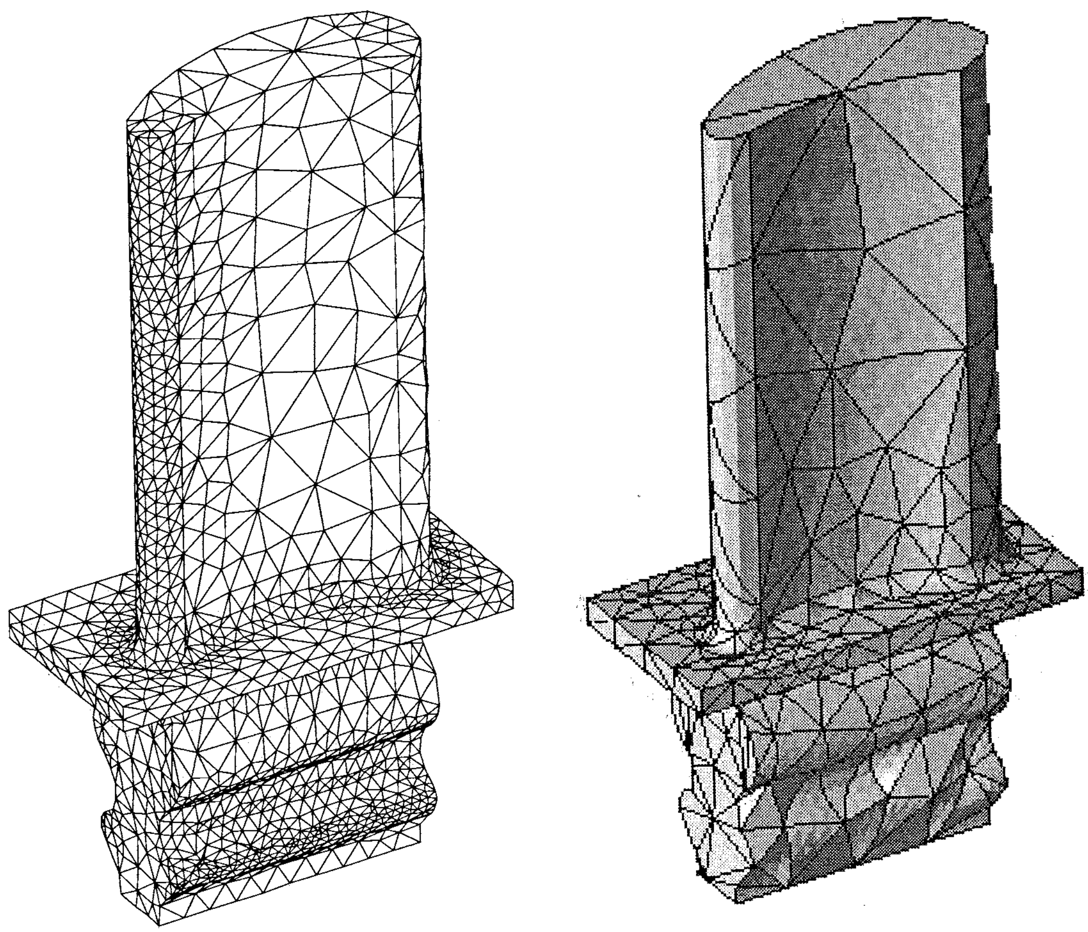


Figure 14 - Picture of model chopsolid_c1



(a) (b)

Figure 15 (a) Straight sided tetrahedral mesh generated by Finite Octree (b) Curved-sided tetrahedral mesh generated by Finite Octree

Table 6 : Mesh control parameters for chopsolid_c1 (straight sided tetrahedral mesh)

Minimum element size	0.0012
Maximum element size	0.02
Curvature refinement method	2
Maximum allowable geometric approximation	0.1

Table 7 : Mesh statistics for chopsolid_c1 (straight sided tetrahedral mesh)

Number of nodes	5296
Number of surface triangles	5316
Number of tetrahedrons	23031
Worst shape (**3r/R**)[a]	0.09
Smallest dihedral angle	12
Largest dihedral angle	152
Largest edge/shortest edge	7
Largest edge/shortest height	10

a. **r** - radius of inscribed sphere, **R** - radius of circumscribed sphere

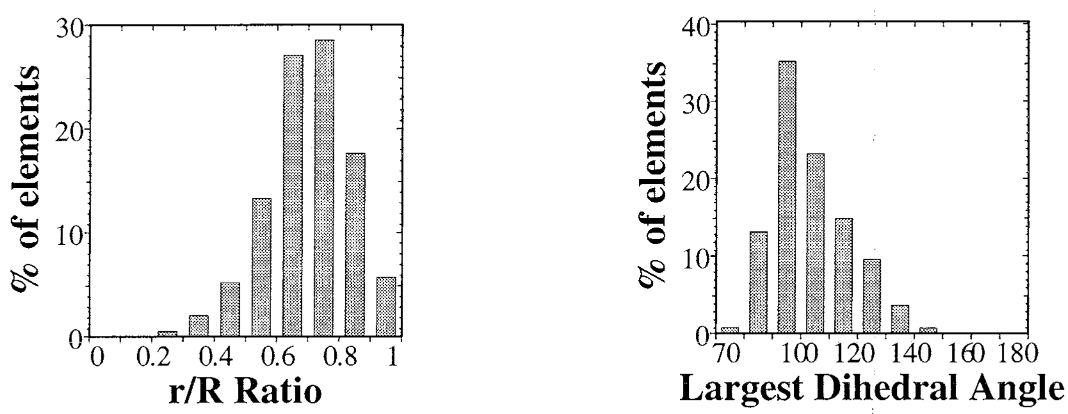


Figure 16 Histogram of element characteristics for straight-sided mesh of chopsolid_c1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 8 : Mesh control parameters for chopsolid_c1 (curved- sided tetrahedral mesh)

Minimum element size	0.0048
Maximum element size	0.0768

Table 9 : Mesh statistics for chopsolid_c1 (curved sided tetrahedral mesh)

Number of nodes	4081
Number of surface triangles	892
Number of tetrahedrons	2346
Worst shape (**3r/R**)	0.1
Smallest dihedral angle	12
Largest dihedral angle	154
Largest edge/shortest edge	9
Largest edge/shortest height	10

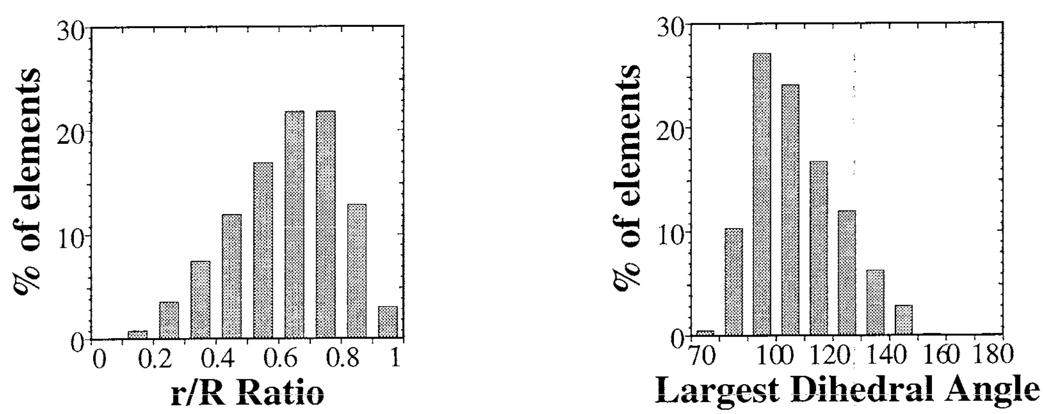


Figure 17 Histogram of element characteristics for curved-sided mesh of chopsolid_c1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

blade_w1

I. Header Information

1. Problem name/ID number:	blade_w1
2. Communication #:	1
3. Organization sent by:	P&W through PDA
4. Date sent:	September 3, 1993
5. Organization received by:	SCOREC, RPI
6. Date received:	September 3, 1993
7. Retrieval of example:	Edit e-mail to discard unwanted portions
8. Type of file:	Parasolid transmit file from UG
9. Picture of model:	See Figure 19 on Page 25

II. Issues and Comments

A straight sided and curved sided tetrahedral mesh was requested for the model. P&W suggested that the model be modified by putting a vertical slot in it and meshed.The model was accordingly modified using Parasolid Kernel Interface Driver (KID)[3] and named blade_w1r1 (See Figure 24 on Page 29). The modified Parasolid model was created by creating a block whose lateral faces were parallel to the sides of the model and then subtracting the block from the model.

III. Discussion

1. **Activity summary**: A straight sided and curved-sided tetrahedral mesh was generated for the model blade_w1 with suitable mesh gradations using the current version of Finite Octree. Modifications were made to this model by making a vertical slot in the model such that the slots sides are parallel to the sides of the top face of the model. The modified model, blade_w1r1, shown in Figure 24 on Page 29, was meshed.

   The problem of over-refinement in some portions of the model was examined and the functionality in Finite Octree to eliminate the representation of small model features in the mesh applied to this model.

2. **Explanation**: Finite Octree automatic mesh generator supports a wide range of mesh controls for getting meshes of the desired quality for a model. Some of these controls explicitly regulate the element sizes while others turn on automatic refinement procedures. One such latter option is curvature based refinement procedures which cause more refinement in the vicinity of highly curved boundaries than on gently curved or straight sided ones. Finite Octree also has the capability to refine in the presence of small features to avoid large aspect ratios or even remove small mesh entities caused by model entities that users consider to be small. These and other mesh controls are described in [1][2].

   Since the model has a number of small features, small segment checking, small feature elimination and curvature-based refinement were turned on.

3. **Suggestions:** Since this example part has several faces of different curvatures, the curvature-based refinement was used to automatically control mesh gradation. Among the two types of curvature based refinement procedures available in Finite Octree, the second method (which controls the controls the percentage of a finite element segment that the geometric approximation represents) was used. This gave good mesh gradations where required.

   Since, the model has some sections which are relatively thinner than the others small segment refinement was turned on. Also, mesh features due to extremely small model features (less than 1/500th of the model size) were eliminated to control excessive refinement.

4. **Results:** Shown in Figure 18 and Figure 20 are pictures of straight sided tetrahedral mesh of the part blade_w1 generated without explicitly dealing with small features in the model. In the first mesh, small segment checking was turned on and element sizes were allowed to get quite small while in the second mesh small segment checking was turned off and elements were restricted from getting too small.

   Note the excessive refinement in some portions of the mesh in Figure 18. Shown magnified in Figure 19 is the portion of the geometric model where the extra refinement occurred. It can be seen that the model has an edge between two vertices that are separated by approximately five-thousandths of the model size. In such a situation, if no special procedures are applied, Finite Octree may refine the mesh locally to maintain topological compatibility of meshes with the model and to control element aspect ratios if small segment checking is on. On the other hand, if the maximum refinement is contained below the required amount, elements with large aspect ratios are usually generated in that area. This can clearly be seen in the mesh with refinement limited (Figure 20) which has a worst aspect ratio of 128.

   Figure 20 shows the mesh for the same model with removal of small mesh entities arising from the small model feature. Clearly, the number of elements in the vicinity of the small feature is reduced. Comparison of the statistics for the first and third mesh shows a 25% decrease in the number of elements in the mesh without the small feature and improvements in all the element shape measures compared to the mesh in Figure 20. Comparing the statistics of the second and the third meshes, (for which the number of elements is nearly the same), improvements can be seen in the worst shapes. Figure 22 shows histograms of element characteristics for the mesh with the small feature removed.

   Figure 23 shows the curved sided mesh generated for the model blade_w1. Table 11 shows mesh statistics for the curved mesh of blade_w1. Note that mesh with curved sided elements for blade_w1 has some elements that have been uncurved to prevent them from becoming invalid or unacceptably shaped.

   Shown in Figure 25 is the mesh of the modified part blade_w1r1.

5. **Outstanding issues:** Some elements edges in the curved-side mesh have been uncurved because curving them would have made them unacceptably shaped or caused them to penetrate neighboring elements. Work is in-progress to always be able to curve of the elements.

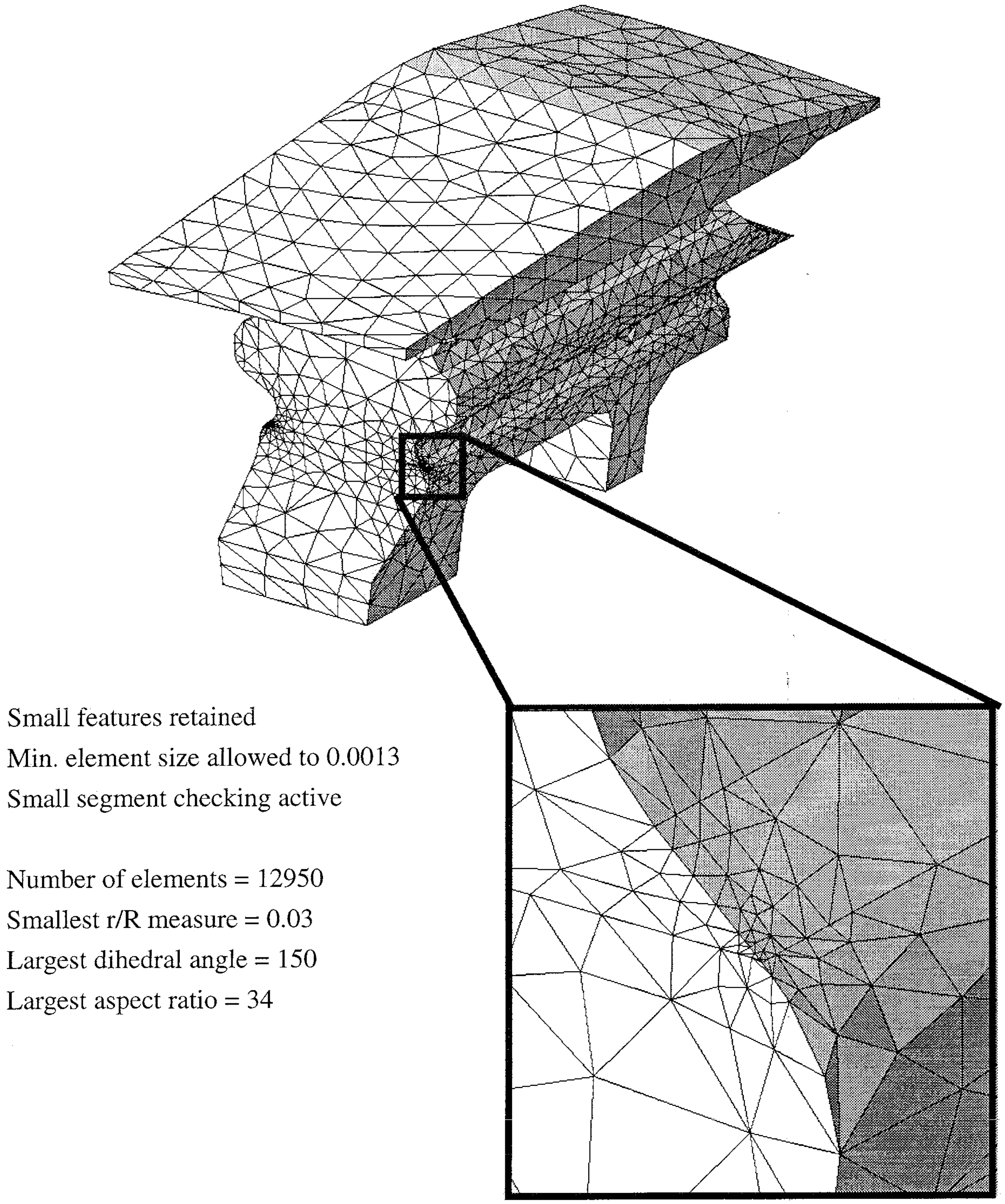


Figure 18 Straight sided tetrahedral mesh for blade_w1 with small features retained and considerable refinement permitted

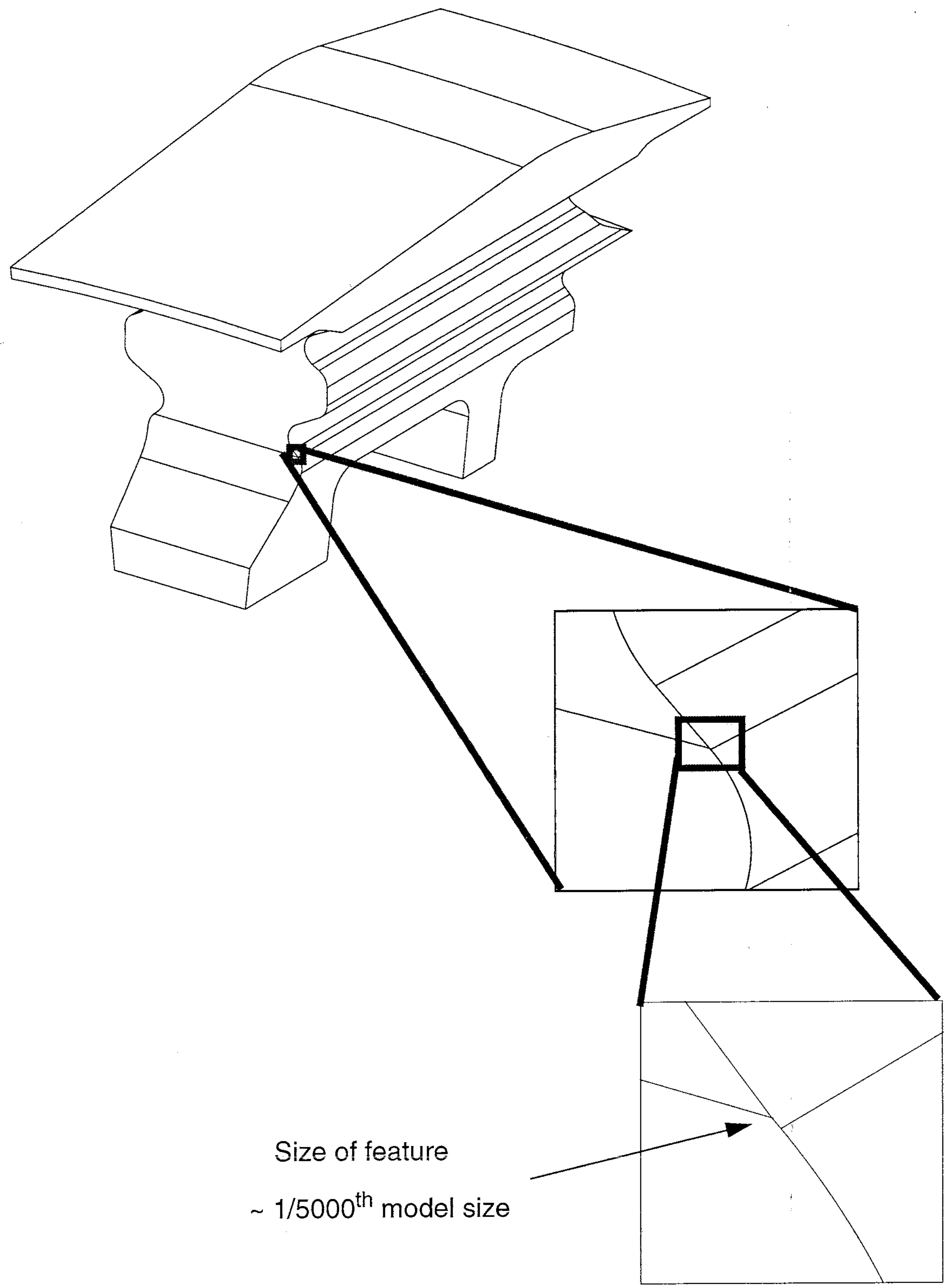
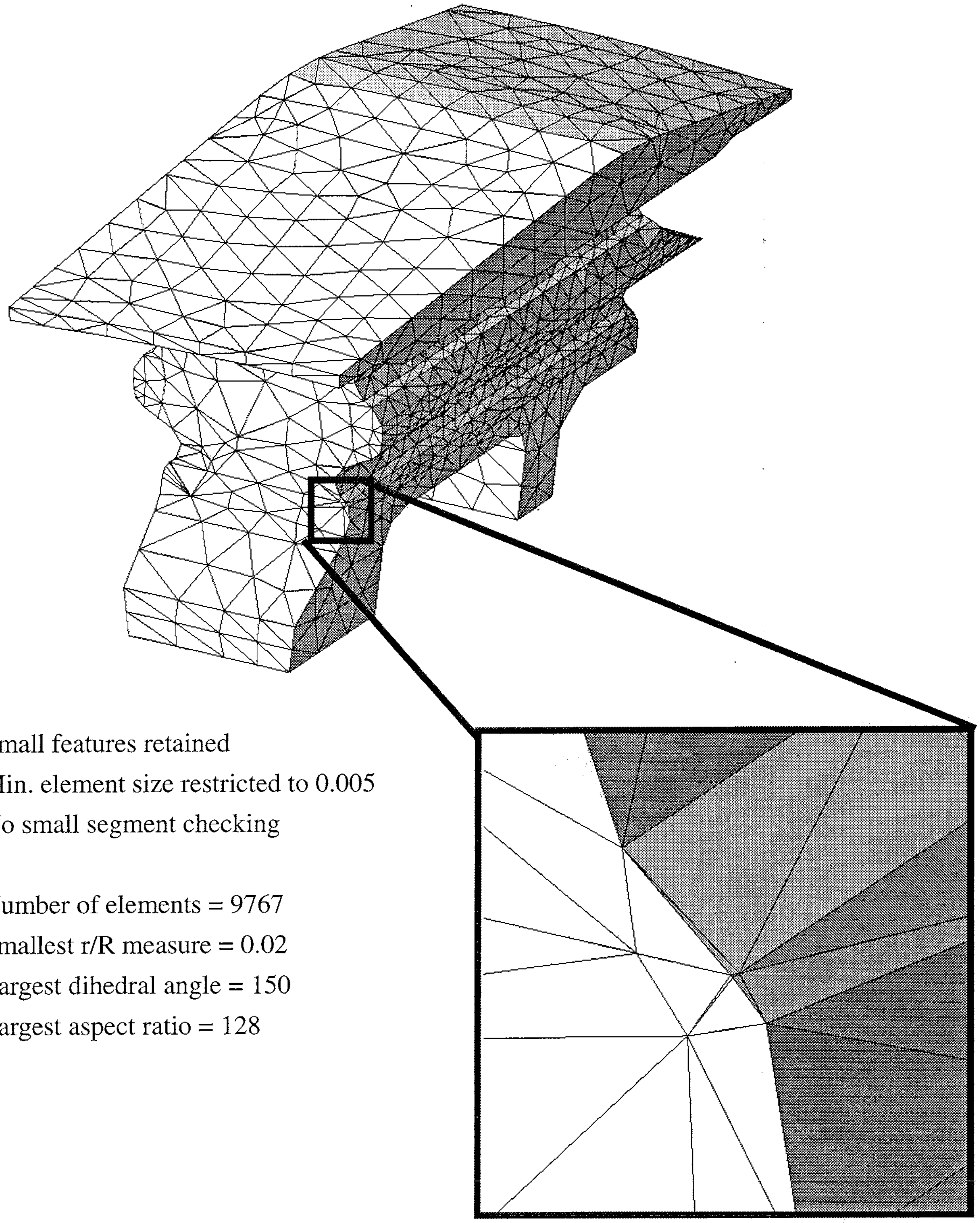


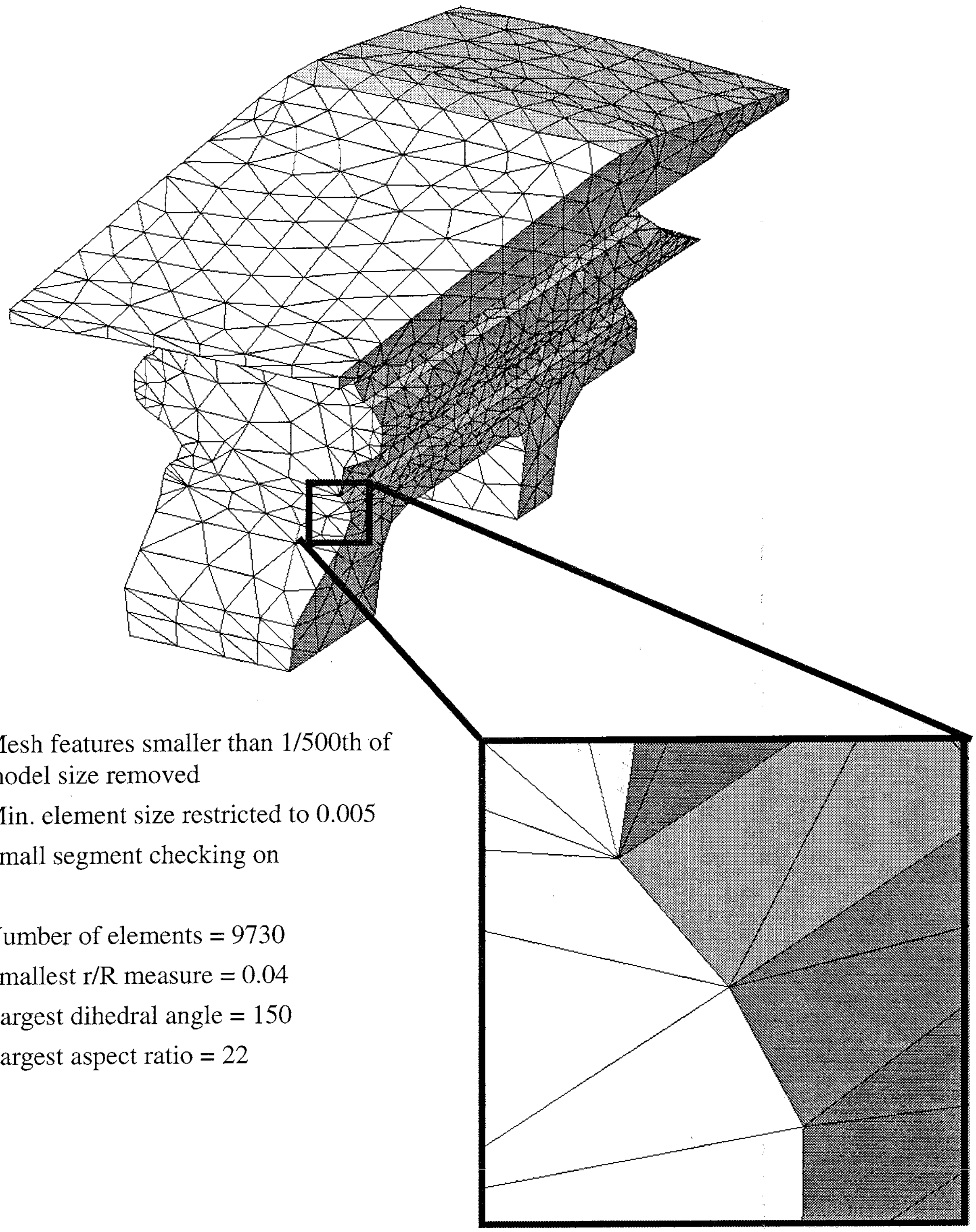
Figure 19 Off diagonal view of the model blade_w1 and the location of one of the small features in the model



Small features retained
Min. element size restricted to 0.005
No small segment checking

Number of elements = 9767
Smallest r/R measure = 0.02
Largest dihedral angle = 150
Largest aspect ratio = 128

Figure 20 Straight sided mesh with small features retained - Inset showing the mesh in the vicinity of the feature



Mesh features smaller than 1/500th of model size removed

Min. element size restricted to 0.005

Small segment checking on

Number of elements = 9730

Smallest r/R measure = 0.04

Largest dihedral angle = 150

Largest aspect ratio = 22

Figure 21 Straight sided mesh with small features removed - Inset showing the mesh in the vicinity of the feature

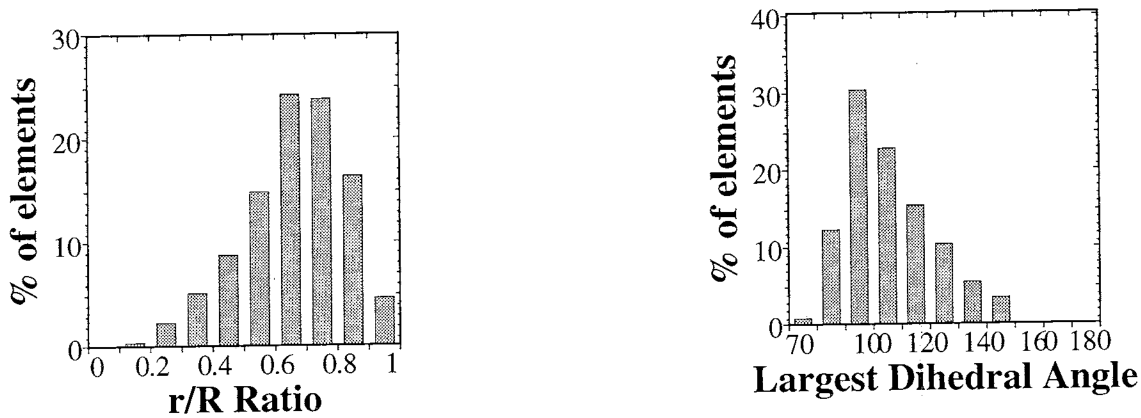


Figure 22 Histogram of element characteristics (r/R ratio and largest dihedral angle) for straight-sided meshes of blade_w1 with small features removed and refinement capped

Table 10 : Mesh control parameters for blade_w1 (curved sided tetrahedral mesh)

Minimum refinement level	0.003
Maximum allowable refinement level	0.01
Curvature refinement method	2
Maximum allowable geometric approximation	0.4
Check for small segments	1 (On)
Maximum allowable longest edge to shortest edge ratio	25
Remove small features smaller than 1/500th of the model size	

Table 11 : Mesh statistics for blade_w1 (curved sided tetrahedral mesh)

Number of nodes	6282
Number of surface triangles	1466
Number of tetrahedrons	3538
Worst shape of corresponding straight sided element (**3r/R**)	0.06
Smallest dihedral angle	4.5
Largest dihedral angle	151
Largest edge/shortest edge	11
Largest edge/ shortest height	20

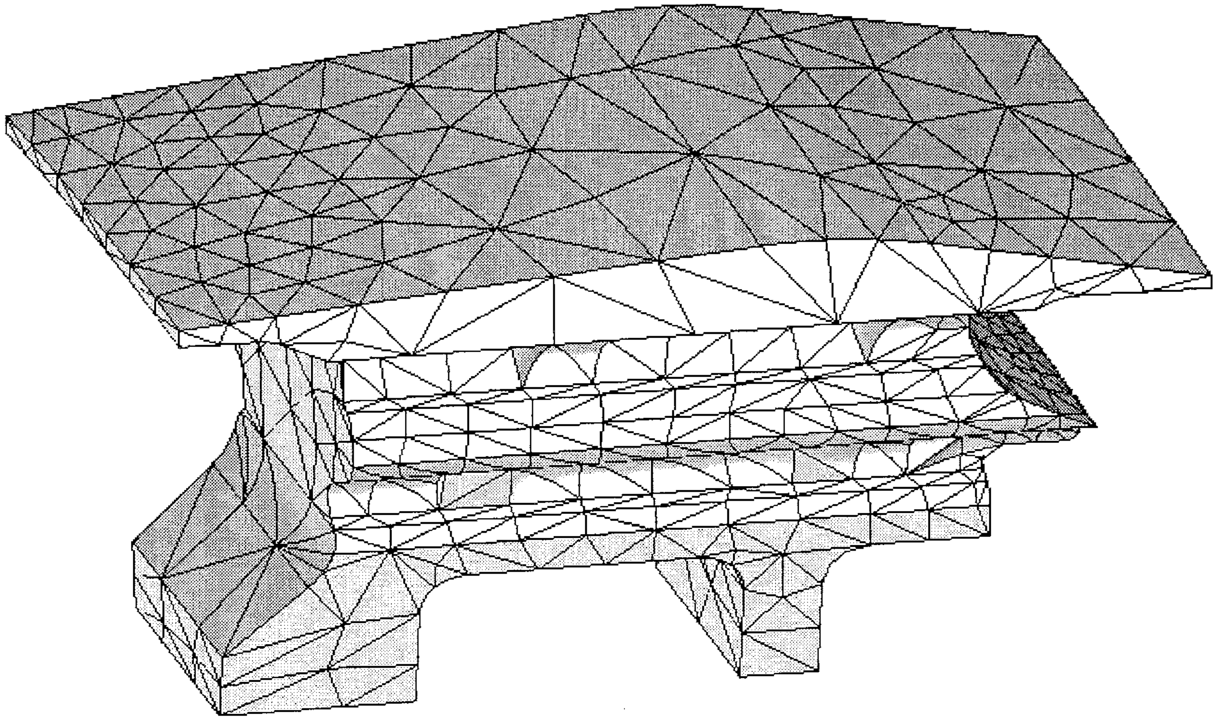


Figure 23 Curved-sided tetrahedral mesh of blade_w1

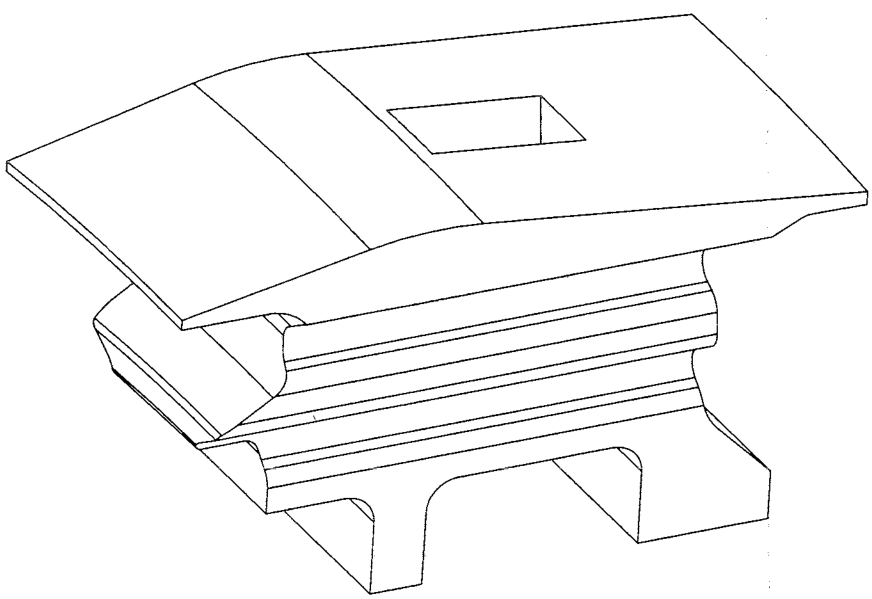


Figure 24 - Isometric view of blade_w1r1

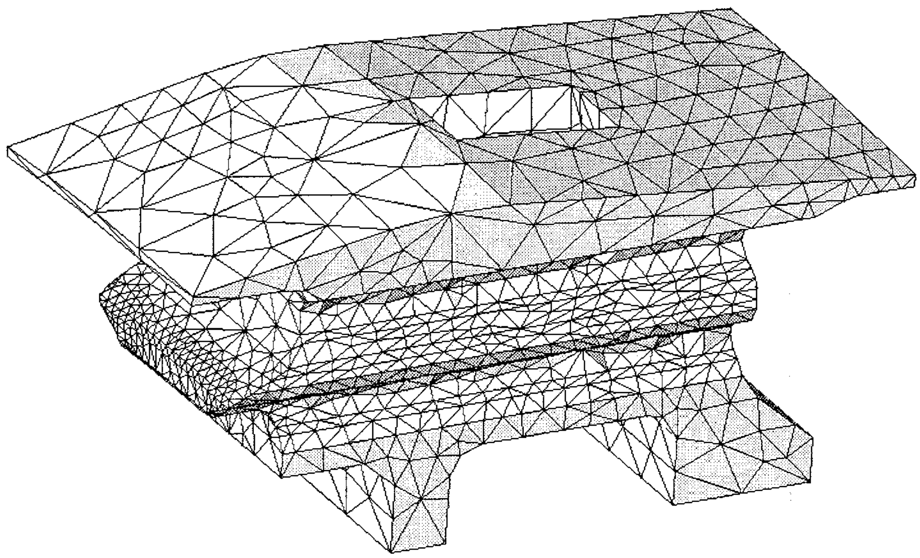


Figure 25 Straight-sided mesh of modified model with refinement around the slot

seal_g1

I. Header Information

1. Problem name/ID number: seal_g1
2. Communication #: 1
3. Organization sent by: GEAE through PDA
4. Date sent: May 94
5. Organization received by: SCOREC, RPI
6. Date received: May 94
7. Retrieval of example: tar from floppy and uncompress
8. Type of file: Parasolid transmit file
9. Picture of model: PROPRIETARY

II. Issues and Comments on Initial Mesh

Part referred to RPI because of trouble meshing it with Finite Octree in P3 v1.2-1.

III. Discussion

In the initial mesh generation attempt, Finite Octree was able to mesh this part for specific mesh controls while it exits for others after detecting a model inconsistency. The specific error message of Finite Octree was that a model entity closes upon itself. Using the model entity number output by Finite Octree, entity was located in the model.

Figure 26a shows the hidden line drawing of the same model with part of it cut away. This model passes all of Parasolid v5.3 default checks. However, when the problem edge is sketched in along with the part, an inconsistency shows up (Figure 26b). The dotted lines in the drawing are recognized by Parasolid as belonging to a face with 4 edges. From the figure, it seems that there is an inconsistency between the topology and geometry of the model. Furthermore, Parasolid identifies this curve as being a circle and one of the faces connected to it as cylindrical.

That the above situation is an inconsistency, is further clarified by Figure 27. Figure 27a shows a sketch of the problem face connected to the edge while the faceted representation of the face is represented by Parasolid as shown in Figure 27b.

This information was communicated back to GE and it was discovered that the face was a blend that had not yet been fixed in the model. This model was fixed and sent back to RPI.

IV. Results

Good meshes were generated for this model.

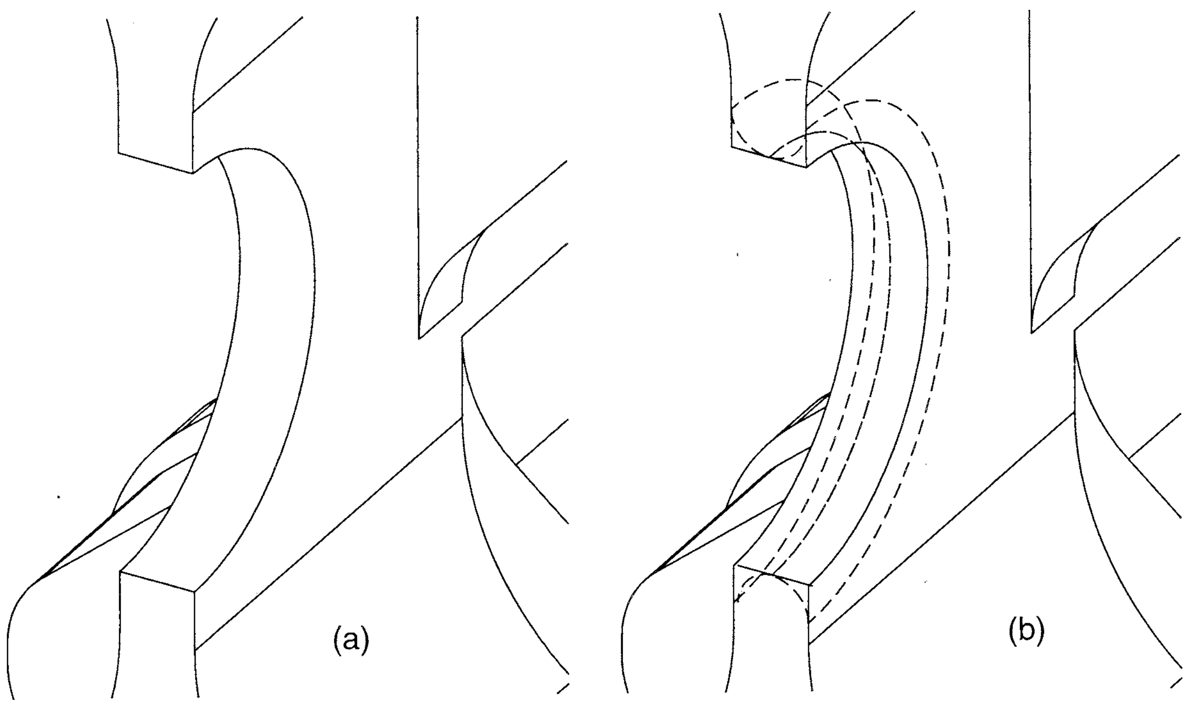
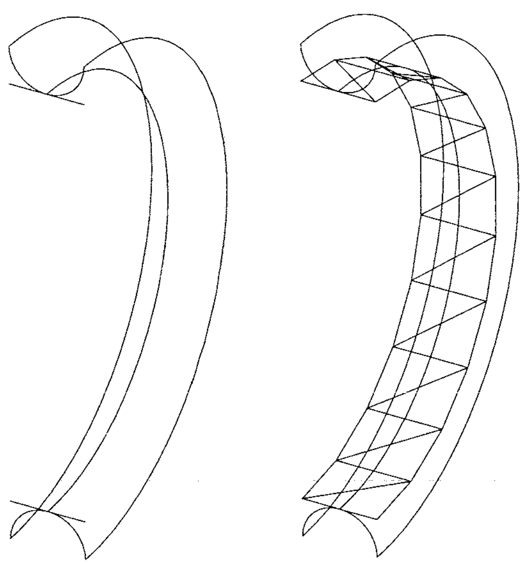


Figure 26 (a) Hidden line view of sectioned part where problem is suspected. (b) Hidden line view of (a) with problem edges and faces overlaid (in dotted lines)



(a) (b)

Figure 27 (a) Wireframe drawing of problem face (b) Faceted representation of face by Parasolid KID.

Table 12 : Mesh control parameters (straight sided tetrahedral mesh)

Minimum element size	0.003
Maximum element size	0.005
Curvature refinement method	2
Maximum allowable geometric approximation	0.4
Eliminate mesh features smaller than 1/1000th of the model size	

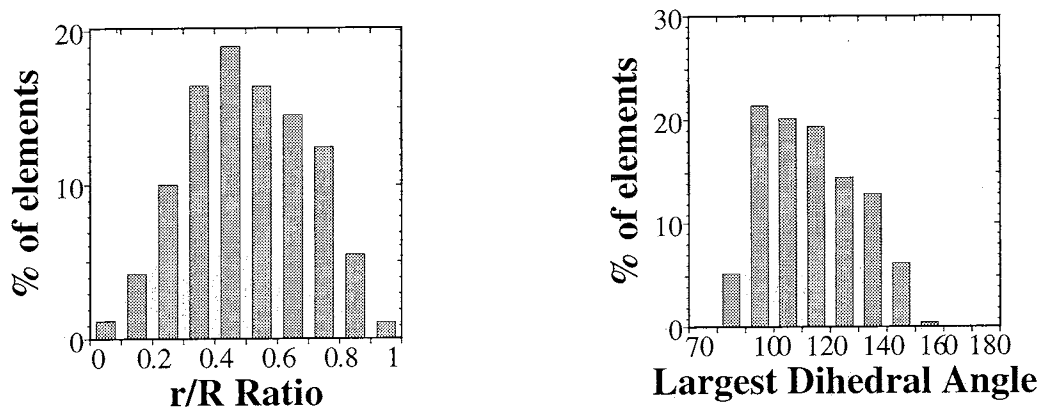


Figure 28 Histogram of element characteristics for straight-sided mesh (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 13 : Mesh statistics (straight sided tetrahedral mesh)

Number of nodes	6088
Number of surface triangles	1858
Number of tetrahedrons	3083
Worst shape (**3r/R**)	0.04
Smallest dihedral angle	3
Largest dihedral angle	156
Largest edge/shortest edge	35
Largest edge/ shortest height	40

1873_g1

I. Header Information

1. Problem name/ID number: 1873_g1
2. Communication #: 1
3. Organization sent by: GE
4. Date sent:
5. Organization received by: SCOREC, RPI
6. Date received:
7. Retrieval of example:
8. Type of file: Parasolid transmit file
9. Picture of model: PROPRIETARY

II. Issues and Comments on Initial Mesh

Part could not be meshed by Finite Octree in PATRAN3.

III. Discussion:

In versions of Parasolid before 6.0, the modeler gave a system error during curvature evaluation. Also, a line-face intersection was missed. Both problems were reported to Shape Data and fixed in version 6.0. The model was meshed using version 6.0 and later versions of Parasolid.

The part has several small features which were identified and suitable mesh controls were applied to eliminate them.

IV. Results:

Good meshes were generated for the part with the help of small feature elimination and dihedral angle improvement procedures in Finite Octree.

Table 14 : Mesh control parameters (straight sided tetrahedral mesh)

Minimum element size	0.0025
Maximum element size	0.01
Curvature refinement method	2
Maximum allowable geometric approximation	0.2
Check for small segments	1(On)
Maximum requested longest edge to shortest edge ratio	20
Eliminate mesh features smaller than $1/200^{th}$ of the model size	

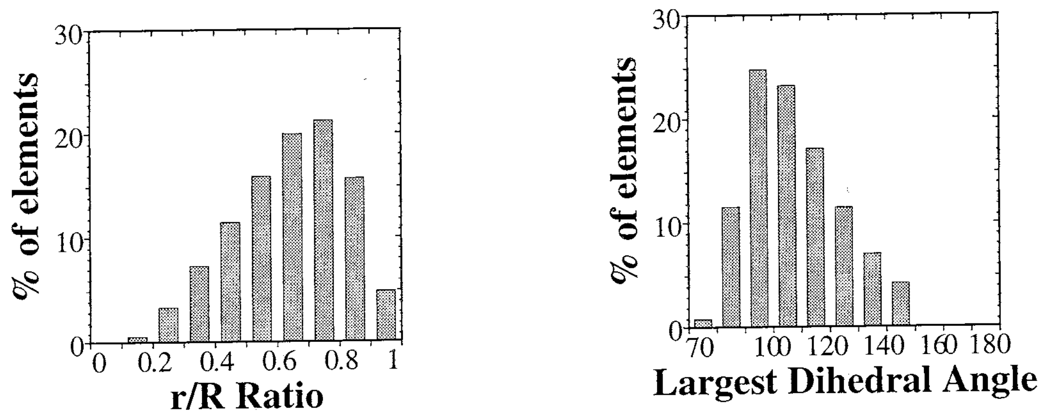


Figure 29 Histogram of element characteristics for straight-sided mesh (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 15 : Mesh statistics (straight sided tetrahedral mesh)

Number of nodes	9881
Number of surface triangles	16484
Number of tetrahedrons	32970
Worst shape (**3r/R**)	0.05
Smallest dihedral angle	5
Largest dihedral angle	155
Largest edge/shortest edge	20
Largest edge/ shortest height	27

afcore_h1n1

I. Header Information

1. Problem name/ID number: afcore_h1n1
2. Communication #: 1
3. Organization sent by: HC
4. Date sent: September 29, 93
5. Organization received by: SCOREC, RPI
6. Date received: October 1, 93
7. Retrieval of example: execute "bar xvf /dev/rfd0c howmet1.prt"
8. Type of file: UG part file
9. Picture of model: PROPRIETARY

II. Issues and Comments on Initial Mesh

Meshes do not approximate model well.

III. Discussion

A straight-sided and curved sided tetrahedral mesh was generated for this model. Investigation of excessive refinements in portions of the domain during initial attempts led to discovery of a bug in the Finite Octree mesh generation code. This bug was fixed and a properly graded mesh was generated for the model.

IV. Results

Good straight and curved side meshes were generated for the model.

Table 16 : Mesh control parameters (straight sided tetrahedral mesh)

Minimum element size	0.0025
Maximum element size	0.017
Curvature refinement method	2
Maximum allowable geometric approximation	0.1

Table 17 : Mesh statistics for howmet_h1 (straight sided tetrahedral mesh)

Number of nodes	2030
Number of surface triangles	2922
Number of tetrahedrons	7241
Worst shape (**3r/R**)	0.1
Smallest dihedral angle	10
Largest dihedral angle	147
Largest edge/shortest edge	6
Largest edge/ shortest height	11

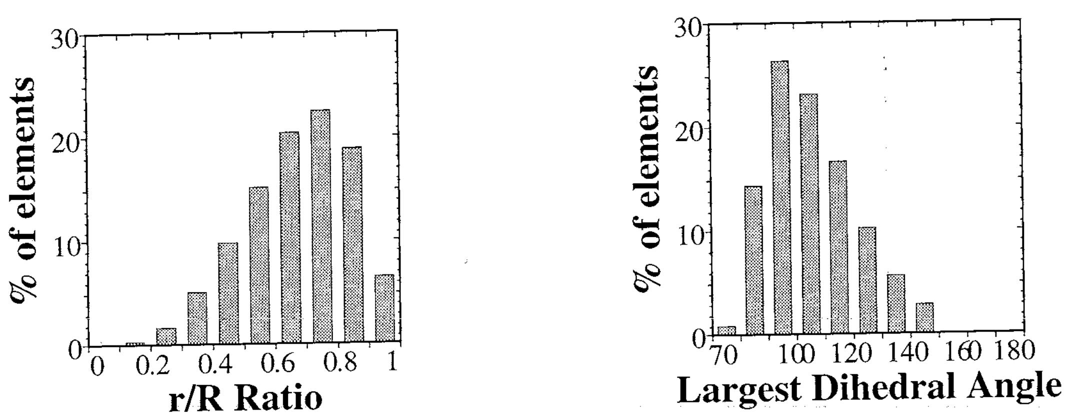


Figure 30 Histogram of element characteristics for straight-sided mesh of howmet_h1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 18 : Mesh control parameters (curved sided tetrahedral mesh)

Minimum element size	0.0085
Maximum element size	0.0045
Curvature refinement method	2
Maximum allowable geometric approximation	0.1

Table 19 : Mesh statistics for howmet_h1 (curved sided tetrahedral mesh)

Number of nodes	4125
Number of surface triangles	1258
Number of tetrahedrons	2081
Worst shape (**3r/R**)	0.1
Smallest dihedral angle	8
Largest dihedral angle	163
Largest edge/shortest edge	6
Largest edge/ shortest height	12

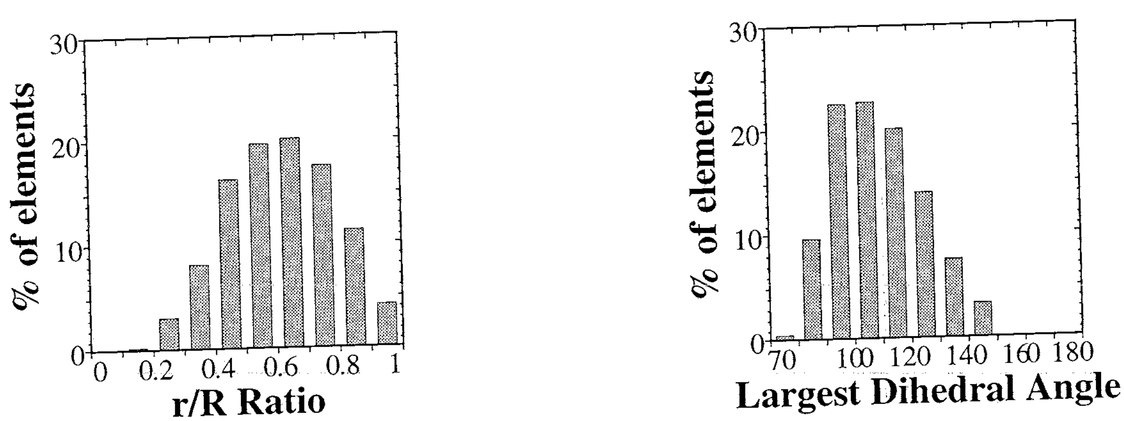


Figure 31 Histogram of element characteristics for curved-sided mesh of afcore_h1n1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

PW_ncrsr2a1

I. Header Information

1. Problem name/ID number: PW_ncrsr2a1
2. Communication #: 1
3. Organization sent by: HC
4. Date sent: September 27, 93
5. Organization received by: SCOREC, RPI
6. Date received: October 1, 93
7. Retrieval of example: Sun 3.5" floppy diskette execute "bar xvf /dev/rfd0c PW_ncrsr2a1.prt"
8. Type of file: UG part file
9. Picture of model: See Figure 32 on Page 40 and Figure 33 on Page 40

II. Issues and Comments on Initial Mesh

1. Two parts ncrsr-test2.prt and ncrsr-test3.prt were received from P&W by HC. The parts were UG solid models of non-concentric ring strut, with and without fillets respectively. The HC team could not read these parts into PATRAN3. Subsequently, they sliced off a small section of the solid off the top to make PATRAN3 read it; this part (without fillets) was renamed PW_ncrsr2a1.prt.
2. Part referred to RPI because meshes generated by Finite Octree in PATRAN3 had incorrect element connections and poor geometric approximation (See Figure 34a).

III. Discussion and Results

Finite Octree meshes with good geometric approximation were generated for this model.

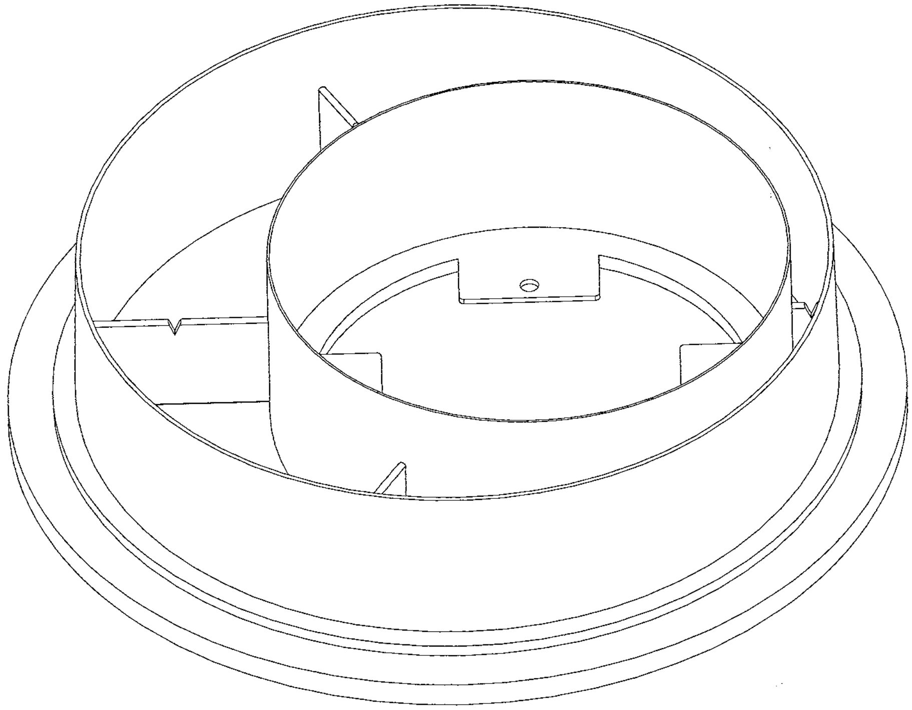


Figure 32 - Off top view of model (View 1)

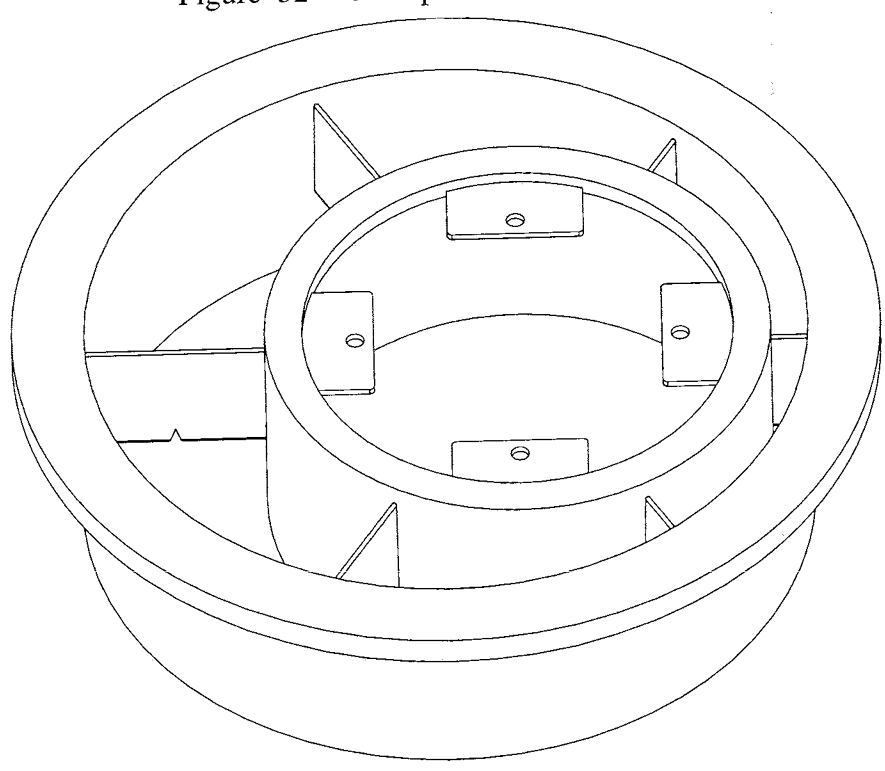


Figure 33 - Off bottom view of model (View 2)

(a)

(b)

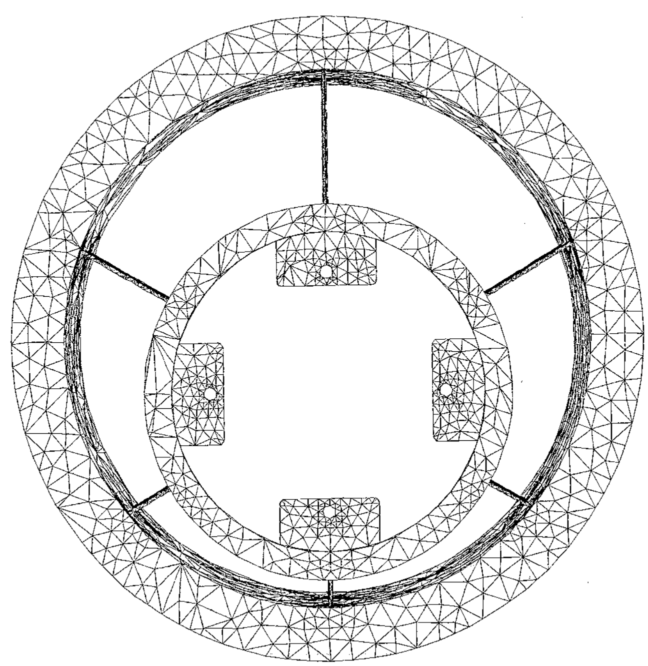


Figure 34 (a) Straight sided tetrahedral mesh generated by old Finite Octree in PATRAN3 (b) Top view of mesh in current Finite Octree

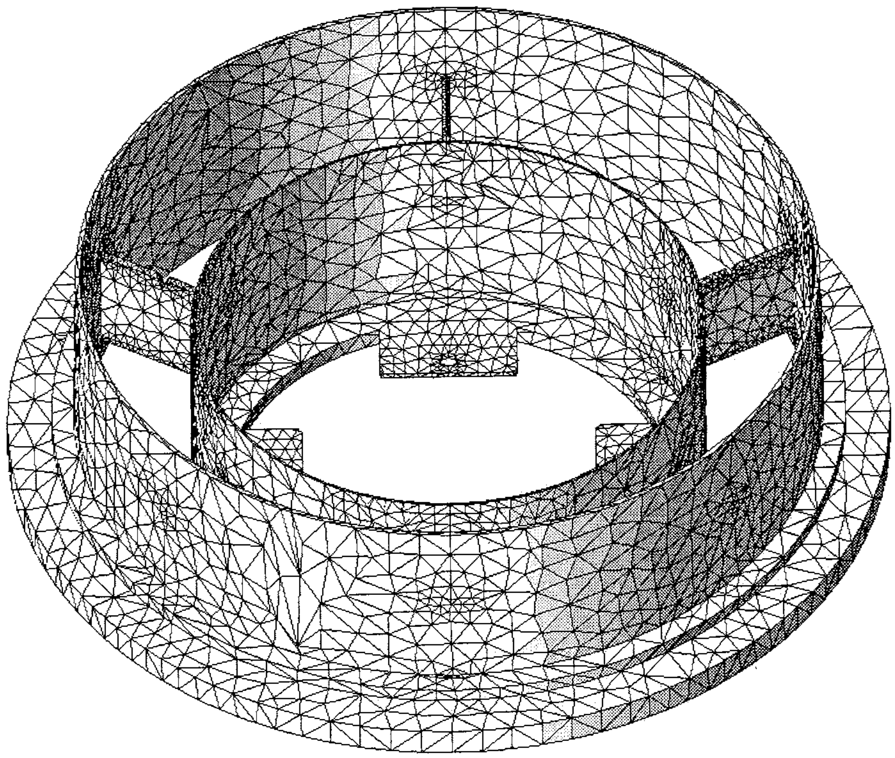


Figure 35 - Straight sided tetrahedral mesh for the model generated with curvature-dependent refinement and small segment checking

Table 20 : Mesh control parameters for PW_ncrsr2a1 (straight sided tetrahedral mesh)

Minimum element size	0.003
Maximum element size	0.01
Curvature refinement method	2
Maximum allowable geometric approximation	0.04
Check for small segments	1 (On)
Maximum requested longest edge to smallest edge ratio	20

Table 21 : Mesh statistics for PW_ncrsr2a1 (straight sided tetrahedral mesh)

Number of nodes	7150
Number of surface triangles	13482
Number of tetrahedrons	20927
Worst shape (**3r/R**)[a]	0.03
Smallest dihedral angle	2
Largest dihedral angle	163
Largest aspect ratio	27
Largest edge/ shortest height	34

a. **r** - radius of inscribed sphere, **R** - radius of circumscribed sphere

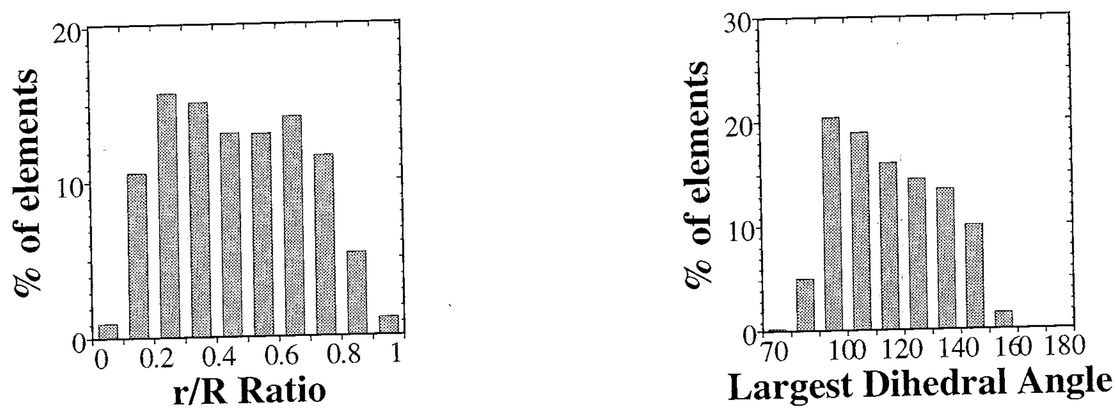


Figure 37 Histogram of element characteristics of straight-sided mesh of PW_ncrsr2a1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 22 : Mesh control parameters for PW_ncrsr2a1 (curved sided tetrahedral mesh)

Minimum element size	0.0045
Maximum element size	0.02
Curvature refinement method	2
Maximum allowable geometric approximation	0.4
Check for small segments	1 (On)
Maximum requested longest edge to smallest edge ratio	50

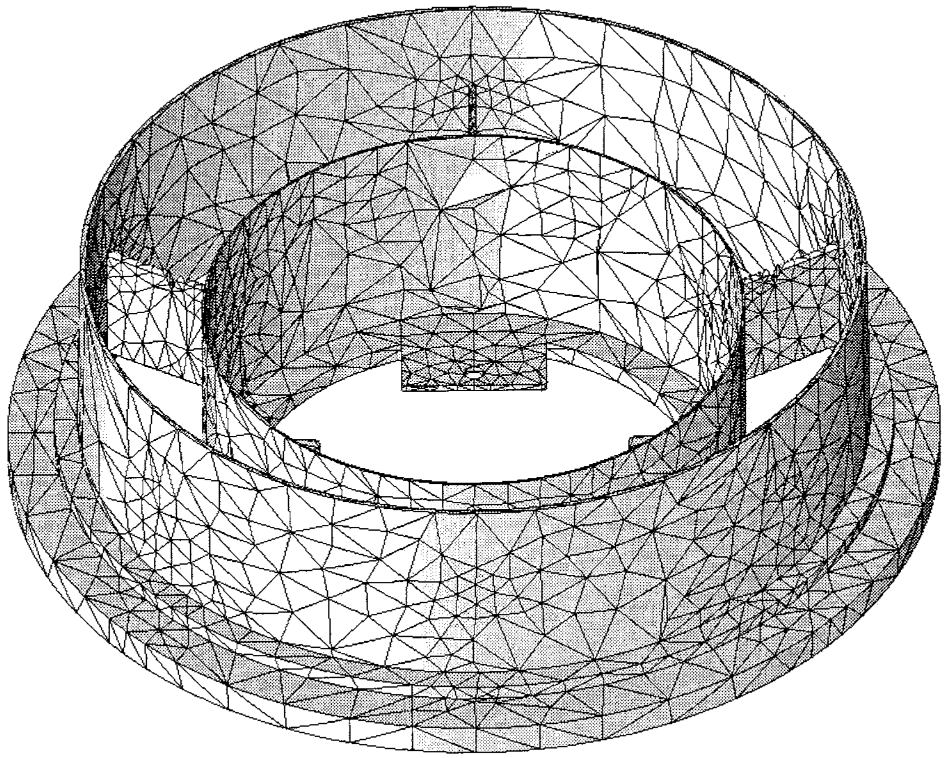
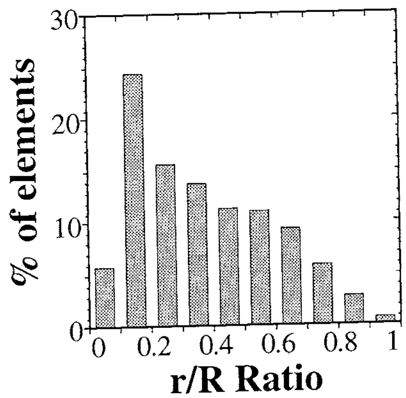


Figure 36 - Curved sided tetrahedral mesh for the model PW_ncrsr2a1.

Table 23 : Mesh statistics for PW_ncrsr2a1 (curved sided tetrahedral mesh)

Number of nodes	19148
Number of surface triangles	6352
Number of tetrahedrons	9368
Worst shape (**3r/R**)	0.02
Smallest dihedral angle	1
Largest dihedral angle	164
Largest edge/shortest edge	36
Largest edge/shortest height	51



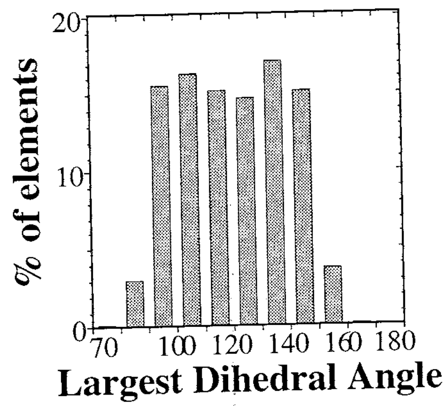


Figure 38 Histogram of element characteristics of curved-sided mesh of PW_ncrsr2a1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

204sprue_d1

I. Header Information

1. Problem name/ID number: 204sprue_d1
2. Communication #: 1
3. Organization sent by: PDA
4. Date sent: October 11, 1993
5. Organization received by: SCOREC, RPI
6. Date received: October 12, 1993
7. Retrieval of example: Edit e-mail, uudecode file and decompress
8. Type of file: UG part file
9. Picture of model: See Figure 39 on Page 47

II. Issues and Comments

Generate straight sided and curved sided tetrahedral meshes for example.

III. Discussion

The model consisted of an assembly of solid objects making the model a non-manifold model. Using procedures developed to build non-manifold representations from manifold models, the non-manifold model for this object was built and meshed.

IV. Results

Good straight sided meshes generated for this model.

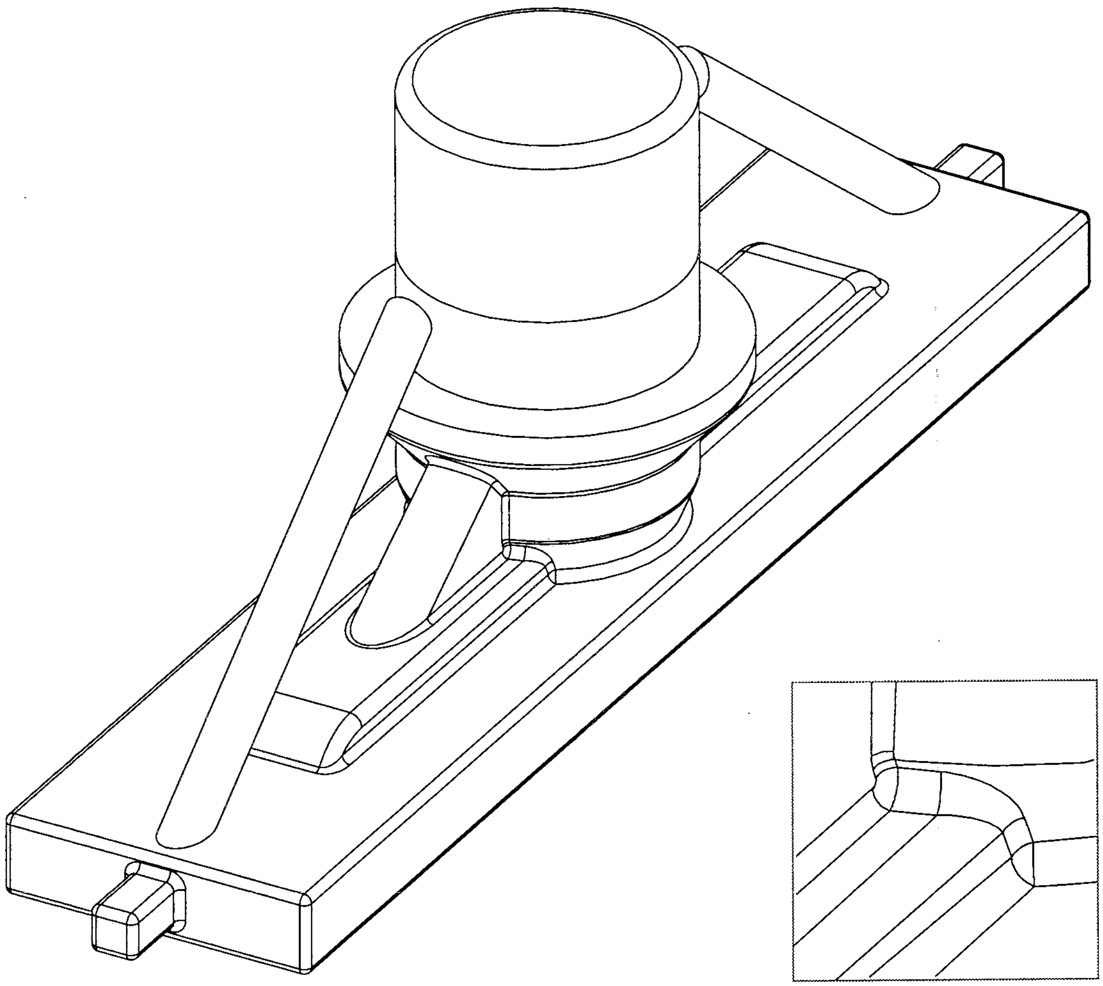


Figure 39 Geometric model of 204sprue and zoom in of fillets on model

Table 24 : Mesh control parameters for204sprue_d1 (straight sided tetrahedral mesh)

Minimum element size	0.005
Maximum element size	0.02
Curvature refinement method	2
Maximum allowable geometric approximation	0.04
Check for small segments	1 (On)
Maximum requested longest edge to smallest edge ratio	50

Table 25 Mesh statistics for 204sprue_d1 (straight sided tetrahedral mesh)

Number of nodes	5120
Number of surface triangles	6807
Number of tetrahedrons	20021
Worst shape (**3r/R**)	0.02
Smallest dihedral angle	4
Largest dihedral angle	167
Largest edge/shortest edge	16
Largest edge/ shortest height	22

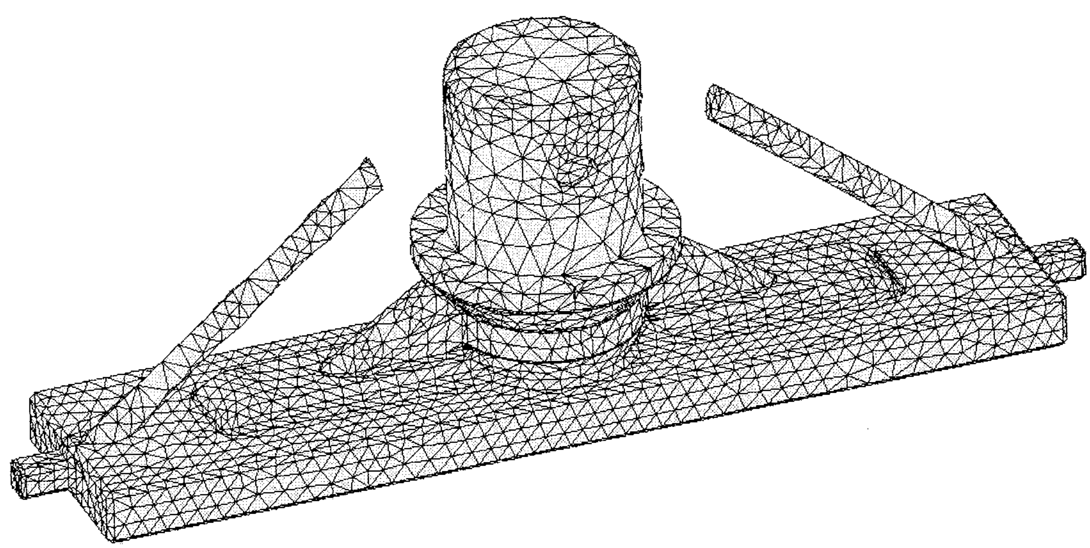


Figure 40 Straight sided tetrahedral mesh generated using curvature dependent refinement

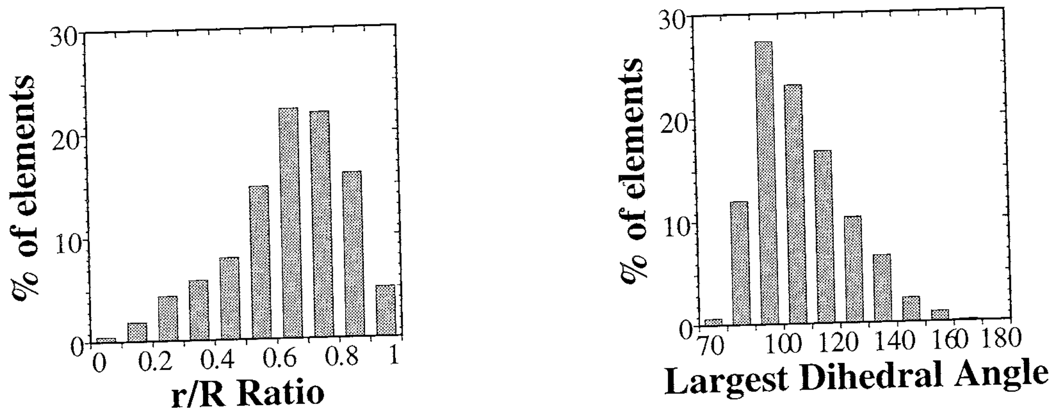


Figure 41 Histogram of element characteristics for straight-sided mesh of 204sprue_d1 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

11265sprue

I. Header Information

1.	Problem name/ID number:	11265sprue
2.	Communication #:	1
3.	Organization sent by:	PCC through PDA
4.	Date sent:	October, 93
5.	Organization received by:	SCOREC, RPI
6.	Date received:	October, 93
7.	Retrieval of example:	E-mail
8.	Type of file:	UG part file
9.	Picture of model:	See Figure 42 on Page 51

II. Issues and Comments on Initial Mesh

Good straight and curved-sided meshes requested.

III. Discussion

Meshes generated using a combination of curvature dependent refinement, small segment checking and small feature removal.

IV. Results

Good straight and curved sided meshes generated for model.

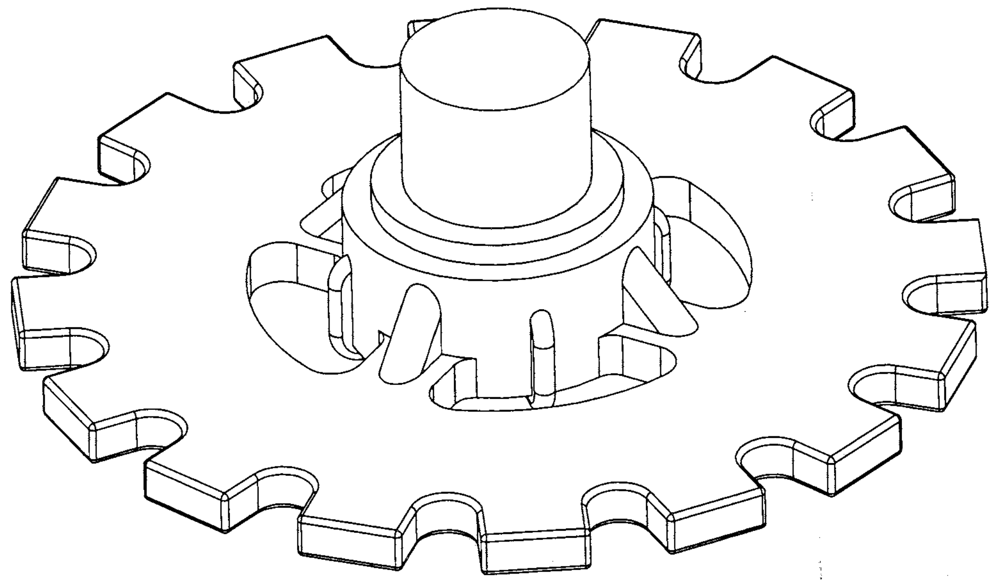


Figure 42 - Off top view of model 11265sprue

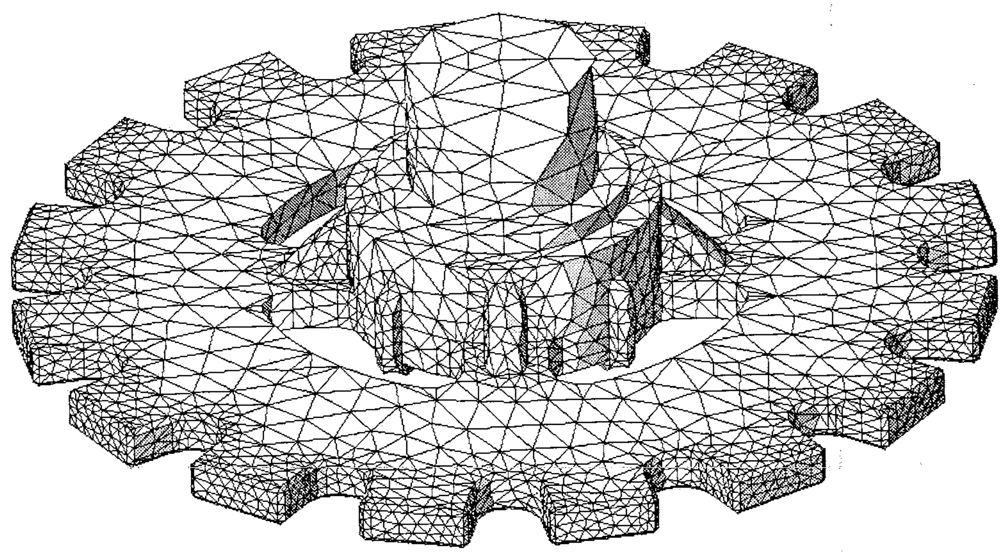


Figure 43 - Straight-sided tetrahedral mesh for 11265sprue with curvature-based refinement and small feature checking

Table 26 : Mesh control parameters for 11265sprue (straight sided tetrahedral mesh)

Minimum element size	0.0045
Maximum element size	.0365
Curvature refinement method	2
Maximum allowable geometric approximation	0.15

Table 27 Mesh statistics for 11265sprue (straight sided tetrahedral mesh)

Number of nodes	6820
Number of surface triangles	9666
Number of tetrahedrons	24602
Worst shape (**3r/R**)	0.1
Smallest dihedral angle	6
Largest dihedral angle	145
Largest edge/shortest edge	9
Largest edge/ shortest height	17

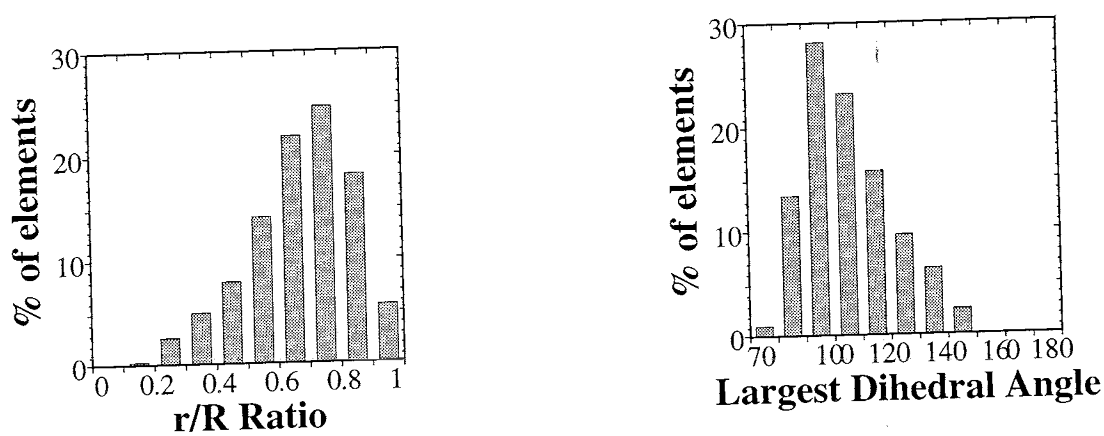


Figure 45 - Histogram of element characteristics for straight-sided mesh of 11265sprue (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

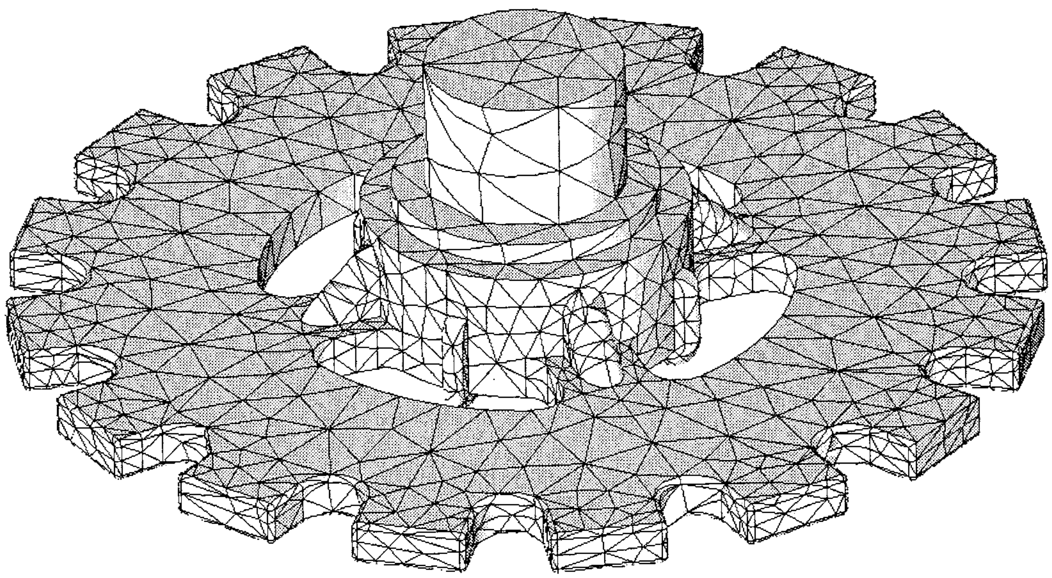


Figure 44 Curved-sided mesh generated by Finite Octree with retriangulation procedures for allowing curving of elements

Table 28 : Mesh control parameters (curved sided tetrahedral mesh)

Minimum element size	0.0045
Maximum element size	.0365
Curvature refinement method	2
Maximum allowable geometric approximation	0.15

Table 29 Mesh statistics for 11265sprue(curved sided tetrahedral mesh)

Number of nodes	14926
Number of surface triangles	4194
Number of tetrahedrons	7820
Worst shape (**3r/R**)	0.05
Smallest dihedral angle	6
Largest dihedral angle	161
Largest edge/shortest edge	13
Largest edge/ shortest height	19

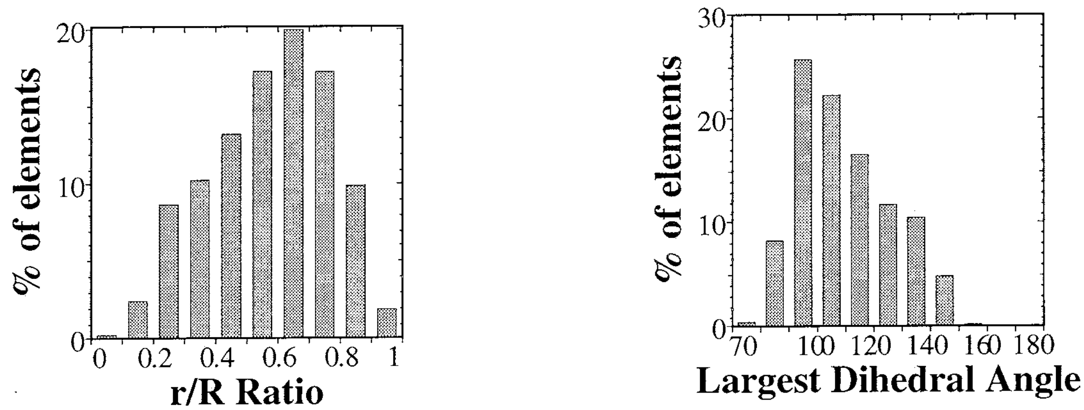


Figure 46 - Histogram of element characteristics for curved-sided mesh of 11265sprue (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

gegenblade2

I. Header Information

1.	Problem name/ID number:	gegenblade2
2.	Communication #:	1
3.	Organization sent by:	GE
4.	Date sent:	
5.	Organization received by:	SCOREC, RPI
6.	Date received:	
7.	Retrieval of example:	uudecode and uncompress mail file
8.	Type of file:	Parasolid transmit file
9.	Picture of model:	See Figure 47 on Page 56

II. Issues and Comments on Initial Mesh

Part does not mesh with Finite Octree in PATRAN3.

III. Discussion

Parasolid v5 could not mesh this model due to a missed edge-plane intersection. This was reported to Shape Data and was fixed in v6. The part was then successfully meshed by Finite Octree.

IV. Results

Good meshes were generated for the model.

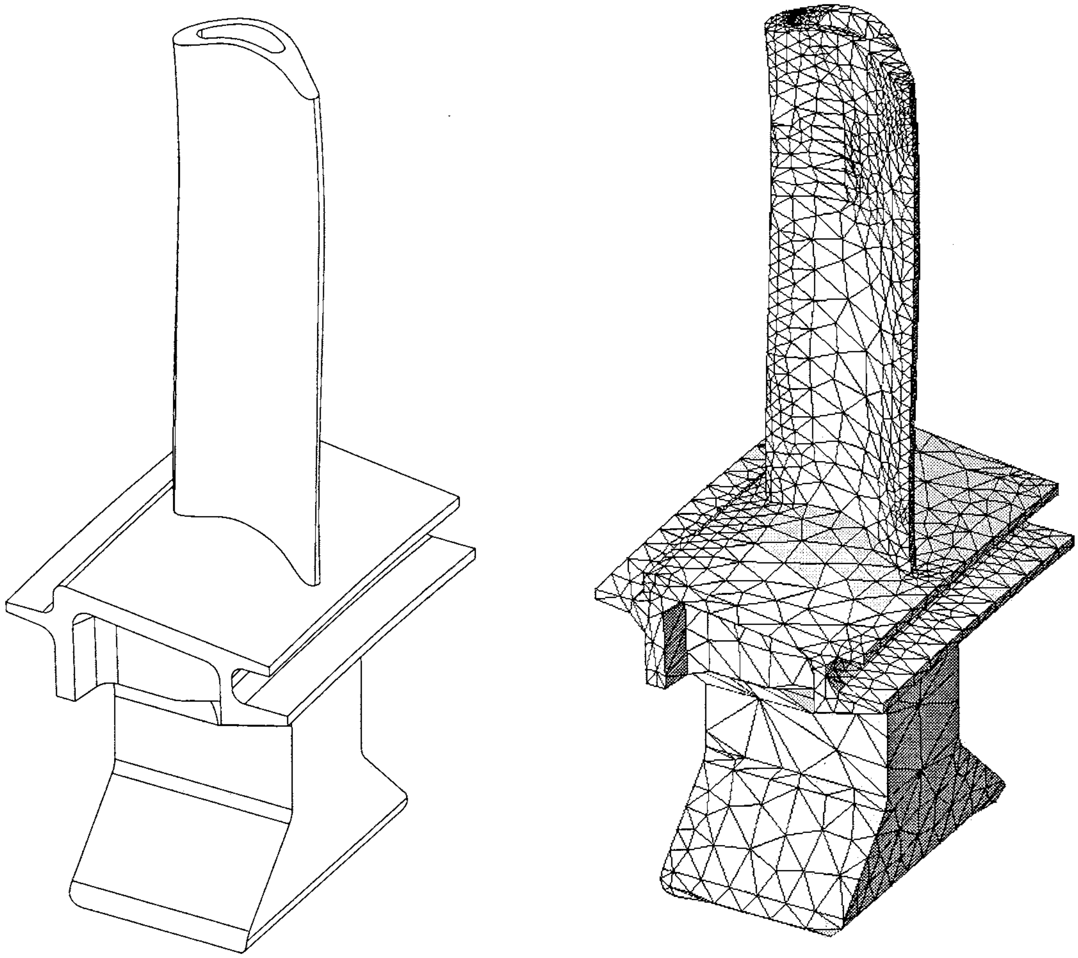


Figure 47 ICCA model gegenblade2 and Finite Octree mesh

Table 30 : Mesh control parameters (straight sided tetrahedral mesh)

Minimum element size	0.001
Maximum element size	0.009
Curvature refinement method	2
Maximum allowable geometric approximation	0.2
Check for small segments and refine	0 (Off)
Maximum requested longest edge to shortest edge ratio	10
Remove features smaller than 1/1000th of the model size	

Table 31 : Mesh statistics for gegenblade2 (straight sided tetrahedral mesh)

Number of nodes	3003
Number of surface triangles	4280
Number of tetrahedrons	10944
Worst shape (**3r/R**)	0.04
Smallest dihedral angle	3
Largest dihedral angle	156
Largest edge/shortest edge	17
Largest edge/ shortest height	20

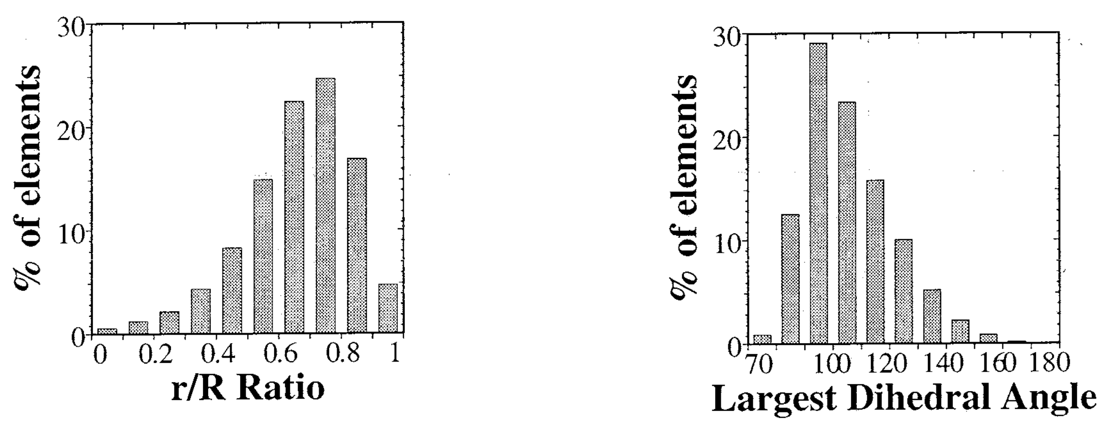


Figure 48 Histogram of element characteristics for straight-sided mesh of gegenblade2 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

gegennozzle, gegennozle_hollow, gegennozzle_blended

I. Header Information

1. Problem name/ID number:	gegennozzle, gegennozzle_hollow, gegennozzle_blended
2. Communication #:	1
3. Organization sent by:	GE
4. Date sent:	May 27, 94
5. Organization received by:	SCOREC, RPI
6. Date received:	May 27, 94
7. Retrieval of example:	uudecode and uncompress mail file
8. Type of file:	Parasolid transmit file
9. Picture of model:	See Figure 49 on Page 59

II. Issues and Comments for Initial Mesh

Part could not be meshed with Finite Octree in PATRAN3

III. Discussion

gegennozzle, gegenozzle_hollow and gegennozzle_blended are similar generic nozzle models from GE. All three were meshed with similar mesh controls.

IV. Results

Good meshes generated for models with curvature dependent refinement, small segment checking.

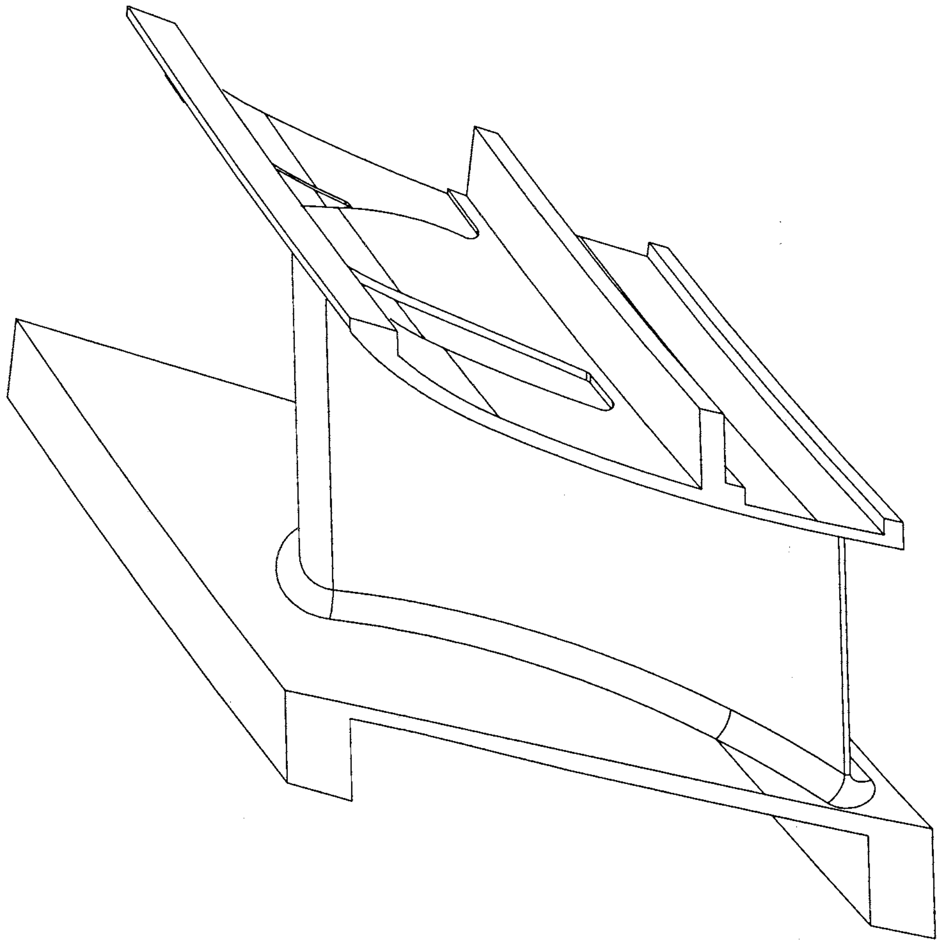


Figure 49 Isometric view of model gegennozzle

Table 32 : Mesh control parameters (straight sided tetrahedral mesh)

Minimum element size	0.003
Maximum element size	0.011
Curvature refinement method	2
Maximum allowable geometric approximation	0.1
Check for small segments and refine	1 (On)
Maximum requested longest edge to shortest edge ratio	10

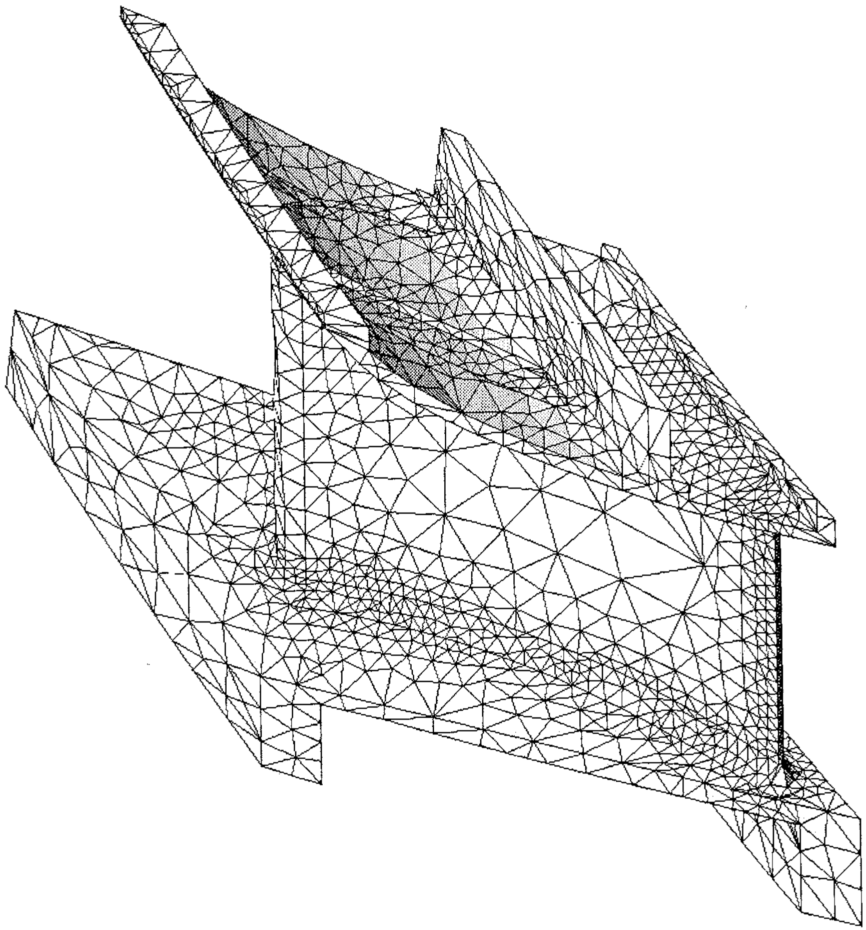
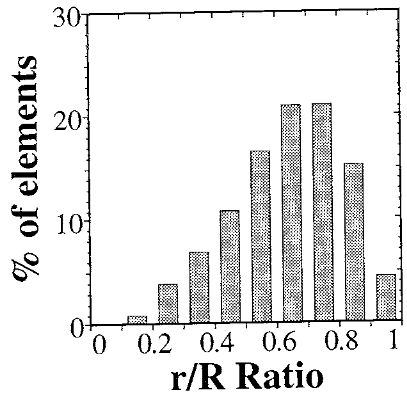


Figure 50 Straight sided tetrahedral mesh for the model generated with curvature-dependent refinement

Table 33 : Mesh statistics for gegennozzle (straight sided tetrahedral mesh)

Number of nodes	4436
Number of surface triangles	6594
Number of tetrahedrons	16286
Worst shape (**3r/R**)	0.06
Smallest dihedral angle	7
Largest dihedral angle	152
Largest edge/shortest edge	10
Largest edge/ shortest height	15



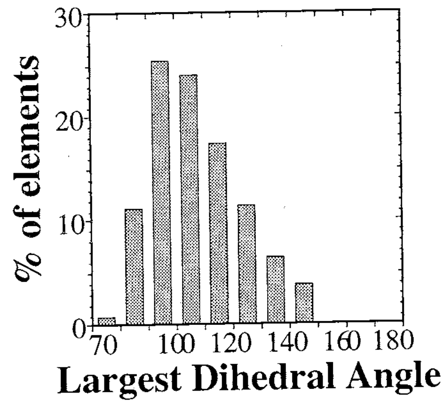
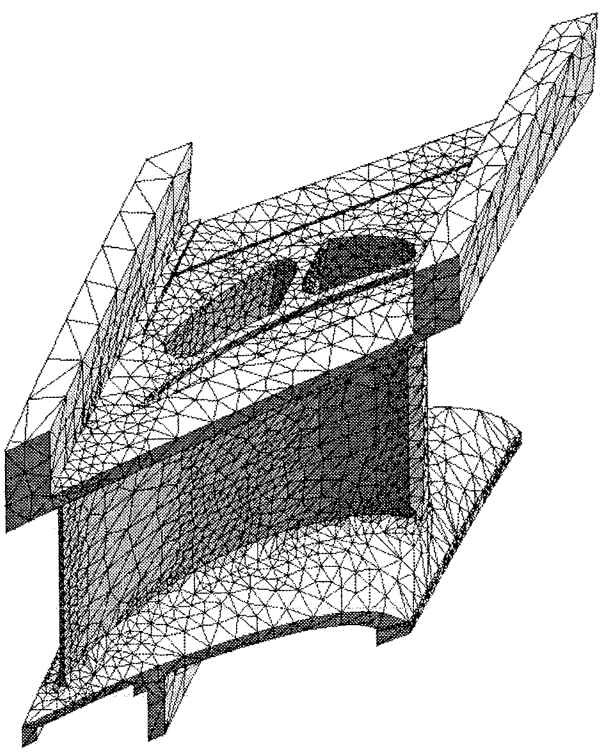


Figure 51 Histogram of element characteristics for straight-sided mesh of gegennozzle (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements



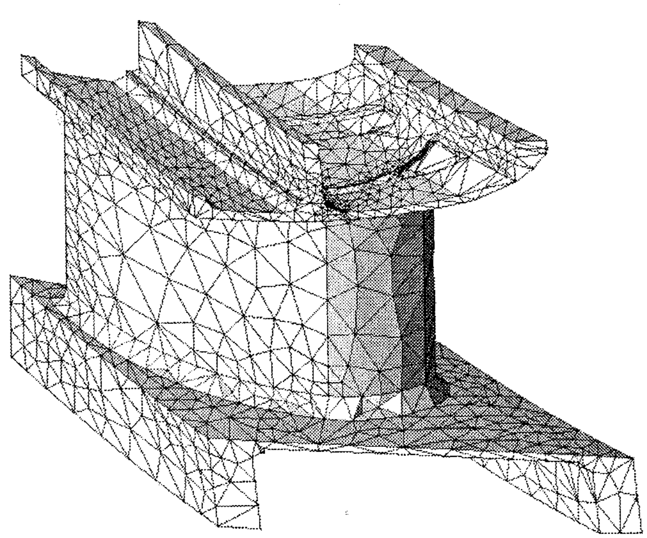


Figure 52 Meshes for gegennozzle_blended and gegennozzle_hollow

airfoil, 1fv102, 1fv1027688

I. Header Information

1. Problem name/ID number: airfoil, 1fv102, 1fv1027688
2. Communication #: 1
3. Organization sent by: PW
4. Date sent: October 94
5. Organization received by: SCOREC, RPI
6. Date received: October 94
7. Retrieval of example: tar xvf <device_name>
8. Type of file: Parasolid transmit files
9. Picture of model: See Figure 53 on Page 63

II. Issues and Comments on Initial Mesh

Models could be meshed by Finite Octree but were not of satisfactory quality.

III. Discussion

The models have a large number of small faces on the sides of the airfoils (see Figure 53). If the mesh is too coarse near the sides, meshes with large number of connections at a few vertices result. Due to the particular characteristics of the model and the mesh topology, mesh optimization procedures may be constrained in improving the mesh. Therefore, it is desirable to apply mesh controls such that the element sizes in the vicinity shown are on the order of the size of the "square" faces on the sides of the airfoil.

IV. Results

Good meshes generated for the model using knowledge of model features described above and applying suitable mesh controls.

Table 34 : Mesh control parameters for 1fv102 (straight sided tetrahedral mesh)

Minimum element size	0.0019
Maximum element size	0.0075
Curvature refinement method	2
Maximum allowable geometric approximation	0.3
Check for small segments	1 (On)
Maximum allowable longest edge to shortest edge ratio	25
Eliminate mesh features smaller than 1/1000th of the model size	

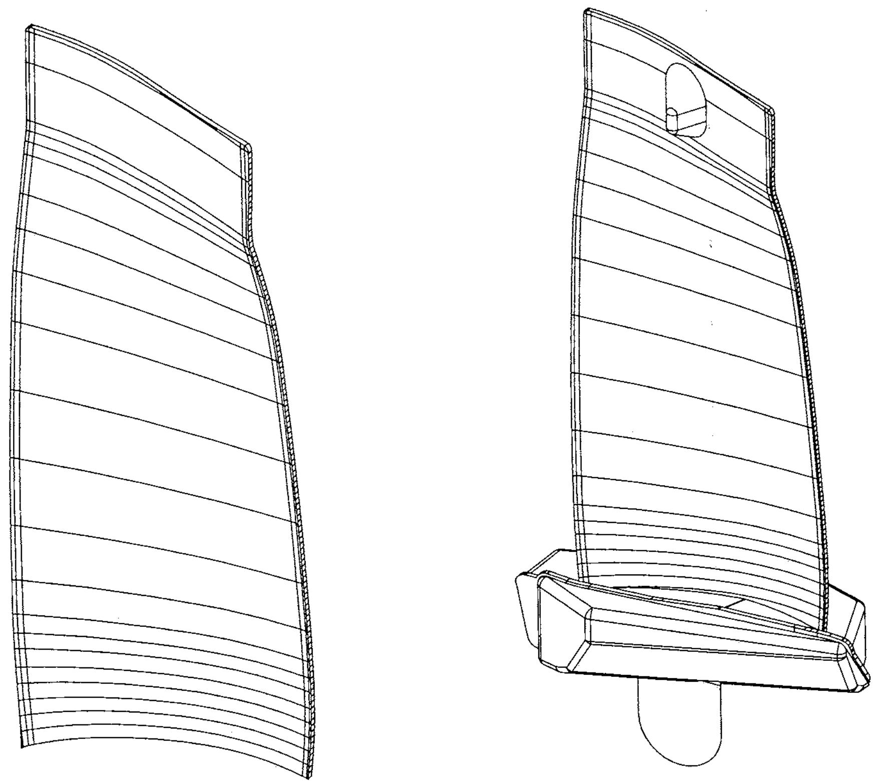


Figure 53 Geometric models airfoil and 1fv102 (1fv1027688 is similar to 1fv102)

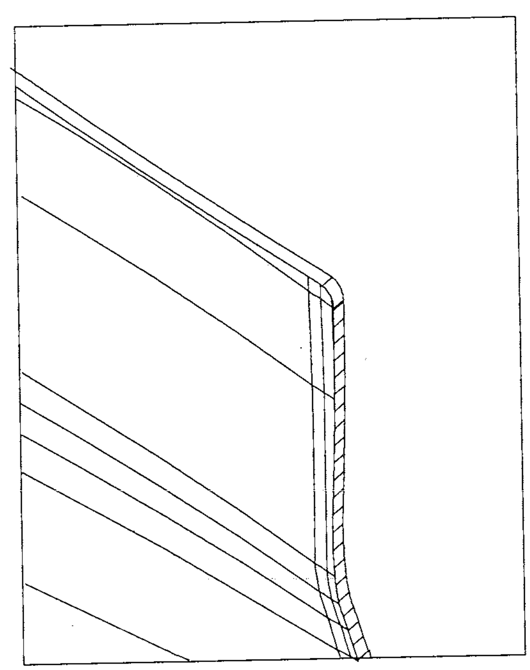


Figure 54 Zoom-in of side of airfoil. This topology can cause some mesh vertices to have large number of connections if the mesh is too coarse.

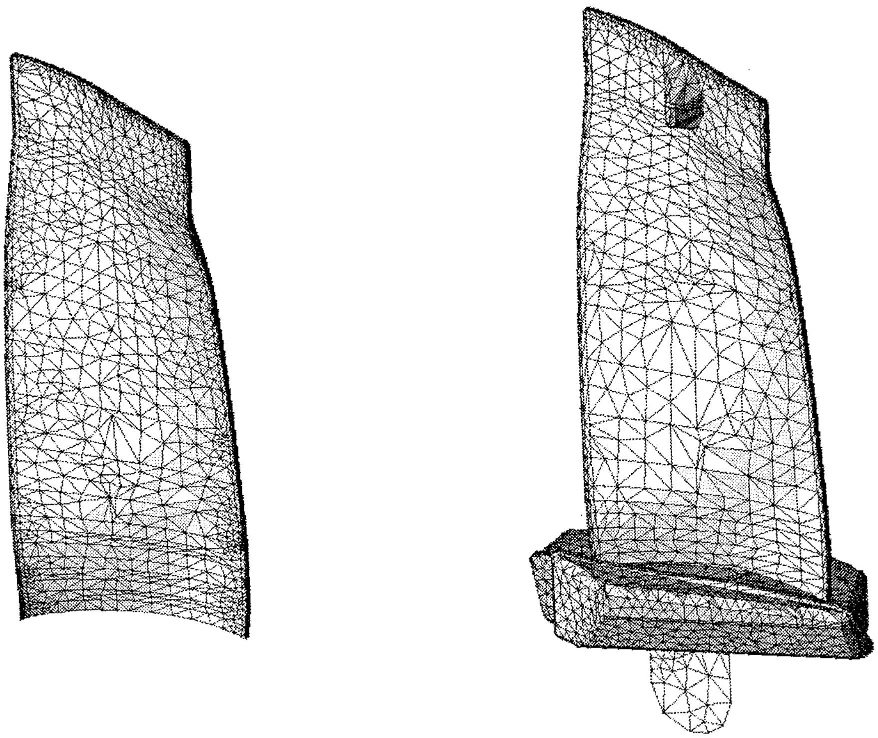
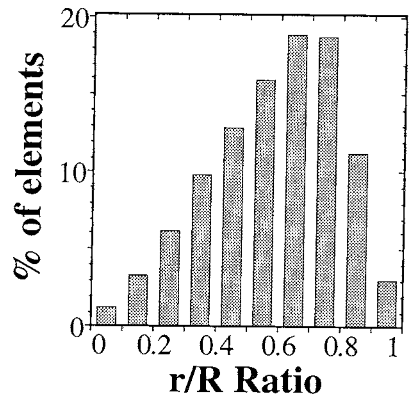


Figure 55 Straight sided tetrahedral meshes for airfoil and 1fv102

Table 35 : Mesh statistics for 1fv102 (straight sided tetrahedral mesh)

Number of nodes	4384
Number of surface triangles	6846
Number of tetrahedrons	14720
Worst shape (**3r/R**)	0.02
Smallest dihedral angle	3
Largest dihedral angle	166
Largest edge/shortest edge	29
Largest edge/ shortest height	45



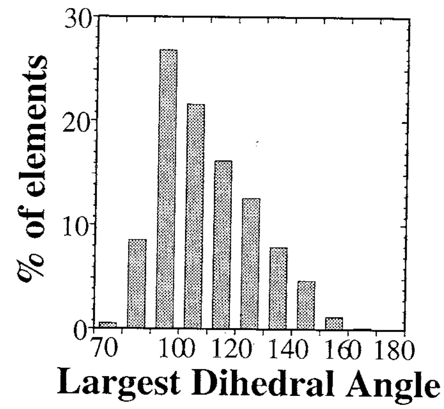


Figure 56 Histogram of element characteristics for straight-sided mesh of 1fv102 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

11219sprue

I. Header Information

1.	Problem name/ID number:	11219sprue
2.	Communication #:	1
3.	Organization sent by:	PCC through PDA
4.	Date sent:	October 12, 93
5.	Organization received by:	SCOREC, RPI
6.	Date received:	October 12, 93
7.	Retrieval of example:	E-mail
8.	Type of file:	UG part file
9.	Picture of model:	See Figure 57 on Page 67

II. Issues and Comments on Initial Mesh

Good meshes requested for model

III. Discussion

The model contains a number of small features, curved faces and small segments. These were taken into account while applying the mesh controls.

IV. Results

Good straight sided meshes obtained for model using Finite Octree.

Table 36 : Mesh control parameters (straight sided tetrahedral mesh)

Minimum element size	0.005
Maximum element size	0.02
Curvature refinement method	2
Maximum allowable geometric approximation	0.3
Check for small segments	1 (On)
Remove small features smaller than 1/200 of the model size and connected to elements with longest to shortest edge ratio greater than 5	

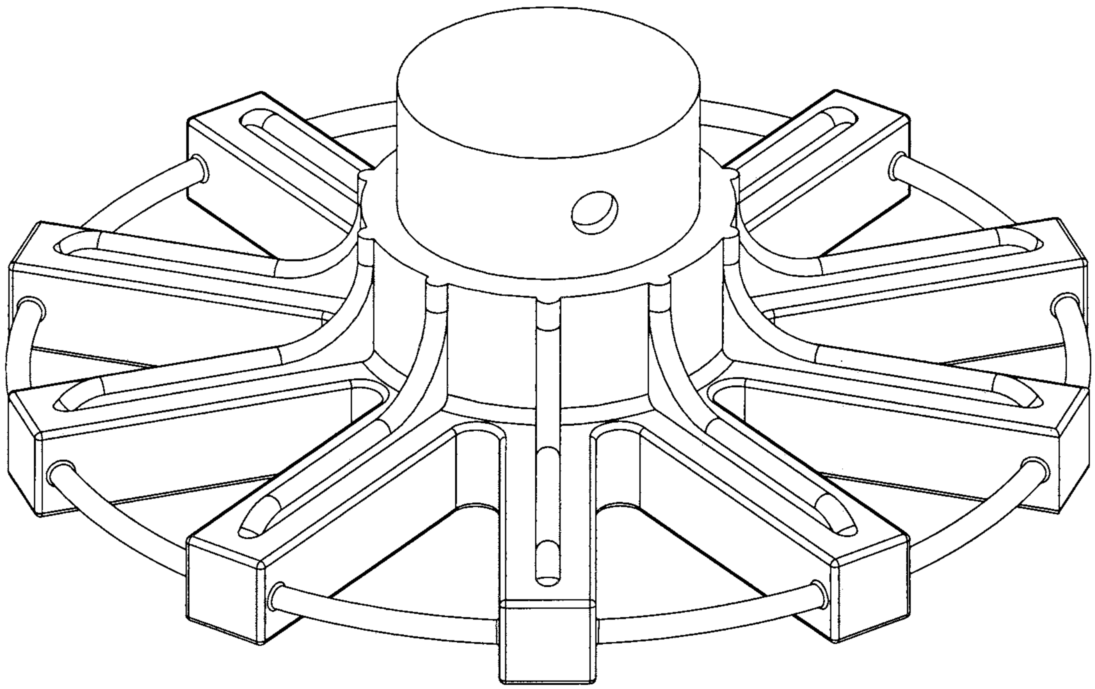


Figure 57 - Off top view of model 11219sprue

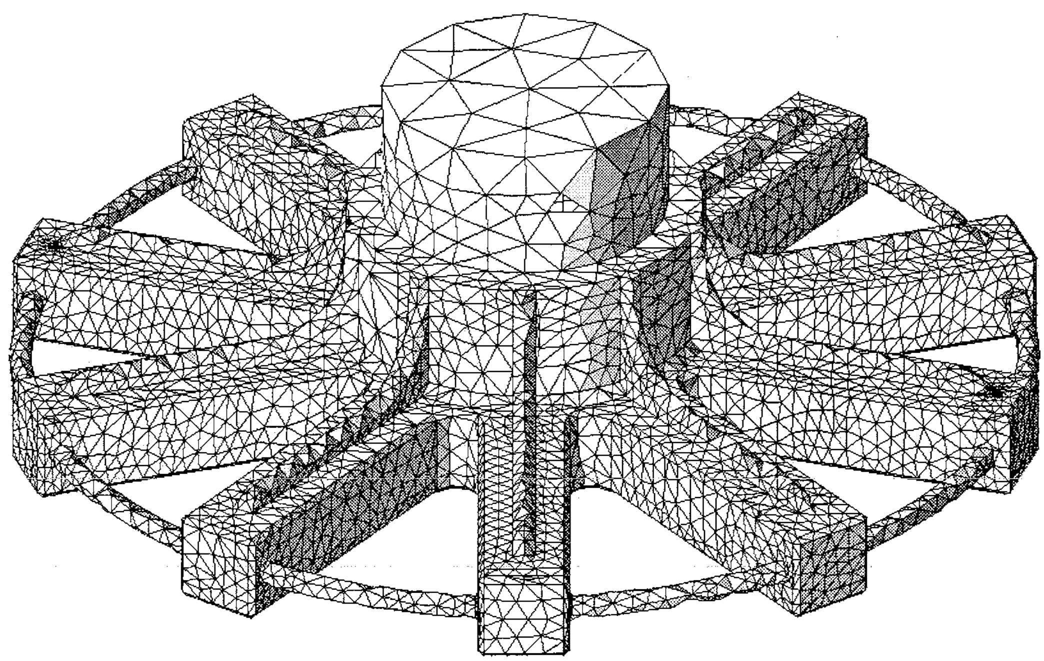


Figure 58 - Straight-side tetrahedral mesh for 11219sprue

Table 37 Mesh statistics for 11219sprue(straight sided tetrahedral mesh)

Number of nodes	12087
Number of surface triangles	14966
Number of tetrahedrons	47465
Worst shape (**3r/R**)	0.02
Smallest dihedral angle	1
Largest dihedral angle	153
Largest edge/shortest edge	80
Largest edge/ shortest height	109

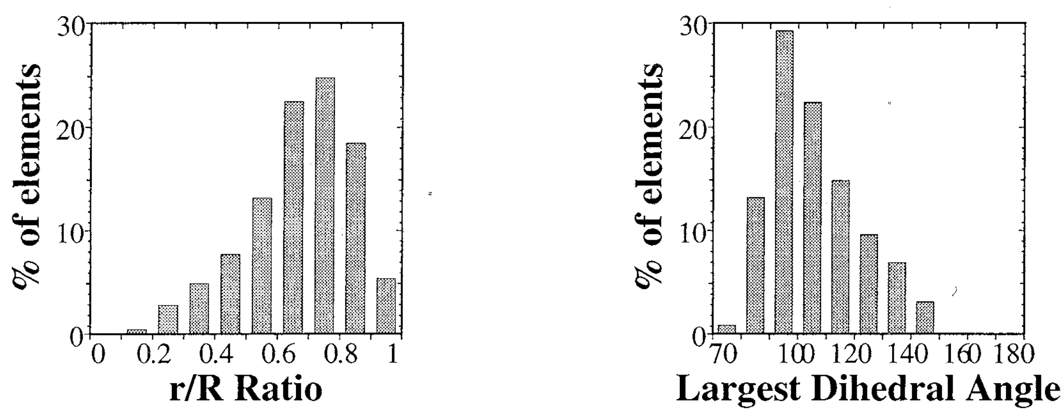


Figure 59 Histogram of element characteristics for straight-sided mesh of 11219sprue(a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

gate3

I. Header Information

1. Problem name/ID number: gate3
2. Communication #: 1
3. Organization sent by: PDA
4. Date sent:
5. Organization received by: SCOREC, RPI
6. Date received:
7. Retrieval of example:
8. Type of file: Parasolid transmit file
9. Picture of model: See Figure 60 on Page 70

II. Issues and Comments on Initial Mesh

Good meshes requested for model.

III. Discussion

This model had number of small features which were identified and eliminated by the small feature elimination procedure in Finite Octree.

IV. Results

Meshes of good quality generated with improved versions of Finite Octree.

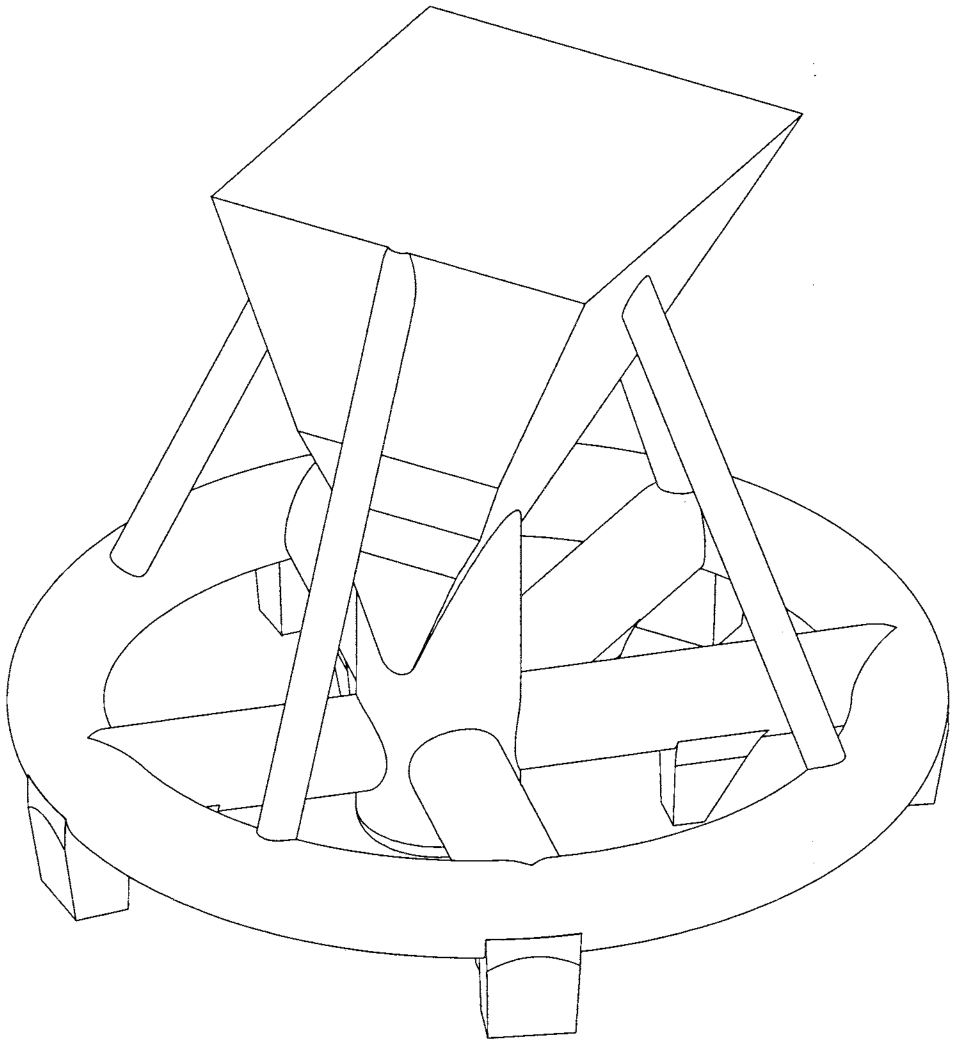
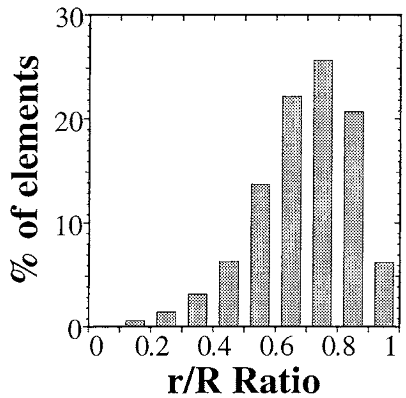


Figure 60 Isometric view of model gate3

Table 38 : Mesh control parameters (straight sided tetrahedral mesh)

Minimum element size	0.005
Maximum element size	0.02
Curvature refinement method	2
Maximum allowable geometric approximation	0.15
Check for small segments	0 (Off)
Eliminate mesh features smaller than 1/2000th of the model size	



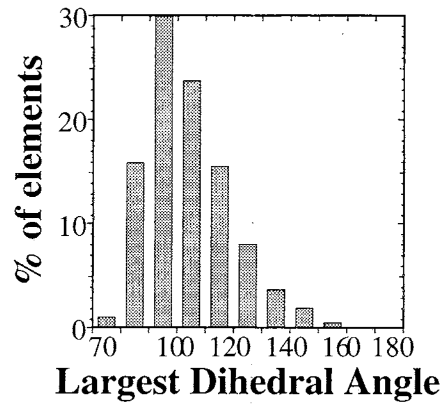


Figure 62 Histogram of element characteristics for straight-sided mesh (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 39 : Mesh statistics (straight sided tetrahedral mesh)

Number of nodes	4305
Number of surface triangles	6032
Number of tetrahedrons	15066
Worst shape (**3r/R**)	0.08
Smallest dihedral angle	5
Largest dihedral angle	153
Largest edge/shortest edge	12
Largest edge/ shortest height	18

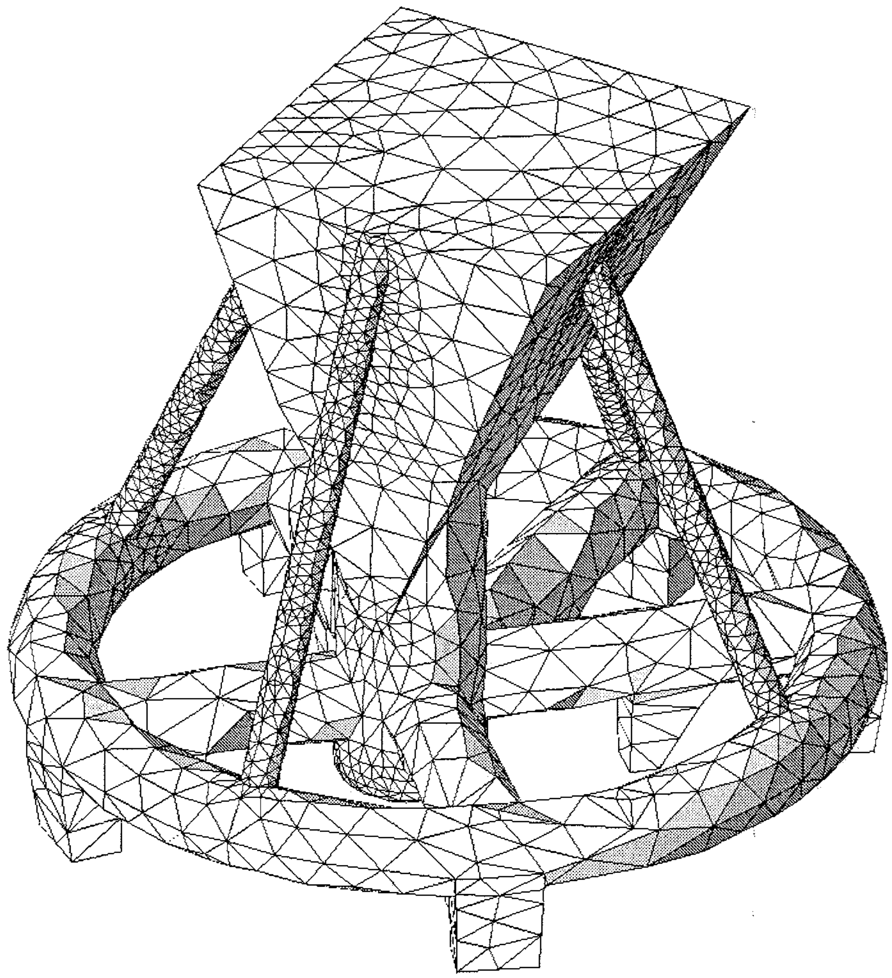


Figure 61 Straight sided tetrahedral mesh for gate3 generated with curvature-dependent refinement

laportwheel, ncrsr_g1f1, ncrsr_g1n1, ncrsr_w1f1, ncrsr_w1n1, v10-pw-rsr1f

I. Header Information

1.	Problem name/ID number:	laportwheel
2.	Communication #:	1
3.	Organization sent by:	HC
4.	Date sent:	September 27, 93
5.	Organization received by:	SCOREC, RPI
6.	Date received:	October 1, 93
7.	Retrieval of example:	Sun 3.5" floppy diskette execute "bar xvf /dev/rfd0c laportwheel.prt"
8.	Type of file:	UG part file
9.	Picture of model:	See Figure 63 on Page 74

II. Issues and Comments

1. Simple ring-strut-ring arrangement without fillets.
2. Finite Octree mesh with default parameters was not satisfactory. Request made to demonstrate the use of mesh controls to get good tetrahedral meshes for the model.

III. Discussion and Results

Straight sided meshes were generated by Finite Octree with suitable mesh controls.

ncrsr_g1f1, ncrsr_w1f1, ncrsr_g1n1, ncrsr_w1n1 and v10-pw-rsr1f are models similar to laportwheel and PW_ncrsr2a1. Satisfactory results similar to the results for laportwheel were obtained for these models.

Table 40 : Mesh control parameters for laportwheel (straight sided tetrahedral mesh)

Minimum element size	0.015
Maximum element size	0.03
Curvature refinement method	2
Maximum allowable geometric approximation	0.3
Check for small segments	1 (On)
Maximum requested longest edge to smallest edge ratio	5

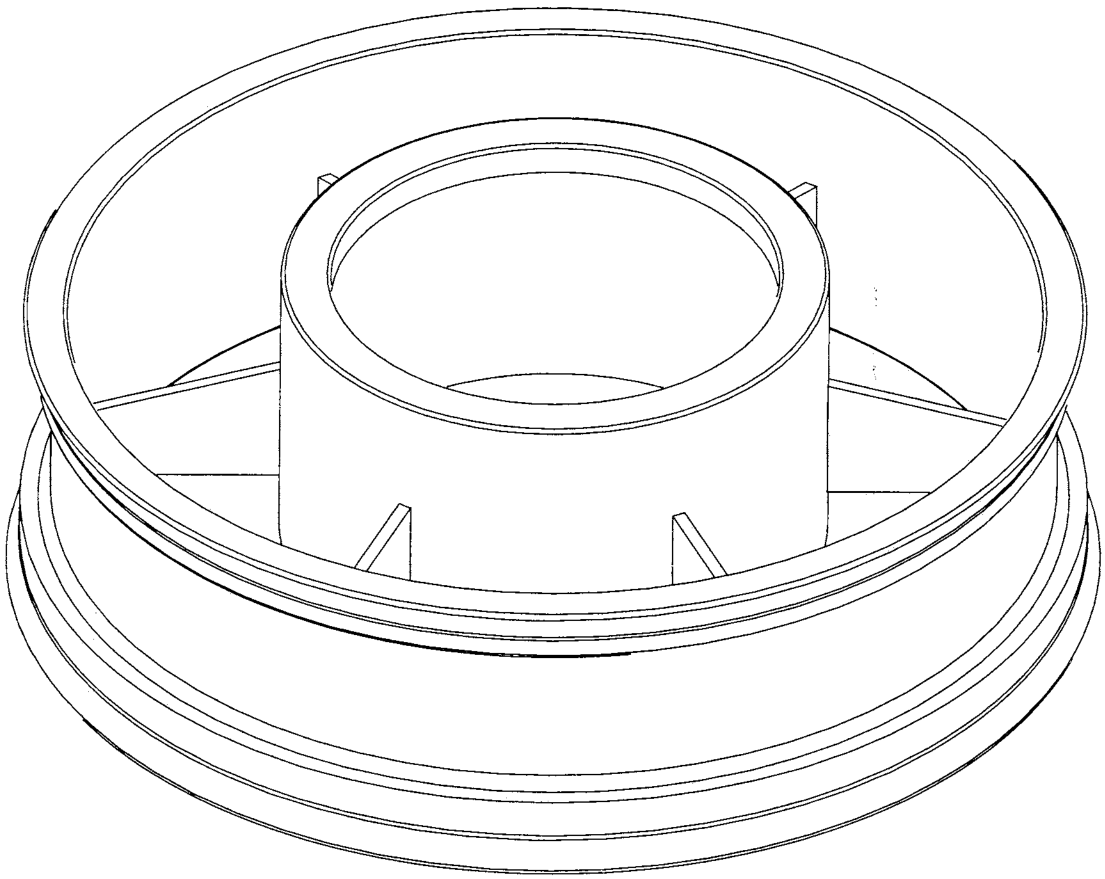


Figure 63 -View of model laportwheel

Table 41 : Mesh statistics for laportwheel (straight sided tetrahedral mesh)

Number of nodes	18617
Number of surface triangles	24220
Number of tetrahedrons	72527
Worst shape (**3r/R**)	0.04
Smallest dihedral angle	3
Largest dihedral angle	157
Largest aspect ratio	15
Largest edge/ shortest height	22

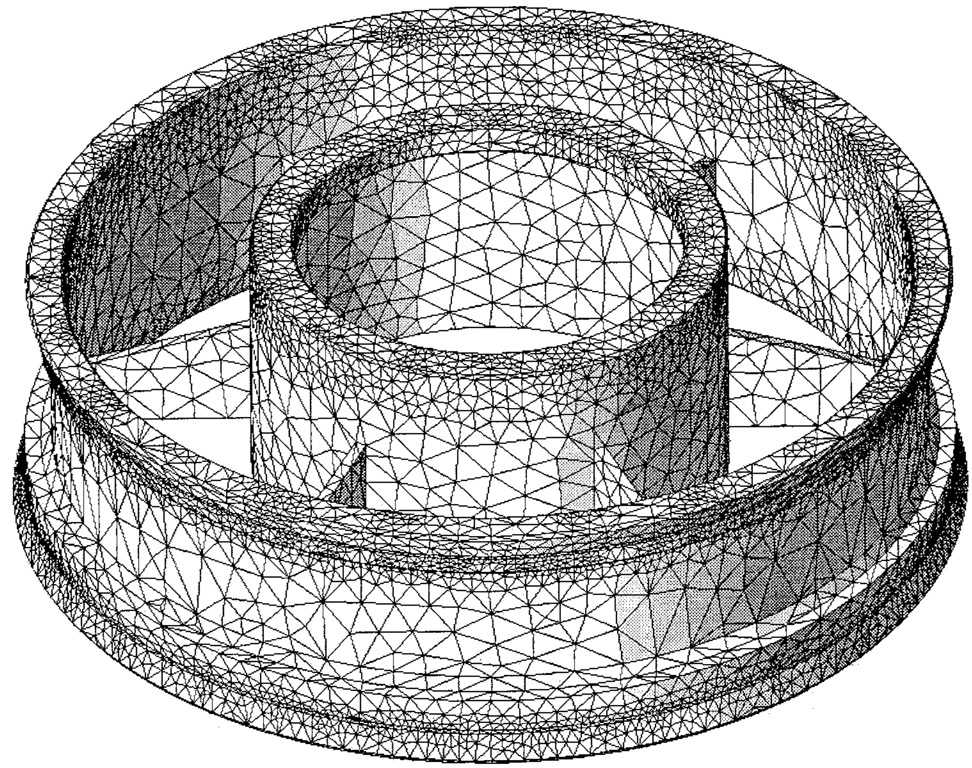


Figure 64 - Straight sided tetrahedral mesh for the model

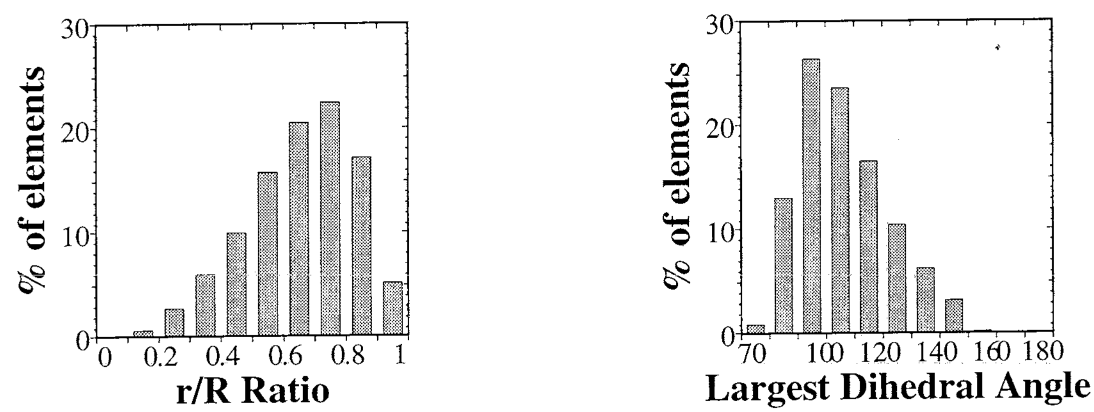


Figure 65 Histogram of element characteristics of straight-sided mesh of laportwheel (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

test8_blended, test8_blocked

I. Header Information

1.	Problem name/ID number:	test8_blended, test8_blocked
2.	Communication #:	1
3.	Organization sent by:	HC
4.	Date sent:	
5.	Organization received by:	SCOREC, RPI
6.	Date received:	
7.	Retrieval of example:	Sun 1/4" magnetic tape
8.	Type of file:	UG part file
9.	Picture of model:	See Figure 66 on Page 77

II. Issues and Comments

1. Models are multi-material and constructed in UG as assemblies of objects.
2. Preprocessing of assembly required to build non-manifold model for meshing.
3. test8_blocked is similar to test8_blended except that it lacks edge blends.

III. Discussion

1. Developed capability to build non-manifold representation for meshing by Finite Octree starting from an assembly of solid objects.
2. Meshes were generated for each of the models by Finite Octree with suitable mesh controls.

IV. Results

Good quality meshes were obtained from Finite Octree.

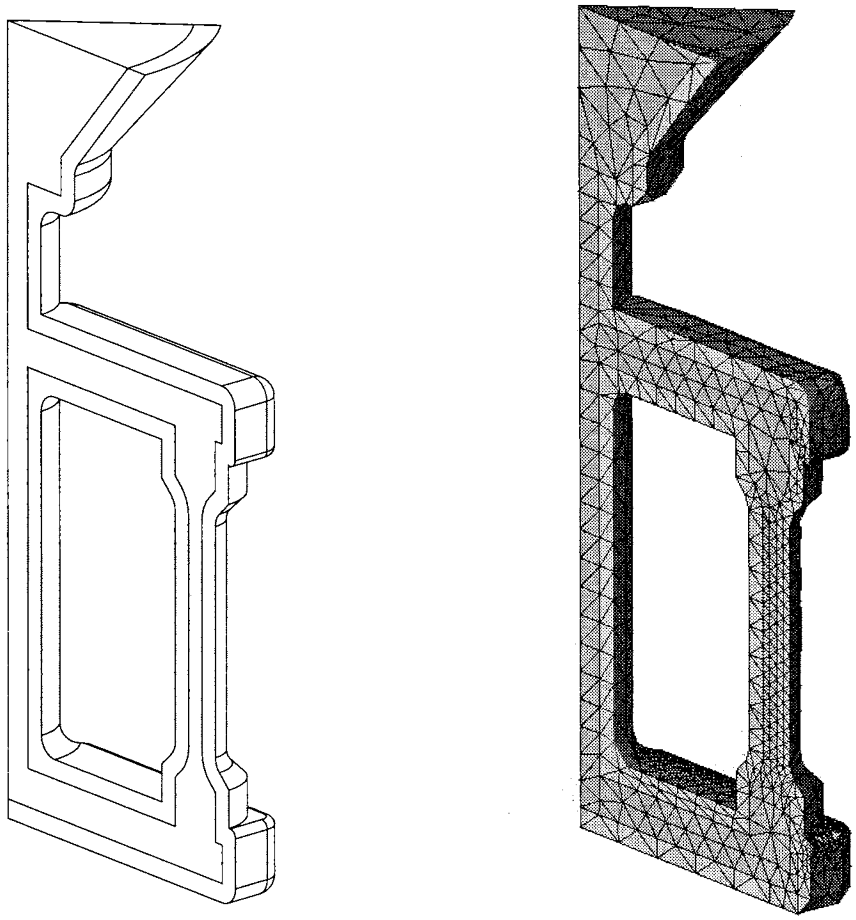


Figure 66 - (a) Picture of model test8_blended (b) Straight sided tetrahedral mesh generated by current Finite Octree

Table 42 : Mesh control parameters for test8_blended (straight sided tetrahedral mesh)

Minimum element size	0.002
Maximum element size	0.016
Curvature refinement method	2
Maximum allowable geometric approximation	0.15
Check for small segments	1 (On)
Maximum requested longest edge to smallest edge ratio	30

Table 43 : Mesh statistics for test8_blended (straight sided tetrahedral mesh)

Number of nodes	2667
Number of surface triangles	3965
Number of tetrahedrons	10667
Worst shape (**3r/R**)	0.05
Smallest dihedral angle	5
Largest dihedral angle	149
Largest aspect ratio	9
Largest edge/ shortest height	20

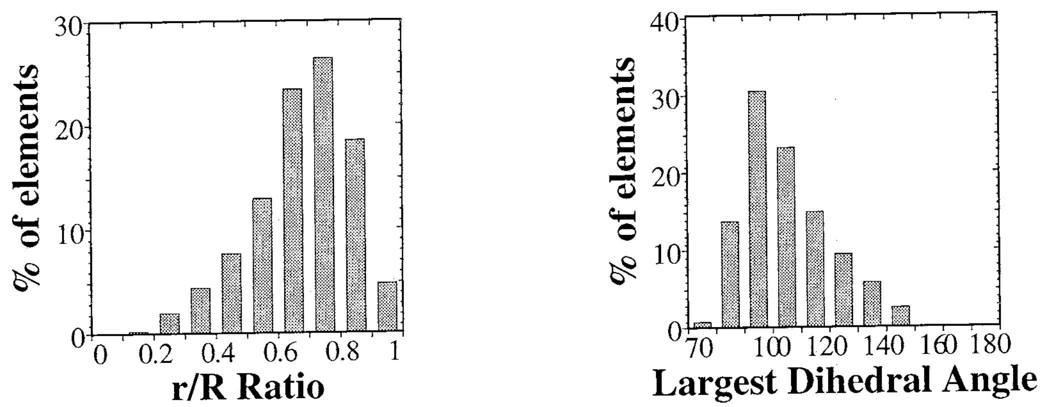


Figure 67 Histogram of element characteristics of straight-sided mesh of test8_blended (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

test9

I. Header Information

1.	Problem name/ID number:	test9
2.	Communication #:	1
3.	Organization sent by:	HC
4.	Date sent:	
5.	Organization received by:	SCOREC, RPI
6.	Date received:	
7.	Retrieval of example:	Sun 1/4” magnetic tape
8.	Type of file:	UG part file
9.	Picture of model:	See Figure 68 on Page 80

II. Issues and Comments on Initial Mesh

Good meshes requested for model

III. Discussion

Straight sided and curved sided tetrahedral meshes was generated for each of the models by Finite Octree with suitable mesh controls. The initial mesh was examined to detect the cause for some poor shaped elements. This revealed some small features in the model. The model was then meshed once more with appropriate modifications to the mesh controls.

IV. Results

Good meshes generated for model.

Table 44 : Mesh control parameters for test9 (straight sided tetrahedral mesh)

Minimum element size	0.005
Maximum element size	0.01
Curvature refinement method	2
Maximum allowable geometric approximation	0.3
Check for small segments	1 (On)
Maximum requested longest edge to smallest edge ratio	10
Remove small feature smaller than size	0.001

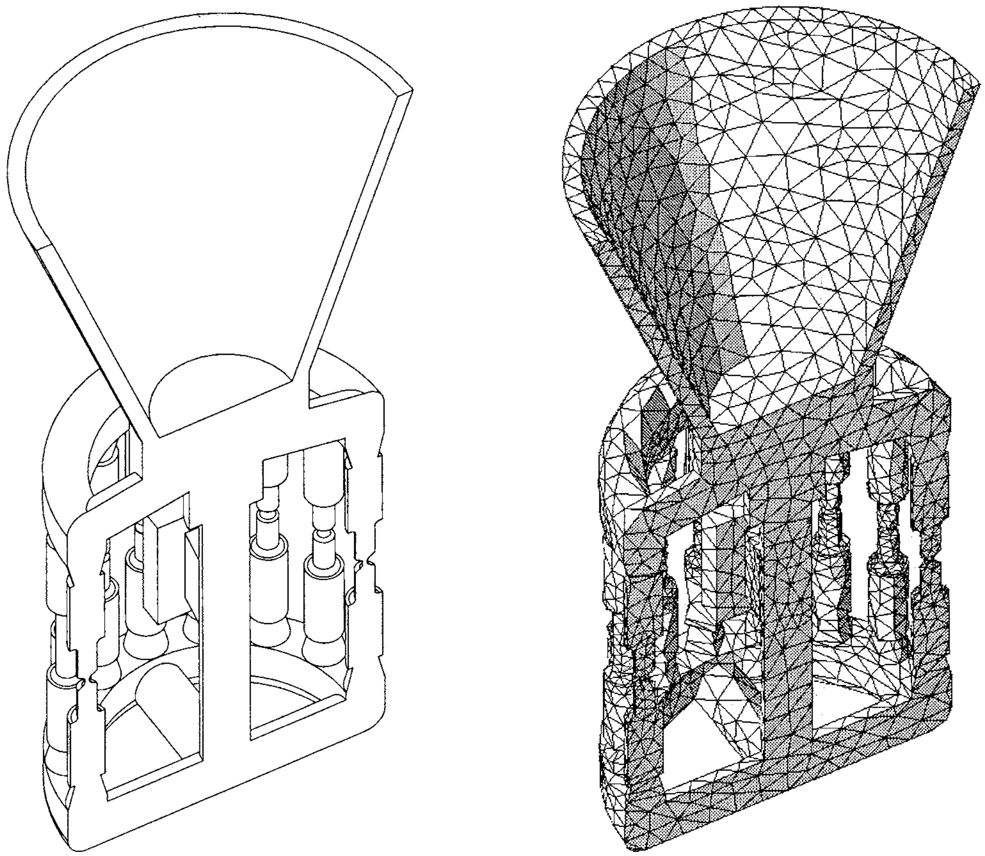
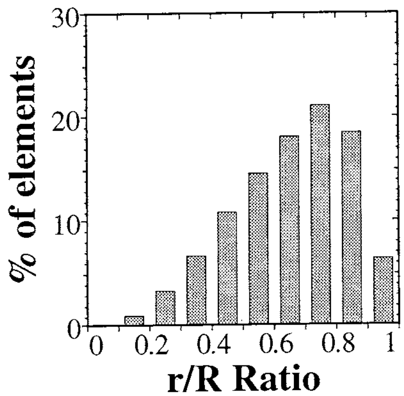


Figure 68 - Model and Finite Octree mesh of test9

Table 45 : Mesh statistics for test9 (straight sided tetrahedral mesh)

Number of nodes	4080
Number of surface triangles	6998
Number of tetrahedrons	11977
Worst shape (**3r/R**)	0.04
Smallest dihedral angle	5
Largest dihedral angle	154
Largest aspect ratio	13
Largest edge/ shortest height	18



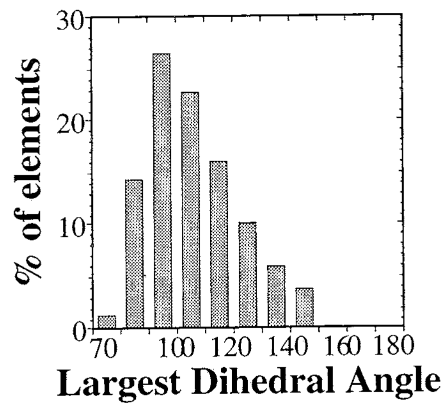


Figure 69 Histogram of element characteristics of straight-sided mesh of test9 (a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

final_c1, final_r1

I. Header Information

1. Problem name/ID number: final_c1
2. Communication #: 1
3. Organization sent by: PCC
4. Date sent: February 9, 94
5. Organization received by: SCOREC, RPI
6. Date received: February 9, 94
7. Retrieval of example:
8. Type of file: Parasolid transmit file
9. Picture of model: See Figure 70 on Page 83

II. Issues and Comments on Initial Mesh

PCC encountered difficulty in meshing model with Finite Octree in PATRAN.

III. Discussion

Attempts at meshing this model led to discovery of an error in the geometric model which was reported to PCC. Then the model was modified (final_r1) to remove the defective model entity by punching a hole larger than the problem hole and the meshing tried on this valid model. This uncovered a missed intersection by the modeler. This was communicated to the appropriate team at Shape Data, England. Later releases of Parasolid fixed the missed intersection problem.

IV. Results

The initial meshes were debugged to locate the cause of poorly shaped elements. This led to the identification of small features in the model and a deficiency in the mesh optimization code. Changes were made to the mesh controls and good meshes were obtained with an improved version of Finite Octree.

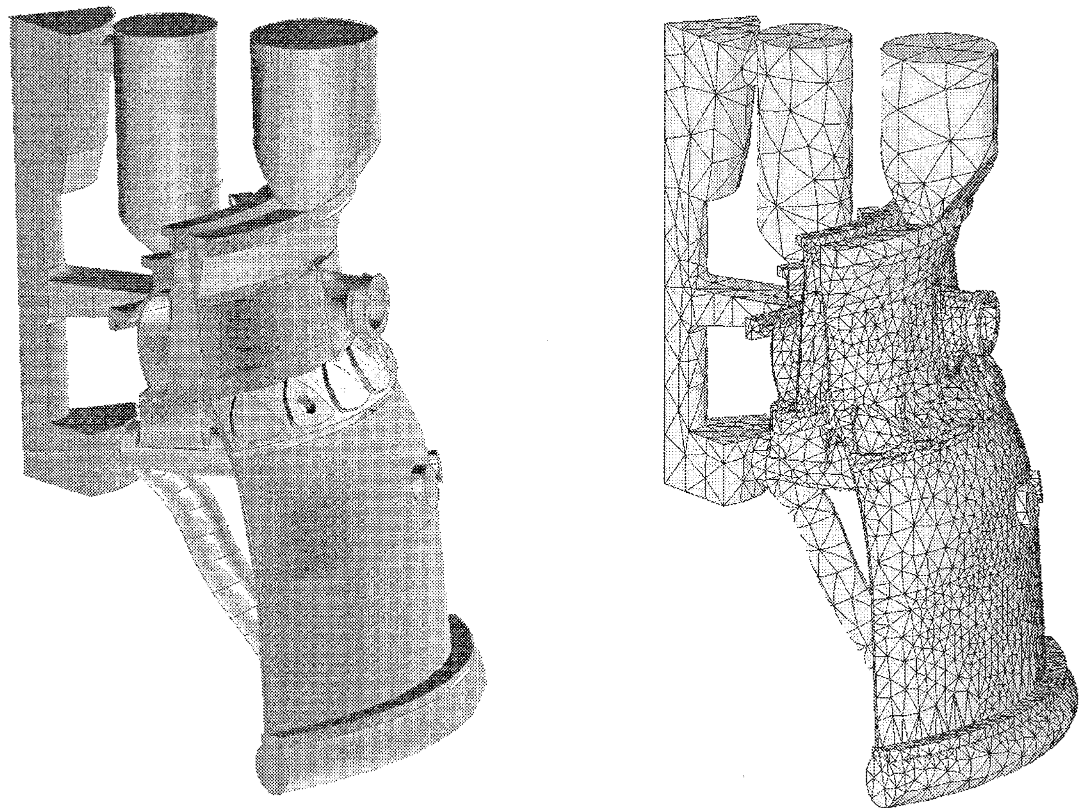


Figure 70 ICCA model final_r1 and mesh generated by Finite Octree

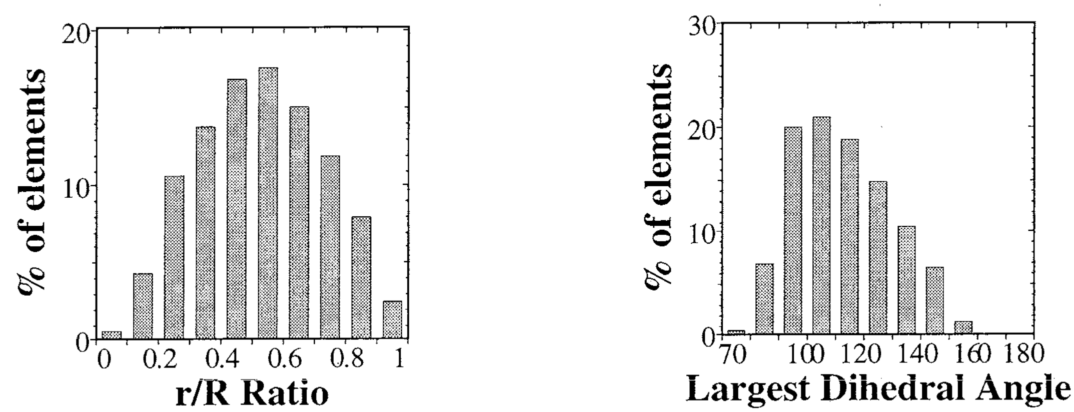


Figure 71 Histogram of element characteristics for straight-sided mesh of final_r1
(a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 46 : Mesh control parameters for final_r1 (curved sided tetrahedral mesh)

Minimum element size	0.005
Maximum element size	0.04
Curvature refinement method	2
Maximum allowable geometric approximation	0.35
Check for small segments	1 (On)
Maximum requested longest edge to shortest edge ratio	10
Remove features smaller than $1/300^{th}$ of the model size	

Table 47 : Mesh statistics for final_r1 (straight sided tetrahedral mesh)

Number of nodes	52419
Number of surface triangles	15534
Number of tetrahedrons	27337
Worst shape (**3r/R**)	0.001
Smallest dihedral angle	0.2
Largest dihedral angle	165
Largest edge/shortest edge	99
Largest edge/shortest height	772

so373_h1

I. Header Information

1. Problem name/ID number: so373_h1
2. Communication #: 1
3. Organization sent by: HC
4. Date sent: March 30, 94
5. Organization received by: SCOREC, RPI
6. Date received: April 4, 94
7. Retrieval of example: execute "bar xvf /dev/rfd0c so373.prt"
8. Type of file: UG part file
9. Picture of model: PROPRIEATARY

II. Issues and Comments

Unsatisfactory meshes produce by Finite Octree in PATRAN3

III. Discussion

Activity summary: The UG part file provided contained a 2-vane segment on one level and the cores on the other. These were combined into an assembly and written out as a parasolid file and this part named so373_h1. The model was then meshed as a non-manifold model.

IV. Results:

Work is in progress to improve the quality of the mesh for this model.

segment_h1

I. Header Information

1.	Problem name/ID number:	segment_h1
2.	Communication #:	1
3.	Organization sent by:	HC
4.	Date sent:	January, 94
5.	Organization received by:	SCOREC, RPI
6.	Date received:	January, 94
7.	Retrieval of example:	execute "bar xvf /dev/rfd0c howmet1.prt"
8.	Type of file:	UG part file
9.	Picture of model:	PROPRIETARY

II. Issues and Comments

Part could not be loaded into P3

III. Discussion

This is a three-vane segment part with hollow vanes. The outer surface of each vane is a single very high order B-surface. The inner surface is of lesser complexity. Due to the widely varying curvature of the surfaces (with very high curvature portions being near the leading and trailing edges of the blade), the second method of curvature based refinement is recommended. However, since it is very expensive to query the modeler for the curvature of such high order free form surfaces, curvature based refinement slows the mesh generation down.

Also, since the vanes are hollow and represent thin sections, small segment checking may be used. Finally small feature removal for features smaller than $1/1000^{th}$ of the model size is suggested to be used.

IV. Results:

Given in Table 48 are mesh controls used to generate a straight side mesh for this part. Table 49 shows the mesh statistics for the part and Figure 72 shows the histograms of element shapes for the mesh

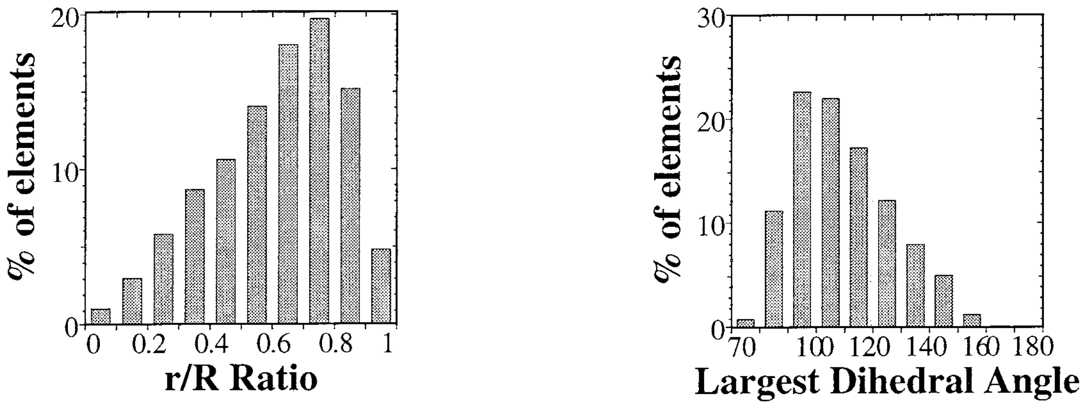


Figure 72 Histogram of element characteristics (r/R ratio and largest dihedral angle) for straight-sided mesh of segment_h1

Table 48 : Mesh control parameters for segment_h1 (straight sided tetrahedral mesh)

Minimum refinement level	0.0009
Maximum allowable refinement level	0.00375
Curvature refinement method	2
Maximum allowable geometric approximation	0.15
Check for small segments	1 (On)
Remove mesh features smaller than $1/1000^{th}$ of the model size and connected to elements with longest to shortest edge ratio more than 20	

Table 49 : Mesh statistics for segment_h1(straight sided tetrahedral mesh)

Number of nodes	34364
Number of surface triangles	52170
Number of tetrahedrons	126362
Worst shape of corresponding straight sided element (**3r/R**)	0.003
Smallest dihedral angle	0.2
Largest dihedral angle	167
Largest edge/shortest edge	497
Largest edge/ shortest height	572

vane_h1n1

I. Header Information

1. Problem name/ID number: vane_h1n1
2. Communication #: 1
3. Organization sent by: PW
4. Date sent:
5. Organization received by: SCOREC, RPI
6. Date received:
7. Retrieval of example:
8. Type of file: Parasolid transmit files

II. Issues and Comments on Initial Mesh

Good meshes requested for part.

III. Discussion

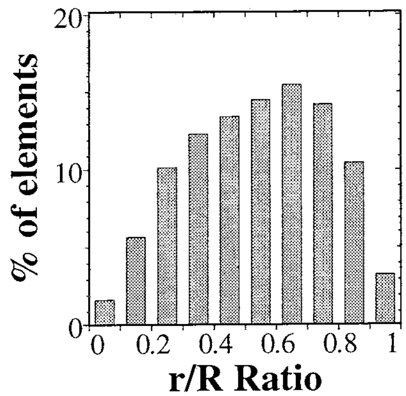
This part is similar to segment_h1 except that the vane surfaces are simpler.

IV. Results:

Good straight-sided meshes generated for part by Finite Octree.

Table 50 : Mesh control parameters for vane_h1n1(straight sided tetrahedral mesh)

Minimum element size	0.002
Maximum element size	0.008
Curvature refinement method	2
Maximum allowable geometric approximation	0.05
Check for small segments	0 (Off)
Maximum requested longest edge to shortest edge ratio	20
Eliminate mesh features smaller than 1/2000th of the model size	



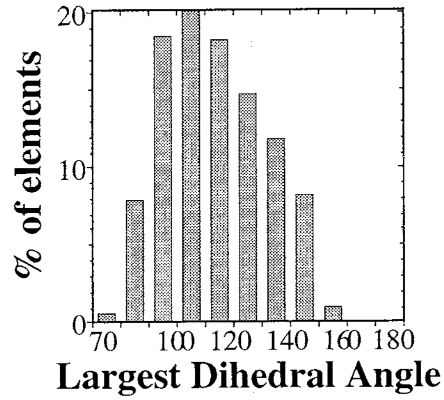


Figure 73 Histogram of element characteristics for straight-sided mesh of vane_h1n1(a) Distribution of element shapes (3r/R) (b) Distribution of largest dihedral angles of elements

Table 51 : Mesh statistics for vane_h1n1(straight sided tetrahedral mesh)

Number of nodes	18449
Number of surface triangles	32348
Number of tetrahedrons	61946
Worst shape (**3r/R**)	0.01
Smallest dihedral angle	1
Largest dihedral angle	159
Largest edge/shortest edge	79
Largest edge/ shortest height	108

hcnew0595, hc0695

I. Header Information

1. Problem name/ID number: hcnew0595
2. Communication #: 1
3. Organization sent by: HC
4. Date sent: May 95
5. Organization received by: SCOREC, RPI
6. Date received: May 95
7. Retrieval of example: ftp
8. Type of file: Parasolid transmit file from UG
9. Picture of model: PROPRIETARY

II. Issues and Comments

Models referred to RPI due to inability to mesh with Finite Octree interfaced to Parasolid v6.0

III. Discussion

On debugging the model hcnew0595, a missed edge-plane intersection was detected and reported to Shape Data. The model was able to be meshed by changing the tolerance marginally on this edge. Attempts to mesh this part with other mesh controls revealed extremely thin faces on one of the webs. 4 zoom-ins of this part of the model resulting in a final magnification factor of 10^4 are shown in Figure 74. The width of the smallest face is only 10 times the modeler's default tolerance of $1X10^{-8}$. This causes a near tangency situation for some of the mesh controls.

After learning about these features, the modeling team created a new model (hc0695) without these small features. This model could not be meshed on-site at Howmet. However, it did mesh successfully at RPI with Finite Octree interfaced to a later version of Parasolid indicating the possibility of a potential missed intersection in the older release. The mesh for this model was ftped to Howmet for analysis.

Although the mesh controls shown are for uniform refinement with small feature removal so as to closely match the original mesh controls applied by Howmet, curvature refinement is recommended for this model.

IV. Results:

Good meshes were generated for the model hc0695. Only statistics are shown for this as it is proprietary to the company and pictures of the model or meshes cannot be shown.

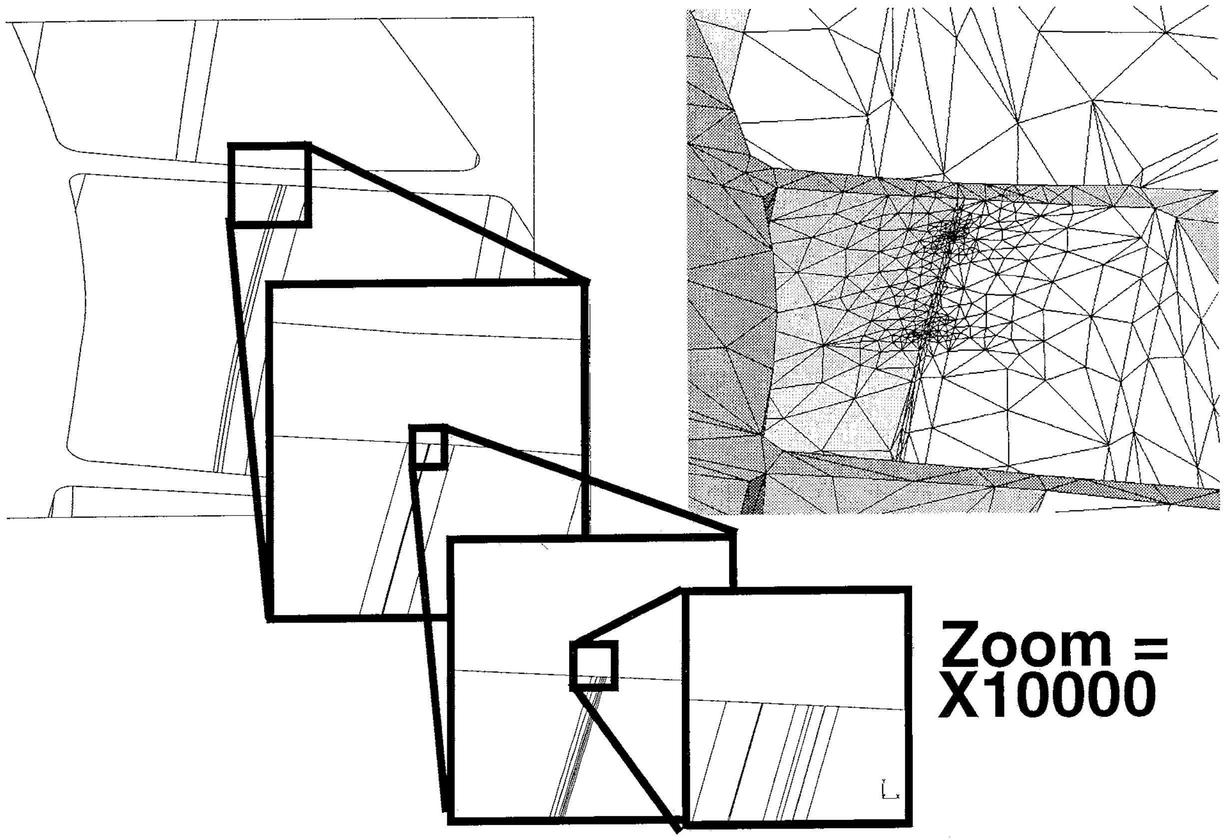


Figure 74 Sliver faces in the model hcnew0595 and the mesh refinement caused thereby

Table 52 : Mesh control parameters for hc0695

Minimum refinement level	0.0001
Maximum allowable refinement level	0.01
Remove mesh features smaller than 1/200th of the model size and connected to elements with longest to shortest edge ratio more than 5	

Table 53 : Mesh statistics for hc0695 (straight sided tetrahedral mesh)

Number of nodes	6185
Number of surface triangles	12166
Number of tetrahedrons	18802
Worst shape of corresponding straight sided element (**3r/R**)	0.03
Smallest dihedral angle	2
Largest dihedral angle	163
Largest edge/shortest edge	27
Largest edge/ shortest height	54

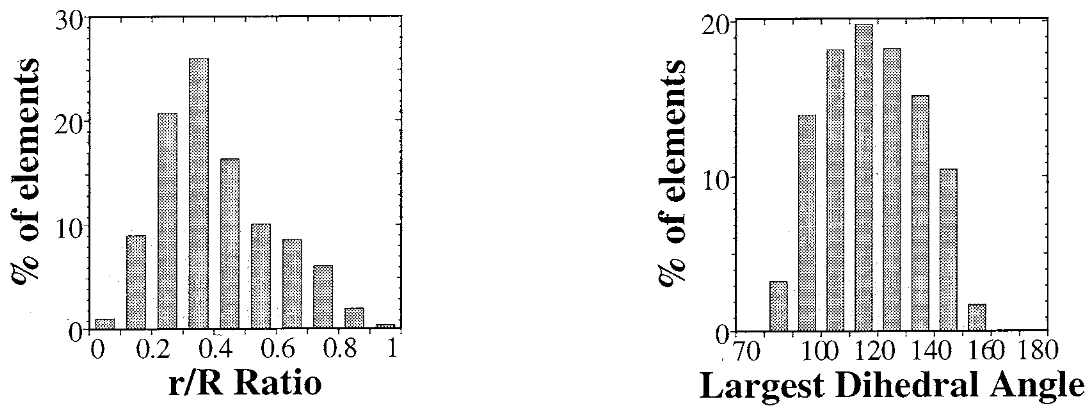


Figure 75 Histogram of element characteristics (r/R ratio and largest dihedral angle) for straight-sided mesh of hc0695

t4cast

I. Header Information

1. Problem name/ID number: t4cast
2. Communication #: 1
3. Organization sent by: HC
4. Date sent: December 94
5. Organization received by: SCOREC, RPI
6. Date received: December 94
7. Retrieval of example: tar xvf <device_name> from 1/4" tape
8. Type of file: Parasolid transmit file from UG
9. Picture of model: PROPRIETARY

II. Issues and Comments:

This part was referred since it could not be meshed with Finite Octree in P3.

III. Discussion:

Meshing with Finite Octree interfaced Parasolid 5.3 was attempted but modeler would not load the model. The problem was debugged in detail and many methods were tried to mend the model, none of which succeeded. This part was then referred to Shape Data who confirmed a problem in v5.3 of Parasolid. A modified part (t4cast_new) was ftped to SCOREC for meshing before v6.0 was released. Another round of debugging with the part revealed blends which were invalid. The blends were removed from the model (t4cast_r2) and the part was meshed for some mesh controls. For other mesh controls, the modeler missed an intersection which was reported to Shape Data. Also, reported was a problem in evaluation of parameters of some surfaces in the model.

IV. Results:

Shown in Table 54 are the mesh control parameters for t4cast_new. The statistics for the mesh generated by Finite Octree are shown in Table 55 and Figure 76. Pictures of the model and mesh cannot be shown for this part as it is proprietary to the company.

Table 54 : Mesh control parameters for t4cast_new (straight sided tetrahedral mesh)

Minimum refinement level	0.005
Maximum allowable refinement level	0.02
Check for small segments and refine	1 (On)
Requested maximum longest to shortest edge ratio	10
Remove mesh features smaller than $1/1000^{th}$ of the model size and connected to elements with longest to shortest edge ratio more than 10	

Table 55 : Mesh statistics for t4cast_new (straight sided tetrahedral mesh)

Number of nodes	8517
Number of surface triangles	16162
Number of tetrahedrons	26106
Worst shape of corresponding straight sided element (**3r/R**)	0.01
Smallest dihedral angle	2
Largest dihedral angle	165
Largest edge/shortest edge	40
Largest edge/ shortest height	44

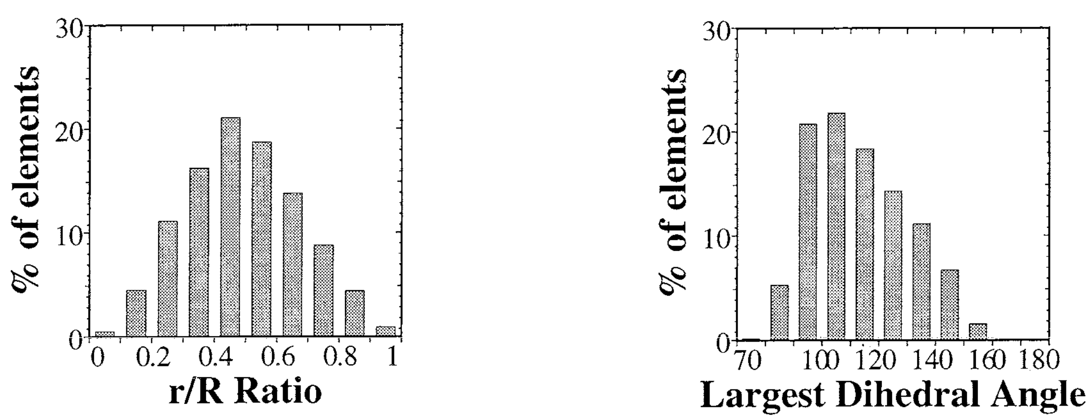


Figure 76 Histogram of element characteristics (r/R ratio and largest dihedral angle) for straight-sided mesh of t4cast_new

fuel

I. Header Information

1. Problem name/ID number: fuel
2. Communication #: 1
3. Organization sent by: HC
4. Date sent: May 95
5. Organization received by: SCOREC, RPI
6. Date received: May 95
7. Retrieval of example: ftp
8. Type of file: Parasolid transmit file from UG
9. Picture of model: PROPRIETARY

II. Issues and Comments on Initial Mesh

Finite Octree running out of memory during mesh generation.

III. Discussion

Examining the mesh controls used for initial mesh generation attempt indicated that the mesh requested was very large (> million elements). This was attributed to a mismatch in the units used in Parasolid and the units used to specify mesh sizes by Howmet. The mesh controls were then modified and the part remeshed to get smaller mesh.

IV. Results

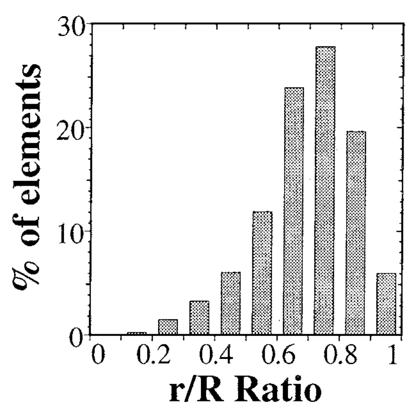
Good straight sided mesh obtained for part.

Table 56 : Mesh control parameters for fuel (straight sided tetrahedral mesh)

Minimum refinement level	0.002
Maximum allowable refinement level	0.4
Curvature refinement method	2
Maximum allowable geometric approximation	0.1
Remove mesh features smaller than $1/1000^{th}$ of the model size and connected to elements with longest to shortest edge ratio more than 50	

Table 57 : Mesh statistics for fuel (straight sided tetrahedral mesh)

Number of nodes	5001
Number of surface triangles	3926
Number of tetrahedrons	23866
Worst shape of corresponding straight sided element (**3r/R**)	0.07
Smallest dihedral angle	6
Largest dihedral angle	149
Largest edge/shortest edge	9
Largest edge/ shortest height	15



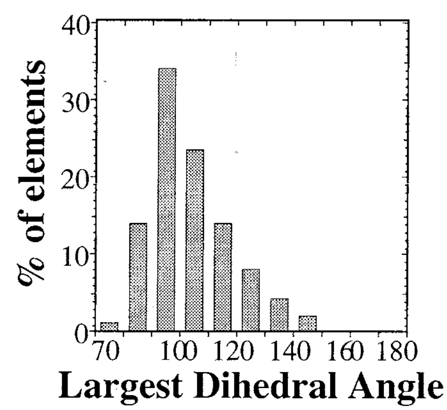


Figure 77 Histogram of element characteristics (r/R ratio and largest dihedral angle) for straight-sided mesh of fuel

GE airfoil verification part: lpbld/1386m42

I. Header Information

1.	Problem name/ID number:	lpbld/1386m42
2.	Communication #:	1
3.	Organization sent by:	GE
4.	Date sent:	November 94
5.	Organization received by:	SCOREC, RPI
6.	Date received:	November 94
7.	Retrieval of example:	tar xvf <device>
8.	Type of file:	Parasolid transmit file from UG
9.	Picture of model:	PROPRIETARY

II. Issues and Comments

This model is the airfoil validation part from GE.

III. Discussion

Straight sided meshes generated for model

IV. Results:

Good straight and curved-sided meshes generated for the model. Only statistics are shown for the model 9529m89_g1 as this model is proprietary to the company and pictures of the model or meshes cannot be shown.

Table 58 : Mesh control parameters for 9529m89_g1 (curved sided tetrahedral mesh)

Minimum refinement level	0.001
Maximum allowable refinement level	0.005
Curvature refinement method	2
Maximum allowable geometric approximation	0.2
Remove mesh features smaller than $1/1000^{th}$ of the model size and connected to elements with longest to shortest edge ratio more than 20	

Table 59 : Mesh statistics for lpbld (straight sided tetrahedral mesh)

Number of nodes	4293
Number of surface triangles	6078
Number of tetrahedrons	15613
Worst shape of corresponding straight sided element (**3r/R**)	0.03
Smallest dihedral angle	2
Largest dihedral angle	154
Largest edge/shortest edge	32
Largest edge/ shortest height	49

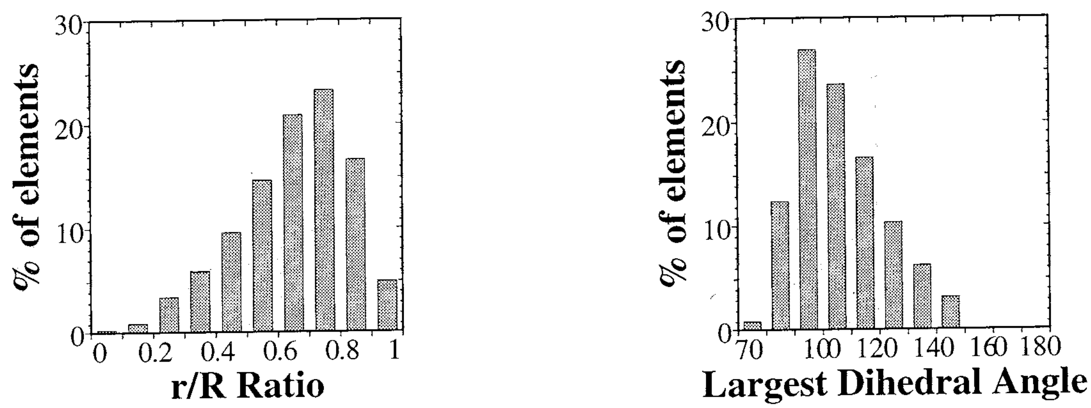


Figure 78 Histogram of element characteristics (r/R ratio and largest dihedral angle) for straight-sided mesh of lpbld

PW airfoil verification part with gating: af_val_pw, af_gating

I. Header Information

1. Problem name/ID number: af_val_pw, af_gating
2. Communication #: 1
3. Organization sent by: P&W, PCC
4. Date sent: March 95
5. Organization received by: SCOREC, RPI
6. Date received: March 95
7. Retrieval of example: tar xvf <device>
8. Type of file: Parasolid transmit file from UG
9. Picture of model: PROPRIETARY

II. Issues and Comments

af_val_pw is the airfoil verification part from Pratt & Whitney and af_gating is two of the airfoil parts with gating attached by PCC. af_gating is a multi-material model

III. Discussion

Coarse and fine curved-sided tetrahedral meshes were successfully generated for the two models. Since af_gating is a multi-material model, the PATRAN neutral file output routine of Finite Octree was modified to properly write out different material IDs for elements belonging to different material regions.

Since the airfoils have surfaces with widely varying curvature, the second method of curvature based refinement was turned on for meshing this part. The refinement control to check for small segments was turned off because the thin sections of the model are also the parts which will be refined due to curvature-based refinement. However, small feature removal was turned on to remove features smaller than $1/200^{th}$ of the model size of af_val_pw and $1/500^{th}$ of the model size for af_gating.

IV. Results

Good straight and curved-sided meshes were generated for model. Only statistics are shown for both models as these models are proprietary to the respective company and pictures of the model or meshes cannot be shown.

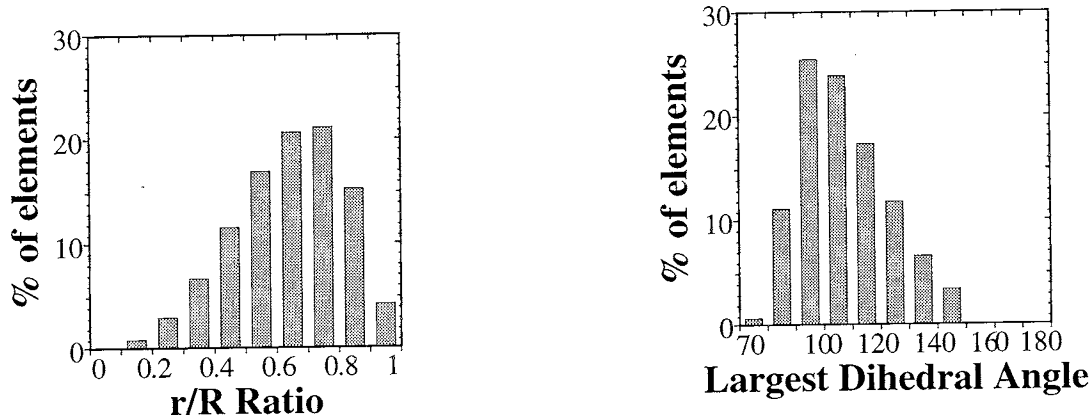


Figure 79 Histogram of element characteristics (r/R ratio and largest dihedral angle) for curved-sided mesh of af_val_pw

Table 60 : Mesh control parameters for af_val_pw (curved sided tetrahedral mesh)

Minimum refinement level	0.001
Maximum allowable refinement level	0.004
Curvature refinement method	2
Maximum allowable geometric approximation	0.2
Check for small segments	0 (Off)
Maximum allowable longest edge to shortest edge ratio	20
Remove small features smaller than 1/200th of the model size	

Table 61 : Mesh statistics for af_val_pw (curved sided tetrahedral mesh)

Number of nodes	21594
Number of surface triangles	5510
Number of tetrahedrons	11836
Worst shape of corresponding straight sided element (**3r/R**)	0.03
Smallest dihedral angle	1
Largest dihedral angle	150
Largest edge/shortest edge	83
Largest edge/ shortest height	84

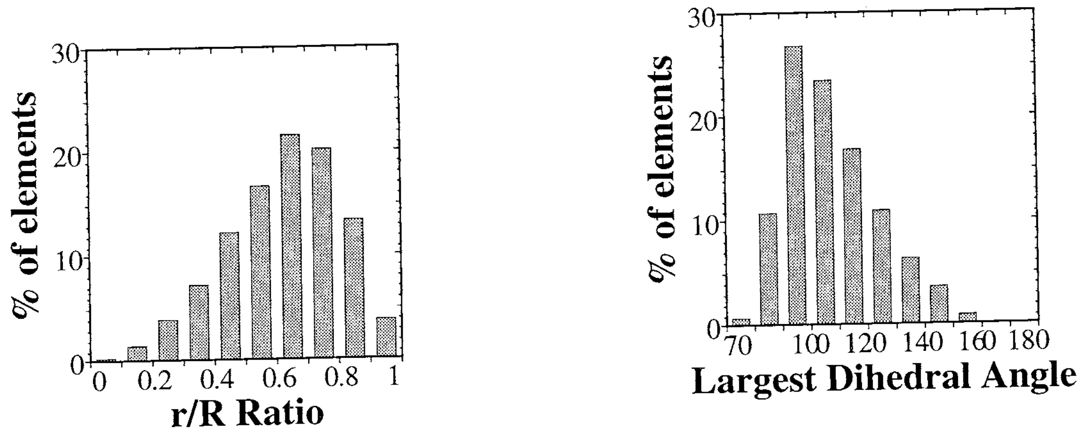


Figure 80 Histogram of element characteristics (r/R ratio and largest dihedral angle) for curved-sided mesh of af_gating

Table 62 : Mesh control parameters for af_gating (curved sided tetrahedral mesh)

Minimum refinement level	0.0017
Maximum allowable refinement level	0.01
Curvature refinement method	2
Maximum allowable geometric approximation	0.1
Check for small segments	0 (Off)
Maximum allowable longest edge to shortest edge ratio	20
Remove small features smaller than 1/500th of the model size	

Table 63 : Mesh statistics for af_gating (curved sided tetrahedral mesh)

Number of nodes	47844
Number of surface triangles	13018
Number of tetrahedrons	25321
Worst shape of corresponding straight sided element (**3r/R**)	0.006
Smallest dihedral angle	1
Largest dihedral angle	166
Largest edge/shortest edge	35
Largest edge/ shortest height	68

GE structural verification part: 9529m89_g1

I. Header Information

1. Problem name/ID number: 9529m89_g1
2. Communication #: 1
3. Organization sent by: GE
4. Date sent: November 94
5. Organization received by: SCOREC, RPI
6. Date received: November 94
7. Retrieval of example: tar xvf <device>
8. Type of file: Parasolid transmit file from UG
9. Picture of model: PROPRIETARY

II. Issues and Comments

This model is the structural validation part from GE.

III. Discussion

Turn on curvature based refinement and request small feature elimination for mesh features smaller than 0.0015 times model size and connected to elements with longest to shortest edge ration greater than 10.

IV. Results:

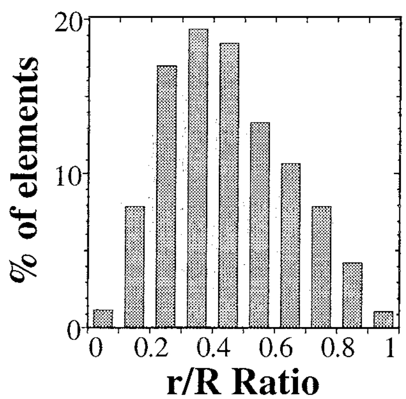
Only statistics are shown for the model 9529m89_g1 as this model is proprietary to the company and pictures of the model or meshes cannot be shown.

Table 64 : Mesh control parameters for 9529m89_g1 (curved sided tetrahedral mesh)

Minimum refinement level	0.01
Maximum allowable refinement level	0.1
Curvature refinement method	2
Maximum allowable geometric approximation	0.2
Check for small segments	0 (Off)
Maximum allowable longest edge to shortest edge ratio	10
Remove small features smaller than 0.0015 times the model size	

Table 65 : Mesh statistics for 9529m89_g1 (curved sided tetrahedral mesh)

Number of nodes	87662
Number of surface triangles	27786
Number of tetrahedrons	44641
Worst shape of corresponding straight sided element (**3r/R**)	0.01
Smallest dihedral angle	2
Largest dihedral angle	162
Largest edge/shortest edge	32
Largest edge/ shortest height	53



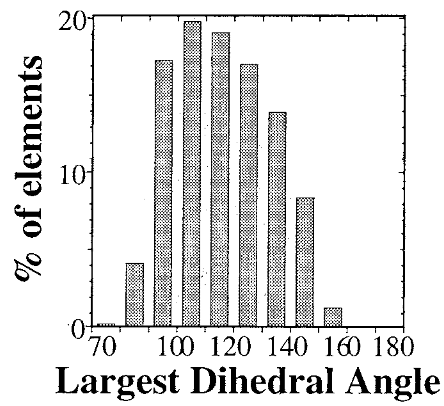


Figure 81 Histogram of element characteristics (r/R ratio and largest dihedral angle) for curved-sided mesh of 9529m89_g1

GE structural verification part with gating: str_gating_sect1

I. Header Information

1. Problem name/ID number: str_gating_sect1
2. Communication #: 1
3. Organization sent by: GE, PCC
4. Date sent: March 95
5. Organization received by: SCOREC, RPI
6. Date received: March 95
7. Retrieval of example: tar xvf <device>
8. Type of file: Parasolid transmit file from UG
9. Picture of model: PROPRIETARY

II. Issues and Comments

This model is a 90 degree sector of the model GE model 9529m89 with gating attached by PCC. The original model sent to RPI was the full GE part with gating attached. Meshing of the 90 degree sector was attempted after many model/modeler problems were discovered in the original model.

III. Discussion

The activity summary for meshing of this model include debugging and fixing of the model str_gating, writing program to reduce tolerances on the model while maintaining model validity and generation of straight-sided mesh for the model.

The original model, str_gating, was a non-manifold model with two material regions. "Matching" edges on this model from the two material regions were not recognized by the non-manifold modeling procedures as coincident because one of the curves was a circle while the other was a B-curve. The model was then modified at RPI so that the two geometries were identical and the non-manifold representation was built for meshing by Finite Octree.

In the meshing of this model, a missed edge-plane intersection was detected and the real reason for it established as an incorrect bounding box for the edge being returned by the modeler. This box was being used in the intersection inquiry and therefore, the modeler was rejecting the intersection point which lay outside the box. This problem was reported to Shape Data and was acknowledge as a regression from v6.0. This problem is to be fixed in Parasolid v6.2. In the meantime, Finite Octree interface to Parasolid was modified to take into account this problem.

Further meshing efforts revealed a near tangency situation in the model due to very high tolerance (greater than 10^5 times the default tolerance) on a model edge and model face. Face insertion routines of Finite Octree were enhanced to deal with this situation. Closer examination of the model revealed many more entities with high tolerances, the maximum being only 3 orders of magnitude smaller than the model size. Since the model is quite complex and has many small details whose size approaches this tolerance, it is likely to have many more near tangent situations. To rectify the situation a program was written that automatically reduces the tolerances on entities to as low a value as possible without invalidating the model.

Meshing trials of the reduced tolerance part indicated another missed intersection problem.

It was then decided that it would be easier to debug a smaller version of this model and therefore, PCC picked a suitable sector of the model to mesh. This 90 degree sector of the model, str_gating_sect1, meshed easily and good results were obtained.

Curvature based refinement was used to generate a mesh for the model and mesh features smaller than $1/1000^{th}$ the model size and connected to elements with edge length ratio greater than 10 were removed.

IV. Results:

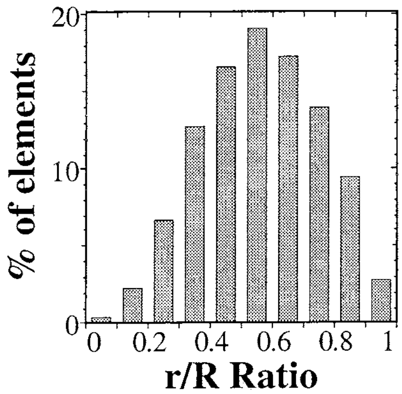
Good straight and curved sided meshes were generated for the model. Only statistics are shown for the model str_gating_sect1 as this model is proprietary to the company and pictures of the model or meshes cannot be shown.

Table 66 : Mesh control parameters for str_gating_sect1 (straight sided tetrahedral mesh)

Minimum refinement level	0.01
Maximum allowable refinement level	0.04
Curvature refinement method	2
Maximum allowable geometric approximation	0.15
Check for small segments	0 (Off)
Maximum allowable longest edge to shortest edge ratio	10
Remove small features smaller than 1/1000th of the model size	

Table 67 : Mesh statistics for str_gating_sect1 (straight sided tetrahedral mesh)

Number of nodes	9449
Number of surface triangles	16398
Number of tetrahedrons	30627
Worst shape of corresponding straight sided element (**3r/R**)	0.03
Smallest dihedral angle	2
Largest dihedral angle	155
Largest edge/shortest edge	31
Largest edge/ shortest height	42



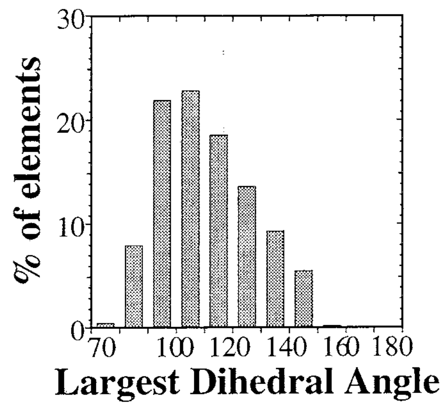


Figure 82 Histogram of element characteristics (r/R ratio and largest dihedral angle) for straight-sided mesh of str_gating_sect1

PW structural verification part with and without gating: 50j780, pw22095, pw22095wg

I. Header Information

1. Problem name/ID number: pw22095, pw22095wg
2. Communication #: 1
3. Organization sent by: PW, HC
4. Organization received by: SCOREC, RPI
5. Date received: Nov 94 (parts without gating)
   May 95 (part with gating)
6. Type of file: Parasolid transmit files from UG
7. Picture of model: PROPRIETARY

II. Issues and Comments

The part pw22095 is 105 degree segment of the Pratt and Whitney structural verification model. The original parts sent for meshing included a 55.5 degree segment, and a 120 degree segment. Subsequently, a revised 120 degree segment and 105 degree segment were shipped. pw22095 is the 105 degree segment with cleanup of some of the small model features. The part pw22095wg is the final structural verification part with gating by Howmet.

III. Discussion

Mesh generation attempts of the parts 55_5seg and 50j780_105seg led to enhancements of octant level loop building procedures of Finite Octree. After these changes, the parts meshed successfully. The part 50j780_120seg2 meshed without augmentation of periodic faces. On the other hand, if the model was augmented, the modeler missed an intersection with one of the faces. This problem was reported to Shape Data. In all these models a self-intersecting blend was identified.

The model pw22095 was meshed for some mesh controls while for others the modeler missed an intersection between an edge and a plane. This was reported to Shape Data. Mesh generation of the model detected a tiny pocket-shaped hole completely inside the model. Finite Octree's tetrahedronization procedures were enhanced to deal with the situation and the part was meshed. Similarly, the model pw22095wg, which is the multi-material verification part with gating attached was also meshed.

Since the part is complex, turning on curvature-based refinement may considerably increase the time required to mesh the part. In such a case, it may be efficient to generate a uniformly finer mesh. Small feature removal is strongly recommended for this model.

IV. Results:

Pictures of these models or meshes cannot be shown as they proprietary to the respective companies. Work is in-progress to improve the mesh quality for the models.

block_h1n1, block, sblade_h1n1, chicklet, bracket

I. Header Information

1. Problem name/ID number: block_h1n1, block, sblade_h1n1, chicklet
2. Communication #: 1
3. Organization sent by:
4. Date sent:
5. Organization received by: SCOREC, RPI
6. Date received:
7. Retrieval of example:
8. Type of file:
9. Picture of model:
10. Mesh generation software used:

II. Issues and Comments

Simple test models made for initiating the testing process

III. Results

Shown in Figure 83 are meshes generated by Finite Octree for the models. The quality of the meshes was good.

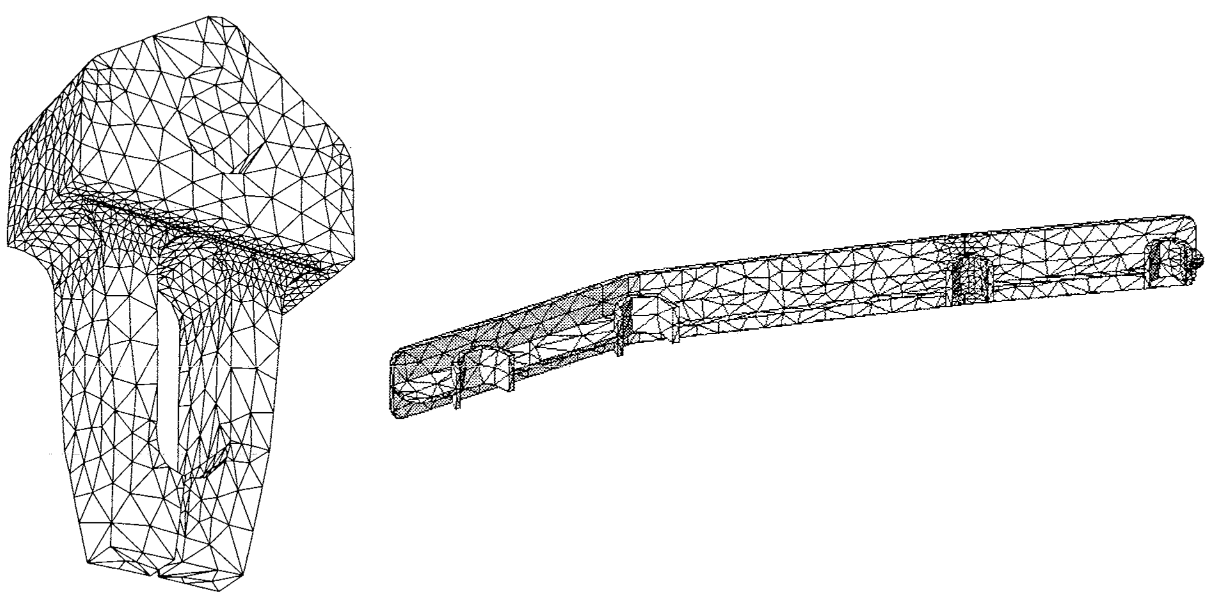


Figure 83 Meshes for models chicklet and bracket

References

1 R. Garimella, S. Dey, R. Ramamoorthy, M. Georges and M. Shepard. "Specification of mesh control Function in Finite Octree," Technical Report # 5, Scientific Computation Research Center, Rensselaer Polytechnic Institute, Troy, NY, Dec 1993.

2 R. Garimella, S. Dey, R. Ramamoorthy, M. Georges and M. Shepard. "Finite Octree Mesh Generation and Output Options," Technical Report # 6, Scientific Computation Research Center, Rensselaer Polytechnic Institute, Troy, NY, Dec 1993.

3 Shape Data Limited, Parker's House, 46, Regent Street, Cambridge CB2 1DB, England. *PARASOLID v4.0 Programming Reference Manual*, August 1991.

4 M. S. Shephard and M. K. Georges. "Automatic three-dimensional mesh generation by the Finite Octree technique" *Int. J. Numer. Meth. Engng.,* 32(4):709-749, 1991.

5 M. S. Shephard, M. K. Georges and H. L. deCougny. "Geometric modeling interactions required to support a fully automatic mesh generator" In Bernd Hamann and Ramon Sarraga, eds., *Finite Elements, Grid Generation and Geometric Design*, in preparation.

6 S. Dey. *Curvature sensitive refinement in 3D automatic mesh generation*, Master's Thesis, Scientific Computation Research Center, Rensselaer Polytechnic Institute, Troy, NY 12180.