Film formation studies using Basilisk

Wojciech Aniszewski, Stéphane Zaleski, Stéphane Popinet

Institut Jean Le Rond d'Alembert -CNRS UMR 7190 - **Sorbonne Université (formerly: Paris 6)**

Basilisk & Gerris User Meeting
Princeton, November 15-16, 2017.

Groenveld (1970):[1]

Main idea: simplify N-S equations to

$$\mu \frac{\partial^2 u_y}{\partial y^2} = \rho g \quad (1)$$

resulting in a parabolic profile inside the film. Defining dimensionless flux $Q = \frac{q}{u}\sqrt{\frac{\rho g}{\mu u}}$ and thickness $T = h\sqrt{\frac{\rho g}{\mu u}}$, (Blok & von Rossum, 1948) claim

$$Q = T(1 - \frac{1}{3}T^2) \quad (2)$$

integrating (1) around stagnation point "A" and using (2) yields $T_D = 0.52$ with $Q = 0.47$ around "D" point in Figure 2.

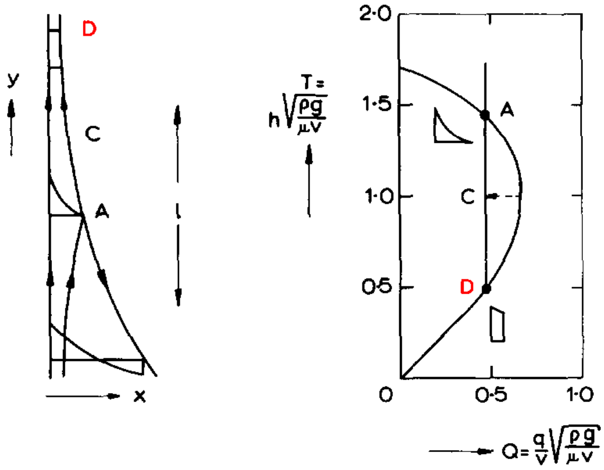


Figure: Thickness T vs. flux Q in high-Re number withdrawal (Groenveld, 70). A: stagnation point, C: acceleration region, D-the h_+ region.

[1] P. Groenveld. "Laminar withdrawal with appreciable inertial forces". In: *Chemical Engineering Science* 25 (1970), pp. 1267–1273.

We find the high-inertia withdrawal theory of Groenveld[2] applicable.

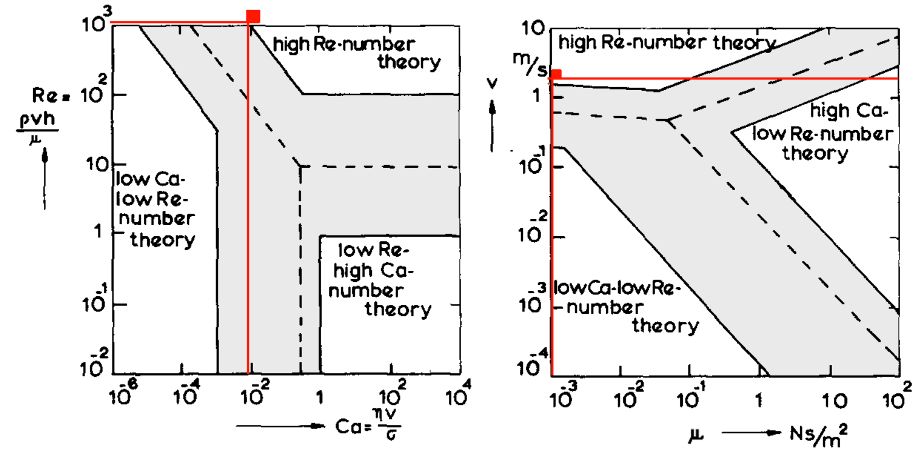


Figure: Presented case in (Re, Ca) and (v, μ) parameter spaces.

Groenveld's hi-Re theory predicts generally thicker films than LLD (capillary-dominated). Weak points: wave formations on the film in this regime.
$\mathrm{Ca} = 9.05 \cdot 10^{-3}$, $\mathrm{Re} \in [160, 220]$ (capillary-h_0 thickness).

[2] Groenveld, "Laminar withdrawal with appreciable inertial forces".

There's no way around this: "Groenveld's thickness"

$$h_D \approx 1.64 \cdot 10^{-4}, \qquad (3)$$

i.e. 163 μm.
For reference, in a domain of $L = .65$, $\Delta = L/2^{14} \approx 39$ μm

Figure: Film interface reconstructed at varying levels of refinement in Basilisk.

- **Basilisk** code (descendant of *Gerris*, also by S. Popinet[3]);
- Optimized for **speed** (hence the name) in serial and parallel runs;
- Built-in **C** parser/lexer for “targetted” minimalized compilations;
- Universal ODE/PDE (multiphysics) solver, **GPL** licence;
- Quad- and oct-tree grid structures available;
- Adaptive mesh refinement using wavelet-based approximation of discretization error;
- Beginner-friendly programming macros, very well documented [4], growing user base.

[3] S. Popinet. “An accurate adaptive solver for surface-tension driven interfacial flows”. In: *Journal of Computational Physics* 228 (16 2009), pp. 5838–5866.

[4] `http://basilisk.fr`

```
event init ( t = 0) {

    restore(file=''dump'');
    fraction(f,0.0937 - y);

}
```

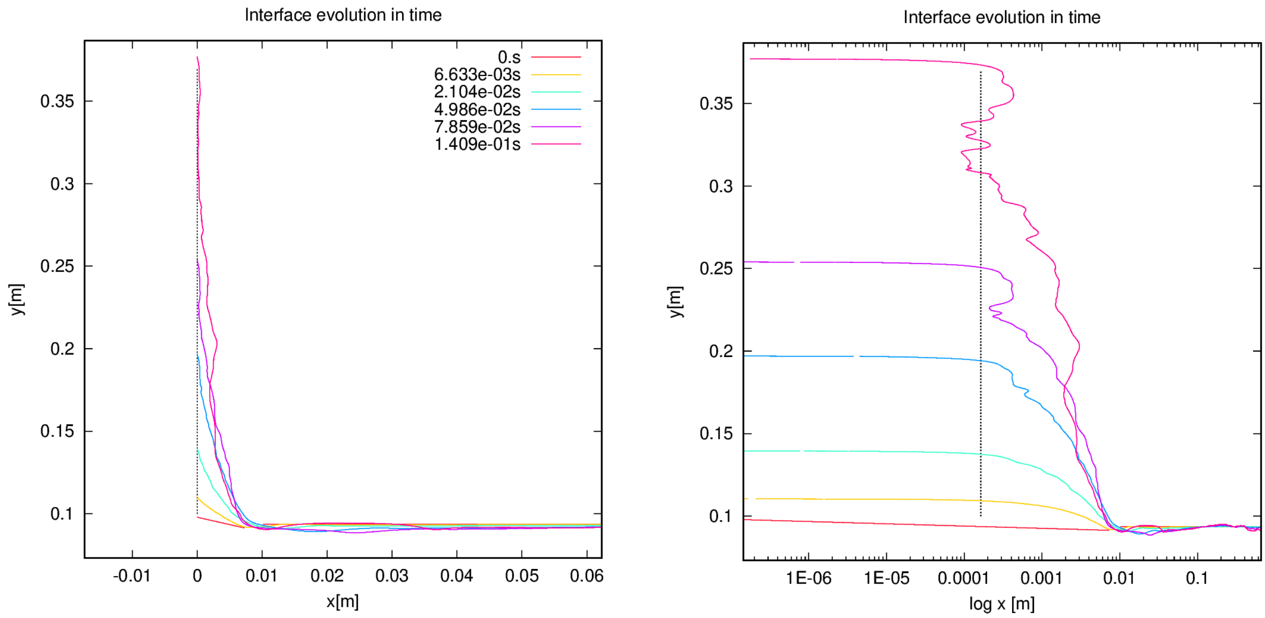
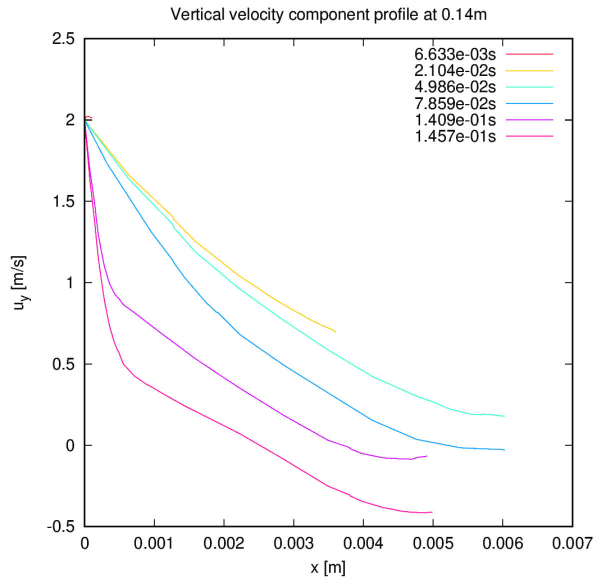


Figure: Interface geometry at chosen t values (with x in dec and log). The dashed line is 'Groenveld's thickness' of 163μ m.



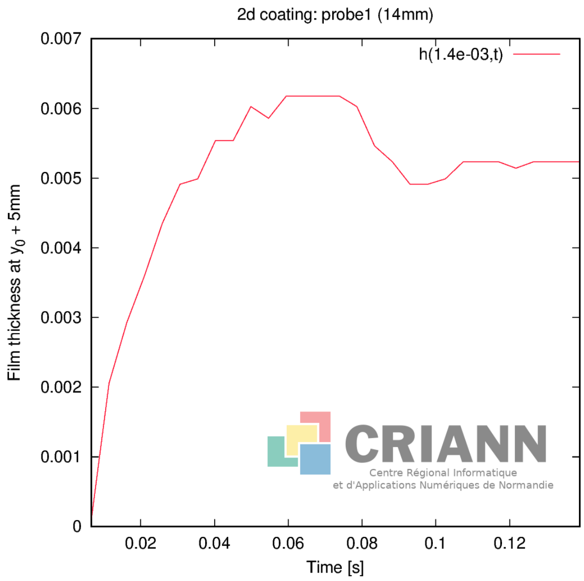


Figure: Left: $u_y(x)$ profiles through the film at varying t values taken from Fig. 4. Right: Film thickness evolution at $h = 0.14$m.

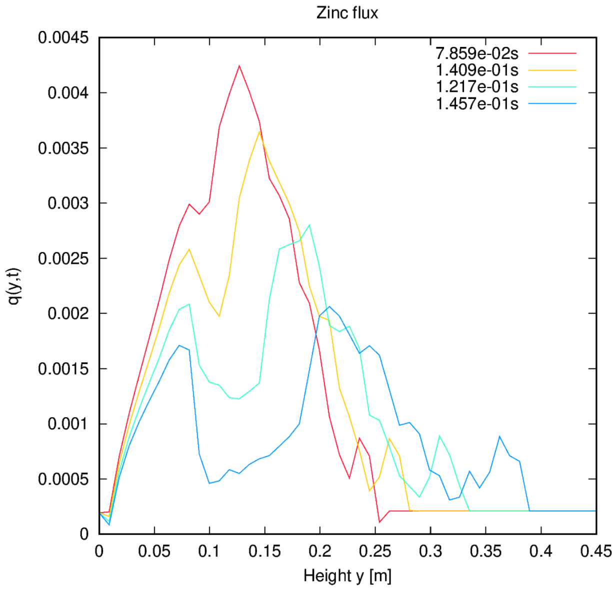


Figure: Net flux distribution along y axis at varying time in the simulation using 2^{14} (16384^2 equivalent) grid.

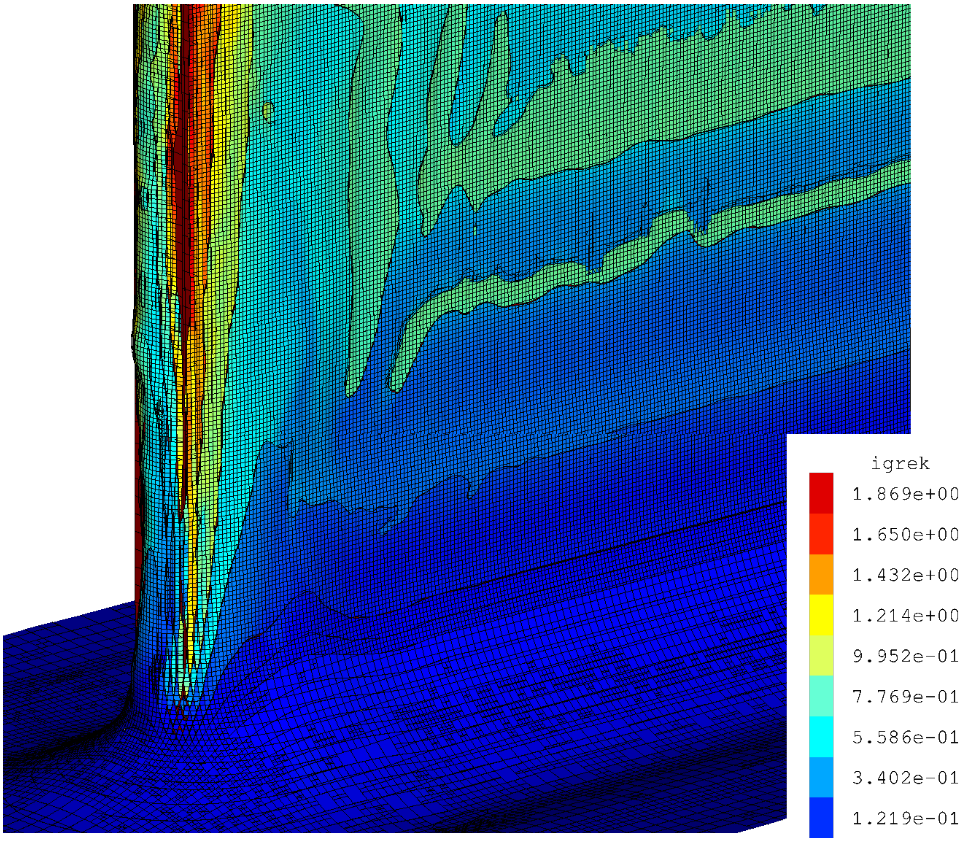
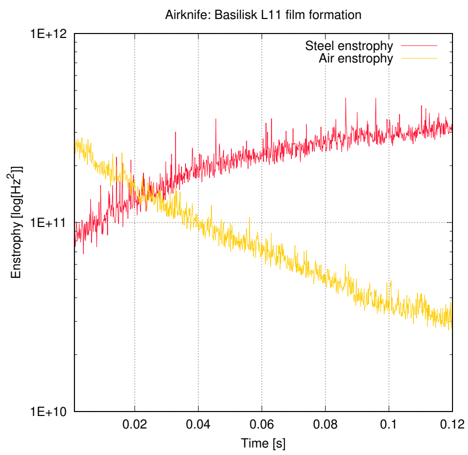


Figure: Three dimensional film geometry at $t \approx 0.1$s into the coating process. The surface is colored with y velocity component.



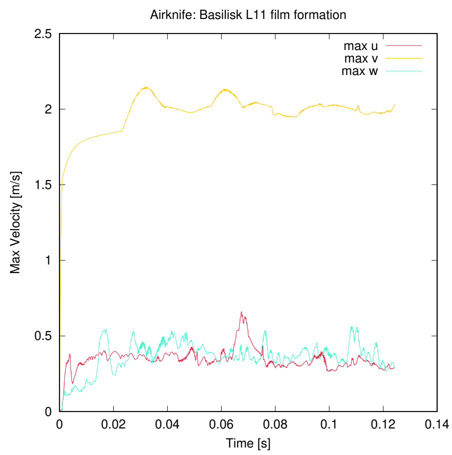


Figure: 3D Coating simulation with a 2^{11}-equivalent grid: global velocity maxima (left) and enstrophy integrals (right) for individual phases.

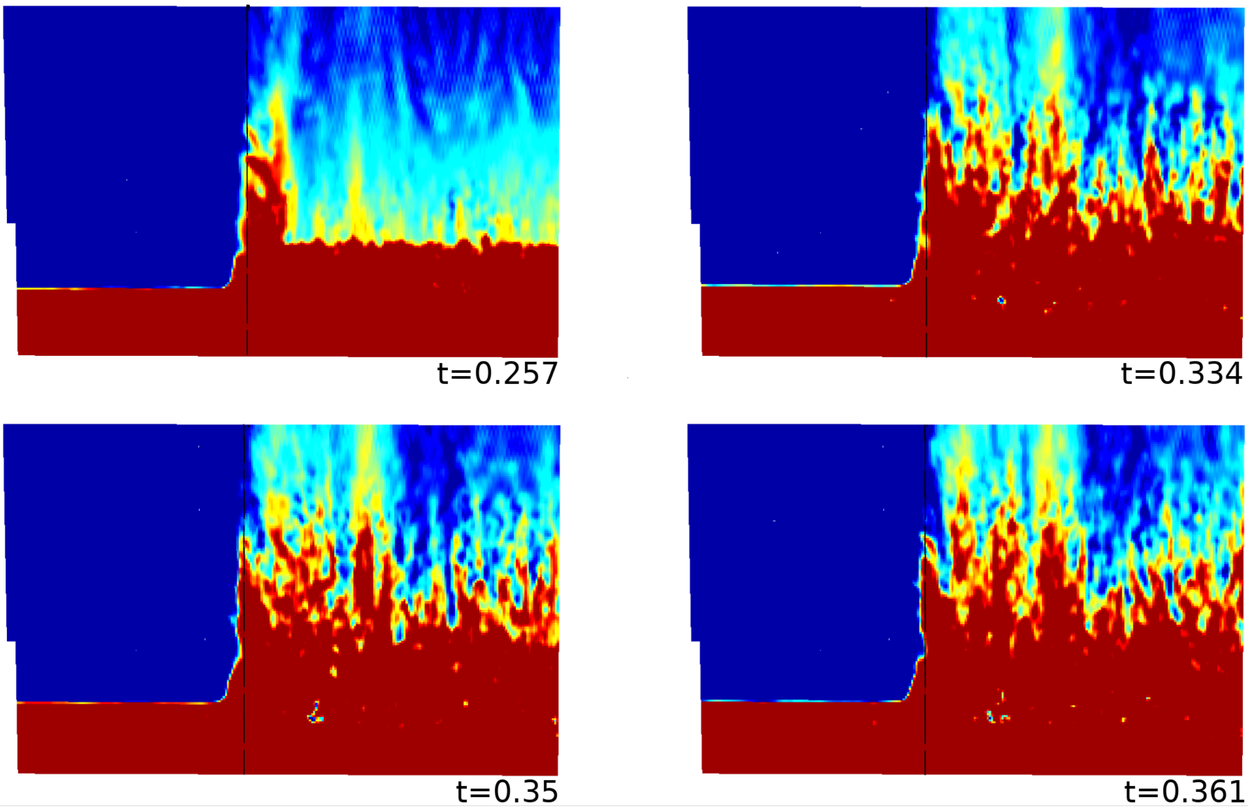


Figure: System geometry in simulation using 2^{10}-equivalent grid: Cutplane through $x = 0.005$m at $t \in [0.257, 0.361]s$.

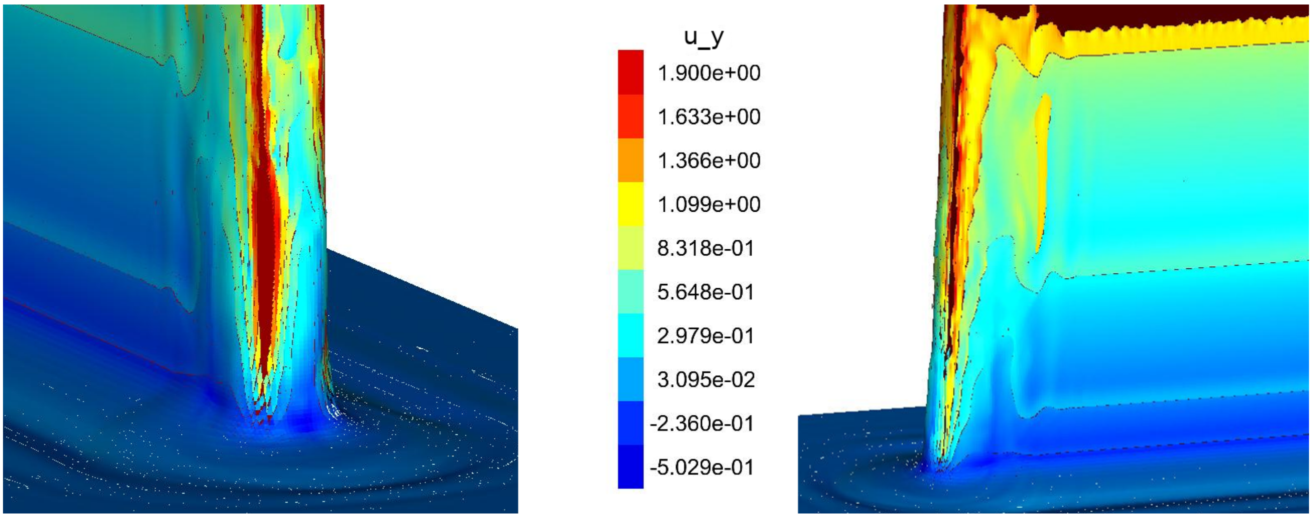


Figure: System geometry in simulation using 2^{11} equivalent grid: $t \approx 0.06$s

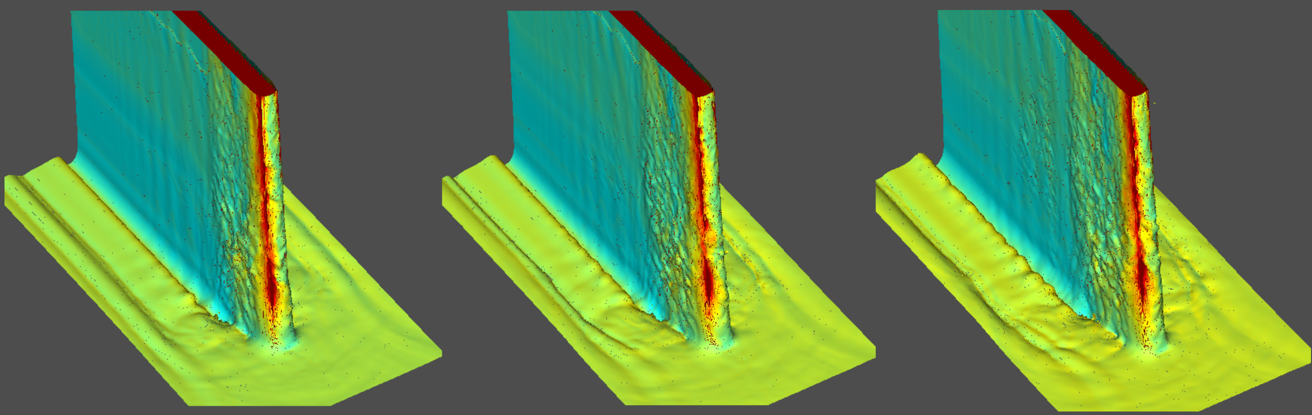


Figure: Coating using 2^{11} grid, $t \in [0.25, 0.29]$s.

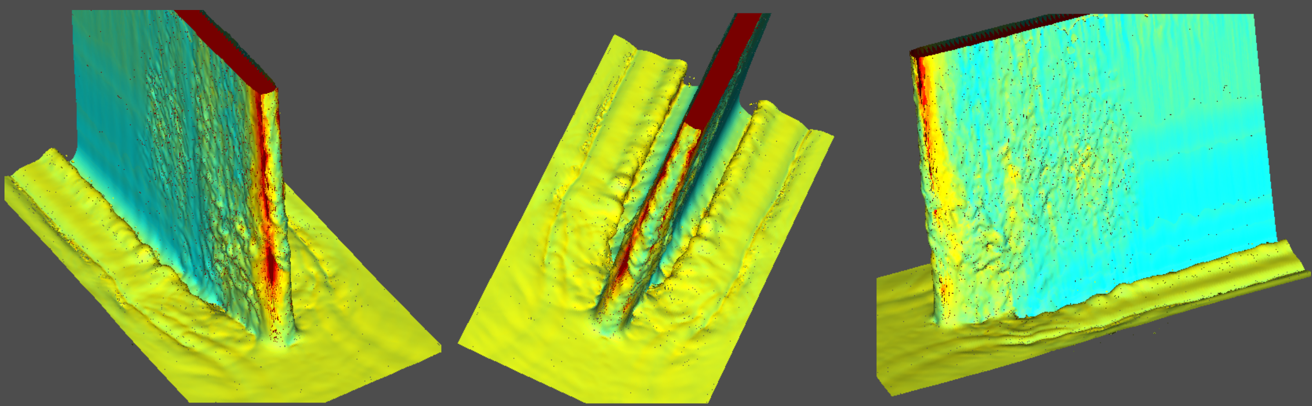


Figure: Coating using 2^{11} grid, $t \approx 0.32$s.