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# Analysis Tools for Design Engineers

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## ABSTRACT

The successful use of analysis by design engineers during the product development process strongly depends on the choice of those analysis tools that offer easy integration with CAD and provide reliable results, while not requiring an in-depth expertise in analysis.

The intention of this paper is to assist in choosing those tools that are best suited for use by design engineers. We start with a summary of differences between analysis performed by a design engineer and by an analyst. Next, we discuss advantages and disadvantages of commercially available analysis methods, from the point of view of design engineers.

In conclusion we recommend that design engineers use either the p method of the Finite Element Analysis or the Precise Solids Method and offer hints as to which one is advantageous depending on particular analysis problem.

## INTRODUCTION

Competitive pressures demanding that new products be developed fast and cost efficiently have pressured design engineers to analyze designs in progress rather than to rely on the traditional prototyping and testing approach. It is obvious that only the most effective analysis tools should be used to support a design in progress. Given the variety of available software products, this choice is not always clear.

The intention of this paper is to make this choice easier by reviewing traditional and emerging analysis technologies and evaluating their usefulness for design engineers.

## ANALYSIS FOR DESIGN ENGINEERS

Let's summarize typical features of analysis as performed by a design engineer:

- Analysis is one of many design tools
- Analysis and design are performed concurrently
- Results are used instantly in the next design iteration to modify the design while it is still in the electronic format
- Analysis is performed on geometry developed in (almost always) solid CAD system
- Typical analysis type is linear static, modal or steady state thermal
- The user has in-depth understanding of the product but does not have specialized analysis training

## AVAILABLE ANALYSIS METHODS

Since 1970's the Finite Element Methods has dominated the analysis market. Other methods like e.g. the Boundary Element Method have never gained a wide acceptance but remain important tools for niche applications.

We will limit our discussion to mainstream analysis tools based on the Finite Element Method and its derivatives.

### FINITE ELEMENT ANALYSIS

All tools based on the Finite Element Analysis, require discretization (commonly called meshing) of CAD geometry before an analysis can commence. The mesh-ability is the pre-requisite condition placing demanding requirements on geometry. To make geometry meshable and to assure a reasonably low number of elements, CAD geometry must be converted into analysis specific geometry. Consequently, an interface between these two geometries must be introduced (figure 1).

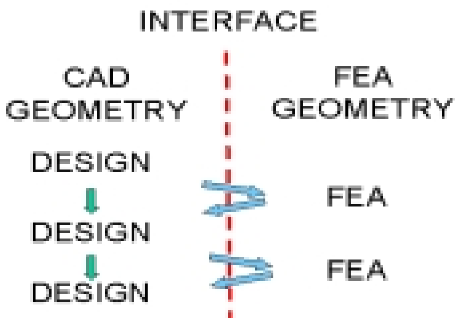


Figure 1

Concurrent CAD-FEA process is disrupted by the need of alternating between CAD and FEA specific geometry.

Two FEA methods (h and p) have been implemented into commercial analysis software. The ubiquitous h-method of FEA has been in use for the last thirty years. Ten years ago, it has been joined by the p-method. h and p methods significantly differ in analysis capabilities and in the extent of the required modifications to CAD geometry.

h-method of FEA uses elements with field variable (e.g. displacement) described by first or second order polynomials. This limits element shapes to simple geometric primitives (figure 2) and typically requires meshes with large number of small elements. Geometry must be extensively defeatured, idealized and cleaned-up before it can be meshed (see appendix). Even though meshing is most often done automatically, user's judgment is still necessary to decide if the mesh is acceptable.

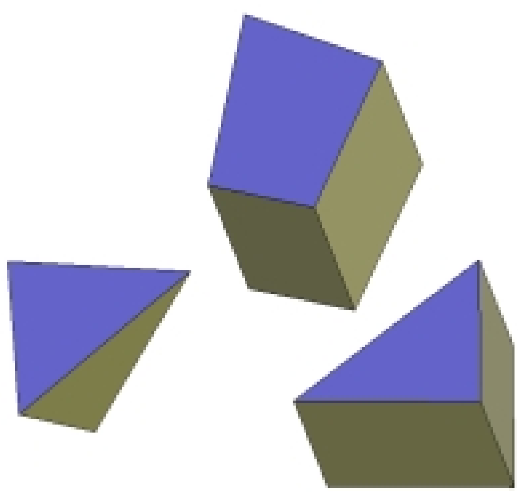

Figure 2

Simple element shapes are available in h-method.

One of the most challenging tasks is meshing thin features where user's intervention is routinely needed to assure correct mesh.

Meshing problems are compounded by the need to choose the proper element type from large libraries of specialized elements. Error analysis in h-method requires a tedious process of mesh refinement and is rarely done in practice. On the positive side, h-method offers analysis capabilities that are unmatched by other methods. However, most design engineers seldom use those advanced analysis capabilities.

p-method of FEA uses elements of more complex shapes (figure 3) with field variables described by higher order polynomials (up to 9$^{th}$ order). This allows for larger elements that map precisely to geometry and correctly represent thin solid features. More deviation from the ideal shape is allowed, so the automesher finds it easier to the complete meshing process while creating elements of acceptable shapes. p-method iterative solution allows for automatic calculation of relative (convergence) errors. The ability to correctly represent thin features and to map elements precisely to geometry reduces the need for idealizations and defeaturing.

Present day p-method implementations cover simple types of analysis: linear with limited non-linear capabilities. As compared to h-method, there is less need for user's judgment. Also, automatic p-element meshing is more likely to produce a correct mesh.

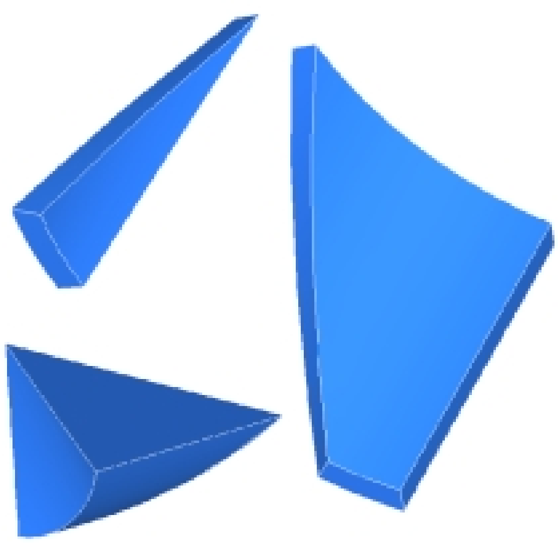

Figure 3

More complex element shapes are available in p-method.

PRECISE SOLID METHOD

An emerging technology, a derivative of the Finite Element Method called the Precise Solid Method (PSM) has recently joined the analysis market. The PSM is based on the External Finite Element Approximation Method [(1)]. The analysis is conducted directly on solid CAD geometry. Defeaturing, idealization and cleanup are not required. Consequently, there is no need to introduce analysis specific geometry.

Even though the PSM is a meshless method, discretization is still necessary. The solid CAD geometry needs to be split into subparts to facilitate reasonably simple approximation of field variables by polynomials (up to $12^{th}$ order) and by non-algebraic stress concentration functions. The stress concentration functions are deployed if solely polynomial approximation would produce too high errors. The combined use of polynomial and non-algebraic approximation of field variables allow for any shape of subparts (figure 4). Both relative (convergence) errors and absolute boundary conditions errors are automatically calculated.

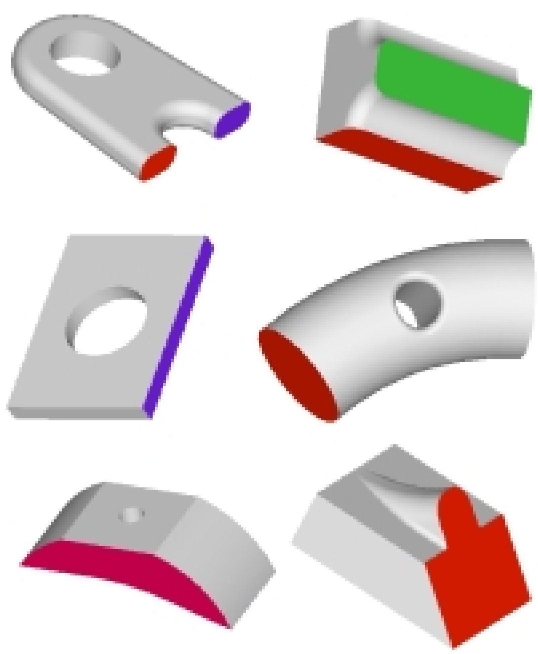

Figure 4

Subparts in the PSM are of arbitrary shape.

The fact that PSM works directly with solid CAD geometry and only with solid CAD geometry, may be seen as a disadvantage limiting the choice of modeling techniques to 3D solid representations or as an advantage relieving the user from the need to convert CAD geometry into analysis specific geometry.

h-method is represented by a large number of well-established software tools like, for example, ANSYS, NASTRAN or ABAQUS to mention just a few. p-method has been implemented e.g. in Pro/MECHANICA and STRESSCHECK. The PSM has been implemented in PROCISION.

## SELECTING THE MOST SUITABLE ANALYSIS METHOD

Our evaluation criteria of software tools that are best suited for design engineer are as follows:

- Since defeaturing and idealization are not value added tasks and often require high expertise in analysis, CAD geometry and analysis specific geometry should be as close as possible. Ideally, analysis would be conducted directly on CAD with no modifications at all. If possible, CAD–FEA interfacing should be eliminated, not just improved

- Results should be minimally (if at all) dependent on user's judgment.

- Result errors, always present as in any numerical method, should be automatically calculated.

- Data exchange between CAD and analysis software should be invisible to users

In the view of the above, the h-method, a powerful but demanding analysis tool, is well suited for analysts but less so for design engineers. p method of FEA and the Precise Solids Method both are well suited for concurrent design analysis. Which one is better, this will depend on the type of analyzed problem.

In some cases the introduction of analysis specific geometry is difficult to avoid. A typical example is a thin wall structure suitable for analysis with shell elements or beam structure suitable for analysis with beam elements (figure 5). In both cases the tool of choice would be p-method allowing for shell and beam representations. The PSM can be used on these parts but would require tedious splitting into subparts.

p-method is also very effective on mesh-able solid geometries i.e. those requiring minimal or no preparation effort as the p-method works very well with thin features, correctly representing bending with even one layer of elements (figure 6).

PSM is well used on geometry that needs to be represented as solid geometry and would require significant modifications to make it mesh-able with a reasonable number of elements (figure 7). For those problems, no need for defeaturing offsets time spent on manual splitting of solid geometry into subparts. PSM also shows advantages when used on “dirty” geometry in need for “clean-up” prior to meshing in traditional FEA.

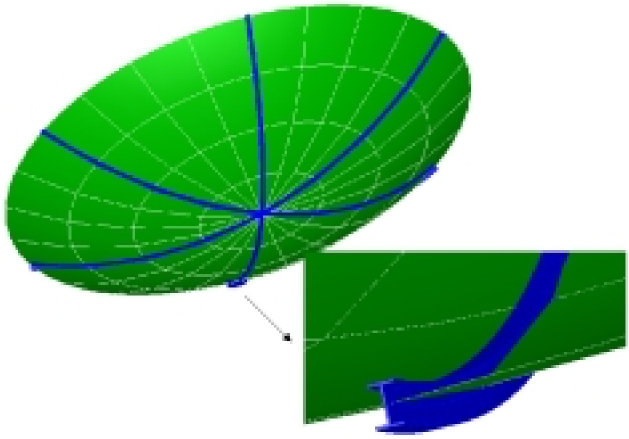

Figure 5

Structure suitable for shell and beam element representation is a good candidate for FEA p-method.

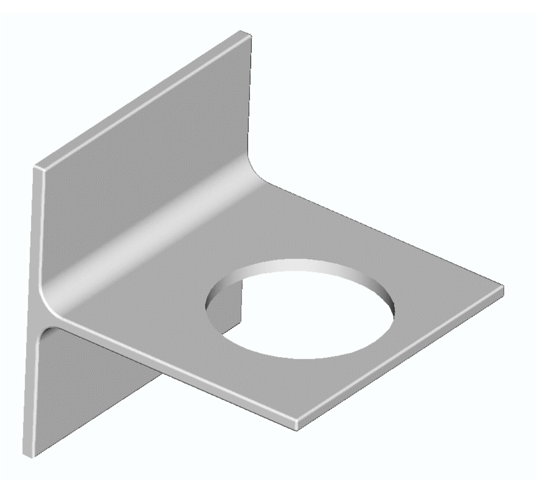

Figure 6

Simple solid geometry with thin features that need solid representation (here due to the fillets) is a good candidate for p-method.

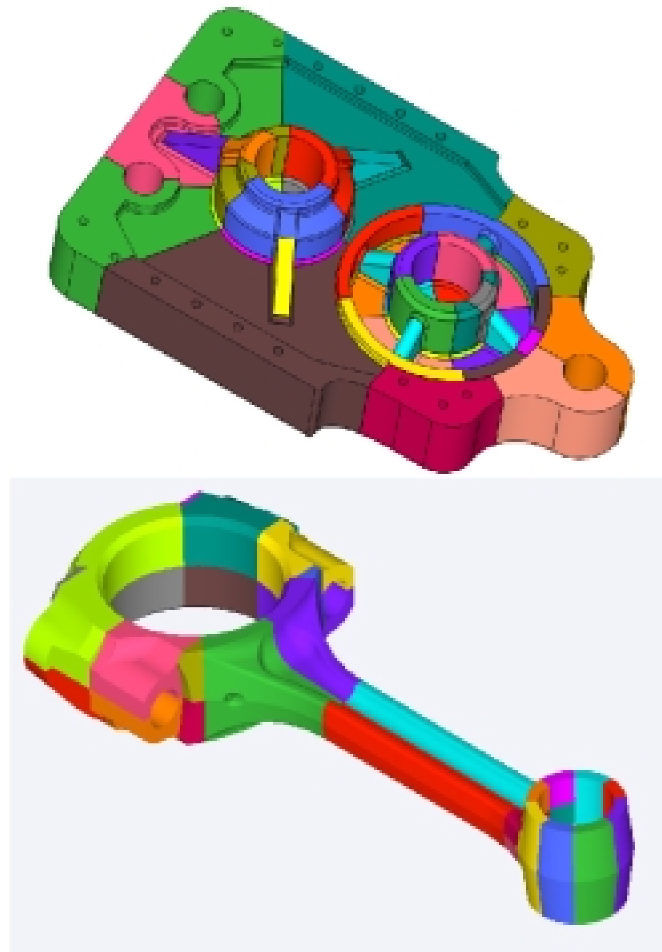

Figure 7

Complex solid geometry, that would require major modifications to make it meshable for use by FEA, can be analyzed “as is”, with no simplifications with the PSM. Division into subparts is shown.

The decision which method should be selected (assuming, of course, that both are available) will depend on the nature of geometry to be analyzed. Sheet metal parts, girders, beam structures etc. requiring beam or shell representations call for FEA p-method (figure 8). Inherently complex parts like Injection molded, die-casted, forged parts can be efficiently analyzed with PSM. For those complex parts, the PSM also offers faster solution times than FEA (figure 9).

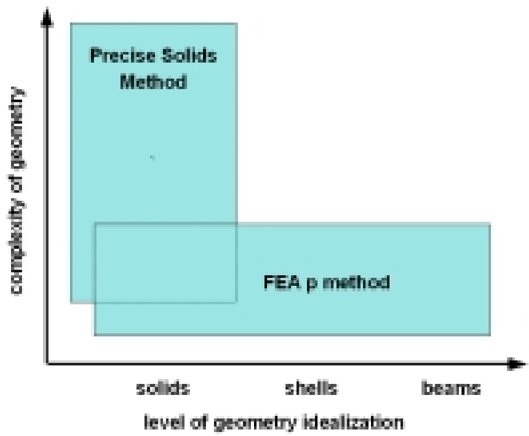


Figure 8

The applicability of FEA p-method and the PSM to different modeling approaches.

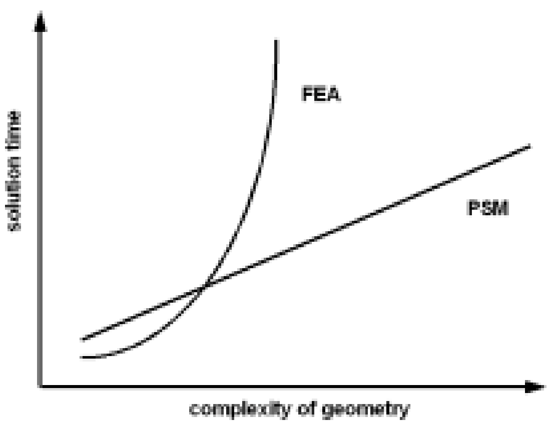


Figure 9

The relative speed of solution in the FEA p-method and in the PSM, shown as a function of the complexity of geometry.

## CONCLUSION

Out of three available methods, FEA h-method is best left in the capable hands of analysts. FEA p-method and the PSM are both well suited for use by design engineer concurrently with the design process.

<u>Use p-method if:</u>

Geometry is suitable for beam or shell element representation

Geometry is suitable for solid representation, meshes with little preparation and meshing produces reasonably low number of elements

<u>Use the PSM if:</u>

Geometry is complex and would require significant defeaturing and/or idealization to make it mesh-able and/or to contain the FEA model size

Geometry has quality problems requiring clean-up prior to meshing in FEA

## REFERENCES

1 Victor Apanovitch; External Finite Element Approximation Method
Minsk 1991. – 171 c. ISBN 5-339-00597-6.

Title of original in Russian:
Апанович В.Н. Метод внешних конечноэлементных аппроксимаций. –Мн.: Выш.шк.,

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## APPENDIX

**DEFEATURING** (figure 10) removes geometry details, which are deemed unimportant for analysis. Defeaturing runs the risk of removing those details that actually are important for analysis and requires careful engineering judgment. Present day very complex geometries, created at ease with powerful CAD systems, make this judgment even more difficult.

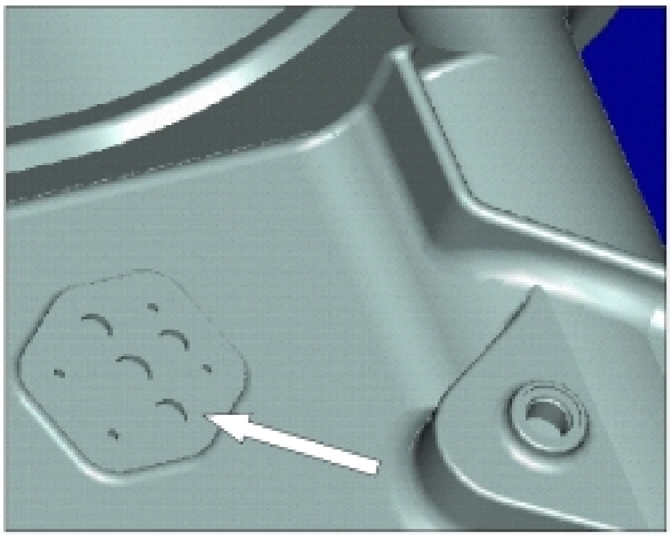

Figure 10

An example of structurally insignificant detail; it should be removed to enable meshing.

**CLEANUP** (figure 11) consists of various actions bringing the quality of CAD geometry up to FEA standards. As opposed to the need of defeaturing and idealization, arising from inherent limitation of FEA, the need for cleanup results most often from poor solid modeling practices (e.g. multiple entities, tangent lines, gaps between solids)

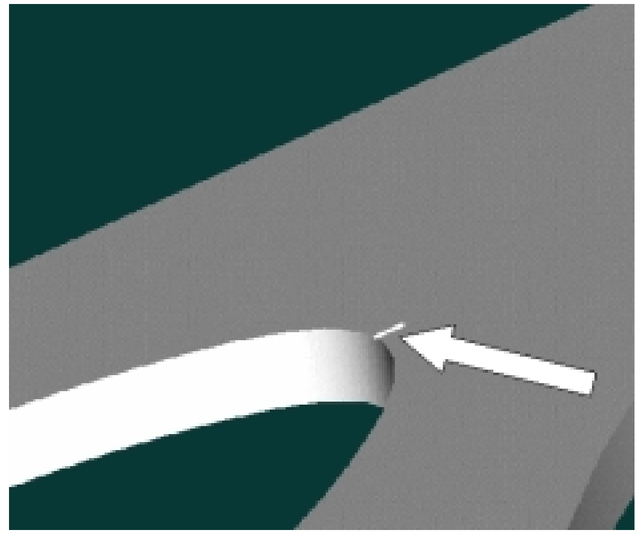

Figure 11

Example of geometry clean-up; a “sliver” needs to be removed prior to meshing.

**IDEALIZATION** (figure 12) changes the way geometry is represented A typical example of idealization is replacing thin solid geometry with mid-plane surface suitable for shell element meshing. Those thin features would be otherwise very difficult or impossible to mesh with solid elements. Idealization calls for a major departure from manufacturing specific CAD geometry.

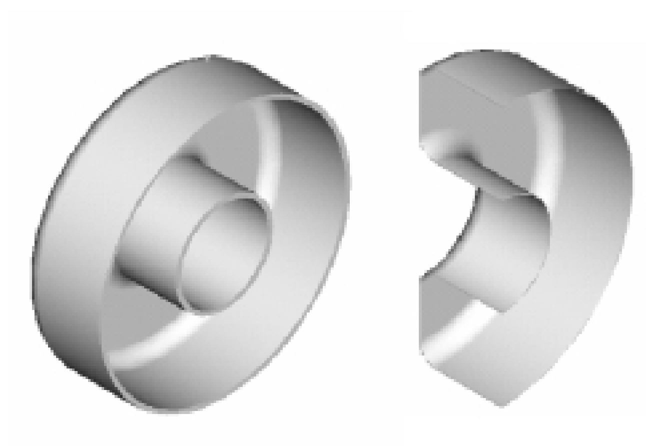

Figure 12

A typical example of idealization: replacing thin solid geometry with mid-plane surface to enable shell element representation; modeling one half of the model geometry by applying symmetry boundary conditions.