



An integrated package for computer aided optimum design

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ABSTRACT

In this paper Fortran and C versions of the Computer Aided Multicriterion Optimization System (CAMOS) are described. This system is created to integrate the multicriterion optimization techniques with computer aided design processes. For each optimum design problem a separate module is created. The structure of this module is described. The possibilities and advantages of using both CAMOS and computer aided design modules linked to the system are shown using two application examples: designing multiple clutch brake and coil compression spring.

INTRODUCTION

Many different optimization systems and software packages have been developed recently especially for structural design. Examples of such systems are: SAPOP (Eschenauer et al [1]), OCTOPUS (Esping et al [2]), CAOS (Rasmussen et al [3] and OPT3 (Wang and Ragsdel [4]). All of these large and sophisticated systems are designed to solve complex optimum design problems using the finite element method, sensitivity analysis etc. A large group of design problems especially in mechanical engineering requires an easy to use optimization system which can solve different types of optimization models which can be modified during the computer aided optimum design session. An example of such a system is the one developed by Schittkowski [5] which is the Fortran package for solving different nonlinear models with continuous variable. A similar character has the the author's system CAMOS (Computer Aided Multicriterion Optimization System) which can solve the optimization models of continuous, integer, discrete and mixed continuous - integer and continuous - discrete types. The system is oriented to optimal design of machine elements and assemblies. There are two versions of CAMOS coded in Fortran (Osyczka [6]) and in C which



is under development. The Fortran version of CAMOS is useful for problems which use rich Fortran scientific libraries or those which have been already coded in this language, whereas the C version is more user friendly and is more convenient for design automation. Both versions are designed to integrate problem analysis, its optimization and decision making into one entity and the way it is done is described in this paper.

DESCRIPTION OF CAMOS

CAMOS is designed to solve single and multicriterion optimization problems of the form:

$$\min_{\mathbf{x} \in \mathbb{R}^n} \{ f(\mathbf{x}) : h(\mathbf{x})=0, g(\mathbf{x}) \geq 0 \}$$

where: \mathbf{x} - vector of decision variables,
 $f(\mathbf{x})$ - vector of objective functions,
 $h(\mathbf{x})$ - vector of equality constraints,
 $g(\mathbf{x})$ - vector of inequality constraints.

The optimization models can be of continuous, integer, discrete and mixed continuous - integer and continuous - discrete types.

CAMOS contains the following function minimization methods:

1. Random Search (RS) method.
2. Direct Search (DS) method.
3. Simplex (SX) method.
4. Variable Matrix (VM) method.
5. Flexible Tolerance (FT) method.

The user may extend the list of these methods by adding his own function minimization method.

The random search method can be combined with each of the iterative methods, i.e. with DS, SX, VM and FT methods. For continuous programming models all of the above methods can be used. For integer and discrete programming models only the random search method can be used. For mixed continuous and integer, and mixed continuous and discrete programming models, the random search method or the random search method combined with any of the iterative methods can be used.

The following multicriterion optimization methods are available:

1. min-max method,
2. weighting min-max method,
3. global criterion method,
4. weighting objectives method,
5. normed weighting objectives methods,
6. method for generating a set of Pareto optimal solution.

As it was mentioned before there are two versions of CAMOS coded in Fortran and C. Both versions have the same possibilities, but their structures are different.

Fortran version of CAMOS

The Fortran version of CAMOS has sequential structure and it is run interactively. The way of running this version is shown in Fig.1 where the copy of the screen is presented while running a



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COMPUTER      AIDED      MULTICRITERION  OPTIMIZATION  SYSTEM
BY A.OSYCZKA, TECHNICAL UNIVERSITY OF CRACOW, POLAND, VERSION 2.1F,1992
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---PLEASE SPECIFY THE TYPE OF YOUR PROBLEM---
1
---PLEASE ENTER GENERAL DATA---
2 2 0 1 0 0
DO YOU WISH TO CHECK YOUR MODEL FOR THE GIVEN VALUES OF X(I) (Y/N) ?
n
---PLEASE SPECIFY THE TYPE OF YOUR MODEL---
h
          *** HELP TEXT ***
PLEASE SELECT ONE OF THE FOLLOWING:
1 - CONTINUOUS NONLINEAR PROGRAMMING MODEL
2 - INTEGER NONLINEAR PROGRAMMING MODEL
3 - MIXED CONTINUOUS AND INTEGER NONLINEAR PROGRAMMING MODEL
4 - DISCRETE NONLINEAR PROGRAMMING MODEL
5 - MIXED CONTINUOUS AND DISCRETE NONLINEAR PROGRAMMING MODEL
1
---PLEASE SELECT FUNCTION MINIMIZATION METHOD---
-2
---PLEASE ENTER THE STARTING POINT---
5 5
---PLEASE SELECT ONE OF THE FOLLOWING---
1 - MINIMA ARE CALCULATED BY THE SYSTEM
2 - MINIMA WILL BE GIVEN BY THE USER
3 - CALCULATIONS OF MINIMA ARE OMITTED
1
          *** WAIT, MINIMA ARE CALCULATED
-----
          CALCULATED MINIMA OF THE OBJECTIVE FUNCTIONS
-----
MINIMUM OF 1 OBJECTIVE FUNCTION
VALUE OF 1 OBJECTIVE FUNCTION = .2985172E+02
VECTOR OF DECISION VARIABLES
.4727539E+01 .5012402E+01
VALUES OF INEQUALITY CONSTRAINTS
.2260059E+01 .2528191E-04
---PLEASE SELECT ONE OF THE FOLLOWING---
1 - CHANGING THE STARTING POINT
2 - CHANGING FUNCTION MINIMIZATION METHOD
3 - CHANGING THE TYPE OF YOUR MODEL
4 - CHANGING THE GENERAL DATA
5 - START FROM THE BEGINNING
6 - END OF CALCULATIONS
6
DO YOU REALLY WISH TO STOP YOUR CALCULATIONS (Y/N)?
y
END OF JOB , THANK YOU

```

Figure 1. Example of running Fortran version of CAMOS

simple single criterion optimization problem. In this figure the data introduced by the user are in bold symbols. HELP text provides the user with all information he needs while running the system. The sequence of questions and data the system will ask the user depends on his answers to the previous questions. Thus the system will only ask about the data it needs for the problem under running. After the optimization process there are



several possibilities to return to points which may improve the obtained solution.

C version of CAMOS

This version has a window structure the idea of which is shown in Fig. 2. The main menu options presented across the top of the window have the following meanings:

"Status" defines the stage of work with CAMOS.

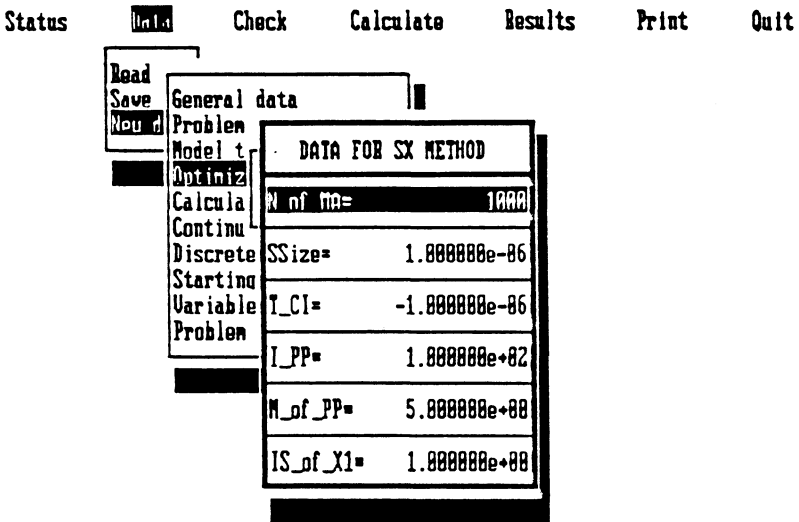
"Data" is used for introducing all necessary data for design and optimization processes. The default values of some data are automatically defined at the beginning of the session, but the user can change them at any time he wants.

"Check" provides the possibilities of checking the optimization model for the values of decision variables given by the designer.

"Calculate" is used for seeking the separately attainable minima and the optimum with respect to the chosen method and criteria.

"Results" presents on the screen the optimization results and a schematic view of the optimal solution.

"Print" enables to print data and results, from the report stored as a session history.



ENTER Exit ARROWS MovedScroll ANY-KEY New data ESC Menu F1 Help

Figure 2. General structure of C version of CAMOS



"Quit" leaves CAMOS for DOS.

At the bottom of the screen the uses for various function keys currently active are defined.

The context-sensitive HELP is implemented in the system. The help text is provided on selecting the desired menu option and pressing the F1 key.

For both versions of CAMOS the optimization problem is introduced into the system by means of module **NONPRO** (**Nonlinear Programming**) which is a user-supplied module, the structure of which is described below.

STRUCTURE OF NONPRO FOR COMPUTER AIDED OPTIMUM DESIGN

NONPRO is divided into three parts which are responsible for input data arrangement, optimization model and, results representation.

Part 1 introduces the problem dependent data connected with the design the NONPRO is written for. The constant parameters which are typical of a problem are entered at this point. The data for these parameters are introduced during the computer aided session with CAMOS and they can be modified while running the system. The input data for the problem are divided into two groups: necessary data and additional data. The necessary data are those which the designer has to know while starting the design. The additional data are divided into three groups: geometric, materials and other data. The designer may know the values for these data or use the Prompt System which is designed to find or calculate all additional data for the design under consideration. This refers to all coefficients, material properties and upper and lower bounds on the decision variables. In the latter case the Prompt System will first find a preliminary solution which is far from the optimal one but which will make it possible to evaluate automatically the reasonable values of upper and lower bounds.

Part 2 is responsible for the optimization model. In this part the values of the objective and constraint functions are evaluated for the current values of decision variables. No restrictions are imposed on the way of evaluating these functions. Each optimization model is built to be flexible enough to satisfy designers' different requirements. Some of the quantities are considered both as the objective functions and constraints. If the designer wants to consider them only as constraints he may solve the optimization model using zero value weighting coefficients for these objective functions. He may also run the system assuming that only some of the objective functions are taken into consideration. If he does not know what constraints are imposed on these quantities, he may impose large values on the upper bounds of these constraints so that they will always be satisfied and after the minimization process he will see what the separately attainable minima are. He may also consider the requirement: I would like to minimize this quantity as well as have it no greater than the specified maximum.

Part 3 calculates and prints problem dependent results and



gives a schematic view on the solution presented on the screen. If the designer is satisfied with the solution the function NONPRO may create automatically an output file which can be read by AutoCAD. This file creates an advanced design using the values of decision variables at the optimum and taking under consideration typical proportions of the specific design.

APPLICATION EXAMPLES

Two application examples will show the advantages of using CAMOS in designing machine elements. The first one deals with designing multiple clutch brake and the results are shown while running Fortran version of the system. The second example presents the optimization model and the results of optimization for designing a coil compression spring. These results are presented in the form of the copies of the screen for the most important fragments of the computer aided session with C version of CAMOS.

Optimum design of a multiple clutch brake

Optimization model

The vector of decision variables is $\mathbf{x} = [R_1, R_o, A, F, Z]^T$,

where:

R_1 = inner radius, mm,

R_o = outer radius, mm

A = thickness of the disc, mm,

F = actuating force, N,

Z = number of friction surfaces.

The number of friction surfaces can assume only integer values. Thus the optimization model is of a mixed continuous - integer type.

The vector of objective functions is

$$\mathbf{f}(\mathbf{x}) = [f_1(\mathbf{x}), f_2(\mathbf{x}), f_3(\mathbf{x}), f_4(\mathbf{x}), f_5(\mathbf{x})]^T,$$

where:

$f_1(\mathbf{x})$ = mass of the brake, kg,

$f_2(\mathbf{x})$ = stopping time, s,

$f_3(\mathbf{x})$ = number of friction surfaces,

$f_4(\mathbf{x})$ = outer radius, mm,

$f_5(\mathbf{x})$ = actuating force, N.

Sixteen geometric and behaviour constraints are imposed on the design. The first ten constraints are the bounds on the decision variables. The remaining constraints are pressure, temperature, relative speed of slipstick, stopping time, generated torque and the actuating force. Four of the constraints refer to the quantities which are represented by the second, third, fourth and fifth objective function. For example the outer radius is the fourth objective function and at the same



time is bounded by the constraint. In this way the optimization model is flexible and can meet all the designer's requirements.

Results

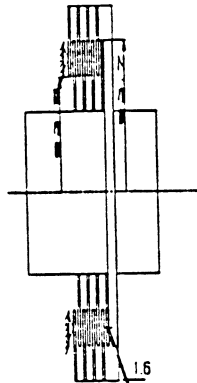
The results of optimization are shown in Fig.3 where the final stage of computer aided optimum design session with

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WEIGHTING MIN-MAX METHOD
-----
---PLEASE ENTER THE WEIGHTING COEFFICIENTS---
.1 .1 .1 .6 .1
*** PLEASE WAIT , OPTIMUM IS CALCULATED
VALUE OF THE MINIMIZED QUANTITY = .1333333E+00
VALUE OF 1 OBJECTIVE FUNCTION = .9747257E+01
VALUE OF 2 OBJECTIVE FUNCTION = .1314230E+02
VALUE OF 3 OBJECTIVE FUNCTION = .7000000E+01
VALUE OF 4 OBJECTIVE FUNCTION = .8374538E+02
VALUE OF 5 OBJECTIVE FUNCTION = .4109824E+03
VECTOR OF DECISION VARIABLES
.6350054E+02 .8374538E+02 .1667986E+01 .4109824E+03
.7000000E+01
VALUES OF INEQUALITY CONSTRAINTS
.8500635E+01 .2625462E+02 .2447472E+01 .1679860E+00
.1332014E+01 .1582212E+02 .3000000E+01 .8000000E+01
.9956114E+01 .9148869E+00 .8060605E+01 .1857326E-02
.2220604E+01 .1314267E+02 .4109824E+03 .5890176E+03
DO YOU WISH THE PROBLEM DEPENDENT RESULTS TO BE PRINTED (Y/N) ?
y
---SELECT THE NUMBER OF SUPPORTED DEVICE---
9
--- PLEASE SELECT THE RESOLUTION CODE
OR THE NAME OF THE FILE TO OUTPUT ---
DO YOU WISH *** HELP TEXT *** (Y/N) ?
n
br.bp

```

GRAPHICAL ILLUSTRATION OF THE SOLUTION



7.
FRICTION PAIRS

Figure 3. Results of optimization of multiple clutch brake



Fortran version of CAMOS is presented. The FORTPLOT package (Jeffrey [7]) is used here for obtaining the graphical illustration of the solution. FORTPLOT HP file can be transferred to another CAD program. For example the Graphic Data Transfer program developed by Harayanan and Dundar [8] reads the file, so a further computer aided design session can be carried on.

Optimum design of a coil compression spring

Optimization model

The vector of decision variables is $\mathbf{x} = [d, D, L, N]^T$, where:

- d = wire diameter, mm,
- D = mean coil diameter, mm
- L = free length, mm,
- N = number of active coils

The number of active coils can assume only integer values. Thus the optimization model is of a mixed continuous - integer type.

The vector of objective functions is

$\mathbf{f}(\mathbf{x}) = [f_1(\mathbf{x}), f_2(\mathbf{x}), f_3(\mathbf{x})]^T$, where:

- $f_1(\mathbf{x})$ = mass of the spring, kg,
- $f_2(\mathbf{x})$ = outer diameter of the spring, mm,
- $f_3(\mathbf{x})$ = length of the spring, mm.

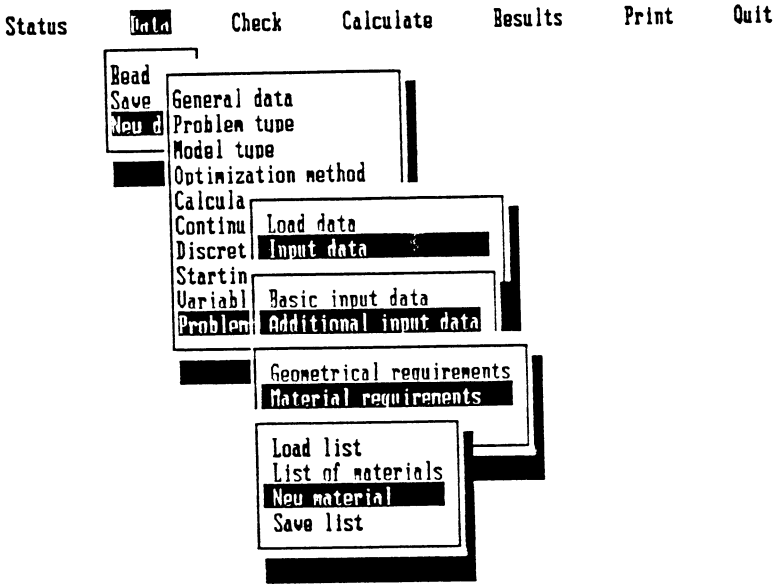
Fifteen geometric and behaviour constraints are imposed on the design. These constraints are the bounds on the decision variables, shear stress constraint, buckling constraint and required deflection constraint. The quantities which are considered as second, third objective functions are also written as the constraints. Thus the optimization model should satisfy different requirements of the designer.

Results

In Figs. 4, 5, 6 and 7 four copies of the screen, which represent the idea of the automation and optimization process while designing coil spring are shown. Fig. 4 shows the way of introducing problem dependent data. Here the necessary data are: maximum working load, deflection under maximum working load and deflection tolerance. For the remaining problem dependent data the designer may use the "Prompt System" as presented in Fig. 5. Fig. 6 shows the final stage of running CAMOS and NONPRO module for the coil spring design. In this case a "Schematic View" on the optimal solution is shown. If the designer is satisfied with this solution, NONPRO module creates *.scr file which is then read automatically by AutoCAD and which creates the design as presented in Fig. 7.

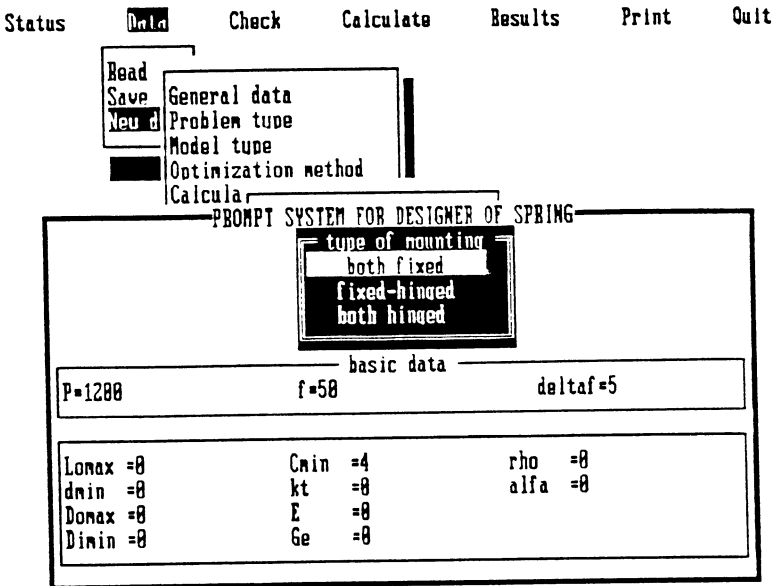


Optimization of Structural Systems



ESC Menu F1 Help

Figure 4. The way of introducing the problem dependent data



ESC Menu F1 Help

Figure 5. "Prompt system" for design of the coil spring



GRAPHICAL ILLUSTRATION OF THE SOLUTION

scale 1 : 1

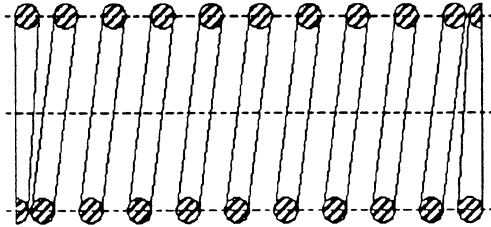
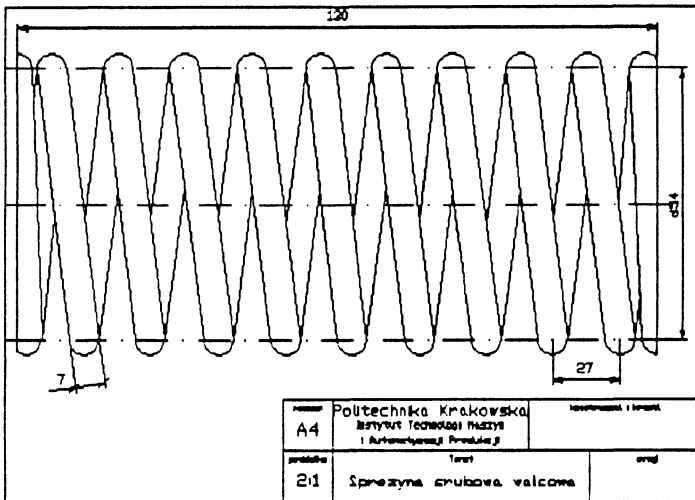


Figure 6. "Schematic View" on the optimal solution of the coil spring

Layer 1 8nap

8.00,8.00



- AUTOCAD
- *****
- SETUP
- BLOCKS
- DIM:
- DISPLAY
- DRAW
- EDIT
- INQUIRY
- LAYER:
- SETTINGS
- PLOT
- UTILITY
- 3D
- SAVE:

Text: ?

Command: regen Regenerating drawing.

Command: end

Figure 7. Drawing in AutoCAD obtained automatically from the file created by NONPRO module



FINAL REMARKS

The system described in the paper is both a flexible and an efficient tool for solving different optimization problems which have computer aided design forms. The system is built for further development considering both function minimization methods which can be attached to the system and optimization problems which can be solved using the system. The computer library of NONPRO modules for different computer aided optimum design problems is under development. The "Prompt System" will be developed to an "Expert System".

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