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A C C E S S - 1

Approximation Concepts Code for Efficient Structural Synthesis

PROGRAM DOCUMENTATION and USER'S GUIDE

by Hirokazu Miura and Lucien A. Schmit, Jr.

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16. Abstract

This report serves as program documentation and user's guide for the ACCESS-1 computer program. ACCESS-1 is a research oriented program which implements a collection of approximation concepts to achieve excellent efficiency in structural synthesis. The finite element method is used for structural analysis and general mathematical programming algorithms are applied in the design optimization procedure.

Implementation of the computer program, preparation of input data and basic program structure are described, and three illustrative examples are given. This report together with Ref. 1 (NASA CR-2552) and the computer program give a complete account of the ACCESS-1 program.

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SUMMARY

This report presents information that is required for use of the ACCESS-1 computer program. ACCESS-1 is a research-oriented computer program designed to test the actual performance of various new concepts and techniques in structural synthesis. The historical and technical background of this program is described in detail in Refs. 1 and 2, together with a number of well documented numerical examples.

The current version has three types of finite elements, namely, truss elements (TRUSS), isotropic constant strain triangular membrane elements (CST), and isotropic symmetric shear panel elements (SSP). Structural weight will be minimized by modifying the sizes of these elements--cross sectional areas of TRUSS elements, and thicknesses of CST and SSP elements. Design constraints may be imposed on nodal displacements, tensile and/or compressive stresses in TRUSS elements, von Mises combined stresses in CST and SSP elements, together with the minimum and maximum bounds on cross sectional areas of TRUSS elements and on thicknesses of CST and SSP elements.

There are two distinct general optimization programs which can be used in ACCESS-1. One is CONMIN (Ref. 3) which applies a modified method of feasible directions and the other is NEWSUMT which implements a sequence of unconstrained minimization technique (SUMT), using a modified Newton's method (Ref. 4) for the unconstrained minimizations.

ACCESS-1 is an all in-core program and all routines are written in standard FORTRAN IV language. No advanced coding techniques are

used, thus engineers with basic programming experiences can modify or restructure the program for their own purposes. Consequently, one may make the best use of ACCESS-1 as a research tool to test or demonstrate new ideas or techniques through example problems of modest size. For example, the basic version of this program declares array sizes to accommodate problems having up to 210 elements, 70 nodes and 2 load conditions.

ACCESS-1

Approximation Concepts Code for Efficient Structural Synthesis
Program Documentation and User's Guide

1. Introduction

The ACCESS-1 computer program was developed to demonstrate the effectiveness of a structural synthesis capability formed by combining finite element analysis techniques and mathematical programming algorithms using an innovative collection of approximation concepts. Three types of finite elements are available: namely, truss elements of uniform cross sectional areas (TRUSS), isotropic constant strain triangular membrane elements of uniform thicknesses (CST) and isotropic symmetric shear panel elements of uniform thicknesses (SSP). Structures with prescribed configuration and material constants are optimized so that their structural weight is minimized by modifying the sizing of finite elements, i.e., cross sectional areas of TRUSS elements, thicknesses of CST and SSP elements. Design constraints may be imposed on all or selected nodal displacements, tensile and/or compressive stresses in TRUSS elements, von Mises combined stresses in CST and SSP elements, together with the minimum and maximum bounds on element sizing variables.

The fundamental structure of the ACCESS-1 program is illustrated in Fig. 1. Upon activation, the preprocessor reads input data and completes data processing which is not affected by changes of design variables (i.e., element sizes), and the results are stored in a convenient form for future retrieval. The design process control block (DPC) supervises the design iteration procedure as follows. The given initial design data is transferred to the approximate problem generator. which performs a complete finite element structural analysis, constraint function calculation, as well as constraint deletion and sensitivity analysis of retained constraints. Values of retained constraints and their sensitivity data together with the closed form description of the weight function complete the approximate problem statement which will be transferred to the optimization algorithm (OA) block through DPC. OA will improve the design using one of the well established constrained function minimization algorithms to operate on the current approximate problem statement. An improved design is proposed to DPC and the data for structural analysis is updated based on this new proposal. This step completes one stage of the design iteration procedure. The iterative process is then continued until at least one of the termination criteria is satisfied.

Note two important features here. First, the conventional finite element method of structural analysis is divided into two parts: i.e., the preprocessor and a part of the APG block. It is desirable to include as much data processing as possible in the preprocessor. Second, the optimization algorithm is asked to improve the design with respect to the explicit but approximate problem statement, which may or may not be linear. Hence the program used in the OA block may be completely independent of structural problems and practically any inequality constrained function minimization algorithm can be used.

Currently there are two distinct general optimization program options available in ACCESS-1. One is CONMIN (Ref. 3) which applies a modified method of feasible directions and the other is NEWSUMT which implements a sequence of unconstrained minimizations technique using a modified Newton's method (Ref. 4) for the unconstrained minimizations. Corresponding to each optimizer, a distinct main program and interface subroutines are supplied. The structure and program configuration of these two versions are shown in Figs. 2 and 3. Minor differences between these two versions (especially in the DPC block) are attributed to the fact that the NEWSUMT optimizer includes certain functions associated with the DPC block as well as those of the OA block.

All routines are written in standard FORTRAN IV language and they have been tested on: (a) the IBM 360/91 using the FORTRAN-H and WATFIV compilers at UCLA: and (b) the CDC 6600 using the FTNX compiler at UC Berkeley via a remote batch terminal located at the NASA Ames Research Center. Implementation on other types of computers will be straightforward provided those computers have the required main memory capacity. The efficiency of ACCESS-1 when applied to relatively large scale problems could be improved by using advanced coding techniques. However, in its present form, it should be possible for anyone with basic practical programming experience in FORTRAN to understand and, if necessary, to restructure or modify any of the subroutines with relative ease. If new ideas or techniques are to be tested, it usually takes a considerable amount of time and effort to develop a new computer program. Experiences show that ACCESS-1 may be used conveniently as the base program for the purpose of such experiments. An example of minor program modification is given in Appendix E, where a method to replace SSP elements with conventional symmetric pure shear elements is described.

The ACCESS-2 program, currently being developed, will handle significantly larger problems than ACCESS-1, with more involved constraints (e.g. thermal effects, fiber composite materials, and natural frequency constraints). The ACCESS-2 program makes effective use of dynamic array allocation and auxilliary data storage, hence it can solve larger problems than ACCESS-1 using less main memory capacity. On the other hand, program modifications of ACCESS-2 will require more careful coding and data restructuring.

2. Program Implementation

Both the CONMIN and NEWSUMT versions of ACCESS-1 may be executed as a stand-alone program. All routines are written in standard FORTRAN IV language and use only ANS FORTRAN intrinsic functions. In additon, if a CPU timing function is available on the user's installation, useful CPU time data at the end of each stage and also at the end of a job will be printed by replacing the dummy routines CPUTIM and CTIME with appropriate ones. Examples of these routines are given in Appendix A for the IBM 360/91 at UCLA, the CDC 6600 at UC Berkeley and the IBM 360/67 at the NASA Ames Research Center.

The declared array sizes of the basic version are determined to accommodate problems with 70 elements of each type, 70 nodes, 2 load conditions and 40 design variables. If desired, the number of elements may be increased by using the space allocated to the subsequent element types, where the element type sequence is TRUSS, CST and SSP. In other words, 210 truss elements may be used, provided neither CST nor SSP elements are used, or 140 CST elements may be used, if no SSP elements are used. To accommodate problems which exceed these capacities, array sizes declared in the program must be modified accordingly.

If program overlay is not used, the basic NEWSUMT and CONMIN versions may require as much as 323 K bytes and 366 K bytes of main memory on IBM 360/91 at UCLA, respectively. On CDC 6600 computers at NASA Langley Research Center, the NEWSUMT version requires 220_8K words. When program overlay is implemented as given in Figs. 4 and 5, the main memory requirements on IBM 360/91 is reduced to 270 K bytes for both versions. Program overlay won't be so effective on CDC 6600 computers, because the proportion of program instructions in the main memory requirement is much smaller than IBM 360 series computers.

Depending on the problem and/or the choice of parameters, the declared capacity of certain arrays may be exceeded; in such cases, processing will be terminated automatically, and appropriate messages will be printed out.

3. Program Organization

Implementation of the basic procedure outlined in Fig. 1 is carried out as indicated in Figs. 2 and 3. Primary functions of all subroutines are listed in Table 1, and this facilitates understanding of Figs. 2 and 3. Furthermore, all key subroutines contain enough comment cards so that the computer program listings also serve as a part of the program documentation.

Data transfer between the subroutines is carried out primarily through labeled COMMON blocks. Labeled COMMON blocks appearing in each subroutine or function are summarized in Table 2. In case it is necessary to modify the array sizes, care should be taken to modify all associated array declaration statements. In additon, argument lists of the statements to call the following subroutines must be modified.

SADM05 SAD007 SAD008 SADMM8

Some users may wish to improve array allocation efficiency. This could be accomplished by allocating a few large arrays dynamically. For this purpose the following arrays are suggested as likely candidates:

DG: gradient of retained constraints

AK: master stiffness matrix

DU: gradient of displacement degrees of freedom

Note that the selective inverse matrix of AK shares the same memory position with DG.

Currently, two control parameters IDG and IOPT are not utilized for their intended purposes. Therefore, they may be used to provide additional control capability in modifying this program.

A useful example is given in Appendix D, where creation of an option to replace SSP elements with pure shear elements by modifying a part of the program is discussed. This example is shown to encourage users of this program to modify it, if required, to test new features. Another option which is already implemented in the base versions use IDG = 5 to remove regionalization of stress constraints. If IDC = 5 is specified in the input data, stress constraints are imposed on all stress-constrained elements. (see Sec. 4.4)

4. Structural Model and Input Data Preparation

It is assumed that the reader is familiar with elastic structural analysis via the finite element displacement method, and also with associated structural modelling techniques and typical data preparation procedure. Sufficient information in preparing the input data cards is given in Appendix B, therefore explanations given in this section are limited to the subjects which require somewhat detailed technical discussion to avoid possible misunderstandings.

4.1 Node/Element Numbering Scheme

The solution of linear simultaneous equations is obtained by a sequence of calls for SAD007 and SAD008. The coefficient matrix (= master stiffness matrix) is stored in a vector form within the skyline of the non-zero elements; i.e., there are no operations or no storage allocations with elements that remain zero during the solution (see Fig. 6 of Ref. 1). The coefficient matrix is decomposed to LDL^T form by SAD007 and back and forward substitutions are then carried out by SAD008. The decomposed matrix DL^T is overwritten in the memory area where the stiffness matrix is originally formed. The elements of pointer vector IIK indicate the positions of the diagonal elements for the matrix stored in a vector form. This scheme allows somewhat more flexible node/element numbering arrangement than the ordinary band equation solver. It is better, however, to take the same care in preparing data as for banded matrix solution scheme; i.e., differences among node numbers associated with an element must be kept as small as possible for all elements.

4.2 Symmetric Wing Model

If the webs of a symmetric wing are modelled with SSP elements, only an upper (or a lower) half of the wing is modelled and x,y displacements and loadings are anti-symmetric with respect to the x-y plane. Displacements and loadings in the z direction are identical for both sides of the x-y plane. For example, if a cantilever beam such as that shown in Fig. 6(a) is to be modelled using two SSP elements, then the simplified model should be that shown in Fig. 6(b). Note that only half of the loads must be applied to the node 3, since the other half is implicitly applied to the conjugate node 3' (which does not exist explicitly in the model). The neutral plane coincides with the x-y plane and SSP elements are always vertical to the x-y plane. The example 1 given in Appendix C will be helpful in understanding this feature.

4.3 Two and Three Dimensional Structures

ACCESS-1 treats planar (two dimensional) and spatial (three dimensional) structures separately. If a structure is declared to be planar by specifying ID = 2, the structure lies on the x-y plane and the displacements in the z direction are automatically suppressed. In planar structures, nodes whose x and y displacement degrees of freedom are free should not be classified as boundary nodes.

4.4 Design Variable Linking

General concept of design variable linking is discussed in Sec. 2.3.1 of Ref. 1. In ACCESS 1, if the sizes of some group of finite elements of the same type are controlled by a single design variable, these elements are defined to belong to the same linking group. Sizes of the elements in a linking group are modified in proportion to the initial sizes given in the input data.

Also design variable linking groups are used to define "regions" for the regionalization of stress constraints. General idea of regionalization is given in Sec. 2.4.1 of Ref. 1. Elements which belong to the same design variable linking group form a region and only one stress constraint per group and per load condition is considered for each group in any stage of the iterative design procedure. Selection of the representative elements is not rigidly fixed, but dynamically updated at the beginning of each stage. If the location of critical stress shifts frequently within a region between two consecutive stages, iteration process may be unstable, although this type of instability was not observed in solving any of the problems given in Ref. 1. However, if the user desires to remove the regionalization of stress constraints, specify IDG = 5. Otherwise IDG = 0.

4.5 Configuration/Material Group

If there are a number of elements of the same type having identical configuration and material properties, then these elements belong to the same configuration/material group. For example, the single-material planar-truss structure shown in Fig. 7 has only two configuration/material groups. Configuration/material grouping is used to achieve a reasonable compromise between limitations on main memory space and the desire for efficient run times. The element stiffness matrices in the local coordinate system for unit design variable value are identical for all elements in the same configuration/material group. It is interesting to note that the local stiffness matrices of CST elements are independent of absolute edge lengths and only dependent on shape.

4.6 Computation of Constraints and Control Parameters

All constraints are normalized so that the constraint function assumes the values between 0.0 and -1.0, approximately.

Stress Constraints

$$0.5\ (\sigma-\sigma_a^{(U)})/(\sigma_a^{(U)}-\sigma_a^{(L)}) \leq 0$$

$$0.5(\sigma_a^{(L)}-\sigma)/(\sigma_a^{(U)}-\sigma_a^{(L)}) \leq 0$$

Displacement Constraints

$$0.5(\delta-\delta_a^{(U)})/(\delta_a^{(U)}-\delta_a^{(L)}) \leq 0$$

$$0.5(\delta_a^{(L)}-\delta)/(\delta_a^{(U)}-\delta_a^{(L)}) \leq 0$$

Side Constraints

$$1.0 - D^{(U)}/D \leq 0$$

$$D^{(L)}/D - 1.0 \leq 0$$

σ : computed stress

δ : computed displacement

σ_a : allowable stress

δ_a : allowable displacement

D : sizing variable

(U) : upper limit

(L) : lower limit

As explained in the following section, optimization will be carried out in the linked reciprocal variable space. Therefore, for statically determinate structures, all constraints shown above are linear in this space, including side constraints.

In the preprocessor (SETCON), all constraints are identified and after deleting strictly redundant side constraints, they are enumerated and associated pointer vectors to characterize them are prepared. After structural analysis in the APG block, all constraint values are evaluated. Due to constraint regionalization and truncation based on the computed constraint values, a significant part of constraints are truncated from further consideration during the particular design stage. Then sensitivity of these retained small set of constraints are computed with respect to the linked reciprocal variables.

•JSIGNG: sign convention of inequality constraints

Feasible regions in the design space are defined as follows:

$h_q(\vec{D}) \leq 0 \quad q = 1,2,\ldots NTC$ Structural Analysis CONMIN optimizer

$h_q(\vec{D}) \geq 0 \quad q = 1,2,\ldots NTC$ NEWSUMT optimizer

However, the NEWSUMT optimizer has a built-in option to accept an analysis program, in which feasible regions are defined for non-positive values of design constraints. This option is activated by specifying JSIGNG equal to -1.

•SPM: starting point margin

If an initial design is infeasible, the initial design is uniformly scaled up so that all constraints become satisfied with certain margins. The minimum margin for the most critical constraint is given by

$$\underset{q}{\mathrm{Max}}[h_q(\vec{D})] = -(SPM-1.0).$$

If it is necessary to change the scaling procedure, the subroutine SUBALY must be modified.

•TRF,TRFINC and TRFMAX: constraint truncation control parameters

In the APG block, when all constraint function values $h_q(D)$ are evaluated, critical and potentially critical constraints are selected to form the explicit approximate problem statement. A constraint $h_q(\vec{D})$ is to be retained as critical or potentially critical if

$$h_q(\vec{D}) \geq C - TRF*[\underset{q}{\mathrm{Max}}(h_q(\vec{D}))-C] = TBV$$

where

$Max(h_q(\vec{D}))$: the maximum constraint value in each type of constraint

C: preassigned constant in SETPOS

- 1.0 for stress and displacement constraints
- 1.2 for side constraints

TRF: initial value is given as an input data and modified at the end of each design iteration stage by TRF = Min(TRF*TRFMUL, TRFMAX)

The relation between TRF and the truncation boundary value TBV is illustrated in Fig. 8. Note that TBV is gradually lowered in absolute value so as to truncate more constraints as the design procedure converges.

4.7 Optimizer Control Parameters - NEWSUMT Version

• EPSEA, EPSARS, EPSODM: convergence criteria

EPSEA: Stage convergence criterion

Iteration process will be terminated, if three consecutive stages produce designs which satisfy

$$(OBJ_p - OBJ_{p-1})/OBJ_p < EPSEA$$

$$(OBJ_{p-1} - OBJ_{p-2})/OBJ_{p-1} < EPSEA$$

EPSARS: Convergence criterion applied to the results of 3 sequential unconstrained minimizations without updating the approximate problem statement. This is applicable only if MAXARS > 3.

EPSODM: Convergence criterion in the golden section minimum search procedure. Convergence is achieved if at a certain state,

$$(|TLL-TL| + |TL-TR| + |TR-TRR|)/|TR+TL| \leq EPSODM$$

and

$$ARR - ALL \leq 0.05$$

are satisfied. (See Fig. 9)

·STEPMX: Maximum allowable change in any components of the design vector during a single stage in the NEWSUMT optimizer. Usually, it is not necessary to use this feature, but if some constraints are found to be highly nonlinear and errors due to the first order Taylor series expansions are excessive, this parameter will be useful to confine the design within a reasonable range during one stage of the overall iterative design procedure.

·DELTAC: Initial transition point for extended penalty functions.

4.8 Optimizer Control Parameters - CONMIN Version

·EPSSTG: Same as EPSEA in §. 4.7.

·EPSVJK: Same as EPSVJK in §. 4.7.

·ITMAX: Maximum allowable number of iterations in the CONMIN optimizer. Here, one iteration is equivalent to one direction search followed by a one-dimensional minimization.

·CTL: Initial width of active region of constraints. A constraint is defined to be

violated if $h_q(\vec{D}) > 0$

active if $0 \geq h_q(\vec{D}) \geq CTL$

non-active if $CTL > h_q(\vec{D})$

Note that CTL < 0. (default value = -0.01)

·CTLMIN: Upper limit of CTL. This is not an important parameter for ACCESS-1, and it is recommended that the default value of -0.001 be used.

·DELFUN: Convergence criterion among one dimensional minimizations. Iteration process will be terminated, if in two consecutive iterations, $ABS(1.0-OBJ_{J-1}/OBJ_J) < DELFUN$, and the current design is feasible.

4.9 Printout Control Parameters

There are two parameters used to control the line printer output quantity, namely IPRINT and JPRINT. The greater the integer numbers assigned to these parameters, the more detailed output will be printed.

·IPRINT controls printouts from all programs except those from optimizers. Brief summary of the output items is given in Table 3. Standard output will be obtained by assigning IPRINT = 2.

·JPRINT controls output from optimizers (see Table 4). Standard values are 2 for NEWSUMT and 1 for CONMIN.

4.10 System of Units

Input data of ACCESS 1 computer program may be prepared in any unit systems as long as they are consistent. For example, if the units for length and force are decided to be centimeter and Newton, respectively, then the unit for pressure or stress must be N/cm^2. Example problems given in Appendix C are presented both in the International System (IS) of Units and in the U.S. Customery (US) Units. Computer input data examples are prepared using numerical values associated with the US Units, simply because all the examples were presented originally in various literature in the US Units.

5. Restrictions and Limitations

As explained in the previous sections, the problem size which the base version can solve is limited to

70 elements for each element type

20 design variables for each type of element, but the total should not exceed 40

70 nodes

2 load conditions.

These numbers may be easily modified by changing the sizes of arrays declared in the program. However, it is not practical to solve large problems using ACCESS-1, even if the computer has large main memory capacity.

The program permits the imposition of upper bounds on element sizes as well as lower and upper bounds on positive and negative displacements or stresses, respectively. However, this type of constraint, when violated, may cause difficulties in convergence. This is because these constraints cannot be satisfied by uniformly scaling up the design variables. Both optimizers have capabilities to start from an infeasible initial design, however, the iteration history may be unstable when one or more constraints are violated, especially when the NEWSUMT version is used. This shortcoming will be eliminated in ACCESS-2.

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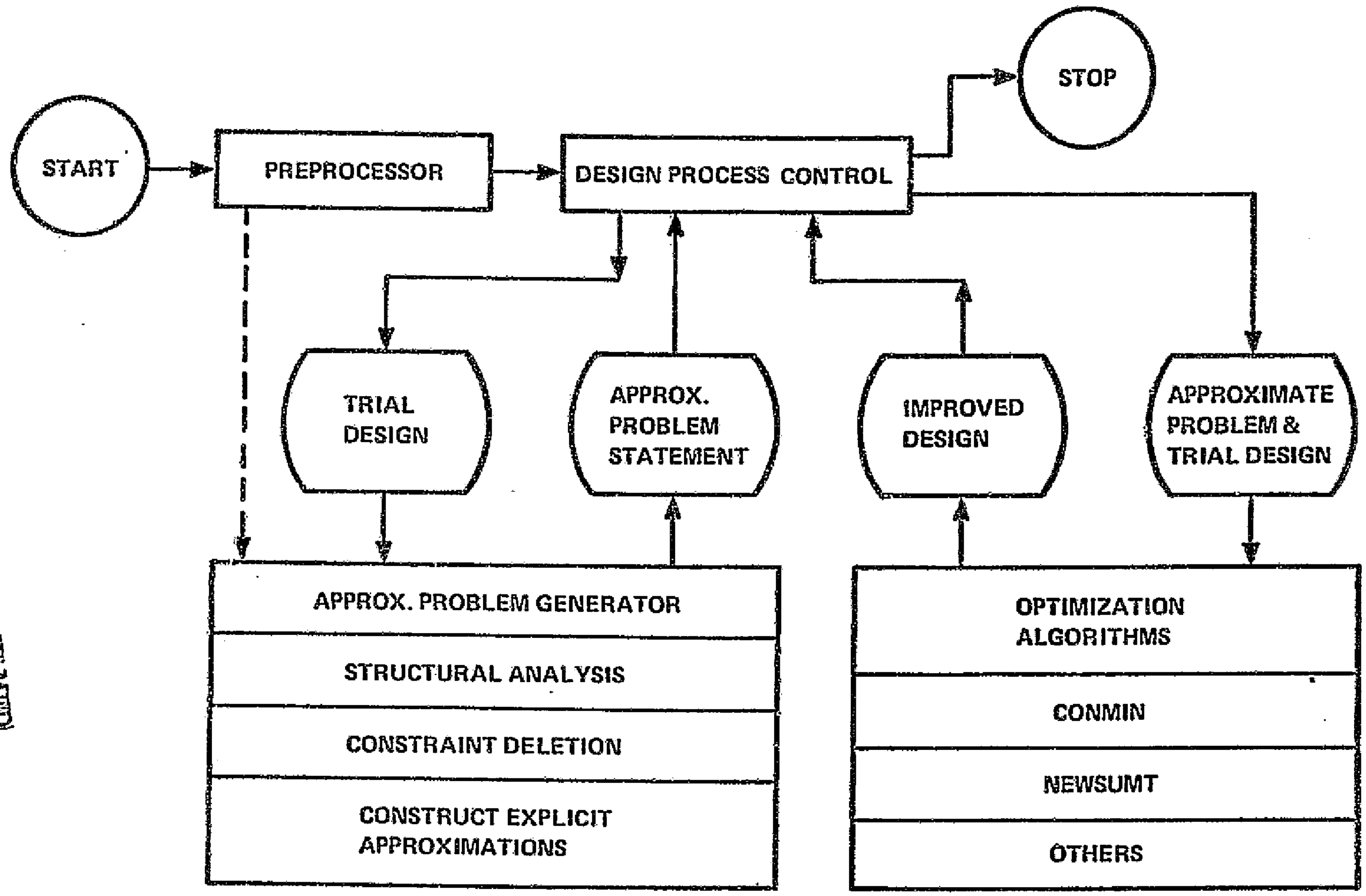
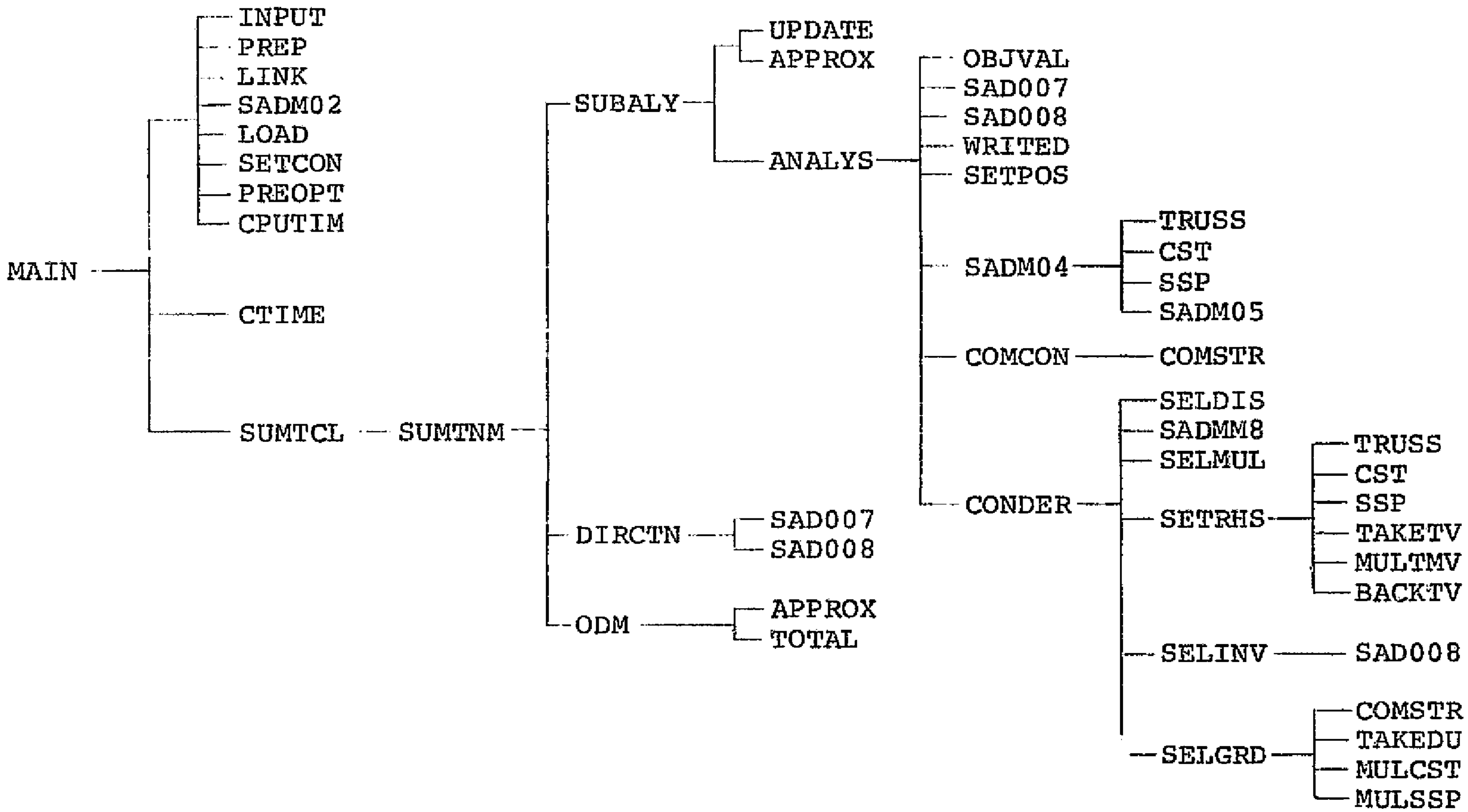


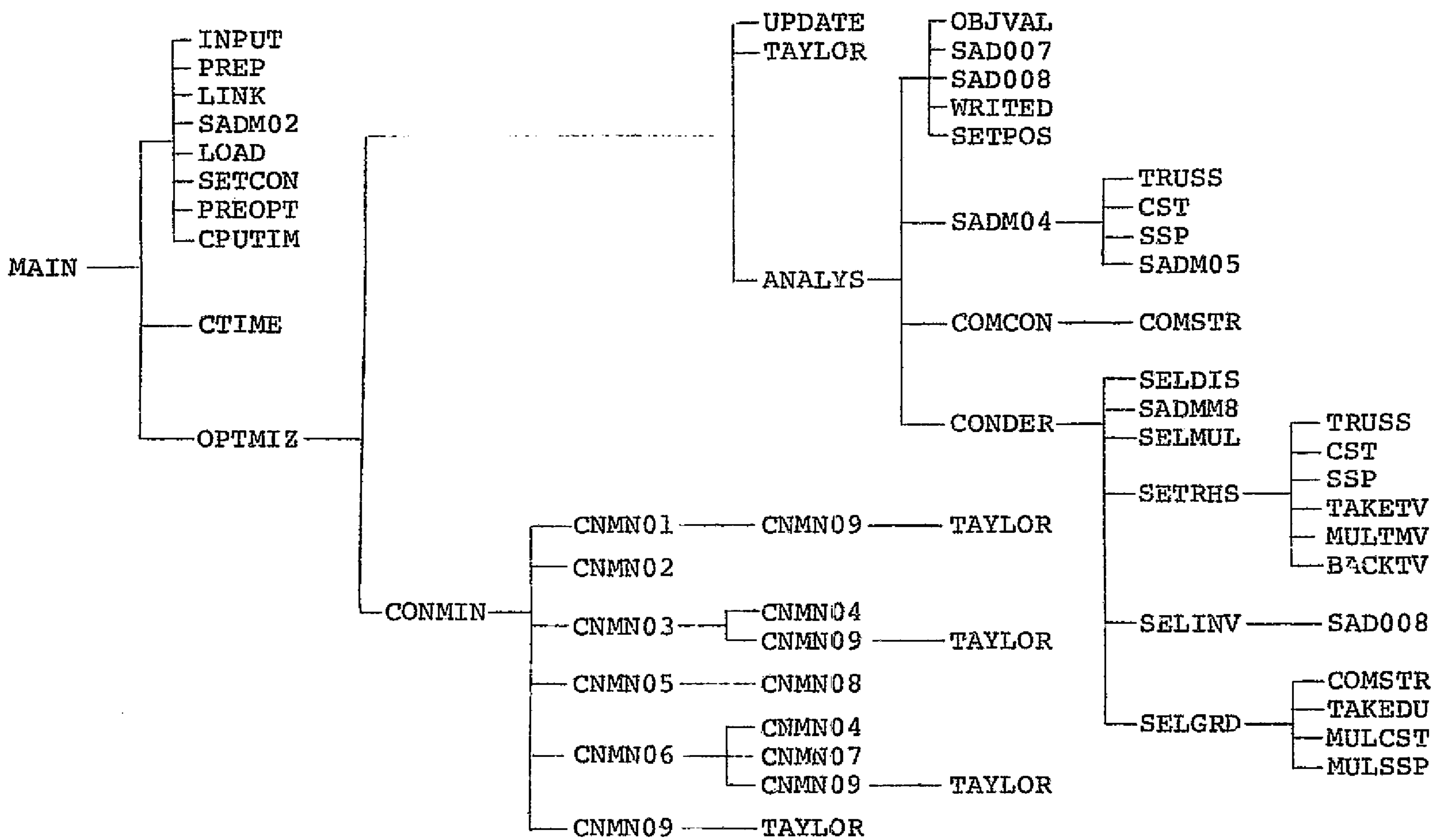
Figure 1. ACCESS 1 Basic Organization.

Fig. 2 ACCESS-1 Program Organization (NEWSUMT Version)



5,670 cards altogether (FORTRAN source program)

Fig. 3 ACCESS-1 Program Organization (CONMIN Version)



6,811 cards altogether (FORTRAN source program)

Fig. 4 ACCESS-1 Program Overlay Structure (NEWSUMT Version) on IBM 360/91 UCLA Campus Computing Network

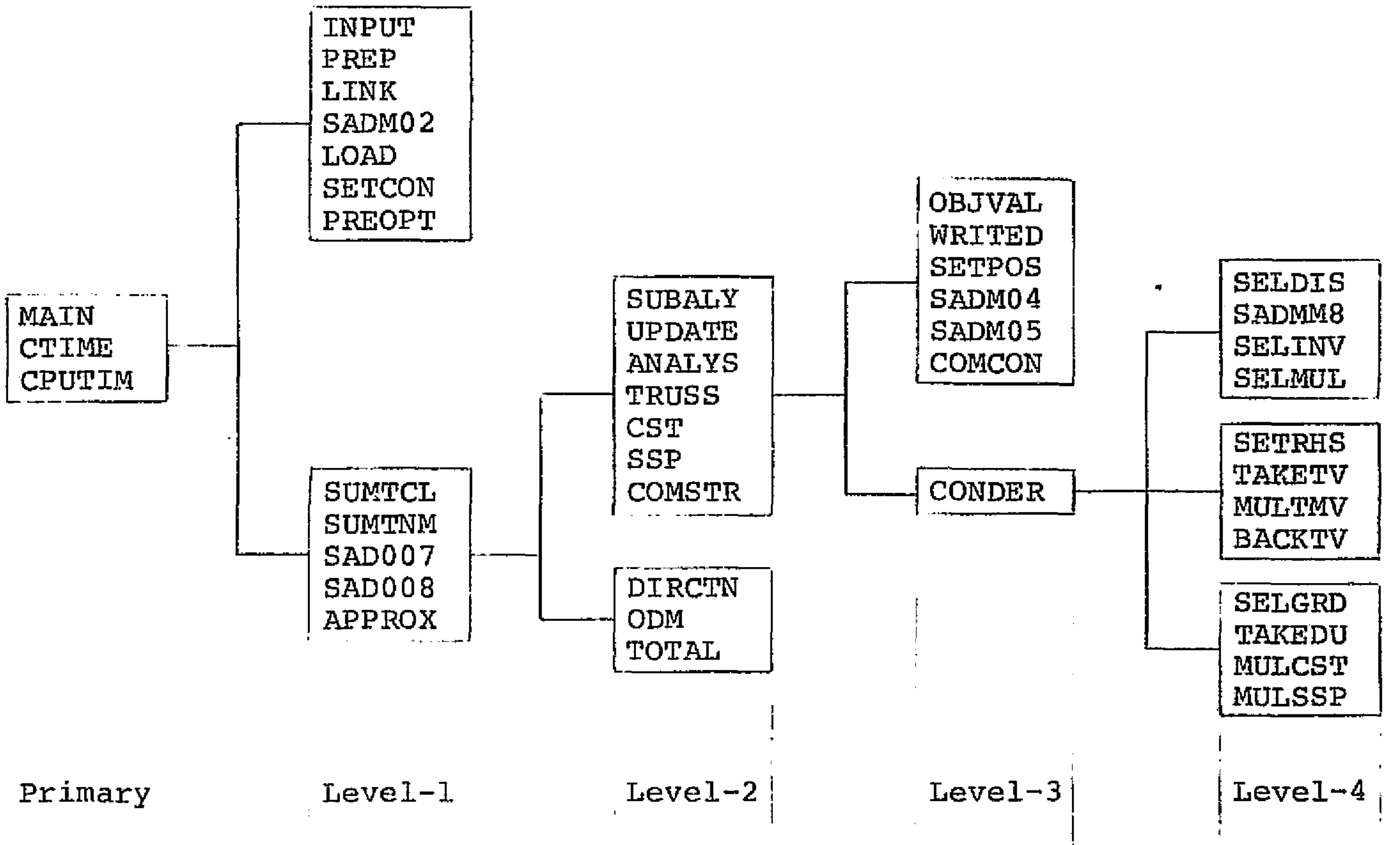
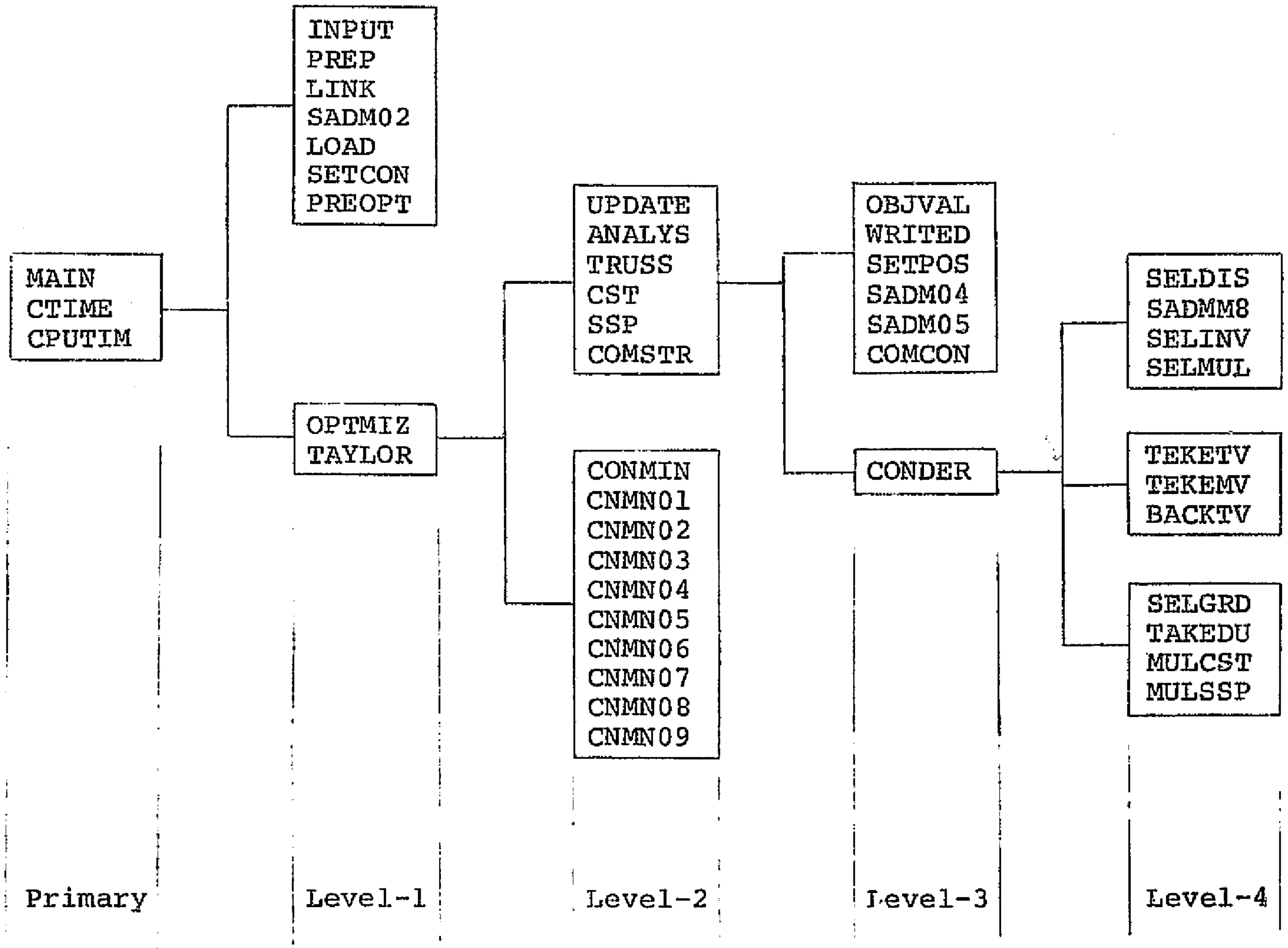


Fig. 5 ACCESS-1 Program Overlay Structure (CONMIN Version) on IBM 360/91 UCLA Campus Computing Network



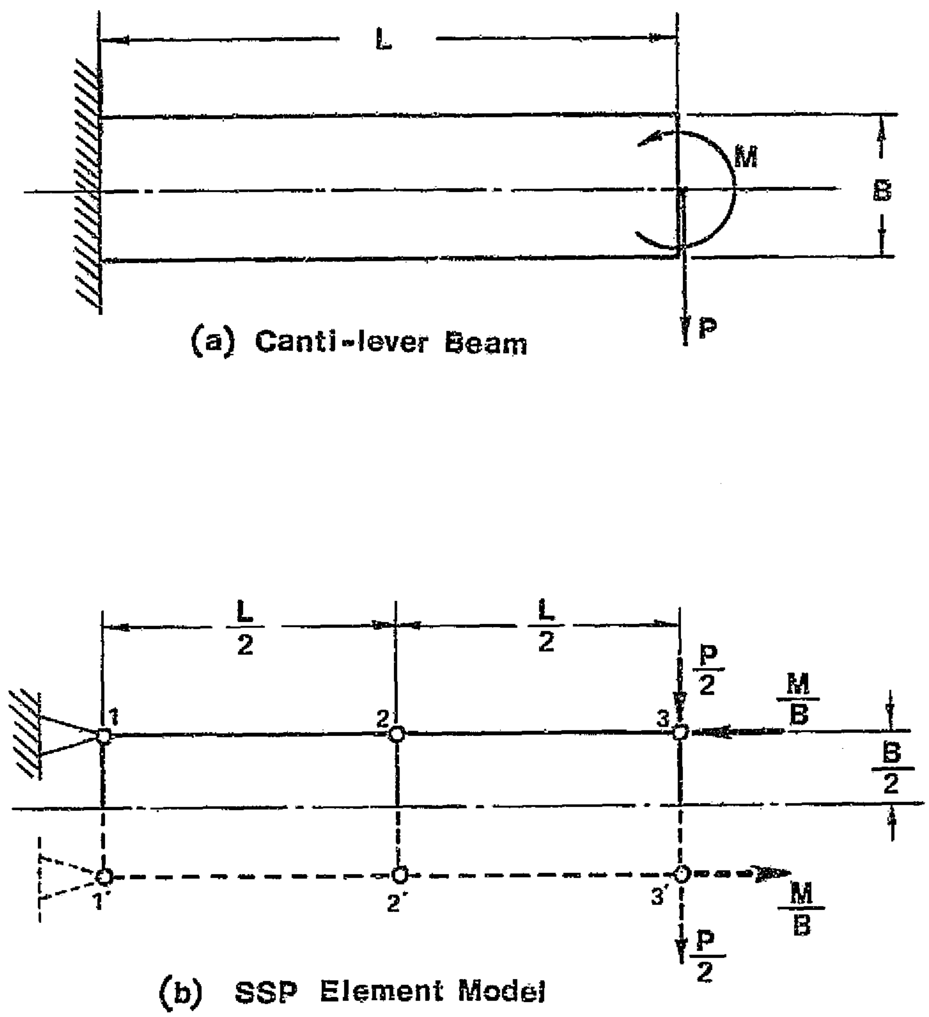
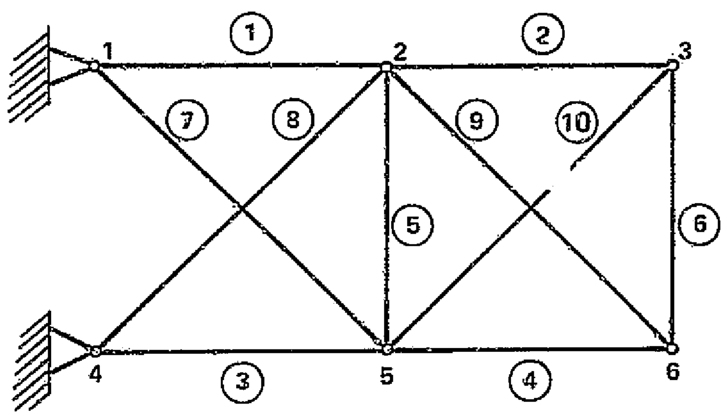


Fig. 6 SSP Element Model Example



Configuration Material

Group 1 [1, 2, 3, 4, 5, 6]

Group 2 [7, 8, 9, 10]

Fig. 7 Ten-Bar Planar Truss

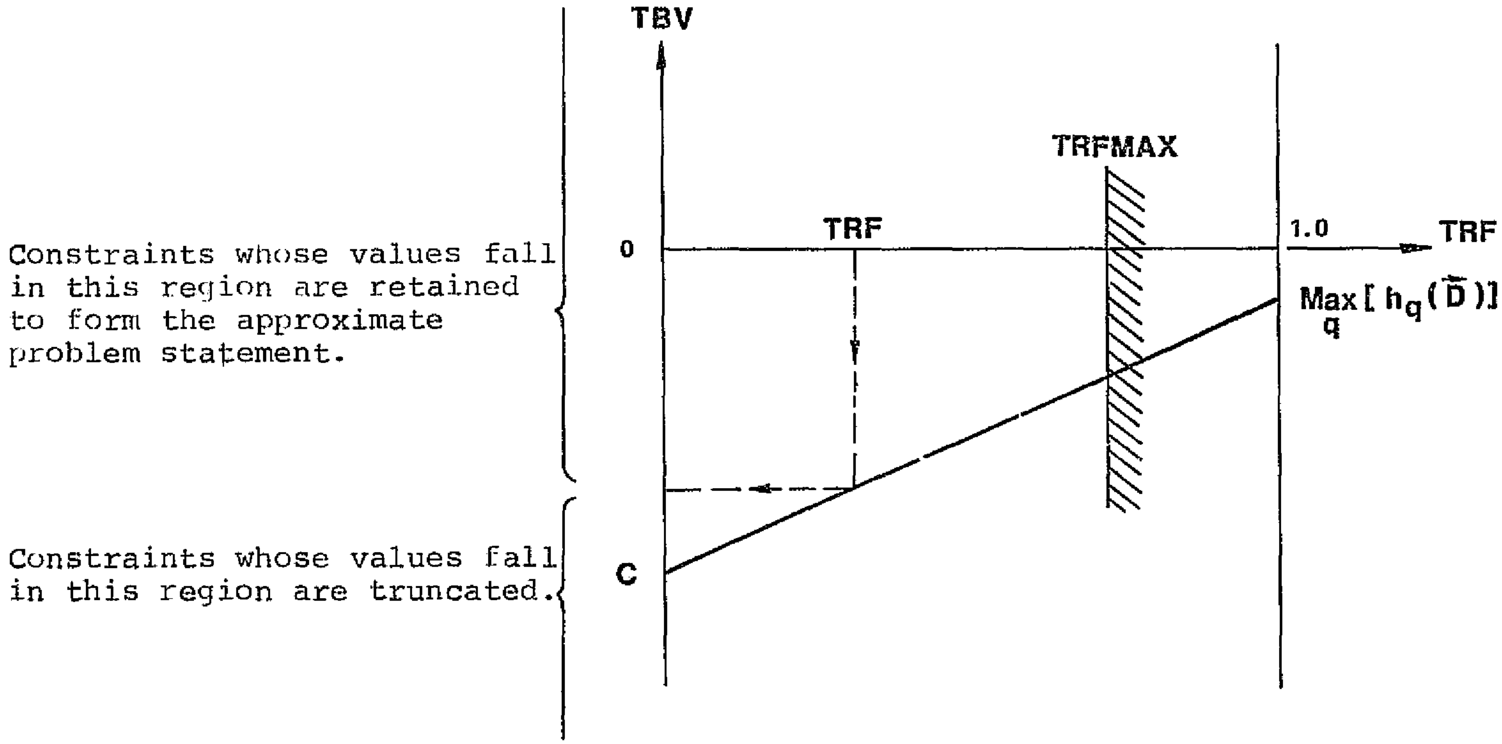
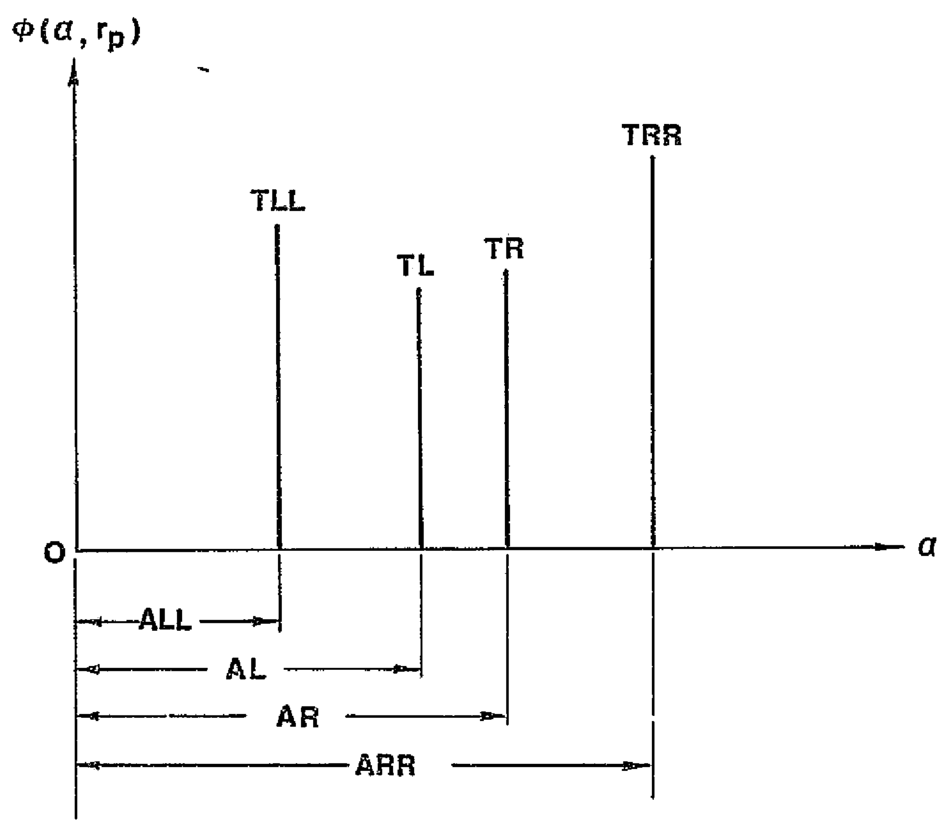


Fig. 8 Constraint Truncation Boundary Value vs. Truncation Factor



$$\frac{ARR - AR}{ARR - ALL} = \frac{AL - ALL}{ARR - ALL} = \frac{3 - \sqrt{5}}{2}$$

Fig. 9 Golden Section Algorithm

TABLE 1. FUNCTIONS OF ALL ROUTINES

ANALYS	Main subroutine in the APG block. Organize finite element structural analysis, constraint calculation, constraint deletion and selective gradient computation.
APPROX*	Computes objective function and constraint function values for the approximate, explicit problem.
BACKTV	Pseudo load vectors for displacement sensitivity computation are assembled by this routine. Given the product of element stiffness matrix and corresponding displacement state of the element, each component of the product vector is transferred to the appropriate position of the global pseudo vector.
COMCON	Computes all constraint function values based on the current analysis results.
COMSTR	Compute stress state of the specified finite element. Axial stress for TRUSS elements, three plane stress components and von Mises combined stress for CST and SSP elements.
CONDER	Organizes selective sensitivity computation of retained constraints.
CPUTIM	Dummy subroutine (c.f. Appendix A).
CST	Computes an element stiffness matrix in the global coordinate system for a given CST element.
DIRCTN*	Determines the direction vector in the NEWSUMT optimizer by means of modified Newton's algorithm.
INPUT	Reads input data except for the optimizer control cards. Writes the input data in a readable format.
LINK	Forms the initial linking table.
LOAD	Assembles load vectors for all load conditions.
MAIN*	Main program.
MULCST	Computes sensitivity of von Mises combined stress of the specified CST element, given displacement sensitivity.
MULSSP	Computes sensitivity of von Mises combined stress of the specified SSP element, given displacement sensitivity.
MULTMV	Carries out post multiplication of a vector to a symmetric square matrix stored in a vector form. Used in assembling pseudo load vectors.

* Subroutines used in the NEWSUMT version only.

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Table 1. FUNCTION OF ALL ROUTINES (continued)

OBJVAL	Computes structural weight at the beginning of each stage.
ODM *	Carries out one dimensional minimization by means of the golden section algorithm.
PREOPT	Check satisfaction of side constraints for the initial design. Computes element weight for unit value of sizing variable. Computes weight coefficients for the initial stage.
PREP	Identifies representative elements for each linking and configuration group. Computes element shapes, direction cosines of the local coordinate axes, and an element stiffness matrix in the local coordinate system.
SAD007	Decomposes real, symmetric positive definite matrix into a product of three matrices; i.e., a lower triangular, a diagonal and an upper triangular matrices. $[K] = [L][D][L]^T$.
SAD008	Back and forward substitution to solve a system $[L][D][L]^T\vec{U} = \vec{P}$ for $\vec{U}$.
SADM02	Computes two pointer vectors, JC and IIK. JC indicates boundary conditions for the displacement vectors. IIK contains the position of the diagonal elements of the master stiffness matrix.
SADM04	Assembles the master stiffness matrix, given element stiffness matrices in the global coordinate system.
SADM05	Called by SADM04 and performs additions of element stiffness matrices in appropriate positions of the master stiffness matrix.
SADMM8	Same as SAD008, except for the additional capability to skip processing some of the right hand side vectors.
SELDIS	Identifies displacement degrees of freedom, which may be associated at least one of the retained behavior constraints (displacement or stress constraints).
SELGRD	Assembles the selective gradient vectors for retained set of constraints.
SELINV	Computes selective inverse matrix of the master stiffness matrix.
SELMUL	Performs pre-multiplication of the selective inverse matrix to the right hand side vectors to obtain selective sensitivity of the displacement degrees of freedom.
SETCON	Identifies all constraints and prepares arrays used in constraint function evaluation procedure.

* Subroutine used in the NEWSUMT vresion only.

Table 1. FUNCTION OF ALL ROUTINES (continued)

SETPOS	Set up the posture table by deleting constraints which are not likely to influence design process at current stage.
SETRHS	Set up the pseudo load vector for the displacement sensitivity computation.
SSP	Computes an element stiffness matrix in the global coordinate system for a given SSP element.
SUBALY*	Interface between the finite element analysis program and the NEWSUMT optimizer.
SUMTCL*	Reads NEWSUMT optimizer control parameters and activates NEWSUMT optimizer.
SUMTNM*	Primary routine of the design process control block (DPC) in Fig. 1. Also organizes the NEWSUMT optimizer.
TAKEDU	Picks up components of the displacement sensitivity vectors to form displacement sensitivity vectors for a given element.
TAKETV	Picks up components of the displacement vectors to form displacement vectors for a given element.
TOTAL*	Forms the total function by summing up the objective and penalty functions.
TRUSS	Computes an element stiffness matrix in the global coordinate system for a given truss element.
UPDATE	Updates the sizing variables of each finite element.
WRITED	Print nodal displacement state.

* Subroutines used in the NEWSUMT version only. These routines must be replaced by the routines listed in the next page to implement the CONMIN version of ACCESS-1.

Table 1. FUNCTION OF ALL ROUTINES (continued)

CONMIN	Primary subroutine of the CONMIN optimizer. Organization of constrained function minimization procedure by means of the method of feasible directions.
CNMN01	Calculation of gradient information by means of the one step forward finite difference.
CNMN02	Determination of conjugate direction vector or direction of steepest descent for unconstrained function minimization.
CNMN03	Solution of one dimensional search in unconstrained minimization using 2-point quadratic, 3-point cubic and 4-point cubic interpolations, sequentially.
CNMN04	Called by CNMN03 and carry out specified interpolations.
CNMN05	Direction finding by the modified method of feasible directions.
CNMN06	Organization of constrained one dimensional minimizations.
CNMN07	Called by CNMN06 and carry out specified interpolations.
CNMN08	Special linear programming algorithm with one quadratic constraint.
CNMN09	Un-scale and re-scale design variables before and after evaluation of the objective function.
MAIN	Main program of the CONMIN version of ACCESS-1.
OPTMIZ	Implementation of all functions of the DPC(Design Process Control) block. See fig. 1.
TAYLOR	Objective and constraint function evaluations based on the current approximate problem statement.

Subroutines listed on this page are used in the CONMIN version only.

Table 2 Labeled COMMON Blocks

Labeled COMMON Blocks	(sub) routines																					
	MAIN	INPUT	PREP	LINK	SADM02	LOAD	SETCON	PREOPT	ANALYS	UPDATE	OBJVAL	SADM04	TRUSS	CST	SSP	SADM05	SAD007	SAD008	WRITED	COMCON	COMSTR	SETPOS
BLKA01		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●
BLKA02		●	●	●		●	●	●	●	●	●		●	●	●					●	●	
BLKA03			●			●		●	●													
BLKA04			●			●	●	●					●	●	●						●	
BLKA05					●	●	●		●			●				●			●	●	●	
BLKA06																						
BLKA07																						
BLKA08									●													
BLKB02				●				●	●	●												
BLKC01		●	●				●															
BLKC02	●	●	●				●	●	●											●		
BLKC03							●	●	●											●		●
BLKC07									●											●		●
BLKT01			●			●	●					●										
BLKT02					●	●	●		●			●								●		●
BLKT04																						
RESULT	●			●					●													
DESIGN																						
INTERN																						
CONTRL																						
STAGEN																						
COUNTN																						
COUNT	●								●													
TIME	●								●													
OVERFL					●		●															●

● indicates that the associated COMMON blocks must be declared in the corresponding routine.

Table 2 Labeled COMMON Blocks (continued)

Labeled COMMON Blocks	(sub) routines													NEWSUMT Version						
	CONDER	SELDIS	SETRHS	TAKETV	MULTMV	BACKTV	SELINV	SADMM8	SELMUL	SELGRD	TAKEDU	MULCST	MULSSP	SUMTCL	SUMTNM	DIRCTN	ODM	SUBALY	APPROX	TOTAL
BLKA01	●	●	●	●						●		●	●					●		
BLKA02			●	●						●		●	●					●		
BLKA03																				
BLKA04										●		●	●							
BLKA05	●	●	●	●			●			●										
BLKA06																				
BLKA07																				
BLKA08																				
BLKB02			●							●								●		
BLKC01																				
BLKC02										●								●		
BLKC03		●								●										
BLKC07	●	●	●					●	●	●										
BLKT01																				
BLKT02	●	●	●	●			●		●	●										
BLKT04			●											●	●					
RESULT														●	●	●	●	●	●	
DESIGN														●	●	●	●	●	●	
INTERN														●	●	●	●	●	●	
CONTRL														●	●	●	●	●	●	●
STAGEN															●			●		
COUNTN														●	●			●	●	
COUNT	●														●			●	●	
TIME	●														●			●	●	
OVERFL	●																			

● indicates that the associated COMMON blocks must be declared in the corresponding routines.

Table 2 Labeled COMMON Blocks (continued)

		(sub) routines												
		CONMIN version												
		MAIN	OPTMIZ	TAYLOR	CONMIN	CNMN01	CNMN02	CNMN03	CNMN04	CNMN05	CNMN06	CNMN07	CNMN08	CNMN09
Labeled COMMON Blocks	BLKA01		●											
	BLKA02		●											
	BLKA08	●												
	BLKB02		●											
	BLKC02		●											
	BLKT04		●											
	RESULT	●	●	●										
	OVERFL	●												
	TIME	●	●	●										
	COUNT	●	●	●										
	TEMPOL		●	●										
	TRANSF													
	CNMN1		●	●	●	●	●	●	●	●	●	●	●	●

● indicates that the associated COMMON blocks must be declared in the corresponding routine.

Table 3 Analysis Printout Control - IPRINT

All messages above the horizontal line corresponding to each value of IPRINT are printed.

IPRINT	Information printed
	Messages prior to any error termination
	Final results
	Time and counting statistics of the job
-1	
	Input data summary
0	
	Reduced design variables at each stage
	Element sizing variables at each stage
	Weight information at each stage
	Displacement state at each stage
	Scaling-up information (if any)
1	
	Posture table
	Required memory allocation for DG, DU and AK
	Detailed scaling-up data (if any)
	Stress state of all stress constrained elements
2*	
	All constraint values
3	
	Weight coefficients
	Gradient of retained constraints
	Updated linking table at each stage
	Basic pointer vectors, JC and IIK
	Load vectors
4	
5	
	Identification of representative elements
	Element data (lengths, direction cosines, element stiffness matrices in the local system)
6	
	Master stiffness matrix
7	
	Element stiffness matrices in the global system
	Constraint identification for all constraints

* Standard value

Table 4 Optimizer Printout Control - JPRINT

All messages above the horizontal line corresponding to each value of JPRINT are printed.

JPRINT	NEWSUMT Version Information printed
	Messages prior to any error termination
0	
	SUMT control parameters Iteration stage summary
1	
	Maximum step warning
2*	
	Direction vectors Response surface convergence check data
3	
	Direction search data Detailed one dimensional minimization data

JPRINT	CONMIN Version Information printed
	No printing
0	
	Initial and final function information
1*	
	First debugging level. Print all of above plus control parameters. Print function value and X-vector at each iteration.
2	
	Second debugging level. Print all of above plus all constraint values, number of active or violated constraints, direction vectors move parameters and miscellaneous information. The constraint parameter, BETA, printed under this option approaches zero as the optimum objective is achieved.
3	
	Complete debugging. Print all of above plus gradients of objective function, active or violated constraint functions and miscellaneous information.

* Standard value

APPENDIX A

CPU TIMING ROUTINES

1. UCLA IBM 360/91 FORTRAN-H version

A subroutine CPUTIM is a dummy routine and the function CTIME(1) gives the remaining CPU time in seconds. This function is not included in the FORTPAN Library, therefore a dataset SYS1.CCNFLIB must be concatinated to SYS1.FORTLIB

```
      SUBROUTINE CPUTIM(T.DT.IP)
      T = 0.0
      DT = 0.0
      RETURN
      END
```

2. Berkeley CDC 6600 FTRX compiler

A subroutine SECOND(T) is in the FORTRAN Library and T is CPU time in seconds used by the run.

```
      SUBROUTINE CPUTIM(T.DT.IT)*
      IF(IT.LE.0) GO TO 100
      CALL SECOND(T1)
      T1 = T1 - T0
      DT = T1 - T
      T = T1
      RETURN
  100 T = 0.0
      DT = 0.0
      CALL SECOND(T0)
```

*Written by Dr. Joseph Mullen, Jr., NASA Ames Research Center

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```
      RETURN
      END

      FUNCTION CTIME(I)
      DATA T,DT/0., 0./
      CALL CPUTIM(T.DT.1)
      CTIME = 1000.0 - T
      RETURN
      END
```

3. NASA Ames IBM 360/67 FORTRAN H

A function INTVAL and a subroutine SETTIM are in the FORTRAN Library and INTVAL gives CPU time used since the last call of SETTIM in mili-seconds units.

```
      SUBROUTINE CPUTIM(T.DT.IT)
      IF(IT.LE.) GO TO 100
      IT1 = INTVAL(0.0)
      T1 = FLOAT(IT1)/100.0
      DT = T1 - T
      T = T1
      RETURN
  100 END

      FUNCTION CTIME(I)
      DATA T,DT/0.,0./
      CALL CPUTIM(T.DT.1)
      CTIME = 1000.0 - T
      RETURN
      END
```

APPENDIX B

INPUT DATA DESCRIPTION

The input data description in the card image format given at the end of this Appendix should be referred to in preparing an input data deck for the ACCESS-1 computer program. Example problems given in Appendix C will also be helpful.

Input Data Cards.

I. Job description and heading (I1, 79A1)

The first column is used as follows

0 or blank: ordinary heading card, whose content in 2-80 columns will be printed in the first part of the output list.

1 : indication of the last heading card.

2 : request for immediate normal termination of this job.

Any number of cards may be used to describe or to comment the job. Note that the last heading card must have "1" punched in the first column. Without this, all of your data may be regarded as heading cards.

II. Job control parameters (3I5)

IDG : not used

IPRINT: print out control (see §4.9 and Table 3)

IOPT : not used

III. Basic structural data

(4I5)

IN : number of nodes

ID : spatial dimensions (2 or 3) (see §4.3)

IBN: number of nodes where boundary conditions are specified.

INL: number of load conditions.

(3I5)

IDRT(j): number of linked design variable groups for the jth element type. (j = 1,2,3)

j = 1 TRUSS

j = 2 CST

j = 3 SSP

(3I5)

ICRT(j): number of configuration/material groups for the jth element type (j = 1,2,3)

(3I5)

IETP(j): number of jth type elements

IV. Node coordinates (I3, 2X, 3E15.6)

N : node number

X(N): X-coordinate of the node N

Y(N): Y-coordinate of the node N

Z(N): Z-coordinate of the node N

V. Element data

For each element type, the following sequence of cards is required.

(I3) : element type identification

Note ; The element type identification cards are necessary for all element types, even if the corresponding type of elements is not used in the structure.

(2I5, 3E15.4, 3I5, 5X, I5): TRUSS and SSP

or (2I5, 3E15.4, 5I5) : CST

M : member number

IDVRj(M) : design variable linking group number of the Mth member in the jth element type

DVj(M) : initial size of the Mth member

DVULj(M) : upper limit of the Mth member size

DVLLj(M) : lower limit of the Mth member size

ICVRj(M) : configuration group number of the Mth member

INODj(1,M): node number of the P local node

INODj(2,M): node number of the Q local node

INODj(3,M): node number of the R local node (CST only)

IVC(M,j) : side constraint code of the Mth element

-1: lower limit only

0: non-negativity only

1: upper limit and non-negativity

2: both upper and lower limits

(2I5) : CST only

IPGR(M,K) : pressure load group number for the Kth load condition on the Mth element; put "0" or blank if no pressure load on any element for the load condition.

Note ; CST elements require two cards per element, while TRUSS and CST elements require only one card per element.

VI. Configuration/Material group data

For each element type, the following sequence of cards is required.

(I3) : element type identification

Note ; The element type identification cards are necessary for all element types, even if the corresponding type of elements is not used in the structure.

Note : If the element type identification is given as a negative number, it indicates that the material constants for this type are identical for all the configuration/material groups, thus only the material data card for the first group is required.

(6E12.4)

ASUj(I): allowable upper stress limit for the jth element type, Ith configuration/material group

ASLj(I): allowable lower stress limit

RHOj(I): specific weight

Ej(I) : Young's modulus

RNUj(I): Poisson's ratio

VII. Boundary conditions

(I3, 2X, 3I5)

IBD(I): node number of the Ith boundary node

IBX(I): Boundary condition codes to x,y,z directions

IBY(I): 0: free degree of freedom

IBZ(I): 1: fixed degree of freedom

VIII. Load conditions

For each distinct load condition, the following sequence of cards is required.

(2I5)

ILLNOD(K): number of nodes subject to non-zero external loads for the Kth load condition

IPLTYP(K): number of pressure magnitude groups

(I3, 2X, 3E15.6)

ILLN(I,K): node number of the Ith loaded node for the Kth load condition

CLLMX(I,K): Magnitudes of lumped external loads applied to
CLLMY(I,K): the Ith loaded node for the Kth load condition,
CLLMZ(I,K): in x,y,z directions, respectively.

(E12.4) not required if IPLTYP(K) = 0

CPLM(I,K): magnitude of the Ith pressure group for the Kth load condition

IX. Constraints

(2E15.4)

SPM: starting point margin (see §4.6)

TRF: initial truncation factor (see §4.6)

(3I5)

ISCT(J): stress constraint code for the Jth element type

- 1 : read the stress constraint codes ISC(m,J) element by element
- 0 : no stress constraint for all elements in the Jth element type
- -1: all elements of the Jth type are constrained by lower bounds only
- -2: all elements of the Jth type are constrained by upper bounds only
- -3: all elements of the Jth type are constrained by upper and lower bounds

(16I5): required only for the element type whose ISCT(J) is positive

ISC(m,J): element stress constraint code for the mth element of the Jth type

- -1: lower bound only
- 0 : no stress constraint

1 : upper bound only

2 : both upper and lower bounds

(I5)

IDCT: number of displacement degrees of freedom on which finite displacement constraints are imposed

(3I5, 2E15.4)

NA : node number associated with the constrained displacement degrees of freedom

JA : direction (x=1, y=2, z=3)

IDC(JA,NA): constraint code

-1: constrained by lower limit only

0: no constraint

1: constrained by upper limit only

2: constrained by both upper and lower limits

DISUL(JA,NA): upper limit

DISLL(JA,NA): lower limit

(I5)

IVCT: side constraint code

0: no side constraint

1: apply the code specified on each element description card. (IVC(M,j))

X. Optimization control

NEWSUMT Version

(7I5)

MAXIFS: maximum allowable number of golden section iterations

MAXODM: maximum allowable number of one dimensional minimizations in an unconstrained minimization

MAXARS: maximum allowable number of unconstrained minimizations for an approximate problem statement

MAXNAA: maximum allowable number of iteration stages

JSIGNG: sign convention of constraints

1 : if feasible region is defined as $h_q(\vec{D}) \geq 0$

$q = 1,2,\ldots,Q$

-1: if feasible region is defined as $h_q(\vec{D}) \leq 0$

$q = 1,2,\ldots,Q$

JPRINT: print out control for the NEWSUMT optimizer (see §4.9 and Table 4)

(8F8.5, F8.2, E8.1)

EPSODM: convergence criterion among a sequence of one dimensional minimizations

EPSARS: convergence criterion among a sequence of unconstrained minimizations

EPSEA : convergence criterion among a sequence of iteration stages

EPSVJK: pseudo load vectors truncation criterion

CUTARP: response factor (or penalty multiplier) reduction ratio

STEPMX: maximum allowable change of design variable components for an approximate problem statement

DELTAC: initial transition point for the extended penalty function

TRFMUL: trunction factor increment ratio

TRFMAX: upper limit of truncation factor

RPMIN : minimum allowable limit for response factor

CONMIN Version

(I5, 4E15.5)

MAXSTG: maximum allowable number of iteration stages

EPSSTG: convergence criterion amont iteration stages

TRFINC: truncation factor increment ratio

TRFMAX: upper limit of truncation factor

EPSVJK: pseudo load vectors truncation criterion

(2I5, 3E15.5)

JPRINT: print out control for the CONMIN optimizer (see §4.9 and Table 4)

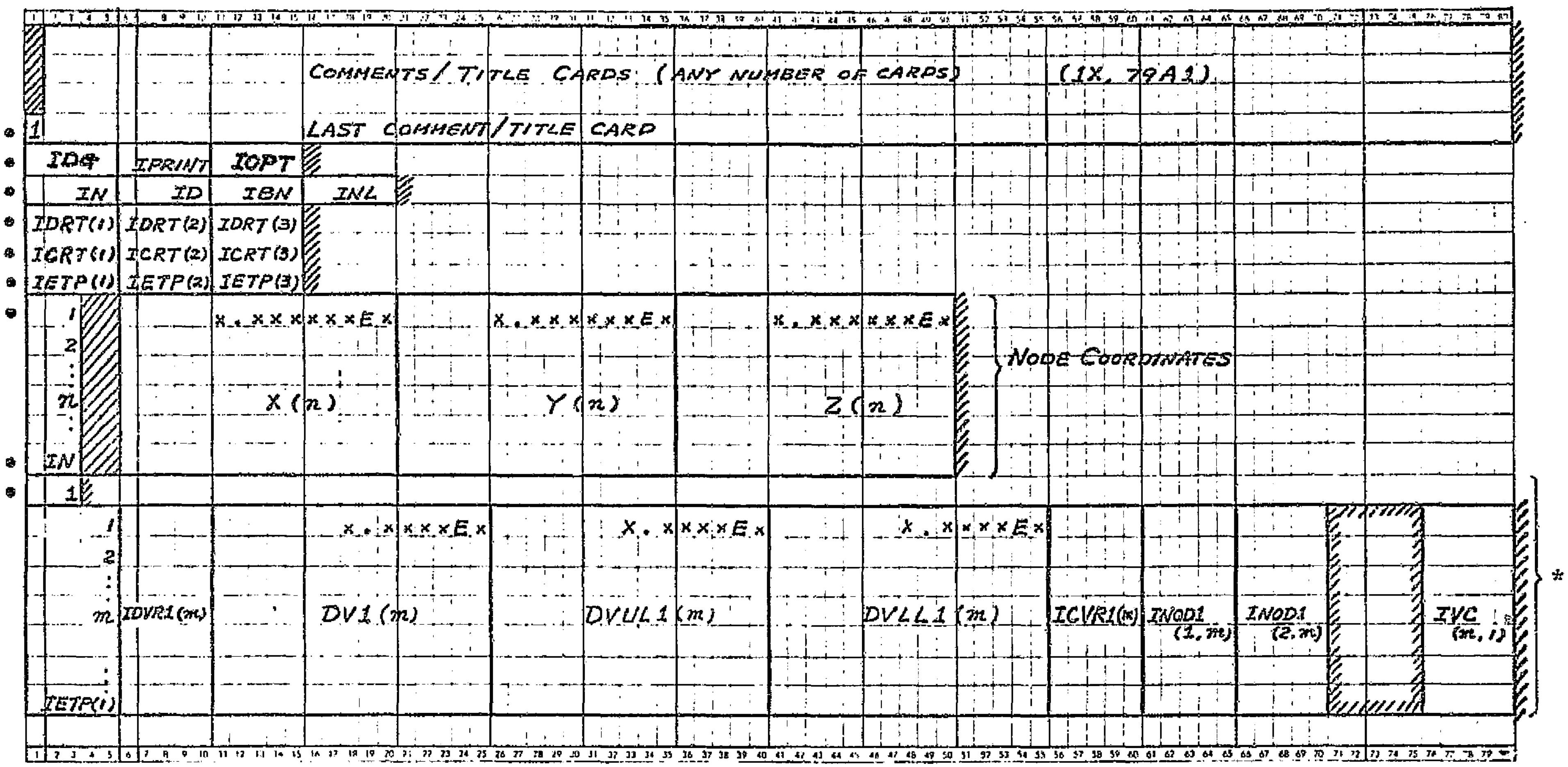
ITMAX : maximum number of iterations in CONMIN

CTL : active constraint width (see §4.8)

CTLMIN: lower limit of CTL (see §4.8)

DELFUN: CONMIN iteration convergence criterion

ACCESS-1 Data in Card Image Format



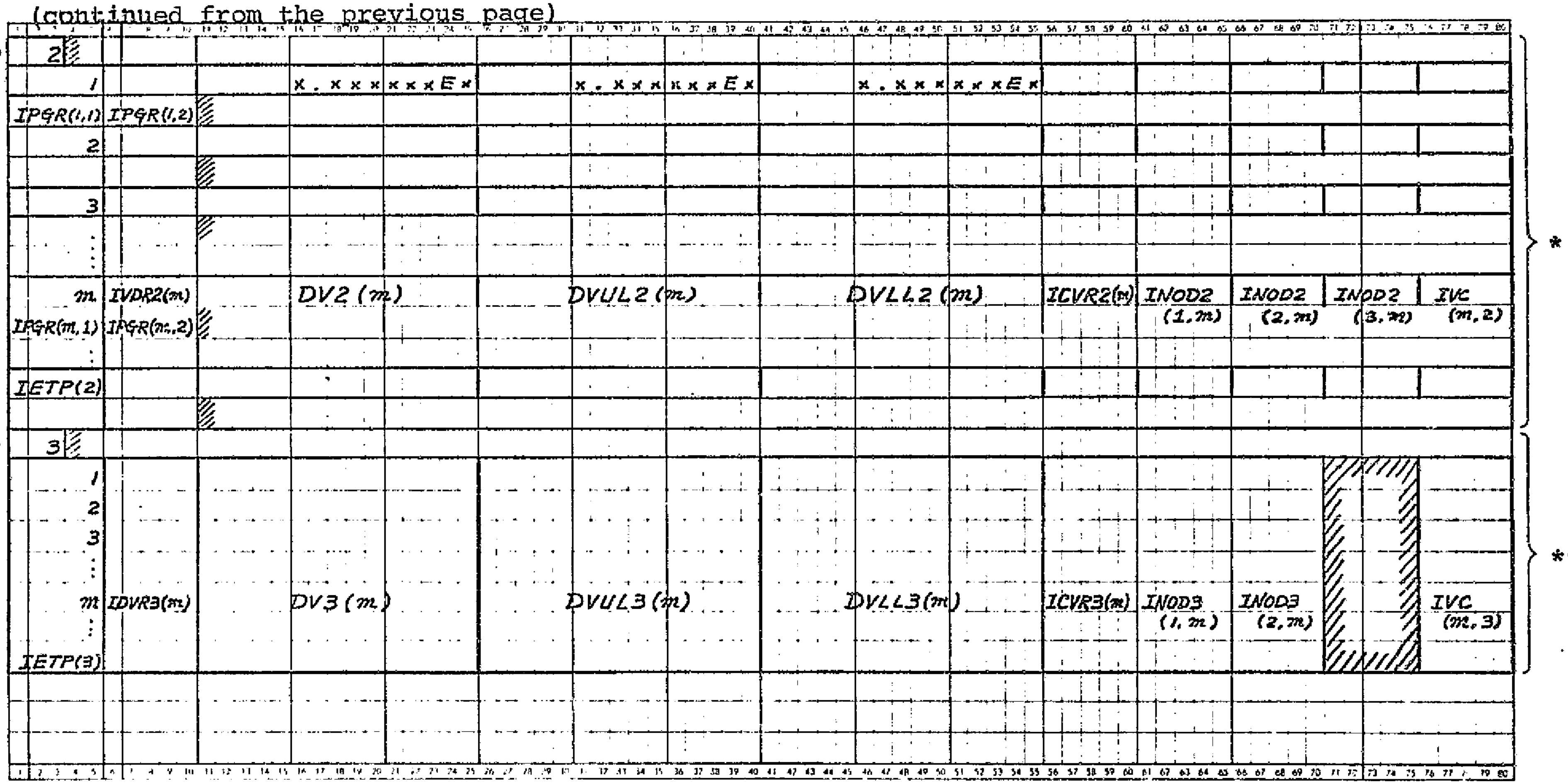
(continued to the next page)

● Data cards which must be present in any case.

* TRUSS elements description.

ACCESS-1 Data in Card Image Format

(continued from the previous page)



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- • Data cards which must be present in any case.
- * CST elements description.
- ** SSP elements description.

ACCESS-1 Data in Card Image Format

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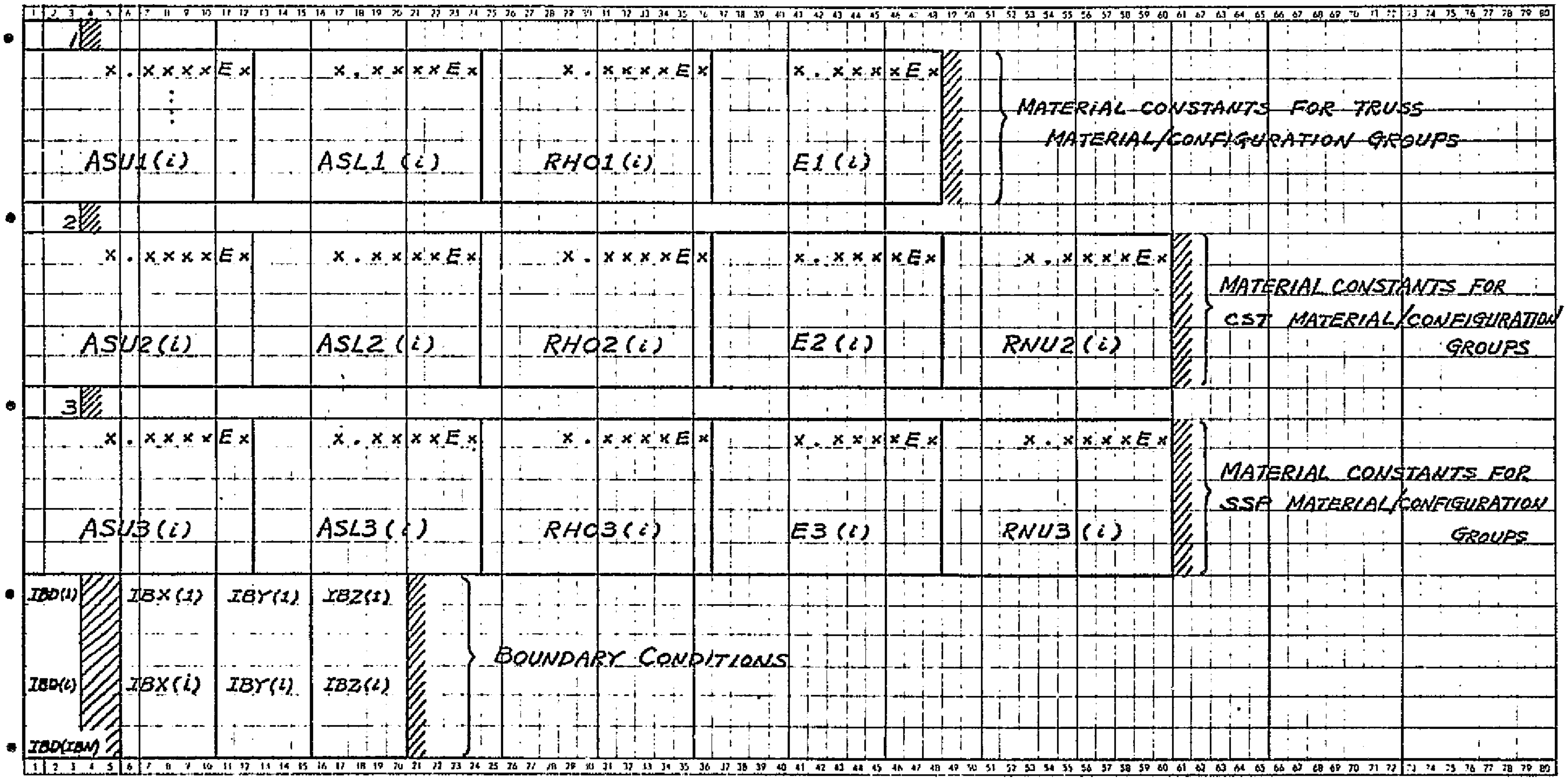

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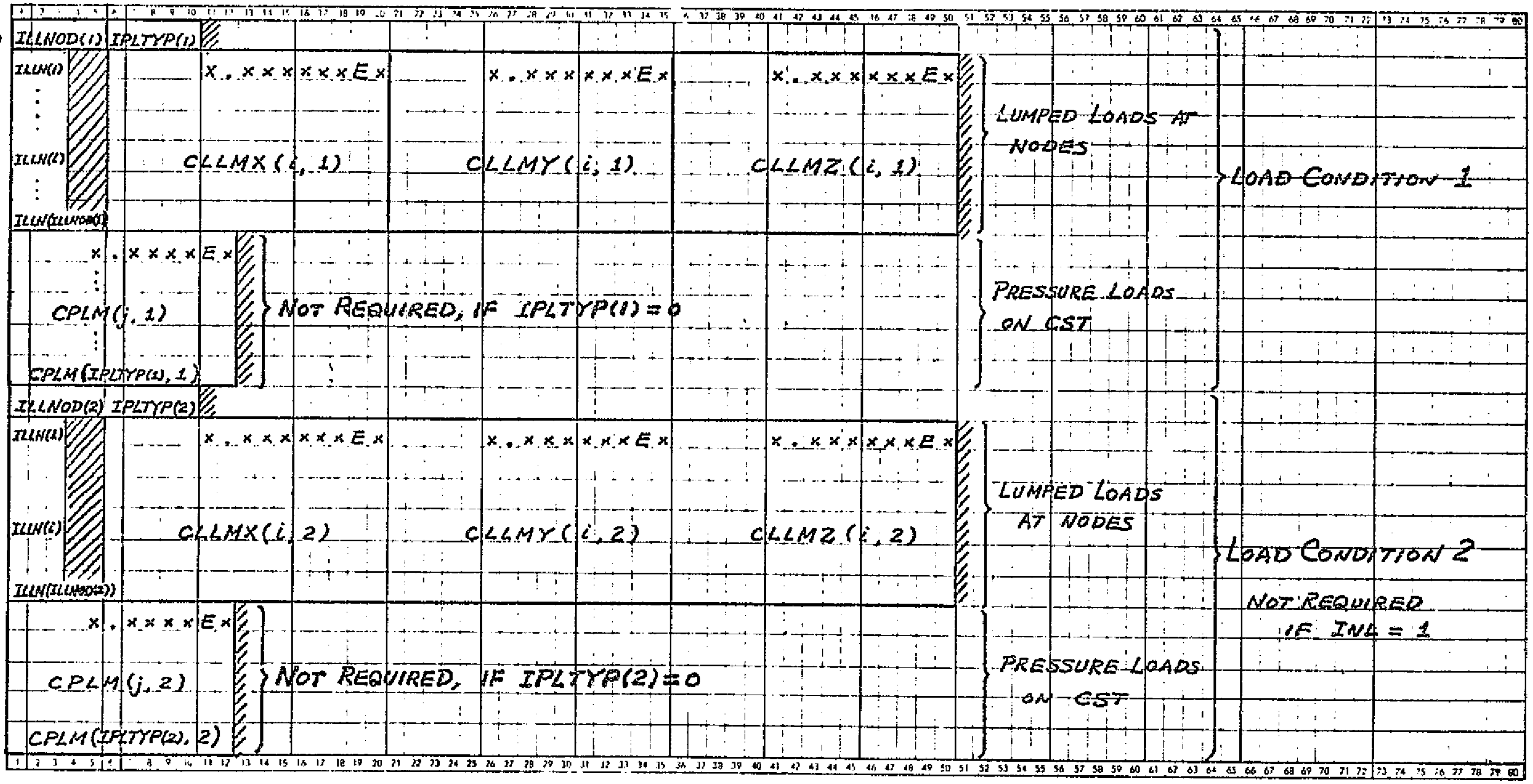
• Data cards which must be present in any case.

ACCESS-1 Data in Card Image Format

(continued from the previous page)



(continued to the next page)

• Data cards which must be present in any case.

ACCESS-1 Data in Card Image Format

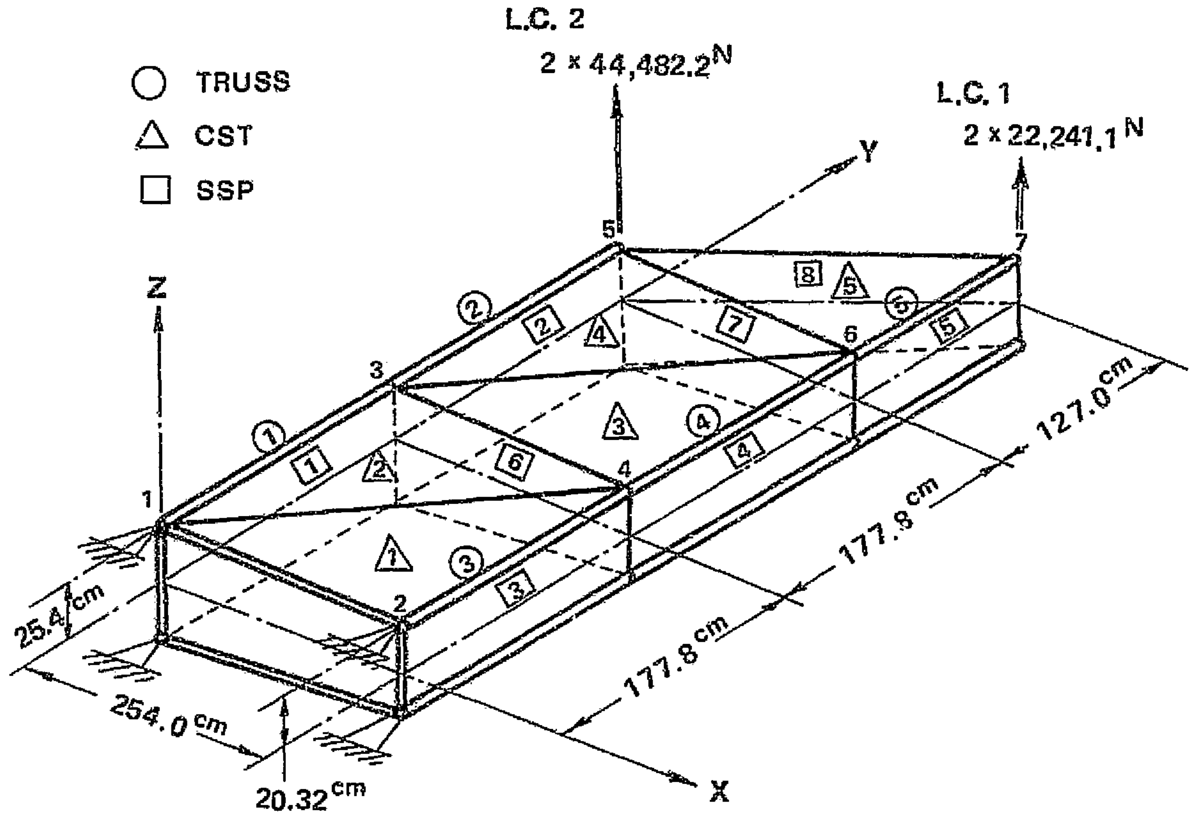
(continued from the previous page)

•	SPM	x . x x x x E x	TRF	x . x x x x E x					
•	ISCT(1)	ISCT(2)	ISCT(3)						
				ISC (m, MTYP)	(m = 1, IETP(MTYP))			(16I5)	
		REQUIRED ONLY FOR ELEMENT TYPES 'MTYP' SUCH AS ISCT(MTYP) > 0							
•	IDCT								
	NA_1	JA_1			x . x x x x E x		x . x x x x E x		
	NA_2	JA_2							
	⋮	⋮							
	NA_i	JA_i	$IDC(JA_i, NA_i)$		$DISUL(JA_i, NA_i)$		$DISLL(JA_i, NA_i)$		
	⋮	⋮							
	NA_{IDCT}	JA_{IDCT}							
•	IVCT								
	NEWSUMT VERSION CONTROL CARDS								
*	MAXIFS	MAXODM	MAXARS	MAXNAA	JSIGNG	LMODEL	JPRINT		
	EPSODM	EPSARS	EPSEA	EPSVJK	CUTARP	DELTAC	TRFMUL	TRFMAX	STEPMX	RPMIN
	CONMIN VERSION CONTROL CARDS								
*	MAXSTG	EPSSTG	TRFINC	TRFMAX	EPSVJK				
	JPRINT	ITMAX	CTL	CTLMIN	DELFUN				
**									
†	2								

- • Data cards which must be present in any case.
- * Either one of the two sets of control cards must be present.
- ** Data cards for the other jobs may be placed directly after optimizer control cards.
- † Either this card or four blank cards will terminate this run.

APPENDIX C

DATA EXAMPLES



Material:	Aluminum Alloy E = 0.68948 x 10^7 N/cm^2 ρ = 0.0027680 Kg/cm^3
Stress limits:	Upper limit = 0.68948 x 10^4 N/cm^2 Lower limit = -0.68948 x 10^4 (truss only)
Displacement limit:	±5.08 cm in Z-direction for all nodes
Side constraints:	Min. area of truss elements = 0.64516 cm^2 Min. thickness of CST and SSP = 0.0508 cm
Load conditions:	Two distinct load conditions as shown above

Example 1. 18 Element Wing Box (IS Units)

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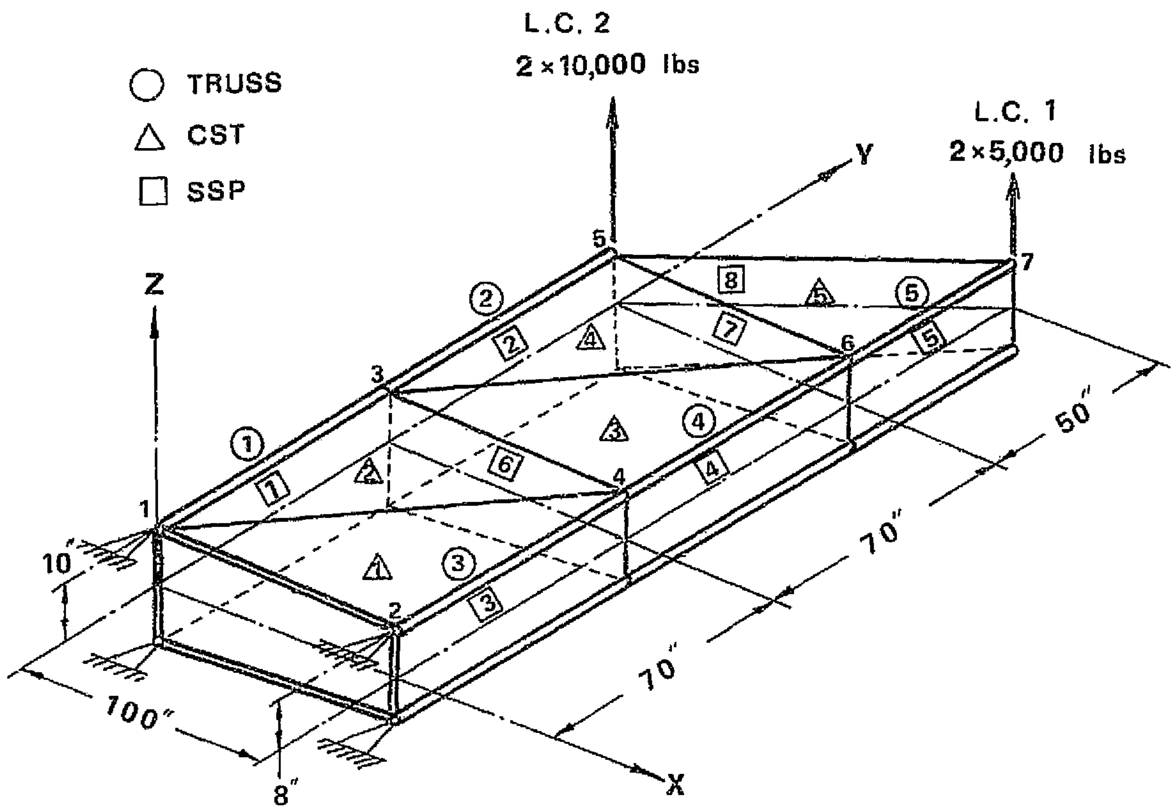


Material;	Aluminum $E = 10^7$ psi $\rho = 0.1$ lb/in^3
Stress Limits:	Upper bounds = 10^4 psi
	Lower bounds = -10^4 psi (truss only)
Displacement Limits:	±2.0 in. in z-direction for all nodes
Side Constraints:	Min. area of truss elements 0.1 in^2
	Min. thickness of CST and SSP 0.02 in.
Load Conditions:	Two distinct load conditions as shown above.

Example 1. 18 Element Wing Box (U.S. Customery Units) (Problem 8 in Ref. 1)

Example 1 18-Element Wing Box -- NEWSUMT Optimizer

comments:

```
    EIGHTEEN ELEMENT WING BOX DESIGN EXAMPLE
      REF. AFFDL-TR-70-165
      WEBS ARE MODELLED WITH SSP ELEMENTS
      5 TRUSS,  5 CST,   AND  8 SSP ELEMENTS
1    16 DESIGN VARIABLES
```

```
     0    2    0
     7    3    2    2
     4    3    8
     2    2    5
     5    5    8
```

node coordinates:

```
     1              0.0000E0     0.0000E0     0.1000E2
     2              0.1000E3     0.0000E0     0.8000E1
     3              0.0000E0     0.7000E2     0.1000E2
     4              0.1000E3     0.7000E2     0.8000E1
     5              0.0000E0     0.1400E3     0.1000E2
     6              0.1000E3     0.1400E3     0.8000E1
     7              0.1000E3     0.1900E3     0.8000E1
```

truss element data:

```
     1
       1    1        0.9800E0     0.2000E1     0.1000E0     1    1    3         -1
       2    2        0.9800E0     0.2000E1     0.1000E0     1    3    5         -1
       3    3        0.9800E0     0.2000E1     0.1000E0     1    2    4         -1
       4    4        0.9800E0     0.2000E1     0.1000E0     1    4    6         -1
       5    5        0.9800E0     0.2000E1     0.1000E0     2    6    7         -1
```

CST element data:

```
     2
       1    1        0.1960E0     0.1000E1     0.0200E0     1    1    2    4    -1
       2    1        0.1960E0     0.1000E1     0.0200E0     1    4    3    1    -1
       3    2        0.1960E0     0.1000E1     0.0200E0     1    3    4    6    -1
       4    2        0.1960E0     0.1000E1     0.0200E0     1    6    5    3    -1
       5    3        0.1960E0     0.1000E1     0.0200E0     2    5    6    7    -1
```

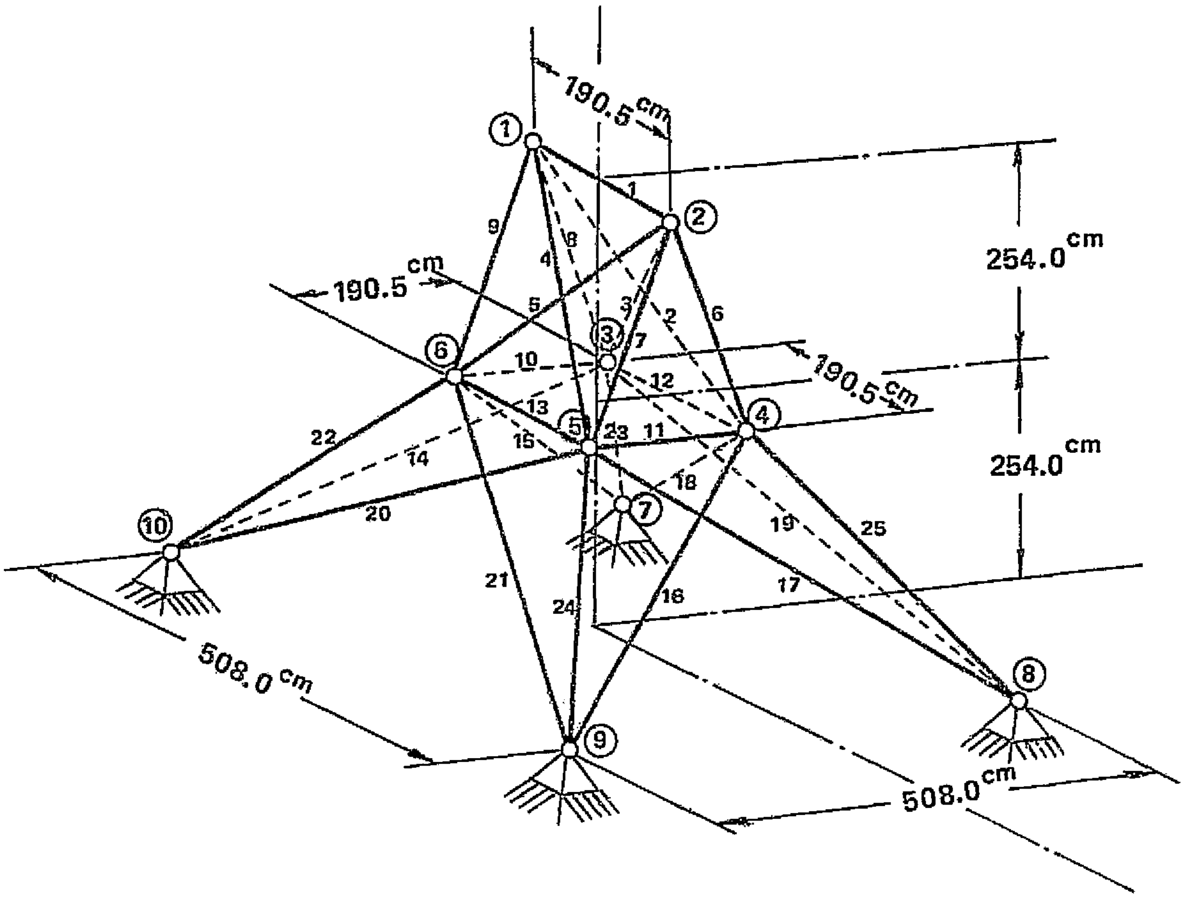
(continued to the next page)

Col. 10 20 30 40 50 60 70 80

```
3
   1    1       0.1960E0       0.1000E1       0.0200E0     1    1    3       -1   } SSP element
   2    2       0.1960E0       0.1000E1       0.0200E0     1    3    5       -1   }  data
   3    3       0.1960E0       0.1000E1       0.0200E0     2    2    4       -1   }
   4    4       0.1960E0       0.1000E1       0.0200E0     2    4    6       -1   }
   5    5       0.1960E0       0.1000E1       0.0200E0     3    6    7       -1   }
   6    6       0.1960E0       0.1000E1       0.0200E0     4    3    4       -1   }
   7    7       0.1960E0       0.1000E1       0.0200E0     4    5    6       -1   }
   8    8       0.1960E0       0.1000E1       0.0200E0     5    5    7       -1   }
1
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8                    } TRUSS material/config. group data
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8                    }
2
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8    0.3000E0        } CST material/config. group data
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8    0.3000E0        }
3
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8    0.3000E0        } SSP material/config. group data
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8    0.3000E0        }
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8    0.3000E0        }
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8    0.3000E0        }
  0.1000E5   -0.1000E5    0.1000E0    0.1000E8    0.3000E0        }
1     1    1    1                                                 } Boundary conditions
2     1    1    1                                                 }
   1   0                                                          } Load conditions
7      0.0000000E0     0.0000000E0     0.5000000E4                }
   1   0                                                          }
5      0.0000000E0     0.0000000E0     0.1000000E5                }
     0.1500E1        0.3000E0                                     } Constraints specification data
 -3   -2   -2                                                     }
  5                                                               }
  3    3    2      0.2000E1      -0.2000E1                        }
  4    3    2      0.2000E1      -0.2000E1                        }
  5    3    2      0.2000E1      -0.2000E1                        }
  6    3    2      0.2000E1      -0.2000E1                        }
  7    3    2      0.2000E1      -0.2000E1                        }
  1
 20    5    2   15   -1    1    2                                                          } NEWSUMT optimizer
0.00050 0.00100 0.00100 0.00000 0.30000 0.00200 1.20000 0.60000  100.00 1.0E-12            }  control
```

} 4 or more blank cards, if this is the last job to be processed in this run.

Col. 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80



Node Numbers	Allowable Compression Stress (N/cm^2)
1	24195.06
2 ~ 5	7991.02
6 ~ 9	11931.36
10, 11	24195.06
12, 13	24195.06
14 ~ 17	4660.16
18 ~ 21	4798.06
22 ~ 25	7640.76

Load Cond.	Node	External Loads (N)		
		X	Y	Z
1	1	4448.22	44482.2	-22241.1
	2	0.0	44482.2	-22241.1
	3	2224.11	0.0	0.0
	6	2224.11	0.0	0.0
2	1	0.0	88964.4	-22241.1
	2	0.0	-88964.4	-22241.1

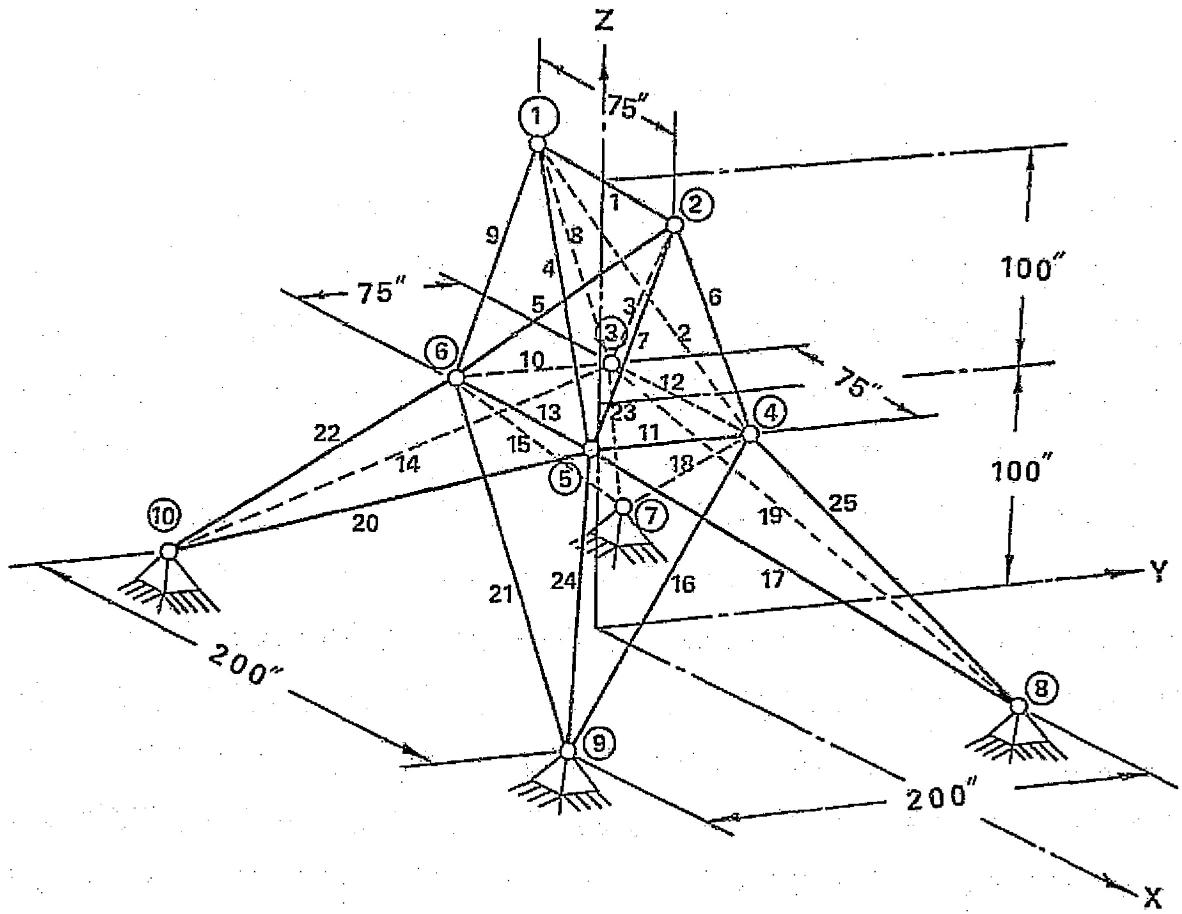
Material: Aluminum Alloy $E = 0.68948 \times 10^7$ N/cm^2
$\rho = 0.0027680$ Kg/cm^3

Stress limits: Tension = 27579.2 N/cm^2
Compression = see table above

Displacement limits: 0.8890 cm on all nodes and in all directions

Side constraints: Min. area = 0.064516 cm^2

Example 2 25-Bar Truss (IS Units)



Node Numbers	Allowable Compression Stress (psi)
1	35092.0
2 ~ 5	11590.0
6, ~ 9	17305.0
10, 11	35092.0
12, 13	35092.0
14 ~ 17	6759.0
18 ~ 21	6959.0
22 ~ 25	11082.0

Load Cond.	Node	External Loads (lbs) X	Y	Z
1	1	1000.0	10000.0	-5000.0
	2	0.0	10000.0	-5000.0
	3	500.0	0.0	0.0
	6	500.0	0.0	0.0
2	1	0.0	20000.0	-5000.0
	2	0.0	-20000.0	-5000.0

Material:	Aluminum, $E=10^7$ psi, $\rho=0.1$ pci
Stress Limits:	Tension=40000.0 psi, (see Table above for Compression)
Cross Sectional Area Lower Limits:	0.01 in^2
Upper Limits:	none specified
Displacement Limits:	0.35 in. on all nodes and in all directions

Example 2 25-Bar Truss (U.S. Customery Units) (Problem 5 in Ref. 1)

Example 2 25-Bar Truss Structure -- CONMIN Optimizer

comments:

```
25 BAR TRUSS STRUCTURE DESIGN FOR MINIMUM WEIGHT
8 DESIGN VARIABLES,  2 LOAD CONDITIONS
STRESS, DISPLACEMENT AND MINIMUM SIZE CONSTRAINTS
   OPTIMIZATION VIA CONMIN OPTIMIZER
                                        JUNE, 1975
1
   6     2     0
  10     3     4     2
   8     0     0
   6     0     0
  25     0     0
```

node coordinates:

```
  1      -0.375000E2       0.000000E0       0.200000E3
  2       0.375000E2       0.000000E0       0.200000E3
  3      -0.375000E2       0.375000E2       0.100000E3
  4       0.375000E2       0.375000E2       0.100000E3
  5       0.375000E2      -0.375000E2       0.100000E3
  6      -0.375000E2      -0.375000E2       0.100000E3
  7      -0.100000E3       0.100000E3       0.000000E0
  8       0.100000E3       0.100000E3       0.000000E0
  9       0.100000E3      -0.100000E3       0.000000E0
 10      -0.100000E3      -0.100000E3       0.000000E0
```

truss element data:

```
 1
   1    1      2.0000E0                 0.0100E0    1    1    2      -1
   2    2      2.0000E0                 0.0100E0    2    1    4      -1
   3    2      2.0000E0                 0.0100E0    2    2    3      -1
   4    2      2.0000E0                 0.0100E0    2    1    5      -1
   5    2      2.0000E0                 0.0100E0    2    2    6      -1
   6    3      2.0000E0                 0.0100E0    3    2    4      -1
   7    3      2.0000E0                 0.0100E0    3    2    5      -1
   8    3      2.0000E0                 0.0100E0    3    1    3      -1
   9    3      2.0000E0                 0.0100E0    3    1    6      -1
  10    4      2.0000E0                 0.0100E0    1    3    6      -1
  11    4      2.0000E0                 0.0100E0    1    4    5      -1
  12    5      2.0000E0                 0.0100E0    1    3    4      -1
  13    5      2.0000E0                 0.0100E0    1    5    6      -1
  14    6      2.0000E0                 0.0100E0    4    3   10      -1
  15    6      2.0000E0                 0.0100E0    4    6    7      -1
  16    6      2.0000E0                 0.0100E0    4    4    9      -1
  17    6      2.0000E0                 0.0100E0    4    5    8      -1
  18    7      2.0000E0                 0.0100E0    5    4    7      -1
  19    7      2.0000E0                 0.0100E0    5    3    8      -1
```

(continued to the next page)

```
20     7          2.0000E0                              0.0100E0    5    5   10         -1
21     7          2.0000E0                              0.0100E0    5    6    9         -1
22     8          2.0000E0                              0.0100E0    6    6   10         -1
23     8          2.0000E0                              0.0100E0    6    3    7         -1
24     8          2.0000E0                              0.0100E0    6    5    9         -1
25     8          2.0000E0                              0.0100E0    6    4    9         -1
2
3
1
   4.0000E4    -2.3093E4    0.1000E0    1.0000E7
   4.0000E4    -1.1590E4    0.1000E0    1.0000E7
   4.0000E4    -1.7305E4    0.1000E0    1.0000E7
   4.0000E4    -0.6759E4    0.1000E0    1.0000E7
   4.0000E4    -0.6353E4    0.1000E0    1.0000E7
   4.0000E4    -1.1083E4    0.1000E0    1.0000E7
2
3
4
7      1    1    1
8      1    1    1
9      1    1    1
10     1    1    1
   4   0    0
1        0.1000000E4      0.1000000E5     -0.5000000E4
2        0.0000000E0      0.1000000E5     -0.5000000E4
3        0.5000000E3      0.0000000E0      0.0000000E0
6        0.5000000E3      0.0000000E0      0.0000000E0
   2   0    0
1        0.0000000E0      0.2000000E5     -0.5000000E4
2        0.0000000E0     -0.2000000E5     -0.5000000E4
        0.1500E1             0.1000E0
  -3    0
  18
   1    1    2           0.3500E0           -0.3500E0
   1    2    2           0.3500E0           -0.3500E0
   1    3    2           0.3500E0           -0.3500E0
   2    1    2           0.3500E0           -0.3500E0
   2    2    2           0.3500E0           -0.3500E0
   2    3    2           0.3500E0           -0.3500E0
   3    1    2           0.3500E0           -0.3500E0
   3    2    2           0.3500E0           -0.3500E0
   3    3    2           0.3500E0           -0.3500E0
   4    1    2           0.3500E0           -0.3500E0
   4    2    2           0.3500E0           -0.3500E0
   4    3    2           0.3500E0           -0.3500E0
   5    1    2           0.3500E0           -0.3500E0
   5    2    2           0.3500E0           -0.3500E0
   5    3    2           0.3500E0           -0.3500E0
   6    1    2           0.3500E0           -0.3500E0
   6    2    2           0.3500E0           -0.3500E0
   6    3    2           0.3500E0           -0.3500E0
   1
  20       0.0010000E0      1.2000000E0      0.5000000E0      0.0000000E0
   1   20    -0.0100000E0      0.0050000E0      0.0000000E0
2
```

truss material/config. group data

boundary conditions

load condition 1

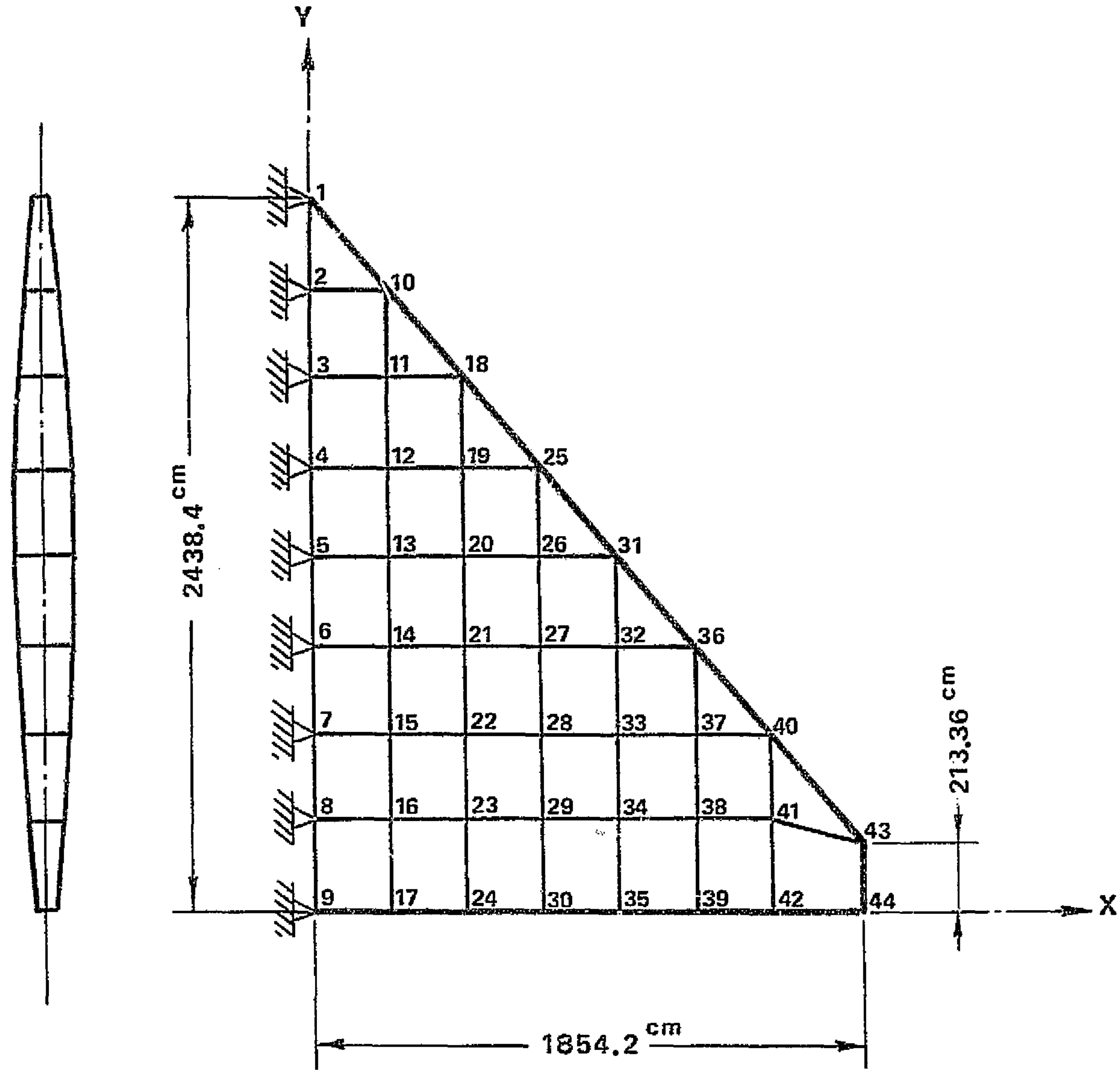
load condition 2

constraint specification data

CONMIN optimizer control

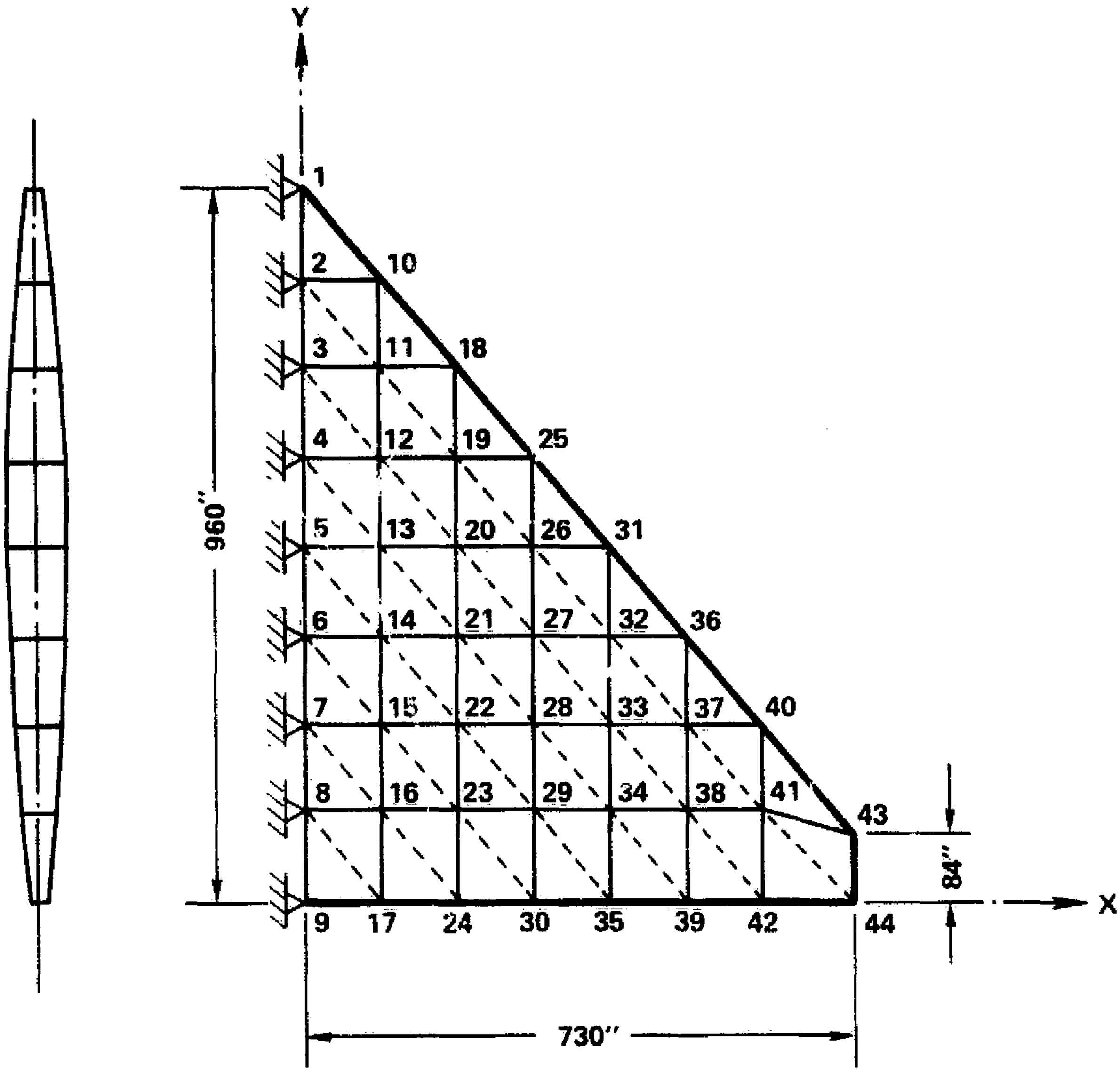
indicates end of this run.

ORIGINAL PAGE IS
OF POOR QUALITY



Material:	Titanium E = 11.3061 x 10^6 N/cm^2 ρ = 0.0044288 Kg/cm^3
Stress limits:	Upper limit 86,184.38 N/cm^2
Displacement limits:	Linear envelope with 256.032 cm at the tip nodes
Load condition:	0.689475 N/cm^2 equivalent

Example 3. Delta Wing (IS Units)



Material: Titanium

Stress Limits: 125,000 psi

Displacement Limits: Linear envelope with 100.8 inches at the tip nodes.

Load Condition: 144 lbs/ft^2 equivalent.

Example 3 Delta Wing (U.S. Customery Units)
(Problem 10C in Ref.1)

```
DELTA WING DESIGN OPTIMIZATION   [illegible]   PROBLEM 10C IN NASA-CR-5225
  TITANIUM THIN SYMMETRIC DELTA WING DESIGN PROBLEM FOR STATIC CONSTRAINTS
        REF.   W.J.STROUD  ET.AL.   NASA TN D-6534,  1971
              63 ELEMENTS   16 DESIGN VARIABLES FOR CST ELEMENTS
              70 ELEMENTS   12 DESIGN VARIABLES FOR SSP ELEMENTS
                  STARTING POINT 1,   MODEL=1
1
   0      2      0
  44      3      0      1
   0     16     12
   0      5     70
   0     63     70
  1        0.000000D0        0.960000D3        0.646779D1
  2        0.000000D0        0.840000D3        0.114712D2
  3        0.000000D0        0.720000D3        0.150102D2
  4        0.000000D0        0.600000D3        0.170847D2
  5        0.000000D0        0.480000D3        0.176949D2
  6        0.000000D0        0.360000D3        0.168407D2
  7        0.000000D0        0.240000D3        0.145220D2
  8        0.000000D0        0.120000D3        0.107390D2
  9        0.000000D0        0.000000D0        0.549152D1
 10        0.100000D3        0.840000D3        0.638490D1
 11        0.100000D3        0.720000D3        0.111396D2
 12        0.100000D3        0.600000D3        0.142641D2
 13        0.100000D3        0.480000D3        0.157585D2
 14        0.100000D3        0.360000D3        0.156226D2
 15        0.100000D3        0.240000D3        0.138566D2
 16        0.100000D3        0.120000D3        0.104604D2
 17        0.100000D3        0.000000D0        0.543396D1
 18        0.200000D3        0.720000D3        0.628085D1
 19        0.200000D3        0.600000D3        0.107234D2
 20        0.200000D3        0.480000D3        0.133277D2
 21        0.200000D3        0.360000D3        0.140936D2
 22        0.200000D3        0.240000D3        0.130213D2
 23        0.200000D3        0.120000D3        0.101106D2
 24        0.200000D3        0.000000D0        0.536170D1
 25        0.300000D3        0.600000D3        0.614634D1
 26        0.300000D3        0.480000D3        0.101854D2
 27        0.300000D3        0.360000D3        0.121171D2
 28        0.300000D3        0.240000D3        0.119415D2
 29        0.300000D3        0.120000D3        0.965954D1
 30        0.300000D3        0.000000D0        0.526829D1
 31        0.400000D3        0.480000D3        0.596571D1
 32        0.400000D3        0.360000D3        0.946285D1
 33        0.400000D3        0.240000D3        0.104914D2
 34        0.400000D3        0.120000D3        0.905143D1
 35        0.400000D3        0.000000D0        0.514286D1
 36        0.500000D3        0.360000D3        0.571034D1
 37        0.500000D3        0.240000D3        0.844138D1
 38        0.500000D3        0.120000D3        0.819310D1
 39        0.500000D3        0.000000D0        0.496552D1
 40        0.600000D3        0.240000D3        0.532174D1
 41        0.600000D3        0.120000D3        0.688695D1
 42        0.600000D3        0.000000D0        0.469565D1
 43        0.730000D3        0.360000D2        0.436000D1
 44        0.730000D3        0.000000D0        0.395918D1
```

COMMENTS OR HEADINGS

PRIMARY CONTROL PARAMETERS

NODE COORDINATES

This data was prepared initially for the double precision version of ACCESS 1 computer program.

1
2

1	1	0.1000D0	0.0200D0	1	1	2	10	-1
2	1	0.1000D0	0.0200D0	2	2	11	10	-1
3	1	0.1000D0	0.0200D0	1	2	3	11	-1
4	1	0.1000D0	0.0200D0	1	10	11	18	-1
[illegible]	2	0.1000D0	0.0200D0	2	3	12	11	-1
6	2	0.1000D0	0.0200D0	1	3	4	12	-1
[illegible]	2	0.1000D0	0.0200D0	2	4	13	12	-1
[illegible]	2	0.1000D0	0.0200D0	1	4	5	13	-1
	3	0.1000D0	0.0200D0	2	5	14	13	-1
10	3	0.1000D0	0.0200D0	1	5	6	14	-1
11	3	0.1000D0	0.0200D0	2	6	15	14	-1
12	3	0.1000D0	0.0200D0	1	6	7	15	-1
13	4	0.1000D0	0.0200D0	2	7	16	15	-1
14	4	0.1000D0	0.0200D0	1	7	8	16	-1
15	4	0.1000D0	0.0200D0	2	8	17	16	-1
16	4	0.1000D0	0.0200D0	1	8	9	17	-1
17	5	0.1000D0	0.0200D0	2	11	19	18	-1
18	5	0.1000D0	0.0200D0	1	11	12	19	-1
19	5	0.1000D0	0.0200D0	2	12	20	19	-1
20	5	0.1000D0	0.0200D0	1	12	13	20	-1
21	6	0.1000D0	0.0200D0	2	13	21	20	-1
22	6	0.1000D0	0.0200D0	1	13	14	21	-1
23	6	0.1000D0	0.0200D0	2	14	22	21	-1
24	6	0.1000D0	0.0200D0	1	14	15	22	-1
25	7	0.1000D0	0.0200D0	2	15	23	22	-1
26	7	0.1000D0	0.0200D0	1	15	16	23	-1
27	7	0.1000D0	0.0200D0	2	16	24	23	-1
28	7	0.1000D0	0.0200D0	1	16	17	24	-1

Note that 2 cards/element are required for CST.

CST ELEMENT DESCRIPTION

29	8	0.1000D0	0.0200D0	1	18	19	25	-1
30	8	0.1000D0	0.0200D0	2	19	26	25	-1
31	8	0.1000D0	0.0200D0	1	19	20	26	-1
32	8	0.1000D0	0.0200D0	1	25	26	31	-1
33	9	0.1000D0	0.0200D0	2	20	27	26	-1
34	9	0.1000D0	0.0200D0	1	20	21	27	-1
35	9	0.1000D0	0.0200D0	2	21	28	27	-1
36	9	0.1000D0	0.0200D0	1	21	22	28	-1
37	10	0.1000D0	0.0200D0	2	22	29	28	-1
38	10	0.1000D0	0.0200D0	1	22	23	29	-1
39	10	0.1000D0	0.0200D0	2	23	30	29	-1
40	10	0.1000D0	0.0200D0	1	23	24	30	-1
41	11	0.1000D0	0.0200D0	2	26	32	31	-1
42	11	0.1000D0	0.0200D0	1	26	27	32	-1
43	11	0.1000D0	0.0200D0	2	27	33	32	-1
44	11	0.1000D0	0.0200D0	1	27	28	33	-1
45	12	0.1000D0	0.0200D0	2	28	34	33	-1
46	12	0.1000D0	0.0200D0	1	28	29	34	-1
47	12	0.1000D0	0.0200D0	2	29	35	34	-1
48	12	0.1000D0	0.0200D0	1	29	30	35	-1
49	13	0.1000D0	0.0200D0	1	31	32	36	-1
50	13	0.1000D0	0.0200D0	2	32	37	36	-1
51	13	0.1000D0	0.0200D0	1	32	33	37	-1
52	13	0.1000D0	0.0200D0	1	36	37	40	-1
53	14	0.1000D0	0.0200D0	2	33	38	37	-1
54	14	0.1000D0	0.0200D0	1	33	34	38	-1
55	14	0.1000D0	0.0200D0	2	34	39	38	-1
56	14	0.1000D0	0.0200D0	1	34	35	39	-1
57	15	0.1000D0	0.0200D0	2	37	41	40	-1

CST ELEMENT DESCRIPTION

58	15	0.1000D0	0.0200D0	1	37	38	41	-1	CST ELEMENT DESCRIPTION
59	15	0.1000D0	0.0200D0	2	38	42	41	-1	
60	15	0.1000D0	0.0200D0	1	38	39	42	-1	
61	15	0.1000D0	0.0200D0	3	40	41	43	-1	
62	16	0.1000D0	0.0200D0	4	41	44	43	-1	
63	16	0.1000D0	0.0200D0	5	41	42	44	-1	
1	1	0.1500D0	0.0200D0	1	10	11		-1	SSP ELEMENT DESCRIPTION
2	1	0.1500D0	0.0200D0	2	11	12		-1	
3	1	0.1500D0	0.0200D0	3	12	13		-1	
4	1	0.1500D0	0.0200D0	4	13	14		-1	
5	1	0.1500D0	0.0200D0	5	14	15		-1	
6	1	0.1500D0	0.0200D0	6	15	16		-1	
7	1	0.1500D0	0.0200D0	7	16	17		-1	
8	1	0.1500D0	0.0200D0	8	18	19		-1	
9	1	0.1500D0	0.0200D0	9	19	20		-1	
10	1	0.1500D0	0.0200D0	10	20	21		-1	
11	1	0.1500D0	0.0200D0	11	21	22		-1	
12	1	0.1500D0	0.0200D0	12	22	23		-1	
13	1	0.1500D0	0.0200D0	13	23	24		-1	
14	2	0.1500D0	0.0200D0	14	25	26		-1	
15	2	0.1500D0	0.0200D0	15	26	27		-1	
16	2	0.1500D0	0.0200D0	16	27	28		-1	
17	2	0.1500D0	0.0200D0	17	28	29		-1	
18	2	0.1500D0	0.0200D0	18	29	30		-1	
19	2	0.1500D0	0.0200D0	19	31	32		-1	
20	2	0.1500D0	0.0200D0	20	32	33		-1	
21	2	0.1500D0	0.0200D0	21	33	34		-1	
22	2	0.1500D0	0.0200D0	22	34	35		-1	
23	3	0.1500D0	0.0200D0	23	36	37		-1	
24	3	0.1500D0	0.0200D0	24	37	38		-1	
25	3	0.1500D0	0.0200D0	25	38	39		-1	
26	3	0.1500D0	0.0200D0	25	40	41		-1	
27	3	0.1500D0	0.0200D0	27	41	42		-1	
28	3	0.1500D0	0.0200D0	28	43	44		-1	
29	4	0.1500D0	0.0200D0	29	2	10		-1	
30	4	0.1500D0	0.0200D0	30	3	11		-1	
31	5	0.1500D0	0.0200D0	31	11	18		-1	
32	6	0.1500D0	0.0200D0	32	4	12		-1	
33	6	0.1500D0	0.0200D0	33	12	19		-1	
34	6	0.1500D0	0.0200D0	34	19	25		-1	
35	7	0.1500D0	0.0200D0	35	5	13		-1	
36	7	0.1500D0	0.0200D0	36	13	20		-1	
37	7	0.1500D0	0.0200D0	37	20	26		-1	
38	7	0.1500D0	0.0200D0	38	26	31		-1	
39	8	0.1500D0	0.0200D0	39	6	14		-1	
40	8	0.1500D0	0.0200D0	40	14	21		-1	
41	8	0.1500D0	0.0200D0	41	21	27		-1	
42	8	0.1500D0	0.0200D0	42	27	32		-1	
43	8	0.1500D0	0.0200D0	43	32	36		-1	
44	9	0.1500D0	0.0200D0	44	7	15		-1	
45	9	0.1500D0	0.0200D0	45	15	22		-1	

```
 46   9   0.150000D0                                      0.020000D0   46   22   28      -1
 47   9   0.150000D0                                      0.020000D0   47   28   33      -1
 48   9   0.150000D0                                      0.020000D0   48   33   37      -1
 49   9   0.150000D0                                      0.020000D0   49   37   40      -1
 50  10   0.150000D0                                      0.020000D0   50    8   16      -1
 51  10   0.150000D0                                      0.020000D0   51   16   23      -1
 52  10   0.150000D0                                      0.020000D0   52   23   29      -1
 53  10   0.150000D0                                      0.020000D0   53   29   34      -1
 54  10   0.150000D0                                      0.020000D0   54   34   38      -1
 55  10   0.150000D0                                      0.020000D0   55   38   41      -1
 56  10   0.150000D0                                      0.020000D0   56   41   43      -1
 57  11   0.150000D0                                      0.020000D0   57    9   17      -1
 58  11   0.150000D0                                      0.020000D0   58   17   24      -1
 59  11   0.150000D0                                      0.020000D0   59   24   30      -1
 60  11   0.150000D0                                      0.020000D0   60   30   35      -1
 61  11   0.150000D0                                      0.020000D0   61   35   39      -1
 62  11   0.150000D0                                      0.020000D0   62   39   42      -1
 63  11   0.150000D0                                      0.020000D0   63   42   44      -1
 64  12   0.150000D0                                      0.020000D0   64    1   10      -1
 65  12   0.150000D0                                      0.020000D0   65   10   18      -1
 66  12   0.150000D0                                      0.020000D0   66   18   25      -1
 67  12   0.150000D0                                      0.020000D0   67   25   31      -1
 68  12   0.150000D0                                      0.020000D0   68   31   36      -1
 69  12   0.150000D0                                      0.020000D0   69   36   40      -1
 70  12   0.150000D0                                      0.020000D0   70   40   43      -1
  1
 -2
   0.1250D6    -0.1250D6     0.1600D0     0.1640D8     0.3000D0
 -3
   0.1250D6    -0.1250D6     0.1600D0     0.1640D8     0.3000D0
  1       1       1       1
  2       1       1       1
  3       1       1       1
  4       1       1       1
  5       1       1       1
  6       1       1       1
  7       1       1       1
  8       1       1       1
  9       1       1       1
   35     0
 10                                      0.807500D4
 11                                      0.807500D4
 12                                      0.807500D4
 13                                      0.807500D4
 14                                      0.807500D4
 15                                      0.807500D4
 16                                      0.807500D4
 17                                      0.807500D4
 18                                      0.807500D4
 19                                      0.807500D4
 20                                      0.807500D4
 21                                      0.807500D4
 22                                      0.807500D4
 23                                      0.807500D4
 24                                      0.807500D4
 25                                      0.807500D4
 26                                      0.807500D4
 27                                      0.807500D4
```

SSP Element Description (elements 46–70)

Material Constants (lines -2, -3)

Boundary Conditions (nodes 1–9)

Load Conditions (nodes 10–27)

```
28                                      0.807500D4   }
29                                      0.807500D4   }
30                                      0.807500D4   }
31                                      0.807500D4   }  LOAD CONDITIONS
32                                      0.807500D4   }
33                                      0.807500D4   }
34                                      0.807500D4   }
35                                      0.807500D4   }
36                                      0.807500D4   }
37                                      0.807500D4   }
38                                      0.807500D4   }
39                                      0.807500D4   }
40                                      0.807500D4   }
41                                      0.807500D4   }
42                                      0.807500D4   }
43                                      0.807500D4   }
44                                      0.807500D4   }
     0.150001         0.100000                     <--- START POINT MARGIN & INITIAL TRUNCATION FACTOR
 0    -2     -2                                    <--- STRESS CONSTRAINT SPEC.
35
10    3      2        0.1400D2      -0.1400D2   }
11    3      2        0.1400D2      -0.1400D2   }
12    3      2        0.1400D2      -0.1400D2   }
13    3      2        0.1400D2      -0.1400D2   }
14    3      2        0.1400D2      -0.1400D2   }
15    3      2        0.1400D2      -0.1400D2   }
16    3      2        0.1400D2      -0.   00D2   }
17    3      2        0.1400D2      -0.   00D2   }
18    3      2        0.2800D2      -0.2800D2   }
19    3      2        0.2800D2      -0.2800D2   }
20    3      2        0.2800D2      -0.2800D2   }
21    3      2        0.2800D2      -0.2800D2   }
22    3      2        0.2800D2      -0.2800D2   }
23    3      2        0.2800D2      -0.2800D2   }
24    3      2        0.2800D2      -0.2800D2   }  DISPLACEMENT CONSTRAINTS
25    3      2        0.4200D2      -0.4200D2   }
26    3      2        0.4200D2      -0.4200D2   }
27    3      2        0.4200D2      -0.4200D2   }
28    3      2        0.4200D2      -0.4200D2   }
29    3      2        0.4200D2      -0.4200D2   }
30    3      2        0.4200D2      -0.4200D2   }
31    3      2        0.5600D2      -0.5600D2   }
32    3      2        0.5600D2      -0.5600D2   }
33    3      2        0.5600D2      -0.5600D2   }
34    3      2        0.5600D2      -0.5600D2   }
35    3      2        0.5600D2      -0.5600D2   }
36    3      2        0.7000D2      -0.7000D2   }
37    3      2        0.7000D2      -0.7000D2   }
38    3      2        0.7000D2      -0.7000D2   }
39    3      2        0.7000D2      -0.7000D2   }
40    3      2        0.8400D2      -0.8400D2   }
41    3      2        0.8400D2      -0.8400D2   }
42    3      2        0.8400D2      -0.8400D2   }
43    3      2        1.0080D2      -1.0080D2   }
44    3      2        1.0080D2      -1.0080D2   }
 1                                               <--- SIDE CONSTRAINT SPEC.
20       5        2     15       -1        1        2                                                   } NEWSUMT
0.00100 0.00100 0.00100 0.00000 0.30000 0.00200 1.20000 0.60000  100.00 1.0E-12 } OPTIMIZER
                                                                                                         } CONTROL
```

APPENDIX D

OUTPUT EXAMPLE -- Example 1

A part of output listing for example problem 1 (18 element box wing) is given. The NEWSUMT version was used with printout parameters as IPRINT=2 and JPRINT=2. From the beginning to the end of the first stage is listed without deletion. Printouts for the intermediate stages (i.e. stages 2 to 8) are omitted, since they are simple repetitions of the first stage output as far as the output format is concerned. The final summary of the job is included in the end.

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```
EIGHTEEN ELEMENT WING BOX DESIGN EXAMPLE
  REF. AFFDL-TR-79-165
  WEBS ARE MODELLED WITH SSP ELEMENTS
  5 TRUSS, 5 CST, AND 8 SSP ELEMENTS
 16 DESIGN VARIABLES
```

PROGRAM CONTROL PARAMETERS

DATA GENERATION	0
PRINT OUT CONTROL	2
OPTIMIZATION CONTROL	0

SYSTEM PARAMETERS

NO. OF NODES	7
TOTAL NO. OF ELEMENTS	18
DIMENSION OF THE SPACE	3
NO. OF ELEMENT TYPES	3
NO. OF LOAD CONDITIONS	2

	NO. OF DV. GROUPS	NO. OF CONFIGURATION GROUPS	TOTAL NO. OF ELEMENTS
TRUSS	5	2	5
CST	3	2	5
SHEAR PANEL	8	3	8

NODE NUMBER	X	Y	Z
1	0.0	0.0	0.1000E 02
2	0.1000E 03	0.0	0.6000E 01
3	0.0	0.7000E 02	0.1000E 02
4	0.1000E 03	0.7000E 02	0.3000E 01
5	0.0	0.1400E 03	0.1000E 02
6	0.1000E 03	0.1400E 03	0.8000E 01
7	0.1000E 03	0.1900E 03	0.8000E 01

ELEMENT NO.	NODE 1	NODE 2	NODE 3	GROUP	DESIGN VARIABLE INITIAL VALUE	DESIGN VARIABLE UPPER BOUND	DESIGN VARIABLE LOWER BOUND	CONFIGURATION GROUP	PRESSURE LOAD GROUP LC=1	2	3	4	5
TRUSS ELEMENTS (DV.=CROSS SECTIONAL AREA)													
1	1	3		1	0.5800E 00	0.2000E 01	0.1000E 00	1					
2	3	5		2	0.5800E 00	0.2000E 01	0.1000E 00	1					
3	2	4		3	0.5800E 00	0.2000E 01	0.1000E 00	1					
4	4	6		4	0.5800E 00	0.2000E 01	0.1000E 00	1					
5	6	7		5	0.5800E 00	0.2000E 01	0.1000E 00	2					
CONSTANT STRAIN TRIANGULAR ELEMENTS (DV.=THICKNESS)													
1	1	2	4	1	0.1960E 00	0.1000E 01	0.2000E-01	1	0	0			
2	4	3	1	1	0.1960E 00	0.1000E 01	0.2000E-01	1	0	0			
3	3	4	6	2	0.1960E 00	0.1000E 01	0.2000E-01	1	0	0			
4	6	5	3	2	0.1960E 00	0.1000E 01	0.2000E-01	1	0	0			
5	5	6	7	3	0.1960E 00	0.1000E 01	0.2000E-01	2	0	0			
SYMMETRIC SHEAR ELEMENTS (DV.=THICKNESS)													
1	1	3		1	0.1960E 00	0.1000E 01	0.2000E-01	1					
2	3	5		2	0.1960E 00	0.1000E 01	0.2000E-01	1					
3	2	4		3	0.1960E 00	0.1000E 01	0.2000E-01	2					
4	4	6		4	0.1960E 00	0.1000E 01	0.2000E-01	2					
5	6	7		5	0.1960E 00	0.1000E 01	0.2000E-01	3					
6	3	4		6	0.1550E 00	0.1000E 01	0.2000E-01	4					
7	5	5		7	0.1960E 00	0.1000E 01	0.2000E-01	4					
8	5	7		8	0.1960E 00	0.1000E 01	0.2000E-01	5					

CONFIGURATION GROUP

GROUP NO.	UPPER STRESS LIMIT	LOWER STRESS LIMIT	SPECIFIC WEIGHT	YOUNGS MODULUS	POISSONS RATIO
TRUSS ELEMENT					
1	0.100000E 05	-0.100000E 05	0.100000E 00	0.100000E 08	
2	0.100000E 05	-0.100000E 03	0.100000E 00	0.100000E 08	
CONSTANT STRAIN TRIANGULAR ELEMENTS					
1	0.100000E 05	-0.100000E 05	0.100000E 00	0.100000E 08	0.300000E 00
2	0.100000E 05	-0.100000E 05	0.100000E 00	0.100000E 08	0.300000E 00
SYMMETRIC SHEAR PANEL					
1	0.100000E 05	-0.100000E 05	0.100000E 00	0.100000E 08	0.300000E 00
2	0.100000E 05	-0.100000E 05	0.100000E 00	0.100000E 08	0.300000E 00
3	0.100000E 05	-0.100000E 05	0.100000E 00	0.100000E 08	0.300000E 00
4	0.100000E 05	-0.100000E 05	0.100000E 00	0.100000E 08	0.300000E 00
5	0.100000E 05	-0.100000E 05	0.100000E 00	0.100000E 08	0.300000E 00

DISPLACEMENT BOUNDARY CONDITIONS

NODE NO.	BOUNDARY CODES* X	Y	Z	PRESCRIBED DISPLACEMENT X	Y	Z
1	1	1	1	0.0	0.0	0.0
2	1	1	1	0.0	0.0	0.0

* -1=PRESCRIBED, 0=FREE, 1=FIXED

LOAD CONDITIONS

LOAD CONDITION 1

LUMPED LOAD AT NODES

NODE NO.	MAGNITUDES OF LOADS X	Y	Z
7	0.0	0.0	0.5000E 04

LOAD CONDITION 2

LUMPED LOAD AT NODES

NODE NO.	MAGNITUDES OF LOADS X	Y	Z
5	0.0	0.0	0.1000E 05

CONSTRAINTS

STARTING POINT MARGIN 0.1500E 01
TRUNCATION FACTOR 0.3000E 00

STRESS CONSTRAINTS

MEMBER NO.STRESS CONSTRAINT CODE*

TRUSS ELEMENTS
ALL ELEMENTS ARE CONSTRAINED BY BOTH UPPER AND LOWER BOUNDS

CST ELEMENTS
ALL ELEMENTS ARE CONSTRAINED BY UPPER BOUNDS ONLY

SSP ELEMENTS
ALL ELEMENTS ARE CONSTRAINED BY UPPER BOUNDS ONLY

* -1 : LOWER BOUND ONLY. 0 : NO CONSTRAINTS
1 : UPPER BOUND ONLY. 2 : BOTH UPPER AND LOWER BOUNDS

DISPLACEMENT CONSTRAINTS

NODE NUMBER	DIRECTION	CODE *	UPPER BOUND	LOWER BOUND
3	3	2	0.2000E 01	-0.2000E 01
4	3	2	0.2000E 01	-0.2000E 01
5	3	2	0.2000E 01	-0.2000E 01
6	3	2	0.2000E 01	-0.2000E 01
7	3	2	0.2000E 01	-0.2000E 01

* -1 : LOWER BOUND ONLY. 0 : NO CONSTRAINTS
1 : UPPER BOUND ONLY. 2 : BOTH UPPER AND LOWER BOUNDS

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SIDE CONSTRAINTS

MEMBER NO.	SIDE CONSTRAINT CODE*	UPPER BOUND	LOWER BOUND
TRUSS ELEMENTS			
1	-1	0.2000E 01	0.1000E 00
2	-1	0.2000E 01	0.1000E 00
3	-1	0.2000E 01	0.1000E 00
4	-1	0.2000E 01	0.1000E 00
5	-1	0.2000E 01	0.1000E 00
CST ELEMENTS			
1	-1	0.1000E 01	0.2000E-01
2	-1	0.1000E 01	0.2000E-01
3	-1	0.1000E 01	0.2000E-01
4	-1	0.1000E 01	0.2000E-01
5	-1	0.1000E 01	0.2000E-01
SSP ELEMENTS			
1	-1	0.1000E 01	0.2000E-01
2	-1	0.1000E 01	0.2000E-01
3	-1	0.1000E 01	0.2000E-01
4	-1	0.1000E 01	0.2000E-01
5	-1	0.1000E 01	0.2000E-01
6	-1	0.1000E 01	0.2000E-01
7	-1	0.1000E 01	0.2000E-01
8	-1	0.1000E 01	0.2000E-01

* -1 : LOWER BOUND ONLY, 0 : NO CONSTRAINTS
1 : UPPER BOUND ONLY, 2 : BOTH UPPER AND LOWER BOUNDS

****

GENERAL CONSTRAINED FUNCTION MINIMIZATION

BY MEANS OF

SUMT WITH MODIFIED NEWTON METHOD

****

CONTROL PARAMETERS

EMODEL	1
JSTGNG	-1
JPRINT	2
MAXNAA	15
MAXANS	2
MAXECM	5
MAXITS	20
STEPMX	100.00
[illegible]	0.00100
[illegible]	0.0 [illegible]
[illegible]	0.0 [illegible]
[illegible]	0.0
DELTAC	[illegible]
CUTARP	[illegible]
[illegible]	0.[illegible]
RPMIN	[illegible]
[illegible]	1.[illegible]
[illegible]	[illegible]

SYSTEM PARAMETERS

[illegible]	1[illegible]

End of Preprocessor –

—— · —— BEGINNING OF STAGE 1 —— · ——

```
******************************
COMPLETE ANALYSIS - CONTROL= 6
******************************

 CURRENT REDUCED DESIGN VECTOR
     0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01
     0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01

 CURRENT DESIGN

   ELEMENT TYPE  1
       0.9800E 00  0.9800E 00  0.9800E 00  0.9800E 00  0.9800E 00

   ELEMENT TYPE  2
       0.1960E 00  0.1960E 00  0.1960E 00  0.1960E 00  0.1960E 00

   ELEMENT TYPE  3
       0.1960E 00  0.1960E 00  0.1960E 00  0.1960E 00  0.1960E 00  0.1960E 00  0.1960E 00  0.1960E 00

 STRUCTURAL WEIGHT OF UPPER HALF OF ONE WING = 0.46802833E 03   ONE WING = 0.93607666E 03
   TRUSS ELEMENTS =        0.32340CE 02
   CST ELEMENTS =          0.323465E 03
   SSP ELEMENTS =          0.112234E 03
```

NODAL DISPLACEMENTS

NODE	X	Y	Z	NODE	X	Y	Z
LOAD CONDITION 1							
1	0.0	0.0	0.0	2	0.0	0.0	0.0
3	-0.10672E-01	-0.84573E-01	0.93597E-01	4	-0.26425E-02	-0.25021E-01	0.15944E 00
5	-0.13655E-01	-0.17736E-01	0.3[illegible] 00	6	-0.11536E-01	-0.42044E-01	0.4[illegible]E 00
7	-0.17236E-01	-0.48[illegible]E-01	0.8312[illegible] 00				
LOAD CONDITION 2							
1	0.0	0.0	0.0	2	0.0	0.0	0.0
3	0.57794E-02	-0.420[illegible]E-01	0.3[illegible] 00	4	0.14370E-01	-0.24147E-01	0.1214[illegible]E 00
5	0.20713E-01	-0.5[illegible]E-01	0.64546E 00	6	0.20019E-01	-0.37172E-01,	0.40979E 00
7	0.21547E-01	-0.37990E-01	0.8507[illegible]E 00				

COMPUTED STRESS

TRUSS AXIAL STRESS			CST VON MISES STRESS			SSP VON MISES STRESS	STRESS COMPONENTS IN LOCAL SYSTEM SIGMA-X	SIGMA-Y	TAU-XY
TRUSS	1	-0.3510E 04							
TRUSS	2	-0.1660E 04							
TRUSS	3	-0.3717E 04							
TRUSS	4	-0.2089E 04							
TRUSS	5	-0.1284E 04							
			CST	1	0.3673E 04		-0.4085E 04	-0.1225E 04	-0.5[illegible]E 03
			CST	2	0.368[illegible] 04		-0.3630E 04	-0.3971E 0[illegible]	-0.7[illegible] 03
			CST	3	0.278[illegible]		-0.2267E 04	0.5607[illegible] 01	-0.[illegible] 03
			CST	4	0.[illegible]		-0.1[illegible] 04	-0.106[illegible]	-0.[illegible] 03

		CST	5	0.2267E 04			-0.1256E 04	0.9062E 02	-0.1372E 04
					SSP 1	0.35[illegible]E 04	-0.3510E 04	0.0	0.4251E 03
					SSP 2	0.[illegible]7E 04	-0.1380E 04	0.0	0.7300E 03
					SSP 3	0.5714E 04	-0.3717E 04	0.0	0.2235E 04
					SSP 4	0.4222E 04	-0.2289E 04	0.0	0.2048E 04
					SSP 5	0.3431E 04	-0.1284E 04	0.0	0.1837E 04
					SSP 6	0.1044E 04	0.[illegible]230E 03	0.0	-0.3759E 03
					SSP 7	0.8603E 03	0.8059E 03	0.0	-0.1738E 03
					SSP 8	0.1690E 04	-0.2346E 03	0.0	0.1033E 04
TRUSS 1	-0.6005E 04								
TRUSS 2	-0.1658E 04								
TRUSS 3	-0.3450E 04								
TRUSS 4	-0.1860E 04								
TRUSS 5	-0.1637E 03								
		CST	1	0.3556E 04			-0.3791E 04	-0.1137E 04	0.6539E 03
		CST	2	0.6029E 04			-0.6245E 04	-0.7979E 03	0.7528E 03
		CST	3	0.2353E 04			-0.1690E 04	0.5686E 03	0.6826E 03
		CST	4	0.2382E 04			-0.1689E 04	-0.1027E 03	0.5972E 03
		CST	5	0.8103E 03			-0.4676E 02	0.3898E 03	0.4018E 03
					SSP 1	0.3904E 04	-0.6005E 04	0.0	0.4547E 04
					SSP 2	0.7856E 04	-0.1658E 04	0.0	0.4434E 04
					SSP 3	0.3764E 04	-0.3450E 04	0.0	0.8696E 03
					SSP 4	0.2596E 04	-0.1860E 04	0.0	0.1046E 04
					SSP 5	0.3591E 03	-0.1637E 03	0.0	0.5456E 03
					SSP 6	0.8907E 03	0.8592E 03	0.0	0.1355E 03
					SSP 7	0.6957E 03	-0.6934E 02	0.0	-0.2996E 03
					SSP 8	0.1047E 04	0.7169E 03	0.0	-0.4402E 03

POSTURE TABLE

POSTURE TABLE TRUNCATION DATA
TRUNCATION FACTORS, SIDE = 0.300 STRESS = 0.300 DISPLACEMENT = 0.500
CUTOFF POINTS -1.109 -0.703 -0.800

NO. OF EFFECTIVE CONSTRAINTS = 34 NO. OF TOTAL CONSTRAINTS = 82
41 % IS RETAINED AS POTENTIALLY CRITICAL

EFFECTIVE CONST. NO.	CONST. NO.	VALUE OF CONSTRAINTS	TYPE	MEMBER TYPE DIRECTION	NODE MEMBER	LOAD CONDITION
1	1	-0.8580E 00	SIDE	1	-1	
2	2	-0.8560E 00	SIDE	1	-2	
3	3	-0.8590E 00	SIDE	1	-3	
4	4	-0.8380E 00	SIDE	1	-4	
5	5	-0.8580E 00	SIDE	1	-5	
6	6	-0.8580E 00	SIDE	2	-1	
7	7	-0.8930E 00	SIDE	2	-3	
8	8	-0.8580E 00	SIDE	2	-5	
9	9	-0.8580E 00	SIDE	3	-1	
10	10	-0.8580E 00	SIDE	3	-2	
11	11	-0.8580E 00	SIDE	3	-3	
12	12	-0.8589E 00	SIDE	3	-4	
13	13	-0.8910E 00	SIDE	3	-5	
14	14	-0.8580E 00	SIDE	3	-6	
15	15	-0.8580E 00	SIDE	3	-7	
16	16	-0.8580E 00	SIDE	3	-9	
17	55	-0.5570E-02	STRESS	3	1	2
18	56	-0.2144E 00	STRESS	3	2	2
19	51	-0.3571E 00	STRESS	2	2	2
20	40	-0.3995E 00	STRESS	1	-1	2
21	34	-0.4236E 00	STRESS	3	3	1
22	35	-0.5778E 00	STRESS	3	4	1
23	57	-0.6236E 00	STRESS	3	3	2
24	21	-0.6283E 00	STRESS	1	-3	1
25	28	-0.6311E 00	STRESS	2	2	1
26	32	-0.6408E 00	STRESS	3	1	1
27	17	-0.6490E 00	STRESS	1	-1	1
28	44	-0.6590E 00	STRESS	1	-3	2
29	36	-0.6509E 00	STRESS	3	5	1
30	74	-0.6773E 00	DISPLACEMENT	3	5	2
31	77	-0.7528E 00	DISPLACEMENT	3	6	1
32	78	-0.7956E 00	DISPLACEMENT	3	6	2
33	81	-0.5994E 00	DISPLACEMENT	3	7	1
34	82	-0.6746E 00	DISPLACEMENT	3	7	2

CONSTRAINT DERIVATIVE INFORMATION

15 DISPLACEMENT DOF.S ARE RETAINED OUT OF 15 OF TOTAL NUMBER OF FREE DOF.S. RETAINED RATIO =100 %

32 PSEUDO LOAD VECTORS ARE RETAINED OUT OF POSSIBLE 32 VECTORS. RETAINED RATIO = 100 %

SELECTIVE INVERSE MATRIX SCHEME IS SELECTED FOR DISPLACEMENT GRADIENT COMPUTATION

```
ACTUAL CORE REQUIREMENTS FOR LARGE ARRAYS
  MASTER STIFFNESS MATRIX        102
  GRADIENT OF DISPLACEMENTS      480
  GRADIENT OF CONSTRAINTS        544
  INVERSE OF STIFFNESS MATRIX    225   (IF NECESSARY)

ANALYSIS PROGRAM TIME STATISTICS
  UPDATE VARIABLES AND OBJECTIVE EVALUATION     0.0145 SEC
  STIFFNESS MATRIX ASSEMBLING                   0.0117
  DECOMPOSING                                   0.0050
  BACK SUBSTITUTION FOR DISPLACEMENTS           0.0039
  CONSTRAINT EVALUATION                         0.0375
  SET UP POSTURE TABLE                          0.0404
  CONSTRAINT GRADIENT EVALUATION                0.0904
    DISPLACEMENT SELECTION                          0.0033
    RIGHT HAND SIDE SET UP                          0.0203
    SELECTIVE INVERSE OF STIFFNESS MATRIX           0.0136
    SELECTIVE MULTIPLICATION OF INVERSE MATRIX      0.0184
    SELECTIVE BACK SUBSTITUTION                     0.0
    SELECTIVE GRADIENT OF CONSTRAINTS               0.0308
                                    ------------------------
                         ANALYSIS TOTAL    0.2138

EFFECTIVE NUMBER OF CONSTRIANTS =   34
NUMBER OF VIOLATED CONSTRAINTS  =    0
NUMBER OF ACTIVE CONSTRAINTS    =    0

************************************************************************************************************************

INITIAL DESIGN ANALYSIS SUMMARY

  OBJECTIVE FUNCTION =  0.4680383[illegible]E 03

  REDUCED DESIGN VARIABLES
      0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01
      0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01

  CONSTRAINT VALUES
      0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00
      0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.8980E 00  0.9576E-02  0.2144E 00  0.3971E 00  0.[illegible]E 00
      0.4280E 00  0.5776E 00  0.6236E 00  0.6283E 00  0.[illegible]E 00  0.6408E 00  0.6490E 00  0.6550E 00  0.6569E 00  0.6773E 00
      0.7520E 00  0.7556E 00  0.5554E 00  0.6746E 00
```

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```
---------------------------------
 OPTIMIZATION OF MODEL NO.  1         RESPONSE FACTOR = 0.44133E 01        ACTIVE WIDTH OF CONSTRAINTS = 0.20000E-02
---------------------------------


RESULTS SUMMARY OF THIS STAGE
  NUMBER OF RESPONSE SURFACES                  2
  NUMBER OF ONE DIMENSIONAL MINIMIZATIONS      7
  OBJECTIVE FUNCTION VALUE          0.29257?E 03
    PENALTY PART=    0.240720E 03   PENALTY/WEIGHT=    0.822?65E 00

  TIME REQUIRED FOR OPTIMIZATION           0.3445  SEC
  CUMULATIVE TIME UP TO THIS STAGE         0.5771  SEC

  REDUCED DESIGN VARIABLES
      0.2674?E 00  0.3118?E 01  0.2015E 01  0.2924E 01  0.29??E 01  0.1337E 01  0.3218E 01  0.3394E 01  0.7137E 00  0.??0?E 00
      0.5423E 00  0.8202E 00  0.1248E 01  0.3397E 01  0.3399E 01  0.3358E 01

  CONSTRAINT VALUES
      0.9727E 00  0.6819E 00  0.7544E 00  0.7017E 00  0.6576E 00  0.663?E 00  0.6614E 00  0.6537E 00  0.9272E 00  0.9407E 00
      0.9447E 00  0.9153E 00  0.9726E 00  0.6533E 00  0.6532E 00  0.6574E 00  0.5710E-01  0.3569E 00  0.1283E 00  0.1446E 00
      0.4838E 00  0.2813E 00  0.6316E 00  0.4291E 00  0.5317E 00  0.5968E 00  0.6053E 00  0.6533E 00  0.4014E 00  0.5580E 00
      0.5913E 00  0.7591E 00  0.2482E 00  0.5653E 00
```

——— END OF STAGE 1 ———

——— BEGINNING OF STAGE 2 ———

```
*******************************
COMPLETE ANALYSIS - CONTROL= 2
*******************************

  CURRENT REDUCED DESIGN VECTOR
      0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01
      0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01

  CURRENT DESIGN

    ELEMENT TYPE  1
      0.3665E 01  0.3143E 00  0.4863E 00  0.3382E 00  0.3307E 00

    ELEMENT TYPE  2
      0.1466E 00  0.1466E 00  0.5907E-01  0.5907E-01  0.5775E-01

    ELEMENT TYPE  3
      0.2746E 00  0.3374E 00  0.3614E 00  0.2361E 00  0.1576E 00  0.5769E-01  0.5767E-01  0.5837E-01

  STRUCTURAL WEIGHT OF UPPER HALF OF ONE WING = 0.29253271E 03   ONE WING = 0.58506543E 03
    TRUSS ELEMENTS =        0.3535?3E 02
    CST ELEMENTS =          0.158436E 03
    SSP ELEMENTS =          0.5884??E 02
```

•
•
•

OUTPUT FROM SUCCEEDING STAGES

•
•
•

```
****************************************************************************************************************************************************

FINAL RESULTS OF OPTIMIZATION

OBJECTIVE FUNCTION =  0.23148257E 03

REDUCED DESIGN VARIABLES
     0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01
     0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01  0.1000E 01

CONSTRAINT VALUES
     0.5479E-03  0.6021E-03  0.2493E 00  0.5563E-03  0.3719E 00  0.2460E-03  0.2590E-03  0.3539E 00 -0.1931E-07  0.5154E-04
     0.3144E-03  0.1623E-03  0.4242E-03  0.6984E-03  0.7610E-03  0.2339E-01  0.1058E 00  0.1061E 00  0.1773E 00  0.1793E 00
     0.1035E 00  0.2164E 00  0.3037E 00  0.3841E 00  0.3864E 00  0.3381E 00  0.2541E-03


CUMULATIVE NUMBER OF RESPONSE SURFACES            10
CUMULATIVE NUMBER OF ONE DIMENSIONAL MINIMIZATION 43


NUMBER OF EXACT ANALYSES         9
NUMBER OF APPROXIMATE ANALYSES 411


   TIME AND COUNTING STATISTICS OF THIS JOB

    COMPUTATION TIME REQUIRED

     INITIAL PREPARATIONS                          0.2454   SEC
     DESIGN STAGES TOTAL                           4.1207
       OPTIMIZATION                                 1.3750
         APPROXIMATE FUNCTION EVALUATIONS            0.5764
       ANALYSES                                     2.0634
         UPDATING AND OBJECTIVE CALCULATIONS         0.1271
         STIFFNESS MATRIX ASSEMBLING                 0.1075
         DECOMPOSING STIFFNESS MATRIX                0.0404
         BACK SUBSTITUTIONS                          0.0291
         CONSTRAINT CALCULATION                      0.3377
         SET UP RESTORE TABLE                        0.3734
         CONSTRAINT GRADIENT                         0.9657
           DISPLACEMENT SELECTION                      0.0203
           RIGHT HAND SIDE SET UP                      0.1744
           SELECTIVE INVERSE MATRIX                    0.1053
           SELECTIVE MULTIPLICATION                    0.1533
           SELECTIVE BACK SUBSTITUTION                 0.0
           SELECTIVE GRADIENT OF CONSTRAINTS           0.4102
                            ----------------------------------
                             TOTAL EXECUTION TIME   4.3671


    COUNTING INFORMATION

     NUMBER OF STAGES PERFORMED                 8
     NUMBER OF COMPLETE ANALYSES                9
     NO. OF FUNCTION VALUE CALLS BY OPTIMIZER 411
     NO. OF GRADIENT CALLS BY OPTIMIZER       411

     TOTAL NUMBER OF CONSTRAINTS               62

     AVERAGE NO. OF EFFECTIVE CONSTRAINTS      33

     NO. OF INDEPENDENT DESIGN VARIABLES       16
```

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END OF JOB

APPENDIX E

PROGRAM MODIFICATION TO REPLACE SSP ELEMENTS

WITH SYMMETRIC PURE SHEAR ELEMENTS

Element stiffness matrix for a pure shear element can be shown as

$$[k_e] = \frac{Et}{4(1+\nu)} \begin{bmatrix} \alpha & -1 & \alpha & 1 \\ -1 & 1/\alpha & -1 & -1/\alpha \\ \alpha & -1 & \alpha & 1 \\ 1 & 1/\alpha & 1 & -1/\alpha \end{bmatrix}$$

where

E: Modulus of elasticity

ν: Poisson's ratio

t: Thickness of the element

α: Aspect ratio a/b

a: length of the element

b: full depth of the element

Stress state is

$$\sigma_x = 0$$

$$\sigma_y = 0$$

$$\tau_{xy} = \frac{E}{2(1+\nu)} \left(\frac{\tilde{u}_p + \tilde{u}_q}{b} - \frac{\tilde{v}_p - \tilde{v}_q}{a} \right)$$

where

$\tilde{u}_p, \tilde{v}_p$: x, y displacement of p node in local coordinate system

$\tilde{u}_q, \tilde{v}_q$: x, y displacement of q node in local coordinate system

Stress constraint is written as

$$|\tau_{xy}| \leq \tau_{allowable} \text{ (input data)}$$

Only modifications to be made are stiffness matrix, stress computation and gradient of stress computation. By tracing the program description, it will be obvious that PREP, COMSTR and MULSSP must be modified, accordingly.

Let us decide to use IOPT parameter and assume that all SSP elements are replaced by pure shear elements if IOPT = -1. The following modifications will be required.

PREP

9 lines below statement number 380

```
      C=E3(I)/(12.0E0*(1.0E0+RNU3(I)))
      F=2.0E0*(1.0E0+RNU3(I))/AR
      IF(IOPT.EQ.-1) F=0.0  <------  Insert
      IH=(I-1)*10
```

COMSTR

14 lines below statement number 250

```
      SXY=(V(1)+V(3))*B-(V(2)-V(4))*A
      IF(IOPT.EQ.-1) GO TO 252 -
      STRMIS=SX*SX+3.0E0*SXY*SXY
      STRMIS=SQRT(STRMIS)          Insert
      GO TO 260
 252  SX=0.0
      STRMIS=ABS(SXY)
 260  CONTINUE
```

[illegible]

4 lines from the end of COMMON/BLKA04

```
      R=1.0/(1.0+RNU3(I))
      IF(IOPT.EQ.-1) GO TO 100 --  Insert
      ARSXY=A*R*SXY
      TA(6)=3.0*ARSXY
```

```
      GO TO 110
  100 C=0.5*R*E3(I)
      IF (SXY.LT.0.0) C=-C
      TA(1)=B*DCSPX(M)          <---- Insert
      TA(2)=B*DCSPY(M)
      TA(3)=-A
      TA(4)=TA(1)
      TA(5)=TA(2)
      TA(6)=A
  110 DSIG=0.0
```

It must be confirmed that IOPT is transferred to all of these three subroutines: in other words, check if common block BLKA01 is declared in each of these routines.

Also the allowable upper stress limits for SSP elements should be selected properly. If the distortion energy criterion (von Mises combined stress criterion) is used, $\tau_{allowable} = \frac{1}{\sqrt{3}} \sigma_{yield}$. If conventional shear stress criterion is preferred, $\tau_{allowable} = \frac{1}{2} \sigma_{yield}$.