

# 熔融紡糸における ドローレゾナンスの実験とシミュレーション

## Experiment and Simulation of Draw Resonance in Melt Spinning

山形大学(工)

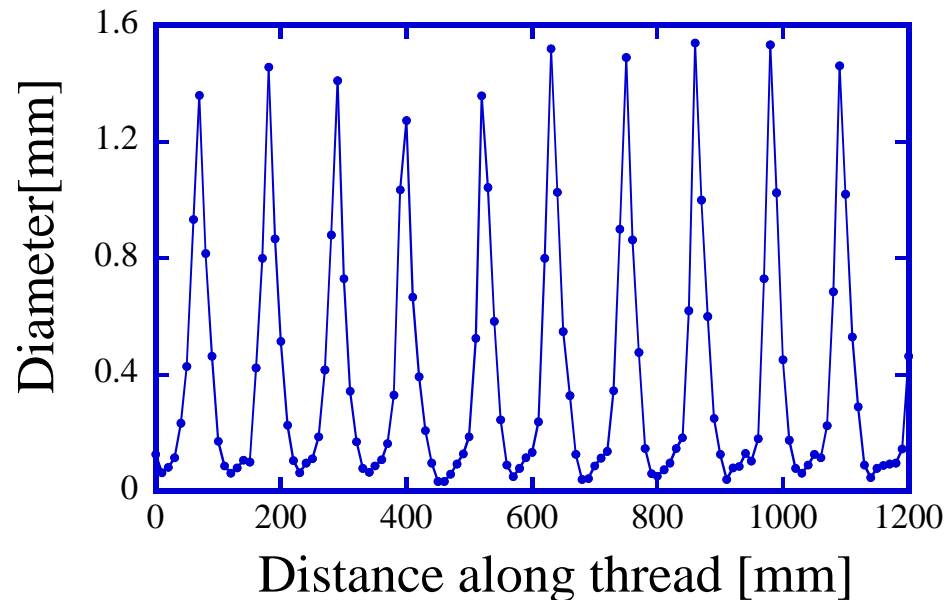
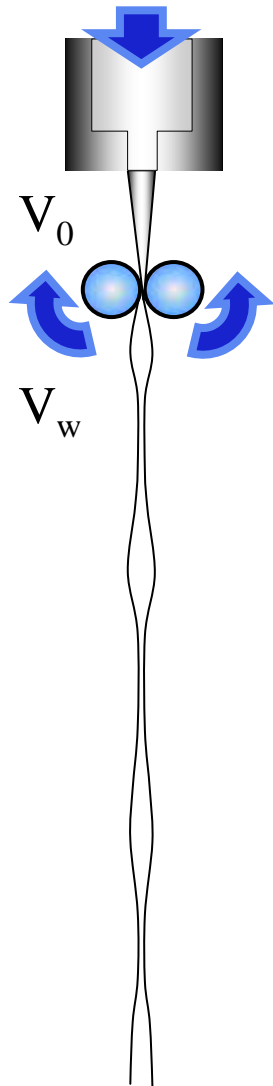
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# What's Draw Resonance ?

The phenomenon of changing the diameter of taking-up thread periodically



$\Phi = 26.67$   
 $L/D = 10/2$   
 $T = 190^\circ\text{C}$   
Air gap = 10mm

Draw Down Ratio

$$\phi = \frac{V_w}{V_0}$$

Elongational Strain

$$\varepsilon = \ln \frac{V_w}{V_0}$$

$V_w$ : Take-up Velocity

$V_0$ : Extrude Velocity

Figure 1 Draw resonance image figure.

# Purpose

溶融紡糸の支配方程式を用いた  
ニュートン流体の  
シミュレーションプログラムを作成、  
及び実験との比較

# Sample

ポリプロピレン (PP) (チッソ石油化学(株))

Table 1 Main characteristics of PP.

MFR	Mw	Mw/Mn	Tm(°C)	Tc(°C)
0.7	360,000	4.6	157.2	106.5

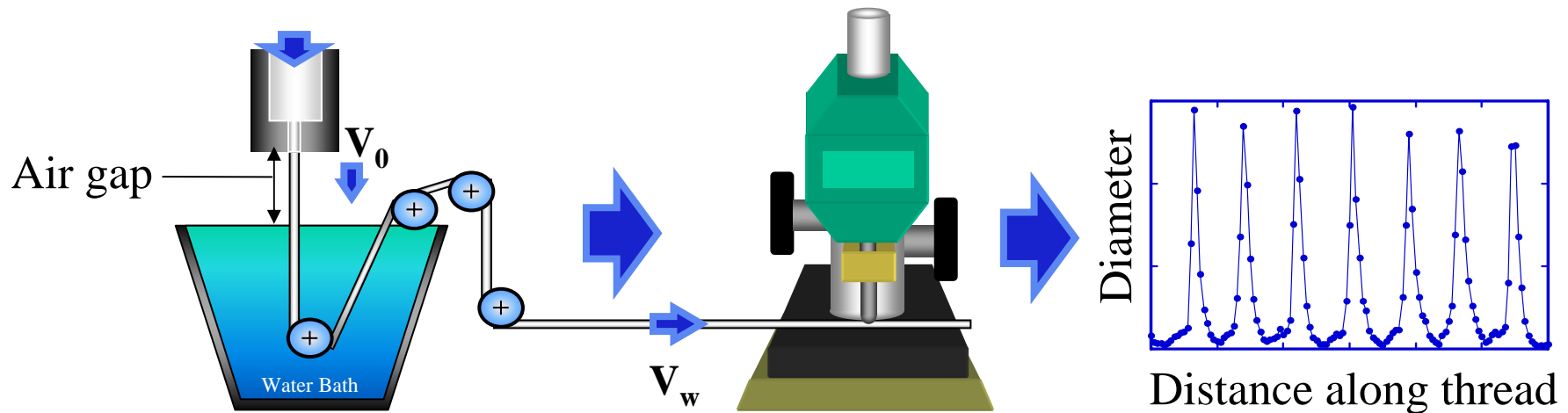
# Experiments

Table 2 Spinning Conditions.

$T[^\circ\text{C}]$	<i>Air Gap</i> [mm]	<i>Capillary Diameter</i> [mm]	<i>Capillary Length</i> [mm]
190	10	2	10
$V_w$ [m/min]	$V_0$ [m/min]	$\phi$	$\epsilon$
1.0	0.075	13.33	2.59
1.5	0.075	20.00	3.00
2.0	0.075	26.67	3.28
2.5	0.075	33.33	3.50
3.0	0.075	40.00	3.68
3.5	0.075	46.67	3.84

# Experiments

## Draw resonance can be occurred by using water cooled melt spinning



Generation of draw resonance

Diameter measurement  
of taken-up thread

**Figure 2 Schematic diagram of water-cooled melt spinning.**

# Simulation

## The governing equation of the melt spinning

### Continuity equation

$$\frac{\partial A_{t,x}}{\partial t} + \frac{\partial (A_{t,x} V_{t,x})}{\partial x} = 0$$



$$\frac{\partial \tilde{A}_{\tilde{t},\tilde{x}}}{\partial \tilde{t}} + \frac{\partial (\tilde{A}_{\tilde{t},\tilde{x}} \tilde{V}_{\tilde{t},\tilde{x}})}{\partial \tilde{x}} = 0$$

**Nondimensional  
form**

### Equation of motion

$$\frac{\partial V_{t,x}}{\partial x} = \frac{F_t}{\eta A_{t,x}}$$



$$\frac{\partial \tilde{V}_{\tilde{t},\tilde{x}}}{\partial \tilde{x}} = \frac{\tilde{F}_{\tilde{t}}}{\tilde{A}_{\tilde{t},\tilde{x}}}$$



$$\tilde{F}_{\tilde{t}} = \frac{\tilde{V}_w - \tilde{V}_0}{\int_0^1 \frac{1.0}{\tilde{A}_{\tilde{t},\tilde{x}}} d\tilde{x}}$$

**Tension**

### Initial condition

$$\tilde{t} = 0 ; 0 \leq \tilde{x} \leq 1$$

$$\tilde{A}_{0,\tilde{x}} = 1.0$$

$$\tilde{V}_{0,\tilde{x}} = 1.0$$

**or**

$$\tilde{A}_{0,\tilde{x}} = \exp(-\log(V_w) * \tilde{x})$$

$$\tilde{V}_{0,\tilde{x}} = \exp(\log(V_w) * \tilde{x})$$

### Boundary condition

$$\tilde{x} = 0 (\tilde{t} > 0) ; \tilde{A}_{\tilde{t},0} = 1.0, \tilde{V}_{\tilde{t},0} = 1.0$$

$$\tilde{x} = 1 (\tilde{t} > 0) ; \tilde{V}_{\tilde{t},1} = \tilde{V}_w$$

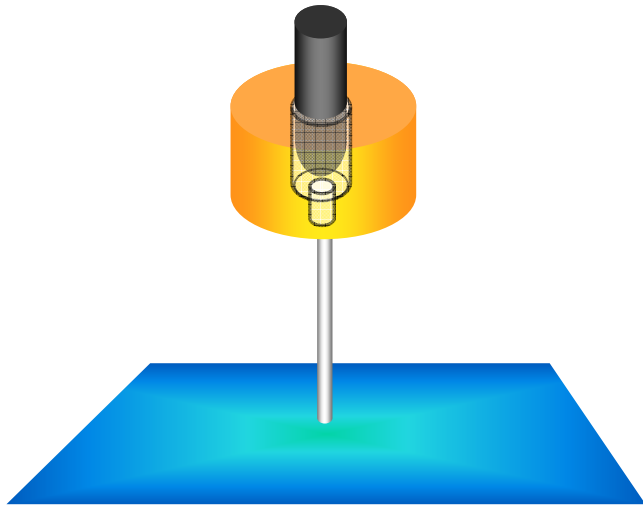
# Simulation

Parameter



$\tilde{A}(\tilde{t}, \tilde{x})$

## シミュレーションの検討



初期条件

空間分割数  $\Delta x$

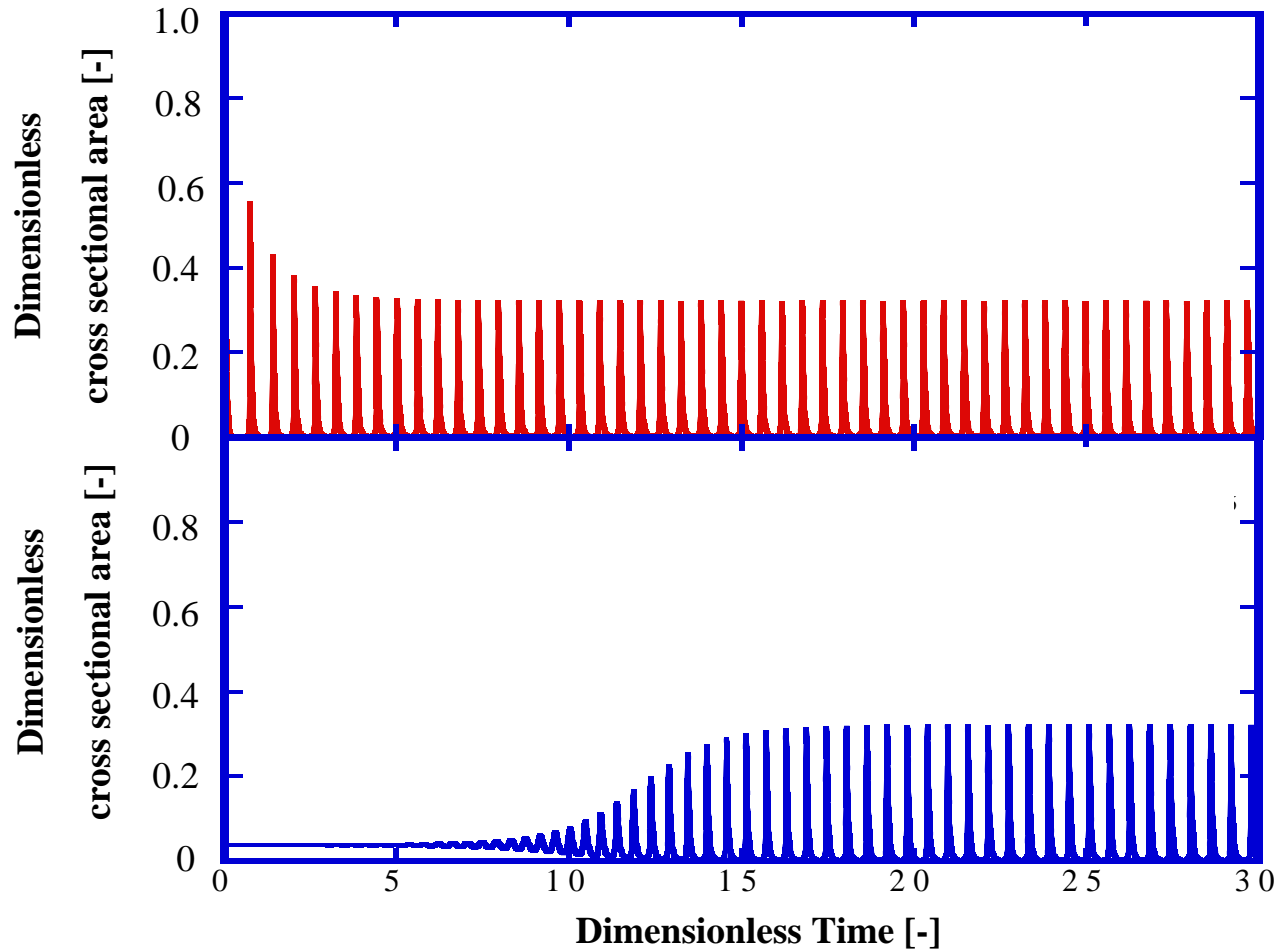
時間分割数  $\Delta t$



振幅・周期の変化を調べる

# Simulation

~ Initial Condition ~



**-Conditions-**

$$\Phi = 26.67$$

$$\Delta t = 1.0 \times 10^{-6}$$

$$\Delta x = 500$$

**Initial condition**

$$\tilde{A}_{0,\tilde{x}} = 1.0$$

$$\tilde{V}_{0,\tilde{x}} = 1.0$$

$$\Phi = 26.67$$

$$\Delta t = 1.0 \times 10^{-6}$$

$$\Delta x = 500$$

**Initial condition**

$$\tilde{A}_{0,\tilde{x}} = \exp(-\log(Vw) * \tilde{x})$$

$$\tilde{V}_{0,\tilde{x}} = \exp(\log(Vw) * \tilde{x})$$

Figure 3 Influence on the waveform by the different initial conditions.



# Simulation

~ Initial Condition ~

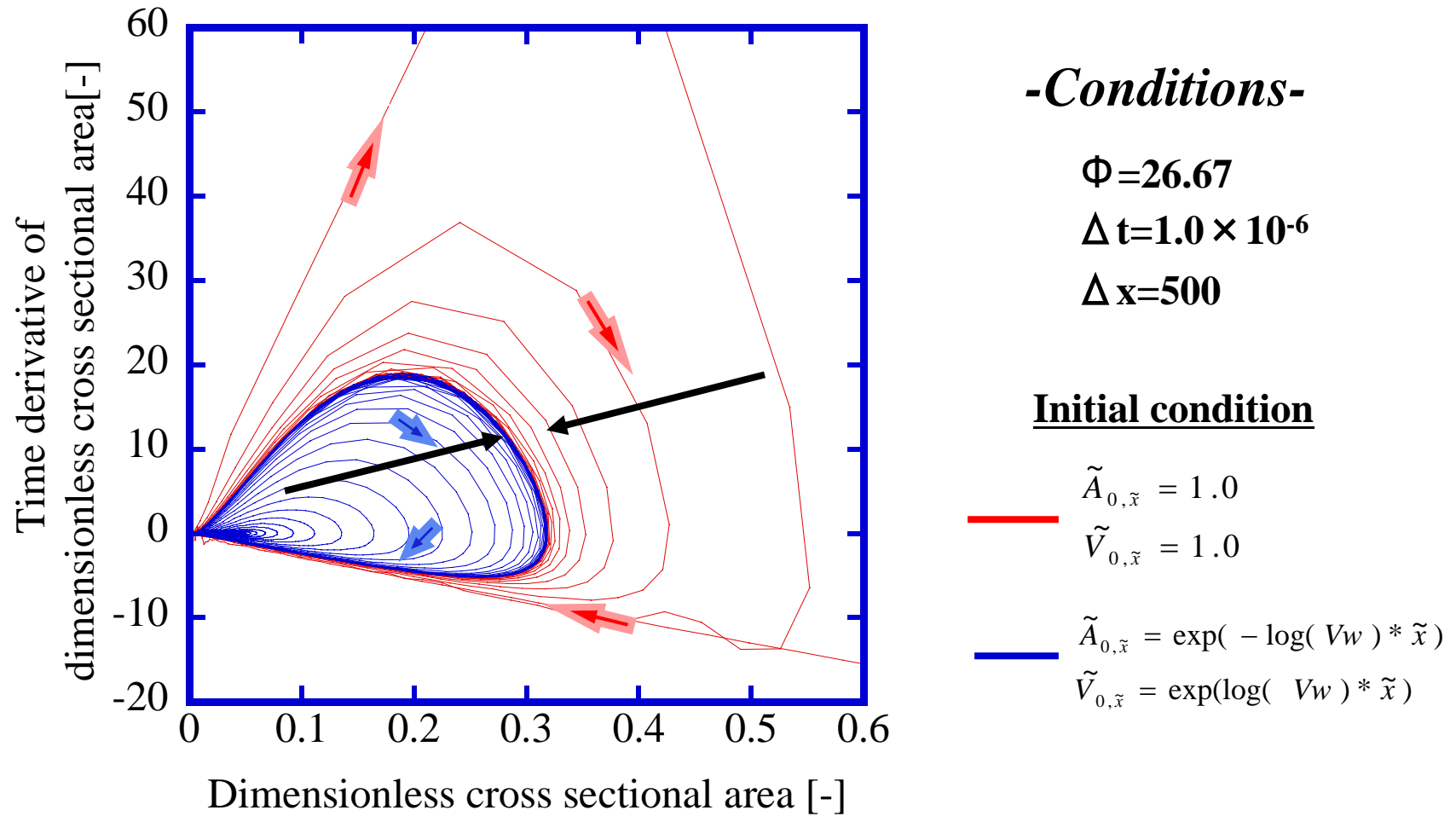
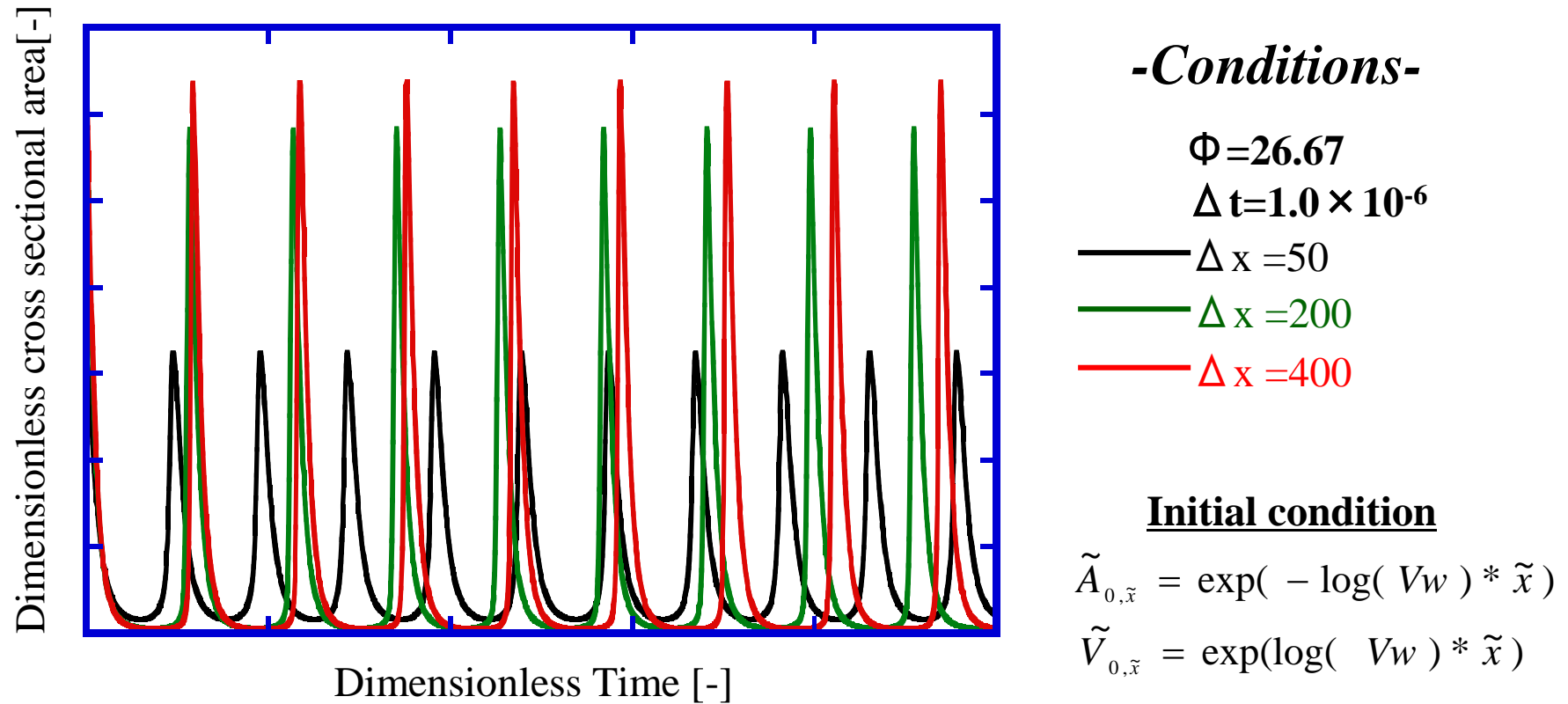


Figure 4 Waveform convergence by the different initial conditions.

# Simulation

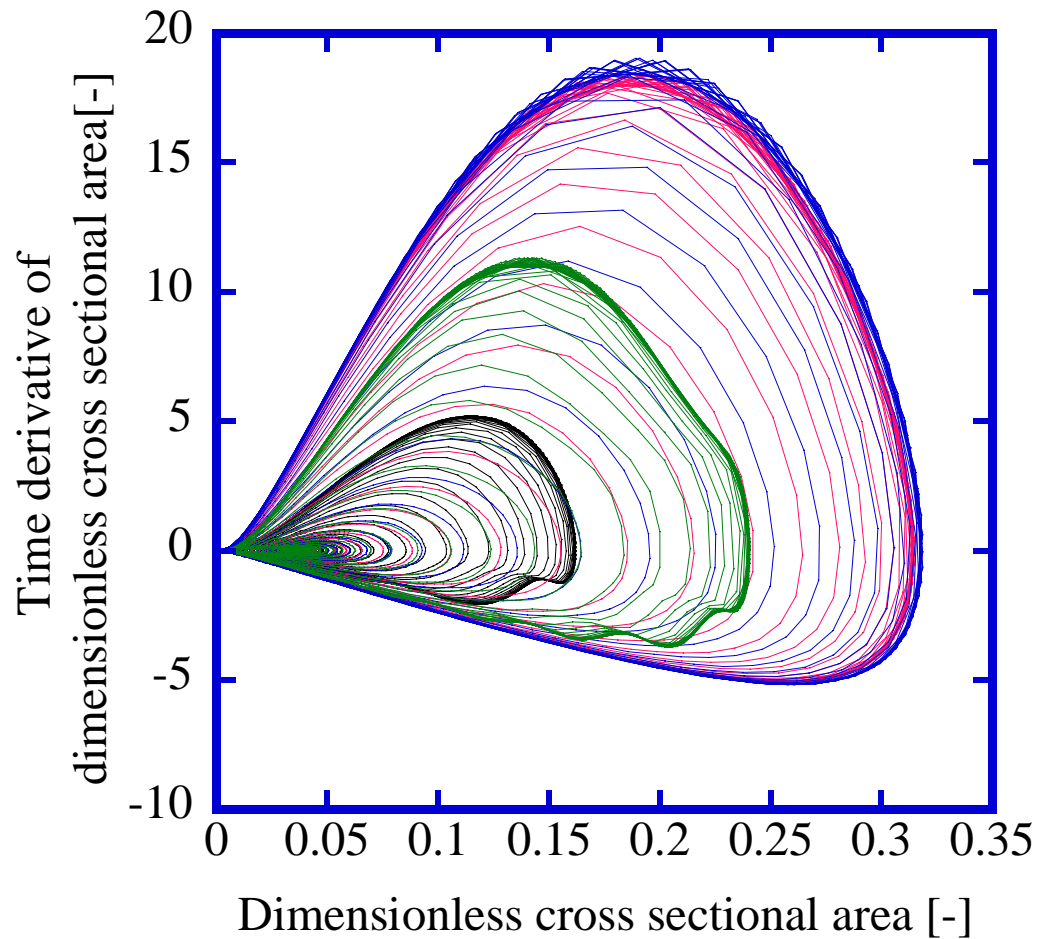
## ~Division of Space~



**Figure 5 Increasing of the Oscillation Period by division of space ( $\Delta x$ ).**

# Simulation

~ Division of space ~



**-Conditions-**

$$\Phi = 26.67$$

$$\Delta t = 1.0 \times 10^{-6}$$

$$\Delta x = 50$$

$$\Delta x = 200$$

$$\Delta x = 400$$

$$\Delta x = 500$$

**Initial condition**

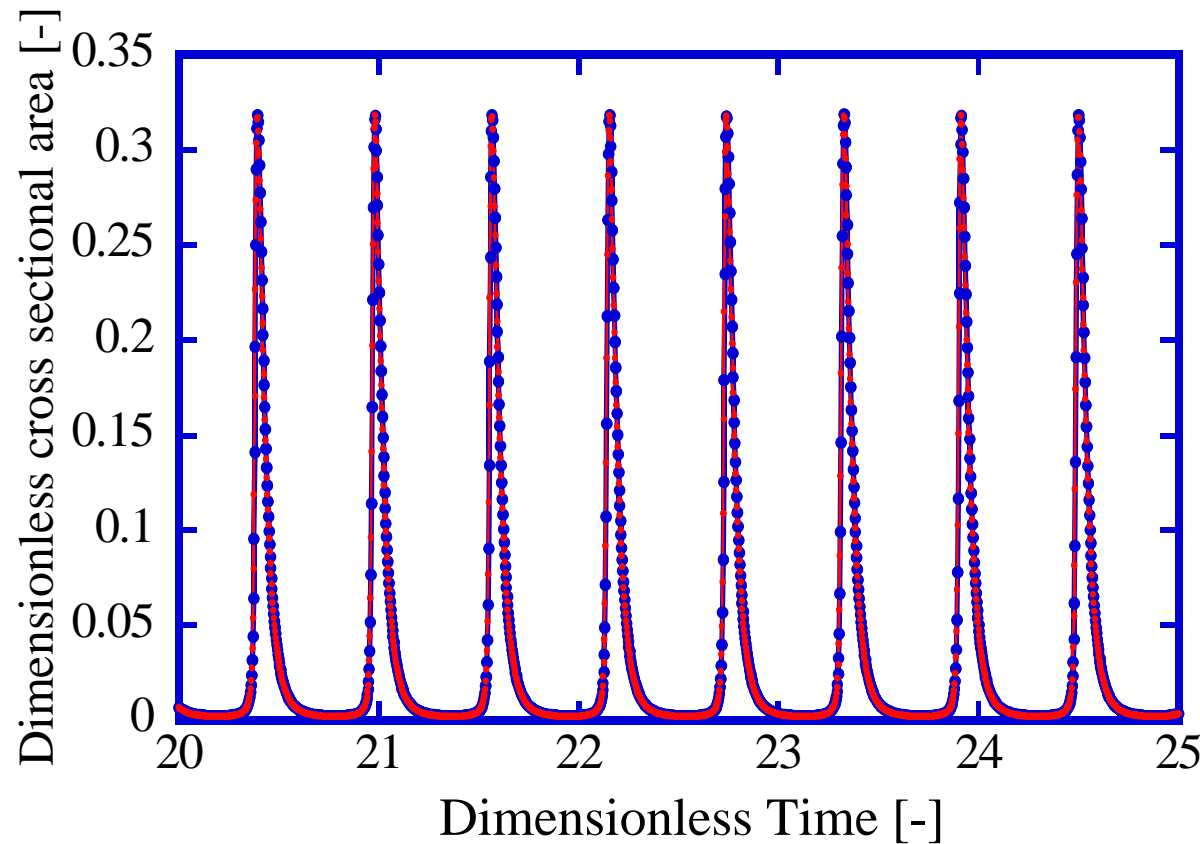
$$\tilde{A}_{0,\tilde{x}} = \exp(-\log(Vw) * \tilde{x})$$

$$\tilde{V}_{0,\tilde{x}} = \exp(\log(Vw) * \tilde{x})$$

**Figure 6 Convergence of the amplitude by division of space ( $\Delta x$ ).**

# Simulation

~ Division Time ~



**-Conditions-**

$$\Phi = 26.67$$

$$\Delta t = 1.0 \times 10^{-6}$$

$$\Delta t = 1.0 \times 10^{-7}$$

$$\Delta x = 500$$

**Initial condition**

$$\tilde{A}_{0,\tilde{x}} = \exp(-\log(V_w) * \tilde{x})$$

$$\tilde{V}_{0,\tilde{x}} = \exp(\log(V_w) * \tilde{x})$$

**Figure 7** The difference in the waveform by division time ( $\Delta t$ ).

# Simulation

- ・初期条件による影響は外と内からのサイクルがほぼ同じ収束を見せることにより、ないと言える。

- ・ $N$ の上昇とともに振幅および波長は増大していく。 $\Delta x=400$ ほどでその増加は収束する。精度を考慮すると $\Delta x=500$ 以上が望ましい。

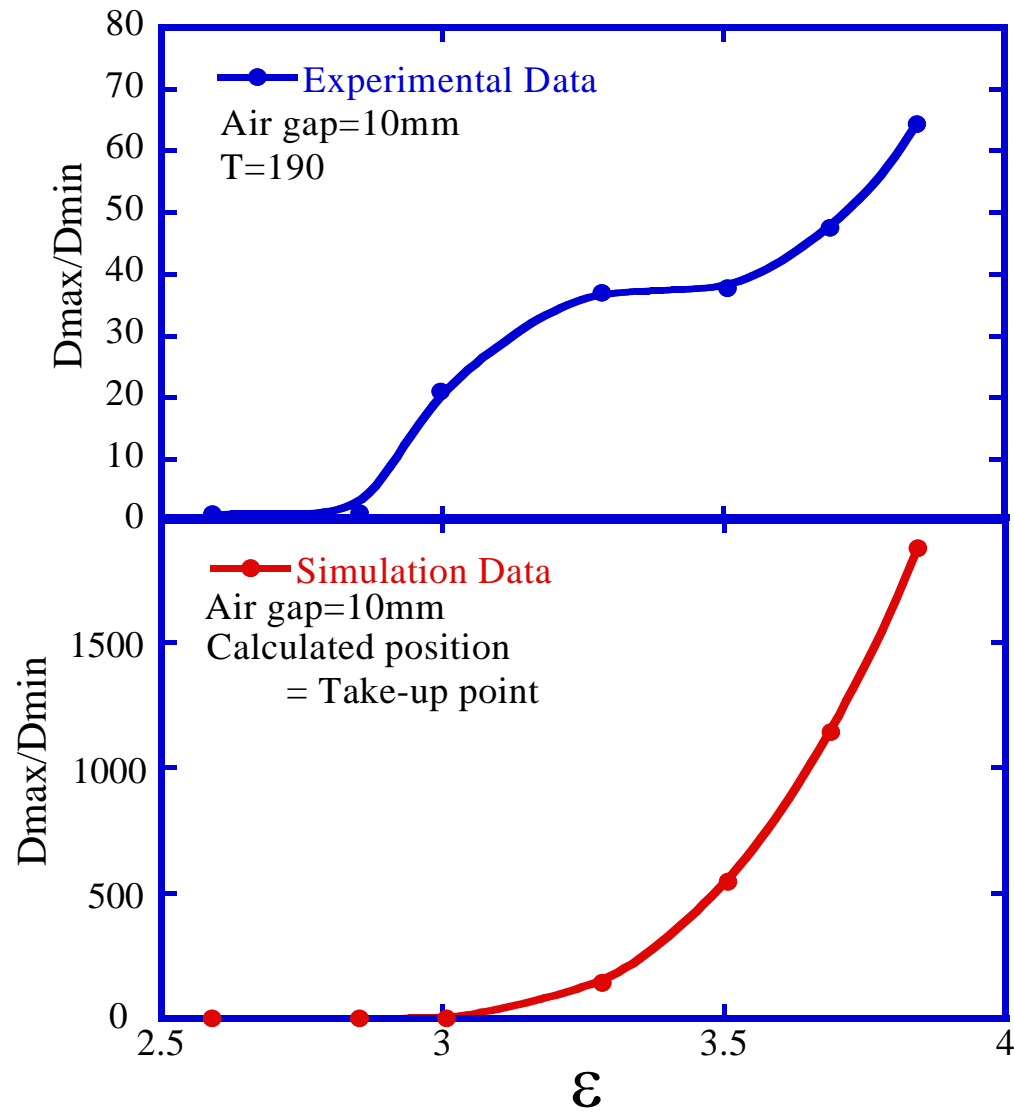
- ・ $\Delta t=10^{-6}$ と $10^{-7}$ は、 $\Delta x$ が同じならばほぼ同じ波形を見せることから計算時間を考慮して $\Delta t=10^{-6}$ が最適であると言える。(  $\Delta x=500$  で  $\Delta t=10^{-6}$ 以下では値が発散してしまう)

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**精度は $N$ にのみ依存する**

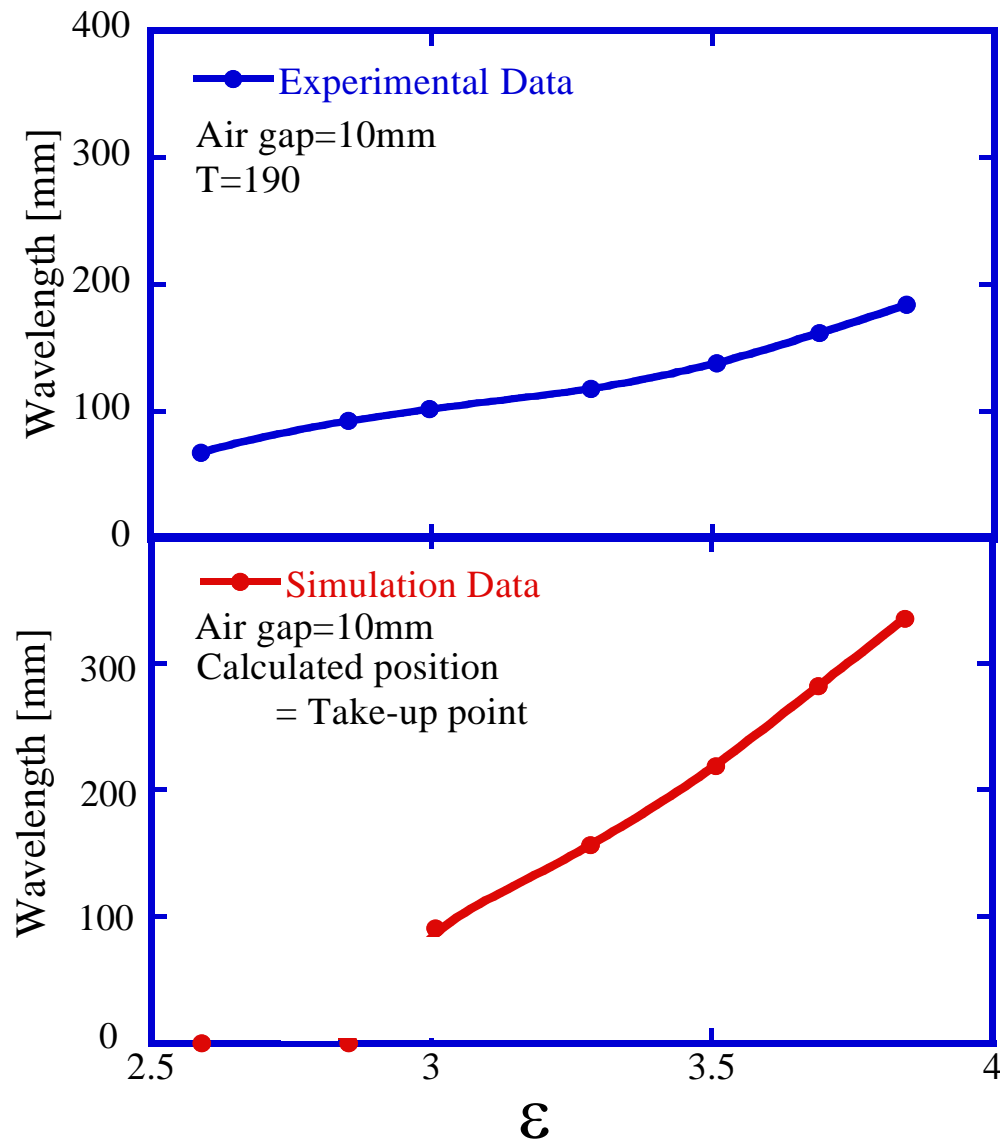
**最適な計算条件  $\Delta t=10^{-6}$ 、 $\Delta x=500$**

# Results



**Figure 8 Comparison of an amplitude ratio between a Simulation and an Experiment.**

# Results



**Figure 9 Comparison of an wavelength of between a Simulation and an Experiment.**

# Conclusion

- ・ニュートン流体のシミュレーションを作成し実験と比較することができた。
- ・シミュレーションの良好な精度をえるためには  $x=500$ 以上の精度が必要である。
- ・絶対的な値は異なるが の増加と共に振幅比及び波長が増加する様子を再現できた。
- ・振幅と波長の増大は伸長ひずみによるものであると考えられる。