Survey of Mechanical Options for the BABAR Drift Chamber

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The Goal

Deliver a low mass drift chamber (a box with 200,000 parts) for installation in BaBar by June 1998 (7×10^7 s from now).

The Risk

Options are under consideration for several major technology choices that still involve R&D.

Long-term impact: might not meet schedule.

Short-term impact: the attendant uncertainty tends to block progress on other aspects of the project.

Major Mechanical Options

1. Endplate:

   – Flat or shaped?

   – Al or carbon fiber?

2. Inner Cylinder:

   – Load bearing or not?

   – Carbon-fiber/Al (or Be?) foil or Be/stainless-steel?

3. Joint (between endplates and cylinders):

   – no design

   – not testable until final assembly

   – final assembly not until after 6 months of stringing in baseline design

4. Assembly/Stringing:

   – Manual or semiautomatic?

   – String horizontally; assembly cylinders after, or

   – String vertically; assemble cylinders before?

Survey of Large Cylindrical Drift Chambers

Table 1. Survey of Large Cylindrical Drift Chambers

	JADE	Mark II	TASSO	CLEO	ARGUS	Benichou	VENUS	Mark III	OPAL	SLD	CLEO II	Mark II	CDF	KEDR	AMY	ZEUS	BES	KLOE
Reference	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Chamber size																		
R_min (mm)		373	320	172	150	400	250	140	250	200	175	192	277	125		162	155	~200
R_max (mm)	800	1509	1280	950	859	1700	1260	1140	1850	1000	945	1519	1380	535	787	850	1150	1000
L_max (mm)	3000	2692	3520	1930	2000	4500	3000	2340	4000	1800	2150	2300	3214	100	1792	2030	2120	3300
Wire/cell parameters																		
Sense wires	1536	3204	2340	5304	5940	12880	7104	528	3816	5120	12240	5832	6156	1512	9048	4608	2808	~12000
Other wires		9612	7020	15912	24588	64400	21312	1584	?	32640	36240	?	30448	14520	27144	19584	16572	~36000
Total layers	48	16	15	17	36	40	29	62	159	80	51	72	72	56	40	72	40	~48
Stereo layers		10	6	8	18	9	9	10		48	11	36	36	24	15	32	20	~24
R_min (mm)		414	367	213	180		286	175		238	199	246	309		155	182	195	
R_max (mm)		1448	1222	892			1213			961	901	1448	1320		639	794	1095	
Geometry	jet	square	square	square	square	hex	square	rect.	jet	jet	square	jet	jet	jet	hex	jet	jet	square
Max drift (mm)	70	18	16	6	18	10	10	30	250	30	7		40	30	6	25	31	15
Min. resolution (micron)	150	150	220	210	150		150	250	110	55	100	125	200	40	140	100	200	~100
dE/dx resolution (%)	10				5.6			15	3.5	7	7.1	7.2				6	9	
Endplates																		
Material	Rohacell	Al + H-C	Al	Al	Al	Al	Al	Al + H-C	Al	Al	Al	Al	Al	Gl-F	Al	Al	Al	Al or C-F
Thickness (mm)		76	35		30	5	21	76	28	5.1	31.8	50.8	50.8	21	30	20	40	
Geometry	flat + rib	flat + cone	flat	flat	flat	cone	sphere	flat	cone	parabola	flat	flat	flat	flat	stepped	flat	flat	sphere
Wire load (tonnes)	1.2		2.3		3.1	33.7	6.8		14	13.3	6.8	20	25	3.4	4.5	5.9		
Max deflection (mm)		8				3	0.6		0.5		7.9		1.4	3		*1.8*		~1
Outer cylinder																		
Material		Al	Al		Al	H-C	C-F	Al	Al	Al + H-C	Al + H-C	Al	Al	Gl-F	Al	Al	Al	rods
Thickness		6	6		6	25	5	6			8	12.7	6.4	5	posts	6	10	
Inner cylinder																		
Material		Lexan	Gl-F		C-F	foil	C-F	paper	foil	Al + H-C	C-F	Be	C-F	C-F	Kevlar	Al + foam	C-F	foil
Thickness		3	5		3.3		1	1			0.75	2	2	1.5	1	1.4 + 9	2	
Load bearing		no	yes			no	no	no	no	yes	no		yes		no	yes		no
Stringing		horiz.									vert.		horiz.			vert.		
Prestressing		rods								rods	rods		wires	external	rods	rods		
C-F - carbon-fiber/epoxy, Gl-F = glass-fiber/epoxy, H-C = honeycomb																		

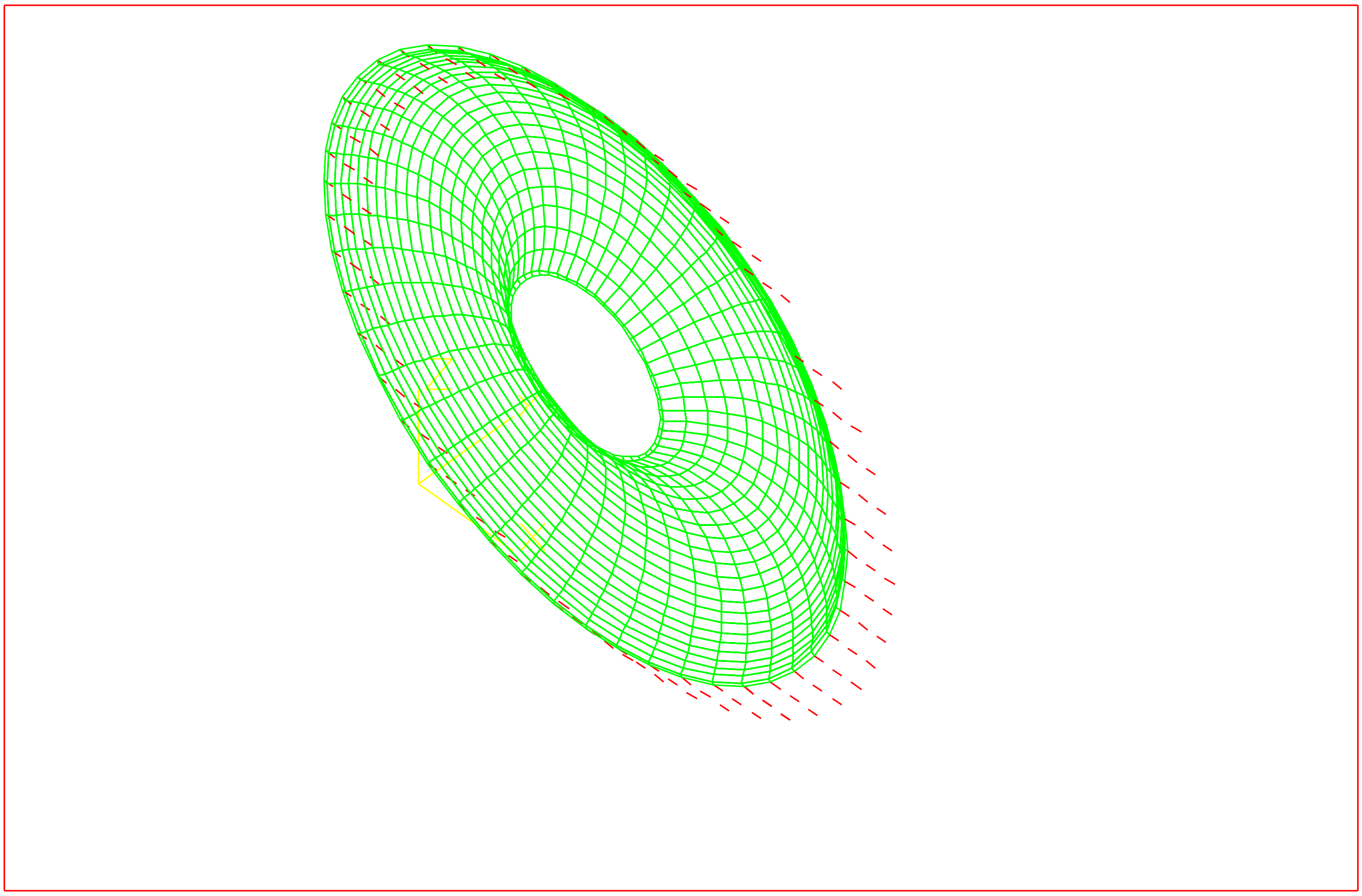
⇒ Many variations of drift-chamber concept can be built.

Forward Endplate

Goal: low number of radiation lengths

maximum track length

Best solution (my opinion): Al toroidal cap with wire load supported at both inner and outer cylinders



– FEA analysis indicates could use only 2.5 mm Al:

Peak stress < 24 MPa $= 1/10$ ultimate strength,

Maximum deflection $= 250\ \mu$m.

Stress $\propto 1/$thickness.

Displacement $\propto 1/$thickness.

(See TNDC-96-25.)

– Similar to endplates built for SLD.

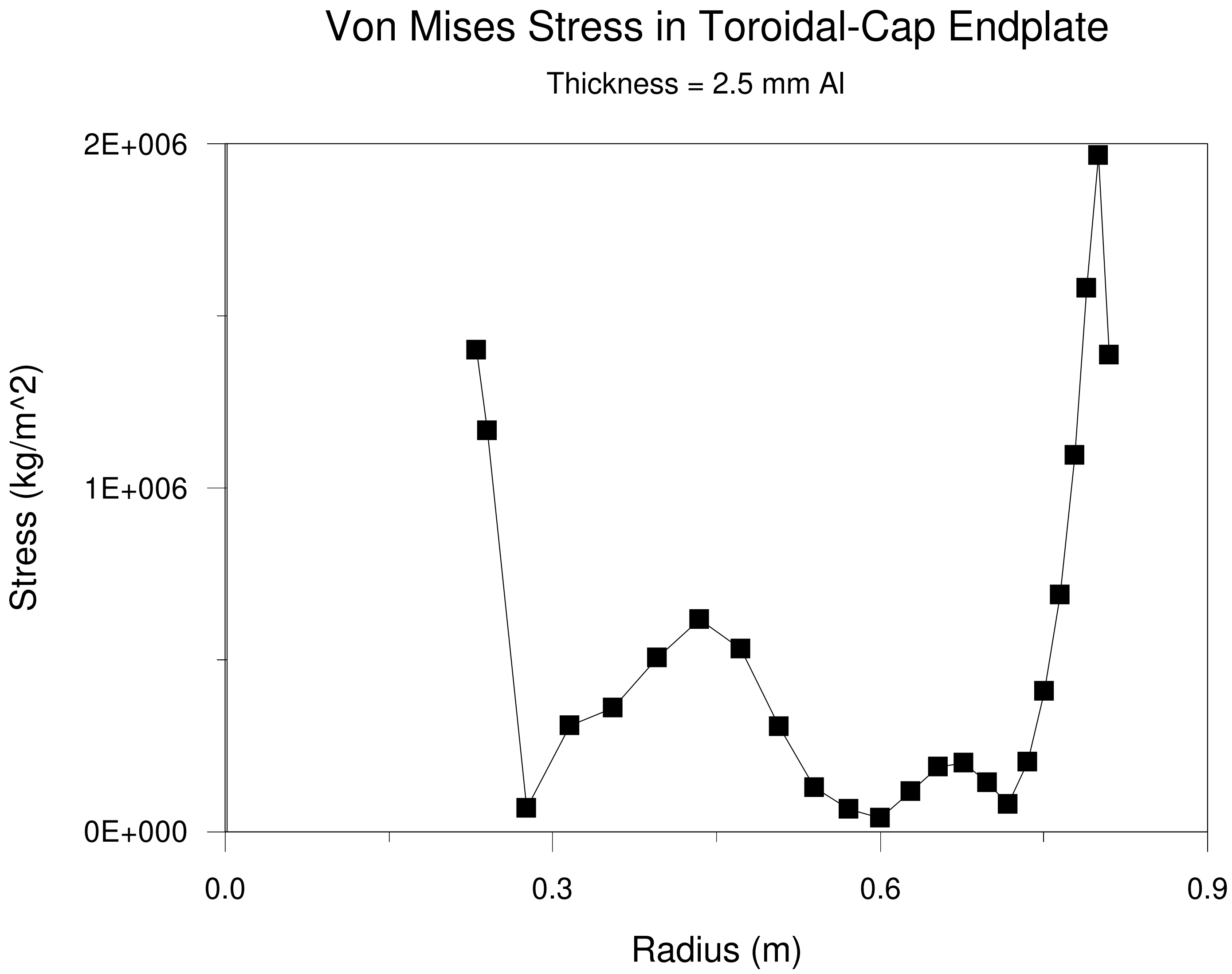
– Disadvantages:

Time to hog out plate from block (use spun casting?).

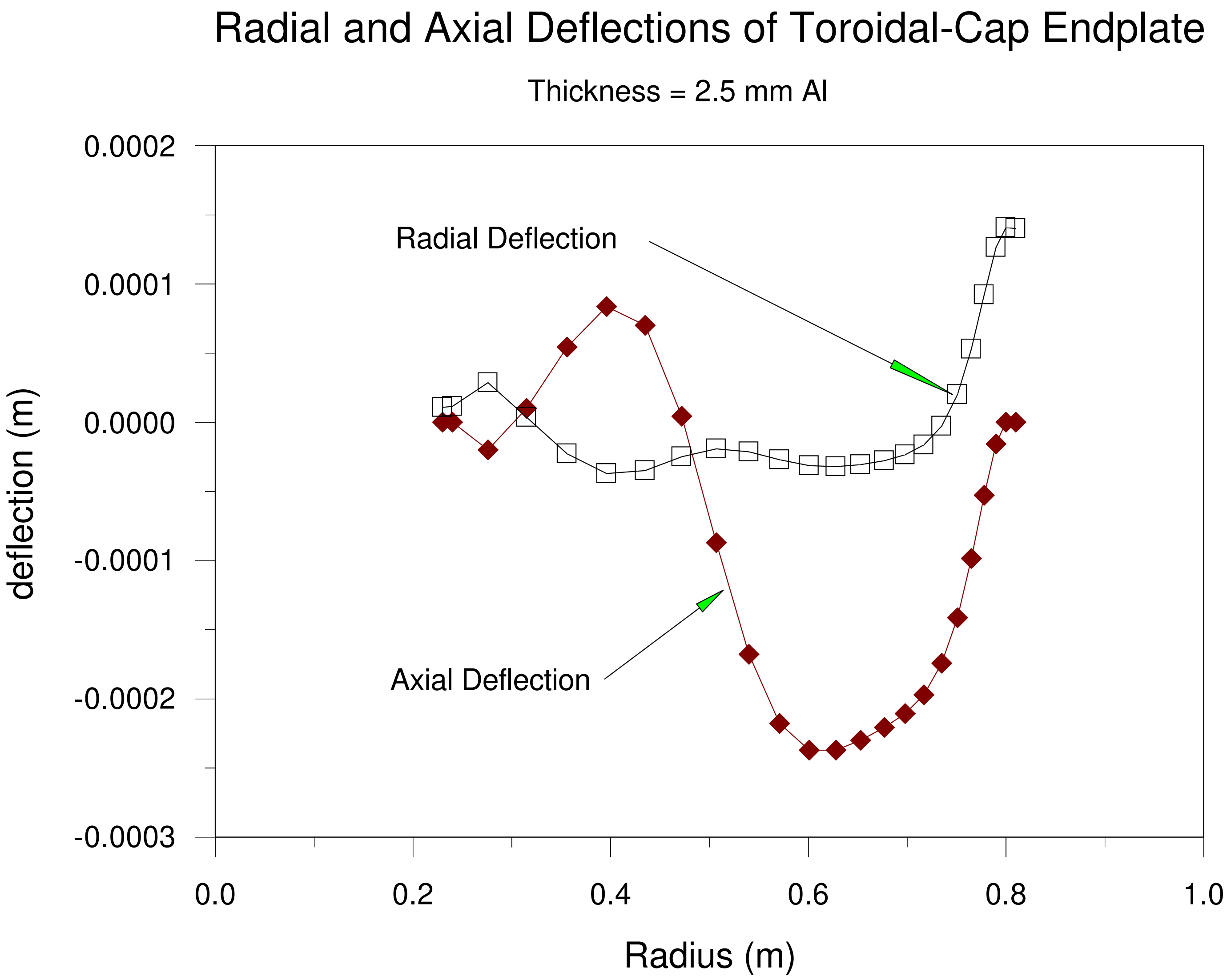
Any shaped enplate must have stiffening rings to

suppress radial spread

$\Rightarrow$ localized region with higher radiation lengths.



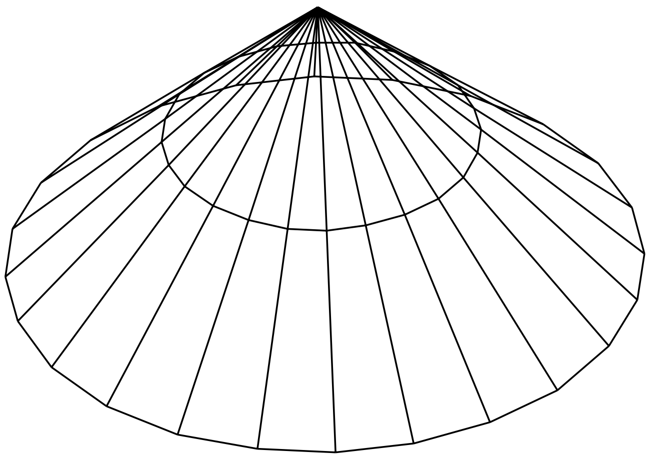
Von Mises Stress in Toroidal-Cap Endplate
Thickness = 2.5 mm Al
Stress (kg/m^2)
2E+006
1E+006
0E+000
0.0
0.3
0.6
0.9
Radius (m)

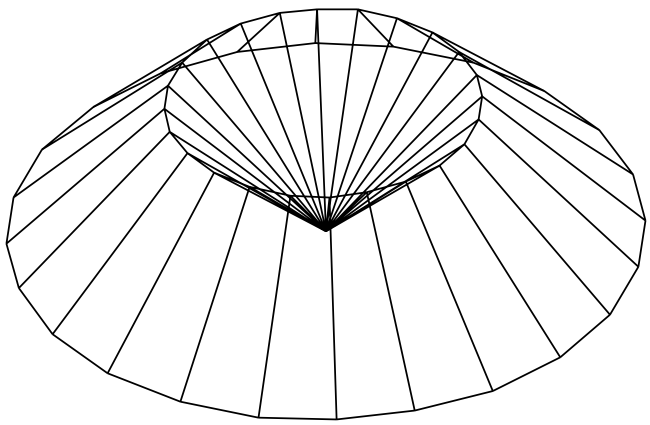

Radial and Axial Deflections of Toroidal-Cap Endplate
Thickness = 2.5 mm Al
Radial Deflection
Axial Deflection
deflection (m)
Radius (m)
0.0002
0.0001
0.0000
-0.0001
-0.0002
-0.0003
0.0
0.2
0.4
0.6
0.8
1.0

Shaped Carbon-Fiber Endplates

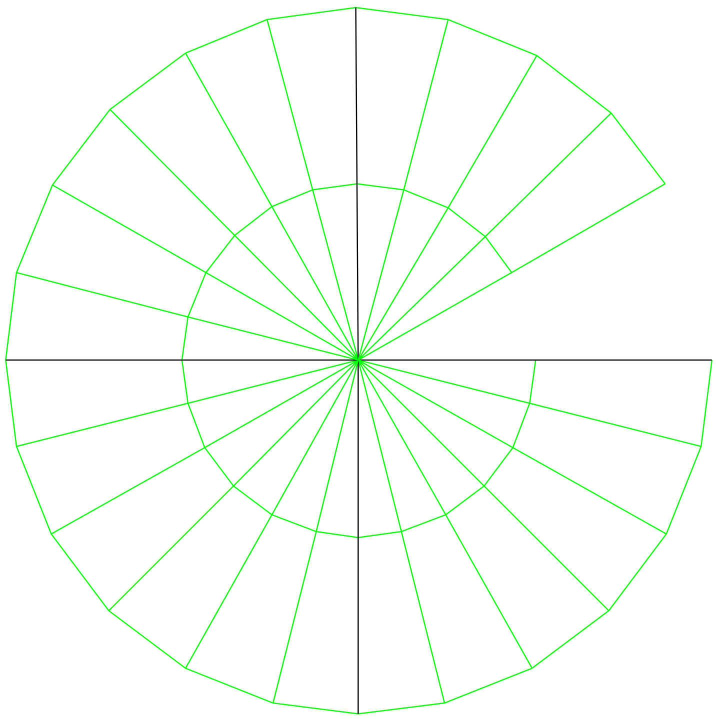
(See TNDC-96-21 and -25.)

Cones and bicones can be made from flat sheets:

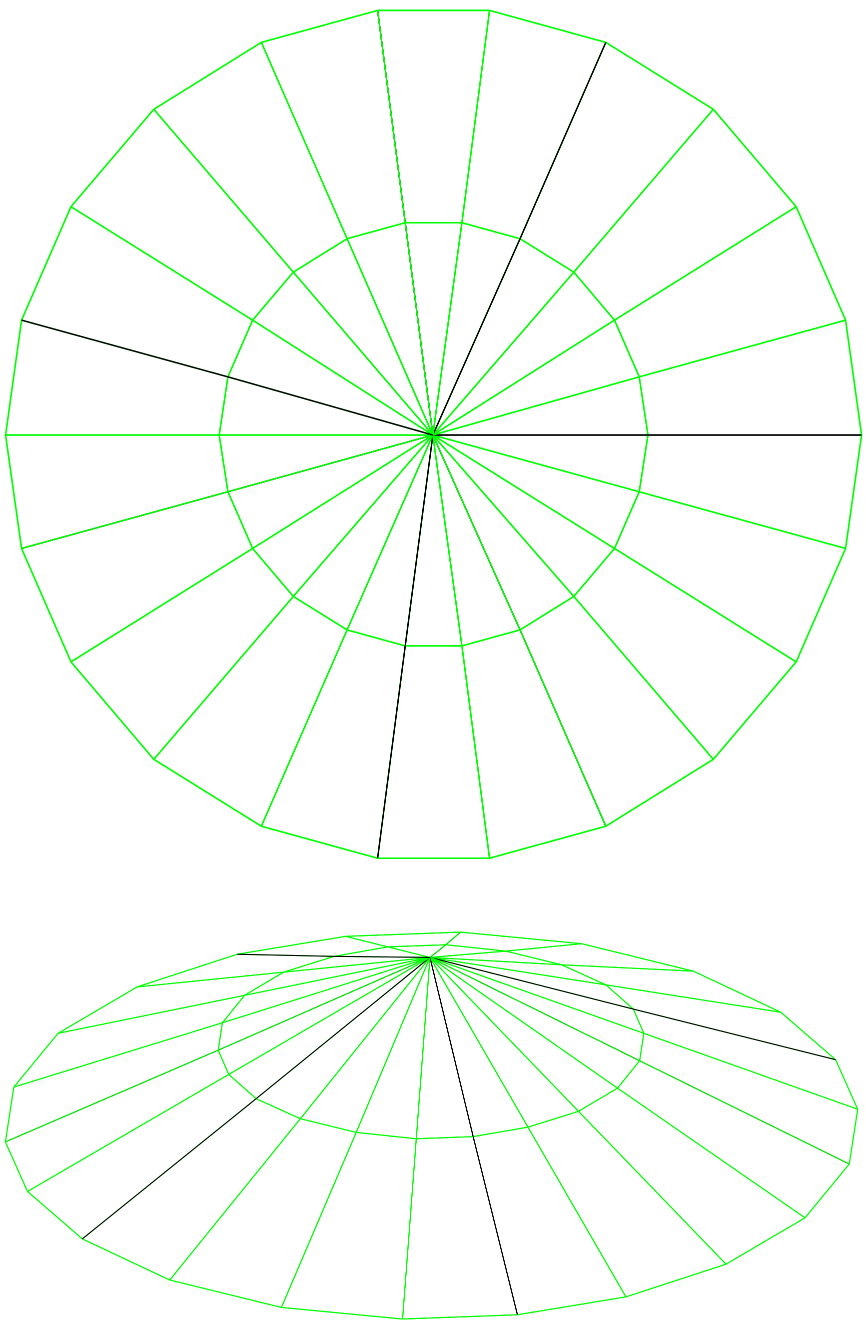




A 23.6° cone can be made if a 30° sector is cut out.



A layup of 11 (or 22, 33...) sheets would have 11 directions in which fibers are along cone generators, and would have fibers in 6 directions at any point.

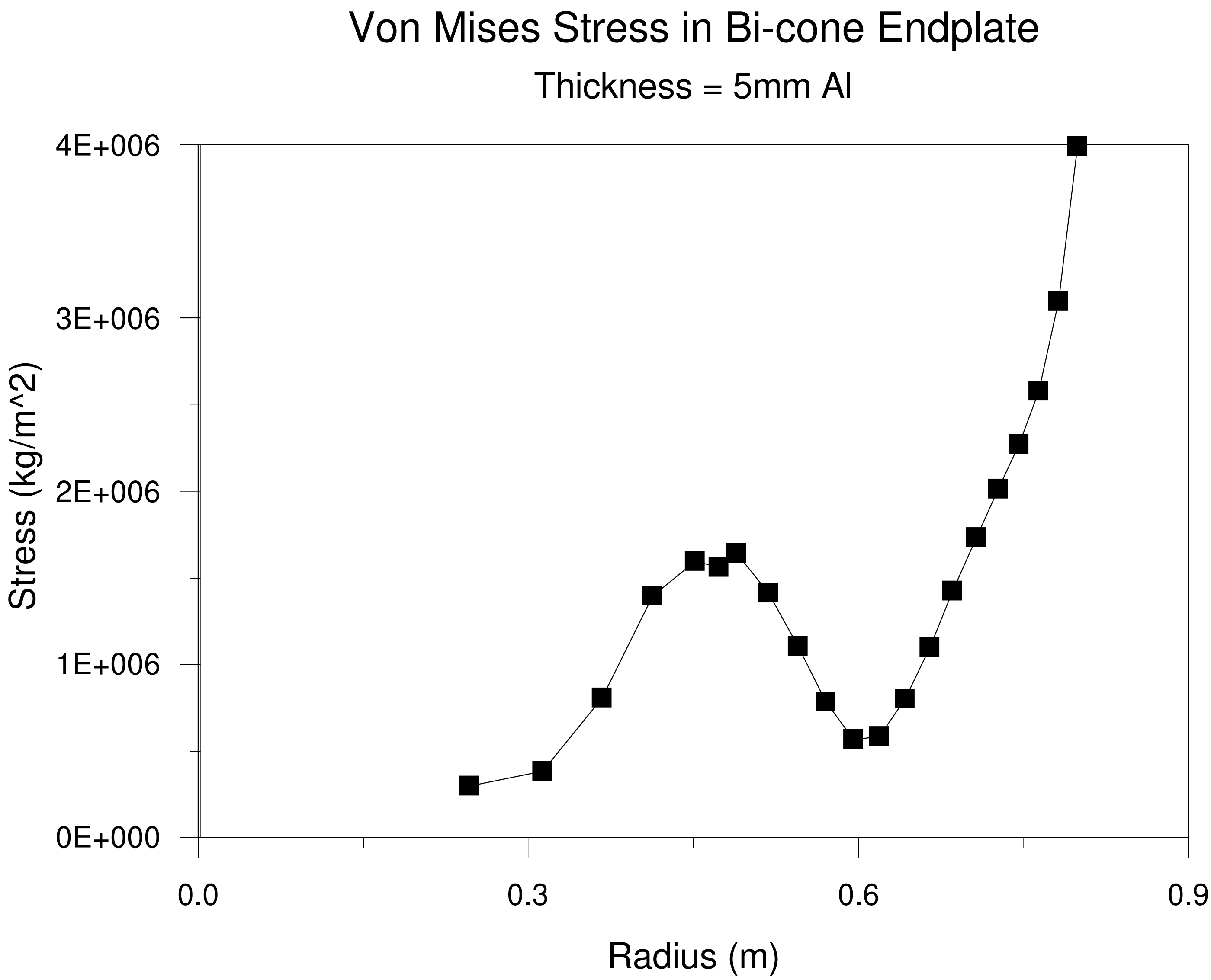


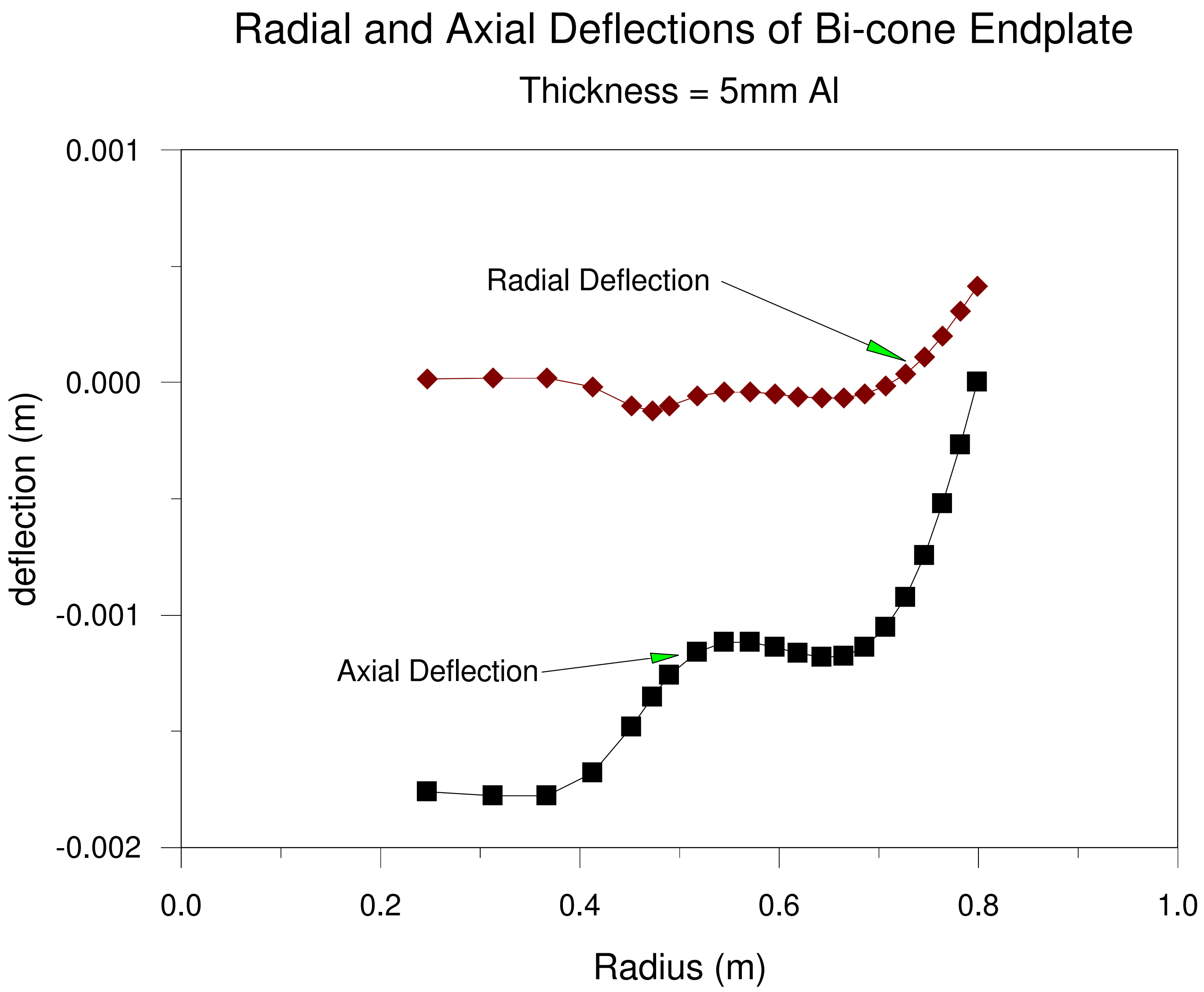
FEA Analysis

If supported only at outer radius a bicone should be at least 8 mm thick, and a cone at least 12 mm thick.

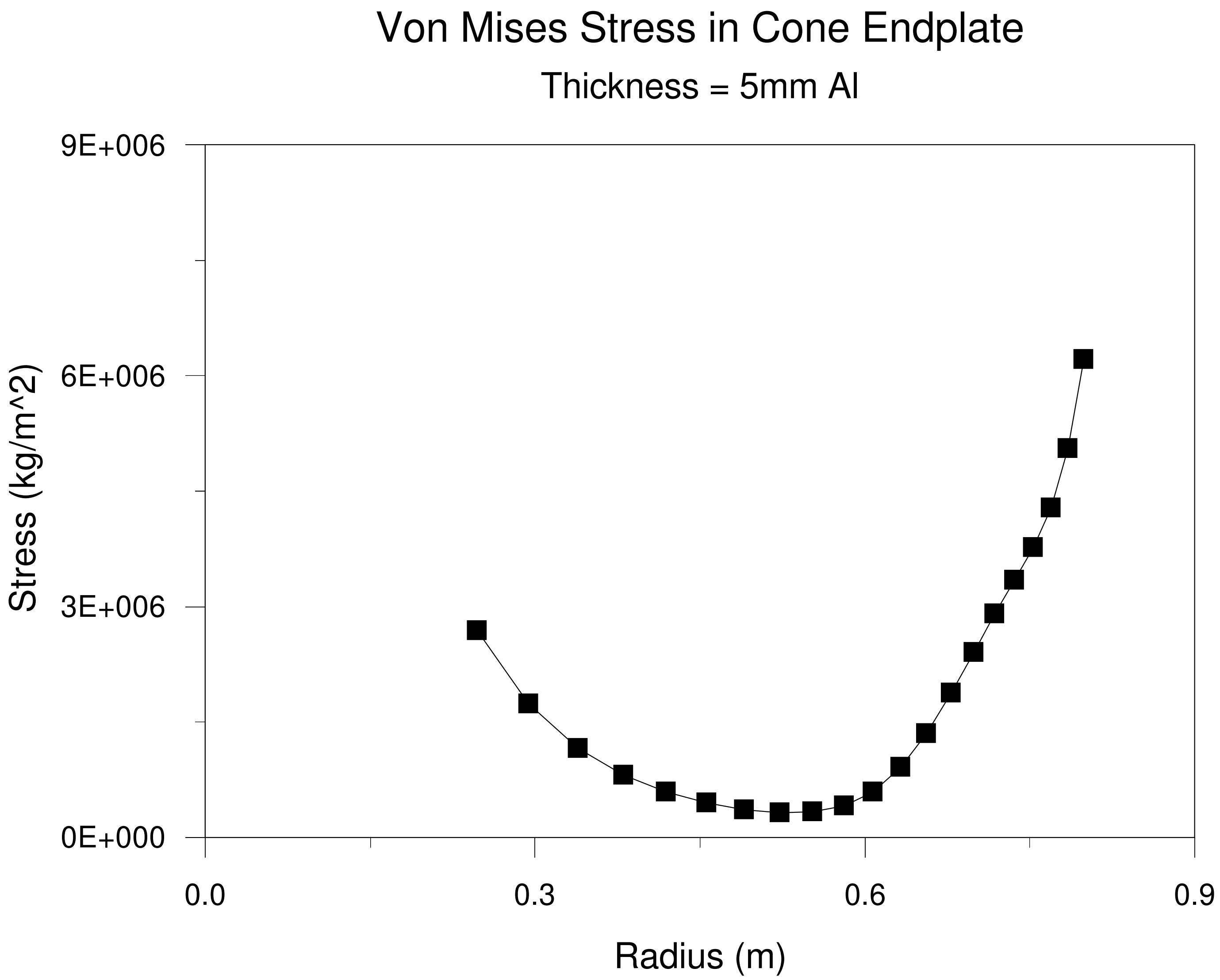
Peak displacements = 1.3 mm in bicone and 1.5 mm in cone.

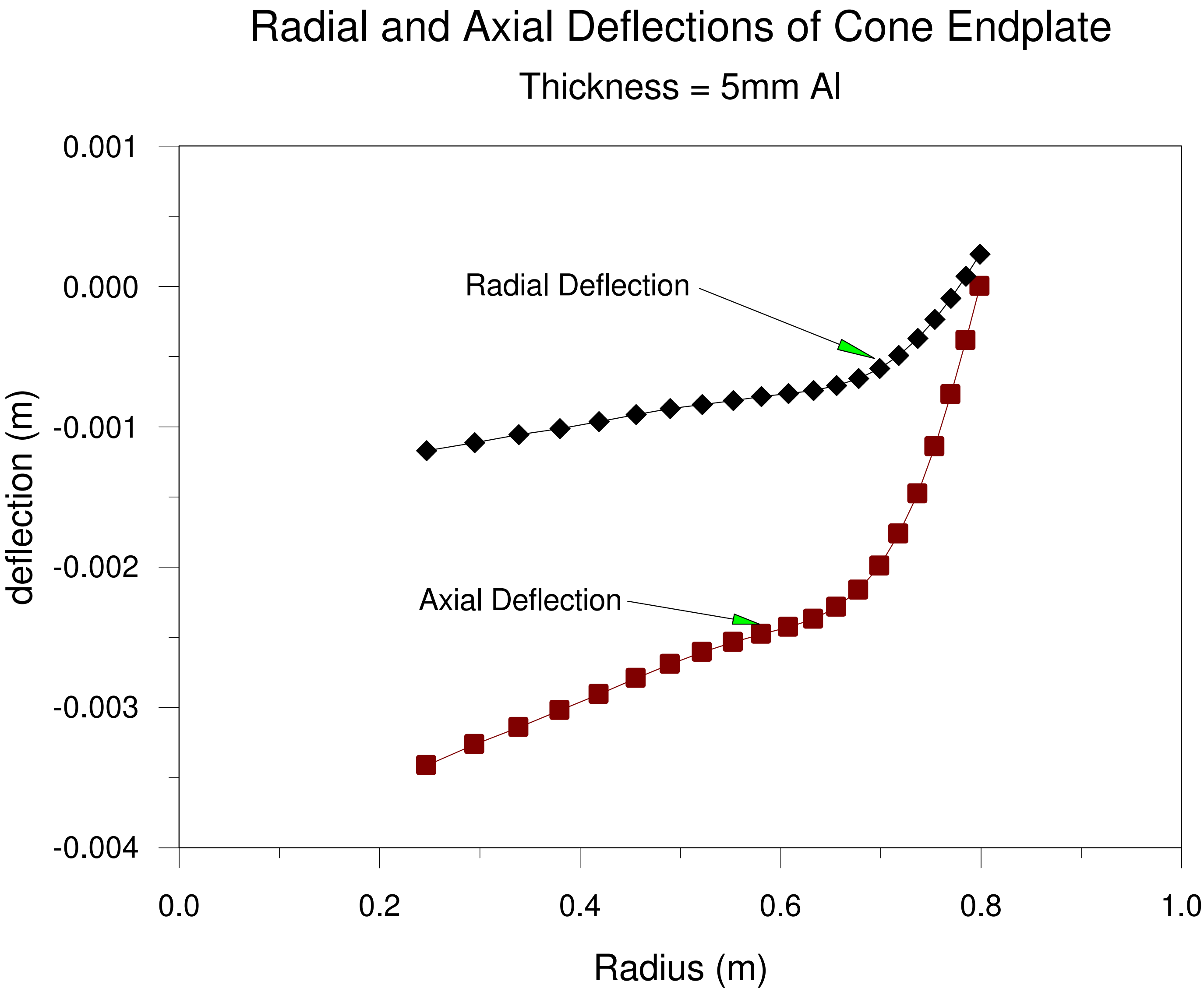
Scale results of FEA analysis on following pages for Al by 10/thickness[mm] in case of carbon-fiber.


Von Mises Stress in Bi-cone Endplate
Thickness = 5mm Al
Stress (kg/m^2)
4E+006
3E+006
2E+006
1E+006
0E+000
0.0
0.3
0.6
0.9
Radius (m)



Radial and Axial Deflections of Bi-cone Endplate
Thickness = 5mm Al
0.001
0.000
-0.001
-0.002
deflection (m)
Radial Deflection
Axial Deflection
0.0
0.2
0.4
0.6
0.8
1.0
Radius (m)


Von Mises Stress in Cone Endplate
Thickness = 5mm Al
9E+006
6E+006
3E+006
0E+000
Stress (kg/m^2)
0.0
0.3
0.6
0.9
Radius (m)



Radial and Axial Deflections of Cone Endplate
Thickness = 5mm Al
Radial Deflection
Axial Deflection
deflection (m)
Radius (m)
0.001
0.000
-0.001
-0.002
-0.003
-0.004
0.0
0.2
0.4
0.6
0.8
1.0

Flat Endplate – Supported at Outer Edge

(See TNDC-96-20 and -24.)

Analytic analyses available (Roark and Young).

Maximum stress = 1/10 ultimate stress $\Rightarrow$

3.2 cm Al, maximum displacement = 3.3 mm

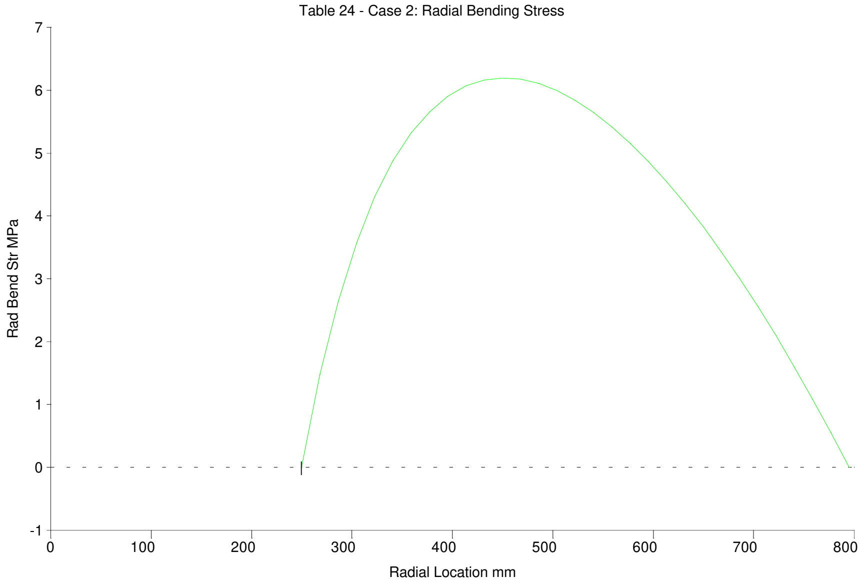
3.7 mm carbon-fiber, maximum displacement = 2.9 mm.

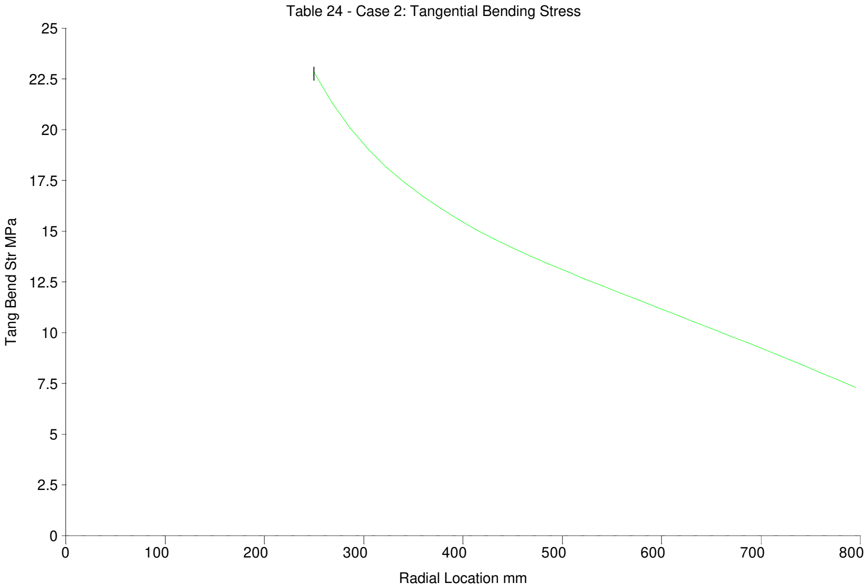
Scaling laws for bending flat plates:

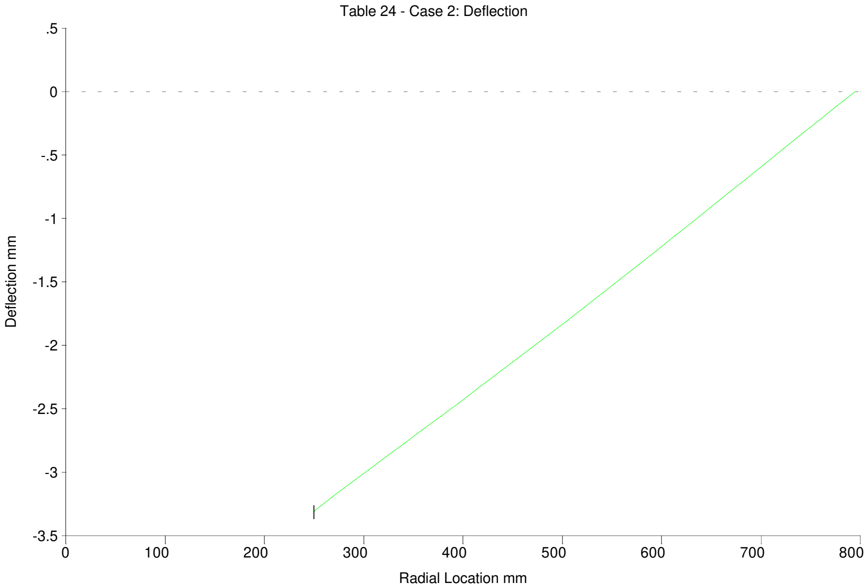
stress $\propto$ 1/thickness^2

Displamcement $\propto$ 1/(modulus$\cdot$thickness^3).

3.2-cm-thick flat Al endplate, supported outer edge







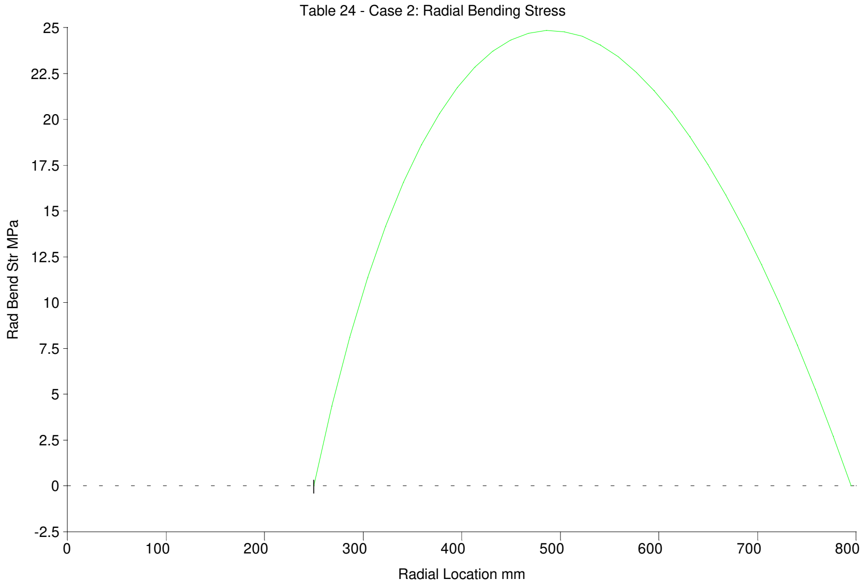
Flat Endplate – Supported at Both Edges

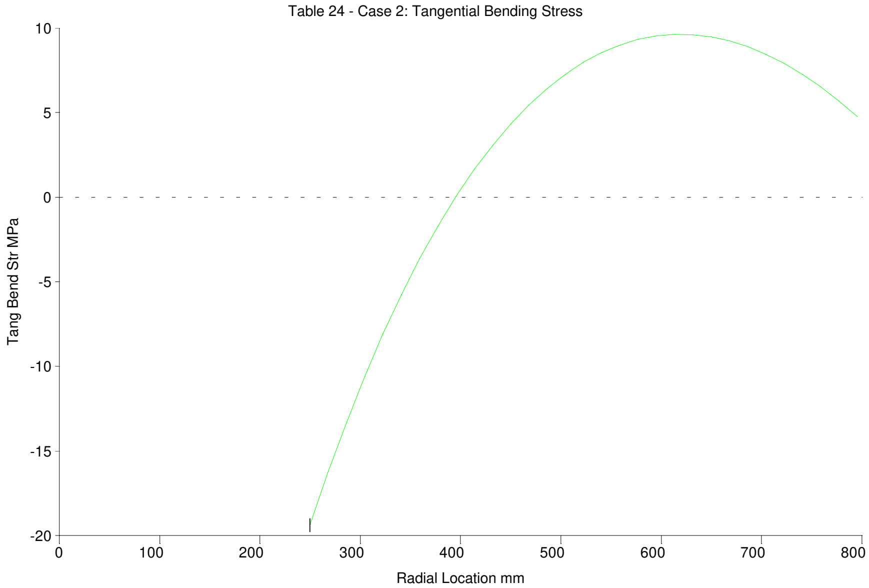
Maximum stress = 1/10 ultimate stress $\Rightarrow$

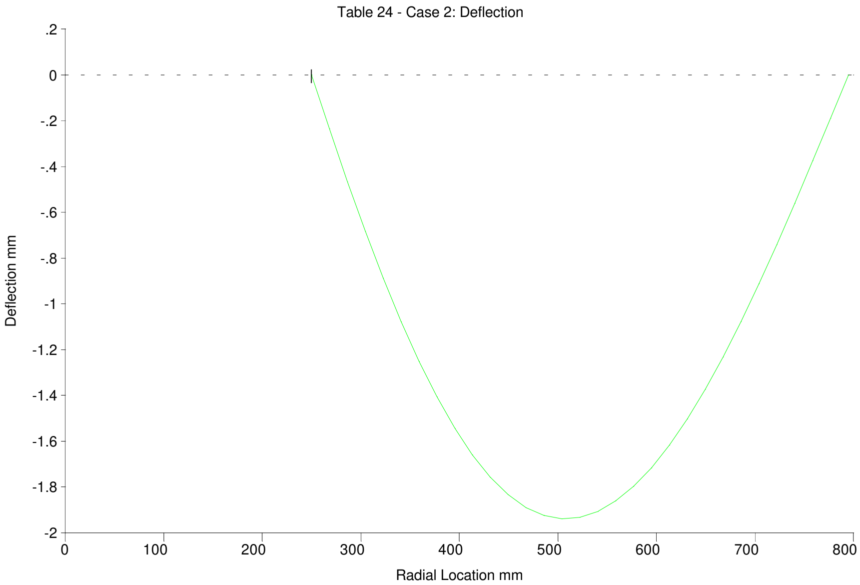
1.2 cm Al, maximum displacement = 2.2 mm

1.4 mm carbon-fiber, maximum displacement = 1.4 mm.

1.2-cm-thick flat Al endplate, supported both edges







Summary of Front Endplate Options

The thickness t of the plates was chosen so the peak stress under 3500 kg wire load is 1/10 the ultimate stress.

The ordering below represents my personal preference.

Geometry	Material	t (cm)	X_0	Support	Deflection (mm)
Toroidal	Al	0.25	2.8%	Both	0.25
Flat	Al	1.2	13.5%	Both	2.2
Flat	C-F	1.4	5.6%	Both	1.4
Flat	Al	3.2	36%	Outer	3.3
Flat	C-F	3.7	15%	Outer	2.9
Bicone	C-F	0.8	3.2%	Outer	1.3
Cone	C-F	1.2	4.8%	Outer	1.5

Should the Inner Cylinder Be Load Bearing?

(See TNDC-96-20.)

If both inner and outer cylinders are load bearing the stresses in the endplates are reduced, permitting thinner endplates.

Thin cylindrical shells under axial load can fail by buckling:

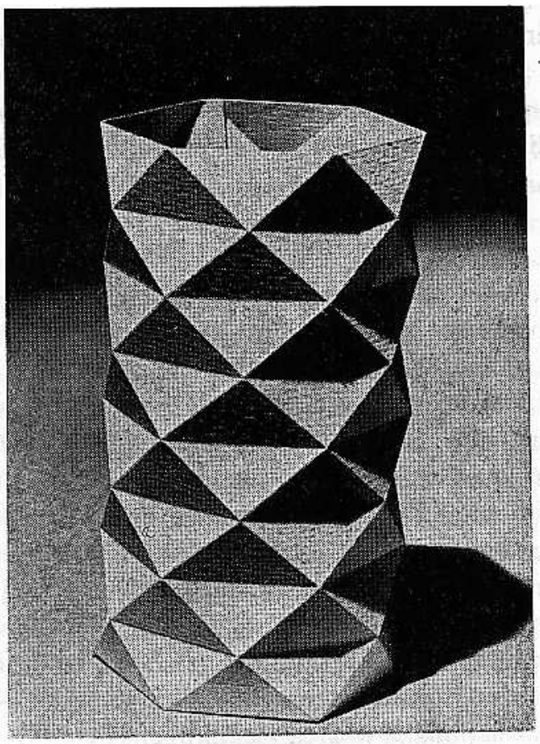


Fig. 2.6. The Yoshimura-pattern

$$F_{\max} = \frac{\pi^3 E t^{9/4} r^{1/4}}{6 l^{1/2} (1 - \nu^2)^{5/8}}, \qquad \text{(semi-empirical).}$$

Laboratory Test

Cylinder of radius 6″ and length 36″ from a sheet of G-10 ($E = 2.5 \times 10^6$ psi, $\nu = 0.3$) about $0.018'' = 450\ \mu$m thick.

The calculated buckling force is then 425 pounds.

The G-10 tube buckled under 715-Lb load.

⇒ Semi-empirical formula gives a lower bound on the buckling force.

Summary of Load Bearing Cylinder Options

Thickness t such that wire load = 1/10 the buckling load.

3/5 of the wire load should be carried by the inner cylinder, *i.e.*, 1400 kg out of 3500 kg.

The length l of the cylinders is taken as 3 m.

Material	E (GPa)	r (cm)	t (mm)	X_0	Compression (μm)
C-F	140	24	1.5	0.6%	108
Be	300	24	1.1	0.3%	76
C-F	140	80	1.6	0.64%	14

Carbon-fiber cylinders would need an aluminum foil laminate to provide rf shielding. If this laminate is, say, 350 μm thick it would add an additional 0.4% radiation length.

Is a Be cylinder worth the trouble?