3-D Simulation of Non-EvaporatingDiesel Spray by Means of LES Task 1.5F

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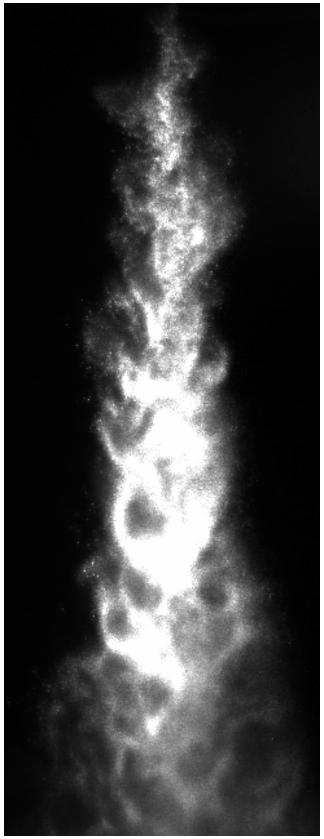
CONTENTS

Diesel spray structure



Sectional image
(Experiment)

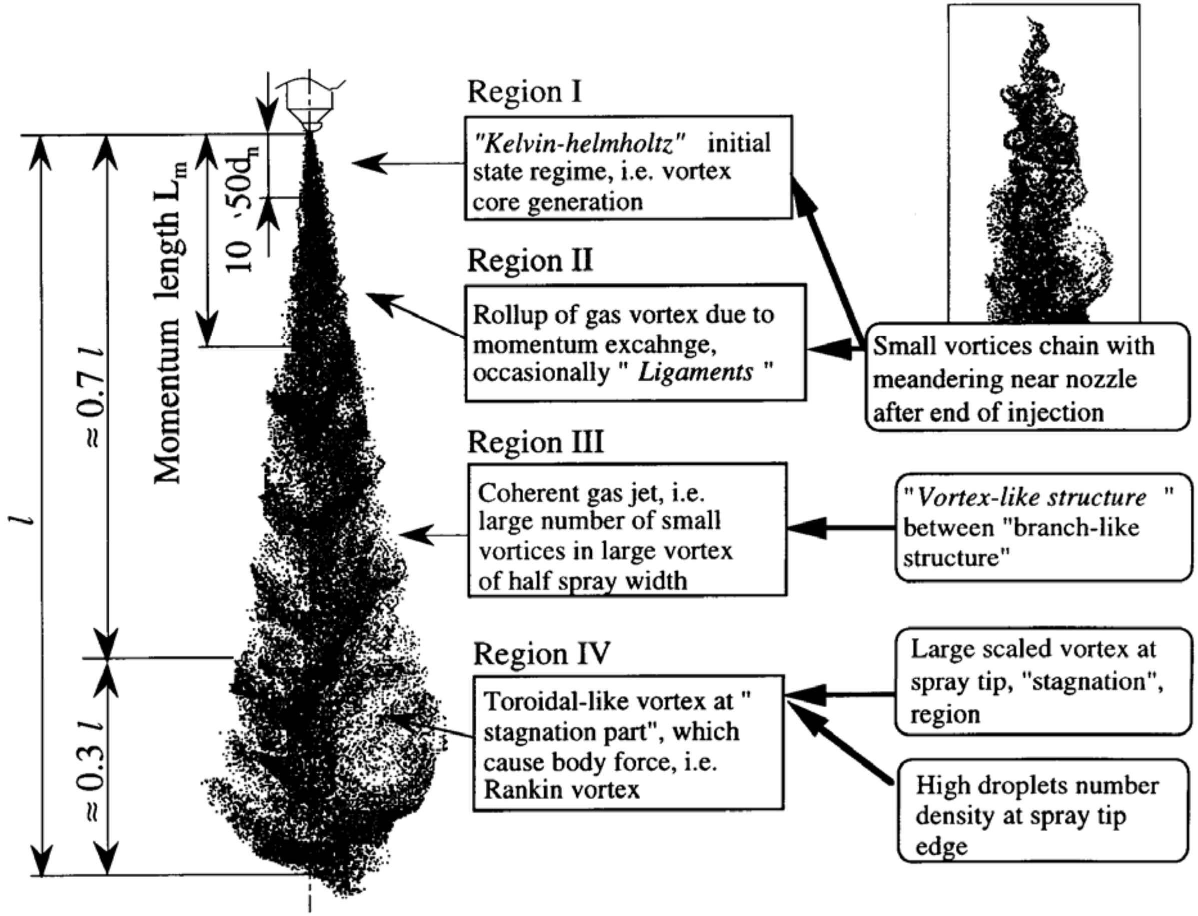


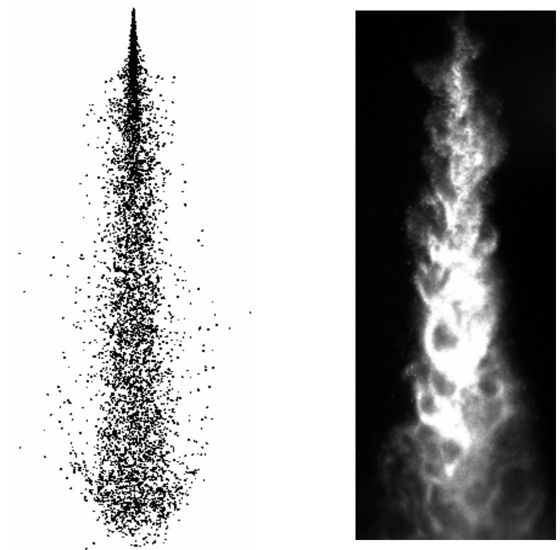
Fig.3 Model of inner structure of diesel spray

T. Dan et al.,"Effect of Ambient Gas Properties for Characteristics of Non-Reacting Diesel Fuel Spray", SAE paper 970352, pp.219-221 (1997).

Diesel spray simulation

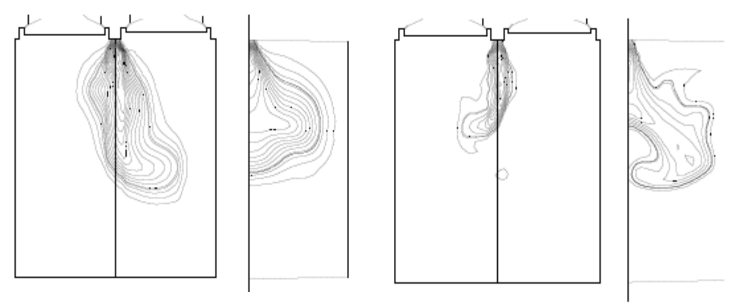
- RANS approach
  - KIVA, Star-CD, Fire, Fluent
  - DDM+RANS
    - Low CPU time + Robustness
    - Cycle averaged velocity

- LES approach
  - KIVALES , Sone , Menon
    (Computational Combustion Laboratry , 2000)
  - DDM+LES
    - High accuracy
    - Instantaneous flow field
    - Coherent vortex



KIVA3V(RANS) Exp.

Sectional image



(a)KIVA3V (b)KIVALES

Sone et al.,"KIVALES:Large-Eddy Simulations of Internal Combustion Engines. Part I: Theory and Formulation", Computational Combustion Laboratory (2000)

Purpose of this study

The objective is the numerical simulation of a non-evaporative diesel spray in constant volume vessel using LES

(1) KIVALES code was constructed to build in LES to KIVA code.

(2) The simulated results compared with the experimental results, such as spray shape, spray tip penetration and sauter mean diameter.

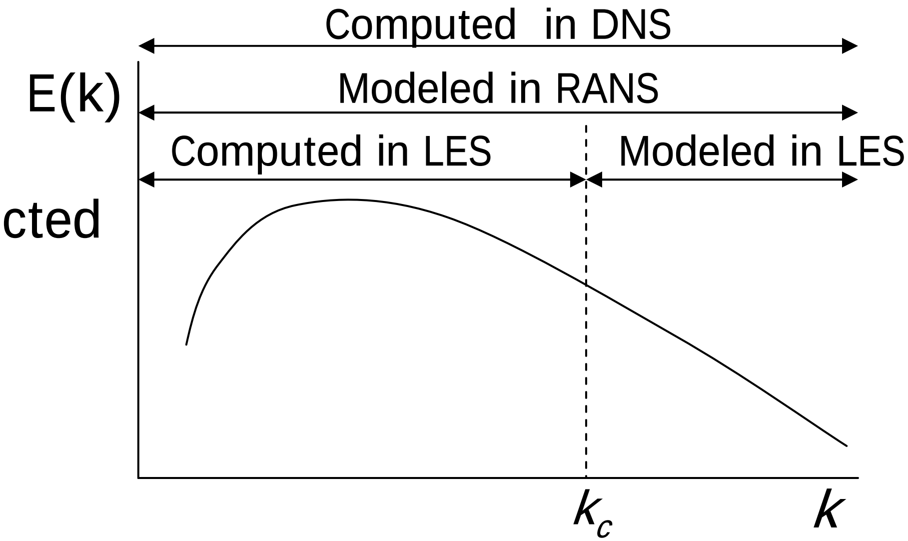
(3) 3-D flow of the surroundings around the spray was visualized by means of the laplacian pressure and examined the effect of this flow on the process of the formation of diesel spray.

CONTENTS

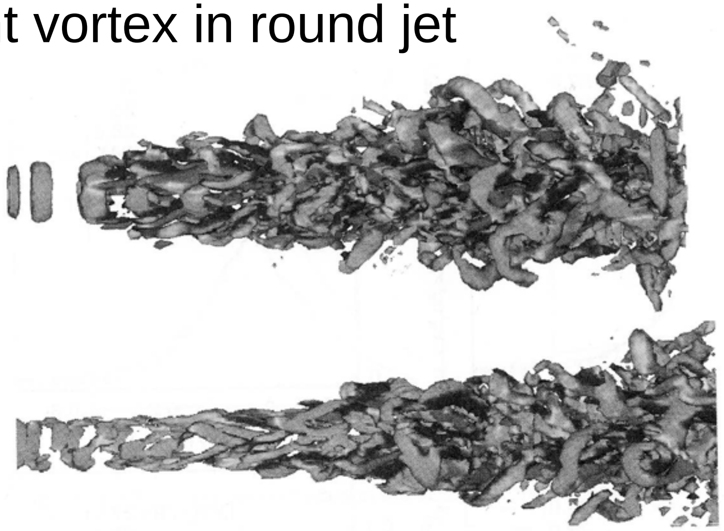
LES and RANS

LES(Large Eddy Simulation)

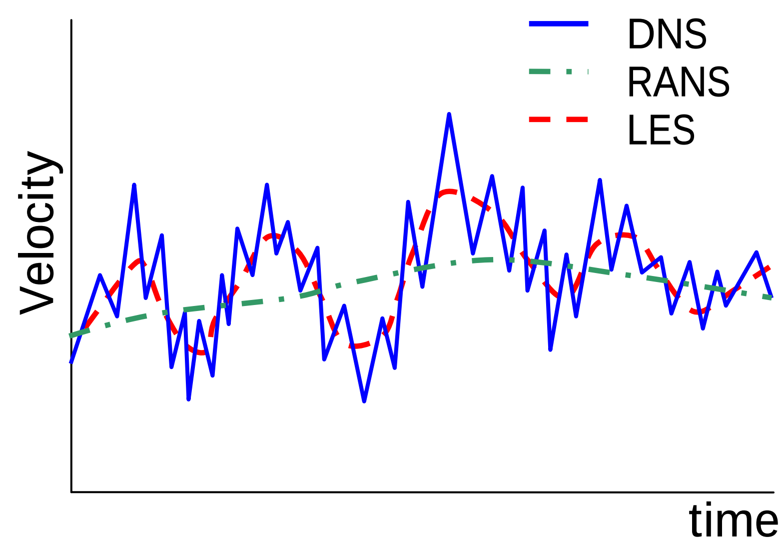
- High Accuracy for turbulent flow
- Instantaneous and 3D flow are predicted
- Coherent vortex



Coherent vortex in round jet



"Large Eddy Simulations of Turbulence",MARCEL LESIEUR et.al..



Governing equations

Continue equation

$$\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_j}{\partial x_j} = \overline{\dot{\rho}^s}$$

Momentum equation

$$\frac{\partial \bar{\rho}\tilde{u}_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\bar{\rho}\tilde{u}_i\tilde{u}_j - \bar{\tau}_{ij} + \tau_{ij}^{sgs}\right) = \overline{F_i^s}$$

Internal energy equation

$$\frac{\partial \bar{\rho}\tilde{e}}{\partial t} + \frac{\partial \bar{\rho}\tilde{u}_j\tilde{e}}{\partial x_j} = -\bar{p}\frac{\partial \tilde{u}_j}{\partial x_j} - \frac{\partial h_j^{sgs}}{\partial x_j} - \frac{\partial \tilde{q}_j}{\partial x_j}$$

$$+\bar{\sigma}_{ij}\frac{\partial \tilde{u}_j}{\partial x_j} + \Theta^{sgs} + \Pi^{sgs} + \overline{\dot{Q}^s}$$

Chemical speasies equation

$$\frac{\partial \bar{\rho}\tilde{Y}_m}{\partial t} + \frac{\partial}{\partial x_j}\left(\bar{\rho}\tilde{u}_j\tilde{Y}_m - \bar{\rho}\bar{D}_m\frac{\partial \tilde{Y}_m}{\partial x_j} + \Phi_{j,m}^{sgs}\right) = \overline{\dot{\rho}_m^s}$$

SGS modeling

SGS stress model

$$\tau^{sgs} = 2\bar{\rho}\upsilon_t\left(\tilde{S}_{ij} - \frac{1}{3}\tilde{S}_{kk}\delta_{ij}\right) + \frac{2}{3}\bar{\rho}k^{sgs}\delta_{ij}$$

k-*Δ* model

$$\upsilon_t = C_\upsilon k^{sgs\,1/2}/\bar{\Delta}$$

$$\bar{\Delta} = V_{cell}^{\ 1/3}$$

$$\frac{\partial\left(\bar{\rho}k^{sgs}\right)}{\partial t} + \frac{\partial\bar{\rho}\tilde{u}_j k^{sgs}}{\partial x_j}$$

$$= -\tau_{ij}^{sgs}\frac{\partial\tilde{u}_i}{\partial x_j} - D^{sgs} + \frac{\partial}{\partial x_j}\left(\bar{\rho}\frac{\upsilon_t}{\mathrm{Pr}_t}\frac{\partial k^{sgs}}{\partial x_j}\right) + \dot{W}^s$$

SGS model:
gradient diffusion model

$$h_{i,m}^{sgs} = -\bar{\rho}\frac{\upsilon_t C_p}{\mathrm{Pr}_t}\frac{\partial\tilde{T}}{\partial x_j}$$

$$\Phi_{i,m}^{sgs} = -\bar{\rho}\frac{\upsilon_t}{Sc_t}\frac{\partial\tilde{Y}_m}{\partial x_i}$$

$$\Theta^{sgs} = D^{sgs}$$

$$= \frac{C_\varepsilon\bar{\rho}k^{sgs\,3/2}}{\bar{\Delta}}$$

Computational model

Computational code	KIVALES	KIVA
Turbulent model	LES with k-Δ model	RANS with RNG k-ε model
Gas phase	Finite Volume method based on ALE	
Convective term	Interpolated-donor cell differencing scheme	
Spray model	Droplet Discrete Method (DDM)	
Droplet	Rigid sphere	
Breakup	Modified TAB model (K=10/3→8/9, ϕ=2→ 6)	
Velocity interpolation	Nordin model (n=2)	
Collesion and coallecence	O'Rourke model	

Computational conditions

*Dan, T., Takagishi, S., Senda and J., Fujimoto, H., SAE technical paper 970352, pp.219-234, (1997) .

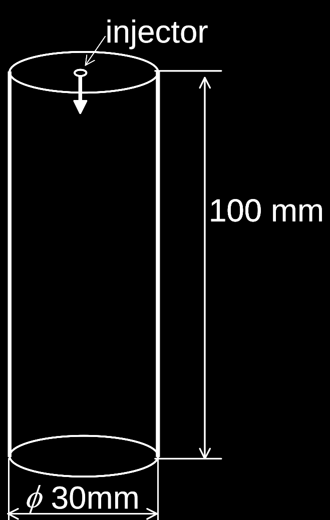
Hole diameter	[mm]	0.20
Injection pressure	[MPa]	77
Injection duration	[ms]	1.8
Fuel		n-tridecane
Fuel amount	[mg]	12
Fuel temperature	[K]	300
Ambient gas		N_2
Ambient pressure	[MPa]	1.5
Ambient density	[kg/m^3]	17.3
Ambient temperature	[K]	300

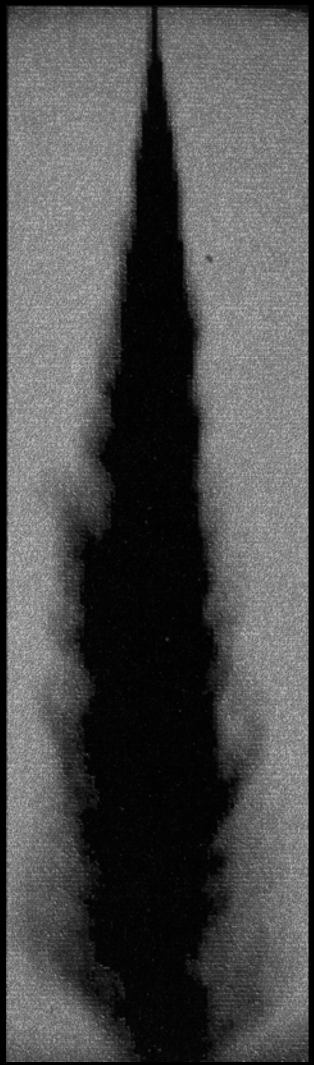
CONTENTS

Diesel spray simulation
(L)LES (R)RANS

t = 0.0 ms - 3.0 ms
p_{inj} 77 MPa
ρ_a 17.3 kg/m^3
t_{inj} 1.8 ms

Computational grid
60x60x200
(720,000)
CPU time
140 hour

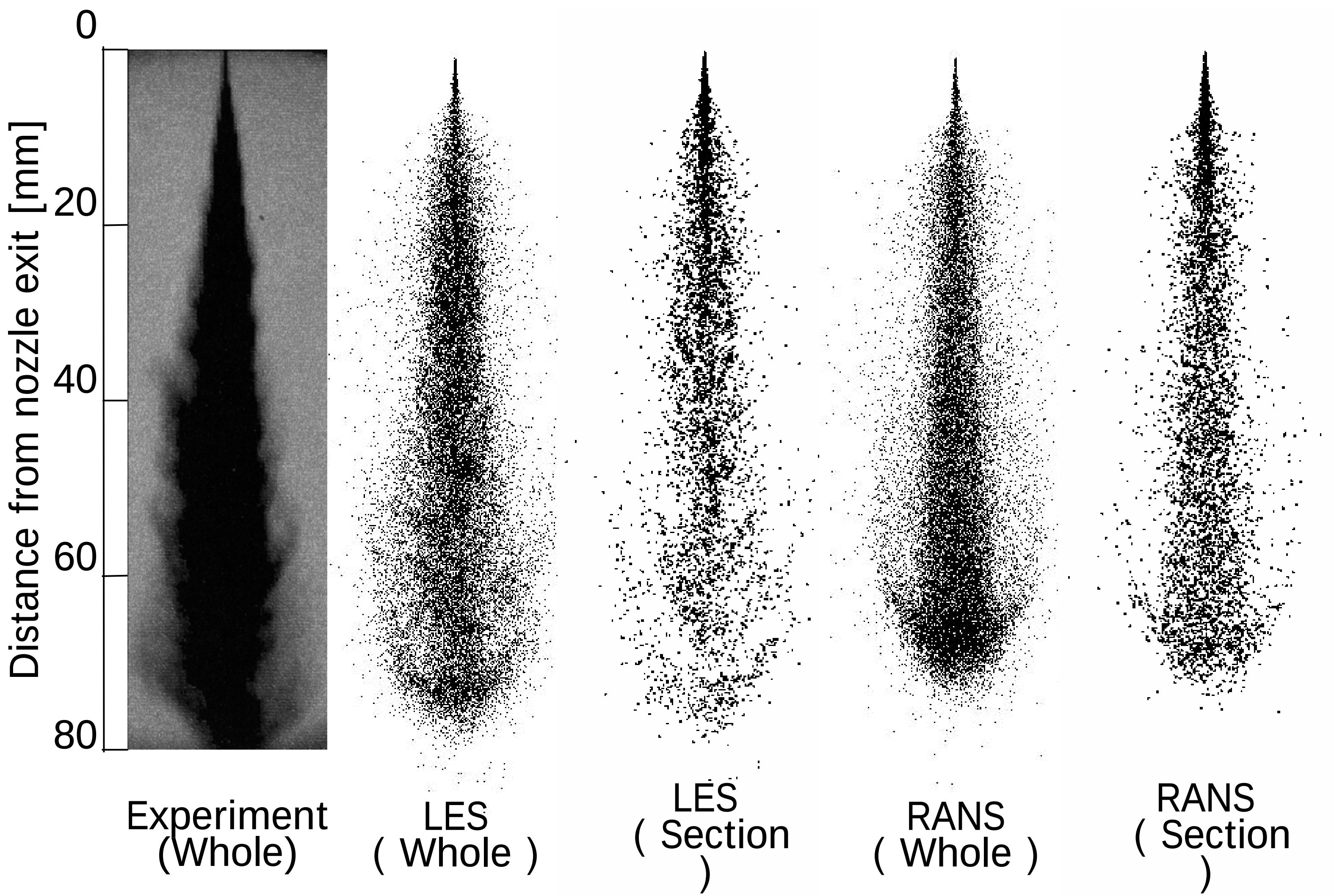




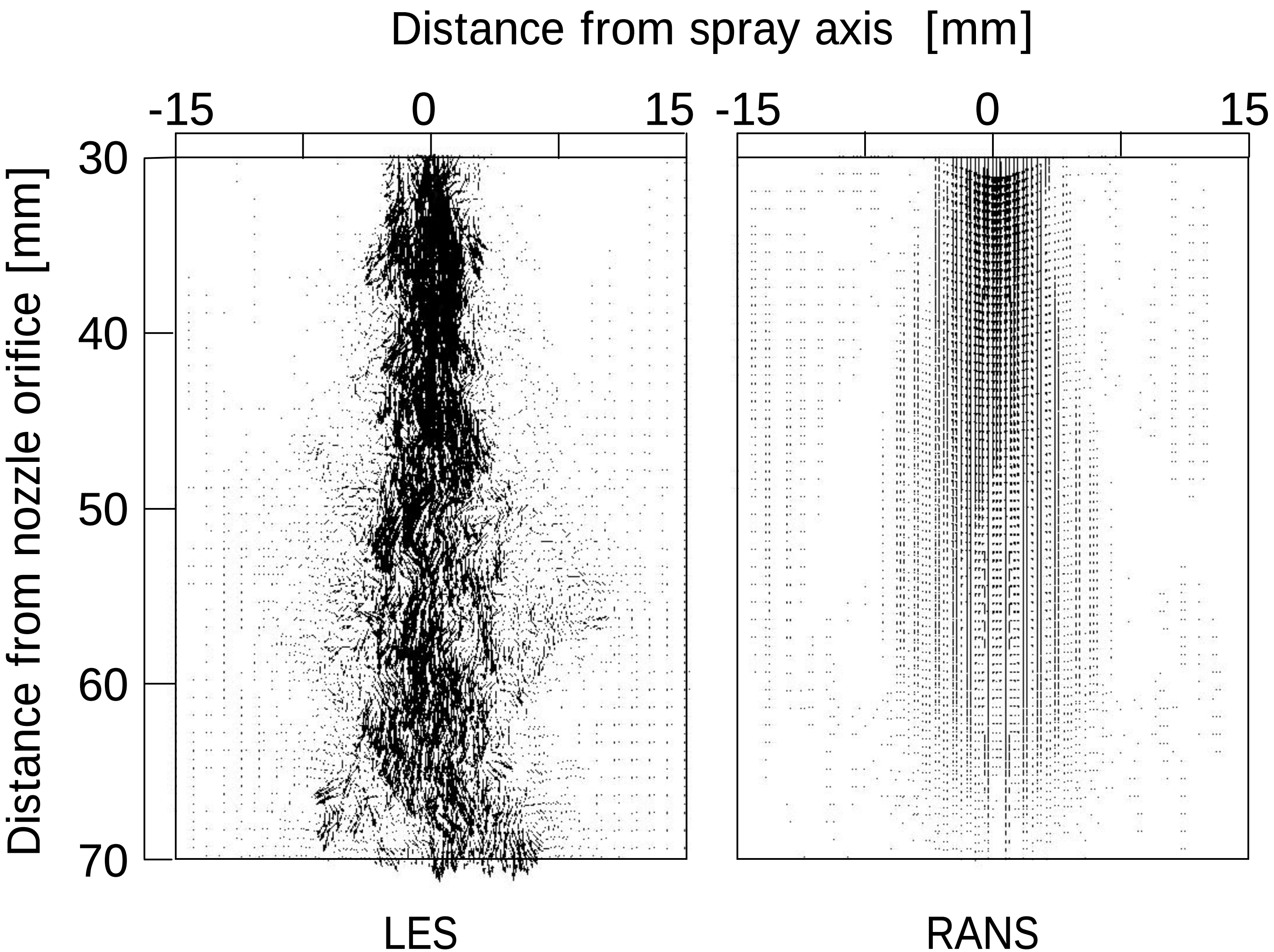
Experiment ※
(t =1,8ms)

※Takagishi, S.,
master's thesis,
Doshisha University (1996

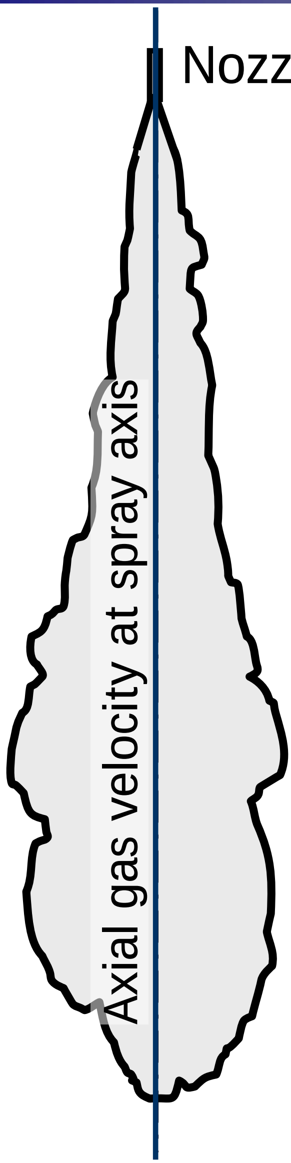
Spray shape obtained by LES and RANS

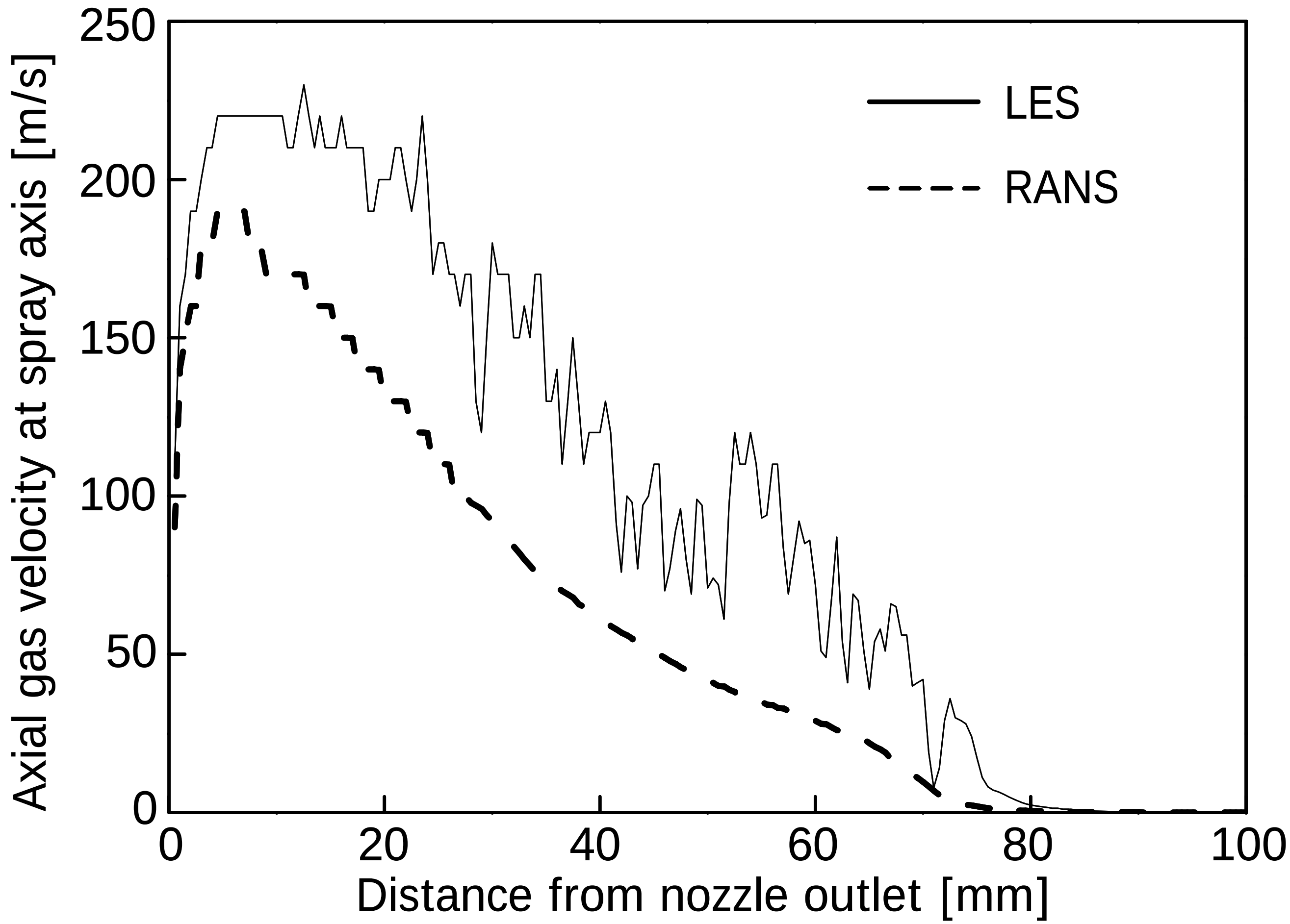


Instantaneous velocity distribution at cross section at 1.8ms

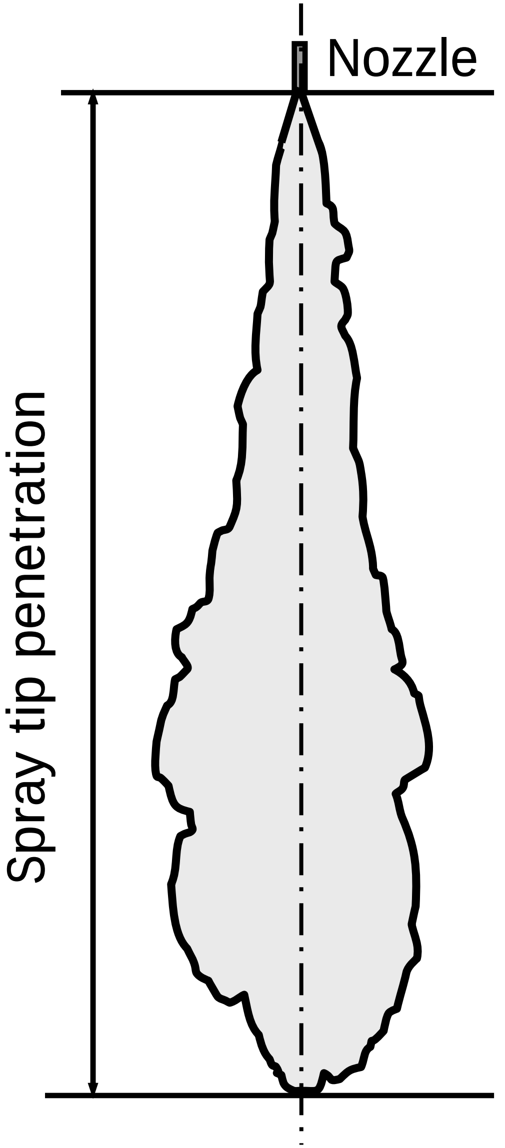


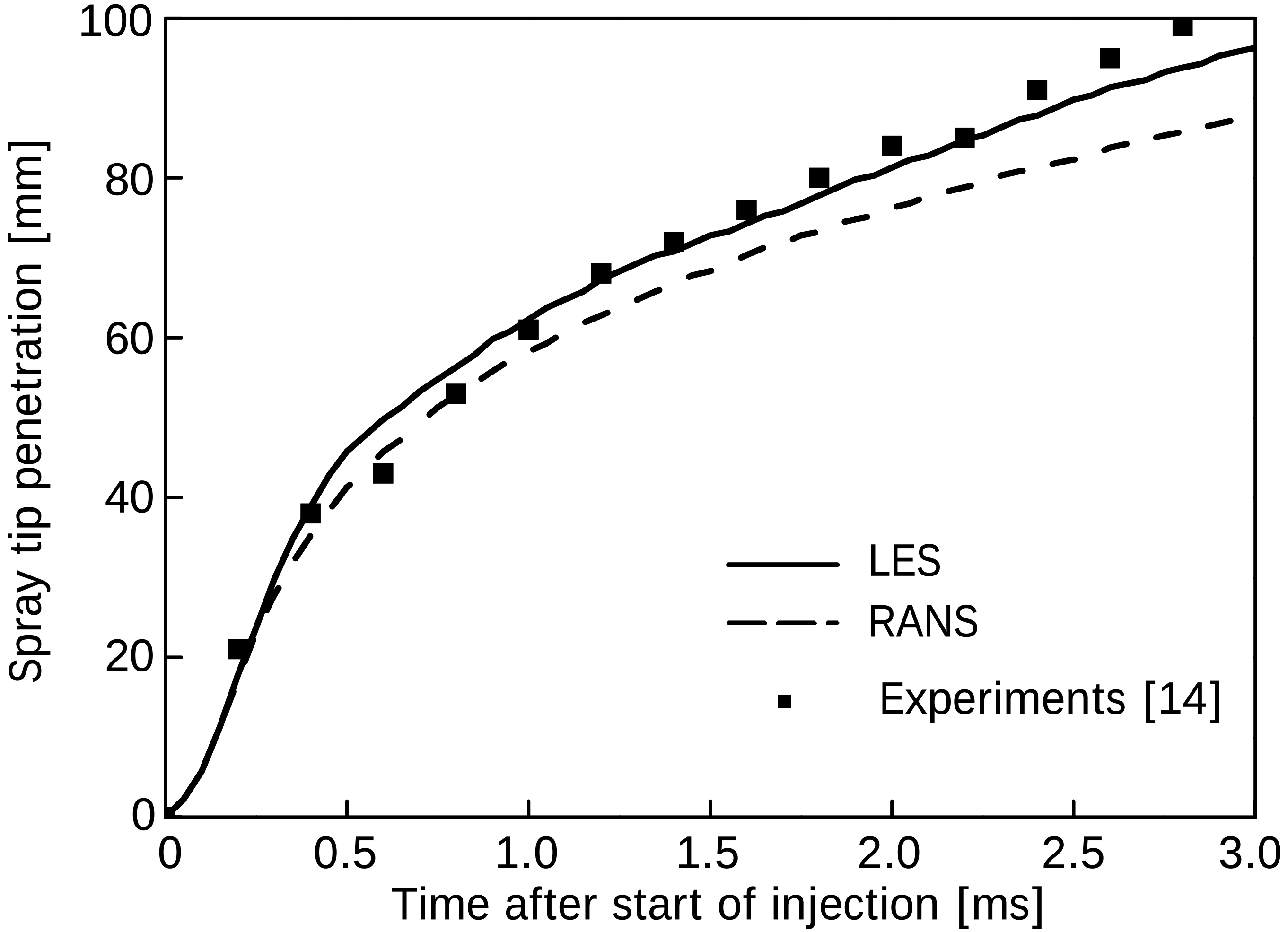
Distribution of instantaneous axial gas velocity at spray axis (1.8ms)



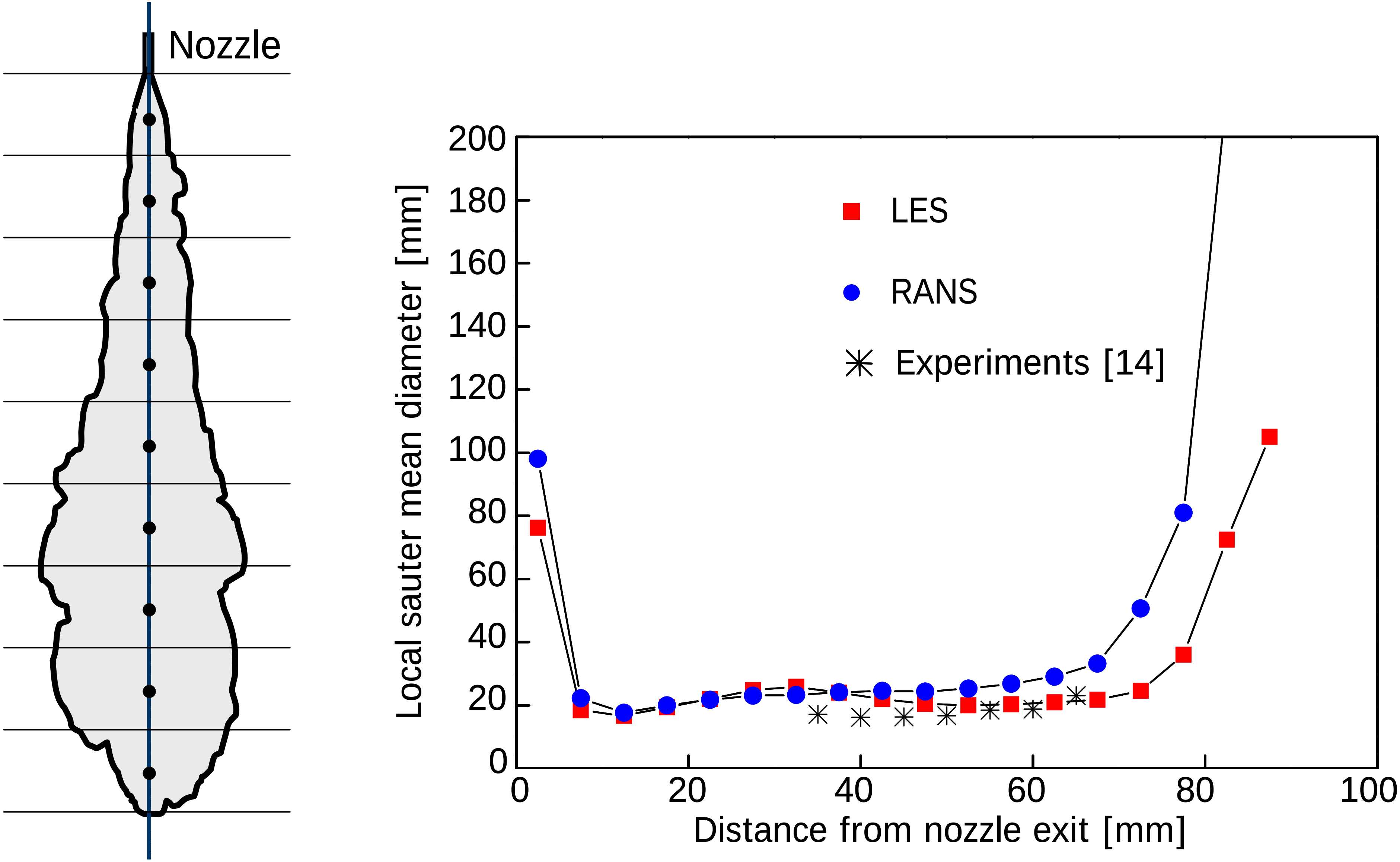


Comparison of spray tip penetration obtained by LES and RANS with that of experiments

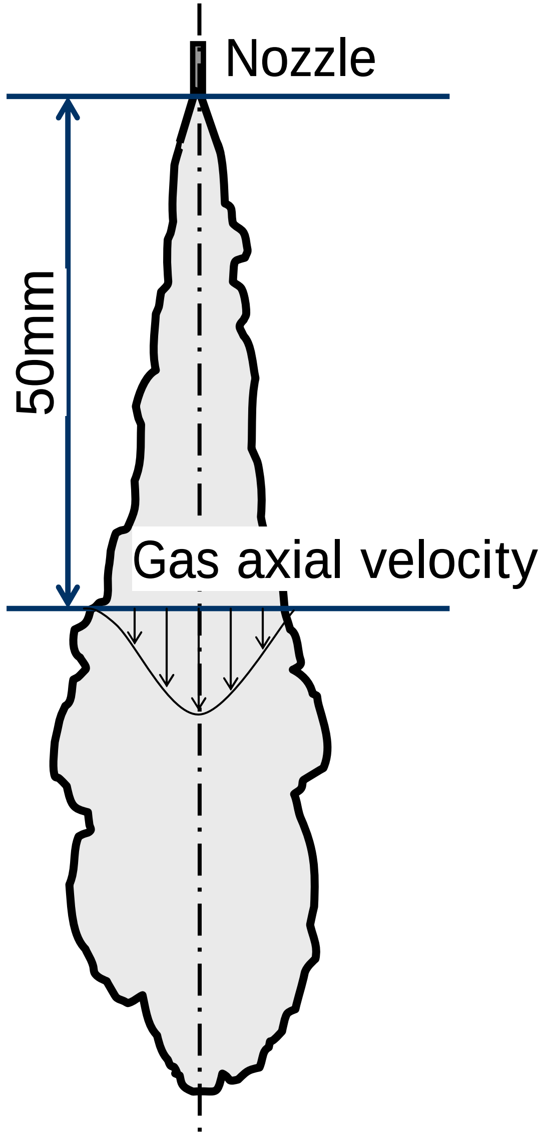


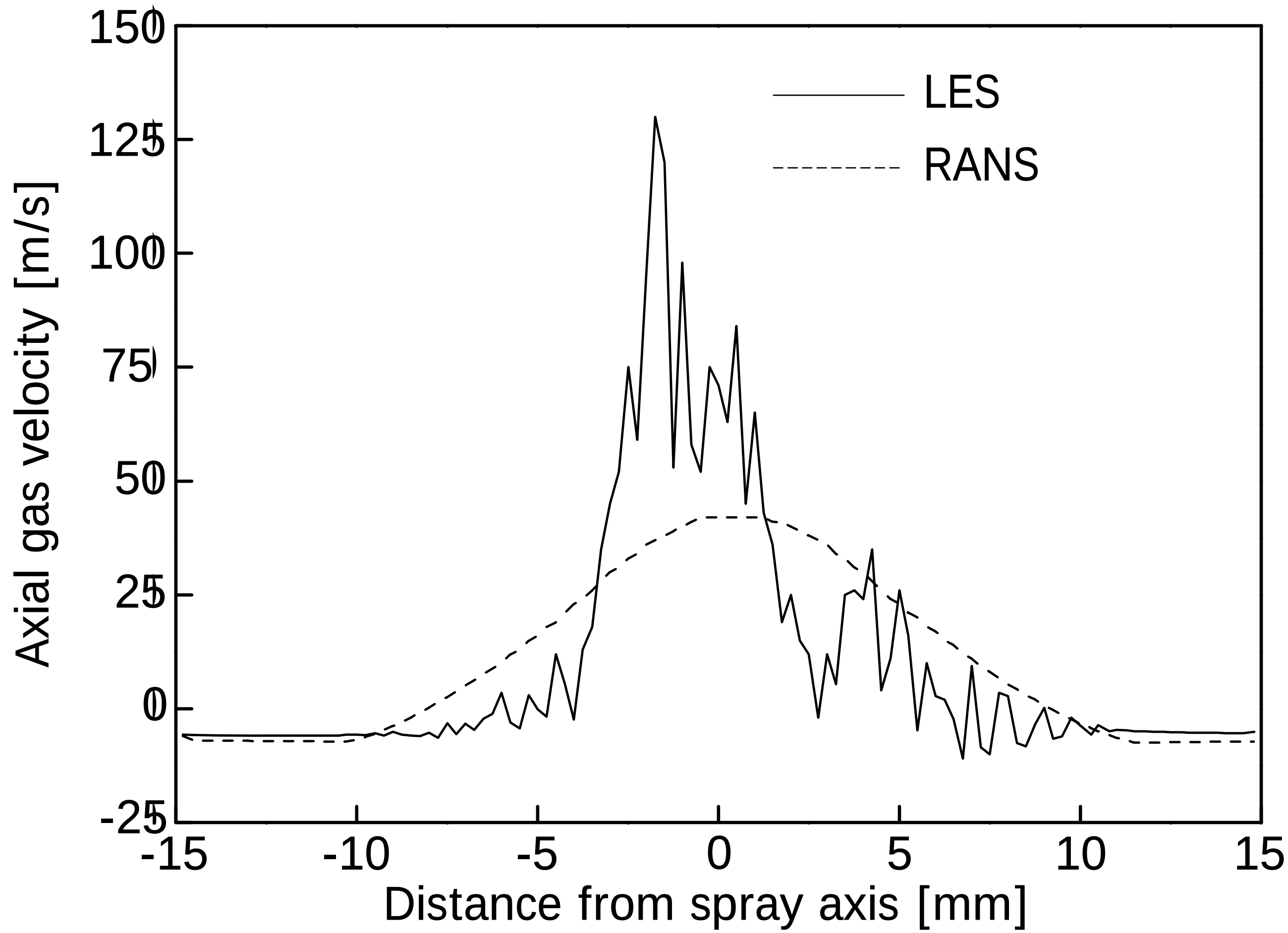


Comparison of SMD obtained by LES and RANS with that of experiments at 1.8 ms



Radial distribution of instantaneous axial velocity (50 [mm] from nozzle exit)



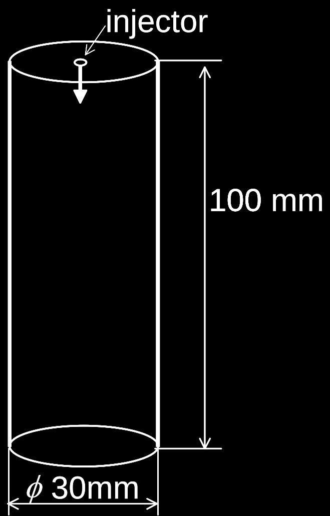


Coherent vortex (RANS)

p_{inj} 77 MPa
ρ_a 17.3 kg/m^3
t_{inj} 1.8 ms

Computational grid
60x60x200
(720,000)

CPU time
140 hour



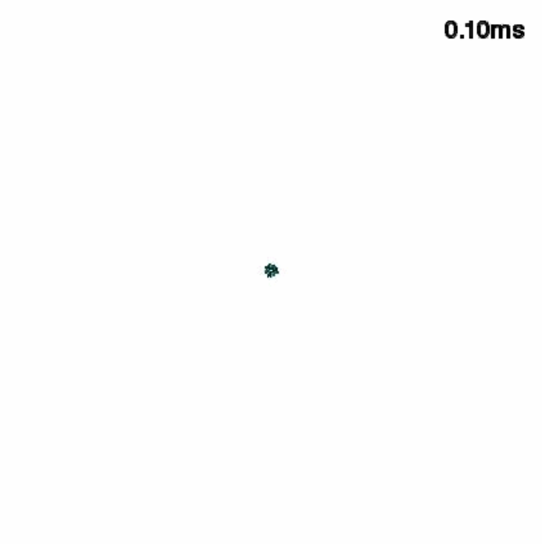
Coherent vortex (LES)

p_{inj} 77 MPa
ρ_a 17.3 kg/m^3
t_{inj} 1.8 ms

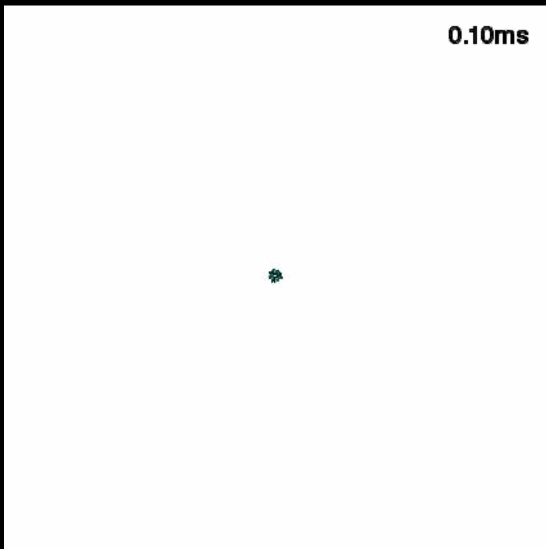
Computational grid
60x60x200
(720,000)

CPU time
140 hour

Top View

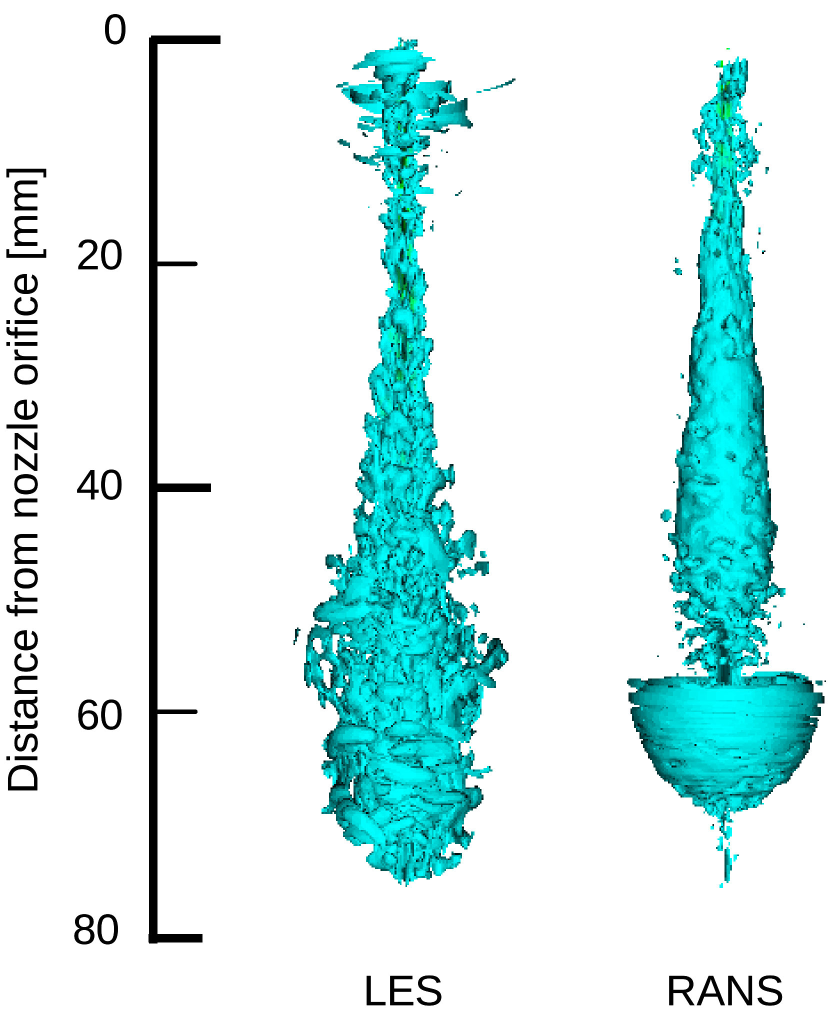


Bottom View

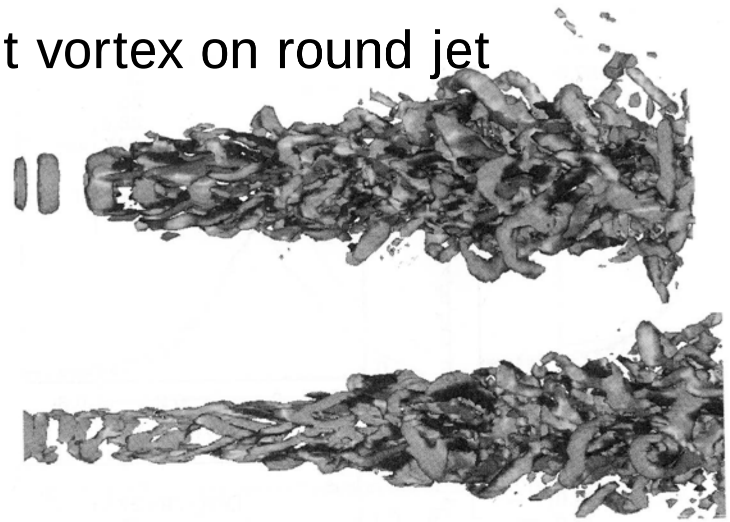


Coherent Vortex

t=1.8ms

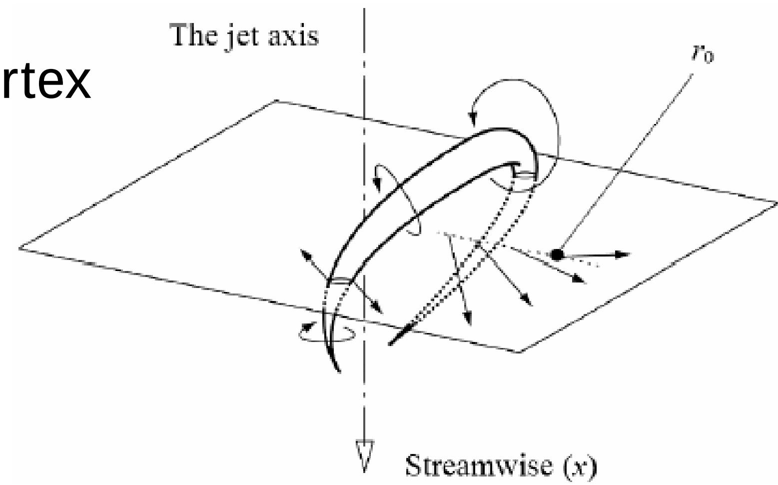


Coherent vortex on round jet



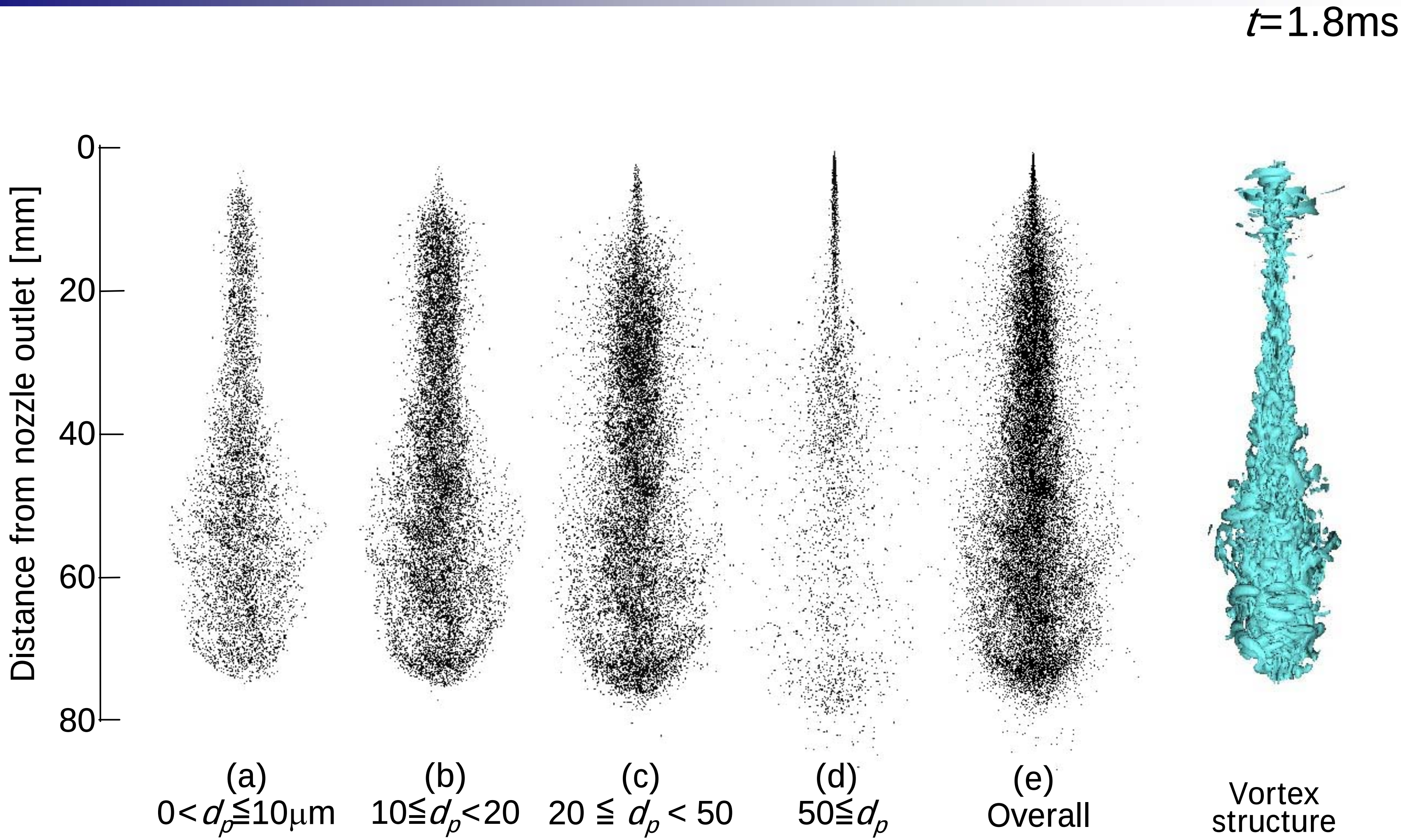
“Large Eddy Simulations of Turbulence”,MARCEL LESIEUR et.al..

Hairpin vortex



“On the vortical structure in a round jet”, Matsuda et.al..

Droplet dispersion by Coherent vortex



Conclusion

1. It is possible to simulate the heterogeneous structure of a diesel spray by the method proposed in this work.
2. The spray tip penetration and SMD obtained through the simulation agree well with that shown through the experiments.
3. It is able to simulate the detailed 3-D structure of vortex in a diesel spray. The structure is almost the same as that of a coaxial jet.
4. It is capable of explaining the actual phenomena in a diesel spray by the simulated result.
5. There is the capability of the application of LES to not only an evaporating diesel spray but also a burning diesel spray.

Thank you for your kind attention!