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Summary of Research

Design Through Manufacturing:
The Solid Model-Finite Element Analysis Interface

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DESIGN THROUGH MANUFACTURING: THE SOLID MODEL-FINITE ELEMENT ANALYSIS INTERFACE

PROJECT DESCRIPTION

State-of-the-art computer aided design (CAD) presently affords engineers the opportunity to create solid models of machine parts reflecting every detail of the finished product. Ideally, in the aerospace industry, these models should fulfill two very important functions:

(1) provide numerical control information for automated manufacturing of precision parts, and
(2) enable analysts to easily evaluate the stress levels (using finite element analysis – FEA) for all structurally significant parts used in aircraft and space vehicles.

Today's state-of-the-art CAD programs perform function (1) very well, providing an excellent model for precision manufacturing. But they do not provide a straightforward and simple means of automating the translation from CAD to FEA models, especially for aircraft-type structures. Presently, the process of preparing CAD models for FEA consumes a great deal of the analyst's time.

This report summarizes initial developmental work on the Automatic CAD-FEA Interface (ACFI) Project, a research program intended to make the translation from CAD to FEA model seamless and automatic. Four software packages have been developed and are discussed below.

1. Automatic Revised Version Copy Program (REV)

Purpose

The standard ProE "Save As" command saves a file with another name, but the original file is still the open file (this is different from conventional Windows commands where "Save As" closes the open file and activates the new one). The REV program saves the old file and activates a copy of that file under a new name.

This program automatically:

- Saves a copy of an open Part file with a new name in the current working directory
- Erases the original file
- Activates the newly saved file

2. Automatic Round, Chamfer and Hole Removal Program (XRC)

Purpose

Most rounds and chamfers, and many holes, do not change the state of stress in a structure; in order to simplify the finite element meshing process, they should be removed before the solid model is exported for analysis. The XRC program performs this function.

This program automatically:

- Removes ***most*** rounds, chamfers and holes from a ProE part (some cannot be removed because they have children that are not rounds, chamfers or holes)
- Generates a log which lists:
  - Rounds not deleted, their IDs and their childrens' IDs
  - Rounds deleted and their IDs
  - Chamfers not deleted, their IDs and their childrens' IDs
  - Chamfers deleted and their IDs
  - Holes not deleted, their IDs and their childrens' IDs
  - Holes deleted and their IDs

3. Automatic Recognition and Extraction Program (REX)

Purpose

Thin or long features should be exported from CAD to FEA programs as surfaces and lines rather than solids. This permits automatic meshing with shell or beam elements rather than 3-D tetrahedral elements. Shell or beam elements better characterize the behavior of thin or long features yielding faster and superior results. The REX program identifies the geometric nature of a single object, categorizes it as a thin plate, beam, or solid and, if it is a thin plate or beam, exports its geometry to an IGES file (for import to an FEA program).

This program automatically:

- Recognizes if an object is a rectangular or cylindrical thin plate, beam, or block.
- Extracts the midsurface of a thin plate and exports it as an Initial Graphics Exchange Specification (IGES) file to the working directory.
- Extracts the neutral axis of a beam and exports it as an Initial Graphics Exchange Specification (IGES) file to the working directory.
- Generates a log which lists:
  - Object type (thin plate, beam, or block)
  - Log file name
  - Part name
  - Mid-surface file name (for thin objects)
  - Neutral axis file name (for long objects)
  - Model units

- Surface Ids
- Surface types
- Surface areas
- Area ratios (quotients – see Theory section below)
- Total number of surfaces

Theory

An assumption for small deflection plate theory is that the thickness of the plate is small compared to its other dimensions[1,2]. The smallest in-plane dimension of the rectangular plate must be at least ten times larger than its thickness[3]. For a circular plate, the diameter must be at least ten times larger than its thickness.

For beams, the elastic flexure formula describes the stress distribution in a beam due to bending. In order for this formula to be valid, the beam must be long enough so that shear forces do not cause warping of the cross section. The length of the beam must be at least ten times larger than the height in order to make the shearing effects negligible. For a cylindrical beam, the length:diameter ratio must be at least ten[3].

REX performs object recognition using the definitions of "thin" and "long" based on the above assumptions. Therefore, a surface is considered "large" if the calculated quotient (see below) is greater than 0.1. The values 0.2 and 20 are used for cylindrical objects because in ProEngineer, cylindrical surfaces are split into two curved surfaces.

<u>Rectangular Object Recognition</u>

REX visits all surfaces of an object, determines the surface area of each, and sends this information to a text file. Each surface area is used to determine if the object is a thin plate, block, or beam. For rectangular objects, the program calculates a quotient by taking the largest surface area of the object and dividing all the surface areas by this value. If the quotient is less than 0.1 the program ignores the surface, but if it is greater than 0.1 the program recognizes this as a "large" surface. After gathering all of the quotient information for each surface, the program determines the object type by counting the number of large surfaces. The following is the number of large surfaces for each object type:

(1) Thin Plate $\rightarrow$ 2 large surfaces

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[1] Dimarogonas, A. D. Machine Design, A CAD Approach, Wiley-Interscience, John Wiley & Sons, Inc. [2001], New York, NY.
[2] Beer, F. P., Johnston, E. R. Jr., and DeWolf, J. T. Mechanics of Materials, 3rd ed., McGraw Hill [2002], New York, NY.
[3] Szilard, Rudolph. Theory and Analysis of Plates: Classical and Numerical Methods, Prentice-Hall [1973], Englewood Cliffs, NJ.

(2) Beam → 4 large surfaces
(3) Block → 6 large surfaces

Cylindrical object recognition

REX gathers the surface information in the same manner as above. After the data is collected, the program calculates a quotient by dividing all surface areas by the largest planar surface. This ensures that the quotient shows the ratio of length:diameter (in the case of a cylindrical beam) or height:diameter (in the case of a cylindrical plate). The program then checks the largest cylindrical surface and the ratio associated with it. The following ranges are used to determine the type:

(1) Cylindrical Plate → Quotient < 0.2
(2) Cylindrical Block → 0.2 < Quotient < 20
(3) Cylindrical Beam → 20 < Quotient

4. Feature Extraction and Automatic Analysis Program

Purpose

A designer will often want to test a single feature of a complex part "on-the-fly" while it is being developed to see if it will have the required strength characteristics. This program will extract individual Pro/E part features to Pro/Mechanica for localized testing, and it will define and perform a Pro/Mechanica analysis. This is done through a series of Pro/Toolkit programs, mapkeys and macros.

The program EXT automatically:

- Recognizes if the model is a part or an assembly.
- Recognizes the current displayed representation:
  - If a simplified representation has been activated, the program automatically begins the analysis process on this representation
  - If the Master representation is activated, the program asks the user if he wishes to analyze the entire model or just some features of the model.
    - If the user wishes to analyze the entire model, the program automatically begins the analysis process on the master representation.
    - If the user wishes to extract features, the program creates the simplified representation of the specified feature(s) (if model is a part) or of the specified part(s) (if model is an assembly) and activates the last simplified representation created as the one to be displayed. Then the program automatically begins the analysis process on this representation.

Then the mapkeys automatically:

- Allow you to choose the material in the material library.

- Allow you to define as many point, edge or surface constraints and loads as you wish.
- Automatically define a static analysis using the parameters you entered and send you to Independent Mode.

Then the macros automatically:

- Mesh the model.
- Retrieve the convergence plot of the maximum Von Mises stress and the magnitude of the Von Mises stress in the model.

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