[](https://www.comsol.com/)

Variante normoteso

|  |  |
| --- | --- |
| Report date | Jun 21, 2024, 5:28:10 PM |

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# Global Definitions

|  |  |
| --- | --- |
| Date | Jun 18, 2024, 6:09:03 PM |

Global settings

|  |  |
| --- | --- |
| Name | Variante normoteso.mph |
| Path | C:\Users\user\Desktop\Progetti biomacchine\Variante\_normoteso.mph |
| Version | COMSOL Multiphysics 6.2 (Build: 339) |
| Unit system | SI |

Used products

|  |
| --- |
| CAD Import Module |
| COMSOL Multiphysics |

Computer information

|  |  |
| --- | --- |
| CPU | Intel64 Family 6 Model 142 Stepping 10, 4 cores, 15.88 GB RAM |
| Operating system | Windows 10 |

## Parameters

Parameters 1

| **Name** | **Expression** | **Value** | **Description** |
| --- | --- | --- | --- |
| Qin | 4.8 [l/min] | 8E−5 m³/s | Portata sanguigna in ingresso dell'aorta ascendente |
| Pout\_min | 80 [mmHg] | 10666 Pa | Pressione sanguigna metà diastole (pressione minima) |
| Pout\_max | 120 [mmHg] | 15999 Pa | Pressione sanguigna picco sistolico (pressione massima) |

## Shared Properties

### Default Model Inputs

|  |  |
| --- | --- |
| Tag | cminpt |

## Materials

### Blood

Basic

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Density | 1060 | kg/m³ |
| Dynamic viscosity | 0.0035 | Pa·s |

# Component 1

|  |  |
| --- | --- |
| Date | Jun 17, 2024, 10:15:59 AM |

Settings

| **Description** | **Value** |
| --- | --- |
| Unit system | Same as global system (SI) |
| Geometry shape function | Automatic |

Spatial frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| x | y | z |

Material frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| X | Y | Z |

Geometry frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| Xg | Yg | Zg |

Mesh frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| Xm | Ym | Zm |

## Definitions

### Coordinate Systems

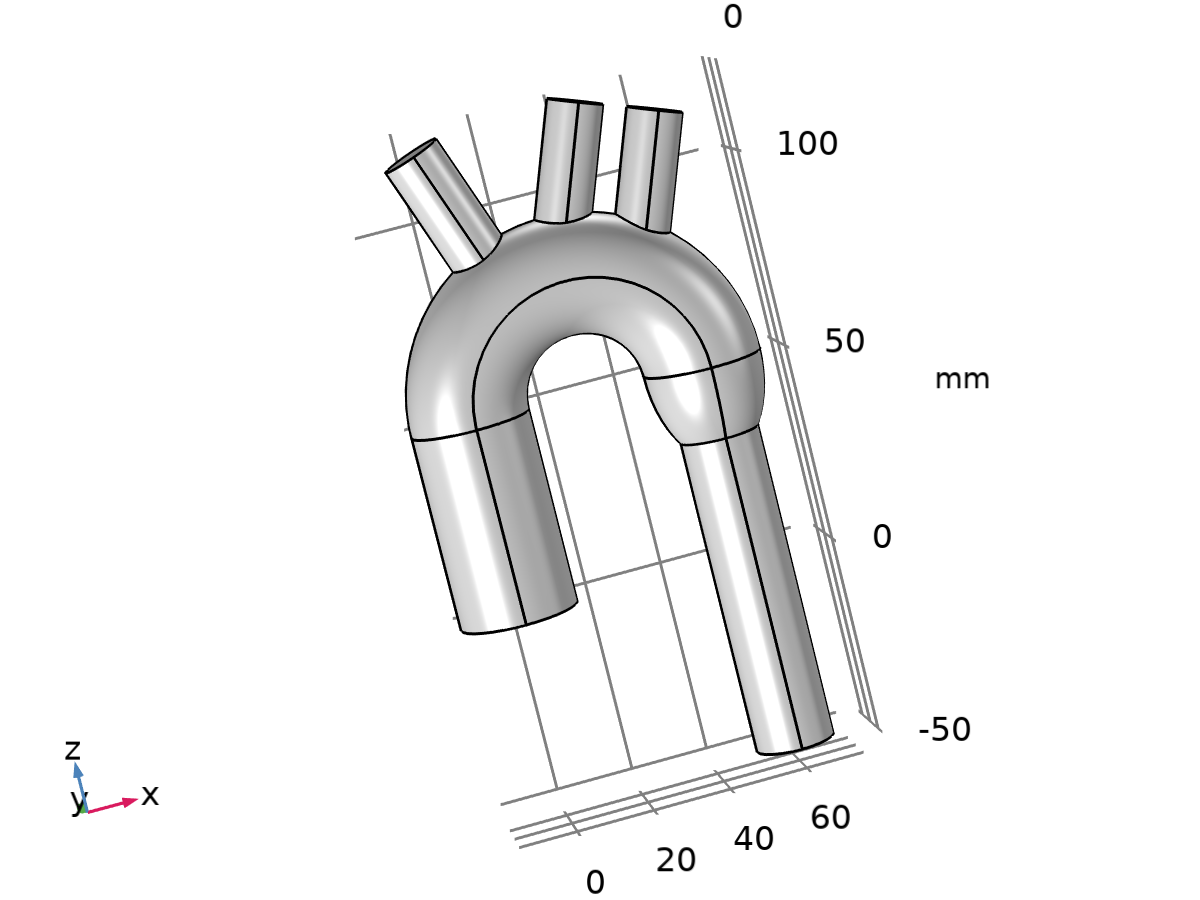
#### Boundary System 1

|  |  |
| --- | --- |
| Coordinate system type | Boundary system |
| Tag | sys1 |

Coordinate names

| **First** | **Second** | **Third** |
| --- | --- | --- |
| t1 | t2 | n |

## Geometry 1



Geometry 1

Units

|  |  |
| --- | --- |
| Length unit | mm |
| Angular unit | deg |

Geometry statistics

| **Description** | **Value** |
| --- | --- |
| Space dimension | 3 |
| Number of domains | 1 |
| Number of boundaries | 33 |
| Number of edges | 75 |
| Number of vertices | 44 |

### Aorta ascendente (wp1)

Unite objects

| **Description** | **Value** |
| --- | --- |
| Unite objects | On |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

#### Plane Geometry (sequence2D)

##### Circle 1 (c1)

Position

| **Description** | **Value** |
| --- | --- |
| Position | {0, 0} |

Size and shape

| **Description** | **Value** |
| --- | --- |
| Radius | 15 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 17, 2024, 10:23:17 AM |

### Extrude 1 (ext1)

General

| **Description** | **Value** |
| --- | --- |
| Work plane | [Aorta ascendente (wp1)](#cs8047242) |

Distances

| **Distances (mm)** |
| --- |
| 50 |

Scales

| **Scales xw** | **Scales yw** |
| --- | --- |
| 1 | 1 |

Displacements

| **Displacements xw (mm)** | **Displacements yw (mm)** |
| --- | --- |
| 0 | 0 |

Twist angles

| **Twist angles (deg)** |
| --- |
| 0 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

### Aorta discendente (wp2)

Unite objects

| **Description** | **Value** |
| --- | --- |
| Unite objects | On |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

#### Plane Geometry (sequence2D)

##### Circle 1 (c1)

Position

| **Description** | **Value** |
| --- | --- |
| Position | {60, 0} |

Size and shape

| **Description** | **Value** |
| --- | --- |
| Radius | 10 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 17, 2024, 10:29:04 AM |

### Extrude 2 (ext2)

General

| **Description** | **Value** |
| --- | --- |
| Work plane | [Aorta discendente (wp2)](#cs5322676) |

Distances

| **Distances (mm)** |
| --- |
| 100 |

Distances

| **Description** | **Value** |
| --- | --- |
| Reverse direction | On |

Scales

| **Scales xw** | **Scales yw** |
| --- | --- |
| 1 | 1 |

Displacements

| **Displacements xw (mm)** | **Displacements yw (mm)** |
| --- | --- |
| 0 | 0 |

Twist angles

| **Twist angles (deg)** |
| --- |
| 0 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

### Arco aortico (wp3)

Unite objects

| **Description** | **Value** |
| --- | --- |
| Unite objects | On |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

#### Plane Geometry (sequence2D)

##### Circle 1 (c1)

Position

| **Description** | **Value** |
| --- | --- |
| Position | {60, 0} |

Size and shape

| **Description** | **Value** |
| --- | --- |
| Radius | 15 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 17, 2024, 1:01:19 PM |

### Work Plane 4 (wp4)

Plane definition

| **Description** | **Value** |
| --- | --- |
| Plane | zx - plane |

Unite objects

| **Description** | **Value** |
| --- | --- |
| Unite objects | On |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

#### Plane Geometry (sequence2D)

##### Circular Arc 1 (ca1)

Selections of resulting entities

| **Description** | **Value** |
| --- | --- |
| Resulting objects selection | On |

Settings

| **Description** | **Value** |
| --- | --- |
| Specify | Endpoints and radius |
| Center | {50, 30} |
| Radius | 30 |
| Starting point | {50, 0} |
| Endpoint | {50, 60} |
| Start angle | 270 |
| End angle | 90 |
| Clockwise | On |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 17, 2024, 1:19:35 PM |

### Sweep 1 (swe1)

Settings

| **Description** | **Value** |
| --- | --- |
| Create cross-sectional faces | On |
| Include all inputs in Form Union/Assembly | Off |
| Manual control of sweep direction | Off |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

### Ellipsoid 1 (elp1)

Position

| **Description** | **Value** |
| --- | --- |
| Position | {60, 0, 50} |

Axis

| **Description** | **Value** |
| --- | --- |
| Axis type | z - axis |

Size

| **Description** | **Value** |
| --- | --- |
| a-semiaxis | 15 |
| b-semiaxis | 15 |
| c-semiaxis | 25 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

### Work Plane 5 (wp5)

Plane definition

| **Description** | **Value** |
| --- | --- |
| Plane type | Transformed |
| Displacement | {0, 0, 80} |
| Axis type | yw - axis |
| Rotation angle | -20 |

Unite objects

| **Description** | **Value** |
| --- | --- |
| Unite objects | On |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

#### Plane Geometry (sequence2D)

##### Circle 1 (c1)

Position

| **Description** | **Value** |
| --- | --- |
| Position | {15, 0} |

Size and shape

| **Description** | **Value** |
| --- | --- |
| Radius | 7.5 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 17, 2024, 3:56:55 PM |

### Work Plane 6 (wp6)

Plane definition

| **Description** | **Value** |
| --- | --- |
| Plane type | Transformed |
| Displacement | {0, 0, 100} |
| Axis type | yw - axis |
| Rotation angle | 20 |

Unite objects

| **Description** | **Value** |
| --- | --- |
| Unite objects | On |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

#### Plane Geometry (sequence2D)

##### Circle 1 (c1)

Position

| **Description** | **Value** |
| --- | --- |
| Position | {35, 0} |

Size and shape

| **Description** | **Value** |
| --- | --- |
| Radius | 7 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 1:48:05 PM |

##### Circle 2 (c2)

Position

| **Description** | **Value** |
| --- | --- |
| Position | {55, 0} |

Size and shape

| **Description** | **Value** |
| --- | --- |
| Radius | 7 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 1:52:19 PM |

### Extrude 3 (ext3)

General

| **Description** | **Value** |
| --- | --- |
| Work plane | [Work Plane 5 (wp5)](#cs7140960) |

Distances

| **Distances (mm)** |
| --- |
| 35 |

Scales

| **Scales xw** | **Scales yw** |
| --- | --- |
| 1 | 1 |

Displacements

| **Displacements xw (mm)** | **Displacements yw (mm)** |
| --- | --- |
| 0 | 0 |

Twist angles

| **Twist angles (deg)** |
| --- |
| 0 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

### Extrude 4 (ext4)

General

| **Description** | **Value** |
| --- | --- |
| Work plane | [Work Plane 6 (wp6)](#cs1161143) |

Distances

| **Distances (mm)** |
| --- |
| 35 |

Scales

| **Scales xw** | **Scales yw** |
| --- | --- |
| 1 | 1 |

Displacements

| **Displacements xw (mm)** | **Displacements yw (mm)** |
| --- | --- |
| 0 | 0 |

Twist angles

| **Twist angles (deg)** |
| --- |
| 0 |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

### Union 1 (uni1)

Compose

| **Description** | **Value** |
| --- | --- |
| Keep interior boundaries | Off |

Information

| **Description** | **Value** |
| --- | --- |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

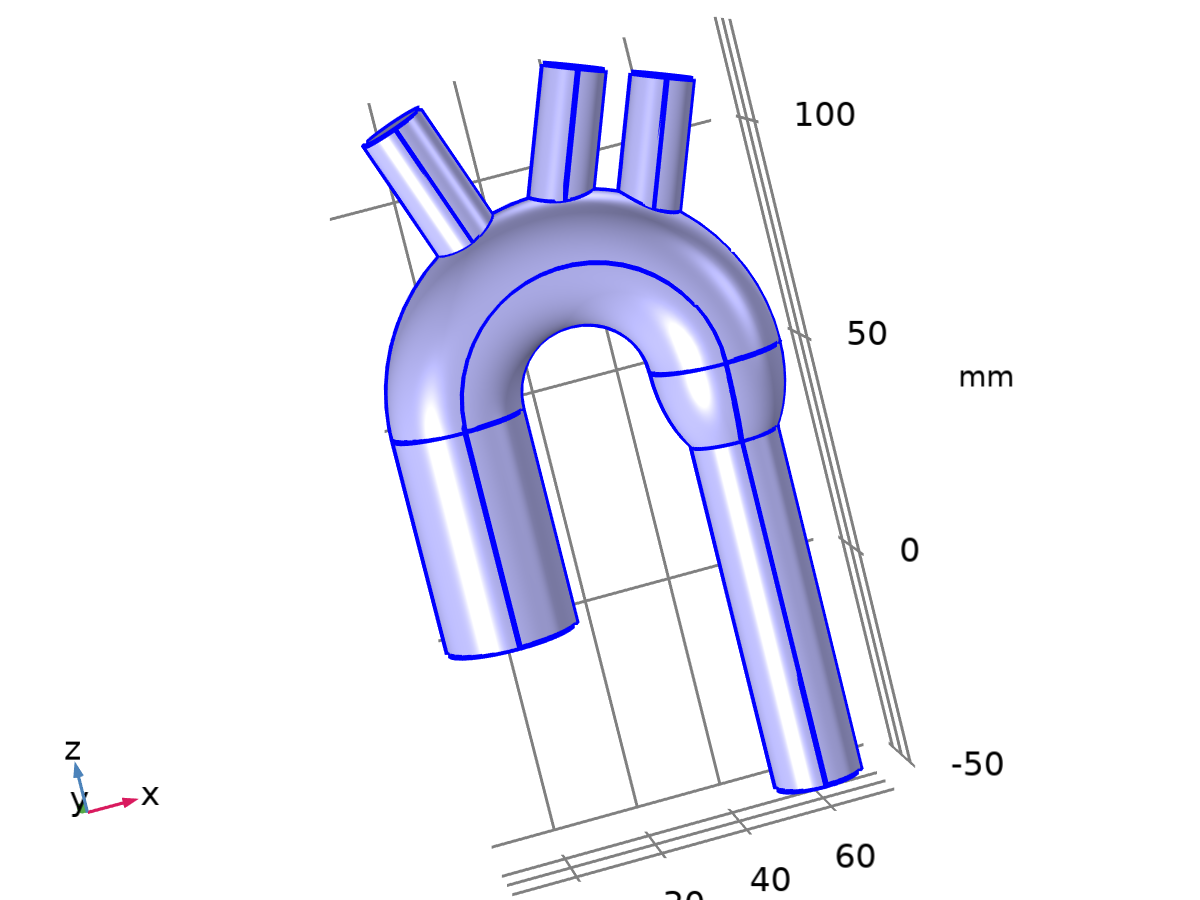
### Form Union (fin)

Information

| **Description** | **Value** |
| --- | --- |
| Details | {Formed union of 1 solid object., Union has 1 domain, 33 boundaries, 75 edges, and 44 vertices.} |
| Last build time | < 1 second |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:41:16 PM |

## Materials

### Blood



Blood

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

Material parameters

| **Name** | **Value** | **Unit** | **Property group** |
| --- | --- | --- | --- |
| Density | 1060 | kg/m³ | Basic |
| Dynamic viscosity | 0.0035 | Pa·s | Basic |

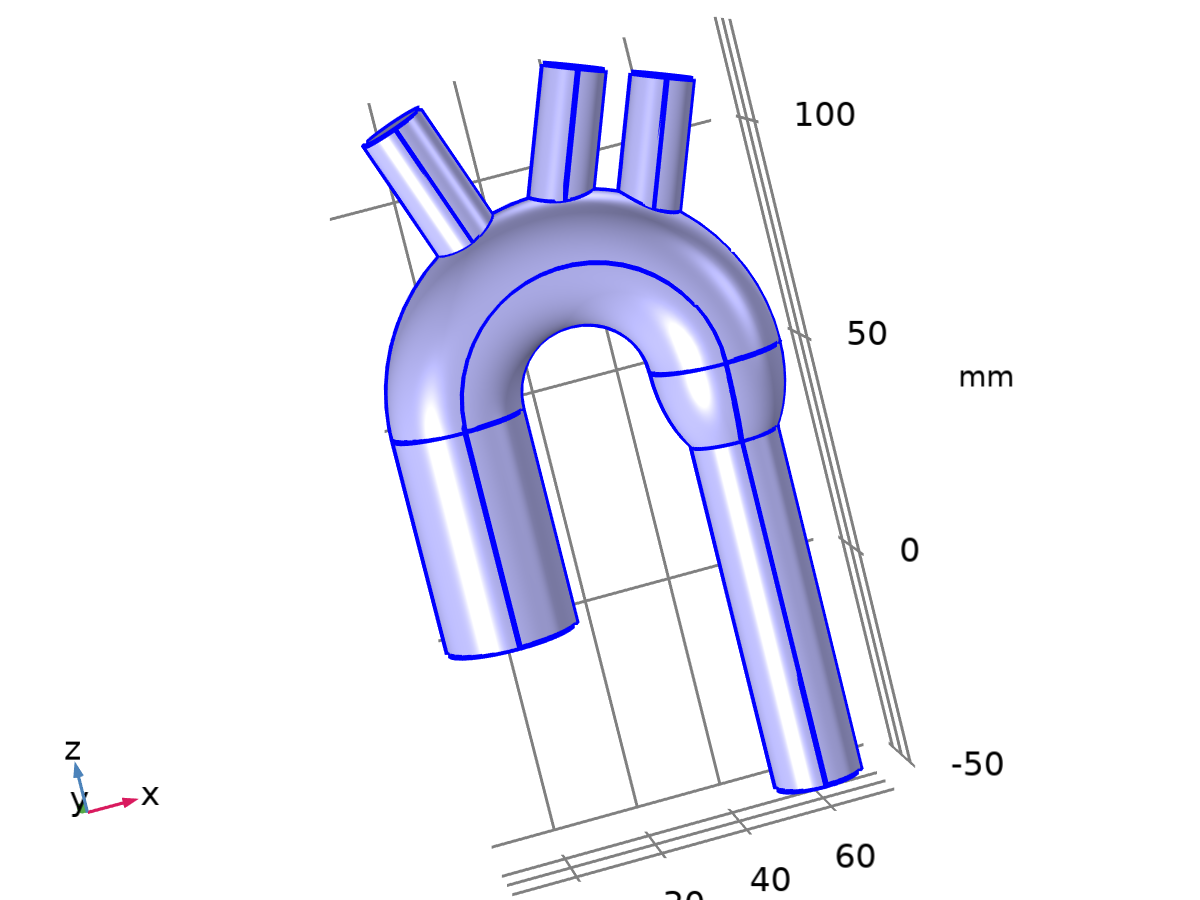
Basic

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Density | 1060 | kg/m³ |
| Dynamic viscosity | 0.0035 | Pa·s |

## Laminar Flow

Used products

|  |
| --- |
| COMSOL Multiphysics |



Laminar Flow

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

Equations





### Interface Settings

#### Discretization

Settings

| **Description** | **Value** |
| --- | --- |
| Discretization of fluids | P1 + P1 |

Settings

| **Description** | **Value** |
| --- | --- |
| Equation form | Study controlled |

#### Physical Model

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Neglect inertial term (Stokes flow) | Off |  |
| Compressibility | Incompressible flow |  |
| Enable porous media domains | Off |  |
| Include gravity | Off |  |
| Reference temperature | User defined |  |
| Reference temperature | 293.15 | K |
| Reference pressure level | 1.0133E5 | Pa |

#### Turbulence

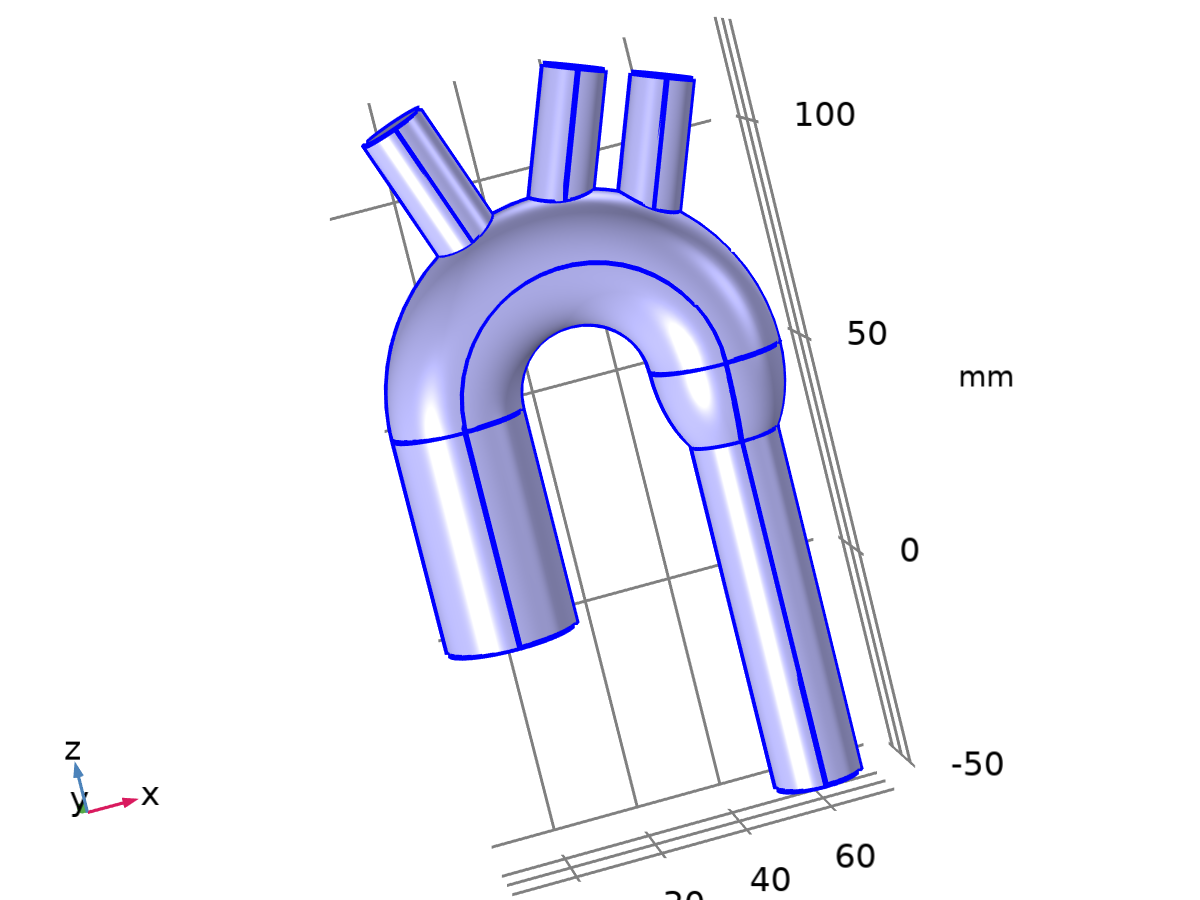
Settings

| **Description** | **Value** |
| --- | --- |
| Turbulence model type | None |

### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| spf.Tref | model.input.Tref | K | Reference temperature | Global | Meta |
| spf.dz | 1 | m | Thickness | Domain 1 |  |
| spf.pref | 1[atm] | Pa | Reference pressure level | Domain 1 |  |
| spf.pA | p+spf.pref | Pa | Absolute pressure | Domain 1 |  |
| spf.hasWF | 0 |  | Help variable | Boundaries 1–33 |  |
| spf.dt\_CFL | 1/max(spf.maxop(sqrt(emetric\_spatial(u-d(x,TIME),v-d(y,TIME),w-d(z,TIME)))),eps) | s | Time step, CFL=1 | Global |  |
| spf.Qvd\_tot | spf.intop(spf.Qvd) | W | Total viscous dissipation | Global |  |
| spf.K\_stressx | spf.K\_stress\_tensorxx\*spf.nxmesh+spf.K\_stress\_tensorxy\*spf.nymesh+spf.K\_stress\_tensorxz\*spf.nzmesh | N/m² | Viscous stress, exterior boundaries, x-component | Boundaries 1–33 |  |
| spf.K\_stressy | spf.K\_stress\_tensoryx\*spf.nxmesh+spf.K\_stress\_tensoryy\*spf.nymesh+spf.K\_stress\_tensoryz\*spf.nzmesh | N/m² | Viscous stress, exterior boundaries, y-component | Boundaries 1–33 |  |
| spf.K\_stressz | spf.K\_stress\_tensorzx\*spf.nxmesh+spf.K\_stress\_tensorzy\*spf.nymesh+spf.K\_stress\_tensorzz\*spf.nzmesh | N/m² | Viscous stress, exterior boundaries, z-component | Boundaries 1–33 |  |
| spf.T\_stressx | spf.T\_stress\_tensorxx\*spf.nxmesh+spf.T\_stress\_tensorxy\*spf.nymesh+spf.T\_stress\_tensorxz\*spf.nzmesh | N/m² | Total traction, exterior boundaries, x-component | Boundaries 1–33 |  |
| spf.T\_stressy | spf.T\_stress\_tensoryx\*spf.nxmesh+spf.T\_stress\_tensoryy\*spf.nymesh+spf.T\_stress\_tensoryz\*spf.nzmesh | N/m² | Total traction, exterior boundaries, y-component | Boundaries 1–33 |  |
| spf.T\_stressz | spf.T\_stress\_tensorzx\*spf.nxmesh+spf.T\_stress\_tensorzy\*spf.nymesh+spf.T\_stress\_tensorzz\*spf.nzmesh | N/m² | Total traction, exterior boundaries, z-component | Boundaries 1–33 |  |
| spf.K\_stress\_dx | down(spf.K\_stress\_tensorxx)\*spf.dnxmesh+down(spf.K\_stress\_tensorxy)\*spf.dnymesh+down(spf.K\_stress\_tensorxz)\*spf.dnzmesh | N/m² | Viscous stress, interior boundaries, downside, x-component | Boundaries 1–33 |  |
| spf.K\_stress\_dy | down(spf.K\_stress\_tensoryx)\*spf.dnxmesh+down(spf.K\_stress\_tensoryy)\*spf.dnymesh+down(spf.K\_stress\_tensoryz)\*spf.dnzmesh | N/m² | Viscous stress, interior boundaries, downside, y-component | Boundaries 1–33 |  |
| spf.K\_stress\_dz | down(spf.K\_stress\_tensorzx)\*spf.dnxmesh+down(spf.K\_stress\_tensorzy)\*spf.dnymesh+down(spf.K\_stress\_tensorzz)\*spf.dnzmesh | N/m² | Viscous stress, interior boundaries, downside, z-component | Boundaries 1–33 |  |
| spf.T\_stress\_dx | down(spf.T\_stress\_tensorxx)\*spf.dnxmesh+down(spf.T\_stress\_tensorxy)\*spf.dnymesh+down(spf.T\_stress\_tensorxz)\*spf.dnzmesh | N/m² | Total traction, interior boundaries, downside, x-component | Boundaries 1–33 |  |
| spf.T\_stress\_dy | down(spf.T\_stress\_tensoryx)\*spf.dnxmesh+down(spf.T\_stress\_tensoryy)\*spf.dnymesh+down(spf.T\_stress\_tensoryz)\*spf.dnzmesh | N/m² | Total traction, interior boundaries, downside, y-component | Boundaries 1–33 |  |
| spf.T\_stress\_dz | down(spf.T\_stress\_tensorzx)\*spf.dnxmesh+down(spf.T\_stress\_tensorzy)\*spf.dnymesh+down(spf.T\_stress\_tensorzz)\*spf.dnzmesh | N/m² | Total traction, interior boundaries, downside, z-component | Boundaries 1–33 |  |
| 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(-45+niterCMP,9),0) |  | Local CFL number | Domain 1 |  |
| spf.locCFL | max(CFLCMP,sqrt(eps)) | 1 | Local CFL number | Global |  |
| spf.geometryLengthScale | 0.007500000000000002 | m | Geometry length scale | Domain 1 |  |
| spf.time\_step\_inv | max(sqrt(emetric\_spatial(u,v,w)\*2^gmg\_level^2),spf.nu/spf.geometryLengthScale^2) | Hz | Inverse time step | Domain 1 |  |
| spf.tsti | nojac(spf.time\_step\_inv/spf.locCFL) | 1/s | Help variable | Domain 1 |  |
| spf.nx | dnx | 1 | Normal vector, x-component | Boundaries 1–33 |  |
| spf.ny | dny | 1 | Normal vector, y-component | Boundaries 1–33 |  |
| spf.nz | dnz | 1 | Normal vector, z-component | Boundaries 1–33 |  |
| spf.nxmesh | dnxmesh | 1 | Normal vector, x-component | Boundaries 1–33 |  |
| spf.nymesh | dnymesh | 1 | Normal vector, y-component | Boundaries 1–33 |  |
| spf.nzmesh | dnzmesh | 1 | Normal vector, z-component | Boundaries 1–33 |  |

### Fluid Properties 1

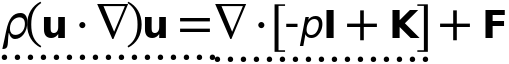


Fluid Properties 1

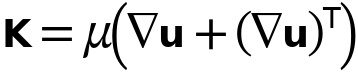
Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

Equations







#### Fluid Properties

Settings

| **Description** | **Value** |
| --- | --- |
| Density | From material |
| Constitutive relation | Specify dynamic viscosity |
| Dynamic viscosity | From material |

#### Model Input

Settings

| **Description** | **Value** |
| --- | --- |
| Temperature | Common model input |

Properties from material

| **Property** | **Material** | **Property group** |
| --- | --- | --- |
| Density | Blood | Basic |
| Dynamic viscosity | Blood | Basic |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| spf.nu | spf.mu/spf.rho | m²/s | Kinematic viscosity | Domain 1 |  |
| spf.mu | material.mu | Pa·s | Dynamic viscosity | Domain 1 | Meta |
| spf.rho | subst(material.rho,spf.fp1.minput\_temperature,spf.Trho,spf.fp1.minput\_pressure,spf.prho) | kg/m³ | Density | Domain 1 | Meta |
| spf.Trho | spf.Tref | K | Temperature for density evaluation | Domain 1 |  |
| spf.prho | spf.pref | Pa | Pressure for the evaluation of density | Domain 1 |  |
| spf.rhoref | subst(material.rho,spf.fp1.minput\_temperature,spf.Tref,spf.fp1.minput\_pressure,spf.pref) | kg/m³ | Reference density | Domain 1 | Meta |
| spf.mumat | material.mu | Pa·s | Dynamic viscosity | Domain 1 | Meta |
| spf.srijxx | ux | 1/s | Strain rate tensor, xx-component | Domain 1 |  |
| spf.srijyx | 0.5\*(vx+uy) | 1/s | Strain rate tensor, yx-component | Domain 1 |  |
| spf.srijzx | 0.5\*(wx+uz) | 1/s | Strain rate tensor, zx-component | Domain 1 |  |
| spf.srijxy | 0.5\*(uy+vx) | 1/s | Strain rate tensor, xy-component | Domain 1 |  |
| spf.srijyy | vy | 1/s | Strain rate tensor, yy-component | Domain 1 |  |
| spf.srijzy | 0.5\*(wy+vz) | 1/s | Strain rate tensor, zy-component | Domain 1 |  |
| spf.srijxz | 0.5\*(uz+wx) | 1/s | Strain rate tensor, xz-component | Domain 1 |  |
| spf.srijyz | 0.5\*(vz+wy) | 1/s | Strain rate tensor, yz-component | Domain 1 |  |
| spf.srijzz | wz | 1/s | Strain rate tensor, zz-component | Domain 1 |  |
| spf.rrijxx | 0 | 1/s | Rotation rate tensor, xx-component | Domain 1 |  |
| spf.rrijyx | 0.5\*(vx-uy) | 1/s | Rotation rate tensor, yx-component | Domain 1 |  |
| spf.rrijzx | 0.5\*(wx-uz) | 1/s | Rotation rate tensor, zx-component | Domain 1 |  |
| spf.rrijxy | 0.5\*(uy-vx) | 1/s | Rotation rate tensor, xy-component | Domain 1 |  |
| spf.rrijyy | 0 | 1/s | Rotation rate tensor, yy-component | Domain 1 |  |
| spf.rrijzy | 0.5\*(wy-vz) | 1/s | Rotation rate tensor, zy-component | Domain 1 |  |
| spf.rrijxz | 0.5\*(uz-wx) | 1/s | Rotation rate tensor, xz-component | Domain 1 |  |
| spf.rrijyz | 0.5\*(vz-wy) | 1/s | Rotation rate tensor, yz-component | Domain 1 |  |
| spf.rrijzz | 0 | 1/s | Rotation rate tensor, zz-component | Domain 1 |  |
| spf.sr | sqrt(2\*spf.srijxx^2+2\*spf.srijxy^2+2\*spf.srijxz^2+2\*spf.srijyx^2+2\*spf.srijyy^2+2\*spf.srijyz^2+2\*spf.srijzx^2+2\*spf.srijzy^2+2\*spf.srijzz^2+eps) | 1/s | Shear rate | Domain 1 |  |
| spf.rr | sqrt(2\*spf.rrijxx^2+2\*spf.rrijxy^2+2\*spf.rrijxz^2+2\*spf.rrijyx^2+2\*spf.rrijyy^2+2\*spf.rrijyz^2+2\*spf.rrijzx^2+2\*spf.rrijzy^2+2\*spf.rrijzz^2+eps) | 1/s | Rotation rate | Domain 1 |  |
| spf.divu | ux+vy+wz | 1/s | Divergence of velocity field | Domain 1 |  |
| spf.Fx | 0 | N/m³ | Volume force, x-component | Domain 1 | + operation |
| spf.Fy | 0 | N/m³ | Volume force, y-component | Domain 1 | + operation |
| spf.Fz | 0 | N/m³ | Volume force, z-component | Domain 1 | + operation |
| spf.U | sqrt(u^2+v^2+w^2) | m/s | Velocity magnitude | Domain 1 |  |
| spf.vorticityx | wy-vz | 1/s | Vorticity field, x-component | Domain 1 |  |
| spf.vorticityy | -wx+uz | 1/s | Vorticity field, y-component | Domain 1 |  |
| spf.vorticityz | vx-uy | 1/s | Vorticity field, z-component | Domain 1 |  |
| spf.vort\_magn | sqrt(spf.vorticityx^2+spf.vorticityy^2+spf.vorticityz^2) | 1/s | Vorticity magnitude | Domain 1 |  |
| spf.cellRe | 0.25\*spf.rho\*sqrt(emetric\_spatial(u-d(x,TIME),v-d(y,TIME),w-d(z,TIME))/emetric2\_spatial)/spf.mu | 1 | Cell Reynolds number | Domain 1 |  |
| spf.betaT | 0 | 1/Pa | Isothermal compressibility coefficient | Domain 1 |  |
| spf.Qm | 0 | kg/(m³·s) | Source term | Domain 1 | + operation |
| spf.Fgtotx | 0 | N/m³ | Gravity force, x-component | Domain 1 | + operation |
| spf.Fgtoty | 0 | N/m³ | Gravity force, y-component | Domain 1 | + operation |
| spf.Fgtotz | 0 | N/m³ | Gravity force, z-component | Domain 1 | + operation |
| spf.Qm\_aco | 0 | kg/(m³·s) | Acoustic mass source | Domain 1 |  |
| spf.F\_acox | 0 | N/m³ | Acoustic volume force, x-component | Domain 1 |  |
| spf.F\_acoy | 0 | N/m³ | Acoustic volume force, y-component | Domain 1 |  |
| spf.F\_acoz | 0 | N/m³ | Acoustic volume force, z-component | Domain 1 |  |
| spf.gamma\_sr | sqrt(2\*spf.srijxx^2+2\*spf.srijxy^2+2\*spf.srijxz^2+2\*spf.srijyx^2+2\*spf.srijyy^2+2\*spf.srijyz^2+2\*spf.srijzx^2+2\*spf.srijzy^2+2\*spf.srijzz^2+eps) | 1/s | Shear rate | Domain 1 |  |
| spf.mu\_eff | spf.mu+spf.muT | Pa·s | Effective dynamic viscosity | Domain 1 |  |
| spf.muT | 0 | Pa·s | Turbulent dynamic viscosity | Domain 1 | + operation |
| spf.T\_stress\_tensorxx | spf.K\_stress\_tensorxx-p | N/m² | Total stress tensor, xx-component | Domain 1 | + operation |
| spf.T\_stress\_tensoryx | spf.K\_stress\_tensoryx | N/m² | Total stress tensor, yx-component | Domain 1 | + operation |
| spf.T\_stress\_tensorzx | spf.K\_stress\_tensorzx | N/m² | Total stress tensor, zx-component | Domain 1 | + operation |
| spf.T\_stress\_tensorxy | spf.K\_stress\_tensorxy | N/m² | Total stress tensor, xy-component | Domain 1 | + operation |
| spf.T\_stress\_tensoryy | spf.K\_stress\_tensoryy-p | N/m² | Total stress tensor, yy-component | Domain 1 | + operation |
| spf.T\_stress\_tensorzy | spf.K\_stress\_tensorzy | N/m² | Total stress tensor, zy-component | Domain 1 | + operation |
| spf.T\_stress\_tensorxz | spf.K\_stress\_tensorxz | N/m² | Total stress tensor, xz-component | Domain 1 | + operation |
| spf.T\_stress\_tensoryz | spf.K\_stress\_tensoryz | N/m² | Total stress tensor, yz-component | Domain 1 | + operation |
| spf.T\_stress\_tensorzz | spf.K\_stress\_tensorzz-p | N/m² | Total stress tensor, zz-component | Domain 1 | + operation |
| spf.K\_stress\_tensorxx | 2\*spf.mu\_eff\*ux | N/m² | Viscous stress tensor, xx-component | Domain 1 | + operation |
| spf.K\_stress\_tensoryx | spf.mu\_eff\*(vx+uy) | N/m² | Viscous stress tensor, yx-component | Domain 1 | + operation |
| spf.K\_stress\_tensorzx | spf.mu\_eff\*(wx+uz) | N/m² | Viscous stress tensor, zx-component | Domain 1 | + operation |
| spf.K\_stress\_tensorxy | spf.mu\_eff\*(uy+vx) | N/m² | Viscous stress tensor, xy-component | Domain 1 | + operation |
| spf.K\_stress\_tensoryy | 2\*spf.mu\_eff\*vy | N/m² | Viscous stress tensor, yy-component | Domain 1 | + operation |
| spf.K\_stress\_tensorzy | spf.mu\_eff\*(wy+vz) | N/m² | Viscous stress tensor, zy-component | Domain 1 | + operation |
| spf.K\_stress\_tensorxz | spf.mu\_eff\*(uz+wx) | N/m² | Viscous stress tensor, xz-component | Domain 1 | + operation |
| spf.K\_stress\_tensoryz | spf.mu\_eff\*(vz+wy) | N/m² | Viscous stress tensor, yz-component | Domain 1 | + operation |
| spf.K\_stress\_tensorzz | 2\*spf.mu\_eff\*wz | N/m² | Viscous stress tensor, zz-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testxx | 2\*spf.mu\_eff\*test(ux) | N/m² | Viscous stress tensor test, xx-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testyx | spf.mu\_eff\*(test(vx)+test(uy)) | N/m² | Viscous stress tensor test, yx-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testzx | spf.mu\_eff\*(test(wx)+test(uz)) | N/m² | Viscous stress tensor test, zx-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testxy | spf.mu\_eff\*(test(uy)+test(vx)) | N/m² | Viscous stress tensor test, xy-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testyy | 2\*spf.mu\_eff\*test(vy) | N/m² | Viscous stress tensor test, yy-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testzy | spf.mu\_eff\*(test(wy)+test(vz)) | N/m² | Viscous stress tensor test, zy-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testxz | spf.mu\_eff\*(test(uz)+test(wx)) | N/m² | Viscous stress tensor test, xz-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testyz | spf.mu\_eff\*(test(vz)+test(wy)) | N/m² | Viscous stress tensor test, yz-component | Domain 1 | + operation |
| spf.K\_stress\_tensor\_testzz | 2\*spf.mu\_eff\*test(wz) | N/m² | Viscous stress tensor test, zz-component | Domain 1 | + operation |
| spf.upwind\_helpx | u-d(x,TIME) | m/s | Upwind term, x-component | Domain 1 | + operation |
| spf.upwind\_helpy | v-d(y,TIME) | m/s | Upwind term, y-component | Domain 1 | + operation |
| spf.upwind\_helpz | w-d(z,TIME) | m/s | Upwind term, z-component | Domain 1 | + operation |
| spf.continuityEquation | spf.rho\*spf.divu | kg/(m³·s) | Continuity equation | Domain 1 |  |
| spf.contCoeff | spf.rho | kg/m³ | Help variable | Domain 1 |  |
| spf.tau\_vdxx | 2\*spf.mu\*spf.srijxx | Pa | Viscous stress tensor, xx-component | Domain 1 | + operation |
| spf.tau\_vdyx | 2\*spf.mu\*spf.srijyx | Pa | Viscous stress tensor, yx-component | Domain 1 | + operation |
| spf.tau\_vdzx | 2\*spf.mu\*spf.srijzx | Pa | Viscous stress tensor, zx-component | Domain 1 | + operation |
| spf.tau\_vdxy | 2\*spf.mu\*spf.srijxy | Pa | Viscous stress tensor, xy-component | Domain 1 | + operation |
| spf.tau\_vdyy | 2\*spf.mu\*spf.srijyy | Pa | Viscous stress tensor, yy-component | Domain 1 | + operation |
| spf.tau\_vdzy | 2\*spf.mu\*spf.srijzy | Pa | Viscous stress tensor, zy-component | Domain 1 | + operation |
| spf.tau\_vdxz | 2\*spf.mu\*spf.srijxz | Pa | Viscous stress tensor, xz-component | Domain 1 | + operation |
| spf.tau\_vdyz | 2\*spf.mu\*spf.srijyz | Pa | Viscous stress tensor, yz-component | Domain 1 | + operation |
| spf.tau\_vdzz | 2\*spf.mu\*spf.srijzz | Pa | Viscous stress tensor, zz-component | Domain 1 | + operation |
| spf.Qvd | spf.tau\_vdxx\*ux+spf.tau\_vdxy\*uy+spf.tau\_vdxz\*uz+spf.tau\_vdyx\*vx+spf.tau\_vdyy\*vy+spf.tau\_vdyz\*vz+spf.tau\_vdzx\*wx+spf.tau\_vdzy\*wy+spf.tau\_vdzz\*wz | W/m³ | Viscous dissipation | Domain 1 | + operation |
| spf.epsilon\_p | 1 | 1 | Porosity | Domain 1 |  |
| spf.epsilon\_p\_pos | 1 | 1 | Positive porosity | Domain 1 |  |
| spf.Fst\_tensorxx | 0 | N/m² | Surface tension force, xx-component | Domain 1 | + operation |
| spf.Fst\_tensoryx | 0 | N/m² | Surface tension force, yx-component | Domain 1 | + operation |
| spf.Fst\_tensorzx | 0 | N/m² | Surface tension force, zx-component | Domain 1 | + operation |
| spf.Fst\_tensorxy | 0 | N/m² | Surface tension force, xy-component | Domain 1 | + operation |
| spf.Fst\_tensoryy | 0 | N/m² | Surface tension force, yy-component | Domain 1 | + operation |
| spf.Fst\_tensorzy | 0 | N/m² | Surface tension force, zy-component | Domain 1 | + operation |
| spf.Fst\_tensorxz | 0 | N/m² | Surface tension force, xz-component | Domain 1 | + operation |
| spf.Fst\_tensoryz | 0 | N/m² | Surface tension force, yz-component | Domain 1 | + operation |
| spf.Fst\_tensorzz | 0 | N/m² | Surface tension force, zz-component | Domain 1 | + operation |
| spf.res\_u | px+spf.rho\*u\*ux+spf.rho\*v\*uy+spf.rho\*w\*uz-(d(2\*ux,x)+d(uy+vx,y)+d(uz+wx,z))\*spf.mu-spf.Fx | N/m³ | Equation residual | Domain 1 |  |
| spf.res\_v | spf.rho\*u\*vx+py+spf.rho\*v\*vy+spf.rho\*w\*vz-(d(vx+uy,x)+d(2\*vy,y)+d(vz+wy,z))\*spf.mu-spf.Fy | N/m³ | Equation residual | Domain 1 |  |
| spf.res\_w | spf.rho\*u\*wx+spf.rho\*v\*wy+pz+spf.rho\*w\*wz-(d(wx+uz,x)+d(wy+vz,y)+d(2\*wz,z))\*spf.mu-spf.Fz | N/m³ | Equation residual | Domain 1 |  |
| spf.res\_p | spf.rho\*spf.divu | kg/(m³·s) | Pressure equation residual | Domain 1 |  |

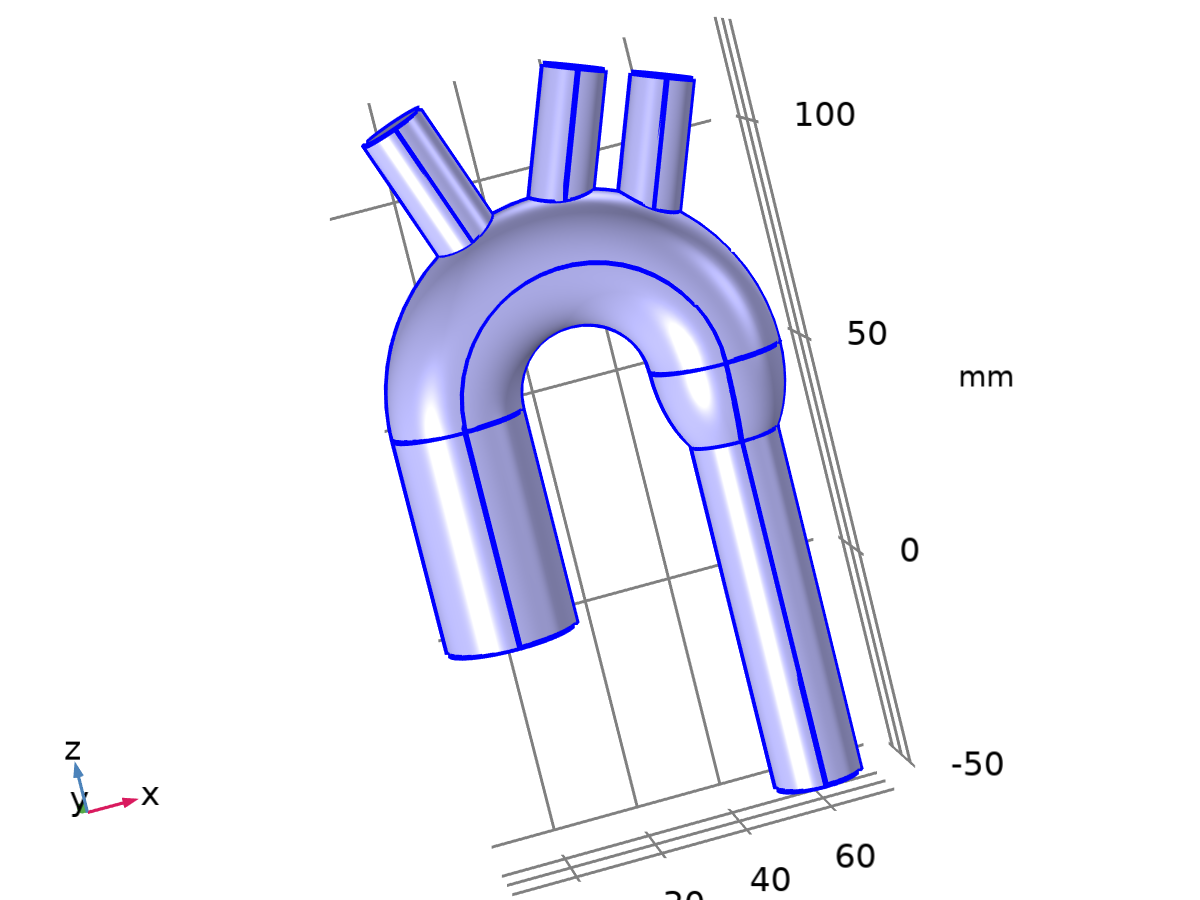
#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** |
| --- | --- | --- | --- | --- | --- |
| u | Lagrange (Linear) | m/s | Velocity field, x-component | Spatial | Domain 1 |
| v | Lagrange (Linear) | m/s | Velocity field, y-component | Spatial | Domain 1 |
| w | Lagrange (Linear) | m/s | Velocity field, z-component | Spatial | Domain 1 |
| p | Lagrange (Linear) | Pa | Pressure | Spatial | Domain 1 |

#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| (p-spf.K\_stress\_tensorxx)\*test(ux)-spf.K\_stress\_tensorxy\*test(uy)-spf.K\_stress\_tensorxz\*test(uz)-spf.K\_stress\_tensoryx\*test(vx)+(p-spf.K\_stress\_tensoryy)\*test(vy)-spf.K\_stress\_tensoryz\*test(vz)-spf.K\_stress\_tensorzx\*test(wx)-spf.K\_stress\_tensorzy\*test(wy)+(p-spf.K\_stress\_tensorzz)\*test(wz) | 2 | Spatial | Domain 1 |
| spf.Fx\*test(u)+spf.Fy\*test(v)+spf.Fz\*test(w) | 2 | Spatial | Domain 1 |
| spf.rho\*(-(d(u,x)\*u+d(u,y)\*v+d(u,z)\*w)\*test(u)-(d(v,x)\*u+d(v,y)\*v+d(v,z)\*w)\*test(v)-(d(w,x)\*u+d(w,y)\*v+d(w,z)\*w)\*test(w)) | 2 | Spatial | Domain 1 |
| -spf.continuityEquation\*test(p) | 2 | Spatial | Domain 1 |
| spf.streamlinens | 2 | Spatial | Domain 1 |
| spf.crosswindns | 2 | Spatial | Domain 1 |
| if(spf.usePseudoTimeStepping>0,spf.rho\*spf.tsti,0)\*(-(u-nojac(u))\*test(u)-(v-nojac(v))\*test(v)-(w-nojac(w))\*test(w)) | 2 | Spatial | Domain 1 |

### Initial Values 1



Initial Values 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: All domains |

#### Initial Values

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Velocity field, x-component | 0 | m/s |
| Velocity field, y-component | 0 | m/s |
| Velocity field, z-component | 0 | m/s |
| Pressure | 0 | Pa |

#### Coordinate System Selection

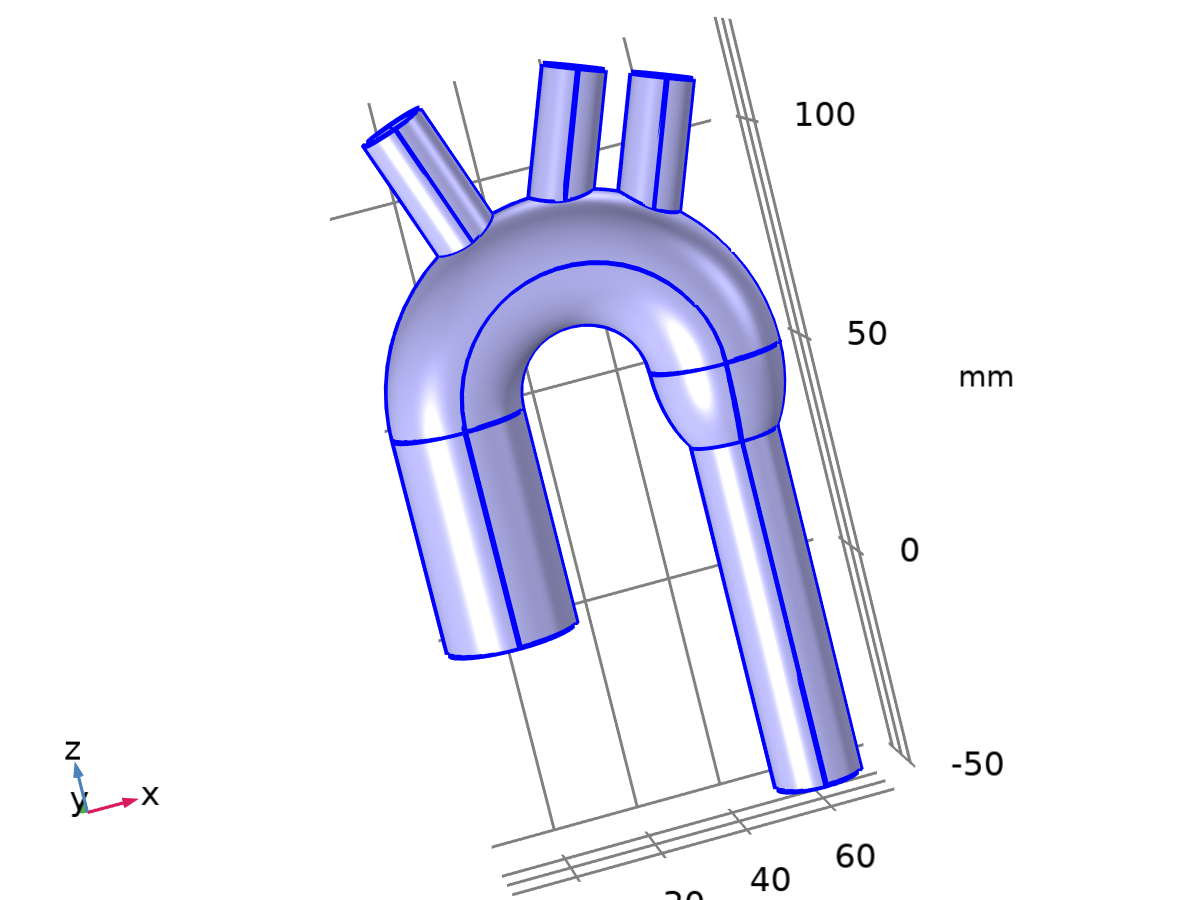
Settings

| **Description** | **Value** |
| --- | --- |
| Coordinate system | Global coordinate system |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| spf.u\_initx | 0 | m/s | Velocity field, x-component | Domain 1 |
| spf.u\_inity | 0 | m/s | Velocity field, y-component | Domain 1 |
| spf.u\_initz | 0 | m/s | Velocity field, z-component | Domain 1 |
| spf.p\_init | 0 | Pa | Pressure | Domain 1 |

### Wall 1



Wall 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: All boundaries |

Equations



#### Boundary Condition

Settings

| **Description** | **Value** |
| --- | --- |
| Wall condition | No slip |

#### Wall Movement

Settings

| **Description** | **Value** |
| --- | --- |
| Translational velocity | Automatic from frame |
| Sliding wall | Off |

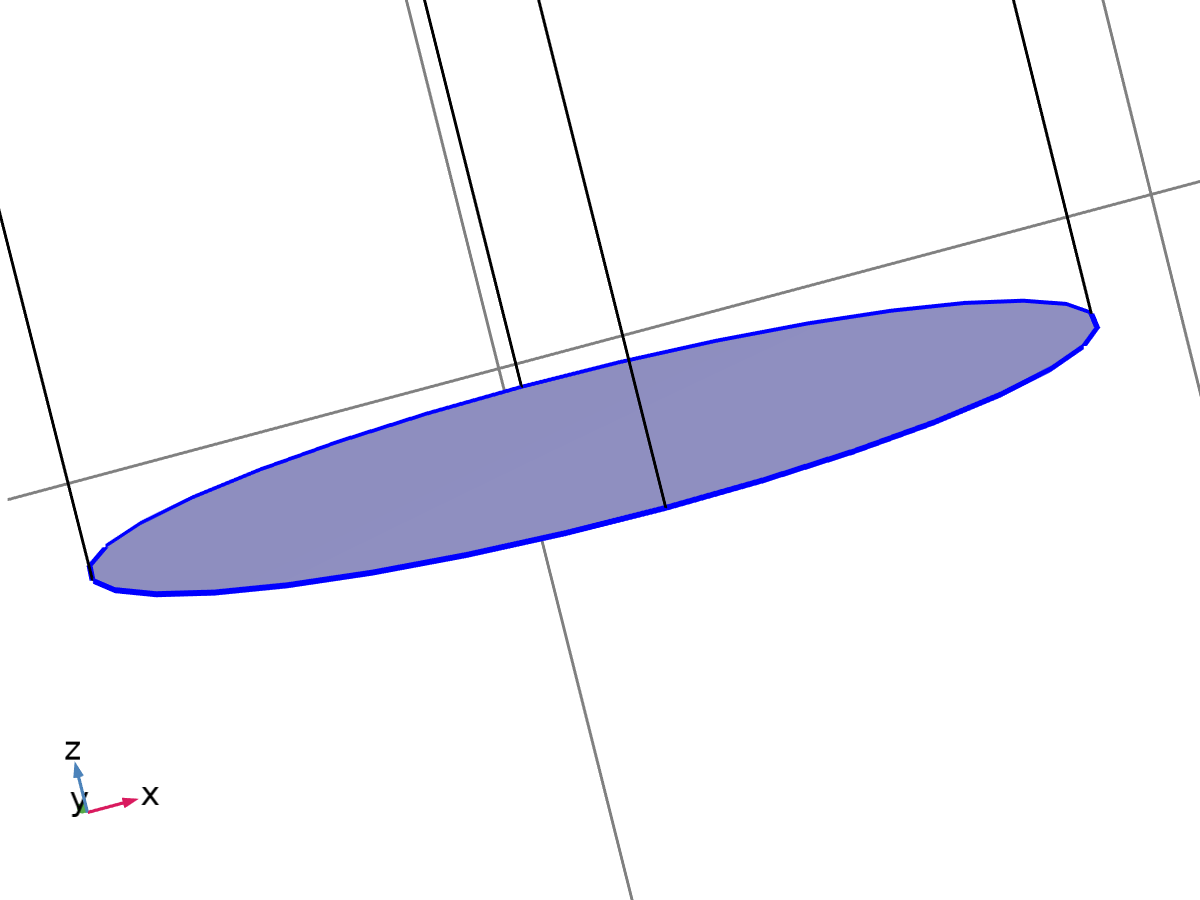
#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| spf.ubndx | spf.utrx+spf.usx | m/s | Velocity at boundary, x-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.ubndy | spf.utry+spf.usy | m/s | Velocity at boundary, y-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.ubndz | spf.utrz+spf.usz | m/s | Velocity at boundary, z-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.usx | 0 | m/s | Velocity of sliding wall, x-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.usy | 0 | m/s | Velocity of sliding wall, y-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.usz | 0 | m/s | Velocity of sliding wall, z-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.utrx | 0 | m/s | Velocity of moving wall, x-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.utry | 0 | m/s | Velocity of moving wall, y-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.utrz | 0 | m/s | Velocity of moving wall, z-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |
| spf.uLeakagex | 0 | m/s | Leakage velocity, x-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 | + operation |
| spf.uLeakagey | 0 | m/s | Leakage velocity, y-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 | + operation |
| spf.uLeakagez | 0 | m/s | Leakage velocity, z-component | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 | + operation |
| spf.noSlipWall | 1 | 1 | Help variable | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |  |

#### Constraints

| **Constraint** | **Constraint force** | **Shape function** | **Selection** | **Details** |
| --- | --- | --- | --- | --- |
| -u+spf.ubndx+spf.uLeakagex | test(-u) | Lagrange (Linear) | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 | Elemental |
| -v+spf.ubndy+spf.uLeakagey | test(-v) | Lagrange (Linear) | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 | Elemental |
| -w+spf.ubndz+spf.uLeakagez | test(-w) | Lagrange (Linear) | Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 | Elemental |

### Inlet 1

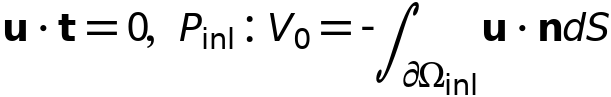


Inlet 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: Boundary 3 |

Equations



#### Boundary Condition

Settings

| **Description** | **Value** |
| --- | --- |
| Boundary condition | Fully developed flow |
| Apply condition on each disjoint selection separately | On |

#### Fully Developed Flow

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Fully developed flow option | Flow rate |  |
| Flow rate | Qin | m³/s |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| spf.nu | spf.mu/spf.rho | m²/s | Kinematic viscosity | Boundary 3 |
| spf.KStressn\_avx | spf.K\_stress\_tensorxx\*spf.nxmesh+spf.K\_stress\_tensorxy\*spf.nymesh+spf.K\_stress\_tensorxz\*spf.nzmesh | N/m² | Average viscous stress, x-component | Boundary 3 |
| spf.KStressn\_avy | spf.K\_stress\_tensoryx\*spf.nxmesh+spf.K\_stress\_tensoryy\*spf.nymesh+spf.K\_stress\_tensoryz\*spf.nzmesh | N/m² | Average viscous stress, y-component | Boundary 3 |
| spf.KStressn\_avz | spf.K\_stress\_tensorzx\*spf.nxmesh+spf.K\_stress\_tensorzy\*spf.nymesh+spf.K\_stress\_tensorzz\*spf.nzmesh | N/m² | Average viscous stress, z-component | Boundary 3 |
| spf.KStressTestn\_avx | spf.K\_stress\_tensor\_testxx\*spf.nxmesh+spf.K\_stress\_tensor\_testxy\*spf.nymesh+spf.K\_stress\_tensor\_testxz\*spf.nzmesh | N/m² | Average viscous stress, x-component | Boundary 3 |
| spf.KStressTestn\_avy | spf.K\_stress\_tensor\_testyx\*spf.nxmesh+spf.K\_stress\_tensor\_testyy\*spf.nymesh+spf.K\_stress\_tensor\_testyz\*spf.nzmesh | N/m² | Average viscous stress, y-component | Boundary 3 |
| spf.KStressTestn\_avz | spf.K\_stress\_tensor\_testzx\*spf.nxmesh+spf.K\_stress\_tensor\_testzy\*spf.nymesh+spf.K\_stress\_tensor\_testzz\*spf.nzmesh | N/m² | Average viscous stress, z-component | Boundary 3 |
| spf.ujumpx | spf.ut\_herex-spf.ut\_therex | m/s | Velocity jump, x-component | Boundary 3 |
| spf.ujumpy | spf.ut\_herey-spf.ut\_therey | m/s | Velocity jump, y-component | Boundary 3 |
| spf.ujumpz | spf.ut\_herez-spf.ut\_therez | m/s | Velocity jump, z-component | Boundary 3 |
| spf.meshVol | meshvol\_spatial | m² |  | Boundary 3 |
| spf.meshVolInt | down(meshvol\_spatial) | m³ | Volume of interior mesh element | Boundary 3 |
| spf.c\_here | 36\*nojac(down((spf.mu+spf.muT)/spf.epsilon\_p))\*spf.meshVol/spf.meshVolInt | Pa·s/m | Intermediate variable | Boundary 3 |
| spf.sigma\_dg\_ns | 4\*spf.c\_here | kg/(m²·s) |  | Boundary 3 |
| spf.inl1.V0fdf | Qin | m³/s | Flow rate | Global |
| spf.inl1.dz | spf.dz | m | Channel thickness | Boundary 3 |
| spf.un\_here | u\*nojac(spf.nxmesh)+v\*nojac(spf.nymesh)+w\*nojac(spf.nzmesh) | m/s | Intermediate variable | Boundary 3 |
| spf.ut\_herex | u-spf.un\_here\*nojac(spf.nxmesh) | m/s | Intermediate variable, x-component | Boundary 3 |
| spf.ut\_herey | v-spf.un\_here\*nojac(spf.nymesh) | m/s | Intermediate variable, y-component | Boundary 3 |
| spf.ut\_herez | w-spf.un\_here\*nojac(spf.nzmesh) | m/s | Intermediate variable, z-component | Boundary 3 |
| spf.un\_there | 0 | m/s | Intermediate variable | Boundary 3 |
| spf.ut\_therex | -spf.un\_there\*nojac(spf.nxmesh) | m/s | Intermediate variable, x-component | Boundary 3 |
| spf.ut\_therey | -spf.un\_there\*nojac(spf.nymesh) | m/s | Intermediate variable, y-component | Boundary 3 |
| spf.ut\_therez | -spf.un\_there\*nojac(spf.nzmesh) | m/s | Intermediate variable, z-component | Boundary 3 |
| spf.unTestx | (test(u)\*spf.nxmesh+test(v)\*spf.nymesh+test(w)\*spf.nzmesh)\*spf.nxmesh | m/s |  | Boundary 3 |
| spf.unTesty | (test(u)\*spf.nxmesh+test(v)\*spf.nymesh+test(w)\*spf.nzmesh)\*spf.nymesh | m/s |  | Boundary 3 |
| spf.unTestz | (test(u)\*spf.nxmesh+test(v)\*spf.nymesh+test(w)\*spf.nzmesh)\*spf.nzmesh | m/s |  | Boundary 3 |
| spf.inl1.pHydroCompensation | 0 | Pa | Hydrostatic pressure | Global |
| spf.d | 1 |  | Length | Boundary 3 |
| spf.inl1.L | 10\*sqrt(spf.inl1.intop(1)) | m | Entrance length | Global |
| spf.inl1.side | 3 |  | Help variable | Edge 2 |
| spf.inl1.side | 3 |  | Help variable | Edge 3 |
| spf.inl1.side | 3 |  | Help variable | Edge 11 |
| spf.inl1.side | 3 |  | Help variable | Edge 15 |
| spf.inl1.side\_down | 3 |  | Help variable | Edge 2 |
| spf.inl1.side\_down | 3 |  | Help variable | Edge 3 |
| spf.inl1.side\_down | 3 |  | Help variable | Edge 11 |
| spf.inl1.side\_down | 3 |  | Help variable | Edge 15 |
| spf.inl1.volumeFlowRate | spf.inl1.intop(u\*spf.nxmesh+v\*spf.nymesh+w\*spf.nzmesh) | m³/s | Outward volume flow rate across feature selection | Global |
| spf.inl1.massFlowRate | spf.inl1.intop(spf.rho\*(u\*spf.nxmesh+v\*spf.nymesh+w\*spf.nzmesh)) | kg/s | Outward mass flow rate across feature selection | Global |
| spf.inl1.pAverage | spf.inl1.aveop(p) | Pa | Pressure average over feature selection | Global |
| spf.inl1.Vinlfdf | -spf.inl1.volumeFlowRate | m³/s | Boundary integral of velocity | Global |
| spf.inl1.Area | spf.inl1.intop(spf.d) | m² | Boundary area | Global |

#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** |
| --- | --- | --- | --- | --- | --- |
| spf.inl1.Pinlfdf | ODE | Pa | Help ode variable for fully developed flow |  | Global |

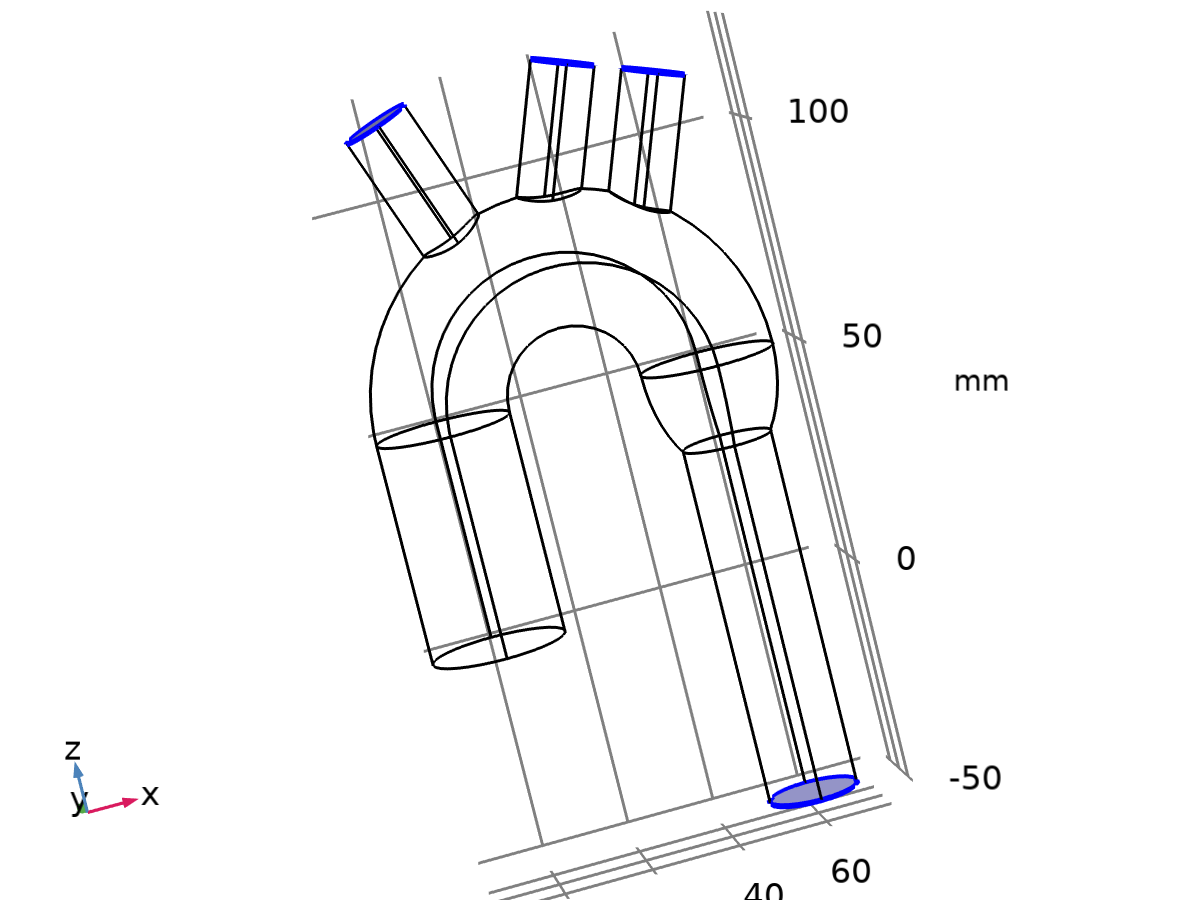
#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| spf.KStressn\_avx\*test(spf.ut\_herex)+spf.KStressn\_avy\*test(spf.ut\_herey)+spf.KStressn\_avz\*test(spf.ut\_herez)+spf.KStressTestn\_avx\*spf.ujumpx+spf.KStressTestn\_avy\*spf.ujumpy+spf.KStressTestn\_avz\*spf.ujumpz-spf.sigma\_dg\_ns\*spf.ujumpx\*test(spf.ut\_herex)-spf.sigma\_dg\_ns\*spf.ujumpy\*test(spf.ut\_herey)-spf.sigma\_dg\_ns\*spf.ujumpz\*test(spf.ut\_herez) | 2 | Spatial | Boundary 3 |
| ((-2\*spf.mu\_eff\*uTx/spf.epsilon\_p+0.5\*(p+spf.inl1.Pinlfdf))\*dtang(spf.unTestx,x)-spf.mu\_eff\*(uTy+vTx)\*dtang(spf.unTesty,x)/spf.epsilon\_p-spf.mu\_eff\*(uTz+wTx)\*dtang(spf.unTestz,x)/spf.epsilon\_p-spf.mu\_eff\*(uTy+vTx)\*dtang(spf.unTestx,y)/spf.epsilon\_p+(-2\*spf.mu\_eff\*vTy/spf.epsilon\_p+0.5\*(p+spf.inl1.Pinlfdf))\*dtang(spf.unTesty,y)-spf.mu\_eff\*(vTz+wTy)\*dtang(spf.unTestz,y)/spf.epsilon\_p-spf.mu\_eff\*(uTz+wTx)\*dtang(spf.unTestx,z)/spf.epsilon\_p-spf.mu\_eff\*(vTz+wTy)\*dtang(spf.unTesty,z)/spf.epsilon\_p+(-2\*spf.mu\_eff\*wTz/spf.epsilon\_p+0.5\*(p+spf.inl1.Pinlfdf))\*dtang(spf.unTestz,z))\*spf.inl1.L-(spf.nxmesh\*test(u)+spf.nymesh\*test(v)+spf.nzmesh\*test(w))\*spf.inl1.Pinlfdf | 2 | Spatial | Boundary 3 |
| (spf.inl1.Vinlfdf-spf.inl1.V0fdf)\*test(spf.inl1.Pinlfdf) | 2 |  | Global |

#### Constraints

| **Constraint** | **Constraint force** | **Shape function** | **Selection** | **Details** |
| --- | --- | --- | --- | --- |
| -u+spf.ubndx | test(-u) | Lagrange (Linear) | Edges 2–3, 11, 15 | Elemental |
| -v+spf.ubndy | test(-v) | Lagrange (Linear) | Edges 2–3, 11, 15 | Elemental |
| -w+spf.ubndz | test(-w) | Lagrange (Linear) | Edges 2–3, 11, 15 | Elemental |
| -spf.inl1.side\_up(u)+spf.ubndx | test(-spf.inl1.side\_up(u)) | Lagrange (Linear) | No edges | Elemental |
| -spf.inl1.side\_up(v)+spf.ubndy | test(-spf.inl1.side\_up(v)) | Lagrange (Linear) | No edges | Elemental |
| -spf.inl1.side\_up(w)+spf.ubndz | test(-spf.inl1.side\_up(w)) | Lagrange (Linear) | No edges | Elemental |
| -spf.inl1.side\_down(u)+spf.ubndx | test(-spf.inl1.side\_down(u)) | Lagrange (Linear) | No edges | Elemental |
| -spf.inl1.side\_down(v)+spf.ubndy | test(-spf.inl1.side\_down(v)) | Lagrange (Linear) | No edges | Elemental |
| -spf.inl1.side\_down(w)+spf.ubndz | test(-spf.inl1.side\_down(w)) | Lagrange (Linear) | No edges | Elemental |

### Outlet 1



Outlet 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: Boundaries 6, 19, 26, 29 |

Equations





#### Boundary Condition

Settings

| **Description** | **Value** |
| --- | --- |
| Boundary condition | Pressure |

#### Pressure Conditions

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Pressure | Static |  |
| Pressure | Pout\_max | Pa |
| Normal flow | Off |  |
| Suppress backflow | On |  |

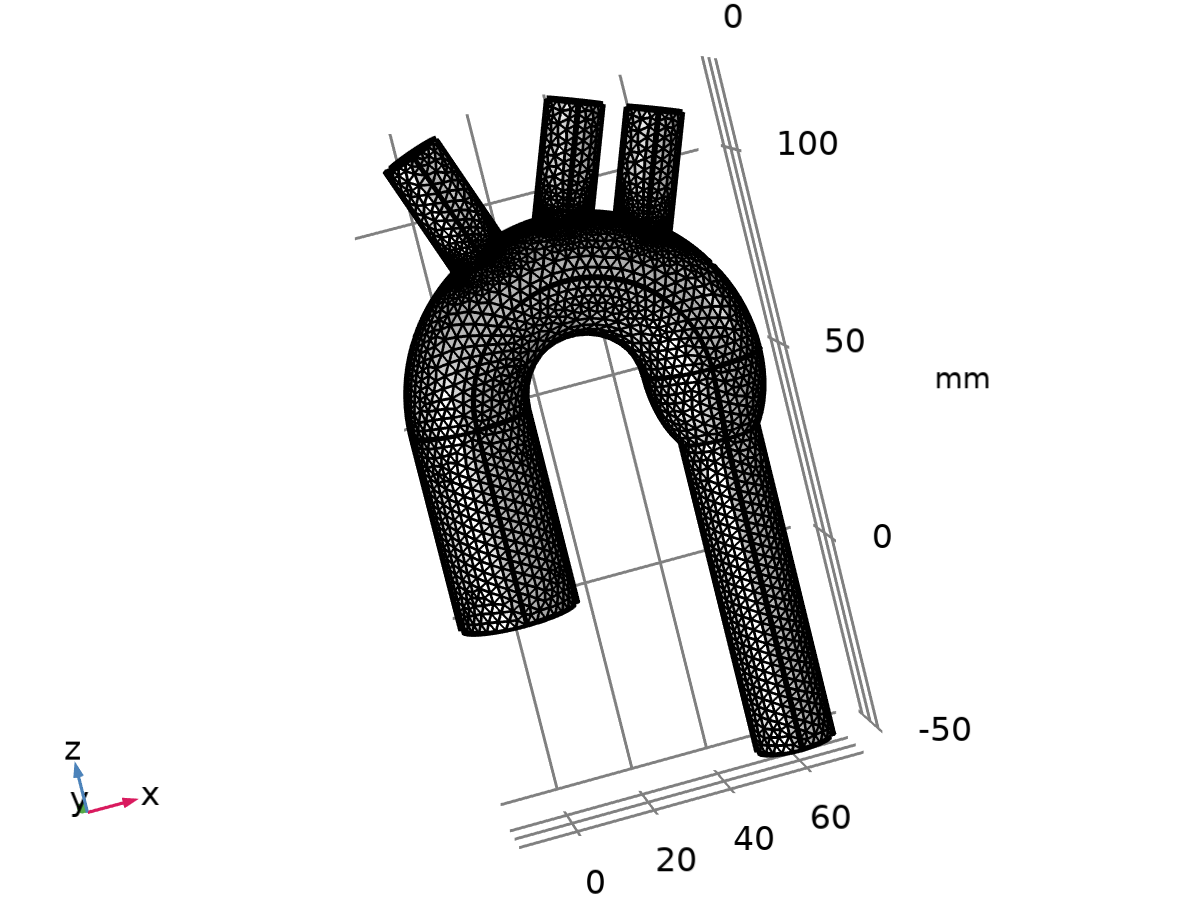
#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| spf.meshVol | meshvol\_spatial | m² |  | Boundaries 6, 19, 26, 29 |
| spf.meshVolInt | down(meshvol\_spatial) | m³ | Volume of interior mesh element | Boundaries 6, 19, 26, 29 |
| spf.rhoFace | down(spf.rho) | kg/m³ | Density face value | Boundaries 6, 19, 26, 29 |
| spf.umxTnFace | spf.upwind\_helpx\*spf.nxmesh+spf.upwind\_helpy\*spf.nymesh+spf.upwind\_helpz\*spf.nzmesh | m/s | Relative velocity on face | Boundaries 6, 19, 26, 29 |
| spf.p0 | Pout\_max | Pa | Pressure | Boundaries 6, 19, 26, 29 |
| spf.out1.Uav | 0 | m/s | Average velocity | Global |
| spf.out1.p0avfdf | 0 | Pa | Average pressure | Global |
| spf.out1.dz | spf.dz | m | Channel thickness | Boundaries 6, 19, 26, 29 |
| spf.out1.Mflow | spf.out1.massFlowRate | kg/s | Mass flow | Global |
| spf.f0 | spf.p0+spf.uNormal\*(spf.backflowPenaltyDiff-spf.backflowPenaltyConv)\*(spf.uNormal<0) | N/m² | Normal stress | Boundaries 6, 19, 26, 29 |
| spf.uNormal | u\*nojac(spf.nxmesh)+v\*nojac(spf.nymesh)+w\*nojac(spf.nzmesh) | m/s | Normal velocity | Boundaries 6, 19, 26, 29 |
| spf.out1.c\_here | 144/spf.epsilon\_p | 1 | Intermediate variable | Boundaries 6, 19, 26, 29 |
| spf.backflowPenaltyDiff | spf.out1.c\_here\*min((down(spf.mu)+spf.muT)\*spf.meshVol/spf.meshVolInt,down(spf.rho)\*abs(spf.uNormal)/down(spf.epsilon\_p)) | Pa·s/m | Backflow penalty parameter, diffusive contribution | Boundaries 6, 19, 26, 29 |
| spf.backflowPenaltyConv | spf.rhoFace\*spf.umxTnFace/spf.epsilon\_p^2 | kg/(m²·s) | Backflow penalty parameter, convective contribution | Boundaries 6, 19, 26, 29 |
| spf.out1.upwind\_ns | spf.backflowPenaltyConv\*spf.uNormal | Pa | Upwind term | Boundaries 6, 19, 26, 29 |
| spf.out1.volumeFlowRate | spf.out1.intop(u\*spf.nxmesh+v\*spf.nymesh+w\*spf.nzmesh) | m³/s | Outward volume flow rate across feature selection | Global |
| spf.out1.massFlowRate | spf.out1.intop(spf.rho\*(u\*spf.nxmesh+v\*spf.nymesh+w\*spf.nzmesh)) | kg/s | Outward mass flow rate across feature selection | Global |
| spf.out1.pAverage | spf.out1.aveop(p) | Pa | Pressure average over feature selection | Global |

#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| -spf.f0\*(test(u)\*spf.nxmesh+test(v)\*spf.nymesh+test(w)\*spf.nzmesh) | 2 | Spatial | Boundaries 6, 19, 26, 29 |

## Mesh 1



Mesh 1

Mesh statistics

| **Description** | **Value** |
| --- | --- |
| Status | Complete mesh |
| Mesh vertices | 29642 |
| Tetrahedra | 98201 |
| Pyramids | 560 |
| Prisms | 20212 |
| Number of elements | 118973 |
| Minimum element quality | 0.09678 |
| Average element quality | 0.6895 |
| Element volume ratio | 7.0466E-4 |
| Mesh volume | 1.514E5 mm³ |

### Size (size)

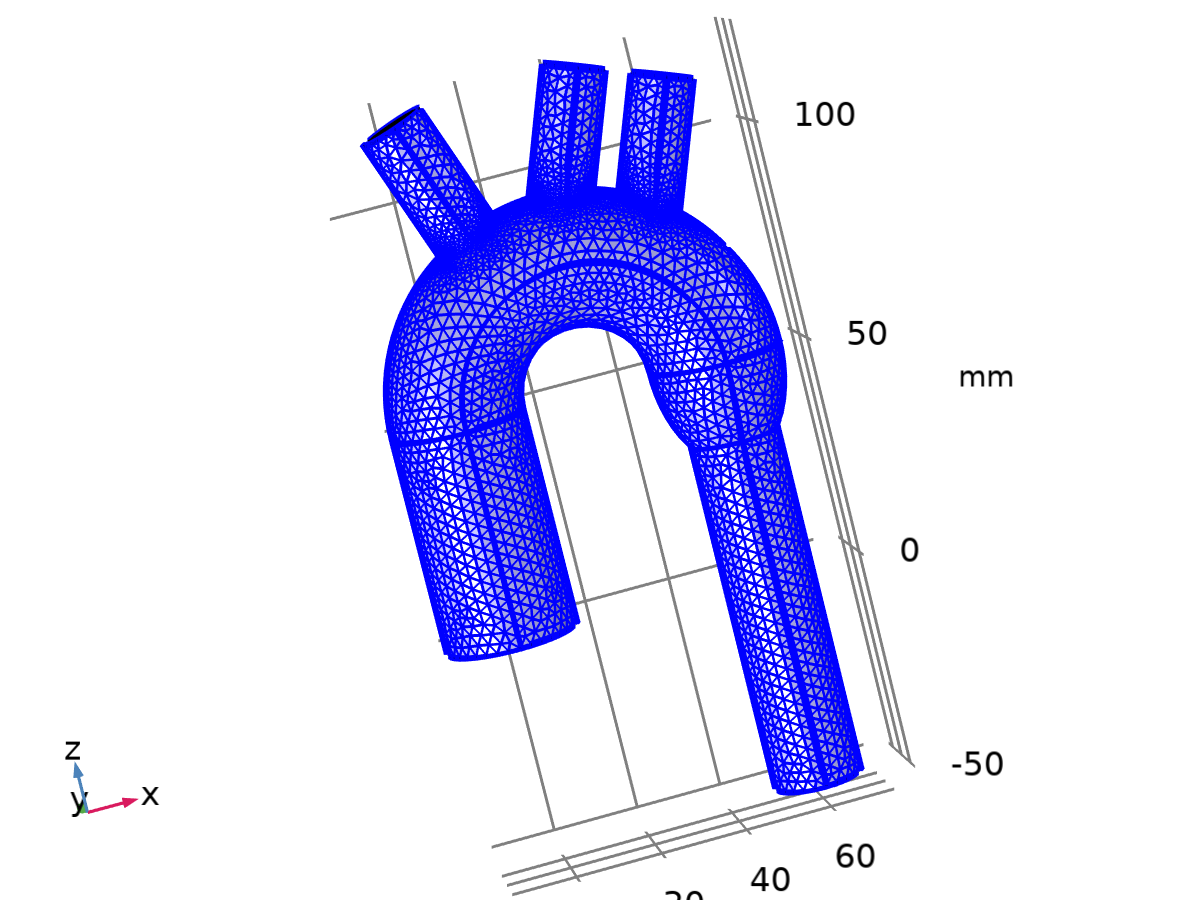
Settings

| **Description** | **Value** |
| --- | --- |
| Calibrate for | Fluid dynamics |
| Maximum element size | 5.2 |
| Minimum element size | 1.56 |
| Curvature factor | 0.7 |
| Resolution of narrow regions | 0.6 |
| Maximum element growth rate | 1.2 |
| Predefined size | Coarse |

### Size 1 (size1)

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |



Size 1

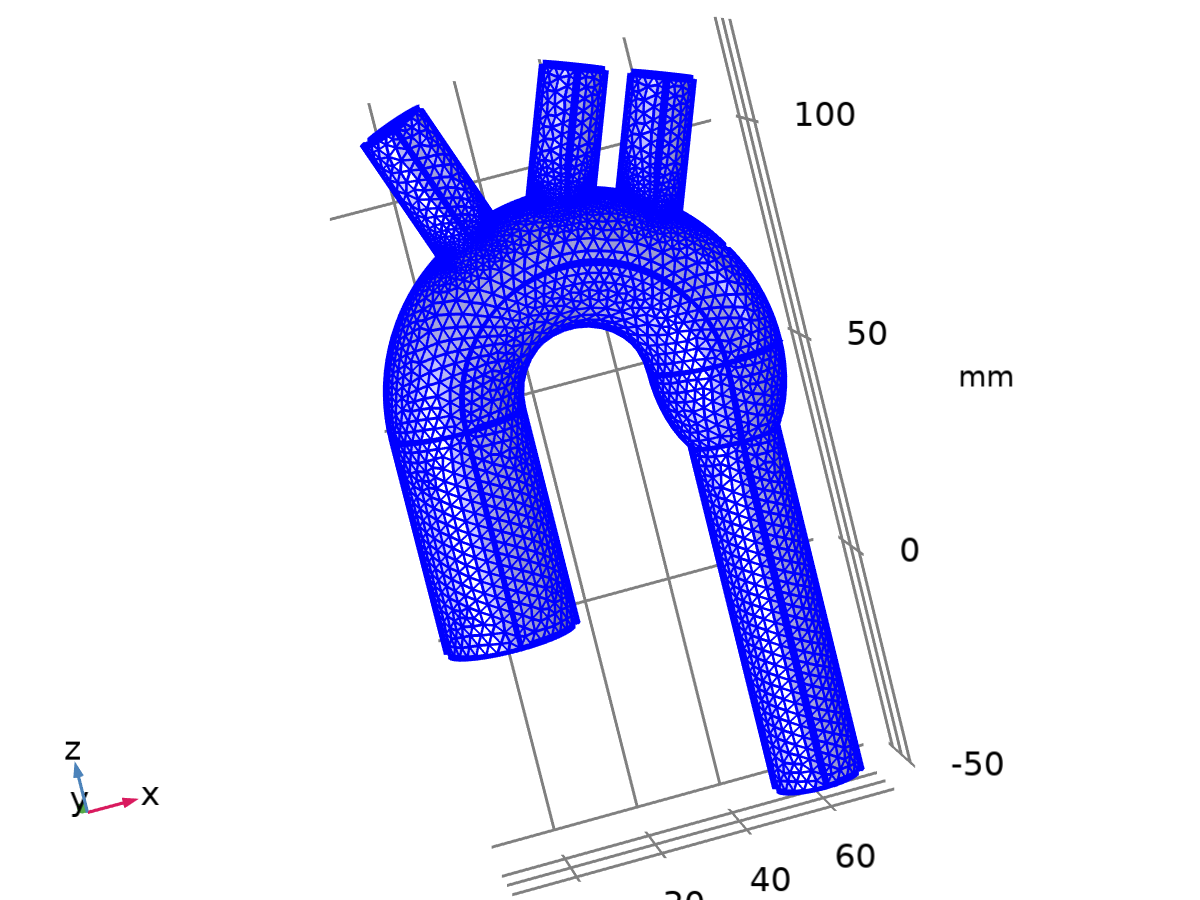
Settings

| **Description** | **Value** |
| --- | --- |
| Calibrate for | Fluid dynamics |
| Maximum element size | 2.75 |
| Minimum element size | 0.52 |
| Curvature factor | 0.5 |
| Resolution of narrow regions | 0.8 |
| Maximum element growth rate | 1.13 |
| Predefined size | Fine |

### Corner Refinement 1 (cr1)

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: Domain 1 |

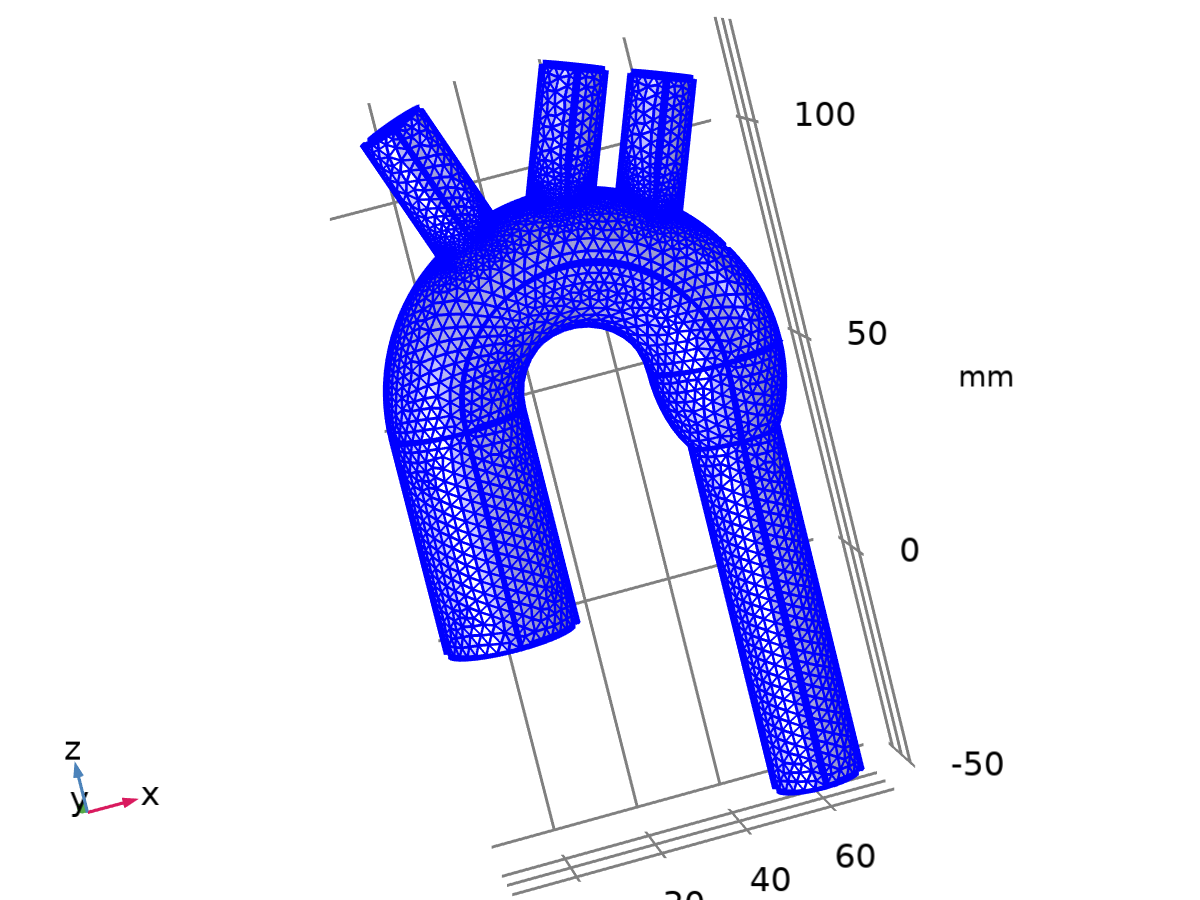


Corner Refinement 1

### Free Tetrahedral 1 (ftet1)

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Remaining |



Free Tetrahedral 1

Settings

| **Description** | **Value** |
| --- | --- |
| Avoid inverted curved elements | On |

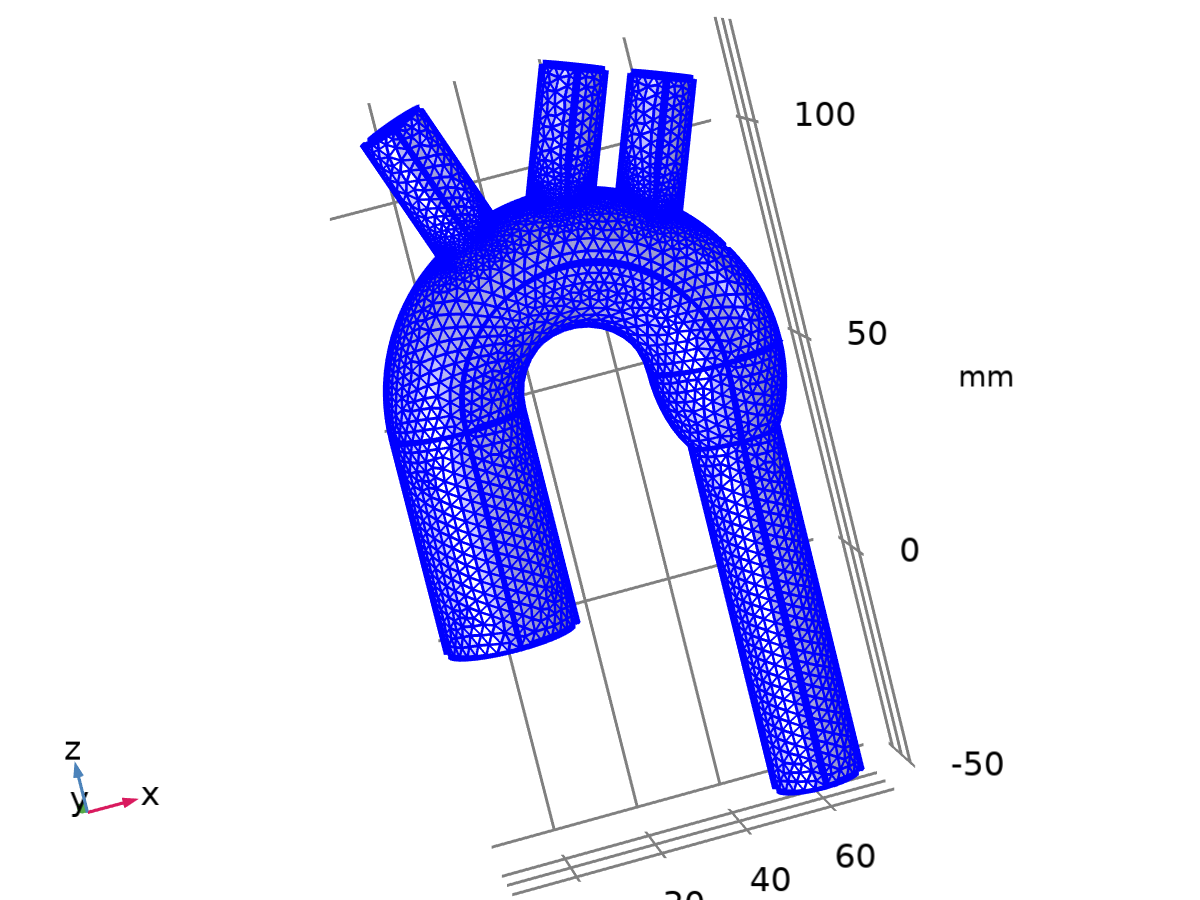
Information

| **Description** | **Value** |
| --- | --- |
| Last build time | 4 seconds |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:47:17 PM |

### Boundary Layers 1 (bl1)

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 3: Domain 1 |



Boundary Layers 1

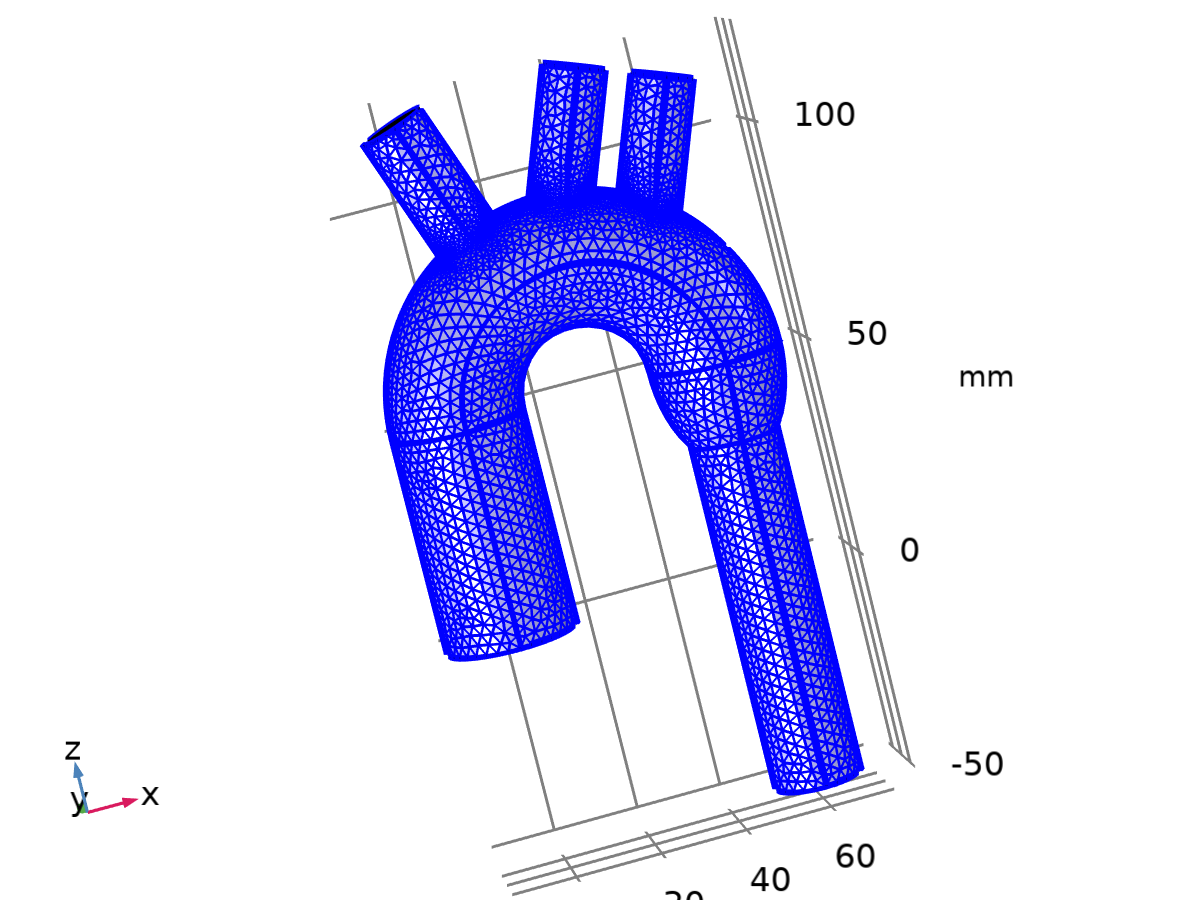
Information

| **Description** | **Value** |
| --- | --- |
| Handling of sharp edges | Trimming |
| Last build time | 7 seconds |
| Built with | COMSOL 6.2.0.339 (win64), Jun 18, 2024, 5:47:25 PM |

#### Boundary Layer Properties 1 (blp1)

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 2: Boundaries 1–2, 4–5, 7–18, 20–25, 27–28, 30–33 |



Boundary Layer Properties 1

Settings

| **Description** | **Value** |
| --- | --- |
| Number of layers | 2 |
| Thickness adjustment factor | 5 |

# Study 1

Computation information

|  |  |
| --- | --- |
| Computation time | 58 s |

## Stationary

Study settings

| **Description** | **Value** |
| --- | --- |
| Include geometric nonlinearity | Off |

Physics and variables selection

| **Physics interface** | **Solve for** | **Equation form** |
| --- | --- | --- |
| Laminar Flow (spf) | On | Automatic (Stationary) |

Store in output

| **Interface** | **Output** | **Selection** |
| --- | --- | --- |
| Laminar Flow (spf) | Physics controlled |  |

Mesh selection

| **Component** | **Mesh** |
| --- | --- |
| Component 1 | Mesh 1 |

## Solver Configurations

### Solution 1

#### Compile Equations: Stationary (st1)

Study and step

| **Description** | **Value** |
| --- | --- |
| Use study | [Study 1](#cs5380865) |
| Use study step | Stationary |

Log

<---- Compile Equations: Stationary in Study 1/Solution 1 (sol1) ---------------

Started at Jun 21, 2024, 5:25:58 PM.

Geometry shape function: Linear Lagrange

Running on Intel64 Family 6 Model 142 Stepping 10, GenuineIntel.

Using 1 socket with 4 cores in total on Francesco.

Available memory: 16.26 GB.

Time: 1 s.

Physical memory: 1.51 GB

Virtual memory: 1.62 GB

Ended at Jun 21, 2024, 5:25:59 PM.

----- Compile Equations: Stationary in Study 1/Solution 1 (sol1) -------------->

#### Dependent Variables 1 (v1)

General

| **Description** | **Value** |
| --- | --- |
| Defined by study step | [Step 1: Stationary](#cs2736674) |

Log

<---- Dependent Variables 1 in Study 1/Solution 1 (sol1) -----------------------

Started at Jun 21, 2024, 5:25:59 PM.

Solution time: 0 s.

Physical memory: 1.51 GB

Virtual memory: 1.62 GB

Ended at Jun 21, 2024, 5:25:59 PM.

----- Dependent Variables 1 in Study 1/Solution 1 (sol1) ---------------------->

##### Pressure (comp1.p) (comp1\_p)

General

| **Description** | **Value** |
| --- | --- |
| Field components | comp1.p |

##### Velocity Field (comp1.u) (comp1\_u)

General

| **Description** | **Value** |
| --- | --- |
| Field components | {comp1.u, comp1.v, comp1.w} |
| Internal variables | comp1.spf.isFluidHasBeenSolved |

##### Help Ode Variable for Fully Developed Flow (comp1.spf.inl1.Pinlfdf) (comp1\_spf\_inl1\_Pinlfdf)

General

| **Description** | **Value** |
| --- | --- |
| State components | comp1.spf.inl1.Pinlfdf |

#### Stationary Solver 1 (s1)

General

| **Description** | **Value** |
| --- | --- |
| Defined by study step | [Step 1: Stationary](#cs2736674) |

Log

<---- Stationary Solver 1 in Study 1/Solution 1 (sol1) -------------------------

Started at Jun 21, 2024, 5:25:59 PM.

Nonlinear solver

Number of degrees of freedom solved for: 118569 (plus 1 internal DOFs).

Nonsymmetric matrix found.

Scales for dependent variables:

Pressure (comp1.p): 0.12

Velocity Field (comp1.u): 0.43

Help Ode Variable for Fully Developed Flow (comp1.spf.inl1.Pinlfdf): 1

Orthonormal null-space function used.

Iter      SolEst      ResEst     Damping    Stepsize #Res #Jac #Sol LinIt   LinErr   LinRes

   1          81     1.5e+04   0.0100000          82    2    1    2     1  0.00066  0.00092

   2         6.7     2.7e+04   0.1000000         7.4    3    2    5     3  0.00029  0.00081

   3         2.4     2.6e+05   1.0000000        0.77    4    3    8    13     0.08     0.13

   4       0.097     1.3e+05   1.0000000        0.14    5    4   11    42    0.099    0.021

   5       0.067       1e+05   0.2757322       0.096    7    5   15    56    0.065        -

   6       0.038     5.5e+04   1.0000000       0.066    8    6   18    61      0.1        -

   7       0.016     5.2e+04   1.0000000       0.037    9    7   21    68     0.12        -

   8      0.0055     3.3e+04   1.0000000       0.018   10    8   24    73    0.047        -

   9      0.0023       1e+04   1.0000000      0.0081   11    9   27    76    0.023        -

  10      0.0011     3.5e+03   1.0000000      0.0037   12   10   30    79    0.012        -

  11      0.0043     9.3e+02   1.0000000       0.019   14   11   33    82   0.0052        -

  12      0.0016     4.6e+02   1.0000000      0.0069   15   12   36    85    0.019        -

  13      0.0007     1.7e+02   1.0000000      0.0026   17   13   39    88   0.0095        -

Solution time: 57 s.

Physical memory: 1.78 GB

Virtual memory: 1.99 GB

Ended at Jun 21, 2024, 5:26:56 PM.

----- Stationary Solver 1 in Study 1/Solution 1 (sol1) ------------------------>

##### Advanced (aDef)

Assembly settings

| **Description** | **Value** |
| --- | --- |
| Reuse sparsity pattern | On |

##### Fully Coupled 1 (fc1)

General

| **Description** | **Value** |
| --- | --- |
| Linear solver | [AMG, fluid flow variables (spf)](#cs3385678) |

Method and termination

| **Description** | **Value** |
| --- | --- |
| Initial damping factor | 0.01 |
| Maximum number of iterations | 100 |

##### AMG, fluid flow variables (spf) (i1)

General

| **Description** | **Value** |
| --- | --- |
| Nonlinear-based error norm | On |
| Maximum number of iterations | 1000 |

Error

| **Description** | **Value** |
| --- | --- |
| Factor in error estimate | 20 |

###### Multigrid 1 (mg1)

General

| **Description** | **Value** |
| --- | --- |
| Solver | Smoothed aggregation AMG |
| Maximum number of DOFs at coarsest level | 80000 |
| Strength of connections | 0.02 |
| Construct prolongators componentwise | On |
| Prolongator smoothing | Off |

Presmoother (pr)

SCGS 1 (sc1)

Main

| **Description** | **Value** |
| --- | --- |
| Sweep type | SSOR |
| Number of iterations | 0 |
| Vanka | On |
| Variables | Help Ode Variable for Fully Developed Flow (comp1.spf.inl1.Pinlfdf) |
| Use approximate factorization | On |
| Use Schur complement approximation for blocks with size larger than | 1000 |

Postsmoother (po)

SCGS 1 (sc1)

Main

| **Description** | **Value** |
| --- | --- |
| Sweep type | SSOR |
| Number of iterations | 1 |
| Vanka | On |
| Variables | Help Ode Variable for Fully Developed Flow (comp1.spf.inl1.Pinlfdf) |
| Use approximate factorization | On |
| Use Schur complement approximation for blocks with size larger than | 1000 |

Coarse Solver (cs)

Direct 1 (d1)

General

| **Description** | **Value** |
| --- | --- |
| Solver | PARDISO |
| Pivoting perturbation | 1E-13 |

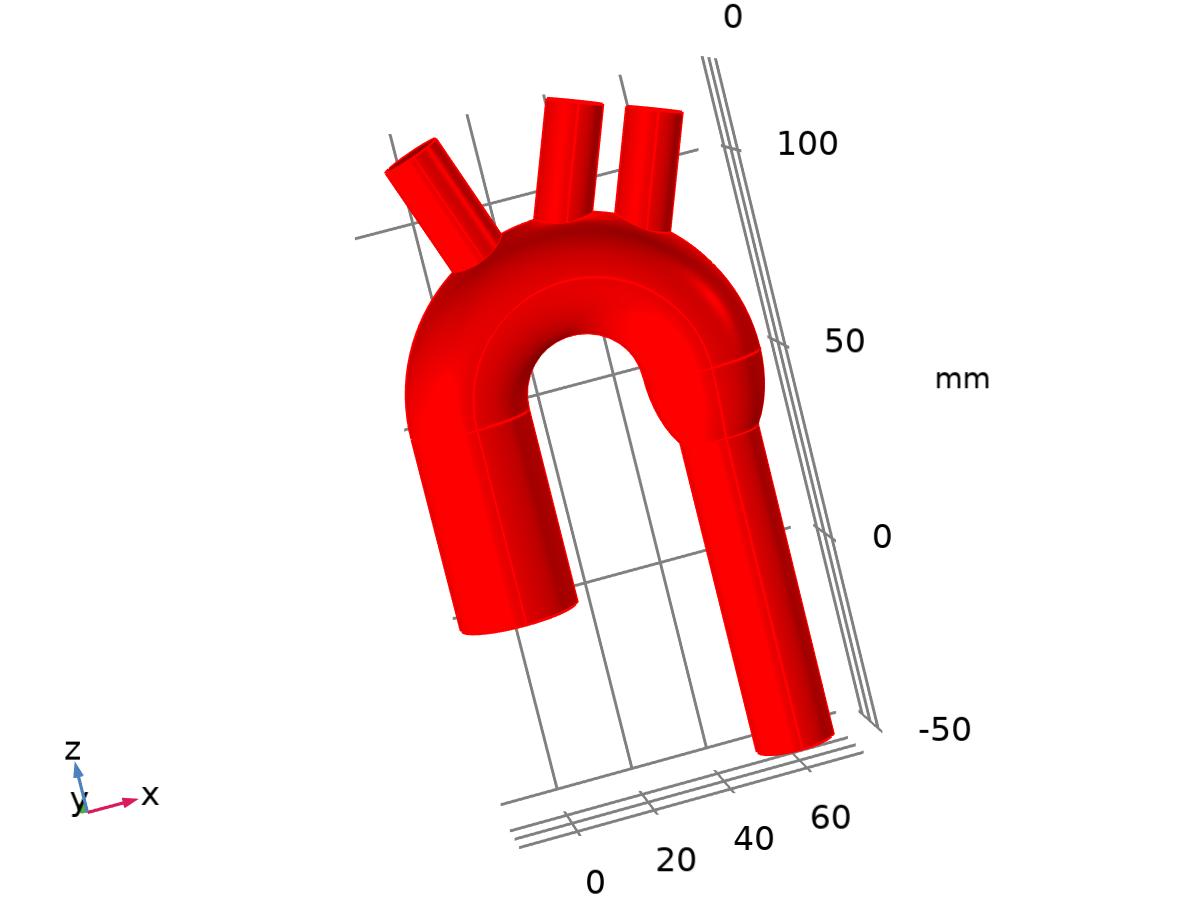
# Results

## Datasets

### Study 1/Solution 1

Solution

| **Description** | **Value** |
| --- | --- |
| Solution | [Solution 1 (sol1)](#cs8519881) |
| Component | Component 1 (comp1) |



Dataset: Study 1/Solution 1

### Exterior Walls

Data

| **Description** | **Value** |
| --- | --- |
| Dataset | [Study 1/Solution 1 (sol1)](#cs5667178) |

Parameterization

| **Description** | **Value** |
| --- | --- |
| x- and y-axes | Surface parameters |

## Plot Groups

### Velocity (spf)

[COMSOLlink[]]

Slice: Velocity magnitude (m/s) Streamline: Velocity field

### Pressure (spf)

[COMSOLlink[]]

Surface: Pressure (Pa)