DEVELOPMENT OF A DESIGN OPTIMIZATION INTERFACE TO LS-DYNA

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ABSTRACT

A design study tool called VisualDOC to couple optimization technology with LS-DYNA program is presented. A general methodology to interface optimization capabilities to LS-DYNA is available in VisualDOC. Here the user will open the appropriate window to edit LS-DYNA input and output files to create a catalog of variables and responses. The input file is used to create the catalog of possible design variables, and the output file is used to create the catalog of responses, which could be used as possible objective functions and/or constraints later in the optimization process. This is performed using a very flexible interactive approach. VisualDOC automatically generates the interface routine (in FORTRAN 77) to interface LS-DYNA with the VisualDOC optimization in a very friendly manner, and the user does not need to write a single line of computer code.

INTRODUCTION

Although optimization technology has received attention in engineering problem solving, it has not yet received the degree of acceptance that might be expected considering the power of this technology. Two key reasons have been identified that contribute to this. The first reason is the cost of adding optimization technology to existing commercial software (such as LS-DYNA), when a clear market has not yet been established. The second reason is the fear that optimization is a specialized technology, and thus requires special expertise to use it. The first issue can be addressed by providing the capability to use optimization with the existing analysis programs without the need for extensive programming. It lets the engineers use optimization in the short term, and demonstrates its value. This may provide the necessary motivation to the analysis program developers to make the investment in a more closely coupled optimization capability in the future. The second issue can be addressed by providing user-friendly software, which can graphically interface optimization with the analysis program. VisualDOC is such a design optimization tool, which addresses some these issues, and allows users to interface design optimization with LS-DYNA program.

The first step in interfacing LS-DYNA with VisualDOC [Ref. 1] optimization is to perform one successful analysis run. Then this analysis input and output files will be used to create a catalog of variables and responses. The generation of optimization data using VisualDOC generally consists of the following steps.

- Generate analysis data first. Analyze the structure using the analysis data, and make the analysis output available.

- Create a catalog of variables & responses using the analysis input and output files. The input parameters in the catalog will come from the data in the input file, and similarly the output parameters in the catalog will come from the output file.

- Once the catalog of variables and responses has been defined, specify the design variables, objective functions and constraints, if any.

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- Now you are ready to generate the interface subroutine, named ANALIZ. VisualDOC automatically generates it. The information exchange between the VisualDOC optimizer and the LS-DYNA program takes place here. Basically this subroutine calls LS-DYNA program via system calls to run the analysis, retrieves the updated response values from the analysis output, sends the updated response values to the VisualDOC optimizer, receives the modified design variable values from the optimizer, updates the analysis input data, and runs the analysis program again until the optimization convergence is achieved.

- Now VisualDOC will compile/link the ANALIZ subroutine with the VisualDOC optimization library, and generate the final executable code.

- Run the final executable module. This could be run either from within the VisualDOC window or from outside the VisualDOC window at the shell (or MSDOS) prompt.

- You may also view the optimization results, and generate the necessary design plots for better understanding of the optimization process.

THE VisualDOC DESIGN STUDY TOOL

VisualDOC is a graphics based design optimization tool that lets you combine optimization technology with analysis program. Its optimization engine is based on general purpose optimization software DOT [Ref. 2] and DOC [Ref. 3]. Using the powerful graphical user interface, users can define their design optimization problems. Here you may calculate the design responses using your own program. VisualDOC supports a direct interface to LS-DYNA software, so that optimization capabilities can be added to LS-DYNA. VisualDOC has been written with user-convenience in mind and the specific user-convenience features include:

- A catalog of variables and responses are created first, and they are printed as part of the VisualDOC output. The catalog includes a user-supplied description of each entry.

- There are two ways to automatically link design variables. Variables can be linked linearly with other design variables, or "synthetically" linked with equations supplied via the VisualDOC windows.

- Responses can be generated by linking them to other responses or "synthetically" with user-supplied equations provided via. VisualDOC windows. This allows for generating responses not calculated by the analysis code.

- Multiobjective optimization can be performed.

- Discrete and integer variable optimization can be performed.

- Third-party analysis programs, such as DYNA3D, can be used to calculate responses. No programming is necessary.

The Figure 1 shows the main window of VisualDOC.

THE VisualDOC DESIGN PROCESS

Design Optimization studies using VisualDOC start with the creation of a design project file. Once the design project has been created, the user can create multiple "design task files" to solve a particular design optimization problem. VisualDOC windows are used to create different elements of the design project.

A catalog of variables and responses to be used in the optimization process is created first. This is done using the **Catalog** window. The basic idea is to identify all the input and output parameters that will be used during optimization, and include them in a catalog. If third party analysis program, such as LS-DYNA, is used, analysis input and output files are used to create the catalog items.

The **Variable** window is used to specify the variables to be used during optimization, and to provide lower and upper bounds, if any, and initial values, if the user wants to override the initial values specified in the

user's analysis program. When the **Variable** window is opened, the user sees only those entries in the catalog that were identified as inputs, because these are the parameters that can be changed during
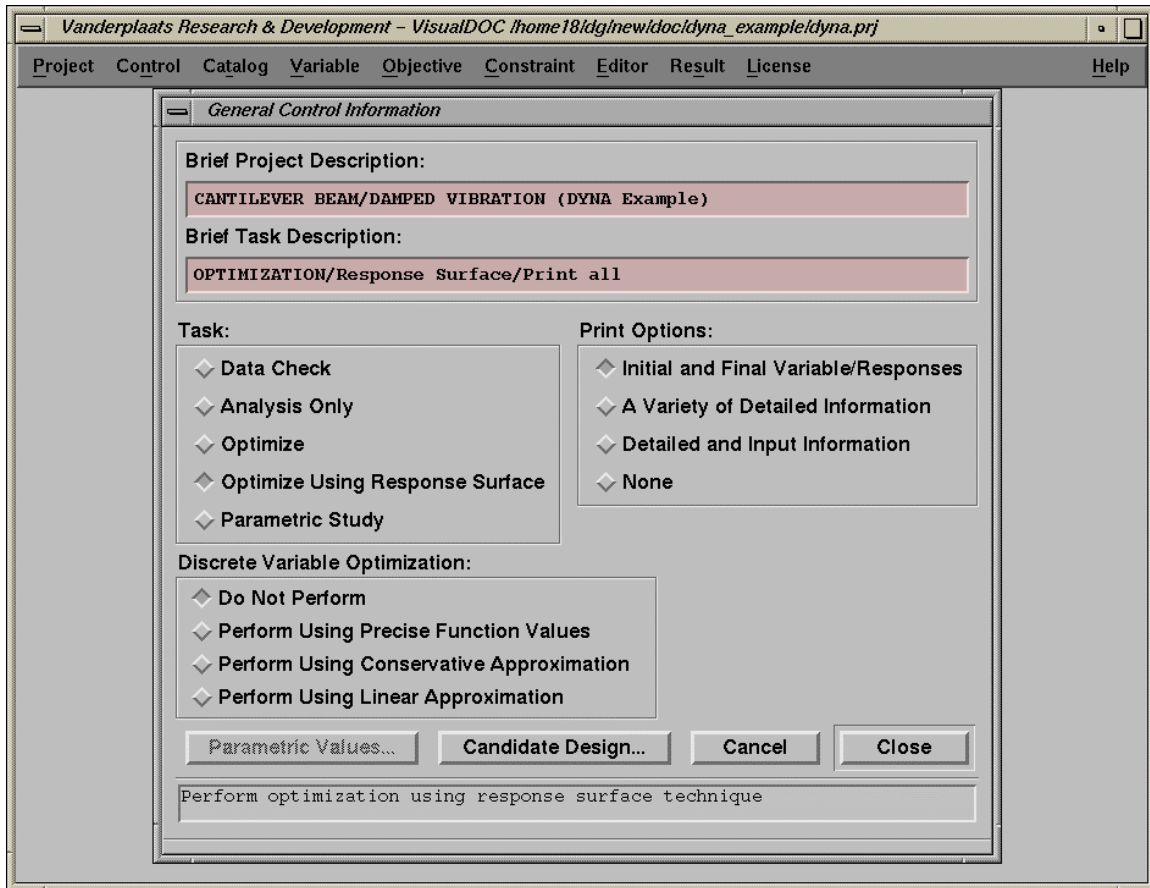

Figure 1: VisualDOC Main Window

optimization. The user may also specify if a particular variable is continuous or discrete, or if it is linked linearly or non-linearly to other variables.

Similarly, when the user opens the **Objective** function window, and sees all the variables, both input and output, listed here. The user may tag one or more variables/responses as objective functions. Here multi-objective optimization is allowed, and the user may specify target values, weighting factors, etc. Like design variables, objective functions could also be linked with other variables, as well as with other responses.

If constrained optimization is to be performed, the user will open the **Constraint** window. In this window, only variables that were tagged as output parameters (responses) in the catalog are displayed. The user may select all or some of these responses as constraints to be used during optimization, and provides lower and/or upper bounds, and optional scaling factors. Constraints could also be linked to other variables and responses.

There are also a number of other windows to specify related information such as sets of discrete values of variables, equations for synthetic variables and responses etc. The user can also specify various control parameters such as whether to use direct or response surface optimization, print control, convergence criteria, etc.

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The Catalog of Variable & Responses

There are two windows available here to create the catalog of variables and responses. While using LS-DYNA as the analysis program, choose **Catalog->Third party Analysis Program Available** to open the following VisualDOC window.
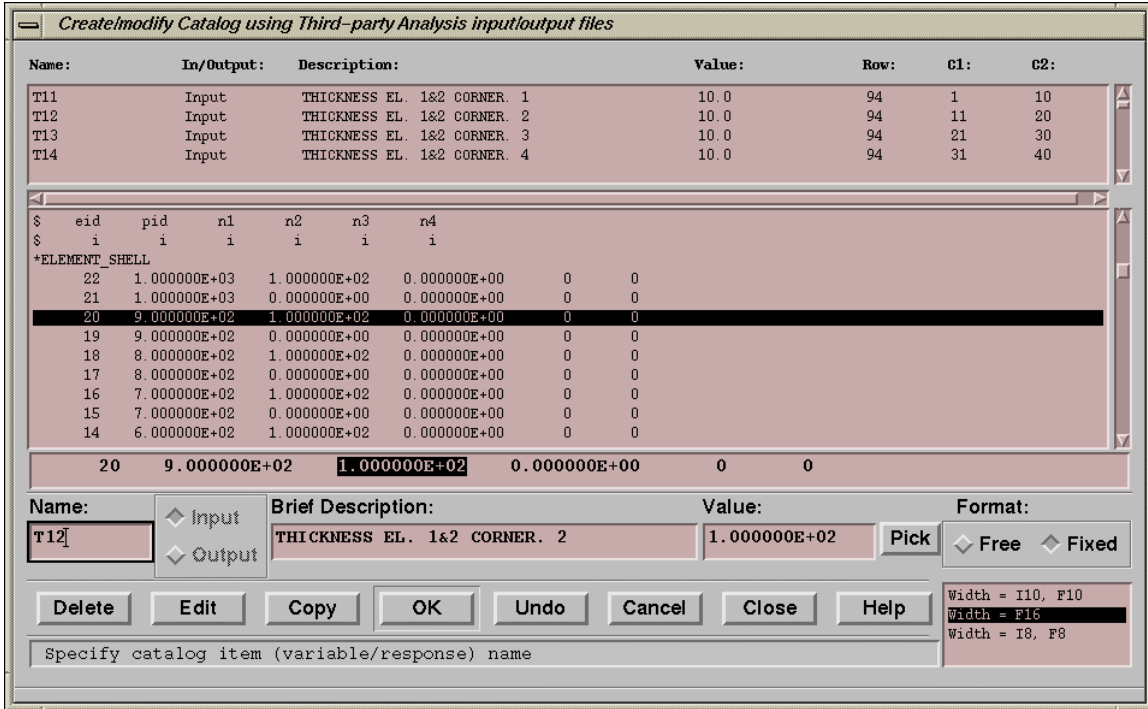

Figure 2: VisualDOC Catalog of Variables and Responses

Here you will open the LS-DYNA input file to create a list of potential design variables. Any real number in the input file could be associated with a design variable. First highlight the variable value in the input file, and then provide a name and a brief description (optional) to it. Whenever an LS-DYNA input file is loaded, VisualDOC automatically determines the format of the input data, and displays it here. The user has the option of changing the original format by clicking on the appropriate buttons. Once the creation of the input catalog is over, VisualDOC automatically stores this information in the project file for later use. In a similar manner, the LS-DYNA output file is loaded on the same VisualDOC window, and response variables, which could be used as objective functions and constraints are picked. It may be noted here that only independent responses are tagged here. Linked or "synthetic" responses could be defined separately on the same window.

Design Variable Information

Once the catalog of variables and responses has been created, you may click on the **Variable** icon to open the variable window as shown here in figure 3. Here only those items in the catalog that were specified as input parameters are listed. Here you may select which parameters to be used as design variables, their initial values, and upper and lower bounds. Discrete and integer variable optimizations are allowed. For discrete variables, you need to specify a discrete set ID identifying a set of permissible discrete values. Here you may also define dependent design variables. A dependent design variable is defined as a design variable whose value depends on other independent variables. If the value of a dependent design variable is a linear function of one or more independent design variables, it is referred as "linked" variable in VisualDOC. On the other hand, if the value of a dependent design variable is nonlinear function of one or more independent variable, it is referred as "synthetic" variable, and the relationship is specified using an equation statement. As an example, if you are using a four noded shell element in LS-DYNA, may have

four thickness values at four corners of the element. If you want to keep the thickness uniform all over the element, you may treat one thickness as an independent design variable, and others as dependent variables (either linked or synthetic). This not only reduces the total number of design variables in the model, but also is a necessity in many situations.
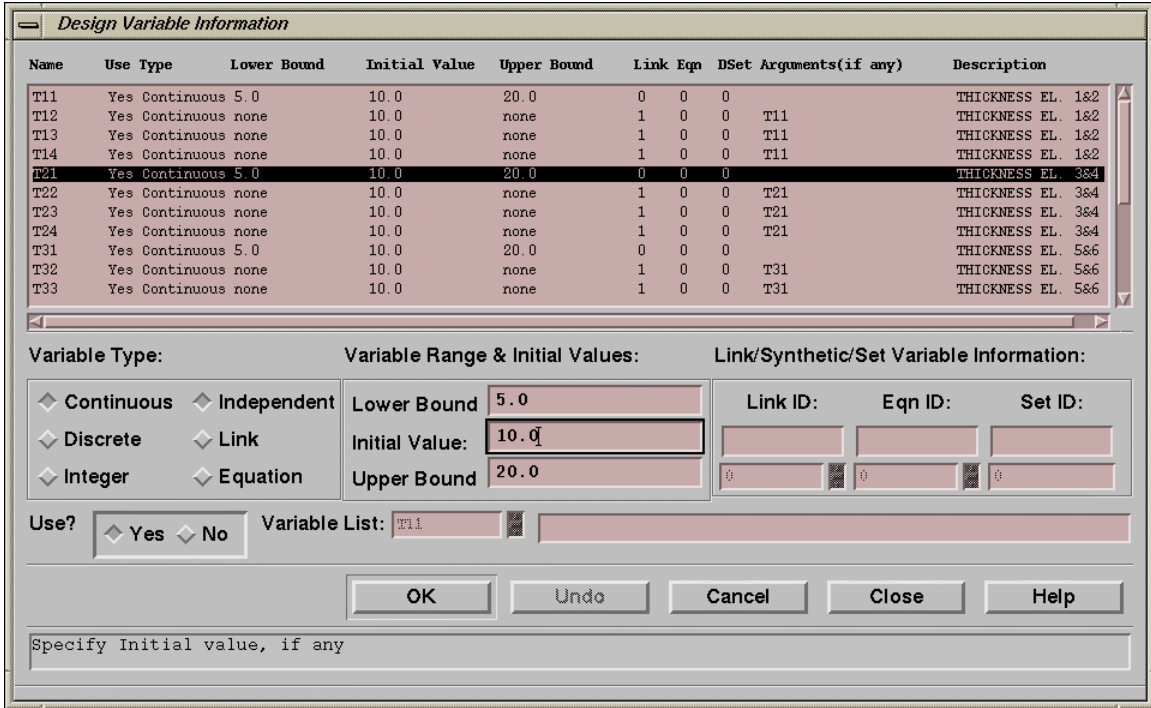

Figure 3: VisualDOC Variable Window

Design Objective Function Information

The next step in design data preparation is to specify the design objection function, which you want to minimize or maximize. Click on the **Objective** icon to open the objective function window as shown here in figure 4. This window shows a list of possible objective functions. All the parameters in the catalog, both **Input** and **Output** are displayed as potential objective functions. Here you may specify which objective function you wish to **Minimize** or **Maximize** in your present optimization task. An objective function can be direct, linked or synthetic response. Multiobjective optimization can also be performed by providing multiple objective functions. If multiobjective optimization is performed, one or more objective function may have target values. In that case, in addition to target value, you also need to specify the worst value and importance factor (default=1.0). It may be noted here that there is no unique solution while performing multiobjective optimization. The result will depend on the target value, importance factor and the worst value specified.

Design Constraint Information

Choose the **Constraint** icon to open the design constraint window as shown in figure 5. If a catalog of variables and responses has already been defined, this window will show a list of possible constraint functions. All the parameters in the catalog that were tagged as Output are displayed here as potential constraint functions.
Here you will specify which constraints you wish to use in the present optimization task, and their bounds. Again, a constraint could be direct, linked or synthetic response.

Once this basic information about the optimization task is specified, you may open the control window (see Figure 1) to provide some more information about the present optimization task. Now that the optimization project is defined well, you may create the optimization data. This is done by choosing **Project-> Generate Design Data** menu. Once the design data is ready, you are ready to perform design optimization
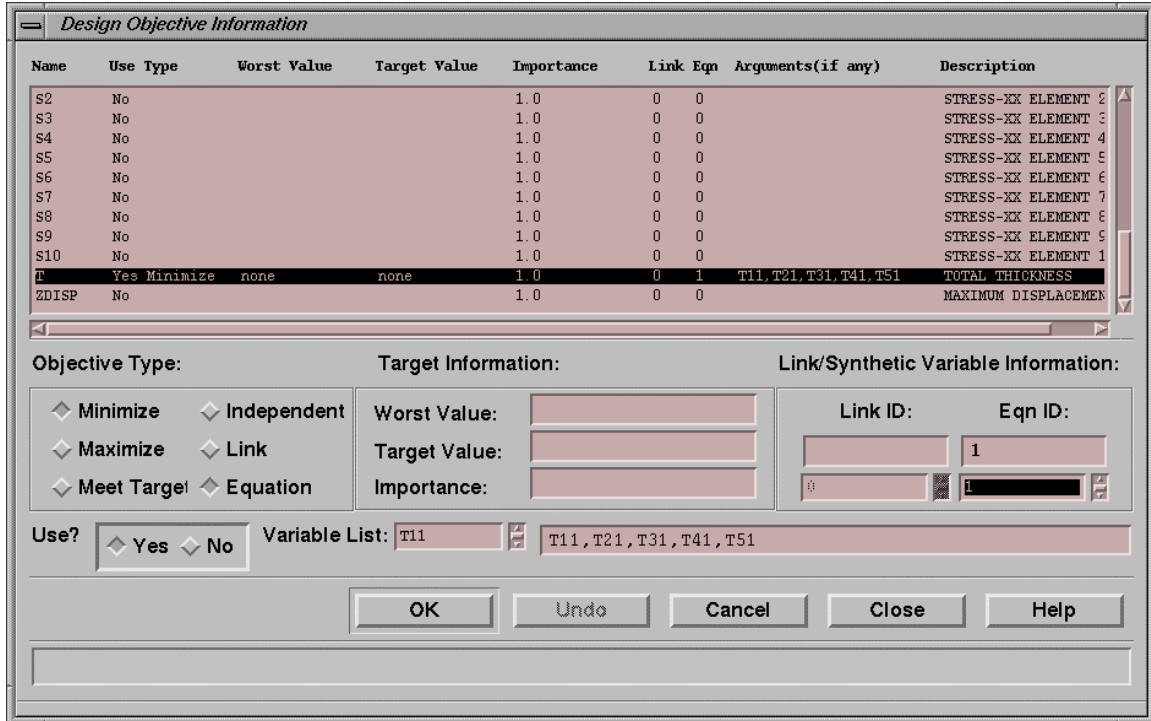

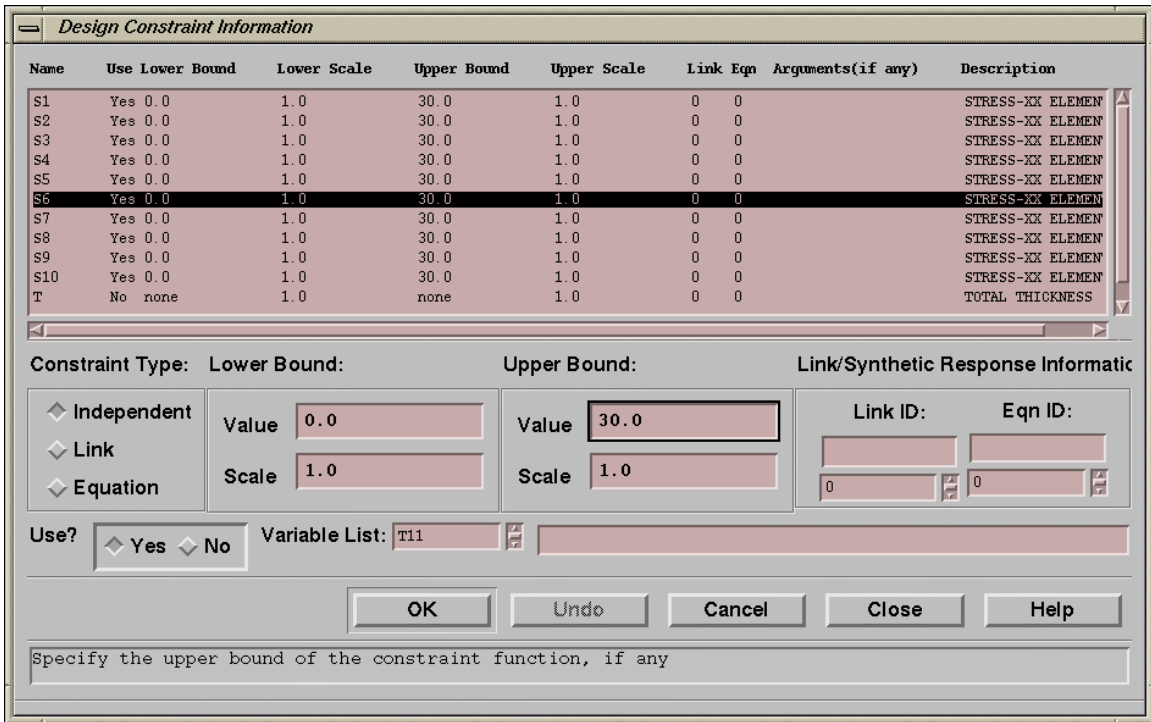Figure 4: VisualDOC Objective Function Window
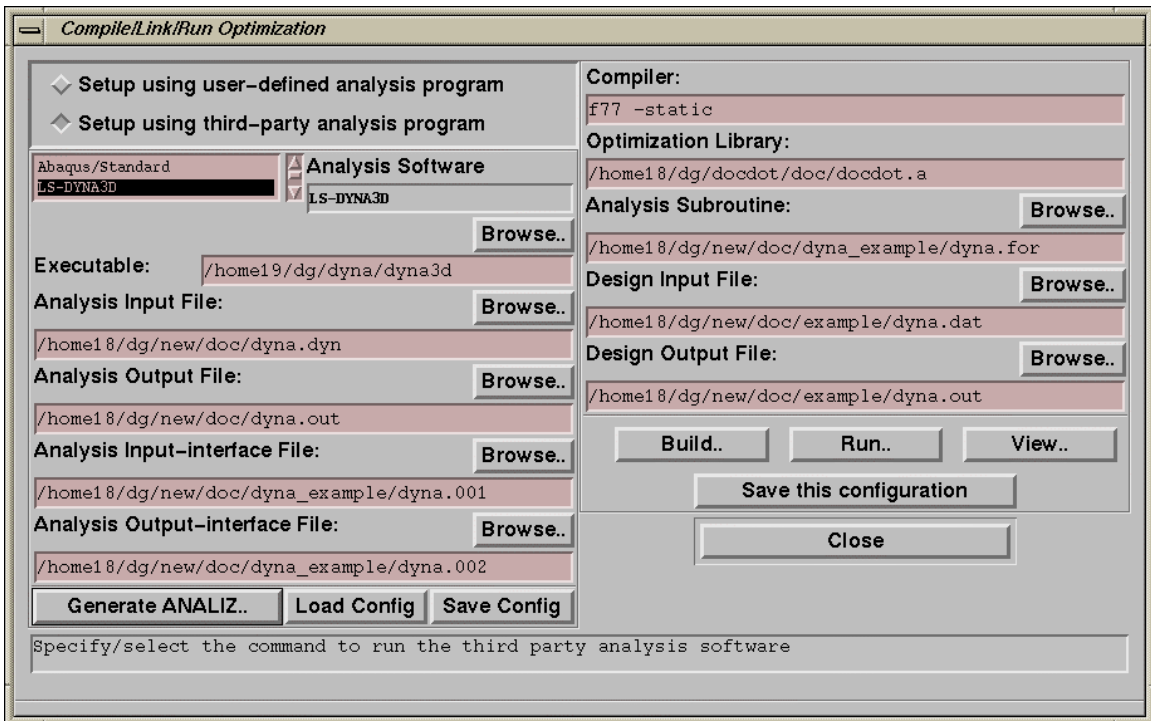
Figure 5: VisualDOC Constraint Function Window

Figure 6: VisualDOC Compile/Link/Run Optimization Window

using LS-DYNA. To do this click on the **Project->Build/Run Optimization menu,** and this will open the window as shown in figure 6.

Using this window, you can automatically generate the ANALIZ subroutine, link this subroutine with the VisualDOC optimization library, and perform optimization with LS-DYNA. All these activities could also be performed at the console prompt from outside the VisualDOC environment.

POST PROCESSING

The purpose of this module is to assist the user in reviewing the optimization or other results, and in performing "what-if" studies. The user may wish to trace the optimization progress to gain insight into his/her design. This could be done in several ways. The user may simply plot the objective functions versus iteration time. If there are multiple objective functions, the plotting the progress of each of them in the form of xy-plot will provide insight into how they compete. The Figure 7 shows such a plot as an example. Additionally, the user may plot the gradient of the objective functions and active and near active constraints, as well as the resulting search direction. The key idea here is that the user can view important information about the design progress. Thus, the user can choose to continue, terminate or perhaps modify the design specifications to direct the optimization process.

AN EXAMPLE USING LS-DYNA

Here LS-DYNA requires special handling of output files because the required information is output in several files. Here we combine all output files into a single file for creating the catalog, and for retrieving the responses. Here, a ten element cantilevered beam is optimized using both direct optimization with finite difference gradients, and response surface approximations. The beam was modeled using Belytchko-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 created 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. The example is taken from
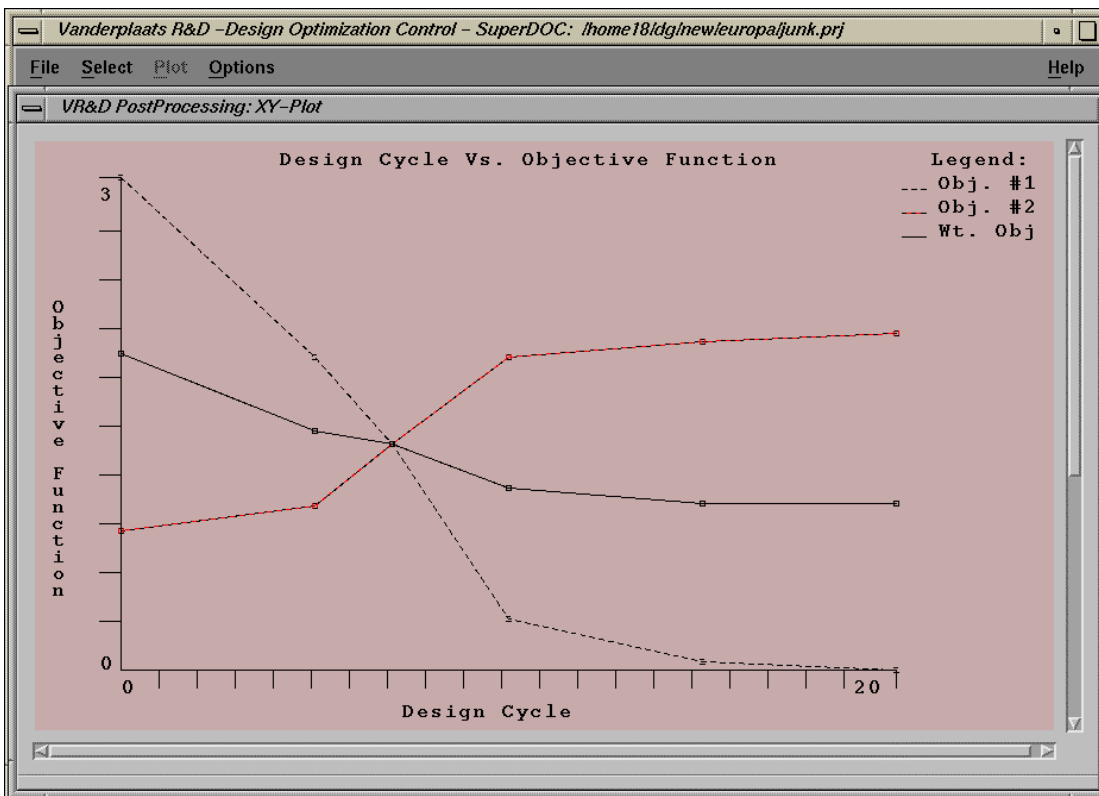
the LS-DYNA Manual Section: CONTROL-DAMPING, and uses the input file beam.dr.214.k. The dynamic calculation ends at 1.0 second.
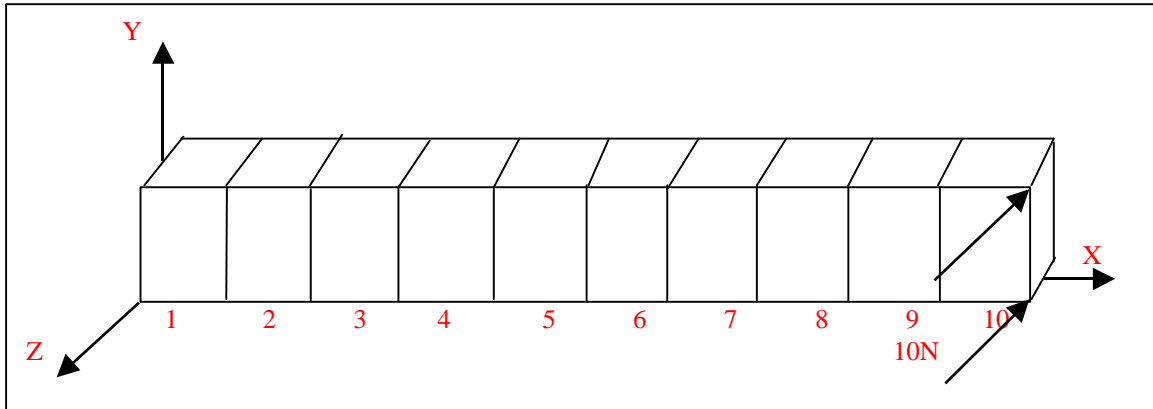

Figure 8: LS-DYNA Cantilever Beam Model

Problem Statement

Design Variables: 5 independent design variables as shown below, and 15 dependent (linked) design variables.

Name	Description	Initial Value
T11	Thickness of elements 1&2	10.0 mm
T21	Thickness of elements 3&4	10.0 mm
T31	Thickness of elements 5&6	10.0 mm
T41	Thickness of elements 7&8	10.0 mm
T51	Thickness of elements 9&10	10.0 mm

Objective: One synthetic objective function as shown here.

Name	Type
Total Thickness T=T11+T21+T31+T41+T51	Minimize

Constraints: A total of 11 constraints as shown below.

Name	Value
Principal Stress at each element surface $|S_{xx}|$	$\leq 25.0 \text{ N/mm}^2$
Displacement at tip, ZDISP	≤ 20.0 mm

RESULTS:

Design Variables:

Name	Final Value (mm)	
	Direct Optimization	Response Surface
T11	11.471	11.489
T21	10.229	10.181
T31	8.729	8.718
T41	6.975	7.084
T51	5.000	5.000

Objective Function:

Name	Final Value (mm)	
	Direct Optimization	Response Surface
T	42.404	42.472

Constraints:

Name	Final Value (mm)		Status
	Direct Optimization	Response Surface	
S1	25.007	24.920	Active
S2	22.374	22.297	Inactive
S3	24.817	25.062	Active
S4	21.508	21.720	Inactive
S5	24.995	25.058	Active
S6	20.450	20.502	Inactive
S7	24.910	24.419	Inactive
S8	17.793	17.250	Inactive
S9	20.776	20.776	Inactive

S10	6.9307	6.9306	Inactive
ZDISP	19.991	19.914	Active

Discussion:

The results for the two cases (direct optimization with finite difference gradient and optimization using response surface techniques) are essentially same. The optimization with response surface approximations converged much faster. It took 26 function evaluations as opposed to 61 function evaluations in direct optimization. Experience indicates optimization with response surface approximations is more efficient for problems of under about 10 design variables.

SUMMARY AND CONCLUSIONS

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. VisualDOC is such a design optimization study tool. It expands the technology base to greatly improve ease of use and to provide a unique capability to perform design studies and interpret results. Development of VisualDOC optimization interface to LS-DYNA provides some basic capabilities to use optimization while solving problems with a nonlinear finite element code. Although this may not be the most efficient way to provide optimization capabilities in LS-DYNA, it provides a workable design optimization capability.

ACKNOWLEDGMENT

REFERENCES

1. "VisualDOC Users Manual," Vanderplaats Research & Development, Inc., Colorado Springs, CO, 1998.

2. "DOT Users Manual," Vanderplaats Research & Development, Inc., Colorado Springs, CO, 1995.

3. "DOC Users Manual," Vanderplaats Research & Development, Inc., Colorado Springs, CO, 1995.