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NAVAL POSTGRADUATE SCHOOL

Monterey, California

COPES - A FORTRAN CONTROL PROGRAM FOR ENGINEERING SYNTHESIS

BY

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A FORTRAN COntrol Program for Engineering Synthesis (COPES) has been developed for solving engineering design problems. The program maximizes or minimizes a numerically defined objective function subject to a set of inequality constraint functions. COPES uses the optimization program, CONMIN, which includes the conjugate direction method of Fletcher and Reeves for unconstrained function minimization and a modification of

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Zoutendijk's method of feasible directions for constrained function minimization. Additionally, approximation techniques are available for use in optimization, and trade-off studies may be performed. A simple design example demonstrates the program capabilities. Programming guidelines are presented followed by sample input data and output for each program option.

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ABSTRACT

A FORTRAN COntrol Program for Engineering Synthesis (COPES) has been developed for solving engineering design problems. The program maximizes or minimizes a numerically defined objective function subject to a set of inequality constraint functions. COPES uses the optimization program, CONMIN, which includes the conjugate direction method of Fletcher and Reeves for unconstrained function minimization and a modification of Zoutendijk's method of feasible directions for constrained function minimization. Additionally, approximation techniques are available for use in optimization, and trade-off studies may be performed. A simple design example demonstrates the program capabilities. Programming guidelines are presented followed by sample input data and output for each program option.

I. INTRODUCTION

Most design processes require the minimization or maximization of some parameter which may be called the design objective. For the design to be acceptable, it must satisfy a variety of physical, aesthetic, economic and, on occasion, political limitations which are referred to here as design constraints. While part of the design problem may not be easily quantified, most of the design criteria can be described in numerical terms.

To the extend that the problem can be stated in numerical terms, a computer program can be written to perform the necessary calculations. For this reason, computer analysis is commonplace in most engineering organizations. For example, in structural design, the configuration, materials and loads may be defined and a finite element analysis computer code is used to calculate stresses, deflections and other response quantities of interest. If any of these parameters are not within the prescribed bounds, the engineer may change the structural member sizes and re-run the program. The computer code therefore provides only the analysis of a proposed design, with the engineer making the actual design decisions. This approach to design, which may be called computer-aided design, is commonly used today.

Another common use of analysis codes is in trade-off studies. For example, an aircraft trajectory analysis code may be run repetitively for several payloads, calculating the aircraft range, to determine the range-payload sensitivity.

A logical extension to computer-aided design is fully automated design, where the computer makes the actual design decisions, or to perform trade-off studies with a minimum of man-machine interaction. The purpose of the COPES program is to provide this automated design and trade-off capability. The user must provide a FORTRAN analysis program for analysis of the particular problem being considered. This analysis program is written according to a simple set of guidelines so that it can be easily coupled to the COPES program for automated design synthesis.

This document describes the capabilities of the COPES program and its usage. A simple design example is first presented to demonstrate the program capabilities. Guidelines are given for writing analysis codes which can be coupled directly to COPES. Finally the data organization is outlined and sample data is presented.

The most commonly used option of the COPES program will be for design optimization. Two approaches are available for this purpose. The first (NCALC = 2) is direct optimization of the function by the CONMIN optimization sub-program [Ref. 1]. An alternative to this is through the use of approximation techniques (NCALC = 6, Ref. 2). This second option is usually more efficient for problems of under 6 design variables but which requires costly analysis, especially when multiple optimizations are to be performed.

DESIGN EXAMPLE

Assume it is required to design the cantilevered beam shown in Fig. 1. The objective is to find the minimum volume of material which will support the concentrated load. That is;

$$\text{Minimize Volume} = B \cdot H \cdot L \qquad (1)$$

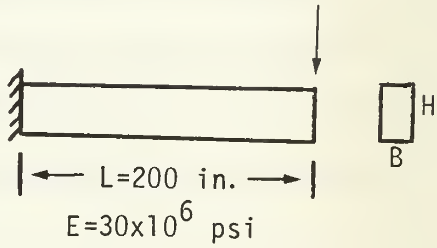

Figure 1 - Cantilevered Beam

The bending stress in the beam must not exceed 20,000 psi;

$$\sigma_b = \frac{Mc}{I} = \frac{6PL}{BH^2} \leq 20{,}000 \qquad (2)$$

The shear stress must not exceed 10,000 psi;

$$\nu = \frac{3}{2}\,\frac{P}{A} = \frac{3P}{2BH} \leq 10{,}000 \qquad (3)$$

and the deflection under the load must not exceed one inch;

$$\delta = \frac{PL^3}{3EI} = \frac{4PL^3}{EBH^3} \leq 1.0 \qquad (4)$$

Additionally, geometric limits are imposed on the beam size so that;

$$0.5 \leq B \leq 5.0 \qquad (5)$$

$$1.0 < H \leq 20.0 \qquad (6)$$

$$H/B \leq 10.0 \qquad (7)$$

Equation (1), the design objective, provides a measure of the efficiency of the design, while Eqs. (2-7) define the criteria which the structure must satisfy, and are referred to as constraints.

This design problem may be stated in general form;

Minimize $F(\overline{X})$

Subject to:

$G_j(\overline{X}) \leq 0 \qquad i = 1,m$

$X_i^{\ell} \leq X_i \leq X_i^{u}$

where $\overline{X}$ is a vector containing the design variables B and H and $G_j(\overline{X})$ are the constraints defined by Equations (2-7). There are eight constraints on the design. The objective and constraints are functions of the design variables.

While this problem is straightforward, its solution is not trivial because it is not known which constraints will be critical (i.e. which $G_j(\overline{X}) = 0$) at the optimum.

One design approach is to assume that the bending and the displacement constraints are critical, so that Equations (2) and (4) are equalities, and then solve the two simultaneous equations for the design variables B and H. The remaining constraints are then checked to be sure they are satisfied, and if not, they are used to obtain a new design satisfying all constraints. When a design is obtained where two $G_j(\overline{X}) = 0$ and the remaining $G_j(\overline{X}) \leq 0$, it is an acceptable design.

The design obtained here yields a volume of 6750 and satisfies all constraints. Note, however, that the objective function of Equation (1) played no part in the choice of design variables so that, using this approach, there is no assurance that a minimum volume design will be produced [Ref. 3]. More importantly, it is desirable to devise techniques for optimum design of systems which may be defined by more than two variables and by much more complex analysis, where the optimum design cannot be determined by inspection.

The COPES program provides this general capability by the use of the optimization program CONMIN [Ref. 1]. To use this design capability, a FORTRAN code must be provided which will calculate the various parameters. In writing the analysis code; 1) it is written in subroutine form with SUBROUTINE ANALIZ (ICALC) as the main routine, 2) it is segmented into INPUT, EXECUTION AND OUTPUT and 3) all parameters which may be design variables, object functions or constraints are contained in a single labeled common block called GLOBCM.

To demonstrate the simplicity with which a design-oriented analysis code can be written, the following FORTRAN subroutine was produced for the analysis of the cantilevered beam in Figure 1.

```
      SUBROUTINE ANALIZ (ICALC)
      COMMON /GLOBCM/ B,H,VOL,BSTRES,SHRSTR,DELTA,HB,E,AL
      IF (ICALC.GT.1) GO TO 10
C --- INPUT OR INITIALIZATION.
      B=2.5
      H=10.
      P=10,000.
      E=30.E+6
      AL=200.
      WRITE (6,30)AL,P,E,B,H
      RETURN
C --- EXECUTION.
10    CONTINUE
      VOL=AL*B*H
      BSTRES=6.*P*AL/(B*H*H)
      SHRSTR=1.5*P/(B*H)
      DELTA=4.*P*(AL**3)/(E*B*(H**3))
      HB=H/B
      IF (ICALC.LT.3) RETURN
C --- PRINT RESULTS.
20    WRITE (6,30)AL,P,E,B,H
      WRITE (6,40)VOL,BSTRES,SHRSTR,DELTA,HB
30    FORMAT(/////5X,17HCANTILEVERED BEAM//5X,8HAL =,F9.3/5X,
     * 8HP     =,E12.5/5X,8HE     =,E12.5//5X,8HB     =,F9.3/5X,
     * 8HH     =,F9.3)
40    FORMAT(/5X,8HVOL    =,F9.3//5X,8HBSTRES=,E12.5/5X,
        8HSHRSTR=
     * E12.5/5X,8HDELTA=,E12.5/5X,8HH/B     =,F9.3)
      RETURN
      END
```

This routine may be executed as a simple analysis program by the following main program;

```
C     MAIN PROGRAM TO EXECUTE SUBROUTINE ANALIZ.
      DO 10 I = 1,3
10    CALL ANALIZ (I)
      STOP
      END
```

Moreover, ANALIZ can be coupled directly to the COPES program to perform this same function, or to perform optimization or trade-off studies.

This subroutine was coupled to COPES and an optimization was performed (NCALC = 2) to yield the following design;

CANTILEVERED BEAM

L	= 200.00
P	= .10000E+05
E	= .30000E+08
B	= 1.82
H	= 18.16
VOL	= 6607.61
BSTRES	= .20002E+05
SHRSTR	= .45402E+03
DELTA	= .97906E+00
H/B	= 9.98

The parameters L, P, E, B and H were input to the program and the remaining parameters were calculated. The design variables B and H were changed during the optimization process to obtain this design.

This design was achieved with 45 calls to ANALIZ with ICALC = 2 (45 analyses). This design could surely have been found with fewer analyses were it performed by hand calculations. However, once having written the analysis subroutine, numerous other designs may be obtained for different materials, loading, or design stresses with only minimal effort. Furthermore, the design obtained here of volume = 6607.6 is very near the theoretical optimum of 6603.9, while that which satisfied stress and displacement constraints simultaneously was not.

This very simple design example underscores the power of numerical optimization techniques and the ease with which they may be applied. The key to efficient use of the COPES program is the requirement that the ANALIZ code be written in a standard format so that it may be coupled to COPES without modification. The following section contains guidelines for writing a design-oriented analysis code.

II. PROGRAMMING GUIDELINES

In developing any computer code for engineering analysis, it is prudent to write the code in such a way that it is easily coupled to a general synthesis program such as COPES. Therefore, a general programming practice is outlined here which in no way inhibits the use of the computer program in its traditional role as an analytic tool, but allows for simple adaptation to COPES. This approach is considered good programming practice and provides considerable flexibility of design options. Only five basic rules must be followed:

I. Write the code in subroutine form with the primary routine called as; SUBROUTINE ANALIZ (ICALC) The name ANALIZ is compatable with the COPES program and ICALC is a calculation control. Note that subroutine ANALIZ may call numerous other subroutines as required to perform the necessary calculations.

II. Segment the program into INPUT, EXECUTION and OUTPUT. The calculation control, ICALC, will determine the portion of the analysis code to be executed.

ICALC = 1; the program reads all data required to perform the analysis. Also, any initialization of constants which will be used repetitively during execution is done here. This initial input information is printed here for later reference and for program debugging.

ICALC = 2: the program performs the execution phase of the analysis task. No data reading or printing is done here, except on user-defined scratch disc. Data may be printed here during program debugging, in which case it should be controlled by a print control parameter which is read during input. In this way, this print may be turned off after the program is debugged, but may be used again during future program expansion and debugging. The reason that printing is not normally allowed during execution is that when optimization is being done, the code will be called many times with ICALC = 2, resulting in voluminous print.

ICALC = 3: the results of the analysis are printed. Also the essential input parameters which may have been changed during optimization should be printed here for easy reference. In some cases, so much information is generated when ICALC = 2 that it would be inefficient to store it internally or on disc for printing when ICALC = 3. In this case, it may be desirable to actually execute when ICALC = 3 with a print code turned on to print his intermediate information. However, this approach should be avoided because it requires an additional complete execution of the program.

In summary, when;

ICALC = 1 Read input data.

ICALC = 2 Execute the analysis.

ICALC = 3 Print the results.

III. Store all parameters which may be design variables, objective functions or constraints in a single labeled common block called GLOBCM. The order in which they are stored is arbitrary. A listing of the COPES program should be checked to see how many parameters my be stored in GLOBCM (the dimension of ARRAY). Initial distribution of COPES allows for 1500 parameters.

IV. During execution or output, no parameters which are read during input should be updated. For example, if variable X is initialized during input, the execution segment must not update X such as X = X + 3.2. Instead a new variable, Y = X + 3.2 should be defined.

V. Write all programs in standard language, avoiding machine dependent capabilities such as multiple entry point (IBM), DEFINE statements (UNIVAC) and seven letter FORTRAN names (CDC). While this guideline is not essential to the use of the analysis code within the COPES program, it makes the analysis code much more transportable between different computer systems, a capability which easily justifies a slight reduction in efficiency on a given machine.

Adherence to these guidelines not only leads to a more readable and machine independent computer code, but allows this code to be coupled to the COPES program <u>without modification</u>.

Having written the analysis code, it may be executed either with a simple main program or within the COPES program to perform the analysis. To insure that guideline IV is followed, the following main test program is recommended. Note that this program calls ANNALIZ twice with ICALC = 2 and ICALC = 3, to show that the same result is obtained repetitively

```
    C  MAIN PROGRAM TO CHECK SUBROUTINE ANALIZ,
    C  READ, EXECUTE AND PRINT.
       DO 10 ICALC = 1, 3
   10  CALL ANALIZ (ICALC)
    C  EXECUTE AND PRINT AGAIN TO BE SURE THE RESULTS
    C  DO NOT CHANGE.
       DO 20 ICALC = 2, 3
   20  CALL ANALIZ (ICALC)
       STOP
       END
```

This program was executed with the ANALIZ subroutine for the cantilevered beam example to yield the following result:

```
CANTILEVERED BEAM

AL    = 200.00
P     = .10000E+05
E     = .30000E+08
B     = 2.00
H     = 5.00
```

CANTILEVERED BEAM

```
AL       = 200.00
P        = .10000E+05
E        = .30000E+08
B        = 2.00
H        = 5.00
VOL      = 2000.00
BSTRES   = .24000E+06
SHRSTR   = .15000E+04
DELTA    = .42667E+02
H/B      = 2.50
```


CANTILEVERED BEAM

```
AL       = 200.00
P        = .10000E+05
E        = .30000E+08
B        = 2.00
H        = 5.00
VOL      = 2000.00
BSTRES   = .24000E+06
SHRSTR   = .15000E+04
DELTA    = .42667E+02
H/B      = 2.50
```


This design was used as the initial design for the optimization presented previously. Note that, while the volume here is lower than the optimum, the bending stress and displacement each exceed the imposed limits by more than an order of magnitude.

Once the analysis code has been written, it can be coupled to the COPES program without modification. If it is desired to perform a simple analysis using COPES, only three data cards are required for the COPES program, namely a TITLE card, a control parameter, NCALC = 1, and an END card. If the optimization or parametric analysis (sensitivity) capabilities of COPES are to be used, additional data must be read. This data will identify which parameters in the global common block, GLOBCM, are used. To set up the COPES data, the user must have a basic understanding of how the data in the global common block is accessed by COPES. This is outlined in the following section.

III. DATA MANAGEMENT

In order to perform design operations, the COPES program must access the data in common block GLOBCM. This is done by defining the location in GLOBCM where a specified parameter resides. For example, consider the common block for the cantilevered beam;

```
COMMON/GLOBCM/B,H,VOL,BSTRES,SHRSTR,DELTA,HB,E,AL
```

The volume of material, VOL, is the third parameter in the common block; that is, it resides in location 3, referred to as the global location number. Similarly the bending stress, BSTRES, is in global location 4 and the beam width is in global location 1. Thus, the parameters are referred to by their respective location numbers in global common.

For convenience in preparing data for the COPES program, a simple "CATALOG" of parameters may be defined. For the cantilevered beam, this catalog would be;

GLOBAL LOCATION	FORTRAN NAME	DEFINITION
1	B	Beam width
2	H	Beam height
3	VOL	Volume of Material
4	BSTRES	Maximum bending stress
5	SHRSTR	Maximum shear stress
6	DELTA	Deflection under the load
7	HB	Ratio, H/B

GLOBAL LOCATION	FORTRAN NAME	DEFINITION
8	E	Young's modulus
9	AL	Length of beam

As another example, consider a global common block containing arrays;

COMMON/GLOBCM/A, Y(10), Q, C(2,2), H

The variable catalog for this common block is;

GLOBAL LOCATION	FORTRAN NAME	DEFINITION
1	A	Area
2	Y(10)	Vector of y-coordinates
12	Q	•
13	C(2,2)	•
17	H	etc.

The dimensions are given with the FORTRAN name as a reminder that the parameter is an array. In this case, the third parameter in the Y array is in global location 4. Remembering that arrays are stored column by column the C(1,2) array location is in global location 15.

It will be seen that identifying parameters according to their location in GLOBCM provides a great deal of flexibility in using the COPES program for design.

Appendix A contains blank forms for writing the variable catalog for the user's particular problem.

IV. COPES TERMINOLOGY

The copes program currently provides six specific capabilities;

1. Simple analysis, just as if COPES was not used.
2. Optimization - Minimization or maximization of one calculated function with limits imposed on other functions using the CONMIN subprogram.
3. Sensitivity analysis - the effect of changing one or more design variables on one or more calculated functions.
4. Two-variable function space - analysis for all specified combinations of two design variables.
5. Optimum sensitivity - same as sensitivity analysis except at each step, the design optimized with respect to the remaining independent design variables.
6. Approximate optimization - optimization using approximation techniques. Usually more efficient than standard optimization for up to 6 design variables or if multiple optimizations are to be performed.

In defining the data required to execute the COPES program, the following definitions are useful:

Design Variables - Those parameters which the optimization program is allowed to change in order to improve the design. Design variables appear only on the right hand side of equations in the analysis program. COPES considers two types of design variables, independent and dependent. If two or more variables are always required to have the same value or be in a constant ratio, one is the independent variable while the remaining are dependent variables. For example, if the height is required to be 10 times the width of the cantilever beam, B would be the independent variable while H would be the dependent variable.

Objective Function - The parameter which is to be minimized or maximized during optimization. Also the parameters calculated as functions of specified design variables during a sensitivity or two-variable function space study. Objective functions always occur on the left side of equations, unless the objective function is also a design variable (the beam height may be minimized as an objective function if it is also a design variable. In this case the minimum height is found for which no constraints are violated). An objective function may be linear or non-linear, implicit or explicit, but must be a function of the design variables to be meaningful.

Constraint - Any parameter which must not exceed specified bounds for the design to be acceptable. Constraint functions, always appear on the left side of equations. Just as for objective functions, constraints may be linear or non-linear, implicit or explicit, but must be functions of the design variables.

Constraint Set - A group of constraints which appear consecutively in the global common block and which all have the same limits imposed. This is a convenience which allows several constraints to be identified with a minimum of data.

Global Common - Common block GLOBCM containing design information.

Global Location - Location of a particular parameter in GLOBCM.

V. COPES DATA

The COPES program reads data from unit 5 and writes output on unit 6. Units 20 and 40 are used as scratch files. The scratch file numbers may be changed by changing two cards at the beginning of the COPES program.

In order to execute the COPES program it is necessary to provide formatted data for COPES, followed by data for the ANALIZ program which is coupled to COPES. This section defines the data which is required by COPES. The data is segmented into "BLOCKS" for convenience. All formats are alphanumeric for TITLE, and END cards, F10 for real data and I10 for integer data.

The COPES data begins with a TITLE card and ends with an END card. This is followed by data to be read by the user supplied subroutine ANALIZ or when ICALC = 1.

Comment cards may be inserted anywhere in the COPES data stack prior to the END card, and are identified by a dollar sign ($) in column 1.

Data coding forms are provided in Appendix B.

VI. UNFORMATTED DATA INPUT

While the user's sheet defines COPES data in formatted fields of ten, the data may actually be read in a simplified fashion by separating data by commas or one or more blanks. If more than one number is contained on an unformatted data card, a comma must appear somewhere on the card. If exponential numbers such as 2.5+10 are read on an unformatted card, there must be no embedded blanks. Unformatted cards may be intermingled with formatted cards. Real numbers on an unformatted card should have a decimal point.

Examples:

Unformatted data;

```
5,7,1.3,1.0+20,0,-5.1
5,7,1.3,1.0+20,,-5.1
5 7 1.3 1.0+20,, -5.1
5      7  1.3, 1.0+20 0 -5.1
```

Equivalent formatted data;

col→ 10	20	30	40	50	60	70	80
5	7	1.3	1.0+20	0	-5.1		

Unformatted data;

```
2
2,3
2 3
```

Equivalent formatted data;

col→	10	20	30		
	2			Note:	This data has been right justified.
	2	3			
2 3				Note:	This data contains no commas, so it is assumed to be formatted already.

Unformatted data;

1,2,3,4,5,6,7,8,9,10,11

Equivalent formatted data;

col→	10	20	30	40	50	60	70	80
	1	2	3	4	5	6	7	8
	9	10	11					

Note that two formatted data cards are created here.

Unformatted data;

1,2,3,4,5,6,

7,8,9,10,11

Equivalent formatted data;

col→	10	20	30	40	50	60	60	80
	1	2	3	4	5	6		
	7	8	9	10	11			

Note that the above two examples do not produce the same formatted data cards.

DATA BLOCK A

DESCRIPTION: Title card.

FORMAT AND EXAMPLE

1 2 3 4 5 6 7 8	FORMAT
TITLE	20A4
CANTILEVERED BEAM DESIGN	

FIELD	CONTENTS
1-8	Any 80 character title may be given on this card.

DATA BLOCK B

DESCRIPTION: Program Control Parameters

FORMAT AND EXAMPLE

1	2	3	4	5	6	7		FORMAT
NCALC	NDV	NSV	N2VAR	NXAPRX	IPNPUT	IPDBG		7I10
2	2	3	5	2	0	0		

FIELD CONTENTS

1 NCALC: Calculation Control

0 - Read input and stop. Data of blocks A, B and V is required. Remaining data is optional.

1 - One cycle through program. The same as executing ANALIZ stand-alone. Data of blocks A, B and V is required. Remaining data is optional.

2 - Optimization. Data of blocks A-I and V is required. Remaining data is optional.

3 - Sensitivity analysis. Data of blocks A, B, P, Q and V is required. Remaining data is optional.

4 - Two variable function space. Data of blocks A, B, and R-V is required. Remaining data is optional.

FIELD		CONTENTS
1 - cont.	NCALC:	
	5 -	Optimum Sensitivity. Data of blocks A-I, P, Q, and V is required. Remaining data is optional.
	6 -	Optimization using approximation techniques. Data of blocks A-0 and V is required. Remaining data is optional.
2	NDV:	Number of independent design variables in optimization.
3	NSV:	Number of variables on which sensitivity analysis will be performed.
4	N2VAR:	Number of objective functions in a two variable function space study.
5	NXAPRX:	Number of X-variables for approximate analysis/optimization.
6	IPNPUT:	Input print control.
	0	- Print card images of data plus formatted print of input data.
	1	- Formatted print only of input data.
	2	- No print of input data.
7	IPDBG:	Debug print control.

DATA BLOCK C OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Integer optimization control parameters.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMX1		7I10
5	0	0	0	0	0	0		

FIELD	CONTENTS
1	IPRINT: Print control used in optimization.

0 - No print during optimization.

1 - Print initial and final optimization information.

2 - Print above plus objective function value and design variable values at each iteration.

3 - Print above plus constraint values, direction vector and move parameter at each iteration.

4 - Print above plus gradient information.

5 - Print above plus each proposed design vector, objective function and constraint values during the one-dimensional search.

FIELD		CONTENTS
2	ITMAX:	Maximum number of optimization iterations allowed. DEFAULT = 20.
3	ICNDIR:	Conjugate direction restart parameter. DEFAULT = NDV + 1.
4	NSCAL:	Scaling parameter. GT.0 - Scale design variable to order of magnitude one every NSCAL iterations. LT.0 - Scale design variables according to user-input scaling values. Suggested values are 0 or NDV + 1.
5	ITRM:	Number of consecutive iterations which must satisfy relative or absolute convergence criterion before optimization process is terminated. DEFAULT = 3.
6	LINOBJ:	Linear objective function identifier. If the optimization objective is known to be a linear function of the design variables, set LINOBJ = 1. DEFAULT = Nonlinear.
7	NACMX1:	One plus the maximum number of active constraints anticipated. DEFAULT = NDV + 2. If CONMIN writes an error message that the number of active and violated constraints exceeds N3-1, then NACMX1 must be increased (Note that NACMX1 = N3).

DATA BLOCK D OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Floating point optimization program parameters.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
FDCH	FDCHM	CT	CTMIN	CTL	CTLMIN	THETA		7F10
0.0	0.0	0.0	0.0	0.0	0.0	0.0		
DELFUN	DABFUN	ALPHAX	ABOBJI					4F10
0.0	0.0	0.0	0.0					

NOTE: TWO CARDS ARE READ HERE.

FIELD		CONTENT
1	FDCH:	Relative change in design variables in calculating finite difference gradients. DEFAULT = 0.01.
2	FDCHM:	Minimum absolute step in finite difference gradient calculations. DEFAULT = 0.01.

FIELD		CONTENTS
3	CT:	Constraint thickness parameter. DEFAULT = -0.1.
4	CTMIN:	Minimum absolute value of CT considered in the optimization process. DEFAULT = 0.004.
5	CTL:	Constraint thickness parameter for linear constraints. DEFAULT = -0.01.
6	CTLMIN:	Minimum absolute value of CTL considered in the optimization process. DEFAULT = 0.001.
7	THETA:	Mean value of the push-off factor in the Method of Feasible Directions. DEFAULT = 1.0.
1	DELFUN:	Minimum relative change in objective function to indicate convergence of the optimization process. DEFAULT = 0.001.
2	DABFUN:	Minimum absolute change in objective function to indicate convergence of the optimization process. DEFAULT = 0.001 times the initial objective value.
3	ALPHAX:	Maximum fractional change in any design variable for first estimate of the step in the one-dimensional search. DEFAULT = 0.1.
4	ABOBJI:	Expected fractional change in the objective function for first estimate of the step in the one-dimensional search. DEFAULT = 0.1.

REMARKS:

1) The DEFAULT values for these parameters usually work well.

DATA BLOCK E OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Total number of design variables, design objective identification and sign.

FORMAT AND EXAMPLE

1	2	3		FORMAT
NDVTOT	IOBJ	SGNOPT		2I10,F10
0	3	-1.0		

FIELD		CONTENTS
1	NDVTOT:	Total number of variables linked to the design variables. This option allows two or more parameters to be assigned to a single design variable. The value of each parameter is the value of the design variable times a multiplier, which may be different for each parameter. DEFAULT = NDV.
2	IOBJ:	Global variable location associated with the objective function in optimization.
3	SGNOPT:	Sign used to identify whether function is to be maximized or minimized. +1.0 indicates maximization. -1.0 indicates minimization. If SGNOPT is not unity in magnitude, it acts as a multiplier as well, to scale the magnitude of the objective.

DATA BLOCK F OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Design variable bounds, initial values and scaling factors.

FORMAT AND EXAMPLE

1	2	3	4		FORMAT
VLB	VUB	X	SCAL		4F10
.5	5.	0.0	0.0		

NOTE: READ ONE CARD FOR EACH OF THE NDV INDEPENDENT DESIGN VARIABLES.

FIELD		CONTENTS
1	VLB:	Lower bound on the design variable. If VLB.LT.-1.0E+15, no lower bound.
2	VUB:	Upper bound on the design variable. If VUB.GT.1.0E+15, no upper bound.
3	X:	Initial value of the design variable. If X is non-zero, this will supercede the value initialized by the user-supplied subroutine ANALIZ.
4	SCAL:	Design variable scale factor. Not used if NSCAL.GE.0 in Block C.

DATA BLOCK G OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Design variable identification.

FORMAT AND EXAMPLE

1	2	3		FORMAT
NDSGN	IDSGN	AMULT		2I10,F10
1	1	1.0		

NOTE: READ ONE CARD FOR EACH OF THE NDVTOT DESIGN VARIABLES.

FIELD		CONTENTS
1	NDSGN:	Design variable number associated with this parameter.
2	IDSGN:	Global variable number associated with this parameter.
3	AMULT:	Constant multiplier on this parameter. The value of the parameter will be the value of the design parameter, NDSGN, times AMULT. DEFAULT = 1.0.

DATA BLOCK H OMIT IF NDV = 0 IN BLOCK B

DESCRIPTION: Number of constraint sets.

FORMAT AND EXAMPLE

1		FORMAT
NCONS		I10
4		

FIELD	CONTENTS
1	NCONS: Number of constraint sets in the optimization problem.

REMARKS

1) If two or more adjacent parameters in the global common block have the same limits imposed, these are part of the same constraint set.

DATA BLOCK I OMIT IF NDV = 0 IN BLOCK B, OR NCONS = 0 IN BLOCK H

DESCRIPTION: Constraint identification and constraint bounds.

FORMAT AND EXAMPLE

1	2	3	4		FORMAT
ICON	JCON	LCON			3I10
4	0	0			
BL	SCAL1	BU	SCAL2		4F10
-1.0 +20	0.0	20000.	0.0		

NOTE: READ TWO CARDS FOR EACH OF THE NCONS CONSTRIANT SETS.

FIELD		CONTENTS
1	ICON:	First global number corresponding to the constriant set.
2	JCON:	Last global number corresponding to the constriant set. DEFAULT = ICON.
3	LCON:	Linear constraint identifier for this constraint set. LCON = 1 indicates linear constraints.

FIELD		CONTENTS
1	BL:	Lower bound on the constrained variables. If BL.LT.-1.0E+15, no lower bound.
2	SCAL1:	Normalization factor on lower bound. DEFAULT = MAX of ABS(BL), 0.1.
3	BU:	Upper bound on the constrained variables. If BU.GT.1.0E+15, no upper bound.
4	SCAL2:	Normalization factor on upper bound. DEFAULT = MAX of ABS(BU), 0.1.

REMARKS

1) The normalization factor should usually be defaulted.

2) The constraint functions sent to CONMIN are of the form;

   (BL - 'VALUE)/SCAL1 .LE. 0.0 and (VALUE - BU)/SCAL2 .LE. 0.0.

3) Each constrained parameter is converted to two constraints in CONMIN unless ABS(BL) or ABS(BU) exceeds 1.0E+15, in which case no constraint is created for that bound.

DATA BLOCK J OMIT IF NXAPRX = 0 IN BLOCK B

DESCRIPTION: Approximate analysis/optimization control parameters.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
NG	NXS	NXFS	NXA	INOM	ISCRX	ISCRXF	IPAPRX	8I10
5	1	1	1	0	0	0	1	
KMIN	KMAX	NPMAX	JNOM	INXLOC	INFLOC	MAXTRM		7I10
0	0	0	0	0	0			

FIELD		CONTENTS
1	NF:	Number of functions to be approximated, Default = number of optimization objective and constraint functions.
2	NXS:	Number of X-vectors read as data.
3	NXFS:	Number of X-F pairs read as data.
4	NXA:	If non-zero, the design variables read by SUBROUTINE ANALIZ form an X-vector.
5	INOM:	Nominal X-vector. Default = best available.

FIELD		CONTENTS
6	ISCRX:	File from which NXS X-vectors are read. Default = 5.
7	ISCRXF:	File from which NXFS X-F pairs of data are read. Default = 5.
8	IPAPRX:	Print Control. Values of 0-4 with increasing amounts of print for larger IPAPRX.
1	KMIN:	Minimum number of approximation iterations. Default = 2 * NDV + 1 - NXS - NXFS - NXA.
2	KMAX:	Maximum number of approximation iterations. Default = 3 * NXAPRX + 3 * (NXAPRX + NXAPRX**2)/2 + 1 - NXS - NXFS - NXA.
3	NPMAX:	Maximum number of designs retained for Taylor series expansion.
4	JNOM:	Number of iterations after which the best design is picked as nominal. Default = 2 * NXAPRX + (NXAPRX + NXAPRX**2).
5	INXLOC:	X-variable global location identifier. If INXLOC = 0, the Taylor series expansion is on the design variables listed in BLOCK G.
6	INFLOC:	Function global location identifier. If INFLOC = 0, the objective and constraint functions identified in BLOCKS E AND I are the functions on which the Taylor series expansion in performed.
7	MAXTRM:	Terms retained in Taylor series expansion. 1 - Linear only. 2 - Linear plus diagonal elements of Hessian Matrix. 3 - Full 2nd order expansion. DEFAULT = 3.

REMARKS

1) If ISCRX and/or ISCRXF file number is other than 5, the data read from that file is assumed to be binary data.

2) If NXS = NXFS = 0, NXA is defaulted to NXA = 1, even if it is read as zero. Also, a second vector of design variables is automatically defined by COPES to yield two independent designs to start the optimization.

DATA BLOCK K OMIT IF NXAPRX = 0 IN BLOCK B

DESCRIPTION: Bounds and multipliers for approximate optimization.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
DX1	DX2	DX3	DX4	DX5	...	...	...	8F10
.5	2.							
XFACT1	XFACT2							2F10
0.	0.							

NOTE: TWO OR MORE CARDS ARE READ HERE.

FIELD		CONTENTS
1-8	DXI:	Allowable change (in magnitude) of the Ith design variable during each approximate optimization.
1	XFACT1:	Multiplier on DXI when the diagonal elements of the H matrix are available. Default = 1.5.
2	XFACT2:	Multiplier on DXI when all elements of the H matrix are available.

DATA BLOCK L OMIT IF NXAPRX = 0 IN BLOCK B OR INXLOC = 0 IN BLOCK J

DESCRIPTION: Global locations of approximating variables.

FORMAT AND EXAMPLE:

1	2	3	4	5	6	7	8	FORMAT
LOCX1	LOCX2	LOCX3	LOCX4	.....	......	.....	.....	8I10
1	2							

NOTE: MORE THAN ONE CARD MAY BE READ HERE.

FIELD	CONTENTS
1-8	LOCXI: Global location of Ith approximating variable.

REMARKS

1) If INXLOC = 0 in BLOCK J, this data is not read. In this case, the data is defaulted to be the global locations of the design variables (IDSGN values in BLOCK G).

DATA BLOCK M OMIT IF NXAPRX = 0 IN BLOCK B OR INFLOC = 0 IN BLOCK J

DESCRIPTION: Global locations of functions to be approximated.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
LOCF1	LOCF2	LOCF3	LOCF4	.....	.....	.....	.....	8I10
3	5	6	4					

NOTE: MORE THAN ONE CARD MAY BE READ HERE.

FIELD	CONTENTS
1-8	LOCFI: Global location of Ith function to be approximated.

REMARKS

1) If INFLOC = 0 in BLOCK J, this data is not read. In this case, the data is defaulted to be the global locations of the objective function (IOBJ in BLOCK E) followed by the global locations of the constrained parameters (ICON-JCON in BLOCK I).

DATA BLOCK N OMIT IF NXAPRX = 0 in BLOCK B OR NXS = 0 IN BLOCK J

DESCRIPTION: X-Vectors for approximate optimization.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
XI1	XI2	XI3	XI4	...	...	...	...	8F10
4.	15.							

NOTE: NXS SETS OF DATA ARE READ HERE.

NOTE: MORE THAN ONE CARD MAY BE READ FOR EACH SET OF DATA.

FIELD	CONTENTS
1-8	XIJ: Jth value of Ith X-vector, J = 1, NXAPRX.

DATA BLOCK O OMIT IF NXAPRX = 0 IN BLOCK B OR NXFS = 0 IN BLOCK J

DESCRIPTION: X-F pairs of information for approximate optimization.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
X1	X2	X3	X4	...	...	...	...	8F10
2.	18.							
Y1	Y2	Y3	Y4	Y5	...	...	...	8F10
7200.	416.667	.914495	18518.519					

NOTE: NXFS SETS OF DATA ARE READ HERE.

NOTE: MORE THAN ONE CARD MAY BE REQUIRED FOR XI OR YI.

NOTE: NXAPRX VALUES OF X AND NF VALUES OF Y ARE READ FOR EACH SET OF DATA.

FIELD	CONTENTS
1-8	XI: Ith value of X, I = 1,NXAPRX.
1-8	YI: Ith value of Y, I = 1,NF.

DATA BLOCK P OMIT IF NSV = 0 IN BLOCK B

DESCRIPTION: Sensitivity objectives.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
NSOBJ	IPSENS							2I10
5	0							
NSN1	NSN2	NSN3	NSN4	NSN5	...	...	...	8I10
3	4	5	6	7				

NOTE: TWO OR MORE CARDS ARE READ HERE.

FIELD		CONTENTS
1	NSOBJ:	Number of seperate objective functions to be calculated as functions of the sensitivity variables.
2	IPSENS:	Print control. If IPSENS.GT.0, detailed print will be called at each step in the sensitivity analysis. DEFAULT = No print.
1-8	NSNI:	Global variable number associated with the i-th sensitivity function.

REMARKS

1) More than eight sensitivity objectives are allowed. Add data cards as required to contain data.

DATA BLOCK Q OMIT IF NSV = 0 IN BLOCK B

DESCRIPTION: Sensitivity variables.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
ISENS	NSENS							2I10
9	4							
SNS1	SNS2	SNS3	SNS4	....	....	....	....	8F10
200.	100.	150.	250.					

NOTE: READ ONE SET OF DATA FOR EACH OF THE NSV SENSITIVITY VARIABLES.

NOTE: TWO OR MORE CARDS ARE READ FOR EACH SET OF DATA.

FIELD		CONTENTS
1	ISENS:	Global variable number associated with the sensitivity variable.
2	NSENS:	Number of values of this sensitivity variable to be read on the next card.
1-8	SENSI:	Values of the sensitivity variable. I = 1,NSENS. I = 1 corresponds to the nominal value.

REMARKS

1) More than eight values of the sensitivity variable are allowed. Add data cards as required to contain the data.

DATA BLOCK R OMIT IF N2VAR = 0 IN BLOCK B

DESCRIPTION: Two variable function space control parameters.

FORMAT AND EXAMPLE

1	2	3	4	5		FORMAT
N2VX	M2VX	N2VY	M2VY	IP2VAR		5I10
1	4	2	5	0		

FIELD		CONTENTS
1	N2VX:	Global location of the X-variable in the two variable function space.
2	M2VX:	Number of values of X to be considered.
3	N2VY:	Global location of the Y-variable in the two variable function space.
4	M2VY:	Number of values of Y to be considered.
5	IP2VAR:	Print control. If IP2VAR.GT.0, detailed print will be called at each step (each X-Y combination). DEFAULT = No print.

DATA BLOCK S OMIT IF N2VAR = 0 IN BLOCK B

DESCRIPTION: Functions to be evaluated in the two variable function space study.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
NZ1	NZ2	NZ3	NZ4	NZ5	...	...	...	8I10
3	4	5	6	7				

FIELD		CONTENTS
1-8	NZI:	Global location corresponding to the Ith function of X and Y to be calculated. N2VAR values are read here.

REMARKS

1) More than eight functions are allowed. Add data cards as required to contain the data.

DATA BLOCK T OMIT IF N2VAR = 0 IN BLOCK B

DESCRIPTION: Values of the X-variable in a two variable function space study.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
X1	X2	X3	X4	...	...	...	...	8F10
0.5	1.0	1.5	2.0					

FIELD		CONTENTS
1-8	XI:	Values of the X-variable in the two variable function space. M2VX values are read here.

REMARKS

1) More than eight values are allowed. Add data cards as required to contain the data.

DATA BLOCK U OMIT IF N2VAR = 0 IN BLOCK B

DESCRIPTION: Values of the Y-variable in a two variable function space study.

FORMAT AND EXAMPLE

1	2	3	4	5	6	7	8	FORMAT
Y1	Y2	Y3	Y4	Y5	...	...	...	8F10
4.0	8.0	12.0	16.0	20.0				

FIELD	CONTENTS
1-8	YI: Values of the Y-variable in the two variable function space. M2VY values are read here.

REMARKS

1) More than eight values are allowed. Add data cards as required to contain the data.

DATA BLOCK V

DESCRIPTION: COPES data 'END' card.

FORMAT AND EXAMPLE

1		FORMAT
END		3A1
END		

FIELD	CONTENTS
1	The word 'END' in columns 1-3.

REMARKS

1) This card MUST appear at the end of the COPES data.
2) This ends the COPES input data.
3) Data for the user-supplied routine, ANALIZ, follows this.

VII. SAMPLE COMPUTER SOLUTIONS

Sample solutions are presented here for the various COPES program options defined by the parameter NCALC in DATA BLOCK B. The ANALIZ routine given in the design example section was used to produce the results given here. Note that SUBROUTINE ANALYZ does not read data, so only COPES data is required here. In the usual case where data is read as input to the analysis routine, this data would follow directly after the COPES 'END' card.

The output from a COPES program execution includes a title page followed by a copy of the input data. Then the required program executions are performed and final output information is printed. Figures 2-7 contain output for all options of COPES as follows:

NCALC	FIGURE	PROBLEM SOLVED
1	2	Analysis only
2	3	Optimization by CONMIN
3	4	Sensitivity study
4	5	Two-variable function space study
5	6	Optimum sensitivity
6	7	Optimization using approximation techniques

Note that data for the COPES program is read depending on the value of the parameters NDV, NSV, N2VAR and NXAPRX in DATA BLOCK B. The actual program execution is determined by the value of NCALC. Therefore, data may be read for all program options even though only one option of the program is to be executed. Figure 8 is a copy of the combined data for all the previous examples. This data may be used for any program option simply by changing the value of NCALC. Figure 9 is a copy of this same data using the simplified data input mode and Figure 10 is the same data without the comment cards.

```
CCCCCCC   CCCCCCC   PPPPPPP   EEEEEEE   SSSSSSS
C         C     C   P     P   E         S
C         C     C   P     P   E         S
C         C     C   PPPPPPP   EEEE      SSSSSSS
C         C     C   P         E               S
C         C     C   P         E               S
CCCCCCC   CCCCCCC   P         EEEEEEE   SSSSSSS


              C O N T R O L   P R O G R A M
                          F O R
          E N G I N E E R I N G   S Y N T H E S I S


                        T I T L E
CANTILEVERED BEAM ANALYSIS AND DESIGN


CARD IMAGES OF CONTROL DATA

CARD                        IMAGE

  1)  CANTILEVERED BEAM ANALYSIS AND DESIGN
  2)            1
  3)  END
```

FIG. 2 - ANALYSIS ONLY

```
TITLE:
CANTILEVERED BEAM ANALYSIS AND DESIGN


CONTROL PARAMETERS;
CALCULATION CONTROL,                         NCALC =    1
NUMBER OF GLOBAL DESIGN VARIABLES,             NCV =    0
NUMBER OF SENSITIVITY VARIABLES,               NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,            N2VAR =    0
NUMBER OF APPROXIMATING VAR.                NXAPRX =    0
INPUT INFORMATION PRINT CODE,               IPNPUT =    0
DEBUG PRINT CODE,                            IPDBG =    0


CALCULATION CONTROL, NCALC
VALUE    MEANING
  1      SINGLE ANALYSIS
  2      OPTIMIZATION
  3      SENSITIVITY
  4      TWO-VARIABLE FUNCTION SPACE
  5      OPTIMUM SENSITIVITY
  6      APPROXIMATE OPTIMIZATION


* * ESTIMATED DATA STORAGE REQUIREMENTS

          REAL                                  INTEGER
INPUT  EXECUTION  AVAILABLE        INPUT  EXECUTION  AVAILABLE
  9         9       5000             1         1        1000


CANTILEVERED BEAM

AL       =  200.000
P        = 0.10000E 05
E        = 0.30000E 08

B        =    2.500
H        =   10.000
```

FIG. 2 - CONT.

```
CANTILEVERED BEAM

AL       =  2CC.000
P        = C.10000E 05
E        = 0.3C000E 08

B        =    2.500
H        =   10.000

VCL      = 5000.000

BSTRES   = C.48CC0E 05
SHRSTR   = C.6CCC0E C3
DELTA    = C.42667E 01
F/E      =    4.0C0


PRCGRAM CALLS TO ANALIZ

   ICALC    CALLS
     1        1
     2        1
     3        1
```

FIG. 2 - CONCLD.

```
CCCCCCC   CCCCCCC   PPPPPPP   EEEEEEE   SSSSSSS
C         C     O   P     P   E         S
C         C     O   P     P   E         S
C         C     C   PPPPPPP   EEEE      SSSSSSS
C         C     C   P         E               S
C         C     C   P         E               S
CCCCCCC   COOCOOO   P         EEEEEEE   SSSSSSS


            C O N T R O L   P R O G R A M
                        F O R
       E N G I N E E R I N G   S Y N T H E S I S


                      T I T L E
CANTILEVERED BEAM ANALYSIS AND DESIGN


CARD IMAGES OF CONTROL DATA

CARD                         IMAGE

  1)  CANTILEVERED BEAM ANALYSIS AND DESIGN
  2)  $ DATA BLOCK B
  3)  $    NCALC        NDV
  4)           2           2
  5)  $ DATA BLOCK C - DEFAULT ALL BUT PRINT CONTROL
  6)  $   IPRINT
  7)           1
```

FIG. 3 - OPTIMIZATION

```
 8)  $ DATA BLOCK C - ALL DEFAULTS
 9)  0.
 9)             0.
10)  C.
10)             C.
11)  $ CATA BLCCK E
12)  $   NDVTOT          IOBJ     SGNOPT
13)          0              3       -1.
14)  $ DATA BLOCK F
15)  $  VLB          VUB
16)  $ WICTH, B
17)     .5          5.
18)  $ HEIGHT, H
19)     1.          20.
20)  $ CATA BLCCK G
21)  $     NDSGN       ICSGN       AMULT
22)  $ WICTH, B
23)          1           1         1.
24)  $ HEIGHT, H
25)          2           2         1.
26)  $ DATA BLCCK H
27)  $     NCONS
28)          4
29)  $ CATA BLCCK I
30)  $      ICCN         JCON         LCON
31)  $   BL         SCAL1        BU            SCAL2
32)  $ CCNSTRAINT ON BSTRES
33)          4            0            0
34)  -1.0    +20     0.        200CO.          C.
35)  $ CCNSTRAINT CN SHRSTR
36)          5            0            0
37)  -1.C    +2C     C.        100CO.          0.
38)  $ CCNSTRAINT CN CELTA
39)          6            0            0
40)  -1.0    +20     C.        1.          0.
41)  $ CONSTRAINT ON H/B
42)          7            0            0
43)  -1.C    +20     0.        10.         C.
44)  $ DATA BLOCKS J-L ARE NOT REQUIRED.
45)  $ DATA BLOCK V
46)  $ RECUIREC ENC CARD
47)  END
```

FIG. 3 - CONT.

```
TITLE:
CANTILEVERED BEAM ANALYSIS AND DESIGN


CONTROL PARAMETERS:
CALCULATION CONTROL,                     NCALC =    2
NUMBER OF GLOBAL DESIGN VARIABLES,         NDV =    2
NUMBER OF SENSITIVITY VARIABLES,           NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,        N2VAR =    0
NUMBER OF APPROXIMATING VAR.            NXAPRX =    0
INPUT INFORMATION PRINT CODE,           IPNPUT =    0
DEBUG PRINT CODE,                        IPDBG =    0

CALCULATION CONTROL, NCALC
VALUE    MEANING
  1      SINGLE ANALYSIS
  2      OPTIMIZATION
  3      SENSITIVITY
  4      TWO-VARIABLE FUNCTION SPACE
  5      OPTIMUM SENSITIVITY
  6      APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE                  =    3
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = -0.1000E 01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT   ITMAX    ICNDIR    NSCAL    ITRM    LINOBJ   NACMX1   NFDG
  1        (        0         0        0        0        4       0

 FDCH               FDCHM              CT                 CTMIN
 0.0                0.0                0.0                0.0

 CTL                CTLMIN             THETA              PHI
 0.0                0.C                0.0                C.C

 DELFUN             DABFUN             ALPHAX             ABOBJ1
 0.0                C.C                0.0                0.0
```

FIG. 3 - CONT.

```
DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.        LOWER            UPPER          INITIAL
NO.          BOUND            BOUND           VALUE          SCALE
  1      0.50000E 00     0.50000E 01      0.0            0.0
  2      0.10000E 01     0.20000E 02      0.0            0.0

DESIGN VARIABLES
       D. V.      GLOBAL     MULTIPLYING
ID      NO.      VAR. NO.      FACTOR
 1       1           1       0.10000E 01
 2       2           2       0.10000E 01

CONSTRAINT INFORMATION

THERE ARE  4 CONSTRAINT SETS
       GLOBAL  GLOBAL  LINEAR        LOWER         NORMALIZATION       UPPER        NORMALIZATION
 ID    VAR. 1  VAR. 2    ID          BOUND            FACTOR           BOUND           FACTOR
  1      4       0       0       -0.11000E 16     0.11000E 16     0.20000E 05     0.20000E 05
  2      5       0       0       -0.11000E 16     0.11000E 16     0.10000E 05     0.10000E 05
  3      6       0       0       -0.11000E 16     0.11000E 16     0.10000E 01     0.10000E 01
  4      7       0       0       -0.11000E 16     0.11000E 16     0.10000E 02     0.10000E 02
TOTAL NUMBER OF CONSTRAINED PARAMETERS =    4


* * ESTIMATED DATA STORAGE REQUIREMENTS

            REAL                               INTEGER
INPUT  EXECUTION  AVAILABLE      INPUT  EXECUTION  AVAILABLE
 37       129        5000          21       41        1000


CANTILEVERED BEAM

AL      =   200.000
P       =  0.10000E 05
E       =  0.30000E 08

B       =     2.500
H       =    10.000
```

FIG. 3 - CONT.

```
CANTILEVERED BEAM

AL     =  200.000
P      = 0.10000E 05
E      = 0.30000E 08

B      =    2.500
H      =   10.000

VOL    = 5000.000

BSTRES = 0.48000E 05
SHRSTR = 0.60000E 03
DELTA  = 0.42667E 01
H/B    =    4.000
```

```
* * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                     *
*                   C O N M I N                       *
*                                                     *
*               FORTRAN PROGRAM FOR                   *
*                                                     *
*        CONSTRAINED FUNCTION MINIMIZATION            *
*                                                     *
* * * * * * * * * * * * * * * * * * * * * * * * * * *

INITIAL FUNCTION INFORMATION

OBJ =    0.500000E 04

DECISION VARIABLES (X-VECTOR)
  1)    0.25000E 01  0.10000E 02

CONSTRAINT VALUES (G-VECTOR)
  1)    0.14000E 01 -0.94000E 00  0.32667E 01 -0.60000E 00
```

FIG. 3 - CONT.

```
FINAL OPTIMIZATION INFORMATION

 OBJ =    0.66C938E 04

 DECISION VARIABLES (X-VECTOR)
   1)     0.18179E 01  0.18179E 02

 CONSTRAINT VALUES (G-VECTOR)
   1)   -0.12367E-02 -0.95461E 00 -0.23254E-01 -0.31948E-04

 THERE ARE     2 ACTIVE CONSTRAINTS
 CONSTRAINT NUMBERS ARE
     1    4

 THERE ARE     0 VIOLATED CONSTRAINTS

 THERE ARE     0 ACTIVE SIDE CONSTRAINTS

 TERMINATION CRITERION
      ABS(1-OBJ(I-1)/OBJ(I)) LESS THAN DELFUN FOR  3 ITERATIONS
      ABS(OBJ(I)-OBJ(I-1))   LESS THAN DABFUN FOR  3 ITERATIONS

 NUMBER OF ITERATIONS =    9

 OBJECTIVE FUNCTION WAS EVALUATED          35  TIMES

 CONSTRAINT FUNCTIONS WERE EVALUATED       35  TIMES
```

FIG. 3 - CONT.

```
OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION      3      FUNCTION VALUE 0.66094E 04

DESIGN VARIABLES

          C. V.      GLOBAL        LOWER                          UPPER
    ID     NO.      VAR. NO.       BOUND          VALUE           BOUND
     1      1           1       0.5C0C0E 00    0.18179E C1    0.50000E 01
     2      2           2       0.1C000E C1    0.18179E C2    0.20CC0E C2


DESIGN CONSTRAINTS

           GLOBAL       LOWER                        UPPER
     ID   VAR. NO.      BOUND          VALUE         BOUND
      1       4     -C.11000E 16   0.19975E 05   0.20C0CE 05
      2       5     -0.11000E 16   0.45390E 03   0.10000E 05
      3       6     -0.11000E 16   0.97675E 00   0.10C0CE 01
      4       7     -0.11000E 16   C.99997E 01   0.10000E 02


CANTILEVERED BEAM

AL       =  2CC.C00
P        =  C.10000E 05
E        =  0.3CCC0E 08

B        =    1.818
H        =   18.179

VCL      =  6609.375

BSTRES   =  C.19975E 05
SHRSTR   =  0.4539CE C3
DELTA    =  C.97675E CC
H/B      =   10.0CC


PROGRAM CALLS TO ANALIZ

    ICALC    CALLS
      1        1
      2       36
      3        2
```

FIG. 3 - CONCLUDED

```
CCCCCCC   CCCCCCO   PPPPPPP   EEEEEEE   SSSSSSS
C         O     C   P     P   E         S
C         C     O   P     P   E         S
C         C     C   PPPPPPP   EEEE      SSSSSSS
C         C     O   P         E               S
C         O     C   P         E               S
CCCCCCC   COOOOOO   P         EEEEEEE   SSSSSSS

       C O N T R O L   P R O G R A M
                   F O R
   E N G I N E E R I N G   S Y N T H E S I S


                 T I T L E
   CANTILEVERED BEAM ANALYSIS AND DESIGN
```

FIG. 4 - SENSITIVITY STUDY

CARD IMAGES OF CONTROL DATA

```
CARD                       IMAGE

  1)  CANTILEVERED BEAM ANALYSIS AND DESIGN
  2)  $ DATA BLOCK B
  3)  $     NCALC         NDV         NSV
  4)            3           0           3
  5)  $ DATA BLOCKS C-C ARE NOT REQUIRED
  6)  $ DATA BLOCK P
  7)  $     NSOBJ
  8)            5
  9)  $      NSN1        NSN2        NSN3        NSN4        NSN5
 10)            3           4           5           6           7
 11)  $ DATA BLOCK Q
 12)  $     ISENS       NSENS
 13)  $      SNS1        SNS2        SNS3        SNS4
 14)  $ BEAM LENGTH
 15)            9           4
 16)        200.        100.        150.        250.
 17)  $ BEAM WIDTH
 18)            1           3
 19)          2.        1.5         2.5
 20)  $ BEAM HEIGHT
 21)            2           2
 22)          5.        20.
 23)  $ DATA BLOCKS R-U ARE NOT REQUIRED
 24)  $ DATA BLOCK V
 25)  $ REQUIRED END CARD
 26)  END
```

FIG. 4 - CONT.

```
TITLE:
CANTILEVEREC EEAM ANALYSIS AND DESIGN


CCNTROL PARAMETERS;
CALCULATICN CCNTRCL,                         NCALC =     3
NUMBEF CF GLOBAL CESIGN VARIABLES,             NDV =     0
NUMBER OF SENSITIVITY VARIABLES,               NSV =     3
NUMBER OF FUNCTIONS IN TWO-SPACE,            N2VAR =     0
NUMBER CF APPRCXIMATING VAR.                NXAPRX =     0
INPUT INFORMATICN PRINT CODE,               IPNPLT =     0
DEBUG FRINT CODE,                            IPDBG =     0

CALCULATICN CONTROL, NCALC
VALUE    MEANING
  1      SINGLE ANALYSIS
  2      OPTIMIZATION
  3      SENSITIVITY
  4      TWC-VARIABLE FUNCTION SPACE
  5      OPTIMUM SENSITIVITY
  6      APPRCXIMATE OPTIMIZATION


* * SENSITIVITY INFORMATION

PRINT CCNTRCL,              IPSENS =    C
NUMBER OF SENSITIVITY CBJECTIVES =    5

GLOBAL NUMEERS ASSOCIATED WITH SENSITIVITY OBJECTIVES
    3    4    5    6    7

           GLCBAL     NOMINAL
NUMBER   VARIABLE      VALUE        OFF-NCMINAL VALUES
   1         9      C.20C00E 03   0.1000E 03 C.1500E 03 0.2500E 03
   2         1      C.20C00E 01   0.1500E 01 C.2500E 01
   3         2      0.50C00E 01   0.2000E 02


* * ESTIMATEC CATA STORAGE REQUIREMENTS

            REAL                                 INTEGER
INPUT   EXECUTICN   AVAILABLE        INPUT   EXECUTICN   AVAILABLE
  18        23        50CC             12        12        10CO
```

FIG. 4 - CONT.

```
                    CANTILEVERED BEAM

                    AL      =   200.000
                    P       = 0.10000E 05
                    E       = 0.30000E 08

                    B       =     2.500
                    H       =    10.000


STANDARD SENSITIVITY ANALYSIS RESULTS  (NCALC=3)

TITLE
CANTILEVERED BEAM ANALYSIS AND DESIGN

NUMBER OF SENSITIVITY VARIABLES, NSV          =    3
NUMBER OF SENSITIVITY OBJECTIVES, NSOBJ       =    5

GLOBAL NUMBERS ASSOCIATED WITH SENSITIVITY VARIABLES
    9    1    2

GLOBAL NUMBERS ASSOCIATED WITH SENSITIVITY OBJECTIVES
    3    4    5    6    7


NOMINAL DESIGN INFORMATION

VALUES OF SENSITIVITY VARIABLES
  0.20000E 03  0.20000E 01  0.50000E 01

VALUES OF SENSITIVITY OBJECTIVE FUNCTIONS
  0.20000E 04  0.24000E 06  0.15000E 04  0.42667E 02  0.25000E 01
```

FIG. 4 - CONT.

```
SENSITIVITY ANALYSIS RESULTS

GLOBAL VARIABLE     5

     X                      F(X)

0.1000E 03        0.1000E 04   0.1200E 06   0.1500E 04   0.5333E 01
                  0.2500E 01

0.1500E 03        0.1500E 04   0.1800E 06   0.1500E 04   0.1800E 02
                  0.2500E 01

0.2500E 03        0.2500E 04   0.3000E 06   0.1500E 04   0.8333E 02
                  0.2500E 01

GLOBAL VARIABLE     1

     X                      F(X)

0.1500E 01        0.1500E 04   0.3200E 06   0.2000E 04   0.5689E 02
                  0.3333E 01

0.2500E 01        0.2500E 04   0.1920E 06   0.1200E 04   0.3413E 02
                  0.2000E 01

GLOBAL VARIABLE     2

     X                      F(X)

0.2000E 02        0.8000E 04   0.1500E 05   0.3750E 03   0.6667E 00
                  0.1000E 02


PROGRAM CALLS TO ANALIZ

   ICALC   CALLS
     1       1
     2       7
     3       0
```

FIG. 4 - CONCLUDED

```
CCCCCCC   COOOOOO   PPPPPPP   EEEEEEE   SSSSSSS
C         O     O   P     P   E         S
C         O     O   P     P   E         S
C         O     O   PPPPPPP   EEEE      SSSSSSS
C         O     O   P         E               S
C         O     O   P         E               S
CCCCCCC   OOOOOOO   P         EEEEEEE   SSSSSSS
```

C O N T R O L   P R O G R A M

F O R

E N G I N E E R I N G   S Y N T H E S I S

T I T L E

CANTILEVERED BEAM ANALYSIS AND DESIGN

FIG. 5 - TWO-VARIABLE FUNCTION SPACE STUDY

CARD IMAGES OF CONTROL DATA

```
CARD                      IMAGE

  1)  CANTILEVERED BEAM ANALYSIS AND DESIGN
  2)  $ DATA BLOCK B
  3)  $    NCALC          NDV         NSV       N2VAR
  4)           4            0           0           5
  5)  $ DATA BLOCKS C-Q ARE NOT REQUIRED
  6)  $ DATA BLOCK R
  7)  $      N2VX         M2VX        N2VY        M2VY
  8)           1            4           2           5
  9)  $ DATA BLOCK S
 10)  $      NZ1          NZ2         NZ3         NZ4         NZ5
 11)           3            4           5           6           7
 12)  $ DATA BLOCK T
 13)  $ VALUES OF WIDTH, B
 14)  $  X1         X2         X3         X4
 15)     .5         1.         1.5        2.
 16)  $ DATA BLOCK U
 17)  $ VALUES OF HEIGHT, H
 18)  $  Y1         Y2         Y3         Y4         Y5
 19)     4.         8.         12.        16.        20.
 20)  $ DATA BLOCK V
 21)  $ REQUIRED END CARD
 22)  END
```

FIG. 5 - CONT.

```
TITLE:
CANTILEVERED BEAM ANALYSIS AND DESIGN


CONTROL PARAMETERS:
CALCULATION CONTROL,                          NCALC  =    4
NUMBER OF GLOBAL DESIGN VARIABLES,              NDV  =    0
NUMBER OF SENSITIVITY VARIABLES,                NSV  =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,             N2VAR  =    5
NUMBER OF APPROXIMATING VAR.                 NXAPRX  =    0
INPUT INFORMATION PRINT CODE,                IPNPUT  =    0
DEBUG PRINT CODE,                             IPDBG  =    0


CALCULATION CONTROL, NCALC
VALUE    MEANING
  1      SINGLE ANALYSIS
  2      OPTIMIZATION
  3      SENSITIVITY
  4      TWO-VARIABLE FUNCTION SPACE
  5      OPTIMUM SENSITIVITY
  6      APPROXIMATE OPTIMIZATION


* * TWO-VARIABLE FUNCTION SPACE MAPPING INFORMATION

PRINT CONTROL, IP2VAR =    0

GLOBAL VARIABLE NUMBERS ASSOCIATED WITH F(X,Y), M2VZ
    3    4    5    6    7


GLOBAL VARIABLE NUMBER CORRESPONDING TO X, N2VX =    1

VALUES OF X-VARIABLE
0.5000E 00   0.1000E 01   0.1500E 01   0.2000E 01


GLOBAL VARIABLE NUMBER CORRESPONDING TO Y, N2VY =    2

VALUES OF Y-VARIABLE
0.4000E 01   0.8000E 01   0.1200E 02   0.1600E 02   0.2000E 02

* * ESTIMATED DATA STORAGE REQUIREMENTS

              REAL                                INTEGER
INPUT   EXECUTION   AVAILABLE        INPUT   EXECUTION   AVAILABLE
  18        23        5000              6        6          1000
```

FIG. 5 - CONT.

```
CANTILEVERED BEAM

AL      =   200.000
F       =  0.10000E 05
E       =  0.30000E 08

B       =     2.500
H       =    10.000


TWO-VARIABLE FUNCTION SPACE RESULTS

TITLE
CANTILEVERED BEAM ANALYSIS AND DESIGN


GLOBAL NUMBER ASSOCIATED WITH X-VARIABLE, N2VX =     1

GLOBAL NUMBER ASSOCIATED WITH Y-VARIABLE, N2VY =     2

GLOBAL NUMBERS ASSOCIATED WITH F(X,Y)
     3      4      5      6      7

     X            Y                          F(X,Y)

0.5000E 00   0.4000E 01     0.4000E 03   0.1500E 07   0.7500E 04   0.3333E 03
                            0.8000E 01

             0.8000E 01     0.8000E 03   0.3750E 06   0.3750E 04   0.4167E 02
                            0.1600E 02

             0.1200E 02     0.1200E 04   0.1667E 06   0.2500E 04   0.1235E 02
                            0.2400E 02

             0.1600E 02     0.1600E 04   0.9375E 05   0.1875E 04   0.5208E 01
                            0.3200E 02

             0.2000E 02     0.2000E 04   0.6000E 05   0.1500E 04   0.2667E 01
                            0.4000E 02
```

FIG. 5 - CONT.

X	Y	F(X,Y)			
C.1000E 01	0.2000E 02	C.40C0E 04 0.20C0E 02	0.3000E 05	C.7500E 03	C.1333E 01
	0.1600E 02	0.3200E 04 C.16C0E 02	0.4688E 05	C.9375E 03	0.2604E 01
	0.1200E 02	C.24C0E 04 0.12C0E 02	0.8333E 05	0.1250E C4	C.6173E 01
	C.8000E 01	0.1600E 04 C.8000E 01	0.1875E 06	0.1875E C4	0.2083E 02
	0.4000E 01	0.80C0E 03 0.40C0E 01	C.7500E 06	0.3750E C4	C.1667E 03

X	Y	F(X,Y)			
C.15CCE C1	0.4000E 01	0.12C0E 04 0.2667E 01	0.5000E 06	C.25C0E 04	0.1111E 03
	0.8000E C1	0.24C0E 04 0.5333E 01	0.1250E 06	C.1250E C4	C.1389E 02
	C.1200E 02	0.3600E 04 0.8000E 01	0.5556E C5	C.8333E 03	0.4115E 01
	0.1600E C2	0.4800E 04 C.1067E 02	0.3125E 05	C.6250E 03	0.1736E 01
	C.2000E 02	0.6000E 04 0.1333E 02	C.2000E 05	C.5000E 03	0.8889E C0

FIG. 5 - CONT.

X	Y	F(X,Y)			
C.20C0E C1	0.2000E C2	C.80C0E 04 C.10C0E 02	C.1500E 05	C.3750E C3	0.6667E 0C
	0.1600E 02	0.64C0E 04 0.8000E 01	0.2344E 05	0.4688E C3	C.1302E 01
	0.1200E C2	C.48C0E 04 0.6000E 01	0.4167E 05	C.6250E C3	0.3086E 01
	0.8000E 01	0.32C0E 04 0.4000E 01	0.9375E 05	C.9375E 03	C.1C42E 02
	C.4CCCE C1	0.16C0E 04 C.2000E 01	0.3750E 06	0.1875E 04	0.8333E C2

PRCGRAM CALLS TC ANALIZ

ICALC	CALLS
1	1
2	2C
3	C

FIG. 5 - CONCLUDED

```
CCCCCCC   CCCCCCO   PPPPPPP   EEEEEEE   SSSSSSS
C         C     C   P     P   E         S
C         C     O   P     P   E         S
C         C     C   PPPPPPP   EEEE      SSSSSSS
C         C     O   P         E               S
C         O     O   P         E               S
CCCCCCC   CCOOOOO   P         EEEEEEE   SSSSSSS
```

C O N T R O L   P R O G R A M

F O R

E N G I N E E R I N G   S Y N T H E S I S

T I T L E

CANTILEVERED BEAM ANALYSIS AND DESIGN

FIG. 6 - OPTIMUM SENSITIVITY

```
CARC IMAGES CF CCNTRCL CATA

CARC                       IMAGE

  1)   CANTILEVERED EEAM ANALYSIS AND CESIGN
  2)   $ DATA BLCCK B
  3)   $    NCALC         NDV        NSV
  4)         5              2          3
  5)   $ CATA BLOCK C - DEFAULT ALL BUT PRINT CONTROL
  6)   $   IPRINT
  7)         1
  8)   $ DATA BLOCK C - ALL DEFAULTS
  9)   0.
  9)         0.
 1C)   0.
 1C)         C.
 11)   $ CATA BLOCK E
 12)   $   NDVTOT        IOBJ    SGNCPT
 13)         C             3      -1.
 14)   $ DATA BLOCK F
 15)   $  VLB        VUB
 16)   $ WICTH, B
 17)    .5          5.
 18)   $ HEIGHT, H
 19)    1.          2C.
 20)   $ CATA BLOCK G
 21)   $    NDSGN      ICSGN     AMULT
 22)   $ WICTH, B
 23)         1           1     1.
 24)   $ HEIGHT, H
 25)         2           2     1.
```

FIG. 6 - CONT.

```
$ DATA BLOCK H
$    NCONS
        4
$ DATA BLOCK I
$     ICON        JCON        LCON
$   BL        SCAL1        BU        SCAL2
$ CONSTRAINT ON ESTRES
        4           0           0
-1.0    +20   0.          20000.        0.
$ CONSTRAINT ON SHRSTR
        5           0           0
-1.0    +20   0.          10000.        0.
$ CONSTRAINT ON DELTA
        6           0           0
-1.0    +20   0.          1.        0.
$ CONSTRAINT ON H/B
        7           0           0
-1.0    +20   0.          10.       0.
$ DATA BLOCKS J-O ARE NOT REQUIRED
$ DATA BLOCK P
$    NSOBJ
        7
$      NSN1        NSN2        NSN3        NSN4        NSN5        NSN6        NSN7
        3           4           5           6           7           1           2
$ DATA BLOCK Q
$    ISENS       NSENS
$     SNS1        SNS2        SNS3        SNS4
$ BEAM LENGTH
        9           4
   200.       100.       150.       250.
$ BEAM WIDTH
        1           3
   2.         1.5        2.5
$ BEAM HEIGHT
        2           2
   5.         20.
$ OMIT DATA BLOCKS R-U BECAUSE N2VAR = 0
$ DATA BLOCK V
$ REQUIRED END CARD
END
```

FIG. 6 - CONT.

```
TITLE:
CANTILEVEREC BEAM ANALYSIS AND DESIGN


CCNTROL PARAMETERS:
CALCLLATICN CCNTROL,                        NCALC =     5
NUMBEF CF GLOEAL CESIGN VARIABLES,            NDV =     2
NUMBER OF SENSITIVITY VARIABLES,              NSV =     3
NUMBER CF FLNCTIONS IN TWO-SPACE,           N2VAR =     0
NUMBER CF APPROXIMATING VAR.               NXAPRX =     0
INPLT INFORMATICN PRINT CODE,              IPNPLT =     0
CEBLG PRINT CODE,                           IPDEG =     0

CALCULATICN CCNTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TWC-VARIABLE FLNCTICN SPACE
  5     OPTIMUM SENSITIVITY
  6     APPRCXIMATE CPTIMIZATION


* * CPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER CF OBJECTIVE                 =    3
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION)  = -0.1000E 01

CONMIN PARAMETERS (IF ZERO, CCNMIN DEFAULT WILL OVER-RIDE)

IPRINT  ITMAX   ICNDIR   NSCAL   ITRM   LINOBJ  NACMX1  NFDG
  1       C       0        0       0      0       4       0

 FCCH            FCCHM            CT              CTMIN
 0.0             0.0              0.0             0.0

 CTL             CTLMIN           THETA           PHI
 0.0             0.C              0.0             0.0

 CELFUN          DABFUN           ALPHAX          ABOBJ1
 0.0             0.0              0.0             0.0
```

FIG. 6 - CONT.

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.50000E 00	0.50000E 01	0.0	0.0
2	0.10000E 01	0.20000E 02	0.0	0.0

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	1	0.10000E 01
2	2	2	0.10000E 01

CONSTRAINT INFORMATION

THERE ARE 4 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	4	0	0	-0.11000E 16	0.11000E 16	0.20000E 05	0.20000E 05
2	5	0	0	-0.11000E 16	0.11000E 16	0.10000E 05	0.10000E 05
3	6	0	0	-0.11000E 16	0.11000E 16	0.10000E 01	0.10000E 01
4	7	0	0	-0.11000E 16	0.11000E 16	0.10000E 02	0.10000E 02

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 4

* * SENSITIVITY INFORMATION

PRINT CONTROL, IPSENS = 0
NUMBER OF SENSITIVITY OBJECTIVES = 7

GLOBAL NUMBERS ASSOCIATED WITH SENSITIVITY OBJECTIVES
3 4 5 6 7 1 2

FIG. 6 - CONT.

```
                GLOBAL      NOMINAL
NUMBER        VARIABLE       VALUE          OFF-NOMINAL VALUES
  1               9        C.2CCCOE 03    0.1000E 03 0.1500E 03 C.2500E 03
  2               1        0.20C00E 01    0.1500E 01 0.2500E 01
  3               2        C.5CCCCE 01    0.2000E 02


* * ESTIMATED DATA STORAGE REQUIREMENTS

                REAL                                      INTEGER
INPUT        EXECUTION     AVAILABLE           INPUT     EXECUTION    AVAILABLE
  46            161          5000                34          58          1000



CANTILEVERED BEAM

AL         =   200.000
P          =  C.1CC00E 05
E          =  C.30000E 08

B          =     2.500
H          =    1C.CCC
```

FIG. 6 - CONT.

```
OPTIMUM SENSITIVITY ANALYSIS RESULTS (NCALC=5)

TITLE
CANTILEVERED BEAM ANALYSIS AND DESIGN

NUMBER OF SENSITIVITY VARIABLES, NSV          =    3
NUMBER OF SENSITIVITY OBJECTIVES, NSOBJ       =    7

GLOBAL NUMBERS ASSOCIATED WITH SENSITIVITY VARIABLES
     9    1    2

GLOBAL NUMBERS ASSOCIATED WITH SENSITIVITY OBJECTIVES
     3    4    5    6    7    1    2


NOMINAL DESIGN INFORMATION

VALUES OF SENSITIVITY VARIABLES
  0.20000E 03  0.20000E 01  0.50000E 01

VALUES OF SENSITIVITY OBJECTIVE FUNCTIONS
  0.20000E 04  0.24000E 06  0.15000E 04  0.42667E 02  0.25000E 01
  0.20000E 01  0.50000E 01
```

FIG. 6 - CONT.

```
SENSITIVITY ANALYSIS RESULTS

GLOBAL VARIABLE     9

     X                        F(X)

C.1000E 03       C.2C82E 04   0.1997E 05   C.7205E 03   0.3076E CC
                 0.1CCCE 02   0.1443E 01   0.1443E 02

C.1500E 03       0.4096E 04   0.1594E C5   C.5493E 03   0.6035E CC
                 C.1000E 02   0.1652E 01   C.1652E 02

0.25C0E 03       C.1303E 05   0.1439E 05   0.2878E C3   C.9993E 0C
                 0.7674E 01   0.2606E 01   0.2000E 02

GLCBAL VARIABLE     1

     X                        F(X)

C.15CCE 01       0.6CCCE 04   0.2C00E 05   0.5000E 03   C.8889E 00
                 0.1333E 02   0.1500E 01   C.2000E 02

C.25CCE C1       C.6137E 04   0.1812E 05   C.3687E C3   C.9898E 0C
                 0.6510E 01   0.2500E 01   C.1627E 02

GLCBAL VARIABLE     2

     X                        F(X)

0.2000E 02       0.1C42E 05   0.1151E 05   0.2878E C3   C.5116E 00
                 0.7674E 01   0.2606E 01   C.2000E 02


PRCGRAM CALLS TC ANALIZ
   ICALC   CALLS
     1        1
     2      103
     3        C
```

FIG. 6 - CONCLUDED

```
CCCCCCC   COCCCCC   PPPPPPP   EEEEEEE   SSSSSSS
C         O     O   P     P   E         S
C         C     C   P     P   E         S
C         C     O   PPPPPPP   EEEE      SSSSSSS
C         C     C   P         E               S
C         C     O   P         E               S
CCCCCCC   COCCCCC   P         EEEEEEE   SSSSSSS


           C O N T R O L   P R O G R A M
                       F O R
       E N G I N E E R I N G   S Y N T H E S I S


                     T I T L E
CANTILEVERED BEAM ANALYSIS AND DESIGN

CARD IMAGES OF CONTROL DATA

CARD                       IMAGE

  1)   CANTILEVERED BEAM ANALYSIS AND DESIGN
  2)   $ DATA BLOCK B
  3)   $    NCALC         NDV        NSV      N2VAR     NXAPRX
  4)            6           2          0          0          1
  5)   $ DATA BLOCK C - DEFAULT ALL BUT PRINT CONTROL
  6)   $   IPRINT
  7)            1
  8)   $ DATA BLOCK C - ALL DEFAULTS
  9)   C.
  9)            0.
 10)   0.
 10)            C.
 11)   $ DATA BLOCK E
 12)   $   NDVTOT        IOBJ     SGNOPT
 13)            0           3        -1.
```

FIG. 7 - OPTIMIZATION USING APPROXIMATION TECHNIQUES

```
$ DATA BLOCK F
$   VLB          VUB
$ WIDTH, B
   .5          5.
$ HEIGHT, H
   1.          20.
$ DATA BLOCK G
$      NDSGN        IDSGN        AMULT
$ WIDTH, B
         1            1          1.
$ HEIGHT, H
         2            2          1.
$ DATA BLOCK H
$      NCONS
         4
$ DATA BLOCK I
$        ICON          JCON          LCON
$    BL          SCAL1          BU          SCAL2
$ CONSTRAINT ON BSTRES
         4             0             0
-1.0    +20    0.         20000.          0.
$ CONSTRAINT ON SHRSTR
         5             0             0
-1.0    +20    0.         10000.          0.
$ CONSTRAINT ON DELTA
         6             0             0
-1.0    +20    0.          1.          0.
$ CONSTRAINT ON H/B
         7             0             0
-1.0    +20    0.         10.          0.
$ DATA BLOCK J
$ USE DEFAULTS WHERE POSSIBLE EXCEPT PRINT CONTROL AND CANDIDATE DESIGNS
$          NF          NXS          NSFS          NXA          INCM          ISCRX          ISCRXF          IPAPRX
           0            4             0             0             0             0              0               1
$        KMIN         KMAX         NPMAX         JNCM        INXLCC        INFLCC         MAXTRM
           0            0             0             0             0             0              0
$ DATA BLOCK K
$   DX1          DX2
    .5           2.
$ XFACT1      XFACT2
   0.           0.
$ DATA BLOCK L NOT REQUIRED (INXLOC = 0)
$ DATA BLOCK M NOT REQUIRED (INFLOC = 0)
$ DATA BLOCK N. READ 4 CANDIDATE DESIGNS
$      X1          X2
       1.          15.
       2.          20.
       4.          10.
       3.          12.
$ DATA BLOCK O NOT REQUIRED (NXFS = 0)
$ DATA BLOCKS P-U ARE NOT REQUIRED.
$ DATA BLOCK V
$ REQUIRED END CARD
END
```

FIG. 7 - CONT.

```
TITLE:
CANTILEVERED BEAM ANALYSIS AND DESIGN


CONTROL PARAMETERS:
CALCULATION CONTROL,                      NCALC =    6
NUMBER OF GLOBAL DESIGN VARIABLES,          NDV =    2
NUMBER OF SENSITIVITY VARIABLES,            NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,         N2VAR =    0
NUMBER OF APPROXIMATING VAR.             NXAPRX =    1
INPUT INFORMATION PRINT CODE,            IPNPUT =    0
DEBUG PRINT CODE,                         IPDEG =    0

CALCULATION CONTROL, NCALC
VALUE    MEANING
  1      SINGLE ANALYSIS
  2      OPTIMIZATION
  3      SENSITIVITY
  4      TWO-VARIABLE FUNCTION SPACE
  5      OPTIMUM SENSITIVITY
  6      APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE                 =    3
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = -0.10000E 01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT   ITMAX    ICNDIR    NSCAL    ITRM    LINOBJ   NACMX1   NFDG
  1        C        0         0        0        0        6        0

 FDCH              FDCHM              CT                CTMIN
 0.0               0.C                0.0               0.0

 CTL               CTLMIN             THETA             PHI
 0.0               0.0                0.0               0.0

 DELFUN            DABFUN             ALPHAX            ABOBJ1
 0.0               0.C                0.0               0.0

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.      LOWER            UPPER          INITIAL
NO.        BOUND            BOUND           VALUE            SCALE
 1      0.50000E 00     0.50000E 01      0.0             0.0
 2      0.10000E 01     0.20000E 02      0.0             0.0
```

FIG. 7 - CONT.

```
DESIGN VARIABLES
        D. V.        GLOBAL       MULTIPLYING
ID       NO.       VAR. NO.         FACTOR
 1        1           1          0.10000E 01
 2        2           2          0.10000E 01

CONSTRAINT INFORMATION

THERE ARE  4 CONSTRAINT SETS
        GLOBAL   GLOBAL   LINEAR        LOWER        NORMALIZATION        UPPER        NORMALIZATION
  ID    VAR. 1   VAR. 2     ID          BOUND           FACTOR            BOUND            FACTOR
   1       4        0        0      -0.11000E 16    0.11000E 16      0.20000E 05      0.20000E 05
   2       5        0        0      -0.11000E 16    0.11000E 16      0.10000E 05      0.10000E 05
   3       6        0        0      -0.11000E 16    0.11000E 16      0.10000E 01      0.10000E 01
   4       7        0        0      -0.11000E 16    0.11000E 16      0.10000E 02      0.10000E 02

TOTAL NUMBER OF CONSTRAINED PARAMETERS =     4


* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

NUMBER OF FUNCTIONS APPROXIMATED, NF  =     0
NUMBER OF INPUT X-VECTORS,        NPS =     4
NUMBER OF INPUT X-F PAIRS,       NPFS =     0
X-VECTOR FROM ANALIZ,             NPA =     0
NOMINAL DESIGN,                  INOM =     0
READ UNIT FOR X-VECTORS,        ISCRX =     5
READ UNIT FOR X-F PAIRS,       ISCRXF =     5
PRINT CONTROL,                 IPAPRX =     1

MINIMUM APPROXIMATING CYCLES,    KMIN =     1
MAXIMUM APPROXIMATING CYCLES,    KMAX =    12
MAXIMUM DESIGNS USED IN FIT,    NPMAX =    10
NOMINAL DESIGN PARAMETER,        JNOM =    10
X-LOCATION INPUT PARAMETER,    INXLOC =     0
F-LOCATION INPUT PARAMETER,    INFLOC =     0
TAYLER SERIES I.C. CODE,       MAXTRM =     3


DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.5000E 00  0.2000E 01

MULTIPLIER ON DELX,            XFACT1 =  0.1500E 01
MULTIPLIER ON DELX,            XFACT2 =  0.2000E 01
```

FIG. 7 - CONT.

```
GLOBAL LOCATIONS OF X-VARIABLES
    1    2

GLOBAL LOCATIONS OF FUNCTIONS
    3    4    5    6    7


X-VECTORS INPUT FROM UNIT     5

NUMBER     1        DESIGN     1
C.10C0E C1  C.15CCE C2

NUMBER     2        DESIGN     2
C.2000E C1  C.2000E C2

NUMBER     3        DESIGN     3
C.40CCE C1  0.1000E C2

NUMBER     4        DESIGN     4
0.30CCE C1  C.12CCE C2


* * ESTIMATED DATA STORAGE REQUIREMENTS

            REAL                                INTEGER
INPUT   EXECUTION   AVAILABLE      INPUT   EXECUTION   AVAILABLE
  37       212        5CC0           28        60         1000


CANTILEVERED BEAM

AL      =   2CC.CC0
P       =  C.10CCCE C5
E       =  C.30000E C8

B       =     2.500
H       =    1C.CC0
```

FIG. 7 - CONT.

```
APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION     1 IS THE OBJECTIVE

APPROXIMATING FUNCTIONS ASSOCIATED WITH CONSTRAINTS
    2    3    4    5

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2


BEGIN ITERATION NUMBER     1

NOMINAL DESIGN NUMBER =     2

X-VECTOR
  0.20000E 01  0.20000E 02

FUNCTION VALUES
  0.80000E 04  0.15000E 05  0.37500E 03  0.66667E 00  0.10000E 02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.61480E-01 -0.11224E 01

X-VECTOR
  0.19385E 01  0.18878E 02

APPROXIMATE FUNCTION VALUES
  0.73964E 04  0.19745E 05  0.44117E 03  0.10002E 01  0.99918E 01

PRECISE FUNCTION VALUES
  0.73189E 04  0.17371E 05  0.40990E 03  0.81794E 00  0.97381E 01


BEGIN ITERATION NUMBER     2

NOMINAL DESIGN NUMBER =     5

X-VECTOR
  0.19385E 01  0.18878E 02

FUNCTION VALUES
  0.73189E 04  0.17371E 05  0.40990E 03  0.81794E 00  0.97381E 01
```

FIG. 7 - CONT.

```
RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.21965E-01 -0.13725E 01

X-VECTOR
  0.19605E 01  0.17505E 02

APPROXIMATE FUNCTION VALUES
  0.67872E 04  0.19684E 05  0.43322E 03  0.10001E 01  0.90402E 01

PRECISE FUNCTION VALUES
  0.68637E 04  0.19975E 05  0.43708E 03  0.10143E 01  0.89289E 01


BEGIN ITERATION NUMBER    3

NOMINAL DESIGN NUMBER =    6

X-VECTOR
  0.19605E 01  0.17505E 02

FUNCTION VALUES
  0.68637E 04  0.19975E 05  0.43708E 03  0.10143E 01  0.89289E 01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.10136E 00  0.77502E 00

X-VECTOR
  0.18591E 01  0.18280E 02

APPROXIMATE FUNCTION VALUES
  0.67980E 04  0.19998E 05  0.45218E 03  0.98844E 00  0.10000E 02

PRECISE FUNCTION VALUES
  0.67970E 04  0.19316E 05  0.44137E 03  0.93927E 00  0.98326E 01
```

FIG. 7 - CONT.

```
BEGIN ITERATICN NUMBER    4

NOMINAL DESIGN NUMBER =    7

X-VECTCR
  C.18551E C1  0.18280E 02

FUNCTICN VALUES
  0.67970E 04  0.19316E 05  C.44137E 03  0.93927E 00  C.98326E 01

RESULTS OF APPROXIMATE CPTIMIZATION

CELTA-X VECTOR
 -0.34965E-C1 -C.92469E-01

X-VECTCR
  C.18242E 01  0.18188E 02

APPRCXIMATE FUNCTICN VALUES
  C.66354E C4  C.20001E 05  0.45387E 03  C.98035E 00  C.99933E 01

PRECISE FUNCTION VALUES
  C.66354E C4  0.19887E 05  0.45212E 03  0.97195E 00  C.99704E 01


BEGIN ITERATICN NUMBER    5

NCMINAL CESIGN NUMBER =    8

X-VECTCR
  0.18242E 01  C.18188E 02

FUNCTICN VALUES
  0.66354E C4  0.19887E 05  0.45212E 03  0.97195E 00  C.99704E C1

RESULTS OF APPROXIMATE CPTIMIZATION

DELTA-X VECTOR
 -0.59226E-C2 -C.87478E-02

X-VECTCR
  C.18182E C1  0.18179E 02

APPROXIMATE FUNCTION VALUES
  C.661C7E 04  0.19983E 05  0.45399E 03  0.97747E C0  C.10000E 02

PRECISE FUNCTION VALUES
  C.661C7E C4  0.19971E 05  0.45381E C3  0.97652E 00  C.99981E 01
```

FIG. 7 - CONT.

```
BEGIN ITERATION NUMBER     6

NOMINAL DESIGN NUMBER =     9

X-VECTOR
  0.18182E 01  0.18179E 02

FUNCTION VALUES
  0.66107E 04  0.19971E 05  0.45381E 03  0.97652E 00  0.99981E 01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.15702E-04 -0.10826E-01

X-VECTOR
  0.18182E 01  0.18168E 02

APPROXIMATE FUNCTION VALUES
  0.66067E 04  0.20000E 05  0.45417E 03  0.97861E 00  0.99935E 01

PRECISE FUNCTION VALUES
  0.66067E 04  0.19995E 05  0.45409E 03  0.97828E 00  0.99922E 01


BEGIN ITERATION NUMBER     7

NOMINAL DESIGN NUMBER =    10

X-VECTOR
  0.18182E 01  0.18168E 02

FUNCTION VALUES
  0.66067E 04  0.19995E 05  0.45409E 03  0.97828E 00  0.99922E 01

RESULTS OF APPROXIMATE OPTIMIZATION

OPTIMIZATION HAS PRODUCED AN X-VECTOR WHICH IS THE SAME AS A PREVIOUS DESIGN

DELTA-X VECTOR
  0.0          0.0

X-VECTOR
  0.18182E 01  0.18168E 02
```

FIG. 7 - CONT.

```
THE FOLLOWING DESIGN IS NOT THE APPROXIMATE OPTIMUM

DELTA-X VECTOR
  0.50000E-02  0.20000E-01

X-VECTOR
  0.18232E 01  0.18188E 02

APPROXIMATE FUNCTION VALUES
  0.66321E 04  0.19881E 05  0.45210E 03  0.97124E 00  0.99727E 01

PRECISE FUNCTION VALUES
  0.66321E 04  0.19896E 05  0.45234E 03  0.97238E 00  0.99758E 01


BEGIN ITERATION NUMBER     8

NOMINAL DESIGN NUMBER =   10

X-VECTOR
  0.18182E 01  0.18168E 02

FUNCTION VALUES
  0.66067E 04  0.19995E 05  0.45409E 03  0.97828E 00  0.99922E 01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.0          0.0

X-VECTOR
  0.18182E 01  0.18168E 02

APPROXIMATE FUNCTION VALUES
  0.66067E 04  0.19995E 05  0.45409E 03  0.97828E 00  0.99922E 01

TWO CONSECUTIVE APPROXIMATE OPTIMIZATIONS HAVE PRODUCED THE SAME DESIGN

OPTIMIZATION TERMINATED
```

FIG. 7 - CONT.

```
FINAL RESULT CF APPRCXIMATE OPTIMIZATICN

NOMINAL DESIGN NUMBER =    10

X-VECTOR
   C.18182E C1   0.18168E 02

FUNCTICN VALUES
   0.66C67E 04   0.19995E 05   C.45409E 03   0.97828E 00   C.99922E 01



RESULTS CF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
CANTILEVEFED BEAM ANALYSIS AND DESIGN


GLOBAL LCCATICNS OF X-VARIABLES
    1     2

GLCBAL LCCATICNS CF FUNCTIONS, F(X)
    3     4     5     6     7

APPRCXIMATICN IS BASEC CN   11 DESIGNS

NOMINAL CESIGN IS CESIGN NUMBER   10

VALUES OF X-VARIABLES
   0.1818E C1   C.1817E 02

VALUES CF FUNCTIONS, F(X)
   0.6607E 04   0.2CCCE 05   0.4541E 03   0.9783E 00   0.9992E 01
```

FIG. 7 - CONT.

```
COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER    1 = GLOBAL VARIABLE    3

LINEAR TERMS, DEL F
   0.3633E 04   0.3637E 03

NON-LINEAR TERMS, F, BEGINING WITH DIAGONAL ELEMENT

ROW    1
  -0.6992E 00   0.1999E 03

ROW    2
   0.2882E-01

PARAMETER    2 = GLOBAL VARIABLE    4

LINEAR TERMS, DEL F
  -0.1231E 05  -0.2663E 04

NON-LINEAR TERMS, F, BEGINING WITH DIAGONAL ELEMENT

ROW    1
   0.1481E 05   0.2444E 04

ROW    2
   0.7024E 03

PARAMETER    3 = GLOBAL VARIABLE    5

LINEAR TERMS, DEL F
  -0.2674E 03  -0.3274E 02

NON-LINEAR TERMS, F, BEGINING WITH DIAGONAL ELEMENT

ROW    1
   0.2493E 03   0.3669E 02

ROW    2
   0.8920E 01
```

FIG. 7 - CONT.

```
PARAMETER     4 = GLOBAL VARIABLE     6

LINEAR TERMS, DEL F
  -0.6454E 00  -0.1925E 00

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW     1
   0.1021E 01    0.1589E 00

ROW     2
   0.5775E-01

PARAMETER     5 = GLOBAL VARIABLE     7

LINEAR TERMS, DEL F
  -0.5611E 01    0.4252E 00

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW     1
   0.2661E 01    0.1113E 00

ROW     2
   0.1162E 00
```

FIG. 7 - CONT.

```
OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION     3     FUNCTION VALUE 0.66067E 04

DESIGN VARIABLES

        D. V.     GLOBAL         LOWER                          UPPER
  ID     NO.     VAR. NO.        BOUND          VALUE           BOUND
   1      1          1       0.50000E 00    0.18182E 01    0.50000E 01
   2      2          2       0.10000E 01    0.18168E 02    0.20000E 02


DESIGN CONSTRAINTS

        GLOBAL        LOWER                          UPPER
  ID   VAR. NO.       BOUND          VALUE           BOUND
   1       4     -0.11000E 16   0.19995E 05    0.20000E 05
   2       5     -0.11000E 16   0.45409E 03    0.10000E 05
   3       6     -0.11000E 16   0.97828E 00    0.10000E 01
   4       7     -0.11000E 16   0.99922E 01    0.10000E 02


CANTILEVERED BEAM

AL      =  200.000
P       = 0.10000E 05
E       = 0.30000E 08

B       =    1.818
H       =   18.168

VOL     = 6606.660

BSTRES  = 0.19995E 05
SHRSTR  = 0.45409E 03
DELTA   = 0.97828E 00
H/B     =    9.992

PROGRAM CALLS TO ANALIZ

   ICALC    CALLS
     1        1
     2       11
     3        1
```

FIG. 7 - CONCLUDED

```
CANTILEVERED BEAM ANALYSIS AND DESIGN
$ DATA BLOCK B
$     NCALC         NDV         NSV      N2VAR      NXAPRX
          4           2           3          5           1
$ DATA BLOCK C - DEFAULT ALL BUT PRINT CONTROL
$    IPRINT
          1
$ DATA BLOCK D - ALL DEFAULTS
0.
0.
$ DATA BLOCK E
$    NDVTOT        IOBJ     SGNCPT
          0           3       -1.
$ DATA BLOCK F
$  VLB         VLB
$ WIDTH, B
  .5        5.
$ HEIGHT, H
  1.        20.
$ DATA BLOCK G
$     NDSGN       IDSGN      AMULT
$ WIDTH, B
          1           1      1.
$ HEIGHT, H
          2           2      1.
$ DATA BLOCK H
$     NCONS
          4
$ DATA BLOCK I
$      ICON        JCON       LCON
$   BL        SCAL1        BU         SCAL2
$ CONSTRAINT ON BSTRES
          4           0           0
-1.0    +20     0.        20000.        0.
$ CONSTRAINT ON SHRSTR
          5           0           0
-1.0    +20     0.        10000.        0.
$ CONSTRAINT ON DELTA
          6           0           0
-1.0    +20     0.        1.        0.
$ CONSTRAINT ON H/B
          7           0           0
-1.0    +20     0.        10.       0.
$ DATA BLOCK J
$ USE DEFAULTS WHERE POSSIBLE EXCEPT PRINT CONTROL AND CANDIDATE DESIGNS
$          NF         NXS        NSFS         NXA        INOM       ISCRX      ISCRXF      IPAPRX
            0           4           0           0           0           0           0           1
$        KMIN        KMAX       NPMAX        JNOM      INXLOC      INFLOC      MAXTRM
            0           0           0           0           0           0           0
```

FIG. 8 - COMBINED DATA INPUT

```
$ CATA BLOCK K
$  DX1        DX2
    .5         2.
$ XFACT1     XFACT2
    0.         0.
$ CATA BLOCK L NOT REQUIRED (INXLOC = 0)
$ CATA BLCCK M NCT REQUIRED (INFLOC = 0)
$ DATA BLOCK N. READ 4 CANDIDATE DESIGNS
$     X1          X2
      1.          15.
      2.          20.
      4.          10.
      3.          12.
$ CATA BLCCK O NOT REQUIREC (NXFS = 0)
$ DATA BLCCK P
$     NSOBJ
          5
$      NSN1        NSN2        NSN3        NSN4        NSN5
          3           4           5           6           7
$ CATA BLCCK G
$     ISENS       NSENS
$      SNS1        SNS2        SNS3        SNS4
$ BEAM LENGTH
          5           4
    200.        100.        150.        250.
$ BEAM WIDTH
          1           3
      2.        1.5         2.5
$ BEAM HEIGHT
          2           2
      5.        20.
$ CATA BLCCK R
$      N2VX        M2VX        N2VY        M2VY
          1           4           2           5
$ CATA BLOCK S
$       NZ1         NZ2         NZ3         NZ4         NZ5
          3           4           5           6           7
$ DATA BLOCK T
$ VALUES CF WIDTH, B
$  X1         X2          X3          X4
   .5         1.          1.5         2.
$ CATA BLOCK U
$ VALUES OF HEIGHT, H
$  Y1         Y2          Y3          Y4          Y5
   4.         8.          12.         16.         20.
$ CATA BLOCK V
$ RECUIREC ENC CARC
END
```

FIG. 8 - CONCLUDED

```
CANTILEVERED BEAM ANALYSIS AND DESIGN
$ DATA BLOCK B
$     NCALC        NDV        NSV      N2VAR     NXAPRX
6,2,3,5,1
$ DATA BLOCK C - DEFAULT ALL BUT PRINT CONTROL
$    IPRINT
1
$ DATA BLOCK D - ALL DEFAULTS
0.
0.
$ DATA BLOCK E
$    NDVTOT       IOBJ     SGNOPT
0,3,-1.
$ DATA BLOCK F
$   VLB        VUB
$ WIDTH, B
.5,5.
$ HEIGHT, H
1.,20.
$ DATA BLOCK G
$     NDSGN      IDSGN      AMULT
$ WIDTH, B
1,1,1.
$ HEIGHT, H
2,2,1.
$ DATA BLOCK H
$     NCONS
4
$ DATA BLOCK I
$      ICON        JCON        LCON
$    BL       SCAL1        BU          SCAL2
$ CONSTRAINT ON BSTRES
4
-1.0+20,0.,20000.
$ CONSTRAINT ON SHRSTR
5
-1.0+20,0.,10000.
$ CONSTRAINT ON DELTA
6
-1.0+20,0.,10.
$ CONSTRAINT ON H/B
7
-1.0+20,0.,10.
$ DATA BLOCK J
$ USE DEFAULTS WHERE POSSIBLE EXCEPT PRINT CONTROL AND CANDIDATE DESIGNS
$        NF        NXS        NSFS         NXA        INOM       ISCRX      ISCRXF      IPAPRX
0,4,,,,,,1
$      KMIN       KMAX       NFMAX        JNOM      INXLOC      INFLOC      MAXTFM
0
```

FIG. 9 - SIMPLIFIED DATA INPUT

```
$ CATA BLCCK K
$  DX1          CX2
.5,2.
$ XFACT1     XFACT2
0.
$ CATA BLCCK L NOT REQUIREC (INXLOC = 0)

$ CATA BLOCK M NCT REQUIREC (INFLOC = 0)
$ DATA BLOCK N. READ 4 CANDIDATE DESIGNS
$     X1          X2
1.,15.
2.,20.
4.,10.
3.,12.
$ DATA BLCCK O NOT REQUIRED (NXFS = C)
$ CATA BLCCK P
$     NSOBJ
5
$       NSN1        NSN2        NSN3        NSN4        NSN5
3,4,5,6,7
$ DATA BLOCK Q
$      ISENS       NSENS
$       SNS1        SNS2        SNS3        SNS4
$ BEAM LENGTH
9,4
200.,100.,150.,250.
$ BEAM WICTH
1,3
2.,1.5,2.5
$ BEAM HEIGHT
2,2
5.,20.
$ CATA BLOCK R
$       N2VX        M2VX        N2VY        M2VY
1,4,2,5
$ CATA BLCCK S
$         NZ1         NZ2         NZ3         NZ4         NZ5
3,4,5,6,7
$ CATA BLCCK T
$ VALUES CF WICTH, B
$  X1           X2          X3          X4
.5,1.,1.5,2.
$ DATA BLCCK U
$ VALUES OF HEIGHT, H
$  Y1           Y2          Y3          Y4          Y5
4.,8.,12.,16.,20.
$ CATA BLCCK V
$ REQUIREC END CARD
END
```

FIG. 9 - CONCLUDED

```
CANTILEVERED BEAM ANALYSIS AND DESIGN
6,2,3,5,1
1
0.
0.
0,3,-1.
.5,5.
1.,20.
1,1,1.
2,2,1.
4
4
-1.0+20,0.,20000.
5
-1.0+20,0.,10000.
6
-1.0+20,0.,10.
7
-1.0+20,0.,10.
0,4,,,,,,1
0
.5,2.
0.
1.,15.
2.,20.
4.,10.
3.,12.
5
3,4,5,6,7
9,4
200.,100.,150.,250.
1,3
2.,1.5,2.5
2,2
5.,20.
1,4,2,5
3,4,5,6,7
.5,1.,1.5,2.
4.,8.,12.,16.,20.
END
```

FIG. 10 - SIMPLIFIED DATA INPUT WITHOUT COMMENT CARDS

VIII. REFERENCES

1. Vanderplaats, G. N., CONMIN - A Fortran Program for Constrained Function Minimization. User's Manual. NASA Technical Memorandum TMX-62282. Ames Research Center, August, 1973.

2. Vanderplaats, G. N., Approximation Concepts for Numerical Airfoil Design, NASA Technical Paper 1370, Ames Research Center, March, 1979.

3. Schmit, L. A., "Structural Design by Systematic Synthesis," Proc. 2nd Conference on Electronic Computation, ASCE, New York, 1960, pp. 105-122.

APPENDIX A

GLOBAL CATALOG FORMS

GLOBAL CATALOG

GLOBAL LOCATION	FORTRAN NAME	DEFINITION

APPENDIX B

COPES DATA FORMS

COPES DATA

DATA BLOCK A

	TITLE	FORMAT
*		20A4

DATA BLOCK B

+	$								COMMENT
	NCALC	NDV	NSV	N2VAR	NXAPRX	IPNPUT	IPDBG		FORMAT
*									7I10

DATA BLOCK C - OMIT IF NDV = 0

+	$								COMMENT
	IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMX1	NFDG	FORMAT
*									8I10

COPES DATA

DATA BLOCK D - OMIT IF NDV = 0

+	$								COMMENT
	FDCH	FDCHM	CT	CTMIN	CTL	CTLMIN	THETA		FORMAT
*									7F10
	DELFUN	DABFUN	ALPHAX	ABOBJ1					FORMAT
*									4F10
*									

DATA BLOCK E - OMIT IF NDV = 0

+	$				COMMENT
	NDVTOT	IOBJ	SGNOBJ		FORMAT
*					2I10,F10

DATA BLOCK F - OMIT IF NDV = 0

+	$					COMMENT
	VLB	VUB	X	SCAL		FORMAT
*						4F10

<u>COPES DATA</u>

DATA BLOCK F - CONT.

COPES DATA

DATA BLOCK G - OMIT IF NDV = 0

+	$				COMMENT
	NDSGN	IDSGN	AMULT		FORMAT
*					2I10,F10

COPES DATA

DATA BLOCK H - OMIT IF NDV = 0

+	$				COMMENT
	NCONS				FORMAT
*					I10

DATA BLOCK I - OMIT IF NDV = 0 OR NCONS = 0

+	$					COMMENT
	ICON	JCON	LCON			FORMAT
*						3I10
+	$					COMMENT
	BL	SCAL1	BU	SCAL2		FORMAT
*						4F10
	$					
	ICON	JCON	LCON			

COPES DATA

DATA BLOCK I - CONT.

$					
BL	SCAL1	BU	SCAL2		
$					
ICON	JCON	LCON			
$					
BL	SCAL1	BU	SCAL2		
$					
ICON	JCON	LCON			
$					
BL	SCAL1	BU	SCAL2		

COPES DATA

DATA BLOCK J - OMIT IF NXAPRX = 0

+	$								COMMENT
	NF	NXS	NXFS	NXA	INOM	ISCRX	ISCRXF	IPAPRX	FORMAT
*									8I10
	KMIN	KMAX	NPMAX	JNOM	INXLOC	INFLOC	MAXTRM		FORMAT
*									7I10

DATA BLOCK K - OMIT IF NXAPRX = 0

+	$								COMMENT
	DX1	DX2	DX3	DX4	DX5	DX6	DX7	DX8	FORMAT
*									8F10
*									8F10
	XFACT1	XFACT2							FORMAT
*									2F10

COPES DATA

DATA BLOCK L - OMIT IF NXAPRX = 0 OR INXLOC = 0

+	$								COMMENT
	LOCX1	LOCX2	LOCX3	LOCX4	LOCX5	LOCX6	LOCX7	LOCX8	FORMAT
*									8I10
*									8I10

DATA BLOCK M - OMIT IF NXAPRX = 0 OR INFLOC = 0

+	$								COMMENT
	LOCF1	LOCF2	LOCF3	LOCF4	LOCF5	LOCF6	LOCF7	LOCF8	FORMAT
*									8I10
*									8I10

COPES DATA

DATA BLOCK N - OMIT IF NXS = 0

+	$								COMMENT
	XI1	XI2	XI3	XI4	XI5	XI6	XI7	XI8	FORMAT
*									8F10
*									8F10
	$								COMMENT
	XI1	XI2	XI3	XI4	XI5	XI6	XI7	XI8	FORMAT
									8F10
									8F10
	$								COMMENT
	XI1	XI2	XI3	XI4	XI5	XI6	XI7	XI8	FORMAT
									8F10
									8F10
	$								COMMENT
	XI1	XI2	XI3	XI4	XI5	XI6	XI7	XI8	FORMAT
									8F10
									8F10

COPES DATA

DATA BLOCK O - OMIT IF NXFS = 0

+	$								COMMENT
	X1	X2	X3	X4	X5	X6	X7	X8	FORMAT
*									8F10
									8F10
	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	FORMAT
*									8F10
									8F10
	$								COMMENT
	X1	X2	X3	X4	X5	X6	X7	X8	FORMAT
									8F10
									8F10
	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	FORMAT
									8F10
									8F10

COPES DATA

DATA BLOCK P - OMIT IF NSV = 0

+	$								COMMENT
	NSOBJ	IPSENS							FORMAT
*									2I10
+	$								COMMENT
	NSN1	NSN2	NSN3	NSN4	NSN5	NSN6	NSN7	NSN8	FORMAT
*									8I10

COPES DATA

DATA BLOCK Q - OMIT IF NSV = 0

+	$								COMMENT
	ISENS	NSENS							FORMAT
*									2I10
+	$								COMMENT
	SNS1	SNS2	SNS3	SNS4	SNS5	SNS6	SNS7	SNS8	FORMAT
*									8F10

+	$								COMMENT
	ISENS	NSENS							FORMAT
*									2I10
+	$								COMMENT
	SNS1	SNS2	SNS3	SNS4	SNS5	SNS6	SNS7	SNS8	FORMAT
*									8F10

COPES DATA

DATA BLOCK Q - CONT.

+	$								COMMENT
	ISENS	NSNES							FORMAT
*									2I10
+	$								COMMENT
	SNS1	SNS2	SNS3	SNS4	SNS5	SNS6	SNS7	SNS8	FORMAT
*									8F10

DATA BLOCK R - OMIT IF N2VAR = 0

+	$					COMMENT
	N2VX	M2VX	N2VY	M2VY		FORMAT
*						4I10

COPES DATA

DATA BLOCK S - OMIT IF N2VAR = 0

+	$								COMMENT
	NZ1	NZ2	NZ3	NZ4	NZ5	NZ6	NZ7	NZ8	FORMAT
*									8I10

DATA BLOCK T - OMIT IF N2VAR = 0

+	$								COMMENT
	X1	X2	X3	X4	X5	X6	X7	X8	FORMAT
*									8F10

COPES DATA

DATA BLOCK U - OMIT IF N2VAR = 0

+	$								COMMENT
	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	FORMAT
*									8F10

DATA BLOCK V - COPES END OF DATA CARD

	END		FORMAT
*	END		3A1

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