Elements of modeling and simulation researches of multibody systems

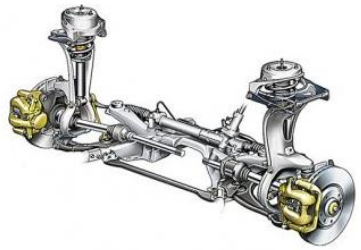
1. Modeling and simulation of multibody systems
2. Basics of modeling in MD.Adams systems
3. Projects

Modeling and simulation of multibody systems

What are the multibody systems?

Mechanisms, machines - cars, airplanes, robots, suspensions, engines, mechanisms, …

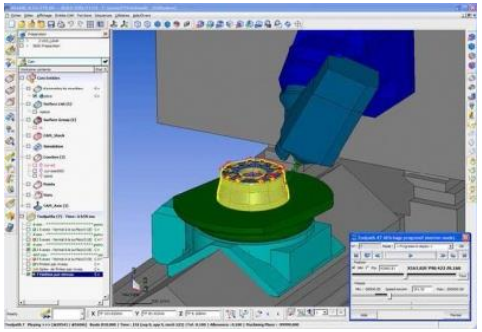





Modeling and simulation of multibody systems

Modeling and simulation of multibody systems -

- applications of the theoretical background in designing of machines using computer aided designing method.



Main problems to solve:

- modeling of machines and mechanisms,
- simulation researches - kinematics, dynamics
- analyzing of results of simulations
- solving design problems of machines

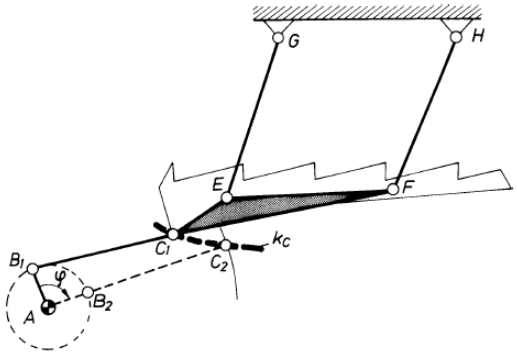
Main target – create and designing better machines using computer aided methods in easiest ways.

Modeling and simulation of multibody systems

Knowledge needed to understand modeling and simulation (theoretical background) of multibody systems:

- structural analysis,
- type synthesis,
- kinematic analysis,
- dynamic analysis,
- geometric synthesis,

of mechanism and machines.



Main target – to understand physical phenomena in designing and operation of machines.

Modeling of multibody systems

Main problems:

to determine number n of bodies,

to determine number p_i and i-class of joints,

to determine number W degree of freedom (mobility),

to determine external loads (forces, torques)

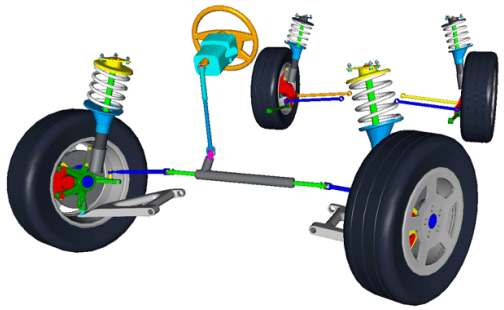
to determine motion drivers q_i,

to create kinematic scheme and model

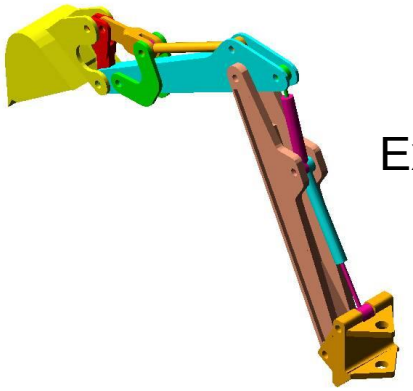
of real multibody system (machine).

Theoretical background:

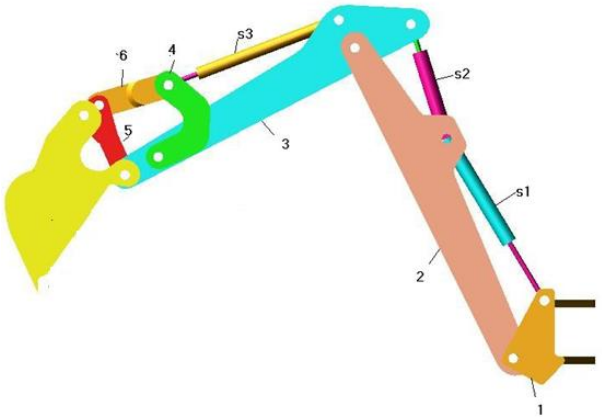
- structural analysis of machines.



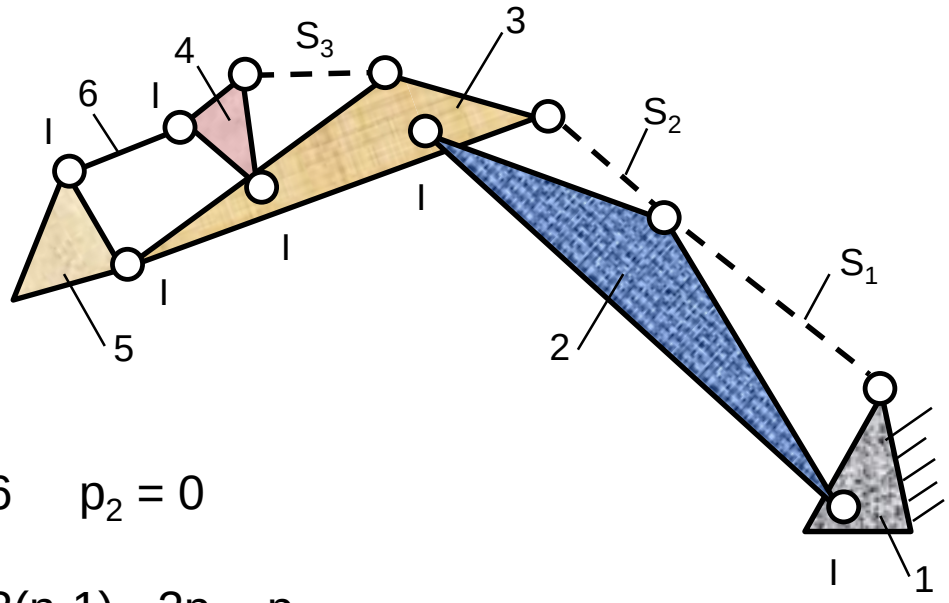
Modeling of multibody systems - kinematic scheme, mobility



Excavator



Kinematic Scheme of Excavator



n = 6

$p_1 = 6 \quad p_2 = 0$

$W = 3(n-1) - 2p_1 - p_2$

$W = 3(6-1) - 2x6 - 0 = 3$

Motion Drivers = 3 = S_1, S_2, S_3

Simulation researches of multibody systems

Simulation researches relay on building virtual model of designing machines and making the kinematic or dynamic analysis in computer system.

Goals of simulation:

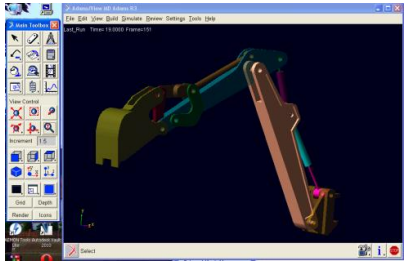
- determining parameters of designing machine (power, velocities, acceleration, forces …),
- solving design problems of machines,
- virtual testing of new machines.

Steps of virtual designing machines

1. Preparing model of machines in computer design systems
2. Making proper simulation – kinematic or dynamic
3. Analysis of simulation results (diagrams, animations, numbers)
4. Verifying of correctness of designing parameters:

   if parameters are correct go to step 5,

   if parameters are not correct change geometric date of bodies and got o step 1.
5. Finish of virtual prototyping - start creating real prototype of machine.



Computer Aided Design System

What Computer Aided Design system?

- Finite Element Method Systems
- Solid Modeling System
- Stress Analysis System
- Manufacturing System, etc.

Dynamic Analysis Systems

Dynamic analysis of multibody system

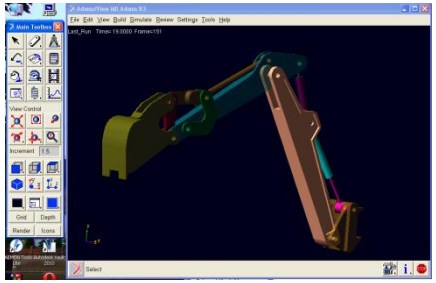
1. Simulation and Analysis of Mechanisms (SAM)
2. MSC.Working Model
3. LMS DADS (Dynamic Analysis Design system)
4. VirtuaLab.Motion

5. **MD.ADAMS**

MD. ADAMS – MSC Software solution for design

ADAMS – **A**utomatic **D**ynamic **A**nalysis of **M**echanical **S**ystems

MD.Adams is a computer system for modeling and making virtual simulation researches of plane and space machines (eg. car, airplane, robots, excavators, suspensions, slider crank mechanism, ...).



MD.Adams target: designing of machines by simulation researches.

MD. Adams – steps of virtual designing

- Modeling of plane and space machines,
- Preprocesing data – create motions driver, loading (forces and torques, mass, etc.), planning motions,
- Making simulation – kinematic, dynamic,
- Postprocessing data – animations of motions, graphic diagrams, numeric tables,
- Complex postprocessing – making parametric models, optimizations.

Designing by simulation researches

MD. Adams – basics od modeling

MD.Adams is created in different version for computer operation system: Windows, Linux and IBM Unix. The rules of modeling are the same. Further information will be presented for Windows version.

MD.Adams is complex computer program built with many specialized modules. Main modules are:

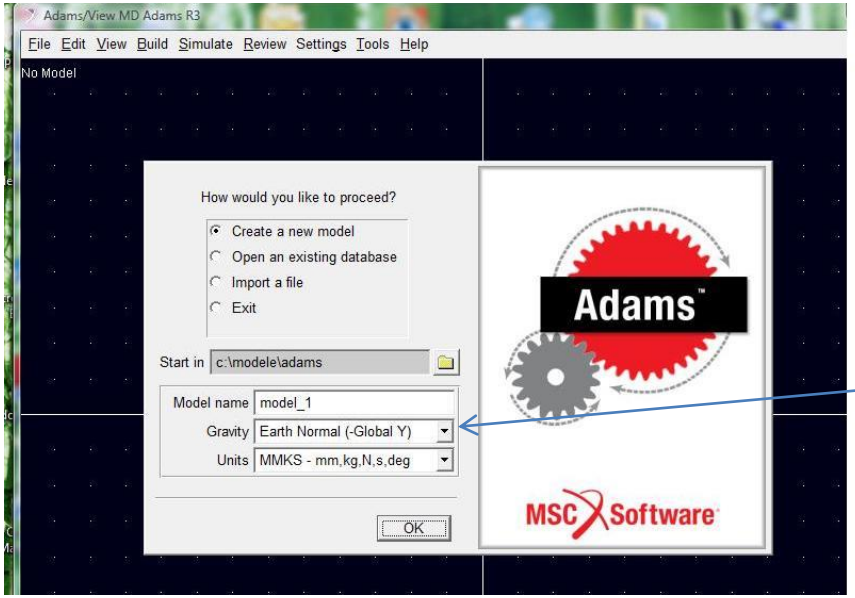
Adams/View – integrated module for creating models in a graphical environment and to initiate processes of calculation and results (postprocessing)

Adams/Solver – module for dynamic and kinematic calculation

Adams/Postprocessor – module for analysis of results (animation, graph, tables)

MD. Adams – basics od modeling

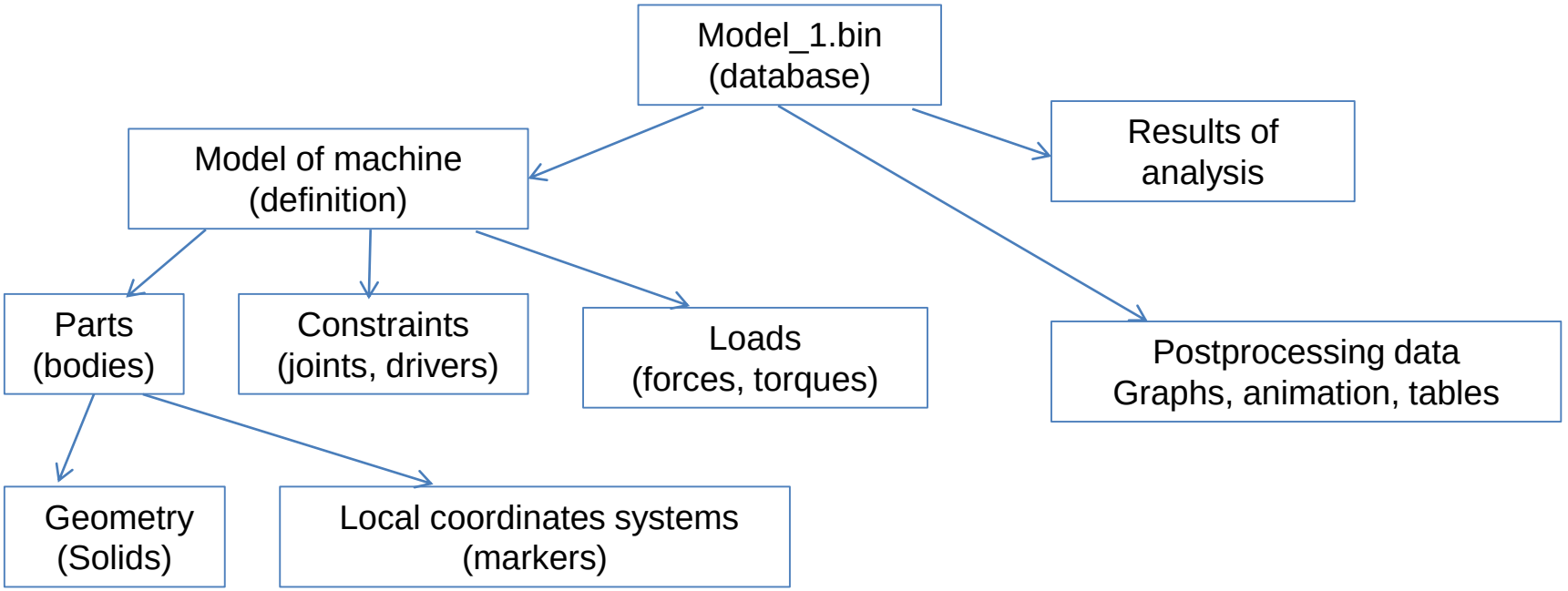
To initiate a start of Adams system we should run Adams/View module by clicking icon on desktop.



In the welcome window we can choose starting option: Create/Open/Import model of machine or exit.
When the option Create a new model is chosen we need to enter the name of model, select the direction of gravity and system unit.

MD. Adams – structure of model database

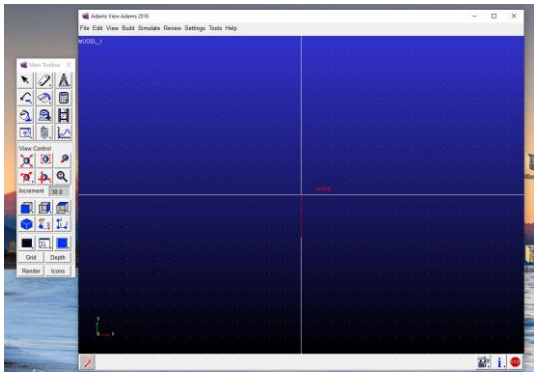
New model is saved in database with name with extension bin.
(eg. model_1.bin). The database structure is given below.



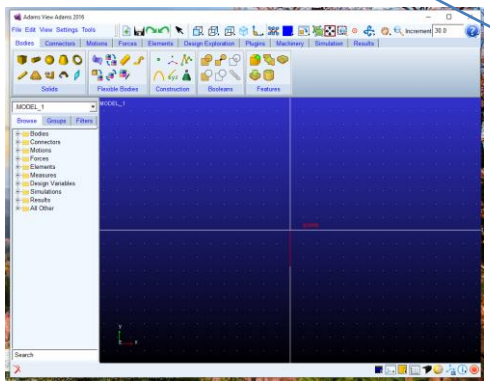
System MD.Adams has 2 form of interface: Default and Classic.

System MD.Adams has 2 forms of interface: Default and Classic. Switching between interface views could be done with the top menu command: Settings-Interface Style.

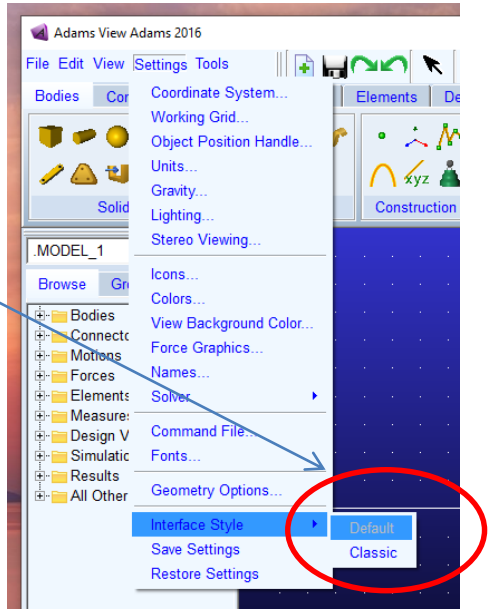
The presentation is made for the MD.Adams program with the Classic view.



Classic view

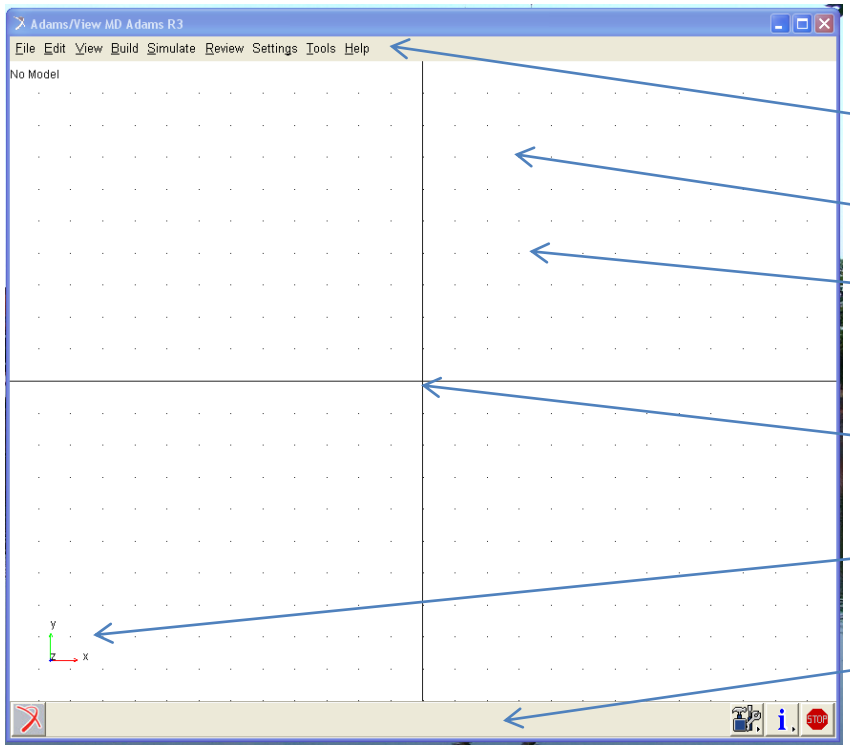


Default view



MD. Adams – graphical environment

Main Adams window



Text Menu Bar

Graphics window

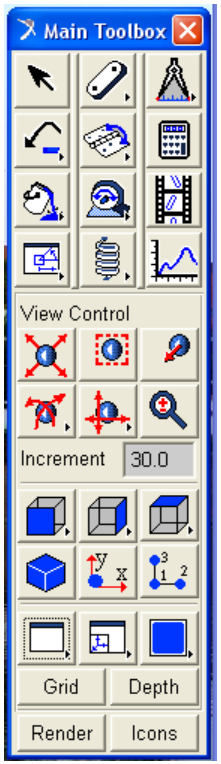
Points of grid

Axes and origin of global coordinates system

Icon of global coordinate system

Status Bar

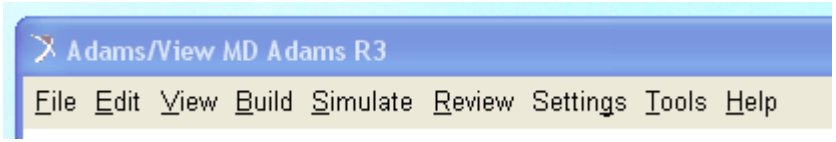
Main Toolbox



MD. Adams – structure of command

All operation in Adams system we can make using command from Main Text Menu or Main Toolbox.

Main Text Menu Commands:

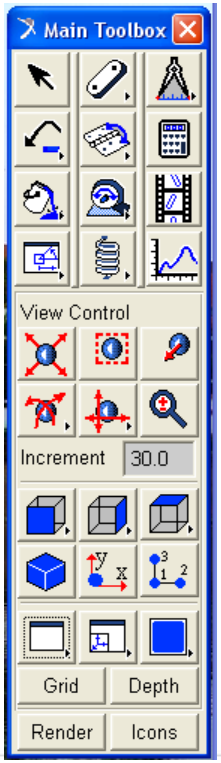


File – set of file and print commands,
Edit – set of modify and edit commands,
View – set of command to changing way of model view,
Build – set of command to create model,

Simulate – set of command to initiate and prepare simualtions,
Review – set of postprocesing operation (animatiom, plot),
Settings – main settings of system
Tools – set of commands to run additional tools,
Help – system help and information.

MD. Adams – structure of commands

Main Toolboxes commands (some icon hides a palette of icons):

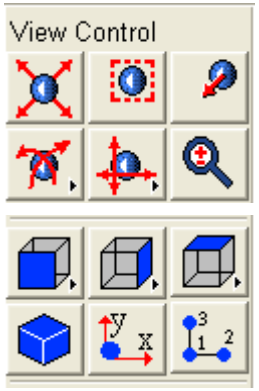


- select
- undo, redo
- change color
- change position
- measure
- bulid part
- joint
- motion driver
- forces

- simulation

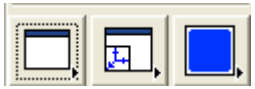
- animation

- plot

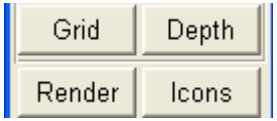


- view control command

- standard point of view



- settings of graphics windows

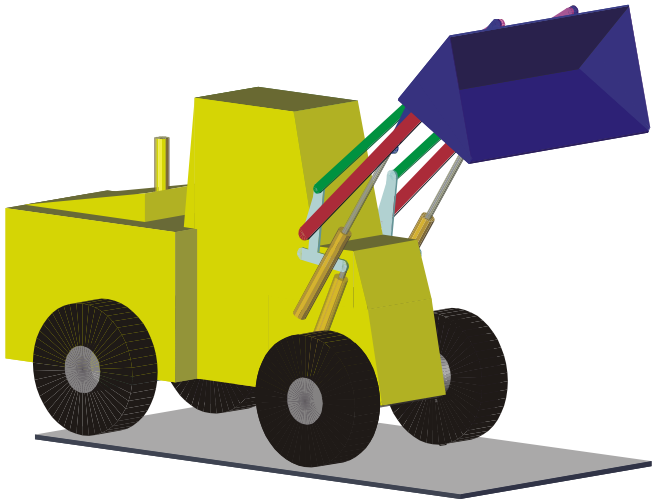


- on/off graphic operation

MD. Adams – building model

Steps to prepare model of machine:

- definition parts/bodies (solids and geometry, points/markers),
- definition joints between bodies,
- definition loads (forces, torques),
- definition motion drivers.

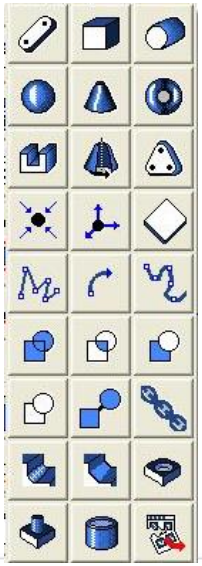


MD. Adams – building parts

Part of modeling machine is built of geometric elements (solids) with mass and inertia. Every part has center of mass. We can located point of interested (markers) on part.

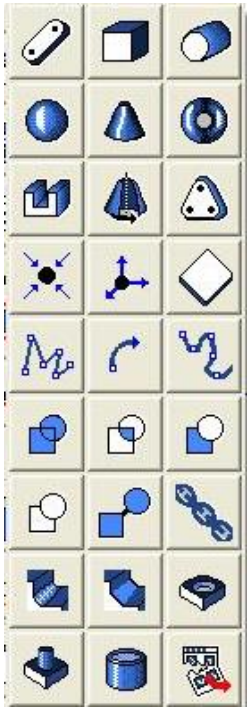
To build the part we use command build part  from Main Toolbox. Under the icon is hidden palette of icons.

To open that palette we need to pick the icon  and then click right mouse button.



Palette build part command.

MD. Adams – building parts



Set of commands:

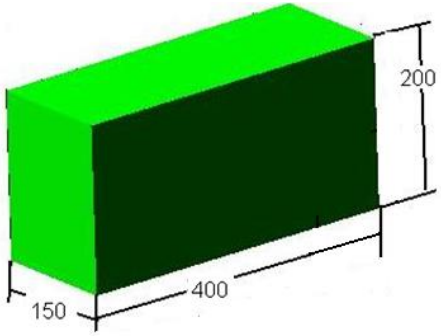
to create solids (link, box, cylinder, sphere, frustum, torus, extrusion solid, revolution solid, plate, point, markers),

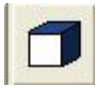
to create polyline, arc, spline,

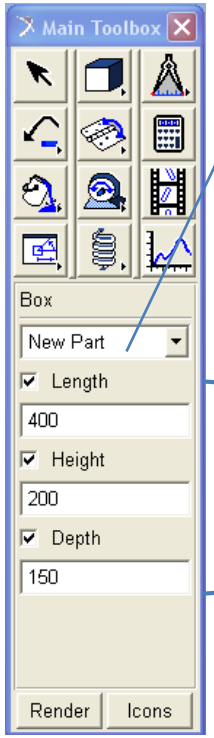
to make boolean operation on solid: unite, intersect, difference, merge, split, chain,

to shape solid: chamfer, fillet, hole, boss, shell.

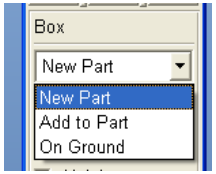
MD. Adams – building parts - example



To create new part in form of box using mouse we choose from Main Toolbox command Box 

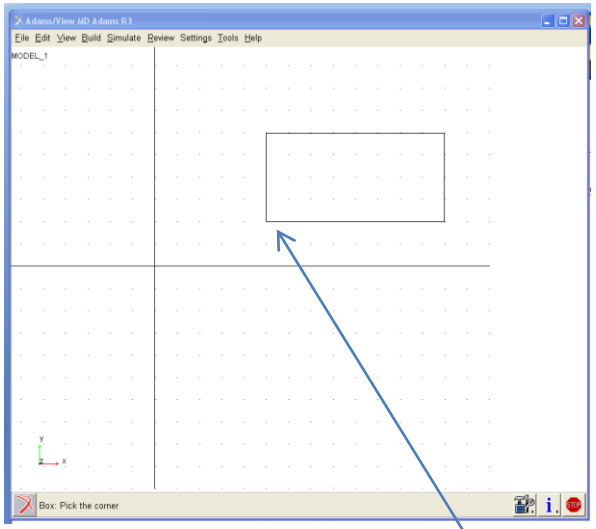


Working zone of Main Toolbox for every command - appropriate form



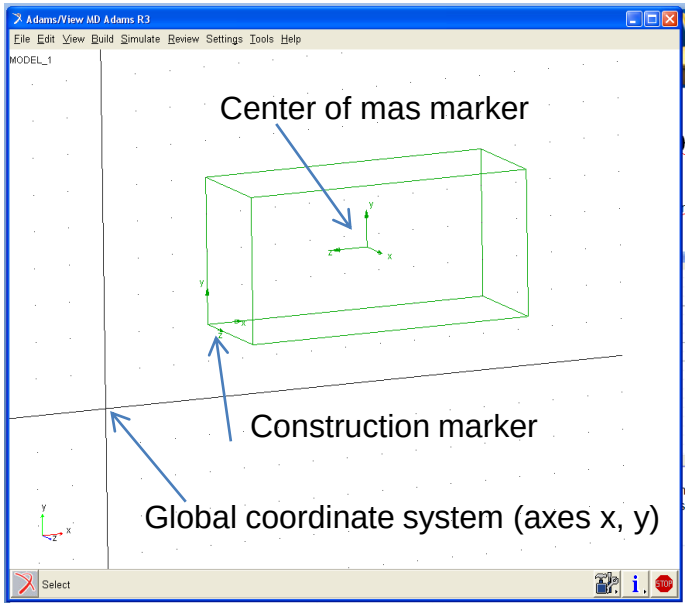
Here we choose option: New Part.

Dimension of box (we can write data with or without unit)



At the last step using mouse we pick in the graphic window position of box.

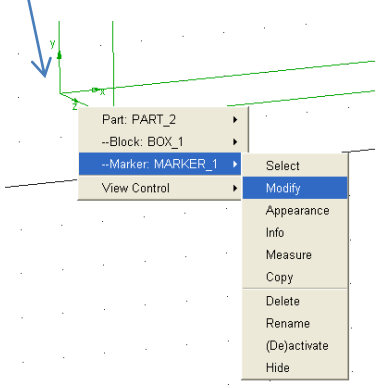
MD. Adams – building parts – position in global coordinate system

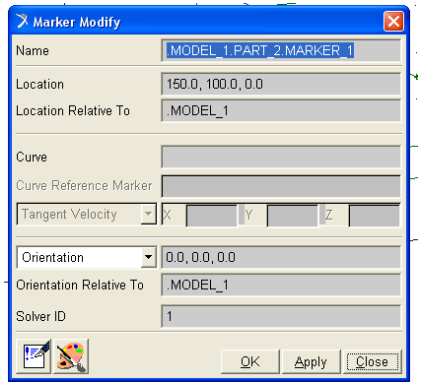


The parts have construction markers (box has one construction marker) and center of mass marker.
To change position of part we modify location and orientation of construction marker.

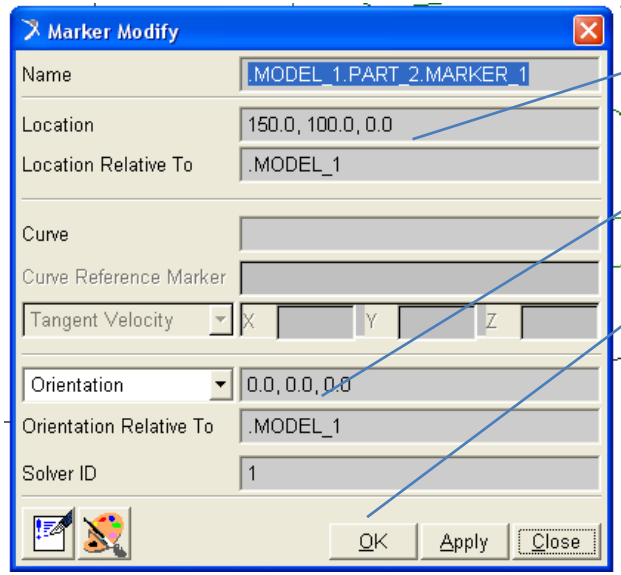
For example we will move part to global xyz location (0, 0, 0) and we rotate part about 90º along x axis.

To modify data of marker we move mouse to construction marker and click right mouse button then we choose name of marker and command Modify to open window with marker data.



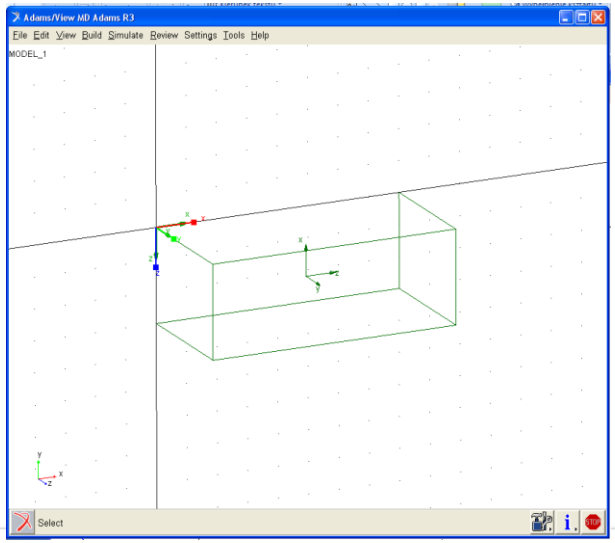


MD. Adams – building parts – position in global coordinate system

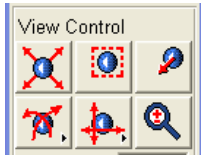


Location in global coordinates system (x, y, z). We edit data and write here: 0, 0, 0.

Angle of rotation about axes zxz of marker: α_z, α_x, α_z.
We write here: 0, 90, 0.
To finish operation changing position we click Apply and then OK.



Tip:
If we want to change point of view, scale we can use option View Control from Toolbox.



MD. Adams – building joints

Second step after building parts is definition of kinematic joints between parts.

MD.Adams have included library of standard kinematic joint (revolute, translational, cylindrical, …) and have tools to create atypical joints.

To build the joint we use command Build Joint  from Main Toolbox. Under the icon is hidden palette of icons.

To open that palette we need to pick the icon and then click right mouse button.

Palette Joints command.

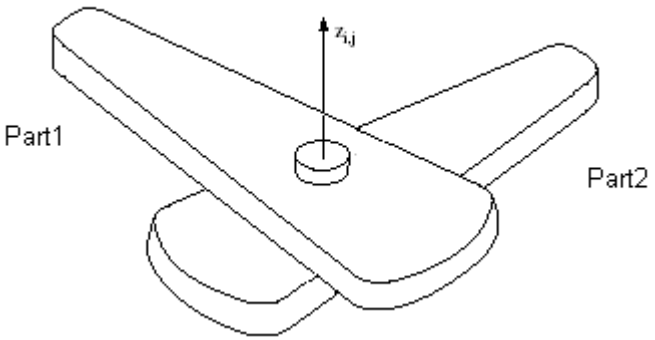
MD. Adams – building joints

Palette of Joints:

- revolute,
- universal,
- fixed,
- translational,
- constant velocity,
- cam – point-curve,
- cylindrical,

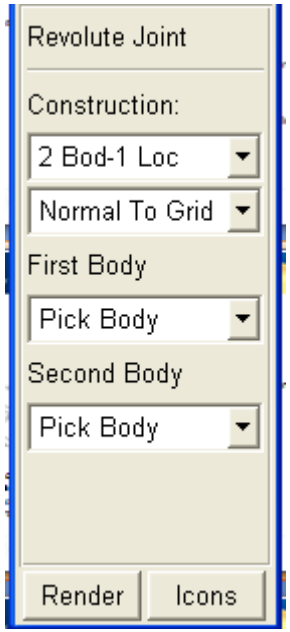
- coupler
- cam – curve-curve,
- spherical,
- screw,
- general constraint,
- planar,
- gear.

MD. Adams – building joints example - revolute joint



Revolute joint – one degree of freedom joint. Revolute joints provide single-axis rotation between two parts.

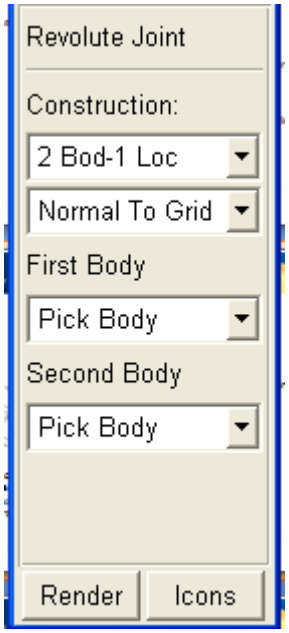
 - Icon Revolute Joint



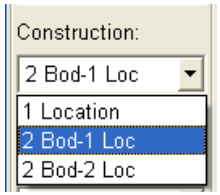
Parameter for building Revolute Joint

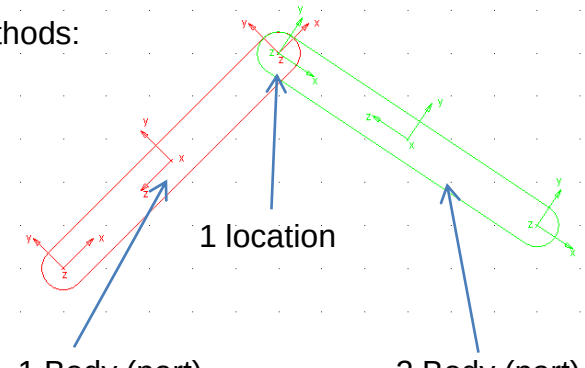
MD. Adams – building joints example - revolute joint

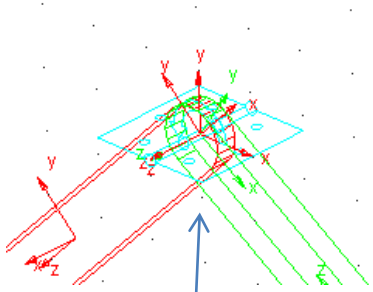
Before the definition revolute joint should be created two parts with two markers.



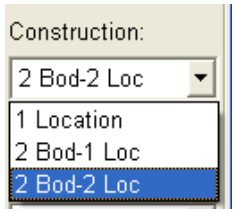
Two construction methods:
2 Bodies – 1 location

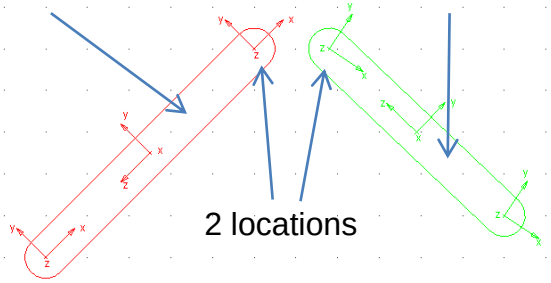


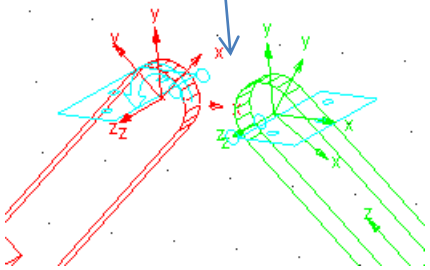




2 Bodies - 2 location



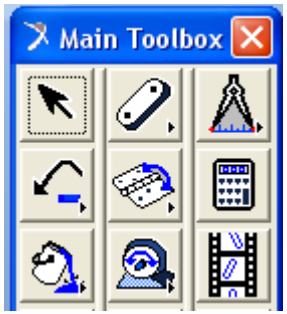




MD. Adams – motion drivers

For preparing kinematic simulation is needed to define motion drivers. Motion driver is function which describes variability selected coordinate in time. In Adams are three defined motion drivers: rotational, translational and general.

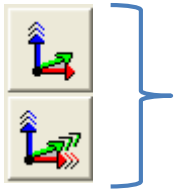
To define the motion drives we use command define Motion Driver  from Main Toolbox. Under the icon is hidden palette of icons.



To open that palette we need to pick the icon and then click right mouse button.

Pallete of motion driver command

Rotational motion driver
Translational motion driver



General motion driver (one/six coordinates)

MD. Adams – forces (torques)

Forces (torques) define loads on parts. In Adams are defined loads: force/torques vector (one/three components), special forces (tire, contact, friction, …), flexible connectors for connect two bodies and modal forces (for distributing a force to one or more, or all nodes of a flexible body).

To define the motion drives we use command Forces  from Main Toolbox. Under the icon is hidden palette of icons.

To open that palette we need to pick the icon and then click right mouse button.

MD. Adams – forces (torques) descriptions

Palette of Forces:

Command to define force/torques vector, one, three and general six components

Definition linear and rotational springs

Contact Force

Tire force

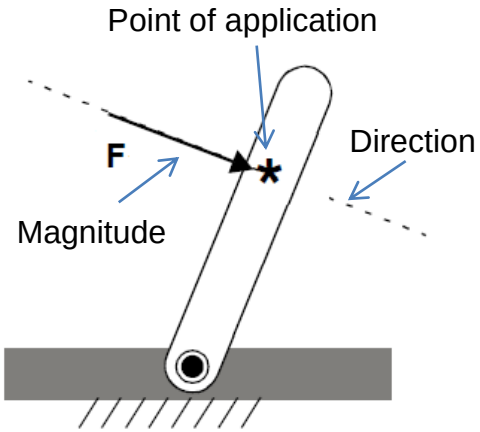
Gravity

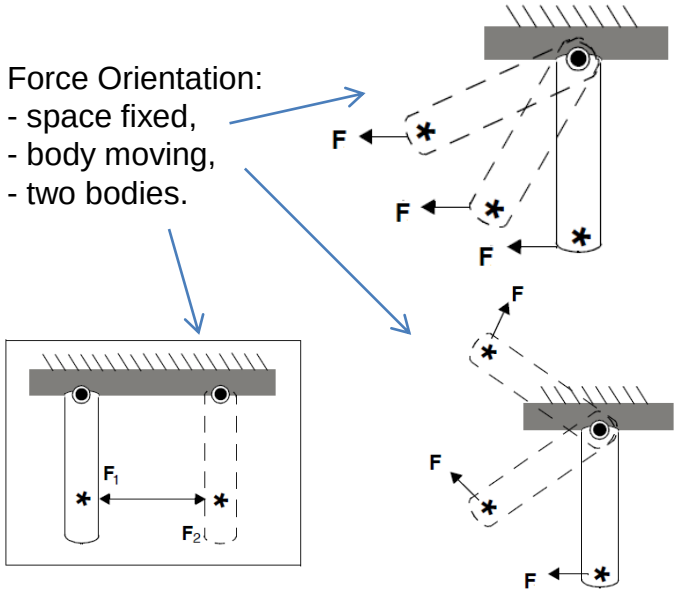
Definition flexible connector: bushing, field and beam

Modal Force

MD. Adams – vector forces (torques) descriptions

Vector forces (torques) need to define following data: point of application, magnitude, direction and orientation.





MD. Adams – simulation

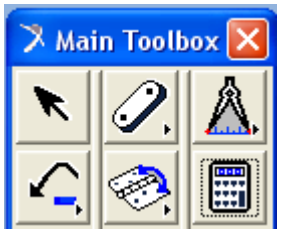
In the reason to make virtual simulation of the machine Adams gives possibilities to perform the following analysis:

Kinematic - simulation enables you to determine the range of values for the displacement, velocity, and acceleration of any point of interest in the model independent of forces applied to it. This type of simulation, therefore, is only available for models with number of motion drivers equal to mobility (DOF). If you specify the mass and inertia properties of bodies in your model, a kinematic simulation also calculates the corresponding applied and reaction forces required to generate the prescribed motions.

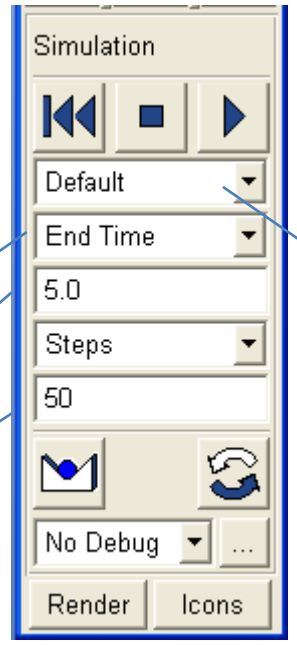
Dynamic - simulation provides a time-history solution for displacements, velocities, accelerations, and internal reaction forces in your model driven by a set of external forces. It is a computationally demanding simulation and is meant to be used with models that have mobility (DOF) greater than motion drivers.

Static - simulation attempts to find a configuration for the parts in your model for which all the forces balance. This configuration is often referred to as an equilibrium configuration. Velocities and accelerations are set to zero for static simulations, so inertial forces are not taken into consideration. A static simulation is for use with models that have one or more DOF so ADAMS/Solver can move parts around as it seeks to balance all the forces acting on the model.

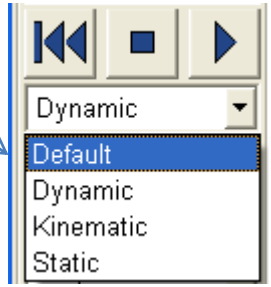
MD. Adams – making simulation



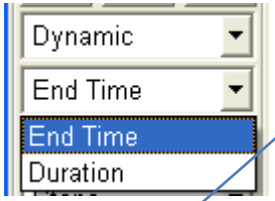
To initiate simulation we choose and click simulation icon  and open simulation palette.



Simulation control command: reset, stop, start.



Here we choose simulation (Default – Adams makes decision)



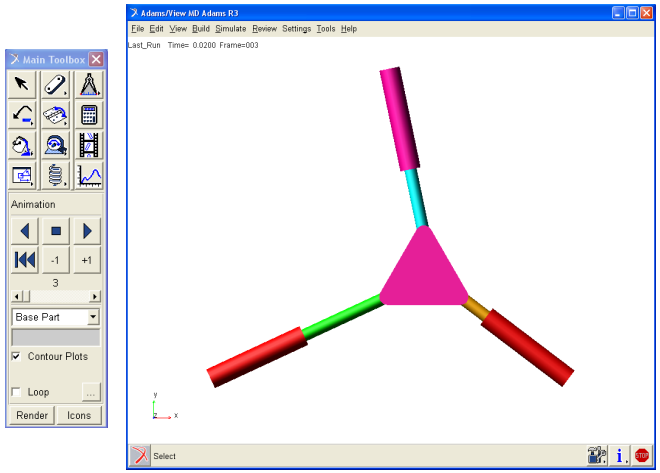
Here we choose:
End Time or Duration of simulation.

Parameters of simulation:
End Time: 5 s,
Steps: 50.

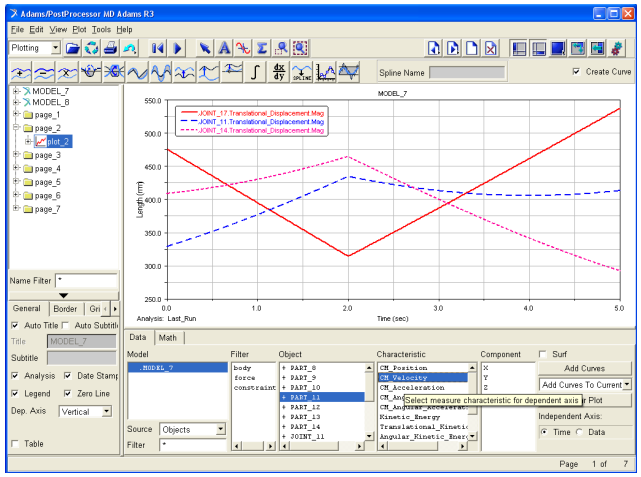
MD. Adams – postprocessing

Results of simulation can be presented in form of animation or plots. Animations are presented in main graphic windows and plots in specialized module Adams/Postprocessor.

Animations in main graphic windows

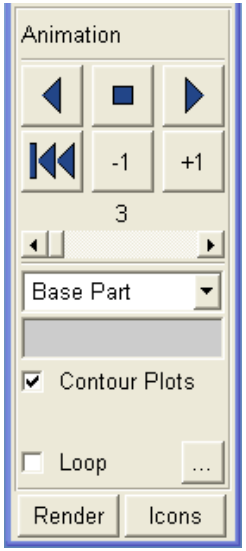


Adams/Postprocessor



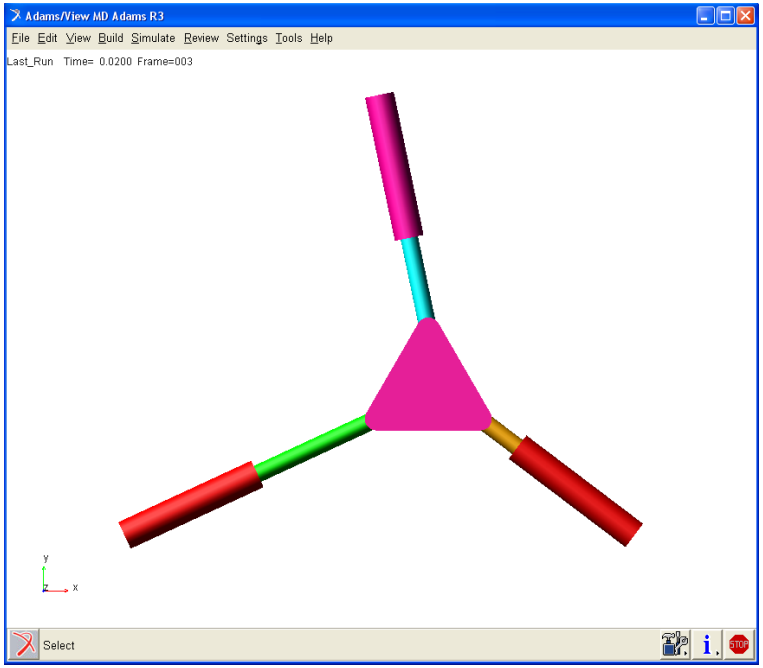
MD. Adams – animation

To start animation click: 
and open Animation palette.



Animation Control Command: Rewers, Stop, Forward, Reset, Steping +/- Motion

Graphic window with displayed animation



MD. Adams – plotting

To start plotting: 
in Adams/Postprocessor.

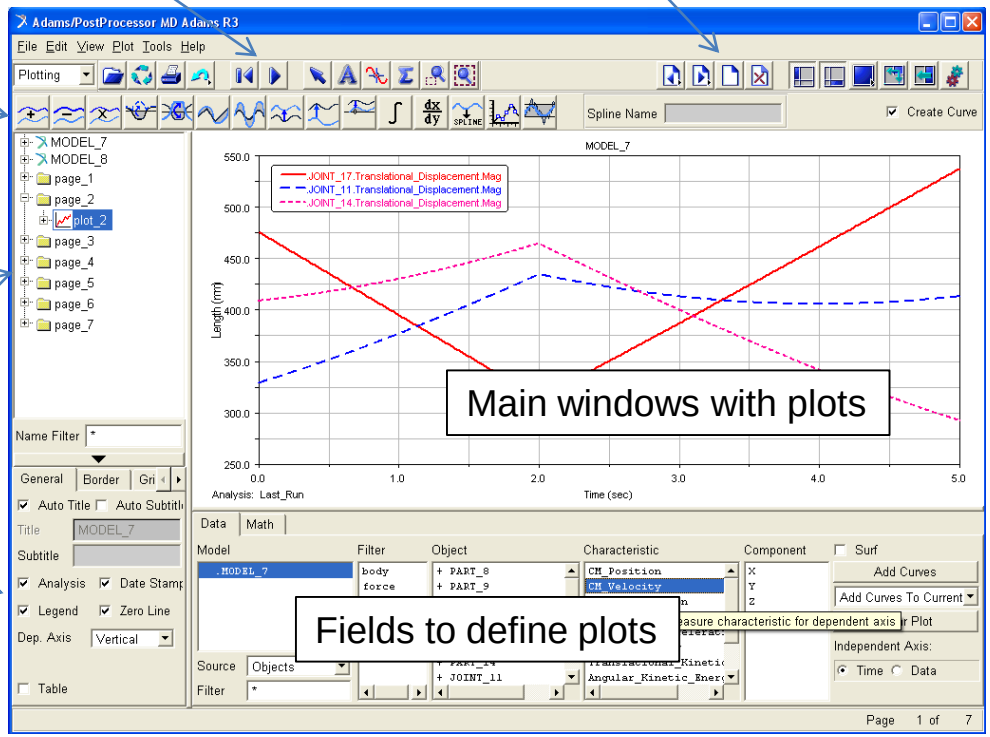
Main toolbar

Icon to creates pages with plots

Plots toolbar

Window to control pages and plots

Properties of curves



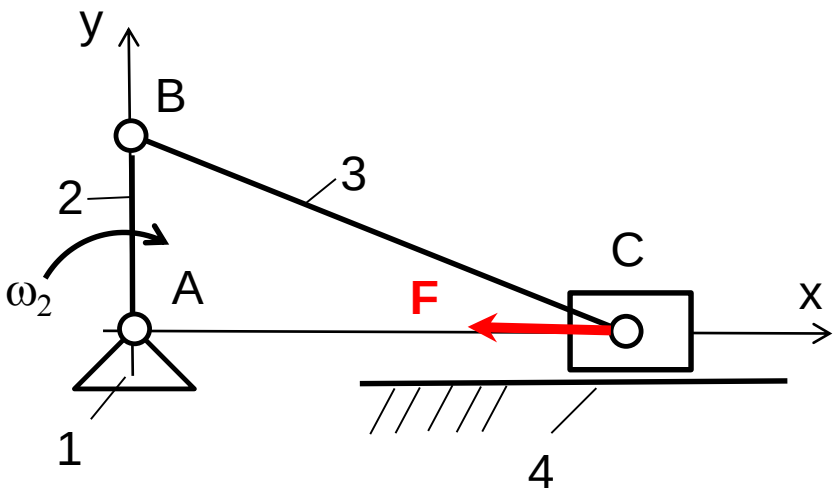
MD. Adams – simulation of crank-slider mechanism

For given kinematics scheme and of the crank-slider mechanism:

- to build the model with given geometry of the links in the computer system,
- to make simulation of the one full cycles t_c of motion.

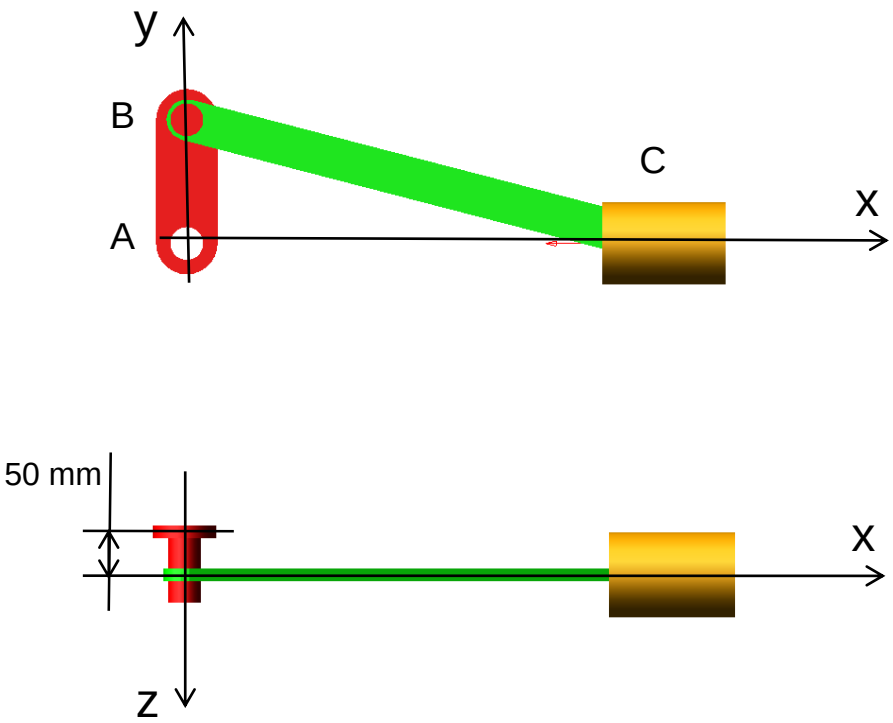
For given mechanism:

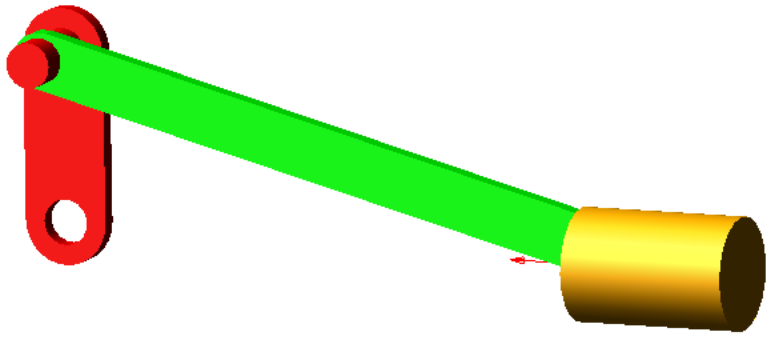
- to determine the runs of displacements $x_C(t)$, velocities $v_C^x(t)$ and accelerations of point $a_C^x(t)$,
- to determine the runs of unknown driving torque M_2 for the mechanism,
- to determine the runs of force F in revolute joint B.



AB = 150 mm
BC = 600 mm
$\omega_2 = 4\pi$ rad/s = 720 deg/s
t_c = 0.5 s
F =100 N

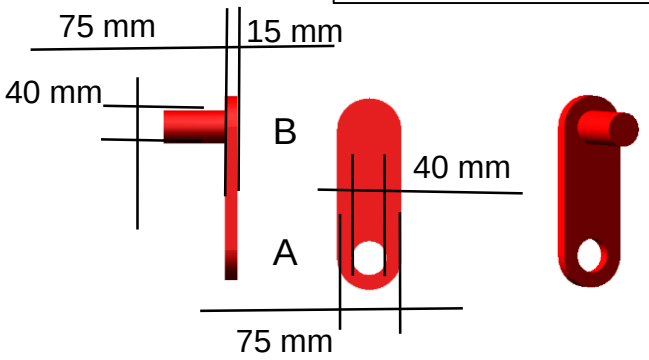
MD. Adams – simulation of crank-slider mechanism



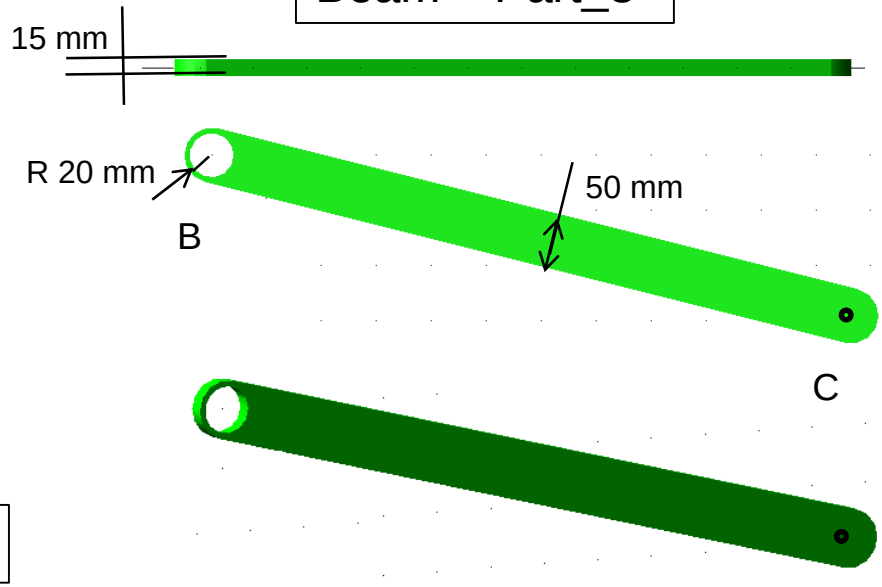


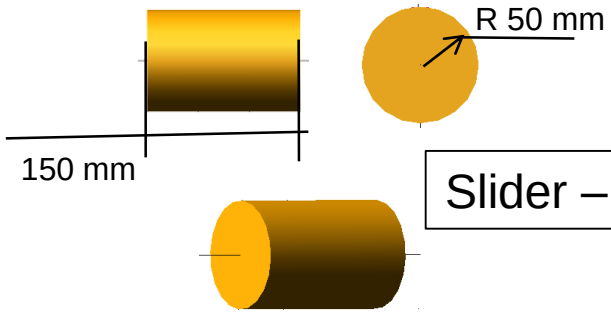
MD. Adams – simulation of crank-slider mechanism

Crank – Part_2



Beam – Part_3



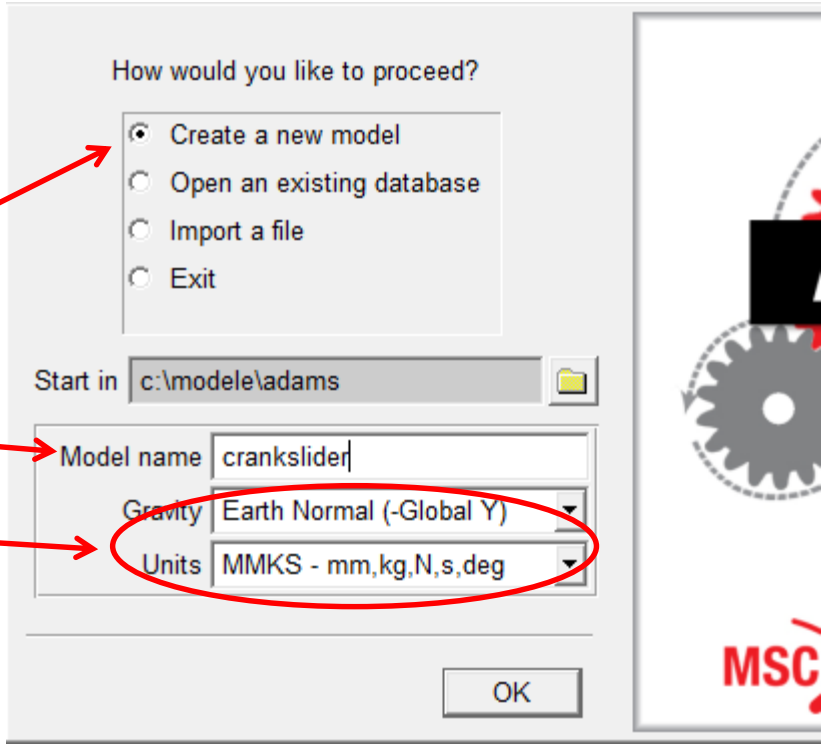


Slider – Part_4

MD. Adams – simulation of crank-slider mechanism

Starting project:

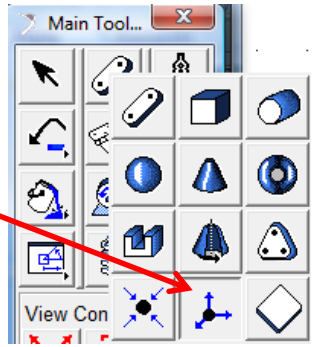
1. Start Adams/View by clicking icon on Desktop
2. Choose option: Create a new model
3. Write model name: crankslider
4. Choose gravity (-Y) and units (mm, kg, N, s, deg)

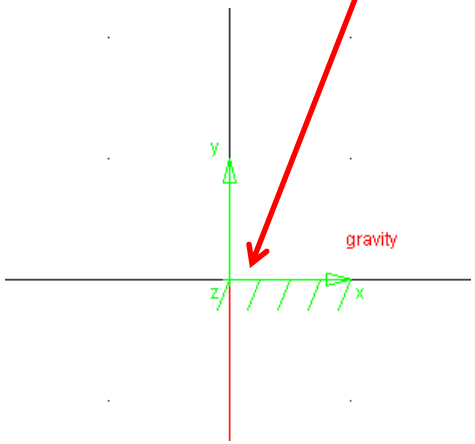


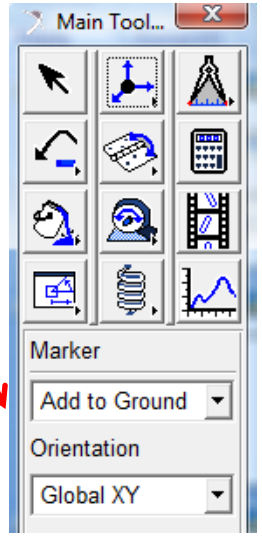
MD. Adams – simulation of crank-slider mechanism

Definition of marker on ground for joint A:

1. Open Build palette with Marker icon and click it.
2. In Marker fields choose option: Add to ground
3. In graphic window use mouse and choose position of marker (anywhere) and click.



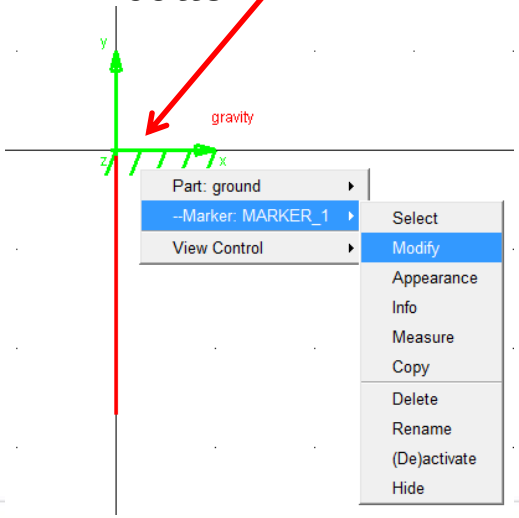


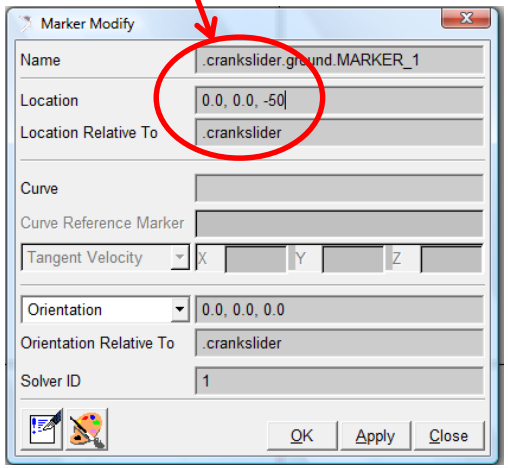


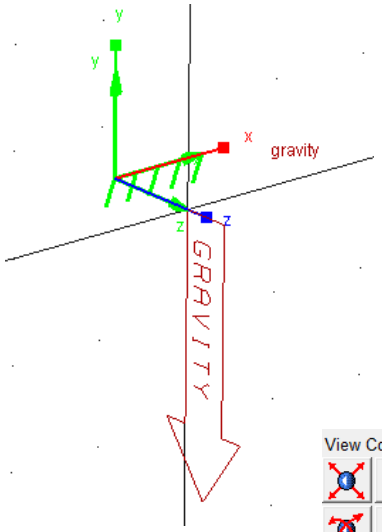
MD. Adams – simulation of crank-slider mechanism

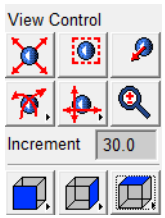
Modifying position of marker in joint A:

1. Move mouse to marker and click right mouse button and choose marker name (Marker_1) and click option Modify.
2. In Marker Modify window in the field Location write coordinate (x, y, z): 0, 0, -50 and click OK button.







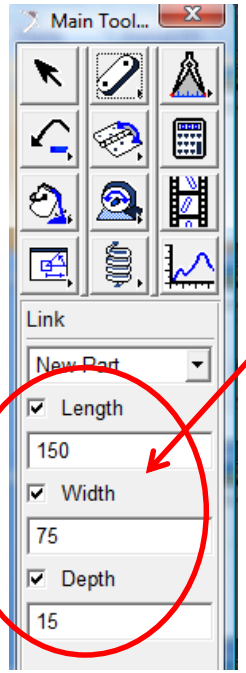


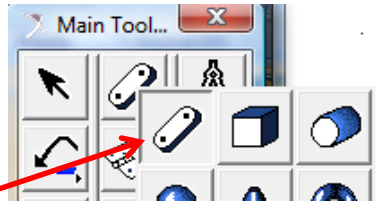
Tip:
To change point of view use command Rotate 

to go back to standard View use 

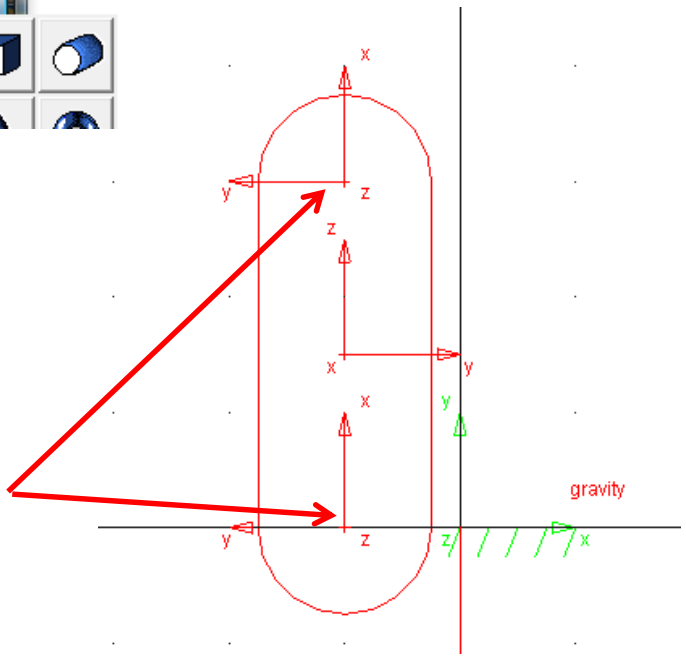
MD. Adams – simulation of crank-slider mechanism

Definition of Part_2 - crank:





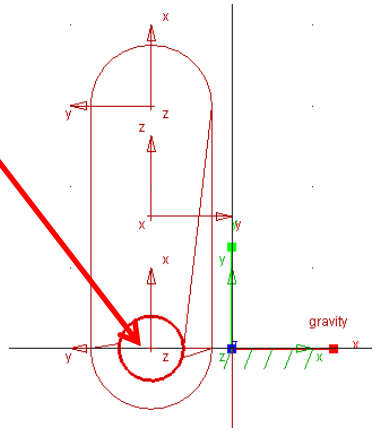
1. Open Build palette and choose Link Icon.
2. In the Link fields write Length, Width and Depth.
3. Using two clicks in Graphic window select two point (as in figure).

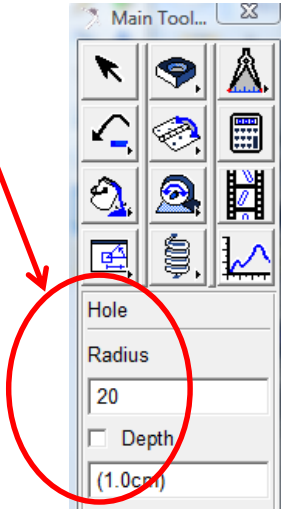


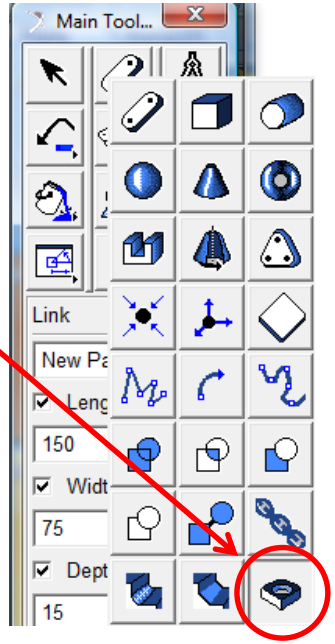
MD. Adams – simulation of crank-slider mechanism

Making a hole in point A:

1. Open Build palette and choose Hole Icon.
2. In the fields of Hole write radius.
3. Using two clicks in Graphic window select part and center of hole (as in figure).



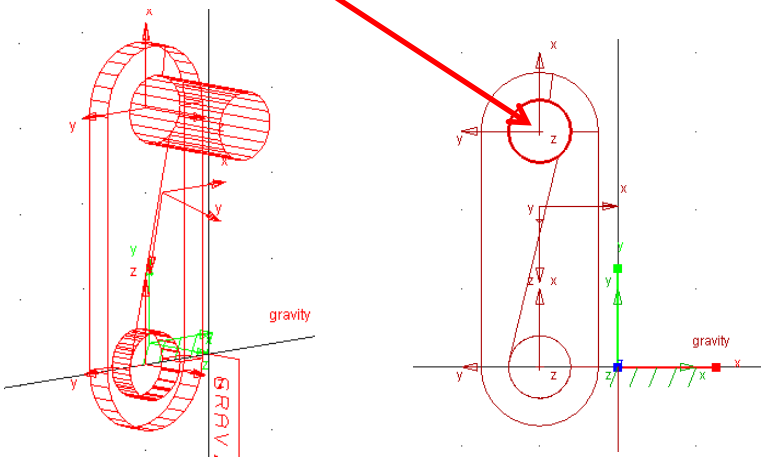


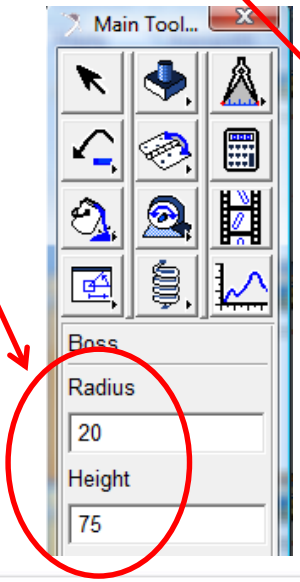


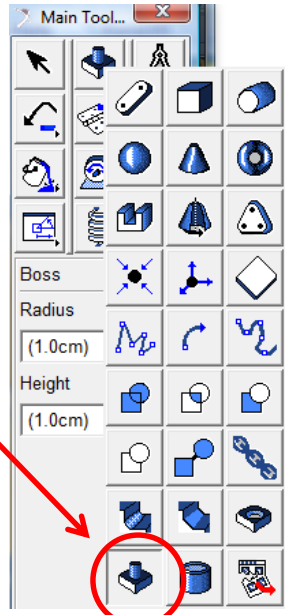
MD. Adams – simulation of crank-slider mechanism

Making a Boss in point B:

1. Open Build palette and choose Boss Icon.
2. In the fields of Boss write radius and height.
3. Using two clicks in Graphic window select part and center of Boss (as in figure).



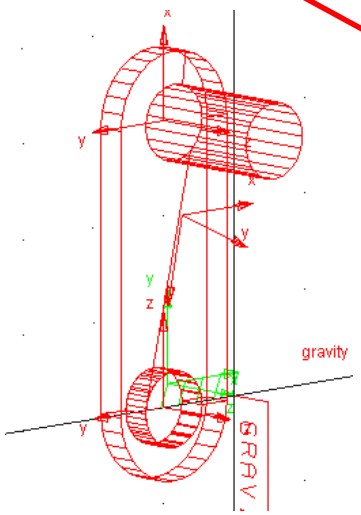


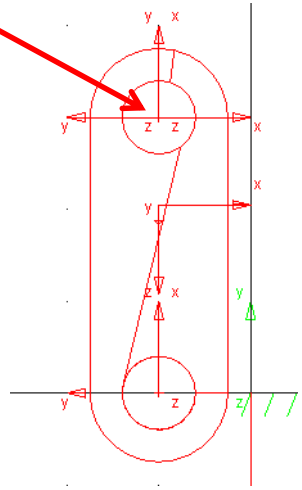


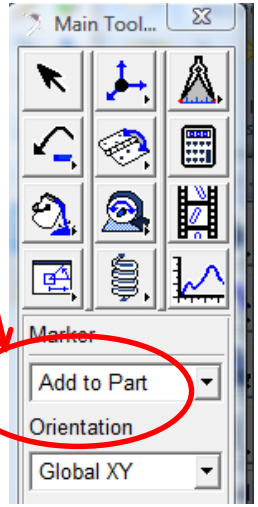
MD. Adams – simulation of crank-slider mechanism

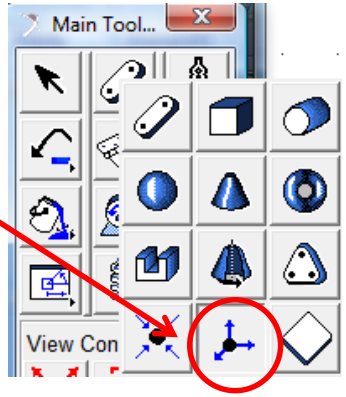
Definition of marker on Part_2 (crank) for joint B:

1. Open Build palette with Marker icon and click it.
2. In Marker fields choose option: Add to Part
3. Using two clicks in Graphic window select part and position of marker (as in figure).





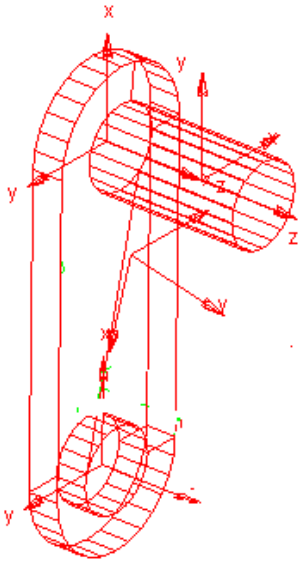


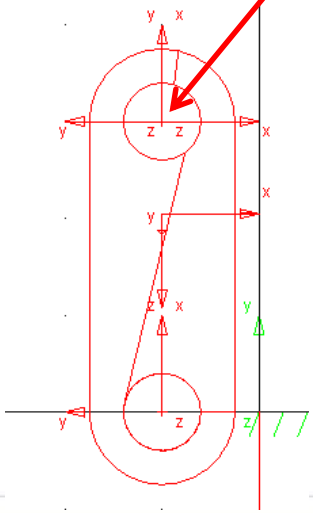


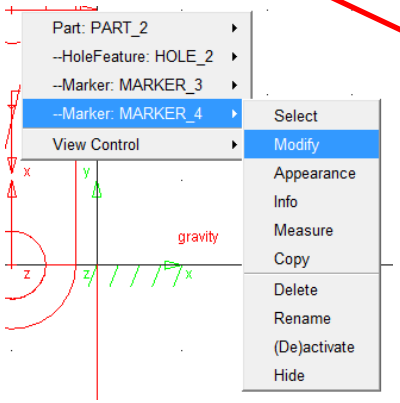
MD. Adams – simulation of crank-slider mechanism

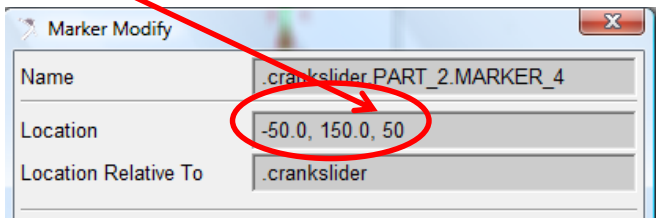
Modifying position of marker in point B on crank:

1. Move mouse to marker and click right mouse button and choose marker name (Marker_4) and click option Modify.
2. In Marker Modify window in the field Location change only z coordinate (z=50) and click OK button.

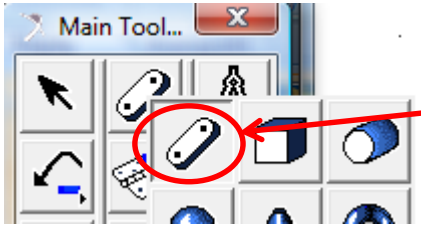


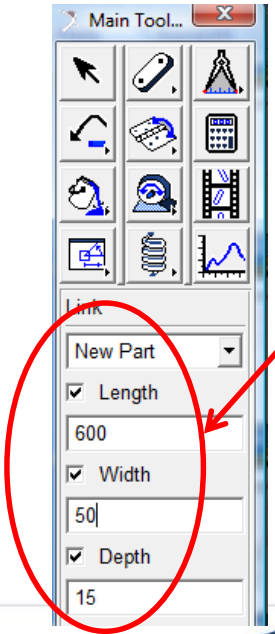






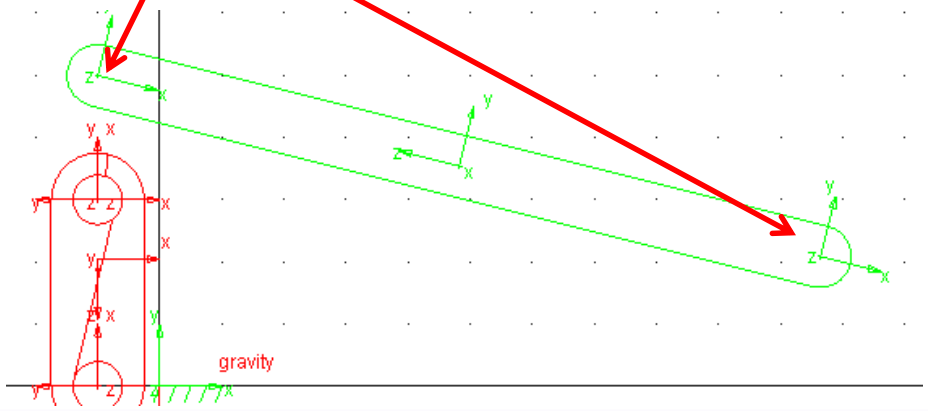
MD. Adams – simulation of crank-slider mechanism





Definition of Part_3 beam:

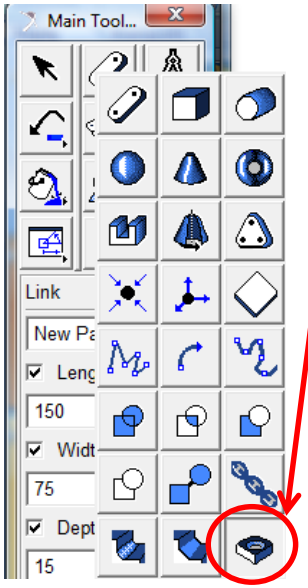
1. Open Build palette and choose Link Icon.
2. In the Link fields write Length, Width and Depth.
3. Using two clicks in Graphic window select two point (as in figure).

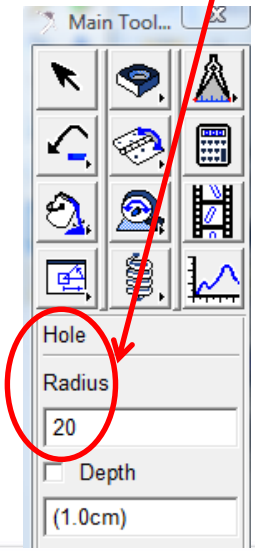


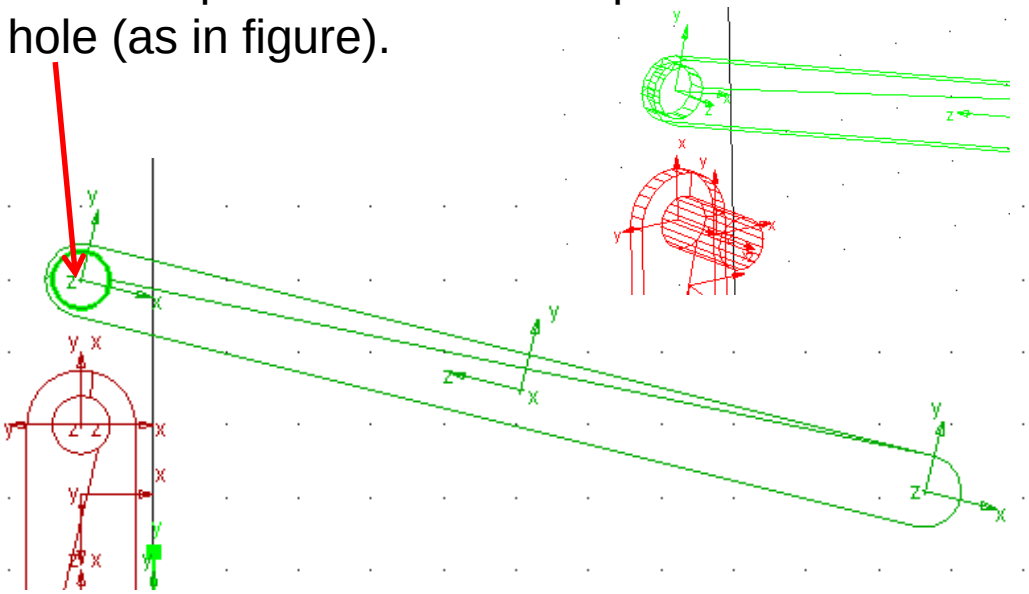
MD. Adams – simulation of crank-slider mechanism

Making a hole in point B on Beam:

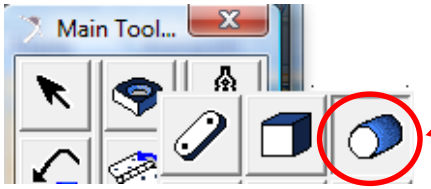
1. Open Build palette and choose Hole Icon.
2. In the fields of Hole write radius.
3. Using two clicks in Graphic window select part and center of hole (as in figure).

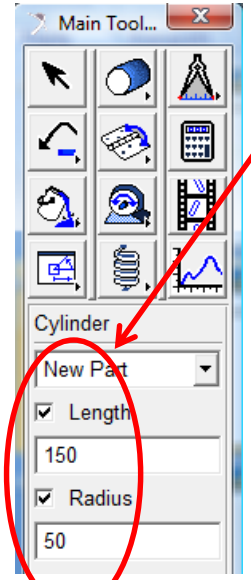






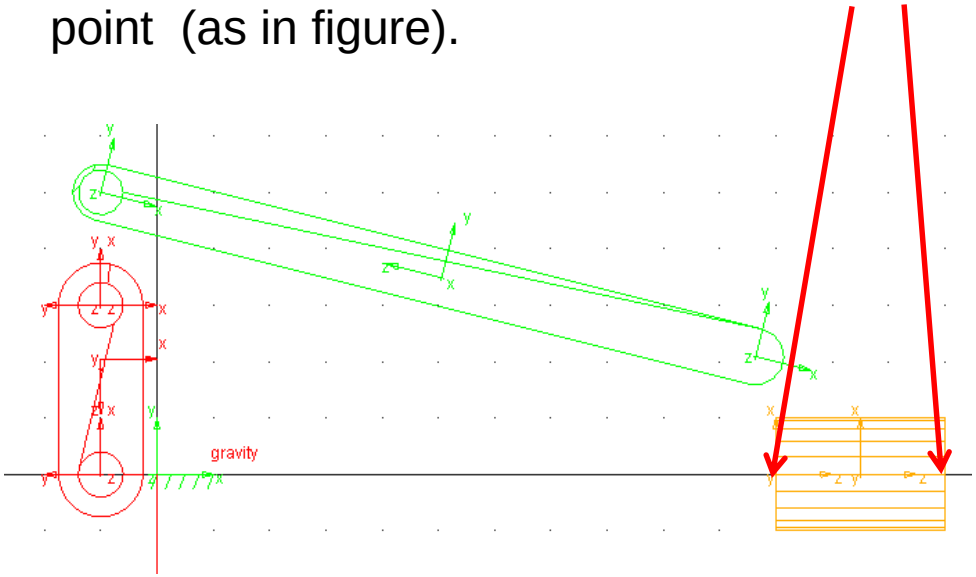
MD. Adams – simulation of crank-slider mechanism



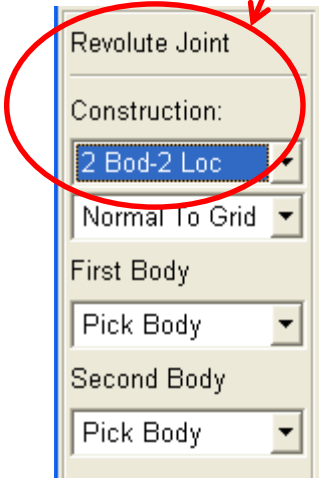


Definition of Part_4 slider:

1. Open Build palette and choose Cylinder Icon.
2. In the Link fields write Length and Radius.
3. Using two clicks in Graphic window select two point (as in figure).

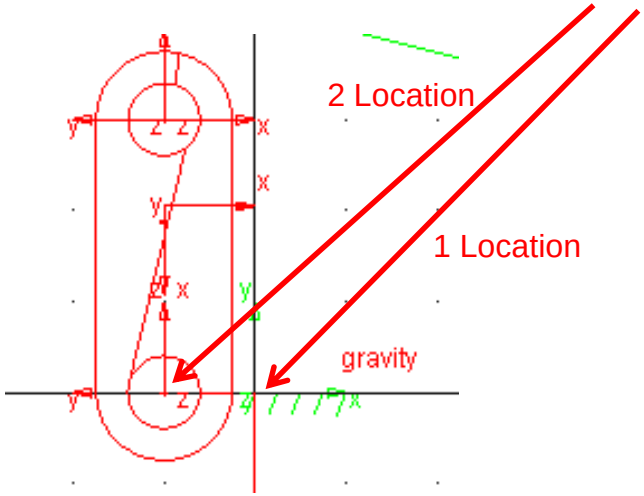


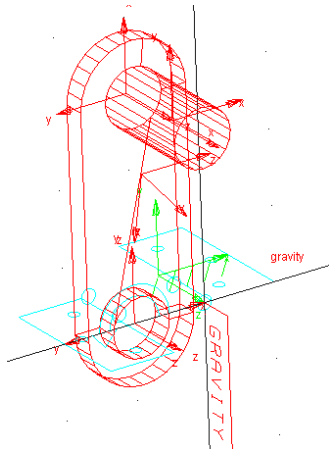
MD. Adams – simulation of crank-slider mechanism



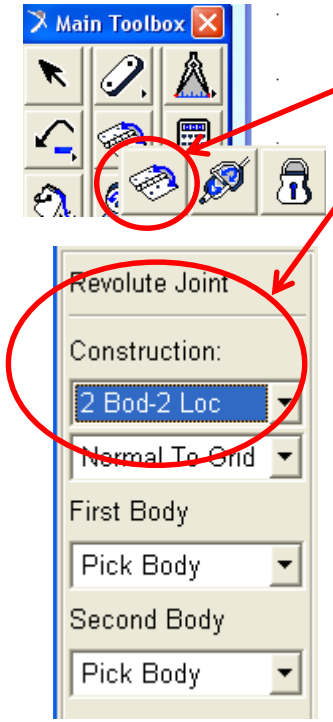
Definition of Revolute Joint A between ground and crank:

1. Open Joint palette and choose Revolute Joint Icon.
2. In the Revolute fields choose Construction option: 2 Bod-2 Loc.
3. Using clicks in Graphic window select 2 Bodies ground and crank and then select 2 Location (2 markers) (as in figure).



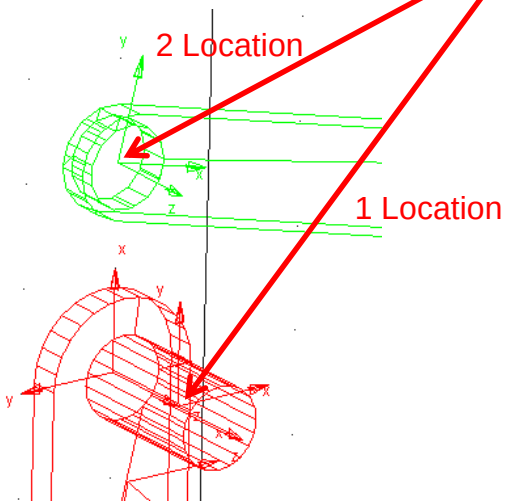


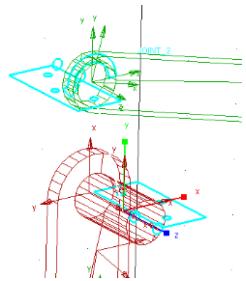
MD. Adams – simulation of crank-slider mechanism



Definition of Revolute Joint B between crank and beam:

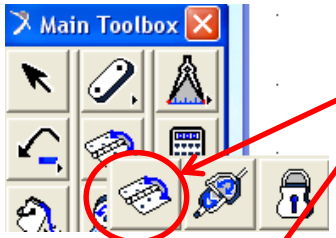
1. Open Joint palette and choose Revolute Joint Icon.
2. In the Revolute fields choose Construction option: 2 Bod-2 Loc.
3. Using clicks in Graphic window select 2 Bodies crank and beam and then select 2 Location (2 markers) (as in figure).

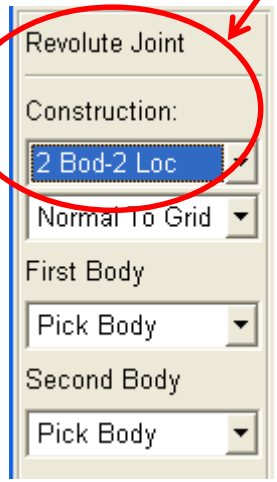




Tip:
Before joint definition resize and change point of view.

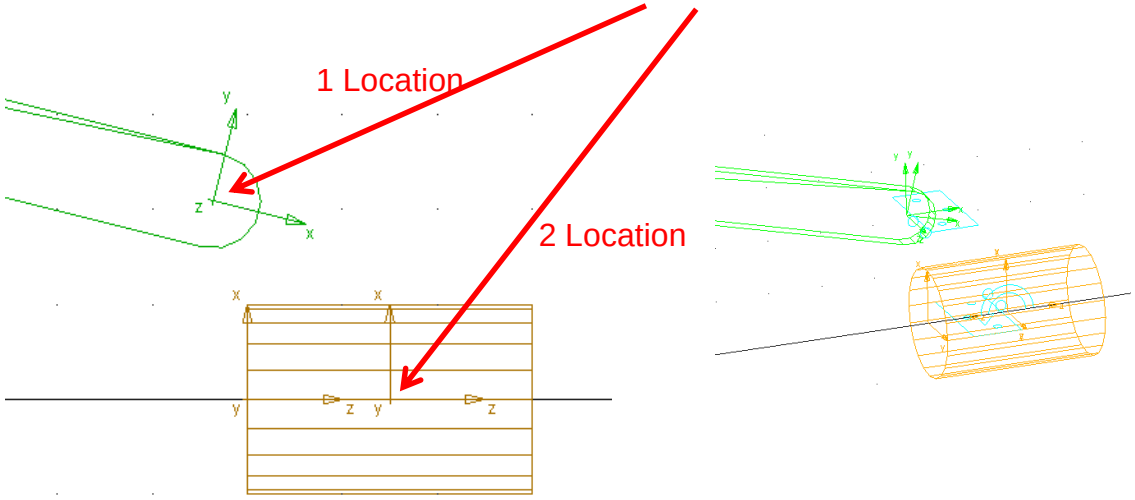
MD. Adams – simulation of crank-slider mechanism



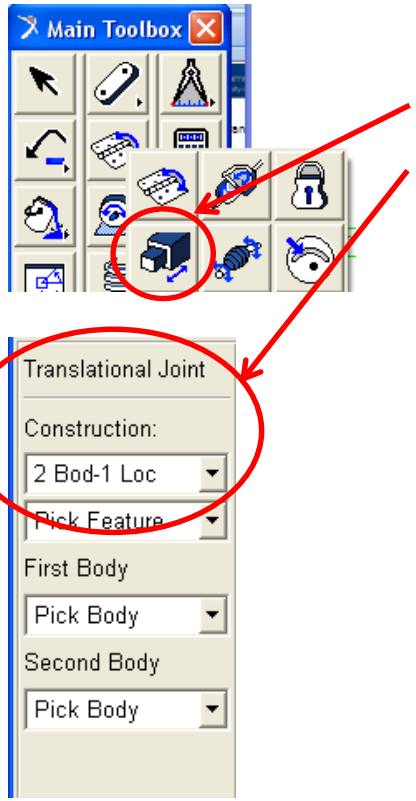


Definition of Revolute Joint C between beam and slider:

1. Open Joint palette and choose Revolute Joint Icon.
2. In the Revolute fields choose Construction option: 2 Bod-2 Loc.
3. Using clicks in Graphic window select 2 Bodies beam and slider and then select 2 Location (2 markers) (as in figure).

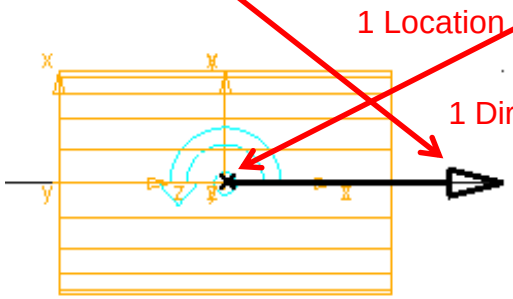


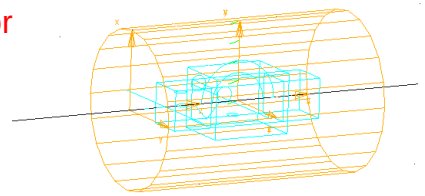
MD. Adams – simulation of crank-slider mechanism



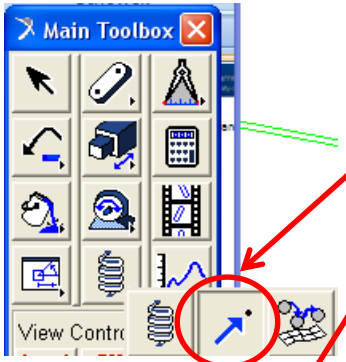
Definition of Translational Joint between ground and slider:

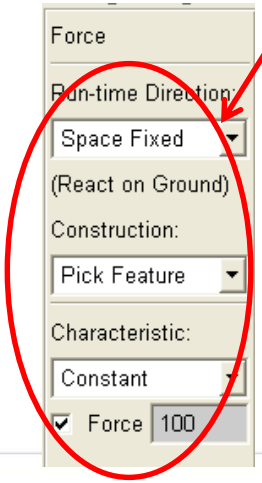
1. Open Joint palette and choose Translational Joint Icon.
2. In the Translational Joint fields choose Construction option: 2 Bod-1 Loc.
3. Using clicks in Graphic window select 2 Bodies ground and slider and then select 1 Location (1 marker) and 1 direction vector (as in figure).





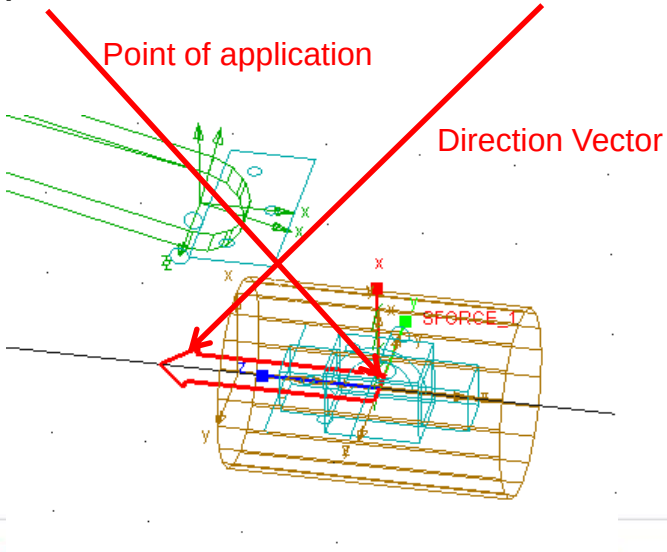
MD. Adams – simulation of crank-slider mechanism



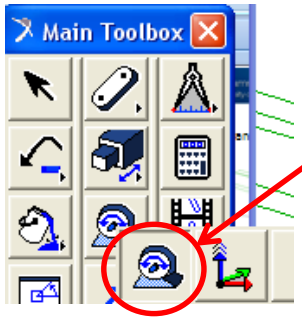


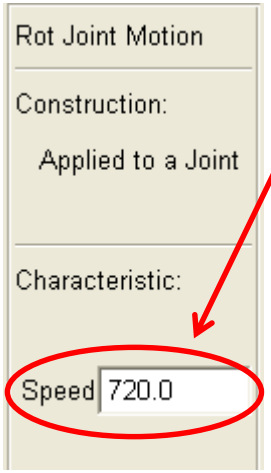
Definition of Force F acting on slider:

1. Open Force palette and choose Force Vector Icon.
2. In the Force fields choose option: Space Fixed, Constatnt and write 100 N.
3. Using clicks in Graphic Window select body - slider and point of application, then select direction vector (as in figure).



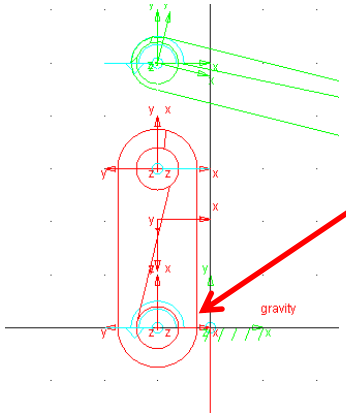
MD. Adams – simulation of crank-slider mechanism

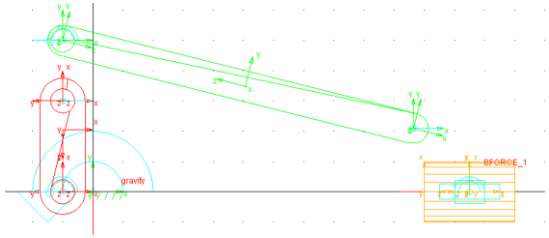




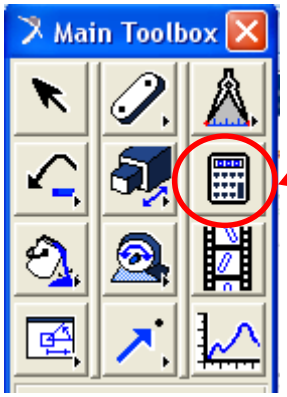
Definition of Rotational Joint Motion in joint A:

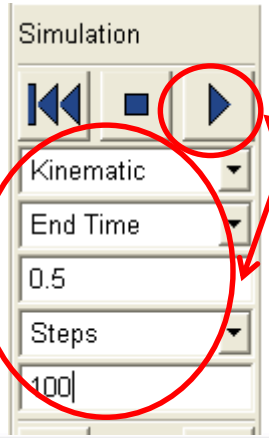
1. Open Motion Driver palette and choose Rotational Joint Motion.
2. In the Rotational Joint Motion fields write speed: 720 deg/s.
3. Using click in Graphic Window select joint A (as in figure).





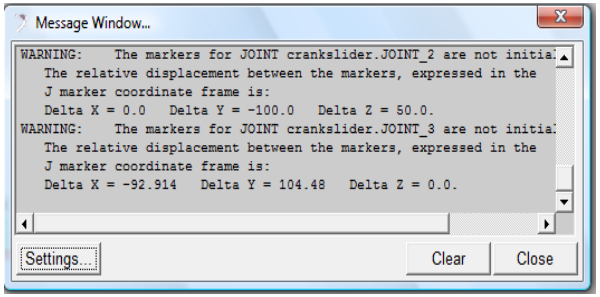
MD. Adams – simulation of crank-slider mechanism



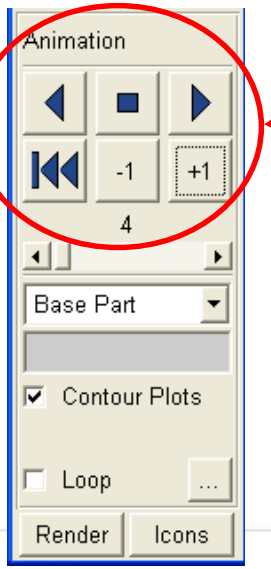


Making simulation:

1. Move mouse to Simulation Icon click simulation icon.
2. In simulation fields choose options:
   - Kinematic
   - End time
   - 0.5
   - Steps
   - 100
3. Start simulation – clik start icon.
4. Read text from Message Window.

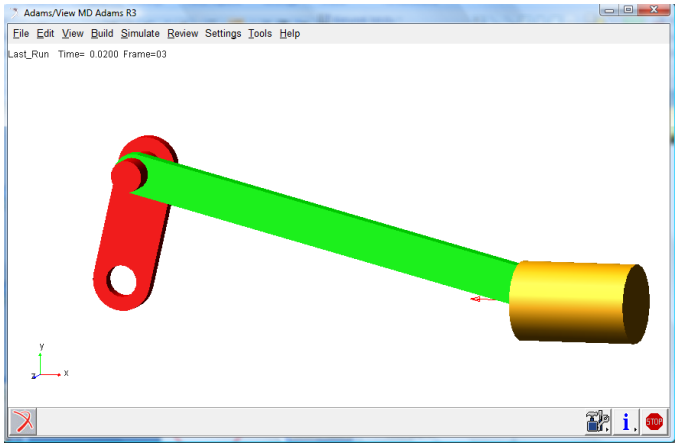


MD. Adams – simulation of crank-slider mechanism

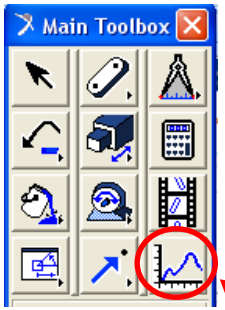


Making animation:

1. Move mouse to Animation Icon and click icon.
2. Control animation using Control Command: Rewers, Stop, Forward, Reset, Steping +/-1 Motion
3. Observe simulation in Main Graphic Window.

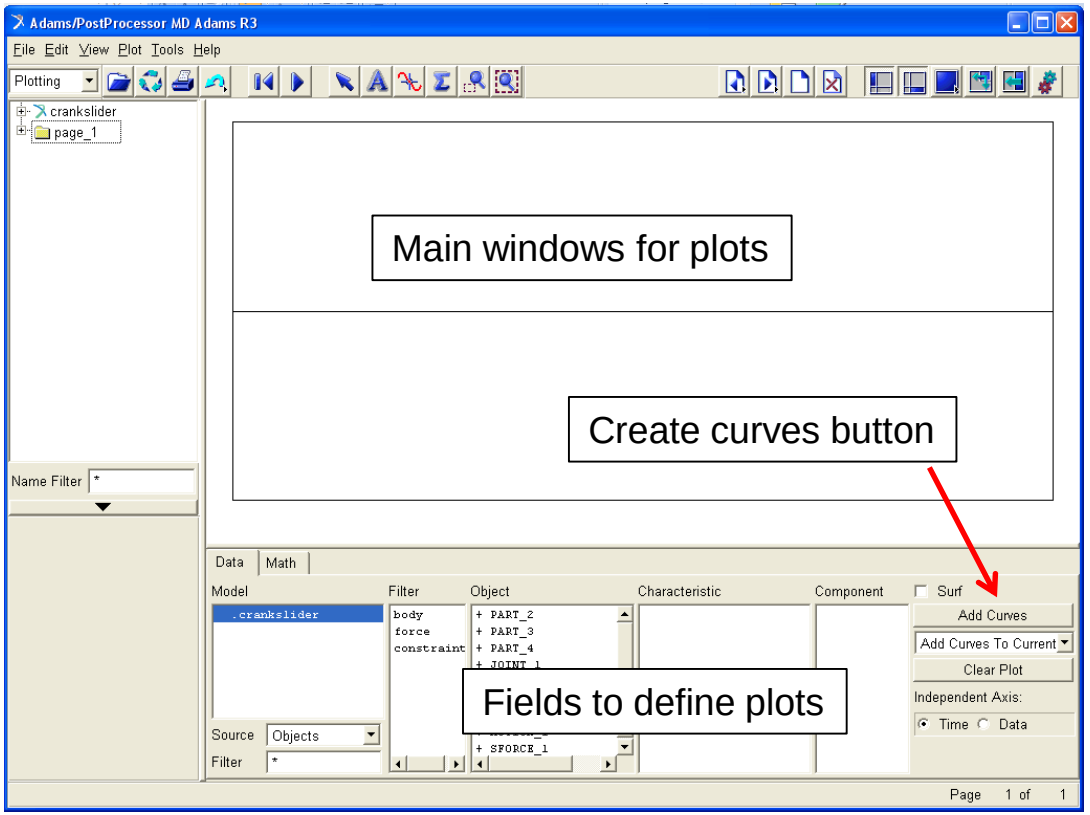


MD. Adams – simulation of crank-slider mechanism



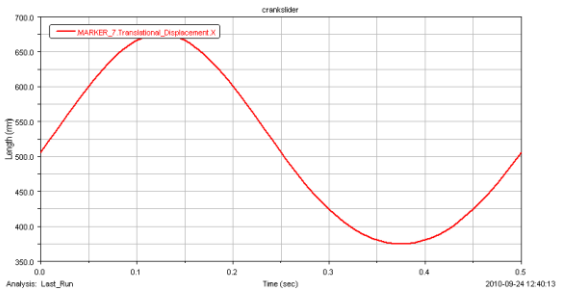
Making plots:

1. Move mouse to Plotting Icon and click icon to start Adams/Plotting module.
2. Define curves.



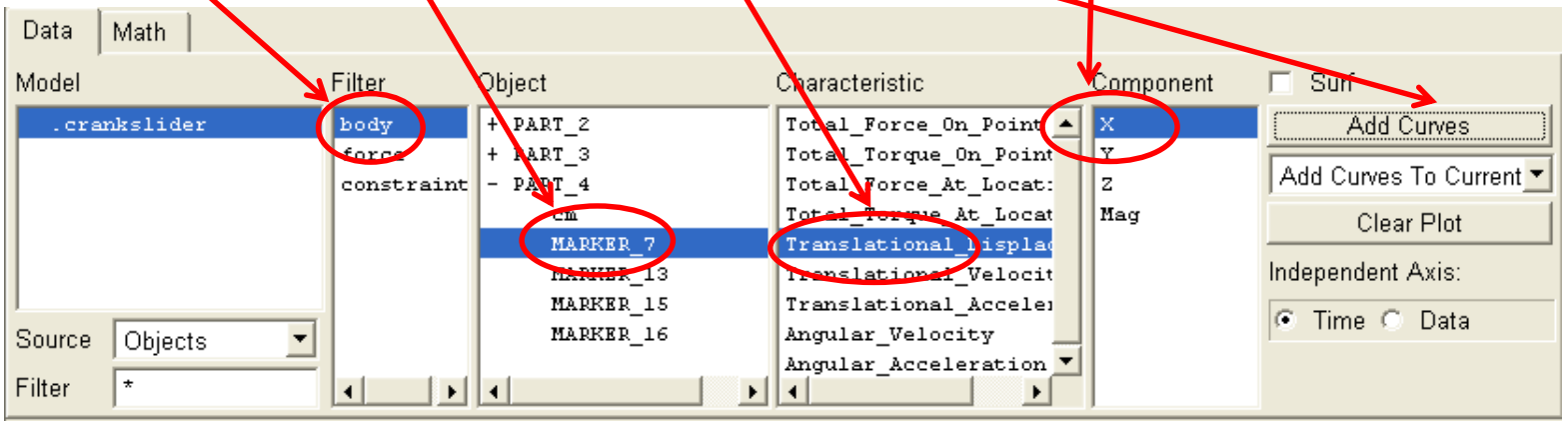
MD. Adams – simulation of crank-slider mechanism

Curve: translational displacement of point E - $x_E(t)$



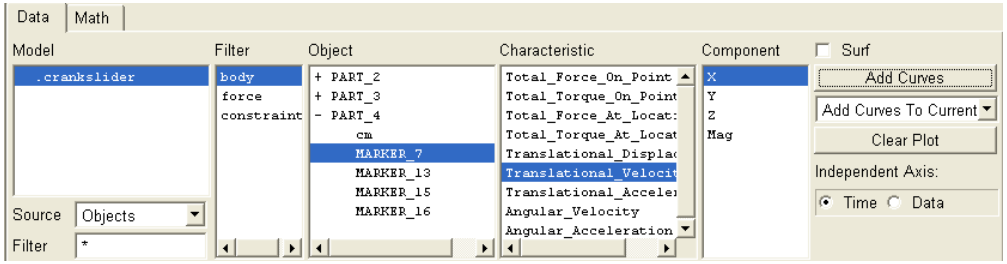
Choose option:
Body – Part_4_Marker_7 – Translational_Displacement – X

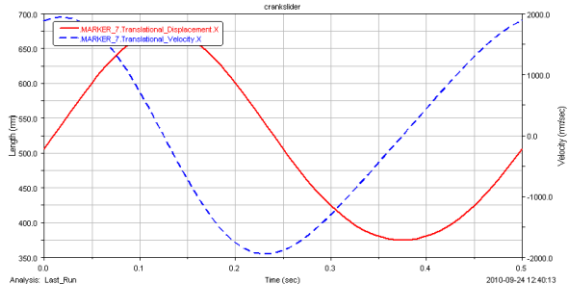
Click Add Curves



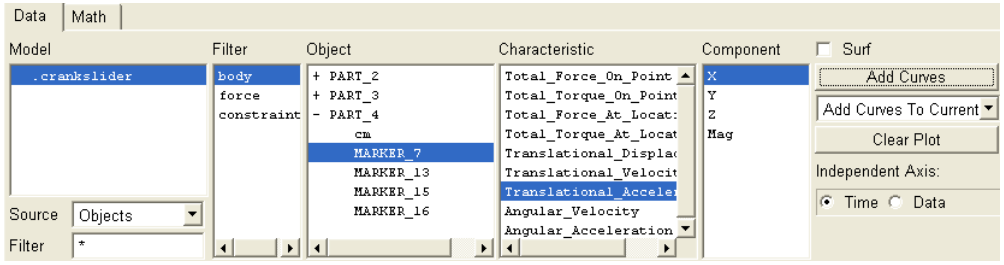
MD. Adams – simulation of crank-slider mechanism

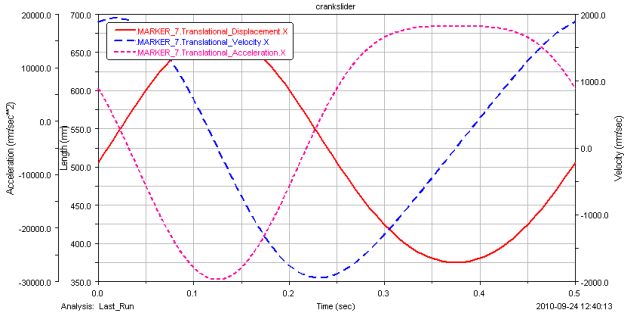
Curve: velocity v_x of point E - $v^E_x(t)$





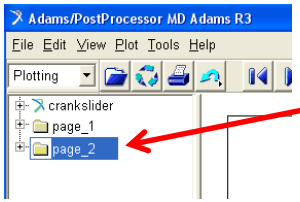
Curve: acceleration a_x of point E - $a^E_x(t)$





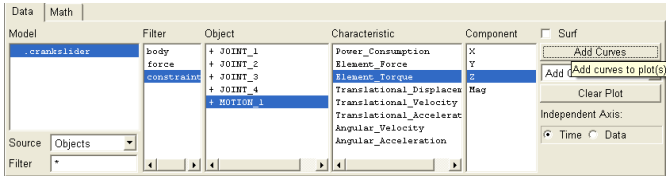
MD. Adams – simulation of crank-slider mechanism

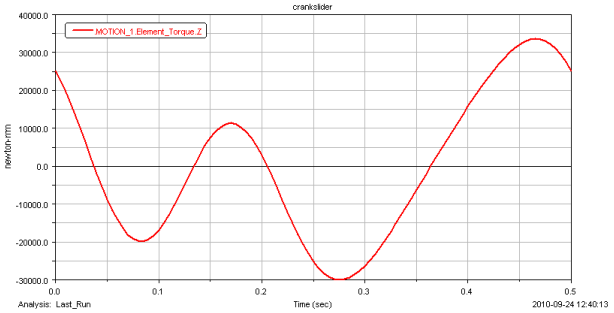
Create new page for plots



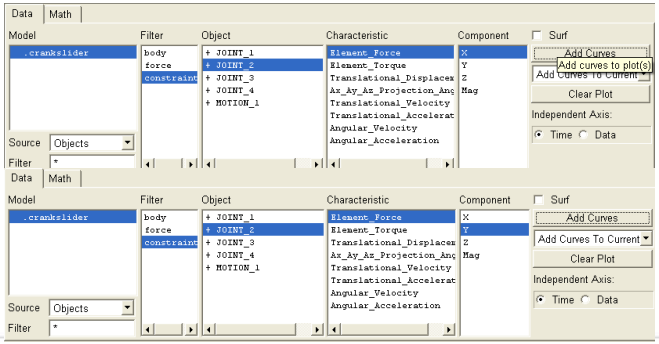
Switch to new page

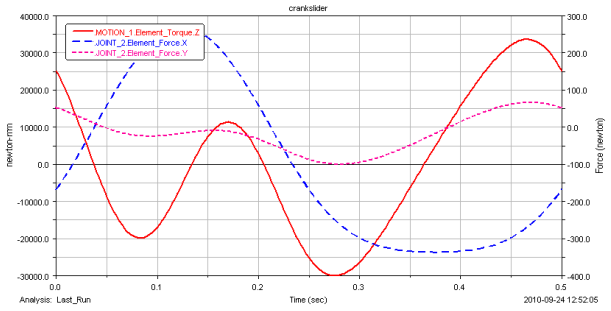
Curve: Driving troque Mc(t) in rotational driver





Curves: Force in joint B Fx(t) and Fy(t)





References

1. Gronowicz A. i inni: Teoria maszyn i mechanizmów. Zestaw problemów analizy i projektowania. Oficyna wydawnicza PWr. Wrocław 2000.
2. Gronowicz A.: Podstawy analizy układów kinematycznych. Oficyna wydawnicza PWr. Wrocław 2003.
3. Haug E.J.: Computer Aided Kinematics and Dynamics of Mechanical Systems. Allyn and Bacon, Boston 1989.
4. Manual of the MD.Adams system.
5. *Miller S.: Teoria maszyn i mechanizmów. Analiza układów mechanicznych. Oficyna wydawnicza PWr. Wrocław 1996.*
6. Norton R., L.: Design of Machinery, An introduction to the synthesis and analysis of mechanisms of machines. WCB, McGraw-Hill, Boston, 1999.
7. Shabana A. Ahmed: Computational Dynamics, . A Wiley-Interscience Publications, NewYork, 1994.
8. Waldron J., Kinzel G.; Kinematics, dynamics and design of machinery, John Wiley & Sons, Inc. New York, 1999.
9. Wojtyra M., Fraczek J.: Metoda układów wieloczłonowych w dynamice mechanizmów. Oficyna Wydawnicza Politechniki Warszawskiej, 2007.