

# ISUS-APEX\_2000m

12L\_60x60

Prepared By:

Requested By:

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| List of Symbols |                                                                             |                    |                  |
|-----------------|-----------------------------------------------------------------------------|--------------------|------------------|
| Symbol          | Description                                                                 | English Units      | SI Units         |
| A               | [A] extensional stiffness matrix for CLT                                    | lb/in              | N/m              |
| [A]             | [A] inverse extensional stiffness matrix for CLT                            | in/lb              | m/N              |
| A Inverse       | [B] coupling stiffness matrix for CLT                                       | lb                 | N                |
| B               | [B] inverse coupling stiffness matrix for CLT                               | 1/lb               | 1/N              |
| B Inverse       | b (subscript)                                                               |                    |                  |
| C               | Distance to extreme fiber from neutral axis                                 | in                 | m                |
| c (subscript)   | Denotes "core" material                                                     |                    |                  |
| CS Area         | Cross sectional area                                                        | in <sup>2</sup>    | m <sup>2</sup>   |
| CTcr            | Critical torque factor                                                      |                    |                  |
| CTE             | Coefficient of thermal expansion                                            | in/in/°F           | m/m/°C           |
| CME             | Coefficient of moisture expansion                                           | in/in/%moisture    | m/m/%moisture    |
| dCell           | Honeycomb core cell diameter                                                | in                 | m                |
| D               | [D] bending stiffness matrix for CLT                                        | lb-in              | N-m              |
| D Inverse       | [D] inverse bending stiffness matrix for CLT                                | 1/(lb-in)          | 1/(N-m)          |
| DEN             | Density                                                                     | lb/in <sup>3</sup> | g/m <sup>3</sup> |
| DENc            | Density of the core (not the density of the material the core is made from) | lb/in <sup>3</sup> | g/m <sup>3</sup> |
| +e, +eps        | Tensile strain                                                              | in/in              | m/m              |
| -e, -eps        | Compression strain                                                          | in/in              | m/m              |
| E               | Young's modulus                                                             | lb/in <sup>2</sup> | Pa               |
| Ec              | Compressive modulus of a core material                                      | lb/in <sup>2</sup> | Pa               |
| End area        | End area                                                                    | in <sup>2</sup>    | m <sup>2</sup>   |
| f (subscript)   | Denotes "fiber" or "face sheet" for sandwich plates                         |                    |                  |
| G               | Shear modulus                                                               | lb/in <sup>2</sup> | Pa               |
| gage            | Honeycomb core cell wall thickness                                          | in                 | m                |
| gam             | Shear strain                                                                | in/in              | m/m              |
| GcL             | Core shear modulus in a sandwich plate, x-direction                         | lb/in <sup>2</sup> | Pa               |
| GcW             | Core shear modulus in a sandwich plate, y-direction                         | lb/in <sup>2</sup> | Pa               |
| I               | Area moment of inertia of a beam cross section                              | in <sup>4</sup>    | m <sup>4</sup>   |
| J               | Polar moment of inertia of a beam/tube cross section                        |                    |                  |
| K               | Thermal Conductivity                                                        | Btu/(hr-ft-°F)     | W/(m-°K)         |
| k (subscript)   | Denotes "curvature"                                                         |                    |                  |
| L               | Plate length in the X-direction, Beam length                                | in                 | m                |
| m (subscript)   | Denotes "matrix"                                                            |                    |                  |
| %m              | Percent moisture content                                                    | %                  | %                |
| N               | Resultant plate load                                                        | lb/in              | N/m              |
| NU              | Poisson's ratio                                                             | lb/in              | N/m              |
| P               | Concentrated point load                                                     | lb                 | N                |
| p               | Uniform distributed load                                                    | lb/in <sup>2</sup> | Pa               |













Prepared By:

|              |              |              |
|--------------|--------------|--------------|
| 2.87809E+06  | 3.79974E+06  | -2.27042E+06 |
| 3.79974E+06  | 1.27191E+07  | -6.25214E+06 |
| -2.27042E+06 | -6.25214E+06 | 4.29827E+06  |

| Properties - 2D  |              |
|------------------|--------------|
| Title            | Value        |
| Ex (psi)         | 1.74294E+06  |
| Ey (psi)         | 7.70256E+06  |
| Gxy (psi)        | 4.29827E+06  |
| NUxy             | 2.98743E-01  |
| NUyx             | 1.32023E+00  |
| Exb (psi)        | 1.74294E+06  |
| Eyb (psi)        | 7.70256E+06  |
| Gxyb (psi)       | 4.29827E+06  |
| NUxyb            | -2.98743E-01 |
| NUyxb            | -1.32023E+00 |
| CTEx (in/in/F)   | 6.59291E-06  |
| CTEy (in/in/F)   | -1.41574E-06 |
| CTExy (in/in/F)  | 2.41670E-22  |
| CTExk (1/in/F)   | -5.13690E-21 |
| CTEyk (1/in/F)   | 2.83865E-21  |
| CTExyk (1/in/F)  | -5.13690E-21 |
| CMEEx (in/in/%m) | 3.30971E-03  |
| CMEy (in/in/%m)  | 9.69092E-04  |
| CMExy (in/in/%m) | 6.85516E-20  |
| CMEExk (1/in/F)  | 1.43646E-18  |
| CMEyk (1/in/F)   | 4.99008E-19  |
| CMEyk (1/in/F)   | 2.77325E-03  |
| Density (lb/in3) | 5.70000E-02  |
| Thickness (in)   | 1.47000E-01  |

| Properties - 3D |             |
|-----------------|-------------|
| Title           | Value       |
| Ex (psi)        | 1.74294E+06 |
| Ey (psi)        | 7.70256E+06 |
| Ez (psi)        | 1.54212E+06 |

|                               |              |
|-------------------------------|--------------|
| Gxy (psi)                     | 4.29939E+06  |
| Gxz (psi)                     | 5.89000E+05  |
| Gyz (psi)                     | 7.63000E+05  |
| NUxy                          | 2.98743E-01  |
| NUyx                          | 1.32023E+00  |
| NUxz                          | 2.87650E-01  |
| NUzx                          | 2.54507E-01  |
| NUyz                          | -1.56956E-01 |
| NUzy                          | -3.14240E-02 |
| CTEx (in/in/F)                | 6.57948E-06  |
| CTEy (in/in/F)                | -1.44030E-06 |
| CTEz (in/in/F)                | 1.48472E-05  |
| CTEyz (in/in/F)               | 0.00000E+00  |
| CTEzx (in/in/F)               | 0.00000E+00  |
| CTExy (in/in/F)               | 2.41689E-22  |
| CME <sub>x</sub> (in/in/%m)   | 3.30579E-03  |
| CME <sub>y</sub> (in/in/%m)   | 9.61914E-04  |
| CME <sub>z</sub> (in/in/%m)   | 5.72214E-03  |
| CME <sub>yz</sub> (in/in/%m)  | 0.00000E+00  |
| CME <sub>zx</sub> (in/in/%m)  | 0.00000E+00  |
| CME <sub>xy</sub> (in/in/%m)  | 7.65754E-20  |
| K <sub>x</sub> (Btu/hr/ft/F)  | 1.06905E+00  |
| K <sub>y</sub> (Btu/hr/ft/F)  | 2.45035E+00  |
| K <sub>z</sub> (Btu/hr/ft/F)  | 3.78400E-01  |
| K <sub>xy</sub> (Btu/hr/ft/F) | 0.00000E+00  |
| Density (lb/in <sup>3</sup> ) | 5.70000E-02  |
| Thickness (in)                | 1.47000E-01  |

## Tube/Beam Analysis

### Tube Geometry



Cross Section : Circle

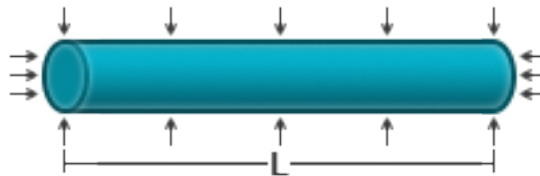
R - Radius (in) : 1.12750E+00

### Section Properties

Section Properties

Cross Section: Circle  
Radius(in): 1.12750E+00  
Ex(psi) = 1.74294E+06  
Thickness(in) = 1.47000E-01  
Ix(in<sup>4</sup>) = 8.03008E-01  
ExIx(lb-in<sup>2</sup>) = 1.39959E+06  
Iy(in<sup>4</sup>) = 8.03008E-01  
ExIy(lb-in<sup>2</sup>) = 1.39959E+06  
Cmin (in) = -1.27450E+00  
Cmax (in) = 1.27450E+00  
Gxy(psi) = 4.29827E+06  
K(in<sup>4</sup>) = 1.60602E+00  
GxyJ(lb-in<sup>2</sup>) = 6.90310E+06  
Radius Gyration(in) = 8.50824E-01  
Area(in<sup>2</sup>) = 1.10928E+00  
Weight/Length(lb/in) = 6.32288E-02

## Cylinder Stability



Torsion Load (lb-in) : 2.93100E+03

Load Type : Axial Compression + External Pressure

Compression Load (lb) : 1.49570E+04

Axial Compression Layup Type : Special, Mid Plane Symmetry [B]=0

Length (in) : 1.57500E+01

Max. Longitudinal Buckle Half Waves (in) : 50

Max. Circumferential Buckle Waves (in) : 50

### Results

Axial Compression + External Pressure

Valid for laminates which are:

Symmetric [Bij] = [0]

Balanced All ()16 and ()26 terms = 0

Length(in) = 15.75

Applied Compression(lb) = 14957

Applied External Pressure(psi) = 2931

Critical Compression(lb) = 7.56147E+05

n = 5 m = 30

Rc = 1.97805E-02

Critical Lateral Pressure(psi) = 6.00227E+03

n = 2 m = 1

Rlp = -4.88316E-01

Rc + Rlp = -4.68535E-01 must be <1

Critical Hydrostatic Pressure(psi) = 5.95951E+03

n = 2 m = 1

Rhp = -4.91819E-01

Rc + Rhp = -4.72038E-01 must be <1

### Pressure Vessel

Axial Load (lb) : -1.49570E+04

P - Pressure (psi) : 0.00000E+00

Thick Wall : Yes

External Pressure (psi) : 2.93100E+03

Torque (lb-in) : 0.00000E+00

Temperature Change (F) : 0

| Failure Criteria |            |
|------------------|------------|
| Name             | Parameters |
| MaxStress        |            |

| Tabular Results |         |              |              |             |               |
|-----------------|---------|--------------|--------------|-------------|---------------|
| Ply#-Loc        | Radius  | Delta Radius | Axial Strain | Hoop Strain | Radial Strain |
| 1-B             | 1.1275  | -0.00129657  | -0.00312393  | -0.00114996 | 0.0016646     |
| 1-M             | 1.13362 | -0.00128666  | -0.00312393  | -0.00113499 | 0.00157446    |
| 1-T             | 1.13975 | -0.00127728  | -0.00312393  | -0.00112067 | 0.00148588    |

|      |         |             |             |              |               |
|------|---------|-------------|-------------|--------------|---------------|
| 2-B  | 1.13975 | -0.00127728 | -0.00312393 | -0.00112067  | 0.00148678    |
| 2-M  | 1.14588 | -0.00126844 | -0.00312393 | -0.00110696  | 0.00140041    |
| 2-T  | 1.152   | -0.00126013 | -0.00312393 | -0.00109386  | 0.00131551    |
| 3-B  | 1.152   | -0.00126013 | -0.00312393 | -0.00109386  | 0.0013146     |
| 3-M  | 1.15813 | -0.00125233 | -0.00312393 | -0.00108135  | 0.00123043    |
| 3-T  | 1.16425 | -0.00124505 | -0.00312393 | -0.0010694   | 0.00114763    |
| 4-B  | 1.16425 | -0.00124505 | -0.00312393 | -0.0010694   | 0.00114854    |
| 4-M  | 1.17038 | -0.00123826 | -0.00312393 | -0.00105801  | 0.00106777    |
| 4-T  | 1.1765  | -0.00123197 | -0.00312393 | -0.00104715  | 0.000988275   |
| 5-B  | 1.1765  | -0.00123197 | -0.00312393 | -0.00104715  | 0.00098735    |
| 5-M  | 1.18263 | -0.00122616 | -0.00312393 | -0.00103681  | 0.00090841    |
| 5-T  | 1.18875 | -0.00122084 | -0.00312393 | -0.00102699  | 0.00083068    |
| 6-B  | 1.18875 | -0.00122084 | -0.00312393 | -0.00102699  | 0.000831614   |
| 6-M  | 1.19488 | -0.00121598 | -0.00312393 | -0.00101766  | 0.000755747   |
| 6-T  | 1.201   | -0.00121158 | -0.00312393 | -0.00100881  | 0.00068101    |
| 7-B  | 1.201   | -0.00121158 | -0.00312393 | -0.00100881  | 0.000680066   |
| 7-M  | 1.20713 | -0.00120764 | -0.00312393 | -0.00100043  | 0.00060573    |
| 7-T  | 1.21325 | -0.00120416 | -0.00312393 | -0.000992504 | 0.000532457   |
| 8-B  | 1.21325 | -0.00120416 | -0.00312393 | -0.000992504 | 0.000533411   |
| 8-M  | 1.21938 | -0.00120111 | -0.00312393 | -0.000985019 | 0.000461861   |
| 8-T  | 1.2255  | -0.0011985  | -0.00312393 | -0.000977964 | 0.000391307   |
| 9-B  | 1.2255  | -0.0011985  | -0.00312393 | -0.000977964 | 0.000390344   |
| 9-M  | 1.23163 | -0.00119632 | -0.00312393 | -0.000971335 | 0.000320059   |
| 9-T  | 1.23775 | -0.00119457 | -0.00312393 | -0.000965116 | 0.000250711   |
| 10-B | 1.23775 | -0.00119457 | -0.00312393 | -0.000965116 | 0.000251684   |
| 10-M | 1.24388 | -0.00119324 | -0.00312393 | -0.000959292 | 0.000183938   |
| 10-T | 1.25    | -0.00119232 | -0.00312393 | -0.000953854 | 0.000117068   |
| 11-B | 1.25    | -0.00119232 | -0.00312393 | -0.000953854 | 0.000116086   |
| 11-M | 1.25613 | -0.00119181 | -0.00312393 | -0.0009488   | 4.93718e-005  |
| 11-T | 1.26225 | -0.00119171 | -0.00312393 | -0.000944117 | -1.65159e-005 |
| 12-B | 1.26225 | -0.00119171 | -0.00312393 | -0.000944117 | -1.55237e-005 |
| 12-M | 1.26838 | -0.001192   | -0.00312393 | -0.000939788 | -7.99168e-005 |
| 12-T | 1.2745  | -0.00119269 | -0.00312393 | -0.000935809 | -0.000143537  |

| Tabular Results cont'd |               |              |             |               |              |
|------------------------|---------------|--------------|-------------|---------------|--------------|
| Ply#-Loc               | Shear Strain  | Axial Stress | Hoop Stress | Radial Stress | Shear Stress |
| 1-B                    | -1.72613e-005 | -13399.7     | -26604.4    | 0             | -14356.5     |

|      |               |          |          |          |          |
|------|---------------|----------|----------|----------|----------|
| 1-M  | -1.73551e-005 | -13400   | -26467.4 | -143.371 | -14259.7 |
| 1-T  | -1.74488e-005 | -13401.9 | -26337.8 | -284.484 | -14166.9 |
| 2-B  | -1.74488e-005 | -13322.7 | -26119.6 | -284.484 | 14016.9  |
| 2-M  | -1.75426e-005 | -13325.1 | -25995.4 | -422.245 | 13927.3  |
| 2-T  | -1.76364e-005 | -13329.1 | -25878   | -557.898 | 13841.5  |
| 3-B  | -1.76364e-005 | -13409.2 | -26098.5 | -557.898 | -13993.1 |
| 3-M  | -1.77301e-005 | -13415.4 | -25989.5 | -692.684 | -13911.8 |
| 3-T  | -1.78239e-005 | -13423   | -25887.1 | -825.496 | -13834.1 |
| 4-B  | -1.78239e-005 | -13342.1 | -25664.2 | -825.496 | 13680.9  |
| 4-M  | -1.79177e-005 | -13350.2 | -25566.4 | -955.227 | 13605.9  |
| 4-T  | -1.80114e-005 | -13359.5 | -25474.7 | -1083.11 | 13534.3  |
| 5-B  | -1.80114e-005 | -13441.3 | -25700   | -1083.11 | -13689.1 |
| 5-M  | -1.81052e-005 | -13452.9 | -25616   | -1210.39 | -13621.7 |
| 5-T  | -1.8199e-005  | -13465.7 | -25537.8 | -1335.93 | -13557.5 |
| 6-B  | -1.8199e-005  | -13383   | -25310.3 | -1335.93 | 13401    |
| 6-M  | -1.82927e-005 | -13396.1 | -25236.1 | -1458.64 | 13339.1  |
| 6-T  | -1.83865e-005 | -13410.4 | -25167.5 | -1579.72 | 13280.2  |
| 7-B  | -1.83865e-005 | -13493.9 | -25397.4 | -1579.72 | -13438.3 |
| 7-M  | -1.84803e-005 | -13510.3 | -25335.8 | -1700.41 | -13383.2 |
| 7-T  | -1.85741e-005 | -13527.8 | -25279.4 | -1819.59 | -13331   |
| 8-B  | -1.85741e-005 | -13443.4 | -25047.2 | -1819.59 | 13171.3  |
| 8-M  | -1.86678e-005 | -13461.1 | -24994.3 | -1936.13 | 13121.2  |
| 8-T  | -1.87616e-005 | -13479.8 | -24946.3 | -2051.25 | 13073.7  |
| 9-B  | -1.87616e-005 | -13565   | -25180.9 | -2051.25 | -13235   |
| 9-M  | -1.88554e-005 | -13585.7 | -25139.5 | -2166.17 | -13191   |
| 9-T  | -1.89491e-005 | -13607.5 | -25102.7 | -2279.76 | -13149.6 |
| 10-B | -1.89491e-005 | -13521.4 | -24865.8 | -2279.76 | 12986.7  |
| 10-M | -1.90429e-005 | -13543.3 | -24832   | -2390.9  | 12947    |
| 10-T | -1.91367e-005 | -13566.1 | -24802.7 | -2500.78 | 12909.8  |
| 11-B | -1.91367e-005 | -13653   | -25042   | -2500.78 | -13074.3 |
| 11-M | -1.92304e-005 | -13677.7 | -25018.7 | -2610.64 | -13040.3 |
| 11-T | -1.93242e-005 | -13703.3 | -24999.7 | -2719.32 | -13008.6 |
| 12-B | -1.93242e-005 | -13615.6 | -24758.1 | -2719.32 | 12842.5  |
| 12-M | -1.9418e-005  | -13641.2 | -24741.6 | -2825.71 | 12812.3  |
| 12-T | -1.95118e-005 | -13667.7 | -24729.1 | -2931    | 12784.3  |

Tabular Results cont'd

| <b>Ply#-Loc</b> | <b>Failure Index</b> | <b>Safety Factor</b> | <b>Failure Mode</b> |
|-----------------|----------------------|----------------------|---------------------|
| 1-B             | 0.182538             | 5.4783               | 0                   |
| 1-M             | 0.182143             | 5.49019              | 0                   |
| 1-T             | 0.181764             | 5.50163              | 0                   |
| 2-B             | 0.182446             | 5.48108              | 0                   |
| 2-M             | 0.182087             | 5.49188              | 0                   |
| 2-T             | 0.181744             | 5.50224              | 0                   |
| 3-B             | 0.181055             | 5.52317              | 0                   |
| 3-M             | 0.180724             | 5.53329              | 0                   |
| 3-T             | 0.180408             | 5.54298              | 0                   |
| 4-B             | 0.181104             | 5.52168              | 0                   |
| 4-M             | 0.180806             | 5.53077              | 0                   |
| 4-T             | 0.180523             | 5.53947              | 0                   |
| 5-B             | 0.179819             | 5.56114              | 0                   |
| 5-M             | 0.179546             | 5.56962              | 0                   |
| 5-T             | 0.179285             | 5.5777               | 0                   |
| 6-B             | 0.179996             | 5.55568              | 0                   |
| 6-M             | 0.179752             | 5.56321              | 0                   |
| 6-T             | 0.179521             | 5.57037              | 0                   |
| 7-B             | 0.178803             | 5.59274              | 0                   |
| 7-M             | 0.178581             | 5.5997               | 0                   |
| 7-T             | 0.178371             | 5.6063               | 0                   |
| 8-B             | 0.179096             | 5.58359              | 0                   |
| 8-M             | 0.178901             | 5.58968              | 0                   |
| 8-T             | 0.178717             | 5.59543              | 0                   |
| 9-B             | 0.177985             | 5.61847              | 0                   |
| 9-M             | 0.177808             | 5.62403              | 0                   |
| 9-T             | 0.177643             | 5.62927              | 0                   |
| 10-B            | 0.178383             | 5.60592              | 0                   |
| 10-M            | 0.178232             | 5.61068              | 0                   |
| 10-T            | 0.17809              | 5.61513              | 0                   |
| 11-B            | 0.177343             | 5.63879              | 0                   |
| 11-M            | 0.177208             | 5.64308              | 0                   |
| 11-T            | 0.177083             | 5.64707              | 0                   |
| 12-B            | 0.177838             | 5.6231               | 0                   |
| 12-M            | 0.177726             | 5.62664              | 0                   |
| 12-T            | 0.177623             | 5.6299               | 0                   |

