A CFD investigation of thermal hot spots in the ignition process of DEM based three-dimensional propellant beds

Daniel Tomaschewski

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Motivation

Why we care about the ignition process

Requirements

- Reproducibility from shot to shot for consistent performance
  - Depends heavily on igniter design
- Interior ballistic safety
  - Pressure waves can be caused by bad igniter design

Current challenges

- New ignition charge formulations
- Shorter igniter for tank ammunition

Complex ignition phenomena are occuring that we don´t understand in much detail!

Shooting Panzerhaubitze 2000 [1].

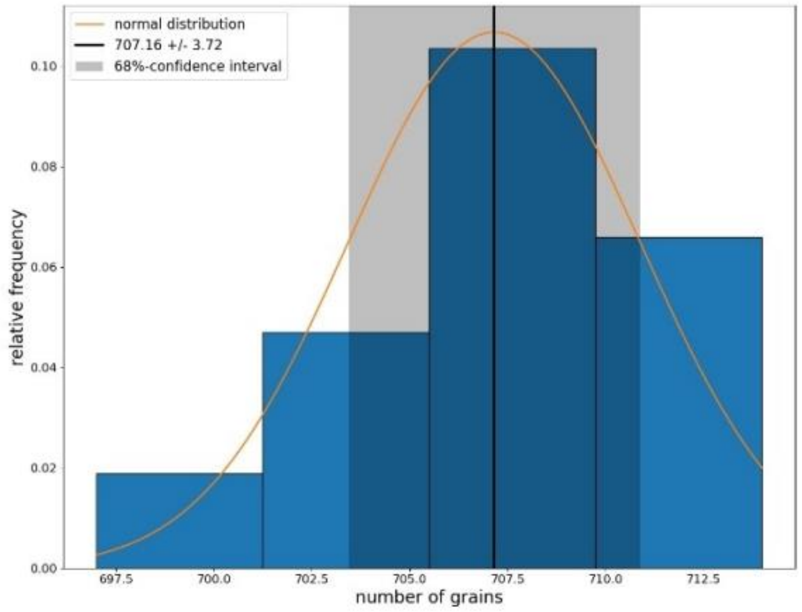
120mm – IM HE-T tank ammunition [2].

[1] https://de.wikipeida.de/wiki/Panzeraubitze_2000
[2] https://www.gd-ots.com/munitions/large-caliber-ammunition/

Motivation

Simulation and optimization of the loading density

- Previous work in 2022 based on a discrete Element method at Fraunhofer ICT [3]
- LD optimization based on statistical dataset through numerical simulations
- Arbitary geometries possible
- Resulting loading density can be used for further simulations
  - E.g. 0D/1D Gun Simulation



Resulting number of grains for L/D=1 in 25 simulation runs [3].

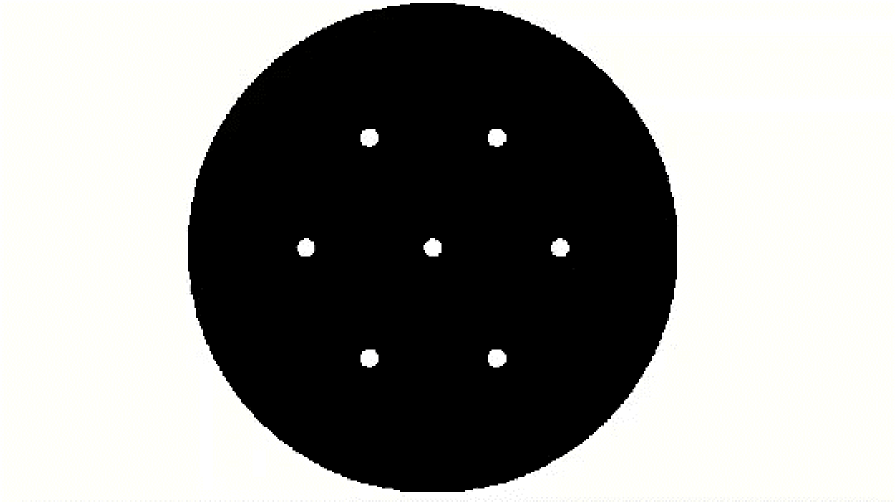
Simulated bed of JA2 propellant grains in a 700 cm3 vessel with transparent walls [3].

[3] Wurster, S., Lietz, M., & Sprengel, D. (2022). Simulation of the Loading Density for Gun Propellants with Arbitrary Shapes Using a Discrete Element Method. Propellants, Explosives, Pyrotechnics, 47(7)

Motivation

Simulation and optimization of the ignition process

- Ignition heavily depends on:
  - Igniter formulation
  - Igniter design
  - Propellant distribution
- Typical ignition/combustion models:
  - Burning based on form function
    - Ignition takes place on the whole propellant surface simultaneously
  - Detailed igniter and propellant geometry not represented in computational domain



Two dimensional numerical deflagration of a 7-perforated cylindrical propellant.

Complex ignition phenomena difficult to simulate with current IB-codes

→ Development of detailed three-dimensional simulation workflow to analyse and optimize ignition phase

[2] https://www.gd-ots.com/munitions/large-caliber-ammunition/

Simulation of statistical three-dimensional propellant beds

Discrete Element Method

Discrete Element Method

- Well established numerical method
- Tracking of single particles possible
- Based on Newton's laws of motion
  - $m_i \cdot \frac{d^2 x_i}{d^2 t} = f_i + m_i \cdot g$ (Translation)
  - $I_i \cdot \frac{dw_i}{dt} = M_i$ (Rotation)
- Treatment of various forces acting on the particle measurable

Simulation e.g. via RockyDEM (Ansys)

- Arbitary particle geometry
  - Import via stl-file possible
- Arbitary Vessels
  - Consideration of igniters possible
- Translative, rotational, normal forces, friction etc. measurable
  - Choice between various material models
- Modeling of breakage possible
- Export of the bulk as stl-file

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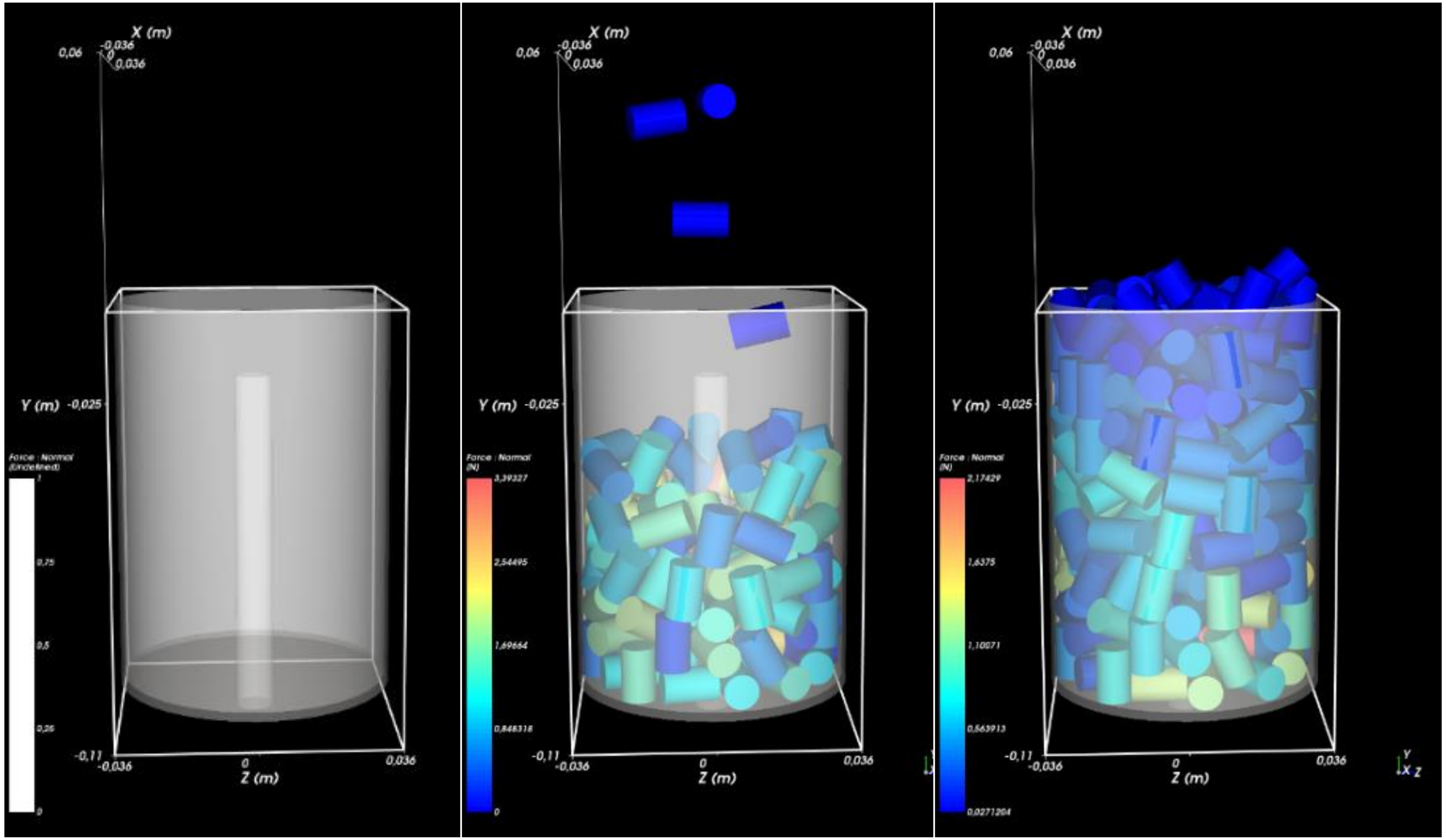
Simulation of statistical three-dimensional propellant beds

The filling process

Generic test case

- Vessel
  - Diameter $d_v = 70\ mm$
  - Height $h_v = 110\ mm$
- Igniter
  - Diameter $d_i = 10\ mm$
  - Height $h_i = 40\ mm$ and $80\ mm$
- Propellant (~JA2)
  - Diameter $d_p = 9\ mm$
  - Height $h_p = 14\ mm$
- Filling speed of $v_{fill} = 3\ m/s$



Normal Forces acting on the particles in the filling process at different time steps.

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Simulation of the fluid flow

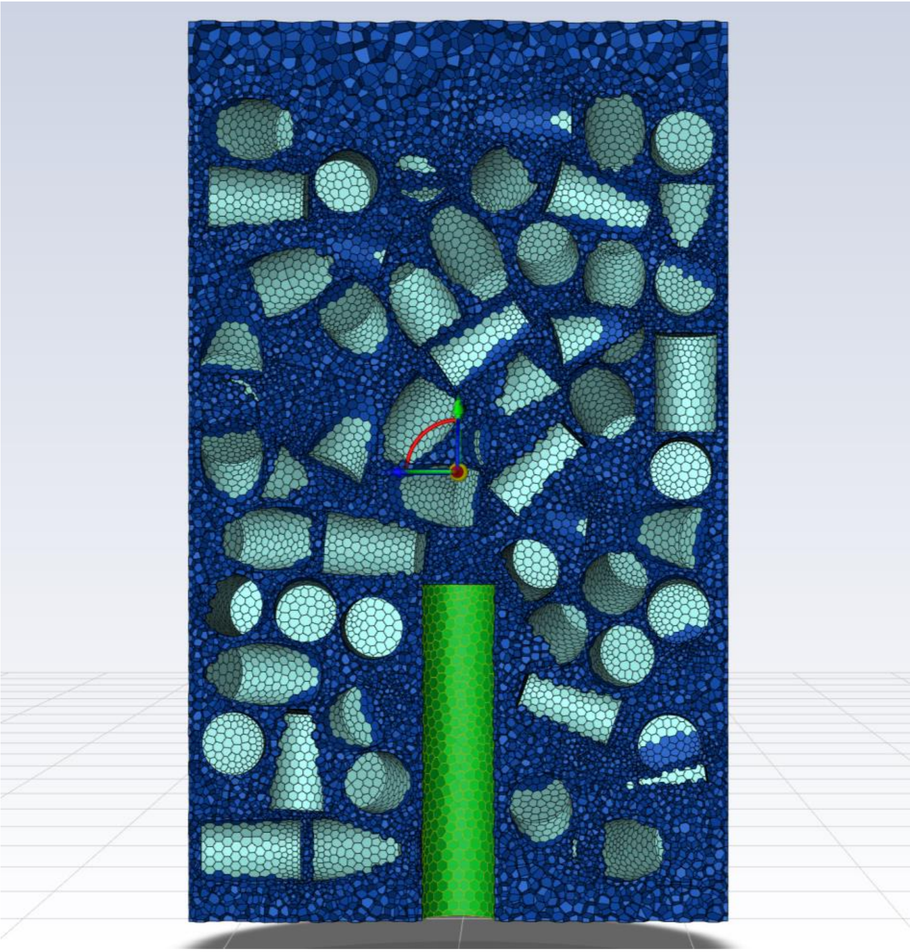
Ansys Fluent as a first try

Mathematical model

- Fluid flow described by compressible Navier-Stokes-equation
- K-omega-SST as Turbulence model
- Equation of state via ideal gas law
- Heat transfer through conservation of energy

Simulation setup

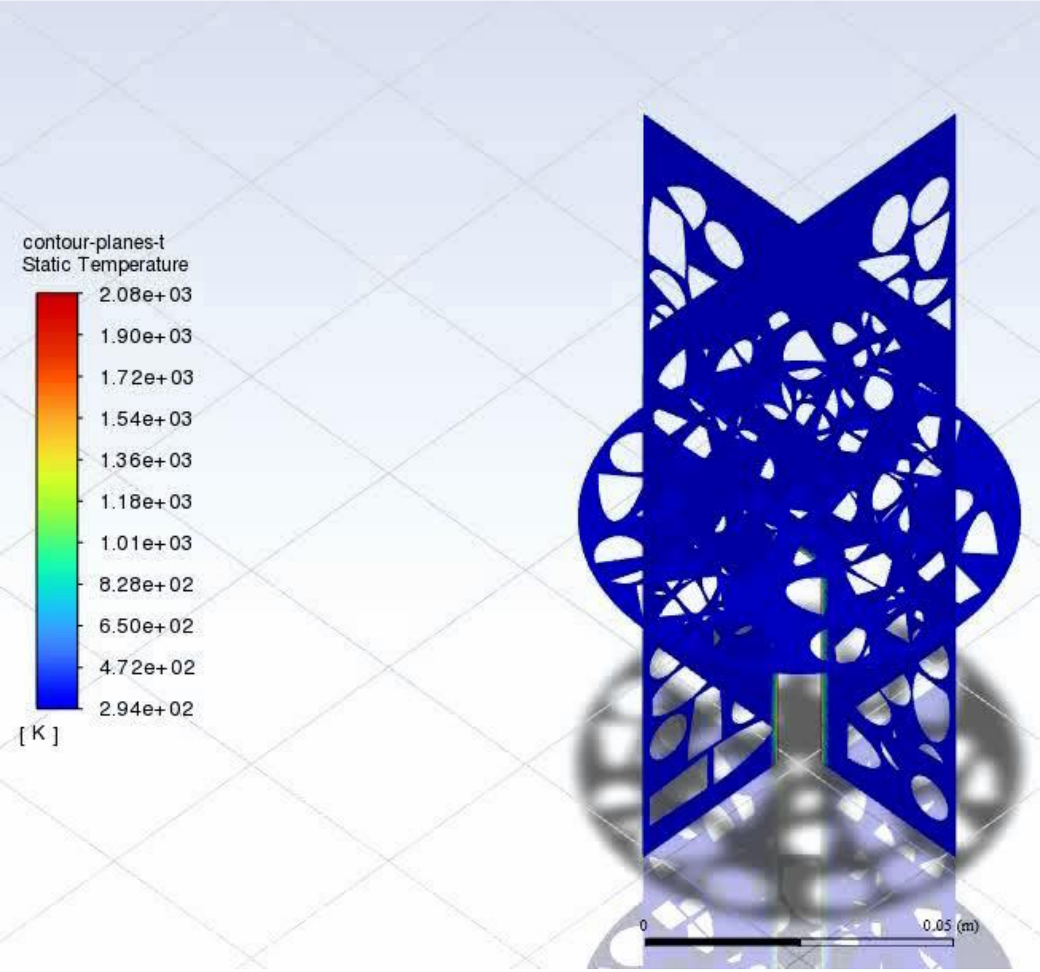
- Ignition Gases simplified as generic hot gas, no particles
- Boundary and initial conditions
  - Inflow of hot gas through whole surface of central core igniter
  - Surface of combustion chamber as convective wall
  - Surface of propellants as convective wall
- Discretized by implicit methods of second order
- Adaptive time step size based on CFL condition



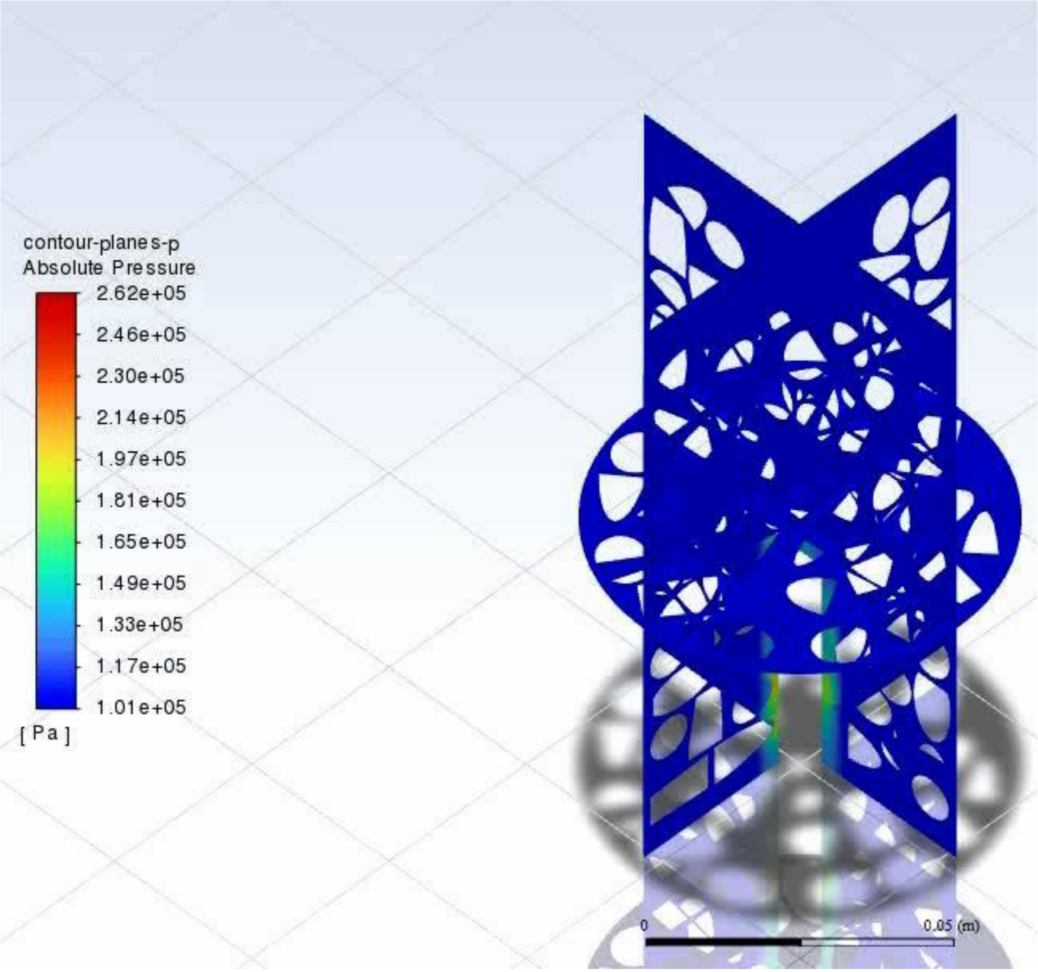
Discretized computational domain consisting of the gap area between the particles.

Simulation of pressure and temperature distribution

Multidimensional slices of the combustion chamber



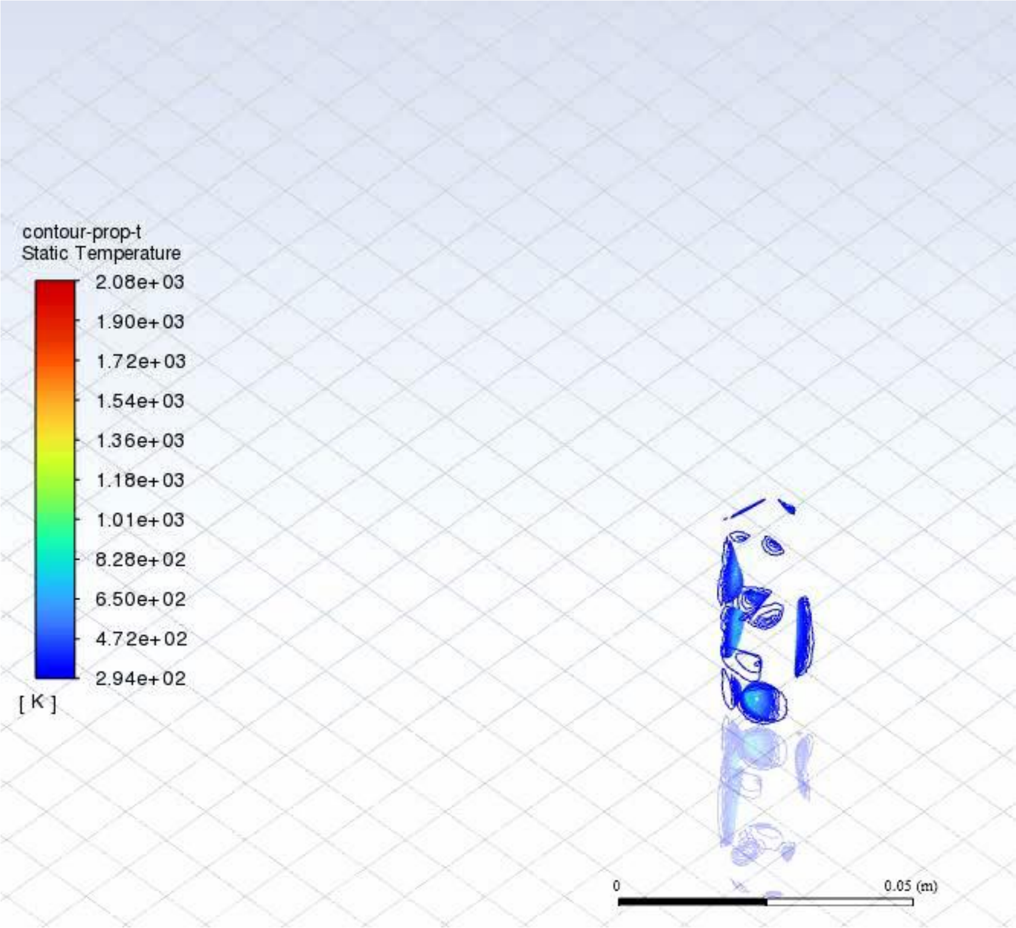
Temperature Distribution in the gaps in the combustion chamber.



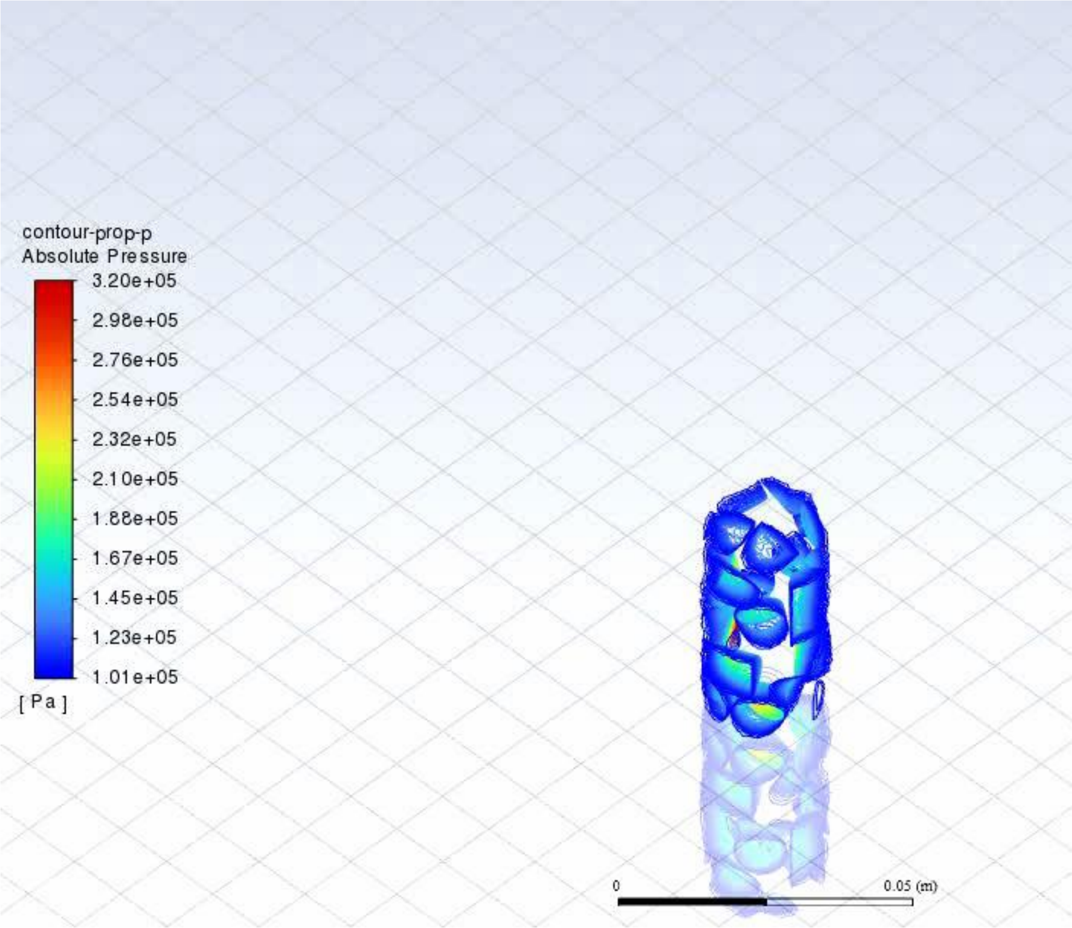
Pressure Distribution in the gaps in the combustion chamber.

Simulation of pressure and temperature distribution

Boundary values of the particles



Temperature Distribution on the propellant surfaces.

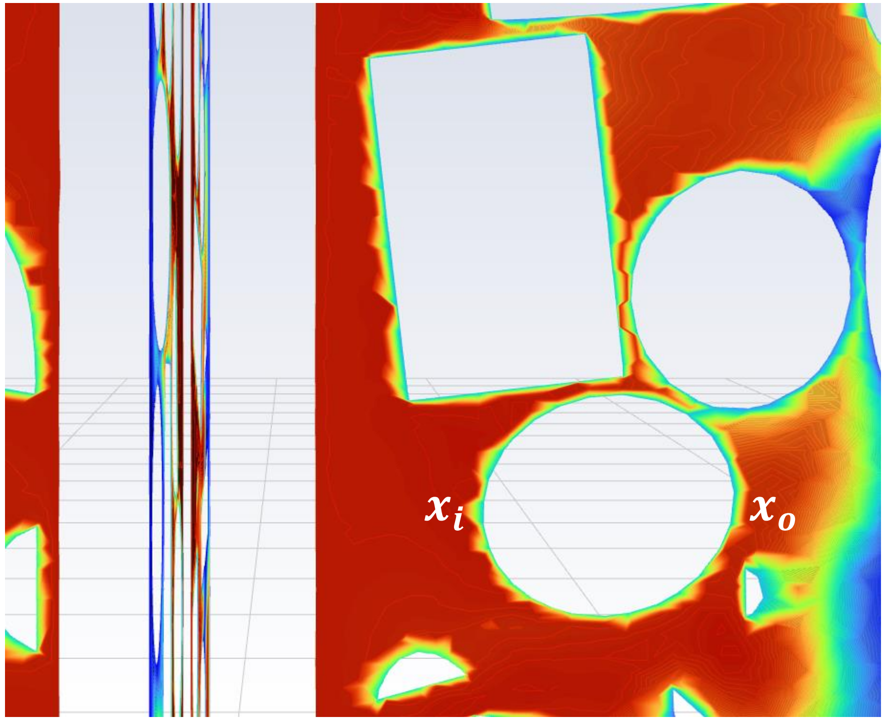


Pressure Distribution on the propellant surfaces

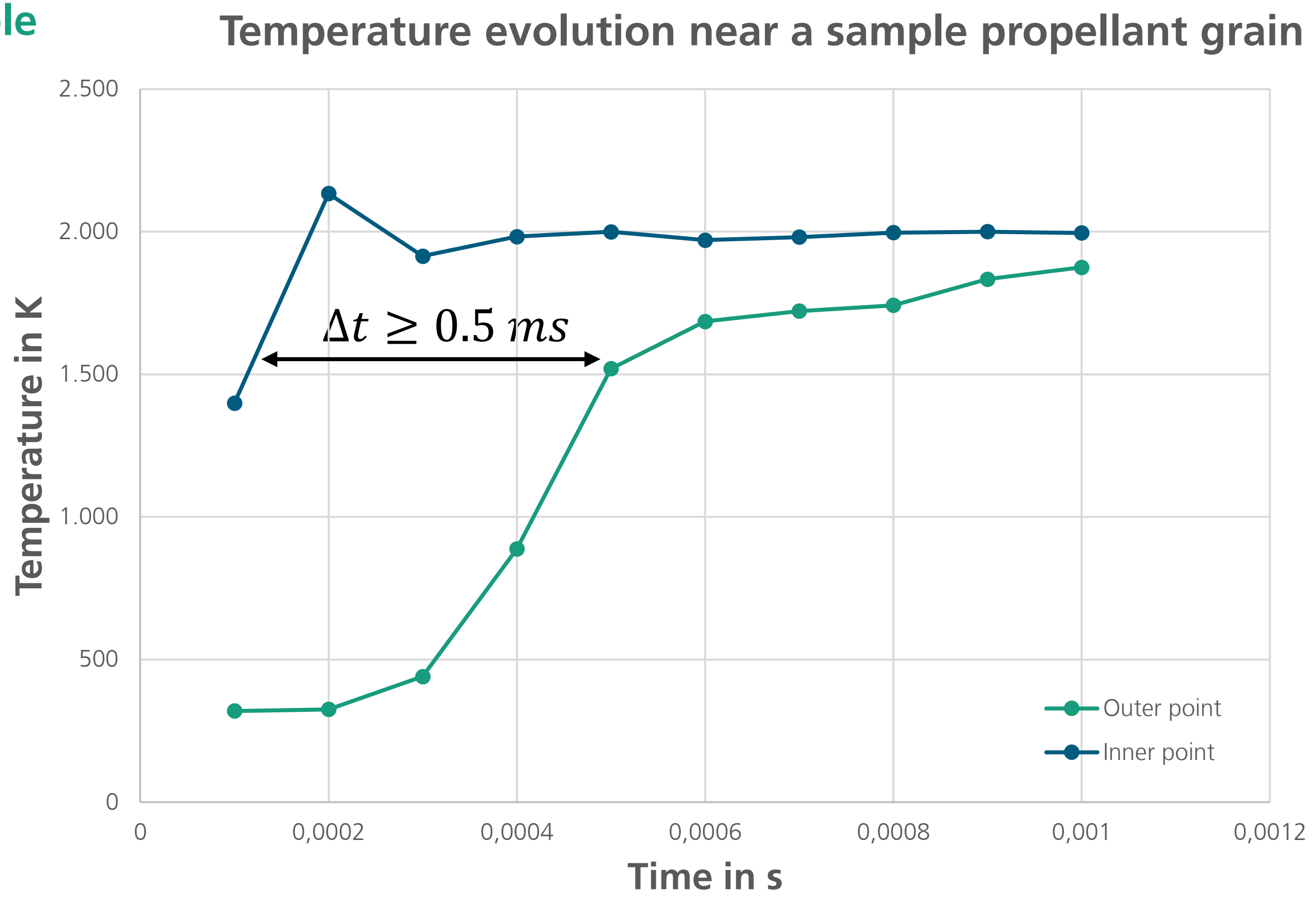
Detailed temperature distribution on a sole propellant

Particle surface heating delay

Detailed investigation of early ignition stage possible



Sample points on the igniter faced side and the opposing side of a propellant inside the simulated propellant bed.



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Conclusion and outlook

Work in progress and future Work

- Computational time still unreasonably high
  - Parallel computation on HPC cluster
- Overlapping of some particles due to DEM
  - Internal meshing tool not unconditionally useable
  - Some particles need to slightly shrinked (1-2%)

- More realistic modelling of the igniter (Particles)
- Direct coupling to RockyDEM to account for movement of propellant bed
- …

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Thanks for your Attention!

Contact

M. Sc. Daniel Tomaschewski
Interior Ballistics and Detonics
Department Energetic Systems
Tel. +49 721 4640-709
daniel.tomaschewski@ict.fraunhofer.de

Fraunhofer ICT
Joseph-von-Fraunhofer Str. 7
76327 Pfinztal
www.ict.fraunhofer.de

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