Simulating unsteady, compressible, two phase flow through a rocket injector channel using 1D model

Symulowanie nieustalonego, ściśliwego przepływu dwufazowego we wtryskiwaczu silnika rakietowego, z użyciem modelu 1D

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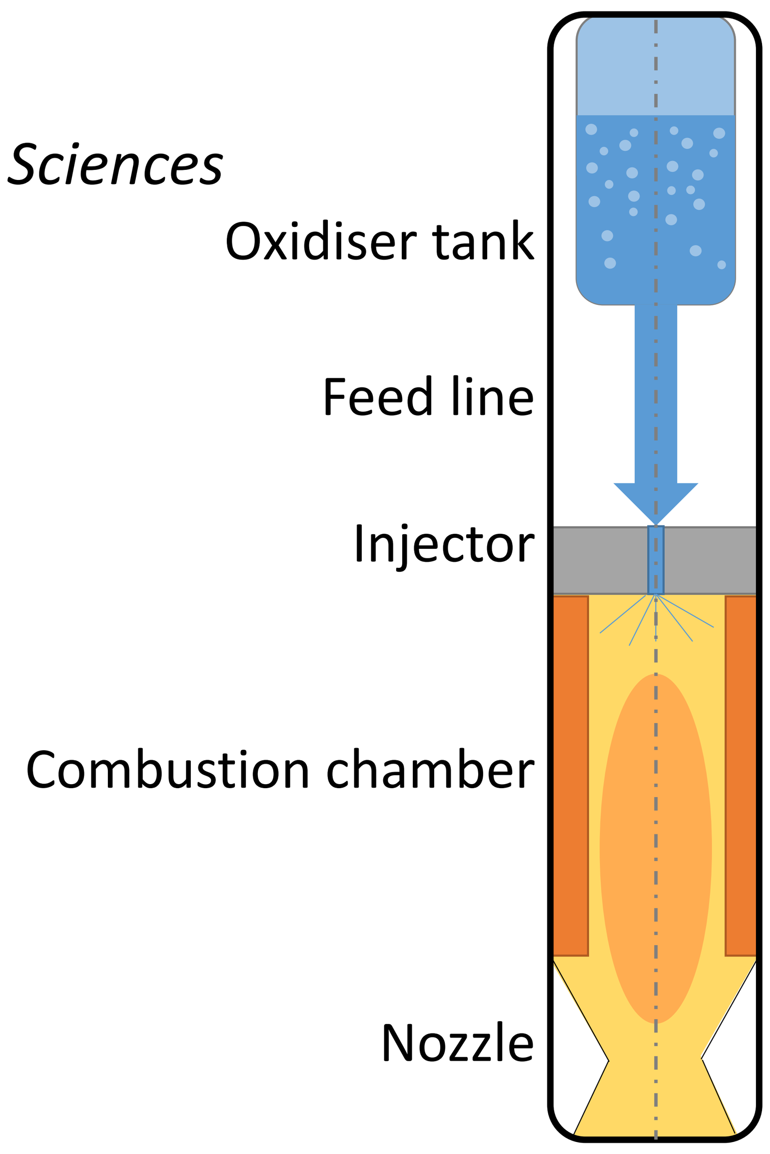


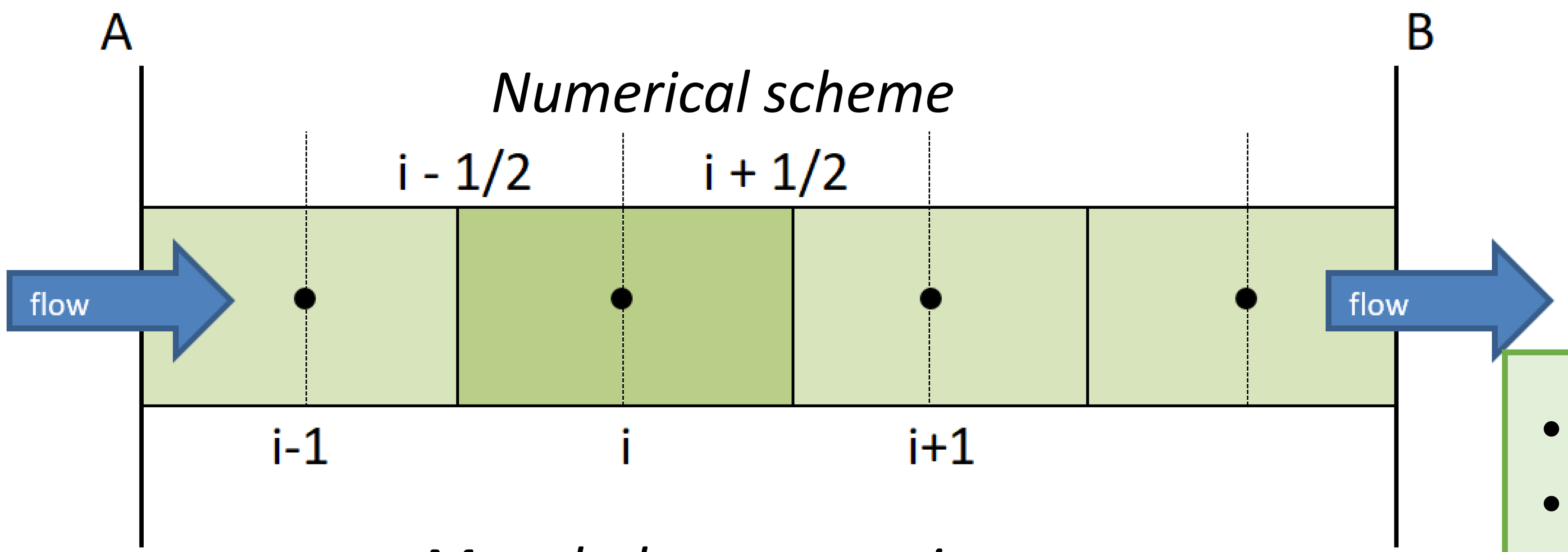
Hybrid rocket engine schematics

Motivation

Proper simulation of injection of oxidiser into rocket combustion chamber is crucial for predicting operating conditions within the combustion chamber and therefore the whole engine.

Amount of mass injected depends mostly on upstream parameters (pressure, void fraction, temperature) and injector geometry.

Accurate flow prediction needed!



Mass balance equation

$$\frac{\partial \rho}{\partial t} + \frac{1}{A}\frac{\partial \rho w A}{\partial z} = 0$$

Key element for modeling two phase flow is the equation of state. Continuous function for density of liquid, vapour and mixture is needed.
This is done by defining specific volume in terms of void fraction and spec. volume of phases:

$$v_{mix} = \mathrm{x} * v_{vap} + (1 - \mathrm{x}) * v_{lqd}$$

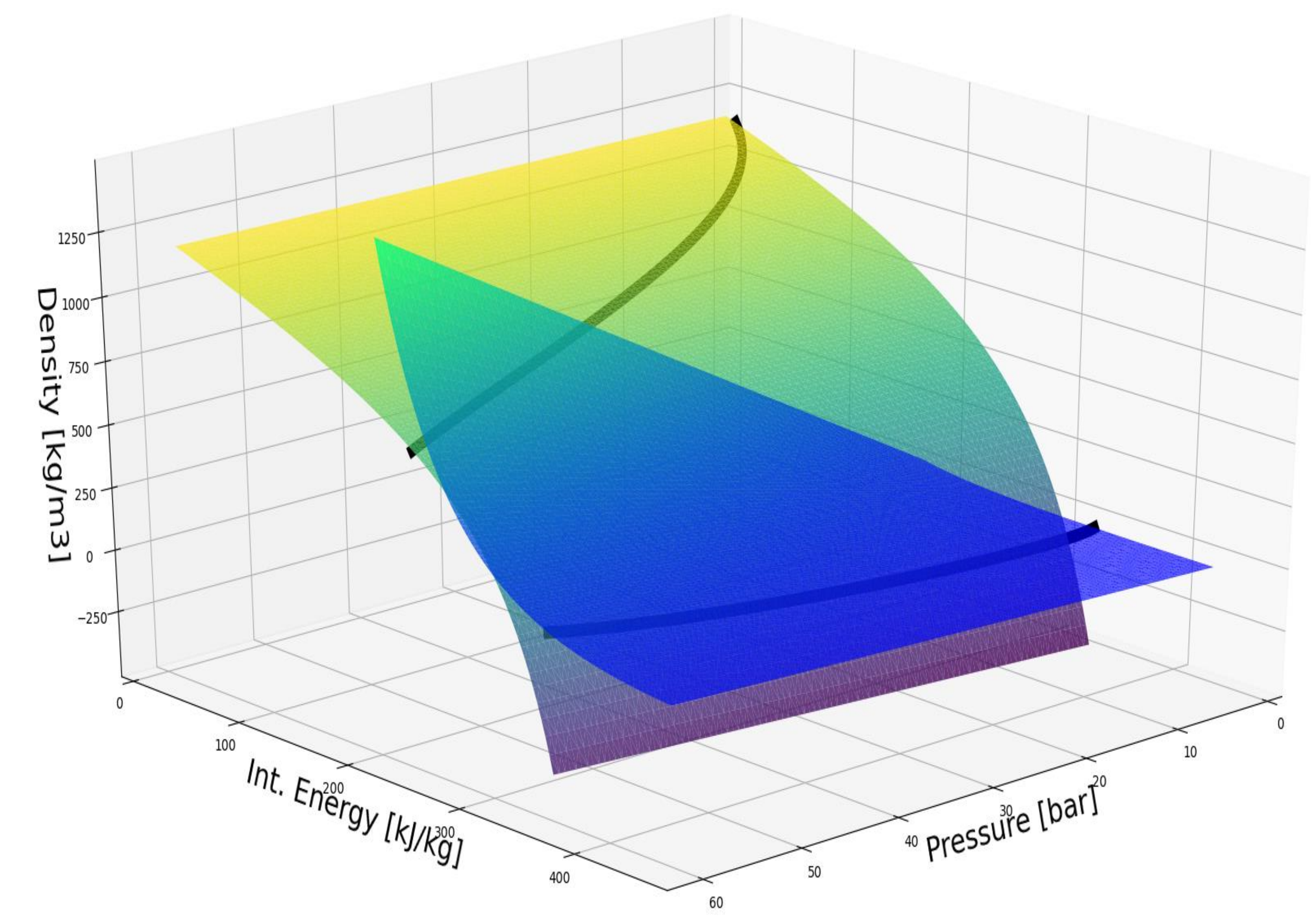
To make model less rigid and more realistic, relaxation equation was added:

$$\frac{\partial \mathrm{x}}{\partial t} + w\frac{\partial \mathrm{x}}{\partial z} = \frac{\mathrm{x} - \bar{x}}{\theta}$$

This allows fluid to be temporarily past saturation line, in subcooled or superheated state. This requires smooth equations for density on both sides of the saturation lines.

Method

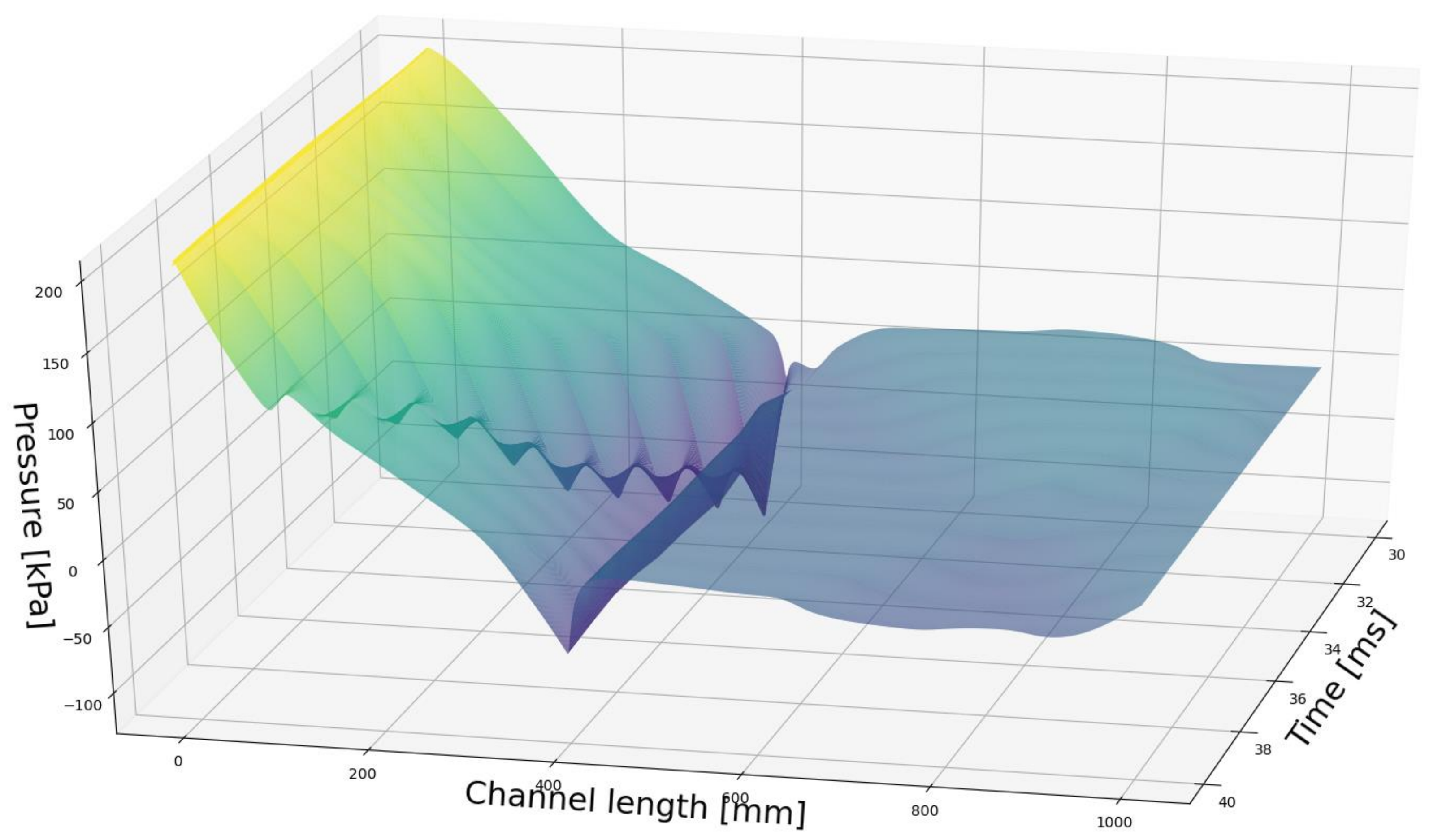
- Mixed, implicit / explicit scheme is used
- Scalars (pressure, density, int. energy, void fraction) are calculated within cells (whole number indexes)
- Velocity is calculated on cell borders (half indexes)
- Mass, void fraction, momentum, and energy equations are used to determine **pressure**, **internal energy**, **void fraction** and **density**



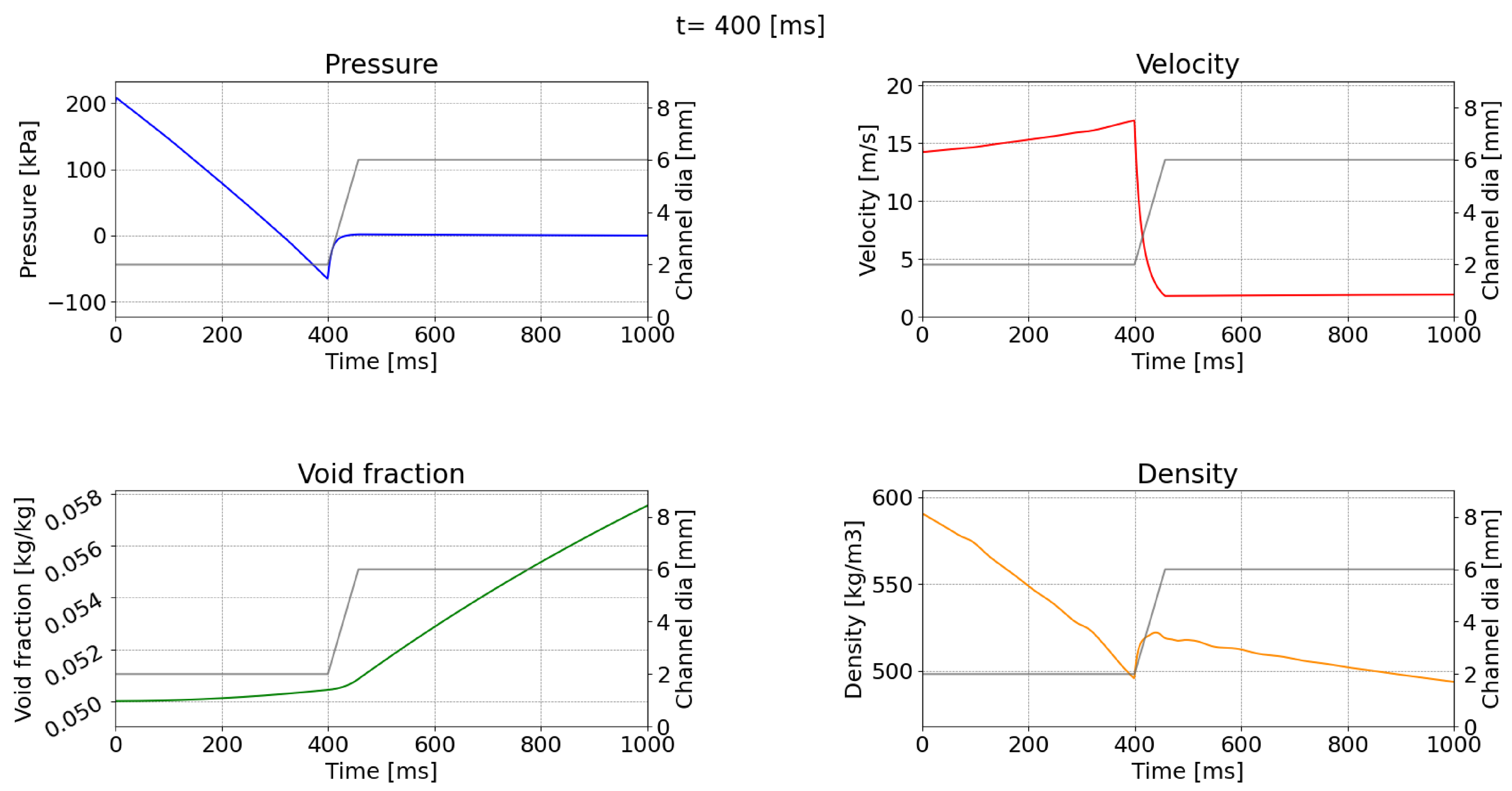
Density plot of liquid and vapour phases, with saturation lines in black

Results

1m long diverging channel, 2 bar of pressure difference



Pressure plot over channel length, from 30 ms to 40 ms flow time



Notation

ρ	density	**v**	specific volume	$\bar{x}$	mean void fraction
w	velocity	**x**	void fraction	θ	relaxation time
A	area				
z	axial dimension				

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