Presenting DualSPHysics with a Chrono Project implementation. New developments, capabilities and practical examples

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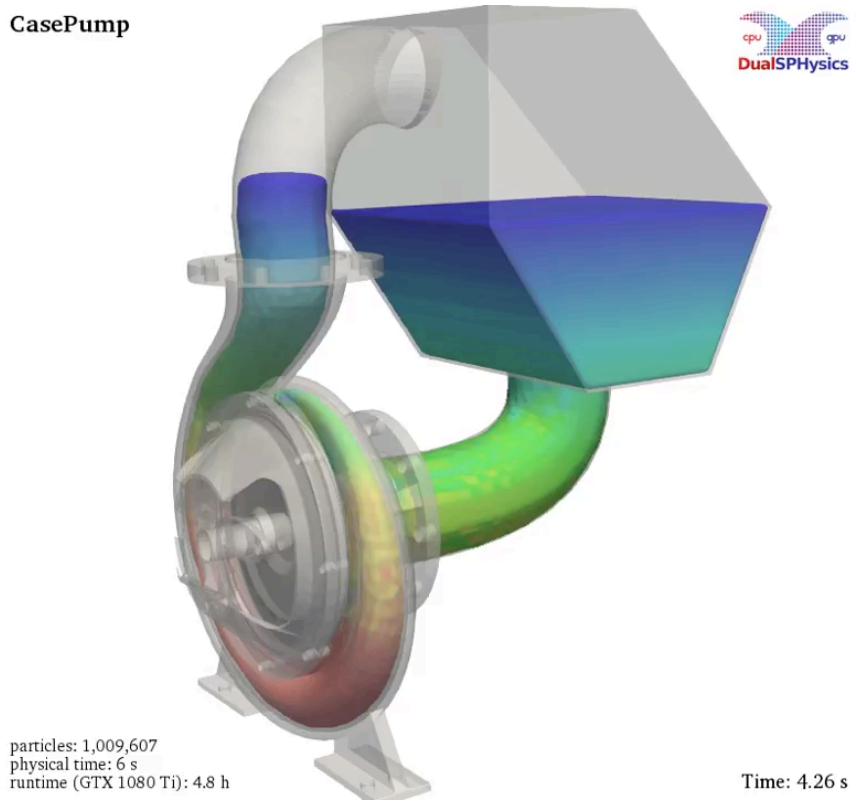
General motivation

Mechanical **contacts** and **constrains** are ubiquitous in natural and industrial processes, ranging from simple linear mechanisms to intricate highly non-linear problems.

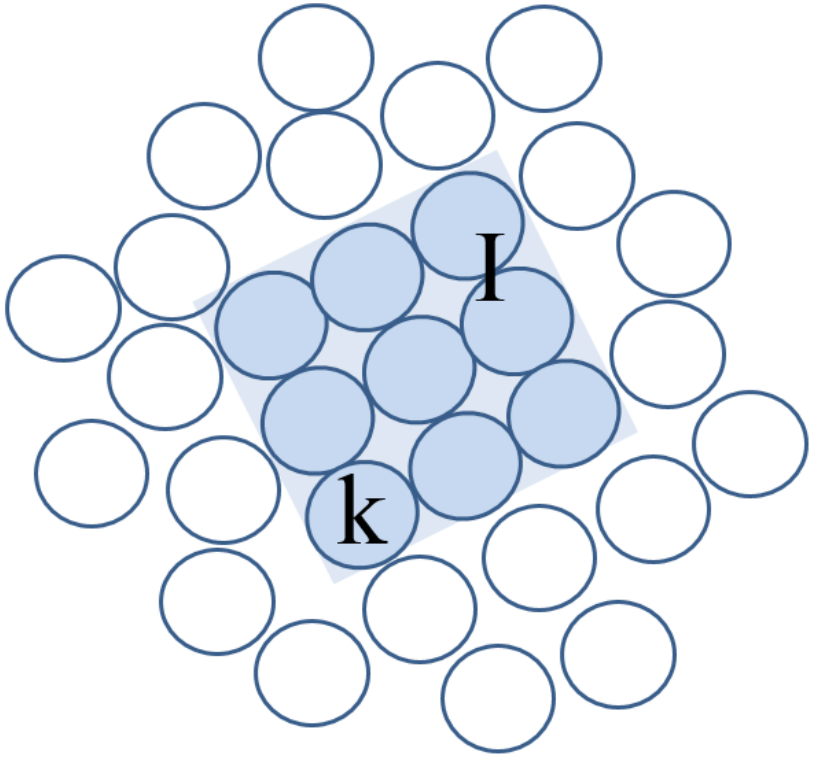
DualSPHysics offers a solid-solid distributed contact discrete element method (**DCDEM)** model, but:

- **Not** unconditionally stable contact description
- Difficult to model **intricate** mechanisms
- Complex **friction** models hurt performance unacceptably for HPC code



Rigid bodies in DualSPHysics

Conserving the **relative positions** of a group of particles, these can be made to describe a solid body.



$$M_I \frac{d\boldsymbol{V}_I}{dt} = \sum_{k \in I} m_k \frac{d\boldsymbol{v}_k}{dt}$$

$$I_I \frac{d\boldsymbol{\Omega}_I}{dt} = \sum_{k \in I} m_k (\boldsymbol{r}_k - \boldsymbol{R}_I) \times \frac{d\boldsymbol{v}_k}{dt}$$

$$\boldsymbol{v}_k = \boldsymbol{V}_I + \boldsymbol{\Omega}_I \times (\boldsymbol{r}_k - \boldsymbol{R}_I)$$

The **inertia tensor** is computed on the fly for the system of material points, making no assumptions on shape, *i.e.* it is **exact for the discretized system**.

Project Chrono

Project Chrono is a **physics-based** modeling and simulation **library** based on a **platform-independent**, **open-source** design - much like DualSPHysics

- Wide set of joints (spherical, revolute joint, prismatic, universal joint, glyph, with limits, etc.)
- Unilateral constraints
- Exact Coulomb friction model, for precise stick-slip of bodies
- Springs and dampers, even with non-linear features
- Recent support for linear and nonlinear Finite Element Analysis - Euler-Bernoulli beams, bars, shells, cables.

http://projectchrono.org

Implementation on DualSPHysics

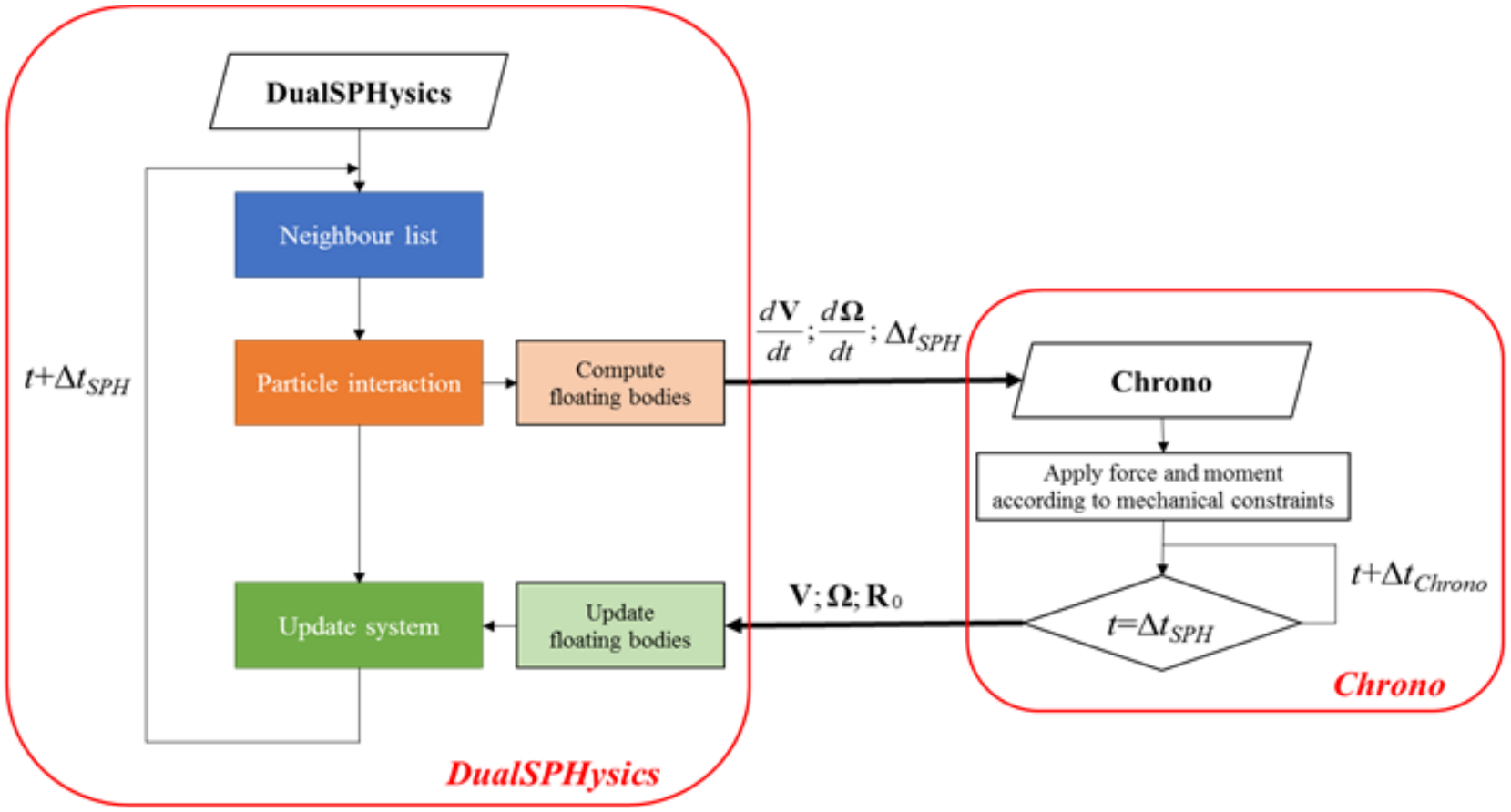
Difficulties along the (unfinished) way

- Project Chrono is a library, not an application
- Typical workflow is writing C++ code with your model, using the library API, compile and run
- Like DualSPHysics, the code is in active development

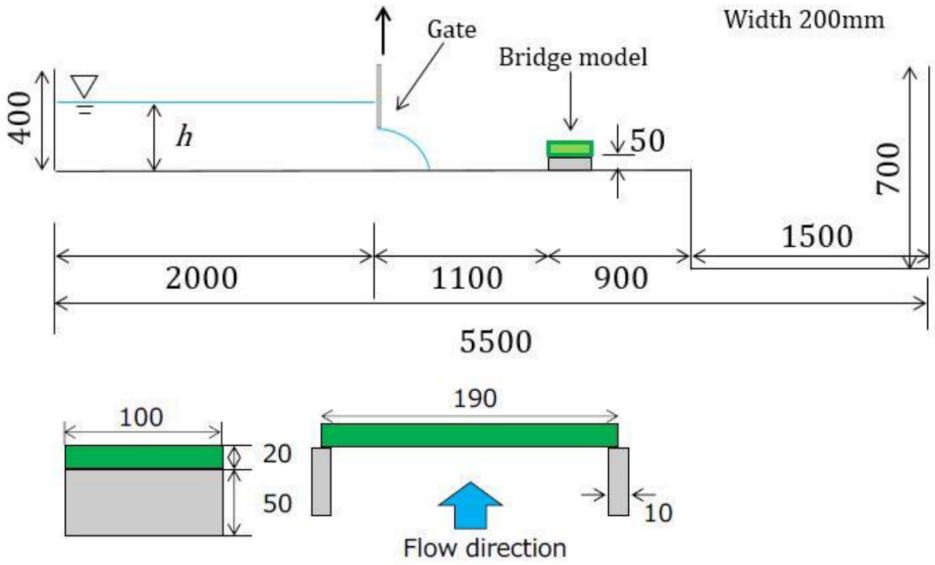
- Project Chrono is very large. Thousands of API calls are available
- Documentation is, unsurprisingly, limited (much better than most projects)
- Several key concepts are different such as coordinate systems, I/O, …

Limited functionality is available in v4.3 – no periodic conditions; no imposed motion

Implementation on DualSPHysics

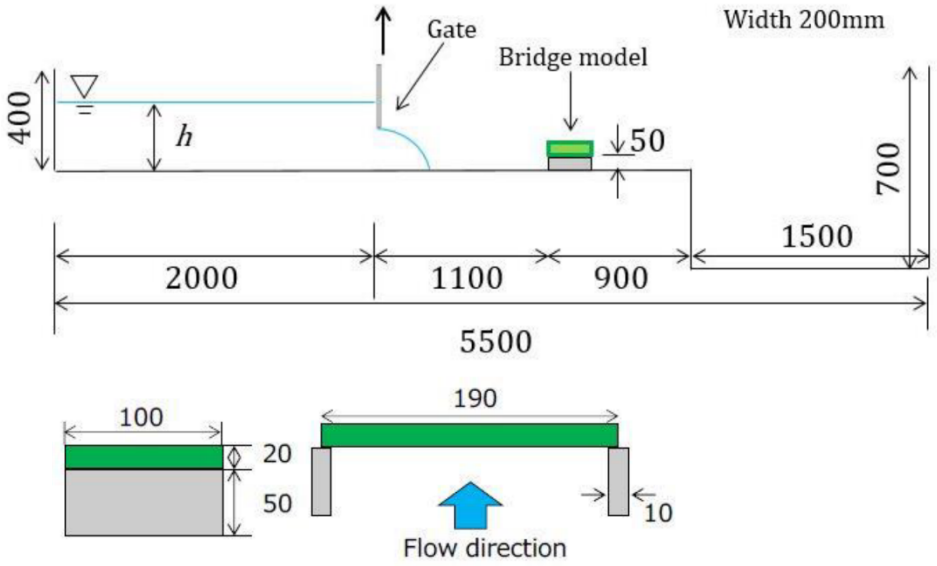


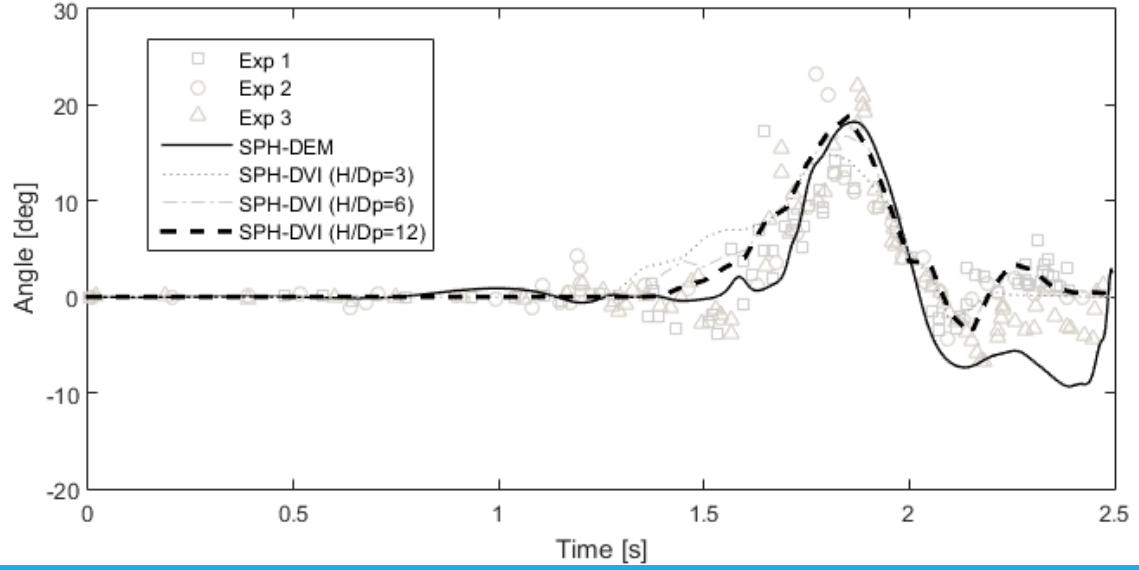
Validations - I

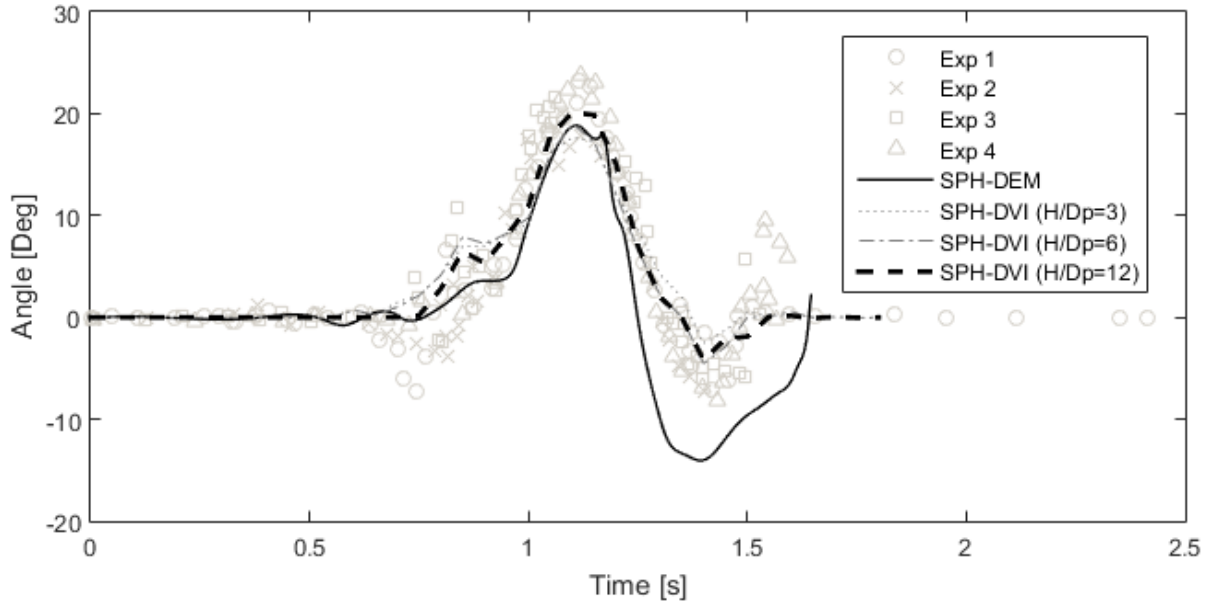


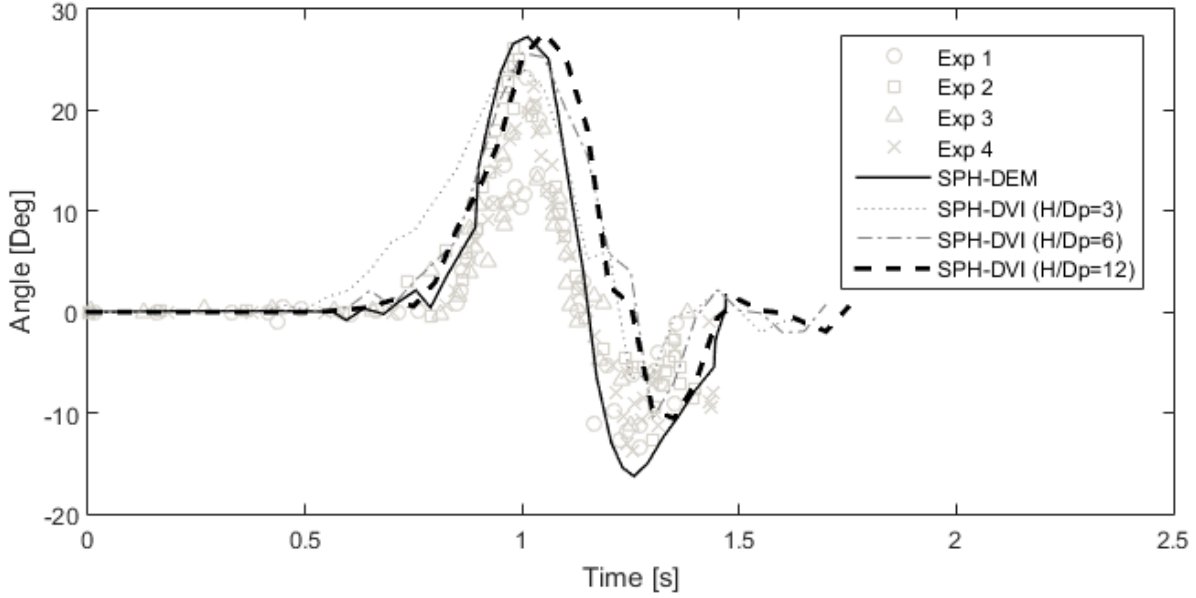
B. Chandra and M. Asai, *Verification and validation of the fluid-rigid body interaction simulation by the smoothed particle hydrodynamics method*, in Proceedings of Computational Engineering Conference JSCES, vol. 21, 2016.

Validations - I









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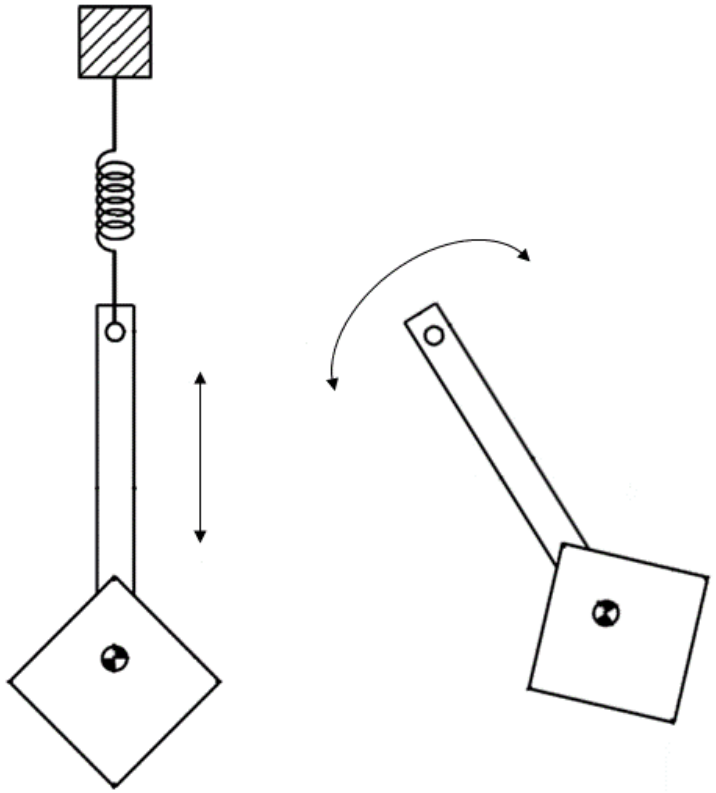
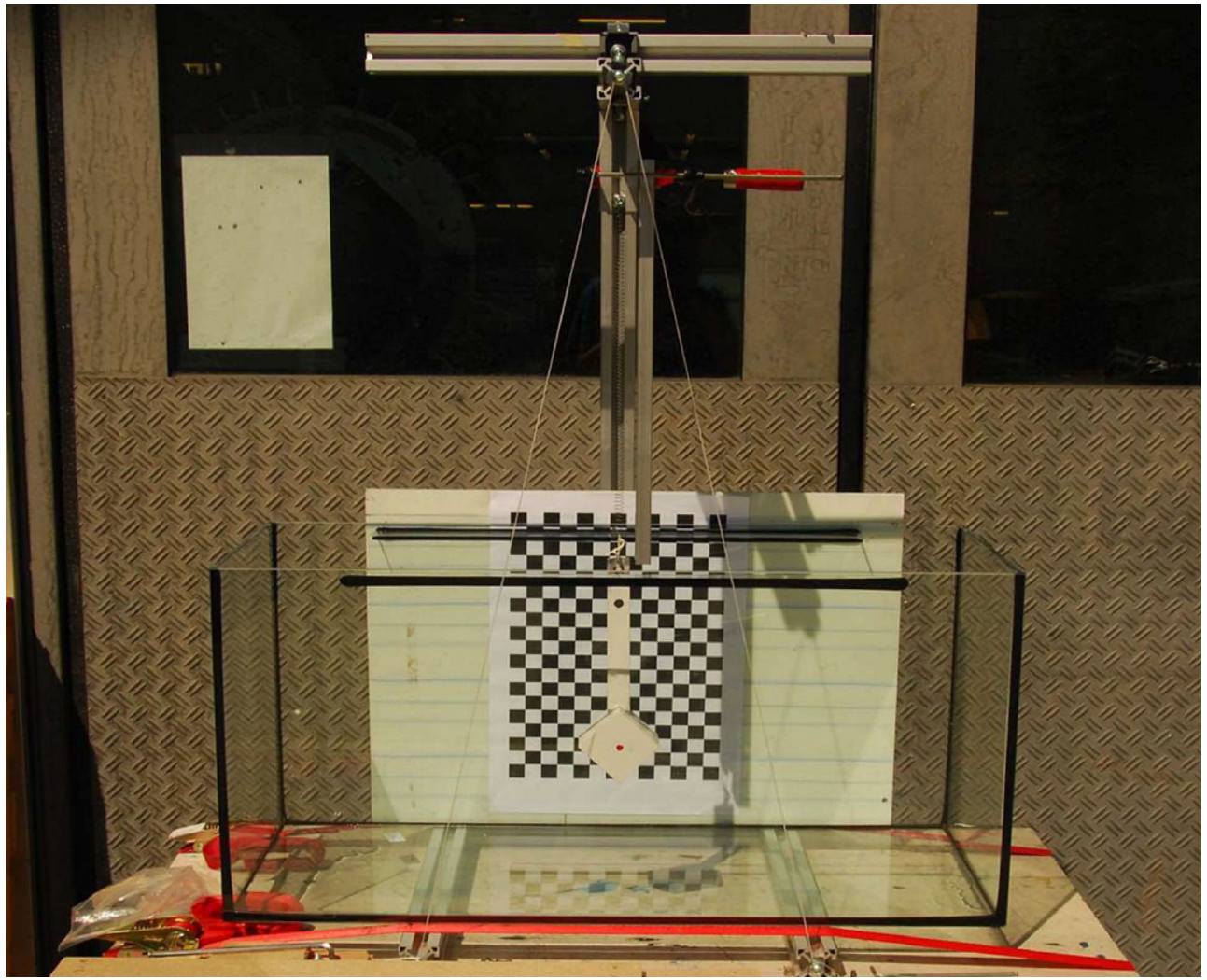
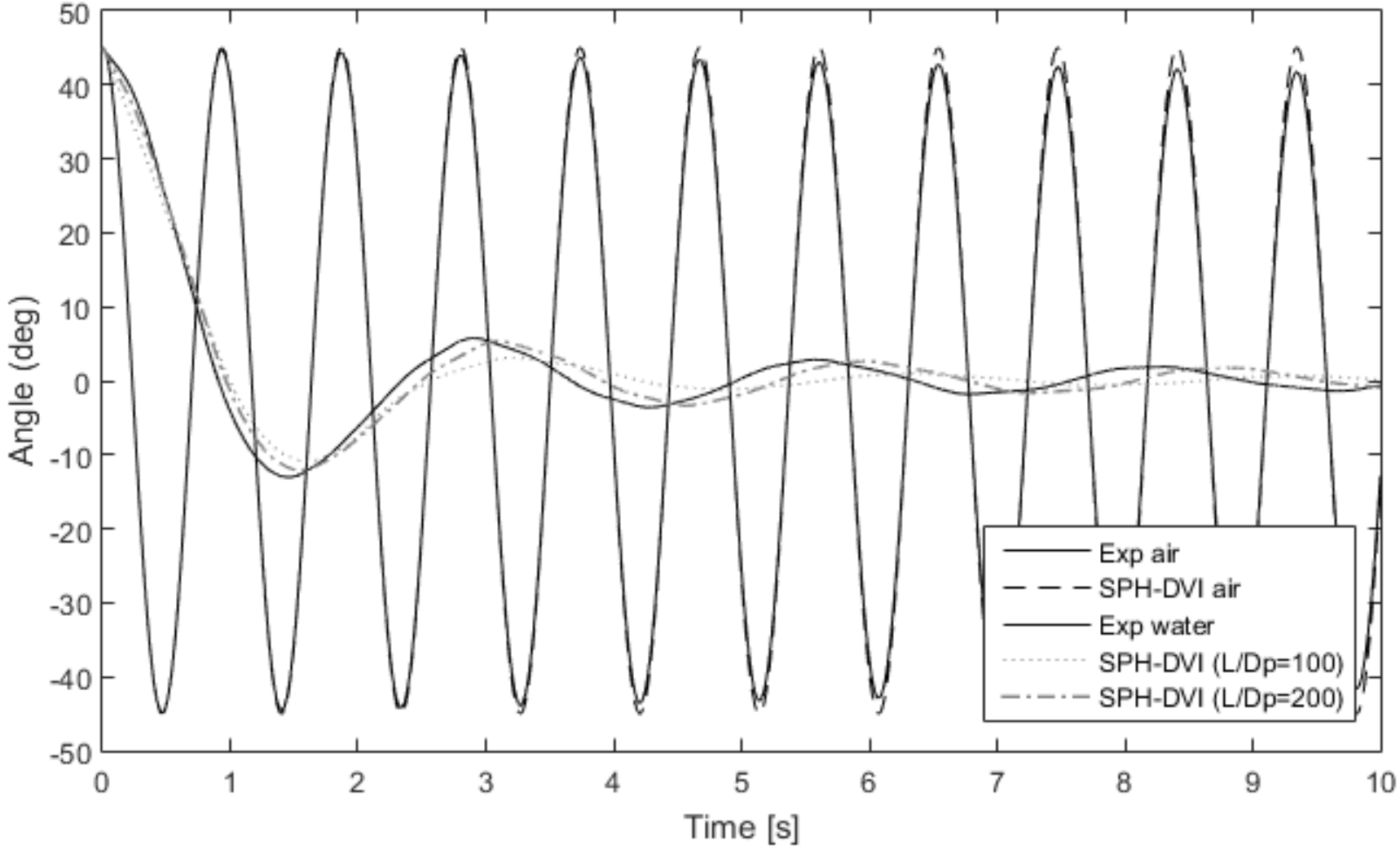




M. Arnold, M. Kretschmer, J. Koch, P.W. Cheng, F. Biskup et al., *A validation method for fluid-structure-interaction simulations based on submerged free decay experiments*, in The Twenty-fifth International Ocean and Polar Engineering Conference. International Society of Offshore and Polar Engineers, 2015.

Validations - II



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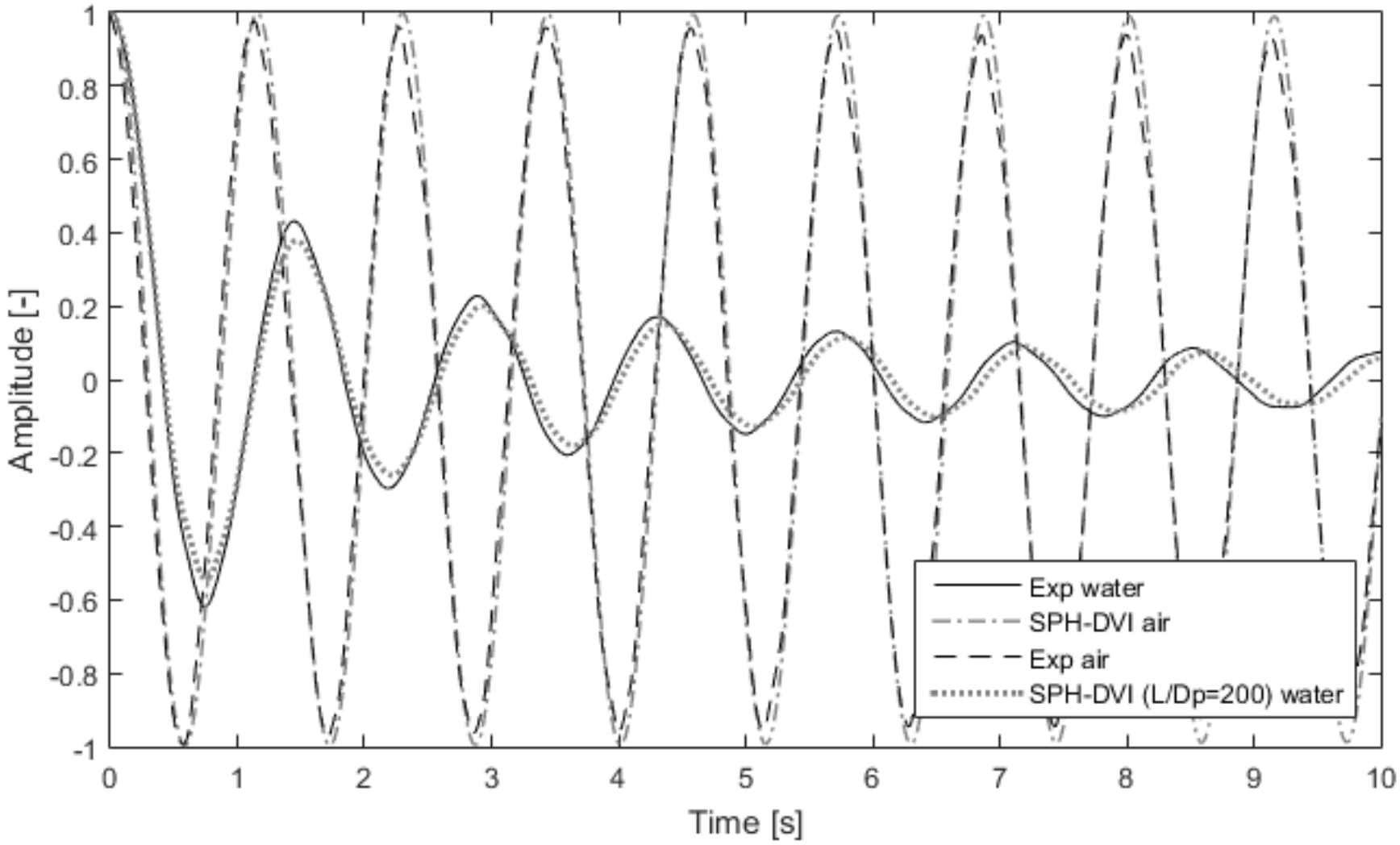

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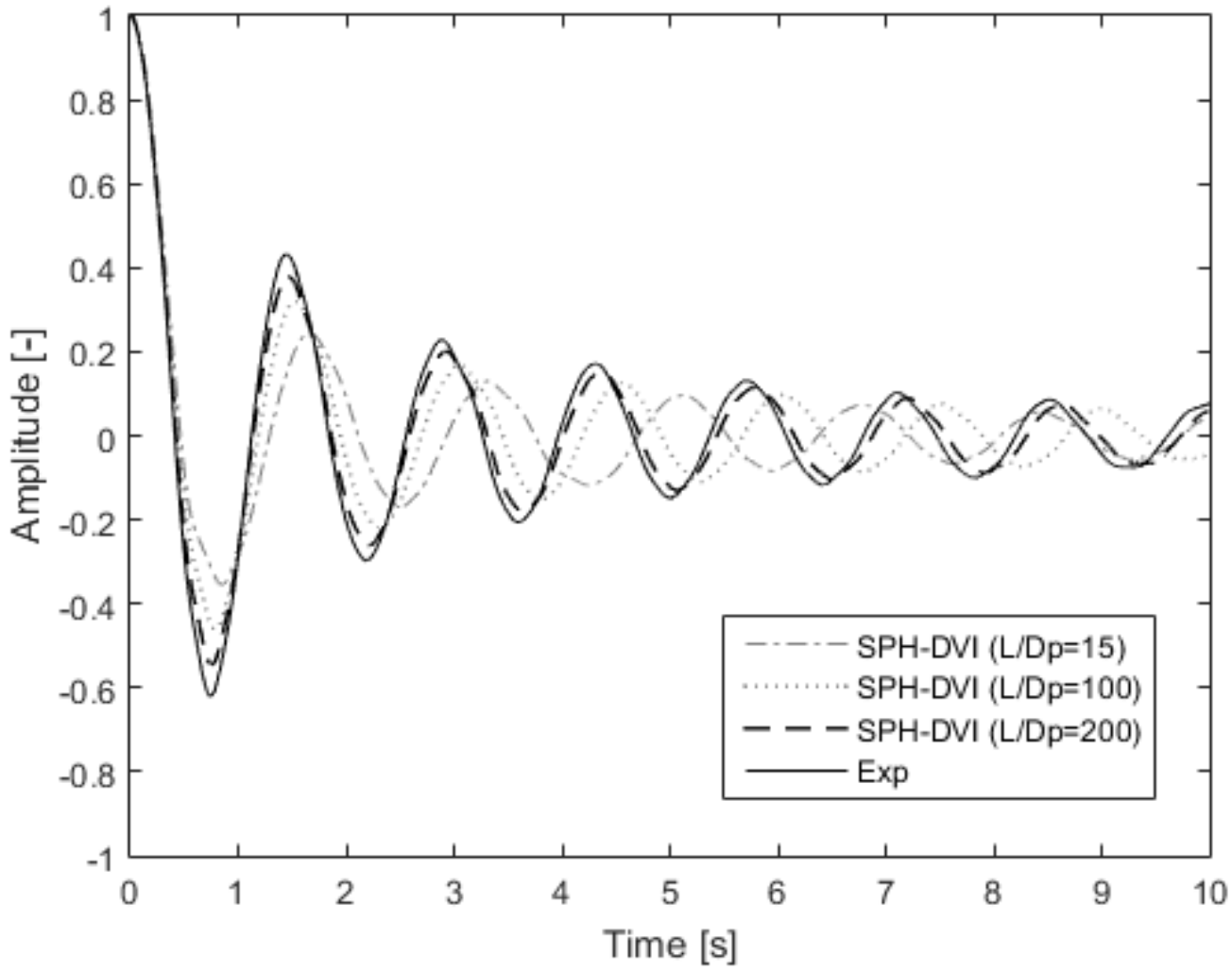
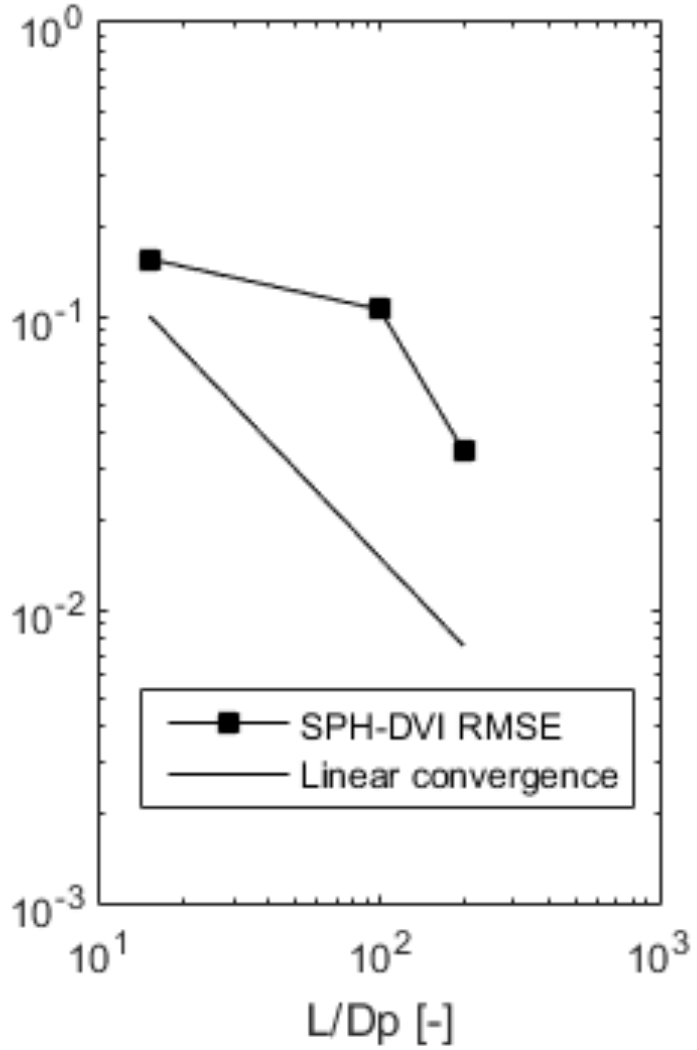
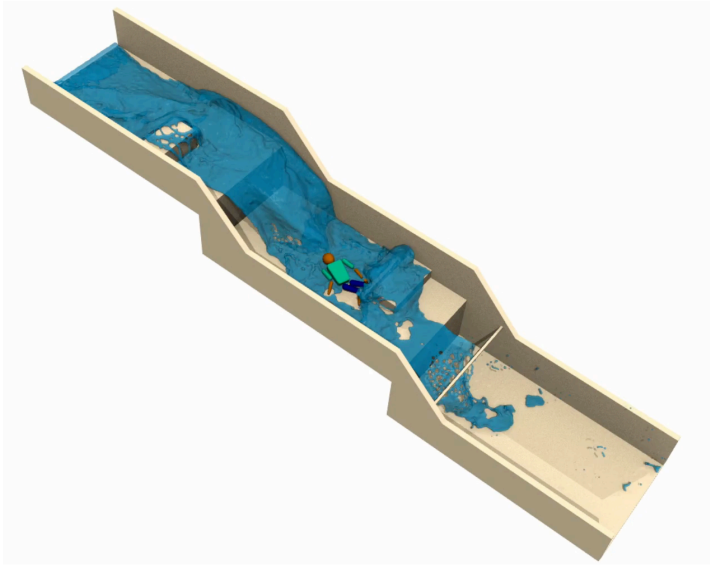
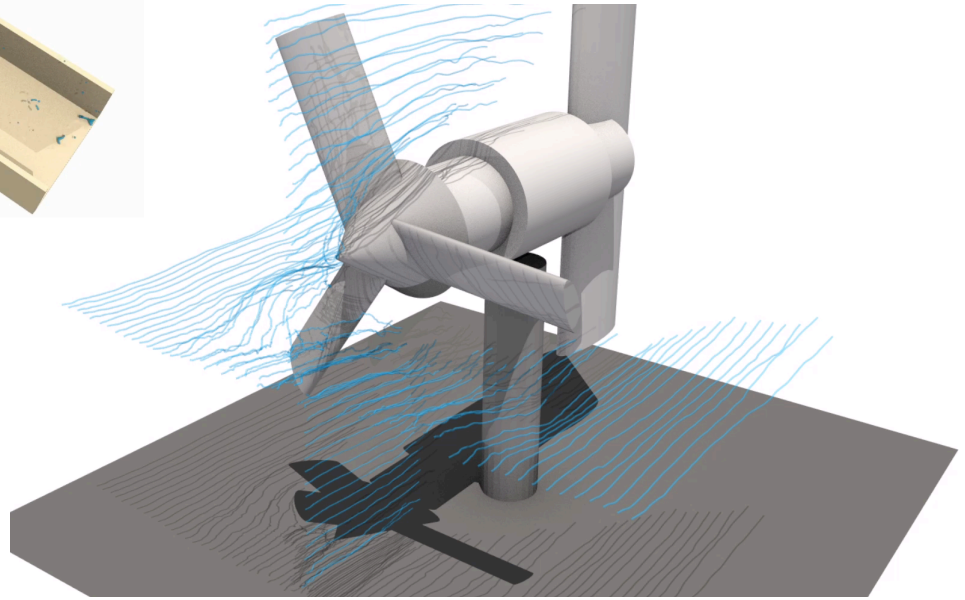


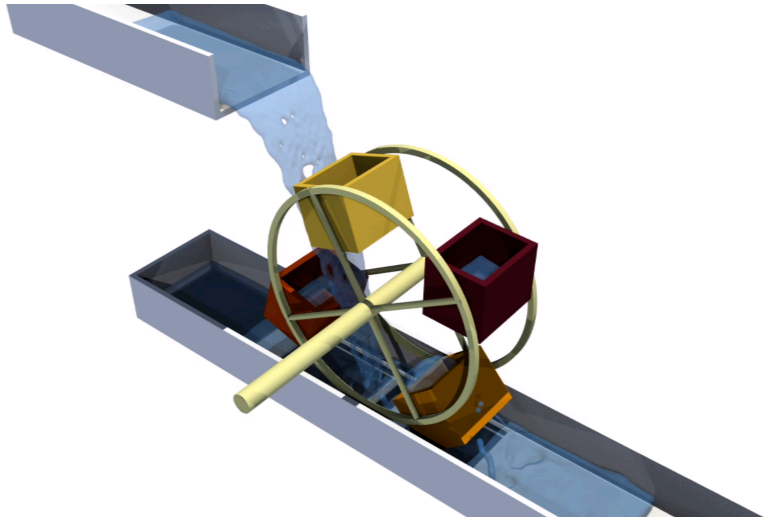


Applications?

If it moves with and by a fluid-solid system we want to model it







How to use it?

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                <bodyfixed id="Domain" mkbound="0" modelfile="AutoActual" />
                <bodyfloating id="Jumper" mkbound="1" modelfile="AutoActual" />
                <link_linearspring idbody1="Domain" idbody2="Jumper">
                    <point_fb1 x="0.95" y="0.5" z="10" comment="Point in body 1" />
                    <point_fb2 x="0.95" y="0.5" z="9.5" comment="Point in body 2" />
                    <stiffness value="1000" comment="stiffness" />
                    <damping value="100" comment="damping" />
                    <rest_length value="3" comment="spring equilibrium length" />
                </link_linearspring>
            </chrono>
        </special>
        <parameters>
            <parameter key="PosDouble" value="1" comment="Precision in particle interaction 0:Simple, 1:Double, 2:Uses and saves double (default=0)" />
            <parameter key="StepAlgorithm" value="2" comment="Step Algorithm 1:Verlet, 2:Symplectic (default=1)" />
            <parameter key="VerletSteps" value="40" comment="Verlet only: Number of steps to apply Euler timestepping (default=40)" />
            <parameter key="Kernel" value="2" comment="Interaction Kernel 1:Cubic Spline, 2:Wendland (default=2)" />
            <parameter key="ViscoTreatment" value="1" comment="Viscosity formulation 1:Artificial, 2:Laminar+SPS (default=1)" />
            <parameter key="Visco" value="0.01" comment="Viscosity value" />
            <parameter key="ViscoBoundFactor" value="0" comment="Multiply viscosity value with boundary (default=1)" />
            <parameter key="DeltaSPH" value="0.1" comment="DeltaSPH value, 0.1 is the typical value, with 0 disabled (default=0)" />
            <parameter key="#Shifting" value="0" comment="Shifting mode 0:None, 1:Ignore bound, 2:Ignore fixed, 3:Full (default=0)" />
            <parameter key="#ShiftCoef" value="-2" comment="Coefficient for shifting computation (default=-2)" />
            <parameter key="#ShiftTFS" value="1.5" comment="Threshold to detect free surface. Typically 1.5 for 2D and 2.75 for 3D (default=0)" />
            <parameter key="RigidAlgorithm" value="3" comment="Rigid Algorithm 1:SPH, 2:DEM, 3:Chrono (default=1)" />
            <parameter key="FtPause" value="0.0" comment="Time to freeze the floatings at simulation start (warmup) (default=0)" units_comment="seconds" />
            <parameter key="CoefDtMin" value="0.05" comment="Coefficient to calculate minimum time step dtmin=coefdtmin*h/speedsound (default=0.05)" />
            <parameter key="#DtIni" value="0.0001" comment="Initial time step (default=h/speedsound)" units_comment="seconds" />
            <parameter key="#DtMin" value="0.00001" comment="Minimum time step (default=coefdtmin*h/speedsound)" units_comment="seconds" />
            <parameter key="#DtFixed" value="DtFixed.dat" comment="Dt values are loaded from file (default=disabled)" />
            <parameter key="DtAllParticles" value="0" comment="Velocity of particles used to calculate DT. 1:All, 0:Only fluid/floating (default=0)" />
            <parameter key="TimeMax" value="10" comment="Time of simulation" units_comment="seconds" />
            <parameter key="TimeOut" value="0.01" comment="Time out data" units_comment="seconds" />
            <parameter key="IncZ" value="0.5" comment="Increase of Z+" units_comment="decimal" />
            <parameter key="PartsOutMax" value="1" comment="%/100 of fluid particles allowed to be excluded from domain (default=1)" units_comment="decimal" />
            <parameter key="RhopOutMin" value="700" comment="Minimum rhop valid (default=700)" units_comment="kg/m^3" />
            <parameter key="RhopOutMax" value="1300" comment="Maximum rhop valid (default=1300)" units_comment="kg/m^3" />
            <parameter key="DomainFixed" value="-3:-1:0:5:2:10" comment="The domain is fixed with the specified values (xmin:ymin:zmin:xmax:ymax:zmax)" units_comment="metres (m)" />
        </parameters>
    </execution>
</case>
```

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<case app="GenCase4 v4.0.033 (14-11-2016)" date="11-07-2018 18:38:46">
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                    <point_fb2 x="0.95" y="0.5" z="9.5" comment="Point in body 2" />
                    <stiffness value="1000" comment="stiffness" />
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            </chrono>
        </special>
        <parameters>
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            <parameter key="StepAlgorithm" value="2" comment="Step Algorithm 1:Verlet,
            <parameter key="VerletSteps" value="40" comment="Verlet only: Number of st
            <parameter key="Kernel" value="2" comment="Interaction Kernel 1:Cubic Spli
            <parameter key="ViscoTreatment" value="1" comment="Viscosity formulation 1
            <parameter key="Visco" value="0.01" comment="Viscosity value" />
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            <parameter key="DeltaSPH" value="0.1" comment="DeltaSPH value, 0.1 is the
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            <parameter key="#ShiftCoef" value="-2" comment="Coefficient for shifting c
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            <parameter key="RigidAlgorithm" value="3" comment="Rigid Algorithm 1:SPH,
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            <parameter key="#DtMin" value="0.00001" comment="Minimum time step (defaul
            <parameter key="#DtFixed" value="DtFixed.dat" comment="Dt values are loade
            <parameter key="DtAllParticles" value="0" comment="Velocity of particles u
            <parameter key="TimeMax" value="10" comment="Time of simulation" units_com
            <parameter key="TimeOut" value="0.01" comment="Time out data" units_commen
            <parameter key="IncZ" value="0.5" comment="Increase of Z+" units_comment="
            <parameter key="PartsOutMax" value="1" comment="%/100 of fluid particles a
            <parameter key="RhopOutMin" value="700" comment="Minimum rhop valid (defau
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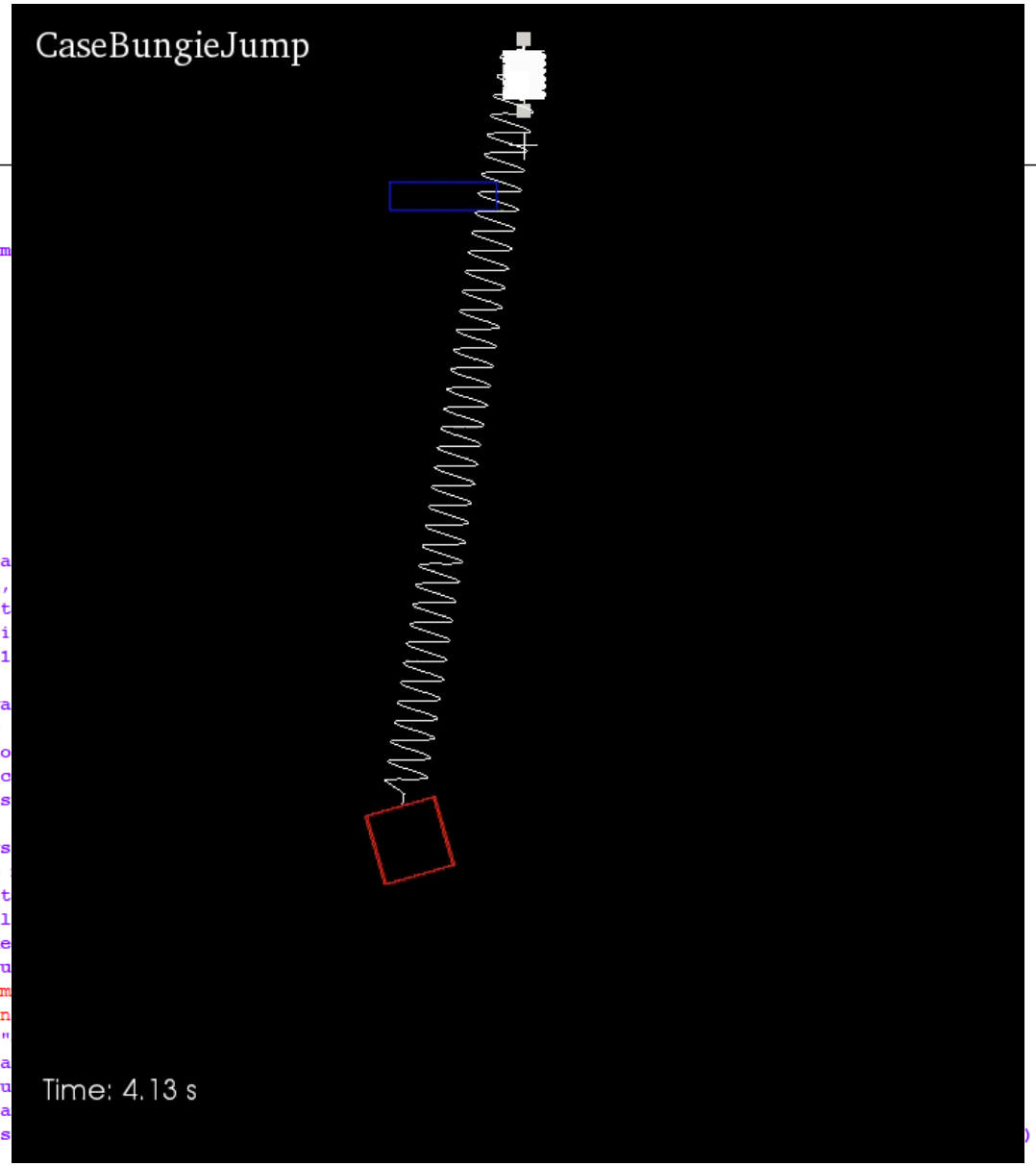

Going through the examples – Case 1

```
        <mainlist>
            <setshapemode>real | bound</setshapemode>
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                <boxfill>bottom | left | right | front | back</boxfill>
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            </drawcylinder>
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            <drawcylinder radius="0.05" mask="1">
                <point x="5" y="6" z="5" />
                <point x="5" y="7" z="5" />
            </drawcylinder>
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            <drawcylinder radius="0.05" mask="1">
                <point x="5" y="7" z="5" />
                <point x="5" y="8" z="5" />
            </drawcylinder>
            <setmkbound mk="3" />
            <drawcylinder radius="0.05" mask="1">
                <point x="5" y="8" z="5" />
                <point x="5" y="9" z="5" />
            </drawcylinder>
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    </commands>
</geometry>
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</floatings>
<properties>
    <propertyfile file="Floating_Materials.xml" path="materials" />
</properties>
```

Going through the examples – Case 1

```
        <mainlist>
            <setshapemode>real | bound</setshapemode>
            <setmkbound mk="5" />
            <drawbox>
                <boxfill>bottom | left | right | front | back</boxfil
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                <point x="5" y="6" z="5" />
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            <setmkbound mk="3" />
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                <point x="5" y="8" z="5" />
                <point x="5" y="9" z="5" />
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            <shapeout file="" reset="true" />
        </mainlist>
    </commands>
</geometry>
<floatings>
    <floating mkbound="0-3" relativeweight="1.0" property="steel" />
</floatings>
<properties>
    <propertyfile file="Floating_Materials.xml" path="materials" />
</properties>
```

```
    <floatings>
        <floating mkbound="0-3" relativeweight="1.0" property="steel" />
    </floatings>
    <properties>
        <propertyfile file="Floating_Materials.xml" path="materials" />
    </properties>
</casedef>
<execution>
    <special>
        <chrono>
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            <bodyfloating id="arm" mkbound="0-3" />
            <link_spheric idbody1="arm0">
                <rotpoint x="5" y="5" z="5" comment="Point for rotation" />
                <stiffness value="0" comment="Torsional stiffness [N/rad]" />
                <damping value="0" comment="Torsional damping [-]" />
            </link_spheric>
            <link_spheric idbody1="arm0" idbody2="arm1">
                <rotpoint x="5" y="6" z="5" comment="Point for rotation" />
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                <damping value="0" comment="Torsional damping [-]" />
            </link_spheric>
            <link_spheric idbody1="arm1" idbody2="arm2">
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                <stiffness value="0" comment="Torsional stiffness [N/rad]" />
                <damping value="0" comment="Torsional damping [-]" />
            </link_spheric>
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                <rotpoint x="5" y="8" z="5" comment="Point for rotation" />
                <stiffness value="0" comment="Torsional stiffness [N/rad]" />
                <damping value="0" comment="Torsional damping [-]" />
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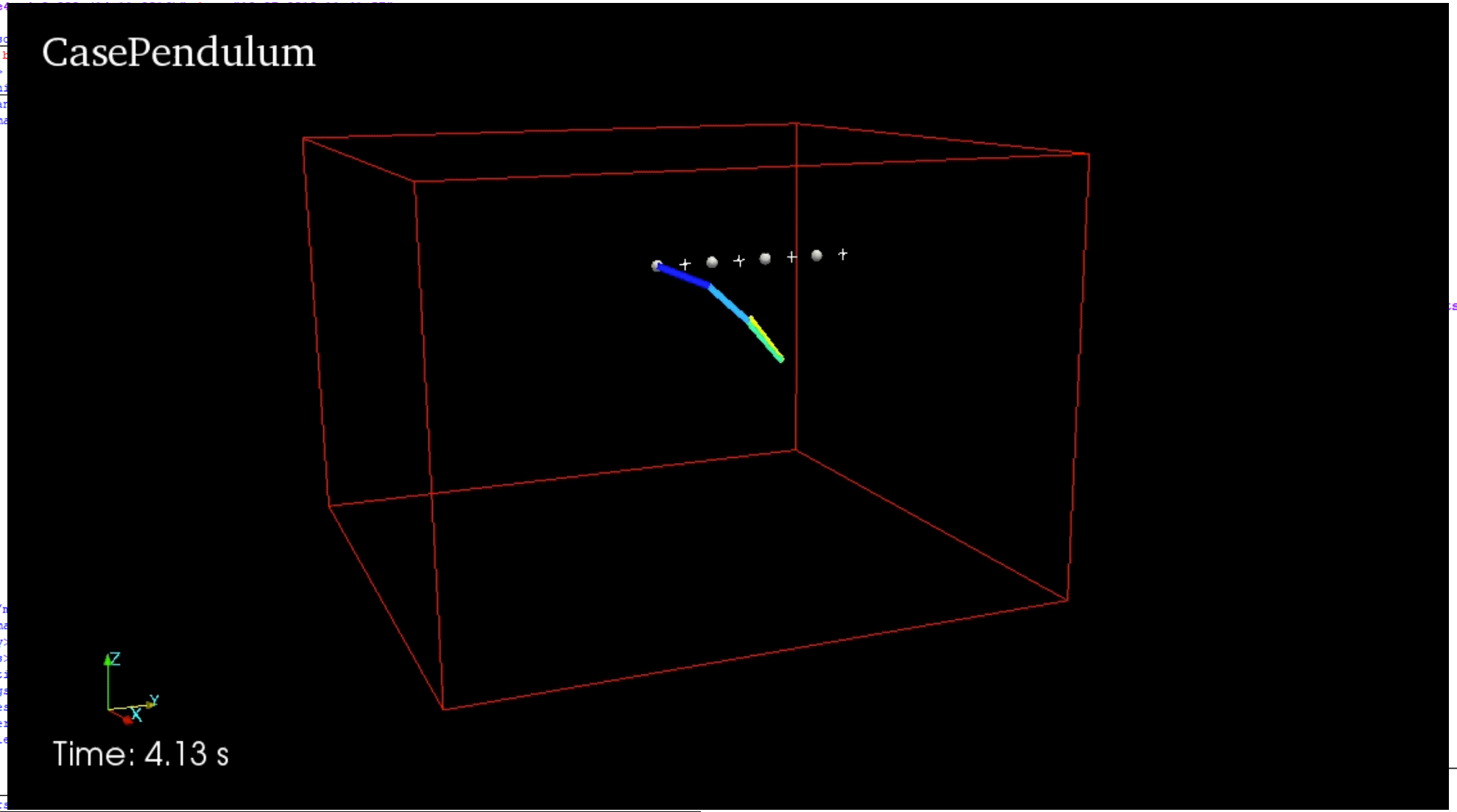
    </special>
    <parameters>
</execution>
</case>
```

Going through the examples – Case 1



Going through the examples – Case 1.1

```
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        <floating mkbound="4" relativeweight="2.5" property="steel" />
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        </links>
    </properties>
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<execution>
    <special>
        <chrono>
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            <bodyfixed id="domain" mkbound="10" modelfile="AutoActual" modelnormal="invert"
            <bodyfloating id="arm" mkbound="0-3" />
            <bodyfloating id="ball" mkbound="4" modelfile="AutoActual" />
            <bodyfloating id="box" mkbound="51-66" modelfile="AutoActual" />
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                <rotpoint x="5" y="5" z="5.2" comment="Point for rotation" />
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                <damping value="0" comment="Torsional damping [-]" />
            </link_spheric>
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                <damping value="0" comment="Torsional damping [-]" />
            </link_spheric>
            <link_spheric idbody1="arm1" idbody2="arm2">
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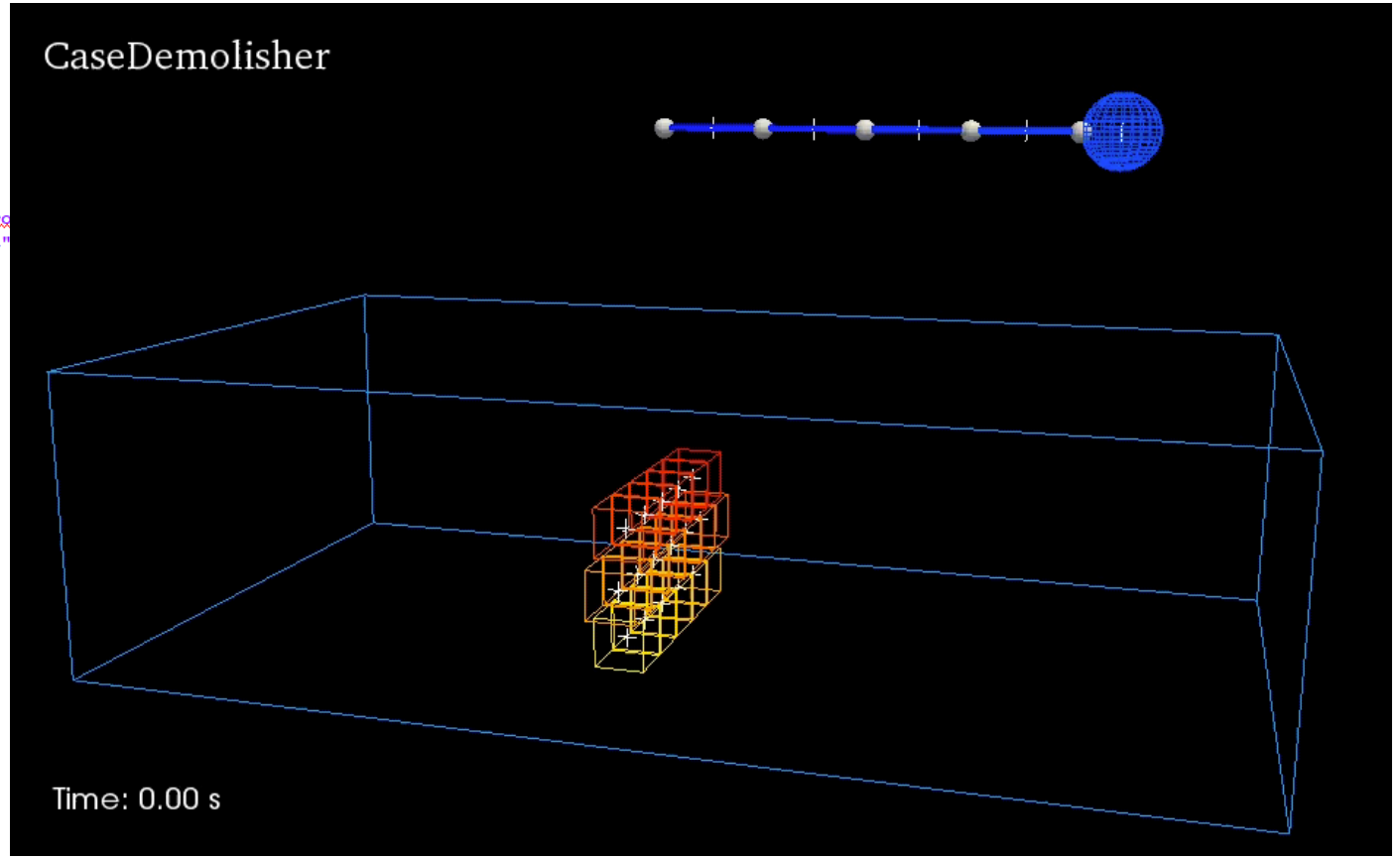
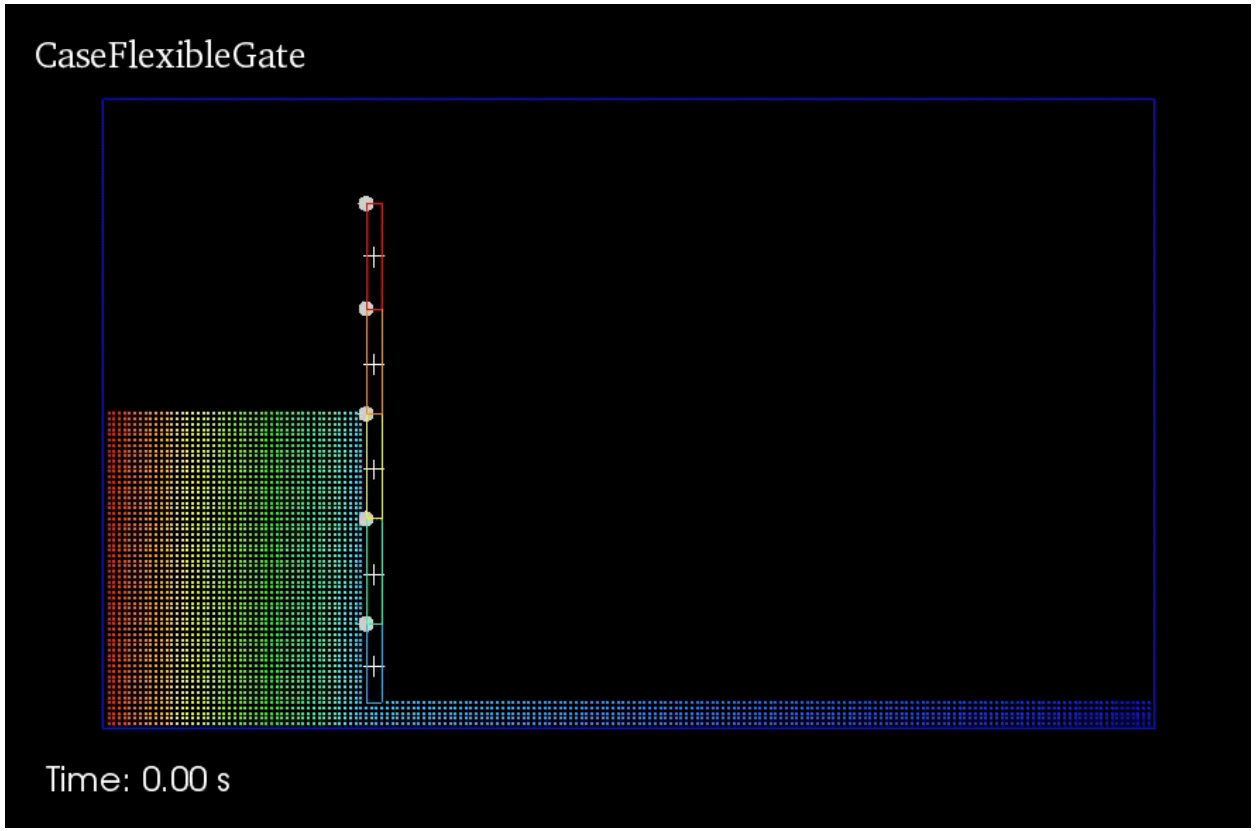
                <stiffness value="0" comment="Torsional stiffness [N/rad]" />
                <damping value="0" comment="Torsional damping [-]" />
            </link_spheric>
            <link_spheric idbody1="arm2" idbody2="arm3">
                <rotpoint x="8" y="5" z="5.2" comment="Point for rotation" />
                <stiffness value="0" comment="Torsional stiffness [N/rad]" />
                <damping value="0" comment="Torsional damping [-]" />
            </link_spheric>
            <link_spheric idbody1="arm3" idbody2="ball">
                <rotpoint x="9" y="5" z="5.2" comment="Point for rotation" />
                <stiffness value="0" comment="Torsional stiffness [N/rad]" />
                <damping value="0" comment="Torsional damping [-]" />
            </link_spheric>
        </chrono>
    </special>
```



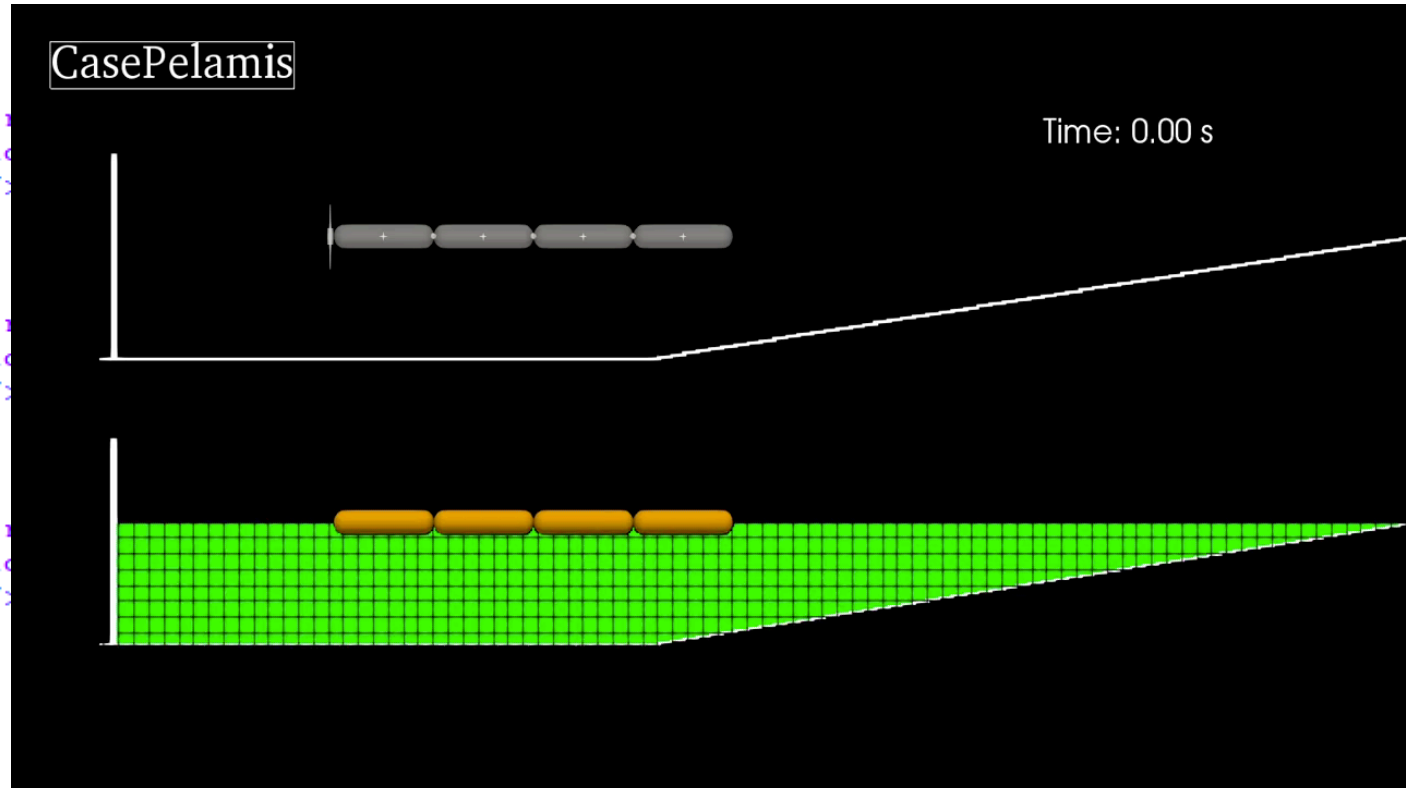
Going through the examples – Case 3

```
<special>
    <chrono>
        <schemescale value="1" comment="Scale used to create the initial scheme of Chrono objects (default=1)" />
        <bodyfixed id="domain" mkbound="0" />
        <bodyfloating id="hinged" mkbound="1-5" />
        <link_hinge idbody1="hinged1" idbody2="hinged2">
            <rotpoint x="0.5" y="0" z="0.2" comment="Point for rotation" />
            <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" />
            <stiffness value="750" comment="Torsional stiffness" />
            <damping value="50" comment="Torsional damping" />
        </link_hinge>
        <link_hinge idbody1="hinged2" idbody2="hinged3">
            <rotpoint x="0.5" y="0" z="0.4" comment="Point for rotation" />
            <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" />
            <stiffness value="750" comment="Torsional stiffness" />
            <damping value="50" comment="Torsional damping" />
        </link_hinge>
        <link_hinge idbody1="hinged3" idbody2="hinged4">
            <rotpoint x="0.5" y="0" z="0.6" comment="Point for rotation" />
            <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" />
            <stiffness value="750" comment="Torsional stiffness" />
            <damping value="50" comment="Torsional damping" />
        </link_hinge>
        <link_hinge idbody1="hinged4" idbody2="hinged5">
            <rotpoint x="0.5" y="0" z="0.8" comment="Point for rotation" />
            <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" />
            <stiffness value="750" comment="Torsional stiffness" />
            <damping value="50" comment="Torsional damping" />
        </link_hinge>
        <link_hinge idbody1="hinged5">
            <rotpoint x="0.5" y="0" z="1.0" comment="Point for rotation" />
            <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" />
            <stiffness value="750" comment="Torsional stiffness" />
            <damping value="50" comment="Torsional damping" />
        </link_hinge>
    </chrono>
</special>
```

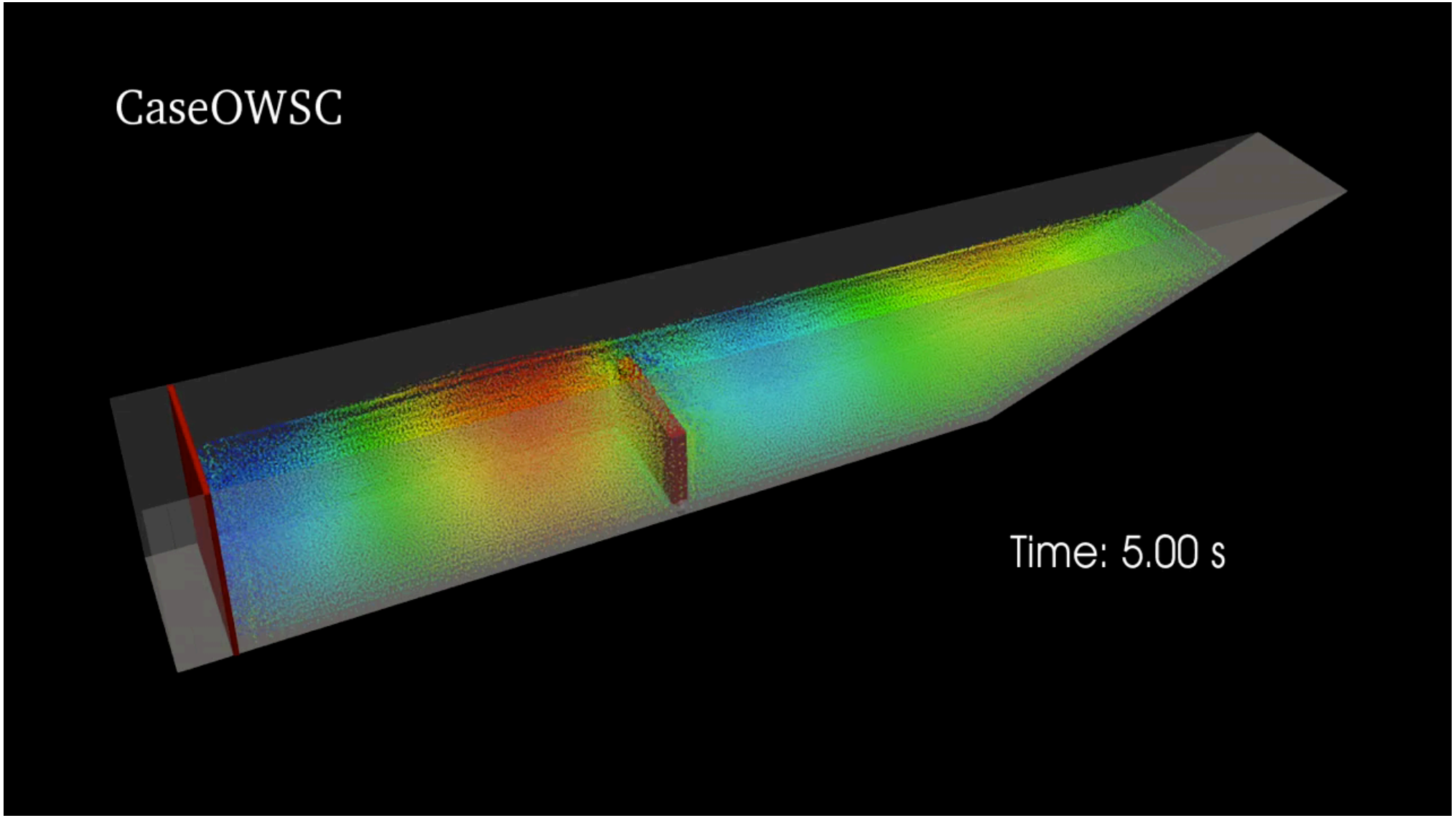


Going through the examples – Case 4

```
<special>
    <chrono>
        <schemescale value="1" comment="Scale used to create the initial scheme of Chrono objects (default=1)" />
        <bodyfloating id="arm" mkbound="0-3" />
        <link_pointline idbody1="arm0">
            <rotpoint x="5.8" y="0" z="1.5" comment="Point for rotation" />
            <rotvector x="0" y="0" z="1" comment="Vector direction for rotation" />
            <stiffness value="0" comment="Torsional stiffness" />
            <damping value="0" comment="Torsional damping" />
        </link_pointline>
        <link_hinge idbody1="arm0" idbody2="arm1">
            <rotpoint x="7.15" y="0" z="1.5" comment="Point for
            <rotvector x="0" y="1" z="0" comment="Vector directi
            <stiffness value="0" comment="Torsional stiffness" />
            <damping value="0" comment="Torsional damping" />
        </link_hinge>
        <link_hinge idbody1="arm1" idbody2="arm2">
            <rotpoint x="8.45" y="0" z="1.5" comment="Point for
            <rotvector x="0" y="1" z="0" comment="Vector directi
            <stiffness value="0" comment="Torsional stiffness" />
            <damping value="0" comment="Torsional damping" />
        </link_hinge>
        <link_hinge idbody1="arm2" idbody2="arm3">
            <rotpoint x="9.75" y="0" z="1.5" comment="Point for
            <rotvector x="0" y="1" z="0" comment="Vector directi
            <stiffness value="0" comment="Torsional stiffness" />
            <damping value="0" comment="Torsional damping" />
        </link_hinge>
    </chrono>
</special>
```



Going through the examples – Case 5

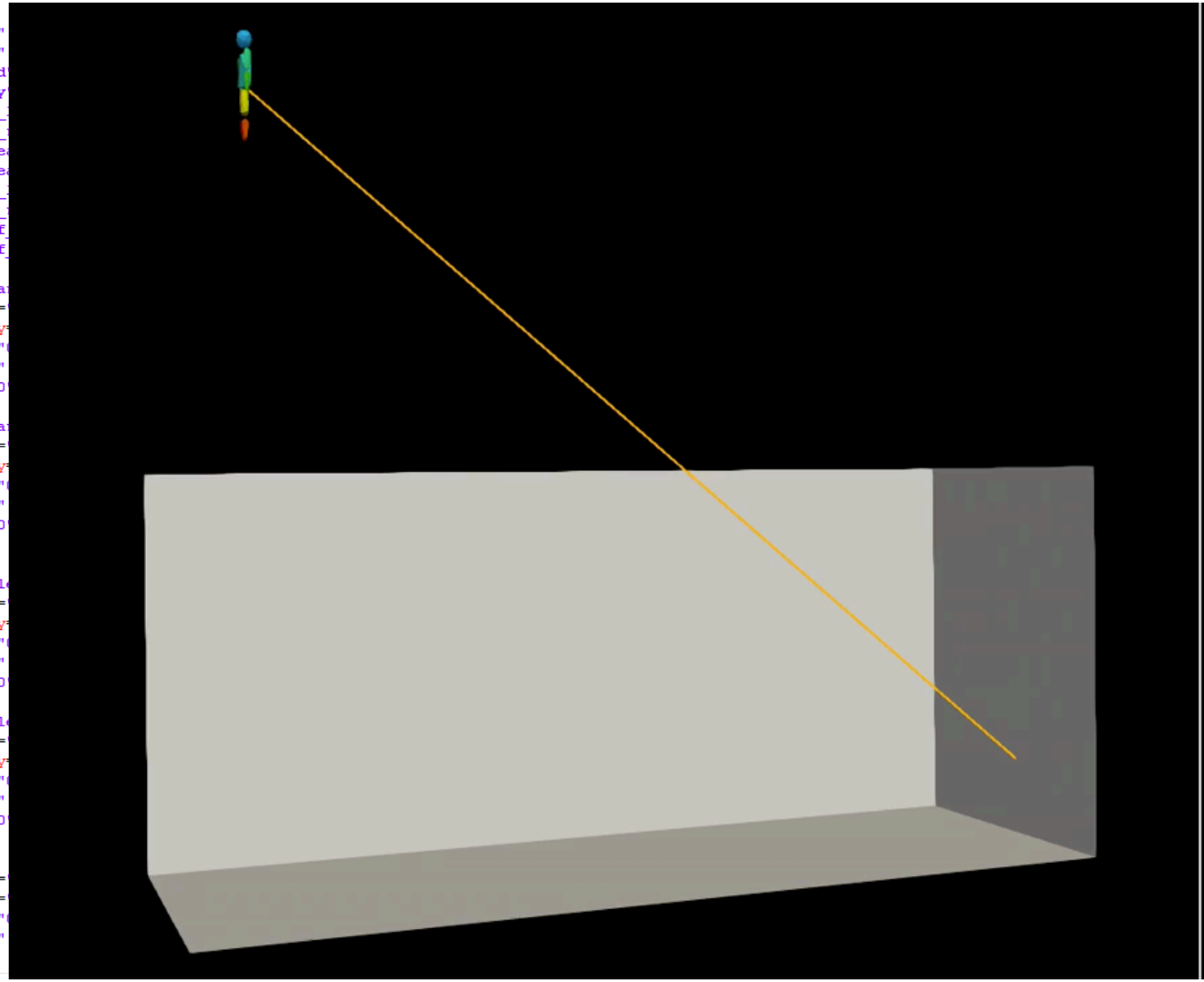


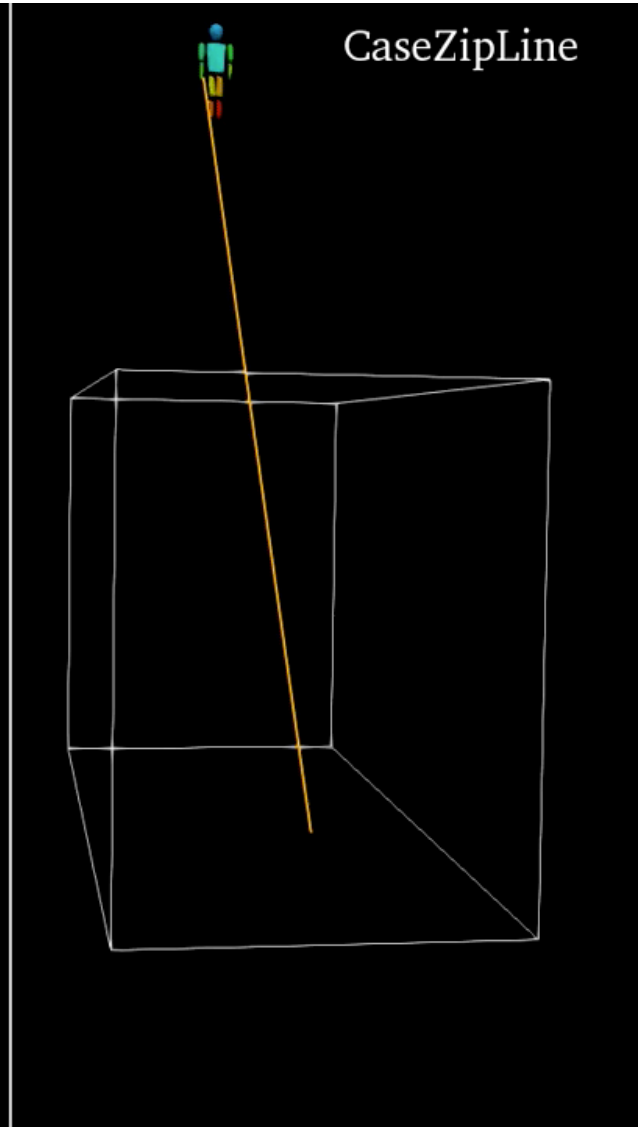
Going through the examples – Case 6

```
<chrono>
    <savedata value="0.02" comment="Saves CSV with data exchange for each time interval (0=all steps)" />
    <bodyfixed id="domain" mkbound="1" modelfile="AutoActual" modelnormal="invert" />
    <bodyfloating id="head" mkbound="2" modelfile="AutoActual" />
    <bodyfloating id="body" mkbound="3" modelfile="AutoActual" />
    <bodyfloating id="arm_left" mkbound="4" modelfile="AutoActual" />
    <bodyfloating id="arm_right" mkbound="5" modelfile="AutoActual" />
    <bodyfloating id="forearm_left" mkbound="6" modelfile="AutoActual" />
    <bodyfloating id="forearm_right" mkbound="7" modelfile="AutoActual" />
    <bodyfloating id="leg_left" mkbound="8" modelfile="AutoActual" />
    <bodyfloating id="leg_right" mkbound="9" modelfile="AutoActual" />
    <bodyfloating id="calf_left" mkbound="10" modelfile="AutoActual" />
    <bodyfloating id="calf_right" mkbound="11" modelfile="AutoActual" />
    <!-- Elbows -->
    <link_hinge idbody1="arm_left" idbody2="forearm_left">
        <rotpoint x="0" y="-.18" z="-.381" comment="Point for rotation" />
        <rotvector x="1" y="0" z="0" comment="Vector direction for rotation" />
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="0" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
    <link_hinge idbody1="arm_right" idbody2="forearm_right">
        <rotpoint x="0" y=".18" z="-.381" comment="Point for rotation" />
        <rotvector x="1" y="0" z="0" comment="Vector direction for rotation" />
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="0" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
    <!-- Knees -->
    <link_hinge idbody1="leg_left" idbody2="calf_left">
        <rotpoint x="0" y="-.055" z="-.837" comment="Point for rotation" />
        <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" />
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="0" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
    <link_hinge idbody1="leg_right" idbody2="calf_right">
        <rotpoint x="0" y=".055" z="-.837" comment="Point for rotation" />
        <rotvector x="0" y="1" z="0" comment="Vector direction for rotation" />
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="0" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
    <!-- Neck -->
    <link_spheric idbody1="head" idbody2="body">
        <rotpoint x="0" y="0" z="-.125" comment="Point for rotation" />
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="0" comment="Torsional damping" />
    </link_spheric>
```

Going through the examples – Case 6

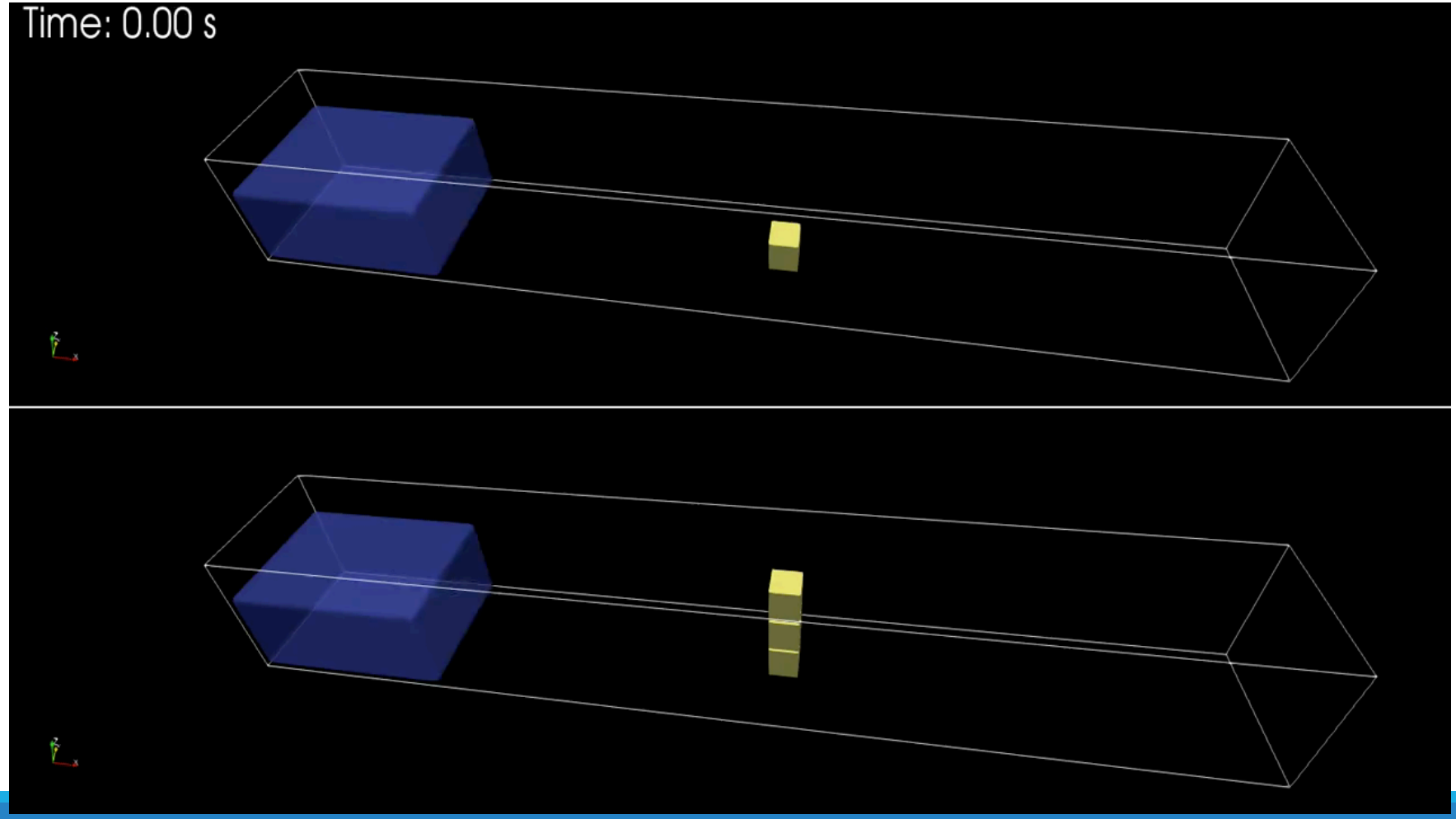
```
<chrono>
    <savedata value="0.02"
    <bodyfixed id="domain"
    <bodyfloating id="head
    <bodyfloating id="body
    <bodyfloating id="arm_
    <bodyfloating id="arm_
    <bodyfloating id="fore
    <bodyfloating id="fore
    <bodyfloating id="leg_
    <bodyfloating id="leg_
    <bodyfloating id="calf_
    <bodyfloating id="calf_
    <!-- Elbows -->
    <link_hinge idbody1="a
        <rotpoint x="0" y=
        <rotvector x="1" y
        <stiffness value="
        <damping value="0"
        <friction value="0
    </link_hinge>
    <link_hinge idbody1="a
        <rotpoint x="0" y=
        <rotvector x="1" y
        <stiffness value="
        <damping value="0"
        <friction value="0
    </link_hinge>
    <!-- Knees -->
    <link_hinge idbody1="l
        <rotpoint x="0" y=
        <rotvector x="0" y
        <stiffness value="
        <damping value="0"
        <friction value="0
    </link_hinge>
    <link_hinge idbody1="l
        <rotpoint x="0" y=
        <rotvector x="0" y
        <stiffness value="
        <damping value="0"
        <friction value="0
    </link_hinge>
    <!-- Neck -->
    <link_spheric idbody1=
        <rotpoint x="0" y=
        <stiffness value="
        <damping value="0"
    </link_spheric>
```





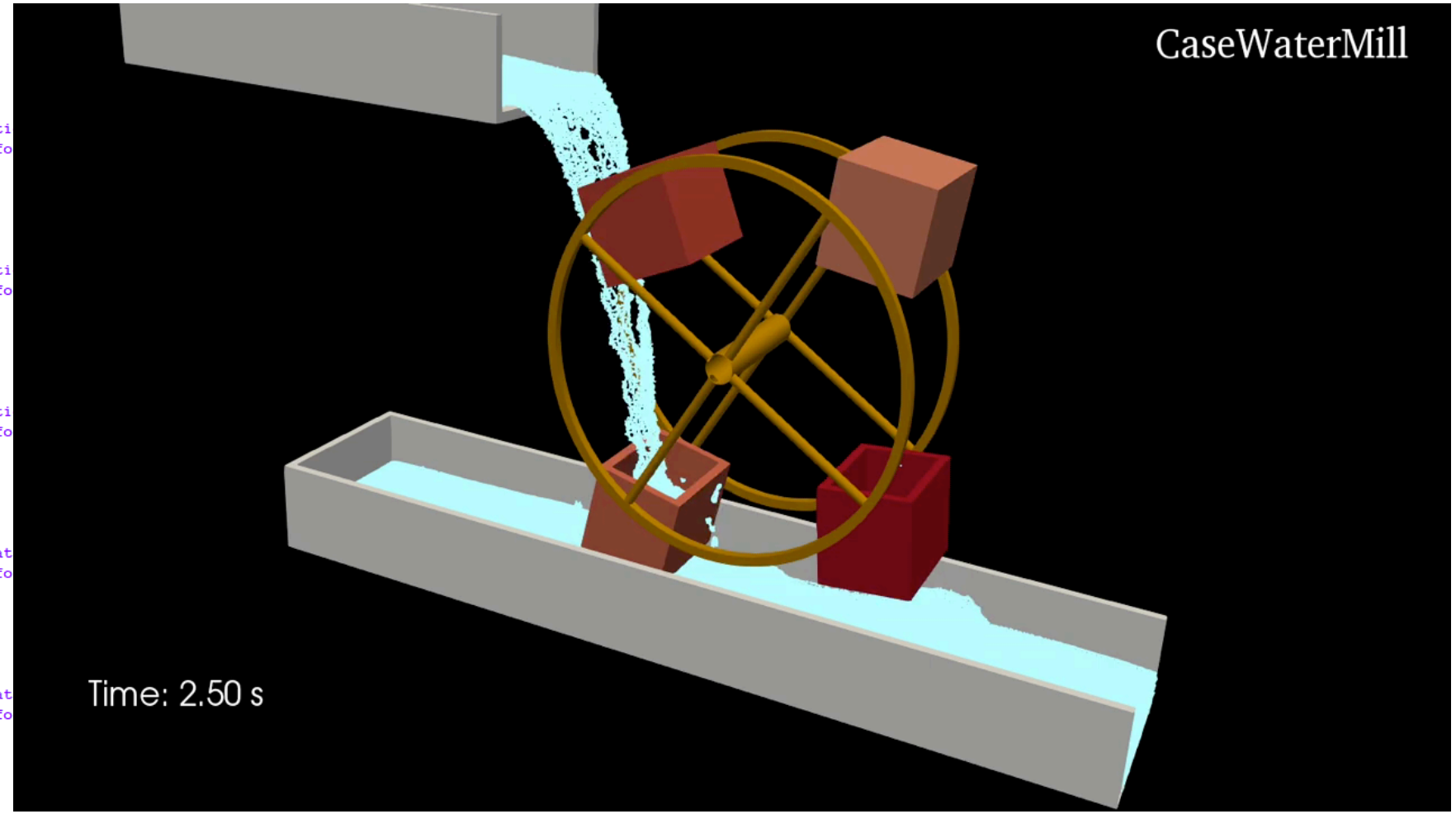
Going through the examples – Case 7

```
<chrono>
    <schemescale value="1" comment="Scale used to create the initial scheme of Chrono objects (default=1)" />
    <bodyfloating id="cube" mkbound="51-53" modelfile="AutoActual" />
    <bodyfixed id="tank" mkbound="0" modelfile="AutoActual" modelnormal="invert" />
</chrono>
```

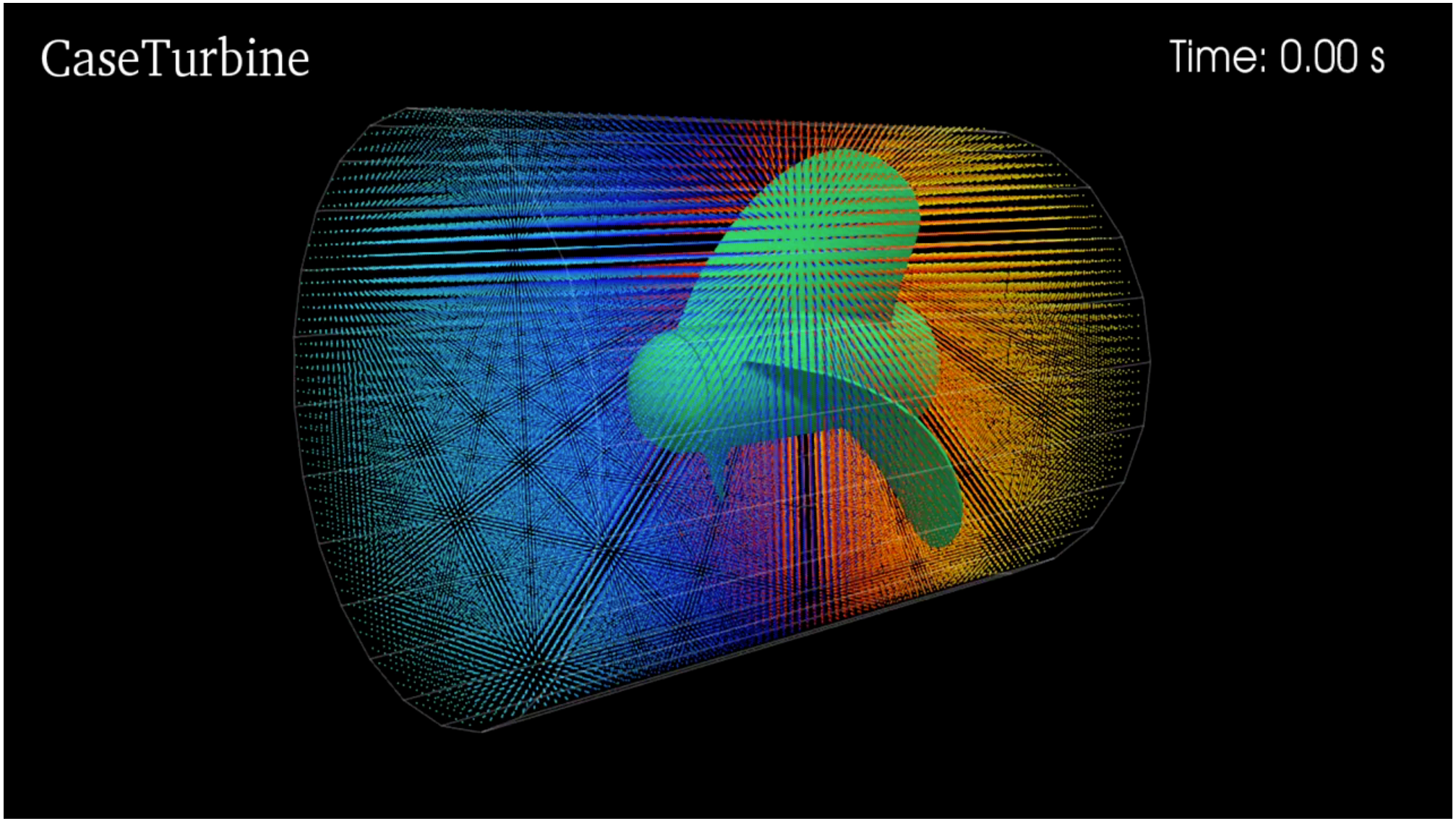


Going through the examples – Case 8

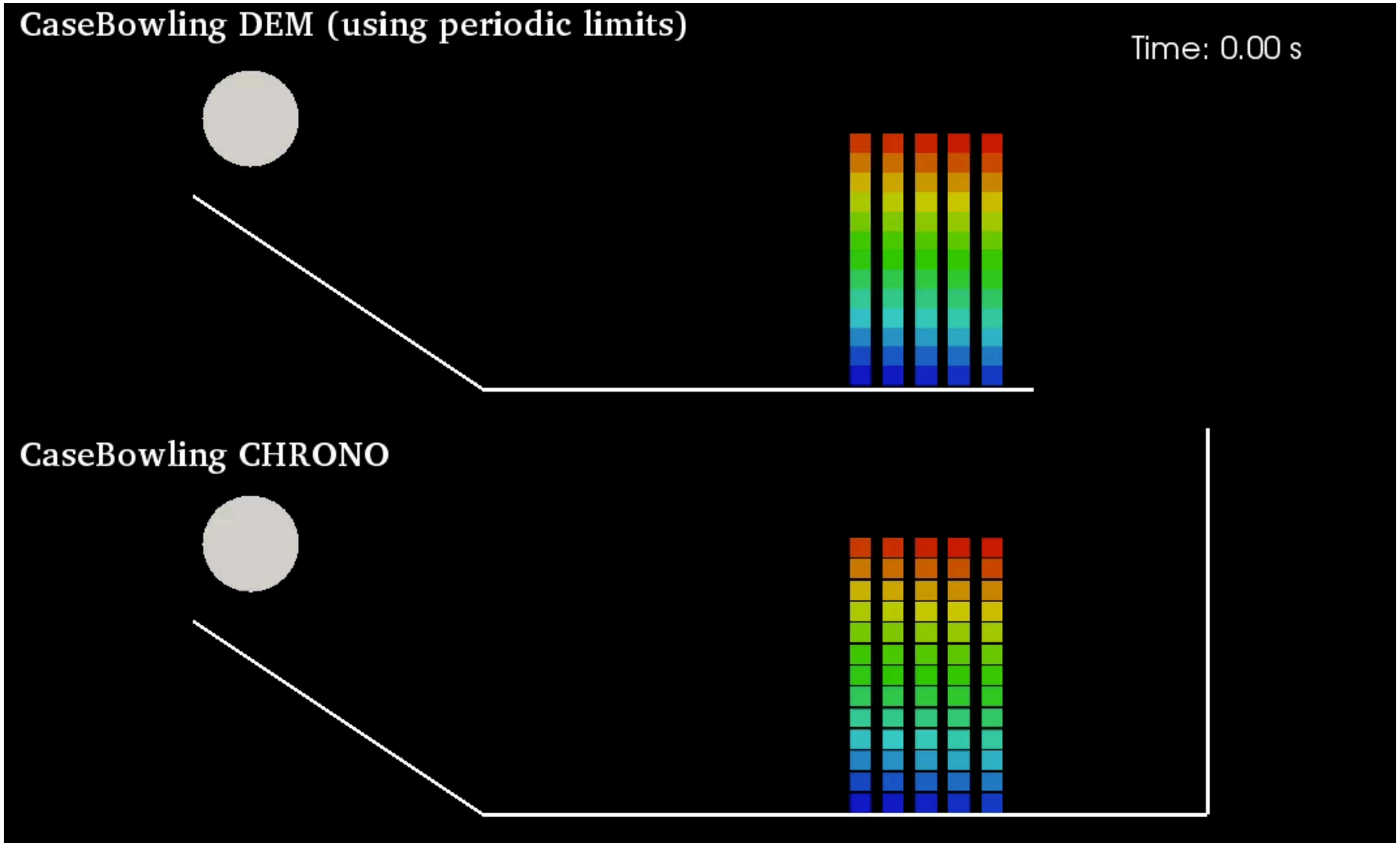
```
<chrono>
    <savedata value="0.01" comment="Saves CSV with data exchange for each time interval (0=all steps)" />
    <bodyfixed id="domain" mkbound="0"/>
    <bodyfloating id="weel" mkbound="1"/>
    <bodyfloating id="bucket1" mkbound="2"/>
    <bodyfloating id="bucket2" mkbound="3"/>
    <bodyfloating id="bucket3" mkbound="4"/>
    <bodyfloating id="bucket4" mkbound="5"/>
    <link_hinge idbody1="weel">
        <rotpoint x="5.5" y="0" z="3.0" comment="Point for rotati
        <rotvector x="0" y="1" z="0" comment="Vector direction fo
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="500" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
    <link_hinge idbody1="weel" idbody2="bucket1">
        <rotpoint x="5.5" y="0" z="1.1" comment="Point for rotati
        <rotvector x="0" y="1" z="0" comment="Vector direction fo
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="100" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
    <link_hinge idbody1="weel" idbody2="bucket2">
        <rotpoint x="5.5" y="0" z="4.8" comment="Point for rotati
        <rotvector x="0" y="1" z="0" comment="Vector direction fo
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="100" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
    <link_hinge idbody1="weel" idbody2="bucket3">
        <rotpoint x="7.35" y="0" z="3.0" comment="Point for rotat
        <rotvector x="0" y="1" z="0" comment="Vector direction fo
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="100" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
    <link_hinge idbody1="weel" idbody2="bucket4">
        <rotpoint x="3.65" y="0" z="3.0" comment="Point for rotat
        <rotvector x="0" y="1" z="0" comment="Vector direction fo
        <stiffness value="0" comment="Torsional stiffness" />
        <damping value="100" comment="Torsional damping" />
        <friction value="0" comment="Friction coefficient" />
    </link_hinge>
</chrono>
```



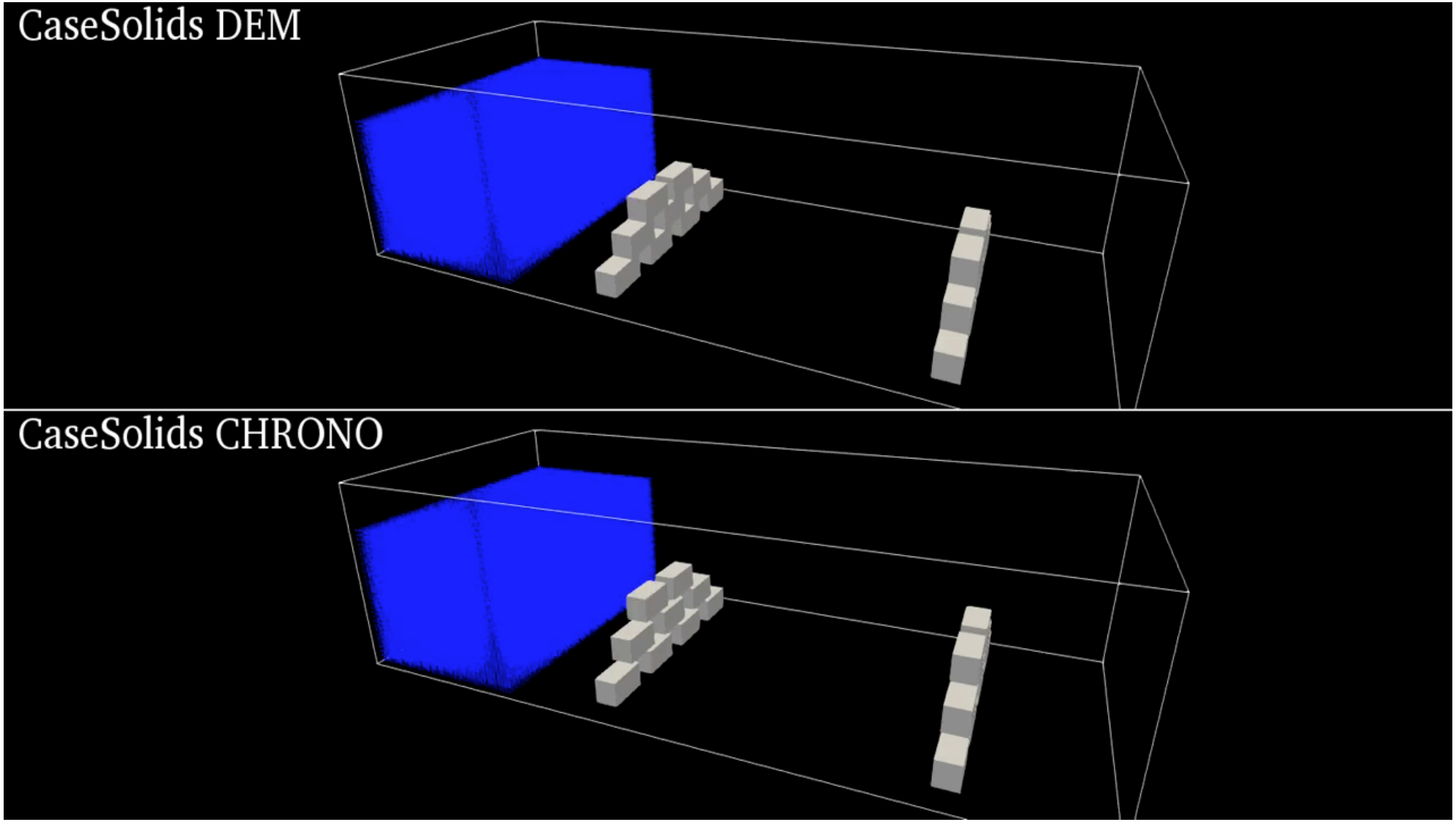
Going through the examples – Case 9



Going through the examples – Case 10



Going through the examples – Case 10.1



What is available in 4.3

Contact modelling

- Able to replace the DCDEM model available in DualSPHysics
- Uses two values: restitution and kinematic friction coefficient, using the input system already in place for the DEM model

Mechanical restrictions

- Hinge, spherical, point line (spherical on an axis) and linear springs
- All of these can be defined with a corresponding stiffness and damping parameters
- No limits to restrictions

A separate project implements the classes that abstract the Chrono library calls.

This project is currently compiled as a .dll shared library that DualSPHysics uses.

For 4.3, this dll is a black box, we are not releasing the source code yet.

Conclusions and future work

- DualSPHysics now supports kinematic constraints
- The implemented constrains allow you to model many different and complex cases, since you can combine them
- The contact algorithms are now much more robust and resolution-independant

- DualSPHysics abstracts the Chrono Project for the user
- Bodies going through periodic planes are not supported yet
- Bodies with imposed motion are not used in the interaction yet
- Meshes with high triangle counts lead to high computation times (only CPU yet)

- Deformable elements (elastoplaticity)
- Execution of contact problems should be doable in GPU