Cutting Fluid Aerosol Generation in Turning Operation

Alexander Atmadi

Zhong Chen

Cutting Fluids

- Purpose:
  - Cooling
  - Lubricating
  - Chip removing
- Hazard:
  - Skin and respiratory irritation
  - Combustible
- OSHA limit : 5 mg/m^3

Aerosol Generation Mechanism

- Spin-off (centrifugal force)
- Splash (impact)
- Evaporation (high temperature)

Scope of Study

Quantitatively describe the generation of cutting fluid aerosol in a turning operation performed on a horizontal lathe in the context of :

- spin-off
- splash

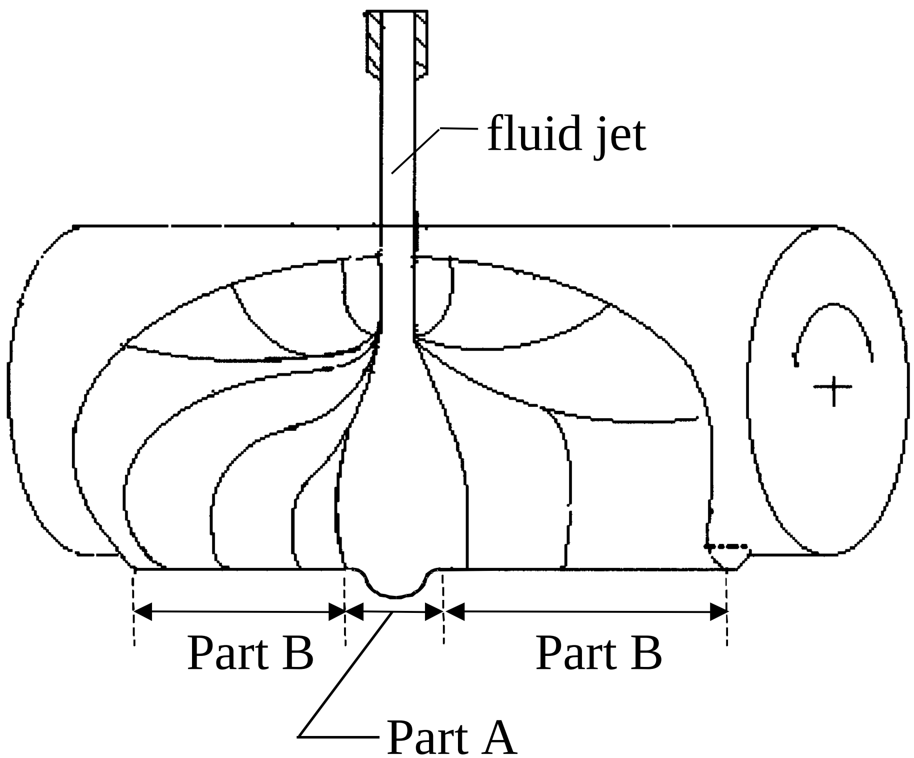
Background Theories

- Fluid motion
- Model of statistical distribution
- Airborne particulate generation rate

Parameters

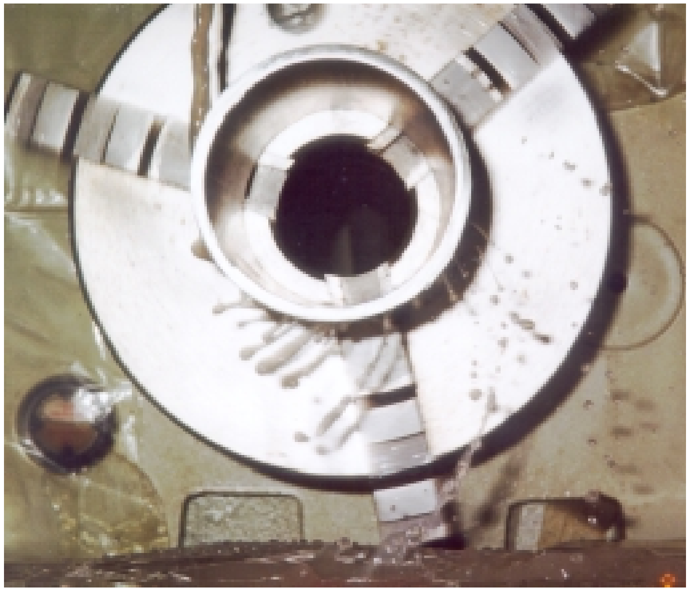
- Fluid properties
- Fluid application conditions
- Machining process parameters

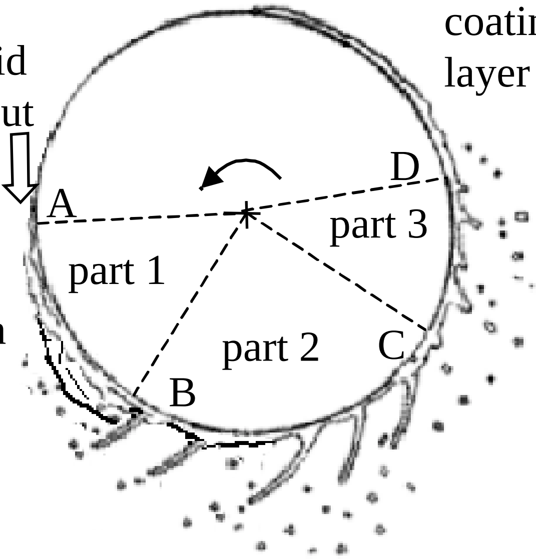
Spin-off: Complete Process



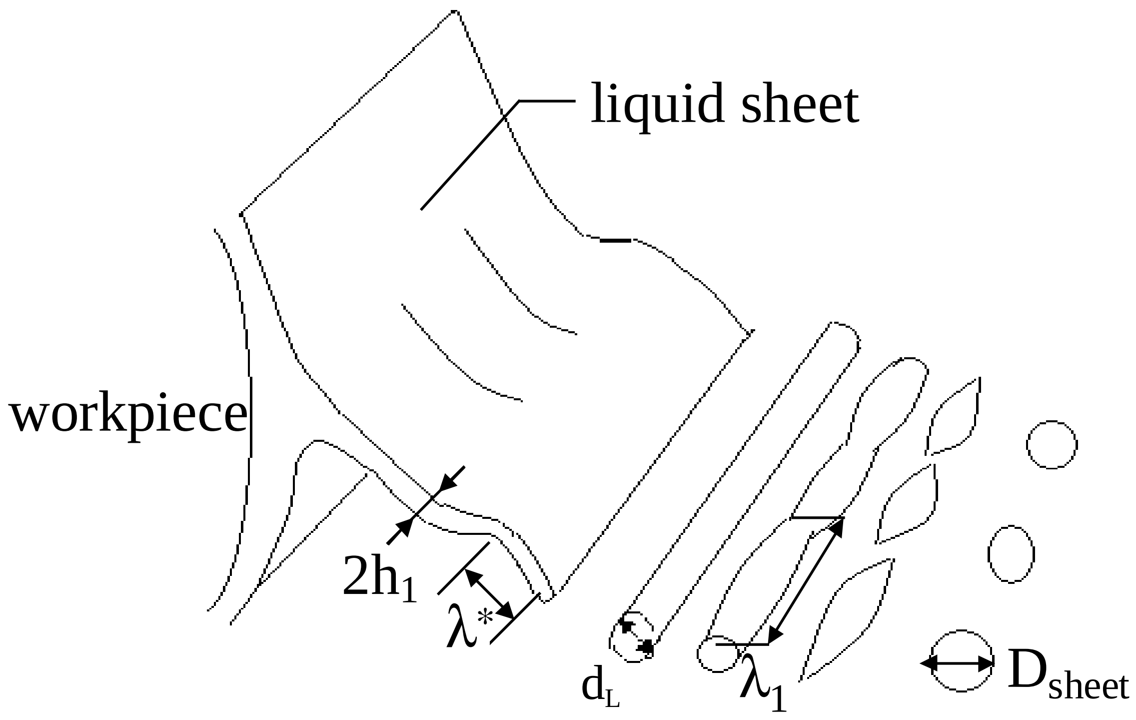
Spin-off mechanism containing a rotary disk part (A) and a liquid sheet part (B)

Spin-off: Rotary Disk Atomization Model





Spin-off: Liquid Sheet Model



Spin-off: Film Atomization Mode

$$D_f = \frac{105 Q_f^{0.5} \sigma^{0.4}}{1.7 \Omega R^{0.8} \rho^{0.4}}$$

$$Q_{1-2} = C_1 \pi R^2 \sqrt{\nu \Omega}\, \mathrm{Re}^{0.667}\, We^{-0.883}$$

Spin-off: Ligament Atomization Mode

$$D_\ell = C' R \left(\frac{1}{N_\ell} \right)^{2/7} \left(\frac{\rho Q_\ell^2}{R^3 \sigma} \right)^{1/7} We^{-2/7}$$

$$Q_{1-2} = C_1 \pi R^2 \sqrt{\nu \Omega}\, \mathrm{Re}^{0.667}\, We^{-0.883}$$

$$Q_{2-3} = 0.192 C_2 \pi R^2 \sqrt{\nu \Omega}\, \mathrm{Re}^{0.95}\, We^{-1.15}$$

Spin-off: Droplet Atomization Mode

$$D_d = \sqrt{6}\left(\frac{\sigma}{\rho}\right)^{1/2}\left(\frac{R}{{V_\theta}^2}\right)^{1/2}$$

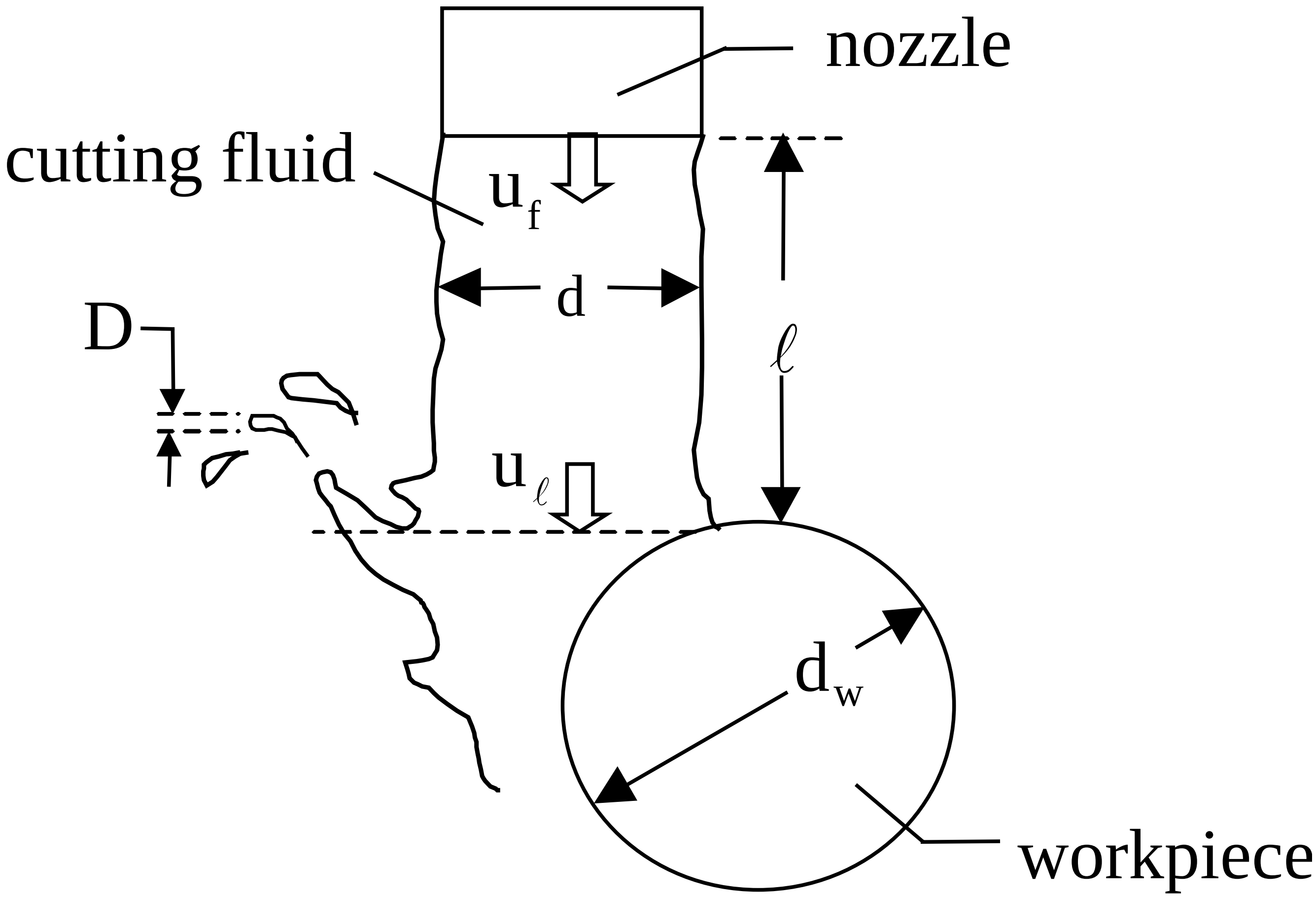
$$Q_{2-3} = 0.192 C_2 \pi R^2 \sqrt{\nu\Omega}\,\mathrm{Re}^{0.95}\,We^{-1.15}$$

Spin-off: Liquid Sheet Atomization Mode

$$D_s = 2.12\sqrt{2h_s\lambda^*}$$

$$Q_c = w\int_0^{h_o} V_c\,dr = w\left(\Omega R h_o - \frac{g h_o^3}{3\nu}\right)$$

Splash: Complete Process



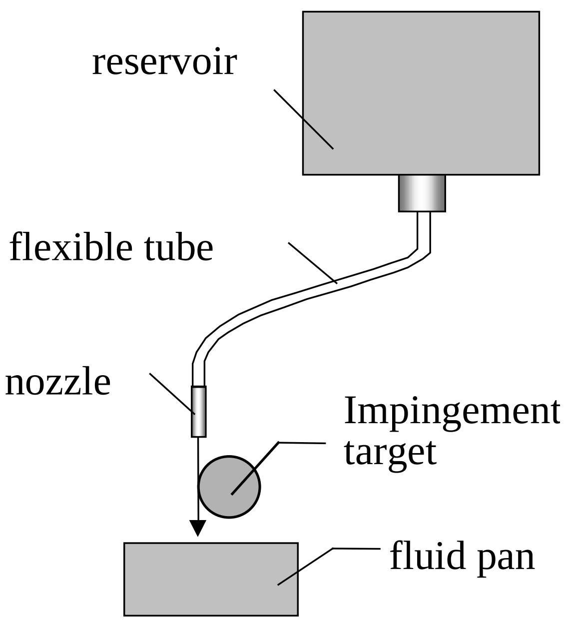
Splash: Droplet Diameter

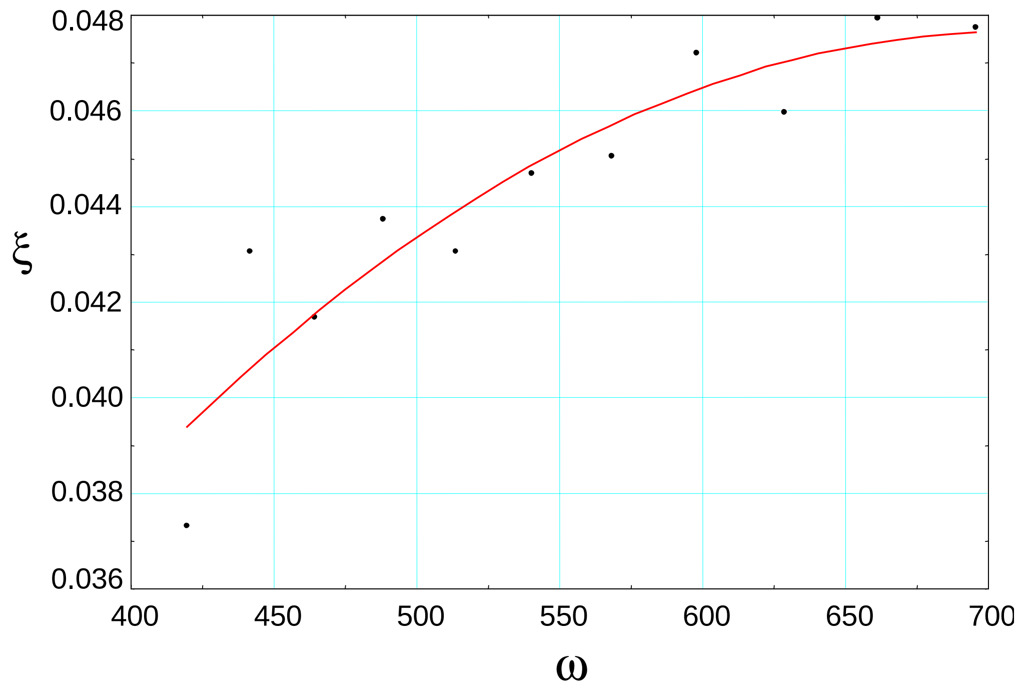
$$\mathrm{SMD} = \frac{27}{\mathrm{N}}\left(\frac{\sigma}{2\mathrm{R}\rho}\right)^{0.5}\left(1 + 0.003\frac{\mathrm{Q_j}}{2\mathrm{R}\nu}\right)$$

$$\xi = K_1 + K_2\omega + K_3\omega^2$$

$$\omega = \mathrm{We} \times e^{\frac{0.971\ell}{\mathrm{d}\sqrt{\mathrm{We}}}}$$

Splash: Experiment to Determine Coefficient K





Particle Size Distribution

$$\Phi(D) = 1 - \exp\left[-0.693\left(\frac{D}{D_m}\right)^{\delta}\right]$$

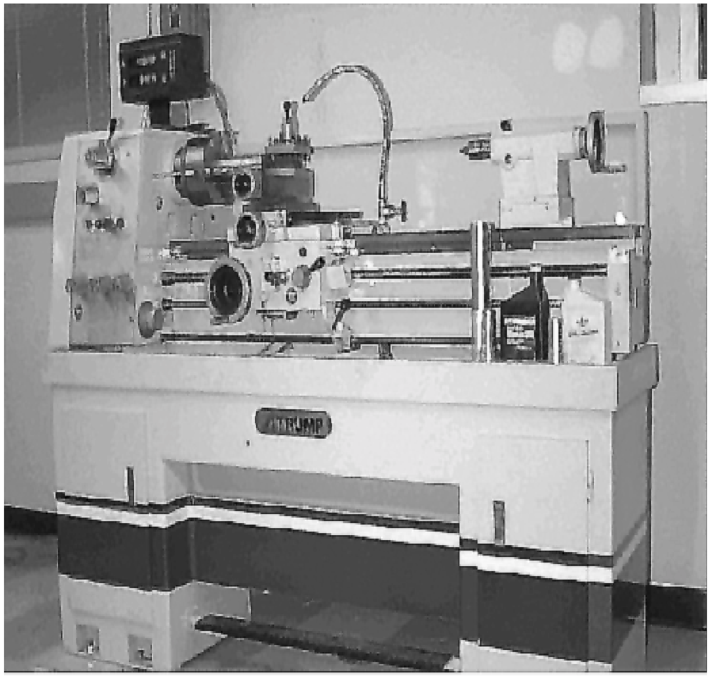
- The equations to calculate droplet diameter yields exact diameter
- In reality, there are some variations in the droplet diameter due to various conditions

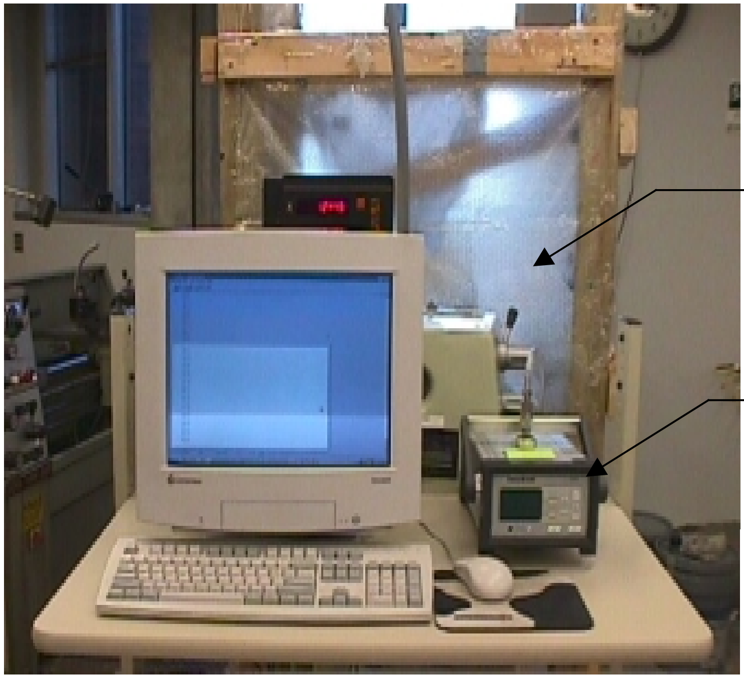
Aerosol Generation Rate

$$\dot{\eta}_{spin-off} = \left(\dot{M}_f \Phi_f(D) + \dot{M}_\ell \Phi_\ell(D) + \dot{M}_d \Phi_d(D) + \dot{M}_s \Phi_s(D)\right) / Vol$$

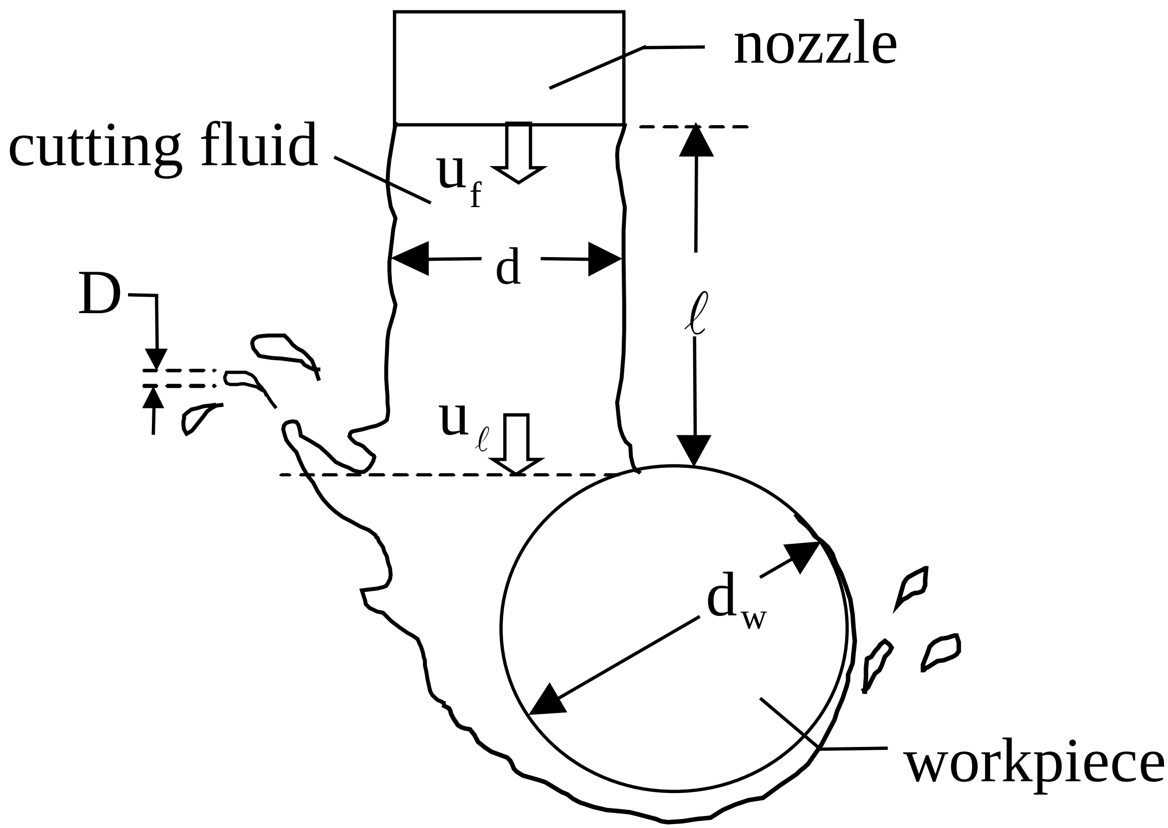
$$\dot{\eta}_{splash} = \beta \xi \rho u_f \left(\frac{\pi d^2}{4}\right) \Phi_{splash}(D) / Vol$$

Experimental Verification

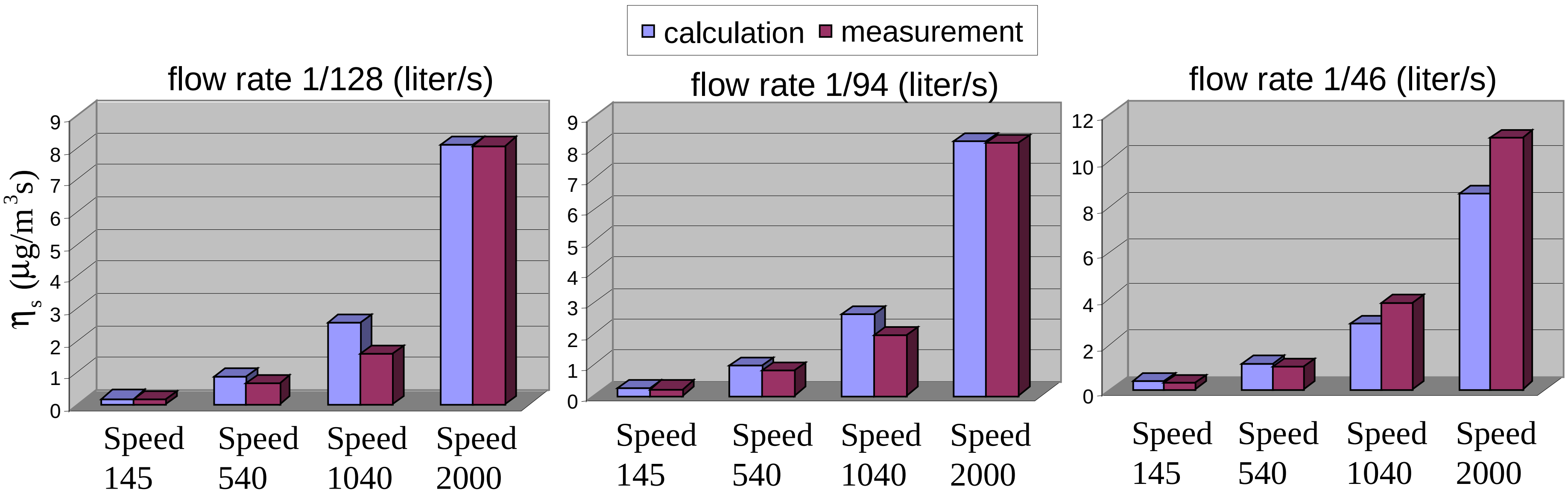




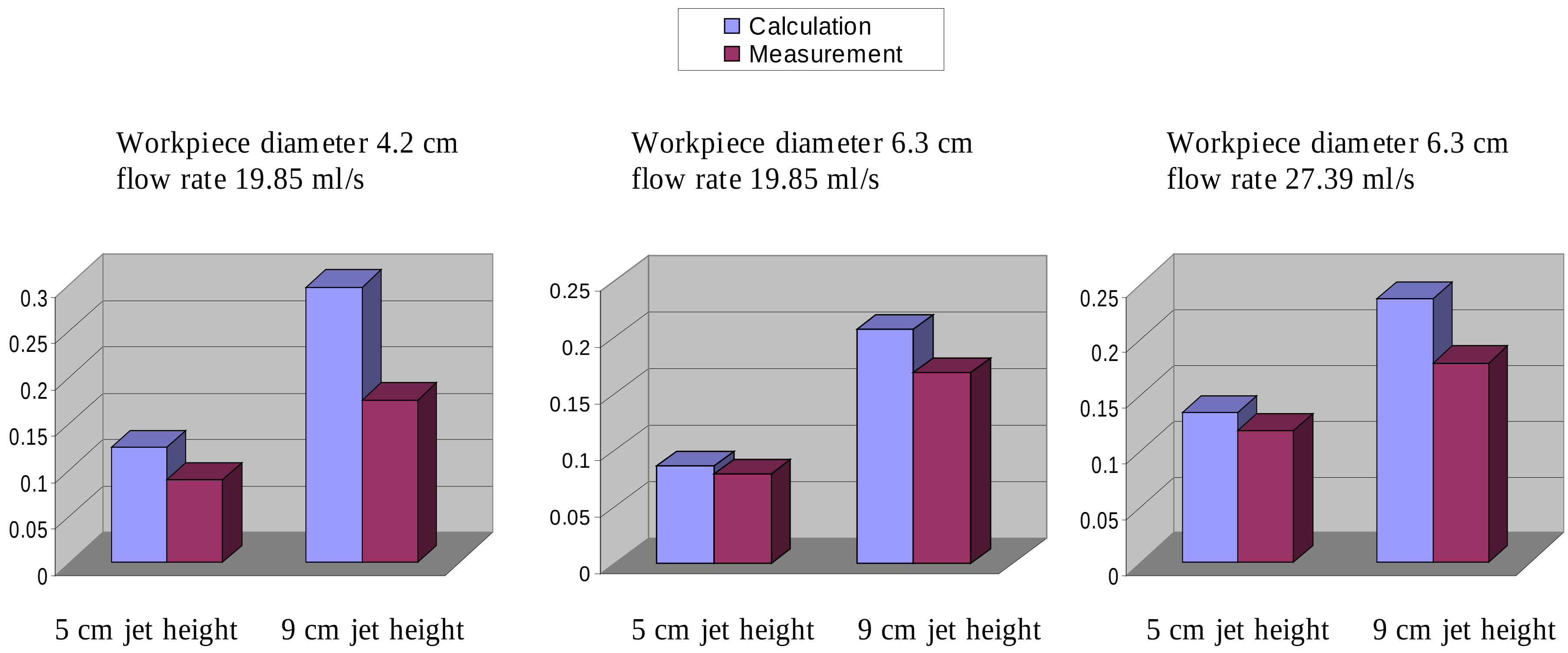
Probe Location



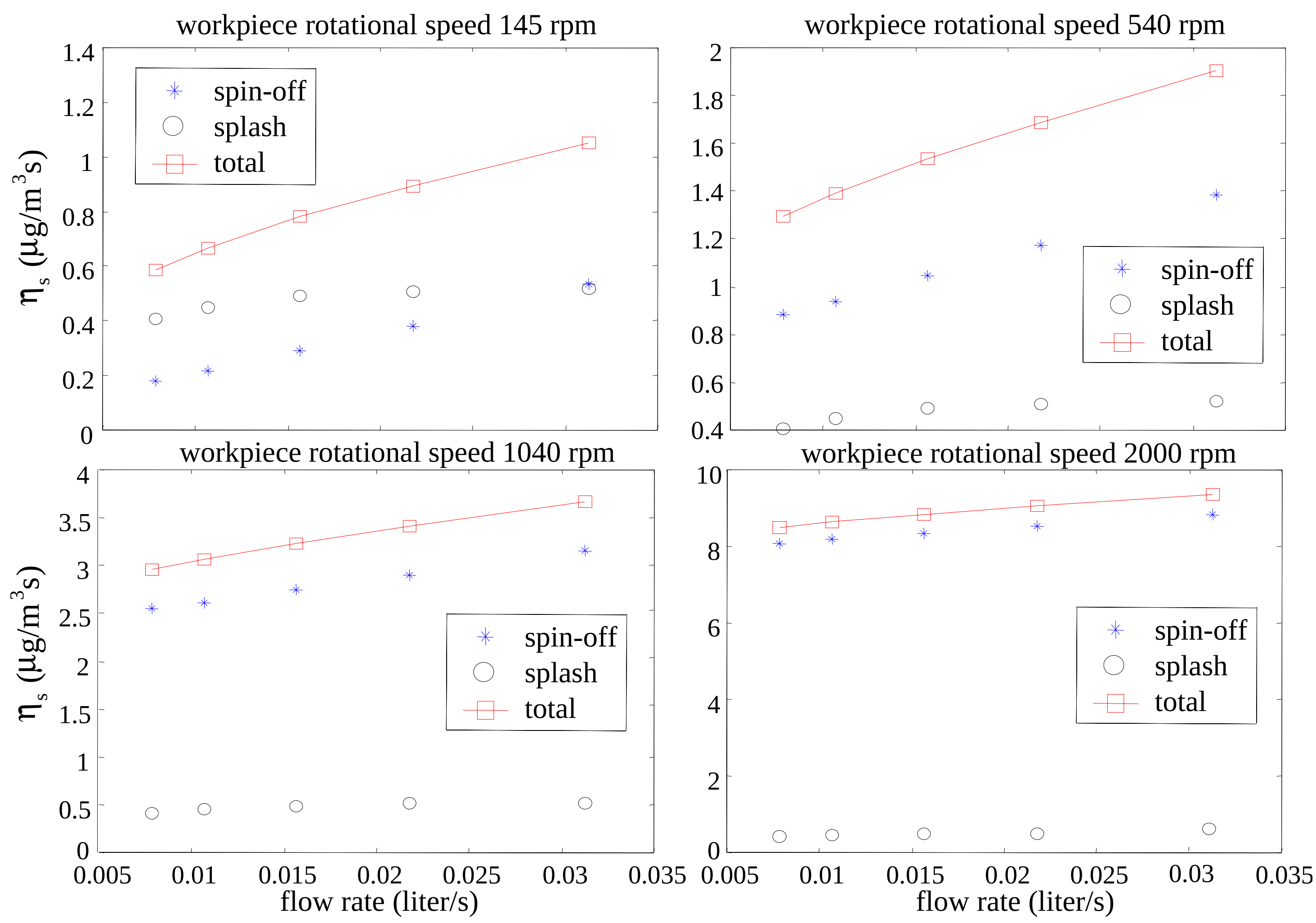
Spin-off: Analytical and Experimental Results of Aerosol Generation Rate



Splash: Analytical and Experimental Results of Aerosol Generation Rate



Total Aerosol Generation Rate Under Various Conditions



Conclusion

- The aerosol generation rate increases with the increase of :
  - flow rate
  - rotational speed
  - jet distance
- There is a good agreement between the analytical and theoretical results