# Generate Heart Valve Geometry

## Import Model:

1. File 🡪 Import 🡪 Step: D:\Simulation\1\_CAD Modell CREO\HeartValve\_20250613\AorticValveCAD.stp
2. Scale Factor = 0.1 🡪 Conversion mm in cm
3. Identify all parts in positive x- and y -Direction 🡪 1/6 of complete model. Include Commissure Region in positive x-y- direction (violet).

Ein Bild, das Cartoon, Kinderkunst enthält.

KI-generierte Inhalte können fehlerhaft sein. Ein Bild, das Design enthält.

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1. Delete all other parts
2. Remove unnecessary vertices: Curve 🡪 Merge 🡪 Piecewise, Remove Raw Edge 🡪 Select Sinus upper edge which is in contact with the free edge

Ein Bild, das Screenshot, Grafiksoftware, Multimedia-Software, Design enthält.

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1. Stitch Surfaces: GeoTol 🡪 Stitch 🡪 Choose all aortic root surfaces, Repeat with 2 leaflet surfaces. Click non-manifold mode for stitching surfaces at edges where 3 or more Surfaces come in contact. 🡪 All Lines between surfaces should be black (two surfaces) or violet (three surfaces). Outer Edges are light blue.

Ein Bild, das Design enthält.

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1. Save as project: D:\Simulation\2\_Geometrie LS-DYNA\geometry\_20250613\AorticValveGeometry\_1.proj

## Create Smooth Leaflet Surfaces:

1. Hide aortic root surfaces
2. Reflect the two leaflet surfaces: GeoTol 🡪 Transf 🡪 Reflect 🡪 Plane: NormY 🡪 Copy
3. Curve 🡪 Break 🡪 Method: Parameter 🡪 Only Create Break Points.
   1. Use N Segment = 10 for each of the Free Edge Lines
   2. Use N Segment = 10 for each of the Belly-Coaptation Zone Edges
   3. Use N Segment = 5 for the two Commissure Lines & the Symmetry Line in the y-Plane. For z > 0
   4. Use N Segment = 10 for the Symmetry Line in the y-Plane for z<0
   5. Use N Segment = 15 for the two Basal Attachment Edges.

Higher values reproduce the original surface better but are more angular. Lower values ensure a rounder geometry with fewer kinks.

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1. Curve 🡪 Spline 🡪 Untick Piecewise, Tick Sort Points
   1. Use all Points on the free edge, expect the one on the symmetry line, for the smoothed Free Edge. (red line)
   2. For the Commissure & Basal Attachment Lines (green lines) use all points except the 2 points at z=0 to create a smooth transition between Commissure and Basal Attachment. Don’t forget the point on the symmetry line!

Ein Bild, das rot, Karminrot, Flagge enthält.

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RefGeo 🡪 Plane 🡪 Create two planes. One with Normal 0,0,1 and one with 0,1,0

Trim the red and green line at the two planes to create the missing vertices

Ein Bild, das Reihe, Himmel, Diagramm enthält.

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1. Use all point on the z=0 surface except the one at the symmetry line (y=0) to create a smooth Directrix Curve of the leaflet between belly and coaptation area.
2. Trim the line to create the missing vertex on y=0 plane.

Ein Bild, das Reihe, Himmel enthält.

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1. GeoTol 🡪 Trim 🡪 Use Curves as Trim Tool and trimmed entity to trim curves at intersections with other curves
2. Create a Spline. Use all points on the symmetry line except the one directly below the free edge.

Ein Bild, das Reihe, Steigung enthält.

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1. Surf 🡪 N-Side 🡪 Click all 4 edges of the coaptation region in the positive x-y Plane. Repeat this with the 3 edges for the Belly in the positive x-y- Plane.

Ein Bild, das Farbigkeit, Grün enthält.

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1. Save as project: D:\Simulation\2\_Geometrie LS-DYNA\geometry\_20250613\AorticValveGeometry\_2.proj

## Create structured Shell Mesh

1. Curve 🡪 break 🡪 Parameter, N Segment = 2, Only Create Break Points for Free Edge, Coaptation-Line, Symmetry Line and Basal Attachment Line.
2. Curve 🡪 Point 🡪 X=0.7753508 cm, Y =0.5085122 cm, Z=-0.3476466 cm
3. GeoTol 🡪 Project 🡪 Destination Belly Surface, Source is the created Point
4. Curve 🡪 Line 🡪 Point/Point. Create lines from Break Point on edges to Point on Belly Surface. Create Line from free edge middle to Coaptation Point Middle.
5. GeoTol 🡪 Project. Project all 4 lines onto the Leaflet Surfaces.
6. GeoTol 🡪 Trim 🡪 Trim Belly Surface and Coaptation Surface by projected Lines as Trim Tools.
7. GeoTol 🡪 Transform 🡪 Reflect, Choose all 5 Trimmed Surfaces, Tick Copy. Choose NormY as plane.

Ein Bild, das Grün, Farbigkeit enthält.

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1. Mesh 🡪 N-Line Mesh 🡪 Type: 4 Lines Shell 🡪 Click edges in counter-Clockwise direction starting with the right edge. Click Mesh It and Accept. Repeat this for all 10 surfaces. Use N1 =N2 = N3 = N4 = 5 for coarse mesh with 250 elements per leaflet 🡪 750 elements for complete valve. Use N1-N4 = 10 for medium mesh with 1000 elements per leaflet 🡪 3000 elements for complete valve. Use N1-N4 = 20 for fine mesh with 4000 elements per leaflet 🡪 12000 for complete valve.
2. EleTol 🡪 Element Editing 🡪 Direction 🡪 Check if all arrows point towards the free edge 🡪 This is the local positive x-Direction of the elements.
3. EleTol 🡪 MovCop 🡪 Select all 10 mesh parts and Move with PID = 1. Apply.
4. EleTol 🡪 Duplicate Nodes 🡪 Show Dup Nodes 🡪 Merge Dup Nodes. Make Sure that all nodes are included. Otherwise increase the tolerance and check again.
5. EleTol 🡪 Smooth 🡪 Use default values
6. Application 🡪 Model Checking 🡪 General Checking. Perform Quality Check for Shell Mesh
   1. Aspect Ratio = 1.03 - 1.48; 1.03-1.53; 1.01-1.57
   2. Warpage = 0.0593 – 6.23; 0-3.27; 0-1.65
   3. Min Quad Angle = 70.9-89.5; 68.2-89.8; 63.7-89.9
   4. Max Quad Angle = 90.5-124; 90.3-125; 90.1-125
   5. Skewness = 0.0524-16.1; 0.0135-21.2; 0.0035-26.1
   6. Jacobian = 0.778-0.992; 0.786-0.996; 0.79-0.998
   7. Feature Angle = 1.67-20.5; 0.745-13; 0.245-9.44
7. For the medium and fine mesh: EleTol 🡪 Smooth 🡪 Select all Elements, Lock the nodes in the picture. Use Options like in the picture to smooth the belly and coaptation areas, while keeping the symmetry line and the coaptation belly Line.

Ein Bild, das Screenshot, Text, Grafiksoftware, Multimedia-Software enthält.

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1. Save as project: D:\Simulation\2\_Geometrie LS-DYNA\geometry\_20250613\AorticValveGeometry\_3.proj

## Create non-uniform Thickness Distribution.

1. EleTol 🡪 MovCop. Choose elements that have the same thickness and give them a separate part ID. Check Picture 6 for the chosen Thickness Levels. The free Edge is thinner than the coaptation Zone which lies approx. 1-2 mm below the Free Edge. The Belly is the thinnest part. The Basal Attachment is comparable to the coaptation area.

Ein Bild, das Farbigkeit enthält.

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For the middle Mesh first create the same spatial distribution, then create Transition Zones between each of the three layers.

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KI-generierte Inhalte können fehlerhaft sein.

1. Model 🡪 Keyword 🡪 Section 🡪 Shell 🡪 T1 = Insert Thickness of layer & press enter. Title should include the thickness. Repeat for every thickness level that should be created. Belly (green, Part 3) = 0.42 mm = 0.042 mm, Coaptation & Basal Attachment (red, Part 1) = 0.53 mm = 0.053 cm, Nodulus = 1.05 mm = 0.105 cm. Transition Zone (blue, Part 2) = 0.475 mm = 0.0475 cm

For the middle mesh: Use Additional: Transition Zone (yellow, Part 4) = 0.04475 cm, Transition Zone (Brown, Part 5) = 0.05025 cm

For the fine mesh: Use Additional: Transition Zone (Red, Part 6) = 0.043375, Transition Zone (Dark Blue, Part 7) = 0.046125, Transition Zone (Green, Part 8) = 0.048875, Transition Zone (Yellow, Part 9) = 0.051625

Ein Bild, das Muster, Kreis, Kunst enthält.

KI-generierte Inhalte können fehlerhaft sein.

|  |  |  |  |
| --- | --- | --- | --- |
| Part 1 | Red | Coarse | 0.053 cm |
| Part 2 | Blue | Coarse | 0.0475 cm |
| Part 3 | Green | Coarse | 0.042 cm |
| Part 4 | Yellow | Medium | 0.04475 cm |
| Part 5 | Brown | Medium | 0.05025 cm |
| Part 6 | Red | Fine | 0.043375 cm |
| Part 7 | Dark Blue | Fine | 0.046125 cm |
| Part 8 | Green | Fine | 0.048875 cm |
| Part 9 | Yellow | Fine | 0.051625 cm |

1. Model 🡪 Keyword 🡪 Part 🡪 Apply correct SECID for every part.
2. Model 🡪 Appear 🡪 Tick option Thick and click AllVis. Check if the Thickness Distribution is correct.
3. Mesh 🡪 EleGen 🡪 Solid 🡪 Solid by: Shell Thickness, Untick Delete Shell, Enter number of segments through thickness = 1. Create.
4. Save as project: D:\Simulation\2\_Geometrie LS-DYNA\geometry\_20250613\AorticValveGeometry\_4.proj

## Create Nodulus

1. EleTol 🡪 Measure 🡪 DistN2N 🡪 Select the node, where the centre of the nodulus should be located. Click the node on the other side of the valve to see the actual thickness. Here: second node beneath the free edge at the symmetry line: coarse: 0.050631 cm, For middle: 0.0519651 cm, For Fine: 0.0523125 cm

Ein Bild, das Screenshot, Himmel, Reihe, gelb enthält.

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1. Calculate difference distance between nodulus thickness and actual thickness: Coarse: 0.105 cm – 0.050631 = 0.054369 cm

Middle: 0.105 cm – 0.0519651 = 0.0530349 cm

Fine: 0.105 cm – 0.0523125 = 0.0526875 cm

1. EleTol 🡪 Transform 🡪 Translate 🡪 Direction: N1-N2 🡪 Click Nodes 1 and 2 for the direction. Click the point you want to translate on the fibrosa. Here: Second vertex below free edge at symmetry line. Tick Copy Node Option, No. of copies: 1 🡪 Tran+
2. Curve 🡪 Spline 🡪 Interpolate Points, untick Piecewise. Select the points to create the nodulus wire. See the picture.

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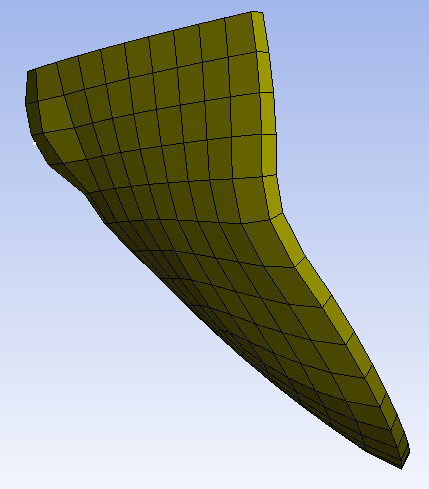
1. Use GeoTol 🡪 Trim 🡪 Multi Trim and trim all splines at each other
2. Surf 🡪 N-Side 🡪 Create 4 Nodulus surfaces by clicking the edges.

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1. Use Mesh 🡪 AutoMesh and mesh all 4 surfaces. Click compute and reduce the size of the mesh by factor 10 to have a very fine mesh
2. EleTol 🡪 Transform 🡪 Project 🡪 Plane: To Mesh, Vector Projection with -1,0,0, Tick Positive Direction Only, Select Nodes and Choose all elements of the nodulus mesh

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1. Save as project: D:\Simulation\2\_Geometrie LS-DYNA\geometry\_20250613\AorticValveGeometry\_5.proj

## Create finished heart valve mesh

1. Create elements through thickness:
   1. For coarse and fine mesh: Mesh 🡪 EleEdit 🡪 Split/Merge 🡪 Solid 🡪 Last Option 🡪 Click Heart Valve Mesh. Note: This way you can only create 1,2,4, 8 etc. elements through the thickness! If you want other values use the following approach!
   2. For Middle: Create two shell Sets, one for the fibrosa surface and one for the ventricular surface: Mesh 🡪 Element Generation 🡪 Shell 🡪 Shell By: Solid Face. Select all Surface elements of the respective surface: See Picture on the left.

Then create a solid between the two shell surfaces with the desired number of elements through the thickness: Mesh 🡪 Element Generation 🡪 Solid 🡪 Solid By: Two Shell Sets, Tick new node, Click Set 1 and choose Fibrosa surface, Use the red point on Fibrosa as N1 and the green point as N2, Use Ventricular Surface as Set2, Red Node on Ventricularis as N1 and Green one as N2. Choose number of segments. See picture on the right!

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1. Check Mesh Quality: Medium Mesh, Fine Mesh
   1. Minimum Angle: 51.94-89.37; 53.56-89.65
   2. Maximum Angle: 90.631-124.7; 90.38-124.93
   3. Distortion Index: 0.5857-0.991537; 0.6025-0.9937
   4. Aspect Ratio: 1.93-5.8; 1.40-3.66
2. Create other two leaflets: EleTol 🡪 Transform 🡪 Rotate, 120 degress, Copy Elements, No. of copies = 2
3. Don’t forget to delete the node used for Nodulus Creation!
4. Save as project: D:\Simulation\2\_Geometrie LS-DYNA\geometry\_20250613\AorticValveGeometry\_6.proj
5. Save as keyword: D:\Simulation\2\_Geometrie LS-DYNA\geometry\_20250613\AorticValveMesh\_Coarse.k