(370-071015)

User Manual

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ESSS

GRANULAR DYNAMICS INTERNATIONAL

WWW.ROCKY-DEM.COM

User Manual

V 3.7.0

Contents

1. Software Overview

Rocky is a 3D Discrete Element Method (DEM) modeling program that simulates how a particle group flows around a boundary in a conveyor chute, mill, or other bulk materials handling design.

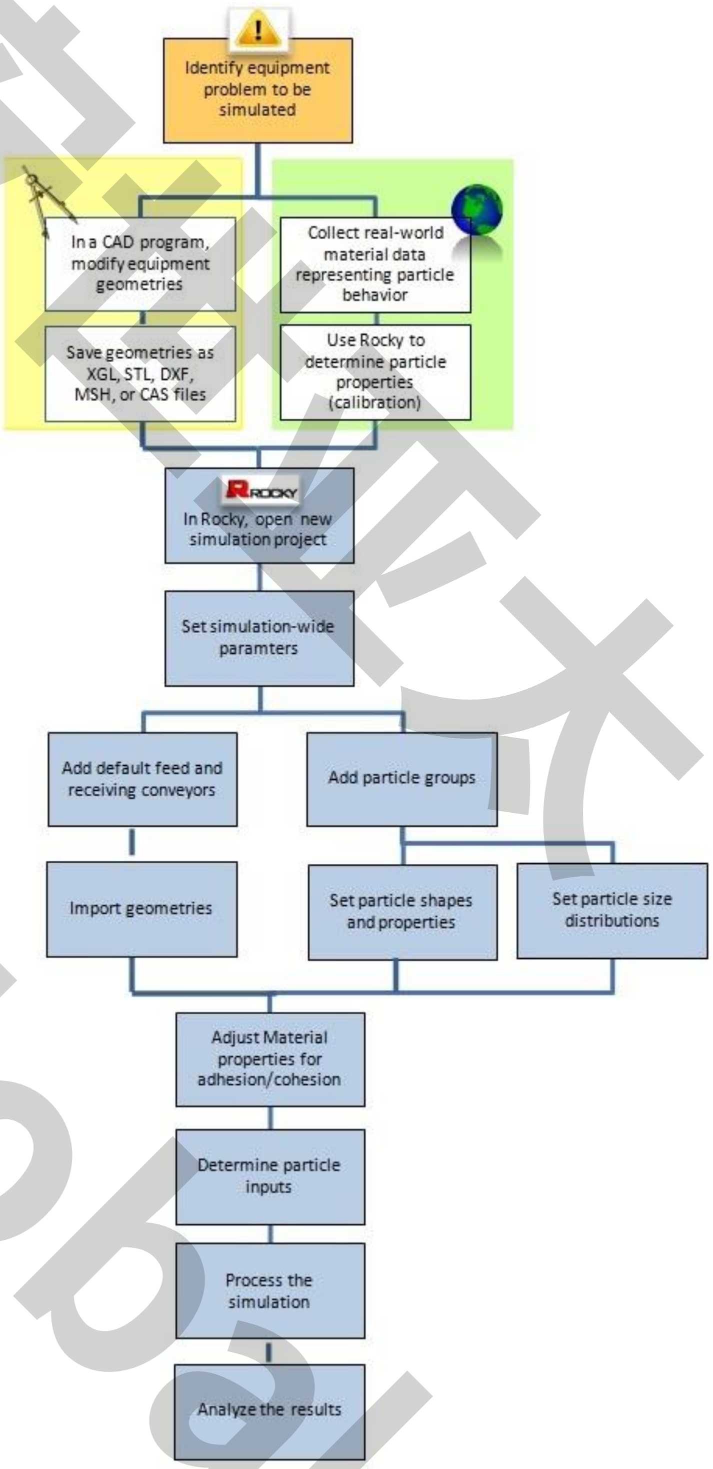
Engineers use Rocky to test and adjust geometries based upon the metrics Rocky provides. In this way, Rocky helps manufacturing organizations:

- Increase belt and liner life and capacity
- Eliminate blockages and liner punctures
- Decrease spillage and product degradation
- Reduce dust, noise, and belt power
- Define ore trajectories
- Optimize belt tracking
- Minimize liner wear and maintenance

A typical scenario for Rocky usage is provided in the flow diagram in Figure 1.

This section includes the following topics:

- Program Features
- What's New
- System Requirements
- Best Practices



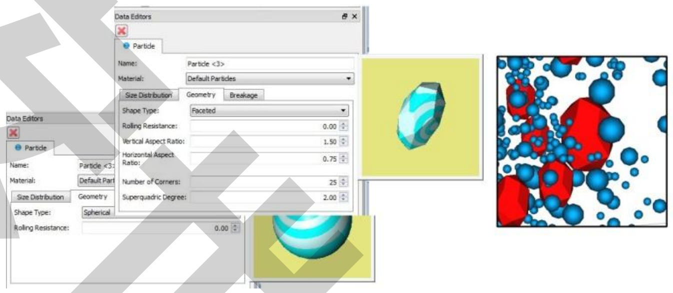
Identify equipment problem to be simulated
In a CAD program, modify equipment geometries
Save geometries as XGL, STL, DXF, MSH, or CAS files
Collect real-world material data representing particle behavior
Use Rocky to determine particle properties (calibration)
ROCKY
In Rocky, open new simulation project
Set simulation-wide paramters
Add default feed and receiving conveyors
Import geometries
Add particle groups
Set particle shapes and properties
Set particle size distributions
Adjust Material properties for adhesion/cohesion
Determine particle inputs
Process the simulation
Analyze the results

Figure 1: Typical scenario for using Rocky software

PROGRAM FEATURES

Rocky is a powerful tool for evaluating the performance of your bulk flow handling geometries. The main features included within this version of Rocky are described below. You can also review a list of Rocky capabilities on the website here: http://rocky-dem.com/index.php?pg=capability.

- **Simulates particles of various shapes, sizes, and combinations**
  Rocky uses realistic contact rheology, which allows the choice from a nearly limitless array of particle shapes, sizes, and combinations, including faceted polyhedrons, rods, pellets, and briquettes.



Data Editors

Particle

Name: Particle <3>

Material: Default Particles

Size Distribution | Geometry | Breakage

Shape Type: Faceted

Rolling Resistance: 0.00

Vertical Aspect Ratio: 1.50

Horizontal Aspect Ratio: 0.75

Number of Corners: 25

Superquadric Degree: 2.00

Data Editors

Particle

Name: Particle <3>

Material: Default Part

Size Distribution | Geometry

Shape Type: Spherical

Rolling Resistance: 0.00

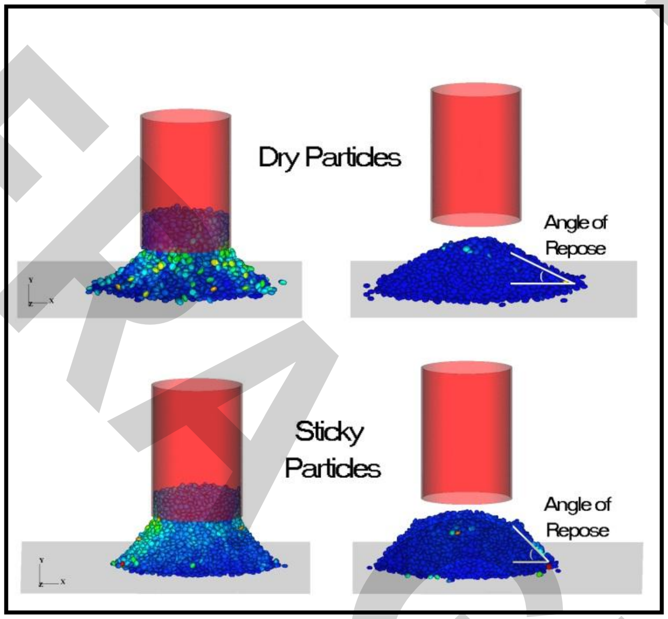
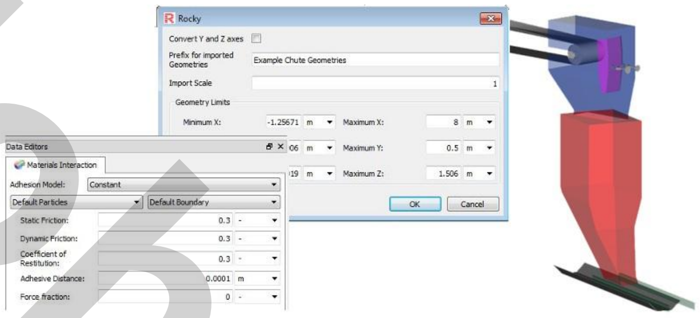


Figure 2: Particle Laboratory Calibrations

- **Replicates dry, wet, sticky, and dust-like particles**
  Rocky uses a concept of “sticky particles” to simulate how moist particles–such as clay–behave differently than dry particles in a materials handling design.

- **Processes simulations faster and with double precision**
  Parallel scaling features enable Rocky to process your simulations up to 25 times faster using up to 32 multi-core processors. Compared to single precision, this provides superior contact mechanics accuracy.

- **Simplifies simulation setup**
  User-friendly menus and dialogs allows quick input of parameters. In addition, Rocky includes over 100 editable parameters, which allows for maximum customization.



Rocky

Convert Y and Z axes ☐

Prefix for imported Geometries: Example Chute Geometries

Import Scale: 1

Geometry Limits

Minimum X: -1.25671 m | Maximum X: 8 m

06 m | Maximum Y: 0.5 m

19 m | Maximum Z: 1.506 m

OK | Cancel

Data Editors

Materials Interaction

Adhesion Model: Constant

Default Particles | Default Boundary

Static Friction: 0.3 -

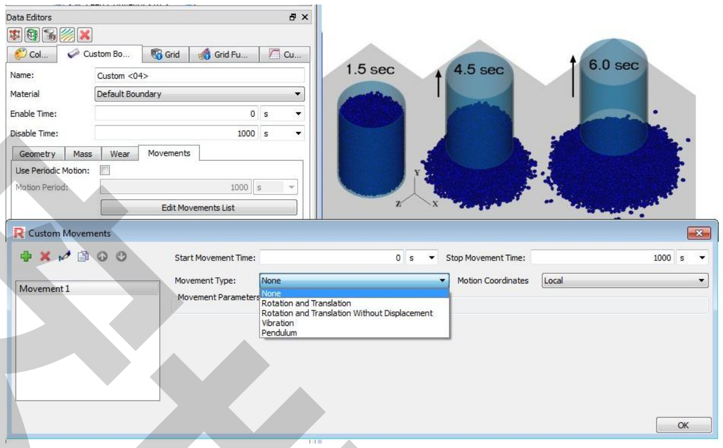
Dynamic Friction: 0.3 -

Coefficient of Restitution: 0.3 -

Adhesive Distance: 0.0001 m

Force fraction: 0 -

- **Enables geometry import from a variety of CAD programs**
  Rocky can import STL, XGL, and DXF 3D faces geometry files directly into the software. This allows the user to see how particles act upon on an exact design while still enabling you to iterate utilizing tools already in use.



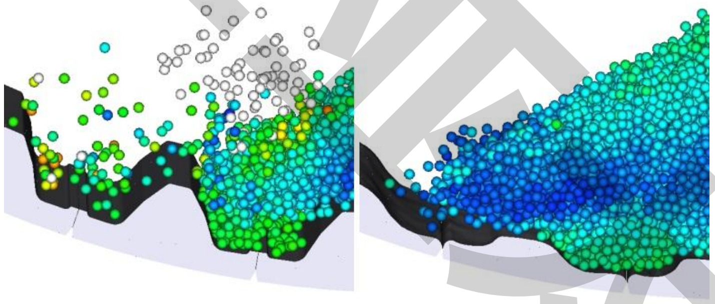
Data Editors

Name: Custom <04>
Material: Default Boundary
Enable Time: 0 s
Disable Time: 1000 s
Use Periodic Motion: ☐
Motion Period: 1000 s

Custom Movements

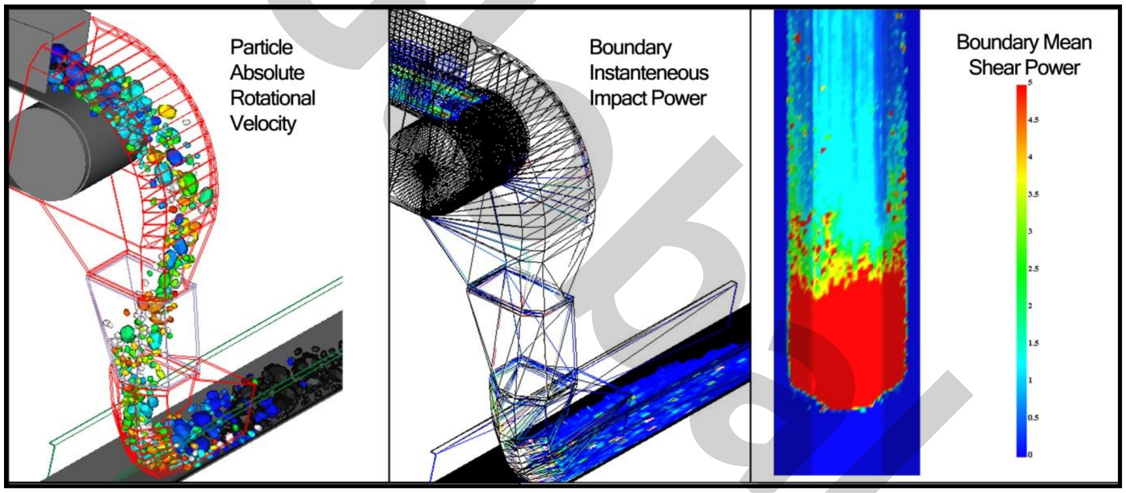
Movement 1
Start Movement Time: 0 s
Stop Movement Time: 1000 s
Movement Type: None
Motion Coordinates: Local

- **Facilitates animated boundaries**
  Rocky has the capability to create moving, rotating, swinging, and vibrating boundaries, such as gates that lift and rotate, or screens that vibrate, adding another level of realism to the simulations.



- **Modifies Geometries to Show Wear**
  Rocky includes functionality that enables you to easily see how wear will affect a geometry. Shear work applied by particles will appear to dissolve chute and mill liners right before your eyes.

- **Displays results in easy-to-understand formats**
  Rocky uses different colors to represent how certain parameters and calculations–such as power draw, shear intensities, and belt and liner wear–act upon the particles and boundaries in your design. This enables you to see how the design performed even before the metrics and graphs are reviewed.


Particle Absolute Rotational Velocity
Boundary Instanteneous Impact Power
Boundary Mean Shear Power
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

What's New

Each new release of Rocky includes a list of what features and functionality have changed since the last released version. This list is displayed automatically whenever you chose to upgrade your version. Or, to review the list at any other time, from the **Help** menu, click **Changelog**.

System Requirements

Rocky has been designed to be used in conjunction with common CAD design tools, such as Autodesk Inventor and AutoCAD. As a result, Rocky will have similar system requirements. Please see below for minimum system requirements and optional recommendations.

Minimum Requirements:

- 64-bit Windows 7
- A video card that supports OpenGL graphics
- 4 GB of free disk space
- 4 GB of RAM
- Two-button mouse with center wheel
- Screen resolution of 1280 x 1024

Recommended:

- 8 GB of free disk space
- 8 GB of RAM
- Quad-core or better processor (Intel Core i5, Intel Core i7, or Intel Xeon processor)
- A Nvidia GPU card with at least 4 GB memory and fast double-precision processing capabilities (Telsa K40, Telsa K80, Titan, Titan Black, or Titan Z)
- Autodesk Inventor or other CAD software
- Microsoft Excel or other spreadsheet software
- AVI-compatible media player

Best Practices

The engineers who developed and tested Rocky have compiled the following set of best practices to help you get the most out of using the software. These recommendations are best used in conjunction with the user assistance content that follows.

What would you like to learn about?

- Best Practices for Faster Processing
- Best Practices for Creating Geometries for Import
- Best Practices for Setting up Geometries
- Best Practices for Setting Up Particles

Best Practices for Faster Processing

The amount of time it takes for Rocky to process a simulation depends upon many factors, including but not limited to:

- The processing speed of the computer Rocky is running upon
- The number, size, and complexity of the particles being simulated
- The simulation time step, which is defined by particle size, density, contact loading stiffness(Young's Modulus), and restitution coefficients
- The size of the geometries
- The size of the boundary triangles
- The simulation time (in seconds)
- Whether the simulation files are being saved over a network
- Whether you are using CPU or GPU processing capabilities

While there are no hard-and-fast rules regarding processing speed in Rocky, there are some steps you can take. To speed up your processing time, do one or more of the following:

- Use GPU processing and/or increase your processing power.
- Reduce your particle stiffness. The default stiffness of $1x10^8$ Pa can be safely reduced to $1x10^6$ - $1x10^7$ Pa for narrow size distributions (1:3 or less). This should result in a 3-10x increase in time step.
- Increase your minimum particle size.
- Reduce the complexity (sides, corners, size distributions) of your particles.
- Shorten the simulation length.
- Increase the size of your boundary triangles. The default value of 0.1 is recommended for all boundaries where you want to see wear data.
- Run and save Rocky files locally; avoid processing and saving Rocky simulations over a network.
- Run only one simulation at a time on any one machine.

To gain an understanding of how much faster GPU processing could be as compared with CPU processing, see http://rocky-dem.com/index.php?pg=gpu_processing.

Best Practices for Creating Geometries for Import

Use the following recommendations when using a CAD program to create geometries for importing into Rocky:

- Orient your design around the origin. For example, when designing conveyor chutes, place the center of the head pulley at (0,0,0), and build your other components around it.
- Include the conveyors in your design but do not import them into Rocky. It is easier to use the conveyors included with Rocky and only import your chutes or other geometries. Use the conveyor dimensions in your CAD design to size and position the Rocky conveyors accordingly.
- Make your design as realistic as possible. Use actual dimensions whenever possible.
- Remove any "hidden" boundaries before saving the file you want to import. Some hidden geometries might be imported into Rocky.

- Color boundary components differently to make it easier to distinguish components before and after import.

Best Practices for Setting up Geometries

Use the following recommendations when setting up geometries in Rocky:

- Only import your non-conveyor geometries into Rocky (i.e., your chute or mill). Use the conveyor designs included within Rocky for your conveyor components.
- Make the conveyor settings as realistic as possible. Any error or shortcut taken in setting up geometries will result in false data.
- Ensure that the triangle size of your feed and receiving conveyors are small enough to avoid deformation of the geometries. Larger triangle sizes (1m for example) might change the overall shape of the conveyor, making your simulation less realistic. It is recommended that the default value of 0.1 be used.
  Note: Triangle size will not affect the shape of custom (imported) boundaries; just the conveyors included with Rocky.
- Ensure that your inlet is large enough to allow your largest particle to pass through, but still slightly smaller than your geometry opening. This will help prevent particles from getting "stuck".
- When setting up multiple inlets, ensure that your inlet locations and Start and Stop Times are configured in such a way as to avoid particle groups from overlapping during the simulation. An inlet will delay releasing its particles until no other particles from other particle groups are in the way.
  Note: This step is unnecessary if **Release Particles without Overlap Check** is selected on the **Solver/General Settings** tab. (From the **Data** panel, click **Solver** and then from the **Data Editors** panel, select **General Settings** on the **Solver** tab.)
- When locating an inlet or default conveyor, first sketch its size and location in a CAD program and then use the resulting coordinates to properly place it within Rocky.
- Ensure that particle speed equals belt speed by the time the particles reach the pulley. Adjust the loading length of the belt to achieve the desired result.
- When setting up custom feeder boxes, ensure that there is enough vertical space between the wall of the box and the entry point of the particles (i.e. top of the feeder box or inlet) for your largest particle. If a particle hits a boundary or other particle before fully entering the simulation, all particles will stop flowing.
  Note: This step is unnecessary if **Release Particles without Overlap Check** is selected on the **Solver/General Settings** tab. (From the **Data** panel, click **Solver** and then from the **Data Editors** panel, select **General Settings** on the **Solver** tab.)

  To prevent this from happening, do one of the following (see also Figure 3 below):

  - Make your inlet smaller.
  - Add a vertical lip to the top of your feeder box.

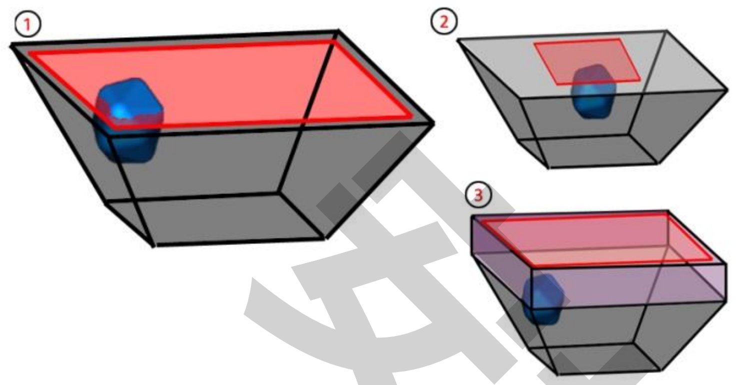


Figure 3:
(1) Angled walls of feeder box prevents particle from fully entering simulation area;
(2) Make the inlet smaller;
(3) Add a lip to the top of the feeder box.

Best Practices for Setting Up Particles

Use the following recommendations when setting up particles in Rocky:

- When setting particle friction values:
  - For rock or granular particles with rougher surfaces, set friction values to 0.6 - 0.7
  - For glass-like particles with smoother surfaces, set friction values no lower than 0.3
- When testing out a new chute design, save time by running a quick simulation with round (sphere) particles to ensure your boundary settings are as you want them. This will take less time and will enable you to iterate on your design faster. Once your boundaries are set and verified, set up your non-round particle combinations and distributions and run that as a final step.

2. Getting Started

Use the following information to get started with Rocky and gain an understanding of its various features and components.

What would you like to do?

- Watch Overview Videos
- Install/Remove Rocky
- Understand the User Interface
- File Types
- Set Your Rocky Preferences
- View Frequently Used Tasks

Watch Overview Videos

To get you started with using the most frequently used features and functionality available within Rocky, our team has prepared some high-level overview and how-to videos. These videos will be later supplemented with more in-depth written user assistance content, but for now these videos are a good place to start learning about the product and its features and capabilities.

To view a video

1. Log into the ESSS customer portal.
   Note: If you do not have access to the customer portal, please contact rocky-support@esss.com.br for assistance
2. Click the link below to open the video you want to watch.
   - How to install Rocky: This 10 minute video provides a detailed look at the steps required to install Rocky and configure the floating licensing server. It is best watched in conjunction with the written instructions for configuring the Rocky 3 floating licensing server.
   - User interface overview: This 5 minute video outlines the major parts of the Rocky user interface, including the menu and tool bars, Data and Data Editors panels, and the various visualization options available.
   - Customizing the Rocky User Interface: This 5 minute video goes over the five main components of the Rocky UI, and how you can show, hide, move, and resize them to your liking.
   - Data panel overview: Outlines the various components of the Data tree, the hierarchical component that a Rocky simulation is built upon. Right-clicking items in the Data panel displays a contextual menu with available actions for the selected item; Left-clicking items in the Data panel displays editable options in the Data Editors panel, which is located just below the Data panel.
   - Rocky Preferences Overview: Goes over the various global preferences that can be set in Rocky including data and time formats, timestep formats, and various visualization settings.
   - Geometries and Particles as Grid Parts: Shows how Geometries and Particles are displayed in Rocky 3D Views, and how changing visualization options changes the coloration to show different results.

- Using the Timestep Toolbar Options: Shows how using the arrows, drop-down list, and playback button on the Timestep toolbar enables you to see progressive results in the Workspace. Also shows how a workspace can be divided up into many different 3D Views and plots.
- Selecting Multiple Options in the Data Panel: Shows the multiple select feature in Rocky that enables you to select multiple items in the Data panel and edit all common parameters at once in the Data Editors panel.
- Opening a Simulation: Shows the various ways you can start a new simulation or edit an existing one.
- Creating a graph (curve or plot): Shows some ways to display and analyze simulation results in Rocky, including creating curves and plots.
- Editing a graph (curve or plot): Demonstrates some ways to change or modify an existing plot or curve within Rocky.
- Changing the 3D View: Demonstrates how to use the toolbar buttons, mouse and keyboard to change the perspective, zoom, rotate, and pan a 3D View in the Workspace.
- Using User Processes to Analyze a Component: Shows how using the User Processes features, including the Plane and Cube options, enables you to divide your geometries to analyze specific sections or components.
- Importing Custom Geometry: Shows how to add your own geometry components into Rocky, and also covers the file options supported.
- Creating an Animation: Shows how to set up an animation of your simulation and save it as an AVI.

Install/Remove Rocky

Instructions for how to install or remove Rocky and also configure the floating licensing server are provided below.

Note: You must be logged into the ESSS customer portal to view the content. If you do not have access to the customer portal, please contact rocky-support@esss.com.br for assistance.

To install ROCKY

1. View the overview video on How to install Rocky.
2. Follow the written instructions for configuring the Rocky 3 floating licensing server.

To remove ROCKY

1. From the **Start** menu, click **All Programs**, click **ESSS**, click **Rocky 3**, and then click **Uninstall Rocky 3**.
2. Follow the instructions provided on your screen.

Understand the User Interface

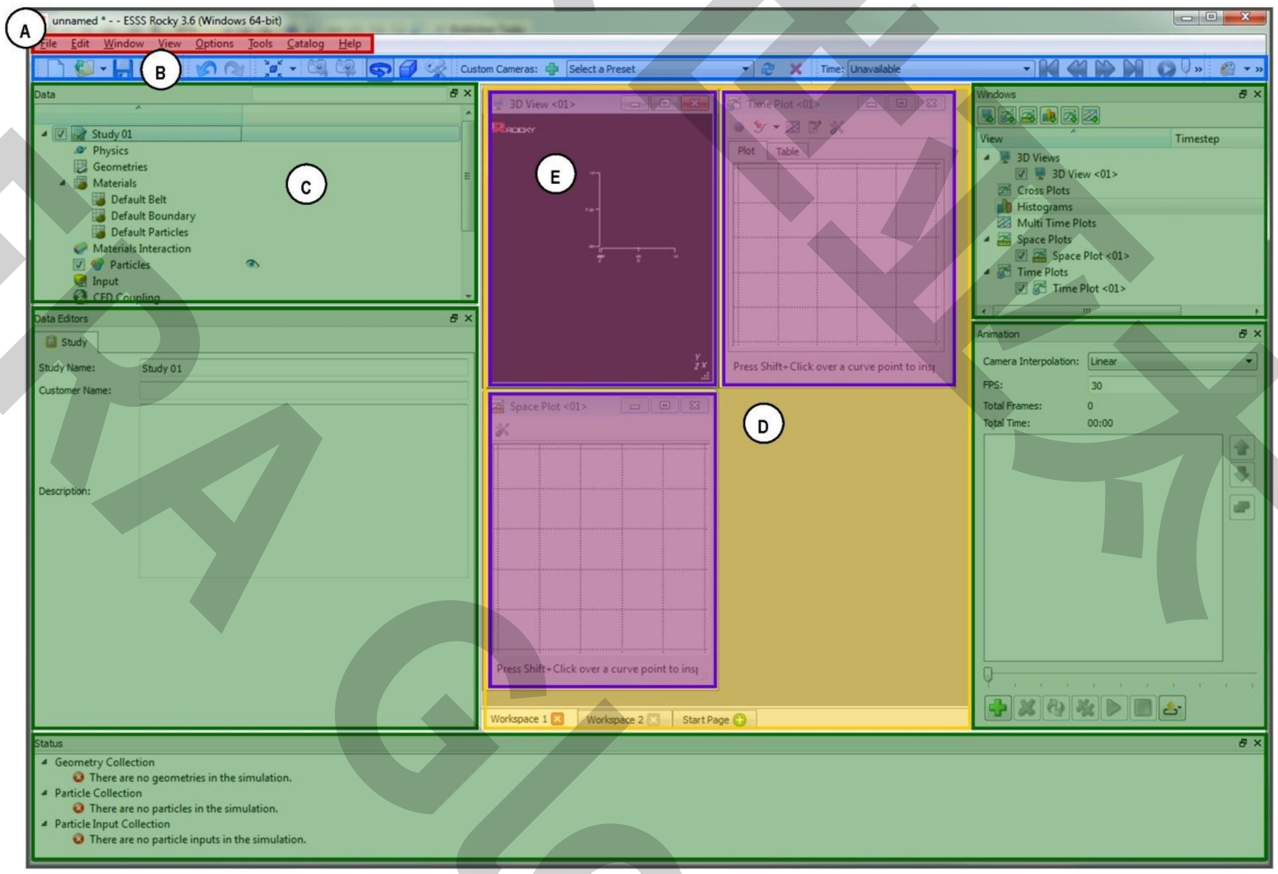
Rocky is a powerful program with a flexible, hierarchical interface. One main screen gives you access to the most frequently used functions and features, and provides you with various views of the simulation. Additional panels allow you to access properties and settings to fine-tune your simulation and view statistics based upon the results.

What would you like to learn about?

- Main UI Components
- Hidden Features
- Keyboard Accessibility and Shortcuts
- File Types

Main UI Components

Use this section to explore the five major parts of the Rocky user interface, and learn when and why you might access them.



Study Name: Study 01
Customer Name:
Description:

Press Shift+Click over a curve point to ins

Camera Interpolation: Linear
FPS: 30
Total Frames: 0
Total Time: 00:00

Geometry Collection
There are no geometries in the simulation.
Particle Collection
There are no particles in the simulation.
Particle Input Collection
There are no particle inputs in the simulation.

A: **Menu** B: **Toolbar** C: **Panel** D: **Workspace** E: **Window**

Figure 4: The five main components of the Rocky User Interface

Menu and Toolbar

The menu and toolbar are located at the very top of the Rocky main screen. From here, you can begin a new simulation, open an existing simulation, save a new simulation, show/hide Rocky panels, organize Rocky windows within the Workspace, access Help, and more.

While the menu is static in its location, the various sections that make up the toolbar can be moved or made to float independent of the screen by clicking a toolbar handle and then dragging it and dropping it with the mouse.

You can also show/hide toolbars by right clicking a toolbar and selecting or deselecting the options at the very bottom of the contextual menu.

Panels

Below the toolbar and surrounding the Workspace are various floating panels that enable you to set parameters and choose options for your simulation and its resulting data. The primary panels for configuring your simulation are the Data and Data Editors panels that appear (by default) to the left of the Workspace; the primary panels for post-processing are the Windows and Windows Editors panels that appear (by default) to the right of the Workspace. Also showing (by default) to the right of the Workspace, you can display various tools panels such as Animations or Macros. You can choose to show/hide multiple panels through both the **View** and **Tools** menus located at the top of the screen.

All panels in Rocky can be resized, moved, nested with other panels, and undocked to float independent of the Rocky main screen. Specifically:

- **To resize a panel**, hover your mouse over a panel boundary until the resize icon appears. Then, click and drag the boundary to the desired width or height.
- **To move a panel to another docked location**, click the panel title and drag to the desired area outside of the Workspace. While still dragging the panel, a preview of new docked locations will be displayed with a blue background. To select a new docked location, release the mouse over the preview of the location you want.
- **To make a nested panel**, click the panel title and then drag it directly over another panel until the lower panel is blue, and then release the mouse. The second panel will appear as a tab at the bottom of the first panel. Select the tab you want to toggle between panels.
- **To make a docked panel float**, click the panel title, drag it towards the center of the screen then release the mouse. Alternatively, you can also click the icon to the left of the panel's close button to make any docked panel float.

Show/hide multiple panels by right clicking a panel's title bar and selecting or deselecting the options at the top and middle of the contextual menu. To learn more about showing, hiding, moving, and resizing objects in the Rocky UI, watch the Customizing the Rocky User Interface video.

Workspace

A Workspace is a collection of Rocky windows. Located in the center of the Rocky screen, the windows that make up a Workspace are where you choose to view the physical components of your simulation setup (3D View windows), and interact with the graphical results of your simulation (plot and histogram windows).

You can have multiple Workspaces for different purposes, such as by analysis type. These are designated by Workspace tabs along the bottom of the Workspace area, which can also be renamed to better help you organize your data.

Window

A window in Rocky is the method by which the physical components or the graphical results of the simulation are viewed. Windows appear only from within a Rocky Workspace, but you can maximize the size of the Window to take advantage of the entire Workspace area, or you can tile several windows in columns by using the options at the bottom of the **Windows** menu.

There are six different types of windows in Rocky as described below:

- **3D View**: Displays the physical geometries of your simulation and shows you a preview of your animations.
- **Cross Plots**: Graphically compares multiple measurements made at a single time or location along two or more axes.
- **Histograms:** Displays in a bar graph data ranges that you select from the **Grid Functions** or **Grids** tabs.
- **Time Plots**: Graphs data across a time period. Also enables you to inspect a particular point in a curve and see the results in table format.
- **Multi-Time Plots**: Like Time Plot, graphs data across a time period but enables multiple plots to be compared in one window.
- **Space Plots**: Graphs one-dimensional (line) data from the **Grid Functions** tab.

Hidden Features

This section covers the not-so-obvious but useful features scattered throughout the Rocky UI and how it might benefit you to use them.

What would you like to do?

- Name Components to Affect Sort Order
- Show/Hide Components by Using Eye icons and Checkboxes
- See Input/Output Relationships in the Data Panel When Component Names are Bold
- Determine the Frequency of Calculations by Pinning/Unpinning Items
- Recognize Data Placeholders
- Double-Click the Status Panel to Jump to the Appropriate UI Location
- Use Colored Text to Validate the Syntax
- Drag/Drop Items into Windows
- Access the Right-Click Menu for Additional Features
- Use the Data Panel Search Bar to Quickly Find Components
- Refer to the Rocky Title Bar for Simulation Progress Details

Name Components to Affect Sort Order

Sorting in Rocky follows the rules for Extended ASCII character codes (For a full list, see Appendix B: ASCII Printable Characters.) In general, Names beginning with spaces are sorted first, followed by most special characters, followed by numbers, followed by uppercase letters, and ending with lowercase letters.

For example, Rocky would sort the following 12 geometry components in the order shown in Figure 5.

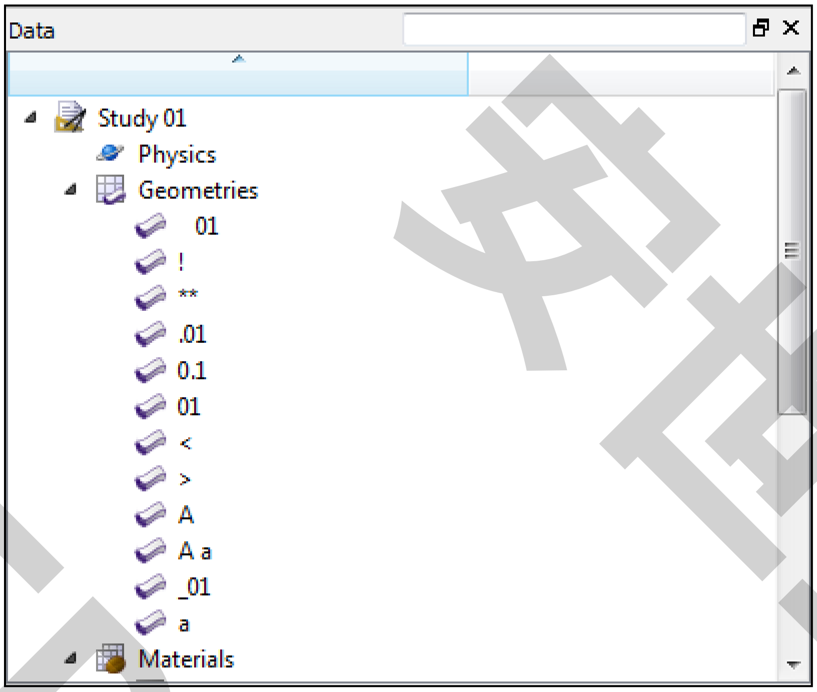


Figure 5: Example sort order in Rocky

Show/Hide Components by Using Eye Icons and Checkboxes

Rocky provides two complementary methods for determining whether a component or family of components will be shown or hidden in the Workspace: The eye icon (Figure 6), which affects the visibility of only that individual component, and the checkbox (Figure 7), which affects the visibility of all sub-components beneath the object.

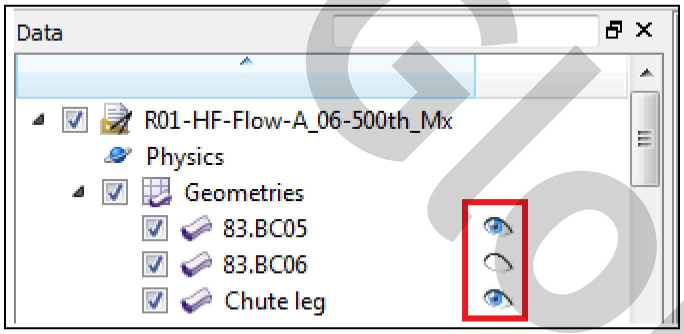


Figure 6: Open and closed eye icons to the right of objects in the Data panel

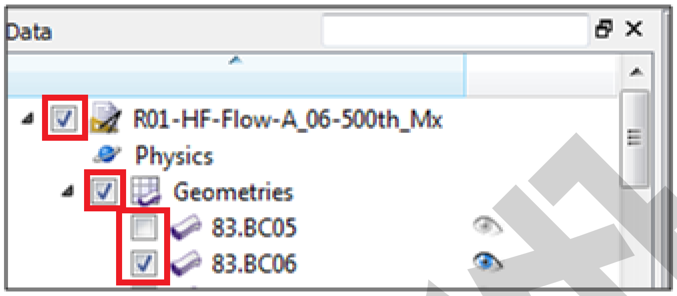


Figure 7: Checkboxes to the left of objects in the Data panel

Eye Icon

An "open" eye icon (default setting) indicates that particular object is visible or shown in 3D View windows, plots, or histograms. A "closed" eye icon keeps that item in the simulation's calculations but makes the object appear invisible or hidden in the window. This is useful for seeing behind one object to another in an animation, for example, or for focusing on a particular curve in a plot.

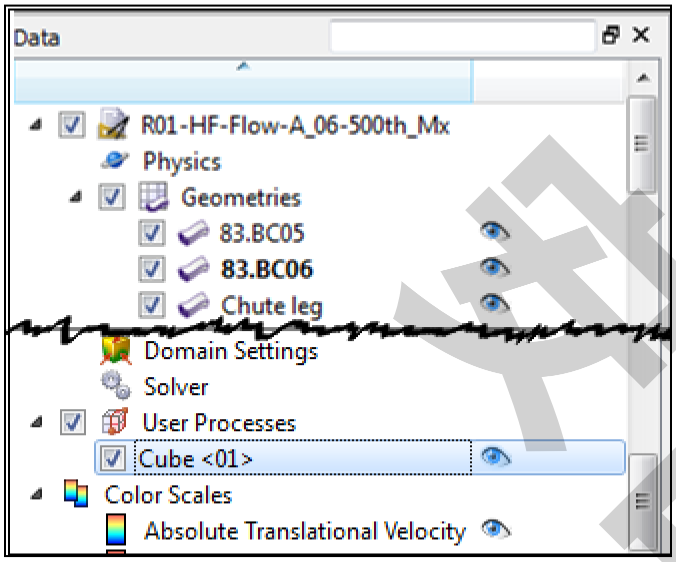
Checkbox

In the Data panel, the checkbox has the same visibility affect as the eye icon but is hierarchical, meaning it affects all children components directly beneath that item in the Data panel. For example, clearing the checkbox to the left of Geometries hides all individual geometry components listed beneath it.

In the Windows panel, the checkbox acts like the eye icon does in the Data panel: it shows/hides the individual object–in this case, various windows in the Workspace. Unlike in the Data panel, checkboxes in the Windows panel are not hierarchical.

See Input/Output Relationships in the Data Panel When Component Names are Bold

Linked objects refers to the ability of a geometry component, Particles, or Air Flow to provide data to a particular User Process, thus establishing an input/output relationship between them. This linkage is illustrated in the Data panel by the name of the object providing the data (output) turning bold when the User Process that is accepting the data (input) is selected, as shown in Figure 8.


Data

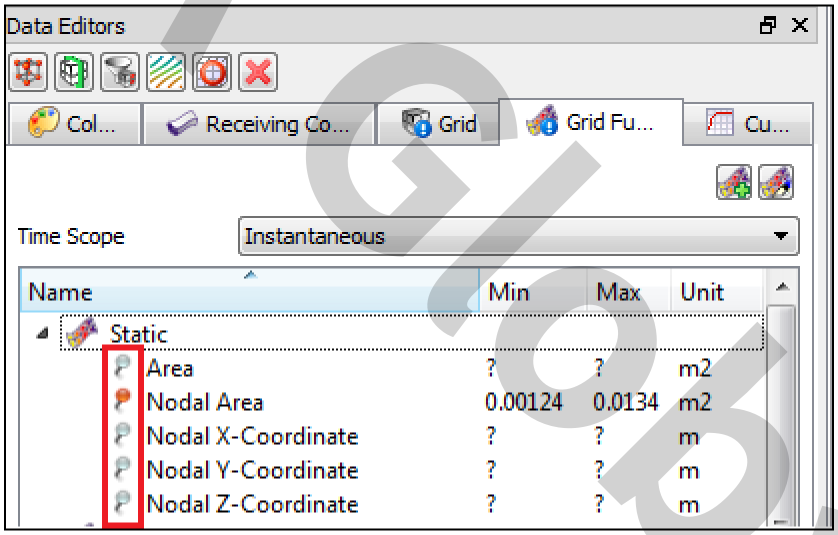
- R01-HF-Flow-A_06-500th_Mx
  - Physics
  - Geometries
    - 83.BC05
    - **83.BC06**
    - Chute leg
  - Domain Settings
  - Solver
  - User Processes
    - Cube <01>
  - Color Scales
    - Absolute Translational Velocity

Figure 8: Example of a geometry component shown in bold when the user process linked to it is selected

To create this kind of input/output relationship, the User Process must be created directly from the object providing the data. In the example above, the “Cube <01> user process was created by selecting the 83.BC06 geometry and then creating a Cube user process from either the Data Editor or right-click menu.

Determine the Frequency of Calculations by Pinning/Unpinning Items

After processing your simulation, you can view various types of data on the **Grid Functions** and **Curves** tabs for your simulation settings like particles and geometry components. Each of the items listed on these tabs has a pin icon to the left of it, as illustrated in Figure 9.


Data Editors

Col... | Receiving Co... | Grid | Grid Fu... | Cu...

Time Scope: Instantaneous

Name	Min	Max	Unit
Static			
Area	?	?	m2
Nodal Area	0.00124	0.0134	m2
Nodal X-Coordinate	?	?	m
Nodal Y-Coordinate	?	?	m
Nodal Z-Coordinate	?	?	m

Figure 9: Pin icons on the Grid Functions tab of the Data Editors panel

The color of these pin icons indicates how often Rocky calculates the particular item, as follows:

- A gray-colored pin (default) indicates that the item will not be calculated for any timestep. Choosing to avoid calculating data that you don't need saves processing time and power during your simulation.
- A red-colored pin indicates that the item will be calculated for each timestep included in the simulation. And if settings affecting those values change, Rocky will recalculate to keep all the values current.
  Important: Choosing to have Rocky calculate the item at each timestep is likely to take up a significant amount of processing time and power. Only choose to pin items for which having all timestep calculations be kept up-to-date and available are truly necessary for your analysis.

Tip: To pin or unpin an item, just click left-click the pin icon.

Alternately, you can choose to have Rocky calculate any values you are interested in once, by right-clicking the item and choosing **Compute Statistics**. This enables you to see values you are interested without taking up as much processing time and power as it would take to pin the same item. The results you get are dependent upon what kind of data item you chose, as described below:

- For items on the **Grid Functions** tab, choosing to **Compute Statistics** results in only the current timestep being calculated.
  Note: Ensure first that **Instantaneous** is selected from the **Time Scope** drop down before taking this step.
- For items on the **Curves** tab, choosing to **Compute Statistics** results in all currently available timesteps being calculated. But unlike pinning an item, choosing to **Compute Statistics** will not continue to recalculate those values should settings change that affect them, or if new timesteps are added to the simulation.

Recognize Data Placeholders

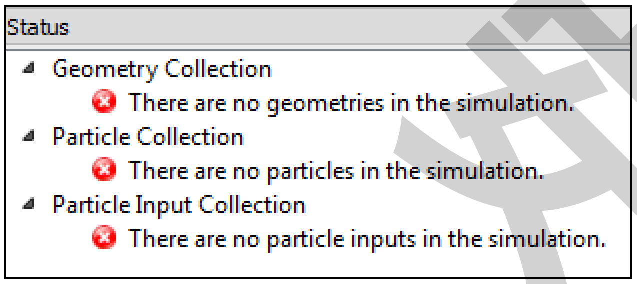
Rocky uses several different characters and strings as placeholders for calculations or explanations that would take up too much room in the UI. Here is a quick list of some placeholders you might run across and what they mean.

Note: These placeholders might appear on the **Grid**, **Grid Functions**, or **Curves** tabs (**Data Editors** panel) for particles and geometry components.

Placeholder	Description
?	Information isn't calculated yet. Same as "Not loaded."
Not loaded	Information isn't calculated yet. Same as "?
-	Not enough information available at this particular timestep in order to calculate the values. Same as "Unable to calculate".
Unable to calculate	Not enough information available at this particular timestep in order to calculate the values. Same as "-".
Unknown	Not enough information is known to calculate the value.
<ind>	Item contains no units for the value displayed. Generally indicates a count of something.

Double-Click the Status Panel to Jump to the Appropriate UI Location

If you have errors listed in the Status panel (Figure 10), you can double-click those errors to be taken to the location in the Data panel where you would address them.



Status
- Geometry Collection
  - There are no geometries in the simulation.
- Particle Collection
  - There are no particles in the simulation.
- Particle Input Collection
  - There are no particle inputs in the simulation.

Figure 10: Example of errors shown on the Status panel

For example, if you double-click the “There are no geometries in the simulation” error, Rocky would enable the **Geometries** item in the **Data** panel.

Use Colored Text to Validate the Syntax of Your Entries

Rocky provides instant feedback for entering functions and variables into a parameter text field by coloring the text as you type, as explained below:

- Red text indicates that the syntax of the active entry isn’t yet valid. The syntax is based upon the rules of the Python programming language. It will tell you whether you have an open parenthesis that needs to be closed, for example.
- Green text indicates that the syntax of the active entry is valid.
  Note: Green text does not indicate that the value, function, or variable of active entry has been formatted correctly or is itself a valid entry. Validation happens after either pressing Enter or clicking away from the text field.
- Black text indicates a currently inactive entry.

Drag/Drop Items into Windows

There are several tasks in Rocky that can be accomplished more easily by dragging items with your mouse and dropping them to another location, as described below:

- **Creating new views of Particles, individual geometry components, or Airflow:** From the **Data** panel, select the component(s) you want to view and then drag and drop them to a window of your choice (3D View, Histogram, or Time Plot). Only the component(s) you selected will be added.
- **Creating new views of data sets**: From the **Data Editors** panel, on the **Curve** or **Grid Function** tab, select the data item(s) you want to show and then drag and drop them into the window type you want (3D View, plots or histograms).
- **Creating multiple Multi-Time plots in a single window**: After adding your first data set, hold the Ctrl key while selecting your next data set and then drag and drop it into the gray area of an existing Multi-Time plot window. Another plot appears in the same window.

Tip: You can also multi-select items to drag and drop. (For example, show multiple geometry components at once in a 3D View.) Just hold the Ctrl or Shift key while left clicking your selections with the mouse, and then drag and drop as usual.

Access the Right-Click Menu for Additional Features

There are a few things in Rocky that can only be accomplished by right-clicking the item, as described below:

- **Adding/Importing geometry components**: From the **Data** panel, right-click **Geometries** to access the menu that enables you to add or import new geometry components.
- **Computing statistics for only the current Timestep**: From the **Data Editors** panel, on the **Curve** or **Grid Function** tab, right-click the data item you want to view values for and then click **Compute Statistics** from the right-click menu.
- **Showing only a few components in a new window**: From the **Data** panel, select the item(s) you want displayed in a new window, right-click your selection, and then from the right-click menu, point to **Show in New** and then click the window type you want. Only the items you selected appear in the new window.
- **Import your own User Process shape for particle analysis**: From the **Data** panel, right-click **Particles**, point to **User Processes**, and then click **Polyhedron (Envelope)**. From the **Select the STL file for the polyhedron** dialog, navigate to the STL file you want, and then click **Open**. The Polyhedron you chose appears under the **User Processes** list.
  Note: You can also create a custom-shaped User Process from any existing User Process that was originally created from a Particle group. (See also See Input/Output Relationships in the Data Panel When Component Names are Bold.) From the **Data** panel, under **User Process**, right-click a User Process that was created from a Particle group and then follow the instructions above.

Use the Data Panel Search Bar to Quickly Find Components

The search bar is located at the very top right of the Data panel, as shown in Figure 11.

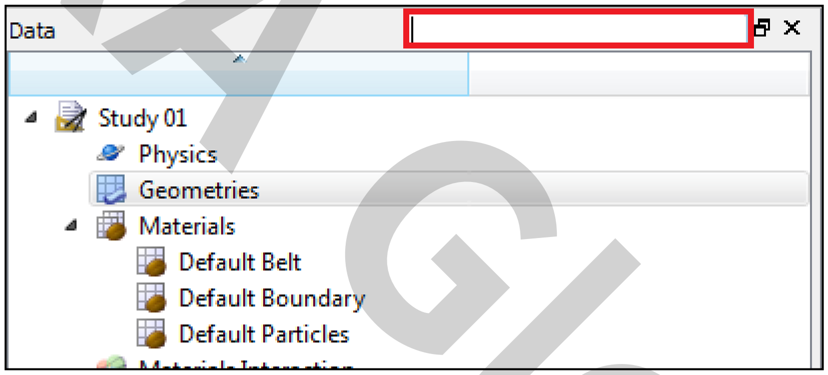


Figure 11: Data panel search bar

When you start typing into it, Rocky immediately displays in the Data panel the entire hierarchy of the component(s) that best match what you typed. In a simulation setup with many different components, using the search bar can help you find what you need faster than scrolling.

Tips:

- To search the names in order from left to right, enter the first few characters of the component you want to find.
  For example, to find all components that begin with “belt,” type `belt` into the search box. You would find “belt 01” and “belt 02” but not “feeder belt” by using this method.

- To search anywhere in the name, type an asterisk (*) followed by the characters anywhere within the name that you want to find.
  For example, to find all components containing "belt" anywhere in the name, type `*belt` into the search box. In this way, you would find the "feeder belt" component as well as "belt 01" and "belt 02."

Refer to the Rocky Title Bar for Simulation Progress Details

When you are actively processing a simulation (see Start a Simulation), the Title bar for the Rocky program displays useful details about the simulation's progress.

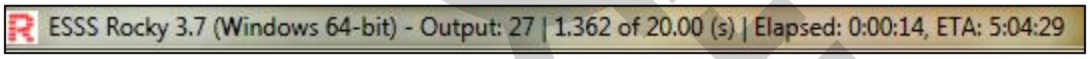

ESSS Rocky 3.7 (Windows 64-bit) - Output: 27 | 1.362 of 20.00 (s) | Elapsed: 0:00:14, ETA: 5:04:29

Figure 12: Example of Title bar progress information shown while a simulation is processing

This progress information in the Title bar includes the following:

- **Output**: The total number of Timestep files that have been saved thus far. In the example in Figure 12, the total number of output files is 27.
- **Current progress**: The particular second of the total Simulation Duration that Rocky is currently calculating. Note that Rocky calculates in finer detail than is typically determined by the Output Frequency in which it saves Timestep files. (See also Table 10: Solver, Time Configuration parameter options). In the example in Figure 12, though Rocky is currently calculating for second 1.362, because the output frequency is set to 0.05 seconds, it won't actually save a 28th Timestep representing 1.4 seconds until the current progress reaches that point.
- **Elapsed**: Amount of real time since starting (or resuming) the simulation processing. In the example in Figure 12, 14 seconds have elapsed since the simulation was resumed.
- **ETA**: Rocky's estimate of how much real time the simulation will take to complete. This is a rough approximation Rocky extrapolates based upon the amount of time the last several timesteps took to calculate. In the example in Figure 12, Rocky estimates that it will take roughly five hours for the 20 second simulation to complete. The ETA will get longer as more and more particles enter the simulation and it takes more time for Rocky to calculate each timestep. Should the simulation reach a point where more particles leave the simulation than enter it, the ETA will begin to get shorter.

Keyboard Accessibility and Shortcuts

While Rocky was not designed for full software accessibility, it does offer some limited features for keyboard control. For example:

- **TAB key**: Press to move from option to option within a Rocky dialog or panel.
- **SPACEBAR**: Press to select or clear a check box, or to select buttons in panels.
- **UP/DOWN ARROW keys**: Press to select list items within a Rocky dialog, Panel, or menu.
- **LEFT/RIGHT ARROW keys**: Press to view different menus or to move horizontally in Rocky dialogs.
- **ESC key**: Press to close a dialog.
- **ENTER**: Press to select a button within Rocky dialogs.

To view the full keyboard shortcut list

1. From the **Options** menu, click **Preferences**.
2. From the **Preferences** dialog, under **Properties**, click **Shortcuts**.

File Types

There are several unique file types used in Rocky, and several common ones. Use the table below to identify when and why certain file types are used.

Note: Only the simulation project file is saved to the directory location you choose. All other files created by Rocky (marked as "System" below) are saved to a project subfolder created automatically within the same directory as your project file. System files are critical for Rocky functioning and should not be edited, moved, or deleted.

Files you choose to export out of Rocky, including animation, image, and data files, are saved to the locations you specify. See the below table for more detail.

Table 1: File Types Used in Rocky

Type	Description	Extension
Rocky Simulation Files		
Simulation project file	Used for storing parameters set for a particular simulation and is also linked to the simulation Timestep files (.rhs) that are created during processing. • One project file is saved for each simulation. • Opening a project file will display the last Timestep (.rhs) file that was saved.	.rocky30
(System) Simulation file	Used for storing information related to the results of the simulation.	.rcy
(System) Simulation Timestep file	During Processing, one Timestep file is saved per output frequency; many Timestep files make up a whole simulation. • Timestep files are accessed by opening the project file (.rocky30) file and then moving the **Timestep** slider in the toolbar to the location you want. • Displaying a Timestep file shows the image (in a 3D View) or data (in a plot or histogram) for that particular moment in the simulation.	.rhs
(System) Solver file	Used for storing information related to solving the simulation.	.rocky20
(System) Solver log file	Records the progress of the solver.	.rocky20.log
(System) Rocky log file	Records information about Rocky useful for error solving purposes.	.rocky20.out

Type	Description	Extension
(System) Rocky script file	Contains scripts and functions that enable Rocky to run properly.	.rocky20.prg
(System) Current Timestep file	This is where ROCKY saves what Timestep file is most current.	_H.txt
Files Exported Out of Rocky		
Simulation statistics file	File created by exporting curves from a plot or histogram, and which can be opened and edited in a spreadsheet program, such as Microsoft Excel.	.csv
Animation file	File created by exporting an animation, and which can be used for viewing a simulation outside of Rocky.	.avi
Image file	Used for saving or exporting a snapshot of what is currently being displayed in a window on the Workspace, or for importing into Rocky as a logo to be shown in the 3D View.	.png .jpg .bmp
Files Imported Into Rocky		
Inventor file	Used for importing geometries into Rocky. Provides a more realistic image when compared with .stl.	.xgl
Inventor, AutoCAD, and SolidWorks files	Used for importing geometries into Rocky. Provides a less realistic image when compared with .xgl.	.stl
AutoCAD file	Used for importing 3D Faces geometry files into Rocky.	.dxf
FLUENT Case File	Used for importing geometries from ANSYS FLUENT into Rocky. Contains the grid, boundary conditions, and solution parameters for a problem. Geometry component names will be retained when importing a CAS file into Rocky.	.cas
FLUENT Mesh File	Used for importing geometries from ANSYS FLUENT into Rocky. Geometry component names will not be retained when importing a MSH file into Rocky.	.msh

Set Your Rocky Preferences

There are several parameters you can set in Rocky that will affect your overall simulation. These include various preferences and unit types, as well as catalogs and variables. These items can be determined before you set up your simulation, or can be modified at any point during the setup process.

What would you like to learn about?

- Setting Your Global Preferences
- Setting Your Unit System
- Defining Your Variables
- Setting Your Application Catalog

Setting Your Global Preferences

Global preferences for Rocky include settings like memory usage, date and time format, and plot and view options. What you choose to set in preferences will affect the rest of the Rocky user interface.

To set your global preferences

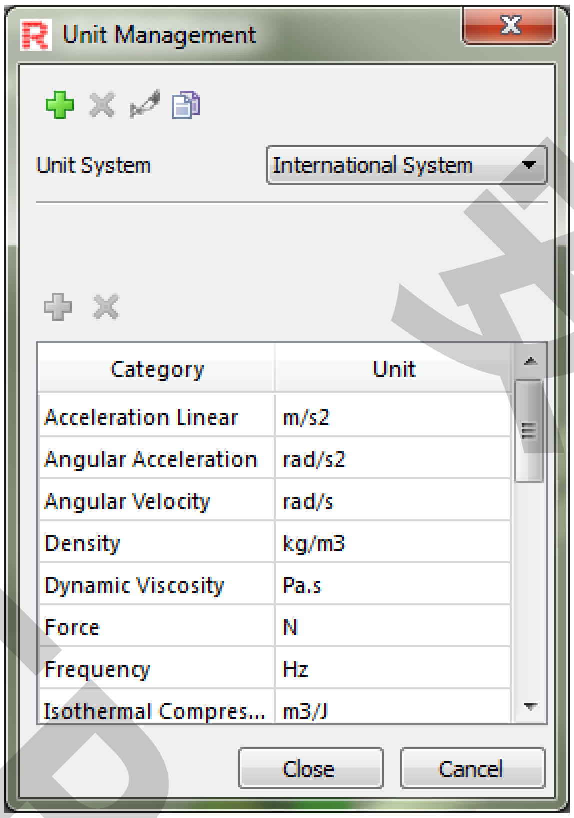
1. From the **Options** menu, click **Preferences**.
2. From the **Preferences** dialog, choose the category you want under **Properties**, and then make the choices you want on the right.
   Note: Shortcuts aren't currently editable.
3. Click **Apply** to save your changes.
4. Repeat steps 2-3 until you have set all the options you want, and then click **OK** to close the dialog.

Setting Your Unit System

Before you begin using Rocky, it is important that you understand the units used in the user interface and set them the way you want. Currently, there are two unit systems included in Rocky: the International System and the English. You can use choose to use one of these two included systems, or you can create your own custom unit system.

Whatever system you choose will provide the default unit settings for all parameters used within Rocky. However, each individual parameter unit can still be changed manually to another unit type at any time.

Use the images and tables below to help you understand your unit system options.


Unit Management

Unit System: International System

Category	Unit
Acceleration Linear	m/s2
Angular Acceleration	rad/s2
Angular Velocity	rad/s
Density	kg/m3
Dynamic Viscosity	Pa.s
Force	N
Frequency	Hz
Isothermal Compres...	m3/J

Figure 13: Unit Management dialog

Table 2: Unit Management dialog options

Setting	Description	Range
Unit System	Sets the unit system used by default throughout Rocky. Choices include: • **International System**: Units based upon the International System of Units (SI). • **English Units**: System based on the customary units of measurement used in the United States. If you have created custom unit systems, those will display in this list also.	Lists all default and custom unit systems for Rocky.
Category	Lists the descriptive name of the item being measured.	Automatic
Unit	Provides the unit symbol that will be used by default for the parameters in Rocky. These are editable when you choose to create a custom system.	Automatic

Table 3: Default Units Used in Rocky

Item	International Unit	International Unit Symbol	English Unit	English Unit Symbol
Acceleration Linear	meter per second squared	m/s^2	foot per second squared	ft/s^2
Angular Acceleration	radian per second squared	rad/s^2	radian per second squared	rad/s^2
Angular Velocity	radian per second	rad/s	radian per second	rad/s
Area	square meter	m^2	square foot	ft^2
Density	kilogram per cubic meter	kg/m^3	pound mass per cubic foot	lb_m/ft^3
Dynamic Viscosity	Pascal second	Pa·s	centipoise	cP
Force	Newton	N	pound force	lb_f
Frequency	hertz	Hz	hertz	Hz
Isothermal Compression	cubic meter per joule	m^3/J	cubic meter per joule	m^3/J
Length	meter	m	foot	ft
Mass	kilogram	kg	pound mass	lb_m
Mass Flow Rate (formerly "Tonnage")	metric tons per hour	t/h	metric tons per hour	t/h
Mass per Energy	kilogram per joule	kg/J	pound mass per British thermal unit	lb_m/Btu
Moment of Force (formerly "Torque")	Newton meter	N·m	foot pound force	$lb_f \cdot ft$
Moment of Inertia	kilogram meter squared	kg·m²	square foot pound mass	$lb_m \cdot ft^2$
Plane Angle	degree	dega	degree	dega
Power	watts	W	horsepower	hp
Pressure	Pascal	Pa	pascal	Pa
Specific Energy	joules per kilogram	J/kg	British thermal unit per pound mass	Btu/lb_m
Specific Power	watts per kilogram	W/kg	watts per kilogram	W/kg
Time	second	s	second	s
Velocity	meter per second	m/s	feet per second	ft/s
Yield Stress	force per unit area	N/m^2	pound force per square inch	lb_f/in^2

To select a unit system to use throughout Rocky

1. From the **Options** menu, click **Unit System Manager**.
2. From the **Unit Management** dialog, choose the option you want from the **Unit System** list, and then click **Close**.

To create a new unit system

1. From the **Options** menu, click **Unit System Manager**.
2. From the **Unit Management** dialog, do one of the following:
   - To create a new unit system based upon an existing one, choose the option you want to copy from the **Unit Systems** list, and then click the **Copy the current Unit System** button.
     A copy of the existing system is created.
   - To create a new blank system, press the **Create a new Unit System** button.
     A blank system is created.
3. Click the **Rename the current Unit System** button and then in the **Enter the new name** box, type the name you want, and then click **OK**.
4. Edit the system list as you want.

To edit a custom unit system

1. From the **Options** menu, click **Unit System Manager**.
2. From the **Unit Management** dialog, choose the custom unit system you want to edit from the **Unit System** list.
   Note: You can only edit custom unit systems that you've added. If you want to edit the International or English system units included in Rocky, you must first make a copy of those systems and then edit the copy.
3. Do one or more of the following:
   - To change the units used, choose the option you want from the **Unit** list.
   - To add a new category, click the **Add** button, and then from the **Add Category** dialog, choose the options you want in the **Category** and **Unit** lists, and then click **OK**.
   - To remove a category, select the category you want to remove and click the **Remove** button.

To remove a custom unit system

1. From the **Options** menu, click **Unit System Manager**.
2. From the **Unit Management** dialog, choose the custom unit system you want to remove from the **Unit System** list, and then click the **Remove the Current Unit System** button.
   Note: You can only remove custom unit systems that you've created. The International and English system units included in Rocky are not removable.

Defining Your Variables

The Expressions/Variables tool in Rocky enables you to define unique placeholders for both Input variables (values used within the Rocky set up parameters) and Output variables (values that are exported out of

Rocky into programs like ANSYS Workbench for tasks like structural analysis). The variables you define can then be used in place of actual numerical values. This is useful in cases where you have common values that are linked (all belts are to be the same width, for example), and/or the values you enter might be changing later in the setup (you want to experiment with three different belt speeds, for example).

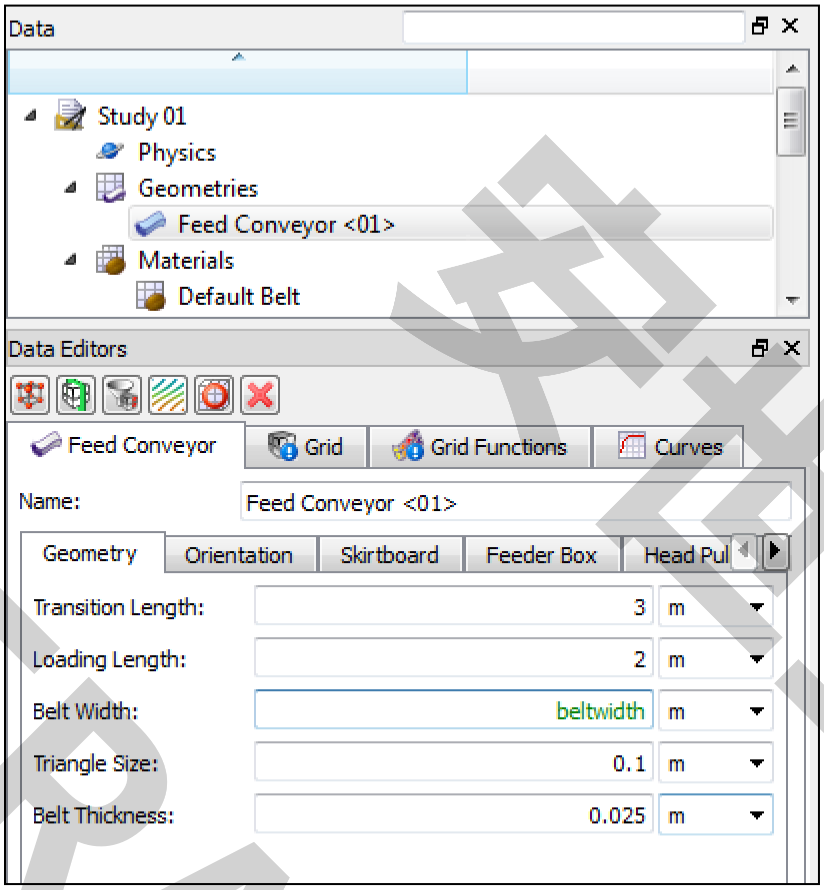
For Input variables, you can enter into the parameter text fields a variable name on its own, or you can use a variable within a mathematical function that you enter into the parameter text field instead. In this way, Rocky enables you to create dynamic relationships between parameters, and enables you to change and update placeholder values quickly. (For a more detailed example, see Appendix D: Use Variables to Test Varying Belt Speeds).

Because it can be hard to remember what parameters use what variables, Rocky uses the Expressions list to help you keep track of where the Input variables are being referenced–even if it is being used within a function or other variable definition. The Expressions list is also useful for verifying what units the variable or function is using for the particular location specified, and for changing the value or units of the variable later without having to locate it again in the Data Editors panel.

Important: Verify that your field units are set the way you want before using or creating a variable–or function including a variable–within a field. Even though variables are saved in the Variables list without units, as soon as a variable–or function including a variable–is used within a parameter field, it takes on whatever units are currently set for that field and those units are then recorded for that specific usage in the Expressions list. Changing the units for the field after the variable or function have already been entered only converts the numerical display to reflect the new units; the original variable or function amount and units are still retained. However, you can change the units and value later by editing it in the Expressions list.

Variables can be defined and used at any point during the setup portion of your simulation. See also Enter Input Variables or Mathematical Functions as Parameter Values.

Use the images and tables below to help you understand how to set your variables.


Data

Study 01
Physics
Geometries
Feed Conveyor <01>
Materials
Default Belt

Data Editors

Feed Conveyor | Grid | Grid Functions | Curves

Name: Feed Conveyor <01>

Geometry | Orientation | Skirtboard | Feeder Box | Head Pul

Transition Length: 3 m
Loading Length: 2 m
Belt Width: beltwidth m
Triangle Size: 0.1 m
Belt Thickness: 0.025 m

Figure 14: Example of entering a variable into a text field

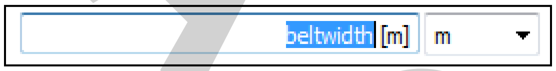

beltwidth [m] m

Figure 15: The variable name and units used for the field appears after double-clicking the field

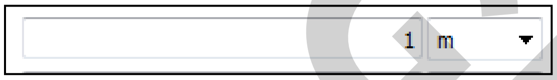
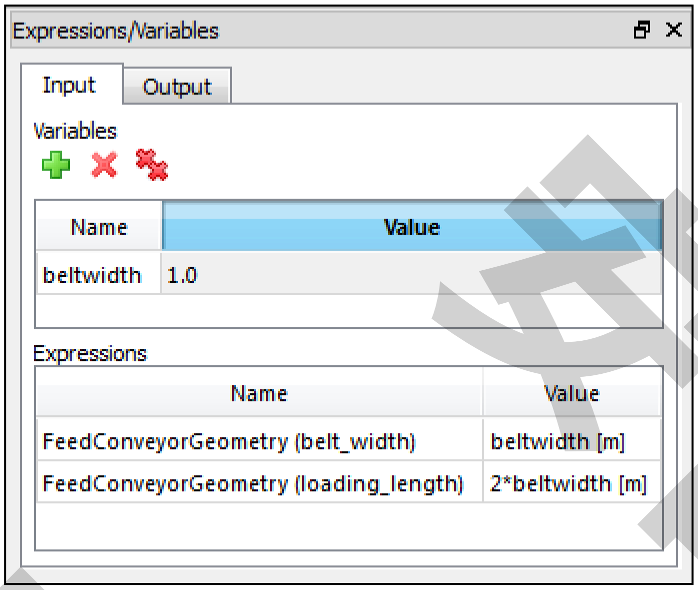

1 m

Figure 16: The current value for the variable entered appears in the field after clicking away from the field


Expressions/Variables

Input | Output

Variables

Name	Value
beltwidth	1.0

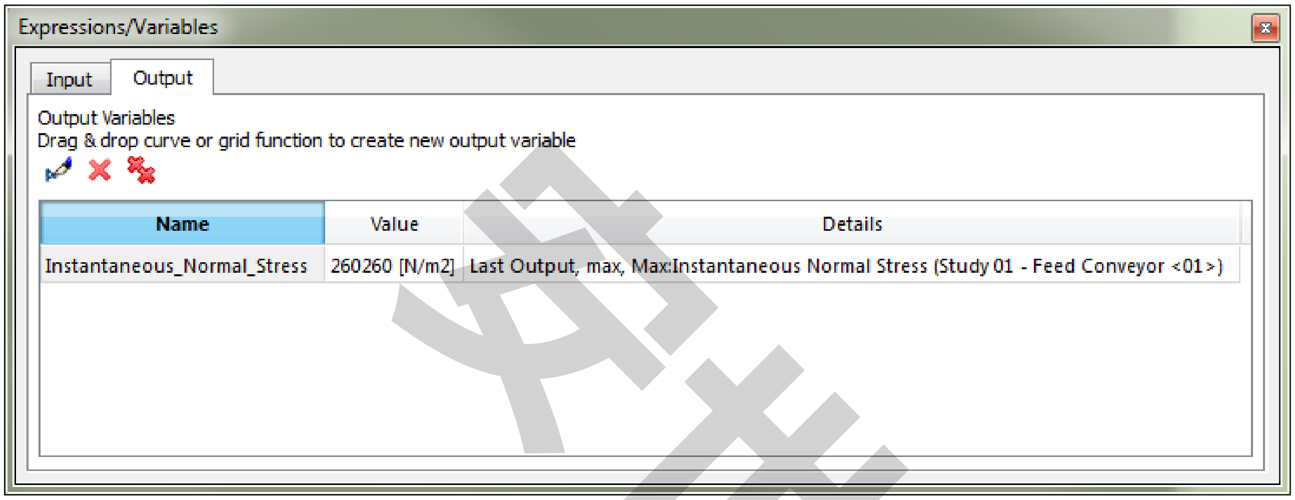
Expressions

Name	Value
FeedConveyorGeometry (belt_width)	beltwidth [m]
FeedConveyorGeometry (loading_length)	2*beltwidth [m]

Figure 17: Expressions/Variables panel, Input tab showing one defined variable being used in two separate locations

Table 4: Expressions/Variables panel, Input tab options

Setting	Description	Range
Variables		
Name	Enables you to specify a unique identifier for the variable.	The name must begin with a letter or underscore and can be followed by as many letters, underscores, or numbers as desired. Spaces and other symbols are not allowed. Letters are case sensitive.
Value	The numeric value–or a function including other existing variable(s)--assigned to the variable name.	Any value; or any valid mathematical function including other existing variable(s), as long as the function doesn't create an infinite loop. (For more information about using functions, see Enter Input Variables or Mathematical Functions as Parameter Values.)
Expressions		
Name	Lists the parameter field and location being used by the variable listed in the **Value** column.	Automatically provided. Cannot be edited.
Value	Lists the variable **Name** and the units it is currently using within the field specified by the Expression **Value** column.	Automatically provided. Can be edited by double-clicking the contents.

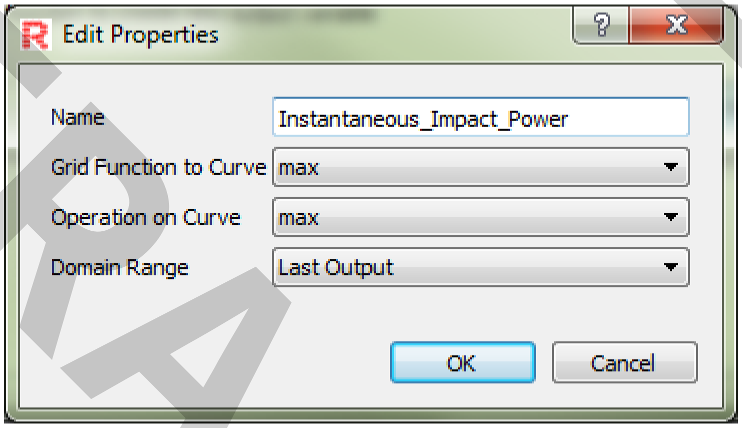

Expressions/Variables

Input | Output

Output Variables
Drag & drop curve or grid function to create new output variable

Name	Value	Details
Instantaneous_Normal_Stress	260260 [N/m2]	Last Output, max, Max:Instantaneous Normal Stress (Study 01 - Feed Conveyor <01>)

Figure 18: Expressions/Variables panel, Output tab showing one defined Grid Function variable


Edit Properties

Name: Instantaneous_Impact_Power
Grid Function to Curve: max
Operation on Curve: max
Domain Range: Last Output

Figure 19: Edit Properties dialog for Output variables

Table 5: Expressions/Variables panel, Output tab and Edit Properties dialog options

Setting	Description	Range
Name	Enables you to specify a unique identifier for the variable. By default, it is the name of the curve or grid function that you have chosen but can be edited as desired.	The name must begin with a letter or underscore and can be followed by as many letters, underscores, or numbers as desired. Spaces and other symbols are not allowed. Letters are case sensitive.
Value	The numerical value assigned to the variable as determined by the curve or grid function that you have chosen and the constraints you have assigned.	Automatically calculated based upon the settings you have chosen.

Setting	Description	Range
Details	A summary of the constraints imposed upon the curve or grid function that results in the **Value** displayed.	Automatically listed based upon the settings you have chosen.
Grid Function to Curve	When the variable is based upon a Grid Function, this is the function that will convert the grid function values at each timestep in the **Domain Range** to a single value. This single value will then be acted upon by the **Operation on Curve** function to get the final **Value**.	Min; Max; Average; Sum; Sum Squared; Variance; Standard Deviation For more information, see About Curve and Grid Functions.
Operation on Curve	If the variable is based upon a Curve function, this is the function that will be applied to it to generate the final **Value** for the variable. If the variable is based upon a Grid Function, this is the function that will be applied to the single value generated from the **Grid Function to Curve** value to achieve a final **Value** for the variable.	Min; Max; Average; Sum; Sum Squared; Variance; Standard Deviation For more information, see About Curve and Grid Functions.

Domain Range	Defines what timesteps of the simulation are included in the final **Value** calculation. The options are as follows:
	• **Application Time Filter**: Use the range settings on the Time Filter dialog to limit the timesteps used. (For more information, see Use the Timestep toolbar.)
	• **All**: Use all available timesteps in the simulation.
	• **Last Output**: Use only the very last (most recent) timestep that was calculated.
	• **Time Range**: Limit the timestep values by a specific range that you choose. (Uses the **Initial** and **Final** values you set.)
	• **Specific Time**: Choose only a single specific timestep. (Uses the **At Time** value you set.)
	• **After Time**: Use all timesteps available after a specific time period of your choosing. (Uses the **Initial** value you set.)
	• **Time Range Relative to Simulation End**: Specify how long before the very end of the simulation to include timesteps. (Uses the **Range from end** value you set.)
		Application Time Filter;
		All;
		Last Output;
		Time Range;
		Specify Time;
		After Time;
		Time Range Relative to Simulation End

Setting	Description	Range
Initial	When **Time Range** or **After Time** is chosen for **Domain Range**, this is the starting time to begin calculations.	Any value between 0 and the final simulation time.
Final	When **Time Range** is chosen for **Domain Range**, this is the ending time when calculations are stopped.	Any value between the **Initial** time and the final simulation time.
At Time	When **Specific Time** is chosen for **Domain Range**, this is the exact moment in which the calculation will be performed.	Any value between 0 and the final simulation time.
Range from end	When **Time Range Relative to Simulation End** is chosen for **Domain Range**, this is the period of time before the final simulation time in which timesteps will be included in the calculation. For example, when you want to include only the last X seconds of the simulation.	Any value between 0 and the final simulation time.

To create a new Input variable from within a parameter field

Note: This method works only when using numerical values to define the variable. If for the variable definition, you want to reference other existing variable(s) within a function, you must define the new variable using the Expressions/Variables panel. (See To create a new Input variable from the Expressions/Variables panel.)

1. Ensure the units for the field are set the way you want.
   Important: Though the variable itself will be saved without units, its use in this particular field will be affected by the units that are displayed during the next step.
2. Directly into the field in which you want to use the variable, enter a name for the new variable, and then press Enter.
   Tips: The name must begin with a letter and must have no spaces. Only letters, numbers, and underscores are recognized (no symbols). Letters are case sensitive.
3. In the **Variable Creation** dialog, enter a numerical value for the variable, and then click **Create variable**. You will notice all of the following events:
   - The variable name is replaced by the numerical value in the parameter field. The variable is also using the units that were set for that field when the variable was entered.
     Tip: Double-click the field to see the full variable name and the units that it is using.
   - The new variable is displayed in two places on the **Input** tab of the **Expressions/Variables** panel (from the **Tools** menu, click **Expressions/Variables**):
     a. Under **Variables**, where it is saved without units for use in other parameter fields.
     b. Under **Expressions**, where the variable name and units applied in that particular usage are saved along with the location of its use.
        Tip: You can edit the value and units recorded here by double-clicking the information in the **Value** column, and then modifying anything before the closing bracket.

To create a new Input variable from the Expressions/Variables panel

1. From the **Input** tab on the **Expressions/Variables** panel (from the **Tools** menu, click **Expressions/Variables**), click the **Add** button.
2. In the **Variable Name** dialog, enter a new name for the variable, and then click **OK**.
   The new variable appears in the list with an initial value of zero and no units.

To edit the value of an existing Input variable

1. From the **Input** tab on the **Expressions/Variables** panel (from the **Tools** menu, click **Expressions/Variables**), double-click the **Value** for the variable **Name** you want to change.
   The **Value** field for that variable becomes active.
2. Enter the new value you want and then press Enter.
   The new value is saved.
   Notes:
   - The variable value is always saved without units. When used in a field, this variable will use in that instance whatever units are currently being displayed for that field.
   - Once used in a field, you cannot change from the field the units being used by the variable in that particular field. (See also To change the units for a variable–or functions using variables--in use by a field.) You can, however, change the units by modifying the **Value** information in the **Expressions/Variables** panel under **Expressions**. Just double-click the **Value** you want to change, and then modify anything you want before the closing bracket.

To change the units for a variable–or functions using variables--in use by a field

- Do one of the following:
  - In the **Expressions/Variables** panel under **Expressions**, find the instance of the variable whose units you want to change, double-click the **Value** for that usage, and then modify the units displayed in the brackets.
  - Remove the variable name–or function using the variable name–from the field, set the units for the field to the ones you want adopted by the variable or function, and then re-enter the variable name–or function using the variable name–again.
    Tip: Double-click the field to see the full variable name–or function using the variable name–and the units that it using in that instance.

To define a new Output variable

1. Set up and process the simulation as you normally would.
2. From the **Curve** or **Grid Function** tab (from the **Data** panel, select **Particles,** the geometry, or user process for which you want data and then in the **Data Editors** panel, select the tab for which you are interested), click and drag the **Name** of the data you want to the **Output** tab of the **Expressions/Variables** panel (from the **Tools** menu, click **Expressions/Variables**) and then release the mouse.
   The data appears as a new variable in the **Output** list.

To edit the details of an Output variable

1. From the **Output** tab of the **Expressions/Variables** panel, select the **Name** of the variable you want to edit, and then click the **Edit** button.
2. From the **Edit Properties** dialog, enter the information you want as explained in Table 5, and then click **OK**.

To remove a single variable

- From either the **Input** or **Output** tab of the **Expressions/Variables** panel, select the **Name** of the variable you want to remove, and then click the **Remove** button.
  Just that variable is removed from the list.
  Note: The last value replaces the variable name in any parameter field the removed variable was being used, and the **Expressions** list recording for that variable is cleared.

To remove all variables

- From either the **Input** of **Output** tabs of the **Expressions/Variables** panel, select a variable to enable the buttons, and then click the **Remove All** button.
  All the variables in the list on that tab are removed from the list.
  Note: The last values replace all the respective variable names in any parameter field the removed variables were being used, and the **Expressions** list recordings for the all the variables are cleared.

Setting Your Application Catalog

<Content coming soon…>

View Frequently Used Tasks

Use this section to quickly find and perform common tasks in Rocky.

What would you like to do?

- Enter Input Variables or Mathematical Functions as Parameter Values
- Enable Moving, Rotating, Vibrating, or Swinging Geometries
- Change the Speed of a Default Conveyor
- See Surface Wear on the Geometry Itself

Enter Input Variables or Mathematical Functions as Parameter Values

You can create Input variables in Rocky (see Defining Your Variables) and then use them in place of actual numerical values in situations where you want more flexibility. These variables can be used alone or within functions.

Tip: Rocky includes several visual feedback mechanisms, like text color, to help you ensure the variable names and mathematical functions you enter are correct. See Use Colored Text to Validate the Syntax of Your Entries for more information.

Important: Verify that your field units are set the way you want before using a variable–or function using a variable--within a field. Even though variables are always saved in the Variables list without units, as soon a variable–or function using a variable--is used within a parameter field, it takes on whatever units are currently set for that field and then those units are recorded for that specific usage in the Expressions list. Changing the units for the field after the variable or function have already been entered only converts the numerical display to reflect the new units; the original variable or function amount and units are still retained. However, you can change the units and value later by editing it in the Expressions list.

To replace a parameter value with a variable

- Using the **Data** and **Data Editors** panels, locate and select the field for the parameter you want to replace, exactly enter the name of the variable you want to use, and then press Enter.
  The current value set for the variable in the **Expressions/Variables** panel is displayed in the field.
  Tip: To see the units that are set for the variable you used, double click the value in the field. The units are displayed in brackets [ ] after the variable name.

To replace a parameter value with a function using a variable

- Using the **Data** and **Data Editors** panels, locate and select the field for the parameter you want to replace, and then enter the function you want to use.
  Tip: For a list of available functions, see Appendix C: Calculation Reference.

Enable Moving, Rotating, Vibrating, or Swinging Geometries

You enable moving, rotating, vibrating, or swinging geometries when you want geometries to animate during the simulation. For example, you might have a mill that rotates, a gate that lifts, or a plate that oscillates. Moving, rotating, vibrating, and swinging parameters can be set only for imported (custom) geometries, but all default conveyors included within Rocky have **Translation and Rotation Without Displacement** values already enabled. This is how the particles appear to move along the conveyor belt even though the conveyor itself is static.

You enable a moving, rotating, vibrating, or swinging geometry by first importing the boundary from a CAD program, and then setting the Translation and Rotation, Vibration, or Pendulum values you want. See also Add and Edit Geometry Components.

This section contains the following procedures regarding movement:

- To enable a geometry to move in a straight line
- To enable a geometry to rotate around a center point (e.g. a rotating mill slice)
- To enable a geometry to rotate freely around a non-center point (e.g., a gate or rubber curtain)
- To enable a geometry to both rotate and move in a straight line
- To enable a vibrating boundary
- To enable a regularly swinging boundary (e.g. a pendulum)
- To enable multiple movements of a geometry in one simulation

- To enable geometry movements to be repeated

To enable a geometry to move in a straight line

1. Ensure the geometry you want to move has already been imported. (See also Add and Edit Geometry Components.)
2. From the **Data** panel, under **Geometries**, select the geometry to want to move in a straight line.
   The parameters for that geometry are displayed in the **Data Editors** panel.
3. From the **Data Editors** panel, on the **Custom Boundary** tab, determine when you want the geometry to appear and/or disappear by entering the number of seconds you want for **Enable Time** and **Disable Time**.
   Tip: To keep the geometry visible during the entire simulation, leave the values at 0 and 1000 (or your maximum simulation time).
4. From the **Movements** sub-tab, click **Edit Movements List**.
5. From the **Custom Movements** dialog, do all of the following:
   a) Determine when you want the geometry to start and stop moving by entering the number of seconds for **Start Movement Time** and **Stop Movement Time**.
   b) From the **Movement Type** list, do one of the following:
      - To have the geometry physically move during the simulation, select **Rotation and Translation**.
      - To keep the geometry stationary but apply velocity to the surface, select **Rotation and Translation without Displacement**.
        Note: You cannot enable free motion or boundary wear simulations with this option.
6. Under **Translation Parameters**, for each of the axes for which you want movement, do one of the following:
   - To have the geometry continue on its path regardless of gravity or the boundaries/particles with which it comes into contact, enter the translational velocity and acceleration for the geometry.
   - To have the boundary move freely under gravity, and interact with the particles with which it comes into contact, select Free Motion , and then enter the force and displacement values you want.
     Notes:
       - Free motion is possible only with **Rotation and Translation**.
       - Geometries will not interact with other geometries.
7. Click **OK** to save your changes and close the dialog.

To enable a geometry to rotate around a center point (e.g. a rotating mill slice)

1. Ensure the geometry you want to rotate has already been imported. (See also Add and Edit Geometry Components.)
2. From the **Data** panel, under **Geometries**, select the geometry to want to rotate.
   The parameters for that geometry are displayed in the **Data Editors** panel.
3. From the **Data Editors** panel, on the **Custom Boundary** tab, determine when you want the geometry to appear and/or disappear by entering the number of seconds you want for **Enable Time** and **Disable Time**.
   Tip: To keep the geometry visible during the entire simulation, leave the values at 0 and 1000 (or your maximum simulation time).

4. If you want to enable free movement of your boundary (possible only with **Rotation and Translation**),from the **Mass** sub-tab, do all of the following:
   a) In the **Boundary Mass** box, enter the geometry's mass.
   b) In the **Moments of Inertia** boxes, enter the values you want for the 3 principal moments of inertia.
   Note: It is assumed that at the beginning of rotation, principal axes of inertia coincide with local x, y, and z axes.
5. From the **Movements** sub-tab, click **Edit Movements List**.
6. From the **Custom Movements** dialog, do all of the following:
   a) Determine when you want the geometry to start and stop moving by entering the number of seconds for **Start Movement Time** and **Stop Movement Time**.
   b) From the **Movement Type** list, do one of the following:
      - To have the geometry physically move during the simulation, select **Rotation and Translation**.
      - To keep the geometry stationary but apply velocity to the surface, select **Rotation and Translation without Displacement**.
      Note: You cannot enable free motion or boundary wear simulations with this option.
7. Under **Rotation Parameters**, for each of the axes for which you want movement, do one of the following:
   - To have the geometry continue to rotate in a set motion regardless of gravity or the boundaries/particles with which it comes into contact, enter the rotational velocity, acceleration and the location of the center point of rotation.
   - To have the boundary move freely under gravity and interact with the particles with which it comes into contact, select Free **Motion**, and then enter the additional torque and center point of rotation location.
   Notes:
      - Free motion is possible only with **Rotation and Translation**.
      - Geometries will not interact with other geometries.
8. Click **OK** to save your changes and close the dialog.

To enable a geometry to rotate freely around a non-center point (e.g., a gate or rubber curtain)

1. Ensure the geometry you want to rotate has already been imported. (See also Add and Edit Geometry Components.)
2. From the **Data** panel, under **Geometries**, select the geometry to want to rotate.
   The parameters for that geometry are displayed in the **Data Editors** panel.
3. From the **Data Editors** panel, on the **Custom Boundary** tab, determine when you want the geometry to appear and/or disappear by entering the number of seconds you want for **Enable Time** and **Disable Time**.
   Tip: To keep the geometry visible during the entire simulation, leave the values at 0 and 1000 (or your maximum simulation time).
4. From the **Mass** sub-tab, do all of the following:
   a) In the **Boundary Mass** box, enter the geometry's mass.
   b) In the **Moments of Inertia** boxes, enter the values you want for the 3 principal moments of inertia.
   Note: It is assumed that at the beginning of rotation, principal axes of inertia coincide with local x, y, and z axes.
5. From the **Movements** sub-tab, click **Edit Movements List**.

6. From the **Custom Movements** dialog, do all of the following:
    a) Determine when you want the geometry to start and stop moving by entering the number of seconds for **Start Movement Time** and **Stop Movement Time**.
    b) From the **Movement Type** list, select **Rotation and Translation**.
7. Under **Rotation Parameters**, for each of the axes for which you want movement, do all of the following:
    a) Select **Free Motion**, and then enter the additional torque and center point of rotation location.
    b) Select **Specify Gravity Center (local)** and then enter the **Gravity Center** location for the geometry.
    Note: Geometries will not interact with other geometries.
8. Click **OK** to save your changes and close the dialog.

To enable a geometry to both rotate and move in a straight line

1. Ensure the geometry you want to move has already been imported. (See also Add and Edit Geometry Components.)
2. From the **Data** panel, under **Geometries**, select the geometry to want to move.
   The parameters for that geometry are displayed in the **Data Editors** panel.
3. From the **Data Editors** panel, on the **Custom Boundary** tab, determine when you want the geometry to appear and/or disappear by entering the number of seconds you want for **Enable Time** and **Disable Time**.
   Tip: To keep the geometry visible during the entire simulation, leave the values at 0 and 1000 (or your maximum simulation time).
4. If you want to enable free movement of your geometry (possible only with **Rotation and Translation**),from the **Mass** sub-tab, do all of the following:
    a) In the **Boundary Mass** box, enter the geometry's mass.
    b) In the **Moments of Inertia** boxes, enter the values you want for the 3 principal moments of inertia.
    Note: It is assumed that at the beginning of rotation, principal axes of inertia coincide with local x, y, and z axes.
5. From the **Movements** sub-tab, click **Edit Movements List**.
6. From the **Custom Movements** dialog, do all of the following:
    a) Determine when you want the geometry to start and stop moving by entering the number of seconds for **Start Movement Time** and **Stop Movement Time**.
    b) From the **Movement Type** list, do one of the following:
        - To have the geometry physically move during the simulation, select **Rotation and Translation**.
        - To keep the geometry stationary but apply velocity to the surface, select **Rotation and Translation without Displacement**.
          Note: You cannot enable free motion or boundary wear simulations with this option.
7. Under **Translation Parameters**, for each of the axes for which you want movement, do one of the following:
    - To have the geometry continue on its path regardless of gravity or the boundaries/particles with which it comes into contact, enter the translational velocity and acceleration for the geometry.
    - To have the geometry move freely under gravity and interact with the particles with which it comes into contact, select **Free Motion**, and then enter the force and displacement values you want.
      Notes:
        - Free motion is possible only with **Rotation and Translation**.

  - Geometries will not interact with other geometries.

8. Under **Rotation Parameters**, for each of the axes for which you want movement, do one of the following:
   - To have the geometry continue to rotate in a set motion regardless of the particles with which it comes into contact, enter the rotational velocity, acceleration, and the location of the center point of rotation.
   - To have the geometry move freely and interact with the particles with which it comes into contact, select Free Motion, and then enter the additional torque and center point of rotation location.
     Notes:
     - Free motion is possible only with **Rotation and Translation**.
     - Geometries will not interact with other geometries.
9. Click **OK** to save your changes and close the dialog.

To enable a vibrating boundary

1. Ensure the geometry you want to vibrate has already been imported. (See also Add and Edit Geometry Components.)
2. From the **Data** panel, under **Geometries**, select the geometry to want to vibrate.
   The parameters for that geometry are displayed in the **Data Editors** panel.
3. From the **Data Editors** panel, on the **Custom Boundary** tab, determine when you want the geometry to appear and/or disappear by entering the number of seconds you want for **Enable Time** and **Disable Time**.
   Tip: To keep the geometry visible during the entire simulation, leave the values at 0 and 1000 (or your maximum simulation time).
4. From the **Movements** sub-tab, click **Edit Movements List**.
5. From the **Custom Movements** dialog, do all of the following:
   a) Determine when you want the geometry to start and stop moving by entering the number of seconds for **Start Movement Time** and **Stop Movement Time**.
   b) From the **Movement Type** list, select **Vibration**.
6. Under **Vibration Parameters**, do all of the following:
   a) In the **Frequency** box, enter how frequently you want oscillation to occur.
   b) Under **First Axis**, do all of the following:
      i. Enter the X, Y, and Z coordinate values for a directional vector of length 1. This will be your first elliptical axis of movement.
         Note: Values entered will be normalized to equal a length of 1.
      ii. In the **Amplitude** box, enter the height of the oscillation curve.
   c) Under **Second Axis**, do all of the following:
      i. Enter the X, Y, and Z coordinate values for a directional vector of length 1 that is perpendicular to the first axis. This will be your second elliptical axis of movement.
         Note: Values entered will be normalized to equal a length of 1 and adjusted to be perpendicular to the first axis.
      ii. In the **Amplitude** box, enter the height of the oscillation curve.
7. Click **OK** to save your changes and close the dialogs.

To enable a regularly swinging boundary (e.g. a pendulum)

Note: Use this procedure when the swinging motion is applied to the geometry in a predictable and regular manner. To enable a boundary that swings freely based upon particles acting upon it, see the procedure To enable a geometry to rotate freely around a non-center point (e.g., a gate or rubber curtain)

1. Ensure the geometry you want to swing has already been imported. (See also Add and Edit Geometry Components.)
2. From the **Data** panel, under **Geometries**, select the geometry to want to swing.
   The parameters for that geometry are displayed in the **Data Editors** panel.
3. From the **Data Editors** panel, on the **Custom Boundary** tab, determine when you want the geometry to appear and/or disappear by entering the number of seconds you want for **Enable Time** and **Disable Time**.
   Tip: To keep the geometry visible during the entire simulation, leave the values at 0 and 1000 (or your maximum simulation time).
4. From the **Movements** sub-tab, click **Edit Movements List**.
5. From the **Custom Movements** dialog, do all of the following:
   a) Determine when you want the geometry to start and stop moving by entering the number of seconds for **Start Movement Time** and **Stop Movement Time**.
   a) From the **Motion Type** list, select **Pendulum**.
6. Under **Pendulum Parameters**, enter the frequency, amplitude, plane, and location of pivot.
7. Click **OK** to save your changes and close the dialog.

To enable multiple movements of a geometry in one simulation

1. Set up your first geometry movement as you normally would.
2. From the **Custom Movements** dialog, above the Movements list, click the **Add** button.
   An addition movement appears in the list.
3. Select the movement you just added, and then set up the additional geometry movement as you normally would.
4. Repeat steps 2-3 until all the movements you want are set up.
5. Click **OK** to save your changes and close the dialogs.

Tips:

- To more easily replicate a movement you have already set up, select the movement you want to replicate, and then above the Movement list, click the Copy button.
- To change the name of a movement, select it and then above the Movement list, click Rename.
- To re-order the movement list, select the movement you want to move, and the above the Movement list, use the Move Up and Move Down buttons to change its location in the list.
- To remove a movement, select it and then above the Movement list, click the **Remove** button.

To enable geometry movements to be repeated

1. Set up your geometry movement(s) as you normally would.
2. From the **Movements** sub-tab (located on the **Custom Boundary** tab within the **Data Editor** panel), select **Use Periodic Motion**, and then in the **Motion Period** box, enter the amount of time for which you want movement to be repeated.

Notes:

- Entering the exact time amount for which you have specified movement(s) will result in a seamless repeat of all movements. Entering a smaller amount of time will result in the latter part of your movement not occurring. Selecting a larger amount of time will result in no movement at the end each period.
- The Enable Time and Disable Time values (located on the Custom Boundary tab within the Data Editor panel) will be applied periodically when **Periodic Motion** is set.

Change the Speed of a Default Conveyor

You can change the speed of a default receiving or feed conveyor at any point during the simulation. For example, you might want to measure reclaiming belt power by starting off a simulation with a feed conveyor stopped until a hopper is filled with particles, and then ending the simulation with the conveyor up to full speed.

To change the speed of a default conveyor

1. Ensure the default conveyor for which you want to change belt speed has already been added. (See also Add and Edit Geometry Components.)
2. From the **Data** panel, under **Geometries**, select the **Receiving Conveyor** or **Feed Conveyor** for which you want to change belt speed.
   The parameters for that geometry are displayed in the **Data Editors** panel.
3. From the **Data Editors** panel, on the **Receiving Conveyor** or **Feed Conveyor** tab, ensure the **Belt Motion** sub-tab is selected, and then do all of the following:
   a) In the **Belt Speed** box, enter the full speed you want the belt to reach after acceleration is complete.
   b) In the **Beginning Start Time** box, enter the amount of time that you want the simulation to run before the belt starts accelerating.
   c) In the **Acceleration Period** box, enter the amount of time you want the belt to increase from full stop to full **Belt Speed**.
   d) In the **Beginning Stop Time** box, enter the amount of time that you want the simulation to run before the belt starts decelerating.
   e) In the **Deceleration Period** box, enter the amount of time that you want the belt to decrease from full **Belt Speed** to full stop.

See Surface Wear on the Geometry Itself

There are two major ways you can use Rocky to gain an understanding of how your geometries will wear over time. One way is by enabling wear surface modification, which changes the physical appearance of the geometry as the simulation progresses. A second way is to view a color map of the surface intensity.

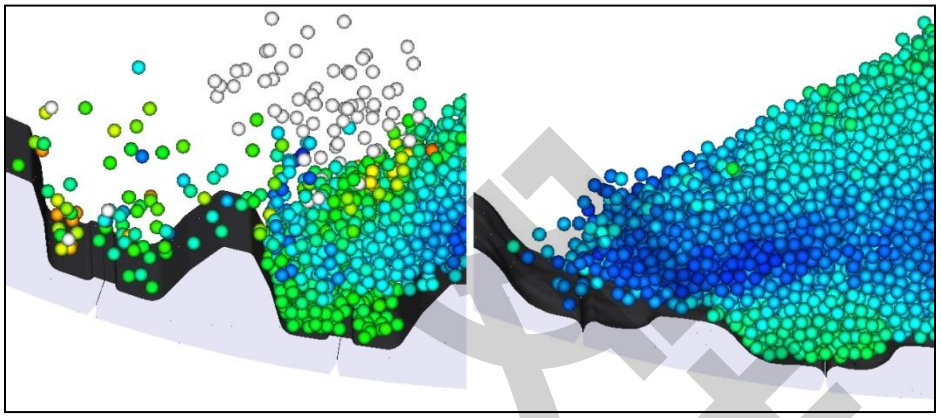
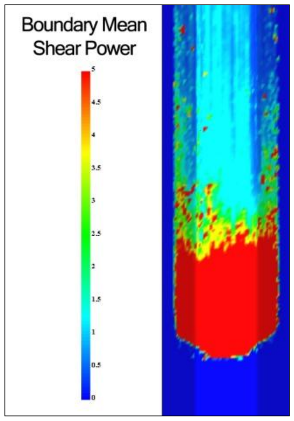



Figure 20: Wear surface modification (left); color map of surface intensity (right)

To view either type of wear data, you need to ensure that you have enabled enough boundary triangles prior to processing your simulation. Too few triangles will result in a jagged or blocky representation rather than a smooth one.

To view surface wear modification on an imported geometry

1. Set up the simulation as you normally would. (See also Set Simulation Parameters).
   Tip: Ensure that your **Statistics / Wear / Breakage Start** time is set to when you want wear data to be collected. (From the **Data** panel, select **Solver** and then from the **Data Editors** panel, locate this value on the **Time Configuration** sub-tab.)
2. Before processing your simulation, from the **Data** panel, under **Geometries**, select the imported (custom) geometry for which you want to enable surface wear.
   The parameters for the geometry become active in the **Data Editors** panel.
3. From the **Data Editors** panel, on the Custom Boundary tab, do all of the following:
   a) From the **Geometry** sub-tab, ensure **Triangle Size** is small enough to enable the wear detail you want. (0.1 m is recommended for most chutes and mills).
   b) From the **Wear** sub-tab, select **Use Wear**, and then enter the **Volume/Shear Work Ratio.**
   Note: This is a calibration step that comes from real-world wear data you have collected on similar types of liners.
4. Process the simulation as you normally would. (See also Process a Simulation.)
   As the simulation progresses, the surfaces of the geometry are modified to show wear.

Note: You cannot use this type of wear with **translation/rotation without displacement** movements.

To view a color map of wear on the default belt or imported geometry itself

1. Set up the simulation as you normally would. (See also Set Simulation Parameters.)
   Tip: Ensure that your **Statistics / Wear / Breakage Start** time is set to when you want wear data to be collected. (From the **Data** panel, select **Solver** and then from the **Data Editors** panel, locate this value on the **Time Configuration** sub-tab.)
2. Before processing your simulation, from the **Data** panel, under **Geometries**, select the default conveyor or imported (custom) geometry for which you want to enable wear.
   The parameters for the geometry become active in the **Data Editors** panel.

3. From the **Data Editors** panel, on the **Geometry** sub-tab, ensure **Triangle Size** is small enough to enable the wear detail you want. (0.1 m is recommended for most chutes and mills).
4. Process the simulation as you normally would. (See also Process a Simulation.)
5. Ensure you have a 3D View displayed in the Workspace. (See also Create a 3D View.)
6. When processing is complete enough to show the wear you want to visualize, from the first drop down list on the **Coloring Settings** toolbar, choose the data you want to display (e.g., **Mean Shear Power**.)
   The geometries in your simulation change color and a color legend is displayed in the 3D View.
7. Do the following to adjust the view and color map as desired:
   a) To better focus on the area you want to view, use the mouse to pan, rotate, and zoom.
   b) To hide all items but the belt or geometry you want to focus on, use the eye icons to the left of the geometries and particles in the **Data** panel.
   c) To modify the color bar, right-click the color legend and change the options listed.
   d) To focus on a different time period within the simulation, use the arrows or slider on the Timestep toolbar.

3. Setting Up a Simulation

Before you can process a simulation, you must first set the parameters upon which the simulation will be based. These parameters are set within the Data and Data Editors panels of the Rocky user interface. They include such settings as project name; particle type, size, and shape; geometry type and location; materials and interactions; airflow; and more.

Rocky comes preset with default values that you can use right away without modification if you choose. However, the minimum requirements for processing a simulation include setting up each of the following three items:

1. One inlet geometry
   Note: The inlet can either be from a default feed conveyor or from a separate inlet geometry that you've added to the simulation.
2. One particle group
3. One input

What would you like to do?

- Open a Simulation
- Save a Simulation
- Set Simulation Parameters
- Verify Simulation Size

Open a Simulation Project

Rocky opens by default with no new simulation project, so you must first choose what kind of project you want. To begin a new project or edit an existing one, follow one of the procedures below.

To begin a new simulation project

- From the **File** menu, click **New Project**.
  The **Data** panel is populated with default sections including Study, Physics, and Geometries.

To open an existing simulation project

1. From the **File** menu, click **Open Project**.
2. In the **Look in** list, click the drive or folder that contains the .rocky30 file you want to open.
3. In the folder list, locate and open the folder that contains the file.
4. Click the .rocky30 file you want, and then click **Open**.
   The file opens with the settings you have saved.

Save a Simulation Project

When you save a simulation project, you are saving into a .rocky30 file the various parameters you have specified in the Rocky user interface. When you choose to process a simulation, you will be asked to save the simulation project before processing. As you process, the simulation timestep files are saved automatically.

You can also choose to save an image of what is currently being shown in the Workspace. Save an image when you need only a static snapshot of one moment during the simulation. (See also Create and Save an Animation.)

To save a new simulation project

1. From the **File** menu, click **Save**.
2. In the **Save in** list, click the drive or folder of the location to which you want to save the file.
3. In the **File name** box, enter a name for the file, and then click **Save**.

To save an exact copy of the simulation project, including the simulation results

1. From the **File** menu, click **Save As**.
2. From the **Save As** dialog, choose the first option, "**Save As a New Project and Copy Simulation Results**", and then click **OK**.
3. In the **Save in** list, click the drive or folder of the location to which you want to save the file.
4. In the **File name** box, enter a name for the file, and then click **Save**.

To save a copy of only the simulation settings; not the simulation results

1. From the **File** menu, click **Save As**.
2. From the **Save As** dialog, choose the second option, "**Save As a New Project but DON"T Copy Simulation Results**", and then click **OK**.
3. In the **Save in** list, click the drive or folder of the location to which you want to save the file.
4. In the **File name** box, enter a name for the file, and then click **Save**.

To save a copy of a partially processed simulation for restart purposes

1. From the Toolbar, ensure that the **Timestep** slider is set to the point in the simulation you want the copy to start with.
2. From the **File** menu, click **Save As**.
3. From the **Save As** dialog, choose the third option, "**Save as a New Project for Restart**", and then click **OK**.
4. In the **Save in** list, click the drive or folder of the location to which you want to save the file.
5. In the **File name** box, enter a name for the file, and then click **Save**.

Note: When you open the copy, the **Timestep** slider will be reset to zero (0) but the simulation will start from the Timestep file you choose in step #1.

To save over the current simulation project

- From the **File** menu, click **Save**.

To save an image of the 3D View, Plot, or Histogram

1. In the Workspace, select the 3D View, Plot or Histogram for which you want to save an image.

2. From the **Window** menu, click **Save Image**.
3. In the **Save in** list, click the drive or folder of the location to which you want to save the file.
4. In the **File name** box, enter a name for the file.
5. In the **Save as type** list, choose the type of image file you want, and then click **Save**.

SET SIMULATION PARAMETERS

Whether you are beginning a new simulation or modifying an existing one, it is a good idea to ensure that your simulation parameters are set exactly the way you want before you start processing. Once you Start a Simulation and begin processing, you cannot go back and change the settings without losing the simulation results that have been created.

Setting simulation parameters involves setting simulation-wide values as well as parameters specific to particles, geometries, materials, interactions, inputs, and more.

What would you like to do?

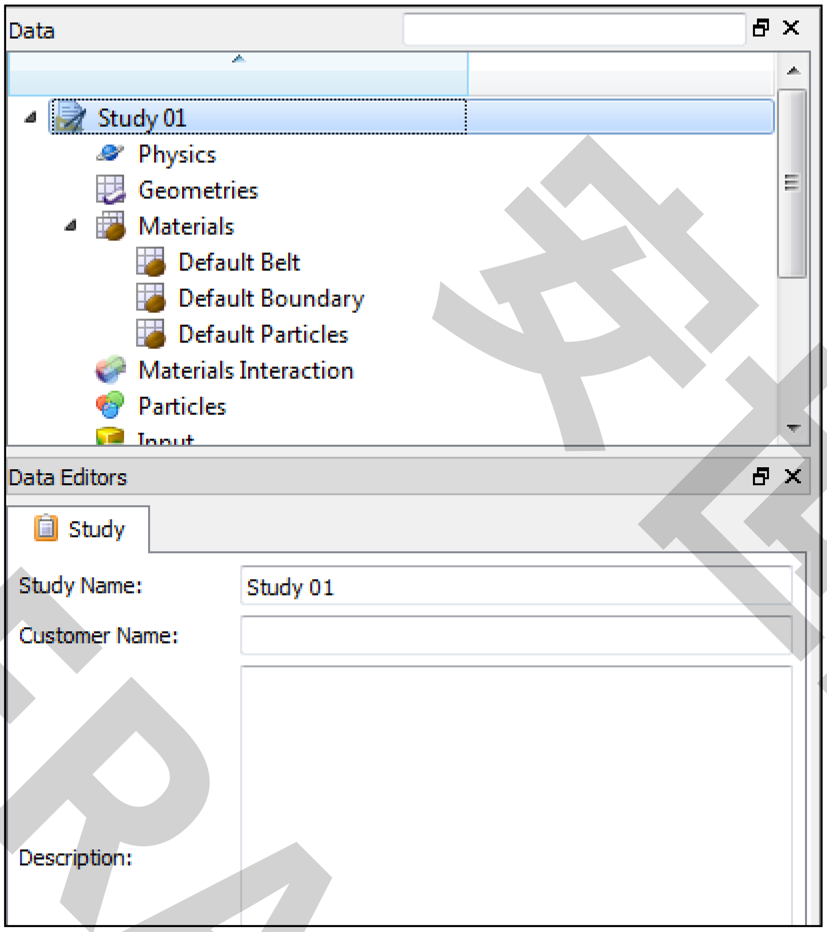
- Set Simulation-Wide Parameters
- Add and Edit Geometry Components
- Modify Material Composition
- Modify Material Interaction and Adhesion Values
- Add and Edit Particle Groups
- Add and Edit Particle Inputs
- Set or Modify Air Flow Properties
- Verify Simulation Size

SET SIMULATION-WIDE PARAMETERS

You set simulation-wide parameters when you want to change the default values provided by Rocky to affect your whole simulation. Simulation-wide parameters are settings that include simulation title, customer name, and simulation time length. It is also where you choose when statistics for belt and boundary wear, and energy spectra begin recording; and whether you want to use gravity components or periodic boundaries for your mill simulations.

Simulation-wide parameters are set by first selecting the Study, Physics, Domain Settings, and Solver sections in the Data panel and then editing the results in the Data Editors panel. These values can be set at any time before you begin processing your simulation.

Use the figures and tables below to help you understand the various parameters you can set for the simulation in general.



Data

Study 01
Physics
Geometries
Materials
Default Belt
Default Boundary
Default Particles
Materials Interaction
Particles
Input

Data Editors

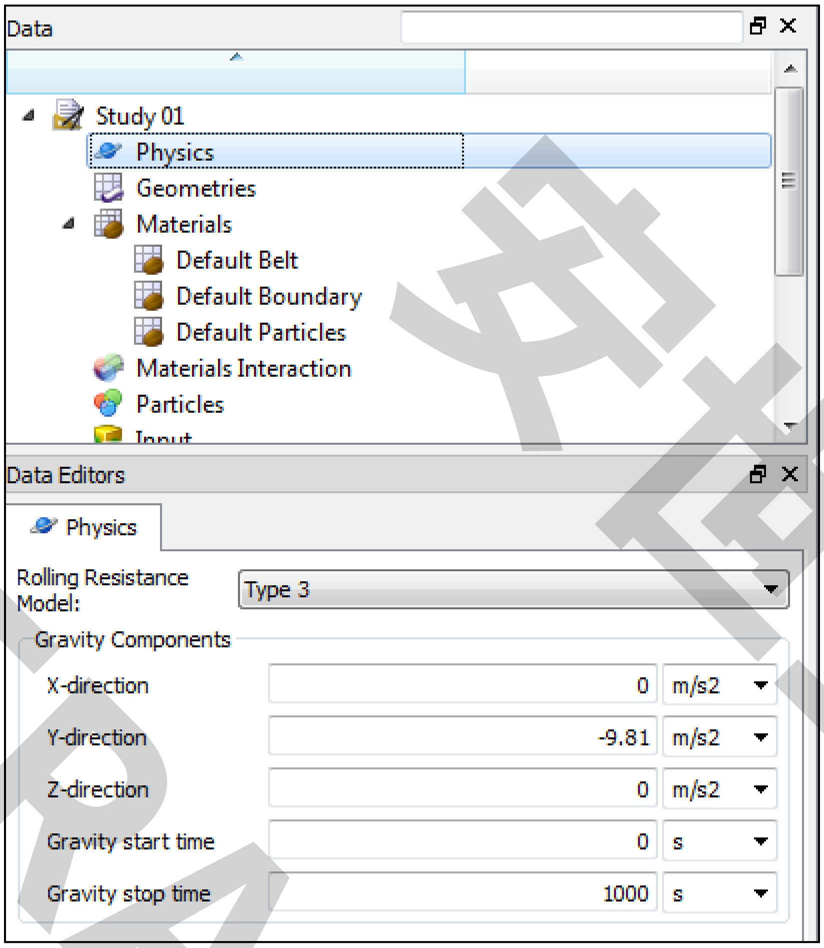
Study

Study Name: Study 01
Customer Name:
Description:

Figure 21: Study parameters in the Data Editors panel

Table 6: Study parameter options

Setting	Description	Range
Study Name	Name of the simulation you are working on. For example, “Transfer Chute B with corn.”	No limit
Customer Name	Name of the customer for whom you are doing the simulation.	No limit
Description	Description of the simulation.	N o limit



Rolling Resistance Model: Type 3

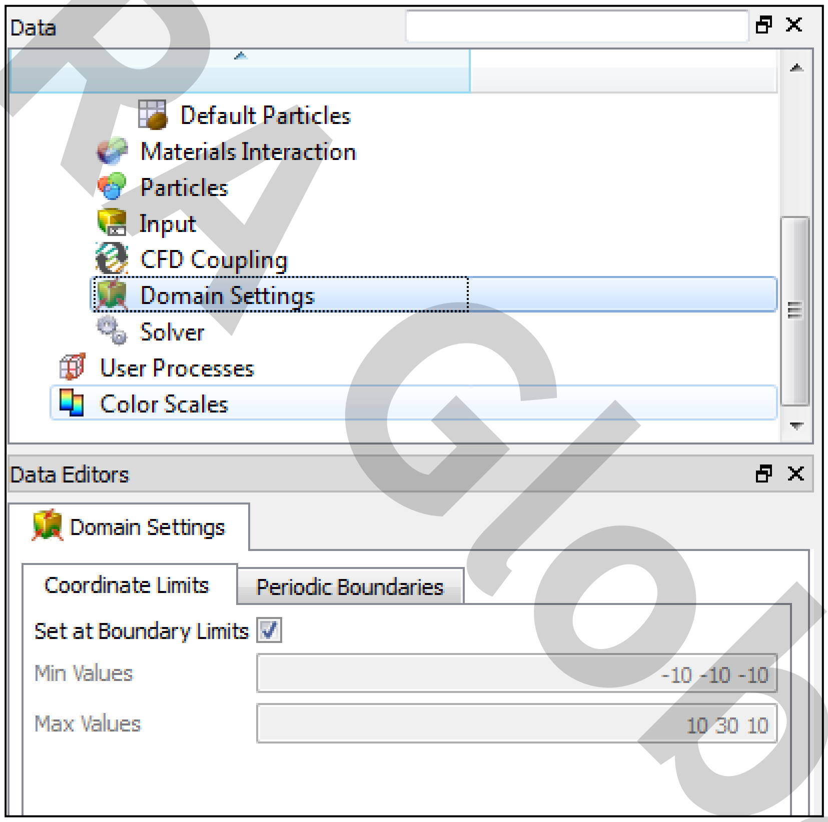
Gravity Components		
X-direction	0	m/s2
Y-direction	-9.81	m/s2
Z-direction	0	m/s2
Gravity start time	0	s
Gravity stop time	1000	s

Figure 22: Physics parameters in the Data Editors panel

Table 7: Physics parameter options

Setting	Description	Range
Rolling Resistance Model	The type of rolling resistance calculation used in the simulation: • **Type 1**: Also known as a "Type A" model, this is a directional constant torque model of the type typically used by other DEM programs. This model should typically only be used when you want a high angle of repose without using adhesion values. • **Type 3**: Also known as a "Type C" model, this is an elastic-plastic spring-dashpot model that tends to provide more realistic results when adhesion values are being used. This is the model recommended for most simulations. For more information on the calculations used to form these models, see the 2010 article "Assessment of rolling resistance models in discrete element simulations" by Chen, Rotter, and Ooi.	Type 1; Type 3

Setting	Description	Range
Gravity Components		
X-direction	Used to change the direction that gravity affects particles and free boundaries, this is the amount of acceleration (in meters per second squared) applied horizontally during the simulation.	No limit
Y-direction	Used to change the direction that gravity affects particles and free boundaries, this is the amount of acceleration (in meters per second squared) applied vertically during the simulation. Note: The default value is -9.81 m/s^2, which accounts for the affect of Earth's gravity pulling objects downward.	No limit
Z-direction	Used to change the direction that gravity affects particles and free boundaries, this is the amount of acceleration (in meters per second squared) applied out-of-plane during the simulation.	No limit
Gravity Start Time	The duration you want to wait before gravity components are activated.	Positive values
Gravity Stop Time	The duration you want to wait before gravity components are deactivated.	Positive values

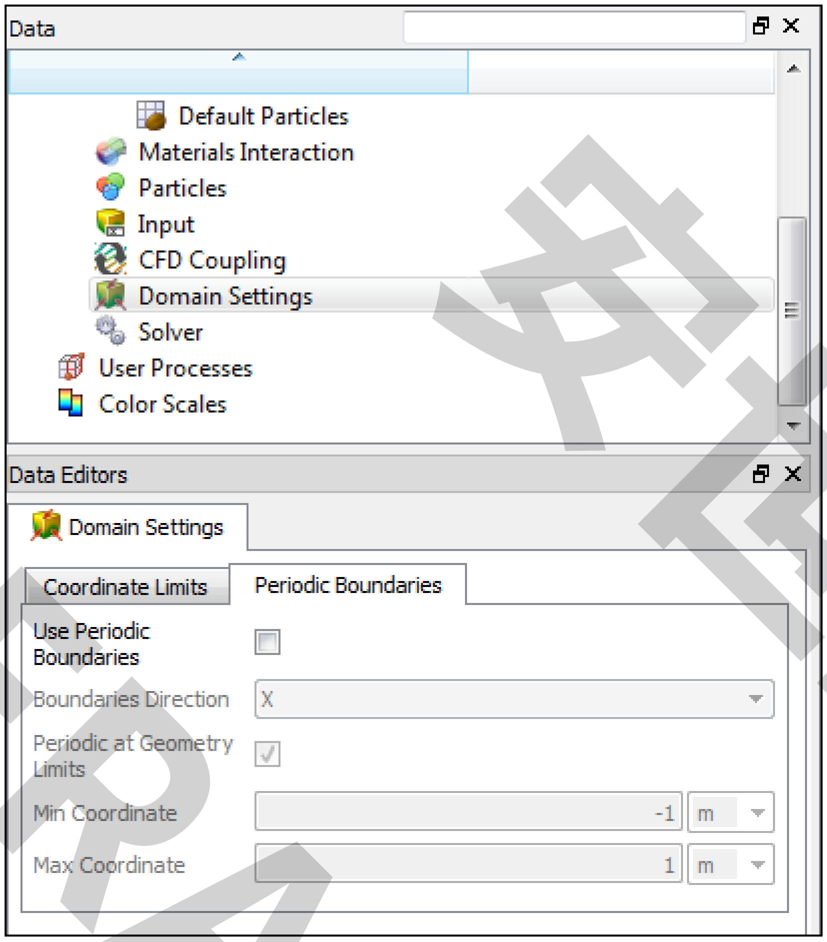


Set at Boundary Limits ✓
Min Values -10 -10 -10
Max Values 10 30 10

Figure 23: Domain Settings, Coordinate Limits parameters in the Data Editors panel

Table 8: Study parameter options

Setting	Description	Range
Set at Boundary Limits	When selected, automatically sets the coordinate limits of the simulation at the extreme ends of the existing geometries. When geometries change or move, the limits will be changed also. Notes: • Selecting this item will cause particles to disappear from the simulation when they reach the end of a geometry. • Clearing this item will cause particles to disappear from the simulation based on the values you set in the **Min Values** and **Max Values** fields. • Because the limits are dynamic due to the changing and moving of geometries, the limits will not be visible in the 3D View. You can, however, see the boundary limit values by viewing the **Simulation Summary** screen. (See Processing a Simulation for more information.)	Turns on or off
Min Values	When **Set at Boundary Limits** is cleared, enables you to set the minimum values for the simulation coordinate limits in the following format: `X Y Z` The limits will be visible in the 3D View.	No limit for X, Y, and Z values but must be lower than **Max Values**
Max Values	When **Set at Boundary Limits** is cleared, enables you to set the maximum values for the simulation coordinate limits in the following format: `X Y Z` The limits will be visible in the 3D View.	No limit for X, Y, and Z values but must be higher than **Min Values**



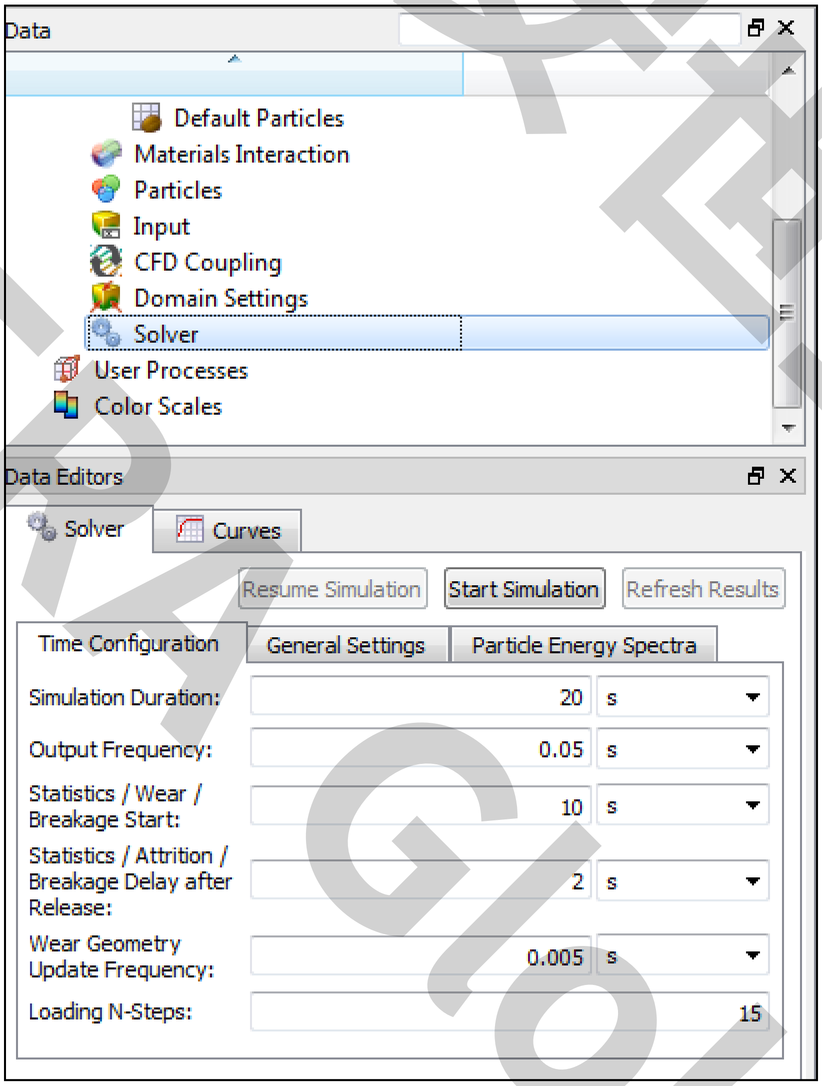
Use Periodic Boundaries: ☐
Boundaries Direction: X
Periodic at Geometry Limits: ✓
Min Coordinate: -1 m
Max Coordinate: 1 m

Figure 24: Domain Settings, Periodic Boundaries parameters in the Data Editors panel

Table 9: Domain Settings, Periodic Boundaries parameter options

Setting	Description	Range
Use Periodic Boundaries	When selected, two parallel planes appear at the edges of the boundary limits along the axis specified in the **Boundary Direction** box. Particles that exit the simulation through one plane will reappear in the simulation through the other plane. This is useful for simulating cross sections or slices of mills; particles flung out of one side of the mill cross section can be recycled back into the simulation from the other side.	Turns on or off
Boundaries Direction	When **Use Periodic Boundaries** is selected, this value determines the direction periodic boundaries are enabled.	X; Y; Z
Periodic at Geometry Limits	When selected, the periodic boundary will be located at the farthest edge of the geometries. When cleared, the **Min. Coordinate** and **Max. Coordinate** values will be used.	Turns on or off

Setting	Description	Range
Min Coordinate	Location along the axis specified in the **Boundaries Direction** box to place the first periodic boundary.	No limit
Max Coordinate	Location along the axis specified in the **Boundaries Direction** box to place the second periodic boundary.	No limit

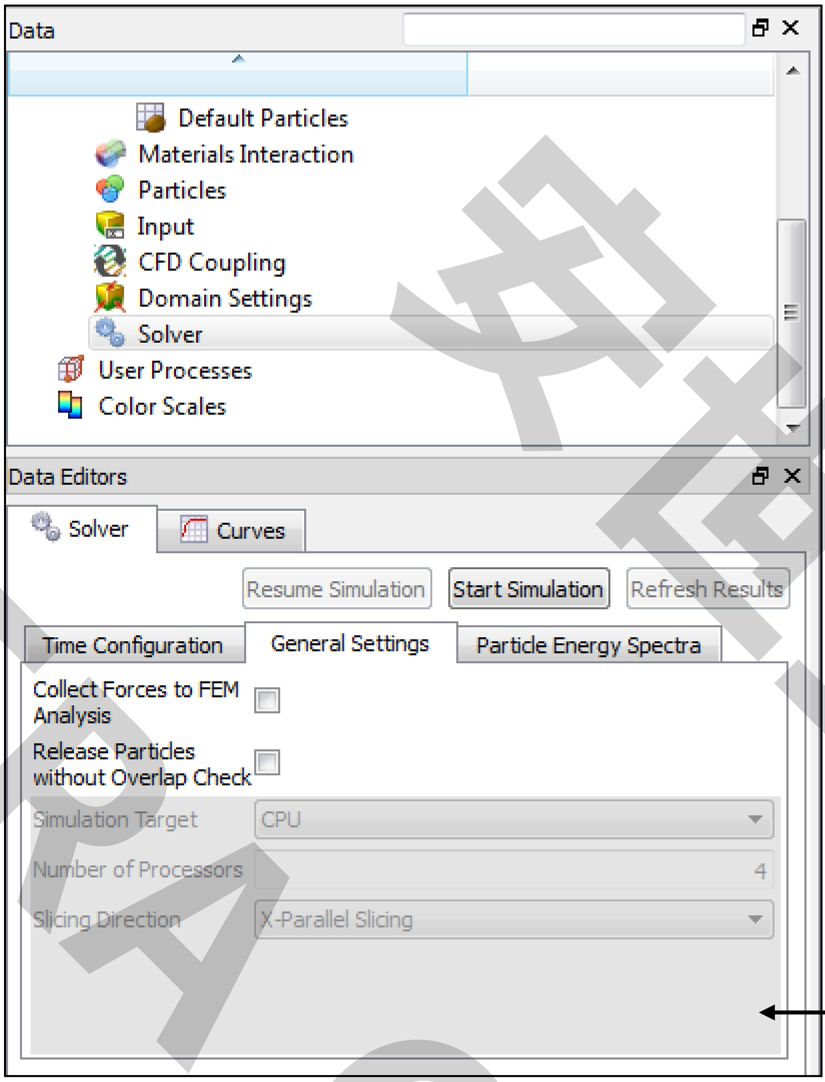


Simulation Duration: 20 s
Output Frequency: 0.05 s
Statistics / Wear / Breakage Start: 10 s
Statistics / Attrition / Breakage Delay after Release: 2 s
Wear Geometry Update Frequency: 0.005 s
Loading N-Steps: 15

Figure 25: Solver, Time Configuration parameters in the Data Editors panel

Table 10: Solver, Time Configuration parameter options

Setting	Description	Range
Simulation Duration	The total amount of time that you want the simulation to run. Tips: • When calculating the **Duration** value, be sure to account for the length and speed of your conveyors, the tonnage of your particles, and so on. • You can extend the duration at a later point by changing this value to a higher number.	Positive values
Output Frequency	The time frequency by which you want your Timestep files to be saved. Tip: To prevent rotating or vibrating boundaries from appearing like they are moving backwards, divide the movement by 2 and then set your output frequency as slightly lower than that value.	Value must be positive but less than **Duration**.
Statistics / Wear / Breakage Start	The amount of time you want to wait before starting to calculate simulation statistics like belt and boundary wear, energy spectra, and particle breakage. IMPORTANT: Because belt and boundary wear, energy spectra, and breakage are calculated as an average over time, it is important that you set statistics to be collected *after* steady state has been reached. In a typical chute, this is usually less than 10 seconds into a simulation but if you have a very long chute or very slow moving particles, it might be best to start collecting statistics data later into the simulation.	Value must be positive but less than **Duration**.
Statistics / Attrition / Breakage Delay after Release	The amount of time you want to wait after a particle has been released before starting to calculate particle attrition, particle energy spectra, or particle breakage.	Value must be positive but less than **Duration**.
Wear Geometry Update Frequency	Amount of time between wear geometry updates. A smaller value will produce smoother transitions between updates but might increase processing time; a larger value will produce rougher transitions between updates, but will take less time to process. See also See Surface Wear on the Geometry Itself.)	Positive
Loading N-Steps	Value used to calculate Timesteps. In general, the lower the value, the faster the processing but the more unstable the results. Higher values (for example, above 15) are recommended if you are interested in collecting particle energy spectra or calculating breakage.	10-30



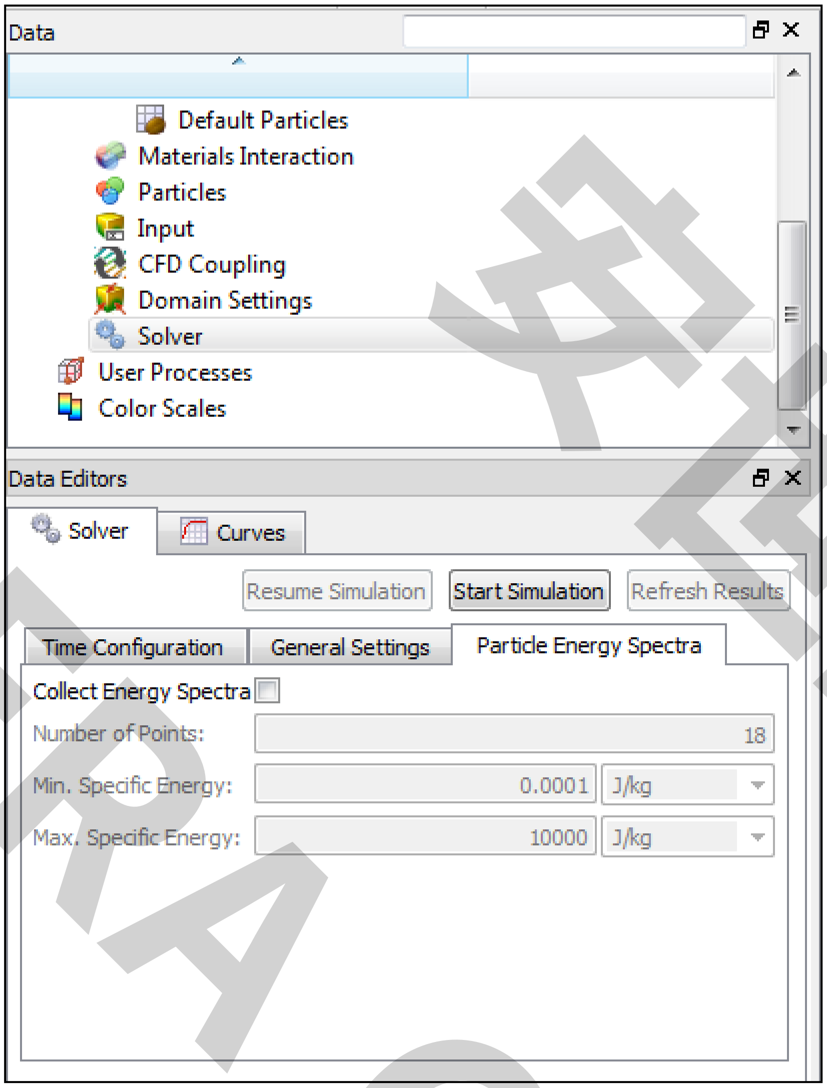
Collect Forces to FEM Analysis ☐
Release Particles without Overlap Check ☐
Simulation Target: CPU
Number of Processors: 4
Slicing Direction: X-Parallel Slicing

Note: We will cover these last three options in the Start a Simulation section.

Figure 26: Solver, General Settings parameters in the Data Editors panel

Table 11: Solver, General Settings parameter options

Setting	Description	Range
Collect Forces to FEM Analysis	When selected, enables boundary forces to be collected into a separate TXT file, which can be imported into a separate Finite Element Method (FEM) tool for analysis.	Turns on or off
Release Particles without Overlap Check	When selected, overrides the setting that delays particles from discharging from an inlet if other particles or boundaries are in the way. **WARNING:** Selecting this item with large particles or high particle velocities could cause problems with your simulation and might result in Rocky hanging or shutting down.	Turns on or off



Collect Energy Spectra ☐
Number of Points: 18
Min. Specific Energy: 0.0001 J/kg
Max. Specific Energy: 10000 J/kg

Figure 27: Solver, Particle Energy Spectra parameters in the Data Editors panel

Table 12: Solver, Particle Energy Spectra parameter options

Setting	Description	Range
Collect Energy Spectra	When selected, energy spectra data will be recorded beginning from the time the **Statistics / Wear / Breakage Start** value is reached. Tip: The **Statistics / Wear / Breakage Start** value is set on the **Solver**, **Time Configuration** tab in the **Data Editors** panel.	Turns on or off
Number of Points	The number of points on specific energy that will be used to calculate the energy spectra.	Positive values
Min. Specific Energy	The minimum energy value for which energy spectra will be recorded.	Positive values

Setting	Description	Range
Max. Specific Energy	The maximum energy value for which energy spectra will be recorded.	Positive values

To set simulation-wide parameters

- From the **Data** panel, select in turn each of the items listed below and then in the **Data Editors** panel for each item, enter the values you want:
  a) The top-most "**Study**" item
  b) **Physics**
  c) **Domain Settings** (including both the **Coordinate Limits** and **Periodic Boundaries** tabs)
  d) **Solver** (including all three of the **Time Configuration**, **General Settings**, and **Particle Energy Spectra** tabs)

Add and Edit Geometry Components

Geometries (sometimes referred to as "boundaries") are the physical components that make up your chute, mill, or other materials handling design. They can include geometries included within Rocky, such as receiving conveyors, feed conveyors, inlets; and also custom geometries that you import from various CAD programs.

You can add as many components to your simulation in any combination you desire. However, before you are able to process a simulation, you must have a minimum of at least one inlet (this can be either from a default feed conveyor or from a separate inlet that you've added to the simulation).

Once you add the geometries you want, you can then change the parameters to achieve the behavior you want. The parameters you change can include the size, shape, and behavior of the default geometries included within Rocky, or special movements of the custom geometries you've imported, such as gates that lift or turn, for example.

What would you like to do?

- Add Geometry Components
- Edit Geometry Parameters

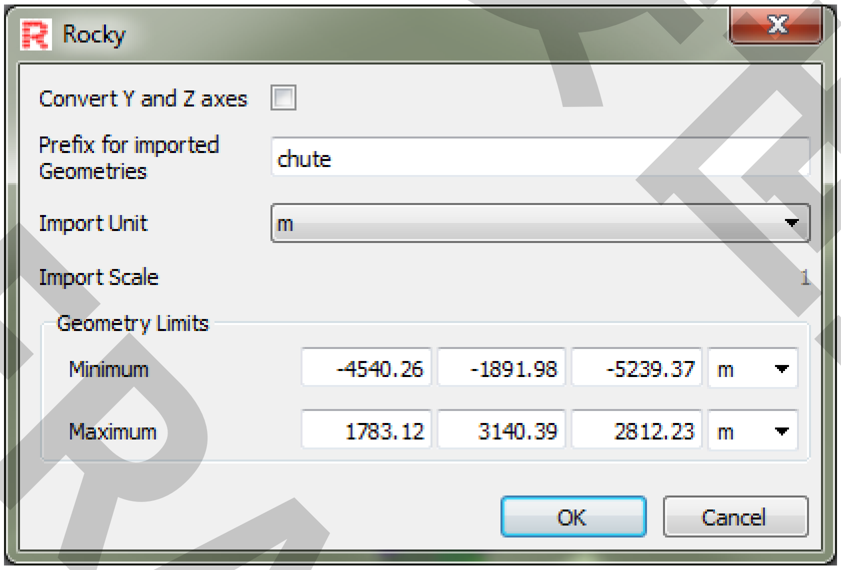
Add Geometry Components

There are two categories of geometries that you can add to your simulation: Default geometries, which include feed conveyors, receiving conveyors, and inlets that are included with Rocky; and Custom geometries that you import from a CAD program.

The benefits of choosing a default conveyor geometry are ease of set-up for typical transfer chute designs: the default conveyors have common elements like skirtboards and belt rolls included in the design and come set up to have the conveyor surface move around the head pulley. These items can be specified for an imported conveyor as well but will take more setup and configuration effort. Also note that an imported feed conveyor will need to have an inlet added to the design in order to function.

All other non-conveyor geometries, including chute or mill components, will need to be imported into Rocky. Custom geometries have the benefit of allowing movement–such as translation or pendulum actions–to be applied to the individual components.

Use the figure and table below to understand the various import parameters you can set for your custom geometry and then use the procedures that follow to learn about how to add geometry components to your simulation setup.



Convert Y and Z axes: ☐
Prefix for imported Geometries: chute
Import Unit: m
Import Scale: 1

Geometry Limits

Minimum	-4540.26	-1891.98	-5239.37	m
Maximum	1783.12	3140.39	2812.23	m

Figure 28: Rocky dialog displaying import options for custom geometries

Table 13: Import options displayed in the Rocky dialog

Setting	Description	Range
Convert Y and Z axes	Selecting this option will change the axis of the imported geometry.	Turns on or off
Prefix for imported Geometries	For STL, XGL, and MSH files only, sets the name for the geometry that will be displayed in the Geometries list. If the geometry contains multiple components, each component will have this same name appended by a unique number. Note: For DXF and CAS files, the names given to the components in the CAD program will be automatically imported.	99 character limit
Import Unit	Enables you to change the units of the imported geometry.	Various units of length
Import Scale	Displays the import scale based upon the Import Unit set. For example, if Import Unit is left as the default value, the Import Scale will be 1.	Automatically determined

Setting	Description	Range
Geometry Limits		
Minimum	The coordinates (in X Y X format) of the lowest points geometry triangles are drawn.	No limit
Maximum	The coordinates (in X Y X format) of the highest points geometry triangles are drawn.	No limit

To add a new default geometry (Feed Conveyor, Receiving Conveyor, or Inlet)

1. From the **Data** panel, right-click **Geometries**, point to **Create**, and then choose the geometry you want to add.
   The item you chose is now listed alphabetically (case sensitive) in the **Data** panel below **Geometries**.
2. Repeat step 1 for as many default geometries that you want in your simulation.

Tip: To see an image of the geometry you've added, create a 3D View. (See Create a 3D View for more information.)

To import a geometry file from a CAD program

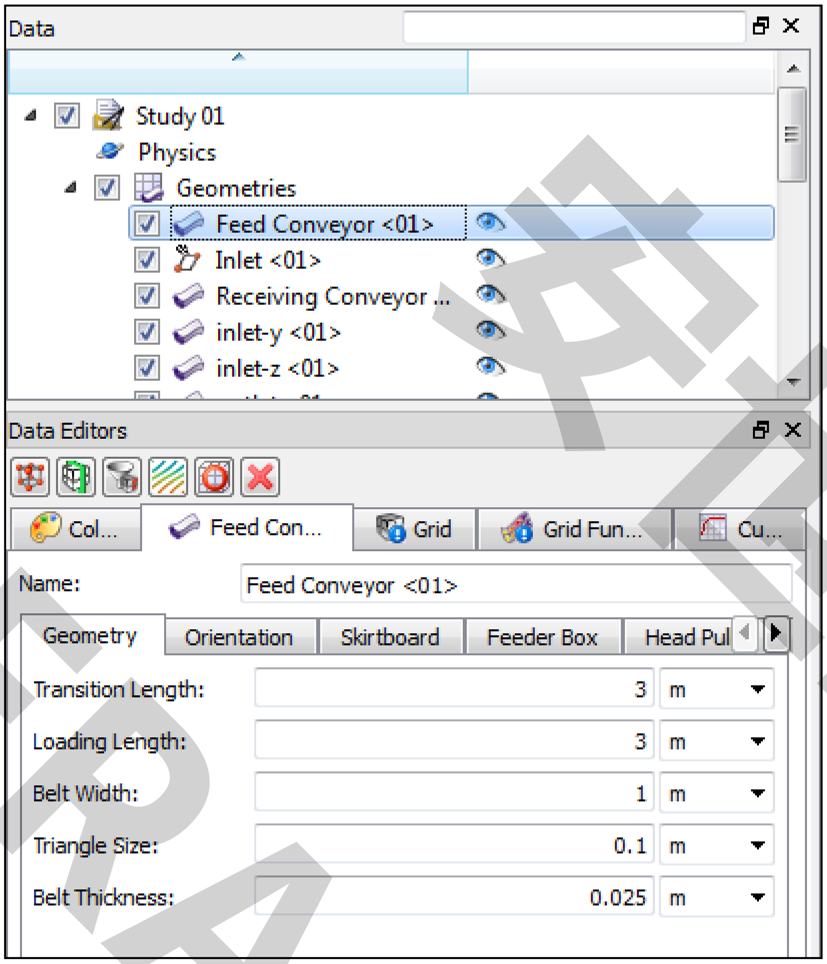
1. From the **Data** panel, right-click **Geometries**, point to **Import**, and then click **Custom Geometry**.
2. From the **Select file to import** dialog, locate and select the XGL, STL, DXF 3D faces, CAS, or MSH file you want to import, and then click **Open**.
   Note: If you haven't already saved your simulation project, you will be asked to do so before continuing. See To save a new simulation project for more information on this step.
3. From the **Rocky** dialog, choose the import options you want, and then click **OK**.
   The item or items you imported are now listed alphabetically (case sensitive) in the **Data** panel below **Geometries**.
4. Repeat steps 1-3 for as many custom geometries that you want in your simulation.

Tip: To see an image of the geometry you've imported, create a 3D View. (See Create a 3D View for more information.)

Edit Geometry Parameters

Once you've added or imported the geometries you want, you can then edit their various parameters. There are unique parameters provided for all four of the geometry types you can add to your simulation: feed conveyors, inlets, receiving conveyors, and imported (custom) geometries. Each of those parameter sets will be detailed in the content to follow.

Use the figures and table below to understand the various parameters you can set for a default feed conveyor.


Data

Study 01
Physics
Geometries
Feed Conveyor <01>
Inlet <01>
Receiving Conveyor ...
inlet-y <01>
inlet-z <01>

Data Editors

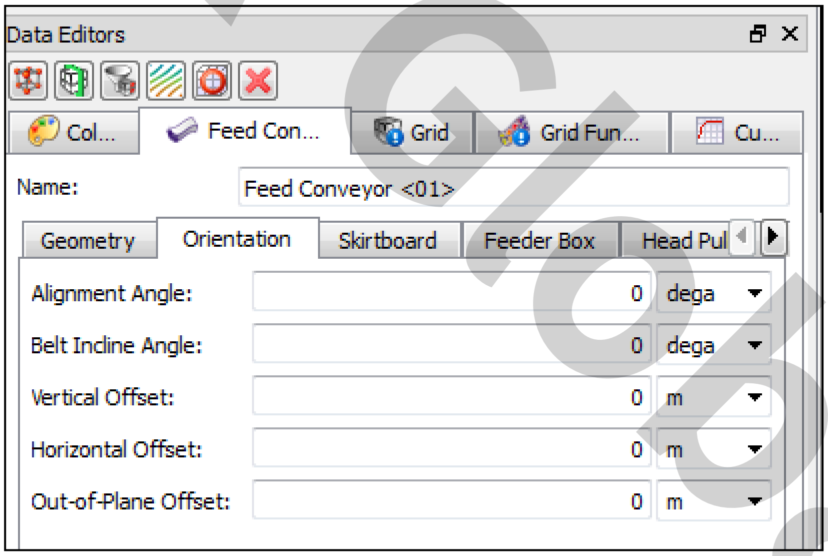
Col... | Feed Con... | Grid | Grid Fun... | Cu...

Name: Feed Conveyor <01>

Geometry | Orientation | Skirtboard | Feeder Box | Head Pul

Transition Length: 3 m
Loading Length: 3 m
Belt Width: 1 m
Triangle Size: 0.1 m
Belt Thickness: 0.025 m

Figure 29: Default Feed Conveyor, Geometry parameters in the Data Editors panel


Data Editors

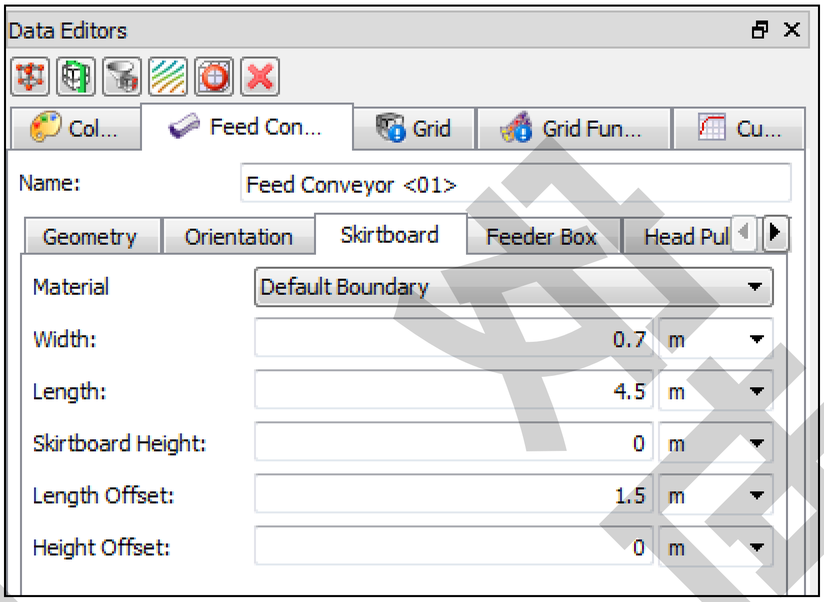
Col... | Feed Con... | Grid | Grid Fun... | Cu...

Name: Feed Conveyor <01>

Geometry | Orientation | Skirtboard | Feeder Box | Head Pul

Alignment Angle: 0 dega
Belt Incline Angle: 0 dega
Vertical Offset: 0 m
Horizontal Offset: 0 m
Out-of-Plane Offset: 0 m

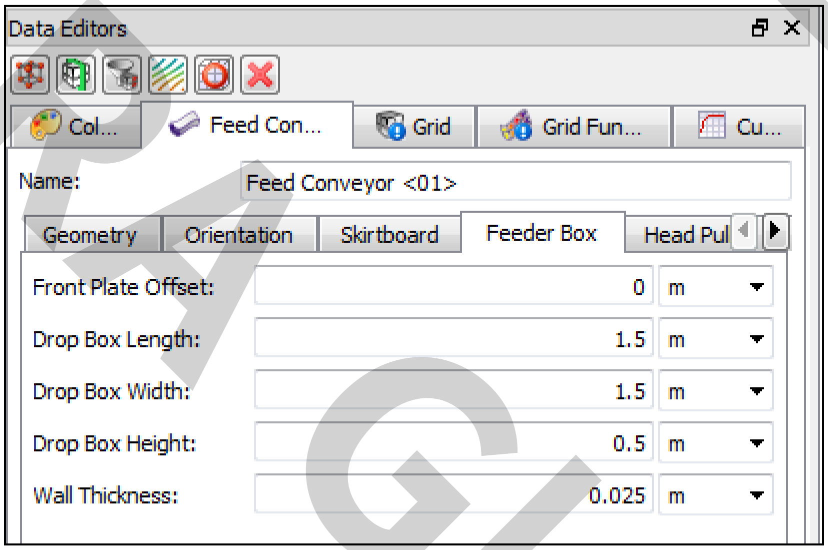
Figure 30: Default Feed Conveyor, Orientation parameters in the Data Editors panel



Name: Feed Conveyor <01>

Material	Default Boundary	
Width:	0.7	m
Length:	4.5	m
Skirtboard Height:	0	m
Length Offset:	1.5	m
Height Offset:	0	m

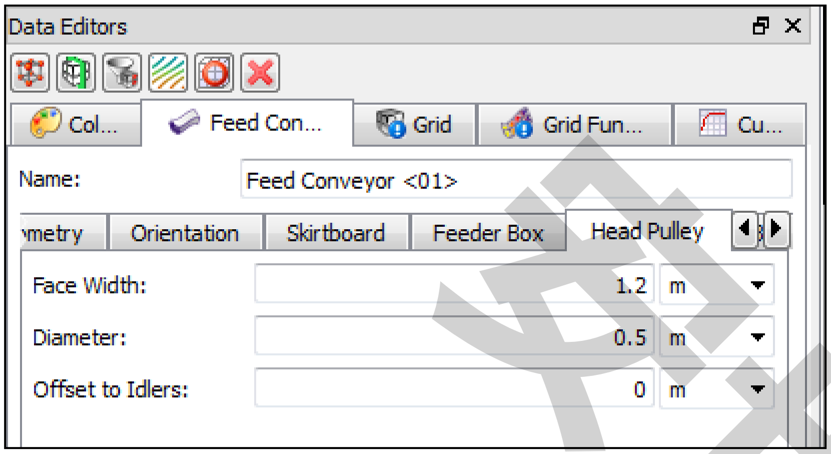
Figure 31: Default Feed Conveyor, Skirtboard parameters in the Data Editors panel



Name: Feed Conveyor <01>

Front Plate Offset:	0	m
Drop Box Length:	1.5	m
Drop Box Width:	1.5	m
Drop Box Height:	0.5	m
Wall Thickness:	0.025	m

Figure 32: Default Feed Conveyor, Feeder Box parameters in the Data Editors panel



Data Editors

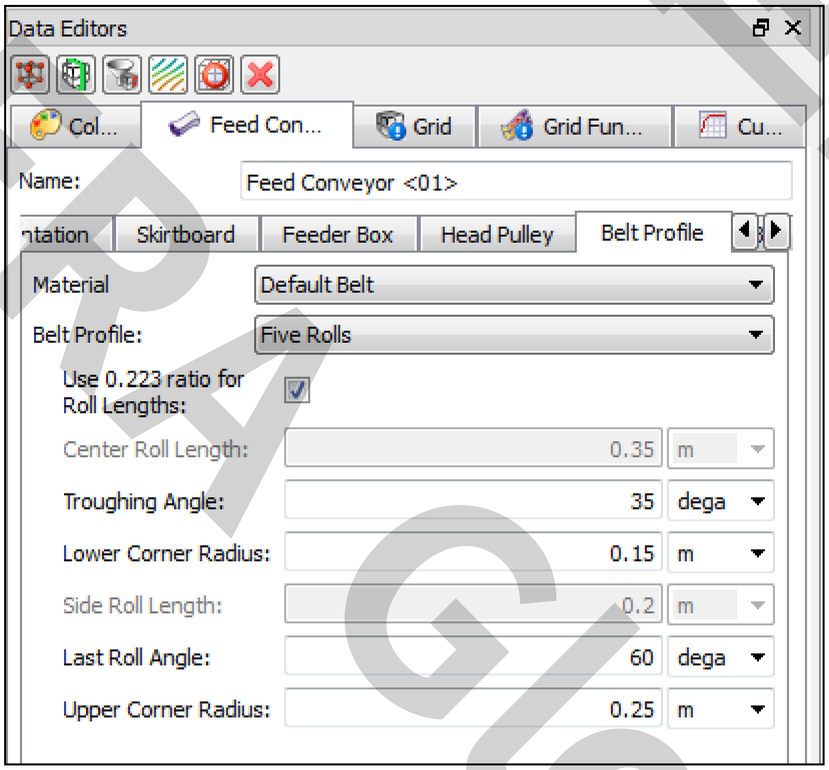
Col... | Feed Con... | Grid | Grid Fun... | Cu...

Name: Feed Conveyor <01>

metry | Orientation | Skirtboard | Feeder Box | Head Pulley

Face Width:	1.2	m
Diameter:	0.5	m
Offset to Idlers:	0	m

Figure 33: Default Feed Conveyor, Head Pulley parameters in the Data Editors panel



Data Editors

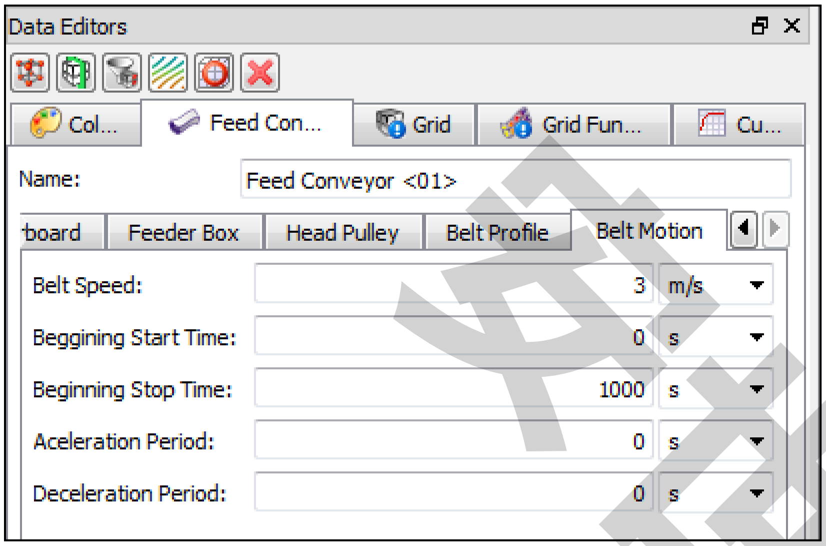
Col... | Feed Con... | Grid | Grid Fun... | Cu...

Name: Feed Conveyor <01>

ntation | Skirtboard | Feeder Box | Head Pulley | Belt Profile

Material	Default Belt	
Belt Profile:	Five Rolls	
Use 0.223 ratio for Roll Lengths:	✓	
Center Roll Length:	0.35	m
Troughing Angle:	35	dega
Lower Corner Radius:	0.15	m
Side Roll Length:	0.2	m
Last Roll Angle:	60	dega
Upper Corner Radius:	0.25	m

Figure 34: Default Feed Conveyor, Belt Profile parameters in the Data Editors panel



Name: Feed Conveyor <01>

Belt Speed: 3 m/s

Beggining Start Time: 0 s

Beginning Stop Time: 1000 s

Aceleration Period: 0 s

Deceleration Period: 0 s

Figure 35:Default Feed Conveyor, Belt Motion parameters in the Data Editors panel

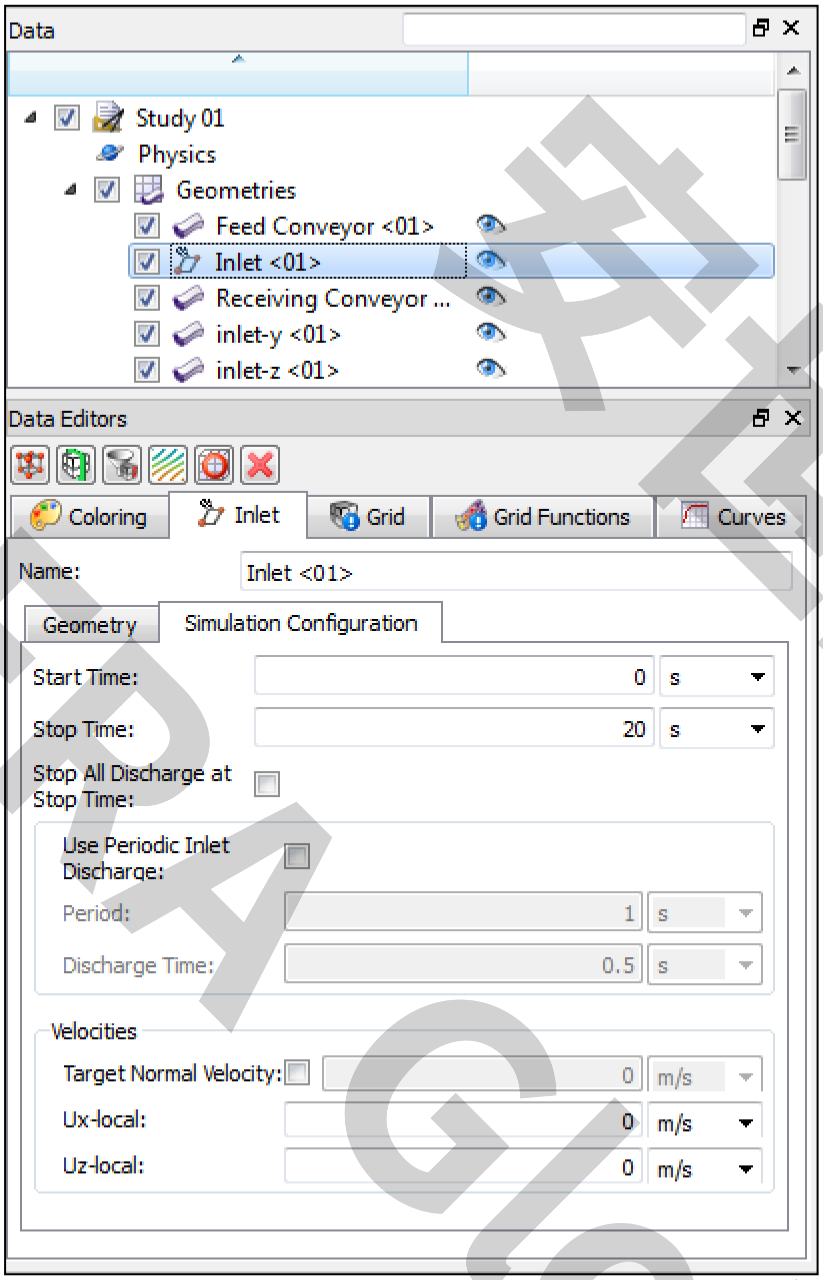
Table 14: Default Feed Conveyor parameter options (all tabs)

Setting	Description	Range
Name	Enables you to specify a unique identifier for the geometry component.	No limit
Geometry		
Transition Length	Length of the transition or ending portion of the conveyor belt.	Positive values
Loading Length	Length of the loading or beginning portion of the conveyor belt.	Positive values
Belt Width	Width of the conveyor belt.	Positive values
Triangle Size	Size of the triangular components into which the boundary is divided. In general, the smaller the triangle size, the more accurate the wear calculations.	Positive values
Belt Thickness	Thickness of the conveyor belt. Affects visualization only; does not affect calculations.	Positive values
Orientation		
Alignment Angle	Angle the top (carry) part of the conveyor will be placed on the horizontal plane.	No limit
Belt Incline Angle	Angle the conveyor will be placed on the vertical plane.	No limit
Vertical Offset	Distance away from zero on the Y axis that the conveyor will be placed.	No limit
Horizontal Offset	Distance away from zero on the X axis that the conveyor will be placed.	No limit

Setting	Description	Range
Out-of-Plane Offset	Distance away from zero on the Z axis that the conveyor will be placed.	No limit
Return Belt Angle	Angle the bottom (return) part of the conveyor will be placed on the horizontal plane.	No limit
Skirtboard		
Material	Defines the density and loading stiffness (Young's Modulus) of the skirtboard based upon the options you've set in the Materials list. (See Modify Material Compositions for more information.)	List is based upon the Materials that have been defined
Width	Width of the conveyor skirtboard.	Positive values
Length	Length of the conveyor skirtboard.	Positive values
Skirtboard Height	Height of the conveyor skirtboard.	Positive values
Length Offset	Horizontal distance away from the beginning of the belt to place the skirtboard.	Positive values
Height Offset	Vertical distance away from the belt to place the skirtboard.	Positive values
Feeder Box		
Front Plate Offset	Length that the front plate will extend from the edge of the feeder box over the conveyor belt.	Positive values
Drop Box Length	Length of the feeder box.	Positive values
Drop Box Width	Width of the feeder box.	Positive values
Drop Box Height	Height of the feeder box.	Positive values
Wall Thickness	Thickness of the feeder box and skirtboard walls.	Positive values
Head Pulley		
Face Width	Width of the conveyor pulley.	Positive values
Diameter	Diameter of the conveyor pulley.	Positive values
Offset to Idlers	Vertical distance away from the belt that the idlers will be placed.	No limit
Belt Profile		
Material	Defines the density and loading stiffness (Young's Modulus) of the belt based upon the options you've set in the Materials list. (See Modify Material Compositions for more information.)	List is based upon the Materials that have been defined
Belt Profile	Amount of rolls that support the conveyor belt.	1, 2, 3, or 5 rolls
Use 0.371 ratio for Center Roll Length	When 3 rolls are selected, automatically calculates center roll length as 0.371 of the **Belt Width**.	Turns on or off
Center Roll Length	When 3 or 5 rolls are selected, this specifies the length of the center roll.	Positive values

Setting	Description	Range
Troughing Angle	The degree by which the belt trough is formed between the side and center rolls.	0>90
Lower Corner Radius	Radius of the inside corner between the center and side rolls. The bigger the value, the smoother the transition.	Positive values
Side Roll Length	When 5 rolls are selected, this specifies the length of the two side rolls closest to the center roll.	Positive values
Use 0.223 ratio for Roll Lengths	When 5 rolls are selected, automatically calculates the side roll length as 0.223 of the **Belt Width**.	Turns on or off
Last Roll Angle	When 5 rolls are selected, this specifies the degree by which the belt trough is formed between the side and outer rolls.	0<90
Upper Corner Radius	When 5 rolls are selected, this specifies the radius of the inside corner between the side and outer rolls. The bigger the value, the smoother the transition.	Positive values
Belt Motion		
Belt Speed	Full speed of the conveyor belt after it completes the **Acceleration Period**.	Positive values
Beginning Start Time	The time you want the belt to begin moving. This is when the **Acceleration Period** begins.	Positive values
Beginning Stop Time	The time you want the belt to begin stopping. This is when the **Deceleration Period** begins.	Positive values
Acceleration Period	The length of time you want the belt to take to reach full **Belt Speed**. Acceleration starts at the **Beginning Start Time** and ends after the time period you specify here.	Positive values
Deceleration Period	The length of time you want the belt to take to come to a full stop. Deceleration starts at the **Beginning Stop Time** and ends after the time period you specify here.	Positive values

Use the figures and table below to understand the various parameters you can set for a default inlet.



Data

- Study 01
  - Physics
  - Geometries
    - Feed Conveyor <01>
    - Inlet <01>
    - Receiving Conveyor ...
    - inlet-y <01>
    - inlet-z <01>

Data Editors

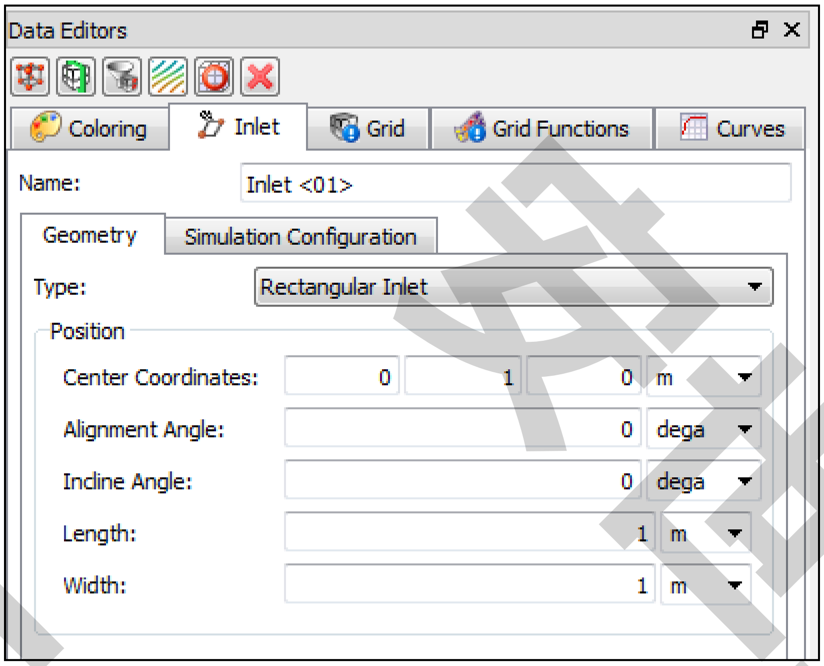
Name: Inlet <01>

Start Time:	0	s
Stop Time:	20	s
Stop All Discharge at Stop Time:	☐	
Use Periodic Inlet Discharge:	☐	
Period:	1	s
Discharge Time:	0.5	s

Velocities

Target Normal Velocity: ☐	0	m/s
Ux-local:	0	m/s
Uz-local:	0	m/s

Figure 36: Default Inlet, Simulation Configuration parameters in the Data Editors panel



Data Editors

Coloring | Inlet | Grid | Grid Functions | Curves

Name: Inlet <01>

Geometry | Simulation Configuration

Type: Rectangular Inlet

Position

Center Coordinates: 0 1 0 m

Alignment Angle: 0 dega

Incline Angle: 0 dega

Length: 1 m

Width: 1 m

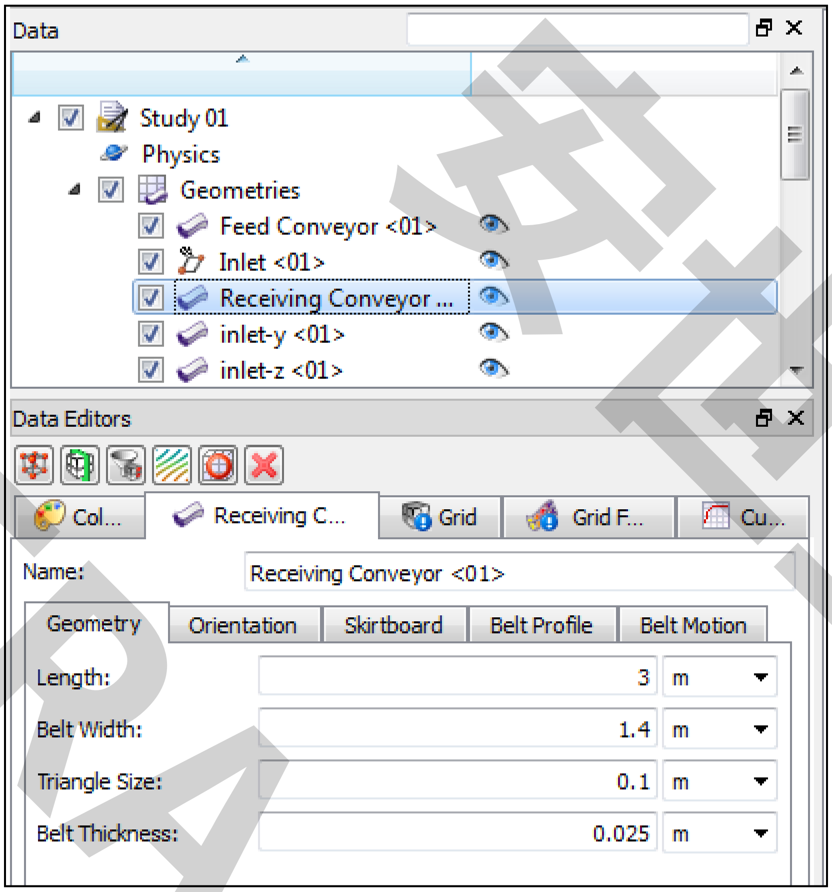
Figure 37: Default Inlet, Geometry parameters in the Data Editors panel

Table 15: Default Inlet parameter options (both tabs)

Setting	Description	Range
Name	Enables you to specify a unique identifier for the geometry component.	No limit
Simulation Configuration		
Start Time	The time you want particles to begin dropping from the inlet.	Positive values
Stop Time	The time you want particles to stop dropping from the inlet.	Positive values
Stop All Discharge at Stop Time	In cases where the inlet delays particle release due to other particles or boundaries being in the way, selecting this item ensures that particles stop releasing at the **Stop Time**. If this item is cleared, particles will stop releasing when the originally calculated number of particles have been released.	Turns on or off
Use Periodic Inlet Discharge	When selected, enables particles to be released from an inlet in periodic bursts. When cleared, particles will be released in a continuous flow.	Turns on or off
Period	Amount of time between discharges.	Positive values
Discharge Time	Amount of time each period of discharge lasts.	Positive values
Target Normal Velocity	When selected, enables you to set the normal speed of the particles being released from the inlet. The speed is measured in local coordinates.	Positive values (but limited by flow rate)
Ux-local	Horizontal speed of the particles being released from the inlet. Measured in local coordinates.	No limit

Setting	Description	Range
Uz-local	Out-of-plane speed of the particles being released from the inlet. Measured in local coordinates.	No limit
Geometry		
Type	Determines the shape of the inlet. You can create rectangular, circular, and donut-shaped inlets.	Rectangular; Circular
Center Coordinates	Location of the inlet’s center point along the X, Y, and Z axes respectively.	No limit
Alignment Angle	The amount of rotation around the Y-axis.	No limit
Length	For rectangular inlets, the length of the inlet sides.	No limit
Width	For rectangular inlets, the width of the inlet.	No limit
Incline Angle	The amount of rotation with respect to the horizontal plane.	No limit
Min. Radius	Used for making donut- or ring-shaped inlets, this is the size of the inlet's inner radius. • For donut- or ring-shaped inlets, make value > 0 (greater than zero). • For circular inlets, make value = 0 (equal to zero).	Positive values
Max. Radius	For circular inlets, this is the size of the inlet's outer radius.	Positive values

Use the following figures and table to understand the various parameters that you can set for a default receiving conveyor.



Name: Receiving Conveyor <01>

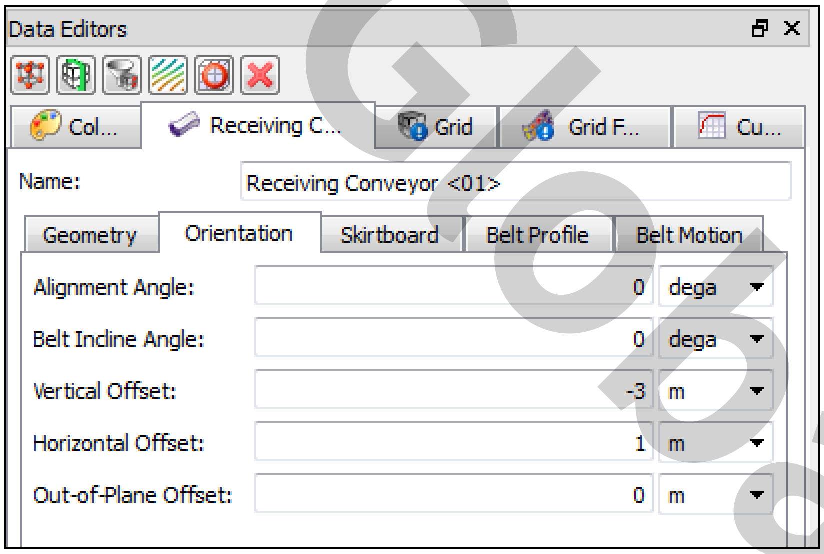
Length: 3 m

Belt Width: 1.4 m

Triangle Size: 0.1 m

Belt Thickness: 0.025 m

Figure 38: Default Receiving Conveyor, Geometry parameters in the Data Editors panel



Name: Receiving Conveyor <01>

Alignment Angle: 0 dega

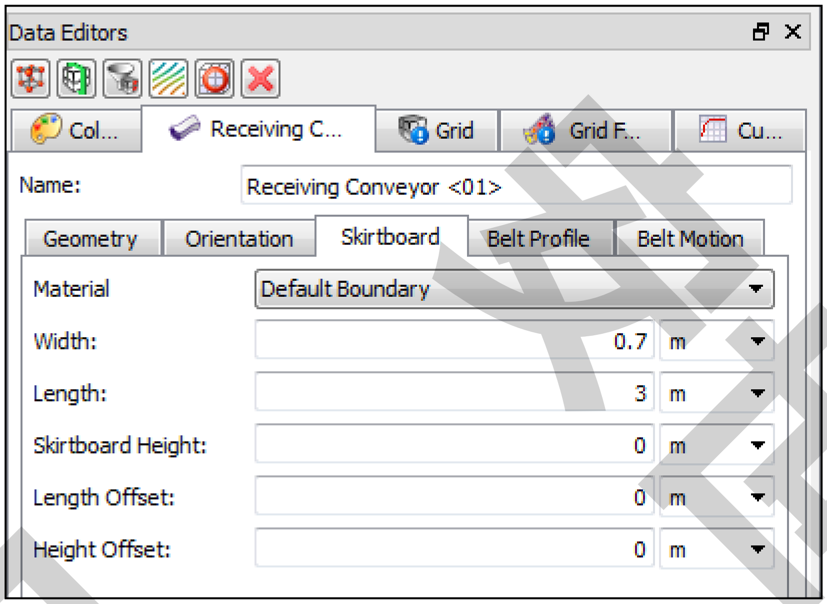
Belt Incline Angle: 0 dega

Vertical Offset: -3 m

Horizontal Offset: 1 m

Out-of-Plane Offset: 0 m

Figure 39: Default Receiving Conveyor, Orientation parameters in the Data Editors panel


Data Editors

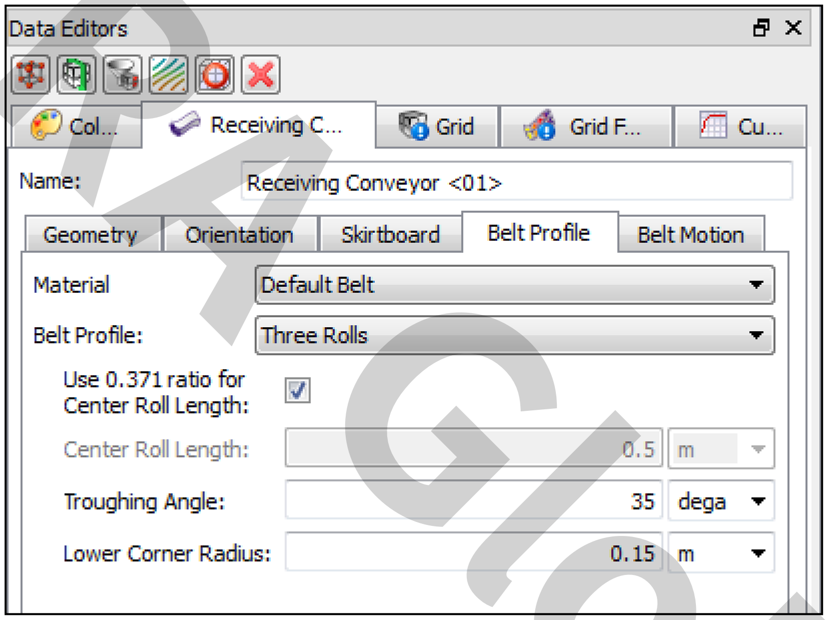
Col... | Receiving C... | Grid | Grid F... | Cu...

Name: Receiving Conveyor <01>

Geometry | Orientation | Skirtboard | Belt Profile | Belt Motion

Material	Default Boundary	
Width:	0.7	m
Length:	3	m
Skirtboard Height:	0	m
Length Offset:	0	m
Height Offset:	0	m

Figure 40: Default Receiving Conveyor, Skirtboard parameters in the Data Editors panel


Data Editors

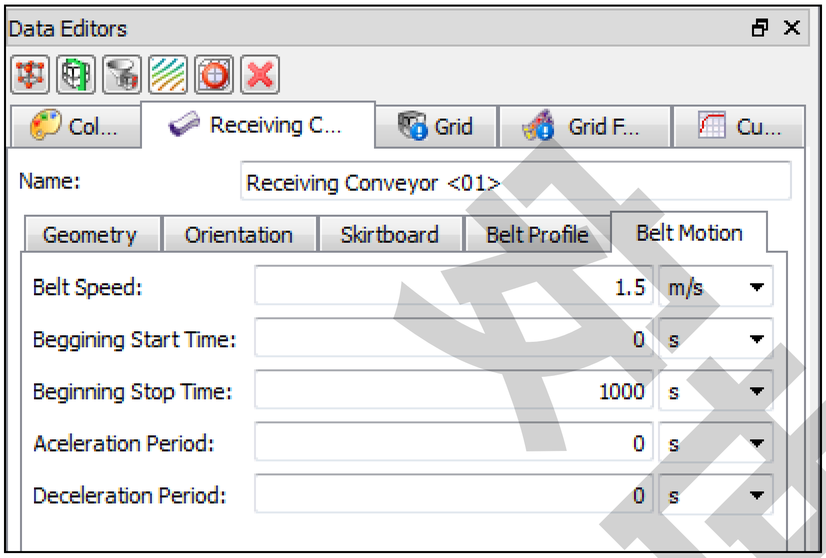
Col... | Receiving C... | Grid | Grid F... | Cu...

Name: Receiving Conveyor <01>

Geometry | Orientation | Skirtboard | Belt Profile | Belt Motion

Material	Default Belt	
Belt Profile:	Three Rolls	
Use 0.371 ratio for Center Roll Length:	✓	
Center Roll Length:	0.5	m
Troughing Angle:	35	dega
Lower Corner Radius:	0.15	m

Figure 41: Default Receiving Conveyor, Belt Profile parameters in the Data Editors panel



Name: Receiving Conveyor <01>

Belt Speed: 1.5 m/s

Beggining Start Time: 0 s

Beginning Stop Time: 1000 s

Aceleration Period: 0 s

Deceleration Period: 0 s

Figure 42: Default Receiving Conveyor, Belt Motion parameters in the Data Editors panel

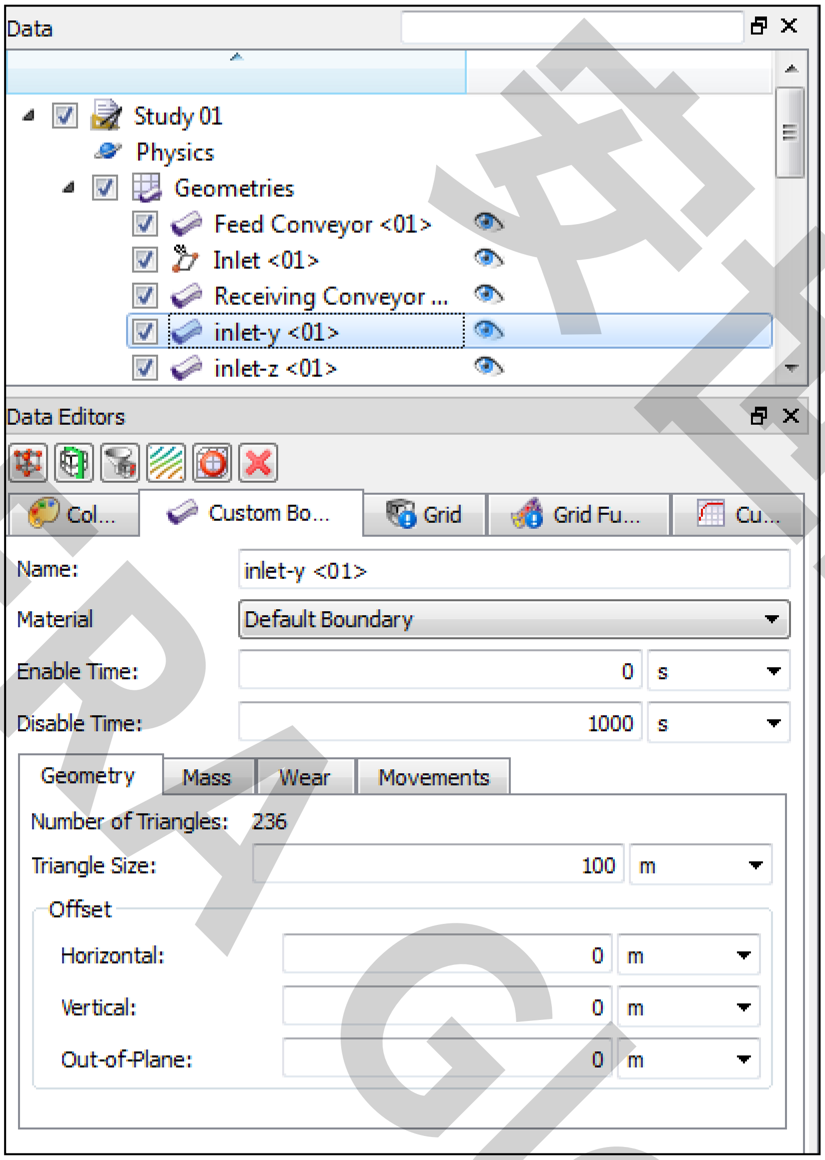
Table 16: Default Receiving Conveyor parameter options (all tabs)

Setting	Description	Range
Name	Enables you to specify a unique identifier for the geometry component.	No limit
Geometry		
Length	Length of the conveyor belt.	Positive values
Belt Width	Width of the conveyor belt.	Positive values
Triangle Size	Size of the triangular components into which the boundary is divided. In general, the smaller the Triangle Size, the more accurate the wear calculations.	Positive values
Belt Thickness	Thickness of the conveyor belt. Affects visualization only; does not affect calculations.	Positive values
Orientation		
Alignment Angle	Angle the top (carry) part of the conveyor will be placed on the horizontal plane.	No limit
Belt Incline Angle	Angle the conveyor will be placed on the vertical plane.	No limit
Vertical Offset	Distance away from zero on the Y axis that the conveyor will be placed.	No limit
Horizontal Offset	Distance away from zero on the X axis that the conveyor will be placed.	No limit
Out-of-Plane Offset	Distance away from zero on the Z axis that the conveyor will be placed.	No limit
Skirtboard		

Setting	Description	Range
Material	Defines the density and loading stiffness (Young's Modulus) of the skirtboard based upon the options you've set in the Materials list. (See Modify Material Compositions for more information.)	List is based upon the Materials that have been defined
Width	Width of the conveyor skirtboard.	Positive values
Length	Length of the conveyor skirtboard.	Positive values
Skirtboard Height	Height of the conveyor skirtboard.	Positive values
Length Offset	Horizontal distance away from the beginning of the belt to place the skirtboard.	Positive values
Height Offset	Vertical distance away from the belt to place the skirtboard.	Positive values
Belt Profile		
Material	Defines the density and loading stiffness (Young's Modulus) of the belt based upon the options you've set in the Materials list. (See Modify Material Compositions for more information.)	List is based upon the Materials that have been defined
Belt Profile	Amount of rolls that support the conveyor belt.	1, 2, 3, or 5 rolls
Use 0.371 ratio for Center Roll Length	When 3 rolls are selected, automatically calculates center roll length as 0.371 of the **Belt Width**.	Turns on or off
Center Roll Length	When 3 or 5 rolls are selected, this specifies the length of the center roll.	Positive values
Troughing Angle	The degree by which the belt trough is formed between the side and center rolls.	0>90
Lower Corner Radius	Radius of the inside corner between the center and side rolls. The bigger the value, the smoother the transition.	Positive values
Side Roll Length	When 5 rolls are selected, this specifies the length of the two side rolls closest to the center roll.	Positive values
Use 0.223 ratio for Roll Lengths	When 5 rolls are selected, automatically calculates the side roll length as 0.223 of the **Belt Width**.	Turns on or off
Last Roll Angle	When 5 rolls are selected, this specifies the degree by which the belt trough is formed between the side and outer rolls.	0<90
Upper Corner Radius	When 5 rolls are selected, this specifies the radius of the inside corner between the side and outer rolls. The bigger the value, the smoother the transition.	Positive values
Belt Motion		
Belt Speed	Full speed of the conveyor belt after it completes the **Acceleration Period**.	Positive values

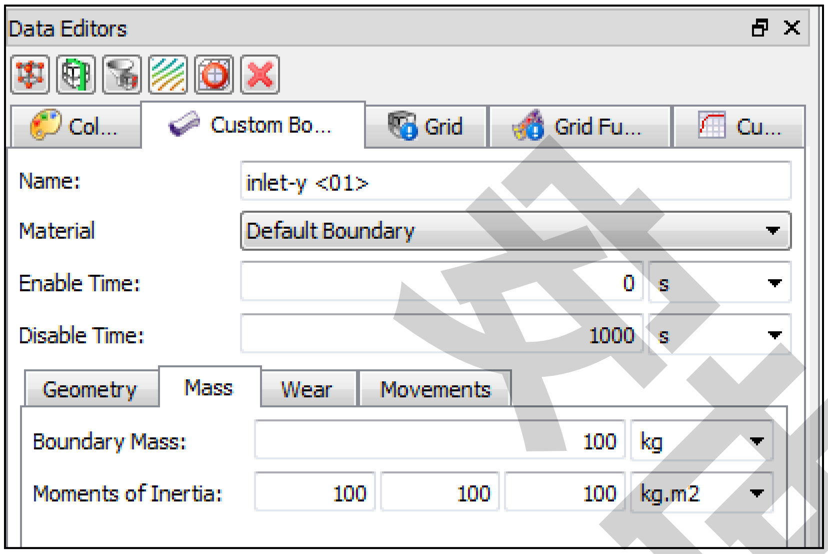
Setting	Description	Range
Beginning Start Time	The time you want the belt to begin moving. This is when the **Acceleration Period** begins.	Positive values
Beginning Stop Time	The time you want the belt to begin stopping. This is when the **Deceleration Period** begins.	Positive values
Acceleration Period	The length of time you want the belt to take to reach full **Belt Speed**. Acceleration starts at the **Beginning Start Time** and ends after the time period you specify here.	Positive values
Deceleration Period	The length of time you want the belt to take to come to a full stop. Deceleration starts at the **Beginning Stop Time** and ends after the time period you specify here.	Positive values

Use the following figures and table to understand the various parameters that you can set for an imported (custom) geometry.



Name: inlet-y <01>
Material: Default Boundary
Enable Time: 0 s
Disable Time: 1000 s
Number of Triangles: 236
Triangle Size: 100 m
Offset
Horizontal: 0 m
Vertical: 0 m
Out-of-Plane: 0 m

Figure 43: Imported (custom) geometry, Geometry parameters in the Data Editors panel



Data Editors

Col... | Custom Bo... | Grid | Grid Fu... | Cu...

Name: inlet-y <01>

Material: Default Boundary

Enable Time: 0 s

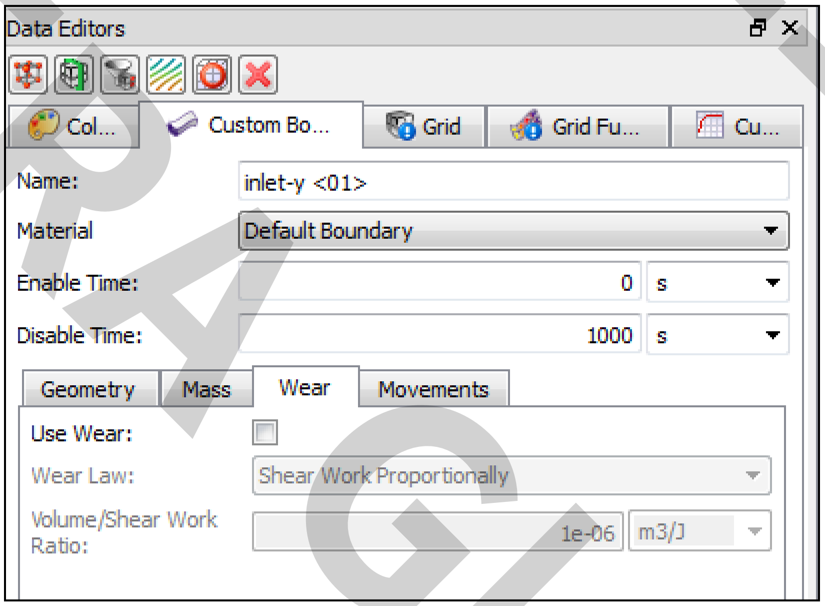
Disable Time: 1000 s

Geometry | Mass | Wear | Movements

Boundary Mass: 100 kg

Moments of Inertia: 100 100 100 kg.m2

Figure 44: Imported (custom) geometry, Mass parameters in the Data Editors panel



Data Editors

Col... | Custom Bo... | Grid | Grid Fu... | Cu...

Name: inlet-y <01>

Material: Default Boundary

Enable Time: 0 s

Disable Time: 1000 s

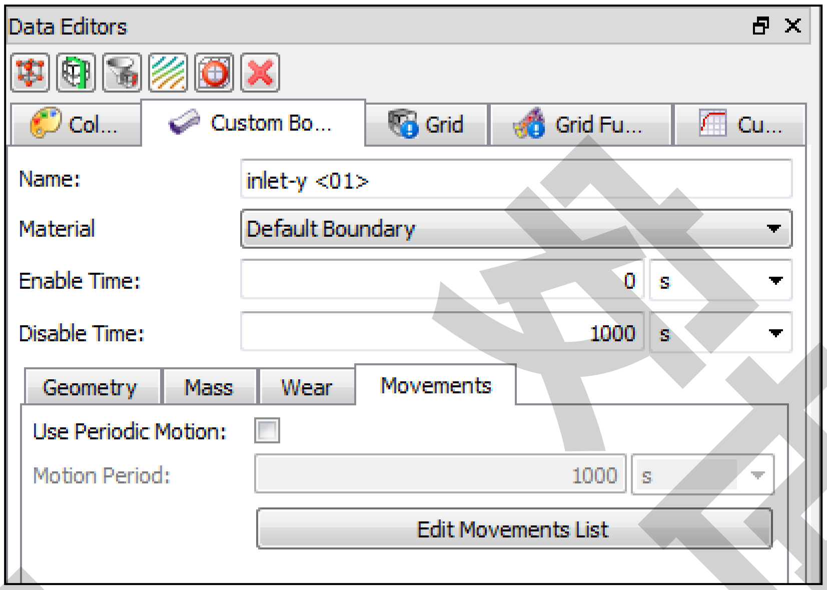
Geometry | Mass | Wear | Movements

Use Wear: ☐

Wear Law: Shear Work Proportionally

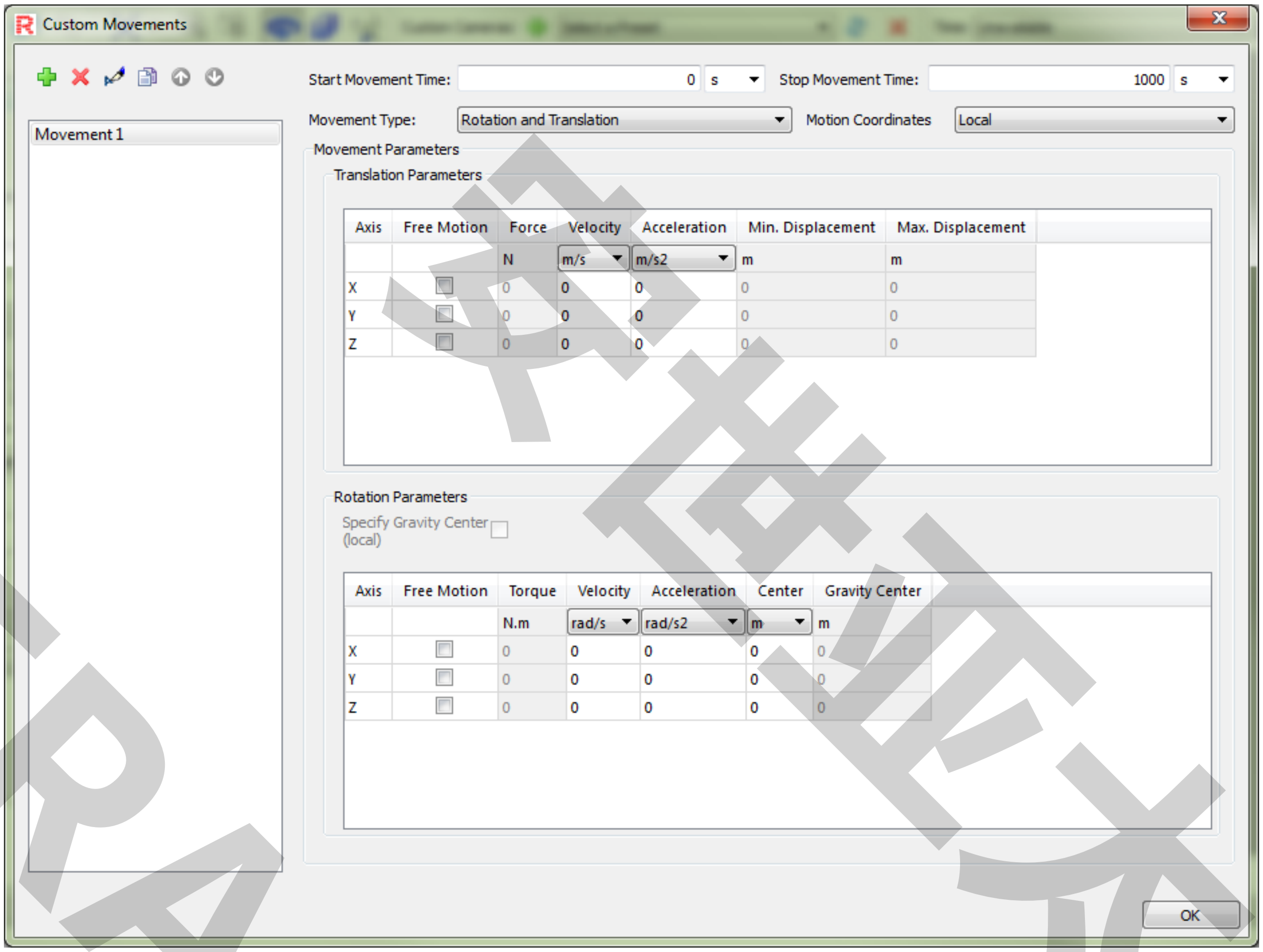
Volume/Shear Work Ratio: 1e-06 m3/J

Figure 45: Imported (custom) geometry, Wear parameters in the Data Editors panel



Name: inlet-y <01>
Material: Default Boundary
Enable Time: 0 s
Disable Time: 1000 s
Use Periodic Motion: ☐
Motion Period: 1000 s

Figure 46: Imported (custom) geometry, Movements parameters in the Data Editors panel



Custom Movements

Movement 1

Start Movement Time: 0 s | Stop Movement Time: 1000 s

Movement Type: Rotation and Translation | Motion Coordinates: Local

Movement Parameters

Translation Parameters

Axis	Free Motion	Force	Velocity	Acceleration	Min. Displacement	Max. Displacement
		N	m/s	m/s2	m	m
X	☐	0	0	0	0	0
Y	☐	0	0	0	0	0
Z	☐	0	0	0	0	0

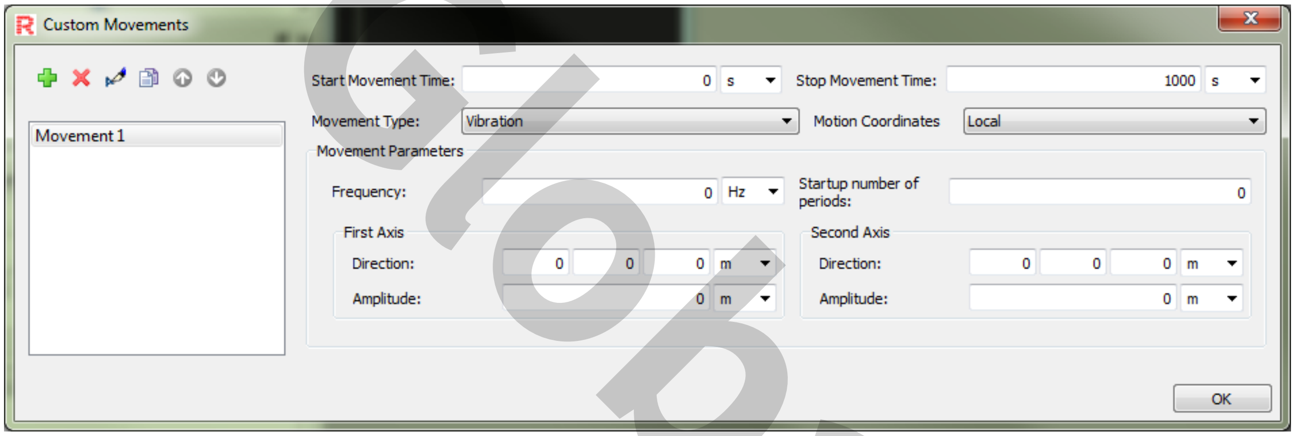
Rotation Parameters

Specify Gravity Center (local) ☐

Axis	Free Motion	Torque	Velocity	Acceleration	Center	Gravity Center
		N.m	rad/s	rad/s2	m	m
X	☐	0	0	0	0	0
Y	☐	0	0	0	0	0
Z	☐	0	0	0	0	0

OK

Figure 47: Custom Movements dialog, Rotation and Translation parameters. (Same parameters as Rotation and Translation Without Displacement.)



Custom Movements

Movement 1

Start Movement Time: 0 s | Stop Movement Time: 1000 s

Movement Type: Vibration | Motion Coordinates: Local

Movement Parameters

Frequency: 0 Hz | Startup number of periods: 0

First Axis

Direction: 0 0 0 m

Amplitude: 0 m

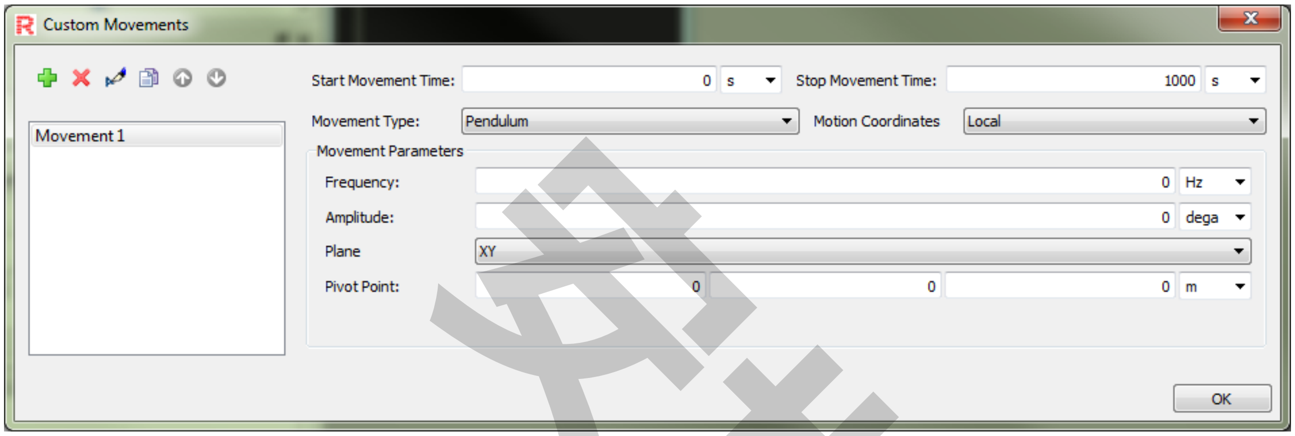
Second Axis

Direction: 0 0 0 m

Amplitude: 0 m

OK

Figure 48: Custom Movements dialog, Vibration parameters


Custom Movements

Movement 1

Start Movement Time: 0 s

Stop Movement Time: 1000 s

Movement Type: Pendulum

Motion Coordinates: Local

Movement Parameters

Frequency: 0 Hz

Amplitude: 0 dega

Plane: XY

Pivot Point: 0 0 0 m

OK

Figure 49: Custom Movements dialog, Pendulum parameters

Table 17: Imported (custom) geometry parameter options (all available)

Setting	Description	Range
Name	Enables you to specify a unique identifier for the geometry component.	Not editable
Material	Defines the density and loading stiffness (Young's Modulus) of the skirtboard based upon the options you've set in the Materials list. (See Modify Material Composition for more information.)	List is based upon the Materials that have been defined
Enable Time	The time you want the geometry to appear in the simulation. Tip: To have the geometry appear at simulation onset, keep **Enable Time** as zero (0).	Positive values
Disable Time	The time you want the geometry to disappear from the simulation. Tip: To have the geometry stay for the duration of the simulation, keep **Disable Time** as 1000 s or the maximum length of your simulation.	Positive values
Geometry		
Number of Triangles	Number of boundary triangles imported from the STL, XGL, DXF 3D faces, CAS, or MSH file.	Not editable
Triangle Size	Size of the individual triangular components into which the geometry is divided. In general, the smaller the triangles, the more accurate the wear calculations.	Positive values
Offset, Horizontal	Distance away from the imported X-axis' coordinate value. This does not create moving geometries; rather this re-locates the original geometry position.	No limit
Offset, Vertical	Distance away from the imported Y-axis' coordinate value. This does not create moving geometries; rather this re-locates the original geometry position.	No limit

Setting	Description	Range
Offset, Out-of-Plane	Distance away from the imported Z-axis' coordinate value. This does not create moving geometries; rather this re-locates the original geometry position.	No limit
Mass		
Boundary Mass	When **Rotation and Translation** and **Free Motion** are selected in the Movements List, this is the mass of the geometry.	Positive values
Moments of Inertia	When **Rotation and Translation** and **Free Motion** are selected in the Movements List, these are the principal moments of inertia along each of the 3 axes. It is assumed that the axes coincide with the x, y, and z axes at the start of the simulation.	Positive values
Wear		
Use Wear	Enables the surface of the geometry to appear modified over time as it gets worn down by particle interaction.	Turns on or off
Wear Law	The calculation used to perform wear modifications of the geometry surface. For this release, only **Shear Work Proportionality** is enabled. This means that the volume of geometry removed is proportional to the shear wear applied to the geometry. Note: You cannot use this type of wear modification if the geometry has movements set up as **translation/rotation without displacement**.	Shear Work Proportionality
Volume/Shear Work Ratio	The amount of surface volume that is removed per shear work applied. Note: This is a calibration step that comes from real-world wear data you have collected using similar types of liners.	Positive values
Movements		
Use Periodic Motion	Enables a motion period to be repeated or looped throughout the simulation. (See also To enable geometry movements to be repeated.)	Turns on or off
Motion Period	When **Periodic Motion** is selected, enables you to enter the amount of time for which movement is repeated or looped throughout the simulation. Tips: • Entering the exact time amount for which you have specified movement(s) will result in a seamless repeat of all movements. • Entering a smaller time amount will result in the latter part of your movement not occurring. • Entering a larger time amount will result in no movement at the end of each period.	Positive values

Setting	Description	Range
Custom Movements (from the **Movements** tab, click **Edit Movements List**)		
Start Movement Time	The time you want geometry movement to begin.	Positive values
Stop Movement Time	The time you want geometry movement to stop.	Positive values

Movement Type	Used to create moving geometries and vibration.
	In general, choose:
	• **Rotation and Translation** when you want the geometry to move physically from one location to another. For example, a gate that rises or a mill that rotates.
	• **Rotation and Translation without Displacement** when you want the geometry to stay stationary but still have surface velocity applied. For example, a stationary conveyor whose belt moves particles.
	• **Vibration** when you want the geometry to oscillate. For example, a vibrating pan feeder.
	• **Pendulum** when you want the geometry to swing back and forth along a center point, like a pendulum.
	Notes:
	• **Translation/Rotation without Displacement** is how all default feed and receiving conveyors in Rocky are set up.
	• The values are set up in the local coordinates system at the beginning of the time period. At zero time, this system coincides with the global system.
	• Any gaps in the movement time periods will be treated as no motion (Movement Type=None).
	(See also Enable Moving, Rotating, Vibrating, or Swinging Geometries.)
		None;
		Rotation and Translation;
		Rotation and Translation without Displacement;
		Vibration;
		Pendulum

Motion Coordinates	Defines which coordinate system the movement values are based on: • **Local**: Coordinate system is relative to the position of the geometry. • **Global**: Coordinate system is relative to the simulation in general. Note: Most movement settings can be either Local or Global but **Center of Rotation** values can only be Local.	Local; Global
Translation Parameters		

Setting	Description	Range
Free Motion	When **Rotation and Translation** is selected, this enables the geometry to move freely along the chosen **Axis** under gravity and particle forces. Notes: • Free movement is affected by particle placement, **Boundary Mass**, and **Force**. • The amount of movement is restricted by **Minimum Displacement** and **Maximum Displacement**. • Free Movement cannot be specified for **Rotation and Translation Without Movement**.	Turns on or off
Force	When **Free Motion** is selected, this enables an external force to be applied to the geometry. For example, the added force of a car pressing down on a wheel.	Positive values
Velocity	This is the translational velocity along the axis.	No limit
Acceleration	This is the linear acceleration along the axis.	No limit
Minimum Displacement	When **Free Motion** is selected, this is the minimum displacement length that the geometry is allowed to freely move.	Positive values
Maximum Displacement	When **Free Motion** is selected, this is the maximum displacement length that the geometry is allowed to freely move.	Positive values
Rotation Parameters		
Specify Gravity Center (local)	If **Free Motion** is selected, selecting this option enables you to use the **Gravity Center** values to specify the coordinates of the center point of gravity. If this option is not selected, center of gravity is assumed to be the same as the center of rotation for the geometry. Note: Even if the **Global** coordinate system is selected, this value will be set within the Local coordinate system.	Turns on or off
Free Motion	When **Rotation and Translation** is selected, this enables the boundary to rotate freely around the chosen **Direction** and under the particles' torque. Free motion is affected by particle placement, **Torque**, and **Moments of Inertia**.	Turns on or off
Torque	When **Free Motion** is selected, this enables an external torque to be applied to the geometry.	No limit
Velocity	This is the rotational velocity along the axis.	No limit
Acceleration	This is the angular acceleration along the axis.	No limit

Setting	Description	Range
Center	This is the location in coordinates of the center point of rotation. Note: Even if the **Global** coordinate system is selected, this value will be set within the Local coordinate system.	No limit
Gravity Center	If both the **Free Motion** and **Specify Gravity Center (local)** options are selected, then this is the location in coordinates of the center point of gravity for the geometry.	No limit
Vibration Parameters		
Frequency	When **Vibration** is selected, this determines how frequently the oscillation of the geometry occurs.	Positive values
First Axis		
Direction	Determines the direction of the first elliptical axis by setting the coordinate values of a direction vector of length 1.	No limit but values entered will be normalized to equal a length of 1
Amplitude	Height of the oscillation curve along the first axis. Lower values produce minor vibration; higher values produce significant vibration.	Positive values
Second Axis		
Direction	Determines the direction of the second elliptical axis by setting the coordinate values of a direction vector of length 1.	No limit but values entered will be normalized to equal a length of 1 and adjusted to be perpendicular to first axis
Amplitude	Height of the oscillation curve along the second axis. Lower values produce minor vibration; higher values produce significant vibration.	Positive values
Pendulum Parameters		
Frequency	When **Pendulum** is selected, this determines how frequently the swinging of the geometry occurs.	No limit
Amplitude	Height (in degrees) of the swing's arch.	Positive values
Plane	The 2-D plane upon which the swinging will occur.	XY, YZ, ZX
Pivot Point	Location in coordinates of the point upon which the geometry will swing. Note: Even if the **Global** coordinate system is selected, this value will be set within the Local coordinate system.	No limit

To edit the parameters for geometry:

1. From the **Data** panel, under **Geometries**, select the name of the geometry that you want to edit. The parameters for that geometry are displayed in the **Data Editors** panel. The tab named with the type of geometry you selected (for example, “Custom Boundary”, “Feed Conveyor”, and so on) will be active.
2. From the **Data Editors** panel, enter the information you want on the active tab, being sure to select each of the various sub-tabs or dialogs that contain parameters you want to modify.

Tip: To set the same value for a parameter across multiple similar geometries, multi-select the geometries you want in the **Data** panel (SHIFT + left-click for a continuous group; CTRL + left-click for discontinuous items) and then change the values you want in the **Data Editor** panel. Only those parameters common across all selected geometries will be editable but any changes made will populate across the selected group.

To remove a geometry

- From the **Data** panel, under **Geometries**, right-click the name of the geometry you want to remove, and then click **Remove Geometry**.

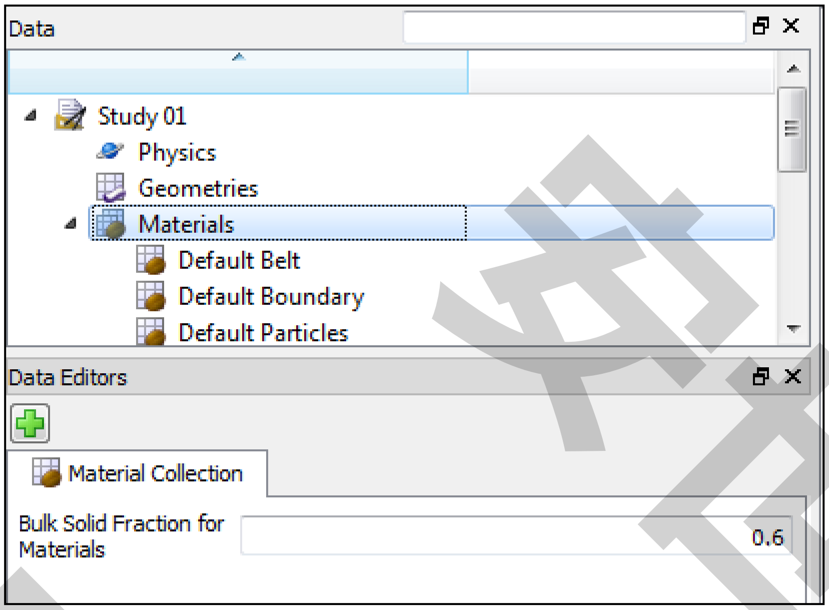
Modify Material Compositions

Rocky enables you to specify unique densities and loading stiffnesses (Young’s Modulus) for the conveyor belts, geometries, and particle sets used in your simulation. This helps you ensure that the various materials being simulated interact with each other in as realistic a way as possible.

By default, Rocky defines three Material sets for each simulation, including one each for Default Belt, Default Boundary, and Default Particle. While you can modify the settings for these default Materials and also add additional Material definitions if you choose, you cannot remove these default Materials from the simulation.

Materials you define here will be used when defining the parameters for Geometries, Particles, and Materials Interactions.

Use the figures and table below to help you understand the various parameters you can modify for Materials.



Data

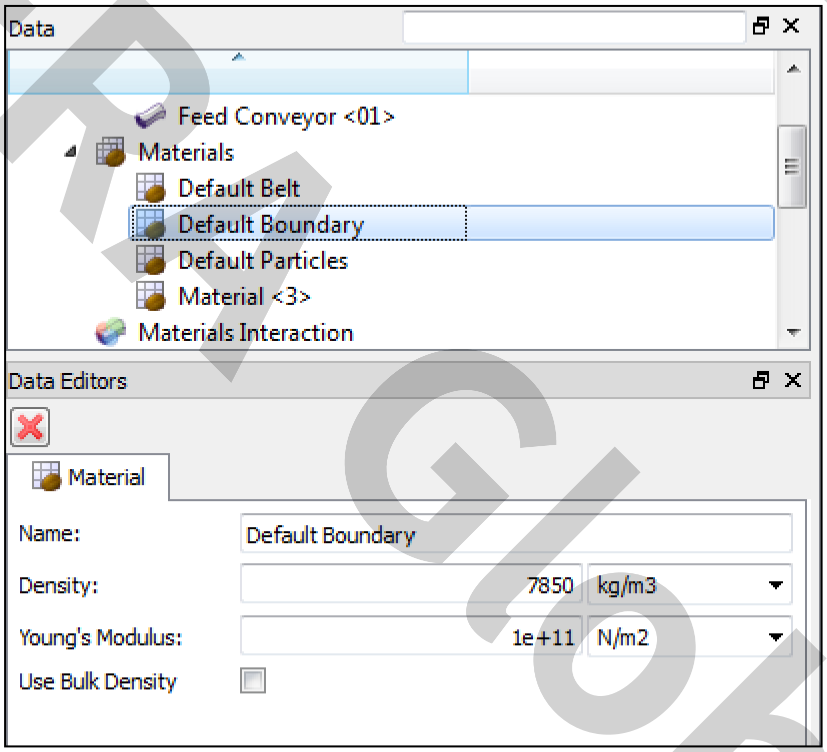
Study 01
Physics
Geometries
Materials
Default Belt
Default Boundary
Default Particles

Data Editors

Material Collection

Bulk Solid Fraction for Materials	0.6

Figure 50: Material parameters in the Data Editors panel



Data

Feed Conveyor <01>
Materials
Default Belt
Default Boundary
Default Particles
Material <3>
Materials Interaction

Data Editors

Material

Name:	Default Boundary	
Density:	7850	kg/m3
Young's Modulus:	1e+11	N/m2
Use Bulk Density	☐	

Figure 51: Default Material parameters in the Data Editors panel

Table 18: Material parameter options (all available)

Setting	Description	Range
Bulk Solid Fraction for Materials	For all Materials that have **Use Bulk Density** selected, this number is applied to the **Density** value. Notes: • This value applies to all Materials in the simulation. • One minus this value is the void ratio of the Materials. (The default void ratio is 0.4.)	0<1
Name	Enables you to specify a unique identifier for the Material.	99 character limit
Density	Density of the Material. How it is used is affected by the **Use Bulk Density** setting.	Positive values
Young's Modulus	Formerly "Loading Stiffness", this value defines how rigidly the Material will interact with another Material. In general, the higher the value, the more accurate the results but the longer the processing time. This value roughly equals Young's material bulk elastic modulus.	Positive values
Use Bulk Density	When selected, **Density** will be divided by **Bulk Solid Fraction for Materials** to determine Material density. When cleared, only the **Density** value will be used.	Turns on or off

To modify parameters for an existing or default Material

1. From the **Data** panel do one of the following:
   - To modify the **Bulk Solid Fraction for Materials** value for all Materials in the simulation, select **Materials**.
   - To modify an individual Material's parameters, under **Materials**, select the name of the Material you want to modify.

   The parameters for the Material you selected are displayed in the **Data Editors** panel.
2. From the **Data Editors** panel, modify the parameters as you want.

To add a new Material

- From the **Data** panel, right-click **Materials** and then click **Create Material**.
  The new Material appears in the **Materials** list in alphabetical (case-sensitive) order.

To remove a (non-default) Material you have added

Note: You can remove only those Materials that you have added. The three default Materials Rocky automatically includes in your simulation are not removable.

- From the **Data** panel, under **Materials**, right click the name of the Material you want to remove, and then click **Remove Material**.

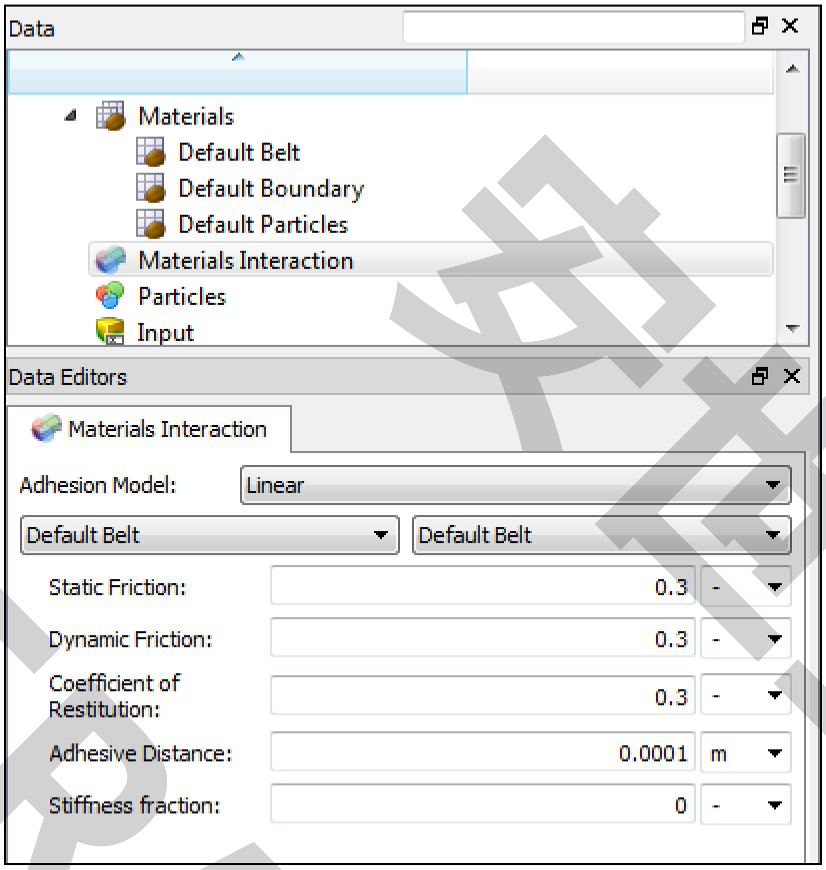
Modify Material Interaction and Adhesion Values

Rocky enables you to specify unique frictions and adhesion values for each Material-to-Material combination that exists in your simulation, including the interaction of a Material to itself, and also to each other Material defined in the Materials list.

Modifying these values enables you to calibrate how “wet” or “sticky” a Material acts when it comes into contact with another Material, enabling you to create simulations that more closely mirror real-world conditions.

Note: Even though Rocky enables you to set interactions of geometries to other geometries, these types of interactions have no value to your simulation. The only values that will affect your simulation are those interactions between particles (particle-to-particle) or between particles and boundaries (particle-to-geometry).

Use the figures and table below to help you understand the various parameters you can modify for Materials Interaction.



Adhesion Model: Linear

Default Belt / Default Belt

Static Friction: 0.3 -

Dynamic Friction: 0.3 -

Coefficient of Restitution: 0.3 -

Adhesive Distance: 0.0001 m

Stiffness fraction: 0 -

Figure 52: Materials Interaction parameters in the Data Editors panel

Table 19: Materials Interaction parameter options

Setting	Description	Range
Adhesion Model	Defines how adhesion between materials are calculated: • **Linear**: Adhesive force increases linearly with the distance between Materials. Uses Stiffness fraction value. • **Constant**: Adhesive force stays constant no matter the distance between Materials. This is the same model that was used in version 2 of Rocky.	Linear; Constant
Static Friction	Maximum ratio of contact tangential force to normal force before onset of sliding.	Positive values (see also Best Practices for Setting Up Particles)
Dynamic Friction	Maximum ratio of contact tangential force to normal force after onset of sliding.	Positive values; usually less than Static Friction (see also Best Practices for Setting Up Particles)

Setting	Description	Range
Coefficient of Restitution	Measure of energy dissipation.	0.1 - 1
Adhesive Distance	The distance between the two Materials before forces are applied.	Positive values
Force fraction	When a Constant Adhesion Model is chosen, this is the ratio of the adhesive force on the first Material to the gravity force of the second Material.	Positive values
Stiffness fraction	When a Linear Adhesion Model is chosen, this is the ratio of adhesive stiffness to the loading elastic stiffness of the contact between the two materials.	0-1

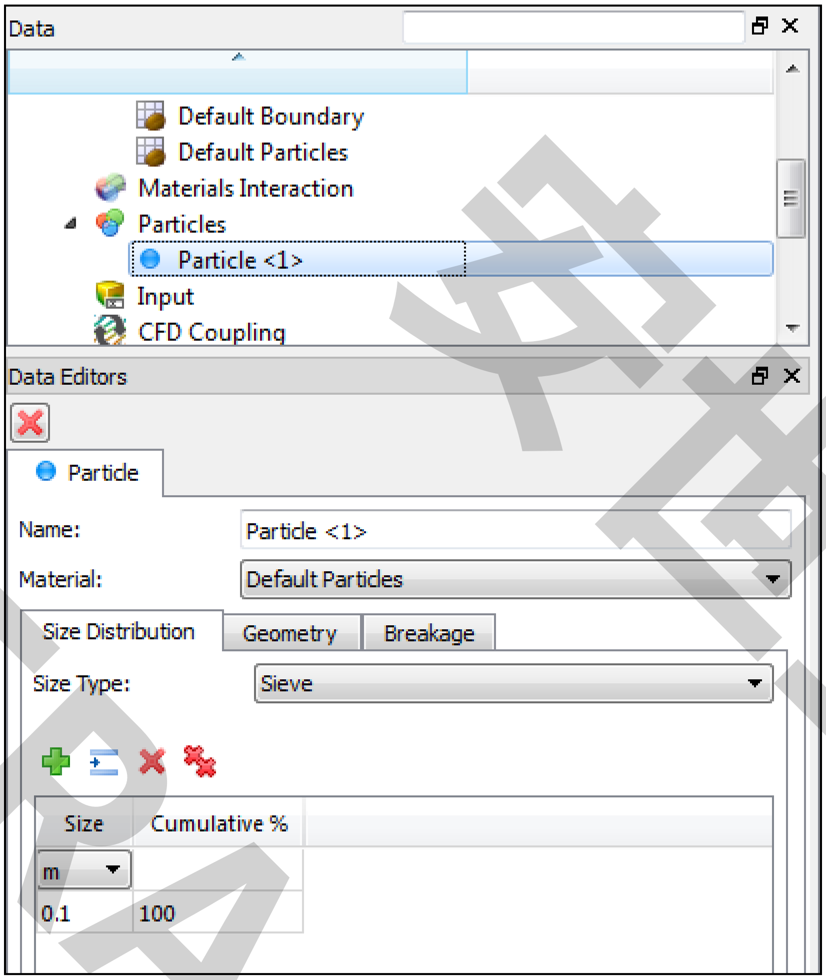
To modify the interaction or adhesion values for a Material-to-Material set

1. From the **Data** panel, select **Materials Interaction**.
   The Materials Interaction parameters become active in the **Data Editors** panel.
2. From the **Data Editors** panel, select what you want for **Adhesion Model**, and then do all of the following:
   a. From **Select Material** list on the left, select the first Material in the Material-to-Material combination for which you want to modify adhesion values.
   b. From the **Select Materials** list on the right, select the next Material in the Material-to-Material combination for which you want to modify adhesion values.
   The parameters that define the interaction between the two Materials you selected appear in the **Data Editors** panel.
   c. Modify the values as you want.
   d. Repeat steps 2a-2c for each of the Material-to-Material combinations you want to modify.

Add and Edit Particle Groups

A particle group is created when you specify the shape of a particular particle, and then choose the size ranges you want replicated in your simulation. You can add as many particle groups containing as many as size ranges each to a given simulation as you like, but you must have added at least one particle group to process a simulation.

Use the figure and table below to help you understand the various parameters you can set for each Particle group.



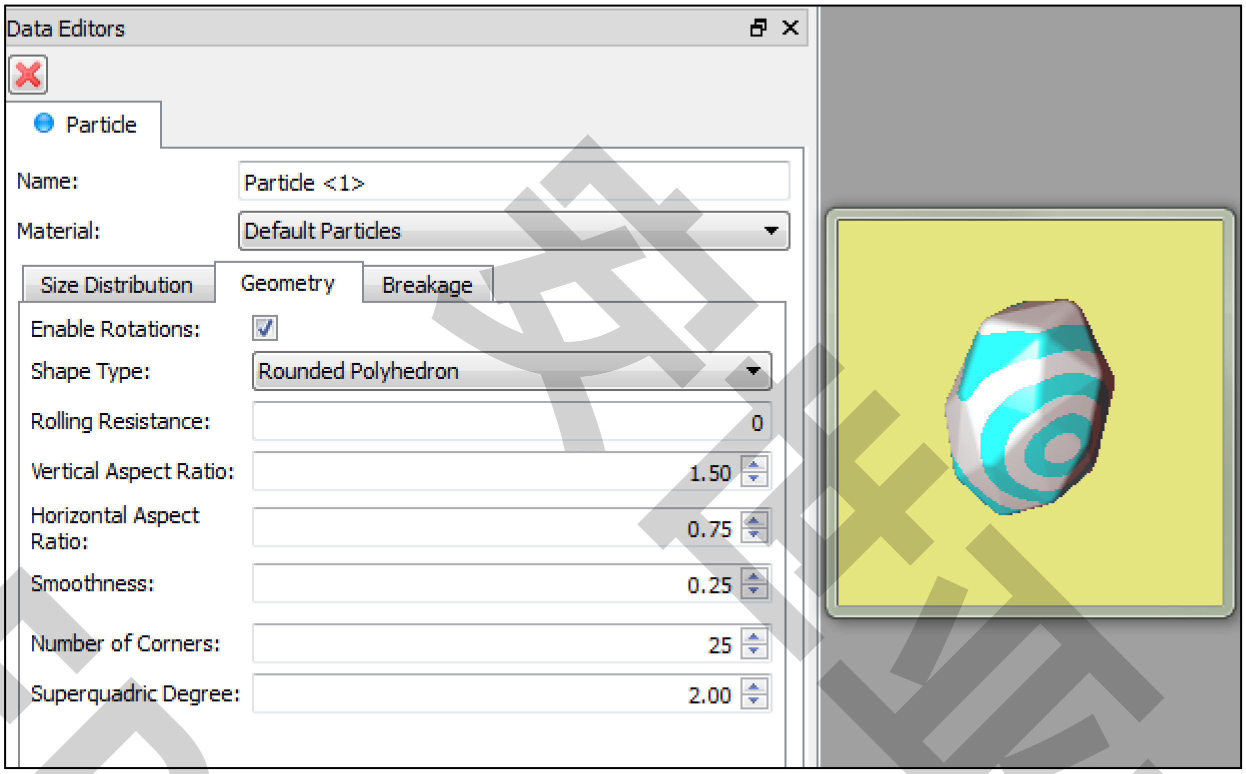
Name: Particle <1>

Material: Default Particles

Size Type: Sieve

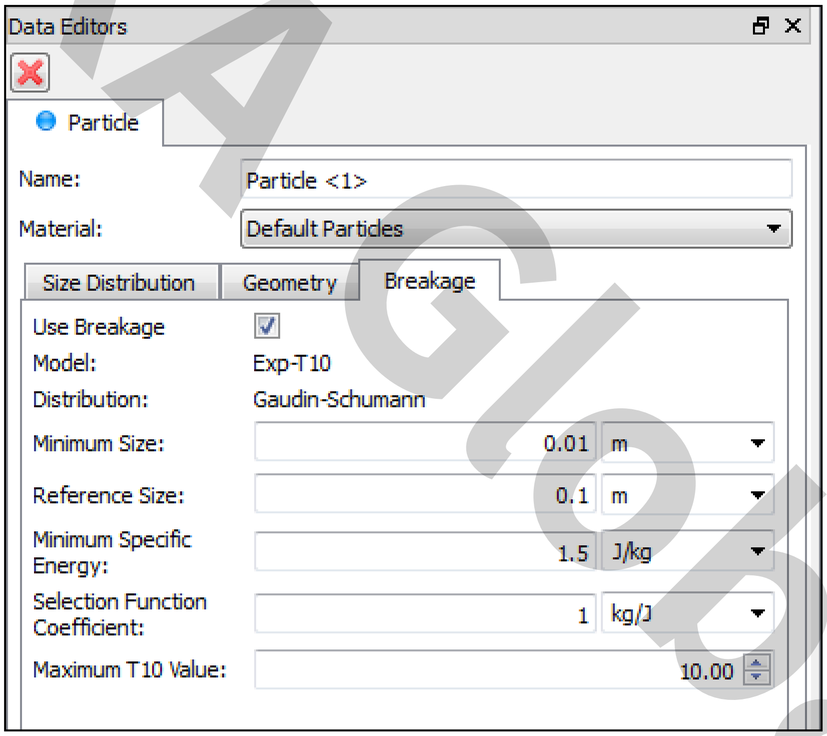
Size	Cumulative %
m	
0.1	100

Figure 53: Particle, Size Distribution parameters in the Data Editors panel



Name:	Particle <1>
Material:	Default Particles
Enable Rotations:	✓
Shape Type:	Rounded Polyhedron
Rolling Resistance:	0
Vertical Aspect Ratio:	1.50
Horizontal Aspect Ratio:	0.75
Smoothness:	0.25
Number of Corners:	25
Superquadric Degree:	2.00

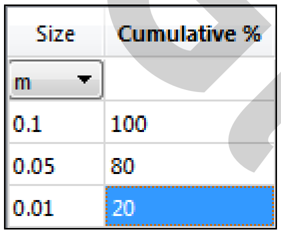
Figure 54: Particle, Geometry parameters in the Data Editors panel



Name:	Particle <1>	
Material:	Default Particles	
Use Breakage	✓	
Model:	Exp-T10	
Distribution:	Gaudin-Schumann	
Minimum Size:	0.01	m
Reference Size:	0.1	m
Minimum Specific Energy:	1.5	J/kg
Selection Function Coefficient:	1	kg/J
Maximum T10 Value:	10.00	

Figure 55: Particle, Breakage parameters in the Data Editors panel

Table 20: Particle parameter options (all tabs)

Setting	Description	Range
Name	Enables you to specify a unique identifier for the particular particle group.	99 character limit
Material	Defines the density and loading stiffness (Young's Modulus) of the Particle group based upon the options you've defined in the Materials list. (See Modify Material Composition for more information.)	List is based upon the Materials that have been defined
Size Distribution		
Size Type	Determines how the size of the particle will be measured. • **Sieve**: Particle size will be based upon the dimensions of a square hole just big enough for the particle to pass through. This use of virtual "mesh" determines the size of the particles no matter what shape they are. • **Equivalent Diameter**: Particle size of irregularly-shaped objects will be based upon the diameter of a sphere of equivalent volume.	Sieve; Equivalent Diameter
Size	The dimension of the particle based upon the **Size Type** value that is set. If only one size is specified for a particle group, only particles of that size will be used during the simulation. This is because the smallest **Size** value specified will always have no range. If more than one size is specified for a particle group, a range of sizes within the **Size** parameter will be used for each **Cumulative %** provided. The one exception is for the smallest **Size** value, which will have no range. For example, for the sizes and percentages specified below:  Size | Cumulative % m | 0.1 | 100 0.05 | 80 0.01 | 20 • 20% (100-80) of the particles will be in various sizes between 0.05 and 0.1 meters. • 60% (80-20) of the particles will be in various sizes between 0.01 and.0.05 meters. • The rest of the particles (20%) will be exactly 0.01 meters in size (no range).	Positive values; sizes should decrease as you go down the **Size Distribution** table

Setting	Description	Range
Cumulative %	Percentage of particle mass that will pass through the virtual “mesh” of the given **Size**. The first mesh (top most value) should be big enough for all particles to pass through (100%). Subsequent meshes should have smaller percentages that pass through. (See also **Size** description above.)	0<100; values should decrease as you go down the **Size Distribution** table
Geometry		
Enable Rotations	When selected, allows the particle to rotate during the simulation.	Turns on or off
Shape Type	The general shape category for the particle. Each type has different parameters that can be modified.	Spherical, Faceted, Rounded Cylinder, Rounded Polygon, Rounded Polyhedron, Briquette; Faceted Cylinder; Custom
Rolling Resistance	Changes how particles roll on the belt surface. A higher value reduces rolling. (See also Best Practices for Setting Up Particles.)	0 - 1
Vertical Aspect Ratio	Changes the height (Y value) of the particle assuming a Z value of 1.	Value limited by list box
Horizontal Aspect Ratio	Changes the width (X value) of the particle assuming a Z value of 1.	Value limited by list box
Smoothness	Changes how smooth or sharp the particle edges are. The higher the value, the smoother the edges.	Value limited by list box
Side Angle	For **Briquettes**, changes the angle of the corners.	Value limited by list box
Number of Corners	Changes how many points a particle's surface has.	Value limited by list box
Superquadric Degree	Changes how square or elliptical a particle appears. The higher the value, the more square the shape.	Value limited by list box
Breakage		
Use Breakage	When selected, enables you to modify the various parameters used to calculate how particles will fracture in the simulation. Note: Breakage models apply only to non-round particle shapes. (From the **Geometry** tab, choose Faceted, Briquette, Faceted Cylinder, or Custom from the **Shape Type** list.)	Turns on or off

Setting	Description	Range
Model	Name of the model that Rocky uses to calculate fracturing. For more information about the breakage model used in Rocky, refer to the 2013 paper by Alex Potapov et al: Computer Simulation of Coal Breakage in Conveyor Transfer Chutes with Rocky Discrete Element Method Package.	Exp-T10
Distribution	Type of fragment distribution size used in the model.	Gaudin-Schumann
Minimum Size	Smallest size the particle fragments can be after breaking.	Any value
Reference Size	L_{ref} in the model equation.	Any value
Minimum Specific Energy	If the total specific energy for a particle that comes into contact with another particle or geometry is less than this value, breakage will not occur. e_{min} in the model equation.	Any value
Selection Function Coefficient	The particle breakage strength parameter, which is a material constant. S in the model equation.	Any value
Maximum T10 Value	Maximum degree of impact breakage, M in the model equation.	Value limited by list box

To add a new Particle group

- From the **Data** panel, right-click **Particles**, and then click **Create Particle**.
  A new Particle is listed under **Particles** in alphabetical (case-sensitive) order.

To modify the parameters of a Particle group

1. From the **Data** panel, under **Particles**, click the name of the Particle group you want to modify.
   The parameters for the Particle become active in the **Data Editors** panel.
2. From the **Data Editors** panel, modify the parameters as you want.

To remove an existing Particle group

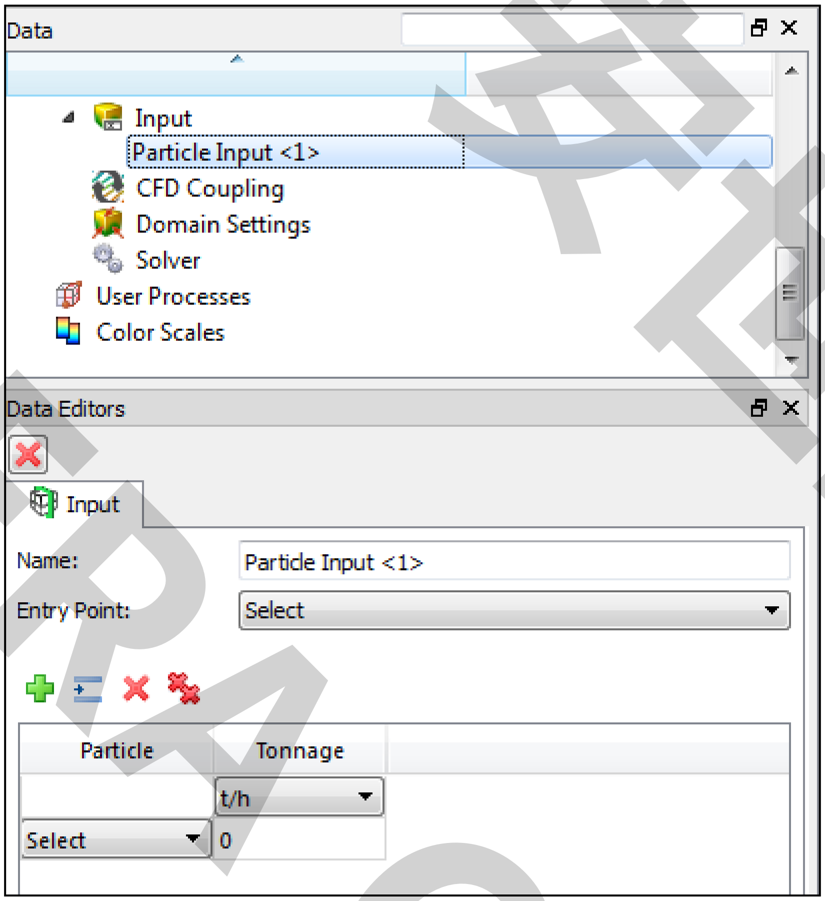
- From the **Data** panel, under **Particles**, right-click the name of the Particle group you want to remove, and then click **Remove Particle**.

Add and Edit Particle Inputs

The Inputs section on the Data panel is where you specify where the various particle groups will be entering your simulation. Particles can enter simulations through the Feed Conveyor geometry, or through any Inlets that you have created.

You can specify as many particle inputs as you like. But before you can process your simulation, you must create at least one Particle Input and provide the Tonnage value for at least one particle group.

Use the figure and table below to help you understand the various parameters you can set for particle inputs.



Name: Particle Input <1>

Entry Point: Select

Particle	Tonnage
	t/h
Select	0

Figure 56: Particle Input, Data Editors panel

Table 21: Particle Input parameter options

Setting	Description	Range
Name	Enables you to specify a unique identifier for the particle input.	99 character limit
Entry Point	The Feed Conveyor or inlet from which the particles are released during the simulation.	Any Feed Conveyor or Inlet that has been included in the simulation
Particle	The particle group that you want to enter the simulation from the Entry Point specified.	Any particle group specified in the simulation
Tonnage	The mass flow rate for the particle group that you want released from this entry point per hour.	Positive values

To create a new Input

1. From the **Data** panel, click **Input**, and the from the **Data Editors** panel, click the **Create Particle Input** button.
   A new Particle Input component appears under **Input** in the **Data** panel.
2. From the **Data** panel, click the Particle Input you just added and then from the **Data Editors** panel, enter the **Name** and set the **Entry Point** you want.
3. Under **Entry Point**, click the **Add** button.
   A new row appears at the bottom of the table.
4. Under **Particle**, choose the particle group that you want and then under **Tonnage**, specify what mass flow rate you want associated with it.
5. Repeat steps 3-4 for each particle group that you want entering the simulation from the **Entry Point** specified.

Tips:

- To insert a new row beneath the selected row, click the **Insert** button.
- To remove the selected row, click the **Remove** button.
- To remove all rows in the table, click the **Remove All** button.

To edit an Input

- From the **Data** panel, click the Particle Input you want to edit, and then from the **Data Editors** panel, modify the settings as desired.

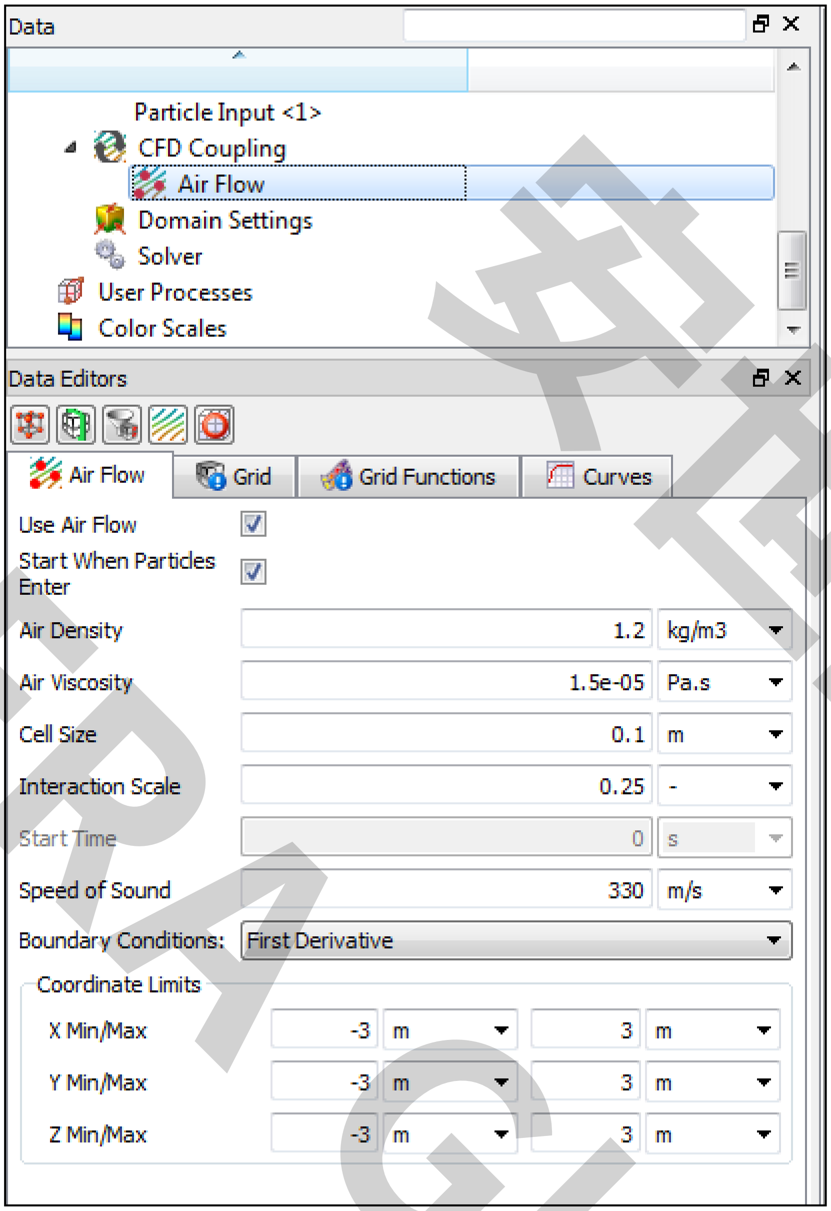
To remove an Input

- From the **Data** panel, click the Particle Input you want to remove, and then from the **Data Editors** panel, click the **Remove** button.

Set or Modify Air Flow Properties

In Rocky, air flow is a CFD Coupling option that represents the way gas and dust-like particles interact with the flow of material in your chute, mill, or other materials handling design. During set up, you can turn on air flow properties; change the density, viscosity, and size of the air flow cells; and set air flow coordinate limits.

Use the figures and table below to understand the various parameters you can set for air flow.



Use Air Flow ✓
Start When Particles Enter ✓
Air Density 1.2 kg/m3
Air Viscosity 1.5e-05 Pa.s
Cell Size 0.1 m
Interaction Scale 0.25 -
Start Time 0 s
Speed of Sound 330 m/s
Boundary Conditions: First Derivative
Coordinate Limits
X Min/Max -3 m 3 m
Y Min/Max -3 m 3 m
Z Min/Max -3 m 3 m

Figure 57: CFD Coupling, Air Flow in Data Editors panel

Table 22: Air Flow Settings

Setting	Description	Range
Use Air Flow	Enables air flow calculations to be included in the simulation.	Turns on or off
Start When Particles Enter	Enables air flow calculations to start as soon as particles appear in the air flow limit box.	Turns on or off
Air Density	The density of the air.	Positive values
Air Viscosity	The viscosity of the air.	Positive values
Cell Size	The size of an air flow cell.	Positive values

Setting	Description	Range
Interaction Scale	Determines the interaction between the particle and the air.	Positive values. (It is recommended that the default value of 0.25 is used.)
Start Time	When **Start When Particles Enter** is cleared, this is the time that air flow calculations begin during the simulation.	Positive values
Speed of Sound	The speed of sound, which is used to calculate air flow.	Positive values
Boundary Conditions		
First Derivative	This order provides more stability to the calculations but less accuracy.	Turns off or on
Second Derivative	This order provides more accuracy to the calculations but less stability.	Turns off or on
Coordinate Limits		
X Min/Max	Distance away from zero on the X axis to place the nearest and farthest corner of the air flow limit box.	No limit
Y Min/Max	Distance away from zero on the Y axis to place the nearest and farthest corners of the air flow limit box.	No limit
Z Min/Max	Distance away from zero on the Z axis to place the nearest and farthest corners of the air flow limit box.	No limit

To turn on air flow properties for a simulation

1. From the **Data** panel, click **CFD Coupling** and then from the **Data Editors** panel, choose **Air Flow** from the **Coupling Mode** list.
   The **Air Flow** component appears in the **Data** panel beneath **CFD Coupling**.
2. In the **Data** panel, click the new **Air Flow** component.
3. From the **Data Editors** panel, on the **Air Flow** tab, ensure the **Use Air Flow** checkbox is enabled, and then modify the settings as you want.

To modify air flow properties

1. From the **Data** panel, under **CFD Coupling**, click **Air Flow**.
2. From the **Data Editors** panel, on the **Air Flow** tab, modify the settings as you want.

To turn off airflow properties

1. From the **Data** panel, under **CFD Coupling**, click **Air Flow**.
2. From the **Data Editors** panel, on the **Air Flow** tab, clear the **Use Air Flow** check box.

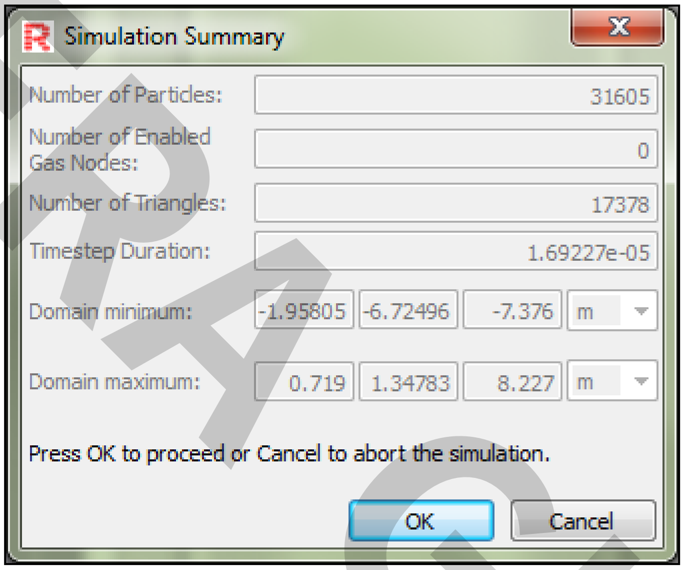
Note: You can also remove Air Flow from your set up completely by choosing **No Coupling** from the **Coupling Mode** list. (From the **Data** panel, click **CFD Coupling** and then from the **Data Editors** panel, make your selection on the **CFD Coupling** tab.)

Verify Simulation Size

Before you process a simulation, it is a good idea to check the **Simulation Summary** dialog to get a rough estimate of the simulation size. Taking this step can help you catch data entry errors, which has the potential of saving you time in processing your simulation.

In general, the higher the values given on the **Simulation Summary** dialog, the longer the simulation will take to process. (See also Best Practices for Faster Processing.)

Use the figure and table below to understand the various types of summary information provided for simulations.


Simulation Summary

Number of Particles: 31605
Number of Enabled Gas Nodes: 0
Number of Triangles: 17378
Timestep Duration: 1.69227e-05
Domain minimum: -1.95805 -6.72496 -7.376 m
Domain maximum: 0.719 1.34783 8.227 m

Press OK to proceed or Cancel to abort the simulation.

Table 23: Simulation Summary

Item	Description
Number of Particles	Total number of particles that will appear in the simulation, from start to finish. The number is calculated based on particle shape, flow rate, tonnage, and density values, as well as simulation time.
Number of Enabled Air Nodes	When airflow is turned on, this is the number of air nodes that will be used during the simulation. The number is calculated based on airflow cell size and airflow boundary limits.
Number of Triangles	Total number of geometry triangles that will be used in the simulation. The number is calculated based on the **Triangle Size** value specified in the various conveyor settings dialogs (Receiving Conveyor Settings, Feed Conveyor Settings, and Custom Boundary Settings).

Item	Description
Timestep Duration	Number of individual calculations Rocky completes for each particle every one second of simulation time. Timestep is an automatic and dynamic value Rocky defines using particle size, density, contact loading stiffness (Young's Modulus), and restitution coefficients. For example, if the time step is 1e-5, for every second of simulated real time 100,000 calculations of forces, positions, and so on will be done on every particle. Note: This number will change based upon simulation parameters.
Domain minimum	The coordinates of the nearest points geometry triangles are drawn. If **Set as Boundary Limits** is selected, once a particle reaches these limits, it will be removed from the calculation and, unless periodic boundaries are selected, will disappear from the Display Area. (This is done to save on processing power.) (See also Set Simulation-Wide Parameters.)
Domain maximum	The coordinates of the farthest points geometry triangles are drawn. If **Set as Boundary Limits** is selected, once a particle reaches these limits, it will be removed from the calculation and, unless periodic boundaries are selected, will disappear from the Display Area. (This is done to save on processing power.) (See also Set Simulation-Wide Parameters.)

To verify the simulation size

1. Ensure that you have set up the minimum requirements for processing. (See also 3. Setting Up a Simulation.)
2. From the **Data** panel, select **Solver** and then from the **Data Editors** panel, click **Start Simulation**.
3. On the **Simulation Summary** dialog, review the information provided and then do one of the following:
   - To return to setting up your simulation, click **Cancel**.
   - To start processing your simulation, click **OK**.

4. Processing a Simulation

After you have set up your simulation (see 3. Setting Up a Simulation), you are ready to process it. Processing is the step in which Rocky calculates at each progressive timestep how each individual particle interacts with every other particle and boundary it comes into contact with.

The time it takes for your simulation to complete will depend upon the complication of the parameters you have set, and the number and type of the processors you have chosen. Based upon these characteristics, your simulation can take anywhere from a few minutes to several days to complete. (See also Best Practices for Faster Processing.)

IMPORTANT: You are only able to set and change parameters during simulation setup so ensure that your settings are correct before processing.

While your simulation is processing, you might stop and restart the simulation several times before your simulation is complete. As the simulation is processing, you can see the progress in a 3D View window or see data collect in a plot or histogram.

What would you like to do?

- Start a Simulation
- Stop a Simulation
- Process Multiple Simulations at Once

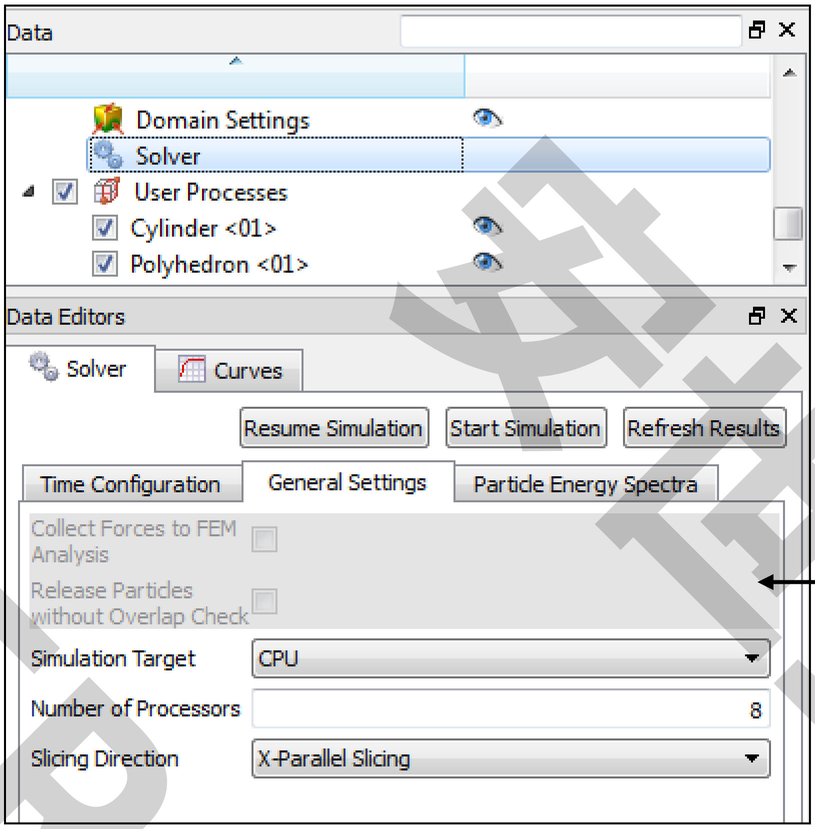
Start a Simulation

You start a simulation either after you have finished setting simulation parameters and are ready to begin the calculations, or have stopped a simulation and want to continue processing it. In this step, you select whether you want CPU or GPU processing, the number of processors, and which direction you want parallel slicing to occur.

While the simulation is processing, you are able to use Rocky to review your simulation settings, create charts, graphs, and 3D Views of the data collected thus far, and more.

The only task you are unable to do while a simulation is processing is change the set up parameters. Doing this would affect the calculations that Rocky is solving. To change the setup parameters, first stop the simulation, change your parameters, and then start your simulation over from the beginning.

Use the image and table below to understand the parameters you can set for processing your simulation.


Data

Domain Settings

Solver

User Processes

Cylinder <01>

Polyhedron <01>

Data Editors

Solver | Curves

Resume Simulation | Start Simulation | Refresh Results

Time Configuration | General Settings | Particle Energy Spectra

Collect Forces to FEM Analysis: ☐

Release Particles without Overlap Check: ☐

Simulation Target: CPU

Number of Processors: 8

Slicing Direction: X-Parallel Slicing

Note: We covered these first two options in the Set Simulation-Wide Parameters section.

Figure 58: Solver, General Settings parameters in the Data Editors panel

Table 24: Processing Area

Setting	Description	Range
Simulation Target	Enables you to select what portion of your computer will be doing the processing.	CPU; GPU
Number of Processors	Sets the number of computer processors (threads) the simulation will use. In general, the more processors used, the faster the simulation will complete. It is recommended that you set this number equal to the amount of cores available, or double the amount of cores if hyper-threading is used. Notes: • Setting more processors than what you have available will slow the simulation. • Windows limits the number of processors to 64 so if you are running Rocky on Windows, it is best to set this value to 64 or less.	Positive values

Parallel Slicing	Sets the direction parallel slicing is made during processing. In general, choose the direction that represents the longest boundary component in your simulation. For example, if your longest boundary is a conveyor oriented along the X-axis, choose X-Parallel Slicing. This setting can help reduce processing time.	X-Parallel Slicing Y-Parallel Slicing Z-Parallel Slicing

To start processing a simulation from the beginning

1. From the **Data** panel, click **Solver** and then from the **Data Editors** panel, ensure the **Solver | General Settings** tab is active.
2. Enter what you want for the **Simulation Target**, **Number of Processors**, and **Slicing Direction** options.
3. Click **Start Simulation**.
   The **Simulation Summary** dialog appears.
4. Review the information in the **Simulation Summary** dialog, and then click **OK**. (For more information about this dialog, see Verify Simulation Size.)
   The simulation progress bar appears at the bottom of the screen and processing begins at the zero Timestep. (See also Refer to the Rocky Title Bar for Simulation Progress Details.) When processing is complete, the progress bar disappears.
   Tips:
   - To see the progress of your simulation in a 3D View window, on the **Solver** tab, click **Refresh Results** and then use the **Play Simulation** button on the Timestep toolbar.
   - To always see the latest results, select the **Auto Refresh** check box on the progress toolbar.
     Note: Selecting this option will take up more processing power than choosing to **Refresh Results** manually.

To resume processing a stopped simulation

- From the **Solver** tab, click **Resume Simulation**.
  Processing continues from the last Timestep that was saved.

Stop a Simulation

There are several reasons why you might want to stop your simulation from processing. For example:

- When you want your computer to take a break from processing, perhaps to do some computer maintenance, with the intent of resuming your simulation again later.
- When you want to prevent Rocky from making any further calculations to the simulation, perhaps because you want to change the simulation parameters and start processing again from the beginning.
- When you have determined you have enough data from the simulation results and no longer need further calculations to be performed.

When you stop a simulation, you can choose to resume it at any time to continue processing from the last saved Timestep. If you decide to change any of the setup parameters, however, you must start processing your simulation from the beginning. (See also Start a Simulation.)

To stop a simulation from processing

- From the **Solver** tab, click **Stop Processing**.

Process Multiple Simulations at Once

The batch processing feature is coming soon. In the meantime, please contact rocky-support@esss.com.br for information about using Rocky scripting features for this purpose.

5. Analyzing a Simulation

In Rocky, you can choose to analyze your simulation results as they are processing, by plotting graphs and viewing statistics, or after the processing is complete, you can save an animation for review outside of the program.

What would you like to do?

- View and Save Simulation Statistics
- Create and Save an Animation

View and Save Simulation Statistics

You view and save simulation statistics either after you have finished processing a simulation or have completed enough of the processing that the data you want to analyze is available.

You can create a plot or histogram to show various data, such as statistics for particles, geometries, belt wear, and energy spectra; or, you can export the data you want to a CSV file to view from a spreadsheet program, such as Microsoft Excel.

<More detail coming soon….>

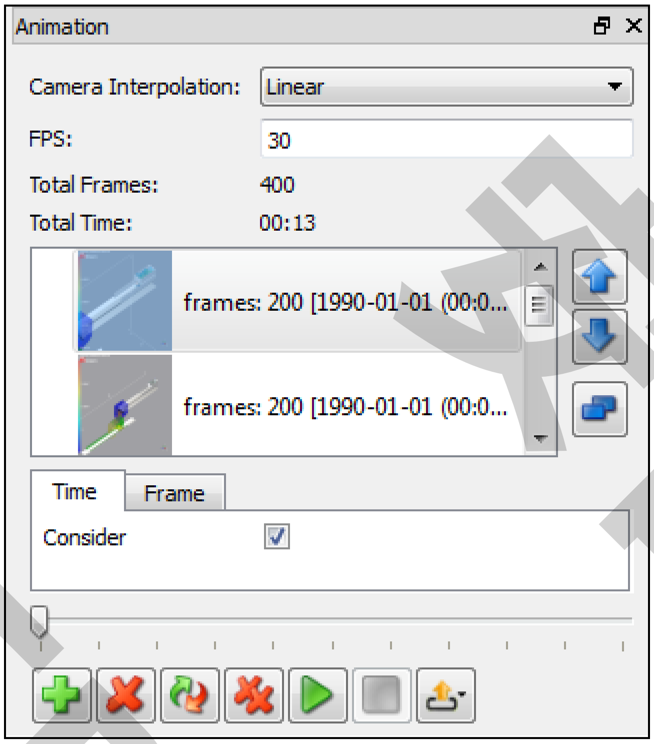
Create and Save an Animation

Once you've completed a simulation, you might want to save the results as an animation file so that you can view it and share it outside of Rocky. Animations are saved as AVI files, which can be opened with many types of media players, and can be set to show linear and spline transitions, 360° wraparound views, and variable frame rates.

When you create an animation, you can choose which portion of the simulation files to include, enabling you to make an animation of the whole simulation or just a portion of it. Any visualization settings that you have set in the 3D View, including the colors, particle shapes, labels, and view angles, will also be replicated in the animation exactly as shown, so it is important to ensure that those settings are as you want before adding your Key Frames.

Tip: For precise animations requiring exact positioning and sequencing, or for creating many similar animations of different simulations, it is recommended that you use Rocky's Macro tool to set up a repeatable script. To get help setting up an animations macro, please contact rocky-support@esss.br.com.

Use the figures and tables below to understand the various parameters you can set for your animation file.


Animation

Camera Interpolation: Linear

FPS: 30

Total Frames: 400

Total Time: 00:13

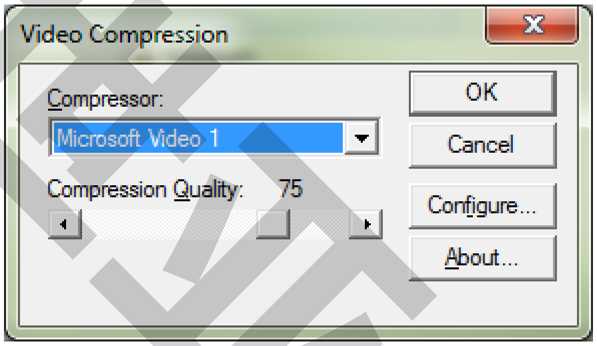
frames: 200 [1990-01-01 (00:0...

frames: 200 [1990-01-01 (00:0...

Time | Frame

Consider ☑

Figure 59: Animation panel


Video Compression

Compressor: Microsoft Video 1

Compression Quality: 75

Figure 60: Video Compression dialog

Table 25: Animation Options

Setting	Description	Range
Camera Interpolation	Determines the type of transition between Key Frames: • **Linear** produces straight-line transitions between Key Frames. • **Spline** produces circular motion transitions between Key Frames. • **No Interpolation** results in a jumping effect between Key Frames with no transition.	Linear, Spline, No Interpolation
FPS	Sets how many Frames Per Second (FPS) the animation will include. A higher FPS will produce a shorter, faster video with higher-quality playback. A lower FPS will produce a longer, slower video with lower-quality playback.	Positive value
Total Frames	Shows how many frames will be included in the overall animation. This number is automatically calculated based upon the Key Frames selected, the **FPS**, and the **Number of Frames** values that are set.	Automatic value

Setting	Description	Range
Total Time	Shows the length of the animation in real time. This number is automatically calculated based upon the Key Frames selected, the **FPS**, and the **Number of Frames** values that are set.	Automatic value
Consider	When this check box is selected, the Key Frame will show during the animation the progressive simulation results for the time frame until the next Key Frame, When the check box is cleared, the selected Key Frame will show only a static image of the simulation results until the next Key Frame.	Turns on or off
Number of Frames	Sets how many individual frames this Key Frame will be separated into. These are the number of frames used before the next Key Frame is activated. Tip: If you want your animation to reflect real time, it is important to keep your frame rate consistent. A general rule of thumb is to set the Number of Frames value equal to the number of seconds between Key Frames multiplied by the FPS you've set. `#Frames = #s x #FPS` Example: If you set your Key Frames to start at 0s, 10s, 15s, and 20s respectively, and you want a FPS of 10 and a real time video of 20s, then: • The Number of Frames for the first Key Frame should be set to 100 (10s x 10FPS = 100 Frames). • The Number of Frames for the second and third Key Frames should be set to 50 (5s x 10FPS = 50 Frames). • The Number of Frames for the fourth and last Key Frame does not affect the animation.	Positive values

Table 26: Video Compression Options

Setting	Description	Range
Compressor Type	The method by which the movie will compress when saved. In general: • **Microsoft Video 1** will be a smaller file size but will be less clear than full frames. • **Full Frames (Uncompressed)** will provide the most clarity, but will be the biggest file size.	Varies by video card. Consult the manual of your particular video card or software for more information on the options available to you.
Compression Quality	Determines the compression ratio of the movie when it is saved. In general, the higher the quality, the clearer the image but the bigger the size of the movie file.	0<100
Temporal Quality Ratio	Helps determine the quality of your video compression. Refer to your computer's operating system manual for more information.	0.01<1.00

To set up an animation

1. Open the simulation containing the results you want to animate.
2. Ensure the **Animation** panel is visible. (From the **Tools** menu, click **Animation**.)
3. Create a Key Frames list by doing the following:
   a. Find or create a 3D View with the visualization settings you want to animate, including the rotation and level of zoom.
   b. Using the Timestep dropdown and/or arrows in the toolbar, choose the particular Timestep with which you want your animation to start. (For example, if you want your animation to start at the beginning, choose the **[0] 0 s** Timestep.)
   c. From the bottom of the **Animation** panel, click the **Add Key Frame** button.
      An image of the Timestep and view you created shows in the Key Frames list.
   d. Set up your next Key Frame by doing one of the following:
      - To show the same view for a period of time, move only your Timestep forward as desired but don't change the view.
      - To transition to another view over a period of time, move your Timestep forward and change your view as desired.
   e. From the bottom of the **Animation** panel, click the **Add Key Frame** button.
      An image of the Timestep and view you created shows in the Key Frames list.
   f. Repeat steps 3d-e as many times as necessary to

Transition Tips:

- To transition quickly between views, leave no Timestep gap between Key Frames.
- To transition slowly between views, leave a Timestep gap between Key Frames equal to the desired transition length.
- To create a 360° wraparound view, include two Key Frames with the same exact view and a Timestep gap equal to the desired amount of time you want the view to pivot around the center point.

complete your animation set up.
Tip: Use the buttons at the bottom and side of the **Animation** panel to help you delete, copy, move, and update Key Frames that you've already created.

4. From the top of the **Animation** panel, determine what kind of transitions you want between your Key Frames by choosing an option from the **Camera Interpolation** list.
5. Determine the speed, length, and quality of your animation by setting the values you want in the **FPS** field for the animation, and **Number of Frames** field for each Key Frame. Use the values displayed for **Total Frames** and **Total Time** to guide you in your selections.
6. At the bottom of the **Animation** panel, click the **Play** button to view a preview of your animation in the Rocky Workspace, and then edit your Key Frames and animation options as desired.

To save an already set-up animation as an AVI

1. From the bottom of the **Animation** panel, click the **Export Animation** button, and then click **AVI**.
2. From the **Export Animation to AVI** dialog, choose the location to which you want to save the AVI file.
3. In the **File name** box, enter a name for the file, and then click **Save**.
4. From the **Video Compression** dialog, choose the **Compressor** type and **Compressor Quality** you want, and then click **Configure**.
5. Verify that the **Temporal Quality Ratio** settings are set the way you want, and then click **OK**.
6. Click **OK** again to save the animation.
   The **Animation Export** screen appears to show you the status of your save and a preview of the progress. When the save is complete, the **Animation Export** screen disappears.

To save a static image of each individual frame in an animation

Tip: Before you start, review the **Total Frames** value displayed in the **Animation** panel to ensure you have set up your animation the way you want. The number of images exported will equal this value.

1. From the bottom of the **Animation** panel, click the **Export Animation** button, and then click **Images**.
2. Form the **Export Animation to Images** dialog, choose the location to which you want to save the series of images.
3. In the **File name** box, enter a name for the images and then from the **Save as type** list, choose what image format you want.
4. Click **Save**.
   The **Animation Export** screen appears to show you the status of your save and a preview of the progress. When the save is complete, the **Animation Export** screen disappears.
   Each image file name will be appended with the corresponding frame number.

6. Getting Help and Support

To get more help understanding the features and capabilities of Rocky, please consult the following resources:

- **Rocky User Manual** (this document). Use the Table of Contents at the beginning of the document or the Search or Find function within your PDF viewer to quickly find the information you need.

  To access the Rocky User Manual, from within the Rocky program, click **User Manual** from the **Help** menu.

- **ESSS Customer Portal.** View Rocky how-to and overview videos, installation instructions, and examples of Rocky simulations. From the portal you can also submit a customer support request and check-up on existing requests.

  To access the ESSS customer portal, from the www.rocky-dem.com website, go to the **Customer Portal** page, click the **Customer Portal** link, and then sign in as instructed. If you do not already have sign-in information for the customer portal, please contact rocky-support@esss.com.br for assistance.

- **Rocky Training.** Sign-up for the next Rocky training session to get a better understanding of how Rocky can help you improve your designs, and get hands-on experience using the product.

  To learn more about Rocky training courses, please contact rocky-support@esss.com.br.

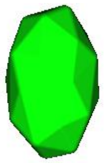
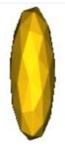
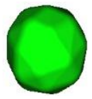
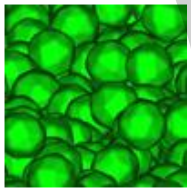
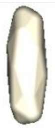
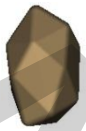
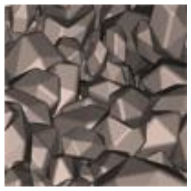
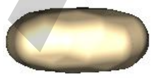
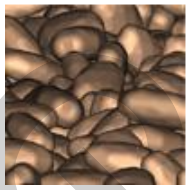
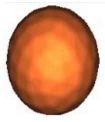
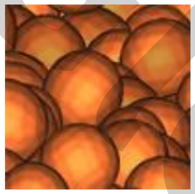
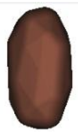
7. Appendices

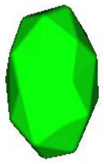
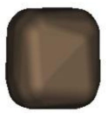
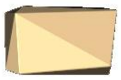
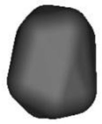
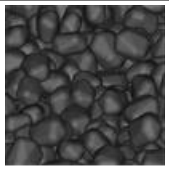
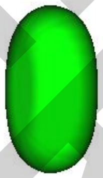
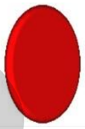
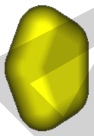
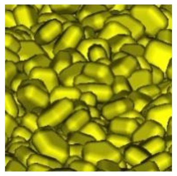
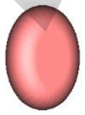
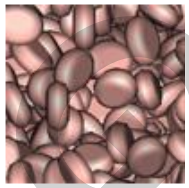
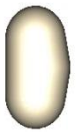
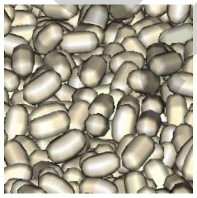
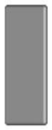
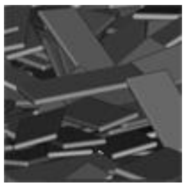
This section contains supplemental information that might assist you with using some of Rocky's more advanced features.

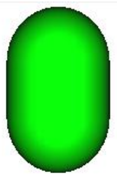
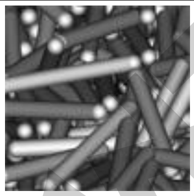
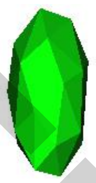
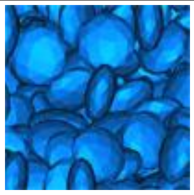
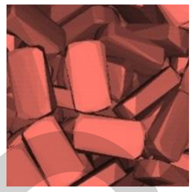
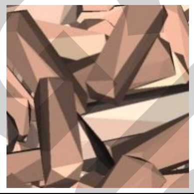
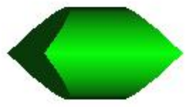
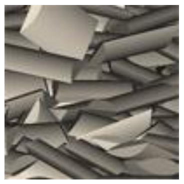
What would you like to review?

- Appendix A: Particle Shape Examples
- Appendix B: ASCII Printable Characters
- Appendix C: Calculation Reference
- Appendix D: Use Variables to Test Varying Belt Speeds

Appendix A: Particle Shape Examples

Start with this Particle Type	To create this shape		Vertical Aspect Ratio	Horizontal Aspect Ratio	Smoothness	Side Angle	Number of Corners	Superquadric Degree
 Rounded Polyhedron	 Barley		2.7	1	0.163	N/A	48	2
	 Pea		1.08	1.08	0.964	N/A	25	2.6
	 Rice		2.55	0.9	0.964	N/A	16	2
	 Rock		1.5	0.75	0.25	N/A	15	2
	 Potato		0.7	1.7	1	N/A	27	2
	 Orange		1.1	1.1	1	N/A	104	2
	 Raisin		1.72	0.7	1	N/A	22	2.8

Start with this Particle Type	To create this shape		Vertical Aspect Ratio	Horizontal Aspect Ratio	Smoothness	Side Angle	Number of Corners	Superquadric Degree
 Rounded Polyhedron	 Chocolate		1.26	1.26	1	N/A	40	10.5
	 Wood Chip		1.44	2.7	0.1	N/A	11	12
	 Coal		1.14	0.7	1	N/A	11	6.2
 Rounded Polygon	 Poker Chip		1.05	0.1	N/A	N/A	32	N/A
	 Corn		1.245	0.532	N/A	N/A	5	N/A
	 Pill		1.215	0.532	N/A	N/A	40	N/A
	 Navy Bean		1.8	0.9	N/A	N/A	3	N/A
	 Sheet Metal		2.37	0.1	N/A	N/A	4	N/A

Start with this Particle Type	To create this shape		Vertical Aspect Ratio	Horizontal Aspect Ratio	Smoothness	Side Angle	Number of Corners	Superquadric Degree
 Rounded Cylinder	Rod		9.41	N/A	N/A	N/A	N/A	N/A
	Capsule		2.57	N/A	N/A	N/A	N/A	N/A
 Faceted	Sharp Rock		1.16	1.08	N/A	N/A	10	2
	Wafer		1.04	0.5	N/A	N/A	57	2
	Brick		0.5	1.76	N/A	N/A	44	12
	Firewood		0.7	2.5	N/A	N/A	14	12
 Briquette	Newspaper		0.6	2.005	N/A	5	60	N/A
	Package		0.3	1.45	N/A	34.5	32	N/A

APPENDIX B: ASCII PRINTABLE CHARACTERS

The below chart for the ASCII printable characters (codes 32-127) is useful for understanding how sort order is determined in Rocky. (See also Name Components to Affect Sort Order).

Symbol	Description
	Space
!	Exclamation mark
"	Double quotes (or speech marks)
#	Number
$	Dollar
%	Percentage
&	Ampersand
'	Single quote
(	Open parenthesis (or open bracket)
)	Close parenthesis (or close bracket)
*	Asterisk
+	Plus
,	Comma
-	Hyphen
.	Period, dot, or full stop
/	Slash or divide
0	Zero
1	One
2	Two
3	Three
4	Four
5	Five
6	Six
7	Seven
8	Eight
9	Nine
:	Colon
;	Semicolon
<	Less than (or open angled bracket)
=	Equals
>	Greater than (or close angled bracket)
?	Question mark
@	At symbol
A	Uppercase A
B	Uppercase B
C	Uppercase C
D	Uppercase D
E	Uppercase E
F	Uppercase F
G	Uppercase G
H	Uppercase H

I	Uppercase I
J	Uppercase J
K	Uppercase K
L	Uppercase L
M	Uppercase M
N	Uppercase N
O	Uppercase O
P	Uppercase P
Q	Uppercase Q
R	Uppercase R
S	Uppercase S
T	Uppercase T
U	Uppercase U
V	Uppercase V
W	Uppercase W
X	Uppercase X
Y	Uppercase Y
Z	Uppercase Z
[	Opening bracket
\	Backslash
]	Closing bracket
^	Caret - circumflex
_	Underscore
`	Grave accent
a	Lowercase a
b	Lowercase b
c	Lowercase c
d	Lowercase d
e	Lowercase e
f	Lowercase f
g	Lowercase g
h	Lowercase h
i	Lowercase i
j	Lowercase j
k	Lowercase k
l	Lowercase l
m	Lowercase m
n	Lowercase n
o	Lowercase o
p	Lowercase p
q	Lowercase q
r	Lowercase r
s	Lowercase s
t	Lowercase t
u	Lowercase u
v	Lowercase v
w	Lowercase w

x	Lowercase x
y	Lowercase y
z	Lowercase z
{	Opening brace
|	Vertical bar
}	Closing brace
~	Equivalency sign - tilde
	Delete

Appendix C: Calculation Reference

Rocky uses expressions to create a new curve or grid function. These expressions are based upon the latest NumPy math routines. (For more information about NumPy math routines, see http://docs.scipy.org/doc/numpy/reference/routines.math.html).

Some examples of operations using curves or grid functions are as follows:

```
A+B
log(A)
A+(B-100)
```

It is also possible to conduct calculations using timesteps, in which case the expression would access the variables using brackets `[ ]`.

For example:

`A[t]-A[t-1]`	would give the delta between 2 timesteps.
`A[0]` → `A[t]-A[0]`	would give the delta from the current time to the first timestep.

Use the Table of Functions below to navigate to the section you are interested in.

Table of Functions

TRIGONOMETRIC FUNCTIONS

SIN

sin(x[, out])

Trigonometric sine, element-wise.

Parameters
----
x : array_like
Angle, in radians (:math:`2 \pi` rad equals 360 degrees).

Returns
----
y : array_like
The sine of each element of x.

See Also
----
arcsin, sinh, cos

Notes

The sine is one of the fundamental functions of trigonometry
(the mathematical study of triangles). Consider a circle of radius
1 centered on the origin. A ray comes in from the :math:`+x` axis,
makes an angle at the origin (measured counter-clockwise from that
axis), and departs from the origin. The :math:`y` coordinate of
the outgoing ray's intersection with the unit circle is the sine
of that angle. It ranges from -1 for :math:`x=3\pi / 2` to
+1 for :math:`\pi / 2.` The function has zeroes where the angle is
a multiple of :math:`\pi`. Sines of angles between :math:`\pi` and
:math:`2\pi` are negative. The numerous properties of the sine and
related functions are included in any standard trigonometry text.

Examples

Print sine of one angle:

```
>>> np.sin(np.pi/2.)
1.0
```

Print sines of an array of angles given in degrees:

```
>>> np.sin(np.array((0., 30., 45., 60., 90.)) * np.pi / 180. )
array([ 0. , 0.5 , 0.70710678, 0.8660254 , 1. ])
```

Plot the sine function:

```
>>> import matplotlib.pylab as plt
>>> x = np.linspace(-np.pi, np.pi, 201)
>>> plt.plot(x, np.sin(x))
>>> plt.xlabel('Angle [rad]')
>>> plt.ylabel('sin(x)')
>>> plt.axis('tight')
>>> plt.show()
```

COS

cos(x[, out])

Cosine elementwise.

Parameters
----
x : array_like
Input array in radians.
out : ndarray, optional

Output array of same shape as `x`.

Returns
----
y : ndarray
The corresponding cosine values.

Raises

ValueError: invalid return array shape
if `out` is provided and `out.shape` != `x.shape` (See Examples)

Notes

If `out` is provided, the function writes the result into it,
and returns a reference to `out`. (See Examples)

References

M. Abramowitz and I. A. Stegun, Handbook of Mathematical Functions.
New York, NY: Dover, 1972.

Examples

```
>>> np.cos(np.array([0, np.pi/2, np.pi]))
array([ 1.00000000e+00, 6.12303177e-17, -1.00000000e+00])
>>>
>>> # Example of providing the optional output parameter
>>> out2 = np.cos([0.1], out1)
>>> out2 is out1
True
>>>
>>> # Example of ValueError due to provision of shape mis-matched `out`
>>> np.cos(np.zeros((3,3)),np.zeros((2,2)))
Traceback (most recent call last):
File "", line 1, in
ValueError: invalid return array shape
```

TAN

tan(x[, out])

Compute tangent element-wise.

Equivalent to ``np.sin(x)/np.cos(x)`` element-wise.

Parameters

----
x : array_like
Input array.
out : ndarray, optional
Output array of same shape as `x`.

Returns
----
y : ndarray
The corresponding tangent values.

Raises

ValueError: invalid return array shape
if `out` is provided and `out.shape` != `x.shape` (See Examples)

Notes

If `out` is provided, the function writes the result into it,
and returns a reference to `out`. (See Examples)

References

M. Abramowitz and I. A. Stegun, Handbook of Mathematical Functions.
New York, NY: Dover, 1972.

Examples

```
>>> from math import pi
>>> np.tan(np.array([-pi,pi/2,pi]))
array([ 1.22460635e-16, 1.63317787e+16, -1.22460635e-16])
>>>
>>> # Example of providing the optional output parameter illustrating
>>> # that what is returned is a reference to said parameter
>>> out2 = np.cos([0.1], out1)
>>> out2 is out1
True
>>>
>>> # Example of ValueError due to provision of shape mis-matched `out`
>>> np.cos(np.zeros((3,3)),np.zeros((2,2)))
Traceback (most recent call last):
File "", line 1, in
ValueError: invalid return array shape
```

ARCSIN

arcsin(x[, out])

Inverse sine, element-wise.

Parameters
----
x : array_like
`y`-coordinate on the unit circle.

out : ndarray, optional
Array of the same shape as `x`, in which to store the results.
See `doc.ufuncs` (Section "Output arguments") for more details.

Returns
----
angle : ndarray
The inverse sine of each element in `x`, in radians and in the
closed interval ``[-pi/2, pi/2]``. If `x` is a scalar, a scalar
is returned, otherwise an array.

See Also
----
sin, cos, arccos, tan, arctan, arctan2, emath.arcsin

Notes

`arcsin` is a multivalued function: for each `x` there are infinitely
many numbers `z` such that :math:`sin(z) = x`. The convention is to
return the angle `z` whose real part lies in [-pi/2, pi/2].

For real-valued input data types, *arcsin* always returns real output.
For each value that cannot be expressed as a real number or infinity,
it yields ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `arcsin` is a complex analytic function that
has, by convention, the branch cuts [-inf, -1] and [1, inf] and is
continuous from above on the former and from below on the latter.

The inverse sine is also known as `asin` or sin^{-1}.

References

Abramowitz, M. and Stegun, I. A., *Handbook of Mathematical Functions*,
10th printing, New York: Dover, 1964, pp. 79ff.
http://www.math.sfu.ca/~cbm/aands/

Examples

```
--------
>>> np.arcsin(1) # pi/2
1.5707963267948966
>>> np.arcsin(-1) # -pi/2
-1.5707963267948966
>>> np.arcsin(0)
0.0
```

ARCCOS

```
arccos(x[, out])

Trigonometric inverse cosine, element-wise.

The inverse of `cos` so that, if ``y = cos(x)``, then ``x = arccos(y)``.

Parameters
----------
x : array_like
`x`-coordinate on the unit circle.
For real arguments, the domain is [-1, 1].

out : ndarray, optional
Array of the same shape as `a`, to store results in. See
`doc.ufuncs` (Section "Output arguments") for more details.

Returns
-------
angle : ndarray
The angle of the ray intersecting the unit circle at the given
`x`-coordinate in radians [0, pi]. If `x` is a scalar then a
scalar is returned, otherwise an array of the same shape as `x`
is returned.

See Also
--------
cos, arctan, arcsin, emath.arccos

Notes
-----
`arccos` is a multivalued function: for each `x` there are infinitely
many numbers `z` such that `cos(z) = x`. The convention is to return
the angle `z` whose real part lies in `[0, pi]`.

For real-valued input data types, `arccos` always returns real output.
For each value that cannot be expressed as a real number or infinity,
it yields ``nan`` and sets the `invalid` floating point error flag.
```

For complex-valued input, `arccos` is a complex analytic function that
has branch cuts `[-inf, -1]` and `[1, inf]` and is continuous from
above on the former and from below on the latter.

The inverse `cos` is also known as `acos` or cos^-1.

References

M. Abramowitz and I.A. Stegun, "Handbook of Mathematical Functions",
10th printing, 1964, pp. 79. http://www.math.sfu.ca/~cbm/aands/

Examples

We expect the arccos of 1 to be 0, and of -1 to be pi:

```
>>> np.arccos([1, -1])
array([ 0. , 3.14159265])
```

Plot arccos:

```
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-1, 1, num=100)
>>> plt.plot(x, np.arccos(x))
>>> plt.axis('tight')
>>> plt.show()
```

ARCTAN

arctan(x[, out])

Trigonometric inverse tangent, element-wise.

The inverse of tan, so that if ``y = tan(x)`` then ``x = arctan(y)``.

Parameters
----
x : array_like
Input values. `arctan` is applied to each element of `x`.

Returns
----
out : ndarray
Out has the same shape as `x`. Its real part is in
``[-pi/2, pi/2]`` (``arctan(+/-inf)`` returns ``+/-pi/2``).
It is a scalar if `x` is a scalar.

See Also
----
arctan2 : The "four quadrant" arctan of the angle formed by (`x`, `y`) and the positive `x`-axis.
angle : Argument of complex values.

Notes

`arctan` is a multi-valued function: for each `x` there are infinitely many numbers `z` such that tan(`z`) = `x`. The convention is to return the angle `z` whose real part lies in [-pi/2, pi/2].

For real-valued input data types, `arctan` always returns real output. For each value that cannot be expressed as a real number or infinity, it yields ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `arctan` is a complex analytic function that has [`1j, infj`] and [`-1j, -infj`] as branch cuts, and is continuous from the left on the former and from the right on the latter.

The inverse tangent is also known as `atan` or tan^{-1}.

References

Abramowitz, M. and Stegun, I. A., *Handbook of Mathematical Functions*, 10th printing, New York: Dover, 1964, pp. 79.
http://www.math.sfu.ca/~cbm/aands/

Examples

We expect the arctan of 0 to be 0, and of 1 to be pi/4:

```
>>> np.arctan([0, 1])
array([ 0. , 0.78539816])

>>> np.pi/4
0.78539816339744828
```

Plot arctan:

```
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-10, 10)
>>> plt.plot(x, np.arctan(x))
>>> plt.axis('tight')
>>> plt.show()
```

HYPOT

hypot(x1, x2[, out])

Given the "legs" of a right triangle, return its hypotenuse.

Equivalent to ``sqrt(x1**2 + x2**2)``, element-wise. If `x1` or
`x2` is scalar_like (i.e., unambiguously cast-able to a scalar type),
it is broadcast for use with each element of the other argument.
(See Examples)

Parameters
----
x1, x2 : array_like
Leg of the triangle(s).
out : ndarray, optional
Array into which the output is placed. Its type is preserved and it
must be of the right shape to hold the output. See doc.ufuncs.

Returns
----
z : ndarray
The hypotenuse of the triangle(s).

Examples

```
>>> np.hypot(3*np.ones((3, 3)), 4*np.ones((3, 3)))
array([[ 5., 5., 5.],
[ 5., 5., 5.],
[ 5., 5., 5.]])
```

Example showing broadcast of scalar_like argument:

```
>>> np.hypot(3*np.ones((3, 3)), [4])
array([[ 5., 5., 5.],
[ 5., 5., 5.],
[ 5., 5., 5.]])
```

ARCTAN2

arctan2(x1, x2[, out])

Element-wise arc tangent of ``x1/x2`` choosing the quadrant correctly.

The quadrant (i.e., branch) is chosen so that ``arctan2(x1, x2)`` is
the signed angle in radians between the ray ending at the origin and
passing through the point (1,0), and the ray ending at the origin and

passing through the point (`x2`, `x1`). (Note the role reversal: the "`y`-coordinate" is the first function parameter, the "`x`-coordinate" is the second.) By IEEE convention, this function is defined for `x2` = +/-0 and for either or both of `x1` and `x2` = +/-inf (see Notes for specific values).

This function is not defined for complex-valued arguments; for the so-called argument of complex values, use `angle`.

Parameters
----
x1 : array_like, real-valued
`y`-coordinates.
x2 : array_like, real-valued
`x`-coordinates. `x2` must be broadcastable to match the shape of `x1` or vice versa.

Returns
----
angle : ndarray
Array of angles in radians, in the range ``[-pi, pi]``.

See Also
----
arctan, tan, angle

Notes
-----
arctan2 is identical to the `atan2` function of the underlying C library. The following special values are defined in the C standard: [1]_

```
====== ====== ================
`x1` `x2` `arctan2(x1,x2)`
====== ====== ================
+/- 0 +0 +/- 0
+/- 0 -0 +/- pi
> 0 +/-inf +0 / +pi
< 0 +/-inf -0 / -pi
+/-inf +inf +/- (pi/4)
+/-inf -inf +/- (3*pi/4)
====== ====== ================
```

Note that +0 and -0 are distinct floating point numbers, as are +inf and -inf.

References

.. [1] ISO/IEC standard 9899:1999, "Programming language C."

Examples

Consider four points in different quadrants:

```
>>> x = np.array([-1, +1, +1, -1])
>>> y = np.array([-1, -1, +1, +1])
>>> np.arctan2(y, x) * 180 / np.pi
array([-135., -45., 45., 135.])
```

Note the order of the parameters. `arctan2` is defined also when `x2` = 0
and at several other special points, obtaining values in
the range ``[-pi, pi]``:

```
>>> np.arctan2([1., -1.], [0., 0.])
array([ 1.57079633, -1.57079633])
>>> np.arctan2([0., 0., np.inf], [+0., -0., np.inf])
array([ 0. , 3.14159265, 0.78539816])
```

DEGREES

degrees(x[, out])

Convert angles from radians to degrees.

Parameters
----
x : array_like
Input array in radians.
out : ndarray, optional
Output array of same shape as x.

Returns
----
y : ndarray of floats
The corresponding degree values; if `out` was supplied this is a
reference to it.

See Also
----
rad2deg : equivalent function

Examples

Convert a radian array to degrees

```
>>> rad = np.arange(12.)*np.pi/6
>>> np.degrees(rad)
array([ 0., 30., 60., 90., 120., 150., 180., 210., 240.,
270., 300., 330.])

>>> out = np.zeros((rad.shape))
>>> r = degrees(rad, out)
>>> np.all(r == out)
True
```

RADIANS

radians(x[, out])

Convert angles from degrees to radians.

Parameters
----
x : array_like
Input array in degrees.
out : ndarray, optional
Output array of same shape as `x`.

Returns
----
y : ndarray
The corresponding radian values.

See Also
----
deg2rad : equivalent function

Examples

Convert a degree array to radians

```
>>> deg = np.arange(12.) * 30.
>>> np.radians(deg)
array([ 0. , 0.52359878, 1.04719755, 1.57079633, 2.0943951 ,
2.61799388, 3.14159265, 3.66519143, 4.1887902 , 4.71238898,
5.23598776, 5.75958653])

>>> out = np.zeros((deg.shape))
>>> ret = np.radians(deg, out)
>>> ret is out
True
```

UNWRAP

Unwrap by changing deltas between values to 2*pi complement.

Unwrap radian phase `p` by changing absolute jumps greater than
`discont` to their 2*pi complement along the given axis.

Parameters
----
p : array_like
Input array.
discont : float, optional
Maximum discontinuity between values, default is ``pi``.
axis : int, optional
Axis along which unwrap will operate, default is the last axis.

Returns
----
out : ndarray
Output array.

See Also
----
rad2deg, deg2rad

Notes

If the discontinuity in `p` is smaller than ``pi``, but larger than
`discont`, no unwrapping is done because taking the 2*pi complement
would only make the discontinuity larger.

Examples

```
>>> phase = np.linspace(0, np.pi, num=5)
>>> phase[3:] += np.pi
>>> phase
array([ 0. , 0.78539816, 1.57079633, 5.49778714, 6.28318531])
>>> np.unwrap(phase)
array([ 0. , 0.78539816, 1.57079633, -0.78539816, 0. ])
```

DEG2RAD

deg2rad(x[, out])

Convert angles from degrees to radians.

Parameters
----
x : array_like
Angles in degrees.

Returns
----
y : ndarray
The corresponding angle in radians.

See Also
----
rad2deg : Convert angles from radians to degrees.
unwrap : Remove large jumps in angle by wrapping.

Notes

.. versionadded:: 1.3.0

``deg2rad(x)`` is ``x * pi / 180``.

Examples

>>> np.deg2rad(180)
3.1415926535897931

RAD2DEG

rad2deg(x[, out])

Convert angles from radians to degrees.

Parameters
----
x : array_like
Angle in radians.
out : ndarray, optional
Array into which the output is placed. Its type is preserved and it
must be of the right shape to hold the output. See doc.ufuncs.

Returns
----
y : ndarray
The corresponding angle in degrees.

See Also
----

deg2rad : Convert angles from degrees to radians.
unwrap : Remove large jumps in angle by wrapping.

Notes

.. versionadded:: 1.3.0

rad2deg(x) is ``180 * x / pi``.

Examples

>>> np.rad2deg(np.pi/2)
90.0

Hyperbolic functions

SINH

sinh(x[, out])

Hyperbolic sine, element-wise.

Equivalent to ``1/2 * (np.exp(x) - np.exp(-x))`` or
``-1j * np.sin(1j*x)``.

Parameters
----
x : array_like
Input array.
out : ndarray, optional
Output array of same shape as `x`.

Returns
----
y : ndarray
The corresponding hyperbolic sine values.

Raises

ValueError: invalid return array shape
if `out` is provided and `out.shape` != `x.shape` (See Examples)

Notes

If `out` is provided, the function writes the result into it,
and returns a reference to `out`. (See Examples)

References

M. Abramowitz and I. A. Stegun, Handbook of Mathematical Functions.
New York, NY: Dover, 1972, pg. 83.

Examples

```
>>> np.sinh(0)
0.0
>>> np.sinh(np.pi*1j/2)
1j
>>> np.sinh(np.pi*1j) # (exact value is 0)
1.2246063538223773e-016j
>>> # Discrepancy due to vagaries of floating point arithmetic.

>>> # Example of providing the optional output parameter
>>> out2 = np.sinh([0.1], out1)
>>> out2 is out1
True

>>> # Example of ValueError due to provision of shape mis-matched `out`
>>> np.sinh(np.zeros((3,3)),np.zeros((2,2)))
Traceback (most recent call last):
File "", line 1, in
ValueError: invalid return array shape
```

COSH

cosh(x[, out])

Hyperbolic cosine, element-wise.

Equivalent to ``1/2 * (np.exp(x) + np.exp(-x))`` and ``np.cos(1j*x)``.

Parameters
----
x : array_like
Input array.

Returns
----
out : ndarray
Output array of same shape as `x`.

Examples

>>> np.cosh(0)
1.0

The hyperbolic cosine describes the shape of a hanging cable:

>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-4, 4, 1000)
>>> plt.plot(x, np.cosh(x))
>>> plt.show()

TANH

tanh(x[, out])

Compute hyperbolic tangent element-wise.

Equivalent to ``np.sinh(x)/np.cosh(x)`` or
``-1j * np.tan(1j*x)``.

Parameters
----
x : array_like
Input array.
out : ndarray, optional
Output array of same shape as `x`.

Returns
----
y : ndarray
The corresponding hyperbolic tangent values.

Raises

ValueError: invalid return array shape
if `out` is provided and `out.shape` != `x.shape` (See Examples)

Notes

If `out` is provided, the function writes the result into it,
and returns a reference to `out`. (See Examples)

References

.. [1] M. Abramowitz and I. A. Stegun, Handbook of Mathematical Functions.
New York, NY: Dover, 1972, pg. 83.

http://www.math.sfu.ca/~cbm/aands/

.. [2] Wikipedia, "Hyperbolic function",
http://en.wikipedia.org/wiki/Hyperbolic_function

Examples

>>> np.tanh((0, np.pi*1j, np.pi*1j/2))
array([0. +0.00000000e+00j, 0. -1.22460635e-16j, 0. +1.63317787e+16j])

>>> # Example of providing the optional output parameter illustrating
>>> # that what is returned is a reference to said parameter
>>> out2 = np.tanh([0.1], out1)
>>> out2 is out1
True

>>> # Example of ValueError due to provision of shape mis-matched `out`
>>> np.tanh(np.zeros((3,3)),np.zeros((2,2)))
Traceback (most recent call last):
File "", line 1, in
ValueError: invalid return array shape

ARCSINH

arcsinh(x[, out])

Inverse hyperbolic sine elementwise.

Parameters
----
x : array_like
Input array.
out : ndarray, optional
Array into which the output is placed. Its type is preserved and it
must be of the right shape to hold the output. See `doc.ufuncs`.

Returns
----
out : ndarray
Array of of the same shape as `x`.

Notes

`arcsinh` is a multivalued function: for each `x` there are infinitely
many numbers `z` such that `sinh(z) = x`. The convention is to return the
`z` whose imaginary part lies in `[-pi/2, pi/2]`.

For real-valued input data types, `arcsinh` always returns real output.
For each value that cannot be expressed as a real number or infinity, it
returns ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `arccos` is a complex analytical function that
has branch cuts `[1j, infj]` and `[-1j, -infj]` and is continuous from
the right on the former and from the left on the latter.

The inverse hyperbolic sine is also known as `asinh` or ``sinh^-1``.

References

.. [1] M. Abramowitz and I.A. Stegun, "Handbook of Mathematical Functions",
10th printing, 1964, pp. 86. http://www.math.sfu.ca/~cbm/aands/
.. [2] Wikipedia, "Inverse hyperbolic function",
http://en.wikipedia.org/wiki/Arcsinh

Examples

```
>>> np.arcsinh(np.array([np.e, 10.0]))
array([ 1.72538256, 2.99822295])
```

ARCCOSH

arccosh(x[, out])

Inverse hyperbolic cosine, elementwise.

Parameters
----
x : array_like
Input array.
out : ndarray, optional
Array of the same shape as `x`, to store results in.
See `doc.ufuncs` (Section "Output arguments") for details.

Returns
----
y : ndarray
Array of the same shape as `x`.

See Also
----

cosh, arcsinh, sinh, arctanh, tanh

Notes

`arccosh` is a multivalued function: for each `x` there are infinitely
many numbers `z` such that `cosh(z) = x`. The convention is to return the
`z` whose imaginary part lies in `[-pi, pi]` and the real part in
``[0, inf]``.

For real-valued input data types, `arccosh` always returns real output.
For each value that cannot be expressed as a real number or infinity, it
yields ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `arccosh` is a complex analytical function that
has a branch cut `[-inf, 1]` and is continuous from above on it.

References

.. [1] M. Abramowitz and I.A. Stegun, "Handbook of Mathematical Functions",
10th printing, 1964, pp. 86. http://www.math.sfu.ca/~cbm/aands/
.. [2] Wikipedia, "Inverse hyperbolic function",
http://en.wikipedia.org/wiki/Arccosh

Examples

```
>>> np.arccosh([np.e, 10.0])
array([ 1.65745445, 2.99322285])
>>> np.arccosh(1)
0.0
```

ARCTANH

arctanh(x[, out])

Inverse hyperbolic tangent elementwise.

Parameters
----
x : array_like
Input array.

Returns
----
out : ndarray
Array of the same shape as `x`.

See Also
----
emath.arctanh

Notes

`arctanh` is a multivalued function: for each `x` there are infinitely
many numbers `z` such that `tanh(z) = x`. The convention is to return the
`z` whose imaginary part lies in `[-pi/2, pi/2]`.

For real-valued input data types, `arctanh` always returns real output.
For each value that cannot be expressed as a real number or infinity, it
yields ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `arctanh` is a complex analytical function that
has branch cuts `[-1, -inf]` and `[1, inf]` and is continuous from
above on the former and from below on the latter.

The inverse hyperbolic tangent is also known as `atanh` or ``tanh^-1``.

References

.. [1] M. Abramowitz and I.A. Stegun, "Handbook of Mathematical Functions",
10th printing, 1964, pp. 86. http://www.math.sfu.ca/~cbm/aands/
.. [2] Wikipedia, "Inverse hyperbolic function",
http://en.wikipedia.org/wiki/Arctanh

Examples

```
>>> np.arctanh([0, -0.5])
array([ 0. , -0.54930614])
```

Rounding

around

Evenly round to the given number of decimals.

Parameters
----
a : array_like
Input data.
decimals : int, optional
Number of decimal places to round to (default: 0). If
decimals is negative, it specifies the number of positions to
the left of the decimal point.
out : ndarray, optional

Alternative output array in which to place the result. It must have
the same shape as the expected output, but the type of the output
values will be cast if necessary. See `doc.ufuncs` (Section
"Output arguments") for details.

Returns
----
rounded_array : ndarray
An array of the same type as `a`, containing the rounded values.
Unless `out` was specified, a new array is created. A reference to
the result is returned.

The real and imaginary parts of complex numbers are rounded
separately. The result of rounding a float is a float.

See Also
----
ndarray.round : equivalent method

ceil, fix, floor, rint, trunc

Notes

For values exactly halfway between rounded decimal values, Numpy
rounds to the nearest even value. Thus 1.5 and 2.5 round to 2.0,
-0.5 and 0.5 round to 0.0, etc. Results may also be surprising due
to the inexact representation of decimal fractions in the IEEE
floating point standard [1]_ and errors introduced when scaling
by powers of ten.

References

.. [1] "Lecture Notes on the Status of IEEE 754", William Kahan,
http://www.cs.berkeley.edu/~wkahan/ieee754status/IEEE754.PDF
.. [2] "How Futile are Mindless Assessments of
Roundoff in Floating-Point Computation?", William Kahan,
http://www.cs.berkeley.edu/~wkahan/Mindless.pdf

Examples

```
>>> np.around([0.37, 1.64])
array([ 0., 2.])
>>> np.around([0.37, 1.64], decimals=1)
array([ 0.4, 1.6])
>>> np.around([.5, 1.5, 2.5, 3.5, 4.5]) # rounds to nearest even value
array([ 0., 2., 2., 4., 4.])
```

```
>>> np.around([1,2,3,11], decimals=1) # ndarray of ints is returned
array([ 1, 2, 3, 11])
>>> np.around([1,2,3,11], decimals=-1)
array([ 0, 0, 0, 10])
```

ROUND

Round an array to the given number of decimals.

Refer to `around` for full documentation.

See Also
----
around : equivalent function

RINT

rint(x[, out])

Round elements of the array to the nearest integer.

Parameters
----
x : array_like
Input array.

Returns
----
out : {ndarray, scalar}
Output array is same shape and type as `x`.

See Also
----
ceil, floor, trunc

Examples

```
>>> a = np.array([-1.7, -1.5, -0.2, 0.2, 1.5, 1.7, 2.0])
>>> np.rint(a)
array([-2., -2., -0., 0., 2., 2., 2.])
```

FIX

Round to nearest integer towards zero.

Round an array of floats element-wise to nearest integer towards zero.
The rounded values are returned as floats.

Parameters
----
x : array_like
An array of floats to be rounded
y : ndarray, optional
Output array

Returns
----
out : ndarray of floats
The array of rounded numbers

See Also
----
trunc, floor, ceil
around : Round to given number of decimals

Examples

```
>>> np.fix(3.14)
3.0
>>> np.fix(3)
3.0
>>> np.fix([2.1, 2.9, -2.1, -2.9])
array([ 2., 2., -2., -2.])
```

FLOOR

floor(x[, out])

Return the floor of the input, element-wise.

The floor of the scalar `x` is the largest integer `i`, such that
`i <= x`. It is often denoted as :math:`\lfloor x \rfloor`.

Parameters
----
x : array_like
Input data.

Returns
----
y : {ndarray, scalar}
The floor of each element in `x`.

See Also
----
ceil, trunc, rint

Notes

Some spreadsheet programs calculate the "floor-towards-zero", in other words ``floor(-2.5) == -2``. NumPy, however, uses the a definition of `floor` such that `floor(-2.5) == -3`.

Examples

```
>>> a = np.array([-1.7, -1.5, -0.2, 0.2, 1.5, 1.7, 2.0])
>>> np.floor(a)
array([-2., -2., -1., 0., 1., 1., 2.])
```

CEIL

ceil(x[, out])

Return the ceiling of the input, element-wise.

The ceil of the scalar `x` is the smallest integer `i`, such that `i >= x`. It is often denoted as :math:`\lceil x \rceil`.

Parameters
----
x : array_like
Input data.

Returns
----
y : {ndarray, scalar}
The ceiling of each element in `x`, with `float` dtype.

See Also
----
floor, trunc, rint

Examples

```
>>> a = np.array([-1.7, -1.5, -0.2, 0.2, 1.5, 1.7, 2.0])
>>> np.ceil(a)
array([-1., -1., -0., 1., 2., 2., 2.])
```

TRUNC

trunc(x[, out])

Return the truncated value of the input, element-wise.

The truncated value of the scalar `x` is the nearest integer `i` which
is closer to zero than `x` is. In short, the fractional part of the
signed number `x` is discarded.

Parameters
----
x : array_like
Input data.

Returns
----
y : {ndarray, scalar}
The truncated value of each element in `x`.

See Also
----
ceil, floor, rint

Notes

.. versionadded:: 1.3.0

Examples

```
>>> a = np.array([-1.7, -1.5, -0.2, 0.2, 1.5, 1.7, 2.0])
>>> np.trunc(a)
array([-1., -1., -0., 0., 1., 1., 2.])
```

Sums, products, differences

PROD

Return the product of array elements over a given axis.

Parameters
----
a : array_like
Input data.
axis : int, optional

```
Axis over which the product is taken. By default, the product
of all elements is calculated.
dtype : data-type, optional
The data-type of the returned array, as well as of the accumulator
in which the elements are multiplied. By default, if `a` is of
integer type, `dtype` is the default platform integer. (Note: if
the type of `a` is unsigned, then so is `dtype`.) Otherwise,
the dtype is the same as that of `a`.
out : ndarray, optional
Alternative output array in which to place the result. It must have
the same shape as the expected output, but the type of the
output values will be cast if necessary.

Returns
-------
product_along_axis : ndarray, see `dtype` parameter above.
An array shaped as `a` but with the specified axis removed.
Returns a reference to `out` if specified.

See Also
--------
ndarray.prod : equivalent method
numpy.doc.ufuncs : Section "Output arguments"

Notes
-----
Arithmetic is modular when using integer types, and no error is
raised on overflow. That means that, on a 32-bit platform:

>>> x = np.array([536870910, 536870910, 536870910, 536870910])
>>> np.prod(x) #random
16

Examples
--------
By default, calculate the product of all elements:

>>> np.prod([1.,2.])
2.0

Even when the input array is two-dimensional:

>>> np.prod([[1.,2.],[3.,4.]])
24.0

But we can also specify the axis over which to multiply:
```

```
>>> np.prod([[1.,2.],[3.,4.]], axis=1)
array([ 2., 12.])
```

If the type of `x` is unsigned, then the output type is
the unsigned platform integer:

```
>>> x = np.array([1, 2, 3], dtype=np.uint8)
>>> np.prod(x).dtype == np.uint
True
```

If `x` is of a signed integer type, then the output type
is the default platform integer:

```
>>> x = np.array([1, 2, 3], dtype=np.int8)
>>> np.prod(x).dtype == np.int
True
```

SUM

Sum of array elements over a given axis.

Parameters
----
a : array_like
Elements to sum.
axis : integer, optional
Axis over which the sum is taken. By default `axis` is None,
and all elements are summed.
dtype : dtype, optional
The type of the returned array and of the accumulator in which
the elements are summed. By default, the dtype of `a` is used.
An exception is when `a` has an integer type with less precision
than the default platform integer. In that case, the default
platform integer is used instead.
out : ndarray, optional
Array into which the output is placed. By default, a new array is
created. If `out` is given, it must be of the appropriate shape
(the shape of `a` with `axis` removed, i.e.,
``numpy.delete(a.shape, axis)``). Its type is preserved. See
`doc.ufuncs` (Section "Output arguments") for more details.

Returns
----
sum_along_axis : ndarray
An array with the same shape as `a`, with the specified
axis removed. If `a` is a 0-d array, or if `axis` is None, a scalar

is returned. If an output array is specified, a reference to
`out` is returned.

See Also
----
ndarray.sum : Equivalent method.

cumsum : Cumulative sum of array elements.

trapz : Integration of array values using the composite trapezoidal rule.

mean, average

Notes

Arithmetic is modular when using integer types, and no error is
raised on overflow.

Examples

```
>>> np.sum([0.5, 1.5])
2.0
>>> np.sum([0.5, 0.7, 0.2, 1.5], dtype=np.int32)
1
>>> np.sum([[0, 1], [0, 5]])
6
>>> np.sum([[0, 1], [0, 5]], axis=0)
array([0, 6])
>>> np.sum([[0, 1], [0, 5]], axis=1)
array([1, 5])
```

If the accumulator is too small, overflow occurs:

```
>>> np.ones(128, dtype=np.int8).sum(dtype=np.int8)
-128
```

NANSUM

Return the sum of array elements over a given axis treating
Not a Numbers (NaNs) as zero.

Parameters
----
a : array_like
Array containing numbers whose sum is desired. If `a` is not an
array, a conversion is attempted.

axis : int, optional
Axis along which the sum is computed. The default is to compute
the sum of the flattened array.

Returns
----
y : ndarray
An array with the same shape as a, with the specified axis removed.
If a is a 0-d array, or if axis is None, a scalar is returned with
the same dtype as `a`.

See Also
----
numpy.sum : Sum across array including Not a Numbers.
isnan : Shows which elements are Not a Number (NaN).
isfinite: Shows which elements are not: Not a Number, positive and
negative infinity

Notes

Numpy uses the IEEE Standard for Binary Floating-Point for Arithmetic
(IEEE 754). This means that Not a Number is not equivalent to infinity.
If positive or negative infinity are present the result is positive or
negative infinity. But if both positive and negative infinity are present,
the result is Not A Number (NaN).

Arithmetic is modular when using integer types (all elements of `a` must
be finite i.e. no elements that are NaNs, positive infinity and negative
infinity because NaNs are floating point types), and no error is raised
on overflow.

Examples

```
>>> np.nansum(1)
1
>>> np.nansum([1])
1
>>> np.nansum([1, np.nan])
1.0
>>> a = np.array([[1, 1], [1, np.nan]])
>>> np.nansum(a)
3.0
>>> np.nansum(a, axis=0)
array([ 2., 1.])
```

When positive infinity and negative infinity are present

```
>>> np.nansum([1, np.nan, np.inf])
inf
>>> np.nansum([1, np.nan, np.NINF])
-inf
>>> np.nansum([1, np.nan, np.inf, np.NINF])
nan
```

CUMPROD

Return the cumulative product of elements along a given axis.

Parameters
----
a : array_like
Input array.
axis : int, optional
Axis along which the cumulative product is computed. By default
the input is flattened.
dtype : dtype, optional
Type of the returned array, as well as of the accumulator in which
the elements are multiplied. If *dtype* is not specified, it
defaults to the dtype of `a`, unless `a` has an integer dtype with
a precision less than that of the default platform integer. In
that case, the default platform integer is used instead.
out : ndarray, optional
Alternative output array in which to place the result. It must
have the same shape and buffer length as the expected output
but the type of the resulting values will be cast if necessary.

Returns
----
cumprod : ndarray
A new array holding the result is returned unless `out` is
specified, in which case a reference to out is returned.

See Also
----
numpy.doc.ufuncs : Section "Output arguments"

Notes

Arithmetic is modular when using integer types, and no error is
raised on overflow.

Examples

```
--------
>>> a = np.array([1,2,3])
>>> np.cumprod(a) # intermediate results 1, 1*2
... # total product 1*2*3 = 6
array([1, 2, 6])
>>> a = np.array([[1, 2, 3], [4, 5, 6]])
>>> np.cumprod(a, dtype=float) # specify type of output
array([ 1., 2., 6., 24., 120., 720.])
```

The cumulative product for each column (i.e., over the rows) of `a`:

```
>>> np.cumprod(a, axis=0)
array([[ 1, 2, 3],
[ 4, 10, 18]])
```

The cumulative product for each row (i.e. over the columns) of `a`:

```
>>> np.cumprod(a,axis=1)
array([[ 1, 2, 6],
[ 4, 20, 120]])
```

CUMSUM

Return the cumulative sum of the elements along a given axis.

Parameters
----
a : array_like
Input array.
axis : int, optional
Axis along which the cumulative sum is computed. The default
(None) is to compute the cumsum over the flattened array.
dtype : dtype, optional
Type of the returned array and of the accumulator in which the
elements are summed. If `dtype` is not specified, it defaults
to the dtype of `a`, unless `a` has an integer dtype with a
precision less than that of the default platform integer. In
that case, the default platform integer is used.
out : ndarray, optional
Alternative output array in which to place the result. It must
have the same shape and buffer length as the expected output
but the type will be cast if necessary. See `doc.ufuncs`
(Section "Output arguments") for more details.

Returns
----

cumsum_along_axis : ndarray.
A new array holding the result is returned unless `out` is
specified, in which case a reference to `out` is returned. The
result has the same size as `a`, and the same shape as `a` if
`axis` is not None or `a` is a 1-d array.

See Also
----
sum : Sum array elements.

trapz : Integration of array values using the composite trapezoidal rule.

Notes

Arithmetic is modular when using integer types, and no error is
raised on overflow.

Examples

```
>>> a = np.array([[1,2,3], [4,5,6]])
>>> a
array([[1, 2, 3],
[4, 5, 6]])
>>> np.cumsum(a)
array([ 1, 3, 6, 10, 15, 21])
>>> np.cumsum(a, dtype=float) # specifies type of output value(s)
array([ 1., 3., 6., 10., 15., 21.])

>>> np.cumsum(a,axis=0) # sum over rows for each of the 3 columns
array([[1, 2, 3],
[5, 7, 9]])
>>> np.cumsum(a,axis=1) # sum over columns for each of the 2 rows
array([[ 1, 3, 6],
[ 4, 9, 15]])
```

DIFF

Calculate the n-th order discrete difference along given axis.

The first order difference is given by ``out[n] = a[n+1] - a[n]`` along
the given axis, higher order differences are calculated by using `diff`
recursively.

Parameters
----

a : array_like
Input array
n : int, optional
The number of times values are differenced.
axis : int, optional
The axis along which the difference is taken, default is the last axis.

Returns
----
out : ndarray
The `n` order differences. The shape of the output is the same as `a`
except along `axis` where the dimension is smaller by `n`.

See Also
----
gradient, ediff1d

Examples

```
>>> x = np.array([1, 2, 4, 7, 0])
>>> np.diff(x)
array([ 1, 2, 3, -7])
>>> np.diff(x, n=2)
array([ 1, 1, -10])

>>> x = np.array([[1, 3, 6, 10], [0, 5, 6, 8]])
>>> np.diff(x)
array([[2, 3, 4],
[5, 1, 2]])
>>> np.diff(x, axis=0)
array([[-1, 2, 0, -2]])
```

EDIFF1D

The differences between consecutive elements of an array.

Parameters
----
ary : array_like
If necessary, will be flattened before the differences are taken.
to_end : array_like, optional
Number(s) to append at the end of the returned differences.
to_begin : array_like, optional
Number(s) to prepend at the beginning of the returned differences.

Returns

----
ed : ndarray
The differences. Loosely, this is ``ary.flat[1:] - ary.flat[:-1]``.

See Also
----
diff, gradient

Notes

When applied to masked arrays, this function drops the mask information
if the `to_begin` and/or `to_end` parameters are used.

Examples

```
>>> x = np.array([1, 2, 4, 7, 0])
>>> np.ediff1d(x)
array([ 1, 2, 3, -7])

>>> np.ediff1d(x, to_begin=-99, to_end=np.array([88, 99]))
array([-99, 1, 2, 3, -7, 88, 99])
```

The returned array is always 1D.

```
>>> y = [[1, 2, 4], [1, 6, 24]]
>>> np.ediff1d(y)
array([ 1, 2, -3, 5, 18])
```

GRADIENT

Return the gradient of an N-dimensional array.

The gradient is computed using central differences in the interior
and first differences at the boundaries. The returned gradient hence has
the same shape as the input array.

Parameters
----
f : array_like
An N-dimensional array containing samples of a scalar function.
`*varargs` : scalars
0, 1, or N scalars specifying the sample distances in each direction,
that is: `dx`, `dy`, `dz`, ... The default distance is 1.

Returns

----
g : ndarray
N arrays of the same shape as `f` giving the derivative of `f` with
respect to each dimension.

Examples

```
>>> x = np.array([1, 2, 4, 7, 11, 16], dtype=np.float)
>>> np.gradient(x)
array([ 1. , 1.5, 2.5, 3.5, 4.5, 5. ])
>>> np.gradient(x, 2)
array([ 0.5 , 0.75, 1.25, 1.75, 2.25, 2.5 ])

>>> np.gradient(np.array([[1, 2, 6], [3, 4, 5]], dtype=np.float))
[array([[ 2., 2., -1.],
[ 2., 2., -1.]]),
array([[ 1. , 2.5, 4. ],
[ 1. , 1. , 1. ]])]
```

CROSS

Return the cross product of two (arrays of) vectors.

The cross product of `a` and `b` in :math:`R^3` is a vector perpendicular
to both `a` and `b`. If `a` and `b` are arrays of vectors, the vectors
are defined by the last axis of `a` and `b` by default, and these axes
can have dimensions 2 or 3. Where the dimension of either `a` or `b` is
2, the third component of the input vector is assumed to be zero and the
cross product calculated accordingly. In cases where both input vectors
have dimension 2, the z-component of the cross product is returned.

Parameters
----
a : array_like
Components of the first vector(s).
b : array_like
Components of the second vector(s).
axisa : int, optional
Axis of `a` that defines the vector(s). By default, the last axis.
axisb : int, optional
Axis of `b` that defines the vector(s). By default, the last axis.
axisc : int, optional
Axis of `c` containing the cross product vector(s). By default, the
last axis.
axis : int, optional
If defined, the axis of `a`, `b` and `c` that defines the vector(s)

and cross product(s). Overrides `axisa`, `axisb` and `axisc`.

Returns
----
c : ndarray
Vector cross product(s).

Raises

ValueError
When the dimension of the vector(s) in `a` and/or `b` does not
equal 2 or 3.

See Also
----
inner : Inner product
outer : Outer product.
ix_ : Construct index arrays.

Examples

Vector cross-product.

```
>>> x = [1, 2, 3]
>>> y = [4, 5, 6]
>>> np.cross(x, y)
array([-3, 6, -3])
```

One vector with dimension 2.

```
>>> x = [1, 2]
>>> y = [4, 5, 6]
>>> np.cross(x, y)
array([12, -6, -3])
```

Equivalently:

```
>>> x = [1, 2, 0]
>>> y = [4, 5, 6]
>>> np.cross(x, y)
array([12, -6, -3])
```

Both vectors with dimension 2.

```
>>> x = [1,2]
>>> y = [4,5]
>>> np.cross(x, y)
```

-3

Multiple vector cross-products. Note that the direction of the cross product vector is defined by the `right-hand rule`.

```
>>> x = np.array([[1,2,3], [4,5,6]])
>>> y = np.array([[4,5,6], [1,2,3]])
>>> np.cross(x, y)
array([[-3, 6, -3],
[ 3, -6, 3]])
```

The orientation of `c` can be changed using the `axisc` keyword.

```
>>> np.cross(x, y, axisc=0)
array([[-3, 3],
[ 6, -6],
[-3, 3]])
```

Change the vector definition of `x` and `y` using `axisa` and `axisb`.

```
>>> x = np.array([[1,2,3], [4,5,6], [7, 8, 9]])
>>> y = np.array([[7, 8, 9], [4,5,6], [1,2,3]])
>>> np.cross(x, y)
array([[ -6, 12, -6],
[ 0, 0, 0],
[ 6, -12, 6]])
>>> np.cross(x, y, axisa=0, axisb=0)
array([[-24, 48, -24],
[-30, 60, -30],
[-36, 72, -36]])
```

TRAPZ

Integrate along the given axis using the composite trapezoidal rule.

Integrate `y` (`x`) along given axis.

Parameters
----
y : array_like
Input array to integrate.
x : array_like, optional
If `x` is None, then spacing between all `y` elements is `dx`.
dx : scalar, optional
If `x` is None, spacing given by `dx` is assumed. Default is 1.
axis : int, optional

Specify the axis.

Returns
----
out : float
Definite integral as approximated by trapezoidal rule.

See Also
----
sum, cumsum

Notes

Image [2]_ illustrates trapezoidal rule -- y-axis locations of points will
be taken from `y` array, by default x-axis distances between points will be
1.0, alternatively they can be provided with `x` array or with `dx` scalar.
Return value will be equal to combined area under the red lines.

References

.. [1] Wikipedia page: http://en.wikipedia.org/wiki/Trapezoidal_rule

.. [2] Illustration image:
http://en.wikipedia.org/wiki/File:Composite_trapezoidal_rule_illustration.png

Examples

```
>>> np.trapz([1,2,3])
4.0
>>> np.trapz([1,2,3], x=[4,6,8])
8.0
>>> np.trapz([1,2,3], dx=2)
8.0
>>> a = np.arange(6).reshape(2, 3)
>>> a
array([[0, 1, 2],
[3, 4, 5]])
>>> np.trapz(a, axis=0)
array([ 1.5, 2.5, 3.5])
>>> np.trapz(a, axis=1)
array([ 2., 8.])
```

Exponents and logarithms

EXP

exp(x[, out])

Calculate the exponential of all elements in the input array.

Parameters
----
x : array_like
Input values.

Returns
----
out : ndarray
Output array, element-wise exponential of `x`.

See Also
----
expm1 : Calculate ``exp(x) - 1`` for all elements in the array.
exp2 : Calculate ``2**x`` for all elements in the array.

Notes

The irrational number ``e`` is also known as Euler's number. It is approximately 2.718281, and is the base of the natural logarithm, ``ln`` (this means that, if :math:`x = \ln y = \log_e y`, then :math:`e^x = y`. For real input, ``exp(x)`` is always positive.

For complex arguments, ``x = a + ib``, we can write :math:`e^x = e^a e^{ib}`. The first term, :math:`e^a`, is already known (it is the real argument, described above). The second term, :math:`e^{ib}`, is :math:`\cos b + i \sin b`, a function with magnitude 1 and a periodic phase.

References

.. [1] Wikipedia, "Exponential function", http://en.wikipedia.org/wiki/Exponential_function
.. [2] M. Abramovitz and I. A. Stegun, "Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables," Dover, 1964, p. 69, http://www.math.sfu.ca/~cbm/aands/page_69.htm

Examples

Plot the magnitude and phase of ``exp(x)`` in the complex plane:

```
>>> import matplotlib.pyplot as plt

>>> x = np.linspace(-2*np.pi, 2*np.pi, 100)
>>> xx = x + 1j * x[:, np.newaxis] # a + ib over complex plane
>>> out = np.exp(xx)

>>> plt.subplot(121)
>>> plt.imshow(np.abs(out),
... extent=[-2*np.pi, 2*np.pi, -2*np.pi, 2*np.pi])
>>> plt.title('Magnitude of exp(x)')

>>> plt.subplot(122)
>>> plt.imshow(np.angle(out),
... extent=[-2*np.pi, 2*np.pi, -2*np.pi, 2*np.pi])
>>> plt.title('Phase (angle) of exp(x)')
>>> plt.show()
```

EXPM1

expm1(x[, out])

Calculate ``exp(x) - 1`` for all elements in the array.

Parameters
----
x : array_like
Input values.

Returns
----
out : ndarray
Element-wise exponential minus one: ``out = exp(x) - 1``.

See Also
----
log1p : ``log(1 + x)``, the inverse of expm1.

Notes

This function provides greater precision than the formula ``exp(x) - 1``
for small values of ``x``.

Examples

The true value of ``exp(1e-10) - 1`` is ``1.00000000005e-10`` to

about 32 significant digits. This example shows the superiority of
expm1 in this case.

```
>>> np.expm1(1e-10)
1.00000000005e-10
>>> np.exp(1e-10) - 1
1.000000082740371e-10
```

exp2

exp2(x[, out])

Calculate `2**p` for all `p` in the input array.

Parameters
----
x : array_like
Input values.

out : ndarray, optional
Array to insert results into.

Returns
----
out : ndarray
Element-wise 2 to the power `x`.

See Also
----
exp : calculate x**p.

Notes

.. versionadded:: 1.3.0

Examples

```
>>> np.exp2([2, 3])
array([ 4., 8.])
```

LOG

log(x[, out])

Natural logarithm, element-wise.

The natural logarithm `log` is the inverse of the exponential function, so that `log(exp(x)) = x`. The natural logarithm is logarithm in base `e`.

```
Parameters
----------
x : array_like
Input value.

Returns
-------
y : ndarray
The natural logarithm of `x`, element-wise.

See Also
--------
log10, log2, log1p, emath.log

Notes
-----
Logarithm is a multivalued function: for each `x` there is an infinite
number of `z` such that `exp(z) = x`. The convention is to return the `z`
whose imaginary part lies in `[-pi, pi]`.

For real-valued input data types, `log` always returns real output. For
each value that cannot be expressed as a real number or infinity, it
yields ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `log` is a complex analytical function that
has a branch cut `[-inf, 0]` and is continuous from above on it. `log`
handles the floating-point negative zero as an infinitesimal negative
number, conforming to the C99 standard.

References
----------
.. [1] M. Abramowitz and I.A. Stegun, "Handbook of Mathematical Functions",
10th printing, 1964, pp. 67. http://www.math.sfu.ca/~cbm/aands/
.. [2] Wikipedia, "Logarithm". http://en.wikipedia.org/wiki/Logarithm

Examples
--------
>>> np.log([1, np.e, np.e**2, 0])
array([ 0., 1., 2., -Inf])
```

LOG10

log10(x[, out])

Return the base 10 logarithm of the input array, element-wise.

Parameters
----
x : array_like
Input values.

Returns
----
y : ndarray
The logarithm to the base 10 of `x`, element-wise. NaNs are
returned where x is negative.

See Also
----
emath.log10

Notes

Logarithm is a multivalued function: for each `x` there is an infinite
number of `z` such that `10**z = x`. The convention is to return the `z`
whose imaginary part lies in `[-pi, pi]`.

For real-valued input data types, `log10` always returns real output. For
each value that cannot be expressed as a real number or infinity, it
yields ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `log10` is a complex analytical function that
has a branch cut `[-inf, 0]` and is continuous from above on it. `log10`
handles the floating-point negative zero as an infinitesimal negative
number, conforming to the C99 standard.

References

.. [1] M. Abramowitz and I.A. Stegun, "Handbook of Mathematical Functions",
10th printing, 1964, pp. 67. http://www.math.sfu.ca/~cbm/aands/
.. [2] Wikipedia, "Logarithm". http://en.wikipedia.org/wiki/Logarithm

Examples

```
>>> np.log10([1e-15, -3.])
array([-15., NaN])
```

LOG2

log2(x[, out])

Base-2 logarithm of `x`.

```
Parameters
----------
x : array_like
Input values.

Returns
-------
y : ndarray
Base-2 logarithm of `x`.

See Also
--------
log, log10, log1p, emath.log2

Notes
-----
.. versionadded:: 1.3.0

Logarithm is a multivalued function: for each `x` there is an infinite
number of `z` such that `2**z = x`. The convention is to return the `z`
whose imaginary part lies in `[-pi, pi]`.

For real-valued input data types, `log2` always returns real output. For
each value that cannot be expressed as a real number or infinity, it
yields ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `log2` is a complex analytical function that
has a branch cut `[-inf, 0]` and is continuous from above on it. `log2`
handles the floating-point negative zero as an infinitesimal negative
number, conforming to the C99 standard.

Examples
--------
>>> x = np.array([0, 1, 2, 2**4])
>>> np.log2(x)
array([-Inf, 0., 1., 4.])

>>> xi = np.array([0+1.j, 1, 2+0.j, 4.j])
>>> np.log2(xi)
array([ 0.+2.26618007j, 0.+0.j , 1.+0.j , 2.+2.26618007j])
```

LOG1P

```
log1p(x[, out])

Return the natural logarithm of one plus the input array, element-wise.
```

Calculates ``log(1 + x)``.

Parameters
----
x : array_like
Input values.

Returns
----
y : ndarray
Natural logarithm of `1 + x`, element-wise.

See Also
----
expm1 : ``exp(x) - 1``, the inverse of `log1p`.

Notes

For real-valued input, `log1p` is accurate also for `x` so small
that `1 + x == 1` in floating-point accuracy.

Logarithm is a multivalued function: for each `x` there is an infinite
number of `z` such that `exp(z) = 1 + x`. The convention is to return
the `z` whose imaginary part lies in `[-pi, pi]`.

For real-valued input data types, `log1p` always returns real output. For
each value that cannot be expressed as a real number or infinity, it
yields ``nan`` and sets the `invalid` floating point error flag.

For complex-valued input, `log1p` is a complex analytical function that
has a branch cut `[-inf, -1]` and is continuous from above on it. `log1p`
handles the floating-point negative zero as an infinitesimal negative
number, conforming to the C99 standard.

References

.. [1] M. Abramowitz and I.A. Stegun, "Handbook of Mathematical Functions",
10th printing, 1964, pp. 67. http://www.math.sfu.ca/~cbm/aands/
.. [2] Wikipedia, "Logarithm". http://en.wikipedia.org/wiki/Logarithm

Examples

```
>>> np.log1p(1e-99)
1e-99
>>> np.log(1 + 1e-99)
0.0
```

LOGADDEXP

logaddexp(x1, x2[, out])

Logarithm of the sum of exponentiations of the inputs.

Calculates ``log(exp(x1) + exp(x2))``. This function is useful in
statistics where the calculated probabilities of events may be so small
as to exceed the range of normal floating point numbers. In such cases
the logarithm of the calculated probability is stored. This function
allows adding probabilities stored in such a fashion.

Parameters
----
x1, x2 : array_like
Input values.

Returns
----
result : ndarray
Logarithm of ``exp(x1) + exp(x2)``.

See Also
----
logaddexp2: Logarithm of the sum of exponentiations of inputs in base-2.

Notes

.. versionadded:: 1.3.0

Examples

```
>>> prob1 = np.log(1e-50)
>>> prob2 = np.log(2.5e-50)
>>> prob12 = np.logaddexp(prob1, prob2)
>>> prob12
-113.87649168120691
>>> np.exp(prob12)
3.5000000000000057e-50
```

LOGADDEXP2

logaddexp2(x1, x2[, out])

Logarithm of the sum of exponentiations of the inputs in base-2.

Calculates ``log2(2**x1 + 2**x2)``. This function is useful in machine

learning when the calculated probabilities of events may be so small
as to exceed the range of normal floating point numbers. In such cases
the base-2 logarithm of the calculated probability can be used instead.
This function allows adding probabilities stored in such a fashion.

Parameters
----
x1, x2 : array_like
Input values.
out : ndarray, optional
Array to store results in.

Returns
----
result : ndarray
Base-2 logarithm of ``2**x1 + 2**x2``.

See Also
----
logaddexp: Logarithm of the sum of exponentiations of the inputs.

Notes

.. versionadded:: 1.3.0

Examples

```
>>> prob1 = np.log2(1e-50)
>>> prob2 = np.log2(2.5e-50)
>>> prob12 = np.logaddexp2(prob1, prob2)
>>> prob1, prob2, prob12
(-166.09640474436813, -164.77447664948076, -164.28904982231052)
>>> 2**prob12
3.4999999999999914e-50
```

Other special functions

i0

Modified Bessel function of the first kind, order 0.

Usually denoted :math:`I_0`. This function does broadcast, but will *not*
"up-cast" int dtype arguments unless accompanied by at least one float or
complex dtype argument (see Raises below).

Parameters
----
x : array_like, dtype float or complex
Argument of the Bessel function.

Returns
----
out : ndarray, shape = x.shape, dtype = x.dtype
The modified Bessel function evaluated at each of the elements of `x`.

Raises

TypeError: array cannot be safely cast to required type
If argument consists exclusively of int dtypes.

See Also
----
scipy.special.iv, scipy.special.ive

Notes

We use the algorithm published by Clenshaw [1]_ and referenced by
Abramowitz and Stegun [2]_, for which the function domain is partitioned
into the two intervals [0,8] and (8,inf), and Chebyshev polynomial
expansions are employed in each interval. Relative error on the domain
[0,30] using IEEE arithmetic is documented [3]_ as having a peak of 5.8e-16
with an rms of 1.4e-16 (n = 30000).

References

.. [1] C. W. Clenshaw, "Chebyshev series for mathematical functions," in
National Physical Laboratory Mathematical Tables, vol. 5, London:
Her Majesty's Stationery Office, 1962.
.. [2] M. Abramowitz and I. A. Stegun, *Handbook of Mathematical
Functions*, 10th printing, New York: Dover, 1964, pp. 379.
http://www.math.sfu.ca/~cbm/aands/page_379.htm
.. [3] http://kobesearch.cpan.org/htdocs/Math-Cephes/Math/Cephes.html

Examples

```
>>> np.i0([0.])
array(1.0)
>>> np.i0([0., 1. + 2j])
array([ 1.00000000+0.j , 0.18785373+0.64616944j])
```

SINC

Return the sinc function.

The sinc function is :math:`\sin(\pi x)/(\pi x)`.

Parameters
----
x : ndarray
Array (possibly multi-dimensional) of values for which to to
calculate ``sinc(x)``.

Returns
----
out : ndarray
``sinc(x)``, which has the same shape as the input.

Notes

``sinc(0)`` is the limit value 1.

The name sinc is short for "sine cardinal" or "sinus cardinalis".

The sinc function is used in various signal processing applications,
including in anti-aliasing, in the construction of a
Lanczos resampling filter, and in interpolation.

For bandlimited interpolation of discrete-time signals, the ideal
interpolation kernel is proportional to the sinc function.

References

.. [1] Weisstein, Eric W. "Sinc Function." From MathWorld--A Wolfram Web
Resource. http://mathworld.wolfram.com/SincFunction.html
.. [2] Wikipedia, "Sinc function",
http://en.wikipedia.org/wiki/Sinc_function

Examples

```
>>> x = np.arange(-20., 21.)/5.
>>> np.sinc(x)
array([ -3.89804309e-17, -4.92362781e-02, -8.40918587e-02,
-8.90384387e-02, -5.84680802e-02, 3.89804309e-17,
6.68206631e-02, 1.16434881e-01, 1.26137788e-01,
8.50444803e-02, -3.89804309e-17, -1.03943254e-01,
-1.89206682e-01, -2.16236208e-01, -1.55914881e-01,
3.89804309e-17, 2.33872321e-01, 5.04551152e-01,
7.56826729e-01, 9.35489284e-01, 1.00000000e+00,
9.35489284e-01, 7.56826729e-01, 5.04551152e-01,
2.33872321e-01, 3.89804309e-17, -1.55914881e-01,
-2.16236208e-01, -1.89206682e-01, -1.03943254e-01,
-3.89804309e-17, 8.50444803e-02, 1.26137788e-01,
1.16434881e-01, 6.68206631e-02, 3.89804309e-17,
-5.84680802e-02, -8.90384387e-02, -8.40918587e-02,
-4.92362781e-02, -3.89804309e-17])

>>> import matplotlib.pyplot as plt
>>> plt.plot(x, np.sinc(x))
[]
>>> plt.title("Sinc Function")

>>> plt.ylabel("Amplitude")

>>> plt.xlabel("X")

>>> plt.show()
```

It works in 2-D as well:

```
>>> x = np.arange(-200., 201.)/50.
>>> xx = np.outer(x, x)
>>> plt.imshow(np.sinc(xx))
```

Floating point routines

signbit

signbit(x[, out])

Returns element-wise True where signbit is set (less than zero).

Parameters
----
x: array_like
The input value(s).
out : ndarray, optional
Array into which the output is placed. Its type is preserved
and it must be of the right shape to hold the output.
See `doc.ufuncs`.

Returns
----
result : ndarray of bool
Output array, or reference to `out` if that was supplied.

Examples

```
>>> np.signbit(-1.2)
True
>>> np.signbit(np.array([1, -2.3, 2.1]))
array([False, True, False], dtype=bool)
```

COPYSIGN

copysign(x1, x2[, out])

Change the sign of x1 to that of x2, element-wise.

If both arguments are arrays or sequences, they have to be of the same length. If `x2` is a scalar, its sign will be copied to all elements of `x1`.

Parameters
----
x1: array_like
Values to change the sign of.
x2: array_like
The sign of `x2` is copied to `x1`.
out : ndarray, optional
Array into which the output is placed. Its type is preserved and it must be of the right shape to hold the output. See doc.ufuncs.

Returns
----
out : array_like
The values of `x1` with the sign of `x2`.

Examples

```
>>> np.copysign(1.3, -1)
-1.3
>>> 1/np.copysign(0, 1)
inf
>>> 1/np.copysign(0, -1)
-inf
```

```
>>> np.copysign([-1, 0, 1], -1.1)
array([-1., -0., -1.])
>>> np.copysign([-1, 0, 1], np.arange(3)-1)
array([-1., 0., 1.])
```

FREXP

frexp(x[, out1, out2])

Split the number, x, into a normalized fraction (y1) and exponent (y2)

LDEXP

ldexp(x1, x2[, out])

Compute y = x1 * 2**x2.

ARITHMETIC OPERATIONS

ADD

add(x1, x2[, out])

Add arguments element-wise.

```
Parameters
----------
x1, x2 : array_like
The arrays to be added. If ``x1.shape != x2.shape``, they must be
broadcastable to a common shape (which may be the shape of one or
the other).

Returns
-------
y : ndarray or scalar
The sum of `x1` and `x2`, element-wise. Returns a scalar if
both `x1` and `x2` are scalars.

Notes
-----
Equivalent to `x1` + `x2` in terms of array broadcasting.

Examples
--------
>>> np.add(1.0, 4.0)
```

```
5.0
>>> x1 = np.arange(9.0).reshape((3, 3))
>>> x2 = np.arange(3.0)
>>> np.add(x1, x2)
array([[ 0., 2., 4.],
[ 3., 5., 7.],
[ 6., 8., 10.]])
```

RECIPROCAL

reciprocal(x[, out])

Return the reciprocal of the argument, element-wise.

Calculates ``1/x``.

Parameters
----
x : array_like
Input array.

Returns
----
y : ndarray
Return array.

Notes

.. note::
This function is not designed to work with integers.

For integer arguments with absolute value larger than 1 the result is
always zero because of the way Python handles integer division.
For integer zero the result is an overflow.

Examples

```
>>> np.reciprocal(2.)
0.5
>>> np.reciprocal([1, 2., 3.33])
array([ 1. , 0.5 , 0.3003003])
```

NEGATIVE

negative(x[, out])

Returns an array with the negative of each element of the original array.

```
Parameters
----------
x : array_like or scalar
Input array.

Returns
-------
y : ndarray or scalar
Returned array or scalar: `y = -x`.

Examples
--------
>>> np.negative([1.,-1.])
array([-1., 1.])
```

MULTIPLY

```
multiply(x1, x2[, out])

Multiply arguments element-wise.

Parameters
----------
x1, x2 : array_like
Input arrays to be multiplied.

Returns
-------
y : ndarray
The product of `x1` and `x2`, element-wise. Returns a scalar if
both `x1` and `x2` are scalars.

Notes
-----
Equivalent to `x1` * `x2` in terms of array broadcasting.

Examples
--------
>>> np.multiply(2.0, 4.0)
8.0

>>> x1 = np.arange(9.0).reshape((3, 3))
>>> x2 = np.arange(3.0)
>>> np.multiply(x1, x2)
array([[ 0., 1., 4.],
[ 0., 4., 10.],
[ 0., 7., 16.]])
```

DIVIDE

divide(x1, x2[, out])

Divide arguments element-wise.

Parameters
----
x1 : array_like
Dividend array.
x2 : array_like
Divisor array.
out : ndarray, optional
Array into which the output is placed. Its type is preserved and it must be of the right shape to hold the output. See doc.ufuncs.

Returns
----
y : {ndarray, scalar}
The quotient `x1/x2`, element-wise. Returns a scalar if both `x1` and `x2` are scalars.

See Also
----
seterr : Set whether to raise or warn on overflow, underflow and division by zero.

Notes

Equivalent to `x1` / `x2` in terms of array-broadcasting.

Behavior on division by zero can be changed using `seterr`.

When both `x1` and `x2` are of an integer type, `divide` will return integers and throw away the fractional part. Moreover, division by zero always yields zero in integer arithmetic.

Examples

```
>>> np.divide(2.0, 4.0)
0.5
>>> x1 = np.arange(9.0).reshape((3, 3))
>>> x2 = np.arange(3.0)
>>> np.divide(x1, x2)
```

```
array([[ NaN, 1. , 1. ],
[ Inf, 4. , 2.5],
[ Inf, 7. , 4. ]])
```

Note the behavior with integer types:

```
>>> np.divide(2, 4)
0
>>> np.divide(2, 4.)
0.5
```

Division by zero always yields zero in integer arithmetic, and does not raise an exception or a warning:

```
>>> np.divide(np.array([0, 1], dtype=int), np.array([0, 0], dtype=int))
array([0, 0])
```

Division by zero can, however, be caught using `seterr`:

```
>>> old_err_state = np.seterr(divide='raise')
>>> np.divide(1, 0)
Traceback (most recent call last):
File "", line 1, in
FloatingPointError: divide by zero encountered in divide

>>> ignored_states = np.seterr(**old_err_state)
>>> np.divide(1, 0)
0
```

POWER

power(x1, x2[, out])

First array elements raised to powers from second array, element-wise.

Raise each base in `x1` to the positionally-corresponding power in `x2`. `x1` and `x2` must be broadcastable to the same shape.

Parameters
----
x1 : array_like
The bases.
x2 : array_like
The exponents.

Returns
----

y : ndarray
The bases in `x1` raised to the exponents in `x2`.

Examples

Cube each element in a list.

```
>>> x1 = range(6)
>>> x1
[0, 1, 2, 3, 4, 5]
>>> np.power(x1, 3)
array([ 0, 1, 8, 27, 64, 125])
```

Raise the bases to different exponents.

```
>>> x2 = [1.0, 2.0, 3.0, 3.0, 2.0, 1.0]
>>> np.power(x1, x2)
array([ 0., 1., 8., 27., 16., 5.])
```

The effect of broadcasting.

```
>>> x2 = np.array([[1, 2, 3, 3, 2, 1], [1, 2, 3, 3, 2, 1]])
>>> x2
array([[1, 2, 3, 3, 2, 1],
[1, 2, 3, 3, 2, 1]])
>>> np.power(x1, x2)
array([[ 0, 1, 8, 27, 16, 5],
[ 0, 1, 8, 27, 16, 5]])
```

SUBTRACT

subtract(x1, x2[, out])

Subtract arguments, element-wise.

Parameters
----
x1, x2 : array_like
The arrays to be subtracted from each other.

Returns
----
y : ndarray
The difference of `x1` and `x2`, element-wise. Returns a scalar if both `x1` and `x2` are scalars.

Notes

Equivalent to ``x1 - x2`` in terms of array broadcasting.

Examples

```
>>> np.subtract(1.0, 4.0)
-3.0

>>> x1 = np.arange(9.0).reshape((3, 3))
>>> x2 = np.arange(3.0)
>>> np.subtract(x1, x2)
array([[ 0., 0., 0.],
[ 3., 3., 3.],
[ 6., 6., 6.]])
```

TRUE_DIVIDE

true_divide(x1, x2[, out])

Returns a true division of the inputs, element-wise.

Instead of the Python traditional 'floor division', this returns a true division. True division adjusts the output type to present the best answer, regardless of input types.

Parameters
----
x1 : array_like
Dividend array.
x2 : array_like
Divisor array.

Returns
----
out : ndarray
Result is scalar if both inputs are scalar, ndarray otherwise.

Notes

The floor division operator ``//`` was added in Python 2.2 making ``//`` and ``/`` equivalent operators. The default floor division operation of ``/`` can be replaced by true division with ``from __future__ import division``.

In Python 3.0, ``//`` is the floor division operator and ``/`` the true division operator. The ``true_divide(x1, x2)`` function is equivalent to true division in Python.

Examples

```
>>> x = np.arange(5)
>>> np.true_divide(x, 4)
array([ 0. , 0.25, 0.5 , 0.75, 1. ])

>>> x/4
array([0, 0, 0, 0, 1])
>>> x//4
array([0, 0, 0, 0, 1])

>>> from __future__ import division
>>> x/4
array([ 0. , 0.25, 0.5 , 0.75, 1. ])
>>> x//4
array([0, 0, 0, 0, 1])
```

FLOOR_DIVIDE

floor_divide(x1, x2[, out])

Return the largest integer smaller or equal to the division of the inputs.

Parameters
----
x1 : array_like
Numerator.
x2 : array_like
Denominator.

Returns
----
y : ndarray
y = floor(`x1`/`x2`)

See Also
----
divide : Standard division.
floor : Round a number to the nearest integer toward minus infinity.
ceil : Round a number to the nearest integer toward infinity.

Examples

```
>>> np.floor_divide(7,3)
2
```

```
>>> np.floor_divide([1., 2., 3., 4.], 2.5)
array([ 0., 0., 1., 1.])
```

FMOD

fmod(x1, x2[, out])

Return the element-wise remainder of division.

This is the NumPy implementation of the Python modulo operator `%`.

Parameters
----
x1 : array_like
Dividend.
x2 : array_like
Divisor.

Returns
----
y : array_like
The remainder of the division of `x1` by `x2`.

See Also
----
remainder : Modulo operation where the quotient is `floor(x1/x2)`.
divide

Notes

The result of the modulo operation for negative dividend and divisors is bound by conventions. In `fmod`, the sign of the remainder is the sign of the dividend. In `remainder`, the sign of the divisor does not affect the sign of the result.

Examples

```
>>> np.fmod([-3, -2, -1, 1, 2, 3], 2)
array([-1, 0, -1, 1, 0, 1])
>>> np.remainder([-3, -2, -1, 1, 2, 3], 2)
array([1, 0, 1, 1, 0, 1])

>>> np.fmod([5, 3], [2, 2.])
array([ 1., 1.])
>>> a = np.arange(-3, 3).reshape(3, 2)
>>> a
array([[-3, -2],
[-1, 0],
[ 1, 2]])
>>> np.fmod(a, [2,2])
array([[-1, 0],
[-1, 0],
[ 1, 0]])
```

MOD

```
remainder(x1, x2[, out])

Return element-wise remainder of division.

Computes ``x1 - floor(x1 / x2) * x2``.

Parameters
----------
x1 : array_like
Dividend array.
x2 : array_like
Divisor array.
out : ndarray, optional
Array into which the output is placed. Its type is preserved and it
must be of the right shape to hold the output. See doc.ufuncs.

Returns
-------
y : ndarray
The remainder of the quotient ``x1/x2``, element-wise. Returns a scalar
if both `x1` and `x2` are scalars.

See Also
--------
divide, floor

Notes
-----
Returns 0 when `x2` is 0 and both `x1` and `x2` are (arrays of) integers.

Examples
--------
>>> np.remainder([4, 7], [2, 3])
array([0, 1])
>>> np.remainder(np.arange(7), 5)
array([0, 1, 2, 3, 4, 0, 1])
```

MODF

modf(x[, out1, out2])

Return the fractional and integral parts of an array, element-wise.

The fractional and integral parts are negative if the given number is
negative.

Parameters
----
x : array_like
Input array.

Returns
----
y1 : ndarray
Fractional part of `x`.
y2 : ndarray
Integral part of `x`.

Notes

For integer input the return values are floats.

Examples

```
>>> np.modf([0, 3.5])
(array([ 0. , 0.5]), array([ 0., 3.]))
>>> np.modf(-0.5)
(-0.5, -0)
```

REMAINDER

remainder(x1, x2[, out])

Return element-wise remainder of division.

Computes ``x1 - floor(x1 / x2) * x2``.

Parameters
----
x1 : array_like
Dividend array.
x2 : array_like
Divisor array.
out : ndarray, optional

Array into which the output is placed. Its type is preserved and it
must be of the right shape to hold the output. See doc.ufuncs.

Returns
----
y : ndarray
The remainder of the quotient ``x1/x2``, element-wise. Returns a scalar
if both `x1` and `x2` are scalars.

See Also
----
divide, floor

Notes

Returns 0 when `x2` is 0 and both `x1` and `x2` are (arrays of) integers.

Examples

```
>>> np.remainder([4, 7], [2, 3])
array([0, 1])
>>> np.remainder(np.arange(7), 5)
array([0, 1, 2, 3, 4, 0, 1])
```

Handling complex numbers

ANGLE

Return the angle of the complex argument.

Parameters
----
z : array_like
A complex number or sequence of complex numbers.
deg : bool, optional
Return angle in degrees if True, radians if False (default).

Returns
----
angle : {ndarray, scalar}
The counterclockwise angle from the positive real axis on
the complex plane, with dtype as numpy.float64.

See Also

----
arctan2
absolute

Examples

```
>>> np.angle([1.0, 1.0j, 1+1j]) # in radians
array([ 0. , 1.57079633, 0.78539816])
>>> np.angle(1+1j, deg=True) # in degrees
45.0
```

REAL

Return the real part of the elements of the array.

Parameters
----
val : array_like
Input array.

Returns
----
out : ndarray
Output array. If `val` is real, the type of `val` is used for the
output. If `val` has complex elements, the returned type is float.

See Also
----
real_if_close, imag, angle

Examples

```
>>> a = np.array([1+2j, 3+4j, 5+6j])
>>> a.real
array([ 1., 3., 5.])
>>> a.real = 9
>>> a
array([ 9.+2.j, 9.+4.j, 9.+6.j])
>>> a.real = np.array([9, 8, 7])
>>> a
array([ 9.+2.j, 8.+4.j, 7.+6.j])
```

IMAG

Return the imaginary part of the elements of the array.

Parameters
----
val : array_like
Input array.

Returns
----
out : ndarray
Output array. If `val` is real, the type of `val` is used for the
output. If `val` has complex elements, the returned type is float.

See Also
----
real, angle, real_if_close

Examples

```
>>> a = np.array([1+2j, 3+4j, 5+6j])
>>> a.imag
array([ 2., 4., 6.])
>>> a.imag = np.array([8, 10, 12])
>>> a
array([ 1. +8.j, 3.+10.j, 5.+12.j])
```

CONJ

conjugate(x[, out])

Return the complex conjugate, element-wise.

The complex conjugate of a complex number is obtained by changing the
sign of its imaginary part.

Parameters
----
x : array_like
Input value.

Returns
----
y : ndarray
The complex conjugate of `x`, with same dtype as `y`.

Examples

```
--------
>>> np.conjugate(1+2j)
(1-2j)

>>> x = np.eye(2) + 1j * np.eye(2)
>>> np.conjugate(x)
array([[ 1.-1.j, 0.-0.j],
[ 0.-0.j, 1.-1.j]])
```

Miscellaneous

CONVOLVE

Returns the discrete, linear convolution of two one-dimensional sequences.

The convolution operator is often seen in signal processing, where it models the effect of a linear time-invariant system on a signal [1]_. In probability theory, the sum of two independent random variables is distributed according to the convolution of their individual distributions.

Parameters
----
a : (N,) array_like
First one-dimensional input array.
v : (M,) array_like
Second one-dimensional input array.
mode : {'full', 'valid', 'same'}, optional
'full':
By default, mode is 'full'. This returns the convolution
at each point of overlap, with an output shape of (N+M-1,). At
the end-points of the convolution, the signals do not overlap
completely, and boundary effects may be seen.

'same':
Mode `same` returns output of length ``max(M, N)``. Boundary
effects are still visible.

'valid':
Mode `valid` returns output of length
``max(M, N) - min(M, N) + 1``. The convolution product is only given
for points where the signals overlap completely. Values outside
the signal boundary have no effect.

```
Returns
-------
out : ndarray
Discrete, linear convolution of `a` and `v`.

See Also
--------
scipy.signal.fftconvolve : Convolve two arrays using the Fast Fourier
Transform.
scipy.linalg.toeplitz : Used to construct the convolution operator.

Notes
-----
The discrete convolution operation is defined as

.. math:: (f * g)[n] = \sum_{m = -\infty}^{\infty} f[m] g[n - m]

It can be shown that a convolution :math:`x(t) * y(t)` in time/space
is equivalent to the multiplication :math:`X(f) Y(f)` in the Fourier
domain, after appropriate padding (padding is necessary to prevent
circular convolution). Since multiplication is more efficient (faster)
than convolution, the function `scipy.signal.fftconvolve` exploits the
FFT to calculate the convolution of large data-sets.

References
----------
.. [1] Wikipedia, "Convolution", http://en.wikipedia.org/wiki/Convolution.

Examples
--------
Note how the convolution operator flips the second array
before "sliding" the two across one another:

>>> np.convolve([1, 2, 3], [0, 1, 0.5])
array([ 0. , 1. , 2.5, 4. , 1.5])

Only return the middle values of the convolution.
Contains boundary effects, where zeros are taken
into account:

>>> np.convolve([1,2,3],[0,1,0.5], 'same')
array([ 1. , 2.5, 4. ])

The two arrays are of the same length, so there
is only one position where they completely overlap:
```

```
>>> np.convolve([1,2,3],[0,1,0.5], 'valid')
array([ 2.5])
```

CLIP

Clip (limit) the values in an array.

Given an interval, values outside the interval are clipped to
the interval edges. For example, if an interval of ``[0, 1]``
is specified, values smaller than 0 become 0, and values larger
than 1 become 1.

Parameters
----
a : array_like
Array containing elements to clip.
a_min : scalar or array_like
Minimum value.
a_max : scalar or array_like
Maximum value. If `a_min` or `a_max` are array_like, then they will
be broadcasted to the shape of `a`.
out : ndarray, optional
The results will be placed in this array. It may be the input
array for in-place clipping. `out` must be of the right shape
to hold the output. Its type is preserved.

Returns
----
clipped_array : ndarray
An array with the elements of `a`, but where values
< `a_min` are replaced with `a_min`, and those > `a_max`
with `a_max`.

See Also
----
numpy.doc.ufuncs : Section "Output arguments"

Examples

```
>>> a = np.arange(10)
>>> np.clip(a, 1, 8)
array([1, 1, 2, 3, 4, 5, 6, 7, 8, 8])
>>> a
array([0, 1, 2, 3, 4, 5, 6, 7, 8, 9])
>>> np.clip(a, 3, 6, out=a)
array([3, 3, 3, 3, 4, 5, 6, 6, 6, 6])
```

```
>>> a = np.arange(10)
>>> a
array([0, 1, 2, 3, 4, 5, 6, 7, 8, 9])
>>> np.clip(a, [3,4,1,1,1,4,4,4,4,4], 8)
array([3, 4, 2, 3, 4, 5, 6, 7, 8, 8])
```

SQRT

```
sqrt(x[, out])

Return the positive square-root of an array, element-wise.

Parameters
----------
x : array_like
The values whose square-roots are required.
out : ndarray, optional
Alternate array object in which to put the result; if provided, it
must have the same shape as `x`

Returns
-------
y : ndarray
An array of the same shape as `x`, containing the positive
square-root of each element in `x`. If any element in `x` is
complex, a complex array is returned (and the square-roots of
negative reals are calculated). If all of the elements in `x`
are real, so is `y`, with negative elements returning ``nan``.
If `out` was provided, `y` is a reference to it.

See Also
--------
lib.scimath.sqrt
A version which returns complex numbers when given negative reals.

Notes
-----
*sqrt* has--consistent with common convention--as its branch cut the
real "interval" [`-inf`, 0), and is continuous from above on it.
(A branch cut is a curve in the complex plane across which a given
complex function fails to be continuous.)

Examples
--------
>>> np.sqrt([1,4,9])
array([ 1., 2., 3.])
```

```
>>> np.sqrt([4, -1, -3+4J])
array([ 2.+0.j, 0.+1.j, 1.+2.j])

>>> np.sqrt([4, -1, numpy.inf])
array([ 2., NaN, Inf])
```

SQUARE

square(x[, out])

Return the element-wise square of the input.

Parameters
----
x : array_like
Input data.

Returns
----
out : ndarray
Element-wise `x*x`, of the same shape and dtype as `x`.
Returns scalar if `x` is a scalar.

See Also
----
numpy.linalg.matrix_power
sqrt
power

Examples

```
>>> np.square([-1j, 1])
array([-1.-0.j, 1.+0.j])
```

ABSOLUTE

absolute(x[, out])

Calculate the absolute value element-wise.

Parameters
----
x : array_like
Input array.

Returns

```
absolute : ndarray
An ndarray containing the absolute value of
each element in `x`. For complex input, ``a + ib``, the
absolute value is :math:`\sqrt{ a^2 + b^2 }`.

Examples
--------
>>> x = np.array([-1.2, 1.2])
>>> np.absolute(x)
array([ 1.2, 1.2])
>>> np.absolute(1.2 + 1j)
1.5620499351813308

Plot the function over ``[-10, 10]``:

>>> import matplotlib.pyplot as plt

>>> x = np.linspace(-10, 10, 101)
>>> plt.plot(x, np.absolute(x))
>>> plt.show()

Plot the function over the complex plane:

>>> xx = x + 1j * x[:, np.newaxis]
>>> plt.imshow(np.abs(xx), extent=[-10, 10, -10, 10])
>>> plt.show()
```

ABS

```
absolute(x[, out])

Calculate the absolute value element-wise.

Parameters
----------
x : array_like
Input array.

Returns
-------
absolute : ndarray
An ndarray containing the absolute value of
each element in `x`. For complex input, ``a + ib``, the
absolute value is :math:`\sqrt{ a^2 + b^2 }`.

Examples
--------
```

```
>>> x = np.array([-1.2, 1.2])
>>> np.absolute(x)
array([ 1.2, 1.2])
>>> np.absolute(1.2 + 1j)
1.5620499351813308
```

Plot the function over ``[-10, 10]``:

```
>>> import matplotlib.pyplot as plt

>>> x = np.linspace(-10, 10, 101)
>>> plt.plot(x, np.absolute(x))
>>> plt.show()
```

Plot the function over the complex plane:

```
>>> xx = x + 1j * x[:, np.newaxis]
>>> plt.imshow(np.abs(xx), extent=[-10, 10, -10, 10])
>>> plt.show()
```

FABS

fabs(x[, out])

Compute the absolute values elementwise.

This function returns the absolute values (positive magnitude) of the data in `x`. Complex values are not handled, use `absolute` to find the absolute values of complex data.

Parameters
----
x : array_like
The array of numbers for which the absolute values are required. If `x` is a scalar, the result `y` will also be a scalar.
out : ndarray, optional
Array into which the output is placed. Its type is preserved and it must be of the right shape to hold the output. See doc.ufuncs.

Returns
----
y : {ndarray, scalar}
The absolute values of `x`, the returned values are always floats.

See Also
----
absolute : Absolute values including `complex` types.

```
Examples
--------
>>> np.fabs(-1)
1.0
>>> np.fabs([-1.2, 1.2])
array([ 1.2, 1.2])
```

SIGN

sign(x[, out])

Returns an element-wise indication of the sign of a number.

The `sign` function returns ``-1 if x < 0, 0 if x==0, 1 if x > 0``.

```
Parameters
----------
x : array_like
Input values.

Returns
-------
y : ndarray
The sign of `x`.

Examples
--------
>>> np.sign([-5., 4.5])
array([-1., 1.])
>>> np.sign(0)
0
```

MAXIMUM

maximum(x1, x2[, out])

Element-wise maximum of array elements.

Compare two arrays and returns a new array containing the element-wise maxima. If one of the elements being compared is a nan, then that element is returned. If both elements are nans then the first is returned. The latter distinction is important for complex nans, which are defined as at least one of the real or imaginary parts being a nan. The net effect is that nans are propagated.

Parameters
----
x1, x2 : array_like
The arrays holding the elements to be compared. They must have
the same shape, or shapes that can be broadcast to a single shape.

Returns
----
y : {ndarray, scalar}
The maximum of `x1` and `x2`, element-wise. Returns scalar if
both `x1` and `x2` are scalars.

See Also
----
minimum :
element-wise minimum

fmax :
element-wise maximum that ignores nans unless both inputs are nans.

fmin :
element-wise minimum that ignores nans unless both inputs are nans.

Notes

Equivalent to ``np.where(x1 > x2, x1, x2)`` but faster and does proper
broadcasting.

Examples

```
>>> np.maximum([2, 3, 4], [1, 5, 2])
array([2, 5, 4])

>>> np.maximum(np.eye(2), [0.5, 2])
array([[ 1. , 2. ],
[ 0.5, 2. ]])

>>> np.maximum([np.nan, 0, np.nan], [0, np.nan, np.nan])
array([ NaN, NaN, NaN])
>>> np.maximum(np.Inf, 1)
inf
```

MAX

Return the maximum of an array or maximum along an axis.

Parameters
----
a : array_like
Input data.
axis : int, optional
Axis along which to operate. By default flattened input is used.
out : ndarray, optional
Alternate output array in which to place the result. Must be of the same shape and buffer length as the expected output. See `doc.ufuncs` (Section "Output arguments") for more details.

Returns
----
amax : ndarray or scalar
Maximum of `a`. If `axis` is None, the result is a scalar value.
If `axis` is given, the result is an array of dimension ``a.ndim - 1``.

See Also
----
nanmax : NaN values are ignored instead of being propagated.
fmax : same behavior as the C99 fmax function.
argmax : indices of the maximum values.

Notes

NaN values are propagated, that is if at least one item is NaN, the corresponding max value will be NaN as well. To ignore NaN values (MATLAB behavior), please use nanmax.

Examples

```
>>> a = np.arange(4).reshape((2,2))
>>> a
array([[0, 1],
[2, 3]])
>>> np.amax(a)
3
>>> np.amax(a, axis=0)
array([2, 3])
>>> np.amax(a, axis=1)
array([1, 3])

>>> b = np.arange(5, dtype=np.float)
>>> b[2] = np.NaN
>>> np.amax(b)
```

```
nan
>>> np.nanmax(b)
4.0
```

MINIMUM

minimum(x1, x2[, out])

Element-wise minimum of array elements.

Compare two arrays and returns a new array containing the element-wise
minima. If one of the elements being compared is a nan, then that element
is returned. If both elements are nans then the first is returned. The
latter distinction is important for complex nans, which are defined as at
least one of the real or imaginary parts being a nan. The net effect is
that nans are propagated.

Parameters
----
x1, x2 : array_like
The arrays holding the elements to be compared. They must have
the same shape, or shapes that can be broadcast to a single shape.

Returns
----
y : {ndarray, scalar}
The minimum of `x1` and `x2`, element-wise. Returns scalar if
both `x1` and `x2` are scalars.

See Also
----
maximum :
element-wise minimum that propagates nans.
fmax :
element-wise maximum that ignores nans unless both inputs are nans.
fmin :
element-wise minimum that ignores nans unless both inputs are nans.

Notes

The minimum is equivalent to ``np.where(x1 <= x2, x1, x2)`` when neither
x1 nor x2 are nans, but it is faster and does proper broadcasting.

Examples

```
>>> np.minimum([2, 3, 4], [1, 5, 2])
array([1, 3, 2])
```

```
>>> np.minimum(np.eye(2), [0.5, 2]) # broadcasting
array([[ 0.5, 0. ],
[ 0. , 1. ]])

>>> np.minimum([np.nan, 0, np.nan],[0, np.nan, np.nan])
array([ NaN, NaN, NaN])
```

MIN

Return the minimum of an array or minimum along an axis.

Parameters
----
a : array_like
Input data.
axis : int, optional
Axis along which to operate. By default a flattened input is used.
out : ndarray, optional
Alternative output array in which to place the result. Must
be of the same shape and buffer length as the expected output.
See `doc.ufuncs` (Section "Output arguments") for more details.

Returns
----
amin : ndarray
A new array or a scalar array with the result.

See Also
----
nanmin: nan values are ignored instead of being propagated
fmin: same behavior as the C99 fmin function
argmin: Return the indices of the minimum values.

amax, nanmax, fmax

Notes

NaN values are propagated, that is if at least one item is nan, the
corresponding min value will be nan as well. To ignore NaN values (matlab
behavior), please use nanmin.

Examples

```
>>> a = np.arange(4).reshape((2,2))
>>> a
```

```
array([[0, 1],
[2, 3]])
>>> np.amin(a) # Minimum of the flattened array
0
>>> np.amin(a, axis=0) # Minima along the first axis
array([0, 1])
>>> np.amin(a, axis=1) # Minima along the second axis
array([0, 2])

>>> b = np.arange(5, dtype=np.float)
>>> b[2] = np.NaN
>>> np.amin(b)
nan
>>> np.nanmin(b)
0.0
```

NAN_TO_NUM

```
Replace nan with zero and inf with finite numbers.

Returns an array or scalar replacing Not a Number (NaN) with zero,
(positive) infinity with a very large number and negative infinity
with a very small (or negative) number.

Parameters
----------
x : array_like
Input data.

Returns
-------
out : ndarray, float
Array with the same shape as `x` and dtype of the element in `x` with
the greatest precision. NaN is replaced by zero, and infinity
(-infinity) is replaced by the largest (smallest or most negative)
floating point value that fits in the output dtype. All finite numbers
are upcast to the output dtype (default float64).

See Also
--------
isinf : Shows which elements are negative or negative infinity.
isneginf : Shows which elements are negative infinity.
isposinf : Shows which elements are positive infinity.
isnan : Shows which elements are Not a Number (NaN).
isfinite : Shows which elements are finite (not NaN, not infinity)
```

Notes

Numpy uses the IEEE Standard for Binary Floating-Point for Arithmetic (IEEE 754). This means that Not a Number is not equivalent to infinity.

Examples

```
>>> np.set_printoptions(precision=8)
>>> x = np.array([np.inf, -np.inf, np.nan, -128, 128])
>>> np.nan_to_num(x)
array([ 1.79769313e+308, -1.79769313e+308, 0.00000000e+000,
-1.28000000e+002, 1.28000000e+002])
```

REAL_IF_CLOSE

If complex input returns a real array if complex parts are close to zero.

"Close to zero" is defined as `tol` * (machine epsilon of the type for `a`).

Parameters
----
a : array_like
Input array.
tol : float
Tolerance in machine epsilons for the complex part of the elements in the array.

Returns
----
out : ndarray
If `a` is real, the type of `a` is used for the output. If `a` has complex elements, the returned type is float.

See Also
----
real, imag, angle

Notes

Machine epsilon varies from machine to machine and between data types but Python floats on most platforms have a machine epsilon equal to 2.2204460492503131e-16. You can use 'np.finfo(np.float).eps' to print out the machine epsilon for floats.

Examples

>>> np.finfo(np.float).eps
2.2204460492503131e-16

>>> np.real_if_close([2.1 + 4e-14j], tol=1000)
array([2.1])
>>> np.real_if_close([2.1 + 4e-13j], tol=1000)
array([2.1 +4.00000000e-13j])

INTERP

One-dimensional linear interpolation.

Returns the one-dimensional piecewise linear interpolant to a function
with given values at discrete data-points.

Parameters
----
x : array_like
The x-coordinates of the interpolated values.

xp : 1-D sequence of floats
The x-coordinates of the data points, must be increasing.

fp : 1-D sequence of floats
The y-coordinates of the data points, same length as `xp`.

left : float, optional
Value to return for `x < xp[0]`, default is `fp[0]`.

right : float, optional
Value to return for `x > xp[-1]`, defaults is `fp[-1]`.

Returns
----
y : {float, ndarray}
The interpolated values, same shape as `x`.

Raises

ValueError
If `xp` and `fp` have different length

Notes

Does not check that the x-coordinate sequence `xp` is increasing.
If `xp` is not increasing, the results are nonsense.
A simple check for increasingness is::

```
np.all(np.diff(xp) > 0)
```

Examples

```
>>> xp = [1, 2, 3]
>>> fp = [3, 2, 0]
>>> np.interp(2.5, xp, fp)
1.0
>>> np.interp([0, 1, 1.5, 2.72, 3.14], xp, fp)
array([ 3. , 3. , 2.5 , 0.56, 0. ])
>>> UNDEF = -99.0
>>> np.interp(3.14, xp, fp, right=UNDEF)
-99.0
```

Plot an interpolant to the sine function:

```
>>> x = np.linspace(0, 2*np.pi, 10)
>>> y = np.sin(x)
>>> xvals = np.linspace(0, 2*np.pi, 50)
>>> yinterp = np.interp(xvals, x, y)
>>> import matplotlib.pyplot as plt
>>> plt.plot(x, y, 'o')
[]
>>> plt.plot(xvals, yinterp, '-x')
[]
>>> plt.show()
```

Appendix D: Use Variables to Test Varying Belt Speeds

Use this example to help you understand how to use variables–and functions using variables–to create useful scenarios for your simulations.

Step 1: Add Chute and Belt Components

This example assumes that you have set up a simulation including all of the following components:

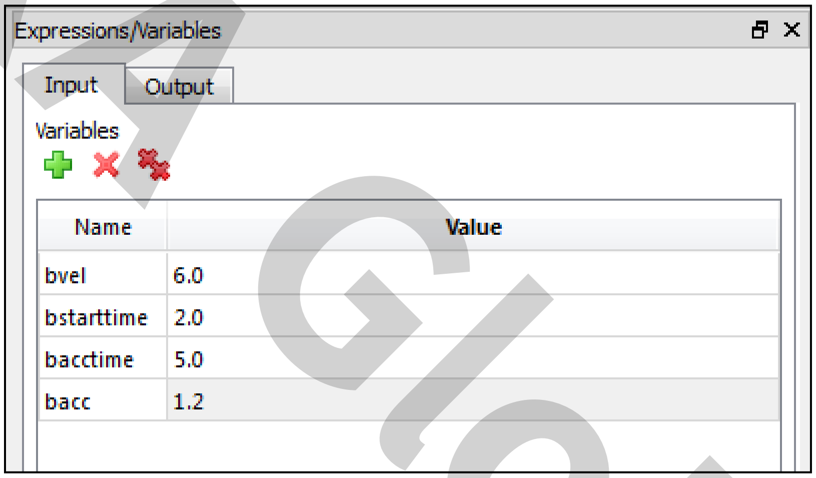
- An imported transfer chute design
- A standard Rocky feed conveyor
- An imported (custom) receiving belt
- A particle set representing granular matter

Step 2: Set Initial Input Variables

Once you have included the necessary components, enter the following variable **Names** and **Values** into the **Expressions/Variables** panel.

bvel =	6
bstarttime =	2
bacctime =	5
bacc =	bvel/bacctime

Note: This function will be converted to 6/5 [m/s2] and will display1.2 in the dialog.



Name	Value
bvel	6.0
bstarttime	2.0
bacctime	5.0
bacc	1.2

Figure 61: Variables entered into the Input tab of the Expressions/Variables panel

Step 3: Use Example Input Variables

Use the new input variables to specify the movements of the receiving conveyor that you have imported. Specifically:

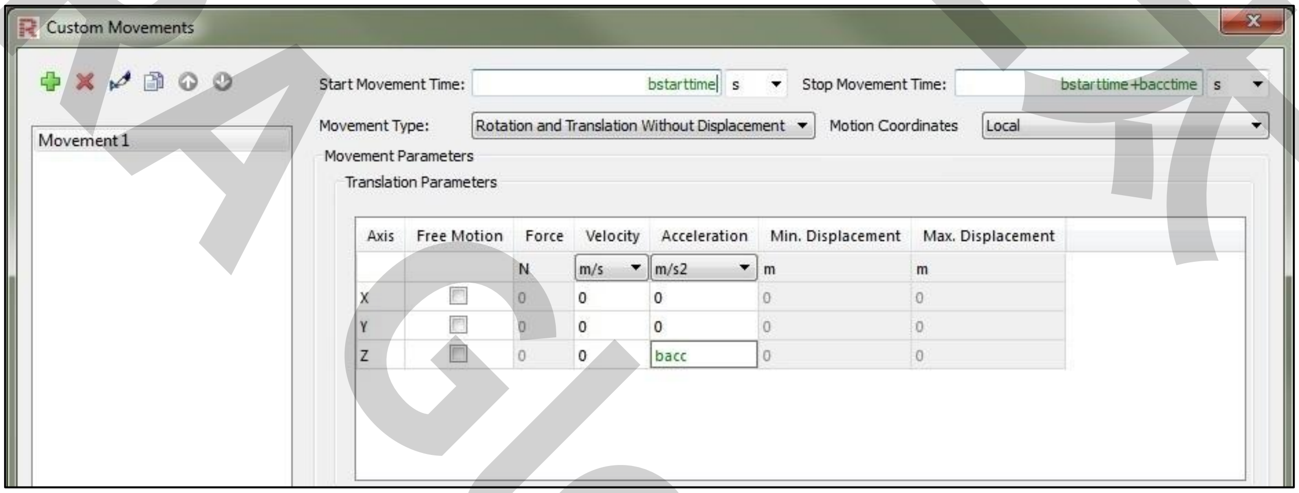
1. In the **Data** panel, choose the custom receiving conveyor that you have imported, and then from the **Data Editors** panel, on the **Custom Boundary** tab, select the **Movements** tab, and then click the **Edit Movements List** button.
2. From the **Custom Movements** dialog, create two separate **Movements** using the following variables. Note: Be sure to specify **Rotation and Translation Without Displacement** for **Movement Type**. For belts like this receiving belt, this setting ensures that the position of the component doesn't change in the simulation.

Movement 1 (see Figure 62 and Figure 63)

• Start Movement Time = bstarttime	(2 [s])	2
• Stop Movement Time = bstarttime+bacctime	(2 +5 [s])	7
• Z Axis Acceleration = bacc	(1.2 [m/s2])	1.2

Movement 2 (see Figure 64 and Figure 65)

• Start Movement Time = bstarttime+bacctime	(2 +5 [s])	7
• Z Axis Velocity = bvel	(6 [s])	6



Start Movement Time: bstarttime s

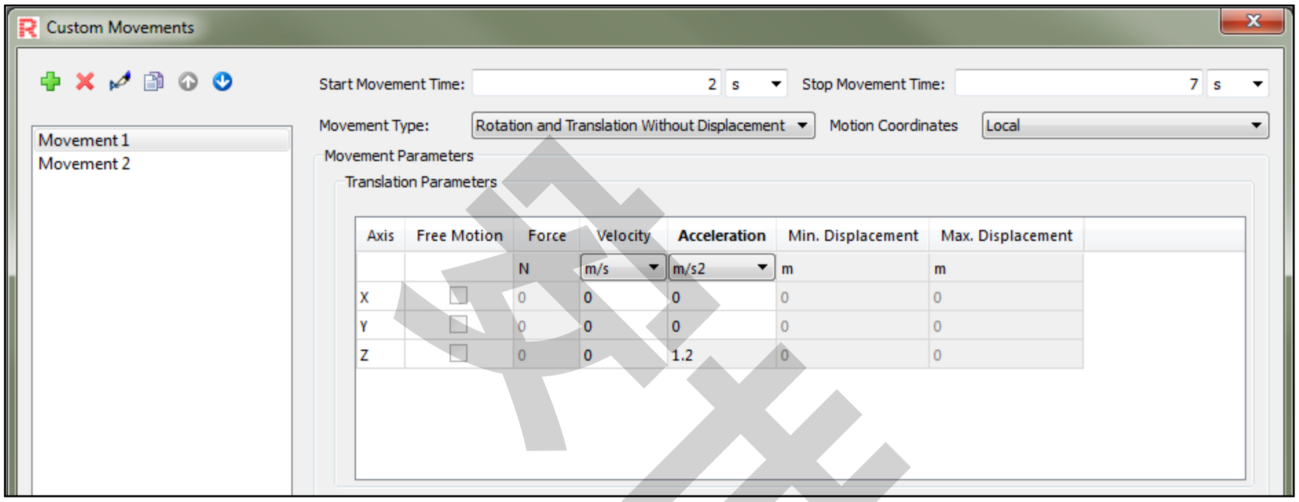
Stop Movement Time: bstarttime+bacctime s

Movement Type: Rotation and Translation Without Displacement

Motion Coordinates: Local

Axis	Free Motion	Force	Velocity	Acceleration	Min. Displacement	Max. Displacement
		N	m/s	m/s2	m	m
X	☐	0	0	0	0	0
Y	☐	0	0	0	0	0
Z	☐	0	0	bacc	0	0

Figure 62: Custom Movements dialog, Movement 1 when variable names are entered (green)



Custom Movements

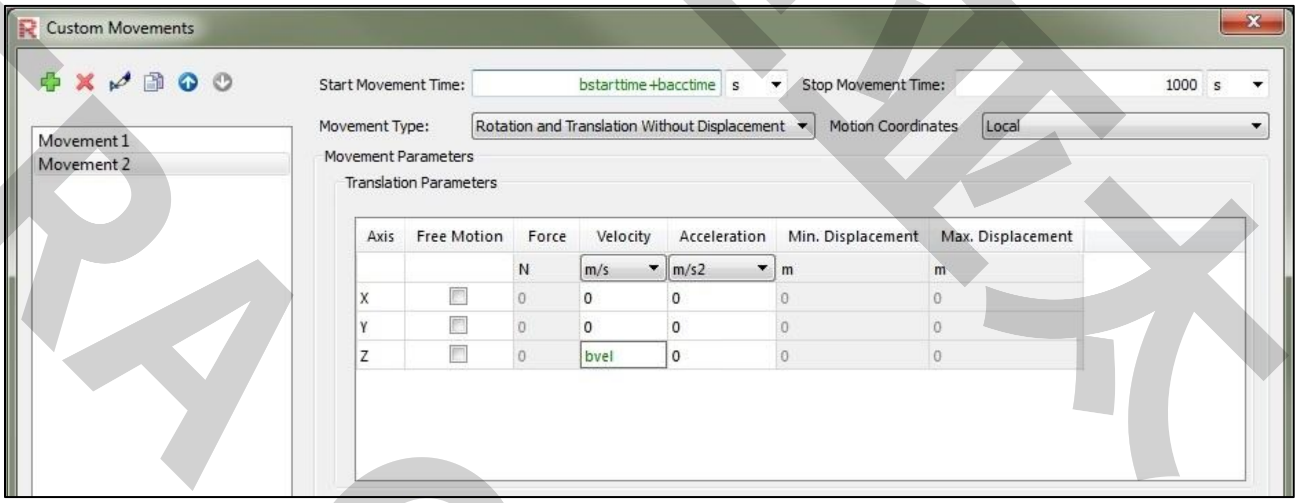
Movement 1
Movement 2

Start Movement Time: 2 s
Stop Movement Time: 7 s
Movement Type: Rotation and Translation Without Displacement
Motion Coordinates: Local

Movement Parameters
Translation Parameters

Axis	Free Motion	Force	Velocity	Acceleration	Min. Displacement	Max. Displacement
		N	m/s	m/s2	m	m
X	☐	0	0	0	0	0
Y	☐	0	0	0	0	0
Z	☐	0	0	1.2	0	0

Figure 63: Custom Movements dialog, Movement 1 after variables are replaced with values (black)



Custom Movements

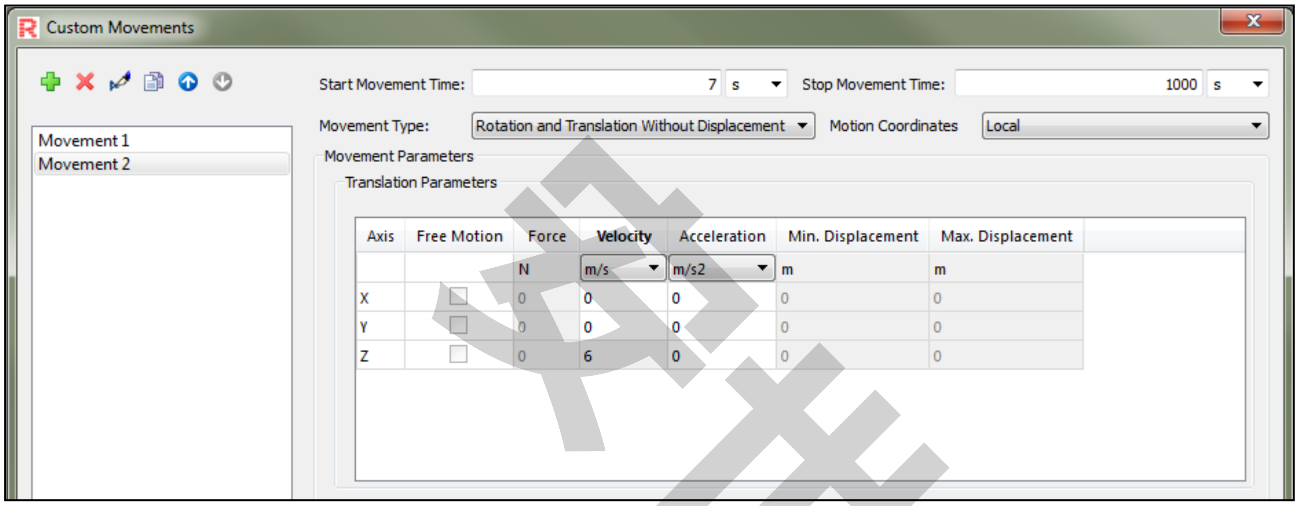
Movement 1
Movement 2

Start Movement Time: bstarttime+bacctime s
Stop Movement Time: 1000 s
Movement Type: Rotation and Translation Without Displacement
Motion Coordinates: Local

Movement Parameters
Translation Parameters

Axis	Free Motion	Force	Velocity	Acceleration	Min. Displacement	Max. Displacement
		N	m/s	m/s2	m	m
X	☐	0	0	0	0	0
Y	☐	0	0	0	0	0
Z	☐	0	bvel	0	0	0

Figure 64: Custom Movements dialog, Movement 2 when variable names are entered (green)



Custom Movements

Start Movement Time: 7 s Stop Movement Time: 1000 s

Movement 1
Movement 2

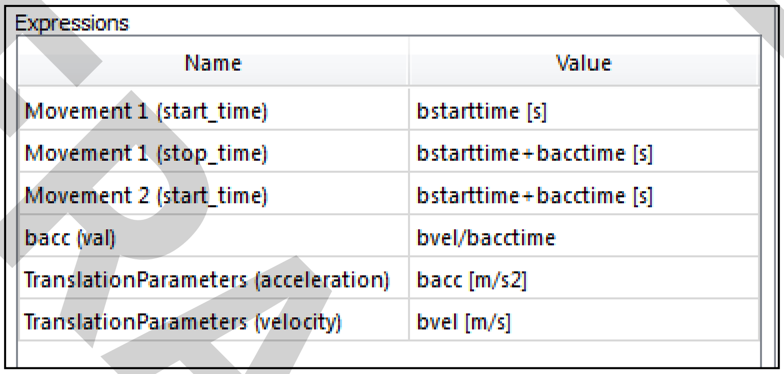
Movement Type: Rotation and Translation Without Displacement Motion Coordinates Local

Movement Parameters

Translation Parameters

Axis	Free Motion	Force	Velocity	Acceleration	Min. Displacement	Max. Displacement
		N	m/s	m/s2	m	m
X	☐	0	0	0	0	0
Y	☐	0	0	0	0	0
Z	☐	0	6	0	0	0

Figure 65: Custom Movements dialog, Movement 2 after variables are replaced with values (black)



Expressions

Name	Value
Movement 1 (start_time)	bstarttime [s]
Movement 1 (stop_time)	bstarttime+bacctime [s]
Movement 2 (start_time)	bstarttime+bacctime [s]
bacc (val)	bvel/bacctime
TranslationParameters (acceleration)	bacc [m/s2]
TranslationParameters (velocity)	bvel [m/s]

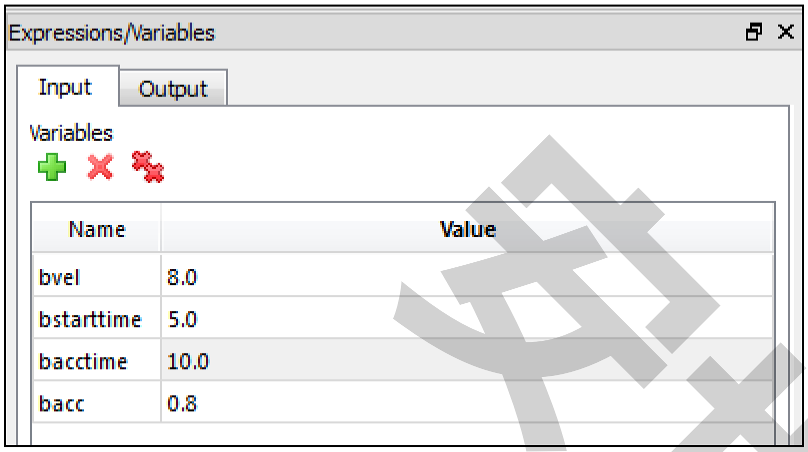
Figure 66: Expressions/Variables panel Expressions list after initial variable entry

Step 4: Change the Value of the Variables

Change the example variables to see how the different values will affect the results. Specifically, change:

- bvel = 8
- bstarttime = 5
- bacctime = 10

Note: Though we didn't change bacc from its original value of bvel/bacctime, because the variables used within its definition have changed, the final value of bacc gets updated to 0.8 in the dialog. (See Figure 67.)


Expressions/Variables

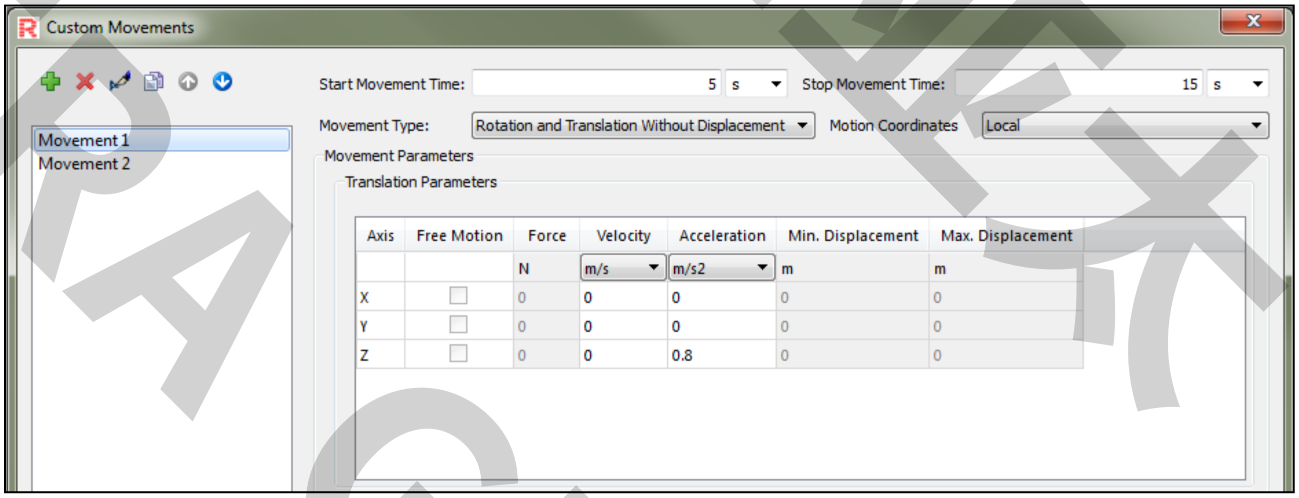
Input | Output

Variables

Name	Value
bvel	8.0
bstarttime	5.0
bacctime	10.0
bacc	0.8

Figure 67: Updated Input Variables in the Expressions/Variables panel

Notice that the values used in the **Custom Movements** dialog have changed accordingly. (See Figure 68 and Figure 69.)


Custom Movements

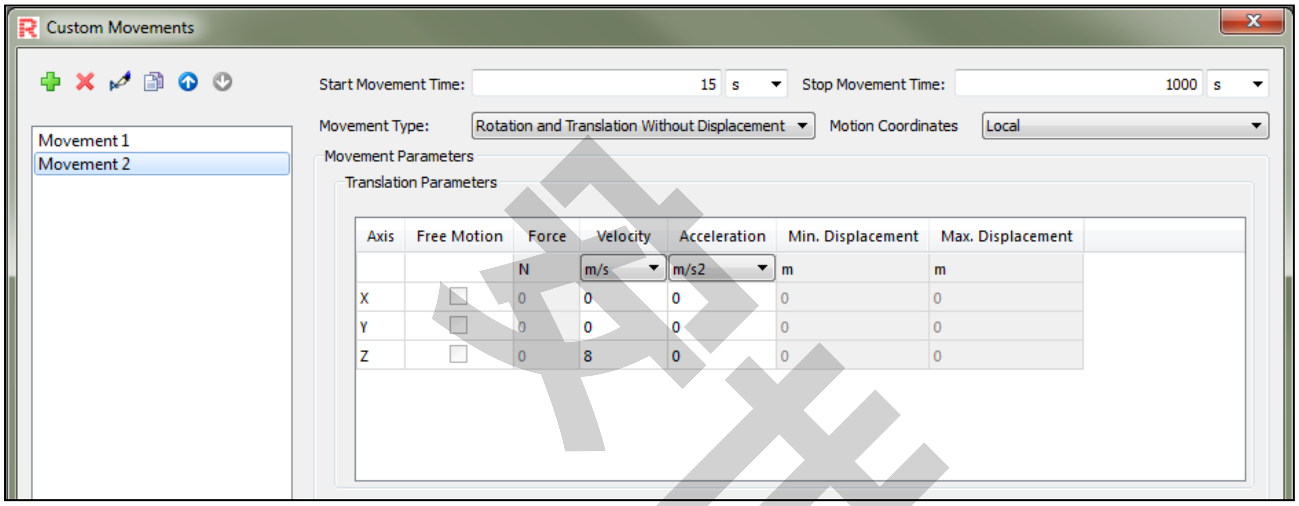
Movement 1
Movement 2

Start Movement Time: 5 s
Stop Movement Time: 15 s
Movement Type: Rotation and Translation Without Displacement
Motion Coordinates: Local

Movement Parameters
Translation Parameters

Axis	Free Motion	Force	Velocity	Acceleration	Min. Displacement	Max. Displacement
		N	m/s	m/s2	m	m
X	☐	0	0	0	0	0
Y	☐	0	0	0	0	0
Z	☐	0	0	0.8	0	0

Figure 68: Changed values for Movement 1



Start Movement Time: 15 s
Stop Movement Time: 1000 s
Movement Type: Rotation and Translation Without Displacement
Motion Coordinates: Local

Axis	Free Motion	Force	Velocity	Acceleration	Min. Displacement	Max. Displacement
		N	m/s	m/s2	m	m
X	☐	0	0	0	0	0
Y	☐	0	0	0	0	0
Z	☐	0	8	0	0	0

Figure 69: Changed values for Movement 2

Goals Achieved Using this Method:

- Enabled a varying acceleration time without having to recalculate actual acceleration.
- The appropriate movement start and stop periods also used the parameters and were therefore updated when the bacctime changes.
- These same parameters can also dictate the particle loading sequence so that it stays synchronized with the belt start up.

Glossary

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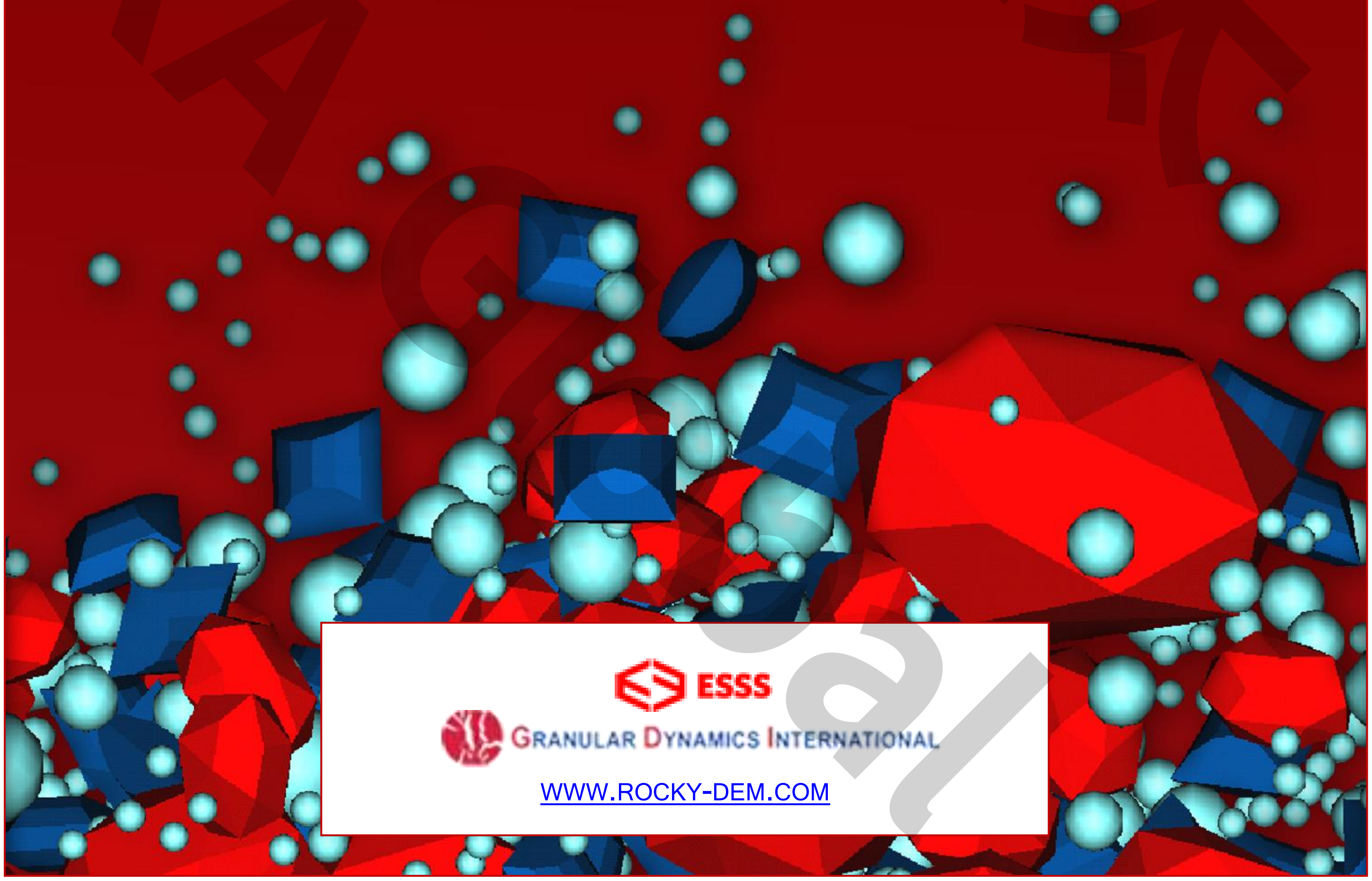
<Coming Soon>

ROCKY 3.0



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