Example 6 - Fuel Tank

Summary
The fluid-structure interaction and the fluid flow are studied in cases of a fuel tank sloshing and overturning. A bi-phase liquid-gas material with an ALE formulation is used to define the interaction between water and air in the fuel tank.

In the case of sloshing, the fuel tank is subjected to a horizontal deceleration. The fuel tank container is modeled with a Lagrangian formulation and undergoes an elasto-plastic material law. Fluid structure coupling is taken into account.

The overturning of the fuel tank is studied by applying a variable deceleration. The tank container is not modeled as the boundary nodes are fixed. The Eulerian formulation is used.

The following two studies are depicted:

- Fluid Structure Coupling
- Fluid Flow
# Fluid Structure Coupling

<table>
<thead>
<tr>
<th>Title</th>
<th>Fuel tank - Fluid Structure Coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>6.1</td>
</tr>
</tbody>
</table>

**Brief Description**
Sloshing inside a fuel tank by simulating the fluid structure coupling. The tank deformation is achieved by applying an imposed velocity on the left corners. Water and air inside the tank are modeled with the ALE formulation. The tank container is described using a Lagrangian formulation.

**Keywords**
- Fluid structure coupling simulation, ALE formulation
- Shell, brick elements
- Hydrodynamic, bi-phase liquid gas material (/MAT/LAW37)

**RADIOSS Options**
- ALE boundary conditions (/ALE/BCS)
- J. Donea Grid Formulation (/ALE/DONEA)
- Boundary conditions (/BCS)
- Gravity (/GRAV)
- Imposed velocity (/IMPVEL)
- ALE material formulation (/ALE/MAT)

**Input File**
Fluid structure coupling: `<install_directory>/demos/hwsolvers/radioss/06_Fuel_tank/1-Tank_sloshing/Fluid_structure_coupling/TANK*`

**RADIOSS Version**
44m

**Technical / Theoretical Level**
Advanced
Overview

Aim of the Problem

A numerical simulation of fluid-structure coupling is performed on sloshing inside a deformable fuel tank. This example uses the ALE (Arbitrary Lagrangian Eulerian) formulation and the hydrodynamic bi-material law (/MAT/LAW37) to model interaction between water, air and the tank container.

Physical Problem Description

A rectangular tank made of steel is partially filled with water, the remainder being supplemented by air. The initial distribution pressure is known and supposed homogeneous. The tank container dimensions are 460 mm x 300 mm x 10 mm, with thickness being at 2 mm.

Deformation of the tank container is generated by an impulse made on the left corners of the tank for analyzing the fluid-structure coupling.

The steel container is modeled using the elasto-plastic model of Johnson-Cook law (/MAT/LAW2) with the following parameters:

- Density: 0.0078 g/mm³
- Young’s modulus: 210000 MPa
- Poisson’s ratio: 0.29
- Yield stress: 180 MPa
- Hardening parameter: 450 MPa
- Hardening exponent: 0.5

The material air-water bi-phase is described in the hydrodynamic bi-material liquid-gas law (/MAT/LAW37) available in ALE RADIOSS document. Material law 37 is specifically designed to model bi-material liquid gas.

The equations used to describe the state of viscosity and pressure are:

- Viscosity:
  \[ S_{ij} = 2\rho \nu \dot{e}_{ij} \]
  \[ \sigma_{kk} = \lambda \dot{\epsilon}_{kk} \]

- Liquid EOS:
  \[ \Delta P = C_1 \mu \] where \( \mu = (P/P_0) - 1 \)

- Gas EOS:
\[ \Delta P_g = P_0 \left( \frac{\rho^*}{\rho_0} \right) - P_0 \]

The equilibrium is defined by: \( P_i = P_g \)

where:

- \( S_i \) is the deviatoric stress tensor
- \( e_i \) is the deviatoric strain tensor

Material parameters are:

- **for liquid:**
  - Initial density: \( 10^{-3} \text{ g/mm}^3 \)
  - Reference density used in the equation of state (E.O.S): \( 10^{-3} \text{ g/mm}^3 \)
  - Liquid reference density: 0.001 g/mm\(^3\)
  - Liquid bulk modulus: 2089 N/mm\(^2\)
  - Initial massic liquid proportion: 100%
  - Shear kinematic viscosity \( = \frac{\mu}{\rho} \): 0.001 mm\(^2\)/ms

- **for gas:**
  - Initial density: \( 1.22 \times 10^{-6} \text{ g/mm}^3 \)
  - Gas reference density: 0.001 g/mm\(^3\)
  - Liquid bulk modulus: 2089 N/mm\(^2\)
  - Initial massic liquid proportion: 0%
  - Shear kinematic viscosity \( = \frac{\mu}{\rho} \): 0.00143 mm\(^2\)/ms
  - Constant perfect gas: 1.4
  - Initial pressure reference gas: 0.1 N/mm\(^2\)

The main solid type 14 properties for air/water parts are:

- Quadratic bulk viscosity/linear bulk viscosity: \( 10^{-20} \)
- Hourglass bulk coefficient: \( 10^{6} \)
Analysis, Assumptions and Modeling Description

Modeling Methodology

Air and water are modeled using the ALE formulation and the bi-material law (/MAT/LAW37). The tank container uses a Lagrangian formulation and an elasto-plastic material law (/MAT/LAW2).

Using the ALE formulation, the brick mesh is only deformed by tank deformation the water flowing through the mesh. The Lagrangian shell nodes still coincide with the material points and the elements deform with
the material: this is known as a Lagrangian mesh. For the ALE mesh, nodes on the boundaries are fixed in order to remain on the border, while the interior nodes are moved.

**RADIOSS Options Used**

Velocities (/IMPVEL) are imposed on the left corners in the X direction.

<table>
<thead>
<tr>
<th>Table 1: Imposed velocity versus time curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (ms⁻¹)</td>
</tr>
<tr>
<td>Time (ms)</td>
</tr>
</tbody>
</table>

Regarding the ALE boundary conditions, constraints are applied on:

- Material velocity
- Grid velocity

All nodes, except those on the border have grid (ALE/BCS) and material (BCS) velocities fixed in the Z-direction. The nodes on the border only have a material velocity (BCS) fixed in the Z-direction.

Both the ALE materials: air and water, must be declared ALE using /ALE/MAT. Note that Lagrangian material is automatically declared Lagrangian.

The /ALE/DONEA option activates the J. Donea grid formulation in order to compute the grid velocity. See the RADIOSS Theory Manual for further explanations about this option.
Simulation Results and Conclusions

Curves and Animations

Fluid – Structure Coupling

Fig 5: X – momentum variation for each part.

Kinematic conditions generate oscillations of the structure.

Fig 6: Density attached to the various brick elements.
Fluid Structure Coupling

Density

Velocity

Time = 12 ms
### Fluid Structure Coupling

**Density**

<table>
<thead>
<tr>
<th>Value</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00100234</td>
<td>Red</td>
</tr>
<tr>
<td>0.00092107</td>
<td>Orange</td>
</tr>
<tr>
<td>0.0008173</td>
<td>Yellow</td>
</tr>
<tr>
<td>0.00070139</td>
<td>Green</td>
</tr>
<tr>
<td>0.00058405</td>
<td>Blue</td>
</tr>
<tr>
<td>0.00046171</td>
<td>Cyan</td>
</tr>
<tr>
<td>0.00033837</td>
<td>Magenta</td>
</tr>
<tr>
<td>0.00021702</td>
<td>Pink</td>
</tr>
<tr>
<td>0.00010465</td>
<td>Gray</td>
</tr>
<tr>
<td>0.00000000</td>
<td>Black</td>
</tr>
</tbody>
</table>

**Velocity**

<table>
<thead>
<tr>
<th>Value</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.7317</td>
<td>Red</td>
</tr>
<tr>
<td>17.586</td>
<td>Orange</td>
</tr>
<tr>
<td>15.765</td>
<td>Yellow</td>
</tr>
<tr>
<td>13.812</td>
<td>Green</td>
</tr>
<tr>
<td>11.839</td>
<td>Blue</td>
</tr>
<tr>
<td>9.8657</td>
<td>Cyan</td>
</tr>
<tr>
<td>7.8926</td>
<td>Magenta</td>
</tr>
<tr>
<td>5.9152</td>
<td>Pink</td>
</tr>
<tr>
<td>3.9435</td>
<td>Gray</td>
</tr>
<tr>
<td>1.9731</td>
<td>Black</td>
</tr>
</tbody>
</table>

**Time** = 42 ms
## Fluid Flow

### Title
Fuel tank - Fluid flow

### Number
6.2

### Brief Description
Fuel tank overturning with simulation of the fluid flow. The reversing tank is modeled using horizontally-applied gravity. The tank container is presumed without deformation and only the water and air inside the tank are taken into consideration using the ALE formulation.

### Keywords
- Fluid flow simulation, ALE formulation
- Brick elements
- Hydrodynamic, bi-phase liquid gas (/MAT/LAW37)

### RADIOSS Options
- ALE boundary conditions (/ALE/BCS)
- J. Donea Grid Formulation (/ALE/DONEA)
- Gravity (/GRAV)
- ALE material formulation (/ALE/MAT)

### Input File
- `Fluid_flow_gravity_1`: `<install_directory>/demos/hwsolvers/radioss/06_Fuel_tank/2-Tank_overturning/Fluid_flow_1/PFTANK`
- `Fluid_flow_gravity_2`: `<install_directory>/demos/hwsolvers/radioss/06_Fuel_tank/2-Tank_overturning/Fluid_flow_2/PFTANK`

### RADIOSS Version
44m

### Technical / Theoretical Level
Advanced
Overview

Aim of the Problem

The fluid flow is studied during the fuel tank overturning. This example uses the ALE (Arbitrary Lagrangian Eulerian) formulation and the hydrodynamic bi-material law (/MAT/LAW37) to simulate interaction between water and air. The tank container is presumed without deformation and it will not be modeled.

Physical Problem Description

A rectangular tank is partially filled with water, the remainder being supplemented by air. The tank turns once around itself on the Y-axis. The overturning is achieved by defining a gravity field in the X direction, which is parallel to the liquid gas interface. All gravity is applied in other directions. The initial distribution pressure is already known and supposed homogeneous. The tank dimensions are 460 mm x 300 mm x 10 mm.

Fig 7: Problem description.

The example deals with two loading cases: an instantaneous rotation of the fuel tank by 90 degrees (gravity function 1) and a progressive rotation (gravity function 2).

The main material properties for the ALE bi-phase air/water are:

- Air density: $1.22 \times 10^6$ g/mm$^3$
- Water density: 0.001 g/mm$^3$
- Gas initial pressure: 0.1 MPa
Analysis, Assumptions and Modeling Description

Modeling Methodology

The bi-material air-water is described in the hydrodynamic material law (/MAT/LAW37). See previous section for information about this law, including full input data.

This loading case does not require a tank container mesh and the model, air and water are only comprised of the brick element using an ALE formulation.

Using the ALE formulation, brick mesh is only deformed by the tank deformation, the water flowing through the mesh. The Lagrangian shell nodes still coincide with the material points, while the elements are deformed with the material: this is the Lagrangian mesh. For the ALE mesh, nodes on boundaries are fixed to remain on the border, while the interior nodes are moved.

**Fig 8: Air and water mesh (ALE bricks).**

*RADIOSS Options Used*

Regarding the ALE boundary conditions (/ALE/BCS), constraints are applied on:

- Material velocity
- Grid velocity

All nodes inside the border have grid and material velocities fixed in the Z direction; the nodes on the left and right sides have a material velocity fixed in the X, Z directions, while the nodes on the high and low sides have a material velocity fixed in the Y, Z directions. The grid velocity is fully fixed on the border, just as the material velocity is fixed on the corners.

A function defines gravity acceleration in the X direction compared with time in order to simulate the rotation effect. Gravity is activated by /GRAV. Two cases are studied depending on the acceleration function chosen:
Gravity is considered for all nodes.

Both ALE materials: air and water, must be declared as ALE using /ALE/MAT. Note that the
• Lagrangian material is automatically declared as Lagrangian.
  The /ALE/DONEA option activates the J. Donea grid formulation in order to compute grid velocity. See
• the RADIOSS Theory Manual for further explanation about this option.
Simulation Results and Conclusions

<table>
<thead>
<tr>
<th>Model with Constant Acceleration (Gravity function 1)</th>
<th>Time = 170 ms</th>
</tr>
</thead>
</table>

**Density**

![Density Graph](image)

**Velocity**

![Velocity Graph](image)
# Model with Constant Acceleration
(Gravity function 1)

<table>
<thead>
<tr>
<th>Time = 280 ms</th>
</tr>
</thead>
</table>

## Density

- **Density Range:** 1.21829e-06 to 0.001

![Density Image](image1)

## Velocity

- **Velocity Range:** 0 to 8.08545

![Velocity Image](image2)
<table>
<thead>
<tr>
<th>Density</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time = 50 ms</td>
<td></td>
</tr>
</tbody>
</table>

**Model with Variable Acceleration**
*(Gravity function 2)*
Model with Variable Acceleration
(Gravity function 2)

Time = 70 ms

Density

Velocity

Gravity function 2
Conclusion
This example allows the study of hydrodynamic bi-material using Law 37 in RADIOSS. ALE and Eulerian formulations are used. The application of boundary conditions in ALE formations and handling the fluid-structure interaction are discussed. Furthermore, the results obtained correctly represent the physical problem.