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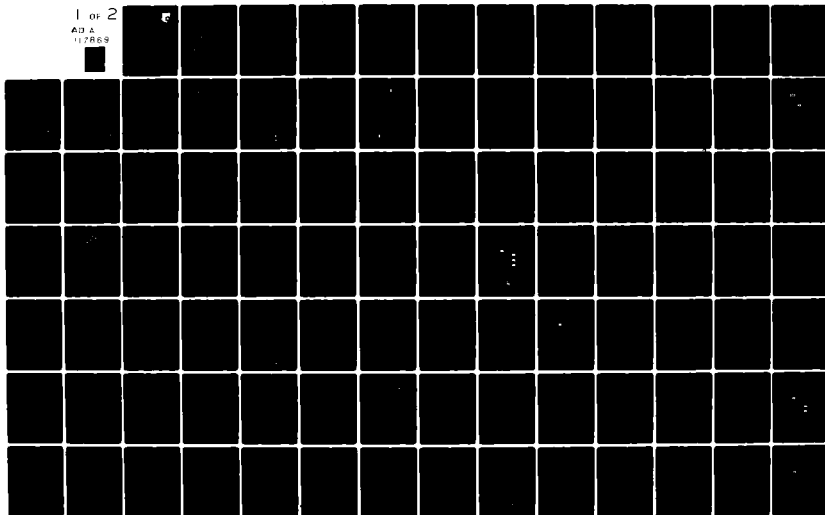
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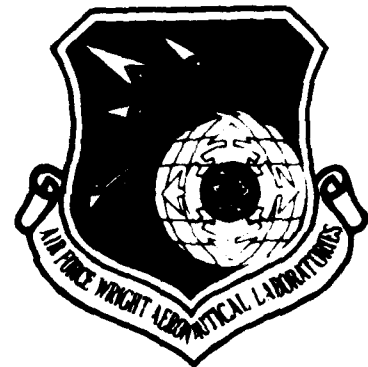
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REVISED INSTRUCTIONS FOR TI-59 COMBINED CARD/MODULE
CALCULATIONS FOR IN-PLANE AND FLEXURAL PROPERTIES OF
SYMMETRIC LAMINATES

STEVEN L. DONALDSON

MECHANICS AND SURFACE INTERACTIONS BRANCH
NONMETALLIC MATERIALS DIVISION

JUNE 1982

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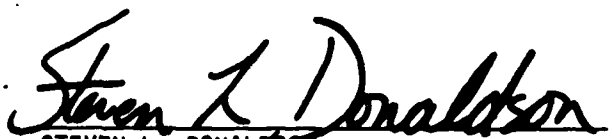
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This technical report has been reviewed and is approved for publication.



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report is an updated and expanded version of AFWAL-TR-81-4116. It contains descriptions and step-by-step instructions for the simple, combined use of magnetic cards with the composite materials module, designed for use in TI-59 programmable calculators. Users do not have to be familiar with TI-59 programming. These programs contain the key calculations of the stiffness and strength of unidirectional and symmetrically laminated composites, including sandwich core laminates. Both in-plane and flexural loadings can be applied, giving in-plane and flexural response. Instant calculations can be made for practical		

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use. With the use of a printer, the results can be immediately and permanently recorded. The equation numbers in this report are from Introduction to Composite Materials by Tsai and Hahn, published by Technomic Publishing Company, Westport, Connecticut, July 1980.

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FOREWORD

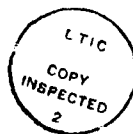
This report was prepared in the Mechanics and Surface Interactions Branch (AFWAL/MLBM), Nonmetallic Materials Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. The work was performed under the support of Project Number 2419, "Nonmetallic Structural Materials", Task Number 241903, "Composite Materials and Mechanics Technology".

The programs are written for Texas Instruments calculators (TI-59's) to operate with or without a printer. However, the use of a printer is highly recommended. The specially designed "Composite Materials Module" must be installed in place of the standard "Master Module".

This report supersedes AFWAL-TR-81-4116, coauthored by Stella Gates and Stephen Tsai. Many of the programming flow charts and example problems in this report are taken from that original publication.

The equations and table numbers which appear in the flow charts and program descriptions are the same as in Introduction to Composite Materials, by Tsai and Hahn, published by Technomic Publishing Company, Westport, Connecticut, July 1980.

Many thanks to Lisa Wilson for skillfully typing the entire report, and to Stephen Tsai for his willingness to help my understanding and presentation of the material.



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NOMENCLATURE

- A_{ij} = laminate in-plane modulus; $i,j = 1,2,6$
unit ply in-plane compliance; $i,j = x,y,s$
- a_{ij} = laminate in-plane modulus; $i,j = 1,2,6$
unit ply in-plane compliance; $i,j = x,y,s$
- A_{ij}^* = normalized laminate in-plane modulus; $i,j = 1,2,6$
- a_{ij}^* = normalized laminate in-plane compliance; $i,j = 1,2,6$
- c = half thickness of core in equivalent number of plies
(fractional c is allowable)
- D_{ij} = laminate flexural modulus; $i,j = 1,2,6$
- d_{ij} = laminate flexural compliance; $i,j = 1,2,6$
- D_{ij}^* = normalized laminate flexural modulus; $i,j = 1,2,6$
- d_{ij}^* = normalized laminate flexural compliance; $i,j = 1,2,6$
- E_i = unit ply engineering constants, $i = x,y,s$
- E_i^o, E_i^f = effective in-plane and flexural Young's and shear moduli;
 $i = 1,2,6$
- F_{ij}, F_i = strength parameters in stress space; $i,j = x,y,s$
- F_{xy}^* = normalized failure interaction term
- G_{ij}, G_i = strength parameters in strain space; $i,j = x,y,s$
- h = total laminate thickness
- h_o = unit ply thickness

NOMENCLATURE

- I_ϵ, R_ϵ = strain invariants
 M_i = moments; $i = 1, 2, 6$
 N_i = stress resultants; $i = 1, 2, 6$
 n = total number of plies
 Q_{ij} = on-axis unit ply modulus; $i, j = x, y, s$
 R_t, R'_t = strength ratio roots of quadratic failure criteria
 S = unit ply shear strength
 S_{ij} = on-axis unit ply compliance; $i, j = x, y, s$
 t = distance of outer surface of ply from laminate mid-plane in equivalent number of plies
 U_i = invariant linear combinations of unit ply moduli; $i = 1$ to 5
 X, X' = unit ply longitudinal tensile and compressive strengths
 Y, Y' = unit ply transverse tensile and compressive strengths
 ϵ_i = on-axis strain for a unit ply; $i = x, y, s$
 laminate strain; $i = 1, 2, 6$ ($\epsilon_i = \epsilon_i(z)$)
 $\epsilon_i^o, \epsilon_i^f$ = in-plane and flexural surface strain; $i = 1, 2, 6$
 k_i = flexural curvature; $i = 1, 2, 6$
 ν_x = unit ply longitudinal Poisson's ratio
 ν_{21}^o, ν_{21}^f = major in-plane and flexural Poisson's ratios

NOMENCLATURE

σ_i = on-axis stress for a unit ply; $i = x, y, s$
 laminate stress; $i = 1, 2, 6$ ($\sigma_i = \sigma_i(z)$)

$\bar{\sigma}_i$ = average in-plane stress; $i = 1, 2, 6$

$\sigma_t^o, \sigma_t^{o'}$ = allowable stresses, in-plane loading

σ_i^f = surface stress, flexural loading; $i = 1, 2, 6$

$\sigma_t^f, \sigma_t^{f'}$ = allowable surface stresses, flexural loading

θ_t = ply orientation w.r.t. the 1-axis

SECTION I

INTRODUCTION

With the use of the Materials Laboratory composites module and Combo cards, the task of calculating in-plane and flexural strength and stiffness properties can be done on a pocket calculator, namely the TI-59. This is not intended to replace the larger programs for more complex hygroscopic, thermal, and other types of analysis. However, the structural designer now has an ability to quickly evaluate the effects of materials selection, laminate stacking, and hybridization on a composite laminate's properties. That is, he can rapidly calculate the in-plane and flexural stiffness matrices, plot failure envelopes, and calculate strength ratios to show a laminate's load carrying abilities. The laminate properties calculated can then be compared to other laminate properties or even isotropic material properties (such as aluminum) to assist the designer in selecting the material and stacking sequence for the desired overall properties. The turn-around time, cost, and access to large computers are hence avoided. The designer can rapidly evaluate many laminates at his desk or drafting table.

The use of a printing cradle (i.e., the PC-1000) is highly recommended, but not necessary, for using the composites module and Combo cards. The printer quickly writes out input and calculated values for permanent storage. If the printer is not used, numbers must be displayed individually and recorded by hand. All Combos designated with a "P" are compatible with the printer. Users without a printer should find the non-"P" designated Combos are easiest to use.

All input, calculations, and output are done by the calculator using a combination (hence "Combo") of two key elements--the Composite Materials Module, which fits into the back of the TI-59, and a set of magnetic Combo cards read by the calculator. The module consists primarily of subroutines called by the programs stored on the cards. The cards are responsible for data input, proper data storage, selective calling of subroutines from the module, and data output. The module is available from the Materials Laboratory (AFWAL/MLBM) for those seriously interested in using it. The Combo cards can be keyed in, recorded, and labeled by the user with little difficulty. Brief instructions for users not familiar with TI-59 programming are given in Appendix C. Complete listings of the programs for each Combo are given in this report, Appendix D.

The TI-59 calculator has a large amount of memory divided into two parts: program memory, up to 480 steps, and data memory, up to 60 registers. These are the initial values or the partitioning set when the calculator is turned on. All Combo cards use this partitioning. These memory locations are also divided into "banks" as follows:

- Bank 1: Program memory, steps 000-239
- 2: Program memory, steps 240-479
- 3: Data registers, 30-59
- 4: Data registers, 00-29

Each magnetic card can record one "bank" per side, or two banks per card. All Combo cards are program steps recorded in banks 1 and 2. When the side of a card is read into the calculator, the bank that is stored on that side of the card replaces the memory (and only that bank) that was in the calculator. Note, then, that reading in a Combo card which is program memory in banks 1 and 2, does not affect the values stored

previously in the data registers, banks 3 and 4.

Use of the Combo cards is divided into two main steps. First, the user must record individual ply properties in their proper data registers. This is done using Combo 0, 1, or 1P. Next, a laminate program (Combo 2, 2P, 3, 3P, 4, 4P) is read into the TI-59 and calculates laminate properties using the ply data already in the data registers. The only ply properties in the data registers that are recalled by the lamination programs are U_i ($i = 1-5$) stored in locations 30-34; G_{ij} ($i, j = x, y$) stored in locations 44-49, and h_0 stored in location 59. These quantities are defined in the section describing Combo 0. Note that once Combo 0, 1, or 1P are used to enter ply properties into their proper registers, these registers (specifically, bank 3) can be recorded onto their own magnetic card. If this is not done, a user would use Combo 0, 1, or 1P to record ply properties, then read in one of the laminate Combos, hence writing over the 0, 1, or 1P program in the program memory. This is satisfactory if the user only wishes to work with one material. If the user is working with a lamination program and wants to change materials, he would have to re-read Combo 0, 1, or 1P (and hence wipe-out the lamination program), key in the new material (which then replaces the old material properties in the data registers), and re-read the lamination Combo card. This is not always convenient and, in the case of the hybrid Combos 4 and 4P, not workable. Instead, one can use Combo 0, 1, or 1P to store material properties in their proper data registers. Next, these material properties can be recorded onto a separate card by pressing **3** **2nd** **▲**. * The display will go blank. A blank card should be inserted into the right side of the calculator. This records data registers 30-59 (bank 3) onto the card. Note that two materials can be stored per card, one per side. Now, to run one of the lamination Combos with that material, one needs

* see note, page 4.

only to read in that material card, which stores the properties in bank 3 of the calculator. Note Combos 0, 1, and 1P were not necessary, and the program memory was not disturbed.

The functions of each Combo are listed in the Table of Contents.

This report differs from its predecessor, AFWAL-TR-81-4116, in several respects. The most obvious difference is the addition of detailed explanations describing the use of each of the Combo cards. Sample problems for the non-printing cards have also been added. The old Combo 1 (Selected Ply Data) has been re-named Combo 0, and a new Combo 1 (User input Ply Data) has been added. Combo 1 now serves the same purpose as Combo 1P, except Combo 1 lacks the printing capability. Inconsistencies in the data input method (whether to initialize before or after the first entry) have been removed. Several program flow charts have also been added.

Combos 4 and 4P, hybrid laminates analysis, have a Materials Laboratory Technical Report especially for their use (AFWAL-TR-81-4183). Users of the hybrid technical report should be aware that the old version of Combo 1 and 1P are given at the beginning of the Combo 4 and 4P report. The new Combos 0, 1, and 1P, as listed in this report, are easier to use and will work with Combo 4 and 4P.

Note from page 3: The calculator will not write onto magnetic cards if the calculator is in a "fixed" format display mode (i.e., the number of digits displayed has been previously set). If the display flashes after attempting to record a card, the card did not record. Press **CLR** **INV** **2nd** **1**. This removes the fixed format. Repeat the card recording procedure as before.

SECTION II

COMBO 0: SELECTED PLY DATA WITHOUT PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 0: SELECTED PLY DATA CARD				
Aluminum				
T300/5208	B/5505	AS/3501	Scotchply	Kev 49/Ep

Combo 0 is one of the cards available for storing material ply properties in their correct memory locations so that the laminate in-plane, flexural, or hybrid properties can be calculated using further appropriate Combo cards. Combo 0 is used when the operator is satisfied with the material properties given on pages 24-26. Its primary advantage over Combo 1 and 1P is that a composite material's stiffness and strength properties are recorded in their proper memory locations (bank 3 and 4) by simply pressing one button corresponding to that material (see Figure 1). With the Combo 0 program stored in bank 1 and 2, pressing A, B, C, D, E, or A' calculates and stores the necessary ply values. Therefore, if a new set of material properties is desired, simply press the corresponding button and the old values will be replaced with the new ones. If one of the laminate cards is stored in banks 1 and 2, and new material properties are desired, it would be cumbersome to restore Combo and press A,...., or A' to restore the material properties. It is, therefore, recommended that, especially when using the hybrid laminate cards (Combos 4 and 4P), each material be given its own separate card side as described in the Introduction.

When one of the materials is selected, the Combo 0 program will store its SI properties in the proper locations. If English properties are desired, press **[E]** and the material's corresponding English properties will replace the metric ones. This step actually converts and restores U_i and h_0 only. The failure parameters G_{ij} , are dimensionless and hence do not change. Recall that U_i , G_{ij} , and h_0 are the only properties that are recalled by the lamination Combos.

Graphically, the program works as shown in Figure 3. The engineering elastic constants are converted to U_i and the failure properties are converted to the G_{ij} . The program listing for Combo 0 is given in Appendix D. A short description of how to key-in and record a program onto a card is given in Appendix C.

The following steps should be followed to use Combo 0:

1. Press **[CLR]**, read side 1, press **[CLR]**, read side 2.*
2. Press A, B, C, D, E, or A' depending on which set of material properties are desired (see Figure 1).

The machine then takes the values of E_x , E_y , ν_x , E_s , X , X' , Y , Y' , S , and F_{xy} *, calculates, and stores (in the locations given in Figure 2) the following properties:

$$\begin{matrix} Q_{xx} \\ Q_{yy} \\ Q_{xy} \\ Q_{ss} \end{matrix} \left[\begin{matrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{matrix} \right] = \begin{bmatrix} Q_{xx} & Q_{xy} & 0 \\ Q_{xy} & Q_{yy} & 0 \\ 0 & 0 & Q_{ss} \end{bmatrix} \left[\begin{matrix} \epsilon_x \\ \epsilon_y \\ \epsilon_s \end{matrix} \right]$$

on-axis modulus (Equation 1.12):

*To read a card side, slide the card into the right side of the calculator in the direction of the arrow corresponding to the side of the card to be read. Retrieve the card from the left side of the calculator. Handle cards only the the edges.

U₁

U₂

U₃

U₄

U₅

linear combinations of modulus (Equation 3.15):

$$U_1 = U_1 (Q_{xx}, Q_{yy}, Q_{xx}, Q_{ss}) \text{ etc.}$$

used in lamination calculations

G_{xx}

G_{yy}

G_{xy}

G_{ss}

G_x

G_y

dimensionless strength parameters (Equation 7.11 and 7.28). Failure occurs when:

$$G_{ij} \epsilon_i \epsilon_k + G_i \epsilon_i = 1$$

Note that ply thickness, h_0 , is also stored. The calculator is now ready to accept any of the lamination Combos.

3. Convert ply data to English units if desired (see Figure 1).
4. Store results from bank 3 onto a separate card (if desired).

Step	Procedure	Press	Display
1	Select Material		
	T300/5208	A	216.59641
	Boron/5505	B	214.39805
	AS/3501	C	130.57541
	Scotchply 1002	D	198.05771
	Kevlar 49/Epoxy	E	350.87335
	Aluminum	2nd 1	0
2	Convert from SI to English	2nd 2	39.4

Figure 1. Combo 0 Instruction Chart

00	15	30 U_1	45 F_{yy}, G_{yy}
01	16 G_{xx}	31 U_2	46 F_{xy}, G_{xy}
02	17 G_{yy}	32 U_3	47 F_{ss}, G_{ss}
03	18 G_{xy}	33 U_4	48 F_x, G_x
04	19 G_{ss}	34 U_5	49 F_y, G_y
05	20 G_x	35	50
06	21 G_y	36	51
07	22	37	52
08	23 x	38	53
09	24 x'	39	54
10 Q_{xx}	25 F_x, v	40	55
11 Q_{yy}	26 E_y, Y'	41	56
12 Q_{xy}	27 E_s, S	42	57
13 Q_{ss}	28 v_x, F_{xy}^*	43	58
14	29	44 F_{xx}, G_{xx}	59 h_0

Figure 2. Combo 0 Storage Memories

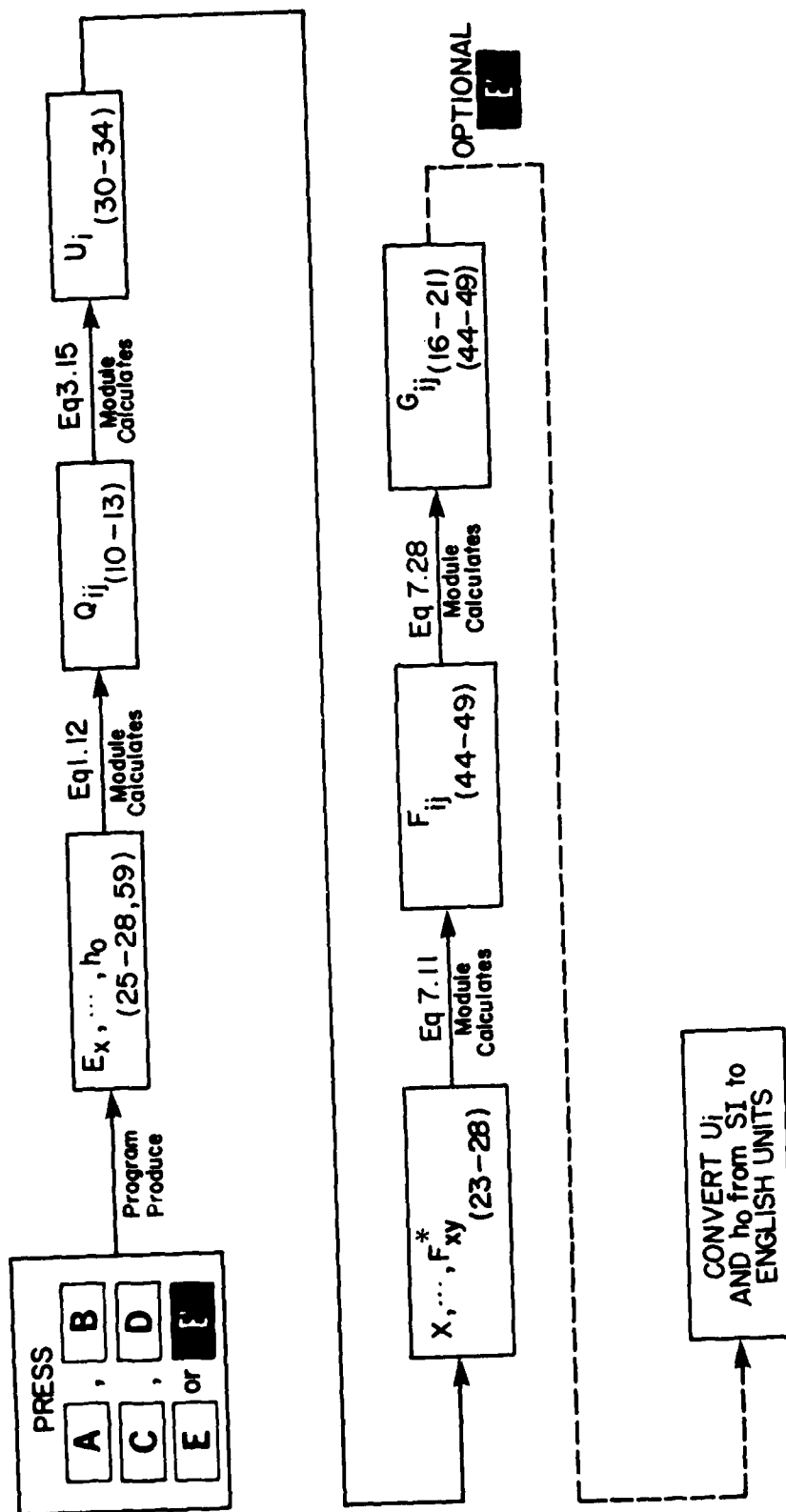


Figure 3. Combo 0 Flow Chart

SECTION III

COMBO 1: USER INPUT PLY DATA WITHOUT PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 1: USER INPUT PLY DATA w/o PRINTER				
Q_{ij}, S_{ij}	U_i	A_{ij}	F_{ij}	G_{ij}
$E_x, \dots, h_0$	$X, \dots, F_{xy}^*$	SI $\rightarrow$ Engl	Engl $\rightarrow$ SI	

Combo 1 is another one of the cards available for use in storing material ply properties in their correct memory locations (see Figure 6). Once these properties are in the data registers, one of the lamination programs can be read and used. Combo 1 is used when the user wishes to input his own ply data, and no printer is available. The user may input values with SI or English units. Once this is done, all subsequent calculations, including lamination calculations, will be done in the system entered. The systems can be changed as long as the Combo 1 program is still stored by pressing C or D (see Figure 4). As with Combo 0, this changes and restores the U_i and h_0 values only. The Combo 1 program listing is given in Appendix D.

This program can be used by following these steps:

1. Press **[CLR]**, read side 1, press **[CLR]**, read side 2.
2. Enter E_x , E_y , ν_x , E_s , h_0 as shown in Figure 4.

The machine calculates:

$$\begin{matrix} Q_{xx} \\ Q_{yy} \\ Q_{xy} \\ Q_{ss} \end{matrix} \left[\begin{array}{c} \sigma_x \\ \sigma_y \\ \sigma_s \end{array} \right] = \begin{bmatrix} Q_{xx} & Q_{xy} & 0 \\ Q_{xy} & Q_{yy} & 0 \\ 0 & 0 & Q_{ss} \end{bmatrix} \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \epsilon_s \end{bmatrix}$$

on-axis modulus (Equation 1.12):

$$\begin{matrix} S_{xx} \\ S_{yy} \\ S_{xy} \\ S_{ss} \end{matrix} \left[\begin{array}{c} \epsilon_x \\ \epsilon_y \\ \epsilon_s \end{array} \right] = \begin{bmatrix} S_{xx} & S_{xy} & 0 \\ S_{xy} & S_{yy} & 0 \\ 0 & 0 & S_{ss} \end{bmatrix} \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{bmatrix}$$

on-axis compliance (Equation 1.9):

$$\begin{matrix} U_1 \\ U_2 \\ U_3 \\ U_4 \\ U_5 \end{matrix} \left[\begin{array}{c} \text{linear combinations of modulus (Equation 3.15):} \\ U_1 = U_1 (Q_{xx}, Q_{yy}, Q_{xy}, Q_{ss}) \text{ etc.} \\ \text{used in lamination calculations} \end{array} \right]$$

$$\begin{matrix} A_{xx} \\ A_{yy} \\ A_{xy} \\ A_{ss} \end{matrix} \left[\begin{array}{c} = Q_{xx} h_o \\ = Q_{yy} h_o \\ = Q_{xy} h_o \\ = Q_{ss} h_o \end{array} \right] \quad \text{On-axis A matrix for one ply}$$

$$\begin{matrix} a_{xx} \\ a_{yy} \\ a_{xy} \\ a_{ss} \end{matrix} \left[\begin{array}{c} \text{inversion of on-axis A matrix for one ply (inversion} \\ \text{of previous matrix)} \end{array} \right]$$

3. Display Q_{ij} , S_{ij} , U_i , A_{ij} , and/or a_{ij} as desired (see Figure 5).
4. Enter X , X' , Y , Y' , S , F_{xy} * as shown in Figure 4.

The machine calculates:

F_{xx}	Strength parameters in stress space (Equations 7.11, 7.12, 7.13, 7.15)
F_{yy}	
F_{xy}	
F_{ss}	
F_x	
F_y	

G_{xx}	Strength parameters in strain space (Equation 7.28)
G_{yy}	
G_{xy}	
G_{ss}	
G_x	
G_y	

The calculator is now ready to accept any of the lamination programs.

5. Display F_{ij} and/or G_{ij} as desired (see Figure 5).
6. Make SI $\rightarrow$ English or English $\rightarrow$ SI changes if desired (see Figure 4).
7. Transfer results from storage registers (bank 3) onto one side of a card if desired.

Step	Procedure	Press	Display
1a	Enter E_x	A	4
b	E_y	R/S	3
c	v_x	R/S	2
d	E_s	R/S	1
e	h_o	R/S	1.1
*			
2a	Enter X	B	5
b	X'	R/S	4
c	Y	R/S	3
d	Y'	R/S	2
e	S	R/S	1
f	F_{xy}^*	R/S	1.5
**			
3a	Convert from SI to English	C	h_o (English Units)
b	Convert from English to SI	D	h_o (SI Units)

Figure 4. Combo 1 Instruction Chart

Step	Procedure	Press	Display
*	Display Q_{ij} and S_{ij}	A'	Q_{xx}
		R/S,R/S,...	Q_{yy}, Q_{xy}, Q_{ss}
		R/S,R/S,...	$S_{xx}, S_{yy}, S_{xy}, S_{ss}, 1.2$
	Display U_i	B'	U_1
		R/S,R/S,...	$U_2, U_3, U_4, U_5, 1.3$
	Display A_{ij} and a_{ij}	C'	A_{xx}
		R/S,R/S,...	A_{yy}, A_{xy}, A_{ss}
		R/S,R/S,...	$a_{xx}, a_{yy}, a_{xy}, a_{ss}, 1.4$
**	Display F_{ij}	D'	F_{xx}
		R/S,R/S,...	$F_{yy}, F_{xy}, F_{ss}, F_x, F_y, 1.6$
	Display G_{ij}	E'	G_{xx}
		R/S,R/S,...	$G_{yy}, G_{xy}, G_{ss}, G_x, G_y, 1.7$

Figure 5. Combo 1 Options

00	15	30 U_1	45 F_{yy}, G_{yy}
01	16 S_{xx}, G_{xx}	31 U_2	46 F_{xy}, G_{xy}
02	17 S_{yy}, G_{yy}	32 U_3	47 F_{ss}, G_{ss}
03	18 S_{xy}, G_{xy}	33 U_4	48 F_x, G_s
04	19 S_{ss}, G_{ss}	34 U_5	49 F_y, G_y
05	20 G_x	35	50
06	21 G_y	36	51 F_{xx}
07	22	37	52 F_{yy}
08	23 x	38	53 F_{xy}
09	24 x'	39	54 F_{ss}
10 Q_{xx}	25 E_x, Y	40	55 F_x
11 Q_{yy}	26 E_y, Y'	41	56 F_y
12 Q_{xy}	27 E_s, S	42	57
13 Q_{ss}	28 v_x, F_{xy}^*	43	58
14	29	44 F_{xx}, G_{xx}	59 h_0

Figure 6. Combo 1 Storage Memories

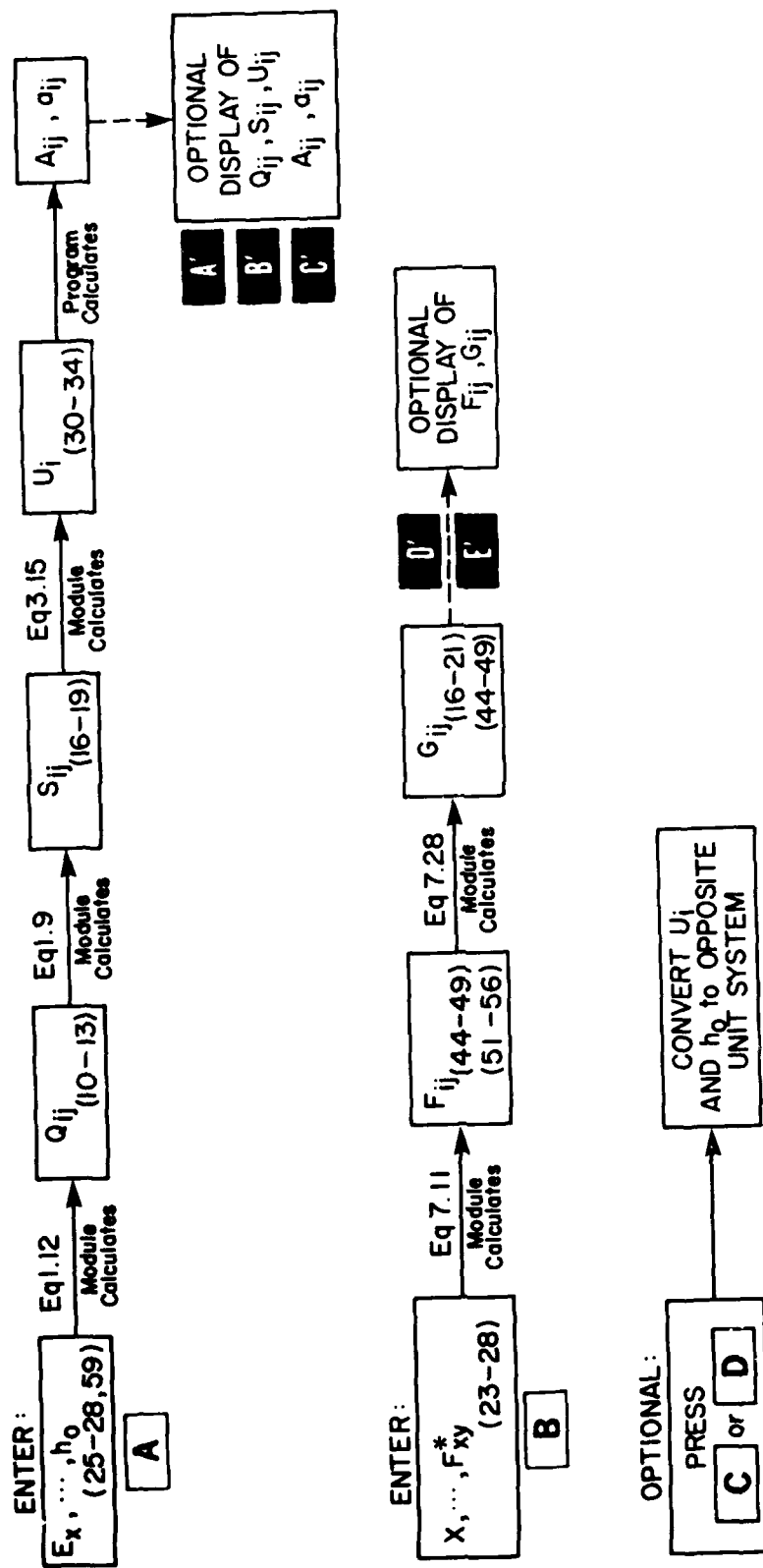


Figure 7. Combo 1 Flow Chart

COMBO 1 SAMPLE PROBLEM: USER INPUT PLY DATA

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
Enter E_x (181 E09)	A	4	Enter X (1.5 E09)	B	5
E_y (10.3 E09)	R/S	3	X' (1.5 E09)	R/S	4
ν_x (280 E-3)	R/S	2	Y (40 E06)	R/S	3
E_s (7.17 E09)	R/S	1	Y' (246 E06)	R/S	2
h_0 (125 E-6)	R/S	1.1	S (68 E06)	R/S	1
Display Q_{ij}	A'	181.811 09 10.348 09 2.897 09 7.170 09	F_{xy}^* (-.5)	R/S	1.5
Display S_{ij}	R/S	5.525-12 97.087-12 -1.547-12 139.470-12	Display F_{ij}	D'	444.444-01 101.626-18 -3.360-18 216.263-18 0.000 00 20.935-09
Display U_i	B'	76.368 09 85.732 09 19.710 09 22.607 09 26.880 09	Display G_{ij}	E'	12.004 03 10.681 03 -3.069 03 11.116 03 30.647 00 216.596 00
Display A_{ij}	C'	22.726 06 1.293 06 362.116 03 896.250 03	Convert SI → English	C	4.925-03
Display a_{ij}	R/S	44.199-09 776.699-09 -12.376-09 1.116-06	Display U_i	B'	11.076 06 12.434 06 2.859 06 3.279 06 3.899 06

SECTION IV

COMBO 1P: USER INPUT PLY DATA WITH PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 1P: USER INPUT PLY DATA w/PRINTER				
$E_x, \dots, h_0$	$X, \dots, F_{xy}^*$	SI→Engl	Engl→SI	

Combo 1P is the final program card used to input, calculate, and store ply properties in their correct memory registers. It should be the Combo selected when the user wishes to input his own ply stiffness and failure data, and has a printing cradle available. Combo 1P is identical to Combo 1 except the results of the calculations made by 1P are automatically printed. The SI to English or English to SI conversions are made exactly as described in the Combo 1 instructions. The Combo 1P program is listed in Appendix D.

Combo 1P can be used by following these steps:

1. Press **CLR**, read side 1, press **CLR**, read side 2.
2. Enter E_x , E_y , ν_x , E_s , and h_0 as described in Figure 8. These will be labeled "E" and "H" on the printer. The machine calculates and prints automatically:

Q_{xx} , Q_{yy} , Q_{xy} , Q_{ss} . Labeled "Q" by printer.

S_{xx} , S_{yy} , S_{xy} , S_{ss} . Labeled "S" by printer.

U_1 , U_2 , U_3 , U_4 , U_5 . Labeled "U" by printer.

A_{xx} , A_{yy} , A_{xy} , A_{ss} . Labeled "A" by printer.

a_{xx} , a_{yy} , a_{xy} , a_{ss} . Labeled "AI" by printer.

The definitions of the above quantities are given in the section describing Combo 1.

3. Enter X , X' , Y , Y' , S , and F_{xy}^* as described in Figure 8. These will be labeled "X" and "FXY".

The machine calculates and displays automatically:

F_{xx} , F_{yy} , F_{xy} , F_{ss} , F_x , F_y . Labeled "F" by printer.

G_{xx} , G_{yy} , G_{xy} , G_{ss} , G_x , G_y . Labeled "G" by printer.

The calculator is now ready to accept any lamination Combo.

4. Make SI $\rightarrow$ English or English $\rightarrow$ SI changes if desired. The machine will calculate, store, and print a new set of U_i (labeled "U'") and a new h_0 (labeled "H'").

5. Transfer results from storage registers (bank 3) onto one side of a card if desired.

Step	Procedure	Press	Display	Printer Label	Printout
1a	Enter E_x	A	4	E	E_x
b	E_y	R/S	3		E_y
c	v_x	R/S	2		v_x
d	E_s	R/S	1		E_s
e	h_o	R/S		H	h_o
				Q	$Q_{xx}, Q_{yy}, Q_{xy}, Q_{ss}$
				S	$S_{xx}, S_{yy}, S_{xy}, S_{ss}$
				U	U_1, U_2, U_3, U_4, U_5
				A	$A_{xx}, A_{yy}, A_{xy}, A_{ss}$
				AI	$a_{xx}, a_{yy}, a_{xy}, a_{ss}$
			1.1		
2a	Enter X	B	5	X	X
b	X'	R/S	4		X'
c	Y	R/S	3		Y
d	Y'	R/S	2		Y'
e	S	R/S	1		S
f	F_{xy}^*	R/S		FX Y	F_{xy}^*
				F	$F_{xx}, F_{yy}, F_{xy}, F_{ss}, F_x, F_y$
				G	$G_{xx}, G_{yy}, G_{xy}, G_{ss}, G_x, G_y$
			1.2		
3	Convert SI → English	C		U' H'	U_1, U_2, U_3, U_4, U_5 (Engl) h_o (Engl)
			h_o (Engl)		
4	Convert English → SI	D		U'	U_1, U_2, U_3, U_4, U_5 (SI) h_o (SI)
			h_o (SI)		

Figure 8. Combo 1P Instruction Chart

00	15	30 u_1	45 F_{yy}, G_{yy}
01	16 S_{xx}, G_{xx}	31 u_2	46 F_{xy}, G_{xy}
02	17 S_{yy}, G_{yy}	32 u_3	47 F_{ss}, G_{ss}
03	18 S_{xy}, G_{xy}	33 u_4	48 F_x, G_x
04	19 S_{ss}, G_{ss}	34 u_5	49 F_y, G_y
05	20 G_x	35	50
06	21 G_y	36	51
07	22	37	52
08	23 x	38	53
09	24 x'	39	54
10 Q_{xx}	25 E_x, y	40	55
11 Q_{yy}	26 E_y, y'	41	56
12 Q_{xy}	27 E_s, s	42	57
13 Q_{ss}	28 v_x, F_{xy}^*	43	58
14	29	44 F_{xx}, G_{xx}	59 h_0

Figure 9. Combo 1P Storage Memories

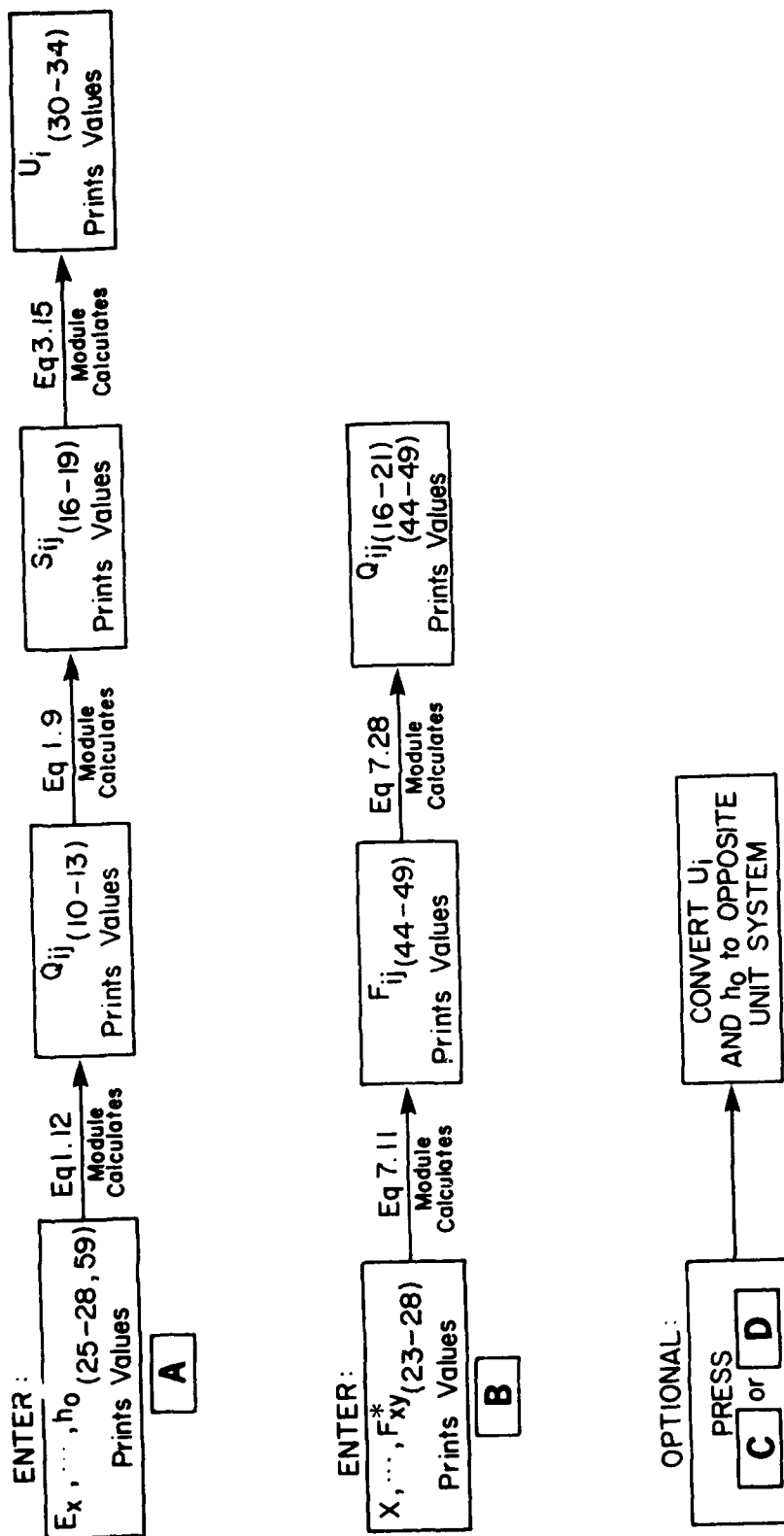


Figure 10. Combo 1P Flow Chart

COMBO 1P SAMPLE PROBLEM: USER INPUT PLY DATA

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
Enter E_x	A	E	Enter X	B	X
E_y	R/S	181.000 09	X'	R/S	1.500 09
ν_x	R/S	10.300 09	y	R/S	1.500 09
E_s	R/S	280.000-03	y'	R/S	40.000 06
		7.170 09	S	R/S	246.000 06
Enter h_o	R/S	H	Enter F_{xy}^*	R/S	68.000 06
		125.000-06			FXy
Print Q_{ij}		Q			-500.000-03
		181.811 09	Print F_{ij}		F
		10.346 09			444.444-21
		2.897 09			101.626-18
		7.170 09			-3.360-18
Print S_{ij}		S			216.263-18
		5.525-12	Print G_{ij}		0.000 00
		97.087-12			20.935-09
		-1.547-12			G
		139.470-12			12.004 03
Print U_i		U			10.681 03
		76.368 09	Convert SI $\rightarrow$ English	C	-3.069 03
		85.732 09			11.118 03
		19.710 09	Print U_i (English)		60.647 00
		22.607 09			216.596 00
		26.880 09			U'
Print A_{ij}		A			11.076 06
		22.726 06			12.434 06
		1.293 06			2.859 06
		362.116 03			3.279 06
		896.250 03			3.899 06
Print a_{ij}		AI	Print h_o (English)		H'
		44.199-09			4.925-03
		776.699-09			
		-12.376-09			
		1.116-06			

T300/5208

B(4)/5505

SI	ENGLISH	SI	ENGLISH
E	E	E	E
181.000 09	26.251 06	204.000 09	29.587 06
10.500 09	1.494 06	18.500 09	2.683 06
280.000-03	280.000-03	230.000-03	230.000-03
7.170 09	1.040 06	5.590 09	810.732 03
H	H	H	H
125.000-06	4.925-03	125.000-06	4.925-03
Q	Q	Q	Q
181.811 09	26.369 06	204.983 09	29.729 06
10.346 09	1.501 06	18.589 09	2.696 06
2.897 09	420.149 03	4.276 09	620.089 03
7.170 09	1.040 06	5.590 09	810.732 03
S	S	S	S
5.725-12	38.094-09	4.302-12	33.799-09
97.087-12	669.417-09	54.054-12	372.703-09
-1.547-12	-10.666-09	-1.127-12	-7.774-09
139.470-12	961.646-09	178.891-12	1.233-06
U	U	U	U
76.368 09	11.076 06	87.704 09	12.720 06
85.732 09	12.434 06	93.197 09	13.517 06
19.710 09	2.859 06	24.083 09	3.493 06
22.607 09	3.279 06	28.358 09	4.113 06
26.880 09	3.899 06	29.673 09	4.304 06
A	A	A	A
32.726 06	129.865 03	25.62 06	146.417 03
1.293 06	7.390 03	2.324 06	13.278 03
362.116 03	2.069 03	534.439 03	3.054 03
896.250 03	5.121 03	698.750 03	3.993 03
AI	AI	AI	AI
44.199-09	7.735-06	39.216-09	6.863-06
776.699-09	135.822-06	432.432-09	75.676-06
-12.076-09	-2.166-06	-9.020-09	-1.573-06
1.116-06	195.258-06	1.431-06	250.447-06
X	X	X	X
1.500 09	217.549 03	1.260 09	18.741 03
1.500 09	217.549 03	2.500 09	362.582 03
40.000 06	5.501 02	51.000 06	2.847 03
246.000 06	35.678 03	202.000 06	29.197 03
68.000 06	2.262 03	67.000 06	3.717 03
FXV	FXV	FXV	FXV
-500.000-03	-500.000-03	-500.000-03	-500.000-03
F	F	F	F
444.444-21	21.129-12	317.460-21	15.092-12
101.626-18	4.831-09	91.156-18	3.858-09
-3.360-18	-159.753-12	-2.538-18	-120.654-12
216.263-18	10.281-09	222.767-18	10.591-09
0.000 00	0.000 00	393.651-12	2.714-06
20.935-09	144.347-06	11.443-09	78.899-06
G	G	G	G
12.004 03	12.004 03	10.374 03	10.374 03
10.681 03	10.681 03	27.646 03	27.646 03
-3.069 03	-3.069 03	-2.989 03	-2.989 03
11.118 03	11.118 03	6.961 03	6.961 03
60.647 00	60.647 00	129.616 00	129.616 00
216.596 00	216.596 00	214.398 00	214.398 00
U'	U'	U'	U'
11.076 06	76.368 09	12.720 06	87.704 09
12.434 06	85.732 09	13.517 06	93.197 09
2.859 06	19.710 09	3.493 06	24.083 09
3.279 06	22.607 09	4.113 06	28.358 09
3.899 06	26.880 09	4.304 06	29.673 09
H'	H'	H'	H'
4.925-03	125.000-06	4.925-03	125.000-06

AS/3501

SCOTCHPLY 10'2

SI	ENGLISH	SI	ENGLISH
E	E	E	E
138.000 09	20.015 06	38.600 09	5.598 04
8.960 09	1.299 06	8.270 09	1.199 06
300.000-03	300.000-03	260.000-03	260.000-03
7.100 09	1.030 06	4.140 09	600.435 03
H	H	H	H
125.000-06	4.925-03	125.000-06	4.925-03
Q	Q	Q	Q
138.811 09	20.132 06	39.167 09	5.681 06
9.013 09	1.307 06	8.392 09	1.217 06
2.704 09	392.139 03	2.182 09	316.432 03
7.100 09	1.030 06	4.140 09	600.435 03
S	S	S	S
7.246-12	49.964-09	25.907-12	178.627-09
111.607-12	769.531-09	120.919-12	833.736-09
-2.174-12	-14.989-09	-6.736-12	-46.443-09
140.845-12	971.127-09	241.546-12	1.665-06
U	U	U	U
59.660 09	8.653 06	20.450 09	2.966 06
64.899 09	9.413 06	15.388 09	2.232 06
14.252 09	2.067 06	3.329 09	482.872 03
16.956 09	2.459 06	5.511 09	799.304 03
21.352 09	3.097 06	7.469 09	1.083 06
A	A	A	A
17.351 06	99.151 03	4.896 06	27.977 03
1.127 06	6.438 03	1.049 06	5.994 03
337.975 03	1.931 03	272.725 03	1.558 03
887.500 03	5.071 03	517.500 03	2.957 03
AI	AI	AI	AI
57.971-09	10.145-06	207.254-09	36.269-06
892.857-09	156.250-06	967.352-09	169.287-06
-17.391-09	-3.043-06	-53.886-09	-9.430-06
1.127-06	197.183-06	1.932-06	338.164-06
X	X	X	X
1.447 09	209.862 03	1.062 09	154.025 03
1.447 09	209.862 03	610.000 06	88.470 03
51.700 06	7.498 03	31.000 06	4.496 03
206.000 06	29.877 03	118.000 06	17.114 03
93.000 06	13.488 03	72.000 06	10.442 03
FXV	FXV	FXV	FXV
-500.000-03	-500.000-03	-500.000-03	-500.000-03
F	F	F	F
477.598-21	22.706-12	1.544-18	73.386-12
93.895-18	4.464-09	273.373-18	12.996-09
-3.348-18	-159.181-12	-10.271-18	-488.303-12
115.620-18	5.497-09	192.901-18	9.171-09
0.000 00	0.000 00	-697.725-12	-4.811-06
14.488-09	99.895-06	23.783-09	163.987-06
G	G	G	G
7.376 03	7.376 03	1.914 03	1.914 03
7.467 03	7.467 03	18.882 03	18.882 03
-1.746 03	-1.746 03	1.712 03	1.712 03
5.828 03	5.828 03	3.306 03	3.306 03
39.173 00	39.173 00	24.563 00	24.563 00
130.575 00	130.575 00	198.058 00	198.058 00
U'	U'	U'	U'
8.653 06	59.660 09	2.966 06	20.450 09
9.413 06	64.899 09	2.232 06	15.388 09
2.067 06	14.252 09	482.872 03	3.329 09
2.459 06	16.956 09	799.304 03	5.511 09
3.097 06	21.352 09	1.083 06	7.469 09
H'	H'	H'	H'
4.925-03	125.000-06	4.925-03	125.000-06

KEYLAR 49/EPOXY

ALUMINUM

SI	ENGLISH	SI	ENGLISH
E	E	E	E
76.000 09	11.022 06	69.000 09	10.007 06
5.500 09	797.679 03	69.000 09	10.007 06
340.000-03	340.000-03	300.000-03	300.000-03
2.300 09	333.575 03	26.538 09	3.849 06
H	H	H	H
125.000-06	4.925-03	1.000 00	1.000 00
Q	Q	Q	Q
76.641 09	11.115 06	75.824 09	10.997 06
5.546 09	804.409 03	75.824 09	10.997 06
1.886 09	273.499 03	22.747 09	3.299 06
2.300 09	333.575 03	26.538 09	3.849 06
S	S	S	S
13.158-12	90.724-09	14.493-12	99.928-09
181.818-12	1.254-06	14.493-12	99.928-09
-4.474-12	-30.846-09	-4.348-12	-29.978-09
434.793-12	2.998-06	37.681-12	259.812-09
U	U	U	U
32.442 09	4.705 06	75.824 09	10.997 06
35.547 09	5.156 06	0.000 00	0.000 00
8.652 09	1.255 06	40.000-03 ≈ 0	88.455-03 ≈ 0
10.538 09	1.528 06	22.747 09	3.299 06
10.952 09	1.588 06	26.538 09	3.849 06
A	A	A	A
2.580 06	54.744 03	75.824 09	10.997 06
693.300 03	3.962 03	75.824 09	10.997 06
235.723 03	1.347 03	22.747 09	3.299 06
287.300 03	1.643 03	26.538 09	3.849 06
AI	AI	AI	AI
105.263-09	18.421-06	14.493-12	99.928-09
1.455-06	254.545-06	14.493-12	99.928-09
-35.789-09	-6.263-06	-4.348-12	-29.978-09
3.478-06	608.696-06	37.681-12	259.812-09
X	X	X	X
1.400 09	203.046 03	400.000 06	58.012 03
335.000 06	34.083 03	400.000 06	58.012 03
12.000 06	1.740 03	400.000 06	58.012 03
53.000 06	7.687 03	400.000 06	58.012 03
34.000 06	4.931 03	330.000 06	33.158 03
FWY	FWY	FWY	FWY
-500.000-03	-500.000-03	-500.000-03	-500.000-03
F	F	F	F
3.040-18	144.502-12	6.250-18	297.131-12
1.573-15	74.750-09	6.250-18	297.131-12
-34.566-18	-1.643-09	-3.125-18	-148.566-12
865.052-18	41.125-09	18.904-18	898.696-12
-3.541-09	-24.415-06	0.000 00	0.000 00
64.465-09	444.489-06	0.000 00	0.000 00
G	G	G	G
13.454 03	13.454 03	28.387 03	28.387 03
47.657 03	47.657 03	28.387 03	28.387 03
2.069 03	2.069 03	1.976 03	1.976 03
4.576 03	4.576 03	13.314 03	13.314 03
-149.822 00	-149.822 00	0.000 00	0.000 00
350.873 00	350.873 00	0.000 00	0.000 00
U'	U'	U'	U'
4.705 06	32.442 09	10.997 06	75.824 09
5.156 06	35.547 09	0.000 00	0.000 00
1.255 06	8.652 09	5.801-06 ≈ 0	609.897 00 ≈ 0
1.528 06	10.538 09	3.299 06	22.747 09
1.588 06	10.952 09	3.849 06	26.538 09
H'	H'	H'	H'
4.925-03	125.000-06	39.400 00	25.381-03

SECTION V

COMBO 2: IN-PLANE PROPERTIES WITHOUT PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 2: IN-PLANE PROPERTIES w/o PRINTER				
Core	A_{ij}, a_{ij}	A_{ij}^*, a_{ij}^*	Unit Ply	I_ϵ, R_ϵ
$n, \theta_t \rightarrow E_i^o$	$N_i \rightarrow \epsilon_i$	$\theta_t \rightarrow R_t, R_t'$	$\sigma_t^o, \sigma_t^{o'}$	$\epsilon_i^o, \theta_t \rightarrow R_t$

The Combo 2 program will recall the unit ply data stored in bank 3, then drive the composite materials module to calculate the laminate stiffness matrix, compliance matrix, and the apparent elastic constants. For a given loading condition, the program calculates strain components, strain invariants, and strength ratios (allowable stress to applied stress). Failure envelopes in stress and strain space can be plotted using Combo 2. It is to be used when no printer is available. Essentially, Combo 2 accepts the ply stacking sequence and laminate loading as its input. Note that sandwich laminates which contain a core are acceptable. The Combo 2 program is listed in Appendix D.

To use Combo 2:

1. Have U_i , G_{ij} , and h_o for the desired material and in the desired units stored in bank 3.
2. Press **CLR**, read side 1, press **CLR**, read side 2.
3. No core: Enter n , the total number of plies, then press **A**.
Enter θ_1 , R/S, θ_2 , R/S, ..., $\theta_{n/2}$, R/S. The θ_t are entered

with the orientation of the outside ply (top or bottom ply) of the stack first. Further ply orientations are then entered in a sequence working progressively towards the laminate mid-plane.

See Figure 11.

Core: Enter n , the total number of plies plus the total number of ply thicknesses that make up core; press **A**. Enter θ_1 , R/S, θ_2 , R/S,... After entering one angle for each ply orientation (note less than n entries), press A' . See Figures 11 and 12 for details.

The machine calculates:

$$\begin{array}{l} E_1^o \\ E_2^o \\ \nu_{21}^o \\ E_6^o \end{array} \left\{ \begin{array}{l} \text{effective in-plane laminate moduli (Equation 4.18)} \\ E_1^o = \frac{1}{a_{11}h}, \text{ etc.} \end{array} \right.$$

$$\begin{array}{l} A_{11} \\ A_{22} \\ A_{12} \\ A_{66} \\ A_{16} \\ A_{26} \end{array} \left\{ \begin{array}{l} \text{in-plane stiffness matrix (Table 4.3, Equation 4.31)} \\ \begin{Bmatrix} N_1 \\ N_2 \\ N_6 \end{Bmatrix} = \begin{Bmatrix} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_3 h \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_1^o \\ \epsilon_2^o \\ \epsilon_6^o \end{Bmatrix} \end{array} \right.$$

$$\begin{array}{l} a_{11} \\ a_{22} \\ a_{12} \\ a_{66} \\ a_{16} \\ a_{26} \end{array} \left\{ \begin{array}{l} \text{inversion of } [A]: \\ \begin{Bmatrix} \epsilon_1^o \\ \epsilon_2^o \\ \epsilon_6^o \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{16} \\ a_{12} & a_{22} & a_{26} \\ a_{16} & a_{26} & a_{66} \end{bmatrix} \begin{Bmatrix} N_1 \\ N_2 \\ N_6 \end{Bmatrix} \end{array} \right.$$

$$\begin{array}{l}
 A_{11}^* \\
 A_{22}^* \\
 A_{12}^* \\
 A_{66}^* \\
 A_{16}^* \\
 A_{26}^*
 \end{array}
 \left| \begin{array}{l}
 A_{ij}/h: \\
 \left\{ \begin{array}{c} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_6 h \end{array} \right\} = \left\{ \begin{array}{c} N_1 \\ N_2 \\ N_6 \end{array} \right\} = \left[\begin{array}{c} \\ \\ \\ \end{array} \right] A \left\{ \begin{array}{c} \epsilon_1^o \\ \epsilon_2^o \\ \epsilon_6^o \end{array} \right\} ; \left\{ \begin{array}{c} \bar{\sigma}_1 \\ \bar{\sigma}_2 \\ \bar{\sigma}_6 \end{array} \right\} = \left[\begin{array}{c} \\ \\ \\ \end{array} \right] A^* \left\{ \begin{array}{c} \epsilon_1^o \\ \epsilon_2^o \\ \epsilon_6^o \end{array} \right\}
 \end{array} \right.$$

$$\begin{array}{l}
 a_{11}^* \\
 a_{22}^* \\
 a_{12}^* \\
 a_{66}^* \\
 a_{16}^* \\
 a_{26}^*
 \end{array}
 \left| \begin{array}{l}
 a_{ij}h: \\
 \left\{ \begin{array}{c} \epsilon_1^o \\ \epsilon_2^o \\ \epsilon_6^o \end{array} \right\} = \left[\begin{array}{c} \\ \\ \\ \end{array} \right] a \left\{ \begin{array}{c} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_6 h \end{array} \right\} ; \left\{ \begin{array}{c} \epsilon_1^o \\ \epsilon_2^o \\ \epsilon_6^o \end{array} \right\} = \left[\begin{array}{c} \\ \\ \\ \end{array} \right] a^* \left\{ \begin{array}{c} \bar{\sigma}_1 \\ \bar{\sigma}_2 \\ \bar{\sigma}_6 \end{array} \right\}
 \end{array} \right.$$

4. The display will show E_1^o . The user has the option of displaying the rest of the engineering constants, A_{ij} , a_{ij} , A_{ij}^* , and/or a_{ij}^* . See Figure 12 for instructions.
5. At this point, the user must input the load. There are two options:
 - a. Input selective unit loads to determine failure envelopes and maximum loading allowable.
 - b. Input an actual loading case to determine strain invariants and strength ratios.

Case a deals with the locus of the failure envelope for a selected ply orientation as shown in Figure 14. For a given loading path ($N_1:N_2:N_3$ ratio remains fixed), it calculates where the path pierces the envelope, i.e., the maximum allowable

stress values along that proportional loading line. By selecting various proportional loading lines, the envelope can be plotted. The data for a sample case is shown in Figure 13 and is plotted in Figure 14. Case b, being an actual loading case, is a point which lies, for allowable loading, somewhere within the envelope.

Case a)

Enter N_1, N_2, N_6 as instructed in Figure 11. To find the values of σ_1^o at the piercing point for a given proportional loading (loading line) enter $N_i = 1$, and the other two N's to set the $N_1 : N_2 : N_6$ ratio as desired.

6. Enter θ_t , the orientation of the ply to be examined (See Figure 11).

The machine calculates:

$$\left. \begin{array}{l} R_t \\ R'_t \end{array} \right\} \text{ Not used for Case a.}$$

7. Press D. The machine calculates:

$$\left. \begin{array}{l} \sigma_t^o = R_t/h \\ \sigma_t^{o'} = R'_t/h \end{array} \right\} \begin{array}{l} \bar{\sigma}_i \text{ values that pierce failure envelope:} \\ N_i \text{ was set } = 1 = \bar{\sigma}_i h; \bar{\sigma}_i = 1/h \end{array}$$

$$R_t = \frac{\bar{\sigma}_i \text{ allowable}}{\bar{\sigma}_i \text{ applied}} = \frac{\bar{\sigma}_i \text{ allowable}}{1/h}$$

$$\bar{\sigma}_i \text{ allowable} = R_t/h = \sigma_t^o$$

Recall $\sigma_t^o, \sigma_t^{o'}$ as desired. The two values of R (and hence two values of σ_t^o) arise because the failure criteria is quadratic in R (Equation 7.64), hence R has two roots. Each of these roots corresponds to a point where the loading line intersects the elliptic failure envelope.

Note that the entire envelope for a laminate is a superposition of all

envelopes for every value of θ_t in the laminate. The first ply failure envelope is then the innermost trace of the superpositioned curves. The outer boundary is the ultimate failure envelope.

The failure envelope can also be plotted in strain space. This technique is best illustrated by Figures 12 and 15. For a given ply orientation, the failure envelope is independent of the laminate stacking (independent of A_{ij}). The total laminate failure envelope is again a superposition of individual envelopes.

Case b)

Enter actual N_1 , N_2 , N_6 as instructed in Figure 11.

The machine calculates:

$$\left. \begin{aligned} I_\epsilon &= 1/2 (\epsilon_1^\circ + \epsilon_2^\circ) \\ R_\epsilon &= [1/4 (\epsilon_1^\circ - \epsilon_2^\circ)^2 + 1/4 \epsilon_6^2]^{1/2} \end{aligned} \right\} \begin{array}{l} \text{Strain invariants (Equation 2.50)} \\ \text{used to calculate on-axis ply} \\ \text{strains} \end{array}$$

Note ϵ_1° , ϵ_2° , ϵ_6° are stored in locations 23, 24, and 25 and can be recalled if desired.

6. Display I_ϵ and R_ϵ if desired (See Figure 12).

7. Enter θ_t , the orientation of the ply to be examined (See Figure 11).

The machine calculates:

$$\left. \begin{array}{l} R_t \\ R'_t \end{array} \right\} \begin{array}{l} \text{strength ratios (Equation 7.48)} \\ \\ \end{array}$$

$$R = \frac{\bar{\sigma}_i \text{ allowable}}{\bar{\sigma}_i \text{ applied}} = \frac{\epsilon_i^\circ \text{ allowable}}{\epsilon_i^\circ \text{ induced}}$$

$$\left. \begin{array}{l} \sigma_t^\circ \\ \sigma_t^{\circ'} \end{array} \right\} \begin{array}{l} \text{not used for case b.} \end{array}$$

8. Recall R_t and R'_t as desired by following the instructions in Figure 11.

The material engineering properties for a single ply can be calculated and displayed by pressing **D**. The A_{ij} ($i,j = x,y,s$) and a_{ij} can then be recovered by pressing **B**. Finally, the Q_{ij} and S_{ij} can be displayed by pressing **C**. The user should exercise caution here, because when **C** is pressed, the original material data in bank 3 is destroyed. Further lamination calculations cannot be completed until the storage registers are returned to their original condition.

STEP	PROCEDURE	PRESS	DISPLAY
1	Enter ply data		
2a	Enter n	A	n/2
b	θ_1	R/S	n/2 - 1
c	θ_2	R/S	n, 2 - 2
*	$\vdots$	$\vdots$	$\vdots$
	$\theta_{n/2 - 1}$		1
	$\theta_{n/2}$	R/S, R/S, ...	$E_1^o, E_2^o, v_{21}^o, E_6^o, 6.1$
**			
3a	Enter N_1	B	6.2
b	N_2	R/S	6.6
c	N_6	R/S	60

4	Enter θ_t	C	R_t
		R/S	R'_t
		R/S	60
5	Display $\sigma_t^o, \sigma_t^{o'}$	D	σ_t^o
		R/S	$\sigma_t^{o'}$
		R/S	60

6	Unit ply data	D'	E_x
		R/S, R/S, ...	E_y, v_x, E_s

Figure 11. Combo 2 Instruction Chart

STEP	PROCEDURE	PRESS	DISPLAY
*	For sandwich construction	A' R/S,R/S,...	when display = c E_1^o $E_2^o, \nu_{21}^o, E_6^o, 6.1$
**	Display A_{ij}, a_{ij} Display A_{ij}^*, a_{ij}^*	B' R/S,R/S,...	A_{11} $A_{22}, A_{12}, A_{66}, A_{16}, A_{26}$ $a_{11}, a_{22}, a_{12}, a_{66}, a_{16}, a_{26}$
		C' R/S,R/S,...	A_{11}^* $A_{22}^*, A_{12}^*, A_{66}^*, A_{16}^*, A_{26}^*$ $a_{11}^*, a_{22}^*, a_{12}^*, a_{66}^*, a_{16}^*, a_{26}^*$
***	Calculate strain invariants	E' R/S R/S	I_ϵ R_ϵ 60
****	Calculate failure envelopes (strain-space) Enter ϵ_1^o ϵ_2^o ϵ_6^o Enter θ	E R/S R/S R/S R/S R/S	8.1 8.2 60 R R' 60

Figure 12. Combo 2 Options

N_1, N_2, N_3 (N/m)	θ_t (deg)	σ_t^o (GPa)	$\sigma_t^{o'}$ (GPa)
1, 0, 0	0	.682	1.11
	90	.373	2.27
0, 1, 0	0	.373	2.27
	90	.682	1.11
1, 1, 0	0	.302	1.96
	90	.302	1.96
-1, 1, 0	0	.351	.856
	90	.856	.351
.35, 1, 0	0	.356	2.66
	90	.512	1.65
1, .35, 0	0	.512	1.65
	90	.356	2.66

Figure 13. Failure Envelope Data in Stress Space for T300/5208 [0/90]_s; $N_6 = 0$.

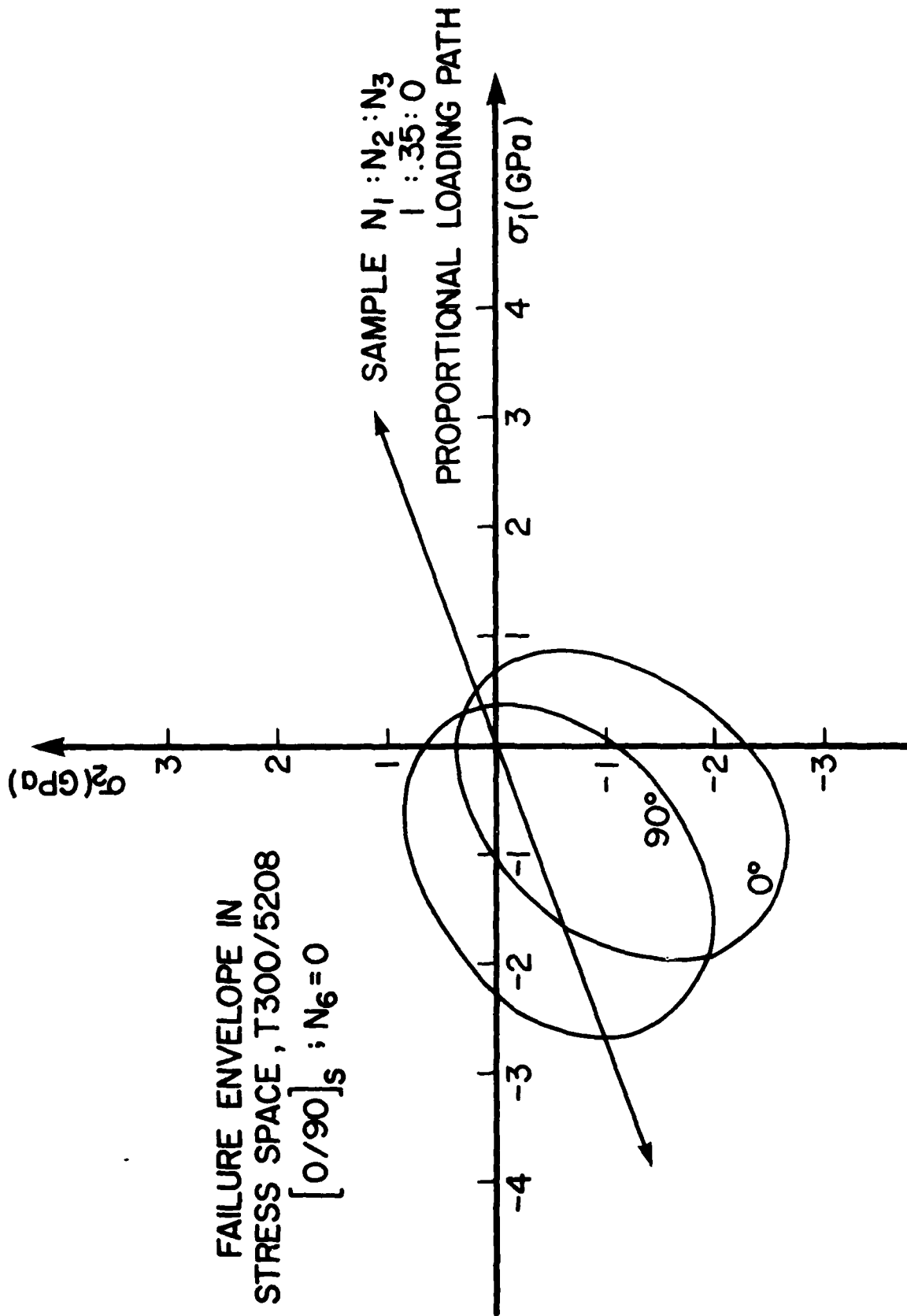


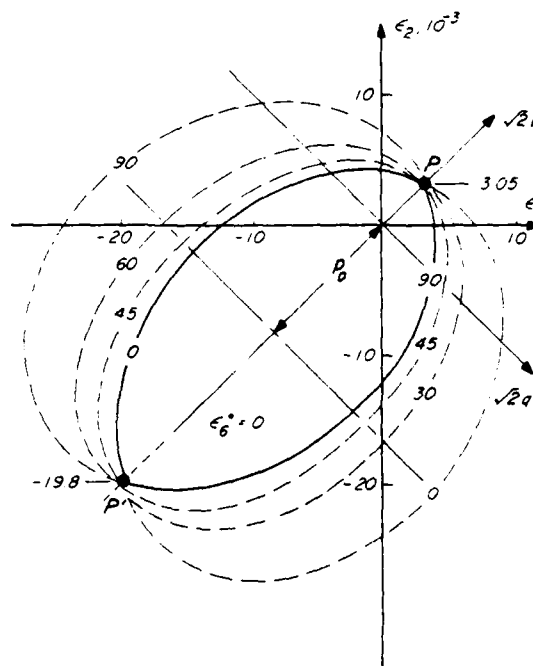
Figure 14

$$= R_t, R'_t$$

PROCEDURE	KEY	DISPLAY
Enter $\varepsilon_1^o = 1$	E	8.1
$\varepsilon_2^o = 0$	R/S	8.2
$\varepsilon_6^o = 0$	R/S	60
$\vartheta_t = 0$	R/S	$R_t = 6.94 \times 10^{-3}$
	R/S	$R'_t = 11.97 \times 10^{-3}$
	R/S	60
$\vartheta_t = 45$	R/S	$R_t = 4.74 \times 10^{-3}$
	R/S	$R'_t = 13.83 \times 10^{-3}$
	R/S	60
$\vartheta_t = 90$	R/S	$R_t = 3.88 \times 10^{-3}$
	R/S	$R'_t = 24.16 \times 10^{-3}$
	R/S	60

PROCEDURE	KEY	DISPLAY
Enter $\varepsilon_1^\circ = 1$	E	8.1
$\varepsilon_2^\circ = -1$	R/S	8.2
$\varepsilon_6^\circ = 0$	R/S	60
$\vartheta_t = 0$	R/S	$R_t = 9.19 \times 10^{-3}$
	R/S	$R'_t = 3.78 \times 10^{-3}$
	R/S	60
$\vartheta_t = 45$	R/S	$R_t = 4.74 \times 10^{-3}$
	R/S	$R'_t = 4.74 \times 10^{-3}$
	R/S	60
$\vartheta_t = 90$	R/S	$R_t = 3.78 \times 10^{-3}$
	R/S	$R'_t = 9.19 \times 10^{-3}$
	R/S	60

PROCEDURE	KEY	DISPLAY
Enter $\varepsilon_1^o = 0$	E	8.1
$\varepsilon_2^o = 1$	R/S	8.2
$\varepsilon_6^o = 0$	R/S	60
$\varepsilon_t = 0$	R/S	$R_t = 3.88 \times 10^{-3}$
	R/S	$R'_t = 24.16 \times 10^{-3}$
	R/S	60
$\theta_t = 45$	R/S	$R_t = 4.74 \times 10^{-3}$
	R/S	$R'_t = 13.83 \times 10^{-3}$
	R/S	60
$\theta_t = 90$	R/S	$R_t = 6.94 \times 10^{-3}$
	R/S	$R'_t = 11.97 \times 10^{-3}$
	R/S	60



Failure envelopes of T300/5208 off-axis plies in the normal strain space

Figure 15

00	USED	15	A_{26}	30	U_1	45	G_{yy}
01	USED	16	a_{11}, G_{xx}	31	U_2	46	G_{xy}
02	USED	17	a_{22}, G_{yy}	32	U_3	47	G_{ss}
03	USED	18	a_{12}, G_{xy}	33	U_4	48	G_x
04	USED	19	a_{66}, G_{ss}	34	U_5	49	G_y
05	$n, n/2$	20	a_{16}, G_x	35	θ	50	
06	R_t	21	a_{26}, G_y	36	V_0	51	
07	R'_t	22	$ A $	37	V_1	52	
08	$1/h$	23	ϵ_1°	38	V_3	53	p
09	h	24	ϵ_2°	39	$V_2, \sqrt{\quad}$	54	q
10	A_{11}	25	ϵ_6°	40	V_4	55	r
11	A_{22}	26	$N_1, 0$	41	θ	56	a
12	A_{12}	27	$N_2, 0$	42	USED	57	$-b/2a$
13	A_{66}	28	$N_6, 0$	43	USED	58	c/a
14	A_{16}	29	USED	44	G_{xx}	59	h_0

Figure 16. Combo 2 Storage Memories

COMBO CARD #2

IN-PLANE STIFFNESS & STRENGTH (OFF PRINTER)

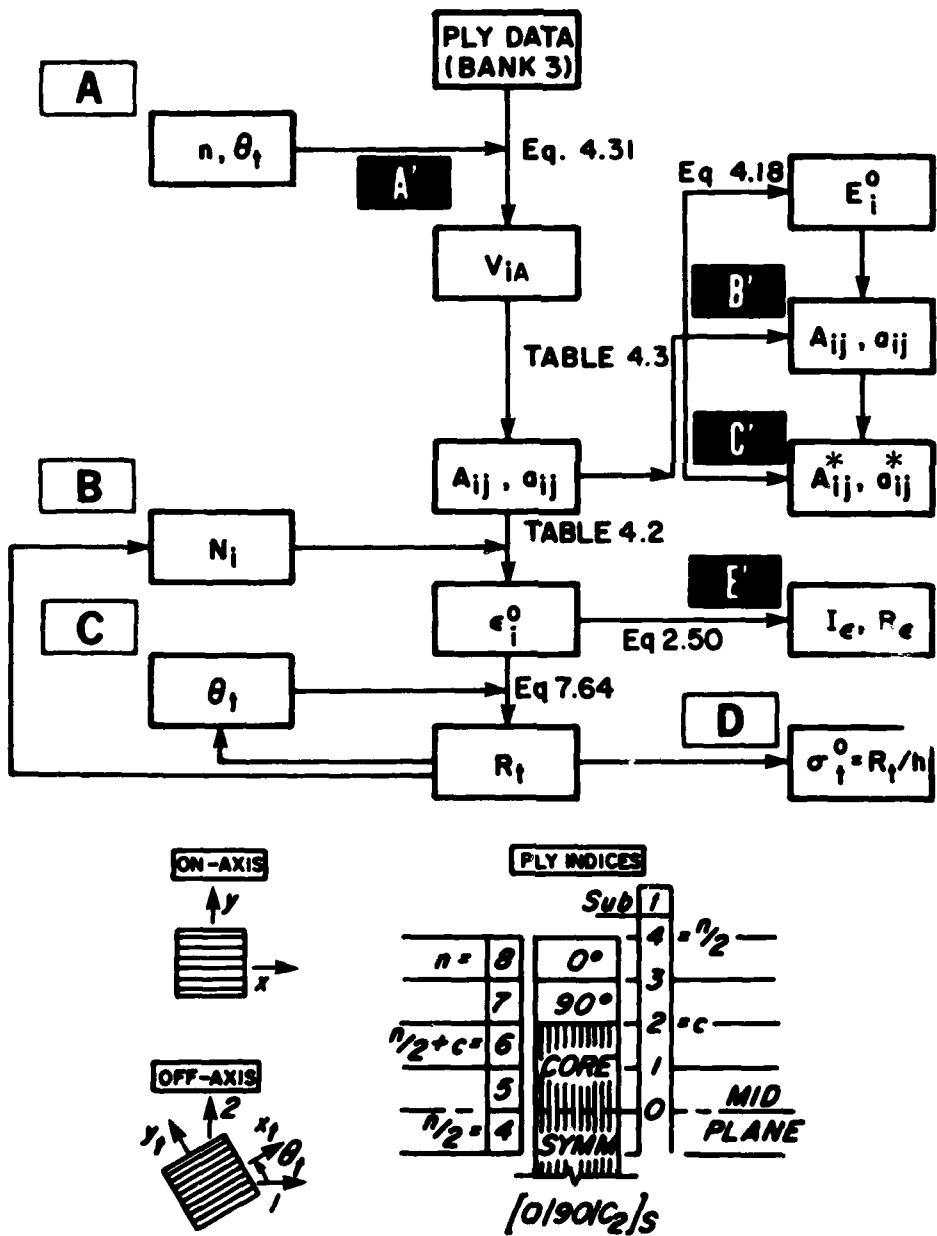


Figure 17. Combo 2 Flow Chart

Combo 2 Sample Problems

The sample problems listed in this section are to aid the user in getting started with the Combo cards/Composite Materials Module. As one works through the sample problems, the user should follow along with the instruction charts, Figures 11 and 12. The sample problems should be followed vertically down the left half of the page, then vertically down the right.

The sample problems with a core denote the core as, say, C_4 , meaning the half-core is four times the unit ply thickness, or the total core thickness is eight times the unit ply thickness. A typical real-world core would undoubtedly be much thicker. The user can have a laminate with a core thickness that is not an integer multiple of the unit ply thickness. This would require that n is also not an integer.

All units in the sample problems are as follows:

θ_t	degrees
E_i^o	Pa
ν_{21}^o	dimensionless
A_{ij}	N/m
a_{ij}	m/N
A_{ij}^*	Pa (N/m^2)
a_{ij}^*	1/Pa (m^2/N)
I_e, R_e, R_t, R_t'	dimensionless
$\sigma_t^o, \sigma_t^{o'}$	Pa

English unit calculations can be completed just as easily. When the material properties in Bank 3 are stored in English units, loads can be entered in lbs/in, etc., provided their dimensions are consistent with the units used to enter the unit ply data.

The six sample problems are discussed below:

- #1 and #2 As one would expect, the engineering properties for the $[0_2]_T$ laminate are those of a unit ply. The stiffness and compliance matrices can be retrieved. The order of the engineering properties, stiffness, and compliance components are shown in Figure 18. Next, a unit load in the one direction is applied. The 0° ply is then examined (it is the only orientation available), and the failure stresses are found. Although R_t , the strength ratio, has no meaning for an input unit load, recall $\sigma_t^\circ = R_t/h$, or $R_t = \sigma_t^\circ h$ for the unit load case. But $N_i = \sigma_t^\circ h$, so the failure $N_i = R_t$. This failure N_i is applied to the laminate and, since we are at the failure condition, $R_t = 1$. σ_t° and $\sigma_t^{\circ'}$ have no meaning when a non-unit load is applied. The strain invariants can be displayed if desired. For a unit load input, they are meaningless. A unit load is then applied in the 2-direction. Strength in this direction, as one would expect, is much lower.
- #3 This example demonstrates that after a given loading has been applied, each θ_t must be examined (0° and 90° , in this case) for its own failure load. The lowest of the failure loads is the first ply failure for the laminate. In this example, the 90° ply fails first for uniaxial loading in the 0° direction.
- #4 The $[45/-45]_S$ laminate example shows how much weaker this stacking is than the $[0/90]_S$ laminate, under

uniaxial loading in the 1-direction. If one examined shear carrying abilities, however, the $[45/-45]_s$ would be superior.

#5 Example #5 is a more realistic type of laminate that one would encounter. Because the failure criteria is applied to each ply individually, the failure loads for all plies must be examined.

#6 The laminate in this example is similar to the sample #5 laminate, except that a core has been added to separate the symmetric laminate into halves. The Young's moduli and shear modulus are halved due simply to a doubling of the total laminate thickness. Looking at uniaxial tension effects in the 0° ply, one can see that the load carrying ability, in N/m, is the same as the laminate without the core. The failure stresses are halved due only to the non-load carrying thickness addition of the core. The core for the in-plane loading case shows no advantage over the laminate without the core. The features of a core will be shown later in the flexural loading case.

COMBO 2 SAMPLE PROBLEM #1: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER $n = 2$ $\theta_1 = 0$ DISPLAY E_i^o (optional)	A	1	ENTER $N_1 = 1$	B	6.2
			$N_2 = 0$	R/S	6.6
			$N_6 = 0$	R/S	60
			ENTER $\theta_t = 0$	C	$R_t = 375.000 \text{ E03}$
			DISPLAY R_t'	R/S	375.000 E03
	R/S	$E_1^o = 181.000 \text{ E09}$	σ^o	D	1.500 E09
		10.300 E09	$\sigma^{o'}$	R/S	1.500 E09
		280.000 E-3			
		7.170 E09			
DISPLAY A_{ij} (optional)	B'	45.453 06	ENTER $N_1 = 375. \text{ E03}$	B	6.2
	R/S	2.587 06	$N_2 = 0$	R/S	6.6
	"	724.231 03	$N_6 = 0$	R/S	60
	"	1.792 06			
	"	0.000 00			
	"	0.000 00			
DISPLAY a_{ij} (optional)	R/S	22.099-09	ENTER $\theta_t = 0$	C	$R_t = 1.000 \text{ E00}$
	"	388.350-09	DISPLAY R_t'	R/S	1.000 E00
	"	-6.188-09			
	"	557.880-09			
	"	0.000 00			
	"	0.000 00			
DISPLAY A_{ij}^* (optional)	C'	181.811 09			
	R/S	10.346 09			
	"	2.897 09			
	"	7.170 09			
	"	0.000 00			
	"	0.000 00			
DISPLAY a_{ij}^* (optional)	R/S	5.525-12			
	"	97.087-12			
	"	-1.547-12			
	"	139.470-12			
	"	0.000 00			
	"	0.000 00			

COMBO 2 SAMPLE PROBLEM #2: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER $n = 2$ $\theta_1 = 0$ PRINT E_i° (optional)	A	1	ENTER $N_1 = 0$	B	6.2
	R/S	$E_1^\circ = 181.000 \text{ E09}$	$N_2 = 1$	R/S	6.6
	R/S	10.300 E09	$N_6 = 0$	R/S	60
	R/S	280.000 E-3			
DISPLAY A_{ij} (optional)	B'	45.453 06 2.587 06 724.231 03 1.792 06 0.000 00 0.000 00	ENTER $\theta_t = 0$	C	$R_t = 10.000 \text{ E03}$
	R/S		DISPLAY R_t'	R/S	61.500 E03
	"		σ°	R/S	40.000 E06
	"		$\sigma^{\circ'}$	R/S	246.000 E06
DISPLAY a_{ij} (optional)	R/S	22.099-09 388.350-09 -6.188-09 557.880-09 0.000 00 0.000 00	ENTER $N_1 = 0$	B	6.2
	"		$N_2 =$		
	"		10.0 E03	R/S	6.6
	"		$N_6 = 0$	R/S	60
DISPLAY A_{ij}^* (optional)	C'	181.811 09 10.346 09 2.897 09 7.170 09 0.000 00 0.000 00	ENTER $\theta_t = 0$	C	$R_t = 1.000 \text{ E00}$
	R/S		DISPLAY R_t'	R/S	6.150 E00
	"				
DISPLAY a_{ij}^* (optional)	R/S	5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00			
	"				
	"				
	"				
	"				
	"				

COMBO 2 SAMPLE PROBLEM #3: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0/90]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER $n = 4$ $\theta_1 = 0$ $\theta_2 = 90$ PRINT E_i^o (optional)	A	2	ENTER $N_1 = 1$	B	6.2
	R/S	1	$N_2 = 0$	R/S	6.6
	R/S	$E_1^o = 95.991 \text{ E09}$	$N_6 = 0$	R/S	60
	R/S	95.991 E09	ENTER $e_t = 0$	C	$R_t = 340.941 \text{ E03}$
	R/S	30.152 E-3	DISPLAY R_t^1	R/S	553.853 E03
	R/S	7.170 E09	σ^o	D	681.882 E06
	B'	48.039 06	$\sigma^{o'}$	R/S	1.108 E09
	R/S	48.039 06	ENTER $e_t = 90$	C	$R_t = 186.698 \text{ E03}$
	"	1.448 06	DISPLAY R_t^1	R/S	1.134 E06
	"	3.585 06	σ^o	D	373.396 E06
DISPLAY A_{ij} (optional)	"	0.000 00	$\sigma^{o'}$	R/S	2.269 E09
	"	0.000 00			
	R/S	20.835-09			
	"	20.835-09			
	"	-628.215-12			
DISPLAY a_{ij} (optional)	"	278.940-09			
	"	0.000 00			
	"	0.000 00			
	R/S	96.079 09			
	"	96.079 09			
DISPLAY A_{ij}^* (optional)	"	2.897 09			
	"	7.170 09			
	"	0.000 00			
	"	0.000 00			
	"	0.000 00			
DISPLAY a_{ij}^* (optional)	R/S	10.418-12			
	"	10.418-12			
	"	-314.108-15			
	"	139.470-12			
	"	0.000 00			
	"	0.000 00			

COMBO 2 SAMPLE PROBLEM #4: IN-PLANE STIFFNESS AND STRENGTH
LAMINATE: $[45, -45]_s$ MATERIAL: T300/5208

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
			ENTER $N_1 = 1$	B	6.2
			$N_2 = 0$	R/S	6.6
			$N_6 = 0$	R/S	60
			ENTER $\theta_t = 45$	C	$R_t = 61.614 \text{ E03}$
			DISPLAY R'_t	R/S	74.466 E03
			σ°	D	123.228 E06
			$\sigma^{\circ'}$	R/S	148.932 E06
ENTER $n = 4$	A	2			
$\theta_1 = 45$	R/S	1			
$\theta_2 = -45$	R/S	$E_1^\circ = 25.051 \text{ E09}$	ENTER $\theta_t = -45$	C	$R_t = 61.614 \text{ E03}$
DISPLAY E_i°	R/S	25.051 E09	DISPLAY R'_t	R/S	74.466 E03
(optional)	R/S	746.902 E-3	σ°	D	123.228 E06
	R/S	46.591 E09	$\sigma^{\circ'}$	R/S	148.932 E06
DISPLAY A_{ij}	B'	28.329 06			
(optional)	R/S	28.329 06			
	"	21.159 06			
	"	23.295 06			
	"	0.000 00			
	"	0.000 00			
DISPLAY a_{ij}	R/S	79.839-09			
(optional)	"	79.839-09			
	"	-59.632-09			
	"	42.927-09			
	"	0.000 00			
	"	0.000 00			
DISPLAY A_{ij}^*	C'	56.658 09			
(optional)	R/S	56.658 09			
	"	42.318 09			
	"	46.591 09			
	"	0.000 00			
	"	0.000 00			
DISPLAY a_{ij}^*	R/S	39.919-12			
(optional)	"	39.919-12			
	"	-29.816-12			
	"	21.463-12			
	"	0.000 00			
	"	0.000-00			

COMBO 2 SAMPLE PROBLEM #5: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: [0/90/45/-45]_s

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER n = 8 $\theta_1 = 0$ $\theta_2 = 90$ $\theta_3 = 45$ $\theta_4 = 45$ DISPLAY E_j^o (optional)	A R/S " " " "	4 3 2 1 $E_1^o = 69.676 \text{ E09}$ 69.676 E09 296.031 E-3 26.880 E09	ENTER $N_1 = 1$	B	6.2
			$N_2 = 0$	R/S	6.6
			$N_6 = 0$	R/S	60
			ENTER $\theta_t = 0$	C	$R_t = 581.811 \text{ E03}$
			DISPLAY R_t'	R/S	565.417 E03
			σ^o	D	581.811 E06
DISPLAY A_{ij} (optional)	B' R/S " " " "	76.368 06 76.368 06 22.607 06 26.880 06 0.000 00 0.000 00	$\sigma^{o'}$	R/S	565.417 E06
			ENTER $\theta_t = 90$	C	$R_t = 276.119 \text{ E03}$
			DISPLAY R_t'	R/S	1.298 E06
			σ^o	D	276.119 E06
			$\sigma^{o'}$	R/S	1.298 E09
			ENTER $\theta_t = 45$	C	$R_t = 346.996 \text{ E03}$
DISPLAY a_{ij} (optional)	R/S " " " " "	14.352-09 14.352-09 -4.249-09 37.202-09 0.000 00 0.000 00	DISPLAY R_t'	R/S	675.075 E03
			σ^o	D	346.996 E06
			$\sigma^{o'}$	R/S	675.075 E06
			ENTER $\theta_t = -45$	C	$R_t = 346.996 \text{ E03}$
			DISPLAY R_t'	R/S	675.075 E03
			σ^o	D	346.996 E06
DISPLAY A_{ij}^* (optional)	C' R/S " " " "	76.368 09 76.368 09 22.607 09 26.880 09 0.000 00 0.000 00	$\sigma^{o'}$	R/S	675.075 E06
			DISPLAY a_{ij}^*	R/S	14.352-12
			σ^o	D	14.352-12
			$\sigma^{o'}$	R/S	-4.249-12
				D	37.202-12
				D	0.000 00
DISPLAY a_{ij}^* (optional)	R/S " " " " "	14.352-12 14.352-12 -4.249-12 37.202-12 0.000 00 0.000 00		D	0.000 00
				D	0.000 00
				D	0.000 00
				D	0.000 00
				D	0.000 00
				D	0.000 00

COMBO 2 SAMPLE PROBLEM #6: IN-PLANE STIFFNESS AND STRENGTH
 LAMINATE: $[0/90/45/-45/C_4]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
			ENTER $N_1 = 1$	B	6.2
			$N_2 = 0$	R/S	6.6
			$N_6 = 0$	R/S	60
ENTER $n = 16$	A	8	ENTER $\theta_t = 0$	C	$R_t = 581.811 \text{ E03}$
$\theta_1 = 0$	R/S	7	DISPLAY R'_t	R/S	565.417 E03
$\theta_2 = 90$	"	6	σ°	D	290.906 E06
$\theta_3 = 45$	"	5	$\sigma^{\circ'}$	R/S	282.709 E06
$\theta_4 = -45$	"	4			
	A'	$E_1^\circ = 34.838 \text{ E09}$	ENTER $\theta_t = 90$	C	$R_t = 276.119 \text{ E03}$
DISPLAY E_i°	R/S	34.838 E09	DISPLAY R'_t	R/S	1.298 E06
	"	296.031 E-3	σ°	D	138.060 E06
	"	13.440 E09	$\sigma^{\circ'}$	R/S	648.792 E06
DISPLAY A_{ij}	B'	76.368 06			
(optional)	R/S	76.368 06	ENTER $\theta_t = 45$	C	$R_t = 346.996 \text{ E03}$
	"	22.607 06	DISPLAY R'_t	R/S	675.075 E03
	"	26.880 06	σ°	R/S	173.498 E06
	"	0.000 00	$\sigma^{\circ'}$	R/S	337.538 E06
	"	0.000 00			
DISPLAY a_{ij}	R/S	14.352-09			
(optional)	"	14.352-09			
	"	-4.249-09			
	"	37.202-09			
	"	0.000 00			
	"	0.000 00			
DISPLAY A_{ij}^*	C'	38.184 09			
(optional)	R/S	38.184 09			
	"	11.304 09			
	"	13.440 09			
	"	0.000 00			
	"	0.000 00			
DISPLAY a_{ij}^*	R/S	28.704-12			
(optional)	"	28.704-12			
	"	-8.497-12			
	"	74.404-12			
	"	0.000 00			
	"	0.000 00			

SECTION VI

COMBO 2P: IN-PLANE STIFFNESS AND STRENGTH OF SYMMETRIC LAMINATES WITH PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 2P: IN-PLANE PROPERTIES w/PRINTER				
Core				
$n, \theta_t \rightarrow E_j^o, A_s$	$N_i \rightarrow I_\epsilon, R_\epsilon$	$\theta_t \rightarrow R_t, \sigma_t^o$		

The Combo 2P program is similar to the Combo 2 program but it can be used with a printer. Because of program memory limitations, Combo 2P cannot be used to directly plot failure envelopes in strain space (strain space plots can be made using E_1^o , E_2^o , ν_{21} , E_6^o , and failure stresses). In stress space, however, it works the same as Combo 2. It also lacks the ability to recover unit ply data which Combo 2 can. The program is listed in Appendix D. Sample problems follow this section.

To use Combo 2P:

1. Have U_j , G_{ij} , and h_0 for the desired material and in the desired units stored in bank 3.
2. Press **CLR**, read side 1, press **CLR**, read side 2.
3. No Core: Enter n , the total number of plies, then press **A**. Enter θ_1 , R/S, θ_2 , R/S, ..., $\theta_{n/2}$, R/S. See Figure 18.
Core: Enter n , the total number of plies plus the total number of ply thicknesses that make up the core; press **A**. Enter θ_1 , R/S, θ_2 , R/S, ... After entering one angle for each ply orientation (note less than n entries), press **A**. See Figures 18 and 19.

The machine calculates and prints automatically:

$E_1^o, E_2^o, v_{21}^o, E_6^o$	Labeled "E*" by printer
$A_{11}, A_{22}, A_{12}, A_{66}, A_{16}, A_{26}$	Labeled "A" by printer
$a_{11}, a_{22}, a_{12}, a_{66}, a_{16}, a_{26}$	Labeled "AI" by printer
$A_{11}^*, A_{22}^*, A_{12}^*, A_{66}^*, A_{16}^*, A_{26}^*$	Labeled "A*" by printer
$a_{11}^*, a_{22}^*, a_{12}^*, a_{66}^*, a_{16}^*, a_{26}^*$	Labeled "A*I" by printer

The definitions of the above quantities are given in the section describing Combo 2.

4. Enter (as shown in Figure 18) N_1, N_2, N_6 as selected unit loads or an actual loading case. This selection is discussed in detail in the Combo 2 section.

The machine calculates and prints:

I_ϵ, R_ϵ Labeled "eI" by printer.

5. Enter θ_t according to Figure 18.

The machine calculates and prints:

R_t, R_t' Labeled "R" by printer

$\sigma_t^o, \sigma_t^{o'}$ Labeled " Σ " by printer

The definitions of the above quantities are given in the section describing Combo 2.

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
1	Enter ply data				
2a	Enter n	A		n	n/2
b	θ_1	R/S		θ_1	n/2 - 1
c	θ_2	R/S		θ_2	n/2 - 2
.	.	.		.	.
.	.	.		.	.
.	$\theta_{n/2 - 1}$	R/S		$\theta_{n/2 - 1}$	1
*	$\theta_{n/2}$	R/S		SYM	
			E*	$E_1^o, E_2^o, v_{21}^o, E_6^o$	
			A	$A_{11}, A_{22}, A_{12}, A_{66}, A_{16}, A_{26}$	
			AI	$a_{11}, a_{22}, a_{12}, a_{66}, a_{16}, a_{26}$	
			A*	$A_{11}^*, A_{22}^*, A_{12}^*, A_{66}^*, A_{16}^*, A_{26}^*$	
			A*I	$a_{11}^*, a_{22}^*, a_{12}^*, a_{66}^*, a_{16}^*, a_{26}^*$	6.1
3a	Enter N_1	B	N	N_1	6.2
b	N_2	R/S		N_2	6.6
c	N_6	R/S		N_6	
			eI	I_ϵ, R_ϵ	60
4	Enter θ_t	C	$\uparrow$	θ_t	
			R	R_t, R'_t	
			Σ	$\sigma_t^o, \sigma_t^{o'}$	60

Figure 18. Combo 2P Instruction Chart

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
*	For sandwich construction	A'	CR	when display = c c SYM	
			E*	printout will continue as previously described in Step 1	6.1

Figure 19. Combo 2P Options

00	USED	15	A_{26}	30	U_1	45	G_{yy}
01	USED	16	a_{11}, G_{xx}	31	U_2	46	G_{xy}
02	USED	17	a_{22}, G_{yy}	32	U_3	47	G_{ss}
03	USED	18	a_{12}, G_{xy}	33	U_4	48	G_x
04	USED	19	a_{66}, G_{ss}	34	U_5	49	G_y
05	$n, n/2$	20	a_{16}, G_x	35	θ	50	
06	R_t	21	a_{26}, G_y	36	V_0	51	
07	R'_t	22	$ A $	37	V_1	52	
08	$1/h$	23	ϵ_1^o	38	V_3	53	p
09	h	24	ϵ_2^o	39	$V_2, \sqrt{\quad}$	54	q
10	A_{11}	25	ϵ_6^o	40	V_4	55	r
11	A_{22}	26	$N_1, 0$	41	θ	56	a
12	A_{12}	27	$N_2, 0$	42	USED	57	$-b/2a$
13	A_{66}	28	$N_6, 0$	43	USED	58	c/a
14	A_{16}	29	USED	44	G_{xx}	59	h_o

Figure 20. Combo 2P Storage Memories

COMBO CARD #2P IN-PLANE STIFFNESS & STRENGTH (ON PRINTER)

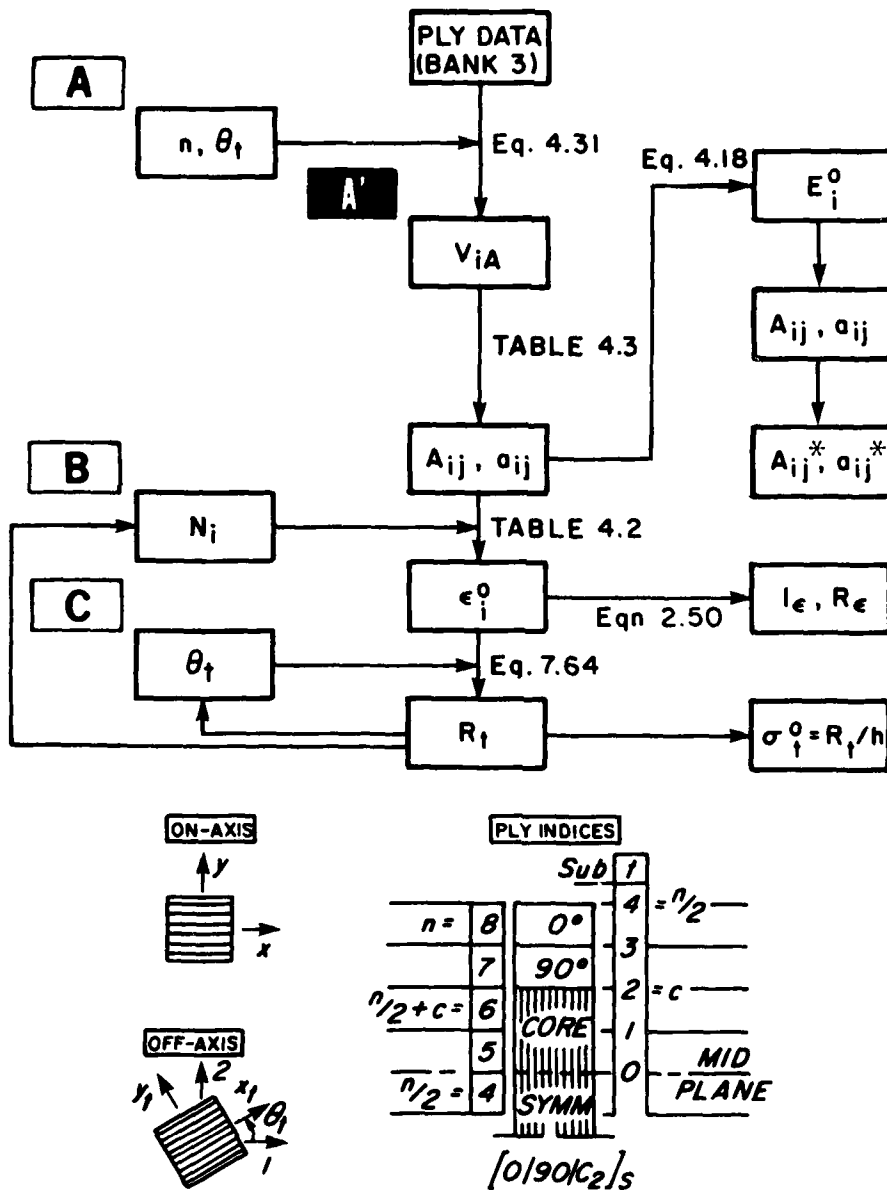


Figure 21. Combo 2P Flow Chart

Combo 2P Sample Problems

The sample problems listed in this section are to aid the user in getting started with the Combo cards/Composite Materials Module. As one works through the sample problems, the user should follow along with the instruction charts, Figures 18 and 19. The sample problems should be followed vertically down the left half of the page, then vertically down the right. Note that the example problems' printer tape extends beyond the blocks describing the printer output. This corresponds to re-entering a new loading condition or examining a different ply orientation. The "looping" done here is best shown in the program diagram, Figure 21.

The sample problems with a core denote the core as, say, C_4 , meaning the half-core is four times the unit ply thickness, or the total core thickness is eight times the unit ply thickness. A typical real-world core would undoubtedly be much thicker. The user can have a laminate with a core thickness that is not an integer multiple of the unit ply thickness. This would require that n is also not an integer.

All units in the sample problems are as follows:

θ_t	degrees
E_j^o	Pa
ν_{21}^o	dimensionless
A_{1j}	N/m
a_{1j}	m/N
A_{1j}^*	Pa (N/m^2)
a_{1j}^*	$1/\text{Pa}$ (m^2/N)
I_e, R_e, R_t, R_t'	dimensionless
σ_t^o, σ_t'	Pa

English unit calculations can be completed just as easily. When the material properties in Bank 3 are stored in English units, loads can be entered in lbs/in, etc., provided their dimensions are consistent with the units used to enter the unit ply data.

The six sample problems are discussed below:

#1 and #2 As one would expect, the engineering properties for the $[0_2]_T$ laminate are those of a unit ply. The stiffness and compliance matrices can be retrieved. The order of the engineering properties, stiffness, and compliance components are shown in Figure 18. Next, a unit load in the one direction is applied. The 0° ply is then examined (it is the only orientation available), and the failure stresses are found.

Although R_t , the strength ratio, has no meaning for an input unit load, recall $\sigma_t^o = R_t/h$, or $R_t = \sigma_t^o h$ for the unit load case. But $N_i = \sigma_t^o h$, so the failure $N_i = R_t$. This failure N_i is applied to the laminate and, since we are at the failure condition, $R_t = 1$. σ_t^o and σ_t^o' have no meaning when a non-unit load is applied. The strain invariants can be displayed if desired. For a unit load input, they are meaningless. A unit load is then applied in the 2-direction. Strength in this direction, as one would expect, is much lower.

#3 This example demonstrates that after a given loading has been applied, each θ_t must be examined (0° and 90° , in this case) for its own failure load. The lowest of the failure loads is the first ply failure for the

laminate. In this example, the 90° ply fails first for uniaxial loading in the 0° direction.

- #4 The $[45/-45]_s$ laminate example shows how much weaker this stacking is than the $[0/90]_s$ laminate, under uniaxial loading in the 1-direction. If one examined shear carrying abilities, however, the $[45/-45]_s$ would be superior.
- #5 Example #5 is a more realistic type of laminate that one would encounter. Because the failure criteria is applied to each ply individually, the failure loads for all plies must be examined. The -45° ply should also have been examined, but space did not allow this.
- #6 The laminate in this example is similar to the sample #5 laminate, except that a core has been added to separate the symmetric laminate into halves. The Young's moduli and shear modulus are halved due simply to a doubling of the total laminate thickness. Looking at uniaxial tension effects in the 0° ply, one can see that the load carrying ability, in N/m, is the same as the laminate without the core. The failure stresses are halved due only to the non-load carrying thickness addition of the core. The core for the in-plane loading case shows no advantage over the laminate without the core. The features of a core will be shown later in the flexural loading case.

COMBO 2P SAMPLE PROBLEM #1: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	2.000 00	ENTER N_1	B	N
ENTER ϵ_1	R/S	0.000 00 BYD	N_2	R/S	1.000 00
PRINT E_i^o		E+	N_6	R/S	0.000 00
PRINT A_{ij}		181.000 09 10.300 09 280.000-03 7.170 09	PRINT I_{ϵ}		eI
PRINT a_{ij}		R	R_{ϵ}		7.958-09 14.144-09
PRINT A_{ij}^*		45.453 06 2.587 06 724.231 03 1.732 06 0.000 00 2.100 00	ENTER θ_t	C	T
PRINT a_{ij}^*		EI	PRINT R_t		0.000 00
PRINT a_{ij}^*		32.033-09 333.350-09 -6.188-09 557.680-09 0.000 00 0.000 00	R'_t		R
		R*	PRINT σ^o		375.000 03 375.000 03
		181.811 09 10.346 09 2.897 09 7.170 09 0.000 00 0.000 00	$\sigma^{o'}$		Σ
		R*I			1.500 09 1.500 09
		5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00			N
					375.000 03 0.000 00 0.000 00
					eI
					2.983-03 5.304-03
					T
					0.000 00
					R
					1.000 00 1.000 00
					Σ
					4.000 03 4.000 03

COMBO 2P SAMPLE PROBLEM #2: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	1.000 00	ENTER N_1	B	N
ENTER θ_1	R/S	0.000 00 SYM	N_2	R/S	0.000 00
PRINT E_i^o		E^* 181.000 09 10.300 09 280.000 09 7.170 09	N_6	R/S	0.000 00
PRINT A_{ij}		A 45.453 08 2.587 08 724.231 08 1.782 08 0.000 00 0.000 00	PRINT I_{ϵ}		eI 181.081 09 187.269 09
PRINT a_{ij}		AI 22.099 09 388.350 09 -6.189 09 557.880 09 0.000 00 0.000 00	ENTER θ_t	C	$\uparrow$ 0.000 00
PRINT A_{ij}^*		A^* 181.811 09 10.346 09 2.897 09 7.170 09 0.000 00 0.000 00	PRINT R_t		R 10.000 09 61.500 09
PRINT a_{ij}^*		A^*I 5.525 12 97.087 12 -1.547 12 139.470 12 0.000 00 0.000 00	PRINT σ^o		I 40.000 08 248.000 08
					N 0.000 00 10.000 08 0.000 00
					eI 1.911 09 1.973 09
					$\uparrow$ 0.000 00
					R 1.000 00 6.150 00
					I 4.000 09 24.600 09

COMBO 2P SAMPLE PROBLEM #3: IN-PLANE STIFFNESS AND STRENGTH
 LAMINATE: $[0/90]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	4. 00	ENTER N_1	B	N
ENTER θ_1	R/S	0.000 00	N_2	R/S	1.000 00
θ_2	R/S	90.000 00	N_6	R/S	0.000 00
		SYM			
PRINT E_i^o		E*	PRINT I_{ϵ}		eI
		95.991 09	R_{ϵ}		10.104-09
		95.991 09			10.732-09
		30.152-03	ENTER θ_t	C	τ
		7.170 09			0.000 00
PRINT A_{ij}		A	PRINT R_t		R
		48.039 06	R'_t		340.941 03
		48.039 06			553.853 03
		1.448 06	PRINT σ^o		Σ
		3.585 06	$\sigma^{o'}$		681.882 06
		0.000 00			1.108 09
		0.000 00			$\uparrow$
PRINT a_{ij}		AI			90.000 00
		20.835-09			R
		20.835-09			186.698 03
		-628.215-12			1.134 06
		278.940-09			Σ
		0.000 00			373.396 06
		0.000 00			2.269 09
PRINT A_{ij}^*		A*			
		96.079 09			
		96.079 09			
		2.897 09			
		7.170 09			
		0.000 00			
		0.000 00			
PRINT a_{ij}^*		A*I			
		10.418-12			
		10.418-12			
		-314.108-15			
		139.470-12			
		0.000 00			
		0.000 00			

COMBO 2P SAMPLE PROBLEM #4: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: [45/-45]_s

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	4.000 00	ENTER N ₁	B	N
ENTER θ_1	R/S	45.000 00	N ₂	R/S	1.000 00
θ_2	R/S	-45.000 00	N ₆	R/S	0.000 00
PRINT E _i ^o		SYM	PRINT I _{ϵ}		eI
		E*	R _{ϵ}		10.104-09
		25.051 09			69.735-09
		25.051 09	ENTER θ_t	C	↑
		746.902-03			45.000 00
		46.591 09	PRINT R _t		R
PRINT A _{ij}		A	R' _t		61.614 03
		28.329 06			74.466 03
		28.329 06	PRINT σ^o		Σ
		21.159 06	$\sigma^{o'}$		123.228 06
		23.295 06			148.932 06
		0.000 00			↑
		0.000 00			-45.000 00
PRINT a _{ij}		AI			R
		79.839-09			61.614 03
		79.839-09			74.466 03
		-59.632-09			Σ
		42.927-09			123.228 06
		0.000 00			148.932 06
		0.000 00			
PRINT A _{ij} [*]		A*			
		56.658 09			
		56.658 09			
		42.318 09			
		46.591 09			
		0.000 00			
		0.000 00			
PRINT a _{ij} [*]		A*I			
		39.919-12			
		39.919-12			
		-29.816-12			
		21.463-12			
		0.000 00			
		0.000 00			

COMBO 2P SAMPLE PROBLEM #5: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: [0/90/45/-45]_s

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	8. 00	ENTER N ₁	B	
ENTER θ_1	R/S	0.000 00	N ₂	R/S	N
θ_2	R/S	90.000 00	N ₆	R/S	1.000 00
θ_3	R/S	45.000 00			0.000 00
θ_4	R/S	-45.000 00			0.000 00
		S/M	PRINT I _e		eI
PRINT E _i ^o		E*	R _e		5.052-09
		69.676 09			9.300-09
		69.676 09	ENTER θ_t	C	↑
		296.031-03			0.000 00
		26.880 09	PRINT R _t		R
PRINT A _{ij}		A	R' _t		581.811 03
		76.368 06			565.417 03
		76.368 06	PRINT σ^o		Σ
		22.607 06	$\sigma^{o'}$		581.811 06
		26.880 06			565.417 06
		0.000 00			↑
		0.000 00			90.000 00
PRINT a _{ij}		A1			R
		14.352-09			276.119 03
		14.352-09			1.298 06
		-4.249-09			Σ
		37.202-09			276.119 06
		0.000 00			1.298 09
		0.000 00			↑
PRINT A _{ij} [*]		A*			45.000 00
		76.368 09			R
		76.368 09			346.996 03
		22.607 09			675.075 03
		26.880 09			Σ
		0.000 00			346.996 06
		0.000 00			675.075 06
PRINT a _{ij} [*]		A*I			
		14.352-12			
		14.352-12			
		-4.249-12			
		37.202-12			
		0.000 00			
		0.000 00			

COMBO 2P SAMPLE PROBLEM #6: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: [0/90/45/-45/C₄]

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	16.000 00	ENTER N ₁	B	N
ENTER θ_1	R/S	0.000 00	N ₂	R/S	1.000 00
θ_2	R/S	90.000 00	N ₆	R/S	0.000 00
θ_3	R/S	45.000 00	PRINT I _e		eI
θ_4	R/S	-45.000 00	R _e		5.052-09
	A'	CR			9.300-09
		4.000 00	ENTER θ_t	C	↑
		SYM			0.000 00
PRINT E _i ^o		E*	PRINT R _t		R
		34.838 09			581.811 03
		34.838 09	R' _t		565.417 03
		296.031-03	PRINT σ^o		Σ
		13.440 09	$\sigma^{o'}$		290.906 06
PRINT A _{ij}		A			282.709 06
		76.368 06			↑
		76.368 06			90.000 00
		22.607 06			R
		26.880 06			276.119 03
		0.000 00			1.298 06
		0.000 00			Σ
PRINT a _{ij}		AI			138.060 06
		14.352-09			648.792 06
		14.352-09			↑
		-4.249-09			45.000 00
		37.202-09			R
		0.000 00			346.996 03
		0.000 00			675.075 03
PRINT A _{ij} [*]		A*			Σ
		38.184 09			173.498 06
		38.184 09			337.538 06
		11.304 09			
		13.440 09			
		0.000 00			
		0.000 00			
PRINT a _{ij} [*]		A*I			
		28.704-12			
		28.704-12			
		-8.497-12			
		74.404-12			
		0.000 00			
		0.000 00			

SECTION VII

COMBO 3: FLEXURAL PROPERTIES WITHOUT PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 3: FLEXURAL PROPERTIES w/o PRINTER				
Core	D_{ij}, d_{ij}	D_{ij}^*, d_{ij}^*		
$n, \theta_t \rightarrow E_i^f$	$M_i \rightarrow k_i$	$\theta_t, t \rightarrow R_t, R_t'$	$\sigma_t^f, \sigma_t^{f'}$	

Combo 3 is a program which takes the ply properties from the storage memories and calculates laminate flexural properties. These include apparent elastic constants, flexural stiffness and compliance matrices, strength ratios, and allowable bending moments. It can be used to quickly plot failure envelopes in moment-space. This combo should be used when no printer is available. Appendix D contains a listing of the entire program.

To use Combo 3:

1. Have U_i , G_{ij} , and h_0 for the desired material and in the desired units stored in bank 3.
2. Press **CLR**, read side 1, press **CLR**, read side 2.
3. No core: Enter n , the total number of plies, then press **A**. Enter $\theta_1, R/S, \dots, \theta_{n/2}, R/S$. The θ_t are entered with the orientation of the outermost ply of the stack first. Further θ_t are entered in order as t approaches the laminate mid-plane.

Core: Enter n, the total number of plies plus the total number of ply thicknesses that make up the core; press **A**. Enter θ_1 R/S, θ_2 , R/S,... After entering one angle for each ply orientation (note less than n entries), press **A**. See Figures 22 and 23 for details.

The machine calculates:

$$\begin{array}{l} E_1^f \\ E_2^f \\ \nu_{21}^f \\ E_6^f \end{array} \left\{ \begin{array}{l} \text{effective flexural laminate moduli (Equations 5.21, 5.22, 5.23)} \\ E_1^f = \frac{12}{h^3 d_{11}}, \text{ etc.} \end{array} \right.$$

$$\begin{array}{l} D_{11} \\ D_{22} \\ D_{12} \\ D_{66} \\ D_{16} \\ D_{26} \end{array} \left\{ \begin{array}{l} \text{flexural stiffness matrix (Table 5.3, Equation 5.40)} \\ \begin{Bmatrix} M_1 \\ M_2 \\ M_6 \end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} k_1 \\ k_2 \\ k_6 \end{Bmatrix} \quad \text{where } \begin{array}{l} \epsilon_1^f(z) = zk_1 \\ \epsilon_2^f(z) = zk_2 \\ \epsilon_6^f(z) = zk_6 \end{array} \end{array} \right.$$

$$\begin{array}{l} d_{11} \\ d_{22} \\ d_{12} \\ d_{66} \\ d_{16} \\ d_{26} \end{array} \left\{ \begin{array}{l} \text{inversion of [D]:} \\ \begin{Bmatrix} k_1 \\ k_2 \\ k_6 \end{Bmatrix} = \begin{bmatrix} d_{11} & d_{12} & d_{16} \\ d_{12} & d_{22} & d_{26} \\ d_{16} & d_{26} & d_{66} \end{bmatrix} \begin{Bmatrix} M_1 \\ M_2 \\ M_6 \end{Bmatrix} \end{array} \right.$$

$$\begin{array}{l}
 D_{11}^* \\
 D_{22}^* \\
 D_{12}^* \\
 D_{66}^* \\
 D_{16}^* \\
 D_{26}^*
 \end{array}
 \left[\begin{array}{l}
 D_{ij}/h^*; h^* = (1 - z_c)^3 h^3 / 12 \text{ (Equations 5.30, 5.49):} \\
 \begin{Bmatrix} \sigma_1^f \\ \sigma_2^f \\ \sigma_6^f \end{Bmatrix} = \begin{bmatrix} & & \\ & D^* & \\ & & \end{bmatrix} \begin{Bmatrix} \epsilon_1^f \\ \epsilon_2^f \\ \epsilon_6^f \end{Bmatrix}
 \end{array} \right]$$

note: σ_i^f and ϵ_i^f are defined in Appendix A.

$$\begin{array}{l}
 d_{11}^* \\
 d_{22}^* \\
 d_{12}^* \\
 d_{66}^* \\
 d_{16}^* \\
 d_{26}^*
 \end{array}
 \left[\begin{array}{l}
 d_{ij} h^*: \\
 \begin{Bmatrix} \epsilon_1^f \\ \epsilon_2^f \\ \epsilon_6^f \end{Bmatrix} = \begin{bmatrix} & & \\ & d^* & \\ & & \end{bmatrix} \begin{Bmatrix} \sigma_1^f \\ \sigma_2^f \\ \sigma_6^f \end{Bmatrix}
 \end{array} \right]$$

4. The display will show E_1^f . The user has the option of displaying the rest of the engineering constants, D_{ij} , d_{ij} , D_{ij}^* , and/or d_{ij}^* . See Figures 22 and 23 for instructions.
5. At this point, the user must input the load. There are two options:
 - a) Input selective unit loads to determine failure envelopes and maximum loading allowable.
 - b) Input an actual loading case to determine strength ratios.

Case a deals with the locus of the failure envelope for a selected ply in the laminate. For a given loading path (constant $M_1 = M_2 = M_6$); it calculates where the path pierces the envelope, i.e., the maximum allowable σ_t^f values along that proportional loading line. Using a technique similar to the

one detailed in the Combo 2 explanation, failure envelopes can be plotted. Case b, an actual input loading case, is a point which lies, for an allowable loading, somewhere within the envelope.

Case a)

Enter M_1, M_2, M_6 as instructed in Figure 22. To find the values of σ_i^f which pierce the failure envelope (for a given proportional loading), enter $M_i = 1$, and the other two M's to set the $M_1 : M_2 : M_6$ ratio as desired.

6. Enter θ_t and t , the orientation and the ply number of the ply to be examined (see Figure 22).

The machine calculates:

$$\left. \begin{matrix} R_t \\ R'_t \end{matrix} \right\} \text{ not used for case a.}$$

7. Press D. The machine calculates:

$$\left. \begin{matrix} \sigma_i^f \\ \sigma_f^f \\ \sigma_j^f \end{matrix} \right\} \text{ Values of } \sigma_i^f \text{ (} \sigma_i^f \text{ is defined in Appendix A), when } N_i = 1, \text{ which pierce the failure envelope:}$$

$$M_i = 1 = \int \sigma_i z dz = \frac{h^2}{6} \sigma_i^f ; \sigma_i^f = \frac{6}{h^2}$$

$$\sigma_{i,allow}^f = R_t \sigma_{i,appl}^f = \frac{6}{h^2} R_t$$

If the applied moment at failure is desired:

$$M_{i,allow} = \frac{h^2}{6} \sigma_{i,allow}^f$$

To find failure envelopes or simply check failure points for the entire laminate, it is not necessary to make one run for each of the plies. Instead, make one run for each ply angle (θ_t) and

choose t to be the outermost ply with that orientation, since it experiences the highest stress.

Case b)

Enter actual M_1, M_2, M_6 as instructed in Figure 22.

The machine calculates:

k_1, k_2 , and k_6 , which are then stored in locations 23, 24, and 25.

They can be recalled if desired.

6. Enter θ_t and t , the orientation and the number of the ply to be examined (see Figure 22).

The machine calculates:

$$\left. \begin{array}{l} R_t \\ R'_t \end{array} \right\} \text{ strength ratios:}$$
$$M_{i,\text{allowable}} = R_t M_{i,\text{applied}}$$
$$\sigma_{i,\text{allowable}}^f = R_t \sigma_{i,\text{applied}}^f$$

7. Recall R_t and R'_t as desired by following the instructions in Figure 22.

Again, as in case a, it is not necessary to examine the failure moments for every ply in the laminate. Simply calculate strength ratios for one ply per orientation angle. The ply selected for a given orientation should be the outermost ply with that orientation, since it receives greater bending stress than the more interior plies.

STEP	PROCEDURE	PRESS	DISPLAY
1	Enter ply data		
2a	Enter n	A	n/2
b	θ_1	R/S	n/2 - 1
c	θ_2	R/S	n/2 - 2
	$\vdots$	$\vdots$	$\vdots$
	$\vdots$	$\vdots$	$\vdots$
*	$\theta_{n/2 - 1}$		1
	$\theta_{n/2}$	R/S, R/S,...	$E_1^f, E_2^f, v_{21}^f, E_6^f, 6.1$
**			
3a	Enter M_1	B	6.2
b	M_2	R/S	6.6
c	M_6	R/S	60
4a	Enter θ_t	C	37
b	t	R/S	R_t
		R/S	R_t'
		R/S	60
5	Display $\sigma^f, \sigma^{f'}$	D	σ_t^f
		R/S	$\sigma_t^{f'}$
		R/S	60

Figure 22. Combo 3 Instruction Chart

STEP	PROCEDURE	PRESS	DISPLAY
*	For sandwich construction	A' R/S, R/S,...	when display = c E_1^f $E_2^f, \nu_{21}^f, E_6^f, 6.1$
**	Display D_{ij}, d_{ij} Display D_{ij}^*, d_{ij}^*	B' R/S, R/S, ... C' R/S, R/S, ...	D_{11} $D_{22}, D_{12}, D_{66}, D_{16}, D_{26}$ $d_{11}, d_{22}, d_{12}, d_{66}, d_{16}, d_{26}, 6.1$ D_{11}^* $D_{22}^*, D_{12}^*, D_{66}^*, D_{16}^*, D_{26}^*$ $d_{11}^*, d_{22}^*, d_{12}^*, d_{66}^*, d_{16}^*, d_{26}^*, 6.1$

Figure 23. Combo 3 Options

00	USED	15	D_{26}	30	U_1	45	G_{yy}
01	USED	16	d_{11}, G_{xx}	31	U_2	46	G_{xy}
02	USED	17	d_{22}, G_{yy}	32	U_3	47	G_{ss}
03	USED	18	d_{12}, G_{xy}	33	U_4	48	G_x
04	USED	19	d_{66}, G_{ss}	34	U_5	49	G_y
05	$n, n/2, t$	20	d_{16}, G_x	35	θ	50	
06	R_t	21	d_{26}, G_y	36	V_0	51	
07	R'_t	22	$ D $	37	V_1	52	
08	$12/h^3$	23	k_1, ϵ_1	38	V_3	53	p
09	h	24	k_2, ϵ_2	39	$V_2, \sqrt{\quad}$	54	q
10	D_{11}	25	k_6, ϵ_6	40	V_4	55	r
11	D_{22}	26	$M_1, 0$	41	θ	56	a
12	D_{12}	27	$M_2, 0$	42	USED	57	$-b/2a$
13	D_{66}	28	$M_6, 0$	43	USED	58	c/a
14	D_{16}	29	USED	44	G_{xx}	59	h_o

Figure 24. Combo 3 Storage Memories

COMBO CARD #3 FLEXURAL STIFFNESS & STRENGTH (OFF PRINTER)

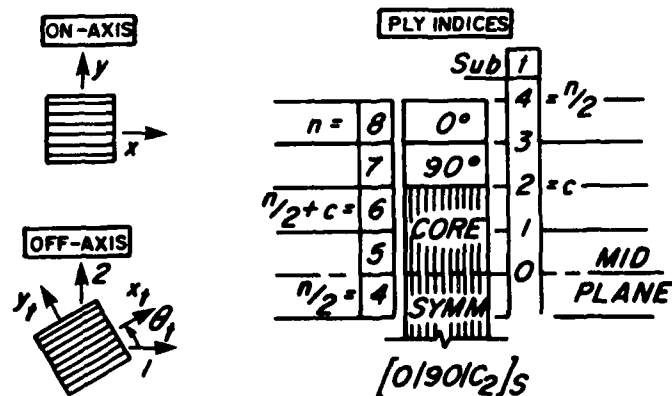
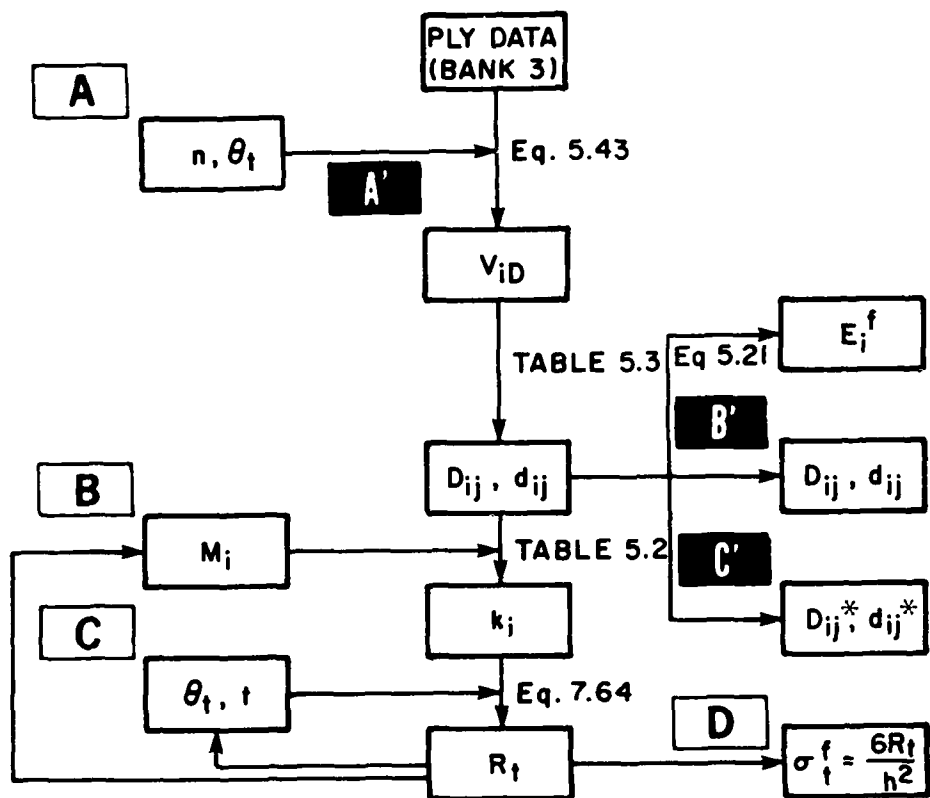


Figure 25. Combo 3 Flow Chart

Combo 3 Sample Problems

As in the Combo 2 section, one should follow the instruction charts, Figures 22 and 23, when working through the sample problems. The sample problems should be followed vertically down the left half of the page, then the right.

The entry of sample problems with a core is exactly the same as that described in Combo 2 and 2P. Again, a core that is a non-integer multiple of unit ply thickness is permissible. Problem #3 demonstrates this.

Additional units for this Combo are, in the case of the sample problems listed:

D_{ij}	$N\text{-}m$
d_{ij}	$1/N\text{-}m$
D_{ij}^*	$N/m^2 \text{ (Pa)}$
d_{ij}^*	$m^2/N \text{ (1/Pa)}$

English unit calculations can be completed just as easily. When the material properties in Bank 3 are stored in English units, loads can be entered in in-lbs/in, etc., provided their dimensions are consistent with the units used to enter the unit ply data.

The six sample problems are discussed below:

- #1 The failure σ_t^f is calculated, then the failure moment $= h^2/6 \sigma_t^f$ is applied to show $R_t = 1$ can be recovered.
- #2 This laminate is the same as the one in example #1, except the plies have been separated by a core. Note that for the same ply weight, the maximum moment allowable increases 250% from the original laminate.
- #3 Increasing the core thickness further increases the

maximum allowable bending moment. This example also demonstrates how to enter a core thickness that is not an integer multiple of unit ply thickness.

#4, #5, #6 This example shows that for the quasi-isotropic lay-up under bending w.r.t. the 1-axis only, the 90° ply fails first. By halving the ply weight and adding a core, 57.8% of the strength is recovered. Or, by taking the original #4 laminate and doubling its thickness with a core, its bending strength is 235% of what it was originally. The bending strength increase due to a lightweight core is obvious.

COMBO 3 SAMPLE PROBLEM #1: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER $n = 2$ $\theta_1 = 0$ DISPLAY E_i^f	A	1	ENTER $M_1 = 1$	B	6.2
	R/S	$E_1^f = 181.000 \text{ E09}$	$M_2 = 0$	R/S	6.6
	R/S	10.300 E09	$M_6 = 0$	R/S	60
	R/S	280.000 E-3	ENTER $\theta_t = 0$ $t = 1$ DISPLAY R_t' σ_t^f σ^f	C	37
	R/S	7.170 E09		R/S	$R_t = 15.625 \text{ E00}$
DISPLAY D_{ij} (optional)	B'	236.733-03		R/S	15.625 E00
	R/S	13.472-03		D	1.500 E09
	"	3.772-03		R/S	1.500 E09
	"	9.336-03	ENTER $M_1 =$ 15.625 E00 $M_2 = 0$ $M_6 = 0$	B	6.2
	"	0.000 00		R/S	6.6
	"	0.000 00		R/S	60
DISPLAY d_{ij} (optional)	R/S	4.243 00		C	37
	"	74.563 00		R/S	$k_t = 1.000 \text{ E00}$
	"	-1.188 00	DISPLAY R_t'	R/S	1.000 E00
	"	107.113 00			
	"	0.000 00			
	"	0.000 00			
	"	0.000 00			
DISPLAY D_{ij}^* (optional)	C'	181.811 09			
	R/S	10.346 09			
	"	2.897 09			
	"	7.170 09			
	"	0.000 00			
	"	0.000 00			
DISPLAY d_{ij}^* (optional)	R/S	5.525-12			
	"	97.087-12			
	"	-1.547-12			
	"	139.470-12			
	"	0.000 00			
	"	0.000 00			

COMBO 3 SAMPLE PROBLEM #2: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/C]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER $n = 4$ $\theta_1 = 0$ DISPLAY E_1^f (optional)	A	2	ENTER $M_1 = 1$	B	6.2
	R/S	1	$M_2 = 0$	R/S	6.6
	A'	$E_1^f = 158.375 \text{ E09}$	$M_6 = 0$	R/S	60
	R/S	9.012 E09	ENTER $\theta_t = 0$	C	37
	R/S	280.000 E-3	$t = 2$	R/S	$R_t = 54.688 \text{ E00}$
DISPLAY D_{ij} (optional)	R/S	6.274 E09	DISPLAY R_t'	R/S	54.688 E00
	B'	1.657 00	σ^f	D	1.313 E09
	R/S	94.301-03	$\sigma^{f'}$	R/S	1.313 E09
	"	26.404-03			
	"	65.352-03	ENTER $M_1 =$		
DISPLAY d_{ij} (optional)	"	0.000 00	54.688 E00	B	6.2
	"	0.000 00	$M_2 = 0$	R/S	6.6
	R/S	606.156-03	$M_6 = 0$	R/S	60
	"	10.652 00	ENTER $\theta_t = 0$	C	37
	"	-169.724-03	$t = 2$	R/S	$R_t = 999.991 \text{ E-3}$
DISPLAY D_{ij}^* (optional)	"	15.302 00	DISPLAY R_t'	R/S	999.991 E-3
	"	0.000 00			
	"	0.000 00			
	C'	159.085 09			
	R/S	9.053 09			
DISPLAY d_{ij}^* (optional)	"	2.535 09			
	"	6.274 09			
	"	0.000 00			
	"	0.000 00			
	R/S	6.314-12			
	"	110.957-12			
	"	-1.768-12			
	"	159.394-12			
	"	0.000 00			
	"	0.000 00			

COMBO 3 SAMPLE PROBLEM #3: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/c_1, 3]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER $n = 4.6$ $\theta_1 = 0$ DISPLAY E_i^f (optional)	A	2.3	ENTER $M_1 = 1$	B	6.2
	R/S	1.3	$M_2 = 0$	R/S	6.6
	A'	$E_1^f = 148.317 \text{ E09}$	$M_6 = 0$	R/S	60
	R/S	8.440 E09	ENTER $\theta_t = 0$	C	37
	R/S	280.000 E-3	$t = 2.3$	R/S	$R_t = 67.731 \text{ E00}$
DISPLAY D_{ij} (optional)	R/S	5.875 E09	DISPLAY R_t'	R/S	67.731 E00
	B'	2.360 00	σ^f	D	1.229 E09
	R/S	134.311-03	$\sigma^{f'}$	R/S	1.229 E09
	"	37.607-03	ENTER $M_1 =$	B	6.2
	"	93.079-03	67.73 E00		
DISPLAY d_{ij} (optional)	"	0.000 00	$M_2 = 0$	R/S	6.6
	"	0.000 00	$M_6 = 0$	R/S	60
	R/S	425.586-03	ENTER $\theta_t = 0$	C	37
	"	7.479 00	$t = 2.3$	R/S	$R_t = 1.000 \text{ E00}$
	"	-119.164-03	DISPLAY R_t'	R/S	1.000 E00
DISPLAY D_{ij}^* (optional)	"	10.744 00			
	"	0.000 00			
	"	0.000 00			
	C'	148.981 09			
	R/S	8.478 09			
DISPLAY d_{ij}^* (optional)	"	2.374 09			
	"	5.875 09			
	"	0.000 00			
	"	0.000 00			
	R/S	6.742-12			
	"	118.482-12			
	"	-1.888-12			
	"	170.204-12			
	"	0.000 00			
	"	0.000 00			

COMBO 3 SAMPLE PROBLEM #4: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: [0/90/45/-45/C₄]_s

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY	
ENTER $n = 16$ $\theta_1 = 0$ $\theta_2 = 90$ $\theta_3 = 45$ $\theta_4 = -45$ DISPLAY E_i^f (optional)	A	8	ENTER $M_1 = 1$	B	6.2	
	R/S	7	$M_2 = 0$	R/S	6.6	
	R/S	6	$M_6 = 0$	R/S	60	
	R/S	5	ENTER $\theta_t = 0$ $t = 8$ DISPLAY R_t^f σ^f $\sigma^{f'}$	C	37	
	R/S	4		R/S	$R_t = 404.279 \text{ E00}$	
	A'	$E_1^f = 76.080 \text{ E09}$		R/S	456.532 E00	
	R/S	62.542 E09		D	606.419 E06	
	R/S	213.704 E-3		R/S	684.799 E06	
	R/S	17.830 E09	ENTER $\theta_t = 90$ $t = 7$ DISPLAY R_t^f σ^f $\sigma^{f'}$	C	37	
	B'	52.932 00		R/S	$R_t = 228.559 \text{ E00}$	
R/S	43.555 00	R/S		1.160 E03		
"	9.492 00	D		342.839 E06		
"	11.985 00	R/S		1.740 E09		
"	1.674 00	ENTER $\theta_t = 45$ $t = 6$ DISPLAY R_t^f σ^f $\sigma^{f'}$	C	37		
"	1.674 00		R/S	$R_t = 324.324 \text{ E00}$		
DISPLAY d_{ij} (optional)	R/S		19.716-03	R/S	743.545 E00	
	"		23.984-03	D	486.486 E06	
	"		-4.213-03	R/S	1.115 E09	
	"		84.129-03	ENTER $\theta_t = 45$ $t = 6$ DISPLAY R_t^f σ^f $\sigma^{f'}$	C R/S R/S D R/S	37 $R_t = 324.324 \text{ E00}$ 743.545 E00 486.486 E06 1.115 E09
	"		-2.166-03			
	"		-2.762-03			
DISPLAY D_{ij}^* (optional)	C'		79.398 09			
	R/S		65.333 09			
	"		14.238 09			
	"		17.977 09			
	"		2.512 09			
DISPLAY d_{ij}^* (optional)	"		2.512 09			
	R/S		13.144-12			
	"		15.989-12			
	"		-2.809-12			
	"		56.086-12			
	"		-1.444-12			
	"		-1.842-12			

COMBO 3 SAMPLE PROBLEM #5: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2/90_2/45_2/-45_2]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER $n = 16$	A	8	ENTER $M_1 = 1$	B	6.2
$\theta_1 = 0$	R/S	7	$M_2 = 0$	R/S	6.6
.	.	.	$M_6 = 0$	R/S	60
.	.	.			
$\theta_8 = -45$	R/S	$E_1^f = 113.287 \text{ E09}$	ENTER $\theta_t = 0$	C	37
DISPLAY E_i^f	R/S	65.334 E09	$t = 8$	R/S	$R_t = 545.875 \text{ E00}$
(optional)	R/S	98.770 E-3	DISPLAY R_t'	R/S	762.093 E00
	R/S	11.747 E09	σ^f	D	818.812 E06
DISPLAY D_{ij}	B'	76.842 00	$\sigma^{f'}$	R/S	1.143 E09
(optional)	R/S	44.693 00			
	"	5.216 00	ENTER $\theta_t = 90$	C	37
	"	8.065 00	$t = 6$	R/S	$R_t = 389.456 \text{ E00}$
	"	2.679 00	DISPLAY R_t'	R/S	2.100 E03
	"	2.679 00	σ^f	D	584.185 E06
DISPLAY d_{ij}	R/S	13.241-03	$\sigma^{f'}$	R/S	3.150 E09
(optional)	"	22.959-03			
	"	-1.308-03	ENTER $\theta_t = 45$	C	37
	"	127.697-03	$t = 4$	R/S	$R_t = 671.467 \text{ E00}$
	"	-3.964-03	DISPLAY R_t'	R/S	1.970 E03
	"	-7.192-03	σ^f	D	1.007 E09
DISPLAY D_{ij}^*	C'	115.263 09	$\sigma^{f'}$	R/S	2.955 E09
(optional)	R/S	67.039 09			
	"	7.825 09			
	"	12.098 09			
	"	4.019 09			
	"	4.019 09			
DISPLAY d_{ij}^*	R/S	8.827-12			
(optional)	"	15.306-12			
	"	-871.852-15			
	"	85.132-12			
	"	-2.643-12			
	"	-4.795-12			

COMBO 3 SAMPLE PROBLEM #6: FLEXURAL STIFFNESS AND STRENGTH
 LAMINATE: $[0_2/90_2/45_2/-45_2/C_8]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
ENTER $n = 32$	A	16	ENTER $M_1 = 1$	B	6.2
$\theta_1 = 0$	R/S	15	$M_2 = 0$	R/S	6.6
$\vdots$			$M_6 = 0$	R/S	60
$\theta_8 = -45$	R/S	8	ENTER $\theta_t = 0$	C	37
	A'	$E_1^f = 76.080 \text{ E09}$	$t = 16$	R/S	$R_t = 1.617 \text{ E03}$
DISPLAY E_1^f	R/S	62.542 E09	DISPLAY R_t'	R/S	1.826 E03
(optional)	R/S	213.704 E-3	σ^f	D	606.419 E06
	R/S	17.830 E09	$\sigma^{f'}$	R/S	684.799 E06
DISPLAY D_{ij}	B'	423.459 00	ENTER $\theta_t = 90$	C	37
(optional)	R/S	348.443 00	$t = 14$	R/S	$R_t = 914.237 \text{ E00}$
	"	75.935 00	DISPLAY R_t'	R/S	4.639 E03
	"	95.876 00	σ^f	D	342.839 E06
	"	13.396 00	$\sigma^{f'}$	R/S	1.740 E09
	"	13.396 00	ENTER $\theta_t = 45$	C	37
DISPLAY d_{ij}	R/S	2.465-03	$t = 12$	R/S	$R_t = 1.297 \text{ E03}$
(optional)	"	2.998-03	DISPLAY R_t'	R/S	2.974 E03
	"	-526.677-06	σ^f	D	486.486 E06
	"	10.516-03	$\sigma^{f'}$	R/S	1.115 E09
	"	-270.752-06			
	"	-345.284-06			
DISPLAY D_{ij}^*	C'	79.398 09			
(optional)	R/S	65.333 09			
	"	14.238 09			
	"	17.977 09			
	"	2.512 09			
	"	2.512 09			
DISPLAY d_{ij}^*	R/S	13.144-12			
(optional)	"	15.989-12			
	"	-2.809-12			
	"	56.086-12			
	"	-1.444-12			
	"	-1.842-12			

SECTION VIII

COMBO 3P: FLEXURAL STIFFNESS AND STRENGTH OF SYMMETRIC LAMINATES WITH PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 3P: FLEXURAL PROPERTIES w/PRINTER				
Core				
$n, \theta_t \rightarrow E_i^f, D_s^f$	$M_i \rightarrow k_i$	$\theta_t, t \rightarrow R_t, \sigma_t^f$		

Combo 3P is essentially the same program as Combo 3 with the addition of printing commands in the program. A series of sample problems are given at the end of this section. The entire program is listed in Appendix D.

To use Combo 3P:

1. Have U_i , G_{ij} , and h_0 for the desired material and in the desired units stored in bank 3.

2. Press **CLR**, read side 1, press **CLR**, read side 2.

3. No core: Enter n , the total number of plies, then press **A**.

Enter θ_1 , R/S, θ_2 , R/S, ..., $\theta_{n/2}$, R/S. See Figure 26.

Core: Enter n , the total number of plies plus the total number of ply thicknesses that make up the core, press **A**. Enter θ_1 , R/S, θ_2 , R/S, ... After entering one angle for each ply orientation (note less than n entries), press **A**. See Figures 26 and 27 for details.

The machine calculates and prints:

$E_1^f, E_2^f, \nu_{21}^f, E_6^f$ Labeled "E*" by printer

$D_{11}, D_{22}, D_{12}, D_{16}, D_{26}$ Labeled "D" by printer

$d_{11}, d_{22}, d_{12}, d_{16}, d_{26}$

$D_{11}^*, D_{22}^*, D_{12}^*, D_{16}^*, D_{26}^*$ Labeled "D*" by printer

$d_{11}^*, d_{22}^*, d_{12}^*, d_{16}^*, d_{26}^*$

The definitions of the above quantities are given in the section describing Combo 3.

4. Enter M_1, M_2, M_6 (as shown in Figure 26) as selected unit loads or an actual loading case. This selection is discussed in detail in the Combo 3 section.
5. Enter θ_t and t , the orientation and the ply number of the ply to be examined.

The machine calculates and prints:

R_t, R_t' Labeled "R" by printer

$\sigma_t^f, \sigma_t^{f'}$ Labeled " Σ " by printer

The definitions of the above quantities are also given in the section describing Combo 3.

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
1	Enter ply data				
2a	Enter n	A		n	n/2
b	θ_1	R/S		θ_1	n/2 - 1
c	θ_2	R/S		θ_2	n/2 - 2
.	.	.		.	.
.	.	.		.	.
.	.	.		.	.
*	$\theta_{n/2 - 1}$	R/S		$\theta_{n/2 - 1}$	1
	$\theta_{n/2}$	R/S		SYM	
			E*	$E_1^f, E_2^f, \nu_{21}^f, E_6^f$	
			D	$D_{11}, D_{22}, D_{12}, D_{66}, D_{16}, D_{26}$	
				$d_{11}, d_{22}, d_{12}, d_{66}, d_{16}, d_{26}$	
			D*	$D_{11}^*, D_{22}^*, D_{12}^*, D_{66}^*, D_{16}^*, D_{26}^*$	
				$d_{11}^*, d_{22}^*, d_{12}^*, d_{66}^*, d_{16}^*, d_{26}^*$	6.1
3a	Enter M_1	B	M	M_1	6.2
b	M_2	R/S		M_2	6.6
c	M_6	R/S		M_6	60
4a	Enter θ_t	C	$\uparrow, T$	θ_t	37
b	t	R/S		t	
			R	R_t, R_t'	
			Σ	$\sigma_t^f, \sigma_t^{f'}$	60

Figure 26. Combo 3P Instruction Chart

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
*	For sandwich construction	A'	CR	when display = c c SYM	
			E*	printout will continue as previously described in Step 1	6.1

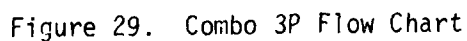
Figure 27. Combo 3P Options

00	USED	15	D_{26}	30	U_1	45	G_{yy}
01	USED	16	d_{11}, G_{xx}	31	U_2	46	G_{xy}
02	USED	17	d_{22}, G_{yy}	32	U_3	47	G_{ss}
03	USED	18	d_{12}, G_{xy}	33	U_4	48	G_x
04	USED	19	d_{66}, G_{ss}	34	U_5	49	G_y
05	$n, n/2, t$	20	d_{16}, G_x	35	θ	50	
06	R_t	21	d_{26}, G_y	36	V_0	51	
07	R'_t	22	$ D $	37	V_1	52	
08	$12/h^3$	23	k_1, ϵ_1	38	V_3	53	p
09	h	24	k_2, ϵ_2	39	$V_2, \sqrt{\quad}$	54	q
10	D_{11}	25	k_6, ϵ_6	40	V_4	55	r
11	D_{22}	26	$M_1, 0$	41	θ	56	a
12	D_{12}	27	$M_2, 0$	42	USED	57	$-b/2a$
13	D_{66}	28	$M_6, 0$	43	USED	58	c/a
14	D_{16}	29	USED	44	G_{xx}	59	h_o

Figure 28. Combo 3P Storage Memories

```

graph TD
    A[A] --> n_theta[n, θt]
    PLY[PLY DATA  
(BANK 3)] --> Eq543[Eq. 5.43]
    n_theta --> Eq543
    Eq543 --> V_iD[ViD]
    V_iD --> TABLE53[TABLE 5.3]
    TABLE53 --> D_ij_d_ij[Dij, dij]
    D_ij_d_ij --> TABLE52[TABLE 5.2]
    TABLE52 --> k_i[ki]
    k_i --> Eq764[Eq. 7.64]
    Eq764 --> R_t[Rt]
    R_t --> sigma_t_f["σtf =  $\frac{6R_t}{h^2}$ "]
    sigma_t_f --> theta_z["θt, zt"]
    theta_z --> Eq764
    B[B] --> M_i[Mi]
    M_i --> TABLE52
    C[C] --> R_t
    R_t --> C
    D_ij_d_ij --> Eq521[Eq. 5.21]
    Eq521 --> E_i_f[Eif]
    E_i_f --> D_ij_d_ij_2[Dij, dij]
    D_ij_d_ij_2 --> D_ij_d_ij_2_star["Dij*, dij*"]
    
```



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AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH F/G 11/4
INSTRUCTIONS FOR TI-59 COMBINED CARD/MODULE CALCULATIONS FOR IN--ETC(U)
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Combo 3P Sample Problems

As in the Combo 2 section, one should follow the instruction charts, Figures 26 and 27, when working through the sample problems. The sample problems should be followed vertically down the left half of the page, then the right. Note that the example problems' printer tape extends beyond the blocks describing the printer output. This corresponds to re-entering a new loading condition or examining a different ply orientation. The "looping" done here is best shown in the program diagram, Figure 29.

The entry of sample problems with a core is exactly the same as that described in Combo 2 and 2P. Again, a core that is a non-integer multiple of unit ply thickness is permissible. Problem #3 demonstrates this.

Additional units for this Combo are, in the case of the sample problems listed:

D_{ij}	N-m
d_{ij}	1/N-m
D_{ij}^*	N/m ² (Pa)
d_{ij}^*	m ² /N (1/Pa)

English unit calculations can be completed just as easily. When the material properties in Bank 3 are stored in English units, loads can be entered in in-lbs/in, etc., provided their dimensions are consistent with the units used to enter the unit ply data.

The six sample problems are discussed below:

- #1 The failure σ_t^f is calculated, then the failure moment $= h^2/6 \sigma_t^f$ is applied to show $R_t = 1$ can be recovered.
- #2 This laminate is the same as the one in example #1, except the inner plies have been separated by a core. Note

that for the same ply weight, the maximum moment allowable increases 250% from the original laminate.

#3 Increasing the core thickness further increases the maximum allowable bending moment. This example also demonstrates how to enter a core thickness that is not an integer multiple of unit ply thickness.

#4, #5, #6 This example shows that for the quasi-isotropic lay-up under bending w.r.t. the 1-axis only, the 90° ply fails first. By halving the ply weight and adding a core, 57.8% of the strength is recovered. Or, by taking the original #4 laminate and doubling its thickness with a core, its bending strength is 235% of what it was originally. The bending strength increase due to a lightweight core is obvious.

COMBO 3P SAMPLE PROBLEM #1: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	2. 00	ENTER M_1	B	M
ENTER θ_1	R/S	0.000 00 SYM	M_2	R/S	1.000 00 0.000 00
PRINT E_i^f		E* 181.000 09 10.300 09 280.000-03 7.170 09	M_6	R/S	0.000 00
PRINT D_{ij}		D 236.733-03 13.472-03 3.772-03 9.336-03 0.000 00 0.000 00	ENTER θ_t	C	$\uparrow$, T
PRINT d_{ij}		4.243 00 74.563 00 -1.188 00 107.113 00 0.000 00 0.000 00	t	R/S	0.000 00 1.000 00
PRINT D_{ij}^*		D* 181.811 09 10.346 09 2.897 09 7.170 09 0.000 00 0.000 00	PRINT R_t		R
PRINT d_{ij}^*		5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00	R_t'		15.625 00 15.625 00
			PRINT $\sigma_{f'}^f$		Σ
					1.500 09 1.500 09
					M
					15.625 00 0.000 00 0.000 00
					$\uparrow$, T
					0.000 00 1.000 00
					R
					1.000 00 1.000 00
					Σ
					96.000 06 96.000 06

COMBO 3P SAMPLE PROBLEM #2: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/C]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	4. 00	ENTER M_1	B	M
ENTER θ_1	R/S A'	0.000 00 CR 1.000 00 SYM	M_2	R/S	1.000 00
PRINT E_j^f		E* 158.375 09 9.012 09 280.000-03 6.274 09	M_6	R/S	0.000 00 0.000 00
PRINT D_{ij}		D 1.657 00 94.301-03 26.404-03 65.352-03 0.000 00 0.000 00	ENTER θ_t	C	t, T
PRINT d_{ij}		606.156-03 10.652 00 -169.724-03 15.302 00 0.000 00 0.000 00	t	R/S	0.000 00 2.000 00
PRINT D_{ij}^*		D* 159.085 09 9.053 09 2.535 09 6.274 09 0.000 00 0.000 00	PRINT R_t		R
PRINT d_{ij}^*		6.314-12 110.957-12 -1.768-12 159.394-12 0.000 00 0.000 00	R_t'		54.688 00 54.688 00
			PRINT σ_f^f		Σ
			$\sigma_{f'}$		1.313 09 1.313 09
					M
					54.688 00 0.000 00 0.000 00
					t, T
					0.000 00 2.000 00
					R
					999.991-03 999.991-03
					Σ
					24.000 06 24.000 06

COMBO 3P SAMPLE PROBLEM #3: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/c_{1.3}]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
			ENTER M_1	B	
			M_2	R/S	M
			M_6	R/S	1.000 00
					0.000 00
					0.000 00
ENTER n	A	4.6 00	ENTER θ_t	C	t, T
ENTER θ_1	R/S	0.000 00	t	R/S	0.000 00
	A'	CR			2.300 00
		1.300 00	PRINT R_t		R
		SYM	R'_t		67.731 00
					67.731 00
PRINT E_i^f		E*	PRINT σ_f^f		Σ
		148.317 09	$\sigma_{f'}$		1.229 09
		8.440 09			1.229 09
		280.000-03			
		5.875 09			
PRINT D_{ij}		D			M
		2.360 00			67.731 00
		134.311-03			0.000 00
		37.607-03			0.000 00
		93.079-03			
		0.000 00			t, T
		0.000 00			0.000 00
					2.300 00
PRINT d_{ij}		425.586-03			R
		7.479 00			1.000 00
		-119.164-03			1.000 00
		10.744 00			
		0.000 00			Σ
		0.000 00			18.147 06
					18.147 06
PRINT D_{ij}^*		D*			
		148.981 09			
		8.478 09			
		2.374 09			
		5.875 09			
		0.000 00			
		0.000 00			
PRINT d_{ij}^*		6.742-12			
		118.482-12			
		-1.888-12			
		170.204-12			
		0.000 00			
		0.000 00			

COMBO 3P SAMPLE PROBLEM #4: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2/90_2/45_2/-45_2]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	16.000 00	ENTER M_1	B	M
ENTER θ_1	R/S	0.000 00	M_2	R/S	1.000 00
.	.	0.000 00	M_6	R/S	0.000 00
.	.	90.000 00	ENTER θ_t	C	$\uparrow, T$
.	.	90.000 00	t	R/S	0.000 00
.	.	45.000 00			8.000 00
.	.	45.000 00	PRINT R_t		R
θ_8	R/S	-45.000 00	R'_t		545.875 00
		-45.000 00			762.093 00
		SYM	PRINT σ_f		Σ
PRINT E_i^f		E*	$\sigma_{f'}$		818.812 06
		113.287 09			1.143 09
		65.334 09			$\uparrow, T$
		98.770-03			90.000 00
		11.747 09			6.000 00
PRINT D_{ij}		D			R
		76.842 00			389.456 00
		44.693 00			2.100 03
		5.216 00			Σ
		8.065 00			584.185 06
		2.679 00			3.150 09
		2.679 00			$\uparrow, T$
PRINT d_{ij}		13.241-03			45.000 00
		22.959-03			4.000 00
		-1.308-03			R
		127.697-03			671.467 00
		-3.964-03			1.970 03
		-7.192-03			Σ
PRINT D_{ij}^*		D*			1.007 09
		115.263 09			2.955 09
		67.039 09			
		7.825 09			
		12.098 09			
		4.019 09			
		4.019 09			
PRINT d_{ij}^*		8.827-12			
		15.306-12			
		-871.852-15			
		85.132-12			
		-2.643-12			
		-4.795-12			

COMBO 3P SAMPLE PROBLEM #5: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/90/45/-45/C_4]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	16.000 00	ENTER M_1	B	M
			M_2	R/S	1.000 00
			M_6	R/S	0.000 00
ENTER θ_1	R/S	0.000 00	ENTER θ_t	C	$\uparrow, T$
θ_2	R/S	90.000 00	t	R/S	0.000 00
θ_3	R/S	45.000 00			8.000 00
θ_4	R/S	-45.000 00	PRINT R_t		R
	A'	CR	R'_t		404.279 00
		4.000 00			456.532 00
		SYM	PRINT σ_f^f		Σ
PRINT E_i^f		E^*			606.419 06
		76.080 09			684.799 06
		62.542 09			
		213.704-03			$\uparrow, T$
		17.830 09			90.000 00
					7.000 00
PRINT D_{ij}		D			R
		52.932 00			228.559 00
		43.555 00			1.160 03
		9.492 00			Σ
		11.985 00			342.839 06
		1.674 00			1.740 09
		1.674 00			$\uparrow, T$
PRINT d_{ij}		19.716-03			45.000 00
		23.984-03			6.000 00
		-4.213-03			R
		84.129-03			324.324 00
		-2.166-03			743.545 00
		-2.762-03			Σ
PRINT D_{ij}^*		D^*			486.486 06
		79.398 09			1.115 09
		65.333 09			
		14.238 09			
		17.977 09			
		2.512 09			
		2.512 09			
PRINT d_{ij}^*		13.144-12			
		15.989-12			
		-2.809-12			
		56.086-12			
		-1.444-12			
		-1.842-12			

COMBO 3P SAMPLE PROBLEM #6: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2/90_2/45_2/-45_2/C_8]_s$

MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	32.000 00	ENTER M ₁	B	M
ENTER θ_1	R/S	0.000 00	M ₂	R/S	1.000 00
.	.	0.000 00	M ₆	R/S	0.000 00
.	.	90.000 00			0.000 00
.	.	90.000 00	ENTER θ_t	C	t, T
.	.	45.000 00	t	R/S	0.000 00
.	.	45.000 00			16.000 00
.	.	-45.000 00	PRINT R _t		R
08	R/S	-45.000 00	R' _t		1.617 03
	A'	CR			1.826 03
		8.000 00	PRINT σ^f		Σ
		SYM	σ^f		606.419 06
PRINT E _i ^f		E*			684.799 06
		76.080 09			t, T
		62.542 09			90.000 00
		213.704 -03			14.000 00
		17.830 09			R
PRINT D _{ij}		D			914.237 00
		423.459 00			4.639 03
		348.443 00			Σ
		75.935 00			342.839 06
		95.876 00			1.740 09
		13.396 00			t, T
		13.396 00			45.000 00
PRINT d _{ij}		2.465 -03			12.000 00
		2.998 -03			R
		-526.677 -06			1.297 03
		10.516 -03			2.974 03
		-270.752 -06			Σ
		-345.284 -06			486.486 06
PRINT D _{ij} [*]		D*			1.115 09
		79.398 09			
		65.333 09			
		14.238 09			
		17.977 09			
		2.512 09			
		2.512 09			
PRINT d _{ij} [*]		13.144 -12			
		15.989 -12			
		-2.809 -12			
		56.086 -12			
		-1.444 -12			
		-1.842 -12			

APPENDIX A

Description of Applied and Resultant Stress and Strain

Any combination of six different loads can be applied to the desired laminate (see Figure A-8). Three in-plane loads can be applied using Combo 2 or 2P, and three flexural loads can be applied using Combo 3 or 3P. Combined loading (simultaneous in-plane and flexural loading) can be done with the existing Combo cards, using the explanation given in Appendix B. The following sections describe the stresses and strains for in-plane, flexural, and combined loading cases. All drawings are for a sample $[0/90/45/-45]_5$ laminate, loaded uniaxially in the 1-direction. All figures are drawn with respect to the 1-direction (σ_1 , ϵ_1 , etc). One could also load the laminate with respect to the 1, 2 (normal), and 6 (shear) references and examine the results in any of the 1, 2 and 6 references.

In-Plane:

All Combos are based on the plate under plane stress assumptions.

The applied stresses are:

$$\bar{\sigma}_1 = 1/h \int_{-h/2}^{h/2} \sigma_1 dz$$

$$\bar{\sigma}_2 = 1/h \int_{-h/2}^{h/2} \sigma_2 dz$$

$$\bar{\sigma}_6 = 1/h \int_{-h/2}^{h/2} \sigma_6 dz$$

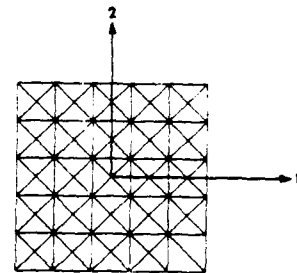


Figure A-1

These average stresses are often multiplied by laminate thickness.

$$N_1 = \bar{\sigma}_1 h$$

$$N_2 = \bar{\sigma}_2 h$$

$$N_6 = \bar{\sigma}_6 h$$

These average applied stresses are actually re-distributed in the laminate, ply-by-ply. This is because the resultant strain is constant across the laminate (see Figure A-3), but the stiffness matrices, $[Q]$ (in the 1-2 system) vary according to ply orientation angle. The resultant stress distribution may look like:

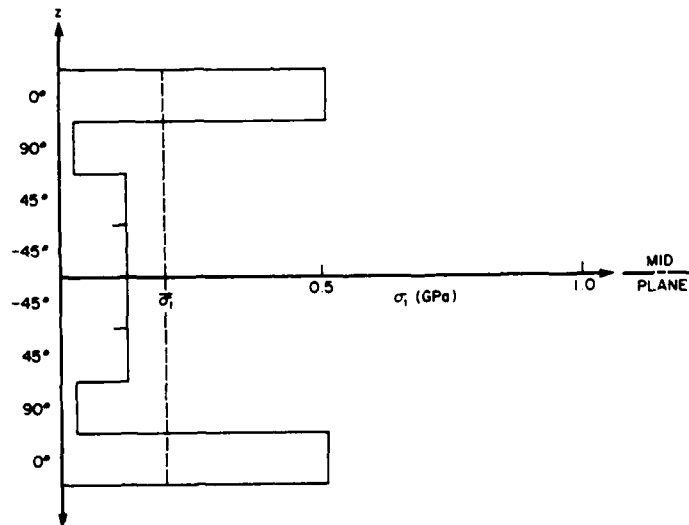


Figure A-2

Because of the thin plate assumption, the resulting strain is constant through the laminate thickness:

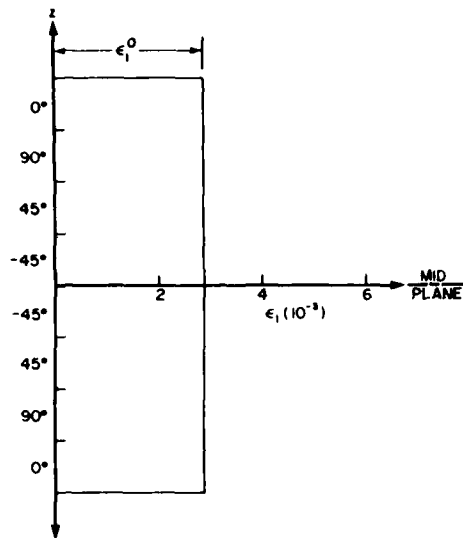


Figure A-3

The laminate stretches but does not curve or warp.

Flexural:

Bending moments applied to a laminate are similarly only average moments:

$$M_1 = \int_{-h/2}^{h/2} \sigma_1 z dz$$

$$M_2 = \int_{-h/2}^{h/2} \sigma_2 z dz$$

$$M_6 = \int_{-h/2}^{h/2} \sigma_6 z dz$$

The applied moments distribute themselves as stresses that vary ply-to-ply and linearly through each ply thickness:

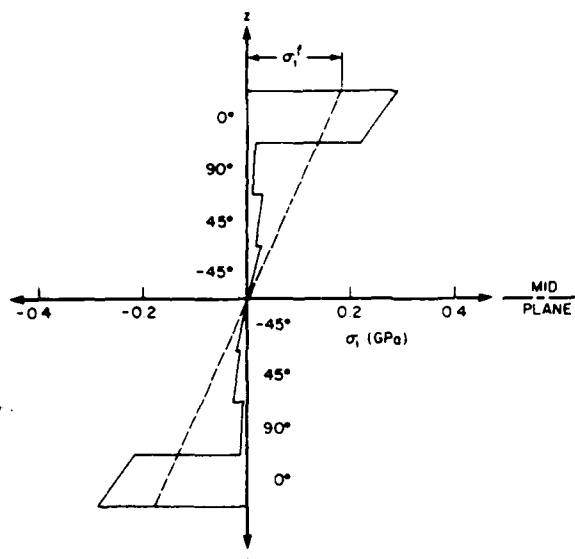


Figure A-4

The M_i , actually a combination of weighted stresses that vary through the thickness can be thought of as an averaged moment that varies linearly through the thickness. This gives rise to an averaged surface stress, σ_i^f :

$$\begin{aligned} M_i &= 2 (\text{area})(\text{moment arm}) \\ &= 2 [1/2(h/2) \sigma_i^f h/3] \\ &= h^2/6 \sigma_i^f \end{aligned}$$

These produce a linearly varying strain:

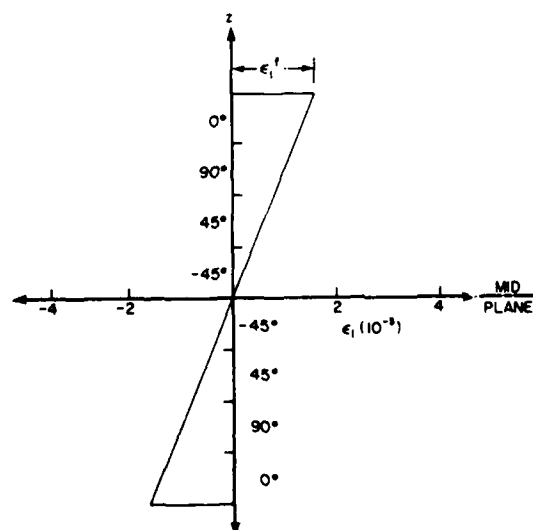


Figure A-5

The laminate curves but does not stretch along its centerline.

Combined In-Plane and Flexural:

Strain across the laminate thickness is simply a sum of the in-plane and flexural strain:

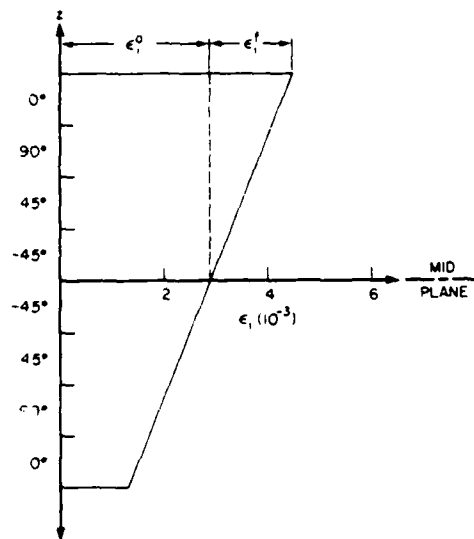


Figure A-6

The stress across the laminate can be related to this strain via the off-axis stiffness matrix for each ply:

$$\begin{aligned}
 \{\sigma_i\}_t &= [Q]_t \{\epsilon_i\}_t \\
 &= [Q]_t \{\epsilon_i^o + \epsilon_i^f\}_t \\
 &= [Q]_t \{\epsilon_i^o\}_t + [Q]_t \{\epsilon_i^f\}_t \\
 &= [Q]_t \{\epsilon_i^o\}_t + z[Q]_t \{k_i\}_t
 \end{aligned}$$

Stress, therefore, is also a simple addition of the in-plane and flexural stress. This would appear as:

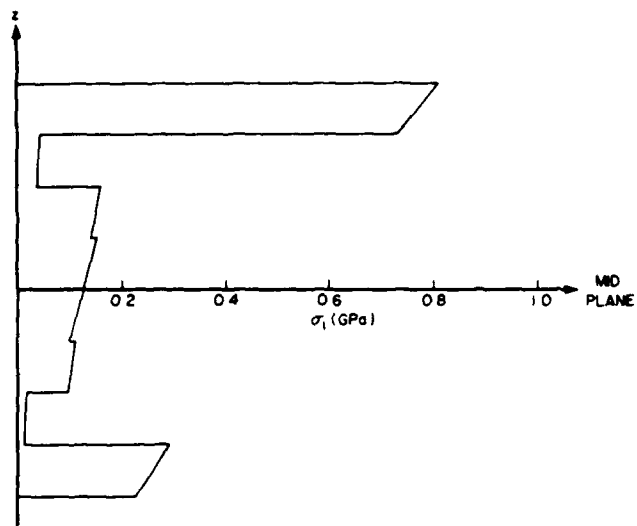
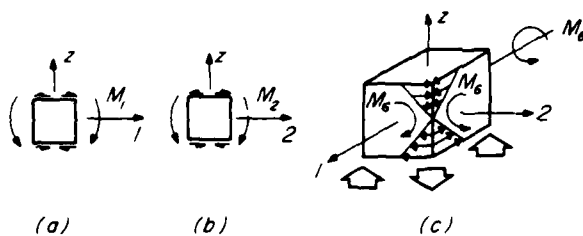
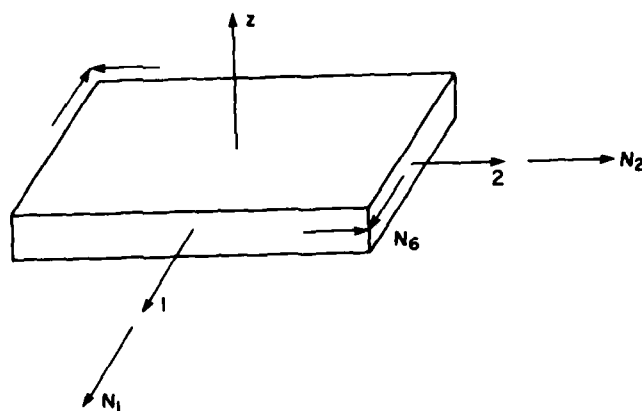


Figure A-7



The positive directions of components of moment. Bending moments are shown in (a) and (b). In (c), positive twisting moment appears as clockwise torque on the positive 1-axis face; counterclockwise on the positive 2-axis face. The effect of the positive twisting moment can be duplicated by four self-equilibrating forces acting at the corners as shown.

Figure A-8: Positive In-Plane and Flexural Loading Directions.

APPENDIX B

Instructions for Combined In-Plane and Flexural Loadings

The Combo cards discussed in the preceding sections, together with the Composite Materials Module, can also calculate strength ratios for laminated plates under combined in-plane and flexural loading conditions. The procedure used to do this is best illustrated with an example:

It is desired that a $[0/90/45/-45]_S$, T300/5208 laminate carry the following loads:

$$N_1 = 200 \times 10^3 \text{ N/m}$$

$$N_2 = 0$$

$$N_6 = 0$$

$$M_1 = 30 \text{ N-m/m}$$

$$M_2 = 0$$

$$M_6 = 0$$

Is this an allowable loading? What are the safety factors?

These questions are answered by calculating strength ratios for each ply. This is done with the following steps:

1. Use Combo 2 or 2P to enter the laminate stacking and in-plane loading, N_i . Recall the ϵ_i^o from registers 23, 24 and 25 by pressing **RCL** **2** **3**, etc (see Figure 16). This gives:

$$\epsilon_1^o = 2.870 \times 10^{-3}$$

$$\epsilon_2^o = -849.7 \times 10^{-6}$$

$$\epsilon_6^o = 0$$

These strains are constant for all plies in the laminate (see Figure A-3).

2. Use Combo 3 or 3P to enter the laminate stacking and flexural loading, M_i . Recall the k_i from registers 23, 24 and 25:

$$k_1 = 3.178 \text{ 1/m}$$

$$k_2 = -313.9 \times 10^{-3}$$

$$k_6 = -951.4 \times 10^{-3}$$

Using:

$$\epsilon_i = \epsilon_i^0 + zk_i \quad (\text{see Figure A-6}).$$

$$z = th_0$$

Calculate for each ply ($h_0 = 125 \times 10^{-6} \text{ m}$):

$$\begin{aligned} \theta_t = 0^\circ, t = 4 \quad \epsilon_1 &= 4.459 \times 10^{-3} \\ \epsilon_2 &= -1.006 \times 10^{-3} \\ \epsilon_6 &= -475.7 \times 10^{-6} \end{aligned}$$

$$\begin{aligned} \theta_t = 90^\circ, t = 3 \quad \epsilon_1 &= 4.062 \times 10^{-3} \\ \epsilon_2 &= -967.4 \times 10^{-6} \\ \epsilon_6 &= -356.8 \times 10^{-6} \end{aligned}$$

$$\begin{aligned} \theta_t = 45^\circ, t = 2 \quad \epsilon_1 &= 3.665 \times 10^{-3} \\ \epsilon_2 &= -928.2 \times 10^{-6} \\ \epsilon_6 &= -237.9 \times 10^{-6} \end{aligned}$$

$$\begin{aligned} \theta_t = -45^\circ, t = 1 \quad \epsilon_1 &= 3.267 \times 10^{-3} \\ \epsilon_2 &= -888.9 \times 10^{-6} \\ \epsilon_6 &= -118.9 \times 10^{-6} \end{aligned}$$

These are the strains in the outermost surface of each ply due to the combined loading. Recall that Combo 2 has the ability to input strains directly to calculate strength ratios (Combo 2P cannot do this). Therefore:

3. Read in Combo 2, then enter the laminate stacking. Enter the ϵ_i for each of the plies using the button as shown in Figure 12. Record the R_t values. For this example, they are:

$$R_0 = 1.800$$

$$R_{90} = .972$$

$$R_{45} = 1.33$$

$$R_{-45} = 1.54$$

If one were to examine the strength ratios for the given in-plane loading only or flexural loading only, none of the plies would fail. However, the combination of loads will cause the 90° ply to fail ($R \leq 1$). To avoid failure, the loads would have to be reduced, or, to carry the original loads, the laminate stacking should be modified.

APPENDIX C

Instructions for Keying in a Program

1. Turn on calculator.
2. Press **LRN**, display shows 000 00.
3. Begin key punching. Press the key label that corresponds to the program step desired. The calculator will automatically advance to the next line number.
4. Continue with entire program.
5. Press **LRN**. The display should return to normal.
6. Press **1** **2nd** **▲** *. The display will go blank. Insert card, right-side-up, into the slot on the right side of the calculator. Retrieve card on the left side.
7. Press **2** **2nd** **▲**. Insert the card upside-down into the slot. Retrieve card.
8. Label card accordingly.

If you make any errors, you can easily "edit" the program without having to re-key the entire program. Consult TI-59 owner's manual for information.

* The calculator will not write onto magnetic cards if the calculator is in a "fixed" format display mode (i.e., the number of digits displayed has been previously set). If the display flashes after attempting to record a card, the card did not record. Press **CLR** **INV** **2nd** **▲**. This removes the fixed format. Repeat the card recording procedure as before.

APPENDIX D

Program Listings

COMBO 0: Selected Ply Data without Printer

000	76	LBL	T300-	060	71	SBR	Fig	120	02	2	180	52	EE
001	11	A	5208	061	98	ADV		121	05	5	181	07	7
002	47	CMS		062	36	PGM		122	52	EE	182	42	STD
003	57	ENG		063	08	08	Gij	123	06	6	183	26	26
004	01	1		064	71	SBR		124	94	+/-	184	04	4
005	08	8		065	80	GRD		125	42	STD	185	01	1
006	01	1	Ex	066	43	RCL		126	59	59	186	04	4
007	52	EE		067	16	16		127	71	SBR	187	52	EE
008	09	9		068	42	STD		128	35	1/X	188	07	7
009	42	STD		069	44	44		129	01	1	189	42	STD
010	25	25		070	43	RCL		130	04	4	190	24	27
011	01	1		071	17	17		131	04	4	191	93	.
012	00	0		072	42	STD		132	07	7	192	02	2
013	03	3	Ey	073	45	45		133	52	EE	193	06	6
014	52	EE		074	43	RCL		134	06	6	194	42	STD
015	08	8		075	18	18		135	42	STD	195	26	28
016	42	STD		076	42	STD		136	23	23	196	01	1
017	26	26		077	46	46		137	42	STD	197	02	2
018	07	7		078	43	RCL		138	24	24	198	05	5
019	01	1		079	19	19		139	05	5	199	52	EE
020	07	7	Es	080	42	STD		140	01	1	200	06	6
021	52	EE		081	47	47		141	07	7	201	94	+/-
022	07	7		082	43	RCL		142	52	EE	202	42	STD
023	42	STD		083	20	20		143	05	5	203	59	59
024	27	27		084	42	STD		144	42	STD	204	71	SBR
025	93	.		085	48	48		145	25	25	205	35	1/X
026	02	2	2x	086	43	RCL		146	02	2	206	01	1
027	08	8		087	21	21		147	00	0	207	00	0
028	42	STD		088	42	STD		148	06	6	208	06	6
029	28	28		089	49	49		149	52	EE	209	02	2
030	01	1		090	91	R/S		150	06	6	210	52	EE
031	02	2		091	76	LBL		151	42	STD	211	06	6
032	05	5	ho	092	13	C	AS-	152	26	26	212	42	STD
033	52	EE		093	47	CMS	3501	153	09	9	213	23	23
034	06	6		094	57	ENG		154	03	3	214	06	6
035	94	+/-		095	01	1		155	52	EE	215	01	1
036	42	STD		096	03	3		156	06	6	216	52	EE
037	59	59		097	08	8		157	42	STD	217	07	7
038	71	SBR		098	52	EE		158	27	27	218	42	STD
039	35	1/X		099	09	9		159	93	.	219	24	24
040	36	PGM		100	42	STD		160	05	5	220	03	3
041	08	08	X...	101	25	25		161	94	+/-	221	01	1
042	10	E'		102	08	8		162	42	STD	222	52	EE
043	71	SBR		103	09	9		163	28	28	223	06	6
044	45	YX		104	06	6		164	71	SBR	224	42	STD
045	76	LBL		105	52	EE		165	45	YX	225	25	25
046	35	1/X		106	07	7		166	76	LBL	226	01	1
047	36	PGM		107	42	STD		167	14	B	227	01	1
048	01	01	Qij	108	26	26		168	47	CMS	228	08	8
049	71	SBR		109	07	7		169	57	ENG	229	52	EE
050	57	ENG		110	01	1		170	03	3	230	06	6
051	36	PGM		111	52	EE		171	08	8	231	42	STD
052	01	01	Uj	112	08	8		172	06	6	232	26	26
053	71	SBR		113	42	STD		173	52	EE	233	07	7
054	52	EE		114	27	27		174	08	8	234	02	2
055	92	R/S		115	93	.		175	42	STD	235	52	EE
056	76	LBL		116	03	3		176	25	25	236	06	6
057	45	YX		117	42	STD		177	08	8	237	42	STD
058	36	PGM		118	28	28		178	02	2	238	27	27
059	08	08		119	01	1	107	179	07	7	239	93	

Scotch-
ply
1002

240	05	5
241	94	+/-
242	42	STD
243	28	28
244	71	SBR
245	45	YX
246	76	LBL
247	16	A ¹
248	47	CMS
249	57	ENG
250	06	6
251	09	9
252	52	EE
253	09	9
254	42	STD
255	25	25
256	42	STD
257	26	26
258	55	+
259	02	2
260	93	.
261	06	6
262	95	=
263	42	STD
264	27	27
265	93	.
266	03	3
267	42	STD
268	28	28
269	01	1
270	42	STD
271	59	59
272	71	SBR
273	35	1/X
274	04	4
275	52	EE
276	08	8
277	42	STD
278	23	23
279	42	STD
280	24	24
281	42	STD
282	25	25
283	42	STD
284	26	26
285	02	2
286	03	3
287	52	EE
288	07	7
289	42	STD
290	27	27
291	93	.
292	05	5
293	94	+/-
294	42	STD
295	28	28
296	71	SBR
297	45	YX
298	76	LBL
299	10	E ¹

300	06	6
301	08	8
302	09	9
303	05	5
304	35	1/X
305	49	PRD
306	30	30
307	49	PRD
308	31	31
309	49	PRD
310	32	32
311	49	PRD
312	33	33
313	49	PRD
314	34	34
315	95	=
316	03	3
317	09	9
318	93	.
319	04	4
320	49	PRD
321	59	59
322	91	R/S
323	76	LBL
324	12	B
325	47	CMS
326	57	ENG
327	02	.2
328	00	0
329	04	4
330	52	EE
331	09	9
332	42	STD
333	25	25
334	01	1
335	08	8
336	93	.
337	05	5
338	52	EE
339	09	9
340	42	STD
341	26	26
342	93	.
343	02	2
344	03	3
345	42	STD
346	28	28
347	05	5
348	93	.
349	05	5
350	09	9
351	52	EE
352	09	9
353	42	STD
354	27	27
355	01	1
356	02	2
357	05	5
358	52	EE
359	06	6

360	94	+/-
361	42	STD
362	59	59
363	71	SBR
364	35	1/X
365	01	1
366	02	2
367	08	6
368	52	EE
369	07	7
370	42	STD
371	23	23
372	02	2
373	05	5
374	52	EE
375	08	8
376	42	STD
377	24	24
378	06	6
379	01	1
380	52	EE
381	06	6
382	42	STD
383	25	25
384	02	2
385	00	0
386	02	2
387	52	EE
388	06	6
389	42	STD
390	26	26
391	06	6
392	07	7
393	52	EE
394	06	6
395	42	STD
396	27	27
397	93	.
398	05	5
399	94	+/-
400	42	STD
401	28	28
402	71	SBR
403	45	YX
404	76	LBL
405	15	E
406	47	CMS
407	57	ENG
408	07	7
409	06	6
410	52	EE
411	09	9
412	42	STD
413	25	25
414	05	5
415	05	5
416	52	EE
417	08	8
418	42	STD
419	22	22

420	02	2
421	03	3
422	52	EE
423	08	8
424	42	STD
425	27	27
426	93	.
427	03	3
428	04	4
429	42	STD
430	28	28
431	01	1
432	02	2
433	05	5
434	52	EE
435	06	6
436	94	+/-
437	42	STD
438	59	59
439	71	SBR
440	35	1/X
441	01	1
442	04	4
443	52	EE
444	08	8
445	42	STD
446	23	23
447	02	2
448	03	3
449	05	5
450	52	EE
451	06	6
452	42	STD
453	24	24
454	01	1
455	02	2
456	52	EE
457	06	6
458	42	STD
459	25	25
460	05	5
461	03	3
462	52	EE
463	06	6
464	42	STD
465	26	26
466	03	3
467	04	4
468	52	EE
469	06	6
470	42	STD
471	27	27
472	93	.
473	05	5
474	94	+/-
475	42	STD
476	28	28
477	71	SBR
478	45	YX
479	00	0

COMBO 1: User Input Ply Data without Printer

000	76	LBL	060	16	16	120	91	R/S	180	91	R/S
001	11	9	061	91	R/S	121	43	RCL	181	42	STD Y'
002	47	CMS	062	43	RCL	122	13	13	182	26	26
003	57	ENG	063	17	17	123	65	X	183	03	2
004	58	FIX	064	91	R/S	124	43	RCL	184	95	=
005	03	03	065	43	RCL	125	59	59	185	91	R/S
006	42	STD	066	18	18	126	95	=	186	42	STD S
007	25	25	067	91	R/S	127	91	R/S	187	27	27
008	04	4	068	43	RCL	128	43	RCL	188	01	1
009	95	=	069	19	19	129	16	16	189	95	=
010	91	R/S	070	91	R/S	130	55	+	190	91	R/S
011	42	STD	071	01	1	131	43	RCL	191	42	STD F _x *
012	26	26	072	93	.	132	59	59	192	28	28
013	03	3	073	02	2	133	95	=	193	36	PGM
014	95	=	074	95	=	134	91	R/S	194	08	08 F _{ij}
015	91	R/S	075	91	R/S	135	43	RCL	195	71	SBR
016	42	STD	076	76	LBL	136	17	17	196	98	ADM
017	28	28	077	17	B'	137	55	+	197	36	PGM
018	02	2	078	43	RCL	138	43	RCL	198	08	08 G _{ij}
019	95	=	079	30	30	139	59	59	199	71	SBR
020	91	R/S	080	91	R/S	140	95	=	200	80	GRD
021	42	STD	081	43	RCL	141	91	R/S	201	43	RCL
022	27	27	082	31	31	142	43	RCL	202	44	44
023	01	1	083	91	R/S	143	18	18	203	42	STD
024	95	=	084	43	RCL	144	55	+	204	51	51
025	91	R/S	085	32	32	145	43	RCL	205	43	RCL
026	42	STD	086	91	R/S	146	59	59	206	45	45
027	59	59	087	43	RCL	147	95	=	207	42	STD
028	36	PGM	088	33	33	148	91	R/S	208	52	52
029	01	01	089	91	R/S	149	43	RCL	209	43	RCL
030	71	SBR	090	43	RCL	150	19	19	210	46	46
031	57	ENG	091	34	34	151	55	+	211	42	STD
032	36	PGM	092	91	R/S	152	43	RCL	212	53	53
033	11	11	093	01	1	153	59	59	213	43	RCL
034	71	SBR	094	93	.	154	95	=	214	47	47
035	35	1/X	095	03	3	155	91	R/S	215	42	STD
036	36	PGM	096	95	=	156	01	1	216	54	54
037	01	01	097	91	R/S	157	93	.	217	43	RCL
038	71	SBR	098	76	LBL	158	04	4	218	48	48
039	52	EE	099	18	C'	159	95	=	219	42	STD
040	01	1	100	43	RCL	160	91	R/S	220	55	55
041	93	.	101	10	10	161	76	LBL	221	43	RCL
042	01	1	102	65	X	162	12	B	222	49	49
043	95	=	103	43	RCL	163	57	ENG	223	42	STD
044	91	R/S	104	59	59	164	58	FIX	224	56	56
045	76	LBL	105	95	=	165	03	03	225	43	RCL
046	16	A'	106	91	R/S	166	42	STD	226	16	16
047	43	RCL	107	43	RCL	167	23	23	227	42	STD
048	10	10	108	11	11	168	05	5	228	44	44
049	91	R/S	109	65	X	169	95	=	229	43	RCL
050	43	RCL	110	43	RCL	170	91	R/S	230	17	17
051	11	11	111	59	59	171	42	STD	231	42	STD
052	91	R/S	112	95	=	172	24	24	232	45	45
053	43	RCL	113	91	R/S	173	04	4	233	43	RCL
054	12	12	114	43	RCL	174	95	=	234	18	18
055	91	R/S	115	12	12	175	91	R/S	235	42	STD
056	43	RCL	116	65	X	176	42	STD	236	46	46
057	13	13	117	43	RCL	177	25	25	237	43	RCL
058	91	R/S	118	59	59	178	03	3	238	19	19
059	43	RCL	119	95	=	179	95	=	239	42	STD

109 Calculate and Display A_{ij} and a_{ij} Display U_i

X
X'
Y

Transfer F_{ij} and G_{ij}

2340	47	47
2341	43	RCL
2342	20	20
2343	42	STO
2344	48	48
2345	43	RCL
2346	21	21
2347	42	STO
2348	49	49
2349	01	1
2350	93	.
2351	05	5
2352	95	=
2353	91	R/S
2354	76	LBL
2355	19	D
2356	43	RCL
2357	51	51
2358	91	R/S
2359	43	RCL
2360	52	52
2361	91	R/S
2362	43	RCL
2363	53	53
2364	91	R/S
2365	43	RCL
2366	54	54
2367	91	R/S
2368	43	RCL
2369	55	55
2370	91	R/S
2371	43	RCL
2372	56	56
2373	91	R/S
2374	01	1
2375	93	.
2376	06	6
2377	95	=
2378	91	R/S
2379	76	LBL
2380	10	D
2381	43	RCL
2382	44	44
2383	91	R/S
2384	43	RCL
2385	45	45
2386	91	R/S
2387	43	RCL
2388	46	46
2389	91	R/S
2390	43	RCL
2391	47	47
2392	91	R/S
2393	43	RCL
2394	48	48
2395	91	R/S
2396	43	RCL
2397	49	49
2398	91	R/S
2399	01	1

Display Fij

Display Gij

300	93	.
301	07	7
302	95	=
303	91	R/S
304	76	LBL
305	13	D
306	08	8
307	08	8
308	09	9
309	05	5
310	25	1/X
311	49	PRD
312	30	30
313	49	PRD
314	31	31
315	49	PRD
316	32	32
317	49	PRD
318	33	33
319	49	PRD
320	34	34
321	95	=
322	03	3
323	09	9
324	93	.
325	04	4
326	49	PRD
327	59	59
328	43	RCL
329	59	59
330	95	=
331	91	R/S
332	76	LBL
333	14	D
334	06	6
335	08	8
336	09	9
337	05	5
338	49	PRD
339	30	30
340	49	PRD
341	31	31
342	49	PRD
343	32	32
344	49	PRD
345	33	33
346	49	PRD
347	34	34
348	95	=
349	03	3
350	09	9
351	93	.
352	04	4
353	25	1/X
354	49	PRD
355	59	59
356	43	RCL
357	59	59
358	95	=
359	91	R/S

SI-
Engl.

Engl-
SI

COMBO 1P: User Input Ply Data with Printer

000	76	LBL	
001	11	A	
002	47	CMS	
003	42	STD	E_x
004	25	25	
005	57	ENG	
006	58	FIX	
007	03	03	
008	01	1	
009	07	7	
010	00	0	
011	00	0	
012	42	STD	
013	02	02	
014	36	PGM	
015	11	11	
016	71	SBR	
017	90	LST	
018	43	RCL	
019	25	25	
020	99	PRT	
021	04	4	
022	95	=	
023	91	R/S	
024	42	STD	E_y
025	26	26	
026	99	PRT	
027	03	3	
028	95	=	
029	91	R/S	
030	42	STD	v_x
031	28	28	
032	99	PRT	
033	02	2	
034	95	=	
035	91	R/S	
036	42	STD	E_z
037	27	27	
038	99	PRT	
039	98	ADV	
040	01	1	
041	95	=	
042	91	R/S	
043	42	STD	v_y
044	59	59	
045	02	2	
046	03	3	
047	00	0	
048	00	0	
049	42	STD	
050	02	02	
051	36	PGM	
052	11	11	
053	71	SBR	
054	90	LST	
055	43	RCL	
056	59	59	
057	99	PRT	
058	98	ADV	
059	36	PGM	

060	01	01	
061	71	SBR	Q_{ij}
062	57	ENG	
063	03	3	
064	04	4	
065	00	0	
066	00	0	
067	42	STD	
068	02	02	
069	36	PGM	
070	11	11	
071	71	SBR	
072	90	LST	
073	43	RCL	
074	10	10	
075	99	PRT	
076	43	RCL	
077	11	11	
078	99	PRT	
079	43	RCL	
080	12	12	
081	99	PRT	
082	43	RCL	
083	13	13	
084	99	PRT	
085	98	ADV	
086	36	PGM	
087	11	11	S_{ij}
088	71	SBR	
089	35	1/X	
090	03	3	
091	06	6	
092	00	0	
093	00	0	
094	42	STD	
095	02	02	
096	36	PGM	
097	11	11	
098	71	SBR	
099	90	LST	
100	43	RCL	
101	16	16	
102	99	PRT	
103	43	RCL	
104	17	17	
105	99	PRT	
106	43	RCL	
107	18	18	
108	99	PRT	
109	43	RCL	
110	19	19	
111	99	PRT	
112	98	ADV	
113	36	PGM	
114	01	01	U_i
115	71	SBR	
116	52	EE	
117	04	4	
118	01	1	
119	00	0	111

120	00	0	
121	42	STD	
122	02	02	
123	36	PGM	
124	11	11	
125	71	SBR	
126	90	LST	
127	43	RCL	
128	30	30	
129	99	PRT	
130	43	RCL	
131	31	31	
132	99	PRT	
133	43	RCL	
134	32	32	
135	99	PRT	
136	43	RCL	
137	33	33	
138	99	PRT	
139	43	RCL	
140	34	34	
141	99	PRT	
142	98	ADV	
143	01	1	
144	03	3	
145	00	0	
146	00	0	
147	42	STD	
148	02	02	
149	36	PGM	
150	11	11	
151	71	SBR	
152	90	LST	
153	43	RCL	
154	10	10	
155	65	X	
156	43	RCL	
157	59	59	
158	95	=	
159	99	PRT	
160	43	RCL	
161	11	11	
162	65	X	
163	43	RCL	
164	59	59	
165	95	=	
166	99	PRT	
167	43	RCL	
168	12	12	
169	65	X	
170	43	RCL	
171	59	59	
172	95	=	
173	99	PRT	
174	43	RCL	
175	13	13	
176	65	X	
177	43	RCL	
178	59	59	
179	95	=	

Print U_i

Calculate and Print A_{ij}

180	99	99	
181	01	01	
182	01	01	
183	00	00	
184	00	00	
185	04	4	
186	42	STD	
187	02	02	
188	36	PGM	
189	11	11	
190	71	SBR	
191	90	LST	
192	43	RCL	
193	28	28	
194	99	PRT	
195	43	RCL	
196	59	59	
197	95	=	
198	99	PRT	
199	43	RCL	
200	17	17	
201	55	+	
202	43	RCL	
203	59	59	
204	95	=	
205	99	PRT	
206	43	RCL	
207	18	18	
208	55	+	
209	43	RCL	
210	59	59	
211	95	=	
212	99	PRT	
213	43	RCL	
214	19	19	
215	55	+	
216	43	RCL	
217	59	59	
218	95	=	
219	99	PRT	
220	98	ADV	
221	01	1	
222	93	.	
223	01	1	
224	95	=	
225	91	R/S	
226	78	LST	
227	12	12	
228	42	STD	
229	28	28	
230	57	ENG	
231	58	P13	
232	03	03	
233	04	4	
234	04	4	
235	00	0	
236	00	0	
237	42	STD	
238	02	02	
239	36	PGM	

Calculate and Print a_{ij}

X

240	11	11
241	71	SBR
242	90	LST
243	43	RCL
244	23	23
245	99	PRT
246	05	5
247	95	=
248	91	R/S
249	42	STO
250	24	24
251	99	PRT
252	04	4
253	95	=
254	91	R/S
255	42	STO
256	25	25
257	99	PRT
258	03	3
259	95	=
260	91	R/S
261	42	STO
262	26	26
263	99	PRT
264	02	2
265	95	=
266	91	R/S
267	42	STO
268	27	27
269	99	PRT
270	98	ADV
271	02	2
272	01	1
273	04	4
274	04	4
275	04	4
276	05	5
277	42	STO
278	02	02
279	36	PGM
280	11	11
281	71	SBR
282	90	LST
283	01	1
284	95	=
285	91	R/S
286	42	STO
287	28	28
288	99	PRT
289	98	ADV
290	36	PGM
291	08	08
292	71	SBR
293	98	ADV
294	02	2
295	01	1
296	00	0
297	00	0
298	42	STO
299	02	02

X'

Y

Y'

S

F₂*

F₂

300	36	PGM
301	11	11
302	71	SBR
303	90	LST
304	43	RCL
305	44	44
306	99	PRT
307	43	RCL
308	45	45
309	99	PRT
310	43	RCL
311	46	46
312	99	PRT
313	43	RCL
314	47	47
315	99	PRT
316	43	RCL
317	48	48
318	99	PRT
319	43	RCL
320	49	49
321	99	PRT
322	98	ADV
323	36	PGM
324	08	08
325	71	SBR
326	80	GRD
327	02	2
328	02	2
329	00	0
330	00	0
331	42	STO
332	02	02
333	36	PGM
334	11	11
335	71	SBR
336	90	LST
337	43	RCL
338	16	16
339	99	PRT
340	42	STO
341	44	44
342	43	RCL
343	17	17
344	99	PRT
345	42	STO
346	45	45
347	43	RCL
348	18	18
349	99	PRT
350	42	STO
351	46	46
352	43	RCL
353	19	19
354	99	PRT
355	42	STO
356	47	47
357	43	RCL
358	20	20
359	99	PRT

Print Fig

G₂

G₂

Print and Transfer

360	42	STO
361	48	48
362	43	RCL
363	43	RCL
364	43	RCL
365	42	STO
366	49	49
367	98	ADV
368	98	ADV
369	98	ADV
370	01	1
371	93	.
372	02	2
373	95	=
374	91	R/S
375	76	LBL
376	13	0
377	06	6
378	08	8
379	09	9
380	05	5
381	35	1/X
382	49	PRD
383	30	30
384	49	PRD
385	31	31
386	49	PRD
387	32	32
388	49	PRD
389	33	33
390	49	PRD
391	34	34
392	95	=
393	03	3
394	09	9
395	93	.
396	04	4
397	49	PRD
398	59	59
399	71	SBR
400	33	X ²
401	76	LBL
402	14	D
403	06	6
404	08	8
405	09	9
406	05	5
407	49	PRD
408	30	30
409	49	PRD
410	31	31
411	49	PRD
412	32	32
413	49	PRD
414	33	33
415	49	PRD
416	34	34
417	95	=
418	03	3
419	09	9

SI
Enl.

SI
Enl.

420	93	.
421	04	4
422	85	85
423	49	49
424	93	.
425	93	.
426	93	.
427	93	.
428	01	1
429	06	6
430	05	5
431	42	STO
432	02	02
433	36	PGM
434	11	11
435	71	SBR
436	90	LST
437	43	RCL
438	30	30
439	99	PRT
440	43	RCL
441	31	31
442	99	PRT
443	43	RCL
444	32	32
445	99	PRT
446	43	RCL
447	33	33
448	99	PRT
449	43	RCL
450	34	34
451	99	PRT
452	98	ADV
453	02	2
454	03	3
455	06	6
456	05	5
457	42	STO
458	02	02
459	36	PGM
460	11	11
461	71	SBR
462	90	LST
463	43	RCL
464	39	39
465	99	PRT
466	98	ADV
467	91	R/S
468	00	0
469	00	0
470	00	0
471	00	0
472	00	0
473	00	0
474	00	0
475	00	0
476	00	0
477	00	0
478	00	0
479	00	0

Print Converted U_i and h₀

COMBO 2: In-Plane Stiffness and Strength without Printer

000	76	LBL	060	43	RCL	120	43	RCL	180	65	x
001	11	A	061	09	09	121	18	18	181	43	RCL
002	42	STD	062	35	1/X	122	91	R/S	182	09	09
003	05	05 <i>n</i>	063	42	STD	123	43	RCL	183	95	=
004	65	x	064	08	08	124	19	19	184	91	R/S
005	43	RCL	065	55	+	125	91	R/S	185	43	RCL
006	59	59	066	43	RCL	126	43	RCL	186	17	17
007	95	=	067	16	16	127	20	20	187	65	x
008	42	STD	068	95	= <i>E₀</i>	128	91	R/S	188	43	RCL
009	09	09 <i>h</i>	069	91	R/S	129	43	RCL	189	09	09
010	57	ENG	070	43	RCL	130	21	21	190	95	=
011	58	FIX	071	08	08	131	91	R/S	191	91	R/S
012	03	03	072	55	+	132	71	SBR	192	43	RCL
013	00	0	073	43	RCL	133	52	EE	193	18	18
014	36	PGM	074	17	17	134	76	LBL	194	65	x
015	12	12 <i>V₀</i>	075	95	= <i>E₀</i>	135	18	18	195	43	RCL
016	71	SBR	076	91	R/S	136	43	RCL	196	09	09
017	61	GTD	077	43	RCL	137	10	10	197	95	=
018	93	.	078	18	18	138	55	+	198	91	R/S
019	05	5	079	55	+	139	43	RCL	199	43	RCL
020	49	PRD <i>N/2</i>	080	43	RCL	140	09	09	200	19	19
021	05	05	081	16	16	141	95	=	201	65	x
022	43	RCL	082	95	=	142	91	R/S	202	43	RCL
023	05	05 <i>t</i>	083	94	+/-	143	43	RCL	203	09	09
024	91	R/S	084	91	R/S	144	11	11	204	95	=
025	94	+/-	085	43	RCL	145	55	+	205	91	R/S
026	42	STD	086	08	08	146	43	RCL	206	43	RCL
027	35	35 <i>Q</i>	087	55	+	147	09	09	207	20	20
028	01	1	088	43	RCL	148	95	=	208	65	x
029	42	STD	089	19	19	149	91	R/S	209	43	RCL
030	04	04	090	95	= <i>E₀</i>	150	43	RCL	210	09	09
031	44	SUM	091	91	R/S	151	12	12	211	95	=
032	36	36	092	71	SBR	152	55	+	212	91	R/S
033	36	PGM	093	52	EE	153	43	RCL	213	43	RCL
034	12	12 <i>ΣV₀</i>	094	76	LBL	154	09	09	214	21	21
035	71	SBR	095	17	B'	155	95	=	215	65	x
036	71	SBR	096	43	RCL	156	91	R/S	216	43	RCL
037	97	US2	097	10	10	157	43	RCL	217	09	09
038	05	05	098	91	R/S	158	13	13	218	95	=
039	00	00	099	43	RCL	159	55	+	219	91	R/S
040	22	22	100	11	11	160	43	RCL	220	76	LBL
041	76	LBL	101	91	R/S	161	09	09	221	52	EE
042	16	A' <i>Q₀</i>	102	43	RCL	162	95	=	222	06	6
043	43	RCL	103	12	12	163	91	R/S	223	93	.
044	59	59	104	91	R/S	164	43	RCL	224	01	1
045	65	x	105	43	RCL	165	14	14	225	95	=
046	02	2	106	13	13	166	55	+	226	91	R/S
047	95	=	107	91	R/S	167	43	RCL	227	76	LBL
048	36	PGM	108	43	RCL	168	09	09	228	12	12
049	12	12 <i>V₀</i>	109	14	14	169	95	=	229	42	STD
050	71	SBR	110	91	R/S	170	91	R/S	230	26	26 <i>N₁</i>
051	61	GTD	111	43	RCL	171	43	RCL	231	06	6
052	36	PGM	112	15	15	172	15	15	232	93	.
053	11	11 <i>A_{ij}</i>	113	91	R/S	173	55	+	233	02	2
054	71	SBR	114	43	RCL	174	43	RCL	234	95	=
055	23	LNK	115	16	16	175	09	09	235	91	R/S
056	36	PGM	116	91	R/S	176	95	=	236	42	STD
057	11	11 <i>a_{ij}</i>	117	43	RCL	177	91	R/S	237	27	27 <i>N₂</i>
058	71	SBR	118	17	17	178	43	RCL	238	06	6
059	35	1/X	119	91	R/S	179	16	16	239	93	.

240	06	6		300	76	LBL		360	42	STD	E_i^0
241	95	=		301	24	CE	θ	361	24	24	E_i^0
242	91	R/S		302	06	6	θ	362	08	8	
243	42	STD	N_6	303	00	0	θ	363	93	.	
244	28	28		304	95	=		364	02	2	
245	36	PGM		305	91	R/S		365	95	=	
246	11	11		306	76	LBL		366	91	R/S	
247	71	SBR	a_{ij}	307	13	0	θ_t	367	42	STD	E_i
248	35	1/X		308	42	STD		368	25	25	E_i
249	36	PGM		309	41	41		369	71	SBR	
250	10	10	E_i^0	310	36	PGM		370	33	X ²	
251	71	SBR		311	10	10	$E_i(R)$	371	76	LBL	
252	89	1		312	71	SBR		372	19	D'	Unit
253	76	LBL		313	54	0		373	57	ENG	Ph
254	33	X ²		314	00	0		374	58	FIX	Data
255	36	PGM		315	42	STD		375	03	03	
256	10	10	p_{ij}	316	26	26		376	43	RCL	
257	71	SBR		317	42	STD	E_i^0	377	59	59	
258	34	FX		318	27	27		378	42	STD	
259	43	RCL		319	42	STD		379	09	09	
260	44	44		320	28	28		380	42	STD	
261	42	STD		321	36	PGM	R_t	381	36	36	
262	16	16		322	08	08	R_t	382	42	STD	
263	43	RCL		323	71	SBR	R_t	383	37	37	
264	45	45		324	30	TAN		384	42	STD	
265	42	STD		325	43	RCL		385	39	39	
266	17	17		326	06	06		386	00	0	
267	43	RCL		327	91	R/S	R_t	387	42	STD	
268	46	46		328	43	RCL	R_t	388	38	38	
269	42	STD		329	07	07		389	42	STD	
270	18	18		330	91	R/S	Display	390	40	40	
271	43	RCL		331	71	SBR		391	61	GTO	
272	47	47		332	24	CE		392	00	00	
273	42	STD		333	76	LBL		393	52	52	
274	19	19		334	14	D		394	00	0	
275	43	RCL		335	43	RCL		395	00	0	
276	48	48		336	06	06		396	00	0	
277	42	STD		337	55	+		397	00	0	
278	20	20		338	43	RCL		398	00	0	
279	43	RCL		339	09	09		399	00	0	
280	49	49		340	95	=	θ_t	400	00	0	
281	42	STD		341	91	R/S		401	00	0	
282	21	21		342	43	RCL		402	00	0	
283	71	SBR		343	07	07		403	00	0	
284	24	CE		344	55	+		404	00	0	
285	76	LBL		345	43	RCL		405	00	0	
286	10	E'		346	09	09		406	00	0	
287	43	RCL		347	95	=	θ_t	407	00	0	
288	53	53	I_k	348	91	R/S		408	00	0	
289	91	R/S		349	71	SBR		409	00	0	
290	43	RCL		350	24	CE		410	00	0	
291	54	54		351	76	LBL		411	00	0	
292	33	X ²		352	15	E		412	00	0	
293	85	+		353	42	STD	E_i^0	413	00	0	
294	43	RCL		354	23	23		414	00	0	
295	55	55		355	08	8		415	00	0	
296	33	X ²		356	93	.		416	00	0	
297	95	=		357	01	1		417	00	0	
298	34	FX	R_k	358	95	=		418	00	0	
299	91	R/S		359	91	R/S		419	00	0	

COMBO 2P: In-Plane Stiffness and Strength with Printer

000	76	LBL	060	99	PRT	120	43	RCL	180	99	PRT
001	11	A	061	76	LBL	121	18	18	181	43	RCL
002	42	STD	062	53	(	122	55	+	182	18	18
003	05	05 n	063	43	RCL	123	43	RCL	183	99	PRT
004	99	PRT	064	59	59	124	16	16	184	43	RCL
005	98	ADV	065	65	*	125	95	=	185	18	18
006	65	*	066	02	2	126	94	+/-	186	99	PRT
007	43	RCL	067	95	=	127	99	PRT	187	43	RCL
008	59	59	068	36	PGM	128	43	RCL	188	20	20
009	95	=	069	12	12 V_{iA}	129	08	08	189	99	PRT
010	42	STD h	070	71	SBR	130	55	+	190	43	RCL
011	09	09 h	071	61	GTO	131	43	RCL	191	21	21
012	57	ENG	072	03	3	132	19	19 F_0	192	99	PRT
013	58	FIX	073	06	6	133	95	=	193	98	ADV
014	03	03	074	04	4	134	99	PRT	194	01	1
015	00	0	075	05	5	135	98	ADV	195	03	3
016	36	PGM	076	03	3	136	01	1	196	05	5
017	12	12 V_{iA}	077	00	0	137	03	3	197	01	1
018	71	SBR	078	42	STD	138	00	0	198	42	STD
019	61	GTO	079	02	02	139	00	0	199	02	02
020	93	.	080	36	PGM	140	42	STD	200	36	PGM
021	05	5	081	11	11	141	02	02	201	11	11
022	49	PRD $n/2$	082	71	SBR	142	36	PGM	202	71	SBR
023	05	05	083	90	LST	143	11	11	203	90	LST
024	43	RCL t	084	98	ADV	144	71	SBR	204	61	GTO
025	05	05	085	36	PGM	145	90	LST	205	02	02
026	91	R/S	086	11	11 A_{ij}	146	43	RCL	206	15	15
027	99	PRT	087	71	SBR	147	10	10	207	76	LBL
028	94	+/-	088	23	LNK	148	99	PRT	208	23	LNK
029	42	STD θ_c	089	36	PGM	149	43	RCL	209	55	+
030	35	35	090	11	11 a_{ij}	150	11	11	210	43	RCL
031	01	1	091	71	SBR	151	99	PRT	211	09	09
032	42	STD	092	35	1/X	152	43	RCL	212	95	=
033	04	04	093	01	1	153	12	12	213	99	PRT
034	44	SUM	094	07	7	154	99	PRT	214	92	RTN
035	36	36	095	05	5	155	43	RCL	215	43	RCL
036	36	PGM	096	01	1	156	13	13	216	10	10
037	12	12 V_{iA}	097	42	STD	157	99	PRT	217	71	SBR
038	71	SBR	098	02	02	158	43	RCL	218	23	LNK
039	71	SBR	099	36	PGM	159	14	14	219	43	RCL
040	97	DSZ	100	11	11	160	99	PRT	220	11	11
041	05	05	101	71	SBR	161	43	RCL	221	71	SBR
042	00	00	102	90	LST	162	15	15	222	23	LNK
043	24	24	103	43	RCL	163	99	PRT	223	43	RCL
044	71	SBR	104	09	09	164	98	ADV	224	12	12
045	53	(	105	35	1/X	165	01	1	225	71	SBR
046	76	LBL	106	42	STD	166	03	3	226	23	LNK
047	16	A' C_{02}	107	08	08 m_0	167	02	2	227	43	RCL
048	01	1	108	55	+	168	04	4	228	13	13
049	05	5	109	43	RCL	169	42	STD	229	71	SBR
050	03	3	110	16	16	170	02	02	230	23	LNK
051	05	5	111	95	=	171	36	PGM	231	43	RCL
052	42	STD	112	99	PRT	172	11	11	232	14	14
053	02	02	113	43	RCL	173	71	SBR	233	71	SBR
054	36	PGM	114	08	08 m_0	174	90	LST	234	23	LNK
055	11	11	115	55	+	175	43	RCL	235	43	RCL
056	71	SBR	116	43	RCL	176	16	16	236	15	15
057	90	LST	117	17	17	177	99	PRT	237	71	SBR
058	43	RCL	118	95	=	178	43	RCL	238	23	LNK
059	05	05	119	99	PRT	179	17	17	239	98	ADV

Print A_{ij}

Print a_{ij}

A_{ijh}

Print A_{ij}^*

240	01	1	300	00	0	360	34	FX	420	42	STD
241	03	3	301	42	STD	361	99	PRT	421	28	28
242	05	5	302	02	02	362	99	ADV	422	36	PGM
243	01	1	303	36	PGM	363	43	RCL	423	08	08
244	02	2	304	11	11	364	44	44	424	71	SBR
245	04	4	305	71	SBR	365	42	STD	425	30	TAN
246	42	STD	306	90	LST	366	16	16	426	03	:
247	02	02	307	43	RCL	367	43	RCL	427	05	:
248	36	PGM	308	26	26	368	45	45	428	00	0
249	11	11	309	99	PRT	369	42	STD	429	00	0
250	71	SBR	310	06	6	370	17	17	430	42	STD
251	90	LST	311	93	.	371	43	RCL	431	02	02
252	61	GTD	312	02	2	372	46	46	432	36	PGM
253	02	02	313	95	=	373	42	STD	433	11	11
254	63	63	314	91	R/S	374	18	18	434	71	SBR
255	76	LBL	315	99	PRT	375	43	RCL	435	90	LST
256	22	INV	316	42	STD	376	47	47	436	43	RCL
257	65	X	317	27	27	377	42	STD	437	06	06
258	43	RCL	318	06	6	378	19	19	438	99	PRT
259	09	09	319	93	.	379	43	RCL	439	43	RCL
260	95	=	320	06	6	380	48	48	440	07	07
261	99	PRT	321	95	=	381	42	STD	441	99	PRT
262	92	RTN	322	91	R/S	382	20	20	442	98	ADV
263	43	RCL	323	99	PRT	383	43	RCL	443	07	7
264	16	16	324	98	ADV	384	49	49	444	07	7
265	71	SBR	325	42	STD	385	42	STD	445	00	0
266	22	INV	326	28	28	386	21	21	446	00	0
267	43	RCL	327	36	PGM	387	76	LBL	447	42	STD
268	17	17	328	11	11	388	24	CE	448	02	02
269	71	SBR	329	71	SBR	389	06	6	449	36	PGM
270	22	INV	330	35	1/X	390	00	0	450	11	11
271	43	RCL	331	36	PGM	391	95	=	451	71	SBR
272	18	18	332	10	10	392	91	R/S	452	90	LST
273	71	SBR	333	71	SBR	393	76	LBL	453	43	RCL
274	22	INV	334	89	.	394	13	0	454	06	06
275	43	RCL	335	36	PGM	395	42	STD	455	55	+
276	19	19	336	10	10	396	41	41	456	43	RCL
277	71	SBR	337	71	SBR	397	06	6	457	09	09
278	22	INV	338	34	FX	398	00	0	458	95	=
279	43	RCL	339	05	5	399	00	0	459	99	PRT
280	20	20	340	04	4	400	00	0	460	43	RCL
281	71	SBR	341	02	2	401	42	STD	461	07	07
282	22	INV	342	04	4	402	02	02	462	55	+
283	43	RCL	343	42	STD	403	36	PGM	463	43	RCL
284	21	21	344	02	02	404	11	11	464	09	09
285	71	SBR	345	36	PGM	405	71	SBR	465	95	=
286	22	INV	346	11	11	406	90	LST	466	99	PRT
287	98	ADV	347	71	SBR	407	43	RCL	467	98	ADV
288	06	6	348	90	LST	408	41	41	468	71	SBR
289	93	.	349	43	RCL	409	99	PRT	469	24	CE
290	01	1	350	53	53	410	98	ADV	470	00	0
291	95	=	351	99	PRT	411	36	PGM	471	00	0
292	91	R/S	352	43	RCL	412	10	10	472	00	0
293	76	LBL	353	54	54	413	71	SBR	473	00	0
294	12	8	354	33	X ²	414	54	.	474	00	0
295	42	STD	355	85	+	415	00	0	475	00	0
296	26	26	356	43	RCL	416	42	STD	476	00	0
297	03	3	357	55	55	417	26	26	477	00	0
298	01	1	358	33	X ²	418	42	STD	478	00	0
299	00	0	359	95	=	419	27	27	479	00	0

a_{ij}h

N₂

N₆

a_{ij}

E_i°

p_{ij}r

I_c

R_c

E_i°(0)

E_i°(0)

E_i°(0)

E_i°(0)

Transfer G_{ij}

0

0

0_t

0

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0

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0

Print R_t, R_t'

Calculate & Print G_c

0_t

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COMBO 3: Flexural Stiffness and Strength without Printer

```

000 76 LBL
001 11 A
002 42 STD
003 05 05
004 65 X
005 43 RCL
006 59 59
007 95 =
008 42 STD
009 09 09
010 57 ENG
011 58 FIX
012 03 03
013 00 0
014 36 PGM
015 12 12
016 71 SBR
017 61 GTD
018 43 RCL
019 05 05
020 55 +
021 02 2
022 95 =
023 42 STD
024 05 05
025 42 STD
026 06 06
027 75 -
028 01 1
029 95 =
030 42 STD
031 07 07
032 43 RCL
033 05 05
034 91 R/S
035 94 +/-
036 42 STD
037 35 35
038 43 RCL
039 06 06
040 45 YX
041 03 3
042 75 -
043 43 RCL
044 07 07
045 45 YX
046 03 3
047 95 =
048 42 STD
049 04 04
050 44 SUM
051 36 36
052 36 PGM
053 12 12
054 71 SBR
055 71 SBR
056 97 DSZ
057 05 05
058 00 00
059 32 32

```

n

h

V_{iD}

O₃

n/2

t

Z V_{iD}

```

060 76 LBL
061 16 R*
062 43 RCL
063 59 59
064 45 YX
065 03 3
066 65 X
067 02 2
068 55 +
069 03 3
070 95 =
071 36 PGM
072 12 12
073 71 SBR
074 61 GTD
075 36 PGM
076 11 11
077 71 SBR
078 23 LNX
079 36 PGM
080 11 11
081 71 SBR
082 35 1/X
083 01 1
084 02 2
085 55 +
086 43 RCL
087 09 09
088 45 YX
089 03 3
090 95 =
091 42 STD
092 08 08
093 55 +
094 43 RCL
095 16 16
096 95 =
097 91 R/S
098 43 RCL
099 08 08
100 55 +
101 43 RCL
102 17 17
103 95 =
104 91 R/S
105 43 RCL
106 18 18
107 55 +
108 43 RCL
109 16 16
110 95 =
111 94 +/-
112 91 R/S
113 43 RCL
114 08 08
115 55 +
116 43 RCL
117 19 19
118 95 =
119 91 R/S

```

Core

V_{iD}

D_{ij}

d_{ij}

E₁^f

E₂^f

2₂^f

E_c^f

117

```

120 71 SBR
121 52 EE
122 76 LBL
123 17 R*
124 43 RCL
125 10 10
126 91 R/S
127 43 RCL
128 11 11
129 91 R/S
130 43 RCL
131 12 12
132 91 R/S
133 43 RCL
134 13 13
135 91 R/S
136 43 RCL
137 14 14
138 91 R/S
139 43 RCL
140 15 15
141 91 R/S
142 43 RCL
143 16 16
144 91 R/S
145 43 RCL
146 17 17
147 91 R/S
148 43 RCL
149 18 18
150 91 R/S
151 43 RCL
152 19 19
153 91 R/S
154 43 RCL
155 20 20
156 91 R/S
157 43 RCL
158 21 21
159 91 R/S
160 71 SBR
161 52 EE
162 76 LBL
163 18 C*
164 43 RCL
165 10 10
166 65 X
167 43 RCL
168 08 08
169 95 =
170 91 R/S
171 43 RCL
172 11 11
173 65 X
174 43 RCL
175 08 08
176 95 =
177 91 R/S
178 43 RCL
179 12 12

```

D_{ij}

d_{ij}

```

180 65
181 43
182 08
183 08
184 08
185 08
186 08
187 08
188 43
189 08
190 95
191 91
192 43
193 14
194 65
195 43
196 08
197 95
198 91
199 43
200 15
201 65
202 43
203 08
204 95
205 91
206 43
207 16
208 55
209 43
210 08
211 95
212 91
213 43
214 17
215 55
216 43
217 08
218 95
219 91
220 43
221 18
222 55
223 43
224 08
225 95
226 91
227 43
228 19
229 55
230 43
231 08
232 95
233 91
234 43
235 20
236 55
237 43
238 08
239 95

```

*D_{ij}**

*d_{ij}**

240	91	R/S
241	43	RCL
242	21	21
243	55	-
244	43	RCL
245	03	03
246	95	=
247	91	R/S
248	76	LBL
249	52	EE
250	06	6
251	93	.
252	01	1
253	95	=
254	91	R/S
255	76	LBL
256	12	B
257	42	STD
258	26	26
259	06	6
260	93	.
261	02	2
262	95	=
263	91	R/S
264	42	STD
265	27	27
266	06	6
267	93	.
268	06	6
269	95	=
270	91	R/S
271	42	STD
272	28	28
273	36	PGM
274	11	11
275	71	SBR
276	35	1/X
277	36	PGM
278	10	10
279	71	SBR
280	89	1
281	36	PGM
282	10	10
283	71	SBR
284	34	1/X
285	43	RCL
286	44	44
287	42	STD
288	16	16
289	43	RCL
290	45	45
291	42	STD
292	17	17
293	43	RCL
294	46	46
295	42	STD
296	18	18
297	43	RCL
298	47	47
299	42	STD

M_1

M_2

M_6

d_{ij}

k_i

p_{ij}

Transfer G_{ij}

300	19	19
301	43	RCL
302	48	48
303	42	STD
304	20	20
305	43	RCL
306	49	49
307	42	STD
308	21	21
309	76	LBL
310	24	CE
311	06	6
312	00	0
313	95	=
314	91	R/S
315	76	LBL
316	13	0
317	42	STD
318	41	41
319	03	3
320	07	7
321	95	=
322	91	R/S
323	42	STD
324	05	05
325	36	PGM
326	10	10
327	71	SBR
328	54	0
329	43	RCL
330	05	-05
331	65	x
332	43	RCL
333	59	59
334	95	=
335	49	PRD
336	23	23
337	49	PRD
338	24	24
339	49	PRD
340	25	25
341	00	0
342	42	STD
343	26	26
344	42	STD
345	27	27
346	42	STD
347	28	28
348	36	PGM
349	08	08
350	71	SBR
351	30	TAN
352	43	RCL
353	06	06
354	91	R/S
355	43	RCL
356	07	07
357	91	R/S
358	71	SBR
359	24	CE

Prompter

θ_t

t

$k_i(\theta_i)$

z_t

$\epsilon_i(\theta_i)$

$\epsilon_i^N = 0$

R_t

R_t'

Display R_t, R_t'

360	76	LBL
361	14	D
362	43	RCL
363	06	06
364	55	-
365	43	RCL
366	09	09
367	33	33
368	65	x
369	06	6
370	95	=
371	91	R/S
372	55	-
373	43	RCL
374	06	06
375	65	x
376	43	RCL
377	07	07
378	95	=
379	91	R/S
380	71	SBR
381	24	CE
382	00	0
383	00	0
384	00	0
385	00	0
386	00	0
387	00	0
388	00	0
389	00	0
390	00	0
391	00	0
392	00	0
393	00	0
394	00	0
395	00	0
396	00	0
397	00	0
398	00	0
399	00	0
400	00	0
401	00	0
402	00	0
403	00	0
404	00	0
405	00	0
406	00	0
407	00	0
408	00	0
409	00	0
410	00	0
411	00	0
412	00	0
413	00	0
414	00	0
415	00	0
416	00	0
417	00	0
418	00	0
419	00	0

σ_t^f

$\sigma_t^{f'}$

[illegible]

Print dig

$$\frac{12D_{ij}}{h^3}$$

240 23 LNX
 241 43 RCL
 242 12 12
 243 71 SBR
 244 23 LNX
 245 43 RCL
 246 13 13
 247 71 SBR
 248 23 LNX
 249 43 RCL
 250 14 14
 251 71 SBR
 252 23 LNX
 253 43 RCL
 254 15 15
 255 71 SBR
 256 23 LNX
 257 98 ADV
 258 61 GTO
 259 02 02
 260 69 69
 261 76 LBL
 262 22 INV
 263 55 +
 264 43 RCL
 265 08 08
 266 95 =
 267 99 FRT
 268 92 RTN
 269 43 RCL
 270 16 16
 271 71 SBR
 272 22 INV
 273 43 RCL
 274 17 17
 275 71 SBR
 276 22 INV
 277 43 RCL
 278 18 18
 279 71 SBR
 280 22 INV
 281 43 RCL
 282 19 19
 283 71 SBR
 284 22 INV
 285 43 RCL
 286 20 20
 287 71 SBR
 288 22 INV
 289 43 RCL
 290 21 21
 291 71 SBR
 292 22 INV
 293 98 ADV
 294 06 6
 295 93 .
 296 01 1
 297 95 =
 298 91 R/S
 299 76 LBL

Dij*

dij*
 12

dij*

300 12 B
 301 42 STD
 302 26 26
 303 03 3
 304 00 0
 305 00 0
 306 00 0
 307 42 STD
 308 02 02
 309 36 PGM
 310 11 11
 311 71 SBR
 312 90 LST
 313 43 RCL
 314 26 26
 315 99 PRT
 316 06 6
 317 93 .
 318 02 2
 319 95 =
 320 91 R/S
 321 99 PRT
 322 42 STD
 323 27 27
 324 06 6
 325 93 .
 326 06 6
 327 95 =
 328 91 R/S
 329 99 PRT
 330 98 ADV
 331 42 STD
 332 28 28
 333 36 PGM
 334 11 11
 335 71 SBR
 336 35 1/X
 337 36 PGM
 338 10 10
 339 71 SBR
 340 89 1
 341 36 PGM
 342 10 10
 343 71 SBR
 344 34 1/X
 345 43 RCL
 346 44 44
 347 42 STD
 348 16 16
 349 43 RCL
 350 45 45
 351 42 STD
 352 17 17
 353 43 RCL
 354 46 46
 355 42 STD
 356 18 18
 357 43 RCL
 358 47 47
 359 42 STD

M₁

M₂

M₆

dij

k_i

p,q,r

Transfer Gij
 120

360 19 19
 361 43 RCL
 362 43 43
 363 42 STD
 364 20 20
 365 43 RCL
 366 49 49
 367 42 STD
 368 21 21
 369 76 LBL
 370 24 0E
 371 06 6
 372 00 0
 373 95 =
 374 91 R/S
 375 76 LBL
 376 13 0
 377 42 STD
 378 41 41
 379 06 6
 380 00 0
 381 05 5
 382 07 7
 383 03 3
 384 07 7
 385 42 STD
 386 02 02
 387 36 PGM
 388 11 11
 389 71 SBR
 390 90 LST
 391 43 RCL
 392 41 41
 393 99 PRT
 394 03 3
 395 07 7
 396 95 =
 397 91 R/S
 398 42 STD
 399 05 05
 400 99 PRT
 401 98 ADV
 402 36 PGM
 403 10 10
 404 71 SBR
 405 54 1
 406 43 RCL
 407 05 05
 408 65 X
 409 43 RCL
 410 59 59
 411 95 =
 412 49 PRT
 413 23 23
 414 49 PRT
 415 24 24
 416 49 PRT
 417 25 25
 418 00 0
 419 42 STD

prompter

0₂

11

k_i(0₂)

N₂

ε_i(0₂)

420 19 19
 421 43 RCL
 422 43 43
 423 42 STD
 424 20 20
 425 43 RCL
 426 49 49
 427 42 STD
 428 21 21
 429 76 LBL
 430 24 0E
 431 06 6
 432 00 0
 433 95 =
 434 91 R/S
 435 76 LBL
 436 13 0
 437 42 STD
 438 41 41
 439 06 6
 440 00 0
 441 05 5
 442 07 7
 443 03 3
 444 07 7
 445 42 STD
 446 02 02
 447 36 PGM
 448 11 11
 449 71 SBR
 450 90 LST
 451 43 RCL
 452 41 41
 453 99 PRT
 454 03 3
 455 07 7
 456 95 =
 457 91 R/S
 458 42 STD
 459 05 05
 460 99 PRT
 461 98 ADV
 462 36 PGM
 463 10 10
 464 71 SBR
 465 54 1
 466 43 RCL
 467 05 05
 468 65 X
 469 43 RCL
 470 59 59
 471 95 =
 472 49 PRT
 473 23 23
 474 49 PRT
 475 24 24
 476 49 PRT
 477 25 25
 478 00 0
 479 42 STD

R₂² = 0

Print R₂, R₂'

0₂²

0₂²

FILMED
9-8