10th Homework – Solution

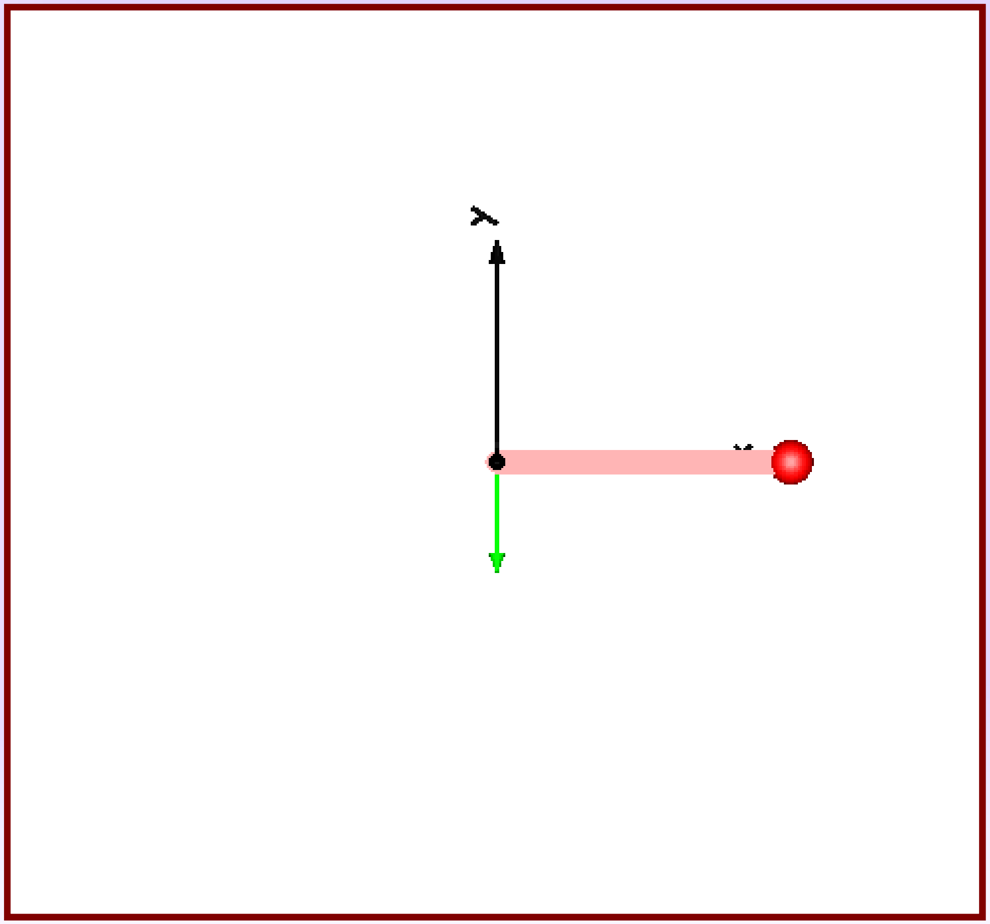
- In this homework, we shall attempt the modeling of a planar mechanical system.
- We shall do so once by employing the planar mechanical sub-library of ***MultiBondLib***, and once by working with a multi-bond graph directly.
- The version using the sub-library can be animated, whereas the direct version cannot be animated.

- Description of the problem
- The ElastoGap model
- Planar mechanical (wrapped) thread-pendulum model
- Multi-bond graph (direct) thread-pendulum model

A Thread-Pendulum Model

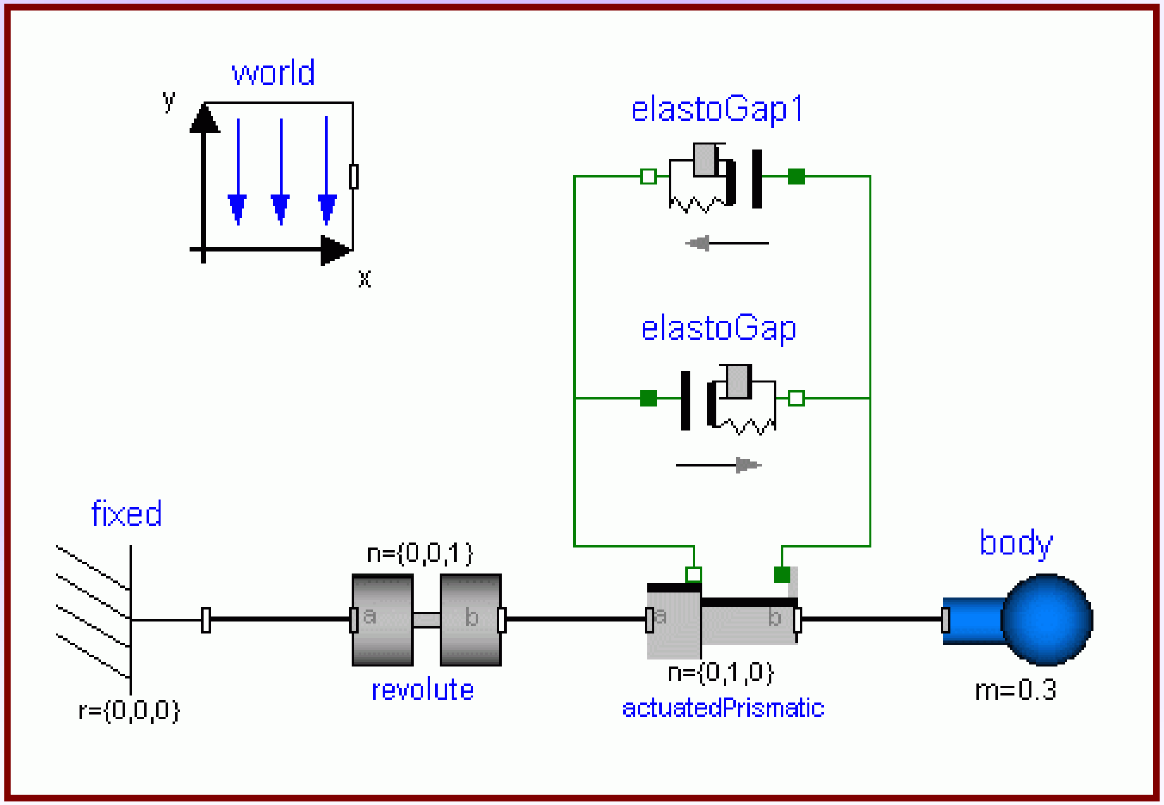
- In this homework problem, we shall be dealing with modeling and simulating a thread-pendulum.
- A thread-pendulum is a variant of the pendulum that we have been discussing previously. Here, the mass hangs on an infinitely thin mass-less thread instead of an infinitely thin rigid bar.
- Consequently, the mass has now two mechanical degrees of freedom rather than one.
- When the mass is at an elevation higher than the origin and is moving at a velocity that is too small, it will switch to a free-fall motion that lasts until the thread is fully extended again.

A Thread-Pendulum Model II



A Thread-Pendulum Model III

- The thread-pendulum can be described easily using the multi-body systems sub-library of the ***Modelica standard library***:



A Thread-Pendulum Model IV

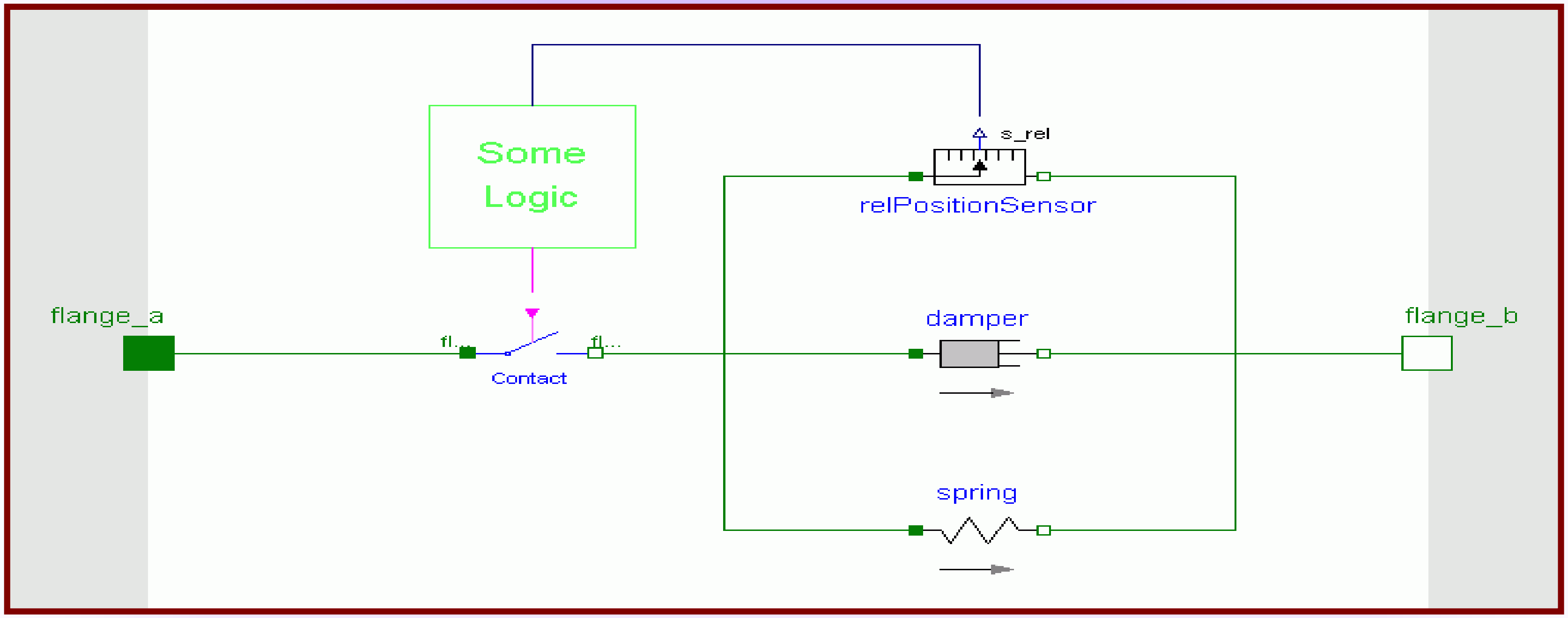
- We wish to simulate the pendulum using polar coordinates.
- Hence we start out with a revolute joint around the inertial frame. The ***multi-body systems (MBS)*** library makes use of the state selection algorithm to get ***Dymola*** to choose the relative angle and angular velocity as two state variables.
- The model then proceeds with a prismatic joint, adding the second mechanical degree of freedom. The MBS library uses the state selection algorithm to convince ***Dymola*** to use the relative position and velocity of the prismatic joint as the other two state variables.
- Hence we operate in polar coordinates around the origin (inertial frame).

A Thread-Pendulum Model V

- We still need to implement the constraint: the mass of the pendulum cannot move to a position that is farther away from the origin than the length of the thread.
- This constraint is tricky to implement. Let us consider for a moment a train engine impacting with a buffer-stop at a finite velocity.
- If the buffer-stop is infinitely rigid, the remaining kinetic energy of the train would have to be destroyed instantly, which requires an infinite force. This will either damage the locomotive, or the buffer-stop or both.
- Therefore, a real buffer-stop is flexible. It has a stiff spring and a damper built into the stop.

The ElastoGap Model

- We might be inclined to model the buffer-stop in the following fashion:



- When the train engine makes contact with the buffer-stop, the switch closes, and the spring/damper system becomes active.

The ElastoGap Model II

- Unfortunately, this approach fails.
- If the spring is modeled as a capacitor, then the capacitor only becomes active after contact. This means that the number of differential equations would increase by one at contact, which is something that ***Dymola*** currently doesn't support.
- Remember that all switches must be placed inside algebraic loops.
- If the spring is modeled as a modulated effort source, the spring won't have positional information available while the switch is open, and therefore cannot compute the spring force.

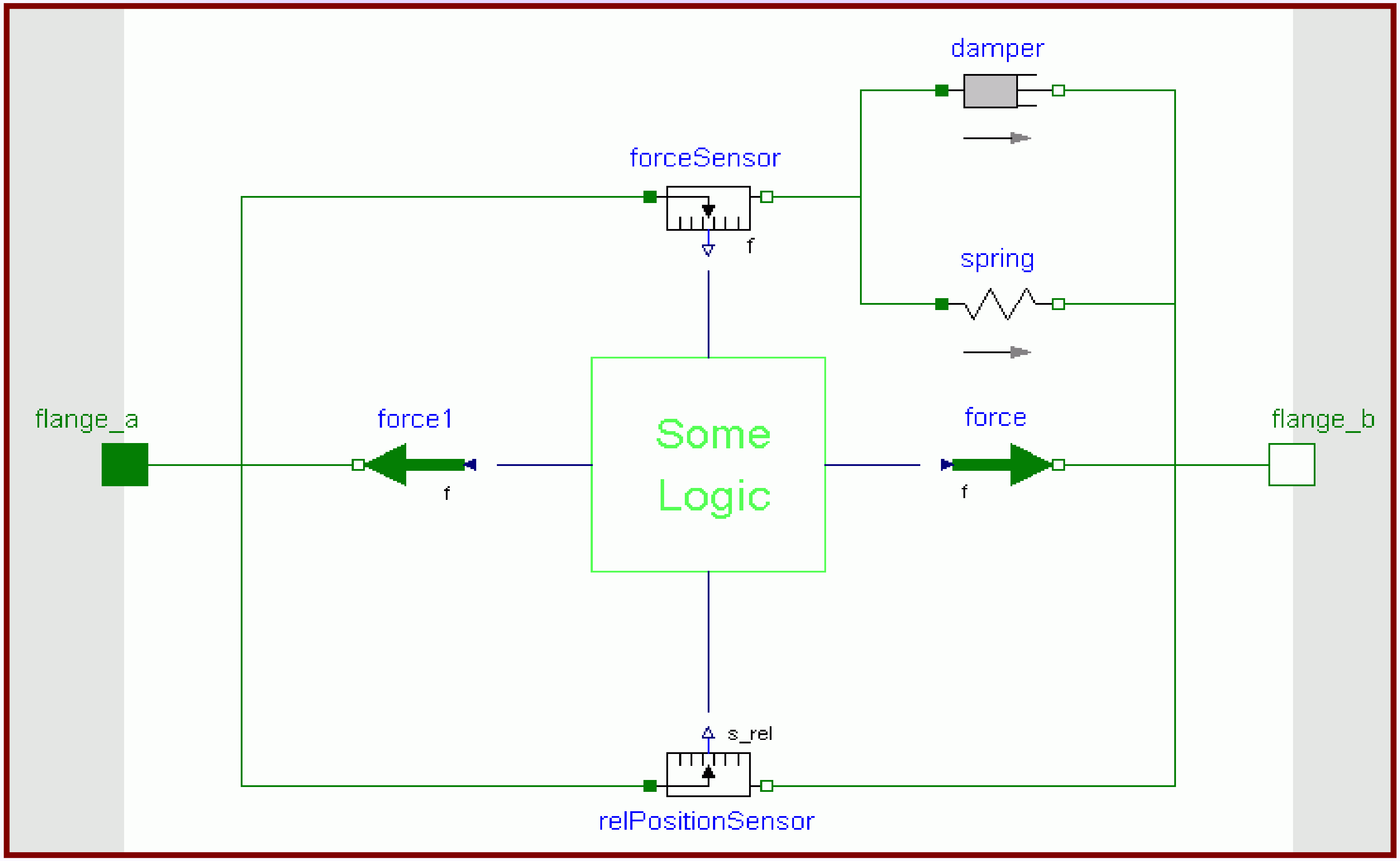
The ElastoGap Model III

- We wish the re-create the thread-pendulum model using the planar mechanical sub-library of ***MultiBondLib***.
- Unfortunately, the 1D translational sub-library of ***BondLib*** doesn't offer an ElastoGap model yet.
- Hence your first task will be to create one.
- Of course, you could simply use the connectors of the 1D translational sub-library of ***BondLib*** and copy the equation model over from the corresponding sub-library of the ***Modelica standard library***.
- However, that would be no fun. You are supposed to create a graphical ElastoGap model.

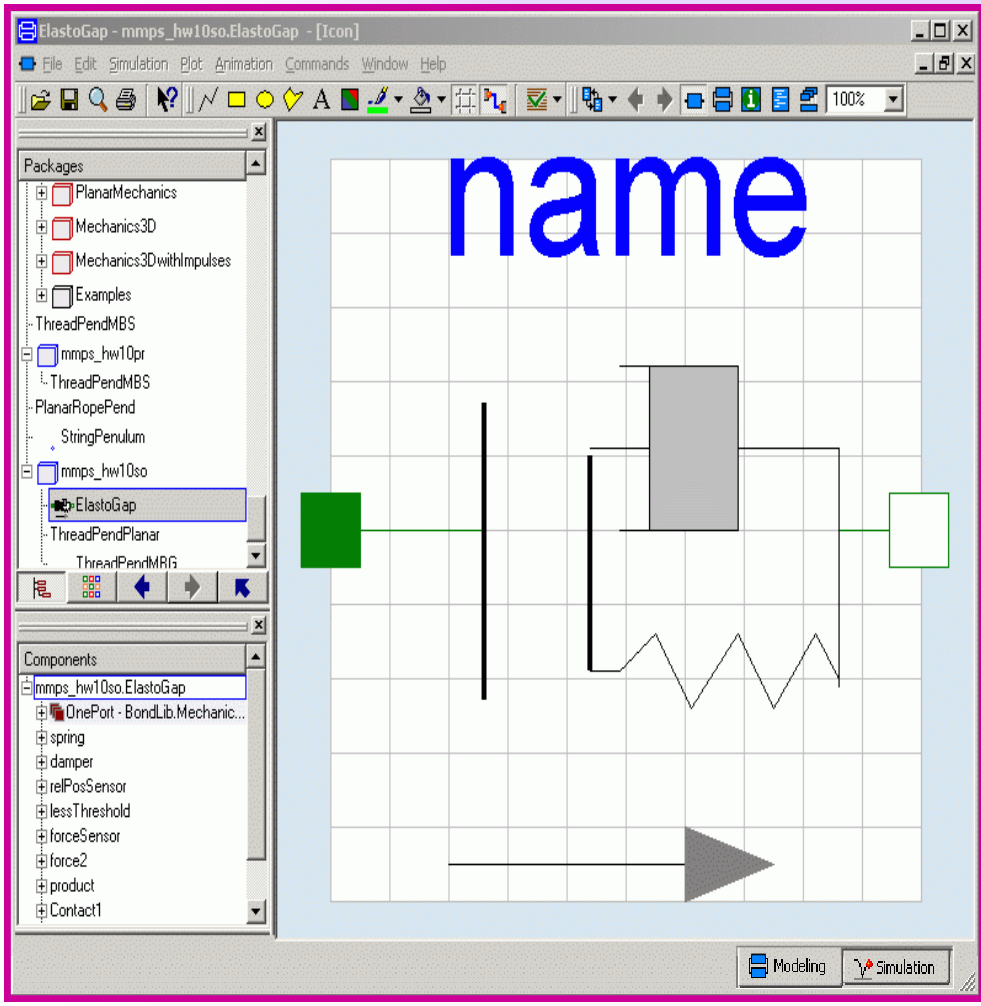
The ElastoGap Model IV

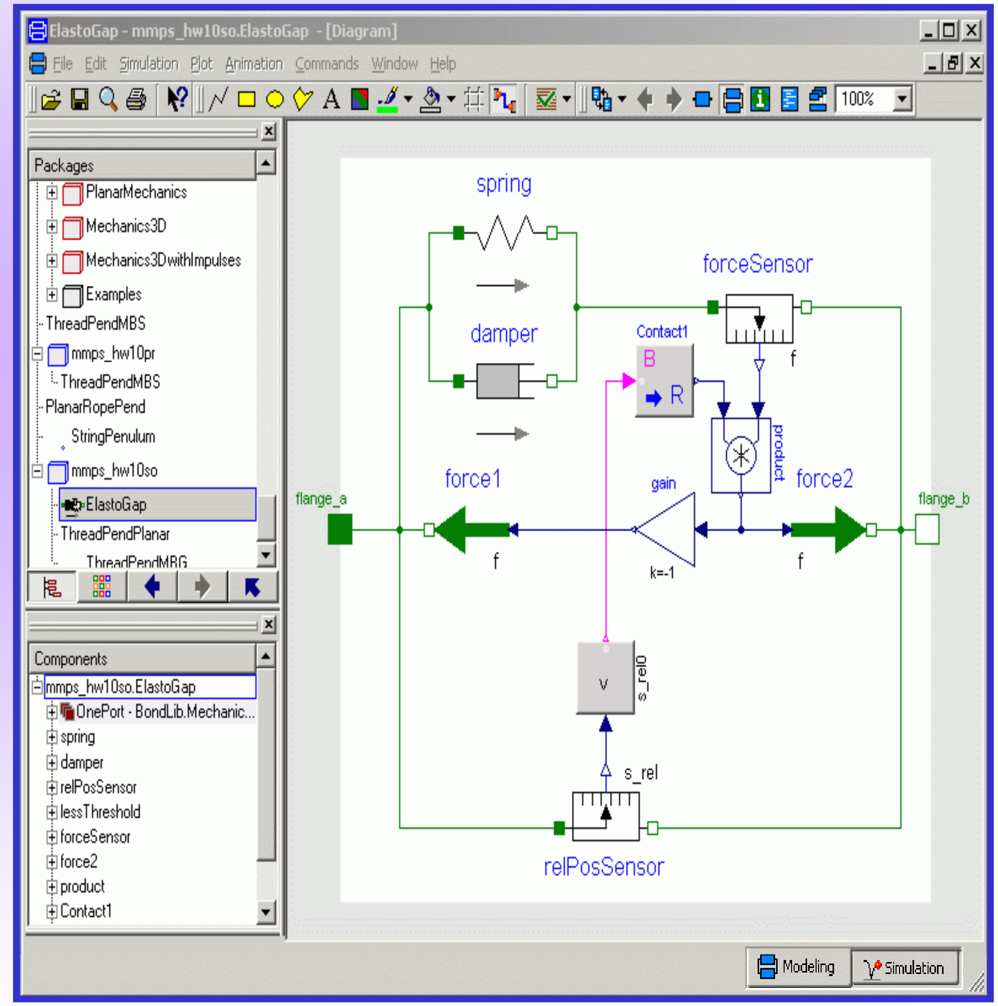
- In order for this to work, the spring/damper system must be continuously engaged. You cannot use a switch.
- One way how this task can be accomplished is by measuring not only the relative position between the two flanges, but also the force into the spring/damper system. You may then apply a pair of additional force sources at the two flanges that compensate the pair of forces (same magnitude, opposite sign) of the spring/damper system, whenever there is no contact, such that the total force at the two flanges adds up to zero.

The ElastoGap Model V

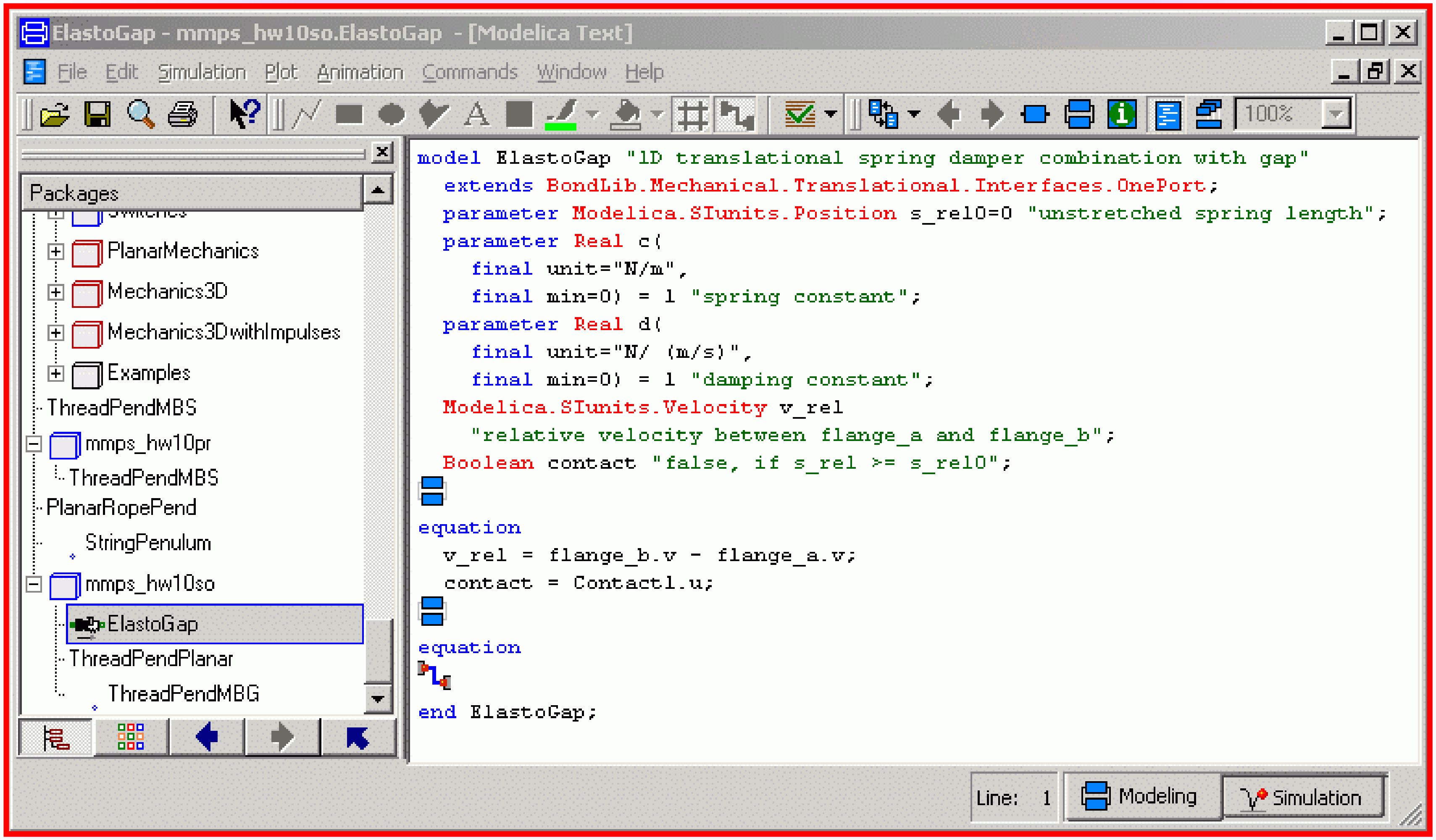


The ElastoGap Model VI





The ElastoGap Model VII



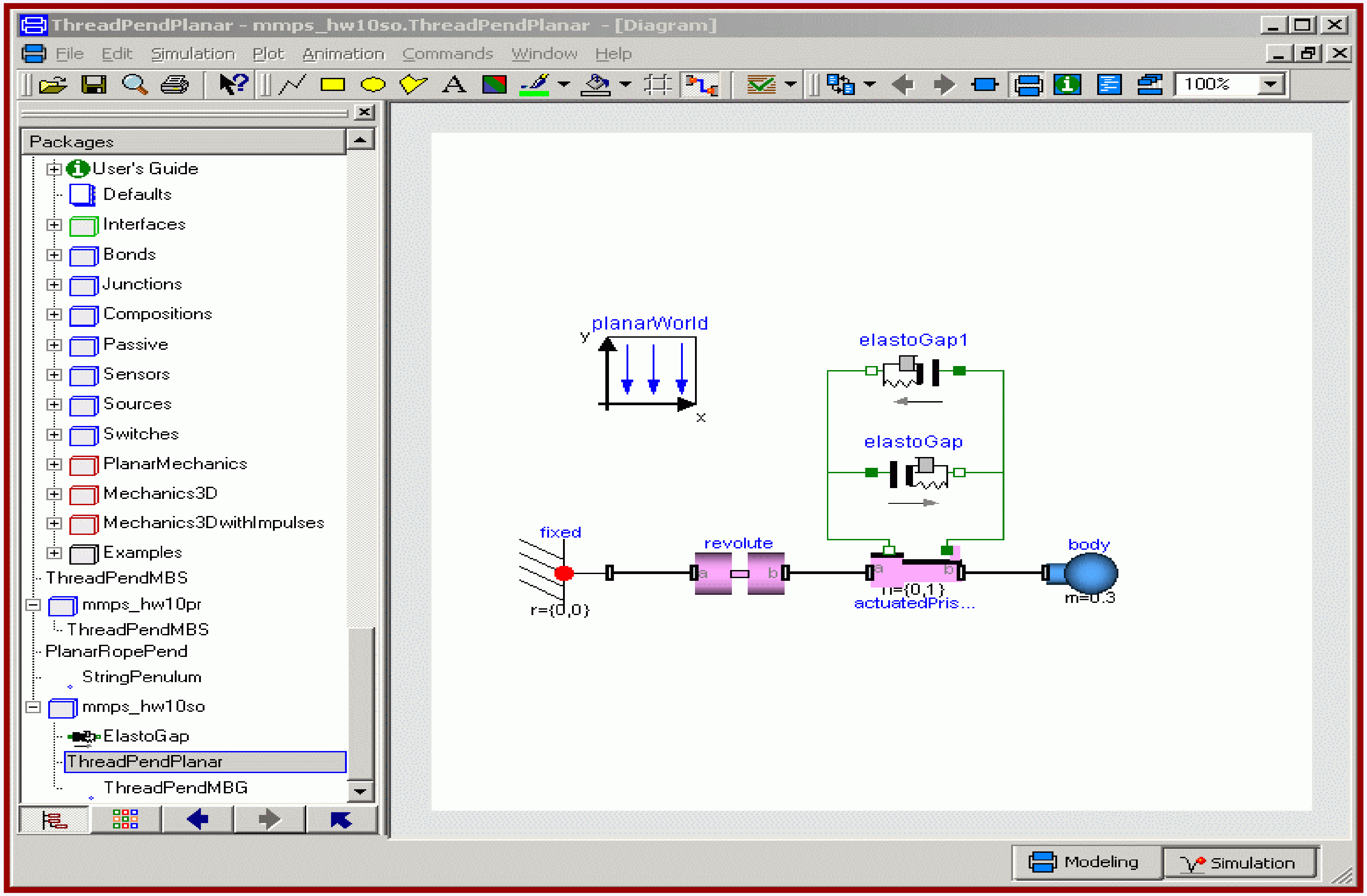
The Planar Thread-Pendulum Model

- For the thread-pendulum model, we need two ElastoGap models, because in every direction there are always two constraints, i.e., two positions, where the thread is completely stretched.
- You are now to re-create the thread-pendulum model from elements of the planar mechanical sub-library of ***MultiBondLib***, and the previously created ElastoGap model.
- You have access to the 3D mechanical model using the MBS library. You can read all of the necessary parameter values out from it.

The Planar Thread-Pendulum Model II

- Duplicate the animated planar model and simulate it.
- The MBS library normalizes the angles differently from the planar library, i.e., you'll need to modify two parameters of the model in order to avoid getting a motion that is mirrored at the vertical axis.
- Compare the number of equations before and after optimization obtained by the two models as well as their execution efficiencies.

The Planar Thread-Pendulum Model III



The Planar Thread-Pendulum Model IV

Messages - Dymola

Syntax Error | Translation | Dialog Error | Simulation

Translation of mmps_hw10pr.ThreadPendMBS:
DAE having 1591 scalar unknowns and 1591 scalar equations.

STATISTICS

Original Model
Number of components: 64
Variables: 731
Constants: 0
Parameters: 137 (210 scalars)
Unknowns: 594 (1591 scalars)
Differentiated variables: 16 scalars
Equations: 542
Nontrivial : 360

Translated Model
Constants: 1191 scalars
Free parameters: 65 scalars
Parameter depending: 189 scalars
Inputs: 0
Outputs: 0
Continuous time states: 4 scalars
Time-varying variables: 48 scalars
Alias variables: 334 scalars
Number of mixed real/discrete systems of equations: 0
Sizes of linear systems of equations: {6}
Sizes after manipulation of the linear systems: {2}
Sizes of nonlinear systems of equations: { }
Sizes after manipulation of the nonlinear systems: { }
Number of numerical Jacobians: 0

Finished
// experiment StopTime=5
Finished

Standard MBS 3D Library

Messages - Dymola

Syntax Error | Translation | Dialog Error | Simulation

Translation of mmps_hw10so.ThreadPendPlanar:
DAE having 2614 scalar unknowns and 2614 scalar equations.

STATISTICS

Original Model
Number of components: 221
Variables: 1876
Constants: 0
Parameters: 331 (384 scalars)
Unknowns: 1545 (2614 scalars)
Differentiated variables: 15 scalars
Equations: 1243
Nontrivial : 757

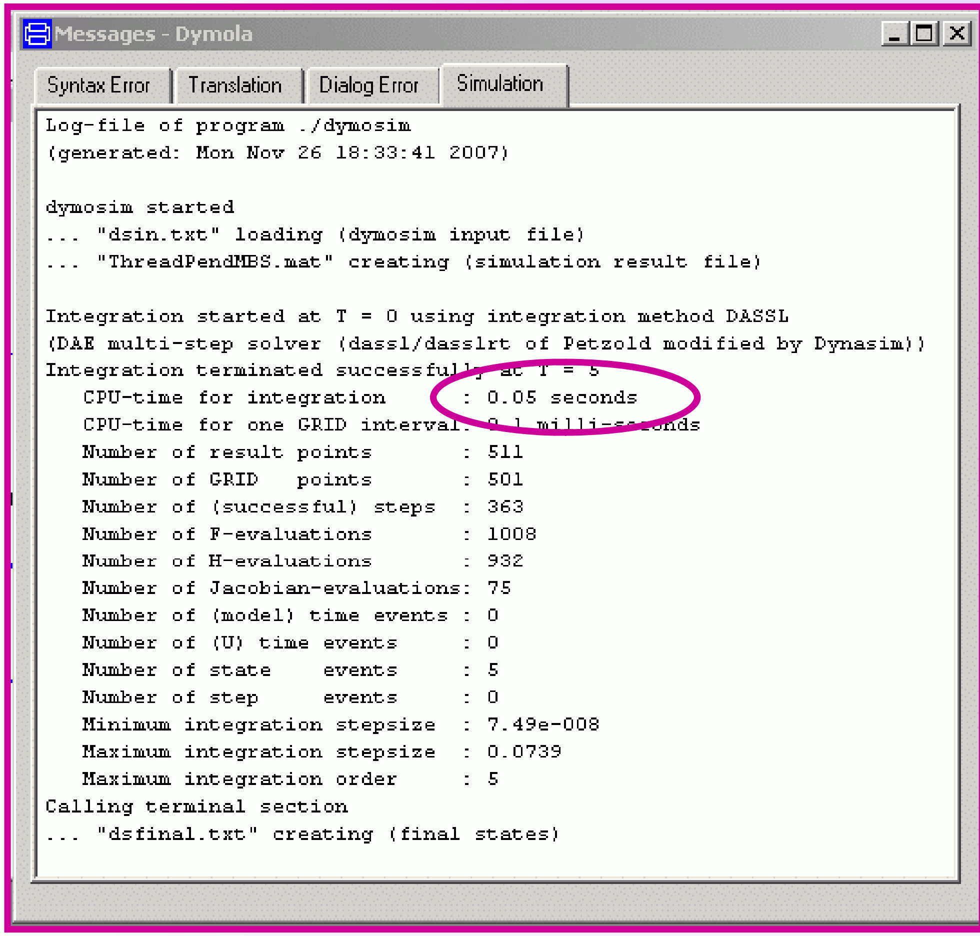
Translated Model
Constants: 1261 scalars
Free parameters: 82 scalars
Parameter depending: 328 scalars
Inputs: 0
Outputs: 0
Continuous time states: 4 scalars
Time-varying variables: 71 scalars
Alias variables: 1320 scalars
Assumed default initial conditions: 1
LogDefaultInitialConditions=true; gives mo
Number of mixed real/discrete systems of
Sizes of linear systems of equations: {15}
Sizes after manipulation of the linear syste
Sizes of nonlinear systems of equations: {
Sizes after manipulation of the nonlinear sy
Number of numerical Jacobians: 0

Finished
Finished

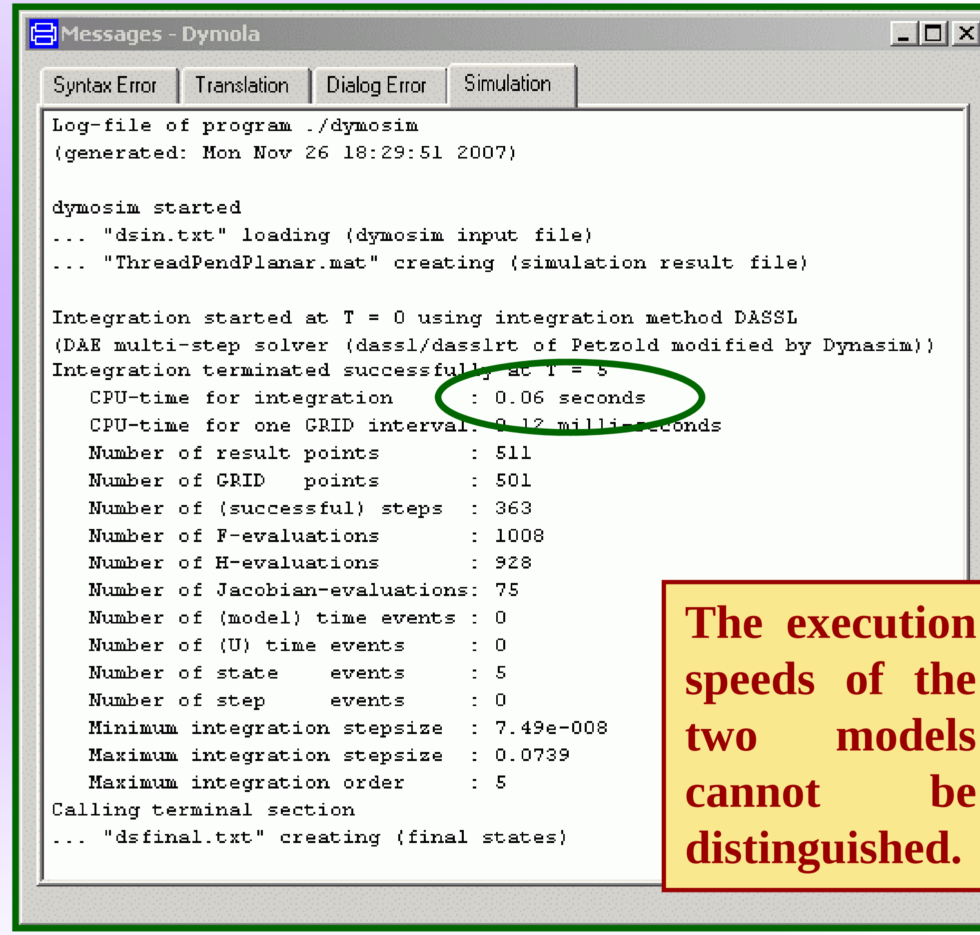
MBG Mechanical 2D Library

The planar solution has initially more equations due to the bond graphs. The compiled model still has more equations due to the graphical *ElastoGap* model.

The Planar Thread-Pendulum Model V



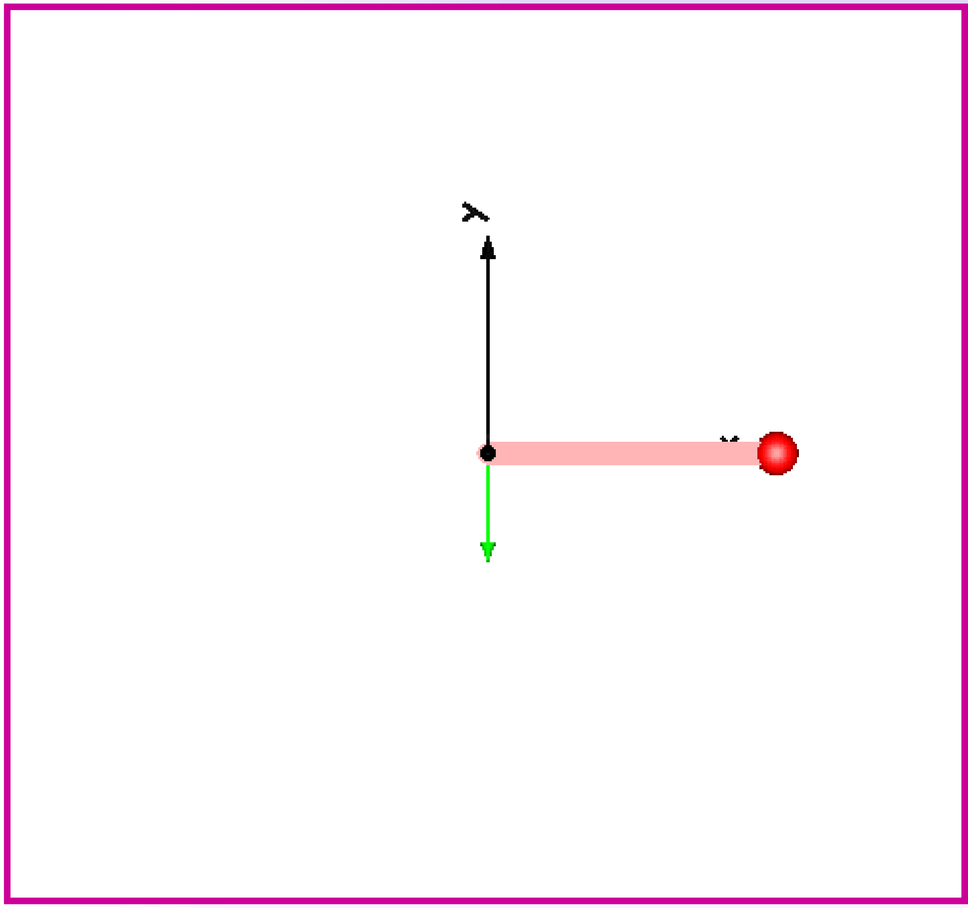
Standard MBS 3D Library



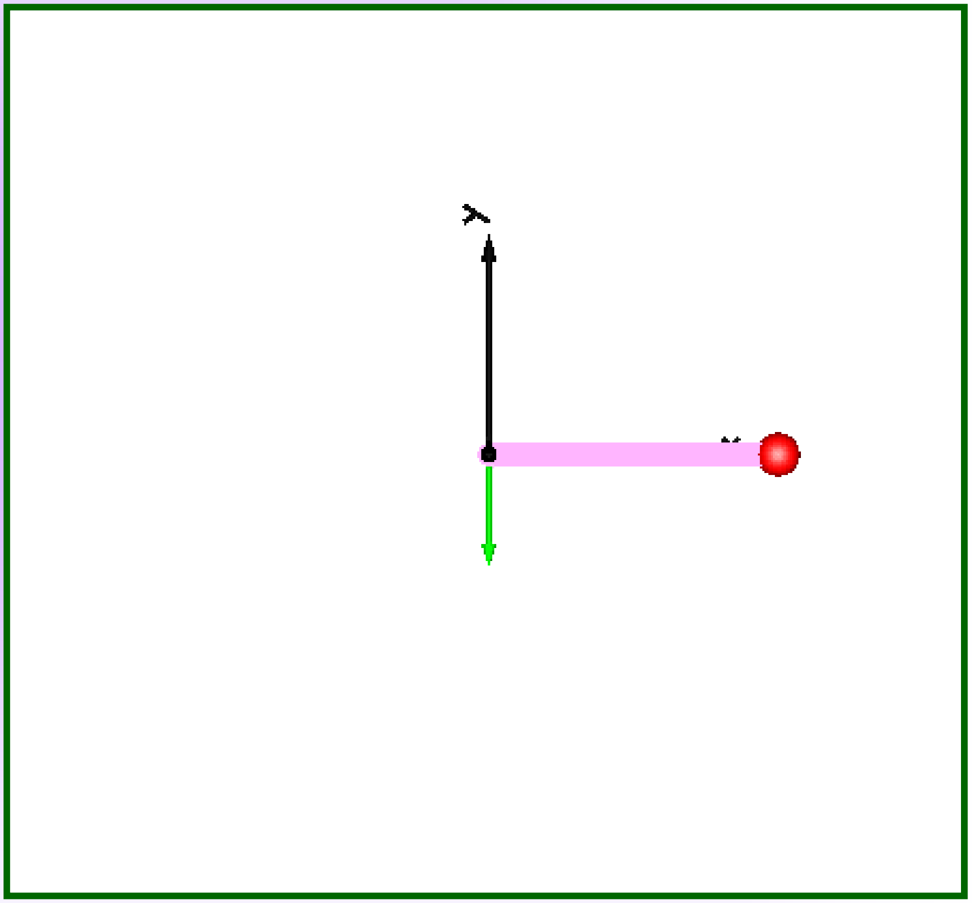
The execution speeds of the two models cannot be distinguished.

MBG Mechanical 2D Library

The Planar Thread-Pendulum Model VI



Standard MBS 3D Library

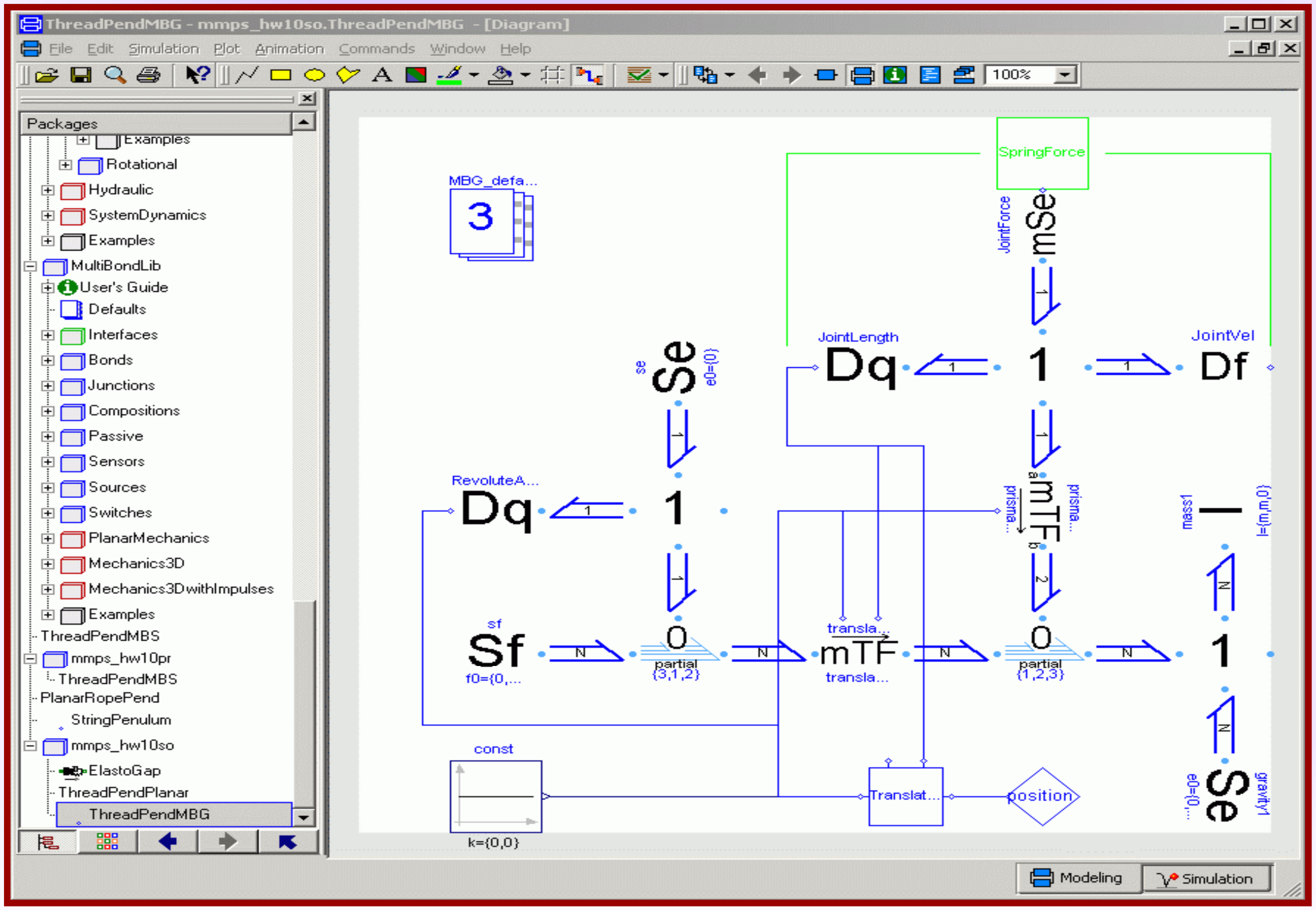


MBG Mechanical 2D Library

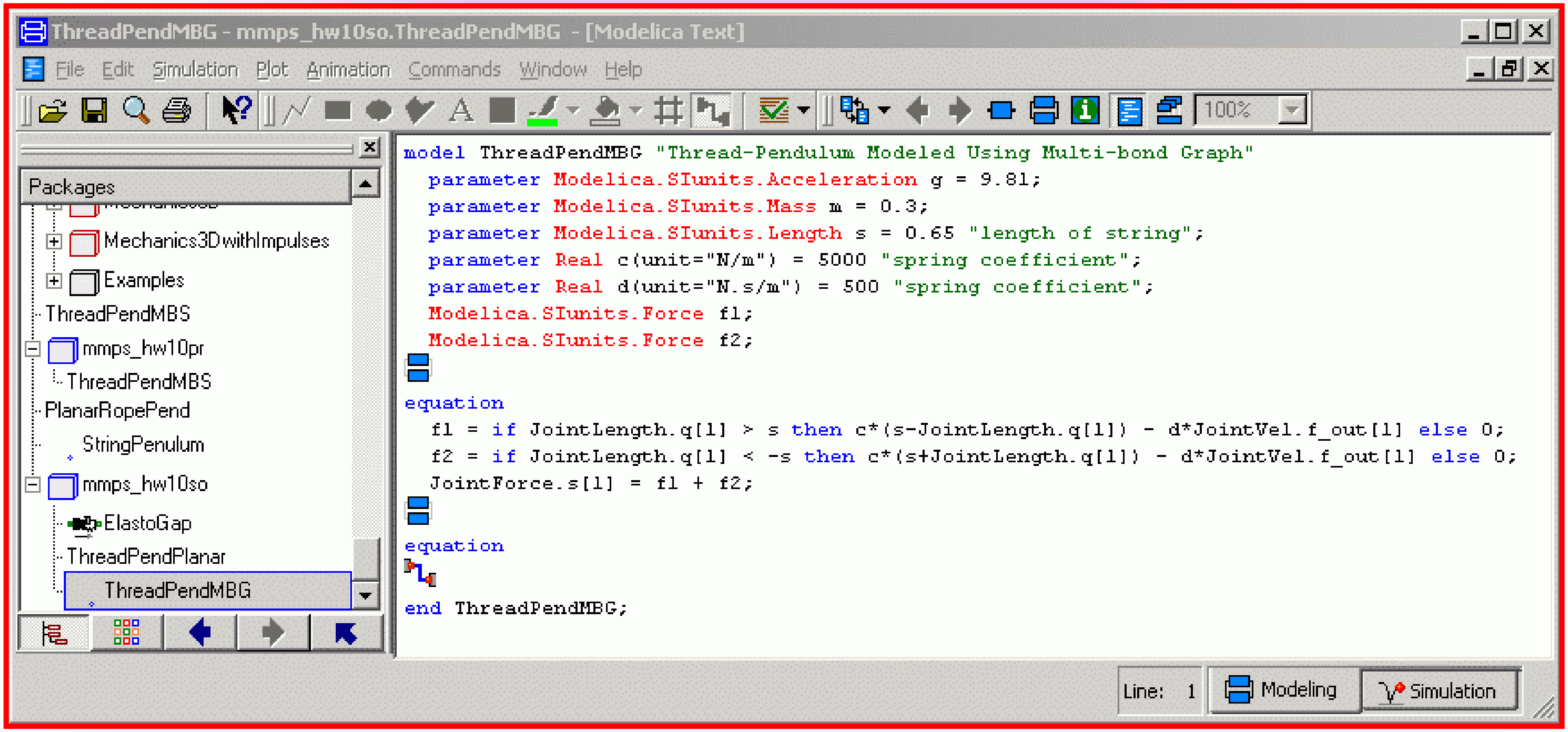
The Multi-bond Graph Thread-Pendulum Model

- You are now supposed to create a third model of the thread-pendulum, this time using a direct multi-bond graph approach, i.e., without wrapping.
- You may formulate the two constraints in the equation window, i.e., you don't need to create a direct bond-graph version of the ElastoGap model.
- This model cannot be animated. Plot the vertical motion of the pendulum mass against its horizontal motion.
- Compare the number of equations and execution speed with the previous two solutions.

The Multi-bond Graph Thread-Pendulum Model II



The Multi-bond Graph Thread-Pendulum Model III



The Multi-bond Graph Thread-Pendulum Model IV

```
Messages - Dymola
Syntax Error | Translation | Dialog Error | Simulation

Translation of mmps_hw10pr.ThreadPendMBS:
DAE having 1591 scalar unknowns and 1591 scalar equations.

STATISTICS

Original Model
  Number of components: 64
  Variables: 731
    Constants: 0
    Parameters: 137 (210 scalars)
    Unknowns: 594 (1591 scalars)
    Differentiated variables: 16 scalars
  Equations: 542
    Nontrivial : 360

Translated Model
  Constants: 1191 scalars
  Free parameters: 65 scalars
  Parameter depending: 189 scalars
  Inputs: 0
  Outputs: 0
  Continuous time states: 4 scalars
  Time-varying variables: 48 scalars
  Alias variables: 334 scalars
  Number of mixed real/discrete systems of equations: 0
  Sizes of linear systems of equations: {6}
  Sizes after manipulation of the linear systems: {2}
  Sizes of nonlinear systems of equations: { }
  Sizes after manipulation of the nonlinear systems: { }
  Number of numerical Jacobians: 0

Finished
// experiment StopTime=5
Finished
```

Standard MBS 3D Library

```
Messages - Dymola
Syntax Error | Translation | Dialog Error | Simulation

Translation of mmps_hw10so.ThreadPendMBG:
DAE having 390 scalar unknowns and 390 scalar equations.

STATISTICS

Original Model
  Number of components: 34
  Variables: 382
    Constants: 0
    Parameters: 144 (163 scalars)
    Unknowns: 238 (390 scalars)
    Differentiated variables: 6 scalars
  Equations: 202
    Nontrivial : 106

Translated Model
  Constants: 217 scalars
  Free parameters: 12 scalars
  Parameter depending: 58 scalars
  Inputs: 0
  Outputs: 0
  Continuous time states: 4 scalars
  Time-varying variables: 19 scalars
  Alias variables: 258 scalars
  Assumed default initial conditions: 1
   LogDefaultInitialConditions=true; gives mo
  Number of mixed real/discrete systems of
  Sizes of linear systems of equations: {2, 6}
  Sizes after manipulation of the linear syste
  Sizes of nonlinear systems of equations: {
  Sizes after manipulation of the nonlinear sy
  Number of numerical Jacobians: 0

Finished
Finished
```

MBG Library (I

The direct solution contains far fewer equations initially, in part because wrapping has been avoided, but mostly because of the missing animation. Also the compiled model contains less equations due to the missing animation equations.

The Multi-bond Graph Thread-Pendulum Model V

Messages - Dymola

Syntax Error | Translation | Dialog Error | Simulation

```
Log-file of program ./dymosim
(generated: Mon Nov 26 18:33:41 2007)

dymosim started
... "dsin.txt" loading (dymosim input file)
... "ThreadPendMBS.mat" creating (simulation result file)

Integration started at T = 0 using integration method DASSL
(DAE multi-step solver (dassl/dasslrt of Petzold modified by Dynasim))
Integration terminated successfully at T = 5
   CPU-time for integration      : 0.05 seconds
   CPU-time for one GRID interval: 0.1 milli-seconds
   Number of result points       : 511
   Number of GRID   points       : 501
   Number of (successful) steps  : 363
   Number of F-evaluations       : 1008
   Number of H-evaluations       : 932
   Number of Jacobian-evaluations: 75
   Number of (model) time events : 0
   Number of (U) time events     : 0
   Number of state    events     : 5
   Number of step     events     : 0
   Minimum integration stepsize  : 7.49e-008
   Maximum integration stepsize  : 0.0739
   Maximum integration order     : 5
Calling terminal section
... "dsfinal.txt" creating (final states)
```

Standard MBS 3D Library

Messages - Dymola

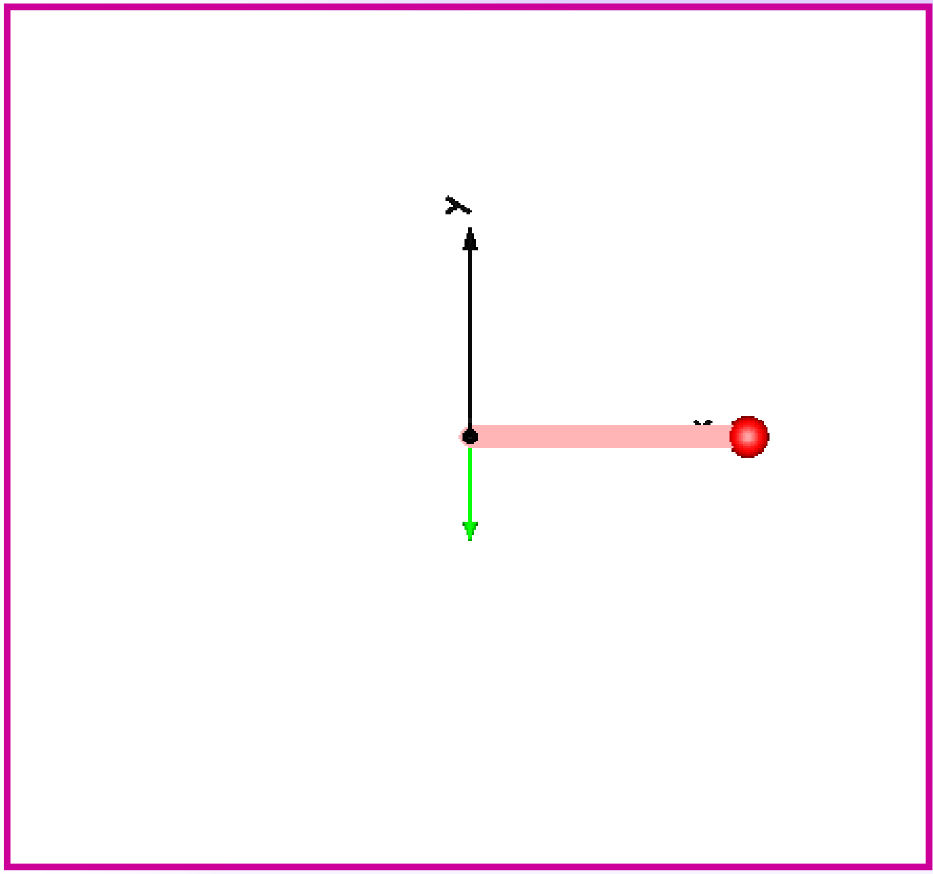
Syntax Error | Translation | Dialog Error | Simulation

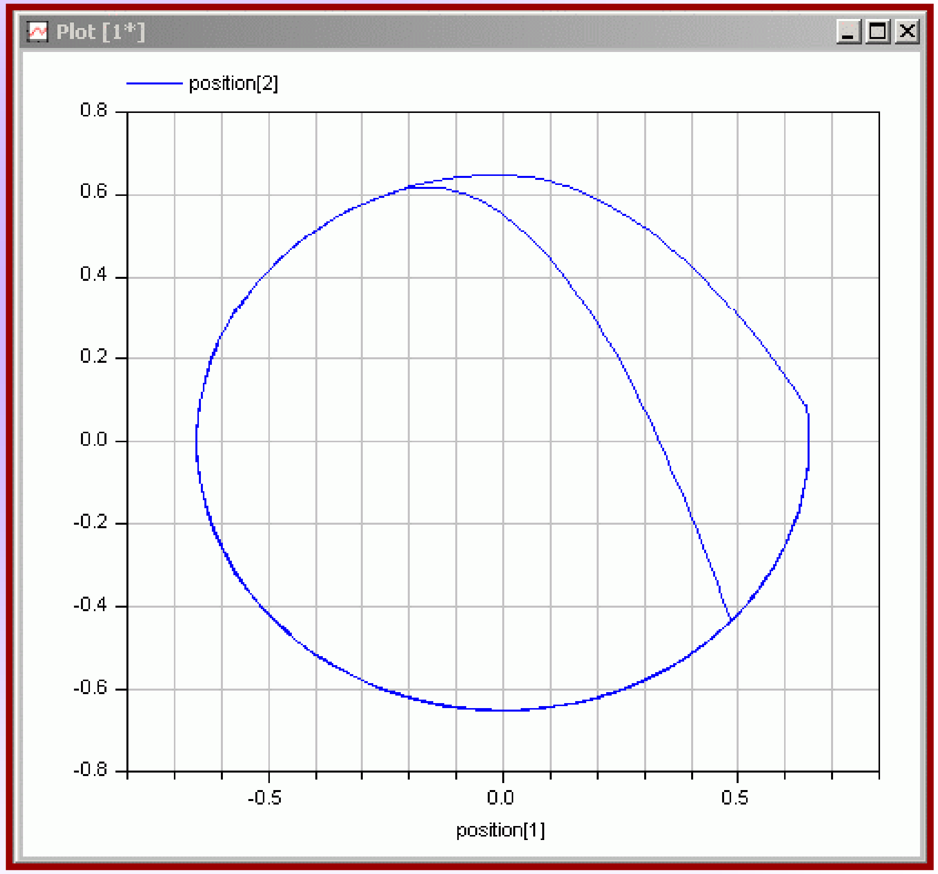
```
Log-file of program ./dymosim
(generated: Mon Nov 26 18:45:39 2007)

dymosim started
... "dsin.txt" loading (dymosim input file)
... "ThreadPendMBG.mat" creating (simulation result file)

Integration started at T = 0 using integration method DASSL
(DAE multi-step solver (dassl/dasslrt of Petzold modified by Dynasim))
Integration terminated successfully at T = 5
   CPU-time for integration      : 0.06 seconds
   CPU-time for one GRID interval: 0.12 milli-seconds
   Number of result points       : 511
   Number of GRID   points       : 501
   Number of (successful) steps  : 363
   Number of F-evaluations       : 1008
   Number of H-evaluations       : 929
   Number of Jacobian-evaluations: 75
   Number of (model) time events : 0
   Number of (U) time events     : 0
   Number of state    events     : 5
   Number of step     events     : 0
   Minimum integration stepsize  : 7.49e-008
   Maximum integration stepsize  : 0.0739
   Maximum integration order     : 5
Calling terminal section
... "dsfinal.txt" creating (final states)
```

MBG Library (Direct)

The execution speeds of the three models cannot be distinguished.

The Multi-bond Graph Thread-Pendulum Model VI





Standard MBS 3D Library

MBG Library (Direct)