Deposition of Volcanic Ash within Gas Turbine Aeroengines

J. Dean, C. Taltavull, M. Shinozaki, K. Roberts and T. W. Clyne

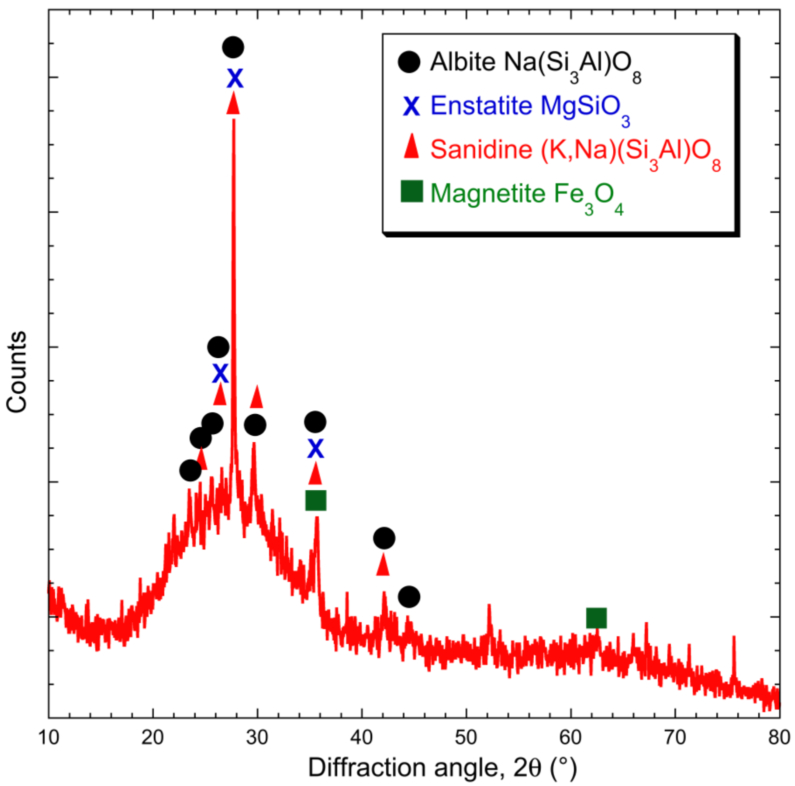
doubleprecision
fea and multiphysics

The Gordon Laboratory

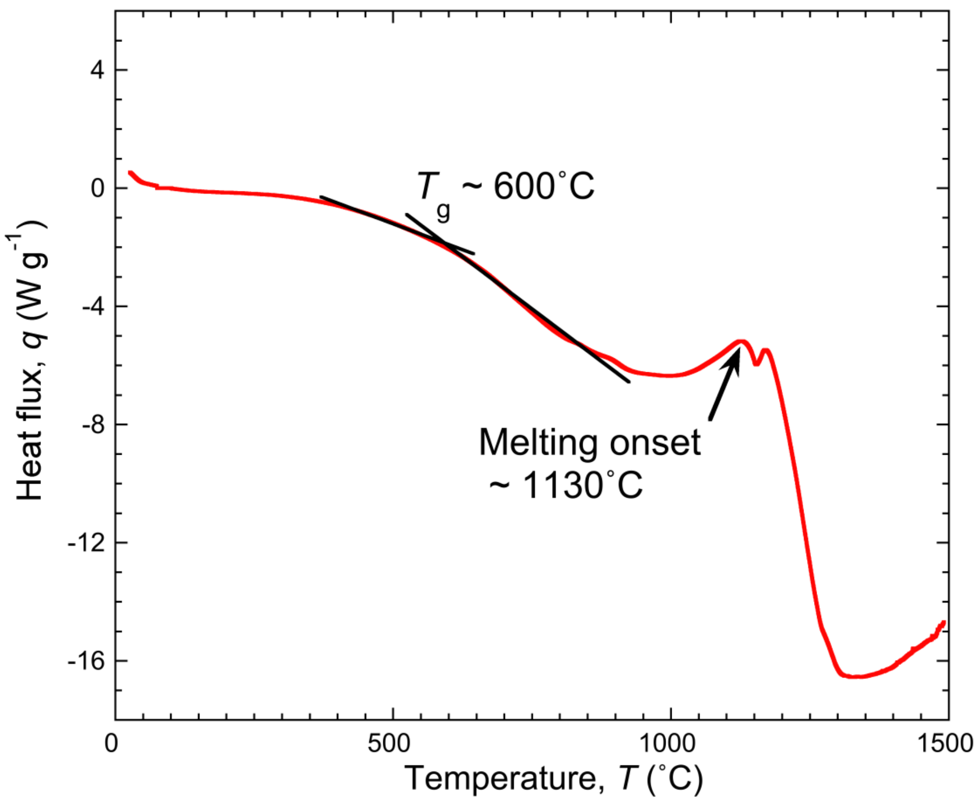
Talk Outline

- Likelihood of Ingested CMAS Particles being Deposited within a Gas Turbine
- Deposition Characteristics – Combustion Chamber Simulation Experiments
- Numerical Modelling of the Combustion Chamber Simulation Experiments

Phase Constitution of Volcanic Ash (Laki, Iceland)



XRD spectrum

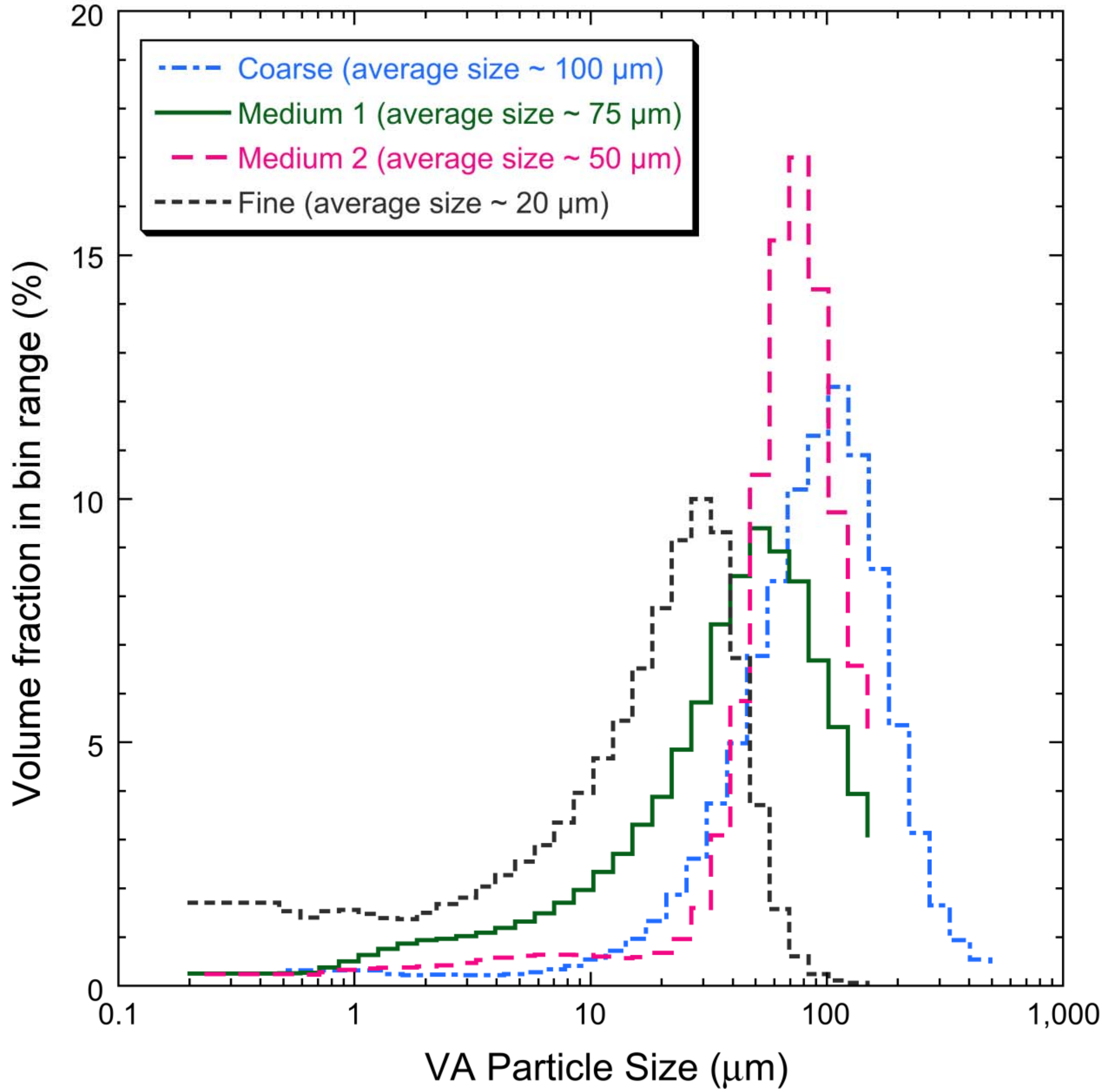


DSC plot

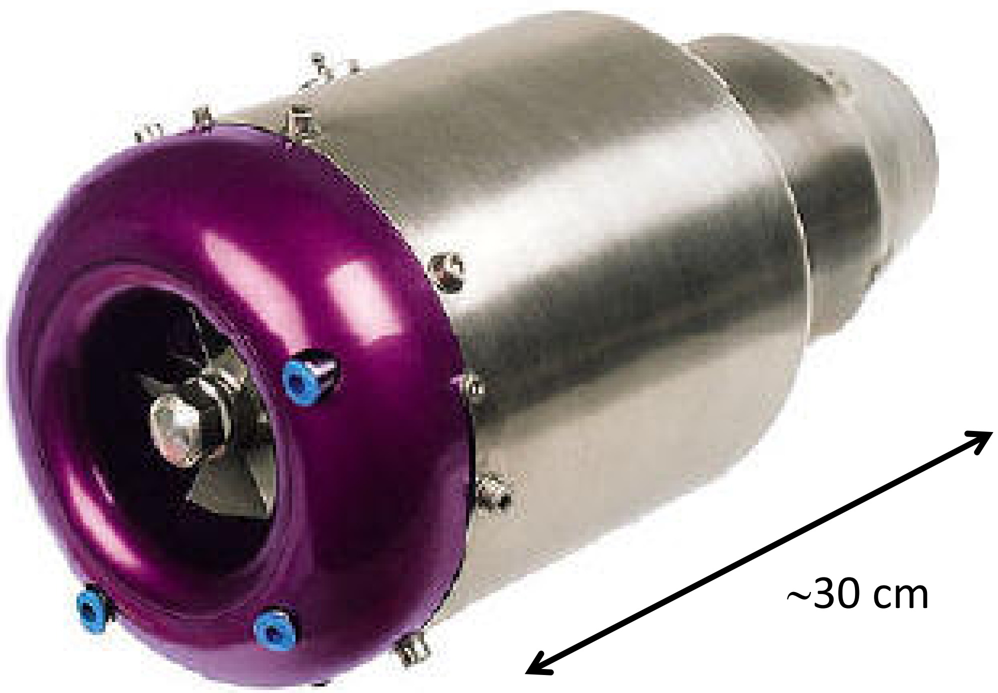
80-90% Amorphous

Particle Softening at T_g

Particle Size Distributions for Sieved Volcanic Ash



Experimental Set-up for Ingestion of VA into a Turbojet Engine



Pegasus Turbojet

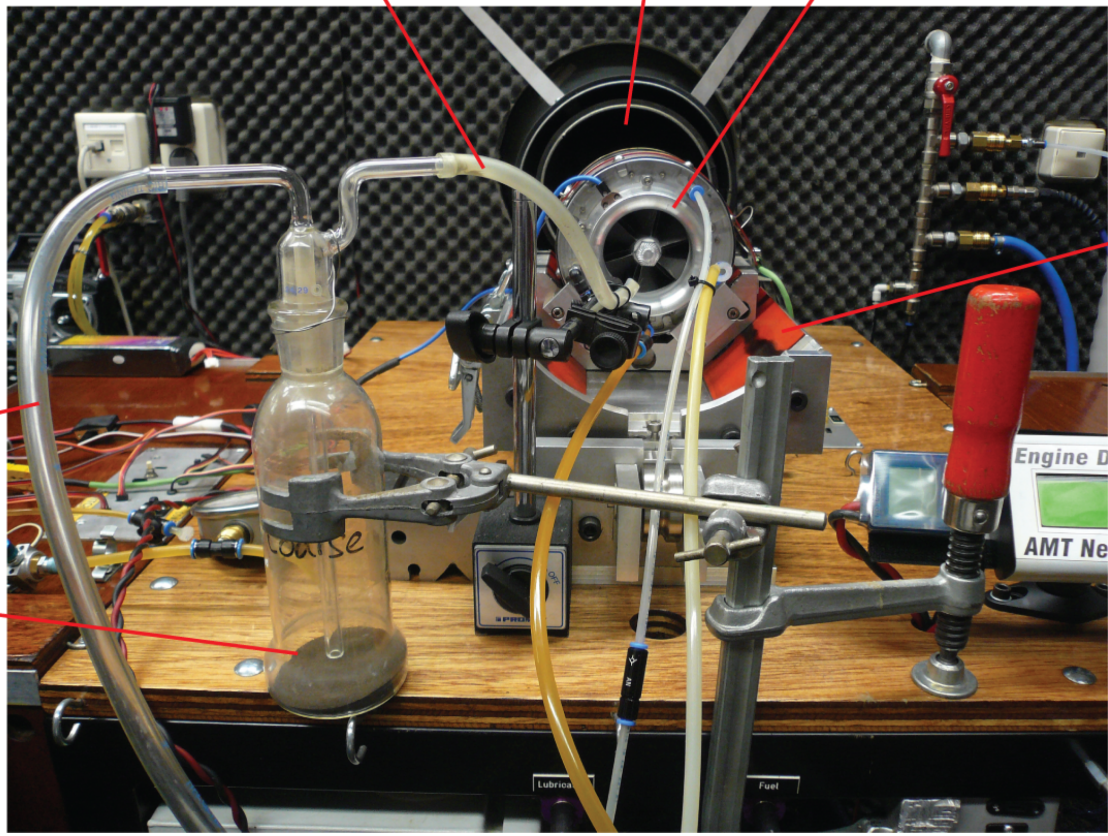
140 N Thrust @ 120,000 rpm

Experimental Set-up for Ingestion of VA into a Turbojet Engine

Engine exhaust extraction

VA feeding tube

Jet engine intake



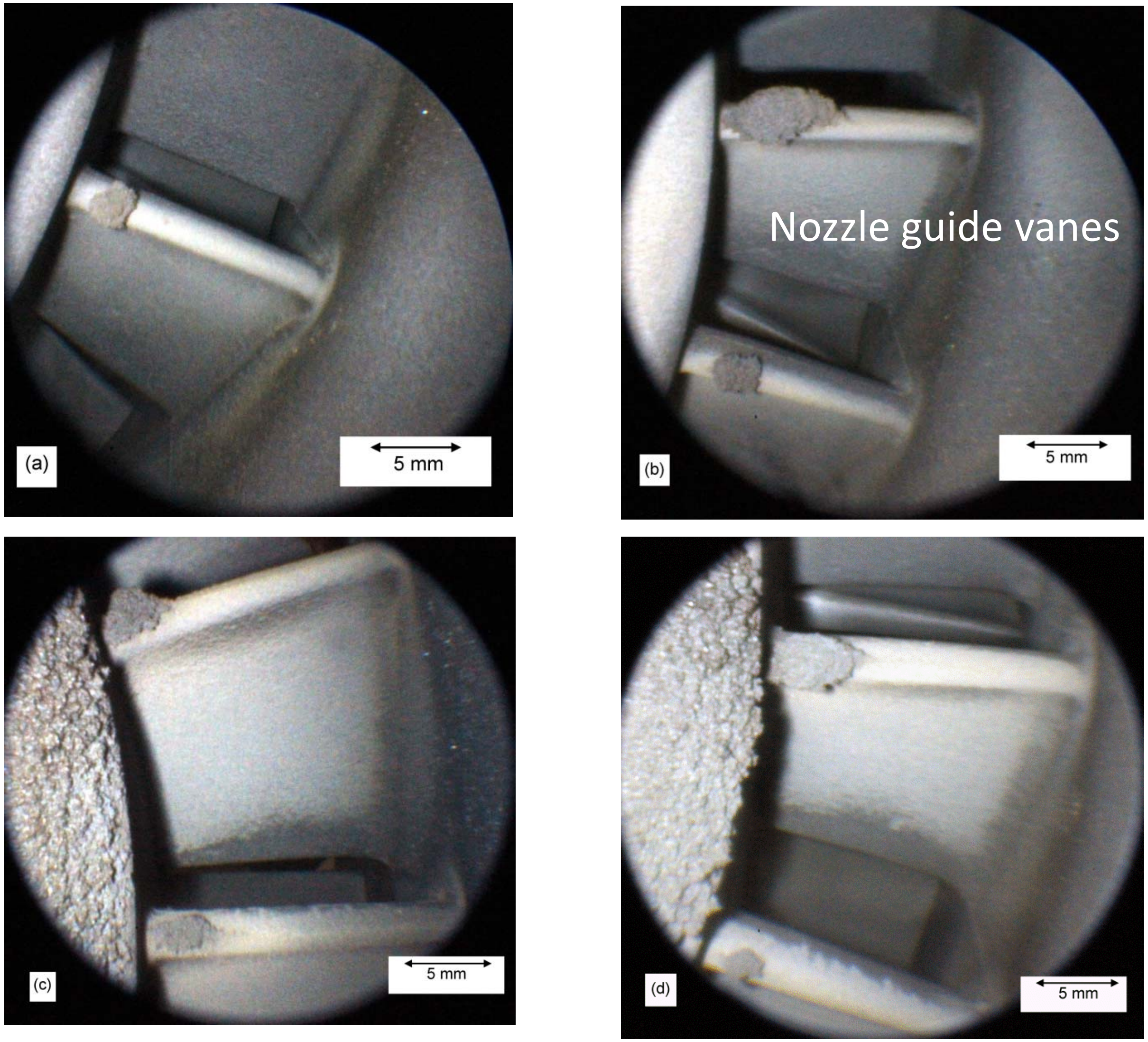
Engine mount for thrust measurement

Tube connecting to compressed air line

Dreschel bottle containing VA

Internal Deposition, viewed with an Optical Fibre Set-up

TET ~ 1070°C



Deposition Characteristics

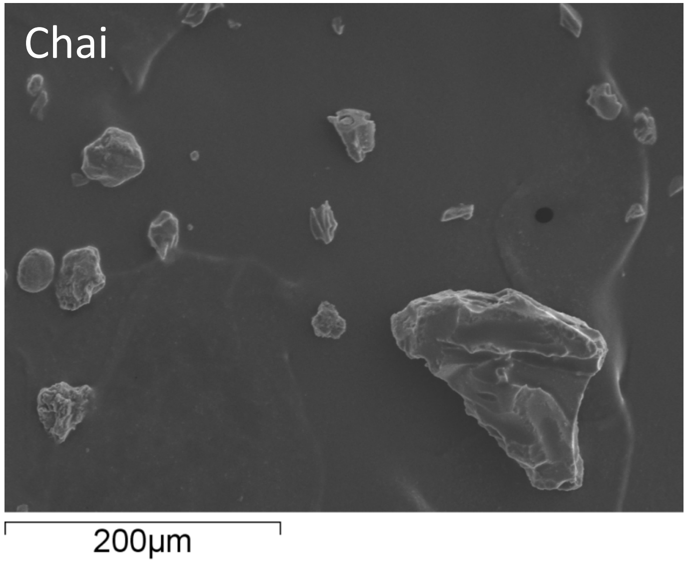
Significance of ash characteristics…

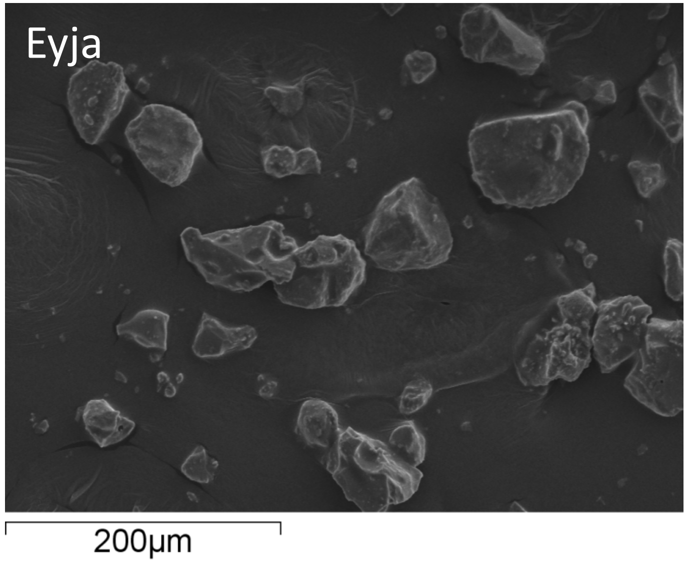
- *Phase constitution (amorphous content)*
- *Softening temperature, T_g*
- *Particle Size (distribution)*

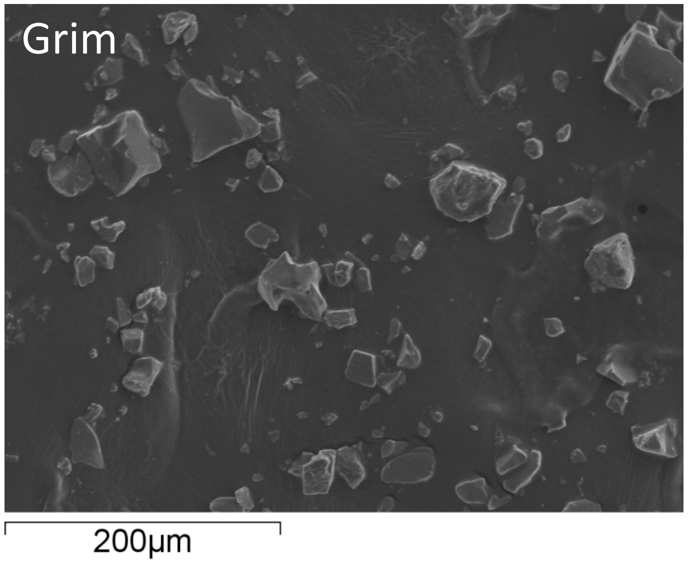
…in determining whether deposition is likely for given engine operating conditions

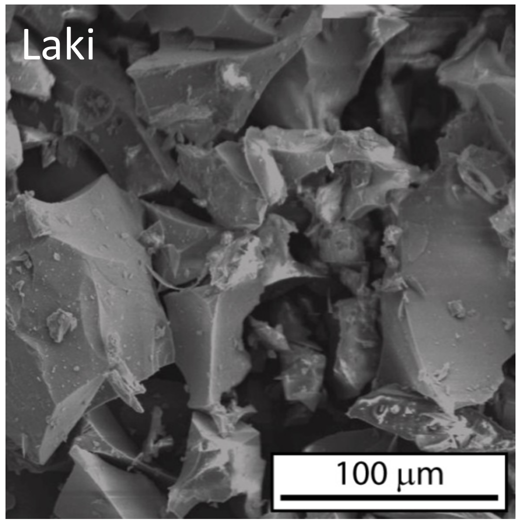
What combination of these characteristics are bad for the engine? Can we develop a useful set of guidelines?

Deposition Characteristics
Combustion Chamber Simulation Experiments

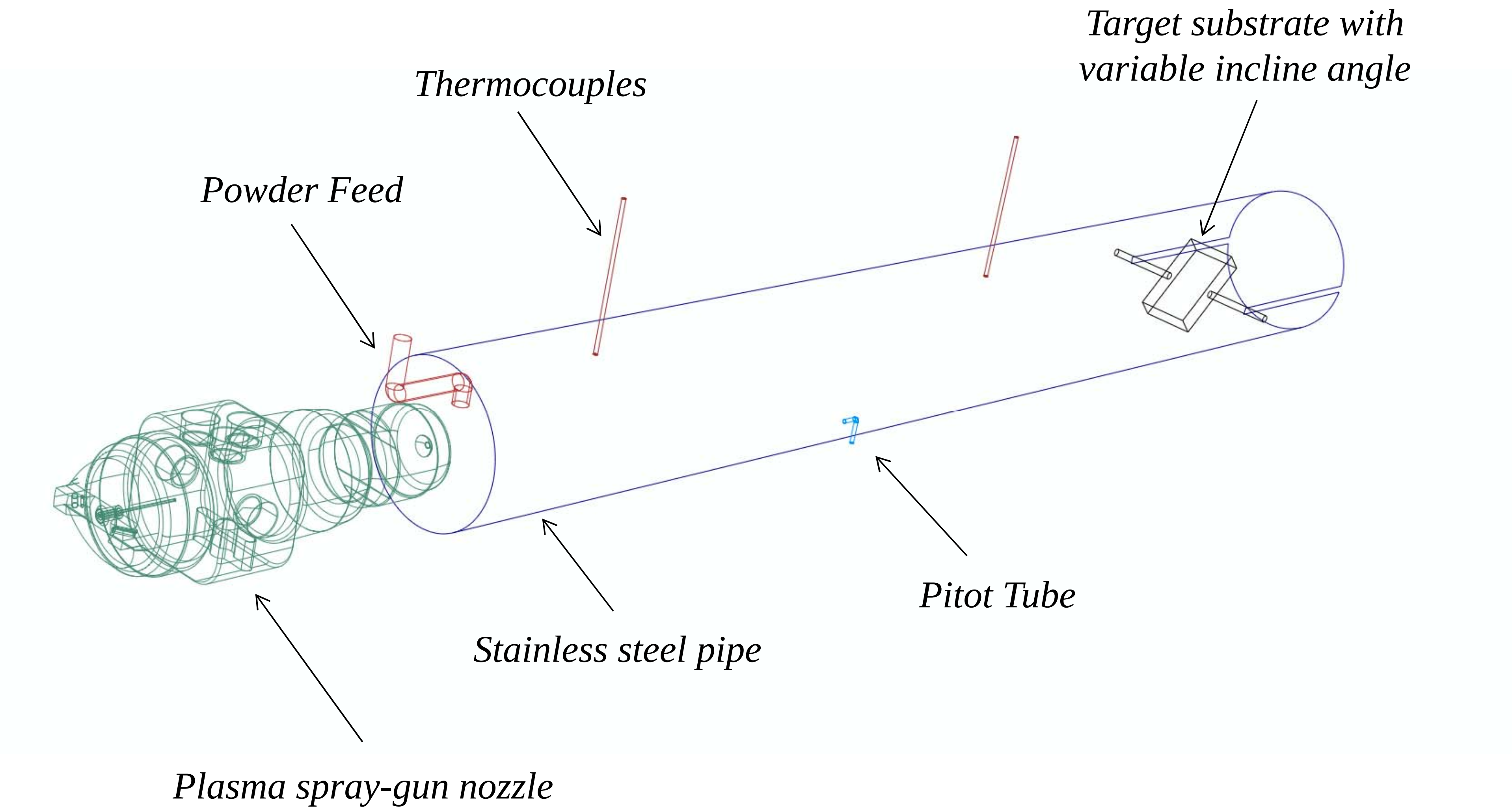




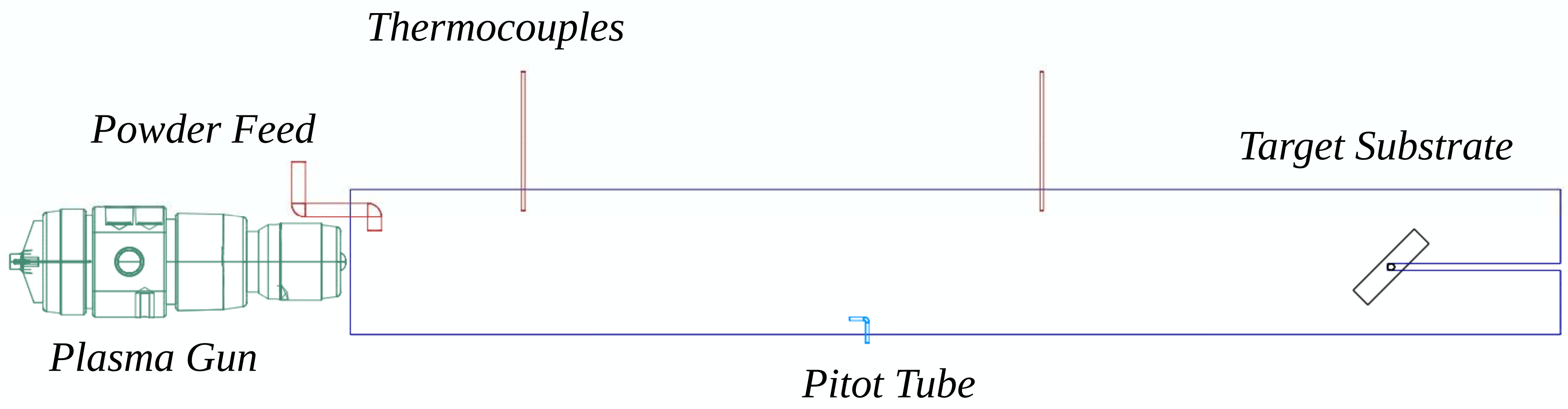




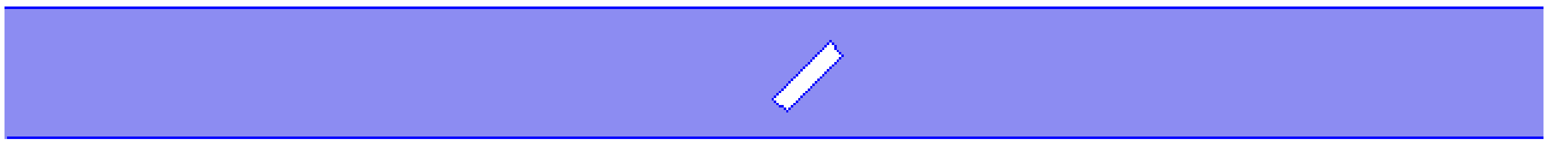
Deposition Characteristics
Combustion Chamber Simulation Experiments



Deposition Characteristics
Combustion Chamber Simulation Experiments



Numerical Modelling of the Combustion Chamber Simulation Experiments



Numerical Modelling of the Combustion Chamber Simulation Experiments

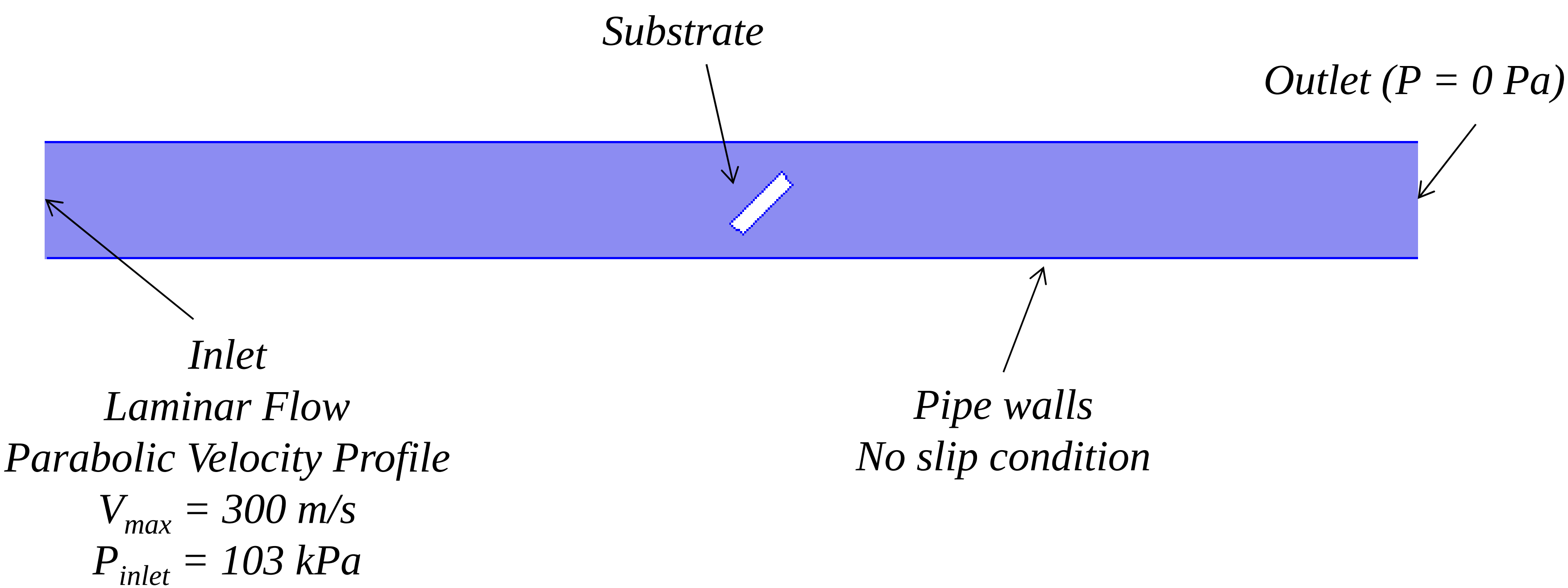
COMSOL MULTIPHYSICS®

Air

T = 293 K

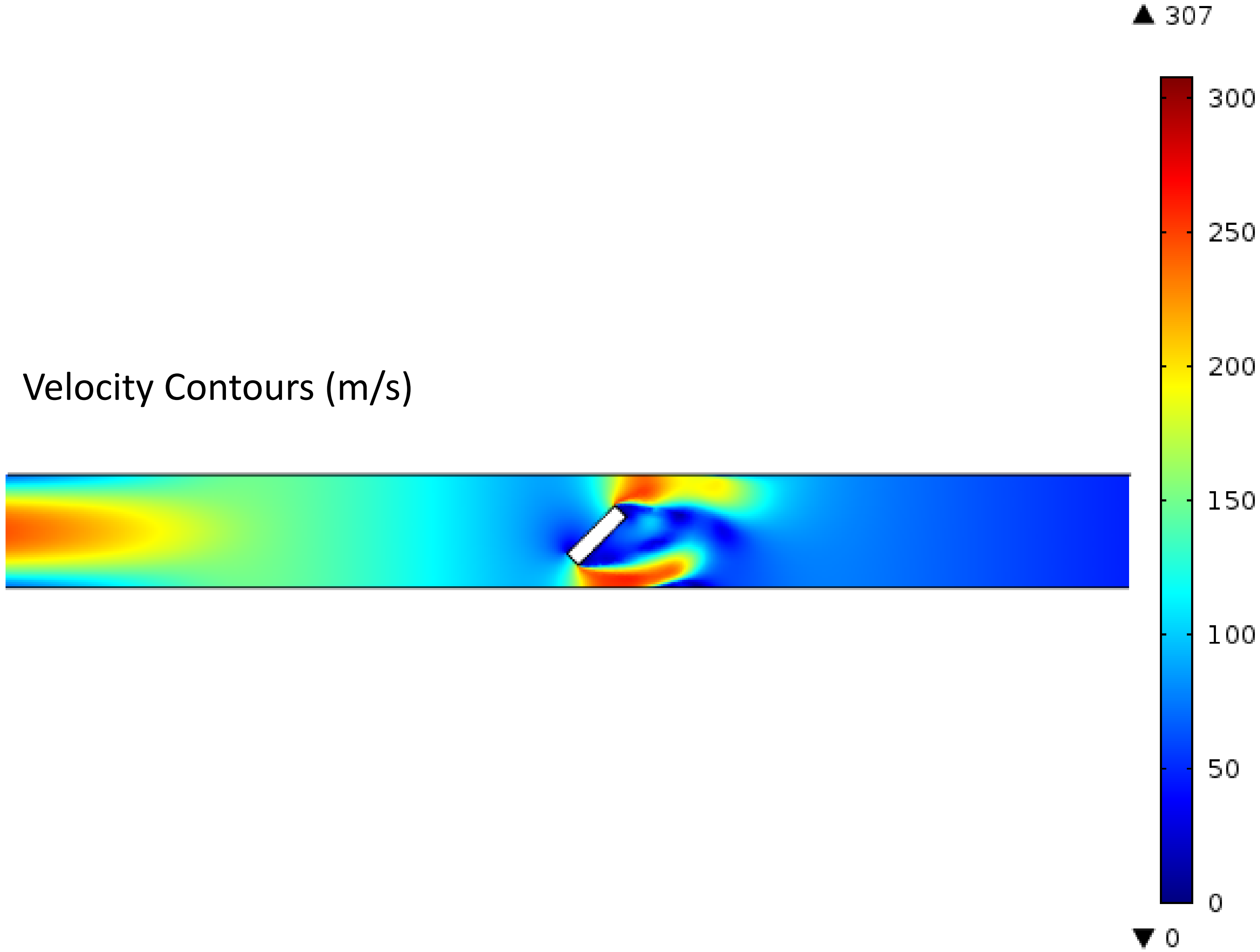
ρ = 1.3 kg/m^3

μ = 1.98×10^{-5} Pa.s



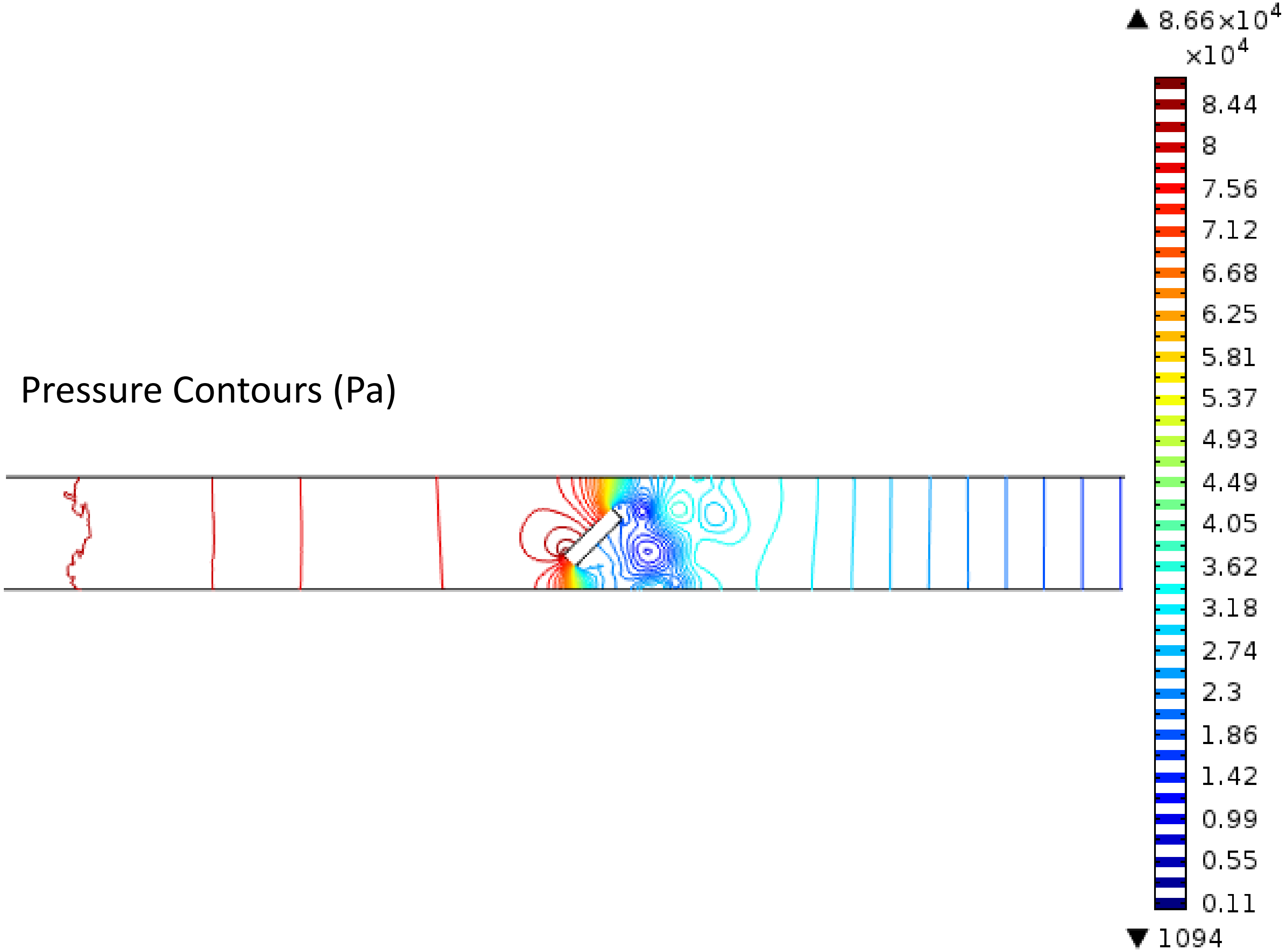
Numerical Modelling of the Combustion Chamber Simulation Experiments

Velocity Contours (m/s)



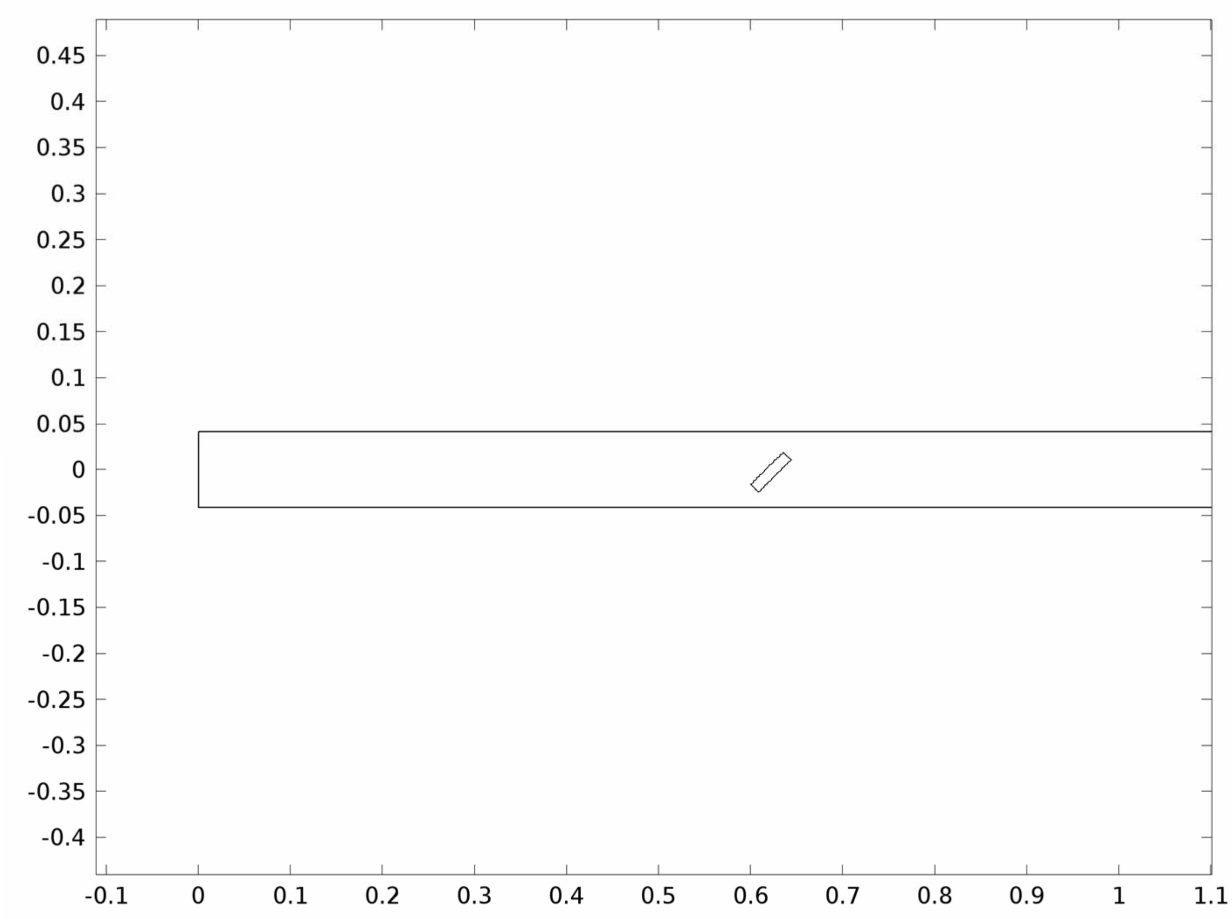
Numerical Modelling of the Combustion Chamber Simulation Experiments

Pressure Contours (Pa)

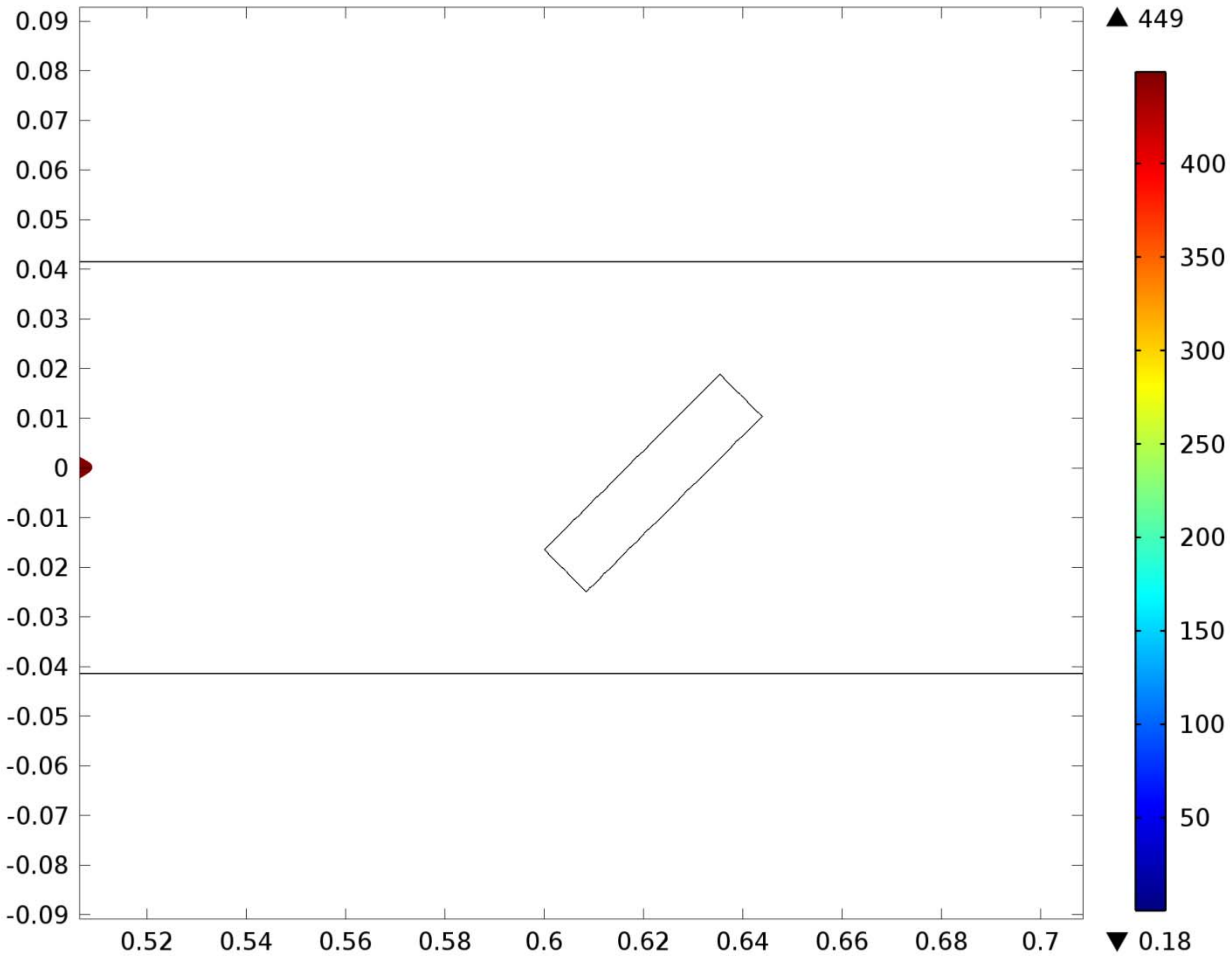


Numerical Modelling of the Combustion Chamber Simulation Experiments

Drop 200 μm diameter particles into the gas stream (m =9.2×10^{-9} kg)

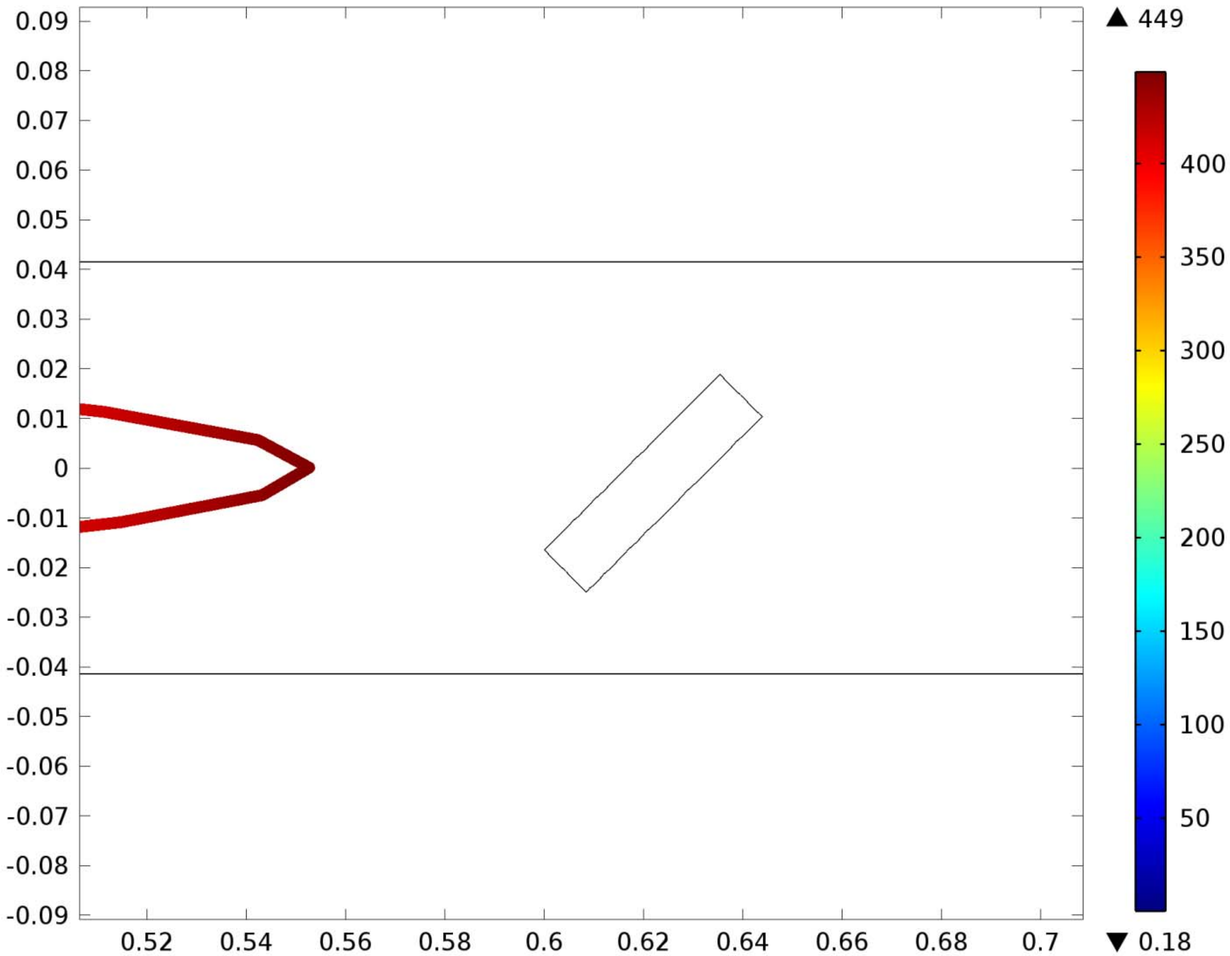


Numerical Modelling of the Combustion Chamber Simulation Experiments



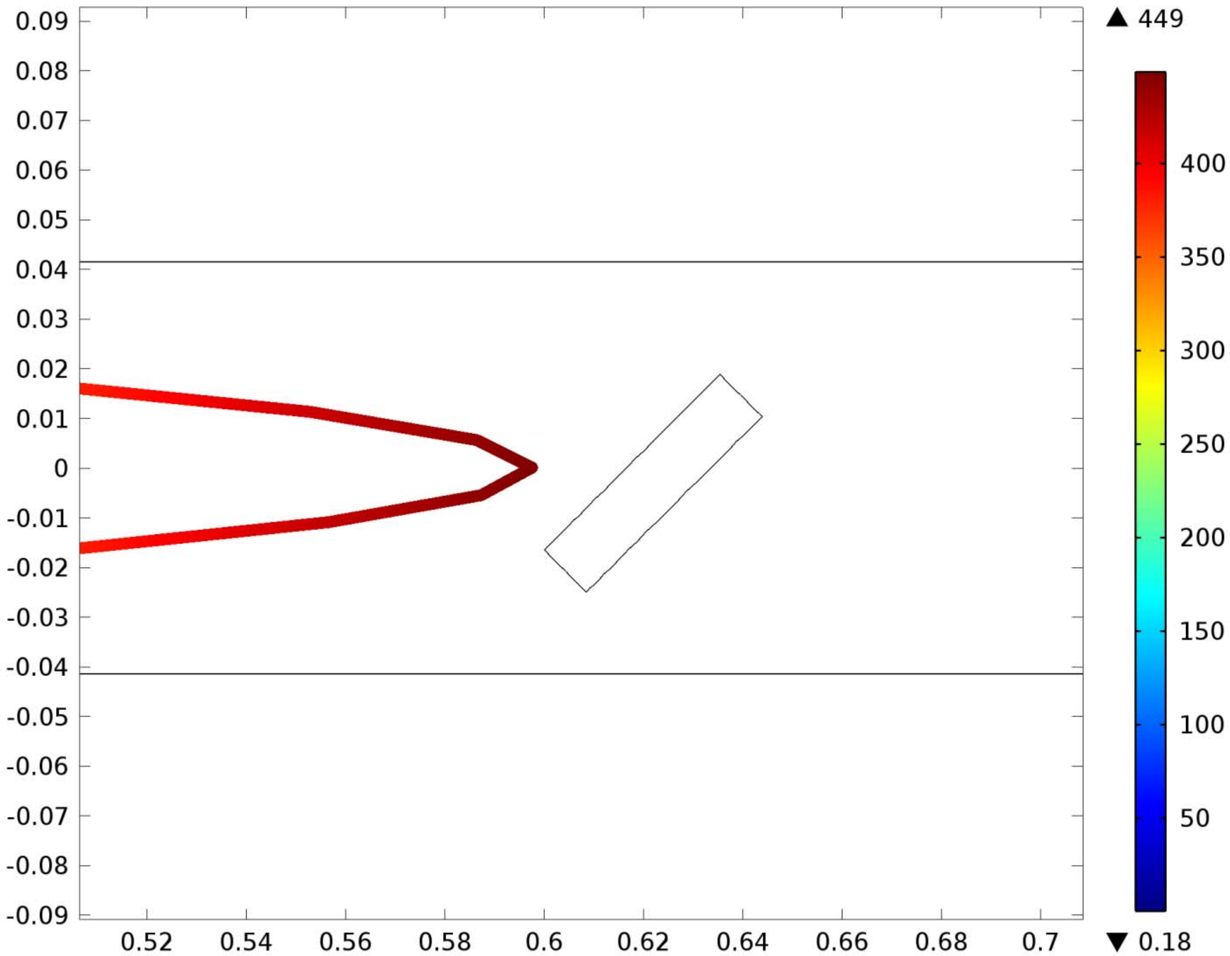
t = 0 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



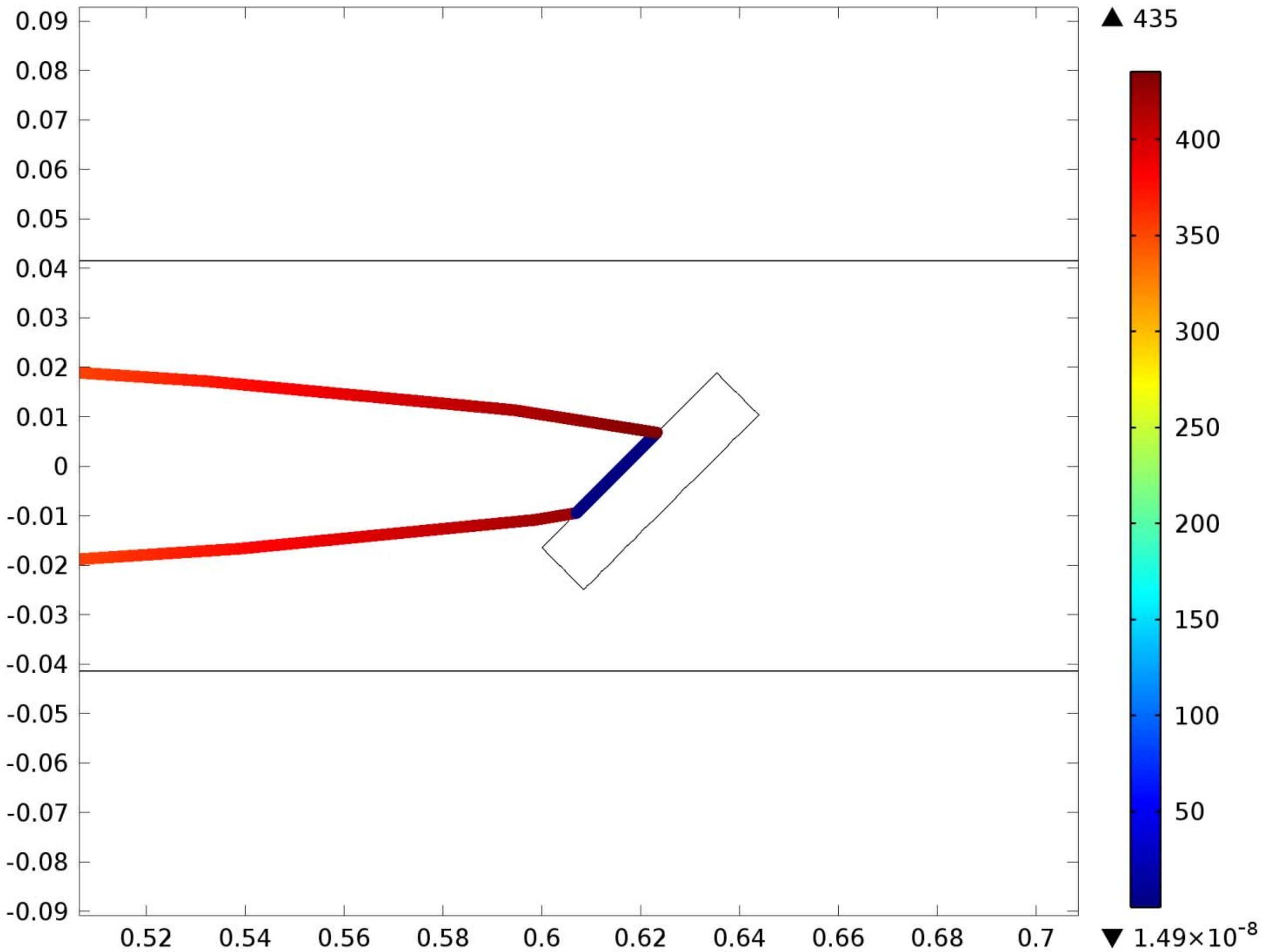
t = 1 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



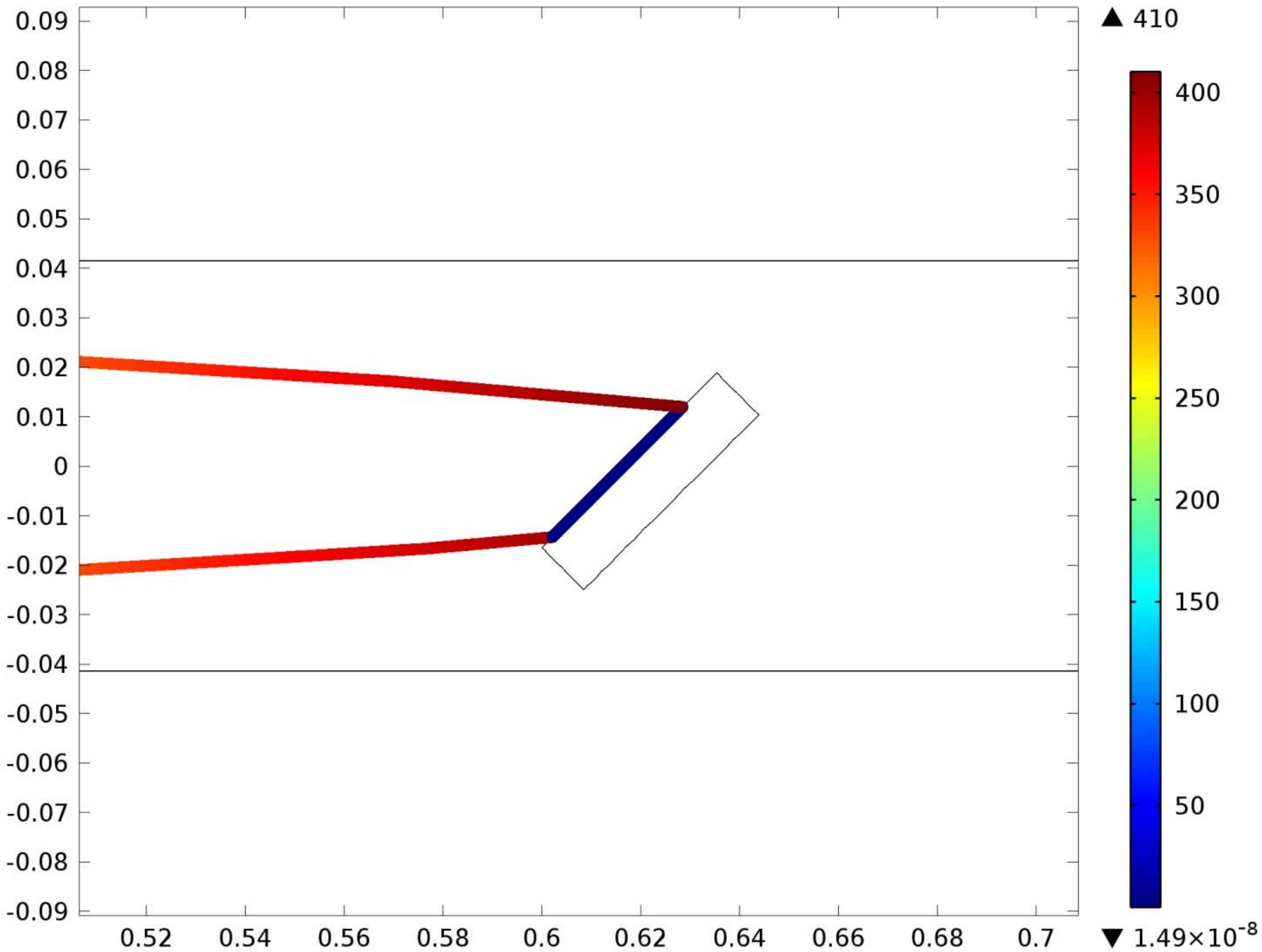
t = 2 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



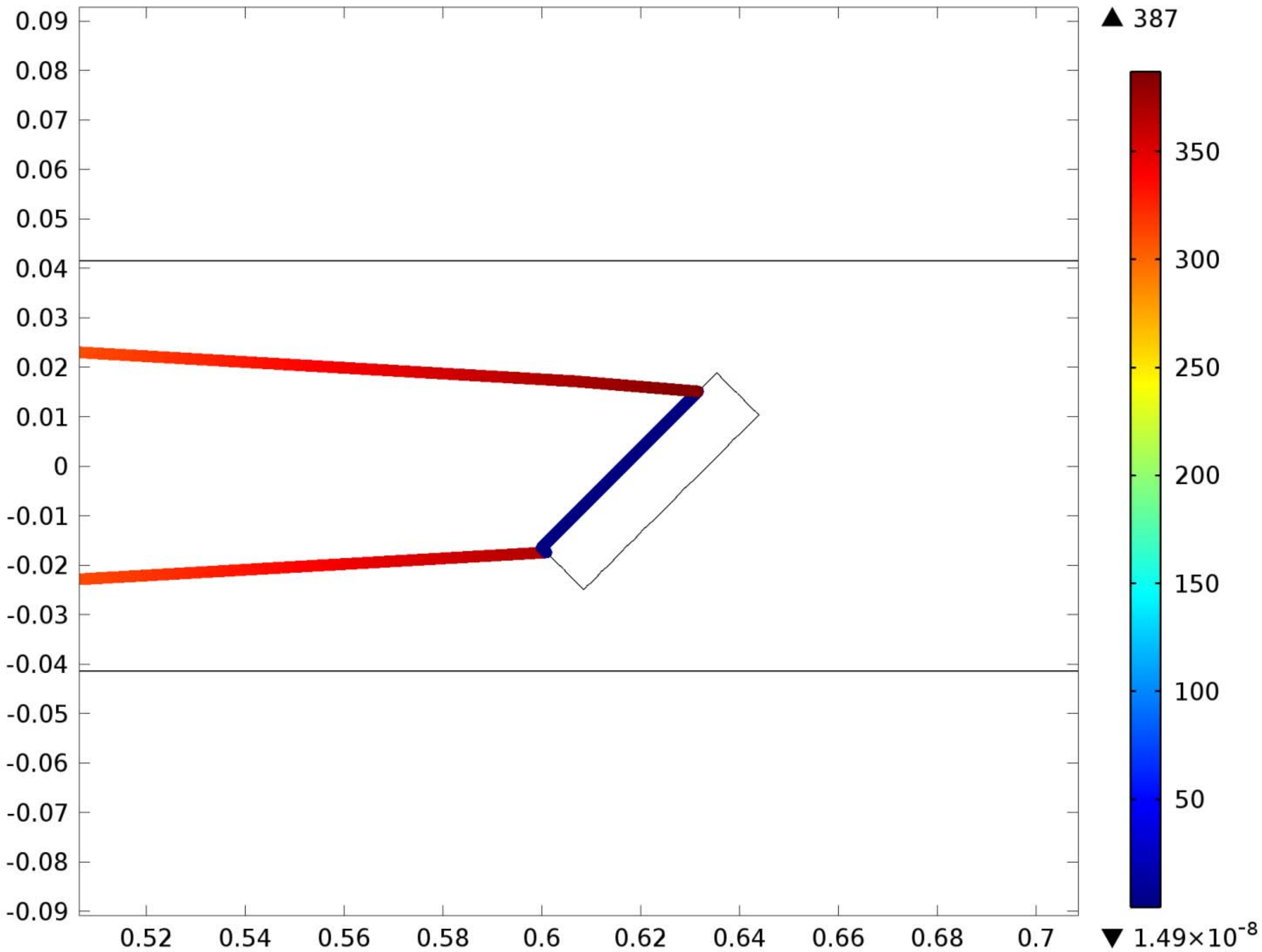
t = 3 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



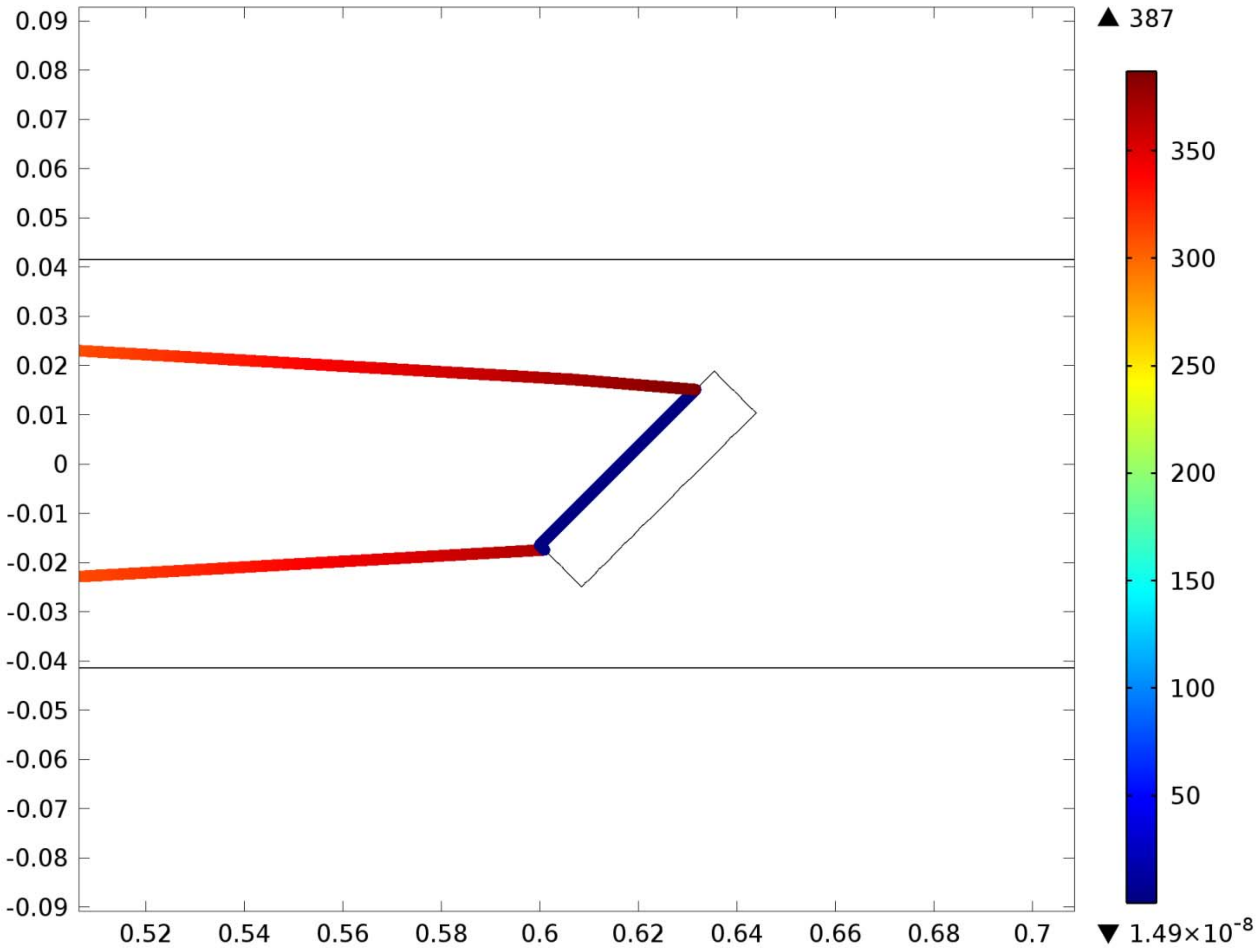
t = 4 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



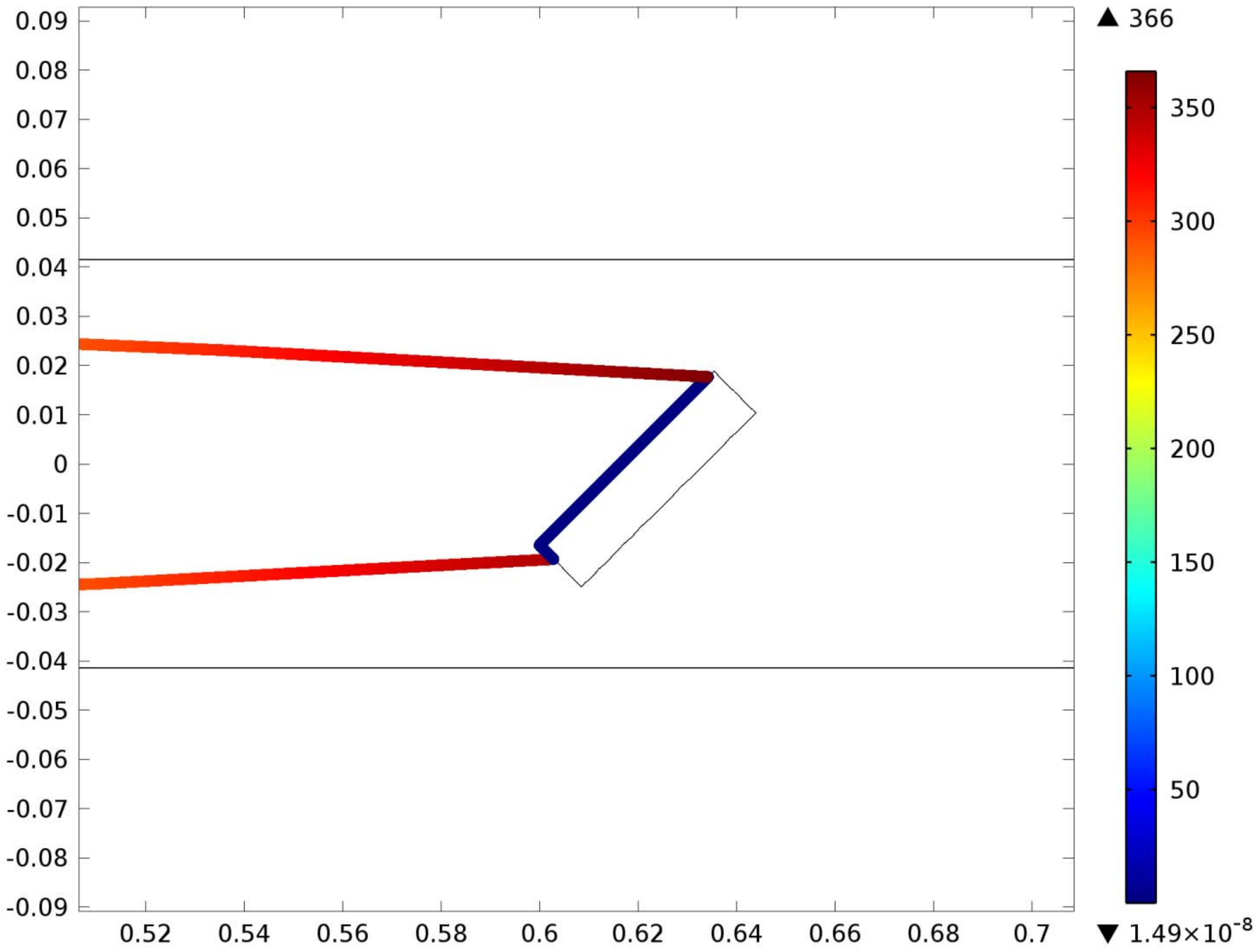
t = 5 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



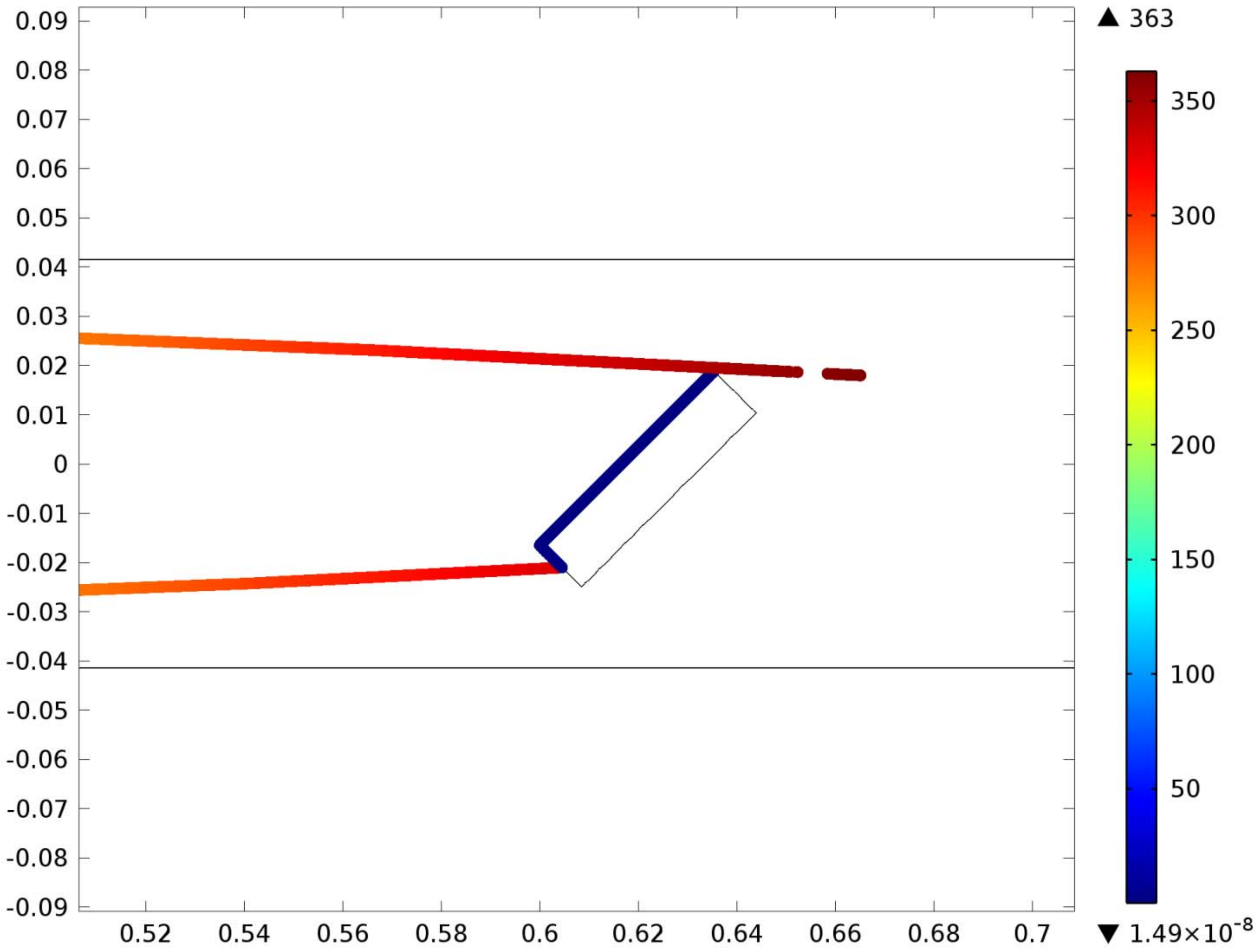
t = 6 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



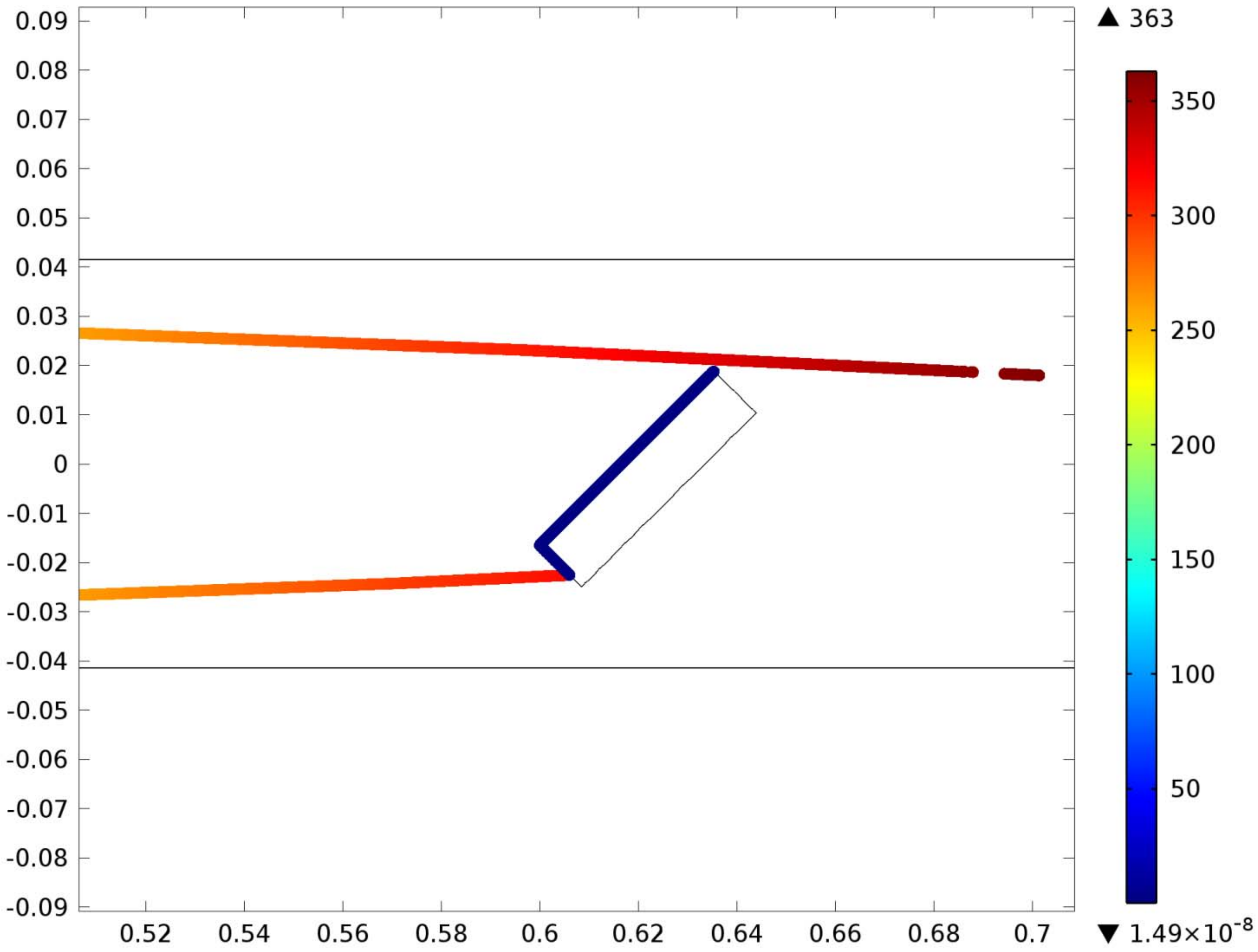
t = 7 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



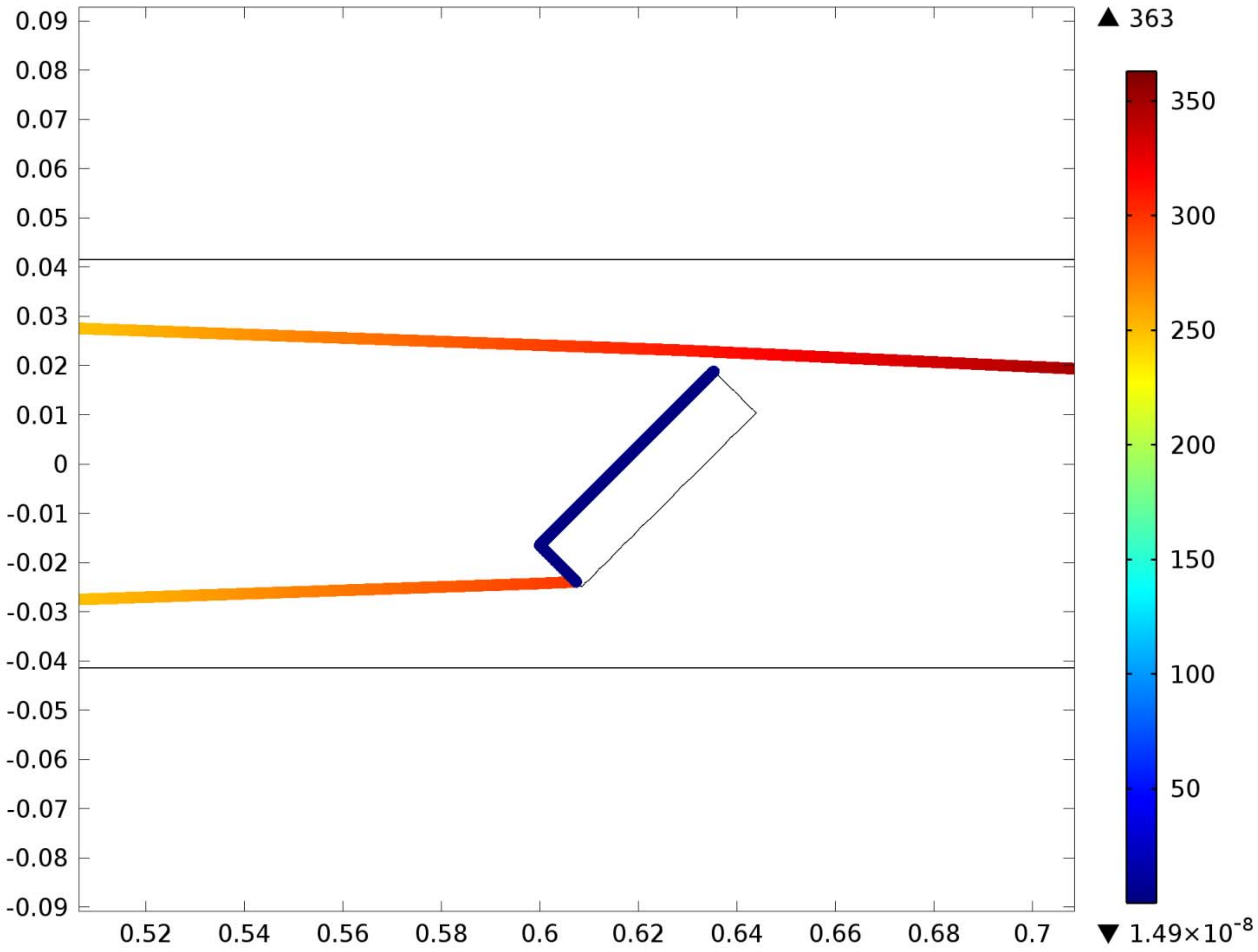
t = 8 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



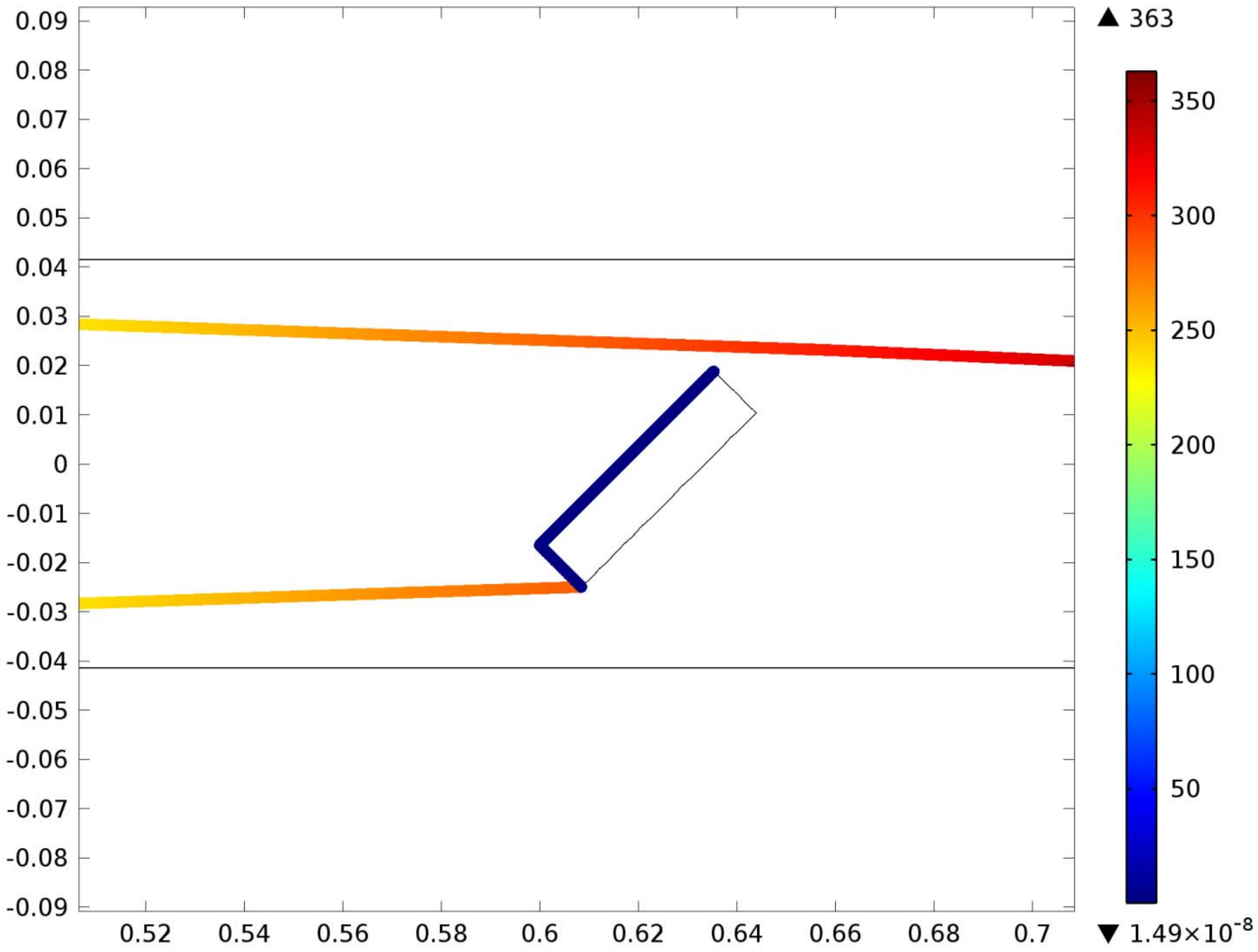
t = 9 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



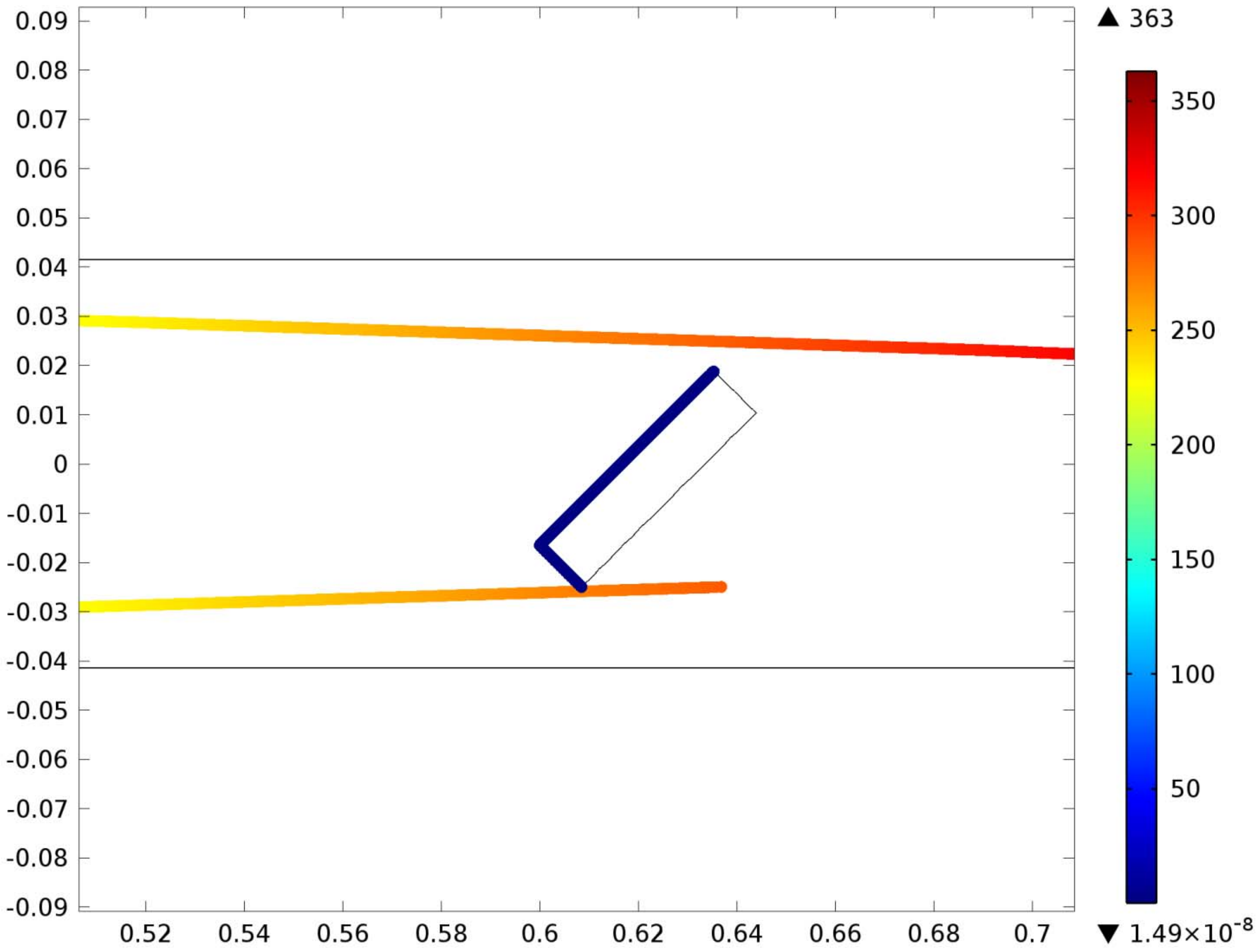
t = 10 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



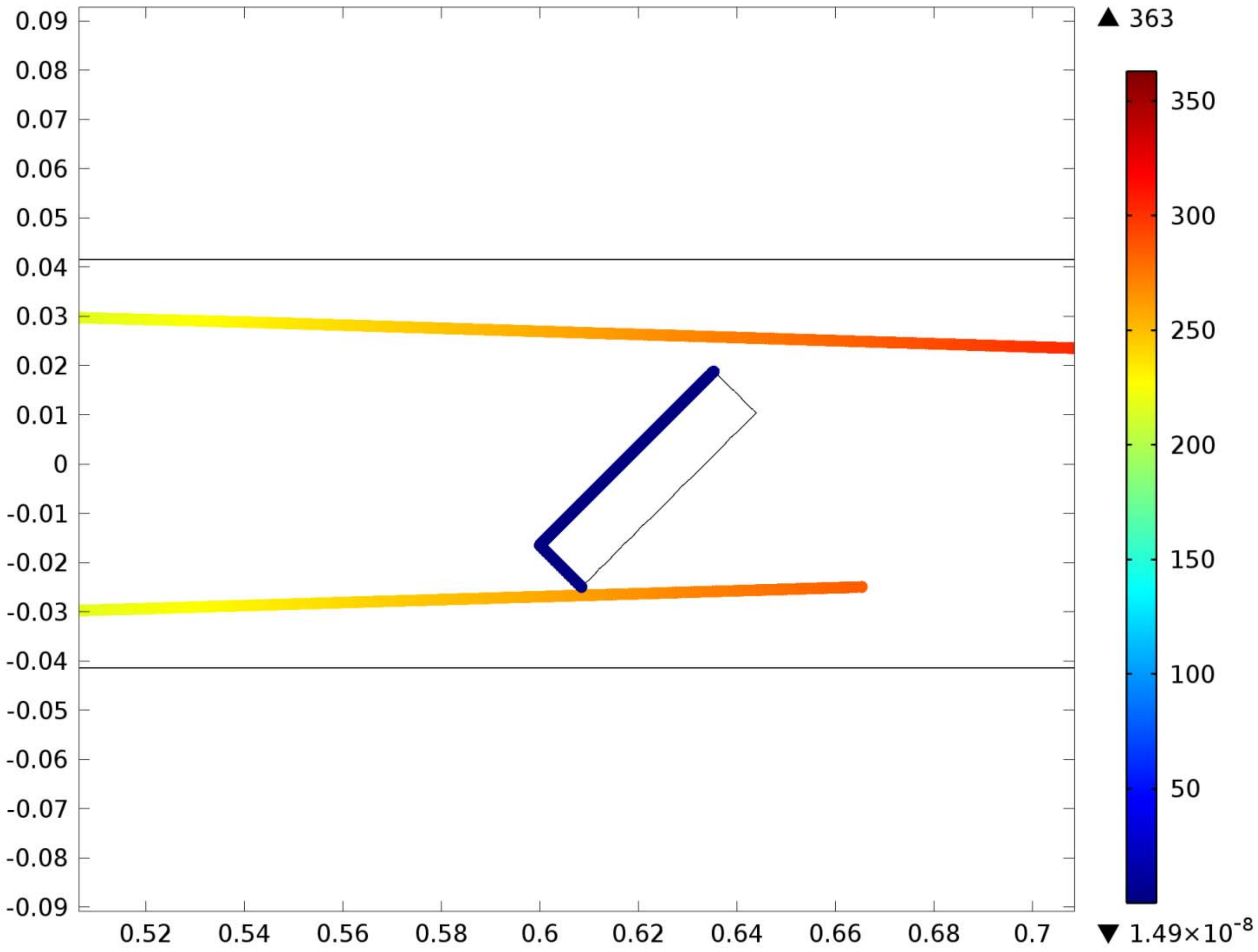
t = 11 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



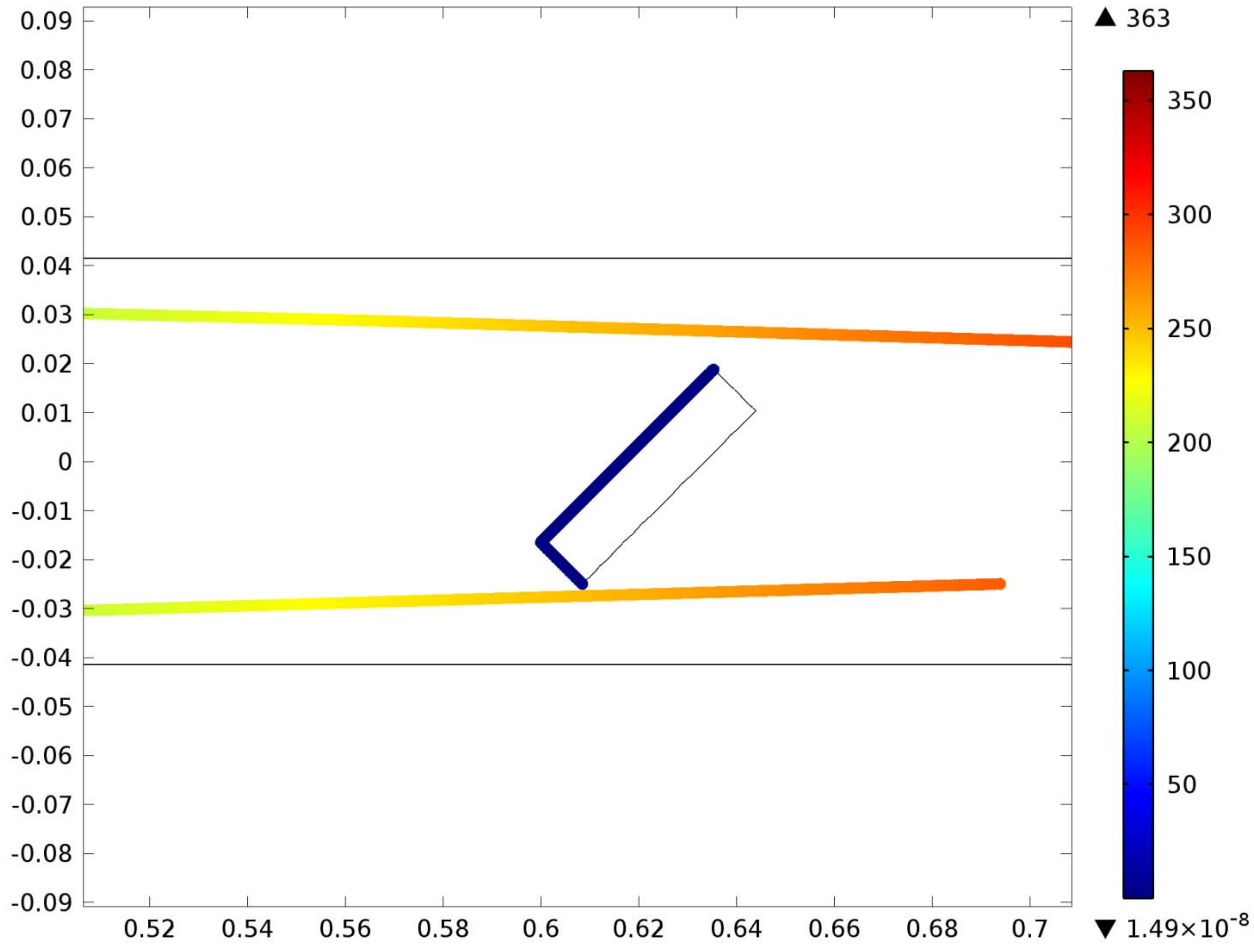
t = 12 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



t = 13 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments

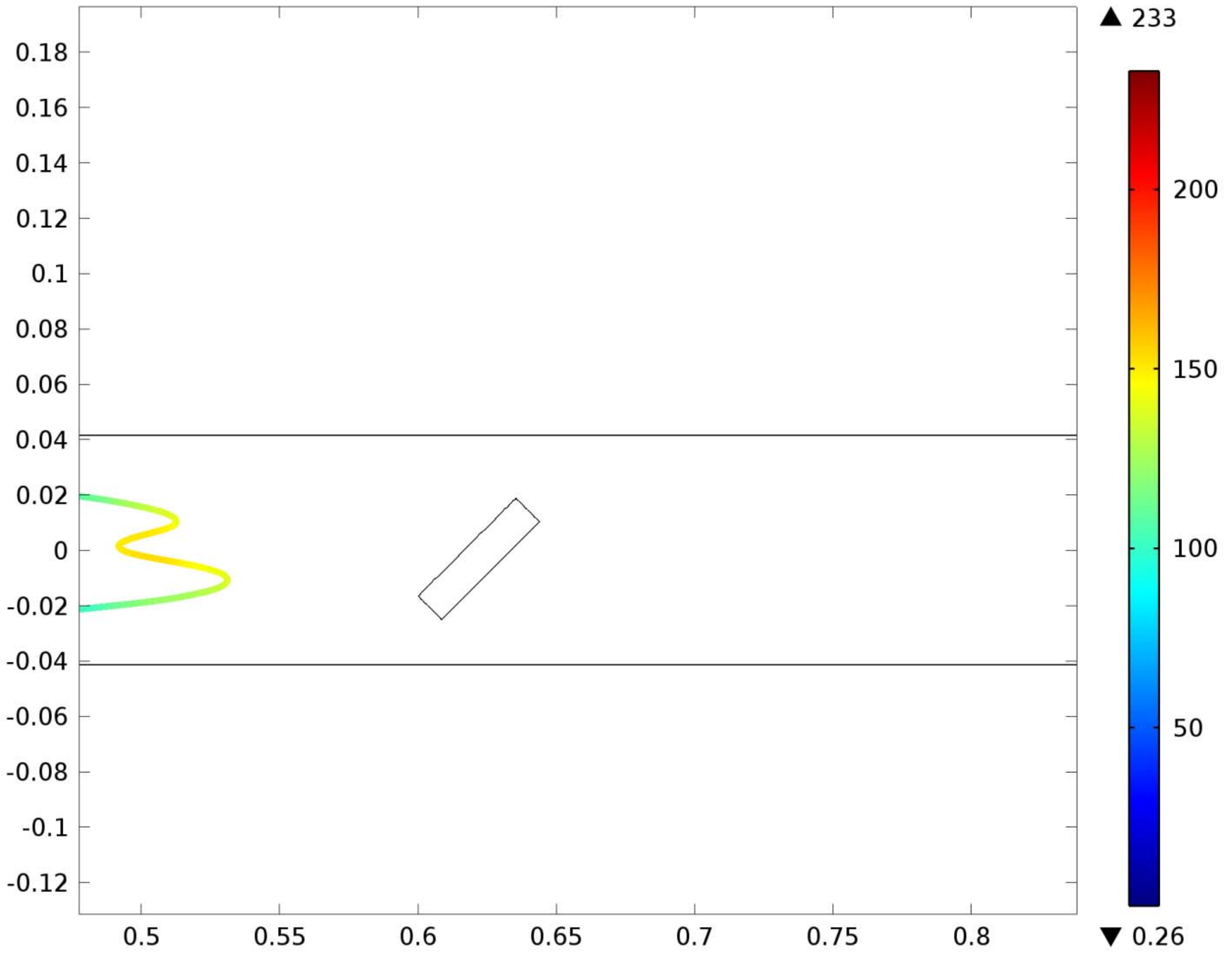


t = 14 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments

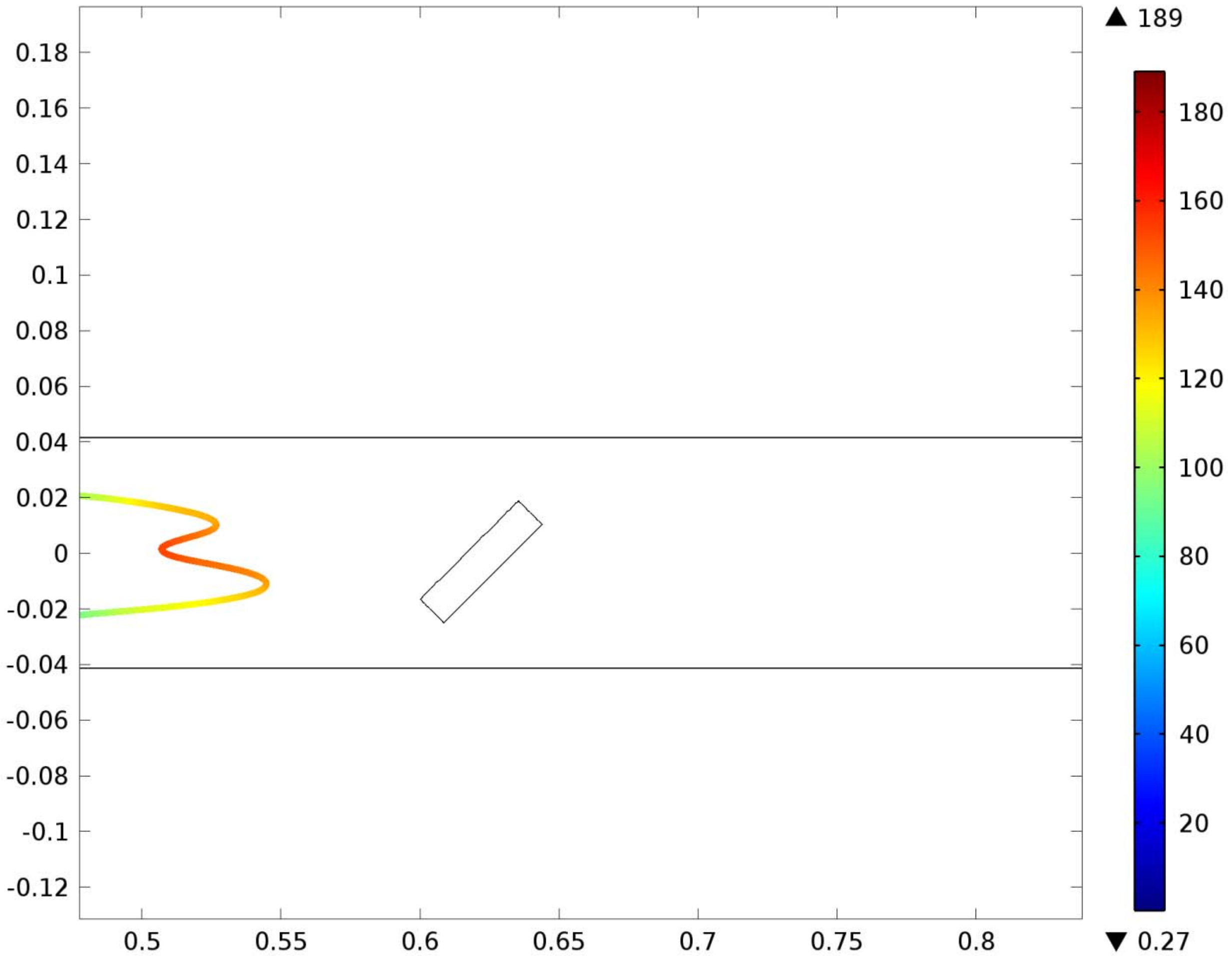
Drop 1 μm diameter particles into the gas stream ($m = 1.2 \times 10^{-15}$ kg)

Numerical Modelling of the Combustion Chamber Simulation Experiments



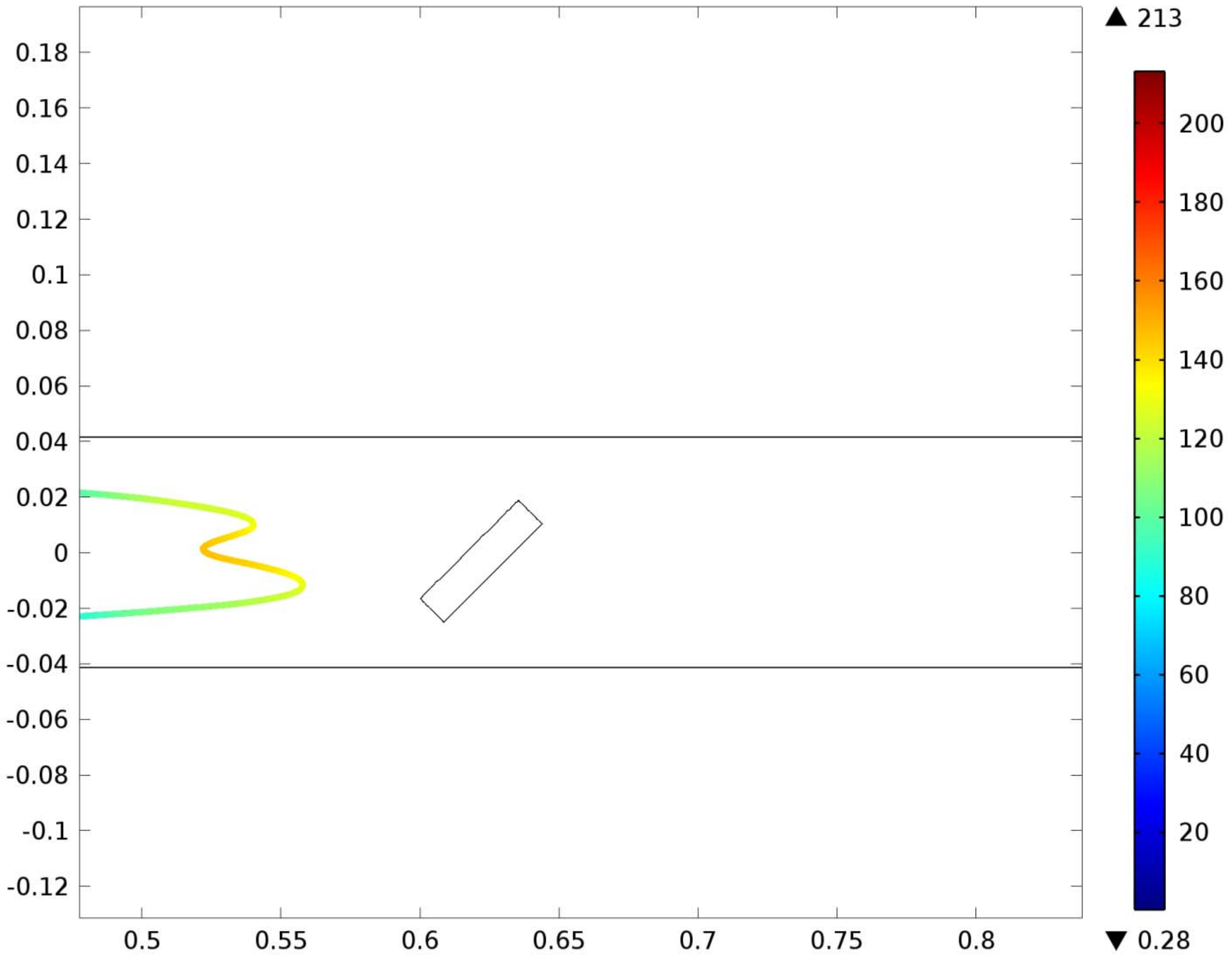
t = 0 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



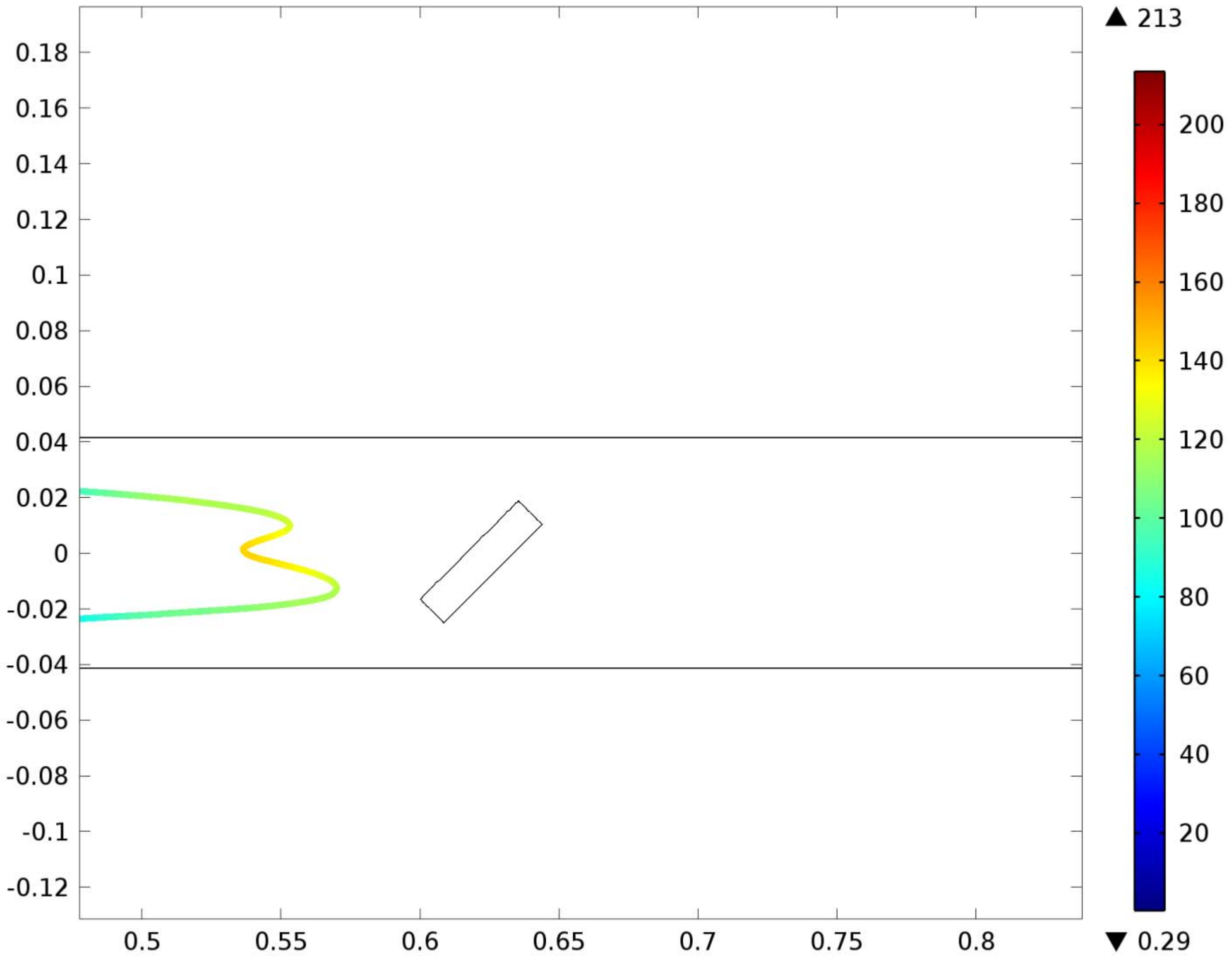
t = 1 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



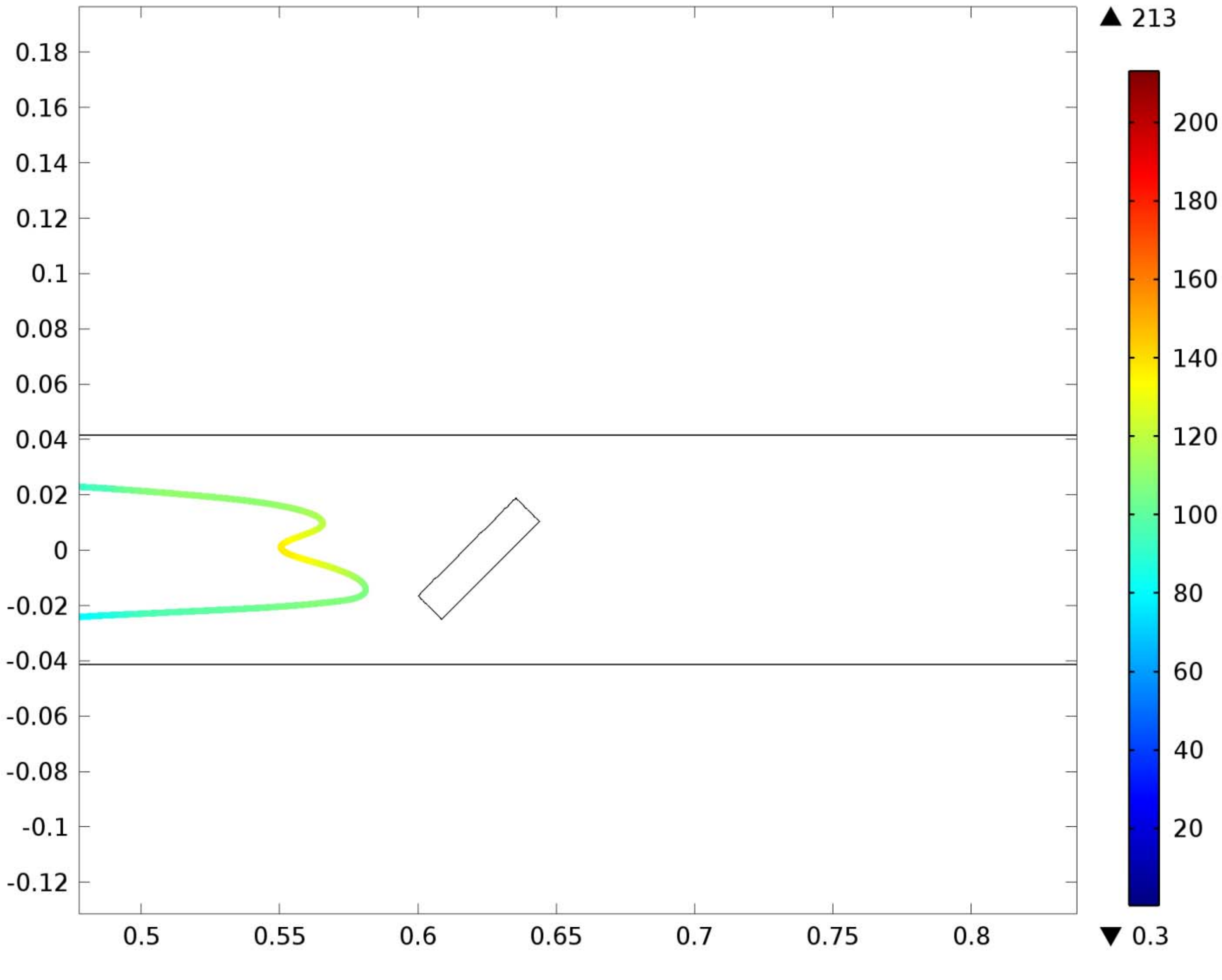
t = 2 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



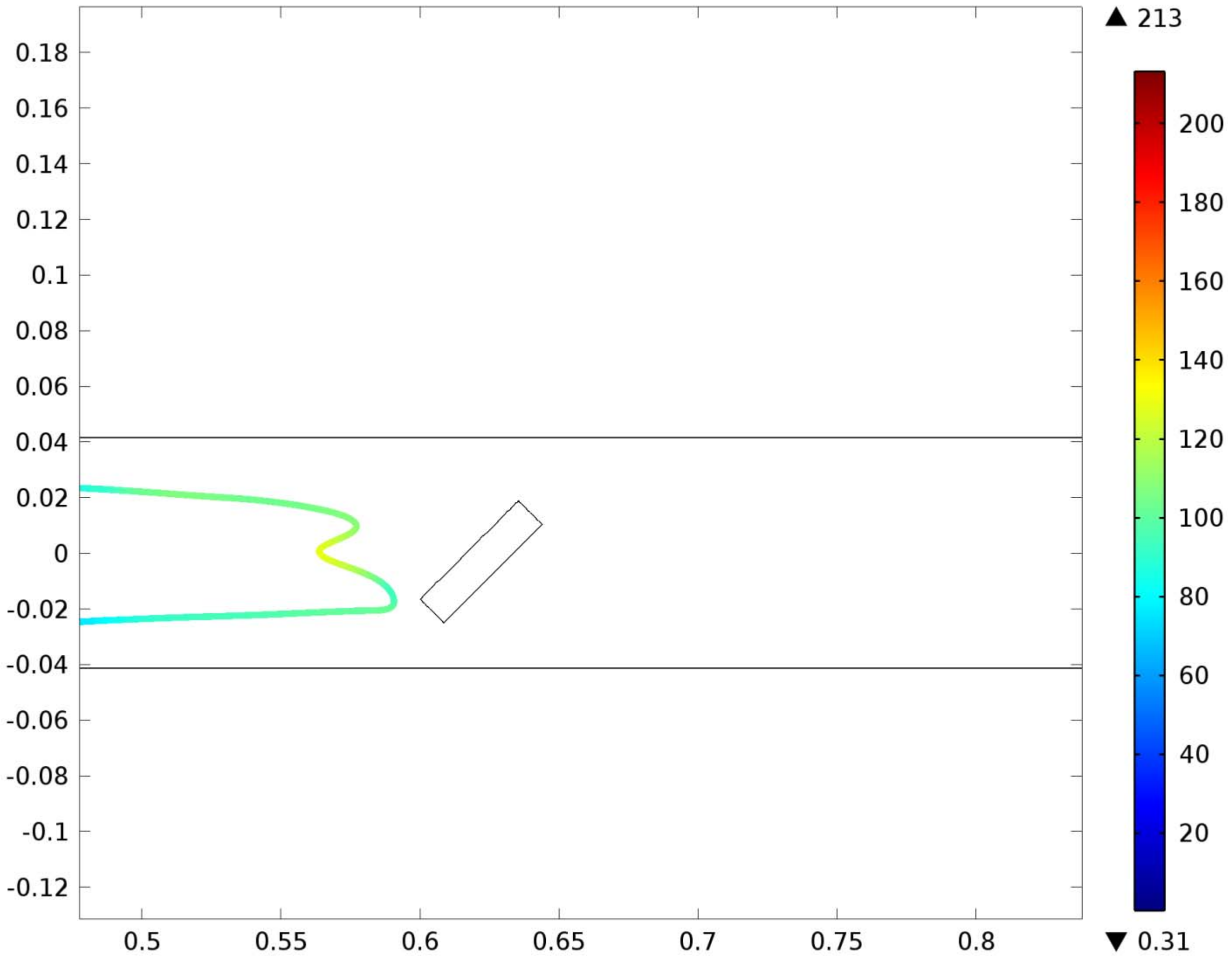
t = 3 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



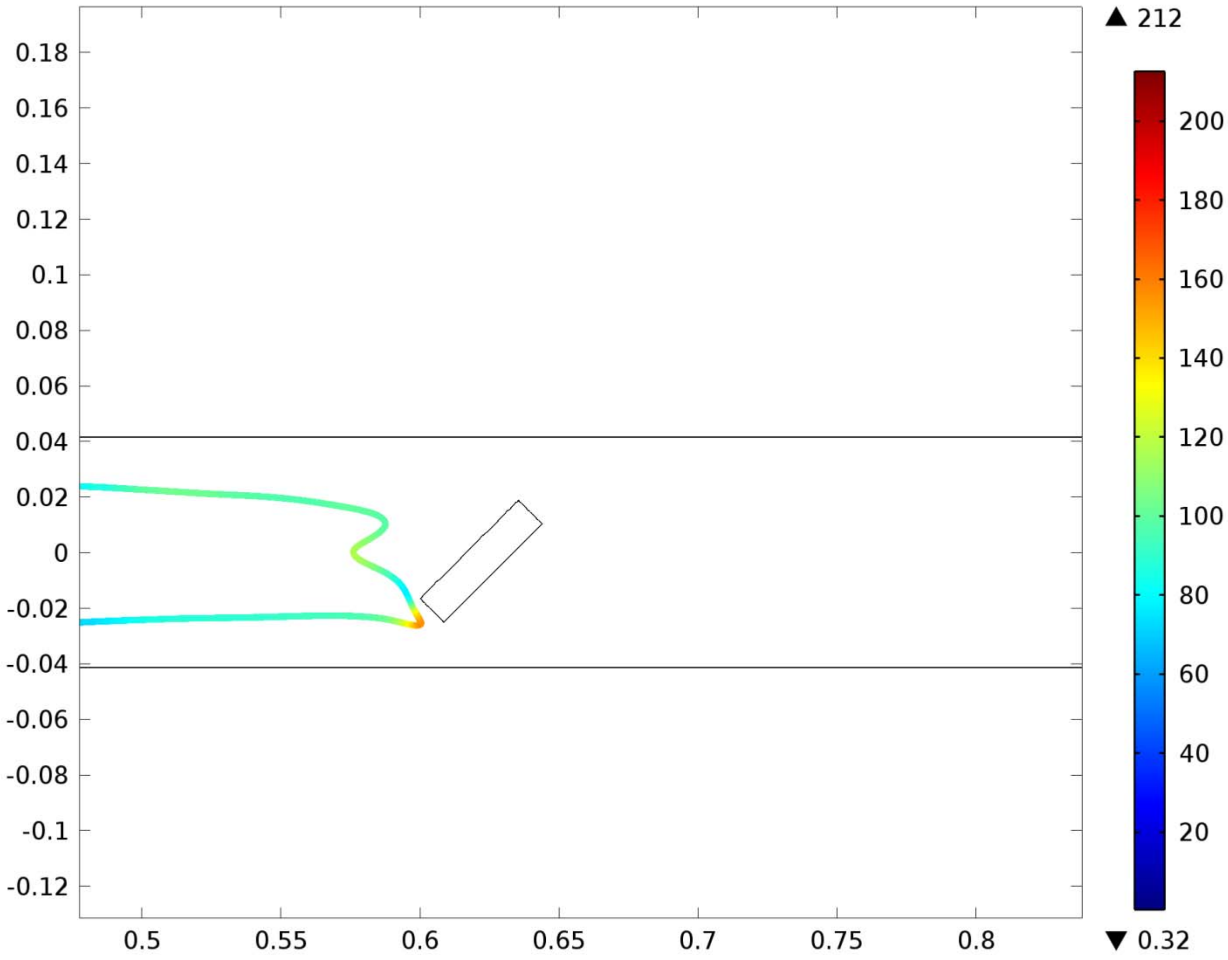
t = 4 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



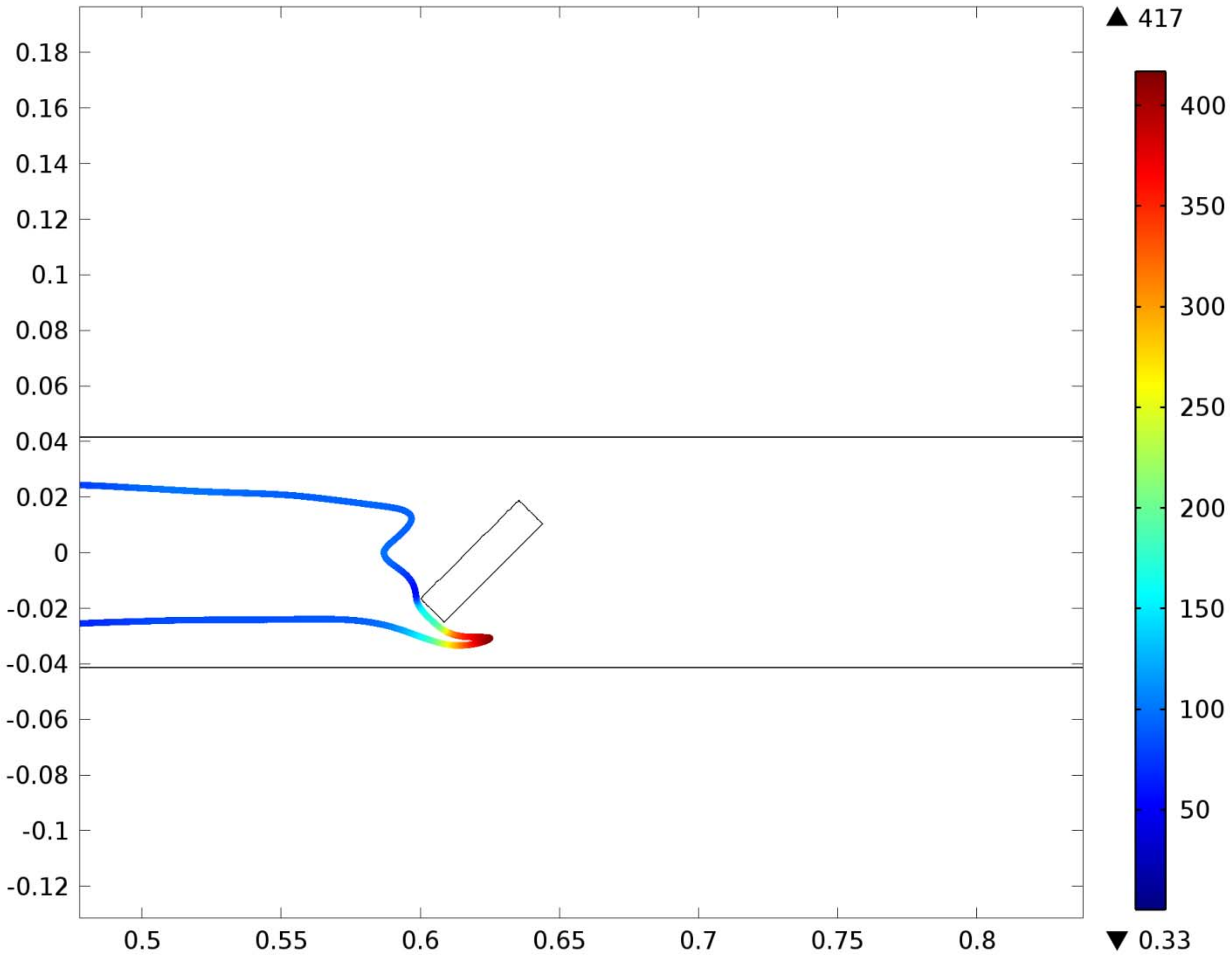
t = 5 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



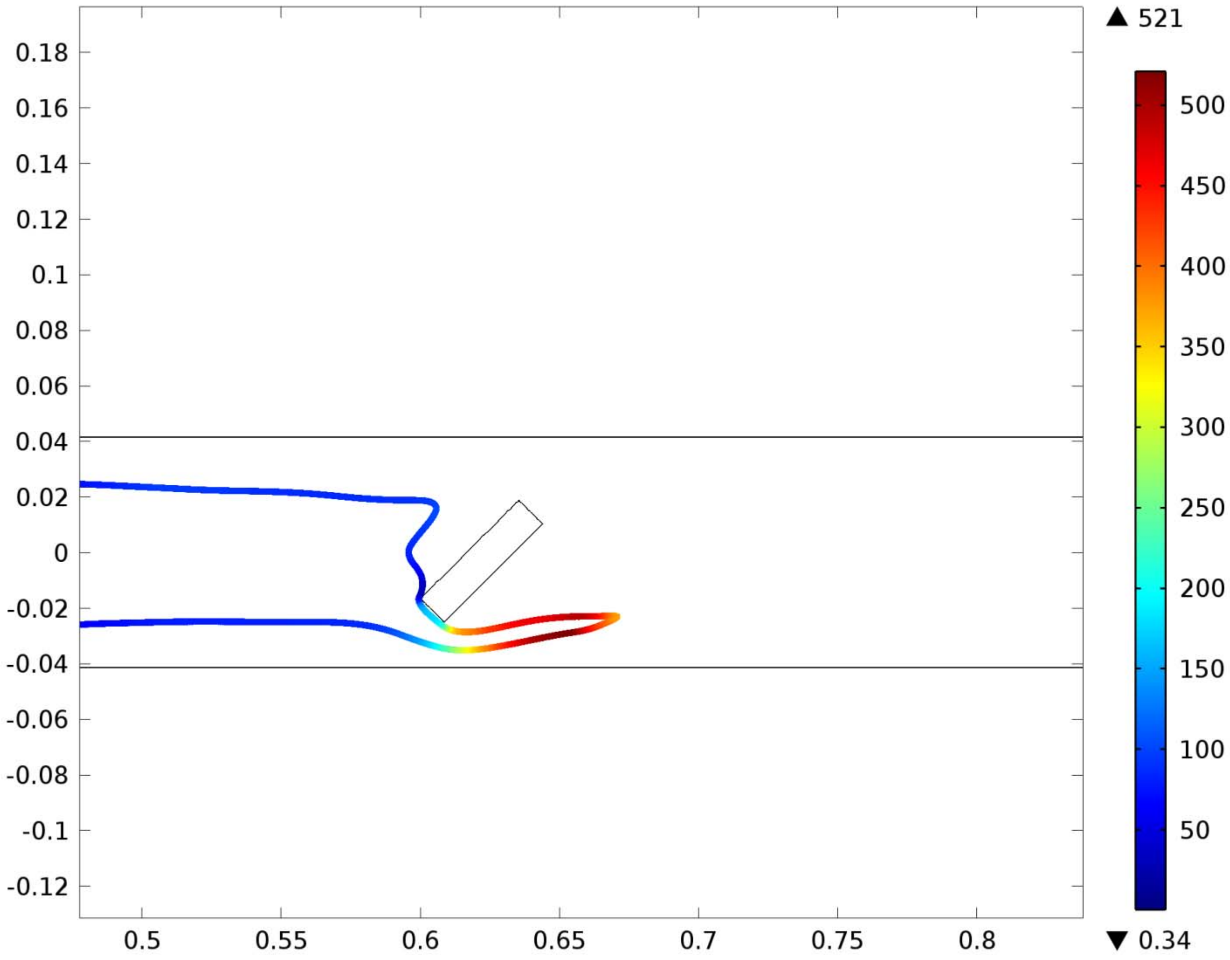
t = 6 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



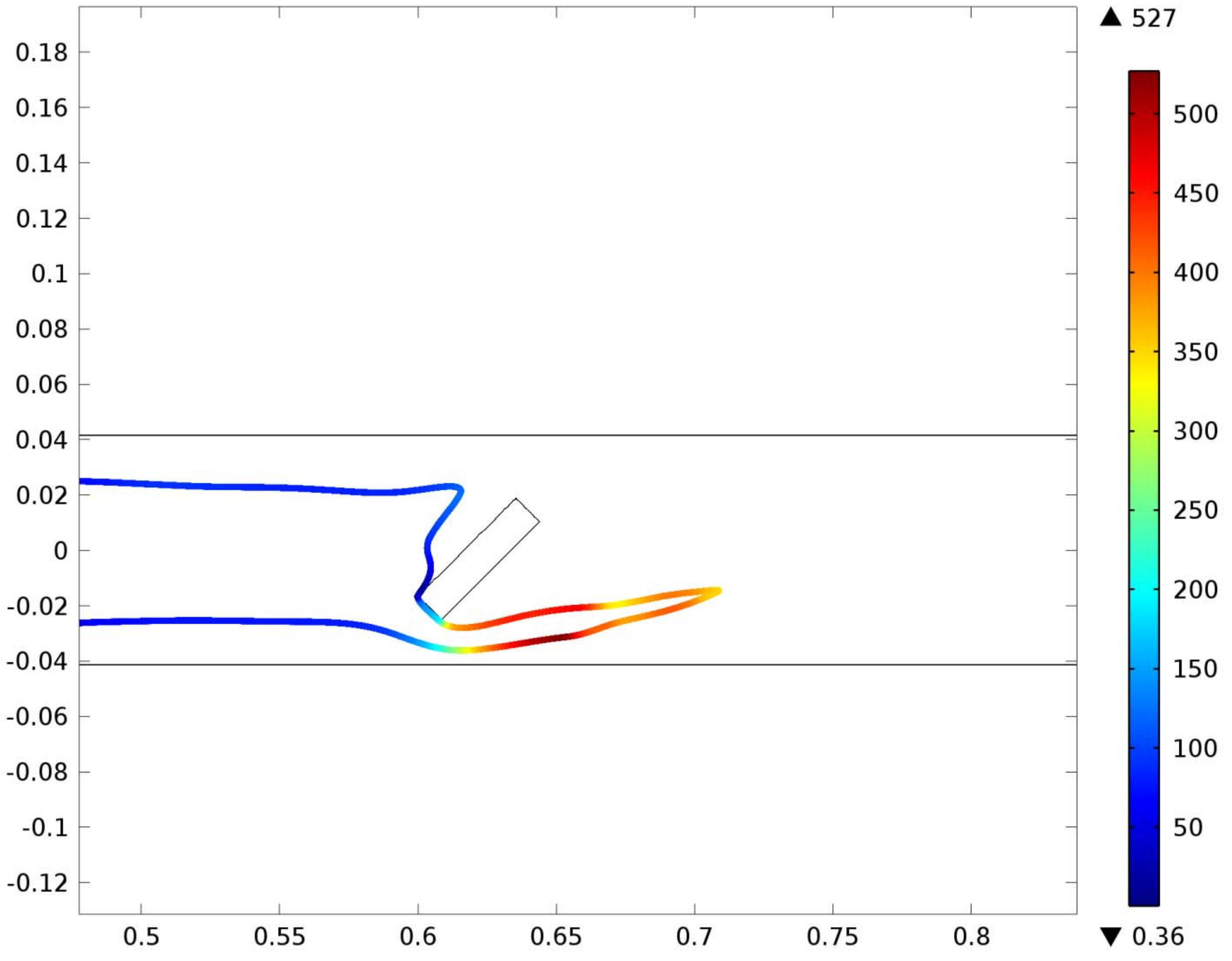
t = 7 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



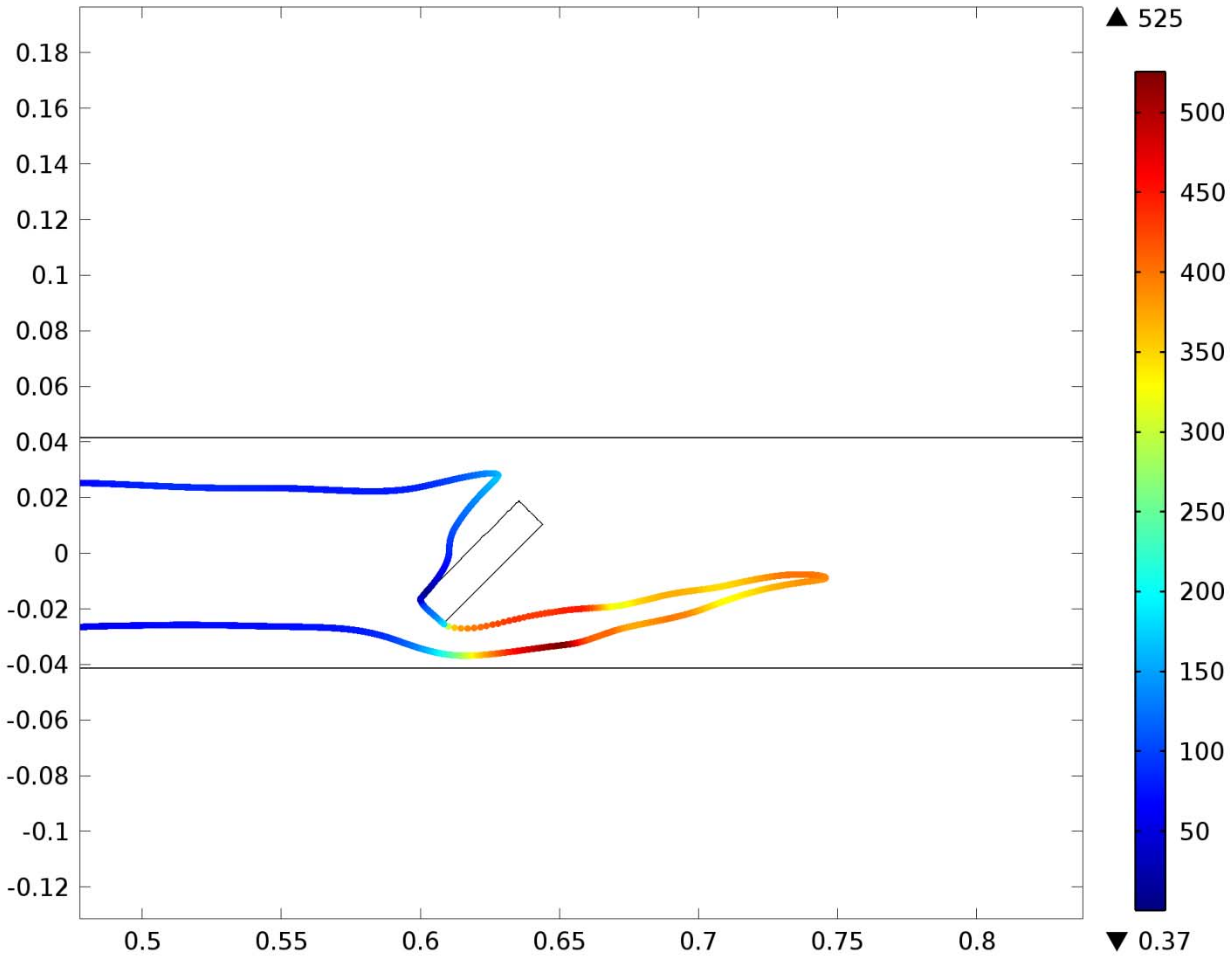
t = 8 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



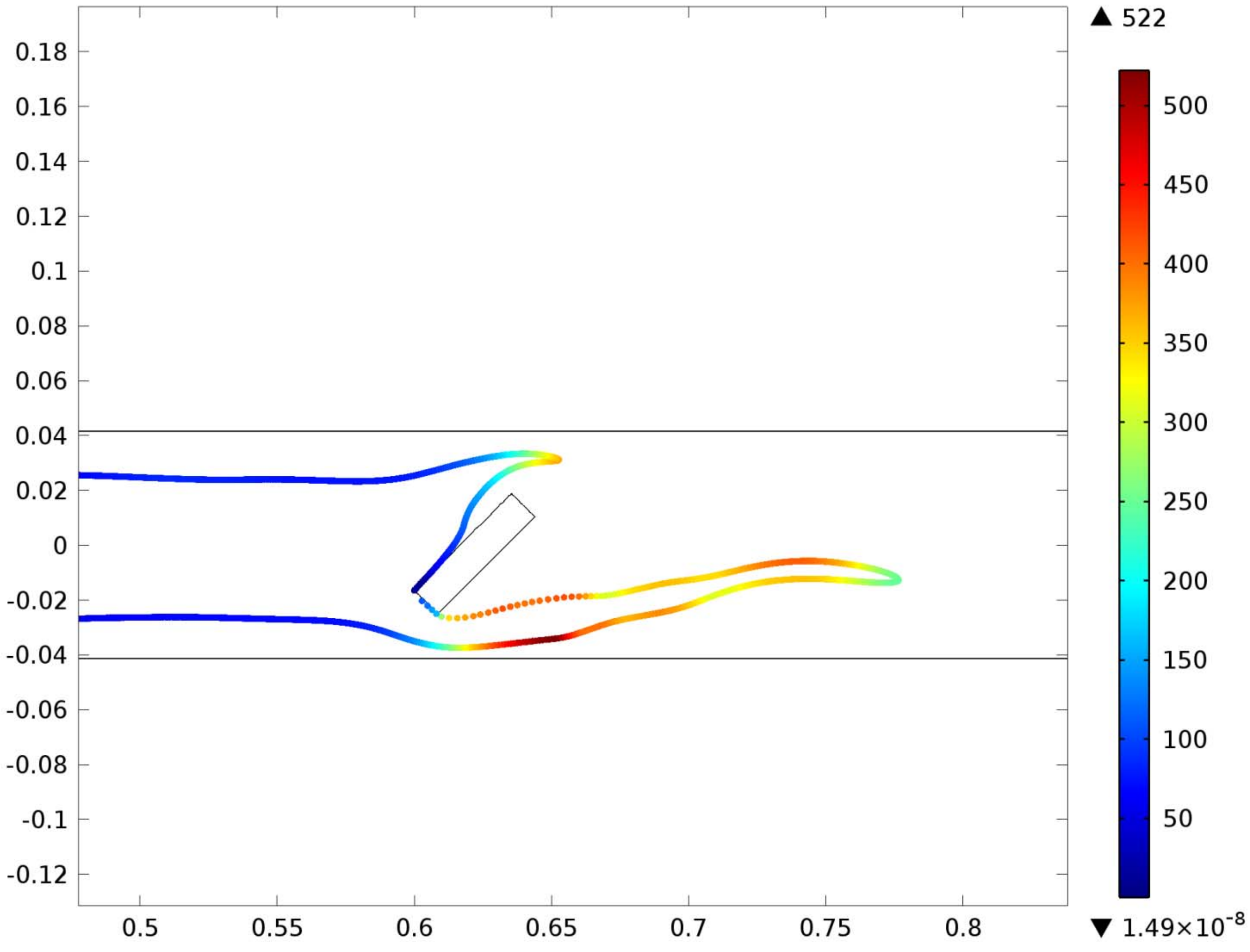
t = 9 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



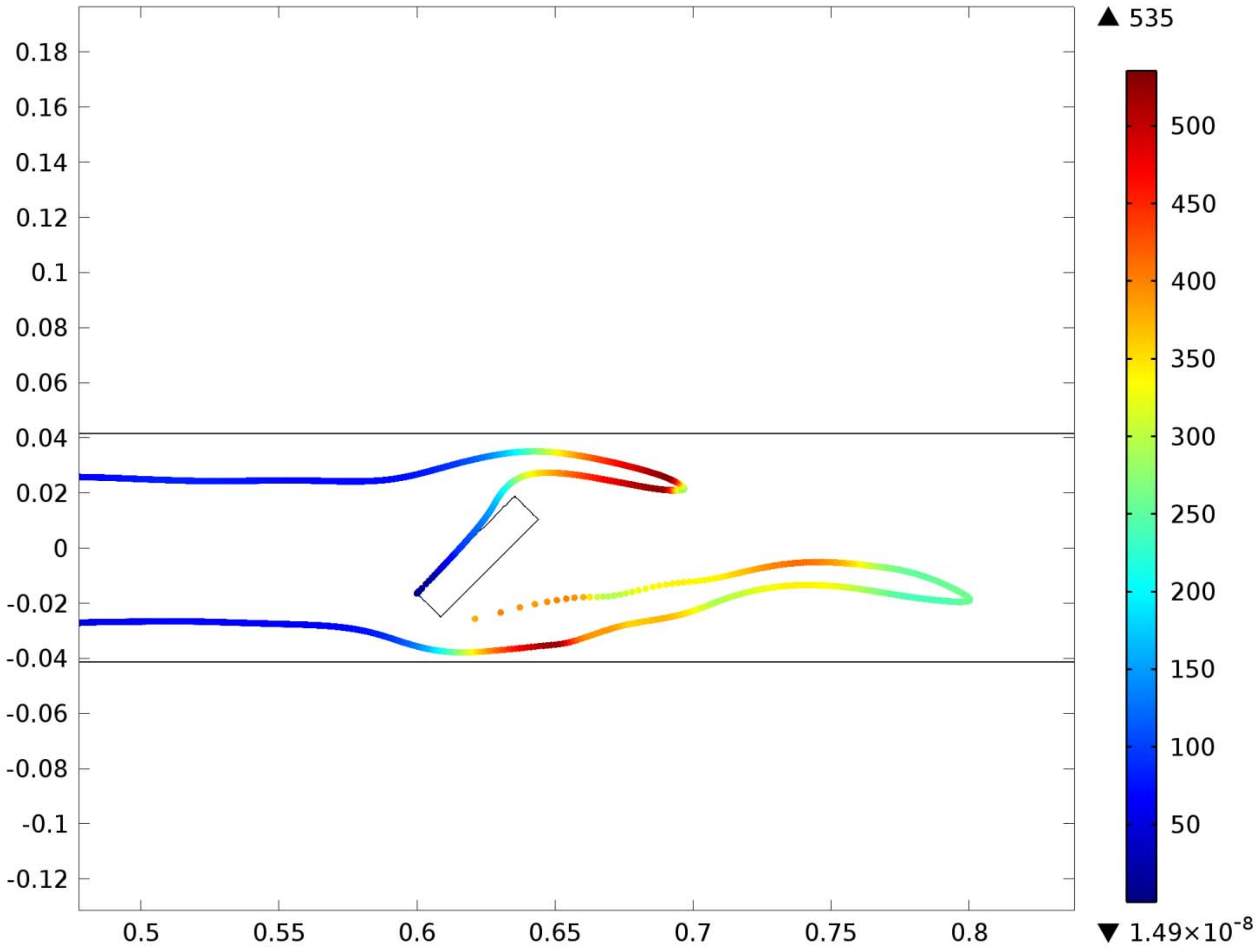
t = 10 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



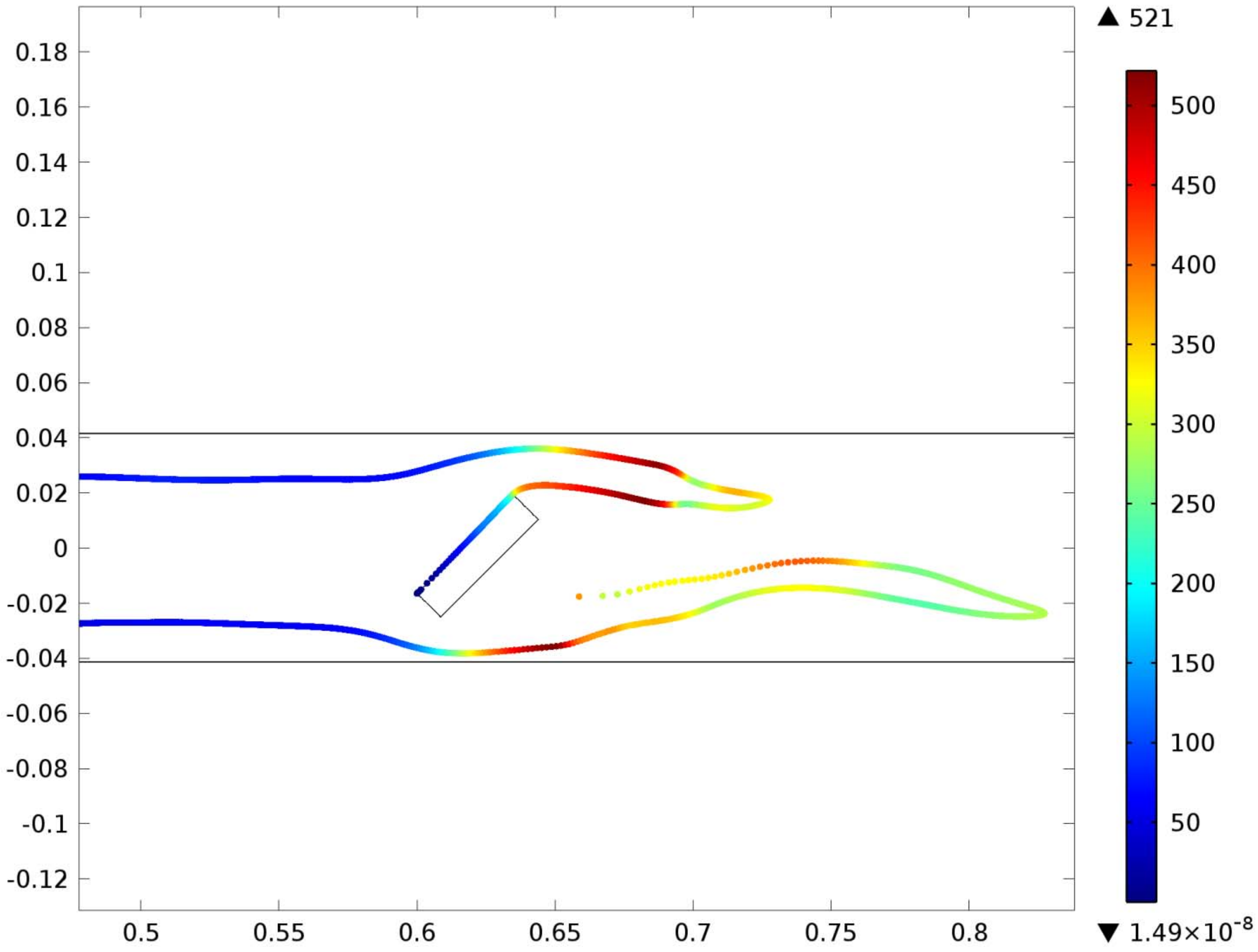
t = 11 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



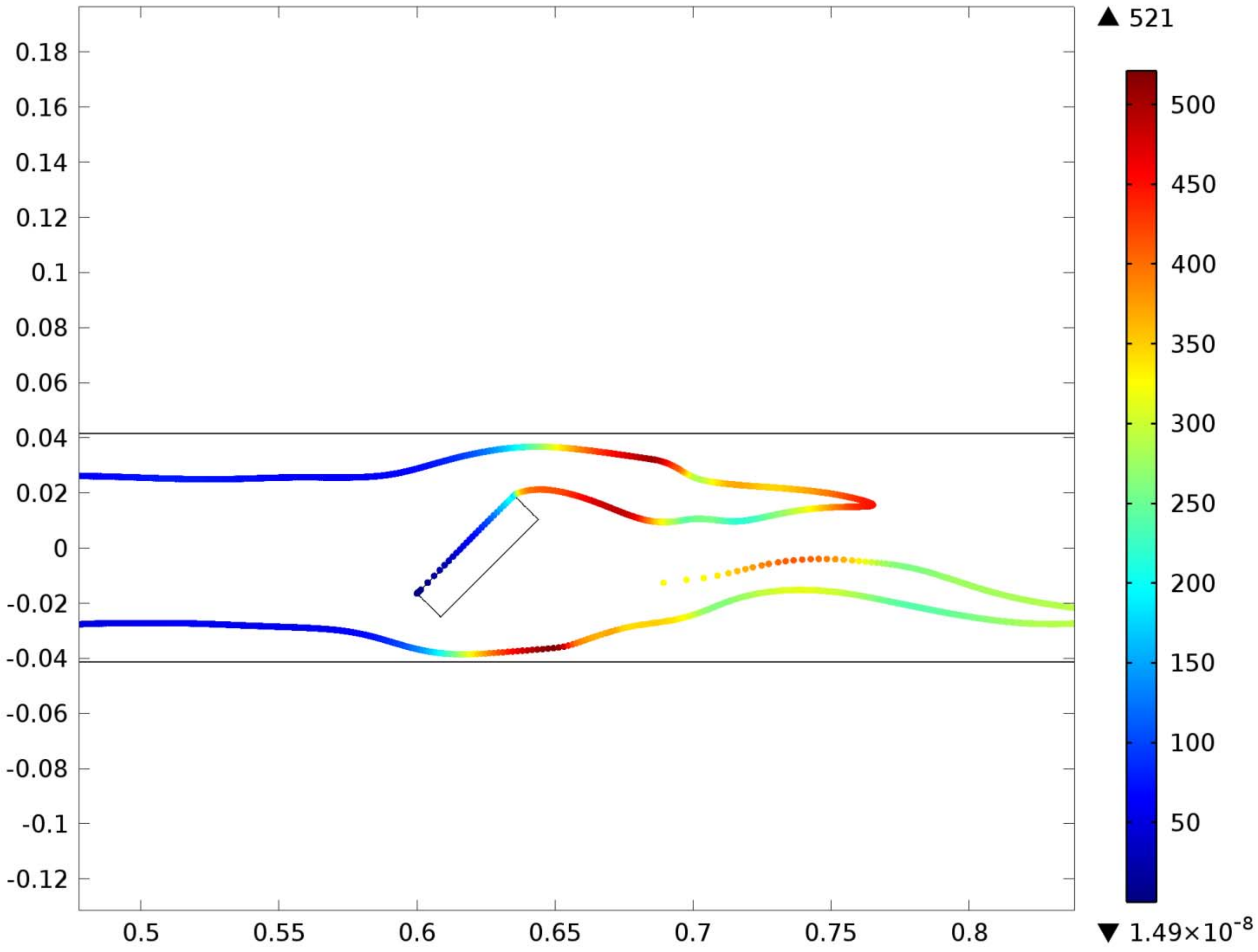
t = 12 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



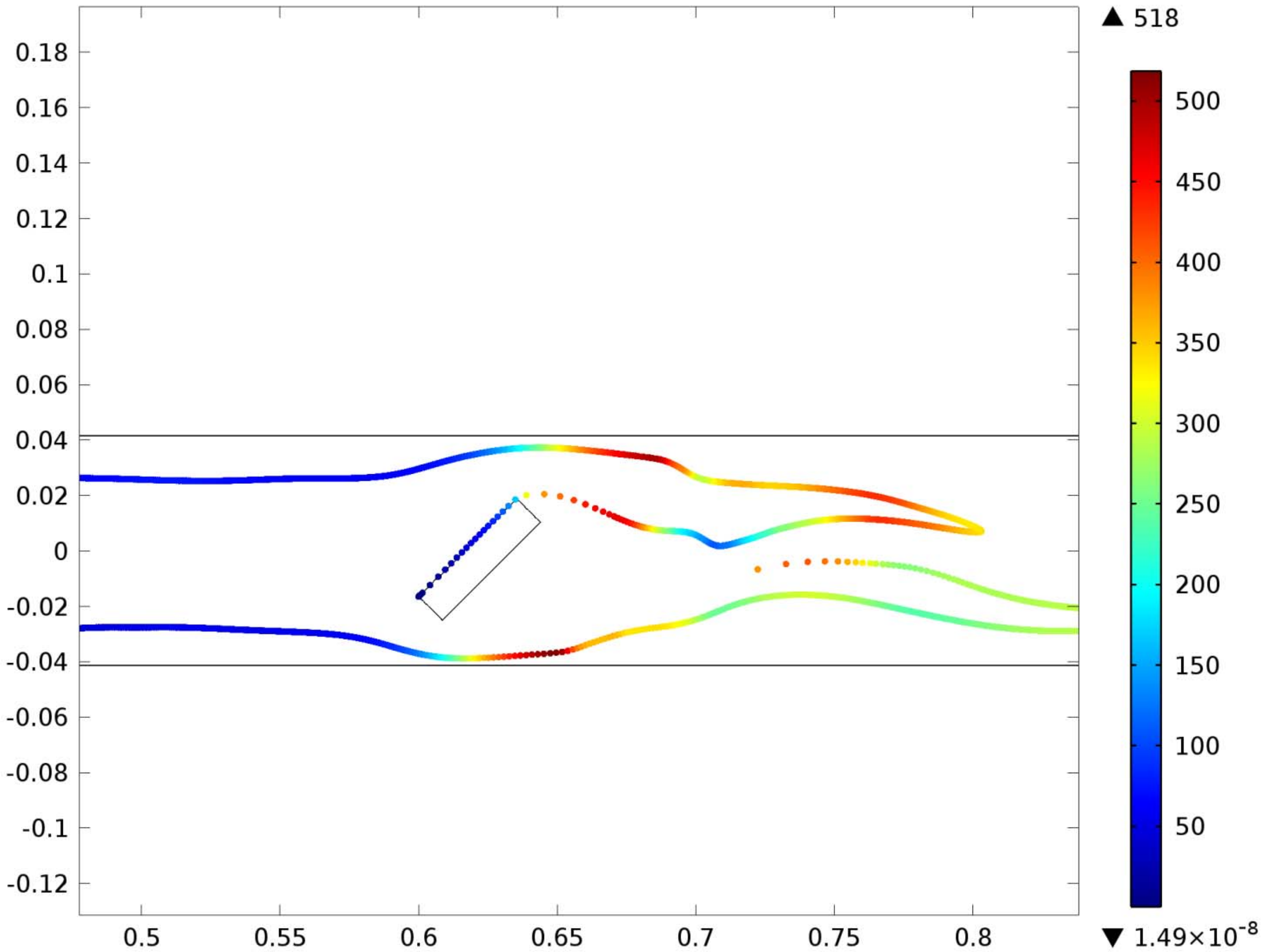
t = 13 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



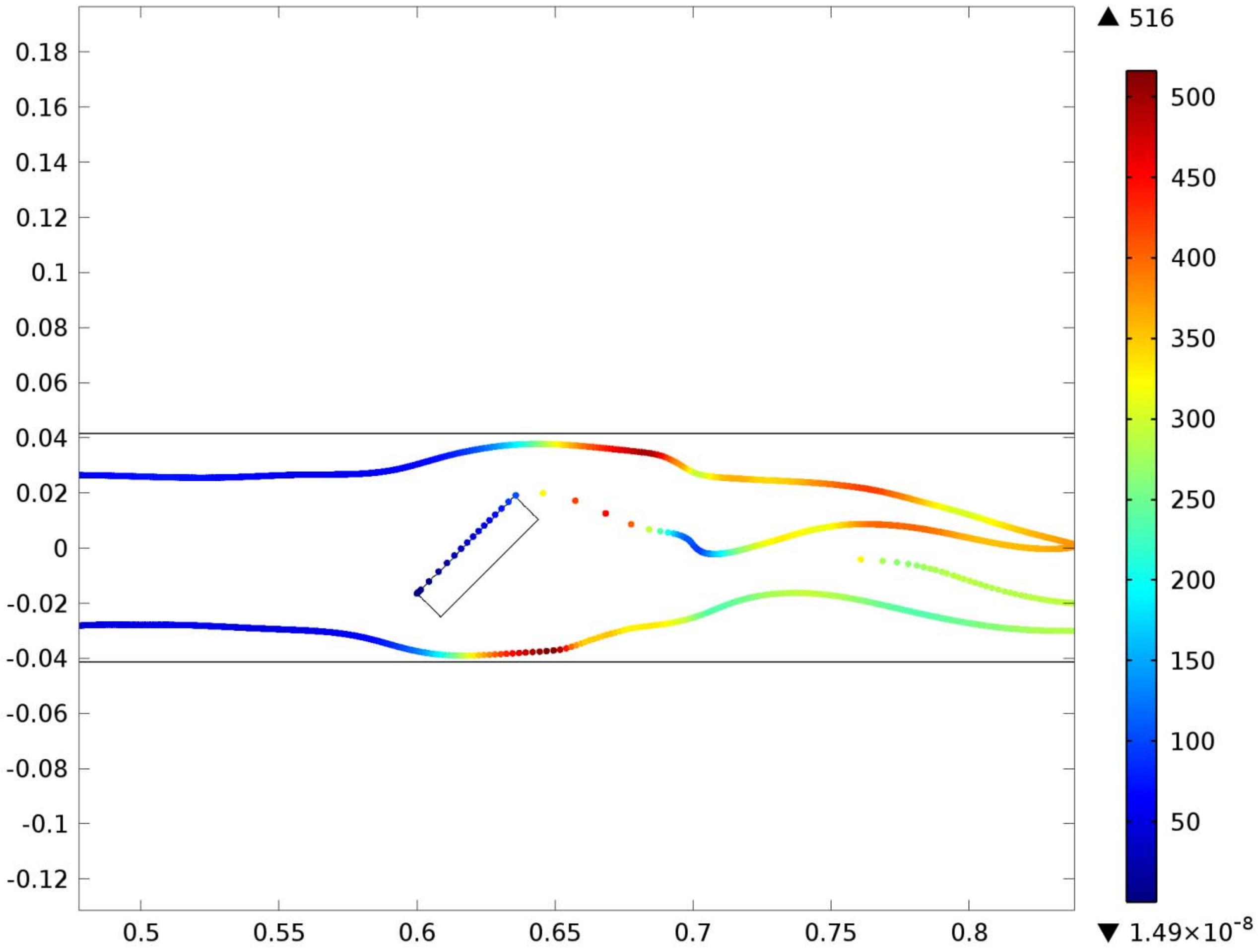
t = 14 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



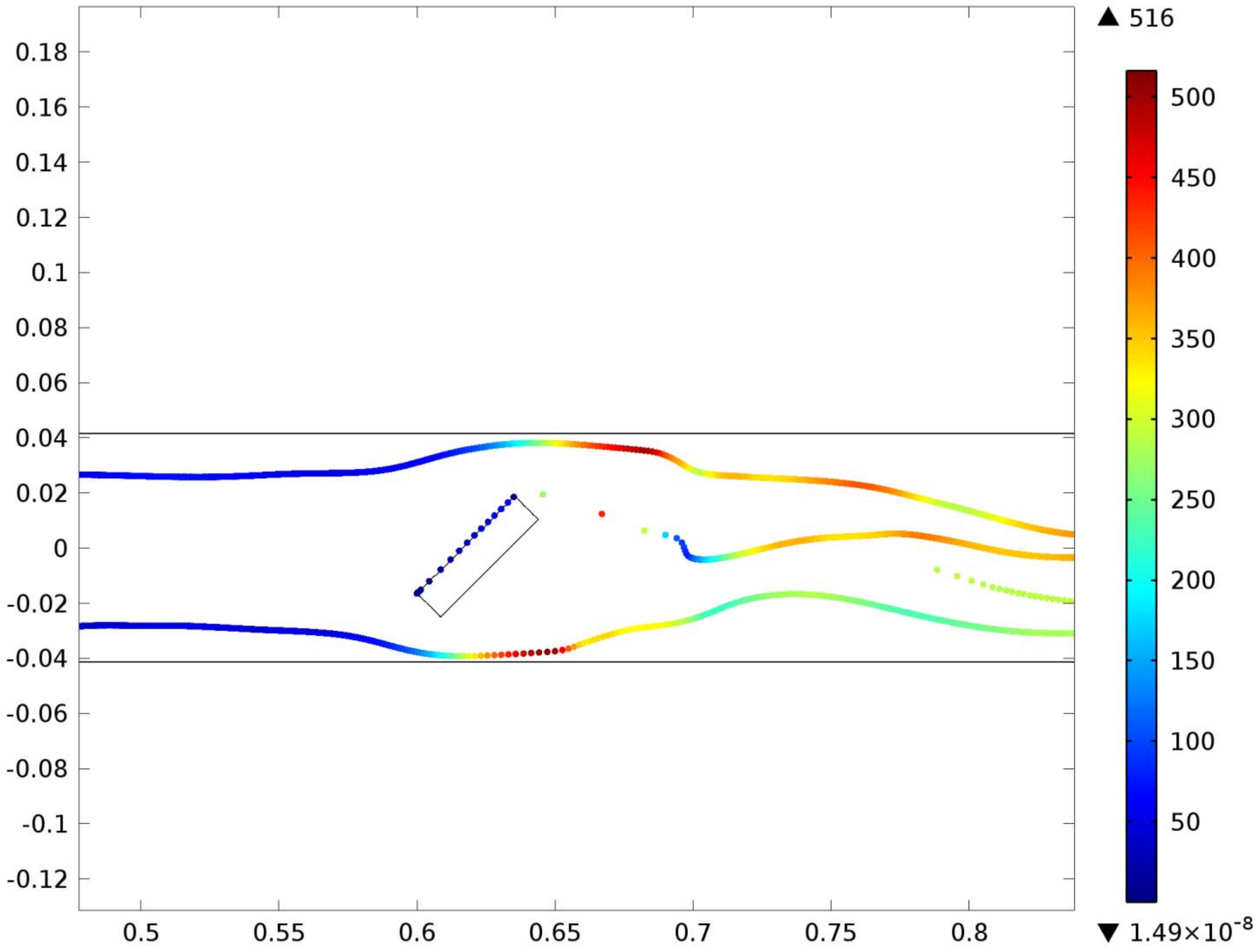
t = 15 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



t = 16 ms

Numerical Modelling of the Combustion Chamber Simulation Experiments



t = 17 ms

Conclusions

Early experiments with a micro-turbine indicate that the deposition of ingested ash appears to be favoured by:

- High glassy content (and low T_g)
- Intermediate particle size
- High gas temperature

The effect of these characteristics on deposition rates will be investigated further using a simulated engine set-up in Cambridge and a range of volcanic ashes, in combination with CFD modelling. Criteria for deposition will be obtained.