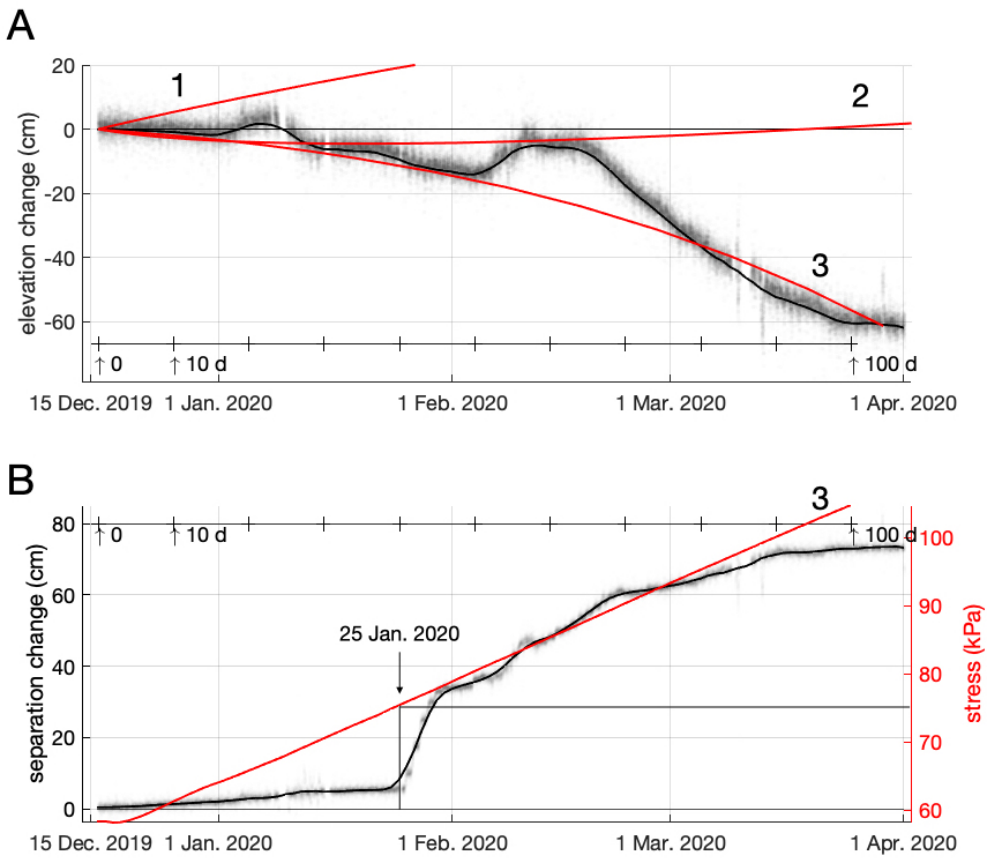
Experiment 3 of the study reported in "Observed and modelled meltwater-induced flexure and fracture at a doline on George VI Ice Shelf, Antarctica"



Report date	Jul 24, 2023, 3:05:14 PM

SUMMARY

This is the description of Experiment 3 cited in the above study by Banwell, Willis, Stevens, Dell and MacAyeal. Experiments 1 and 2 can be reconstructed by simple changes to this code.

Contents

1 Global Definitions

Date	Sep 15, 2022, 2:35:24 PM

GLOBAL SETTINGS

Name	Doline V5.0.mph
Path	/Users/drm7/Library/Mobile Documents/com~apple~CloudDocs/Doline_model/Doline_V5.0.mph
Version	COMSOL Multiphysics 6.1 (Build: 357)

USED PRODUCTS

CFD Module
COMSOL Multiphysics

COMPUTER INFORMATION

CPU	Intel(R) Xeon(R) W-3245 CPU @ 3.20GHz, 16 cores, 96 GB RAM
Operating system	Mac OS X

1.1 PARAMETERS

PARAMETERS 1

Name	Expression	Value	Description
L	1670	1670	radius of domain
g	9.81	9.81	
rho_i	900	900	
rho_sw	1028	1028	
rho_fw	1000	1000	
E	1e10	1E10	
Poisson	1/3	0.33333	
H	240	240	
d	5	5	
Radius	130	130	
doline_depth	(1 - rho_i/rho_sw)*H	29.883	
H_doline	40	40	
water_depth	rho_i/rho_fw*(325^2 - 125^2)/125^2*ablation	5.184	
ablation	1	1	
transition	200	200	
doline_floor	0	0	
sec_in_day	24*3600	86400	
A	2.4e-15	2.4E−15	
flow_exponent	3	3	
Aplus	A^(-1/flow_exponent)	74690	
Bbar	1.8e8	1.8E8	
Inner_radius	Radius/3	43.333	
Outer_radius	Radius	130	
sensitivity	.75	0.75	
Delta_Z	20	20	
strain_rate	2e-10	2E−10	
wall_movement	strain_rate*(L + Radius + transition)	4E−7	
sample_wall_velocity	40*wall_movement*24*3600	1.3824	
sec_in_year	365*sec_in_day	3.1536E7	

1.2 SHARED PROPERTIES

1.2.1 Default Model Inputs

Tag	cminpt

2 Component 1

SETTINGS

Description	Value
Unit system	Same as global system (SI)

2.1 DEFINITIONS

2.1.1 Variables

2.1.1.1 Variables 1

SELECTION

Geometric entity level	Entire model

Name	Expression	Unit	Description
s	(1 - rho_i/rho_sw)*H		
b	-rho_i/rho_sw*H		
seawater_pressure_wet	-rho_sw*g_const*(z + w2)		
seawater_pressure_dry	-rho_sw*g_const*(z + w)		
nu	1E14		
vonmises	1/sqrt(2)*sqrt((Principle_stress.e1 - Principle_stress.e2)^2 + (Principle_stress.e1 - Principle_stress.e3)^2 + (Principle_stress.e2 - Principle_stress.e3)^2)		
nu_effective	1/2*B/(EII^(1 - 1/flow_exponent)) + 1e3		
EII	sqrt(Principle_strainrate.e1^2 + Principle_strainrate.e2^2 + Principle_strainrate.e3^2 + 1e-25)		
Max_effective	rho_i*nu_effective/E		
d_center	A_cumulative*(330^2 - 130^2)/(130^2)*rho_i/rho_fw	s	
Adot_forced	0.005/sec_in_day		
A_cumulative	Adot_forced*t	s	
d_ring	A_cumulative*(rho_i/rho_fw)*((700^2 - 330^2)/(1200^2 - 700^2) + 0*(1500^2 - 1200^2)/(1200^2 - 700^2))	s	

2.1.1.2 ice stiffness variables

SELECTION

Geometric entity level	Entire model

Name	Expression	Unit	Description
sigma_basin	(z + rho_i/rho_sw*H_doline)/H_doline	m	
sigma_shelf	(z + rho_i/rho_sw*H)/H	m	
sigma_ramp	(z + rho_i/rho_sw*Hramp)/Hramp		

Name	Expression	Unit	Description
Hramp	H_doline+ (H - H_doline)*(r - Radius)/(transition)	m	
sigma	sigma_basin*(r<Radius) + sigma_ramp*(r>=Radius)*(r<(Radius + transition)) + sigma_shelf*(r>=Radius + transition)		Surface tension coefficient
T	-2 - 6*sigma		
B	B_o*exp(Q/3/Rgas/(T + 273.15))		
Rgas	8.3143		
Q	1.2E5		
B_o	1.5		

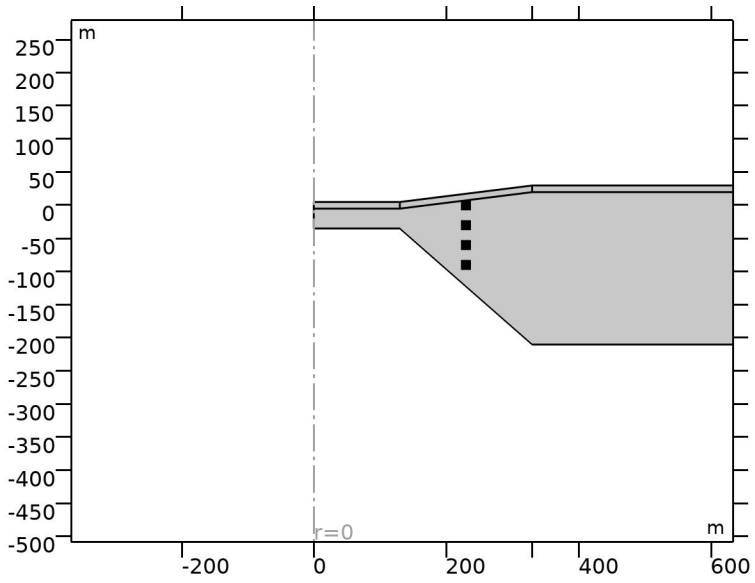
2.1.2 Variable Utilities

2.1.2.1 Strain_rate

Tag	mat1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1



Selection

INPUT MATRIX

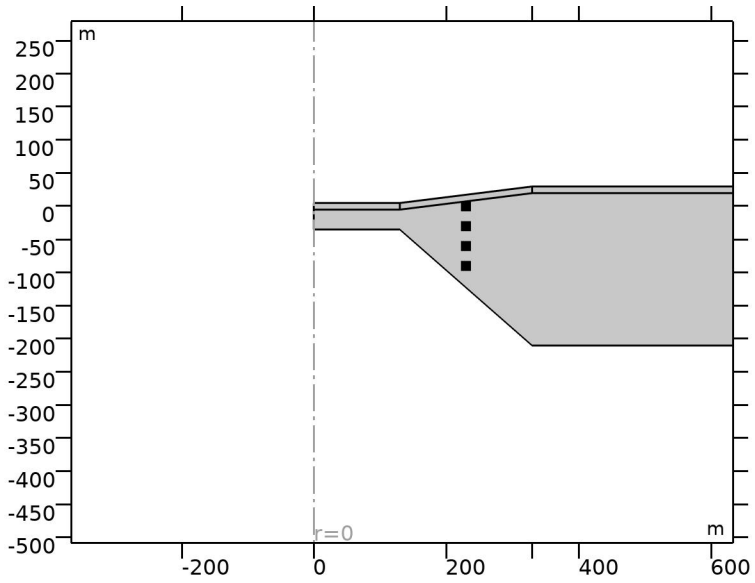
Description	Value
Matrix format	Symmetric
Input matrix	{{d(u, r), 0, 1/2*(d(u, z) + d(w, r))}, {0, v/r, 0}, {1/2*(d(u, z) + d(w, r)), 0, d(w, z)}}

2.1.2.2 stress

Tag	mat2

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1



Selection

INPUT MATRIX

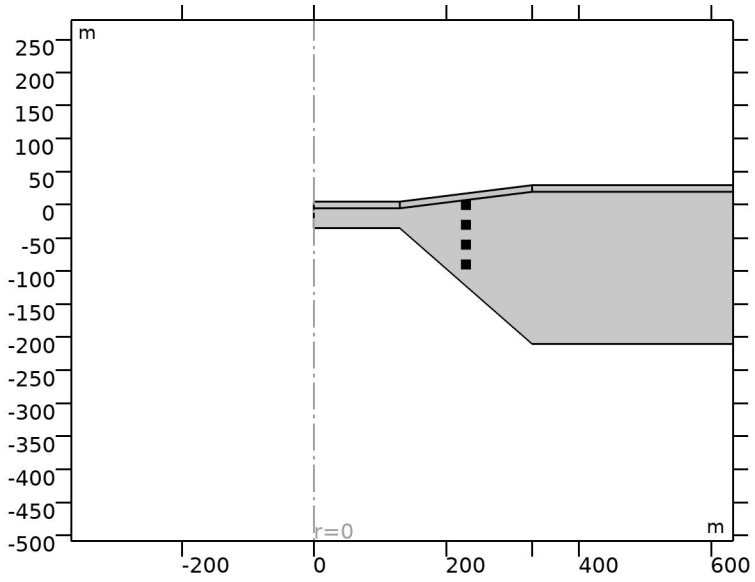
Description	Value
Matrix format	Symmetric
Input matrix	{{2*nu_effective*Strain_rate11, 0, 2*nu_effective*Strain_rate13}, {0, 2*nu_effective*Strain_rate22, 0}, {2*nu_effective*Strain_rate13, 0, 2*nu_effective*Strain_rate33}}

2.1.2.3 Principle_stress

Tag	matdiag1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1



Selection

INPUT MATRIX

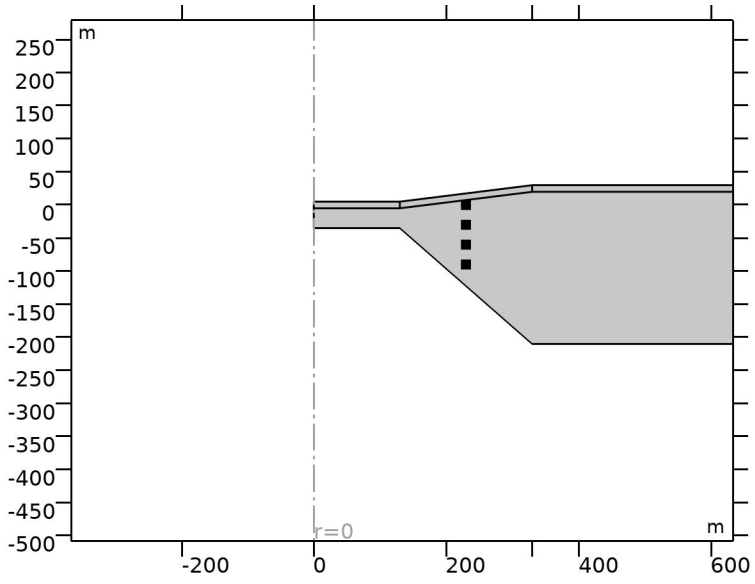
Description	Value
Input matrix	{{T11, 0, T13}, {0, T22, 0}, {T13, 0, T33}}

2.1.2.4 Principle_strainrate

Tag	matdiag2

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1



Selection

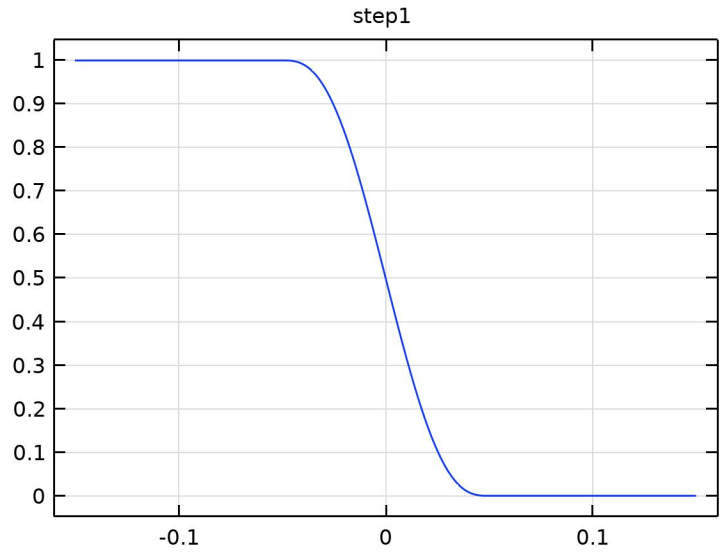
INPUT MATRIX

Description	Value
Input matrix	{{Strain_rate11, Strain_rate12, Strain_rate13}, {Strain_rate12, Strain_rate22, Strain_rate23}, {Strain_rate13, Strain_rate23, Strain_rate33}}

2.1.3 Functions

2.1.3.1 Step 1

Function name	step1
Function type	Step



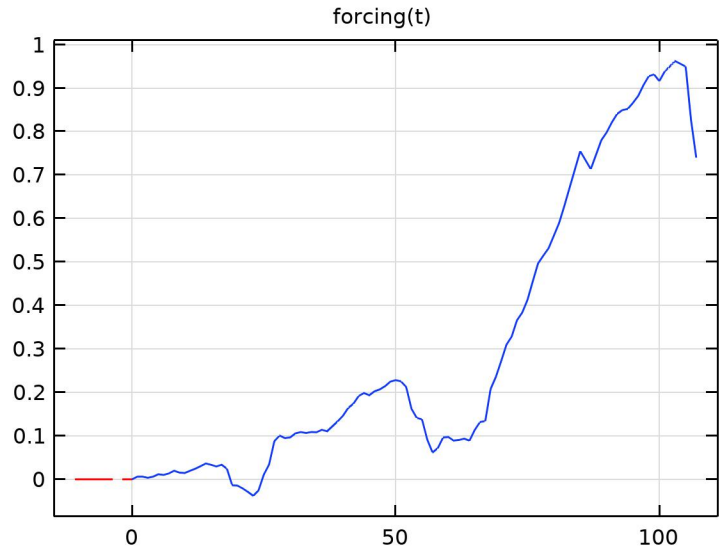
Step 1

PARAMETERS

Description	Value
Location	0
From	1
To	0

2.1.3.2 Interpolation 1

Function names	forcing
Function type	Interpolation



Interpolation 1

UNITS

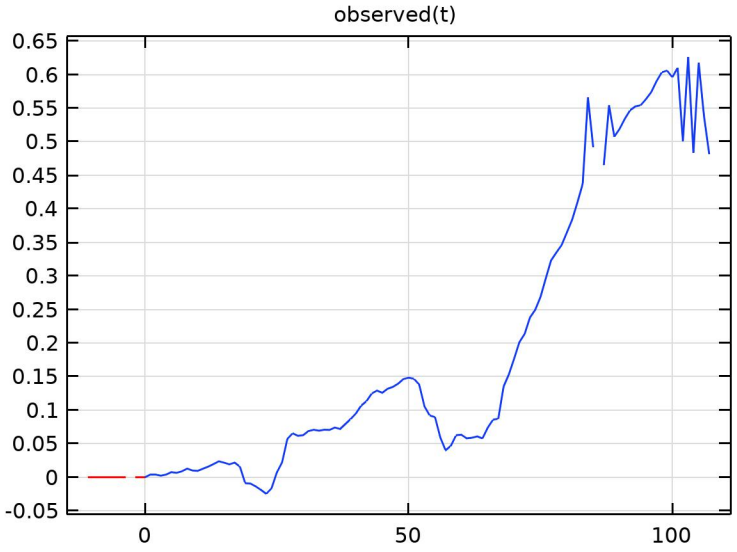
Function	Unit
forcing	

UNITS

Argument	Unit
t	

2.1.3.3 Interpolation 2

Function names	observed
Function type	Interpolation



Interpolation 2

UNITS

Function	Unit
observed	

UNITS

Argument	Unit
t	

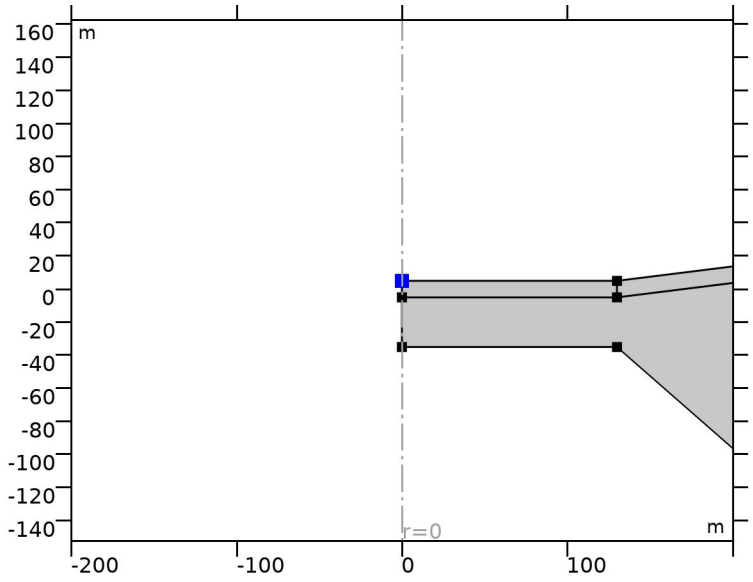
2.1.4 Probes

2.1.4.1 GPS10

Probe type	Point probe

SELECTION

Geometric entity level	Point
Selection	Geometry geom1: Dimension 0: Point 3



Selection

EXPRESSION

Description	Value
Expression	spatial.dz
Table and plot unit	m
Description	Spatial mesh displacement z

INTEGRATION SETTINGS

Description	Value
Frame	Material

TABLE AND WINDOW SETTINGS

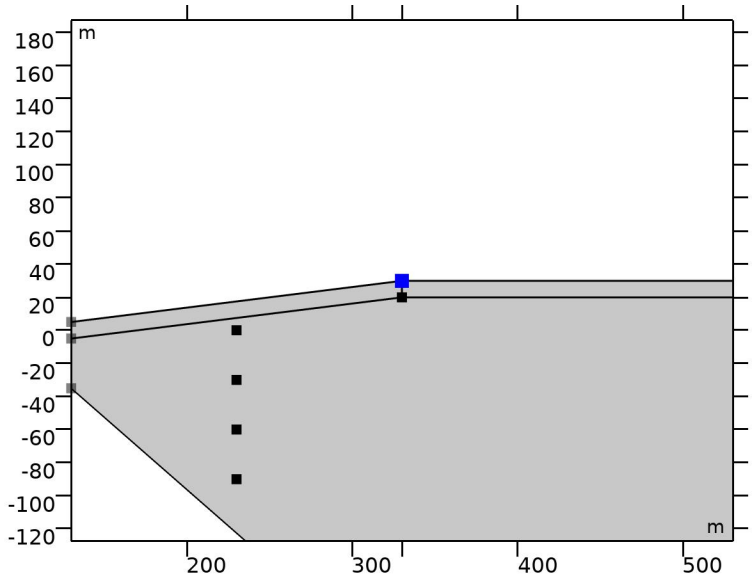
Description	Value
Output table	Probe Table 1
Plot window	Probe Plot 3

2.1.4.2 GPS01

Probe type	Point probe

SELECTION

Geometric entity level	Point
Selection	Geometry geom1: Dimension 0: Point 13



Selection

EXPRESSION

Description	Value
Expression	spatial.dz
Table and plot unit	m
Description	Spatial mesh displacement z

INTEGRATION SETTINGS

Description	Value
Frame	Material

TABLE AND WINDOW SETTINGS

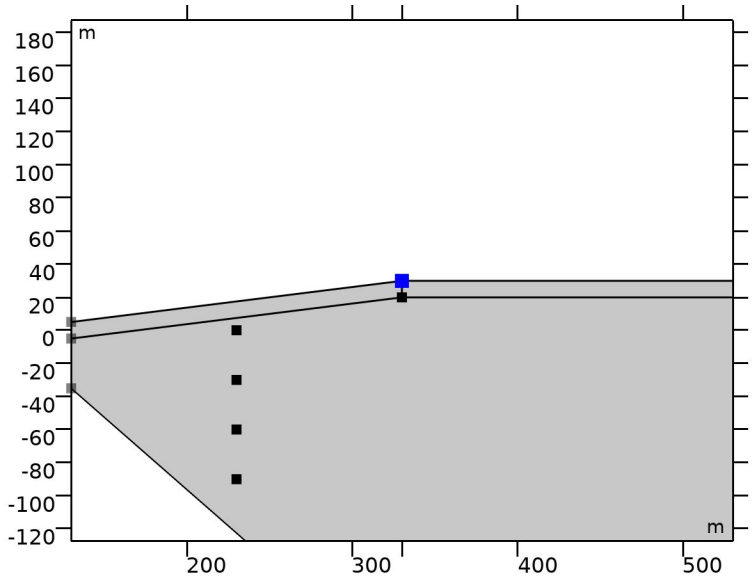
Description	Value
Output table	Probe Table 1
Plot window	Probe Plot 3

2.1.4.3 Horizontal_Distance

Probe type	Point probe

SELECTION

Geometric entity level	Point
Selection	Geometry geom1: Dimension 0: Point 13



Selection

EXPRESSION

Description	Value
Expression	spatial.dr
Table and plot unit	m
Description	Spatial mesh displacement r

INTEGRATION SETTINGS

Description	Value
Frame	Material

TABLE AND WINDOW SETTINGS

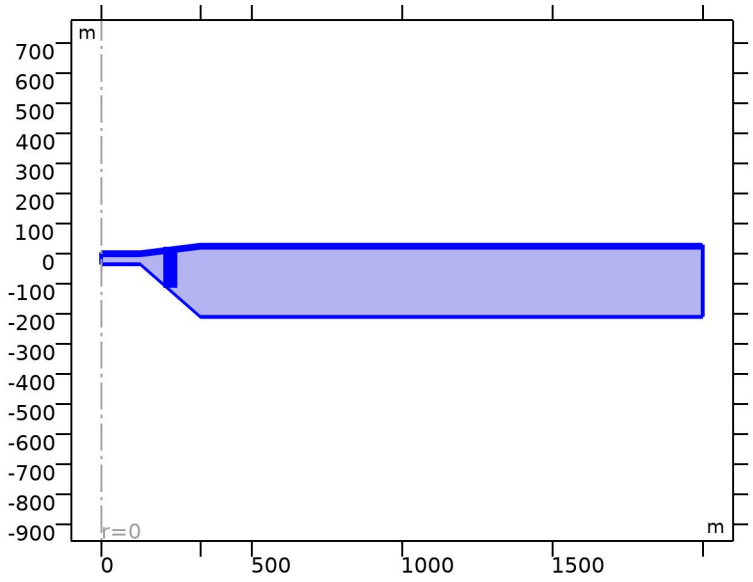
Description	Value
Output table	Probe Table 1
Plot window	Probe Plot 3

2.1.4.4 Minimum Maxwell time

Probe type	Domain probe

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains



Selection

EXPRESSION

Description	Value
Expression	rho_i*nu_effective/sec_in_day/E
Description	rho_i*nu_effective/sec_in_day/E

TABLE AND WINDOW SETTINGS

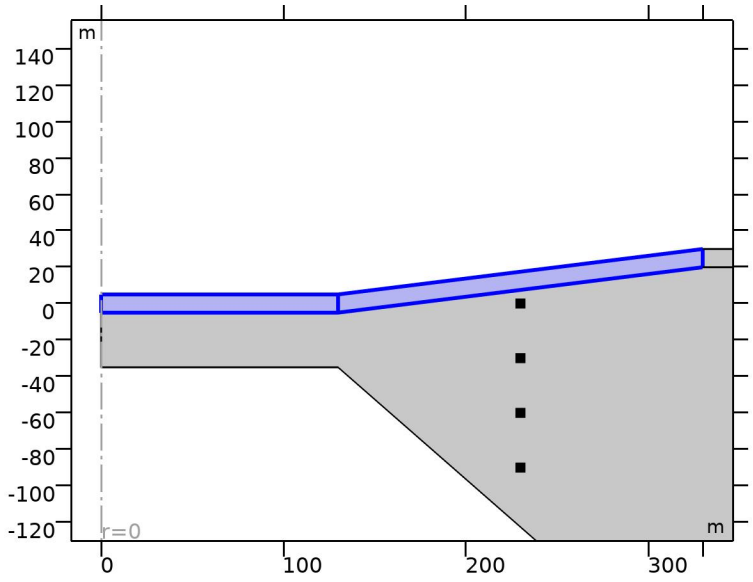
Description	Value
Output table	Probe Table 1
Plot window	Probe Plot 3

2.1.4.5 vonMises Probe

Probe type	Domain probe

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domains 2–3



Selection

PROBE TYPE

Description	Value
Type	Maximum

EXPRESSION

Description	Value
Expression	vonmises/1e3
Description	vonmises/1e3

TABLE AND WINDOW SETTINGS

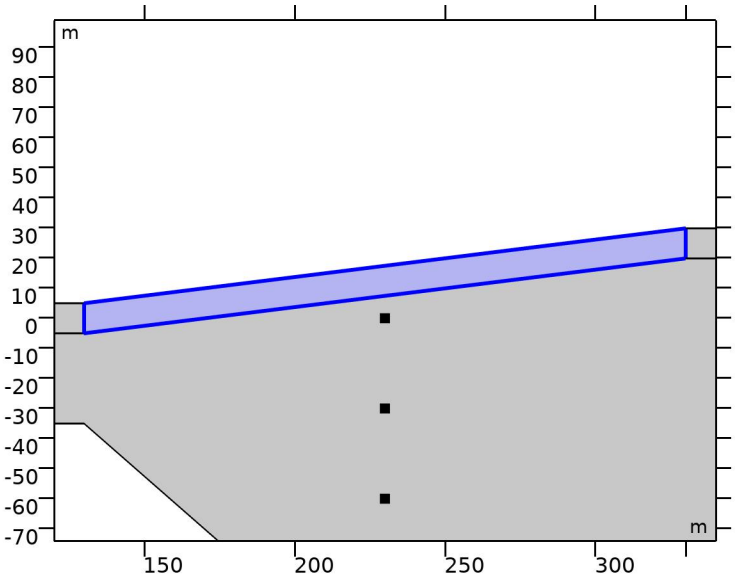
Description	Value
Output table	Probe Table 1
Plot window	Probe Plot 3

2.1.4.6 maximum T_rr in upper 10 m of ice shelf inside of doline rim

Probe type	Domain probe

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 3



Selection

PROBE TYPE

Description	Value
Type	Maximum

EXPRESSION

Description	Value
Expression	Principle_stress.e1/1e3
Description	Principle_stress.e1/1e3

TABLE AND WINDOW SETTINGS

Description	Value
Output table	Probe Table 1
Plot window	Probe Plot 4

2.1.4.7 Global Variable Probe 1

Probe type	Global variable probe

EXPRESSION

Description	Value
Expression	A_cumulative
Table and plot unit	s

TABLE AND WINDOW SETTINGS

Description	Value
Output table	Probe Table 1

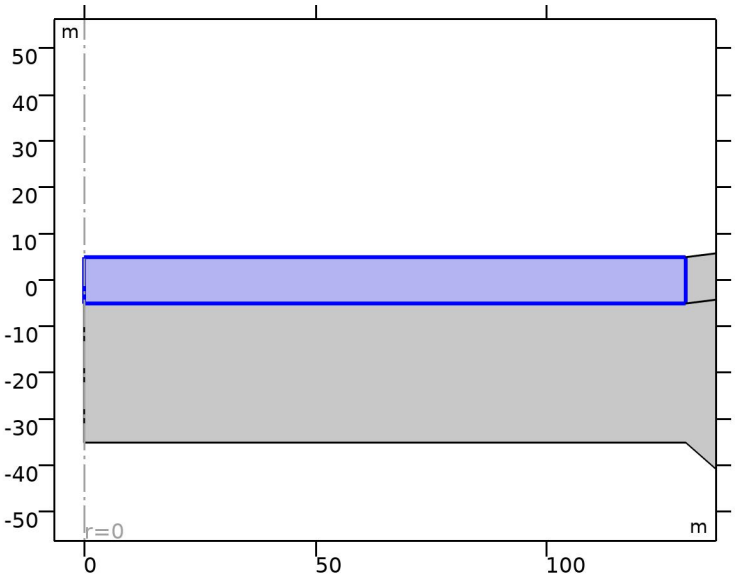
Description	Value
Plot window	Probe Plot 4

2.1.4.8 maximum T_rr in upper 10 m of ice shelf inside of doline ramp

Probe type	Domain probe

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 2



Selection

PROBE TYPE

Description	Value
Type	Maximum

EXPRESSION

Description	Value
Expression	Principle_stress.e1/1e3
Description	Principle_stress.e1/1e3

TABLE AND WINDOW SETTINGS

Description	Value
Output table	Probe Table 1
Plot window	Probe Plot 4

2.1.5 Coordinate Systems

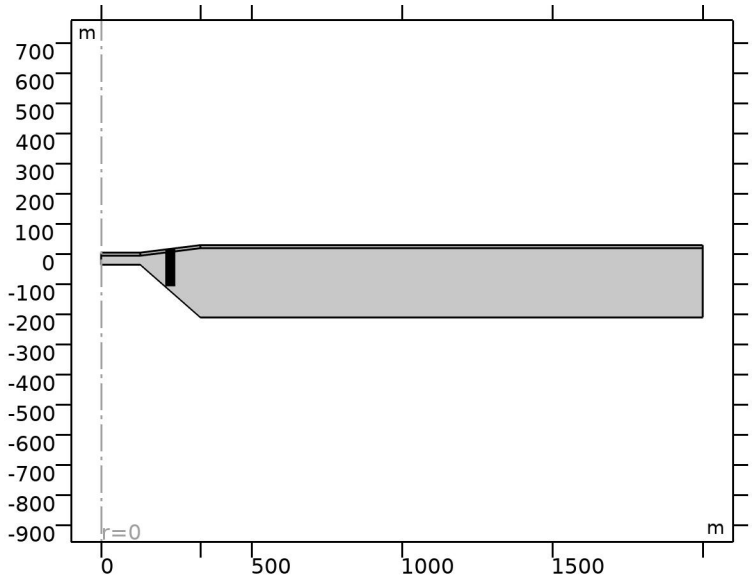
2.1.5.1 Boundary System 1

Coordinate system type	Boundary system
Tag	sys1

COORDINATE NAMES

First	Second	Third
t1	to	n

2.2 GEOMETRY 1



Geometry 1

UNITS

Length unit	m
Angular unit	deg

GEOMETRY STATISTICS

Description	Value
Space dimension	2
Number of domains	4
Number of boundaries	15
Number of vertices	16

2.2.1 Rectangle 1 (r1)

POSITION

Description	Value
Position	{L/2 + Radius + transition, -rho_i/rho_sw*H + H/2}
Base	Center

SIZE

Description	Value
Width	L
Height	H

2.2.2 Rectangle 2 (r2)

POSITION

Description	Value
Position	{0, -rho_i/rho_sw*H_doline}

SIZE

Description	Value
Width	Radius
Height	H_doline

2.2.3 Polygon 1 (pol1)

OBJECT TYPE

Description	Value
Type	Solid

COORDINATES

Description	Value
Data source	Table

COORDINATES

r (m)	z (m)
Radius	-rho_i/rho_sw*H_doline
Radius+transition	-rho_i/rho_sw*H
Radius+transition	(1-rho_i/rho_sw)*H
Radius	(1-rho_i/rho_sw)*H_doline
Radius	-rho_i/rho_sw*H_doline

2.2.4 Union 1 (uni1)

COMPOSE

Description	Value
Keep interior boundaries	Off

2.2.5 Point 1 (pt1)

POINT

Description	Value
Point coordinate	{230, 0}

2.2.6 Polygon 3 (pol3)

OBJECT TYPE

Description	Value
Type	Open curve

COORDINATES

Description	Value
Data source	Table

COORDINATES

r (m)	z (m)
0	(1-rho_i/rho_sw)*H_doline-10
Radius	(1-rho_i/rho_sw)*H_doline-10
Radius+transition	(1-rho_i/rho_sw)*H-10
L+Radius+transition	(1-rho_i/rho_sw)*H-10

2.2.7 Array 1 (arr1)

SETTINGS

Description	Value
Array type	Linear
Size	4
Displacement	{0, -30}

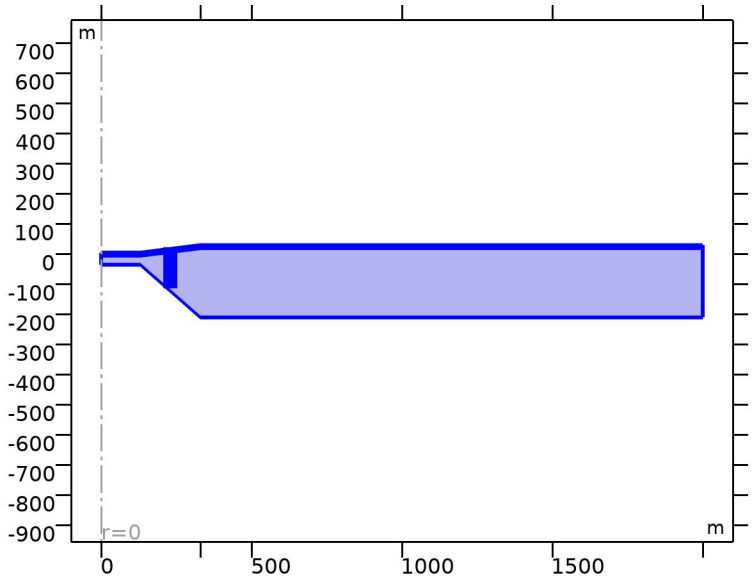
2.3 MOVING MESH

2.3.1 Deforming Domain 1

Tag	free1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domains 1–4



Selection

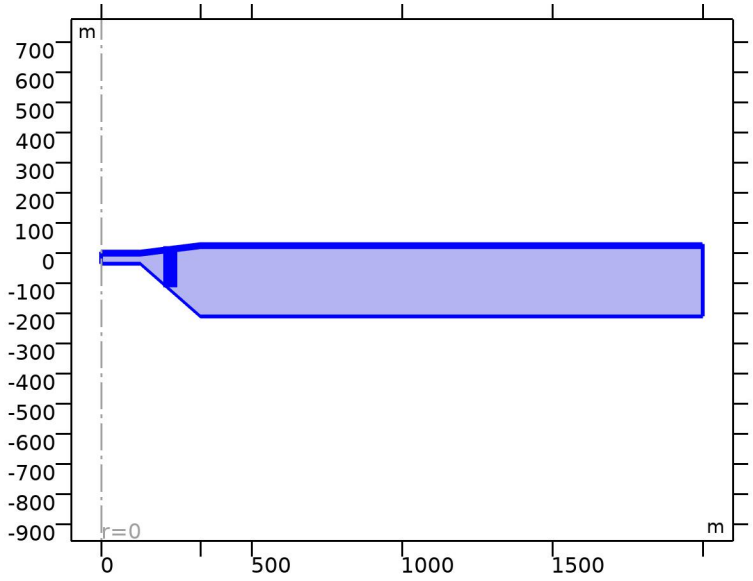
INITIAL DEFORMATION

Description	Value
Initial deformation	{0, 0, 0}

2.4 CREEPING FLOW

USED PRODUCTS

CFD Module
COMSOL Multiphysics



Creeping Flow

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

EQUATIONS

$$\rho\frac{\partial \mathbf{u}}{\partial t} = \nabla \cdot [-p\mathbf{I} + \mathbf{K}] + \mathbf{F}$$
$$\rho\nabla \cdot \mathbf{u} = 0$$

2.4.1 Interface Settings

2.4.1.1 Discretization

SETTINGS

Description	**Value**
Discretization of fluids	P2 + P1

SETTINGS

Description	**Value**
Equation form	Study controlled

2.4.1.2 Physical Model

SETTINGS

Description	Value	Unit
Neglect inertial term (Stokes flow)	On	
Compressibility	Incompressible flow	
Swirl flow	Off	
Enable porous media domains	Off	
Include gravity	Off	
Reference temperature	User defined	
Reference temperature	293.15	K
Reference pressure level	0	Pa

2.4.1.3 Turbulence

SETTINGS

Description	Value
Turbulence model type	None

2.4.1.4 Consistent Stabilization

SETTINGS

Description	Value
Streamline diffusion	On
Crosswind diffusion	On
Use dynamic subgrid time scale	On

2.4.1.5 Inconsistent Stabilization

SETTINGS

Description	Value
Isotropic diffusion	Off

2.4.1.6 Advanced Settings

SETTINGS

Description	Value
Use pseudo time stepping for stationary equation form	Automatic from physics
CFL number expression	Automatic
Use Block Navier-Stokes preconditioner in time dependent studies	Off

2.4.2 Variables

Name	Expression	Unit	Description	Selection	Details

Name	Expression	Unit	Description	Selection	Details
spf.Tref	model.input.Tref	K	Reference temperature	Global	Meta
spf.dz	1	m	Thickness	Domains 1–4	
spf.pref	0[atm]	Pa	Reference pressure level	Domains 1–4	
spf.pA	p+spf.pref	Pa	Absolute pressure	Domains 1–4	
spf.hasWF	0		Help variable	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.hasWF_u	0		Help variable	Boundaries 4, 7–8, 11–12	
spf.hasWF_d	0		Help variable	Boundaries 4, 7–8, 11–12	
spf.dt_CFL	1/max(spf.maxop(sqrt(emetric_spatial(u-d(r,TIME),w-d(z,TIME)))),eps)	s	Time step, CFL=1	Global	
spf.CFL_number	timestep/spf.dt_CFL	1	CFL number	Global	
spf.Qvd_tot	spf.intop(2*spf.Qvd*pi*r)	W	Total viscous dissipation	Global	
spf.K_stressr	spf.K_stress_tensorrr*spf.nrmesh+spf.K_stress_tensorrphi*spf.nphimesh+spf.K_stress_tensorrz*spf.nzmesh	N/m²	Viscous force, exterior boundaries, r-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.K_stressphi	spf.K_stress_tensorphir*spf.nrmesh+spf.K_stress_tensorphiphi*spf.nphimesh+spf.K_stress_tensorphiz*spf.nzmesh	N/m²	Viscous force, exterior boundaries, phi-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.K_stressz	spf.K_stress_tensorzr*spf.nrmesh+spf.K_stress_tensorzphi*spf.nphimesh+spf.K_stress_tensorzz*spf.nzmesh	N/m²	Viscous force, exterior boundaries, z-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.T_stressr	spf.T_stress_tensorrr*spf.nrmesh+spf.T_stress_tensorrphi*spf.nphimesh+spf.T_stress_tensorrz*spf.nzmesh	N/m²	Total traction, exterior boundaries, r-component	Boundaries 1–3, 5–6, 9–10, 13–15	

Name	Expression	Unit	Description	Selection	Details
spf.T_stressphi	spf.T_stress_tensorphir*spf.nrmesh+spf.T_stress_tensorphiphi*spf.nphimesh+spf.T_stress_tensorphiz*spf.nzmesh	N/m²	Total traction, exterior boundaries, phi-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.T_stressz	spf.T_stress_tensorzr*spf.nrmesh+spf.T_stress_tensorzphi*spf.nphimesh+spf.T_stress_tensorzz*spf.nzmesh	N/m²	Total traction, exterior boundaries, z-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.K_stress_dr	down(spf.K_stress_tensorrr)*spf.nrmesh+down(spf.K_stress_tensorrphi)*spf.nphimesh+down(spf.K_stress_tensorrz)*spf.nzmesh	N/m²	Viscous force, interior boundaries, downside, r-component	Boundaries 4, 7–8, 11–12	
spf.K_stress_dphi	down(spf.K_stress_tensorphir)*spf.nrmesh+down(spf.K_stress_tensorphiphi)*spf.nphimesh+down(spf.K_stress_tensorphiz)*spf.nzmesh	N/m²	Viscous force, interior boundaries, downside, phi-component	Boundaries 4, 7–8, 11–12	
spf.K_stress_dz	down(spf.K_stress_tensorzr)*spf.nrmesh+down(spf.K_stress_tensorzphi)*spf.nphimesh+down(spf.K_stress_tensorzz)*spf.nzmesh	N/m²	Viscous force, interior boundaries, downside, z-component	Boundaries 4, 7–8, 11–12	
spf.K_stress_dr	down(spf.K_stress_tensorrr)*spf.dnrmesh+down(spf.K_stress_tensorrphi)*spf.dnphimesh+down(spf.K_stress_tensorrz)*spf.dnzmesh	N/m²	Viscous force, interior boundaries, downside, r-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.K_stress_dphi	down(spf.K_stress_tensorphir)*spf.dnrmesh+down(spf.K_stress_tensorphiphi)*spf.dnphimesh+down(spf.K_stress_tensorphiz)*spf.dnzmesh	N/m²	Viscous force, interior boundaries, downside, phi-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.K_stress_dz	down(spf.K_stress_tensorzr)*spf.dnrmesh+down(spf.K_stress_tens	N/m²	Viscous force, interior boundaries,	Boundaries 1–3, 5–6, 9–10, 13–15	

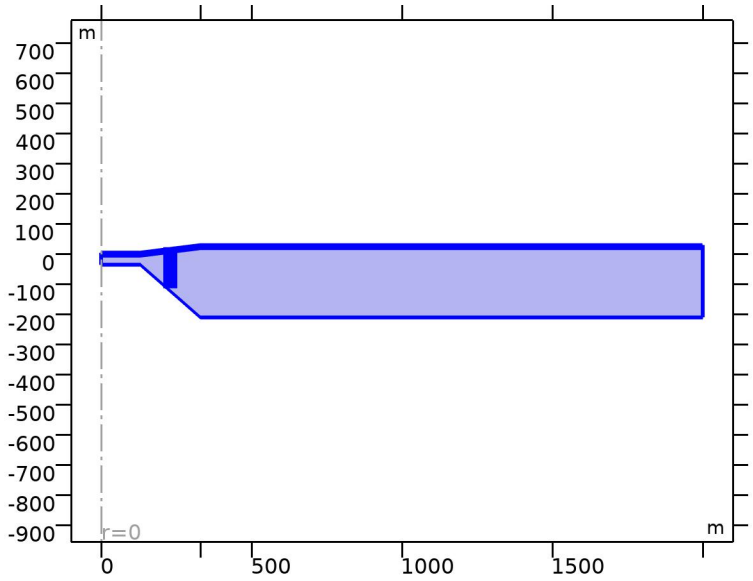
Name	Expression	Unit	Description	Selection	Details
	orzphi)*spf.dnphimesh+down(spf.K_stress_tensorzz)*spf.dnzmesh		downside, z-component		
spf.K_stress_ur	-up(spf.K_stress_tensorrr)*spf.nrmesh-up(spf.K_stress_tensorrphi)*spf.nphimesh-up(spf.K_stress_tensorrz)*spf.nzmesh	N/m²	Viscous force, interior boundaries, upside, r-component	Boundaries 4, 7–8, 11–12	
spf.K_stress_uphi	-up(spf.K_stress_tensorphir)*spf.nrmesh-up(spf.K_stress_tensorphiphi)*spf.nphimesh-up(spf.K_stress_tensorphiz)*spf.nzmesh	N/m²	Viscous force, interior boundaries, upside, phi-component	Boundaries 4, 7–8, 11–12	
spf.K_stress_uz	-up(spf.K_stress_tensorzr)*spf.nrmesh-up(spf.K_stress_tensorzphi)*spf.nphimesh-up(spf.K_stress_tensorzz)*spf.nzmesh	N/m²	Viscous force, interior boundaries, upside, z-component	Boundaries 4, 7–8, 11–12	
spf.T_stress_dr	down(spf.T_stress_tensorrr)*spf.nrmesh+down(spf.T_stress_tensorrphi)*spf.nphimesh+down(spf.T_stress_tensorrz)*spf.nzmesh	N/m²	Total traction, interior boundaries, downside, r-component	Boundaries 4, 7–8, 11–12	
spf.T_stress_dphi	down(spf.T_stress_tensorphir)*spf.nrmesh+down(spf.T_stress_tensorphiphi)*spf.nphimesh+down(spf.T_stress_tensorphiz)*spf.nzmesh	N/m²	Total traction, interior boundaries, downside, phi-component	Boundaries 4, 7–8, 11–12	
spf.T_stress_dz	down(spf.T_stress_tensorzr)*spf.nrmesh+down(spf.T_stress_tensorzphi)*spf.nphimesh+down(spf.T_stress_tensorzz)*spf.nzmesh	N/m²	Total traction, interior boundaries, downside, z-component	Boundaries 4, 7–8, 11–12	
spf.T_stress_dr	down(spf.T_stress_tensorrr)*spf.dnrmesh+down(spf.T_stress_tens	N/m²	Total traction, interior boundaries,	Boundaries 1–3, 5–6, 9–10, 13–15	

Name	Expression	Unit	Description	Selection	Details
	orrphi)*spf.dnphimesh+down(spf.T_stress_tensorrz)*spf.dnzmesh		downside, r-component		
spf.T_stress_dphi	down(spf.T_stress_tensorphir)*spf.dnrmesh+down(spf.T_stress_tensorphiphi)*spf.dnphimesh+down(spf.T_stress_tensorphiz)*spf.dnzmesh	N/m²	Total traction, interior boundaries, downside, phi-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.T_stress_dz	down(spf.T_stress_tensorzr)*spf.dnrmesh+down(spf.T_stress_tensorzphi)*spf.dnphimesh+down(spf.T_stress_tensorzz)*spf.dnzmesh	N/m²	Total traction, interior boundaries, downside, z-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.T_stress_ur	-up(spf.T_stress_tensorrr)*spf.nrmesh-up(spf.T_stress_tensorrphi)*spf.nphimesh-up(spf.T_stress_tensorrz)*spf.nzmesh	N/m²	Total traction, interior boundaries, upside, r-component	Boundaries 4, 7–8, 11–12	
spf.T_stress_uphi	-up(spf.T_stress_tensorphir)*spf.nrmesh-up(spf.T_stress_tensorphiphi)*spf.nphimesh-up(spf.T_stress_tensorphiz)*spf.nzmesh	N/m²	Total traction, interior boundaries, upside, phi-component	Boundaries 4, 7–8, 11–12	
spf.T_stress_uz	-up(spf.T_stress_tensorzr)*spf.nrmesh-up(spf.T_stress_tensorzphi)*spf.nphimesh-up(spf.T_stress_tensorzz)*spf.nzmesh	N/m²	Total traction, interior boundaries, upside, z-component	Boundaries 4, 7–8, 11–12	
spf.usePseudoTimeStepping	isrunningpseudotimestepping	1	Help variable	Global	
spf.localCFLvalue	1.3^min(niterCMP,9)+if(niterCMP>=25,9*1.3^min(-25+niterCMP,9),0)+if(niterCMP>=45,90*1.3^min(-		Local CFL number	Domains 1–4	

Name	Expression	Unit	Description	Selection	Details
	45+niterCMP,9),0)				
spf.locCFL	max(CFLCMP,sqrt(eps))	1	Local CFL number	Global	
spf.geometryLengthScale	60.00000000000001	m	Geometry length scale	Domains 1–4	
spf.time_step_inv	max(sqrt(emetric_spatial(u,w)*2^if(gmg_level<2,0,-1+gmg_level)^2),spf.nu/spf.geometryLengthScale^2)	Hz	Inverse time step	Domains 1–4	
spf.tsti	nojac(spf.time_step_inv/spf.locCFL)	1/s	Help variable	Domains 1–4	
spf.nr	nr	1	Normal vector, r-component	Boundaries 4, 7–8, 11–12	
spf.nphi	0	1	Normal vector, phi-component	Boundaries 4, 7–8, 11–12	
spf.nz	nz	1	Normal vector, z-component	Boundaries 4, 7–8, 11–12	
spf.nr	dnr	1	Normal vector, r-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.nphi	0	1	Normal vector, phi-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.nz	dnz	1	Normal vector, z-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.nrmesh	nrmesh	1	Normal vector, r-component	Boundaries 4, 7–8, 11–12	
spf.nphimesh	0	1	Normal vector, phi-component	Boundaries 4, 7–8, 11–12	
spf.nzmesh	nzmesh	1	Normal vector, z-component	Boundaries 4, 7–8, 11–12	
spf.nrmesh	dnrmesh	1	Normal vector, r-component	Boundaries 1–3, 5–6, 9–10, 13–15	
spf.nphimesh	0	1	Normal vector, phi-component	Boundaries 1–3, 5–6, 9–10, 13–15	

Name	Expression	Unit	Description	Selection	Details
spf.nzmesh	dnzmesh	1	Normal vector, z-component	Boundaries 1–3, 5–6, 9–10, 13–15	

2.4.3 Fluid Properties 1



Fluid Properties 1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

EQUATIONS

2.4.3.1 Fluid Properties

SETTINGS

Description	Value	Unit
Density	User defined	
Density	rho_i	kg/m³
	Specify dynamic viscosity	
Dynamic viscosity	User defined	
Dynamic viscosity	nu_effective	Pa·s

2.4.3.2 Variables

Name	Expression	Unit	Description	Selection	Details
spf.Fr	0	N/m³	Volume force, r-	Domains 1–4	+ operation

Name	Expression	Unit	Description	Selection	Details
			component		
spf.Fphi	0	N/m³	Volume force, phi-component	Domains 1–4	+ operation
spf.Fz	0	N/m³	Volume force, z-component	Domains 1–4	+ operation
spf.mu	material.mu	Pa·s	Dynamic viscosity	Domains 1–4	Meta
spf.rho	material.rho	kg/m³	Density	Domains 1–4	Meta
urt	urTIME-urr*d(r,TIME)-urz*d(z,TIME)	1/s²	Gradient of u, r component, first time derivative	Domains 1–4	
uzt	uzTIME-uzr*d(r,TIME)-uzz*d(z,TIME)	1/s²	Gradient of u, z component, first time derivative	Domains 1–4	
urtt	d(urTIME-urr*d(r,TIME)-urz*d(z,TIME),TIME)-d(urTIME-urr*d(r,TIME)-urz*d(z,TIME),r)*d(r,TIME)-d(urTIME-urr*d(r,TIME)-urz*d(z,TIME),z)*d(z,TIME)	1/s³	Gradient of u, r component, second time derivative	Domains 1–4	
uztt	d(uzTIME-uzr*d(r,TIME)-uzz*d(z,TIME),TIME)-d(uzTIME-uzr*d(r,TIME)-uzz*d(z,TIME),r)*d(r,TIME)-d(uzTIME-uzr*d(r,TIME)-uzz*d(z,TIME),z)*d(z,TIME)	1/s³	Gradient of u, z component, second time derivative	Domains 1–4	
wrt	wrTIME-wrr*d(r,TIME)-wrz*d(z,TIME)	1/s²	Gradient of w, r component, first time derivative	Domains 1–4	
wzt	wzTIME-wzr*d(r,TIME)-wzz*d(z,TIME)	1/s²	Gradient of w, z component, first time derivative	Domains 1–4	
wrtt	d(wrTIME-wrr*d(r,TIME)-wrz*d(z,TIME),TIME)-d(wrTIME-wrr*d(r,TIME)-	1/s³	Gradient of w, r component, second time derivative	Domains 1–4	

Name	Expression	Unit	Description	Selection	Details
	wrz*d(z,TIME),r)*d(r,TIME)-d(wrTIME-wrr*d(r,TIME)-wrz*d(z,TIME),z)*d(z,TIME)				
wztt	d(wzTIME-wzr*d(r,TIME)-wzz*d(z,TIME),TIME)-d(wzTIME-wzr*d(r,TIME)-wzz*d(z,TIME),r)*d(r,TIME)-d(wzTIME-wzr*d(r,TIME)-wzz*d(z,TIME),z)*d(z,TIME)	$1/s^3$	Gradient of w, z component, second time derivative	Domains 1–4	
ut	uTIME-ur*d(r,TIME)-uz*d(z,TIME)	m/s^2	Velocity field, first time derivative, r-component	Domains 1–4	
wt	wTIME-wr*d(r,TIME)-wz*d(z,TIME)	m/s^2	Velocity field, first time derivative, z-component	Domains 1–4	
utt	d(uTIME-ur*d(r,TIME)-uz*d(z,TIME),TIME)-d(uTIME-ur*d(r,TIME)-uz*d(z,TIME),r)*d(r,TIME)-d(uTIME-ur*d(r,TIME)-uz*d(z,TIME),z)*d(z,TIME)	m/s^3	Velocity field, second time derivative, r-component	Domains 1–4	
wtt	d(wTIME-wr*d(r,TIME)-wz*d(z,TIME),TIME)-d(wTIME-wr*d(r,TIME)-wz*d(z,TIME),r)*d(r,TIME)-d(wTIME-wr*d(r,TIME)-wz*d(z,TIME),z)*d(z,TIME)	m/s^3	Velocity field, second time derivative, z-component	Domains 1–4	
prt	prTIME-prr*d(r,TIME)-prz*d(z,TIME)	W/m^4	Gradient of p, r component, first time derivative	Domains 1–4	
pzt	pzTIME-	W/m^4	Gradient of p, z	Domains 1–4	

Name	Expression	Unit	Description	Selection	Details
	pzr*d(r,TIME)-pzz*d(z,TIME)		component, first time derivative		
prtt	d(prTIME-prr*d(r,TIME)-prz*d(z,TIME),TIME)-d(prTIME-prr*d(r,TIME)-prz*d(z,TIME),r)*d(r,TIME)-d(prTIME-prr*d(r,TIME)-prz*d(z,TIME),z)*d(z,TIME)	$kg/(m^2 \cdot s^4)$	Gradient of p, r component, second time derivative	Domains 1–4	
pztt	d(pzTIME-pzr*d(r,TIME)-pzz*d(z,TIME),TIME)-d(pzTIME-pzr*d(r,TIME)-pzz*d(z,TIME),r)*d(r,TIME)-d(pzTIME-pzr*d(r,TIME)-pzz*d(z,TIME),z)*d(z,TIME)	$kg/(m^2 \cdot s^4)$	Gradient of p, z component, second time derivative	Domains 1–4	
pt	pTIME-pr*d(r,TIME)-pz*d(z,TIME)	Pa/s	Pressure, first time derivative	Domains 1–4	
ptt	d(pTIME-pr*d(r,TIME)-pz*d(z,TIME),TIME)-d(pTIME-pr*d(r,TIME)-pz*d(z,TIME),r)*d(r,TIME)-d(pTIME-pr*d(r,TIME)-pz*d(z,TIME),z)*d(z,TIME)	Pa/s^2	Pressure, second time derivative	Domains 1–4	
spf.Trho	spf.fp1.minput_temperature	K	Temperature for density evaluation	Domains 1–4	
spf.prho	spf.fp1.minput_pressure	Pa	Pressure for the evaluation of density	Domains 1–4	
spf.rhoref	subst(material.rho,minput.T,spf.Tref,minput.pA,spf.pref)	kg/m^3	Reference density	Domains 1–4	Meta
spf.mumat	material.mu	Pa·s	Dynamic viscosity	Domains 1–4	Meta

Name	Expression	Unit	Description	Selection	Details
spf.srijrr	ur	1/s	Strain rate tensor, rr-component	Domains 1–4	
spf.srijphir	0	1/s	Strain rate tensor, phir-component	Domains 1–4	
spf.srijzr	0.5*(wr+uz)	1/s	Strain rate tensor, zr-component	Domains 1–4	
spf.srijrphi	0	1/s	Strain rate tensor, rphi-component	Domains 1–4	
spf.srijphiphi	if(abs(r)<0.001*h_spatial,ur,u/r)	1/s	Strain rate tensor, phiphi-component	Domains 1–4	
spf.srijzphi	0	1/s	Strain rate tensor, zphi-component	Domains 1–4	
spf.srijrz	0.5*(uz+wr)	1/s	Strain rate tensor, rz-component	Domains 1–4	
spf.srijphiz	0	1/s	Strain rate tensor, phiz-component	Domains 1–4	
spf.srijzz	wz	1/s	Strain rate tensor, zz-component	Domains 1–4	
spf.rrijrr	0	1/s	Rotation rate tensor, rr-component	Domains 1–4	
spf.rrijphir	0	1/s	Rotation rate tensor, phir-component	Domains 1–4	
spf.rrijzr	0.5*(wr-uz)	1/s	Rotation rate tensor, zr-component	Domains 1–4	
spf.rrijrphi	0	1/s	Rotation rate tensor, rphi-component	Domains 1–4	
spf.rrijphiphi	0	1/s	Rotation rate tensor, phiphi-component	Domains 1–4	
spf.rrijzphi	0	1/s	Rotation rate tensor, zphi-component	Domains 1–4	
spf.rrijrz	0.5*(uz-wr)	1/s	Rotation rate tensor, rz-component	Domains 1–4	
spf.rrijphiz	0	1/s	Rotation rate tensor, phiz-	Domains 1–4	

Name	Expression	Unit	Description	Selection	Details
			component		
spf.rrijzz	0	1/s	Rotation rate tensor, zz-component	Domains 1–4	
spf.sr	sqrt(2*spf.srijrr^2+2*spf.srijrphi^2+2*spf.srijrz^2+2*spf.srijphir^2+2*spf.srijphiphi^2+2*spf.srijphiz^2+2*spf.srijzr^2+2*spf.srijzphi^2+2*spf.srijzz^2+eps)	1/s	Shear rate	Domains 1–4	
spf.rr	sqrt(2*spf.rrijrr^2+2*spf.rrijrphi^2+2*spf.rrijrz^2+2*spf.rrijphir^2+2*spf.rrijphiphi^2+2*spf.rrijphiz^2+2*spf.rrijzr^2+2*spf.rrijzphi^2+2*spf.rrijzz^2+eps)	1/s	Rotation rate	Domains 1–4	
spf.divu	ur+if(abs(r)<0.001*h_spatial,ur,u/r)+wz	1/s	Divergence of velocity field	Domains 1–4	
spf.U	sqrt(u^2+w^2)	m/s	Velocity magnitude	Domains 1–4	
spf.vorticityr	0	1/s	Vorticity field, r-component	Domains 1–4	
spf.vorticityphi	-wr+uz	1/s	Vorticity field, phi-component	Domains 1–4	
spf.vorticityz	0	1/s	Vorticity field, z-component	Domains 1–4	
spf.vort_magn	sqrt(spf.vorticityr^2+spf.vorticityphi^2+spf.vorticityz^2)	1/s	Vorticity magnitude	Domains 1–4	
spf.cellRe	0.25*spf.rho*sqrt(emetric_spatial(u-d(r,TIME),w-d(z,TIME))/emetric2_spatial)/spf.mu	1	Cell Reynolds number	Domains 1–4	
spf.nu	spf.mu/spf.rho	m^2/s	Kinematic viscosity	Domains 1–4	
spf.betaT	0	1/Pa	Isothermal compressibility coefficient	Domains 1–4	

Name	Expression	Unit	Description	Selection	Details
spf.Qm	0	kg/(m³·s)	Source term	Domains 1–4	+ operation
spf.Fgtotr	0	N/m³	Gravity force, r-component	Domains 1–4	+ operation
spf.Fgtotphi	0	N/m³	Gravity force, phi-component	Domains 1–4	+ operation
spf.Fgtotz	0	N/m³	Gravity force, z-component	Domains 1–4	+ operation
spf.Qm_aco	0	kg/(m³·s)	Acoustic mass source	Domains 1–4	
spf.F_acor	0	N/m³	Acoustic volume force, r-component	Domains 1–4	
spf.F_acophi	0	N/m³	Acoustic volume force, phi-component	Domains 1–4	
spf.F_acoz	0	N/m³	Acoustic volume force, z-component	Domains 1–4	
spf.gamma_sr	sqrt(2*spf.srijrr^2+2*spf.srijrphi^2+2*spf.srijrz^2+2*spf.srijphir^2+2*spf.srijphiphi^2+2*spf.srijphiz^2+2*spf.srijzr^2+2*spf.srijzphi^2+2*spf.srijzz^2+eps)	1/s	Shear rate	Domains 1–4	
spf.mu_eff	spf.mu+spf.muT	Pa·s	Effective dynamic viscosity	Domains 1–4	
spf.muT	0	Pa·s	Turbulent dynamic viscosity	Domains 1–4	+ operation
spf.T_stress_tensorrr	spf.K_stress_tensorrr-p	N/m²	Total stress tensor, rr-component	Domains 1–4	+ operation
spf.T_stress_tensorphir	spf.K_stress_tensorphir	N/m²	Total stress tensor, phir-component	Domains 1–4	+ operation
spf.T_stress_tensorzr	spf.K_stress_tensorzr	N/m²	Total stress tensor, zr-component	Domains 1–4	+ operation
spf.T_stress_tensorrphi	spf.K_stress_tensorrphi	N/m²	Total stress tensor, rphi-component	Domains 1–4	+ operation

Name	Expression	Unit	Description	Selection	Details
spf.T_stress_tensorphiphi	spf.K_stress_tensorphiphi-p	N/m²	Total stress tensor, phiphi-component	Domains 1–4	+ operation
spf.T_stress_tensorzphi	spf.K_stress_tensorzphi	N/m²	Total stress tensor, zphi-component	Domains 1–4	+ operation
spf.T_stress_tensorrz	spf.K_stress_tensorrz	N/m²	Total stress tensor, rz-component	Domains 1–4	+ operation
spf.T_stress_tensorphiz	spf.K_stress_tensorphiz	N/m²	Total stress tensor, phiz-component	Domains 1–4	+ operation
spf.T_stress_tensorzz	spf.K_stress_tensorzz-p	N/m²	Total stress tensor, zz-component	Domains 1–4	+ operation
spf.K_stress_tensorrr	2*spf.mu_eff*ur	N/m²	Viscous stress tensor, rr-component	Domains 1–4	+ operation
spf.K_stress_tensorphir	0	N/m²	Viscous stress tensor, phir-component	Domains 1–4	+ operation
spf.K_stress_tensorzr	spf.mu_eff*(wr+uz)	N/m²	Viscous stress tensor, zr-component	Domains 1–4	+ operation
spf.K_stress_tensorrphi	0	N/m²	Viscous stress tensor, rphi-component	Domains 1–4	+ operation
spf.K_stress_tensorphiphi	2*spf.mu_eff*if(abs(r)<0.001*h_spatial,ur,u/r)	N/m²	Viscous stress tensor, phiphi-component	Domains 1–4	+ operation
spf.K_stress_tensorzphi	0	N/m²	Viscous stress tensor, zphi-component	Domains 1–4	+ operation
spf.K_stress_tensorrz	spf.mu_eff*(uz+wr)	N/m²	Viscous stress tensor, rz-component	Domains 1–4	+ operation
spf.K_stress_tensorphiz	0	N/m²	Viscous stress tensor, phiz-component	Domains 1–4	+ operation
spf.K_stress_tensorzz	2*spf.mu_eff*wz	N/m²	Viscous stress tensor, zz-component	Domains 1–4	+ operation

Name	Expression	Unit	Description	Selection	Details
spf.K_stress_tensor_testrr	2*spf.mu_eff*test(ur)	N/m²	Viscous stress tensor test, rr-component	Domains 1–4	+ operation
spf.K_stress_tensor_testphir	0	N/m²	Viscous stress tensor test, phir-component	Domains 1–4	+ operation
spf.K_stress_tensor_testzr	spf.mu_eff*(test(wr)+test(uz))	N/m²	Viscous stress tensor test, zr-component	Domains 1–4	+ operation
spf.K_stress_tensor_testrphi	0	N/m²	Viscous stress tensor test, rphi-component	Domains 1–4	+ operation
spf.K_stress_tensor_testphiphi	2*spf.mu_eff*if(abs(r)<0.001*h_spatial,test(ur),test(u)/r)	N/m²	Viscous stress tensor test, phiphi-component	Domains 1–4	+ operation
spf.K_stress_tensor_testzphi	0	N/m²	Viscous stress tensor test, zphi-component	Domains 1–4	+ operation
spf.K_stress_tensor_testrz	spf.mu_eff*(test(uz)+test(wr))	N/m²	Viscous stress tensor test, rz-component	Domains 1–4	+ operation
spf.K_stress_tensor_testphiz	0	N/m²	Viscous stress tensor test, phiz-component	Domains 1–4	+ operation
spf.K_stress_tensor_testzz	2*spf.mu_eff*test(wz)	N/m²	Viscous stress tensor test, zz-component	Domains 1–4	+ operation
spf.upwind_helpr	-d(r,TIME)	m/s	Upwind term, r-component	Domains 1–4	+ operation
spf.upwind_helpphi	0	m/s	Upwind term, phi-component	Domains 1–4	+ operation
spf.upwind_helpz	-d(z,TIME)	m/s	Upwind term, z-component	Domains 1–4	+ operation
spf.continuityEquation	spf.rho*spf.divu	kg/(m³·s)	Continuity equation	Domains 1–4	
spf.contCoeff	spf.rho	kg/m³	Help variable	Domains 1–4	
spf.tau_vdrr	2*spf.mu*spf.srijrr	Pa	Viscous stress tensor, rr-component	Domains 1–4	+ operation
spf.tau_vdphir	2*spf.mu*spf.srijphir	Pa	Viscous stress tensor, phir-	Domains 1–4	+ operation

Name	Expression	Unit	Description	Selection	Details
			component		
spf.tau_vdzr	2*spf.mu*spf.srijzr	Pa	Viscous stress tensor, zr-component	Domains 1–4	+ operation
spf.tau_vdrphi	2*spf.mu*spf.srijrphi	Pa	Viscous stress tensor, rphi-component	Domains 1–4	+ operation
spf.tau_vdphiphi	2*spf.mu*spf.srijphiphi	Pa	Viscous stress tensor, phiphi-component	Domains 1–4	+ operation
spf.tau_vdzphi	2*spf.mu*spf.srijzphi	Pa	Viscous stress tensor, zphi-component	Domains 1–4	+ operation
spf.tau_vdrz	2*spf.mu*spf.srijrz	Pa	Viscous stress tensor, rz-component	Domains 1–4	+ operation
spf.tau_vdphiz	2*spf.mu*spf.srijphiz	Pa	Viscous stress tensor, phiz-component	Domains 1–4	+ operation
spf.tau_vdzz	2*spf.mu*spf.srijzz	Pa	Viscous stress tensor, zz-component	Domains 1–4	+ operation
spf.Qvd	spf.tau_vdrr*ur+spf.tau_vdrz*uz+spf.tau_vdphiphi*if(abs(r)<0.001*h_spatial,ur,u/r)+spf.tau_vdzr*wr+spf.tau_vdzz*wz	W/m^3	Viscous dissipation	Domains 1–4	+ operation
spf.epsilon_p	1	1	Porosity	Domains 1–4	
spf.epsilon_p_pos	1	1	Positive porosity	Domains 1–4	
spf.Fst_tensorrr	0	N/m^2	Surface tension force, rr-component	Domains 1–4	+ operation
spf.Fst_tensorphir	0	N/m^2	Surface tension force, phir-component	Domains 1–4	+ operation
spf.Fst_tensorzr	0	N/m^2	Surface tension force, zr-component	Domains 1–4	+ operation
spf.Fst_tensorrphi	0	N/m^2	Surface tension force, rphi-component	Domains 1–4	+ operation

Name	Expression	Unit	Description	Selection	Details
spf.Fst_tensorphiphi	0	N/m²	Surface tension force, phiphi-component	Domains 1–4	+ operation
spf.Fst_tensorzphi	0	N/m²	Surface tension force, zphi-component	Domains 1–4	+ operation
spf.Fst_tensorrz	0	N/m²	Surface tension force, rz-component	Domains 1–4	+ operation
spf.Fst_tensorphiz	0	N/m²	Surface tension force, phiz-component	Domains 1–4	+ operation
spf.Fst_tensorzz	0	N/m²	Surface tension force, zz-component	Domains 1–4	+ operation
spf.res_u	spf.rho*(uTIME-d(u,r)*d(r,TIME)-d(u,z)*d(z,TIME))+pr-(d(2*ur,r)+if(abs(r)<0.001*h_spatial,d(2*ur,r),2*ur/r)+d(uz+wr,z)-2*if(abs(r)<0.001*h_spatial,ur,u/r)/r)*spf.mu-spf.Fr	N/m³	Equation residual	Domains 1–4	
spf.res_v	-spf.Fphi	N/m³	Equation residual	Domains 1–4	
spf.res_w	spf.rho*(wTIME-d(w,r)*d(r,TIME)-d(w,z)*d(z,TIME))+pz-(d(wr+uz,r)+if(abs(r)<0.001*h_spatial,d(wr+uz,r),(wr+uz)/r)+d(2*wz,z))*spf.mu-spf.Fz	N/m³	Equation residual	Domains 1–4	
spf.res_p	spf.rho*spf.divu	kg/(m³·s)	Pressure equation residual	Domains 1–4	

2.4.3.3 Shape functions

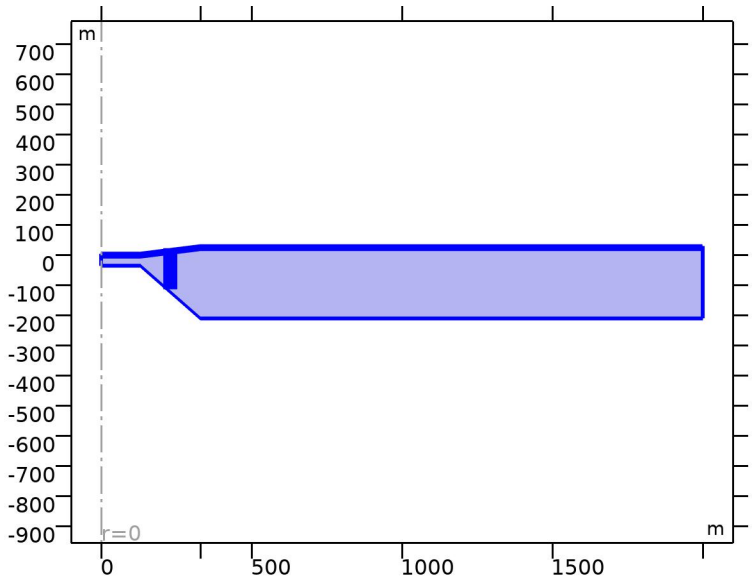
Name	Shape function	Unit	Description	Shape frame	Selection
u	Lagrange (Quadratic)	m/s	Velocity field, r-component	Spatial	Domains 1–4

Name	Shape function	Unit	Description	Shape frame	Selection
w	Lagrange (Quadratic)	m/s	Velocity field, z-component	Spatial	Domains 1–4
u	Lagrange (Quadratic)	m/s	Velocity field, r-component	Spatial	Domains 1–4
w	Lagrange (Quadratic)	m/s	Velocity field, z-component	Spatial	Domains 1–4
p	Lagrange (Linear)	Pa	Pressure	Spatial	Domains 1–4

2.4.3.4 Weak Expressions

Weak expression	Integration order	Integration frame	Selection
2*spf.rho*(-(uTIME-ur*d(r,TIME)-uz*d(z,TIME))*test(u)-(wTIME-wr*d(r,TIME)-wz*d(z,TIME))*test(w))*pi*r	4	Spatial	Domains 1–4
2*((p-spf.K_stress_tensorrr)*test(ur)-spf.K_stress_tensorrz*test(uz)+(p-spf.K_stress_tensorphiphi)*if(abs(r)<0.001*h_spatial,test(ur),test(u)/r)-spf.K_stress_tensorzr*test(wr)+(p-spf.K_stress_tensorzz)*test(wz))*pi*r	4	Spatial	Domains 1–4
2*(spf.Fr*test(u)+spf.Fz*test(w))*pi*r	4	Spatial	Domains 1–4
-2*spf.continuityEquation*test(p)*pi*r	4	Spatial	Domains 1–4
2*spf.streamlinens*pi*r	4	Spatial	Domains 1–4

2.4.4 Initial Values 1



Initial Values 1

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: All domains

2.4.4.1 Initial Values

SETTINGS

Description	Value	Unit
Velocity field, r-component	0	m/s
Velocity field, phi-component	0	m/s
Velocity field, z-component	0	m/s
Pressure	0	Pa

2.4.4.2 Coordinate System Selection

SETTINGS

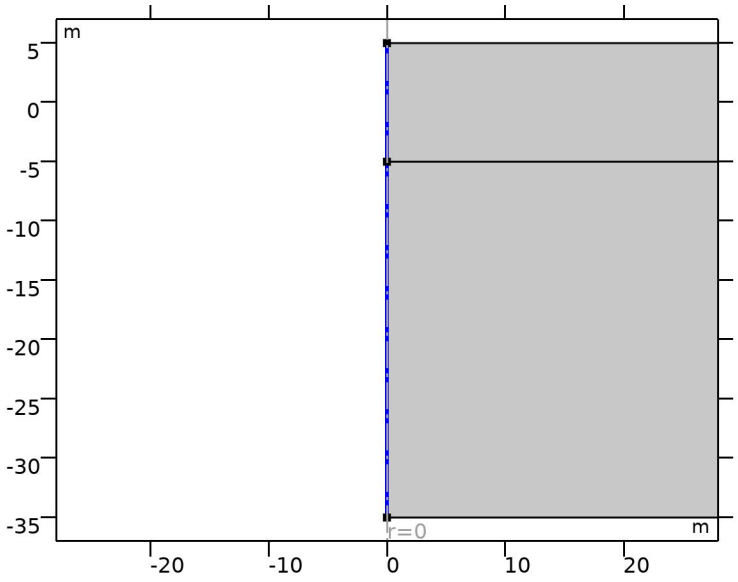
Description	Value
Coordinate system	Global coordinate system

2.4.4.3 Variables

Name	Expression	Unit	Description	Selection
spf.u_initr	0	m/s	Velocity field, r-component	Domains 1–4
spf.u_initphi	0	m/s	Velocity field, phi-component	Domains 1–4
spf.u_initz	0	m/s	Velocity field, z-component	Domains 1–4

Name	Expression	Unit	Description	Selection
spf.p_init	0	Pa	Pressure	Domains 1–4

2.4.5 Axial Symmetry 1



Axial Symmetry 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 1: All boundaries

2.4.5.1 Constraint Settings

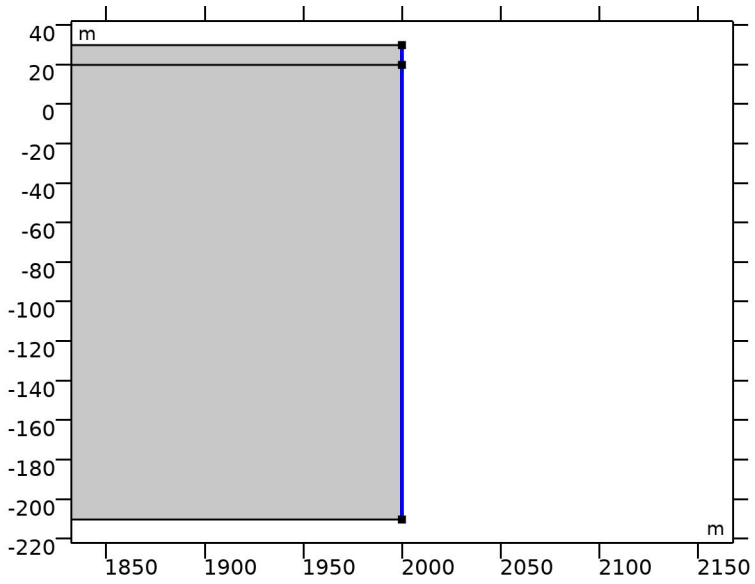
SETTINGS

Description	Value
Apply reaction terms on	All physics (symmetric)
Constraint method	Elemental

2.4.5.2 Constraints

Constraint	Constraint force	Shape function	Selection	Details
-u	test(-u)	Lagrange (Quadratic)	Boundaries 1, 3	Elemental

2.4.6 outer wall



outer wall

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 1: All boundaries

EQUATIONS

2.4.6.1 Boundary Condition

SETTINGS

Description	Value
Wall condition	Slip

2.4.6.2 Wall Movement

SETTINGS

Description	Value	Unit
Translational velocity	Manual	
Velocity of moving wall, r-component	wall_movement	m/s
Velocity of moving wall, phi-component	0	m/s
Velocity of moving wall, z-component	0	m/s

2.4.6.3 Constraint Settings

SETTINGS

Description	Value
Constraints	Default

Description	Value
Apply reaction terms on	Individual dependent variables
Constraint method	Elemental

2.4.6.4 Variables

Name	Expression	Unit	Description	Selection	Details
spf.ubndr	spf.utrr+spf.usr	m/s	Velocity at boundary, r-component	Boundaries 14–15	
spf.ubndphi	spf.utrphi+spf.usphi	m/s	Velocity at boundary, phi-component	Boundaries 14–15	
spf.ubndz	spf.utrz+spf.usz	m/s	Velocity at boundary, z-component	Boundaries 14–15	
spf.utrr	wall_movement	m/s	Velocity of moving wall, r-component	Boundaries 14–15	
spf.utrphi	0	m/s	Velocity of moving wall, phi-component	Boundaries 14–15	
spf.utrz	0	m/s	Velocity of moving wall, z-component	Boundaries 14–15	
spf.usr	0	m/s	Velocity of sliding wall, r-component	Boundaries 14–15	
spf.usphi	0	m/s	Velocity of sliding wall, phi-component	Boundaries 14–15	
spf.usz	0	m/s	Velocity of sliding wall, z-component	Boundaries 14–15	
spf.uLeakager	0	m/s	Leakage velocity, r-component	Boundaries 14–15	+ operation
spf.uLeakagephi	0	m/s	Leakage velocity, phi-component	Boundaries 14–15	+ operation
spf.uLeakagez	0	m/s	Leakage velocity, z-component	Boundaries 14–15	+ operation
spf.noSlipWall	0	1	Help variable	Boundaries 14–15	
spf.un_here	u*nojac(spf.nrmesh)+ w*nojac(spf.nzmesh)	m/s	Intermediate variable	Boundaries 14–15	

Name	Expression	Unit	Description	Selection	Details
spf.u_herer	spf.un_here*nojac(spf.nrmesh)	m/s	Intermediate variable, r-component	Boundaries 14–15	
spf.u_herephi	spf.un_here*nojac(spf.nphimesh)	m/s	Intermediate variable, phi-component	Boundaries 14–15	
spf.u_herez	spf.un_here*nojac(spf.nzmesh)	m/s	Intermediate variable, z-component	Boundaries 14–15	
spf.un_there	(spf.ubndr+spf.uLeakager)*nojac(spf.nrmesh)+(spf.ubndphi+spf.uLeakagephi)*nojac(spf.nphimesh)+(spf.ubndz+spf.uLeakagez)*nojac(spf.nzmesh)	m/s	Intermediate variable	Boundaries 14–15	
spf.u_therer	spf.un_there*nojac(spf.nrmesh)	m/s	Intermediate variable, r-component	Boundaries 14–15	
spf.u_therephi	spf.un_there*nojac(spf.nphimesh)	m/s	Intermediate variable, phi-component	Boundaries 14–15	
spf.u_therez	spf.un_there*nojac(spf.nzmesh)	m/s	Intermediate variable, z-component	Boundaries 14–15	
spf.unJump	spf.un_here-spf.un_there	m/s	Jump in normal velocity	Boundaries 14–15	
spf.KStressn_avr	spf.K_stress_tensorrr*spf.nrmesh+spf.K_stress_tensorrphi*spf.nphimesh+spf.K_stress_tensorrz*spf.nzmesh	N/m^2	Average viscous stress, r-component	Boundaries 14–15	
spf.KStressn_avphi	spf.K_stress_tensorphir*spf.nrmesh+spf.K_stress_tensorphiphi*spf.nphimesh+spf.K_stress_tensorphiz*spf.nzmesh	N/m^2	Average viscous stress, phi-component	Boundaries 14–15	
spf.KStressn_avz	spf.K_stress_tensorzr*spf.nrmesh+spf.K_stress_tensorzphi*spf.nphimesh+spf.K_stress_tensorzz*spf.nzmesh	N/m^2	Average viscous stress, z-component	Boundaries 14–15	

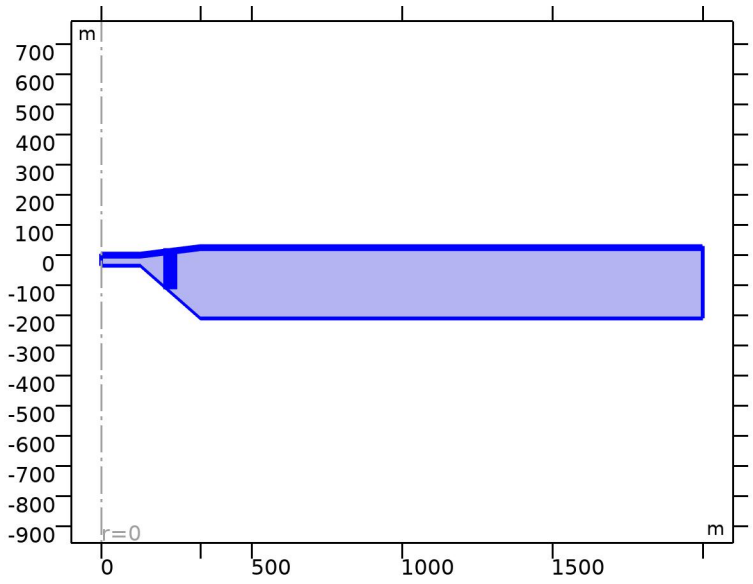
Name	Expression	Unit	Description	Selection	Details
spf.KStressTestn_avr	spf.K_stress_tensor_testrr*spf.nrmesh+spf.K_stress_tensor_testrphi*spf.nphimesh+spf.K_stress_tensor_testrz*spf.nzmesh	N/m²	Average viscous stress, r-component	Boundaries 14–15	
spf.KStressTestn_avphi	spf.K_stress_tensor_testphir*spf.nrmesh+spf.K_stress_tensor_testphiphi*spf.nphimesh+spf.K_stress_tensor_testphiz*spf.nzmesh	N/m²	Average viscous stress, phi-component	Boundaries 14–15	
spf.KStressTestn_avz	spf.K_stress_tensor_testzr*spf.nrmesh+spf.K_stress_tensor_testzphi*spf.nphimesh+spf.K_stress_tensor_testzz*spf.nzmesh	N/m²	Average viscous stress, z-component	Boundaries 14–15	
spf.ujumpr	spf.u_herer-spf.u_therer	m/s	Velocity jump, r-component	Boundaries 14–15	
spf.ujumpphi	spf.u_herephi-spf.u_therephi	m/s	Velocity jump, phi-component	Boundaries 14–15	
spf.ujumpz	spf.u_herez-spf.u_therez	m/s	Velocity jump, z-component	Boundaries 14–15	
spf.contCoeffFace	down(spf.contCoeff)	kg/m³	Help variable	Boundaries 14–15	
spf.rhoFace	down(spf.rho)	kg/m³	Density face value	Boundaries 14–15	
spf.c_here	72*nojac(down(spf.mu+spf.muT)/down(1))*spf.meshVol/spf.meshVolInt	Pa·s/m	Intermediate variable	Boundaries 14–15	
spf.meshVol	meshvol_spatial	m		Boundaries 14–15	
spf.meshVolInt	down(meshvol_spatial)	m²	Volume of interior mesh element	Boundaries 14–15	
spf.sigma_dg_ns	4*spf.c_here	Pa·s/m		Boundaries 14–15	
spf.umxTnFace	(spf.upwind_helpr*spf.nrmesh+spf.upwind_helpphi*spf.nphimesh+spf.upwind_helpz*s	m/s	Relative velocity on face	Boundaries 14–15	

Name	Expression	Unit	Description	Selection	Details
	pf.nzmesh<0)*(spf.upwind_helpr*spf.nrmesh+spf.upwind_helpphi*spf.nphimesh+spf.upwind_helpz*spf.nzmesh)				
spf.upwind_ns	spf.rhoFace*spf.umxTnFace*spf.unJump*test(spf.un_here)/down(1)^2	W/m²	Upwind term	Boundaries 14–15	
spf.upwindCont	spf.contCoeffFace*spf.unJump*test(p)	kg²/(m³·s³)	Upwind term for continuity equation	Boundaries 14–15	
spf.pFace	p	Pa	Pressure face value	Boundaries 14–15	
spf.consFlux	-spf.pFace*test(spf.un_here)	W/m²	Conservative flux	Boundaries 14–15	+ operation

2.4.6.5 Weak Expressions

Weak expression	Integration order	Integration frame	Selection
2*(spf.KStressn_avr*test(spf.u_herer)+spf.KStressn_avphi*test(spf.u_herephi)+spf.KStressn_avz*test(spf.u_herez)+spf.KStressTestn_avr*spf.ujumpr+spf.KStressTestn_avphi*spf.ujumpphi+spf.KStressTestn_avz*spf.ujumpz-spf.sigma_dg_ns*spf.unJump*test(spf.un_here)+spf.upwind_ns+spf.upwindCont+spf.consFlux)*pi*r	4	Spatial	Boundaries 14–15

2.4.7 Gravity (turn on or off)



Gravity (turn on or off)

SELECTION

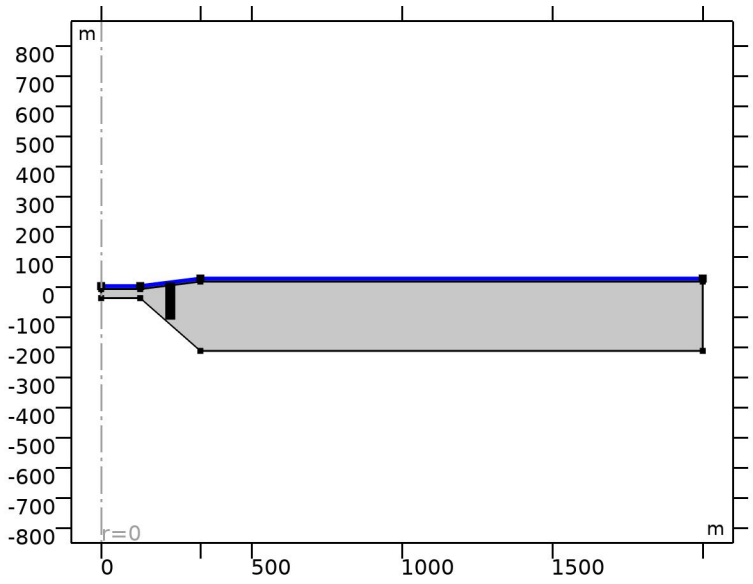
Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domains 1–4

EQUATIONS

2.4.7.1 Variables

Name	Expression	Unit	Description	Selection	Details
spf.Fr	0	N/m³	Volume force, r-component	Domains 1–4	+ operation
spf.Fphi	0	N/m³	Volume force, phi-component	Domains 1–4	+ operation
spf.Fz	-g_const*rho_i	N/m³	Volume force, z-component	Domains 1–4	+ operation

2.4.8 Free Surface 1



Free Surface 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 1: Boundaries 5, 9, 13

EQUATIONS

2.4.8.1 Free Surface

SETTINGS

Description	Value	Unit
External pressure	0	Pa

2.4.8.2 Surface Tension

SETTINGS

Description	Value
Include surface tension force in momentum equation	Off

2.4.8.3 Mass Flux

SETTINGS

Description	Value	Unit
Mass flux	User defined	
Mass flux	0	kg/(m^2·s)

2.4.8.4 Variables

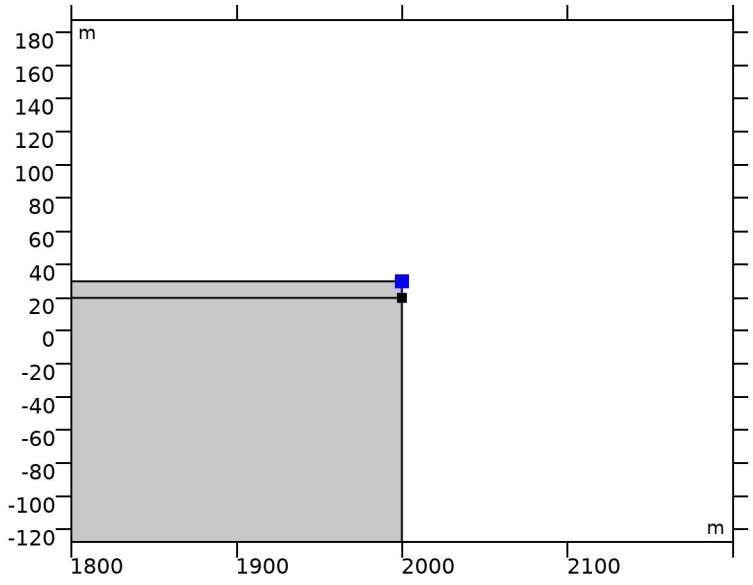
Name	Expression	Unit	Description	Selection
spf.ubndr	d(r,TIME)	m/s	Velocity at boundary, r-component	Boundaries 5, 9, 13
spf.ubndphi	0	m/s	Velocity at boundary, phi-component	Boundaries 5, 9, 13
spf.ubndz	d(z,TIME)	m/s	Velocity at boundary, z-component	Boundaries 5, 9, 13
spf.pext	0	Pa	External pressure	Boundaries 5, 9, 13
spf.Mf	0[kg/(m^2*s)]	kg/(m²·s)	Mass flux	Boundaries 5, 9, 13
spf.sigma	0	N/m	Surface tension coefficient	Boundaries 5, 9, 13
spf.vn	(u-spf.Mf*spf.iNr/spf.rho)*spf.dnrmesh-spf.Mf*spf.iNphi*spf.dnphimesh/spf.rho+(w-spf.Mf*spf.iNz/spf.rho)*spf.dnzmesh	m/s	Normal mesh velocity	Boundaries 5, 9, 13
spf.iNr	spf.nrmesh	1	Interface normal, r-component	Boundaries 5, 9, 13
spf.iNphi	spf.nphimesh	1	Interface normal, phi-component	Boundaries 5, 9, 13
spf.iNz	spf.nzmesh	1	Interface normal, z-component	Boundaries 5, 9, 13
spf.Tstrr	spf.sigma*(1-spf.iNr^2)	N/m	Help variable, rr-component	Boundaries 5, 9, 13
spf.Tstphir	-spf.sigma*spf.iNphi*spf.iNr	N/m	Help variable, phir-component	Boundaries 5, 9, 13
spf.Tstzr	-spf.sigma*spf.iNz*spf.iNr	N/m	Help variable, zr-component	Boundaries 5, 9, 13
spf.Tstrphi	-spf.sigma*spf.iNr*spf.iNphi	N/m	Help variable, rphi-component	Boundaries 5, 9, 13

Name	Expression	Unit	Description	Selection
spf.Tstphiphi	spf.sigma*(1-spf.iNphi^2)	N/m	Help variable, phiphi-component	Boundaries 5, 9, 13
spf.Tstzphi	-spf.sigma*spf.iNz*spf.iNphi	N/m	Help variable, zphi-component	Boundaries 5, 9, 13
spf.Tstrz	-spf.sigma*spf.iNr*spf.iNz	N/m	Help variable, rz-component	Boundaries 5, 9, 13
spf.Tstphiz	-spf.sigma*spf.iNphi*spf.iNz	N/m	Help variable, phiz-component	Boundaries 5, 9, 13
spf.Tstzz	spf.sigma*(1-spf.iNz^2)	N/m	Help variable, zz-component	Boundaries 5, 9, 13

2.4.8.5 Weak Expressions

Weak expression	Integration order	Integration frame	Selection
2*(-spf.pext*(spf.iNr*test(u)+spf.iNz*test(w))-spf.sigma*(test(uTr)+test(u)/r+test(wTz)))*pi*r	4	Spatial	Boundaries 5, 9, 13

2.4.8.6 Contact Angle 1



Contact Angle 1

SELECTION

Geometric entity level	Point

Selection	Geometry geom1: Dimension 0: All points

Contact Angle

SETTINGS

Description	Value	Unit
Specify contact angle	Directly	
Contact angle	1.5708	rad

Normal Wall Velocity

SETTINGS

Description	Value
Constrain wall-normal velocity	Off

Variables

Name	Expression	Unit	Description	Selection
spf.thetac	pi/2[rad]	rad	Contact angle	Point 16
spf.nwallr	spf.nrmesh	1	Help variable, r-component	Boundary 15
spf.nwallphi	spf.nphimesh	1	Help variable, phi-component	Boundary 15
spf.nwallz	spf.nzmesh	1	Help variable, z-component	Boundary 15
spf.sN_denom	nojac(max(sqrt(spf.nwallr^2+spf.nwallphi^2+spf.nwallz^2),eps))	1	Help variable	Point 16
spf.sNr	spf.nwallr/spf.sN_denom	1	Surface normal, r-component	Point 16
spf.sNphi	spf.nwallphi/spf.sN_denom	1	Surface normal, phi-component	Point 16
spf.sNz	spf.nwallz/spf.sN_denom	1	Surface normal, z-component	Point 16
spf.tc_denom	nojac(max(sqrt((spf.sNz*spf.iNphi-spf.sNphi*spf.iNz)^2+(-spf.sNz*spf.iNr+spf.sNr*spf.iNz)^2+(spf.sNphi*spf.iNr-spf.sNr*spf.iNphi)^2),eps))	1	Help variable	Point 16
spf.tcr	(spf.sNz*spf.iNphi-spf.sNphi*spf.iNz)/spf.tc_denom	1	Contact tangent, r-component	Point 16

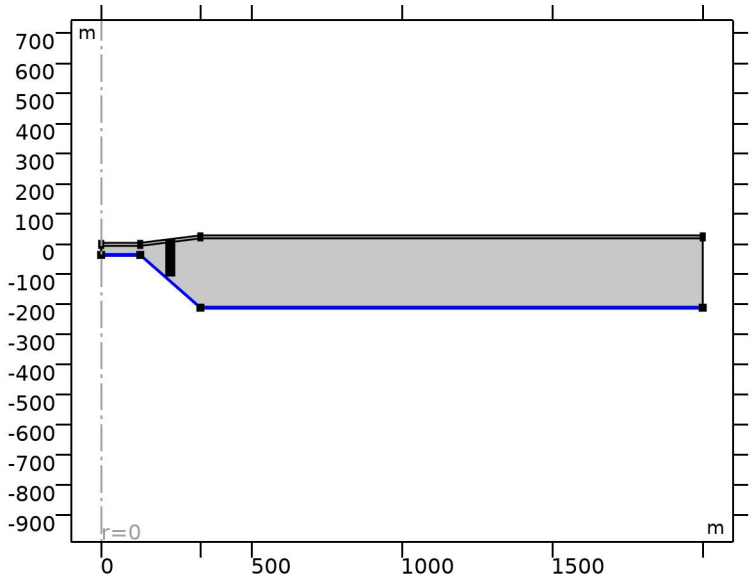
Name	Expression	Unit	Description	Selection
spf.tcphi	(-spf.sNz*spf.iNr+spf.sNr*spf.iNz)/spf.tc_denom	1	Contact tangent, phi-component	Point 16
spf.tcz	(spf.sNphi*spf.iNr-spf.sNr*spf.iNphi)/spf.tc_denom	1	Contact tangent, z-component	Point 16
spf.mi_denom	nojac(max(sqrt((spf.sNz*spf.iNphi-spf.sNphi*spf.iNz)^2+(-spf.sNz*spf.iNr+spf.sNr*spf.iNz)^2+(spf.sNphi*spf.iNr-spf.sNr*spf.iNphi)^2),eps))	1	Help variable	Point 16
spf.mir	(spf.sNz*spf.iNphi-spf.sNphi*spf.iNz)/spf.mi_denom	1	Interface binormal, r-component	Point 16
spf.miphi	(-spf.sNz*spf.iNr+spf.sNr*spf.iNz)/spf.mi_denom	1	Interface binormal, phi-component	Point 16
spf.miz	(spf.sNphi*spf.iNr-spf.sNr*spf.iNphi)/spf.mi_denom	1	Interface binormal, z-component	Point 16
spf.ms_denom	nojac(max(sqrt((spf.iNr-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNr)^2+(spf.iNphi-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNphi)^2+(spf.iNz-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNz)^2),eps))	1	Help variable	Point 16
spf.msr	(spf.iNr-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNr)/spf.ms_denom	1	Surface binormal, r-component	Point 16
spf.msphi	(spf.iNphi-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNphi)/spf.ms_denom	1	Surface binormal, phi-component	Point 16
spf.msz	(spf.iNz-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNz)/spf.ms_denom	1	Surface binormal, z-component	Point 16

Weak Expressions

Weak expression	Integration order	Integration frame	Selection
2*spf.sigma*cos(spf.thetac)*(spf.msr*test(u)+spf.msz*test(w))*pi*r	4	Spatial	Point 16
2*spf.sigma*sin(spf.thetac)*(spf.sNr*tes	4	Spatial	Point 16

Weak expression	Integration order	Integration frame	Selection
t(u)+spf.sNz*test(w))*pi*r			

2.4.9 bottom (hydrostatic sea water pressure)



bottom (hydrostatic sea water pressure)

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 1: Boundaries 2, 6, 10

EQUATIONS

2.4.9.1 Free Surface

SETTINGS

Description	Value	Unit
External pressure	-rho_sw*g_const*z	Pa

2.4.9.2 Surface Tension

SETTINGS

Description	Value
Include surface tension force in momentum equation	Off

2.4.9.3 Mass Flux

SETTINGS

Description	Value	Unit
Mass flux	User defined	

Description	Value	Unit
Mass flux	0	kg/(m²·s)

2.4.9.4 Variables

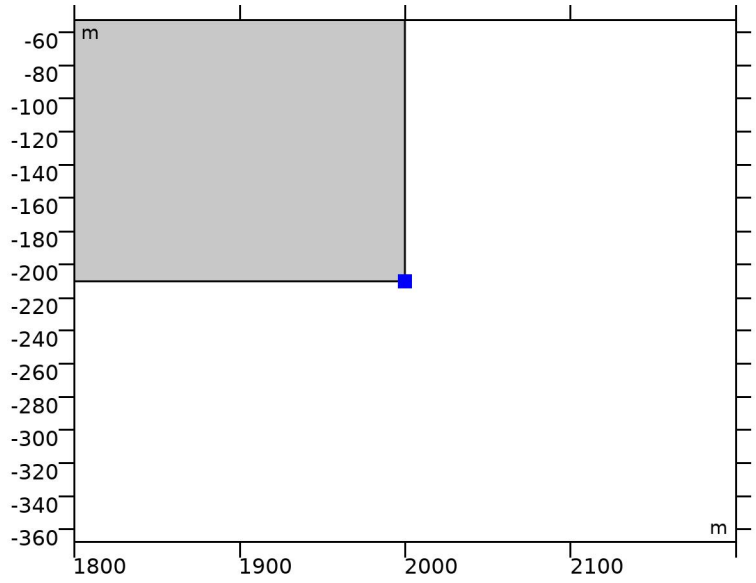
Name	Expression	Unit	Description	Selection
spf.ubndr	d(r,TIME)	m/s	Velocity at boundary, r-component	Boundaries 2, 6, 10
spf.ubndphi	0	m/s	Velocity at boundary, phi-component	Boundaries 2, 6, 10
spf.ubndz	d(z,TIME)	m/s	Velocity at boundary, z-component	Boundaries 2, 6, 10
spf.pext	-rho_sw*g_const*z	Pa	External pressure	Boundaries 2, 6, 10
spf.Mf	0[kg/(m^2*s)]	kg/(m²·s)	Mass flux	Boundaries 2, 6, 10
spf.sigma	0	N/m	Surface tension coefficient	Boundaries 2, 6, 10
spf.vn	(u-spf.Mf*spf.iNr/spf.rho)*spf.dnrmesh-spf.Mf*spf.iNphi*spf.dnphimesh/spf.rho+(w-spf.Mf*spf.iNz/spf.rho)*spf.dnzmesh	m/s	Normal mesh velocity	Boundaries 2, 6, 10
spf.iNr	spf.nrmesh	1	Interface normal, r-component	Boundaries 2, 6, 10
spf.iNphi	spf.nphimesh	1	Interface normal, phi-component	Boundaries 2, 6, 10
spf.iNz	spf.nzmesh	1	Interface normal, z-component	Boundaries 2, 6, 10
spf.Tstrr	spf.sigma*(1-spf.iNr^2)	N/m	Help variable, rr-component	Boundaries 2, 6, 10
spf.Tstphir	-spf.sigma*spf.iNphi*spf.iNr	N/m	Help variable, phir-component	Boundaries 2, 6, 10
spf.Tstzr	-spf.sigma*spf.iNz*spf.iNr	N/m	Help variable, zr-component	Boundaries 2, 6, 10

Name	Expression	Unit	Description	Selection
spf.Tstrphi	-spf.sigma*spf.iNr*spf.iNphi	N/m	Help variable, rphi-component	Boundaries 2, 6, 10
spf.Tstphiphi	spf.sigma*(1-spf.iNphi^2)	N/m	Help variable, phiphi-component	Boundaries 2, 6, 10
spf.Tstzphi	-spf.sigma*spf.iNz*spf.iNphi	N/m	Help variable, zphi-component	Boundaries 2, 6, 10
spf.Tstrz	-spf.sigma*spf.iNr*spf.iNz	N/m	Help variable, rz-component	Boundaries 2, 6, 10
spf.Tstphiz	-spf.sigma*spf.iNphi*spf.iNz	N/m	Help variable, phiz-component	Boundaries 2, 6, 10
spf.Tstzz	spf.sigma*(1-spf.iNz^2)	N/m	Help variable, zz-component	Boundaries 2, 6, 10

2.4.9.5 Weak Expressions

Weak expression	Integration order	Integration frame	Selection
2*(-spf.pext*(spf.iNr*test(u)+spf.iNz*test(w))-spf.sigma*(test(uTr)+test(u)/r+test(wTz)))*pi*r	4	Spatial	Boundaries 2, 6, 10

2.4.9.6 Contact Angle 1



Contact Angle 1

SELECTION

Geometric entity level	Point
Selection	Geometry geom1: Dimension 0: All points

Contact Angle

SETTINGS

Description	Value	Unit
Specify contact angle	Directly	
Contact angle	1.5708	rad

Normal Wall Velocity

SETTINGS

Description	Value
Constrain wall-normal velocity	Off

Variables

Name	Expression	Unit	Description	Selection
spf.thetac	pi/2[rad]	rad	Contact angle	Point 14
spf.nwallr	spf.nrmesh	1	Help variable, r-component	Boundary 14
spf.nwallphi	spf.nphimesh	1	Help variable, phi-component	Boundary 14
spf.nwallz	spf.nzmesh	1	Help variable, z-component	Boundary 14
spf.sN_denom	nojac(max(sqrt(spf.nwallr^2+spf.nwallphi^2+spf.nwallz^2),eps))	1	Help variable	Point 14
spf.sNr	spf.nwallr/spf.sN_denom	1	Surface normal, r-component	Point 14
spf.sNphi	spf.nwallphi/spf.sN_denom	1	Surface normal, phi-component	Point 14
spf.sNz	spf.nwallz/spf.sN_denom	1	Surface normal, z-component	Point 14
spf.tc_denom	nojac(max(sqrt((spf.sNz*spf.iNphi-spf.sNphi*spf.iNz)^2+(-spf.sNz*spf.iNr+spf.sNr*spf.iNz)^2+(spf.sNphi*spf.iNr-spf.sNr*spf.iNphi)^2),eps))	1	Help variable	Point 14
spf.tcr	(spf.sNz*spf.iNphi-	1	Contact	Point 14

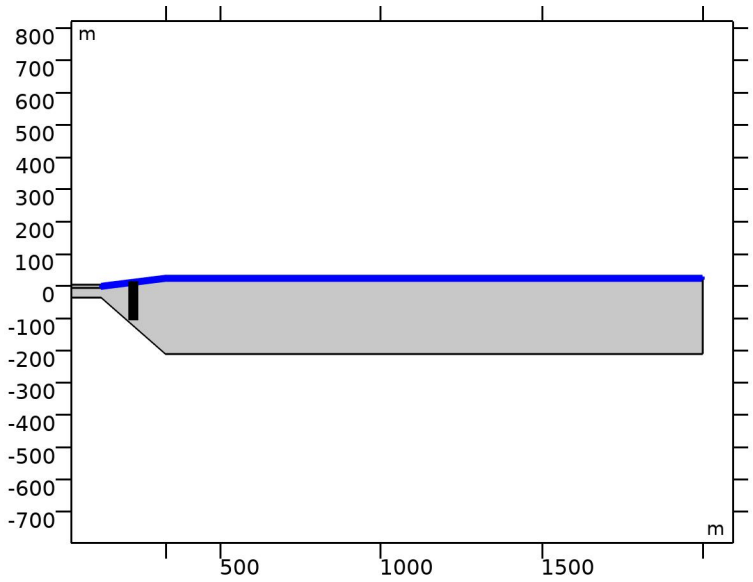
Name	Expression	Unit	Description	Selection
	spf.sNphi*spf.iNz)/spf.tc_denom		tangent, r-component	
spf.tcphi	(-spf.sNz*spf.iNr+spf.sNr*spf.iNz)/spf.tc_denom	1	Contact tangent, phi-component	Point 14
spf.tcz	(spf.sNphi*spf.iNr-spf.sNr*spf.iNphi)/spf.tc_denom	1	Contact tangent, z-component	Point 14
spf.mi_denom	nojac(max(sqrt((spf.sNz*spf.iNphi-spf.sNphi*spf.iNz)^2+(-spf.sNz*spf.iNr+spf.sNr*spf.iNz)^2+(spf.sNphi*spf.iNr-spf.sNr*spf.iNphi)^2),eps))	1	Help variable	Point 14
spf.mir	(spf.sNz*spf.iNphi-spf.sNphi*spf.iNz)/spf.mi_denom	1	Interface binormal, r-component	Point 14
spf.miphi	(-spf.sNz*spf.iNr+spf.sNr*spf.iNz)/spf.mi_denom	1	Interface binormal, phi-component	Point 14
spf.miz	(spf.sNphi*spf.iNr-spf.sNr*spf.iNphi)/spf.mi_denom	1	Interface binormal, z-component	Point 14
spf.ms_denom	nojac(max(sqrt((spf.iNr-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNr)^2+(spf.iNphi-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNphi)^2+(spf.iNz-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNz)^2),eps))	1	Help variable	Point 14
spf.msr	(spf.iNr-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNr)/spf.ms_denom	1	Surface binormal, r-component	Point 14
spf.msphi	(spf.iNphi-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNphi)/spf.ms_denom	1	Surface binormal, phi-component	Point 14
spf.msz	(spf.iNz-(spf.sNr*spf.iNr+spf.sNphi*spf.iNphi+spf.sNz*spf.iNz)*spf.sNz)/spf.ms_denom	1	Surface binormal, z-component	Point 14

Weak Expressions

Weak expression	Integration order	Integration frame	Selection
2*spf.sigma*cos(spf.thetac)*(spf.msr*te	4	Spatial	Point 14

Weak expression	Integration order	Integration frame	Selection
st(u)+spf.msz*test(w))*pi*r			
2*spf.sigma*sin(spf.thetac)*(spf.sNr*test(u)+spf.sNz*test(w))*pi*r	4	Spatial	Point 14

2.4.10 Ablation load (as body force in thin layer)



Ablation load (as body force in thin layer)

SELECTION

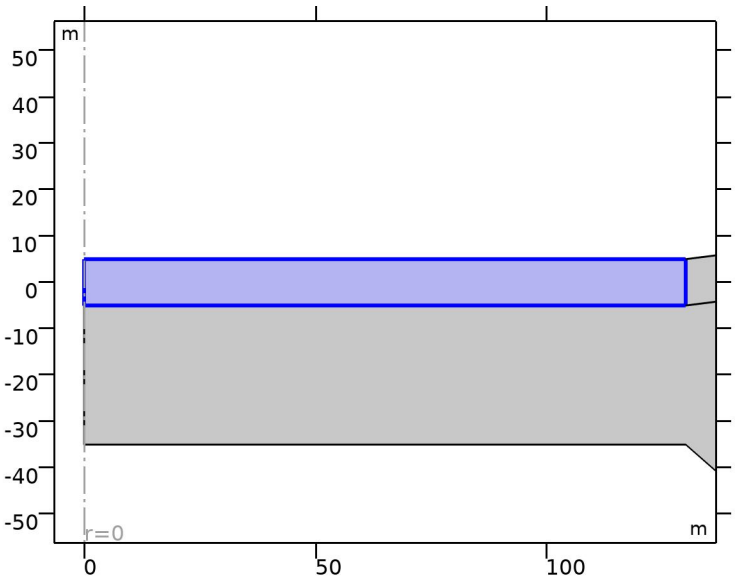
Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domains 3–4

EQUATIONS

2.4.10.1 Variables

Name	Expression	Unit	Description	Selection	Details
spf.Fr	0	N/m³	Volume force, r-component	Domains 3–4	+ operation
spf.Fphi	0	N/m³	Volume force, phi-component	Domains 3–4	+ operation
spf.Fz	0.1*rho_i*g_const*A_cumulative	N/m³	Volume force, z-component	Domains 3–4	+ operation

2.4.11 Lake load (as body force in thin layer) 1



Lake load (as body force in thin layer) 1

SELECTION

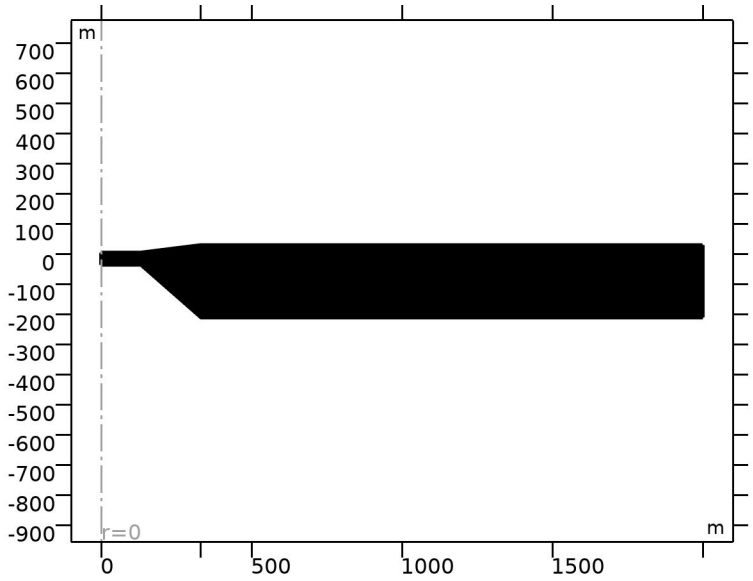
Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 2

EQUATIONS

2.4.11.1 Variables

Name	Expression	Unit	Description	Selection	Details
spf.Fr	0	N/m³	Volume force, r-component	Domain 2	+ operation
spf.Fphi	0	N/m³	Volume force, phi-component	Domain 2	+ operation
spf.Fz	-0.1*rho_fw*g_const*d_center	N/m³	Volume force, z-component	Domain 2	+ operation

2.5 MESH 1



Mesh 1

2.5.1 Size (size)

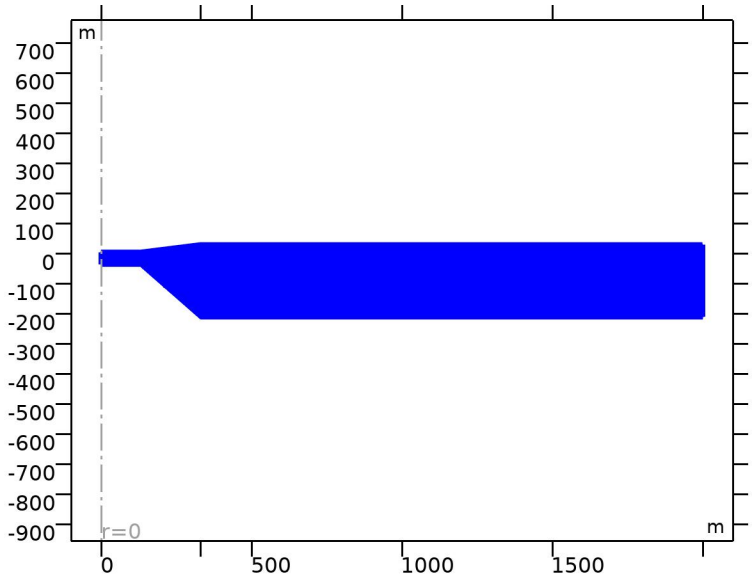
SETTINGS

Description	Value
Calibrate for	Fluid dynamics
Maximum element size	6.72
Minimum element size	0.096
Curvature factor	0.25
Predefined size	Finer

2.5.2 Free Triangular 1 (ftri1)

SELECTION

Geometric entity level	Domain
Selection	Remaining



Free Triangular 1

SETTINGS

Description	Value
Number of iterations	4
Maximum element depth to process	4
Last build time	0
Built with	COMSOL 6.1.0.252 (maci64)|2022 - 11 - 12T14:20:05.702389

3 Study 1

COMPUTATION INFORMATION

Computation time	2 h 30 min 47 s

3.1 TIME DEPENDENT

Times	Unit
range(0,1,100)	d

STUDY SETTINGS

Description	Value
Include geometric nonlinearity	On

STUDY SETTINGS

Description	Value
Time unit	d
Output times	{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100}

PHYSICS AND VARIABLES SELECTION

Physics interface	Solve for	Equation form
Creeping Flow (spf)	On	Automatic (Time dependent)
Moving mesh (Component 1)	On	Automatic

MESH SELECTION

Component	Mesh
Component 1	Mesh 1

3.2 SOLVER CONFIGURATIONS

3.2.1 Solution 1

3.2.1.1 Compile Equations: Time Dependent (st1)

STUDY AND STEP

Description	Value
Use study	Study 1
Use study step	Time Dependent

3.2.1.2 Dependent Variables 1 (v1)

GENERAL

Description	Value
Defined by study step	Time Dependent

RESIDUAL SCALING

Description	Value
Method	Manual

INITIAL VALUE CALCULATION CONSTANTS

Constant name	Initial value source
t	range(0,1,100)
timestep	0.1[d]

Pressure (comp1.p) (comp1_p)

GENERAL

Description	Value
Field components	comp1.p

Spatial mesh displacement (comp1.spatial.disp) (comp1_spatial_disp)

GENERAL

Description	Value
Field components	{comp1.spatial.u, comp1.spatial.w}

SCALING

Description	Value
Method	Manual
Scale	4.9677

Lagrange multiplier (comp1.spatial.lm) (comp1_spatial_lm)

GENERAL

Description	Value
Field components	comp1.spatial.lm

Lagrange multiplier (comp1.spatial.lm_nv) (comp1_spatial_lm_nv)

GENERAL

Description	Value
Field components	comp1.spatial.lm_nv

Velocity field (spatial frame) (comp1.u) (comp1_u)

GENERAL

Description	Value
Field components	{comp1.u, comp1.w}
Internal variables	{comp1.spf.dt2Inv_u, comp1.spf.isFluidHasBeenSolved}

3.2.1.3 Time-Dependent Solver 1 (t1)

GENERAL

Description	Value
Defined by study step	Time Dependent
Time unit	d
Output times	{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100}
Relative tolerance	0.005

ABSOLUTE TOLERANCE

Description	Value
Tolerance factor	0.05
Method	Scaled
Tolerance factor	1

ABSOLUTE TOLERANCE

Field	Method	Tolerance method	Tolerance factor	Derivative tolerance method	Tolerance for time derivatives	Tolerance	Tolerance for time derivatives
Pressure (comp1.p)	Scaled	Factor	1	Automatic	1	0.001	0.001

Field	Method	Tolerance method	Tolerance factor	Derivative tolerance method	Tolerance for time derivatives	Tolerance	Tolerance for time derivatives
Spatial mesh displacement (comp1.spatial.disp)	Use global	Factor	0.1	Automatic	1	0.001	0.001
Lagrange multiplier (comp1.spatial.lm)	Use global	Factor	0.1	Automatic	1	0.001	0.001
Lagrange multiplier (comp1.spatial.lm_nv)	Use global	Factor	0.1	Automatic	1	0.001	0.001
Velocity field (spatial frame) (comp1.u)	Use global	Factor	0.1	Automatic	1	0.001	0.001

TIME STEPPING

Description	Value
Maximum BDF order	2
Nonlinear controller	On
Fraction of initial step for Backward Euler	0.01
Error estimation	Exclude algebraic

RESULTS WHILE SOLVING

Description	Value
Plot	On
Plot group	Displacement (vertical)

Advanced (aDef)

ASSEMBLY SETTINGS

Description	Value
Reuse sparsity pattern	On

Fully Coupled 1 (fc1)

GENERAL

Description	Value
Linear solver	Direct, fluid flow variables () (merged)

METHOD AND TERMINATION

Description	Value
Damping factor	0.9
Jacobian update	On every iteration
Maximum number of iterations	8
Tolerance factor	0.5
Stabilization and acceleration	Anderson acceleration
Dimension of iteration space	5
Mixing parameter	0.9
Iteration delay	1

Direct, fluid flow variables () (merged) (d1)

GENERAL

Description	Value
Solver	PARDISO
Pivoting perturbation	1E-13

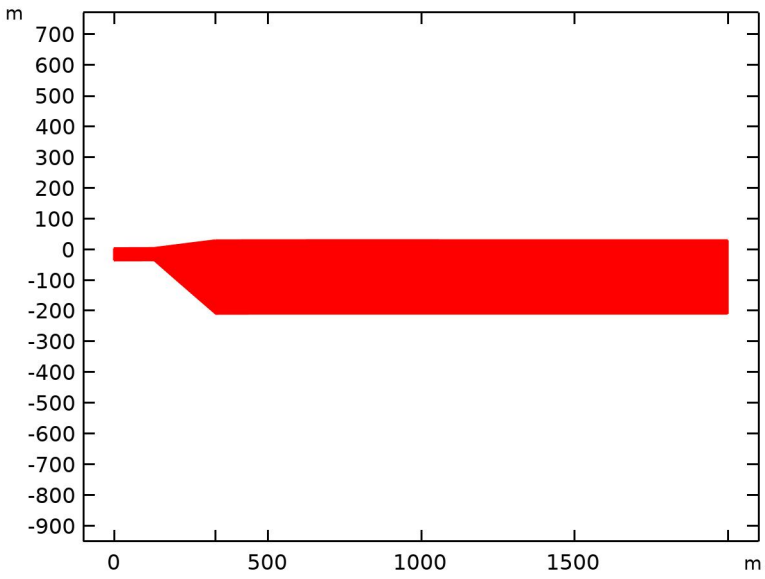
4 Results

4.1 DATASETS

4.1.1 Study 1/Solution 1

SOLUTION

Description	Value
Solution	Solution 1
Component	Component 1 (comp1)



Dataset: Study 1/Solution 1

4.1.2 Revolution 2D

DATA

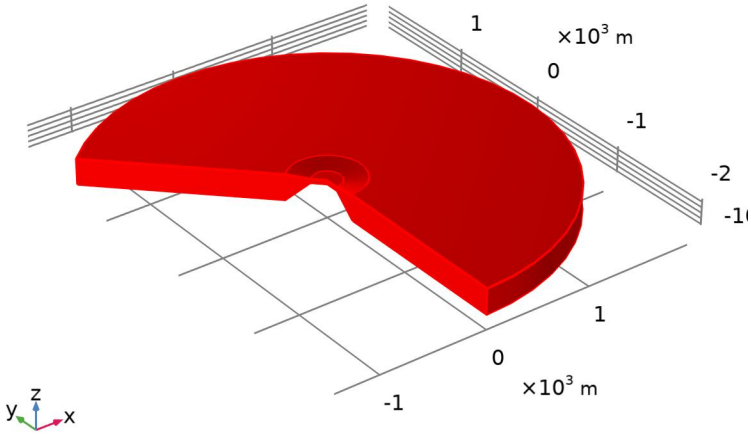
Description	Value
Dataset	Study 1/Solution 1

AXIS DATA

Description	Value
Axis entry method	Two points
Points	{{0, 0}, {0, 1}}

REVOLUTION LAYERS

Description	Value
Start angle	-90
Revolution angle	225

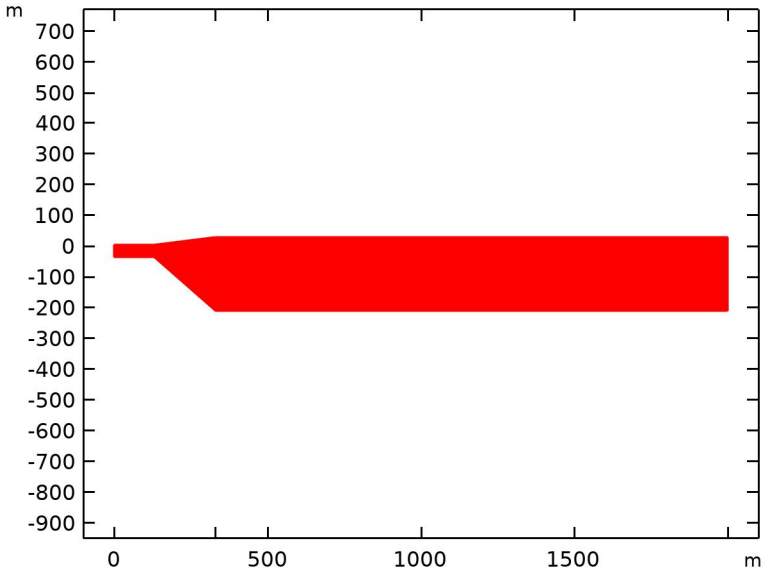


Dataset: Revolution 2D

4.1.3 Probe Solution 2

SOLUTION

Description	Value
Solution	Solution 1
Component	Component 1 (comp1)
Frame	Material (R, PHI, Z)



Dataset: Probe Solution 2

4.1.4 GPS10

SELECTION

Geometric entity level	Point
Selection	Geometry geom1: Dimension 0: Point 3

DATA

Description	Value
Dataset	Probe Solution 2

SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

4.1.5 GPS01

SELECTION

Geometric entity level	Point
Selection	Geometry geom1: Dimension 0: Point 13

DATA

Description	Value
Dataset	Probe Solution 2

SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

4.1.6 bottom edge

DATA

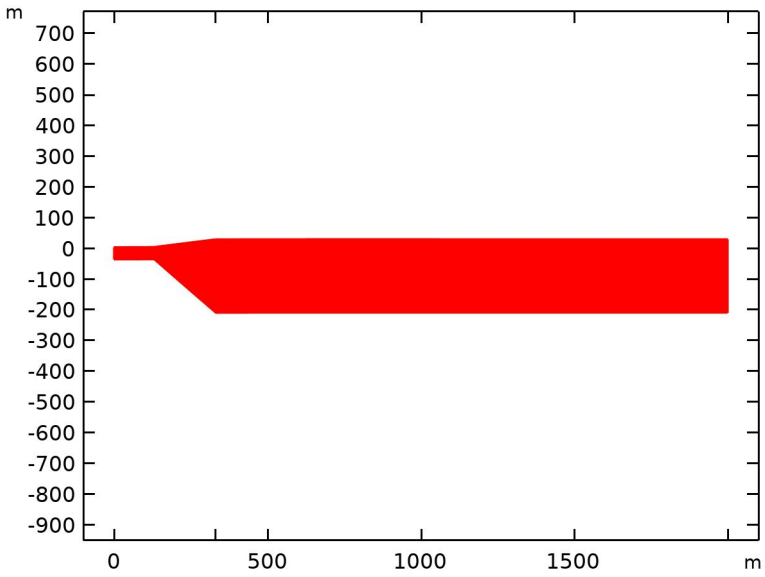
Description	Value
Dataset	Study 1/Solution 1

4.1.7 Probe Solution 3

SOLUTION

Description	Value

Description	Value
Solution	Solution 1
Component	Component 1 (comp1)



Dataset: Probe Solution 3

4.1.8 Minimum Maxwell time

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domains 1–4

DATA

Description	Value
Dataset	Probe Solution 3

SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

4.1.9 vonMises Probe

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domains 2–3

DATA

Description	Value
Dataset	Probe Solution 3

SETTINGS

Description	Value
Lagrange order	4

4.1.10 Horizontal_Distance

SELECTION

Geometric entity level	Point
Selection	Geometry geom1: Dimension 0: Point 13

DATA

Description	Value
Dataset	Probe Solution 2

SETTINGS

Description	Value
Method	Integration
Integration order	4
Integration order	On

4.1.11 Grid 1D 1

DATA

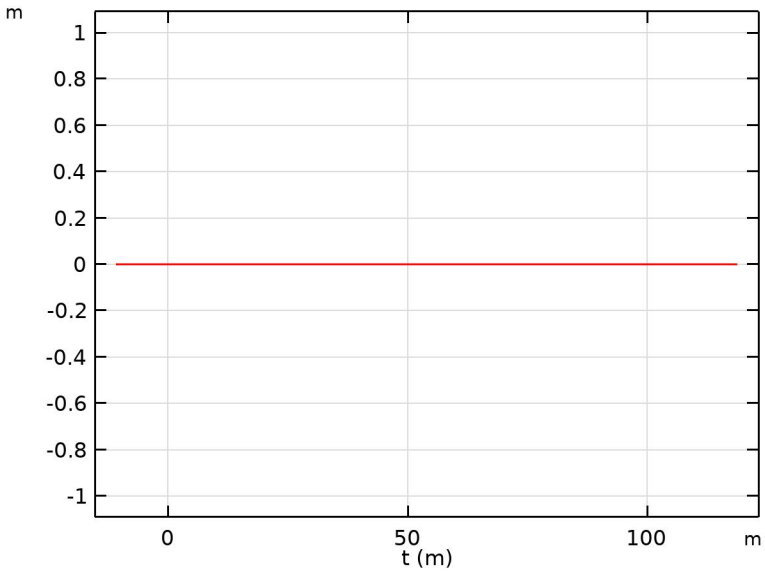
Description	Value
Function	Interpolation 2
Refresh	

PARAMETER BOUNDS

Description	Value
Name	t
Minimum	-10.8
Maximum	118.8

GRID

Description	Value
Resolution	10000
Point distribution	Mixed uniform/exponential



Dataset: Grid 1D 1

4.1.12 maximum T_rr in upper 10 m of ice shelf inside of doline rim

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 3

DATA

Description	Value
Dataset	Probe Solution 3

SETTINGS

Description	Value
Lagrange order	4

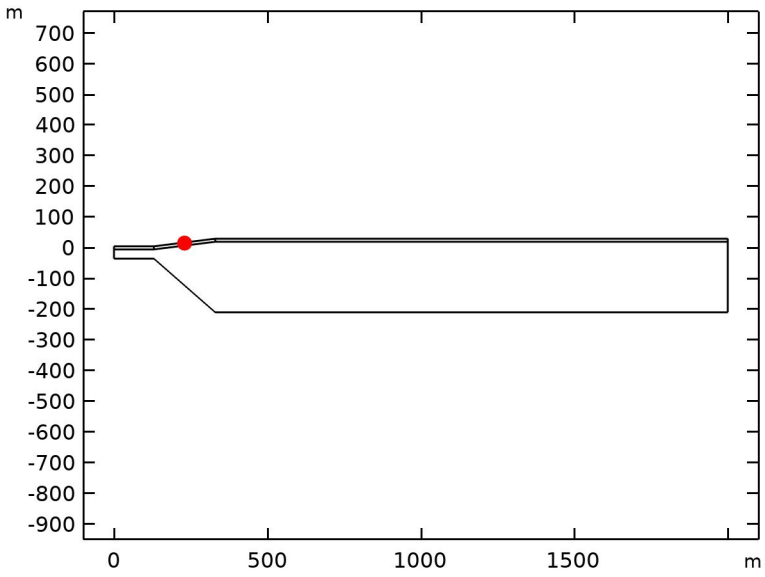
4.1.13 Cut Point 2D 1

DATA

Description	Value
Dataset	Study 1/Solution 1

POINT DATA

Description	Value
Entry method	Coordinates
r	230
z	(1 - rho_i/rho_sw)*(H + H_doline)/2 - 2



Dataset: Cut Point 2D 1

4.1.14 Cut Point 2D 2

DATA

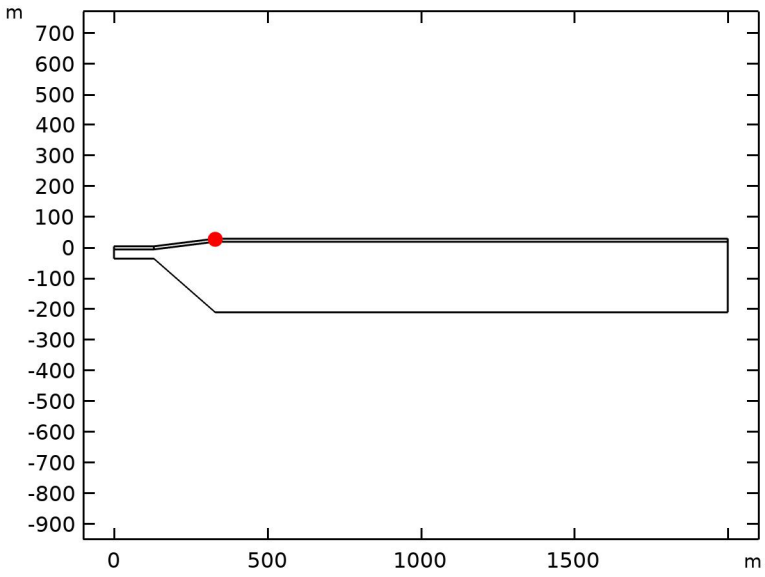
Description	Value
Dataset	Study 1/Solution 1

POINT DATA

Description	Value
Entry method	Coordinates
r	330
z	(1 - rho_i/rho_sw)*H - 2

ADVANCED

Description	Value
Point number variable	cpt1n



Dataset: Cut Point 2D 2

4.1.15 Cut Point 2D 3

DATA

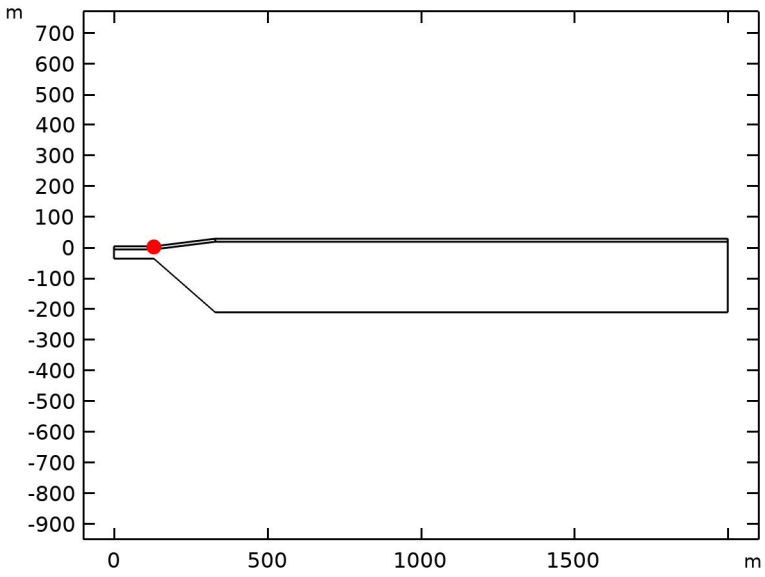
Description	Value
Dataset	Study 1/Solution 1

POINT DATA

Description	Value
Entry method	Coordinates
r	130
z	(1 - rho_i/rho_sw)*H_doline-2

ADVANCED

Description	Value
Point number variable	cpt1n



Dataset: Cut Point 2D 3

4.1.16 Cut Point 2D 4

DATA

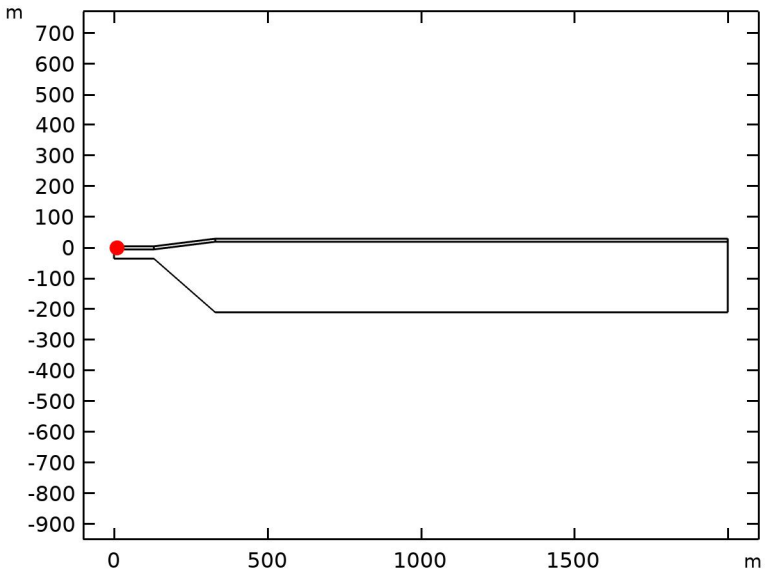
Description	Value
Dataset	Study 1/Solution 1

POINT DATA

Description	Value
Entry method	Coordinates
r	10
z	(1 - rho_i/rho_sw)*H_doline-5

ADVANCED

Description	Value
Point number variable	cpt1n



Dataset: Cut Point 2D 4

4.1.17 maximum T_rr in upper 10 m of ice shelf inside of doline ramp

SELECTION

Geometric entity level	Domain
Selection	Geometry geom1: Dimension 2: Domain 2

DATA

Description	Value
Dataset	Probe Solution 3

SETTINGS

Description	Value
Lagrange order	4

4.2 DERIVED VALUES

4.2.1 GPS10

OUTPUT

Evaluated in	Probe Table 1

DATA

Description	Value
Dataset	GPS10

EXPRESSIONS

Expression	Unit	Description
spatial.dz	m	Spatial mesh displacement z

4.2.2 GPS01

OUTPUT

Evaluated in	Probe Table 1

DATA

Description	Value
Dataset	GPS01

EXPRESSIONS

Expression	Unit	Description
spatial.dz	m	Spatial mesh displacement z

4.2.3 Minimum Maxwell time

OUTPUT

Evaluated in	Probe Table 1

DATA

Description	Value
Dataset	Minimum Maxwell time

EXPRESSIONS

Expression	Unit	Description
rho_i*nu_effective/sec_in_day/E		

4.2.4 Point Evaluation 4

DATA

Description	Value
Dataset	Study 1/Solution 1

EXPRESSIONS

Expression	Unit	Description
Adot_forced		

4.2.5 vonMises Probe

OUTPUT

Evaluated in	Probe Table 1

DATA

Description	Value
Dataset	vonMises Probe

EXPRESSIONS

Expression	Unit	Description
vonmises/1e3		

4.2.6 Horizontal_Distance

OUTPUT

Evaluated in	Probe Table 1

DATA

Description	Value
Dataset	Horizontal_Distance

EXPRESSIONS

Expression	Unit	Description
spatial.dr	m	Spatial mesh displacement r

4.2.7 maximum T_rr in upper 10 m of ice shelf inside of doline rim

OUTPUT

Evaluated in	Probe Table 1

DATA

Description	Value
Dataset	maximum T_rr in upper 10 m of ice shelf inside of doline rim

EXPRESSIONS

Expression	Unit	Description
Principle_stress.e1/1e3		

4.2.8 Global Variable Probe 1

OUTPUT

Evaluated in	Probe Table 1

DATA

Description	Value
Dataset	Probe Solution 2

EXPRESSIONS

Expression	Unit	Description
A_cumulative	s	

4.2.9 maximum T_rr in upper 10 m of ice shelf inside of doline ramp

OUTPUT

Evaluated in	Probe Table 1

DATA

Description	Value
Dataset	maximum T_rr in upper 10 m of ice shelf inside of doline ramp

EXPRESSIONS

Expression	Unit	Description
Principle_stress.e1/1e3		

4.3 TABLES

4.3.1 Probe Table 1

Time (d)	Principle_stress.e1/1e3, maximum T_rr in upper 10 m of ice shelf inside of doline ramp
0	58.372
1	58.364
2	58.176
3	58.222
4	58.444
5	58.789
6	59.215
7	59.691
8	60.196
9	60.716
10	61.24
11	61.758
12	62.27
13	62.765
14	63.241
15	63.657
16	64.036
17	64.454
18	64.881
19	65.317
20	65.761
21	66.218
22	66.671
23	67.117
24	67.558
25	68.04
26	68.545
27	69.042
28	69.532
29	70.026
30	70.529
31	71.024

Time (d)	Principle_stress.e1/1e3, maximum T_rr in upper 10 m of ice shelf inside of doline ramp
32	71.512
33	71.994
34	72.469
35	72.938
36	73.401
37	73.858
38	74.371
39	74.882
40	75.387
41	75.884
42	76.375
43	76.86
44	77.338
45	77.81
46	78.306
47	78.832
48	79.351
49	79.863
50	80.369
51	80.868
52	81.36
53	81.847
54	82.328
55	82.828
56	83.329
57	83.829
58	84.329
59	84.828
60	85.326
61	85.823
62	86.32
63	86.815
64	87.31
65	87.812
66	88.314

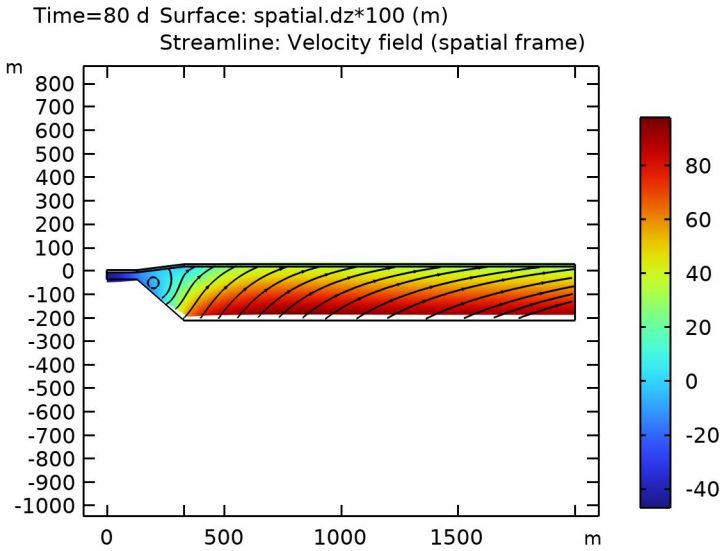
Time (d)	Principle_stress.e1/1e3, maximum T_rr in upper 10 m of ice shelf inside of doline ramp
67	88.816
68	89.319
69	89.822
70	90.325
71	90.828
72	91.331
73	91.834
74	92.337
75	92.83
76	93.321
77	93.809
78	94.296
79	94.782
80	95.265
81	95.747
82	96.228
83	96.706
84	97.183
85	97.665
86	98.147
87	98.629
88	99.11
89	99.591
90	100.07
91	100.55
92	101.03
93	101.51
94	101.99
95	102.46
96	102.92
97	103.39
98	103.85
99	104.32
100	104.78

4.3.2 Evaluation 2D

Interactive 2D values

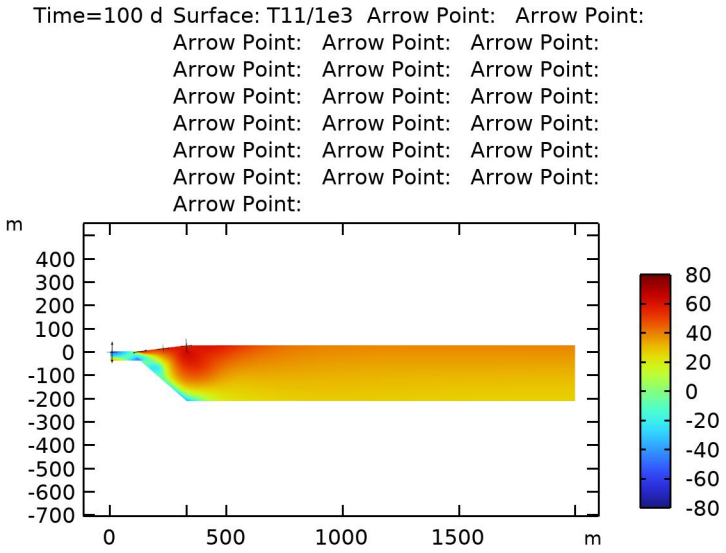
4.4 PLOT GROUPS

4.4.1 Displacement (vertical)



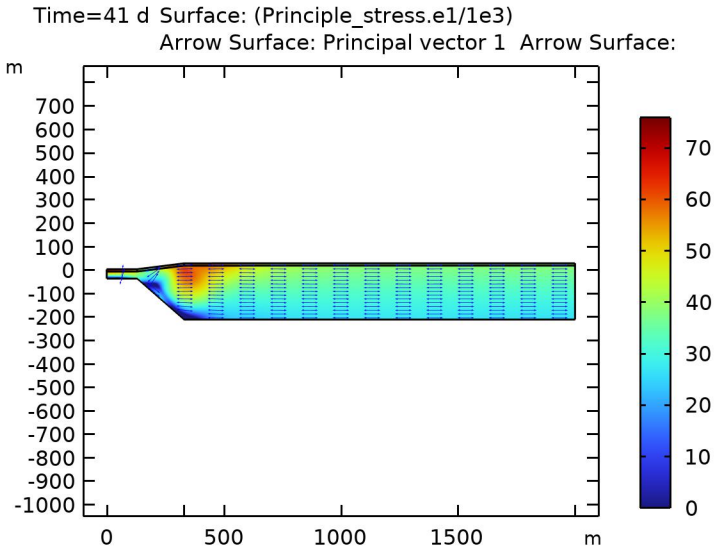
*Surface: spatial.dz*100 (m) Streamline: Velocity field (spatial frame)*

4.4.2 Stress (principle 1)



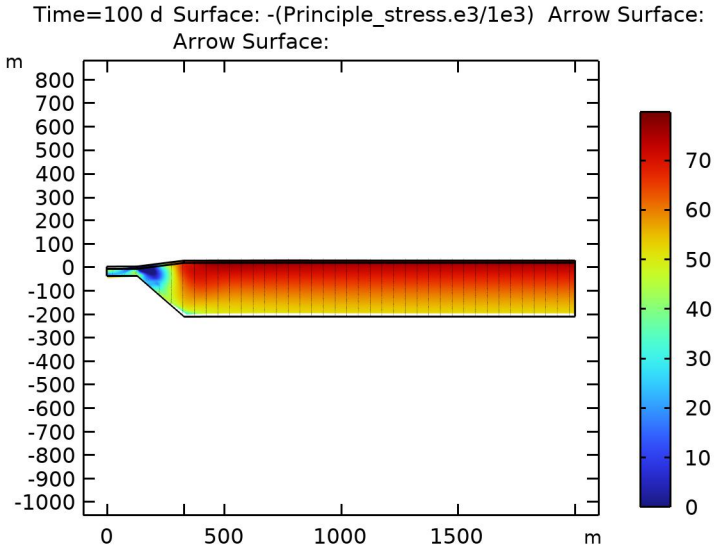
Surface: T11/1e3 Arrow Point:

4.4.3 Stress (principle 2) 1.1



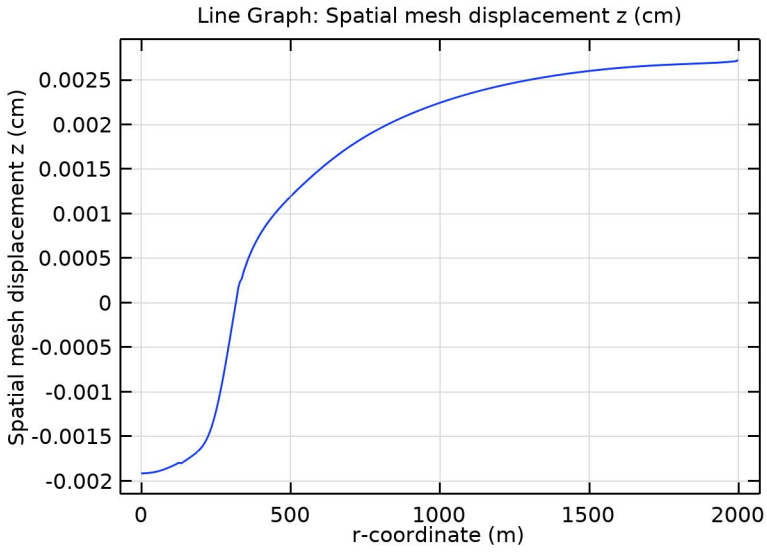
Surface: (Principle_stress.e1/1e3) Arrow Surface: Principal vector 1 Arrow Surface:

4.4.4 Stress (principle 3) 1



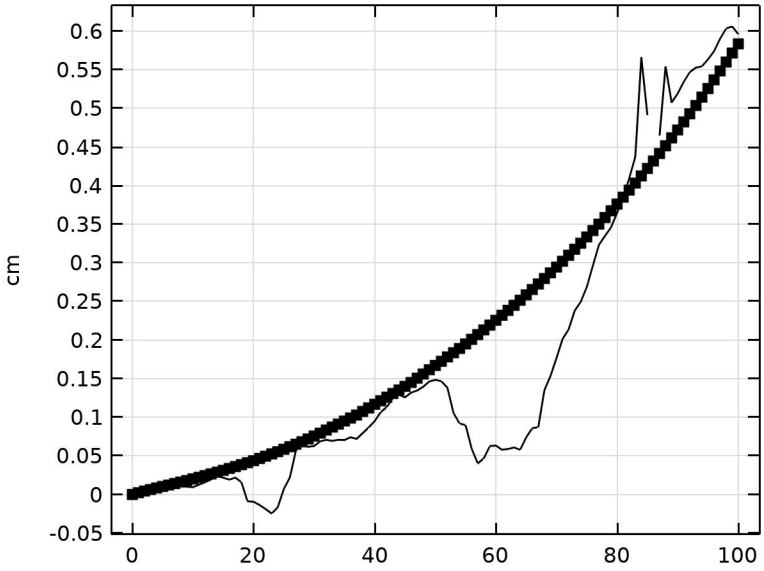
Surface: -(Principle_stress.e3/1e3) Arrow Surface: Arrow Surface:

4.4.5 deflection as function of r

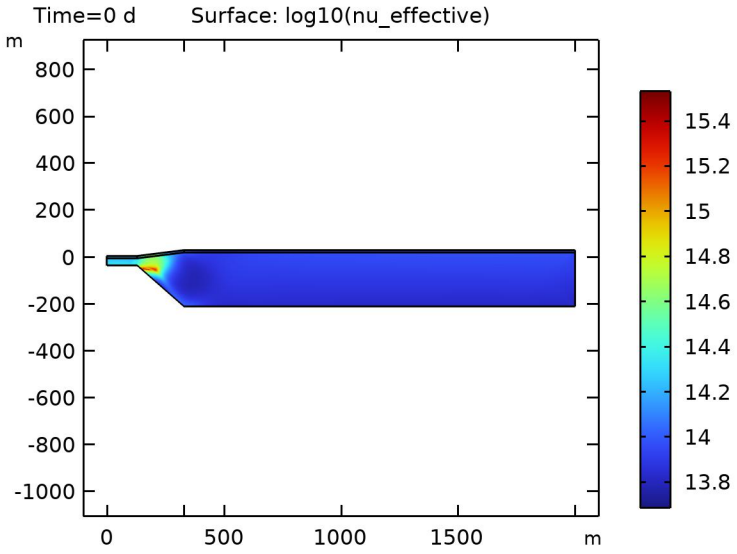


Line Graph: Spatial mesh displacement z (cm)

4.4.6 vertical elevation difference as function of time

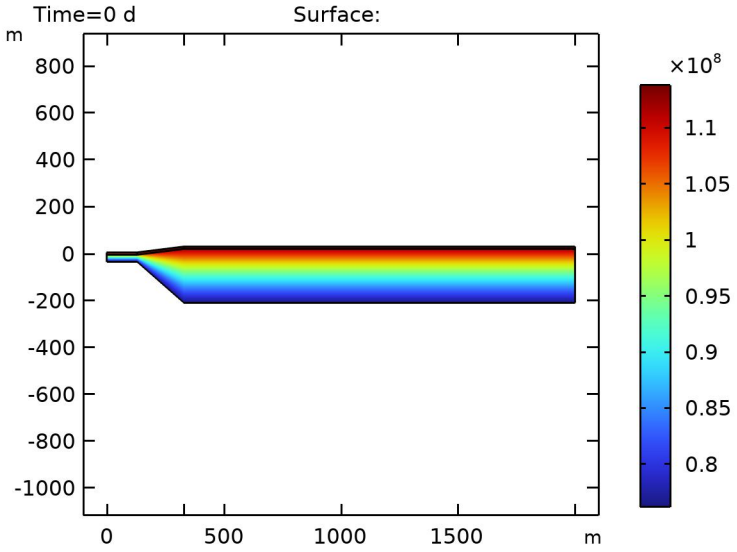


4.4.7 effective viscosity



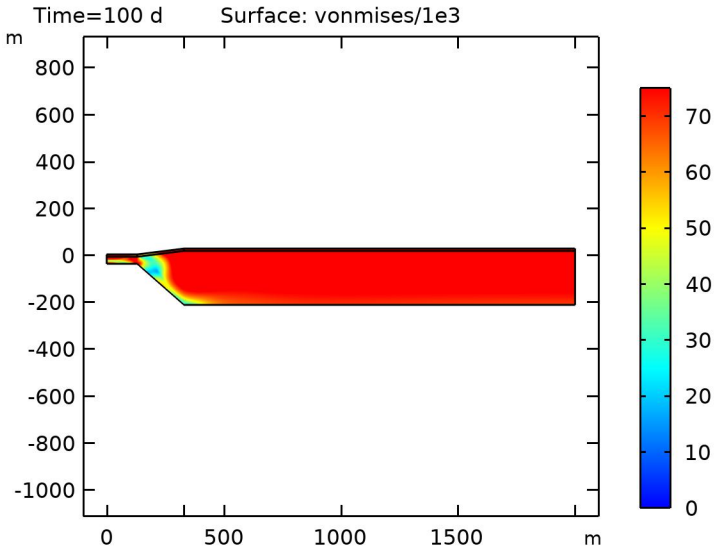
Surface: log10(nu_effective)

4.4.8 B value



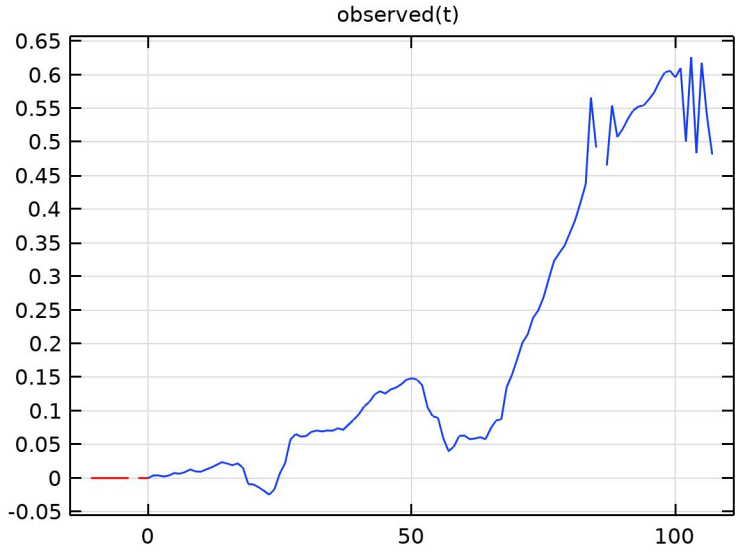
Surface:

4.4.9 Von Mises Stress



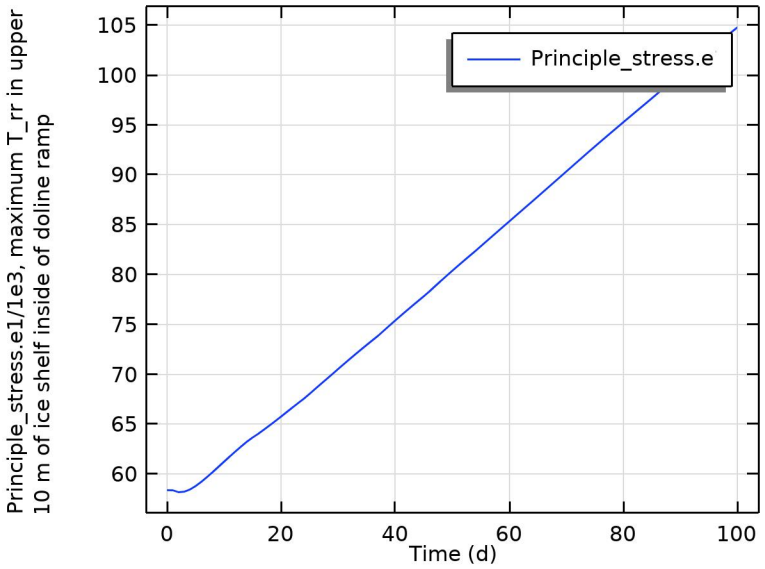
Surface: vonmises/1e3

4.4.10 1D Plot Group 25



observed(t)

4.4.11 Probe Plot Group 26



4.4.12 Probe Plot Group 28