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WINGBOX •

Validation V1

WINGBOX

Author : Dr Argiris KAMOULAKOS

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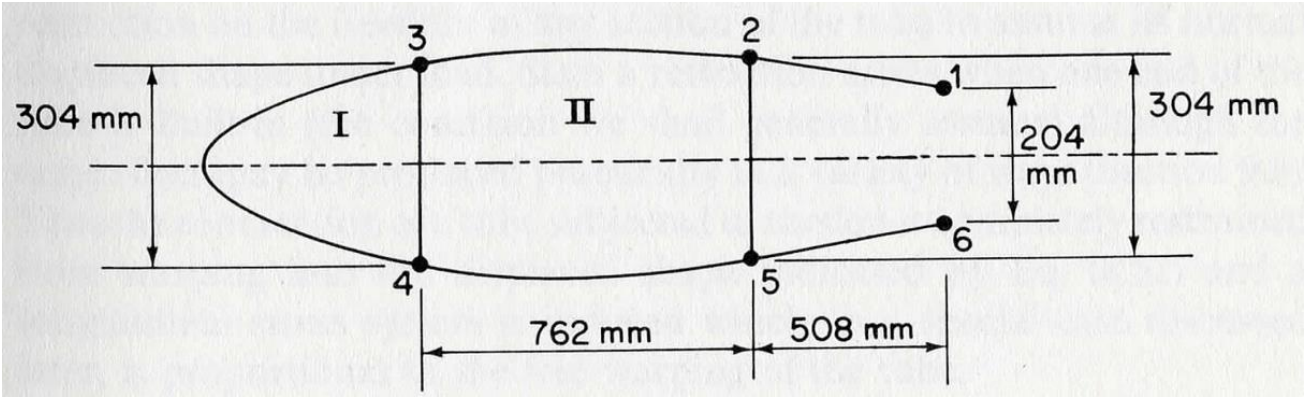
Validation from known cases

The following cases are a subset of many cases that were used to validate WINGBOX. The ones presented here are taken from the book of T.H.G. MEGSON.

Some small differences might exist between the results given by MEGSON and they are due to some modelling approximations done, or number of decimals used in the hand-calculations of the book.

Multicell example for the validation of the Shear Center

The following section was modelled:



With the following properties:

Wall	*Length* (mm)	*Thickness* (mm)	*Boom*	*Area* (mm^2)	*Cell*	*Area* (mm^2)
12, 56	510	0·559	1, 6	645	I	93 000
23, 45	765	0·915	2, 5	1290	II	258 000
34^o	1015	0·559	3, 4	1935		
34^i	304	2·030				
25	304	1·625				

It is assumed that the axial stresses are carried only by the booms.

The Reference value for the location of the Shear Center is quoted as behind the spar 34 within the Cell II, along the centreline and at a distance:

240 mm.

To analyse it with WINGBOX, we introduced a 7th node at the apex of Cell I, linking nodes 3 and 4. This was taken as the origin of the axes.

A unit force was applied in the spar 34 in the Y direction, just to trigger the shear center calculation.

The output obtained contained amongst others the following information:

```
COORDINATES OF NODE    1 :    1754.000000    102.000000      0.000000
COORDINATES OF NODE    2 :    1246.000000    152.000000      0.000000
COORDINATES OF NODE    3 :     484.000000    152.000000      0.000000
COORDINATES OF NODE    4 :     484.000000   -152.000000      0.000000
```

```
COORDINATES OF NODE    5 :    1246.000000   -152.000000      0.000000
COORDINATES OF NODE    6 :    1754.000000   -102.000000      0.000000
COORDINATES OF NODE    7 :       0.000000      0.000000      0.000000

WX=  0.000000E+00   WY=  0.000000E+00
SX=  0.000000E+00   SY=  0.100000E+01
BMX=  0.000000E+00  BMY=  0.000000E+00

X DISTANCE OF SY FORCE APPLICATION:  484.0000

CENTROID :     949.666667      0.000000      0.000000

SECTIONAL-AREA=    7740.000000
```

Second moments about Centroid:

```
IXX=  0.162442E+09  IYY=  0.190032E+10  IXY= -0.745058E-08
I11=  0.162442E+09  I22=  0.190032E+10  I12= -0.745058E-08  I33=  0.206276E+10

NEUTRAL AXIS INCLINATION :    0.00 DEGREES

SHEAR CENTRE COORDINATES=      731.5441       -0.0000        0.0000

SHEAR CENTER
I11=  0.162442E+09  I22=  0.226857E+10  I12=  0.119209E-06  I33=  0.243101E+10
```

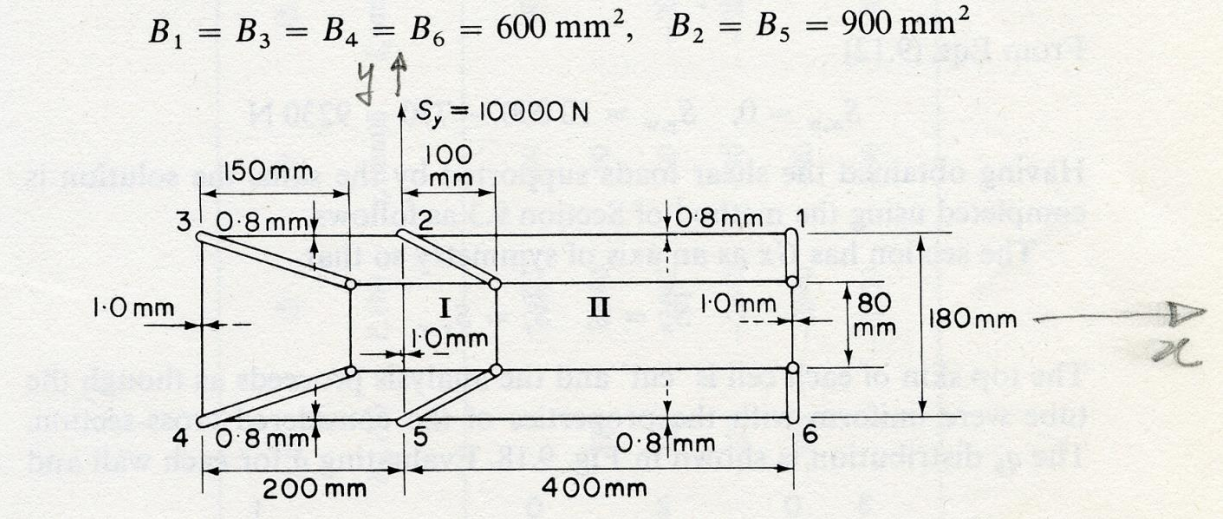
Since the spar 34 is at a distance 484mm then the Shear Centre location is

$$731.5 - 484 = \mathbf{247.5mm}$$

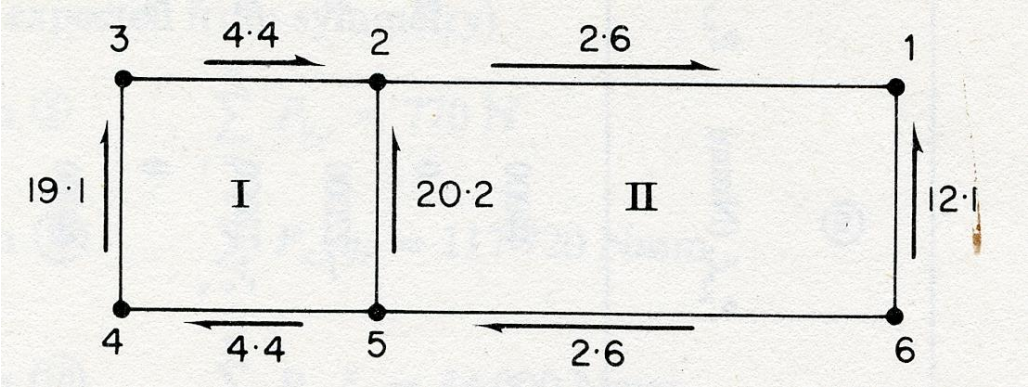
The quoted value was **240mm**, the difference with WINGBOXX is due to the approximation of the shape of the Cell I, which appears parabolic in the definition while it was modelled as triangular (of the same length 1015mm) for the sake of simplicity for this exercise.

Multicell example for the validation of the Taper

The following tapered section was loaded by a Shear Force as on the diagram and a Bending Moment of -1650000 Nmm. The length of the tapered multicell was 1200mm.



The shear flows on the larger section where to be found. The reference answer is as below:

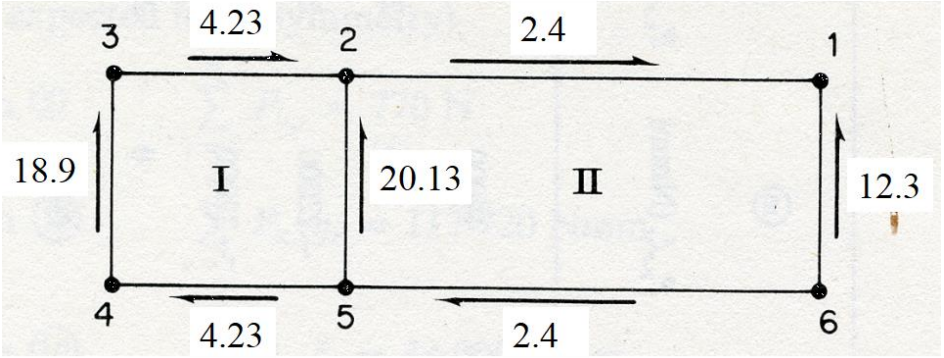


Analysing it with WINGBOX and assuming a counterclockwise positive shear flow convention, the following was obtained for the larger section:

```
COORDINATES OF NODE    1 :     600.000000     90.000000      0.000000
                               600.000000     40.000000   1200.000000
COORDINATES OF NODE    2 :     200.000000     90.000000      0.000000
                               300.000000     40.000000   1200.000000
COORDINATES OF NODE    3 :       0.000000     90.000000      0.000000
                               150.000000     40.000000   1200.000000
COORDINATES OF NODE    4 :       0.000000    -90.000000      0.000000
                               150.000000    -40.000000   1200.000000
COORDINATES OF NODE    5 :     200.000000    -90.000000      0.000000
                               300.000000    -40.000000   1200.000000
COORDINATES OF NODE    6 :     600.000000    -90.000000      0.000000
                               600.000000    -40.000000   1200.000000
```

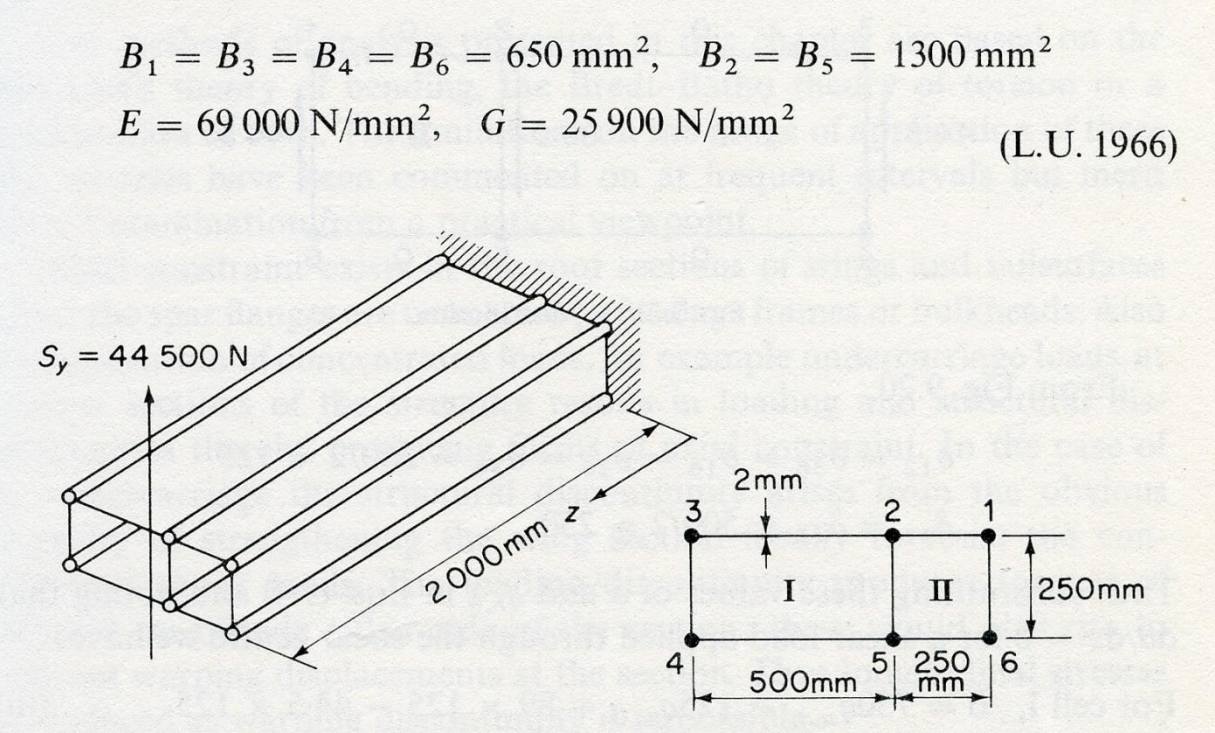
```
WX=   0.000000E+00    WY=   0.000000E+00
SX=   0.000000E+00    SY=   0.100000E+05
BMX= -0.165000E+07    BMY=   0.000000E+00


SXBAR-taper= -0.568434E-13   SYBAR-taper=   0.923611E+04


CENTROID :     257.142857       0.000000       0.000000

SECTIONAL-AREA=    4200.000000

IXX=   0.340200E+08   IYY=   0.226286E+09   IXY=   0.000000E+00
I11=   0.340200E+08   I22=   0.226286E+09   I12=   0.000000E+00   I33=   0.260306E+09


SHEAR CENTRE COORDINATES=       258.7709         0.0000         0.0000


SHEAR CENTER
I11=   0.340200E+08   I22=   0.226297E+09   I12=   0.000000E+00   I33=   0.260317E+09


SHEAR FLOW for Cell:   1   NODAL SEGMENT:     2     3
VALUES:      -4.228287      -4.228287      -4.228287      -4.228287      -4.228287      -4.228287

SHEAR FLOW for Cell:   1   NODAL SEGMENT:     3     4
VALUES:     -18.888781     -18.888781     -18.888781     -18.888781     -18.888781     -18.888781

SHEAR FLOW for Cell:   1   NODAL SEGMENT:     4     5
VALUES:      -4.228287      -4.228287      -4.228287      -4.228287      -4.228287      -4.228287

SHEAR FLOW for Cell:   1   NODAL SEGMENT:     5     2
VALUES:      20.131879      20.131879      20.131879      20.131879      20.131879      20.131879

SHEAR FLOW for Cell:   2   NODAL SEGMENT:     1     2
VALUES:      -2.369425      -2.369425      -2.369425      -2.369425      -2.369425      -2.369425

SHEAR FLOW for Cell:   2   NODAL SEGMENT:     2     5
VALUES:     -20.131879     -20.131879     -20.131879     -20.131879     -20.131879     -20.131879

SHEAR FLOW for Cell:   2   NODAL SEGMENT:     5     6
VALUES:      -2.369425      -2.369425      -2.369425      -2.369425      -2.369425      -2.369425

SHEAR FLOW for Cell:   2   NODAL SEGMENT:     6     1
VALUES:      12.291068      12.291068      12.291068      12.291068      12.291068      12.291068
```

which gives pictorially :



Multicell example for the validation of the Displacements

The following section was loaded by a Shear Force as on the diagram passing from the Shear Center. The length of the multicell was 2000mm.



The vertical displacement due to the shear force was referenced to be:

$$\Delta = 23{\cdot}5\ \text{mm}.$$

Analysing it with WINGBOX and assuming a counterclockwise positive shear flow convention, the following was obtained for the section:

First an analysis was done with a fictitious location of the application of the vertical shear force just to get WINGBOX to calculate the Shear Center. This was found to be :

```
SHEAR CENTRE COORDINATES=      432.0652      125.0000        0.0000
```

Then the above location was used as the application point of the shear force and the following was obtained:

```
COORDINATES OF NODE    1 :     750.000000    250.000000      0.000000
                               750.000000    250.000000   2000.000000
COORDINATES OF NODE    2 :     500.000000    250.000000      0.000000
                               500.000000    250.000000   2000.000000
COORDINATES OF NODE    3 :       0.000000    250.000000      0.000000
```

```
                                  0.000000    250.000000   2000.000000
COORDINATES OF NODE    4 :        0.000000      0.000000      0.000000
                                  0.000000      0.000000   2000.000000
COORDINATES OF NODE    5 :      500.000000      0.000000      0.000000
                                 500.000000      0.000000   2000.000000
COORDINATES OF NODE    6 :      750.000000      0.000000      0.000000
                                 750.000000      0.000000   2000.000000

WX=  0.000000E+00   WY=  0.000000E+00
SX=  0.000000E+00   SY=  0.445000E+05
BMX=  0.000000E+00  BMY=  0.000000E+00

X DISTANCE OF SY FORCE APPLICATION:  432.0652

CENTROID :    437.500000    125.000000      0.000000

SECTIONAL-AREA=   5200.000000

IXX=  0.812500E+08  IYY=  0.385938E+09  IXY=  0.000000E+00
I11=  0.812500E+08  I22=  0.385938E+09  I12=  0.000000E+00  I33=  0.467188E+09

WXBAR=  0.000000E+00  WYBAR=  0.000000E+00
SXBAR=  0.000000E+00  SYBAR=  0.445000E+05
BMXBAR=  0.000000E+00  BMYBAR=  0.000000E+00

SXBAR-taper=  0.000000E+00  SYBAR-taper=  0.445000E+05

NEUTRAL AXIS INCLINATION :    0.00 DEGREES

SHEAR CENTRE COORDINATES=      432.0652      125.0000        0.0000

SHEAR CENTER
I11=  0.812500E+08  I22=  0.386091E+09  I12= -0.372529E-08  I33=  0.467341E+09

X-DISPLACEMENT:  -0.00000  -0.00000  -0.00000  -0.00000  -0.00000
Y-DISPLACEMENT:  23.59890  16.84710  10.60331   5.37553   1.67175
X-ROTATION:  -0.91004  -0.87364  -0.76443  -0.58243  -0.32761
Y-ROTATION:   0.00000   0.00000   0.00000   0.00000   0.00000
Z-ROTATION:  -0.00000  -0.00000  -0.00000  -0.00000  -0.00000
```

The above displacement and rotation (in degrees) results correspond to the distributions along the flexural axis of the multicell, from the tip to the “encastre” end. Five segments were assigned for the distribution definition.

It can be seen that the maximum vertical displacement (along the flexural axis of the beam) is **23.5989 mm** as compared to **23.5mm reference**.

Also the shear flow distribution was found as:

```
SHEAR FLOW for Cell:  1  NODAL SEGMENT:    2    3
VALUES:     -5.804350     -5.804350     -5.804350     -5.804350     -5.804350     -5.804350
SHEAR FLOW for Cell:  1  NODAL SEGMENT:    3    4
VALUES:    -50.304350    -50.304350    -50.304350    -50.304350    -50.304350    -50.304350
SHEAR FLOW for Cell:  1  NODAL SEGMENT:    4    5
VALUES:     -5.804350     -5.804350     -5.804350     -5.804350     -5.804350     -5.804350
SHEAR FLOW for Cell:  1  NODAL SEGMENT:    5    2
VALUES:     73.521739     73.521739     73.521739     73.521739     73.521739     73.521739
SHEAR FLOW for Cell:  2  NODAL SEGMENT:    1    2
VALUES:      9.673911      9.673911      9.673911      9.673911      9.673911      9.673911
SHEAR FLOW for Cell:  2  NODAL SEGMENT:    2    5
VALUES:    -73.521739    -73.521739    -73.521739    -73.521739    -73.521739    -73.521739
SHEAR FLOW for Cell:  2  NODAL SEGMENT:    5    6
VALUES:      9.673911      9.673911      9.673911      9.673911      9.673911      9.673911
SHEAR FLOW for Cell:  2  NODAL SEGMENT:    6    1
VALUES:     54.173911     54.173911     54.173911     54.173911     54.173911     54.173911
```

while the reference values were:

$$q_{0,12} = 9{\cdot}6 \text{ N/mm}, \quad q_{0,23} = -5{\cdot}8 \text{ N/mm}, \quad q_{0,43} = 50{\cdot}3 \text{ N/mm},$$
$$q_{0,45} = -5{\cdot}8 \text{ N/mm}, \quad q_{0,56} = 9{\cdot}6 \text{ N/mm}, \quad q_{0,61} = 54{\cdot}1 \text{ N/mm},$$
$$q_{0,52} = 73{\cdot}6 \text{ N/mm}$$