N84-26755

NASA Technical Memorandum 83700

ICAN: Integrated Composites Analyzer

P. L. N. Murthy and C. C. Chamis
Lewis Research Center
Cleveland, Ohio

Prepared for the
Twenty-fifth Structures, Structural Dynamics and Materials Conference
cosponsored by the AIAA, ASME, ASCE, and AHS
Palm Springs, California, May 14-16, 1984

NASA

TABLE OF CONTENTS

ICAN: INTEGRATED COMPOSITES ANALYZER

P. L. N. Murthy and C. C. Chamis
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-2158

SUMMARY

A computer code ICAN (Integrated Composites Analyzer), has been developed to analyze/design fiber composite structures. The program includes composite mechanics theories which resulted from extensive research that has been conducted over the past fifteen years at NASA Lewis Research Center. These theories account for environmental effects and are applicable to intraply hybrid composites, interply hybrid composites and combinations of these, as well as conventional laminate analysis. Key features and capabilities of ICAN are described. A sample input data set and selected output are provided to illustrate its generality/versatility and user friendly structure.

SYMBOLS

C_f, C_m	fiber and matrix heat capacities
d_f	filament (fiber) equivalent diameter
E_f, E_{f11}, etc.	elastic constants of fiber
E_m, E_{m11}, etc.	elastic constants of matrix
G_f, G_{f12}, etc.	fiber shear modulus
G_m, G_{m12}, etc.	matrix shear modulus
K_{f11}, K_{f22}	fiber heat conductivities
K_m	matrix heat conductivity
K_v	void heat conductivity
M_x, M_y, M_{xy}	applied bending moments
N_x, N_y, N_{xy}	applied membrane forces
N_f	number of fibers per end
$N_{\ell c}$	number of load conditions
N_{ms}	number of material systems
N_ℓ	number of layers
S_{fT}, S_{fC}	fiber tensile and compressive strengths
S_{mT}, S_{mC}, S_{mS}	matrix tensile, compressive and shear strengths
T_{cu}, T_{gdr}, T_u	cure temperature, dry glass transition temperature and use temperature
α_f, α_{f11}, etc.	thermal expansion coefficients of fiber
α_m	thermal expansion coefficient of matrix

$\epsilon_{mT}, \epsilon_{mC}, \epsilon_{mS}, \epsilon_{mTo\gamma}$	matrix allowable strain limits
ν_{f12}, ν_{f23}	fiber Poisson's ratios
ν_m	matrix Poisson's ratio ply orientation angle
θ_f	fiber mass density
ρ_m	matrix mass density

INTRODUCTION

The most cost effective way to analyze/design fiber composite structures is through the use of computer codes. Composite analysis computer codes to date have been based mainly on "classical" laminate theory. Over the past fifteen years, extensive research has been conducted at NASA Lewis Research Center to develop composite mechanics theories and analysis methods from micromechanics to new finite elements. These theories and analysis methods account for environmental effects and are applicable to intraply hybrid composites, interply hybrid composites and combinations thereby. Most of these theories are represented by simplified equations which have been corroborated by experimental results and finite element analysis. The composite mechanics theories with their respective simplified equations constitute a structured theory which is: (1) "upward integrated" from material behavior space to structural analysis; and (2) "top-down traced" from structural response to material behavior space (see fig. 1). This structured theory has been incorporated into a computer code called ICAN (Integrated Composites Analyzer). A brief history of the developments pertaining to composite mechanics and related computer codes which led to the evolution of ICAN is described in the following paragraphs.

The importance of and need for a multilevel analysis in designing structural components with multilayered fiber composites were recognized about 20 years ago (ref. 1). A multilevel analysis computer code (MFCA: Multilayered Fiber Composites Analysis) which was found to be efficient in predicting the structural response of multilayered fiber composites (given the constituent materials properties, the fabrication process, and the composite geometry) is documented in reference 2.

Intraply hybrid composites are logical sequel to conventional composites and to interply hybrid composites. Recently, theoretical and experimental investigations have been conducted on the mechanical behavior of intraply hybrids at Lewis Research Center (refs. 3 to 5). The theoretical methods and equations described in these references together with those for hygrothermal effects (ref. 6) have been integrated into a computer code for predicting hygral, thermal and mechanical properties of, and thereby "designing", intraply hybrid composites. This code is identified as INHYD for INtraply HYbrid Composite Design (ref. 7).

The computer code ICAN, is a synergistic combination of the aforementioned computer programs MFCA and INHYD together with several significant enhancements. It utilizes the micromechanics design of INHYD and the laminate theory of MFCA to build a comprehensive analysis/design capability for structural composites. Additional features unique to ICAN are as follows:

(1) Ply stress-strain influence coefficients

(2) Microstresses and microstress influence coefficients

(3) Stress concentration factors at a circular hole

(4) Predictions of probable delamination locations around a circular hole

(5) Poisson's ratio mismatch details near a straight free edge

(6) Free edge stresses

(7) Material cards for finite element analysis for NASTRAN (COSMIC, MSC) and MARC

(8) Laminate failure stresses based upon first ply failure and fiber breakage criteria, with and without hygrothermal degradation

(9) Transverse shear stresses and normal stresses

(10) Explicit specification of interply layers

In addition, ICAN has its own data base of material properties for commonly used fibers and matrices. The user needs to specify only the coded names for the constituents. The program searches and selects the appropriate properties from its data base. Furthermore, the input data preparation has been simplified substantially through the introduction of partial free-field format to lessen the burden on the user. The output formats have also been improved significantly for easier interpretation of the results. All these enhancements make ICAN significantly more inclusive and more user-friendly than its predecessors.

The complete documentation of ICAN with compiled listing, user instructions, programmers manual and sample cases for each option is available in reference 8). Also, the program will be made available through COSMIC -- Computer Software Management and Information Center, Suite 112, Barrow Hall, Athens, Georgia 30602. The objective of this paper is to describe the computer code from the engineer's/analyst's usage viewpoint. Therefore, the description is limited to input-output and application versatility.

SCOPE AND DEFINITIONS

ICAN is primarily designed to analyze the hygrothermomechanical response/properties of fiber reinforced/resin matrix type layered composites, given the local membrane loads and bending moments. Three types of layers are recognized by the program. They are: (1) the standard composite system which consists entirely of a primary composite made of one type of fiber and matrix; (2) the intraply hybrid composite system which consists of a primary composite and a secondary composite arranged in a prescribed manner within a layer (for purposes of identification, the primary composite in the hybrid is the one which constitutes the largest volume ratio); (3) the interply layer which consists of the matrix. Up to ten different material systems and one thousand layers (plies, interplies, combinations) can be handled by ICAN at the present time. The number of different loading conditions (forces or displacements) that can be handled in one run is ten; however, the limits can be modified with relative ease. In addition, ICAN recognizes moisture and/or temperature gradients through the thickness.

THEORIES INCLUDED IN ICAN

The complete details of the equations in the code are given in reference 8. Prediction of composite hygrothermomechanical properties is achieved through use of the various micromechanics theories mentioned earlier. Laminate properties are obtained through macromechanics and laminate theory. Classical laminate theory is used to predict local stresses and strains. The free edge stress calculations are based upon the approach outlined in reference 9 with enhancements to accommodate interply layer and local characteristics of the adjacent ply. The stress concentration factors around a circular hole are obtained using the equations given in reference 10. The laminate failure stress analysis utilizes two criteria: (1) the first ply failure based upon the maximum strength, and (2) the first ply failure based upon the fiber breakage. Complete laminate failure analysis is performed using two different ply combined-stress failure criteria and one interply delamination criterion for each specified load condition.

ICAN COMPUTER PROGRAM STRUCTURE

The modular structure of the code is illustrated in the flow chart in figure 2. The various modules of the program in the order in which they are called, the inputs to the subroutines, and the generated output from the modules are identified in a symbolic manner. Each module in turn accesses several common subroutines (a few auxiliary subroutines are not shown). A brief description of the multilevel operations performed by ICAN during a typical run is given below.

The first phase of the run consists of assimilating the input data. The geometry, the number/details of loading conditions, the constituent materials with details pertaining to the fiber and matrix volume ratios, the primary and the secondary composite contents, and the temperature gradients and moisture content for each layer are read from the user submitted input data. A summary of the input data is printed out along with the input data echo.

The second phase of the run consists of interpreting the user supplied code words for the constituent materials and retrieving the properties from the resident data base of ICAN. These are then supplied to the modules which perform micromechanics analyses and obtain the lamina properties. The lamina properties are returned to the ICAN main program which is the executive module of the code. The modules involved in this phase are IDGER, BANKRD, INHYB (INHYD MAIN), HTM, COMPP, FIBMT and FLEXX.

The last phase of the run consists of integrating the individual layer properties (using laminate theory) to generate laminate properties, and of performing a complete laminate stress analysis. During this phase, several other operations such as generating a summary of laminate failure stress analysis, free edge stresses, stress concentration factors around a circular hole, etc., are also performed. The modules and subroutines involved in this phase are FESTRE, EDGSTR, MSCBFL, COMSA, GPCFD2, GACD3, NUDIFS, STRCNF, MCRSTR, MINCOF and FLRLD.

The detailed descriptions of these various subroutines including the governing equations are given in reference 8.

ICAN INPUT DATA PREPARATION

The input data for ICAN is supplied through six different card groups of information. Most of these data cards are identified by a mnemonic to indicate the card group it belongs to in the input data deck. Each physical card is divided into fields of eight columns with one entry per field being allowed. The mnemonic is entered in format A8 and the integers in format I8. The real numbers may be entered anywhere in the appropriate field. The following is a brief description of each card group.

(1) Title card -- Any title of length up to 80 characters including blanks may be supplied on this card.

(2) Starting data card -- This card has a mnemonic 'STDATA'. It contains the overall laminate and loading details. Included are the number of plies N_ℓ, the number of different material systems N_{ms}, and the number of loading conditions $N_{\ell c}$.

(3) Booleans -- A set of Booleans 'COMSAT' 'RINDV', 'BIDE' 'CSANB', and 'NONUDF' are defined through these cards. There are 5 cards -- one per each logical variable. The format is L6. The function of each variable is explained below:

(a) COMSAT -- The letter T on the card will direct the program to perform a complete laminate analysis. A letter F would terminate the program prior to performing the laminate stress analysis.

(b) RINDV -- The letter T is entered on the card if the displacements are inputs; otherwise, the letter F is entered.

(c) BIDE -- The letter T is entered on the card if the interply layer contributions on the composite are desired; otherwise, the letter F is entered.

(d) CSANB -- The letter T is entered in the card if the composite has both membrane and bending symmetry; otherwise, the letter F is entered.

(e) NONUDF -- The letter T is entered if the detailed Poisson's ratio differences chart is to be suppressed; otherwise, the letter F is entered.

(4) Ply Descriptors Card Group -- All the cards in this group have a mnemonic 'PLY'. There are N_ℓ number of cards (corresponding to N_ℓ number of plies) with eight entries on each card. The first entry is 'PLY'. The second and third are identification numbers for the ply and the material system respectively. The fourth and fifth are the use temperature (T_u) and the cure temperature (T_{cu}). The sixth entry is the amount of moisture weight percentage (M). The seventh and the eighth entries are the orientation angle θ of the ply and the thickness of the ply respectively. A default value of 0.005 in. is taken for the thickness if this entry is missing. The material system identification number should be different not only for

different composite systems but also whenever the use temperature or moisture content vary from ply to ply.

(5) Constituent Materials Descriptors -- All the cards in this group have mnemonic 'MATCRD'. There are N_{ms} numbers of cards with 10 entries in each card. The first entry is 'MATCRD'. The second and the third are coded words for fiber and matrix material of the primary composite. The code words are entered in 2A4 format. For example, the code for AS type fiber is 'AS--' and epoxy matrix is 'EPOX'. A directory of codes for several fibers and matrices is provided in appendix B. The user may choose any combination of fiber and matrix for a composite system or incorporate his own as described in the DATA BASE section. The fourth and the fifth entries pertain to the details of the primary composite system. They are the primary fiber volume ratio and the primary void volume ratio, respectively. The next two entries refer to the secondary composite system which is applicable in the case of an intraply hybrid composite ply. It should be the same as the second and third entries for standard composite systems. The next entry is the secondary composite system volume ratio. The last two entries are the fiber volume ratio and the void volume ratio for the secondary composite system. These are zero when intraply hybrids are not selected.

(6) Load Cards -- All the cards in this group start with mnemonic 'PLOAD'. There are three cards for each loading condition. Thus, the total number of cards are $3N\ell_c$. The first card under each loading condition contains entries N_x, N_y and N_{xy}, the membrane loads, and $T_{hcs}\theta$ the orientation of the loads with respect to the structural axes. The second card contains the bending resultants M_x, M_y and M_{xy}. The last card contains the transverse shear resultant DM_x and DM_y and transverse pressures P_u and P_ℓ.

A sample set of input data is illustrated in table I for a four ply symmetric laminate. It has two different material systems. The 0° plies are of AS graphite fiber/intermediate modulus low strength epoxy matrix composite. The 90° plies are made of a hybrid composite. The primary composite is S-Glass/high modulus high strength epoxy (SGLA/HMHS). The secondary composite is AS graphite/intermediate modulus high strength epoxy. The use and the cure temperatures are 70° F. The moisture content is zero.

Input data for additional composite systems may be easily prepared. This is done by selecting a desired fiber and matrix from the available materials listed in appendix B (FBMTDATA.BANK), and modifying the appropriate entries in the input data sample illustration.

ICAN OUTPUT

The ICAN output succinctly summarizes its features. The following is a list of results that are printed out by the program:

(1) ICAN logo

(2) ICAN coordinate systems

(3) ICAN input data echo

(4) The input data summary

(5) The fiber and the matrix (constituent materials) properties of primary and secondary composites; the ply level properties

(6) The composite 3-D strain-stress and stress-strain relations about the structural axes; MAT9 card for MSC/NASTRAN solid elements

(7) The composite properties

(8) The composite constitutive equations about the structural axes

(9) The reduced bending and axial stiffnesses

(10) Some useful data for finite element analysis

(11) The displacement-force relations for the current load condition

(12) The ply hygrothermomechanical properties/response

(13) The details of Poisson's ratio mismatch among the plies

(14) Free edge stresses

(15) The microstresses and microstress influence coefficients for each different composite material system

(16) Stress concentration/intensity factors around a circular hole

(17) Locations of probable delamination around circular holes

(18) Ply stress and strain influence coefficients

(19) Laminate failure stresses based on the first ply failure/maximum stress criteria

(20) A summary of the laminate failure stresses based upon two alternatives -- the first ply failure and the fiber breakage.

Selected parts of the ICAN output for the sample input data given in table I is shown in appendix A.

DATA BASE OF CONSTITUENT PROPERTIES (FBMTDATA.BANK)

The constituent properties database is a unique feature of the computer code ICAN. Its primary aim is to reduce the burden on user in preparing properly formatted data for the program. The user only needs to specify the coded names for the fiber and matrix. The format of the data has been structured so as to enable the user to introduce new contents or to modify existing entries as appropriate to his needs. Data for four fibers and three matrices are provided in the present package. A brief description follows.

The fiber properties are arranged in five physical cards of length 80 columns. The first card contains a four character code name of fiber in format A4. The second through the fifth cards start with a two letters mnemonic to indicate the type of properties that follow. The format on any of these cards is (A4, 7E10.3) except for the second card. The second card is in format (A3, I6, 7E10.3). The mnemonics FP, FE, FT and FS stand for fiber physical, elastic, thermal and strength related properties. The entries on these cards are explained below:

Card 1: Four character coded name for fiber

Card 2: FP N_f, d_f, ρ_f

Card 3: FE E_{f11}, E_{f22}, ν_{f12}, ν_{f23}, G_{f12}, G_{f23}

Card 4: FT α_{f11}, α_{f22}, K_{f11}, K_{f22}, C_f

Card 5: FS S_{fT}, S_{fC}

The matrix properties are arranged next after the line "OVER END OF FIBER PROPERTIES". They have essentially the same format as those for fiber property cards. There are, however, six physical cards for each matrix material. The mnemonics used are MP, ME, MT, MS and MV. They stand for matrix physical, elastic, thermal, strength related and miscellaneous properties respectively. The format for the first card is (A4) and for the rest of the cards (A3, 7E10.3). The entries in each card are discussed below:

Card 1: Four character coded name for matrix

Card 2: MP ρ_m

Card 3: ME E_m, γ_m, α_m

Card 4: MT K_m, C_m

Card 5: MS S_{mT}, S_{mC}, S_{mS}, ϵ_{mT}, ϵ_{mC}, ϵ_{mS}, ϵ_{mTor}

Card 6: MV K_v, T_{gdr}

The data base presently contains properties for T-300 (T300), AS graphite (AS--), S-Glass (SGLA) and HMS (HMSF) fibers. The available matrix materials are -- high modulus high strength (HMHS), intermediate modulus high strength (IMHS) and intermediate modulus low strength (IMLS) -- which are epoxy type resins. The complete list of properties is shown in appendix B.

ICAN EXTENSIONS AND COUPLING

The program can be extended to predict wave propagation parameters like the bulk and shear wave velocities, properties such as impact resistance and fatigue. The program can be coupled with complex structural analyses codes where it can serve as a preprocessor and a postprocessor. It is planned to couple ICAN with three integrated computer programs under in-house development: CODSTRAN - Composite Durability Structural Analysis (ref. 11); COBSTRAN - Composite Blade Structural Analysis (ref. 12); and CISTRAN - Composite Impact Structural Analysis (ref. 13).

CONCLUSIONS

A computer program ICAN (Integrated Composites Analyzer) has been developed to perform all the essential aspects of mechanics/analysis/design of multilayered fiber composites. The program is modular, open-ended and user friendly. It can handle a variety of composite systems having one type of fiber and one matrix as constituents as well as intraply and interply hybrid composite systems. It can also simulate isotropic layers by considering a primary composite system with negligible fiber volume content. This feature is specifically useful in modeling thin interply matrix layers. The program can account for hygrothermal conditions and various combinations of in-plane and bending loads. Usage of this code is illustrated with a sample input and the generated output. Some of the key features of output are stress concentration factors around a circular hole, locations of probable delamination, a summary of the laminate failure stress analysis, free edge stresses, microstresses and ply stress/strain influence coefficients. These features make ICAN a powerful, cost-effective tool to analyze/design fiber composite structures and components.

S U M M A R Y   O F   I N P U T   D A T A

FOUR PLY SYMMETRIC LAMINATE. ICAN SAMPLE INPUT DATA.

\- - -   CASE   CONTROL   DECK   - - -

NUMBER OF LAYERS	NL	=	4
NUMBER OF LOADING CONDITIONS	NLC	=	1
NUMBER OF MATERIAL SYSTEMS	NMS	=	2

COMSAT	CSANB	BIDE	RINDV	NONUDF
T	F	F	F	T

\- - -   LAMINATE   CONFIGURATION   - - -

PLY	NO	MID	DELTAT	DELTAM	THETA	T-NESS
PLY	1	1	0.000	0.0%	0.0	0.010
PLY	2	2	0.000	0.0%	90.0	0.005
PLY	3	2	0.000	0.0%	90.0	0.005
PLY	4	1	0.000	0.0%	0.0	0.010

\- - -   COMPOSITE MATERIAL SYSTEMS   - - -

MATCRD	MID	PRIMARY	VFP	VVP	SECONDARY	VSC	VFS	VVS
MATCRD	1	AS--IMLS	0.55	0.02	AS--IMLS	0.00	0.57	0.03
MATCRD	2	SGLAHMHS	0.55	0.01	AS--IMHS	0.40	0.57	0.01

\- - -   LOADING CONDITIONS   - - -

PRESCRIBED LOADS FOR THE LOAD CONDITION 1

INPLANE LOADS	NX	=	1000.0000	LB/IN
	NY	=	0.0000	LB/IN
	NXY	=	0.0000	LB/IN
BENDING LOADS	MX	=	0.0000	LB.IN/IN
	MY	=	0.0000	LB.IN/IN
	MXY	=	0.0000	LB.IN/IN
TRANSVERSE LOADS	DMX/QX	=	0.0000	LB/IN
	DMY/QY	=	0.0000	LB/IN
TRANSVERSE PRESSURE	PU	=	0.0000	LB/SQ. IN.
TRANSVERSE PRESSURE	PL	=	0.0000	LB/SQ. IN.

--> CONSTITUENT PROPERTIES: ECHO FROM DATA BANK. <--

PRIMARY FIBER PROPERTIES; AS-- FIBER

1	ELASTIC MODULI	EFP1	0.3100E 08
2		EFP2	0.2000E 07
3	SHEAR MODULI	GFP12	0.2000E 07
4		GFP23	0.1000E 07
5	POISSON'S RATIO	NUFP12	0.2000E 00
6		NUFP23	0.2500E 00
7	THERM. EXP. COEF.	CTEFP1	-0.5500E-06
8		CTEFP2	0.5600E-05
9	DENSITY	RHOFP	0.6300E-01
10	NO. OF FIBERS/END	NFP	0.1000E 05
11	FIBER DIAMETER	DIFP	0.3000E-03
12	HEAT CAPACITY	CFPC	0.1700E 00
13	HEAT CONDUCTIVITY	KFP1	0.5800E 03
14		KFP2	0.5800E 02
15		KFP3	0.5800E 02
16	STRENGTHS	SFPT	0.4000E 06
17		SFPC	0.4000E 06

PRIMARY MATRIX PROPERTIES;- IMLS MATRIX. DRY RT. PROPERTIES.

1	ELASTIC MODULUS	EMP	0.5000E 06
2	SHEAR MODULUS	GMP	0.1773E 06
3	POISSON'S RATIO	NUMP	0.4100E 00
4	THERM. EXP. COEF.	CTEMP	0.5700E-04
5	DENSITY	RHOMP	0.4600E-01
6	HEAT CAPACITY	CMPC	0.2500E 00
7	HEAT CONDUCTIVITY	KMP	0.1250E 01
8	STRENGTHS	SMPT	0.7000E 04
9		SMPC	0.2100E 05
10		SMPS	0.7000E 04
11	MOISTURE COEF	BTAMP	0.4000E-02
12	DIFFUSIVITY	DIFMP	0.2000E-03

PRIMARY COMPOSITE PROPERTIES; 55/ 43 AS--/IMLS

BASED ON MICROMECHANICS OF INTRAPLY HYBRID COMPOSITES: ELASTIC AND THERMAL PROPERTIES.

FIBER VOLUME RATIO - 0.550 MATRIX VOLUME RATIO - 0.430 VOID VOLUME RATIO - 0.020
VOID CONDUCTIVITY - 0.22499990E 00

1	ELASTIC MODULI	EPC1	0.1726E 08
2		EPC2	0.1127E 07
3		EPC3	0.1127E 07
4	SHEAR MODULI	GPC12	0.5470E 06
5		GPC23	0.3238E 06
6		GPC13	0.5470E 06
7	POISSON'S RATIO	NUPC12	0.2945E 00
8		NUPC23	0.4821E 00
9		NUPC13	0.2945E 00
10	THERM. EXP. COEF.	CTEPC1	0.1418E-06
11		CTEPC2	0.2464E-04
12		CTEPC3	0.2464E-04
13	DENSITY	RHOPC	0.5443E-01
14	HEAT CAPACITY	CPC	-0.1991E 00
15	HEAT CONDUCTIVITY	KPC1	0.3195E 03
16		KPC2	0.3702E 01
17		KPC3	0.3702E 01
18	STRENGTHS	SPC1T	0.2228E 06
19		SPC1C	0.8764E 05
20		SPC2T	0.5006E 04
21		SPC2C	0.1502E 05
22		SPC12	0.5126E 04
23	MOIST. DIFFUSIVITY	DPC1	0.8600E-04
24		DPC2	0.5163E-04
25		DPC3	0.5168E-04
26	MOIST. EXP. COEF.	BTAPC1	0.4981E-04
27		BTAPC2	0.1452E-02
28		BTAPC3	0.1452E-02
29	FLEXURAL MODULI	EPC1F	0.1726E 08
30		EPC2F	0.1127E 07
31	STRENGTHS	SPC23	0.3983E 04
32		SPC1F	0.1572E 06
33		SPC2F	0.9387E 04
34		SPCSB	0.7689E 04
35	PLY THICKNESS	TPC	0.5000E-02
36	INTERPLY THICKNESS	PLPC	0.5850E-04
37	INTERFIBER SPACING	PLPCS	0.5850E-04

HYBRID COMPOSITE PROPERTIES; 60/40 SGLA/HMHS/AS--/IMHS
BASED ON MICROMECHANICS OF INTRAPLY HYBRID COMPOSITES: ELASTIC AND THERMAL PROPERTIES.

PRIMARY COMPOSITE VOLUME RATIO - 0.600 SECONDARY COMPOSITE VOLUME RATIO - 0.400

1	ELASTIC MODULI	EHC1	0.1144E 08
2		EHC2	0.1696E 07
3		EHC3	0.1945E 07
4	SHEAR MODULI	GHC12	0.7551E 06
5		GHC23	0.4561E 06
6		GHC13	0.7941E 06
7	POISSON'S RATIO	NUHC12	0.2663E 00
8		NUHC23	0.3985E 00
9		NUHC13	0.2689E 00
10	THERM. EXP. COEF.	CTEHC1	0.1603E-05
11		CTEHC2	0.1601E-04
12		CTEHC3	0.1634E-04
13	DENSITY	RHOHC	0.6334E-01
14	HEAT CAPACITY	CHC	0.1943E 00
15	HEAT CONDUCTIVITY	KHC1	0.1352E 03
16		KHC2	0.2305E 01
17		KHC3	0.2305E 01
18	STRENGTHS	SHC1T	0.2168E 06
19		SHC1C	0.1665E 06
20		SHC2T	0.9915E 04
21		SHC2C	0.2314E 05
22		SHC12	0.1195E 05
23	MOIST. DIFFUSIVITY	DHC1	0.8736E-04
24		DHC2	0.5117E-04
25		DPC3	0.5117E-04
26	MOIST. EXP. COEF.	BTAHC1	0.9858E-04
27		BTAHC2	0.8565E-03
28		BTAHC3	0.1455E-02
29	FLEXURAL MODULI	EHC1F	0.1144E 08
30		EHC2F	0.1696E 07
31	STRENGTHS	SHC23	0.1019E 05
32		SHC1F	0.2355E 06
33		SHC2F	0.1735E 05
34		SHCSB	0.1793E 05
35	PLY THICKNESS	THC	0.5000E-02
36	INTERPLY THICKNESS	PLHC	0.5215E-04
37	INTERFIBER SPACING	PLHCS	0.5215E-04
38	FIBER VOL. RATIO	VFH	0.5580E 00
39	MOISTURE CONTENT	M	0.0000
40	MATRIX VOL. RATIO	VMH	0.4320E 00

3-D COMPOSITE STRAIN STRESS TEMPERATURE MOISTURE RELATIONS - STRUCTURAL AXES

	-1-	-2-	-3-	-4-	-5-	-6-	-DT-	-DM-
1	0.6976E-07	-0.5952E-08	-0.2727E-07	0.0000	0.0000	0.3255E-13	0.1102E-05	0.1009E-03
2	-0.5952E-08	0.1962E-06	-0.8485E-07	0.0000	0.0000	-0.1464E-11	0.5805E-05	0.3370E-03
3	-0.2727E-07	-0.8485E-07	0.5614E-06	0.0000	0.0000	0.6682E-12	0.2839E-04	0.1859E-02
4	0.0000	0.0000	0.0000	0.2139E-05	0.5229E-12	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.5229E-12	0.1935E-05	0.0000	0.0000	0.0000
6	0.3255E-13	-0.1464E-11	0.6682E-12	0.0000	0.0000	0.1622E-05	-0.4330E-10	-0.2425E-08

3-D COMPOSITE STRESS STRAIN RELATIONS - STRUCTURAL AXES

	-1-	-2-	-3-	-4-	-5-	-6-
1	0.1473E 08	0.8093E 06	0.8377E 06	0.0000	0.0000	0.8960E-01
2	0.8093E 06	0.5499E 07	0.8703E 06	0.0000	0.0000	0.4587E 01
3	0.8377E 06	0.8703E 06	0.1953E 07	0.0000	0.0000	-0.3603E-01
4	0.0000	0.0000	0.0000	0.4676E 06	-0.1263E 00	0.0000
5	0.0000	0.0000	0.0000	-0.1263E 00	0.5167E 06	0.0000
6	0.8960E-01	0.4587E 01	-0.3603E-01	0.0000	0.0000	0.6164E 06

MAT9 CARD FOR MSC/NASTRAN SOLID ELEMENTS

```
G11,G12,G13,G14,G15,G16,G22,G23,G24,G25,G26,G33,G34,G35,G36,G44,G45,G46,G55,G56,G66
 0.14731064E 08 0.80927925E 06 0.83770038E 06 0.89597344E-01      0.00000000      0.00000000 0.54987690E 07 0.87032406E 06
 0.45865879E 01      0.00000000      0.00000000 0.19533170E 07-0.36027569E-01      0.00000000      0.00000000 0.61636813E 06
     0.00000000      0.00000000 0.46757519E 06-0.12633294E 00 0.51670638E 06
```

REDUCED STIFFNESS MATRIX		
0.36441E 06	0.11230E 05	0.32006E-02
0.11230E 05	0.13830E 06	0.12165E 00
0.32006E-02	0.12165E 00	0.18491E 05

REDUCED BENDING REGIDITIES		
0.37763E 02	0.76104E 00	0.26672E-07
0.76104E 00	0.34106E 01	0.10100E-05
0.26672E-07	0.10100E-05	0.12401E 01

S O M E U S E F U L D A T A F O R F.E. A N A L Y S I S

COMPOSITE THICKNESS FOR F.E. ANALYSIS = 0.30000E-01

PROPERTIES FOR F.E. ANALYSIS E11,E12,E13,E22,E23,E33 PROPERTIES SCALED BY 10**-6
0.22533E-01 -0.67069E-02 -0.29339E-07 0.21747E 00 0.14296E-05 0.16224E 01

BENDING EQUIVALENT PROPERTIES NUCXY, NCYX, ECXX, ECYY, GCXY
0.22261E 00 0.20153E-01 0.16708E 08 0.15126E 07 0.55473E 06

NASTRAN MEMBRANE EQUIVALENT ELASTIC COEFFICIENTS G11,G12,G13,G22,G23,G33
0.12147E 08 0.37462E 06 0.10669E 00 0.46099E 07 0.40551E 01 0.61637E 06

NASTRAN BENDING EQUIVALENT ELASTIC COEFFICIENTS G11,G12,G13,G22,G23,G33
0.16784E 08 0.33024E 06 0.11854E-01 0.15194E 07 0.45056E 00 0.55473E 06

	DISP.	DISPLACEMENT FORCE RELATIONS -1-	-2-	-3-	-4-	-5-	-6-	COMBINED FORCES
1	0.2751E-02	0.2751E-05	-0.2236E-06	0.9946E-12	0.1818E-12	-0.9021E-11	-0.2356E-15	0.1000E 04
2	-0.2236E-03	-0.2236E-06	0.7249E-05	-0.4765E-10	-0.5895E-11	0.2925E-09	0.1283E-14	0.0000
3	0.9946E-09	0.9946E-12	-0.4765E-10	0.5408E-04	-0.3466E-16	0.2237E-14	-0.1181E-19	0.0000
4	0.1818E-09	0.1818E-12	-0.5895E-11	-0.3466E-16	0.2660E-01	-0.5922E-02	0.4241E-08	0.0000
5	-0.9021E-08	-0.9021E-11	0.2925E-09	0.2237E-14	-0.5922E-02	0.2938E 00	-0.2385E-06	0.0000
6	-0.2356E-13	-0.2356E-16	0.1283E-14	-0.1181E-19	0.4241E-08	-0.2385E-06	0.8012E 00	0.0000

NOTE: THE DISPLACEMENTS ARE REFERENCE PLANE MEMBRANE STRAINS (UX , VY , VXPUY) AND CURVATURES (WXX , WYY , WXY)

FOR LOAD CONDITIONS					
MEMBRANE LOADS NBS(X,Y,XY-M)	ARE	1000.	0.	0.	
BENDING LOADS MBS(X,Y,XY-M)	ARE	0.	0.	0.	
QXZ,QYZ AND APPLIED PRESSURES	ARE	0.	0.	0.	0.
NOTE : NO MOISTURE OR TEMPERATURE					

LAYER PROPERTIES, ROWS-PROPERTY, COLUMNS-LAYER

	PLY NUMBER	1	2	3	4
	MATERIAL SYSTEM	AS--/IMLS AS--/IMLS	SGLA/HMHS AS--/IMHS	SGLA/HMHS AS--/IMHS	AS--/IMLS AS--/IMLS
	ORIENTATION	0.0	90.0	90.0	0.0
1	KV	0.2000E-01	0.1000E-01	0.1000E-01	0.2000E-01
2	KF	0.5500E 00	0.5580E 00	0.5580E 00	0.5500E 00
3	KFB	0.5390E 00	0.5524E 00	0.5524E 00	0.5390E 00
4	KM	0.4500E 00	0.4420E 00	0.4420E 00	0.4500E 00
5	KMB	0.4410E 00	0.4376E 00	0.4376E 00	0.4410E 00
6	RHOL	0.5443E-01	0.6334E-01	0.6334E-01	0.5443E-01
7	TL	0.1000E-01	0.5000E-02	0.5000E-02	0.1000E-01
8	DELTA	0.3850E-04	0.5215E-04	0.5215E-04	0.3850E-04
9	ZLOC	0.0000	0.0000	0.0000	0.0000
10	ZB	0.5000E-02	0.1250E-01	0.1750E-01	0.2500E-01
11	ZOC	-0.1000E-01	-0.2500E-02	0.2500E-02	0.1000E-01
12	THCS	0.0000	0.0000	0.0000	0.0000
13	THLC	0.0000	0.1571E 01	0.1571E 01	0.0000
14	THLS	0.0000	0.1571E 01	0.1571E 01	0.0000
15	SC11	0.2101E 08	0.1323E 08	0.1323E 08	0.2101E 08
16	SC12	0.7797E 06	0.8684E 06	0.8684E 06	0.7797E 06
17	SC13	0.7797E 06	0.8684E 06	0.8684E 06	0.7797E 06
18	SC22	0.1631E 07	0.2166E 07	0.2166E 07	0.1631E 07
19	SC23	0.8713E 06	0.9537E 06	0.9537E 06	0.8713E 06
20	SC33	0.1776E 07	0.2307E 07	0.2307E 07	0.1776E 07
21	SC44	0.3233E 06	0.4561E 06	0.4561E 06	0.3233E 06
22	SC55	0.5470E 06	0.7551E 06	0.7551E 06	0.5470E 06
23	SC66	0.5470E 06	0.7551E 06	0.7551E 06	0.5470E 06
24	CTE11	0.1410E-06	0.1603E-05	0.1603E-05	0.1410E-06
25	CTE22	0.2464E-04	0.1601E-04	0.1601E-04	0.2464E-04
26	CTE33	0.2464E-04	0.1601E-04	0.1601E-04	0.2464E-04
27	HK11	0.3195E 03	0.1352E 03	0.1352E 03	0.3195E 03
28	HK22	0.3702E 01	0.2305E 01	0.2305E 01	0.3702E 01
29	HK33	0.3702E 01	0.2305E 01	0.2305E 01	0.3702E 01
30	HCL	0.1991E 00	0.1943E 00	0.1943E 00	0.1991E 00
31	EL11	0.1726E 08	0.1144E 08	0.1144E 08	0.1726E 08
32	EL22	0.1127E 07	0.1696E 07	0.1696E 07	0.1127E 07
33	EL33	0.1127E 07	0.1696E 07	0.1696E 07	0.1127E 07
34	GL23	0.3233E 06	0.4561E 06	0.4561E 06	0.3233E 06
35	GL13	0.5470E 06	0.7551E 06	0.7551E 06	0.5470E 06
36	GL12	0.5470E 06	0.7551E 06	0.7551E 06	0.5470E 06
37	NUL12	0.2945E 00	0.2663E 00	0.2663E 00	0.2945E 00
38	NUL21	0.1922E-01	0.3947E-01	0.3947E-01	0.1922E-01
39	NUL13	0.2945E 00	0.2663E 00	0.2663E 00	0.2945E 00
40	NUL31	0.1922E-01	0.3947E-01	0.3947E-01	0.1922E-01
41	NUL23	0.4821E 00	0.3985E 00	0.3985E 00	0.4821E 00
42	NUL32	0.4821E 00	0.3985E 00	0.3985E 00	0.4821E 00
43	DPL1	0.8600E-04	0.8736E-04	0.8736E-04	0.8600E-04
44	DPL2	0.5168E-04	0.5117E-04	0.5117E-04	0.5168E-04
45	DPL3	0.5168E-04	0.5117E-04	0.5117E-04	0.5168E-04
46	BTAL1	0.4981E-04	0.9853E-04	0.9853E-04	0.4981E-04
47	BTAL2	0.1452E-02	0.8565E-03	0.8565E-03	0.1452E-02
48	BTAL3	0.1452E-02	0.1455E-02	0.1455E-02	0.1452E-02
49	ILMFC	0.0000	0.8405E 02	0.8916E 02	0.8405E 02
50	TEMPD	0.0000	0.0000	0.0000	0.0000
51	LSC11T	0.2228E 06	0.2168E 06	0.2168E 06	0.2228E 06
52	LSC11C	0.8764E 05	0.1665E 06	0.1665E 06	0.8764E 05
53	LSC11D	0.8764E 05	0.1665E 06	0.1665E 06	0.8764E 05
54	LSC22T	0.5006E 04	0.9915E 04	0.9915E 04	0.5006E 04
55	LSC22C	0.1502E 05	0.2314E 05	0.2314E 05	0.1502E 05
56	LSC12	0.5126E 04	0.1195E 05	0.1195E 05	0.5126E 04
57	LSC23	0.3983E 04	0.1019E 05	0.1019E 05	0.3983E 04
58	LSCC23	0.0000	0.6196E 05	0.1351E 06	0.4417E 05
59	LSCC13	0.0000	0.7303E 05	0.8147E 05	0.5230E 05
60	LSCDF	0.0000	0.4164E-03	0.3925E-03	0.4164E-03
61	KL12AB	0.9853E 00	0.9075E 00	0.9075E 00	0.9853E 00
62	MDEIE	0.9646E 00	0.7801E 00	0.7801E 00	0.9646E 00
63	RELROT	0.0000	0.1000E 01	0.1000E 01	0.1000E 01
64	EPS11	0.2751E-02	-0.2236E-03	-0.2236E-03	0.2751E-02
65	EPS22	-0.2236E-03	0.2751E-02	0.2751E-02	-0.2236E-03
66	EPS12	0.9946E-09	-0.8536E-08	-0.8536E-08	0.9946E-09
67	SIG11	0.4769E 05	-0.1329E 04	-0.1329E 04	0.4769E 05
68	SIG22	0.6647E 03	0.4614E 04	0.4614E 04	0.6647E 03
69	SIG12	0.5441E-03	-0.6445E-02	-0.6445E-02	0.5441E-03
70	DELFI	0.0000	-0.4765E-08	0.0000	0.4765E-08
71	HFC	0.1121E 01	0.6393E 00	0.6393E 00	0.1121E 01
72	MPCTGE	0.0000	0.0000	0.0000	0.0000
73	SIG13	0.0000	0.0000	0.0000	0.0000
74	SIG23	0.0000	0.0000	0.0000	0.0000
75	SIG33	0.0000	0.0000	0.0000	0.0000

S T R E S S   C O N C E N T R A T I O N   F A C T O R S
(AROUND A CIRCULAR HOLE)

NOTE: K1XX --> STRESS CONCENTRATION FACTOR DUE TO SIGMA XX
K1YY --> STRESS CONCENTRATION FACTOR DUE TO SIGMA YY
K1XY --> STRESS CONCENTRATION FACTOR DUE TO SIGMA XY
LAYUP --> 0 90 90 0

THETA	K1XX	K1YY	K1XY	THETA	K1XX	K1YY	K1XY
0.0	-0.6160	3.8562	0.0000	180.0	-0.6160	3.8562	0.0002
5.0	-0.5709	3.6729	-1.1975	185.0	-0.5709	3.6723	-1.1973
10.0	-0.4572	3.2155	-2.1209	190.0	-0.4572	3.2155	-2.1208
15.0	-0.3168	2.6650	-2.6886	195.0	-0.3168	2.6649	-2.6885
20.0	-0.1799	2.1516	-2.9777	200.0	-0.1799	2.1515	-2.9777
25.0	-0.0569	1.7253	-3.1020	205.0	-0.0570	1.7252	-3.1020
30.0	0.0532	1.3875	-3.1493	210.0	0.0532	1.3875	-3.1493
35.0	0.1566	1.1225	-3.1741	215.0	0.1566	1.1225	-3.1741
40.0	0.2613	0.9117	-3.2080	220.0	0.2613	0.9116	-3.2080
45.0	0.3764	0.7383	-3.2701	225.0	0.3764	0.7382	-3.2701
50.0	0.5138	0.5879	-3.3730	230.0	0.5137	0.5879	-3.3730
55.0	0.6898	0.4473	-3.5263	235.0	0.6898	0.4472	-3.5262
60.0	0.9302	0.3019	-3.7367	240.0	0.9301	0.3018	-3.7367
65.0	1.2764	0.1331	-4.0029	245.0	1.2763	0.1331	-4.0028
70.0	1.7980	-0.0864	-4.2958	250.0	1.7979	-0.0865	-4.2957
75.0	2.6025	-0.3968	-4.5006	255.0	2.6023	-0.3969	-4.5006
80.0	3.7983	-0.8378	-4.2743	260.0	3.7980	-0.8379	-4.2744
85.0	5.2236	-1.3548	-2.9009	265.0	5.2233	-1.3549	-2.9013
90.0	5.9765	-1.6233	-0.0001	270.0	5.9765	-1.6233	-0.0008
95.0	5.2287	-1.3549	2.9007	275.0	5.2290	-1.3550	2.9003
100.0	3.7984	-0.8379	4.2743	280.0	3.7987	-0.8380	4.2741
105.0	2.6026	-0.3969	4.5007	285.0	2.6028	-0.3970	4.5007
110.0	1.7980	-0.0865	4.2958	290.0	1.7982	-0.0865	4.2958
115.0	1.2764	0.1330	4.0029	295.0	1.2765	0.1330	4.0030
120.0	0.9302	0.3018	3.7367	300.0	0.9303	0.3018	3.7368
125.0	0.6899	0.4472	3.5263	305.0	0.6899	0.4472	3.5263
130.0	0.5138	0.5879	3.3730	310.0	0.5138	0.5878	3.3731
135.0	0.3764	0.7382	3.2702	315.0	0.3764	0.7382	3.2702
140.0	0.2613	0.9116	3.2081	320.0	0.2613	0.9116	3.2081
145.0	0.1567	1.1225	3.1741	325.0	0.1567	1.1224	3.1741
150.0	0.0532	1.3875	3.1493	330.0	0.0532	1.3874	3.1493
155.0	-0.0569	1.7252	3.1021	335.0	-0.0569	1.7251	3.1021
160.0	-0.1799	2.1515	2.9777	340.0	-0.1798	2.1514	2.9773
165.0	-0.3168	2.6648	2.6886	345.0	-0.3163	2.6647	2.6887
170.0	-0.4571	3.2155	2.1210	350.0	-0.4571	3.2153	2.1211
175.0	-0.5709	3.6728	1.1976	355.0	-0.5709	3.6728	1.1979

L A M I N A T E   F A I L U R E   L O A D   A N A L Y S I S

LAYUP --> 0 90 90 0

LAMINATE FAILURE LOADS BASED UPON FIRST PLY FAILURE CRITERIA (NO TEMPERATURE OR MOISTURE STRESSES)

PLY NO. = 1 THETA = 0.00 MATERIAL SYSTEM = AS--IMLS AS--IMLS

LOADS	SL11T	SL11C	SL22T	SL22C	SL12S	FAIL. LOAD	MODE
	222.7741	87.6392	5.0065	15.0194	5.1261		
	KSI	KSI	KSI	KSI	KSI	KSI	
SCXXT MIN (	155.699	-61.252	251.063	-753.188	0.000)	155.699	SL11T
SCXXC MIN (	-155.699	61.252	-251.063	753.188	0.000)	61.252	SL11C
SCYYT MIN (	-5076.305	1997.015	20.504	-61.511	0.000)	20.504	SL22T
SCYYC MIN (	5076.305	-1997.015	-20.504	61.511	0.000)	61.511	SL22C
SCXYS MIN (	0.000	0.000	**********	**********	5.776)	5.776	SL12S

LAMINATE FAILURE LOADS BASED UPON FIRST PLY FAILURE CRITERIA (NO TEMPERATURE OR MOISTURE STRESSES)

PLY NO. = 2 THETA = 90.00 MATERIAL SYSTEM = SGLAHMHS AS--IMHS

LOADS	SL11T	SL11C	SL22T	SL22C	SL12S	FAIL. LOAD	MODE
	216.8321	166.5112	9.9151	23.1353	11.9513		
	KSI	KSI	KSI	KSI	KSI	KSI	
SCXXT MIN (	-5436.801	4175.063	71.638	-167.155	0.000)	71.638	SL22T
SCXXC MIN (	5436.801	-4175.063	-71.638	167.155	0.000)	167.155	SL22C
SCYYT MIN (	86.330	-66.295	112.967	-263.589	**********)	86.330	SL11T
SCYYC MIN (	-86.330	66.295	-112.967	263.589	**********)	66.295	SL11C
SCXYS MIN (	**********	**********	**********	**********	9.756)	9.756	SL12S

LAMINATE FAILURE LOADS BASED UPON FIRST PLY FAILURE CRITERIA (NO TEMPERATURE OR MOISTURE STRESSES)

PLY NO. = 3 THETA = 90.00 MATERIAL SYSTEM = SGLAHMHS AS--IMHS

LOADS	SL11T	SL11C	SL22T	SL22C	SL12S	FAIL. LOAD	MODE
	216.8321	166.5112	9.9151	23.1353	11.9513		
	KSI	KSI	KSI	KSI	KSI	KSI	
SCXXT MIN (	-5436.801	4175.063	71.638	-167.155	0.000)	71.638	SL22T
SCXXC MIN (	5436.801	-4175.063	-71.638	167.155	0.000)	167.155	SL22C
SCYYT MIN (	86.330	-66.295	112.967	-263.589	**********)	86.330	SL11T
SCYYC MIN (	-86.330	66.295	-112.967	263.589	**********)	66.295	SL11C
SCXYS MIN (	**********	**********	**********	**********	9.756)	9.756	SL12S

LAYUP --> 0 90 90 0

LAMINATE FAILURE LOADS BASED UPON FIRST PLY FAILURE CRITERIA (NO TEMPERATURE OR MOISTURE STRESSES)

PLY NO. = 4 THETA = 0.00 MATERIAL SYSTEM = AS--IMLS AS--IMLS

LOADS	SL11T	SL11C	SL22T	SL22C	SL12S	FAIL. LOAD	MODE
	222.7741	87.6392	5.0065	15.0194	5.1261		
	KSI	KSI	KSI	KSI	KSI	KSI	
SCXXT MIN (	155.699	-61.252	251.062	-753.187	0.000)	155.699	SL11T
SCXXC MIN (	-155.699	61.252	-251.062	753.187	0.000)	61.252	SL11C
SCYYT MIN (	-5076.309	1997.017	20.504	-61.511	0.000)	20.504	SL22T
SCYYC MIN (	5076.309	-1997.017	-20.504	61.511	0.000)	61.511	SL22C
SCXYS MIN (	0.000	0.000	**********	**********	5.776)	5.776	SL12S

S U M M A R Y

LAMINATE FAILURE LOAD ANALYSIS - (NO TEMPERATURE OR MOISTURE STRESSES)
(BASED UPON FIRST PLY FAILURE)

LOAD TYPE	LOAD IN KSI	FAILURE MODE	PLY NO.	THETA	MATERIAL SYSTEM
SCXXT	71.638	SL22T	3	90.0	SGLAHMHS AS--IMHS
SCXXC	61.252	SL11C	4	0.0	AS--IMLS AS--IMLS
SCYYT	20.504	SL22T	1	0.0	AS--IMLS AS--IMLS
SCYYC	61.511	SL22C	1	0.0	AS--IMLS AS--IMLS
SCXYS	5.776	SL12S	4	0.0	AS--IMLS AS--IMLS

LAMINATE FAILURE LOAD ANALYSIS - (NO TEMPERATURE OR MOISTURE STRESSES)
(BASED UPON FIBER FAILURE)

LOAD TYPE	LOAD IN KSI	FAILURE MODE	PLY NO.	THETA	MATERIAL SYSTEM
SCXXT	155.699	SL11T	4	0.0	AS--IMLS AS--IMLS
SCXXC	61.252	SL11C	4	0.0	AS--IMLS AS--IMLS
SCYYT	86.330	SL11T	2	90.0	SGLAHMHS AS--IMHS
SCYYC	66.295	SL11C	2	90.0	SGLAHMHS AS--IMHS
SCXYS	*********	N/A			

NOTE: IF THERE IS NO ANGLE PLY "SCXYS" BASED UPON FIBRE FAILURE IS NOT PREDICTED.

```
T300  GRAPHITE FIBER.
FP   3000 0.300E-03 0.640E-01
FE  0.320E 08 0.200E 07 0.200E 00 0.250E 00 0.130E 07 0.700E 06
FT -0.550E-06 0.560E-05 0.580E 03 0.580E 02 0.170E 00
FS  0.350E 06 0.300E 06     0.000     0.000     0.000     0.000
AS--  GRAPHITE FIBER.
FP  10000 0.300E-03 0.630E-01
FE  0.310E 08 0.200E 07 0.200E 00 0.250E 00 0.200E 07 0.100E 07
FT -0.550E-06 0.560E-05 0.580E 03 0.580E 02 0.170E 00
FS  0.400E 06 0.400E 06     0.000     0.000     0.000     0.000
SGLA   S- GLASS FIBER.
FP    204 0.360E-03 0.900E-01
FE  0.124E 08 0.124E 08 0.200E 00 0.200E 00 0.517E 07 0.517E 07
FT  0.280E-05 0.280E-05 0.750E 01 0.750E 01 0.170E 00
FS  0.360E 06 0.300E 06 0.360E 06 0.300E 06 0.180E 06 0.180E 06
HMSF  HIGH MODULUS SURFACE TREATED FIBER.
FP  10000 0.300E-03 0.703E-01
FE  0.550E 08 0.900E 06 0.200E 00 0.250E 00 0.110E 07 0.700E 06
FT -0.550E-06 0.560E-05 0.580E 03 0.580E 02 0.170E 00
FS  0.280E 06 0.200E 06     0.000     0.000     0.000     0.000
OVER   END OF FIBER PROPERTIES.
HMHS  HIGH MODULUS HIGH STRENGTH MATRIX.
MP  0.450E-01
ME  0.750E 06 0.350E 00 0.400E-04
MT  0.125E 01 0.250E 00
MS  0.200E 05 0.500E 05 0.150E 05 0.200E-01 0.500E-01
0.400E-01 0.400E-01
MV  0.225E 00 0.420E 03
IMHS  INTERMEDIATE MODULUS HIGH STRENGTH MATRIX.
MP  0.440E-01
ME  0.500E 06 0.350E 00 0.360E-04
MT  0.125E 01 0.250E 00
MS  0.150E 05 0.350E 05 0.130E 05 0.200E-01 0.500E-01
0.350E-01 0.350E-01
MV  0.225E 00 0.420E 03
IMLS  INTERMEDIATE MODULUS LOW STRENGTH MATRIX.
MP  0.460E-01
ME  0.500E 06 0.410E 00 0.570E-04
MT  0.125E 01 0.250E 00
MS  0.700E 04 0.210E 05 0.700E 04 0.140E-01 0.420E-01
0.320E-01 0.320E-01
MV  0.225E 00 0.420E 03
OVER   END OF MATRIX PROPERTIES.
```

REFERENCES

1. Chamis, C. C., "Design Oriented Analysis and Synthesis of Multilayered-Filamentary Structural Panels," Ph.D. Thesis, Case Western Reserve University, Cleveland, Ohio, 1967.

2. Chamis, C. C., "Computer Code for the Analysis of Multilayered Fiber Composites - User's Manual," NASA TN D-7013, 1971.

3. Chamis, C. C. and Sinclair, J. H., "Prediction of Properties of Intraply Hybrid Composites," NASA TM-79087, 1979.

4. Chamis, C. C. and Sinclair, J. H., "Micromechanics of Intraply Hybrid Composite: Elastic and Thermal Properties," NASA TM-79253, 1979.

5. Chamis, C. C., Lark, R. F. and Sinclair, J. H., "Mechanical Property Characterization of Intraply Hybrid Composites," NASA TM-79306, 1979.

6. Chamis, C. C., Lark, R. F. and Sinclair, J. H., "An Integrated Theory for Predicting the Hydrothermomechanical Response of Advanced Composite Structural Components," NASA TM-73812, 1977.

7. Chamis, C. C. and Sinclair, J. H., "INHYD: Computer Code for Intraply Hybrid Composite Design," NASA TP-2239, 1983.

8. Murthy, P. L. N. and Chamis, C. C., "ICAN: Integrated Composite Analyzer Users and Programmers Manual. NASA TP in preparation, 1984.

9. Pagano, N. J. and Pipes, R. B., "Some Observations on the Interlaminar Strength of Composite Laminates," International Journal of Mechanical Sciences, Vol. 15, No. 8, 1973, pp. 679-688.

10. Lekhnitskii, S. G. and Brandstatter, J. J., eds., Theory of Elasticity of an Anisotropic Elastic Body, Holden-Day, San Francisco, 1963.

11. Chamis, C. C. and Smith, G. T., "CODSTRAN: Composite Durability Structural Analysis," NASA TM-79070, 1978.

12. Chamis, C. C. and Minich, M. D., "Structural Response of a Fiber Composite Compressor Fan Blade Airfoil," NASA TM X-71623, 1975.

13. Chamis, C. C. and Sinclair, J. H., "Analysis of High Velocity Impact on Hybrid Composite Fan Blades," NASA TM-79133, 1979.

TABLE I. - ICAN: SAMPLE INPUT DATA

```
Four ply symmetric laminate.  ICAN sample input data.

STDA     4      1      2
T
F
F
F
T
PLY      1      1      70.00      70.0      0.0      0.0      0.010
PLY      2      2      70.00      70.0       .0     90.0       .005
PLY      3      2      70.00      70.0       .0     90.0       .005
PLY      4      1      70.00      70.0       .0     90.0       .010

MATCRDAS--IMLS      0.55      0.02      AS--IMLS      0.0      0.57      0.03
MATCRDSGLAHMHS      0.55       .01      AS--IMHS       .4       .57       .01
PLOAD 1000.         0.0       0.0       0.0
PLOAD 0.0           0.0       0.0
PLOAD 0.0           0.0
```

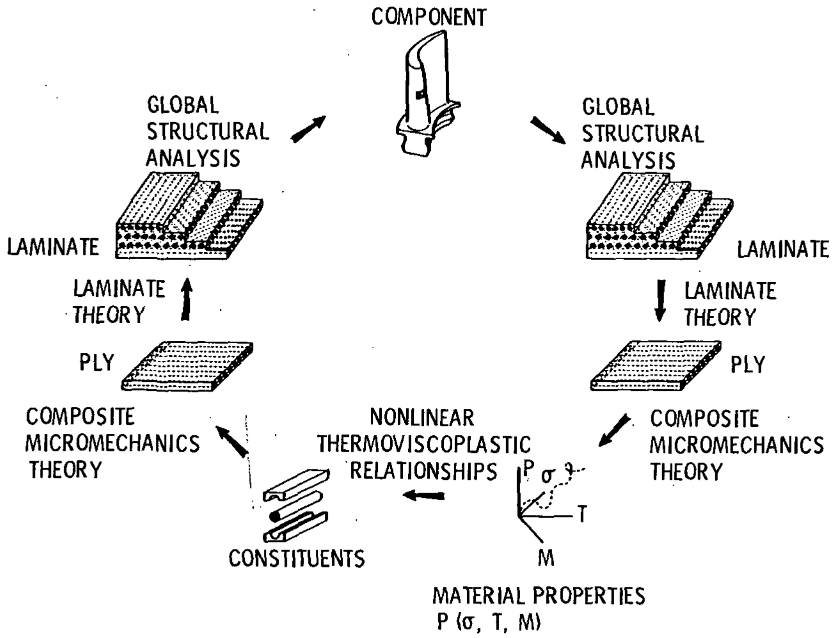

Figure 1. - Upward integrated and top-down traced structured theory.

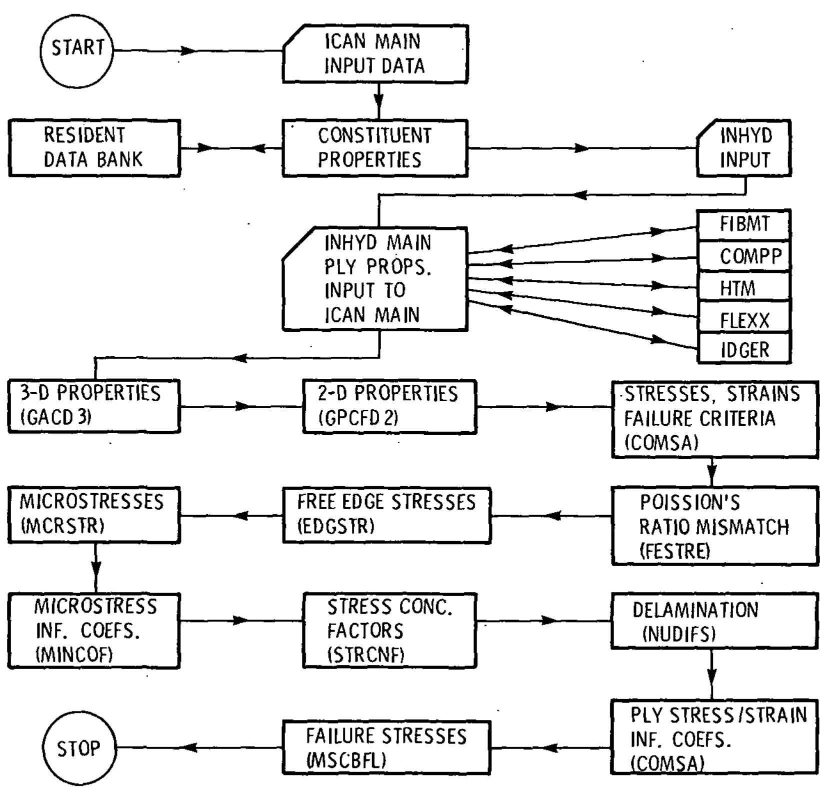

Figure 2. - ICAN: flow chart.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-83700		
4. Title and Subtitle ICAN: INTEGRATED COMPOSITES ANALYZER		5. Report Date
		6. Performing Organization Code 505-33-5B
7. Author(s) P. L. N. Murthy and C. C. Chamis		8. Performing Organization Report No. E-2158
		10. Work Unit No.
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

P. L. N. Murthy, NRC-NASA Research Associate. Prepared for the Twenty-fifth Structures, Structural Dynamics and Materials Conference cosponsored by the AIAA, ASME, ASCE, and AHS, Palm Springs, California, May 14-16, 1984.

16. Abstract

A computer code ICAN (Integrated Composites ANalyzer), has been developed to analyze/design fiber composite structures. The program includes composite mechanics theories which resulted from extensive research that has been conducted over the past fifteen years at NASA Lewis Research Center. These theories account for environmental effects and are applicable to intraply hybrid composites, interply hybrid composites and combinations of these, as well as conventional laminate analysis. Key features and capabilities of ICAN are described. A sample input data set and selected output are provided to illustrate its generality/versatility and user-friendly structure.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Composite mechanics; Micromechanics; Macromechanics; Structural analysis; Stress concentration factor; Free edge stresses; Hygrothermomechanical response; Influence coefficients; Laminate analysis; Microstresses; Hygrothermal degradation; Delamination; Failure criteria; Enviromental effects; Intraply hybrid composites; Interply hybrid composites; Mechanical properties; Thermal properties; Hygral properties; Data base	Unclassified - unlimited STAR Category 24

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22161

National Aeronautics and
Space Administration

Washington, D.C.
20546

Official Business
Penalty for Private Use, $300

SPECIAL FOURTH CLASS MAIL
BOOK

U.S. MAIL

Postage and Fees Paid
National Aeronautics and
Space Administration
NASA-451

NASA

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return