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Graphics and Composite Material Computer Program Enhancements for SPAR

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GRAPHICS AND COMPOSITE MATERIAL COMPUTER PROGRAM FOR USE WITH SPAR

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SUMMARY

The SPAR computer software system is used for finite element structural and thermal analysis. This report contains user documentation of additional computer programs that have been developed for use in conjunction with SPAR. These programs plot digital data, simplify input for composite material section properties and compute lamina stresses and strains. Sample problems are presented including execution procedures, program input and tabulated and graphical output.

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INTRODUCTION

Studies of structural configurations using finite element models yield large amounts of data which must be analyzed. Effective evaluation of these data can be enhanced by a graphical representation. This paper contains the user documentation for computer programs developed or modified to interface with the data base of the SPAR level 14 finite element computer code (reference 1). These capabilities are used in the interpretation of results and in reducing input to the composite material section properties of the SPAR computer code. These capabilities include; (1) a hidden line graphics program for plotting the deformed and undeformed finite element model; (2) a contour plotting program; and (3) a capability for the development of composite material section properties and subsequent postprocessing of lamina stresses and strains into a more convenient form. These programs are written in FORTRAN IV language for the Control Data Cyber series digital computers with the Network Operating System (NOS). The plotting program contains adequate comment statements to allow conversion to any plotting system.

SYMBOLS

$X \quad Y \quad Z$ - Coordinate system fixed in model

$X_0 \quad Y_0 \quad Z_0$ - Coordinate system containing viewing planes

z - Coordinate through the thickness

$\sigma_x \quad \sigma_y \quad \tau_{xy}$ - Normal and shear stresses in the elemental reference frame

$\sigma_1 \; \sigma_2 \; \tau_{12}$ - Normal and shear stresses in the principal material coordinate systems

$\varepsilon_x \; \varepsilon_y \; \gamma_{xy}$ - Normal and shear strains in the elemental reference frame

$\varepsilon_1 \; \varepsilon_2 \; \gamma_{12}$ - Normal and shear strains in the principal material coordinate system

E11 E22 E33 - Three dimensional extensional
G12 G12 G23 and shear moduli and Poisson's
UN12 UN13 UN23 ratio

RHO - Material density

t - Finite element thickness

h_i - Distance from neutral axis

k - Layer numbers

Program Capabilities

The three capabilities described in this report were developed as preprocessors or post processors to SPAR, interacting only with the SPARLA data base. By implementing these capabilities in this fashion the impact on subsequent versions of SPAR would be minimized. The necessary I/O and data handling routines employed in these capabilities are described in reference (2).

Another common feature of these capabilities is dynamic addressing of storage (DAS). By utilizing DAS all problem dependent vectors of data are stored in a single working vector in blank COMMON. This allows the user to specify only the central memory necessary to solve the problem. The working vector, blank COMMON, begins at the first word address following the loaded program and extends to the end of the available central memory as defined by the user.

The concept of element groups and types, in SPAR, can enable a user to greatly reduce the complexity of modeling and interpreting the results of a structure. In a similar fashion the three capabilities utilize this concept to allow the user to specify parts of the structure to be operated upon. This is performed by the selection of sets of element groups and types. No option exists to select specific elements within a particular group.

HIDDEN LINE REMOVAL GRAPHICS PROGRAM - HIDLIN

The hidden-line graphics program, denoted as HIDLIN, is a modification of that presented in references 3 and 4 which was an option to the general orthographic plotting program of reference 5. Plots of the deformed and undeformed finite element model in a 3-D rectangular Cartesian coordinate system are generated on a 2-D viewing plane by HIDLIN. The deformed plots are of nodal translations such as static displacements and vibration or buckling modes. Such plots are very useful in debugging complex finite element models and in visualizing the overall structural response of the model.

Comparison of figures 1 and 2 illustrates the clarity of a composite cross beam model drawn by HIDLIN versus a drawing of all elements by SPAR. The deformed plot is shown in figure 3.

Another example of the usefulness of HIDLIN is depicted in figures 4 through 7 showing the finite element model used in supersonic cruise aircraft research at NASA - Langley Research Center (ref. 6). This model consists of rods, shear webs and triangular and quadrilateral membrane and aleotropic elements. The full undeformed finite element model of the aircraft model is presented in figure 4 with figures 5 and 6 representing the undeformed and deformed HIDLIN plots respectively. Figure 7 represents the HIDLIN drawing of just the shear webs of the model depicting the internal structure. Upon inspection of figures 1 through 7 the advantages of using HIDLIN is evident in debugging and visualizing the structural response of the finite element models.

Plots can be generated for structural models containing any combination of 1, 2 and 3-D elements. Faces of the solid elements (3-D) are internally converted by the program to triangular or quadrilateral (2-D) elements for computation purposes. In terms of SPAR nomenclature the elements the user can specify are; E21-E24, E31-E33, E41-E44, S41, S61, S81.

Graphic errors in the form of partially drawn "hidden elements" can occur during a normal execution of HIDLIN. These errors, if they occur, do not greatly detract from the overall appearance of the structure and do not reduce the program's effectiveness in debugging complex finite element models or in depicting overall structural response as seen by comparing figures 3 and 8. To eliminate these errors, the user can rotate the model a few degrees or adjust DMAG. DMAG, used in checking an element's visibility, is the parameter that controls the amount an element is reduced about its center. The causes of these errors are numerical roundoff and a limitation on the number of segments of a partially hidden element.

The additional computation required to reduce or eliminate these errors is not justifiable.

Input data.- The input data deck is shown schematically in Figure 9 and is described in detail in this section. SPAR data base SPARLA must be disc resident prior to the execution of HIDLIN.

SPARLA data.- The SPARLA data base must contain the basic structure topology prior to execution of HIDLIN.

SPARLA DATA SET NAME	DESCRIPTION
JLOC BTAB 2 5	Data set containing nodal coordinates
DEFO POSI MASK MASK	Data set containing nodal translations in similar format as JLOC BTAB. This data set is used in deformed plots only. This data set can be developed through use of the TRAN function in processor AUS.
DEF E21 MASK MASK ⋮ " E24 " " " E31 " " ⋮ " E33 " " " E41 " " ⋮ " E44 " " " S41 " " " S61 " " " S81 " "	Data sets containing element connectivities.

User defined data.- User defined data includes a NAMELIST statement and data defining element type and group numbers of the plotted structure.

NAMELIST MAX.- This NAMELIST contains values to allocate storage and values specifying various program options.

FORTRAN NAME	DEFAULT VALUE	DESCRIPTION
IDISP	0	Deformed plot parameter 0 - undeformed plot 1 - deformed plot
NCKELE		Estimate of the total number of triangular and quadrilateral finite elements (must be equal to or greater than the actual numbers)
DSCALE	1.0	Displacement magnification factor used when IDISP=1
DELX, DELY	1.0	Origin shift factor in the scaled and rotated coordinate systems
KHORZ	1	Integer designating the horizontal axis of the viewing plane where $1=X_o$; $2=Y_o$; $3=Z_o$
KVERT	2	Integer designating the vertical axis of the viewing plane where $1=X_o$; $2=Y_o$; $3=Z_o$

FORTRAN NAME	DEFAULT VALUE	DESCRIPTION
PHI	0.0	Angular rotation of model about its X-axis in degrees (performed third)
THETA	0.0	Angular rotation of model about Y-axis in degrees (performed second)
PSI	0.0	Angular rotation of model about its Z-axis in degrees (performed first)
PSCALE	1.0	Joint coordinate magnification factor
DMAG	.99	Reduction factor used in reducing the size of each element about its center for checking visibility of an element.

The scaling of the joint coordinates (XYZ) and deformations (DISP) and the translation of the plotting origin (DELX, DELY) is described by the following equation;

$$XYZ^{plot} = XYZ_{model}^{original} * PSCALE + DISP * DSCALE + DEL(X \text{ or } Y).$$

The following card(s) determine element type and group number to be considered by the program.

COLUMN	FORTRAN VARIABLE	
1-5 (Right adjusted)	NGRP	Element group number
6-10 "	NELT	Spar Element Type
	21	E21
	22	E22
	⋮	⋮
	44	E44
	441	S41
	661	S61
	881	S81

An estimate of the field length required to run HIDLIN is given as follows:

$$FL_{10} = 18355 + 6* (NNOD + NCKELE)$$

where NNOD is the number of nodes and NCKELE is the sum of the triangular and quadrilateral finite elements.

Output.- The input NAMELIST MAX is printed to verify input data, followed by the length of blank common required for program execution. The third section of output is a listing of element types and group numbers that are being plotted. An example of input and output (printed and plotted) is presented in sample problem 1.

CONTOUR PLOTTING

The contour plotting capability consists of two programs which are executed sequentially. The first program, denoted as STR, extracts user designated topology and stress information from the SPARLA library and sets up two input files for the contour plotting program, STCR. Using the input data developed by STR, STCR plots contours over the specified structure. Besides the contour levels only the border of the specified structure is drawn to reduce confusion. Three plots are generated corresponding to σ_x, σ_y, and τ_{xy} stresses. Figure 10 depicts stress contours of the upper flange of the composite cross beam structure shown in figures 1 through 3.

PREPROCESSOR FOR CONTOUR PLOTTING - STR

STR extracts stress and topology data resident in the SPARLA library and sets up two input files for the contour plotting program STCR. The user designates the element types and group numbers in specifying the desired structure. Triangular and quadrilateral membrane and aleotropic elements are considered in SPAR nomenclature as E31, E33, E41, E43 elements. All the elements in the specific groups are included in the input file for STCR.

Stresses as calculated in SPAR are oriented in the local elemental reference frame. These local reference frames can vary from element to element and must be transformed to a common reference frame. This transformation is accomplished by rotating these local stresses by the angle θ which the user must input into the SPAR material property (MATC) table.

Input data.- The input data deck is shown schematically in Figure 9 and is described in detail in this section. SPAR data base SPARLA must be disk resident prior to the execution of STR.

SPARLA data.- The SPARLA data base must contain the basic structure topology and stress information prior to execution of STR.

SPARLA DATA SET NAME	DESCRIPTION
JLOC BTAB 2 5	Data set containing nodal coordinates
MATC BTAB MASK MASK	Data set containing material property table
SA BTAB MASK MASK	Data set containing section property table
STRS E31 MASK MASK " E33 " " " E41 " " " E43 " "	Data sets containing element connectivities and stress information

User defined data.- User defined data includes a NAMELIST statement and data defining element type and group numbers of the plotted structure.

NAMELIST MAN.- This NAMELIST contains topology and stress parameters pertinent to the execution of STR. MAN also contains the appropriate NAMELIST parameters used in NAMELIST MAX of program STCR.

FORTRAN NAME	DEFAULT VALUE	DESCRIPTION
III	1	Horizontal axis on viewing plane where 1=X, 2=Y, 3=Z are the model coordinate system
JJJ	2	Vertical axis on viewing plane where 1=X, 2=Y, 3=Z are the model coordinate system
IPOS	0	Location of stress calculation for SPAR finite elements 0 z = 0 (mid-plane) 6 z = t/2 (upper-surface) 12 z = -t/2 (lower-surface)
ICEN	0	Location of stress component (this parameter common to STR and STCR) 0 centroidal stress 1 nodal stress

The following parameters are required in this NAMELIST and are passed to program STCR.

SCLX, SCLY	1.0	Joint coordinate scale factor
XSHFT, YSHFT	1.0	Origin shift factor
NCONT	5	Number of contour levels
ILAB	0	Contour labeling parameter 0 - No 1 - Yes
HGHT	.1	Size of contour label

FORTRAN NAME	DEFAULT VALUE	DESCRIPTION
ICOPT	0	Contour specification parameter 0 - program specifies contour based upon the formula $SS(J) = \frac{(\quad I \quad)}{NCONT+1} * (SMAX(J)-SMIN(J)) + SMIN(J)$ $I=1, NCONT; J=1, 2, 3$ Where SS is the stress contour level and J=1, 2, 3 represents the stress component σ_x, σ_y, τ_{xy}, respectively 1 - user specifies contour levels based upon the formula $SS(J) = (I-1) * DSIG(J) + SIG(J)$
SIG(J)	0.0	Starting stress contour level
DSIG(J)	0.0	Stress contour level increment
RNDOFF	1.0E-7	Roundoff error parameter used to eliminate small deviations from 0.0 level contour
ILEROY	0	Leroy plotting option 0 - No 1 - Yes

The following card(s) determine element type and group number to be considered in this program.

COLUMN	FORTRAN VARIABLE		
1-5 (Right adjusted)	NN	Element type	
		Spar Element	NN
		E31	31
		E33	33
		E41	41
		E43	43
6-10 (Right adjusted)	NG1	Element Group Number	

The user can stack several different type and group cards to define the appropriate structure.

An estimate of the field length required to run STR is given as follows:

$$FL_{10} = 15589 + 3 * NNOD + 9 * NMAT + 43 * NSECT + NNN * NEL$$

$$\text{where } NNN = \begin{matrix} 9 & \text{if } ICEN = & 0 \\ 16 & & 1 \end{matrix}$$

NNOD is the number of nodes in the model, NMAT and NSECT are the number of entries in the MATC and SA tables respectively, NEL is the number of finite elements to be plotted and ICEN defines where the stresses are computed on the elements.

Output.- The output from this program is in two forms, printed and disk or tape resident. Input NAMELIST MAN is printed to verify input data, followed by the length of blank common required for program execution. The third section of output is a listing of the element types and group numbers that are to be plotted. The disk resident output from this routine to be used in the contour plotter is formatted in card images and located on tape 9 and tape 10. The data structure of tape 9 consists of; NAMELIST MAX, sequential ordering of joints and element connectivities. Tape 10 contains the elemental centroidal or nodal stresses (σ_x, σ_y, τ_{xy}).

CONTOUR PLOTTING PROGRAM - STCR

The contour plotting program, STCR, draws the border of the specified structure along with specified contour levels. Those contours intersecting the border can be optionally labeled corresponding to the printed output. The contour levels are tabulated in the program output. The method of drawing contours employed in STCR is analogous to that of reference 5 and will not be discussed here. Three contour plots, depicting σ_x, σ_y, and τ_{xy}, are drawn during a program execution as demonstrated in sample problem 2.

The contours depicted in figures 10a through 10c have sharp corners and small extensions which could mislead the interpretation of results by a novice user of a finite element program. These corners are a result of the stress averaging at the element nodes and calculation of the contour line segment. These contours can be made smoother by using a finer mesh of elements.

Input data.- If program STCR is executed sequentially after STR, no additional input is necessary. The following data are given to allow this program to be used alone. Tape 9 (input file) contains NAMELIST MAX, sequential ordering of joints and element connectivities while tape 10 contains element centroidal or nodal stresses (σ_x, σ_y, τ_{xy}).

NAMELIST MAX.- This NAMELIST contains all the parameters necessary to control the contour plotting.

FORTRAN NAME	DEFAULT VALUE	DESCRIPTION
NNOD		Number of nodes
NEL		Number of elements

See NAMELIST MAX of program STR for description of the following: SCLX, SCLY, XSHFT, YSHFT, NCONT, ILAB, HGHT, ICOPT, SIG(3), DSIG(3), RNDOFF, ILEROY.

- Sequential ordering of nodal coordinates

  X_c, Y_c; (NNOD cards) (2F10.4)
- Element Connectivities (NEL cards) (4I5)
- Element centroidal or nodal stresses

if	ICEN=0	centroidal stresses
		σ_x, σ_y, τ_{xy} (3F10.4)
if	ICEN=1	nodal stresses
		σ_x (4F10.4)
		σ_y (4F10.4)
		τ_{xy} (4F10.4)

An estimate of the field length required to run STCR is given as follows:

$$FL_{10} = 18088 + 6* \text{NNOD} + 4* \text{NEL}$$

where NNOD and NEL are the number of nodes and finite elements respectively.

Output.- NAMELIST MAX is printed to verify input. The length of blank common is indicated. The contour number and its associated value is listed. A typical plotted output is shown in sample problem 2.

COMPOSITE LAMINATE CAPABILITY

The composite laminate program consists of two programs; SAT, which is used to calculate the section property table (SA data set), and program STST for the determination of lamina stresses and strains in the elemental and principal material directions. The input of composite laminate section properties into SPAR is possible by direct input of the laminate stiffness coefficient matrix or by ply-by-ply specification of the lamina stiffness matrix. Either method requires the user to execute additional programs, separate from SPAR, to generate this input data. In the execution of program SAT the user defines the necessary orthotropic material properties and the appropriate stacking sequence for each section while the program performs all necessary calculations for the SPAR SA table entries.

The stress recovery in SPAR has two forms. For all elements with section types other than LAMINATE the laminate stress resultants or average laminate stresses are computed while the LAMINATE section type provides for the calculation of stresses on a ply-by-ply basis only. Neither of these allow for the direct determination of strains in the elemental or principal material reference direction. In addition to the SPAR generated stress data the user can have program STST calculate stresses and strains in the elemental and principal material directions on a ply-by-ply basis. This information can be optionally directed to a file in a format consistent with input for the contour plotting program STCR.

SHELL SECTION PROPERTIES PROGRAM - SAT

The SAT program generates shell section properties, SA table entries, applicable to composite materials. Besides the SA table data set, developed by SAT, a data set containing constituent section properties, denoted as ARMY COMP (NLAY) 0, is stored in the SPARLA library. These data sets in addition to the stress resultants computed by SPAR are used by program STST in computing lamina stresses and strains of the appropriate elements. The SA tables generated by SAT are applicable to the following SA sections; isotropic, membrane, plate, uncoupled and coupled.

The user specifies the constituent material properties to be used in developing all the different section properties. Each different section is defined with respect to ply orientation, lamina thickness and constituent materials. Sign convention and consistency with the mathematical formulation of SPAR is maintained. Figure 11 depicts sign convention and typical laminate construction.

Input data.- The input data deck is shown schematically in figure 12 and is described in detail in this section. SPAR library SPARLA must be disk resident prior to the execution of SAT.

Comment card.- One card required to identify the data deck.

NAMELIST MAX.- This NAMELIST sets up the required number of cards to be read later for different section properties. Note, there are no default values in this namelist.

FORTRAN VARIABLE	DESCRIPTION
NSECT	Number of different section properties to be developed
NLAY	Maximum number of layers in a section
NMAT	Number of different material properties to be input

NAMELIST PROP.- This NAMELIST contains the material identification number and its associated properties.

FORTRAN VARIABLE	DESCRIPTION
IMAT	Material property identification (number not to exceed NMAT)
E11, E22, E33, G12, G13, G23, UN12, UN13, UN23	Three dimensional material properties
RHO	Material density

NAMELIST SECT.- This NAMELIST contains the section topology information to be read in NSECT times.

FORTRAN VARIABLE	DESCRIPTION
ILAY	Number of layers in section
ISPARM	SPAR material number corresponding to MATC table entry
ISPTYP	SPAR section type
ZSHFT	Neutral axis shift

ISPTYP	SPAR SECTION TYPE
1	membrane
2	plate
3	uncoupled
4	coupled
3	isotropic

The following layer identification card(s) to be read ILAY times for each section.

COLUMN	FORTRAN VARIABLE	DESCRIPTION
1-10	THETA(I)	lamina rotation angle, relative to the elemental and material coordinate systems, refer to figure 11(b)
11-20	T(I)	lamina thickness
21-25 (Right adjusted)	M(I)	lamina material number (IMAT)

SPAR stress recovery cards

FORTRAN VARIABLE	DESCRIPTION
F(I, J)	SPAR stress recovery parameter I=1, 2, 3; J=1, 2, 3, 4, 5, 6 (18 entries) Format (8E10.3)

An estimate of the field length required to run SAT is given as follows:

$$FL_{10} = 18867 + 37 * NMAT + (12 * NLAY + 140) * NSECT + NLAY$$

where NMAT is the number of different materials, NLAY is the maximum number of layers in any laminate and NSECT is the number of sections (SA table entries).

Output.- All input NAMELISTS are printed along with the [ABD] matrices (a 6 x 6 laminate coefficient stiffness matrix) and their inverses for each section (SA table entry). An example of input and output is presented in sample problem 3.

STRESS-STRAIN CALCULATION PROGRAM - STST

Program STST determines lamina stresses and strains in the elemental and principal material directions. A contour plotting option is available to the user in the creation of a stress or strain file applicable to program STCR. As was the case in programs HIDLIN and STR the user defines the structure of interest by specifying group numbers and element types. All the elements within such a specification would have their lamina stresses and strains computed. Successive specifications can be defined to establish the desired structure.

Input data.- The input data deck is shown schematically in Figure 9 and is described in detail in this section. SPAR library SPARLA must be disc resident prior to execution with data set ARMY COMP (NLAY) 0, generated by program SAT, resident.

SPARLA data.- The SPARLA data base must contain the constituent material properties for each section, as generated by SAT, and stress information prior to the execution of STST.

SPARLA DATA SET NAME	DESCRIPTION
ARMY COMP (NLAY) 0	Data set containing the constituent material properties for each section
STRS E31 MASK MASK " E33 " " " E41 " " " E43 " "	Data set containing element stress information
MATC BTAB MASK MASK	Data set containing material property table

User defined data.- User defined data includes a NAMELIST statement and data defining element type and group numbers of the plotted structure.

NAMELIST MAX.-

FORTRAN VARIABLE	DEFAULT	DESCRIPTION
IPLAY	1	Layer number for plotting
IGRPH	0	Plotting parameter No = 0 Yes = 1 $\equiv \sigma_x, \sigma_y, \tau_{xy}$ 2 $\equiv \varepsilon_x, \varepsilon_y, \gamma_{xy}$

FORTRAN VARIABLE	DEFAULT	DESCRIPTION
		$3 \equiv \sigma_1, \sigma_2, \tau_{12}$ $4 \equiv \varepsilon_1, \varepsilon_2, \gamma_{12}$
PER	.5	Ratio defining where the stresses, though the thickness, in each layer are computed. PER is relative to the lower edge of each lamina. NOTE: PER = .5 is mid-surface

The following card(s) indicate the element type group number to be considered by the program.

COLUMN	FORTRAN VARIABLE	DESCRIPTION
1-5 (Right adjusted)	NELE	Element type
6-10 (Right adjusted)	NGRP	Element group number

NELE	SPAR ELEMENT TYPE
31	E31
33	E33
41	E41
43	E43

An estimate of the field length required to run STST is given as follows:

$$FL_{10} = 24249 + 24* \text{NMAT} + \text{NSECT}* (11* \text{NLAY} + 44)$$

where NMAT is the number of different materials, NSECT is the number of sections (SA table entries) and NLAY is the maximum number of layers in any laminate.

Output.- The input NAMELIST MAX is printed out along with information pertaining to laminate construction generated by SAT. For each element of the specified group and type the laminate strains and curvatures and lamina stresses and strains in the elemental and principal material directions are printed. Stresses or strains for designated layers are printed on tape 10 for use in conjunction with program STCR. An example of input and output is presented in the sample problem 4.

Concluding Remarks

The computer codes described in this report have been found to reduce hand manipulation of data and improve visualization of results. The HIDLIN program proved beneficial in debugging complex finite element models and visualizing the overall response of the model. The composite material programs SAT and STST greatly reduce the manipulation of input data and extend the computational capability of SPAR. The contour plotting program used in conjunction with SPAR or program STST significantly adds to the stress plotting capabilities currently available in SPAR.

REFERENCES

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3. Farley, Gary L.: Interactive Structural Optimization With Strength and Flutter Constraints. M.S. Thesis, The George Washington University, 1976.
4. Farley, Gary L.: Three Dimension Hidden Line Plotting Algorithm with Contour Capabilities. VPI-E-77-9, 1977.
5. Giles, Gary L.: Digital Computer Programs for Generating Oblique Orthographic Projections and Contour Plots. NASA TN D-7797, 1975.
6. Giles, Gary L.; and McCullers, L. A.: Simultaneous Calculation of Aircraft Design Loads and Structural Member Sizes. AIAA Preprint No. 75-965, August 1975.

SAMPLE PROBLEMS

Problem 1

This example illustrates the input, output, and typical plot from program HIDLIN. The Calcomp plotter with Leroy pen was utilized to plot figure 2. A listing of input data cards follows:

```
$MAX PHI=-45,THETA=+45.,PSI=45.,NCKELE=450,IDISP=0,DSCALE=100.,ILEROY=1$END
   1   43
   2   43
   3   43
   4   43
   5   43
   6   43
   7   43
   8   43
   9   43
  10   43
  16   43
  11   43
  12   43
  13   43
  14   43
  15   43
  17   43
  18   43
   1   33
   2   33
```

The output listing for Problem 1 follows.

```
$MAX

IDISP    = 1.

NCKELE   = 450.

DSCALE   = .1E+03.

DELX     = .1E+01.

DELY     = .1E+01.

KHORZ    = 1.

KVERT    = 2.

PHI      = -.45E+02.

THETA    = .45E+02.

PSI      = .45E+02.

PSCALE   = .1E+01.

DMAG     = .99E+00.

ILEROY   = 1.

$END
 STORAGE REQUIRED IN COMMON (DEC.)       3910
 STORAGE REQUIRED IN COMMON (OCT.)00007506



 GROUP NUMBER=     1
 ELEMENT TYPE=    43
 GROUP NUMBER=     2
 ELEMENT TYPE=    43
 GROUP NUMBER=     3
 ELEMENT TYPE=    43
 GROUP NUMBER=     4
 ELEMENT TYPE=    43
 GROUP NUMBER=     5
 ELEMENT TYPE=    43
     UP NUMBER=     6
 
 GR                1
 ELEMENT TYPE=    33
 GROUP NUMBER=     2
```

Problem 2

This example illustrates the input and output data from programs STR and STCR. A Calcomp plotter with Leroy pen was utilized to plot (figure 10) the stress contours on the upper flange of a composite cross beam. A listing of input data cards follows:

```
$MAN III=1,JJJ=3,NCONT=20,ILAB=1,ICOPT=1,SIG(1)=-4500,SIG(2)=-4000,ILEROY=1,
SIG(3)=-1000,DSIG(1)=500,DSIG(2)=500,DSIG(3)=200,ICEN=0,SCLX=.5,SCLY=.5 $END
  43    6
  43    7
  43    8
  43   14
  33    2
```

The output listing for program STR of Sample Problem 2 is shown below.

```
$MAN

III      = 1,

JJJ      = 3,

SCLX     = .5E+00,

SCLY     = .5E+00,

XSHFT    = .1E+01,

YSHFT    = .1E+01,

ICEN     = 0,

NCONT    = 20,

IPOS     = 0,

ILAB     = 1,

HGHT     = .1E+00,

ICORT    = 1,

SIG      = -.45E+04, -.4E+04, -.1E+04,

DSIG     = .5E+03, .5E+03, .2E+03,

ILECOY   = 1,

RNDOFF   = .1E-06,

$END
 STORAGE USED IN COMMON + 7 OR 16 X NEL (DEC.)        2319
 STORAGE USED IN COMMON + 7 OR 20 X NEL (OCT.)00004417



 ELEMENT TYPE=    43
 GROUP NUMBER=     6
 ELEMENT TYPE=    43
 GROUP NUMBER=     7
 ELEMENT TYPE=    43
 GROUP NUMBER=     8
 ELEMENT TYPE=    43
 GROUP NUMBER=    14
 ELEMENT TYPE=    33
```

The output listing for program STCR of Sample Problem 2 is shown below.

```
$MAX

NNOD     = 403.

NEL      = 76.

ICEN     = 0.

XSHFT    = .1E+01.

YSHFT    = .1E+01,

SCLX     = .5E+00.

SCLY     = .5E+00.

NCONT    = 20.

ILAB     = 1.

HGHT     = .1E+00.

STG      = -.45E+04. -.4E+04. -.1E+04.

CSTG     = .5E+03. .5E+03. .2E+03.

ICOPT    = 1.

ILFROY   = 1.

RNDOFF   = .1E-06.

$END
 STORAGE USED IN COMMON (DEC.)        2723
 STORAGE USED IN COMMON (OCT.)00005243



 MAX-MIN STRESS VALUES
                .647E+03 -.748E+04
                .882E+04 -.583E+03
                .678E+03 -.678E+03

 STRESS       1         CONTOUR NUMBER  1   VALUE -.4500000E+04
                                                   .4000000E+04
 STRESS       1         CONTOUR NUMBER  2   VALUE -.
 STRESS       3         CONTOUR NUMBER  3   VALUE -.5000000
 STRESS       3         CONTOUR NUMBER  4   VALUE -.4000000E+03
```

Problem 3

This example illustrates the input and output from program SAT which computes the SA Table entries for SPARLA. A listing of input data cards follows:

```
 SAMPLE CASE FOR PROGRAM SAT
$MAX NSECT=2,NLAY=6.NMAT=2 $END
$PROP IMAT=1,E11=17.E6.E22=2.E6,G12=.52E6,UN12=.38 $END
$PROP IMAT=2,E11=9.E6.E22=9.E6,G12=.6E6,UN12=.3 $END
$SECT ILAY=4,ISPARM=1.ISPTYP=4 $END
      45.       .0455     2
     -45.       .0455     2
     -45.       .0455     2
      45.       .0455     2
      1.0        1.0       1.0       0.0       0.0       0.0       1.0       1.0
      1.0        0.0       0.0       0.0       1.0       1.0       1.0       0.0
      0.0        0.0
$SECT ILAY=5,ISPARM=3.ISPTYP=4 $END
      0.0       .033      1
      45.       .026      2
      0.0       .044      1
      45.       .026      2
      0.0       .033      1
      1.0        1.0       1.0       0.0       0.0       0.0       1.0       1.0
      1.0        0.0       0.0       0.0       1.0       1.0       1.0       0.0
      0.0        0.0
```

The output listing for program SAT of Sample Problem 3 is shown below.

```
*SMAX

NSECT   = 2.

NLAY    = 6.

NMAT    = 2.

*END
 STORAGE USED IN COMMON (DEC.)      505
 STORAGE USED IN COMMON (OCT.)00000771


 MAT       E11          E22          E33          G12          G13          G23
  1     .170E+08     .200E+07     0.           .520E+06     0.           0.
  2     .900E+07     .900E+07     0.           .600E+06     0.           0.
 MAT       UN12         UN13         UN23         RHO
  1      .32000E+00    0.           0.           0.
  2      .30000E+00    0.           0.           0.

*SECT

ILAY    = 4.

ISPARM  = 1.

ISPTYP  = 4.

ZSHFT   = 0.0.

*END
      THETA       THICKNESS      MAT
    .450E+02   .455E-01         2
   -.450E+02   .455E-01         2
   -.450E+02   .455E-01         2
    .450E+02   .455E-01         2

 STRESS RECOVERY PARAMETERS (F)
 .100E+01  .100E+01  .100E+01 0.          0.          0.          .100E+01  .100E+01
 .100E+01 0.          0.          0.          .100E+01  .100E+01  .100E+01 0.
        0.
    MATRIX OF SECTION      1
         .1279200E+07  .1060800E+07 0.                        .8149073E-09  .6984910E-09 -.8271806E-24
         .1060800E+07  .1279200E+07 0.                        .6984919E-09  .8149073E-09  .8271806E-24
         0.            0.            .6300000E+06  .8271806E-24 -.8271806E-24 -.4074536E-09
         [illegible]9073E-09  .6984910E-09  .8271806E-24  .3531018E+04  .2929162E+04 -.8421812E-11
         [illegible]19E-09  .8149073E-09 -.8271806E-24  .2929162E+04  .3531018E+04  .8421812E-11
         [illegible]-24  .8271806E-24 -.4074536E-09 -.8421812E-11  .8421812E-11  .1739010E+04
         .1[illegible]            [illegible]ECTION     1
         .11[illegible]                    [illegible]842F-48 -.4921572F-18  .3920282F-18 -.2104063E-32
         .1[illegible]
        -.61[illegible]                                                          [illegible]18  .2104063E-32
 INVERSE OF ABD MATRIX FOR SECTION      2                                                  [illegible]190R0E-18
                                                                                           [illegible]-17
         .4969776E-06 -.3273310E-06 -.4039149E-20 -.1025409E-18  .6406131E-[illegible]
        -.3273310E-06  .1912556E-05  .1097556E-19  .6314132E-19 -.5084095E-18  .29[illegible]
        -.4039149E-20  .1097556E-19  .4215952E-05  .8066020E-33 -.2786041E-32  .1452134[illegible]
        -.1025409E-18  .6314132E-19  .8066020E-33  .1964996E-03 -.1139101E-03  .1215824E-17
         .6406131E-19 -.5084095E-18 -.2786041E-32 -.1139101E-03  .1015177E-02 -.4422450E-17
        -.9230211E-33  .2973610E-32  .1452134E-17  .1215824E-17 -.4422450E-17  .2630017E-02


 ECHO OF SA TABLE


 .4000000E+01  .1000000E+01 0.            .2503053E-05 -.2075702E-05  .2503053E-05 -.1998842E-48  .1998842E-48
 .1987302E-05 -.4921572E-18  .3920282E-18  .3017557E-32  .9067936E-03  .3920282E-18 -.4921572E-18 -.3017557E-32
-.7510758E-03  .9067936E-03 -.2104063E-32  .2104063E-32  .3719090E-18  .8033214E-17 -.8033214E-17  .5750398E-03
 .1000000E+01  .1000000E+01  .1000000E+01  .1000000E+01 0.            0.            0.            .1000000E+01
 .1000000E+01  .1000000E+01 0.            0.            0.            .1000000E+01  .1000000E+01  .1000000E+01
0.            0.            0.            .4000000E+01  .3000000E+01 0.            .4969776E-06 -.3273310E-06
 .1912556E-05 -.4039149E-20  .1097556E-19  .4215852E-05 -.1025409E-18  .6314132F-19  .8066020F-33  .1964996E-03

 .6406131E-19 -.5084095E-18 -.2786041E-32 -.1139101E-03  .1015177E-02 -.9230211E-33  .2973610E-32  .1452134E-17
 .1215824E-17 -.4422450E-17  .2630017E-02  .1000000E+01  .1000000E+01  .1000000E+01  .1000000E+01 0.
0.            0.            .1000000E+01  .1000000E+01  .1000000E+01 0.            0.            0.
 .1000000E+01  .1000000E+01  .1000000E+01 0.            0.            0.
```

Problem 4

This example illustrates the input and output of program STST lamina stress and strains. This example uses the file ARMY COMP (NLAY) 0 from problem 3. A listing of input data cards follows:

```
[illegible]LAY  [illegible]=0.[illegible]
  23      1
```

The output listing for program STST of Sample Problem 4 is shown below.

```
$MAX
IPLAY   = 1,
IGRPH   = 0,
PER     = 0.0,
$END


     NUMBER OF MATERIALS =      3
     MAXIMUM NUMBER OF LAYERS/SECTION =     20
     NUMBER OF SA TABLE ENTREES =     23


    STORAGE USED IN COMMON (DEC.)       6145
    STORAGE USED IN COMMON (OCT.)00014001


  GROUP NUMBER      1  ELEMENT TYPE 23
 ID LN      SGX      EPX        SG1     EP1          SGY     EPY         SG2     EP2      TAUXY    GMXY      TAU12    GM12


MID-PLANE STRAINS      .668E-03 -.879E-03  .498E-03   CURVATURES      .290E-02 -.157E-02 -.678E-03
  1  1      -57.  .00021    -10777. -.00063    -10777. -.00063      -57.  .00021      314.  .00060     -314. -.00060
  1  2     3726.  .00024      3726.  .00024     -1133. -.00065    -1133. -.00065      310.  .00060      310.  .00060
  1  3       98.  .00031    -11598. -.00068    -11598. -.00068       98.  .00031      303.  .00058     -303. -.00058
  1  4     5341.  .00034      5341.  .00034     -1165. -.00070    -1165. -.00070      299.  .00057      299.  .00057
  1  5      201.  .00037    -12145. -.00072    -12145. -.00072      201.  .00037      295.  .00057     -295. -.00057
  1  6     6955.  .00044      6955.  .00044     -1196. -.00075    -1196. -.00075      287.  .00055      287.  .00055
  1  7      356.  .00047    -12965. -.00077    -12965. -.00077      356.  .00047      283.  .00054     -283. -.00054
  1  8     8032.  .00050      8032.  .00050     -1217. -.00079    -1217. -.00079      279.  .00054      279.  .00054
  1  9      511.  .00056    -13785. -.00082    -13785. -.00082      511.  .00056      272.  .00052     -272. -.00052
  1 10     -709.  .00060       212.  .00039     -2431. -.00084    -3351. -.00064     1782.  .00051     -861. -.00143
  1 11     -197.  .00073     -2855. -.00058     -2163. -.00091      495.  .00039     1675.  .00048      983.  .00164
  1 12      315.  .00096     -2358. -.00051     -1895. -.00098      778.  .00039     1568.  .00045     1105.  .00194
  1 13      876.  .00099      1061.  .00039     -1627. -.00105    -1862. -.00045     1461.  .00042    -1227. -.00204

MID-PLANE STRAINS      .668E-03 -.879E-03 -.498E-03   CURVATURES      .290E-02 -.157E-02  .678E-03
  2  1      -57.  .00021    -10777. -.00063    -10777. -.00063      -57.  .00021     -314. -.00060      314.  .00060
  2  2     3726.  .00024      3726.  .00024     -1133. -.00065    -1133. -.00065     -310. -.00060     -310. -.00060
  2  3       98.  .00031    -11598. -.00068    -11598. -.00068       98.  .00031     -303. -.00058      303.  .00058
  2  4     5341.  .00034      5341.  .00034     -1165. -.00070    -1165. -.00070     -299. -.00057     -299. -.00057
  2  5      201.  .00037    -12145. -.00072    -12145. -.00072      201.  .00037     -295. -.00057      295.  .00057
  2  6     6955.  .00044      6955.  .00044     -1196. -.00075    -1196. -.00075     -287. -.00055     -287. -.00055
  2  7      356.  .00047    -12965. -.00077    -12965. -.00077      356.  .00047     -283. -.00054      283.  .00054
     8     8032.  .00050      8032.  .00050     -1217. -.00079    -1217. -.00079     -279. -.00054            00054
            511.  .00056    -13785. -.00082    -13785. -.00082      511.  .00056     -27
           -709.  .00060     -3351. -.00064     -2431. -.00084      212.  .00039
 14          97.  .00073       495.  .00039     -2163. -.00091    -2855. -                                59.
 14  3            .00086       778.  .00039     -1895. -.00098                        -.00198      -27. -.00005
 14  4               099     -1862. -.00045     -1627.                          -10233. -.00192       10.  .00002
 14  5    -                                                            .00209    -6704. -.00186        6.  .00001
 14  6     5740.                                                -668. -.00158    -9190. -.00175      -38. -.00007
 14  7    -7653. -.000                                .  .00053     1626.  .00188    -6443. -.00169       55.  .00010
 14  8     5192. -.00022     17464. [illegible]  11526.  .00052     -706. -.00151    -8494. -.00163      -71. -.00014
 14  9    -7599. -.00027    -11854. -.00144     -2879.  .00049     1377.  .00166    -6181. -.00151      103.  .00020
 14 10      134. -.00029       421.  .00023      2298.  .00048     2012. -.00004     -648. -.00145     -979. -.00163
 14 11    -1709. -.00039      1492. -.00001      1709.  .00043     -992.  .00005     -376. -.00121      853.  .00142
 14 12    -2553. -.00049       972.  .00002      1119.  .00038    -2406. -.00013     -105. -.00097      727.  .00121
 14 13    -3896. -.00059     -3819. -.00031       530.  .00033      453.  .00005      166. -.00073     -601. -.00100

MID-PLANE STRAINS     -.340E-03  .264E-03  .248E-02   CURVATURES     -.137E-02 -.758E-03 -.707E-02
 15  1   -16586. -.00012    -26989. -.00333     -7501.  .00038     2602.  .00359    14036.  .00359      391.  .00075
 15  2     9253. -.00014     30860.  .00351     19742.  .00037    -1864. -.00327    15503.  .00352     -374. -.00072
 15  3   -16260. -.00017    -25869. -.00315     -7240.  .00036     2369.  .00334    13384.  .00336      340.  .00065
 15  4     8442. -.00018     28471.  .00326     18199.  .00035    -1829. -.00309    14347.  .00328     -323. -.00062
 15  5   -15842. -.00020    -25123. -.00303     -7067.  .00034     2214.  .00317    12949.  .00320      305.  .00059
 15  6     7632. -.00023     26092.  .00301     16656.  .00032    -1794. -.00291    13190.  .00305     -271. -.00052
 15  7   -15216. -.00025    -24004. -.00285     -6806.  .00032     1981.  .00292    12296.  .00297      254.  .00049
 15  8     7091. -.00026     24489.  .00284     15628.  .00031    -1770. -.00279    12419.  .00289     -237. -.00046
 15  9   -14550. -.00029    -22885. -.00267     -6546.  .00029     1749.  .00267    11643.  .00274      203.  .00039
 15 10      459. -.00031     -1381. -.00064      -752.  .00028     1088.  .00062     1945.  .00266    -1620. -.00270
 15 11     -547. -.00037        -7.  .00045      -992.  .00025    -1532. -.00057     1618.  .00234     1445.  .00241
 15 12    -1553. -.00043     -1102.  .00028     -1232.  .00021    -1684. -.00050     1292.  .00202     1269.  .00211
 15 13    -2559. -.00049     -1835. -.00042     -1472.  .00018    -2196.  .00011      966.  .00169    -1093. -.00182
```

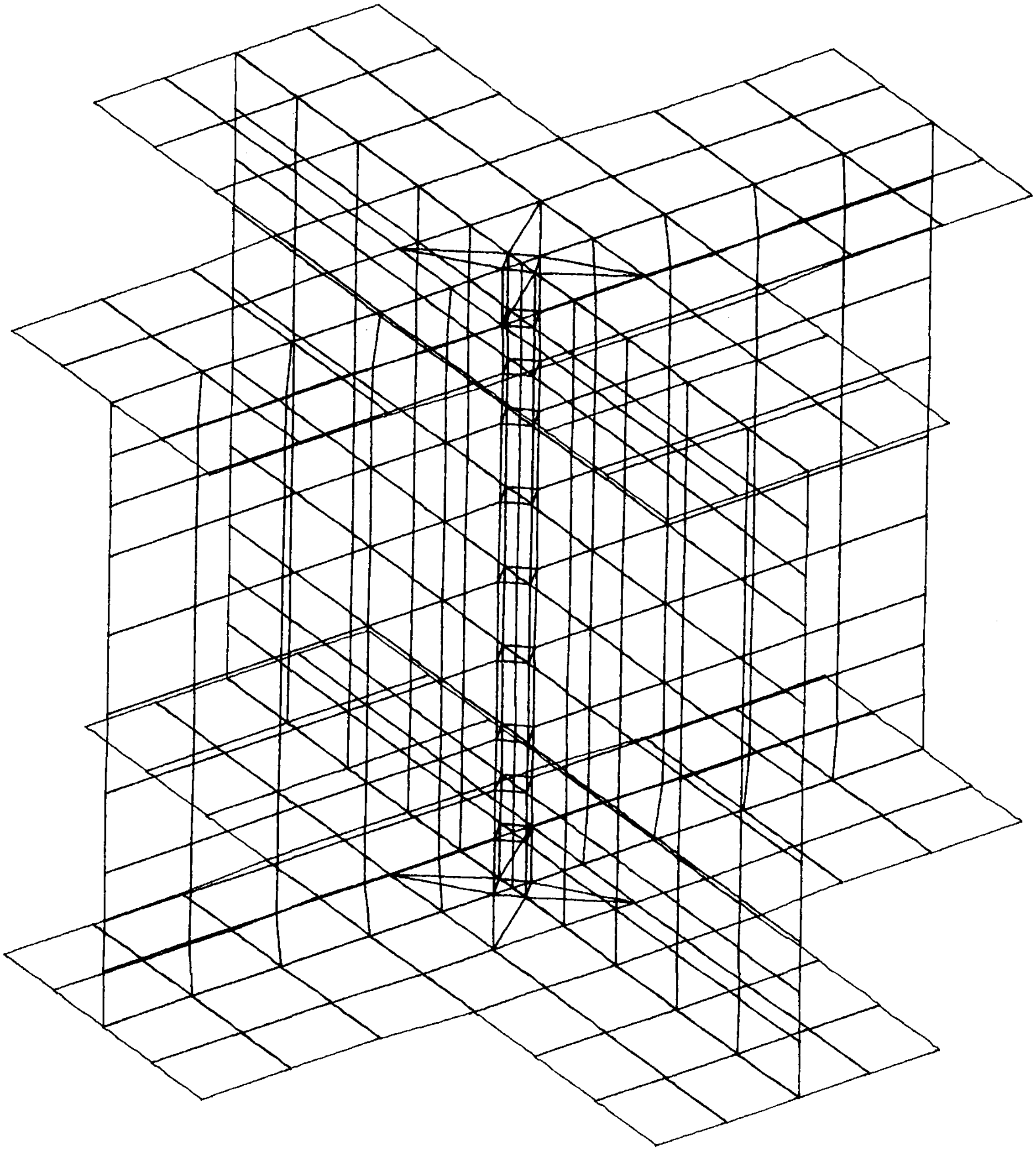


Figure (1).- Composite Cross Beam Finite Element Model, Drawn Using SPAR.

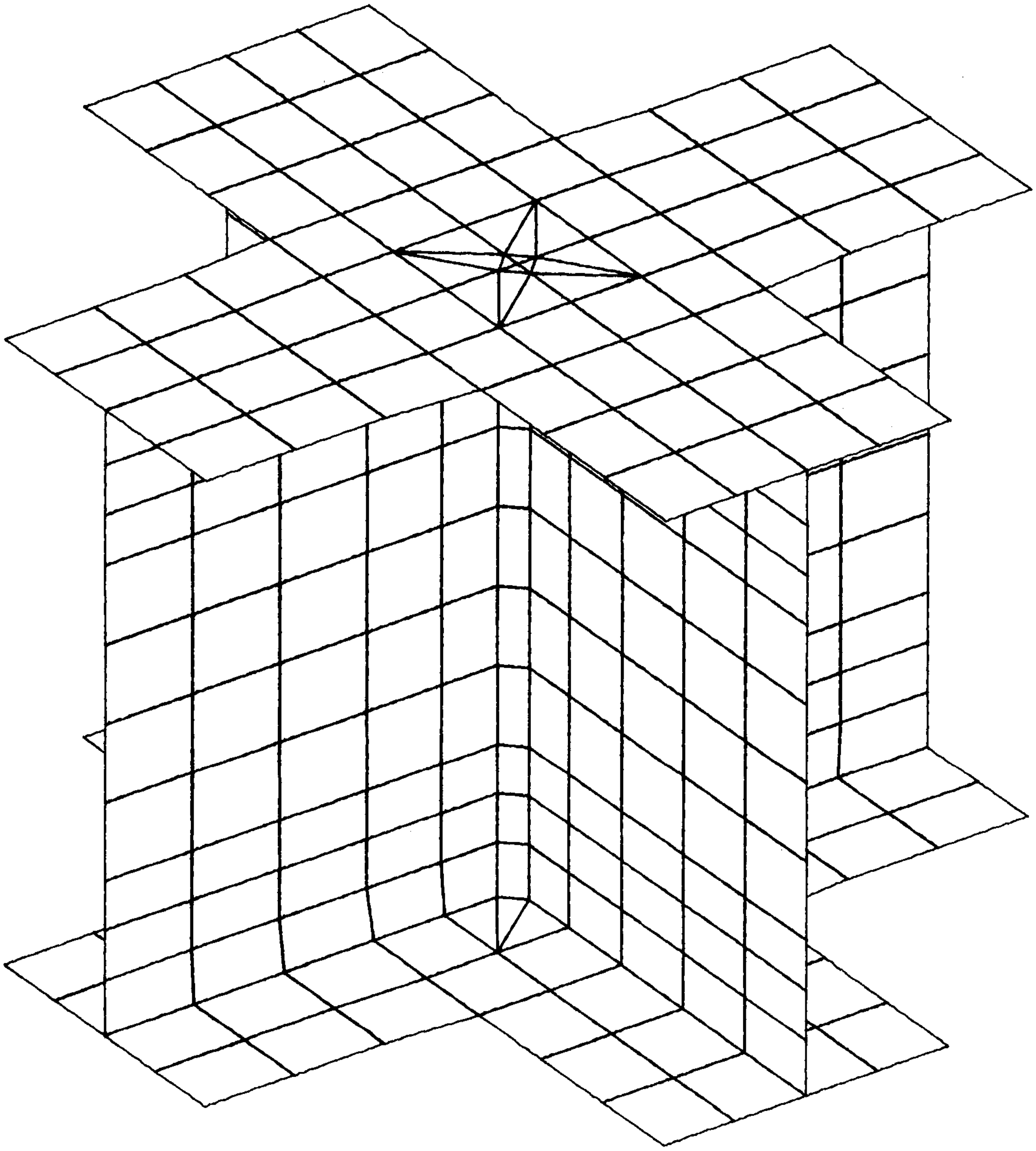


Figure (2).- Undeformed Composite Cross Beam Finite Element Model With Hidden Lines Removed, Drawn Using HIDLIN.

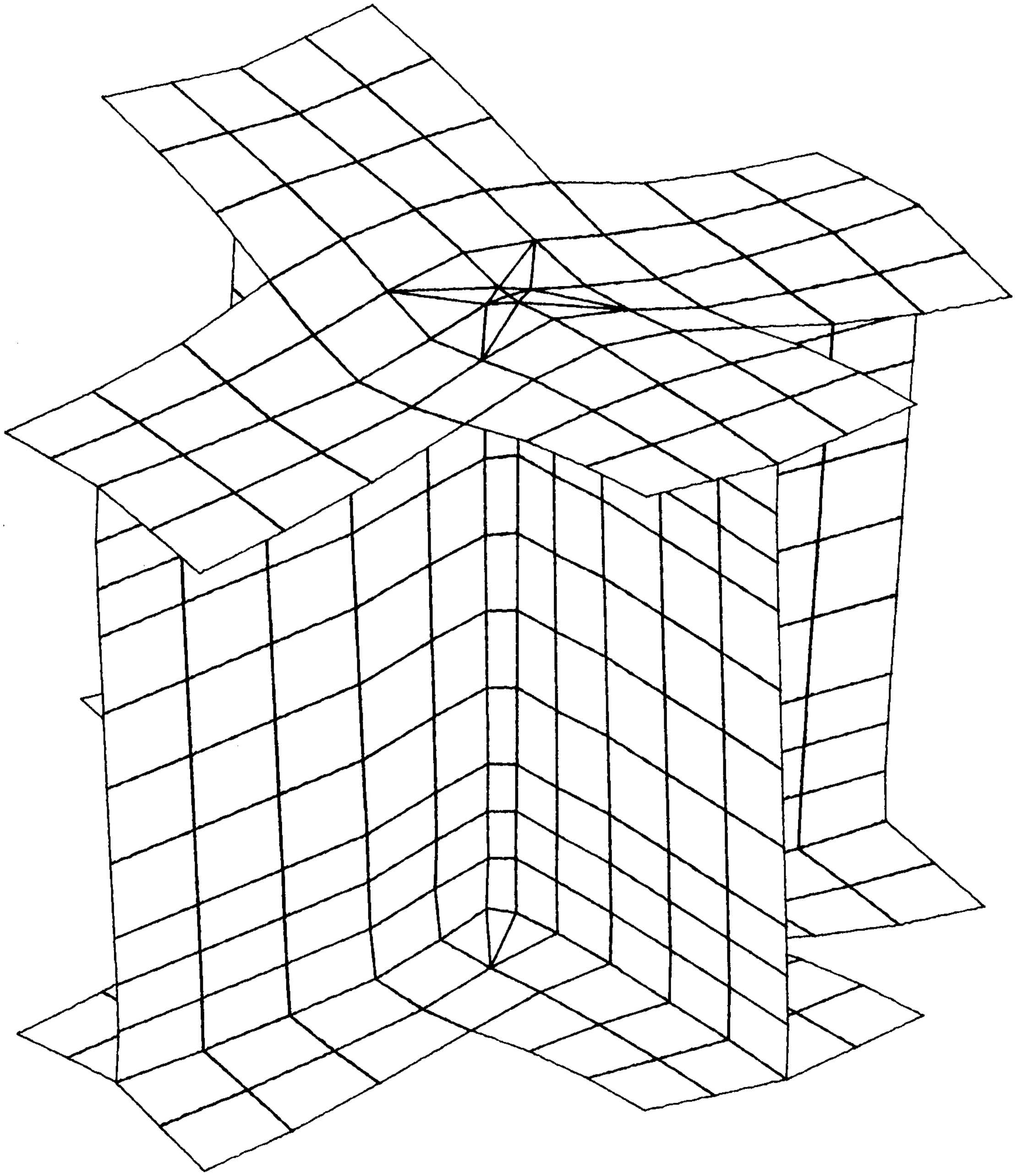


Figure (3).- Deformed Composite Cross Beam Finite Element Model with Hidden Lines Removed, Drawn Using HIDLIN.

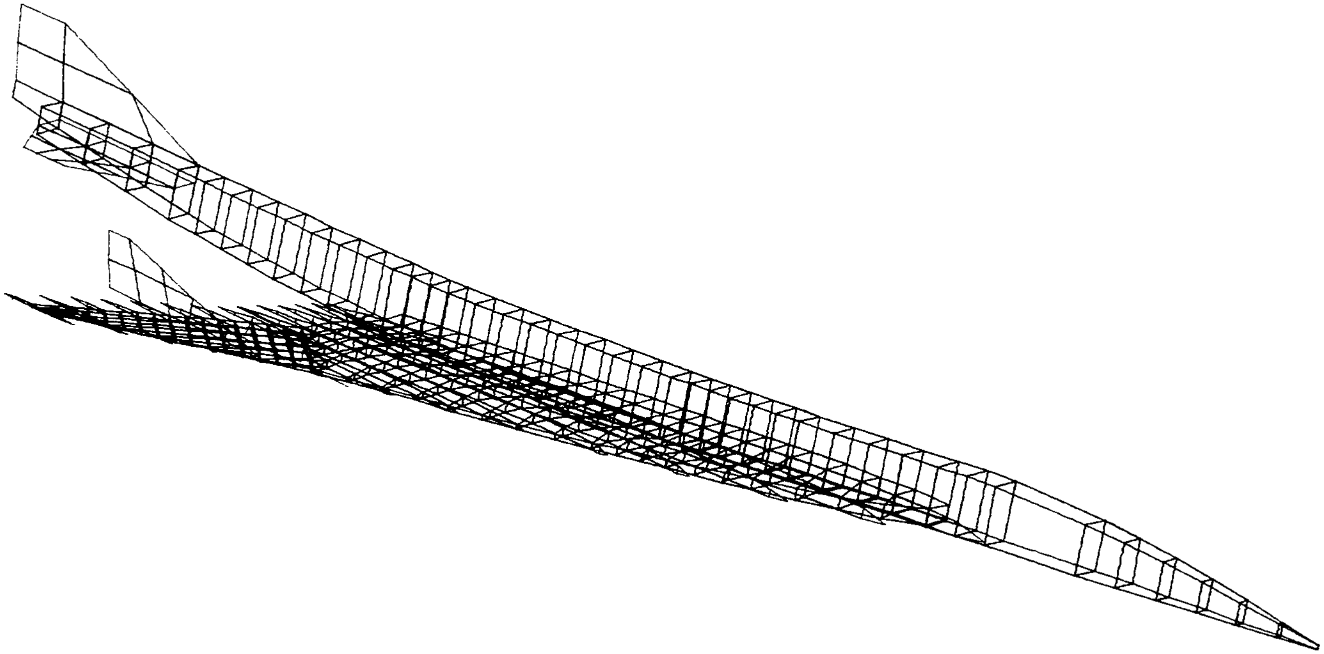


Figure (4).- Finite Element Model of Supersonic Cruise Aircraft, Drawn Using SPAR.

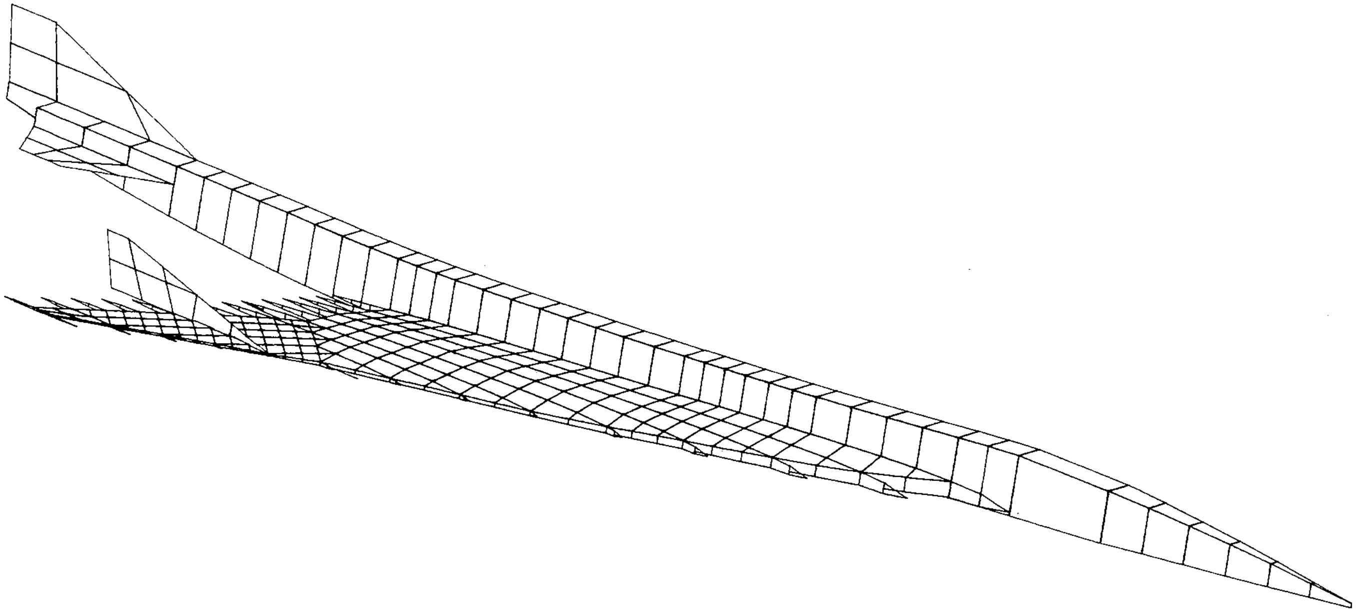


Figure (5).- Undeformed Finite Element Model of Supersonic Cruise Aircraft, Drawn Using HIDLIN.

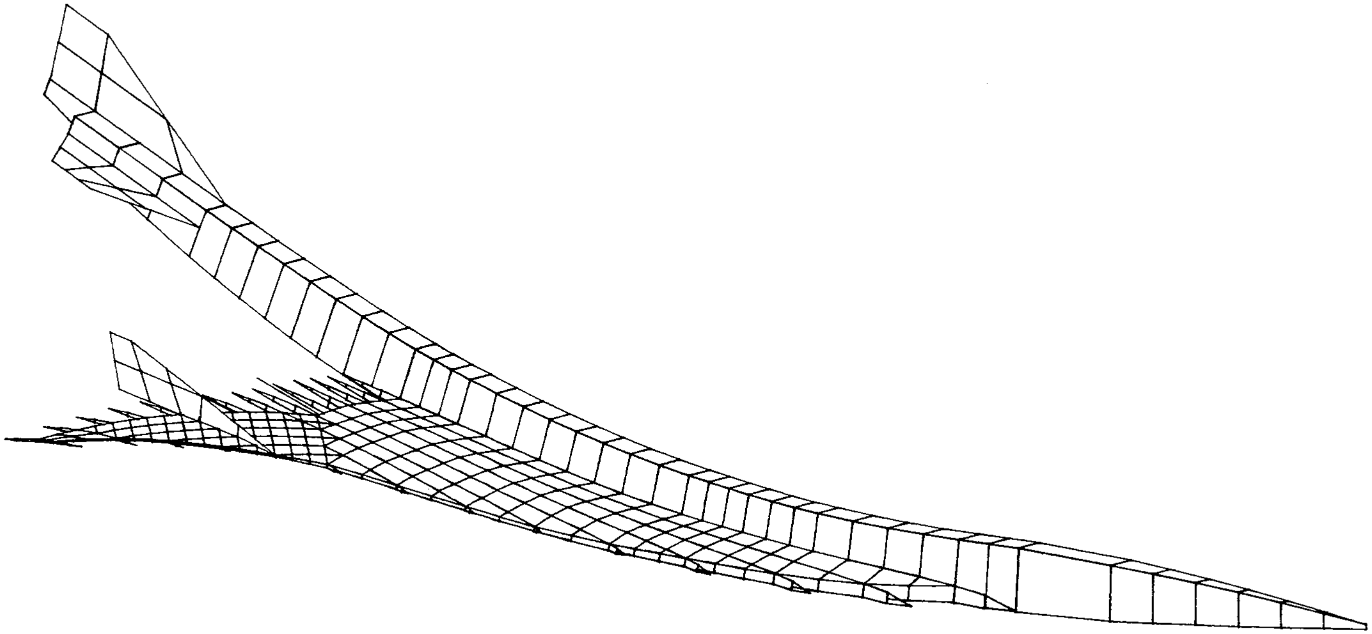


Figure (6).- Deformed Finite Element Model of Supersonic Cruise Aircraft, Drawn Using HIDLIN.

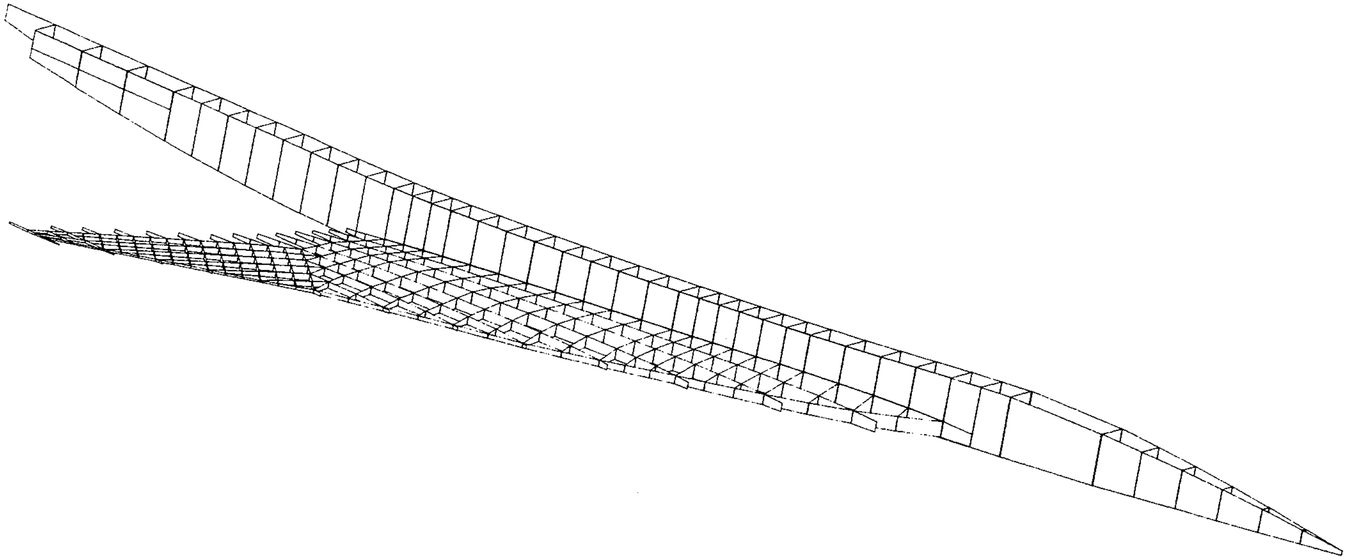


Figure (7).- Internal Finite Element Structure of Supersonic Cruise Aircraft, Drawn Using HIDLIN.

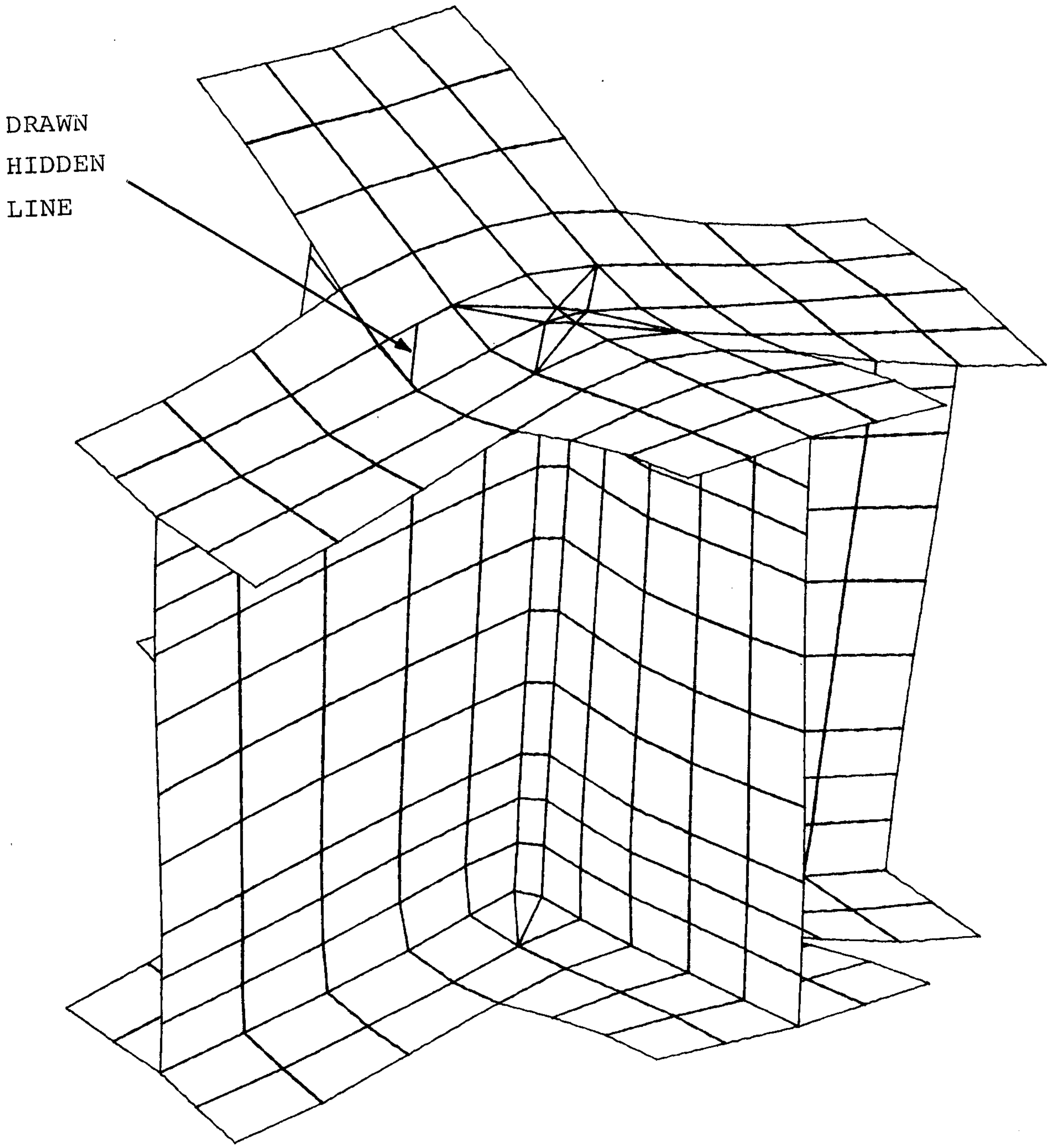


Figure (8).- Composite Cross Beam Finite Element Model With Most of The Hidden Lines Removed, Drawn Using HIDLIN.

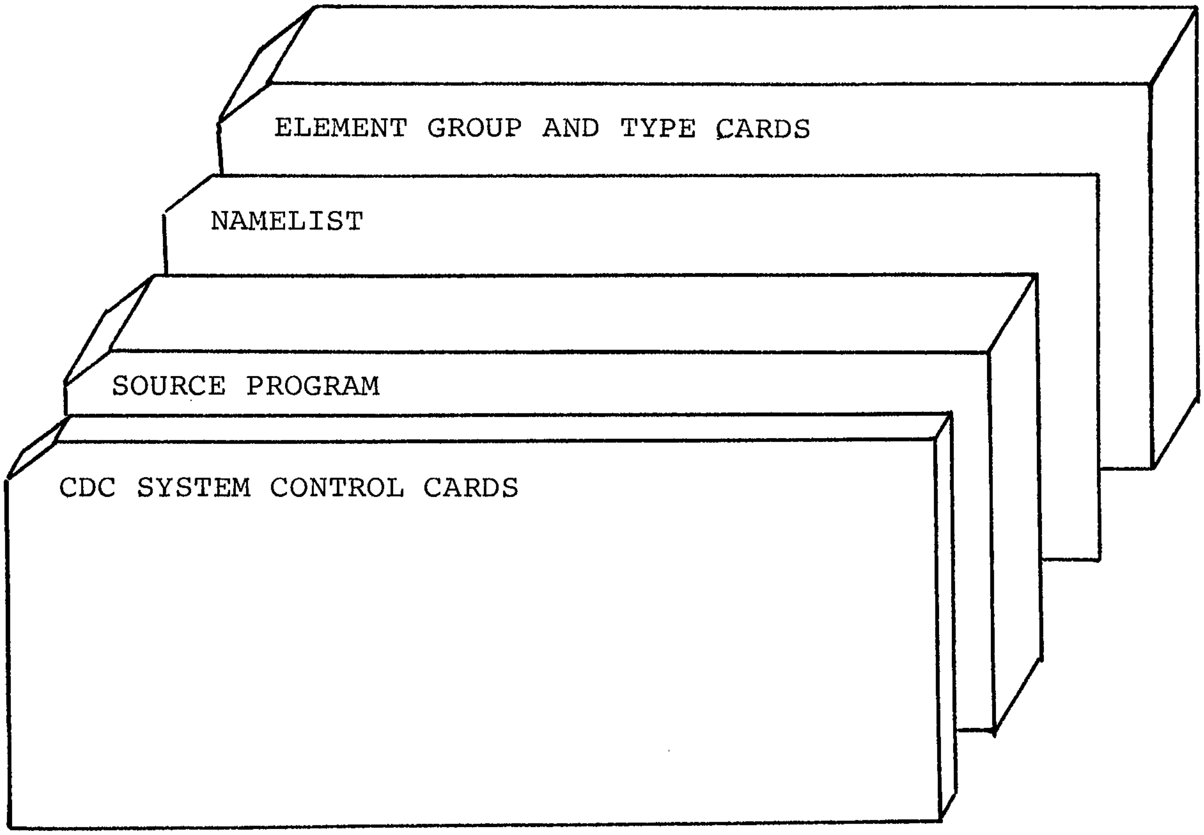


Figure (9).- Typical Program Setup.

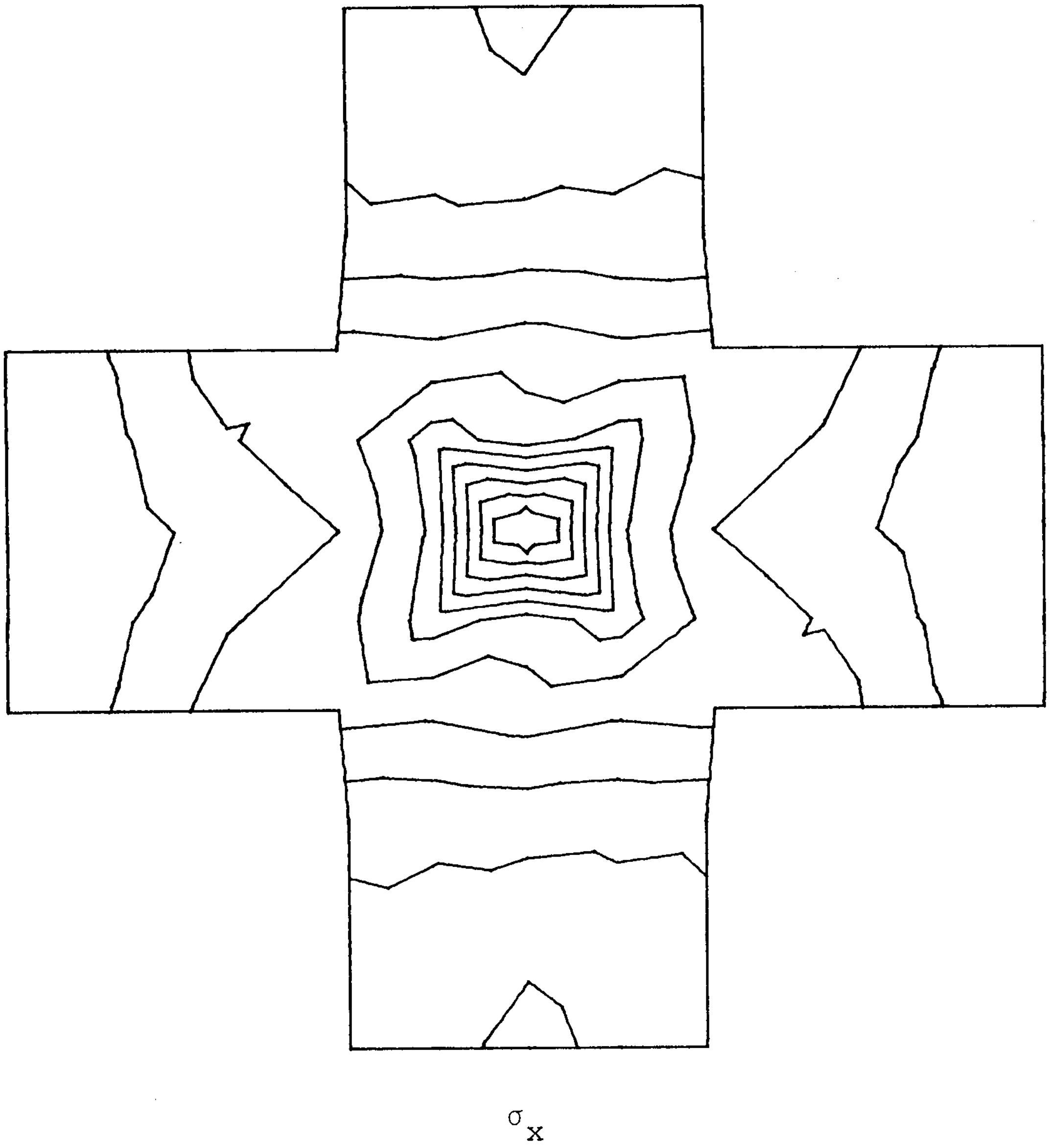
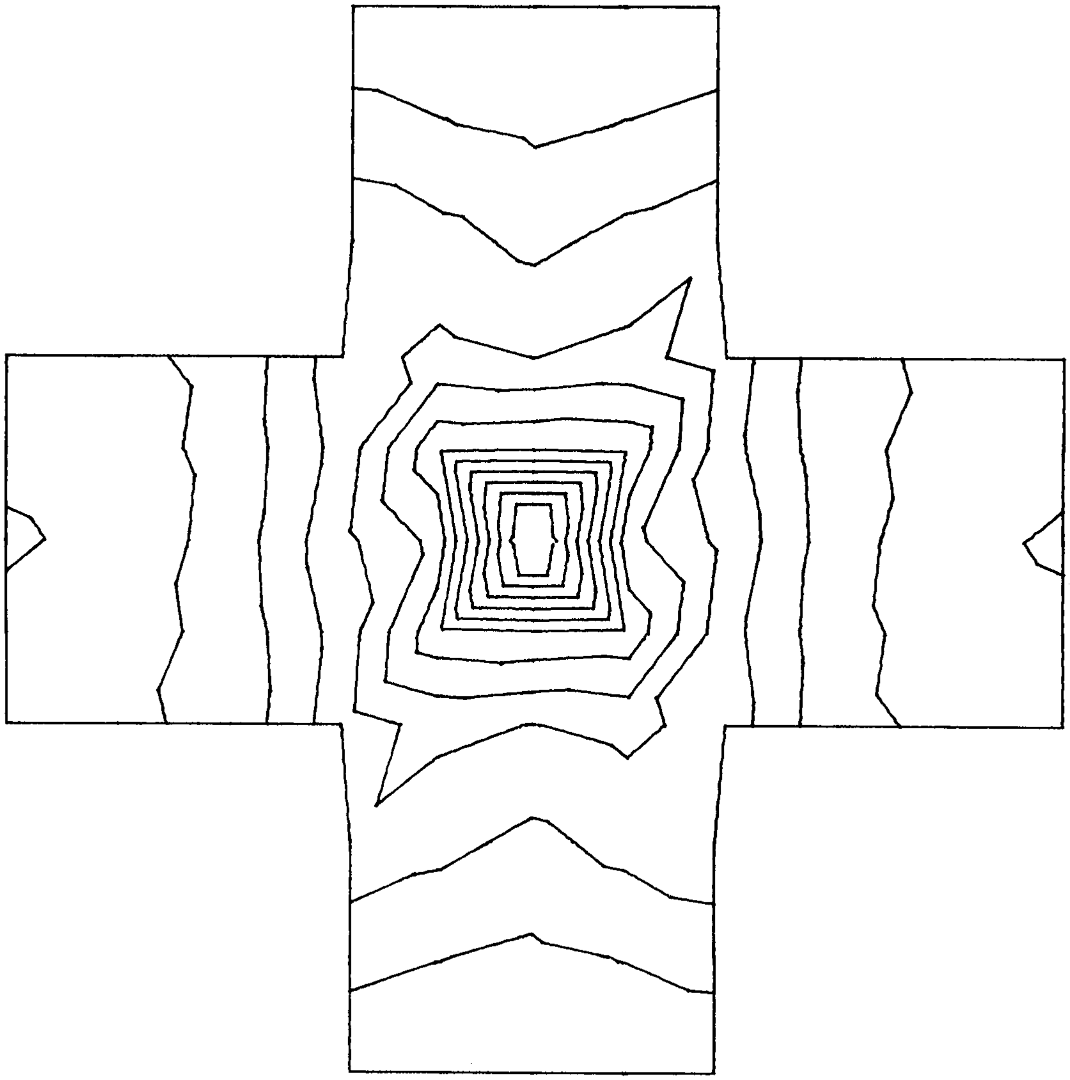


Figure (10a).- σ_x Stress Contours of Upper Flange of Composite Cross Beam Structure.



σ_y

Figure (10b).- σ_y Stress Contours of Upper Flange of Composite Cross Beam Structure.

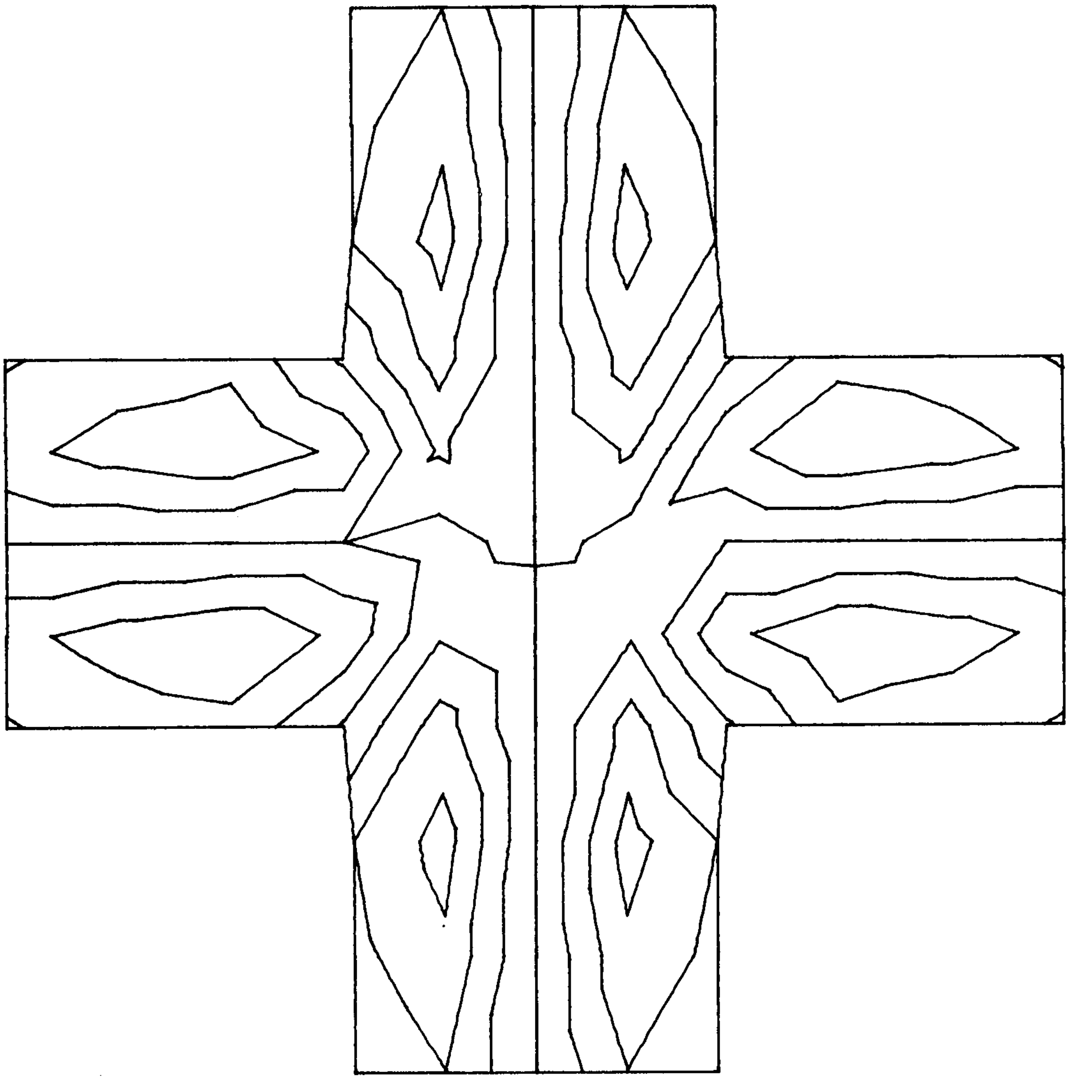


Figure (10c).- τ_{xy} Stress Contours of Upper Flange of Composite Cross Beam Structure.

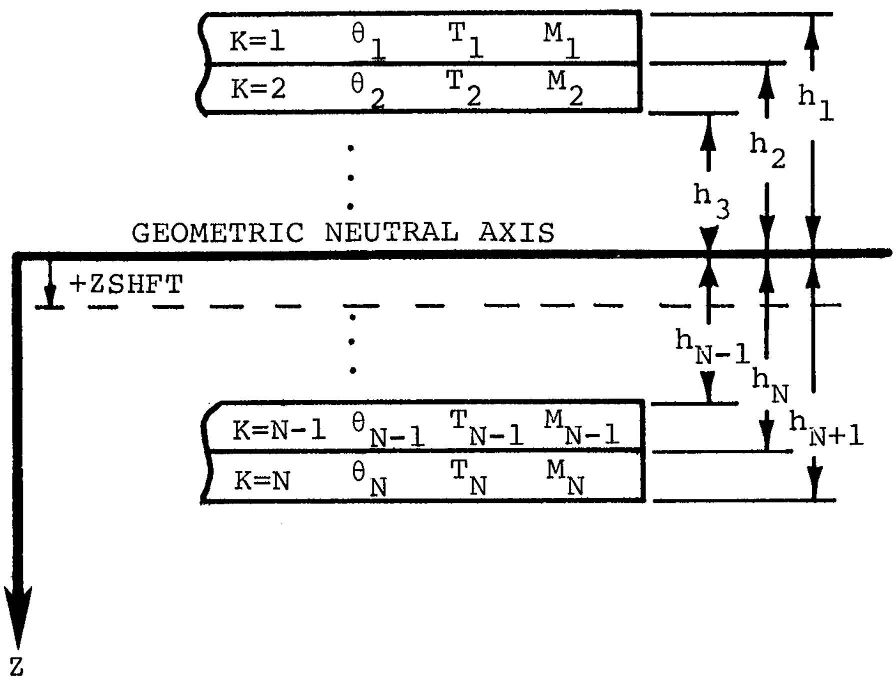


Figure (11a).- Composite Laminate Sign Convention and Construction.

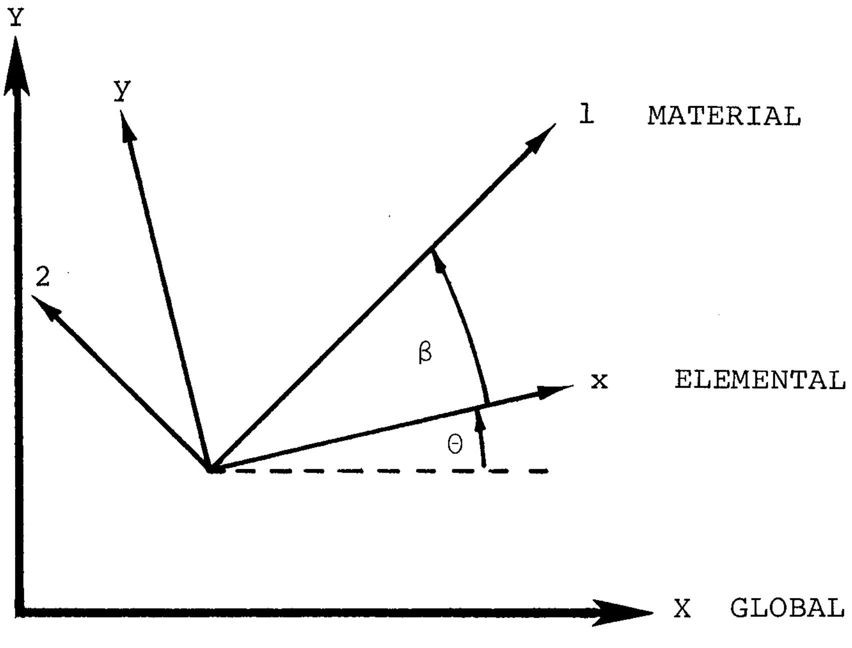


Figure (11b).- Composite Laminate Coordinate System.

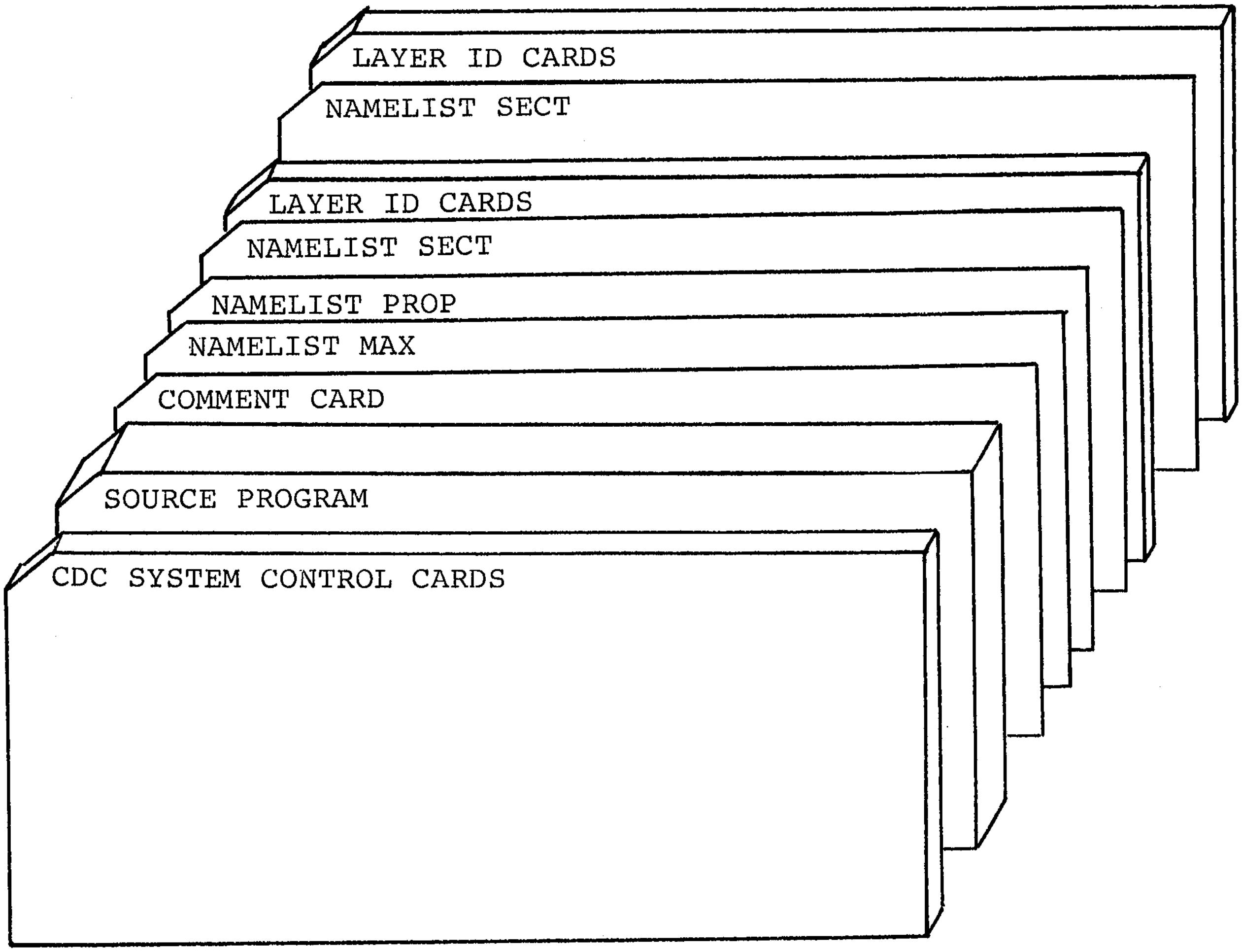


Figure (12).- Program SAT Deck Setup.

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15. Supplementary Notes

The authors are employed by the Structures Laboratory, USARTL (AVRADCOM).

16. Abstract

The SPAR computer software system is used for finite element structural and thermal analysis. This report contains user documentation of additional computer programs that have been developed for use in conjunction with SPAR. These programs plot digital data, simplify input for composite material section properties and compute lamina stresses and strains. Sample problems are presented including execution procedures, program input and tabulated and graphical output.

17. Key Words (Suggested by Author(s)) Computer Graphics SPAR Hidden Line Composite Materials Stress Contours	18. Distribution Statement Unclassified - Unlimited Subject Category 61

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