CAD Based Optimization

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Introduction

In one form or the other one of the primary goals of simulation technology over the years has been to optimize designs. On the whole this has been a manual process involving the generation of multiple mathematical models which have been used to validate a given design, and also to compare different configurations of a design. Although the use of simulation techniques has proven to be an invaluable part of the engineering design cycle they has not yet had the impact everyone desires.

In order to help engineers to shorten the design cycle optimization software has been added to existing packages. Even with these new technologies we are still not seeing the kinds of efficiencies that design firms have hoped for. The reasons for why simulation applications, and FEA in particular, have not had their fullest impact to obtain optimized designs are long and varied. Some of these factors include:

- FEA has been hard to use and therefore has been relegated to just a handful of specialist rather than mainstream design engineers.
- Optimization technology itself has been slow to mature.
- The CAD software used for design, and FEA software used for simulation have been stand-alone systems which simply don't talk to each other very well.

This paper describes a system which marries geometric construction tools, simulation software, along with topology and shape optimization technologies which can be utilized by engineers early in the design cycle to reduce the time needed to bring new products to market. By integrating these formerly disparate functions under one umbrella we have taken a giant step forward to achieve efficiencies which were unthinkable just a few years ago.

The Optimization Problem

Optimization can be used in a variety of situations to help identify potential improvements to a design. In simple terms, optimization techniques require users to identify the following:

- An objective function - e.g., minimize weight
- The relevant design variables - e.g., radius of hole, length of an edge, thickness of a plate
- The side constraints on the system - e.g., stress less than 'x', frequency greater than 'y'

For design purposes there are basically three different optimization types which are in use:

1. Sizing used for determining the optimal property parameters such the cross section of a beam or the thickness of a shell.
2. Shape used for determining the best values of geometric parameters.
3. Topology used to find alternative shapes potentially involving gross changes in the geometry and associated topological entities.

All three of these techniques are available in MSC products each having it's own scope of applicability to various stages of the design cycle. Sizing optimization has been available in MSC/NASTRAN for a number of years and is the most mature of all of the techniques. Although sizing optimization is worthwhile, by it's very nature is limited in scope. Shape optimization has also been an integral part of MSC/NASTRAN for several releases and is most useful for fine tuning geometric parameters. As implemented, it is a gradient based technique that is most effective when you are close to the optimal geometric configuration. Topology optimization is the newest member of the MSC product suite in the form of MSC/CONSTRUCT. MSC/CONSTRUCT is an optimality based technique with which enhanced shapes can be generated that can represent new geometries which can be radically different from the initial design configuration.

Topology optimization is most effectively used in preliminary design situations in order to obtain candidate designs which maybe significantly different from each other.

There are of course many other different forms of optimization technology which can be used for design. Included in this list are technologies such as design of experiments and response surface methods, stochastic based optimization and knowledge based optimization. These are additional technologies which can be used to aid us in our efforts to obtain optimal designs, but are beyond the scope of this paper.

The Current System

Currently the typical usage scenario for obtaining optimized designs can be shown by the following diagram.

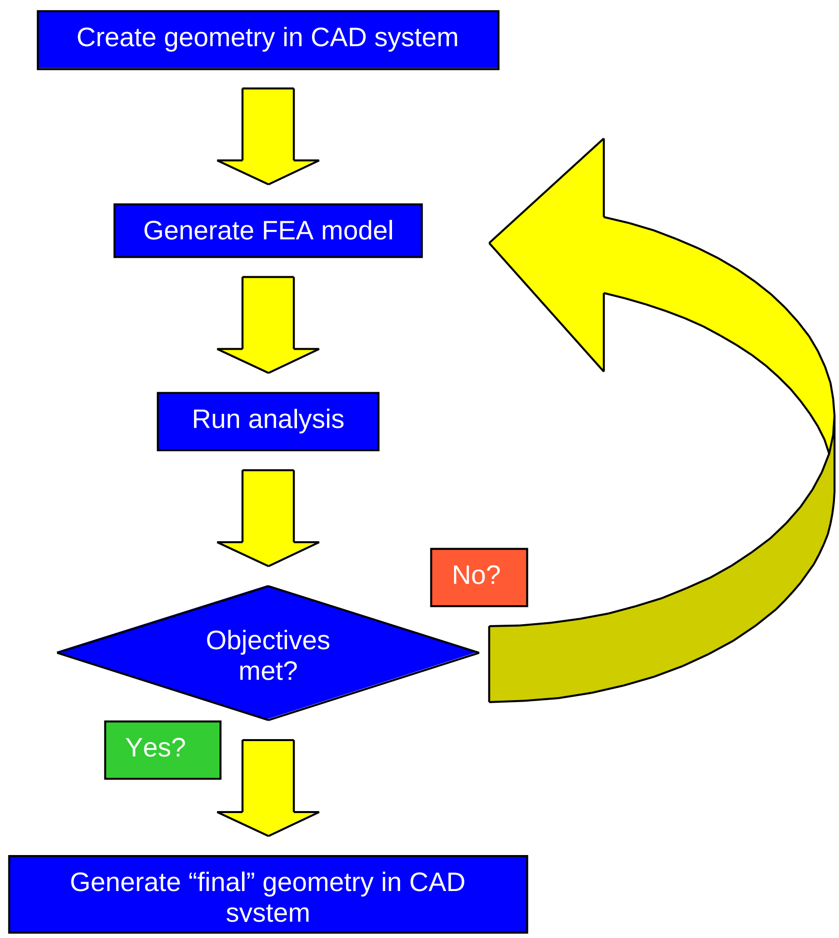

Figure 1

The main points are as follows:

- A CAD system is employed to construct the geometry and the associated parameters. After the geometric model is generated the appropriate file(s) containing the geometric data is exported to the FEA software *without* the parameters.
- The geometry is imported into an FEA preprocessor where a mesh, loads and boundary conditions, relevant properties and problem setup information is generated. The biggest bottleneck here is the importation of the geometry and the usual loss of data which occurs.
- The resulting model is then analyzed using MSC/NASTRAN with SOL200 from which new values of the design variables are gotten.

or

- Multiple analyses are run with manual updates of the finite element model to determine better values for the design variables.
- The new design variables are then *manually* entered into the CAD system to obtain the optimized shape.

This procedure works, but has several bottlenecks that hamper our abilities to more efficiently obtain optimized shapes. The following discussion represents those areas which have the most influence on the overall process.

Since the design is initially done in the CAD system it is inherently limited by the starting configuration which is chosen. This is due to the fact that there is a given set of geometric parameters that can be altered which by their very nature will limit the scope of the design space that can be examined. There is very little chance that a completely different geometric configuration can be derived from the changes that are prescribed for the parameters.

If you make the assumption that you have a good starting design, i.e., reasonably close to optimal, the single most limiting factor is the data transfer from the geometry system (CAD) to the optimization system (FEA). A complete optimization may require several rounds of import, analysis, model update, re-import, re-analysis, re-update, and so on. This requires very robust data exchange mechanisms between the geometry and optimization systems for which we only have partial solutions today.

Once you do have the geometry in the optimization system the big problem of how to modify the design variables then becomes the next hurdle which must be overcome. If the optimization procedure of MSC/NASTRAN via SOL200 is used then the so-called "shape basis vectors" must be generated. This can be accomplished by using an auxiliary model, or using facilities of the optimization system if they are offered. Also, unless a very special system is put in place the design variables which are optimized in this phase have nothing or little to do with the parameters specified during the geometric construction phase.

Finally, once you have obtained optimal values for the design variables the link back to the CAD system is currently non-existent. This is a completely manual process by which you take the new values for the parameters and use the CAD system functionality to alter the existing values and then regenerate the geometric model to obtain the new configuration.

The New System

Although the current methodology does result in better designs, to improve the flow and obtain a more efficient system the bottlenecks which currently exist must be eliminated. One way to do this is to take these stand alone packages and merge them together into a single unified piece of software. This is the philosophy which has been incorporated into the MSC/InCheck product line.

The following diagram shows a new methodology which can be used to obtain optimized designs in a more efficient fashion.

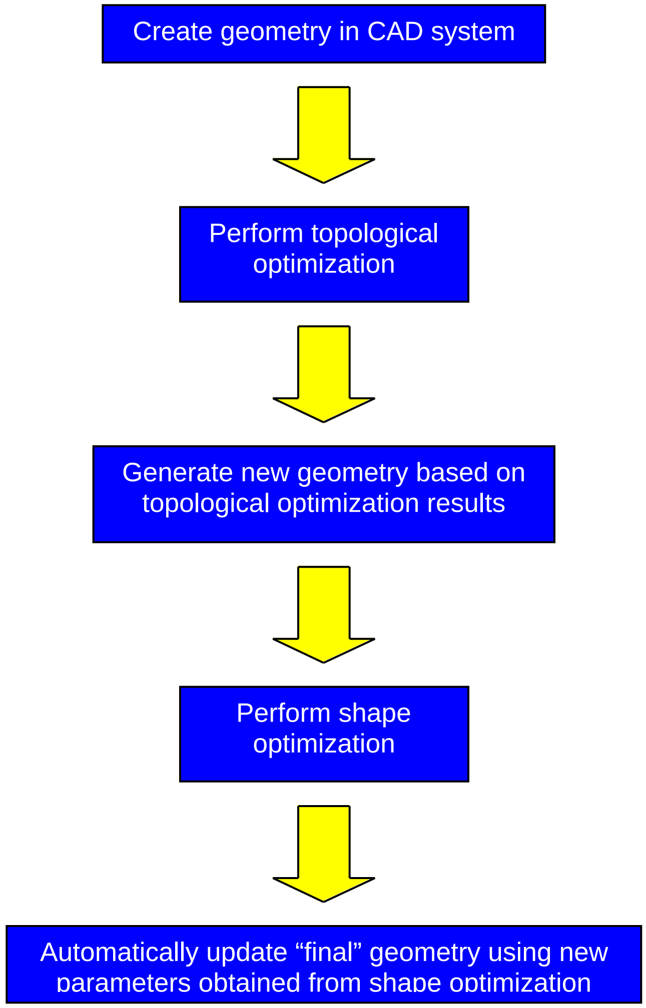

Figure 2

There are several key points that this diagram points out:

- It is applicable to both the conceptual and final design phases. The use of topology (optimality criteria) optimization with MSC/CONSTRUCT allows you to explore a broader area of the design space and minimize the chances of getting stuck around a local optimum. The use of shape (gradient based) optimization that SOL200 of MSC/NASTRAN provides allows you take the best of the topologically based configurations and modify the geometric parameters to further refine the design.
- There is no transfer of data required as the process is performed using a single system. The CAD geometry and the CAE model are also full associative

allowing a greater amount of flexibility to perform parametric studies if desired.

- The geometric parameters specified in the CAD system during geometric construction are the same ones used to generate the shape basis vectors for use in MSC/NASTRAN.
- The new values computed for the design variables are immediately available to the CAD system can be used to automatically update the geometric model.

The system is not perfect, but can be effectively used to study many different design alternatives in a reasonable time frame. There are several functional points which must be added to the current system. These include a better way to link the results from the topology optimization back to the CAD geometry, handling topological changes which occur during the shape optimization procedure, discreet changes in design variables and manufacturing related information. Although these features are useful, the lack of them does not detract from the benefits that MSC/InCheck provides.

Example Problems

The following example demonstrates how the MSC/CONSTRUCT and MSC/InCheck systems can be used to obtain an optimized design.

In this example we will take a wishbone connector through the process of going from a conceptual state to a final, optimized one. The process is to take the initial design and have the software automatically optimize it, first using a topology algorithm and then a shape one.

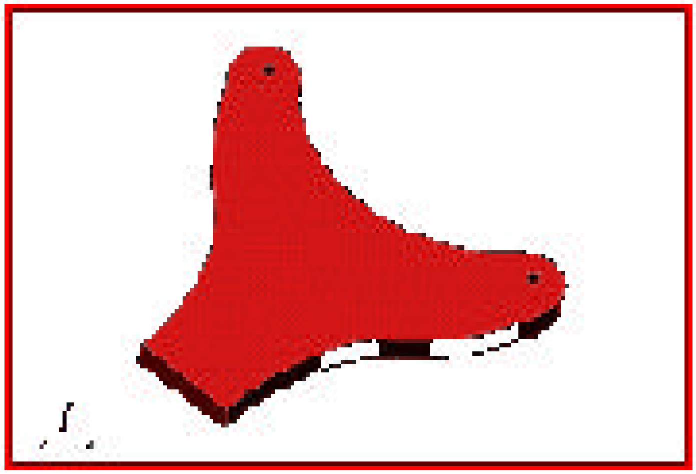

Figure 3

The initial design is shown in Figure 3. This model is typically generated in a CAD system with the associated parameters. The intent is reduce the weight of this part by utilizing automated optimization to obtain new design configurations.

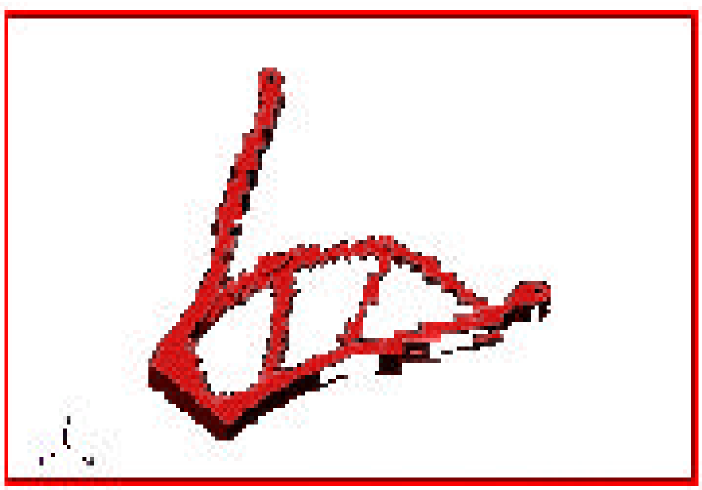

Figure 4

Figure 4 shows the initial part after it has had its topology optimized. As you can see a substantial amount of material has been removed from the original configuration. Due to the finite element nature of the topology optimization the geometry is of an erose nature and must be smoothed using the facilities of a CAD system.

Figure 5

Figure 5 shows the new geometry based upon the results of the topology optimization. As you can see, the results of the topology optimization (see Figure 4) have been used as a guideline for determining the new geometric configuration.

Figure 6

The final shape is show in Figure 6. This shape was obtained by taking the new geometric configuration as show in Figure 5 and utilizing the shape optimization facilities found in MSC/InCheck.

Conclusions

A new system representing the integration of several different disciplines is showing the promise of having a significant impact on a typical engineering design cycle. The merging of geometry, FEA, topology and shape optimization engines into a unified software package can lessen the time required to obtain an optimized design, while at the same time getting us closer to finding true global optimums. Although technologies such as design of experiments have not been discussed their inclusion into the process must also be considered. The ultimate goal, however, must also include manufacturability considerations, in addition to the performance ones, to encompass all aspects of the product.