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AFWAL-TR-82-4081

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

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JUNE 1982

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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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SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)* 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.

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 <u>Introduction to Composite Materials</u>, 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.

TABLE OF CONTENTS

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, E^f_i = 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_0 = unit ply thickness

NOMENCLATURE

$I_\varepsilon, R_\varepsilon$ = 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; $i = 1,2,6$ $(\varepsilon_i = \varepsilon_i(z))$

$\varepsilon_i^\circ, \varepsilon_i^f$ = 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

$\nu_{21}^\circ, \nu_{21}^f$ = 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

$\sigma^{\circ}_t, \sigma^{\circ\prime}_t$ = allowable stresses, in-plane loading

σ^f_i = surface stress, flexural loading; i = 1,2,6

$\sigma^f_t, \sigma^{f\prime}_t$ = 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-100C) 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 proer 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 play 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 play 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 $\boxed{3}\,\boxed{\text{2nd}}$ [illegible]. * 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 distrubed.

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** [illegible]. 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 $\boxed{\text{CLR}}$, read side 1, press $\boxed{\text{CLR}}$, 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:

Q_{xx} on-axis modulus (Equation 1.12):

Q_{yy}

Q_{xy}

Q_{ss}

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{Bmatrix} = \begin{bmatrix} Q_{xx} & Q_{xy} & 0 \\ Q_{xy} & Q_{yy} & 0 \\ 0 & 0 & Q_{ss} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_s \end{Bmatrix}$$

---

*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.

U_1 U_2 U_3 U_4 U_5	linear combinations of modulus (Equation 3.15): $U_1 = U_1 (Q_{xx}, Q_{yy}, Q_{xx}, Q_{ss})$ 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: $G_{ij}\varepsilon_i\varepsilon_k + G_i\varepsilon_i = 1$

Note that ply thickness, h_o, 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 ■	0
2	Convert from SI to English	2nd ■	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 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 ν_x, F_{xy}^*	43	58
14	29	44 F_{xx}, G_{xx}	59 h_o

Figure 2. Combo 0 Storage Memories

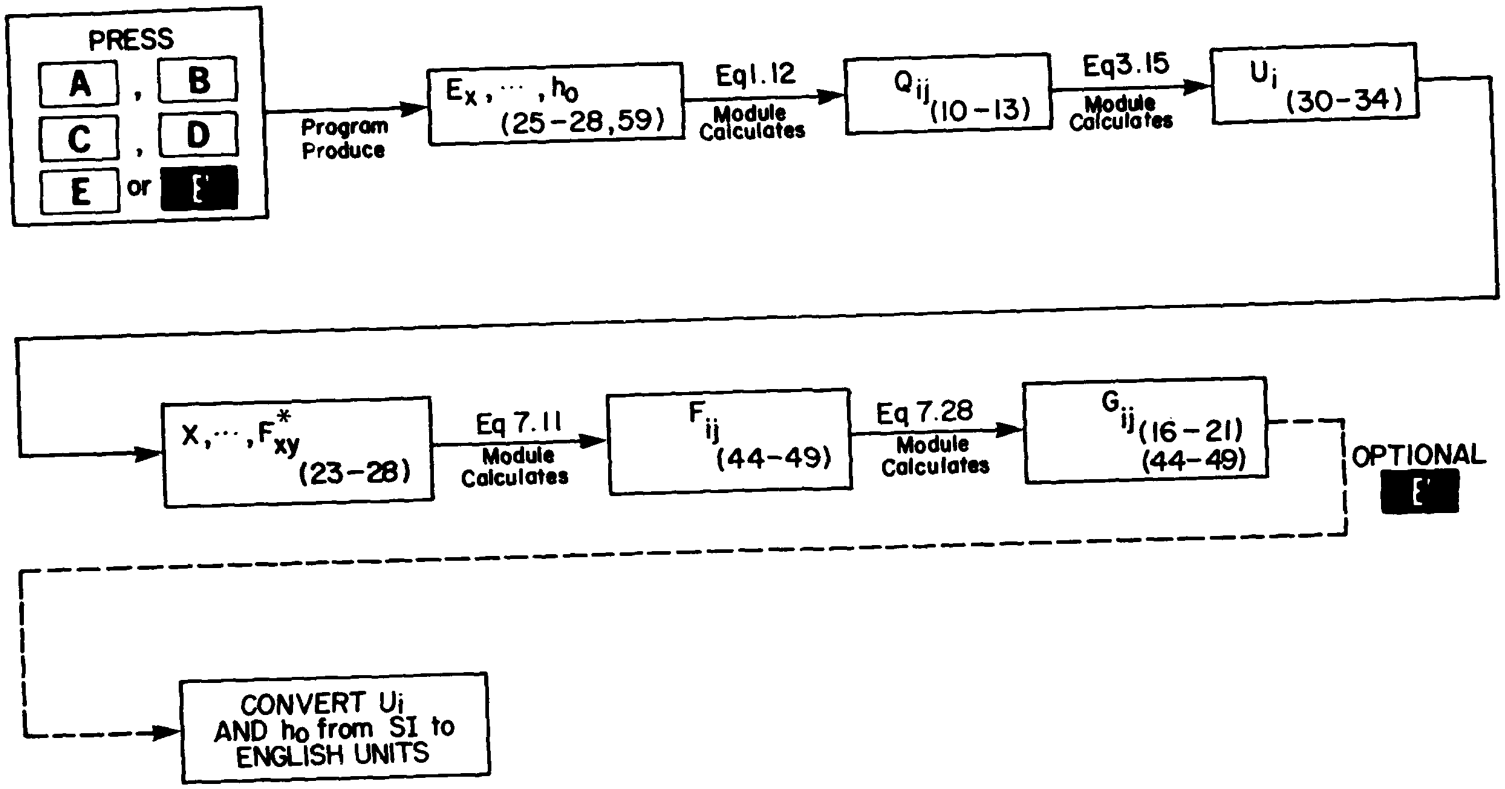


Figure 3. Combo 0 Flow Chart

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}
$E_x,\ldots,h_o$	$X,\ldots,F_{xy}^{*}$	SI→Engl	Engl→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_o values only. The Combo 1 program listing is given in Appendix D.

This program can be used by following these steps:

1. Press $\boxed{\text{CLR}}$, read side 1, press $\boxed{\text{CLR}}$, read side 2.
2. Enter E_x, E_y, ν_x, E_s, h_o as shown in Figure 4.

The machine calculates:

Q_{xx}
Q_{yy}
Q_{xy}
Q_{ss}

on-axis modulus (Equation 1.12):

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{Bmatrix} = \begin{bmatrix} Q_{xx} & Q_{xy} & 0 \\ Q_{xy} & Q_{yy} & 0 \\ 0 & 0 & Q_{ss} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_s \end{Bmatrix}$$

S_{xx}
S_{yy}
S_{xy}
S_{ss}

on-axis compliance (Equation 1.9):

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_s \end{Bmatrix} = \begin{bmatrix} \\ Q \\ \\ \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{Bmatrix} = \begin{bmatrix} S_{xx} & S_{xy} & 0 \\ S_{xy} & S_{yy} & 0 \\ 0 & 0 & S_{ss} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{Bmatrix}$$

U_1
U_2
U_3
U_4
U_5

linear combinations of modulus (Equation 3.15):

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

used in lamination calculations

$A_{xx} = Q_{xx}h_o$
$A_{yy} = Q_{yy}h_o$
$A_{xy} = Q_{xy}h_o$
$A_{ss} = Q_{ss}h_o$

On-axis A matrix for one ply

a_{xx}
a_{yy}
a_{xy}
a_{ss}

inversion of on-axis A matrix for one ply (inversion of previous matrix)

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, Fxy* as shown in Figure 4.

The machine calculates:

F_{xx}
F_{yy}
F_{xy}
F_{ss}
F_x
F_y

Strength parameters in stress space (Equations 7.11, 7.12, 7.13, 7.15)

G_{xx}
G_{yy}
G_{xy}
G_{ss}
G_x
G_y

Strength parameters in strain space (Equation 7.28)

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 → English or English → 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	ν_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 ν_x, F_{xy}^*	43	58
14	29	44 F_{xx}, G_{xx}	59 h_o

Figure 6. Combo 1 Storage Memories

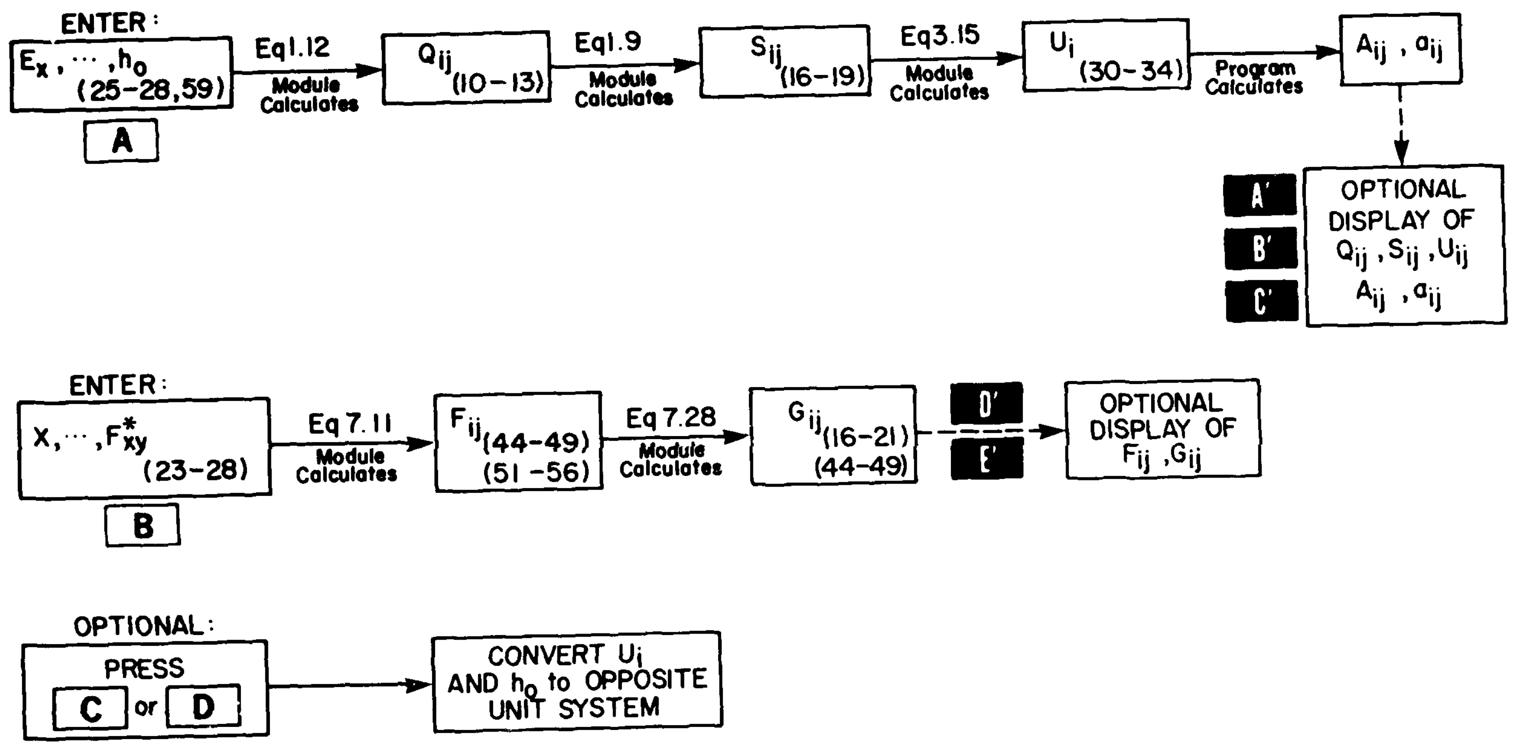


Figure 7. Combo 1 Flow Chart

COMBO 1 SAMPLE PROBLEM: USER INPUT PLY DATA

PROCEDURE	KEY	DISPLAY
Enter E_x (181 E09)	A	4
E_y (10.3 E09)	R/S	3
ν_x (280 E-3)	R/S	2
E_s (7.17 E09)	R/S	1
h_0 (125 E-6)	R/S	1.1
Display Q_{ij}	A' R/S " "	181.811 09 10.346 09 2.897 09 7.170 09
Display S_{ij}	R/S " " "	5.525-12 97.087-12 -1.547-12 139.470-12
Display U_i	B' R/S " " "	76.368 09 85.732 09 19.710 09 22.607 09 26.880 09
Display A_{ij}	C' R/S " "	22.726 06 1.293 06 362.116 03 896.250 03
Display a_{ij}	R/S " " "	44.199-09 776.699-09 -12.376-09 1.116-06

PROCEDURE	KEY	DISPLAY
Enter X (1.5 E09)	B	5
X' (1.5 E09)	R/S	4
Y (40 E06)	R/S	3
Y' (246 E06)	R/S	2
S (68 E06)	R/S	1
F_{xy}^* (-.5)	R/S	1.5
Display F_{ij}	D' R/S " " " "	444.444-21 101.626-18 -3.360-18 216.263-18 0.000 00 20.935-09
Display G_{ij}	E' R/S " " " "	12.004 03 10.681 03 -3.069 03 11.118 03 60.647 00 216.596 00
Convert SI → English	C	4.925-03
Display U_i	B' R/S " " "	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

<table>
<tr><th colspan="5">AFWAL/MLBM CARD MODULE FOR TI-59</th></tr>
<tr><th colspan="5">COMBO 1P: USER INPUT PLY DATA w/PRINTER</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>$E_x,\ldots,h_o$</td><td>$X,\ldots,F_{xy}^*$</td><td>SI→Engl</td><td>Engl→SI</td><td></td></tr>
</table>

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 $\boxed{\text{CLR}}$, read side 1, press $\boxed{\text{CLR}}$, read side 2.

2. Enter E_x, E_y, ν_x, E_s, and h_o 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 → English or English → SI changes if desired. The machine will calculate, store, and print a new set of U_i (labeled "U'") and a new h_o (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	ν_x	R/S	2		ν_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	Fxy*	R/S		FXY	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'	U_1, U_2, U_3, U_4, U_5 (Engl)
			h_o(Engl)	H'	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 ν_x, F_{xy}^*	43	58
14	29	44 F_{xx}, G_{xx}	59 h_o

Figure 9. Combo 1P Storage Memories

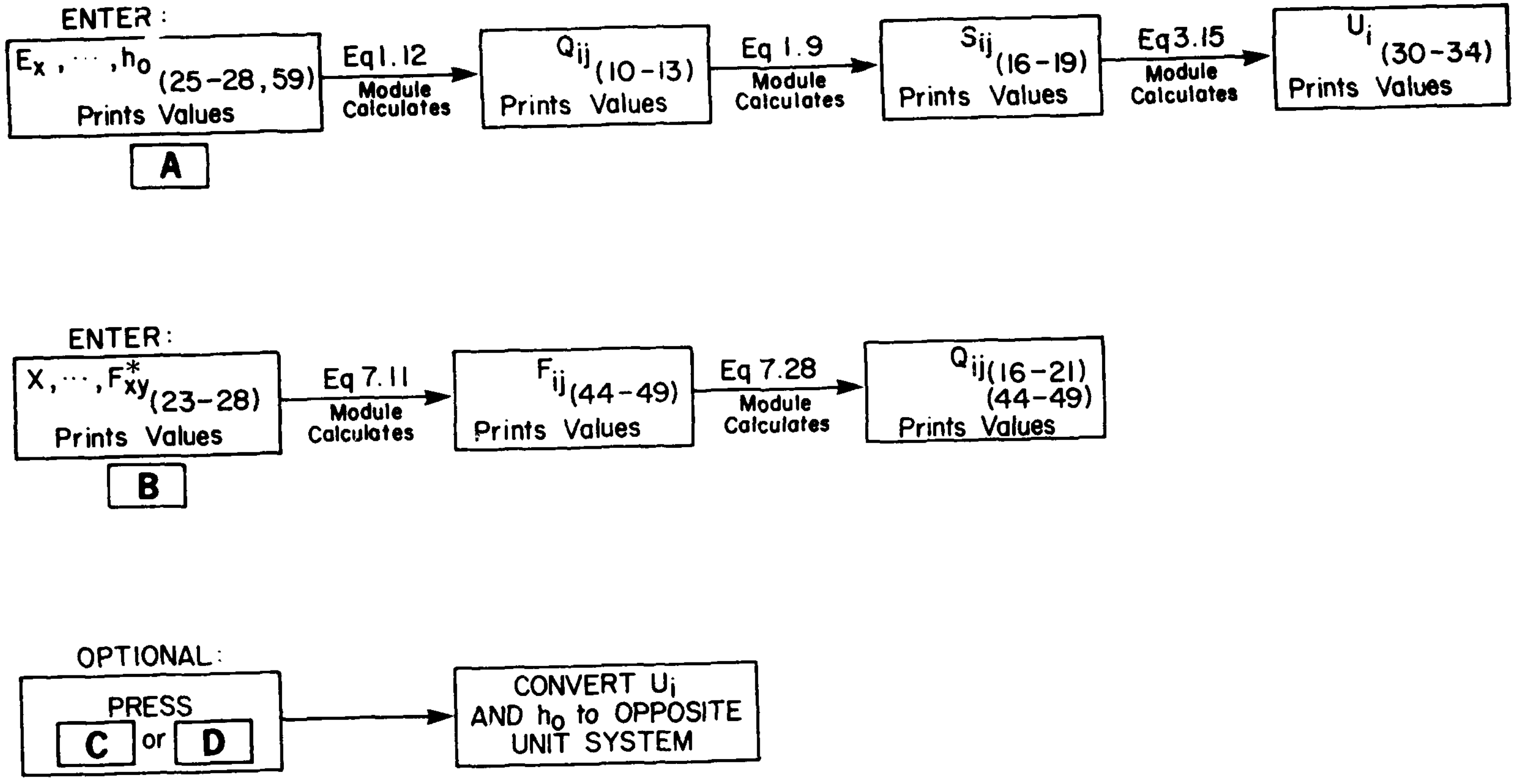


Figure 10. Combo 1P Flow Chart

COMBO 1P SAMPLE PROBLEM: USER INPUT PLY DATA

PROCEDURE	KEY	PRINT
Enter E_x E_y ν_x E_s	A R/S R/S R/S	E 181.000 09 10.300 09 280.000-03 7.170 09
Enter h_o	R/S	H 125.000-06
Print Q_{ij}		Q 181.811 09 10.346 09 2.897 09 7.170 09
Print S_{ij}		S 5.525-12 97.087-12 -1.547-12 139.470-12
Print U_i		U 76.368 09 85.732 09 19.710 09 22.607 09 26.880 09
Print A_{ij}		A 22.726 06 1.293 06 362.116 03 896.250 03
Print a_{ij}		AI 44.199-09 776.699-09 -12.376-09 1.116-06

PROCEDURE	KEY	PRINT
Enter X X' Y Y' S	B R/S R/S R/S R/S	X 1.500 09 1.500 09 40.000 06 246.000 06 68.000 06
Enter F_{xy}*	R/S	FXY -500.000-03
Print F_{ij}		F 444.444-21 101.626-18 -3.360-18 216.263-18 0.000 00 20.935-09
Print G_{ij}		G 12.004 03 10.681 03 -3.069 03 11.118 03 60.647 00 216.596 00
Convert SI → English	C	
Print U_i (English)		U' 11.076 06 12.434 06 2.859 06 3.279 06 3.899 06
Print h_o (English)		H' 4.925-03

```
         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
     10.300 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
      5.525-12           38.094-09            4.902-12           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
     22.726 06          129.865 03           25.623 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            3.393 03

        AI                  AI                  AI                  AI
     44.199-09            7.735-06           39.216-09            6.863-06
    776.699-09          135.922-06          432.432-09           75.676-06
    -12.376-09           -2.166-06           -9.020-09           -1.578-06
      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          182.741 03
      1.500 09          217.549 03            2.500 09          362.582 03
     40.000 06            5.801 03           61.000 06            8.847 03
    246.000 06           35.678 03          202.000 06           29.297 03
     68.000 06            9.862 03           67.000 06            9.717 03

        FXY                 FXY                 FXY                 FXY
   -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           81.156-18            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 1002	
	SI	ENGLISH	SI	ENGLISH
E	138.000 09 8.960 09 300.000-03 7.100 09	20.015 06 1.299 06 300.000-03 1.030 06	38.600 09 8.270 09 260.000-03 4.140 09	5.598 06 1.199 06 260.000-03 600.435 03
H	125.000-06	4.925-03	125.000-06	4.925-03
Q	138.811 09 9.013 09 2.704 09 7.100 09	20.132 06 1.307 06 392.139 03 1.030 06	39.167 09 8.392 09 2.182 09 4.140 09	5.681 06 1.217 06 316.432 03 600.435 03
S	7.246-12 111.607-12 -2.174-12 140.845-12	49.964-09 769.531-09 -14.989-09 971.127-09	25.907-12 120.919-12 -6.736-12 241.546-12	178.627-09 833.736-09 -46.443-09 1.665-06
U	59.660 09 64.899 09 14.252 09 16.956 09 21.352 09	8.653 06 9.413 06 2.067 06 2.459 06 3.097 06	20.450 09 15.388 09 3.329 09 5.511 09 7.469 09	2.966 06 2.232 06 482.872 03 799.304 03 1.083 06
A	17.351 06 1.127 06 337.975 03 887.500 03	99.151 03 6.438 03 1.931 03 5.071 03	4.896 06 1.049 06 272.725 03 517.500 03	27.977 03 5.994 03 1.558 03 2.957 03
AI	57.971-09 892.857-09 -17.391-09 1.127-06	10.145-06 156.250-06 -3.043-06 197.183-06	207.254-09 967.352-09 -53.886-09 1.932-06	36.269-06 169.287-06 -9.430-06 338.164-06
X	1.447 09 1.447 09 51.700 06 206.000 06 93.000 06	209.862 03 209.862 03 7.498 03 29.877 03 13.488 03	1.062 09 610.000 06 31.000 06 118.000 06 72.000 06	154.025 03 88.470 03 4.496 03 17.114 03 10.442 03
FXY	-500.000-03	-500.000-03	-500.000-03	-500.000-03
F	477.598-21 93.895-18 -3.348-18 115.620-18 0.000 00 14.488-09	22.706-12 4.464-09 -159.181-12 5.497-09 0.000 00 99.895-06	1.544-18 273.373-18 -10.271-18 192.901-18 -697.725-12 23.783-09	73.386-12 12.996-09 -488.303-12 9.171-09 -4.811-06 163.987-06
G	7.376 03 7.467 03 -1.746 03 5.828 03 39.173 00 130.575 00	7.376 03 7.467 03 -1.746 03 5.828 03 39.173 00 130.575 00	1.914 03 18.882 03 1.712 03 3.306 03 24.563 00 198.058 00	1.914 03 18.882 03 1.712 03 3.306 03 24.563 00 198.058 00
U'	8.653 06 9.413 06 2.067 06 2.459 06 3.097 06	59.660 09 64.899 09 14.252 09 16.956 09 21.352 09	2.966 06 2.232 06 482.872 03 799.304 03 1.083 06	20.450 09 15.388 09 3.329 09 5.511 09 7.469 09
H'	4.925-03	125.000-06	4.925-03	125.000-06

KEVLAR 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
434.783-12	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
9.580 06	54.744 03	75.824 09	10.997 06
693.300 03	3.962 03	75.824 09	10.997 06
235.722 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	58.013 03
235.000 06	34.083 03	400.000 06	58.013 03
12.000 06	1.740 03	400.000 06	58.013 03
53.000 06	7.687 03	400.000 06	58.013 03
34.000 06	4.931 03	230.000 06	33.358 03
FXY	FXY	FXY	FXY
-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
1.572-15	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	898.396-12
-2.541-09	-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}
$n, \theta_t \rightarrow E^o_i$	$N_i \rightarrow \epsilon_i$	$\theta_t \rightarrow R_t, R'_t$	$\sigma^o_t, \sigma^{o'}_t$	$\epsilon^o_i, \theta_t \rightarrow R_t$

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 $\boxed{\text{CLR}}$, read side 1, press $\boxed{\text{CLR}}$, read side 2.
3. No core: Enter n, the total number of plies, then press $\boxed{\text{A}}$. 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 $\boxed{A}$. 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:

E_1°
E_2°
ν_{21}°
E_6°

effective in-plane laminate moduli (Equation 4.18)

$$E_1^\circ = \frac{1}{a_{11}h} \text{ , etc.}$$

A_{11}
A_{22}
A_{12}
A_{66}
A_{16}
A_{26}

in-plane stiffness matrix (Table 4.3, Equation 4.31)

$$\begin{Bmatrix} N_1 \\ N_2 \\ N_6 \end{Bmatrix} = \begin{Bmatrix} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_3 h \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1^\circ \\ \varepsilon_2^\circ \\ \varepsilon_6^\circ \end{Bmatrix}$$

a_{11}
a_{22}
a_{12}
a_{66}
a_{16}
a_{26}

inversion of [A]:

$$\begin{Bmatrix} \varepsilon_1^\circ \\ \varepsilon_2^\circ \\ \varepsilon_6^\circ \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{16} \\ a_{12} & a_{22} & a_{26} \\ a_{16} & a_{26} & a_{66} \end{bmatrix} \begin{Bmatrix} N_1 \\ N_2 \\ N_6 \end{Bmatrix}$$

$$\begin{matrix} A^*_{11} \\ A^*_{22} \\ A^*_{12} \\ A^*_{66} \\ A^*_{16} \\ A^*_{26} \end{matrix} \left[\begin{array}{l} A_{ij}/h: \\ \begin{Bmatrix} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_6 h \end{Bmatrix} = \begin{Bmatrix} N_1 \\ N_2 \\ N_6 \end{Bmatrix} = \begin{bmatrix} & & \\ & A & \\ & & \end{bmatrix} \begin{Bmatrix} \varepsilon_1^o \\ \varepsilon_2^o \\ \varepsilon_6^o \end{Bmatrix} ; \begin{Bmatrix} \bar{\sigma}_1 \\ \bar{\sigma}_2 \\ \bar{\sigma}_6 \end{Bmatrix} = \begin{bmatrix} & & \\ & A^* & \\ & & \end{bmatrix} \begin{Bmatrix} \varepsilon_1^o \\ \varepsilon_2^o \\ \varepsilon_6^o \end{Bmatrix} \end{array} \right.$$

$$\begin{matrix} a^*_{11} \\ a^*_{22} \\ a^*_{12} \\ a^*_{66} \\ a^*_{16} \\ a^*_{26} \end{matrix} \left[\begin{array}{l} a_{ij} h: \\ \begin{Bmatrix} \varepsilon_1^o \\ \varepsilon_2^o \\ \varepsilon_6^o \end{Bmatrix} = \begin{bmatrix} & & \\ & a & \\ & & \end{bmatrix} \begin{Bmatrix} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_6 h \end{Bmatrix} ; \begin{Bmatrix} \varepsilon_1^o \\ \varepsilon_2^o \\ \varepsilon_6^o \end{Bmatrix} = \begin{bmatrix} & & \\ & a^* & \\ & & \end{bmatrix} \begin{Bmatrix} \bar{\sigma}_1 \\ \bar{\sigma}_2 \\ \bar{\sigma}_6 \end{Bmatrix} \end{array} \right.$$

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° 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:

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

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

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

Recall σ_t°, $\sigma_t^{\circ\prime}$ as desired. The two values of R (and hence two values of σ_t°) 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:

$$\left.\begin{aligned} I_\varepsilon &= 1/2\ (\varepsilon_1^\circ + \varepsilon_2^\circ) \\ R_\varepsilon &= [1/4\ (\varepsilon_1^\circ - \varepsilon_2^\circ)^2 + 1/4\ \varepsilon_6^2]^{1/2} \end{aligned}\right\} \text{Strain invariants (Equation 2.50) used to calculate on-axis ply strains}$$

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:

$$\left.\begin{matrix} R_t \\ R_t' \end{matrix}\right\} \text{strength ratios (Equation 7.48)}$$

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

$$\left.\begin{matrix} \sigma_t^\circ \\ \sigma_t^{\circ\prime} \end{matrix}\right\} \text{not used for case b.}$$

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
*	⋮	⋮	⋮
	$\Theta_{n/2 - 1}$		1
	$\Theta_{n/2}$	R/S,R/S,...	E_1°, E_2°, ν_{21}°, E_6°, 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 σ_t°,$\sigma_t^{\circ\prime}$	D	σ_t°
		R/S	$\sigma_t^{\circ\prime}$
		R/S	60
****			
6	Unit ply data	D'	E_x
		R/S,R/S,...	E_y,ν_x,E_s

Figure 11. Combo 2 Instruction Chart

STEP	PROCEDURE	PRESS	DISPLAY
*	For sandwich construction		when display = c
		A'	E°_1
		R/S,R/S,...	E°_2, ν°_{21}, E°_6, 6.1
**	Display A_{ij}, a_{ij}	B'	A_{11}
		R/S,R/S,...	A_{22}, A_{12}, A_{66}, A_{16}, A_{26}
			a_{11}, a_{22}, a_{12}, a_{66}, a_{16}, a_{26}
	Display A^*_{ij}, a^*_{ij}	C'	A^*_{11}
		R/S,R/S,...	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'	I_ε
		R/S	R_ε
		R/S	60
****	Calculate failure envelopes (strain-space)		
	Enter ε°_1	E	8.1
	ε°_2	R/S	8.2
	ε°_6	R/S	60
	Enter Θ	R/S	R
		R/S	R'
		R/S	60

Figure 12. Combo 2 Options

N_1, N_2, N_3 (N/m)	θ_t (deg)	σ°_t (GPa)	$\sigma^{\circ\prime}_t$ (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 $[0/90]_s$; $N_6 = 0$.

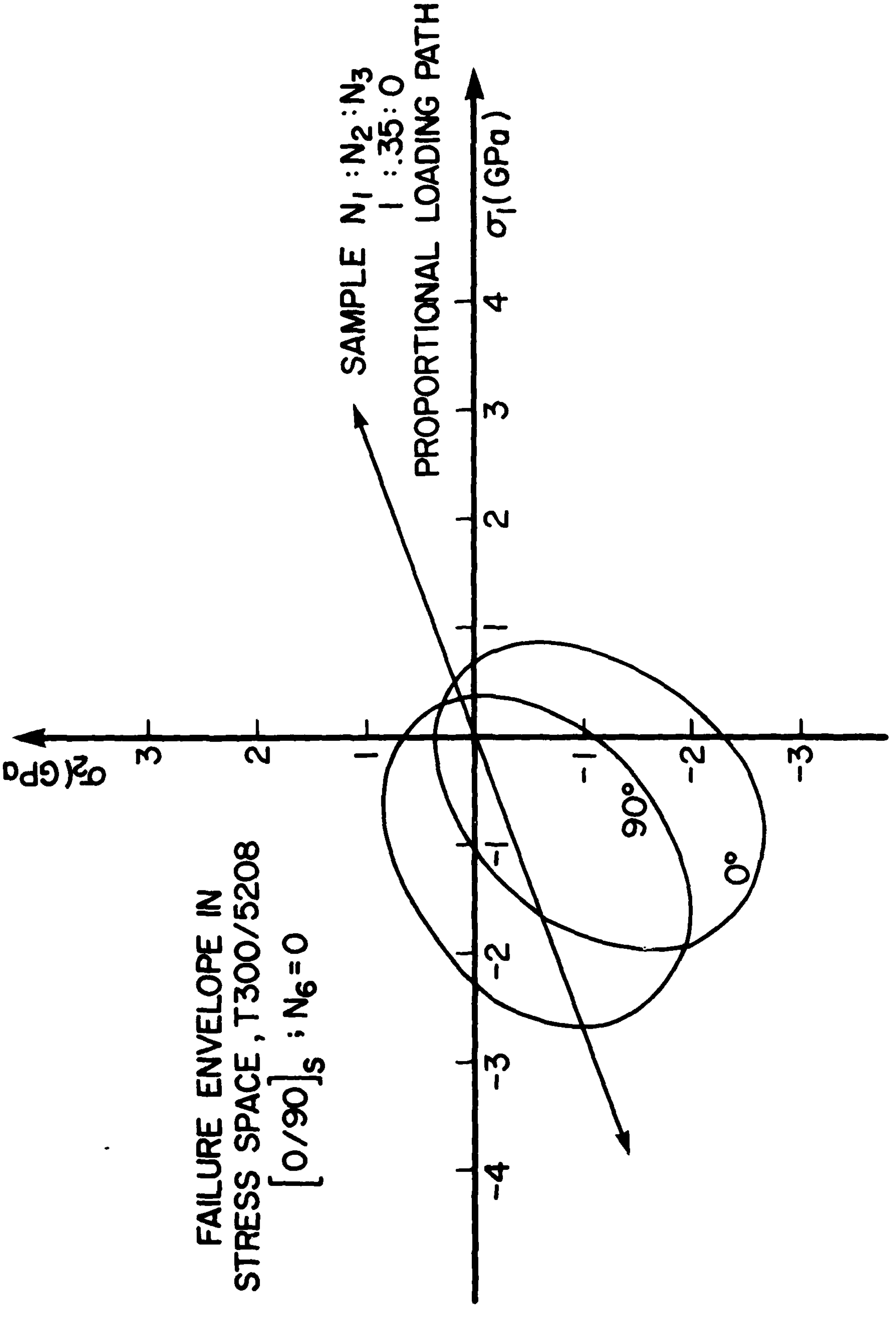

FAILURE ENVELOPE IN
STRESS SPACE, T300/5208
$[0/90]_S$; $N_6=0$
SAMPLE $N_1:N_2:N_3$
1 : .35 : 0
PROPORTIONAL LOADING PATH
σ_1(GPa)
σ_2(GPa)
90°
0°
4
3
2
1
-1
-2
-3
-4
3
2
1
-1
-2
-3

Figure 14

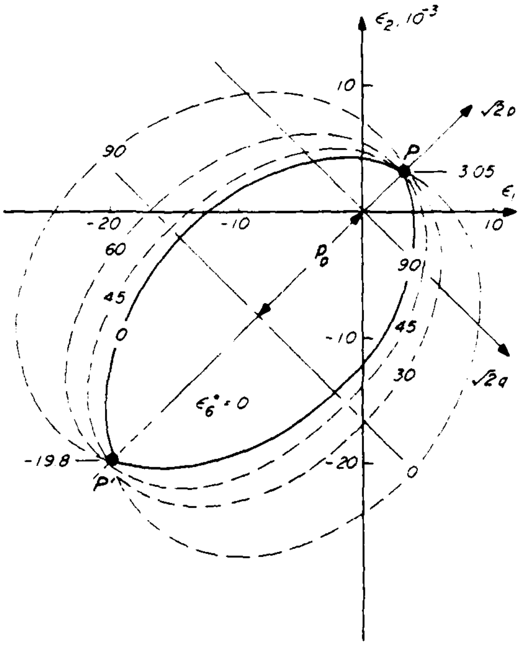
Note: The actual strains at failure for an input unit strain ($\varepsilon_i^\circ = 1$) are the two values of R_t: $\varepsilon_{i,fail}^\circ = R_t \varepsilon_{i,input}^\circ$

$$= R_t, R_t'$$

PROCEDURE	KEY	DISPLAY
Enter $\varepsilon_1^\circ = 1$	E	8.1
$\varepsilon_2^\circ = 0$	R/S	8.2
$\varepsilon_6^\circ = 0$	R/S	60
$\theta_t = 0$	R/S	$R_t = 6.94\text{x}10^{-3}$
	R/S	$R_t' = 11.97\text{x}10^{-3}$
	R/S	60
$\theta_t = 45$	R/S	$R_t = 4.74\text{x}10^{-3}$
	R/S	$R_t' = 13.83\text{x}10^{-3}$
	R/S	60
$\theta_t = 90$	R/S	$R_t = 3.88\text{x}10^{-3}$
	R/S	$R_t' = 24.16\text{x}10^{-3}$
	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
$\theta_t = 0$	R/S	$R_t = 9.19\text{x}10^{-3}$
	R/S	$R_t' = 3.78\text{x}10^{-3}$
	R/S	60
$\theta_t = 45$	R/S	$R_t = 4.74\text{x}10^{-3}$
	R/S	$R_t' = 4.74\text{x}10^{-3}$
	R/S	60
$\theta_t = 90$	R/S	$R_t = 3.78\text{x}10^{-3}$
	R/S	$R_t' = 9.19\text{x}10^{-3}$
	R/S	60

PROCEDURE	KEY	DISPLAY
Enter $\varepsilon_1^\circ = 0$	E	8.1
$\varepsilon_2^\circ = 1$	R/S	8.2
$\varepsilon_6^\circ = 0$	R/S	60
$\theta_t = 0$	R/S	$R_t = 3.88\text{x}10^{-3}$
	R/S	$R_t' = 24.16\text{x}10^{-3}$
	R/S	60
$\theta_t = 45$	R/S	$R_t = 4.74\text{x}10^{-3}$
	R/S	$R_t' = 13.83\text{x}10^{-3}$
	R/S	60
$\theta_t = 90$	R/S	$R_t = 6.94\text{x}10^{-3}$
	R/S	$R_t' = 11.97\text{x}10^{-3}$
	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_o	51	
07	R'_t	22	$\lvert A \rvert$	37	V_1	52	
08	1/h	23	ε°_1	38	V_3	53	p
09	h	24	ε°_2	39	V_2, $\sqrt{}$	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_o

Figure 16. Combo 2 Storage Memories

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

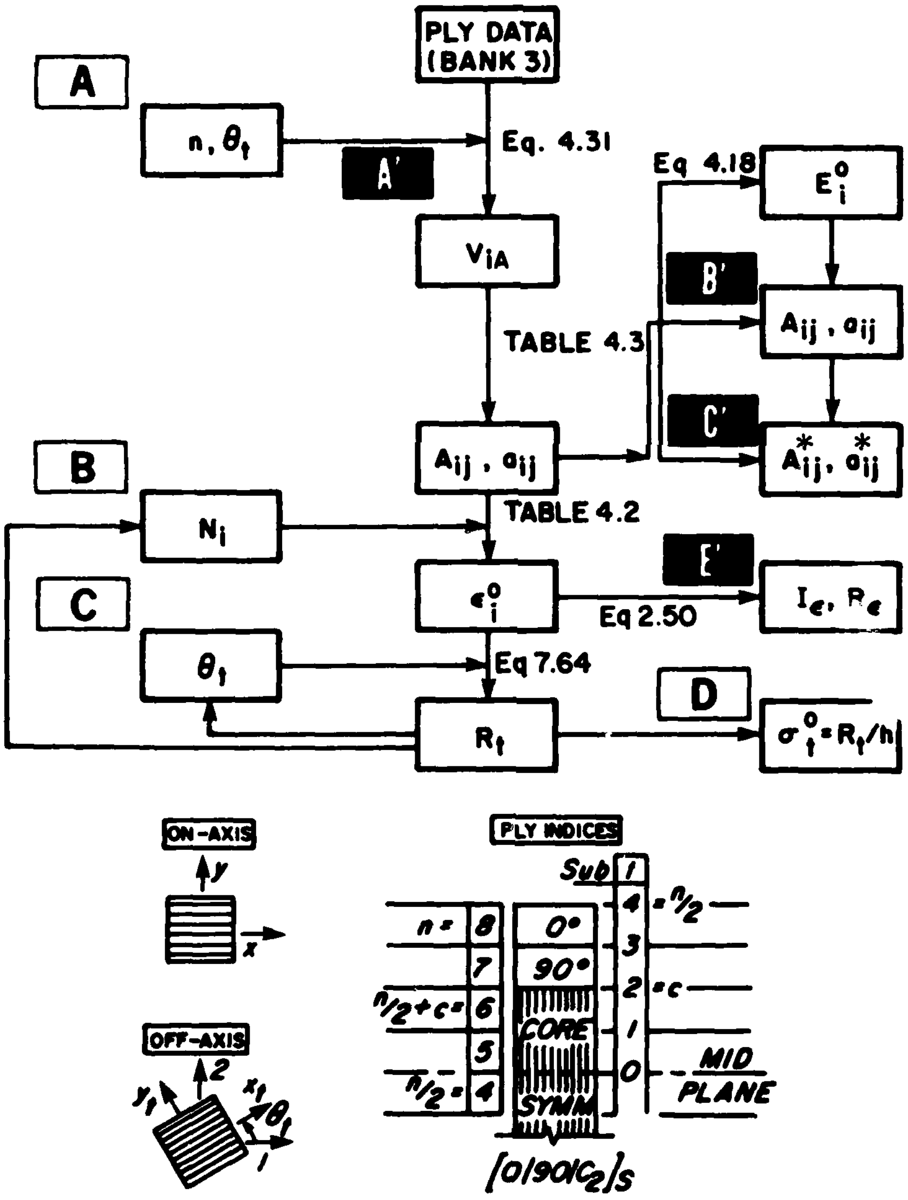


Figure 17. Combo 2 Flow Chart

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°	Pa
ν_{21}°	dimensionless
A_{ij}	N/m
a_{ij}	m/N
A^*_{ij}	Pa (N/m^2)
a^*_{ij}	1/Pa (m^2/N)
$I_\varepsilon, R_\varepsilon, R_t, R'_t$	dimensionless
$\sigma_t^\circ, \sigma_t^{\circ\prime}$	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 $\sigma_t^{\circ\prime}$ 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
ENTER n = 2	A	1
θ_1 = 0	R/S	E_1° = 181.000 E09
DISPLAY E_i°	R/S	10.300 E09
(optional)	R/S	280.000 E-3
	R/S	7.170 E09
DISPLAY A_{ij} (optional)	B' R/S " " " "	45.453 06 2.587 06 724.231 03 1.792 06 0.000 00 0.000 00
DISPLAY a_{ij} (optional)	R/S " " " " "	22.099-09 388.350-09 -6.188-09 557.880-09 0.000 00 0.000 00
DISPLAY A_{ij}^* (optional)	C' R/S " " " "	181.811 09 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

PROCEDURE	KEY	DISPLAY
ENTER N_1 = 1	B	6.2
N_2 = 0	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 0	C	R_t = 375.000 E03
DISPLAY R_t'	R/S	375.000 E03
σ°	D	1.500 E09
$\sigma^{\circ\prime}$	R/S	1.500 E09
ENTER N_1 = 375. E03	B	6.2
N_2 = 0	R/S	6.6
N_6 = 0	R/S	60
DISPLAY I_ε	E'	2.983 E-3
(optional) R_ε	R/S	5.304 E-3
ENTER θ_t = 0	C	R_t = 1.000 E00
DISPLAY R_t'	R/S	1.000 E00

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

LAMINATE: $[0_2]_T$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 2	A	1
θ_1 = 0	R/S	E_1° = 181.000 E09
PRINT E_i°	R/S	10.300 E09
(optional)	R/S	280.000 E-3
	R/S	7.170 E09
DISPLAY A_{ij}	B'	45.453 06
(optional)		2.587 06
	R/S	724.231 03
	"	1.792 06
	"	0.000 00
	"	0.000 00
	"	
DISPLAY a_{ij}	R/S	22.099-09
(optional)	"	388.350-09
	"	-6.188-09
	"	557.880-09
	"	0.000 00
	"	0.000 00
DISPLAY A_{ij}^*	C'	181.811 09
(optional)	R/S	10.346 09
	"	2.897 09
	"	7.170 09
	"	0.000 00
	"	0.000 00
DISPLAY a_{ij}^*	R/S	5.525-12
(optional)	"	97.087-12
	"	-1.547-12
	"	139.470-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER N_1 = 0	B	6.2
N_2 = 1	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 0	C	R_t = 10.000 E03
DISPLAY R_t'	R/S	61.500 E03
σ°	R/S	40.000 E06
$\sigma^{\circ\prime}$	R/S	246.000 E06
ENTER N_1 = 0	B	6.2
N_2 =		
10.0 E03	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 0	C	R_t = 1.000 E00
DISPLAY R_t'	R/S	6.150 E00

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

LAMINATE: $[0/90]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 4	A	2
θ_1 = 0	R/S	1
θ_2 = 90	R/S	E_1° = 95.991 E09
PRINT E_i°	R/S	95.991 E09
(optional)	R/S	30.152 E-3
	R/S	7.170 E09
DISPLAY A_{ij}	B'	48.039 06 48.039 06
(optional)	R/S	1.448 06
	"	3.585 06
	"	0.000 00
	"	0.000 00
	"	
DISPLAY a_{ij} (optional)	R/S " " " " "	20.835-09 20.835-09 -628.215-12 278.940-09 0.000 00 0.000 00
DISPLAY A_{ij}^* (optional)	C' R/S " " " "	96.079 09 96.079 09 2.897 09 7.170 09 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

PROCEDURE	KEY	DISPLAY
ENTER N_1 = 1	B	6.2
N_2 = 0	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 0	C	R_t = 340.941 E03
DISPLAY R_t'	R/S	553.853 E03
σ°	D	681.882 E06
$\sigma^\circ{}'$	R/S	1.108 E09
ENTER θ_t = 90	C	R_t = 186.698 E03
DISPLAY R_t'	R/S	1.134 E06
σ°	D	373.396 E06
$\sigma^\circ{}'$	R/S	2.269 E09

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

LAMINATE: $[45, -45]_s$ 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 $\theta_t = 45$	C	R_t = 61.614 E03
			DISPLAY R_t'	R/S	74.466 E03
			$\sigma°$	D	123.228 E06
ENTER n = 4	A	2	$\sigma°'$	R/S	148.932 E06
$\theta_1 = 45$	R/S	1			
$\theta_2 = -45$	R/S	$E_1°$ = 25.051 E09	ENTER $\theta_t = -45$	C	R_t = 61.614 E03
DISPLAY $E_i°$	R/S	25.051 E09	DISPLAY R_t'	R/S	74.466 E03
(optional)	R/S	746.902 E-3	$\sigma°$	D	123.228 E06
	R/S	46.591 E09	$\sigma°'$	R/S	148.932 E06
DISPLAY A_{ij} (optional)	B' R/S " " " "	28.329 06 28.329 06 21.159 06 23.295 06 0.000 00 0.000 00			
DISPLAY a_{ij} (optional)	R/S " " " " "	79.839-09 79.839-09 -59.632-09 42.927-09 0.000 00 0.000 00			
DISPLAY A_{ij}^* (optional)	C' R/S " " " "	56.658 09 56.658 09 42.318 09 46.591 09 0.000 00 0.000 00			
DISPLAY a_{ij}^* (optional)	R/S " " " " "	39.919-12 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
ENTER n = 8	A	4
$\theta_1 = 0$	R/S	3
$\theta_2 = 90$	"	2
$\theta_3 = 45$	"	1
$\theta_4 = 45$	"	E_1° = 69.676 E09
DISPLAY E_i°	"	69.676 E09
(optional)	"	296.031 E-3
	"	26.880 E09
DISPLAY A_{ij}	B'	76.368 06
(optional)	R/S	76.368 06
	"	22.607 06
	"	26.880 06
	"	0.000 00
	"	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'	76.368 09
(optional)	R/S	76.368 09
	"	22.607 09
	"	26.880 09
	"	0.000 00
	"	0.000 00
DISPLAY a_{ij}^*	R/S	14.352-12
(optional)	"	14.352-12
	"	-4.249-12
	"	37.202-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER $N_1 = 1$	B	6.2
$N_2 = 0$	R/S	6.6
$N_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	R_t = 581.811 E03
DISPLAY R_t'	R/S	565.417 E03
σ°	D	581.811 E06
$\sigma^{\circ\prime}$	R/S	565.417 E06
ENTER $\theta_t = 90$	C	R_t = 276.119 E03
DISPLAY R_t'	R/S	1.298 E06
σ°	D	276.119 E06
$\sigma^{\circ\prime}$	R/S	1.298 E09
ENTER $\theta_t = 45$	C	R_t = 346.996 E03
DISPLAY R_t'	R/S	675.075 E03
σ°	D	346.996 E06
$\sigma^{\circ\prime}$	R/S	675.075 E06
ENTER $\theta_t = -45$	C	R_t = 346.996 E03
DISPLAY R_t'	R/S	675.075 E03
σ°	D	346.996 E06
$\sigma^{\circ\prime}$	R/S	675.075 E06

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

LAMINATE: $[0/90/45/-45/C_4]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 16	A	8
$\theta_1 = 0$	R/S	7
$\theta_2 = 90$	"	6
$\theta_3 = 45$	"	5
$\theta_4 = -45$	"	4
	A'	$E_1^\circ = 34.838$ E09
DISPLAY E_i°	R/S	34.838 E09
	"	296.031 E-3
	"	13.440 E09
DISPLAY A_{ij}	B'	76.368 06
(optional)	R/S	76.368 06
	"	22.607 06
	"	26.880 06
	"	0.000 00
	"	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

PROCEDURE	KEY	DISPLAY
ENTER $N_1 = 1$	B	6.2
$N_2 = 0$	R/S	6.6
$N_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	$R_t = 581.811$ E03
DISPLAY R_t'	R/S	565.417 E03
σ°	D	290.906 E06
$\sigma^{\circ\prime}$	R/S	282.709 E06
ENTER $\theta_t = 90$	C	$R_t = 276.119$ E03
DISPLAY R_t'	R/S	1.298 E06
σ°	D	138.060 E06
$\sigma^{\circ\prime}$	R/S	648.792 E06
ENTER $\theta_t = 45$	C	$R_t = 346.996$ E03
DISPLAY R_t'	R/S	675.075 E03
σ°	R/S	173.498 E06
$\sigma^{\circ\prime}$	R/S	337.538 E06

SECTION VI

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

<table>
<tr><td colspan="5">AFWAL/MLBM CARD MODULE FOR TI-59</td></tr>
<tr><td colspan="5">COMBO 2P: IN-PLANE PROPERTIES w/PRINTER</td></tr>
<tr><td>Core</td><td></td><td></td><td></td><td></td></tr>
<tr><td>$n, \theta_t \rightarrow E^o_i$, A's</td><td>$N_i \rightarrow I_\epsilon, R_\epsilon$</td><td>$\theta_t, \rightarrow R_t, \sigma_t^o$</td><td></td><td></td></tr>
</table>

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^o_1, E^o_2, ν_{21}, E^o_6, 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_i, G_{ij}, and h_0 for the desired material and in the desired units stored in bank 3.
2. Press $\boxed{\text{CLR}}$, read side 1, press $\boxed{\text{CLR}}$, read side 2.
3. No Core: Enter n, the total number of plies, then press $\boxed{\text{A}}$. 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 $\boxed{\text{A}}$. 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°, E_2°, ν_{21}°, E_6°	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

σ_t°, $\sigma_t^{\circ\prime}$ 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*	$E_1^\circ, E_2^\circ, \nu_{21}^\circ, E_6^\circ$	
			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	$I_\varepsilon, R_\varepsilon$	60
4	Enter Θ_t	C	↑	Θ_t	
			R	R_t, R_t'	
			Σ	$\sigma_t^\circ, \sigma_t^{\circ\prime}$	60

Figure 18. Combo 2P Instruction Chart

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
*	For sandwich construction			when display = c	
		A'	CR	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_o	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, $\sqrt{\ }$	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_o

Figure 20. Combo 2P Storage Memories

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

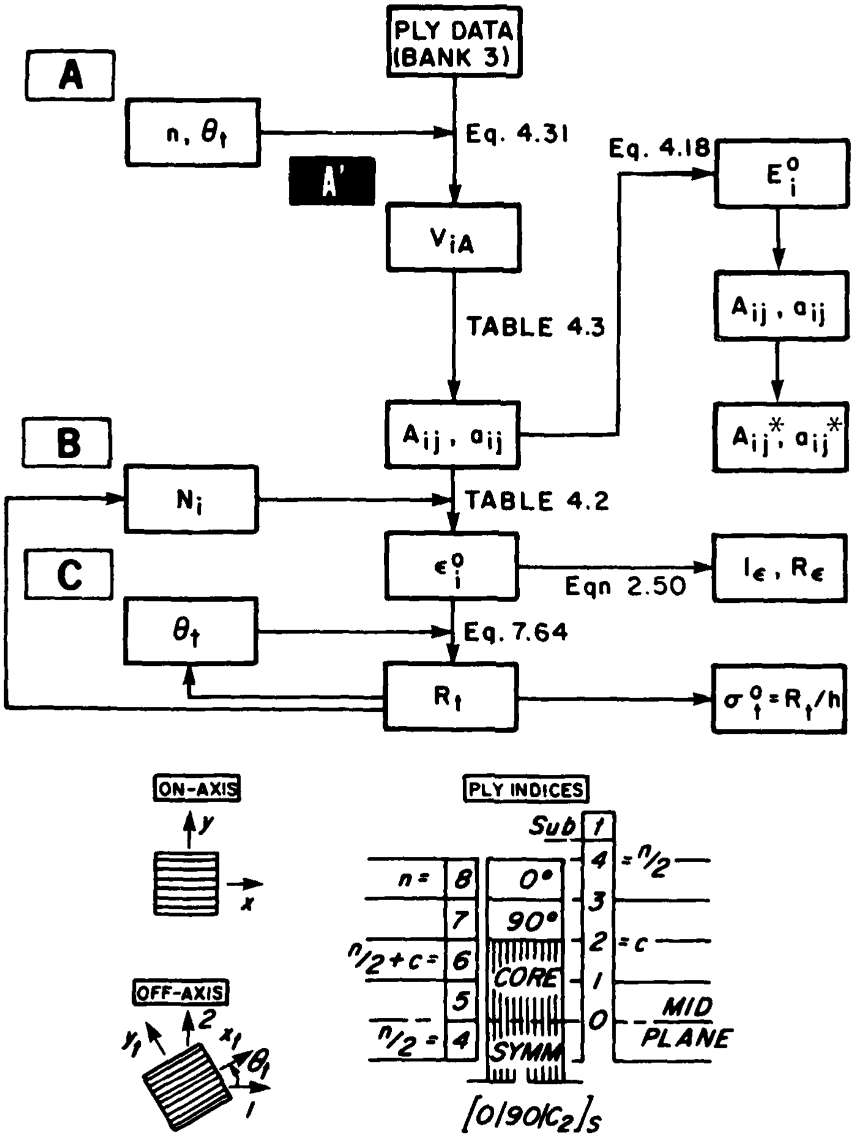


Figure 21. Combo 2P Flow Chart

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_i°	Pa
ν_{21}°	dimensionless
A_{ij}	N/m
a_{ij}	m/N
A_{ij}^*	Pa (N/m^2)
a_{ij}^*	1/Pa (m^2/N)
$I_\varepsilon, R_\varepsilon, R_t, R_t'$	dimensionless
$\sigma_t^\circ, \sigma_t^{\circ\prime}$	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 $\sigma^\circ_t = R_t/h$, or $R_t = \sigma^\circ_t h$ for the unit load case. But $N_i = \sigma^\circ_t h$, 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 $\sigma^{\circ\prime}_t$ 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
ENTER n	A	2.000 00
ENTER θ_1	R/S	0.000 00 SYM
PRINT E_i°		E+ 181.000 09 10.300 09 290.000-03 7.170 09
PRINT A_{ij}		A 45.453 06 2.587 06 724.231 03 1.792 06 0.000 00 0.000 00
PRINT a_{ij}		AI 22.095-09 388.350-09 -6.188-09 557.880-09 0.000 00 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 a^*_{ij}		A*I 5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER N_1 N_2 N_6	B R/S R/S	N 1.000 00 0.000 00 0.000 00
PRINT I_ε R_ε		εI 7.956-09 14.144-09
ENTER Θ_t	C	↑ 0.000 00
PRINT R_t R'_t		R 375.000 03 375.000 03
PRINT σ° $\sigma^{\circ\prime}$		Σ 1.500 09 1.500 09
		N 375.000 03 0.000 00 0.000 00
		εI 2.983-03 5.304-03
		↑ 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
ENTER n	A	1.000 00
ENTER θ_1	R/S	0.000 00 SYM
PRINT E_i°		E* 181.000 09 10.300 09 280.000-03 7.170 09
PRINT A_{ij}		A 45.453 06 2.587 06 724.231 03 1.792 06 0.000 00 0.000 00
PRINT a_{ij}		AI 22.099-09 388.350-09 -6.188-09 557.880-09 0.000 00 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 a_{ij}^*		A*I 5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER N_1 N_2 N_6	B R/S R/S	N 0.000 00 1.000 00 0.000 00
PRINT I_ε R_ε		eI 191.081-09 197.269-09
ENTER Θ_t	C	† 0.000 00
PRINT R_t R'_t		R 10.000 03 61.500 03
PRINT σ° $\sigma^{\circ\prime}$		Σ 40.000 06 246.000 06
		N 0.000 00 10.000 03 0.000 00
		eI 1.911-03 1.972-03
		† 0.000 00
		R 1.000 00 6.150 00
		Σ 4.000 03 24.600 03

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

LAMINATE: $[0/90]_s$ **MATERIAL:** T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	4. 00
ENTER θ_1 θ_2	R/S R/S	0.000 00 90.000 00 SYM
PRINT E_i°		E* 95.991 09 95.991 09 30.152-03 7.170 09
PRINT A_{ij}		A 48.039 06 48.039 06 1.448 06 3.585 06 0.000 00 0.000 00
PRINT a_{ij}		AI 20.835-09 20.835-09 -628.215-12 278.940-09 0.000 00 0.000 00
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

PROCEDURE	KEY	PRINT
ENTER N_1 N_2 N_6	B R/S R/S	N 1.000 00 0.000 00 0.000 00
PRINT I_ε R_ε		εI 10.104-09 10.732-09
ENTER Θ_t	C	↑ 0.000 00
PRINT R_t R_t'		R 340.941 03 553.853 03
PRINT σ° $\sigma^{\circ\prime}$		Σ 681.882 06 1.108 09
		↑ 90.000 00 R 186.698 03 1.134 06 Σ 373.396 06 2.269 09

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

LAMINATE: $[45/-45]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	4.000 00
ENTER θ_1	R/S	45.000 00
θ_2	R/S	-45.000 00 SYM
PRINT E_i°		E* 25.051 09 25.051 09 746.902-03 46.591 09
PRINT A_{ij}		A 28.329 06 28.329 06 21.159 06 23.295 06 0.000 00 0.000 00
PRINT a_{ij}		AI 79.839-09 79.839-09 -59.632-09 42.927-09 0.000 00 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

PROCEDURE	KEY	PRINT
ENTER N_1	B	N 1.000 00
N_2	R/S	0.000 00
N_6	R/S	0.000 00
PRINT I_ε		eI 10.104-09
R_ε		69.735-09
ENTER Θ_t	C	† 45.000 00
PRINT R_t		R 61.614 03
R'_t		74.466 03
PRINT σ°		Σ 123.228 06
$\sigma^{\circ\prime}$		148.932 06
		† -45.000 00
		R 61.614 03 74.466 03
		Σ 123.228 06 148.932 06

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

LAMINATE: $[0/90/45/-45]_s$ **MATERIAL:** T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	8. 00
ENTER θ_1 θ_2 θ_3 θ_4	R/S R/S R/S R/S	0.000 00 90.000 00 45.000 00 -45.000 00 SYM
PRINT E_i°		E* 69.676 09 69.676 09 296.031-03 26.880 09
PRINT A_{ij}		A 76.368 06 76.368 06 22.607 06 26.880 06 0.000 00 0.000 00
PRINT a_{ij}		AI 14.352-09 14.352-09 -4.249-09 37.202-09 0.000 00 0.000 00
PRINT A_{ij}^*		A* 76.368 09 76.368 09 22.607 09 26.880 09 0.000 00 0.000 00
PRINT a_{ij}^*		A*I 14.352-12 14.352-12 -4.249-12 37.202-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER N_1 N_2 N_6	B R/S R/S	N 1.000 00 0.000 00 0.000 00
PRINT I_ε R_ε		eI 5.052-09 9.300-09
ENTER Θ_t	C	↑ 0.000 00
PRINT R_t R_t'		R 581.811 03 565.417 03
PRINT σ° $\sigma^{\circ\prime}$		Σ 581.811 06 565.417 06
		↑ 90.000 00
		R 276.119 03 1.298 06
		Σ 276.119 06 1.298 09
		↑ 45.000 00
		R 346.996 03 675.075 03
		Σ 346.996 06 675.075 06

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

LAMINATE: $[0/90/45/-45/C_4]$ **MATERIAL:** T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	16.000 00
ENTER θ_1	R/S	0.000 00
θ_2	R/S	90.000 00
θ_3	R/S	45.000 00
θ_4	R/S	-45.000 00
	A'	CR
		4.000 00
		SYM
PRINT E_i°		E*
		34.838 09
		34.838 09
		296.031-03
		13.440 09
PRINT A_{ij}		A
		76.368 06
		76.368 06
		22.607 06
		26.880 06
		0.000 00
		0.000 00
PRINT a_{ij}		AI
		14.352-09
		14.352-09
		-4.249-09
		37.202-09
		0.000 00
		0.000 00
PRINT A^*_{ij}		A*
		38.184 09
		38.184 09
		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

PROCEDURE	KEY	PRINT
ENTER N_1	B	N
		1.000 00
N_2	R/S	0.000 00
N_6	R/S	0.000 00
PRINT I_ε		eI
		5.052-09
R_ε		9.300-09
ENTER Θ_t	C	↑
		0.000 00
PRINT R_t		R
		581.811 03
R'_t		565.417 03
PRINT σ°		Σ
		290.906 06
$\sigma^{\circ\prime}$		282.709 06
		↑
		90.000 00
		R
		276.119 03
		1.298 06
		Σ
		138.060 06
		648.792 06
		↑
		45.000 00
		R
		346.996 03
		675.075 03
		Σ
		173.498 06
		337.538 06

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 $\boxed{\text{CLR}}$, read side 1, press $\boxed{\text{CLR}}$, read side 2.
3. No core: Enter n, the total number of plies, then press $\boxed{\text{A}}$. Enter θ_1, R/S,..., $\theta_{n/2}$, 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 $\boxed{A}$. 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:

E_1^f
E_2^f
ν_{21}^f
E_6^f

effective flexural laminate moduli (Equations 5.21, 5.22, 5.23)

$$E_1^f = \frac{12}{h^3 d_{11}} \text{ , etc.}$$

D_{11}
D_{22}
D_{12}
D_{66}
D_{16}
D_{26}

flexural stiffness matrix (Table 5.3, Equation 5.40)

$$\begin{Bmatrix} M_1 \\ M_2 \\ M_6 \end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} k_1 \\ k_2 \\ k_6 \end{Bmatrix} \quad \text{where } \begin{aligned} \varepsilon_1^f(z) &= zk_1 \\ \varepsilon_2^f(z) &= zk_2 \\ \varepsilon_6^f(z) &= zk_6 \end{aligned}$$

d_{11}
d_{22}
d_{12}
d_{66}
d_{16}
d_{26}

inversion of [D]:

$$\begin{Bmatrix} k_1 \\ k_2 \\ k_6 \end{Bmatrix} = \begin{bmatrix} d_{11} & d_{12} & d_{16} \\ d_{12} & d_{22} & d_{26} \\ d_{16} & d_{26} & d_{66} \end{bmatrix} \begin{Bmatrix} M_1 \\ M_2 \\ M_6 \end{Bmatrix}$$

D^*_{11}
D^*_{22}
D^*_{12}
D^*_{66}
D^*_{16}
D^*_{26}

$D_{ij}/h^*; h^* = (1 - z_c)^3 h^3/12$ (Equations 5.30, 5.49):

$$\begin{Bmatrix} \sigma_1^f \\ \sigma_2^f \\ \sigma_6^f \end{Bmatrix} = \begin{bmatrix} & & \\ & D^* & \\ & & \end{bmatrix} \begin{Bmatrix} \varepsilon_1^f \\ \varepsilon_2^f \\ \varepsilon_6^f \end{Bmatrix}$$

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

d^*_{11}
d^*_{22}
d^*_{12}
d^*_{66}
d^*_{16}
d^*_{26}

$d_{ij} h^*$:

$$\begin{Bmatrix} \varepsilon_1^f \\ \varepsilon_2^f \\ \varepsilon_6^f \end{Bmatrix} = \begin{bmatrix} & & \\ & d^* & \\ & & \end{bmatrix} \begin{Bmatrix} \sigma_1^f \\ \sigma_2^f \\ \sigma_6^f \end{Bmatrix}$$

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:

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

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

$$\sigma^f_{i,allow} = R_t \sigma^f_{i,appl} = \frac{6}{h^2} R_t$$

If the applied moment at failure is desired:

$$M_{i,allow} = \frac{h^2}{6} \sigma^f_{i,allow}$$

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:

$$\left.\begin{matrix} R_t \\ R'_t \end{matrix}\right\} \text{strength ratios:}$$

$$M_{i,\text{allowable}} = R_t M_{i,\text{applied}}$$

$$\sigma^f_{i,\text{allowable}} = R_t \sigma^f_{i,\text{applied}}$$

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
	.	.	.
	.	.	.
	.	.	.
*	$\Theta_{n/2 - 1}$		1
	$\Theta_{n/2}$	R/S, R/S,...	E_1^f, E_2^f, ν_{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 σ^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		when display = c
		A'	E_1^f
		R/S, R/S,...	E_2^f, ν_{21}^f, E_6^f, 6.1
**	Display D_{ij}, d_{ij}	B'	D_{11}
		R/S, R/S,...	D_{22}, D_{12}, D_{66}, D_{16}, D_{26}
			d_{11}, d_{22}, d_{12}, d_{66}, d_{16}, d_{26}, 6.1
	Display D^*_{ij}, d^*_{ij}	C'	D^*_{11}
			D^*_{22}, D^*_{12}, D^*_{66}, D^*_{16}, D^*_{26}
		R/S, R/S,...	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_o	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, $\sqrt{}$	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)

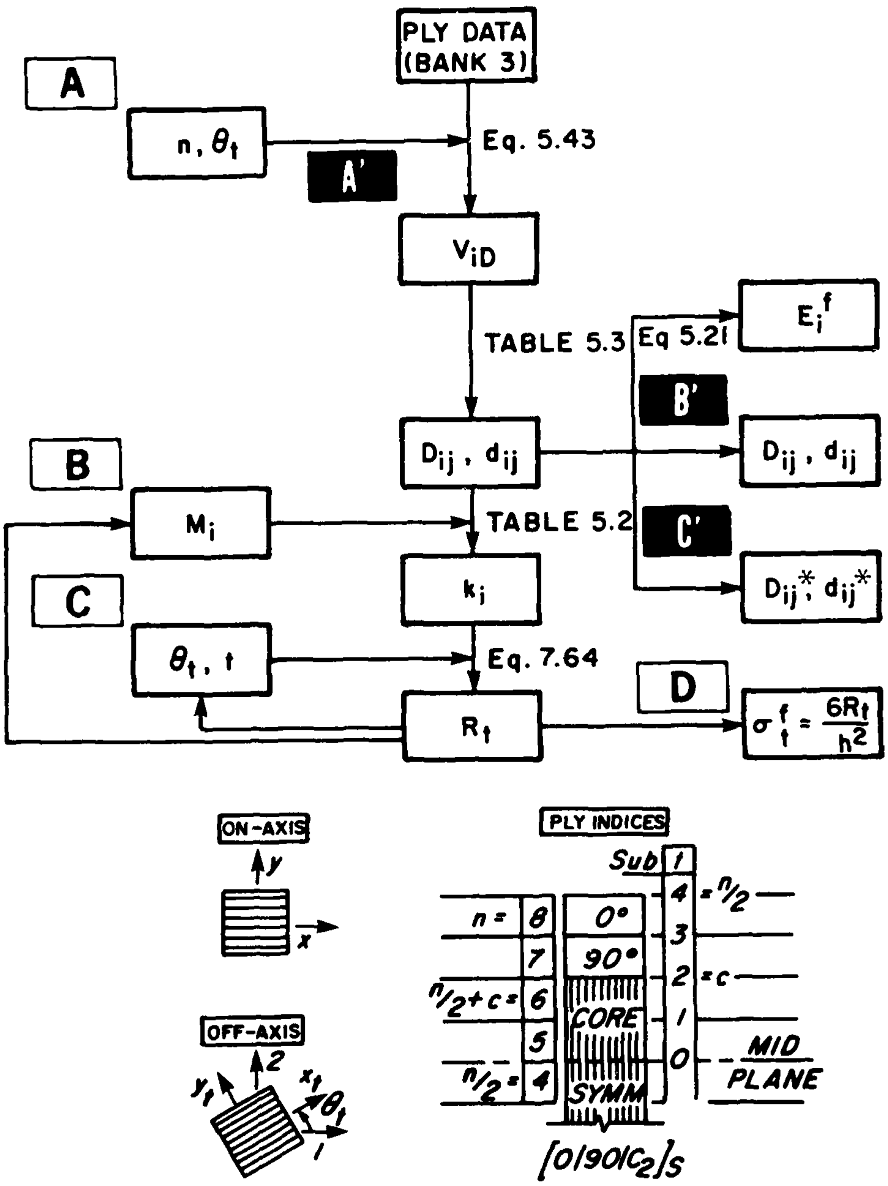


Figure 25. Combo 3 Flow Chart

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 permissable. 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., proveded 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
ENTER n = 2	A	1
θ_1 = 0	R/S	E_1^f = 181.000 E09
DISPLAY E_i^f	R/S	10.300 E09
	R/S	280.000 E-3
	R/S	7.170 E09
DISPLAY D_{ij} (optional)	B'	236.733-03
	R/S	13.472-03
	"	3.772-03
	"	9.336-03
	"	0.000 00
	"	0.000 00
DISPLAY d_{ij} (optional)	R/S	4.243 00
	"	74.563 00
	"	-1.188 00
	"	107.113 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

PROCEDURE	KEY	DISPLAY
ENTER M_1 = 1	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 1	R/S	R_t = 15.625 E00
DISPLAY R_t'	R/S	15.625 E00
σ^f	D	1.500 E09
$\sigma^{f'}$	R/S	1.500 E09
ENTER M_1 = 15.625 E00	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 1	R/S	R_t = 1.000 E00
DISPLAY R_t'	R/S	1.000 E00

COMBO 3 SAMPLE PROBLEM #2: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/C]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n =4	A	2
$\theta_1 = 0$	R/S	1
	A'	E_1^f = 158.375 E09
DISPLAY E_i^f	R/S	9.012 E09
(optional)	R/S	280.000 E-3
	R/S	6.274 E09
DISPLAY D_{ij} (optional)	B' R/S " " " "	1.657 00 94.301-03 26.404-03 65.352-03 0.000 00 0.000 00
DISPLAY d_{ij} (optional)	R/S " " " " "	606.156-03 10.652 00 -169.724-03 15.302 00 0.000 00 0.000 00
DISPLAY D^*_{ij} (optional)	C' R/S " " " "	159.085 09 9.053 09 2.535 09 6.274 09 0.000 00 0.000 00
DISPLAY d^*_{ij} (optional)	R/S " " " " "	6.314-12 110.957-12 -1.768-12 159.394-12 0.000 00 0.000 00

PROCEDURE	KEY	DISPLAY
ENTER $M_1 = 1$	B	6.2
$M_2 = 0$	R/S	6.6
$M_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	37
$t = 2$	R/S	R_t = 54.688 E00
DISPLAY R_t'	R/S	54.688 E00
σ^f	D	1.313 E09
$\sigma^{f'}$	R/S	1.313 E09
ENTER M_1 = 54.688 E00	B	6.2
$M_2 = 0$	R/S	6.6
$M_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	37
$t = 2$	R/S	R_t = 999.991 E-3
DISPLAY R_t'	R/S	999.991 E-3

COMBO 3 SAMPLE PROBLEM #3: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/C_{1.3}]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 4.6	A	2.3
θ_1 = 0	R/S	1.3
	A'	E_1^f = 148.317 E09
DISPLAY E_i^f	R/S	8.440 E09
(optional)	R/S	280.000 E-3
	R/S	5.875 E09
DISPLAY D_{ij}	B'	2.360 00
(optional)	R/S	134.311-03
	"	37.607-03
	"	93.079-03
	"	0.000 00
	"	0.000 00
DISPLAY d_{ij}	R/S	425.586-03
(optional)	"	7.479 00
	"	-119.164-03
	"	10.744 00
	"	0.000 00
	"	0.000 00
DISPLAY D_{ij}^*	C'	148.981 09
(optional)	R/S	8.478 09
	"	2.374 09
	"	5.875 09
	"	0.000 00
	"	0.000 00
DISPLAY d_{ij}^*	R/S	6.742-12
(optional)	"	118.482-12
	"	-1.888-12
	"	170.204-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER M_1 = 1	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 2.3	R/S	R_t = 67.731 E00
DISPLAY R'_t	R/S	67.731 E00
σ^f	D	1.229 E09
$\sigma^{f'}$	R/S	1.229 E09
ENTER M_1 =		
67.73 E00	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 2.3	R/S	R_t = 1.000 E00
DISPLAY R'_t	R/S	1.000 E00

COMBO 3 SAMPLE PROBLEM #4: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/90/45/-45/C_4]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
			ENTER $M_1 = 1$	B	6.2
			$M_2 = 0$	R/S	6.6
			$M_6 = 0$	R/S	60
ENTER n = 16	A	8	ENTER $\theta_t = 0$	C	37
$\theta_1 = 0$	R/S	7	t = 8	R/S	R_t = 404.279 E00
$\theta_2 = 90$	R/S	6	DISPLAY R_t'	R/S	456.532 E00
$\theta_3 = 45$	R/S	5	σ^f	D	606.419 E06
$\theta_4 = -45$	R/S	4	$\sigma^{f'}$	R/S	684.799 E06
	A'	E_1^f = 76.080 E09			
DISPLAY E_i^f	R/S	62.542 E09	ENTER $\theta_t = 90$	C	37
(optional)	R/S	213.704 E-3	t = 7	R/S	R_t = 228.559 E00
	R/S	17.830 E09	DISPLAY R_t'	R/S	1.160 E03
DISPLAY D_{ij} (optional)	B' R/S " " " "	52.932 00 43.555 00 9.492 00 11.985 00 1.674 00 1.674 00	σ^f $\sigma^{f'}$	D R/S	342.839 E06 1.740 E09
DISPLAY d_{ij} (optional)	R/S " " " " "	19.716-03 23.984-03 -4.213-03 84.129-03 -2.166-03 -2.762-03	ENTER $\theta_t = 45$ t = 6 DISPLAY R_t' σ^f $\sigma^{f'}$	C R/S R/S D R/S	37 R_t = 324.324 E00 743.545 E00 486.486 E06 1.115 E09
DISPLAY D_{ij}^* (optional)	C' R/S " " " "	79.398 09 65.333 09 14.238 09 17.977 09 2.512 09 2.512 09			
DISPLAY d_{ij}^* (optional)	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
ENTER n = 16	A	8
θ_1 = 0	R/S	7
.	.	.
.	.	.
.	.	.
θ_8 = -45	R/S	E_1^f = 113.287 E09
DISPLAY E_i^f	R/S	65.334 E09
(optional)	R/S	98.770 E-3
	R/S	11.747 E09
DISPLAY D_{ij} (optional)	B'	76.842 00
	R/S	44.693 00
	"	5.216 00
	"	8.065 00
	"	2.679 00
	"	2.679 00
DISPLAY d_{ij} (optional)	R/S	13.241-03
	"	22.959-03
	"	-1.308-03
	"	127.697-03
	"	-3.964-03
	"	-7.192-03
DISPLAY D_{ij}^* (optional)	C'	115.263 09
	R/S	67.039 09
	"	7.825 09
	"	12.098 09
	"	4.019 09
	"	4.019 09
DISPLAY d_{ij}^* (optional)	R/S	8.827-12
	"	15.306-12
	"	-871.852-15
	"	85.132-12
	"	-2.643-12
	"	-4.795-12
ENTER M_1 = 1	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 8	R/S	R_t = 545.875 E00
DISPLAY R_t'	R/S	762.093 E00
σ^f	D	818.812 E06
$\sigma^{f'}$	R/S	1.143 E09
ENTER θ_t = 90	C	37
t = 6	R/S	R_t = 389.456 E00
DISPLAY R_t'	R/S	2.100 E03
σ^f	D	584.185 E06
$\sigma^{f'}$	R/S	3.150 E09
ENTER θ_t = 45	C	37
t = 4	R/S	R_t = 671.467 E00
DISPLAY R_t'	R/S	1.970 E03
σ^f	D	1.007 E09
$\sigma^{f'}$	R/S	2.955 E09

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
ENTER n = 32	A	16
θ_1 = 0	R/S	15
.		
.		
.		
θ_8 = -45	R/S	8
	A'	E_1^f = 76.080 E09
DISPLAY E_1^f	R/S	62.542 E09
(optional)	R/S	213.704 E-3
	R/S	17.830 E09
DISPLAY D_{ij} (optional)	B'	423.459 00
	R/S	348.443 00
	"	75.935 00
	"	95.876 00
	"	13.396 00
	"	13.396 00
DISPLAY d_{ij} (optional)	R/S	2.465-03
	"	2.998-03
	"	-526.677-06
	"	10.516-03
	"	-270.752-06
	"	-345.284-06
DISPLAY D^*_{ij} (optional)	C'	79.398 09
	R/S	65.333 09
	"	14.238 09
	"	17.977 09
	"	2.512 09
	"	2.512 09
DISPLAY d^*_{ij} (optional)	R/S	13.144-12
	"	15.989-12
	"	-2.809-12
	"	56.086-12
	"	-1.444-12
	"	-1.842-12

PROCEDURE	KEY	DISPLAY
ENTER M_1 = 1	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 16	R/S	R_t = 1.617 E03
DISPLAY R_t'	R/S	1.826 E03
σ^f	D	606.419 E06
$\sigma^{f'}$	R/S	684.799 E06
ENTER θ_t = 90	C	37
t = 14		R_t = 914.237 E00
DISPLAY R_t'	R/S	4.639 E03
σ^f	D	342.839 E06
$\sigma^{f'}$	R/S	1.740 E09
ENTER θ_t = 45	C	37
t = 12	R/S	R_t = 1.297 E03
DISPLAY R_t'	R/S	2.974 E03
σ^f	D	486.486 E06
$\sigma^{f'}$	R/S	1.115 E09

SECTION VIII

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

<table>
<tr><th colspan="5">AFWAL/MLBM CARD MODULE FOR TI-59</th></tr>
<tr><th colspan="5">COMBO 3P: FLEXURAL PROPERTIES w/PRINTER</th></tr>
<tr><td>Core</td><td></td><td></td><td></td><td></td></tr>
<tr><td>$n,\theta_t \rightarrow E_i^f, D's$</td><td>$M_i \rightarrow k_i$</td><td>$\theta_t, t \rightarrow R_t, \sigma_t^f$</td><td></td><td></td></tr>
</table>

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_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. 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	↑, 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			when display = c	
		A'	CR	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_o	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, $\sqrt{}$	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

COMBO CARD #3P
FLEXURAL STIFFNESS & STRENGTH
(ON PRINTER)

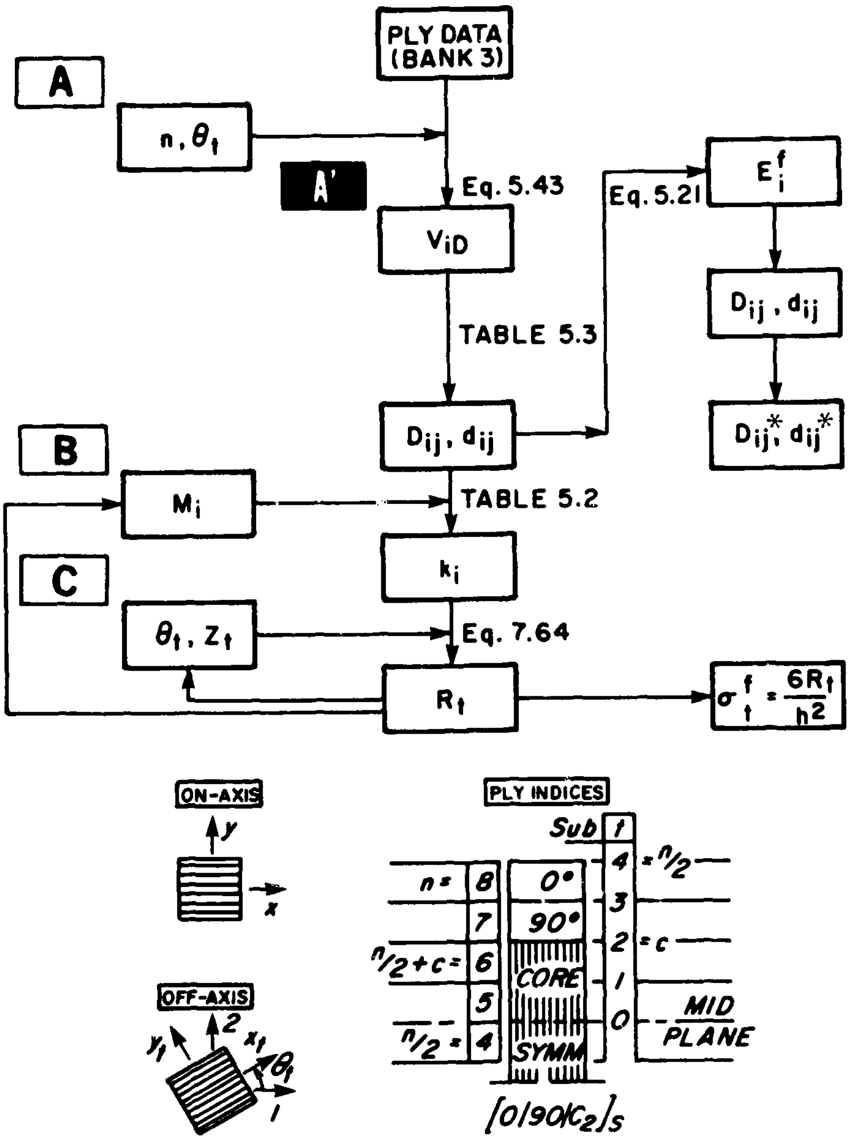


Figure 29. Combo 3P Flow Chart

AD-A117 869   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)
JUN 82   S L DONALDSON
UNCLASSIFIED   AFWAL-TR-82-4081   NL

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DTIC

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^f_t is calculated, then the failure moment $= h^2/6\ \sigma^f_t$ 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
ENTER n	A	2. 00
ENTER θ_1	R/S	0.000 00 SYM
PRINT E_i^f		E* 181.000 09 10.300 09 280.000-03 7.170 09
PRINT D_{ij}		D 236.733-03 13.472-03 3.772-03 9.336-03 0.000 00 0.000 00
PRINT d_{ij}		4.243 00 74.563 00 -1.188 00 107.113 00 0.000 00 0.000 00
PRINT D_{ij}^*		D* 181.811 09 10.346 09 2.897 09 7.170 09 0.000 00 0.000 00
PRINT d_{ij}^*		5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER M_1	B	M 1.000 00
M_2	R/S	0.000 00
M_6	R/S	0.000 00
ENTER Θ_t	C	↑, T 0.000 00
t	R/S	1.000 00
PRINT R_t		R 15.625 00
R_t'		15.625 00
PRINT σ^f		Σ 1.500 09
$\sigma^{f'}$		1.500 09
		M 15.625 00 0.000 00 0.000 00
		↑, 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
ENTER n	A	4. 00
ENTER θ_1	R/S A'	0.000 00 CR 1.000 00 SYM
PRINT E_j^f		E* 158.375 09 9.012 09 280.000-03 6.274 09
PRINT D_{ij}		D 1.657 00 94.301-03 26.404-03 65.352-03 0.000 00 0.000 00
PRINT d_{ij}		606.156-03 10.652 00 -169.724-03 15.302 00 0.000 00 0.000 00
PRINT D^*_{ij}		D* 159.085 09 9.053 09 2.535 09 6.274 09 0.000 00 0.000 00
PRINT d^*_{ij}		6.314-12 110.957-12 -1.768-12 159.394-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER M_1 M_2 M_6	B R/S R/S	M 1.000 00 0.000 00 0.000 00
ENTER Θ_t t	C R/S	↑, T 0.000 00 2.000 00
PRINT R_t R'_t		R 54.688 00 54.688 00
PRINT σ^f $\sigma^{f'}$		Σ 1.313 09 1.313 09
		M 54.688 00 0.000 00 0.000 00
		↑, 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
ENTER n	A	4.6 00
ENTER θ_1	R/S A'	0.000 00 CR 1.300 00 SYM
PRINT E_i^f		E* 148.317 09 8.440 09 280.000-03 5.875 09
PRINT D_{ij}		D 2.360 00 134.311-03 37.607-03 93.079-03 0.000 00 0.000 00
PRINT d_{ij}		425.586-03 7.479 00 -119.164-03 10.744 00 0.000 00 0.000 00
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

PROCEDURE	KEY	PRINT
ENTER M_1 M_2 M_6	B R/S R/S	M 1.000 00 0.000 00 0.000 00
ENTER Θ_t t	C R/S	†, T 0.000 00 2.300 00
PRINT R_t R_t'		R 67.731 00 67.731 00
PRINT σ^f $\sigma^{f'}$		Σ 1.229 09 1.229 09
		M 67.731 00 0.000 00 0.000 00
		†, T 0.000 00 2.300 00
		R 1.000 00 1.000 00
		Σ 18.147 06 18.147 06

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
ENTER n	A	16.000 00
ENTER θ_1	R/S	0.000 00
.	.	0.000 00
.	.	90.000 00
.	.	90.000 00
.	.	45.000 00
.	.	45.000 00
.	.	-45.000 00
θ_8	R/S	-45.000 00
		SYM
PRINT E_i^f		E* 113.287 09 65.334 09 98.770-03 11.747 09
PRINT D_{ij}		D 76.842 00 44.693 00 5.216 00 8.065 00 2.679 00 2.679 00
PRINT d_{ij}		13.241-03 22.959-03 -1.308-03 127.697-03 -3.964-03 -7.192-03
PRINT D_{ij}^*		D* 115.263 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

PROCEDURE	KEY	PRINT
ENTER M_1	B	
M_2	R/S	M 1.000 00 0.000 00
M_6	R/S	0.000 00
ENTER Θ_t	C	↑, T 0.000 00
t	R/S	8.000 00
PRINT R_t R_t'		R 545.875 00 762.093 00
PRINT σ^f $\sigma^{f'}$		Σ 818.812 06 1.143 09
		↑, T 90.000 00 6.000 00
		R 389.456 00 2.100 03
		Σ 584.185 06 3.150 09
		↑, T 45.000 00 4.000 00
		R 671.467 00 1.970 03
		Σ 1.007 09 2.955 09

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

LAMINATE: $[0/90/45/-45/C_4]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	16.000 00
ENTER θ_1 θ_2 θ_3 θ_4	R/S R/S R/S R/S A'	0.000 00 90.000 00 45.000 00 -45.000 00 CR 4.000 00 SYM
PRINT E_i^f		E* 76.080 09 62.542 09 213.704-03 17.830 09
PRINT D_{ij}		D 52.932 00 43.555 00 9.492 00 11.985 00 1.674 00 1.674 00
PRINT d_{ij}		19.716-03 23.984-03 -4.213-03 84.129-03 -2.166-03 -2.762-03
PRINT D_{ij}^*		D* 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 -‘.842-12

PROCEDURE	KEY	PRINT
ENTER M_1 M_2 M_6	B R/S R/S	M 1.000 00 0.000 00 0.000 00
ENTER Θ_t t	C R/S	↑, T 0.000 00 8.000 00
PRINT R_t R_t'		R 404.279 00 456.532 00
PRINT σ^f $\sigma^{f'}$		Σ 606.419 06 684.799 06
		↑, T 90.000 00 7.000 00 R 228.559 00 1.160 03 Σ 342.839 06 1.740 09 ↑, T 45.000 00 6.000 00 R 324.324 00 743.545 00 Σ 486.486 06 1.115 09

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
ENTER n	A	32.000 00
ENTER θ_1	R/S	0.000 00
.	.	0.000 00
.	.	90.000 00
.	.	90.000 00
.	.	45.000 00
.	.	45.000 00
.	.	-45.000 00
θ_8	R/S	-45.000 00
	A'	CR
		8.000 00
		SYM
PRINT E_i^f		E* 76.080 09 62.542 09 213.704-03 17.830 09
PRINT D_{ij}		D 423.459 00 348.443 00 75.935 00 95.876 00 13.396 00 13.396 00
PRINT d_{ij}		2.465-03 2.998-03 -526.677-06 10.516-03 -270.752-06 -345.284-06
PRINT D_{ij}^*		D* 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

PROCEDURE	KEY	PRINT
ENTER M_1 M_2 M_6	B R/S R/S	M 1.000 00 0.000 00 0.000 00
ENTER Θ_t t	C R/S	†, T 0.000 00 16.000 00
PRINT R_t R'_t		R 1.617 03 1.826 03
PRINT σ^f $\sigma^{f'}$		Σ 606.419 06 684.799 06
		†, T 90.000 00 14.000 00
		R 914.237 00 4.639 03
		Σ 342.839 06 1.740 09
		†, T 45.000 00 12.000 00
		R 1.297 03 2.974 03
		Σ 486.486 06 1.115 09

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 $[0/90/45/-45]_S$ 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:

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

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

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

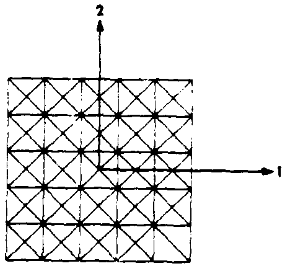


Figure A-1

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:

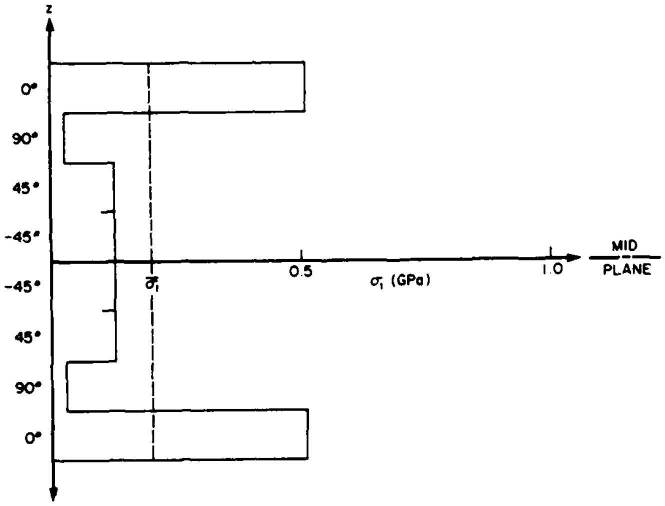


Figure A-2

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

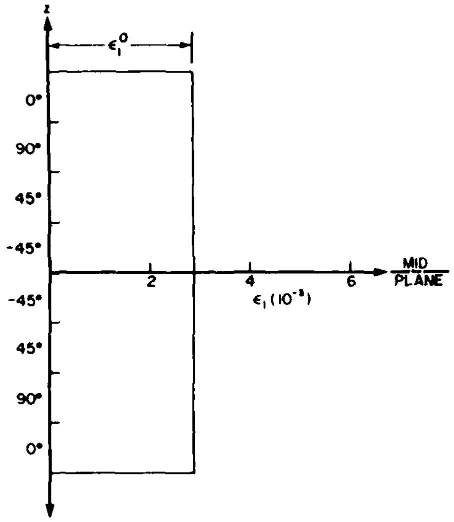


Figure A-3

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:

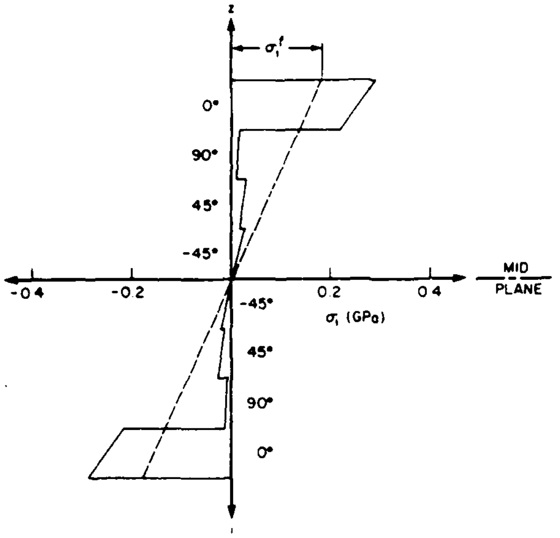


Figure A-4

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:

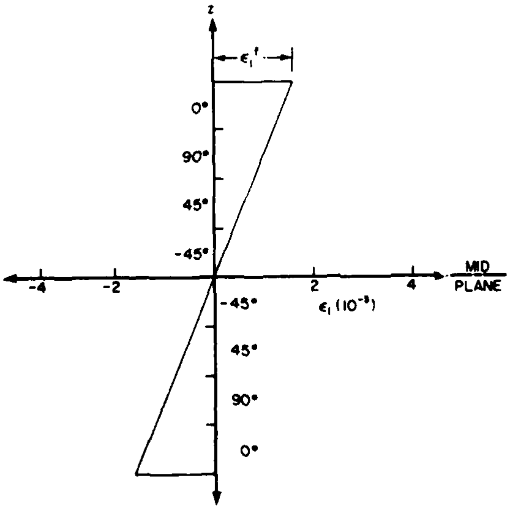


Figure A-5

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:

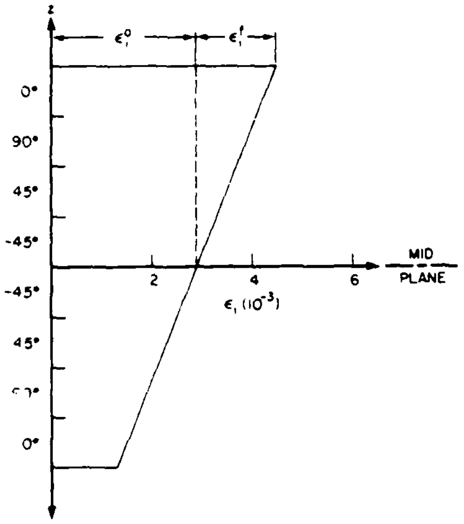


Figure A-6

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

$$\{\sigma_i\}_t = [Q]_t\{\varepsilon_i\}_t$$

$$= [Q]_t\{\varepsilon_i^o + \varepsilon_i^f\}_t$$

$$= [Q]_t\{\varepsilon_i^o\}_t + [Q]_t\{\varepsilon_i^f\}_t$$

$$= [Q]_t\{\varepsilon_i^o\}_t + z[Q]_t\{k_i\}_t$$

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

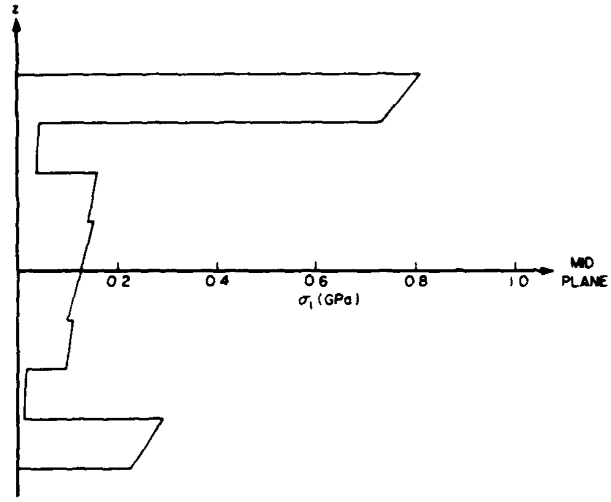
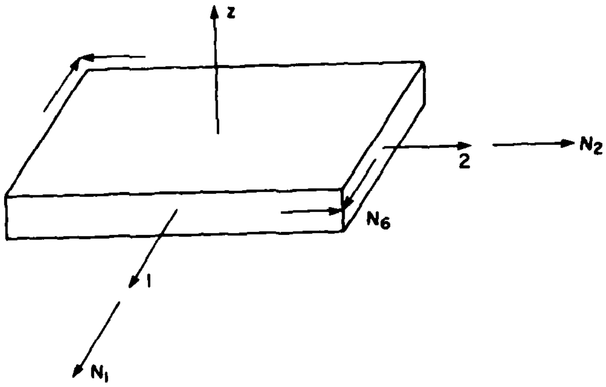
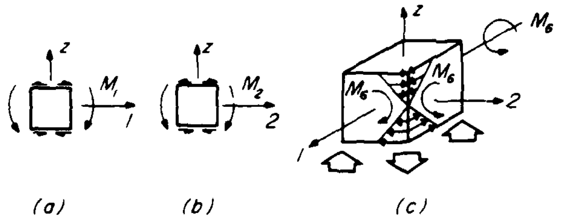


Figure A-7





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:
>
> $N_1 = 200 \times 10^3$ N/m
>
> $N_2 = 0$
>
> $N_6 = 0$
>
> $M_1 = 30$ 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° from registers 23, 24 and 25 by pressing $\boxed{\text{RCL}}$ $\boxed{2}$ $\boxed{3}$, etc (see Figure 16). This gives:

   $\varepsilon_1^\circ = 2.870 \times 10^{-3}$

   $\varepsilon_2^\circ = -849.7 \times 10^{-6}$

   $\varepsilon_6^\circ = 0$

   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:

$k_1 = 3.178$ 1/m

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

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

Using:

$\varepsilon_i = \varepsilon_i^o + zk_i$ (see Figure A-6).

$z = th_o$

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

$\theta_t = 0°$, $t = 4$ $\quad \varepsilon_1 = 4.459 \times 10^{-3}$

$\varepsilon_2 = -1.006 \times 10^{-3}$

$\varepsilon_6 = -475.7 \times 10^{-6}$

$\theta_t = 90°$, $t = 3$ $\quad \varepsilon_1 = 4.062 \times 10^{-3}$

$\varepsilon_2 = -967.4 \times 10^{-6}$

$\varepsilon_6 = -356.8 \times 10^{-6}$

$\theta_t = 45°$, $t = 2$ $\quad \varepsilon_1 = 3.665 \times 10^{-3}$

$\varepsilon_2 = -928.2 \times 10^{-6}$

$\varepsilon_6 = -237.9 \times 10^{-6}$

$\theta_t = -45°$, $t = 1$ $\quad \varepsilon_1 = 3.267 \times 10^{-3}$

$\varepsilon_2 = -888.9 \times 10^{-6}$

$\varepsilon_6 = -118.9 \times 10^{-6}$

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 $\boxed{E}$ 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 [illegible] * 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 [illegible]. 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 [illegible]. 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-
001  11   A   5208
002  47  CMS
003  57  ENG
004  01   1
005  08   8
006  01   1   Ex
007  52  EE
008  09   9
009  42  STO
010  25   25
011  01   1
012  00   0
013  03   3   Ey
014  52  EE
015  08   8
016  42  STO
017  26   26
018  07   7
019  01   1
020  07   7   Es
021  52  EE
022  07   7
023  42  STO
024  27   27
025  93   .
026  02   2   νx
027  08   8
028  42  STO
029  28   28
030  01   1
031  02   2
032  05   5
033  52  EE   ho
034  06   6
035  94  +/-
036  42  STO
037  59   59
038  71  SBR
039  35  1/X
040  36  PGM
041  08   08  X,...
042  10  E'
043  71  SBR
044  45  YX
045  76  LBL
046  35  1/X
047  36  PGM
048  01   01  Qij
049  71  SBR
050  57  ENG
051  36  PGM
052  01   01  Ui
053  71  SBR
054  52  EE
055  92  RTN
056  76  LBL
057  45  YX
058  36  PGM
059  08   08
060  71  SBR  Fij
061  98  ADV
062  36  PGM
063  08   08  Gij
064  71  SBR
065  80  GRD
066  43  RCL
067  16   16
068  42  STO
069  44   44
070  43  RCL
071  17   17
072  42  STO
073  45   45
074  43  RCL
075  18   18
076  42  STO
077  46   46
078  43  RCL
079  19   19
080  42  STO
081  47   47
082  43  RCL
083  20   20
084  42  STO
085  48   48
086  43  RCL
087  21   21
088  42  STO
089  49   49
090  91  R/S
091  76  LBL
092  13   C   AS-
093  47  CMS
094  57  ENG  3501
095  01   1
096  03   3
097  08   8
098  52  EE
099  09   9
100  42  STO
101  25   25
102  08   8
103  09   9
104  06   6
105  52  EE
106  07   7
107  42  STO
108  26   26
109  07   7
110  01   1
111  52  EE
112  08   8
113  42  STO
114  27   27
115  93   .
116  03   3
117  42  STO
118  28   28
119  01   1
120  02   2
121  05   5
122  52  EE
123  06   6
124  94  +/-
125  42  STO
126  59   59
127  71  SBR
128  35  1/X
129  01   1
130  04   4
131  04   4
132  07   7
133  52  EE
134  06   6
135  42  STO
136  23   23
137  42  STO
138  24   24
139  05   5
140  01   1
141  07   7
142  52  EE
143  05   5
144  42  STO
145  25   25
146  02   2
147  00   0
148  06   6
149  52  EE
150  06   6
151  42  STO
152  26   26
153  09   9
154  03   3
155  52  EE
156  06   6
157  42  STO
158  27   27
159  93   .
160  05   5
161  94  +/-
162  42  STO
163  28   28
164  71  SBR
165  45  YX
166  76  LBL
167  14   D   Scotch-
168  47  CMS  ply
169  57  ENG  1002
170  03   3
171  08   8
172  06   6
173  52  EE
174  08   8
175  42  STO
176  25   25
177  08   8
178  02   2
179  07   7
180  52  EE
181  07   7
182  42  STO
183  26   26
184  04   4
185  01   1
186  04   4
187  52  EE
188  07   7
189  42  STO
190  27   27
191  93   .
192  02   2
193  06   6
194  42  STO
195  28   28
196  01   1
197  02   2
198  05   5
199  52  EE
200  06   6
201  94  +/-
202  42  STO
203  59   59
204  71  SBR
205  35  1/X
206  01   1
207  00   0
208  06   6
209  02   2
210  52  EE
211  06   6
212  42  STO
213  23   23
214  06   6
215  01   1
216  52  EE
217  07   7
218  42  STO
219  24   24
220  03   3
221  01   1
222  52  EE
223  06   6
224  42  STO
225  25   25
226  01   1
227  01   1
228  08   8
229  52  EE
230  06   6
231  42  STO
232  26   26
233  07   7
234  02   2
235  52  EE
236  06   6
237  42  STO
238  27   27
239  93
```

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

```
300  06   6   SI →
301  08   8
302  09   9   Engl.
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   B(4)/
325  47  CMS     5505
326  57  ENG
327  02   2
328  00   0
329  04   4
330  52  EE
331  09   9
332  42  STO
333  25   25
334  01   1
335  08   8
336  93   .
337  05   5
338  52  EE
339  09   9
340  42  STO
341  26   26
342  93   .
343  02   2
344  03   3
345  42  STO
346  28   28
347  05   5
348  93   .
349  05   5
350  09   9
351  52  EE
352  09   9
353  42  STO
354  27   27
355  01   1
356  02   2
357  05   5
358  52  EE
359  06   6
```

```
360  94  +/-
361  42  STO
362  59   59
363  71  SBR
364  35  1/X
365  01   1
366  02   2
367  06   6
368  52  EE
369  07   7
370  42  STO
371  23   23
372  02   2
373  05   5
374  52  EE
375  08   8
376  42  STO
377  24   24
378  06   6
379  01   1
380  52  EE
381  06   6
382  42  STO
383  25   25
384  02   2
385  00   0
386  02   2
387  52  EE
388  06   6
389  42  STO
390  26   26
391  06   6
392  07   7
393  52  EE
394  06   6
395  42  STO
396  27   27
397  93   .
398  05   5
399  94  +/-
400  42  STO
401  28   28
402  71  SBR
403  45  YX
404  76  LBL
405  15   E   Kevlar
406  47  CMS  49 -
407  57  ENG
408  07   7   Epoxy
409  06   6
410  52  EE
411  09   9
412  42  STO
413  25   25
414  05   5
415  05   5
416  52  EE
417  08   8
418  42  STO
419  26   26
```

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

COMBO 1: User Input Ply Data without Printer

```
000   76  LBL
001   11   A
002   47  CMS
003   57  ENG
004   58  FIX
005   03   03
006   42  STO   Ex
007   25   25
008   04   4
009   95   =
010   91  R/S
011   42  STO   Ey
012   26   26
013   03   3
014   95   =
015   91  R/S
016   42  STO   νx
017   28   28
018   02   2
019   95   =
020   91  R/S
021   42  STO   Es
022   27   27
023   01   1
024   95   =
025   91  R/S
026   42  STO
027   59   59   ho
028   36  PGM
029   01   01   Qij
030   71  SBR
031   57  ENG
032   36  PGM
033   11   11   Sij
034   71  SBR
035   35  1/X
036   36  PGM
037   01   01   Ui
038   71  SBR
039   52  EE
040   01   1
041   93   .
042   01   1
043   95   =
044   91  R/S
045   76  LBL
046   16  A'
047   43  RCL
048   10   10
049   91  R/S
050   43  RCL
051   11   11
052   91  R/S
053   43  RCL
054   12   12
055   91  R/S
056   43  RCL
057   13   13
058   91  R/S
059   43  RCL
```

Display Qij and Sij

```
060   16   16
061   91  R/S
062   43  RCL
063   17   17
064   91  R/S
065   43  RCL
066   18   18
067   91  R/S
068   43  RCL
069   19   19
070   91  R/S
071   01   1
072   93   .
073   02   2
074   95   =
075   91  R/S
076   76  LBL
077   17  B'
078   43  RCL
079   30   30
080   91  R/S
081   43  RCL
082   31   31
083   91  R/S
084   43  RCL
085   32   32
086   91  R/S
087   43  RCL
088   33   33
089   91  R/S
090   43  RCL
091   34   34
092   91  R/S
093   01   1
094   93   .
095   03   3
096   95   =
097   91  R/S
098   76  LBL
099   18  C'
100   43  RCL
101   10   10
102   65   ×
103   43  RCL
104   59   59
105   95   =
106   91  R/S
107   43  RCL
108   11   11
109   65   ×
110   43  RCL
111   59   59
112   95   =
113   91  R/S
114   43  RCL
115   12   12
116   65   ×
117   43  RCL
118   59   59
119   95   =
```

Display Ui

Calculate and Display Aij and aij

```
120   91  R/S
121   43  RCL
122   13   13
123   65   ×
124   43  RCL
125   59   59
126   95   =
127   91  R/S
128   43  RCL
129   16   16
130   55   ÷
131   43  RCL
132   59   59
133   95   =
134   91  R/S
135   43  RCL
136   17   17
137   55   ÷
138   43  RCL
139   59   59
140   95   =
141   91  R/S
142   43  RCL
143   18   18
144   55   ÷
145   43  RCL
146   59   59
147   95   =
148   91  R/S
149   43  RCL
150   19   19
151   55   ÷
152   43  RCL
153   59   59
154   95   =
155   91  R/S
156   01   1
157   93   .
158   04   4
159   95   =
160   91  R/S
161   76  LBL
162   12   B
163   57  ENG
164   58  FIX
165   03   03
166   42  STO   X
167   23   23
168   05   5
169   95   =
170   91  R/S
171   42  STO   X'
172   24   24
173   04   4
174   95   =
175   91  R/S
176   42  STO   Y
177   25   25
178   03   3
179   95   =
```

```
180   91  R/S
181   42  STO   Y'
182   26   26
183   02   2
184   95   =
185   91  R/S
186   42  STO   S
187   27   27
188   01   1
189   95   =
190   91  R/S
191   42  STO   Fxy*
192   28   28
193   36  PGM
194   08   08   Fij
195   71  SBR
196   98  ADV
197   36  PGM
198   08   08   Gij
199   71  SBR
200   80  GRD
201   43  RCL
202   44   44
203   42  STO
204   51   51
205   43  RCL
206   45   45
207   42  STO
208   52   52
209   43  RCL
210   46   46
211   42  STO
212   53   53
213   43  RCL
214   47   47
215   42  STO
216   54   54
217   43  RCL
218   48   48
219   42  STO
220   55   55
221   43  RCL
222   49   49
223   42  STO
224   56   56
225   43  RCL
226   16   16
227   42  STO
228   44   44
229   43  RCL
230   17   17
231   42  STO
232   45   45
233   43  RCL
234   18   18
235   42  STO
236   46   46
237   43  RCL
238   19   19
239   42  STO
```

Transfer Fij and Gij

```
240   47   47
241   43  RCL
242   20   20
243   42  STO
244   48   48
245   43  RCL
246   21   21
247   42  STO
248   49   49
249   01    1
250   93    .
251   05    5
252   95    =
253   91  R/S
```

Display Fij

```
254   76  LBL
255   19  D'
256   43  RCL
257   51   51
258   91  R/S
259   43  RCL
260   52   52
261   91  R/S
262   43  RCL
263   53   53
264   91  R/S
265   43  RCL
266   54   54
267   91  R/S
268   43  RCL
269   55   55
270   91  R/S
271   43  RCL
272   56   56
273   91  R/S
274   01    1
275   93    .
276   06    6
277   95    =
278   91  R/S
```

Display Gij

```
279   76  LBL
280   10  E'
281   43  RCL
282   44   44
283   91  R/S
284   43  RCL
285   45   45
286   91  R/S
287   43  RCL
288   46   46
289   91  R/S
290   43  RCL
291   47   47
292   91  R/S
293   43  RCL
294   48   48
295   91  R/S
296   43  RCL
297   49   49
298   91  R/S
299   01    1
```

```
300   93    .
301   07    7
302   95    =
303   91  R/S
```

SI→
Engl.

```
304   76  LBL
305   13    C
306   06    6
307   08    8
308   09    9
309   05    5
310   35  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
```

Engl→
SI

```
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   35  1/X
354   49  PRD
355   59   59
356   43  RCL
357   59   59
358   95    =
359   91  R/S
```

COMBO 1P: User Input Ply Data with Printer

```
000  76 LBL
001  11  A
002  47 CMS
003  42 STO     Ex
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 STO
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 STO     Ey
025  26  26
026  99 PRT
027  03  3
028  95  =
029  91 R/S
030  42 STO     νx
031  28  28
032  99 PRT
033  02  2
034  95  =
035  91 R/S
036  42 STO     Es
037  27  27
038  99 PRT
039  98 ADV
040  01  1
041  95  =
042  91 R/S
043  42 STO     ho
044  59  59
045  02  2
046  03  3
047  00  0
048  00  0
049  42 STO
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     Qij
062  57 ENG
063  03  3
064  04  4
065  00  0
066  00  0
067  42 STO
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     Print Qij
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     Sij
088  71 SBR
089  35 1/X
090  03  3
091  06  6
092  00  0
093  00  0
094  42 STO
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     Print Sij
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     Ui
115  71 SBR
116  52 EE
117  04  4
118  01  1
119  00  0   111

120  00  0
121  42 STO
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     Print Ui
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 STO
148  02  02
149  36 PGM
150  11  11
151  71 SBR
152  90 LST
153  43 RCL
154  10  10
155  65  ×
156  43 RCL
157  59  59
158  95  =
159  99 PRT
160  43 RCL
161  11  11
162  65  ×
163  43 RCL     Calculate and Print Aij
164  59  59
165  95  =
166  99 PRT
167  43 RCL
168  12  12
169  65  ×
170  43 RCL
171  59  59
172  95  =
173  99 PRT
174  43 RCL
175  13  13
176  65  ×
177  43 RCL
178  59  59
179  95  =

180  99 PRT
181  98 ADV
182  01  1
183  03  3
184  03  3
185  04  4
186  42 STO
187  02  02
188  36 PGM
189  11  11
190  71 SBR
191  90 LST
192  43 RCL
193  16  16
194  55  ÷
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     Calculate and Print aij
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  76 LBL     X
227  12  B
228  42 STO
229  23  23
230  57 ENG
231  58 FIX
232  03  03
233  04  4
234  04  4
235  00  0
236  00  0
237  42 STO
238  02  02
239  36 PGM
```

```
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  X'
250  24   24
251  99  PRT
252  04    4
253  95    =
254  91  R/S
255  42  STO  Y
256  25   25
257  99  PRT
258  03    3
259  95    =
260  91  R/S
261  42  STO  Y'
262  26   26
263  99  PRT
264  02    2
265  95    =
266  91  R/S
267  42  STO  S
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  Fxy*
287  28   28
288  99  PRT
289  98  ADV
-------------
290  36  PGM
291  08   08  Fij
292  71  SBR
293  98  ADV
-------------
294  02    2
295  01    1
296  00    0
297  00    0
298  42  STO
299  02   02
```

```
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  Gij
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 Fij

Print and Transfer Gij

```
360  42  STO
361  48   48
362  43  RCL
363  21   21
364  99  PRT
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    C
377  06    6  SI→
378  08    8  Engl.
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   X²
-------------
401  76  LBL
402  14    D
403  06    6  Engl→
404  08    8
405  09    9  SI
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
```

```
420  93    .
421  04    4
422  35  1/X
423  49  PRD
424  59   59
-------------
425  71  SBR
426  33   X²
427  04    4
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  59   59
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 h_o

COMBO 2: In-Plane Stiffness and Strength without Printer

```
000  76  LBL
001  11   A
002  42  STO   n
003  05   05
004  65   ×
005  43  RCL
006  59   59
007  95   =
008  42  STO   h
009  09   09
010  57  ENG
011  58  FIX
012  03   03
013  00   0
014  36  PGM   V_iA =
015  12   12   0
016  71  SBR
017  61  GTO
018  93   .
019  05   5
020  49  PRD   N/2
021  05   05
022  43  RCL   t
023  05   05
024  91  R/S
025  94  +/-
026  42  STO   θ_t
027  35   35
028  01   1
029  42  STO
030  04   04
031  44  SUM
032  36   36
033  36  PGM   ΣV_iA
034  12   12
035  71  SBR
036  71  SBR
037  97  DSZ
038  05   05
039  00   00
040  22   22
041  76  LBL
042  16   A'
043  43  RCL   z
044  59   59
045  65   ×
046  02   2
047  95   =
048  36  PGM
049  12   12   V_iA
050  71  SBR
051  61  GTO
052  36  PGM
053  11   11   A_ij
054  71  SBR
055  23  LNX
056  36  PGM
057  11   11
058  71  SBR   a_ij
059  35  1/X
```

```
060  43  RCL
061  09   09
062  35  1/X
063  42  STO
064  08   08
065  55   ÷
066  43  RCL
067  16   16
068  95   =    E_1^0
069  91  R/S
070  43  RCL
071  08   08
072  55   ÷
073  43  RCL
074  17   17
075  95   =    E_2^0
076  91  R/S
077  43  RCL
078  18   18
079  55   ÷
080  43  RCL
081  16   16
082  95   =
083  94  +/-   ν_21^0
084  91  R/S
085  43  RCL
086  08   08
087  55   ÷
088  43  RCL
089  19   19
090  95   =    E_6^0
091  91  R/S
092  71  SBR
093  52  EE
094  76  LBL
095  17   B'
096  43  RCL
097  10   10
098  91  R/S
099  43  RCL
100  11   11
101  91  R/S
102  43  RCL
103  12   12
104  91  R/S
105  43  RCL
106  13   13   Display A_ij
107  91  R/S
108  43  RCL
109  14   14
110  91  R/S
111  43  RCL
112  15   15
113  91  R/S
114  43  RCL
115  16   16
116  91  R/S
117  43  RCL
118  17   17
119  91  R/S
```

```
120  43  RCL
121  18   18
122  91  R/S
123  43  RCL
124  19   19
125  91  R/S
126  43  RCL   Display a_ij
127  20   20
128  91  R/S
129  43  RCL
130  21   21
131  91  R/S
132  71  SBR
133  52  EE
134  76  LBL
135  18   C'
136  43  RCL
137  10   10
138  55   ÷
139  43  RCL
140  09   09
141  95   =
142  91  R/S
143  43  RCL
144  11   11
145  55   ÷
146  43  RCL
147  09   09
148  95   =
149  91  R/S
150  43  RCL
151  12   12
152  55   ÷
153  43  RCL
154  09   09
155  95   =
156  91  R/S
157  43  RCL
158  13   13
159  55   ÷
160  43  RCL
161  09   09
162  95   =
163  91  R/S
164  43  RCL
165  14   14
166  55   ÷
167  43  RCL   Display A*_ij
168  09   09
169  95   =
170  91  R/S
171  43  RCL
172  15   15
173  55   ÷
174  43  RCL
175  09   09
176  95   =
177  91  R/S
178  43  RCL
179  16   16
```

```
180  65   ×
181  43  RCL
182  09   09
183  95   =
184  91  R/S
185  43  RCL
186  17   17
187  65   ×
188  43  RCL
189  09   09
190  95   =
191  91  R/S
192  43  RCL
193  18   18
194  65   ×
195  43  RCL
196  09   09
197  95   =
198  91  R/S
199  43  RCL
200  19   19
201  65   ×
202  43  RCL
203  09   09
204  95   =
205  91  R/S
206  43  RCL
207  20   20
208  65   ×
209  43  RCL
210  09   09
211  95   =
212  91  R/S
213  43  RCL   Display a*_ij
214  21   21
215  65   ×
216  43  RCL
217  09   09
218  95   =
219  91  R/S
220  76  LBL
221  52  EE
222  06   6
223  93   .
224  01   1
225  95   =
226  91  R/S
227  76  LBL
228  12   B
229  42  STO   N_1
230  26   26
231  06   6
232  93   .
233  02   2
234  95   =
235  91  R/S
236  42  STO   N_2
237  27   27
238  06   6
239  93   .
```

```
240   06   6
241   95   =
242   91  R/S
243   42  STO   Nb
244   28   28
245   36  PGM
246   11   11
247   71  SBR   aij
248   35  1/X
249   36  PGM
250   10   10   εi°
251   71  SBR
252   89   π
253   76  LBL
254   33  X²
255   36  PGM
256   10   10
257   71  SBR   p,q,r
258   34  ΓX
259   43  RCL
260   44   44
261   42  STO
262   16   16
263   43  RCL
264   45   45
265   42  STO
266   17   17
267   43  RCL
268   46   46
269   42  STO
270   18   18
271   43  RCL
272   47   47
273   42  STO   Transfer Gij
274   19   19
275   43  RCL
276   48   48
277   42  STO
278   20   20
279   43  RCL
280   49   49
281   42  STO
282   21   21
283   71  SBR
284   24  CE
285   76  LBL
286   10  E'
287   43  RCL
288   53   53   Ia
289   91  R/S
290   43  RCL
291   54   54
292   33  X²
293   85   +
294   43  RCL
295   55   55
296   33  X²
297   95   =
298   34  ΓX   Ra
299   91  R/S
```

```
300   76  LBL
301   24  CE    θ
302   06   6    prompter
303   00   0
304   95   =
305   91  R/S
306   76  LBL
307   13   C    θt
308   42  STO
309   41   41
310   36  PGM
311   10   10   εi(R)
312   71  SBR
313   54   )
314   00   0
315   42  STO
316   26   26
317   42  STO   εi''=0
318   27   27
319   42  STO
320   28   28
321   36  PGM   Rt
322   08   08
323   71  SBR   Rt'
324   30  TAN
325   43  RCL
326   06   06
327   91  R/S   Display Rt', Rt''
328   43  RCL
329   07   07
330   91  R/S
331   71  SBR
332   24  CE
333   76  LBL
334   14   D
335   43  RCL
336   06   06
337   55   ÷
338   43  RCL
339   09   09
340   95   =    σt°
341   91  R/S
342   43  RCL
343   07   07
344   55   ÷
345   43  RCL
346   09   09
347   95   =    σt°'
348   91  R/S
349   71  SBR
350   24  CE
351   76  LBL
352   15   E
353   42  STO   εi°
354   23   23
355   08   8
356   93   .
357   01   1
358   95   =
359   91  R/S
```

```
360   42  STO   ε2°
361   24   24
362   08   8
363   93   .
364   02   2
365   95   =
366   91  R/S
367   42  STO   εi°
368   25   25
369   71  SBR
370   33  X²
371   76  LBL
372   19  D'    Unit
373   57  ENG   Ply
374   58  FIX
375   03   03   Data
376   43  RCL
377   59   59
378   42  STO
379   09   09
380   42  STO
381   36   36
382   42  STO
383   37   37
384   42  STO
385   39   39
386   00   0
387   42  STO
388   38   38
389   42  STO
390   40   40
391   61  GTO
392   00   00
393   52   52
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
```

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

```
000  76  LBL
001  11   A
002  42  STO  n
003  05   05
004  99  PRT
005  98  ADV
006  65   ×
007  43  RCL
008  59   59
009  95   =
010  42  STO  h
011  09   09
012  57  ENG
013  58  FIX
014  03   03
015  00   0
016  36  PGM
017  12   12  ViA²
018  71  SBR  O
019  61  GTO
020  93   .
021  05   5
022  49  PRD  n/2
023  05   05
024  43  RCL  t
025  05   05
026  91  R/S
027  99  PRT
028  94  +/-
029  42  STO  θt
030  35   35
031  01   1
032  42  STO
033  04   04
034  44  SUM
035  36   36
036  36  PGM
037  12   12  ΣViA
038  71  SBR
039  71  SBR
040  97  DSZ
041  05   05
042  00   00
043  24   24
044  71  SBR
045  53   (
046  76  LBL
047  16   A'  Core
048  01   1
049  05   5
050  03   3
051  05   5
052  42  STO
053  02   02
054  36  PGM
055  11   11
056  71  SBR
057  90  LST
058  43  RCL
059  05   05

060  99  PRT
061  76  LBL
062  53   (
063  43  RCL
064  59   59
065  65   ×
066  02   2
067  95   =
068  36  PGM
069  12   12  ViA
070  71  SBR
071  61  GTO
072  03   3
073  06   6
074  04   4
075  05   5
076  03   3
077  00   0
078  42  STO
079  02   02
080  36  PGM
081  11   11
082  71  SBR
083  90  LST
084  98  ADV
085  36  PGM
086  11   11  Aij
087  71  SBR
088  23  LNX
089  36  PGM
090  11   11  aij
091  71  SBR
092  35  1/X
093  01   1
094  07   7
095  05   5
096  01   1
097  42  STO
098  02   02
099  36  PGM
100  11   11
101  71  SBR
102  90  LST
103  43  RCL
104  09   09
105  35  1/X
106  42  STO
107  08   08  E1°
108  55   ÷
109  43  RCL
110  16   16
111  95   =
112  99  PRT
113  43  RCL
114  08   08
115  55   ÷   E2°
116  43  RCL
117  17   17
118  95   =
119  99  PRT

120  43  RCL
121  18   18
122  55   ÷
123  43  RCL
124  16   16  ν21°
125  95   =
126  94  +/-
127  99  PRT
128  43  RCL
129  08   08
130  55   ÷
131  43  RCL  E6°
132  19   19
133  95   =
134  99  PRT
135  98  ADV
136  01   1
137  03   3
138  00   0
139  00   0
140  42  STO
141  02   02
142  36  PGM
143  11   11
144  71  SBR
145  90  LST
146  43  RCL
147  10   10
148  99  PRT
149  43  RCL
150  11   11
151  99  PRT
152  43  RCL
153  12   12  Print Aij
154  99  PRT
155  43  RCL
156  13   13
157  99  PRT
158  43  RCL
159  14   14
160  99  PRT
161  43  RCL
162  15   15
163  99  PRT
164  98  ADV
165  01   1
166  03   3
167  02   2
168  04   4
169  42  STO
170  02   02
171  36  PGM
172  11   11
173  71  SBR
174  90  LST  Print aij
175  43  RCL
176  16   16
177  99  PRT
178  43  RCL
179  17   17

180  99  PRT
181  43  RCL
182  18   18
183  99  PRT
184  43  RCL
185  19   19
186  99  PRT
187  43  RCL
188  20   20
189  99  PRT
190  43  RCL
191  21   21
192  99  PRT
193  98  ADV
194  01   1
195  03   3
196  05   5
197  01   1
198  42  STO
199  02   02
200  36  PGM
201  11   11
202  71  SBR
203  90  LST
204  61  GTO
205  02   02
206  15   15
207  76  LBL
208  23  LNX
209  55   ÷   Aij/h
210  43  RCL
211  09   09
212  95   =
213  99  PRT
214  92  RTN
215  43  RCL
216  10   10
217  71  SBR
218  23  LNX
219  43  RCL
220  11   11
221  71  SBR
222  23  LNX
223  43  RCL
224  12   12
225  71  SBR
226  23  LNX
227  43  RCL
228  13   13  Print A*ij
229  71  SBR
230  23  LNX
231  43  RCL
232  14   14
233  71  SBR
234  23  LNX
235  43  RCL
236  15   15
237  71  SBR
238  23  LNX
239  98  ADV
```

```
240   01   1
241   03   3
242   05   5
243   01   1
244   02   2
245   04   4
246   42  STO
247   02   02
248   36  PGM
249   11   11
250   71  SBR
251   90  LST
252   61  GTO
253   02   02
254   63   63
255   76  LBL
256   22  INV
257   65   ×     aijh
258   43  RCL
259   09   09
260   95   =
261   99  PRT
262   92  RTN
263   43  RCL
264   16   16
265   71  SBR
266   22  INV
267   43  RCL
268   17   17
269   71  SBR
270   22  INV
271   43  RCL
272   18   18
273   71  SBR
274   22  INV
275   43  RCL
276   19   19
277   71  SBR
278   22  INV
279   43  RCL    Print a*ij
280   20   20
281   71  SBR
282   22  INV
283   43  RCL
284   21   21
285   71  SBR
286   22  INV
287   98  ADV
288   06   6
289   93   .
290   01   1
291   95   =
292   91  R/S
293   76  LBL
294   12   B
295   42  STO    N1
296   26   26
297   03   3
298   01   1
299   00   0

300   00   0
301   42  STO
302   02   02
303   36  PGM
304   11   11
305   71  SBR
306   90  LST
307   43  RCL
308   26   26
309   99  PRT
310   06   6
311   93   .
312   02   2
313   95   =
314   91  R/S
315   99  PRT
316   42  STO    N2
317   27   27
318   06   6
319   93   .
320   06   6
321   95   =
322   91  R/S
323   99  PRT
324   98  ADV
325   42  STO    N6
326   28   28
327   36  PGM
328   11   11
329   71  SBR    aij
330   35  1/X
331   36  PGM
332   10   10    εi0
333   71  SBR
334   89   π
335   36  PGM
336   10   10    p,q,r
337   71  SBR
338   34  √X
339   05   5
340   04   4
341   02   2
342   04   4
343   42  STO
344   02   02
345   36  PGM
346   11   11
347   71  SBR
348   90  LST
349   43  RCL
350   53   53    Ic
351   99  PRT
352   43  RCL
353   54   54
354   33  X²
355   85   +     Rc
356   43  RCL
357   55   55
358   33  X²
359   95   =

360   34  √X
361   99  PRT
362   98  ADV
363   43  RCL
364   44   44
365   42  STO
366   16   16
367   43  RCL
368   45   45
369   42  STO
370   17   17
371   43  RCL
372   46   46
373   42  STO
374   18   18
375   43  RCL
376   47   47    Transfer Gij
377   42  STO
378   19   19
379   43  RCL
380   48   48
381   42  STO
382   20   20
383   43  RCL
384   49   49
385   42  STO
386   21   21
387   76  LBL
388   24  CE     θ
389   06   6     prompter
390   00   0
391   95   =
392   91  R/S
393   76  LBL
394   13   C
395   42  STO    θt
396   41   41
397   06   6
398   00   0
399   00   0
400   00   0
401   42  STO
402   02   02
403   36  PGM
404   11   11
405   71  SBR
406   90  LST
407   43  RCL
408   41   41
409   99  PRT
410   98  ADV
411   36  PGM
412   10   10    εi(θo)
413   71  SBR
414   54   )
415   00   0
416   42  STO
417   26   26    εiN=0
418   42  STO
419   27   27

420   42  STO
421   28   28
422   36  PGM    Rt
423   08   08
424   71  SBR    R't
425   30  TAN
426   03   3
427   05   5
428   00   0
429   00   0
430   42  STO
431   02   02
432   36  PGM
433   11   11
434   71  SBR    Print Rt, R't
435   90  LST
436   43  RCL
437   06   06
438   99  PRT
439   43  RCL
440   07   07
441   99  PRT
442   98  ADV
443   07   7
444   07   7
445   00   0
446   00   0
447   42  STO
448   02   02
449   36  PGM    Calculate & Print bt0
450   11   11
451   71  SBR
452   90  LST
453   43  RCL
454   06   06
455   55   ÷
456   43  RCL
457   09   09
458   95   =
459   99  PRT
460   43  RCL
461   07   07
462   55   ÷     t0'
463   43  RCL
464   09   09
465   95   =
466   99  PRT
467   98  ADV
468   71  SBR
469   24  CE
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
```

COMBO 3: Flexural Stiffness and Strength without Printer

```
000   76  LBL
001   11   A
002   42  STO
003   05   05   n
004   65   ×
005   43  RCL
006   59   59
007   95   =
008   42  STO
009   09   09   h
010   57  ENG
011   58  FIX
012   03   03
013   00   0
014   36  PGM
015   12   12   Vi0=
016   71  SBR       0
017   61  GTO
018   43  RCL
019   05   05
020   55   ÷
021   02   2
022   95   =
023   42  STO   n/2
024   05   05
025   42  STO
026   06   06   t
027   75   -
028   01   1
029   95   =
030   42  STO
031   07   07
032   43  RCL
033   05   05
034   91  R/S
035   94  +/-
036   42  STO
037   35   35
038   43  RCL
039   06   06
040   45  Y×
041   03   3
042   75   -
043   43  RCL
044   07   07
045   45  Y×
046   03   3
047   95   =    ΣViD
048   42  STO
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
```

```
060   76  LBL   Core
061   16  A'
062   43  RCL
063   59   59
064   45  Y×
065   03   3
066   65   ×
067   02   2
068   55   ÷
069   03   3
070   95   =
071   36  PGM
072   12   12   ViD
073   71  SBR
074   61  GTO
075   36  PGM
076   11   11   Dij
077   71  SBR
078   23  LNX
079   36  PGM
080   11   11   dij
081   71  SBR
082   35  1/X
083   01   1
084   02   2
085   55   ÷
086   43  RCL
087   09   09
088   45  Y×
089   03   3
090   95   =
091   42  STO
092   08   08
093   55   ÷    E1f
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   E2f
103   95   =
104   91  R/S
105   43  RCL
106   18   18
107   55   ÷
108   43  RCL
109   16   16
110   95   =    ν21f
111   94  +/-
112   91  R/S
113   43  RCL
114   08   08
115   55   ÷
116   43  RCL
117   19   19   E6f
118   95   =
119   91  R/S
```

```
120   71  SBR
121   52  EE
122   76  LBL
123   17  B'
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   Dij
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   dij
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   ×
167   43  RCL
168   08   08
169   95   =
170   91  R/S
171   43  RCL
172   11   11
173   65   ×
174   43  RCL
175   08   08
176   95   =
177   91  R/S
178   43  RCL
179   12   12
```

```
180   65
181   43  RCL
182   08   08
183   95   =
184   91  R/S
185   43  RCL
186   13   13
187   65
188   43  RCL
189   08   08
190   95   =
191   91  R/S
192   43  RCL
193   14   14
194   65   ×    D*ij
195   43  RCL
196   08   08
197   95   =
198   91  R/S
199   43  RCL
200   15   15
201   65   ×
202   43  RCL
203   08   08
204   95   =
205   91  R/S
206   43  RCL
207   16   16
208   55   ÷
209   43  RCL
210   08   08
211   95   =
212   91  R/S
213   43  RCL
214   17   17
215   55   ÷
216   43  RCL
217   08   08
218   95   =
219   91  R/S
220   43  RCL
221   18   18
222   55   ÷
223   43  RCL
224   08   08
225   95   =    d*ij
226   91  R/S
227   43  RCL
228   19   19
229   55   ÷
230   43  RCL
231   08   08
232   95   =
233   91  R/S
234   43  RCL
235   20   20
236   55   ÷
237   43  RCL
238   08   08
239   95   =
```

```
240   91  R/S
241   43  RCL
242   21   21
243   55   ÷
244   43  RCL
245   08   08
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  STO    M1
258   26   26
259   06   6
260   93   .
261   02   2
262   95   =
263   91  R/S
264   42  STO    M2
265   27   27
266   06   6
267   93   .
268   06   6
269   95   =
270   91  R/S
271   42  STO    M6
272   28   28
273   36  PGM
274   11   11
275   71  SBR    dij
276   35  1/X
277   36  PGM
278   10   10
279   71  SBR    ki
280   89   π
281   36  PGM
282   10   10
283   71  SBR    pi,qi,r
284   34  √X
285   43  RCL
286   44   44
287   42  STO
288   16   16
289   43  RCL
290   45   45
291   42  STO    Transfer Gij
292   17   17
293   43  RCL
294   46   46
295   42  STO
296   18   18
297   43  RCL
298   47   47
299   42  STO
```

```
300   19   19
301   43  RCL
302   48   48
303   42  STO
304   20   20
305   43  RCL
306   49   49
307   42  STO
308   21   21
309   76  LBL
310   24  CE
311   06   6     θ prompter
312   00   0
313   95   =
314   91  R/S
315   76  LBL
316   13   C
317   42  STO    θt
318   41   41
319   03   3
320   07   7
321   95   =
322   91  R/S
323   42  STO    t
324   05   05
325   36  PGM
326   10   10
327   71  SBR    ki(θt)
328   54   )
329   43  RCL
330   05   05
331   65   ×
332   43  RCL
333   59   59    zt
334   95   =
335   49  PRD
336   23   23
337   49  PRD
338   24   24    εi(θt)
339   49  PRD
340   25   25
341   00   0
342   42  STO
343   26   26
344   42  STO    εi^N=0
345   27   27
346   42  STO
347   28   28
348   36  PGM    Rt
349   08   08
350   71  SBR    Rt'
351   30  TAN
352   43  RCL
353   06   06
354   91  R/S    Display
355   43  RCL    Rt, Rt'
356   07   07
357   91  R/S
358   71  SBR
359   24  CE
```

```
360   76  LBL
361   14   D
362   43  RCL
363   06   06
364   55   ÷
365   43  RCL
366   09   09
367   33  X²
368   65   ×
369   06   6     σt f
370   95   =
371   91  R/S
372   55   ÷
373   43  RCL
374   06   06
375   65   ×
376   43  RCL
377   07   07    σt f'
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
```

COMBO 3P: Flexural Stiffness and Strength with Printer

```
000  76  LBL
001  11  A
002  42  STO     n
003  05   05
004  99  PRT
005  98  ADV
006  85  +
007  43  RCL
008  59   59
009  95  =
010  42  STO     h
011  09   09
012  57  ENG
013  58  FIX
014  03   03
015  00   0
016  36  PGM
017  12   12     ViD = 0
018  71  SBR
019  61  GTO
020  43  RCL
021  05   05
022  55  ÷
023  02   2
024  95  =
025  42  STO     n/2
026  05   05
027  42  STO     t
028  06   06
029  75  -
030  01   1
031  95  =
032  42  STO
033  07   07
034  43  RCL
035  05   05
036  91  R/S
037  99  PRT
038  94  +/-
039  42  STO
040  35   35
041  43  RCL
042  06   06
043  45  YX
044  03   3
045  75  -
046  43  RCL
047  07   07
048  45  YX
049  03   3
050  95  =
051  42  STO
052  04   04     ΣViD
053  44  SUM
054  36   36
055  36  PGM
056  12   12
057  71  SBR
058  71  SBR
059  97  DSZ

060  05   05
061  00   00
062  34   34
063  71  SBR
064  53  (
065  76  LBL     Core
066  16  A'
067  01   1
068  05   5
069  03   3
070  05   5
071  42  STO
072  02   02
073  36  PGM
074  11   11
075  71  SBR
076  90  LST
077  43  RCL
078  05   05
079  99  PRT
080  76  LBL
081  53  (
082  43  RCL
083  59   59
084  45  YX
085  03   3
086  65  ×
087  02   2
088  55  ÷
089  03   3
090  95  =
091  36  PGM
092  12   12     ViD
093  71  SBR
094  61  GTO
095  03   3
096  06   6
097  04   4
098  05   5
099  03   3
100  00   0
101  42  STO
102  02   02
103  36  PGM
104  11   11
105  71  SBR
106  90  LST
107  98  ADV
108  36  PGM
109  11   11     Dij
110  71  SBR
111  23  LNX
112  36  PGM
113  11   11     dij
114  71  SBR
115  35  1/X
116  01   1
117  07   7
118  05   5
119  01   1

120  42  STO
121  02   02
122  36  PGM
123  11   11
124  71  SBR
125  [illegible]
126  [illegible]
127  02   2
128  55  ÷
129  43  RCL
130  09   09
131  45  YX
132  03   3
133  95  =
134  42  STO
135  08   08
136  55  ÷
137  43  RCL
138  16   16     E1f
139  95  =
140  99  PRT
141  43  RCL
142  08   08
143  55  ÷
144  43  RCL
145  17   17     E2f
146  95  =
147  99  PRT
148  43  RCL
149  18   18
150  55  ÷
151  43  RCL
152  16   16     ν21f
153  95  =
154  94  +/-
155  99  PRT
156  43  RCL
157  08   08
158  55  ÷
159  43  RCL     E6f
160  19   19
161  95  =
162  99  PRT
163  98  ADV
164  01   1
165  06   6
166  00   0
167  00   0
168  42  STO
169  02   02
170  36  PGM
171  11   11
172  71  SBR
173  90  LST
174  43  RCL
175  10   10
176  99  PRT
177  43  RCL
178  11   11
179  99  PRT

180  [illegible]
181  [illegible]
182  [illegible]
183  [illegible]
184  [illegible]
185  [illegible]
186  [illegible]
187  [illegible]
188  [illegible]
189  43  RCL
190  15   15     Print Dij
191  99  PRT
192  98  ADV
193  43  RCL
194  16   16
195  99  PRT
196  43  RCL
197  17   17
198  99  PRT
199  43  RCL
200  18   18
201  99  PRT
202  43  RCL
203  19   19
204  99  PRT
205  43  RCL     Print dij
206  20   20
207  99  PRT
208  43  RCL
209  21   21
210  99  PRT
211  98  ADV
212  01   1
213  06   6
214  05   5
215  01   1
216  42  STO
217  02   02
218  36  PGM
219  11   11
220  71  SBR
221  90  LST
222  61  GTO
223  02   02
224  33   33
225  76  LBL
226  23  LNX     12Dij/h^3
227  65  ×
228  43  RCL
229  08   08
230  95  =
231  99  PRT
232  92  RTN
233  43  RCL
234  10   10
235  71  SBR
236  23  LNX
237  43  RCL
238  11   11
239  71  SBR
```

```
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      Dij*
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   ÷       dij k^3 / 12
264   43  RCL
265   08   08
266   95   =
267   99  PRT
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      dij*
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
```

```
300   12   B
301   42  STO      M1
302   26   26
303   03   3
304   00   0
305   00   0
306   00   0
307   42  STO
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  STO      M2
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  STO      M6
332   28   28
333   36  PGM
334   11   11
335   71  SBR      dij
336   35  1/X
337   36  PGM
338   10   10
339   71  SBR      ki
340   89   π
341   36  PGM
342   10   10      p,q,r
343   71  SBR
344   34  √X
345   43  RCL
346   44   44
347   42  STO
348   16   16
349   43  RCL
350   45   45      Transfer Gij,t
351   42  STO
352   17   17
353   43  RCL
354   46   46
355   42  STO
356   18   18
357   43  RCL
358   47   47
359   42  STO
```

```
360   19   19
361   43  RCL
362   48   48
363   42  STO
364   20   20
365   43  RCL
366   49   49
367   42  STO
368   21   21
369   76  LBL
370   24  CE       θ prompter
371   06   6
372   00   0
373   95   =
374   91  R/S
375   76  LBL
376   13   C
377   42  STO      θt
378   41   41
379   06   6
380   00   0
381   05   5
382   07   7
383   03   3
384   07   7
385   42  STO
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  STO
399   05   05      t
400   99  PRT
401   98  ADV
402   36  PGM
403   10   10      ki(θt)
404   71  SBR
405   54   )
406   43  RCL
407   05   05
408   65   ×
409   43  RCL      Zt
410   59   59
411   95   =
412   49  PRD
413   23   23
414   49  PRD      εi(θt)
415   24   24
416   49  PRD
417   25   25
418   00   0
419   42  STO
```

```
420   [illegible]
421   4[illegible]  [illegible]
422   4[illegible]  [illegible]    εi^N=0
423   [illegible]
424   [illegible]
425   [illegible]  P[illegible]
426   [illegible]8  [illegible]     Rt
427   71  SBR      R't
428   30  TAN
429   03   3
430   05   5
431   00   0
432   00   0
433   42  STO
434   02   02
435   36  PGM
436   11   11
437   71  SBR
438   90  LST
439   43  RCL
440   06   06      Print Rt, R't
441   99  PRT
442   43  RCL
443   07   07
444   99  PRT
445   98  ADV
446   07   7
447   07   7
448   00   0
449   00   0
450   42  STO
451   02   02
452   36  PGM
453   11   11
454   71  SBR
455   90  LST
456   43  RCL
457   06   06
458   55   ÷
459   43  RCL
460   09   09
461   33  X²
462   65   ×       σt^f
463   06   6
464   95   =
465   99  PRT
466   55   ÷
467   43  RCL
468   06   06
469   65   ×       σt^f'
470   43  RCL
471   07   07
472   95   =
473   99  PRT
474   98  ADV
475   71  SBR
476   24  CE
477   00   0
478   00   0
479   00   0
```