# *Cutting Fluid Effects*

# *on Machine Shop Air Quality*

## For IAB2000

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# Problem Description

- Occupational Safety and Health Administration (OSHA) requirements → **0.5 mg/m$^3$**

## Upper Respiratory
[Lubricants in Operation, 1996]

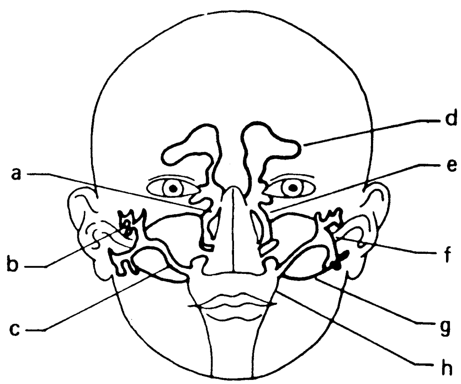



**Fig. 9.5 Upper parts of the respiration tract.**
a Tear duct
b Mastoid process
c Eustachian tubes
d Frontal sinus
e Naso-pharynx
f Middle ear
g Jawbone cavity
h Throat cavity

## Skin Contact
[Lubricants in Operation, 1996]

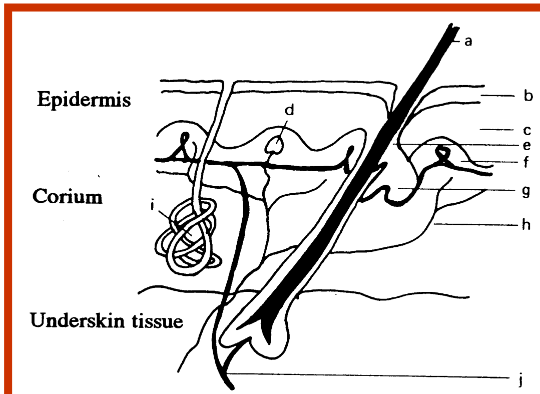
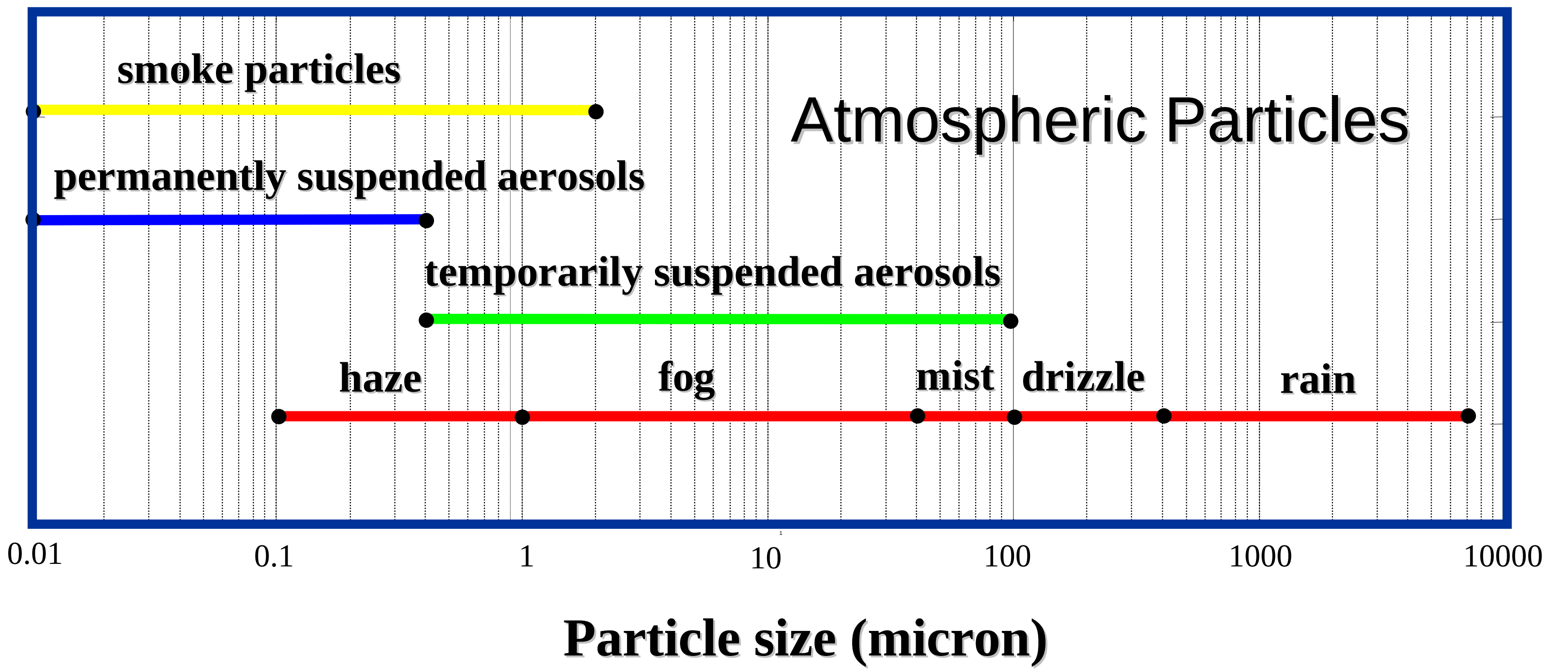


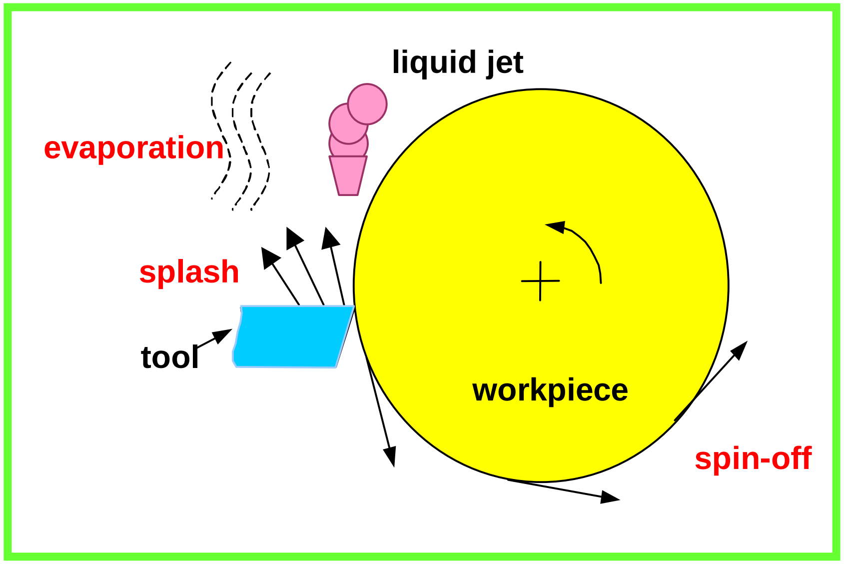

**Fig. 9.8 Skin structure.**
a Hair
b Horny skin
c Nascent skin
d Nerve ending
e Follicle
f Papillary layer
g Sebaceous gland
h Nerve
i Sweat gland
j Blood vessel

# Problem Description (cont.)

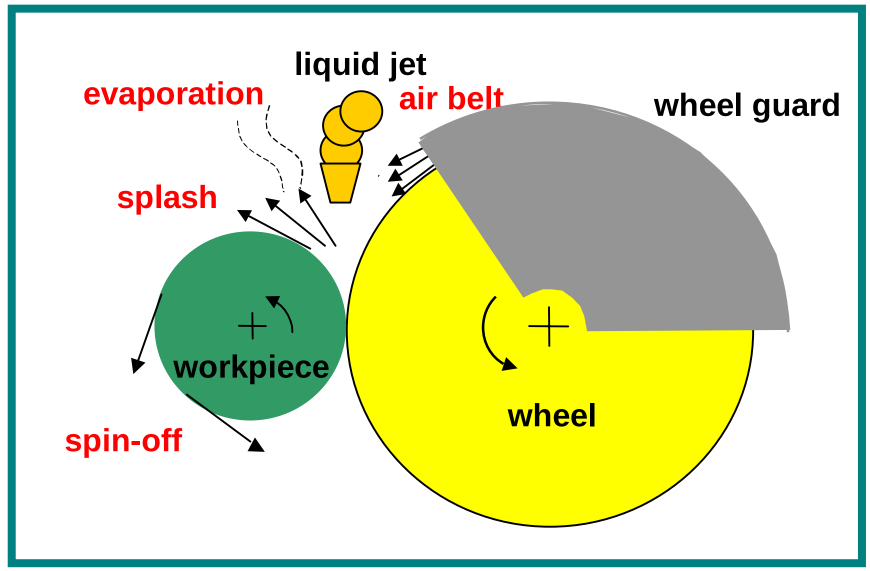


# Problem Description (cont.)

## Turning process




## Grinding process



# *Objectives*

- Quantitative modeling of aerosol generation and dissipation in shop floor environment during turning and grinding processes

- Multivariate validation of methodology based on experiments.

# *Flow Diagram of Modeling*

**Spin-off model** **Splash model** **Evaporation model**

↓

**Statistic distribution model**

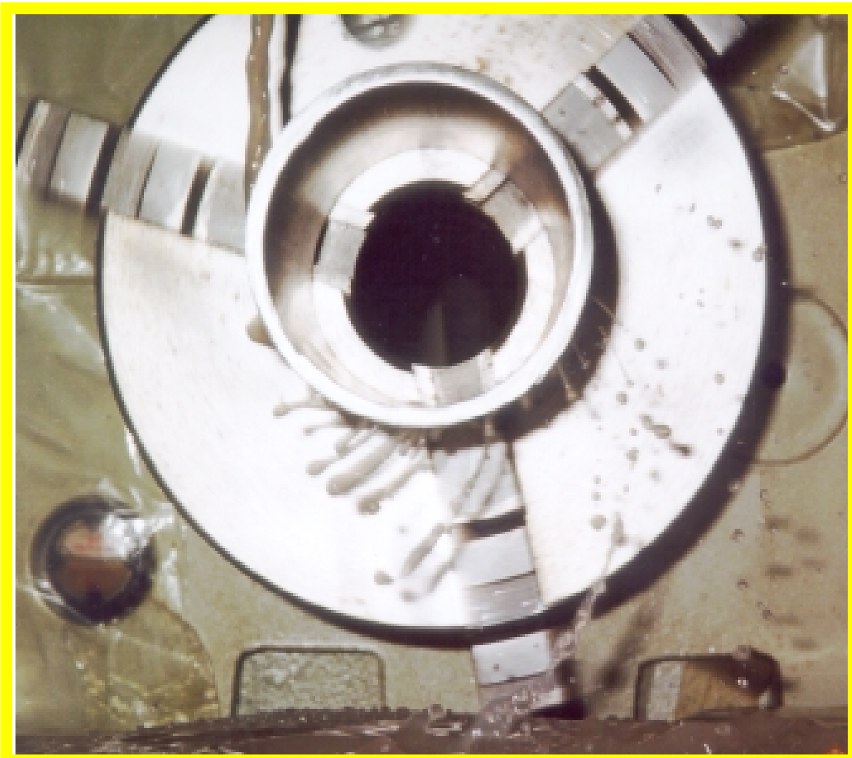
↓

**Dissipation model**

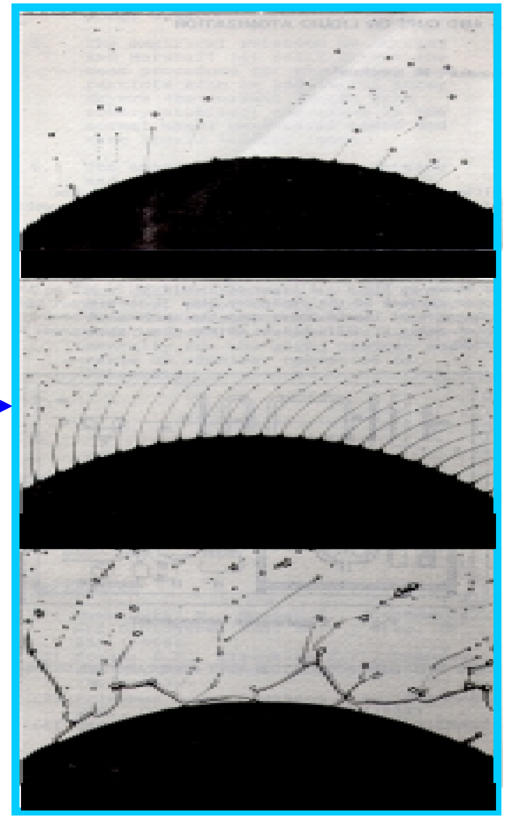
↓

**Aerosol concentration**

# *Spin-off Modeling*



**Photograph of spin-off**



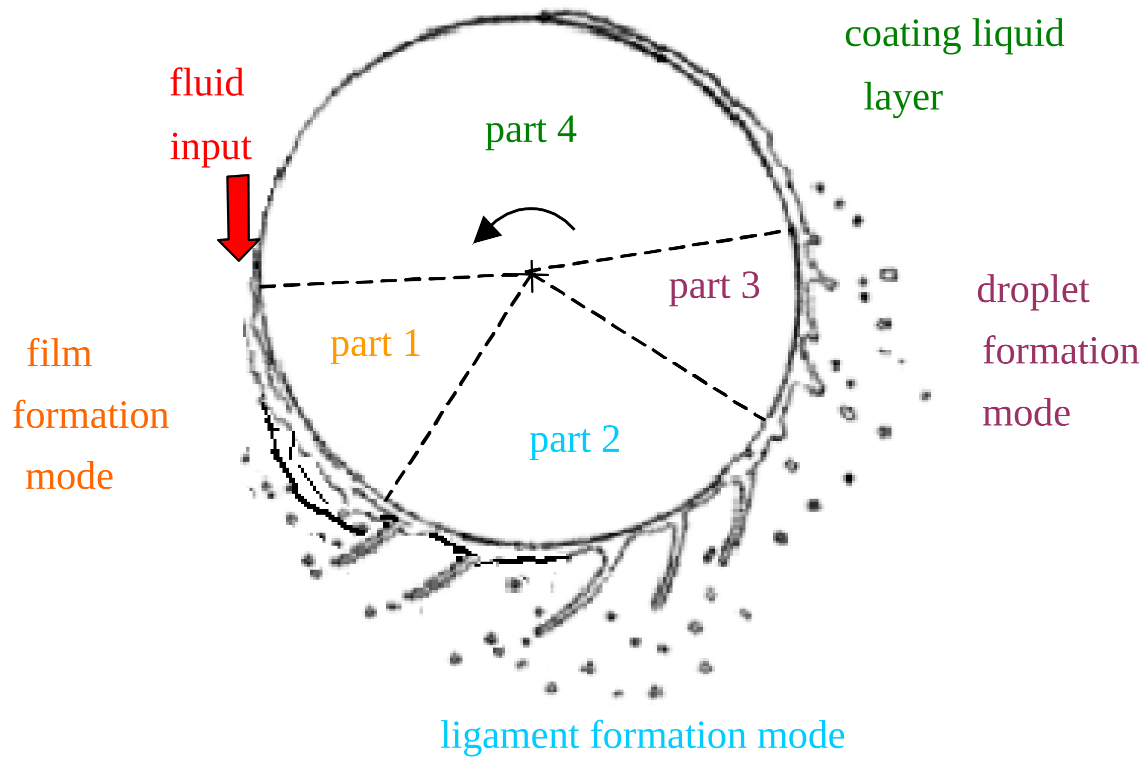
**Drop mode**

**Ligament mode**

**Film mode**

# Spin-off Modeling (cont.)

## Rotating cylindrical peripheral disk atomization model



# Spin-off Modeling (cont.)

- **drop mode**

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

- **ligament formation mode**

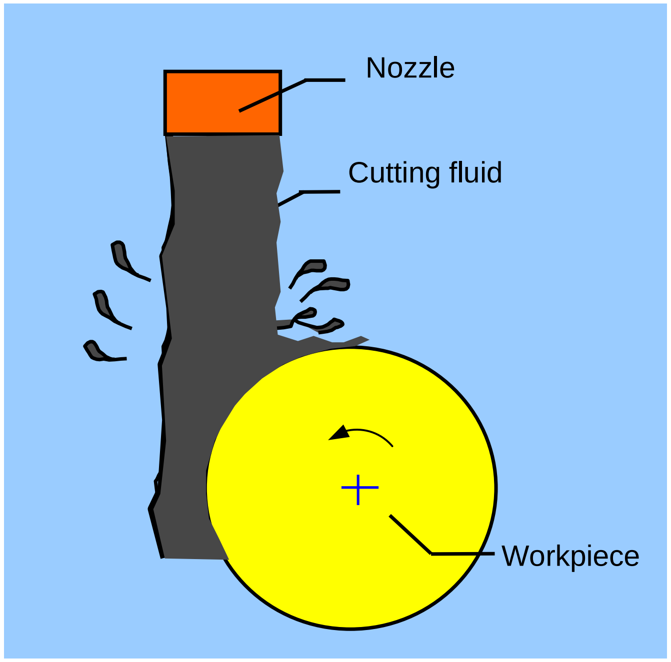
$$D_\ell = C'R\left(\frac{1}{N_\ell}\right)^{2/7}\left(\frac{\rho Q_\ell^2}{R^3\sigma}\right)^{1/7} We^{-2/7}$$

- **film formation mode**

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

# Splash Modeling

- Based on splatter model and atomization theory
- The mechanics of the splash atomization is similar to the mechanism of drop formation mode in spin-off process



# Splash Modeling (cont.)

- **Splash parameter**

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

- **Splash distribution parameter**

$D_m$, SMD, Re etc. => $\delta$

- **Aerosol generation rate in splash process**

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

# *Evaporation modeling*

- **Hertz-Knudsen formula**

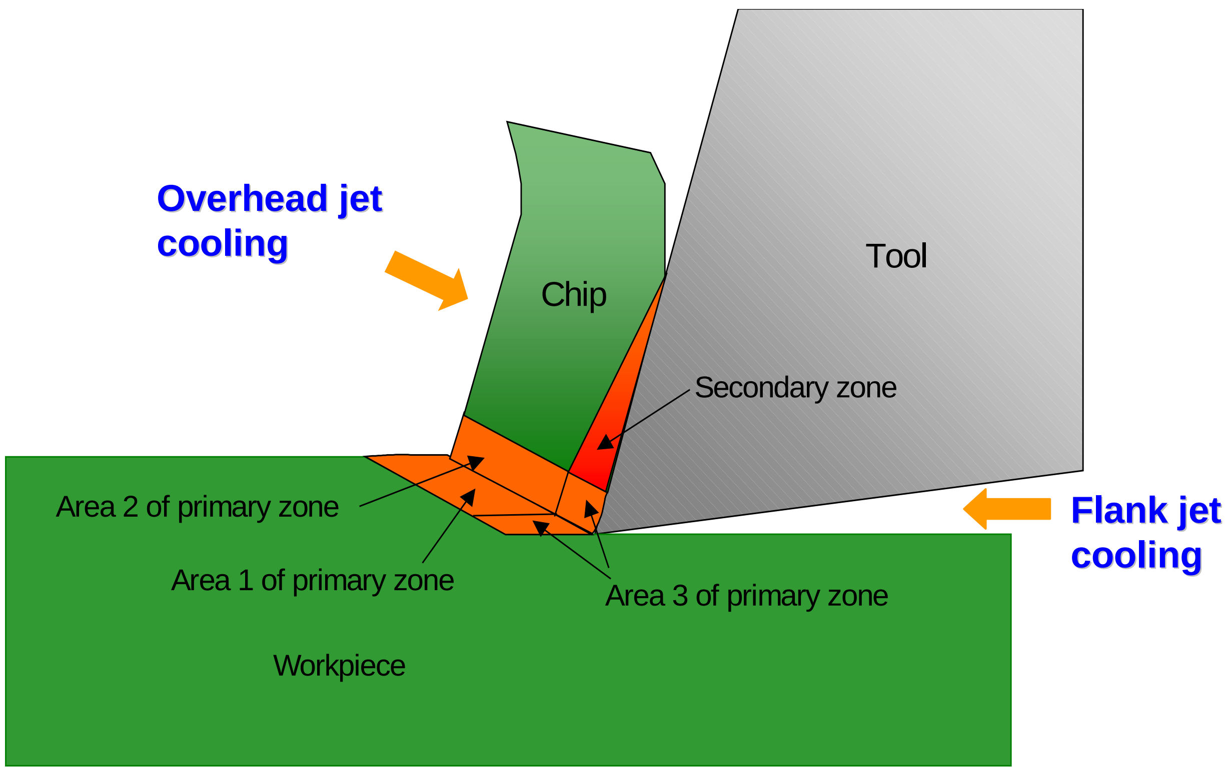
**[Jones, Frank E,1992]**

$$W = E\sqrt{(M/2\pi R)}(P_{tr}/\sqrt{T_{tr}} - P_{min}/\sqrt{T_v})$$

| | |
|---|---|
| **W** | **evaporation rate** |
| **E** | **evaporation coefficient** |
| **M** | **molecular weight of the evaporating substance** |
| **R** | **universal gas constant** |
| **$P_{tr}$, $T_{tr}$** | **vapor pressure and temperature at the interface** |
| **$P_{min}$, $T_v$** | **vapor pressure and temperature at vapor region** |

# *Evaporation modeling*
# *- Temp. distribution calculation*

- **2-D FEM model to calculate temperature distribution**



# Evaporation modeling
# - Temp. distribution calculation

- **Overhead Jet Cooling**

**Using Goldstein and Franchett model to calculate the local heat-transfer coefficients in heat transfer from a flat surface to an oblique impinging liquid jet.**

$$Nu = 1.122 \; A \, (Pr^{1/3}) \, Re_j^{0.7} \, e^{-(B + C \cos \Phi)(r/D)^m}$$

- **Flank Jet Cooling**

**Model of flow parallel to both surfaces**

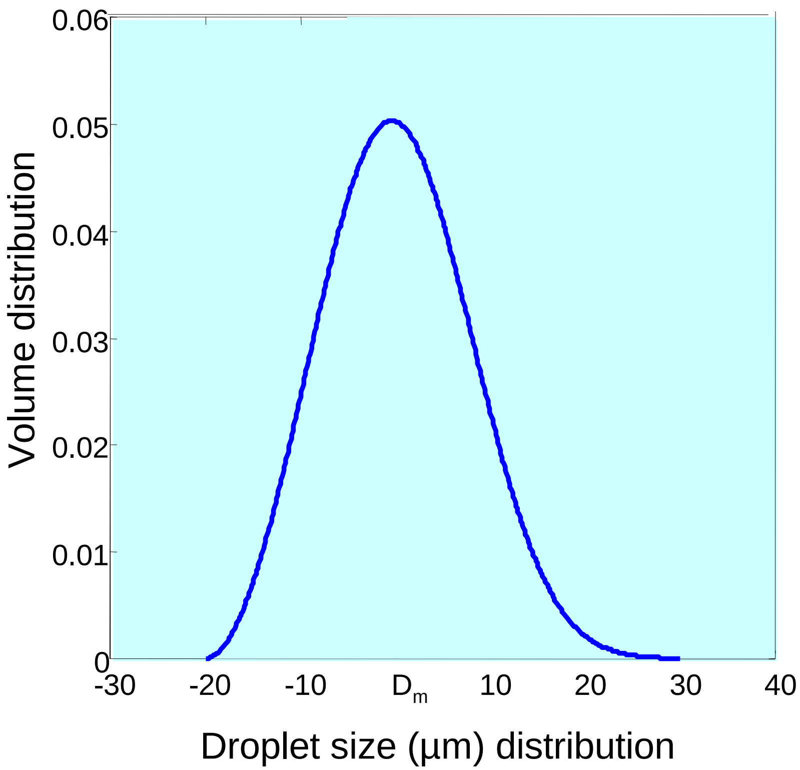
**[Rohsenow w. 1973]**

$$Nu_x = \frac{h_x x}{K} = 0.332 \, (Pr^{1/3})(Re_j^{1/2}) \quad Re_x \leq 5 \times 10^5$$

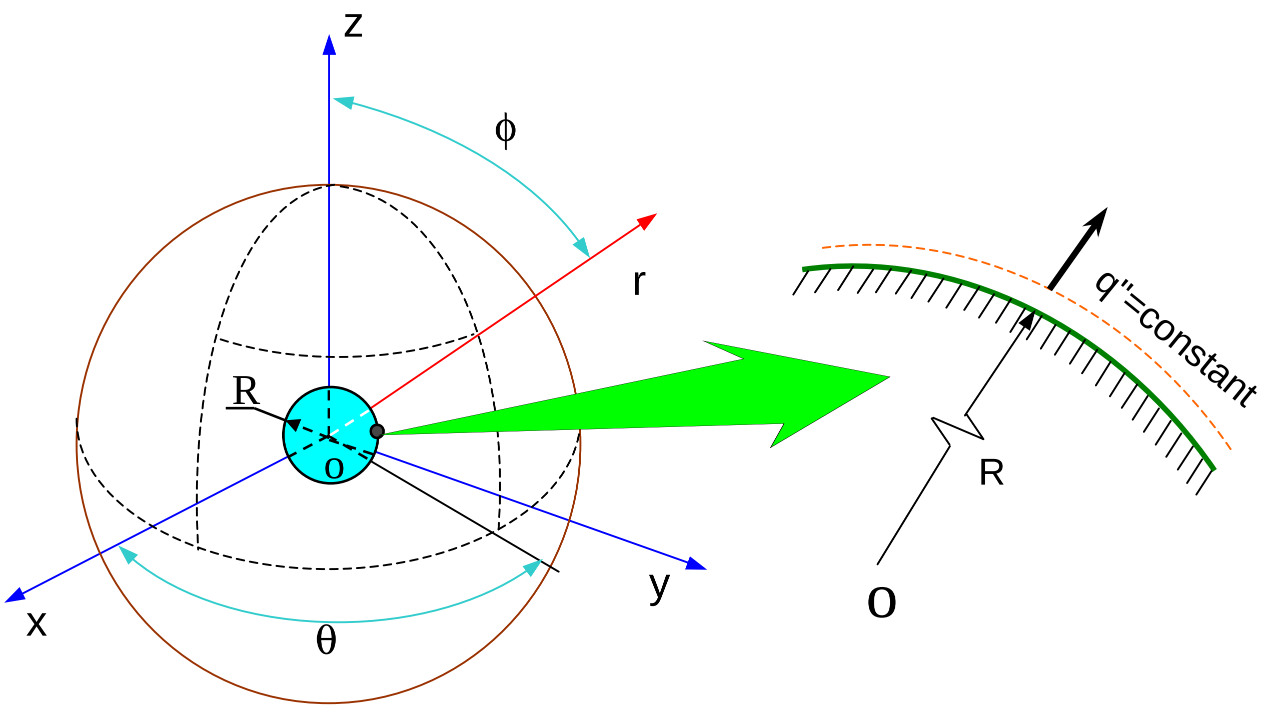
# Statistic Distribution Modeling

- Rosin-Rammler particle size distribution function

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



# Dissipation Modeling



# Dissipation Modeling (cont.)

- **Dissipation Equation:**

$$D_{AB}\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial \eta_A}{\partial r}\right)+D_{AB}\frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial\eta_A}{\partial\theta}\right)+D_{AB}\frac{1}{r^2\sin^2\theta}\frac{\partial^2\eta_A}{\partial\phi^2}=\frac{\partial\eta_A}{\partial t}$$

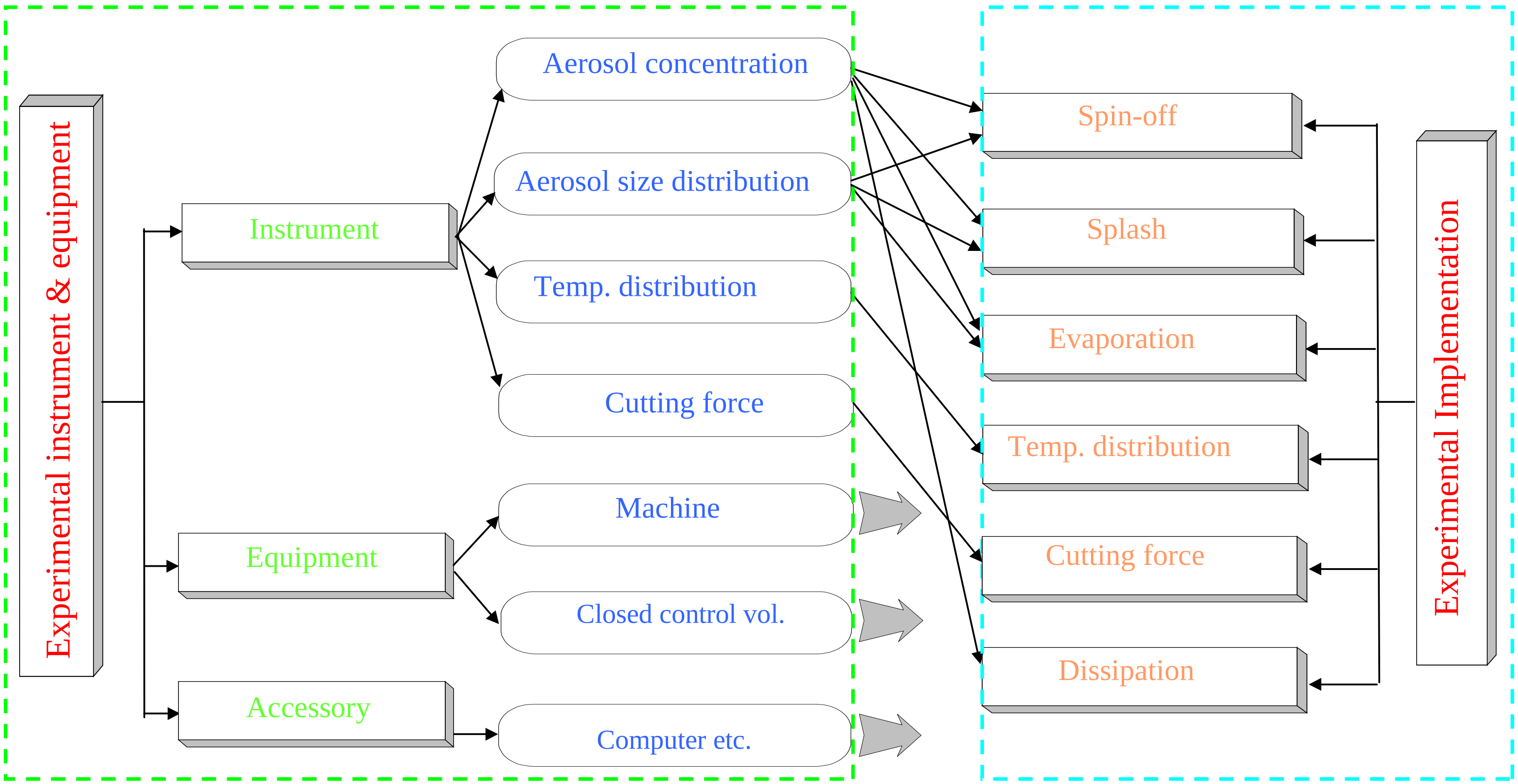
**BC:** $$-D_{AB}\left.\frac{\partial\eta}{\partial s}\right|_{s=R}=q''$$

**IC:** $$\eta(s,0)=\eta_o$$

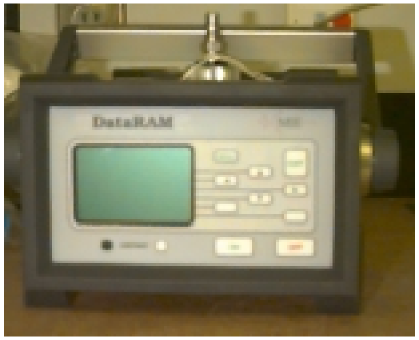
**Chapman-Enskog Formula for Diffusivity:**

$$D_{AB}=1.86\times10^{-7}\,T^{3/2}\,\frac{\sqrt{(M_A+M_B)/M_AM_B}}{p\sigma_{AB}^2\Omega_D}$$

# Experiments



# DataRam Aerosol Monitor



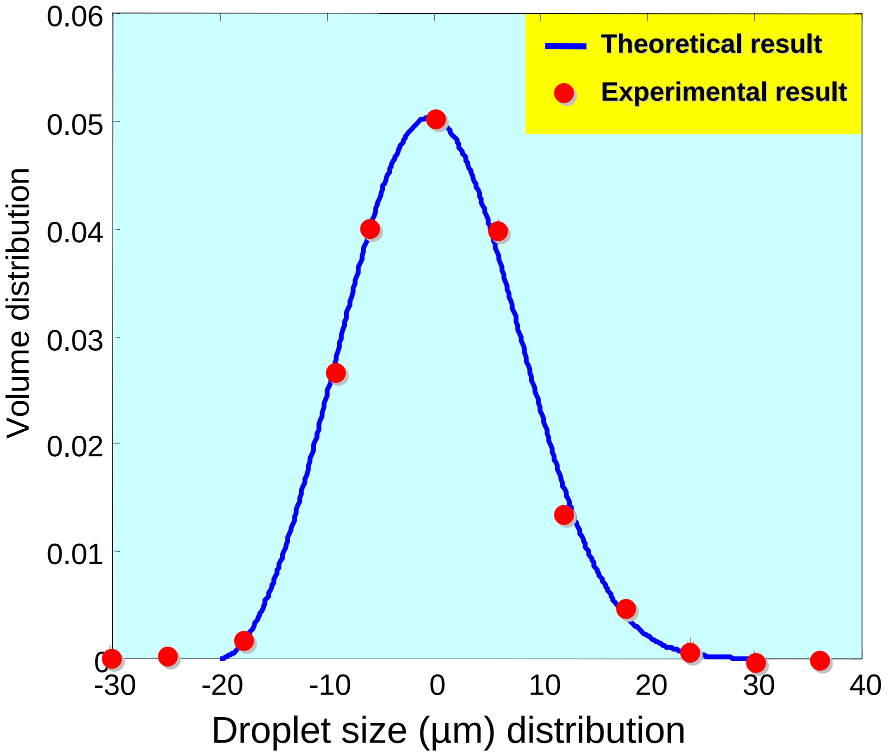

DataRAM

HotMeter

10/2.5 μm Selector

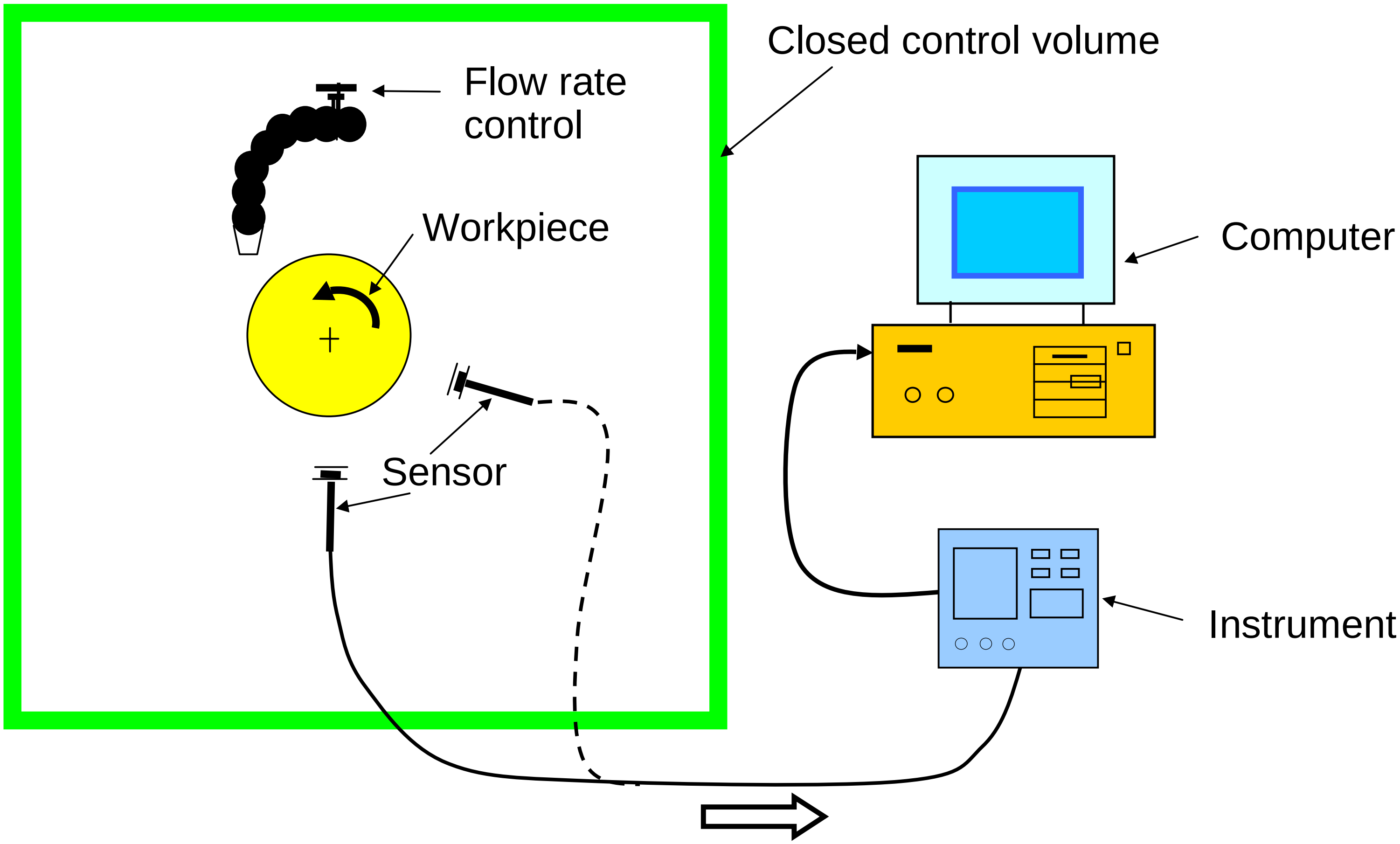
Omni-directional Inlet

# Particle Measuring System

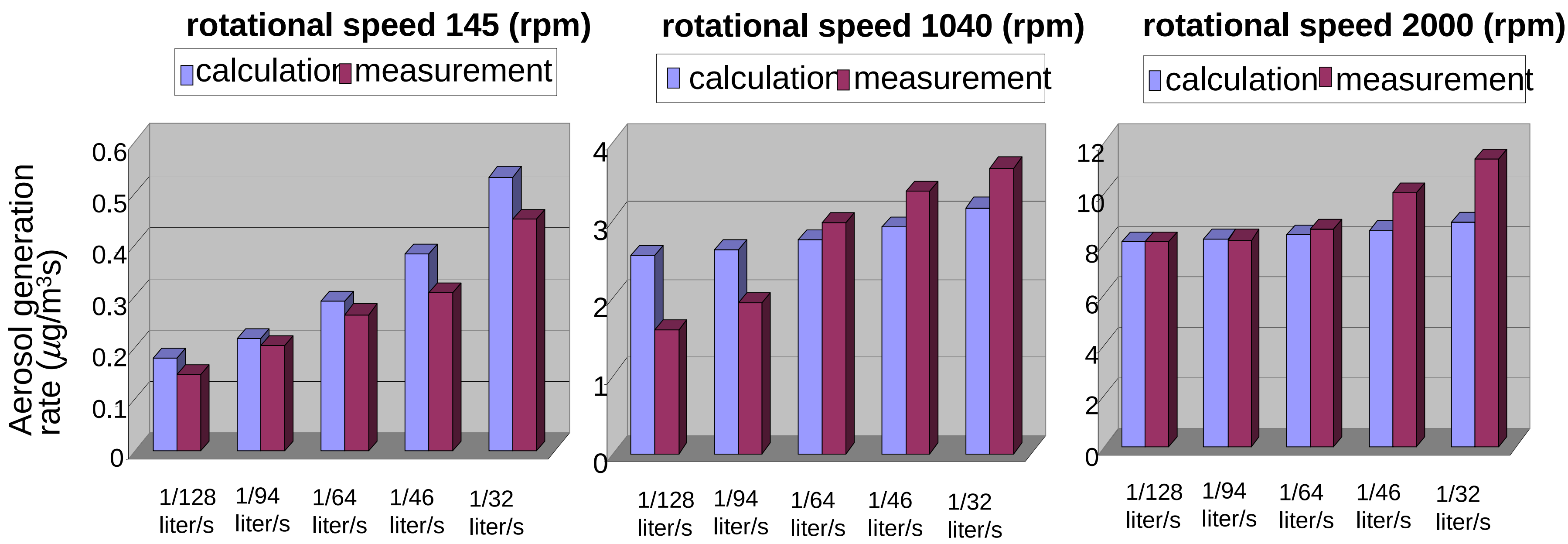


# Experiments (cont.)

- **Experimental setup**

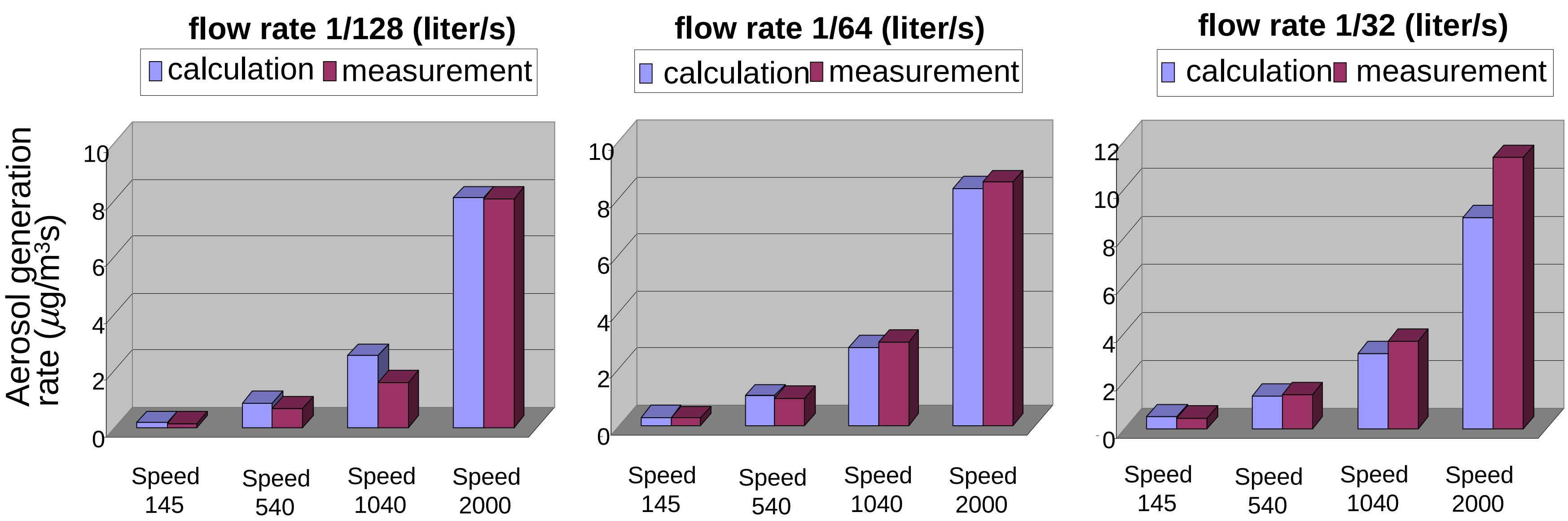


# Spin-off Result



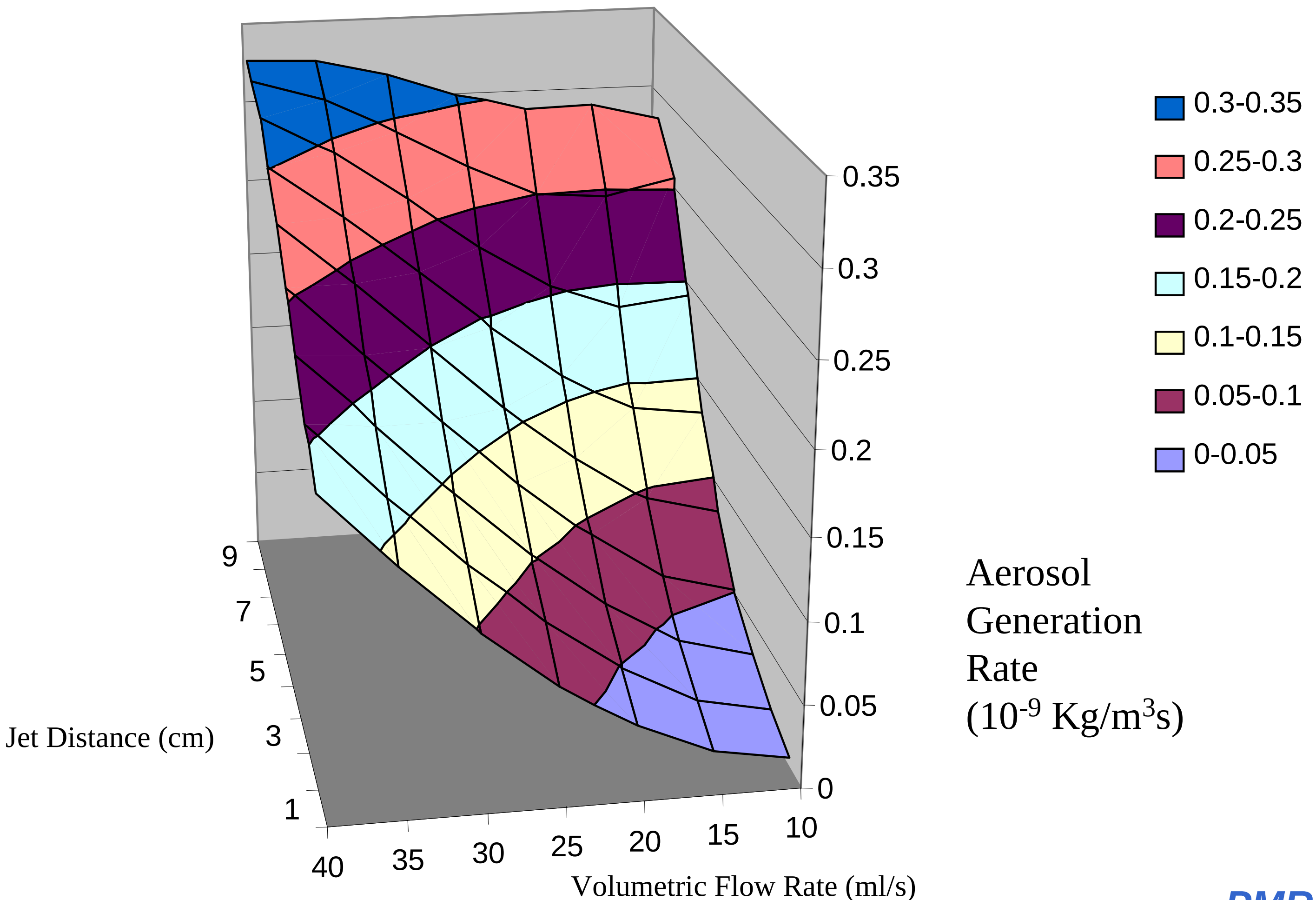

Comparison between analytical result and experimental data under different flow rate and constant rotational speeds

# Spin-off Result (cont.)

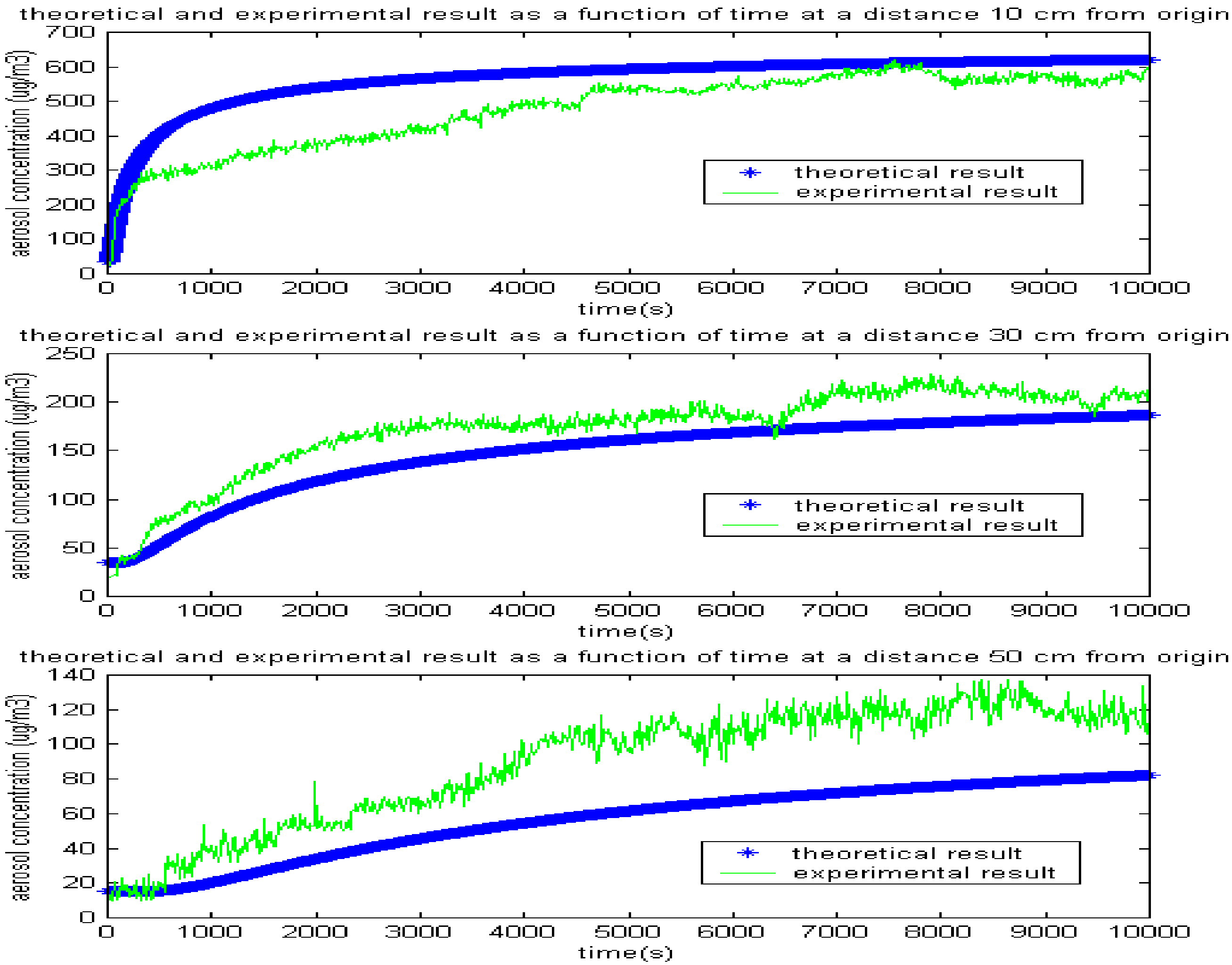



Comparison between analytical result and experimental data under different rotational speeds and constant flow rate

# *Splash Result (cont.)*

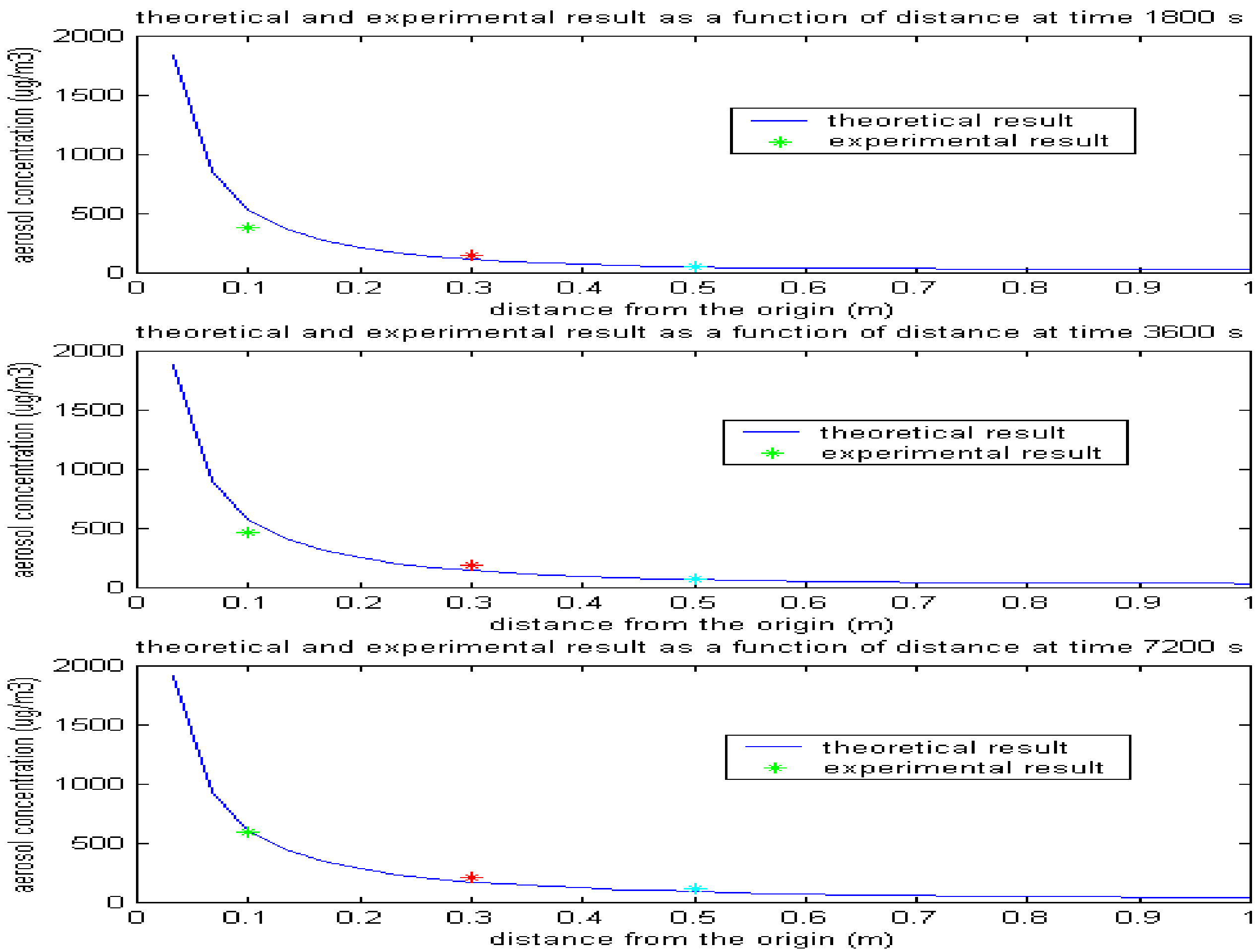


# Dissipation Result




Analytical result and experimental data under speed=1040 rpm and flow rate=1/94 liter/s

# Dissipation Result (cont.)




Analytical result and experimental data under speed=1040 rpm and flow rate=1/94 liter/s

# Conclusion

- The quantified models have been developed based on atomization theory and machining processes mechanics to predict aerosol generation.
- Spin-off process dominates aerosol generation under relatively higher rotational speed or flow rate during turning process.
- Dissipation model makes it possible to predict aerosol concentration as a function of location and time.