NASA/TM–2010-216192

Finite Element Models and Properties of a Stiffened Floor-Equipped Composite Cylinder

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February 2010

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INTRODUCTION

Between 1984 and 1986 the Lockheed-California and Lockheed-Georgia Companies designed and fabricated a composite fuselage cylinder section for use as a test bed to evaluate and demonstrate impact dynamics and acoustic transmission technology that would meet the design requirements of a 1990 large transport aircraft without substantial weight and cost penalties.[1] The floor-equipped, frame and stringer stiffened composite cylinder has been investigated in several analytical and experimental structural-acoustic studies.[2-13] The purpose of this document is to report on the development of a coarse finite element model of the structural components, a coarse finite element model of the acoustic cavities above and below the beam-supported plywood floor, and two dense models consisting of only the structural components. This report summarizes the geometry, the element properties, the material and mechanical properties, the beam cross-section characteristics, the beam element representations and the boundary conditions of the composite cylinder models. The expressions used to calculate the group speeds for the cylinder components are presented.

TEST ARTICLE

The composite cylinder test article (Figure 1) is a 3.66 m long filament-wound, stiffened cylinder with a 1.68 m diameter. The composite material of the cylinder shell consists of carbon fibers embedded in an epoxy resin. The nine-layer ply-sequence of the cylinder shell is ±45, ±32, 90, ∓32, ∓45 for a total thickness of 1.7019 mm. The cylinder is stiffened by ten evenly spaced J-section ring frames and twenty-two evenly spaced hat-section longitudinal stringers. A 12.7 mm thick plywood floor is installed 0.54 m above the bottom of the cylinder. The floor is carried by ten horizontal aluminum beams at the locations of the ring frames. Twenty vertical aluminum beams support the floor, with one pair of supporting beams in each ring frame cross-section and spaced 1.045 m apart. All elements of the fuselage model are rivet-bonded together. Figure 2 depicts a cross-section of the cylinder showing the beam supported floor, a ring frame and the cross-sections of the twenty longitudinal stringers. A support structure consisting of two rigid 0.0889 thick medium-density fiberboard (MDF) endcaps provide constrained edge conditions to the cylinder. The cylinder rests in grooves in the endcaps and the entire structure is held together by four tension rods. A hinged door (0.61 m by 0.61 m) was incorporated in the front endcap to provide access to the interior of the cylinder. The access door can be locked into place by six over-center latches as shown in Figure 1.

FINITE ELEMENT MODELS

One coarse and two dense finite element models were developed for the composite cylinder structure. The ‘CC_baseline.db’ model is the baseline coarse structural model (3470 elements). The ‘CC_acoustic’ model (5452 elements) is a course model of the acoustic cavities above and below the floor and is compatible with the ‘CC_baseline.db’ model. The dense finite element model ‘CC_dense’ totals 76908 structural elements for the same cylinder to allow structural analysis at higher frequencies. The frames and stringers are modeled as beam elements in the baseline model and in the ‘CC_dense’ model. In the ‘CC_dense_plate’ model (102208 elements) the frames and stringers were represented by plate elements. The database files have the extension ‘db’. A damping coefficient of 0.01 was adopted for the structural components. The finite element modeling was performed in the pre-processor MSC.Patran version 2007r2. The finite element models use a rectangular coordinate system with the origin in the cross-sectional plane at one end of the cylinder and the z-axis running along the longitudinal cylinder centerline. The final models were equivalenced to delete multiple nodes at the same location.

CC_baseline.db

The basic ‘CC_baseline.db’ database contains the model information for the coarse finite element model of the composite cylinder and can be visualized in a pre/post-processor such as MSC.Patran. A hidden line isometric view of the course composite cylinder finite element model supported by the two endcaps is presented in Figure 3. In Figure 4 one endcap of the model is removed to show the floor and the supporting beams. The wireframe representations of the baseline coarse cylinder model are depicted in Figures 5 and 6.

Element properties - The baseline coarse finite element model is divided into element property sets having the same material properties and alike geometric attributes (Table 1). The ‘Cyl’ element property set contains all 1334 cylinder shell elements. The nine-layer composite material of the shell is indicated by “9PlyT500-tape”. The one-piece plywood floor is directly attached to the cylinder shell and is carried by ten horizontal floor beams and twenty vertical floor supports, which are shown as three-dimensional beam elements in Figure 7. The floor and floor beams are in separate element property sets (Table 1). The floor supports are divided into two property sets, each containing half of the floor supports sharing the same plane and the same bar orientation. The twenty longitudinal stringers are also in one element property set as they all have the same bar orientation. The bar orientation of each ring frame points to its center node necessitating ten different element property sets (Table 1). The stringer and frame beam elements are depicted in Figure 8. The floor beams and supports are located in cylinder cross-sections containing a ring frame (Figure 9). The element properties of the endcaps are also included in Table 1.

Groups - The model is segmented into logical groups with similar material properties including the cylinder shell, the floor, the floor beams, the floor supports, the longitudinal stringers, the ring frames, and the endcaps. The number of elements, element type, mass and volume are tabulated in Table 2.

Material properties - The mechanical material properties, including the elasticity moduli, the shear modulus, the density and the Poisson ratios are listed in Table 3. The Thornel Carbon Fiber T-500 6k tape and fabric materials were used to define the composite laminates for the cylinder shell and the ring frames. The equivalent orthotropic material properties were computed for the nine-layer composite material of the shell with elasticity moduli of 40.6 GPa and 32.4 GPa in two perpendicular directions (Table 3). The density for the shell is 1590 kg/m^3. The equivalent orthotropic material properties for the ring frames and stringers were computed and are listed in Table 3. The longitudinal stringers were fabricated of Hexcel AS4/3501-6 Carbon Epoxy tape. The floor beams and supports are made of aluminum and are attached to a plywood floor. The density of the plywood floor was measured. The equivalent isotropic plywood mechanical properties were obtained from the ESI VA-One Statistical Energy Analysis (SEA) material database.[14] The medium density fiber (MDF) material properties of the two endcaps are also listed in Table 3.

Composite laminates – The 1.7019 mm thick cylinder shell consists of a nine-layer carbon fiber epoxy tape laminate with ply orientations of ±45, ±32, 90, ∓32, ∓45 (Table 4). The composite layups of the J-section frames and the hat-section stringers are different for the base, the web and the crown (top). However, the finite element beam section definition allows only one material property per element. The equivalent mechanical properties for the crown (top) part of the cross section were chosen to represent each stiffener. The 'J-t' layup for the ring frame and the 'Hat-t' layup for the longitudinal stringer are listed in Table 4.

Cross-section properties - The floor beams and supports were modeled with a U-shaped cross-section (Figure 10). The web of the cross-section was 0.0635 m long with 0.0254 m flanges. The wall thickness was measured as 0.00238 m. The beam section properties are listed in Table 5 including the cross-sectional area, moments of inertia, torsional constant about the centroid, and shear stiffness factors. The off sets and the distances between the centroid and the shear center, the centroid and the origin, and the shear center and the origin are also included in Table 5. The cross-sectional dimensions and section properties of the 'J' shaped ring frames are depicted in Figure 11. The locations of the centroid and the shear center are measured from the lower left hand corner of the cross section. The cross-sectional dimensions and properties of the "hat" shaped longitudinal stringer beam elements are summarized in Figure 12. The beam section properties of the ring frames and the longitudinal stringers are tabulated in Table 5 as well.

Boundary conditions – Clamped boundary conditions were applied to the bases of the two endcaps preventing translation and rotation at the base nodes along the x-, y- and z-axes.

CC_acoustic.db

Hidden line isometric views of the top and bottom acoustic cavities above and below the floor in the baseline 'CC_acoustic' finite element model are presented in Figures 13 and 14. The same circular outline of a virtual surface in the x-y plane through the origin of the cylinder is included in each figure to relate the relative locations of the two cavities. The structural model is the same as the 'CC_baseline.db' model. The purpose of the acoustic finite element models is to allow a modal analysis of the acoustic space and to couple the acoustic space to the cylinder structure for vibro-acoustic analysis. The element property sets of the acoustic cavities are listed in Table 6.

CC_dense.db

The number of elements and the structural details in the 'CC_dense.db' were increased to allow analyses at higher frequencies. The 'CC_dense.db' database contains all the pertinent information of the dense composite cylinder finite element model. Hidden line isometric, front and side views are presented in Figures 15-17. The frames and stringers are again modeled as beam elements but the element size and spacing were chosen such that plate elements for the frames and stringers could easily be incorporated (Figures 18 and 19). The element properties for the finite element sets in the 'CC_dense.db' database are listed in Table 7. The number of elements, element type, mass and volume of the dense finite element groups are tabulated in Table 8. The material properties and the composite layup of the shell, frames and stringers are the same as for the baseline model (Tables 3 and 4).

CC_dense_plate.db

In the 'CC_dense_plate' model the frames and stringers are modeled by plate elements (Figures 20-22). The ring frames run through openings created in the floor. The beam elements supporting the floor run from side to side connecting to the ring frames and the cylinder shell. The element properties for the finite element groups are listed in Table 9. The number of elements, element type, mass and volume of the dense finite element groups are tabulated in Table 10. The composite material lay-up of the cylinder shell is the same as for the previous models (Table 11). The frame and stringer plate elements were modeled with the published[1] composite layups of the crown (top, cJ-t and cHat-t), the web (cJ-w and cHat-w) and the flanges (base, cJ-b and cHat-b) as shown in Table 11. A detailed rendered view of the frame and stringer plate elements is shown in Figure 22. The intersection between the frame and stringer (Figure 23) was modeled with the ring frame flanges wrapping around the stringer, instead of attaching a clip as shown in the figure. The element properties of the frame flanges (pFrame-b) on top of the stringer flanges (pString-Hat-b) are indicated by pFrame-b-hat-b in Table 9. Overlapping of the stringer web and crown (top) by the frame flanges are designated by pFrame-b-hat-w and pFrame-b-hat-t in Table 9. Appropriate offsets of these elements have been included in Table 9.

GROUP SPEEDS

The group velocities[15] were computed for each of the composite cylinder finite element model components. The group velocities are summarized in Tables 12-14.

Acoustic Cavity

The group velocity of the fluid in the acoustic cavity c_g equals the speed of sound c in the enclosure

$$c_g = c$$

Beams

The flexural group velocity is given by

$$c_{gf_x} = \sqrt[4]{\frac{16EI_{yy}\omega^2}{\rho A}}$$

$$c_{gf_y} = \sqrt[4]{\frac{16EI_{xx}\omega^2}{\rho A}}$$

where E is the modulus of elasticity, I_{yy} and I_{xx} are the cross-section second moments of inertia, ω is the rotational frequency, ρ is the mass density and A is the cross-sectional area.

The longitudinal group velocity is defined by

$$c_{gl} = \sqrt{\frac{E}{\rho}}$$

and the torsional group velocity is

$$c_{gt} = \sqrt{\frac{GJ}{\rho I_p}}$$

where G is the shear modulus, J is the torsional moment rigidity, and I_p is the polar moment of inertia, which is the sum of the second moments of the cross-section area about the x- and y-axes. The longitudinal and torsional group velocities are listed in Table 12.

Isotropic plates

The bending stiffness of an isotropic plate is defined by

$$D = \frac{Eh^3}{12(1-\nu^2)}$$

where h is the thickness of the plate and ν is Poisson Ratio.

The flexural group velocity is defined by

$$c_{gf} = \sqrt[4]{\frac{16D\omega^2}{\rho h}}$$

where D is the bending stiffness.

The longitudinal group velocity is given by

$$c_{gl} = \sqrt{\frac{E}{\rho(1-\nu^2)}}$$

The shear modulus for linear elastic materials is

$$G = \frac{E}{2(1+\nu)}$$

and the shear group velocity is defined by

$$c_{gs} = \sqrt{\frac{G}{\rho}}$$

The longitudinal and shear group velocities are listed in Table 13.

Orthotropic plates

The bending stiffness in two orthogonal directions x and y is given by

$$D_x = \frac{E_x h^3}{12(1-\nu_x \nu_y)}$$

and

$$D_y = \frac{E_y h^3}{12(1-\nu_x \nu_y)}$$

The effective torsional stiffness can be written as[16]

$$D_{xy} = \nu_y D_x + \frac{Gh^3}{12}$$

where ν_x and ν_y are the Poisson Ratios in two perpendicular directions.

The equivalent flexural group velocity is given by

$$c_{gf} = \sqrt[4]{\frac{16 D_{xy} \omega^2}{\rho h}}$$

Cylinder Shell

The ring frequency f_r is the frequency at which the longitudinal wavelength in the skin material is equal to the cylinder circumference

$$f_r = \frac{c_{gl}}{\pi d}$$

where c_{gl} is the longitudinal wave speed in the skin material and d is the cylinder diameter. The ring frequency for the composite cylinder shell was calculated to be 1234 Hz.

In the low frequencies, below half the ring frequency, the curvature of the cylinder shell affects the stiffness of the shell and thus the bending group speed.[17] Near the ring frequency and above the cylindrical shell responds like an equivalent flat plate.

For the low frequency range $f < 0.5f_r$ the bending group speed is defined as[17]

$$c_{gc} = \sqrt[4]{\frac{f_r}{f}}\, c_{gf}$$

In the transition frequency range $0.5f_r < f < 0.8f_r$ the bending group speed is written as

$$c_{gc} = \sqrt{\frac{f_r}{f}}\, \frac{c_{gf}}{\sqrt[4]{2}}$$

In the high frequency range $f > 0.8f_r$ the bending group speed of the cylinder shell equals the bending group speed of an equivalent flat plate

$$c_{gc} = c_{gf}$$

The calculated flexural group velocities of the composite cylinder shell are listed in Table 14.

CONCLUSIONS

A baseline coarse finite element model of the composite cylinder structural components, a coarse finite element model of the acoustic cavities above and below the beam-supported plywood floor, and two dense finite element models consisting of only the structural components were developed. The geometry, the element properties, the material and mechanical properties, the beam cross-section characteristics, the beam element representations and the boundary conditions of the composite cylinder models were summarized. The group speeds for the cylinder components were calculated and tabulated.

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TABLES

Table 1. Element property sets in the coarse model database CC_baseline.db.

CC_baseline.db Description	Property Group	Element Property	Element numbers start	end	Material	Type	Offset [m]
Cylinder shell	19	Cyl	300000	301333	9PlyT500-tape	composite	
Floor	15	Floor	350000	350347	Plywood	isotropic	
Floor beams	1	Floor-beam	400000	400059	Al-6061	isotropic	0. -0.0138 -0.03818
Floor supports 1	13	Floor-support1	450000	450039	Al-6061	isotropic	0. -0.0138 0.00000
Floor supports 2	14	Floor-support2			Al-6061	isotropic	0. -0.0138 0.00000
Stringers	4	String-hat-t	100000	100637	Hat-t	composite	0. 0.0156 0.00000
Frame 1	2	Frame-J-t-1	200000	200045	J-t	composite	0. 0.0144 -0.0070
Frame 2	3	Frame-J-t-2	200046	200091	J-t	composite	0. 0.0144 -0.0070
Frame 3	5	Frame-J-t-3	200092	200137	J-t	composite	0. 0.0144 -0.0070
Frame 4	6	Frame-J-t-4	200138	200183	J-t	composite	0. 0.0144 -0.0070
Frame 5	7	Frame-J-t-5	200184	200229	J-t	composite	0. 0.0144 -0.0070
Frame 6	8	Frame-J-t-6	200230	200275	J-t	composite	0. 0.0144 -0.0070
Frame 7	9	Frame-J-t-7	200276	200321	J-t	composite	0. 0.0144 -0.0070
Frame 8	10	Frame-J-t-8	200322	200367	J-t	composite	0. 0.0144 -0.0070
Frame 9	11	Frame-J-t-9	200368	200413	J-t	composite	0. 0.0144 -0.0070
Frame 10	12	Frame-J-t-10	200414	200459	J-t	composite	0. 0.0144 -0.0070
Endcap at origin		Endzero	500000	500279	MDF-support	isotropic	
Both endcaps	17	Endcaps	500000	500559	MDF-support	isotropic	

Table 2. Number of elements, element type, mass and volume of the finite element groups in CC_baseline.db.

CC_baseline.db	Total	Cylinder	Floor	Beams	Supports	Stringers	Frames	Endcaps
# Elements	3470	1334	348	60	40	638	460	560
Element type		Quad	Quad	Beam	Beam	Beam	Beam	Quad
Mass [kg]	606.5	52.01	51.79	11.04	5.04	16.91	15.44	454.12
Volume [m3]	0.7541	0.0328	0.0728	0.00409	0.00187	0.0107	0.0098	0.6221

Table 3. Mechanical material properties in the Composite cylinder finite element models.

Mechanical material properties		E11 [GPa]	E22 [GPa]	G12 [GPa]	ρ [kg/m3]	v12	v21
Thornel Carbon Fiber T-500 6k	Tape	151.0	8.96	5.14	1590	0.30	
	Fabric	70.0	70.0	5.52	1570	0.30	
Cylinder shell 9PlyT500-tape	Composite	40.6	32.4	32.2	1590	0.629	0.502
Ring frame 'J' stiffener	Composite	72.7	28.8	18.3	1574.33	0.753	0.298
Hexcel AS4/3501-6 Carbon Epoxy	Tape	142	10.3	7.2	1580	0.27	
Longitudinal 'Hat' stringer	Composite	95.8	22.9	19.1	1590	0.588	0.141
Al-6061	Isotropic	70.0		26.0	2700	0.30	
Plywood	Isotropic	12.4		4.66	711	0.33	
MDF-support	Isotropic	2.8		1.037	730	0.35	

Table 4. Composite material lay-ups of the cylinder shell, frame and stringer laminates in the CC_baseline.db model.

Composite material lay-up		
Cyl	**J-t**	**Hat-t**
+45t	±45 f	+45t
-45 t	±45 f	-45 t
+32 t	0 t	0 t
-32 t	0 t	0 t
+90 t	0 t	-45 t
-32 t	±45 f	+45t
+32 t	±45 f	0 t
-45 t		0 t
+45t		0 t
		0 t
		0 t
		0 t
		0 t
		0 t
		+45t
		-45 t
		0 t
		0 t
		-45 t
		+45t

Table 5. Beam section properties

Property Parameter	Label		Floor Beams	Floor Supports	Longitudinal Stringers	Ring Frames
Shape			'U'	'U'	'Hat'	'J'
Area	A	[m^2]	0.0002607052	0.0002607052	0.00013166197	0.00018986402
Moments of inertia	Ixx	[m^4]	1.515540E-08	1.515540E-8	4.5194635E-09	7.9322298E-08
	Iyy	[m^4]	1.531684E-07	1.531684E-7	2.1154399E-08	1.2501204E-08
	Ixy	[m^4]	1.039455E-14	1.039455E-14	5.0473680E-16	1.1278424E-08
Torsional constant	J	[m^4]	4.96766E-10	4.96766E-10	6.08348710E-09	2.4960856E-10
Shear stiffness factors	K1		0.2574783	0.2574783	0.2609327	0.3591745
	K2		0.4953249	0.4953249	0.4140227	0.4492481
Distance centroid	horizontal	[m]	0.01378559	0.01378559	-0.007624588	0.008786919
to shear center	vertical	[m]	-1.318182E-08	-1.318182E-8	-2.855553E-7	0.007008278
Distance centroid	horizontal	[m]	0.031750008	0.031750008	0.0254	0.018485796
to origin	vertical	[m]	0.0065278504	0.0065278504	0.0071508703	0.020603789
Distance shear center	horizontal	[m]	0.031750023	0.031750023	0.025400285	0.0096988771
to origin	vertical	[m]	-0.0072577382	-0.0072577382	0.014775459	0.0135955100
Offset	x	[m]	0.0	0.0	0.0	0.0
Offset	y	[m]	-0.0137856	0.0	0.01562641	0.01444645
Offset	z	[m]	-0.03175	0.0	0.0	-0.0070082787

Table 6. Element property sets for the acoustic cavities above and below the floor in the CC_acoustic.db model (air mass density=1.21 kg/m^3; air speed of sound=343 m/s).

CC_acoustic.db Description	Property Group	Element Property	Element Numbers		Total Elements	Material	Type
			start	end			
Top acoustic space	22	Acous-top	600000	603073	3074	air	fluid
Bottom acoustic space	21	Acous-bottom	603074	605451	2378	air	fluid

Table 7. Element property sets in the dense model database CC_dense.db

CC_dense.db Description	Element Property	Element numbers		Total Elements	Material	Type	Offset [m]
		start	end	total			
Cylinder shell	Cyl	300000	337399	37400	9PlyT500-tape	composite	
Floor	Floor	350000	360199	10200	Plywood	isotropic	
Floor beams	Floor-beam	400000	400599	600	Al-6061	isotropic	0. -0.0138 -0.03818
Floor supports	Floor-support	450000	450239	240	Al-6061	isotropic	0. -0.0138 0.00000
Stringers	Stringer-hat-t	100000	103739	3740	Hat-t	composite	0. -0.0138 0.00000
Frame 1	Frame-J-t-1	200000	200219	220	J-t	composite	0. 0.0156 0.00000
Frame 2	Frame-J-t-2	200220	200439	220	J-t	composite	0. 0.0144 -0.0070
Frame 3	Frame-J-t-3	200440	200659	220	J-t	composite	0. 0.0144 -0.0070
Frame 4	Frame-J-t-4	200660	200879	220	J-t	composite	0. 0.0144 -0.0070
Frame 5	Frame-J-t-5	200880	201099	220	J-t	composite	0. 0.0144 -0.0070
Frame 6	Frame-J-t-6	201100	201319	220	J-t	composite	0. 0.0144 -0.0070
Frame 7	Frame-J-t-7	201320	201539	220	J-t	composite	0. 0.0144 -0.0070
Frame 8	Frame-J-t-8	201540	201759	220	J-t	composite	0. 0.0144 -0.0070
Frame 9	Frame-J-t-9	201760	201979	220	J-t	composite	0. 0.0144 -0.0070
Frame 10	Frame-J-t-10	201980	202199	220	J-t	composite	0. 0.0144 -0.0070
Endcap at origin	Endzero	500000	511263	11264	MDF-support	isotropic	
Both endcaps	Endcaps	500000	522527	22528	MDF-support	isotropic	

Table 8. Number of elements, element type, mass and volume of the finite element groups in the dense model.

CC_dense.db	Total	Cylinder	Floor	Beams	Supports	Stringers	Frames	Endcaps
# Elements	76908	37400	10200	560	240	3740	2200	22528
Element type		Quad	Quad	Beam	Beam	Beam	Beam	Hex
Mass [kg]	606.92	51.80	51.77	11.03	5.04	16.74	15.78	454.76
Volume [m3]	0.7537	0.0325	0.0728	0.00409	0.00187	0.0106	0.01	0.623

Table 9. Element property sets in the dense model database (CC_dense_plate.db) which employs plate elements for the ring frames and longitudinal stringers

CC_dense_plate.db Description	Element Property	Element numbers start	end	Total Elements total	Material	Offset
Cylinder shell	Cyl	300000	337399	37400	9PlyT500-tape	
Floor	Floor	350000	360019	10020	Plywood	
Floor beams	Floor-beam	400000	400619	620	Al-6061	
Floor supports	Floor-support	450000	450259	260	Al-6061	
Stringer base	pString-Hat-b	100000	107479	7480	cHat-b	0.001433
Stringer web	pString-Hat-w	120000	127479	7480	cHat-w	0.001433
Stringer top	pString-Hat-t	140000	143739	3740	cHat-t	0.001982
Frame base	pFrame-b	200000	202639	2640	cJ-b	0.001665
Frame base on stringer base	pFrame-b-hat-b	210000	210879	880	cJ-b	0.002490
Frame base on stringer web	pFrame-b-hat-w	220000	220879	880	cJ-b	0.002490
Frame base on stringer top	pFrame-b-Hat-t	230000	230439	440	cJ-b	0.003040
Frame web	pFrame-w	240000	245839	5840	cJ-w	0.001665
Frame top	pFrame-t	250000	251999	2000	cJ-t	0.001558
Endcap at origin	Endzero	500000	511263	11264	MDF-support	
Both endcaps	Endcaps	500000	522527	22528	MDF-support	

Table 10. Finite element groups in the dense model with the frames and stringers modeled with plate elements.

CC_dense_plate.db	Total	Cylinder	Floor	Beams	Supports	Stringers	Frames	Endcaps
# Elements	102208	37400	10020	620	260	18700	12680	22528
Element type		Quad	Quad	Beam	Beam	Quad	Quad	Hex
Mass [kg]	601.37	51.80	50.95	11.03	5.05	13.57	14.21	454.76
Volume [m3]	0.753	0.0326	0.0717	0.00409	0.00187	0.00859	0.00901	0.623

Table 11. Composite material lay-ups of the cylinder shell, frame and stringer laminates in the CC_dense_plate model.

Composite material lay-up						
Cyl	**cJ-b**	**cJ-w**	**cJ-t**	**cHat-b**	**cHat-w**	**cHat-t**
+45t	±45 f	±45 f	±45 f	+45t	+45t	+45t
-45 t	±45 f	±45 f	±45 f	-45 t	-45 t	-45 t
+32 t	0 t	±45 f	0 t	0 t	0 t	0 t
-32 t	0 t	±45 f	0 t	0 t	0 t	0 t
+90 t	0 t		0 t	-45 t	-45 t	-45 t
-32 t	0 t		±45 f	+45t	+45t	+45t
+32 t	±45 f		±45 f	+45t	+45t	0 t
-45 t	±45 f			-45 t	-45 t	0 t
+45t				0 t	0 t	0 t
				0 t	0 t	0 t
				-45 t	-45 t	0 t
				+45t	+45t	0 t
						0 t
						0 t
						+45t
						-45 t
						0 t
						0 t
						-45 t
						+45t

Table 12. Longitudinal and torsional group speeds for the composite cylinder beam element components

	Stringer	Frame	Floor beam
	Group speed [m/s]		
Longitudinal	7762	6796	5092
Torsional	297	169	172

Table 13. Longitudinal and shear group speeds for the composite cylinder plate element components

	Cylinder shell	Floor	Endcaps
	Group speed [m/s]		
Longitudinal	6500	4423.98	2091
Shear	4501	2560.56	1191.87

Table 14. Flexural group speeds for the composite cylinder components

One-third octave band [Hz]	Cylinder shell	Floor	Endcaps	Stringer	Frame	Floor beam
	Flexural group speeds [m/s]					
100	164.58	201.90	367.22	496.63	370.14	556.63
125	174.02	225.73	410.56	555.25	413.83	622.33
160	185.09	255.38	464.50	628.20	468.20	704.09
200	195.71	285.53	519.32	702.34	523.46	787.19
250	206.94	319.23	580.62	785.24	585.25	880.11
315	219.25	358.33	651.75	881.43	656.94	987.92
400	232.74	403.80	734.43	993.26	740.29	1113.26
500	246.10	451.46	821.12	1110.50	827.66	1244.66
630	259.39	506.76	921.71	1246.54	929.05	1397.13
800	259.39	571.06	1038.65	1404.69	1046.92	1574.39
1000	277.66	638.46	1161.24	1570.49	1170.49	1760.22
1250	310.44	713.82	1298.31	1755.86	1308.65	1967.98
1600	351.22	807.59	1468.87	1986.53	1480.57	2226.52
2000	392.67	902.92	1642.25	2221.01	1655.33	2489.33
2500	439.02	1009.49	1836.09	2483.16	1850.71	2783.15
3150	492.80	1133.15	2061.00	2787.34	2077.42	3124.08
4000	555.32	1276.92	2322.49	3140.98	2340.99	3520.44

FIGURES

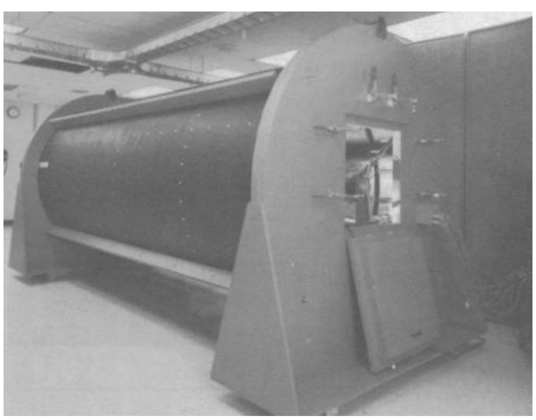

Figure 1. Composite cylinder supported by rigid endcaps showing the access door.

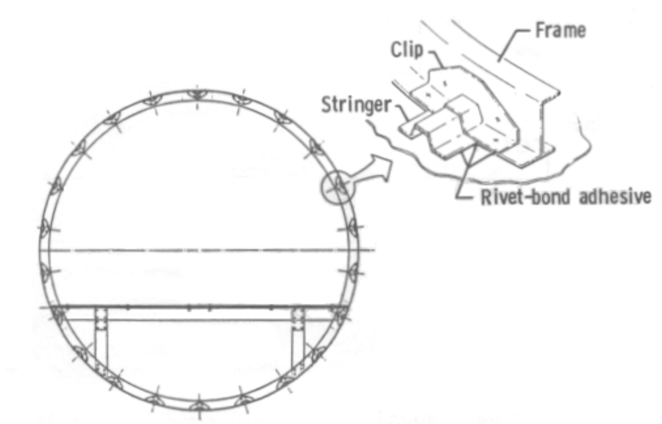

Figure 2. Cross-section of the stiffened, floor-equipped composite cylinder and a detailed view of the rivet-bonded frame-stringer-shell intersection.

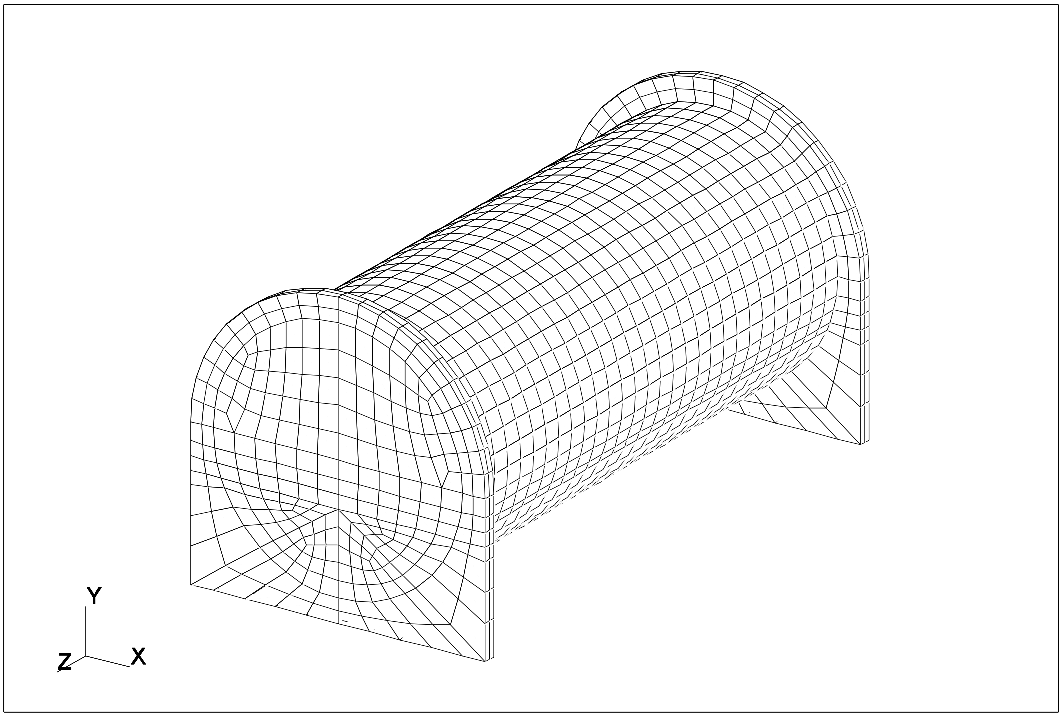

Figure 3. Hidden line isometric view of the composite cylinder finite element model (CC_baseline.db) supported by two endcaps.

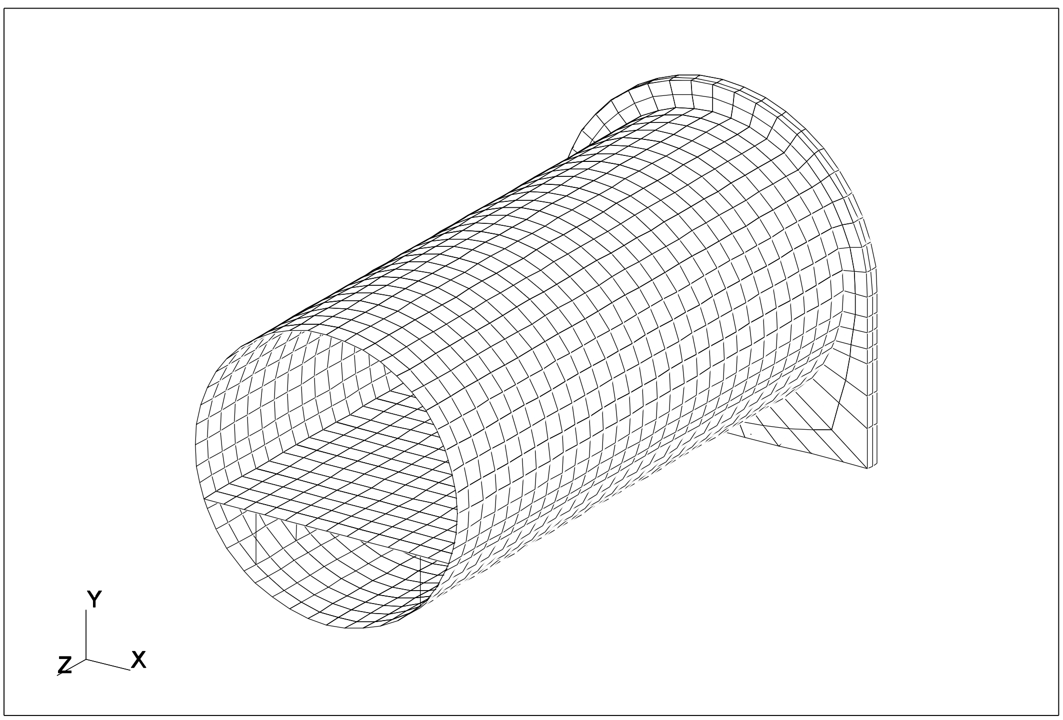

Figure 4. Hidden line isometric view of the composite cylinder finite element model (CC_baseline.db) with one endcap removed.

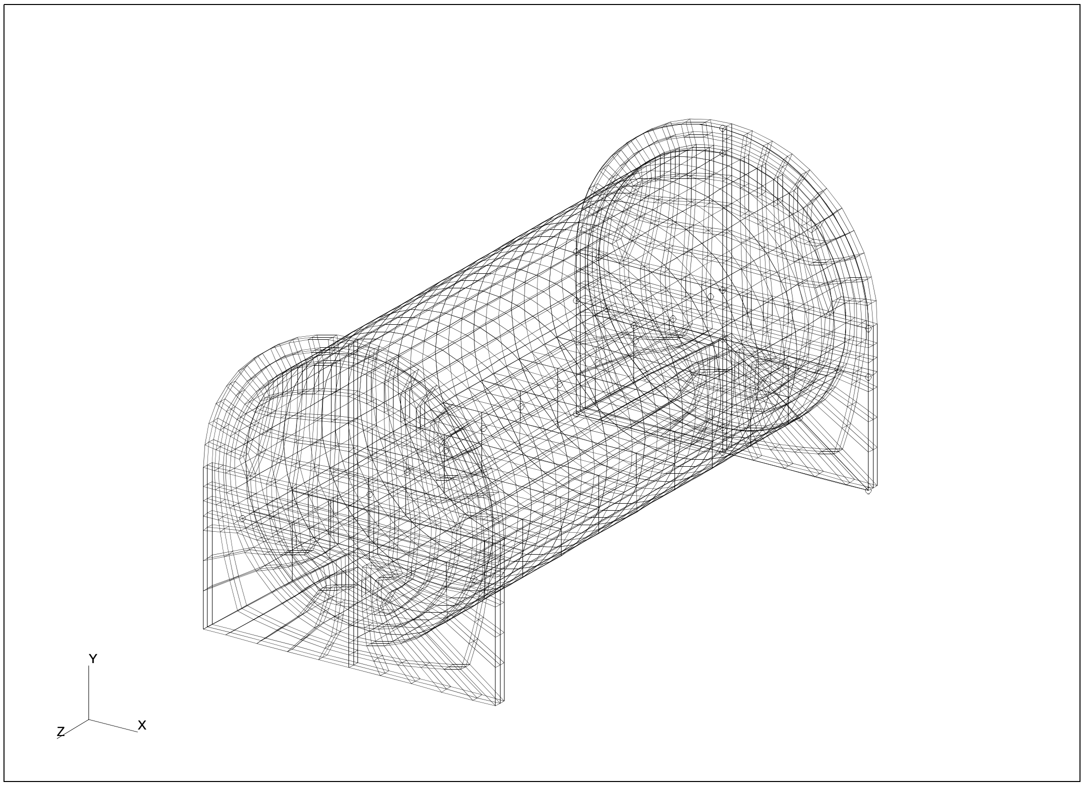

Figure 5. Wireframe isometric view of the composite cylinder finite element model (CC_baseline.db) supported by two endcaps.

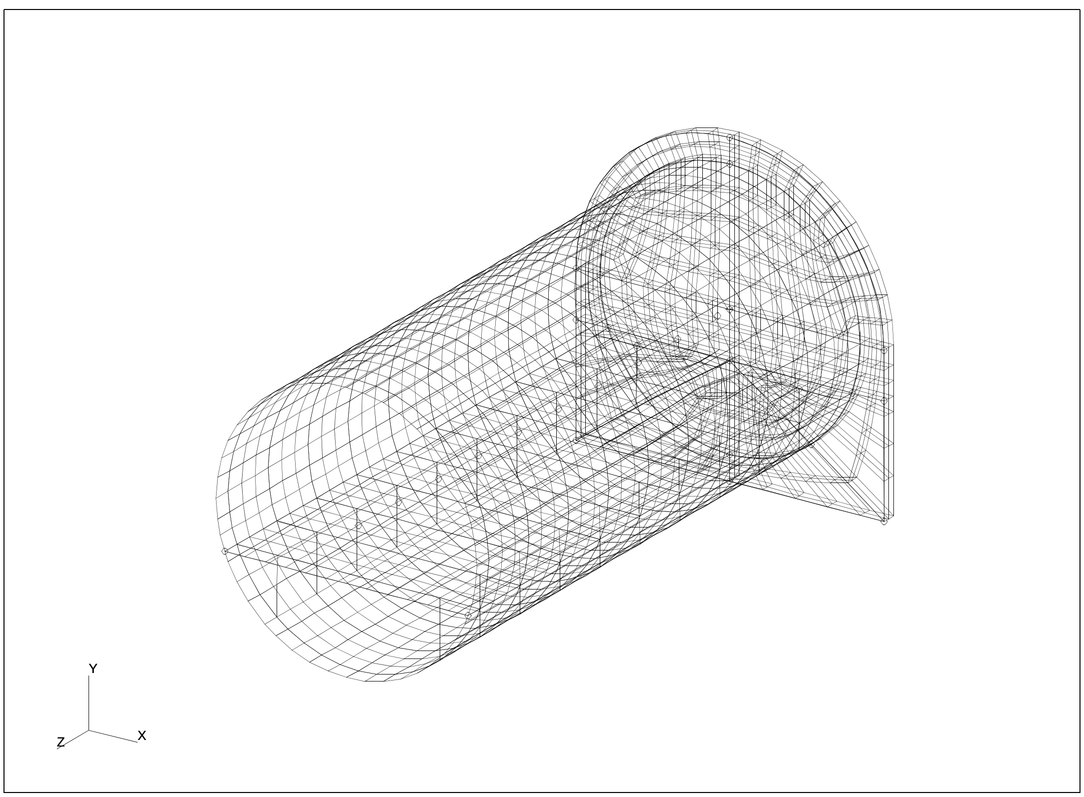

Figure 6. Wireframe isometric view of the composite cylinder finite element model (CC_baseline.db) with one endcap removed.

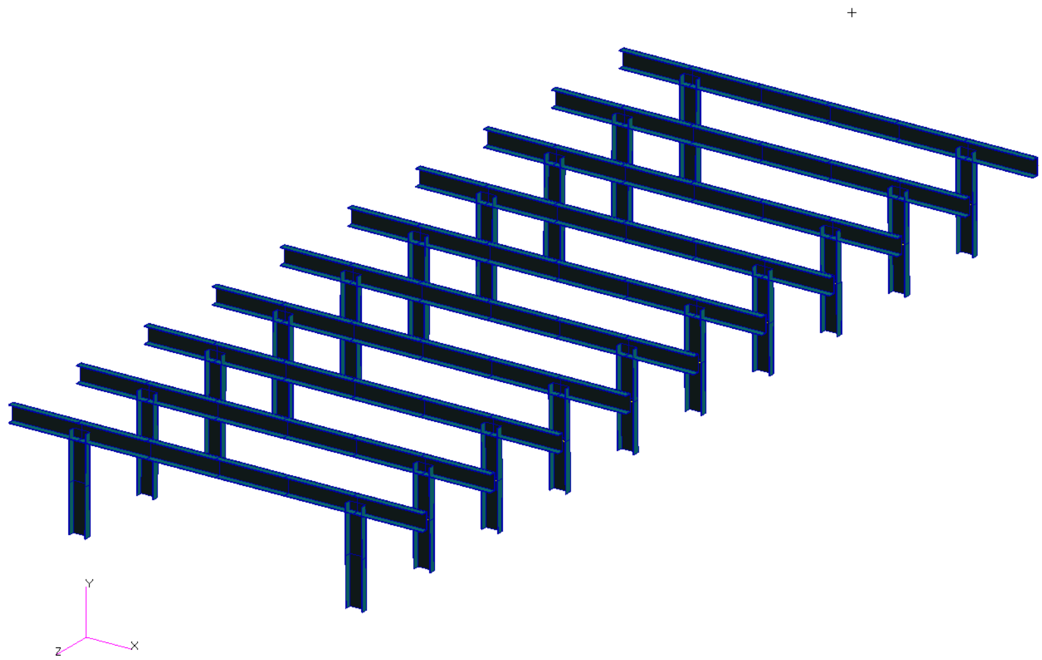

Figure 7. Isometric three-dimensional view of the horizontal floor beams and vertical floor supports.

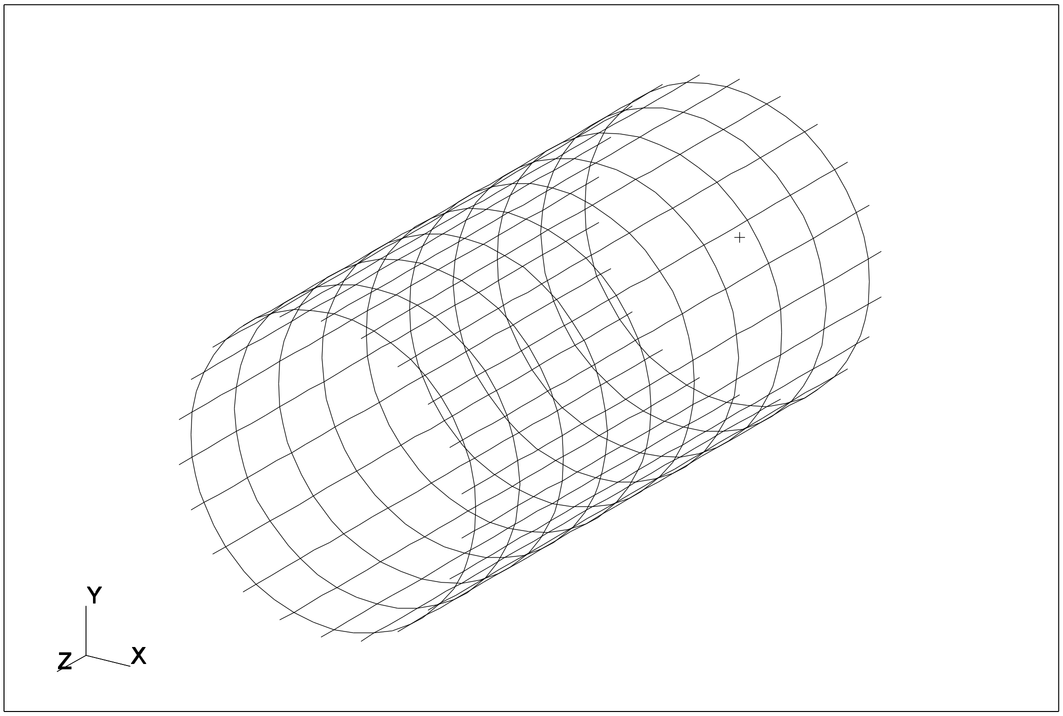

Figure 8. Isometric view of the shell ring frames and longitudinal stringers.

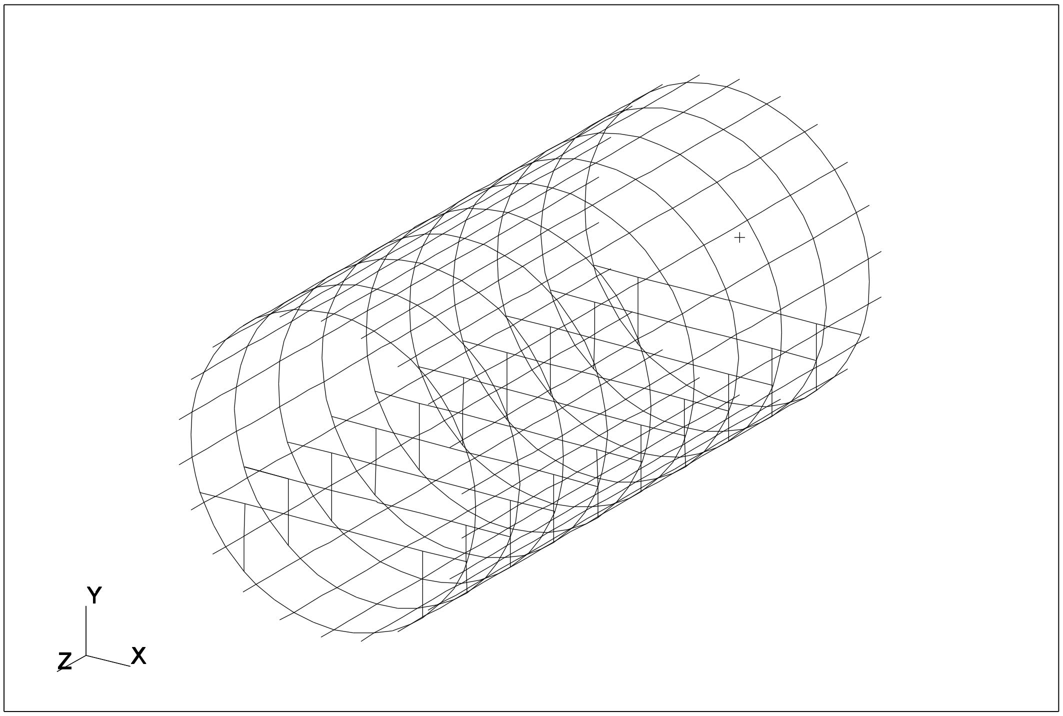

Figure 9. Isometric view of the shell circumferential and longitudinal stiffeners, and floor supporting beams.

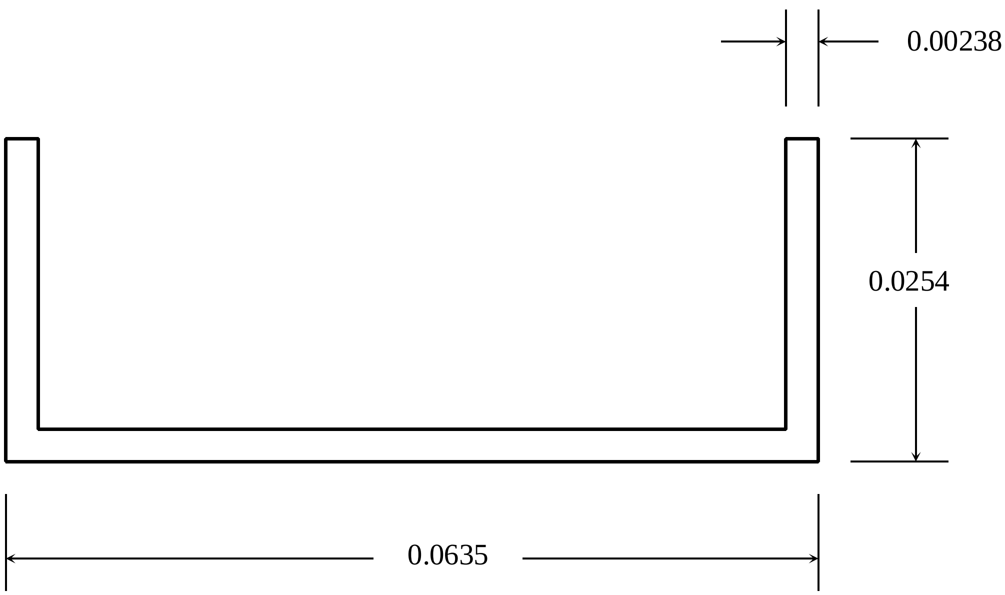

Figure 10. Cross-sectional geometry of the horizontal floor beam and vertical floor support beam elements (dimensions in m).

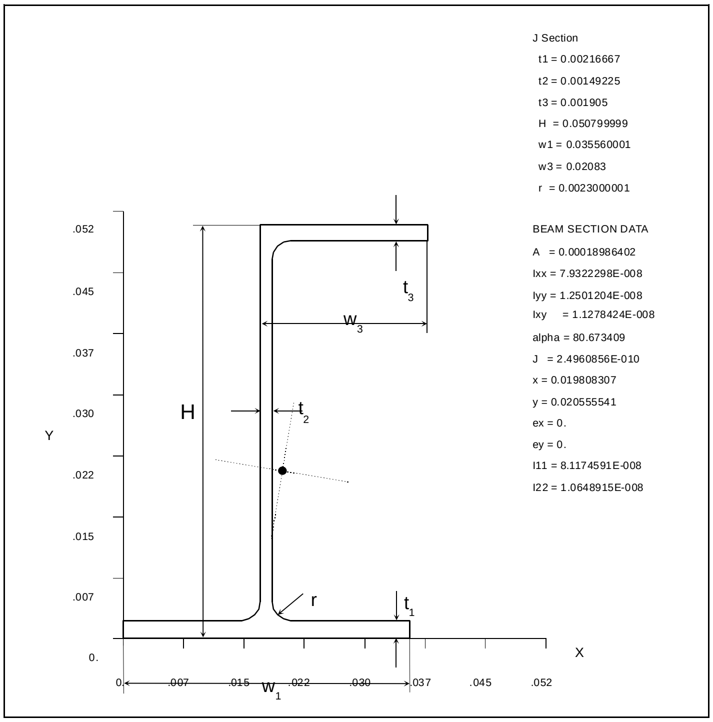

Figure 11. Cross-sectional properties of the ring frame beam elements (dimensions in m).

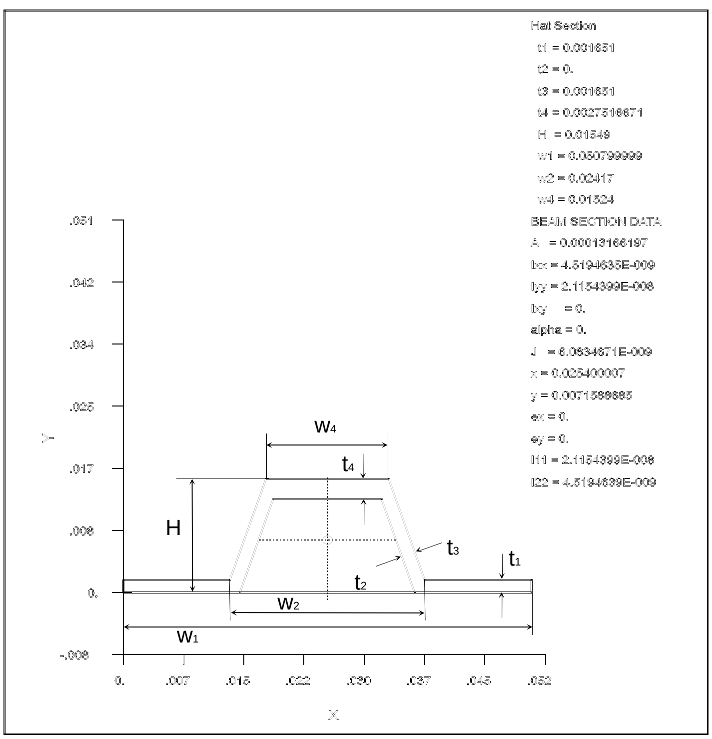

Figure 12. Cross-sectional properties of the longitudinal stringer beam elements (dimensions in m).

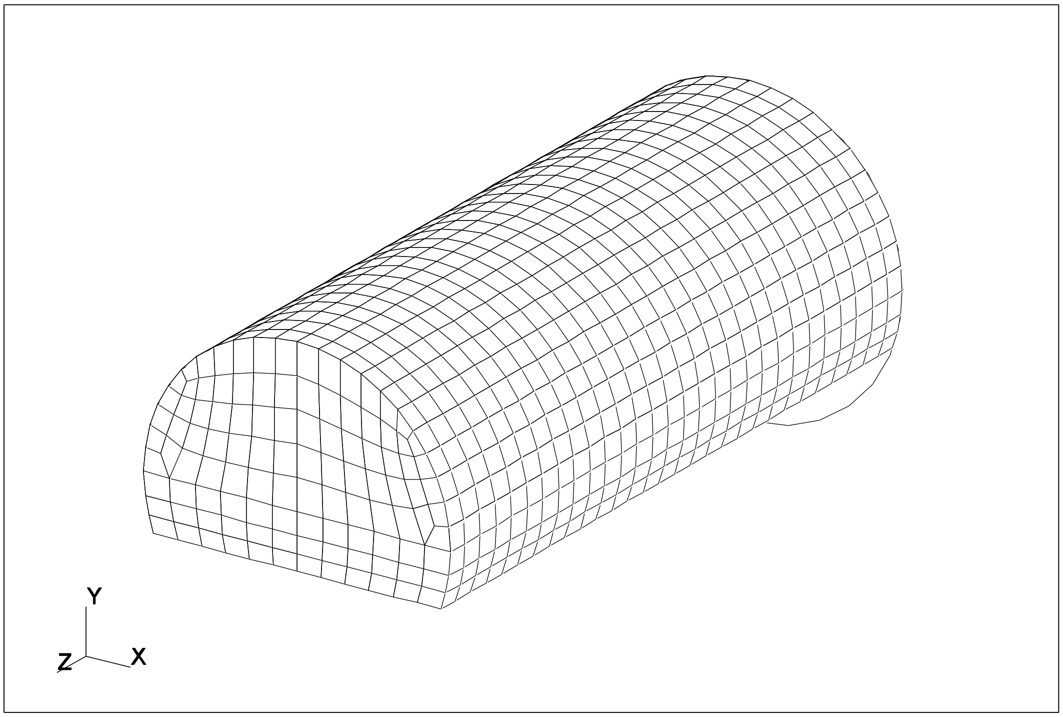

Figure 13. Hidden line isometric view of the coarse top acoustic cavity model (CC_acoustic.db).

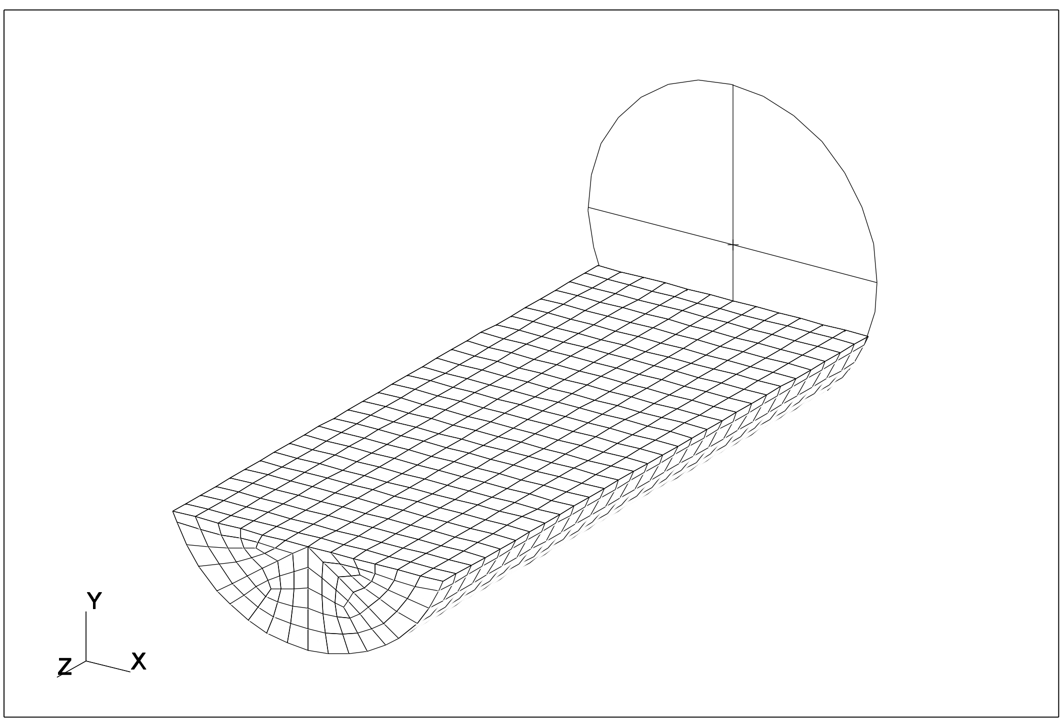

Figure 14. Hidden line isometric view of the coarse bottom acoustic cavity model (CC_acoustic.db).

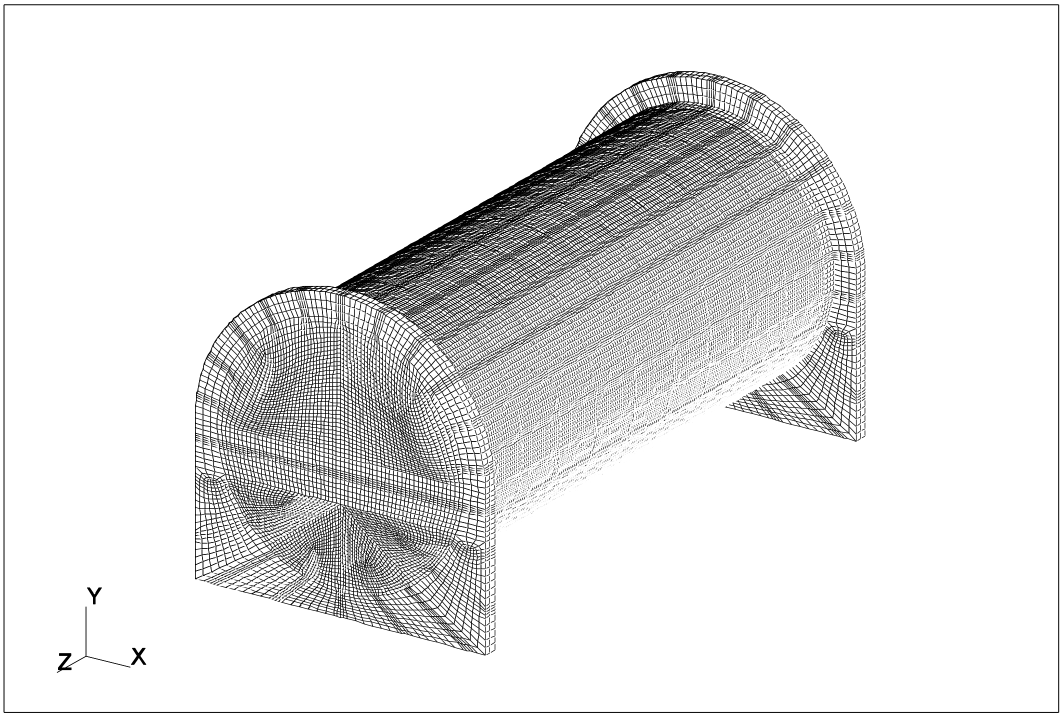

Figure 15. Hidden line isometric view of the dense composite cylinder finite element model (CC_dense.db) supported by two endcaps.

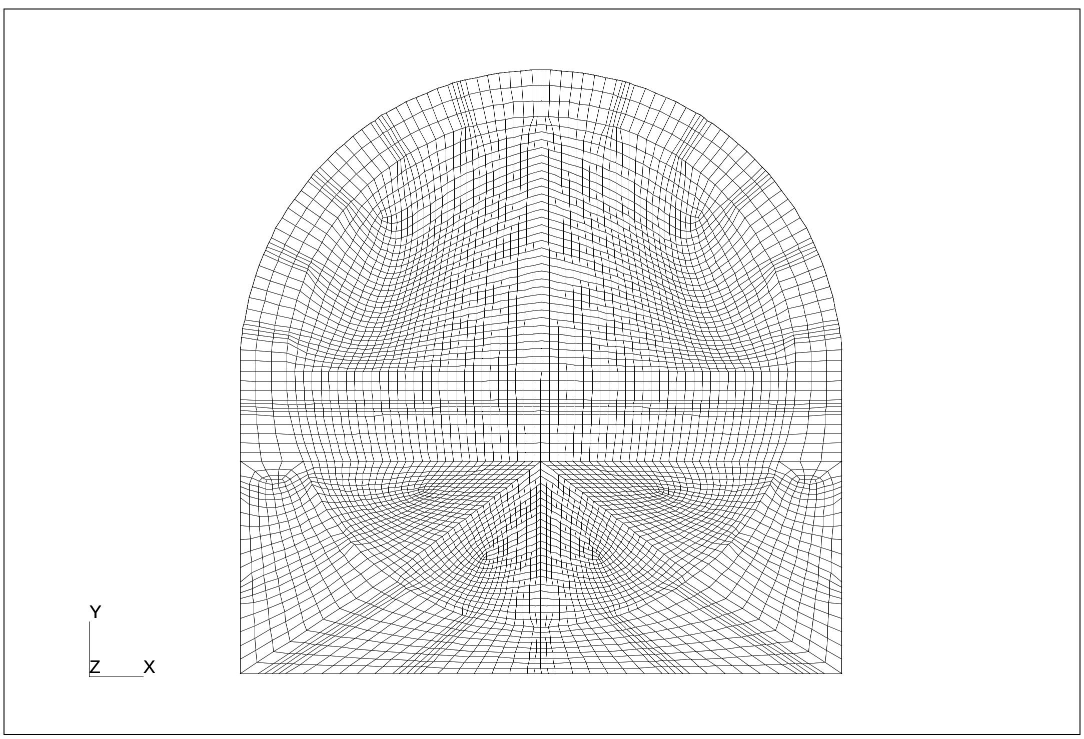

Figure 16. Hidden line front view of the dense composite cylinder finite element model (CC_dense.db).

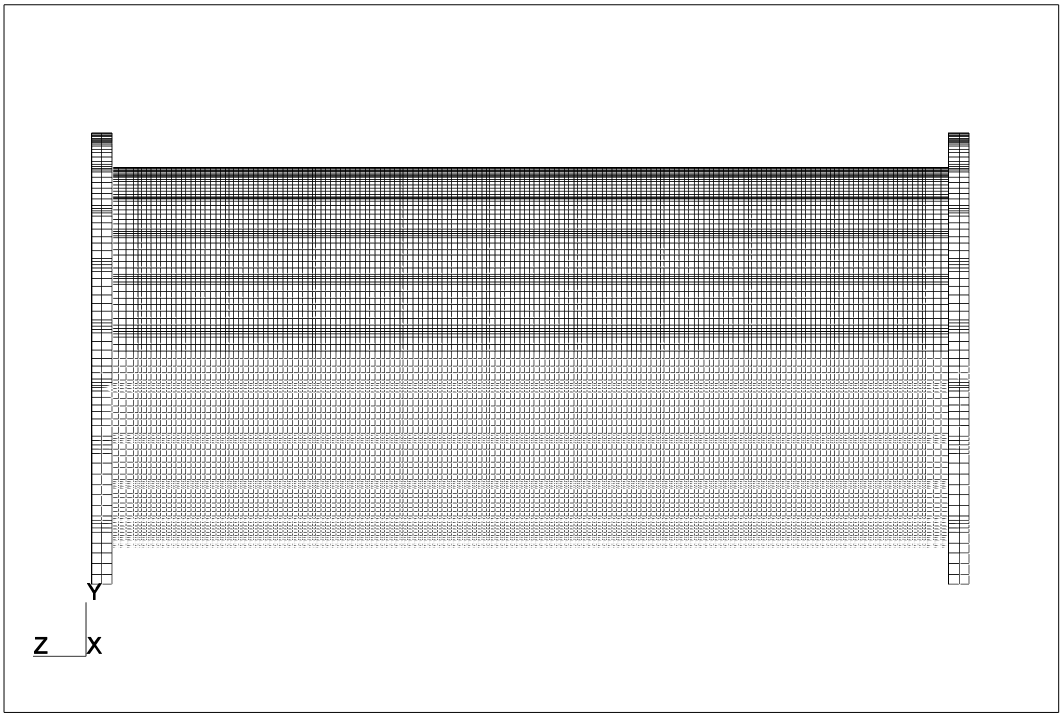

Figure 17. Hidden line side view of the dense composite cylinder finite element model (CC_dense.db).

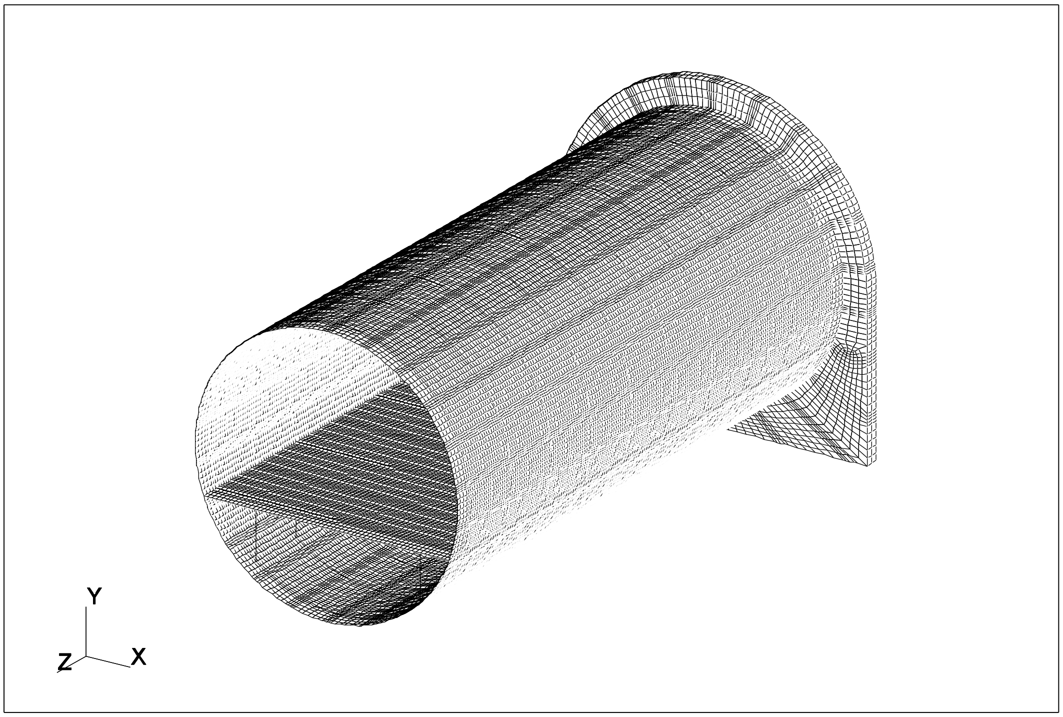

Figure 18. Hidden line isometric view of the dense composite cylinder finite element model (CC_dense.db) with one endcap removed.

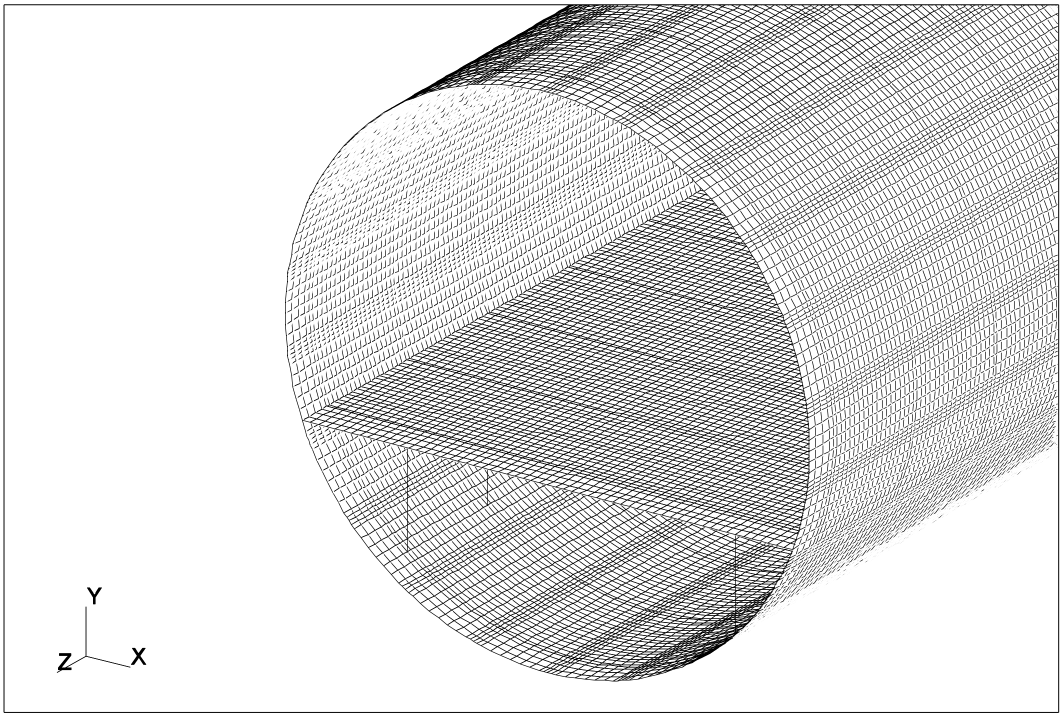

Figure 19. Detailed hidden line view of the open end of the dense composite cylinder finite element model (CC_dense.db).

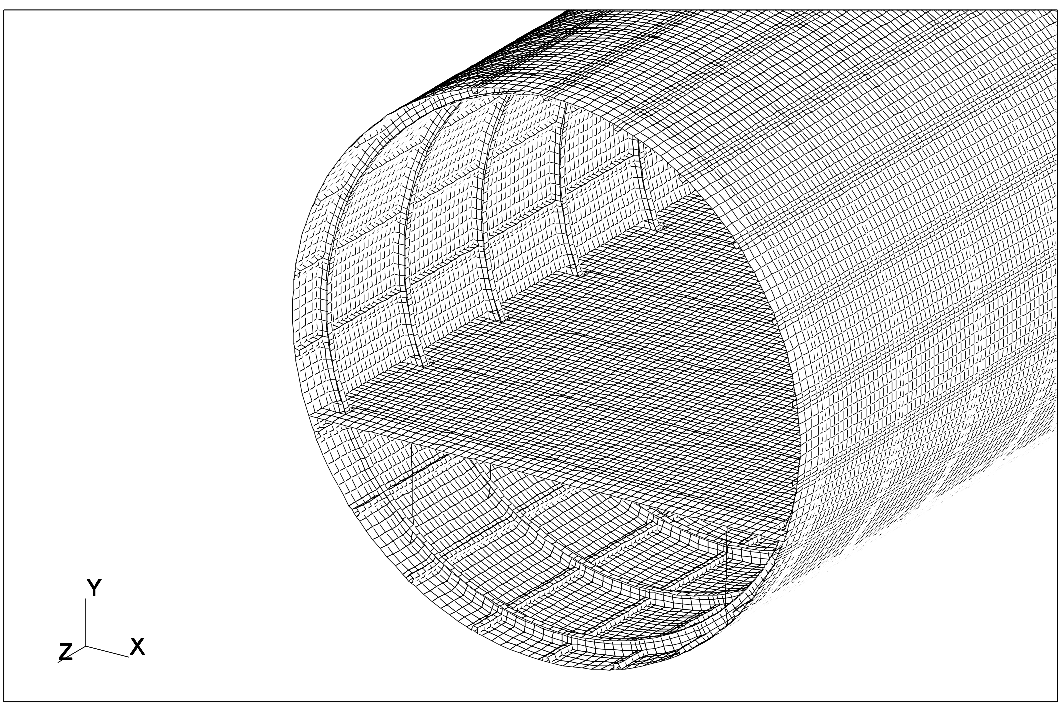

Figure 20. Detailed hidden line view of the open end of the dense composite cylinder finite element model showing the plate elements for the frames and stringers (CC_dense_plate.db).

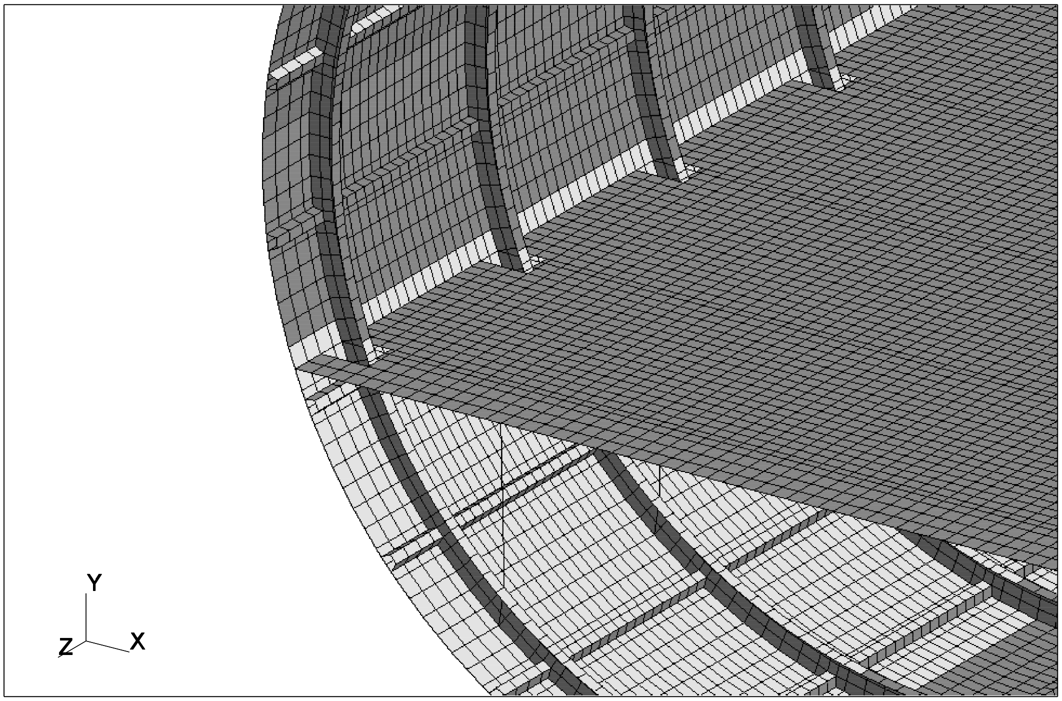

Figure 21. Rendered close-up view of the open end of the dense composite cylinder finite element model showing the plate elements for the frames and stringers (CC_dense_plate.db)

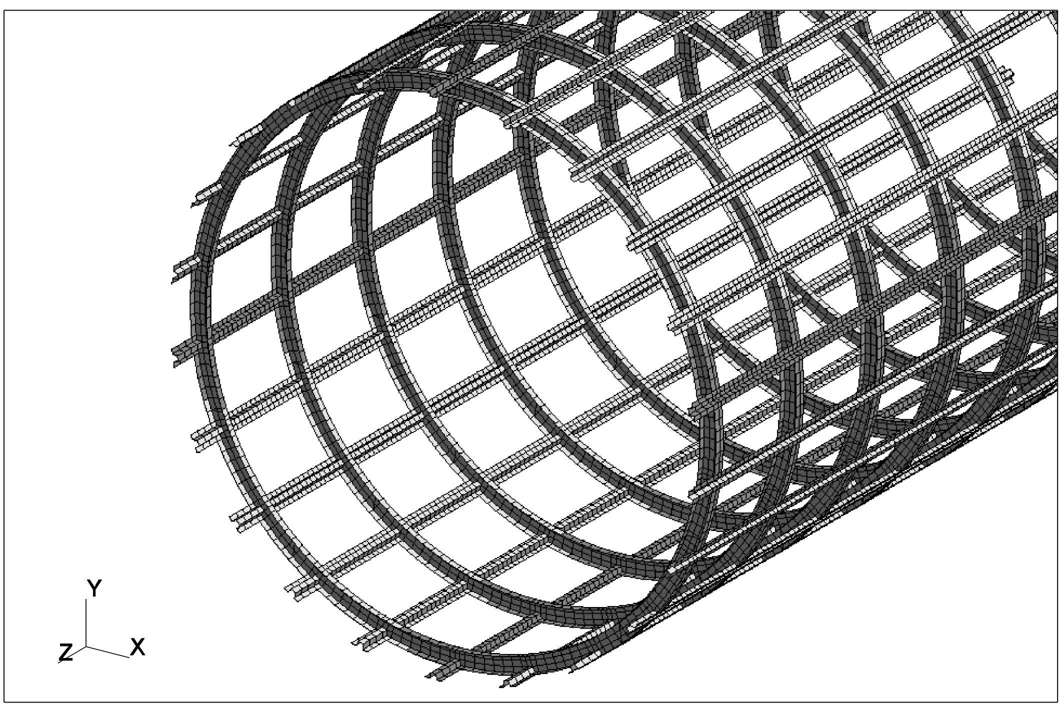

Figure 22. Rendered detailed view of the frames and stringers modeled using plate elements (CC_dense_plate.db).

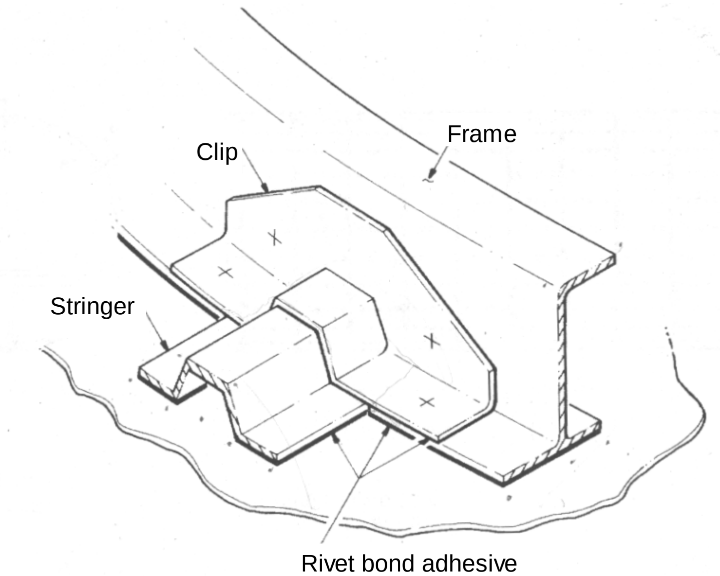

Figure 23. Intersection between longitudinal stringer and ring frame.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01- 02 - 2010

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Finite Element Models and Properties of a Stiffened Floor-Equipped Composite Cylinder

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Grosveld, Ferdinand W.; Schiller, Noah H.; Cabell, Randolph H.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
877868.02.07.07.04.01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-19814

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM-2010-216192

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 71
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Finite element models were developed of a floor-equipped, frame and stringer stiffened composite cylinder including a coarse finite element model of the structural components, a coarse finite element model of the acoustic cavities above and below the beam-supported plywood floor, and two dense models consisting of only the structural components. The report summarizes the geometry, the element properties, the material and mechanical properties, the beam cross-section characteristics, the beam element representations and the boundary conditions of the composite cylinder models. The expressions used to calculate the group speeds for the cylinder components are presented.

15. SUBJECT TERMS
Acoustics; Finite element modeling; Composite cylinders

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(Include area code)*
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