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Composite Blade Structural Analyzer (COBSTRAN) Theoretical/ Programmer's Manual

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COMPOSITE BLADE STRUCTURAL ANALYZER

COBSTRAN

THEORETICAL / PROGRAMMER'S MANUAL

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INTRODUCTION

The intent of this manual is three-fold. It is, first of all, intended to be an introduction to COBSTRAN (COmposite Blade STRuctural ANalyzer) by providing an overall description of the program capabilities and its interaction with general purpose structural analysis codes. Secondly, it describes the organization of the program and the flow of data and analysis through the subroutines. Thirdly, it describes the equations formulated and solved, and the function of each of the seventy-two subroutines. However, the detailed description of the theory used in developing the programmed equations, especially in the composite mechanics and laminate analysis procedures, is properly left to the references from which they were obtained.

Other manuals available are a USER'S MANUAL, describing in detail the input deck set-up and options available to the user, and a DEMONSTRATION MANUAL with selected problems.

COBSTRAN is designed to carry out the many linear analyses required to efficiently model and analyze blade-like structural components made of multilayered angle-plied fiber composites (Figure 1).

Inputs to COBSTRAN are composite constituent fiber and matrix material properties, factors reflecting the fabrication process, composite geometry and model geometry. COBSTRAN determines the ply layup at each grid point and calculates the equivalent homogeneous properties at each grid point.

Outputs are the individual ply properties and nodal composite properties consisting of membrane, bending and coupling stiffnesses. Also, finite element structural analysis grid, connectivity and material data are generated. COBSTRAN generates model finite element data in formats compatible with COSMIC NASTRAN, MSC/NASTRAN and MHOST. MHOST is a Lewis Research Center structural analysis code based on mixed-iterative finite element methodology and is specifically designed for three-dimensional inelastic analyses. Reference to the MHOST code in this manual is for completeness only and its use is discouraged until release of the MHOST code and a fully tested COBSTRAN version.

The laminate decomposition analysis procedure is designed to make use of element stresses from the structural analysis code and information generated in the COBSTRAN preprocessor phase which is stored in temporary files. Membrane forces and moments are calculated in the structural coordinate system for each node in the discrete model of the structure. For each ply layer at each node the stress and strain state is calculated including the results of combined-stress strength failure criteria and Hoffman's failure criteria (Ref. 1).

An additional feature of COBSTRAN is that the geometry input may be an existing COSMIC NASTRAN or MSC/NASTRAN bulk data deck. Material properties are generated within COBSTRAN and a complete finite element model is created in any of the optional output formats. For more details see the NASMIN and MSCMIN program option cards in Section 3 of the USER'S MANUAL.

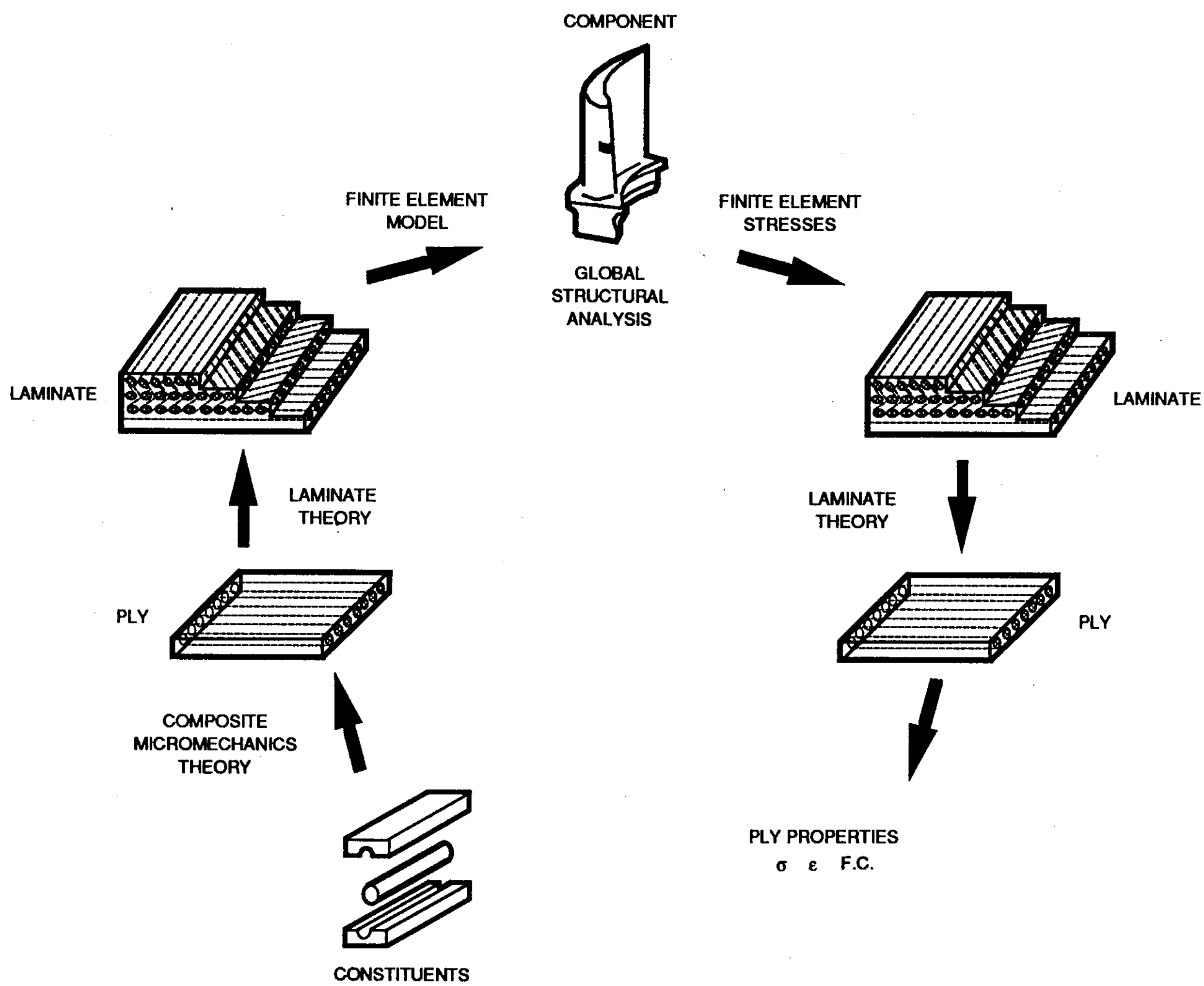

Figure 1. - COBSTRAN analytical process.

SOLUTION FORMATS

Two types of problem solution formats are available in this code. The first format is for a solid composite blade or solid composite blade with hollow core sections of the turboprop or turbofan types. Plate or shell type 2-D elements are created along the blade mid-thickness line and equivalent homogeneous anisotropic material properties are calculated from the composite layup for each element. The second format is for blades of the aircraft wing type construction composed of quadrilateral shell elements on the airfoil surface separated by plate type spars at user selected chord positions. This format is most suitable for long wing-like structures used for wind power generators. This code would also be suitable for the analysis of any composite structure which can be modeled using plate bending or membrane type elements.

As a preprocessor only, COBSTRAN can be used to generate nodes(grids), connectivities and material properties for various configurations which can then be combined into one structural analysis model. COBSTRAN writes these bulk data records to FORTRAN unit KBULK which can be assigned to a user designated file. COBSTRAN was designed primarily to interface with the NASTRAN structural analysis code, therefore, some of the terminology used in this manual will be familiar to NASTRAN users.

When assembled the COBSTRAN input data deck consists of the following five parts.

1. Option deck
2. Parameter deck
3. Composite deck
4. Geometry deck
5. Composite databank (in separate file)

The Option deck identifies the job and type of solution to be performed. Twenty user-selected options are available establishing such items as model input/output format, composite ply order and preparation of data input for the general purpose structural analysis code to be used.

The Parameter deck defines geometry and material property input/output characteristics such as mesh density, number of composite material systems (i.e. fiber/matrix combinations), ply stacking sequence and type of material output (membrane,bending,etc.) for use by the structural analysis code.

The Composite deck defines the characteristics of each ply layer. These are fiber type, matrix type, thickness, fiber volume ratio, orientation angle and ply location, by percent chord and percent span, in the structural model.

The Geometry deck defines the model configuration with a minimum of input values. Four different input formats are available for this data. COBSTRAN's internal interpolation routine is used to generate and refine the mesh pattern as specified by parameter values.

An internal databank is provided with the COBSTRAN code which contains constitutive properties of 21 fiber types, 17 matrix types and correlation coefficients for 31 fiber/matrix combinations. This property databank is provided for user information and guidance only and no responsibility is assumed by the authors as to accuracy or currency of the data. All properties are in customary U.S. units. The databank is stored in subroutines BANKCO, BANKFP, and BANKMP.

For a user supplied databank, a format and definition of properties is provided in Section 4 of the USER'S MANUAL. This databank should be maintained in a separate file which is referenced to FORTRAN unit KDBANK when used with COBSTRAN.

COBSTRAN provides a hierarchial approach to databank aquisition.

a) The user supplied databank is searched for the fiber and matrix properties requested.

b) The internal databank is searched for those properties not found in the user supplied databank.

The source of the properties is indicated in the output.

MESH GENERATION

The mesh generation capability in COBSTRAN is designed to create 2-D plate type meshes under the SOLID option and aircraft wing type meshes under the SHELL/SPAR option. In both cases meshes are created from 2-D elements. Under the SOLID option four types of 2-D mesh patterns may be created from nodal points generated along the mid-thickness line. These patterns are described in User Controlled Parameters, Section 3 of the USER'S MANUAL.

Under the SHELL/SPAR option only quadrilateral elements are utilized. Each airfoil chordwise cross-section is divided into approximately equal spaces but modified for grid points at spar locations. The leading edge section of each airfoil surface is divided into two elements for an improved mesh on a small radius surface.

COMPOSITE MECHANICS

The properties of each layer at each node are calculated using the micromechanics equations programmed in subroutine PLY. These individual layer properties are combined using the laminate theory equations programmed in subroutine PROP forming the elastic property matrix for the node. PLY and PROP are cycled for each node.

LAMINATE DECOMPOSITION

The element stress or strain output from the structural analysis code is used in subroutine STR to calculate the two-dimensional load vector at each node of the descrete structural model. Using these load vectors, the subroutines PLY, PROP and COMSA are cycled for each node calculating the stress and strain state and failure criteria for each lamina.

OUTPUT DATA

The laminate analysis module generates material properties for each node. The nodal values printed are;

Membrane stiffness matrix
Bending stiffness matrix
Coupling stiffness matrix

The finite element data module generates and writes to FORTRAN unit KBULK the following;

Element connectivities
Nodal coordinates
Element material properties

The laminate decomposition module generates and reports for each node the stress, strain and failure criteria for each ply at the node.

A summary of the minimum margins of safety for each node is printed as follows;

Combined stress margin of safety
Hoffman failure margin of safety
Interlaminar shear margin of safety

INTRODUCTION to Program Modules

This section describes the function of each subroutine in COBSTRAN and where appropriate, the equations programmed in each subroutine. The flow of COBSTRAN can be followed by examining the flow chart of the MAINPG program. There are four secondary level executive subroutines called in MAINPG. These are CSOLID to generate a two-dimensional model, CSHELL to generate an aircraft wing type model, SOLVEQ to drive the MHOST program and CPOST to analyze the output of each finite element analysis program and calculate the individual ply stresses, strains and failure criteria.

A list of engineering symbols with their FORTRAN code and description are in SYMBOLS and Code Identifiers, Section 4 of this manual. Additional FORTRAN variables and their descriptions are available in the DICTIONARY, Section 6 of the USER'S MANUAL.

MAINPG

```
CALLS TO -- CINIT      REFLEC     LOGO       OPTION
            CSOLID     CSHELL     SOLVEQ     CPOST


 COMMON /CUNITS/ KDES1,     KKEI,      KBULK,     KREAD,     KOUT,
                 KTTAB,     KDES2,     KPROP1,    KGNP,      KDBANK,
                 KPROP2,    KPOST,     KMHFOR,    KREFL,     KDIAG,
                 KPLOT
 COMMON /BOOL/   BIDE,      DYNA,      PRTOUT,    WINDML,    SOLID,
                 MINICH,    UNSY,      PROFIL,    PROT,      PREP,
                 POST,      MODES,     HOLLOW,    COSD,      MSCD,
                 PLYORD,    RINDV,     TEM,       ZIGZAG,    PRES,
                 COSMIC,    MSCNAS,    MHOST,     EZRD,      ECHO,
                 RANG,      DUMP,      CONE,      MPLOT
 COMMON /DIAGS/  LDIAG(100)
```

The main program initializes program FORTRAN units, stores the user's input deck for later reading, generates the logo and sets program options. The options selected are used to control program flow through the four second level executive subroutines, CSOLID, CSHELL, SOLVEQ and CPOST. The flow charts presented in CSOLID, CSHELL and CPOST describe the subroutines utilized within each of these paths in COBSTRAN.

To modify this program for use with the MHOST code remove 'CHOST' from the lines so labeled in this main program. Subroutine SOLVEQ at the end of this code is the main program for the MHOST analysis code.

These codes are setup for large word machines -64 bits-, to change to double precision, remove 'CDP' from the appropriate lines in this code and modify subroutine SOLVEQ according to its instructions to change the MHOST code.

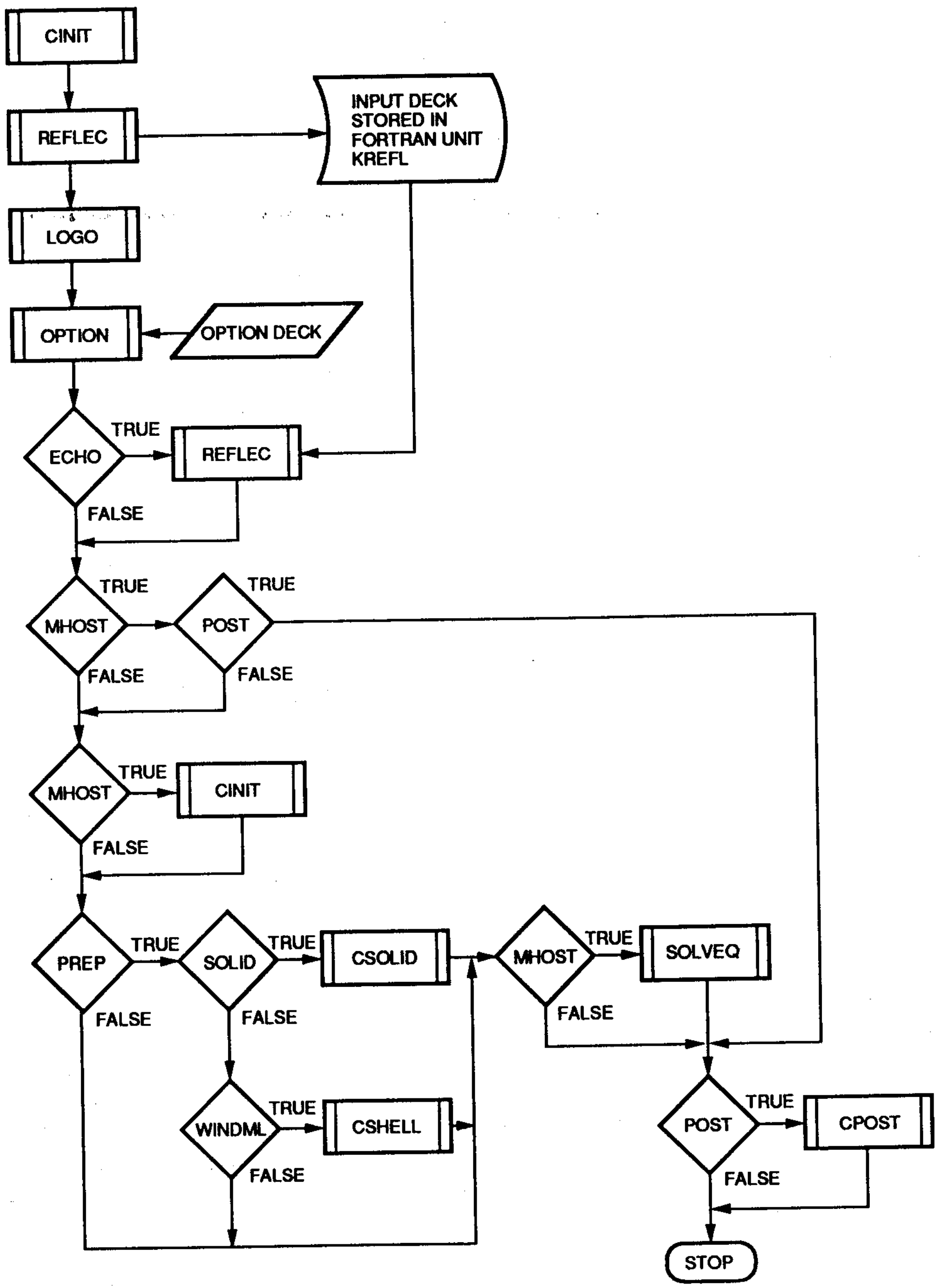

Figure 2. - MAINPG flow chart.

SUBROUTINE BANKCO

CALLED FROM -- BANKRD

CALLS TO -- none

ARGUMENTS (NA1,NA2,COR,IF,IX)

Correlation coefficients for the following fiber/matrix combinations are stored in this subroutine.

Fiber/Matrix	Date	Comment
T300/SPOX	9-26-80	FOR COMPOSITE PROPERTY INPUT BY USER
T300/EPOX	10-26-79	
ALT6/ALT6	8-01-83	
NIKL/NIKL	8-12-83	
HGLA/EPOX	10-11-83	CROSS WEAVE FOR SR7 PROP MODEL
FOAM/FOAM	8-08-83	
HT-S/GK60	11-27-72	
MOD1/EPOX	06-15-72	
MOD2/EPOX	06-15-72	
MOD2/POLY	06-15-72	
HM-S/EPOX	06-15-72	
HT-S/EPOX	06-15-72	
MOD1/POLY	06-15-72	
HT-S/POLY	06-15-72	
BOR4/EPOX	11-07-73	
SGLA/EPOX	11-07-73	
KEVL/EPOC	11-12-73	
HV-S/GV60	11-27-72	
HT-S/PMRP	06-20-74	
BOR4/ALT6	11-07-73	
KEVL/TIT6	07-10-74	
MOD2/BERY	07-10-74	
BOR5/EPOX	02-04-75	
KEVL/EPOX	02-04-75	
SW4M/NM40	02-10-75	
HERC/SSAL	02-04-75	
BOR5/ALT6	01-25-77	
TITF/TIT6	01-25-77	
ADHF/FMTH	01-25-77	
HERC/EPOX	01-25-77	
HOLO/HOLO	03-20-79	

SUBROUTINE BANKFP

CALLED FROM -- BANKRD

CALLS TO -- none

ARGUMENTS (NAF,I1,F1,I2,FP,IF,IX)

Properties of the following fiber materials are stored in this subroutine.

Fiber	Date	Comment
ALT6 ISO	8-01-83	NO REF
NIKL ISO	8-12-83	NO REF
HGLA ISO	10-11-83	CROSS WEAVE FOR SR7 PROP
FOAM	8-08-83	FOR SR7 PROP MODEL (SR7A 5-23-84)
T300 ANIS	10-26-79	NO REF.
MOD2 ANIS	06-15-72	NO REF.
MOD1 ANIS	06-15-72	NO REF.
HM-S ANIS	06-15-72	NO REF.
HT-S ANIS	06-15-72	NO REF.
AS-- ANIS	06-15-72	NO REF.
BOR4 ISO	11-07-73	NO REF.
SGLA ISO	11-07-73	NO REF.
KEVL ANIS	11-07-73	NO REF.
HV-S ANIS	06-15-72	NO REF.
BOR5 ISO	04-11-74	NO REF.
BOR8 ISO	04-11-74	NO REF.
EGLA ISO	04-11-74	NO REF.
SW4M ISO	02-10-75	NO REF.
TITF ISO	01-25-77	NO REF.
ADHF ISO	01-25-77	NO REF.
HOLO	03-20-79	NO REF.

SUBROUTINE BANKMP

CALLED FROM -- BANKRD

CALLS TO -- none

ARGUMENTS (NAM,I1,PM,IF,IX)

Properties of the following matrix materials are stored in this subroutine.

Matrix	Date	Comment
SPOX ISO	9-26-80	FOR COMPOSITE PROPERTY INPUT BY USER (ORIGINAL MODEL SR2C BLADE)
GK60	11-27-72	
FOAM	8-08-83	FOR SR7 PROP MODEL (SR7A 5-23-84)
NIKL	8-12-83	
EPOX ISO	06-15-72	NO REF.
ERLA 4617	06-15-72	NO REF.
POLY	06-15-72	NO REF.
ALT6	11-07-73	
TIT6	11-07-73	MAT.ENG.1967
EPOC	11-12-73	NO REF.
SSAL	11-12-73	MAT.ENG.1967
GV60	11-27-72	
PMRP	06-20-74	
BERY	07-10-74	
NM40	02-10-75	
FMTH	01-25-77	MFCA DATA
HOLO	03-20-79	NO REF.

SUBROUTINE BANKRD

CALLED FROM -- CSHELL   CSOLID

CALLS TO --   BANKCO   BANKFP   BANKMP

ARGUMENTS (CODES,FP,MP,CORC,DF,NF,NT,NPD,NDES,KDBANK,KOUT)

Composite material system descriptions are read into the program by this subroutine. Fiber properties, matrix properties and correlation coefficients from a user supplied databank must be assigned to each COBSTRAN preprocessor run. This databank is stored in FORTRAN unit KDBANK.

Subroutine BANKRD first searches the user supplied databank for the fiber and matrix properties selected in the input deck. If properties are not found in the user supplied databank the internal databank residing in subroutines BANKCO, BANKFP, and BANKMP is searched for the missing properties. Therefore, if only the properties from the internal databank are to be used, a user supplied databank is required containing three records with zero in the first column of each record. Each record refers respectively to fiber, matrix and correlation coefficients.

An output message informs the user regarding the source of the properties.

The selected fiber and matrix properties and the corresponding correlation coefficients are retained in a temporary file for postprocessing.

SUBROUTINE CINIT

CALLED FROM -- MAINPG

CALLS TO -- none

ARGUMENTS -- none

```
 COMMON /CUNITS/ KDES1,     KKEI,      KBULK,      KREAD,      KOUT,
                 KTTAB,     KDES2,     KPROP1,     KGNP,       KDBANK,
                 KPROP2,    KPOST,     KMHFOR,     KREFL,      KDIAG,
                 KPLOT
 COMMON /BOOL/   BIDE,      DYNA,      PRTOUT,     WINDML,     SOLID,
                 MINICH,    UNSY,      PROFIL,     PROT,       PREP,
                 POST,      MODES,     HOLLOW,     COSD,       MSCD,
                 PLYORD,    RINDV,     TEM,        ZIGZAG,     PRES,
                 COSMIC,    MSCNAS,    MHOST,      EZRD,       ECHO,
                 RANG,      DUMP,      CONE,       MPLOT
 COMMON /WINDS/  SY(4,30,5),  MWSCT(30,2),  ALPHA(3,3),   X(30),
                 NXSPC(30),   NSPDES(5),    NGRID,        NELT,
                 NPAST,       THMAX,        NXSECT,       NSPAR,
                 NXSPAR,      NYSPC,        LSP(2,5,30),  NYPTS,
                 NNQ,         NNX,          LSECT(2),     NPTOT,
                 NETOT,       HOLD(10),     MAXPLY,       MPLY(300)
```

This subroutine establishes the FORTRAN units to be used in COBSTRAN. If the MHOST option is selected a second call is made to this subroutine to reset the units to avoid conflict within the MHOST module.

Variable name		FORTRAN unit	FORTRAN unit for MHOST
* KDES1	=	52	52
* KKEI	=	53	53
* KBULK	=	54	54
KDIAG	=	6	6
KREAD	=	5	5
KOUT	=	6	6
KTTAB	=	57	57
KDES2	=	58	58
KPROP1	=	59	59

* KGNP	=	60	60
KDBANK	=	61	61
KPROP2	=	62	62
KREFL	=	63	63
KPLOT	=	64	64
KPOST	=	5	55
KMHFOR	=	90	12

* Data stored on units KDES1, KKEI, KBULK and KGNP must be saved for post-processing of the general purpose structural analysis code. All other units are scratch files.

SUBROUTINE COBSMF

CALLED FROM -- COMSA

CALLS TO -- none

ARGUMENTS (J,FPT,MPT,SIGL,KSMF,SMF,PL)

The strain magnification factors from which the ply unidirectional limiting are constructed are generated in this subroutine. These factors are $\phi_{\mu 22}$, $\phi_{\mu 12}$ and $\phi_{\mu 23}$, for constructing $S_{\ell 22}$, $S_{\ell 12}$ and $S_{\ell 23}$ respectively.

Four user-optional methods are available to compute $\phi_{\mu 22}$, Parabolic strain distribution, Daniel's indirect, Kies's two-dimensional,and Linear strain distribution.

Filament and matrix orthotropy and the effects of voids are included in all of these methods as described in reference 2.

The equations programmed in this subroutine are;

$$VC = \frac{1.0}{\left[1 - \left(\frac{4k_v}{\pi k_m}\right)^{1/2}\right]}$$

$$\bar{k}_f = (1 - k_v)\, k_f$$

$$k_m = (1 - k_f) \qquad \bar{k}_m = (1 - k_v)(1 - k_f)$$

$$C_{f\phi} = \frac{\bar{k}_f}{k_f} \qquad C_{m\phi} = \frac{\bar{k}_m}{(1 - k_f)}$$

$$p = \left(\frac{4\bar{k}_f}{\pi}\right)^{1/2} \qquad PR = \frac{1}{p}$$

The four methods used to compute the strain magnification factor $\phi_{\mu 22}$, are as follows;

(1) Parabolic strain distribution method;

$$\phi_{\mu 22} = \frac{1}{3}\left[\frac{2\,PR}{\frac{E_{m22}}{E_{f22}} + PR - 1.0} + 1.0\right]$$

$$\phi_{\mu 22} \rightarrow \ PL(43,J)$$

(2) Daniel's indirect method

$$\phi_{\mu 22} = k_{\sigma}(1 - \nu^2_{m23})\,\frac{E_{\ell 12}}{E_{m12}}$$

$$k_{\sigma} = 0.83\left[\left(\frac{\pi}{\bar{k}_f}\right)^{1/2} - 2\right]^2 - 1.35\left[\left(\frac{\pi}{\bar{k}_f}\right)^{1/2} - 2\right] + 1.78$$

$$0.35 \le \bar{k}_f \le 0.75 \qquad \text{if not then} \quad \phi_{\mu 22} = 1.0$$

$$\phi_{\mu 22}(VC) \rightarrow \ PL(44,J)$$

(3) Kies's two-dimensional method

$$\bar{A} = \frac{(1 - \nu_{f12}\,\nu_{f21})\, C_{m\phi}\, E_{m22}}{(1 - \nu_{m12}\,\nu_{m21})\, C_{f\phi}\, E_{f22}}$$

$$\bar{B} = \nu_{m12}\,\bar{A}$$

$$S1 = \frac{1}{E_{\ell 22}}\left[1 - \nu_{\ell 21}\, p\,(\nu_{f12} - \bar{B})\right]\, \sigma_{\ell 22}$$

$$S2 = \frac{1}{E_{\ell 11}}\left[p\,(\nu_{f12} - \bar{B}) - \nu_{\ell 12}\right]\, \sigma_{\ell 11}$$

$$\varepsilon_{m22} = \left[\frac{1}{1 + p\,(A - 1)}\right](S1 + S2)$$

$$\varepsilon_{\ell 22} = \frac{\sigma_{\ell 22}}{E_{\ell 22}} - \nu_{\ell 12}\,\frac{\sigma_{\ell 11}}{E_{\ell 11}}$$

$$\phi_{\mu 22} = \begin{cases} \dfrac{\varepsilon_{m22}}{\varepsilon_{\ell 22}} & \text{if } |\varepsilon_{\ell 22}| \geq 1.0\text{x}10^{-30} \\ 1.0 & \text{if } \dfrac{\varepsilon_{m22}}{\varepsilon_{\ell 22}} \leq 1.0 \end{cases}$$

$$\phi_{\mu 22}\,(\mathrm{VC}) \rightarrow \quad \mathrm{PL(45,J)}$$

(4) Linear strain distribution method

$$\phi_{\mu22} = \frac{PR}{\frac{E_{m22}}{E_{f22}} + PR - 1.0}$$

$$\phi_{\mu22}\,(VC) \rightarrow \ PL(46,J)$$

STRAIN MAGNIFICATION FACTOR $\phi_{\mu12}$

$$\phi_{\mu12} = \frac{1}{1 - p\left(1 - \frac{C_{m\phi}\ E_{m12}}{C_{f\phi}\ E_{f12}}\right)}$$

$$\phi_{\mu12}\,(VC) \rightarrow \ PL(47,J)$$

STRAIN MAGNIFICATION FACTOR $\phi_{\mu23}$

$$\phi_{\mu23} = \frac{1}{2\,(1 - p) + (2p - 1)\left(\frac{C_{m\phi}\ E_{m23}}{C_{f\phi}\ E_{f23}}\right)}$$

$$\phi_{\mu23}\,(VC) \rightarrow \ PL(48,J)$$

Inputs to subroutine COBSMF are the ply applied stresses ($\sigma_{\ell 11}$, $\sigma_{\ell 22}$, $\sigma_{\ell 33}$), the void and apparent fiber content, and ply fiber and matrix elastic constants.

The outputs of this subroutine are the magnification factors stored in array PL(43,J) thru PL(48,J). The strain magnification factor selected by the user is transferred by the call argument SMF.

SUBROUTINE COMSA

CALLED FROM -- CPOST

CALLS TO -- COBSMF INVA PLYIN

```
ARGUMENTS (I,PROT,PRTOUT,RINDV,SPARS,KTTAB,KOUT,KSMF,
           MESH,NPAST,NLEP,FC,NSB,MSB,
           CODES,FP,MP,CORC,NT,NPD,THERMO,MDES)

COMMON /PROPER/ PL(71,223)
COMMON /STRA/   DISV1(6,510)
COMMON /PRINT1/ ID(80,5), IOPT(80,30)
COMMON /PRINT2/ NPRT(2,10)
COMMON /PLIN/   FPT(19),MPT(15),CC(6,5),TS3(3),ALPP(3)
COMMON /PROPTY/ EP(16),THP(5),THF(6),AS(9),CS(9),
                BS(9),RA(9),RB(9),DENS
```

In this subroutine the stress and strain state of each ply are computed given the edge membrane force resultants, the ply temperature change and the changes in curvature, In addition, two-ply combined-stress strength criteria and the interply delamination criterion are generated. The equations programmed for the i^{th} ply strain and stress states are

$$\{\varepsilon_{\ell i}\} = [R_{\ell i}]\,[A_{cx}]^{-1}\Big(\{N_{cx}\} + \{N_{c\Delta Tx}\} + [C_{cx}]\,\{w_{cbx}\}\Big) - z[R_{\ell i}]\,\{w_{cbx}\}$$

$$\{\sigma_{\ell i}\} = [E_{\ell i}]^{-1}[R_{\ell i}]\,[A_{cx}]^{-1}\ \Big(\{N_{cx}\} + \{N_{c\Delta Tx}\} + [C_{cx}]\,\{w_{cbx}\}\Big) - [E_{\ell i}]^{-1}\Big(\Delta T_{\ell i}\{\alpha_{\ell i}\} + z\,[R_{\ell i}]\,\{w_{cbx}\}\Big)$$

The composite reference plane strains ε_{csx} and the changes in curvatures are computed from

$$\left\{\frac{\{\varepsilon_{csx}\}}{\{w_{cbx}\}}\right\} = \left[\begin{array}{c|c} [A_{cx}] & [C_{cx}] \\ \hline [C_{cx}] & [D_{cx}] \end{array}\right]^{-1} \left\{\left\{\frac{\{N_{cx}\}}{\{M_{cx}\}}\right\} + \left\{\frac{\{N_{c\Delta Tx}\}}{\{M_{c\Delta Tx}\}}\right\}\right\}$$

when one or both of the membrane force and moment resultants are given.

The strains are generated locally in EPSL and SIGL, respectively, and are stored in PL(64,I) to PL(69,I). The matrices $[R_{\ell i}]$ and $[E_{\ell i}]$ are generated locally from information transferred from PL(14,I) and PL(31,I) to PL(42,I). The distance $z_{\ell i}$ and the ply temperature change $\Delta T_{\ell i}$ are transferred from PL(11,I) and PL(50,I), respectively.

The remaining matrices are;

$$A_{cx} \rightarrow \mathrm{ACX}$$
$$C_{cx} \rightarrow \mathrm{CPC}$$
$$N_{c\Delta Tx} \rightarrow \mathrm{NSDT}$$
$$N_{cx} \rightarrow \mathrm{NSB}_m$$
$$M_{cx} \rightarrow \mathrm{MSB}_m$$

$w_{cbx} \rightarrow \mathrm{WXX}_m$ (local curvature from bending analysis)

where m denotes the load direction.

It is important to note that the stress analysis in the coded form also handles the case where both reference plane membrane strains and the local curvatures are given. In this case the ply strains are given by

$$\{\varepsilon_{\ell xi}\} = \{\varepsilon_{csx}\} - z_{\ell i}\ \{w_{cbx}\}$$

where $\{\varepsilon_{\ell xi}\}$ are the i^{th} ply strains along the structural axis, $\{\varepsilon_{csx}\}$ are the composite reference plane membrane strains, $z_{\ell i}$ is the distance from the reference plane to the centroid of the i^{th} ply, and $\{w_{cbx}\}$ are the composite local curvatures. They are read in the array D_{vm} where m denotes the load direction.

The corresponding i^{th} ply stresses are given by

$$\{\sigma_{\ell i}\} = [E_{\ell i}]^{-1} \left([R_{\ell i}]\{\varepsilon_{\ell xi}\} - \Delta T_{\ell i} \{\alpha_{\ell i}\}\right)$$

where $\{\sigma_{\ell i}\}$ are the i^{th} ply stresses along the material axes, $[E_{\ell i}]$ are the i^{th} ply elastic constants about the material axes, $[R_{\ell i}]$ is the transformation matrix of the i^{th} ply from the ply material coordinate system to the structural coordinate system, $\{\varepsilon_{\ell xi}\}$ are the i^{th} ply strains along the structural axes as given by a previous equation, $\Delta T_{\ell i}$ is the temperature change of the i^{th} ply, and $\{\alpha_{\ell i}\}$ are the thermal coefficients of expansion of the i^{th} ply in its material coordinate system.

The displacement force relations are shown;

Displacement	Displacement force relations	Forces
$\left\{\dfrac{\{U_{cx}\}}{\{W_{cx}\}}\right\}$	$\left[\begin{array}{c\|c} [A_{cx}] & [C_{cx}] \\ \hline [C_{cx}] & [D_{cx}] \end{array}\right]^{-1}$	$\left\{\dfrac{\{N_{cx}\}}{\{M_{cx}\}}\right\}$

Output is by node(grid point) presenting ply stresses, strains and failure criteria for each ply layer.

The failure criterion may be determined by either of the following methods.

(1) Modified distortion energy

$$F = 1 - \left[\left(\frac{\sigma_{\ell 11\alpha}}{S_{\ell 11\alpha}} \right)^2 + \left(\frac{\sigma_{\ell 22\beta}}{S_{\ell 22\beta}} \right)^2 - K_{\ell 12\alpha\beta} \frac{\sigma_{\ell 11\alpha}}{|S_{\ell 11\alpha}|} \frac{\sigma_{\ell 22}}{|S_{\ell 22}|} + \left(\frac{\sigma_{\ell 12S}}{S_{\ell 12S}} \right)^2 + \right]_i \rightarrow \text{PL(62,I)}$$

The parameters α and β are specified as follows:

$$\alpha = \begin{cases} T & \sigma_{\ell 11} \geq 0 \\ C & \sigma_{\ell 11} < 0 \end{cases}$$

$$\beta = \begin{cases} T & \sigma_{\ell 22} \geq 0 \\ C & \sigma_{\ell 22} < 0 \end{cases}$$

$$S_{\ell 11\alpha} = \begin{cases} S_{\ell 11T} & \alpha = T \\ \min(S_{\ell 11C},\ S_{\ell 11CD}) & \alpha = C \end{cases}$$

$$K_{\ell 12\alpha\beta} = K'_{\ell 12\alpha\beta} \frac{(1 + 4\nu_{\ell 12} - \nu_{\ell 13})E_{\ell 22} + (1 - \nu_{\ell 23})E_{\ell 11}}{\left[E_{\ell 11}\ E_{\ell 22}\ (2 + \nu_{\ell 12} + \nu_{\ell 13})\ (2 + \nu_{\ell 21} + \nu_{\ell 23})\right]^{1/2}}$$

$$K'_{\ell 12\alpha\beta} = \begin{cases} \text{CORC}(1,5) & \alpha,\ \beta = T \\ \text{CORC}(2,5) & \alpha = C,\ \beta = T \\ \text{CORC}(4,5) & \alpha = T,\ \beta = C \\ \text{CORC}(3,5) & \alpha,\ \beta = C \end{cases}$$

The multiplyer of $K_{\ell 12\alpha\beta}$ was generated in subroutine COMSA and is stored in PL(61,I). The constants $K'_{\ell 12\alpha\beta}$ constitute theory-experiment correlation factors.

(2) Hoffman's criterion (ref 3):

$$S_{\ell 11C} \leftarrow \min(S_{\ell 11C},\ S_{\ell 11CD})$$

$$F = 1 - \left[\frac{\sigma^2_{\ell 11} - \sigma_{\ell 11}\sigma_{\ell 22}}{S_{\ell 11C} S_{\ell 11T}} + \frac{\sigma^2_{\ell 22}}{S_{\ell 22C} S_{\ell 22T}} + \frac{S_{\ell 11C} - S_{\ell 11T}}{S_{\ell 11C} S_{\ell 11T}} \sigma_{\ell 11} + \frac{S_{\ell 22C} - S_{\ell 22T}}{S_{\ell 22C} S_{\ell 22T}} \sigma_{\ell 22} + \frac{\sigma^2_{\ell 12}}{S^2_{\ell 12S}} \right]_i \rightarrow \text{PL}(71,I)$$

$F > 0$	no failure
$F = 0$	incipient failure
$F < 0$	failure

The interply delamination criterion for the j^{th} interply layer at the m^{th} load condition is governed by

$$\left[1-\left(\frac{|\Delta\phi|}{\Delta\phi_{del}}\right)_j\right] \rightarrow \text{PL(63,I)} \qquad \text{when } i > 1$$

$$\Delta\phi_j = \frac{1}{2}(\varepsilon_{cyy} - \varepsilon_{cxx})(\sin 2\theta_i - \sin 2\theta_{i-1}) + \frac{1}{2}\varepsilon_{cxy}(\cos 2\theta_i - \cos 2\theta_{i-1})$$

$$\{\varepsilon_{cx}\} = [A_{cx}]^{-1}\left(\{N_{cx}\} + \{N_{c\Delta Tx}\} + [C_{cx}]\{w_{cbx}\}\right)$$

or is given by the displacement force equation described previously.

The inputs to the subroutine are the ply angle $\theta_{\ell i}$ measured from the structural axes from PL(14,I), the distance from the reference plane to the centroid of the ply $z_{\ell i}$ from PL(11,I), the ply temperature change $\Delta T_{\ell i}$ from PL(50,I), the interply delamination limit $\Delta\phi_{del\ j}$ from PL(60,I), and the ply thermoelastic properties stored in PL(24 to 26,I) and PL(31 to 42,I). The ply extensional and coupling rigidities A_{cx} = ACX and C_{cx} = CPC; the local curvatures w_{cbx} = WXX; the adjustment constants $K'_{\ell 12TT}$ = CORC(1,5), $K'_{\ell 12CT}$ = CORC(2,5), $K'_{\ell 12TC}$ = CORC(4,5), and $K'_{\ell 12CC}$ = CORC(3,5); and the load conditions N_{cx} = NSB(m).

The subroutine outputs are the modified distortion energy PL(62,I), Hoffman's criterion PL(71,I), the interply delamination criterion PL(63,I), and the adjacent ply relative rotation ($\Delta\phi_j$ from PL(70,I)).

SUBROUTINE CPOST

```
CALLED FROM --  MAINPG

CALLS TO --     COMSA     MHSTR     OUTPUT    PLY
                PLYSHR    PROP      STR

 ARGUMENTS none

 COMMON /CUNITS/ KDES1,    KKEI,     KBULK,    KREAD,    KOUT,
                 KTTAB,    KDES2,    KPROP1,   KGNP,     KDBANK,
                 KPROP2,   KPOST,    KMHFOR,   KREFL,    KDIAG,
                 KPLOT
 COMMON /BOOL/   BIDE,     DYNA,     PRTOUT,   WINDML,   SOLID,
                 MINICH,   UNSY,     PROFIL,   PROT,     PREP,
                 POST,     MODES,    HOLLOW,   COSD,     MSCD,
                 PLYORD,   RINDV,    TEM,      ZIGZAG,   PRES,
                 COSMIC,   MSCNAS,   MHOST,    EZRD,     ECHO,
                 RANG,     DUMP,     CONE,     MPLOT
 COMMON /WINDS/  SY(4,30,5),  MWSCT(30,2),  ALPHA(3,3),   X(30),
                 NXSPC(30),   NSPDES(5),    NGRID,        NELT,
                 NPAST,       THMAX,        NXSECT,       NSPAR,
                 NXSPAR,      NYSPC,        LSP(2,5,30),  NYPTS,
                 NNQ,         NNX,          LSECT(2),     NPTOT,
                 NETOT,       HOLD(10),     MAXPLY,       MPLY(300)
 COMMON /VALUES/ NP, NE, NDES, IMAT, KSMF, IU, JU, XBEG, XEND,
                 NMODE(3), NOPLY, NSECT, MESH, NGROUP, NCOREG,
                 IGRD, MSECT(40), NCOOR(3,8)
 COMMON /PLYS/   THERMO(223),MDES(223),THHF,NLEP
 COMMON /PROPTY/ EP(16),THP(5),THF(6),AS(9),CS(9),
                 BS(9),RA(9),RB(9),DENS
 COMMON /PROPER/ PL(71,223)
 COMMON /MFCA/   CODES(6,40),     PERT(6,40),       FP(19,1,40),
                 MP(15,1,40),     CORC(6,5,40),     DF(40),
                 NF(40),          NT(2,40),         NPD(40)
 COMMON /TABLES/ GNP(12,510),KEI(6,910),NCORDL(910),RAD(2,510)
 COMMON /STRA/   DISV1(6,510)
 COMMON /PRINT1/ ID(80,5), IOPT(80,30)
 COMMON /PRINT2/ NPRT(2,10)
```

This subroutine is a second level executive program. It's purpose is to control the postprocessing phase of the analysis. Element stresses are read from the finite element analysis generated output file and transformed to the COBSTRAN structural coordinate system. Nodal stresses and corresponding nodal membrane forces and moments are calculated. From these loads, ply stresses, strains and failure criteria are determined for each ply layer at each grid point.

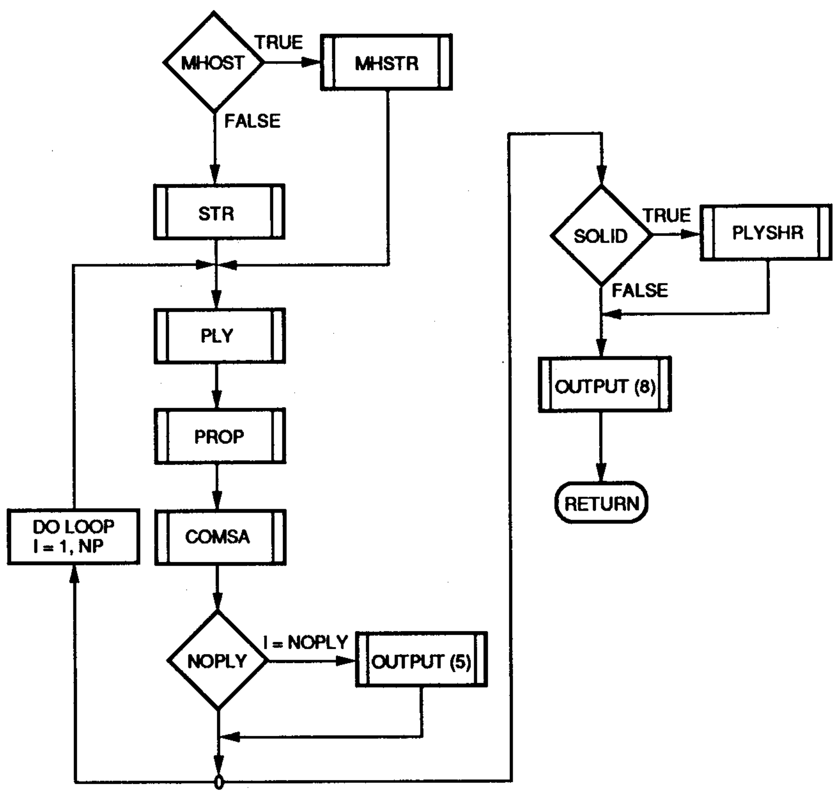

Figure 3. - CPOST flow chart.

SUBROUTINE CSHELL

CALLED FROM -- MAINPG

CALLS TO --				
	BANKRD	MHSHPR	NASTDK	NOLAPR
	OUTPUT	OUTP11	PLTBLK	PLYIN
	WIND	WINOUT	WINPLY	WINPUT
	WREAD	WROTAT	WSPAR	

ARGUMENTS none

```
COMMON /CUNITS/ KDES1,    KKEI,     KBULK,    KREAD,    KOUT,
                KTTAB,    KDES2,    KPROP1,   KGNP,     KDBANK,
                KPROP2,   KPOST,    KMHFOR,   KREFL,    KDIAG,
                KPLOT
COMMON /BOOL/   BIDE,     DYNA,     PRTOUT,   WINDML,   SOLID,
                MINICH,   UNSY,     PROFIL,   PROT,     PREP,
                POST,     MODES,    HOLLOW,   COSD,     MSCD,
                PLYORD,   RINDV,    TEM,      ZIGZAG,   PRES,
                COSMIC,   MSCNAS,   MHOST,    EZRD,     ECHO,
                RANG,     DUMP,     CONE,     MPLOT
COMMON /DIAGS/  LDIAG(100)
COMMON /WINDS/  SY(4,30,5),  MWSCT(30,2),  ALPHA(3,3),  X(30),
                NXSPC(30),   NSPDES(5),    NGRID,       NELT,
                NPAST,       THMAX,        NXSECT,      NSPAR,
                NXSPAR,      NYSPC,        LSP(2,5,30), NYPTS,
                NNQ,         NNX,          LSECT(2),    NPTOT,
                NETOT,       HOLD(10),     MAXPLY,      MPLY(300)
COMMON /VALUES/ NP, NE, NDES, IMAT, KSMF, IU, JU, XBEG, XEND,
                NMODE(3), NOPLY, NSECT, MESH, NGROUP, NCOREG,
                IGRD, MSECT(40), NCOOR(3,8)
COMMON /PLYS/   THERMO(223),MDES(223),THHF,NLEP
COMMON /PROPTY/ EP(16),THP(5),THF(6),AS(9),CS(9),
                BS(9),RA(9),RB(9),DENS
COMMON /PROPER/ PL(71,223)
COMMON /MFCA/   CODES(6,40),     PERT(6,40),      FP(19,1,40),
                MP(15,1,40),     CORC(6,5,40),    DF(40),
                NF(40),          NT(2,40),        NPD(40)
COMMON /TABLES/ GNP(12,510),KEI(6,910),NCORDL(910),RAD(2,510)
COMMON /STIFF/  EX(3,510),AB(6,510),DEN(510)
COMMON /STRA/   DISV1(6,510)
```

This subroutine is a second level executive program. It's purpose is to control the generation of aircraft wing type models composed of quadrilaterial shell elements on an airfoil surface separated by plate type spars.

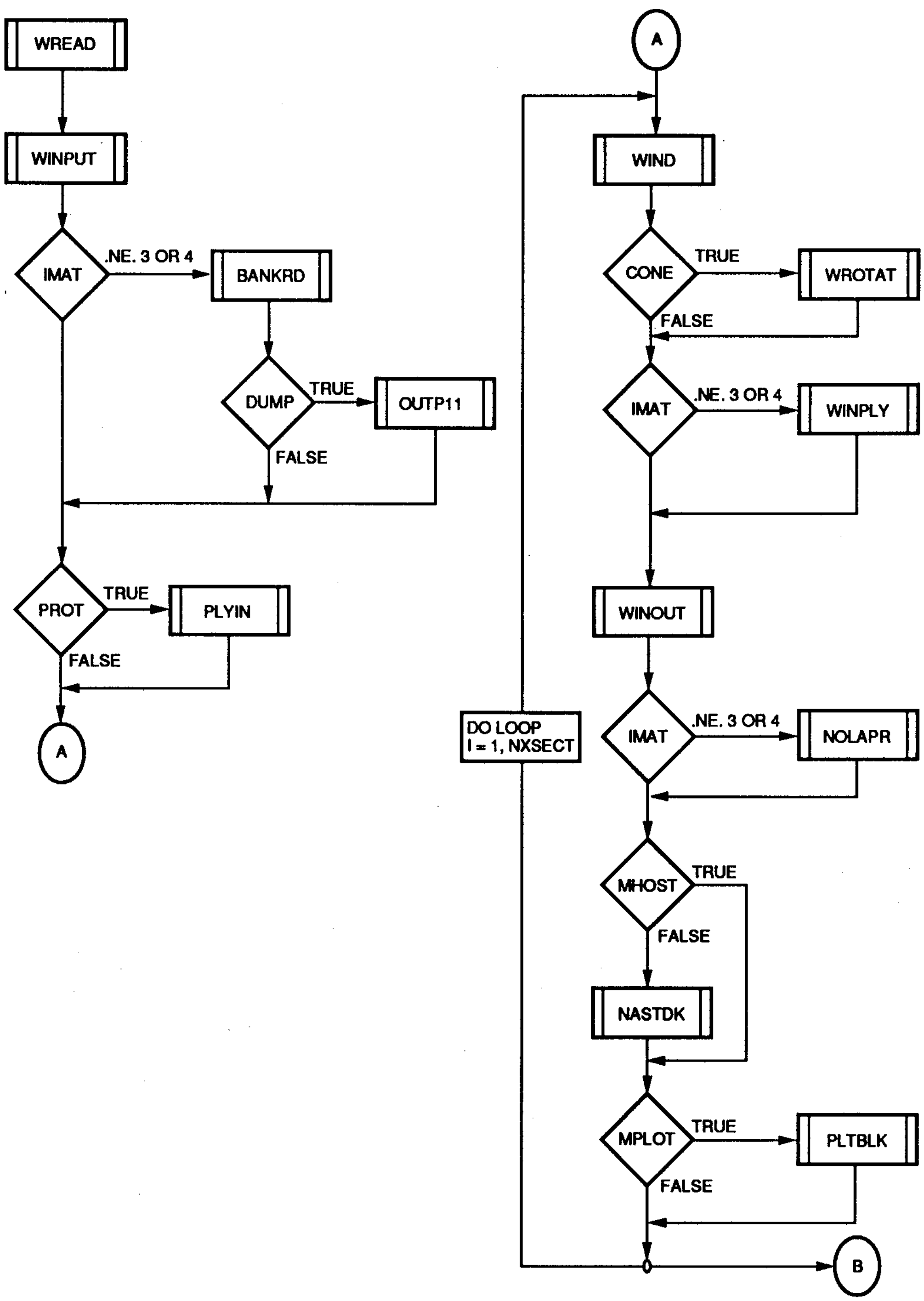

Figure 4a. - CSHELL flow chart.

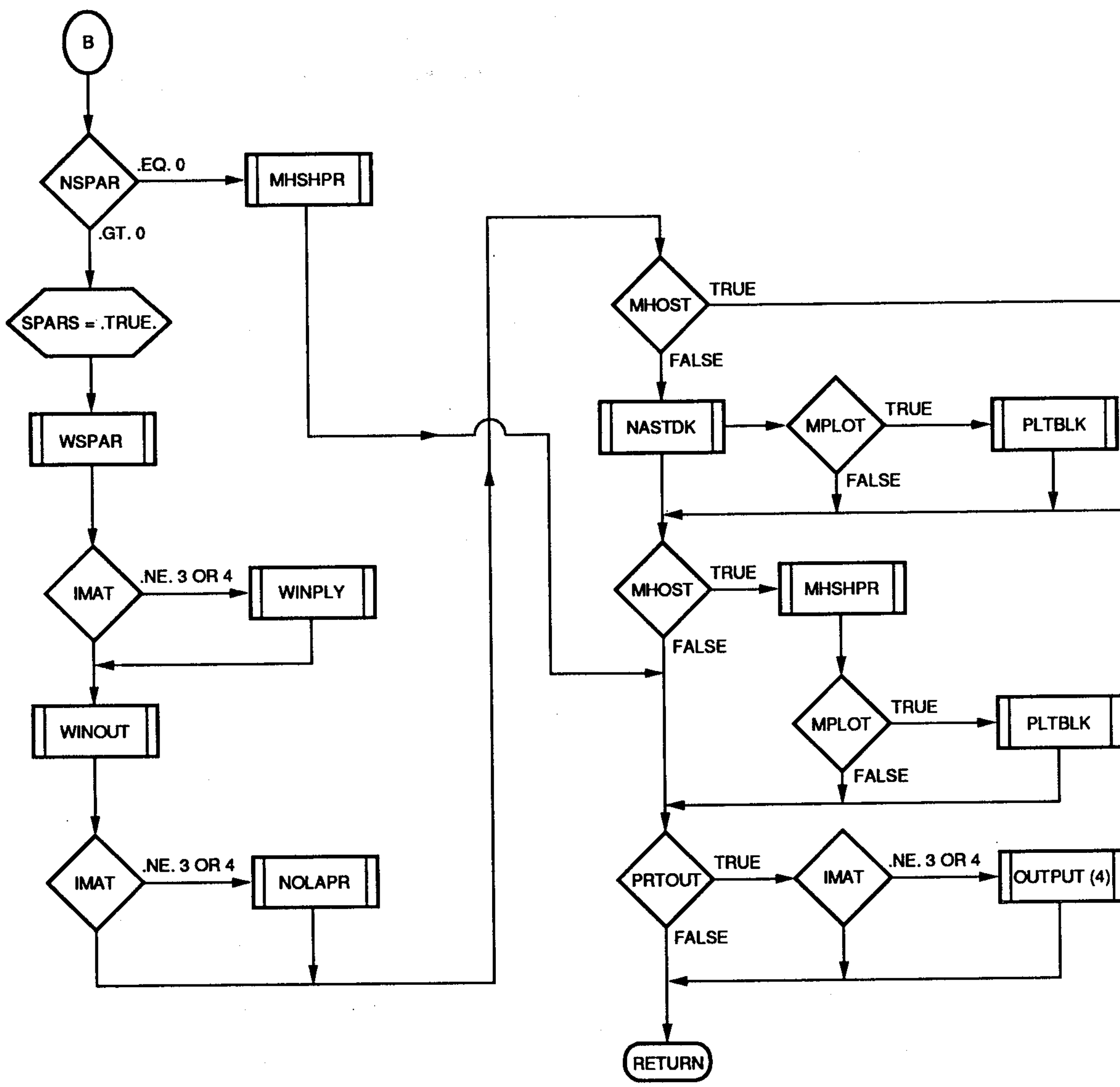

Figure 4b. - CSHELL flow chart

SUBROUTINE CSOLID

```
CALLED FROM --  MAINPG

CALLS TO --     BANKRD    CSREAD    MESHG     MHPREP
                MSCMIN    NASTDK    NASMIN    NOLAPR
                OUTPUT    OUTP10    OUTP11    PLTBLK
                PLYIN     TBGRD     TBPLY

ARGUMENTS none

COMMON /CUNITS/ KDES1,    KKEI,     KBULK,    KREAD,    KOUT,
                KTTAB,    KDES2,    KPROP1,   KGNP,     KDBANK,
                KPROP2,   KPOST,    KMHFOR,   KREFL,    KDIAG,
                KPLOT
COMMON /BOOL/   BIDE,     DYNA,     PRTOUT,   WINDML,   SOLID,
                MINICH,   UNSY,     PROFIL,   PROT,     PREP,
                POST,     MODES,    HOLLOW,   COSD,     MSCD,
                PLYORD,   RINDV,    TEM,      ZIGZAG,   PRES,
                COSMIC,   MSCNAS,   MHOST,    EZRD,     ECHO,
                RANG,     DUMP,     CONE,     MPLOT
COMMON /DIAGS/  LDIAG(100)
COMMON /VALUES/ NP, NE, NDES, IMAT, KSMF, IU, JU, XBEG, XEND,
                NMODE(3), NOPLY, NSECT, MESH, NGROUP, NCOREG,
                IGRD, MSECT(40), NCOOR(3,8)
COMMON /PLYS/   THERMO(223),MDES(223),THHF,NLEP
COMMON /PROPTY/ EP(16),THP(5),THF(6),AS(9),CS(9),
                BS(9),RA(9),RB(9),DENS
COMMON /PROPER/ PL(71,223)
COMMON /MFCA/   CODES(6,40),     PERT(6,40),      FP(19,1,40),
                MP(15,1,40),     CORC(6,5,40),    DF(40),
                NF(40),          NT(2,40),        NPD(40)
COMMON /TABLES/ GNP(12,510),  KEI(6,910), NCORDL(910), RAD(2,510)
COMMON /STIFF/  EX(3,510),  AB(6,510),  DEN(510)
```

This subroutine is a second level executive program. It's purpose is to control the generation of solid (thru-the-thickness) composite blades of the turboprop or turbofan types.

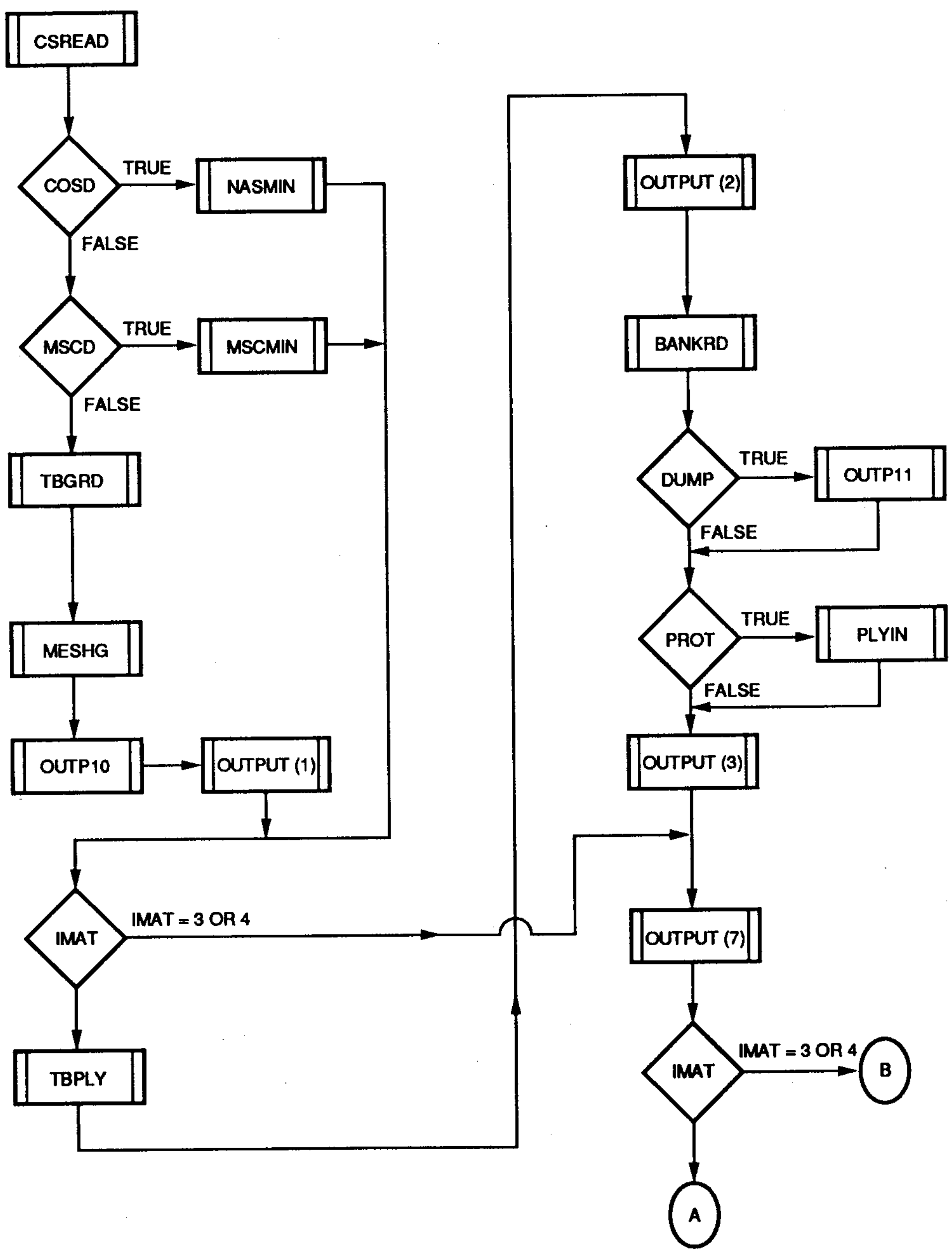

Figure 5a. - CSOLID flow chart.

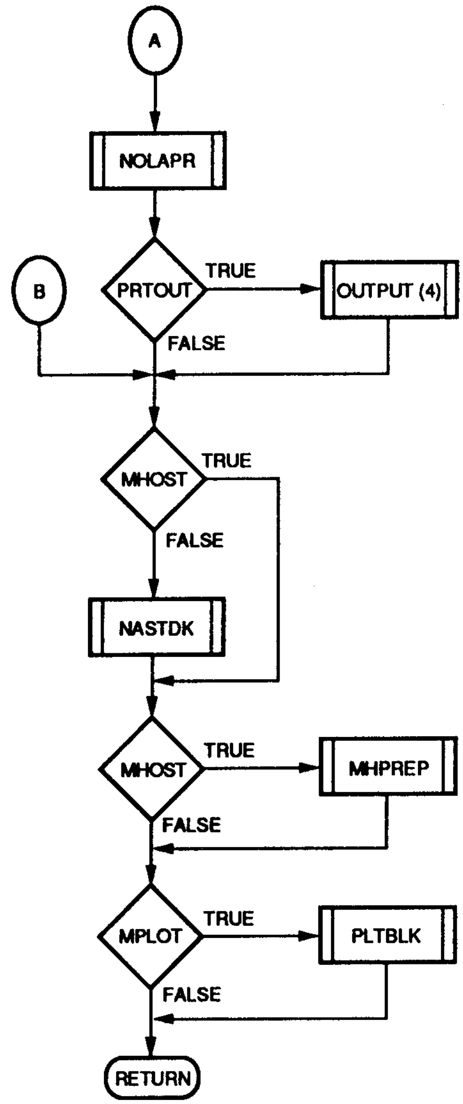

Figure 5b. - CSOLID flow chart.

SUBROUTINE CSREAD

CALLED FROM -- CSOLID

CALLS TO -- EZREAD

ARGUMENTS (COSD, MSCD, PLYORD, HOLLOW, UNSY, PROT, EZRD,
IMAT, NDES, NMODE, NOPLY, NSECT, NCOREG, NGROUP,
IGRD, IU, JU, MESH, MSECT, XBEG, XEND, KREAD,KDIAG,
KBULK, PIN, NCOOR, MAXPLY, LMAX, NGRD, MPLY, NPLY,
KGRD, THWAL, PERT, CODES, NPM, PMOD, HOLD, LDIAG)

This subroutine reads in all data specified in the SOLID option of the USER'S MANUAL. The order and format are as specified in the USER'S MANUAL.

Data is stored in the appropriate arrays in common blocks for use in the program.

SUBROUTINE CTRAN

CALLED FROM -- WINPUT

CALLS TO -- none

ARGUMENTS (X,Y,N,ANG,XA,YA)

This subroutine is used to transform points in a two-dimensional coordinate system by translation and rotation to a new coordinate system.

Input is the x and y arrays of the initial coordinates, the size of the arrays, the rotation angle and the x and y coordinates of the new origin.

The initial x and y arrays are overwritten by the new transformed coordinate values.

```
XPOUT = (Y(I)-YA) * SIN(ANG) + (X(I)-XA) * COS(ANG)

YPOUT = (Y(I)-YA) * COS(ANG) - (X(I)-XA) * SIN(ANG)
```

SUBROUTINE DIAGNO

CALLED FROM -- OPTION

CALLS TO --

This subroutine interprets the user option DIAGNOSTIC and sets flags in the subroutines according to the diagnostic numbers given below. Each word of the logical common LDIAG is initially set to .FALSE. then the words whose number appears on the option DIAG line is set to .TRUE. This turns on the diagnostic print option in the corresponding subroutines. Presently the diagnostic output is designated to FORTRAN unit 6, the usual write unit. This output can be directed to other units by changing the value of KDIAG in subroutine CINIT.

This feature currently exists in the following subroutines but may be added to others as needed by following the examples in these subroutines.

CSREAD	3
FFREAD	18
SPRSET	45
TBGRD	47
TBG01	48
WREAD	54
WINPUT	55
WSPAR	56
WROTAT	58

SUBROUTINE EZREAD

CALLED FROM -- CSREAD

CALLS TO -- FFREAD

ARGUMENTS (KBULK,KREAD,KDIAG,IMAT,NDES,NOPLY,NSECT,
NCOREG,NGROUP,IGRD,IU,JU,MESH,XBEG,XEND,
NXSECT,NSPAR,NXSPAR,NYSPC,
NMODE,MSECT,NSPDES)

This subroutine is a user selected option which provides for a simplified input format for program parameters as specified in the USER'S MANUAL.

Parameters are input by parameter name followed by an equal sign with the following value being that of the named parameter.

SUBROUTINE FFREAD

CALLED FROM -- EZREAD OPTION

CALLS TO -- SMARTY

ARGUMENTS (CH,LG,WHAT,L1,LABEL,IPAR,KBULK,KOUT,KDIAG, RE,IT,LDIAG)

This subroutine is used to support the free-field input format allowed when reading OPTION cards or parameter values.

When called from OPTION this subroutine, acting on one line at a time, first removes all leading blanks and then identifies the next four characters as one word and returns this word to the OPTION subroutine for interpretation.

When called from EZREAD it performs the same function as for the OPTION subroutine and in addition it submits the character string following the equal sign to subroutine SMARTY for determination of integer and real values in the string. These integer and real values are returned to EZREAD in the IT and RE arrays.

FORTRAN unit KBULK is used as a temporary write/read file when a four character string is converted to one word.

SUBROUTINE FLIPIT

CALLED FROM -- PLYSHR SIGMAZ TBGRD

CALLS TO -- none

ARGUMENTS (LU,XX,YY)

This subroutine is used to rearrange the input arrays to subroutine INTRPL. If the arrays are not in accending order this subroutine reverses the order prior to submission to INTRPL and is used to reverse the order after INTRPL.

SUBROUTINE GNPBLK

CALLED FROM -- CSHELL CSOLID

CALLS TO -- none

ARGUMENTS (WINDML,COSD,MSCD,TEM,
NYPTS,NPAST,KBULK,NP,GNP,RAD)

This subroutine generates NASTRAN GRID cards and TEMP cards and stores them in FORTRAN unit KBULK.

The GRID and TEMP cards are in a format common to both COSMIC NASTRAN and MSC/NASTRAN.

SUBROUTINE INTRPL

CALLED FROM --	MIDWAL	PLYSHR	SIGMAZ	TBGRD	
	TBG01	WIND	WINPUT		

CALLS TO -- none

ARGUMENTS (L,X,Y,N,U,V,VDOT)

COMMON /CUNITS/	KDES1,	KKEI,	KBULK,	KREAD,	KOUT,
	KTTAB,	KDES2,	KPROP1,	KGNP,	KDBANK,
	KPROP2,	KPOST,	KMHFOR,	KREFL,	KDIAG,
	KPLOT				

This subroutine is used throughout COBSTRAN for all calculations requiring the interpolation of a single-valued function and/or determination of the first derivative of the function at each interpolated point (ref. 4).

The method is based on a piecewise function for which a portion of the curve between a pair of given points is represented by a third-degree polynomial for a single-valued function. In this method the slope of the curve is determined at each given data point locally by the coordinates of five data points with the data point in question as a center point and two data points on each side. Each piece of the function representing a portion of the curve between a pair of given data points is determined by the coordinates of and the slopes at the points.

When interpolation is made near the end points of the curve, two more points estimated at each end point are used to determine the slope of the curve. Thus the estimation is based on three data points, the end point in question and the two estimated data points.

Arrays containing the x and y values and first derivative of each requested point are returned in the argument of this subroutine.

SUBROUTINE INVA

CALLED FROM -- COMSA PLY PROP

CALLS TO -- none

ARGUMENTS (X,MMM,KOUT)

This subroutine is used to invert a matrix [A] using Gauss elimination with maximum column pivoting. The subroutine returns the inverse in matrix [X] or an error message if the matrix is singular.

SUBROUTINE LOGO

CALLED FROM -- MAINPG

CALLS TO -- none

ARGUMENTS (KOUT)

This subroutine is used to generate the COBSTRAN logo, store comments on major program changes and designates credits and version number.

SUBROUTINE MATANG

CALLED FROM -- MSCBLK NASBLK

CALLS TO -- none

ARGUMENTS (GA,GB,THCONN)

This subroutine calculates the angle between the element coordinate system and the material coordinate system for 2-D elements used in COSMIC NASTRAN and MSC/NASTRAN.

The material coordinate system is defined by the x-x or spanwise direction in the COBSTRAN structural coordinate system. The element coordinate system x-x axis is defined by the first two grid points of the element connectivity generated in subroutine TBGRD. The material angle is the angle between the structural x-x axis and the projection of the element x-x axis on the structural x-y plane.

A1 = x value of point A

A2 = y value of point A

B1 = x value of point B

B2 = y value of point B

$$\theta = \mathrm{ATAN}\left(\frac{B2 - A2}{B1 - A1}\right)$$

SUBROUTINE MATL

CALLED FROM -- none

CALLS TO -- none

ARGUMENTS (WINDML,SPARS,COSD,MSCD,RINDV,HOLD,KBULK,
NPAST,NE,IMAT,MESH,EX,AB,DEN,GNP,KEI,NUML,RAD)

NOT USED IN THE CURRENT VERSION OF COBSTRAN

SUBROUTINE MESHG

CALLED FROM -- CSOLID

CALLS TO -- none

ARGUMENTS (IU,JU,MESH,IGRD,NE,MSECT,KEI)

The blade mesh pattern and element connectivities are generated in this subroutine. Element numbers and related node numbers are stored in a common variable KEI(I,J) where J is the element number and I is the node number.

Four user-optional mesh patterns are available; (1) triangular elements with diagonal sides symmetric about the blade center line,
(2) triangular elements with diagonal sides alternating chordwise,
(3) triangular elements with three corner and three mid-side nodes, and
(4) quadrilateral elements.

Storage locations for these patterns are;

(1) KEI(I,J) J = element number
I = 1,3,5 node numbers

(2) KEI(I,J) J = element number
I = 1,3,5 node numbers

(3) KEI(I,J) J = element number
I = 1,3,5 vertex numbers
I = 2,4,6 mid-side numbers

(4) KEI(I,J) J = element number
I = 1,2,3,4 node numbers

SUBROUTINE MHCONN

CALLED FROM -- MHPRE

CALLS TO -- none

ARGUMENTS (COSD, MSCD, TEM, PRES, NP, NE, NYTPS, NPAST,
KBULK, MESH, GNP, KEI, NCORDL)

This subroutine writes the element connectivities generated in previous subroutines to the FORTRAN unit KBULK in the format required for the MHOST module.

Format of output is

I, K1, K2, K3, K4

where I is the element number and K1 thru K4 are node numbers.

SUBROUTINE MHCOOR

CALLED FROM -- MHPRE

CALLS TO -- none

ARGUMENTS (COSD, MSCD, NP, NYPTS,
NPAST, KBULK, GNP, RAD)

This subroutine writes the nodal coordinates generated in previous subroutines to the FORTRAN unit KBULK in the format rquired for the MHOST module.

The first card generated is '*COOR'.

Format of output is

I, X, Y, Z, t

where I is the element number, X, Y, Z are the coordinates and t is the nodal thickness.

SUBROUTINE MHPREP

CALLED FROM -- CSHELL CSOLID

CALLS TO -- MHCONN MHCOOR MHPROP

ARGUMENTS (WINDML, SPARS, COSD, MSCD, TEM, PRES, NP, NE, NYPTS, NPAST, KBULK, KREAD, KPOST, KPROP1, KPROP2, MESH, IMAT, HOLD, GNP, KEI, RAD, NCORDL)

This subroutine reads in the users input to the MHOST module and rewrites this input file to FORTRAN unit KBULK including the generated nodal coordinates, connectivities, and nodal laminate material properties.

This subroutine interprets the MHOST module input file and appropriately places the nodal coordinates, connectivities and material data.

Upon completion of deck generation this subroutine rewrites the entire file to FORTRAN unit KREAD for use by the MHOST module.

SUBROUTINE MHPROP

CALLED FROM -- MHPRE

CALLS TO -- none

ARGUMENTS (WINDML, SPARS, NP, NYPTS,
NPAST, KBULK, KPROP1, KPROP2, GNP)

This subroutine writes the nodal laminate properties generated in previous subroutines to FORTRAN unit KBULK in the format required for the MHOST module.

Five lines of data are generated for each node;

1) Node range	I to I
2) Membrane stiffness	AS(1 thru 7), AS(9)
3) Coupling stiffness	CS(1 thru 7), CS(9)
4) Bending stiffness	BS(1 thru 7), BS(9)
5) Thermal & density	AX, AY, AXY, DENS

where AX, AY, AXY are thermal coefficients of expansion and DENS is the mass density.

SUBROUTINE MHSHCN

CALLED FROM -- MHSHPR

CALLS TO -- none

ARGUMENTS (SPARS, TEM, PRES, KKEI, KBULK, NCORDL,
NXSECT, NETOT, NPTOT)

This subroutine generates the MHOST input file for a SHELL/SPAR model. Elememt connectivities, distributed loads (pressure) and temperature are written to the MHOST input file.

SUBROUTINE MHSHPR

CALLED FROM -- CSHELL

CALLS TO -- MHSHCN SHELCR SHELPR SPARCR SPARPR

ARGUMENTS (WINDML,SPARS,TEM,PRES,KBULK,KREAD,KPOST,KTTAB, KPROP1, KPROP2, KKEI, IMAT, HOLD, KAD, NCORDL, NXSECT, NETOT, NPTOT, NP, NPTOT1)

This subroutine is the main driver used to generate the MHOST input file. Calls to each subroutine listed creates the MHOST input file in FORTRAN unit KBULK.

SUBROUTINE MHSTR

CALLED FROM -- CPOST

CALLS TO -- none

ARGUMENTS (WINDML, SPARS, PRTOUT, MODES, NTIMES, III,
NP, NYPTS, NPAST, KMHFOR, KOUT, KREAD,
KDES2, NSB, MSB)

Read the nodal forces and moments from MHOST output file FORTRAN unit KMHFOR. Write these forces and moments to FORTRAN unit KDES2 and to KOUT if a printout is selected.

SUBROUTINE MIDWAL

CALLED FROM -- WREAD

CALLS TO -- INTRPL

ARGUMENTS (PIN,L,K,I)

For aircraft wing type structures, the input coordinates are usually provided on the external profile of the blade.

This subroutine modifies the input coordinates such that the nodal points are moved to the mid-thickness line of the shell wall. Input surface coordinates are translated by half of the wall thickness along a normal to the surface. The slope of the surface at each point is determined using the subroutine INTRPL.

This subroutine may be by-passed by using the PROFILE option.

SUBROUTINE MSCBLK

CALLED FROM -- CSHELL CSOLID

CALLS TO -- MATANG RAAANG

ARGUMENTS (WINDML,SPARS,COSD,MSCD,PRES,TEM,RANG,
NPAST,KBULK,NE,MESH,GNP,KEI,NCORDL)

This subroutine generates MSC/NASTRAN bulk data cards CTRIA3, CQUAD4 and PLOAD. Continuation cards for CTRIA3 and CQUAD4 are included with nodal thicknesses.

SUBROUTINE MSCMIN

CALLED FROM -- CSOLID

CALLS TO -- RINTRD

ARGUMENTS (KREAD,KOUT,IU,JU,NSECT,IGRD,NP,NE,
NGNP,NELM,GNP,KEI,NCORDL,RAD)

This subroutine interprets a MSC/NASTRAN bulk data deck containing GRID, CTRIA3 and +CT3 cards and substitutes the corresponding values into arrays GNP and KEI.

Nodal thicknesses are those represented on the connectivity continuation cards.

SUBROUTINE NASBLK

CALLED FROM -- CSHELL CSOLID

CALLS TO -- MATANG RAAANG

ARGUMENTS (WINDML,SPARS,COSD,MSCD,PRES,TEM,RANG,
NPAST,KBULK,NE,MESH,IMAT,GNP,KEI,NCORDL)

This subroutine generates COSMIC/NASTRAN bulk data cards CTRIA1, CQUAD1, CTRIA2, CQUAD2 and PLOAD.

If IMAT = 1 thru 4 TRIA2 or QUAD2 will be generated.

If IMAT = 5 or 6 TRIA1 or QUAD1 will be generated.

SUBROUTINE NASMAT

CALLED FROM -- CSHELL CSOLID

CALLS TO -- none

ARGUMENTS (WINDML,SPARS,COSD,MSCD,RINDV,HOLD,
KBULK,KPROP1,KPROP2,NPAST,NP,NE,IMAT,
MESH,EX,DEN,GNP,KEI,NCORDL)

Element material properties are generated in this subroutine in the format of the NASTRAN structural analysis program.

Arrays AS, BS, EP, CS, RA, RB, and single value DENS are read into this subroutine from temporary disk storage for each node and stored in array SK

The type and number of NASTRAN material cards generated for each element is determined by the user selected value for IMAT.

Eight user-optional property selections are available;

(1) anisotropic material properties based on reduced axial stiffness. One MAT2 card is created per element.

(2) anisotropic material properties based on reduced bending stiffness. One MAT2 card is created per element.

(3) anisotropic material properties supplied by user (same for all elements). One MAT2 card is created per element.

(4) isotropic material properties supplied by user (same for all elements). One MAT1 card is created per element.

(5) anisotropic material properties are based reduced axial stiffness and reduced bending stiffness. Two MAT2 cards are created per element.

(6) anisotropic material properties are based reduced axial stiffness, reduced bending stiffness and transverse shear stiffness. Three MAT2 cards are created per element.

(7) anisotropic material properties are based axial stiffness, bending stiffness and coupling stiffness. Three MAT2 cards are created per element.

(8) anisotropic material properties are based axial stiffness, bending stiffness and coupling stiffness and transverse shear stiffness. Four MAT2 cards are created per element.

The [G] stress-strain matrix required for the NASTRAN MAT2 material card is generated for each element according to the equation;

$$[G]_k = \left(\sum_{i=1}^{NCON} [A]_{ik} \right) \times C_k$$

Membrane	$C(1) = 1 / T$
Bending	$C(2) = (12 * NCON^2) / T^3$
Transverse shear	$C(3) = 1 / NCON$
Coupling	$C(4) = NCON / T^2$

where

[A] = Nodal stiffness matrix

i = Node at which properties exist

$T = \sum_{i=1}^{NCON} t_i$

t = Thickness at node i

NCON = Number of nodes per element

k = Properties related to 1) membrane, 2) bending, 3) transverse shear, 4) coupling

SUBROUTINE NASMIN

CALLED FROM -- CSOLID

CALLS TO -- SMARTY

ARGUMENTS (KREAD,KOUT,IU,JU,NSECT,IGRD,NP,NE,
NGNP,GNP,KEI,NCORDL,RAD)

This subroutine interprets a COSMIC/NASTRAN bulk data deck containing GRID, CTRIA2 and PTRIA2 cards and substitutes the corresponding values into arrays GNP and KEI.

Nodal thicknesses are calculated by averaging the thicknesses of all elements connected at a node. No weighting factors are used.

SUBROUTINE NASTDK

CALLED FROM -- CSOLID CSHELL

CALLS TO -- GNPBLK MSCBLK NASBLK NASMAT PQSBLK

ARGUMENTS (WINDML,SPARS,COSD,MSCD,PRES,TEM,RANG,RINDV,
MSCNAS,COSMIC,KBULK,KPROP1,KPROP2,KOUT,
I,NXSECT,NSPAR,NPAST,NYPTS,NP,NE,IMAT,MESH,
HOLD,EX,DEN,GNP,KEI,NCORDL,RAD)

This subroutine is a driver for the generation of both COSMIC and MSC/NASTRAN bulk data decks. The five subroutines called each generate specific NASTRAN bulk data card formats which are defined under each subroutine.

SUBROUTINE NOLAPR

CALLED FROM -- CSOLID CSHELL

CALLS TO -- OUTPUT PLY PROP

ARGUMENTS (WINDML,PROT,PREP,MODES,COSD,MSCD,TEM,SPARS,
SOLID,BIDE,KDES1,KDES2,KBULK,KOUT,KPROP1,KPROP2,
NGRID,NP,IMAT,THHF,NLEP,NPAST,NXSECT,NOPLY,
NSPAR,NXSPAR,NYPTS,NPTOT,NETOT,CODES,PERT,RAD,
PL,EX,AB,DEN,FP,MP,CORC,DF,NT,THERMO,MDES)

This subroutine is a driver for the generation of equivalent homogeneous anisotropic properties for each node from the ply layers and stack-up order previously determined for each node. Each node is evaluated separately calling subroutine PLY and subroutine PROP. Nodal properties are written to FORTRAN units KPROP1 and KPROP2.

SUBROUTINE OPTION

CALLED FROM -- MAINPG

CALLS TO -- FFREAD

ARGUMENTS (KBULK,KOUT,KREAD,KDIAG,LDIAG)

```
COMMON /BOOL/   BIDE,     DYNA,     PRTOUT,    WINDML,    SOLID,
                MINICH,   UNSY,     PROFIL,    PROT,      PREP,
                POST,     MODES,    HOLLOW,    COSD,      MSCD,
                PLYORD,   RINDV,    TEM,       ZIGZAG,    PRES,
                COSMIC,   MSCNAS,   MHOST,     EZRD,      ECHO,
                RANG,     DUMP,     CONE,      MPLOT
COMMON /PRINT1/ ID(80,5), IOPT(80,30)
COMMON /PRINT2/ NPRT(2,10)
```

This subroutine reads all user option cards and sets all logical controls in accordance with user choices. The "COBSTRAN OPTION SUMMARY" is printed from this subroutine.

This subroutine is designed to promote a user-friendly approach to COBSTRAN input and to allow for ease of modification as new program options become available.

All option cards with the exception of ENDOPTION are stored as logical values in COMMON block /BOOL/. Initially all values in /BOOL/ are set .FALSE.

SUBROUTINE OUTP10

CALLED FROM -- CSOLID

CALLS TO -- none

```
 ARGUMENTS (MAXPLY,LMAX,NXSECT,MPLY,NPLY,KOUT)

 COMMON /BOOL/    BIDE,     DYNA,     PRTOUT,    WINDML,    SOLID,
                  MINICH,   UNSY,     PROFIL,    PROT,      PREP,
                  POST,     MODES,    HOLLOW,    COSD,      MSCD,
                  PLYORD,   RINDV,    TEM,       ZIGZAG,    PRES,
                  COSMIC,   MSCNAS,   MHOST,     EZRD,      ECHO,
                  RANG,     DUMP,     CONE,      MPLOT
 COMMON /PRINT1/ ID(80,5), IOPT(80,30)
 COMMON /PRINT2/ NPRT(2,10)
 COMMON /VALUES/ NP, NE, NDES, IMAT, KSMF, IU, JU, XBEG, XEND,
1                NMODE(3), NOPLY, NSECT, MESH, NGROUP, NCOREG,
2                IGRD, MSECT(40), NCOOR(3,8)
```

This subroutine generates the output page titled "COBSTRAN INPUT SUMMARY" indicating all program options, parameter values and ply stacking sequence to be used by COBSTRAN.

SUBROUTINE OUTP11

CALLED FROM -- CSOLID

CALLS TO -- none

ARGUMENTS (NDES,KOUT,CODES,FP,MP,CORC)

This subroutine generates the user requested print-out of the constituent fiber and matrix properties used in the analysis. This enables the user to examine the values stored in the COBSTRAN internal databank. If modifications are required to these values to meet user requirements, these values may be copied to an external databank, modified and used in the analysis. The same names may be utilized in the external databank as in the internal databank because COBSTRAN will select the external databank prior to the internal databank. This subroutine is activated by the DUMP option.

SUBROUTINE OUTPUT

CALLED FROM -- CPOST CSHELL CSOLID NOLAPR WREAD

CALLS TO -- none

```
ARGUMENTS (III,WINDML,PROT,PREP,MODES,COSD,MSCD,TEM,SPARS,
           NPAST,NXSECT,NSPAR,NXSPAR,NYPTS,NPTOT,NETOT,
           KDES1,KBULK,KOUT,KPROP1,KPROP2,CODES,PERT)

COMMON /VALUES/ NP, NE, NDES, IMAT, KSMF, IU, JU, XBEG, XEND,
                NMODE(3), NOPLY, NSECT, MESH, NGROUP, NCOREG,
                IGRD, MSECT(40), NCOOR(3,8)
COMMON /TABLES/ GNP(12,510),KEI(6,910),NCORDL(910),RAD(2,510)
COMMON /PLYS/   THERMO(223),MDES(223),THHF,NLEP
COMMON /PROPER/ PL(71,223)
COMMON /PRINT1/ ID(80,5), IOPT(80,30)
COMMON /PRINT2/ NPRT(2,10)
COMMON /PROPTY/ EP(16),THP(5),THF(6),AS(9),CS(9),
                BS(9),RA(9),RB(9),DENS
```

Various output formats are available in this subroutine for use at different times throughout the COBSTRAN run. Any one of nine format options is selected in the argument of the call statement.

Nine different formats are printed by this subroutine.

1. Number of nodes/elements and element types
2. Composite types, ply geometry and distribution
3. Table of ply stack-up order for each node
4. Nodal elastic properties
5. Extended ply property output for one node
6. NASTRAN GRID cards to FORTRAN unit KBULK
   MINICH option only (Not available in Version 1.2)
7. Blade geometry
8. Ply failure criteria
9. Nodal radii of curvature

SUBROUTINE PLTBLK

CALLED FROM -- CSOLID CSHELL

CALLS TO -- none

ARGUMENTS (WINDML,SPARS,COSD,MSCD,KPLOT,NYPTS,NPAST,
NP,NE,MESH,GNP,KEI,RAD,NCORDL)

This subroutine generates NASTRAN GRID cards and PLOTEL cards for the COBSTRAN model being created. This deck, written to FORTRAN unit KPLOT, is used for generation of an undeformed model plot. The file is created by using the MPLOT option.

SUBROUTINE PLY

CALLED FROM -- CPOST NOLAPR

CALLS TO -- INVA

ARGUMENTS (BIDE,KOUT,THHF,NLEP,CODES,FP,MP,CORC,DF,NT, THERMO,MDES,PL)

The thermoelastic properties of the single ply are generated in this subroutine. In addition the actual fiber and matrix volume content, the ply thickness, density, and the interfiber spacing are generated. The equations programmed to generate ply properties using constituient properties from the resident databank are;

$$\bar{k}_f = (1.0 - k_v)\, k_f$$

$$\bar{k}_m = (1.0 - k_v)(1.0 - k_f)$$

$$\rho_\ell = \rho_f\ \bar{k}_f + \rho_m\ \bar{k}_m$$

$$\delta_\ell = \left[\left(\frac{\pi}{4\bar{k}_f} \right)^{1/2} - 1 \right] d_f$$

where k_v and k_f are read globally and denote void and fiber volume ratios, respectively. The subscripts f, m and ℓ denote fiber, matrix and ply property, respectively.

The equations programmed to generate the extensional moduli and the thermal coefficients of expansion are;

$$[E_\ell] = [C_{f\ell}]^T [E_f][C_{f\ell}]\bar{k}_f + [C_{m\ell}]^T [E_m][C_{m\ell}]\bar{k}_m$$

and

$$\{\alpha_\ell\} = [C_{f\ell}]^T \{\alpha_f\}\bar{k}_f + [C_m]^T \{\alpha_m\}\bar{k}_m$$

The arrays in the last two equations are given by;

$$[E_{\ell,f,m}] = \begin{bmatrix} \frac{1}{E_{\ell 11}} & -\frac{\nu_{\ell 21}}{E_{\ell 22}} & -\frac{\nu_{\ell 31}}{E_{\ell 33}} \\ -\frac{\nu_{\ell 12}}{E_{\ell 11}} & \frac{1}{E_{\ell 22}} & -\frac{\nu_{\ell 32}}{E_{\ell 33}} \\ -\frac{\nu_{\ell 13}}{E_{\ell 11}} & -\frac{\nu_{\ell 23}}{E_{\ell 22}} & \frac{1}{E_{\ell 33}} \end{bmatrix}_{\ell,f,m}$$

and

$$\{\alpha_{\ell,f,m}\} = [\alpha_1, \alpha_2, \alpha_3]_{\ell,f,m}$$

The arrays $[E_\ell]$,$[E_f]$, and$[E_m]$ are generated locally in the arrays ECL, ECF, and ECM respectively.

The arrays $[C_{f\ell}]$ and $[C_{m\ell}]$ and the constants (defined subsequently) in them are given by;

$$[C_{f\ell}] = \begin{bmatrix} \frac{1}{A\, E_{m11}\, \bar{k}_m} & \frac{1}{A}\left(\frac{\nu_{f21}}{C_f E_{f22}} - \frac{\nu_{m21}}{C_m E_{m22}}\right) & \frac{1}{A}\left(\frac{\nu_{f31}}{C_f E_{f33}} - \frac{\nu_{m31}}{C_m E_{m33}}\right) \\ 0 & 1/C_f & 0 \\ 0 & 0 & 1/C_f \end{bmatrix}$$

and

$$[C_{m\ell}] = \begin{bmatrix} \frac{1}{B\, E_{f11}\, \bar{k}_f} & \frac{1}{B}\left(\frac{\nu_{m21}}{C_m E_{m22}} - \frac{\nu_{f21}}{C_f E_{f22}}\right) & \frac{1}{B}\left(\frac{\nu_{m31}}{C_m E_{m33}} - \frac{\nu_{f31}}{C_f E_{f33}}\right) \\ 0 & 1/C_m & 0 \\ 0 & 0 & 1/C_m \end{bmatrix}$$

where

$$A = \left[\frac{1}{E_{f11}} + \frac{\bar{k}_m}{E_{m11}} \bar{k}_f \right]$$

$$B = \left[\frac{1}{E_{m11}} + \frac{\bar{k}}{E_{f11}} \bar{k}_m \right]$$

$$C_f = \left(\frac{\bar{k}_f}{k_f} \right)^{\beta_f}$$

$$C_m = \left(\frac{\bar{k}_m}{k_m} \right)^{\beta_m} = (1 - k_v)^{\beta_m}$$

$$\beta_f = 1.0$$

$$\beta_m = \begin{cases} \left(\dfrac{1.0}{\bar{k}_m} \right)^{1/\mathrm{CORC}(2,1)} & \text{if } \mathrm{CORC}(2,1) \neq 0 \\ \mathrm{CORC}(2,1) & \text{if } \mathrm{CORC}(2,1) = 0 \end{cases}$$

where the array CORC(m,n) contains the respective correlation coefficients available in the resident databank.

The variables CORC are the empirical (adjustment) factors and are part of the internal databank. The elements in the array CORC constitute experiment-theory correlation (semi-emperical) factors and are selected so that the predicted and experimental results for a particular fiber-matrix system from a particular fabrication process are in good agreement. The variable Bf could be selected to be different from unity if additional adjustment is needed.

The elements in the arrays $[\tilde{C}_{f\ell}]$ and $[\tilde{C}_{m\ell}]$ are generated by substituting

$$\tilde{\beta}_f = 1.0$$

$$\tilde{\beta}_m = \begin{cases} \left(\dfrac{1.0}{k_m} \right)^{1/CORC(4,1)} & \text{if } CORC(4,1) \neq 0 \\ CORC(4,1) & \text{if } CORC(4,1) = 0 \end{cases}$$

The equations programmed for the ply heat capacity and the ply heat conductivities are

$$H_{c\ell i} = \frac{1}{\rho_{\ell i}} (H_{cf}\, \rho_f\, \bar{k}_f + H_{cm}\, \rho_m\, \bar{k}_m)$$

$$\bar{K}_{m\alpha\alpha} = K_{m\alpha\alpha} \left[\frac{2\, \beta_{kv}\, K_{m\alpha\alpha} + K_v - 2k_v(K_{m\alpha\alpha} - K_v)}{2K_{m\alpha\alpha} + K_v - k_v(K_{m\alpha\alpha} - K_v)} \right]$$

and

$$K_{\ell 11} = \beta_{k1}\, \bar{k}_f\, K_{f11} + k_m\, \bar{K}_{m11}$$

The subscript α takes the values (1,2 and 3). The remaining variables are read in globally.

This subroutine is also used to calculate the ply conductivities $K_{\ell 22}$ and $K_{\ell 33}$. The specific equation programmed in this subroutine is

$$K_{\ell\alpha\alpha} = \bar{K}_{m\alpha\alpha}\left[1 - \beta_{k\alpha}\sqrt{\bar{k}_f} + \frac{1}{\frac{1}{\beta_{k\alpha}\sqrt{\bar{k}_f}} - \left(1 - \frac{\bar{K}_{m\alpha\alpha}}{K_{f\alpha\alpha}}\right)}\right]$$

where α takes the values 2 and 3.

The variables are fiber conductivity $K_{f\alpha\alpha}$, matrix conductivity $\bar{K}_{m\alpha\alpha}$ (modified for void effects), actual fiber volume ratio $\bar{k}_f$, correlation factor $\beta_{k\alpha}$, and the computed conductivity $K_{\ell\alpha\alpha}$.

$$BTA = (\beta_{kv}, \beta_{k1}, \beta_{k2}, \beta_{k3})$$

and

$$CHK = \begin{bmatrix} K_{f11} & K_{f22} & K_{f33} & H_{cf} \\ K_{m11} & K_{m22} & K_{m33} & H_{cm} \\ 0 & 0 & 0 & K_v \end{bmatrix}$$

Inputs to subroutine PLY are fiber and matrix material properties and the correlation factors. These properties are read in globally and are $(E, \nu, \rho, H_c, K, \alpha)_{f,m}$, N_f, d_f, VCF, BTA, and $(k_v, k_f)_i$ where i=1 to N_ℓ and N_ℓ is the number of layers). For corresponding code identifiers see APPENDIX A.

The outputs of subroutine PLY are the basic ply properties $(k_f, \bar{k}_m, \rho_\ell, t_\ell$ and $\delta_\ell)$ which are stored in PL(3,I) and PL(5,I) to PL(8,I); the ply stress-strain relations, which are stored in PL(15,I) to PL(23,I); the ply thermal coefficients of expansion, heat conductivities, and heat capacity, which are stored in PL(24,I) to PL(30,I), and the ply moduli and Poisson's ratios, which are stored in PL(31,I) to PL(42,I).

The properties for PL(1-42,I), PL(49,I) and PL(50,I) are generated in, or input to, this subroutine and stored in the PL array.

SUBROUTINE PLYIN

CALLED FROM -- COMSA CSHELL CSOLID

CALLS TO -- none

ARGUMENTS (J,POST,KOUT,NPM,PMOD,
CODES,FP,MP,CORC,PL)

COMMON /PLIN/ FPT(19),MPT(15),CC(6,5),TS3(3),ALPP(3)

This subroutine provides for user-intervention in the generation of layer p if the properties of one or more designated layers are known or if the effects o layer property changes are to be studied.

Properties required for input are; fiber volume ratio, density, longitudinal modulus, transverse modulus, shear modulus, poisson's ratio, longitudinal tensile strength, longitudinal compression strength, transverse tensile strength, transverse compression strength, intralaminar shear longitudinal thermal expansion coefficient, and transverse thermal expansion coefficient.

This subroutine modifies the properties given in the databank for T300 fiber and SPOX matrix so that the combination of the modified properties when processed through the subroutines PLY and PROP will generate a layer with properties equivalent to the input layer properties.

SUBROUTINE PLYSHR

CALLED FROM -- CPOST

CALLS TO -- FLIPIT INTRPL SIGMAZ

```
ARGUMENTS (NP,IU,JU,IGRD,PRTOUT,KDES1,KTTAB,KOUT,
           CODES,MSECT,GNP,FC)

COMMON /PLYS/   THERMO(223),MDES(223),THHF,NLEP
COMMON /STRA/   DISV1(6,510)
COMMON /PRINT1/ ID(80,5), IOPT(80,30)
COMMON /PRINT2/ NPRT(2,10)
COMMON /STIFF/ VF(2,510),    XINT(36),     YINT(36),
               XOUT(36),XM(14,36),DUM(14),VFP(2,510),
               SHL(8,223),SCXZ(223),SCYZ(223),DUMM1(204)
```

Interply shear and tensile stresses are calculated in this subroutine. Also interply limiting shear strengths and margins of safety are computed.

The nodal shear forces V_x and V_y are determined by differentiating nodal bending moments using subroutine INTRPL.

The sign convention used for this analysis is shown in Figure 6a.

Summing moments yields;

$$Q_x = -\frac{\partial M_x}{\partial x} - \frac{\partial M_{xy}}{\partial y}$$

$$Q_y = -\frac{\partial M_y}{\partial y} - \frac{\partial M_{xy}}{\partial x}$$

The interply shear stresses are calculated according to the parabolic shear stress distribution for rectangular cross sections.

$$\tau = \frac{Q}{2I}\left[(h)^2 - y_0^2\right]$$

where $I = \frac{b(2h)^3}{12}$ $b = 1$

therefore

$$\tau = \frac{3}{4}\frac{Q}{h}\left[1 - \left(\frac{y_0}{h}\right)^2\right]$$

The relationship of b, h and y_0 is shown in figure 6b.

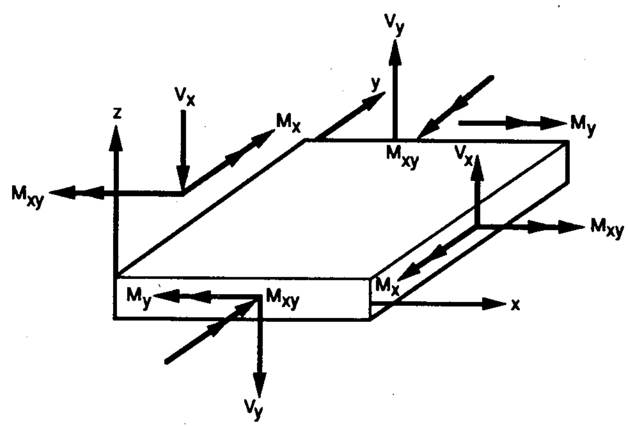

Figure 6a. - Plate element forces.

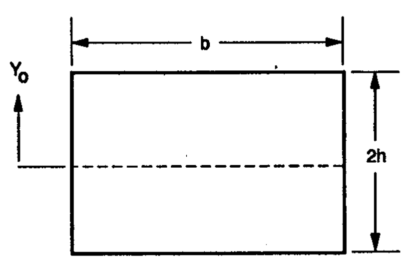

Figure 6b. - Rectangular cross-section variables.

The interply tensile stresses are determined as follows;

Force equlibrium equations

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \sigma_{xy}}{\partial \sigma_z} = 0$$

$$\frac{\partial \sigma_{yx}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \sigma_{yz}}{\partial z} = 0$$

$$\frac{\partial \sigma_{zx}}{\partial x} + \frac{\partial \sigma_{zy}}{\partial y} + \frac{\partial \sigma_z}{\partial z} = 0$$

rewriting the last equation

$$\frac{\partial \sigma_z}{\partial z} = -\frac{\partial \sigma_{zx}}{\partial x} - \frac{\partial \sigma_{zy}}{\partial y}$$

where

$$\sigma_{zx} = \frac{3}{4}\frac{Q_x}{h}\left[1 - \left(\frac{y_0}{h}\right)^2\right]$$

$$\sigma_{zy} = \frac{3}{4}\frac{Q_y}{h}\left[1 - \left(\frac{y_0}{h}\right)^2\right]$$

and where the shears Q_x and Q_y were defined previously.

therefore

$$\frac{\partial \sigma_z}{\partial z} = -\left\{\frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y}\right\}\left\{\frac{3}{4}\frac{1}{h}\left[1 - \left(\frac{y_0}{h}\right)^2\right]\right\}$$

integration of the above equation yields

$$\sigma_z = -\left\{\frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y}\right\}\left\{\frac{3}{4}\left[\frac{y_0}{h} - \frac{1}{3}\left(\frac{y_0}{h}\right)^3\right]\right\} + C$$

Delamination Limiting Strength

When the composite is subjected to loads normal to its plane, or have rapid moment changes, interply layer delamination could be caused by the transverse shear stresses σ_{cxz} and σ_{cyz}.

The limiting condition on these stresses is established by the procedure discussed in Ref. 2, Chapter 2 for obtaining the limiting condition on the ply's intralaminar shear stresses. Adopting that procedure, it can be shown that

$$S_{cxzj} = \beta_{cxz}\left(\frac{\varepsilon_{mps}}{\phi_{\mu cxz}}\right)G_{cxz}$$

$$S_{cyzsj} = \beta_{cyz}\left(\frac{\varepsilon_{mps}}{\phi_{\mu cyz}}\right)G_{cyzj}$$

where

$$\phi_{\mu cxz} = \frac{t_{\ell i+1} + t_{\ell i}}{\delta_{\ell i+1} + \delta_{\ell i} + \dfrac{(t_{\ell i+1} - \delta_{\ell i+1})G_{mi+1}}{G_{\ell xzi+1}} + \dfrac{(t_{\ell i} - \delta_{\ell i})G_{mi}}{G_{\ell xzi}}}$$

$$\phi_{\mu cyz} = \frac{t_{\ell i+1} + t_{\ell i}}{\delta_{\ell i+1} + \delta_{\ell i} + \dfrac{(t_{\ell i+1} - \delta_{\ell i+1})G_{mi+1}}{G_{\ell yzi+1}} + \dfrac{(t_{\ell i} - \delta_{\ell i})G_{mi}}{G_{\ell yzi}}}$$

The moduli G_{cxzj} and G_{cyzj} are the local transverse shear moduli in their respective planes, from (Ref. 2).

$$G_{cxzj} = \frac{t_{\ell i+1} + t_{\ell i}}{\dfrac{t_{\ell i+1}}{G_{\ell xzi+1}} + \dfrac{t_{\ell i}}{G_{\ell xzi}}}$$

$$G_{cyzj} = \frac{t_{\ell i+1} + t_{\ell i}}{\dfrac{t_{\ell i+1}}{G_{\ell yzi+1}} + \dfrac{t_{\ell i}}{G_{\ell yzi}}}$$

The parameters β_{cxz} and β_{cyz} are the theory-experiment correlation factor. Its numerical value is determined from horizontal shear beam tests on composites with coincident material and structural axes (Ref. 2).

The shear moduli $G_{\ell xzi}$ and $G_{\ell yzi}$ are the ply transverse shear moduli $G_{\ell 13}$ and $G_{\ell 23}$ transformed along the structural axes.

SUBROUTINE PQSBLK

CALLED FROM -- NASTDK

CALLS TO -- none

ARGUMENTS (WINDML,SPARS,COSMIC,COSD,MSCD,
KBULK, KOUT, NPAST, NE, IMAT, MESH,
GNP,KEI,NCORDL)

This subroutine generates NASTRAN property (PSHELL cards) for MSC/NASTRAN QUAD4 and TRIA3 elements. Factors on the PSHELL card are left blank. MSC/NASTRAN default values will be used in the analysis unless these cards are edited by the user.

For COSMIC/NASTRAN PQUAD1, PQUAD2, PTRIA1 and PTRIA2 property cards are generated for the corresponding element cards. Factors on the P cards are;

$T1 = t$, $T2 = (t^3)/12$, $T3 = (2/3)*t$

Material property ID numbers are generated and inserted on each P card according to the users selected parameter IMAT.

Material property ID's are;

Series	
100000	Membrane or Reduced Membrane
200000	Bending or Reduced Bending
300000	Tranverse shear
400000	Coupling

SUBROUTINE PROP

CALLED FROM -- CPOST NOLAPR

CALLS TO -- INVA

ARGUMENTS (II,KOUT,KPROP1,KPROP2,NP,IMAT,THHF,NLEP,
NGRID,NYPTS,NPTOT,PL,EX,AB,DEN)

COMMON /PROPTY/ EP(16),THP(5),THF(6),AS(9),CS(9),
BS(9),RA(9),RB(9),DENS

This subroutine generates the three-dimensional thermoelastic properties of the composite about its structural (x,y,z) and material (1,2,3) axes. The angle θ is measured from the x axis of the structural axes system to the material axis of each ply (See Figure 7). These composite properties are generated from the following equations;

$$[E_c] = \frac{1}{t_c}\left[\sum_{i=1}^{N_\ell}(z_{\ell i+1} - z_{\ell i})[R_{\ell i}]^T[E_{\ell i}][R_{\ell i}] + \sum_{j=1}^{N_\ell -1} H_j[S_j]\right]$$

$$\{\alpha_c\} = \frac{1}{t_c}[E_c]^{-1}\sum_{i=1}^{N_\ell}(z_{\ell i+1} - z_{\ell i})[R_{\ell i}]^T[E_{\ell i}]\{\alpha_{\ell i}\}$$

The arrays $\{\alpha_c\}$ and $\{\alpha_{\ell i}\}$ in the preceeding equations are given by

$$\{\alpha_c\} = [\alpha_{cxx}\ \alpha_{cyy}\ \alpha_{czz}\ \alpha_{cyz}\ \alpha_{czx}\ \alpha_{cxy}]^T$$

and

$$\{\alpha_{\ell i}\} = [\alpha_{\ell 11}\ \alpha_{\ell 22}\ \alpha_{\ell 33}\ 0\ 0\ 0]^T$$

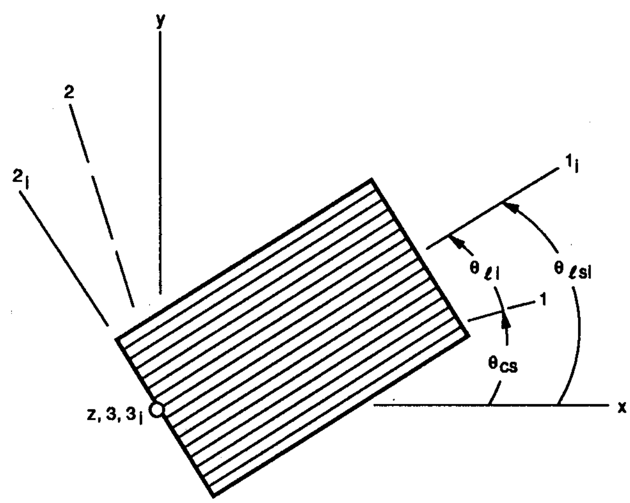

Figure 7. - Ply orientation geometry. Composite structural axes, x, y, z; composite material axes, 1, 2, 3; ply material axes (coincides with fiber direction), 1_l , 2_l , 3_l .

For all practical purposes the two-dimensional thermal coefficients of expansion about the composite structural axes are the same as α_{cxx}, α_{cyy}, α_{cxy} in the array $\{\alpha_c\}$ for the three-dimensional case.

The matrices $[E_c]$, $[E_{\ell i}]$, $[R_{\ell i}]$, and $[S_j]$ are given by

$$[E_c]^{-1} = \begin{bmatrix} \frac{1}{E_{c11}} & -\frac{\nu_{c21}}{E_{c22}} & -\frac{\nu_{c31}}{E_{c33}} & 0 & 0 & 0 \\ -\frac{\nu_{c12}}{E_{c11}} & \frac{1}{E_{c22}} & -\frac{\nu_{c32}}{E_{c33}} & 0 & 0 & 0 \\ -\frac{\nu_{c13}}{E_{c11}} & -\frac{\nu_{c23}}{E_{c22}} & \frac{1}{E_{c33}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{E_{c23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{E_{c31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{E_{c12}} \end{bmatrix}$$

Note that for the case of an anisotropic material, the elements (1,6) (2,6) (3,6) (4,5), and their symmetric parts will not be zero.

$$[E_{\ell i}]^{-1} = \begin{bmatrix} \frac{1}{E_{\ell 11}} & -\frac{\nu_{\ell 21}}{E_{\ell 22}} & -\frac{\nu_{\ell 31}}{E_{\ell 33}} & 0 & 0 & 0 \\ -\frac{\nu_{\ell 12}}{E_{\ell 11}} & \frac{1}{E_{\ell 22}} & -\frac{\nu_{\ell 32}}{E_{\ell 33}} & 0 & 0 & 0 \\ -\frac{\nu_{\ell 13}}{E_{\ell 11}} & -\frac{\nu_{\ell 23}}{E_{\ell 22}} & \frac{1}{E_{\ell 33}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{E_{\ell 23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{E_{\ell 31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{E_{\ell 12}} \end{bmatrix}_i$$

$$[R_{\ell i}] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & 0 & 0 & 0 & 1/2 \sin 2\theta \\ \sin^2\theta & \cos^2\theta & 0 & 0 & 0 & -1/2 \sin 2\theta \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos\theta & \sin\theta & 0 \\ 0 & 0 & 0 & -\sin\theta & \cos\theta & 0 \\ -\sin 2\theta & \sin 2\theta & 0 & 0 & 0 & \cos 2\theta \end{bmatrix}$$

where $\theta = \theta_{\ell i}$ for properties about the composite material axes and $\theta = \theta_{\ell i} + \theta_{cs}$ for properties about the composite structural axes (see Figure 7).

$$[S_j] = \frac{1}{4} \begin{bmatrix} (\sin 2\theta_i - \sin 2\theta_{i-1})^2 & -(\sin 2\theta_i - \sin 2\theta_{i-1})^2 & 0 & 0 & 0 & \begin{array}{r} -(\sin 2\theta_i - \sin 2\theta_{i-1}) \\ \times(\cos 2\theta_i - \cos 2\theta_{i-1}) \end{array} \\ -(\sin 2\theta_i - \sin 2\theta_{i-1})^2 & (\sin 2\theta_i - \sin 2\theta_{i-1})^2 & 0 & 0 & 0 & \begin{array}{r} (\sin 2\theta_i - \sin 2\theta_{i-1}) \\ \times(\cos 2\theta_i - \cos 2\theta_{i-1}) \end{array} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ \begin{array}{r} -(\sin 2\theta_i - \sin 2\theta_{i-1}) \\ \times(\cos 2\theta_i - \cos 2\theta_{i-1}) \end{array} & \begin{array}{r} (\sin 2\theta_i - \sin 2\theta_{i-1}) \\ \times(\cos 2\theta_i - \cos 2\theta_{i-1}) \end{array} & 0 & 0 & 0 & (\cos 2\theta_i - \cos 2\theta_{i-1})^2 \end{bmatrix}$$

where $i>1$ and denotes the ply index. The angles θ_i and θ_{i-1} (Figure 7) are given by

$$\theta_i = \theta_{\ell i} + \theta_{cs}$$

$$\theta_{i-1} = \theta_{\ell i-1} + \theta_{cs}$$

The composite heat capacity is the same for both the three- and two-dimensional cases. It is given by

$$h_c = \frac{1}{t_c} \sum_{i=1}^{N_\ell} h_{\ell i} t_{\ell i}$$

and t_c is given by

$$t_c = \sum_{i=1}^{N_\ell} t_{\ell i}$$

The composite three-dimensional heat conductivities along the composite material axes, assuming an orthotropic composite, are given by

$$K_{c11} = \frac{1}{t_c} \sum_{i=1}^{N_\ell} t_{\ell i}(K_{\ell 11} \cos^2\theta_\ell + K_{\ell 22} \sin^2\theta_\ell)_i$$

$$K_{c22} = \frac{1}{t_c} \sum_{i=1}^{N_\ell} t_{\ell i}(K_{\ell 11} \sin^2\theta_\ell + K_{\ell 22} \cos^2\theta_\ell)_i$$

$$\frac{1}{K_{c33}} = \frac{1}{t_c} \sum_{i=1}^{N_\ell} \left(\frac{t_\ell}{K_{\ell 33}} \right)_i$$

The angle θ_ℓ measured from the material axes (fig. 7).

C-2

The composite two-dimensional heat conductivities along the composite structural axes are given by;

$$K_{cxx} = \frac{1}{t_c} \sum_{i=1}^{N_\ell} t_{\ell i}(K_{\ell 11} \cos^2\theta + K_{\ell 22} \sin^2\theta)_i$$

$$K_{cyy} = \frac{1}{t_c} \sum_{i=1}^{N_\ell} t_{\ell i}(K_{\ell 11} \sin^2\theta + K_{\ell 22} \cos^2\theta)_i$$

$$K_{cyx} = K_{cxy} = \frac{1}{t_c} \sum_{i=1}^{N_\ell} t_{\ell i}(K_{\ell 22} - K_{\ell 11})_i \sin 2\theta_i$$

$$K_{czz} = K_{c33}$$

The angle θ in the last set of equations is measured from the composite structural axes and is equal to $\theta_{cs} + \theta_\ell$.

This subroutine generates the required section properties and the force-deformation-temperature relations for a two-dimensional multilayered composite. It also generates the plane-stress elastic constants for the composite. The force-deformation-temperature relations generated in this procedure are defined in the following equation;

$$\left\{ \frac{\{N_{cx}\}}{\{M_{cx}\}} \right\} = \left[\begin{array}{c|c} [A_{cx}] & [C_{cx}] \\ \hline [C_{cx}] & [D_{cx}] \end{array} \right] \left\{ \frac{\varepsilon_{csx}}{w_{cbx}} \right\} - \left\{ \frac{\{N_{c\Delta Tx}\}}{\{M_{c\Delta Tx}\}} \right\}$$

The generic equations for the elements in the arrays $[A_{cx}]$, $[C_{cx}]$, $[D_{cx}]$, $\{N_{c\Delta Tx}\}$, and $\{M_{c\Delta Tx}\}$ are

$$[A_{cx}] = \sum_{i=1}^{N_\ell} \Delta T_{\ell i}(z_{\ell i+1} - z_{\ell i})[R_{\ell i}]^T[E_{\ell i}]^{-1}[R_{\ell i}] + \sum_{j=1}^{N_\ell -1} H_j[S_j]$$

$$[C_{cx}] = -\frac{1}{2} \sum_{i=1}^{N_\ell} \Delta T_{\ell i}(z^2_{\ell i+1} - z^2_{\ell i})[R_{\ell i}]^T[E_{\ell i}]^{-1}[R_{\ell i}] + \sum_{j=1}^{N_\ell -1} z_{rpj}H_j[S_j]$$

$$[D_{cx}] = -\frac{1}{3} \sum_{i=1}^{N_\ell} \Delta T_{\ell i}(z^3_{\ell i+1} - z^3_{\ell i})[R_{\ell i}]^T[E_{\ell i}]^{-1}[R_{\ell i}] + \sum_{j=1}^{N_\ell -1} z^2_{rpj}H_j[S_j]$$

$$\{N_{c\Delta Tx}\} = \sum_{i=1}^{N_\ell} \Delta T_{\ell i}(z_{\ell i+1} - z_{\ell i})[R_{\ell i}][E_{\ell i}]^{-1}\{\alpha_{\ell i}\}$$

$$\{M_{c\Delta Tx}\} = -\frac{1}{2} \sum_{i=1}^{N_\ell} \Delta T_{\ell i}(z^2_{\ell i+1} - z^2_{\ell i})[R_{\ell i}]^T[E_{\ell i}]^{-1}\{\alpha_{\ell i}\}$$

The arrays $\{\alpha_{\ell i}\}$, $[R_{\ell i}]$, $[E_{\ell i}]$, and $[S_j]$ are;

$$\{\alpha_{\ell i}\} = [\alpha_{11} \quad \alpha_{22} \quad 0]_i^T$$

$$[R_{\ell i}] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & 1/2 \sin 2\theta \\ \sin^2\theta & \cos^2\theta & -1/2 \sin 2\theta \\ -\sin 2\theta & \sin 2\theta & \cos 2\theta \end{bmatrix}_i$$

$$[E_{\ell i}] = \begin{bmatrix} \dfrac{1}{E_{\ell 11}} & -\dfrac{\nu_{\ell 21}}{E_{\ell 22}} & 0 \\ -\dfrac{\nu_{\ell 12}}{E_{\ell 11}} & \dfrac{1}{E_{\ell 22}} & 0 \\ 0 & 0 & \dfrac{1}{G_{\ell 12}} \end{bmatrix}_i$$

$$S_{j22} = S_{j11} = \frac{1}{4}(\sin 2\theta_i - \sin 2\theta_{i-1})^2$$

$$S_{j21} = S_{j12} = -S_{j11}$$

$$S_{j32} = S_{j23} = \frac{1}{4}(\sin 2\theta_i - \sin 2\theta_{i-1})(\cos 2\theta_i - \cos 2\theta_{i-1})$$

$$S_{j31} = S_{j13} = -S_{j23}$$

$$S_{j33} = \frac{1}{4}(\cos 2\theta_i - \cos 2\theta_{i-1})^2$$

Here θ_i equals the $\theta_{cs} + \theta_\ell$ in figure 5.

The reduced bending rigidities (ref. 5) are generated in this procedure according to the equation

$$D_{cx}^R = \left[D_{cx} - C_{cx}\, A_{cx}^{-1}\, C_{cx}\right]$$

The reduced axial stiffnesses are generated in the procedure according to the equation

$$A^R_{cx} = \left[A_{cx} - C_{cx}\, D^{-1}_{cx}\, C_{cx}\right]$$

The two-dimensional composite elastic constants are generated from the following equation (assuming $\Delta T_{\ell i} = \Delta T$ for i=1 to N_ℓ);

$$[E_{cx}]^{-1} = \frac{1}{t_c} \left\{ \sum_{i=1}^{N_\ell} (z_{\ell i+1} - z_{\ell i})[R_{\ell i}]^T [E_{\ell i}]^{-1} [R_{\ell i}] + \sum_{j=1}^{N_\ell - 1} H_j [S_j] \right\}$$

where

$$t_c = \sum_{i=1}^{N_\ell} t_{\ell i}$$

The inputs to this subroutine are N_ℓ, $z_{\ell i+1}$, $z_{\ell i}$, θ_{cs}, $\theta_{\ell i}$, $[E_i]$, H_j, $\{\alpha_{\ell i}\}$, $h_{\ell i}$, and $\{K_{\ell i}\}$, which are all global. Other inputs are $t_{\ell i}$, $\Delta T_{\ell i}$, and θ_i (relative to the composite structural axes), and the ply elastic constants. These quantities are global and are located, respectively in PL(7,I), PL(50,I), PL(14,I), PL(9,I), and PL(31,I) to PL(42,I). The remaining quantities are either generated or are transferred from information stored in PL(8,I), PL(11,I), PL(13,I), PL(15-23,I), PL(24-30,I).

The arrays $[R_{\ell i}]^T$, $[E_{\ell i}]^{-1}$, $[R_{\ell i}]$, and $[S_j]$ and the dimensions $z_{\ell i}$ are generated in this subroutine.

The outputs are t_c and the arrays $[E_c]^{-1}$, $\{\alpha_c\}$, $[E_c]$, h_c, and $\{K_c\}$. The composite thickness t_c is stored in GNP(6,I). The arrays $[E_c]^{-1}$, and $\{\alpha_c\}$, for the composite structural axes are printed out under the heading;

ELASTIC PROPERTIES -- (STRAIN-STRESS TEMPERATURE RELATIONS)

The composite structural axes properties $[E_c]^{-1}$ and $\{\alpha_c\}$ are stored in EP(1) thru EP(16) as global variables. The heat capacity and three-dimensional heat conductivities along the structural axes are stored in THP(1) thru THP(5). The two-dimensional thermal coefficients of expansion along the structural axes are stored in EP(13), EP(14) and EP(16). The two-dimensional heat conductivities and heat capacity along the structural axes are stored in THP(1) thru THP(4). Note that the heat capacity is a scalar quantity and is independent of the reference axes.

The density, heat capacity and three-dimensional heat conductivities stored in array THP are printed under the heading;

THERMAL PROPERTIES

The axial stiffnesses stored in array AS are printed under the heading;

AXIAL STIFFNESS

The bending rigidities stored in array BS are printed under the heading;

BENDING STIFFNESS

The coupling stiffnesses stored in array CS are printed under the heading;

COUPLING STIFFNESS

The reduced axial stiffnesses stored in array RA are printed under the heading;

REDUCED AXIAL STIFFNESS

The reduced bending stiffnesses stored in array RB are printed under the heading;

REDUCED BENDING STIFFNESS

The outputs are the force-deformation-temperature relations, which are stored in the global arrays $AS=A_{cx}$, $RA=A^R_{cx}$, $CS=C_{cx}$, $BS=D_{cx}$, $RB=D^R_{cx}$, $NSDT=N_{c\Delta Tx}$.

The distances $\bar{z}_{\ell i}$ and $z_{\ell i}$, are stored, respectively in PL(10,I), and PL(11,I).

SUBROUTINE RAAANG

CALLED FROM -- MSCBLK NASBLK

CALLS TO -- none

ARGUMENTS (GA,GB,GC,RAANG)

The purpose of this subroutine is to calculate the angle between the element coordinate system and the projection of the COBSTRAN structural x-axis on the plane in which the element lies for 2-D elements used in COSMIC NASTRAN and MSC/NASTRAN.

The material coordinate system is defined by the x-x or spanwise direction in the COBSTRAN structural coordinate system. The element co-ordinate system x-x axis is defined by the first two grid points of the element connectivity generated in subroutine TBGRD. The material angle is the angle between the projection of the structural x-x axis onto the plane of the element and the element x-x axis (fig. 8).

A -> B element x-axis
A -> N projection of the structural x-axis on the plane in which the element lies

Solve for the angle θ
θ is positive if N is on the C side
θ is negative if N is opposite C side

Let the coordinate of each point be represented by the tag 1,2,3 for x,y,z respectively.

therefore;
A1 = x value of point A from the local origin
B2 = y value of point B from the local origin
etc.

The origin lies in a plane normal to the structural x-axis and contains points B and C.

Solving for the coordinates of N;
$N1 = B1 = C1 = 0.0$

Slope of C-B line is $m = \dfrac{C2 - B2}{C3 - B3}$

Also

$$N2 - B2 = m(N3 - B3) \tag{1}$$

$$N2 = -\frac{1}{m} N3 \tag{2}$$

$$N3 = - m(N2) \tag{3}$$

Substituting equation (3) into equation (1)

$$N2 - B2 = m(-mN2 - B2)$$

$$N2 = \frac{-mB3 + B2}{1 + m^2}$$

$$N3 = - mN2$$

Let AA, BB, and NN represent the length of the lines opposite the A, B, N nodes.

$$AA = \sqrt{(B1 - N1)^2 + (B2 - N2)^2 + (B3 - N3)^2}$$

$$BB = \sqrt{(A1 - N1)^2 + (A2 - N2)^2 + (A3 - N3)^2}$$

$$NN = \sqrt{(A1 - B1)^2 + (A2 - B2)^2 + (A3 - B3)^2}$$

$$SS = \frac{AA + BB + NN}{2.0}$$

$$R = \sqrt{\frac{(SS - AA)(SS - BB)(SS - NN)}{SS}}$$

$$\theta = 2.0\left(ATAN \frac{R}{SS - AA}\right)$$

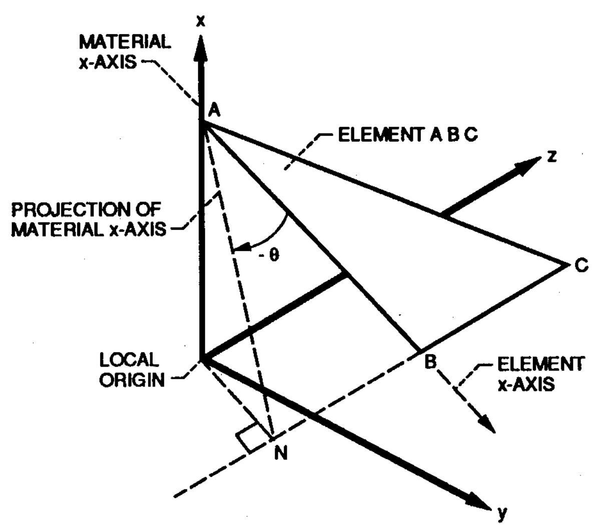

Figure 8. - Determination of material x-axis relative to element x-axis.

SUBROUTINE REFLEC

CALLED FROM -- MAINPG

CALLS TO -- none

ARGUMENTS (N,KREAD,KREFL,KOUT)

This subroutine stores the users input data set in FORTRAN unit KREFL. If subsequent interpretation of the input, indicated by the ECHO option, calls for the printing of the user input data set this subroutine is again called for printing.

SUBROUTINE RINTRD

CALLED FROM -- MSCMIN NASMIN

CALLS TO -- none

ARGUMENTS (L,M,N,R)

NOT USED IN THE CURRENT VERSION OF COBSTRAN

SUBROUTINE SHELCR

CALLED FROM -- MHSHPR

CALLS TO -- none

ARGUMENTS (SPARS,NP,NYPTS,NPAST,GNP,KTTAB,KBULK)

This subroutine writes coordinates for shell grid points to FORTRAN unit KBULK and coordinates for spar grid points to FORTRAN unit KTTAB. Grid point coordinate data is written in the MHOST input format.

SUBROUTINE SHELPR

CALLED FROM -- MHSHPR

CALLS TO -- none

ARGUMENTS (NP, NYPTS, NPAST, KBULK, KPROP1, KPROP2, GNP)

This subroutine writes the membrane, bending and coupling properties of each shell grid point in the MHOST format to FORTRAN unit KBULK.

SUBROUTINE SIGMAZ

CALLED FROM -- PLYSHR

CALLS TO -- FLIPIT INTRPL

ARGUMENTS (IU,MSECT,GNP)

```
COMMON /STIFF/ VF(2,510),     XINT(36),     YINT(36),
               XOUT(36),XM(14,36),DUM(14),VFP(2,510),DUMMY(2434)
```

Derivatives of the nodal shear forces in the spanwise and chordwise direction are calculated in this subroutine. These nodal shear forces are differentiated with respect to x and y using subroutine INTRPL.

Determination of the derivatives of the shear forces is required to calculate the tensile stresses thru-the-thickness.

The shear derivatives are returned to subroutine PLYSHR to calculate thru-the-thickness tensile stresses.

SUBROUTINE SMARTY

CALLED FROM -- FFREAD MSCMIN NASMIN

CALLS TO -- none

ARGUMENTS (L,M,NF,RF,NL,KOUT)

This subroutine is used to interpret a string of integer or real numbers in a free-field format. The values may be separated by commas or blanks. Integer values are returned in array IT and real values are returned in array RE.

This subroutine is used to interpret a given field of characters in which a real or integer number is stored. Integer numbers do not have to be right justified. Trailing blanks are not interpreted as zeros.

This subroutine is used specifically to evaluate eight character fields on NASTRAN bulk data cards.

SUBROUTINE SOLVEQ

CALLED FROM -- MAINPG

CALLS TO -- HOST, BLOCK, INTINT

ARGUMENTS (ISIZE,IWORK)

```
C     COMMON /        / IWORK  ( 100 000 )
      COMMON / MACHIN / IDP
      DIMENSION         IWORK  ( 1 )
C     DATA              ISIZE /  100 000 /
      VERSNO = 4.2D0
```

This subroutine is main driver for the MHOST general purpose finite element structural analysis code.

SUBROUTINE SPARCR

CALLED FROM -- MHSHPR

CALLS TO -- none

ARGUMENTS (NP, NPTOT, GNP, KAD, KTTAB, KBULK)

The local spar node number in GNP(9,I) is incremented by the total number of shell nodes for the creation of duplicate node numbers as required input to MHOST.

IREC is the shell node number corresponding to the spar node.

Write the new spar node number, coordinates and thickness to FORTRAN unit KBULK for generation of duplicate nodes.

SUBROUTINE SPARPR

CALLED FROM -- MHSHPR

CALLS TO -- none

ARGUMENTS (NP, NPTOT, KBULK, KPROP1, KPROP2, GNP)

This subroutine writes the membrane, bending and coupling properties of each spar node to FORTRAN unit KBULK in the MHOST format.

SUBROUTINE SPRSET

CALLED FROM -- WINPUT

CALLS TO -- none

ARGUMENTS (I,K,KK,NNQ,KOUT,KDIAG,NSPAR,DELT,
ZIGZAG,SY,YINT,LSP,LDIAG)

This subroutine determines the spar positions and modifies the chordwise grid positions to satisfy the user requested spar positions.

SUBROUTINE SSTRAN

CALLED FROM -- STR

CALLS TO -- none

ARGUMENTS (X,Y,N,ANG,KDIAG,LDIAG)

The purpose of this subroutine is to transform two-dimensional stress relations to a new coordinate system.

The stress transformation matrix is generated in this subroutine and element stresses are transformed from the element coordinate system to the COBSTRAN structural coordinate system.

The use of option DIAG = 49, in post processing, will print the transformation matrix for each element of the analysis.

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} \cos^2\theta & \sin^2\theta & -\sin 2\theta \\ \sin^2\theta & \cos^2\theta & \sin 2\theta \\ \frac{1}{2}\sin 2\theta & -\frac{1}{2}\sin 2\theta & \cos 2\theta \end{bmatrix} \begin{Bmatrix} \sigma_{x_e} \\ \sigma_{y_e} \\ \sigma_{xy_e} \end{Bmatrix}$$

SUBROUTINE STR

CALLED FROM -- CPOST

CALLS TO -- SSTRAN

ARGUMENTS (NTIMES,III,DYNA,PRTOUT,WINDML,MODES,RINDV,KPOST,
KOUT,KDES2,NP,NE,MESH,NMODE,NPAST,NXSECT,NYPTS)

COMMON /STRA/ DISV1(6,510)
COMMON /TABLES/ GNP(12,510),KEI(6,910),NCORDL(910),RAD(2,510)

This subroutine reads element stresses from a NASTRAN punch output file and calculates the applied membrane loads and applied bending moments at each node.

The punch format of NASTRAN is used to store and recover the element two-dimensional stresses at each surface. When read by this subroutine the stresses on the positive z surface are stored in array XS1 and the stresses from the negative z surface are stored in array XS2.

Subroutine SSTRAN is called to transform these stresses on both surfaces from the NASTRAN element coordinate system to the COBSTRAN structural coordinate system.

The applied membrane loads and applied bending moments at each node are determined from the following equations;

$$\{NSB\} = \frac{1}{k} \sum_{i=1}^{k} t_i \left(\frac{\sigma 1_i + \sigma 2_i}{2} \right)$$

$$\{MSB\} = \frac{1}{12k} \sum_{i=1}^{k} t_i^2 (\sigma 1_i - \sigma 2_i)$$

where

k = Number of elements at node

t = average element thickness

$\sigma 1$, $\sigma 2$ are 2D stresses on upper and lower surface, respectively.

The inputs to this subroutine are element thicknesses and two-dimensional stresses at each surface.

The output is two-dimensional nodal membrane loads and bending moments stored in arrays NSB and MSB and printed out under the heading;

NODAL FORCES AND MOMENTS PER UNIT WIDTH IN STRUCTURAL COORDINATE SYSTEM

$$[N_{cxx}, N_{cyy}, N_{cxy}]$$

$$[M_{cxx}, M_{cyy}, M_{cxy}]$$

SUBROUTINE TBG01

CALLED FROM -- TBGRD

CALLS TO -- INTRPL

ARGUMENTS (NP, NE, IU, JU, MESH, XBEG, XEND, NSECT, NPOS, INFLAG, MSECT, PIN, TIN, XINT, YINT, XOUT, YOUT, VDOT, KDIAG, LDIAG)

This subroutine is utilized if IGRD = 1. For that case all chordwise grid points are divided into JU-1 equal spaces. All other grid point relationships such as z coordinate, thickness and temperature are interpolated.

The blade is then divided equally spanwise into IU-1 spaces and all other grid point relationships are interpolated with respect to the x-axis position.

IU and JU are user input parameters. IU is the number of cross-sections spanwise and JU is the number of grid points chordwise.

SUBROUTINE TBGRD

CALLED FROM -- CSOLID

CALLS TO -- FLIPIT INTRPL TBG01

ARGUMENTS (TEM, PRES, NP, NE, IU, JU, MESH,
XBEG, XEND, NSECT, NCOREG, IGRD, MSECT, PIN,
GNP, NCORDL, NCOOR, RAD, KDIAG, LDIAG)

This subroutine reads blade profile data including temperatures and pressures on both surfaces. The usual input form for the blade profile is x (radial coordinate), y (chordwise coordinate) and, at each y value, two values of z, one for each surface.

These input values may be used directly as nodal properties over which a mesh will be created (IGRD=2) or this input may be used as a bases for interpolating or extrapolating other points and loads to generate a finer mesh (IGRD=1).

For IGRD=1 and IGRD=2 two values are required as input for z and the blade thickness is calculated by this subroutine.

If all coordinates are to be used directly, including thicknesses at the nodes, IGRD=3 is to be selected.

For IGRD = 4 the input form is the same as IGRD = 3 except that the feature of interpolation and extrapolation over the surface is utilized as in IGRD = 1.

SUBROUTINE TBPLY

CALLED FROM -- CSOLID

CALLS TO -- none

ARGUMENTS (PLYORD,UNSY,HOLLOW,COSD,MSCD,KDES1,KOUT,NDES,NP,
IU,JU,IGRD,MSECT,MAXPLY,LMAX,NGRD,CODES,PERT,
MPLY,NPLY,KGRD,THWAL,GNP,RAD)

COMMON /PLYS/ THERMO(223),MDES(223),THHF,NLEP

This subroutine determines the number and type of plys of each nodal point in accordance with the following input procedures;

If the SOLID option is chosen the maximum number of plys for each material is based on a percentage of the thickest node or, if PLYORDER is specified, is based on the node thickness and plys needed to fill that thickness. For all nodes the maximum possible number of plys of each material is used starting at the surface until the node thickness is attained. As each ply is added the remaining thickness is checked until it is less than the thickness of the next ply to be included. If the remaining thickness is greater-than or equal-to the half-thickness of the next ply that ply is added to the analysis at that node.

If PLYORDER option is designated, the ply order thru the second half-thickness will be a mirror image of the first half-thickness ply order specified with the first ply designated placed on the outer surface.

If UNSYMMETRICAL option is designated, a second ply order is required for the opposite half of the blade starting at the outer surface.

If the hollow option is chosen the same procedure is followed as for the solid option except at selected grid points the wall thickness is used and the remaining thickness is composed of the last ply material listed in the input deck.

SUBROUTINE WIND

CALLED FROM -- CSHELL

CALLS TO -- INTRPL

ARGUMENTS (I,KTTAB,NP,NE,NPAST,NNQ,NGRID,NELT,NYPTS,
NXSPC,LSECT,X,GNP,KEI)

COMMON /PROPER/ TTAB(30,8,30,2),DUMMY(1433)

The mesh pattern and element connectivities for quadrilateral elements are defined in this subroutine. Each section is divided spanwise into NXSPC spaces along the x-axis and coordinate values are defined by interpolation between stations.

SUBROUTINE WINOUT

CALLED FROM -- CSHELL

CALLS TO -- none

```
ARGUMENTS  (SPARS,KOUT,KDES1,KDES2,NP,NE,IMAT)

COMMON /TABLES/ GNP(12,510),KEI(6,910),NCORDL(910),RAD(2,510)
COMMON /PLYS/   THERMO(223),MDES(223),THHF,NLEP
COMMON /PRINT1/ ID(80,5), IOPT(80,30)
COMMON /PRINT2/ NPRT(2,10)
```

This subroutine prints the element identification table, nodal geometry table and surface data.

SUBROUTINE WINPLY

CALLED FROM -- CSHELL

CALLS TO -- none

ARGUMENTS (SPARS,PLYORD,KOUT,KDES2,NP,NDES,THMAX,NSPAR, MAXPLY,NSPDES,MPLY,CODES,PERT,GNP)

COMMON /PLYS/ THERMO(223),MDES(223),THHF,NLEP

This subroutine determines the number and type of plys at each nodal point in accordance with the input procedure specified.

The maximum number of plys for each material is based on a percentage of the thickest node or, if the PLYORDER is specified, is based on the node thickness and plys needed to fill that thickness. For other nodes the maximum number of plys of each material is used starting at the surface until the thickness is attained.

The ply order thru the thickness will be a mirror image of the half-thickness order specified with the first ply designated placed on the outer surface. This subroutine is analogous to subroutine TBPLY.

SUBROUTINE WINPUT

CALLED FROM -- CSHELL

CALLS TO -- CTRAN INTRPL SPRSET

ARGUMENTS (KTTAB,KOUT,KDIAG,PIN,TTAB,SY,MWSCT,X,LSP,
LSECT,NGRID,NELT,NXSECT,NSPAR,NXSPAR,NYSPC,
NYPTS,NNQ,NNX,LDIAG,ZIGZAG)

Each input section profile is rotated and translated to a coordinate system with the origin at the leading edge and one axis along a chord line from the leading edge to the trailing edge. each section is then divided into NYSPC equal spaces. The space at the leading edge is then divided in half.

If spars exist at the input section the spar positioning subroutine SPRSET is called to rearrange the equally spaced nodes so the nearest nodal points fall at the spar positions. Holding the spar position, the spaces are again equally divided between spars.

SUBROUTINE WREAD

CALLED FROM -- CSHELL

CALLS TO -- MIDWAL OUTP10 OUTPUT

```
ARGUMENTS  (WINDML,PROFIL,PROT,PREP,MODES,COSD,MSCD,
            CONE,PLYORD,TEM,EZRD,ZIGZAG,KREAD,KOUT,KDIAG,
            PIN,NPM,PMOD,CODES,PERT,LDIAG)

COMMON /VALUES/ NP, NE, NDES, IMAT, KSMF, IU, JU, XBEG, XEND,
                NMODE(3), NOPLY, NSECT, MESH, NGROUP, NCOREG,
                IGRD, MSECT(40), NCOOR(3,8)
COMMON /WINDS/  SY(4,30,5),   MWSCT(30,2),   ALPHA(3,3),   X(30),
                NXSPC(30),    NSPDES(5),     NGRID,        NELT,
                NPAST,        THMAX,         NXSECT,       NSPAR,
                NXSPAR,       NYSPC,         LSP(2,5,30),  NYPTS,
                NNQ,          NNX,           LSECT(2),     NPTOT,
                NETOT,        HOLD(10),      MAXPLY,       MPLY(300)
```

This subroutine reads in all data specified in the SHELL/SPAR option of the USER'S MANUAL. The order and format are as specified in the USER'S MANUAL.

Data is stored in the appropriate arrays in common blocks for use in the program.

SUBROUTINE WROTAT

CALLED FROM -- CSHELL

CALLS TO -- none

ARGUMENTS (KK,NP,KDIAG,ALPHA,GNP,LDIAG)

If CONE is designated in the user options this subroutine calculates a coordinate transformation from a blade oriented coordinate system to a rotational axis coordinate system for all nodal position values using the transformation matrix ALPHA provided by the user.

SUBROUTINE WSPAR

CALLED FROM -- CSHELL

CALLS TO -- none

ARGUMENTS (KDIAG,NP,NE,NELT,NSPAR,NYPTS,NXSPAR,
X,LSP,NXSPC,SY,GNP,KEI,LDIAG)

This subroutine generates the connectivity and grid points for spar elements utilizing the existing shell grid points. Spar thicknesses are also evaluated in this subroutine.

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SYMBOLS and CODE IDENTIFIERS

Engineering symbol	FORTRAN code	Comment
A_{cx}	AS	composite axial stiffness
A^R_{cx}	RA	reduced axial stiffness
BIDE	Boolean	TRUE if interply effects are included
C_{cx}	CS	composite coupling stiffness
D_{cx}	BS	composite flexural rigid-ities
D^R_{cx}	RB	reduced bending rigidities
D_v	DISV,DISVI	displacement vectors
d_f	DIAF	filament equivalent diam-eter
E_c	ECI	elastic property matrix
E_f, E_{cf}	ECF	filament elastic constants
$E_\ell, E_{c\ell}$	ECL	ply elastic constants
E_m, E_{cm}	ECM	matrix elastic constants
$E_{f11}, E_{\ell 11}, E_{m11}$	EF11,EL11,EM11	filament, ply and matrix normal moduli

Engineering symbol	FORTRAN code	Comment
$E_{f12}, E_{\ell 12}, E_{m12}$	EF12,EL12,EM12	filament, ply and matrix shear moduli
$E_{\ell i}$	ELS	ply elastic matrix
H_j	PL(9,I)	interply distortion energy coefficient
H_{kc}	CHK	array of constituent heat conductivities
h_c	HHC	composite heat capacity stored in PC(18) and PC(54)
i,j	I,J	index, generally ply or interply
$K_{c11}, K_{c22}, K_{c33}$	HK11,HK22,HK33	composite three-dimensional heat conductivities along the material axes in PC(15 to 17)
$K_{cxy}, K_{cyy}, K_{cyx}$	HK11,HK22,HK33	composite two-dimensional heat conductivities in PC(51 to 53)
$K_{f11}, K_{\ell 11}, K_{m11}$	CHK	see H_{kc}
k_f, k_v	KF, KV	apparent fiber and void volume ratios
$\bar{k}_f$, $\bar{k}_m$	KFB, KMB	actual fiber and matrix volume ratios

Engineering symbol	FORTRAN code	Comment
$k_{f\ell}$, $k_{v\ell}$	KFL, KVL	ply apparent fiber and void volume ratios
L_{sc}	LSC	array of limiting conditions
$M_{c\Delta Tx}$	MSDT	thermal moments
M_{cx}	MSB	applied moment
m	M	load condition index
N_{cx}	NSB	applied membrane loads
$N_{c\Delta Tx}$	NSDT	thermal force
N_f	NFPE	number of filaments per end
N_ℓ	NL	number of plies
$N_{\ell c}$	NLC	number of load conditions
N_{pc}	NPC	string PROPC length
N_{pl}	NPL	string PROP length
P_c	PC	composite properties array
P_ℓ	PL	ply properties array
$P_{\ell p}$	PROP	string PROP; ply properties identifiers

Engineering symbol	FORTRAN code	Comment
$Q_{f,i,p,r,s}$	QF,I,P,R,S	indices to print out string PROP
R	R	ply transformation matrix
$R_{\ell i}$	RS	ply transformation matrix
S_j	SS	relative rotation matrix (between plys)
$S_{\ell 11T}$ etc.	PL(51 to 59,I)	ply limit stresses
t_ℓ	TL	ply thickness
VC	VC	factor representing void effect on strain magnification factor
w_{cb}	WXX	composite local curvatures relative to the structural axes
α_c	CTL	ply coefficient of thermal expansion three-dimensional in PL(24 to 26)
$\alpha_{f,\ell,m}$	VAF,VAL,VAM	filament, ply, and matrix thermal coefficient of expansion
β_e, γ_e	VCF	correlation factors for ply thermoelastic properties and strain magnification factors

Engineering symbol	FORTRAN code	Comment
β_h	BTA	correlation factors for ply heat conductivities
β_s	BET	correlation factors for ply strength
δ_ℓ	PL(8,I)	interply layer thickness
ε_{csx}	UX	reference plane membrane strains
ε_ℓ	EPS,PL(64 to 66,I)	ply strains
θ_{cs}	THCS	angle between composite material axes and structural axes
$\theta_{\ell i}$, $\theta_{\ell c}$	THLC	angle between ply material axes and composite axes
$\nu_{f12,\ \ell 12,\ m12}$	NUF12,NUL12,NUM12	filament, ply, and matrix Poisson's ratio
π	PI	constant
$\rho_{f,m,\ \ell}$	RHOF,RHOM,RHOL	filament and matrix weight density
σ_ℓ	SIGL,PL(67 to 69,I)	ply stresses

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16. Abstract

This manual describes the organization and flow of data and analysis in the computer code, COBSTRAN (COmposite Blade STRuctural ANalyzer). This code combines composite mechanics and laminate theory with an internal data base of fiber and matrix properties and was developed for the design and analysis of composite turbofan and turboprop blades and composite wind turbine blades. Inputs to the code are constituent fiber and matrix material properties, factors reflecting the fabrication process, composite geometry and blade geometry. COBSTRAN performs the micromechanics and laminate analyses of these fiber composites and generates a NASTRAN finite element model of the blade. This manual describes the equations formulated and solved in the code and the function of each of the seventy-two subroutines. COBSTRAN is written in FORTRAN 77.

17. Key Words (Suggested by Author(s)) Composite mechanics; Turboprop blade; Turbofan blade; Wind turbine blade; Data base; Failure criteria; NASTRAN	18. Distribution Statement Unclassified – Unlimited Subject Category 24

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