Feature Extraction From Solid Model for Manufacturability Assessment

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For Manufacturability Assessment

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Abstract

Assessment of manufacturability of a design with minimum human intervention is in increasing demand. It is, however, very difficult to investigate manufacturability problems with analytical tools in most of the manufacturing processes. In a real manufacturing situation, manufacturability problems are considered only by designers based on the standard design practice and their past experience. In general, manufacturing knowledge is hardly reflected at initial design stage. An expert system equipped with knowledge of manufacturability can be usefully applied to solve these problems.

An expert system that can evaluate designs for their manufacturability must have knowledge of manufacturing requirements as they relate to the design of the part to be produced. However, this type of knowledge is generally in the form of relationships or rules that refer to geometric features of designs. Therefore, an appropriate form of input data for the expert system should be generated from the part design data base.

This article describes a method to extract feature information from the data base of a 3D surface boundary representation for the injection molded part design. The feature information is then passed into a knowledge-based system to perform manufacturability assessment.

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1 INTRODUCTION

As early as possible in the design process, there is an increasing need of assessing the manufacturability of the proposed design. Without this assessment, manufacturing problems will be detected only at the prototype or production stages. The redesign using this feedback will require a substantial amount of time and cost. One example is the design of injection molded parts for automobile lamps. Usually it takes approximately three months to produce a prototype from the time the design is finished. It costs in the magnitude of ten thousand dollars to build each set of injection molding dies. In this case, if all the possible manufacturing problems were detected early in the design process, preferably before molding dies were built, a substantial amount of time and money could be saved.

Therefore, on-line assessment of manufacturability for design with minimum human intervention is in increasing demand. It is, however, very difficult to investigate manufacturability problems with analytical tools in most of the manufacturing processes. For example, analytical tools based on the FEM, which is the most popular, have very limited application in the analysis of some manufacturing processes. In a real manufacturing situation, on the other hand, manufacturability problems are considered only by designers based on the design standard and their past experience. As a matter of fact, knowledge from the experienced engineers in manufacturing field is hardly reflected at initial design stage. Naturally, an expert system equipped with knowledge of design manufacturability is being required to solve these problems. Such an expert system becomes very powerful in the absence of skilled designers. It is also useful in detecting errors which may be made by even skilled designers.

An expert system that can evaluate designs for their manufacturability must have knowledge of manufacturing requirements as they relate to the design of the part to be produced. However, this type of knowledge is generally in the form of relationships or rules that refer to geometric features of designs. Therefore, adequate form of input data for the expert system should be generated from the part design data base. There are two ways of preparing this type of higher level, i.e. feature related, data base. One method is to design with features from the beginning at design stage. The other method is to extract feature information from a conventional 3D CAD data base. But in current practice, designers are not designing with features, and it is very hard to change this practice in the near future. Therefore, the second approach, especially for the injection molded part design, is being investigated in this research.

2 LITERATURE SURVEY

2.1 Designing with Features

A "feature" is a domain specific geometric entity whose 1) presence, location, or dimensions are pertinent to the functionality or manufacturability of the part; or 2) whose availability as a primitive facilitates design in the domain.

The basic concept of the "designing with features" method is to use a domain specific representation method as the front end to the CAD system which accepts commands expressed in terms of a set of feature-primitives. Vaghul et al.[1] implemented a program called IMPARD(Injection Molding PARt Design) to assist the user in designing axisymmetric parts like tubes, vessels, and plates etc.. Luby et al.[2] developed a feature-based design aid, called Casper, for designing aluminum casting parts. Libardi et al.[3] developed a software, called Pedro, to help the user in designing extrusion parts. They provided interface between the feature data base and mechanical analysis tools for computing cross-section properties and for FEM. Problems with this method are :

1. It is almost impossible to design a complex real part only with feature primitives. Even if feature primitives are used in the design, conventional design aids are still needed for non-feature part of the design.

2. It is very hard and also takes too much time to change conventional design practice to feature-based design.

2.2 Extraction of Feature Data from Design Data Base

The basic concept of this approach is to extract higher level geometric feature information from conventional CAD data base. Choi et al.[4] developed an algorithm for the recognition of machined surfaces from a 3D solid model. Machined surfaces were algorithmically recognized from a 3D boundary file, and then their 25D descriptions were obtained for an automated process planning system. Yoshiura et al.[5] discuss top-down approach for the automatic generation of 3D data base from 2D projections of mechanical drawing. Woo[6] dicusses the problem of converting general solid model data structure to a special structures having features useful for finite element analysis. None of this research has addressed the problem of extraction of feature data base which is rich enough to be used in an expert system for manufacturability assessment.

3 Current Research on Feature Extraction from Solid Model

3.1 Overview

There are a number of reasons why injection molding was chosen for the topic of the research. One reason is that injection molding is an important and very complex process in manufacturing. Even if a part is very simple in geometry, the designer has to consider a large number of variables for the manufacturabilrty of the part. Another reason for'taking injection molding process as a good domain for research is that there are a number of heuristics for manufacturability which can be obtained only from the accumulated experience in the manufacturing process. Such heuristics cannot be easily reflected in the initial design because of the lack of communication between designers and production engineers due to the large scale production in most injection molding applications.

In the current research, boundary representation solid model is constructed from a given surface model. Currently, only planar surfaces are supported in our solid modeller. Therefore, if an input surface model contains curved surfaces, those curved surfaces are split into small planar surfaces under the specified error tolerance. Then domain specific features (rib, boss, etc.) are extracted and the feature graph is established. After the feature extraction, evaluation of parameters for each feature is performed and stored in the feature data structure. This data is then transported to expert system for the analysis of manufacturability.

3.2 Feature Extraction

In the feature extraction process, all the surfaces which compose boundary of a certain volumetric feature are searched and stored in the data structure. Currently, location and the type of the each feature is specified by the user, and then all the surfaces which belong to the feature are algorrthmically searched. This process is completely dependent on the type of the feature because of the inherent geometrical characteristics of the each feature. Therefore, each different type of feature requires the unique extraction algorithm. For example [Figure 1], a rib is typically long and thin plate with taper angles, and is attached perpendicular to the base plate. Whereas, a boss is typically cylindrical in shape with an inside hole for a thread. After all the surfaces of the feature are extracted, boundary edges for the feature are identified and stored for the connectivity of adjacent features.

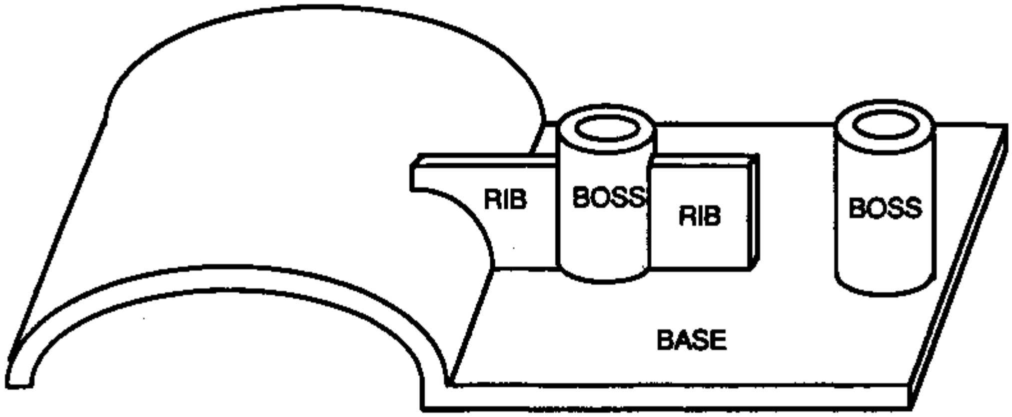

Figure 1: Typical Features in Injection Molded Parts

3.3 Feature Graph

After the feature extraction, high level abstract graph structure, called feature graph [Figure 2], is established for the connectivity of the features. This connectivity information is used in the expert system for the analysis of manufacturability. In the feature graph, feature node contains all the parameters of the feature and pointers to neighbourhood features, and feature link contains the information of common boundary between adjacent features. An example of the feature graph for an injection molded part [Figure 1-1] is given in Appendix I. In this feature graph [Figure I-2], there exist 11 feature nodes and all the connectivity of the features are described with arcs. All the necessary information of the each feature is also stored in the each feature node of the feature graph.

3.4 Parameter Evaluation

The following is a sample of a rule used in the expert system for the manufacturability assessment of injection molded parts[7].

```
Rule 7
( If feature is of type rib
&
  rib_width/base_thickness > 0.7, < 0.8
->
        magnitude of sink =0.5)
```

In the example above, it is obvious that the higher level feature data, i.e. *rib_width* and *basejhickness,* should be evaluated from the lower level CAD data base for the expert system. Parameters for each

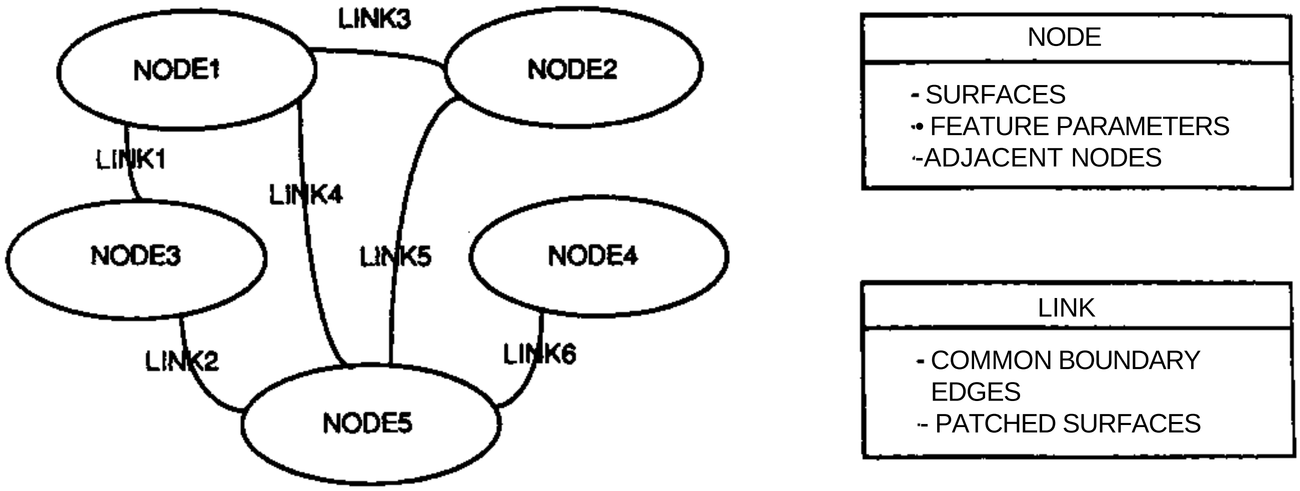

Figure 2: Feature Graph

feature are evaluated from the list of faces which belong to the each feature, i.e. feature node in the graph data structure. Each type of a feature has unique geometric properties and requires feature dependent parameters. Typical examples of the parameters are shown in Appendix II.

3.5 FEM Mesh Generation from Solid Model

A typical injection molded part has a base which is thin shell-shape, and it has some features on the base. Therefore, FEM and flow analysis of injection molded parts are based on 2D mesh with thickness of each element. As a biproduct of the feature extraction, approximate 2D FEM mesh can be formed with the subset of triangular faces of the solid model. Each volumetric feature is shrunk into faces, and then the cavity between two features is patched with triangular faces. This set of triangular faces are used as an input to the FEM analysis package CADMOULD.

4 Future Research Issues

4.1 Automatic Recognition of Features

In the current research, location and type of the feature are specified by the user. Ultimately, this user intervention in feature recognition should be eliminated and automatic feature recognition will be implemented. Two tentative ideas for automatic feature recognition are suggested :

- A feature can be spotted by checking variance of thickness in ejection direction while the whole region of the part is scanned. Then type of the feature should be identified with domain specific rules.

- Assuming that injection molded parts are composed of thin shell or plate, a skeleton model of the part can be built [Appendix III]. Then features can be easily detected by checking topological connectivity of all the surfaces in the skeleton model. Feature recognition with a skeleton model is much easier than with a solid model because a skeleton model provides topologically nonuniform faces, whereas a solid model is composed of topologically undiscriminated uniform set of faces. In the example of Appendix III, a rib can be easily detected by checking edges which have three faces around them.

4.2 Application to Different Domain

Application of this approach to other manufacturing processes will be investigated. Since the current approach depends on the specific domain, some more new concept will be necessary to deal with a new domain of manufacturing process.

I. Example of Feature Graph

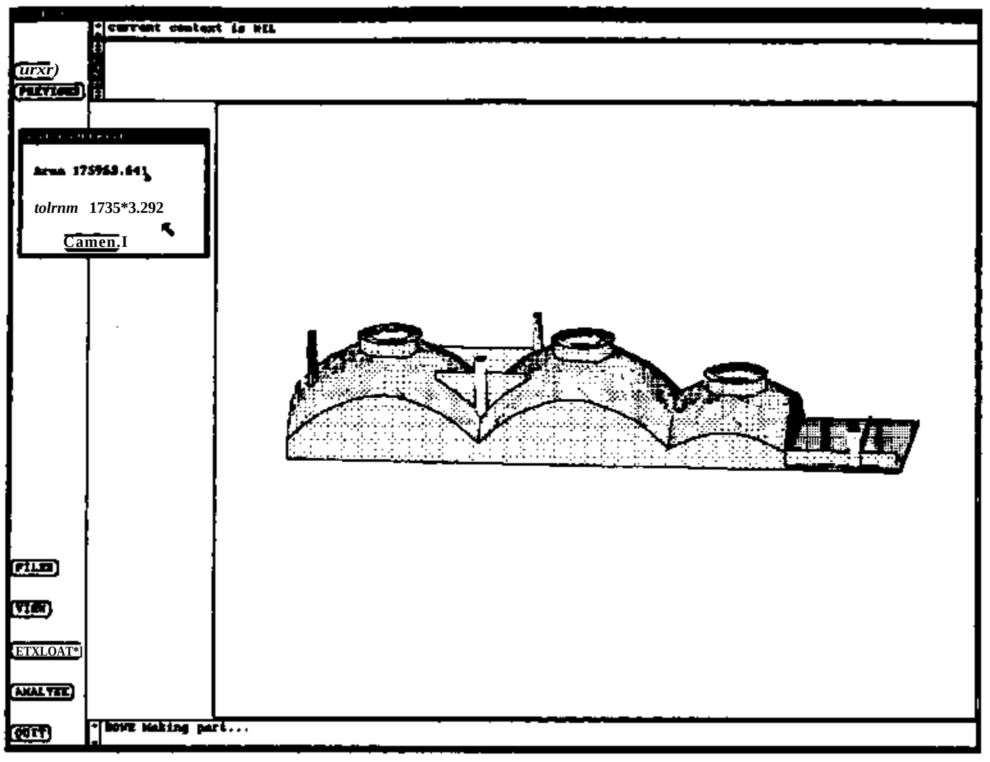

Figure 1-1: Example of an Injection Molded Part

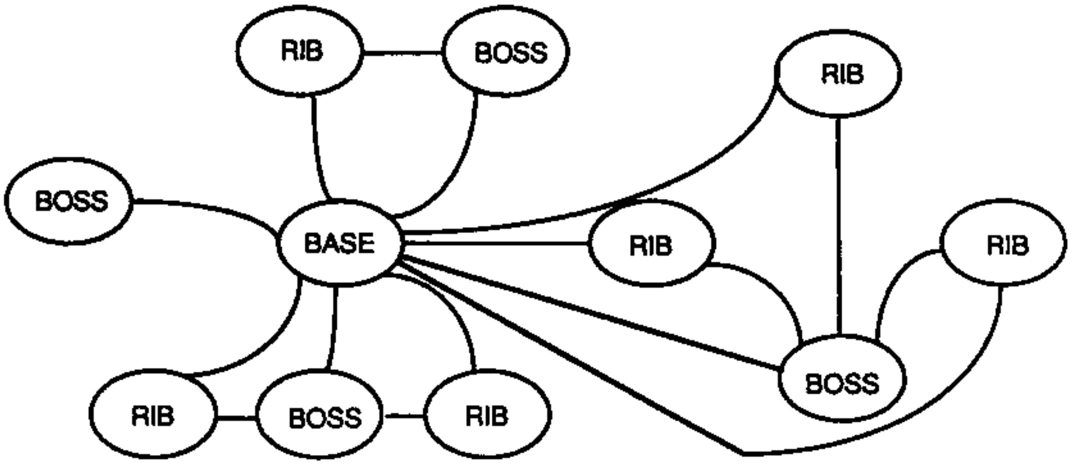

Figure I-2: Feature Graph for the Part Above

II. Feature Parameters in Injection Molded Part

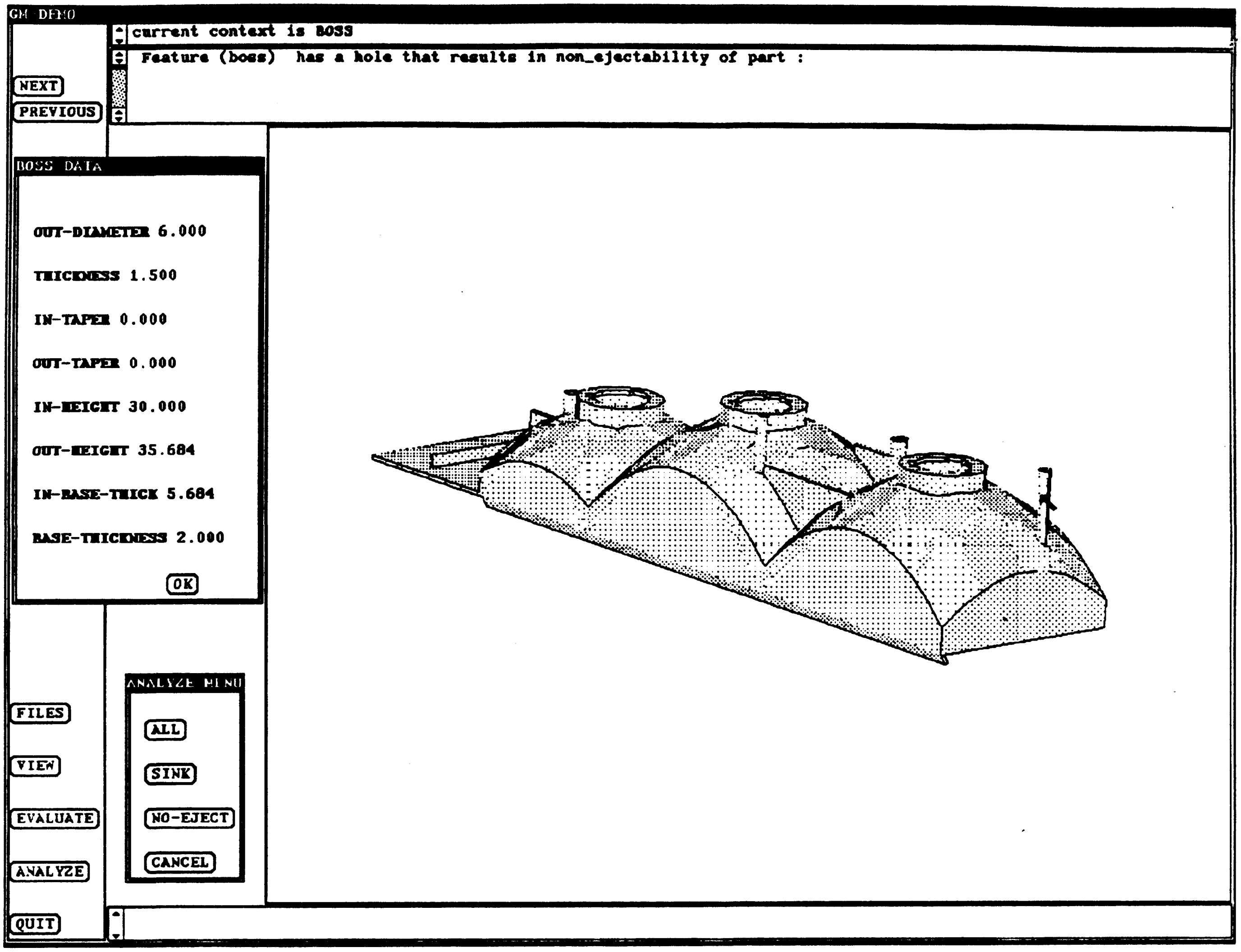

Figure II-1: Parameters for a Boss

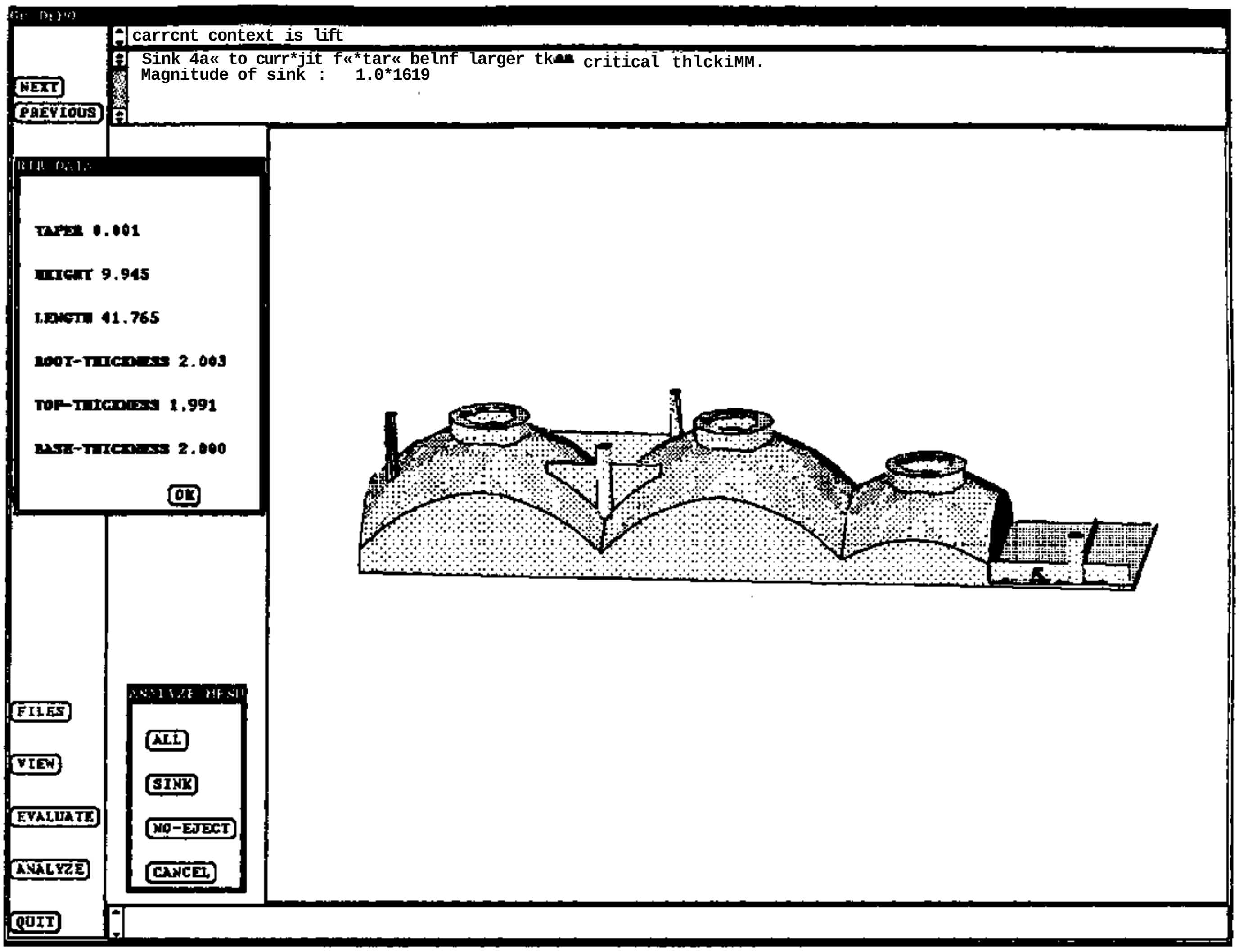

Figure 11-2: Parameters for a Rib

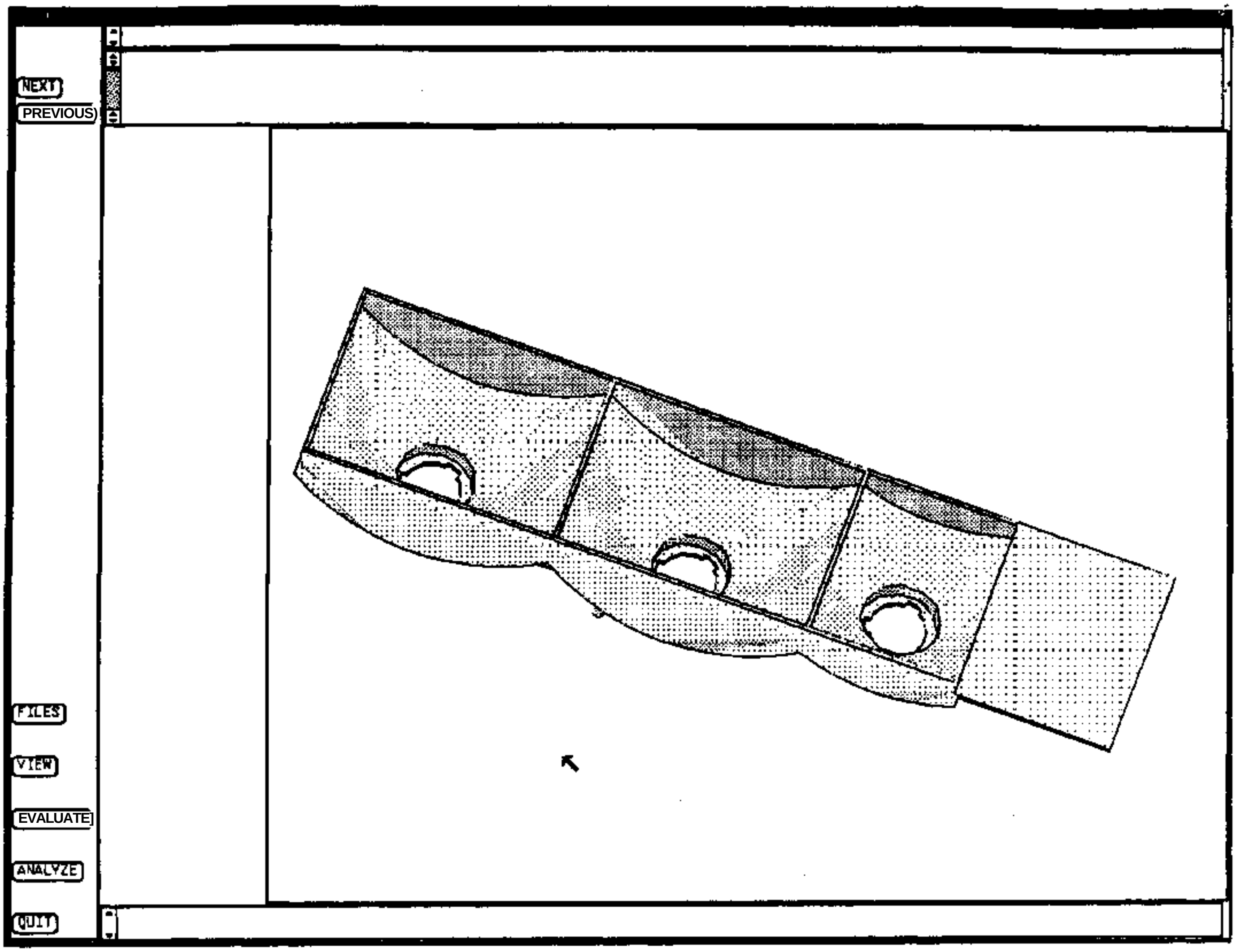

Figure 11-3: Bottom View of the Part

III. Concept of Skeleton Model

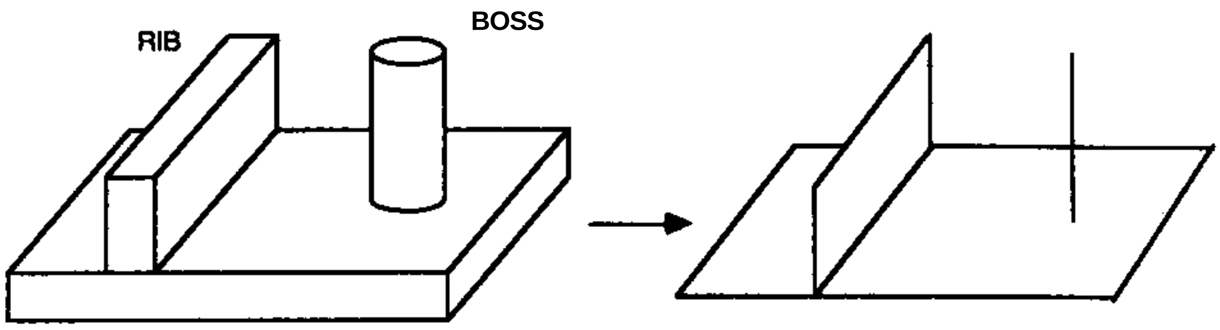

Figure MM: Solid Model and Skeleton Model

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