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COMAND - A FORTRAN PROGRAM FOR

SIMPLIFIED COMPOSITE ANALYSIS AND

DESIGN

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conditions are considere	d.			
The required input	data is defin	ed and exemples	are provide	i to aid
the user in making the p	rogram operat	ional. Average	panel design	n times
are two seconds on an IB	M 360/67 comp	uter. Results	are compared	with
published literature. A	. complete FOR	TRAN listing of	program COM	AND is
provided. In addition,	the optimizat	ion program 🔍 🤍	MIN is requi:	red for
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COMAND - A FORTRAN PROGRAM FOR SIMPLIFIED COMPOSITE ANALYSIS AND DESIGN

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Garret N. Vanderplaats Ames Research Center

INTRODUCTION

Early evaluation of composite materials in aerospace structures requires an efficient means of structural sizing for a given application. It is seldom possible to provide simple stress limits as is customary when designing with conventional isotropic materials, since failure of composites is dependent not only on the properties and orientations of the individual plys, but on the nature of the loading as well. Furthermore, by taking advantage of the ply orthotropicity, the designer is free (within certain limits) to actually design the structural material through the proper choice of ply thicknesses and orientations.

COMAND is one of several programs being developed in the Advanced Vehicle Concepts Branch of Ames Research Center to provide a general and consistent approach to structural analysis and design. This program is for the analysis and design of a multilayered composite subject to inplane loads. The principal method of analysis and the failure criterion considered here are those used by Schmit and Farshi (Ref. 1). The optimization algorithm is the method of feasible directions using program CONMIN, which is described in Reference 2. COMAND is intended to provide first level design information for membrane structural behavior. Another program under development includes more general analysis, loading conditions, and failure criterion.*

*Program COMPOS by J. Mullen, Advanced Vehicle Concepts Branch, Ames Research Center. The analysis and design capabilities and the basic assumptions of the program are presented in Section I. Section II describes the required input to the program and several examples of the results are presented in Section III. Possible future efforts in composite analysis and design are identified in Section IV. The principle equations used in the analysis are presented in Appendix A. Appendix B is a complete program listing.

SECTION I

ASSUMPTIONS AND RESTRICTIONS

Program COMAND can be used to analyze a given composite panel in which the ply thicknesses are prescribed, or to design the ply thicknesses to satisfy strain and stiffness limitations. Ply orientation angles are prescribed, and are not design variables. Typical loading conditions and ply orientations are shown in Figures 1 and 2, respectively.

The composite analysis and design is based on the following assumptions and restrictions.

- The panel is subjected to in-plane loads NX, NY and NYX only. Bending and out-of-plane shear loads are not considered. Multiple loading conditions are considered and up to 10 independent loading conditions are allowed.
- The composite is said to fail when the longitudinal, transverse or shear strain in any single ply exceeds a specified limit in the longitudinal, transverse or shear direction, respectively.
- The composite is said to fail if the stiffness in the structural
 X, Y or XY direction is less than a specified lower limit.

- 4. The individual ply thicknesses are designed to give minimum total panel thickness. Ply thicknesses are treated as continuous variables and several plys may be required to be of equal thickness.
- 5. All plys are of the same material with the same elastic properties and strain limitations. Ply elastic properties (and therefore, those of the composite) are assumed to be the same in tension and compression.
- Ply properties are required as program input. Micromechanics analysis is not performed in the program.
- 7. The composite is assumed to be symmetric about the midplane so that no bending-membrane coupling exists.
- 8. The composite need not be balanced. That is, a ply with +45 degrees fiber orientation need not be balanced with another ply of -45 degrees orientation. Up to 18 different ply orientations are permitted, allowing for design of composites with ply angles at 10 degree intervals. Ply fiber orientation angles are prescribed and are not design variables.
- 9. Temperature effects and temperature loading are not considered, except that the material properties and strain limits must be consistent with the design temperature.

SECTION II

PROGRAM INPUT

All program input is listed here. The variables and their definitions are presented first, followed by data organization. No units are provided

for the variables. It is required that all units be consistent. That is (for example), if loads are in newtons and thicknesses in meters, moduli must be given in newtons per square meter, strains in meters/meter and stiffness in newtons/meter.

Variables:

TITLE(15) Anything may be given as a title.

NCALC Calculation control. If NCALC=0, total composite thickness (weight) is minimized. If NCALC.NE.O. the given composite is analyzed only.

NPLY Number of plys. Up to 18 plys are allowed.

NPV Number of design variables. This is the number of ply thicknesses which are allowed to change independently in the optimization process or the number of different thicknesses prescribed for analysis. 1.LE.NDV.LE.NPLY

NLC Number of loading conditions. Up to 5 loading conditions are allowed.

- IPRINT Print control for the optimization program, CONMIN. IPRINT = 0
 gives no print during the optimization. IPRINT = 1 to IPRINT = 4
 provide increasing degrees of output during optimization.
 IPRINT = 2 is usually desirable.
- LNK(NPLY) Design variable linking. LNK(I) gives variable number (ply thickness) associated with the ITH ply. For example, in a four ply problem (NPLY = 4), $LNK^{T} = (1, 2, 2, 3)$ will impose the requirement that plys 2 and 3 are of the same thickness. In this case NDV = 3.

- X(NDV) Initial thickness of the design variables (IE. X^{T} = .05, .03, .04). If NCALC.NE.O., the composite is analyzed for ply thicknesses defined in X and linked according to LNK. If J = LNK(I), the thickness of the ITH ply is stored in X(J).
- VLB(NDV) Lower bounds on the design variables. VLB(I).GE.0, I = 1,NDV. It is usually desirable to set at least one VLB(I) = 1.0E-10 if lower bounds of zero are desired, in order to prevent the optimization program from attempting to analyze a panel of zero thickness. If NCALC.NE.0. VLB(I) = 0, I = 1, NDV may be input.
- THN(NPLY) Ply orientations in degrees, referenced to the structural X-axis. THN(I) = Ply orientation of the ITH ply.
- EL Ply longitudinal modulus.
- ET Ply transverse modulus.
- GLT Ply shear modulus.
- PRLT Ply major Poisson's ratio (ply transverse Poisson's ratio, PRTL, is calculated internally).
- EPLC Ply longitudinal compressive strain limit (negative number).
- EPLT Ply longitudinal tensile strain limit (positive number).
- EPTT Ply transverse tensile strain limit (positive number).
- GMLT Ply maximum shear strain limit (positive number).
- AllL Lower bound on composite stiffness in the structural X-DIRECTION.
- A22L Lower bound on composite stiffness in the structural Y-DIRECTION.
- A66L Lower bound on composite shear stiffness.
- PN(3, NLC) Loads, column I corresponds to loading condition I, I = 1, NLC. Row J corresponds to load NX, NY and NXY for J = 1, 2 and 3, respectively of load condition I.

Data Organization:

No. of Cards	Information	Format
1	Title - Anything may be given here	1 5A 4
1	NCALC, NPLY, NDV, NLC, IPRINT	515
1	LNK(I),I=1,NPLY	1515
1-3	X(1),I=1,NDV	8F10.2
1-3	VLB(I),I=1,NDV (Blank card(s) if NCALC.NE.0)	8F10.2
1-3	THN(I), I=1, NPLY	8F10.2
1	EL, ET, GLT, FRLT	4F10.2
1	EPLC, EPLT, EPTC, EPTT, GMLT, A11L, A22L, A66L	8F10.2
NLC	PN(J,I),J=1,3 (One card per loading condition)	3F10.2
	Begin with next set of data. Program terminates	
	if 2 blank cards are read here.	

This information is duplicated in Table 1, along with a data form for convenient reference.

SECTION III

EXAMPLES

Several examples are presented here to aid the user in making the program operational and to provide some insight into design using composite Edterials. All examples are for a high strength graphite-epoxy composite.

Typical ply unidirectional properties are listed in Table 2 for a fiber volume fraction of 0.6. The table is reproduced directly from Reference 3. Note that the ultimate strain limits are not specified for longitudinal and transverse strain or for shear. However, reasonable values are readily

obtained by analyzing a single ply of unit thickness, subject to a set of loads which are equal to the ultimate stresses. For example, given a longitudinal load of 180,000 lb/in. the resulting longitudinal strain will be ultimate strain. Therefore, a single ply composite is analyzed for the following load conditions:

Load Condition	NX	NY	NXY
1	180000.	0.	0.
3	0.	-30000.	0.
2	0.	8000.	0.
4	0.	0.	12000

Note that a negative NX load is not imposed because the ultimate longitudinal compressive stress is the same in magnitude as the tensile stress. Therefore, the ultimate strains are also equal in magnitude (but opposite in sign).

The program input variables are now:

TITLE:	Determination of strains - G/E composite.
NCALC = 1	Analysis
NPLY = 1	One ply.
NDV = 1	One thickness.
NLC = 4	Four load conditions.
IPRINT = 0	Not used for analysis.
LNK(1) = 1	Ply thickness = $X(1)$.
X(1) = 1.0	Composite thickness.
VLB(1) = 0.	Not used for analysis.
THN(1) = 0.	Zero degree ply orientation.

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EL = 21,000,000 Longitudinal modulus.

ET = 1,700,000 Transverse modulus

GLT = 650,000 Shear modulus.

PRLT = 0.21 Major Poisson's ratio.

EPLT = EPLC = EPTT = EPTC = GMLT = 0 - Strain limits set to zero since they are not known.

AllL = A22L = A66L = 0 Not meaningful here

PN(I,J) - Loads, given above.

The input data is listed in Table 3 with the corresponding output in Figure 3. The ultimate strains are now the actual ply strains in the direction of the applied load for the corresponding loading condition. For example, since load condition 1 is the ultimate longitudinal stress, the longitudinal strain, EPL, under this load condition is also ultimate. That is:

EPLT = 0.00857 (table 2 gives 0.00870)

Similarly,

EPLC = -0.00857

EPTC = -0.0176

EPTT = 0.00471 (table 2 gives 0.00475)

GMLT = 0.0185

These are now the limit strains to be used in design.

Example 1 - Quasi-isotropic composite

In order to draw a comparison between graphite epoxy composites and the familiar aluminum materials, a simple case is first considered in which plys are oriented at 15 degree intervals (NPLY = 12) and subject to a single

unidirectional load, NX = 20,000 lb/in. (NY=NXY=0). All plys are required to be of the same thickness so that NDV=1 and LNK(I)=1, I,NPLY. The total thickness is minimized. No minimum stiffness limits are imposed, so that A11L=A22L=A661 =0. Lower bounds on the thicknesses are arbitrarily set to 0.00001 in. Initial ply thickness is prescribed as 0.05 in. The input data is listed in Table 4, where the print control for the optimization program, CONMIN, is taken as IPRINT = 2. The program output is listed in Figure 4. The optimum composite thickness is 0.525 inches. The design is constrained by the transverse strain limit in the 90 degree direction (ply number 12). The average stress in the structural X-direction (direction of load) in the composite is 38,000 PSI. Note that this is significantly less than the ultimate stress of 60,002 PSI for a typical aluminum alloy. However, the density of the composite is 0.056 lb/in.**3 as compared to 0.101 lb/in.**3 for aluminum. Therefore, the relative weight of graphite epoxy as compared to aluminum for this example is 0.056*60000/(0.101*38000 = 0.875 giving a 12.5 percent weight savings.

Note that even though the 90 degree ply has failed, some additional load may be carried before all plys fail. Therefore, the failure stress predicted here may be considered analogous to the limit stress, with the ultimate stress being (usually) somewhat higher.

Example 2 - (0. +45, 90) composite design

Due to practical considerations, it is improbable that many different ply orientations will be used in most structures. In this example, the composite is required to be balanced so that the thicknesses of the 445 and -45 degree plys are the same. Then there are three independent design

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variables (NDV = 3) and the ply thickness linking vector becomes LNK^{T} = (1, 2, 2, 3). The ply orientation vector is THN^{T} = (0., 45., -45., 90.). A minimum stiffness of 500,000. lb/in. is required in the structural X-direction. The composite is required to support the following four independent loading conditions:

Load Condition	NX	NY	NXY
1	20000.	0.	0.
2	15000.	-15000.	5000.
3	-15000.	10000.	10000.
4	0.	0.	20000.

The input data is listed in Table 5 and the corresponding output in Fig. 5. The print control for CONMIN is set to IPRINT = 0 in this example and in example 3 for brevity. The optimum composite thickness is 0.578 inches. The active constraints are transverse strain limits and are identified by safety factors of unity in Fig. 5 (3 constraints are active). Example 3 - $(0. \pm 30, \pm 60, 90)$ composite design.

This composite is designed subject to the same constraints and loading conditions as example 2. the only difference is the number of plys and their orientations. The composite is again required to be balanced. In this case, NDV = 4, NPLY = 6, LNK^{T} = (1, 2, 2, 3, 3, 4), and THN^{T} = 0., 30., -30., 60., -60., 90.). The input data and output are listed in Table 6 and Fig. 6, respectively. The optimum composite thickness is 0.532 inches and there are six active strain limit constraints as seen from Fig. 6. Note that although the number of plys and their orientations are different from example 2, the total composite thickness is reduced by less than ten percent.

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An additional exercise of interest is to eliminate plys which comprise a small percentage of the total thickness, and solve the optimization problem again. For example, a composite made up of ± 30 and ± 60 degree ply orientations results in an optimum thickness of 0.526 inches. It is instructive to design the 12 ply composite of example 1 subject to this same set of loads, but allowing for different ply thicknesses (require that the composite be balanced for consistency with examples 2 and 3). The resulting thickness is 0.588 inches. Solution of this case is left as an exercise.

Example 4 - Limit stress vs. ply thickness distribution

In order to assess the applicability of this program to preliminary composite design, results obtained using COMAND are compared here with design curves for a $(0, \pm 45, 90)$ composite subjected to uniaxial tension, compression and shear loading (applied separately). Figures 7-10 are reproduced from Reference 3. A composite with various relative ply thicknesses was analyzed under these separate loading conditions. No stiffness constraints were imposed a nd the lowest factor of safety was found for all strain failure criterion. The calculated stress was then multiplied by this factor to give the failure (limit) stress. The results are plotted on Figures 7-10 for 25 and 50 percent zero degree plys. Figure 10 compares the extensional modulus, E_x .

The results indicate reasonable comparison for compressive stress, shear stress and extensional modulus. However, considerable discrepancy is found in comparing tensile stress limits. This is because the composite is constrained by transverse strain limits on the 90 degree plys. In Reference 3, one or more plys are allowed to fail without assuming composite failure.

When a single ply fails, this ply is assumed to carry no load. The composite is said to fail only when all plys fail individually. This again demonstrates the difference between the limit stress calculated here and the ultimate stress presented in Reference 3. The difference in results between these two assumptions is usually reduced when multiple sets of combined loadings (practical design situations) are considered. N.

SECTION IV

DISCUSSION

A short program has been presented by which first estimates are readily obtained for design requirements of composite structures. The program is easily used and requires minimal execution time. Because the failure criterion are extremely load dependent, some judgement is necessary in choosing permissible ply orientations, so that the existence of a given ply orientation does not prevent attainment of an optimum design. This problem is much less prevalent under multiple loading conditions. However, it does suggest that development of an optimization algorithm capable of completely eliminating plys may be fruitful.

For the results to be meaningful, it is important that this program be applied only to structures satisfying (at least approximately) the restrictions imposed in Section I. Of particular importance are the restrictions of inplane loading and composite symmetry about the midplane.

Recognizing the complexities of composite analysis and design as well as the benefits to be gained through the use of these materials, future development work in this area appears warranted.**

**Several of the topics identified here are currently being included in the COMPOS program by J. Mullen at ARC.

These efforts should include more complex loading such as bending, out of plane shear, and temperature loads on nonsymmetric composites. This necessarily requires the inclusion of more sophisiticated analysis techniques and failure criterion. Panel buckling under various force and displacement boundary conditions is also an area of interest because, with increased composite strengths, stiffness requirements become increasingly important, since the probability of failure in this mode is increased with reduced plate thicknesses. Additionally, analysis and design of composites made up of plys of differing elastic properties is a needed and straight forward extension. This will provide the capability of selective reinforcement of conventional isotropic materials as well as use of various combinations of advanced materials. Finally, these capabilities should be incorporated into a general finite element analysis and design program for application to large scale structures of practical interest.

APPENDIX A

COMPOSITE ANALYSIS AND DESIGN EQUATIONS

Analysis Equations

The equations used for analysis and design are presented here. These equations are consistant with the assumptions listed in Section I. Equation numbers beginning with the letter A are consistant with Reference 1.

The analysis is based on the ply materials properties E_L , E_T , G_{LT} , v_{LT} and v_{TL} , ply thicknesses, t_i , and orientations, θ_i .

The force deformation equations for the kth load condition are;

$$\{N\}_{k} = [A] \{\varepsilon\}_{k}$$
 [A1]

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where

$$\{N\}_{k} = \begin{cases} N_{xk} \\ N_{yk} \\ N_{xyk} \end{cases} \quad \{\varepsilon\}_{k} = \begin{cases} \varepsilon_{xk} \\ \varepsilon_{yk} \\ \gamma_{xyk} \end{cases} = \begin{cases} \frac{\partial v_{k}}{\partial y} \\ \frac{\partial v_{k}}{\partial y} \\ \frac{\partial v_{k}}{\partial x} + \frac{\partial u_{k}}{\partial y} \end{cases}$$

 ${\{N\}}_k$ is the vector of applied in-plane loads referenced to the structural x-axis and ${\{\epsilon\}}_k$ is the corresponding strain state. u and v are the displacements in the coordinate x and y directions, respectively.

$$A_{rs} = \sum_{i=1}^{NPLY} (C_{rs}^{i})t_{i} = 1, 2, 6$$
 [A2]

where t_i is the thickness of the plys oriented at angle θ_i with respect to the structural x-axis. Coefficients $(C_{rs}')_i$ are defined in terms of θ_i and

and the ply elastic constants as

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$$(c_{11}')_{i} = (c_{11})_{i} \quad \ell_{i}^{4} + 2(c_{12})_{i} \quad \ell_{i}^{2} \quad m_{i}^{2}$$

$$+ (c_{22})_{i} \quad m_{i}^{4} + 4(c_{66})_{i} \quad m_{i}^{2} \quad \ell_{i}^{2}$$
[A3]

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$$(c_{12}')_{i} = (c_{11})_{i} \ell_{i}^{2} m_{i}^{2} + (c_{12})_{i} (\ell_{i}^{4} + m_{i}^{4})$$

$$+ (c_{22})_{i} \ell_{i}^{2} m_{i}^{2} - 4(c_{66})_{i} \ell_{i}^{2} m_{i}^{2}$$
[A4]

$$(c_{16}')_{i} = (c_{11})_{i} \ell_{i}^{3} m_{i} + (c_{12})_{i} (m_{i}^{3} \ell_{i} - \ell_{i}^{3} m_{i})$$

$$- (c_{22})_{i} m_{i}^{3} \ell_{i} + 2(c_{66})_{i} (m_{i}^{3} \ell_{i} - m_{i} \ell_{i}^{3})$$
[A5]

$$(c_{22}')_{i} = (c_{11}')_{i} m_{i}^{4} + 2(c_{12}')_{i} m_{i}^{2} \ell_{i}^{2}$$

$$+ (c_{22}')_{i} \ell_{i}^{4} + 4(c_{66}')_{i} m_{i}^{2} \ell_{i}^{2}$$
[A6]

$$(c_{26}^{\prime})_{i} = (c_{11})_{i} m_{i}^{3} \ell_{i} + (c_{12})_{i} (\ell_{i}^{3} m_{i} - m_{i}^{3} \ell_{i})$$

$$- (c_{22})_{i} m_{i} \ell_{i}^{3} + 2(c_{66})_{i} (m_{i} \ell_{i}^{3} - m_{i}^{3} \ell_{i})$$
[A7]

$$(c_{66})_{i} = (c_{11})_{i} m_{i}^{2} \ell_{i}^{2} - 2(c_{12})_{i} m_{i}^{2} \ell_{i}^{2}$$

$$+ (c_{22})_{i} m_{i}^{2} \ell_{i}^{2} + (c_{66})_{i} (\ell_{i}^{2} - m_{i}^{2})^{2}$$
[A8]

where

$$l_{i} = \cos \theta_{i} \qquad m_{i} = \sin \theta_{i} \qquad [A9]$$

$$(c_{11})_{i} = \frac{E_{Li}}{(1 - v_{LTi} v_{TLi})}$$
 [A10]

$$(c_{12})_{i} = \frac{v_{TLi} E_{Li}}{(1 - v_{LTi} v_{TLi})} = \frac{v_{LTi} E_{Ti}}{(1 - v_{LTi} v_{TLi})}$$
[A11]

$$(c_{22})_{i} = \frac{E_{Ti}}{(1 - v_{LTi} v_{TLi})}$$
 [A12]

$$(c_{66})_{i} = G_{LTi}$$
 [A13]

Note that the subscript i is not required on equations [A10]-[A13] since the elastic properties are assumed the same for all plys. The subscript is retained here for consistency.

Given the loads ${\{N\}}_k$, the membrane strains are obtained from equation [A1] as

$$\{\epsilon\}_{k} = [A]^{-1} \{N\}_{k}$$

Finally the strains in the ith ply (kth load condition) are determined from

$$\varepsilon_{1ik} = \ell_{1}^{2} \varepsilon_{xk} + m_{1}^{2} \varepsilon_{yk} + m_{1}\ell_{1} \gamma_{xyk}$$

$$\varepsilon_{2ik} = m_{1}^{2} \varepsilon_{xk} + \ell_{1}^{2} \varepsilon_{yk} - m_{1}\ell_{1} \gamma_{xyk}$$

$$\gamma_{12ik} = -2m_{1}\ell_{1}\varepsilon_{xk} + 2m_{1}\ell_{1}\varepsilon_{yk} + (\ell_{1}^{2} - m_{1}^{2}) \gamma_{xyk}$$
[A14]

If the stresses in the ith ply are required, these may be obtained from the orthotropic elastic stress-strain relationships to be

$$\sigma_{1ik} = (c_{11})_{i} \varepsilon_{1ik} + (c_{12})_{i} \varepsilon_{2ik}$$

$$\sigma_{2ik} = (c_{12})_{i} \varepsilon_{1ik} + (c_{22})_{i} \varepsilon_{2ik}$$

$$\tau_{12ik} = (c_{66})_{i} \gamma_{12ik}$$

(15)

Design Equations

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The design objective is to minimize the total composite thickness (and therefore weight);

Constraints on the design include limit ply strains and lower bounds on stiffness.

The limit strains imposed on the individual plys are expressed as constraint functions as follows:

$$G_{1ik} = \frac{\varepsilon_{1ik}}{EPLC} - 1. \leq 0 \qquad i = 1, \text{ NPLY}, \text{ } k = 1, \text{ NLC}$$

$$G_{2ik} = \frac{\varepsilon_{1ik}}{EPLT} - 1. \leq 0 \qquad i = 1, \text{ NPLY}, \text{ } k = 1, \text{ NLC}$$

$$G_{3ik} = \frac{\varepsilon_{2ik}}{EPTC} - 1. \leq 0 \qquad f = 1, \text{ NPLY}, \text{ } k = 1, \text{ NLC}$$

$$G_{4ik} = \frac{\varepsilon_{2ik}}{EPTT} - 1. \leq 0 \qquad i = 1, \text{ NPLY}, \text{ } k = 1, \text{ NLC}$$

$$G_{5ik} = \frac{|\gamma_{12ik}|}{GMLT} - 1. \leq 0 \qquad i = 1, \text{ NPLY}, \text{ } k = 1, \text{ NLC}$$

where subscript i denotes ply number and subscript k denotes load condition.

Lower bounds on stiffness are expressed as constraint functions;

$$\overline{G}_1 = 1. - A(1,1)/Alll \le 0.$$

 $\overline{G}_2 = 1. - A(2,2)/A22L \le 0.$
 $\overline{G}_3 = 1. - A(3,3)/A66L \le 0.$

Constraints on strains are nonlinear functions of the design variables, t_1 . The values of these constraints are stored in vector G, (five values per ply, one ply after another) for each load condition in sequence. Constraints \overline{G}_1 , \overline{G}_2 and \overline{G}_3 on stiffness are linear functions of the design variables. The values of these constraints are stored after constraints on strains in vector G.

There are 5*NPLY*NLC nonlinear constraints and three linear constraints on the optimization problem. Program "CONMIN" defines a nonlinear constraint as "active" if its value is greater than or equal to a specified value CT (a small negative number). Linear constraints are "active" if their value equals or exceeds a value of CTL. If a given constraint is active the analytic gradient of this constraint with respect to the independent design variables, t₁, must be supplied. This information is obtained by direct differentiation of the constraint functions and is readily calculated using the equations of analysis.

APPENDIX B

PROTRAM LISTING

A complete FORTRAN listing of program "COMAND" is given here. In addition, program "CONMIN" is required and this program is described in reference 2. The general program organization is shown in block diagram form in figure 11. ŕ

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JULY, 1974

PREGRAM CUMAND - & FORTRAM PROGRAM FOR COMPOSITE ANALYSIS 10 20 AND DESIGN. 30 COMMON X(20), DF(20), G(500), ISC(500), IC(20), A(20, 20), S(20), G1(500), •62(50C),C(20),MS1(40),B(20,20),VL8(20),VU8(20),SCAL(20) CUPMER /CNMN1/ [PRINT,NDV,[TMAX,NCON,NS1DE,[CHDIR,NSCAL,NFDG,FDCH, 40 50 IFDCHM,CT,CTNIN,CTL,CILNIN, THE TA, PHI, HAC, DELFUN, DABFUN, LINDB 60 70 2J. LTRN, ITEK, INFOG COMMON /COMPOS/ NPLT/EL/ET/GLT.PRLT/PRTL/EPLC/EPLT/EPTC/EPTT/GMLT/ 80 1NLC, A11L, A221, Ab5L, TN(18), THA(18), CP(3, 3, 18), PN(3, 5), AA(3, 3), BB(3 90 2:3),EF(3),DEP(3),LNK(10) 100 110 DIMENSION TITLE(15) EXTERNAL COMPS 120 PROGRAM FOR MULTILAYERED COMPOSITE PANEL OPTIMIZATION. 130 BY G. N. VANDERPLAATS SEPT., 1473. 140 HASA-AMES RESEARCH CENTER, MEFFETT FIELD, CALIF. 150 REGUIRED DIMENSIONS: TRENPLYI, THN (NPLY), CP(3,3, NPLY), PN(3, NLC), 160 LNK (NPLY). OTHERS HEMAIN AS NOW DIMENSIONED STORAGE REQUIREMENTS (DECIMAL WURDS, COC): 17G 180 PROGRAM -190 CCPANO = 2000 200 COMMIN = 0000 210 ARRAYS * 3000 FOR PIGRAM AS DIMENSIGNED IN REF. 1. Ref. 1 - Vanderplaats, G. N., Scumand - A fortran program for Sifplified Composite Waalysis and Desiyas, MASA TH X-**,***, Z20 230 240 AUG. 1975. Ref. 2 - Schnit, L. A., And Farshi, S.I. Suptinum Laminate Design FGA Strength and Stiffness. Int. J. FOR NUMERICAL METHODS IN ENGINEERING, VOL. 7, NO. 4, PP. 519-336, 1973. Equation Numbers Listed in this program are from the above C 250 26. Ċ 270 С 280 290 300 c REFERLNCE REF. 3 - CONMIN - A FORTRAM PRIGRAM FOR CONSTRAINED FUNCTION 310 Ċ HIMIMIZATIONS USERSS NANUAL, BY G. N. VANDERPLAATS, 320 С NASA TH 1-62,282, AUGUST, 1973. 330 С THIS PRUGFAM USES CONMEN VERSION II, DATED JULY, 1975. 340 С ASSUMPTILKS: 350 C BUUNCARY CONDITIONS ARE PRESCRIPED LUADS NK. NY AND NXY. 360 C ALL PLYS HAVE SAME MATERIAL PROPERTIES AND FAILURE STRAINS. 370 С FAILURE CRITERION ARE MAX PLY LUNGITUDINAL. THANSVERSE AND SHEAR 380 C 390 Č. STRAINS, AND STIFFNESS LIMITS ON ALL, AZZ AND A66. WHEN ANY ONE PLY FAILS, THIS IS DEFINED AS CONPOSITE FAILURE. 600 ċ с MEMBRANE LOADS ONLY - MULTIPLE LOADING CONDITIONS ARE 410 420 c CONSIUERED. SYMPETRY ABEUT HIJPLANE 15 ASSUMED. 430 c COMPOSITE NEED NOT BE BALANCED. 440 £ 450 с NCALC . CALCULATION CONTROL 460 Ċ. OF DE LETIMIZATION 470 C HE.D: D' ANALYSIS DALY 480 C. HPLY = NLPGER OF PLYS. SYNHETRY ASSUMED. PHOGRAM TERMINATED IF NPLY=0. 490 С 500 С

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	COMPOSITE AMALYSIS AND DESIGN PROGRAM - COMAND	JULY,	1974
~	M C - MUMPEN DE 1 DAD COMMITIENS.		610
č	HER - NUMBER OF DESTIN UNITARIES OF INDEPENDENT PLY THICKNESSES		52:
ž	ADV - ADDER OF DESIGN VARIABLES ON INDEPENDENT FET THEOREDSED		630
ž	TUR ABALIJIJ. 100101 - Cjišt (Intjik Eng Frankia.		560
	ITAIN - FRIN GONDE FOR CONTAIN		550
10	PEAU 1991403 11105 USAD 1992403 11105		560
	TE ADIY LA CA ETAD		57/
<u>ر</u>	IT INFLICENED JINTING, INKITA B DESIGN VARIARIE		5.81
ž	ACCEPTATE CTN TTN DIV.		50
v	ASSACTATED ATTA TATA TELEVISION AND AND AND AND AND AND AND AND AND AN		60
r .	TUTTIL TUTTLESC		610
•	1111100 101010111111.0001		6.20
c	TOTAL BUTTAL CONDUCTE TUTEN. SS		630
•	TAINT INTITUE CONFOSITE INTERNESS.		661
	UDJANUA Da JA 1-1 NDIV		6.50
			6 6 6 6
	JELAKII		474
	CH 2=063+X[2]		
20			001
C	LOWER BOUNDS ON DESIGN VARIABLES.		0.41
	READ (5)216) (VEBLI) 1=1,800)		70
ç	PLT UNIENTATION IN JEGREES.		14
	READ (5,216) (HARLISTINCE)		72
¢	PLT HAILAIAL PRUPCHLIES.		73
	READ (5)210) LLPCIAULIPALI		
_	PRTLOPHLT*ET/EL		751
C	STRAIN AND STREFAESS LINITS.		(0)
-	KEAD (57210) EPECSEPTISEPTISERLISATLEAGEL AGEL		
C	LOADS FOR EACH LOAD CONDITION.		
	DG 30 I= I + NLC		791
С	LUADS - NX, NY AND NXY FOR THIS LUAD CONDITION.		80
30	BEAD (76510) (50(7)[)07=103)		81
C	NCON = HUMBER OF CONSTRAINTS.		820
	NCEN+5+NPLY+NLC		831
	DG 40 I=1,NCCN		641
46	150(1)=0		851
	N1=NCCh+1		861
	15C(N1)=1		87(
	15C(N1+1)=1		68
	ISC(N1+2)+1		89
	1F (A111.FT.1.0E-10) NCON#ACON+1		90
	IF (>22L.GT.1.0E-10) NCON=NCUN+1		91
	IF (Accl.GT.1.0E+10) NCUN#NCON+1		92
¢	PAINT INPUT INFURMATION.		93
	IF(NCILC.EC.0) WRITE(6,460)		94
	IF(NCALC.N. () WRITE(6,470)		95
	wRite (6,220)		96
	WRITE 46,150% TITLE		97
	WRITE (6,23C) NPLYANLC		98
	WPITE (6,24w) EL,ET,GLT,PRUT,PRTL		- 99
	WRITE Invest		200

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	GU 50 I=1.NPLY	1010
50	WRITE (6,270) IFTN(1)FTN(I)FINK(1)	1020
	GMLT1=-GALT	1036
	VRITE (0,200) EPLC/EPLT/EPTC/EPTT/GMLTL/GMLT	1040
	WRITE (6,290) All(,A221,A651	1050
	WRITE (6,300)	1060
	00 60 1-L/NLC	1070
60	WRITE (0,310) 1,104(3,1),31	1000
с	INITIALIZE CONMIN PARAMETERS TJ DEFAULT VALJES.	1090
	11 MAK = 30	1100
	NS [D=1	1110
	ICND1#=0	1120
	NSCAL +C	1130
	NFUG=0	1140
	#DCh•C.	1150
	FDLHJ=C.	1160
	CT+C.	1170
	CTMIN=C.	1160
	CTL=0.	1190
	CILCIN-0-	1206
	THE TARC.	1210
	PH I = C .	1220
	DELFUN+3.	15 10
	DARFUM+0.	1240
	L1NUB4=1	1250
	LT 8 N=0	1260
c	CONVERT PLY ANGLES TO RADIANS.	1270
•	Du 76 1-Letrix	1280
	THN111-TON11/227.293776	1290
с	UPPER BOUNLS ON DESIGN VARIABLES ARBITRARILY SET = 100.	1300
70	VIII 1 1 1 0 0 .	1310
ċ	FLY STIFFLESS CONFICIENTS.	1320
•	CALL (TMP) (NELY, THNAFLEFT, GLT, PHLT, PRTL, CP)	1330
	NNI=26	1340
	502+50C	1350
		1360
		1370
		1380
	nng-mu The theater to be extended to impain the information in the state of the state of the state of the state of the	1390
	<pre>Af incarcetaau carc control team stoppast por service as a service and the service and th</pre>	1400
~		1416
·	FA (F) AGAE(313 AEJO(137	1420
	RATIC LUDDEN LOTE LE. 16/1 TITLE	1430
	JUTT 16,37)	1440
		14.50
~	TETERATION AND AFACAT OF TATAL THICKNESS.	1460
	TEL THICKNESSES AND FEREET OF THE INTERACES.	1470
		1440
	V=CRN114	14 20
	13317-010-011	1500
	F6 = F F 7 11 + 3 F	2200

COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

	CUMFOSITE ANALYSIS AND DESIGN PROGRAM - COMAND	JULYP	1974
40	WRITE (0.26() I.IN(I).PCI		1510
č	TOTAL INLERNESS.		1520
-	WRITE (6,340) 083		1530
6	STIFFNESSES AND FLEXABILITIES.		1540
	CALL COMP2 (NPLY, TH+CP+6A+89)		1550
C	PLY SIRAINS AND COMPOSITE STRESSES FOR ALL LOAD CONDITIONS.		1500
	SRITE (0-3-0)		1590
	UD IUL II*IPNLU 19175 - 44 - 2453 - 57		1500
	RKIIC KDJJOLJ LI Pokrstit (Tinking)		1600
	COFFDATE STREET, STARDER, STARDER, STOPPEZ, TEVARE(1,3)000(3,1])		1610
	FOIDLAND, 1300NTL, TI 140012, 7340NTZ, TI 140012, 3340NT3, 111		1620
	12431+6at3.11+PN(1.11+68(3.2)+PN(2.[]+68(3.3)+PN(3.1)		1630
c	PLY STRAINS AND SEFETY FACTURS.		1640
-	DJ 96 J#1shFtY		1650
	THETA-THELJ)		1660
	AL =COS (THL TA)		1670
	ak=S1h(TelEIA)		1660
	AL 2=AL+AL		1040
	an z=ak+an		1710
4	21%A402+ 21%A402+ 21%A402+		1720
	ET1=AL2+ET111+AT2+ET121+AL+AAT+ET31		1730
	CU 2+2. 4A1 4AN4/+DE 214EP/183+6/AI 2+69234FP/33		1740
е	SET STRAINS TO HIMIMUM ABSOLUTE VALUE OF 1.JE-20 TO PREVENT		1750
ē	CIVIDE BY ZEHC.		1760
-	1F (ABS((P1)-LT-1-UE-20) EP1=1-0E-20		1770
	1+ (AUSLEP2).LI.1.06-26,1 EP2=1.06-20		1780
	1F [AUSt_P3]+LT+1+GE=20] £93+1+0E=20		1790
c	SAFETT FACILE.		1600
	SF1+EPLC/LP1		1010
	SF2*LP1C/1P2		1820
	3734-67L13273		18-0
	15 1502 61.0.1 562-5671/572		1850
	1F #491.61.6.5 \$F9##\$F3		1860
	1F (SF1.67.16C.) SF1=160.		1870
	1F ()/2.u1.100.) SF2=100.		1880
	If (SF3.0T.10C.) SF3=100.		1890
	## 112 16+37C1 J+EP1+SF1+EP2+Sf2+EP3+SF3		1400
96	CONTINCE		1910
С	CUMPUSITE STRAINS.		1420
1.7/	WITE COURCE LEPIKINK+1+31		1040
130	CONSTRUCT CTRISSE:		1950
÷	LONFUSINE SIFLADES.		1960
	BR 126 Jabakil		197D
	Int 116 J=1.3		1980
110	G[J]=FN[J,]]/C9J		1990
	1817E (0,400) 1,(G(J),J=1,3)		2000

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JULY: 1974

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	CUMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND	JUL Y .	1974
120	CONTINUE		2010
C	COMPOSITE STIFFNESSES.		2020
	WRITE (6,160)		2030
	Sf = 100.		2040
	IF (AIIL.GT.I.)E-10) SF=AA(1,13/ALIL		2650
	14 (SF.CT.100)) SF=10L.		2060
	WRITE (0,17C) AA(1,1),A11L,SF		2070
	SF=100,		2080
	IF (A22L.GT.1.)E-10) SF=AA(2,2)/A22L		2090
	1F (SF.61.100.) SF-100.		2100
	WRITE (6,106) AA(2,21,A22L,SF		2110
	\$F=10C.		2120
	1F (Attl.GT.1.GE-10) SF=AA(3,3)/A66L		2130
	IF (SF-61-106-) SF+100.		Z140
	WRITE (6,190) AA(3,3),Aa61,SF		2150
	WRITE (6,410)		216u
	DJ 13C 1-1/3		2170
			2180
1.10	88 f1 2 3 = (12 3 = 80 (12 3)		2190
130	AAIIJJJTAAIIJJIAA Franci, tu stuksestaatu oli iti usatos		2200
	CORFUTIE STRESS-STREET RECEILINGERS.		2210
	NKIJE (05420) ((AA(153))3"[53);[=[53]		2220
r	RAILE ADJADU FAMOUSTE Albeth_Stass: gliltynusytes		2230
*	10176 (6.667) (18077-31853 RECPUIDING		2290
Ċ	CORPOSITI FLASTIC CONSTANTS.		2240
-			2220
			2200
	6X7+1./AH(3.3)		2200
	Prd XY==6d(1+221/38(1+1)		2300
	PRYX====================================		2310
	HRITE LONGOU) EXPERIENCE LONG AND		2320
	6J TC 10		2330
c			2340
140	FORRAT (1584)		2350
150	FURMA1 [/14x+5HTITLE/14x+1944]		2360
16C	FURNAT (//2>X)JOHCOMFOSITE MEMBRANE STIFFNESSES/27X, ORACTUAL, 7X,	6H	2370
	1REGUIPEU/27x,SHV4LUE,9X,SHVALJE,8X,GHS.F.1		2390
176	FORMAT (14%,3H411,±13,5,1%,±13,5,3%,F7,2)		2390
100	10RPAT (14x,3HA22,±13.2,1A,€13.5,3x,F7.2)		2400
140	FURPAT (14x,3HAD6,613,5+1X,13,5,3X,F7,2)		2410
200	FORMAT (1615)		2420
210	FOPPAT (SFIC.2)		2430
220	FORMATU//4/14/2000 // SUX, 20HSYRHETRIC COMPOSITE PANEL)		2440
230	TURDAL CAREFORMULA OF PLTS TALSATA 25HND. OF LC	เลย	2450
26.0	- L CUMULISUNG - #131 - ENDEAL (1136), 260314 DULUCDITLE _ 111 DLVE INCUTION AND AND AND AND AND AND AND AND AND AND AND AND AND		2460
240	- THATAKA ANTHEN ANTER FROMEWORKERS - ALL PLES TORAL LAL/201922HLUNG - 1001644 ANTHEN ANTER FROMEWORKERS AND DRAW - FROM AND A		2470
		19	2480
	Belighten reaction and a set of the set of t		2990

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250	FURMAT (//14x,31HPLY THICKNESSES, DELEVIATIONS, 27HAND DESTON DADA	2610
	TABLE NUMBERS/251.424PIY NO. THTCHASSS THETA HEE WAS	26.20
	4.1 HELENALDER THE HELENALDER THE MELENALDER THE THE THE THE	2720
260	FJRNAL (211-19-31-51-5-610.2)	2560
276	FARMAT (15),10,10,10,5,5,20,67,2,6,16)	2340
2 8 0	GUMAT (1/1/1/) JAPLIG FLATE (1/1///// 1/ /////////////////////////	2330
200	113 S.L. M. F. C. M. STRAIN LIGHTSTIAAFZSALGAGIUUINAL SIRAINAGEAF	2560
	1113+3940 AAND+LC+JE13+3/144JE3H IKAHSVEKSE SIRAIN+GE+JE13+599H .A	2570
	CND+LE+PEI3-5/14XP24H SHEAP STRAIN-GE+PEI3-5,9H ANC+LE+PEI3-	2580
	101	2590
2.10	FURNAL 1//352, LOHSTIFFNESS LIMITS/334, 7HA11.GE., E12.5/332, 7HA22.GE	2600
	1 + F12 - 5/ 337 - 7hA65 - 66 + F12 - 2)	2610
300	FURHAL C//46X, SHLUADS/15X, 10HEUAD CUND., SCK, 2HNX, 12X, 2H4Y, 12X, 3HNXY	2620
	1)	2630
310	FGYMA1 (15x,16,6x,612,5,2x,612,5,2x,612,5)	2640
326	FORMAT (1H1/Zo//JOHDESIJN AND/OK ANALYSIS RESULTS)	2650
330	FORMAT UNITSKAISHPLY INFORMATIUN/25%,32HPLY ND. THICKNESS	2660
	1PERCENT)	2670
340	FUPNAT (35%,100,3%,100/234,110FH100NH5S == E32.	2680
	12#43#chiff.cfj	2690
350	FORMAL (////37%, LINGLY STRAINS/33%, 20H5.6 SAFETY FACTOR/33%, 26H	2700
	16PL . LONGITUDINAL STRAIN/33X, 24-FPT . TRANSUFRSH STRAIN/33X, 109	2710
	ZEPLI + SHEAR STRAINI	2720
360	FURMAT (//JCK.)CHLOAD CUND., 15/51.7HPLY NO. ANT ANEPLATIONS. F. AV.	2720
	LIHEFT ADT ANS A TAMPENT TATA ANS A. 1	2760
37L	FORMAT [54,15, 13, 13, 5, 24, 67, 3, 24, 612, 4, 24, 67, 3, 24, 477, 6, 24, 67, 31	3760
360	FRAMAT LITY ACTOR AND ALL STRATUS ALLESDATING TO COMPENSATION	2790
	THEFT & FIDE STRANGER & FIDE STRANGER & FIDE STRANGER AND STRANGER	2700
391.	FileMail 1/2512 2000-481454 STOLEEC 10 CONSCIPTION STOLES	2770
	14K 76516HA-FLAG 76K 77K 77K 77K 77K 77K 77K 77K	2780
6 /1/4	#AUFA1 (1-Y-14 - 7Y-14 - 1 - 1 - 1 - 1	2790
410	ENERAT 12/2/14/2014/2014/2014/2014 02 FT0/2014/04/2014/2014/2014/2014/2014	2800
140	TUDE AT A THE CARTER CONTRACTOR OF STREAS STRAIN RELATIONSHIPS/2019/20	2010
636	Englat flas (SF11 = 155 - 155 - 165	5950
460	TURNAL STUASCHULL = STILS 394ASOHLLS = STL2.394ASOHLLS = SEL2.594AS	2630
	1/3/3/5/5/5/2/ * /112.5/47/5HU26 * /112.5/20K/4HSYHHETRIC/25%,6HC66 *	2840
	C) E 12 4 3 }	2850
434	FUFMAL (7/204,42HLGEFIC.ENTS JF STRAIN-STRESS RELATIONSHIPS/284,20	2660
	LAWELATLD TO STPUCTURAL AKES)	2670
440	FURMAT [163,cHall = ,El2.5,4%,cHal2 = ,El2.5,4%,phal5 = ,El2.5,4%,	2080
	1/32%,6H072 = ,612,5,4%,0H026 = ,612,3/20%,9HSYMMETRIC,25%,6H066 =	2890
	2.612.51	2900
426	#JPHA1 (//20%,27HCOMPOSITE ELASTIC CUNSTANTS/LIX+SHEX = #E12+5,5%	2910
	15HEY + + 12+5+4+6H5XY + + 112+5/9K+7HNUXY + +E12+5+3X+7HNUYK + +E1	2920
	•2•2)	2930
400	FGAMAI(InlySdX, bHDESIGN)	2940
470	FGHMAT(1H1,37k,3HANALYSIS)	2950
	EHD	2960

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JULY, 1974

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COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

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REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

	SUBROUTINE COMPLE (NPLY) THN, EL, ET, GLT, PRLT, PRTL, CPJ	10
	D1HEH5[GN CP(3,3,18), THN(18)	20
c	RDUTINE TO CALCULATE PLY STIFFNESS COEFICIENTS - ALL PLYS THE SAME	30
C	ELASTIC PROPERTIES.	90
ç	BY G. N. VANDERPLANS	50
5	NASAMARES RESEARCH CONFERN RUFFEN FLELUN CAUF.	74
e.	FALENIAL CLADIL PROFERI CON	40
~	FR 1=1+74 1+**FFC 1*FF1() 100471 () + 10	80
÷		100
~	611-21-4781 1416-47160 431	110
÷	C 4 4 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	120
c	616*FR16 766 7861	130
	LAGAILUA ALC Partada	140
c	622°51°784 571 877513 317	150
L	TAPALT ATT	140
c		170
÷	60 10 HELE FELST	160
	DU 10 +-1967() Tu 14-Tu(41)	190
5		200
-		210
		220
		230
		240
	AL 4= AL 2 * AL 2	250
	AM2=AF\$4A	2 50
	43=48+482	270
	5HA+5 4A= PHA	280
c	EQUATION AD	29U
	CP(1)];]=C1]+ALG+2,+C12+ALZ+AM2+C22+AM4+4,+C6A+AL2+AH2	360
C	EQUATION AS	310
	CPl1;2;1;=C1;+A12+A72+C12+{A12+AK4;+C22+A12+AH2-+++C00+AL2+AH2	350
¢	EQUATION AS	334
	C+{1,3,1]_C1]+AL3+AH+C12+{AL\$+AH3-AL3+A4}-C22+AL\$+AH3+2+*C66+{AL\$+AH3	340
	1-akat31	350
C	subtiln be	360
	CP12,2,1)+C11+AH4+2.+C12+AL2+AM2+522+AL4+4.+C66+AL2+AM2	376
C	EQUATION A7	380
	CP12,3,[]+C11+AL+AH3+C12+(AL3+AH-AL+AH31-C22+AL3+AH+2,+C66+1AL3+AH	390
	1-21*2*31	400
ç	EGUATION AB	410
	CP[3,3,1)+C[1+412*A42*2,*C12*412*C42*A42*C22*A12*C40*1464*1464*2**412*6	420
		+30
C	INPUSE STAFEINT UN CAA	440
	LF1C#1#LF1#LF1#C#1} Cuth 1 flw uth 1 fl	440
	CD13.3.7.6.7013.3.1.5 CD13.2.7.6.7013.3.1.5	470
10	CT 1 J F CF 1 / * V * 1 / F J F F F F F F F F F F F F F F F F F	480
10		490
		500

COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND - COMPI

	COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMPO	JL Ya	1974
	SUBROUTINE COMP2 INPLY, TN, CT, A+ 83 SIBROUTINE COMP2 INPLY, TN, CT, A+ 83 SIBENSIJN A(3,3), B(3,3), TN(12), CP(3,3,14) AODTINE TO CALCULATE MEMBRANE STIFFNESSCS AND FLEXIBILITIES OF COMPOSITE MAUE UP OF NPLY PLYS, EACH WITH THE SAME MATERIAL PROPERTIES. BY G. N. VANUERPLAATS SEPT., 1973, AASA-AMES RESEARCH CENTER, HUFFETT FIELD, CALIF. STIFFNESS CUEFICIENTS. 7FPC A.		10 20 40 50 60 70 80
•	E0 10 I=1+3 EJ IC y=1+3		100 110
16 C	A(1,2)=0. Eulid a by Superposition.		120
L	CO 30 1 - 1,5 APLY 1 = Th (1)		150
20	()) 2C (=1,3) ()] 2C (=-1,3) A(1)())=A(1)(),1+T+C≠(1)(k,1)		180
30	CUNTINLE THAT THAT		260
L			220 230 240
c c	FLEARBELITY COEFICIENTS - INVERSE OF STIFFYESS. duild B+A-INVERSE. Deftation 19442-2004(2+3)+2.04(1+2)04(1+3)04(2+3)-4(1+1)04(2+3)04(1)	2	250 260 270
	1,3)-442,2)*2411,3)*441,3)-443,3)*441,23*441,23	-	2005
	0(1,2)=0[*(412,2)*412,3]=412,3]*41(3,3]) 0(1,2)=0[*(411,3]*412,3]=411,3]*41(3,3]) 0(1,3]=ue[*(411,2)*412,3]=411,3]*41(2,2])		310 320
	B:2;2;3;=U_{1}=(A(1,1)=A(3,3)=A(1,3)=A(1,3); 5(2;3)=U_{1}=(A(1,2)=A(1,3)=A(1,1)=A(2;3); 0(3;3)=D_{1}=(A(1,1)=A(2;2)=A(1,2)=A(1;2);)		330 340 350
C	IHPGSE SYPHETKY DV 3. 842217+8(1)2) 843217-84122)		360 370 380
	B(3/21*B(2/3) D(1) = B(2/3)		390
	END		410

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Construction of the second

COMPOSITE ANALYSIS AND DESIGN PROGRAM - LEMAND - COMPO	ULY, 1974
SUBREUTINE CLEP3 (INFL.DBJ.X.DF.G.IC.A.H1.H2.N3)	10
COPHEN /CNMN1/ 1PREMISNOV, ITHAX, HCON, HS LOE, ICNOIR, HSCAL, HEBG, FOCH	, 20
1FOCHA, CT, CTHIN, CTL, CTLHIN, THE TAL, PHI, NAC, DELFUN, DAUFUR, LIND	30
2BJ, LT#H, 1YEP, INFOG	40
01MENSION KAA110DF(N110G(N2)01C(03100173061)	50
EXTERNAL POUTTNE FUR CONNEN FOR COMPOSITE PANEL DESIGN.	60
by G. N. VANDEPPLAATS SEPT., 1973.	70
NASA-APES RESEARCH CENTER, NCFFETT FIELD, CALIF.	60
THIS IS A BUFFER BETWEEN CONMIN AND COMPS.	95
CALL CLAPS (INFO, DUJ, HDV, CT, CTL, MAC, KODF, G, A, IC, MJ, NZ, N3)	100
hETLAN	110

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	COPMEN /CNMH1/ 1PRIMI,MDV,ITHAX,4COM,MSIDE,1CNOIR,MSCAL,MFDG,FDCH,	20	
	1FOCHA, CT, CTHIN, CTL, CTLMIN, THE TAL, PHI, NAC, DELFUN, DAUFUR, LING	30	
	2BJ, LTPH, 1YEP, INFOG	40	
	01MENSION KIA1)+DF(N1)+G(N2)+IC(+3)+++13+++1	50	
C	EXTERNAL POUTTHE FUR CONNER FOR COMPOSITE PANEL DESIGN.	60	
ç	BY G. N. VANDEPPLAATS SEPT. 1973.	20	
٤	NASA-APUS RESEARCH CENTER, ACFEETE FIFLUE, CALIF.	80	
¢	THIS IS A DUFFER BETWEEN CONMIN AND COMPS.	00	
	CALL CLAPS (INFO, DUJ, HDV, CT, CTL, MAC, K, DF, G, A, TC, NJ, NZ, N3)	100	
	HETURN	110	
	ENC	120	

	SUBKELTINE COMPA (INFO)OBJ/KUV/CF/CTL/NAC/X/OF/G/A/1C/NN1/N	10
	CORMING (CLARPIST MP) YEELEFT.() T.PDI T.DDT	20
	IN C. ALL ACTI ANAL STALL AND INTERVIENT CONTACT AND A CONTACT AND A STALL AND A	20
	2+31+EP[3]-5)P[3]-[AC]1H1	50
	DIMENSIJU 1MP(3), KINNI), DECKELL, GINNAL, TOONAL, AGAMA, MULT	
C	ROUTING 10 (ALCULATE FUNCTION VALUE, CONSTRAINT VALUES AND	20
č	GRAUIINE DA FUNCTION AND ACTIVE CONSTANTATIONS FOR COMPASITE	20
Ē	ANALYSIS AND DESIGN PERGRAM - COMAND.	00
É.	AT G. A. VANUE API 647	300
č	NASA-ARLS RESEARCH CENTER, VERMETT FIFTH, CALLE.	110
-	1F (1NFH, 61-2) 69 D) 20	170
С		120
-		140
	UU 10 JeleNFLY	150
	J-LDK(]]	140
	T+E11=>(_)	170
10	C3J=C6J+1A(11	180
	1F (]NEU.1G.1F RETURN	195
	16 (INF0.LE.21 GJ TJ 50	200
20	CONTINUE	210
ç	GRADIENT CF COJECTIVE	220
	CO 36 I=1.NEV	230
30	1-11=C.	240
	89 43 E=1,NPLY	250
	J=LKK[]]	260
40	DFtJ1=LFtJ}+1.	270
	IF (INFOARCO3) RETURN	280
50	CUNTINUL	290
¢	CONSTRAINTS AND GRADIENT DE ACTIVE CONSTRAINTS.	300
	SCTL1+C	310
	IF [[NF]+L44] H4C+O	320
ç	STIFFNESS AND FLEXIBILITIES.	330
	CALL CCHP2 INPLT-TN, CP, 44-301	340
		350
L	INVERSE OF LEGATION AL.	360
	EP(1)=E3(1)=1)=PR(1)=3+ou(1)=2=PPN(2)=[3+GB(1)=DN(3)=1)	370
	LP [2]=D0 [2,1]=PN(],1]+BB(2,2]=PN(2,[]+BB(2,3]=PN(3,[]	380
	CP(3)=B3(3,1)=PN(1,1)=B0(3,2)=PN(2,1)=B0(3,3)=PN(3,1)	396
	DU IFU J=INNFLT	400
		410
	AL_=UJ31AK1AA	420
	AD = 3 4 C 4 4 7 E 1 A J Al 3 = 4 4 1	430
	PC C - AL - AL	440
С	E-LATIEN ATE	450
-	5 P1 # 66 2 6 6 10 1 6 6 80 2 6 - 0 1 2 1 4 61 6 6 6 6 6 7 3 1	NOU 670
		470
		400
		500
		200

CUMPUS. TE ANALYSIS AND DESIGN PROGRAM - COMAND - COMPA

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	COMPOSITE ANALYSIS AND DESIGN PROJRAM - COMAND - COMP4	JUL Y ,	1974
	NI +NCIGT		510
C	IDNGTILDINAL STRAIN CONSTRAINT - COMPRESSION.		520
•	GINCIOLISERI/FRIC-1.		530
	bc 101 +bc 101 +1		540
c	LONGTILITINAL STRATH CONSTRAINT - TENSION.		550
	GINCTETISEP1/Left=1.		500
			570
•	TRANSVIRSE STRAIN CONSTRAINT - COMPRESSION.		580
	GINCTOTISLE2/EPIC-1.		590
	NC 151-NC 161+1		600
•	TRANSVERSE STRAIN CONSTRAINT - TENSION.		610
	GINCTITD=1P2/FPTT-1.		620
	NC 101+NC 1(1+1		630
•	SUEAD STRATE CONSTRAINT.		640
100	GINCTETT ASS (FR3) (GNI T-1.		650
		ALL THE AND	660
			070
			680
	TE (C(V), (L, CT) BAC+PAC+1		690
40			700
00			710
	17 LAGLED MACT OF TO TO TO		720
	NC-NAUTI		730
			740
70			750
			760
	NAL TAL		770
			780
			790
	PLANING/ OF CLEATING - LOUATTIN 37.		800
•	BRADIENT OF STRAINS - CHOATLON STA		810
			820
	00 +0 +2-1-2		830
			840
au	Infinite infinite infinite infinite infinite		450
			860
			870
			880
40			890
			900
			910
	DEP3-2.+F. +AR-IDEPICI-DEPILITIAL2-AREITOLPIST		920
	NACERAL		030
	NI NZ		041
	IF (GINI)-LI-CI) GO TO 100	T.	0.50
C	GRADIENT OF ACTIVE LUNGITUDINAL CONFRESSIVE STRAIN CONSTRAIN	19100	940
	NACENALTI		970
	IF (NAC.EC.NNS) RETURN		0.00
	ALNAC . F J = ALNAC . K J + DEP 1/EPLC		400
	IC (NAC)=NI		1000
106	NI-NI-I		1000

	CUMPOSITE ANALYSIS AND GESIGN PROGRAM - COMAND - COMP4	JUL Y.	1974
	IF (G(N1).LT.CT) 60 TL 110		1010
C	GRADIENT CE ACTIVE LUNGITUDINAL TENSILE STRAIN CONSTRAINT.		1020
2000	NAC=NAC+1		103.
	IF INAL		1040
	ALNAC . KIRALNAC . KIRDEPI/EPIT		1050
	IC (bac) = bi		1060
116	NI aNI +1		1070
	16 (GIN1) (T-CT) 66 10 123		1080
c	CDADIENT OF ACTIVE TRANSVERSE COMPRESSIVE STRAIN CONSTRAINT.		1090
			1100
	TE (NAC-CONNAL RETURN		1110
			1120
	Trinepristinger in the second second		1130
190			1140
120			1150
	A THE ACTIVE TO THE PARTY CALSE. TENETIC CTAIN CONSTRUCT		11.60
	CRACIENT OF ACTIVE TRANSFERSE TENSILE STRAFT CONSTRAINTS		1170
	NAC-NAC-I		1100
	IF (NACLEVINNS) RETORN		1100
	ALNAC, KJ = ALNAC, KJ + DEP2/EP11		1140
	ICTACTONI		1200
130	NI-FIFI		1210
	IF totkij.ti.ti bu i, 140		1220
-	GRADIENT OF ACTIVE SHEAR STRAIN CONSTRAINTS		1240
	NAC+NAC+1		1250
	IF INAC.LO.KN31 REIDEN		1250
	SIGN=1.		1200
	IF (EP3.LI.O.) SIGN=		1270
	ALNAC, FI-ALNAC, KI+SIGN DEP3/GALT		1280
	IC (NAC)=N1		1290
140	CURTINCE		1300
150	CONTINUE		1310
100	CUNTINCE		1320
170	CONTINCE		1330
C	CONSTRAINTS ON STIFFNESS.		1340
	NI-NCILI		1350
1000	IF (AIIL.LI.I.JE-10) 60 10 100		1300
C	CONSTRAINT CN 411.		1370
	NCTGT=NCTGT+1		1380
Self.	G(NCTOT)=1AA(1,1)/A11L		1390
100	IF (AZZL.LT.I.OE-10) GG TJ 193		1400
C	CJNSTFAINT UN A22.		1410
	NCTLT=NCTLT+1		1420
	G(NCTUT)=1AA(2.2)/A22L		1430
190	IF (Accl. 1.1		1440
C	CONSTRAINT ON A66.		1450
	NCILI=NCILI+1		1460
	G(NCTOT)=1AA(3,3)/A66L		1470
200	IF (INFULT.4.DR.NI.EC.NCTJT) RETURN		1480
	1F (A11L.LT.1.0E-10) GU TO 230		1490
	NI INI II		1500

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	CUMPOSITE AMALYSIS AND DESIGN PROJRAM - COMAND - COMP4	JULY: 1974	
	RLINCTOT	510	
C	LUNGITUDINAL STRAIN CONSTRAINT - COMPRESSION.	520	
1.1	GINCTOT)+EP1/EP1C-1.	530	
1 ÷	NCTOT=NCTOT+1	540	1.1
C	LONGITLOINAL STRAIN CONSTRAINT - TERSION.	550	
6 ÷	GINCTOTI=EP1/EPLT-1.	560	
9 T A D	RCTGT=ACTGT+1	570	
C	TRANSVERSE STRAIN CONSTRAINT - COMPRESSION.	580	
	GENCIDTJ=L#2/LPTC=1.	590	-
	ACTOT=ACTOT+1	600	
C	TRANSVERSE STRAIN CONSTRAINT - TENSION.	610	1.1
11	G(NCTLT)=LP2/EPTT-1.	620	
· · ·	NC TUT+NC TLT+1	630	
- C - ``	SHEAR STRATE CONSTRATES.	640	
. *	GINETETY #465 (FP3) / GNLT-1.	600	
	15 (INFO.1.T.6) GT TO 160	560	
	NATIONAL CONTRACTOR AND A	670	1.1
	CO 60 8-51-66 THT	640	1.1
	16 (0)	600	
хπ.	CHUTCH C	700	
		710	
	to the second of an in the	710	
. • •	NGTNACTI	720	
	DD DD II-NGARAG	730	
70	n ta na tatina	140	
. • •	ALLIPUTTO A	720	
1	HAG*NAGU Armitikati	760	
	OR THE LEVEL OF A CONTRACT OF	110	- e 1
	DU IDE SAFIFARLT	780	
, u	URAULTNI UP SIRAINO - EGUATION ST.	800	
÷	UU 00 P15143	810	÷.,
	INFIRITED.	820	
	UB 60 R2+1+3	830	
80	INF(K1)=INP(K1)+GP(K1)KZ+KK)#EN(KZ)	840	
1. K. 1	CO GC KL#1,3 CARDEN CARDEN CONTRACTOR	850 -	
		998	
	00 90 82=1,3	870	
- 40	DEP (K1)+DEP (K1)-93 (K1+K2)+THP(K2)	880	
	DEPIMAL2+DEF(1)+Ad2+DEP(2)+AL*Ad#DEP(3)	890	
	GEP2=AH2+GEP(1)+AC2+UEP(2)-AL+AH+DEP(3)	900	
	DEP3=2.+#:+AH+(0EP(2)-DEP(1))+(AL2-AH2)+DEP(3)	910	
	NACENAC	920	
	HINNZ	930	
	IF (G(NL).LT.CT) GO TO 100	940	
C	GRADIENT OF ACTIVE LUNGITUDINAL COMPRESSIVE STRAIN CONSTRAINT.	950	
1.1.1.1	The Charles NACHEAD Control of the second state of the second state of the second second second second second s	960	
•	IF [WAC.EC.BN3] RETURN	970	
1.1.1	ACHAC + FI = A (MAC + K) +DEP1/EPLC	386	1.1
	a IC(NAC)=N1 - Construction of the second	990	
106	AI#N1+1	1000	
	나는 것 같아요. 그 같아요. 그 같아요. 그는 것 같아요. 그는 것 같아요. 그 그 말아요. 그는 것 같아요. 그는 것	s de la composición d	÷.
2.1			

- 1	IF (GINII.LT.CT) 68 TE 119				
C	GRADIENT OF ACTIVE LUNGITUDINAL T	ENSILE	STRAIN	CONSTRAINT.	
	NAC=NAC+1				道:"你们的问题。"
1.11	IF INAL-LOINNED RETURN		. 194 a.		
11.12	A[BAC,K]=A[NAC,K]+DEP1/EPLT	2 C			
	IC (NAC)=N1				
IIO .	NITUTIT	18.1			
e 1	TH INTERIALISELIE THE THE TOTAL STATE				
Υ.	NECTIVE IN ALLIVE IMANSVERSE UNIT	- 462513	E SIRAL	IN CUNSTRAINT	
	TE INTE LC. NUSS DETILS				
	AINAL +KINAINAC +KIANFS 24020		a seco		
	TO ENACTABLE				
126	Alawit.	da da da			에는 것 같아.
	IF (G(N1).LT.CT) GD TB 130	1.14			
C .	WRACIENT OF ACTIVE TRANSVERSE TEN	STLE ST	RATH CO	INSTRUTION.	
5.0	NAC=HAC+1			and a constitute	
	IF INAC.EQ.NII31 RETURN				
	A(NAC+N)=A(NAC+K)+DEF2/EPTT		1.11		
	IC INACIENI	1.0	1.11		an Alaman an Alaman
130	N1=h1+1	- N. A.	18 a. e.		
2.10	IE IGENIJACTACTI GU TV 140	S1 6 - 5			
C .	GRADIENT OF ACTIVE SHEAR STRAIN C.	INSTRAL	NT		distance in the p
	NAC=NAC+1		- + <u>1</u>	and the second	
2	IF (NAC.LO.NN3) REYURN		10 A. 1	and the set	ant i fitti
	216K+1.		1 I I		
1.1	AF (CF3+L(+U+)))UN=-J+				
	ALMAGENIALMACENITOLOGTOCHS/GALL	the second			
1460	CHETIKI.		1. A.		
150	CONTINUE	all and the			
160 -	CUNTINUE				
170	CONTINLE	이 아이는 것	1.1.1		d Paul gen
Ĉ.	CONSTRAINTS LN STIFFNESS.		1.1.2		
1	N1=NCTLT		1.1		ter an
	IF (AllL.Ll.J.Je-Iu) GO TO Iou		1. J.		
C .	CONSTRAINT ON ALL.				
1.1	HCTOT=NCIGI+1				
	G[NCTRT]=1AA(1.1/A11)				
100	16 1472L.LT.1.0E-10) 66 10 193				
C	CUNSTRAINT UN A22.	1.1			
	NGTLT=NCTCT+1				
· · · ·	GINCTUT)=144(2.2)/422L	1.1			a 2 - 7 19
T80	IF [ActL.11.1.05-10] GJ 10 200			alla de la companya. Notas de la companya	
G	CUNSTRAINT ON A66.	. N	10.00		i parte de la
	NUTLIWACTUT41		19 Jan 19		19. S. M.
	GENERUI)=1AAI3.3)/A666				
£06	- IL ITURIALISAGAUKAMIALUGANGTUTI RETU	JAN S			an she she a

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	COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND - COMPA	JULY	197
	1F (G(N1).LT.CTL) GD TU 230		151
C	GRALIENT OF ACTIVE CUNSTRAINT ON 411.		152
	NAC+NAC+1		153
	IF (NAC.LO.NN3) RETURN		154
	IC(NAC)=N]		155
	DO 210 K=1,NOV		156
210	AINAC,K)=C.		157
	DD 220 KK=1, HPLY .		158
	K=LNK(+K)		159
220	A(hAC+F)=2(hAC+K)-CP(1+1+KK)/A11L		100
230	IF (A22L.LT.1.0E-LO) GL TO 200		161
	N1=N1+1		162
	IF (G(N1).LT.CTL) G3 T0 263		163
:	GRADIENT OF ACTIVE CONSTRAINT ON A22.		164
	NAC=NAC+1		165
	IF (NAC.EC.NN3) RETURN		166
	IC(NAC)=N1		167
	CD 240 X+1+NUV		168
246	AENAC,KJ=C.		169
	60 250 KK=1, NPLY		170
	K+LNK(FK)		171
250	A(NAC, N)=A(NAC, N)-CP(2,2,K)/A22L		172
260	IF (ACCL.LT.1.GE-10) RETURN		173
	N1=N1+1		174
	IF (GINI).LT.CTL) GD TO 290		175
C	GRADIENT LE ACTIVE CONSTRAINT UN AGE.	·	176
	NAC=NAC+1		177
	IF (NAL.EG.NN3) RETURN		178
	IC (NAC)=N1		179
	00 270 K-1,NOV		180
270	A(NAC,K)+C.		181
	DO 26C KK=1,NPLY		182
	K=LNK (KK)		183
065	A(NAC+K)=A(NAC+K)-LP(3+3+KK)/ADDL		184
290	CONTINUE		185
	KETURN		186
	END		187

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- Schmit, L.A., Jr., and Farshi, B.: Optimum Laminate Design for Strength and stiffness. Int. J. For Numerical Methods in Engineering, Vol. 7, No. 4, pp. 519-536, 1973.
- Vanderplaats, Garret, N.: CONMIN A FORTRAN Program for Constrained Function Minimization - User's Manual, NASA TM X-62,282, Aug. 1973.
- Advanced Composites Design Guide, Volume I Design, Wright-Patterson Air Force Base, Ohio, January 1973.

COMAND DATA ORGANIZATION:

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Block	Number of Cards	INFORMATION	FORMAT
A	1	Title - Anything may be given here	15A4
В	1	NCALC, NPLY, NDV, NLC, IPRINT	515
С	1	LNK(I), I=1, NPLY	1215
D	1-3	X(I),I=1,NDV	8F10.2
E	1-3	VLB(I),I=1,NDV (Blank card(s) if NCALC.NE.O)	8F10.2
F	1-3	THN(I), I=1, NPLY	8F10.2
G	1	EL, ET, GLT, PRLT	4F10.2
Н	1	EPLC, EPLT, EPTC, EPTT, GMLT, A11L, A22L, A66L	8F10.2
I	NLC	PN(J,I),J=1,3 (One card per loading condition)	3F10.2
		Begin with next set of data - Program terminates if 2 blank cards are read here.	

TABLE 1 - DATA ORGANIZATION

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COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND



TABLE 1 - DATA ORGANIZATION - CONCLUDED

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JANUARY 1973

	HIGH-STRENGTH GI	RAPHITE/EPOX'	Y -[0]		
	v _f	= 0,60			and the
				RT	350°F
Design strengths*	Longitudinal tensile ultimate	Ksi	$\mathbf{F}_{\mathbf{L}}^{\mathbf{tu}}$	180.0	180.0
	Transverse tensile ultimate	Ksi	$\mathtt{F}_{\mathtt{T}}^{\mathtt{tu}}$	8.0	4.0
	Longitudinal compression ultimate	Ksi	$\mathbf{F}_{\mathbf{L}}^{\mathbf{cu}}$	180.0	70.0
	Transverse compression ultimate	Ksi	F ^{cu} T	30.0	12.0
	In-plane shear ultimate	Ksi	F_{LT}^{su}	12.0	6.8
	Interlaminar shear ultimate	Ksi	F ^{isu}	13.0	8.0
	Ultimate longitudinal strain	µin. /in.	$\epsilon_{\rm L}^{\rm tu}$	8,700.0	9,650.0
	Ultimate transverse strain	µin. /in.	$\epsilon_{\rm T}^{\rm tu}$	4,750.0	4,100.0
Elastic	Longitudinal tension modulus	Msi	E ^t L	21.0	18.7
[typical]	Transverse tension modulus	Msi	$\mathbf{E}_{\mathrm{T}}^{\mathbf{t}}$	1.7	0.87
	Longitudinal compression modulus	Msi	E ^c L	21.0	18.7
	Transverse compression modulus	Msi	E ^c T	1.7	0.87
	In-plane shear modulus	Msi	GLT	0.65	0.32
	Longitudinal Poisson's ratio		ν _{LT}	0.21	0, 21
	Transverse Poisson's ratio		V _{TL}	0.017	0. 01 0
Physical	Density	lb/in. ³	ρ	0. 056	0. 056
constants [typical]	Longitudinal coefficient of thermal expansion	µin. /in. /°F	α _L	-0. 21	-0, 005
	Transverse coefficient of thermal expansion	µin. /in. /°F	a _T	16.0	21.8

TABLE 1. 2.1-III. KEY UNIDIRECTIONAL PROPERTIES

References: 1.2-15, -19, -21 *Typical Design Allowable, reference section 1.2.0

1.2.1 14

Table 2 .- Material properties.

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COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

Col	1 5	11	21	31	41	51	61	71
A	DETERMIN	ATION OF LI	MIT STRAIN	IS - G/E C	OMPOSITE			
В	1	1 1 4	0					
C	1							
D	1.0							
E	0.							
F	0.							
G	21000000.	17000000.	650000.	.21				
H	0.	0.	0.	0.	0.	0.	0.	0.
I	180000.	0.	0.					
	0.	-30000.	0.					
	0.	8000.	0.					
	0.	0.	12000.					
k distanti kerat		Carling		and the second				

TABLE 3 - DETERMINATION OF LIMIT STRAINS - G/E COMPOSITE

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COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

Col Block	1	5	11		21		31		41		51		61		71	
A	QUASI-	ISOTE	ROPIC	COMPO	SITE	UNDER	UNIA	XIAL	LOAD							
В	0	12	1	1	2					:						•
С	1	1	1	1	1	1	1	1	1	1	1	1 1				
											<u> </u>					
D	.05							-								
											ļ					
											ļ				_	
E	.00001										<u> </u>		<u> </u>			a sugar
															_	
							ļ				ļ					
F	0.		15.		-15.		30.		-30.		45.		-45.	·	60.	
	-60.		75.		-75.		90.						<u> </u>			
G	210000	00.	17000	000.	65000	0.	.21									
Н	0085	57	.0085	7	017	6	.0047	1	.0184	4	0.		0.		0.	
I	20000.															
										•						
										_						

TABLE 4 - QUASI-ISOTROPIC COMPOSITE UNDER UNIAXIAL LOAD - EXAMPLE 1

COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

lock	1	5	11		21		31	41	51	61	71
A	(0, 45	5, -4	5, 90)	GRAI	PHITE	EPOXY	COMPOSIT	E - EXAMP	LE 2		
В	0	4	3	4	0						
C	1	2	2	3		L					
D	.1		.1		.1						
E	.00001		.00003	L	.0000	1					
F	0.		45.		-45.		90.				
G	210000	000.	170000	000.	65000	0.	.21				
H	0085	57	.00857	,	017	6	.00471	.0184	500000.	0.	0.
I	20000.		0.		0.						
	15000.		-15000).	5000.						
	-15000).	10000		10000						
	0.		0.		20000						

TABLE 5 - (0, ±45, 90) GRAPHITE EPOXY COMPOSITE - EXAMPLE 2

COMPOSITE ANALYSIS AND DESIGN PROGRAM - COMAND

Col lock	1 5	11	21	31	41	51	61	71
A	(0, 30, -3)	0, 60, -60	, 90) GRAP	HITE EPOXY	COMPOSITE	- EXAMPLE	3.	
В	0 6	4 4	0		and the same			
C	1 2	2 3	3	4				
D	.1	.1	.1	.1				
Е	.00001	.00001	.00001	.00001				
F	0.	30.	-30.	60.	-60.	90.		-
G	21000000.	17000000.	650000.	. 21				
H	00857	.00857	0176	.00471	.0184	500000.	0.	0.
I	20000.	0.	þ.					
	15000. -15000.	-15000. 10000.	5000. 10000.					

TABLE 6 - (6, ±30, ±60, 90) GRAPHITE EPOXY COMPOSITE - EXAMPLE 3



Inplane loads N_x , N_y , N_{xy} Load condition k.

Figure 1.- Typical composite loading.



Symmetric



Figure 2. - Typical ply orientation.

DESIGN AND/OR ANALYSIS RESULTS

DETERMINATION OF LIGIT STRAINS . GAL COMPOSITE

PLY ND, THICKNESS PEACENT 1 1000000+01 100,00 THICKNESS - 1000000+01 100,00

> PLY STRAINS S'F' = SAFETY FACTOR CAL = LONGITUDINAL STRAIN EPT = TRANAVERSE STRAIN EPLT = SMEAR STRAIN

PLY NO. EPL S.F. EPT S.F. EPL' S.F. 1 .85714F=03 0.000 1.18000F=03 0.000 .10000E=19 0.000

COMPUSITE STRAINS REFERENCED TO STRUCTURAL AXIS EPX = .85714F=03 EPY = .18000E=03 FPXY = 0.

37

COMPOSITE STRAINS REFERENCED TO STRUCTURAL AXIS EPX = .10000F=03 EPV = -17A47E=01 FPXY = 0.

PLY NO' EPL 3.F. LPLT 3.F. 1 _.R0000F=04 0.000 .47059E=02 0.000 .10000E=19 0.000

COMPOSITE STRAINS REFERENCED TO STRUCTURAL AXIS EPX = -.80000F=04 EPY = .47059E=02 FPXY = 0.

PLY NO: FPL S.F. FPT S.F. EPLT S.F. 1 .10000F-19 0.000 .1000E-19 0.000 .18462E-01 0.000

COMPOSITE STRAINS REFERENCED TO STRUCTURAL AXIS EPX = 0. FPY - 2. EPXY = ,18462E-01

> MEMBRANE STRESSES IN COMPOSITE LCAD COND. SIGH_=Y TAU+XY 1 +18000F405 0. 0. 2 0. -,30000F405 0. 3 0. - 40000E+C4 0. 4 0. 0. . .12000E+05

Figure 3.- Determination of limit strains - G/E composite.

ANALYSIS

OF

SYNMETRIC COMPOSITE PANEL

TITLE DETERMENTION OF LIMIT STRAINS - G/E COMPOSITE

ND. OF PLYS 1 1

PLY PPOPERTIES - ALL PLYS IDENTICAL LONGITHDINA, MODHLUS - 210008-00 TRANSYRGE JODULUS - 170008-07 SHEAR MODILUS - 650008-00 POISSON'S PATIO, L-T - 210008-00 POISSON'S PATIO, T-L - 170008-01

PLY THICKMERSES, OFFWATTONS, AND DESIGN VARIABLE NUMBERS PLY NO. THICKMERS THETA DES, VAR. NO. 1. 10000F101 0.00 1

		STRATN	LIMITS	
LONGITURINAL	STRAIN. CE.	0.	.AND.Lt.	0.
14ANSVENSF	STRAIN.CE.	.0.	.AND.LE.	-0.
SHEAR	STRAIN, CE.	0.	.AND.LE.	.0.

STTFFNFSS LIMITS 411,6E.=0. 422.6E.=0. 466.6E.=0.

10405 1040 Cn .P. -NY 484 .1800at 0, 0. - 30000E+05 0. . °. 5 0. 12000E+05 0

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

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OF

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4

SYMMETRIC COMPUSITE PANEL

TITLE QUAST-ISOTROPIC COMPOSITE UNDER UNTAKIAL LOAD - EXAMPLE 1

ND.	OF OF	PLYS I RAD	CONVETENS	:	12
 Y P	RUDI		8 - 411 PLVS	Int	INTIE A

PLY PROPERTIES _ ALL PLYS IDENTICAL LONGITHDYAN MODULU = .21000E+08 TRANSVERE HONULUS = .17000E+07 SMLAM MONULUS = .05000E+08 POTSSON'S GATIO, L=1 = .21000E+00 POTSSON'S GATIO, T=L = .17000E+01

 PLY TMIRKMESSES, ODIFMATITIONS, AND DESIGN VARIABLE NUMBENS

 PIY ND, THICKTERS THETA DES, VAR, NO,

 1
 .50000F.01

 3
 .50000F.01

 4
 .50000F.01

 5
 .50000F.01

 5
 .50000F.01

 5
 .50000F.01

 4
 .50000F.01

 5
 .50000F.01

 6
 .50000F.01

 7
 .50000F.01

 8
 .50000F.01

 9
 .50000F.01

 10
 .50000F.01

 11
 .50000F.01

 10
 .50000F.01

 11
 .50000F.01

 11
 .50000F.01

PLY STRAIN LIMITS LONGITUDINAL STRAIN.CE. -.55700E-02 .AND.LE. .85700E-02 TRANSUMPSE STRAIN.CE. -.17600E-01 .AND.LE. .47100E-02 SHF49 STRAIN.CE. -.18400E-01 .AND.LE. .18400E-01

STIFFNESS LIMITS 411.cF. 0. 422.cE. 0. 466.ct. 0.

LPADS 1040 CAND, -SXY. NY .200001.485 0. 0. 1

Figure 4.- Quasi-isotropic G/E composite under uniaxial load - Example 1.

	furnishin .	bounder or the	10959
	ACTUAL	REQUIREN	
	Vai IE	VALUE	5.F.
411	.21075E.0R	-0.	100.00
\$55	.17061+. "*	-0.	100.00
806	. 65000F+0A		100.00

-

191

COLFICIENTS OF STEESS-STRAIN ALLATIONSHIPS FELATER TR STRUCTURAL AXES ELATER TH STRUCTURAL ARES E11 = .21n75f+08 C12 = .35828L+06 C16 = 0. C22 = .17061E+07 C26 = 0. Syntthtr C42 = .65000E+06

COLFICIENTS OF STONIN-STRESS PELATIONSHIPS

COMPOSITE ELASTIC CONSTANTS Fx = .21000E.09 5.4 = .17000E.07 GxY = .05000E.00 4.027 = .21000E.00 407 4 17000E.01

Figure 3.- Concluded.

IPPINT NOV 2 30 60 LINDRJ ITRH . 1 PTHIN 61 e 11 -. 10000F+00 .400008-02 -. 10000E-01 DELFUN THETA DHI .10000F+01 .50000E+01 .10100F=03 FORM FORMU .100004 .01 100000 .01 LOWER ROUNDS ON DECISION VARIABLES (VLA) .10000F-04 11 UPPER ROUNDS ON DECISION VARIARIES (VUR) 11 .10000E+05 ALL CONSTRAINTS ARE NON-I INFAD INITIAL FUNCTION INFORMATION OBJ = .601000F+00 DECISION VANIABLES (X-VECTOR) 11 ,50000E-01 CONSTRAINT VALUES (G-VECTOR) -,14809E+01 -. 51908E:00 11 ·. 501348+00 - 94760F .00 71 -. A5310E.00 -. 13232E.01 -. A3447E.00 -. 10x06E.01 -,94760F.00 -. 11958E .01 131 -. 985758.00 -,74557E.00 191 251 -. 74557E.00 -. 11655E .01 -. 83447F .00 .,11655F+01 ·. 69882E+00 311 3/1 -,99217++00 +.11574F .01 - 41188E .00 - 74557E .00 -,74557E+00 -,41188F,00 -,89259E+00 451 -.20184+.00 -. 853105.00 - 892591 .00 -.11076E+01 -.12136E+01 49) 55 -. 85510s.00 -.850144.00 -. 114991.01 -,12342E+01 -,12495E+00

..............

CONNIN

FURTRAN PROGRAM FUR

CONSTRAINED FUNFTION FINIHIZATION 1) -.15496t.01 -.45042E.00 -,91661E,00 -. 49870t +00 - 94012E 00 12258E 01 NASA/AHES RESEARCH FENTER, MOFFETT FIELD, CALIF. 7) -,122381.01 -,94012E+00 131 - 40122400 - 12238401 - 403724400 - 70924500 - 70924500 - 11892501 - 11892501 - 81084500 - 99105500 - 11799501 - 11799501 - 32791500 - 87875501 - 83213500 VERSION IT JULY, 1975 19) .,13694E.01 -.81084E.00 -.10921E.01 -.32791E.00 -.70924E.00 25) 371 431 49) 551 . 82874E.00 -. 11713t +01 CONSTRAINER FUNCTION MINIMIZATION CONTROL PARAMETERS THAX NCON USIDE ICNDIR NSCAL NFDG ITER . n8J = .52504E.00 0 DECISION VARIABLES (X-VECTOR) .45753F-01 11 CONSTRAINT VALUES (G-VECTOR) - ILKIN -,15496E+01 -,45042E:00 -,91661E:00 -,15116E+01 11 .94012E.00 .12238E.01 75 -,49870E+00 . 12238E.01 -,83213E+00 -1000UE=02 13) . 94012E.00 -,13694L+01 DABFUN 19) ... 98372E.00 .,70924E.00 .13694E.0160000E=03 25) .,709241.00 .11892E.01 -.81084E.00 -.10921E+01 -.10921E.01 -.65582E+00 -.32791E.00 -.70924E.00 31) .11692E.01 -.81084E.00 -.11799E.01 37) -. 99105E+00 -.709246.00 -.87703E+00 -.87703E.00 -.11230E+01 -.11713E.01 -.12676E+01 -11799E.01 -.32791E.00 -87875E.01 -.83213E.00 -83213E.00 -.82874E.00 43) 491 551 ITFR & .52504E:00 NO CHANGE IN UBJ nBJ s DECISION VAPIABLES (X-VECTOR) 1) .43753E-01 CONSTRAINT VALUES (G-VECTOR) -.916512.00 -.13116E+01 -.10000E+01 -.15013E+01 -.12230E.01 -.83213E+00 -.15013E+01 -.44870E+00 -.83213E.00 -.13694E+01 -.63083E+00 -.10044E+01 .15496F.01 .45042F.00 1) -.49870E+00 -.94012E.00 71 -,94012F+00 -,98372E-00 - 12238E .01 .70924E .00 13) -,13694E,01 -,63063E+00 19) .11892E.01 .81084E.00 .11799E.01 -,81084E,00 -,10921E+01 ., 70924E.00 25) -.11892F.01 -,10921E.01 . 65582E+00 31) -.927032.00 -.127276+01 -.100002+01 -.145876+01 -.119586.01 -.855102+00 -.143872+01 -.561342+00 . 32791E.co -,99105C+00 -. 70924E+00 43) -.11799F.01 -.32791E.00 -.67875E.01 -.83213E.00 -.83213E.00 -.82874E.00 -,70924E.00 -,87703E+00 -,56134E+00 *,13232E+01 -,67678E+00 49) . 877036.00 .11230E+01 117136.01 .12676E+01 -,10038E+01 -,67678E+00 .10058E+01 .98575E+00 .10806E+01 - 698821+00 - 706211+00 - 70021E+00 10078E+01

*,10078E+01

-,110768+01

.,99217E+00

-,12136E+01

-,20184E+00

-. 10000E+01

1) .43753E-01 CONSTRAINT VALUES (G-VECTOR) -,13110E+01 .10000E+01 .15013E+01 -. 1501 JE+01 -,13694E+01 -. . 30.31.00 -, 03063E+00 -. 10044E.01

.525n4F.00

Figure 4.- Continued.

NO CHANGE IN OBJ

........... .10921E+0110089E+01 .709248+00 .,99105L+00 -,10089E+01 -,87703E+00 .11230E+01 *.12441E+01 -.87703E.00 -.11230E+01 +,12441E+01 .87875E=01 -,12676E+01 -,14203L-04 -,10000E+01

DECISION VARIABLES (X-VECTOR)

1

nBJ =

ITER .

R 目 ROU U RODUCIBILITY T AGE 53 OF

POOR THE

39

-,49870E+00 -,10044E+01

-,10000E+01 -,15013E+01

-,15013E+01 -,49870E+00

-. 63063E+00 -. 10044E+01

-,12441E+01 -,87875E-01

-,10044E+01 -,98372E+00

-,12441E+01 -,87875E-01

.10044E+01

. 05582E+00

............ -,10089E+01

*,11230E+01

-.14203E-04

..............

-,66426E+00

-,10089E+01

.11230E+01

-,14203E-04

..........

-..........

.10089E.01

..............

-,12441E+01

.,10000E+01

...........

.10089E+01

.,99105E+00

.,12441E+01

-.10000E+01

ITEN a a CHJ # .525n4F:00 NO CHANGE IN OBJ

DECISION VARIABLES (X-VECTOR)

11 .457534 .01

CONSTRAINT VALUER (G-VECTOR) 1) -.15476£401 -.45042£.00 -.91661£.00 -.15116£401 -.10000E+01 -.15015£401 73 -.48070E400 -.94012£.00 -.12258£.01 -.85213£400 -.15013£.01 -.49070E400 19) -.80372£400 -.12258£.01 -.87213£.00 -.1694£401 -.5003£400 -.10044£401 19) -.80372£400 -.10474£.01 -.1584£.01 -.51003£400 -.10044£401 -.98372£400 251 -.70924£400 -.11892£.01 -.81084£.00 -.10921£401 -.65622£400 -.66426£400 251 -.11892£41 -.81084£.00 -.10921£401 -.65562£400 -.66426£400 371 -.9105£401 -.11794£.01 -.3791£.00 -.70924£400 -.10089£401 -.99105£401 373 -.9105£401 -.81084£.00 -.70924£.00 -.70924£400 -.10089£401 -.99105£401 353 -.11794£41 -.81084£.00 -.87703£400 -.11230£401 -.12641£401 49 -.87875£01 -.83213£.00 -.87703£400 -.11230£401 -.12641£401 553 -.83213£400 -.42874£400 -.11713£401 -.12876£401 -.12441£401 -.87875£201 553 -.83213£400 -.82874£400 -.11713£401 -.12876£401 -.12491£401 -.12000£401

FINAL OPTIMIZATION INFORMATION

08J # .525036F+00

OECISION VARIABLES (X-VECTOR)

1) .43753f -01

00E+01 +.15013E+0
00E+0115013E+0
13E+01 0,49870E+
631+0010044E+P
44E.01
82E+00
26E.00 10089E+0
89E+01
30E+01 -,12441E+0
41E+01 =.87875E=0
03F-0410000E+0

40

THERE ARE 1 ACTIVE CONSTRAINTS CONSTRAINT NUMBERS ARE

59

THERE ARE O VIOLATED CONSTRAINTS

THERE ARE O ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION ABS(1=(9J(I=1)/ABJ(I)) LESS THAN DELFUN FOR 5 ITEMATIONS ABS(0BJ(I)=0BJ(I=1)) LESS THAN DABFUN FOR 5 ITEMATIONS

NUMBER OF ITERATIONS . 4

DRJECTIVE FUNCTION WAS EVALUATED	5	TIMES	
CONSTRAINT FUNCTIONS WERE EVALUATED	5	TIMES	
GRADIENT OF OBJECTIVE HAS CALFULATED	s	TIMES	
GRADIENTS OF CONSTRAINTS HERE CALCULATED	s	TIMES	

Figure 4.- Continued.

			LAILN IN	STRUCTURES N		
911	*	.12384E-0A	012 × 927 ×	.38530E.07 12364E.06	016 = 026 =	.19630E-14 .62547E-14
		SYMMETRIC			040 .	.324352.00
		co	HPOST 7F	LASTIC CONSTA	NTS	
EX		*0877E+07	Fy #	.80877E+07	CXA #	.30831E+0/
YXUM		. \$11022+00	NITY .	-31162E+00		

SYMMETRIC	C 21		49576L	07	C20	:	15564E.00 .30831E.07
COEFICIE****	nF	578	IN-STRESS	RELAT	104	5+1	PS

	COEFICITAT	S OF ST	SS-STRAIN F	RELATIONS	HIPS	
C11 •	. N9576E +07	C12 #	27914440	AXES 7 C10 7 C20	: .:	38374E=03 15584E+00

		46.001Ture (s		
	VALUE	VALUE	S.F.	
411	.47030E+07	0.	100.00	
A22	470318+07	0.	100.00	
466	.16187E.07	n.	100.00	

	COMPOSITE	MEMERANE	STIFF	NESSES
	ACTUAL	RFQ	TREA	
	VALUE	VA	LUE	S.F.
411	.47030E+07	0.		100.00
422	470318+07	0.		100.00

LUAD COND.	SIGM.	-X	SIGHANY	TAUex	۲
,	,3809	4F:05 0	•	٥.	
c0	POSITE	FHERANE	STIFFNES	SES	
	ACTUAL	RFG	ITREA		

WEMBHANE STRESSES IN COMPOSITE

	76694r=04	100.000	.31655E=02	1,488	-, 335005+02	
9	.766945-04	100.000	.31655F=02	1,488	.53500E=02	
10	.10539r-02	8,132	429615-02	1,096	-,30888E=02	1.2
11	- 1053902	8,152	429611-02	1.090	.30888E-02	
12	146775-02	5,839	47099E-02	1,000	.12648E=08	10
COMPOST	TE STRATUS REF	ERENCED TO	STRUCTURAL AX	15		
EPX #	47099E-02	EPY = -1	4477E-02 FPE	1 = .,7	#776E=10	

PLY	NO.	FPL	5.F.	EP1	S.F.	EPLT	S.F.
	1	470995-02	1.820	.14677E=02	11,991	-,74776E-10	100,000
	2	429615-02	1,995	.10539E-02	16,700	-, 10888E=02	5,957
	3	429615-02	1,995	10539E-02	10,700	50-38880L	5,957
	4	\$1655F=02	2.707	.76894F=04	61,412	-,53500F-n2	3,459
	5	.316555-02	2.707	76694E=04	61,415	.53500E=02	3,439
	ė.	162115-02	5,287	16211E-02	2,905	01777E-02	2,978
	7	102115-02	5,287	,16211F=02	2,905	.01777E=02	2.978
	8	766948.04	100.000	\$1655E=02	1,488	-,53500t+02	3,439
	9	76694F-04	100.000	31655F=02	1,488	\$3500E+02	5,439
1	0	. 10539r - 02	8,132	429618-02	1,096	-, 30888E=02	5,957
1	1	-,10539==02	8,152	429611-02	1,096	.30888E=02	5,957
1	2	.146775-02	5,839	47099E-02	1.000	.12648E=08	100.000

PDT & TRANSVERSE STRAIN
FPLT & SHEAR STRAIN

1	. 43/538 -01	0.25
2	.43744E-01	8,33
	.03753E-01	8.55
4	. 13753E-01	8,33
5	.a3753F-01	8,35
	.037536.01	8,35
7	#3753E=01	8.55
	. 43753E-01	8,33
	43753E-01	8,33
10	#3753E-01	8.31
11	a \$753E-01	8.53
12	.a \$753E.01	8.55
THICKNESS	\$ -5250aE+00	100,00

		PLY INFORMAT	ON	
PIY	NO.	THICKNESS	PENCEUT	
	1	.a37538.01	8,35	
	>	43754F-01	8.51	

		PLY INFORMATT	0N
r	NO.	THICKNESS	PENCENT
	1	a3753F-01	8.35
	2	43754E-01	8.33
	3	43753E-01	8.55
	4	13753E-01	8.33
	5	a3753F-01	8.35
	6	037536-01	8.35
	7	#3753F-01	0.53
		#3753F-01	8.33

DESIGN AND/OR ANALYSIS RESULTS

TITLE QUAST.	-TSOTROPI	c c n	POSTE	UNDER	INTAXIAL	LOAD	•	EXAMPLE	1
			PLY I	NFORMA	TTON				
	PIY	NO.	THIC	KVESS	PENCE	T			

NF

SYMMETRIC COMPOSITE PANEL

5

4

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TITLE 0, 45, -45, 90 GRAPHITE EPOXY CUMPOSITE . EXAMPLE 2

NO. OF PLYR # 4

PLY PHOPEDTIFS = ALL PLYS IDENTICAL LONGITUDINAL MODULUS = ,21000F+08 TRANSVERSE MCDULUS = ,17000E+07 SHEAN HODILLS = ,17000E+07 POISSON'S RATIO, L=T = ,21000E+00 POISSON'S RATIO, T=L = ,17000E+01

PI Y +5

THTPKNESSES.	ORIENTATIONS.	AND DES	IGN VARIAB	LE NUMBE
PLY NO.	THICKNESS	THETA	DES. VAR	0.
1	.10000F.00	0,00	1	
2	.10000F.00	45,00	2	
3	.100n0F.00	-45,00	5	
4	.100a0E.00	90,00	5	

	P1 ¥	STRATH LTHI	IS	
LONGITUNINAL	STRAIN. OF	85700E02	.AND.LE.	.857001-02
TRANSVERSE	STRAIN. CF.	17600E.01	.AND.LE.	.47100E=02
SHEAD	STRAIN.CE.	.18400E.01	.AND.LE.	.18400E-01

STIFF	WESS LIMITS
A11.6E.	.5000nE+00
422,GE.	0.
446.Et.	0.

			LOADS	
I.OAD	COND.	NX		A.2.Y
	1	.2000nE+n5	0.	0.
	2	.1500nE.n5	150n0F+05	.50000E+04
	3	+.1500nF+05	.10000E+05	.10000E+05
		0	0	20000E+05

Figure 5.- (0, ±45, 90) Graphite epoxy composite - Example 2.

.

40'	1 P1	S.F.	FPT	5.1.	EPLT
1	47019F-02	1.823		508.5	.25485t=02
ż	38460F+03	22.280	1963AF-02	549.0	-,10983E-01
3	190381 -02	4. 164	SRUBUF-01	12.245	.10983F-01
4	. h2811r=02	1.564	470195-02	1,002	-,23485E-02
116044	P SIMAING MEPT	MENLED #	I STHUETURE PI	110	
	4 40. 1 2 3 4	9 40 10 10 10 10 10 10 10 10 10 10 10 10 10	<pre>v 40' FPI S.F. 1 47014F-02 1.833 2 38464F-03 22.280 3 19038F-02 3.564 4 .6281F-02 1.564 4 9051TF ST941~4 4/2FF9E4(ED *f</pre>	y 40 FPI 5.F. FPT 1 470197=02 1.823 628111=02 628111=02 2 354607=03 22,280 106386=02 1.64 544647=03 3	y y

4	19638t-02	1.564	470191-02	1,002	-,23485E

Cotpr = _47014F-02 FPY = _ APA11F=02 LbXA z .234036-02

COMPOSITE STRAINS REFERENCED TO STRUCTURAL AXIS FPX = _41501F-02 EPY = -21131F-02 FPX1 = -109121-09

				LOAD CONC.	3		
P. y	Pr(1)	FPL	S.F.	4 PT	5.F.	EPLT	5.F.
	1	417364 -02	2.053	471576-07	.999	.46970E-02	3,917
	5	201955-02	3.272	20774E-32	8,472	\$0+31988.	2,070
	3	- 207745-02	3,125	26195F-02	1,798	08893E-02	2,070
	4	971571-32	1.817	417565-02	4.217	40970E-0d	5 917

COMPOSITE STRATES "FERENCED TO STRUCTURAL AXIS For = __41730F-02 For = _47457F-07 For = _46970E-02

				INAD COND.	4		
PIY	NU.	FPL	S.F.	FPT	S.F.	EPLT	5.F.
	1	- 169124-09	100,000	. \$22061-UQ	100,000	.45959E=02	1,959
	2	469705-02	1.825	469701-02	5.747	=. 47557E=09	100.000
	3	- 409704-02	1.825	469701-02	1,003	-,13359E-08	100.000
	4	582701.09	100.000	79564F-09	100.000	-,91919E-02	1,959

Figure 5.- Concluded.

		MEMHRA	NE ST	PESSE	S IN COMP	OSITE			
	LOAD COND.		IGMA		SIGHATY		TAU-XY		
	1		3450	SF105	0.	0.			
	2		2590	F.05	.25945E	+05 .8	6482E+04	4	
	3		2594	57.05	17296E	+05 .1	1296E+0	5	
	4	0.			0.		4593E+0	5	
		COMPOS	ITE .	ENBRA	NE STIFFN	ESSES			
		ACTU	JAL	R	EGUIREN				
		VALL	E		VALUE	S.F.			
	411	.58090	F+07	.5	0000F+00	11.0	2		
	122	38556	E+07	0.		100.0	00		
	466	.21290	F+07	0.		100.0	00		
	Coth				etnatu p				
	C. I.C.	EFI			DIST TUP I	AVES			
C 1 1	. 10048	.08	613	10 01	LIGORE . OT	CIA	.461	600E-03	
			125	: :	ALASE OT	C26		925F+00	
	SUMM	THIC	cre			CAD		8251.07	
							1		
	COLF	CIENTS	OF	TRAIN	STRESS R	ELATIONS	HIPS		
		REL	ATEn	TO ST	RUCTURAL	AXES			
911	.120148	06	912		61086E.07	916		345E-14	
			222		18101E-06	426	93	100E-14	
	SYMME	TRIC				960	8 .271	150E-06	
	04					400			

SYMMETRIC	155 =	18101E.06	460	;	.93100E-1 .27156E-0
cor	POSTTE	ELASTIC CONSTA	NTS		

	C (PPOSTTF	ELASTIC CONSTA	NTS	
Fx	.83235t+07	++ =	.55246E.07	Gry #	. 36825E+07
NUXY	.50845E+00	MINYY =	33747E.00		

0, 45, -45, 90 GRAPHITE EPOXY COMPUSITE . EXAMPLE 2

PLV INFORMATION THICHNESS

,159 SHE .00

.18014E.00

.18014F+00

-58507F-01

PLY STRATNS S'F & SAFETY FACTUR PDL = LONGITUPINAL STAIN FDT = TRANSVERSE STAATN EPLT = SHFAR STRAIN

I CAD COND.

21131F-02

102:58-02 10215+-02 41501+-02

I MAD COND. 2

PEHCENT

27.56

10,12

......

100,00

1

8,329

4.011

4.011

-,10912E-04 100,000

.02042E-02 2.955 15167E-08 100.000

2,955

S.F. 1,835 1,675 1,675 1,675 1,835

-.02092E-02

e 13. 1

\$

PLV NO.

1

2

5

e

PLY ND.

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2

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4

ø

S.F. 2.062 9.390 8.390

4.054

41561F=02

102151-02

102150-02

-,211310-02

TTTLE

DESIGN ANALYSIS RESULTS

DESIGN

114

SYMMETRIC COMPOSITE PANEL

0

TITLE n, 3n, -3n, 60, -6n, on GRAPHITE EPOLY COMPUSITE - EX. 3

VO. DE DLYS . DAN CONDITIONS . 4

DLY PHOPFETTES _ ALL PLYS IDENTICAL LONGITINTYAL MODULUS _ .41000F+08 TRA-SYENEE MODULUS _ .17000E+07 SHEAN MUNUUS _ .05000E+00 POISSUMIS PATEA, L=T _ .21000E+00 POISSUMIS PATEA, T=L _ .17000E+01

PLY THIPNNESSES, OPIENTATIONS, AND DESIGN VAHIABLE NUMBERS PLY "", THICKNESS THETA DES, VAH, NO,

1	.100a0s .00	0.00	1
5	.100a0s.00	30,00	2
3	.100n0r.00	+30,00	2
	.100001 .00	60,00	5
5	.10ConF.00	-60,00	5
*	.10°00F.00	90,00	-4

	PLY	STHAT'S LTHE	15	
THANSVERSE	STRATH.CF.	85700E_02 1/600E_01	AND LE	.85700E+02 .47100E+02
RHESO	STRAIN.CE.	.18400E.01	.AND.LE.	.18400t.01

Stiffus SS (1m) TS 411.ct. .5000ct.06 422.cf. 0. 466.cf. 0.

			LOADS	
040	Cn 4D.	NY .	*1.9	- X Y
	1	.200006	•n.	-0.
	5	.1500nt . n5	-,15000F+05	.50000E+04
	4	.1500pf.A5	.10000E+05	.10009E+05
		0.	e.	.20000E+05

DESTGA	AND/OR	ANALySTS	RESULTS
	E M I I I I I I I I I I		

TITLE 0, 30, -30, 60, -60, 98 GRAPHITE EPOXY COMPOSITE - EX, 3

		PLY INFORMAT	TON	
PLY NO.		THICKNESS	PERCENT	
1		.11368E+00	21,35	
5		.91215E-01	17,13	
3		,91215t-01	17,13	
a		.11328E+00	21,28	
5		.11328E+00	21.28	
6		97205t-02	1.85	

HICKNESS	=	.43239E+00	100,00	

	Y STRAINS
S'F	SAFETY FACTOR
f pl	# LONGITURINAL STRAIN
Ept	. TRANSVEPSE STRAIN
FOLT	# SHEAR STRAIN

PL . NO.	EPL	5.5.	LAAD COND.	1 5.F.	EPLT	5.F.
1	.45559F=02	1.977	-,19309E=02	9,115	· 14142E=10	100,000
2	27677F=02	3,094	36468E-03	48,262	-, 34255E+02	5, 391
3	.27677c=02	3,096	36468E=05	48,262	,54255E=02	5,391
4		23,500	.27677E=02	1.702	*,54255E=02	3, 391
5	. 36468r.03	23,500	27677E=02	1,702	54255E+02	5,341
	·. 1930%r.02	4,438	433395-02	1.087	.12260E-08	100,000

COMPOSITE STRAINS REFERENCED TO ETRUCTURAL AXIS Epx = _41339F.n2 EPY = - 19109E.02 FPXY = ...19195E.10

T

PLY	NO'	FPL	5.5.	FPT	2 S.F.	EPLT	S.t.
-	1	469865-02	1,824	606331-02	2,903	.27193E=02	0.700
	2	518565-02	2.690	45503E-02	3,868	#. 79604E=02	2,311
	3	.83061==03	10.318	21953F-02	8.017	.106BOE=01	1.723
	4	21953r=02	3.904	.83062F-01	5,670	-,10680F=01	1.725
	5	- 45503r-02	1.583	31856F-02	1.479	.19604E=02	2.511
	6	606335-02	1,413	46986E.02	500,1	-,27195E-02	6,760

COMPOSITE STHAINS "EFERENCED TO STRUCTURAL AXIS EPX = .469866+0" EPY = .60633F=02 FPKY = .27143L=02

PLY NO.	EPL	5.F.	LOAD COND.	3 S.F.	EPLT	S.F.
1	-,421591-02	2.033	.45249E-02	1.041	.54386E=02	5,303
5	32433==05	26.423	15298E-04	100.000	,10289E+01	1,788
3		1,950	46947E-02	1.003	.48504E-02	3,794
4	469475=02	1,825	418575-02	4,013	.48504E+02	5,790
5	.15297F=04	100.000	. 32433F.03	14,522	-,10289E-01	1,788
	85249F=02	1,894	-42159E-02	4,175	.,54587E=02	3,383

Figure 6.- (0, ±30, ±60, 90) Graphite epoxy composite - Example 3.

Figure 6.- Concluded.

	c	-POSTTF	ELASTIC CONSTA	+ 15	
FX	.80A812+07	Ev :	.010496.07	GEV #	. 54537E+07
* LIXY	. 445531 .00	NIVY .	\$1378E.00		

- CONFILCIENTS OF STOALNESTRESS RELATIONSMIPS HELATED TO STANCTURAL AFES CII = .11537F=06 (1) = .51090E=15 OP2 = .10380E=06 (120 = .10207E=14 Symmetrate (120 = .28955E=00
- 「ハトFICIENTS ハF STDFSS_STHAIN RELATINUSMIPS イドレムモデル TA STRUCTINAL AXES Cil = 10077E+04 Cl> = 31620E+07 ClD = 884078E#04 アンコ = 70071E+07 C20 = 34145E=01 SventTaic Cob = 434537E+07

	C.: HPOSTTE	MENARONE STIFFNE	SSES
	ACTUAL	REGUTREN	
	VALIF	VAL LIF	5.1.
411	. 530481 .07	.50000F+00	10,75
\$22	.317P4t .07	3.	100.00
Ana	.18587E.C.	C .	100.00

	HENHRANE STRESSES	TN COMPOSIT	ŧ
LOAD CONC.	SIGMANY	SIG"A=Y	TAU=XY
1	. 375A7F . 05	0.	0.
2	.26175F .05	+,20175E+05	.9391/L+04
	28175F105	187A31+05	18785E+05
-0	°.	0.	\$7507L+05

COMPOSITE STHAINS HEFFELNCED TO ETRUPTURAL AXIS For # -.14195F-10 FOY = _boade-10 Foxy = .1087/E=01

				I MAD COND.	4		
PIV	Arch .	FPL	5.F.	FPT	5.F.	EPLT	S.F.
	1	·. 19195F · 10	100.000	.00884E-10	100.000	.10877E=01	1.692
	5	.4710fr=02	1.820	47100E-02	5.737	->4586E=02	3,305
	5	47100r=02	1.420	471U0E-02	1,000	.54586E=02	5.303
	4	47100r=02	1,820	47100F-U2	3,757	543878-02	3.585
	5	-,47100r-02	1.820	.47100F-02	1.000	-, 34387E=02	3.303
	÷	- 980745-09	100,000	10204F -08	103,000	-,10877E=01	1,692

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Figure 7.- Ultimate tensile strength F_x^{tu} high-strength graphite/epoxy - $\left[0_1/\pm45_j/90_k\right]^x$ family.



Figure 8.- Ultimate compressive strength F_X^{cu} high-strength graphite/epoxy - $\left[0_i/\pm 45_j/90_k\right]$ family.







Figure 10.- Extensional modulus E_x high-strength graphite/epoxy $-\left[0_1/\pm 45_j/90_k\right]$ family.



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FIGURE 11, - 'COMAND' BLOCK DIAGRAM.

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