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APPLICATIONS OF THE STRUCTURAL OPTIMIZATION PROGRAM OPTSYS

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Abstract

Software tools for structural optimization are now gradually being introduced in the design process. The OPTSYS system is developed primarily for applications on aircraft, space and automotive structures. OPTSYS is a modular system combining the Finite Element (FE) Method with mathematical programming methods. To illustrate the role of OPTSYS in recent projects, three real life applications are presented. A small shape optimization example in a separation system for satellites, a case of mixed shape and sizing optimization in the design of a car suspension component and a large optimization study on a composite wing of a fighter aircraft. The experience of using OPTSYS and the directions of current development are also commented.

Introduction

The structural optimization system OPTSYS is, since 1982, being developed by Saab Aircraft Division and The Aeronautical Research Institute of Sweden. The system originates from an early version of the OASIS system developed by Esping [1] and a major contribution regarding mathematical programming software has been made by Svanberg [2].

The system is primarily based on a FE model (ASKA,ABAQUS) of the structure and for optimal re–design a mathematical programming approach is adopted where a sequence of convex approximations of the initial problem is solved. The gradients are calculated with a semi–analytical approach. OPTSYS is a modular system with well defined interfaces to FE–programs and codes for aeroelasticity. Further information about the methods used in OPTSYS can be found in Esping [1], Svanberg [2] and Brämå [3].

Presently OPTSYS will minimize weight or moment of inertia by modifying cross section dimensions, material directions, node positions and general shape descriptions. Constraints can be defined on displacements, stresses, eigen–frequency, buckling, flutter [4] and aeroelastic efficiency. Other important ingredients are connections to a post processor for colour–graphic presentation of results and the possibility to treat substructured FE models. The most recent development has involved integration of the preprocessor PREFEM [5] for definition of shape variables, the interface to the ABAQUS FE–program and the treatment of discrete variables.

The introduction of computer tools for structural optimization in the design work has now started at Saab–Scania. The goal is that all engineers working with structural analysis and design shall have access to structural optimization software and have the skill to use it efficiently.

The practical impact of the use of OPTSYS has not yet been very large, but a number of applications have, however, proved that substantial contributions to the optimal design process can be achieved.

OPTSYS is now installed at all divisions of Saab–Scania on VAX, CRAY X–MP and APOLLO computers.

Industrial Applications

Separation system for satellites in the ARIANE and ATLAS programs

This 2–dimensional shape optimization illustrates how OPTSYS can be applied also to the small 'every day' design problem. The clamp shown in figure 1 was to be redesigned to reduce the stress concentration in the radius. The two–dimensional FE model shown in figure 2 consists of eight–node membrane elements. The weight was to be minimized by changing the shape of the cross section. The constraints were set so that the maximum stress should be 20 % lower than the original design and the deflection, d, was not allowed to increase more than 10 %. The six independent design variables are indicated in figure 2, four nodes are linked to each variable to maintain a reasonable mesh during optimization. In the final design both constraints had reached their limits and the cross section area had been reduced.

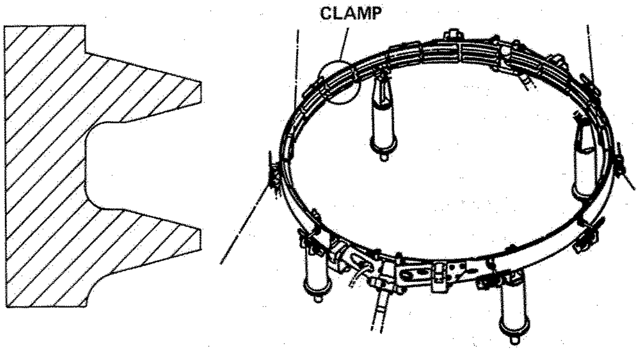

Figure 1. Satellite separation system

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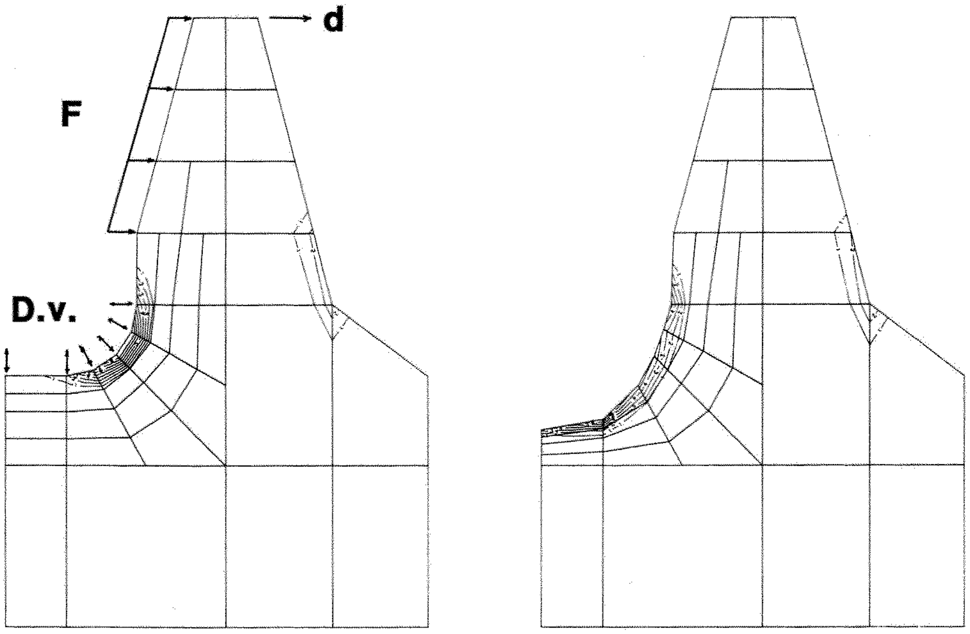

Figure 2. Initial and final design

Shape optimization of a Saab 9000 suspension arm

In order to investigate the performance of a proposed new wishbone design (figure 3) for the Saab 9000 car, an optimization project was initiated. The new design is of forged aluminium, the one in production is built from pressed steel parts. Optimization is important here since a low unsprung weight of the suspension is crucial for a performance car.

A simple problem formulation suitable for a first re–design attempt was sought.

A FE–model consisting of 230 shell elements was applied with three loading cases; maximum straight line braking, maximum lateral acceleration (cornerning) and maximum combined braking/lateral acceleration.

The cross–sectional properties along the wishbone was varied by having the thickness of the elements as variables in the optimization problem. The "inner" boundary was described by B–splines in the geometry description of the preprocessor PREFEM. The control–points of these splines were connected to design variables according to figure 4 (indicated by the arrows). Upper and lower limits on the values of the design variables accounted for various geometrical limitations.

Stress constraints were defined to keep the maximum von Mises stress below the yield stress. The basic stiffness requirement was that the stiffness of the new wishbone should equal the stiffness of the original (steel). This requirement, defined by deflection constraints, is design–wise disputable but a fair starting point for an optimization study.

The resulting optimization problem consisted of 122 thickness–variables, 6 shape–variables, 1300 stress and 6 deflection constraints. Quite a moderate problem size.

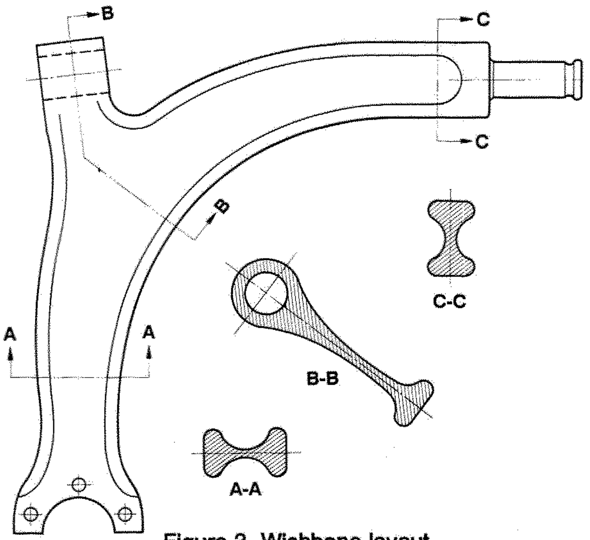

Figure 3. Wishbone layout

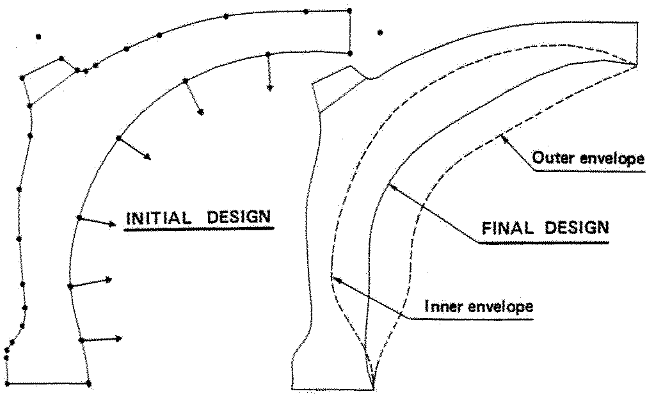

Figure 4. Geometry of initial and final design

The problem was solved in 9 iterations. For a weight increase of 40 percent OPTSYS found an optimal solution with sufficient stiffness (63 percent increase). The final design was determined, for this problem statement, completely by the stiffness requirements, two of which were at the critical limit. The stress constraints had no impact on the solution as they all were non–critical (albeit very close). Results are shown in figures 4, 5 and 6.

The thickness distribution of the final design was dominated by the defined lower limit. The exception being the far "left" part which thickness probably was increased to create enough stiffness for the lateral load.

The average CPU time per iteration, on a VAX 8800, was roughly 550 seconds, the FE analysis part thereof was about 100 seconds.

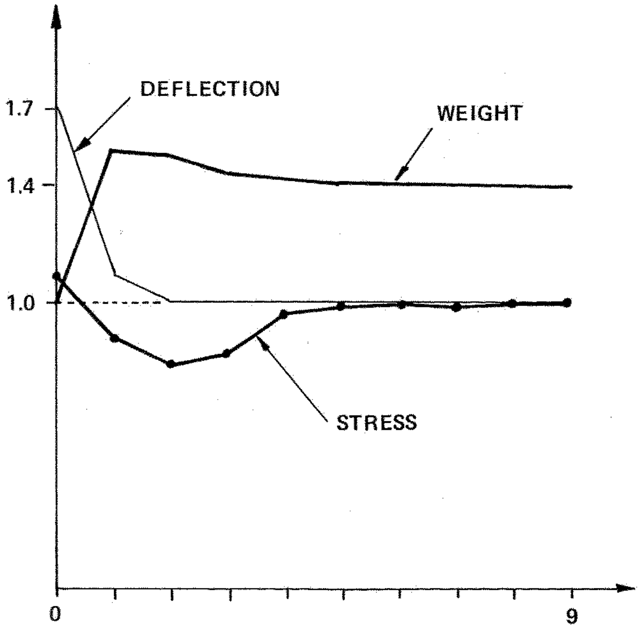

Figure 5. Iteration histories

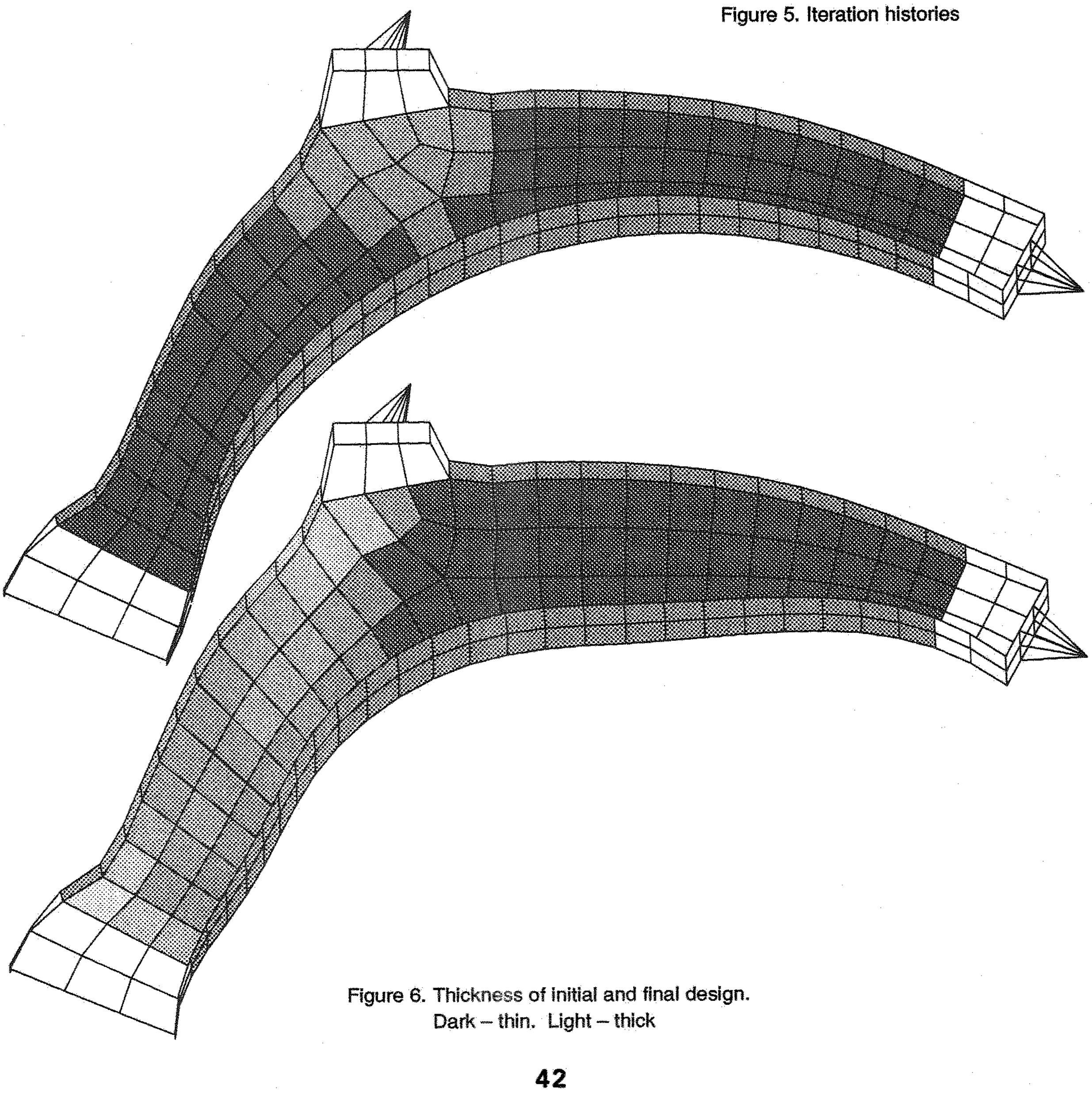

Figure 6. Thickness of initial and final design.
Dark – thin. Light – thick

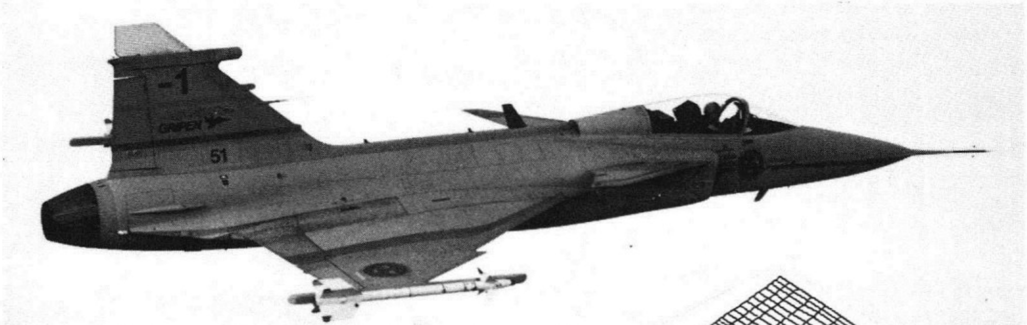

Figure 7. Gripen

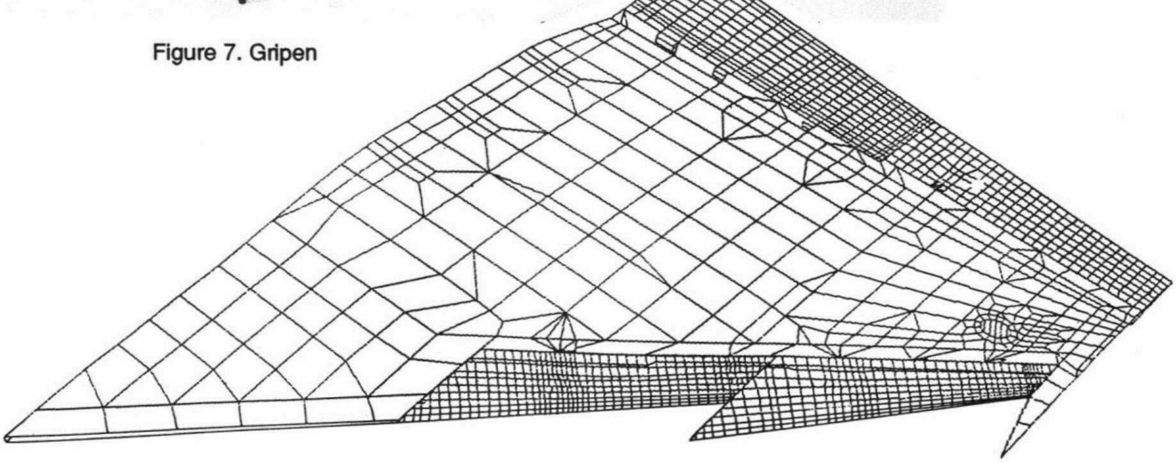

Figure 8. FE–model of the wing

Composite wing of the Gripen aircraft

The main purpose of this very large application was to investigate the possible weight savings for redesign of the wing skins with two choices of new composite materials.

A substructured FE model of the complete aircraft was used (figure 8). By including the optimization–wise active parts of the wing structure in a separate substructure, the amount of calculations needed in each iteration was reduced to a reasonable size. The active substructure contained about 5,000 degrees of freedom compared to the 125,000 in the complete aircraft model. Eight loading cases were selected for this study.

The design variables were associated to layers in 254 different composite stacks. The layup in each stack was defined by three independent variables controlling the number of 0 degree layers, 90 degree layers and +/– 45 degree layers, making a total of 762 design variables. One or several finite elements in the wing panels were then linked to each stack. Explicit constraints were defined on the sum of all thickness variables connected to the same stack to limit the total thickness of the wing panel. Constraints were also imposed on fibre strain and buckling in the composite. A fairly simple handbook method for analysis of panel buckling was used. Constraints on the aircraft performance such as aeroelastic efficiency should ideally also have been included. However, as the criteria was to maintain current performance, it was considered sufficient to formulate the aeroelastic requirements as a number of constraints on the wing torsion. A total of about 20,000 potential constraints were defined of which a few hundred were active in the final design.

Six global iterations were enough to solve this problem for each of the two alternative materials, see figure 9. Each iteration needed approximately 2,000 CPU seconds in the CRAY–1A; 130 seconds for the reanalysis, 1,000 seconds for the gradient calculation and 800 seconds for the solution of the approximate subproblem. The portion of the iteration time consumed by the subproblem solution was much larger here than in small problems. One way to reduce this portion is to lower the accuracy required in the solution of the subproblem.

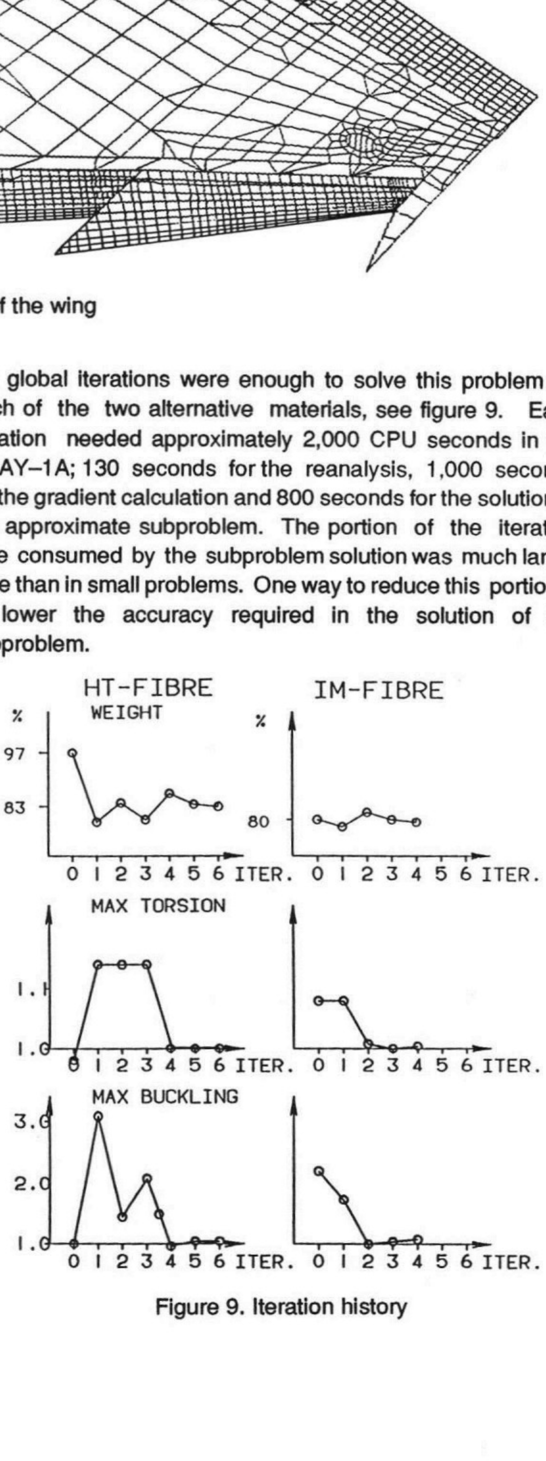

Figure 9. Iteration history

	Initial Wing Design 914–T300	"HT" 6367C–HTA7	"IM" 6376C–IM500
Matrix:	Brittle epoxy	Toughend epoxy	Toughend epoxy
Elastic Modulus: E11	0.97	1.0	1.2
Allowables: ϵ_t	0.8	1.0	1.0
ϵ_c	0.92	1.0	0.86
Price:	0.9	1.0	1.5
Weight saving:	(Not optimized)	14%	20%

Figure 10. Summary of results and material data

The layups produced by OPTSYS have to be adjusted to production requirements impossible to account for in the original problem statement. This manual work leads of course to increased weight and can be very tedious. Good postprocessing aids are absolutely vital when dealing with the huge amount of information created in large applications like this.

A summary of weight savings and the relative data for the composite materials can be found in figure 10. The results in terms of optimal layups will be valuable in a possible future redesign of the wing.

Comments on The Experience of Using OPTSYS

The formulation of the optimization problem is vital. We have experienced that one often ends up with a sequence of refined problem formulations as the solution of one problem tends to generate more knowledge about the behavior of the structure.

When you have a layout problem, as in the wing example, one solution strategy is to begin with a formulation with many independent design variables. Based on the material distribution given by this solution additional variable linking can be introduced. This refined problem definition, containing fewer variables, can then give a solution more attractive from the manufacturing point of view.

Sometimes it is not possible to specify exactly the performance criteria, since a structural optimization problem often is only one part of a global design optimization. Often the designer wants to know how much weight penalty he has to pay for additional performance.

The optimization also has implications on how to build the FE model. The immediate concern is to assure that the model is accurate enough for all combinations of design variable values.The most obvious case is the mesh disturbance caused by shape variables. The division into substructures is also affected, as the computational cost can be significantly reduced if the optimization–wise active parts of the structure are isolated from the passive parts.

Directions of Current Development

OPTSYS is becoming more and more integrated in the CAE environment. Interfaces to pre/post–processors and CAD systems will be improved. The classes of problems that can be addressed will be extended by refining the definition of design variables and introducing new constraint functions. For instance, a possibility to treat acoustic constraints is a highly desired feature in the context of aircraft and automotive structures. The potential of knowledge based techniques in connection with OPTSYS is also being investigated.

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