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FEATURES AND APPLICATIONS OF THE INTEGRATED COMPOSITES ANALYZER (ICAN) CODE

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ABSTRACT

ICAN (Integrated Composites Analyzer), a stand-alone computer code, was developed to analyze and design multilayered fiber composite structures using micromechanics equations and laminate theory (Murthy and Chamis, 1984). Input parameters of this user-friendly program include material system, fiber volume ratio, laminate configuration, fabrication factors, and environmental conditions. Output features include practically all composite hygral, thermal, and mechanical properties that are needed to perform structural/stress analyses in service environments. As such, ICAN is an effective tool for the preliminary design of composite structures (Ginty and Endres, 1986). In addition, ICAN has a resident data bank which houses the properties of a variety of constituent (fiber and matrix) materials with provisions to add new constituent materials as they become available. The objective herein is to discuss the input and output parameters of the ICAN code as well as to describe procedures for both the implementation of new data in the data bank and modeling techniques which enable ICAN to analyze composite woven fabric/cloth structures (Ginty and Chamis, 1986). Finally, new features recently incorporated in the code which yield life predictions and analyses based on cyclic temperatures (Ginty and Chamis, 1988) will be presented.

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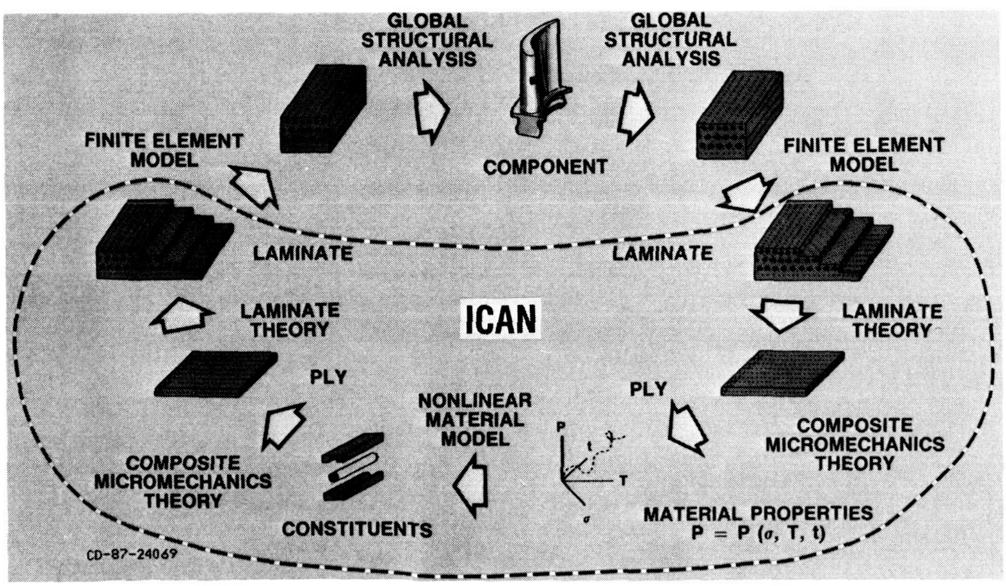
OVERVIEW

THEORIES EMBODIED IN ICAN CODE

The most cost effective way to analyze or design fiber composite structures is through the use of computer codes. Over the past 15 years, extensive research has been conducted at NASA Lewis 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 thereof. Most of these theories are presented 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 structures 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. This structured theory has been incorporated into a computer code called ICAN (integrated composites analyzer). ICAN is a synergistic combination of two other Lewis developed codes: MFCA (multilayered fiber composites analysis) and INHYD (intraply hybrid composite design).

MFCA (Chamis, 1971) is efficient in predicting the structural response of multilayered fiber composites given the constituent material properties, fabrication process, and composite geometry. INHYD (Chamis and Sinclair, 1983) incorporates several composite micromechanics theories, intraply hybrid composite theories, and a hygrothermomechanical theory to predict the mechanical, thermal and hygral properties of intraply hybrid composites. ICAN uses the micromechanics design of INHYD and the laminate theory of MFCA to build a comprehensive analysis and design capability for structural composites. Features unique to ICAN include microstresses, predictions of probable delamination locations around a circular hole, material cards for finite element analysis for NASTRAN (COSMIC and MSC) and MARC, and laminate failure stresses based on first ply failure and fiber fracture criteria, with and without hygrothermal degradation. In addition, ICAN possesses another unique feature in its resident data bank which houses the constituent (fiber/matrix) properties.



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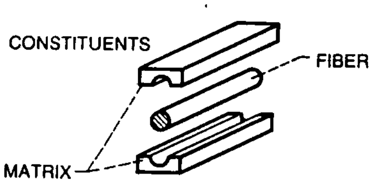
POSTER PRESENTATION

ICAN UNIQUE FEATURE - RESIDENT DATA BANK

One of the unique features of ICAN is its resident data bank which houses the constituent (fiber and matrix) properties. Its primary function is in reducing the burden on the user in preparing properly formatted data for the program. The simplified equations which determine the composite properties require that the user supply 16 fiber properties and 15 matrix properties. Years of literature searches and in-house experimental programs on materials characterization have resulted in the compilation of the existing data bank.

The fiber and matrix are identified with a four-character coded name. Following the fiber entry are four material cards, FP, FE, FT, and FS, representing the fiber's (F), physical, elastic, thermal, and strength properties (P, E, T, and S, respectively). Likewise, the matrix entry is followed by five material cards, MP, ME, MT, MS, and MV, where the matrix (M) properties are represented, as described above, with one additional card (MV), which contains various (V) properties of the matrix. The data bank is designed to be open-ended, allowing the user the ability to add new constituent materials as they appear on the market. In light of the proprietary nature of many new material systems, it is often difficult to obtain constituent properties from the suppliers. As a result, the user may have to resort to approximating these unknown values.



CARD	ICAN FIBER ENTRY
1	FOUR CHARACTER CODED NAME FOR FIBER
2	FP; N_f, d_f, ρ_f
3	FE; E_{f11}, E_{f22}, γ_{f12}, γ_{f23}, G_{f12}, G_{f23}
4	FT; α_{f11}, α_{f22}, K_{f11}, K_{f22}, C_f
5	FS; S_{fT}, S_{fC} (THE REMAINING ENTRIES ARE OPEN FOR FUTURE MODIFICATIONS.)

CARD	ICAN MATRIX ENTRY
1	FOUR CHARACTER CODED NAME FOR MATRIX
2	MP; ρ_m
3	ME; E_m, ν_m, α_m
4	MT; K_m, C_m
5	MS; S_{mT},S_{mC}, S_{mS}, ϵ_{mT}, ϵ_{mC}, ϵ_{mS}, ϵ_{mTOR}
6	MV; K_ν, T_{gdr}

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PORTION OF EXISTING DATA BANK

```
T300
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--
FP   1000  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
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    0.350E 06 0.300E 06  0.000     0.000     0.000     0.000

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.

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

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

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

OVER    END OF MATRIX PROPERITES.
```

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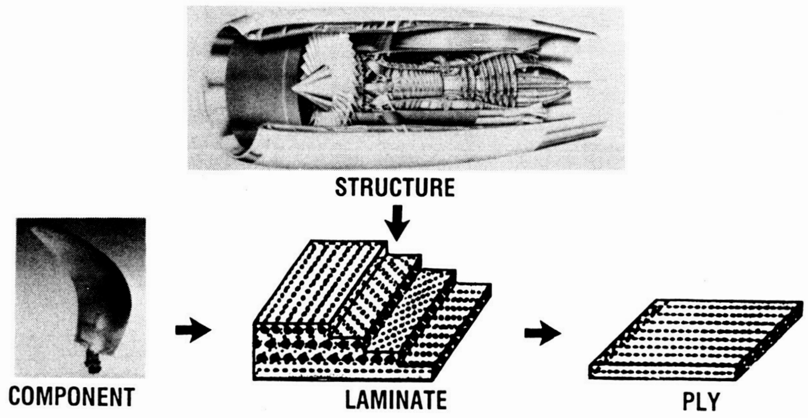
ICAN SIMULATION OF COMPOSITE STRUCTURES

ICAN has always been labeled user-friendly. The primary reason being the straightforward format used for data entry. Herein, the item referred to as a data set is actually the simulation of the composite structure to be analyzed. In order to accurately simulate a structure for analysis, the user must provide the following information: material system, fiber volume ratio, laminate configuration, fabrication factors, environmental conditions, and loading states. To demonstrate, an engine blade with a configuration of $[0/90]_s$ has been chosen for simulation.



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The first line of the data set is reserved for user comments. The next five cards constitute the Booleans, which are discussed in detail in Murthy and Chamis (1984). Now the actual simulation begins as the structure is modeled ply-by-ply. The columns from left to right contain the following information: ply 1 is made from material 1. The analysis is to be conducted at room temperature (70 °F). The cure temperature for the resin is 350 °F. The ply contains 1.8 percent moisture by weight. The fibers in this ply are aligned in the longitudinal (0) direction, and the ply is 0.010 in. thick. The remaining lines are completed in the same fashion. Next, the composite material system must be identified. Here, material 1 is an AS-- fiber (graphite) and IMLS matrix (epoxy resin). The fiber volume ratio is 0.55, and the void volume ratio is 0.02. As was previously mentioned, ICAN analyzes hybrid structures as well. Material 2 in this example is a hybrid consisting of the SGLA fiber and HMHS resin and the AS -- fiber and IMHS resin. In this line the 0.4 indicates that in this particular ply, 40 percent of the material is AS--/IMHS, leaving the remaining 60 percent to be fabricated from SGLA/HMHS, each with its own specified volume ratio. Finally, an axial load of 1000 lb is being applied in the longitudinal direction. Thus, a very complex structure is simulated with ease using this format.

ICAN INPUT DATA SET FOR COMPOSITE BLADE

```
     T                                                   COMSAT
     F                                                   CSANB
     F                                                   BIDE
     F                                                   RINDV
     T                                                   NONUDF
     PLY          1            1  70.00  350.0       1.8        0.0   .010
     PLY          2            2  70.00  350.0       1.8       90.0   .005
     PLY          3            2  70.00  350.0       1.8       90.0   .005
     PLY          4            1  70.00  350.0       1.8        0.0   .010
1MATCRDAS--IMLS      .55         .02    AS--IMLS  0.0      .57      .03
2MATCRDSGLAHMHS      .55         .01    AS--IMHS  0.4      .57      .01
   PLOAD 1000.       0.0         0.0      0.0            NX,NY,NXY,THCS
   PLOAD  0.0        0.0         0.0                     MX,MY,MXY
   PLOAD  0.0        0.0                                 MX/QX,DMY/QY,PRSS
 OPTION       0
```

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ICAN OUTPUT OPTIONS

Another user-friendly feature of the ICAN code is the compartmentalization of output and the user's ability to retrieve only the information that pertains to his/her analysis. This facet of the program is controlled by the last line of input in the data set which is referred to as the option card. For discussion purposes, the output is contained in 20 categories that range from the ICAN logo to a detailed table which lists the stress concentration factors around a circular hole. In actuality, the features in options 1 to 5 are always printed automatically as output. The remaining 15 features are controlled by the option card. Entering a zero will cause all 20 of the features to be printed. If only two or three features are desired, then the user must add a separate option card for each feature at the end of the data set.

The most frequently used options are shown below. Because of the neat arrangement of the data for finite element analysis in option 10, many users employ ICAN as a preprocessor for more complex structural analyses codes such as NASTRAN and MARC. The data in option 10 is read directly as a material (MAT) card into the other codes. For in-house experimental programs, ICAN is often used to simulate the composite specimen and testing environment. The data in option 20 yield a fracture stress that is then used to aid researchers in developing their test plans. Finally, the table of composite properties in option 7 enables researchers to understand the behavior of certain composite materials, particularly when little information has been published in the literature.

SUMMARY

ICAN OPTION	ICAN OUTPUT FEATURE
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 COMPOSITE MATERIAL SYSTEM
16	STRESS CONCENTRATION 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

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OPTION 7

COMPOSITE PROPERTIES - VALID ONLY FOR CONSTANT TEMPERATURE THROUGH THICKNESS
LINES 1 TO 31 3-D COMPOSITE PROPERTIES ABOUT MATERIAL AXES
LINES 33 TO 62 2-D COMPOSITE PROPERTIES ABOUT STRUCTURAL AXES

1	RHOC	0.5552E-01	32	B2DEC	0.0000
2	TC	0.2000E-01	33	CC11	0.1888E 08
3	CC11	0.2148E 08	34	CC12	0.3116E 06
4	CC12	0.6147E 06	35	CC13	0.0000
5	CC13	0.6147E 06	36	CC22	0.1198E 07
6	CC22	0.1549E 07	37	CC23	0.0000
7	CC23	0.7103E 06	38	CC33	0.6233E 06
8	CC33	0.1654E 07	39	EC11	0.1880E 08
9	CC44	0.3623E 06	40	EC22	0.1193E 07
10	CC55	0.6233E 06	41	EC12	0.6233E 06
11	CC66	0.6233E 06	42	NUC12	0.2600E 00
12	CTE11	-0.8883E-07	43	NUC21	0.1650E-01
13	CTE22	0.1733E-04	44	CSN13	0.0000
14	CTE33	0.1733E-04	45	CSN31	0.0000
15	HK11	0.3485E 03	46	CSN23	0.0000
16	HK22	0.4281E 01	47	CSN32	0.0000
17	HK33	0.4281E 01	48	CTE11	-0.8883E-07
18	HHC	0.1955E 00	49	CTE22	0.1733E-04
19	EC11	0.2115E 08	50	CTE12	0.0000
20	EC22	0.1238E 07	51	HK11	0.3485E 03
21	EC33	0.1323E 07	52	HK22	0.4281E 01
22	EC23	0.3623E 06	53	HK12	0.0000
23	EC31	0.6233E 06	54	HHC	0.1955E 00
24	EC12	0.6233E 06	55	DPC11	0.8160E-04
25	NUC12	0.2820E 00	56	DPC22	0.9196E-02
26	NUC21	0.1650E-01	57	DPC33	0.2263E 05
27	NUC13	0.2506E 00	58	DPC12	0.0000
28	NUC31	0.1567E-01	59	BTAC11	0.4255E-04
29	NUC23	0.4234E 00	60	BTAC22	0.1214E-02
30	NUC32	0.4525E 00	61	BTAC33	0.1214E-02
31	ZCOC	0.1000E-01	62	BTAC12	0.0000

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OPTION 10

SOME USEFUL DATA FOR F.E. ANLYSIS

COMPOSITE THICKNESS FOR F.E. ANALYSIS = 0.20000E-01 .

PROPERTIES FOR F.E. ANALYSIS E11,E12,E13,E23,E33 PROPERTIES SCALED BY 10**-6
0.21240E 00 -0.29921E 00 0.00000 0.94600E 00 0.00000 0.34877E 00

BENDING EQUIVALENT PROPERTIES NUCXY, NCYX, ECXX, ECYY, GCXY
0.14080E 01 0.31629E 00 0.47058E 07 0.10571E 07 0.28672E 07

NASTRAN MEMBRANE EQUIVALENT ELASTIC COEFFICIENTS G11,G12,G13,G22,G23,G33
0.84841E 07 0.26834E 07 0.00000 0.19158E 07 0.00000 0.28672E 07

NASTRAN BENDING EQUIVALENT ELASTIC COEFFICIENTS G11,G12,G13,G22,G23,G33
0.84841E 07 0.26834E 07 -0.14305E 01 0.19058E 07 0.17881E 00 0.28672E 07

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OPTION 20

SUMMARY

LAMINATE FAILURE STRESS ANALYSIS -(WITH TEMPERATURE/MOISTURE STRESSES)
(BASED UPON FIRST PLY FAILURE)

(Moisture Content by weight 1.0%)
(Uniform Temperature 200.0F)

LOAD TYPE	STRESS (ksi)	FAILURE MODE	PLY NO.	THETA	MATERIAL	SYSTEM
SCXXT	18.002	SL22C	4	-30.0	AS--IMHS	SGLAHMHS
SCXXC	25.367	SL22T	4	-30.0	AS--IMHS	SGLAHMHS
SCYYT	8.695	SL12S	1	30.0	AS--IMHS	SGLAHMHS
SCYYC	8.695	SL12S	1	30.0	AS--IMHS	SGLAHMHS
SCXYS	22.638	SL22C	4	-30.0	AS--IMHS	SGLAHMHS

LAMINATE FAILURE STRESS ANALYSIS -(WITH TEMPERATURE/MOISTURE STRESSES)
(BASED UPON FIBER FAILURE)

(Moisture Content by weight 1.0%)
(Uniform Temperature 200.0F)

LOAD TYPE	STRESS (ksi)	FAILURE MODE	PLY NO.	THETA	MATERIAL	SYSTEM
SCXXT	100.918	SL11T	1	30.0	AS--IMHS	SGLAHMHS
SCXXC	55.721	SL11C	1	30.0	AS--IMHS	SGLAHMHS
SCYYT	385.355	SL11T	1	30.0	AS--IMHS	SGLAHMHS
SCYYC	212.773	SL11C	1	30.0	AS--IMHS	SGLAHMHS
SCXYS	28.460	SL11C	4	-30.0	AS--IMHS	SGLAHMHS

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

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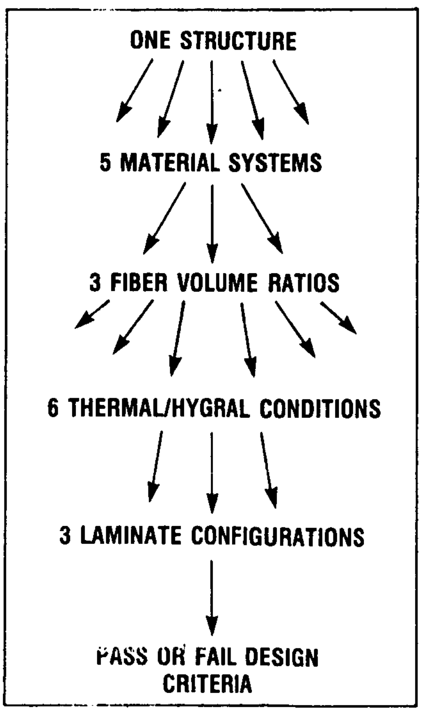
THE POWER OF ICAN IN PARAMETRIC ANALYSES

When considering composites for critical component structures, designers often have difficulty in selecting a material system since handbooks simply do not exist. In addition, composite properties, which they require for detailed structural analysis, are difficult to acquire. One alternative is an experimental characterization program whereby behavior would be monitored and properties would be determined. This route, unfortunately, has a long start up time, is quite costly, and requires a great deal of time for completion. There is an alternative, and that is the use of the ICAN code to conduct the parametric analysis. This will be demonstrated by an example of an in-house program in which ICAN was used effectively.

A communication satellite was to be designed using thin face sheets with a honeycomb interior. The designers had five material system candidates for the faces but were uncertain as to which would be the most suitable for the harsh space environment. They established a design criteria of zero, or negative coefficient of thermal expansion (CTE) of the composite. An experimental test matrix, accounting for all parameters, would require at the minimum, 270 specimens. ICAN was used to model the face sheets with various materials, fiber volume ratios, environmental conditions and laminate configurations. On completion, the predicted composite CTE was compared with the design criteria. In 6 months time and 300 cases later, a design was proposed based on the ICAN parametric studies and results. The contractor proposed the same design 1½ years later based on limited experimental data. Hence, ICAN can be used effectively as a preliminary design tool saving time and money in a project.



ISSUES: —TIMLINESS
—COST-EFFECTIVENESS

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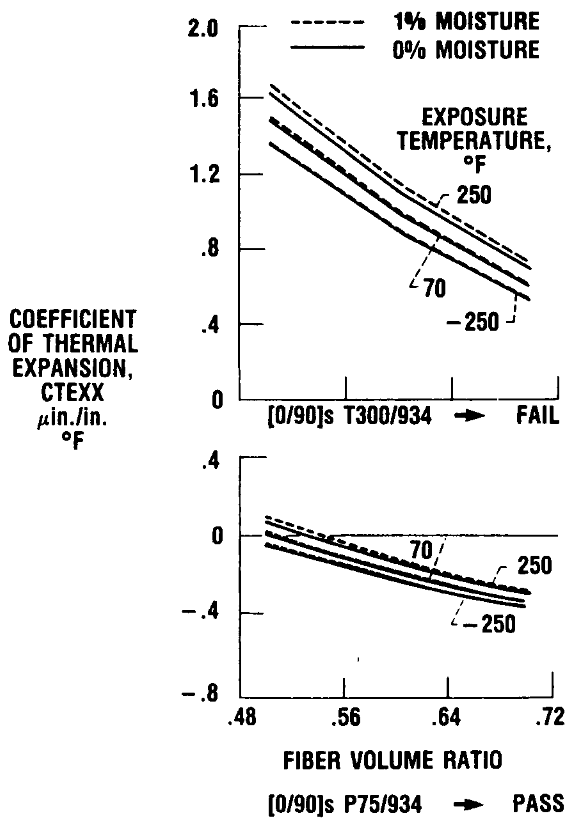

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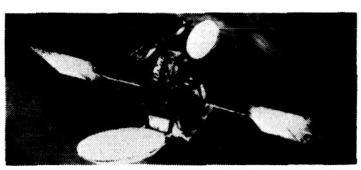
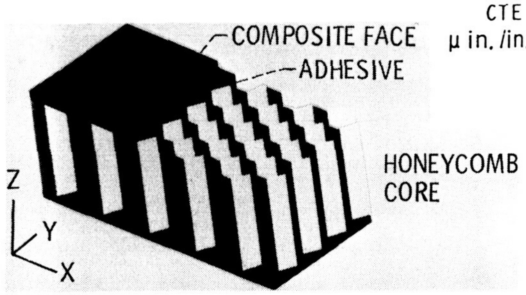
ICAN SANDWICH COMPUTATIONAL SIMULATION (SCS)

Due in part to ICAN's success with the parametric analysis of the composite face sheets, another version of the code was created for the analysis of the entire sandwich structure, which includes composite face sheets, adhesive, and a honeycomb core. The sandwich structure represents one of the antenna on the Lewis Advanced Communication and Technology Satellite (ACTS), which is scheduled for launch in 1990.

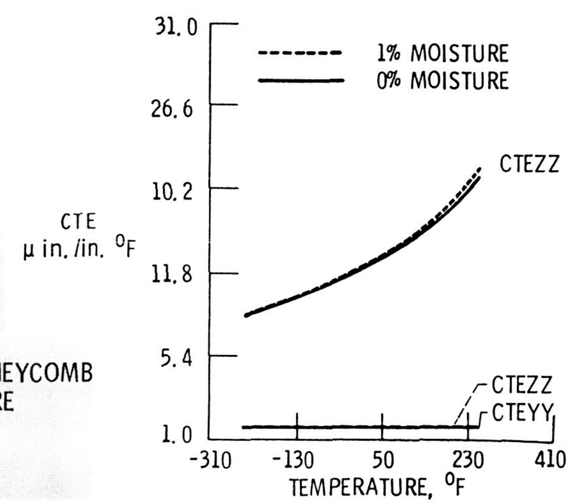
The evolution of ICAN to ICAN/SCS was an arduous procedure requiring four steps: (1) three-dimensional finite element modeling of the entire sandwich, (2) three-dimensional finite element modeling of the sandwich assuming an equivalent homogeneous medium for a core, (3) laminate theory simulation of the honeycomb assumed to be constructed of plies with equivalent properties, and (4) approximate simplified equations for simulating the honeycomb thermal and mechanical properties with an equivalent homogeneous medium. With this version of ICAN, a parametric study was conducted on the sandwich structure, concentrating on the compatibility of CTE's of the various components. Once again, a suitable design was proposed based on ICAN/SCS results.



ACTS (ADVANCED COMMUNICATION TECHNOLOGY SATELLITE)



COMPUTER-GENERATED MODEL OF THE STRUCTURE USED FOR THE ANALYSIS



P75/1934-(0/90)S/ALUMINUM HONEYCOMB (1/4 in. CELL)

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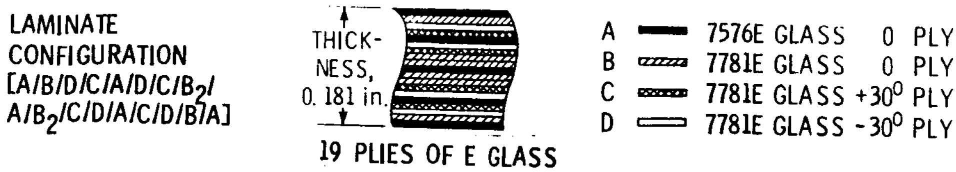
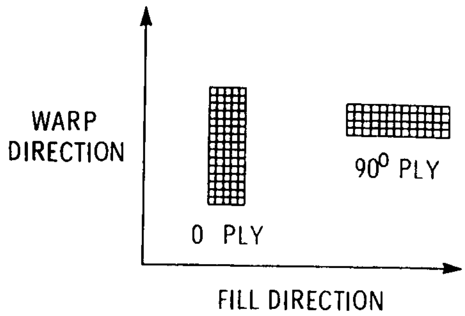
ICAN SIMULATION OF CLOTH/WOVEN FABRIC COMPOSITES

ICAN was designed to analyze aligned continuous-fiber ply composites. However, the applications of woven fabric (cloth) composite prepregs are increasing for aerospace structural parts; therefore, a technique was developed to simulate woven fabric using the existing parameters in the input data set. The technique involves manipulation of the plies and fiber volume ratios. Each cloth ply is modeled as two plies in ICAN. One ply is oriented in the 0, or warp direction of the cloth, and the second ply is oriented in the 90°, or fill direction of the cloth. Equations have been generated that allow the cloth thickness t and fiber volume ratio (FVR) to be accurately simulated using this technique. The thickness t of each ICAN ply is equal to a percentage of the total cloth ply thickness as shown in the equations. The thickness of these two ICAN plies equals the thickness of one cloth ply. Likewise, the FVR is altered in a similar manner. Two material systems corresponding to the 0 and 90° plies are used in ICAN to model the cloth. Each ICAN material system has a different FVR which is a percentage of the given cloth FVR, as shown by the equations. Although this procedure appears cumbersome, it is, in fact, quite easy to implement.

To demonstrate, ICAN was used to simulate various structures fabricated from an E-glass cloth. A comparison experimental program existed enabling us to validate this technique by comparing the predicted results with the measured data. For discussion purposes the most complex laminate in the study is chosen and labeled the representative laminate since it was fabricated from two other glass cloths: 7576 and 7781. The representative laminate consisted of 19 plies in the configuration $[A/B/D/C/A/D/C/B_2/A/B_2/C/D/A/C/D/B/A]$ where A = 7576 at 0 ply, B = 7781 at 0 ply, C = 7781 at +30° ply and D = 7781 at -30° ply. Total thickness for the representative laminate was 0.181 in. The laminates were cured at 340 °F and the specimens were tested at -300 °F and 200 °F.

The ICAN results for longitudinal elastic modulus compare well with the experimental data in all thermal regimes. Thus, another modeling technique enables ICAN to serve as a preliminary design tool for cloth/woven fabric structures.





$$FVR_{0\ ply} = FVR_{cloth}\left(\frac{\text{FIBERS IN WARP DIRECTION}}{\text{LARGEST AMOUNT OF FIBERS IN ANY DIRECTION}}\right)$$

$$FVR_{90^{0}\ ply} = FVR_{cloth}\left(\frac{\text{FIBERS IN FILL DIRECTION}}{\text{LARGEST AMOUNT OF FIBERS IN ANY DIRECTION}}\right)$$

$$t_{0\ ply} = t_{cloth\ ply} \times \left(\frac{\text{FIBERS IN WARP DIRECTION}}{\text{TOTAL FIBERS IN CLOTH PLY}}\right)$$

$$t_{90^{0}\ ply} = t_{cloth\ ply} \times \left(\frac{\text{FIBERS IN FILL DIRECTION}}{\text{TOTAL FIBERS IN CLOTH PLY}}\right)$$

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COMPARISON OF RESULTS

LAMINATE MATERIAL	EXPERIMENTAL			ICAN PREDICTIONS		
	-300 °F	70 °F	200 °F	-300 °F	70 °F	200 °F
	LONGITUDINAL ELASTIC MODULUS, ksi					
7781E-GLASS CLOTH	4600	4370	3970	4589	4251	4076
7576E-GLASS CLOTH	6540	6020	6050	5587	5395	5457
REPRESENTATIVE	5320	4370	4150	4440	4114	3948

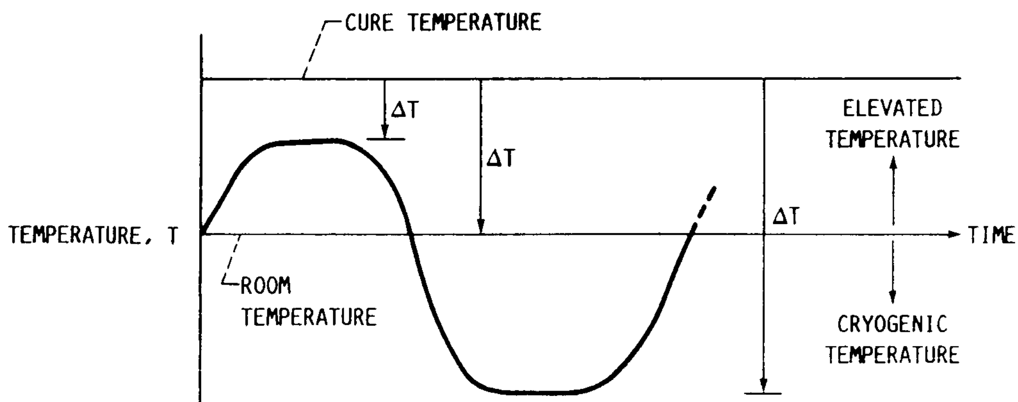
CD-88-33283

ICAN SIMULATION OF THERMAL FATIGUE

As composites are incorporated in the designs of more complex structures, a major and continuing concern is the accurate prediction of the structural durability and damage tolerance of these structures in service environments. Of major concern is temperature, moisture, and mechanical loads, both static and cyclic. Prior to any service environment, a composite usually has endured one thermal cycle resulting from the fabrication process in which the room-temperature resin composite is cured at a rather high temperature of 350 °F. Then the extreme service environment can consist of either high temperatures or cryogenic temperatures, or both, as is the case of an orbiting satellite which encounters high temperatures when facing the sun and low temperatures when behind the Earth. The resin (matrix) is most susceptible to damage from the thermal cycling. This damage takes the form of transply cracks (referred to as microcracking in the literature) which degrade the properties, thereby affecting the structural durability.

To address these critical issues, a predictive model has been formulated that yields the number of thermal cycles (N) to initial transply cracking. The model requires material properties, service conditions, and an empirical value B which is discussed in detail in Chamis and Sinclair (1982). The useful information from the model, as plotted below, will aid designers in making a life assessment for composite structures. In addition, one can also conduct a sensitivity analysis wherein the number of thermal cycles N is based on various composite strengths. As discussed earlier, accurate properties are often not available; therefore, with this analysis, designers can plan their designs within an acceptable range.

This is one of the most recently added features to the ICAN program and although it has not been validated by experimental data, there are plans to do so.

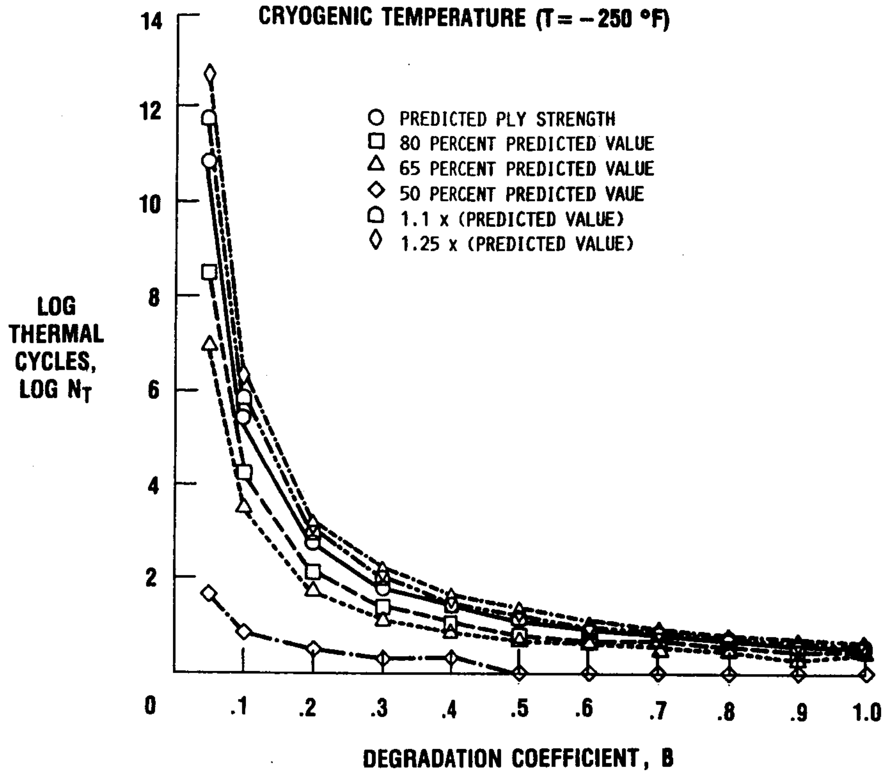


THERMAL CYCLES

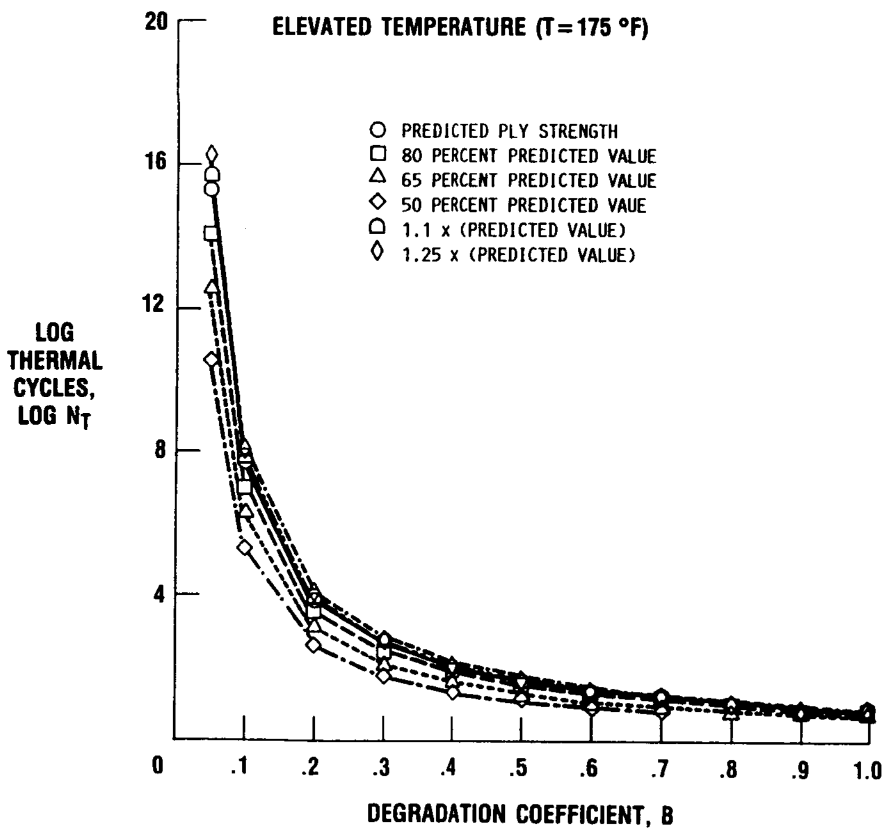
$$\text{LOG } N_T = \frac{1}{B}\left[\left(\frac{T_{GW} - T}{T_{GD} - T_0}\right)^{1/2} - \frac{\sigma_{\ell YYCYC}}{S_{\ell YYO}}\right]$$

$\sigma_{\ell 22CYC}$ = MAXIMUM TRANSVERSE PLY STRESS AT ΔT TO YIELD MAXIMUM $(\sigma_{\ell YYCYC}/S_{\ell YYO})$ RATIO

CD-88-33376



CD-88-33377



CD-88-33378

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