Rotationally symmetric interaction of an impinging drop with a thin wall film of the same liquid – proposal of a benchmark case

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Motivation and Objective

General motivation within CRC/Transregio 150

- Understanding the impingement of a drop onto a thin liquid wall film
  - Exhaust gas after treatment by urea-water solution (SCR)
  - Impact of fuel droplets on oil film in internal combustion engines

Specific motivation – data for validation of numerical methods

- The validation of numerical methods for interface-resolving simulations of two-phase flows requires accurate experimental data
- For rotationally symmetric drop-film interactions such data are lacking but are highly relevant for validation/testing at limited computational expense

Objective

- Provide high quality time-resolved experimental data on crown formation dynamics under conditions where the entire process stays axisymmetric
- Use data to develop and validate phase-field method for high dynamics

Experimental Setup and Measurements

- Silicon oil droplet impinging on a silicon oil wall film (identical liquids)
  - Fixed droplet diameter (1.5 mm)
  - Fixed wall film thickness (0.5 mm)
  - Variable impact velocity
- CMOS high-speed (HS) camera
  - Frame rate: 20000 fps
  - Resolution: 31 μm/pixel
- MATLAB image analysis to determine time evolution of three characteristic crown dimensions
  - Crown diameter at free rim $d_{CT}(t)$
  - Crown diameter at the base $d_{CB}(t)$
  - Crown height $h_C(t)$

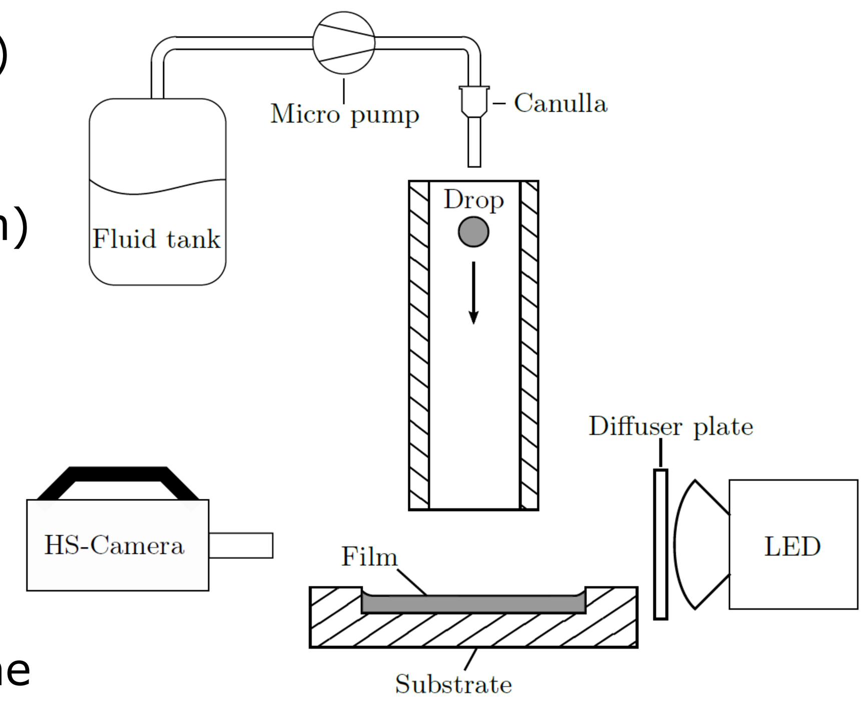

Fig. 1: Sketch of the experimental setup.

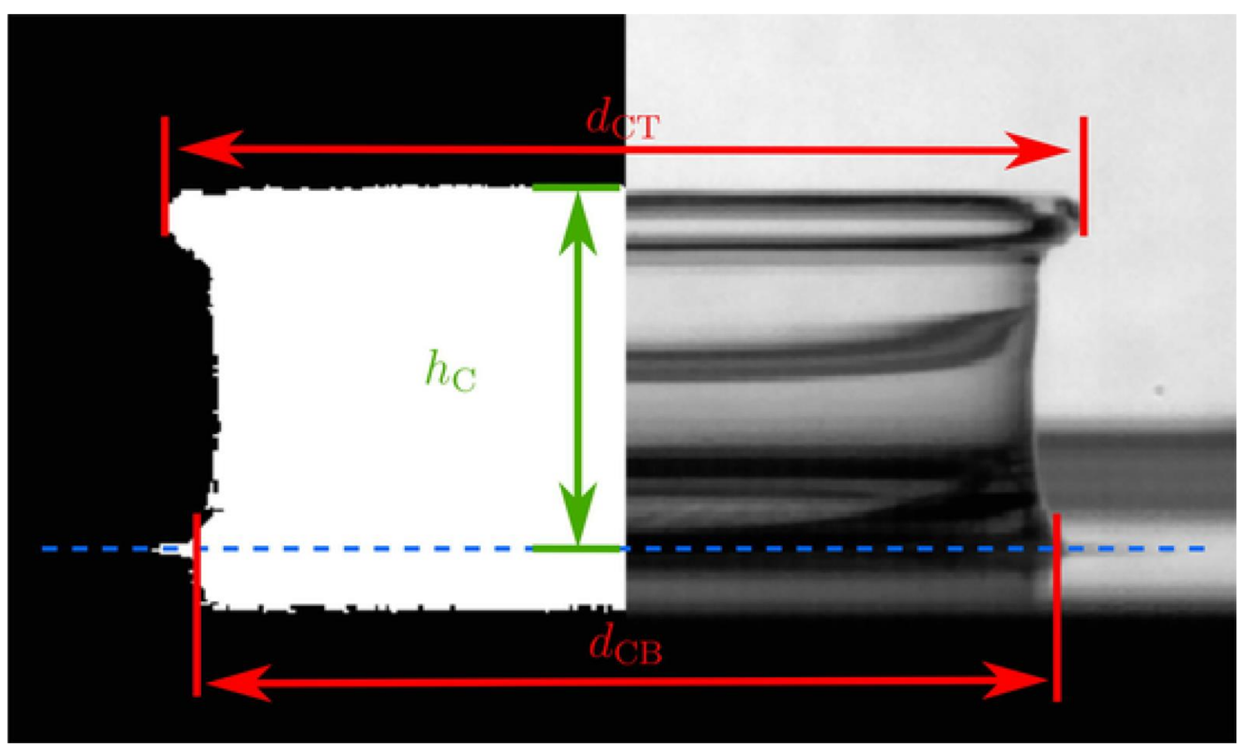

Fig. 2: Montage of raw (right) and binarized image (left). The dashed blue line indicates the film level.

Numerical Method

Diffuse-interface phase-field method

- An energetic variational formulation based on continuum thermodynamics
- Interface is treated as a thin transition layer of finite and prescribed width
- Interface dynamics is modelled via the Cahn-Hilliard equation
- Fluid dynamics is modelled via the Navier-Stokes equations
- Implementation in OpenFOAM extend (computer code `phaseFieldFoam`)

Numerical Setup

- Axisymmetric geometry
- Adaptive mesh refinement at interface

Physical properties

Property	Silicone oil	Air
Density / kg/m^3	920	1.2
Kinematic viscosity / m^2/s	$5e-6$	$1.52e-5$
Surface tension / kg/s^2	0.0177	

Drop impact and film parameters

Property	Value/s
Velocity / m/s	$1-2-3$
Diameter / mm	1.5
Film thickness / mm	0.5

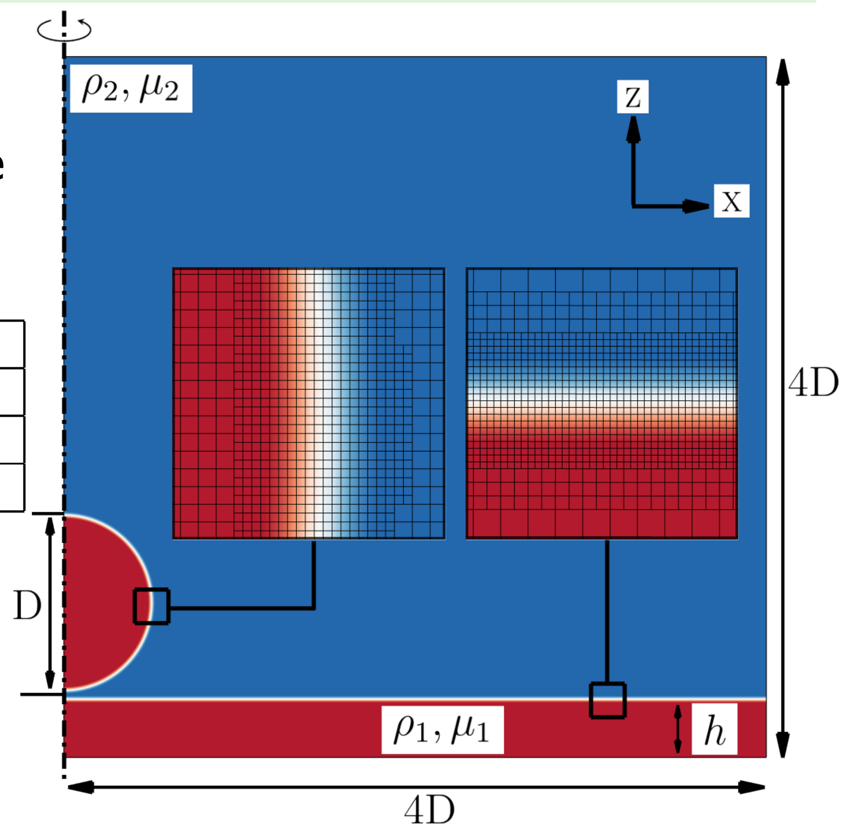

Fig. 3: Computational domain and grid resolution at the interface.

Sample Results – Crown Height

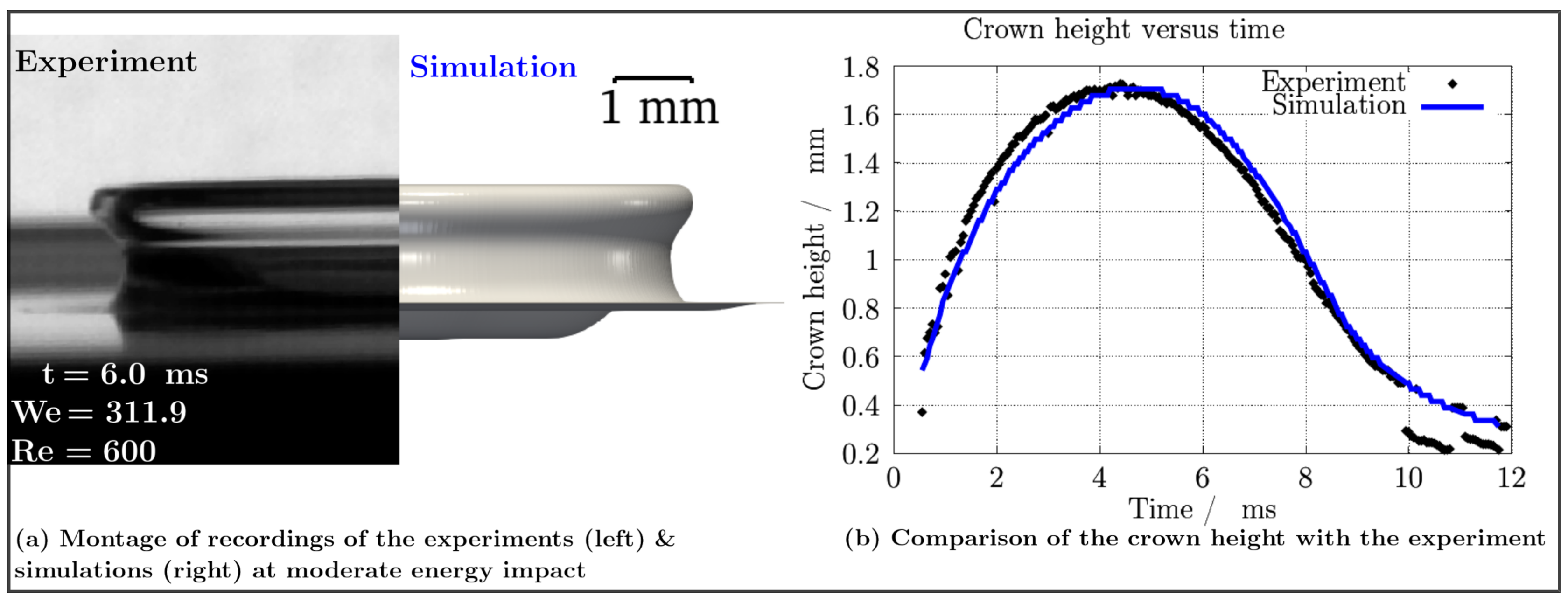

Fig. 4: Comparison of crown shape (left) and height (right) between exp. and simulation for impact velocity 2 m/s.

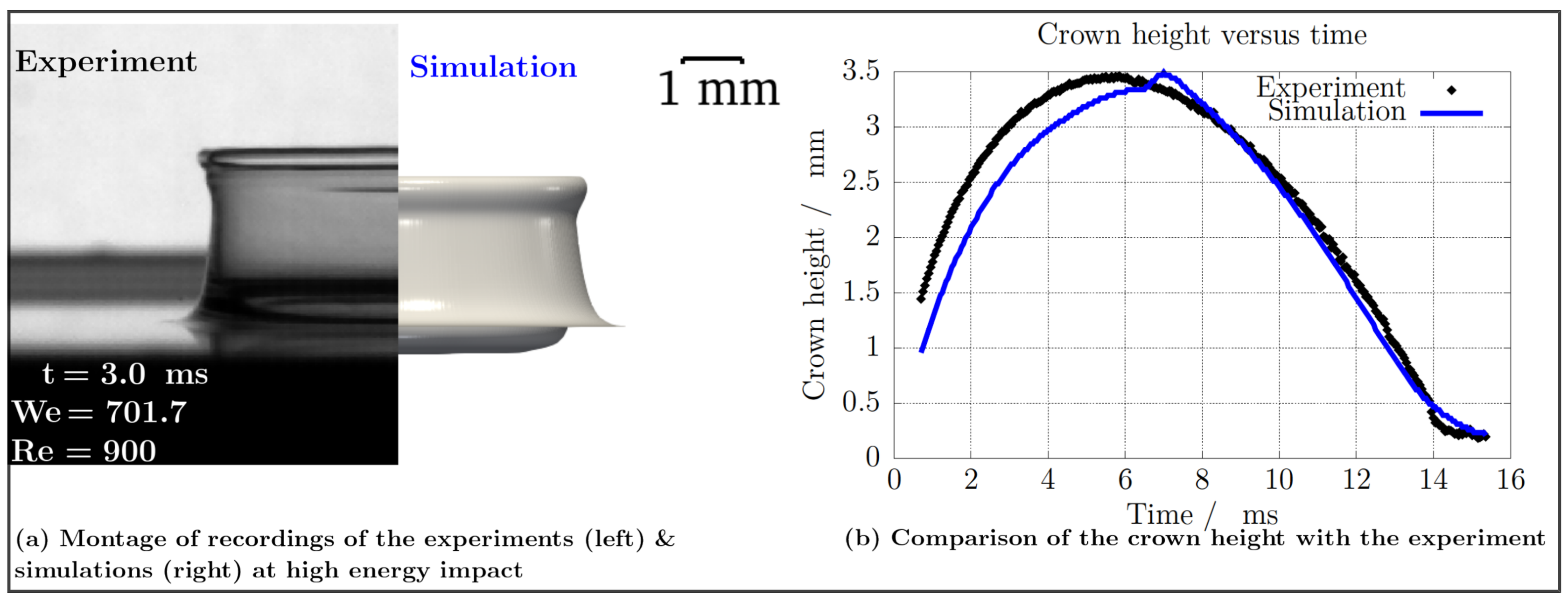

Fig. 5: Comparison of crown shape (left) and height (right) between exp. and simulation for impact velocity 3 m/s.

Conclusions

- Experimental data on the evolution of characteristic crown dimensions during rotationally symmetric drop-wall film interaction are provided for different impact velocities and are suggested as benchmark case
- The data can be used by the community to validate numerical methods and computer codes for interface-resolving two-phase flow simulations
- Findings for the phase-field method (see paper accessible by QR code)
  - When gas-liquid interfacial area is generated during crown formation, the thickness of the forming diffuse interface deviates from the prescribed equilibrium interface thickness
  - Accounting for this deviation by so-called interface relaxation is essential to obtain good agreement for highly dynamic impacts

QR Access Codes

Access to the Paper — *Access to the Benchmark Data* — *Access to the YouTube Animation*

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CRC/Transregio 150
Turbulent, chemically reactive multi-phase flows near walls

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