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Seeking the Chemical Roots of Violence

The Optimum Shape

Researchers at the General Motors Research Laboratories have developed the first integrated system for computer design of mechanical parts with minimum mass. Optimal Shape Generation automatically optimizes the component shape in a single computer run.

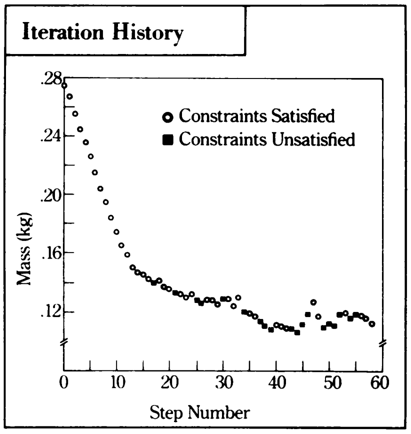


Figure 1: Decreasing mass plotted as a function of design iterations for the component shown in Figure 2.

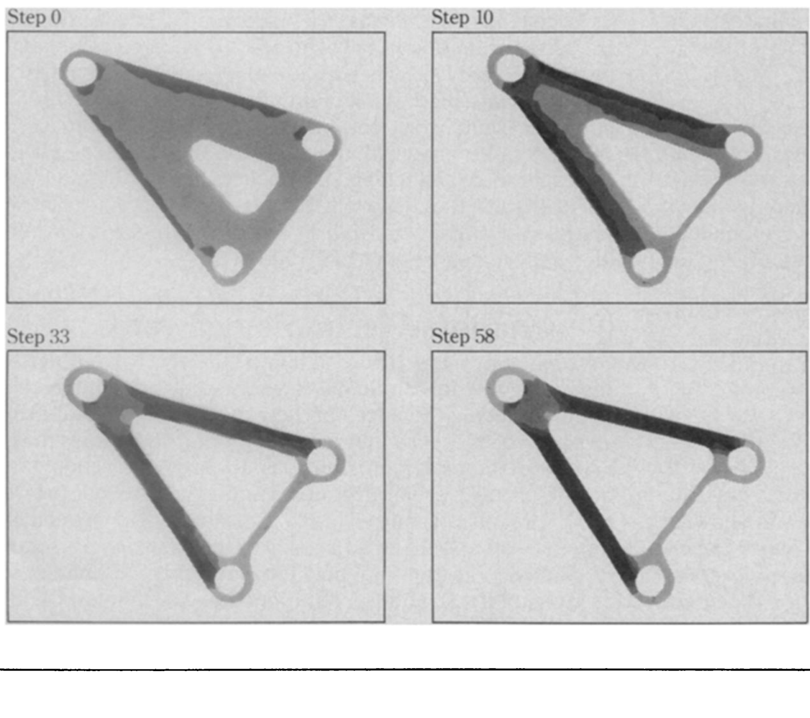
Figure 2: Black-and-white photographs of shapes which appear in color on the CRT screen. Increasing darkness indicates increasing stress levels within the design limits.

COMPUTER-AIDED design systems automate the processes of generating geometric data and engineering drawings of parts, but they do not determine whether these parts meet structural performance requirements. In an ongoing research project at the General Motors Research Laboratories, a system has been developed that automatically ensures that the design meets structural performance constraints. More important, Optimal Shape Generation provides the component shape with the minimum mass capable of satisfying structural demands in a single computer run, without requiring human interaction with the machine.

In the last two decades, extensive research has been done in the area of computer design of structural components. Most of this work has focused on individual aspects of the process. Drs. Jim Bennett and Mark Botkin have succeeded in integrating the process from description of the model through convergence to the optimum solution.

Conventional systems continue distinctions characteristic of age-old "build and test" methods by separating the tasks of design generation and design analysis. Typically, a "designer" uses one computer system to produce engineering drawings of a given part. The task then shifts to an "evaluator" who creates a mathematical model with which to test the design on another computer system. The evaluator determines only whether or not the design meets the requirements. A lengthy interaction between the designer and the evaluator is required to optimize the design. Optimal Shape Generation integrates the process from design generation through design optimization. The system can generate the mathematical model from the design data as the shape changes without requiring additional input, thereby turning the process from a multiperson, multimachine operation into a one-person, one-machine operation.

Since there is no interaction beyond the initial input, a flexible description of the problem is crucial to effective use of the system. The researchers responded to this challenge by developing a geometric format based on a parametric description of the boundary. Defining the problem with geometric data is desirable because it describes the shape of the part in a



form directly suitable for conceptual visualization.

Because the boundary geometric description must be transformed into an analysis model not once but several times, some type of automatic finite element mesh generation is required. The researchers adapted a mesh generation technique which divides a closed region into triangular elements based on a discrete description of the boundary. The sizes of the elements of the mesh are determined by a characteristic length selected for each problem and are related to the need for accurately describing the geometry. Automatic triangulation is used to create a set of connectivities for the discrete points placed uniformly throughout the part's interior with approximately the same density as the boundary points. The combination of boundary data description and automatic mesh generation permits the system to accommodate major changes in shape from the initial design.

ADEQUACY of the triangular meshes to calculate accurate stress levels was next addressed by the development of an adaptive mesh refinement scheme. By evaluating the solution for the uniform mesh created by the choice of characteristic length and identifying areas where the strain energy density changes rapidly, the system selects the areas of the mesh that require mesh refinement. These refinements can take the form of either adding elements in the area to be refined or increasing the order of the finite element polynomial interpolation. The former approach has been taken, because it can be implemented automatically and does not require the formulation of new finite elements.

The culmination of the process introduces an optimization routine which directs the design toward a minimum mass configuration. A mathematical optimization technique is used to change the design to that shape giving minimum mass within the structural constraints. This optimization technique is based upon a sequential first-order Taylor series approximation of the constraints and a feasible directions solution of the problem. Periodic mesh refinements are performed throughout the optimization, since the design is continually changing, and the system must predict the stresses and the behavior of the constraints as the design changes.

"By taking an integrated approach," says Dr. Bennett, "we're able to combine the objectives of reducing the mass of the material and meeting structural performance requirements in a single automatic system."

"We expect," adds Dr. Botkin, "that in the future this technique will become the standard way of designing structural components."

THE MEN BEHIND THE WORK

Drs. Jim Bennett and Mark Botkin are members of the Engineering Mechanics Department at the General Motors Research Laboratories.

Dr. Bennett holds the title of Assistant Department Head. He attended the University of Michigan as an undergraduate and received his graduate degrees from the same institution in the field of aerospace engineering. His Ph.D. thesis concerned non-linear vibrations. Before coming to General Motors in 1973, he taught aeronautical and astronautical engineering at the University of Illinois.

Dr. Botkin is a Staff Research Engineer. He received his undergraduate and graduate degrees from the University of Missouri at Rolla. His graduate work was in the field of civil engineering, and his doctoral thesis concerned structural optimization. Prior to joining General Motors in 1978, he worked for four years as a consultant to computer applications engineers.