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ANALYSIS OF ANISOTROPIC CURVED SHELLS

COMPUTER PROGRAM USER'S MANUAL

v1.0

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INTRODUCTION

PROGRAM DESCRIPTION

The advent of composite structures in aerospace designs and the increasing affordability of those materials have increased the number of applications and the widespread need of analytical tools for the analysis and design of composite structures.

The software here presented is able to analyze (static and linear buckling analyses) stiffened composite panels, flat and cylindrical shells.

UNITS

The program has no built-in units; therefore any consistent unit system is appropriate. This means that, for example, to be consistent with the English system, the following have to be considered $[F] = \text{lb}$. (pound-force), $[L] = \text{in}$. (inches), $[t] = \text{sec(ond)}$, then mass has to be in $[M] = \text{lb-sec}^2/\text{in}$. In a similar way a typical International System derived units often used in structural analysis is $[F] = \text{N}$ (Newton), $[L] = \text{mm}$ (millimeter), $[t] = \text{sec(ond)}$, then mass has to be in $[M] = \text{N-sec}^2/\text{mm} = \text{tons}$.

COORDINATE SYSTEMS, SHELL MODEL DESCRIPTION, SIGN CONVENTION

In the following figures the coordinate systems for shell definition and parameters are shown. The positive load sign convention is depicted in Figure 2. Origin of coordinate system is the shell's lower left corner.

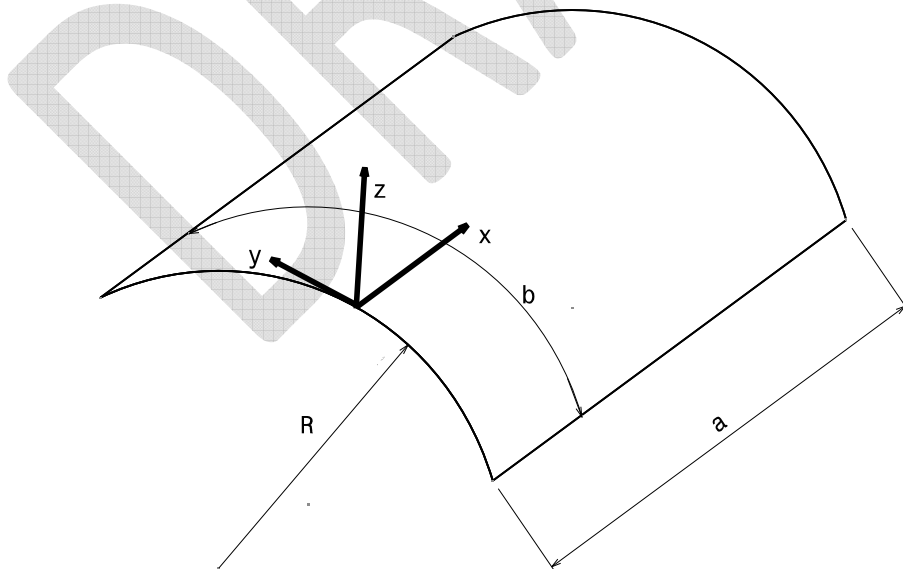


Figure 1. Shell geometry

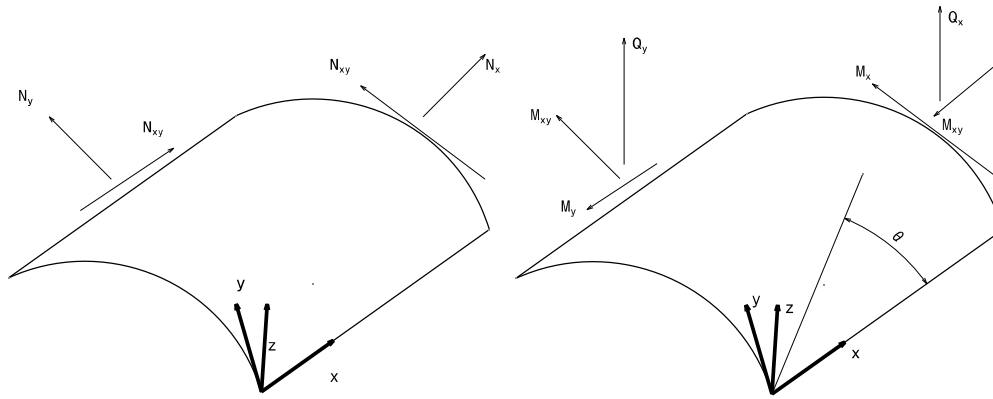


Figure 2. Sign convention for positive loads

TYPES OF ANALYSIS AVAILABLE

The program includes the following capabilities:

A. Types of Analysis

1. Static deflection and strength under complicated variations of edge and lateral loads with complicated support conditions
2. Elastic stability under complicated edge loads
3. Natural frequencies and mode shapes - *Functionality not validated yet.*

B. Geometry

1. Flat panel
2. Cylindrically curved panel
3. Full cylinder (especially orthotropic only) - *Functionality not validated yet.*

C. Construction

1. Sheet with discrete rings and stringers
2. Sandwich with discrete rings and stringers (neglecting core shear).

D. Material - Linearly Elastic

1. Panel - layered anisotropic
2. Stiffeners - orthotropic.

E. Boundary Conditions

1. All combinations of clamped and simply supported; some combinations with free edges
2. Elastic moment restraint on opposite edges.

MODEL DESCRIPTION

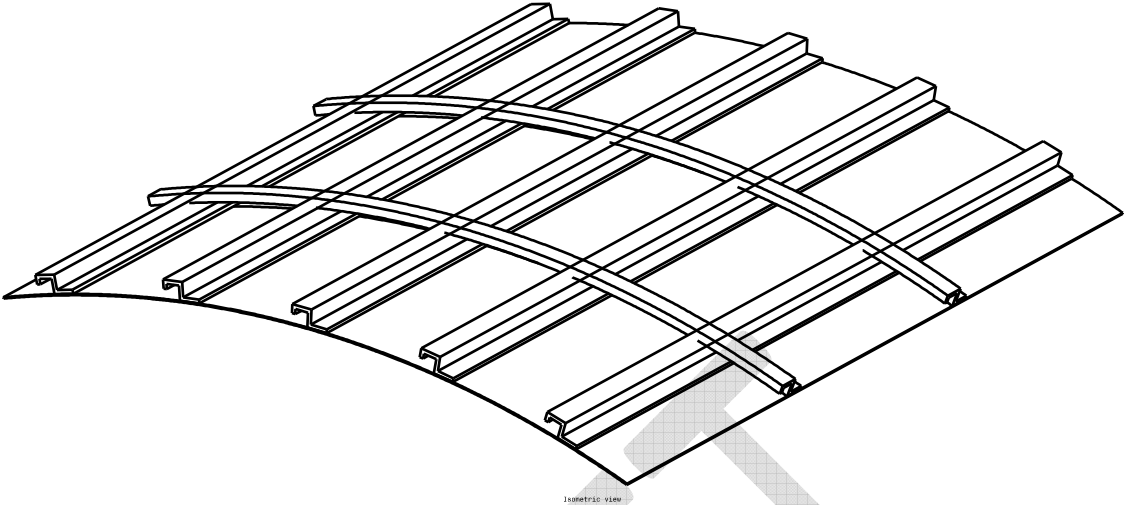
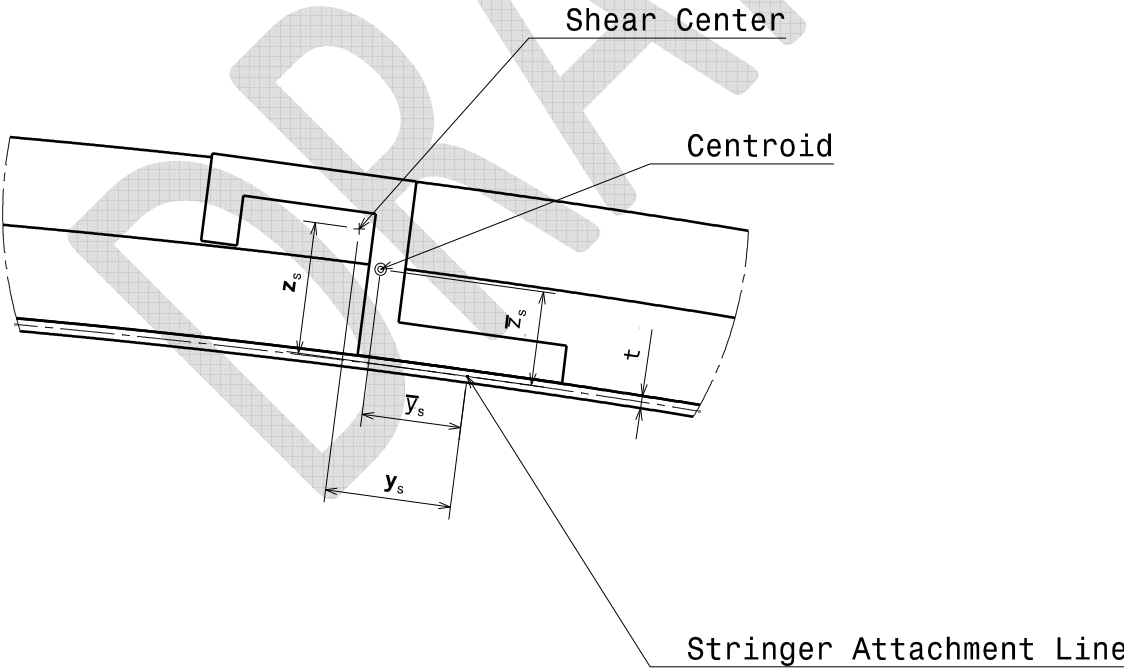


Figure 3. Geometry of discretely stiffened shell



Detail A

Figure 4. External stringer detail

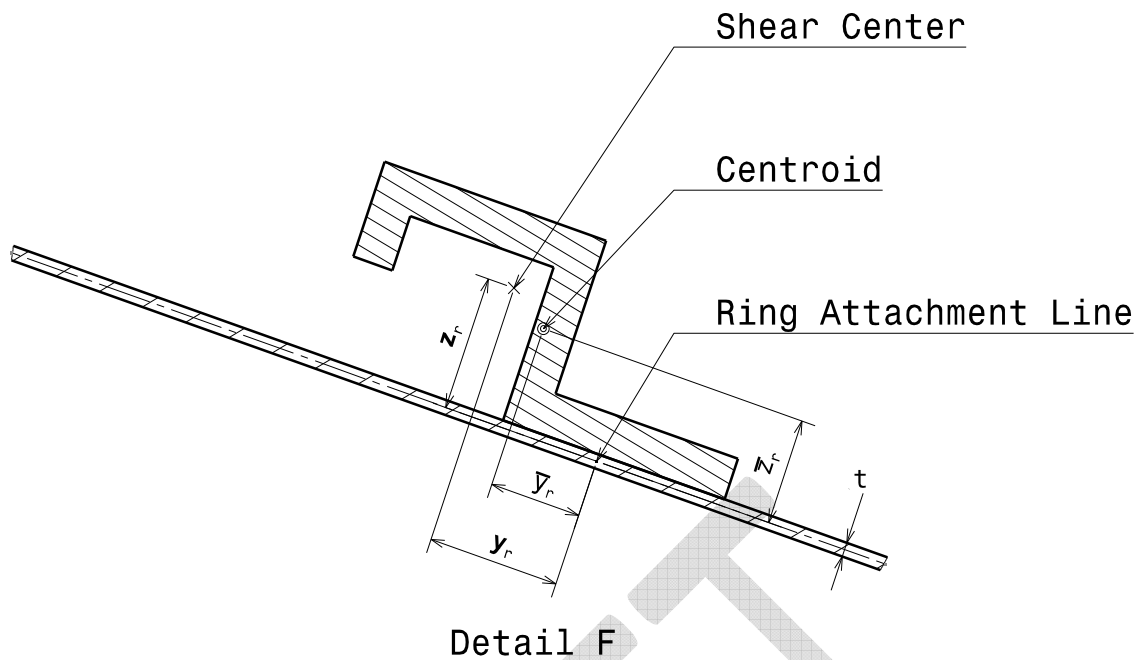


Figure 5. External ring (frame) detail

USER'S INSTRUCTIONS

A description of the data Cards follows:

Card 1. Title

Printed with the output. Any Fortran characters may be used. (1 card only.)

Card 2. IFLAGD, IFLAGB, IFLAGW, IBCX, IBCY, NTX, NTY, ITX, ITY, NMODES, IMATL, NPLYS, IREACT, IOUT, IEDGE, NPNX, NPNY, IPRTN, NQTX, NQTY, IPRTQ, NSTRNG, NRING, NLMASS, NPTLDS, NPTMOM, NLNMOM, NPTSUP, NLNSPR, INTPRT, IFLEX (31 integers).

There is available at the web site a spreadsheet to create this card easily.

IFLAGD = +1, if doing a dynamics problem

= +0, otherwise.

IFLAGB = +1, if 1 buckling eigenvalue is desired

= +2, if 2 buckling values are desired (as for shear buckling)

= +3, if 1 buckling eigenvalue and an imperfection sensitivity analysis are desired

= +4, if 2 buckling eigenvalues and an imperfection sensitivity analysis are desired

= +0, otherwise.

IFLAGW = +1, if doing a deflection analysis with lateral pressure, q

= +2, if doing a deflection analysis with no lateral pressure, q
= +0, otherwise.

IBCX is a tag for the boundary condition in the x-direction.

= +1, for clamped-simply supported

= +2, for simply supported-simply supported

= +3, for clamped-clamped

= +4, for clamped-free

= +5, for simply supported-free

= +6, for free-free

= +7, for elastic restraint. ($w_{,xx} = \alpha_x w_{,x}|_{x=0}$, $w_{,xx} = \beta_x w_{,x}|_{x=a}$)

IBCY is a tag for the boundary condition in the y-direction.

= +0, for a full cylinder

= +1, for clamped-simply supported

= +2, for simply supported-simply supported

= +3, for clamped-clamped

= +4, for clamped-free

= +5, for simply supported-free

= +6, for free-free

= +7, for elastic restraint exactly the same as that in the x-direction

= +8, other elastic restraint. ($w_{,yy} = \alpha_y w_{,y}|_{y=0}$, $w_{,yy} = \beta_y w_{,y}|_{y=b}$)

NTX = Number of terms in the assumed series for u , v , and w , in the x-direction. $1 \leq \text{NTX} \leq 10$.

NTY = Number of terms in the assumed series for u , v , and w , in the y-direction. $1 \leq \text{NTY} \leq 10$.

Note: Although the upper limit on each of the above two numbers is ten, the limit on the size of the matrices generated using them is 150. This means that $\text{NTX} * \text{NTY} \leq 50$.

ITX = The beginning term in the assumed series for u , v , and w . This number sets the range of m (axial wave number) to be considered in the analysis, such that $\text{ITX} \leq m \leq \text{ITX} + \text{NTX} - 1$. The range on ITX is $1 \leq \text{ITX} \leq 20$.

ITY = The beginning term in the assumed series for u , v , and w . This number sets the range of n (circumferential wave number) to be considered in the analysis, such that $\text{ITY} \leq n \leq \text{ITY} + \text{NTY} - 1$. The range on ITY is $1 \leq \text{ITY} \leq 20$.

NMODES = Number of mode shapes to be calculated in a natural frequency problem. $1 \leq \text{NMODES} \leq 20$.

= +0, for a buckling or lateral loads problem.

IMATL = +1, for an isotropic material

= +2, for a laminate with constant ply properties

= +3, for a laminate with variable ply properties

= +4, for a sandwich with orthotropic facings.

NPLYS = Number of plies in the laminate $1 \leq \text{NPLYS} \leq 40$. For an isotropic material, NPLYS = +1. For a sandwich, NPLYS = +3.

IREACT = +1 if the reactions (at the corners, or along the edges of the panel, or at elastic supports) are desired.

= +0, otherwise.

IOUT = An indicator that controls how much output is given and also controls whether a lamina strength analysis is performed. Each of the following output quantities is printed at 625 points over the panel, with the $x = 0$ axis across the top and the $y = 0$ axis down the left hand side.

= +1, for printing the normal deflection, w , only

= +2, for printing w , u , and v (mid-surface deflections)

= +3, for printing w , u , v , ε_x^0 , ε_y^0 , γ_{xy}^0 (mid-surface strains) and κ_x , κ_y , κ_{xy} (curvatures)

= +4, for printing w , u , v , M_x , M_y , M_{xy} (moment resultants), Q_x , Q_y , (transverse shear resultants), and σ_x , σ_y , τ_{xy} , σ_{VM} (stresses, only for isotropic or sandwich, Von Mises stress only for isotropic material)

= +5, for printing w , u , v , M_x , M_y , M_{xy} , Q_x , Q_y , σ_x , σ_y , τ_{xy} , σ_{VM} , ε_x^0 , ε_y^0 , γ_{xy}^0 , κ_x , κ_y , κ_{xy}

= +6, for printing w , σ_x , σ_y , τ_{xy}

= +7, for printing w , ε_1 , ε_2 , γ_{12} , (strains in lamina axes for each ply), RF_1 , RF_2 , RF_{12} (reserve factors for each ply according to the maximum strain theory)

= +8, for printing w , σ_x , σ_y , τ_{xy} , σ_{VM} , ε_1 , ε_2 , γ_{12} , RF_1 , RF_2 , RF_{12}

= +9, for printing w , u , v , M_x , M_y , M_{xy} , Q_x , Q_y , ε_x^0 , ε_y^0 , ε_{xy}^0 , κ_x , κ_y , κ_{xy} , σ_x , σ_y , τ_{xy} , σ_{VM} , ε_1 , ε_2 , γ_{12} , RF_1 , RF_2 , RF_{12}

IEDGE = +1, if edge loads are to be input

= +2, if cylinder end-loads (force, torque, bending moment) are to be input.

= +0, otherwise.

NPNX = Number of terms in the edge loads expressions in the x-direction. $1 \leq \text{NPNX} \leq 10$.

= +0, if IEDGE = +0 or +2.

NPNY = Number of terms in the edge loads expressions in the y-direction. $1 \leq \text{NPNY} \leq 10$.

= +0, if IEDGE = +0 or +2.

IPRTN = +1, if the distributions of the edge loads are to be printed at quarter points of the panel.

= +0, otherwise.

NQTX = Number of terms in the distributed lateral loads expression in the x-direction. $1 \leq \text{NQTX} \leq 10$.

= +0, if IFLAGW = +0 or +2.

NQTY = Number of terms in the distributed lateral loads expression in the y-direction. $1 \leq \text{NQTY} \leq 10$.

= +0, if IFLAGW = +0 or +2.

IPRTQ = +1, if the distribution of the lateral loads is to be printed at quarter points of the panel.

= +0, otherwise.

NSTRNG = Number of stringers. $0 \leq \text{NSTRNG} \leq 100$. (For equally-spaced identical stringers, precede number by a minus sign.)

NRING = Number of rings. $0 \leq \text{NRING} \leq 50$. (For equally-spaced identical rings, precede number by a minus sign.)

NLMASS = Number of lumped masses. $0 \leq \text{NLMASS} \leq 50$.

NPTLDS = Number of concentrated normal loads. $0 \leq \text{NPTLDS} \leq 50$.

NPTMOM = Number of concentrated point moments. $0 \leq \text{NPTMOM} \leq 50$.

NLNMOM = Number of concentrated line moments. $0 \leq \text{NLNMOM} \leq 50$.

NPTSUP = Number of point spring supports. $0 \leq \text{NPTSUP} \leq 50$.

NLNSPR = Number of line spring supports. $0 \leq \text{NLNSPR} \leq 50$.

INTPRT = +1, if the values of the calculated integrals, the matrices generated is to be printed.

= +0, otherwise. (Usually, INTPRT = +0).

IFLEX = Number of points for which influence coefficients are desired.

Card 3. AA, [BB], RR, [MU]

AA = Dimension in the x-direction

BB = Dimension in the y-direction (Note: This is not input for a full cylinder.)

RR = Radius of panel.

MU = Standard deviation of panel thickness.

Card 4. [ALFAX, BETAX], [ALFAY, BETAY]

ALFAX = The constant describing the elastic restraint on the edge $x = 0$. $w_{,xx} = (\text{ALFAX}) w_{,x}$

BETAX = The constant describing the elastic restraint on the edge $x = a$. $w_{,xx} = (-\text{BETAX}) w_{,x}$

ALFAY = The constant describing the elastic restraint on the edge $y = 0$. $w_{,yy} = (\text{ALFAY}) w_{,y}$

BETAY = The constant describing the elastic restraint on the edge $y = b$. $w_{,yy} = (-\text{BETAY}) w_{,y}$

The elastic restraint constants are only input as needed, and if the y-direction quantities are identical to those in the x-direction, only ALFAX and BETAX need be input. All of these constants are input as positive for positive restraint.

Card 5. E , ν , T

E = Young's modulus, $[F][L]**(-2)$

ν = Poisson's ratio, dimensionless

T = Panel thickness, $[L]$.

Card 6. $EC(1)$, $EC(2)$, $EC(3)$, $ET(1)$, $ET(2)$, $ET(3)$

$EC(1)$ = Compressive strain allowable in the 1-direction, $[L]/[L]$.

$EC(2)$ = Compressive strain allowable in the 2-direction, $[L]/[L]$.

$EC(3)$ = Negative shear strain allowable, $[L]/[L]$.

$ET(1)$ = Tensile strain allowable in the 1-direction, $[L]/[L]$.

$ET(2)$ = Tensile strain allowable in the 2-direction, $[L]/[L]$.

$ET(3)$ = Positive shear strain allowable, $[L]/[L]$.

Card 7. E_1 , E_2 , G , ν_{12} , H , $(\theta_i, i = 1, 2, \dots, \text{NPLYS})$

E_1 = Modulus in the 0° direction, $[F][L]**(-2)$.

E_2 = Modulus in the 90° direction, $[F][L]**(-2)$.

G = In-plane shear modulus, $[F][L]**(-2)$.

ν_{12} = Major Poisson's ratio, dimensionless.

H = Thickness of each ply, $[L]$

θ_i = Orientation of the i^{th} ply, starting with the bottom or inner ply, degrees.

Card 8. (E_1) , (E_2) , G , ν_{12} , θ_i , $[EC(1)_i, EC(2)_i, EC(3)_i, ET(1)_i, ET(2)_i, ET(3)_i]$, $i = 1, \dots, \text{NPLYS}$

E_{1i} = Modulus in the 0° direction of the i^{th} ply, $[F][L]**(-2)$

E_{2i} = Modulus in the 90° direction of the i^{th} ply, $[F][L]**(-2)$

G_i = Shear modulus of the i^{th} ply, $[F][L]**(-2)$

$(\nu_{12})_i$ = Major Poisson's ratio of the i^{th} ply, dimensionless

H_i = Thickness of the i^{th} ply, $[L]$.

θ_i = Orientation of the i^{th} ply, degrees.

(The following allowables are input only if a strength analysis is being performed, $\text{IOUT} \geq 7$.)

$EC(1)_i$ = Compressive strain allowable in the 1-direction for the i^{th} ply, [L]/[L].

$EC(2)_i$ = Compressive strain allowable in the 2-direction for the i^{th} ply, [L]/[L].

$EC(3)_i$ = Negative shear strain allowable in the 1-2 plane for the i^{th} ply, [L]/[L].

$ET(1)_i$ = Tensile strain allowable in the 1-direction for the i^{th} ply, [L]/[L].

$ET(2)_i$ = Tensile strain allowable in the 2-direction for the i^{th} ply, [L]/[L].

$ET(3)_i$ = Positive shear strain allowable in the 1-2 plane for the i^{th} ply, [L]/[L].

Card 9. E1, E2, G, ν_{12} , H

E1 = Inner (outer) facing modulus in the 0° direction, [F]*[L]**(-2).

E2 = Inner (outer) facing modulus in the 90° direction, [F]*[L]**(-2).

G = Inner (outer) facing shear modulus, [F]*[L]**(-2).

ν_{12} = Inner (outer) facing major Poisson's ratio, dimensionless.

H = Inner (outer) facing thickness, [L].

(If a strength analysis is not being performed, Card 9 is now repeated for the outer facing properties. If a strength analysis is being performed, Cards 10 and 11 for the inner facing are now input, and then Cards 9, 10 and 11 are input for the outer facing.)

Card 10. EC(1), EC(2), EC(3), ET(1), ET(2), ET(3), MCHK

EC(1) = Inner (outer) facing compressive strain allowable in the 1-direction, [L]/[L].

EC(2) = Inner (outer) facing compressive strain allowable in the 2-direction, [L]/[L].

EC(3) = Inner (outer) facing negative shear strain allowable in the 1-2 plane, [L]/[L].

ET(1) = Inner (outer) facing tensile strain allowable in the 1-direction, [L]/[L].

ET(2) = Inner (outer) facing tensile strain allowable in the 2-direction, [L]/[L].

EC(3) = Inner (outer) facing positive shear strain allowable in the 1-2 plane, [L]/[L].

MCHK = Number of orientations to be checked in the strength analysis of the inner (outer) facing. $1 \leq MCHK \leq 10$.

Card 9. E1, E2, G, ν_{12} , H

E1 = Inner (outer) facing modulus in the 0° direction, [F]*[L]**(-2).

E2 = Inner (outer) facing modulus in the 90 direction, [F]*[L]**(-2).

G = Inner (outer) facing shear modulus, [F]*[L]**(-2).

ν_{12} = Inner (outer) facing major Poisson's ratio, dimensionless.

H = Inner (outer) facing thickness, [L].

(If a strength analysis is not being performed, Card 9 is now repeated for the outer facing properties. If a strength analysis is being performed, Cards 10 and 11 for the inner facing are now input, and then Cards 9, 10 and 11 are input for the outer facing.)

Card 10. EC(1), EC(2), EC(3), ET(1), ET(2), ET(3), MCHK

EC(1) = Inner (outer) facing compressive strain allowable in the 1-direction, [L]/[L].

EC(2) = Inner (outer) facing compressive strain allowable in the 2-direction, [L]/[L].

EC(3) = Inner (outer) facing negative shear strain allowable in the 1-2 plane, [L]/[L].

ET(1) = Inner (outer) facing tensile strain allowable in the 1-direction, [L]/[L].

ET(2) = Inner (outer) facing tensile strain allowable in the 2-direction, [L]/[L].

ET(3) = Inner (outer) facing positive shear strain allowable in the 1-2 plane, [L]/[L].

MCHK = Number of orientations to be checked in the strength analysis of the inner (outer) facing. $1 \leq \text{MCHK} \leq 10$.

Card 11. ANGCHK_i, i = 1, MCHK

ANGCHK_i = Orientations to be checked in the strength analysis of the inner (outer) facing, degrees.

Card 12. H_c, s, E_c, G_L, G_w

H_c = Core thickness, [L]

s, E_c, G_L, G_w **only if IOU_T ≥ 7**

s = Honeycomb core cell size, [L]

E_c = Core modulus, [F]/[L]**2.

G_L = Core shear modulus in ribbon direction (L direction), [F]/[L]**2.

G_w = Core shear modulus in transverse (expansion) direction (W direction), [F]/[L]**2.

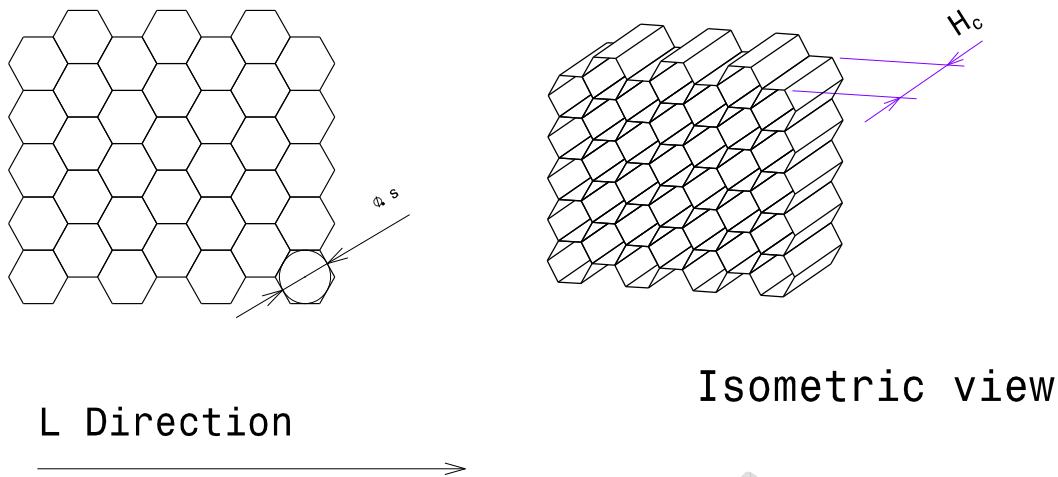


Figure 6. Honeycomb core geometrical definitions

Card 13. [YSTRNG], YBAR, ZBAR, AS, XIYYX, XIYZS, XIZZS, ES, GJS, RHOS

See Figure XX for symbol explanation

YSTRNG = Distance of longitudinal stiffener from $y = 0$. For variable stiffener spacing only.

YBAR = Location of stringer centroid in the y -direction with respect to its line of attachment to the shell, [L]

ZBAR = Location of stringer centroid in the z -direction with respect to the middle surface of the shell at the line of attachment, [L]

AS = Stringer cross-sectional area, [L]**2.

XIYYX = Moment of inertia of the stringer area about the mid-surface y - axis at the line of attachment, [L]**4.

XIYZS = Product of inertia of the stringer area about the mid-surface y - z axis at the line of attachment, [L]**4.

XIZZS = Moment of inertia of the stringer area about the z -axis at the line of attachment, [L]**4.

ES = Stringer modulus of elasticity, [F]*[L]**(-2).

G*JS = Stringer torsional stiffness, [F]*[L]**(+2).

RHOS = Average density of stringer material, [F]*[t]**(2)/[L]**(4).

Card 13 is repeated 'NSTRNG' times, unless equally-spaced identical stringers were specified.

Card 14. [XRING], XBARR, ZBARR, AR, XIXXR, XIZZR, ER, GJR, RHOR

See Figure XX for symbol explanation

XRING = Distance of circumferential stiffener from $x = 0$. For unequally spaced rings.

XBARR = Location of ring centroid in the x -direction with respect to its line of attachment to the shell, [L].

ZBARR = Location of ring centroid in the z-direction with respect to the middle surface of the shell at the line of attachment, [L].

AR = Ring cross-sectional area, [L]**2.

XIXXR = Moment of inertia of the ring area about the mid-surface x-axis at the line of attachment, [L]**4.

XIXZR = Product of inertia of the ring area about the mid-surface x-z axis at the line of attachment, [L]**4.

XIZZR = Moment of inertia of the ring area about the z-axis at the line of attachment, [L]**4

ER = Ring modulus of elasticity, [F]*[L]**(-2).

G*JR = Ring torsional stiffness, [F]*[L]**(+2).

RHOR = Average density of ring material, [F]*[t]**(2)/[L]**(4).

Card 14 is repeated 'NRING' times unless equally-spaced identical rings were specified.

Card 15. DENSE

DENSE = Average material density of the shell material, such that (DENSE)*(Vol. of shell) = Mass of shell), [F]*[t]**(2)/[L]**(4).

Card 16. IX, IY, PMASS

IX = Grid coordinate in x-direction at which lumped mass is located, 1≤IX≤25.

IY = Grid coordinate in y-direction at which lumped mass is located, 1≤IY≤25.

PMASS = Mass, [F]*[t]**(2)/[L].

Card 16 is repeated 'NLMASS' times.

Card 17. PX(1,1), PY(1,1), PXY(1,1), PX(2,1), PY(2,1), PXY(2,1), PX(I, J), PY(I,J), PXY(I,J), I= 1,2...NPNX, J = 1,2...,NPNY

The applied in-plane stress resultants are described by the relations:

$$N_x(x, y) = \sum_{I=1}^{NPNX} \sum_{J=1}^{NPNY} P_x(I, J) \left(\frac{x}{a}\right)^{I-1} \left(\frac{y}{b}\right)^{J-1}$$

$$N_y(x, y) = \sum_{I=1}^{NPNX} \sum_{J=1}^{NPNY} P_y(I, J) \left(\frac{x}{a}\right)^{I-1} \left(\frac{y}{b}\right)^{J-1}$$

$$N_{xy}(x, y) = \sum_{I=1}^{NPNX} \sum_{J=1}^{NPNY} P_{xy}(I, J) \left(\frac{x}{a}\right)^{I-1} \left(\frac{y}{b}\right)^{J-1}$$

Note: Tension stress resultants are taken as positive.

TORQUE = Torque applied to cylinder, [F]*[L].

BNDMOM = Bending moment applied to cylinder, [F]*[L].

Card 19. Q(1,1), Q(2,1), Q(3,1), ...Q(I,J), 1=1, ..., NQTX, J = 1,2..., NQTY

The distributed lateral load is described by the relation

$$q(x, y) = \sum_{I=1}^{NQTX} \sum_{J=1}^{NQTY} Q(I, J) \left(\frac{x}{a}\right)^{I-1} \left(\frac{y}{b}\right)^{J-1}$$

Note: positive loads are in the positive z-direction.

Card 20. IX, IY, PC

IX = Grid coordinate in x-direction, $1 \leq IX \leq 25$.

IY = Grid coordinate in y-direction, $1 \leq IY \leq 25$.

PC = Concentrated load, [F].

Card 20 is repeated 'NPTLDS' times.

Card 21. IX, IY, ITAG, FC

IX = Grid coordinate in x-direction, $1 \leq IX \leq 25$.

IY = Grid coordinate in the y-direction, $1 \leq IY \leq 25$.

ITAG = +1, if the moment is about the x-axis in a vector sense (right-hand rule)

= +2, if the moment is about the y-axis.

FC = Moment, [F]*[L].

Card 21 is repeated 'NPTMOM' times.

Card 22. ITAG, IDIST, PLMOM

ITAG = +1, if the line moment is parallel to the x-axis.

= +2, if the line moment is parallel to the y-axis.

IDIST = Number of grid lines away from the x = 0 or y = 0 axis. $1 \leq IDIST \leq 25$.

PLMOM = Line moment per unit of length, [F].

Card 22 is repeated 'NLNMOM' times.

Card 23. IX, IY, PKC

IX = Grid coordinate in x-direction. $1 \leq IX \leq 25$.

IY = Grid coordinate in y-direction. $1 \leq IY \leq 25$.

PKC = Spring constant, [F]/[L].

Card 23 is repeated 'NPTSUP' times.

Card 24. ITAG, IDIST, PLINE

ITAG = +1, if the line spring is parallel to the x-axis.

= +2, if the line spring is parallel to the y-axis.

IDIST = Number of grid lines away from the x=0 or y=0 axis. $1 \leq IDIST \leq 25$.

PLINE = Spring constant per unit length, [F]/[L].

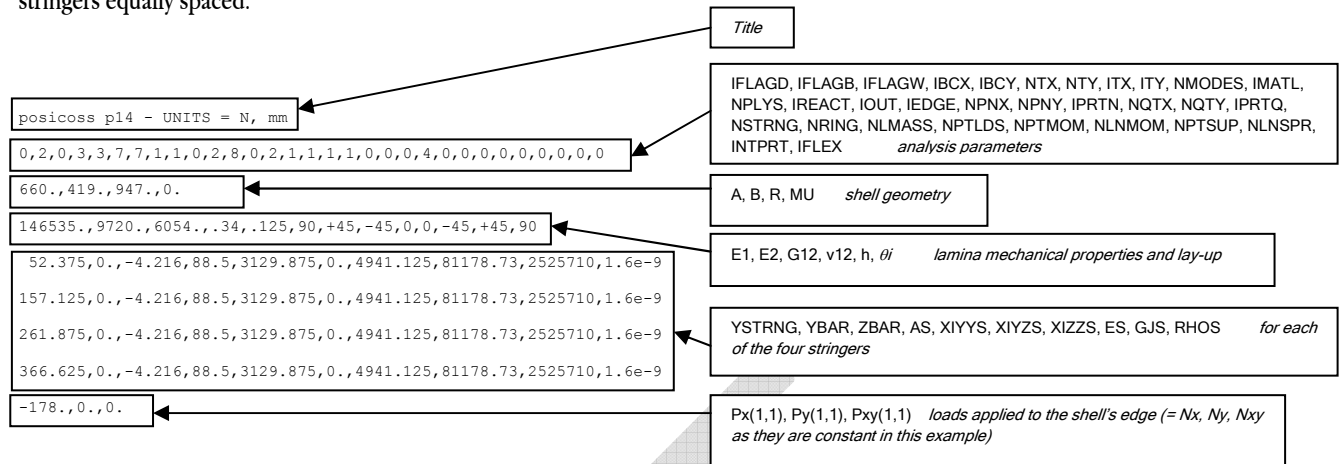
Card 24 is repeated 'NLNSPR' times.

Card 25. XP (I), YP (I), I=1, IFLEX

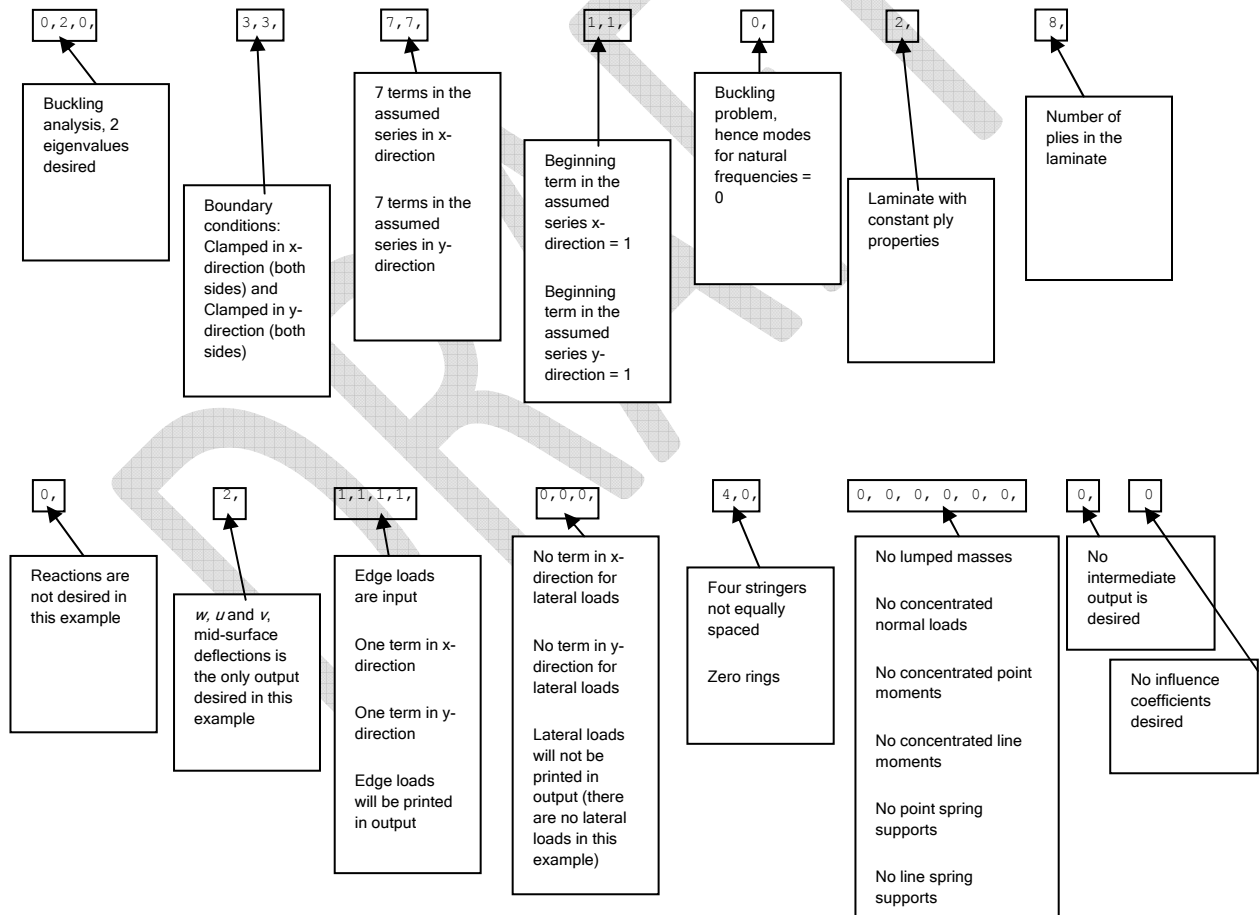
XP (I) = X-coordinate (in %) of Ith flexibility matrix control point.

YP (I) = Y-coordinate (in %) of Ith flexibility matrix control point.

The following list is an example of an input file for the analysis of a composite curved shell reinforced with T-section stringers equally spaced.



A more detailed explanation of the analysis parameters line follows:



OUTPUT DATA DESCRIPTION

First block of output is a punch of input file completely labeled for easy reading.

```
posicoss p14 - UNITS = N, mm
OTHE BOUNDARY CONDITIONS AT X=0 AND X=A ARE
  CLAMPED, CLAMPED
OTHE BOUNDARY CONDITIONS AT Y=0 AND Y=B ARE
  FREE, FREE
OTHER ARE 7 MODES IN THE X DIRECTION, STARTING WITH M = 1 .
THERE ARE 7 MODES IN THE Y DIRECTION, STARTING WITH N = 2 .
OTHE STIFFNESS MATRIX SIZE IS 147 BY 147
OA STABILITY SOLUTION WILL BE SOUGHT
OA = 660.00000
OB = 419.00000
OR = 947.00000
OMU = 0.00000
OFOR THE 8 PLY LAMINATE
OE1 = 0.146535E+06
OE2 = 0.972000E+04
OG = 0.605400E+04
ONU12 = 0.3400
OH(I) = 0.1250
OT = 1.0000
OTHE ORIENTATIONS ARE
  90.0000

  45.0000

-45.0000

  0.0000

  0.0000

-45.0000

  45.0000

  90.0000

1THE CONSTITUTIVE MATRIX IS

  62907.99      19153.56      0.00      0.00      0.00      0.00
  19153.56      62907.99      0.00      0.00      0.00      0.00
  0.00      0.00      21877.22      0.00      0.00      0.00
  0.00      0.00      0.00      2258.19      1348.89      538.56
  0.00      0.00      0.00      1348.89      8720.95      538.56
  0.00      0.00      0.00      538.56      538.56      1575.86

OTHE LAMINATE PROPERTIES ARE
OEX = 0.570763E+05  EY = 0.570763E+05  G = 0.218772E+05  NUXY = 0.3045  NUXX = 0.3045
OTHE STRINGER PROPERTIES FOLLOW --
OL  Y  YBAR  ZBAR  AREA  IYY  IYZ  IZZ  E  GJ  RHO
  1  52.38  0.00  -4.22  88.50  3.1299E+03  0.0000E+00  4.9411E+03  8.1179E+04  2.5257E+06  1.6000E-09
  2  157.13  0.00  -4.22  88.50  3.1299E+03  0.0000E+00  4.9411E+03  8.1179E+04  2.5257E+06  1.6000E-09
  3  261.88  0.00  -4.22  88.50  3.1299E+03  0.0000E+00  4.9411E+03  8.1179E+04  2.5257E+06  1.6000E-09
  4  366.63  0.00  -4.22  88.50  3.1299E+03  0.0000E+00  4.9411E+03  8.1179E+04  2.5257E+06  1.6000E-09
OPX(I,J) FOLLOWS
-1.7800E+02
OPY(I,J) FOLLOWS
0.0000E+00
OPXY(I,J) FOLLOWS
0.0000E+00
```

Most of the output is labeled. The output is of two types: data like the eigenvalue in buckling problems

```
OTHE BUCKLING EIGENVALUE IS 0.4782526 FOR M = 7, N = 4.
```

and 2D maps for variables like displacements, strains, stresses, etc. The coordinate system applicable to these maps is shown in Figure XX, relative to the shell coordinate system. (0, 0) is the **lower left** corner and (a, b) is the **upper right** corner. There is a map of 25 by 25 points equally distributed in x and y-directions. The maps are normalized to the maximum value in the map.

These maps can easily be used to create 3D color plots. The following is an example of the vertical deflection output (w)

```

ITHE W DEFLECTIONS DIVIDED BY 0.329162E+01/10000 FOLLOW
0 3525 7526 5551 -1839 -8400 -8101 -759 7536 9629 3572 -5561 -9999 -5981 3012 9304 7662 -270 -7574 -8180 -2061 5046 7063 3339 0
0 2435 5186 3788 -1352 -5890 -5639 -493 5297 6745 2505 -3875 -6974 -4167 2116 6518 5383 -152 -5270 -5729 -1495 3449 4872 2308 0
0 1276 2706 1945 -777 -3157 -2987 -225 2859 3619 1350 -2053 -3704 -2205 1147 3500 2902 -48 -2790 -3065 -839 1780 2551 1213 0
0 11 20 6 -22 -38 -19 29 73 80 45 -1 19 6 55 84 68 19 -25 -32 -3 31 40 18 0
0 -1223 -2576 -1799 867 3168 2962 228 -2799 -3529 -1278 2087 3725 2258 -1051 -3399 -2853 26 2745 3078 958 -1591 -2385 -1147 0
0 -2136 -4471 -3049 1670 5691 5240 319 -5080 -6351 -2301 3720 6643 4014 -1911 -6125 -5169 -28 4862 5524 1810 -2710 -4156 -2008 0
0 -2440 -5077 -3378 2092 6692 6072 279 -6016 -7459 -2688 4367 7784 4699 -2246 -7202 -6115 -111 5643 6497 2239 -3005 -4729 -2299 0
0 -2044 -4226 -2733 1919 5777 5159 148 -5241 -6435 -2299 3778 6710 4046 -1940 -6225 -5317 -164 4813 5617 2033 -2439 -3949 -1322 0
0 -1117 -2293 -1439 1142 3248 2847 14 -2996 -3634 -1284 2138 3779 2271 -1105 -3527 -3029 -135 2680 3169 1195 -1297 -2160 -1063 0
0 2 1 -11 -32 -49 -50 -35 -16 -5 -11 -25 -36 -33 -19 -6 -4 -15 -31 -41 -38 -25 -12 -2 0
0 979 1968 1114 -1261 -3131 -2662 27 2820 3365 1125 -2089 -3612 -2177 1010 3302 2855 141 -2539 -3073 -1298 1014 1874 940 0
0 1602 3200 1750 -2185 -5235 -4375 154 4803 5655 1849 -3550 -6075 -3626 1749 5598 4831 251 -4270 -5185 -2217 1665 3119 1569 0
0 1799 3578 1913 -2539 -5954 -4922 254 5519 6433 2054 -4102 -6944 -4102 2054 6433 5519 254 -4922 -5954 -2539 1913 3578 1799 0
0 1569 3119 1665 -2217 -5185 -4270 251 4831 5598 1749 -3626 -6075 -3550 1849 5655 4803 154 -4375 -5235 -2185 1750 3200 1602 0
0 940 1874 1014 -1298 -3073 -2539 141 2855 3302 1010 -2177 -3612 -2089 1125 3365 2820 27 -2662 -3131 -1261 1114 1968 979 0
0 -2 -12 -25 -38 -41 -31 -15 -4 6 -19 -33 -36 -25 -11 -5 -16 -35 -50 -49 -32 -11 1 2 0
0 -1063 -2160 -1297 1195 3169 2680 -135 -3029 -3527 -1105 2271 3779 2138 -1284 -3634 -2996 14 2847 3248 1142 -1439 -2293 -1117 0
0 -1932 -3949 -2439 2033 5617 4813 -164 -5317 -6225 -1940 4046 6710 3778 -2299 -6435 -5241 148 5159 5777 1919 -2733 -4226 -2044 0
0 -2299 -4729 -3005 2239 6497 5643 -111 -6115 -7202 -2246 4699 7784 4367 -2688 -7459 -6016 279 6072 6692 2092 -3378 -5077 -2440 0
0 -2008 -4156 -2710 1810 5524 4862 -28 -5169 -6125 -1911 4014 6643 3720 -2301 -6351 -5080 319 5240 5691 1670 -3049 -4471 -2136 0
0 -1147 -2385 -1591 958 3078 2745 26 -2853 -3399 -1051 2258 3725 2087 -1278 -3529 -2799 228 2962 3168 867 -1799 -2576 -1223 0
0 18 40 31 -3 -32 -25 19 68 84 55 6 -19 -1 45 80 73 29 -19 -38 -22 6 20 11 0
0 1213 2551 1780 -839 -3065 -2790 -48 2902 3500 1147 -2205 -3704 -2053 1350 3619 2859 -225 -2987 -3157 -777 1945 2706 1276 0
0 2308 4872 3449 -1495 -5729 -5270 -152 5383 6518 2116 -4167 -6974 -3875 2505 6745 5297 -493 -5639 -5890 -1352 3788 5186 2435 0
0 3339 7063 5046 -2061 -8180 -7574 -270 7662 9304 3012 -5581 -10000 -5561 3571 8629 7536 -759 -8101 -8400 -1839 5551 7526 3525 0
  
```

PROGRAM LIMITATIONS

The ranges of the input parameters are described under INPUT DATA. The main restriction is to keep in mind the assumptions of the analysis, particularly the small-deflection assumption. If the deflections found in a lateral loads problem are greater than the panel thickness, the results are questionable. If a solution mode shape contains large contributions from the highest modal shape input, the solution is questionable, and the analysis should be rerun using the highest mode shape input as the initial term in the new analysis. Since the high-order modes are not sensitive to boundary conditions, the restriction to simply-supported or full cylinder boundary conditions will not make much difference in the results.

EXAMPLE PROBLEMS

EXAMPLE 1. Flat panel, metallic, deflection under lateral loads (uniform pressure)¹. Assume an aluminum plate ($E = 10 \times 10^6$ psi and $\nu = 0.3$), $a = 7.5$ ", and $b = 5$ " with thickness $t = 0.1$ " under a uniform load $p = 10$ psi or concentrated load $P_z = 375$ lbs. at plate center. Here results for simply supported on all edges will be compared.

A) Uniform load 10 psi, check w and σ_y at plate center.

(b) 1) deflection (w) Niu = 0.053"; deflection (w) **48** = 0.0527"

(a) 1) stress (σ_y) Niu = $f = 12125$ psi; stress (σ_y) **48** = $f = 12145.6$ psi

B) Concentrated load $P_z = 375$ lbs, check w and σ_y at plate center.

(c) 1) stress (σ_y) Niu = $f = 74260$ psi; stress (σ_y) **48** = $f = 64108.9$ psi

(d) 1) deflection (w) Niu = 0.156"; deflection (w) **48** = 0.1552"

Input and output files are available for [download at the web site](#).

www.pmbaerospace.com/examples.html

EXAMPLE 2. Buckling of isotropic flat plate simply supported on 4 edges, without reinforcing stiffeners.

¹ This example is based on Niu, M. C-Y. (1999). *Airframe Stress Analysis and Sizing*. Connilit Press Ltd. Hong Kong, p. 191.

Panel size $a \times b = 200 \times 100$ mm, thickness $t = 2$ mm. $E = 73770$ MPa, $\nu = 0.3$. Elastic limit $F_{ty} = 330.9$ MPa

The buckling eigenvalue is requested as well as stresses and strains for the corresponding static load case (to evaluate Von Mises stress to check if loads are under elastic regime). An excerpt of output is shown below:

0THE BUCKLING EIGENVALUE IS 5.4443810 FOR $M = 1, N = 1$.

The static loads run produce the following output:

1THE VON MISES STRESSES ON THE LOWER SURFACE FOLLOW. MAX. VALUE = 15.9

1THE VON MISES STRESSES ON THE UPPER SURFACE FOLLOW. MAX. VALUE = 15.9

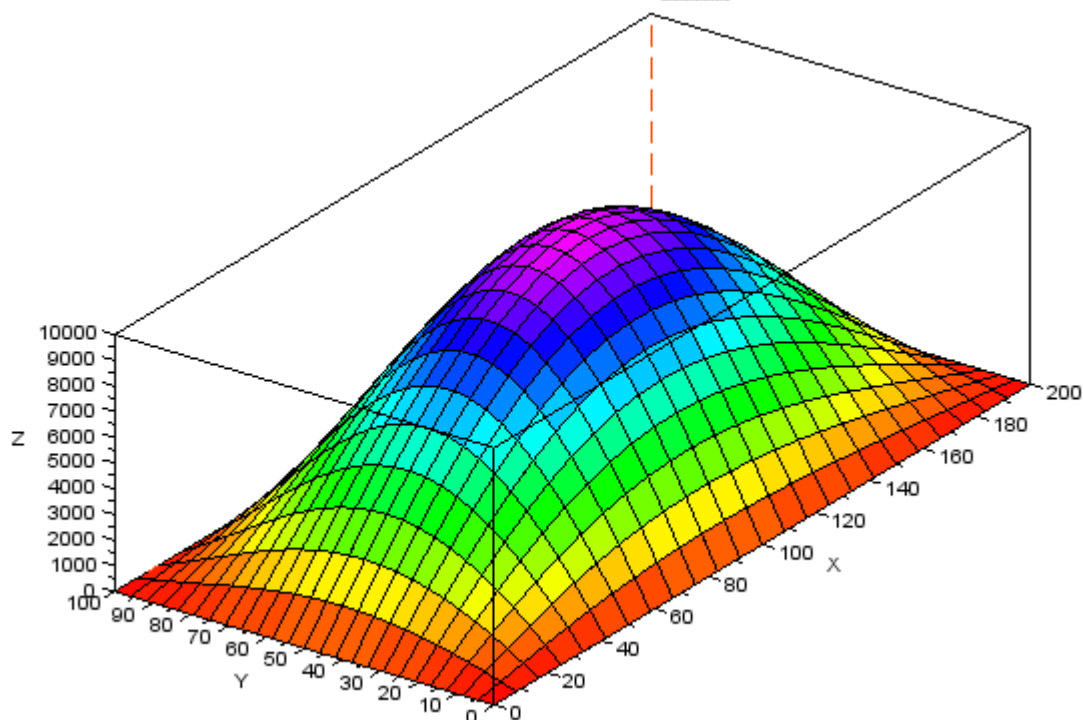


Figure XXX. Mode shape (displacement w) for first buckling eigenvalue 5.44 ($M=1, N=1$)²

EXAMPLE 3. Sandwich panel with orthotropic facings with the following configuration 45/0/45/core/45/0 from outside to inside. Panel is under combined in-plane loads (N_x, N_y, N_{xy}) and facing failure (based on maximum strain criterion) and local stability failure modes are checked (wrinkling, dimpling and shear crimping). Boundary condition is simply supported on four edges.

Wrinkling, dimpling and shear crimping allowables are computed based on faces and core characteristics provided in the input file. See output file in the [following link](#).

0FOR THE INNER FACING OF THE SANDWICH

² Generated using SciLab (www.scilab.org)

THE DIMPLING ALLOWABLES IN THE 1, 2, AND 12 DIRECTIONS ARE 961.71 961.71 607.17 [F]/[L]**2.
 THE WRINKLING ALLOWABLES IN THE 1, 2, AND 12 DIRECTIONS ARE 100.50 100.50 106.08 [F]/[L]**2.
 THE SHEAR CRIMPING ALLOWABLES IN THE 1, 2, AND 12 DIRECTIONS ARE 783.43 480.17 613.33 [F]/[L]**2.

The reserve factors summary is presented at the end of the output file:

1THE MINIMUM RESERVE FACTOR FOR DIMPLING OCCURS IN LAYER 1.
 IT IS LOCATED AT X = 13, Y = 22, AND HAS A VALUE OF 40.08
 1THE MINIMUM RESERVE FACTOR FOR WRINKLING OCCURS IN LAYER 3.
 IT IS LOCATED AT X = 4, Y = 22, AND HAS A VALUE OF 4.894
 1THE MINIMUM RESERVE FACTOR FOR SHEAR CRIMPING OCCURS IN LAYER 3.
 IT IS LOCATED AT X = 4, Y = 22, AND HAS A VALUE OF 23.03
 1THE MINIMUM RESERVE FACTOR FOR FIBER FAILURE OCCURS FOR A STRAIN IN THE 1- DIRECTION AT AN ANGLE THETA OF 45.00 DEGREES IN LAYER 3.
 IT IS LOCATED AT X = 21, Y = 22, AND HAS A VALUE OF 23.61
 1THE MINIMUM RESERVE FACTOR FOR TRANSVERSE MATRIX CRACKING OCCURS FOR A STRAIN IN THE 2- DIRECTION AT AN ANGLE THETA OF 0.00 DEGREES IN LAYER 3.
 IT IS LOCATED AT X = 4, Y = 22, AND HAS A VALUE OF 15.53
 1THE MINIMUM RESERVE FACTOR FOR SHEAR MATRIX CRACKING OCCURS FOR A STRAIN IN THE 12 DIRECTION AT AN ANGLE THETA OF 45.00 DEGREES IN LAYER 1.
 IT IS LOCATED AT X = 22, Y = 4, AND HAS A VALUE OF 24.87
 1THE MINIMUM RESERVE FACTOR OCCURS FOR A STRAIN IN THE 2- DIRECTION AT AN ANGLE THETA OF 0.00 DEGREES IN LAYER 3.
 IT IS LOCATED AT X = 4, Y = 22, AND HAS A VALUE OF 15.53

EXAMPLE 4. Sandwich panel with orthotropic facings with the following configuration 45/0/45/core/45/0 from outside to inside. The panel is simply supported in 3 edges and free in the remaining edge representing typical condition for a trailing edge panel. Maximum deflection under cruise condition ($q = 0.00081$ MPa) is calculated to identify minimum stiffness required and a stress analysis performed for strength (maximum strain criterion). The faces are made of carbon fiber fabric and the core is honeycomb aramid paper. Maximum deflection is 0.224 mm.

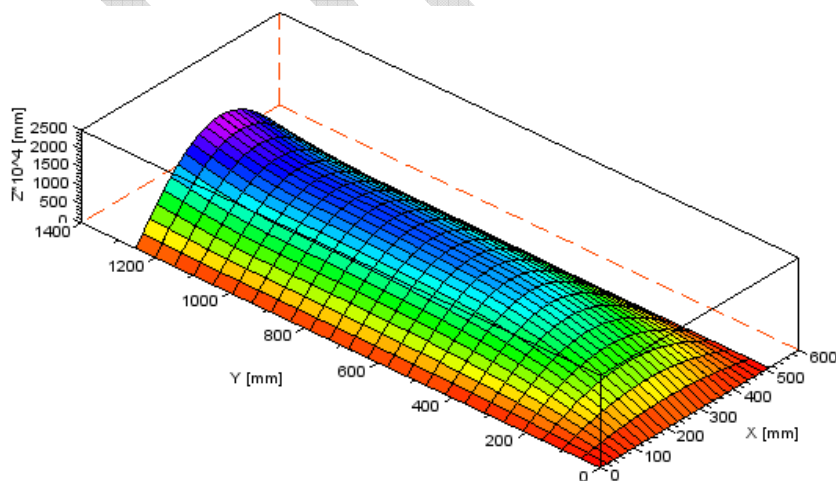


Figure XXX. Example 4 deformed shape.

EXAMPLE 5. Curved shell made of monolithic carbon composite, reinforced with stringers³. The carbon fiber layers have the following properties: $E_1 = 146535$ MPa, $E_2 = 9720$ MPa, $G_{12} = 6054$ MPa, $\nu_{12} = 0.34$ and a ply thickness of 0.125 mm. The panel modeled in this example has the following dimensions: $a \times b = 660 \times 419$ mm and an internal radius of 947 mm. Lay-up is (90/45/-45/0/0/-45/45/90), hence total thickness of skin is 1.00 mm. Regarding the stringers, there are 4 equal stringers with the following dimensions (T-cross section). The stringer lay-up is (+45/-45/+45/-45/+45/-45/0/0/0/0/0/0)S.

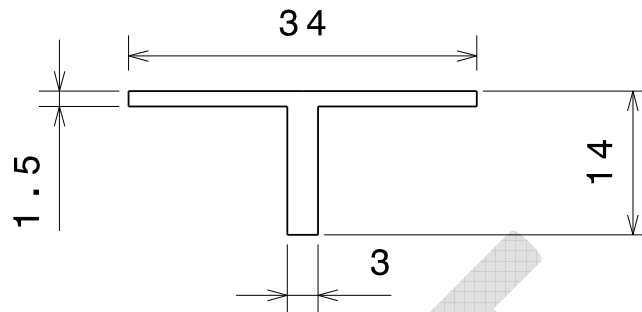


Figure XXX. T-stringer cross section dimensions.

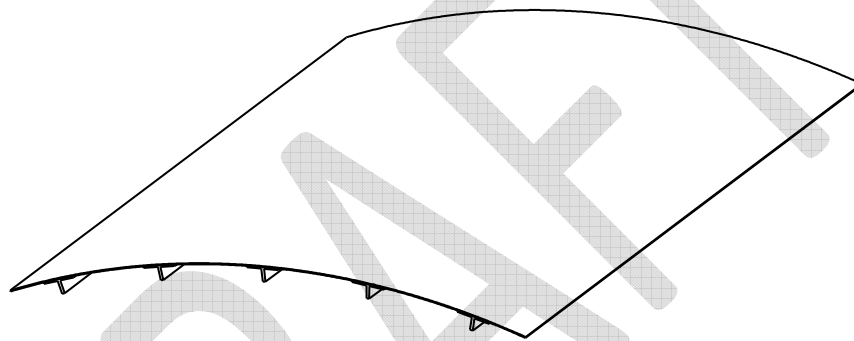


Figure XXX. P14 composite shell geometry³.

Stringer mechanical properties (UNITS = N, mm)

$$E = 84476.63 \text{ MPa}$$

$$G = 21877.22 \text{ MPa}$$

Cross section data (moments are calculated with respect to line of attachment. See Figure XXX)

$$\bar{y} = +0.000 \text{ mm}$$

$$\bar{z} = -4.216 \text{ mm}$$

$$A = 88.50 \text{ mm}^2$$

$$I_{yy} = 3129.8750 \text{ mm}^4$$

$$I_{zz} = 4941.1250 \text{ mm}^4$$

$$I_{yz} = 0 \text{ mm}^4$$

³ R. Zimmermann, H. Klein, A. Kling, Buckling and postbuckling of stringer stiffened fibre composite curved panels – Tests and computations, *Composite Structures*, Volume 73, Issue 2, May 2006, Pages 150-161, ISSN 0263-8223, 10.1016/j.compstruct.2005.11.050.

(<http://www.sciencedirect.com/science/article/pii/S0263822305003806>)

$$J = 150.75 \text{ mm}^4$$

$$\text{Hence } GJ_s = 3297990.9$$

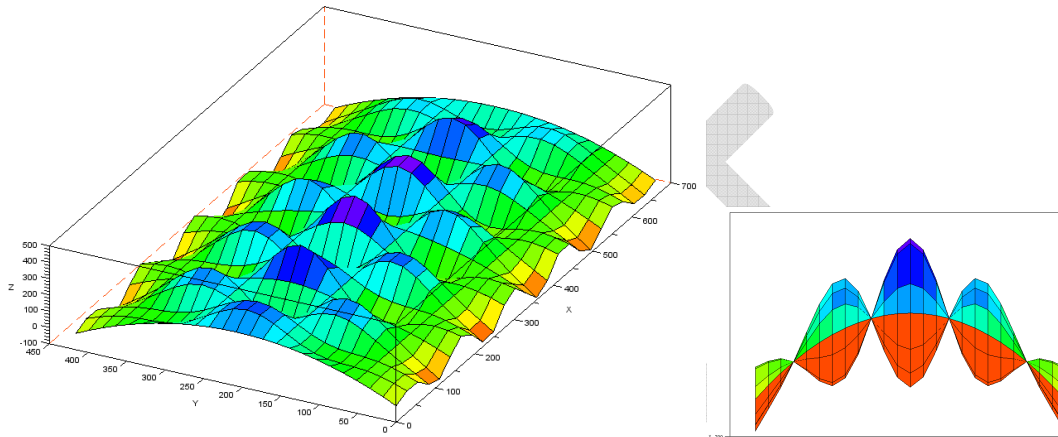


Figure XXX. Example 5 initial buckling mode shape (stringer remain in initial position).

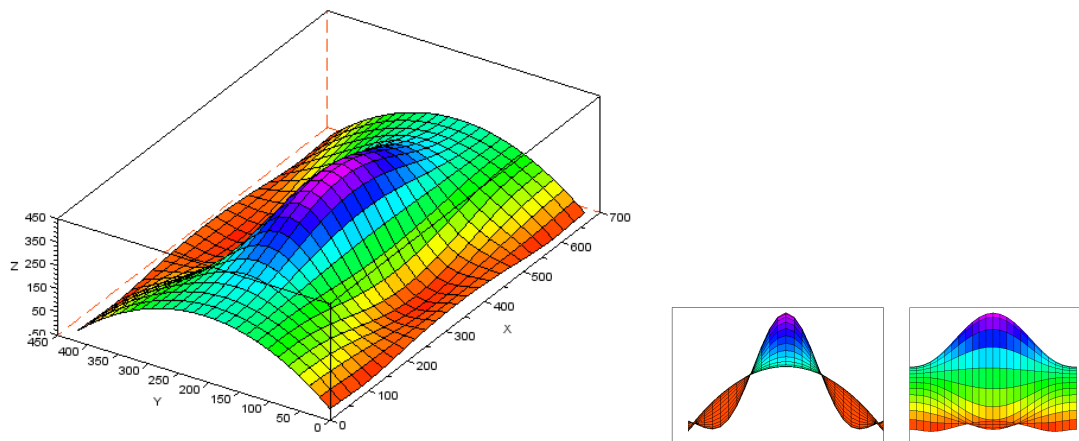


Figure XXX. Example 5 general buckling mode shape (stringer bending).

In the following picture a comparison of the front view for the 2 modes can be seen, showing stringer location ($b/8$ from edge, $b/4$ distance between stringers)

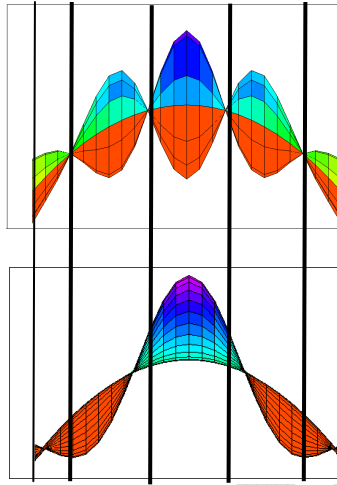


Figure XXX. Example 5 general local and general buckling mode shapes compared.

EXAMPLE 6. Monolithic flat plate in carbon fiber composite. Simply supported on the 4 edges is loaded in plane and strains a reserve factors (=allowable strain/applied strain) are calculated for each ply and at extreme fibers.