MSC/PROBE P-Version Application:
Parametric Finite Element Analysis

by:

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Abstract:

Many recurring problems encountered in industry, though not exactly the same, are similar in nature. These can often be grouped into classes where simple dimensional changes accurately define the problems within a class. The need to change parameter values for an analysis may arise in the design phase for sensitivity and optimization studies or in the production phase to analyze manufacturing discrepancies. Simple parametric analyses are also useful when several groups or individuals analyze similar parts.

The parametric approach in FEA using MSC/PROBE is discussed and illustrated with a 3-D solid model of a bathtub fitting. Model construction techniques are included and simple, front-end preprocessors are proposed. Other parametric applications are also suggested.

1.0 INTRODUCTION

Many recurring problems encountered in industry, though not exactly the same, are similar in nature. These can often be grouped into classes where simple dimensional changes accurately define the problems within a class. The need to change parameter values for an analysis may arise in the design phase for sensitivity and optimization studies or in the production phase to analyze manufacturing discrepancies. Simple parametric analyses are also useful when several groups or individuals analyze similar parts.

Parametric studies with traditional h-version finite element methods can often lead to labor intensive mesh refinements to describe subtle changes in model geometry. This has been facilitated to an extent by some of the powerful (and expensive) mesh generators that are available. These will reduce some of the user tasks, but explicit verification of the solution quality and convergence still require several meshes to be run in the h-extension process.

The p-version FEA program, MSC/PROBE, however, is ideal for parametric studies. Due to the robust nature of the p-version elements, exact mapping of curved surfaces, the use of local coordinate systems, and explicit solution quality tools, parametric changes are easily made, and the solution quality confirmed. Standard libraries of recurring models can be created for use by multiple users and design optimization studies are greatly facilitated.

The parametric approach in FEA using MSC/PROBE is discussed and illustrated with a 3-D solid model of a bathtub fitting. Model construction techniques are included and simple, front-end preprocessors are proposed. Other parametric applications are also suggested.

2.0 PARAMETRIC FEA MODELS USING MSC/PROBE

Successful applications of finite elements to parametric analyses must allow quick, effortless manipulations of the input model, and explicit feedback of the solution quality and results. The analyst must be capable of altering the model geometry without costly changes in the finite element mesh or other model parameters. Also, a direct quantitative measure of the accuracy of the solution from each model is required to guarantee confidence in the results. The advantages implicit with the p-version, and some unique tools found in MSC/PROBE combine to make it an ideal tool for parametric analyses of detailed components. These features and the impact on parametric analyses are discussed in the following sections.

2.1 QUALITY CONTROL AND THE P-VERSION EXTENSION PROCESS

When using the finite element approach, the solution will converge towards the correct solution, (based on the model idealizations), as the number of Degrees of Freedom (DOF) are increased towards infinity. The methods of increasing the DOF in finite elements are called extension processes.

In the h-version of finite elements, where fixed polynomial shape functions are used, "h" represents the characteristic height of the element, and the h-extension process of adding DOF is accomplished by putting more, smaller elements in the model. This means a series of meshes are needed to verify convergence and quantify solution quality.

In the p-version of finite elements, "p" represents the polynomial order of the elemental shape functions. In the p-extension process, DOF are added by simply increasing the p-level of the element without changing the mesh. Convergence rates using p-extensions have been shown to be higher than those using h-extensions, while combining them in the hp-extension gives the highest convergence rates possible using FEA.

MSC/PROBE allows the user to specify polynomial shape functions up to degree eight on a given mesh. Thus, convergence and accuracy are obtained without additional user inputs. If necessary, the mesh can be modified to use the hp-extension process. The solution quality is then verified by checking; 1) strain energy convergence. 2) global and elemental equilibrium. 3) functional convergence (e.g. stress at a point). All three conditions are necessary to guarantee that the solution has converged within acceptable limits.

The number of models involved in a parametric study is increased simply due to the desire to investigate the various geometries. This means that using the h-extension process to verify solution quality multiplies the number of models necessary. The p-extension process inherent in MSC/PROBE provide these results automatically for each model, making additional meshing unnecessary.

2.2 ROBUST P-VERSION ELEMENTS

One of the advantages of the higher order polynomial shape functions is that the elements are far more tolerant of high aspect ratios, acute internal angles, and material properties. Element aspect ratios of 20:1 are common in MSC/PROBE models, (extreme ratios of up to 500:1 have been used successfully in certain applications), and internal angles of 160 degrees can be used comfortably in most areas. Also, numerical locking is less of a problem for incompressible material simulations, and shear locking in shell problems (using MSC/PROBE's thin solid elements) is nonexistent above p-level 3.

What this means in parametric studies is that model geometries can often be changed without remeshing the model. The elements can, in effect, be "stretched" along with the boundary and still perform well. Of course there are limits to this flexibility, but the inherent quality control features provide immediate feedback as to the performance characteristics of any oblique or high aspect ratio elements. The next two sections show several methods where this feature is easily exploited.

2.3 EXACT MAPPING OF CURVED EDGES AND CURVED ELEMENT DEFINITIONS

In many cases the parameters being modified directly involve curved surfaces or interact with curves close by. This may include changing the actual shape of the curve or changing the position of the curve relative to other model features. One simple example is a corner fillet.

In detailed stress analyses, accurate representation of the physical parameters of the component is essential to obtain meaningful results. Because most h-version programs use a linear piecewise approximation to curves, many elements must be used around the area to model the geometry and capture the functional behavior (i.e. stress gradients) in the region. Also, any changes made relative to the curves usually involves costly modifications to the mesh.

MSC/PROBE uses exact mapping of curved edges by using the Blending Function Method. Therefore, extra elements are not necessary to define the curved surface. This, and the higher order shape functions, allow the use of much larger elements in the area of curves. The elements can be directly referenced to the curve definitions, so, if the shape of the curve is changed, the elements will move along with the new curve. Remeshing is rarely needed. Again, this greatly eases certain parametric studies.

2.4 ELEMENT DEFINITIONS USING CURVES AND LOCAL COORDINATE SYSTEMS

As mentioned in the previous section, element boundaries can be referenced directly to curve definitions. These curve definitions can also be referenced to a local coordinate system. This then provides total flexibility in positioning and defining curves and associated elements. Some examples of using these tools in a parametric study are fastener hole positions and diameters, fillet radii, edge distances on lugs, or any other boundary definition that the analyst may desire to change. Again, remeshing is rarely needed in studies of these types.

2.5 INTERACTIVE RESULTS EXTRACTION

Another useful feature provided in MSC/PROBE is interactive postprocessing of the results. Any function of interest is available after the problem is run, and the solution is continuous everywhere within the problem domain. What this means for parametric analyses is that, if changing the parameters of a model shift the critical location or function (stresses, strains, deflections, etc.), no prior knowledge of this is needed (ie. to grade the mesh in that area before the run). The p-version elements will capture this behavior, and the decision about what the critical functions are can be investigated after the solution is available.

3.0 PARAMETRIC MODEL EXAMPLE; 3-D SOLID BATHTUB FITTING

One example was chosen to illustrate some of the concepts discussed in Section 2. The component under study is the channel bathtub fitting shown in Figure 1. The fitting is symmetric, so only half is displayed. The tension load is introduced through one fastener in the endpad and is reacted through the three fasteners though the lower wall. The MSC/PROBE finite element model is also shown in the figure. A 3-D solid model is used for the parametric study.

One of the questions an analyst may wish to investigate is the effect of adding more fasteners to react the tension load. In this case, the model was built in modules where the base module was constructed using the global coordinate system, and each fastener module was constructed using the fastener center as the reference origin. This data was grouped in such a way that to add another fastener, one need only repeat the fastener module with a new reference point. The models with two and three fasteners are shown in Figure 2 along with the fastener module. This shows one way that repeating structures are easily handled using local coordinate systems.

Other items that may be investigated are dimensional changes in the model. Figure 3 shows another model derivative with the endpad and wall thickness changed. Also, the stiffener height was reduced. These changes were made by simply moving relatively few nodal positions. No change to the mesh was necessary for these modifications.

Those parameters listed above, as well as others, such as corner fillet radii, hole diameters, etc., are easily altered and reanalyzed. Each analysis by MSC/PROBE gives explicit feedback of the solution quality, so the accuracy and the effects of the changes are available without multiple models. These types of parametric studies would be useful to the analyst tasked to design and size this particular component. Other uses for parametric studies occur later, in the production cycle.

If the database that was used to size a particular piece were stored for later use, deviations from the original design due to manufacturing problems could be easily evaluated. Figure 4 shows the original three fastener model with two occurrences of misdrilled holes. The first shows the main tension-carrying hole misdrilled to create a short edge distance on the endpad. The second shows the case where two of the reaction holes were drilled too close together. In both these cases, the only modification that was made to the model was the position of the reference axis located at the hole center. Again, no change to the original mesh was necessary. The "stretched" elements performed satisfactorily in each case, and explicit results showing the quality of the solution was available.

All the changes that were shown for this example were made without the use of a preprocessor. The parameters that were modified retained the symmetric nature of the problem, but similar tools could be used to explore unsymmetrical behavior by modelling the mirror image also.

4.0 MSC/PROBE BATCH FILE AND PRE-PROCESSOR ROUTINES

Changes may be made to a MSC/PROBE model either within the architecture of the program or by editing the ASCII batch file. The MSC/PROBE input data forms are structured similar to a spreadsheet, and logical menus to the data forms are provided. The batch file is a concise listing of model data in ASCII format. The user with access to a text editor can easily cut, copy, and alter the data in this format. The batch file can then be loaded into the program and reanalyzed.

When a more automated procedure is desired a simple FORTRAN (or any other language) preprocessor can be written to alter the batch file information. An example may be when a class of analyses is established by a methods group for use by project engineers. This method has been employed to the extent that the user is queried for the relevant parameters of the model, after which the preprocessor writes the batch file, submits the MSC/PROBE job to run, and extracts standard outputs for the user. Here, no knowledge of the MSC/PROBE program is necessary by a large number of engineers that ultimately benefit from it.

The choice of the method to alter model parameters will depend on circumstances specific to the problem being considered.

5.0 OTHER PARAMETRIC EXAMPLES AND APPLICATIONS

Several other examples may be briefly discussed to further illustrate these concepts. Figure 5 shows a parametric model that was created to quickly evaluate the effects of various composite ply orientations in a "T" section. The section represents a typical rib-skin interface found in cocured composite structures. A preprocessor was written that allows the analyst to input the basic dimensions, ply properties and stacking sequences. Loading inputs were generated from the results of a global MSC/NASTRAN model. The preprocessor writes out the MSC/PROBE batch file, runs the model in batch mode, and obtains post-processing results for the analyst. In this case, the flatwise tensile stresses in the radius region and the filler material were the primary functions of interest.

Figure 6 shows another parametric model that was created to study the effects of partially misdrilled holes in flat plates. Here the analyst simply edited the batch file to simulate different material thicknesses, hole depths and running loads. In this case the function of interest was the stress concentration that occurred due to the hole.

Figure 7 shows a crack growth study that was performed to investigate the effect of the crack length on the Stress Intensity Factors, K_I and K_{II}. The elements that surround the crack tip were defined using a local coordinate system located at the tip of the crack. The analyst could then "grow" the crack by simply moving the local coordinate system without recreating the mesh. The Stress Intensity Factors are then automatically calculated by MSC/PROBE, and solution quality and convergence feedback was provided to the analyst for each model.

6.0 CONCLUSIONS

The parametric approach to FEA is a powerful method of evaluating design changes and optimizing configurations. The use of mesh generators can facilitate parametric studies with any FEA code. Though user tasks are reduced, a series of meshes must be used in the h-extension process to guarantee that the solution has converged. Convergence with MSC/PROBE is verified with no additional user inputs. This can be significant since more models are necessary to vary the parameters of interest. MSC/PROBE also contains other tools that make it an ideal tool for parametric studies of detail components. The robust nature of the p-version elements, exact mapping of curved surfaces, the use of local coordinate systems, as well as explicit solution quality tools, make modifications simple and verify the solution accuracy. Several examples were provided to help illustrate these concepts.

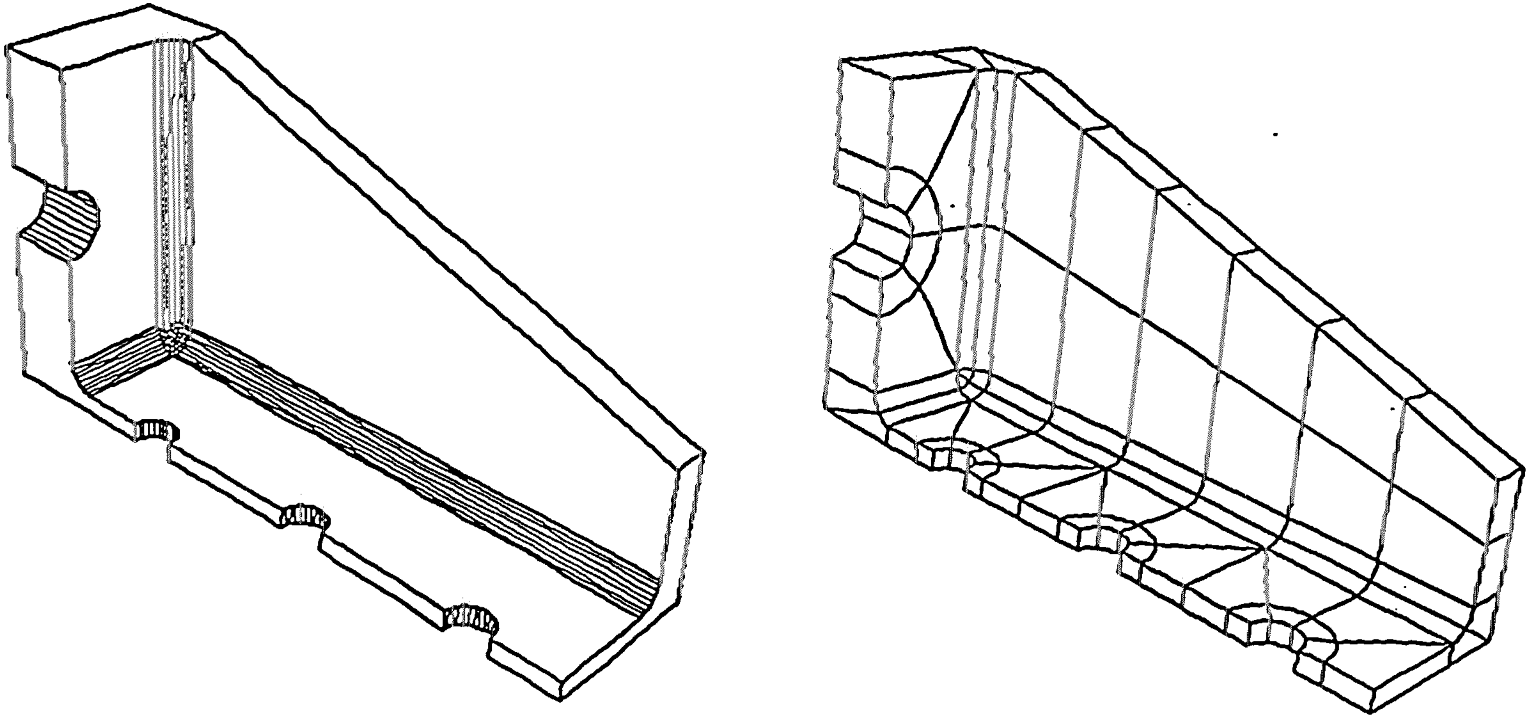
7.0 APPENDIX:

PARAMETRIC ANALYSIS USING MSC/PROBE

- * PARAMETRIC FEA MODELS
  - -MUST ALLOW QUICK EFFORTLESS MANIPULATION OF MODEL PARAMETERS
  - -NO COSTLY OR LABOR INTENSIVE USER TASKS
  - -EXPLICIT Q. C. AND CONVERGENCE CHECKS
  - -RESULTS EASILY EXTRACTED

- * MSC/PROBE: PARAMETRIC STRESS ANALYSIS OF DETAILED COMPONENTS
  - -FASTER CONVERGENCE, NO REMESHING NEEDED
  - -OTHER Q.C. CHECKS PROVIDED TO GUARANTEE SOLUTION ACCURACY
  - -HIGHER ORDER SHAPE FUNCTIONS MORE ROBUST
  - -CURVES MAPPED EXACTLY
  - -ELEMENT BOUNDARIES DEFINED ON CURVES
  - -CURVES & ELEMENT DEFINITIONS WITH LOCAL COORDINATE SYSTEMS
  - -ALL RESULTS AVAILABLE INTERACTIVELY

MSC/PROBE PARAMETRIC BATHTUB MODEL



CHANNEL BATHTUB FITTING

MSC/PROBE SOLID F.E. MESH

FIGURE 1

MSC/PROBE PARAMETRIC BATHTUB MODEL

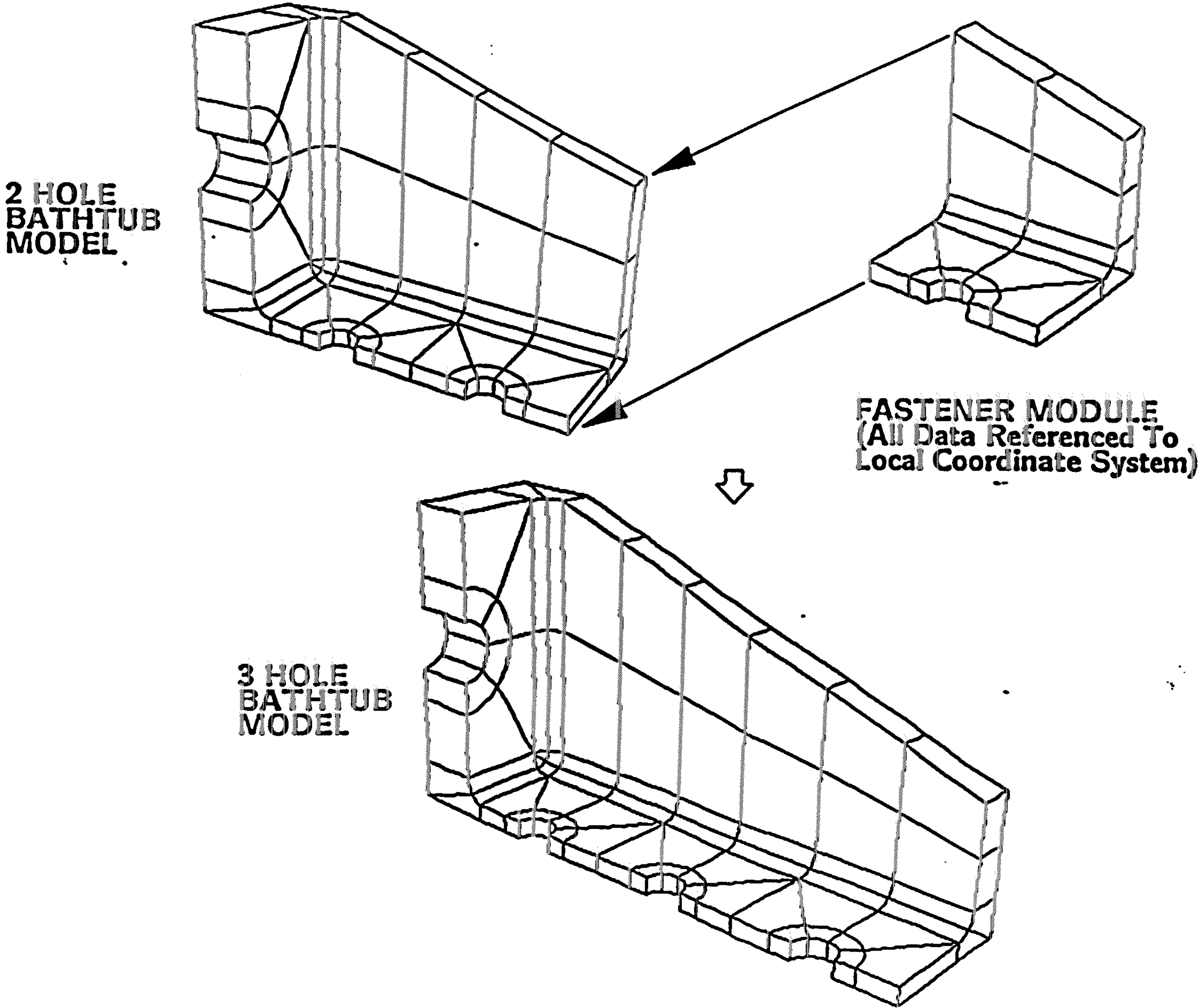
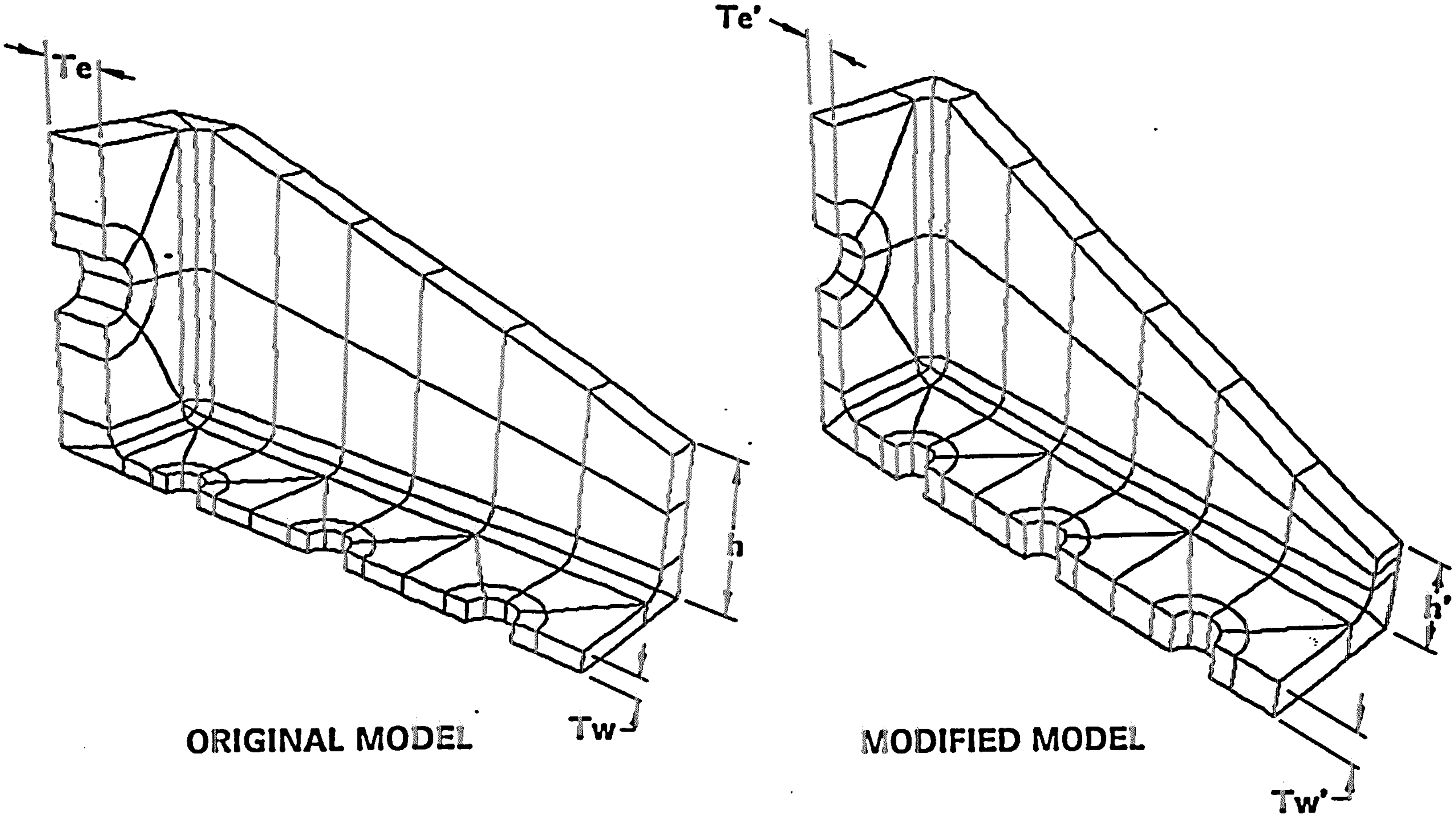


FIGURE 2

MSC/PROBE PARAMETRIC BATHTUB MODEL



ORIGINAL MODEL

MODIFIED MODEL

FIGURE 3

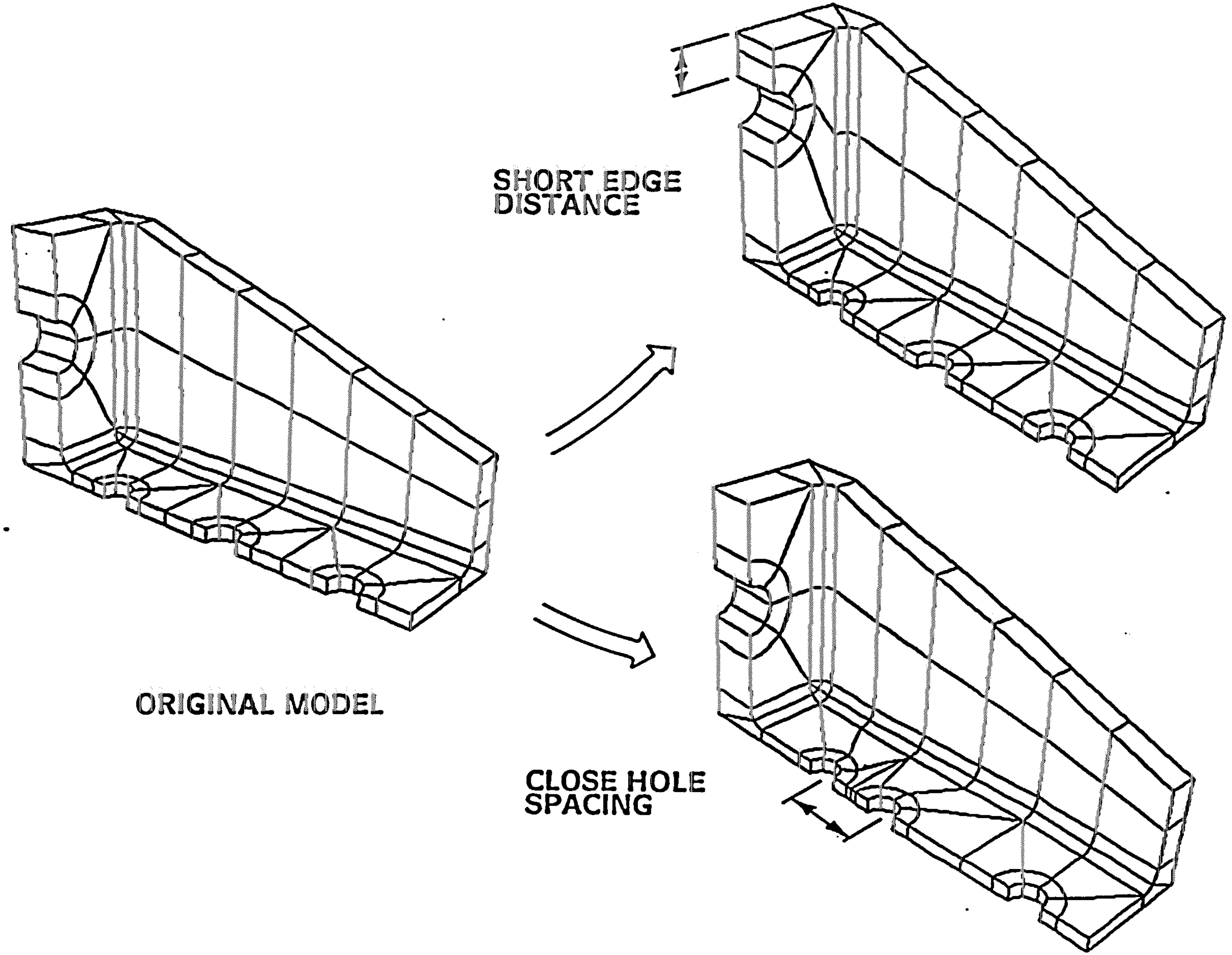
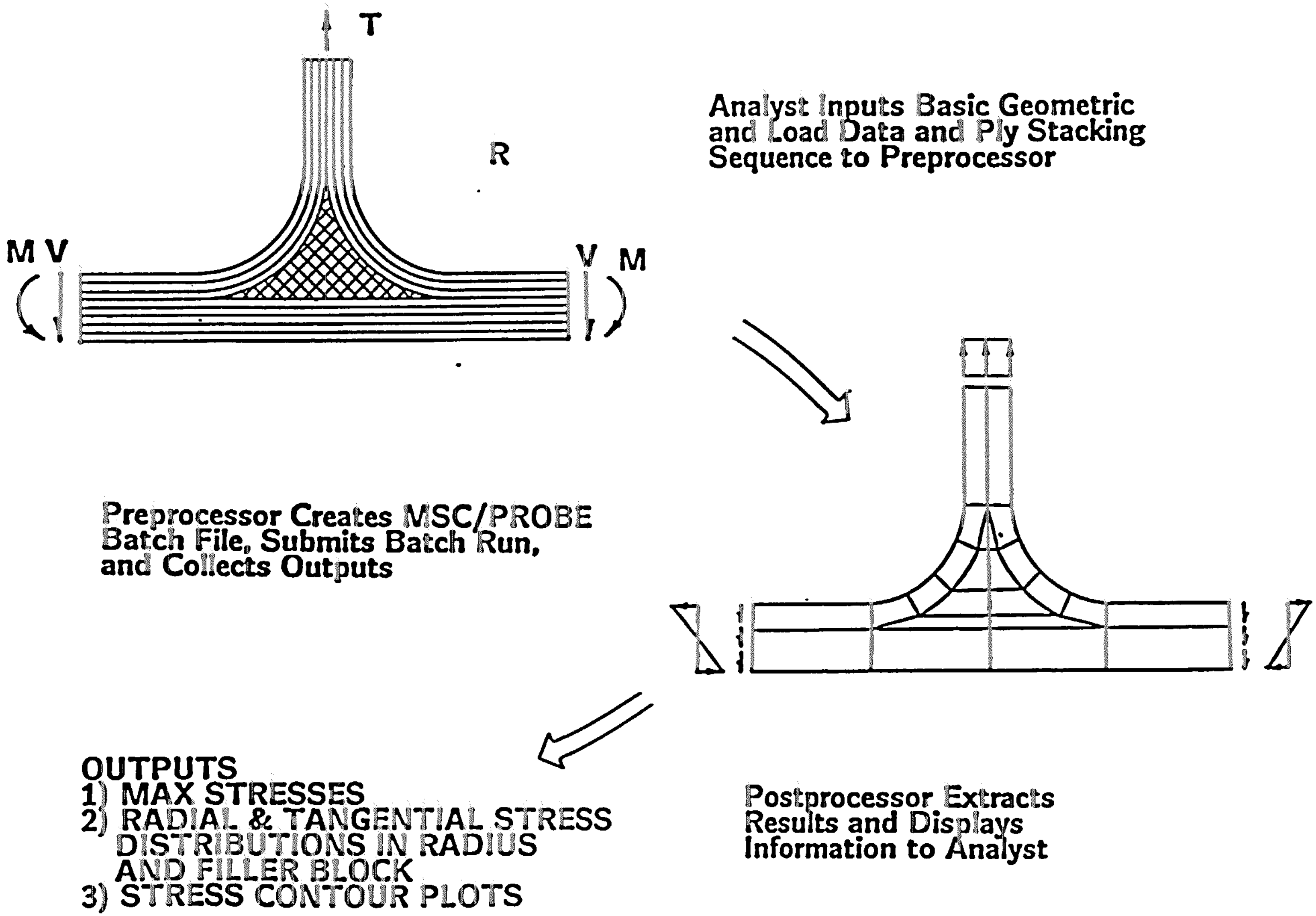

MSC/PROBE PARAMETRIC BATHTUB MODEL

FIGURE 4

MSC/PROBE PARAMETRIC TEE MODEL



Analyst Inputs Basic Geometric and Load Data and Ply Stacking Sequence to Preprocessor

Preprocessor Creates MSC/PROBE Batch File, Submits Batch Run, and Collects Outputs

Postprocessor Extracts Results and Displays Information to Analyst

OUTPUTS
1) MAX STRESSES
2) RADIAL & TANGENTIAL STRESS DISTRIBUTIONS IN RADIUS AND FILLER BLOCK
3) STRESS CONTOUR PLOTS

FIGURE 5

MSC/PROBE PARAMETRIC PLATE WITH PARTIAL HOLE MODEL

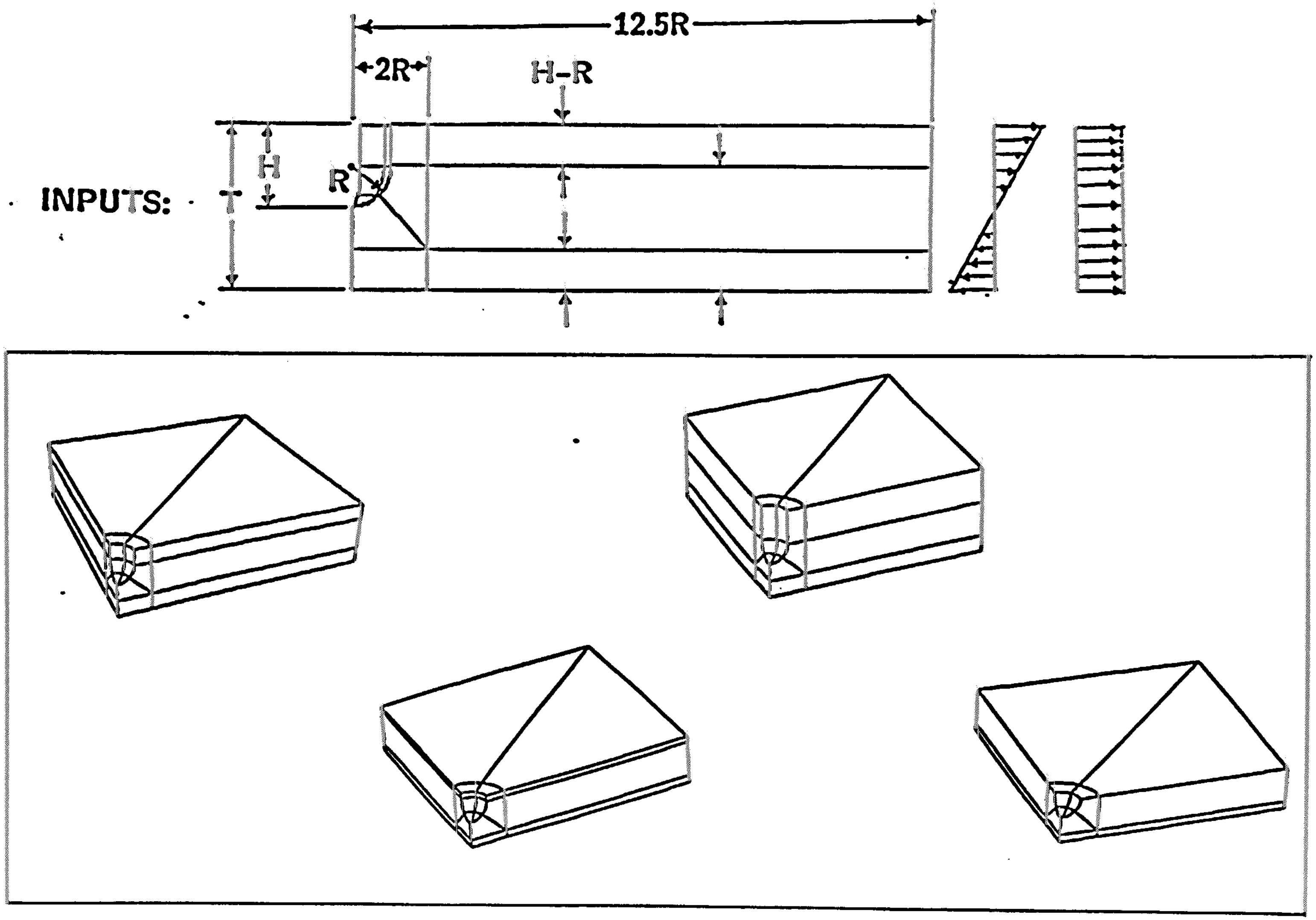
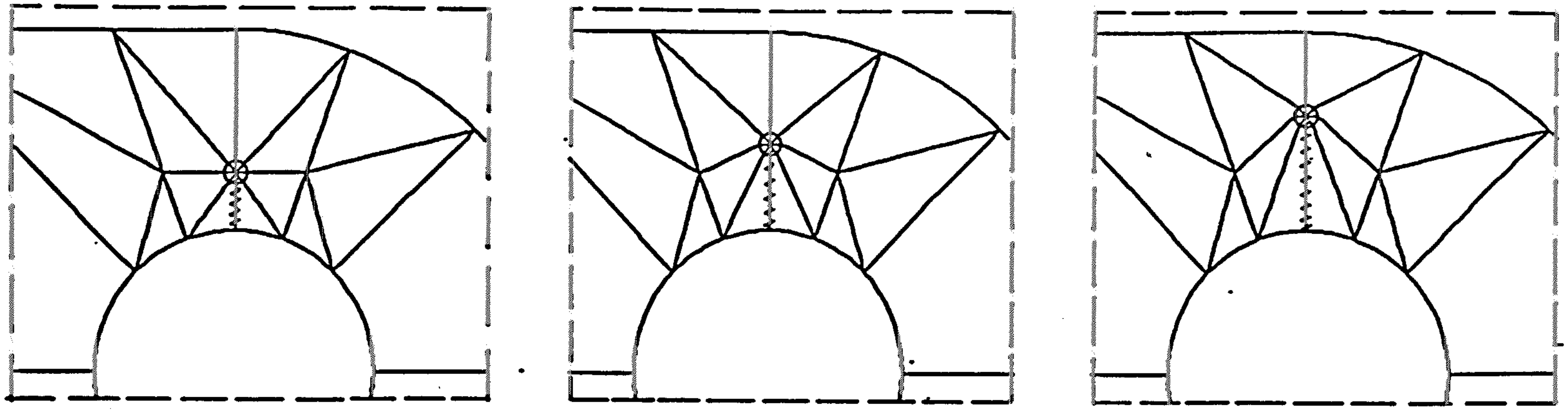


FIGURE 6

MSC/PROBE PARAMETRIC CRACKED LUG MODEL



CRACK LENGTH = .50"
K_I=9.483 K_{II}=-4.616

CRACK LENGTH = .75"
K_I=10.688 K_{II}=-6.181

CRACK LENGTH = 1.0"
K_I=11.953 K_{II}=-7.423

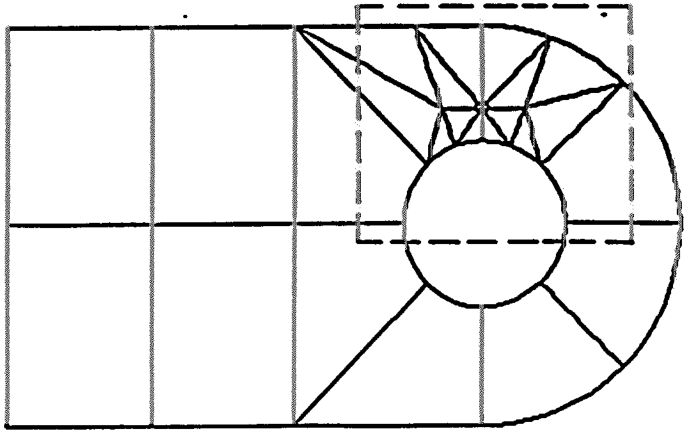


FIGURE 7