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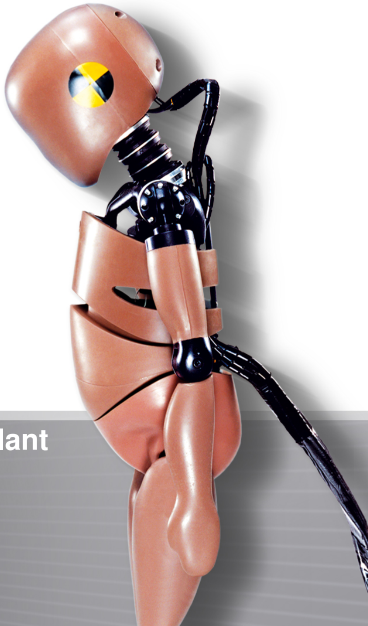


Surface tracking method for solid propellant burning procedure in inflator relevant applications

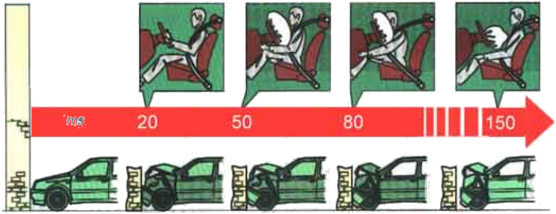
21st Feb 2018

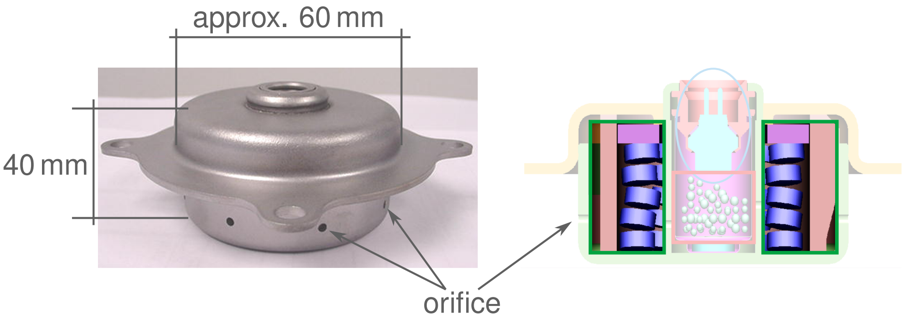
Tilo Laufer

Agenda

- **The Inflator**
  - Description
  - Mode of Operation
- **Classical Solid Propellant Combustion Simulation**
- **New Solution of Solid Propellant Combustion**
  - IsoAdvector Library
- **Simulation of Simple Combustion Phenomena**
  - 2D - Combustion
  - 3D - Combustion
- **Convergence Study - Structured Mesh**
- **Robustness Study - Paralell Computing**
- **Summary & Future Prospects**

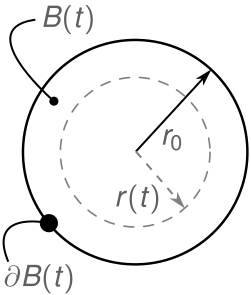
- 1953 first automotive patent
- 1981 Mercedes-Benz introduced first airbag in Europe
  - developed in cooperation with Petri AG (today Takata AG)

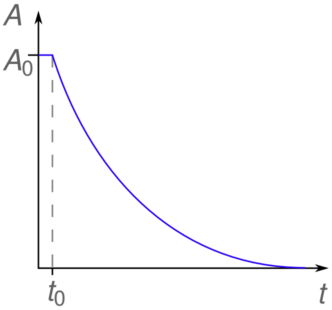




- fill a 60 L airbag in 30 ms with 1.5 bar absolute pressure
- initiator, transfers an electric signal into a chemical reaction
- booster, enhances the initiator reaction
- combustion-chamber, produces a large amount of fluid to fill an airbag

Sphere





- burn rate: $\dot{r}$ in mm/s
- Assumption:
  - $\dot{r} = \text{const. on } \partial B$
- mass flow: $\dot{m}(t) = \dot{r}(t)A(t)\rho_{\text{prop.}}$

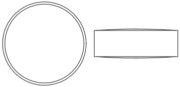
Classical Solid Propellant Combustion Simulation

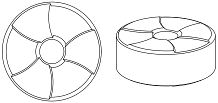
Advantages:

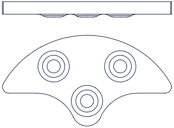
- short simulation time
- ideal for concept studies

Disadvantages:

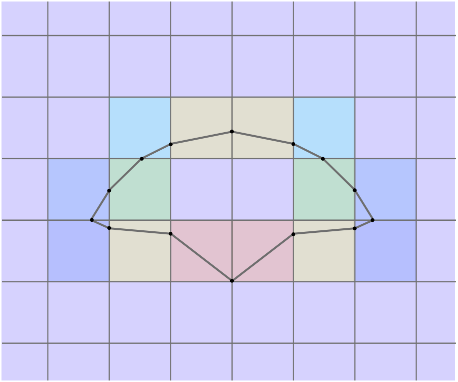
- difficult to describe complex propellant shapes
- no local effects resolvable







interface area per cell



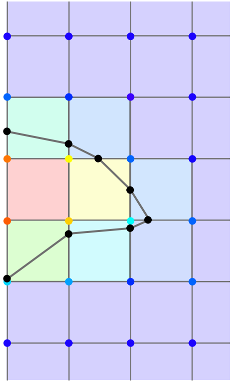
Initialization

1. discretize domain
2. set `volScalarField` accordingly to volume fraction

Solving

3. reconstruct propellant surface from `volScalarField` with iso-surfaces (IsoAdvector)
4. derive surface area per mesh cell

fraction of propellant per cell



How does the ISOADVECTOR library work?

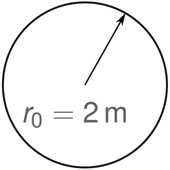
- interpolate the propellant fraction onto the grid points
- find points on cell edges with proper iso-value

  by default iso-value varies from cell to cell
- create intersection face based on interpolated points

Modifications for propellant simulations:

- constant iso-value for iso-face interpolation
- extend ISOADVECTOR library to provide "interface area per cell"-information

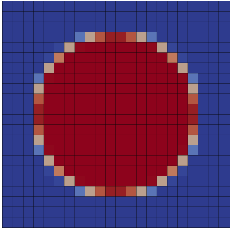
2D-simualtion

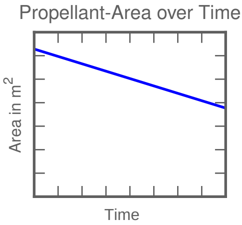


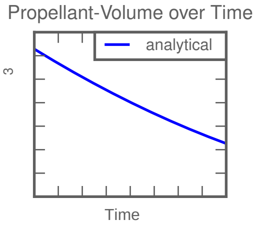
- constant combustion rate: $\dot{r} = 50\,\text{m}/\text{s}$
- analytical combustion solution:

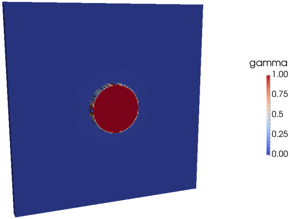
$$A_i = 2\pi r_i h \qquad V_i = \pi r_i^2 h$$

$$A_{i+1} = 2\pi(r_i - \dot{r}\Delta t)h \qquad V_{i+1} = \pi(r_i - \dot{r}\Delta t)^2 h$$

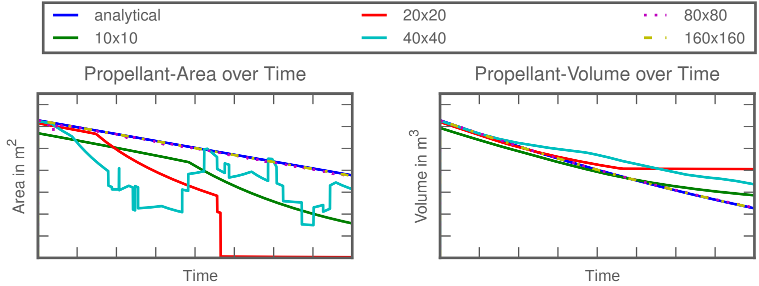




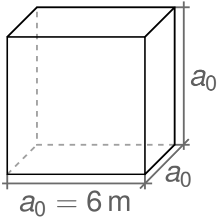


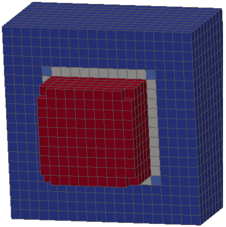


- mesh refinement leads to a converged solution
- a minimum mesh resolution is required for proper results



3D-simualtion



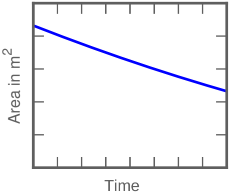


- constant combustion rate: $\dot{r} = 50\,\mathrm{m/s}$
- analytical combustion solution:

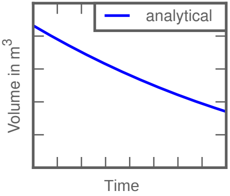
$$A_i = 6a_i^2 \qquad V_i = a_i^3$$

$$A_{i+1} = 6(a_i - \dot{r}\Delta t)^2 \qquad V_{i+1} = (a_i - \dot{r}\Delta t)^3$$

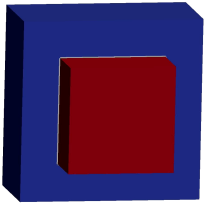
Propellant-area over Time

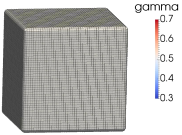


Propellant-Volume over Time

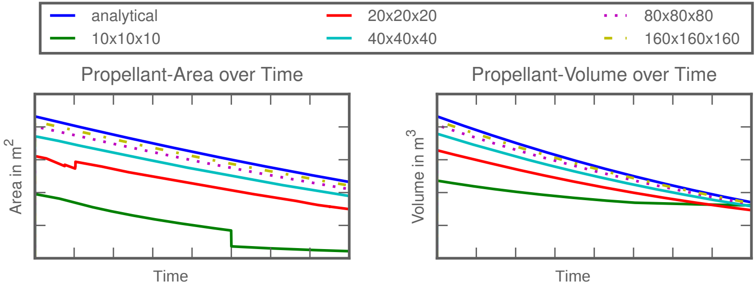


Convergence Study - Structured Mesh



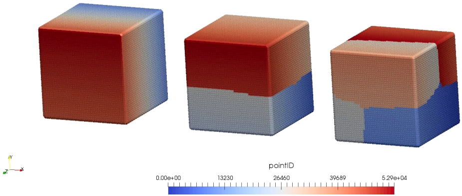


- mesh refinement leads to a converged solution
- a minimum mesh resolution is required for proper results
- converged slower then 2D

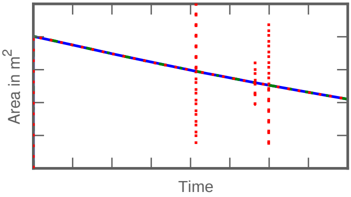


Robustness Study - Paralell Computing

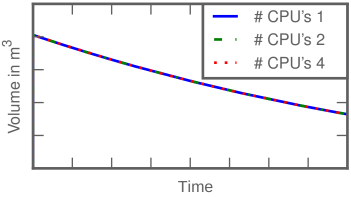
1-CPU 2-CPU's 4-CPU's



Propellant-Area over Time



Propellant-Volume over Time

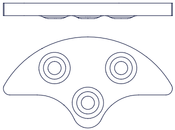


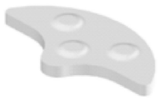
Summary:

- all work has been done with OpenFOAM-3.0.1
- convergence has been proven for 2D- & 3D-Simulations as well as for structured and unstructured meshes
- investigations show a robust behavior in terms of parallelization and time-step size

Future goals for investigation:

- simulation of realistic combustion problems, e.g. ClosedVessel
- combination with `adaptive mesh` refinement





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Thank you for your attention

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