

# GENLAM: GENERAL LAMINATE



**Antonio Miravete**

Ph.D. University of Zaragoza  
Visiting Associate Professor  
Aeronautics & Astronautics  
Stanford University



**Carlos A. Cimini Jr.**

Ph.D. Stanford University  
Visiting Scholar from CEA/UFMG, Brazil  
Aeronautics & Astronautics  
Stanford University

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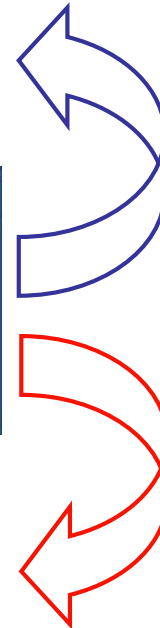
- **FIRST WINDOW – START UP**
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- **INPUT LAMINATE**
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- **INPUT MATERIALS I**
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# GENLAM: FIRST WINDOW – START UP

Continue to the GenLam Main Window



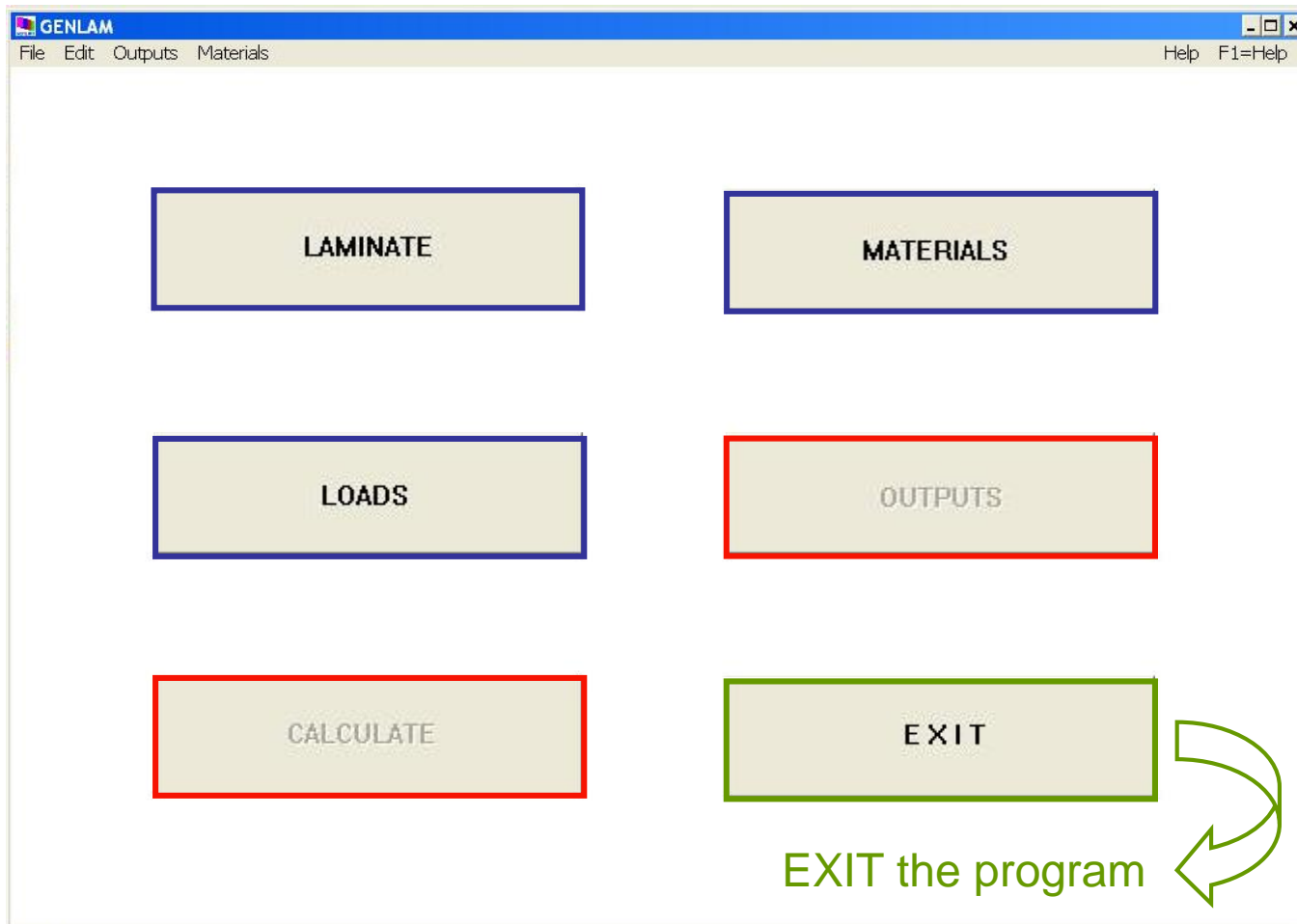
Go to HELP on-line



# GENLAM: SECOND WINDOW – MAIN WINDOW

INPUT (highlighted):  
LAMINATE / MATERIALS / LOADS

After INPUT is given:  
CALCULATE / OUTPUTS



# GENLAM: INPUT LAMINATE

The screenshot shows the 'GENLAM: Input Laminates' dialog box. It includes a 'NOTE: Plies are numbered from the bottom to the top.' and a list of 'Available Materials' (0 alum.mat, 1 as\_h35.mat, 2 as4\_3501.mat, 3 as4\_pk.mat, 4 b4\_n55.mat, 5 core.mat, 6 im6\_epox.mat). The 'Ply Number' is set to 1, 'Material Number' to 0, and 'Repetitions' to 1. The 'Orientation' and 'Material N.' fields contain '[(]\*1'. The 'Symmetry' section has checkboxes for '[n]s' and '[n-1]s''. Buttons for 'OPEN...', 'NEW', 'OK', 'SAVE', 'CALCULATE', and 'CANCEL' are at the bottom. Annotations include: a red arrow pointing to the 'Available Materials' list labeled 'Material database'; a blue arrow pointing to the 'OPEN...' button labeled 'User can OPEN an existing saved laminate or start a NEW laminate'; a red arrow pointing to the 'OK' button labeled 'OK returns the user to GenLam Main Window'; a red arrow pointing to the 'CANCEL' button labeled 'CANCEL clear this input and returns the user to the Main Window'; an orange arrow pointing to the 'SAVE' button labeled 'SAVE will save the input laminate to a file'; and a green arrow pointing to the 'CALCULATE' button labeled 'User have the option of CALCULATE from this window without having to go back to the Main Window'.

**Material database**

**User can OPEN an existing saved laminate or start a NEW laminate**

**OK returns the user to GenLam Main Window**

**CANCEL clear this input and returns the user to the Main Window**

**SAVE will save the input laminate to a file**

**User have the option of CALCULATE from this window without having to go back to the Main Window**

# GENLAM: INPUT LAMINATE

Angle (degrees) and Material Number should be given ply-by-ply (NEXT PLY)

Material database

NOTE: Plies are numbered from the bottom to the top.

Ply Number: 1

Angle [Degrees]:

Material Number: 0

Available Materials:

- 0 alum.mat
- 1 as\_h35.mat
- 2 as4\_3501.mat
- 3 as4\_pk.mat
- 4 b4\_n55.mat
- 5 core.mat
- 6 im6\_epox.mat

Ply number is automatically updated

NEXT PLY

Orientation: [[ ]\*1

Material N. : [[ ]\*1

Repetitions : 1

Symmetry :  [n]s  [n - 1]s'

OPEN... NEW OK

SAVE CALCULATE CANCEL

Number of repetitions and symmetry condition should also be given (mark)

Lay-up Orientation and Material Number are automatically filled ply-by-ply

# GENLAM: INPUT LOADS & DISPLACEMENTS

Hybrid input

Loads (load vector)      Displacements (strains and curvatures)

GENLAM: Loads & Displacements

Total : 0      Load Case    1

Parameter	Unit	Parameter	Unit
N1	[MN/m]	eps1	
N2	[MN/m]	eps2	
N6	[MN/m]	eps6	
M1	[MN]	k1	
M2	[MN]	k2	
M6	[MN]	k6	

HYGROTHERMAL LOADS

NEXT and PREVIOUS change the window to sequential load cases

User can CLEAR the input data at any time

OK returns the user to GenLam Main Window

CANCEL clear this input and returns the user to the Main Window

HYGROTHERMAL LOADS may be given using this button

User have the option of CALCULATE from this window without having to go back to the Main Window

# GENLAM: INPUT LOADS & DISPLACEMENTS

## HYGROTHERMAL LOADS (TEMPERATURE & MOISTURE)

GENLAM: Temperature and Moisture

The temperature difference is the operating temperature minus the stress-free temperature.

Enter the temperature difference:  °C

The moisture content is given in absolute percent by weight.  
(eg. 1/2% is entered as 0.005)

Enter the moisture content:

Safety Factor (SF > 1):

OK

EXIT

OK returns the user to Load Window

EXIT clear this input and returns the user to the Load Window



Temperature Difference ( $\Delta T$ ), Moisture Content ( $\Delta c$ ) and Safety Factor should be given



# GENLAM: INPUT MATERIALS I

Material Name and ply properties should be given

Material database

Material Name: ALUMINUM

Fiber:  Fiber Volumen: ?

Matrix:  Matrix Density: ?

Thickness: 0.125 Density (Kg/m<sup>3</sup>): 2700

Ex [GPa]: 68.9 Ey: 68.9 Ez: ?

Gxy [GPa]: 26.5 Gxz: ? Gyz: ?

Nuxy: 0.3 Nuxz: ? Nuyz: ?

X [MPa]: 206 Y: 206 Z: ?

X': 206 Y': 206 Z': ?

Sxy: 118.9342 Sxz: ? Syz: ?

Fxy\*: -0.5

MATERIALS

- alum.mat
- as\_h35.mat
- as4\_3501.ma
- as4\_pk.mat
- b4\_n55.mat
- core.mat
- im6\_epox.ma
- ishikawa.mat

Save

Exit

New

Delete

Next...

Ply Stiffness

Ply Strength

Tsai-Wu coupling coefficient

SAVE the input material to a file

EXIT returns to Main Window

Input NEW material

DELETE material

NEXT takes the user to the Materials II Window

# GENLAM: INPUT MATERIALS II

Ply hygrothermal coefficients should be given

Material database

The screenshot shows the 'Materials II' window with the following fields and values:

Material Name:	ALUMINUM				
Ef [GPa]:	270	Em:	3.4	Em/Em0:	0.15
$\alpha_{a,Em}$ :	0.5	$\alpha_{b,eta}$ :	0.2	$\alpha_{c,Xm}$ :	0.9
$\gamma_{f,Ef}$ :	0.004	$\alpha_{h,Xf}$ :	0.004	$\alpha_{g,T}$ :	2000
c:	0.5	eta/y:	0.516	eta/s:	0.316
T/cure [°C]:	122	T/glass:	160	T/opr:	22
alpha:	2e-008	alpha:	2.25e-005	alpha:	?
beta x:	0	beta y:	0.6	beta:	?
Eiso [GPa]:	69.7	Xiso:	325		
Eu/EI:	0.916	Xu/XI:	1.56		

The 'MATERIALS' list on the right includes: alum.mat, as\_h35.mat, as4\_3501.ma, as4\_pk.mat, b4\_n55.mat, core.mat, im6\_epox.ma, and ishikawa.mat.

Buttons at the bottom right: Save, Exit, Previous...

Ply thermal expansion coefficients

Ply moisture expansion coefficients

SAVE the input material to a file

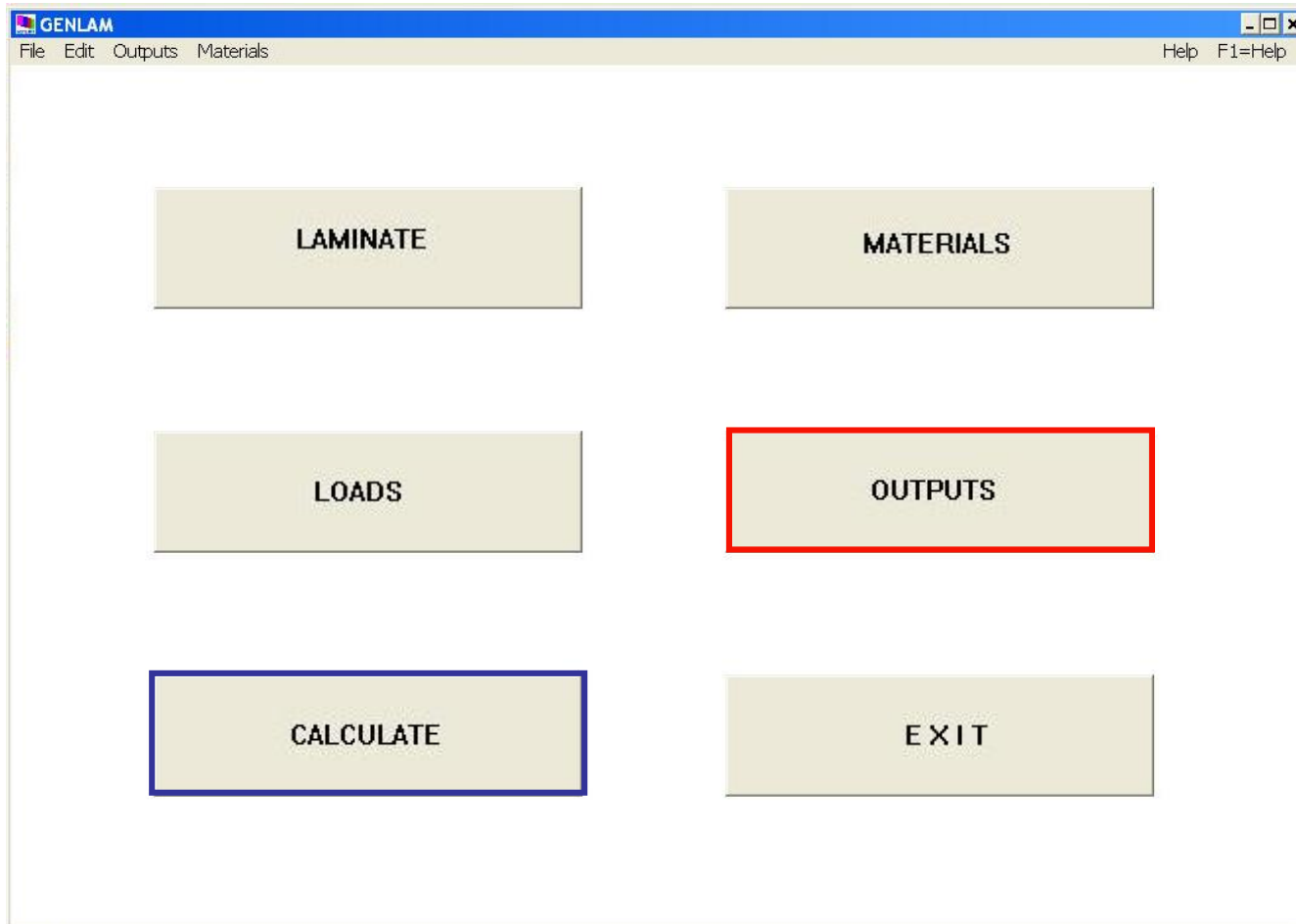
EXIT returns to Main Window

PREVIOUS takes the user to the Materials I Window

# GENLAM: CALCULATE

CALCULATE is highlighted after given LAMINATE / MATERIALS / LOADS

After CALCULATE user can see the OUTPUTS (also highlighted)



# GENLAM: OUTPUTS

**CHARTS : Output Selections**

Select any desired outputs (only one):

- Laminate matrices and engineering constants
  - Absolute Laminate Stiffness Matrix
  - Normalized Laminate Stiffness Matrix
  - Absolute Laminate Compliance Matrix
  - Normalized Laminate Compliance Matrix
  - Engineering Constants
- Laminate strains, curvatures and loads
- Ply strains and stresses
  - Strains
  - Stresses
- Strength ratio, R-values

Load Case :

Max. :

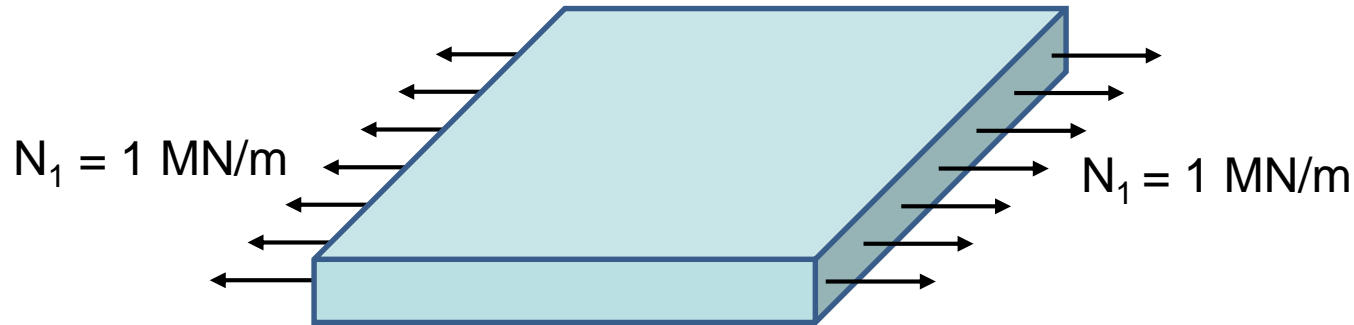
SHOW takes the user to the selected Results Window

EXIT clear this input and returns the user to the Main Window



User should select one of the items: Absolute and Normalized Stiffness and Compliance Matrices, Ply Strain and Stress distributions, Tsai-Wu Strength Ratio for a given Load Case

# GENLAM: EXAMPLE 1



Material: T300/5208

Layups:  $[(0/90)_r]$  (cross-ply) and  $[(+45/-45)_r]$  (angle-ply)

Load vectors:  $N = \{1, 0, 0\}$  [MN/m];  $M = \{0, 0, 0\}$  [MN]

No hygrothermal effects ( $\Delta T = \Delta c = 0$ )

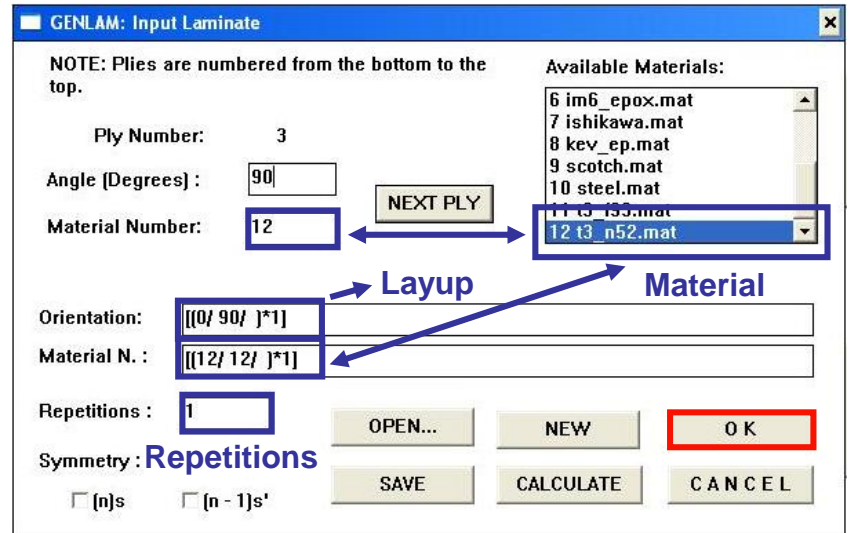
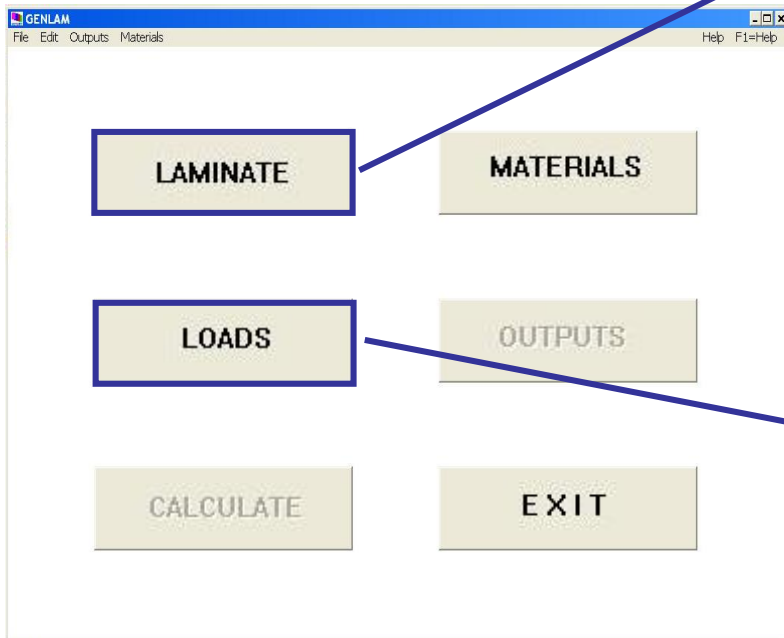
Vary repeating index  $r$  from 1 to 10

Check coupling  $B^*$  matrix

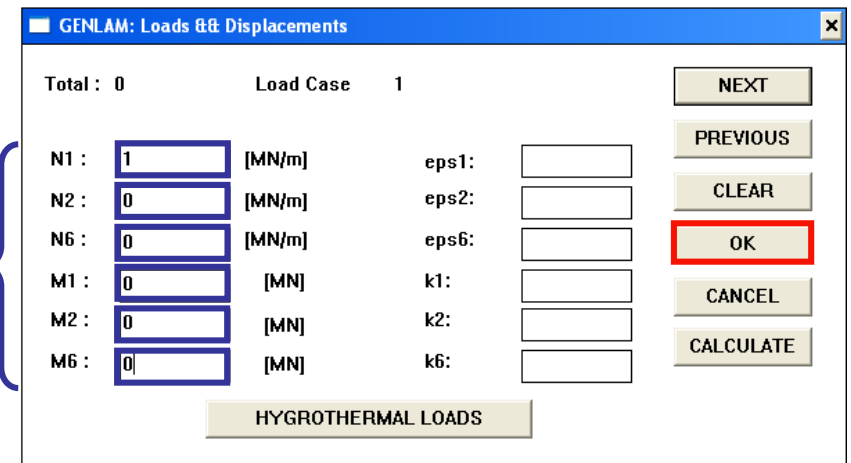
# GENLAM: EXAMPLE 1 – INPUT [(0/90)<sub>r</sub>]



T300/5208 is part of the material database



Mechanical Loads



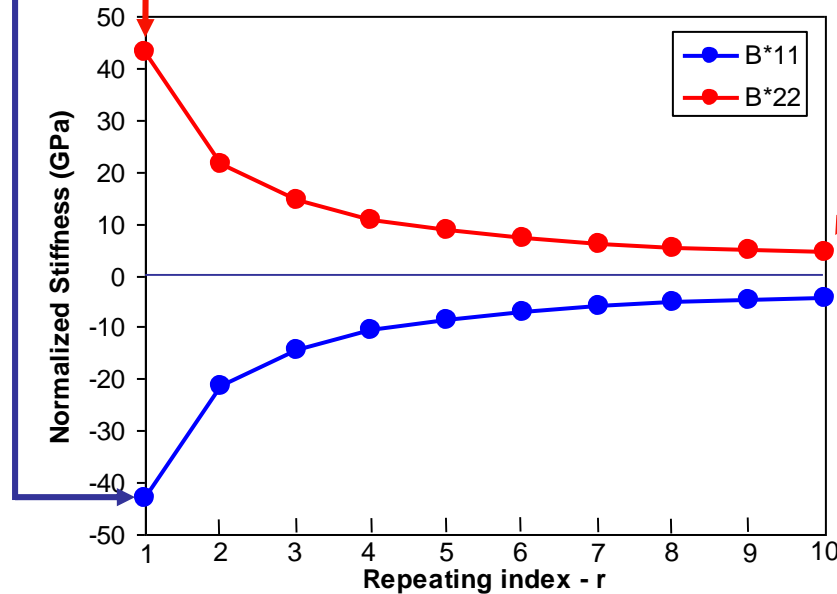
# GENLAM: EXAMPLE 1 – OUTPUT B\* [(0/90)<sub>r</sub>]

r = 1

...

r = 10

MATRIX - GENLAM.TMP							MATRIX - GENLAM.TMP						
NORMALIZED LAMINATE STIFFNESS MATRIX							NORMALIZED LAMINATE STIFFNESS MATRIX						
			A* B*							A* B*			
			3B* D*   [GPa]							3B* D*   [GPa]			
96.079	2.897	0	-42.866	0	0	96.079	2.897	0	-4.287	0	0		
2.897	96.079	0	0	42.866	0	2.897	96.079	0	0	4.287	0		
0	0	7.17	0	0	0	0	0	7.17	0	0	0		
-128.6	0	0	96.079	2.897	0	-12.86	0	0	96.079	2.897	0		
0	128.6	0	2.897	96.079	0	0	12.86	0	2.897	96.079	0		
0	0	0	0	0	7.17	0	0	0	0	0	7.17		

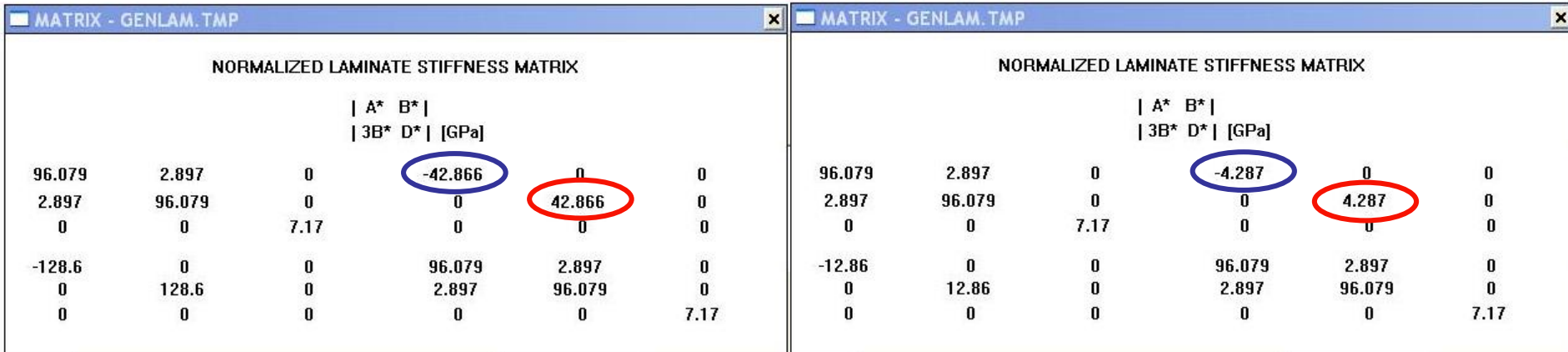


# GENLAM: EXAMPLE 1 – OUTPUT B\* [(0/90)<sub>r</sub>]

r = 1

...

r = 10



Analysis shows that  $B^*_{11}$  and  $B^*_{22}$  are inversely proportional to r

$$\begin{bmatrix} A^*_{ij} & B^*_{ij} \\ 3B^*_{ij} & D^*_{ij} \end{bmatrix} = \begin{bmatrix} 96.0 & 2.9 & 0 & -\frac{42.8}{r} & 0 & 0 \\ 2.9 & 96.0 & 0 & 0 & \frac{42.8}{r} & 0 \\ 0 & 0 & 7.2 & 0 & 0 & 0 \\ \hline -\frac{128.6}{r} & 0 & 0 & 96.0 & 2.9 & 0 \\ 0 & \frac{128.6}{r} & 0 & 2.9 & 96.0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 7.2 \end{bmatrix}$$

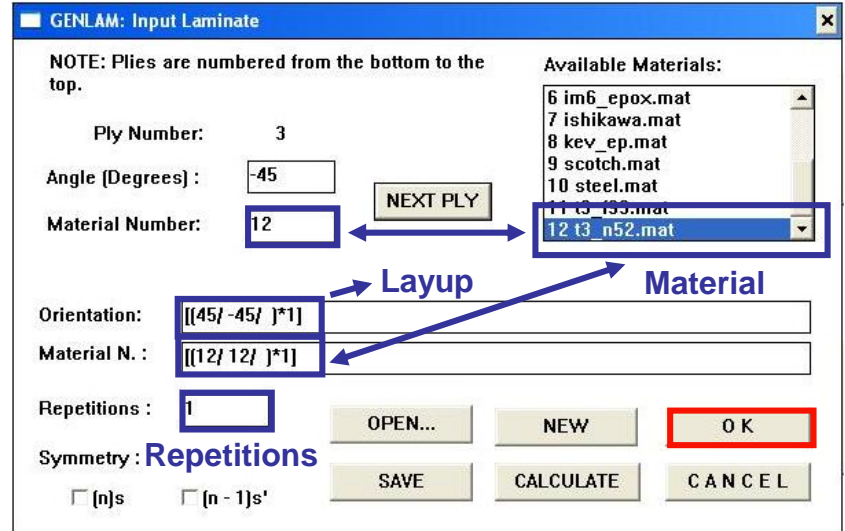
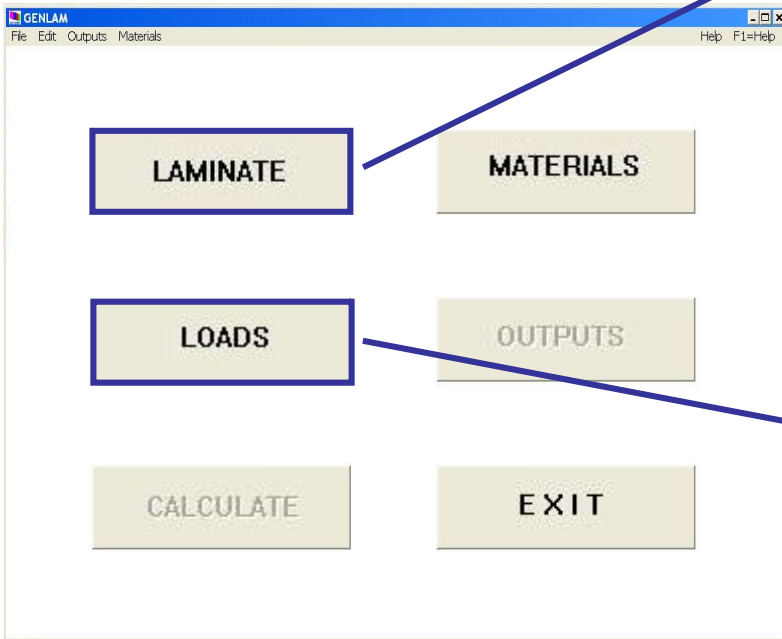
FIGURE 6.6 NORMALIZED STIFFNESS MATRIX OF A CROSS-PLY LAMINATE, HAVING COUPLING COMPONENTS WHICH DECAY WITH REPEATING INDEX



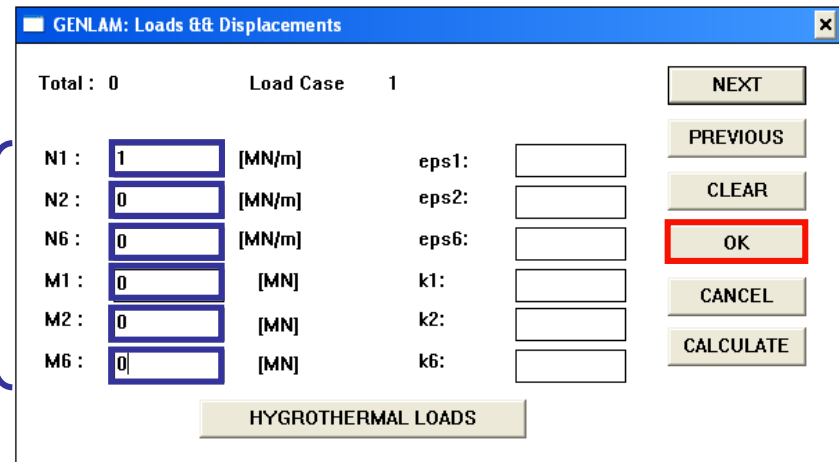
# GENLAM: EXAMPLE 1 – INPUT $[(+45/-45)_r]$



T300/5208 is part of the material database



Mechanical Loads



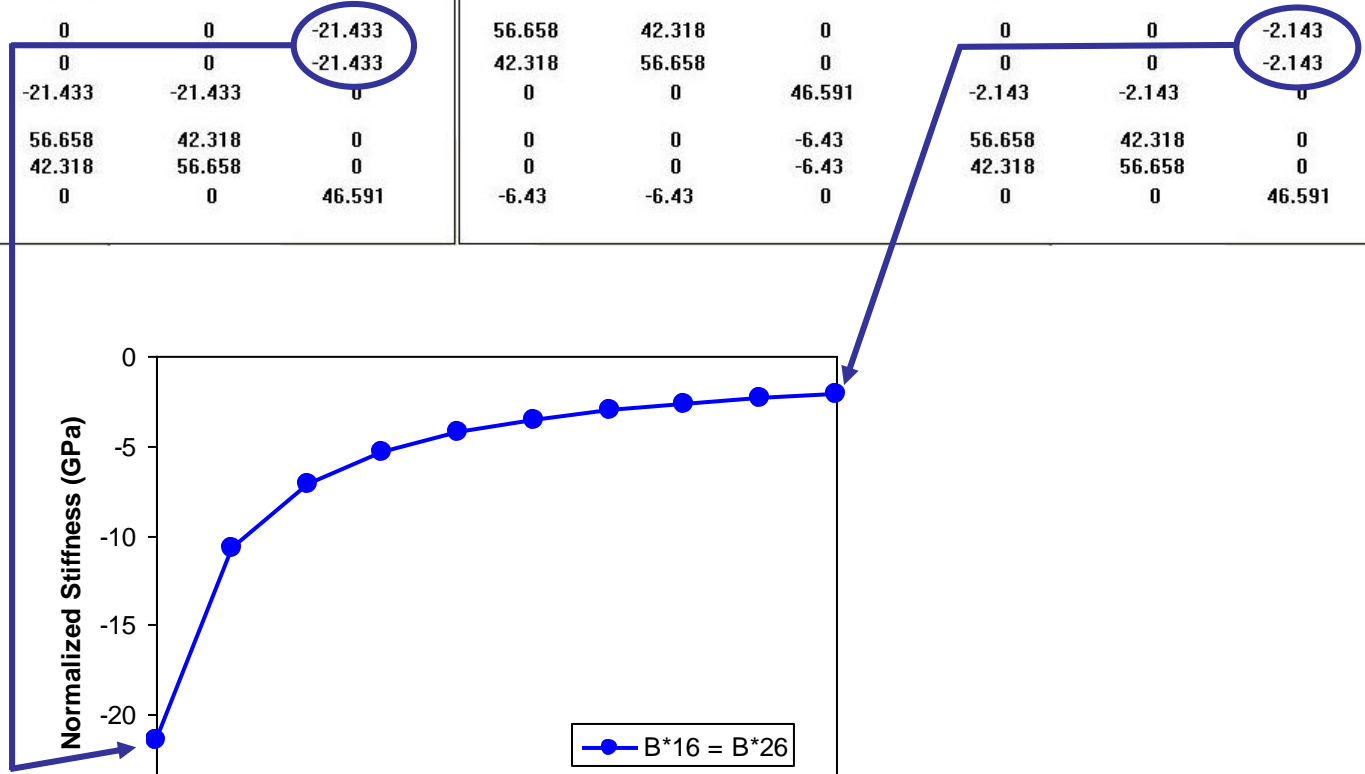
# GENLAM: EXAMPLE 1 – OUTPUT B\* [(+45/-45)<sub>r</sub>]

r = 1

...

r = 10

MATRIX - GENLAM.TMP						MATRIX - GENLAM.TMP					
NORMALIZED LAMINATE STIFFNESS MATRIX						NORMALIZED LAMINATE STIFFNESS MATRIX					
A* B*			3B* D*   [GPa]			A* B*			3B* D*   [GPa]		
56.658	42.318	0	0	0	-21.433	56.658	42.318	0	0	0	-2.143
42.318	56.658	0	0	0	-21.433	42.318	56.658	0	0	0	-2.143
0	0	46.591	-21.433	-21.433	0	0	0	46.591	-2.143	-2.143	0
0	0	-64.299	56.658	42.318	0	0	0	-6.43	56.658	42.318	0
0	0	-64.299	42.318	56.658	0	0	0	-6.43	42.318	56.658	0
-64.299	-64.299	0	0	0	46.591	-6.43	-6.43	0	0	0	46.591



# GENLAM: EXAMPLE 1 – OUTPUT B\* [(+45/-45)<sub>r</sub>]

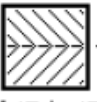
r = 1

...

r = 10

MATRIX - GENLAM.TMP						MATRIX - GENLAM.TMP					
NORMALIZED LAMINATE STIFFNESS MATRIX						NORMALIZED LAMINATE STIFFNESS MATRIX					
A* B*						A* B*					
3B* D*   [GPa]						3B* D*   [GPa]					
56.658	42.318	0	0	0	-21.433	56.658	42.318	0	0	0	-2.143
42.318	56.658	0	0	0	-21.433	42.318	56.658	0	0	0	-2.143
0	0	46.591	-21.433	-21.433	0	0	0	46.591	-2.143	-2.143	0
0	0	-64.299	56.658	42.318	0	0	0	-6.43	56.658	42.318	0
0	0	-64.299	42.318	56.658	0	0	0	-6.43	42.318	56.658	0
-64.299	-64.299	0	0	0	46.591	-6.43	-6.43	0	0	0	46.591

Analysis shows that  $B^*_{16}$  and  $B^*_{26}$  are inversely proportional to r

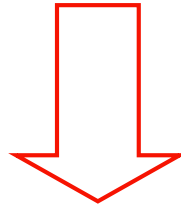


$$\begin{bmatrix} A^*_{ij} & B^*_{ij} \\ 3B^*_{ij} & D^*_{ij} \end{bmatrix} = \begin{bmatrix} 56.6 & 42.3 & 0 & 0 & 0 & -\frac{21.4}{r} \\ 42.3 & 56.6 & 0 & 0 & 0 & -\frac{21.4}{r} \\ 0 & 0 & 46.6 & -\frac{21.4}{r} & -\frac{21.4}{r} & 0 \\ 0 & 0 & -\frac{64.3}{r} & 56.6 & 42.3 & 0 \\ 0 & 0 & -\frac{64.3}{r} & 42.3 & 56.6 & 0 \\ -\frac{64.3}{r} & -\frac{64.3}{r} & 0 & 0 & 0 & 46.6 \end{bmatrix}$$

FIGURE 6.14 STIFFNESS MATRIX OF AN UNSYMMETRIC ANGLE-PLY LAMINATE

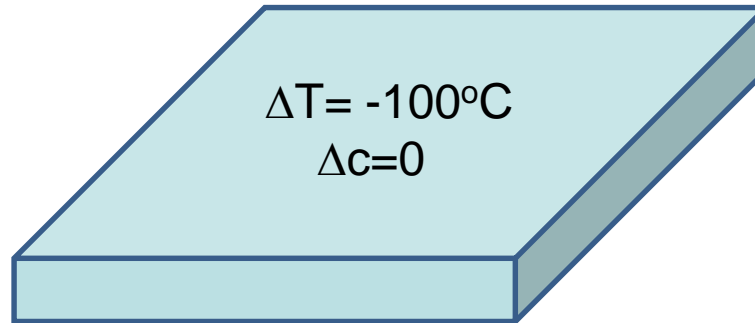
# GENLAM: EXAMPLE 1 - MESSAGE

Terms of coupling  $B^*$  matrix tend to zero with the increase of the repeating index  $r$



Repeat enough sub-laminates and the resulting non-symmetric laminate behavior will approach to a symmetric laminate

# GENLAM: EXAMPLE 2



Material: T300/5208

Layups:  $[(0/90)_r]$  (cross-ply) and  $[(+45/-45)_r]$  (angle-ply)

No mechanical loading

Hygrothermal effects:  $\Delta T = -100^\circ\text{C}$ ;  $\Delta c = 0$

Corresponds to laminate getting out of the autoclave

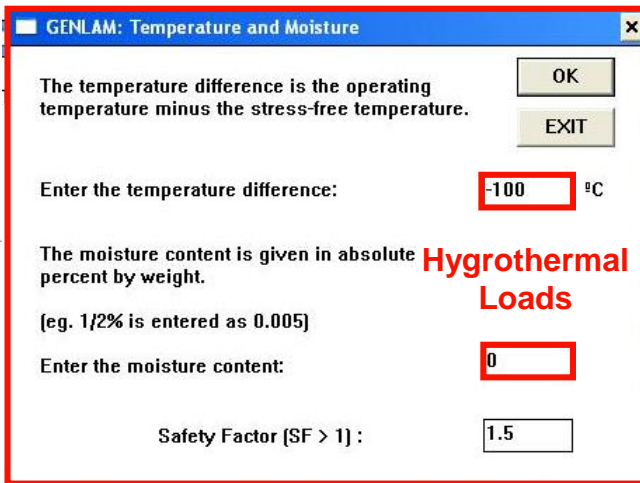
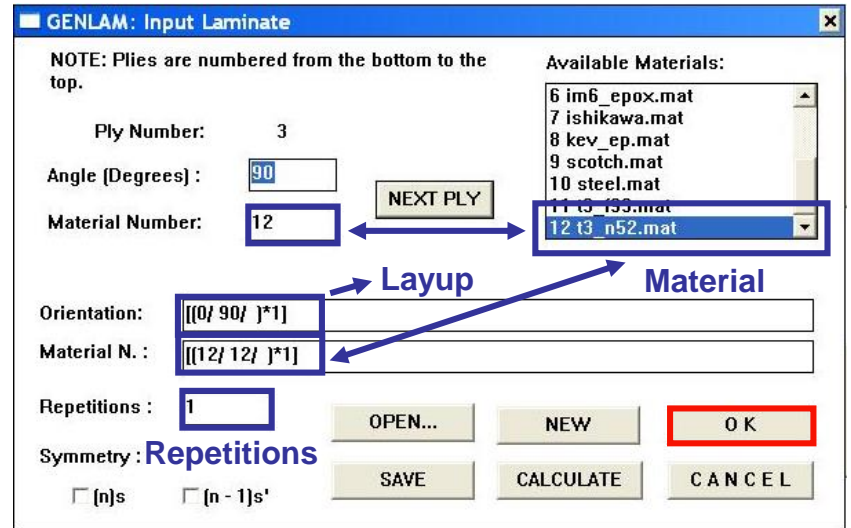
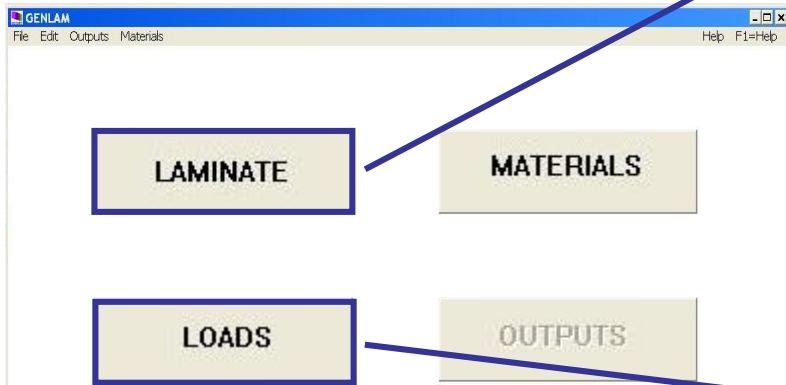
Vary repeating index  $r$  from 1 to 10

Check curvature  $k$  vector

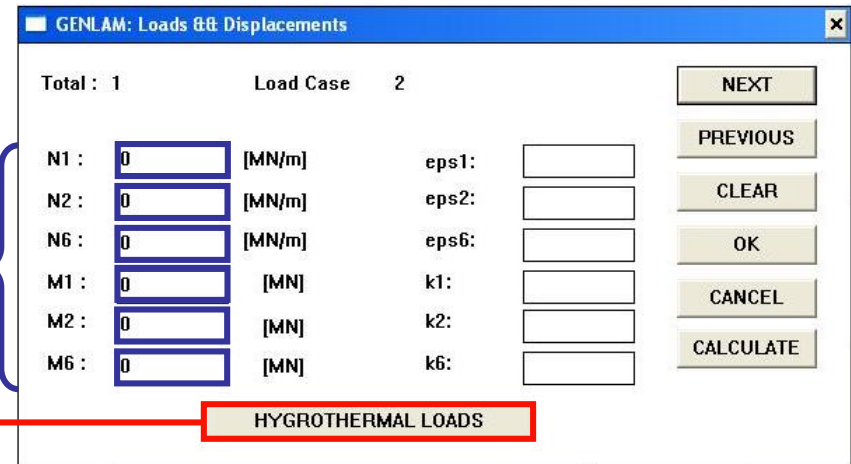
# GENLAM: EXAMPLE 2 – INPUT [(0/90)<sub>r</sub>]



T300/5208 is part of the material database



Mechanical Loads



# GENLAM: EXAMPLE 2 – OUTPUT k [(0/90)<sub>r</sub>]

r = 1

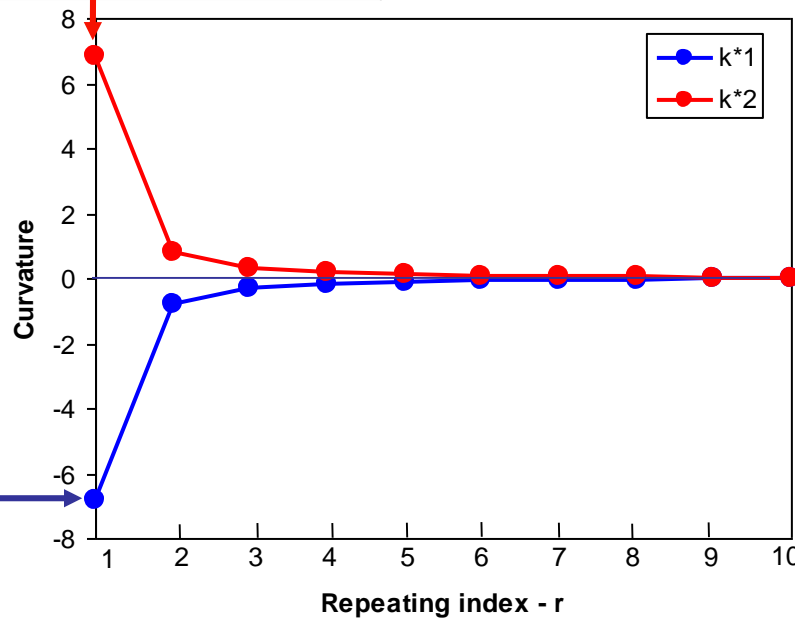
...

r = 10

CURVATURES VALUES FOR LOAD CASE 1									
eps1	eps2	eps6		k1	k2	k6			
-0.00052	-0.00052	-0.00000		-6.80790	6.80790	-0.00000			
eps1o	eps2o	eps6o	(*1E3)	eps1f	eps2f	eps6f			
-0.52095	-0.52095	-0.00000		-0.85098	0.85098	-0.00000			
N1	N2	N6		M1	M2	M6			
0.00000	0.00000	0.00000		0.00000	0.00000	0.00000			
sigma1o	sigma2o	sigma6o	[MPa]	sigma1f	sigma2f	sigma6f			
0.00000	0.00000	0.00000		0.00000	0.00000	0.00000			
Temperature difference : -100 °C				Moisture : 0					

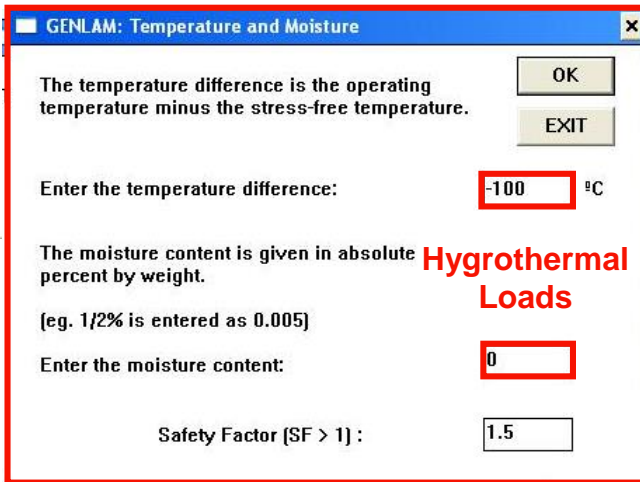
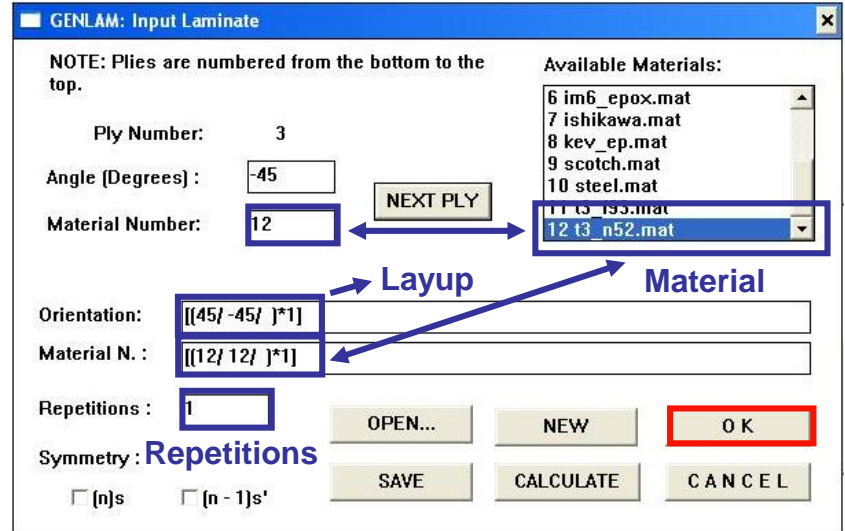
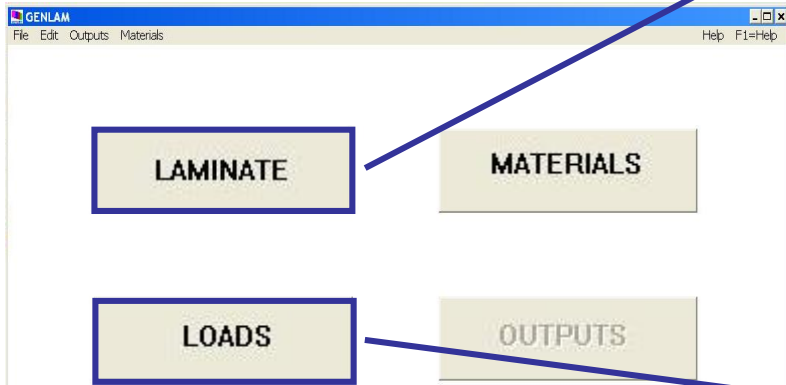
CURVATURES VALUES FOR LOAD CASE 1									
eps1	eps2	eps6		k1	k2	k6			
-0.00015	-0.00015	-0.00000		-0.02755	0.02755	-0.00000			
eps1o	eps2o	eps6o	(*1E3)	eps1f	eps2f	eps6f			
-0.15388	-0.15388	-0.00000		-0.03444	0.03444	-0.00000			
N1	N2	N6		M1	M2	M6			
0.00000	0.00000	0.00000		0.00000	0.00000	0.00000			
sigma1o	sigma2o	sigma6o	[MPa]	sigma1f	sigma2f	sigma6f			
0.00000	0.00000	0.00000		0.00000	0.00000	0.00000			
Temperature difference : -100 °C				Moisture : 0					



# GENLAM: EXAMPLE 2 – INPUT $[(+45/-45)_r]$

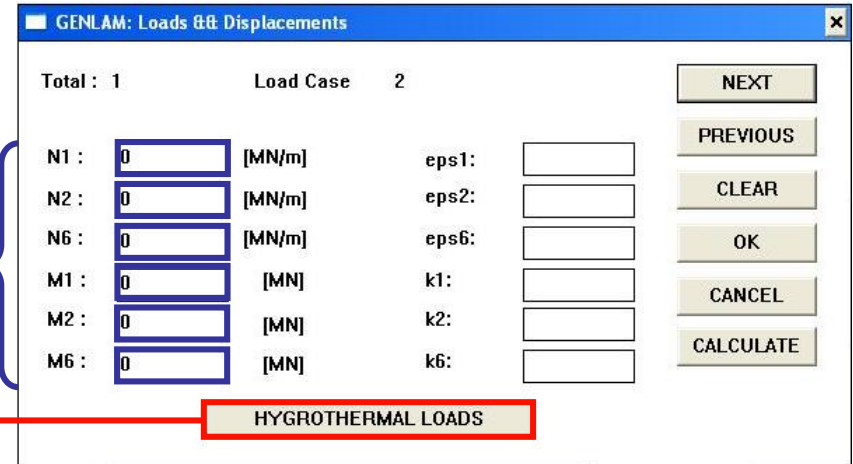


T300/5208 is part of the material database



Mechanical Loads

Hygrothermal Loads



HYGROTHERMAL LOADS



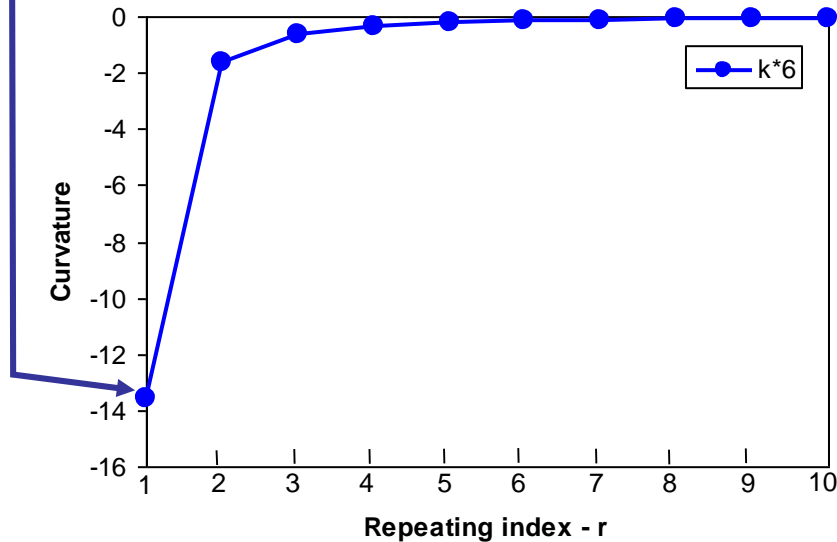
# GENLAM: EXAMPLE 2 – OUTPUT k [(+45/-45)<sub>r</sub>]

r = 1

...

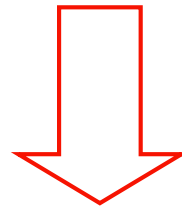
r = 10

CURVATURES VALUES FOR LOAD CASE 1						CURVATURES VALUES FOR LOAD CASE 1							
eps1	eps2	eps6		k1	k2	k6	eps1	eps2	eps6		k1	k2	k6
-0.00052	-0.00052	-0.00000		-0.00000	-0.00000	-13.61600	-0.00015	-0.00015	-0.00000		0.00000	0.00000	-0.05510
eps1o	eps2o	eps6o	[*1E3]	eps1f	eps2f	eps6f	eps1o	eps2o	eps6o	[*1E3]	eps1f	eps2f	eps6f
-0.52095	-0.52095	-0.00000		-0.00000	-0.00000	-1.70200	-0.15388	-0.15388	-0.00000		0.00000	0.00000	-0.06888
N1	N2	N6		M1	M2	M6	N1	N2	N6		M1	M2	M6
0.00000	0.00000	0.00000		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000		0.00000	0.00000	0.00000
sigma1o	sigma2o	sigma6o	[MPa]	sigma1f	sigma2f	sigma6f	sigma1o	sigma2o	sigma6o	[MPa]	sigma1f	sigma2f	sigma6f
0.00000	0.00000	0.00000		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000		0.00000	0.00000	0.00000
Temperature difference : -100 °C				Moisture : 0			Temperature difference : -100 °C				Moisture : 0		

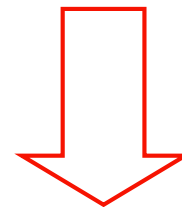


# GENLAM: EXAMPLE 2 - MESSAGE

Terms of coupling  $B^*$  matrix tend to zero with the increase of the repeating index  $r$



Repeat enough sub-laminates and the resulting non-symmetric laminate behavior will approach to a symmetric laminate

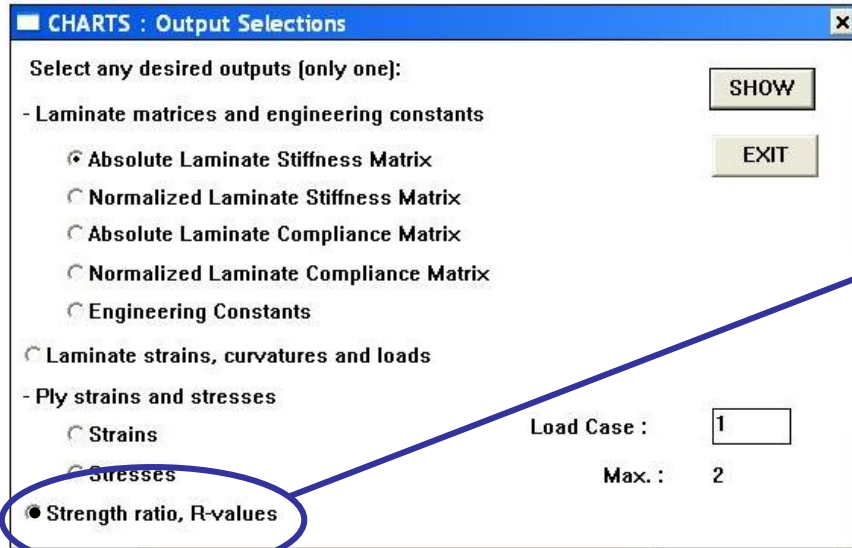


No curvature after curing for homogenized laminates

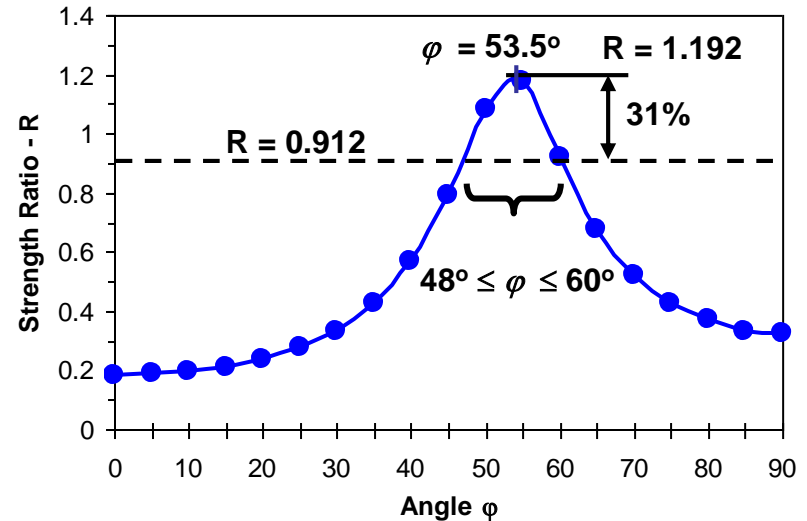
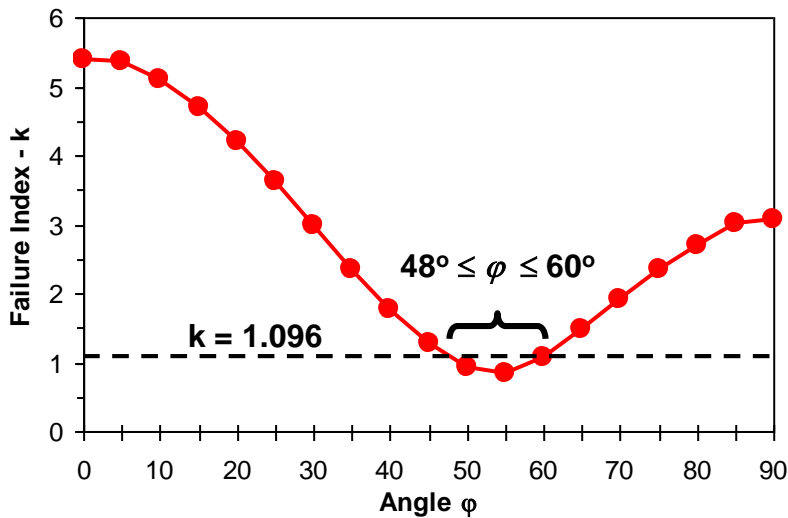
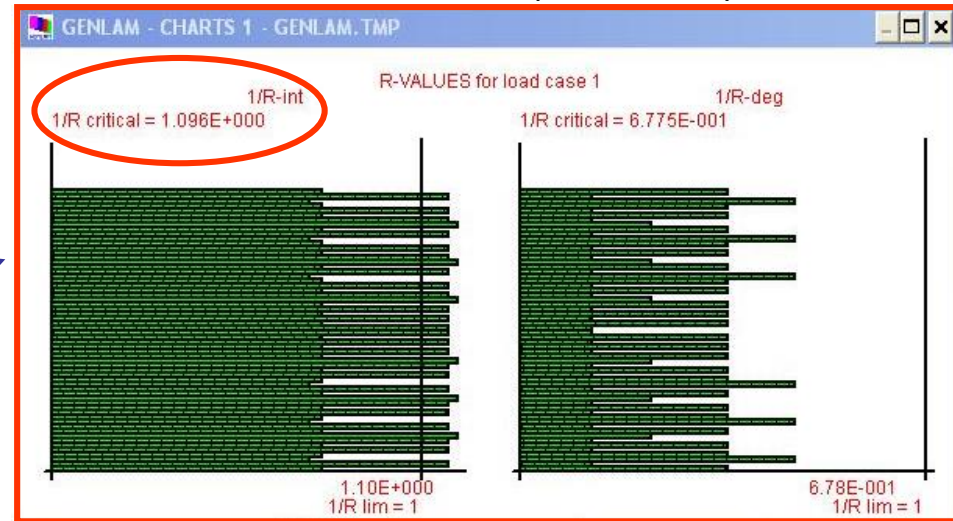


# GENLAM: EXAMPLE 3 – FIRST PLY FAILURE

Output: Strength Ratio

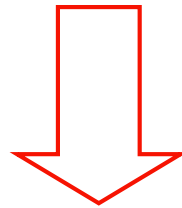


FPF (First Ply Failure) – Tsai-Wu  
Failure Index  $k = 1.096$  ( $R=0.912$ )

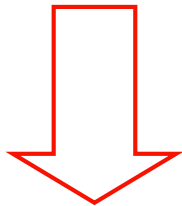


# GENLAM: EXAMPLE 3 - MESSAGE

Complicated symmetric layup with four different angles  
resulted in Failure Index  $k = 1.096$   
(Strength Ratio  $R=0.912$ )

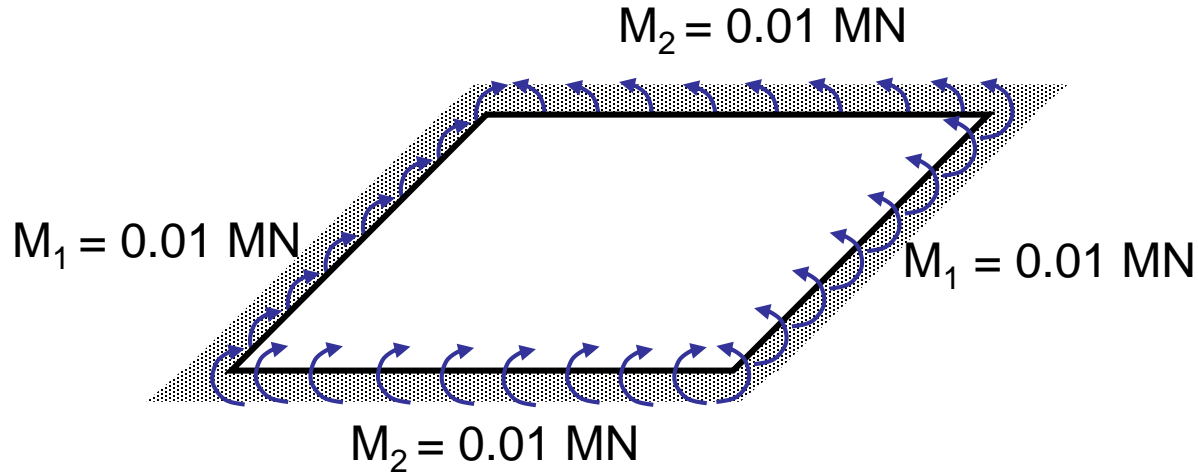


Selected symmetric angle-ply laminates with same thickness  
for different angles resulted in better laminates for angles  
 $48^\circ \leq \varphi \leq 60^\circ$  (31% gain for  $\varphi = 53.5^\circ$ )



Less angles can result in better design

# GENLAM: EXAMPLE 4



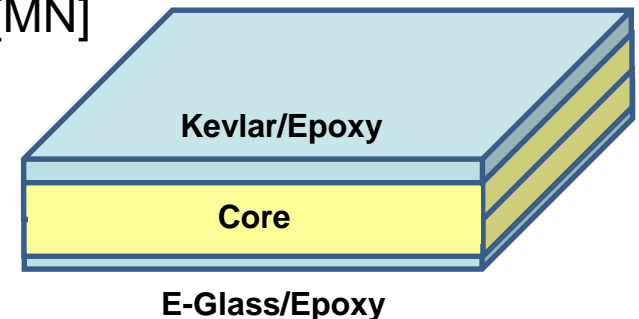
Material/Layup: Top laminate – Kevlar/Epoxy –  $[(90/-45/45/0)_2]$   
Bottom laminate – E-Glass/Epoxy –  $[0/45/-45/90]$   
Core – Thickness of 32 material plies

Load vectors:  $N=\{0,0,0\}$  [MN/m];  $M=\{0.01, 0.01, 0\}$  [MN]

Displacements:  $\varepsilon_1 = \varepsilon_2 = \varepsilon_6 = 0$

Hygrothermal effects:  $\Delta T = -100^\circ\text{C}$ ;  $\Delta c = 0.005$

Evaluate FPF (First Ply Failure Tsai-Wu)



# GENLAM: EXAMPLE 4 – INPUT LAMINATE & BC

## Laminate input

**NOTE: Plies are numbered from the bottom to the top.**

Ply Number: 21

Angle [Degrees]:

Material Number:

Available Materials:

- 4 b4\_n55.mat
- 5 core.mat
- 6 im6\_epox.mat
- 7 ishikawa.mat
- 8 kev\_ep.mat
- 9 scotch.mat
- 10 steel.mat

Orientation:

Material N. :

Repetitions :

Symmetry :  [n]s  [n - 1]s'

Buttons: OPEN..., NEW, OK, SAVE, CALCULATE, CANCEL

## Loads & displacements (strains) input

OBS:

Core ply thickness = 0.5 mm

Material ply thickness = 0.125 mm

Each core ply is equivalent to 4 material plies

32 material plies = 8 core plies

$$M_1 = M_2 = 0.01 \text{ MN}$$

Total : 1 Load Case 1

$\epsilon_1 = \epsilon_2 = \epsilon_6 = 0$

N1 :  [MN/m]

N2 :  [MN/m]

N6 :  [MN/m]

M1 :  [MN]

M2 :  [MN]

M6 :  [MN]

eps1:

eps2:

eps6:

k1:

k2:

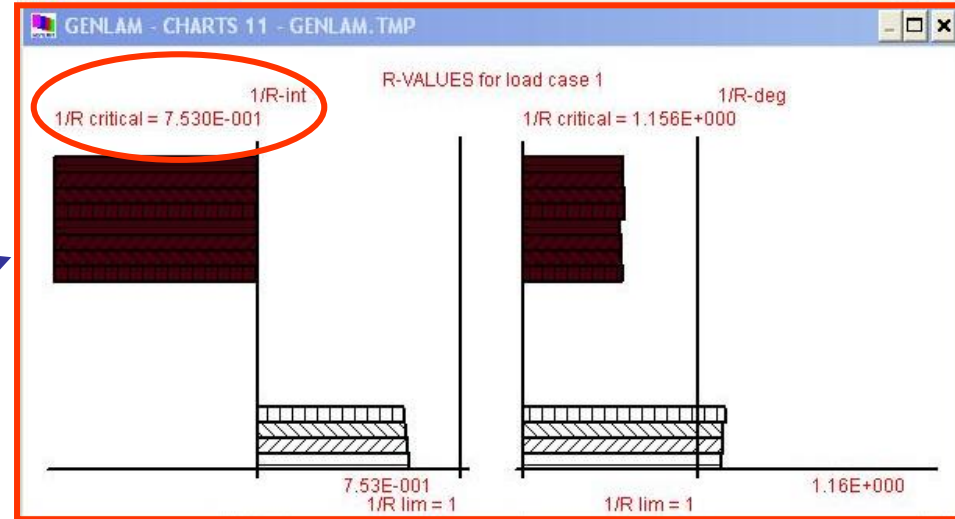
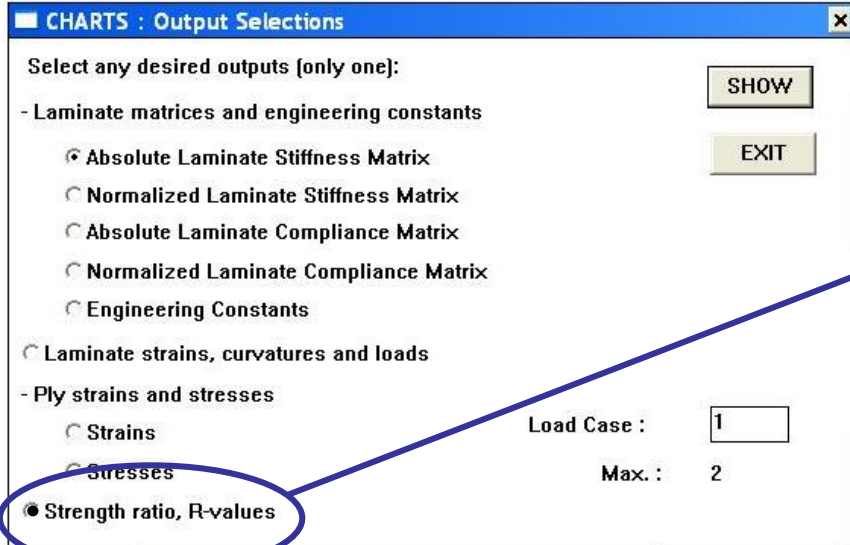
k6:

Buttons: NEXT, PREVIOUS, CLEAR, OK, CANCEL, CALCULATE, HYGROTHERMAL LOADS

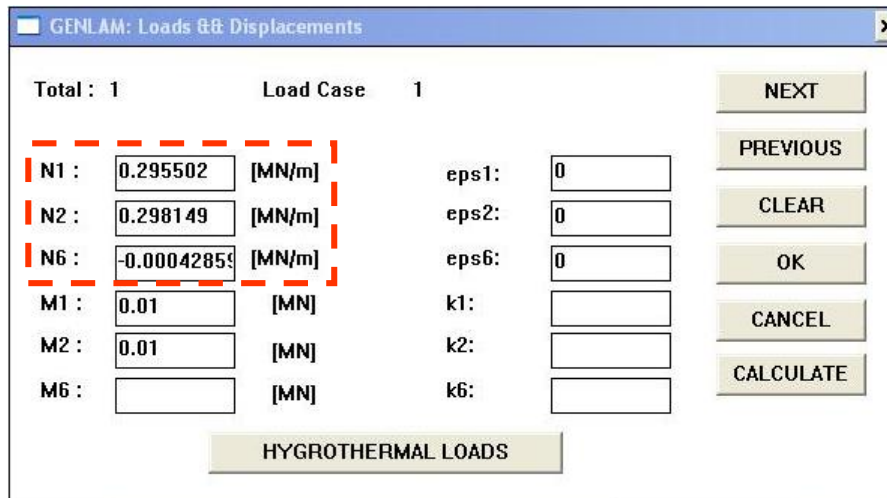
# GENLAM: EXAMPLE 4 – FIRST PLY FAILURE

Output: Strength Ratio

FPF (First Ply Failure) – Tsai-Wu Failure Index  $k = 0.753$  ( $R=1.328$ )



Loads (after calculation)



Internal loads due to the displacement restriction:

$$N_1 = 0.296 \text{ MN/m}$$

$$N_2 = 0.298 \text{ MN/m}$$

$$N_6 \approx 0 \text{ MN/m}$$



# GENLAM: EXAMPLE 4 - MESSAGE

GENLAM flexibility:

Capable to perform analysis for hybrid load / displacement

Capable to perform analysis for sandwich laminates

Top and bottom sub-laminates can be of different materials  
as well as non-symmetric

**THANK YOU**

**QUESTIONS ?**