DEVELOPMENT OF A FLEXIBLE DESIGN OPTIMIZATION CAPABILITY

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ABSTRACT

The development of a design study tool to couple optimization technology with sophisticated analysis software is presented. A graphical user-interface (GUI) to the general purpose optimization software, DOC/DOT, has been developed. Using this GUI, DOC/DOT has been coupled with third-party nonlinear analysis software products to perform design optimization.

Using different GUI objects, the design optimization task is created. Once the optimization task has been defined, the user executes the optimization. The user may also view the results of optimization such as optimization history and critical constraint history by using appropriate windows and visualization tools provided within the graphical user interface.

Interfaces to ABAQUS/Standard and LSDYNA3D software packages have already been completed, and many other third-party software are presently being considered. The overall program capabilities are demonstrated using physical examples.

1.0 INTRODUCTION

The first objective of the present research effort has been to create a graphical user interface to the general purpose optimization software DOC/DOT. The second objective was to interface DOC/DOT optimization capabilities with a number of third-party analysis software. Development of such capabilities will provide a framework for developing multidiscipline design optimization (MDO) capabilities incorporating design information available from different disciplines of interest.

The Design Optimization Tools (DOT) (Ref. 1) is a general purpose nonlinear programming optimizer, while the Design Optimization Control program (DOC) (Ref. 2) aids in linking user's analysis software with DOT. The Graphical User Interface (GUI) created during this study will greatly enhance this software.

In order to expand the capabilities of the DOC/DOT software, a variety of new concepts have been studied and developed. These will provide users with various design

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tools to enhance the design study and optimization process. The key developments and ideas generated during this study are outlined in the following sections.

2.0 CREATION OF A GRAPHICAL USER INTERFACE

The graphical user interface (GUI) is perhaps the most important feature of modern software from the user's perspective. Experience shows that, even if a computer program is very powerful, its application will be severely limited if the user is not "comfortable" with it. This usually translates to "ease of use" and is the key to early acceptance. This is one of the main reasons why optimization has not yet received the widespread use that might be expected, considering the power of this technology.

As part of present effort, the DOC program has been modified to allow the user to couple optimization with a user's analysis program for cases where the source code of the analysis software is not available.

2.1 Preprocessor

The basic philosophy here is to create a fully automated, graphical, design environment which is easy to use for the novice, but provides the flexibility needed by the advanced user. There are two important classes of users for this software.

2.1.1 The User Who Wants to Link His Own Program With DOC.

This is the "high end" user who is willing to modify his source code to meet a specific standard and then link it directly with DOC. He will be willing to create a subroutine ANALIZ (in DOC terminology) and then link it with DOC to provide the most efficient executable software.

2.1.2 The User Who Wants to Access an Executable Program from Within DOC.

This is the more casual user who either does not want to make the effort to modify his code or who does not have access to the source code. In this case, DOC must have access to data file(s) read by the analysis and the output file(s) created from the analysis.. This is the most flexible approach, but it is less efficient due to the fact that the analysis program must be repeatedly loaded and executed.

However, in contrast to other such software, it is not necessary to add any key words or special characters to the input or output files. Within DOC, it is only necessary to highlight a variable in the input file to tag it as a potential design variable, or to highlight a calculated response in the output file to tag it as a candidate objective or constraint function.

2.2 The Windows Interfaces

The first step in creating a design project it to identify all input parameters that may be candidate design variables and to identify all output parameters that may be objective functions or may be constrained. This information will be stored in a "Catalog of Variables and Responses," which is accessed by clicking on the Catalog icon of the main window.

2.2.1 Creating a Catalog of Variables and Responses

For the two classes of users as mentioned above, two separate windows are used. Once the catalog of variables and responses has been created, the remainder of the process is the same for all types of users. Figure 1 gives an example of a catalog window where the user wants to access third-party analysis software (LSDYNA3D).

Once the catalog of variables and responses has been created, it becomes part of the project database, and can be accessed to create specific optimization tasks. Input parameters can be design variables or objective functions (if they are also design variables), while output parameters can only be objective functions or constraints.

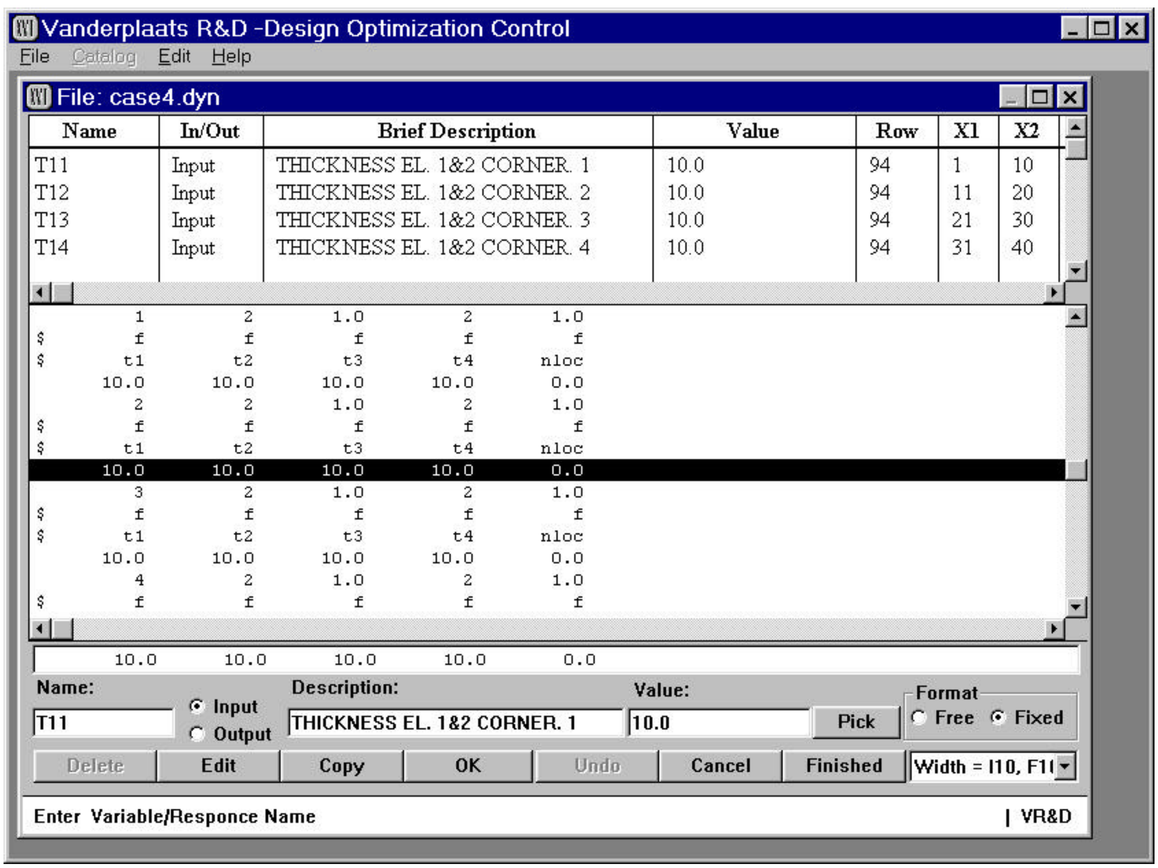

Figure 1: Catalog of Variables and Responses

Here, the user is editing the LS-DYNA3D input file and picking the parameters that can be design variables. In a similar way, the user will edit the LS-DYNA3D output file to choose candidate objective functions and constraints.

2.2.2 Defining the Design Variables

Once the catalog of variables and responses is available, the user can click on the Variables option to open a window like the one shown in Figure 2. Here, all parameters contained in the Catalog that are specified as Input to the user's program are listed. The engineer can now specify which of these parameters he wishes to change during this design task.

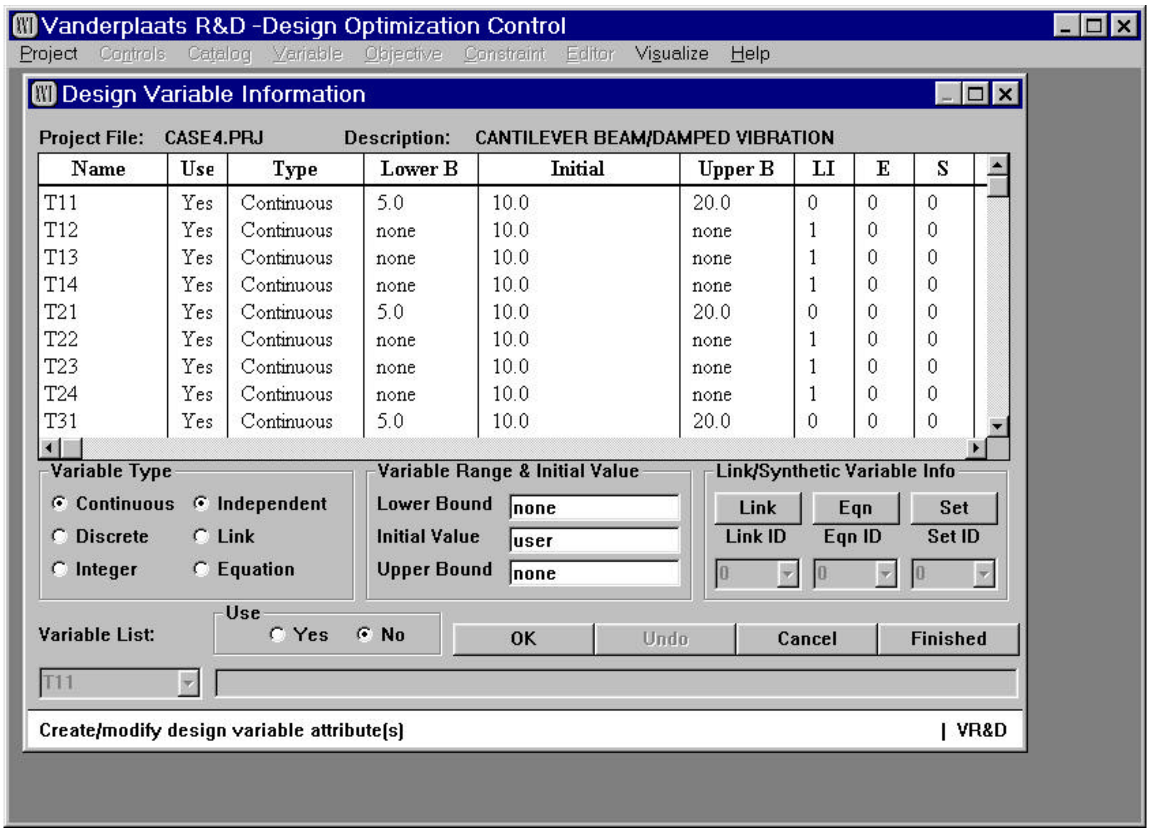

Figure 2: Design Variable Information

2.2.3 Defining the Objective Function(s)

Next, the user may click on the Objective icon to bring up the window as shown in Figure 3. Here, all parameters contained in the Catalog are listed. This is because it is valid to minimize or maximize a design variable which is input to the user's program, so the available objective functions are not limited to output from the analysis.

The objective function may be a linked or synthetic (equation) function of design variables and other responses. Also, multi-objective optimization can be performed simply by specifying multiple objective functions.

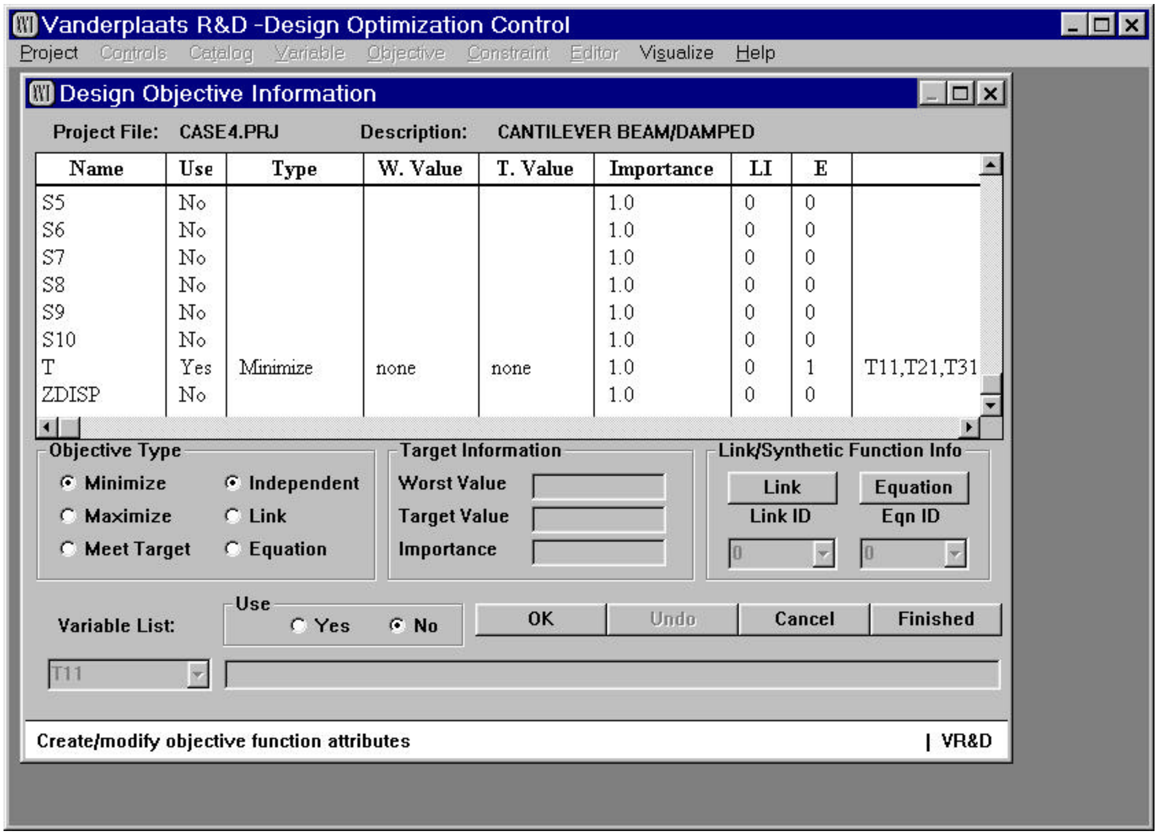

Figure 3: Design Objective Information

2.2.4 Defining the Constraints

Now, the user may click on (not shown here) the Constraints icon to bring up the constraint definition window. Here, only those parameters specified as output in the catalog are shown. In this window, the user can choose those calculated responses that he wishes to constraint. Additionally, he specifies lower and upper bounds, scaling factors, and other related information.

2.2.5 Additional Windows

Several additional windows are available to create control parameters, define discrete variables sets and synthetic functions, input candidate variables and responses for approximate (response surface) optimization, over-ride DOT control parameters, set up parametric studies, etc.

2.3 Presentation of the Optimization Process

The capability discussed below has not yet been added to the DOC GUI, but will be included in the distribution version of the current software, as well as the new software to be developed based on this study.

2.3.1 Results Visualization

In many cases, the user will wish to simply execute the analysis or optimization task he has created. However, many times early in the design process, the user may wish to observe the optimization progress to gain some insight into the design. The key idea here is that the engineer can view important information about the design progress, even as the optimization process is continuing. He may then choose to continue, terminate or perhaps modify the design specifications to direct the optimization process.

3.0 THIRD PARTY ANALYSIS SOFTWARE

Both ABAQUS and LS-DYNA3D were studied as candidate third party software, and were successfully integrated with DOC. The motivation was to demonstrate the graphical user interface and to create a usable capability for solution of real nonlinear structural design problems.

3.1 ABAQUS Example

Several example problems have been solved to demonstrate the capability. A simple example will be given here where ABAQUS solves a nonlinear analysis problem and DOC/DOT is used to perform optimization. The subroutine ANALIZ which DOC calls is generated by the GUI automatically, and is linked with DOC/DOT. The GUI is then used to create the DOC data and view the optimization results.

Here, a simple cantilivered beam under geometrically nonlinear analysis was optimized for minimum material. The example is taken from the ABAQUS user's manual. Figure 4 shows the analysis results.

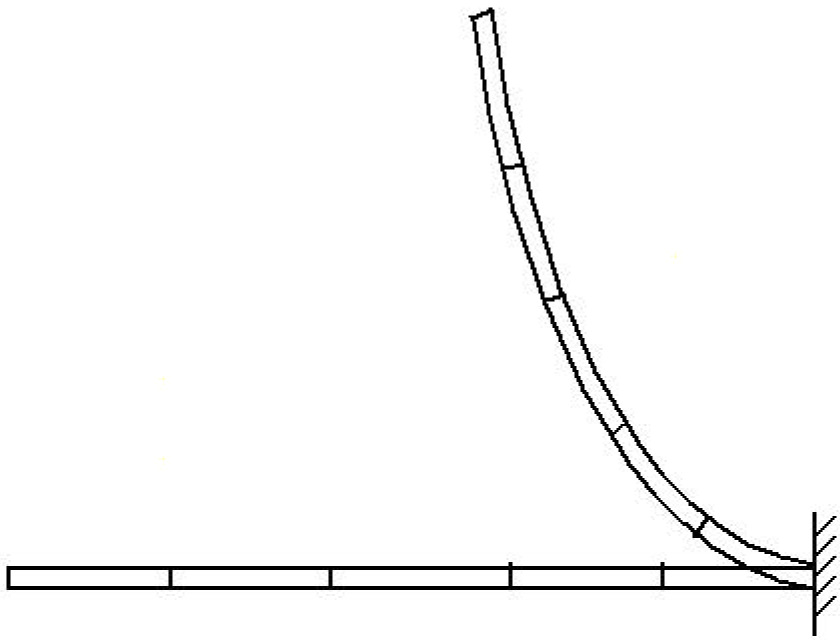

Figure 4: ABAQUS - Displacement Plots of Cantilivered Beam

Problem Statement

Design Variables:

T1: Thickness of Beam Section 1
T2: Thickness of Beam Section 2
T3: Thickness of Beam Section 3

Initial Values:

T1 = 0.01m
T2 = 0.01m
T3 = 0.01m

Objective:

Minimize total C/S Area, calculate using the synthetic function

AREA = F(T1, T2, T3)

Constraints:

Deflection at the beam tip;

Along the x-direction. $0.0 \leq U_x \leq 8.0$ m
Along the y-direction. $0.0 \leq U_x \leq 5.0$ m

Stresses:

Maximum Stress (S_{11}) in all three beam elements $\leq$ 3.0E06 N/m^2
A total of six stress constraints.

Final Design:

T1 = 0.0050 m
T2 = 0.0065 m
T3 = 0.0120 m.

3.2 LS DYNA Example

Here, a ten element cantilivered beam is optimized using both direct optimization with finite difference gradients and approximate optimization. The beam was modeled using Belytschko-Tsay elements where the thickness is defined at each corner. To create a uniform thickness, one thickness was treated as a dependent variable and the other three were treated as dependent variables. Also, elements 1-2, 3-4, etc. were linked by giving each group its own property. The beam is subject to a load at the free end. The beam then vibrates relative to the equilibrium position with damping. This example is taken from the LS-DYNA3D Manual Section: CONTROL_DAMPING, and uses the input file beam.dr.214.k. The dynamic calculation ends at 1.0 second. Figure 6 shows the beam model.

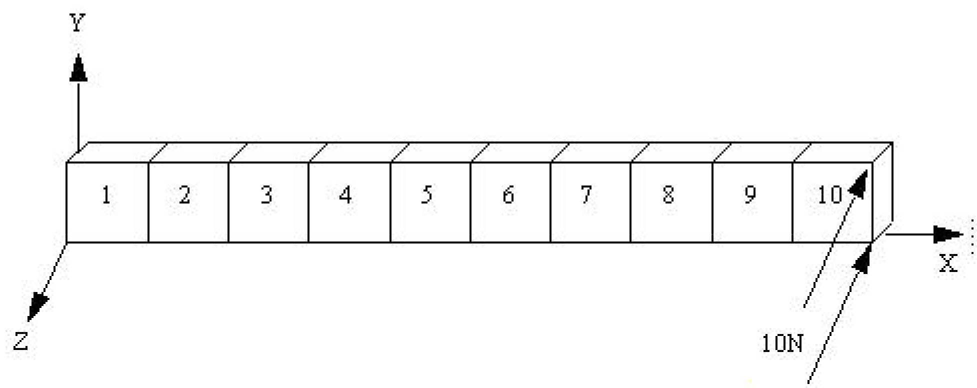

Figure 6: LS-DYNA3D - Cantilevered Beam Model

Problem Statement

Design Variables: (5 independent design variables & 15 dependent design variables
T11 : Thickness of elements 1 & 2
T21 : Thickness of elements 3 & 4
T31 : Thickness of elements 5 & 6
T41 : Thickness of elements 7 & 8
T51 : Thickness of elements 9 &10

Initial Values:
T11 = 10.0 mm
T21 = 10.0 mm
T31 = 10.0 mm
T41 = 10.0 mm
T51 = 10.0 mm

Objective:

Minimize T (Total thickness T = T11+T21+T31+T41+T51)

Constraints:

Stresses: Maximum Principal Stress at each element surface, $|S_{xx}|$, ≤ 25.0 N/mm^2
Displacement: Displacement at tip, ZDISP ≤ 20.0 mm

RESULTS: (Using Approximate Optimization Technique)

Final Design Variables:

T11 = 11.489 mm
T21 = 10.181 mm
T31 = 8.7181 mm
T41 = 7.0840 mm
T51 = 5.0000 mm

Objective Function:

T = 42.472 mm

3.2.1 Discussion

The same problem was solved using direct optimization method (with finite difference gradients), and it took 61 function evaluations while approximation technique took 21 function evaluations. The results for the two cases are essentially the same, while optimization using approximations converged much faster. Experience indicates that approximation techniques are more efficient for problems of under about 10 design variables. If sensitivity information is also used or if this is part of a larger study where many analyses have been performed for other purposes, the number of design variables can be increased.

4.0 POTENTIAL APPLICATIONS

There is a clear need for a general purpose optimization program that will provide a graphical interface to a wide range of analysis software of the user's choice. The key to this effort is to expand the technology base to greatly improve ease of use and to provide a unique capability to perform design studies and interpret results. This is considered to be the most effective way to expand the use of optimization in the engineering community and to make optimization a true everyday design tool.

REFERENCES

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