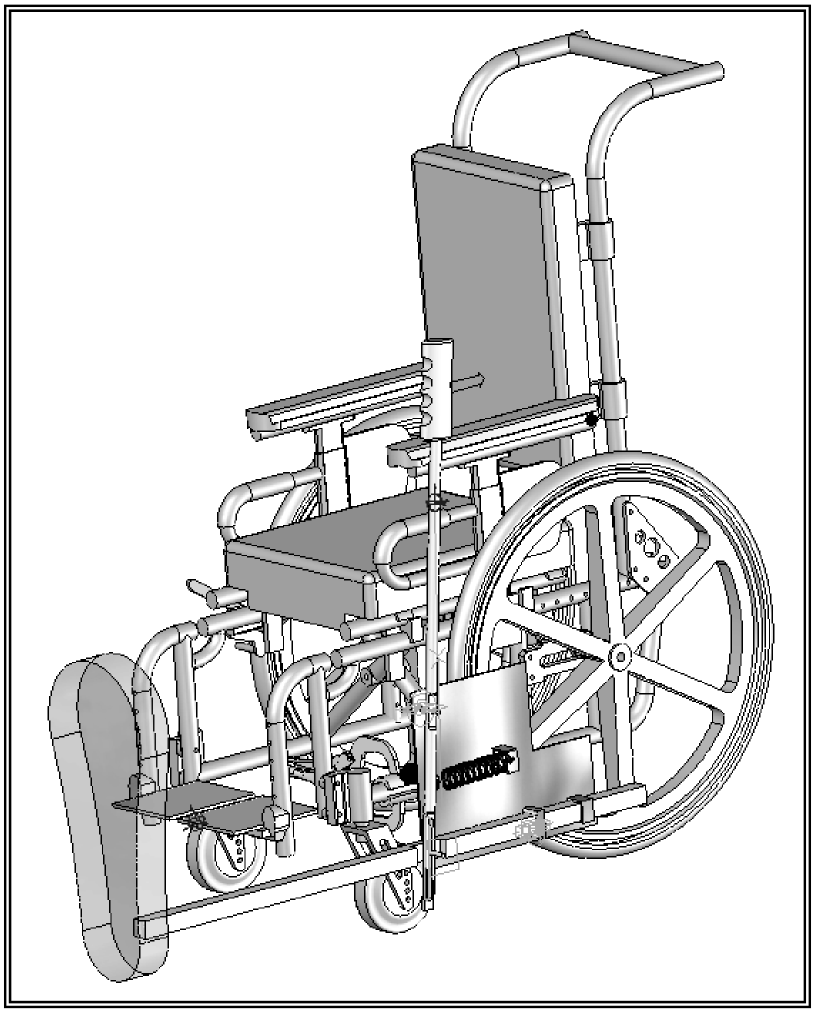
Motion Simulation and Mechanism Design

with COSMOSMotion 2007



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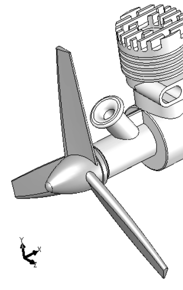
Lesson 1: Introduction to *COSMOSMotion*



1.1 Overview of the Lesson

The purpose of this lesson is to provide you with a brief overview on *COSMOSMotion*. *COSMOSMotion* is a virtual prototyping tool that supports mechanism analysis and design. Instead of building and testing physical prototypes of the mechanism, you may use *COSMOSMotion* to evaluate and refine the mechanism before finalizing the design and entering the functional prototyping stage. *COSMOSMotion* will help you analyze and eventually design better engineering products. More specifically, the software enables you to size motors and actuators, determine power consumption, layout linkages, develop cams, understand gear drives, size springs and dampers, and determine how contacting parts behave, which would usually require tests of physical prototypes. With such information, you will gain insight on how the mechanism works and why it behaves in certain ways. You will be able to modify the design and often achieve better design alternatives using the more convenient and less expensive virtual prototypes. In the long run, using virtual prototyping tools, such as *COSMOSMotion*, will help you become a more experienced and competent design engineer.

In this lesson, we will start with a brief introduction to *COSMOSMotion* and the various types of physical problems that *COSMOSMotion* is capable of solving. We will then discuss capabilities offered by *COSMOSMotion* for creating motion models, conducting motion analyses, and viewing motion analysis results. In the final section, we will mention examples employed in this book and topics to learn from these examples.

Note that materials presented in this lesson will be kept brief. More details on various aspects of mechanism design and analysis using *COSMOSMotion* will be given in later lessons.

1.2 What is *COSMOSMotion*?

COSMOSMotion is a computer software tool that supports engineers to analyze and design mechanisms. *COSMOSMotion* is a module of the *SolidWorks* product family developed by *SolidWorks Corporation*. This software supports users to create virtual mechanisms that answer general questions in product design as described next. An internal combustion engine shown in Figures 1-1 and 1-2 will be used to illustrate some typical questions.

1. Will the components of the mechanism collide in operation? For example, will the connecting rod collide with the inner surface of the piston or the inner surface of the engine case during operation?

2. Will the components in the mechanism you design move according to your intent? For example, will the piston stay entirely in the piston sleeve? Will the system lock up when the firing force aligns vertically with the connecting rod?

3. How much torque or force does it take to drive the mechanism? For example, what will be the minimum firing load to move the piston? Note that in this case, proper friction forces must be added to simulate the resistance of the mechanism before a realistic firing force can be calculated.

4. How fast will the components move; e.g., the longitudinal motion of the piston?

5. What is the reaction force or torque generated at a connection (also called *joint* or *constraint*) between components (or bodies) during motion? For example, what is the reaction force at the joint between the connecting rod and the piston pin? This reaction force is critical since the structural integrity of the piston pin and the connecting rod must be ensured; i.e., they must be strong and durable enough to sustain the load in operation.

The modeling and analysis capabilities in *COSMOSMotion* will help you answer these common questions accurately and realistically, as long as the motion model is properly defined.

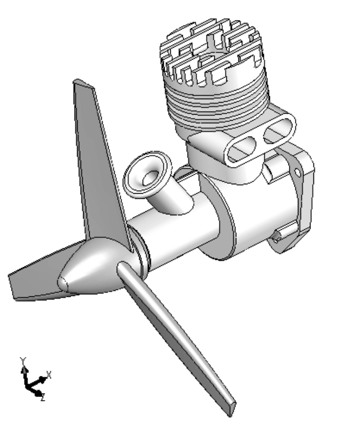


Figure 1-1 An Internal Combustion Engine (Unexploded View)

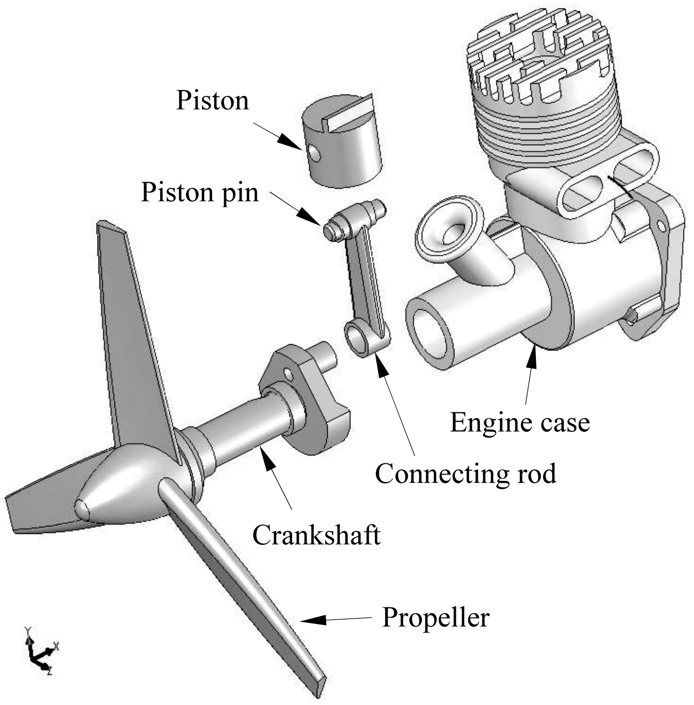
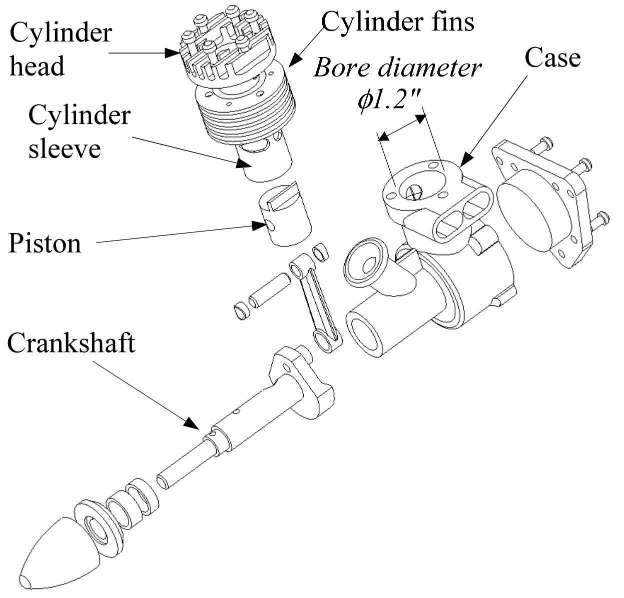


Figure 1-2 Internal Combustion Engine (Exploded View)

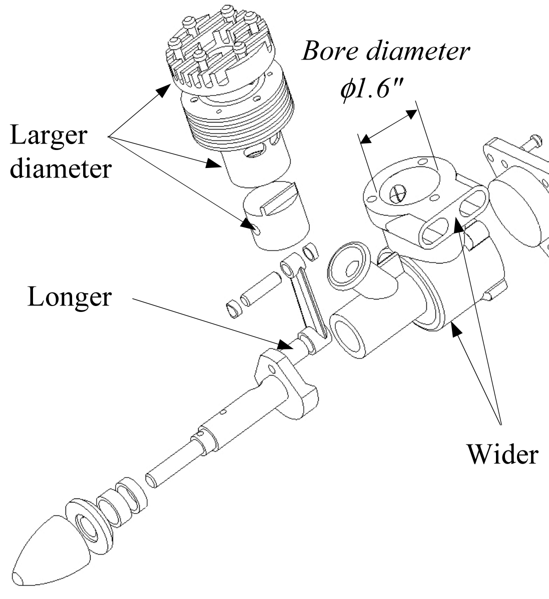
The capabilities available in *COSMOSMotion* also help you search for better design alternatives. A better design alternative is very much problem dependent. It is critical that a design problem be clearly defined by the designer up front before searching for better design alternatives. For the engine example, a better design alternative can be a design that reveals:

1. A smaller reaction force applied to the connecting rod, and
2. No collisions or interference between components.

In order to vary component sizes for exploring better design alternatives, the parts and assembly must be adequately parameterized to capture design intents. At the parts level, design parameterization implies creating solid features and relating dimensions properly. At the assembly level, design parameterization involves defining assembly mates and relating dimensions across parts. When a solid model is fully parameterized, a change in dimension value can be propagated to all parts affected automatically. Parts affected must be rebuilt successfully, and at the same time, they will have to maintain proper position and orientation with respect to one another without violating any assembly mates or revealing part penetration or excessive gaps. For example, in this engine example, a change in the bore diameter of the engine case will alter not only the geometry of the case itself, but all other parts affected, such as the piston, piston sleeve, and even the crankshaft, as illustrated in Figure 1-3. Moreover, they all have to be rebuilt properly and the entire assembly must stay intact through assembly mates.



(a) Bore Diameter 1.2"

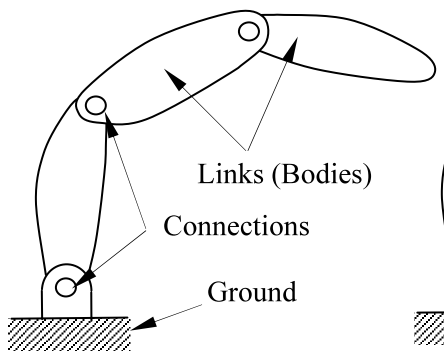


(b) Bore Diameter 1.6"

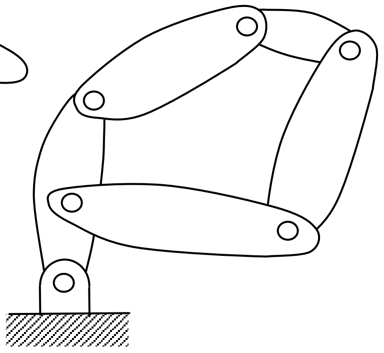
Figure 1-3 A Single-Piston Engine—Exploded View

1.3 Mechanism Design and Motion Analysis

A mechanism is a mechanical device that transfers motion and/or force from a source to an output. It can be an abstraction (simplified model) of a mechanical system. A linkage consists of links (or bodies), which are connected by joints (or connections), such as a revolute joint, to form open or closed chains (or loops, see Figure 1-4). Such kinematic chains, with at least one link fixed, become mechanisms. In this book, all links are assumed rigid. In general, a mechanism can be represented by its corresponding schematic drawing for analysis purpose. For example, a slider-crank mechanism represents the engine motion, as shown in Figure 1-5, which is a closed loop mechanism.



(a) Open Loop Mechanism



(b) Closed Loop Mechanism

Figure 1-4 General Mechanisms

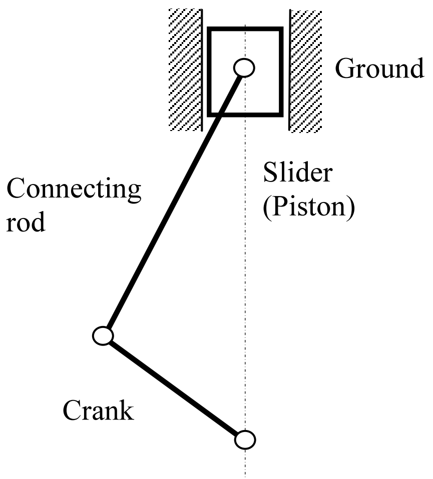


Figure 1-5 Schematic View of the Engine Motion Model

In general, there are two types of motion problems that you will have to solve in order to answer questions regarding mechanism analysis and design: kinematic and dynamic.

Kinematics is the study of motion without regard for the forces that cause the motion. A kinematic mechanism must be driven by a servomotor (or motion driver) so that the position, velocity, and acceleration of each link of the mechanism can be analyzed at any given time. Typically, a kinematic analysis must be conducted before dynamic behavior of the mechanism can be simulated properly.

Dynamic analysis is the study of motion in response to externally applied loads. The dynamic behavior of a mechanism is governed by Newton's laws of motion. The simplest dynamic problem is the particle dynamics introduced in Sophomore Dynamics—for example, a spring-mass-damper system shown in Figure 1-6. In this case, motion of the mass is governed by the following equation derived from Newton's second law,

$$\sum F = p(t) - kx - c\dot{x} = m\ddot{x} \tag{1.1}$$

where (˙) appearing on top of the physical quantities represents time derivative of the quantities, *m* is the total mass of the block, *k* is the spring constant, and *c* is the damping coefficient.

For a rigid body, mass properties (such as the total mass, center of mass, moment of inertia, etc.) are taken into account for dynamic analysis. For example, motion of a pendulum shown in Figure 1-7 is governed by the following equation of motion,

$$\sum M = -mg\ell \sin\theta = I\ddot{\theta} = m\ell^2\ddot{\theta} \tag{1.2}$$

where M is the external moment (or torque), I is the polar moment of inertia of the pendulum, m is the pendulum mass, g is the gravitational acceleration, and $\ddot{\theta}$ is the angular acceleration of the pendulum.

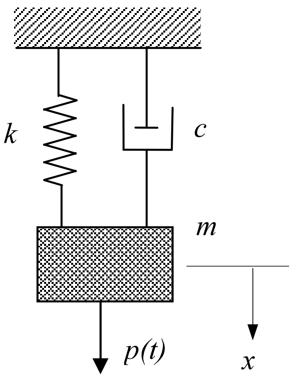


Figure 1-6 The Spring-Mass-Damper System

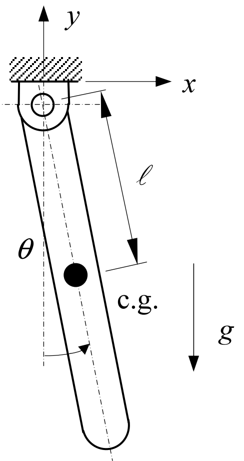


Figure 1-7 A Simple Pendulum

Dynamic analysis of a rigid body system, such as the single piston engine shown in Figure 1-3, is a lot more complicated than the single body problems. Usually, a system of differential and algebraic equations governs the motion and the dynamic behavior of the system. Newton's law must be obeyed by every single body in the system at all time. The motion of the system will be determined by the loads acting on the bodies or joint axes (e.g., a torque driving the system). Reaction loads at the joint connections hold the bodies together.

Note that in *COSMOSMotion*, you may create a kinematic analysis model; e.g., using a motion driver to drive the mechanism; and then carry out dynamic analyses. In dynamic analysis, position, velocity, and acceleration results are identical to those of kinematic analysis. However, the inertia of the bodies will be taken into account for analysis; therefore, reaction forces will be calculated between bodies.

1.4 *COSMOSMotion* Capabilities

Overall Process

The overall process of using *COSMOSMotion* for analyzing a mechanism consists of three main steps: model generation, analysis (or simulation), and result visualization (or post-processing), as illustrated in Figure 1-8. Key entities that constitute a motion model include ground parts that are always fixed, moving parts that are movable, joints and constraints that connect and restrict relative motion between parts, servo motors (or motion drivers) that drive the mechanism for kinematic analysis, external loads (force and torque), and the initial conditions of the mechanism. More details about these entities will be discussed later in this lesson.

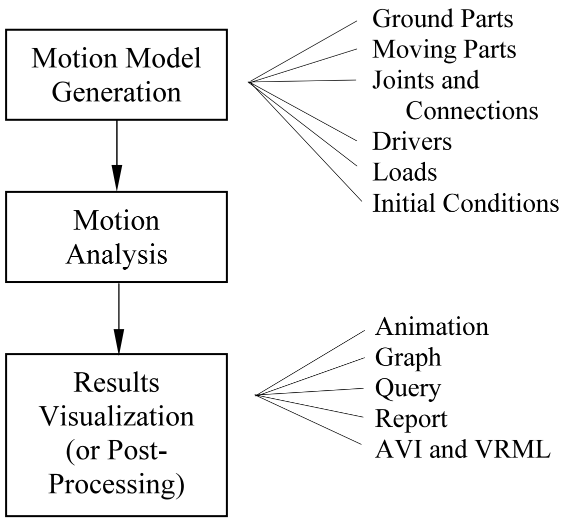


Figure 1-8 General Process of Using *COSMOSMotion*

The analysis or simulation capabilities in *COSMOSMotion* employ simulation engine, *ADAMS/Solver*, which solves the equations of motion for your mechanism. *ADAMS/Solver* calculates the position, velocity, acceleration, and reaction forces acting on each moving part in the mechanism. Typical simulation problems, including static (equilibrium configuration) and motion (kinematic and dynamic), are supported. More details about the analysis capabilities in *COSMOSMotion* will be discussed later in this lesson.

The analysis results can be visualized in various forms. You may animate motion of the mechanism, or generate graphs for more specific information, such as the reaction force of a joint in time domain. You may also query results at specific locations for a given time. Furthermore, you may ask for a report on results that you specified, such as the acceleration of a moving part in the time domain. You may also convert the motion animation to an AVI for faster viewing and file portability. In addition to AVI, you can export animations to VRML format for distribution on the Internet. You can then use Co*smo Player*, a plug-in to your Web browser, to view VRML files. To download *Cosmo Player* for *Windows*, go to http://ovrt.nist.gov/cosmo/.

Operation Mode

COSMOSMotion is embedded in *SolidWorks*. It is indeed an add-on module of *SolidWorks*, and transition from *SolidWorks* to *COSMOSMotion* is seamless. All the solid models, materials, assembly mates, etc. defined in *SolidWorks* are automatically carried over into *COSMOSMotion*. *COSMOSMotion* can be accessed through menus and windows inside *SolidWorks*. The same assembly created in *SolidWorks* can be directly employed for creating motion models in *COSMOSMotion*. In addition, part geometry is essential for mass property computations in motion analysis. In *COSMOSMotion,* all mass properties calculated in *SolidWorks* are ready for use. In addition, the detailed part geometry supports interference checking for the mechanism during motion simulation in *COSMOSMotion*.

User Interfaces

User interface of the *COSMOSMotion* is identical to that of *SolidWorks*, as shown in Figure 1-9. *SolidWorks* users should find it is straightforward to maneuver in *COSMOSMotion*.

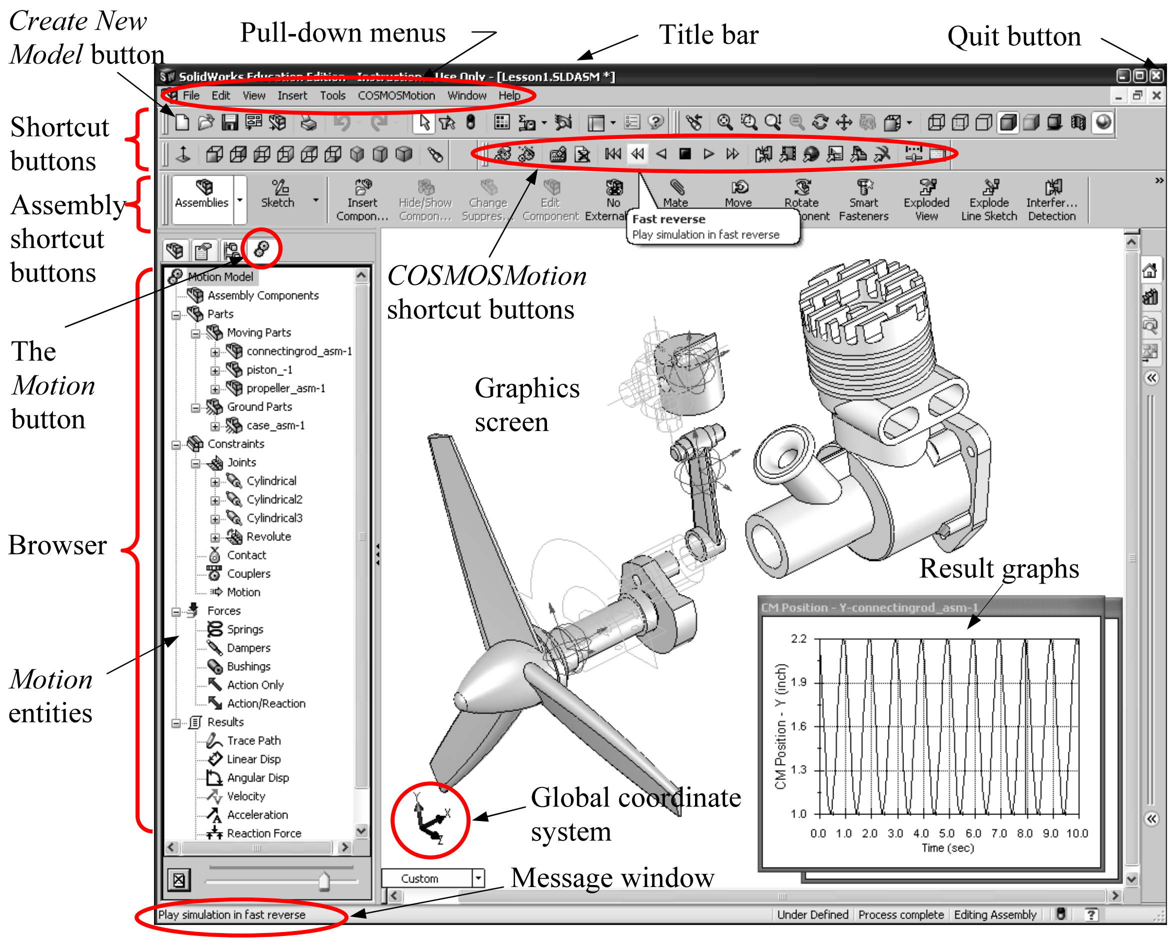


Figure 1-9 User Interface of *COSMOSMotion*

As shown in Figure 1-9, the user interface window of *COSMOSMotion* consists of pull-down menus, shortcut buttons, the browser, the graphics screen, the message window, etc. When *COSMOSMotion* is active, an extra tab (the *Motion* button) is available on top of the browser. This *Motion* button will allow you to access *COSMOSMotion*.

The graphics screen displays the motion model with which you are working. The global coordinate system at the lower left corner of the graphics screen is fixed and serves as the reference for all the physical parameters defined in the motion model. The pull-down menus and the shortcut buttons at the top of the screen provide typical *SolidWorks* functions. The assembly shortcut buttons allow you to assemble your *SolidWorks* model. The *COSMOSMotion* shortcut buttons on top of the graphics screen shown in Figure 1-9 provide all the functions required to create and modify the motion models, create and run analyses, and visualize results.

As you move the mouse over a button, a brief description about the functionality of the button, such as the *Fast Reverse* button shown in Figure 1-9, will appear.

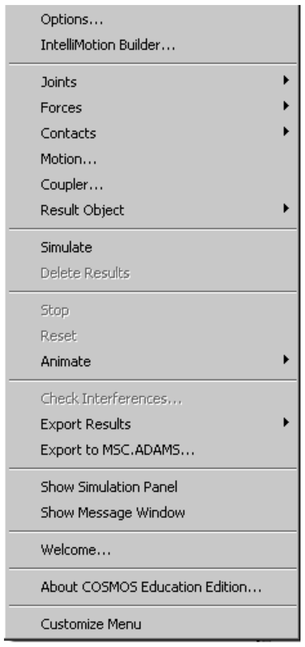


Figure 1-10

When you choose a menu option, the *Message* window, at the lower left corner shown in Figure 1-9, shows a brief description about the option. In addition to these buttons, a *COSMOSMotion* pull-down menu also provides similar options, as shown in Figure 1-10.

When you click the *Motion* button, the browser will provide you with a graphical, hierarchical view of motion model and allow you to access all *COSMOSMotion* functionalities through a combination of drag-and-drop and right-click activated menus.

For example, you may drag and drop *connectingrod_asm-1* under the *Assembly Components*, as shown in Figure 1-11 to *Moving Parts* under the *Parts* branch to define it as a moving part. You may also right click an entity and choose to define or edit its property. For example, you may right click the *Springs* node under *Forces* branch in Figure 1-12, and choose *Add Translational Spring* to add a spring.

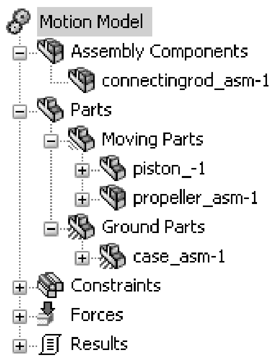


Figure 1-11

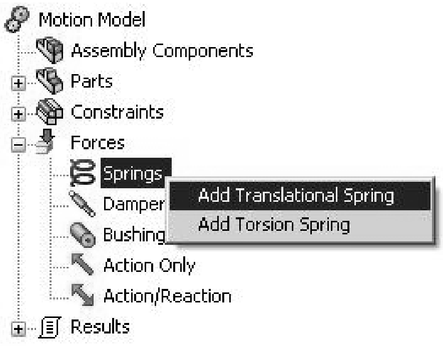


Figure 1-12

Switching back and forth between *COSMOSMotion* and *SolidWorks* assembly mode is straightforward. All you have to do is to click the *Motion* or *Assembly* buttons (on top of the browser) when needed. When you click the *Motion* button to enter *COSMOSMotion*, a different set of entities will be listed in the browser. In addition, an additional toolbar is added to *SolidWorks*, located at the top of the graphics screen, as depicted in Figure 1-13. They are the *COSMOSMotion* shortcut buttons shown in Figure 1-9. This toolbar provides settings, simulation and post processing features. Especially, the *Play Simulation* button is handy when you finish running a simulation and are ready to animate the motion. Click some of the buttons and try to get familiar with their functions. The shortcut buttons in *COSMOSMotion* and their functions are also summarized in Table 1-1 with a few more details.

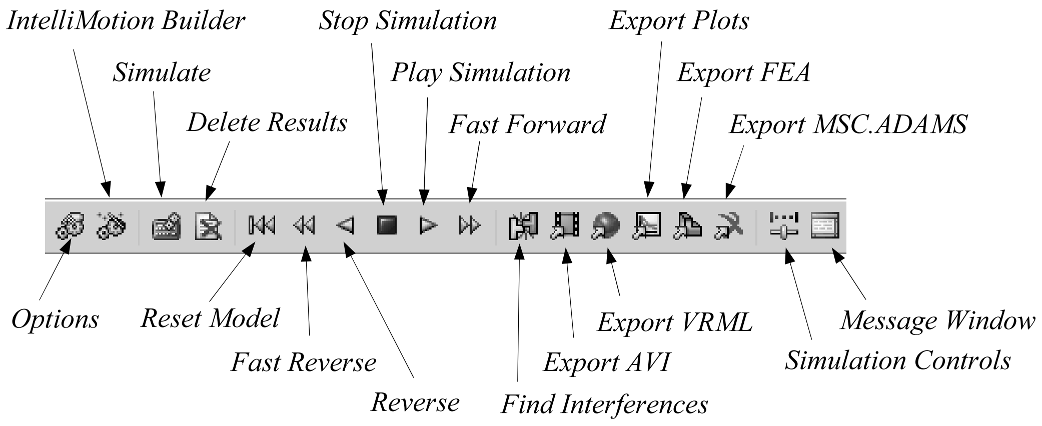


Figure 1-13 The Shortcut Buttons in *COSMOSMotion*

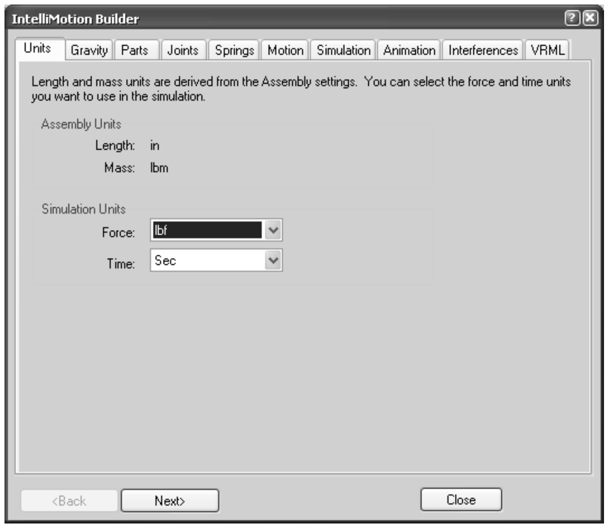
In addition to using the browser, another convenient way of using *COSMOSMotion* is the *IntelliMotion Builder*. The *IntelliMotion Builder* is the primary interface in *COSMOSMotion*. It is a tabbed dialog box and a wizard that leads you through the process of converting an assembly model into a motion model, performing motion simulations, and viewing simulation results.

Table 1-1 The Shortcut Buttons in *COSMOSMotion*

Symbol	Name	Function
	Options	Allow you to control the default values and current settings for the mechanism in the *Options* dialog box. This options button allows you to access five major functions, including display, simulation, animation, results, and plot settings.
	IntelliMotion Builder	The *IntelliMotion Builder* is the primary interface in *COSMOSMotion*.
	Simulate	Simulate the motion of the mechanical system you created.
	Delete Results	Delete the simulation results.
⏮	Reset Model	Reset the mechanism to its original configuration after a simulation or animation.
⏪	Fast Reverse	Play the mechanism in the reverse direction but skips frames so the animation is faster than regular play.
◁	Reverse	Play every frame of the animation in the reverse direction.
■	Stop Simulation	Stop a simulation or animation.
▷	Play Simulation	Play every frame of the animation in the forward direction (*Forward Play*).
⏩	Fast Forward	Play the animation in the forward direction, skipping frames so that the animation is faster than *Forward Play*.
	Find Interferences	All the interferences that occur between the selected components as the assembly move through a specified range of motion.
	Export AVI	Create an AVI movie from your animation.
	Export VRML	Export your animations to VRML format for distribution on the Internet.
	Export Plots	Create a text file that contains results of your simulation.
	Export FEA	Export reaction force results in a form suitable for import by many Finite Element Analysis (FEA) programs
	Export *MSC.ADAMS*	Export your mechanism to *ADAMS/View*.*
	Simulation Controls	Show simulation control. You may also ask *COSMOSMotion* to calculate the total degrees-of-freedom of the mechanism using the *Calculate* button.
	Message Window	Show simulation message in the *Messages* window. You may want to check the messages for possible error or warnings during the simulation.

* ADAMS/View is a motion simulation solution for analyzing the complex behavior of mechanical assemblies. More can be found at http://www.mscsoftware.com/products/adams.cfm.

To use the *IntelliMotion Builder*, click the *IntelliMotion Builder* button or right-click the *Motion Model* node (the root entity of the motion model) from the browser, and then select *IntelliMotion Builder* (see Figure 1-14). The first tab is *Units*, which brings up the *Units* page.



Length and mass units are derived from the Assembly settings. You can select the force and time units you want to use in the simulation.

Assembly Units
Length: in
Mass: lbm

Simulation Units
Force: lbf
Time: Sec

Figure 1-14 The *IntelliMotion Builder*

At the lower-left corner of each page in the *IntelliMotion Builder* are the *Back* and *Next* buttons, which help you move sequentially through the motion model creation, simulation, and animation process. You may also click a tab on top to jump to that page directly, for example *Parts*, to define ground and moving parts. For a new *COSMOSMotion* user, the *IntelliMotion Builder* is very helpful in terms of leading you through the steps of creating simulations models, running simulations, and visualizing the simulation results. For a more experienced user, the drag-and-drop and right-click activated menus may be more convenient.

Table 1-2 gives a brief explanation of each tab available in the *IntelliMotion Builder*.

Table 1-2 The Brief Summary of Capabilities Provided in *IntelliMotion Builder*

Tab Name	Function
Units	Allow you to choose or change units system.
Gravity	Allow you to specify or modify gravity.
Parts	Allows you to specify the assembly components that participate in the motion simulation as both moving and non-moving (ground) parts.
Joints	Allows you to modify joints that were automatically created from assembly constraints and add additional joints to the motion model if necessary.
Springs	Allows you to add springs to the *COSMOSMotion* model.
Motion	Allow you to add motion driver to any joint with at least one open degree of freedom.
Simulation	Allows you to specify basic parameters about the simulation and start *ADAMS/Solver*.
Animation	Allow you to control playback of an animation.
Interference	Allows you to check the *SolidWorks* components for interference as they move.
VRML	Allow you to export your animations to VRML format for distribution on the Internet.

Defining COSMOSMotion Entities

The basic entities of a valid *COSMOSMotion* simulation model consist of ground parts, moving parts, constraints (including joints), initial conditions, and forces and/or drivers. Each of the basic entities will be briefly discussed next. More details can be found in later lessons.

Ground Parts (or Ground Body)

A ground part, or a ground body, represents a fixed reference in space. The first component brought into the assembly is usually stationary; therefore, often becoming a ground part. You will have to identify moving and non-moving parts in your assembly, and assign the non-moving parts as ground parts using either the *IntelliMotion Builder* or the drag-and-drop in the browser.

Moving Parts (or Bodies)

A moving part or body is an entity represents a single rigid component (or link) that moves relatively to other parts (or bodies). A moving part may consist of a single *SolidWorks* part or an assembly composed of multiple parts. When an assembly is assigned as a moving part, none of its composing parts is allowed to move relative to one another within the assembly. A moving part has six degrees of freedom, three translational and three rotational, while a ground part has none. That is, a rigid body can translate and rotate along the *X*-, *Y*-, and *Z*-axes of a coordinate system. Rotation of a rigid body is measured by referring the orientation of its local coordinate system to the global coordinate system, which is shown at the lower left corner on the graphics screen. In *COSMOSMotion*, the local coordinate system is assigned automatically, usually, at the mass center of the part. Mass properties, including total mass, inertia, etc., are calculated using part geometry and material properties referring to the local coordinate system. A moving part has a symbol (see Figure 1-16a) attached, usually located at its mass center, as shown in Figure 1-15.

Constraints

A constraint (or connection) in *COSMOSMotion* can be a joint, contact, or coupler that connects two parts and constrains the relative motion between them. Typical joints include a revolute, cylindrical, spherical, etc. Each independent movement permitted by a constraint is a free degree of freedom (dof). The degrees of freedom that a constraint allows can be translational or rotational along the three perpendicular axes. The free dof is revealed by the symbol of the constraint. For example, the symbol of cylindrical joints, such as those defined in the engine example shown in Figure 1-15, show two concentric cylinders implying two free dof's, a translational and a rotational, both are along the common axis, as illustrated in Figure 1-16b. Also, a revolute joint, for example the one between the propeller and the case shown in Figure 1-15, allows only one rotational dof, as depicted in a hinge symbol shown in Figure 1-16c. Understanding the joint symbols will enable you to read existing motion models. Also, a joint produces equal and opposite reactions (forces and/or torques) on the bodies connected due to Newton's 3rd Law. More about joints will be discussed in later lessons and for a list of commonly employed joints, please refer to Appendix A.

COSMOSMotion automatically converts assembly mates to joints. For example, a concentric mate together with a coincident mate will be converted to a revolute joint. Sometimes, *COSMOSMotion* will simply carry over the assembly mates to motion if there is no adequate joint to convert to, following the mapped mates established internally. For a list of common mapped mates, please refer to Appendix A. You may either stay with the joint set converted by *COSMOSMotion* or delete some of them to create your own. However, it is strongly recommended that you stay with the converted joint set before completing all the examples provided in this book. In all the examples presented in this book, mapped joints or mates are employed without any modification.

Note that instead of completely fixing all the movements, certain dof's (translational and/or rotational) are left to allow designated movement. For example, a motion driver is defined at the rotation dof of the revolute joint in the engine example, as shown in Figure 1-15. This motion driver will rotate the propeller at a prescribed angular velocity. In addition to prescribed velocity, you may use the motion driver to drive the dof at a prescribed displacement or acceleration, both translation and rotational.

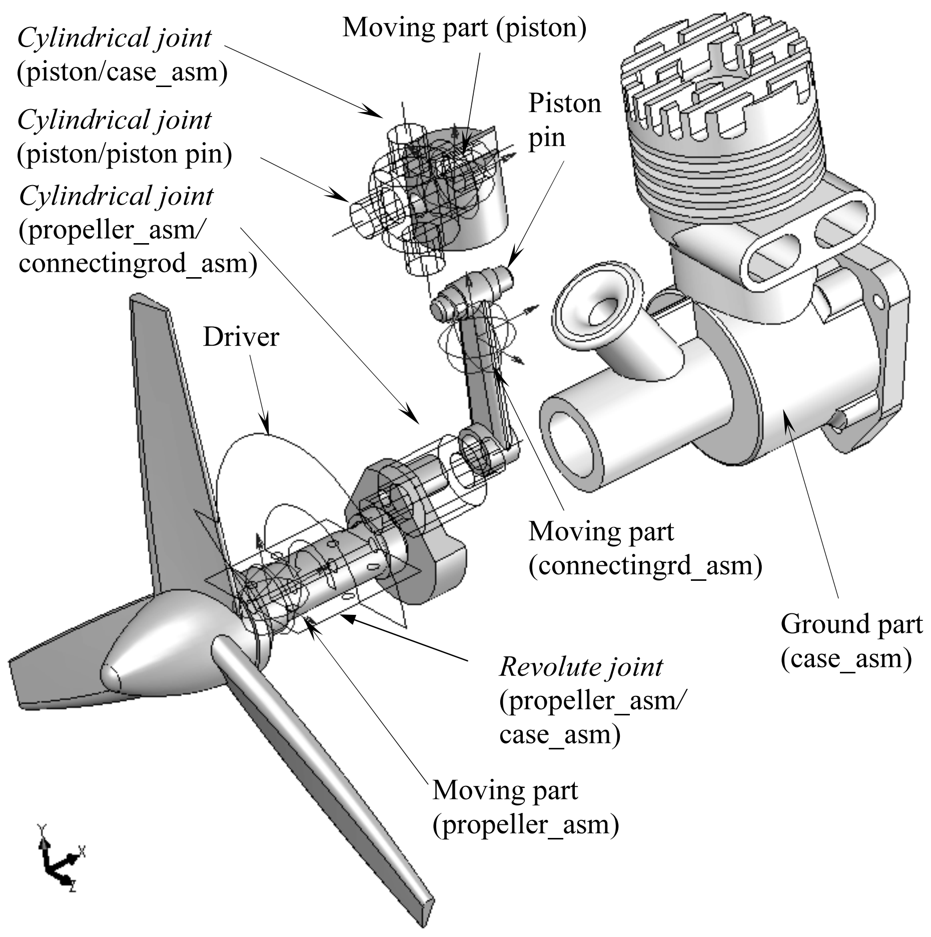
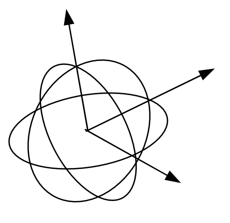
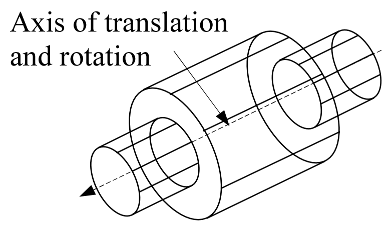
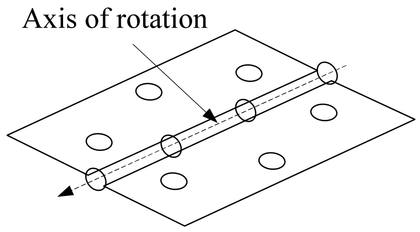


Figure 1-15 A Typical Motion Model in an Exploded View







(a) Moving Part Symbol (b) Cylindrical Joint Symbol (c) Revolute Joint Symbol

Figure 1-16 Symbols of Common Motion Entities

In addition to joints, *COSMOSMotion* provides contact and coupling constraints. The contact constraints help to simulate physical problems more realistically. *COSMOSMotion* supports four types of contact, point-curve, curve-curve, intermittent curve-curve, and 3D contact. Only the first two types of contact impose degree-of-freedom restrictions on the connected parts and are true constraints. The 3D contact is employed most frequently, which applies a force to separate the parts when they are in contact and prevent them from penetrating each other. The 3D contact constraint will become active as soon as the parts are touching.

Joint couplers allow the motion of a revolute, cylindrical, or translational joint to be coupled to the motion of another revolute, cylindrical or translational joint. The two coupled joints may be of the same or different types. For example, a revolute joint may be coupled to a translational joint. The coupled motion may also be of the same or different type. For example, the rotary motion of a revolute joint may be coupled to the rotary motion of a cylindrical joint, or the translational motion of a translational joint may be coupled to the rotary motion of a cylindrical joint. A coupler removes one additional degree of freedom from the motion model.

Degrees of Freedom

As mentioned earlier, an unconstrained body in space has six degrees of freedom; i.e., three translational and three rotational. When joints are added to connect bodies, constraints are imposed to restrict the relative motion between them.

For example, the revolute joint defined in the engine example restricts movement on five dof's so that only one rotational motion is allowed between the propeller assembly and the engine case. Since the engine case is a ground body, the propeller assembly will rotate along the axis of the revolute joint, as illustrated in the symbol shown in Figure 1-16b. Therefore, there is only one degree of freedom left for the propeller assembly. For a given motion model, you can determine its number of degrees of freedom using the Gruebler's count.

COSMOSMotion uses the following equation to calculate the Gruebler's count:

$$D = 6M - N - O \qquad (1.3)$$

where D is the Gruebler's count representing the total degrees of freedom of the mechanism, M is the number of bodies excluding the ground body, N is the number of dof's restricted by all joints, and O is the number of motion drivers defined in the system.

In general, a valid motion model should have a Gruebler's count 0. However, in creating motion models, some joints remove redundant dof's. For example, two hinges, modeled using two revolute joints, support a door. The second revolute joint adds five redundant dof's. The Gruebler's count becomes:

$$D = 6\times 1 - 2\times 5 = -4$$

For kinematic analysis, the Gruebler's count must be equal to or less than 0. The *ADAMS/Solver* recognizes and deactivates redundant constraints during analysis. For a kinematic analysis, if you create a model and try to animate it with a Gruebler's count greater than 0, the animation will not run and an error message will appear.

The single-piston engine shown in Figure 1-15 consists of three bodies (excluding the ground body), one revolute joint and three cylindrical joints. A revolute joint removes five degrees of freedom, and a cylindrical joint removes four dof's. In addition, a motion driver is added to the rotational dof of the revolute joint. Therefore, according to Eq. 1.3, the Gruebler's count for the engine example is

$$D = 6\times 3 - (1\times 5 - 3\times 4) - 1\times 1 = 0$$

If the Gruebler's count is less than zero, the solver will automatically remove redundancies. In this engine example, if the two of the cylindrical joints; between piston and the piston pin, and between the connecting rod and the crank shaft, are replaced by revolute joints, the Gruebler's count becomes

$$D = 6\times(4-1) - (3\times5 - 1\times4) - 1\times1 = -2$$

To get the Gruebler's count to zero, it is often possible to replace joints that remove a large number of constraints with joints that remove a smaller number of constraints and still restrict the mechanism motion in the same way. *COSMOSMotion* detects the redundancies and ignores redundant dof's in all analyses, except for dynamic analysis. In dynamic analysis, the redundancies lead to an outcome with a possibility of incorrect reaction results, yet the motion is correct. For complete and accurate reaction forces, it is critical that you eliminate redundancies from your mechanism. The challenge is to find the joints that will impose non-redundant constraints and still allow for the intended motion. Examples included in this book should give you some ideas in choosing proper joints.

<u>Forces</u>

Forces are used to operate a mechanism. Physically, forces are produced by motors, springs, dampers, gravity, tires, etc. A force entity in *COSMOSMotion* can be a force or torque. *COSMOSMotion* provides three types of forces: applied forces, flexible connectors, and gravity.

Applied forces are forces that cause the mechanism to move in certain ways. Applied forces are very general, but you must supply your own description of the force by specifying a constant force value or expression function, such as a harmonic function. The applied forces in *COSMOSMotion* include action-only force or moment (where force or moment is applied at a point on a single rigid body, and no reaction forces are calculated), action and reaction force and moment, and impact force. The force and moment symbols in *COSMOSMotion* are shown in Figure 1-17 and 1-18, respectively.

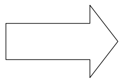


Figure 1-17 The Force (or Translational Driver) Symbol

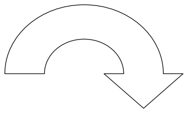
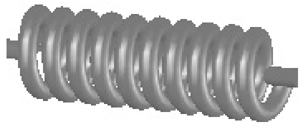
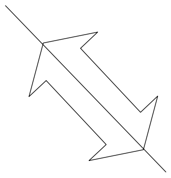


Figure 1-18 The Moment (or Rotational Driver) Symbol

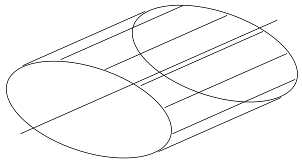
Flexible connectors resist motion and are simpler and easier to use than applied forces because you only supply constant coefficients for the forces, for instance a spring constant. The flexible connectors include translational springs, torsional springs, translational dampers, torsional dampers, and bushings, which symbols are shown in Figure 1-19.



(a) Spring



(b) Damper



(c) Bushing

Figure 1-19 Symbols of the Flexible Connectors

A magnitude and a direction must be included for a force definition. You may select a predefined function, such as a harmonic function, to define the magnitude of the force or moment. For spring and damper, *COSMOSMotion* automatically makes the force magnitude proportional to the distance or velocity between two points, based on the spring constant and damping coefficient entered, respectively. The direction of a force (or moment) can be defined by either along an axis defined by an edge or along the line between two points, where a spring or a damper is defined.

Initial Conditions

In motion simulations, initial conditions consist of initial configuration of the mechanism and initial velocity of one or more components of the mechanism. Motion simulation must start with a properly assembled solid model that determines an initial configuration of the mechanism, composed by position and orientation of individual components. The initial configuration can be completely defined by assembly mates. However, one or more assembly mates will have to be suppressed, if the assembly is fully constrained, to provide adequate movement.

In *COSMOSMotion*, initial velocity is defined as part of definition of a moving part. The initial velocity can be translational or rotational along one of the three axes.

Motion Drivers

Motion drivers are used to impose a particular movement of a joint or part over time. A motion driver specifies position, velocity, or acceleration as a function of time, and can control either translational or rotational motion. The driver symbol is identical to those of Figures 1-17 and 1-18, for translational and rotational, respectively. When properly defined, motion drivers will account for the remaining dof's of the mechanism that brings the Gruebler's count to zero or less.

In the engine example shown in Figure 1-15, a motion driver is defined at the revolute joint to rotate the propeller at a constant angular velocity.

Motion Simulation

The *ADAMS/Solver* employed by *COSMOSMotion* is capable of solving typical engineering problems, such as static (equilibrium configuration), kinematic, and dynamic, etc.

Static analysis is used to find the rest position (equilibrium condition) of a mechanism, in which none of the bodies are moving. A simple example of the static analysis is illustrated in Figure 1-20, in which an equilibrium position of the block is to be determined according to its own mass *m*, the two spring constants k_1 and k_2, and the gravity *g*.

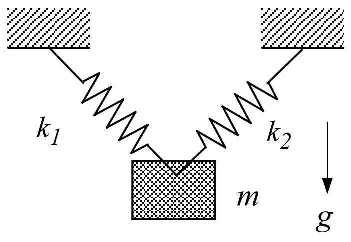


Figure 1-20 Static Analysis

As discussed earlier, kinematics is the study of motion without regard for the forces that cause the motion. A mechanism can be driven by a motion driver (e.g., a servomotor) for a kinematic analysis, where the position, velocity, and acceleration of each link of the mechanism can be analyzed at any given time. Figure 1-21 shows a servomotor drives a mechanism at a constant angular velocity.

Dynamic analysis is used to study the mechanism motion in response to loads, as illustrated in Figure 1-22. This is the most complicated and common, and usually a more time-consuming analysis.

Viewing Results

In *COSMOSMotion*, results of the motion analysis can be realized using animations, graphs, reports, and queries. Animations show the configuration of the mechanism in consecutive time frames. Animations will give you a global view on how the mechanism behaves, for example, the single-piston engine shown in Figure 1-23. You may also export the animation to AVI or VRML for various purposes.

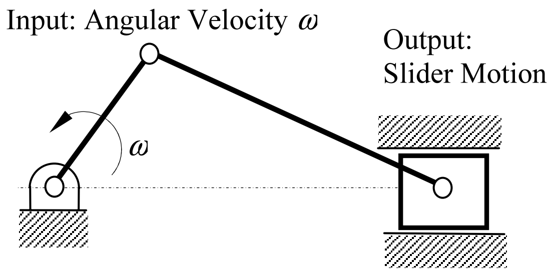


Figure 1-21 Kinematic Analysis

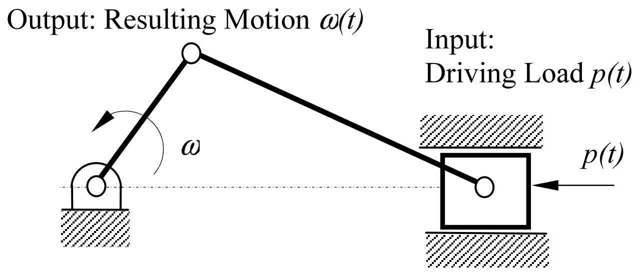

Output: Resulting Motion $\omega(t)$
Input: Driving Load $p(t)$
ω
$p(t)$

Figure 1-22 Dynamic Analysis

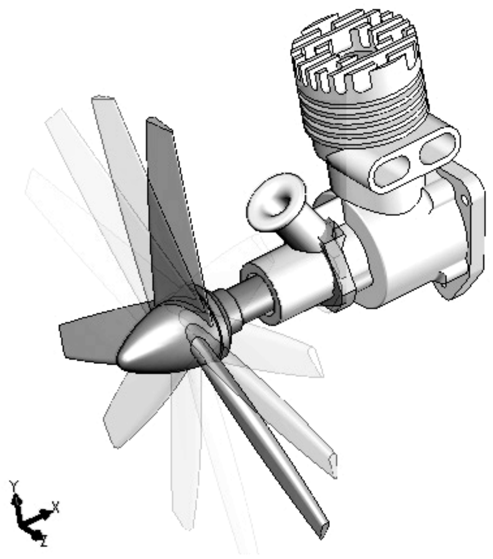


Figure 1-23 Motion Animation

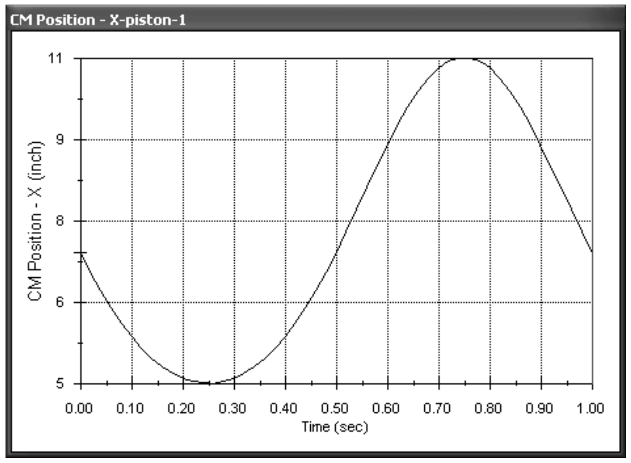


Figure 1-24 Graph of Position of the Piston vs. Time

In addition, you may choose a joint or a part to generate result graphs, for example, the position vs. time of the piston in the engine example shown in Figure 1-24. These graphs give you a quantitative understanding on the characteristics of the mechanism.

You may also query the results by moving the cursor closer to the curve and leave the cursor for a short period. The result data will appear next to the cursor. In addition, you may ask *COSMOSMotion* for a report that includes a complete set of results output in the form of textual data or a Microsoft® Excel spreadsheet.

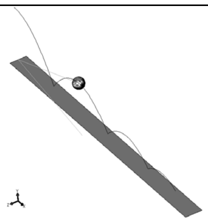
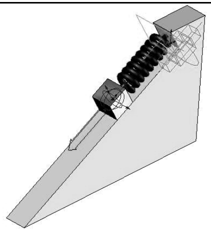
In addition to the capabilities discussed above, *COSMOSMotion* allows you to check interference between bodies during motion (please see *Lesson 5* for more details). Furthermore, the reaction forces calculated can be used to support structural analysis using, for example, *COSMOSWorks*.

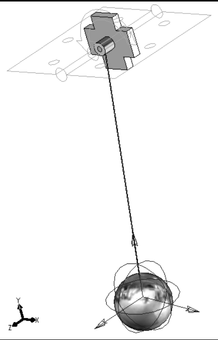
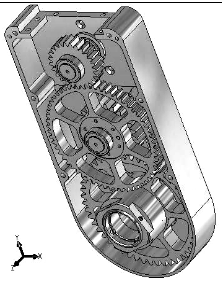
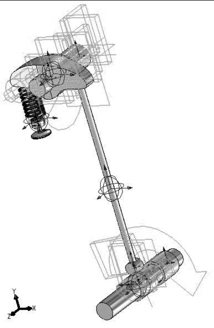
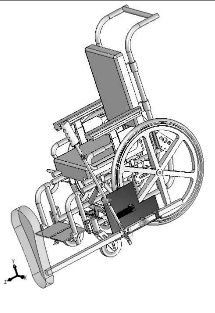
1.5 Motion Examples

Numerous motion examples will be introduced in this book to illustrate the step-by-step details of modeling, simulation, and result visualization capabilities in *COSMOSMotion*. In addition, an application example will be introduced to illustrate the steps and principles of using *COSMOSMotion* for support of mechanism design.

We will start with a simple ball-throwing example in *Lesson 2*. This example will give you a quick run-through on using *COSMOSMotion*. *Lessons 3* through *7* focus on modeling and analysis of basic mechanisms and dynamic systems. In these lessons, you will learn various joint types, including revolute, planar, cylindrical, etc.; forces and connections, including springs, gears, cam-followers; drivers and forces; various analyses; and graphs and results. *Lesson 8* is an application lesson, in which an assistive soccer ball kicking device that can be mounted on a wheelchair will be introduced to show you how to apply what you learn to real-world applications. All examples and main topics to be discussed in each lesson are summarized in the following table.

Table 1-3 Examples Employed for Discussion

Lesson	Title	Motion Model	Problem Type	Things to Learn
2	Ball Throwing Example		Particle Dynamics	1. This lesson offers a quick run-through of general modeling and simulation capabilities in *COSMOSMotion* using *IntelliMotion Builder*. 2. You will learn the general process of using *COSMOSMotion* to construct a motion model, run simulation, and visualize the motion simulation results. 3. Gravity will be turned on and a 3D contact joint will be defined between the ball and the ground to simulate the ball bouncing scenario. 4. Simulation results are verified using analytical equations of motion.
3	Spring-Mass System		Particle Dynamics	1. This is a classical spring-mass system example you learned in Sophomore *Dynamics*. 2. You will learn how to create a mechanical spring, align the block with the slope surface, and add an external force to pull the block. 3. Friction will be added between the block and the slope face. 4. Simulation results are verified using analytical equations of motion.

4	A Simple Pendulum		Particle Dynamics	1. This lesson provides more in depth about creating a revolute joint in *COSMOSMotion*. 2. Simulation results are verified using analytical equations of motion.
5	A Slider Crank Mechanism		Multibody Dynamic Analyses	1. This lesson uses a slider-crank mechanism to discuss more joint types, as well as conduct kinematic and dynamic simulations. 2. In addition to joints, you will learn to create motion driver as well as add a firing force for simulation. 3. The interference checking capability will be discussed. 4. Kinematic analysis results are verified using analytical equations of motion.
6	A Compound Spur Gear Train		Gear Train Analysis	1. This lesson focuses on simulating motion of a spur gear train system. 2. You will learn how to use *SolidWorks* and *COSMOSMotion* to create a gear connection, and simulate the gear train motion. 3. Simulation results are verified using analytical equations.
7	Cam and Follower		Multibody Dynamic Analysis	1. This lesson discusses cam and follower connection. 2. An inlet or outlet valve system of an internal combustion engine will be created and simulated. 3. Position and velocity of the valve will be graphed to monitor the motion of the system as well as assess the engineering design of the system.
8	Assistive Device for Wheelchair Soccer Game		Multibody Dynamic Analysis	1. This is an application lesson. This lesson shows you how to design an assistive device for playing wheelchair soccer game using motion simulations. 2. Numerous joints, spring, and force will be created for the system. 3. Results will be carefully reviewed to assess and modify the design of the system.