VirtuCath™ - User Manual

1. Introduction

Welcome to VirtuCath™!

VirtuCath is a simulation tool designed for the rapid design and digital prototyping of deflectable micro-catheters. Powered by the MuJoCo physics engine from Google DeepMind, VirtuCath enables you to intuitively define catheter properties, observe simulated behavior, and analyze results within an interactive 3D environment. At its core, the application constructs a "digital twin" of your catheter design, allowing you to manipulate its deflection through virtual pullwires and gain insights into its mechanical performance and reach.

VirtuCath is intended as a design aid and for preliminary simulation purposes only. The results generated by this software are based on a simplified physics model and should not be considered a substitute for comprehensive physical prototyping, rigorous testing, or formal Verification and Validation (V&V) activities required for medical devices or other critical applications.

The simulation makes certain assumptions and simplifications, including but not limited to, primarily linear material behaviors and idealized mechanics. Furthermore, axial and shear deformation of the catheter sections is not modeled, under the assumption that the axial and shear stiffness is significantly greater than the bending or torsional stiffness. The simulation does not account for all complex non-linear phenomena such as large elastic deformations, kinking, material hysteresis, or intricate contact mechanics that might be captured by more exhaustive Finite Element Analysis (FEA) packages.

Users should exercise their own professional judgment when interpreting the simulation results and are solely responsible for the design, testing, and validation of any physical product based on or informed by the use of this software. VirtuCath, LLC disclaims any and all liability for decisions made or actions taken based on the information provided by VirtuCath.

This manual serves as your comprehensive guide to the features and usage of VirtuCath.

2. System Requirements

To run VirtuCath, you will need:

- Microsoft Windows 10 or higher.
- A processor capable of handling physics simulations (e.g., Intel Core i5 or AMD Ryzen 5, or newer, is recommended for a smooth experience).
- At least 4GB of RAM (8GB or more recommended).
- A graphics card supporting OpenGL 3.3 or higher for the 3D viewer.

3. Getting Started

3.1. Launching VirtuCath

To launch the application, simply double-click the VirtuCath.exe file.

3.2. Main Window Overview

The VirtuCath main window is divided into several key areas:

- **Menu Bar**: Provides access to file operations.
- **Left Panel (Tabs)**:
  - **Catheter Setup Tab**: Define the physical and mechanical properties of your catheter.
  - **Simulation Control Tab**: Control the simulation in real-time.
- **Middle Panel (3D Viewer)**: Displays an interactive 3D rendering of the catheter simulation.
- **Right Panel (Data Readout)**: Displays multiple key parameters of the simulation.

4. Catheter Setup Tab

The catheter setup wizard guides you through defining the geometry and characteristics of your catheter design.

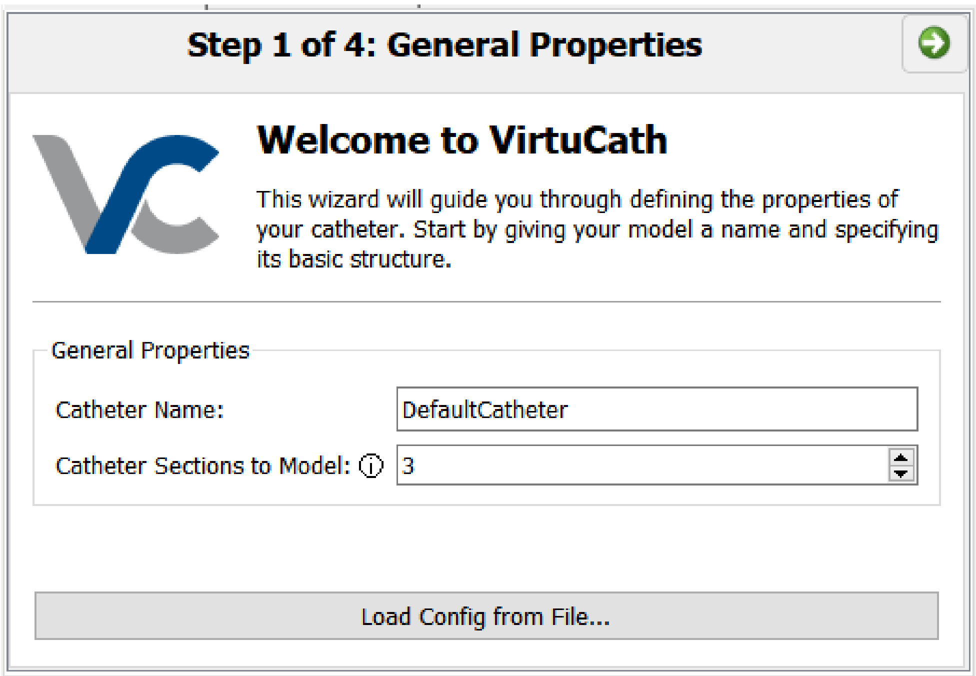
4.1. General Properties

Catheter Name: Assign a unique, descriptive name for your catheter design. This name will be automatically assigned to exported images and data logs.

Number of Catheter Sections: Define how many distinct sections your catheter comprises (e.g., a proximal shaft, a flexible bending section, and a distal tip).

> ℹ️ **Note:** For best performance, define only the flexible or steerable distal portion of the catheter that you intend to simulate. Simulating the entire length of a long device may cause instability or slow performance.

Load Config from File: Loads a previously saved catheter design from a configuration file. This bypasses the setup wizard and immediately generates the interactive model based on the file's parameters. Also accessible via File > Load Config..



4.2. Section Lengths

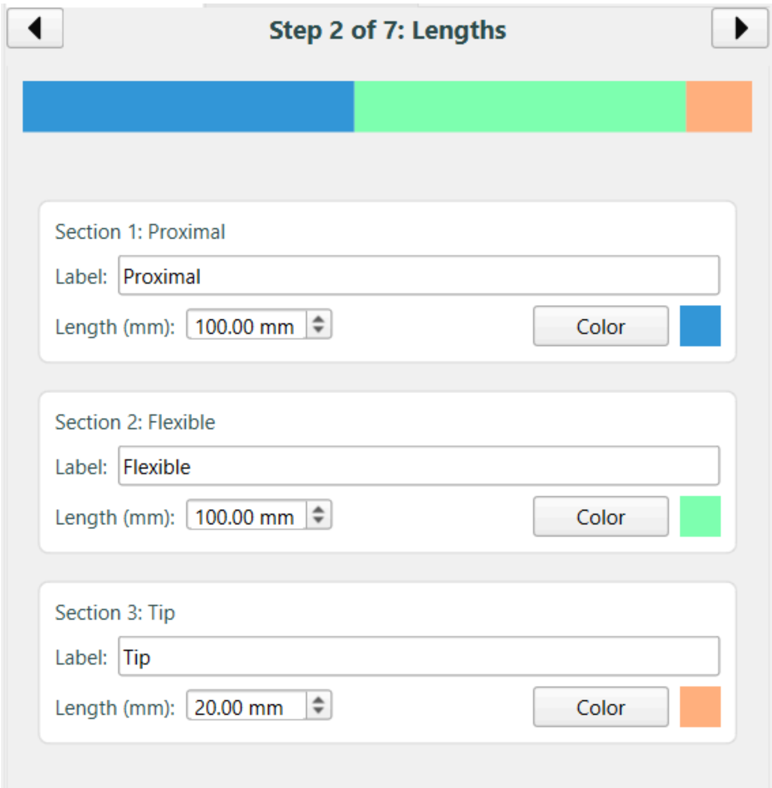
Defined for each section)

Label: Provide a descriptive name for the section (e.g., "Distal Tip"). This name will identify the section in data readouts and exported log files.

Length: Specify the length of this catheter section.

> ℹ️ **Note:** Section length must be between **3 mm** (0.12 in) and **800 mm** (31.5 in). Modeling multiple long sections may decrease simulation performance and stability.

Color: Choose a distinct color to help identify this section in the 3D viewer. Click the color swatch to open the selection dialog.



4.3. Geometry and Actuation

Global Properties:

Overall Diameter: Specify the overall outer diameter of the catheter. This dimension is used for visualization and helps in contextualizing the pullwire offset.

French Size: The software automatically calculates the catheter french size based on the diameter, rounding up to the nearest half french size.

Pullwire Arrangement:

None: Not steerable.

Single Pullwire: Simulates a catheter with one pullwire, typically for uni-directional deflection.

Two Pullwires: Simulates a catheter with two pullwires, oriented 180 degrees apart relative to each other.

Four Pullwires (default) : Simulates a catheter with four pullwires, oriented 90 degrees apart relative to each other. This allows for bi-directional steering.

Radial Offset from Centerline: The perpendicular distance from the catheter's central axis to the centerline of the pullwire(s). This value must be less than the catheter radius.

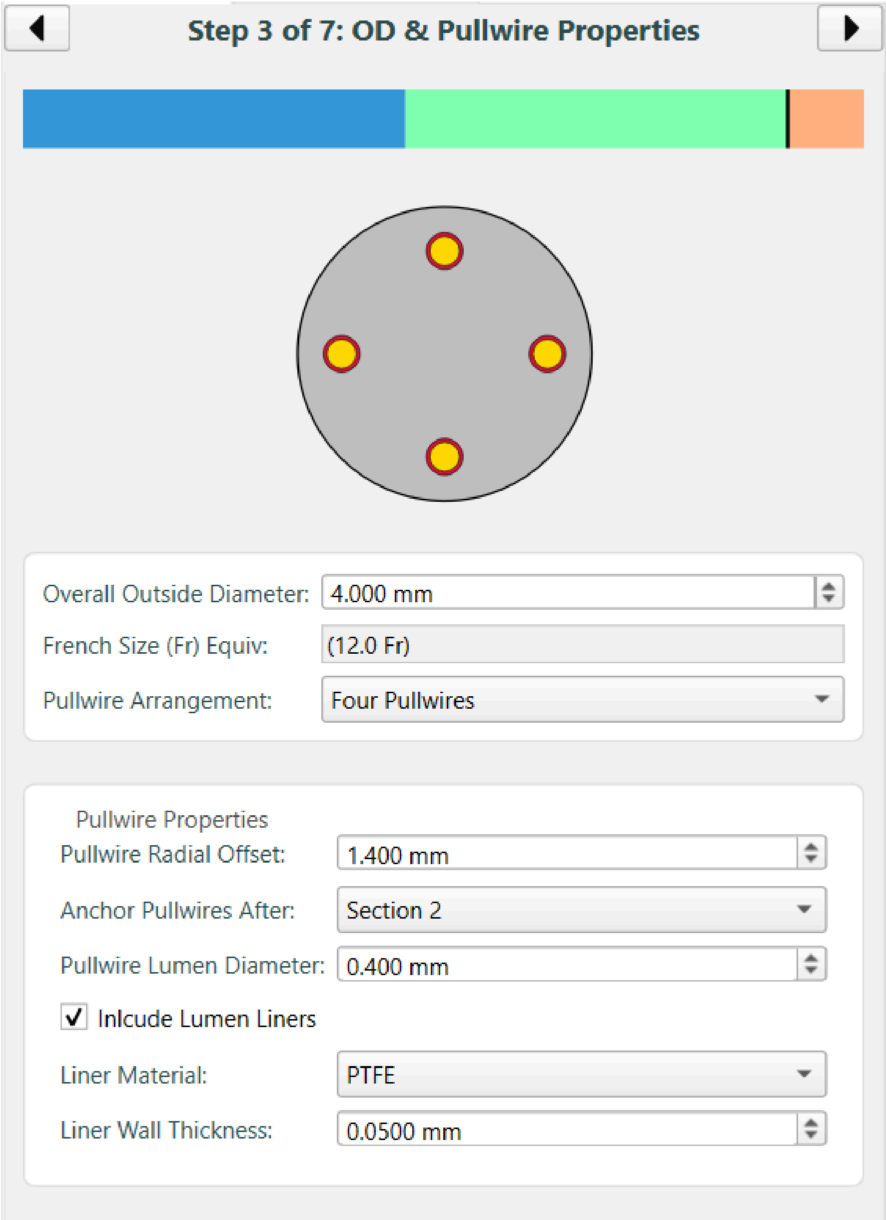
Pullwire Anchoring: Defines after which section the pullwires are anchored on the catheter.

Pullwire Lumen Diameter: This value is used in modeling the section moment of inertia of the catheter sections. If you wish to exclude it from the mechanical analysis, set it to an arbitrary very small value.

Include Lumen Liners:

Use this checkbox to include pullwire lumen liners in the calculation:

- **If unchecked**, the lumens are modeled as unlined
- **If checked,** you can select the liner material and wall thickness


Step 3 of 7: OD & Pullwire Properties
Overall Outside Diameter:
4.000 mm
French Size (Fr) Equiv:
(12.0 Fr)
Pullwire Arrangement:
Four Pullwires
Pullwire Properties
Pullwire Radial Offset:
1.400 mm
Anchor Pullwires After:
Section 2
Pullwire Lumen Diameter:
0.400 mm
Inlcude Lumen Liners
Liner Material:
PTFE
Liner Wall Thickness:
0.0500 mm

4.4. Section Construction

Define the construction for each catheter section.

Number of Layers

Select the number of layers in your catheter constructions. Layers are defined from the outside-in, with Layer 1 being the outermost layer.

Layer Properties

This panel allows you to define the mechanical construction for each specific section of the catheter (as defined in the previous "Lengths" step).

Visual Feedback

At the top of the panel, a Cross-Section Visualizer displays a dynamic, scaled representation of your catheter's layers, materials, and internal lumens. This view updates in real-time as you modify layer properties.

General Settings

Number of Layers - Select the total number of layers in this section's construction.

Manage Materials - Click this button to open the Material Library, where you can create, edit, or import custom polymer and wire materials.

Layer Properties

Layers are defined from the Outside-In, meaning Layer 1 is the outermost jacket, and the final layer is the innermost liner.

Name - An optional label for the layer (e.g., "Outer Jacket," "Braid," "Liner").

Material - Select the polymer or matrix material for this layer. For reinforced layers, this defines the matrix material embedding the wires.

Reinforcement - Choose the structural type of the layer:

- **None** - A pure polymer layer.
- **Braid** - A woven wire reinforcement pattern.
- **Coil** - A helical wire reinforcement pattern.

Thickness -

- *For Non-Reinforced Layers* - Enter the wall thickness manually.
- *For Reinforced Layers* - This field is Read-Only. The software automatically calculates the thickness based on the wire dimensions (2× wire thickness for Braids, 1× wire thickness for Coils).

Dimensions (ID/OD) - Displays the calculated Inner Diameter (ID) and Outer Diameter (OD) based on the cumulative thickness of previous layers.

Reinforcement Settings - If "Braid" or "Coil" is selected, a sub-panel appears to define the wire geometry. A dynamic preview of the pattern (including calculated braid angle) is displayed.

Common Settings:

- **Wire Material** - Select the metal (e.g., Stainless Steel, Nitinol) from the material library.
- **Wire Shape** - Choose between Round or Flat/Ribbon wire.
- **Wire Dimensions -**
    - **Round***:* Enter the wire diameter.
    - **Flat:** A dropdown of common ribbon sizes is provided for quick selection or enter a custom thickness and width.

Braid Specifics:

- **Picks Per Inch (PPI)** - The number of wire crossings per inch of length.
- **Number of Carriers** - The number of bobbins used in the braiding machine (e.g., 16, 32, 64). The calculations assume one wire per carrier.
- **Calculated Angle** - The software displays the resulting braid angle relative to the longitudinal axis.

Coil Specifics:

- **Pitch** - The distance between the center of one wire wrap to the center of the next.

Results:

Bending Stiffness (EI) - Also known as **Flexural Rigidity**, this value defines the section's resistance to bending.

Torsional Stiffness (GJ) - Also known as **Torsional Rigidity**, this value defines the section's resistance to twisting.

Central Lumen ID: Calculated based on the catheter OD and sum of layer thicknesses.

Manual Override Options:

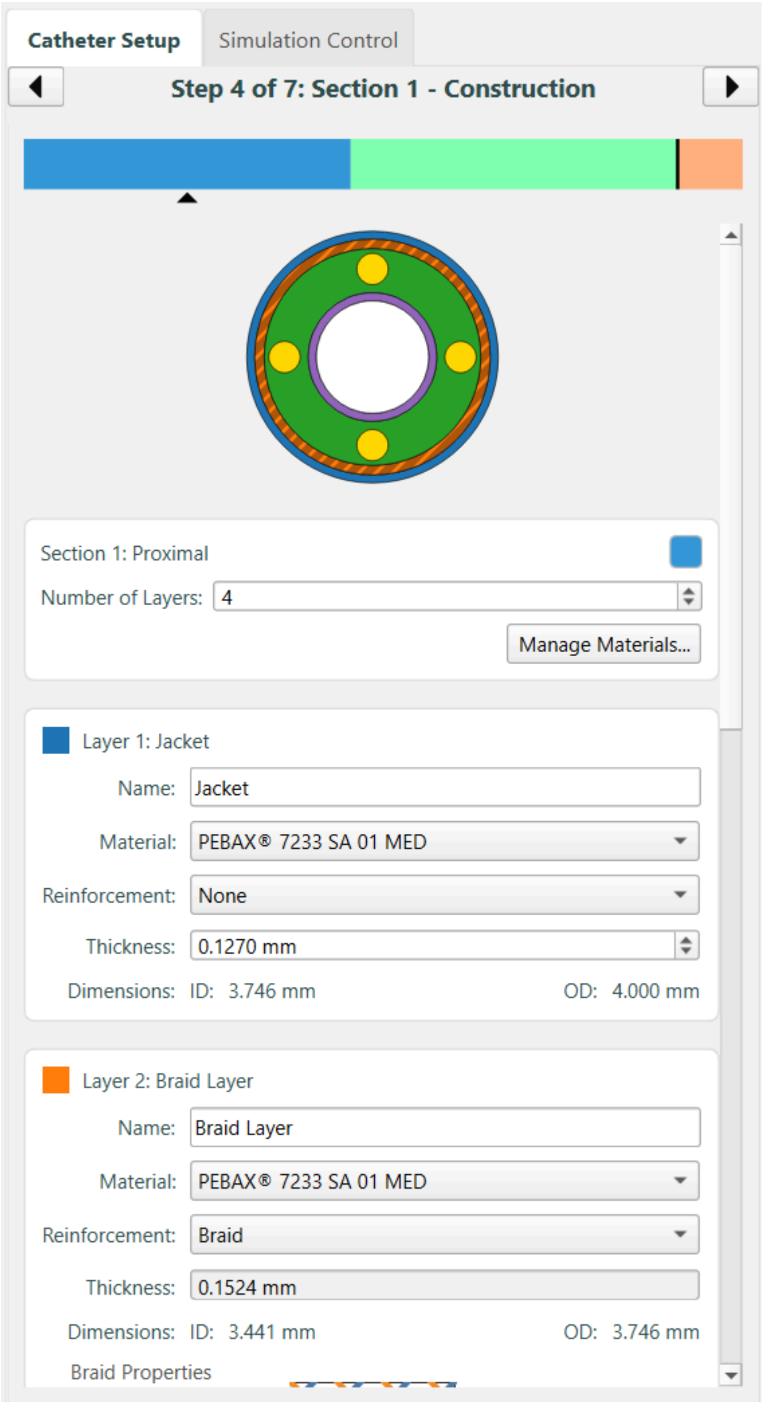
These settings override the detailed catheter construction calculations for the section.

Is Rigid - **If checked**, the section is modeled as a single, non-deformable rigid body. The stiffness fields below are disabled.

Bending Stiffness (EI) - Allows you to manually override the calculated value.

Torsional Stiffness (GJ) - Allows you to manually override the calculated value.

- **Auto Mode**: By default, GJ is set to 10% of the EI value, which is a reasonable approximation for braided catheters.
- **Custom Mode**: To enter a specific number, click the "**Auto**" button to switch it to "**Custom**" mode. This allows you to input your own value.



ℹ️ Note: Multi-Lumen Cross-sections

VirtuCath does not currently support multi-lumen cross-section designs. To simulate a multi-lumen catheter dynamically:

- Calculate the area moment of inertia of the multi-lumen layer. Please note that asymmetric cross-sections are not supported, pick the section moment of inertia of interest for the simulation.
- For a given layer OD, calculate the layer thickness so that the ring segment has the area moment of inertia equivalent to the desired value.
- Some calculated catheter properties like torsional and axial stiffness, kink radius, burst pressure, etc. will not be accurate for a simulated multi-lumen catheter.

ℹ️ Note: Alternative Methods to Determine Stiffness Values (EI & GJ)

Accurate bending stiffness (EI) and torsional stiffness (GJ) values are essential for a realistic simulation. If these properties are unknown for your design, here are three common methods to determine them:

1. Calculation from Geometry

This is ideal if you have a CAD model of the catheter's cross-section and know the material properties.

- **Bending Stiffness (EI):** The material's Young's Modulus (E) multiplied by the cross-section's Area Moment of Inertia (I).
- **Torsional Stiffness (GJ):** The material's Shear Modulus (G) multiplied by the cross-section's Polar Moment of Inertia (J).

2. Physical Measurement

Directly testing a physical sample is the most accurate method, as it captures the real-world performance of the manufactured component.

- **Bending Stiffness (EI)** is typically found using a **three-point bend test**, where a known force is applied to a sample and the resulting deflection is measured.
- **Torsional Stiffness (GJ)** is found by fixing one end of a sample, applying a known angle of twist at the other and measuring the torque.

While high-precision test equipment is ideal, simple benchtop setups can often provide reasonable estimates for simulation purposes.

4.5. Review & Build

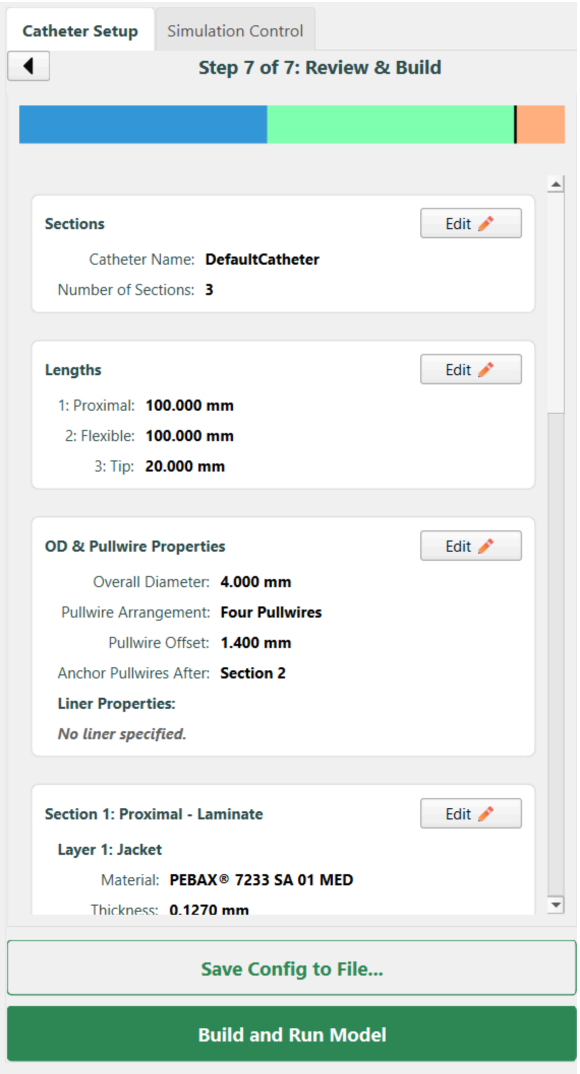
This is the final step where you can review your design before creating the simulation model.

Color Bar: A scaled diagram of your catheter design. A black line indicates the pullwire termination point.

Configuration Summary: Review all entered parameters before building the model. Click the "Edit" link next to any item to return to that section and make changes.

Save Config to File: Saves the current catheter design to a file. This allows you to reload the design later or share it with colleagues. This function is also available from the main menu via File > Save Config..

Build and Run Model: Click this button to generate the simulation. VirtuCath will build the physics model based on your inputs and automatically load it in the interactive 3D viewer.



5. Live Controls

This tab is the primary interface for interacting with the live simulation. It is used to manipulate the catheter's pullwires and manage the state of the physics simulation.

5.1. Simulation Controls

Run/Pause Simulation: This is a toggle button that controls the physics engine. When the simulation is paused, the button text is **Run Simulation**. When active, the text changes to **Pause Simulation**.

> ℹ️ **Note:** The simulation will pause automatically after five minutes of run time. It can be resumed if additional time is needed.

Reset: Stops the simulation, resets the catheter to its initial straight configuration, and clears all data.

5.2. Catheter Motion Controls

This section allows for the control of catheter deflection by simulating pullwire displacement. The controls shown will automatically adapt based on the catheter's pullwire configuration (e.g., the Y-axis control is only enabled for four-pullwire designs).

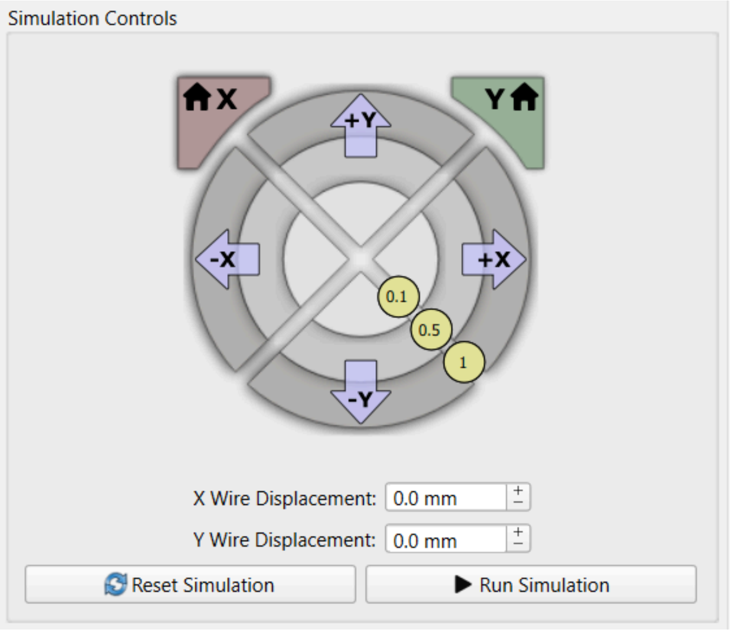
Jog Control (X & Y): This control incrementally adjusts pullwire displacement.

Clicking a button jogs the position in the indicated direction (+X, -X, +Y, or -Y). Each of the three rings corresponds to a different step size, allowing for fine, medium, or coarse adjustments. Clicking the Home button resets that axis to its zero position.

Deflection Input Box Located below the dials, this field serves two functions:

- **Readout**: It displays the current commanded displacement for the axis.

- **Direct Input**: A precise numerical value for deflection can be typed directly into the box.


Simulation Controls
X
Y
+Y
-X
+X
-Y
0.1
0.5
1
X Wire Displacement:
0.0 mm
Y Wire Displacement:
0.0 mm
Reset Simulation
Run Simulation

6. 3D Viewer

The 3D Viewport provides an interactive rendering of the physics simulation.

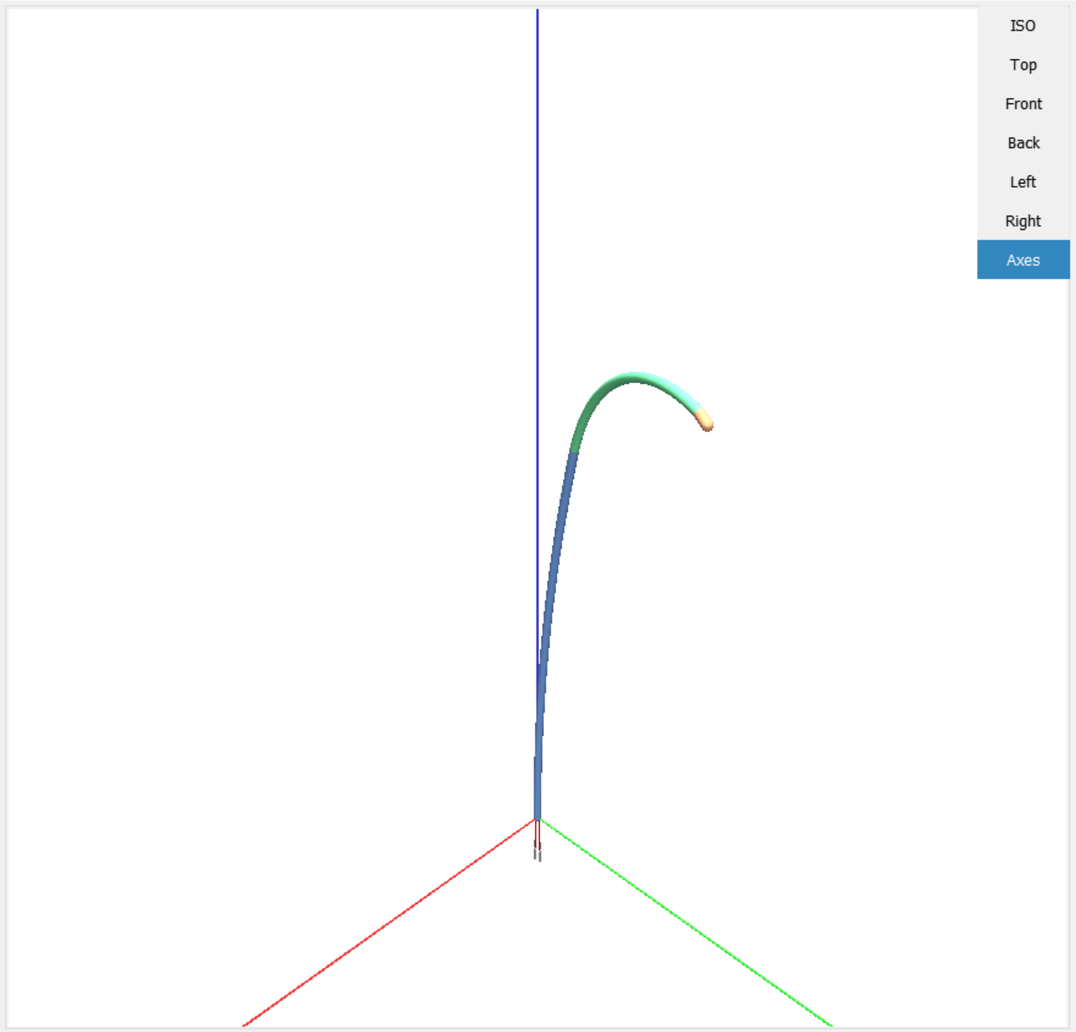
6.1. Mouse Controls

Interact with the 3D view using your mouse:

- **Rotate**: **Left-click and drag** to orbit the camera around the model.
- **Pan: Right-click and drag** to move the view vertically and horizontally.
- **Zoom**: Use the **mouse scroll wheel** to move the camera closer to or further from the model.

6.2. Preset Views

Located in the upper right corner of the 3D viewer, these buttons allow you to quickly snap to standard viewing angles. Use the number keys to snap the camera to standard views and display or hide XYZ axis.



7. Simulation Readout Panel

This panel provides a real-time dashboard of key performance indicators from the simulation.

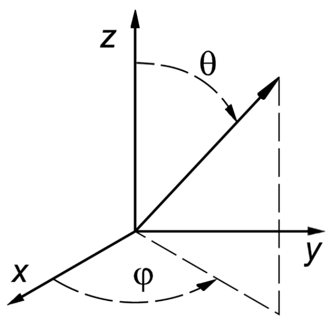
7.1. Overall Performance Metrics

This top section displays key values for the catheter as a whole.

X/Y Pullwire Displacement: The commanded displacement value for the pullwires along each primary axis.

Tip Angle (Theta): The total integrated bend angle of the catheter tip relative to its base, reported in degrees.

Tip Angle (Phi): The azimuthal angle, representing the rotational direction of the bend. A value of 0° indicates a bend purely in the +Y direction, while 90° indicates a bend purely in the +X direction.



X/Y Wire Tension: The simulated reaction force in each individual pullwire.

> ℹ️ **Note:** This value is not accurate during motion due to dynamic effects, wait for the catheter to settle for an accurate tension reading.

Total Strain Energy: The total potential energy stored in the catheter due to bending and twisting.

Tip Position (X,Y,Z): The spatial coordinates of the distal tip of the catheter in the 3D world with the proximal end of the catheter serving as the origin.

Tip Quat (W,X,Y,Z): The orientation of the catheter tip expressed as a quaternion.

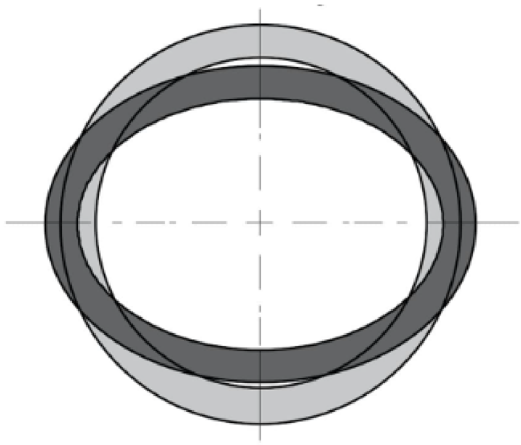
7.2. Per-Section Analysis

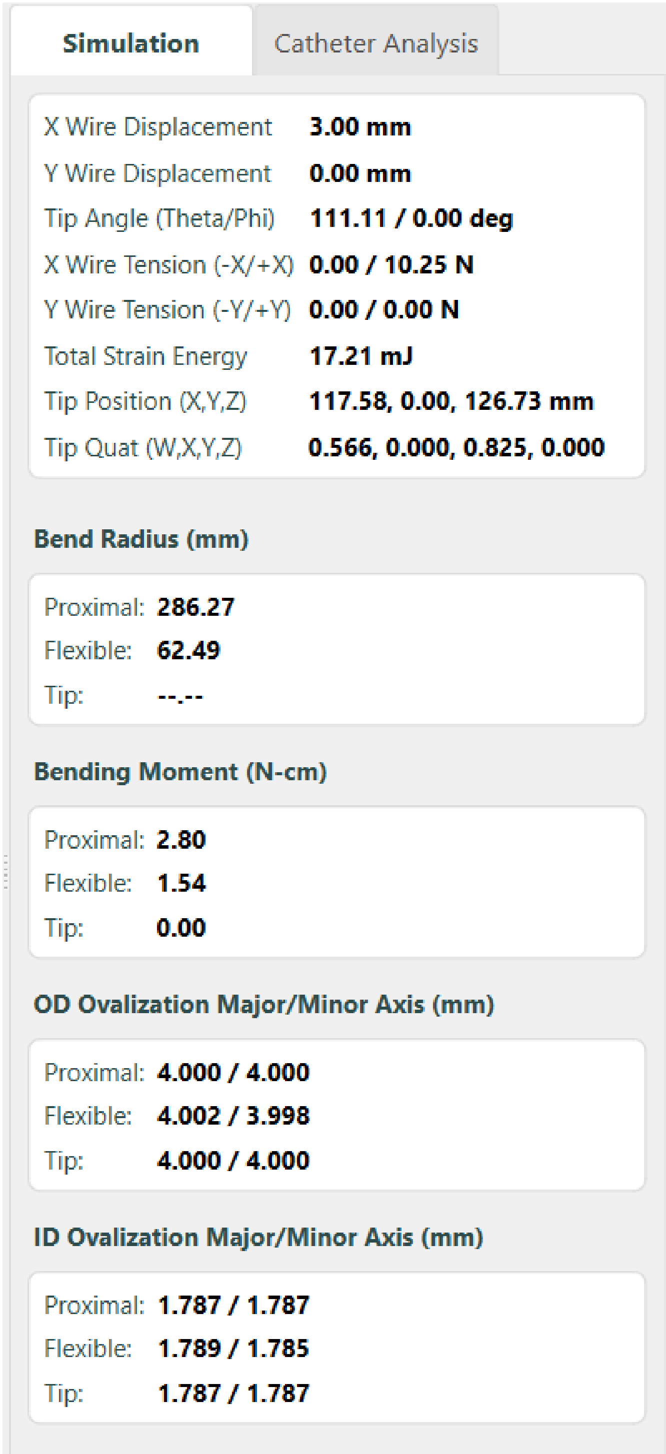
This area provides calculated metrics for each individual flexible section defined in the catheter setup. Rigid sections are excluded from these calculations.

Bend Radius: The simulated radius of curvature for each flexible section. A very large number or "--" indicates the section is currently straight. The value will turn **red** if the bend radius falls below the calculated critical kinking radius.

Bending Moment: The internal moment within each section resulting from deflection forces. The value will turn **red** if the bending moment exceeds the calculated maximum moment at material failure.

Ovalization: When a catheter section is bent, the cross-section deforms into an oval shape. This occurs because differential stresses—tension on the outer curve and compression on the inner curve—cause the section to flatten perpendicular to the plane of bending. This phenomenon is critical to characterize for maintaining Inner Diameter (ID) clearance, as the dimensional change can lead to increased friction when navigating ancillary components. VirtuCath calculates the ovalization of the catheter Outer Diameter (OD) and ID for each section, displaying the resultant major and minor axis dimensions.




Simulation
Catheter Analysis
X Wire Displacement 3.00 mm
Y Wire Displacement 0.00 mm
Tip Angle (Theta/Phi) 111.11 / 0.00 deg
X Wire Tension (-X/+X) 0.00 / 10.25 N
Y Wire Tension (-Y/+Y) 0.00 / 0.00 N
Total Strain Energy 17.21 mJ
Tip Position (X,Y,Z) 117.58, 0.00, 126.73 mm
Tip Quat (W,X,Y,Z) 0.566, 0.000, 0.825, 0.000
Bend Radius (mm)
Proximal: 286.27
Flexible: 62.49
Tip: --.--
Bending Moment (N-cm)
Proximal: 2.80
Flexible: 1.54
Tip: 0.00
OD Ovalization Major/Minor Axis (mm)
Proximal: 4.000 / 4.000
Flexible: 4.002 / 3.998
Tip: 4.000 / 4.000
ID Ovalization Major/Minor Axis (mm)
Proximal: 1.787 / 1.787
Flexible: 1.789 / 1.785
Tip: 1.787 / 1.787

8. Catheter Analysis Panel

8.1. Stiffness Properties

Bending Stiffness (EI): This value, also known as Flexural Rigidity, defines the catheter section's resistance to bending.

Torsional Stiffness (GJ): This value, also known as Torsional Rigidity, defines the catheter section's resistance to twisting.

Axial Stiffness (EA): This value represents the resistance to stretching and compression along the axis.

Linear Density: This is the mass per unit length of the section.

8.2. Failure Mode Analysis

Critical Buckling (Euler): The maximum compressive axial force a section can withstand before it suddenly bows or buckles, representing a crucial measure of the catheter's pushability.

Kink Radius (Brazier): The minimum radius of curvature a section can sustain before structural collapse due to kinking.

Max Moment (Material Failure): The maximum internal bending moment the section can withstand before the material reaches its yield or ultimate stress limit.

Tensile Failure Load: The maximum axial pulling force that can be applied to the section before it breaks.

Torque Failure: The maximum twisting force (torque) that can be applied to the section before it breaks.

Burst Pressure: The maximum internal fluid pressure the section can contain before its wall ruptures.

External Crush Pressure: The maximum external pressure the section can withstand before its structure collapses inward.

8.3. Calculated Reinforcement Characteristics

Braid/coil characteristics are calculated for each reinforced layer for each catheter section.

Angle: Wrap angle of the braid/coil wire.
Pitch: The axial distance between successive wraps of the braid or coil wire.

Coverage: The percentage of the catheter's surface area covered by the reinforcing wires.

9. Menu Bar

The menu bar provides access to file operations, unit system selection, and application help.

9.1. File Menu

- **Load Config**: Opens a file dialog to load a catheter design from a `.json` file. The configuration is automatically applied, and the model is rebuilt.
- **Save Config**: Opens a file dialog to save the current parameters from the "Catheter Setup" tab to a `.json` file.
- **Export**:
  - **Export Image**: Saves the current 3D viewport as a PNG or JPG image file.
  - **Analysis Report (PDF):** Exports a comprehensive analysis and summary report as a PDF document.
  - **Analysis Report (Excel):** Exports a comprehensive analysis and summary report as an Excel spreadsheet.
  - **Simulation Run Log to CSV**: Exports all historical data from the simulation into a single .csv file.
- **Exit**: Closes the application.

9.2. Units Menu

- **Use Metric Units:** Sets all relevant UI displays, controls, and plot axes to metric units (mm, N).
- **Use Imperial Units:** Sets all relevant UI displays, controls, and plot axes to imperial units (in, lbf)

9.3. Materials Menu

- **Manage Material Library:** Opens the material manager dialog, allowing for the customization or addition of new materials.
- **Create Custom Blend:** Opens the polymer blending utility to create custom material blends from existing library materials.

9.4. Help Menu

- **Manual:** Opens the VirtuCath user manual PDF document.
- **About:** Displays information about the application and its version.

10. Licensing & Activation

VirtuCath™ offers flexible licensing options designed to scale from individual innovators to enterprise engineering teams. This section guides you through managing your software license.

10.1. Free Trial

New users automatically receive a **15-day full-feature trial** upon installation.

- **No Key Required:** Simply install and run VirtuCath. The trial starts automatically on the first launch.
- **Full Access:** All simulation and export features are available during the trial period.
- **Expiration:** After 15 days, the software will lock and prompt you to enter a valid license key to continue.

10.2. Purchasing a License

You can purchase a commercial license directly from the website. We offer two primary ways to buy:

Instant Purchase (Credit Card)

Best for individuals and small teams who need immediate access.

1. Visit virtucath.com.
2. Select your plan (Innovator or Team).
3. Complete checkout securely via Paddle.
4. **Instant Delivery:** You will receive an email with your License Key immediately.

Enterprise Quotes (Purchase Order)

Best for corporate procurement requiring a formal quote and invoice.

1. Visit our Quote Request Page.
2. Fill out your company details.
3. **Instant Quote:** You will receive a formal PDF quote via email immediately.
4. **Process:** Reply to that email with your Purchase Order (PO) number. We will then issue the formal invoice and release your license keys.

10.3. Activating Your License

Once you have your License Key (e.g., `VC-INN-XXXX-XXXX`), follow these steps to unlock the full version:

1. Open VirtuCath.
2. In the top menu bar, go to **Help > Activate License**.
3. Enter your License Key in the dialog box.
4. Click **Activate**.
5. **Restart VirtuCath** to apply the changes.

Note: An internet connection is required for the initial activation.

10.4. License Management

Multiple Seats (Team/Business Plans)

If you purchased a multi-seat license (e.g., Team Starter or Business Plan), you will receive **one single Master Key**.

- **Distribution:** Share this same key with your team members.
- **Activation:** Each user activates the software on their own computer using this key.
- **Seat Tracking:** Our system automatically tracks the number of active devices. If you exceed your seat limit, additional activations will be blocked.

Transferring a License (New Computer)

Licenses are "node-locked" to the specific computer hardware.

- **Scenario:** You get a new laptop or an employee leaves the company.
- **Action:** Please email **support@virtucath.com** with your License Key and the name of the old machine you wish to deactivate.
- **Result:** We will remotely free up that seat so you can activate it on the new hardware immediately.

Renewals

- **Manual Renewal:** Licenses do not auto-renew. You will receive a reminder email before your license expires.
- **Seamless Extension:** When you purchase a renewal, your existing License Key is automatically extended. You do **not** need to enter a new key; simply restart the application while connected to the internet, and it will update the expiration date automatically.

10.5. Troubleshooting

Issue	Solution
"Please connect to internet"	The software needs to verify your license periodically (every 30 days). Connect to Wi-Fi and restart the app.
"All seats used"	Your team has used all available activations for this key. Contact support to purchase more seats or deactivate an old machine.
"Invalid Key"	Double-check for typos. Ensure there are no leading/trailing spaces when copying the key.
Trial Expired	Your 15-day evaluation period has ended. Please purchase a license to continue using VirtuCath.

For any other licensing issues, please contact **support@virtucath.com**.