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Modeling of solid propellant burning procedure in inflator relevant applications

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Introduction • the airbag


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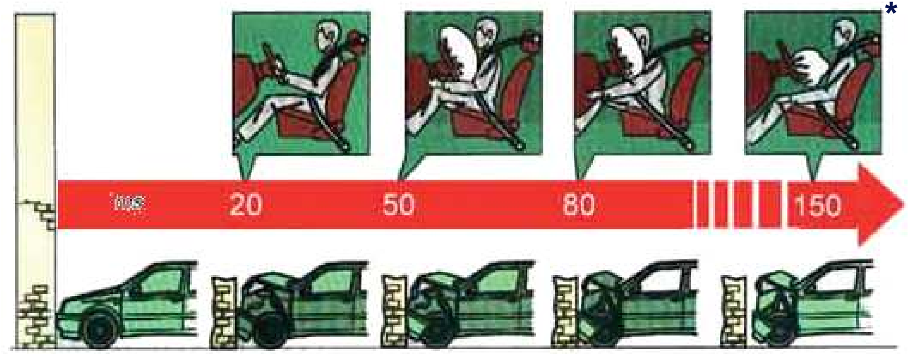

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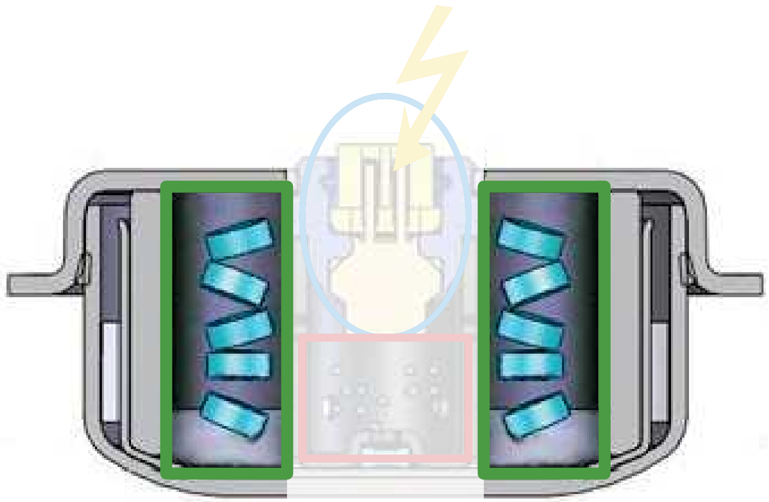
†

- more than 10 Airbags in modern premium cars
- a3ms injury criteria allows up to 80G‘s
  - Red Bull Air Race plane pilot experiences a maximum of 10G‘s

‡ https://www.bglerchenfeld.at/physik/airbag
† https://upload.wikimedia.org/wikipedia/commons/3/39/Driver_airbag_stored.JPG
* https://www.autotrainingcentre.com/wp-content/uploads/2013/11/Airbag-how-am-i-driving.jpg



- fill a 60L airbag within 30ms with 1.5bar 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

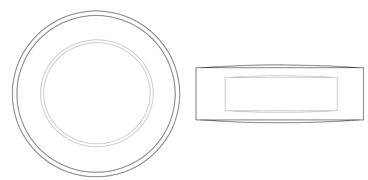
Introduction • problems developing an inflator

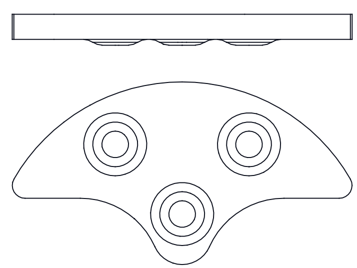
- inflator development is accompanied by many difficulties
  - non steady state behavior
  - short time span of approx. 50ms
  - one can‘t look inside the inflator during combustion

Introduction • problems developing an inflator

- only very few testing data
  - pressure can be measured
  - difficult temperature measurement
  - no velocity measurement

- current approach
  - analytical description of model
    - average pressure
    - ideal gas
    - adiabatic system





I. interface tracking

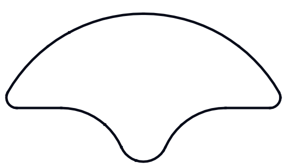
II. propellant BC

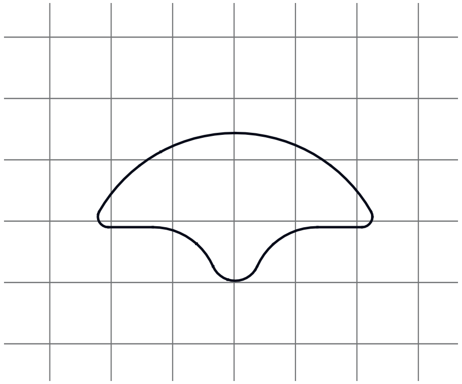
III. combustion modeling

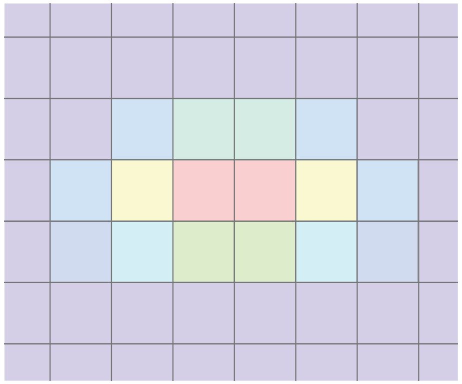
Solution process • propellant surface tracking

- Introduction of `volScalarField lambda`

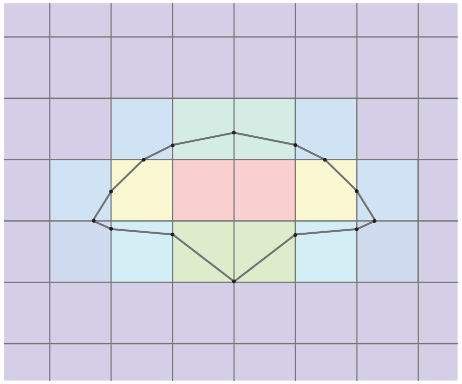
$$\lambda = \frac{V_{\text{propellant}}}{V_{\text{propellant}} + V_{\text{fluid}}}$$

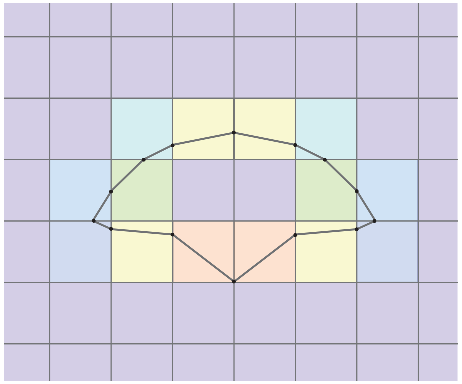






- reconstruction of propellant surface:
  - IsoAdvector - Lib*





* „A computational method for sharp interfaces advection“ by J. Roenhy, H. Bredmose & H. Jasak

Solution process

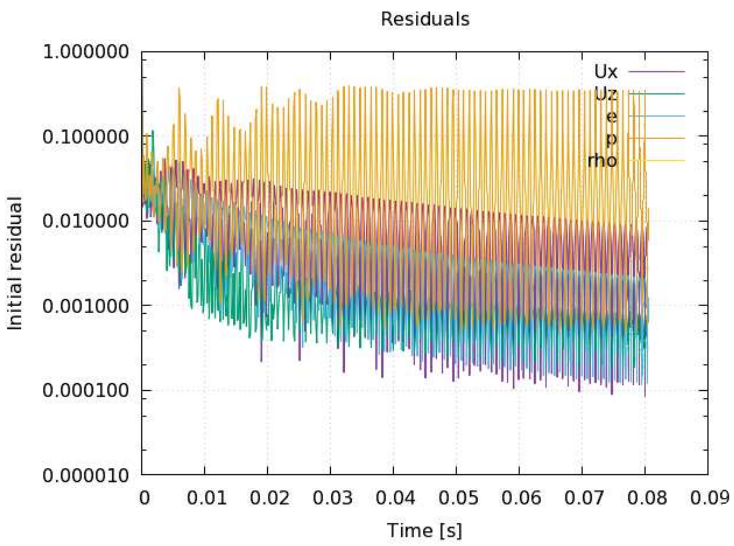
I. interface tracking

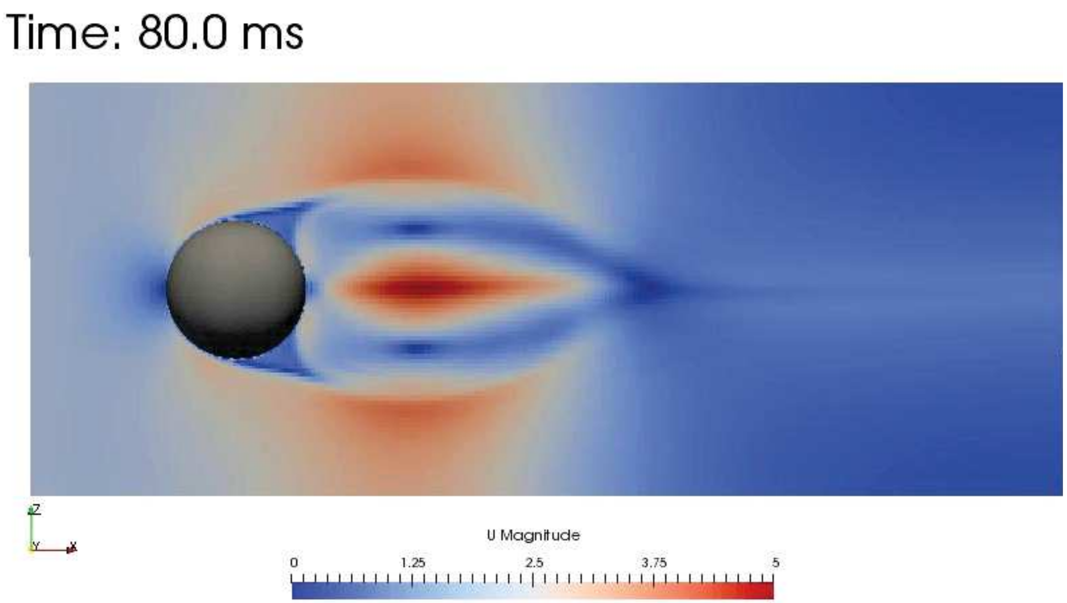
II. propellant BC

III. combustion modeling

Solution process • IBM

- Using Immersed boundary method (IBM) to apply boundary conditions (BC) of the propellant onto the flow field
  - openHFDIB - Lib*
- Problems with PISO-based algorithms
  - e.g. rhoPimpleFoam



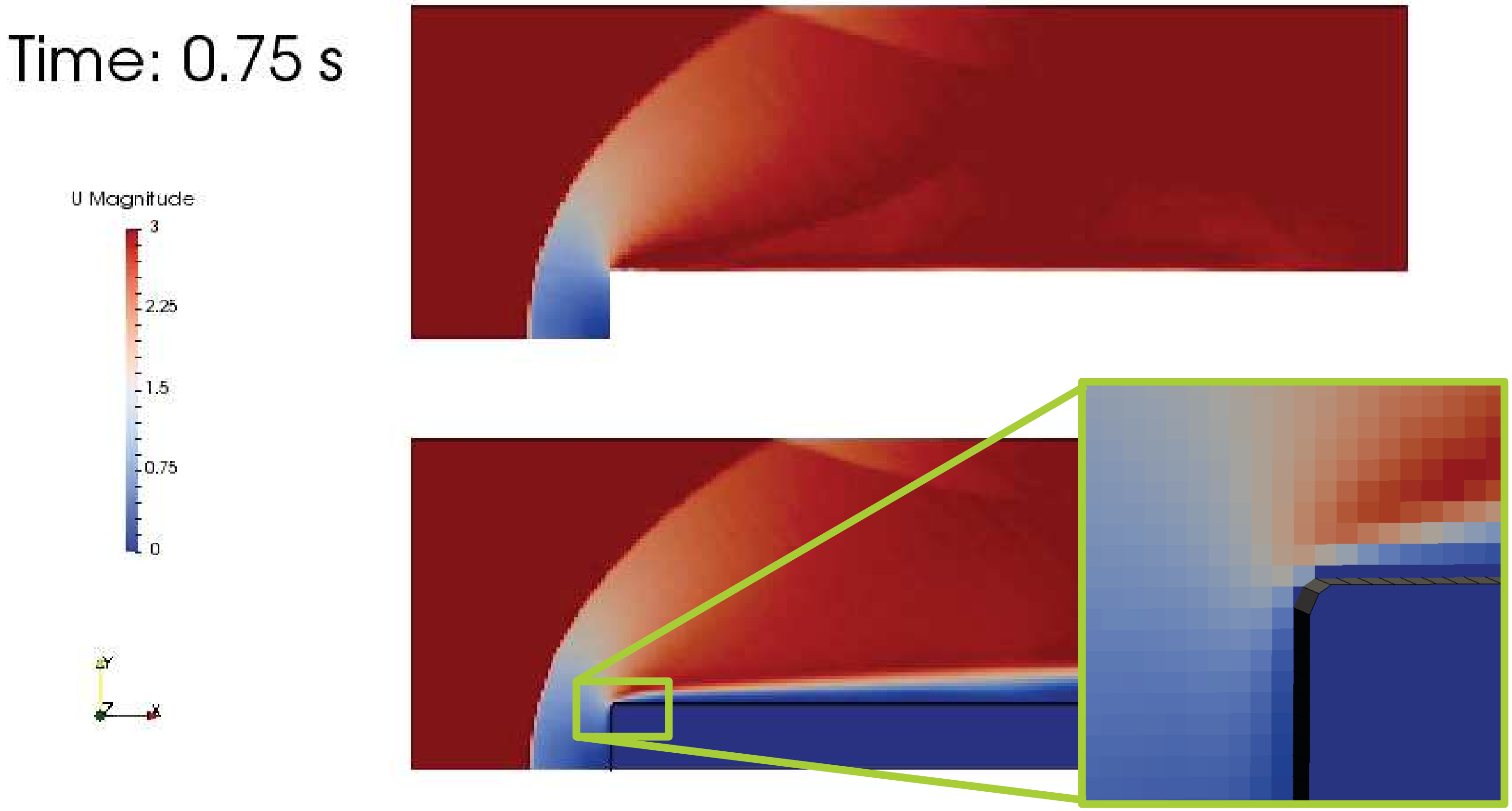


* „A Hybrid Fictitious Domain-Immersed Boundary Method for the Direct Simulation of Heat and Mass Transport in Fluid-Particle Systems“ by F. Municchi, S. Radl & C. Goniva

Solution process • IBM

- Applying IBM on rhoCentralFoam-Solver

  forwardstep – case



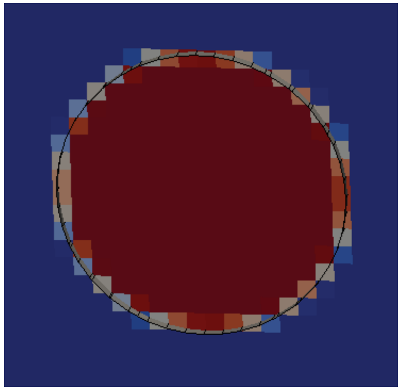
I. interface tracking

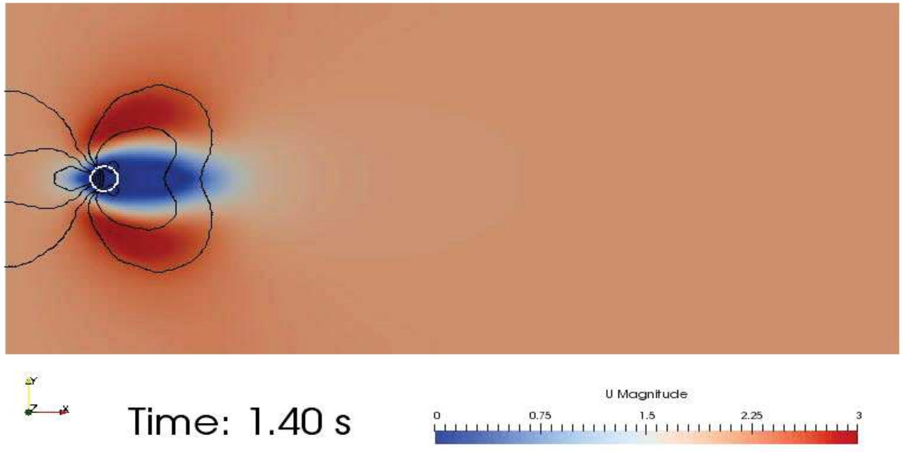
II. propellant BC

III. combustion modeling

- Propellant surface is defined by `volScalarField lambda`
  - `lambda` has to change

```
lambda = max(lambda - dot_r * deltaT, 0.0);
```





- Set of governing equations by Clarke & Lowe*

$$\frac{d}{dt}\int_V U\,dV = -\int_A F_j n_j\,dA + \int_V \left(S_{\mathrm{ch}} + S_{\mathrm{a}}\right) dV$$

$$U = \begin{pmatrix} \rho \\ \rho c^{\alpha} \\ \rho u_i \\ \rho E \end{pmatrix},\quad F_j = \begin{pmatrix} \rho u_j \\ \rho u_j c^{\alpha} \\ \rho u_j u_i + p \\ \rho u_j \left(E + pv\right) \end{pmatrix},\quad S_{\mathrm{ch}} = \begin{pmatrix} 0 \\ \Re^{\alpha} \\ 0 \\ 0 \end{pmatrix},\quad S_{\mathrm{a}} = \begin{pmatrix} \dot{M} \\ \dot{M}^{\alpha} \\ \dot{F} \\ \dot{H} \end{pmatrix}$$

- With the sources:

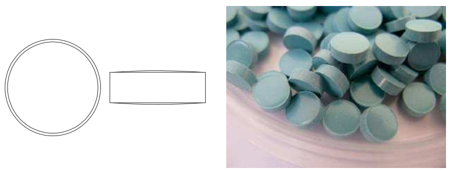
$$\dot{M} = \dot{r}\,\rho_{\mathrm{propellant}}$$
$$\dot{F} = 0 \quad \because \quad u_{\mathrm{fluid}} \gg u_{\mathrm{surf}}$$
$$\dot{H} = \dot{M}\,e_{\mathrm{heat\ of\ explosion}}$$

* „Combustion with Source Flows“ by J.F. Clarke & C.A. Lowe

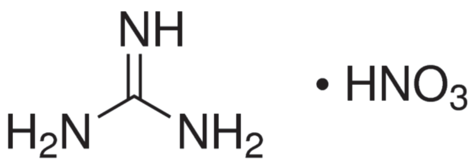
Results

- current state of research

- Applying derived solver onto closed vessel test
  - Volume ≈ **18cm³**
  - Cylinder shaped propellant

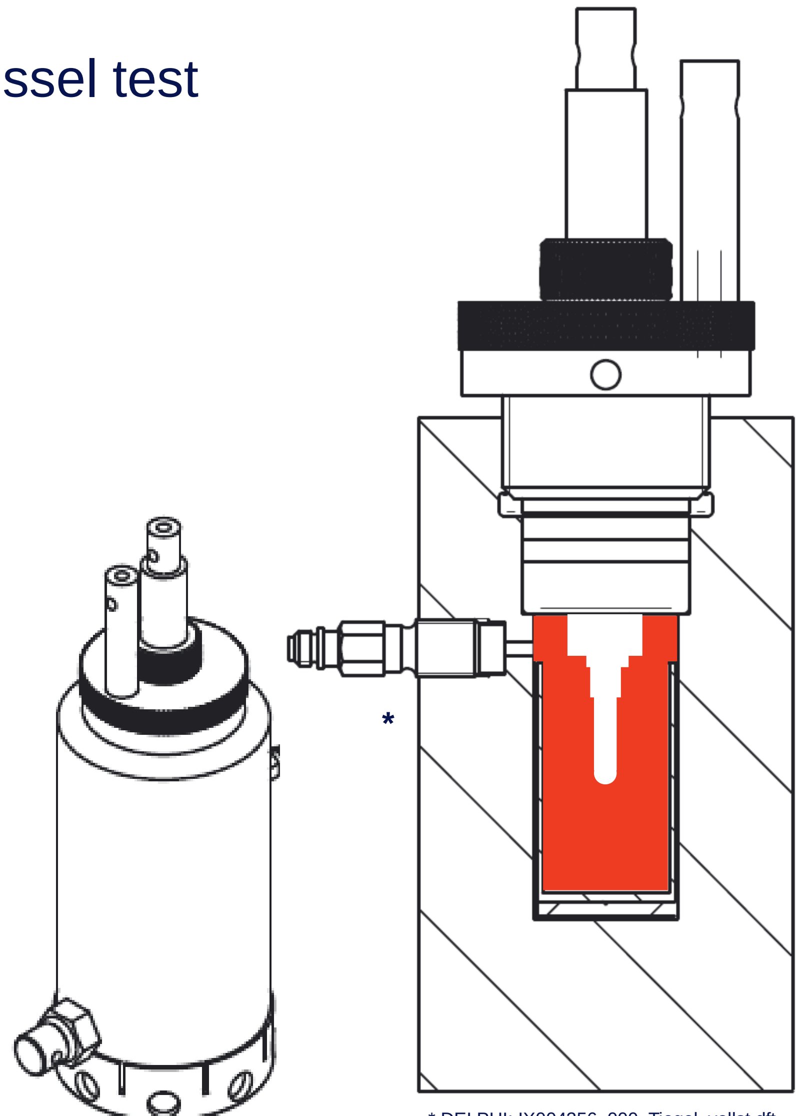


  - 2.5g of Guanidine nitrate propellant



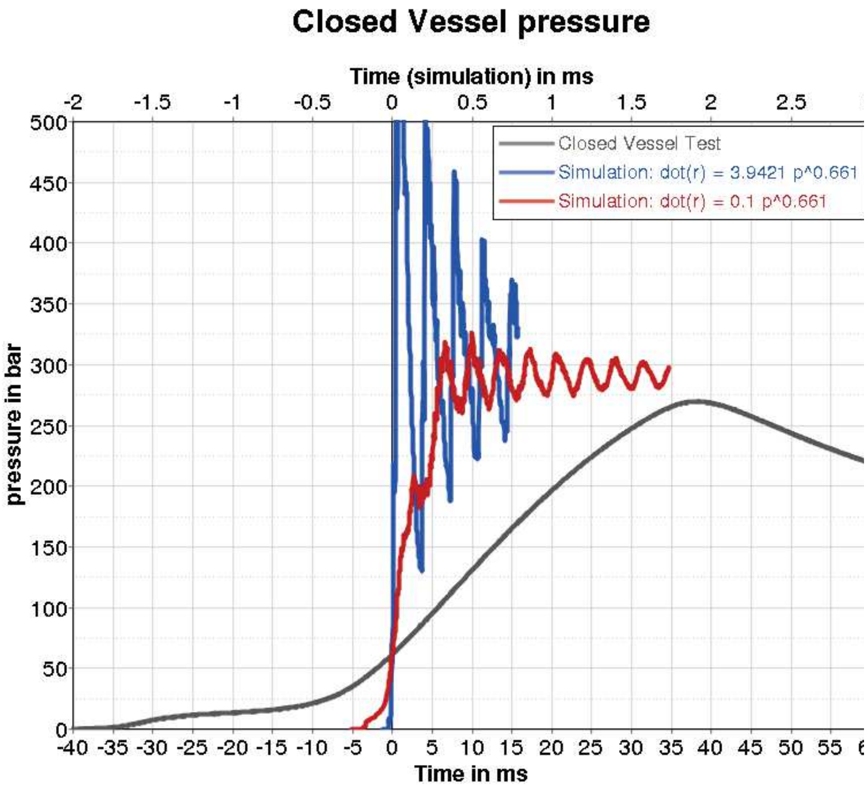
  - Analytical Solutions suggest

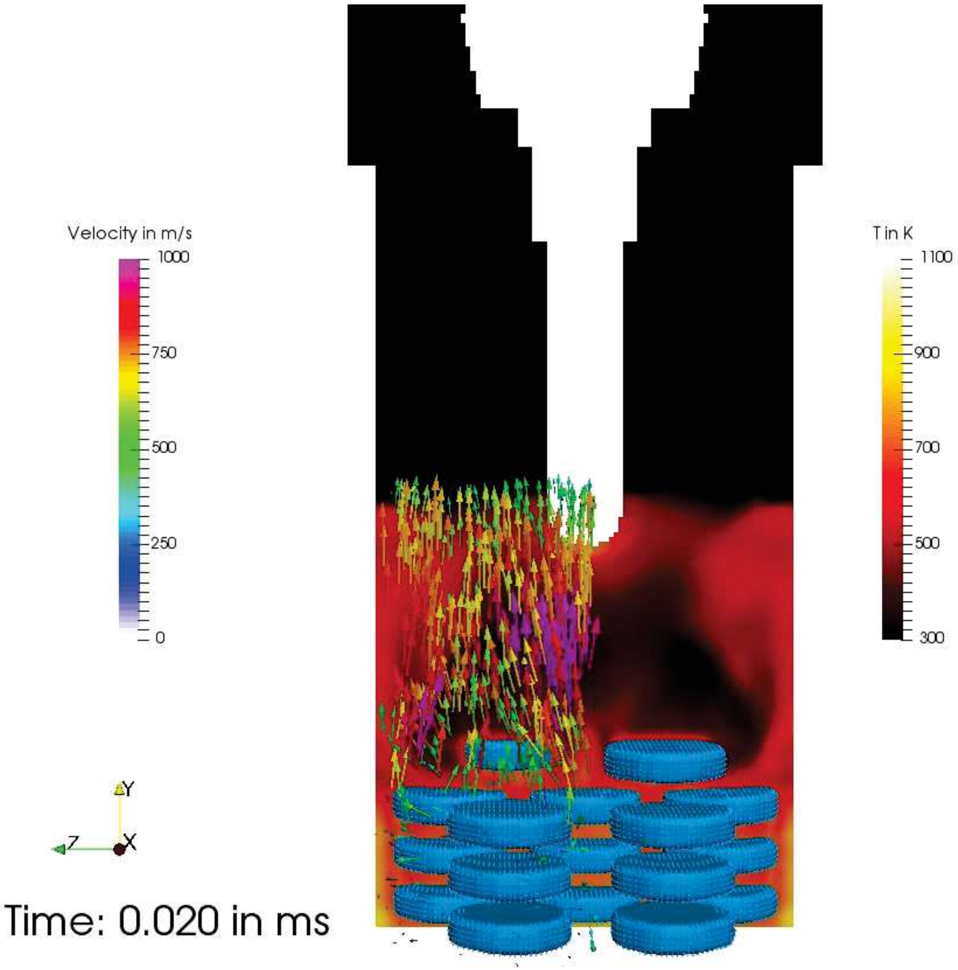
$$\dot{r} = B\,p^{n}$$
$$B = 3.9421$$
$$n = 0.661$$



* DELPHI: IX004256_000_Tiegel_vollst.dft

- Results based on analytical derived combustion law





Results • Summary and Outlook

- Summary:
  - proof of concept
  - OpenFOAM is capable of simulating solid propellant combustion
  - Code works in 2D as well as in 3D cases

- Outlook:
  - validation of methods
  - adding chemistry based combustion
  - Apply CFD simulations onto real inflator related applications

Thank you for your attention!

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