Classical Lamination Theory

Analysis of Composite Laminates

23B0015 : Ayush Bhaskar

Material System: Carbon / Epoxy

Mechanical, Thermal, and Hygroscopic Analysis

1. Introduction & Material Properties

Classical Lamination Theory (CLT) provides a framework to predict the mechanical, thermal, and hygroscopic response of multi-layer composite laminates. Each lamina is treated as a homogeneous orthotropic layer, and the laminate response is obtained by integration through the thickness via the ABD stiffness matrix.

1.1 Material System

All analyses use a unidirectional Carbon/Epoxy ply with the following properties:

Property	Symbol	Value	Unit
Longitudinal Modulus	E_1	135	GPa
Transverse Modulus	E_2	10	GPa
Shear Modulus	G_{12}	5	GPa
Major Poisson's Ratio	ν_{12}	0.30	—
Minor Poisson's Ratio	ν_{21}	0.0222	—
Ply Thickness	t	0.125	mm
CTE — Fibre Direction	α_1	-0.5	$\times 10^{-6}$ /K
CTE — Transverse	α_2	25	$\times 10^{-6}$ /K
CME — Fibre Direction	β_1	0.02	$\times 10^{-3}$ /%M
CME — Transverse	β_2	0.30	$\times 10^{-3}$ /%M

The strongly negative α_1 reflects carbon fibre's near-zero to slightly negative CTE along the fibre. The large positive α_2 is dominated by the matrix. This mismatch is the primary driver of residual thermal stresses in multi-directional laminates.

1.2 Mechanical Load Applied

For all mechanical analyses: Nx = 100 kN/m, Ny = 0, Nxy = 0, with all moments zero. Temperature change $\Delta T = -100$ K and moisture change $\Delta C = 0.02$ (2% by weight) are used for environmental analyses.

2. Laminate Analysis — Mechanical Response

2a. Unidirectional $[0]_n$ and $[90]_n$ Laminates

$[0]_4$ Laminate

All four plies oriented at 0° (fibres along the loading direction x). This represents the maximum stiffness configuration in the x-direction.

Matrix Term	Value	Physical Meaning
A_{11}	67.95 MN/m	Dominant extensional stiffness in x (fibre direction)
A_{22}	5.03 MN/m	Low transverse stiffness (matrix dominated)
A_{12}	1.51 MN/m	Poisson coupling
A_{66}	2.50 MN/m	Shear stiffness
B	≈0	Zero: symmetric and all plies at same angle
D_{11}	1.416 N·m	Bending stiffness in x

Midplane strains: $\varepsilon_a^0 = 1.482\times10^{-3}$, $\varepsilon_y^0 = -4.44\times10^{-4}$ (Poisson contraction), $\gamma_{ay}^0 = 0$

Since B = 0 and $\kappa \approx 0$, all plies carry identical strain, giving uniform $\sigma_a = 200$ MPa through the thickness. In the local 1-2 frame (0°), global and local stresses are identical.

$[90]_4$ Laminate

Fibres perpendicular to loading. A_{11} and A_{22} swap relative to $[0]_4$: $A_{11} = 5.03$ MN/m (matrix direction takes the load), $A_{22} = 67.95$ MN/m.

Key effect: The laminate is 13.5× less stiff in x than $[0]_4$. Midplane strain $\varepsilon_a^0 = 0.02$ (vs 1.48×10^{-3} for $[0]_4$). In the ply local frame, $\sigma_2 = 200$ MPa (transverse stress), which is critical since composite transverse strength is typically only 50–80 MPa, meaning this configuration would fail immediately.

Quantity	$[0]_4$	$[90]_4$
A_{11} (MN/m)	67.95	5.03

Quantity	$[0]_4$	$[90]_4$
A_{22} (MN/m)	5.03	67.95
ε_a^o under 100 kN/m	1.482×10^{-3}	0.020
σ_1 in ply frame (MPa)	200 (fibre stress)	≈0 (no fibre load)
σ_2 in ply frame (MPa)	≈0 (safe)	200 (transverse — critical)
B matrix	0	0

Effect of n: Increasing n scales A proportionally (A ∝ n·t) and D as n^3 (D ∝ n^3). Midplane strains decrease inversely with n. The stress per ply remains constant since each ply carries the same strain.

2b. Cross-Ply Laminates: [0/90]T vs [0/90]s

Both laminates contain equal numbers of 0° and 90° plies, giving identical A matrices. The key differences arise in B, D, and the bending-extension coupling behaviour.

Property	[0/90]T (2 plies)	[0/90]s (4 plies)
$A_{11} = A_{22}$ (MN/m)	18.25	36.49 (2×, double thickness)
B_{11} (N)	−0.983 kN	0 (symmetric)
B_{22} (N)	+0.983 kN	0 (symmetric)
D_{11} (N·m)	0.0950	1.252 (13× larger)
D_{22} (N·m)	0.0950	0.269
κ_a under Nx	128.6 m^{-1} (huge)	≈0 (no curvature)
Ply σ_a — 0° layer (MPa)	595.5 (ply 1)	372.7 (outer 0°)
Ply σ_a — 90° layer (MPa)	204.5 (ply 2)	27.3 (inner 90°)

Key Differences and Comments

- B Matrix: [0/90]T has a non-zero B matrix (B_{11} = −0.983 kN, B_{22} = +0.983 kN) because the 0° and 90° plies are not symmetrically placed about the midplane. This causes bending-extension coupling: a pure membrane load Nx generates a curvature κ_a = 128.6 m^{-1}, which is enormous.
- [0/90]s is symmetric, so B = 0 exactly. A membrane load produces no curvature, which is essential for most structural applications.
- Stress distribution: In [0/90]T, the curvature creates a large strain gradient. The 0° ply (bottom, z = −62.5 μm) carries 595.5 MPa vs 204.5 MPa in the 90° ply. In [0/90]s, the outer 0° plies carry 372.7 MPa and inner 90° plies carry only 27.3 MPa — a much more reasonable distribution.
- D matrix: [0/90]s has D_{11} = 1.252 N·m vs 0.095 N·m for [0/90]T. The outer 0° plies in [0/90]s sit further from the midplane, dramatically increasing bending resistance via the cubic z^3 weighting.
- Practical implication: [0/90]T should be avoided in real structures due to warping. [0/90]s is the standard balanced symmetric cross-ply used in aerospace panels.

2c. Angle-Ply Laminates: [+45/−45] vs [+45/−45/−45/+45]

Property	[+45/−45] (2 plies)	[+45/−45/−45/+45] (4 plies)
$A_{11} = A_{22}$ (MN/m)	10.75	21.50 (2×)
A_{12} (MN/m)	8.25	16.50 (2×)
A_{66} (MN/m)	8.75	17.49 (2×)
$A_{16} = A_{26}$	0	0 (balanced)
$B_{16} = B_{26}$ (N)	−491.6 (significant)	0 (symmetric)
$D_{16} = D_{26}$ (N·m)	0	0.246 (non-zero!)
ε_a^o under Nx	0.02596	0.01132 (stiffer)
γ_{ay}^o under Nx	0	0
κ_{ay} under Nx	128.6 m^{-1}	≈0 (symmetric)
Local τ_{12} (MPa)	±200	±100 (halved due to z-position)

Key Differences and Comments

- A matrix: All terms scale exactly 2× with doubling of plies. The ratio $A_{12}/A_{11} = 0.768$ shows very high Poisson coupling — applying Nx generates large ε_y.
- B matrix: [+45/−45] has $B_{16} = B_{26} = -491.6$ N (membrane-bending-twist coupling). Under Nx, this produces a twisting curvature $\kappa_{ay} = 128.6\ m^{-1}$ — the laminate warps. [+45/−45/−45/+45] is symmetric so B = 0.
- $D_{16} \neq 0$ in [+45/−45/−45/+45]: Even though $A_{16} = 0$ (balanced, so no membrane shear-extension coupling), the bending-twist $D_{16} = 0.246$ N·m is non-zero. This is because the outer plies are +45° and inner are −45°, so the cubic z^3 weighting does NOT cancel. A moment Mx will generate twisting curvature.
- Shear stress: [+45/−45] under Nx generates $\tau_{ay} = \pm 93.7$ MPa in global frame. After rotation to local 1-2 frame: $\tau_{12} = \mp 200$ MPa. In [+45/−45/−45/+45] (B=0, κ=0), all plies have the same ε^o, giving $\tau_{12} = \pm 100$ MPa.
- The [+45/−45/−45/+45] configuration is preferred structurally: no warping under membrane loads and more uniform stress distribution across plies.

2d. Balanced Laminate configuration [0/45/−45/90]s

The quasi-isotropic (QI) laminate uses angles spaced at 360°/N intervals (here N=4: 0°, 45°, −45°, 90°). The symmetric stacking [0/45/−45/90]s (8 plies) is one of the most widely used configurations in aerospace structures.

Isotropy Condition Verification

For a truly quasi-isotropic laminate, the A matrix must satisfy $A_{11} = A_{22}$ and $A_{11} - A_{12} = 2A_{66}$:

Check: $A_{11} - A_{12} = 57.99 - 18.01 = 39.98$ MN/m **$2A_{66}$ = 2 × 19.99 = 39.98 MN/m ✓**

Matrix Property	Value	Comment
$A_{11} = A_{22}$ (MN/m)	57.99	In-plane isotropy confirmed
A_{12} (MN/m)	18.01	Isotropic Poisson coupling
A_{66} (MN/m)	19.99	Effective in-plane shear modulus
$A_{16} = A_{26}$	≈0 (balanced)	No shear-extension coupling
B matrix	≈0 (numeric noise)	Symmetric layup
D_{11} (N·m)	8.017	Much higher than 0/90 or 45 alone
D_{22} (N·m)	2.118	Bending stiffness anisotropic
$D_{16} = D_{26}$ (N·m)	0.492	Non-zero despite balanced A

Ply Stress Distribution under Nx = 100 kN/m

Despite the isotropic membrane response, ply stresses vary significantly between orientations:

Ply (angle)	z_mid (mm)	σ_a (MPa)	σ_γ (MPa)	$\tau_{a\gamma}$ (MPa)
1 & 8 (0°)	±437.5	257.6	−0.20	≈0
2 & 7 (45°)	±312.5	62.5	37.5	41.4
3 & 6 (−45°)	±187.5	62.5	37.5	−41.4
4 & 5 (90°)	±62.5	17.4	−74.8	≈0

Literature context: The QI laminate is used when the in-plane load direction is unknown or variable (e.g. fuselage skins, satellite panels). Its "quasi-isotropic" behaviour only applies to in-plane membrane stiffness — bending remains anisotropic, as $D_{11} \neq D_{22}$ here (8.02 vs 2.12 N·m : from the results of script) because the 0° plies sit at the outermost positions.

3. Thermal Residual Stress Analysis (ΔT = −100 K)

During manufacturing, composite laminates are cured at elevated temperatures (typically 120–180°C for carbon/epoxy). On cooling to room temperature (ΔT ≈ −100 to −150 K), thermal residual stresses develop because plies with different fibre orientations have different CTEs.

3.1 Thermal Resultants Summary

Laminate	NT_a (N/m)	NT_γ (N/m)	MT_a (N)	MT_γ (N)
$[0]_4$	−377.5	−12508.4	0	0
$[90]_4$	−12508.4	−377.5	0	0
[0/90]T	−3221.5	−3221.5	−0.190	+0.190
[0/90]s	−6442.9	−6442.9	≈0	≈0
[+45/−45]	−3221.5	−3221.5	0	−0.190 (twist)

Laminate	NT_a (N/m)	NT_γ (N/m)	MT_a (N)	MT_γ (N)
[+45/−45/−45/+45]	−6442.9	−6442.9	0	0
QI [0/45/−45/90]s	−12885.9	−12885.9	≈0	≈0

3.2 Analysis by Laminate Type

$[0]_4$ and $[90]_4$

These single-angle laminates develop no thermal stresses in the classical sense because all plies are identical — there is no inter-ply constraint. The thermal loads NT represent the restrained thermal resultants if the laminate were held flat, but in a free laminate, it simply expands uniformly. The NT_γ is much larger than NT_a for $[0]_4$ (−12508 vs −377) because $\alpha_2 >> |\alpha_1|$.

[0/90]T

- $NT_a = NT_\gamma = -3221.5$ N/m: Equal in both directions due to 50/50 fibre content.
- $MT_a = -0.190$ N, $MT_\gamma = +0.190$ N: The thermal moment arises from the asymmetry. The 0° ply wants to contract in y (large α_2) but expand in x (negative α_1), while the 90° ply has the reverse. Since they are at different z positions, this creates bending moments. The laminate will warp thermally in addition to mechanically.

[0/90]s

- NT equal in x and y (−6442.9 N/m each) — double the [0/90]T value due to double thickness.
- MT ≈ 0: Symmetry ensures thermal moments cancel. The laminate remains flat after thermal loading — a critical advantage of symmetric layups for manufacturing.

[+45/−45] vs [+45/−45/−45/+45]

[+45/−45]: NT equal in x and y (−3221.5 N/m). However, a thermal twisting moment $MT_{a\gamma} = -0.190$ N develops — the asymmetric +45/−45 layup generates thermal warping about the twist axis. This is a well-known manufacturing problem with unbalanced angle-ply laminates.

[+45/−45/−45/+45]: MT = 0 due to symmetry. No thermal warping.

Quasi-Isotropic [0/45/−45/90]s

$NT_a = NT_\gamma = -12885.9$ N/m — the largest thermal resultant of all configurations. This is because the QI laminate contains all four angles, each contributing thermal loads. The α_2 (25×10^{-6}/K) dominates heavily over α_1 (-0.5×10^{-6}/K), so all non-0° plies contribute strongly. MT ≈ 0 due to symmetry.

Key Observation	Laminates Affected
No thermal moment (MT = 0): safe for manufacturing	$[0]_4$, $[90]_4$, [0/90]s, [+45/−45/−45/+45], QI
Thermal warping (MT ≠ 0): manufacturing defect risk	[0/90]T, [+45/−45]
$NT_a \neq NT_\gamma$: unbalanced in-plane thermal load	$[0]_4$, $[90]_4$
$NT_a = NT_\gamma$: balanced thermal in-plane response	[0/90] family, [45] family, QI

Key Observation	Laminates Affected
Largest thermal resultant magnitude	QI at −12885.9 N/m

4. Combined Thermal + Hygroscopic Residual Stresses

Carbon/Epoxy absorbs moisture from the environment. Saturated conditions at sea level correspond to approximately ΔC = 1–3% by weight. We use ΔC = 2% (ΔC = 0.02) as a representative saturated condition, applied simultaneously with ΔT = −100 K.

4.1 Moisture Resultants

Laminate	NM_a (N/m)	NM_γ (N/m)	MM_a (N)	MM_γ (N)
$[0]_4$	36.24	30.81	0	0
$[90]_4$	30.81	36.24	0	0
[0/90]T	16.76	16.76	-8.49×10^{-5}	$+8.49\times10^{-5}$
[0/90]s	33.52	33.52	≈0	≈0
[+45/−45]	16.76	16.76	0	-8.49×10^{-5}
[+45/−45/−45/+45]	33.52	33.52	0	0
QI	67.05	67.05	≈0	≈0

4.2 Comparison: Thermal vs. Combined (Thermal + Moisture)

Laminate	NT_a+NM_a (N/m)	NT_a only (N/m)	Moisture Effect (N/m)	% Change
$[0]_4$	−341.3	−377.5	+36.2 (relief)	−9.6%
$[90]_4$	−12478	−12508	+30.8 (relief)	−0.2%
[0/90]T	−3204.7	−3221.5	+16.8 (relief)	−0.5%
[0/90]s	−6409.4	−6443.0	+33.5 (relief)	−0.5%
[+45/−45]	−3204.7	−3221.5	+16.8 (relief)	−0.5%
[+45/−45/−45/+45]	−6409.4	−6443.0	+33.5 (relief)	−0.5%
QI	−12819	−12886	+67.0 (relief)	−0.5%

4.3 Physical Explanation of Moisture Effect

Opposing Expansion Directions

The CME coefficients are both positive ($\beta_1 = 0.02\times10^{-3}$/%, $\beta_2 = 0.30\times10^{-3}$/%). Moisture causes swelling in both the fibre and transverse directions. This is the opposite sign to the thermal contraction (ΔT = −100 K causes shrinkage). Therefore:

- Thermal loads: negative (compressive restrained resultants due to cooling shrinkage)
- Moisture loads: positive (tensile restrained resultants due to moisture swelling)
- Combined effect: partial relief of thermal residual stresses

Magnitude Assessment

The moisture-induced NM is 2–3 orders of magnitude smaller than NT:

- NT for $[0]_4$ = −377.5 N/m (thermal, ΔT = −100K)
- NM for $[0]_4$ = +36.2 N/m (moisture, ΔC = 2%)
- Ratio NM/NT ≈ 9.6% for $[0]_4$ x-direction; only 0.2% for y-direction

The $[0]_4$ x-direction sees the most relative relief because NT_a is small (driven by the negative α_1) while NM_a benefits from the positive β_1. The y-direction of all laminates shows minimal change because NT_γ is dominated by the large negative α_2 contribution.

Moment Relief

The moisture moments MM are also orders of magnitude smaller than MT. For asymmetric laminates ([0/90]T and [+45/−45]), the thermal twisting/bending moment is barely affected by moisture saturation. The structural warping problem from asymmetric layups cannot be resolved by moisture uptake.

Key Finding	Implication
Moisture partially relieves thermal residual stresses	Benefit: lower residual stress in service (if wet)
Relief is small (≈0.2–9.6%)	Thermal stresses dominate; moisture is secondary
Symmetric laminates: MM ≈ 0 with moisture	No additional warping from moisture in sym. layups
QI has largest absolute moisture relief (+67 N/m)	More fibre angles = more transverse swelling contributions
Moisture swelling is slow (weeks to months)	Thermal stresses develop immediately at demould

6. Code output :

```
Laminate: [0]n (n=4)
Stacking: [0, 0, 0, 0]

A Matrix:
 [[67953020.13422818  1510067.11409396        0.        ]
 [ 1510067.11409396  5033557.04697987        0.        ]
 [       0.                0.          2500000.        ]]

B Matrix:
 [[0.00000000e+00 0.00000000e+00 0.00000000e+00]
 [0.00000000e+00 2.84217094e-14 0.00000000e+00]
 [0.00000000e+00 0.00000000e+00 0.00000000e+00]]

D Matrix:
 [[1.41568792 0.03145973 0.        ]
 [0.03145973 0.10486577 0.        ]
 [0.         0.         0.05208333]]

Midplane Strain: [ 0.00148148 -0.00044444  0.        ]
Curvature: [-2.69479912e-18  1.21265960e-16  0.00000000e+00]
```

```
Thermal Resultants NT: [  -377.51677852 -12508.38926174      0.        ]
Thermal Moments MT: [0. 0. 0.]

Moisture Resultants NM: [36.24161074 30.80536913  0.        ]
Moisture Moments MM: [0. 0. 0.]

====================================
Laminate: [90]n (n=4)
Stacking: [90, 90, 90, 90]

A Matrix:
 [[5.03355705e+06 1.51006711e+06 9.04101664e-11]
 [1.51006711e+06 6.79530201e+07 3.76229579e-09]
 [9.04101664e-11 3.76229579e-09 2.50000000e+06]]

B Matrix:
 [[2.84217094e-14 0.00000000e+00 0.00000000e+00]
 [0.00000000e+00 0.00000000e+00 2.52435490e-29]
 [0.00000000e+00 2.52435490e-29 0.00000000e+00]]

D Matrix:
 [[1.04865772e-01 3.14597315e-02 1.88354513e-18]
 [3.14597315e-02 1.41568792e+00 7.83811622e-17]
 [1.88354513e-18 7.83811622e-17 5.20833333e-02]]

Midplane Strain: [ 2.00000000e-02 -4.44444444e-04 -5.44287466e-20]
Curvature: [-5.45696821e-15  1.21265960e-16  2.30262415e-31]

Thermal Resultants NT: [-1.25083893e+04 -3.77516779e+02  7.42801708e-13]
Thermal Moments MT: [0. 0. 0.]

Moisture Resultants NM: [3.08053691e+01 3.62416107e+01 3.32873794e-16]
Moisture Moments MM: [0. 0. 0.]

====================================
Laminate: [0/90]T
Stacking: [0, 90]

A Matrix:
 [[1.82466443e+07 7.55033557e+05 2.26025416e-11]
 [7.55033557e+05 1.82466443e+07 9.40573947e-10]
 [2.26025416e-11 9.40573947e-10 1.25000000e+06]]

B Matrix:
 [[-9.83116611e+02  0.00000000e+00  1.41265885e-15]
 [ 0.00000000e+00  9.83116611e+02  5.87858717e-14]
 [ 1.41265885e-15  5.87858717e-14  0.00000000e+00]]

D Matrix:
 [[9.50346057e-02 3.93246644e-03 1.17721571e-19]
 [3.93246644e-03 9.50346057e-02 4.89882264e-18]
 [1.17721571e-19 4.89882264e-18 6.51041667e-03]]

Midplane Strain: [ 1.24297259e-02 -5.14333486e-04  1.69446739e-20]
Curvature: [ 1.28583372e+02  5.53401519e-16 -3.77926115e-16]

Thermal Resultants NT: [-3.22147651e+03 -3.22147651e+03  1.85700427e-13]
Thermal Moments MT: [-1.89544883e-01  1.89544883e-01  1.16062767e-17]

Moisture Resultants NM: [1.67617450e+01 1.67617450e+01 8.32184486e-17]
Moisture Moments MM: [-8.49412752e-05  8.49412752e-05  5.20115304e-21]

====================================
Laminate: [0/90]s
Stacking: [0, 90, 90, 0]

A Matrix:
 [[3.64932886e+07 1.51006711e+06 4.52050832e-11]
 [1.51006711e+06 3.64932886e+07 1.88114789e-09]
 [4.52050832e-11 1.88114789e-09 2.50000000e+06]]

B Matrix:
 [[0.00000000e+00 0.00000000e+00 0.00000000e+00]
```

```
 [0.00000000e+00 8.52651283e-14 0.00000000e+00]
 [0.00000000e+00 0.00000000e+00 0.00000000e+00]]

D Matrix:
 [[1.25183515e+00 3.14597315e-02 2.35443142e-19]
 [3.14597315e-02 2.68718540e-01 9.79764528e-18]
 [2.35443142e-19 9.79764528e-18 5.20833333e-02]]

Midplane Strain: [ 2.74492988e-03 -1.13583306e-04  3.58328849e-20]
Curvature: [-9.08397303e-19  3.61466427e-17 -6.79561165e-33]

Thermal Resultants NT: [-6.44295302e+03 -6.44295302e+03  3.71400854e-13]
Thermal Moments MT: [1.04083409e-17 0.00000000e+00 0.00000000e+00]

Moisture Resultants NM: [3.35234899e+01 3.35234899e+01 1.66436897e-16]
Moisture Moments MM: [0. 0. 0.]

====================================
Laminate: [+45/-45]
Stacking: [45, -45]

A Matrix:
 [[10750838.9261745   8250838.9261745         0.        ]
 [ 8250838.9261745  10750838.9261745         0.        ]
 [       0.                0.          8745805.36912752]]

B Matrix:
 [[   0.             0.          -491.55830537]
 [   0.             0.          -491.55830537]
 [-491.55830537 -491.55830537    0.        ]]

D Matrix:
 [[0.05599395 0.04297312 0.        ]
 [0.04297312 0.05599395 0.        ]
 [0.         0.         0.04555107]]

Midplane Strain: [ 0.0259577 -0.0140423  0.       ]
Curvature: [  0.           0.         128.58337154]

Thermal Resultants NT: [-3221.47651007 -3221.47651007     0.        ]
Thermal Moments MT: [ 0.          0.         -0.18954488]

Moisture Resultants NM: [16.76174497 16.76174497  0.        ]
Moisture Moments MM: [ 0.00000000e+00  0.00000000e+00 -8.49412752e-05]

====================================
Laminate: [+45/-45/-45/+45]
Stacking: [45, -45, -45, 45]

A Matrix:
 [[21501677.85234899 16501677.85234899        0.        ]
 [16501677.85234899 21501677.85234899        0.        ]
 [       0.                0.         17491610.73825504]]

B Matrix:
 [[0. 0. 0.]
 [0. 0. 0.]
 [0. 0. 0.]]

D Matrix:
 [[0.44795162 0.34378496 0.24577915]
 [0.34378496 0.44795162 0.24577915]
 [0.24577915 0.24577915 0.36440856]]

Midplane Strain: [ 0.01131567 -0.00868433  0.        ]
Curvature: [0. 0. 0.]

Thermal Resultants NT: [-6442.95302013 -6442.95302013     0.        ]
Thermal Moments MT: [0. 0. 0.]

Moisture Resultants NM: [33.52348993 33.52348993  0.        ]
Moisture Moments MM: [0. 0. 0.]
```

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====================================
Laminate: Balanced Quasi-Isotropic
Stacking: [0, 45, -45, 90, 90, -45, 45, 0]

A Matrix:
 [[5.79949664e+07 1.80117450e+07 0.00000000e+00]
 [1.80117450e+07 5.79949664e+07 1.86264515e-09]
 [0.00000000e+00 1.86264515e-09 1.99916107e+07]]

B Matrix:
 [[ 9.09494702e-13 -8.52651283e-14  0.00000000e+00]
 [-8.52651283e-14 -2.27373675e-13  0.00000000e+00]
 [ 0.00000000e+00  0.00000000e+00 -5.68434189e-14]]

D Matrix:
 [[8.01650762 1.26673483 0.49155831]
 [1.26673483 2.11780796 0.49155831]
 [0.49155831 0.49155831 1.43172364]]

Midplane Strain: [ 1.90836119e-03 -5.92687904e-04  5.52215259e-20]
Curvature: [-2.49256438e-16  1.54758401e-16  3.24443164e-17]

Thermal Resultants NT: [-1.28859060e+04 -1.28859060e+04  4.54747351e-13]
Thermal Moments MT: [1.17961196e-16 0.00000000e+00 0.00000000e+00]

Moisture Resultants NM: [6.70469799e+01 6.70469799e+01 1.11022302e-16]


Moisture Moments MM: [ 0.00000000e+00 -4.33680869e-19  0.00000000e+00]
```