On the Simulation of Out-of-position Load Cases with the ALE Method

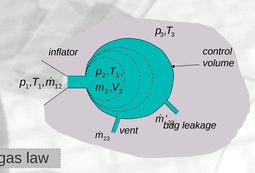
André Haufe & Uli Franz

Motivation

- Airbags have been available and set safety standards in vehicles for decades.
- In recent years, though, many fatal injuries caused by incorrect airbag deployment have been reported, especially if the
  - ➔ Occupant is a baby, toddler or young adult (even if buckled up)
  - ➔ Occupant is improperly seated
  - ➔ Occupant is not buckled up at all etc.
- This has forced NHTSA and Transport Canada to ask for new airbag designs that comply with new tests setups: For instance OoP-tests with 12-month-old, 3-year-old, 6-year-old children and 5th percent adult female dummies.

Classical Airbag Simulation

Wang's hybrid model:



Conservation of mass

$$\dot{m}_{cv} = \dot{m}_i - \dot{m}_e = \dot{m}_{12} - \dot{m}_{23}$$

$$m_{cv} = \int \dot{m}_{cv} dt$$

Pressure is obtained via ideal gas law

$$p_{cv} = \frac{m_{cv} \cdot r \cdot T_{cv}}{V_{cv}}$$

Specific heats are obtained from

$$c_p = \sum f_i c_{p(i)} \qquad c_v = \sum f_i c_{v(i)} \qquad f_i = \text{fraction of gas } i$$

$c_{p(i)}$ = constant pressure specific heat of fraction i

$c_{v(i)}$ = constant volume specific heat of fraction i

r = gas constant = 8.314J/(K mol)

- Major assumption: Uniformly distributed pressure in airbag during inflation process. Thus no discretization of the fluid!!!
- Calculation of internal pressure from scalar gas equations (EOS) and controlled volume of bag.
- For standard applications this approach is justified by the fact, that the impact of the dummy happens after full expansion of airbag.

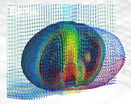
Advantages:

Robust, cheap, mostly exact enough and well tested.

Disadvantages:

No exact flow simulation (first milliseconds not physically correct). Comprehensive validation of the complete airbag model (airbag and inflator) necessary.

State-of-the-Art Advanced Airbag Simulation with Fluid-Structure-Interaction



- Due to the small distance between dummy (occupant) and the inflator, severe injuries and even fatalities may result from the airbag inflation process.
- Thus, for OoP-simulations the interaction of fluid-flow, airbag and dummy is of uttermost importance (FSI)!
- The fluid has to be discretized in order to determine the flow effects (CFD)!
- In order to move the fluid mesh arbitrarily with the car, a suitable mathematical description has to be used.

Advantages:

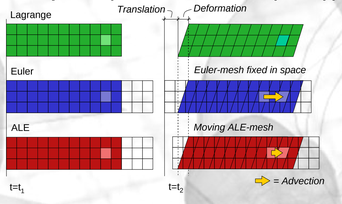
Exact simulation of flow, thus realistic behavior in the first milliseconds.
Exact pressure distribution inside bag.
Validation of inflator separated from actual bag.

Disadvantages:

Extreme increase in computing time.

Technology

Arbitrary Description of Deformations (ALE Approach)



Extension of Explicit Finite Element Cycle

Momentum balance

$$\rho \ddot{\mathbf{x}} + \rho \nabla \dot{\mathbf{x}} (\mathbf{v} - \dot{\mathbf{x}}) = \rho \mathbf{b} + div\, \boldsymbol{\sigma}$$

additional eqn. due to ALE concept

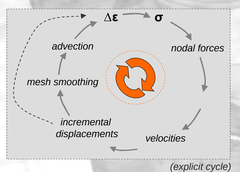
Mass balance

$$\dot{\rho} + \nabla \rho (\mathbf{v} - \dot{\mathbf{x}}) + \rho\, div\, \mathbf{v} = 0$$

Energy equation

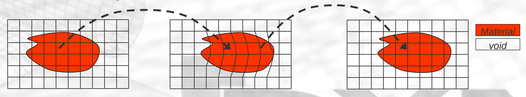
$$\rho \dot{\mathbf{u}} + \rho \nabla \mathbf{u} (\mathbf{v} - \dot{\mathbf{x}}) = \boldsymbol{\sigma} : \mathbf{D} + \rho \mathbf{r} - \nabla \mathbf{q}$$

material velocity — mesh velocity



(explicit cycle)

Advection Cycle

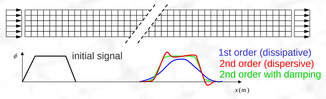


"Lagrangian step"

Smoothing
- Simple average method
- Equipotential smoothing (Winslow 1963, 1990)

Advection
- Donor cell scheme (1st order accurate)
- Van Leer scheme (2nd order accurate)

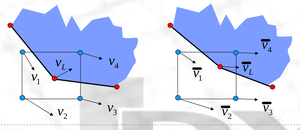
1D Experiment



Coupling of Fluid with Solid

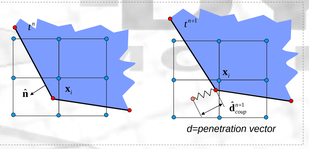
Constraint based method:
Preserves momentum but does not conserves energy

- *Nodal velocities are forced to follow each other*



Penalty based method:
Conserves energy but may be unstable

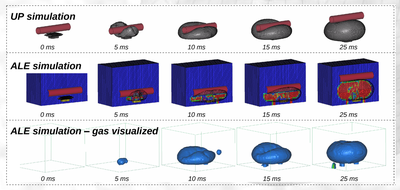
- *Coupling force is proportional to* ***d****, pressure vs. penetration curves can be defined*



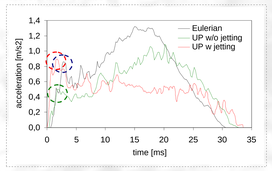
Blockage and porosity can be taken into account.

Examples

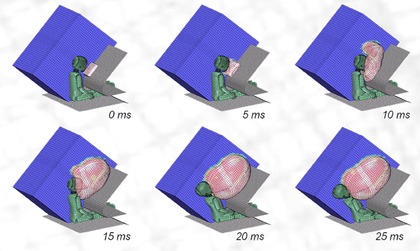
Folded airbag with rigid tube



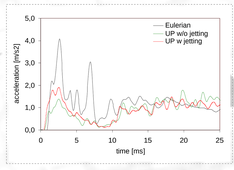
Acceleration of tube



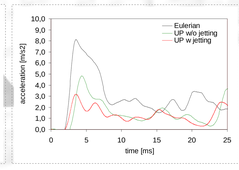
Out-of-Position-Simulation (hybrid-III, 3 year old)



Acceleration of head:



Acceleration of thorax:



For further inquiries please contact:
Dynamore GmbH
Industriestraße 2
70565 Stuttgart
http://www.dynamore.de