WORKSHOP 2.2

Understanding equation-based modeling

Contents

Introduction

In this workshop, the concepts of equation-based and component-based modeling are investigated. The workshop contains four main parts: specifying boundary conditions, initialization, identifying degrees of freedom, and inverting system models. There are parallel exercises for boundary conditions and initialization, one track for mechanical systems and one track for thermodynamic system; they will both show the same features of Modelica.

Creating the package

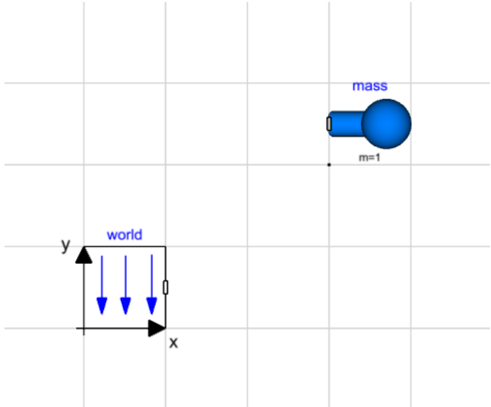
1. Create a new package **W2**. If applicable, place this inside the course package you created for the previous lectures. For example, the complete path could be ***TrainingPack.Day2.W2***.

Boundary conditions and Initialization: Mechanical system

Mass in gravity field

1. In **W2**, create a model called **MassInGravityField**.

2. Drag in a ***Modelica.Mechanics.MultiBody.World***, note that this component will automatically be called **world**, and get the prefix *inner*.
3. Drag in a ***Modelica.Mechanics.MultiBody.Parts.Body***, name it mass and set the mass to 1 kg, see the image below**Error! Reference source not found.**.

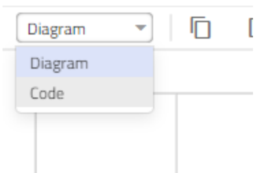


Note: Make sure you name it mass, otherwise modify the examples according to your naming convention.

4. Simulate using default settings (Dynamic, Stop Time = 1s).

Boundary condition 1

5. Extend **MassInGravityField** (right-click on model name in *Library Browser* and select *Extend...*) and call it **MassWithForce**.
6. Add a ***Modelica.Mechanics.MultiBody.Forces.WorldForce*** and call it force.
7. Add a ***Modelica.Blocks.Sources.RealExpression***.
8. We now need to switch to the code layer to make some changes. Open the code editor by selecting "Code" in the dropdown at the top of the modeling canvas:



   a. We need to make a size-3 array of this component so that we can provide an input for the force along each coordinate direction. To do this, append the string "*[3]*" to **realExpression**.

```
model MassWithForce
    extends ImpactTrainingSolutions.Day2.W2.MechanicalTrack.MassInGravityField;
    .Modelica.Mechanics.MultiBody.Forces.WorldForce force annotation(...);
    .Modelica.Blocks.Sources.RealExpression realExpression[3] annotation(...);
    annotation(...);
end MassWithForce;
```

   b. Create a variable ***Modelica.Units.SI.Force*** *f[3]*.

```
model MassWithForce
    extends ImpactTrainingSolutions.Day2.W2.MechanicalTrack.MassInGravityField;
    .Modelica.Mechanics.MultiBody.Forces.WorldForce force annotation(...);
    .Modelica.Blocks.Sources.RealExpression realExpression[3] annotation(...);
    .Modelica.Units.SI.Force f[3];
    annotation(...);
end MassWithForce;
```

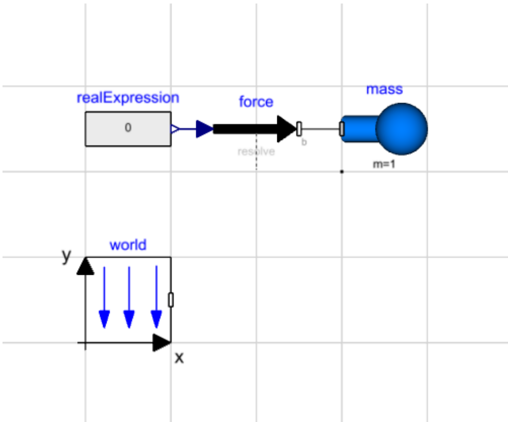
c. Use this force variable in the **realExpression** component, see the figure below.

```
model MassWithForce
    extends ImpactTrainingSolutions.Day2.W2.MechanicalTrack.MassInGravityField;
    .Modelica.Mechanics.MultiBody.Forces.WorldForce force annotation(•••);
    .Modelica.Blocks.Sources.RealExpression realExpression[3](y = f) annotation(•••);
    .Modelica.Units.SI.Force f[3];
    annotation(•••);
end MassWithForce;
```

d. Save the changes and close the code editor.

9. Create connections between **realExpression**, **force** and **mass**. Make sure to select "**:**" for the **realExpression** and **force** connectors.

10. The model should now look like the screenshot below.



11. We need to make one additional change in the code layer. In the equation section, add an equation for the position of the mass: *mass.frame_a.r_0 = {sin(time), 0.1*time, cos(time)};*. The result should now look like the following figure.

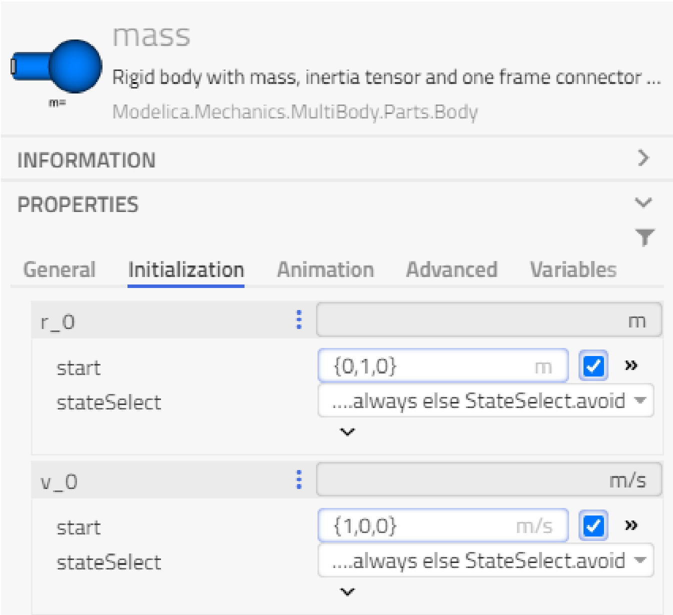
```
model MassWithForce
    extends .Workspace.Day2.Workshop2.MassInGravityField;
    .Modelica.Mechanics.MultiBody.Forces.WorldForce force annotation(•••);
    .Modelica.Blocks.Sources.RealExpression realExpression[3](y=f) annotation(•••);
    Modelica.SIunits.Force f[3];
equation
    mass.frame_a.r_0 = {sin(time), 0.1*time, cos(time)};
    connect(realExpression.y,force.force) annotation(•••);
    connect(force.frame_b,mass.frame_a) annotation(•••);
end MassWithForce;
```

12. It is now time to simulate our model. To better visualize the results, we can use the 3D animation capability in Modelon Impact.

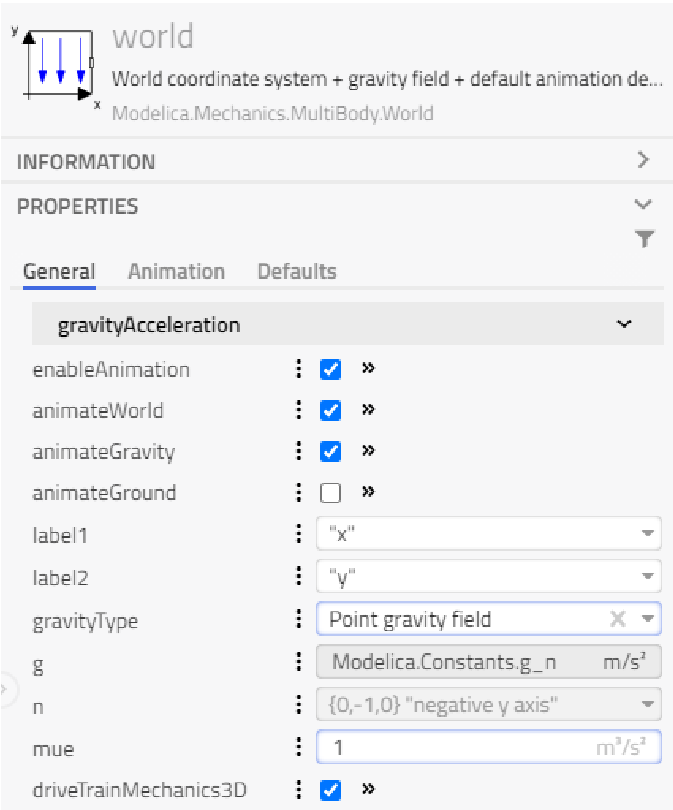
Simulate for 10 seconds and inspect the animation (right-click on canvas and select *View 3D animation*). What does this imply? Compare to the last exercise in this workshop.

Boundary condition 2

13. Extend **MassInGravityField** and call it **MassInPointGravityField**.
14. Set the initial position and velocity of the **mass** to {0,1,0} and {1,0,0}, respectively. See figure below.



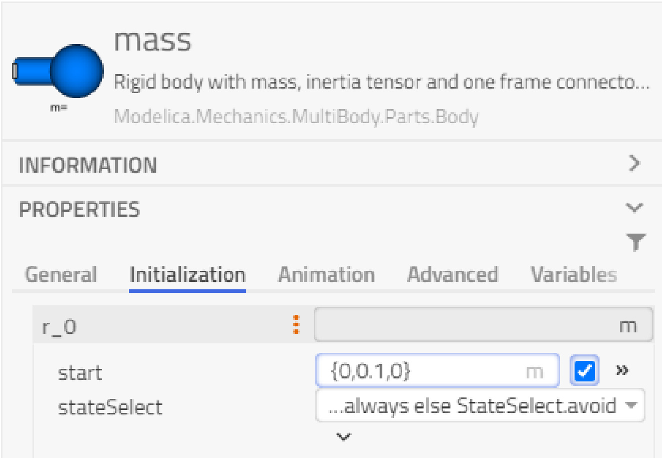
15. In the **world** component, select *point gravity field*, and set *mue* = 1 m^3/s^2 as shown in the figure below.



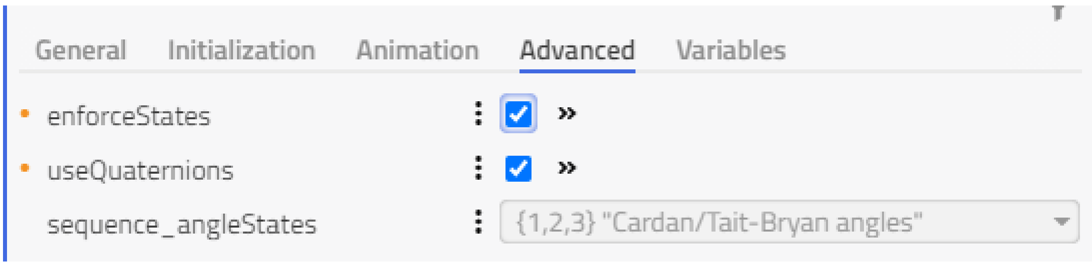
16. Simulate for 10 seconds and inspect the 3D animation.

Boundary condition 3

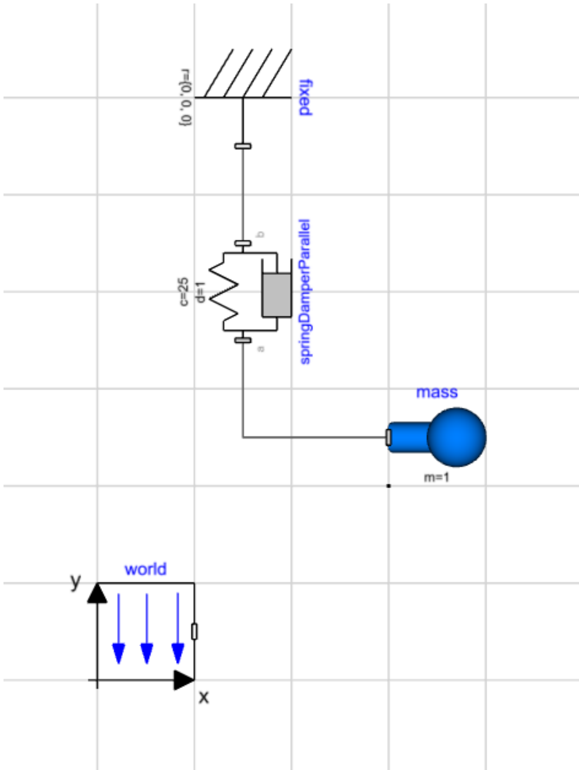
17. Extend **MassInGravityField** and call it **SuspendedMass**.
18. Add a ***Modelica.Mechanics.MultiBody.Parts.Fixed*** and a ***Modelica.Mechanics.MultiBody.Forces.SpringDamperParallel*** with 25 N/m stiffness and 1 Ns/m damping.
19. Set the initial position of the mass "*r_0.start*" to {0,0.1,0}. Make sure to check the checkbox to make the start value fixed.



20. Also set the states in the mass, on the Advanced tab, check enforceStates:



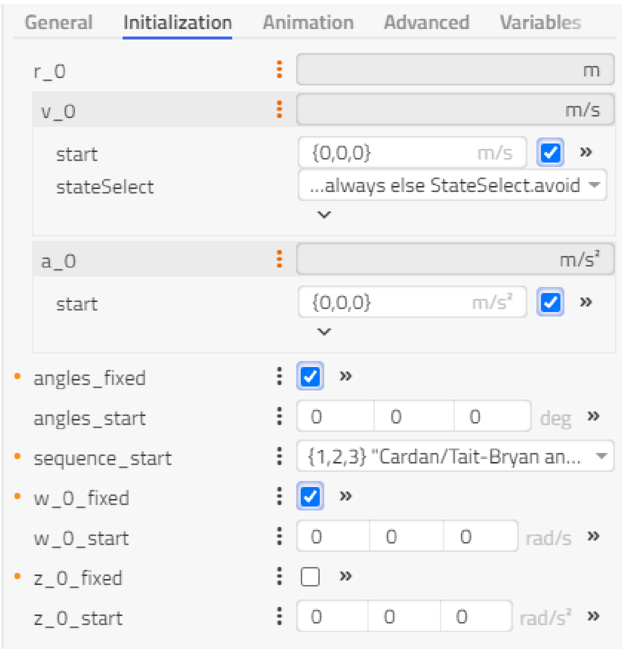
21. Connect the **springDamper** to the **mass** and to the **fixed** to get a model like the one below.



22. Simulate for 10 seconds and inspect the 3D animation.

Initialization

23. Extend **SuspendedMass** and call it **SuspendedMassSteadyState**.
24. In the parameter dialog of **mass**, fix the initial conditions of velocity and acceleration at zero. (Also set angles and w_0_start =0 and w_0_fixed = true, to enforce the rotational states and uncheck fixed for r_0.)

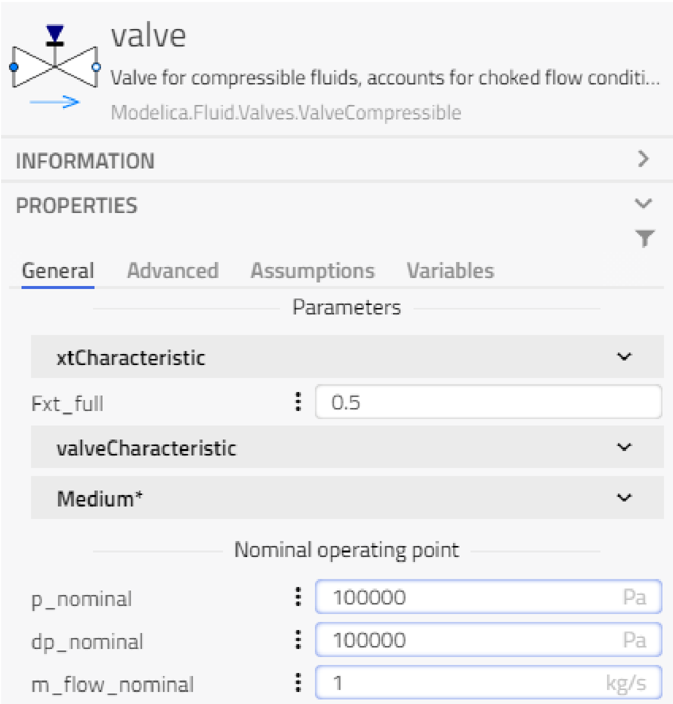


25. Simulate again for 10 seconds and compare the animations with the previous simulation. What is the difference?

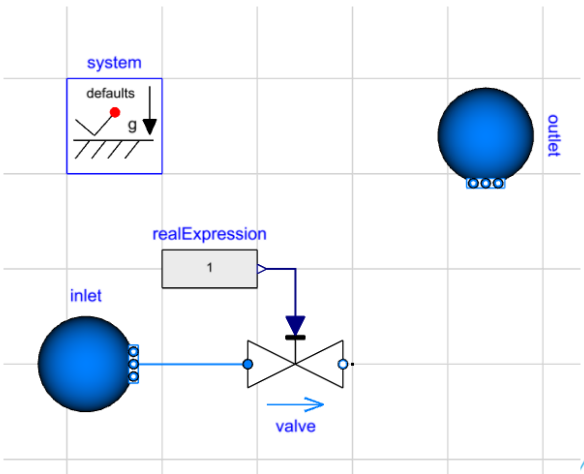
Boundary conditions and Initialization: Thermodynamic system

Mass flow calculation

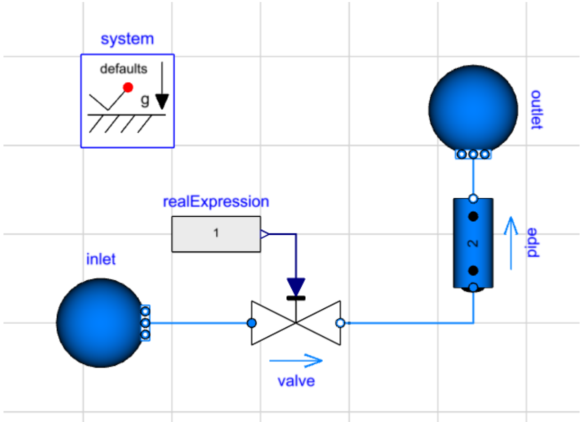
1. In **W2**, create a model called **ValveOpening**.
2. Drag in a ***Modelica.Fluid.System***. Note that this component will automatically be called **system** and get the prefix *inner*.
3. Drag in two ***Modelica.Fluid.Sources.Boundary_pT***, call them **inlet** and **outlet**, respectively. Parametrize the **inlet** pressure to be 2 bar and **outlet** pressure to be 1 bar.
4. Drag in a ***Modelica.Fluid.Valves.ValveCompressible***, call it **valve**. Set its nominal pressure drop and inlet pressure to 1 bar and set nominal mass flow to 1 kg/s – see figure below for reference.



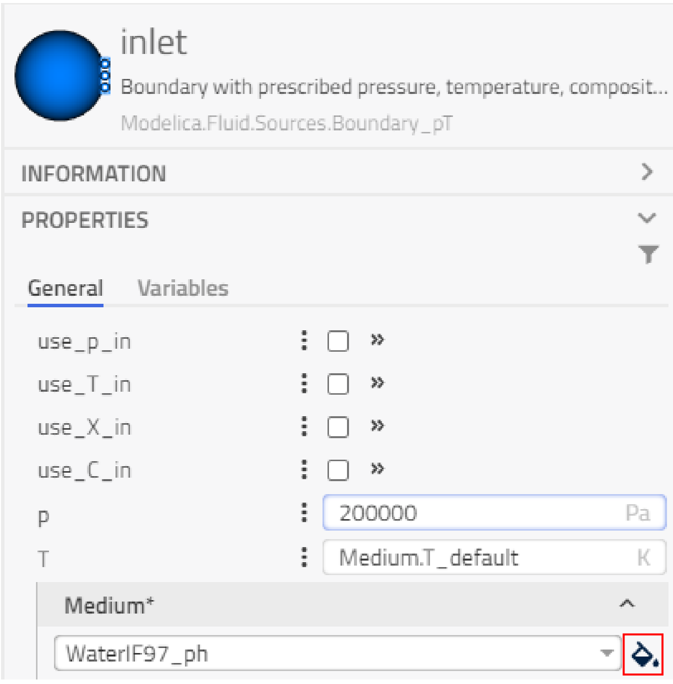
5. Declare a real variable *opening* and set it to 1 (*Real opening = 1 "Valve opening";*) and drag in a ***Modelica.Blocks.Sources.RealExpression***, that outputs the variable *opening*. Connect it to the *valve opening*. Also connect *port_a* of the **valve** to the **inlet**. See figure below.



6. Drag in a pipe, ***Modelica.Fluid.Pipes.DynamicPipe***, and parametrize it with a length of 10 m, diameter of 0.1 m, a height difference between the ports of 10 m. Under the *Advanced* tab of **pipe**, set the model structure to be *port_a – volume – flow model – port_b*, and under the *Initialization* tab set the start temperature to 293.15K. Connect *port_a* of the **pipe** to the **valve** and *port_b* to the **outlet**. The system should now look like the figure below.



7. Now let us set a medium for all the components. Set the medium for **inlet** to **Water using IF97 standard, explicit in *p* and *h***, and click on the propagate button. See the figure below.



8. Simulate the system using default settings. What is the mass flow through the valve?

Boundary condition 1

9. Duplicate the **ValveOpening** model and call it **ValveMassFlow**.
10. In the declaration of the variable *opening*, remove its value (*Real opening "Valve opening";*)
11. Add an equation *valve.m_flow = 0.1;*
    Note that at this point, we have the same number of equations in the system.

```
model ValveMassFlow
    inner .Modelica.Fluid.System system annotation(...);
    .Modelica.Fluid.Sources.Boundary_pT inlet(p = 200000,nPorts = 1,redeclare replaceable package Medium =
    .Modelica.Media.Water.WaterIF97_ph) annotation(...);
    .Modelica.Fluid.Sources.Boundary_pT boundary(nPorts = 1,redeclare replaceable package Medium =
    .Modelica.Media.Water.WaterIF97_ph) annotation(...);
    .Modelica.Fluid.Valves.ValveCompressible valve(p_nominal = 100000,dp_nominal = 100000,m_flow_nominal =
    1,redeclare replaceable package Medium = .Modelica.Media.Water.WaterIF97_ph) annotation(...);
    Real opening "Valve opening";
    .Modelica.Blocks.Sources.RealExpression realExpression(y = opening) annotation(...);
    .Modelica.Fluid.Pipes.DynamicPipe pipe(length = 10,diameter = 0.1,height_ab = 10,modelStructure =
    .Modelica.Fluid.Types.ModelStructure.av_b,T_start = 293.15,redeclare replaceable package Medium =
    .Modelica.Media.Water.WaterIF97_ph) annotation(...);
equation
    valve.m_flow = 0.1;
    connect(pipe.port_b,boundary.ports[1]) annotation(...);    connect(realExpression.y,valve.opening)
    annotation(Line(points = {{-19,24},{-10,24},{-10,8}},color = {0,0,127}));
    connect(valve.port_a,inlet.ports[1]) annotation(...);
    connect(valve.port_b,pipe.port_a) annotation(...);

    annotation(...);
end ValveMassFlow;
```

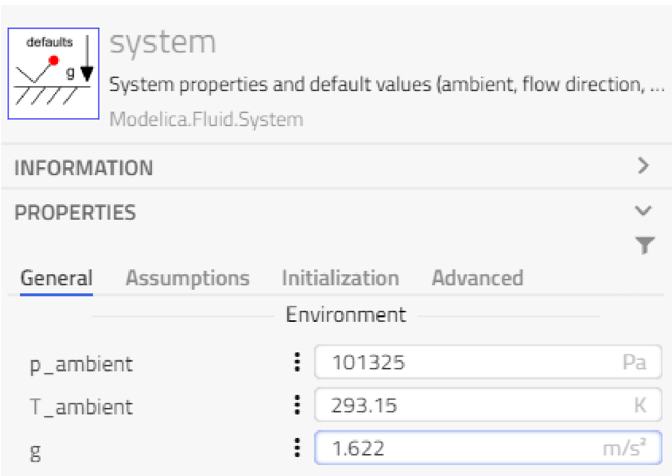
12. Simulate the system. Compare the **valve** opening and mass flow through the **valve** to the previous exercise. Which variables are known and unknown in the equation system?

Boundary condition 2

13. Duplicate the **ValveMassFlow** model to a model called **ValveMassFlowAir**.
14. Change the medium model in all components to “**Air as mixture of N2 and O2**.” You can change the medium in a single component, say inlet, and use the *propagate* button.
15. Simulate the model. Compare the valve opening to the previous exercise. Is it different? Have we changed any equations in the components?

Boundary condition 3

16. Extend the model **ValveOpening** to a model called **ValveOpeningMoon**.
17. Set the gravity in the **system** component so that the gravity is as on the moon, 1.622 m/s^2, see figure below.

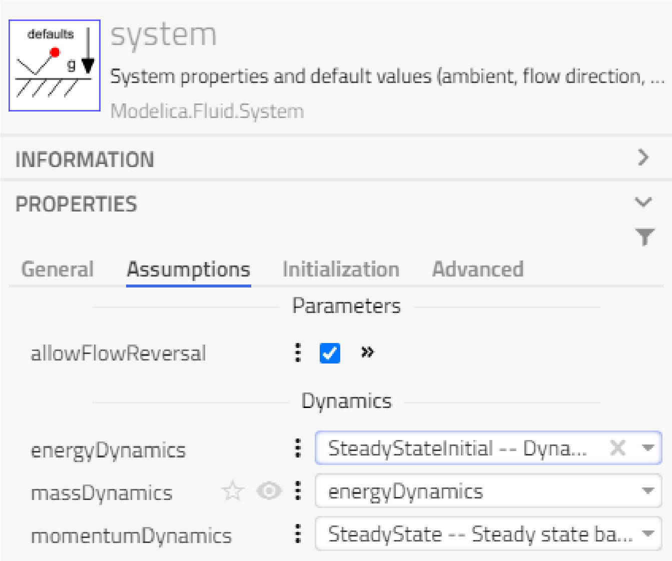


18. Simulate the system and compare the mass flow to the mass flow in the model **ValveOpening**. Are they different, and if so, why are they different? Have we changed any equations in the components? Have the boundaries of the system changed?

Initialization

19. Extend the model **ValveOpening** to a model called **ValveOpeningSteadyStateInit**.

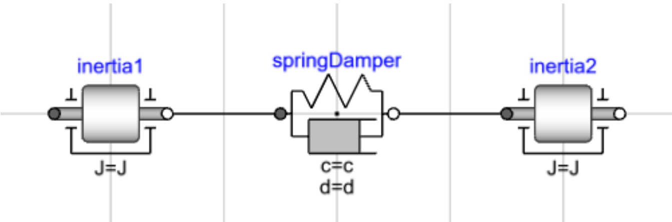
20. Under the *Assumptions* tab of the system component, change the *energyDynamics* to ***Modelica.Fluid.Types.Dynamics.SteadyStateInitial***, see the figure below.



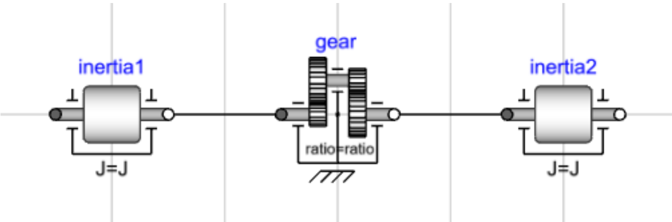
21. Simulate the system. Compare the mass flow and the pressures in the pipe discretization volumes to the result of the **ValveOpening** model. What is the difference between the two simulations?

Identifying Degrees of Freedom

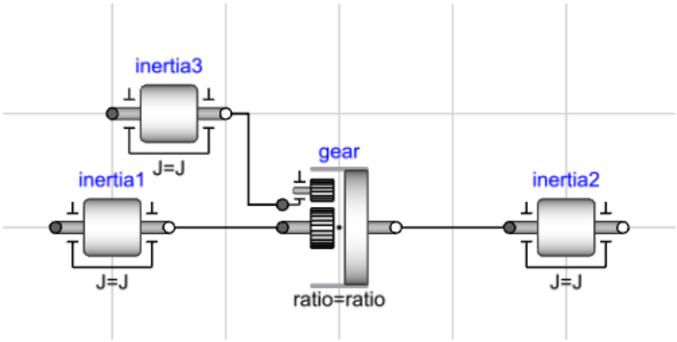
1. Study the systems (a-d) below. How many degrees of freedom and how many states does each system have? Is there a unique set of states?
    a. Two inertias with a spring-damper element, see figure below.



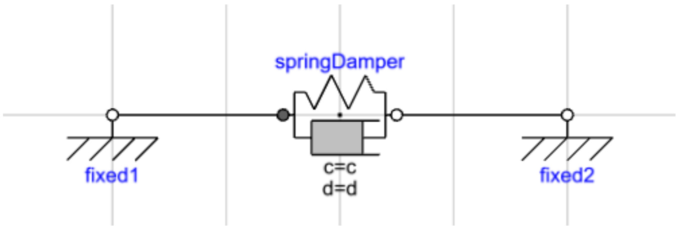
    b. Two inertias with a gear in between, see figure below.



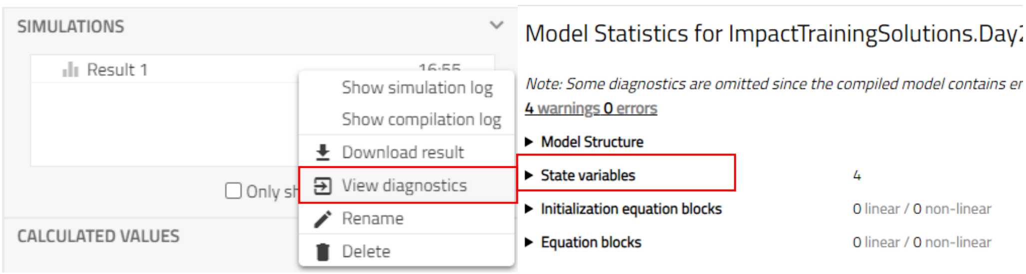
    c. Three inertias with a planetary gear, see figure below.



d. Two fixed elements with a spring-damper in between, see figure below.



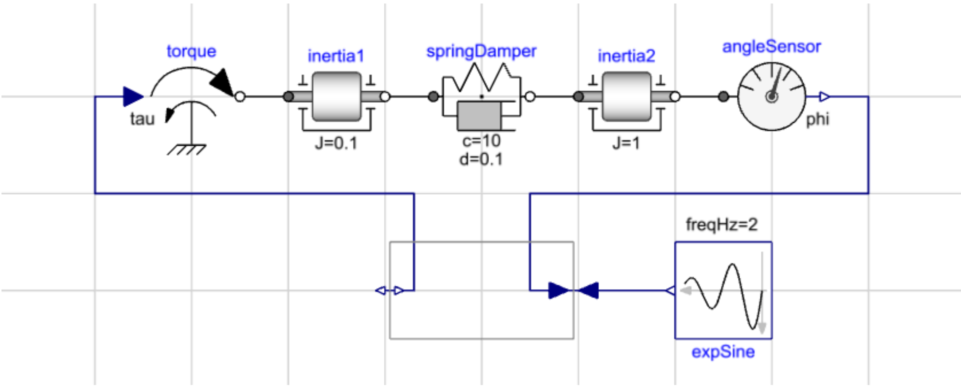
2. Implement the systems above as new models **DegreesOfFreedom1-4**, simulate, and inspect the compilation diagnostics, what states were selected? You can see what states have been selected under **State variables** in the advanced diagnostics.



Do not forget to activate "generate_html_diagnostics" in execution settings to get access to the advanced diagnostics.

Inverting system models

1. Create a new model called **InverseSystem** and build the system below. Use J=0.1 kg.m^2 in **inertia1**; c=10 N.m/rad, d=0.1 N.m.s/rad in **springDamper**; J=1 kg.m^2 in **inertia2**; and set *freqHz*=2 Hz, *damping*=0.5 s^{-1} for **expSine**. The square block in the bottom is a ***Modelica.Block.Math.InverseBlockConstraints***. The model should be like the figure below.



2. Simulate for 10 seconds and plot the torque (*torque.tau*) and angle (*angleSensor.phi*).
3. What problem does the model above solve?

This concludes workshop 2.2. Well done!