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On composite laminates with extensional-anisotropy.

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The definite list of extensionally (membrane) anisotropic composite laminates with up to 21 plies is presented. The listings comprise of individual stacking sequences of entirely non-symmetric laminates, which are characterized in terms of angle- and cross-ply sub-sequence relationships as well as the blend-ratio of unbalanced angle-plies. Dimensionless parameters, including lamination parameters, are provided, from which the extensional and bending stiffness terms are readily calculated and an assessment of the bending stiffness efficiency made for angle- and cross-ply sub-sequences. Comparisons are made between the structural response of extensionally-anisotropic laminates and laminates with both extensional- and bending-anisotropy, which can often be achieved in practice using symmetric configurations. This new class of coupled non-symmetric laminate can also be manufactured flat under a standard elevated temperature curing process, which is contrary to current understanding.

Nomenclature

$\mathbf{A}$,A_{ij}	=	extensional (membrane) stiffness matrix and its elements (i,j = 1, 2, 6)
$\mathbf{B}$,B_{ij}	=	bending-extension-coupling stiffness matrix and its elements (i,j = 1, 2, 6)
$\mathbf{D}$,D_{ij}	=	bending (flexural) stiffness matrix and its elements (i,j = 1, 2, 6)
H	=	laminate thickness (= $n \times t$)
n	=	number of plies in laminate stacking sequence
N_x,N_y	=	in-plane axial load per unit length.
N_{xy}	=	in-plane shear flow.
M_x,M_y	=	bending moments per unit length about principal axes.
M_{xy}	=	twist moment per unit length.
Q_{ij}	=	reduced stiffness (i,j = 1, 2, 6)
Q'_{ij}	=	transformed reduced stiffness (i,j = 1, 2, 6)
t	=	ply thickness
x,y,z	=	principal axes
ε_x,ε_y	=	in-plane axial strains.
γ_{xy}	=	in-plane shear strain.
κ_x,κ_y	=	curvatures about principal axes.
κ_{xy}	=	twist curvature.
ξ_1,ξ_2,ξ_3,ξ_4	=	lamination parameters for extensional stiffness ($\xi_1,\xi_2,\xi_3,\xi_4 = \xi_1^A,\xi_2^A,\xi_3^A,\xi_4^A$)
ξ_9,ξ_{10}	=	lamination parameters for bending stiffness ($\xi_9 = \xi_1^D$, $\xi_{10} = \xi_2^D$)
$\zeta,\zeta_\pm,\zeta_{\circ},\zeta_{\bullet}$	=	bending stiffness parameter for laminate, and angle-ply and cross-ply sub-sequences
+,−,±	=	angle plies, used in stacking sequence definition
○,●	=	cross-plies, used in stacking sequence definition

Matrix sub-scripts

0	=	All elements zero
F	=	All elements finite
S	=	Specially orthotropic form, see Eqs. (3) - (4)

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Keywords

Bend-twist coupling; Buckling; Extensional (or Membrane) Anisotropy; Bending Stiffness Parameters; Lamination Parameters; Laminate Stacking Sequences.

I. Introduction

Composite laminate materials are typically characterized in terms of their response to mechanical (and/or thermal) loading, which is generally associated with a description of the coupling behavior, unique to this type of material, i.e. coupling between in-plane (i.e. extension or membrane) and out-of-plane (i.e. bending or flexure) responses when $B_{ij} \neq 0$ in Eq. (1), coupling between in-plane shear and extension when $A_{16} = A_{26} \neq 0$, and coupling between out-of-plane bending and twisting when $D_{16} = D_{26} \neq 0$.

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ & A_{22} & A_{26} \\ \text{Sym.} & & A_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \tau_{xy} \end{Bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ & B_{22} & B_{26} \\ \text{Sym.} & & B_{66} \end{bmatrix} \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix}$$

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ & B_{22} & B_{26} \\ \text{Sym.} & & B_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \tau_{xy} \end{Bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ & D_{22} & D_{26} \\ \text{Sym.} & & D_{66} \end{bmatrix} \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix} \tag{1}$$

Whilst Eq. (1) describes the well-known **ABD** relation from classical laminate plate theory, it is more often expressed using compact notation:

$$\begin{Bmatrix} \mathbf{N} \\ \mathbf{M} \end{Bmatrix} = \begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{B} & \mathbf{D} \end{bmatrix} \begin{Bmatrix} \boldsymbol{\varepsilon} \\ \boldsymbol{\kappa} \end{Bmatrix} \tag{2}$$

The coupling behavior, which is dependent on the form of the elements in each of the extensional (**A**), coupling (**B**) and bending (**D**) stiffness matrices is now described by an extended subscript notation, defined previously by the Engineering Sciences Data Unit, or ESDU[1] and subsequently augmented for the purposes of this article. Hence, balanced and symmetric stacking sequences, which generally possess bending anisotropy, give rise to coupling between out-of-plane bending and twisting and are referred to by the designation $\mathbf{A}_S\mathbf{B}_0\mathbf{D}_F$, signifying that the elements of the extensional stiffness matrix (**A**) are specially orthotropic in nature, i.e. uncoupled, since

$$A_{16} = A_{26} = 0, \tag{3}$$

the bending-extension coupling matrix (**B**) is null, whilst all elements of the bending stiffness matrix (**D**) are finite, i.e. $D_{ij} \neq 0$.

Laminates possessing extensional anisotropy give rise to coupling between in-plane shear and extension only and, by the same rationale, are referred to by the designation $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$, signifying that all elements of the extensional stiffness matrix (**A**) are finite, i.e. $A_{ij} \neq 0$, the bending-extension coupling matrix (**B**) is null, and the elements of the bending stiffness matrix (**D**) are specially orthotropic in nature, i.e. uncoupled, since

$$D_{16} = D_{26} = 0 \tag{4}$$

This designation is however not listed as part of the ten laminate classifications described in the ESDU data item[1]. Extensional anisotropy is discussed at length in much of the preamble of articles on anisotropic composite laminate materials, but no specific details of stacking sequences for such laminates are given, particularly in the context of angle-ply laminates for use in air vehicle construction. Indeed recently published work[2,3], describing in detail an application for laminates with shear-extension coupling reveals, only through additional calculation of the laminate stiffness terms, that significant bend-twist coupling also exists in the stacking sequences adopted. These observations suggest that there is no current published or accessible data on composite laminate materials with extensionally anisotropic ($\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$) properties. Indeed, this class of coupled non-symmetric laminate can be manufactured flat under a standard elevated temperature curing process given the absence of bending-extension coupling; elastic coupling in non-symmetric laminates is generally understood to produce warping, relative to the intended shape.

This article presents therefore the definitive list of angle-ply stacking sequences for **E**xtensionally **A**nisotropy **L**aminates (or **EAL**s), with the designation $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$, together with the dimensionless stiffness parameters from which the elements of the extensional (**A**) and bending stiffness (**D**) matrices are readily calculated. These new stacking sequences complement the definite list of **F**ully **O**rthotropic **L**aminates (or FOLs), with the designation $\mathbf{A}_S\mathbf{B}_0\mathbf{D}_S$, for up to 21 plies[4-6].

II. Derivation of stacking sequences

Bartholomew[7,8] performed the original work in establishing a definitive list of specially orthotropic laminate stacking sequences ($\mathbf{A}_S\mathbf{B}_0\mathbf{D}_S$), from which the Engineering Sciences Data Unit (ESDU) has since published[9] the so called definitive list with up to 21 plies, including information on extending this list by the addition of orthotropic plies on the top and bottom surface of the laminate. The list contains 75 symmetric sequences and 653 anti-symmetric sequences, together with 49 additional non-symmetric (asymmetric) sequences. This relatively small number of possible sequences for thin laminates clearly leaves limited scope for composite tailoring, particularly where ply terminations are necessary and specially orthotropic characteristics are a design requirement, and was the key motivation leading to the re-development of the definitive list for specially orthotropic angle-ply laminates with up to 21 plies[4-6]. In the derivation of this revised list for standard ply configurations, e.g. ±45, 0 and 90°, the general rule of symmetry is relaxed. Orthotropic plies, as well as angle plies, are therefore no longer constrained to be symmetric about the laminate mid-plane. Consequently, the mixing of 0 and 90° plies requires special attention to avoid violation of the rules for special orthotropy. The resulting sequences are characterized by sub-sequence symmetries using a double prefix notation, the first character of which relates to the form of the angle-ply sub-sequence and the second character to the cross-ply sub-sequence. The double prefix contains any combination of the following characters: *A* to indicate Anti-symmetric form; *N* for Non-symmetric; and *S* for Symmetric. To avoid the trivial solution of a stacking sequence with cross plies only, all sequences have an angle-ply (+) on one surface of the laminate. As a result, the other surface ply may have equal (+) or opposite (–) orientation or it may indeed be an cross ply ($\bigcirc$) of 0 or 90° orientation. A subscript notation, using these three symbols, is employed to differentiate between similar forms of sequence. The form (and number of sequences) in the definitive list[4-6] can be summarized as: *AA* (210), *AN* (14,532), *AS* (21,609), *SC* (12), *SN* (192), *SS* (1,029), $_{+}NS_{+}$ (220), $_{+}NS_{-}$ (296), $_{+}NN_{+}$ (5,498), $_{+}NN_{-}$ (15,188) and $_{+}NN_{\bigcirc}$ (10,041). This is in contrast to the published[9] listings, containing *S* (75), *A* (653) and undefined (49) non-symmetric stacking sequences for laminates with up to 21 plies.

Extensional stiffness terms $A_{16} = A_{26} = 0$ are the key characteristics for specially orthotropic form. However, for computational expedience, this check was not formally included in the algorithm used to determine the definite list of Fully Orthotropic Laminates[4-6], because a simple check confirming that angle plies are balanced, i.e. that $n_+ = n_-$, is sufficient. This check leads to the identification of a highly significant by-product with $A_{16} = A_{26} \neq 0$, resulting from $n_+ \neq n_-$, but with $B_{ij} = D_{16} = D_{26} = 0$, i.e. laminates with extensional anisotropy, and referred to by the designation $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$. Table 1 provides a summary of the number of extensionally anisotropic stacking sequences for each ply-number grouping up to a maximum of 21 plies and provides cross-referencing to the tables of laminate stacking sequences that follow.

Table 1 - Number of extensionally anisotropic stacking sequences ($A_FB_0D_S$) with cross-referencing to Tables of laminate stacking sequences for 7 through 21 ply laminates. Form corresponds to prefix designations for Non-symmetric (N) angle-plies and Non-symmetric (N) cross-plies respectively. Subscripts arranged before and after prefix designations denote angle plies (+, –) or cross plies ($\bigcirc$) and correspond to top ply and bottom ply orientations, respectively.

Form	Number of plies, *n*															Table
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
$_{+}NN_{+}$	-	-	-	-	-	-	-	4	-	8	-	44	-	284	-	5
$_{+}NN_{-}$	-	-	-	-	-	-	-	-	-	-	-	4	-	24	-	6 & 7
$_{+}NN_{\bigcirc}$	-	-	-	-	-	-	-	-	-	-	-	-	-	14	-	8

Arrangement and form of stacking sequence data

For compatibility with the previously published data, similar symbols have been adopted for defining all of the stacking sequences that follow. Additional symbols and parameters are necessarily included to differentiate between each orthotropic ply angle (0° and 90°), given that symmetry about the laminate mid-plane is no longer assumed. Also in common is the assumption of constant ply thickness within the laminate.

As adopted in the published ESDU listings[9], the new sequences are ordered in terms of ascending numbers of plies, n, or ζ (= n^3), which are in turn ordered by ascending value of the bending stiffness parameter for the angle plies ($\zeta_{\pm}$) and finally by one of the two cross ply sub-sequences ($\zeta_{\circ}$) within the laminate. This ordering provides each sequence with a unique designation. The sequences are then listed in Tables 5 – 8 according to sub-sequence symmetry, with form (and number of sequences) $_{+}NN_{+}$ (296), $_{+}NN_{-}$ (28) and $_{+}NN_{\circ}$ (14).

The stiffness parameters are hereby extended to include both cross plies ($\zeta_{\circ}$ and $\zeta_{\bullet}$), including percentage values to indicate the relative proportion ($n_{\pm}/n$, $n_{\circ}/n$ and $n_{\bullet}/n$) and relative contribution to bending stiffness ($\zeta_{\pm}/\zeta$, $\zeta_{\circ}/\zeta$ and $\zeta_{\bullet}/\zeta$) of each ply sub-sequences within the laminate, i.e. a sub-sequence containing either ±, ○ or ● plies.

Comparison of the relative proportion and the contribution to bending stiffness provides a measure of efficiency of the sub-laminate for each ply orientation, in the same sense that the radius of gyration, relating cross-sectional area and second moment of area, provides as assessment of the geometric efficiency of a beam to resist bending.

Whilst the elements (D_{ij}) of the bending stiffness matrix (**D**) are readily obtained from $\zeta_{\pm}$, $\zeta_{\circ}$ and $\zeta_{\bullet}$, as for specially orthotropic laminates ($\mathbf{A}_S\mathbf{B}_0\mathbf{D}_S$), the elements ($A_{ij}$) of the extensional stiffness matrix (**A**) now require a modification with respect to the blend ratio of angle plies. Blend ratio is defined elsewhere[2] as the percentage proportion of negative (n_{-}) to positive (n_{+}) plies. It is redefined here however, to simplify the calculation of the elements of the extensional stiffness matrix, as the ratio of the number of positive (n_{+}) plies to the total number of angle plies ($n_{\pm}$), expressed as a percentage. The laminate sequences of Table 5 possess a blend ratio of 20%, whereas Tables 6, 7 and 8 have blend ratios of 28.6%, 71.4% and 28.6%, respectively. All stacking sequences presented in Tables 5 - 8 have even-ply numbers with non-symmetric angle-ply and cross-ply sub-sequences.

III. Calculation of extensional, coupling and bending stiffness terms

The calculation procedure for the elements (A_{ij} and D_{ij}) of the extensional (**A**) and bending (**D**) stiffness matrices, using the dimensionless parameters provided in Tables 2 – 5, are as follows:

$$A_{ij} = \{n_{\pm}(n_{+}/n_{\pm})Q'_{ij+} + n_{\pm}(1 - n_{+}/n_{\pm})Q'_{ij-} + n_{\circ}Q'_{ij\circ} + n_{\bullet}Q'_{ij\bullet}\} \times t \qquad (5)$$

$$D_{ij} = \{\zeta_{\pm}/2 \times Q'_{ij+} + \zeta_{\pm}/2 \times Q'_{ij-} + \zeta_{\circ}Q'_{ij\circ} + \zeta_{\bullet}Q'_{ij\bullet}\} \times t^3/12 \qquad (6)$$

The form of Eq. (6) was chosen because it is then readily modified to account for laminates with bending anisotropy by replacing $\zeta_{\pm}/2 \times Q'_{ij+}$ with $\zeta_{\pm}(\zeta_{+}/\zeta_{\pm}) \times Q'_{ij+}$ or $\zeta_{+} \times Q'_{ij+}$, and $\zeta_{\pm}/2 \times Q'_{ij-}$ with $\zeta_{\pm}(1 - \zeta_{+}/\zeta_{\pm}) \times Q'_{ij-}$, or $\zeta_{-} \times Q'_{ij-}$. The use of this modified equation requires the calculation of an additional stiffness parameter, ζ_{+}, relating to the bending stiffness contribution of positive (θ) angle plies.

The transformed reduced stiffness terms in Eqs. (5) and (6) are given by:

$$Q'_{11} = Q_{11}\cos^4\theta + 2(Q_{12} + 2Q_{66})\cos^2\theta\sin^2\theta + Q_{22}\sin^4\theta$$

$$Q'_{12} = Q'_{21} = (Q_{11} + Q_{22} - 4Q_{66})\cos^2\theta\sin^2\theta + Q_{12}(\cos^4\theta + \sin^4\theta)$$

$$Q'_{16} = Q'_{61} = \{(Q_{11} - Q_{12} - 2Q_{66})\cos^2\theta + (Q_{12} - Q_{22} + 2Q_{66})\sin^2\theta\}\cos\theta\sin\theta$$

$$Q'_{22} = Q_{11}\sin^4\theta + 2(Q_{12} + 2Q_{66})\cos^2\theta\sin^2\theta + Q_{22}\cos^4\theta$$

$$Q'_{26} = Q'_{62} = \{(Q_{11} - Q_{12} - 2Q_{66})\sin^2\theta + (Q_{12} - Q_{22} + 2Q_{66})\cos^2\theta\}\cos\theta\sin\theta$$

$$Q'_{66} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})\cos^2\theta\sin^2\theta + Q_{66}(\cos^4\theta + \sin^4\theta) \qquad (7)$$

and the reduced stiffness terms by:

$$Q_{11} = E_1/(1 - \nu_{12}\nu_{21})$$

$$Q_{12} = \nu_{12}E_2/(1 - \nu_{12}\nu_{21}) = \nu_{21}E_1/(1 - \nu_{12}\nu_{21})$$

$$Q_{22} = E_2/(1 - \nu_{12}\nu_{21})$$

$$Q_{66} = G_{12} \tag{8}$$

For optimum design of angle ply laminates, lamination parameters are often preferred, since these allow the stiffness terms to be expressed as linear variables. The optimized lamination parameters may then be matched against a corresponding set of laminate stacking sequences. In the context of the parameters presented in the current article, the necessary six lamination parameters are related through the following expressions:

$$\xi_1^A = \xi_1 = \{n_\pm(n_+/n_\pm)\cos(2\theta_+) + n_\pm(1 - n_+/n_\pm)\cos(2\theta_-) + n_\circ\cos(2\theta_\circ) + n_\bullet\cos(2\theta_\bullet)\}/n$$

$$\xi_2^A = \xi_2 = \{n_\pm(n_+/n_\pm)\cos(4\theta_+) + n_\pm(1 - n_+/n_\pm)\cos(4\theta_-) + n_\circ\cos(4\theta_\circ) + n_\bullet\cos(4\theta_\bullet)\}/n$$

$$\xi_3^A = \xi_3 = \{n_\pm(n_+/n_\pm)\sin(2\theta_+) + n_\pm(1 - n_+/n_\pm)\sin(2\theta_-) + n_\circ\sin(2\theta_\circ) + n_\bullet\sin(2\theta_\bullet)\}/n$$

$$\xi_4^A = \xi_4 = \{n_\pm(n_+/n_\pm)\sin(4\theta_+) + n_\pm(1 - n_+/n_\pm)\sin(4\theta_-) + n_\circ\sin(4\theta_\circ) + n_\bullet\sin(4\theta_\bullet)\}/n \tag{9}$$

$$\xi_1^D = \xi_9 = \{\zeta_\pm(\zeta_+/\zeta_\pm)\cos(2\theta_+) + \zeta_\pm(1 - \zeta_+/\zeta_\pm)\cos(2\theta_-) + \zeta_\circ\cos(2\theta_\circ) + \zeta_\bullet\cos(2\theta_\bullet)\}/\zeta$$

$$\xi_2^D = \xi_{10} = \{\zeta_\pm(\zeta_+/\zeta_\pm)\cos(4\theta_+) + \zeta_\pm(1 - \zeta_+/\zeta_\pm)\cos(4\theta_-) + \zeta_\circ\cos(4\theta_\circ) + \zeta_\bullet\cos(4\theta_\bullet)\}/\zeta \tag{10}$$

where the bending stiffness parameter $\zeta_+ = \zeta_- = \zeta_\pm/2$ for ($A_FB_0D_S$) laminates contained in this article, hence Eqs. (10) reduce to:

$$\xi_1^D = \xi_9 = \{\zeta_\pm\cos(2\theta_\pm) + \zeta_\circ\cos(2\theta_\circ) + \zeta_\bullet\cos(2\theta_\bullet)\}/\zeta$$

$$\xi_2^D = \xi_{10} = \{\zeta_\pm\cos(4\theta_\pm) + \zeta_\circ\cos(4\theta_\circ) + \zeta_\bullet\cos(4\theta_\bullet)\}/\zeta \tag{11}$$

Elements of the extensionally anisotropic ($\mathbf{A}_F$) stiffness matrix are related to the lamination parameters by:

$$A_{11} = \{U_1 + \xi_1U_2 + \xi_2U_3\} \times H$$

$$A_{12} = A_{21} = \{-\xi_2U_3 + U_4\} \times H$$

$$A_{22} = \{U_1 - \xi_1U_2 + \xi_2U_3\} \times H$$

$$A_{66} = \{-\xi_2U_3 + U_5\} \times H$$

$$A_{16} = A_{61} = \{\xi_3U_2/2 + \xi_4U_3\} \times H$$

$$A_{26} = A_{62} = \{\xi_3U_2/2 - \xi_4U_3\} \times H \tag{12}$$

and the flexurally orthotropic ($\mathbf{D}_S$) stiffness matrix by:

$$D_{11} = \{U_1 + \xi_9U_2 + \xi_{10}U_3\} \times H^3/12$$

$$D_{12} = \{U_4 - \xi_{10}U_3\} \times H^3/12$$

$$D_{22} = \{U_1 - \xi_9 U_2 + \xi_{10}U_3\} \times H^3/12$$

$$D_{66} = \{-\xi_{10}U_3 + U_5\} \times H^3/12 \tag{13}$$

where the laminate invariants are given in terms of the reduced stiffnesses of Eqs. (8) by:

$$U_1 = \{3Q_{11} + 3Q_{22} + 2Q_{12} + 4Q_{66}\}/8$$

$$U_2 = \{Q_{11} - Q_{22}\}/2$$

$$U_3 = \{Q_{11} + Q_{22} - 2Q_{12} - 4Q_{66}\}/8$$

$$U_4 = \{Q_{11} + Q_{22} + 6Q_{12} - 4Q_{66}\}/8$$

$$U_5 = \{Q_{11} + Q_{22} - 2Q_{12} + 4Q_{66}\}/8 \tag{14}$$

IV. Example calculations

For IM7/8552 carbon-fiber/epoxy material with Young's moduli E_1 = 161.0GPa and E_2 = 11.38GPa, shear modulus G_{12} = 5.17GPa and Poisson ratio ν_{12} = 0.38, lamina thickness t = 0.1397mm and stacking sequence *NN 58*: $[+/\bigcirc/-/+/-_5/\bigcirc/-/\bigcirc/-/\bigcirc/-/+_2/-]_T$, the non-dimensional parameters are verified by the calculations presented in Table 2, where the first two columns provide the ply number and orientation, respectively. Subsequent columns illustrate the summations, for each ply orientation, of $(z_k - z_{k-1})$, $(z_k^2 - z_{k-1}^2)/2$ and $(z_k^3 - z_{k-1}^3)/3$, relating to the **A**, **B** and **D** matrices, respectively. The distance from the laminate mid-plane, z, is expressed in term of ply thickness t, which is assumed to be of unit value.

Table 2 – Calculation procedure for the non-dimensional parameters for an $\mathbf{A_F B_0 D_S}$ laminate.

		A				**B**				**D**			
Ply	θ	$(z_k - z_{k-1})$	$_A\Sigma_\bigcirc$ 4	$_A\Sigma_-$ 10	$_A\Sigma_+$ 4	$(z_k^2 - z_{k-1}^2)/2$	$_B\Sigma_\bigcirc$ 0	$_B\Sigma_-$ 0	$_B\Sigma_+$ 0	$(z_k^3 - z_{k-1}^3)/3$	$_D\Sigma_\bigcirc$ 250	$_D\Sigma_-$ 604	$_D\Sigma_+$ 604
1	+	1			→ 1	-17			→ -17	217			→ 217
2	○	1	→ 1			-15	→ -15			169	→ 169		
3	–	1		→ 1		-13		→ -13		127		→ 127	
4	+	1			→ 1	-11			→ -11	91			→ 91
5	–	1		→ 1		-9		→ -9		61		→ 61	
6	–	1		→ 1		-7		→ -7		37		→ 37	
7	–	1		→ 1		-5		→ -5		19		→ 19	
8	–	1		→ 1		-3		→ -3		7		→ 7	
9	–	1		→ 1		-1		→ -1		1		→ 1	
10	○	1	→ 1			1	→ 1			1	→ 1		
11	–	1		→ 1		3		→ 3		7		→ 7	
12	○	1	→ 1			5	→ 5			19	→ 19		
13	–	1		→ 1		7		→ 7		37		→ 37	
14	○	1	→ 1			9	→ 9			61	→ 61		
15	–	1		→ 1		11		→ 11		91		→ 91	
16	+	1			→ 1	13			→ 13	127			→ 127
17	+	1			→ 1	15			→ 15	169			→ 169
18	–	1		→ 1		17		→ 17		217		→ 217	

The non-dimensional parameters arising from the summations of Table 2 are: n_+ (= $_A\Sigma_+$) = 4, n_- = 10 and $n_\bigcirc$ = 4, where $n_\pm$ = 14, and; ζ_+ (= 4 × $_D\Sigma_+$) = 2416, ζ_- = 2416 and $\zeta_\bigcirc$ = 1000, where $n^3 = 18^3 = \zeta = \zeta_+ + \zeta_- + \zeta_\bigcirc$ = 5832 and $\zeta_\pm$ = 4832. The **B** matrix summations confirm that B_{ij} = 0 for this laminate.

For fiber angles θ = ±45° and 0° in place of symbols ± and ○ respectively, the transformed reduced stiffnesses are given in Table 3, which are readily calculated using Eqs. (7).

Table 3 – Transformed reduced stiffness (N/mm^2) for IM7/8552 carbon-fiber/epoxy with θ = -45°, 45°, 0° and 90°.

θ	Q'_{11}	Q'_{12}	Q'_{16}	Q'_{22}	Q'_{26}	Q'_{66}
-45	50,894	40,554	-37,791	50,894	-37,791	41,355
45	50,894	40,554	37,791	50,894	37,791	41,355
0	162,660	4,369	0	11,497	0	5,170
90	11,497	4,369	0	162,660	0	5,170

and through Eqs. (5) and (6), the final stiffness matrices are derived for the laminate:

$$\begin{bmatrix} A_{11} & A_{12} & A_{16} \\ & A_{22} & A_{26} \\ \text{Sym.} & & A_{66} \end{bmatrix} = \begin{bmatrix} 190{,}433 & 81{,}757 & -31{,}676 \\ & 105{,}963 & -31{,}676 \\ \text{Sym.} & & 83{,}771 \end{bmatrix} \text{N/mm}$$

$$\begin{bmatrix} D_{11} & D_{12} & D_{16} \\ & D_{22} & D_{26} \\ \text{Sym.} & & D_{66} \end{bmatrix} = \begin{bmatrix} 92{,}829 & 45{,}514 & 0 \\ & 58{,}485 & 0 \\ \text{Sym.} & & 46{,}575 \end{bmatrix} \text{N.mm}$$

given that:

$$A_{16} = \{n_\pm(n_+/n_\pm)Q'_{16+} + n_\pm(1 - n_+/n_\pm)Q'_{16-} + n_\bigcirc Q'_{16\bigcirc} + n_\bullet Q'_{16\bullet}\} \times t$$

$$A_{16} = A_{26} = \{14 \times (4/14) \times 37{,}791 + 14(1 - 4/14) \times -37{,}791 + 4 \times 0 + 0 \times 0\} \times 0.1397 = -31{,}676 \text{ N/mm}$$

$$D_{16} = \{\zeta_\pm/2 \times Q'_{16+} + \zeta_\pm/2 \times Q'_{16-} + \zeta_\bigcirc Q'_{16\bigcirc} + \zeta_\bullet Q'_{16\bullet}\} \times t^3/12$$

$$D_{16} = D_{26} = \{2416 \times 37{,}791 + 2416 \times -37{,}791 + 1000 \times 0 + 0 \times 0\} \times 0.1397^3/12 = 0 \text{ N.mm}$$

Noting that $\xi_4^A = \xi_4 = 0$ for θ_+ = 45°, the extensional lamination parameters (ξ_1, ξ_2 and ξ_3) are calculated from Eqs. (9):

$$\xi_1^A = \xi_1 = \{n_\pm(n_+/n_\pm)\cos(2\theta_+) + n_\pm(1 - n_+/n_\pm)\cos(2\theta_-) + n_\bigcirc\cos(2\theta_\bigcirc) + n_\bullet\cos(2\theta_\bullet)\}/n$$

$$\xi_1^A = \xi_1 = \{14 \times (4/14) \times \cos(90°) + 14 \times (1 - 4/14) \times \cos(-90°) + 4 \times \cos(0°) + 0 \times \cos(180°)\}/18 = 0.22$$

$$\xi_2^A = \xi_2 = \{n_\pm(n_+/n_\pm)\cos(4\theta_+) + n_\pm(1 - n_+/n_\pm)\cos(4\theta_-) + n_\bigcirc\cos(4\theta_\bigcirc) + n_\bullet\cos(4\theta_\bullet)\}/n$$

$$\xi_2^A = \xi_2 = \{14 \times (4/14) \times \cos(180°) + 14 \times (1 - 4/14) \times \cos(-180°) + 4 \times \cos(0°) + 0 \times \cos(360°)\}/18 = -0.56$$

$$\xi_3^A = \xi_3 = \{n_\pm(n_+/n_\pm)\sin(2\theta_+) + n_\pm(1 - n_+/n_\pm)\sin(2\theta_-) + n_\bigcirc\sin(2\theta_\bigcirc) + n_\bullet\sin(2\theta_\bullet)\}/n$$

$$\xi_3^A = \xi_3 = \{14 \times (4/14) \times \sin(90°) + 14 \times (1 - 4/14) \times \sin(-90°) + 4 \times \sin(0°) + 0 \times \sin(180°)\}/18 = -0.33$$

and the bending lamination parameters from Eqs. (11):

$$\xi_9 = \{\zeta_{\pm}\cos(2\theta_{\pm}) + \zeta_{\bigcirc}\cos(2\theta_{\bigcirc}) + \zeta_{\bullet}\cos(2\theta_{\bullet})\}/\zeta$$

$$\xi_9 = \{4832 \times \cos(90°) + 1000 \times \cos(0°) + 0 \times \cos(180°)\}/5832 = 0.17$$

$$\xi_{10} = \{\zeta_{\pm}\cos(4\theta_{\pm}) + \zeta_{\bigcirc}\cos(4\theta_{\bigcirc}) + \zeta_{\bullet}\cos(4\theta_{\bullet})\}/\zeta$$

$$\xi_{10} = \{4832 \times \cos(180°) + 1000 \times \cos(0°) + 0 \times \cos(360°)\}/5832 = -0.66$$

A second stacking sequence $[-_2/+_2/\bigcirc/-/\bigcirc/-/\bigcirc/-_5/+_2/\bigcirc/-]_T$ is now presented, demonstrating the use of the modified stiffness equations described below Eq. (6), which account for laminates with additional bending anisotropy, i.e. $\mathbf{A_F B_0 D_F}$. Calculations for the non-dimensional parameters are presented in Table 4, using the same format as Table 2.

Table 4 – Calculation procedure for the non-dimensional parameters for an $\mathbf{A_F B_0 D_F}$ laminate.

		A				**B**				**D**			
Ply	θ	$(z_k - z_{k-1})$	${}_A\Sigma_{\bigcirc}$ <u>4</u>	${}_A\Sigma_-$ <u>10</u>	${}_A\Sigma_+$ <u>4</u>	$(z_k^2 - z_{k-1}^2)/2$	${}_B\Sigma_{\bigcirc}$ <u>0</u>	${}_B\Sigma_-$ <u>0</u>	${}_B\Sigma_+$ <u>0</u>	$(z_k^3 - z_{k-1}^3)/3$	${}_D\Sigma_{\bigcirc}$ <u>250</u>	${}_D\Sigma_-$ <u>772</u>	${}_D\Sigma_+$ <u>436</u>
1	–	1		1		-17		-17		217		217	
2	–	1		1		-15		-15		169		169	
3	+	1			1	-13			-13	127			127
4	+	1			1	-11			-11	91			91
5	○	1	1			-9	-9			61	61		
6	–	1		1		-7		-7		37		37	
7	○	1	1			-5	-5			19	19		
8	–	1		1		-3		-3		7		7	
9	○	1	1			-1	-1			1	1		
10	–	1		1		1		1		1		1	
11	–	1		1		3		3		7		7	
12	–	1		1		5		5		19		19	
13	–	1		1		7		7		37		37	
14	–	1		1		9		9		61		61	
15	+	1			1	11			11	91			91
16	+	1			1	13			13	127			127
17	○	1	1			15	15			169	169		
18	–	1		1		17		17		217		217	

In this laminate the non-dimensional parameters arising from the summations are: n_+ (= ${}_A\Sigma_+$) = 4, n_- = 10 and $n_{\bigcirc}$ = 4, as before, but now ζ_+ (= 4 × ${}_D\Sigma_+$) = 1744, ζ_- = 3088 and $\zeta_{\bigcirc}$ = 1000, where $n^3 = 18^3 = \zeta = \zeta_+ + \zeta_- + \zeta_{\bigcirc}$ = 5832 and $\zeta_{\pm}$ = 4832. The **B** matrix summations again confirm that $B_{ij} = 0$ for this laminate.

For the same material properties and fiber orientations used in the first example, the only change to the stiffness matrices between the two sequences involves the elements D_{16} and D_{26}, which are zero in the first and non-zero in the second, given that:

$$D_{16} = \{\zeta_+ \times Q'_{16+} + \zeta_- \times Q'_{16-} + \zeta_{\bigcirc}Q'_{16\bigcirc} + \zeta_{\bullet}Q'_{16\bullet}\} \times t^3/12$$

$$D_{16} = D_{26} = \{1744 \times 37{,}791 + 3088 \times -37{,}791 + 1000 \times 0 + 0 \times 0\} \times 0.1397^3/12 = -11{,}540 \text{ N.mm}$$

Writing the second stacking sequence in reverse order, i.e. $[-/\bigcirc/+_2/-_5/\bigcirc/-/\bigcirc/-/\bigcirc/+_2/-_2]_T$, does not change the laminate stiffness properties, but reveals that changes from the first sequence, i.e. $[+/\bigcirc/-/+/-_5/\bigcirc/-/\bigcirc/-/\bigcirc/-/+_2/-]_T$, involve only a switch in the signs of ply numbers 1, 3, 15 and 17.

V. Structural Response

This section presents a selection of results illustrating the effect of in-plane coupling behavior. Comparisons are made against a fully uncoupled isotropic ($\mathbf{A}_I\mathbf{B}_0\mathbf{D}_I$) laminate datum configuration, and more importantly, between the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ and $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminates derived in the previous section, in which all elements of the **ABD** matrix are identical except for D_{16} and D_{26}, which are zero in the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ laminate. This latter comparison is particularly important given that $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminates may be readily derived using unbalanced, symmetric configurations, as has been demonstrated elsewhere[2].

In the first set of results, the initial buckling (Eigenvalue) and post-buckling response of a compression (N_x) loaded, simply supported, square plate are considered, see Fig. 1.

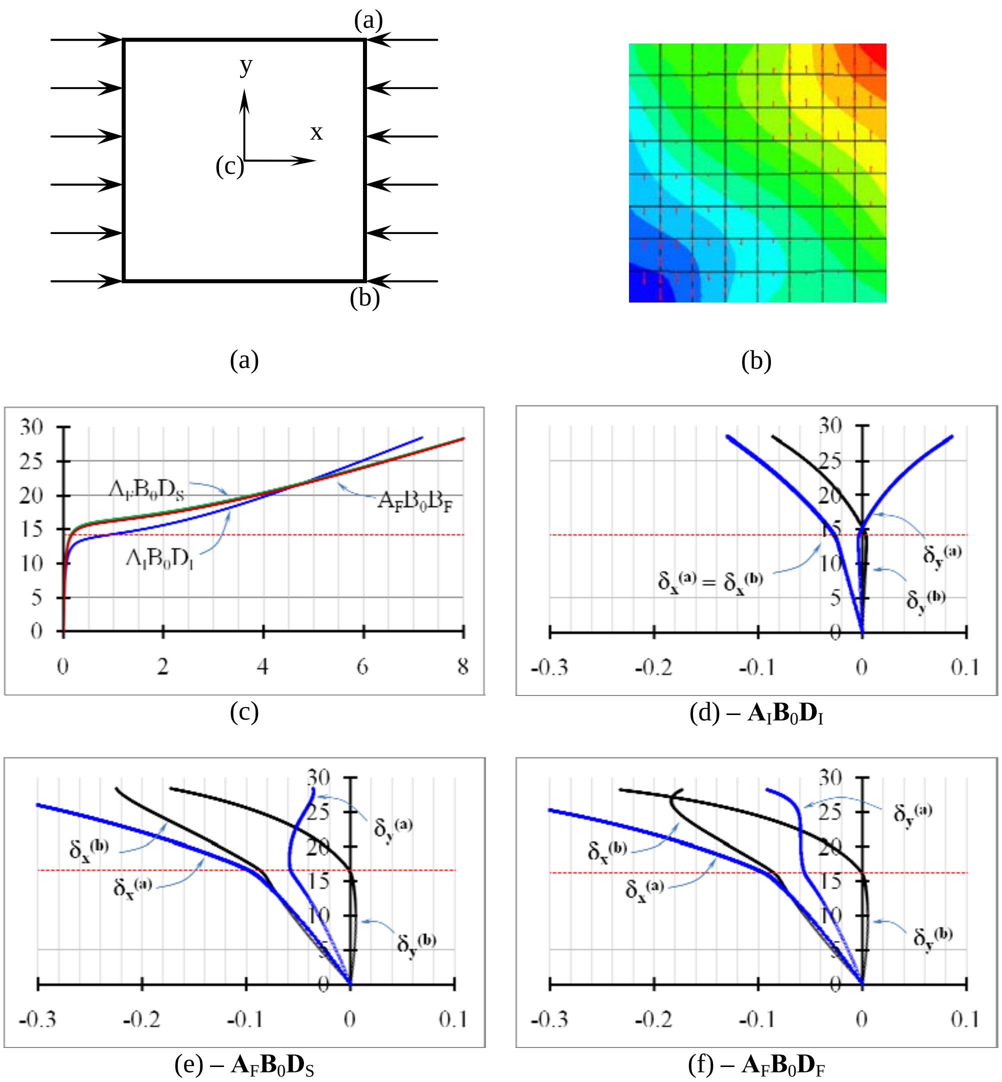

Figure 1 – Compression loaded simply supported square plate: (a) configuration and axis system; (b) In-plane displacement contours δ_y, at load N_x = 18.696 kN. Load (kN) – displacement (mm) curves for: (c) out-of-plane response (δ_z) at plate centre for all three laminates; (c) – (f) in-plane responses (δ_x and δ_y) at corner nodes for $\mathbf{A}_I\mathbf{B}_0\mathbf{D}_I$, $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ and $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminates, respectively. Eigenvalue buckling predictions are superimposed (dotted line) for comparison on: (c) – (d) 14.22 kN (56.9 N/mm); (e) 16.63 kN (66.5 N/mm) and (f) 16.29 kN (65.2 N/mm).

Note that the $\mathbf{A}_I\mathbf{B}_0\mathbf{D}_I$ laminate datum configuration was chosen specifically to allow the Eigenvalue buckling load to be verified against the closed form buckling solution. Hence for compatibility, the boundary conditions for all cases were chosen such that at the plate centre, indicated by point (c) on Fig. 1(a), in-plane displacements, δ_x and

δ_y, are prevented together with in-plane rotation, i.e. rotation about the z-axis. Out-of-plane displacement constraints, δ_z, are also applied to the plate perimeter.

The $\mathbf{A}_I\mathbf{B}_0\mathbf{D}_I$ laminate stacking sequence used is *NN 1071*: $[\pm/-/\bigcirc_3/+_2/\bigcirc/\mp/\pm/-_2/\bigcirc_2/+]_T$, where the angle plies ± represent ±60°. By contrast to the stiffnesses presented in the previous section for the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ and $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminates, the stiffnesses for this laminate are: $A_{11} = A_{22}$ = 173,473, A_{12} = 56,482 and A_{66} = 58,496, and $D_{11} = D_{22}$ = 91,409, D_{12} = 29,762 and D_{66} = 30,823. Note that the principal material axis, i.e. the 0 degree ply direction, corresponds to the y-axis of Fig. 1(a).

Results were generated with the ABAQUS finite element code using a thin plate element (S8R5), configured as shown in Fig. 1(b). Plate dimensions of 250mm × 250mm, together with an 18-ply laminate, of total thickness H = ($n \times t$ = 18 × 0.1397mm =) 2.51mm, ensure that the results are representative of the thin plate solution.

The results reveal that the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminate has an initial buckling strength 14.5% higher than the fully isotropic datum laminate, and that this increases to 16.9% when bend-twist coupling is eliminated, i.e. for the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$.

The post-buckling results represent a 1% (of the laminate thickness, H,) initial imperfection in the form of a single half-wave across both the length and width of the plate. A Riks analysis was performed to generate the results, which represent a maximum load of approximately twice the initial buckling load. The usual load-deflection curves are presented in Fig. 1(c) for all three laminates and the Eigenvalue result for the (perfectly flat) $\mathbf{A}_I\mathbf{B}_0\mathbf{D}_I$ laminate is superimposed for comparison. A comparison of the results from the two analyses clearly requires further consideration. By contrast, the in-plane load-displacement behavior offers more fidelity in this case. Figure 1(d) illustrates the in-plane displacements for the $\mathbf{A}_I\mathbf{B}_0\mathbf{D}_I$ laminate. The δ_x displacements at the two corner nodes, indicated by points (a) and (b) of Fig. 1(b), are identical, as expected, and represent end shortening. In-plane displacements δ_y are of equal and opposite magnitude and arise from Poisson ratio effects, which dissipate after buckling, hence the change in sign in the post-buckled state. The initial (Eigenvalue) buckling prediction can be seen to be in good agreement.

Figures 1(e) and (f) illustrate the response due to membrane anisotropy, which in both cases appears to reduce the onset of initial buckling below that of the Eigenvalue prediction. Comparison of the responses between the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ and $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminates appears to be minimal up to initial buckling, but differ in the post-buckled state due to the bend-twist response of the latter.

A second set of results is now considered for the wing-box configuration illustrated in Fig. 2, previously considered by Baker[2]. This symmetric structural configuration gives rise to bend-twist coupling deformation when unbalanced laminate skins are employed with their relative orientations aligned as shown. A similar configuration is used here, and again the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ and $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminates derived in the previous section are used for comparison, since all elements of the **ABD** matrix are identical except for D_{16} and D_{26}, which are zero in the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ laminate. The wing box structure is simplified as an open section rectangular box with a length of 5m, a width of 400mm and depth of 100mm. One end of the wing box is fully built in and a tip load of 500N is applied at the free end with the resultant coincident with the shear centre.

The $\mathbf{A}_I\mathbf{B}_0\mathbf{D}_I$ laminate was first applied to all skins of the wing-box and the resulting tip deflection calculated as 71.98mm. The top and bottom skins were replaced in turn by the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ laminate and then by the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminate. However, for compatibility of angle plies with the forward and aft spars, which remain as the datum $\mathbf{A}_I\mathbf{B}_0\mathbf{D}_I$ laminate configuration, the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ and $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminates were modified to incorporate angle plies of ±60° rather than ±45°. The $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$ skin configuration gave rise to an average tip displacement of 72.791mm, together with a tip rotation of 0.3397°. Similarly, the $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$ laminate gave rise to an average displacement of 72.793mm, together with a tip rotation of 0.3400°. These results suggest that bending anisotropy of the skin panels has negligible effect on the magnitude of bend-twist coupling deformation of the wing box. Note that the carbon-fiber/epoxy material adopted for this problem had Young's moduli E_1 = 131.0GPa and E_2 = 13.0GPa, shear modulus G_{12} = 6.41GPa and Poisson ratio ν_{12} = 0.38 and principal material axis, i.e. the 0 degree ply direction, corresponded to forward direction indicated on Fig. 2.

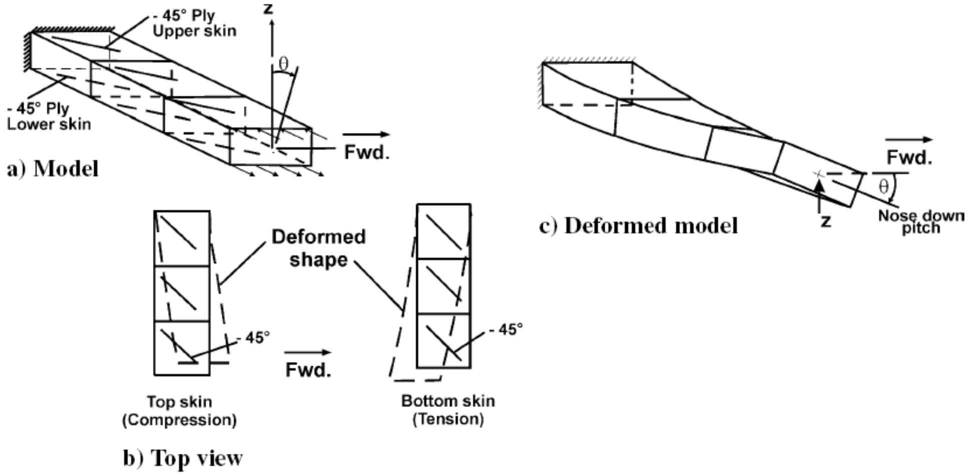

Figure 2 – Cantilever box-beam model (*after Ref. 2*) showing (a) general configuration, uniform stresses due to bending (force resultant acting through shear centre) and relative ply orientations for top and bottom skin; (b) relative deformations (exaggerated) between top and bottom skin and; (c) bend-twist coupling deformation (exaggerated) arising from unbalanced laminate skins.

VI. Concluding remarks

The definitive list of laminate stacking sequences for extensional anisotropy with up to 21 plies has been developed and presented in terms of angle-ply and cross-ply sub-sequence symmetries along with dimensionless parameters from which the laminate stiffness matrix is readily calculated. An assessment of the bending efficiency of each ply sub-sequence can be obtained by simple inspection.

Equations are provided, which relate the six lamination parameters required for this class of laminate to the dimensionless parameters for stacking sequences with general ply angle (±θ).

Extensionally anisotropic laminates may be described using the shorthand notation $\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$, indicating the form of the elements of the extensional, coupling and bending stiffness matrices. Unlike laminates with similar form, e.g. bending anisotropy ($\mathbf{A}_S\mathbf{B}_0\mathbf{D}_F$), extensional and bending anisotropy ($\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$) and full orthotropy ($\mathbf{A}_S\mathbf{B}_0\mathbf{D}_S$), for which the in- and out-of-plane behavior is uncoupled, the definitive list of sequences giving rise to extensional anisotropy uniquely contains even-ply numbers with non-symmetric angle-ply and cross-ply sub-sequences.

This class of coupled non-symmetric laminate can be manufactured flat under a standard elevated temperature curing process by virtue of the decoupled nature between in-plane and out-of-plane behavior.

Preliminary results presented herein suggest that laminates with both extensional and bending anisotropy ($\mathbf{A}_F\mathbf{B}_0\mathbf{D}_F$) have both negligible effect on the bend-twist coupling response of tailored wing-box structures, together with a lower compression buckling load strength compared with laminates possessing purely extensional anisotropy ($\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$).

Acknowledgements and additional remarks

The author gratefully acknowledges Dr P. M. Weaver, from the University of Bristol, for highlighting the existence of a single, 36-ply symmetric laminate $[-_3/+_3/-/+_6/-/+_3/-]_S$ with extensional anisotropy ($\mathbf{A}_F\mathbf{B}_0\mathbf{D}_S$), which implies that there are more sub-sequence symmetries than those identified in the definitive list of up to 21 plies, presented herein. This is aligned with similar observations on Fully Orthotropic Laminates ($\mathbf{A}_S\mathbf{B}_0\mathbf{D}_S$) in which only anti-symmetric sequences exist for laminates with 7, 8, 9, 10 and 11 plies; the many other sub-sequence symmetries, summarized in this article, are realized only as the number of plies is increased.

References

[1]Engineering Sciences Data Unit, “Stiffnesses of laminated plates”, ESDU Item No. 94003, 1994.

[2]Baker, D., “Response of Damaged and Undamaged Tailored Extension-Shear-Coupled Composite Panels,” *Journal of Aircraft*, Vol. 43, No. 2, March - April 2006, pp. 517-527.

[3]Popelka, D., Lindsay, D., Parham, T., Jr., Berry, V., and Baker, D., “Results of an Aeroelastic Tailoring Study for a Composite Tiltrotor Wing,” *American Helicopter Society*, Alexandria, VA, May 1995.

[4]York, C. B., “Laminate stacking sequences for special orthotropy,” University of Glasgow, Department of Aerospace Engineering Research Report No. 06-02, 2006.

[5]York, C. B. “Characterization and Ply Mixing Rules for Non-symmetric Forms of Fully Orthotropic Laminates,” *Proc. 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conf.*, Paper No. AIAA-2007-2083. Honolulu, Hawaii, 2007.

[6]York, C. B. “Stacking sequences for fully orthotropic laminates,” *Journal of Aircraft*, Accepted for publication.

[7]Bartholomew, P., “Ply stacking sequences for laminated plates having in-plane and bending orthotropy,” Royal Aircraft Establishment Technical Report No. 76003, 1976.

[8]Bartholomew, P., “Ply stacking sequences for laminated plates having in-plane and bending orthotropy,” *Fibre Science and Technology*, Vol. 10, No. 4, 1977, pp. 239-253.

[9]Engineering Sciences Data Unit, “Laminate stacking sequences for special orthotropy (Application to fibre reinforced composites)”, ESDU Item No. 82013, 1982.

[10]Fukunaga, H. and Sekine, H., “Stiffness design method of symmetric laminates using lamination parameters”, *AIAA J*, Vol. 30, No. 11, 1992, pp. 2791-2793.

Table 5 – Stacking sequences for 7 through 21 ply laminates of the form $_{+}NN_{+}$ with blend ratio ($n_{+}/n_{\pm}$) = 20%.

Ref.	Sequence	n	$n_{\pm}$	$n_{○}$	$n_{●}$	ζ	$\zeta_{\pm}$	$\zeta_{○}$	$\zeta_{●}$	$n_{\pm}/n$ (%)	$n_{○}/n$ (%)	$n_{●}/n$ (%)	$\zeta_{\pm}/\zeta$ (%)	$\zeta_{○}/\zeta$ (%)	$\zeta_{●}/\zeta$ (%)
NN 1	+ ● − − − ● − − − ● − ● − +	14	10	0	4	2744	2032	0	712	71.4	0.0	28.6	74.1	0.0	25.9
NN 2	+ − ● − ● − − − ● − − − ● +	14	10	0	4	2744	2032	0	712	71.4	0.0	28.6	74.1	0.0	25.9
NN 3	+ − ○ − ○ − − − ○ − − − ○ +	14	10	4	0	2744	2032	712	0	71.4	28.6	0.0	74.1	25.9	0.0
NN 4	+ ○ − − − ○ − − − ○ − ○ − +	14	10	4	0	2744	2032	712	0	71.4	28.6	0.0	74.1	25.9	0.0
NN 5	+ ● − ● − − − ● − ● − − ● ● − +	16	10	0	6	4096	2704	0	1392	62.5	0.0	37.5	66.0	0.0	34.0
NN 6	+ − ● ● − − ● − ● − − − ● − ● +	16	10	0	6	4096	2704	0	1392	62.5	0.0	37.5	66.0	0.0	34.0
NN 7	+ ● − ○ − − − ● − ● − − ○ ● − +	16	10	2	4	4096	2704	488	904	62.5	12.5	25.0	66.0	11.9	22.1
NN 8	+ − ● ○ − − ● − ● − − − ○ − ● +	16	10	2	4	4096	2704	488	904	62.5	12.5	25.0	66.0	11.9	22.1
NN 9	+ − ○ ● − − ○ − ○ − − − ● − ○ +	16	10	4	2	4096	2704	904	488	62.5	25.0	12.5	66.0	22.1	11.9
NN 10	+ ○ − ● − − − ○ − ○ − − ● ○ − +	16	10	4	2	4096	2704	904	488	62.5	25.0	12.5	66.0	22.1	11.9
NN 11	+ − ○ ○ − − ○ − ○ − − − ○ − ○ +	16	10	6	0	4096	2704	1392	0	62.5	37.5	0.0	66.0	34.0	0.0
NN 12	+ ○ − ○ − − − ○ − ○ − − ○ ○ − +	16	10	6	0	4096	2704	1392	0	62.5	37.5	0.0	66.0	34.0	0.0
NN 13	+ ● − ● − ● − ● − − ● − − ● ● ● − +	18	10	0	8	5832	3472	0	2360	55.6	0.0	44.4	59.5	0.0	40.5
NN 14	+ ● − − ● ● − ● − ● − ● − − − ● ● +	18	10	0	8	5832	3472	0	2360	55.6	0.0	44.4	59.5	0.0	40.5
NN 15	+ − ● ● ● − − ● − − ● − ● − ● − ● +	18	10	0	8	5832	3472	0	2360	55.6	0.0	44.4	59.5	0.0	40.5
NN 16	+ ● − − ● ● ● − − − ● − ● − ● − ● +	18	10	0	8	5832	3472	0	2360	55.6	0.0	44.4	59.5	0.0	40.5
NN 17	+ ● − ● − ● − ● − − − ● ● ● − − ● +	18	10	0	8	5832	3472	0	2360	55.6	0.0	44.4	59.5	0.0	40.5
NN 18	+ ● ● − − − ● − ● − ● − ● ● − − ● +	18	10	0	8	5832	3472	0	2360	55.6	0.0	44.4	59.5	0.0	40.5
NN 19	+ ● − ● − ● − ○ − − ○ − − ● ● ● − +	18	10	2	6	5832	3472	56	2304	55.6	11.1	33.3	59.5	1.0	39.5
NN 20	+ − ● ● ● − − ○ − − ○ − ● − ● − ● +	18	10	2	6	5832	3472	56	2304	55.6	11.1	33.3	59.5	1.0	39.5
NN 21	+ ● − − ● ○ ● − − − ● − ○ − ● − ● +	18	10	2	6	5832	3472	296	2064	55.6	11.1	33.3	59.5	5.1	35.4
NN 22	+ ● − ● − ○ − ● − − − ● ○ ● − − ● +	18	10	2	6	5832	3472	296	2064	55.6	11.1	33.3	59.5	5.1	35.4
NN 23	+ ● − − ○ ● ○ − − − ○ − ● − ○ − ● +	18	10	4	4	5832	3472	712	1648	55.6	22.2	22.2	59.5	12.2	28.3
NN 24	+ ● − ○ − ● − ○ − − − ○ ● ○ − − ● +	18	10	4	4	5832	3472	712	1648	55.6	22.2	22.2	59.5	12.2	28.3
NN 25	+ ● − ○ − ● − ● − − ● − − ● ○ ● − +	18	10	2	6	5832	3472	728	1632	55.6	11.1	33.3	59.5	12.5	28.0
NN 26	+ − ● ○ ● − − ● − − ● − ● − ○ − ● +	18	10	2	6	5832	3472	728	1632	55.6	11.1	33.3	59.5	12.5	28.0
NN 27	+ ● − ○ − ● − ○ − − ○ − − ● ○ ● − +	18	10	4	4	5832	3472	784	1576	55.6	22.2	22.2	59.5	13.4	27.0
NN 28	+ − ● ○ ● − − ○ − − ○ − ● − ○ − ● +	18	10	4	4	5832	3472	784	1576	55.6	22.2	22.2	59.5	13.4	27.0
NN 29	+ ● − − ○ ○ − ○ − ○ − ○ − − − ○ ● +	18	10	6	2	5832	3472	1008	1352	55.6	33.3	11.1	59.5	17.3	23.2
NN 30	+ ● − − ○ ○ ○ − − − ○ − ○ − ○ − ● +	18	10	6	2	5832	3472	1008	1352	55.6	33.3	11.1	59.5	17.3	23.2

Continued

Continued

NN 31	+●–○–○–○–	––○○○––●+	18	10	6	2	5832	3472	1008	1352	55.6	33.3	11.1	59.5	17.3	23.2
NN 32	+●○–––○–○	–○–○○––●+	18	10	6	2	5832	3472	1008	1352	55.6	33.3	11.1	59.5	17.3	23.2
NN 33	+●––○○–●–	○–●–––●○+	18	10	4	4	5832	3472	1072	1288	55.6	22.2	22.2	59.5	18.4	22.1
NN 34	+○●–––●–○	–●–○○––●+	18	10	4	4	5832	3472	1072	1288	55.6	22.2	22.2	59.5	18.4	22.1
NN 35	+●○–––○–●	–○–●●––○+	18	10	4	4	5832	3472	1288	1072	55.6	22.2	22.2	59.5	22.1	18.4
NN 36	+○––●●–○–	●–○–––○●+	18	10	4	4	5832	3472	1288	1072	55.6	22.2	22.2	59.5	22.1	18.4
NN 37	+○––●●–●–	●–●–––●○+	18	10	2	6	5832	3472	1352	1008	55.6	11.1	33.3	59.5	23.2	17.3
NN 38	+○––●●●––	–●–●–●–○+	18	10	2	6	5832	3472	1352	1008	55.6	11.1	33.3	59.5	23.2	17.3
NN 39	+○–●–●–●–	––●●●––○+	18	10	2	6	5832	3472	1352	1008	55.6	11.1	33.3	59.5	23.2	17.3
NN 40	+○●–––●–●	–●–●●––○+	18	10	2	6	5832	3472	1352	1008	55.6	11.1	33.3	59.5	23.2	17.3
NN 41	+–○●○––●–	–●–○–●–○+	18	10	4	4	5832	3472	1576	784	55.6	22.2	22.2	59.5	27.0	13.4
NN 42	+○–●–○–●–	–●––○●○–+	18	10	4	4	5832	3472	1576	784	55.6	22.2	22.2	59.5	27.0	13.4
NN 43	+–○●○––○–	–○–○–●–○+	18	10	6	2	5832	3472	1632	728	55.6	33.3	11.1	59.5	28.0	12.5
NN 44	+○–●–○–○–	–○––○●○–+	18	10	6	2	5832	3472	1632	728	55.6	33.3	11.1	59.5	28.0	12.5
NN 45	+○––●○●––	–●–○–●–○+	18	10	4	4	5832	3472	1648	712	55.6	22.2	22.2	59.5	28.3	12.2
NN 46	+○–●–○–●–	––●○●––○+	18	10	4	4	5832	3472	1648	712	55.6	22.2	22.2	59.5	28.3	12.2
NN 47	+○––○●○––	–○–●–○–○+	18	10	6	2	5832	3472	2064	296	55.6	33.3	11.1	59.5	35.4	5.1
NN 48	+○–○–●–○–	––○●○––○+	18	10	6	2	5832	3472	2064	296	55.6	33.3	11.1	59.5	35.4	5.1
NN 49	+–○○○––●–	–●–○–○–○+	18	10	6	2	5832	3472	2304	56	55.6	33.3	11.1	59.5	39.5	1.0
NN 50	+○–○–○–●–	–●––○○○–+	18	10	6	2	5832	3472	2304	56	55.6	33.3	11.1	59.5	39.5	1.0
NN 51	+○––○○–○–	○–○–––○○+	18	10	8	0	5832	3472	2360	0	55.6	44.4	0.0	59.5	40.5	0.0
NN 52	+–○○○––○–	–○–○–○–○+	18	10	8	0	5832	3472	2360	0	55.6	44.4	0.0	59.5	40.5	0.0
NN 53	+○––○○○––	–○–○–○–○+	18	10	8	0	5832	3472	2360	0	55.6	44.4	0.0	59.5	40.5	0.0
NN 54	+○–○–○–○–	––○○○––○+	18	10	8	0	5832	3472	2360	0	55.6	44.4	0.0	59.5	40.5	0.0
NN 55	+○○–––○–○	–○–○○––○+	18	10	8	0	5832	3472	2360	0	55.6	44.4	0.0	59.5	40.5	0.0
NN 56	+○–○–○–○–	–○––○○○–+	18	10	8	0	5832	3472	2360	0	55.6	44.4	0.0	59.5	40.5	0.0
NN 61	+●–●–●●●––	–●––●●●●–+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 62	+●●––●●––●	–●–●–●●●–+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 63	+●●●–––●––	–●●●●●–●–+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 64	+–●–●●●●●–	––●–––●●●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8

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NN 65	+●–●–●–●●– ●●–––●–●●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 66	+–●●●–●–●– ●––●●––●●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 67	+●–●–●–●●● –––●●––●●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 68	+●●–––●●●– ●–●–●––●●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 69	+●●––●–●–● –●●●–––●●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 70	+–●●●●––●– ––●●●–●–●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 71	+●●––●●––– ●●●–●–●–●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 72	+●●–●–––●● –●●–●–●–●+	20	10	0	10	8000	4336	0	3664	50.0	0.0	50.0	54.2	0.0	45.8
NN 73	+●–●–●–●○– ●○–––●–●●+	20	10	2	8	8000	4336	56	3608	50.0	10.0	40.0	54.2	0.7	45.1
NN 74	+●●–●–––○● –○●–●–●–●+	20	10	2	8	8000	4336	56	3608	50.0	10.0	40.0	54.2	0.7	45.1
NN 75	+●●●–––○–– –●○●●●–●–+	20	10	2	8	8000	4336	152	3512	50.0	10.0	40.0	54.2	1.9	43.9
NN 76	+–●–●●●○●– ––○–––●●●+	20	10	2	8	8000	4336	152	3512	50.0	10.0	40.0	54.2	1.9	43.9
NN 77	+●●–––●○●– ●–○–●––●●+	20	10	2	8	8000	4336	152	3512	50.0	10.0	40.0	54.2	1.9	43.9
NN 78	+●●––●–○–● –●○●–––●●+	20	10	2	8	8000	4336	152	3512	50.0	10.0	40.0	54.2	1.9	43.9
NN 79	+●●––●○––● –●–○–●●●–+	20	10	2	8	8000	4336	296	3368	50.0	10.0	40.0	54.2	3.7	42.1
NN 80	+–●●●–○–●– ●––○●––●●+	20	10	2	8	8000	4336	296	3368	50.0	10.0	40.0	54.2	3.7	42.1
NN 81	+●–●–●–○○○ –––●○––●●+	20	10	4	6	8000	4336	352	3312	50.0	20.0	30.0	54.2	4.4	41.4
NN 82	+●●––○●––– ○○○–●–●–●+	20	10	4	6	8000	4336	352	3312	50.0	20.0	30.0	54.2	4.4	41.4
NN 83	+●●––○●––○ –○–○–●●●–+	20	10	4	6	8000	4336	424	3240	50.0	20.0	30.0	54.2	5.3	40.5
NN 84	+–●●●–○–○– ○––●○––●●+	20	10	4	6	8000	4336	424	3240	50.0	20.0	30.0	54.2	5.3	40.5
NN 85	+●●–––○●○– ○–●–○––●●+	20	10	4	6	8000	4336	424	3240	50.0	20.0	30.0	54.2	5.3	40.5
NN 86	+●●––○–●–○ –○●○–––●●+	20	10	4	6	8000	4336	424	3240	50.0	20.0	30.0	54.2	5.3	40.5
NN 87	+●–●–○●●–– –●––○●●●–+	20	10	2	8	8000	4336	488	3176	50.0	10.0	40.0	54.2	6.1	39.7
NN 88	+●–●–○–●●● –––●○––●●+	20	10	2	8	8000	4336	488	3176	50.0	10.0	40.0	54.2	6.1	39.7
NN 89	+–●●●○––●– ––●●○–●–●+	20	10	2	8	8000	4336	488	3176	50.0	10.0	40.0	54.2	6.1	39.7
NN 90	+●●––○●––– ●●●–○–●–●+	20	10	2	8	8000	4336	488	3176	50.0	10.0	40.0	54.2	6.1	39.7
NN 91	+●–●–●○○–– –○––○●●●–+	20	10	4	6	8000	4336	496	3168	50.0	20.0	30.0	54.2	6.2	39.6
NN 92	+–●●●○––○– ––○○●–●–●+	20	10	4	6	8000	4336	496	3168	50.0	20.0	30.0	54.2	6.2	39.6
NN 93	+●●–––○○○– ○–○–○––●●+	20	10	6	4	8000	4336	576	3088	50.0	30.0	20.0	54.2	7.2	38.6
NN 94	+●●––○–○–○ –○○○–––●●+	20	10	6	4	8000	4336	576	3088	50.0	30.0	20.0	54.2	7.2	38.6

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NN 95	+ ● – ● – ○ – ● ○ –	○ ● – – – ○ – ● ● +	20	10	4	6	8000	4336	640	3024	50.0	20.0	30.0	54.2	8.0	37.8
NN 96	+ ● ● – ○ – – – ● ○	– ○ ● – ○ – ● – ● +	20	10	4	6	8000	4336	640	3024	50.0	20.0	30.0	54.2	8.0	37.8
NN 97	+ ● – ● – ○ ● ○ – –	– ○ – – ● ○ ● ● – +	20	10	4	6	8000	4336	712	2952	50.0	20.0	30.0	54.2	8.9	36.9
NN 98	+ ● – ● – ○ – ○ ● –	● ○ – – – ○ – ● ● +	20	10	4	6	8000	4336	712	2952	50.0	20.0	30.0	54.2	8.9	36.9
NN 99	+ – ● ● ○ ● – – ○ –	– – ○ ● ○ – ● – ● +	20	10	4	6	8000	4336	712	2952	50.0	20.0	30.0	54.2	8.9	36.9
NN 100	+ ● ● – ○ – – – ○ ●	– ● ○ – ○ – ● – ● +	20	10	4	6	8000	4336	712	2952	50.0	20.0	30.0	54.2	8.9	36.9
NN 101	+ ● – ● – ○ ○ ● – –	– ○ – – ● ● ○ ● – +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 102	+ ● ● – – ○ ○ – – ●	– ○ – ● – ● ○ ● – +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 103	+ ● ○ ● – – – ● – –	– ○ ○ ○ ● ● – ● – +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 104	+ – ● ○ ● – ● – ○ –	● – – ○ ○ – – ● ● +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 105	+ ● – ○ – ● – ● ○ ●	– – – ○ ○ – – ● ● +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 106	+ ● ○ – – ● – ● – ●	– ○ ○ ○ – – – ● ● +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 107	+ – ● – ● ● ○ ○ ○ –	– – ● – – – ● ○ ● +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 108	+ ● ● – – – ○ ○ ○ –	● – ● – ● – – ○ ● +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 109	+ – ● ○ ● ● – – ○ –	– – ● ○ ○ – ● – ● +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 110	+ ● ● – – ○ ○ – – –	● ○ ● – ● – ○ – ● +	20	10	4	6	8000	4336	928	2736	50.0	20.0	30.0	54.2	11.6	34.2
NN 111	+ ● ○ – – – ● ● ● –	○ – ○ – ○ – – ● ● +	20	10	4	6	8000	4336	1000	2664	50.0	20.0	30.0	54.2	12.5	33.3
NN 112	+ ● – ● – ○ – ○ ● ○	– – – ● ● – – ○ ● +	20	10	4	6	8000	4336	1000	2664	50.0	20.0	30.0	54.2	12.5	33.3
NN 113	+ ● ● – – ○ – ○ – ○	– ● ● ● – – – ○ ● +	20	10	4	6	8000	4336	1000	2664	50.0	20.0	30.0	54.2	12.5	33.3
NN 114	+ ● ○ – – ● ● – – –	○ ● ○ – ○ – ● – ● +	20	10	4	6	8000	4336	1000	2664	50.0	20.0	30.0	54.2	12.5	33.3
NN 115	+ ● – ○ – ● ● ● – –	– ● – – ● ● ○ ● – +	20	10	2	8	8000	4336	1016	2648	50.0	10.0	40.0	54.2	12.7	33.1
NN 116	+ – ● ○ ● ● – – ● –	– – ● ● ● – ○ – ● +	20	10	2	8	8000	4336	1016	2648	50.0	10.0	40.0	54.2	12.7	33.1
NN 117	+ ● ● ○ – – – ○ – –	– ● ● ○ ● ○ – ● – +	20	10	4	6	8000	4336	1096	2568	50.0	20.0	30.0	54.2	13.7	32.1
NN 118	+ – ● – ○ ● ○ ● ● –	– – ○ – – – ○ ● ● +	20	10	4	6	8000	4336	1096	2568	50.0	20.0	30.0	54.2	13.7	32.1
NN 119	+ – ● – ● ○ ● ○ ○ –	– – ● – – – ● ● ○ +	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 120	+ ● – ● – ○ – ○ ○ –	● ● – – – ● – ● ○ +	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 121	+ ● – ● – ○ – ○ ○ ●	– – – ● ● – – ● ○ +	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 122	+ ● ○ – – ● ● – – ○	– ○ – ● – ● ○ ● – +	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 123	+ ○ ● ● – – – ● – –	– ○ ○ ● ○ ● – ● – +	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 124	+ ● – ○ – ● – ● ○ –	○ ● – – – ● – ○ ● +	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6

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NN 125	+–●○●–●–○–	○––●●––○●+	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 126	+○●––●●–––	●○○–○–●–●+	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 127	+○●–●–––●●	–○○–○–●–●+	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 128	+●○–●–––●○	–○●–●–○–●+	20	10	4	6	8000	4336	1216	2448	50.0	20.0	30.0	54.2	15.2	30.6
NN 129	+●–○–●○●––	–●––○○●●–+	20	10	4	6	8000	4336	1264	2400	50.0	20.0	30.0	54.2	15.8	30.0
NN 130	+–●●○○––●–	––●○●–○–●+	20	10	4	6	8000	4336	1264	2400	50.0	20.0	30.0	54.2	15.8	30.0
NN 131	+●–○–●●○––	–○––●●●○–+	20	10	4	6	8000	4336	1288	2376	50.0	20.0	30.0	54.2	16.1	29.7
NN 132	+●●○–––○––	–○●●●●–○–+	20	10	4	6	8000	4336	1288	2376	50.0	20.0	30.0	54.2	16.1	29.7
NN 133	+–○–●●●●○–	––○–––○●●+	20	10	4	6	8000	4336	1288	2376	50.0	20.0	30.0	54.2	16.1	29.7
NN 134	+●–○–●–○●–	●○–––●–○●+	20	10	4	6	8000	4336	1288	2376	50.0	20.0	30.0	54.2	16.1	29.7
NN 135	+–○●●●––○–	––○●●–○–●+	20	10	4	6	8000	4336	1288	2376	50.0	20.0	30.0	54.2	16.1	29.7
NN 136	+●○–●–––○●	–●○–●–○–●+	20	10	4	6	8000	4336	1288	2376	50.0	20.0	30.0	54.2	16.1	29.7
NN 137	+●○––●●––●	–●–●–●●○–+	20	10	2	8	8000	4336	1352	2312	50.0	10.0	40.0	54.2	16.9	28.9
NN 138	+●○●–––●––	–●●●●●–○–+	20	10	2	8	8000	4336	1352	2312	50.0	10.0	40.0	54.2	16.9	28.9
NN 139	+–○–●●●●●–	––●–––●○●+	20	10	2	8	8000	4336	1352	2312	50.0	10.0	40.0	54.2	16.9	28.9
NN 140	+–○●●–●–●–	●––●●––○●+	20	10	2	8	8000	4336	1352	2312	50.0	10.0	40.0	54.2	16.9	28.9
NN 141	+●○–––●●●–	●–●–●––○●+	20	10	2	8	8000	4336	1352	2312	50.0	10.0	40.0	54.2	16.9	28.9
NN 142	+●○––●–●–●	–●●●–––○●+	20	10	2	8	8000	4336	1352	2312	50.0	10.0	40.0	54.2	16.9	28.9
NN 143	+●○●–––○––	–●●●○○–●–+	20	10	4	6	8000	4336	1360	2304	50.0	20.0	30.0	54.2	17.0	28.8
NN 144	+–●–○○●●●–	––○–––●○●+	20	10	4	6	8000	4336	1360	2304	50.0	20.0	30.0	54.2	17.0	28.8
NN 145	+–●●○–○–●–	○––●●––●○+	20	10	4	6	8000	4336	1384	2280	50.0	20.0	30.0	54.2	17.3	28.5
NN 146	+○●––●●––○	–●–○–○●●–+	20	10	4	6	8000	4336	1384	2280	50.0	20.0	30.0	54.2	17.3	28.5
NN 147	+●–○–●–●○○	–––●●––●○+	20	10	4	6	8000	4336	1408	2256	50.0	20.0	30.0	54.2	17.6	28.2
NN 148	+○●––●●–––	○○●–●–○–●+	20	10	4	6	8000	4336	1408	2256	50.0	20.0	30.0	54.2	17.6	28.2
NN 149	+●–○–●–○○○	–––○●––○●+	20	10	6	4	8000	4336	1440	2224	50.0	30.0	20.0	54.2	18.0	27.8
NN 150	+●○––●○–––	○○○–●–○–●+	20	10	6	4	8000	4336	1440	2224	50.0	30.0	20.0	54.2	18.0	27.8
NN 151	+●–○–●–○●–	○●–––●–●○+	20	10	4	6	8000	4336	1456	2208	50.0	20.0	30.0	54.2	18.2	27.6
NN 152	+○●–●–––●○	–●○–●–○–●+	20	10	4	6	8000	4336	1456	2208	50.0	20.0	30.0	54.2	18.2	27.6
NN 153	+●–○–○●●––	–●––○●○●–+	20	10	4	6	8000	4336	1504	2160	50.0	20.0	30.0	54.2	18.8	27.0
NN 154	+●○●–––○––	–●○●●●–○–+	20	10	4	6	8000	4336	1504	2160	50.0	20.0	30.0	54.2	18.8	27.0

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NN 155	+–○–●●●○●–	––○–––●○●+	20	10	4	6	8000	4336	1504	2160	50.0	20.0	30.0	54.2	18.8	27.0
NN 156	+●○–––●○●–	●–○–●––○●+	20	10	4	6	8000	4336	1504	2160	50.0	20.0	30.0	54.2	18.8	27.0
NN 157	+●○––●–○–●	–●○●–––○●+	20	10	4	6	8000	4336	1504	2160	50.0	20.0	30.0	54.2	18.8	27.0
NN 158	+–●○●○––●–	––●●○–○–●+	20	10	4	6	8000	4336	1504	2160	50.0	20.0	30.0	54.2	18.8	27.0
NN 159	+●–○–●–○○–	○○–––●–●○+	20	10	6	4	8000	4336	1512	2152	50.0	30.0	20.0	54.2	18.9	26.9
NN 160	+●–○–●○○––	–○––○●○●–+	20	10	6	4	8000	4336	1512	2152	50.0	30.0	20.0	54.2	18.9	26.9
NN 161	+●○––●○––○	–○–○–●○●–+	20	10	6	4	8000	4336	1512	2152	50.0	30.0	20.0	54.2	18.9	26.9
NN 162	+–●○●–○–○–	○––○●––○●+	20	10	6	4	8000	4336	1512	2152	50.0	30.0	20.0	54.2	18.9	26.9
NN 163	+–●○●○––○–	––○○●–○–●+	20	10	6	4	8000	4336	1512	2152	50.0	30.0	20.0	54.2	18.9	26.9
NN 164	+○●–●–––○○	–○○–●–○–●+	20	10	6	4	8000	4336	1512	2152	50.0	30.0	20.0	54.2	18.9	26.9
NN 165	+–○●●–●–○–	○––●●––●○+	20	10	4	6	8000	4336	1576	2088	50.0	20.0	30.0	54.2	19.7	26.1
NN 166	+●○–––●●○–	○–●–●––●○+	20	10	4	6	8000	4336	1576	2088	50.0	20.0	30.0	54.2	19.7	26.1
NN 167	+○●––●●––○	–○–●–●●○–+	20	10	4	6	8000	4336	1576	2088	50.0	20.0	30.0	54.2	19.7	26.1
NN 168	+●–○–○–●●●	–––○●––○●+	20	10	4	6	8000	4336	1576	2088	50.0	20.0	30.0	54.2	19.7	26.1
NN 169	+○●––●–●–○	–○●●–––○●+	20	10	4	6	8000	4336	1576	2088	50.0	20.0	30.0	54.2	19.7	26.1
NN 170	+●○––●○–––	●●●–○–○–●+	20	10	4	6	8000	4336	1576	2088	50.0	20.0	30.0	54.2	19.7	26.1
NN 171	+●○––●–○–●	–○●●–––●○+	20	10	4	6	8000	4336	1648	2016	50.0	20.0	30.0	54.2	20.6	25.2
NN 172	+●○––●○––●	–●–○–●●○–+	20	10	4	6	8000	4336	1648	2016	50.0	20.0	30.0	54.2	20.6	25.2
NN 173	+–○●●–○–●–	●––○●––○●+	20	10	4	6	8000	4336	1648	2016	50.0	20.0	30.0	54.2	20.6	25.2
NN 174	+○●–––●●○–	●–○–●––○●+	20	10	4	6	8000	4336	1648	2016	50.0	20.0	30.0	54.2	20.6	25.2
NN 175	+–●○●○––●–	––○●●–●–○+	20	10	4	6	8000	4336	1696	1968	50.0	20.0	30.0	54.2	21.2	24.6
NN 176	+○–●–●●○––	–●––○●○●–+	20	10	4	6	8000	4336	1696	1968	50.0	20.0	30.0	54.2	21.2	24.6
NN 177	+●○–––●○○–	○–○–●––●○+	20	10	6	4	8000	4336	1728	1936	50.0	30.0	20.0	54.2	21.6	24.2
NN 178	+●–○–○●○––	–○––●○○●–+	20	10	6	4	8000	4336	1728	1936	50.0	30.0	20.0	54.2	21.6	24.2
NN 179	+○●––●–○–○	–○○●–––○●+	20	10	6	4	8000	4336	1728	1936	50.0	30.0	20.0	54.2	21.6	24.2
NN 180	+–●○○●––○–	––○●○–○–●+	20	10	6	4	8000	4336	1728	1936	50.0	30.0	20.0	54.2	21.6	24.2
NN 181	+○–●–●–●●–	●●–––●–●○+	20	10	2	8	8000	4336	1736	1928	50.0	10.0	40.0	54.2	21.7	24.1
NN 182	+○–●–●–●●●	–––●●––●○+	20	10	2	8	8000	4336	1736	1928	50.0	10.0	40.0	54.2	21.7	24.1
NN 183	+○●–––●●●–	●–●–●––●○+	20	10	2	8	8000	4336	1736	1928	50.0	10.0	40.0	54.2	21.7	24.1
NN 184	+○●––●–●–●	–●●●–––●○+	20	10	2	8	8000	4336	1736	1928	50.0	10.0	40.0	54.2	21.7	24.1

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NN 185	+ ○ ● – – ● ● – – –	● ● ● – ● – ● – ○ +	20	10	2	8	8000	4336	1736	1928	50.0	10.0	40.0	54.2	21.7	24.1
NN 186	+ ○ ● – ● – – – ● ●	– ● ● – ● – ● – ○ +	20	10	2	8	8000	4336	1736	1928	50.0	10.0	40.0	54.2	21.7	24.1
NN 187	+ – ○ – ● ● ○ ● ● –	– – ○ – – – ● ● ○ +	20	10	4	6	8000	4336	1768	1896	50.0	20.0	30.0	54.2	22.1	23.7
NN 188	+ ● ○ – – – ○ ● ● –	● – ○ – ● – – ● ○ +	20	10	4	6	8000	4336	1768	1896	50.0	20.0	30.0	54.2	22.1	23.7
NN 189	+ ● ○ – – ● ○ – – –	● ● ○ – ● – ● – ○ +	20	10	4	6	8000	4336	1768	1896	50.0	20.0	30.0	54.2	22.1	23.7
NN 190	+ ○ ● ● – – – ○ – –	– ● ● ○ ● ● – ○ – +	20	10	4	6	8000	4336	1768	1896	50.0	20.0	30.0	54.2	22.1	23.7
NN 191	+ ○ – ● – ● – ○ ● ●	– – – ○ ● – – ○ ● +	20	10	4	6	8000	4336	1768	1896	50.0	20.0	30.0	54.2	22.1	23.7
NN 192	+ ○ ● – – ● – ○ – ●	– ● ● ○ – – – ○ ● +	20	10	4	6	8000	4336	1768	1896	50.0	20.0	30.0	54.2	22.1	23.7
NN 193	+ ● – ○ – ○ ● ○ – –	– ○ – – ○ ● ● ○ – +	20	10	6	4	8000	4336	1776	1888	50.0	30.0	20.0	54.2	22.2	23.6
NN 194	+ ● ○ – – ○ ● – – ○	– ○ – ○ – ● ● ○ – +	20	10	6	4	8000	4336	1776	1888	50.0	30.0	20.0	54.2	22.2	23.6
NN 195	+ – ○ ● ● – ○ – ○ –	○ – – ● ○ – – ○ ● +	20	10	6	4	8000	4336	1776	1888	50.0	30.0	20.0	54.2	22.2	23.6
NN 196	+ ● ○ – – – ○ ● ○ –	○ – ● – ○ – – ○ ● +	20	10	6	4	8000	4336	1776	1888	50.0	30.0	20.0	54.2	22.2	23.6
NN 197	+ ● ○ – – ○ – ● – ○	– ○ ● ○ – – – ○ ● +	20	10	6	4	8000	4336	1776	1888	50.0	30.0	20.0	54.2	22.2	23.6
NN 198	+ – ○ ● ● ○ – – ○ –	– – ○ ● ○ – ○ – ● +	20	10	6	4	8000	4336	1776	1888	50.0	30.0	20.0	54.2	22.2	23.6
NN 199	+ ○ – ● – ● – ● ○ –	● ○ – – – ● – ● ○ +	20	10	4	6	8000	4336	1792	1872	50.0	20.0	30.0	54.2	22.4	23.4
NN 200	+ ○ ● – ● – – – ○ ●	– ○ ● – ● – ● – ○ +	20	10	4	6	8000	4336	1792	1872	50.0	20.0	30.0	54.2	22.4	23.4
NN 201	+ ● ○ – – ○ ● – – ●	– ● – ● – ○ ○ ● – +	20	10	4	6	8000	4336	1792	1872	50.0	20.0	30.0	54.2	22.4	23.4
NN 202	+ – ● ○ ○ – ● – ● –	● – – ● ○ – – ○ ● +	20	10	4	6	8000	4336	1792	1872	50.0	20.0	30.0	54.2	22.4	23.4
NN 203	+ – ○ ● ● – ○ – ○ –	○ – – ○ ● – – ● ○ +	20	10	6	4	8000	4336	1872	1792	50.0	30.0	20.0	54.2	23.4	22.4
NN 204	+ ○ ● – – ● ○ – – ○	– ○ – ○ – ● ● ○ – +	20	10	6	4	8000	4336	1872	1792	50.0	30.0	20.0	54.2	23.4	22.4
NN 205	+ ● – ○ – ○ – ○ ● –	○ ● – – – ○ – ○ ● +	20	10	6	4	8000	4336	1872	1792	50.0	30.0	20.0	54.2	23.4	22.4
NN 206	+ ● ○ – ○ – – – ● ○	– ● ○ – ○ – ○ – ● +	20	10	6	4	8000	4336	1872	1792	50.0	30.0	20.0	54.2	23.4	22.4
NN 207	+ – ● ○ ○ – ● – ● –	● – – ○ ● – – ● ○ +	20	10	4	6	8000	4336	1888	1776	50.0	20.0	30.0	54.2	23.6	22.2
NN 208	+ ○ ● – – – ● ○ ● –	● – ○ – ● – – ● ○ +	20	10	4	6	8000	4336	1888	1776	50.0	20.0	30.0	54.2	23.6	22.2
NN 209	+ ○ ● – – ● – ○ – ●	– ● ○ ● – – – ● ○ +	20	10	4	6	8000	4336	1888	1776	50.0	20.0	30.0	54.2	23.6	22.2
NN 210	+ – ● ○ ○ ● – – ● –	– – ● ○ ● – ● – ○ +	20	10	4	6	8000	4336	1888	1776	50.0	20.0	30.0	54.2	23.6	22.2
NN 211	+ ○ – ● – ● ○ ● – –	– ● – – ● ○ ○ ● – +	20	10	4	6	8000	4336	1888	1776	50.0	20.0	30.0	54.2	23.6	22.2
NN 212	+ ○ ● – – ● ○ – – ●	– ● – ● – ○ ○ ● – +	20	10	4	6	8000	4336	1888	1776	50.0	20.0	30.0	54.2	23.6	22.2
NN 213	+ ● – ○ – ○ – ● ○ ○	– – – ● ○ – – ● ○ +	20	10	6	4	8000	4336	1896	1768	50.0	30.0	20.0	54.2	23.7	22.1
NN 214	+ ● ○ – – ○ – ● – ○	– ○ ○ ● – – – ● ○ +	20	10	6	4	8000	4336	1896	1768	50.0	30.0	20.0	54.2	23.7	22.1

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NN 215	+●○○–––●––	–○○●○○–●–+	20	10	6	4	8000	4336	1896	1768	50.0	30.0	20.0	54.2	23.7	22.1
NN 216	+–●–○○●○○–	––●–––○○●+	20	10	6	4	8000	4336	1896	1768	50.0	30.0	20.0	54.2	23.7	22.1
NN 217	+○●–––●○○–	○–●–○––○●+	20	10	6	4	8000	4336	1896	1768	50.0	30.0	20.0	54.2	23.7	22.1
NN 218	+○●––○●–––	○○●–○–○–●+	20	10	6	4	8000	4336	1896	1768	50.0	30.0	20.0	54.2	23.7	22.1
NN 219	+●–○–○–○○–	○○–––○–○●+	20	10	8	2	8000	4336	1928	1736	50.0	40.0	10.0	54.2	24.1	21.7
NN 220	+●–○–○–○○○	–––○○––○●+	20	10	8	2	8000	4336	1928	1736	50.0	40.0	10.0	54.2	24.1	21.7
NN 221	+●○–––○○○–	○–○–○––○●+	20	10	8	2	8000	4336	1928	1736	50.0	40.0	10.0	54.2	24.1	21.7
NN 222	+●○––○–○–○	–○○○–––○●+	20	10	8	2	8000	4336	1928	1736	50.0	40.0	10.0	54.2	24.1	21.7
NN 223	+●○––○○–––	○○○–○–○–●+	20	10	8	2	8000	4336	1928	1736	50.0	40.0	10.0	54.2	24.1	21.7
NN 224	+●○–○–––○○	–○○–○–○–●+	20	10	8	2	8000	4336	1928	1736	50.0	40.0	10.0	54.2	24.1	21.7
NN 225	+●○––○–●–●	–●●○–––●○+	20	10	4	6	8000	4336	1936	1728	50.0	20.0	30.0	54.2	24.2	21.6
NN 226	+–○●●○––●–	––●○●–●–○+	20	10	4	6	8000	4336	1936	1728	50.0	20.0	30.0	54.2	24.2	21.6
NN 227	+○–●–●○●––	–●––○●●○–+	20	10	4	6	8000	4336	1936	1728	50.0	20.0	30.0	54.2	24.2	21.6
NN 228	+○●–––○●●–	●–●–○––○●+	20	10	4	6	8000	4336	1936	1728	50.0	20.0	30.0	54.2	24.2	21.6
NN 229	+●–○–○○●––	–○––●○●○–+	20	10	6	4	8000	4336	1968	1696	50.0	30.0	20.0	54.2	24.6	21.2
NN 230	+–○●○●––○–	––●○○–○–●+	20	10	6	4	8000	4336	1968	1696	50.0	30.0	20.0	54.2	24.6	21.2
NN 231	+–●○○–●–○–	○––●○––●○+	20	10	6	4	8000	4336	2016	1648	50.0	30.0	20.0	54.2	25.2	20.6
NN 232	+●○–––○○●–	○–●–○––●○+	20	10	6	4	8000	4336	2016	1648	50.0	30.0	20.0	54.2	25.2	20.6
NN 233	+○●––○●––○	–○–●–○○●–+	20	10	6	4	8000	4336	2016	1648	50.0	30.0	20.0	54.2	25.2	20.6
NN 234	+○●––○–●–○	–●○○–––○●+	20	10	6	4	8000	4336	2016	1648	50.0	30.0	20.0	54.2	25.2	20.6
NN 235	+○–●–●–○○○	–––●○––●○+	20	10	6	4	8000	4336	2088	1576	50.0	30.0	20.0	54.2	26.1	19.7
NN 236	+●○––○–○–●	–●○○–––●○+	20	10	6	4	8000	4336	2088	1576	50.0	30.0	20.0	54.2	26.1	19.7
NN 237	+○●––○●–––	○○○–●–●–○+	20	10	6	4	8000	4336	2088	1576	50.0	30.0	20.0	54.2	26.1	19.7
NN 238	+●○––○○––●	–●–○–○○●–+	20	10	6	4	8000	4336	2088	1576	50.0	30.0	20.0	54.2	26.1	19.7
NN 239	+–●○○–○–●–	●––○○––○●+	20	10	6	4	8000	4336	2088	1576	50.0	30.0	20.0	54.2	26.1	19.7
NN 240	+○●–––○○●–	●–○–○––○●+	20	10	6	4	8000	4336	2088	1576	50.0	30.0	20.0	54.2	26.1	19.7
NN 241	+–○●○–●–●–	●––●○––●○+	20	10	4	6	8000	4336	2152	1512	50.0	20.0	30.0	54.2	26.9	18.9
NN 242	+–○●○●––●–	––●●○–●–○+	20	10	4	6	8000	4336	2152	1512	50.0	20.0	30.0	54.2	26.9	18.9
NN 243	+●○–○–––●●	–●●–○–●–○+	20	10	4	6	8000	4336	2152	1512	50.0	20.0	30.0	54.2	26.9	18.9
NN 244	+○–●–○●●––	–●––●○●○–+	20	10	4	6	8000	4336	2152	1512	50.0	20.0	30.0	54.2	26.9	18.9

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NN 245	+○●––○●––●	–●–●–○●○–+	20	10	4	6	8000	4336	2152	1512	50.0	20.0	30.0	54.2	26.9	18.9
NN 246	+○–●–○–●●–	●●–––○–○●+	20	10	4	6	8000	4336	2152	1512	50.0	20.0	30.0	54.2	26.9	18.9
NN 247	+–●–○○○●○–	––●–––○●○+	20	10	6	4	8000	4336	2160	1504	50.0	30.0	20.0	54.2	27.0	18.8
NN 248	+○●–––○●○–	○–●–○––●○+	20	10	6	4	8000	4336	2160	1504	50.0	30.0	20.0	54.2	27.0	18.8
NN 249	+○●––○–●–○	–○●○–––●○+	20	10	6	4	8000	4336	2160	1504	50.0	30.0	20.0	54.2	27.0	18.8
NN 250	+–○●○●––○–	––○○●–●–○+	20	10	6	4	8000	4336	2160	1504	50.0	30.0	20.0	54.2	27.0	18.8
NN 251	+○●○–––●––	–○●○○○–●–+	20	10	6	4	8000	4336	2160	1504	50.0	30.0	20.0	54.2	27.0	18.8
NN 252	+○–●–●○○––	–○––●○●○–+	20	10	6	4	8000	4336	2160	1504	50.0	30.0	20.0	54.2	27.0	18.8
NN 253	+●○–○–––○●	–○●–○–●–○+	20	10	6	4	8000	4336	2208	1456	50.0	30.0	20.0	54.2	27.6	18.2
NN 254	+○–●–○–●○–	●○–––○–○●+	20	10	6	4	8000	4336	2208	1456	50.0	30.0	20.0	54.2	27.6	18.2
NN 255	+○–●–○–●●●	–––●○––●○+	20	10	4	6	8000	4336	2224	1440	50.0	20.0	30.0	54.2	27.8	18.0
NN 256	+○●––○●–––	●●●–○–●–○+	20	10	4	6	8000	4336	2224	1440	50.0	20.0	30.0	54.2	27.8	18.0
NN 257	+●○––○○–––	●●○–○–●–○+	20	10	6	4	8000	4336	2256	1408	50.0	30.0	20.0	54.2	28.2	17.6
NN 258	+○–●–○–○●●	–––○○––○●+	20	10	6	4	8000	4336	2256	1408	50.0	30.0	20.0	54.2	28.2	17.6
NN 259	+●○––○○––●	–○–●–●○○–+	20	10	6	4	8000	4336	2280	1384	50.0	30.0	20.0	54.2	28.5	17.3
NN 260	+–○○●–●–○–	●––○○––○●+	20	10	6	4	8000	4336	2280	1384	50.0	30.0	20.0	54.2	28.5	17.3
NN 261	+–○–●●○○○–	––●–––○●○+	20	10	6	4	8000	4336	2304	1360	50.0	30.0	20.0	54.2	28.8	17.0
NN 262	+○●○–––●––	–○○○●●–○–+	20	10	6	4	8000	4336	2304	1360	50.0	30.0	20.0	54.2	28.8	17.0
NN 263	+–●–○○○○○–	––○–––○●○+	20	10	8	2	8000	4336	2312	1352	50.0	40.0	10.0	54.2	28.9	16.9
NN 264	+–●○○–○–○–	○––○○––●○+	20	10	8	2	8000	4336	2312	1352	50.0	40.0	10.0	54.2	28.9	16.9
NN 265	+○●–––○○○–	○–○–○––●○+	20	10	8	2	8000	4336	2312	1352	50.0	40.0	10.0	54.2	28.9	16.9
NN 266	+○●––○–○–○	–○○○–––●○+	20	10	8	2	8000	4336	2312	1352	50.0	40.0	10.0	54.2	28.9	16.9
NN 267	+○●––○○––○	–○–○–○○●–+	20	10	8	2	8000	4336	2312	1352	50.0	40.0	10.0	54.2	28.9	16.9
NN 268	+○●○–––○––	–○○○○○–●–+	20	10	8	2	8000	4336	2312	1352	50.0	40.0	10.0	54.2	28.9	16.9
NN 269	+○–●–○–●○–	○●–––○–●○+	20	10	6	4	8000	4336	2376	1288	50.0	30.0	20.0	54.2	29.7	16.1
NN 270	+–●–○○○○●–	––●–––●○○+	20	10	6	4	8000	4336	2376	1288	50.0	30.0	20.0	54.2	29.7	16.1
NN 271	+–●○○○––●–	––●○○–●–○+	20	10	6	4	8000	4336	2376	1288	50.0	30.0	20.0	54.2	29.7	16.1
NN 272	+○●–○–––●○	–○●–○–●–○+	20	10	6	4	8000	4336	2376	1288	50.0	30.0	20.0	54.2	29.7	16.1
NN 273	+○–●–○○●––	–●––○○○●–+	20	10	6	4	8000	4336	2376	1288	50.0	30.0	20.0	54.2	29.7	16.1
NN 274	+○○●–––●––	–●○○○○–●–+	20	10	6	4	8000	4336	2376	1288	50.0	30.0	20.0	54.2	29.7	16.1

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NN 275	+ – ○ ○ ● ● – – ○ –	– – ○ ● ○ – ● – ○ +	20	10	6	4	8000	4336	2400	1264	50.0	30.0	20.0	54.2	30.0	15.8
NN 276	+ ○ – ● – ○ ● ○ – –	– ○ – – ● ● ○ ○ – +	20	10	6	4	8000	4336	2400	1264	50.0	30.0	20.0	54.2	30.0	15.8
NN 277	+ ○ – ● – ○ – ○ ● –	● ○ – – – ○ – ● ○ +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 278	+ – ○ ● ○ – ○ – ● –	● – – ○ ○ – – ● ○ +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 279	+ ○ ● – ○ – – – ○ ●	– ● ○ – ○ – ● – ○ +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 280	+ ● ○ – – ○ ○ – – –	○ ● ● – ● – ○ – ○ +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 281	+ ● ○ – ○ – – – ○ ○	– ● ● – ● – ○ – ○ +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 282	+ ○ ● – – ○ ○ – – ●	– ● – ○ – ○ ● ○ – +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 283	+ ● ○ ○ – – – ○ – –	– ● ● ○ ● ○ – ○ – +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 284	+ – ○ – ○ ● ○ ● ● –	– – ○ – – – ○ ○ ● +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 285	+ ○ – ○ – ● – ● ● –	○ ○ – – – ○ – ○ ● +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 286	+ ○ – ○ – ● – ● ● ○	– – – ○ ○ – – ○ ● +	20	10	6	4	8000	4336	2448	1216	50.0	30.0	20.0	54.2	30.6	15.2
NN 287	+ – ○ – ● ○ ● ○ ○ –	– – ● – – – ● ○ ○ +	20	10	6	4	8000	4336	2568	1096	50.0	30.0	20.0	54.2	32.1	13.7
NN 288	+ ○ ○ ● – – – ● – –	– ○ ○ ● ○ ● – ○ – +	20	10	6	4	8000	4336	2568	1096	50.0	30.0	20.0	54.2	32.1	13.7
NN 289	+ – ○ ● ○ ○ – – ○ –	– – ○ ○ ○ – ● – ○ +	20	10	8	2	8000	4336	2648	1016	50.0	40.0	10.0	54.2	33.1	12.7
NN 290	+ ○ – ● – ○ ○ ○ – –	– ○ – – ○ ○ ● ○ – +	20	10	8	2	8000	4336	2648	1016	50.0	40.0	10.0	54.2	33.1	12.7
NN 291	+ ○ – ○ – ● – ● ○ ●	– – – ○ ○ – – ● ○ +	20	10	6	4	8000	4336	2664	1000	50.0	30.0	20.0	54.2	33.3	12.5
NN 292	+ ○ ○ – – ● – ● – ●	– ○ ○ ○ – – – ● ○ +	20	10	6	4	8000	4336	2664	1000	50.0	30.0	20.0	54.2	33.3	12.5
NN 293	+ ○ ● – – – ○ ○ ○ –	● – ● – ● – – ○ ○ +	20	10	6	4	8000	4336	2664	1000	50.0	30.0	20.0	54.2	33.3	12.5
NN 294	+ ○ ● – – ○ ○ – – –	● ○ ● – ● – ○ – ○ +	20	10	6	4	8000	4336	2664	1000	50.0	30.0	20.0	54.2	33.3	12.5
NN 295	+ – ○ – ○ ○ ● ● ● –	– – ○ – – – ○ ● ○ +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 296	+ ○ ○ – – – ● ● ● –	○ – ○ – ○ – – ● ○ +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 297	+ – ○ ● ○ – ○ – ● –	○ – – ● ● – – ○ ○ +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 298	+ ○ – ● – ○ – ○ ● ○	– – – ● ● – – ○ ○ +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 299	+ ○ ● – – ○ – ○ – ○	– ● ● ● – – – ○ ○ +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 300	+ ○ ○ – – ● ● – – –	○ ● ○ – ○ – ● – ○ +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 301	+ – ○ ● ○ ○ – – ● –	– – ○ ● ● – ○ – ○ +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 302	+ ○ – ○ – ● ● ○ – –	– ● – – ○ ○ ● ○ – +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 303	+ ○ ○ – – ● ● – – ○	– ● – ○ – ○ ● ○ – +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6
NN 304	+ ○ ● ○ – – – ○ – –	– ● ● ● ○ ○ – ○ – +	20	10	6	4	8000	4336	2736	928	50.0	30.0	20.0	54.2	34.2	11.6

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NN 305	+ ○ – ○ – ● – ● ○ –	○ ● – – – ● – ○ ○ +	20	10	6	4	8000	4336	2952	712	50.0	30.0	20.0	54.2	36.9	8.9
NN 306	+ – ○ ○ ● ○ – – ● –	– – ● ○ ● – ○ – ○ +	20	10	6	4	8000	4336	2952	712	50.0	30.0	20.0	54.2	36.9	8.9
NN 307	+ ○ ○ – ● – – – ● ○	– ○ ● – ● – ○ – ○ +	20	10	6	4	8000	4336	2952	712	50.0	30.0	20.0	54.2	36.9	8.9
NN 308	+ ○ – ○ – ● ○ ● – –	– ● – – ○ ● ○ ○ – +	20	10	6	4	8000	4336	2952	712	50.0	30.0	20.0	54.2	36.9	8.9
NN 309	+ ○ – ○ – ● – ○ ● –	● ○ – – – ● – ○ ○ +	20	10	6	4	8000	4336	3024	640	50.0	30.0	20.0	54.2	37.8	8.0
NN 310	+ ○ ○ – ● – – – ○ ●	– ● ○ – ● – ○ – ○ +	20	10	6	4	8000	4336	3024	640	50.0	30.0	20.0	54.2	37.8	8.0
NN 311	+ ○ ○ – – – ● ● ● –	● – ● – ● – – ○ ○ +	20	10	4	6	8000	4336	3088	576	50.0	20.0	30.0	54.2	38.6	7.2
NN 312	+ ○ ○ – – ● – ● – ●	– ● ● ● – – – ○ ○ +	20	10	4	6	8000	4336	3088	576	50.0	20.0	30.0	54.2	38.6	7.2
NN 313	+ – ○ ○ ○ ● – – ● –	– – ● ● ○ – ○ – ○ +	20	10	6	4	8000	4336	3168	496	50.0	30.0	20.0	54.2	39.6	6.2
NN 314	+ ○ – ○ – ○ ● ● – –	– ● – – ● ○ ○ ○ – +	20	10	6	4	8000	4336	3168	496	50.0	30.0	20.0	54.2	39.6	6.2
NN 315	+ ○ – ○ – ● – ○ ○ ○	– – – ○ ● – – ○ ○ +	20	10	8	2	8000	4336	3176	488	50.0	40.0	10.0	54.2	39.7	6.1
NN 316	+ – ○ ○ ○ ● – – ○ –	– – ○ ○ ● – ○ – ○ +	20	10	8	2	8000	4336	3176	488	50.0	40.0	10.0	54.2	39.7	6.1
NN 317	+ ○ ○ – – ● ○ – – –	○ ○ ○ – ● – ○ – ○ +	20	10	8	2	8000	4336	3176	488	50.0	40.0	10.0	54.2	39.7	6.1
NN 318	+ ○ – ○ – ● ○ ○ – –	– ○ – – ● ○ ○ ○ – +	20	10	8	2	8000	4336	3176	488	50.0	40.0	10.0	54.2	39.7	6.1
NN 319	+ – ○ ○ ○ – ● – ● –	● – – ○ ● – – ○ ○ +	20	10	6	4	8000	4336	3240	424	50.0	30.0	20.0	54.2	40.5	5.3
NN 320	+ ○ ○ – – – ● ○ ● –	● – ○ – ● – – ○ ○ +	20	10	6	4	8000	4336	3240	424	50.0	30.0	20.0	54.2	40.5	5.3
NN 321	+ ○ ○ – – ● – ○ – ●	– ● ○ ● – – – ○ ○ +	20	10	6	4	8000	4336	3240	424	50.0	30.0	20.0	54.2	40.5	5.3
NN 322	+ ○ ○ – – ● ○ – – ●	– ● – ● – ○ ○ ○ – +	20	10	6	4	8000	4336	3240	424	50.0	30.0	20.0	54.2	40.5	5.3
NN 323	+ ○ – ○ – ○ – ● ● ●	– – – ○ ● – – ○ ○ +	20	10	6	4	8000	4336	3312	352	50.0	30.0	20.0	54.2	41.4	4.4
NN 324	+ ○ ○ – – ● ○ – – –	● ● ● – ○ – ○ – ○ +	20	10	6	4	8000	4336	3312	352	50.0	30.0	20.0	54.2	41.4	4.4
NN 325	+ – ○ ○ ○ – ● – ○ –	○ – – ● ○ – – ○ ○ +	20	10	8	2	8000	4336	3368	296	50.0	40.0	10.0	54.2	42.1	3.7
NN 326	+ ○ ○ – – ○ ● – – ○	– ○ – ● – ○ ○ ○ – +	20	10	8	2	8000	4336	3368	296	50.0	40.0	10.0	54.2	42.1	3.7
NN 327	+ – ○ – ○ ○ ○ ● ○ –	– – ● – – – ○ ○ ○ +	20	10	8	2	8000	4336	3512	152	50.0	40.0	10.0	54.2	43.9	1.9
NN 328	+ ○ ○ – – – ○ ● ○ –	○ – ● – ○ – – ○ ○ +	20	10	8	2	8000	4336	3512	152	50.0	40.0	10.0	54.2	43.9	1.9
NN 329	+ ○ ○ – – ○ – ● – ○	– ○ ● ○ – – – ○ ○ +	20	10	8	2	8000	4336	3512	152	50.0	40.0	10.0	54.2	43.9	1.9
NN 330	+ ○ ○ ○ – – – ● – –	– ○ ● ○ ○ ○ – ○ – +	20	10	8	2	8000	4336	3512	152	50.0	40.0	10.0	54.2	43.9	1.9
NN 331	+ ○ – ○ – ○ – ○ ● –	○ ● – – – ○ – ○ ○ +	20	10	8	2	8000	4336	3608	56	50.0	40.0	10.0	54.2	45.1	0.7
NN 332	+ ○ ○ – ○ – – – ● ○	– ● ○ – ○ – ○ – ○ +	20	10	8	2	8000	4336	3608	56	50.0	40.0	10.0	54.2	45.1	0.7
NN 333	+ – ○ – ○ ○ ○ ○ ○ –	– – ○ – – – ○ ○ ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 334	+ ○ – ○ – ○ – ○ ○ –	○ ○ – – – ○ – ○ ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0

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NN 335	+ – ○ ○ ○ – ○ – ○ –	○ – – ○ ○ – – ○ ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 336	+ ○ – ○ – ○ – ○ ○ ○	– – – ○ ○ – – ○ ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 337	+ ○ ○ – – – ○ ○ ○ –	○ – ○ – ○ – – ○ ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 338	+ ○ ○ – – ○ – ○ – ○	– ○ ○ ○ – – – ○ ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 339	+ – ○ ○ ○ ○ – – ○ –	– – ○ ○ ○ – ○ – ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 340	+ ○ ○ – – ○ ○ – – –	○ ○ ○ – ○ – ○ – ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 341	+ ○ ○ – ○ – – – ○ ○	– ○ ○ – ○ – ○ – ○ +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 342	+ ○ – ○ – ○ ○ ○ – –	– ○ – – ○ ○ ○ ○ – +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 343	+ ○ ○ – – ○ ○ – – ○	– ○ – ○ – ○ ○ ○ – +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0
NN 344	+ ○ ○ ○ – – – ○ – –	– ○ ○ ○ ○ ○ – ○ – +	20	10	10	0	8000	4336	3664	0	50.0	50.0	0.0	54.2	45.8	0.0

Concluded.

Table 6 – Stacking sequences for 7 through 21 ply laminates of the form $_{+}NN_{-}$ with blend ratio ($n_{+}/n_{\pm}$) = 28.6%.

Ref.	Sequence	n	$n_{\pm}$	$n_{\circ}$	$n_{\bullet}$	ζ	$\zeta_{\pm}$	$\zeta_{\circ}$	$\zeta_{\bullet}$	$n_{\pm}/n$ (%)	$n_{\circ}/n$ (%)	$n_{\bullet}/n$ (%)	$\zeta_{\pm}/\zeta$ (%)	$\zeta_{\circ}/\zeta$ (%)	$\zeta_{\bullet}/\zeta$ (%)
NN 57	+ ● – + – – – – – ● – ● – ● – + + –	18	14	0	4	5832	4832	0	1000	77.8	0.0	22.2	82.9	0.0	17.1
NN 58	+ ○ – + – – – – – ○ – ○ – ○ – + + –	18	14	4	0	5832	4832	1000	0	77.8	22.2	0.0	82.9	17.1	0.0
NN 359	+ – ● + – – ● – ● – ● – – – – ● ● + + –	20	14	0	6	8000	6272	0	1728	70.0	0.0	30.0	78.4	0.0	21.6
NN 360	+ – ● + – – ● ● – – – – ● – ● – ● + + –	20	14	0	6	8000	6272	0	1728	70.0	0.0	30.0	78.4	0.0	21.6
NN 361	+ – ● + ● – – – – – ● – ● – ● ● – + + –	20	14	0	6	8000	6272	0	1728	70.0	0.0	30.0	78.4	0.0	21.6
NN 362	+ ● – + – ● – – – – – ● ● ● – ● – + + –	20	14	0	6	8000	6272	0	1728	70.0	0.0	30.0	78.4	0.0	21.6
NN 367	+ – ● + – – ● ○ – – – – ○ – ● – ● + + –	20	14	2	4	8000	6272	152	1576	70.0	10.0	20.0	78.4	1.9	19.7
NN 369	+ – ● + ○ – – – – – ● – ● – ● ○ – + + –	20	14	2	4	8000	6272	728	1000	70.0	10.0	20.0	78.4	9.1	12.5
NN 371	+ – ○ + ● – – – – – ○ – ○ – ○ ● – + + –	20	14	4	2	8000	6272	1000	728	70.0	20.0	10.0	78.4	12.5	9.1
NN 373	+ – ○ + – – ○ ● – – – – ● – ○ – ○ + + –	20	14	4	2	8000	6272	1576	152	70.0	20.0	10.0	78.4	19.7	1.9
NN 375	+ – ○ + – – ○ – ○ – ○ – – – – ○ ○ + + –	20	14	6	0	8000	6272	1728	0	70.0	30.0	0.0	78.4	21.6	0.0
NN 376	+ – ○ + – – ○ ○ – – – – ○ – ○ – ○ + + –	20	14	6	0	8000	6272	1728	0	70.0	30.0	0.0	78.4	21.6	0.0
NN 377	+ – ○ + ○ – – – – – ○ – ○ – ○ ○ – + + –	20	14	6	0	8000	6272	1728	0	70.0	30.0	0.0	78.4	21.6	0.0
NN 378	+ ○ – + – ○ – – – – – ○ ○ ○ – ○ – + + –	20	14	6	0	8000	6272	1728	0	70.0	30.0	0.0	78.4	21.6	0.0

Table 7 – Stacking sequences for 7 through 21 ply laminates of the form $_{+}NN_{-}$ with blend ratio ($n_{+}/n_{\pm}$) = 71.4%.

Ref.	Sequence		n	$n_{\pm}$	$n_{\circ}$	$n_{\bullet}$	ζ	$\zeta_{\pm}$	$\zeta_{\circ}$	$\zeta_{\bullet}$	$n_{\pm}/n$ (%)	$n_{\circ}/n$ (%)	$n_{\bullet}/n$ (%)	$\zeta_{\pm}/\zeta$ (%)	$\zeta_{\circ}/\zeta$ (%)	$\zeta_{\bullet}/\zeta$ (%)
NN 59	+ − − + ● + ● + ●	+ + + + + − + ● −	18	14	0	4	5832	4832	0	1000	77.8	0.0	22.2	82.9	0.0	17.1
NN 60	+ − − + ○ + ○ + ○	+ + + + + − + ○ −	18	14	4	0	5832	4832	1000	0	77.8	22.2	0.0	82.9	17.1	0.0
NN 363	+ − − + ● + ● ● ● +	+ + + + ● + − + ● −	20	14	0	6	8000	6272	0	1728	70.0	0.0	30.0	78.4	0.0	21.6
NN 364	+ − − + ● ● + ● + ●	+ + + + + ● − ● + −	20	14	0	6	8000	6272	0	1728	70.0	0.0	30.0	78.4	0.0	21.6
NN 365	+ − − ● + ● + ● + +	+ + ● ● + + − ● + −	20	14	0	6	8000	6272	0	1728	70.0	0.0	30.0	78.4	0.0	21.6
NN 366	+ − − ● ● + + + + ●	+ ● + ● + + − ● + −	20	14	0	6	8000	6272	0	1728	70.0	0.0	30.0	78.4	0.0	21.6
NN 368	+ − − ● + ● + ○ + +	+ + ○ ● + + − ● + −	20	14	2	4	8000	6272	152	1576	70.0	10.0	20.0	78.4	1.9	19.7
NN 370	+ − − + ○ ● + ● + ●	+ + + + + ○ − ● + −	20	14	2	4	8000	6272	728	1000	70.0	10.0	20.0	78.4	9.1	12.5
NN 372	+ − − + ● ○ + ○ + ○	+ + + + + ● − ○ + −	20	14	4	2	8000	6272	1000	728	70.0	20.0	10.0	78.4	12.5	9.1
NN 374	+ − − ○ + ○ + ● + +	+ + ● ○ + + − ○ + −	20	14	4	2	8000	6272	1576	152	70.0	20.0	10.0	78.4	19.7	1.9
NN 379	+ − − ○ ○ + + + + ○	+ ○ + ○ + + − ○ + −	20	14	6	0	8000	6272	1728	0	70.0	30.0	0.0	78.4	21.6	0.0
NN 380	+ − − ○ + ○ + ○ + +	+ + ○ ○ + + − ○ + −	20	14	6	0	8000	6272	1728	0	70.0	30.0	0.0	78.4	21.6	0.0
NN 381	+ − − + ○ ○ + ○ + ○	+ + + + + ○ − ○ + −	20	14	6	0	8000	6272	1728	0	70.0	30.0	0.0	78.4	21.6	0.0
NN 382	+ − − + ○ + ○ ○ ○ +	+ + + + ○ + − + ○ −	20	14	6	0	8000	6272	1728	0	70.0	30.0	0.0	78.4	21.6	0.0

Table 8 - Stacking sequences for 7 through 21 ply laminates of the form ${}_{+}NN_{\bigcirc}$ with blend ratio ($n_{+}/n_{\pm}$) = 28.6%.

Ref.	Sequence	n	$n_{\pm}$	$n_{\bigcirc}$	$n_{\bullet}$	ζ	$\zeta_{\pm}$	$\zeta_{\bigcirc}$	$\zeta_{\bullet}$	$n_{\pm}/n$ (%)	$n_{\bigcirc}/n$ (%)	$n_{\bullet}/n$ (%)	$\zeta_{\pm}/\zeta$ (%)	$\zeta_{\bigcirc}/\zeta$ (%)	$\zeta_{\bullet}/\zeta$ (%)
NN 345	+●−●−+−●−− −−●−−●++−●	20	14	0	6	8000	5024	0	2976	70.0	0.0	30.0	62.8	0.0	37.2
NN 346	+●−●−+−○−− −−○−−●++−●	20	14	2	4	8000	5024	152	2824	70.0	10.0	20.0	62.8	1.9	35.3
NN 347	+○−○−+−●−− −−●−−○++−○	20	14	4	2	8000	5024	2824	152	70.0	20.0	10.0	62.8	35.3	1.9
NN 348	+○−○−+−○−− −−○−−○++−○	20	14	6	0	8000	5024	2976	0	70.0	30.0	0.0	62.8	37.2	0.0
NN 349	+−−●+●●−−● −−−−−●+−+●	20	14	0	6	8000	5648	0	2352	70.0	0.0	30.0	70.6	0.0	29.4
NN 350	+●−−+−●●−− −●−●−−+−+●	20	14	0	6	8000	5648	0	2352	70.0	0.0	30.0	70.6	0.0	29.4
NN 351	+●−−+●−−−● ●−−●−−+−+●	20	14	0	6	8000	5648	0	2352	70.0	0.0	30.0	70.6	0.0	29.4
NN 352	+●−−+●−−−○ ○−−●−−+−+●	20	14	2	4	8000	5648	8	2344	70.0	10.0	20.0	70.6	0.1	29.3
NN 353	+●−−+−○●−− −●−○−−+−+●	20	14	2	4	8000	5648	296	2056	70.0	10.0	20.0	70.6	3.7	25.7
NN 354	+○−−+−●○−− −○−●−−+−+○	20	14	4	2	8000	5648	2056	296	70.0	20.0	10.0	70.6	25.7	3.7
NN 355	+○−−+○−−−● ●−−○−−+−+○	20	14	4	2	8000	5648	2344	8	70.0	20.0	10.0	70.6	29.3	0.1
NN 356	+−−○+○○−−○ −−−−−○+−+○	20	14	6	0	8000	5648	2352	0	70.0	30.0	0.0	70.6	29.4	0.0
NN 357	+○−−+−○○−− −○−○−−+−+○	20	14	6	0	8000	5648	2352	0	70.0	30.0	0.0	70.6	29.4	0.0
NN 358	+○−−+○−−−○ ○−−○−−+−+○	20	14	6	0	8000	5648	2352	0	70.0	30.0	0.0	70.6	29.4	0.0