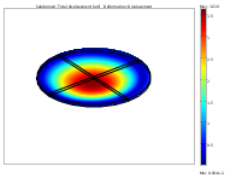
COMSOL Model Report



1. Table of Contents

2. Model Properties

Property	Value
Model name	
Author	
Company	
Department	
Reference	
URL	
Saved date	Sep 27, 2009 8:29:02 PM
Creation date	Aug 28, 2009 10:24:02 AM
COMSOL version	COMSOL 3.5.0.608

File name: /csem/divm/users/intern/ikj/COMSOL_ikj/Zernike/Shell_3.mph

Application modes and modules used in this model:

- Geom1 (3D)
  - Solid, Stress-Strain (Structural Mechanics Module)
  - Optimization

3. Constants

Name	Expression	Value	Description
T0	20[degC]		Ambient temperature
p0	1/250[atm]		Ambient pressure
G0	1[lbf/lb]		Gravity acceleration
Th0	45[deg]		tip/tilt angle
TT0	0.25[um]		tip/tilt amplitude
Z0	0.5[um]		amplitude offset
Lambda0	1[um]		Wavelength

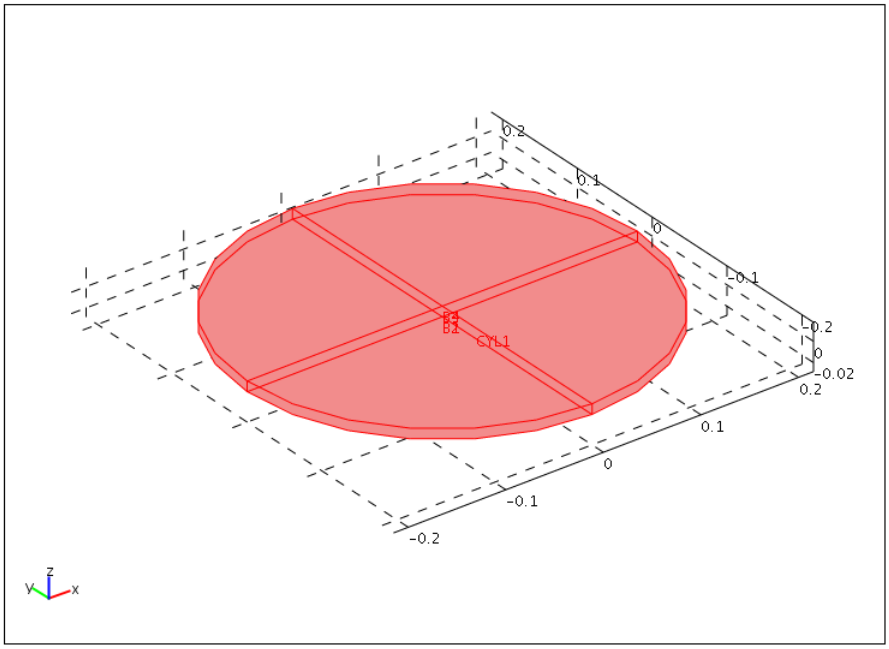
4. Global Expressions

Name	Expression
Zer2	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY+z20*Z_0FocZ+z22c*Z_1AstX+z22s*Z_1AstY+z31c*Z_1ComX+z31s*Z_1ComY+z40*Z_1SphZ+z33 ^2
Zer00	((w-(z00*Z_0PisZ))/Lambda0)^2
Zer11	((w-(z00*Z_0PisZ+z11c*Z_0TipX))/Lambda0)^2
Zer12	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY))/Lambda0)^2
Zer20	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY+z20*Z_0FocZ))/Lambda0)^2
Zer21	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY+z20*Z_0FocZ+z22c*Z_1AstX))/Lambda0)^2
Zer22	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY+z20*Z_0FocZ+z22c*Z_1AstX+z22s*Z_1AstY))/Lambda0)^2
Zer31	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY+z20*Z_0FocZ+z22c*Z_1AstX+z22s*Z_1AstY+z31c*Z_1ComX))/Lambda0)^2
Zer32	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY+z20*Z_0FocZ+z22c*Z_1AstX+z22s*Z_1AstY+z31c*Z_1ComX+z31s*Z_1ComY))/Lambda0)^2
Zer40	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY+z20*Z_0FocZ+z22c*Z_1AstX+z22s*Z_1AstY+z31c*Z_1ComX+z31s*Z_1ComY+z40*Z_1SphZ)
Zer60	((w-(z00*Z_0PisZ+z11c*Z_0TipX+z11s*Z_0TipY+z20*Z_0FocZ+z22c*Z_1AstX+z22s*Z_1AstY+z31c*Z_1ComX+z31s*Z_1ComY+z40*Z_1SphZ-

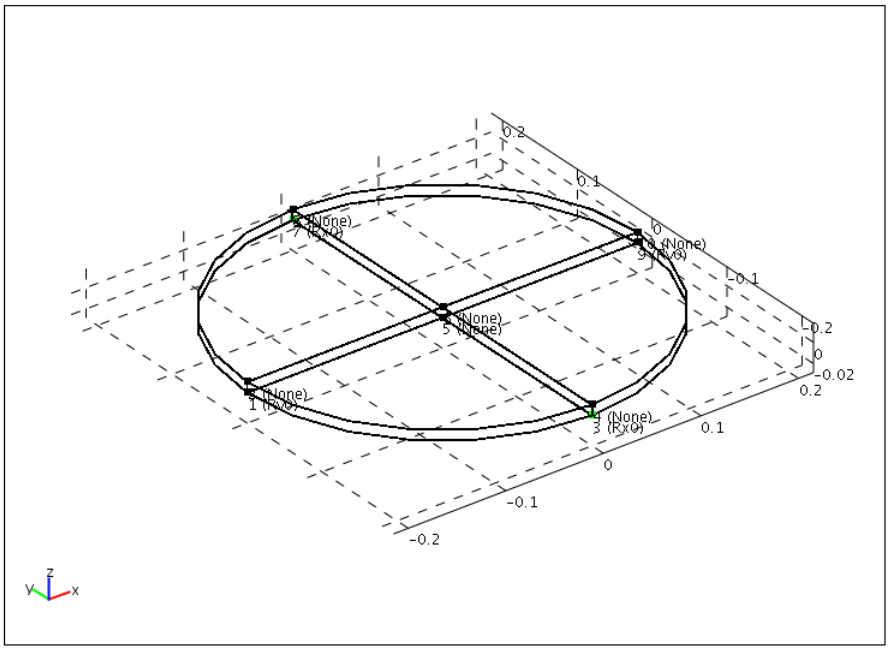
5. Geometry

Number of geometries: 1

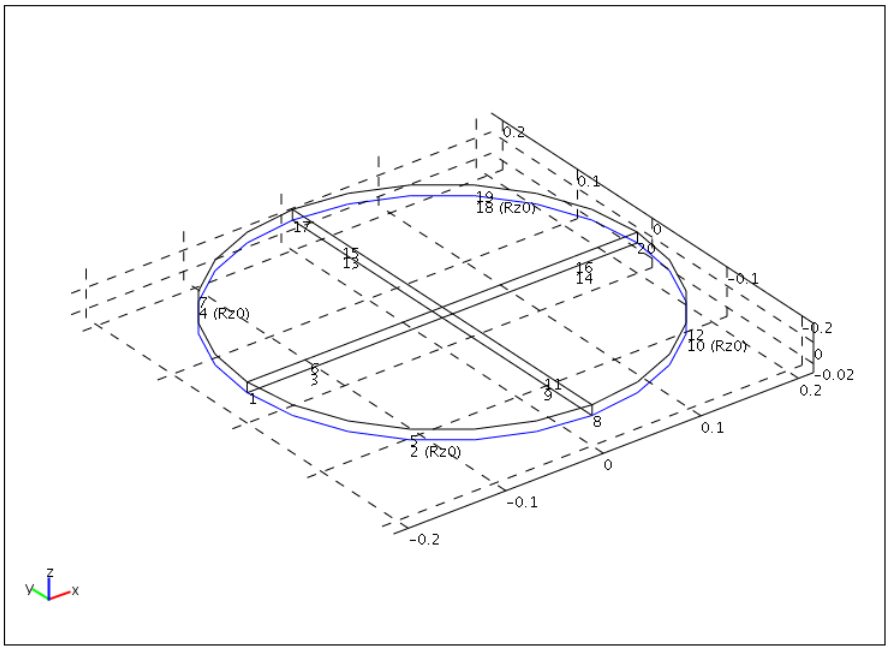
5.1. Geom1



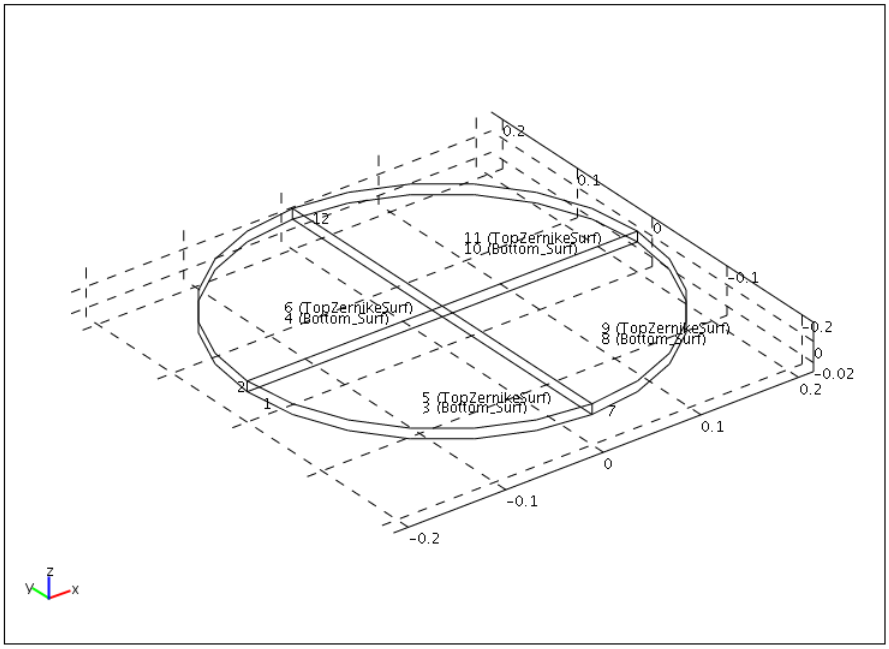
5.1.1. Point mode



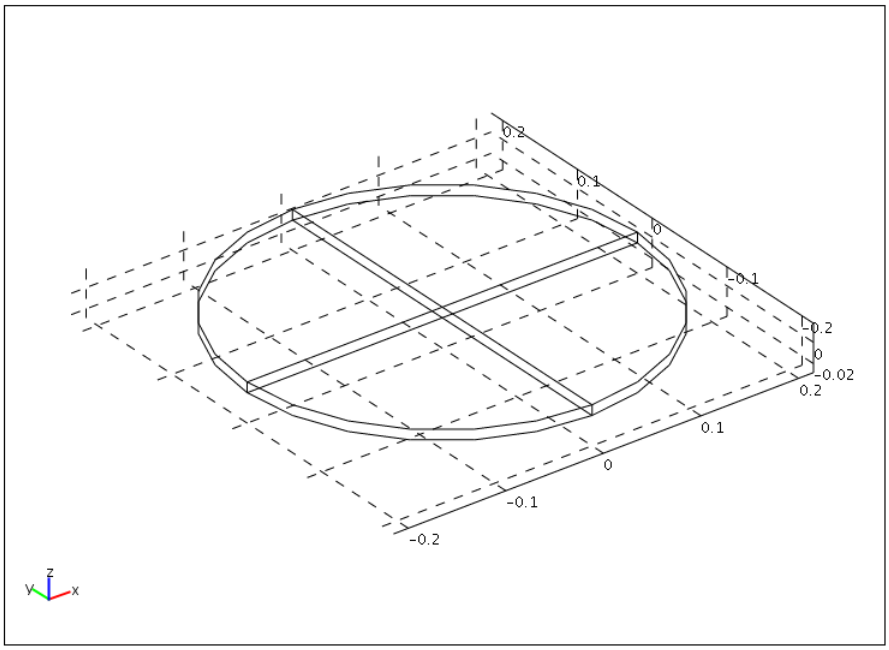
5.1.2. Edge mode



5.1.3. Boundary mode



5.1.4. Subdomain mode



6. Geom1

Space dimensions: 3D

Independent variables: x, y, z

6.1. Scalar Expressions

Name	Expression	Unit	Description
r	sqrt(x^2+y^2)	m	Radius (cylindrical coordinates) Zernike functions Ivar KJELBERG CSEM sa Septembre 2009
Theta	atan2(y,x)	rad	Theta angle cylindrical coordinates)
R0	sqrt(Area_Z/pi)		Average radius (assumed circular)
R	r/R0		Normalised radius
Z_0PisZ	1		rms Piston term (along Z) N=0 M=0 z00 (ZFR Fringe ordering hereafter CODEV rms norm on edge)
Z_0TipX	1/2*R*cos(Theta)		rms on edge (Code 5) Tip_X term (Theta_Y) 1 -1 z11c (rms on surface as per ZEMAX *(N+1) (M=0))
Z_0TipY	1/2*R*sin(Theta)		rms on edge Tilt_Y term (Theta_X) 1 1 z11s (rms on surface as per ZEMAX *2*(N+1) (M><0))
Z_0FocZ	1/sqrt(3)*(2*R^2-1)		rms on edge Focus_Z term (F_Z) 2 0 z20
Z_1AstX	1/sqrt(6)*R^2*cos(2*Theta)		rms on edge Primary Astigmatism X 2 -2 z22c
Z_1AstY	1/sqrt(6)*R^2*sin(2*Theta)		rms on edge Primary Astigmatism Y 2 2 z22s
Z_1ComX	1/sqrt(8)*R*(3*R^2-2)*cos(Theta)		rms on edge Primary Coma X 3 -1 z31c
Z_1ComY	1/sqrt(8)*R*(3*R^2-2)*sin(Theta)		rms on edge Primary Coma Y 3 1 z31s
Z_1SphZ	1/sqrt(5)*(R^2*(6*(R^2-1))+1)		rms on edge Primary Spherical 4 0 z40
Z_1TreX	1/sqrt(8)*R^3*cos(3*Theta)		rms on edge Primary Trefoil X 3 -3 z33c
Z_1TreY	1/sqrt(8)*R^3*sin(3*Theta)		rms on edge Primary Trefoil Y 3 3 z33s
Z_2AstX	1/sqrt(10)*R^2*(4*R^2-3)*cos(2*Theta)		rms on edge Secondry Astigmatism X 4 -2 z42c
Z_2AstY	1/sqrt(10)*R^2*(4*R^2-3)*sin(2*Theta)		rms on edge Secondry Astigmatism Y 4 2 z42s
Z_2ComX	1/sqrt(12)*R*(2*R^2*(5*R^2-6)+3)*cos (Theta)		rms on edge Secondry Coma X 5 -1 z51c
Z_2ComY	1/sqrt(12)*R*(2*R^2*(5*R^2-6)+3)*sin (Theta)		rms on edge Secondry Coma Y 5 1 z51s
Z_2SphZ	1/sqrt(7)*(2*R^2*(5*R^2*(2*R^2-3)+6)-1)		rms on edge Secondry Spherical 6 0 z60
Z_1TetX	1/sqrt(10)*R^4*cos(4*Theta)		rms on edge Primary Tretra X 4 -4 z44c
Z_1TetY	1/sqrt(10)*R^4*sin(4*Theta)		rms on edge Primary Tretra Y 4 4 z44s
Z_2TreX	1/sqrt(12)*R^3*(5*R^2-4)*cos(3*Theta)		rms on edge Secondry Trefoil X 5 -3 z53c
Z_2TreY	1/sqrt(12)*R^3*(5*R^2-4)*sin(3*Theta)		rms on edge Secondry Trefoil Y 5 3 z53s

6.2. Expressions

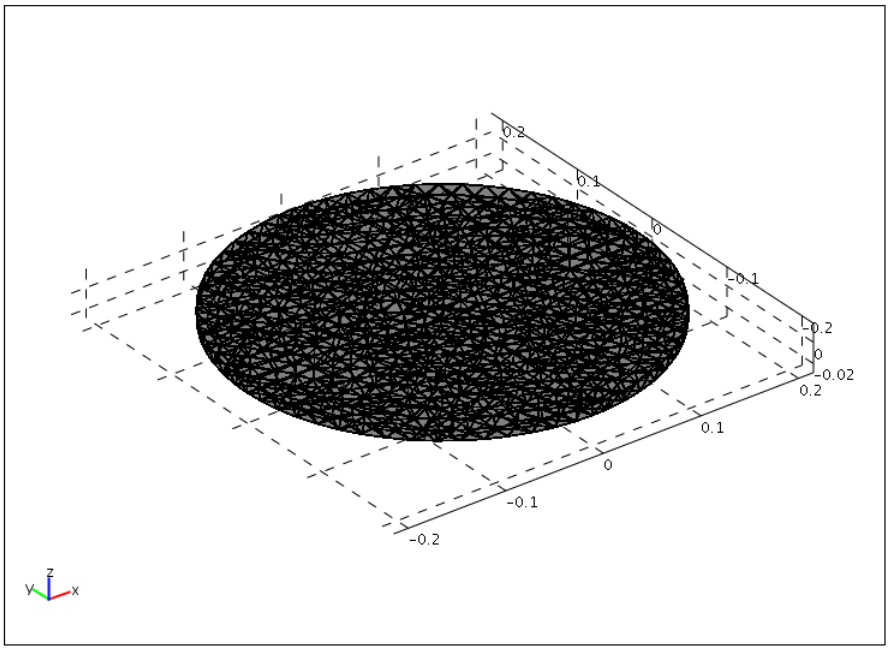
6.2.1. Subdomain Expressions

Subdomain		1
thx	1	0.5*(uz-wx)
thy	1	0.5*(uz-wx)
thz	1	0.5*(vx-uy)

6.3. Mesh

6.3.1. Mesh Statistics

Number of degrees of freedom	21062
Number of mesh points	1198
Number of elements	3424
Tetrahedral	3424
Prism	0
Hexahedral	0
Number of boundary elements	2390
Triangular	2390
Quadrilateral	0
Number of edge elements	224
Number of vertex elements	10
Minimum element quality	0.342
Element volume ratio	0.11



6.4. Application Mode: Solid, Stress-Strain (smsld)

Application mode type: Solid, Stress-Strain (Structural Mechanics Module)

Application mode name: smsld

6.4.1. Scalar Variables

Name	Variable	Value	Unit	Description
t_old_ini	t_old_ini_smsld	-1	s	Initial condition previous time step (contact with dynamic friction)
refpntx	refpntx_smsld	0	m	Reference point moment computation x coord.
refpnty	refpnty_smsld	0	m	Reference point moment computation y coord.
refpntz	refpntz_smsld	0	m	Reference point moment computation z coord.

6.4.2. Application Mode Properties

Property	Value
Default element type	Lagrange - Quadratic
Analysis type	Static
Large deformation	Off
Specify eigenvalues using	Eigenfrequency
Create frame	Off
Deform frame	Frame (ref)
Frame	Frame (ref)
Weak constraints	Off
Constraint type	Ideal

6.4.3. Variables

Dependent variables: u, v, w, p

Shape functions: shlag(2,'u'), shlag(2,'v'), shlag(2,'w')

Interior boundaries not active

6.4.4. Point Settings

Point		1, 9	2, 4-6, 8, 10	3, 7
name		**Ry0**	**None**	**Rx0**
Hx	1	0	0	**1**
Hy	1	**1**	0	0

6.4.5. Edge Settings

Edge		1, 3, 5-9, 11-17, 19-20	2, 4, 10, 18
name			**Rz0**
Constraint z-dir. (Rz)	m	0	**Z0+TT0*(sin(Theta+Th0)+cos(Theta+Th0))**
Hz	1	0	**1**

6.4.6. Boundary Settings

Boundary		1-2, 7, 12	3-4, 8, 10	5-6, 9, 11
name			**Bottom_Surf**	**TopZernikeSurf**

6.4.7. Subdomain Settings

Subdomain		1
Body load (force/volume) z-dir. (Fz)	N/m^3	**-G0*rho_smsld**

6.5. Application Mode: Optimization (opt)

Application mode type: Optimization

Application mode name: opt

6.5.1. Application Mode Properties

Property	**Value**
Default element type	Lagrange - Quadratic
Frame	Frame (ref)

6.5.2. Variables

Dependent variables:

Shape functions:

Interior boundaries not active

6.5.3. Scalar Settings

Scalar		1
Variable (dim)		**{z00;z11c;z11s;z20;z22c;z22s;z31c;z31s;z40;z33c;z33s;z42c;z42s;z51c;z51s;z60;z44c;z44s;z53c;z53s}**

Scalar initial value		1
z00		Lambda0
z11c		Lambda0
z11s		Lambda0
z20		Lambda0
z22c		Lambda0
z22s		Lambda0
z31c		Lambda0
z31s		Lambda0
z40		Lambda0
z33c		Lambda0
z33s		Lambda0
z42c		Lambda0
z42s		Lambda0
z51c		Lambda0
z51s		Lambda0
z60		Lambda0
z44c		Lambda0
z44s		Lambda0
z53c		Lambda0
z53s		Lambda0

6.5.4. Boundary Settings

Boundary		1-4, 7-8, 10, 12	5-6, 9, 11

name		**TopZernikeSurf**
Objective (obj)	0	**(Zer2)**

6.5.5. Subdomain Settings

The subdomain settings only contain default values.

7. Integration Coupling Variables

7.1. Geom1

7.1.1. Source Boundary: 5-6, 9, 11

Name	Value
Variable name	Area_Z
Expression	1
Order	4
Global	Yes

8. Solver Settings

Solve using a script: off

Analysis type	Static
Auto select solver	On
Solver	Stationary
Solution form	Automatic
Symmetric	auto
Adaptive mesh refinement	Off
Optimization/Sensitivity	Off
Plot while solving	Off

8.1. Direct (SPOOLES)

Solver type: Linear system solver

Parameter	Value
Pivot threshold	0.1
Preordering algorithm	Nested dissection

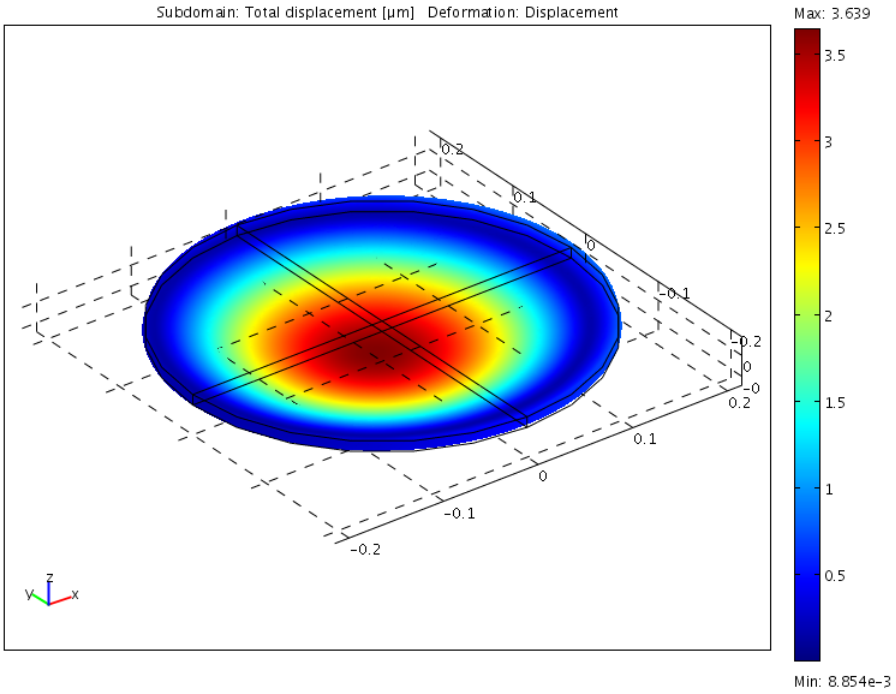
8.2. Stationary

Parameter	Value
Linearity	Automatic
Relative tolerance	1.0E-6
Maximum number of iterations	25
Manual tuning of damping parameters	Off
Highly nonlinear problem	Off
Initial damping factor	1.0
Minimum damping factor	1.0E-4
Restriction for step size update	10.0

8.3. Advanced

Parameter	Value
Constraint handling method	Elimination
Null-space function	Automatic
Automatic assembly block size	On
Assembly block size	1000
Use Hermitian transpose of constraint matrix and in symmetry detection	Off
Use complex functions with real input	Off
Stop if error due to undefined operation	On
Store solution on file	Off
Type of scaling	Automatic
Manual scaling	
Row equilibration	On
Manual control of reassembly	Off
Load constant	On
Constraint constant	On
Mass constant	On
Damping (mass) constant	On
Jacobian constant	On
Constraint Jacobian constant	On

9. Postprocessing



10. Variables

10.1. Point

Name	Description	Unit	Expression
RFx_smsld	Reaction force x-dir.	N	reacf(u)
RFy_smsld	Reaction force y-dir.	N	reacf(v)
RFz_smsld	Reaction force z-dir.	N	reacf(w)
RMxpnt_smsld	Reaction moment x-dir.	N*m	(y-refpnty_smsld) * RFz_smsld-(z-refpntz_smsld) * RFy_smsld
RMypnt_smsld	Reaction moment y-dir.	N*m	(z-refpntz_smsld) * RFx_smsld-(x-refpntx_smsld) * RFz_smsld
RMzpnt_smsld	Reaction moment z-dir.	N*m	(x-refpntx_smsld) * RFy_smsld-(y-refpnty_smsld) * RFx_smsld
Fxg_smsld	Point load in global x dir.	N	0
Fyg_smsld	Point load in global y dir.	N	0
Fzg_smsld	Point load in global z dir.	N	0
disp_smsld	Total displacement	m	sqrt(real(u)^2+real(v)^2+real(w)^2)

10.2. Edge

Name	Description	Unit	Expression
RFx_smsld	Reaction force x-dir.	N	reacf(u)
RFy_smsld	Reaction force y-dir.	N	reacf(v)
RFz_smsld	Reaction force z-dir.	N	reacf(w)
RMx_smsld	Reaction moment x-dir.	N*m	(y-refpnty_smsld) * RFz_smsld-(z-refpntz_smsld) * RFy_smsld
RMy_smsld	Reaction moment y-dir.	N*m	(z-refpntz_smsld) * RFx_smsld-(x-refpntx_smsld) * RFz_smsld
RMz_smsld	Reaction moment z-dir.	N*m	(x-refpntx_smsld) * RFy_smsld-(y-refpnty_smsld) * RFx_smsld
Fxg_smsld	Edge load in global x-dir.	N/m	0
Fyg_smsld	Edge load in global y-dir.	N/m	0
Fzg_smsld	Edge load in global z-dir.	N/m	0
disp_smsld	Total displacement	m	sqrt(real(u)^2+real(v)^2+real(w)^2)

10.3. Boundary

Name	Description	Unit	Expression
RFx_smsld	Reaction force x-dir.	N	reacf(u)
RFy_smsld	Reaction force y-dir.	N	reacf(v)
RFz_smsld	Reaction force z-dir.	N	reacf(w)
RMx_smsld	Reaction moment x-dir.	N*m	(y-refpnty_smsld) * RFz_smsld-(z-refpntz_smsld) * RFy_smsld
RMy_smsld	Reaction moment y-dir.	N*m	(z-refpntz_smsld) * RFx_smsld-(x-refpntx_smsld) * RFz_smsld
RMz_smsld	Reaction moment z-dir.	N*m	(x-refpntx_smsld) * RFy_smsld-(y-refpnty_smsld) * RFx_smsld
Fxg_smsld	Face load in global x-dir.	N/m^2	0
Fyg_smsld	Face load in global y-dir.	N/m^2	0
Fzg_smsld	Face load in global z-dir.	N/m^2	0
disp_smsld	Total displacement	m	sqrt(real(u)^2+real(v)^2+real(w)^2)
Tax_smsld	Surface traction (force/area) in x dir.	Pa	sx_smsld * nx_smsld+sxy_smsld * ny_smsld+sxz_smsld * nz_smsld
Tay_smsld	Surface traction (force/area) in y dir.	Pa	sxy_smsld * nx_smsld+sy_smsld * ny_smsld+syz_smsld * nz_smsld
Taz_smsld	Surface traction (force/area) in z dir.	Pa	sxz_smsld * nx_smsld+syz_smsld * ny_smsld+sz_smsld * nz_smsld

10.4. Subdomain

Name	Description	Unit	Expression
RFx_smsld	Reaction force x-dir.	N	reacf(u)
RFy_smsld	Reaction force y-dir.	N	reacf(v)
RFz_smsld	Reaction force z-dir.	N	reacf(w)
RMx_smsld	Reaction moment x-dir.	N*m	(y-refpnty_smsld) * RFz_smsld-(z-refpntz_smsld) * RFy_smsld
RMy_smsld	Reaction moment y-dir.	N*m	(z-refpntz_smsld) * RFx_smsld-(x-refpntx_smsld) * RFz_smsld
RMz_smsld	Reaction moment z-dir.	N*m	(x-refpntx_smsld) * RFy_smsld-(y-refpnty_smsld) * RFx_smsld
Fxg_smsld	Body load in global x-dir.	N/m^3	0
Fyg_smsld	Body load in global y-dir.	N/m^3	0
Fzg_smsld	Body load in global z-dir.	N/m^3	Fz_smsld
disp_smsld	Total displacement	m	sqrt(real(u)^2+real(v)^2+real(w)^2)
sx_smsld	sx normal stress global sys.	Pa	4 * G_smsld * ex_smsld/3-2 * G_smsld * ey_smsld/3-2 * G_smsld * ez_smsld/3-p
sy_smsld	sy normal stress global sys.	Pa	4 * G_smsld * ey_smsld/3-2 * G_smsld * ex_smsld/3-2 * G_smsld * ez_smsld/3-p
sz_smsld	sz normal stress global sys.	Pa	4 * G_smsld * ez_smsld/3-2 * G_smsld * ex_smsld/3-2 * G_smsld * ey_smsld/3-p
sxy_smsld	sxy shear stress global sys.	Pa	2 * G_smsld * exy_smsld
syz_smsld	syz shear stress global sys.	Pa	2 * G_smsld * eyz_smsld
sxz_smsld	sxz shear stress global sys.	Pa	2 * G_smsld * exz_smsld
ex_smsld	ex normal strain global sys.	1	ux
ey_smsld	ey normal strain global sys.	1	vy
ez_smsld	ez normal strain global sys.	1	wz
exy_smsld	exy shear strain global sys.	1	0.5 * (uy+vx)
eyz_smsld	eyz shear strain global sys.	1	0.5 * (vz+wy)
exz_smsld	exz shear strain global sys.	1	0.5 * (uz+wx)
p	Pressure	Pa	-K_smsld * evol_smsld
cp_smsld	Pressure wave velocity	m/s	sqrt((K_smsld+4 * G_smsld/3)/rho_smsld)
cs_smsld	Shear wave velocity	m/s	sqrt(G_smsld/rho_smsld)
mises_smsld	von Mises stress	Pa	sqrt(sx_smsld^2+sy_smsld^2+sz_smsld^2-sx_smsld * sy_smsld-sy_smsld * sz_smsld-sx_smsld * sz_smsld+3 * sxy_smsld^2+3 * syz_smsld^2+3 * sxz_smsld^2)
Ws_smsld	Strain energy density	J/m^3	0.5 * (sx_smsld * ex_smsld+sy_smsld * ey_smsld+sz_smsld * ez_smsld+2 * sxy_smsld * exy_smsld+2 * syz_smsld * eyz_smsld+2 * sxz_smsld * exz_smsld)
evol_smsld	Volumetric strain	1	ex_smsld+ey_smsld+ez_smsld
Ent_smsld	Entropy per unit volume	J/(m^3*K)	1.2e-05 * (sx_smsld-j * (imag(E_smsld * (1-nu_smsld)/((1+nu_smsld) * (1-2 * nu_smsld))) * ex_smsld+imag(E_smsld * nu_smsld/((1+nu_smsld) * (1-2 * nu_smsld))) * ey_smsld+imag(E_smsld * nu_smsld/((1+nu_smsld) * (1-2 * nu_smsld))) * ez_smsld+imag(0) * exy_smsld+imag(0) * eyz_smsld+imag(0) * exz_smsld)+sy_smsld-j * (imag(E_smsld * nu_smsld/((1+nu_smsld) * (1-2 * nu_smsld))) * ex_smsld+imag(E_smsld * (1-nu_smsld)/((1+nu_smsld) * (1-2 * nu_smsld))) * ey_smsld+imag(E_smsld * nu_smsld/((1+nu_smsld) * (1-2 * nu_smsld))) * ez_smsld+imag(0) * exy_smsld+imag(0) * eyz_smsld+imag(0) * exz_smsld)+sz_smsld-j * (imag(E_smsld * nu_smsld/((1+nu_smsld) * (1-2 * nu_smsld))) * ex_smsld+imag(E_smsld * nu_smsld/((1+nu_smsld) * (1-2 * nu_smsld))) * ey_smsld+imag(E_smsld * (1-nu_smsld)/((1+nu_smsld) * (1-2 * nu_smsld))) * ez_smsld+imag(0) * exy_smsld+imag(0) * eyz_smsld+imag(0) * exz_smsld))
tresca_smsld	Tresca stress	Pa	max(max(abs(s1_smsld-s2_smsld),abs(s2_smsld-s3_smsld)),abs(s1_smsld-s3_smsld))