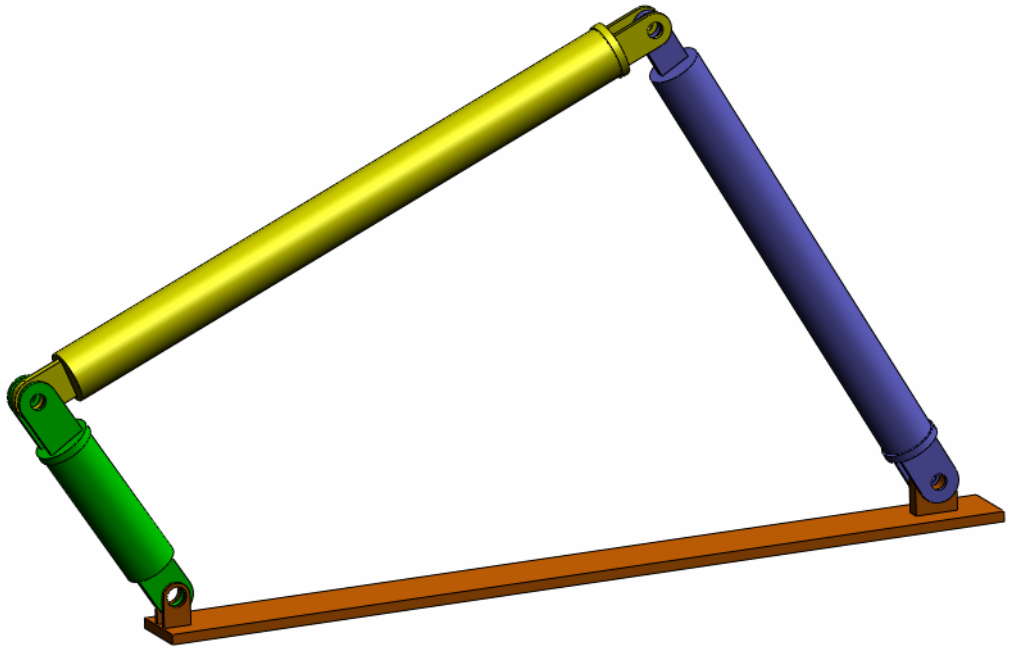
Engineering Design and Technology Series

An Introduction to Motion Analysis Applications with SolidWorks Motion, Student Workbook



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Introduction

About This Course

The *Introduction to Motion Analysis Applications with SolidWorks Motion* and its supporting materials is designed to assist you in learning SolidWorks Motion Simulation in an academic setting. It offers a competency-based approach to learning rigid body kinematics and dynamics concepts.

Online Tutorials

The *Introduction to Motion Analysis Applications with SolidWorks Motion* is a companion resource and is supplemented by the SolidWorks Motion Online Tutorials.

Accessing the Tutorials

To start the Online Tutorials, click **Help, SolidWorks Tutorials, All SolidWorks Tutorials**. The SolidWorks window is resized and a second window will appears next to it with a list of the available tutorials. As you move the pointer over the links, an illustration of the tutorial will appear at the bottom of the window. Click the desired link to start that tutorial.

Conventions

Set your screen resolution to 1280x1024 for optimal viewing of the tutorials.

The following icons appear in the tutorials:

Next » Moves to the next screen in the tutorial.

Represents a note or tip. It is not a link; the information is to the right of the icon. Notes and tips provide time-saving steps and helpful hints.

You can click most toolbar buttons that appear in the lessons to flash the corresponding SolidWorks button.The first time you click the button, an ActiveX control message appears: An ActiveX control on this page might be unsafe to interact with other parts of the page. Do you want to allow this interaction? This is a standard precautionary measure. The ActiveX controls in the Online Tutorials will not harm your system. If you click **No**, the scripts are disabled for that topic. Click **Yes** to run the scripts and flash the button.

Open File or **Set this option** automatically opens the file or sets the option.

Video example shows a video about this step.

A closer look at... links to more information about a topic. Although not required to complete the tutorial, it offers more detail on the subject.

Why did I... links to more information about a procedure, and the reasons for the method given. This information is not required to complete the tutorial.

Printing the Tutorials

If you like, you can print the Online Tutorials by following this procedure:

1. On the tutorial navigation toolbar, click **Show**

.

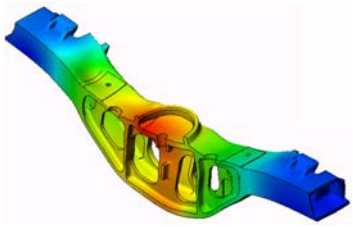
   This displays the table of contents for the Online Tutorials.
2. Right-click the book representing the lesson you wish to print and select **Print** from the shortcut menu.

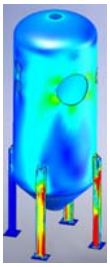
   The **Print Topics** dialog box appears.
3. Select **Print the selected heading and all subtopics**, and click **OK**.
4. Repeat this process for each lesson that you want to print.

SolidWorks Simulation Product Line

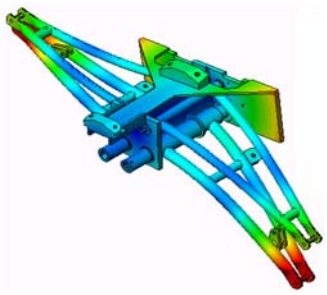
While this course focuses on the introduction to the rigid body dynamics using SolidWorks Motion Simulation, the full product line covers a wide range of analysis areas to consider. The paragraphs below lists the full offering of the SolidWorks Simulation packages and modules.

Static studies provide tools for the linear stress analysis of parts and assemblies loaded by static loads. Typical questions that will be answered using this study type are:
Will my part break under normal operating loads?
Is the model over-designed?
Can my design be modified to increase the safety factor?

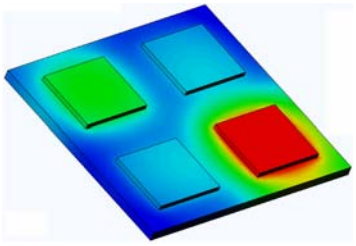




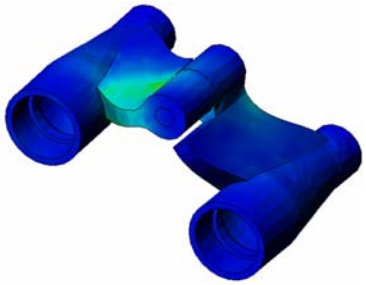
Buckling studies analyze performance of the thin parts loaded in compression. Typical questions that will be answered using this study type are:
Legs of my vessel are strong enough not to fail in yielding; but are they strong enough not to collapse due to loss of stability?
Can my design be modified to ensure stability of the thin components in my assembly?



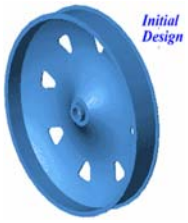
Frequency studies offer tools for the analysis of the natural modes and frequencies. This is essential in the design or many components loaded in both static and dynamic ways. Typical questions that will be answered using this study type are:
Will my part resonate under normal operating loads?
Are the frequency characteristics of my components suitable for the given application?
Can my design be modified to improve the frequency characteristics?



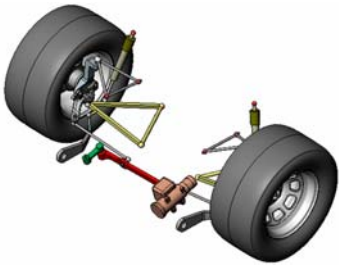
Thermal studies offer tools for the analysis of the heat transfer by means of conduction, convection, and radiation. Typical questions that will be answered using this study type are:
Will the temperatures changes effect my model?
How does my model operate in an environment with temperature fluctuation?
How long does it take for my model to cool down or overheat?
Does temperature change cause my model to expand?
Will the stresses caused by the temperature change cause my product failure (static studies, coupled with thermal studies would be used to answer this question)?



Drop test studies are used to analyze the stress of moving parts or assemblies impacting an obstacle. Typical questions that will be answered using this study type are:
What will happen if my product is mishandled during transportation or dropped?
How does my product behave when dropped on hard wood floor, carpet or concrete?

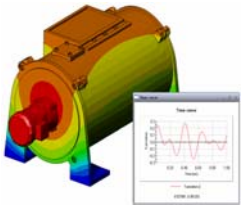


Optimization studies are applied to improve (optimize) your initial design based on a set of selected criteria such as maximum stress, weight, optimum frequency, etc. Typical questions that will be answered using this study type are:
Can the shape of my model be changed while maintaining the design intent?
Can my design be made lighter, smaller, cheaper without compromising strength of performance?

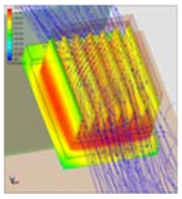


Fatigue studies analyze the resistance of parts and assemblies loaded repetitively over long periods of time. Typical questions that will be answered using this study type are:
Can the life span of my product be estimated accurately?
Will modifying my current design help extend the product life?
Is my model safe when exposed to fluctuating force or temperature loads over long periods of time?
Will redesigning my model help minimize damage caused by fluctuating forces or temperature?

Nonlinear studies provide tools for analyzing stress in parts and assemblies that experience severe loadings and/or large deformations. Typical questions that will be answered using this study type are:
Will parts made of rubber (o-rings for example) or foam perform well under given load?
Does my model experience excessive bending during normal operating conditions?



Dynamics studies analyze objects forced by loads that vary in time. Typical examples could be shock loads of components mounted in vehicles, turbines loaded by oscillatory forces, aircraft components loaded in random fashion, etc. Both linear (small structural deformations, basic material models) and nonlinear (large structural deformations, severe loadings and advanced materials) are available. Typical questions that will be answered using this study type are:
Are my mounts loaded by shock loading when vehicle hits a large pothole on the road designed safely? How much does it deform under such circumstances?



Flow Simulation enables user to analyze the behavior and effect of moving fluids around or within parts and assemblies. Heat transfer in both fluids and solids is considered as well. Pressure and temperature effect can subsequently be transferred into SolidWorks Simulation studies to continue with the stress analysis. Typical questions that will be answered using this modulus are:
Is the fluid moving too fast and will it cause problems in my design?
Is the moving fluid too hot or too cold?
Is the heat transfer in my product efficient? Can it be improved?
How effective is my design at moving fluid through the system?

Composites modulus allows users to simulate structures manufactured from laminated composite materials. Typical questions that will be answered using this modulus are:
Is the composite model failing under the given loading?
Can the structure be made lighter using composite materials while not compromising with the strength and safety?
Will my layered composite delaminate?

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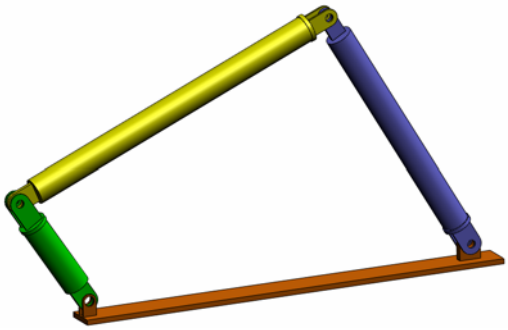
Basic Functionality of SolidWorks Motion

Active Learning Exercise – Motion analysis of a 4 bar mechanism

Use SolidWorks Motion Simulation to perform motion analysis on the `4Bar.SLDASM` assembly shown below. The green link is given an angular displacement of 45 degrees in 1 sec in the clockwise direction and it is required to determine the angular velocity and acceleration of the other links as a function of time. Also we will calculate the torque needed to induce this motion as an in class discussion topic.

The step by step instructions are given below.



Opening the 4Bar.SLDASM document

1. Click **File**, **Open**. In the `Open` dialog box, browse to the `4Bar.SLDASM` assembly located in the corresponding subfolder of the `SolidWorks Curriculum_and_Courseware_2010` folder and click **Open** (or double-click the part).

Checking the SolidWorks Motion Add-In

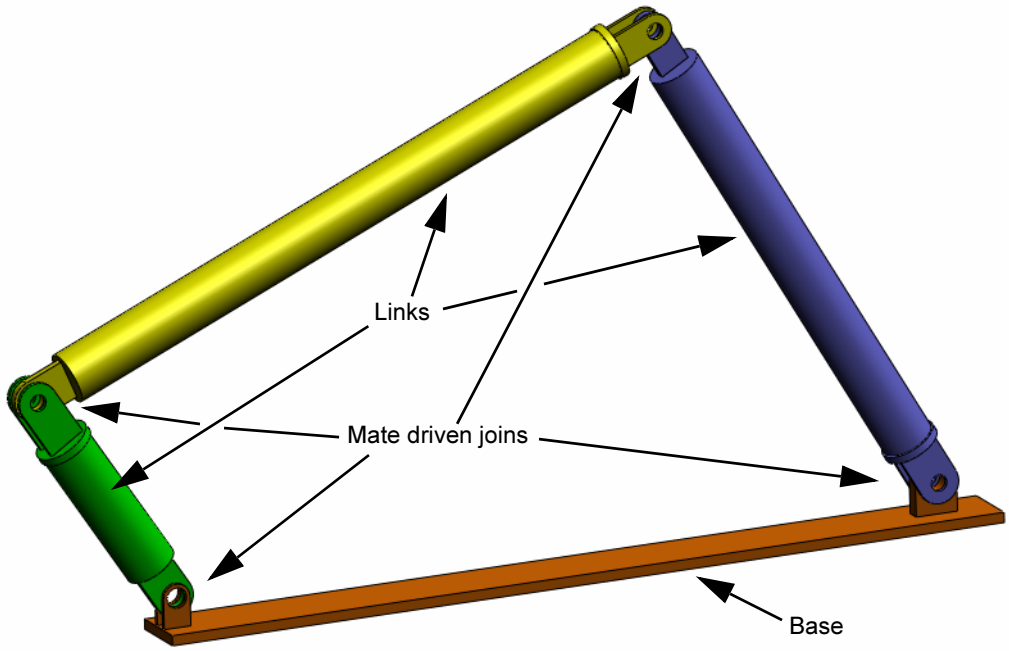
Mate sure that SolidWorks Motion Add-In is activated.

To do so:

1. Click **Tools**, **Add-Ins**. The **Add-Ins** dialog box appears.
2. Make sure that the check boxes next to SolidWorks Motion are checked.
3. Click **OK**.

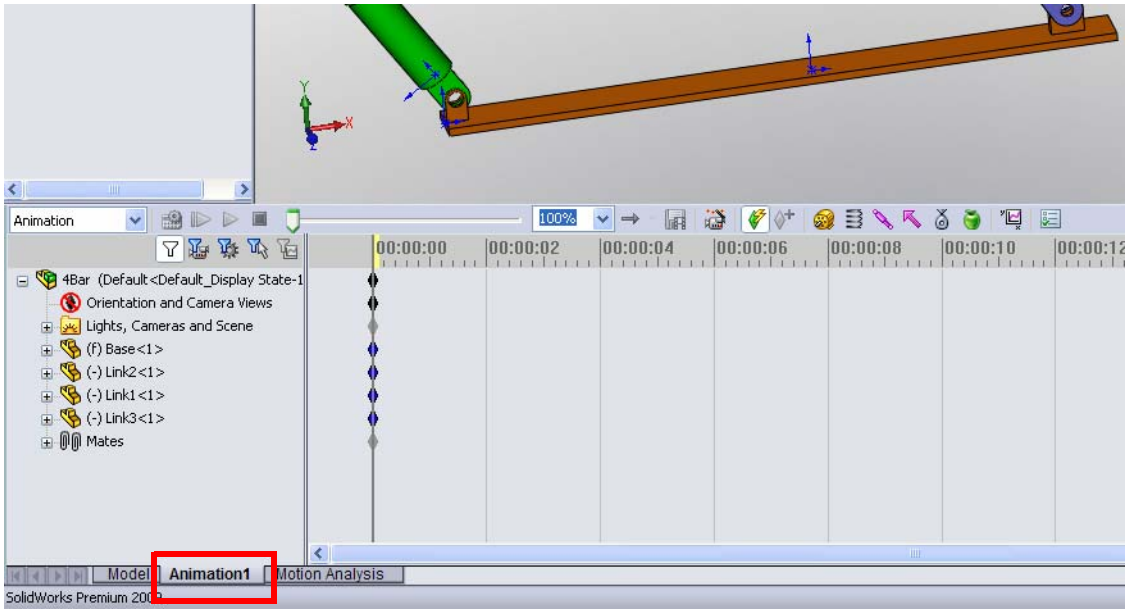
Model Description

This model represents a typical 4 bar linkage mechanism. The Base part is fixed and cannot move. It always stays horizontal and in real life is fixed to the ground. The other three links are connected to each other and to the base with pins. The links are allowed to hinge about the pins in the same plane and any out of plane motion is prevented. When you model this mechanism in SolidWorks we create mates to put the parts in place. SolidWorks Motion automatically translates these mates into the internal joints. Each mate has several degrees of freedom associated with it. For example a concentric mate has only two degrees of freedom (translation and rotation about its axis). For more details on mates and the degrees of freedom they have please refer to the online help on SolidWorks Motion Simulation.



Switching to SolidWorks Motion Manager

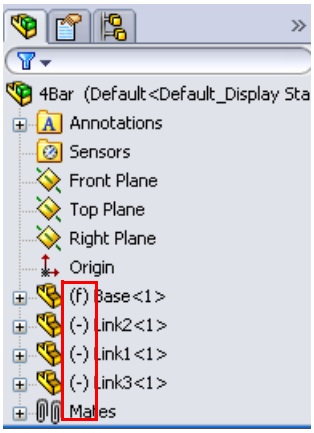
Switch to SolidWorks Motion by clicking the `Animation1` tab in the bottom left hand corner.



SolidWorks Motion takes full advantage of SolidWorks Animator and thus the look and feel of the `SolidWorksMotionManager` is very similar to that of the SolidWorks Animator.

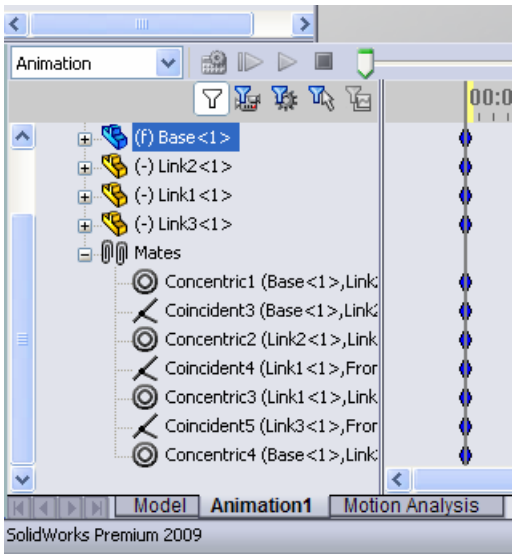
Fixed and Moving Components

Fixed and moving components in SolidWorks Motion are determined by their **Fix**/**Float** status in the SolidWorks model. In our case, `Base` component is fixed while the other three links are moving.



Automatic Creation of internal joints from SolidWorks Assembly Mates

The motion of the mechanism is fully defined by the SolidWorks mates.



Specifying the Input Motion

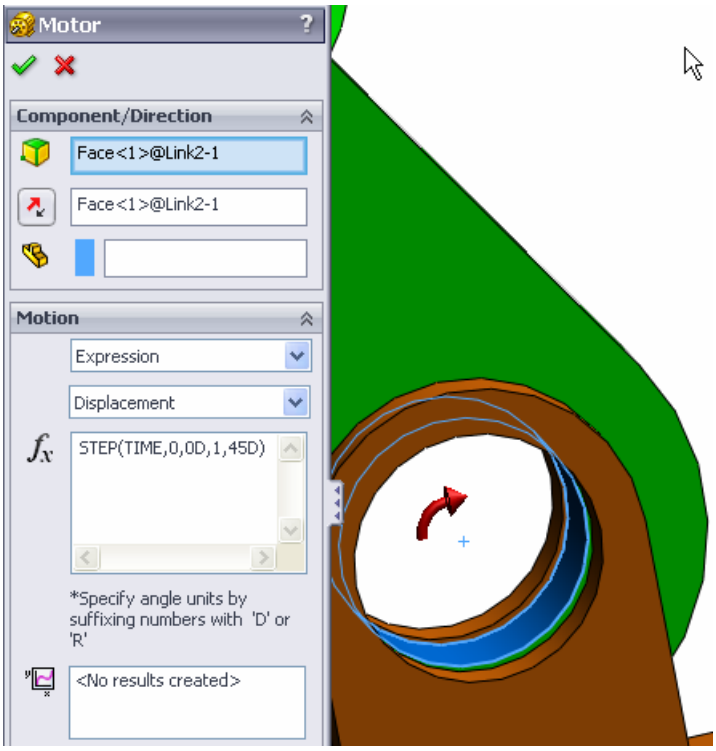
Next we will define a motion to one of the links. In this example we would like to rotate `Link2` by 45 degrees clockwise about the `Base`. To do this we will impose a rotary motion to `Link2` at the location of the concentric mate simulating the pin connection with the `Base`. The angular displacement needs to be achieved in 1 sec and we will use a step function to ensure that `Link2` rotates smoothly from 0 to 45 degrees.

Right click on the **Motor** icon to open the **Motor** dialog.

Under **Motor Type** selet **Rotary Motor**.

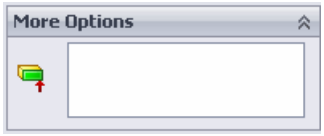
Under **Component/Direction**, select the cylindrical face of `Link2` pinned to the `Base` (see the figure) for both the **Motor Direction** and **Motor Location** fields. The motor will be located at the center of the selected cylindrical face.

Under **Motion** select **Expression**, **Displacement** and enter the following function: **STEP(TIME,0,0D,1,45D)**.



Note: The last field under **Component/Direction** property dialog, **Component to more relative to**, is used to specify reference component for the relative motion input. Since we wish to move `Link2` with respect to the fixed `Base`, this field will be left blank.

The last property dialog, **More Options**, enables user to specify the Load- bearing faces/Edges for the transfer of the motion loads in the SolidWorks Simulation stress analysis software.



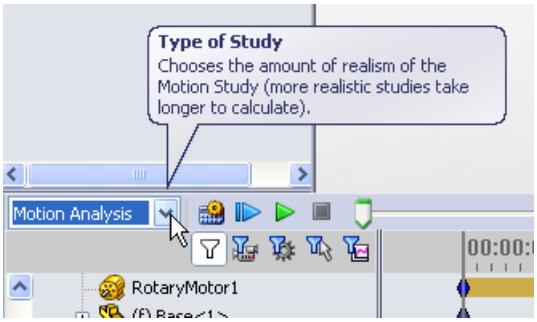
Click **OK** to close the **Motor** dialog.

Motion analysis type

SolidWorks offers three types of the assembly motion simulation:

1. **Animation** is simple motion simulation ignoring the components' inertial properties, contacts, forces and similar. Its use is suited for the verification of the correct mates, for example.
2. **Basic Motion** offers some level of realism by accounting for the inertial properties of the components for example. It does not, however, recognize externally applied forces.
3. **Motion Analysis** is the most sophisticated motion analysis tool reflecting all required analysis features such as inertial properties, external forces, contacts, mate friction etc.

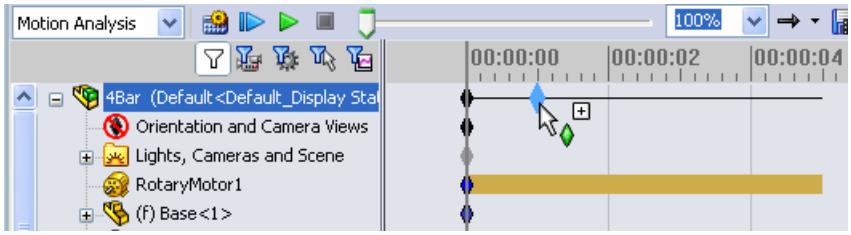
Under **Type of Study** on the left hand side of the SolidWorksMotionManager, select **Motion Analysis**.



Simulation time

The duration of the motion simulation is driven by the topmost time line in the SolidWorksMotionManager. Because SolidWorks Motion sets the default analysis duration to 5 seconds this parameter needs to be modified.

Move the end time key of the topmost timeline from 5 second to a 1 second location.



Note: The zoom keys allow you to zoom in and out on the time line.

Right-clicking on the timeline key allows you to manually input the desired simulation time.

Running the Simulation

In the SolidWorksMotionManager click the **Calculate** icon .

Note the motion simulation during the calculation.

Looking at the Results

Absolute results in the global coordinate system

First let us plot the angluar velocity and acceleration for `Link1`.

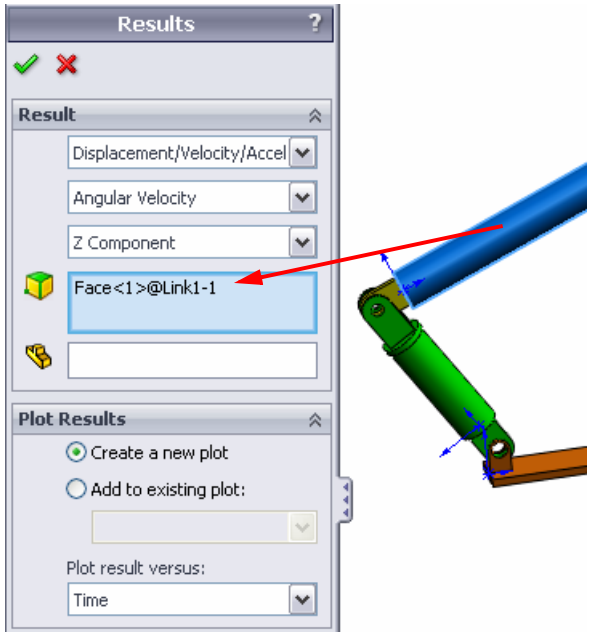
Click the **Results and Plots** icon to open the **Results** dialog.

Under **Results** select **Displacement/ Velocity/Acceleration**, **Angular Velocity** and **Z Component**.

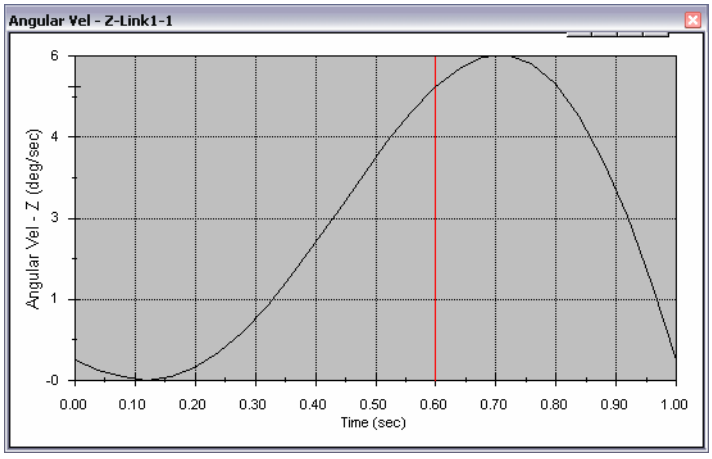
Still under **Results** select `Link1`.

The **Component to define XYZ directions (optional)** field is used to reference our plot results with respect to a local coordinate system of another moving component. To plot the results in the default coordinate system shown in the figure, leave this field empty.

Click **OK** to show the plot.

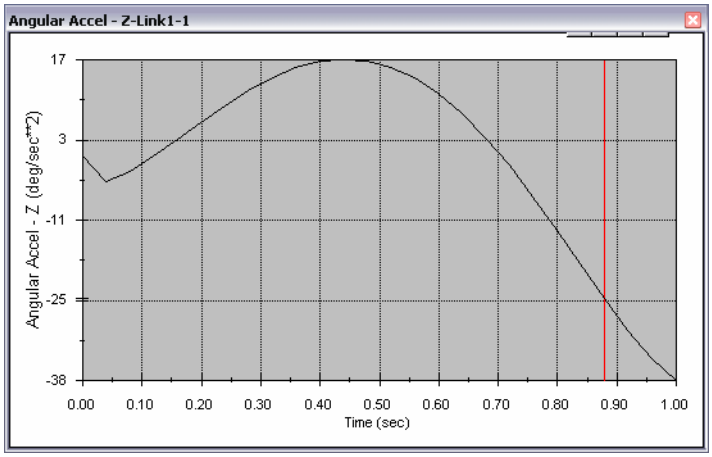


The plot shows the variation of the angular velocity of the center of mass for `Link1` as function of time.



Repeat the above procedure to plot the **Z Component** of the **Angular Acceleration** for the center of mass of `Link1`.

In the global coordinate system, the results indicate the maximum angular velocity and angular acceleration of 6 deg/sec and 38 deg/sec^2, respectively.

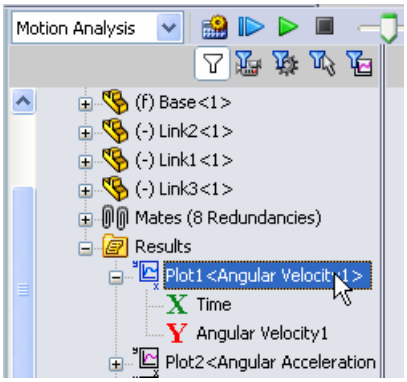


Similarly, create the plots of the **Z Component** of angular velocity and angular acceleration at the center of mass for `Link2` and `Link3`.

Storing and editting result plots

The generated result plot featuers are stored in the newly created `Results` folder on the bottom of the SolidWorksMotionManager.

Right-clicking on any plot feature allows you to hide and show the plot, as well as edit its settings.



More on the Results

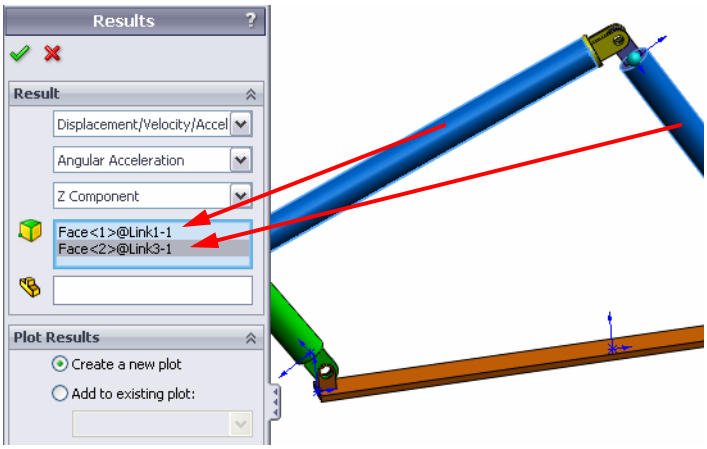
Relative results in global coordinate system

Let us plot the **Z Component** of the relative angluar acceleration of `Link1` with respect to `Link3`.

Expand the `Results` folder. Make sure that `Plot2` is shown. Right-click on `Plot2` and select **Edit Feature**.

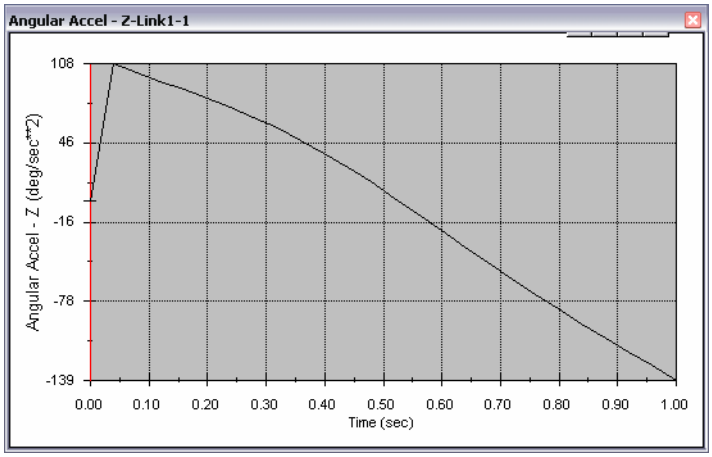
Select `Link3` as the second component in the **Select one or two part faces or one mate/ simulation element to create results** field.

Click **OK** to show the plot.



The plot shows the acceleration magnitude of Link1 (its center of mass) with respect to Link3 (again, its center of mass). The maximum relative acceleration is 139 deg/sec^2 in the negative Z rotational direction.

Note also that the variation of the acceleration chagned significantly when compared to the absolute acceleration result for Link1 alone above.



Note: The positive rotational direction can be determined using the right hand rule. Point the thumb of the right hand into the direction of the axis (in our case it would be the Z axis). Your fingers will then show the positive direction for the Z component of the rotation.

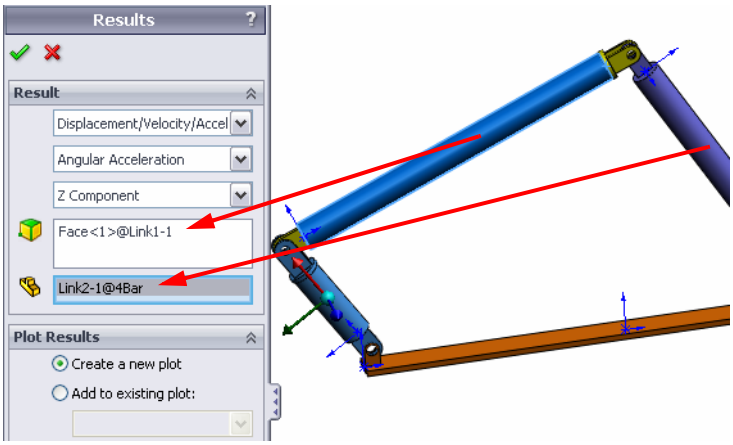
Relative results in local coordinate system

Let us transform the Z component of the absolute acceleration of Link1 into the local coordinate system of Link2.

Edit the above plot, Plot2, delete Link3 from the **Select one or two part faces or one mate/simulation element to create results** field.

Then select Link2 in the **Component to define XYZ directions** field.

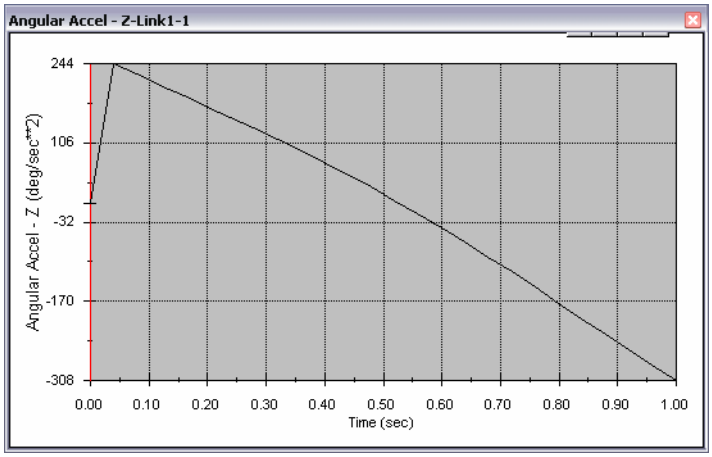
Click **OK** to show the plot.



Note: The triad on the Link2 component indicates the output local coordinate system. Contrary to the global coordinate system which is fixed, local coordinate systems may rotate.. In our case, the selected local coordinate system will rotate because Link2 component rotates as the mechanism moves.

The maximum Z component of absolute acceleration of `Link1` in the local coordinate system of `Link2` is 308 deg/sec^2 in the negative Z rotational direction.

Comparing this absolute result in the local corodinate system to the absolute acceleration in the global coordinate system, we conclude that they are significantly different.



Repeat the above for various selection of components and local coordinate systems.

Create a Trace Path

SolidWorks Motion allows you to graphically display the path that any point on any moving part follows. This is called a trace path. You can create trace path with reference to any fixed part or with reference to any moving component in the assembly. We will create a trace path for a point located on `Link1` component.

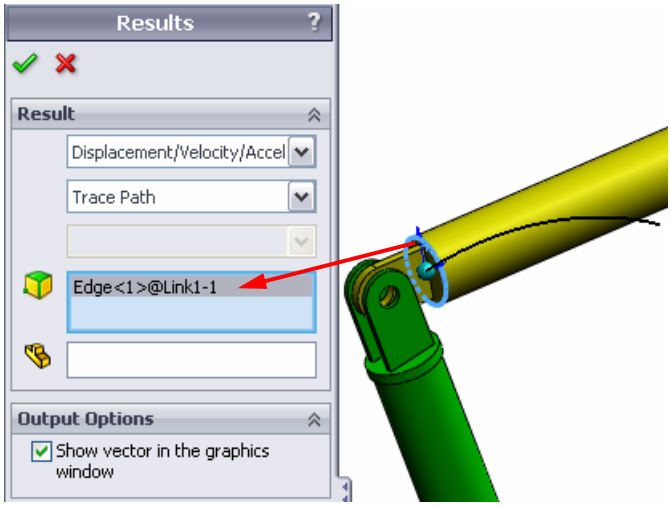
To create a trace path right click on the **Results and Plots** icon.

In the **Results** dialog select **Displacement/Velocity/ Acceleration** and **Trace Path**.

In the first selection field select the circular edge on `Link1` to identify the center point of the circle. The sphere graphically shows the center of the ciircle.

Check the **Show vector in graphics window** check box.

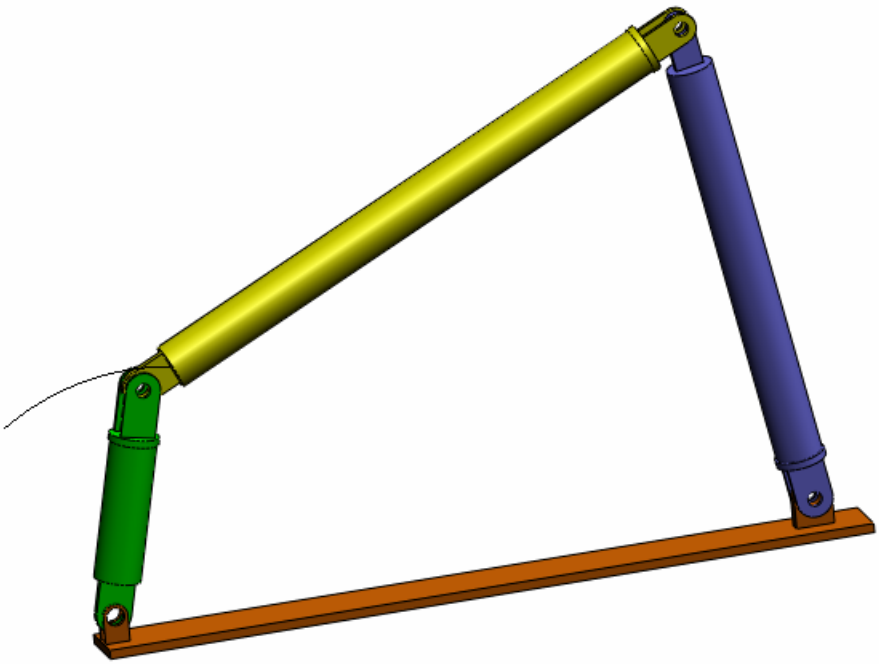
The path will then show on the screen as black curve.



Note: The resulting trace path is by default shown with respect to the fixed ground. To show the trace path with respect to another moving component, one would have to select this reference component as a second item in the same selection field.

Click **OK** to close the **Results** dialog.

Zoom out to see the entire model and **Play** the simulation.



This completes your first SolidWorks Motion simulation.

5 Minute Assessment

1. How do you start a SolidWorks Motion session?

2. How do you activate SolidWorks Motion Add-In?

3. What types of motion analyses are available in SolidWorks?

4. What is analysis?

5. Why analysis is important?

6. What does SolidWorks Motion analysis calculate?

7. Does SolidWorks Motion assume the parts to be rigid or flexible?

8. Why is motion analysis important?

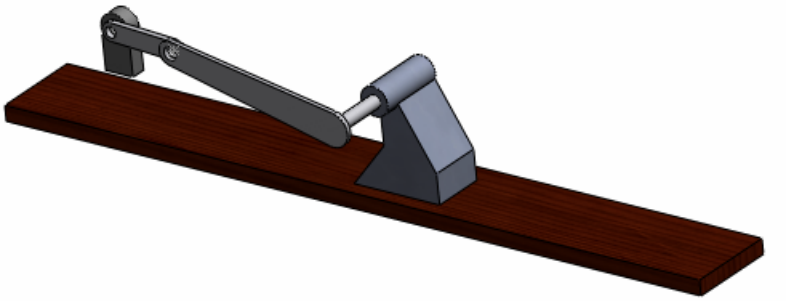
9. What are the main steps in performing motion analysis?

10. What is a trace path?

11. Are Solidworks mates used in SolidWorks Motion model?

Project — Slider Crank Mechanism

In this project you will see how to use SolidWorks Motion to simulate a slider crank mechanism and also calculate the velocity and acceleration of the center of mass of the reciprocating part in the mechanism.



Tasks

1. Open the SliderCrank.sldasm located in the corresponding subfolder of the `SolidWorks Curriculum_and_Courseware_2010` folder and click **Open** (or double-click the part).
2. Review the fixed and moving parts in the assembly.
3. Prescribe uniform 360 deg/sec rotational velocity to the `Crank`. Make sure that the motion is specified at the `BasePart/Crank` pin location. (You can enter **360 deg/sec** directly into the **Motor speed** field. SolidWorks Motion then converts the value to RPM).
4. Run SolidWorks Motion simulation for 5 seconds.
5. Determine the velocity and acceleration of the `MovingPart`.

Lesson 1 Vocabulary Worksheet

Name_____Class: _____ Date:_____

Directions: Fill in the blanks with the proper words.

1. The sequence of creating a model in SolidWorks, manufacturing a prototype, and testing it:

2. The method used by SolidWorks Motion to perform motion analysis:

3. The entity that connects two parts and also governs the relative motion between the two parts:

4. How many degrees of freedom does a free body have? :

5. How many degrees of freedom does a concentric mate have? :

6. How many degrees of freedom does a fixed part have? :

7. A path or trajectory that any point on a moving part follows:

8. The trace path of a reciprocating cylinder with respect to the ground represents a:

9. The types of Motion that can be given to a concentric mate:

10. In SolidWorks Motion the movement of gears can be simulated using:

11. A mechanism that is used to transform rotary motion to reciprocating motion:

12. The ratio of the output torque exerted by the driven link to the necessary input torque required at the driver:

Lesson 1 Quiz

Name: _____Class: _____ Date:_____

Directions: Answer each question by writing the correct answer or answers in the space provided.

1. How to switch between the SolidWorks Motion Manager and SolidWorks Feature Manager?

2. What types of motion analysis can you perform in SolidWorks Motion?

3. How does SolidWorks Motion automatically create internal joints?

4. How do you assign motion to a part mate?

5. If I want to assign a rotary motion to a part smoothly with a given time then how should I assign the motion?

6. How many degrees of freedom does a point-to-point coincident mate have?

7. What is a trace path?

8. Name one application of trace path?