RELEASE and ATMOSPHERIC DISPERSAL of LIQUID AGENTS

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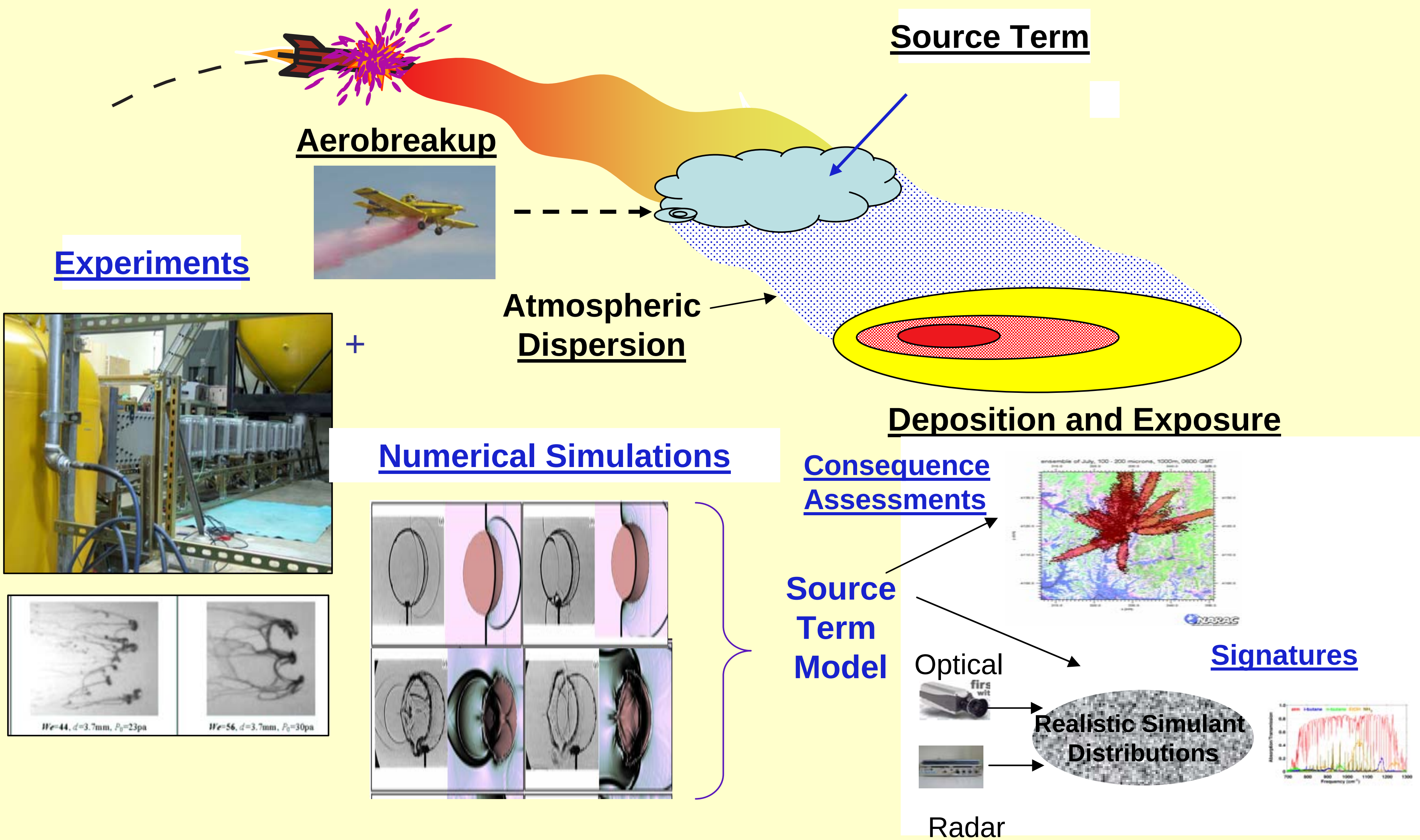
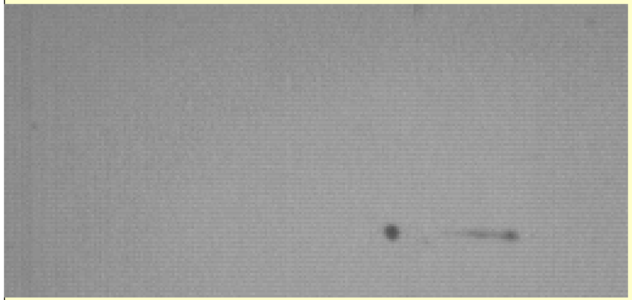
Operational Capability to be Provided



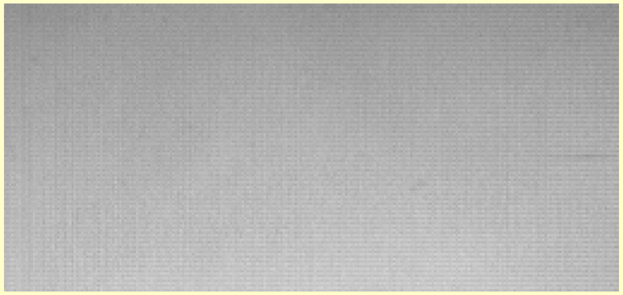
Controlling Mechanisms: VISCOELASTICITY

Rather than breaking into droplets, viscoelastic liquids tear into threads and sheets that resist pinch-off



Newtonian

Viscous



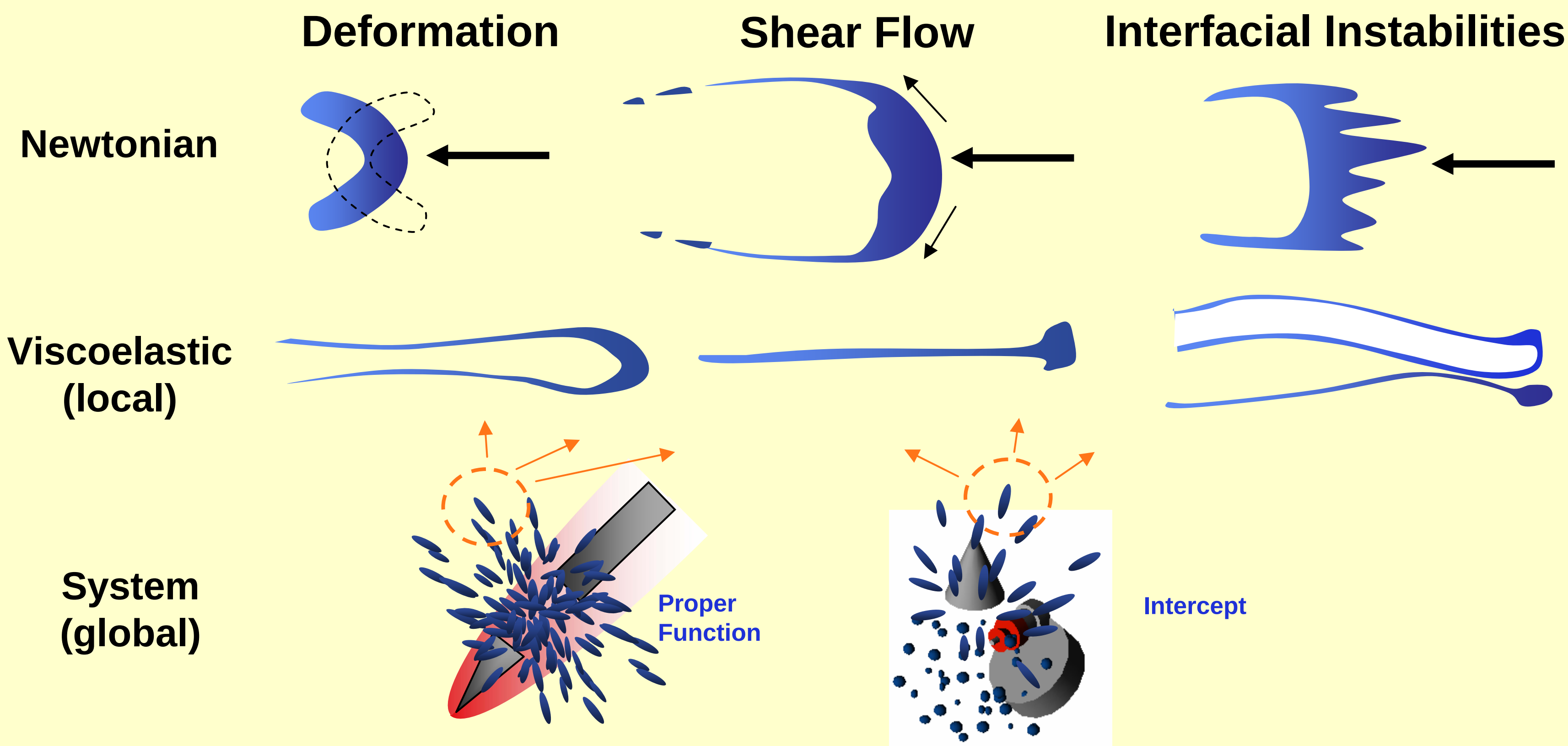
Viscoelastic

"Thickener" is added precisely for the purpose of controlling atomization . . .

Concentration and Length of Polymer Chain selected to "Tailor" Effect

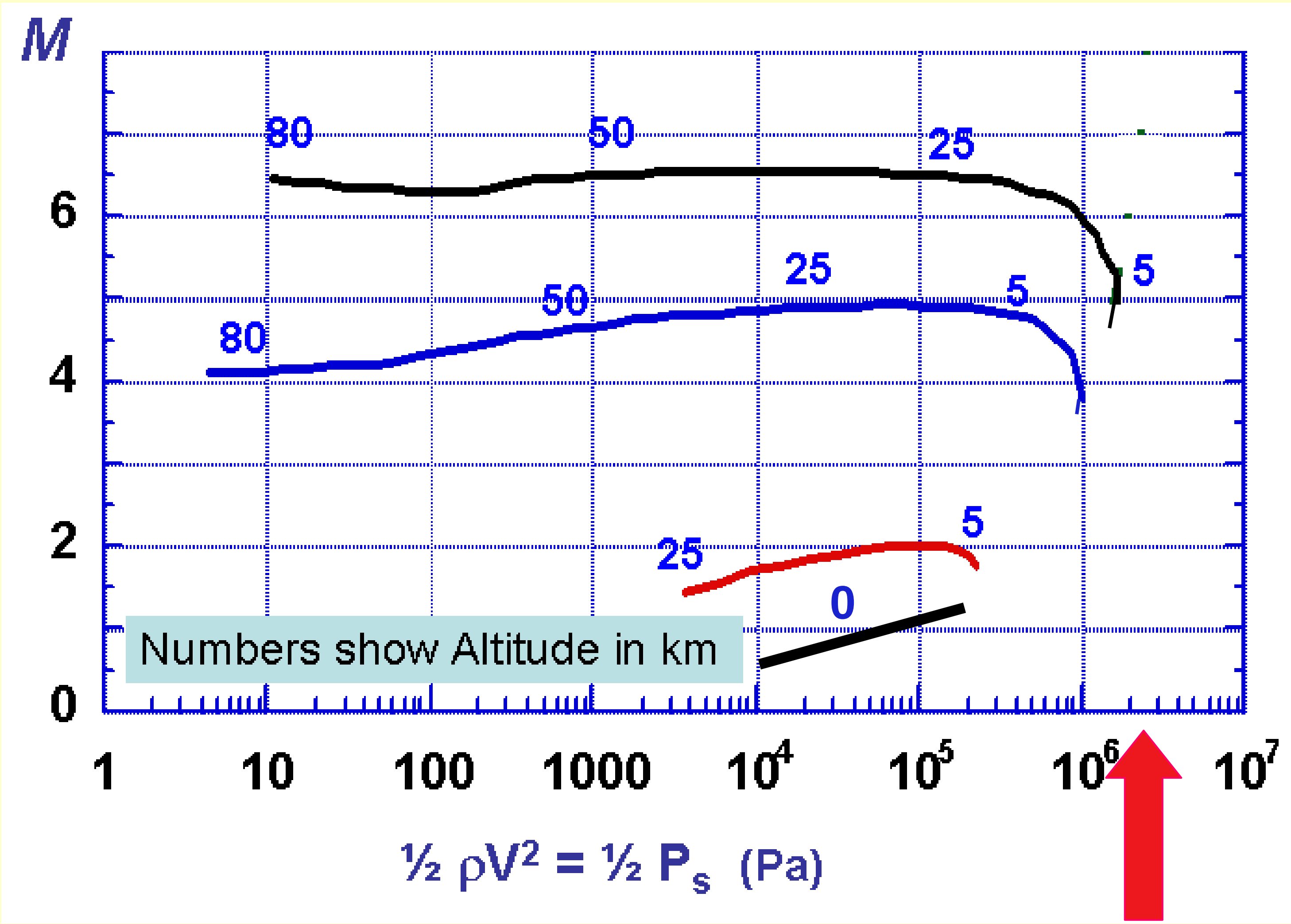
Controlling Mechanisms: Aerodynamic History

Aerodynamic interactions result in a complex superposition of mechanisms that are highly sensitive to ρv^2.



Scaling: From Droplet……to Beer Can…… to Warhead Quantities

All Release Conditions are Achievable in Experiments



Using the Laboratory as Frame of Reference Makes Measurements Possible

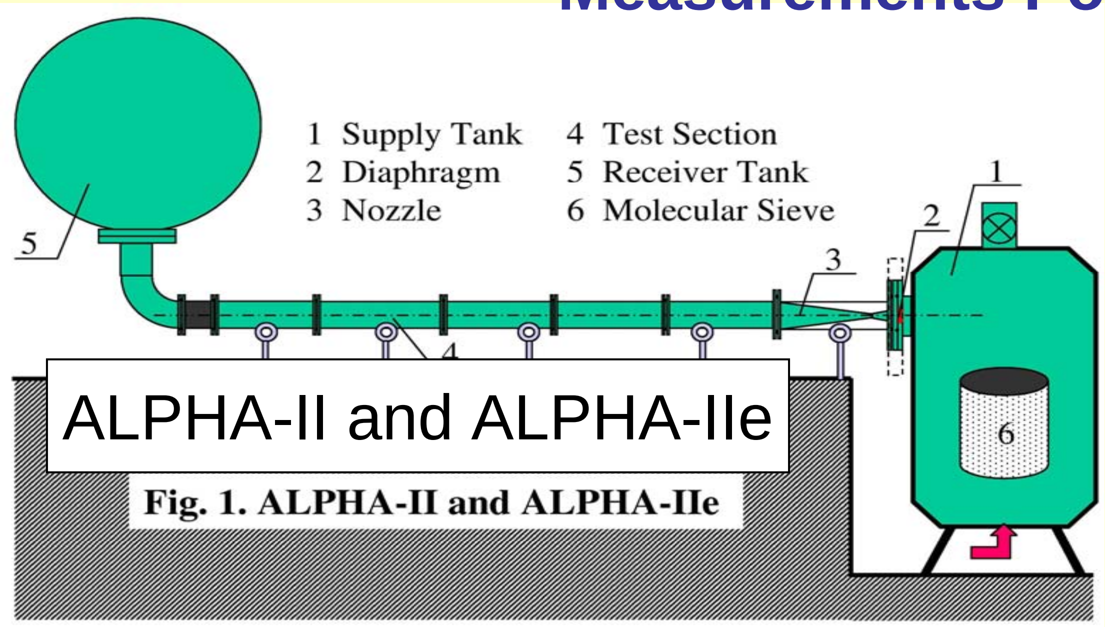
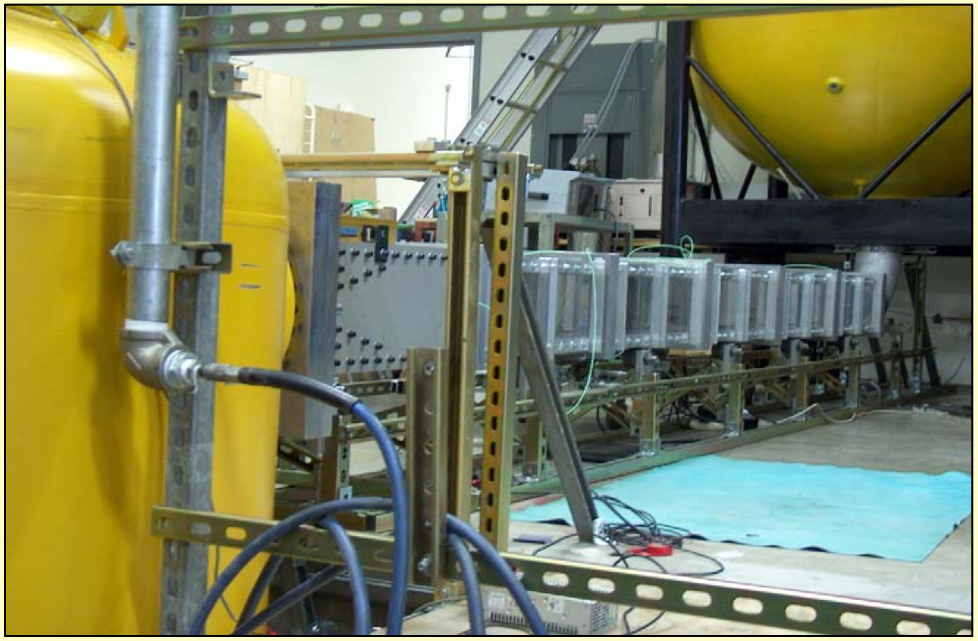


Fig. 1. ALPHA-II and ALPHA-IIe



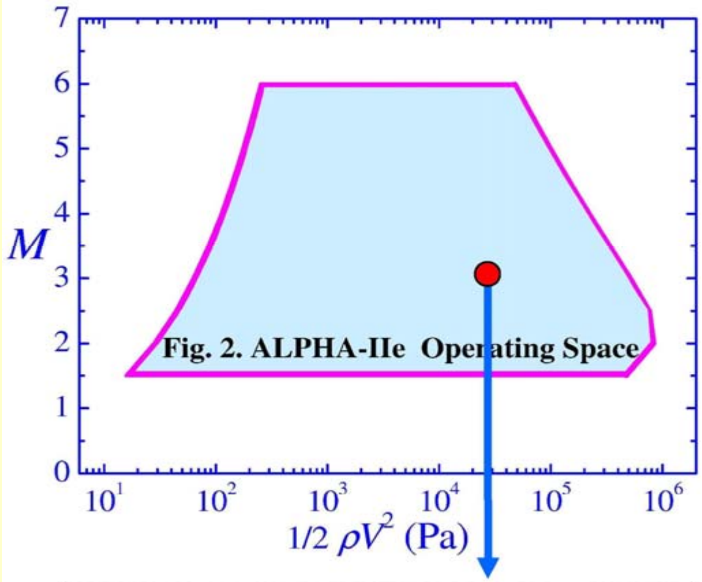


Fig. 2. ALPHA-IIe Operating Space

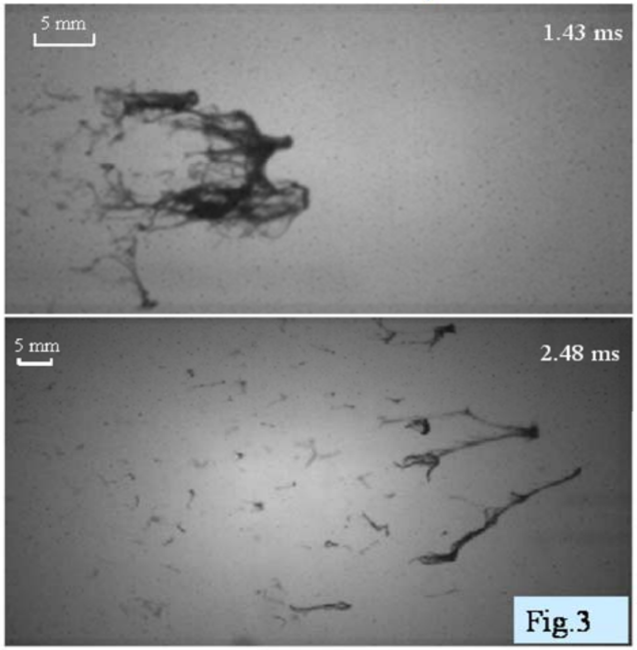
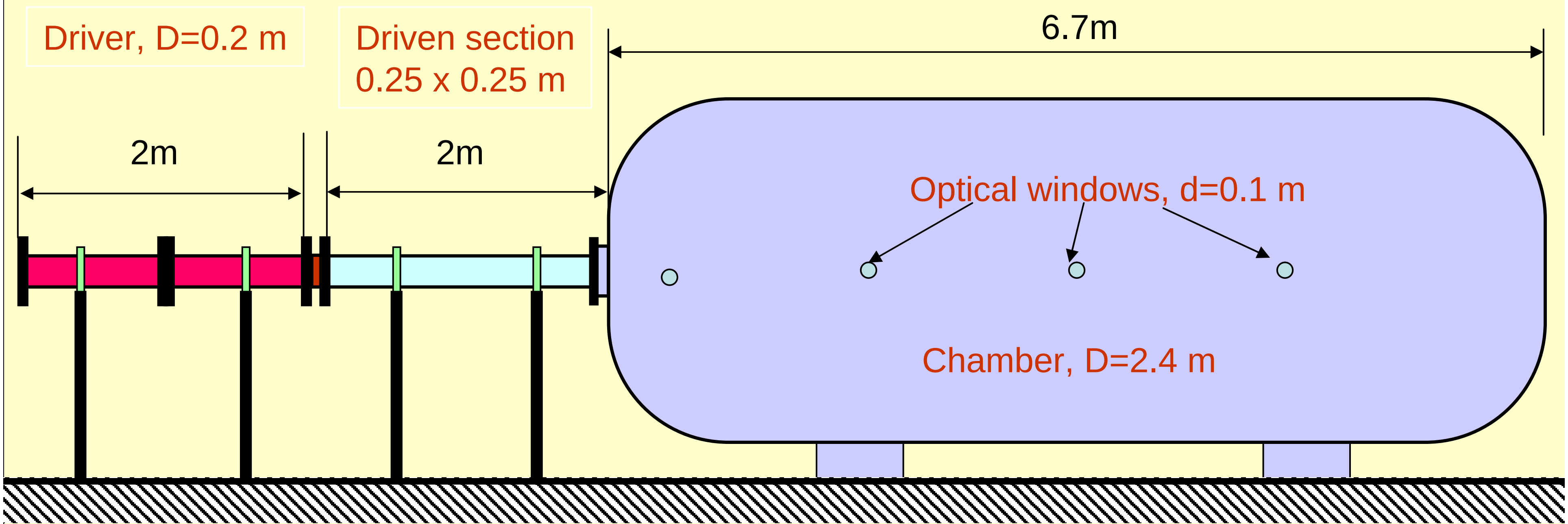
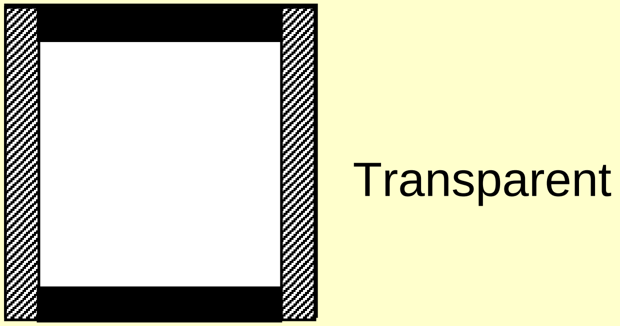


Fig.3

ASOS Overall (1: 45)



Cross section of Expansion section (1:8)



Special : He-N_2 & Discontinuity
Aerodynamic History

A Hierarchy of Objectives

Local Scaling ……. We, M, Oh, R_τ…….. **Lower Bound**

Principally with Experiments/Theory/DNS

System Scaling……….Realistic/Predictive/Adaptable

mass ratio

release (boundary) conditions

aerodynamic history……

shielding

coalescence

shock dynamics

cloud permeability

length scales (We,M,Oh,R_τ)

Principally with Experiments/Theory/EFM

Major Results

- On Data Base development we have proven all aspects of the experimental technique and begun Production Runs (well ahead of schedule),
- We have shown experimentally that VE drops can survive intact at We~ 4,000! Or $1/2\rho v^2 = 2\ 10^5$!
- We developed a theoretical understanding of the mechanisms for Newtonian/Viscous liquid breakup over the whole range of regimes, unified all data, and corrected major, long-standing misconceptions,
- On DNS we achieved the sharp treatment of interfaces, and established capability to compute instabilities on shocked, high acoustic impedance mismatch interfaces.

Scope of this Presentation

- Develop Data Bases (Experiments)

  $10^4 < ½\ rv^2 < 10^5$, M=3 (ALPHA II); ND, VD ;

- Understand Key Physics (Discrete/Dilute)

  Break-up Regimes with Newtonian (Viscous) Liquids

- Understand Key Physics (Discrete/Dilute)

  Break-up Regimes with Viscoelastic Liquids (Small Drops)

- Sharp Treatment of Interfaces

  Fidelity of Instability Prediction by DNS

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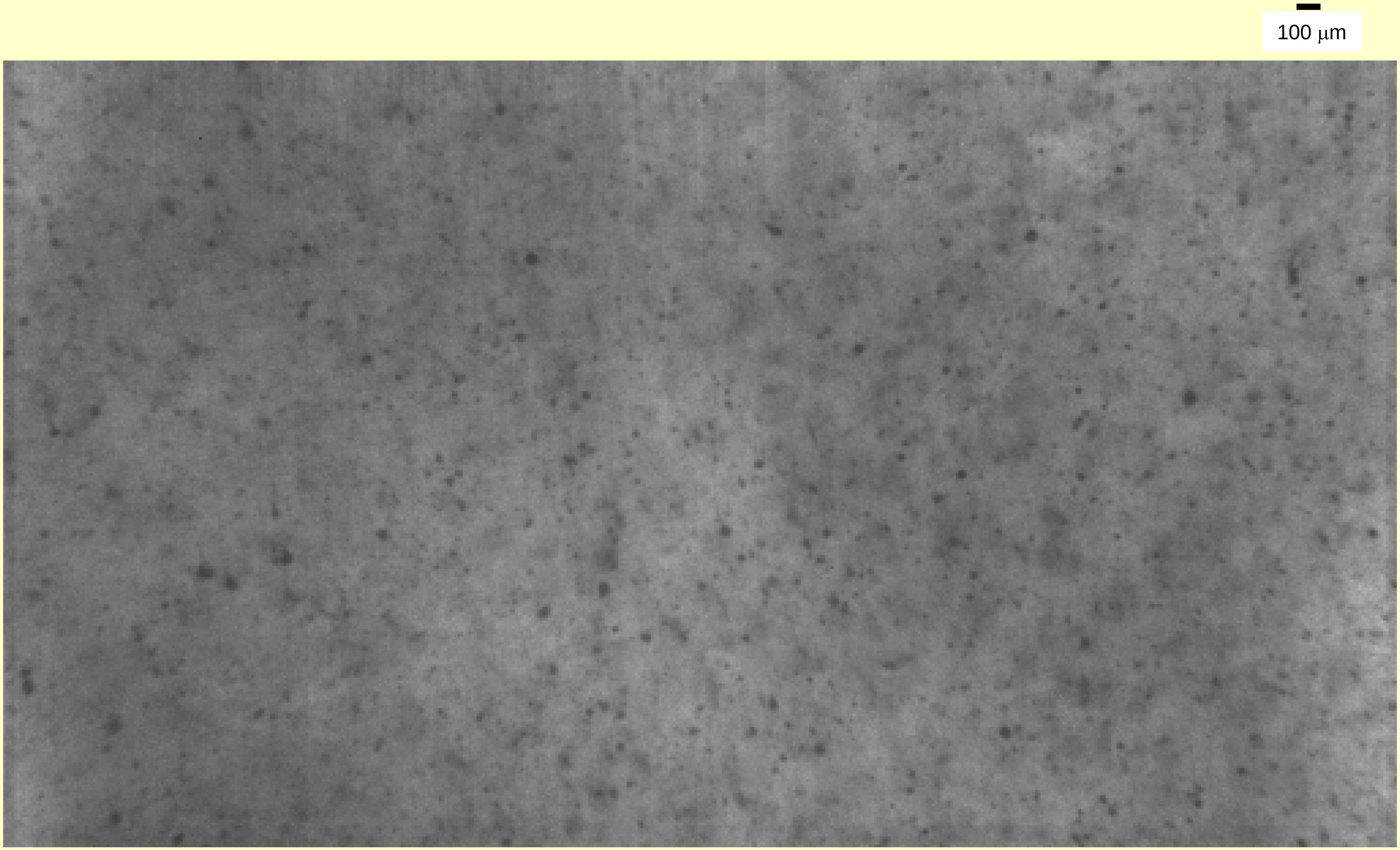
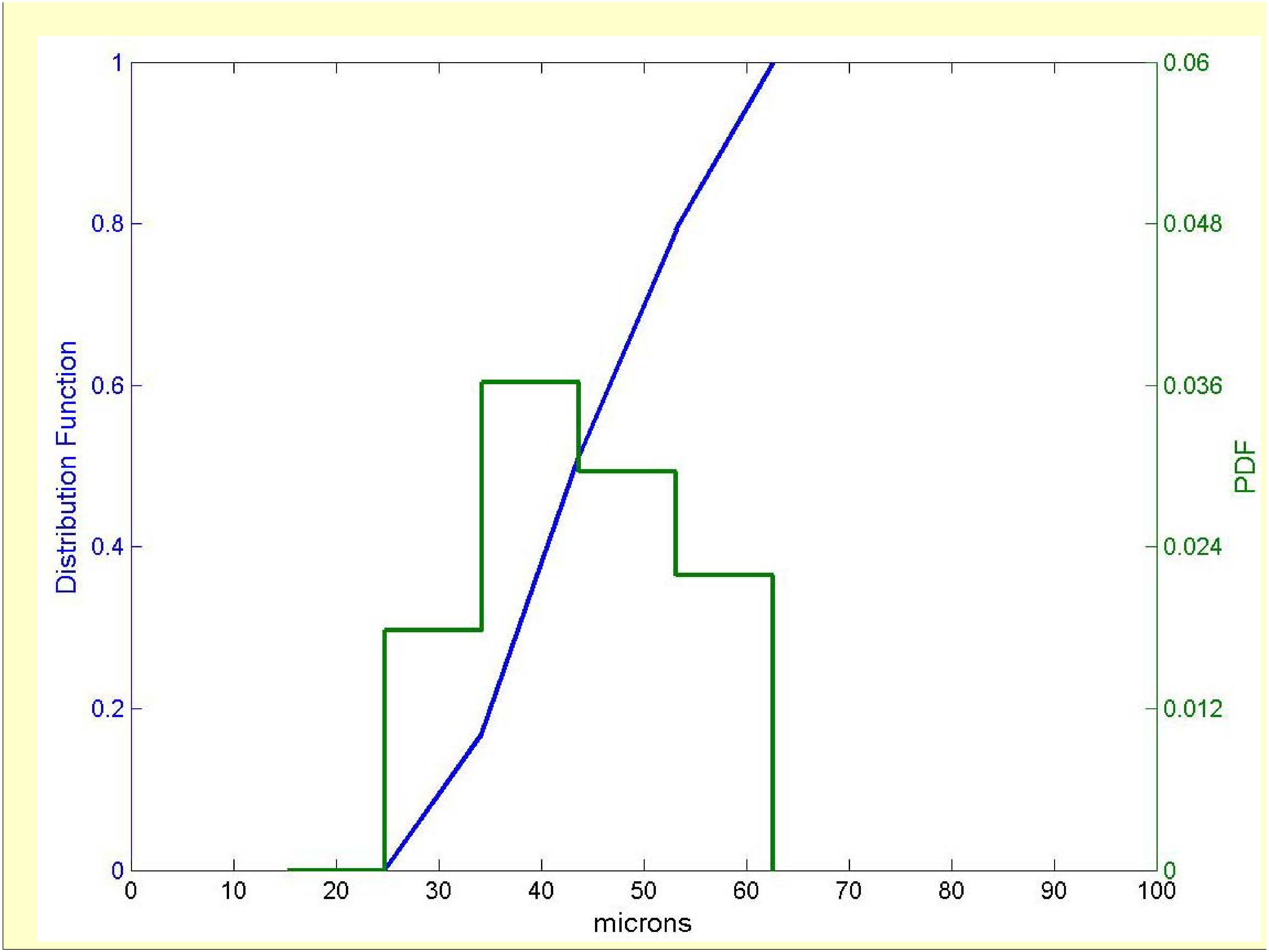
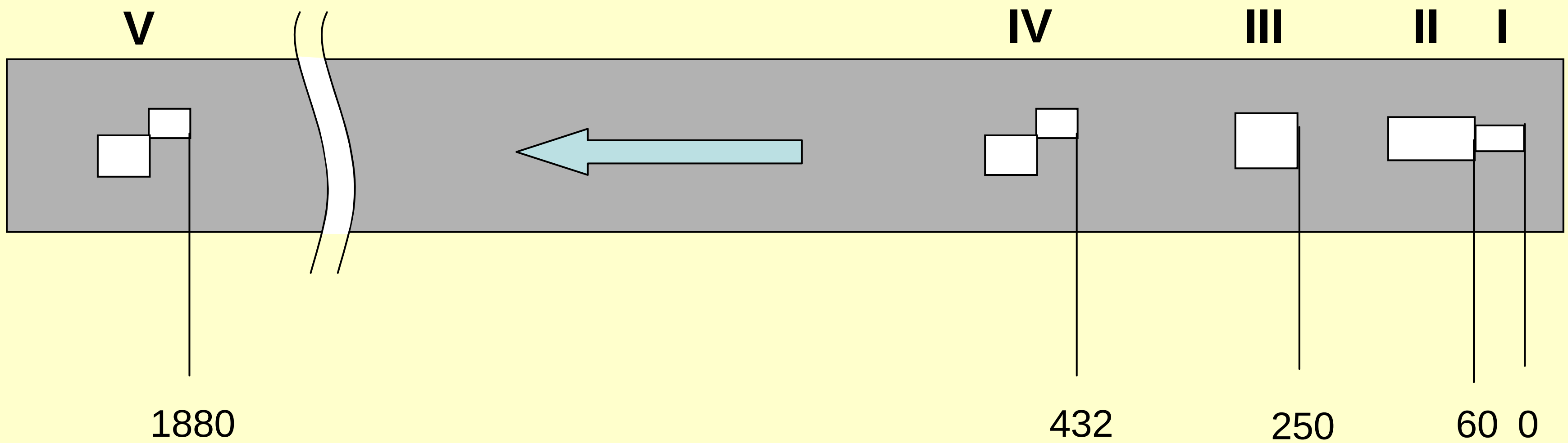
We have the first Newtonian Particle Size Distributions in the shear regime





Distribution Function
PDF
microns
0
0.2
0.4
0.6
0.8
1
0.012
0.024
0.036
0.048
0.06
10
20
30
40
50
60
70
80
90
100

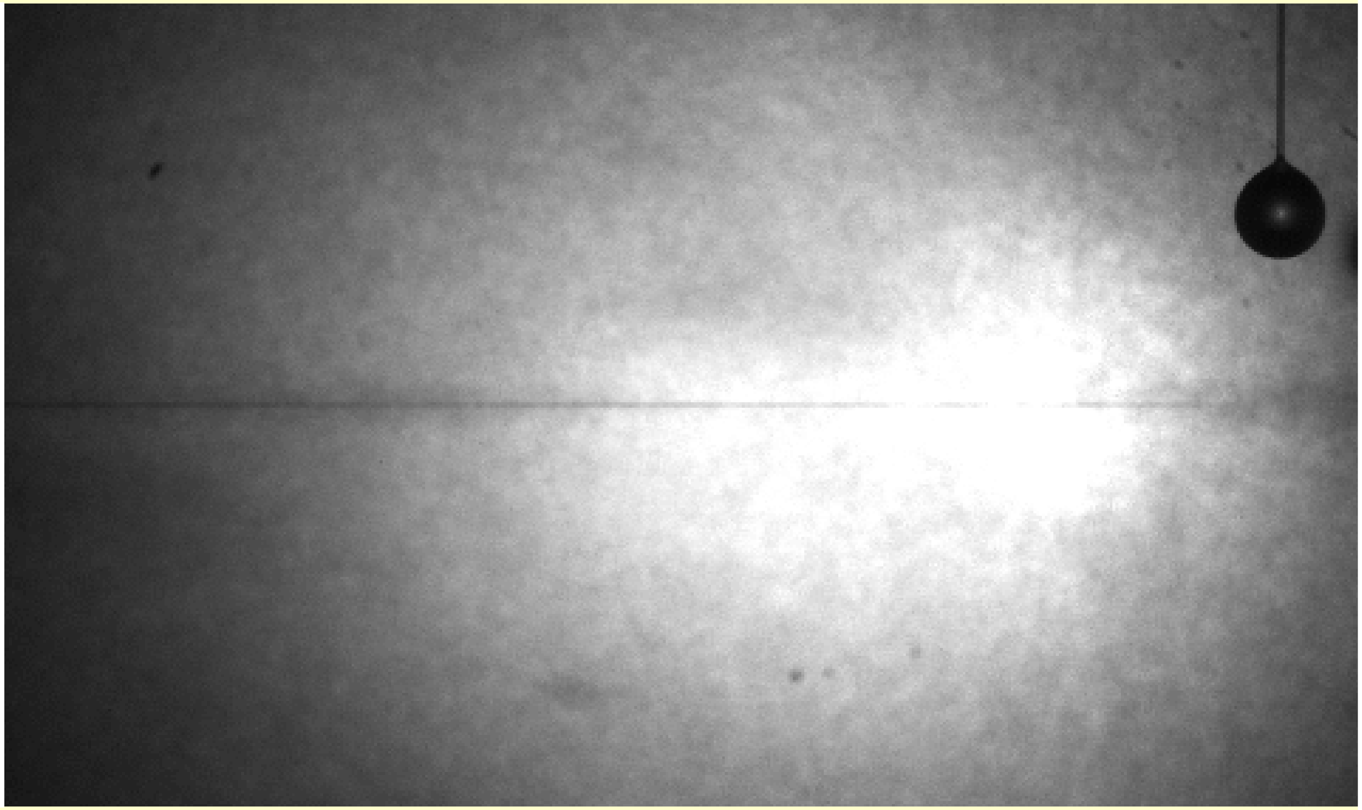
Stage Arrangement



Stages I – V are sampling stages using high-speed cameras.

Unit: mm

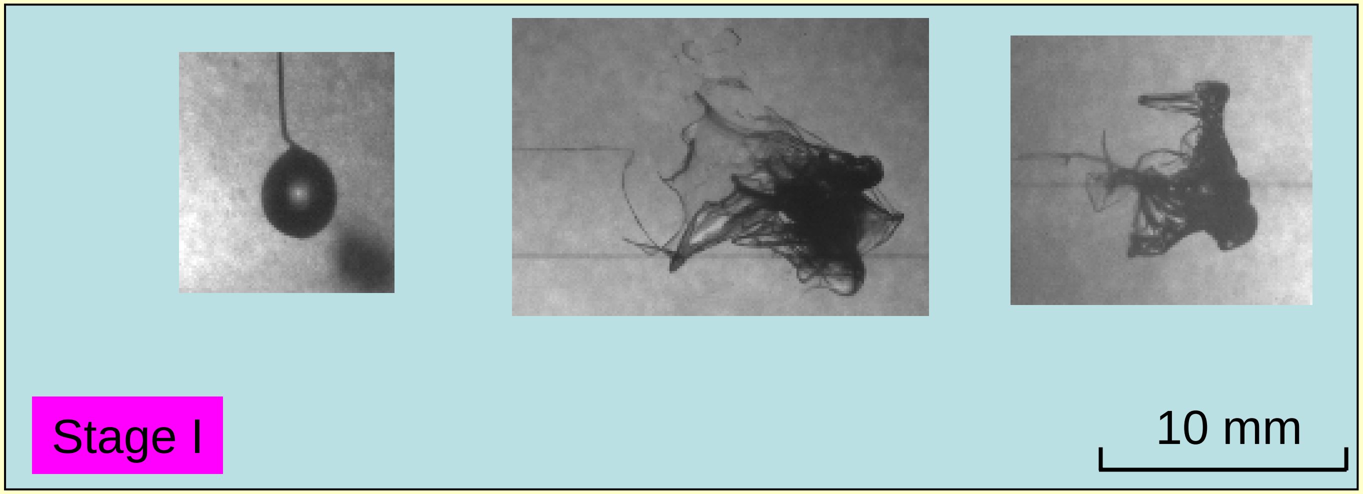
Breakup at ½ ρV^2 of 10^5 Pa



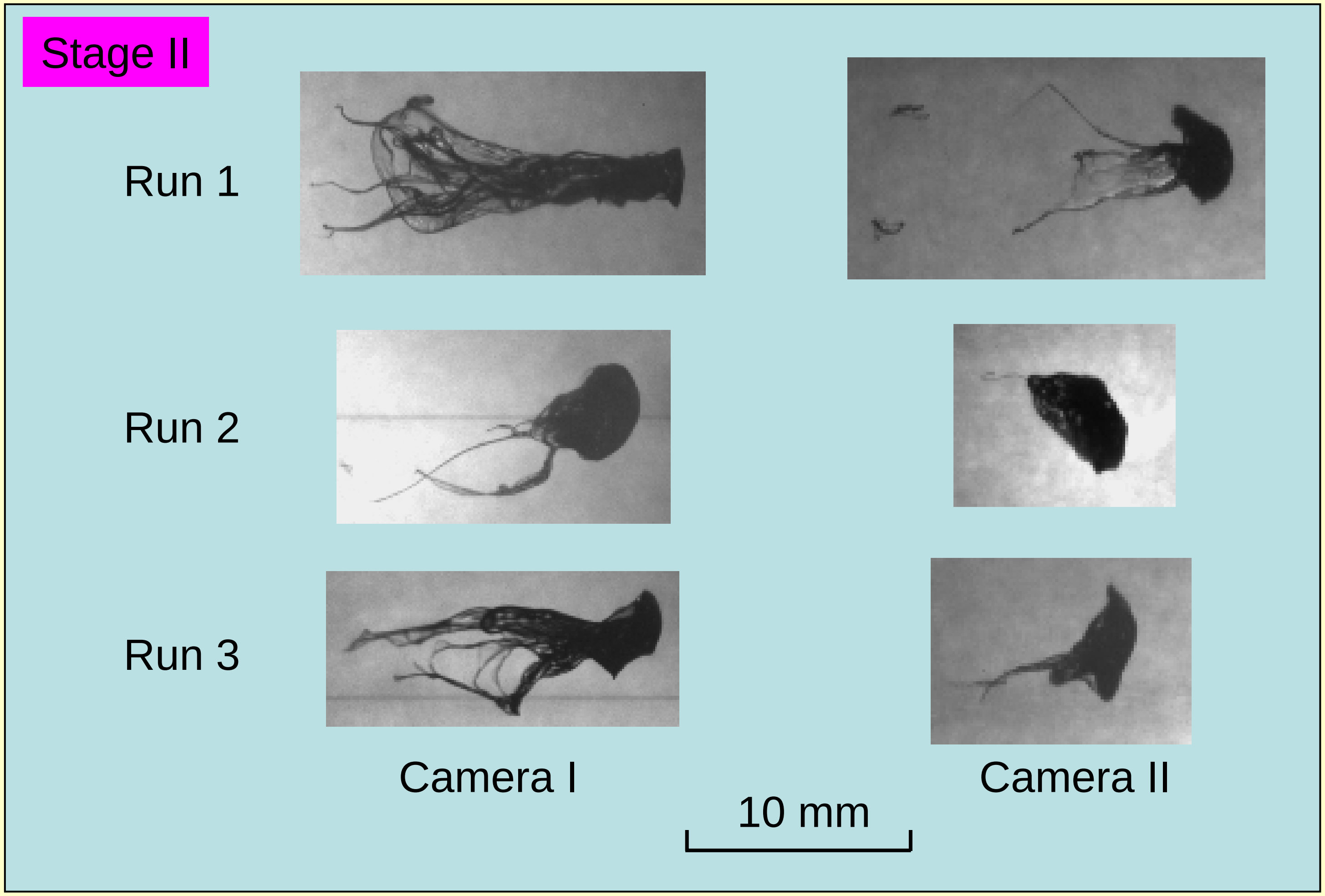
3.8%PSBMA+TBP

***d* = 3.4 mm, *We*=29,000**

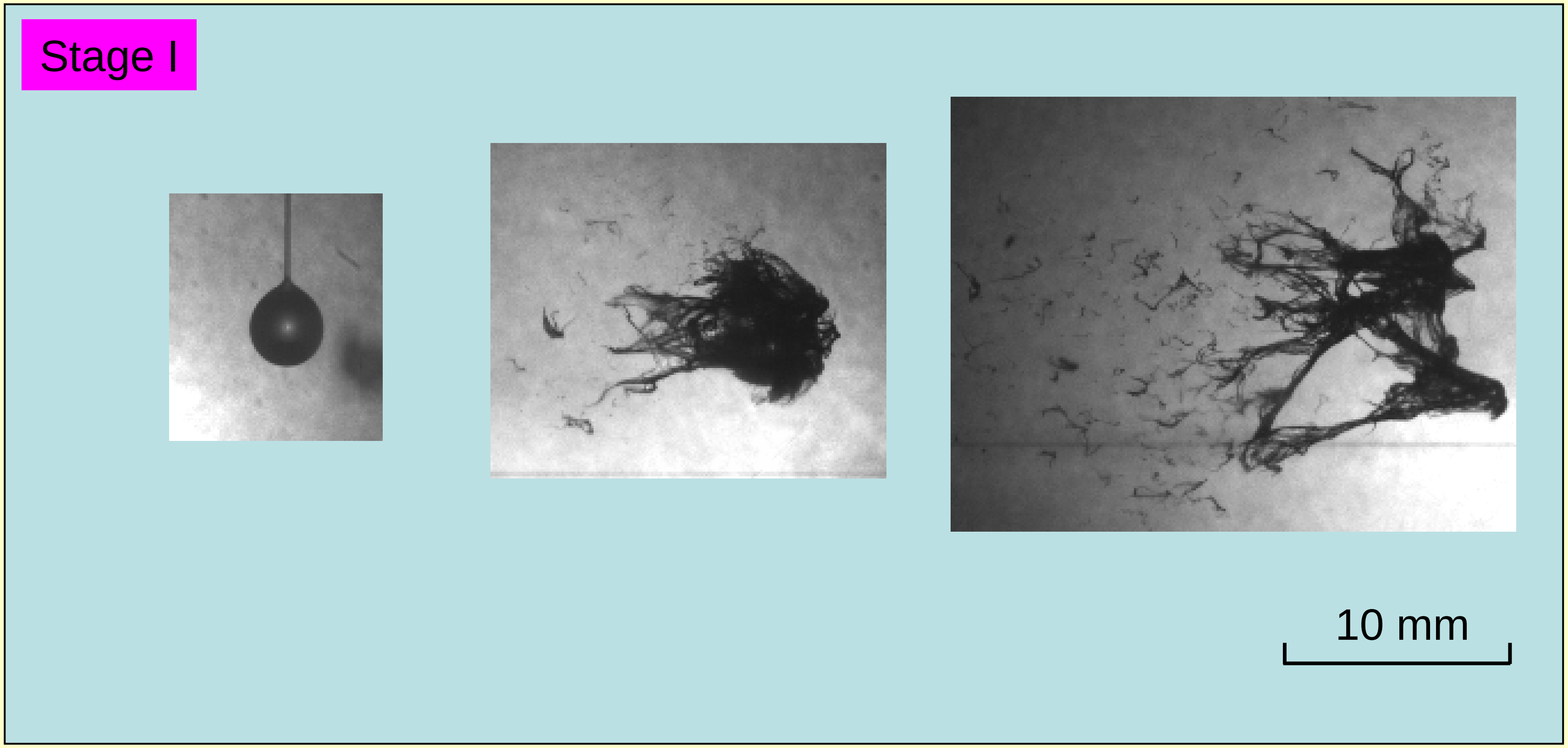
Breakup History at the Dynamic Pressure of 10^4 Pa



Breakup History at the Dynamic Pressure of 10^4 Pa



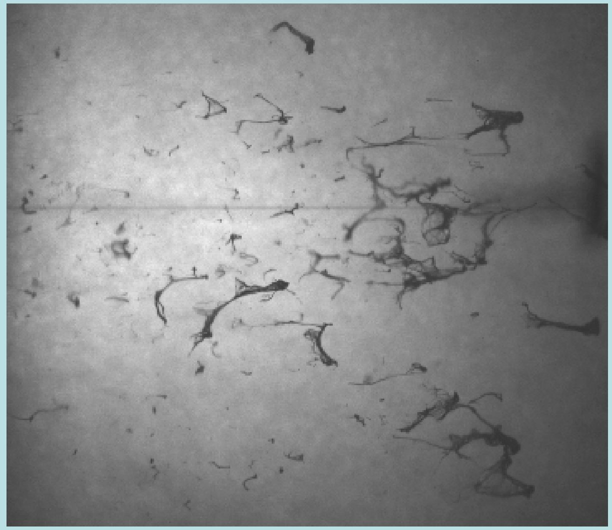
Breakup History of a Polymeric drop at the dynamic pressure of 10^5 Pa

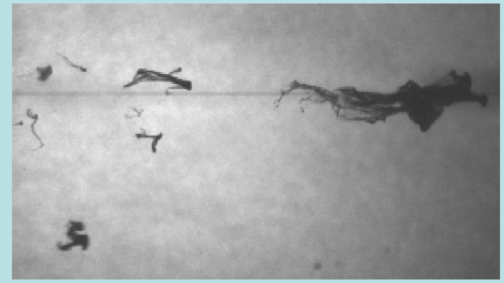


Breakup History at Dynamic Pressure of 10^5 Pa

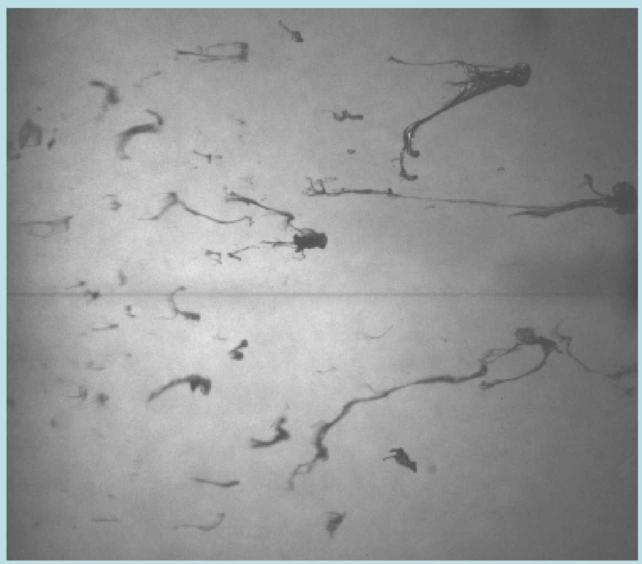
Stage II

Run 2

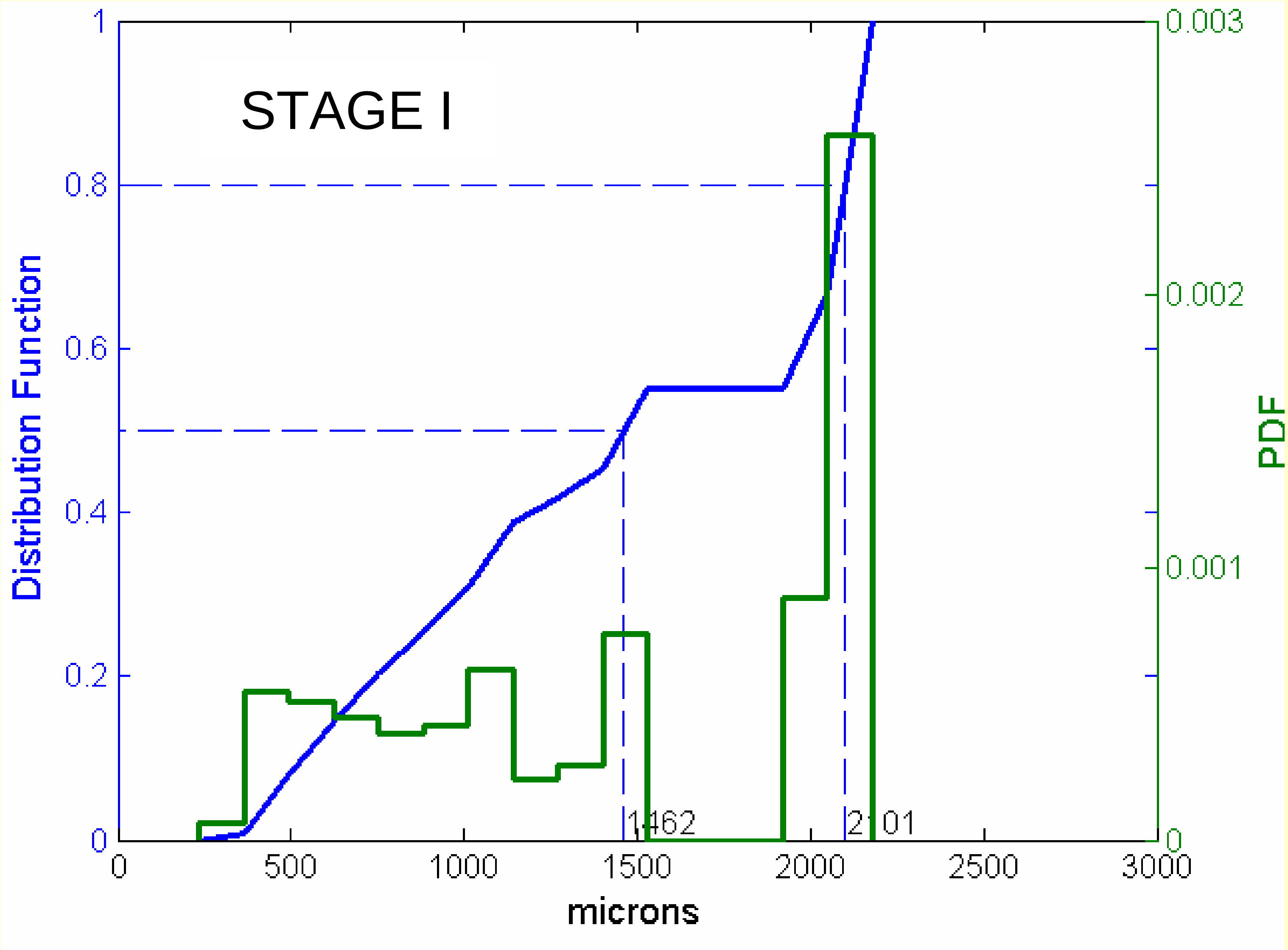




Run 3



10 mm



STAGE I
Distribution Function
PDF
microns
1
0.8
0.6
0.4
0.2
0
0.003
0.002
0.001
0
0
500
1000
1500
2000
2500
3000
1462
2101

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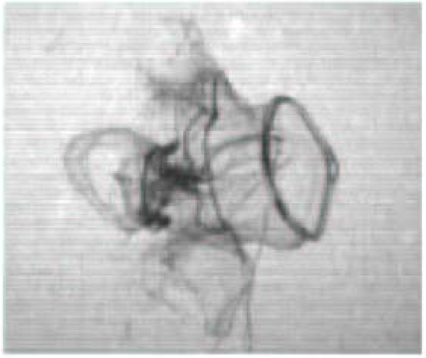
R
T
P



We=28, d=3.8mm, P_0=15pa

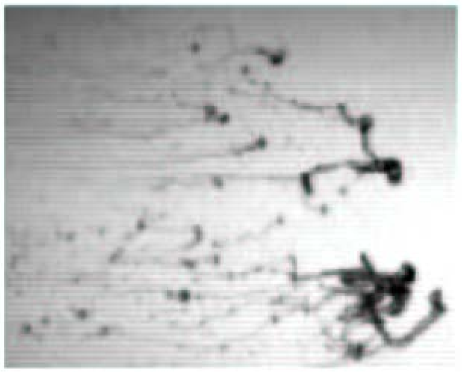
2

We=44, d=3.7mm, P_0=23pa

3

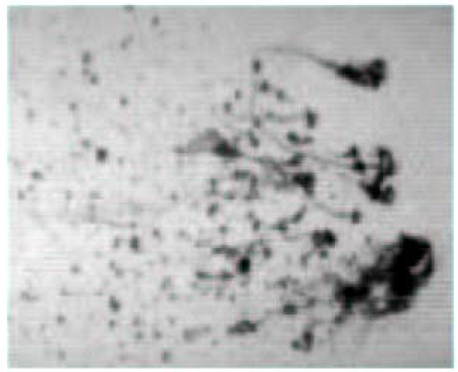
We=56, d=3.7mm, P_0=30pa

4



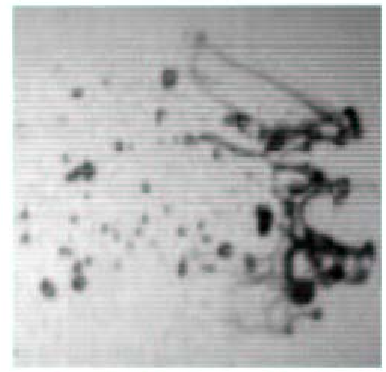
We=58, d=3.7mm, P_0=31pa

2-3



We=63, d=3.7mm, P_0=35pa

3

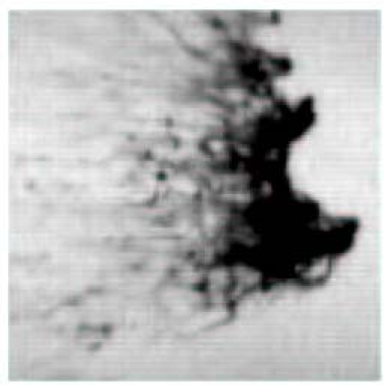


We=68, d=3.7mm, P_0=37pa

3-4

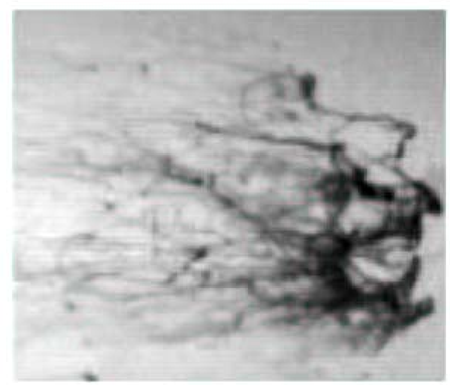
We=109, d=3.9mm, P_0=55pa

4-5



We=183, d=3.7mm, P_0=100pa

4-5

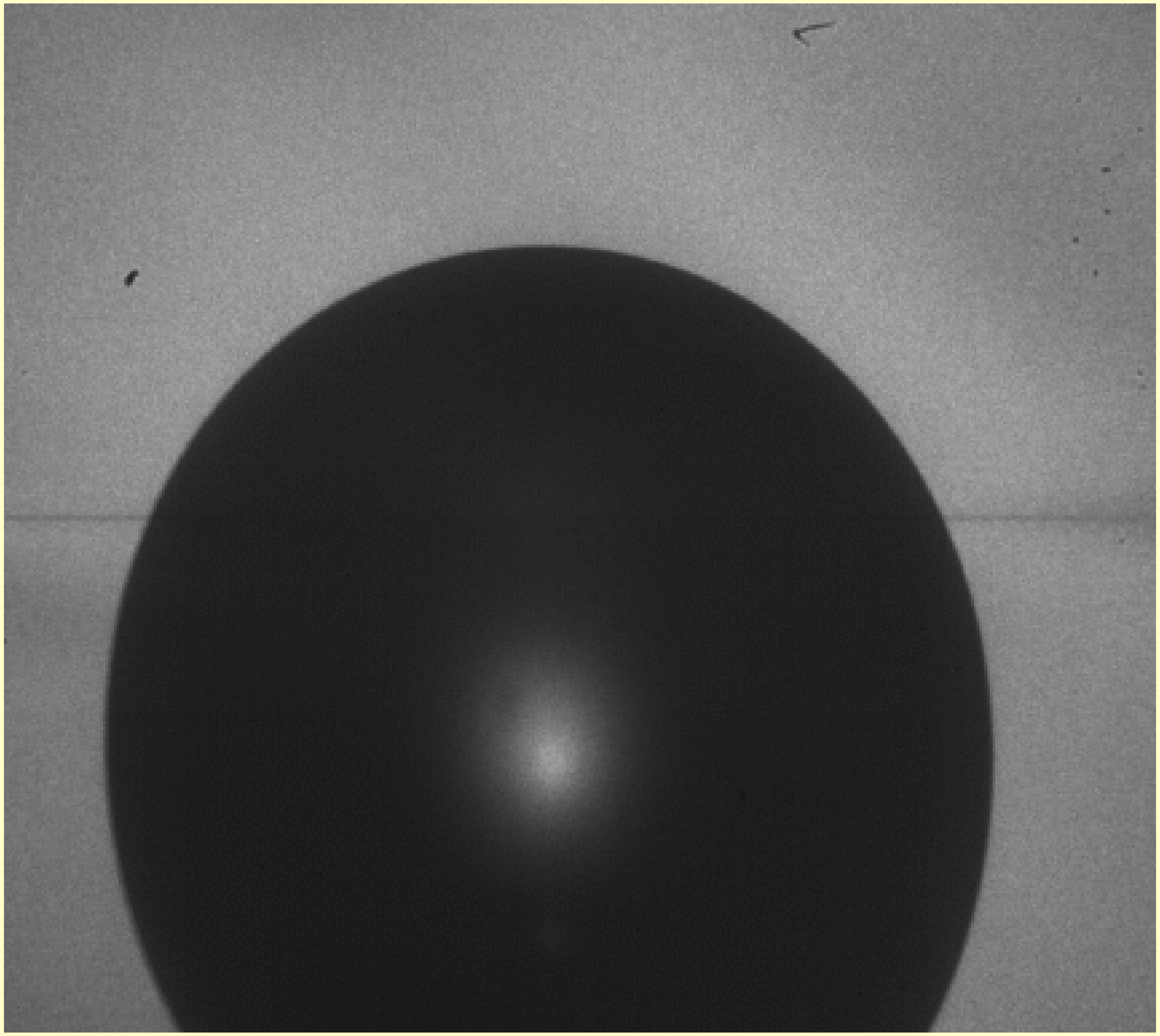


We=299, d=3.7mm, P_0=160pa

9

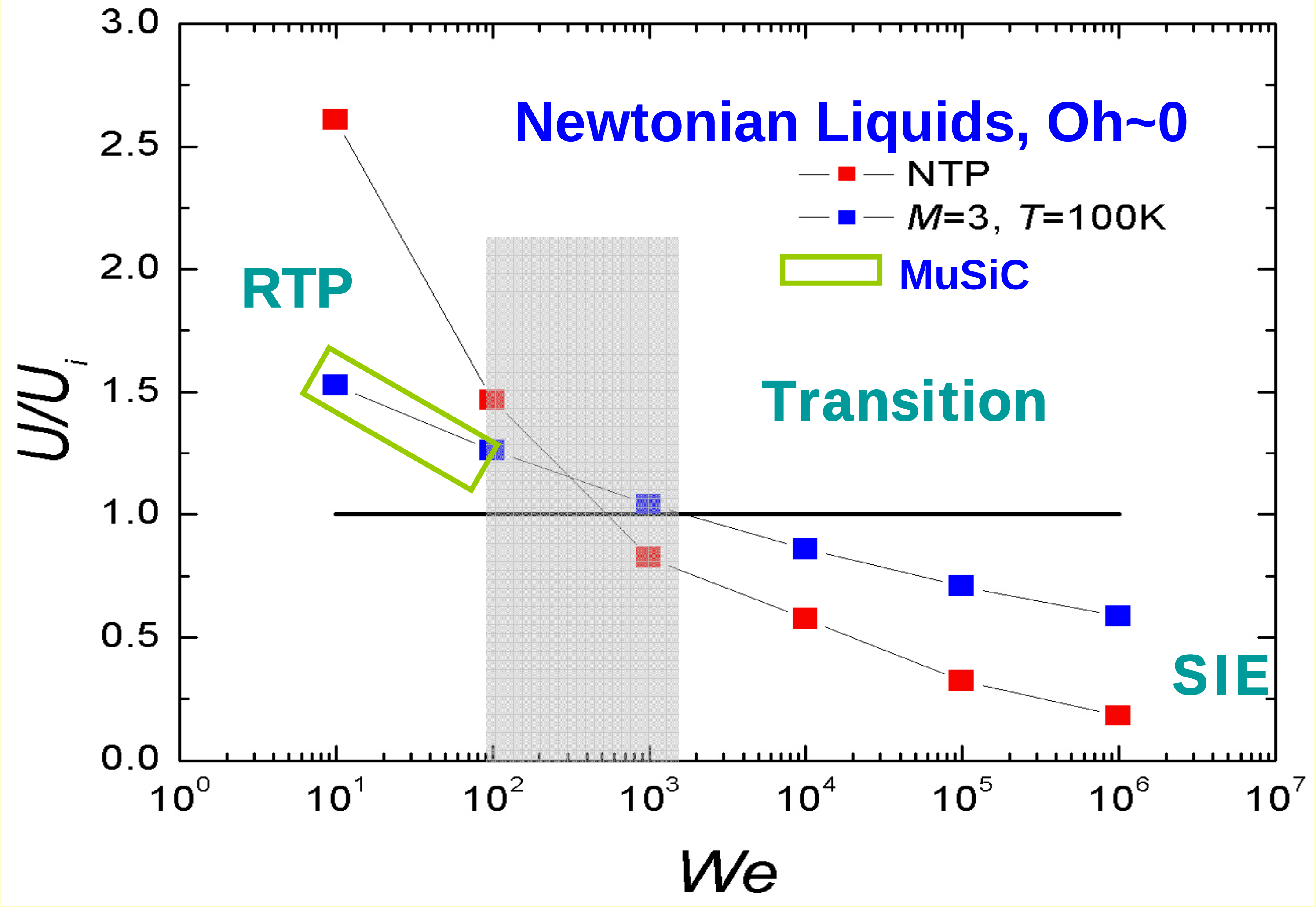
Close-up of a TBP drop at Dynamic Pressure of 10^5 Pa

S
I
E



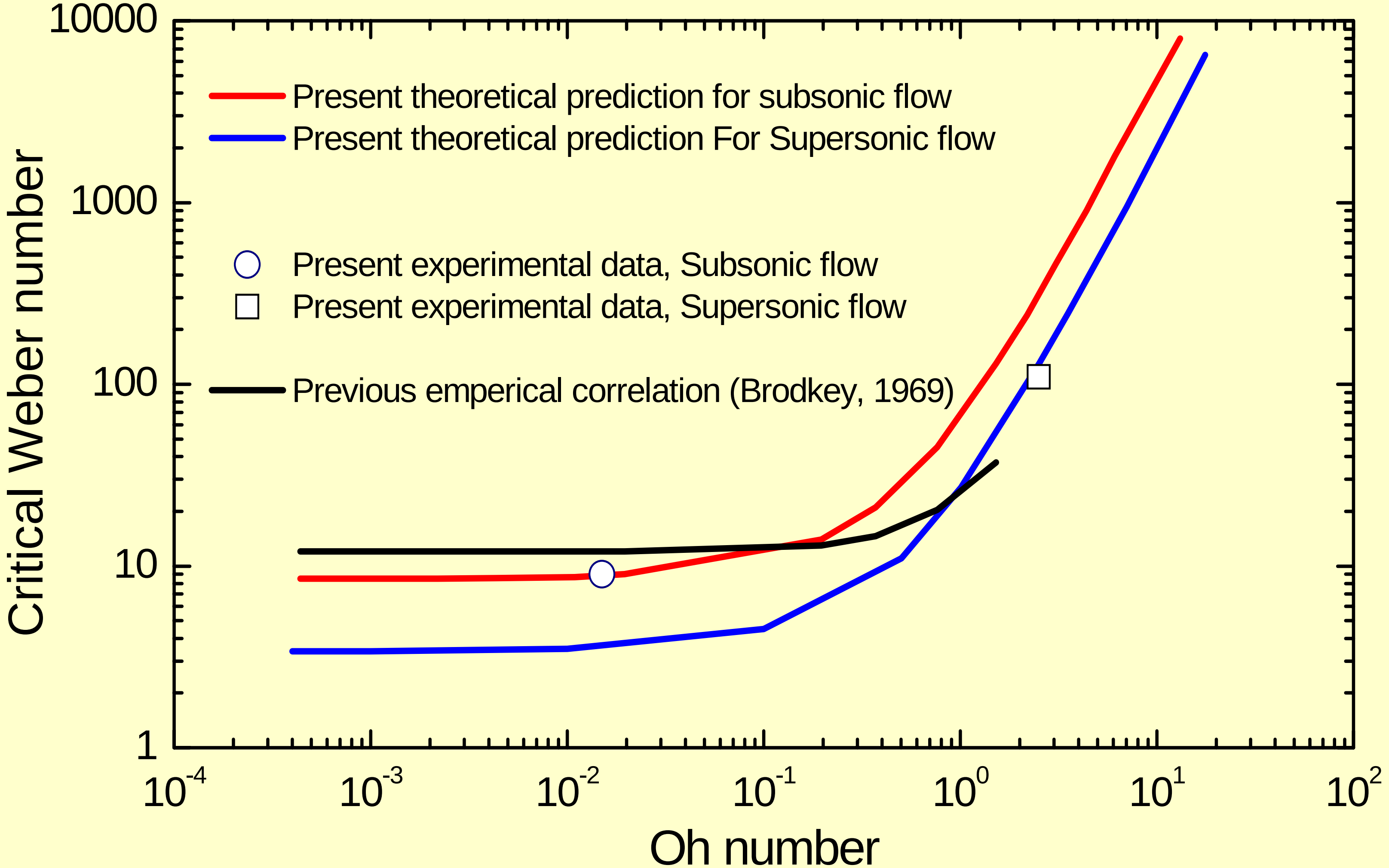
TBP drop, d=3.5 mm, We=31,000
(Movie) Frame-frame time interval=80 μs

We now have a Comprehensive Understanding of the Regimes of Aerobreakup for Newtonian Liquids



T.G.Theofanous, et al,,*ASME JFE*, 2004 and IUTAM Elsevier, 2006.

We now Understand how Viscous, Newtonian Liquids Break up.



Theory: Single Taylor Wave Penetration the Timing works out too.

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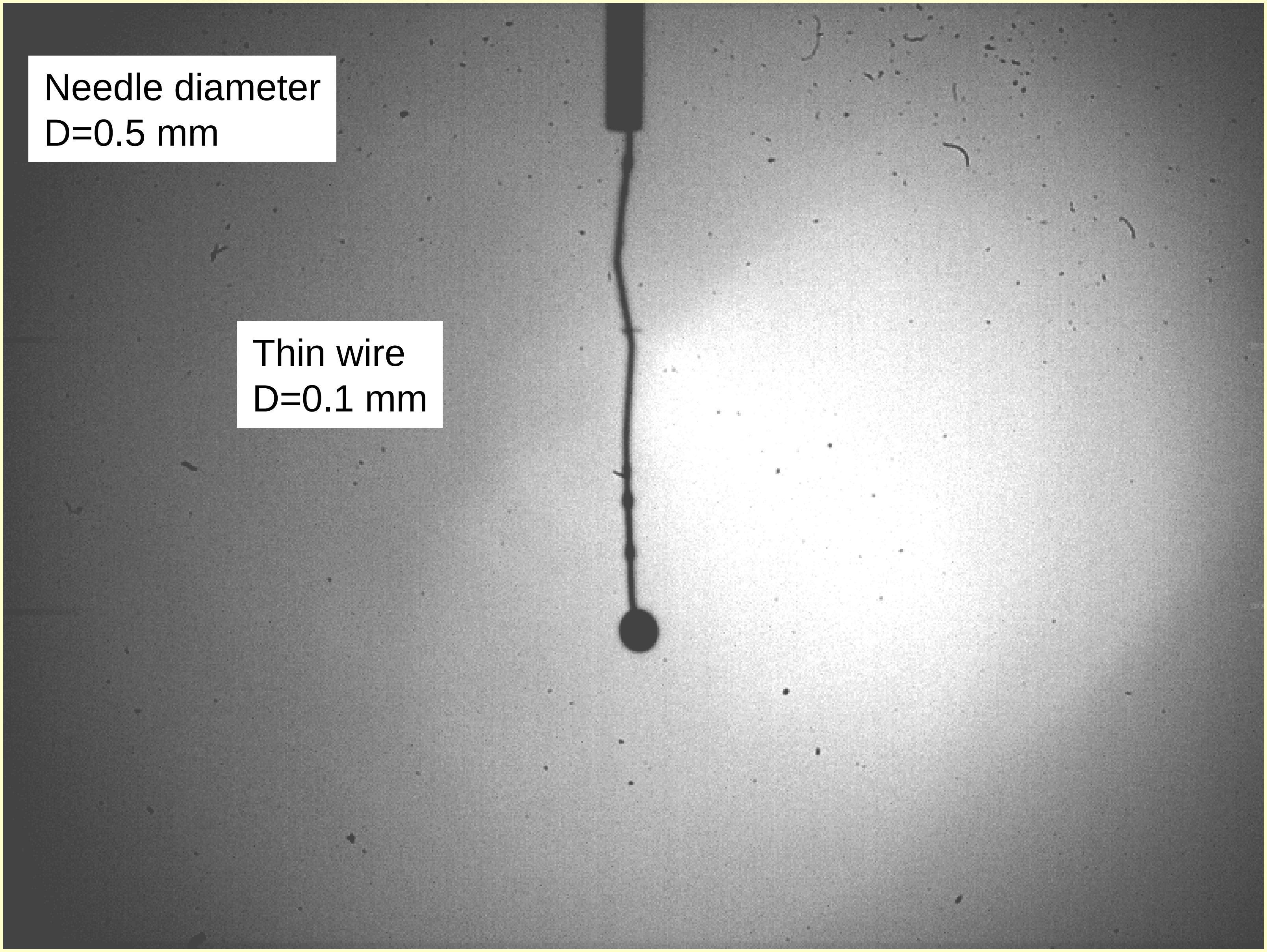
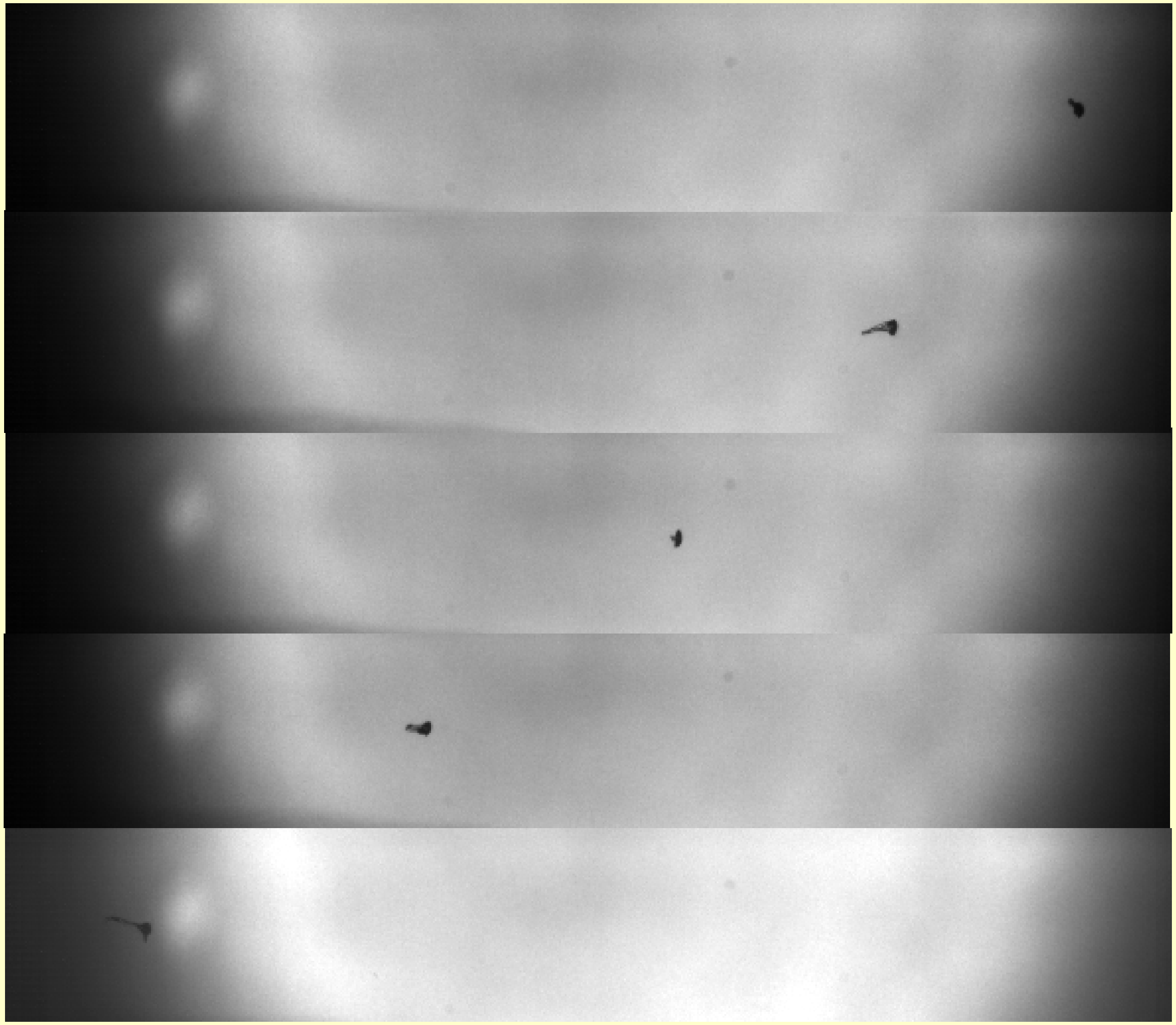
Drop Generator – Polymer Drop

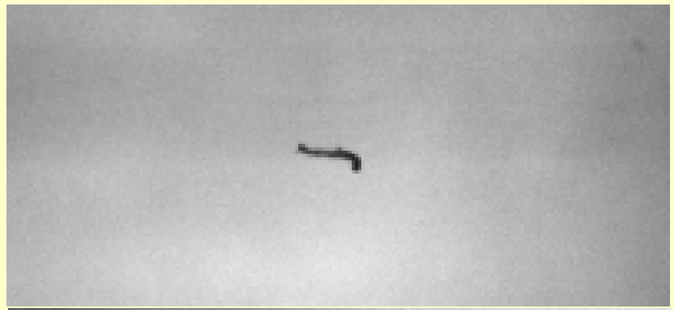


Polymer drop at We_0 = 4500

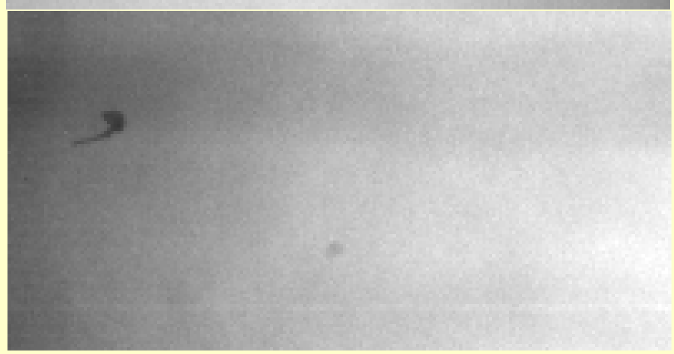


d=0.6 mm, Drop velocity V=200 m/s

Polymer drop at We_0= 4100 , 153mm Downstream



t = 1.175 ms



t = 1.254 ms

d=0.5 mm, Drop velocity V = 335 m/s,

We = 0.21 We_0

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Delta-formulation

Transition from one fluid to another

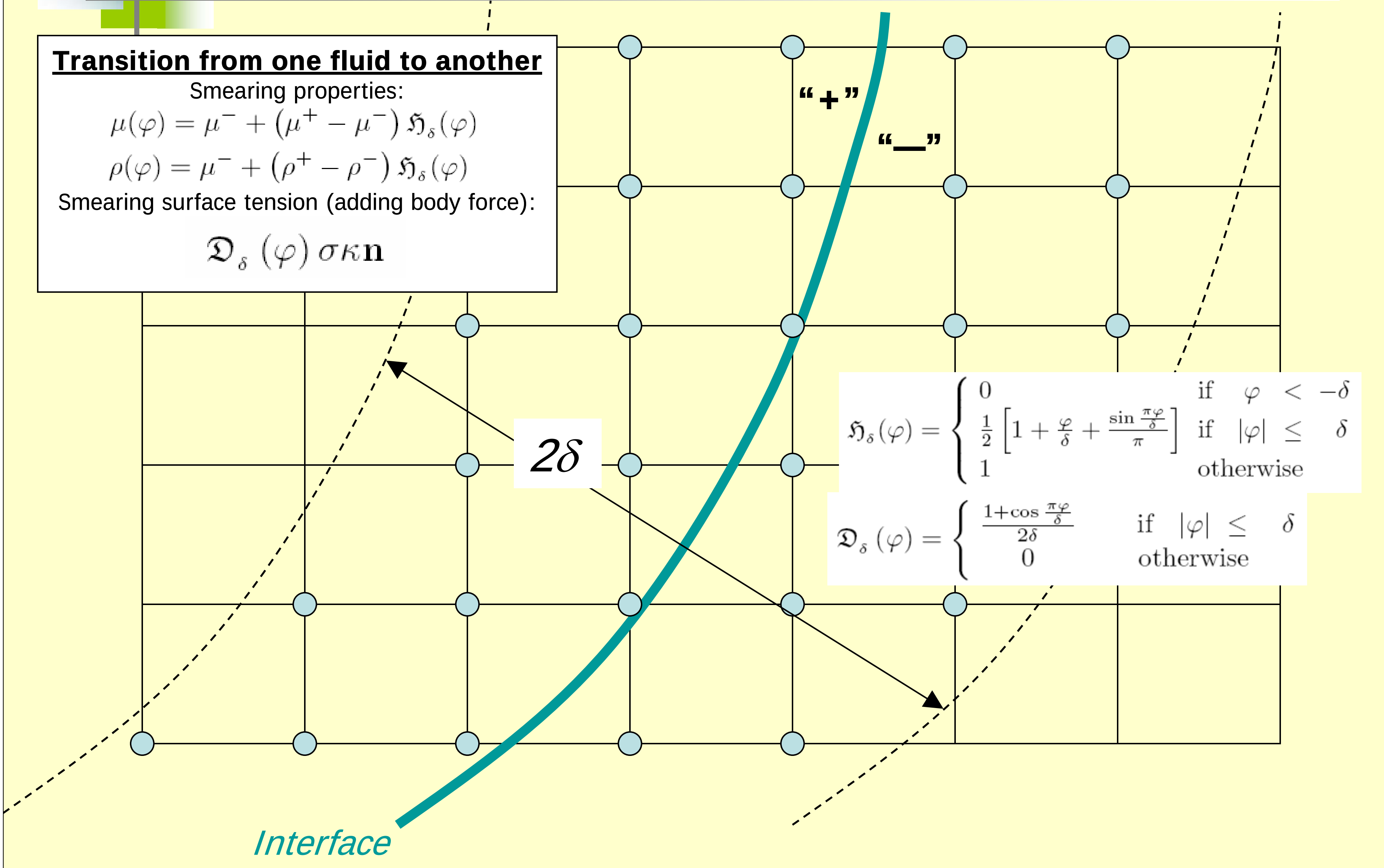
Smearing properties:

$$\mu(\varphi) = \mu^- + \left(\mu^+ - \mu^-\right) \mathfrak{H}_\delta(\varphi)$$

$$\rho(\varphi) = \mu^- + \left(\rho^+ - \rho^-\right) \mathfrak{H}_\delta(\varphi)$$

Smearing surface tension (adding body force):

$$\mathfrak{D}_\delta\left(\varphi\right) \sigma \kappa \mathbf{n}$$



$$\mathfrak{H}_\delta(\varphi) = \begin{cases} 0 & \text{if} \quad \varphi < -\delta \\ \frac{1}{2}\left[1 + \frac{\varphi}{\delta} + \frac{\sin\frac{\pi\varphi}{\delta}}{\pi}\right] & \text{if} \quad |\varphi| \leq \delta \\ 1 & \text{otherwise} \end{cases}$$

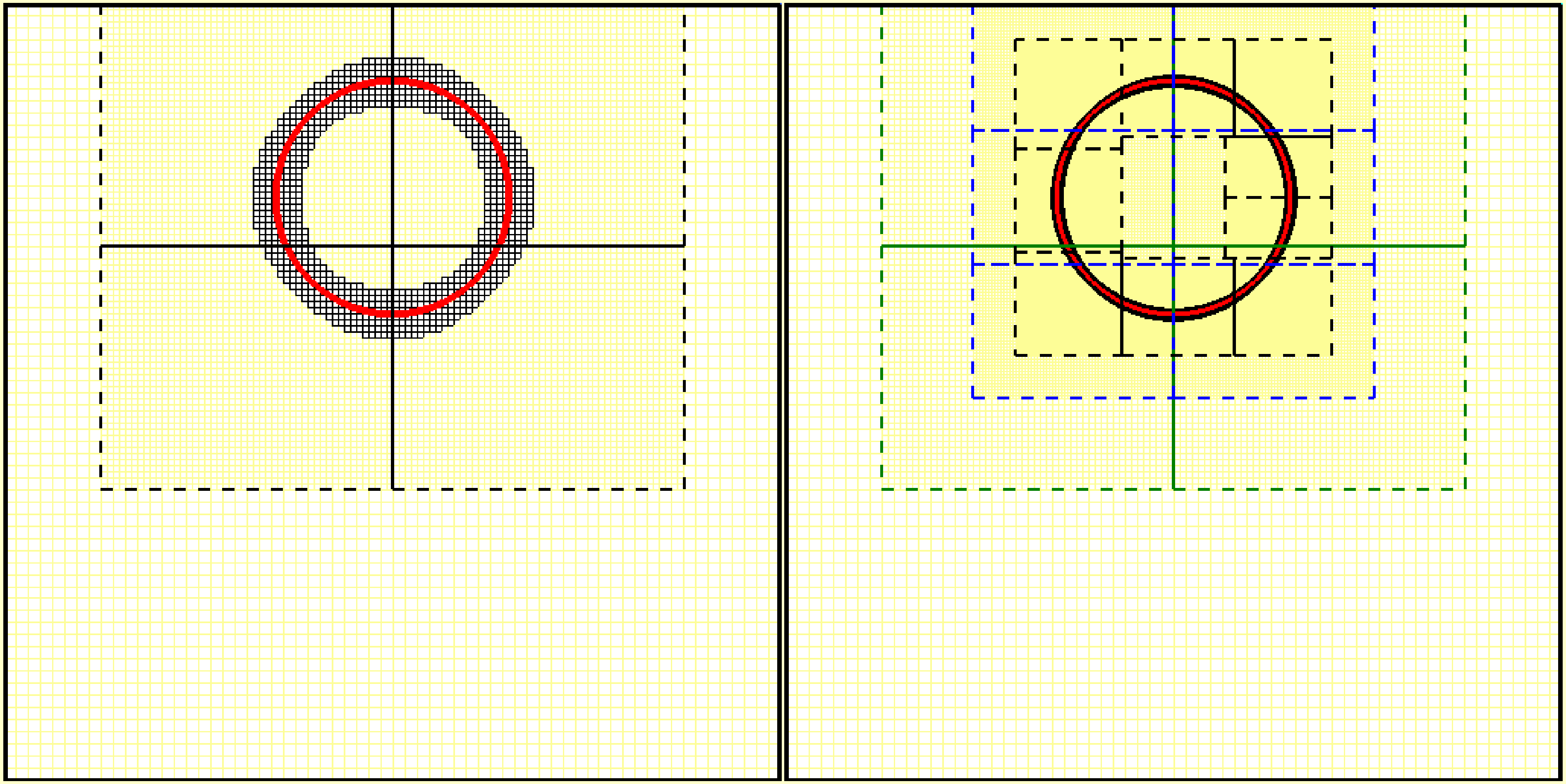
$$\mathfrak{D}_\delta\left(\varphi\right) = \begin{cases} \frac{1+\cos\frac{\pi\varphi}{\delta}}{2\delta} & \text{if} \quad |\varphi| \leq \delta \\ 0 & \text{otherwise} \end{cases}$$

I. aC^3MR

Single Vortex

2 AMR levels: 128^2

4 AMR levels: 512^2 (8 processors)

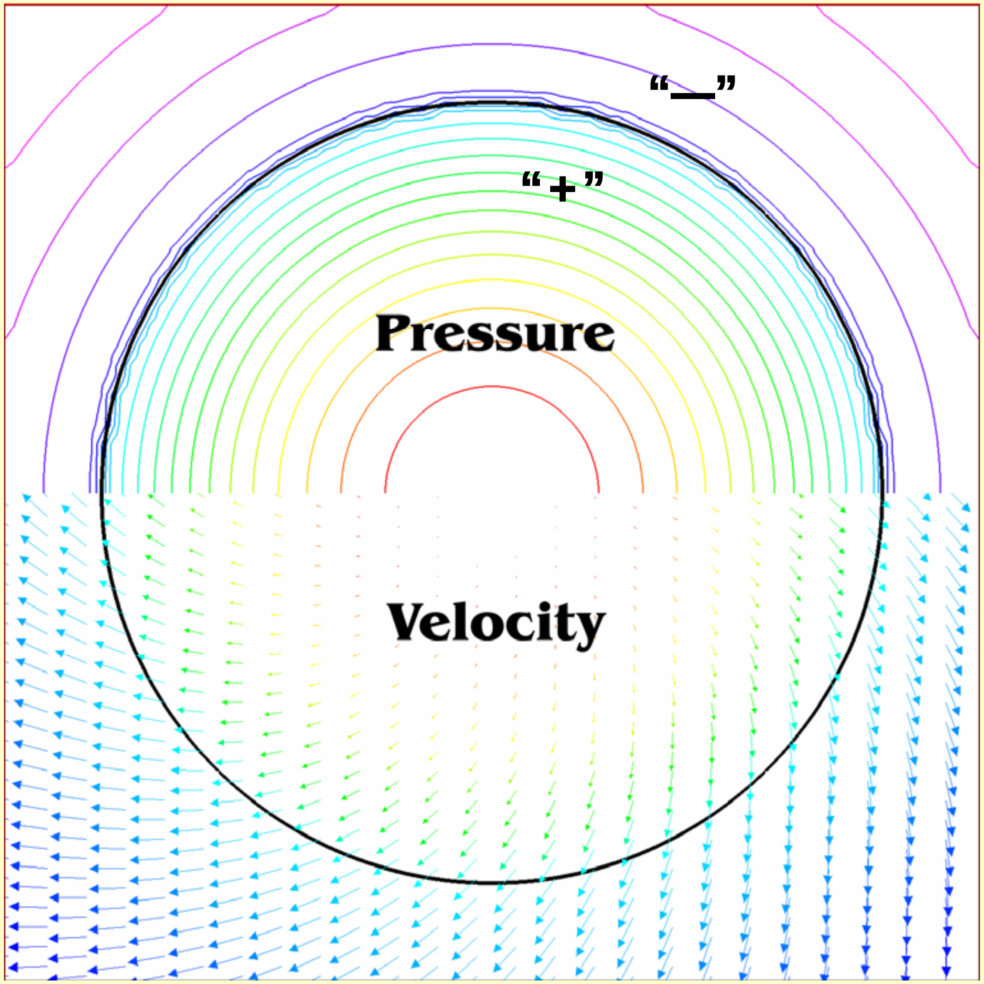


High-resolution simulations

ac³MR

V. Sharp Reconstruction (SR) of interface jump conditions

Grid convergence test



Exact solution:

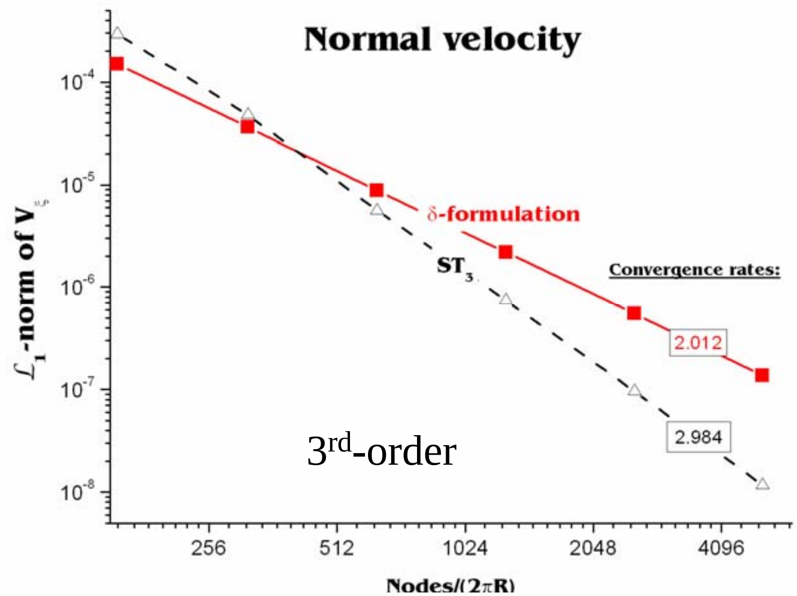
$$
\begin{aligned}
P^{+}(r) &= P_{0} + \left(P_{I}^{+} - P_{0}\right)\left(\tfrac{r}{R}\right)^{2} \\
V_{\xi}^{+}(r) &= V_{\xi_I}\left(\tfrac{r}{R}\right)^{2} \\
V_{\eta}^{+}(r) &= V_{\eta_I}\left(\tfrac{r}{R}\right)^{3}
\end{aligned}
$$

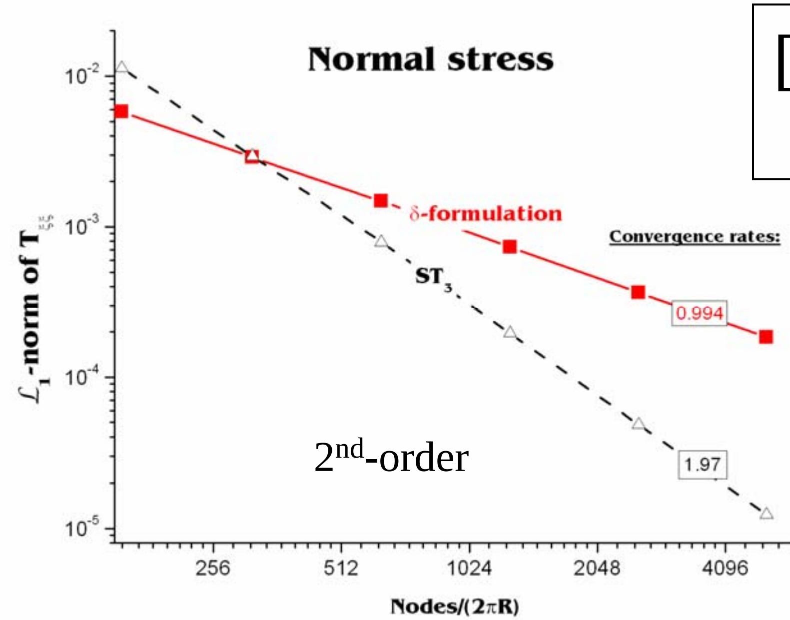
$$
\begin{aligned}
P^{-}(r) &= P_{I}^{-}\tfrac{R}{r} \\
V_{\xi}^{-}(r) &= V_{\xi_I}\left(1 - 2\langle\mu\rangle\tfrac{r}{R}\left(1-\tfrac{r}{R}\right)\right) \\
V_{\eta}^{-}(r) &= V_{\eta_I}\left(1 - 3\langle\mu\rangle\left(1-\tfrac{r}{R}\right)\right)
\end{aligned}
$$

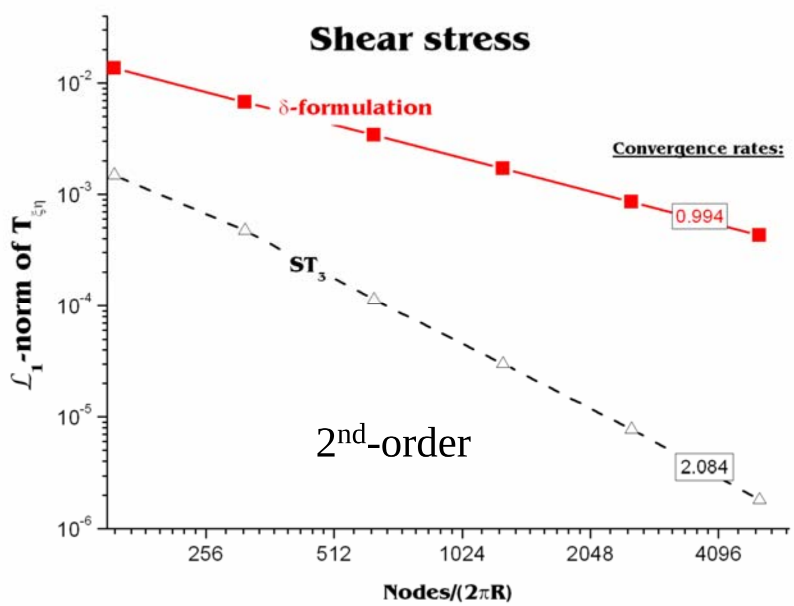
where $P_{0} = 20,\ P_{I}^{+} = 10,\ P_{I}^{-} = P_{I}^{+} - \frac{\sigma}{R},\ \sigma = 1,\ V_{\xi_I} = 1,\ V_{\eta_I} = 1$

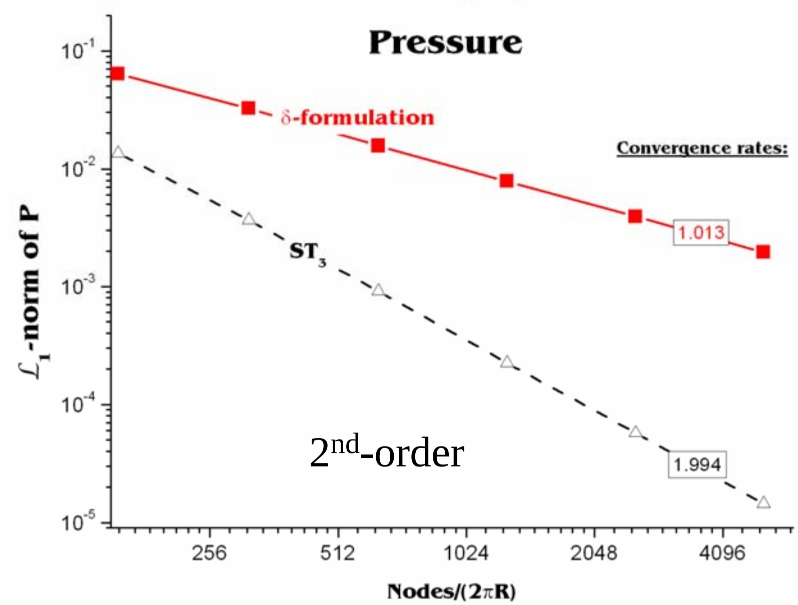
Grid convergence test

$[\mu] = 0$
$\sigma = 0$



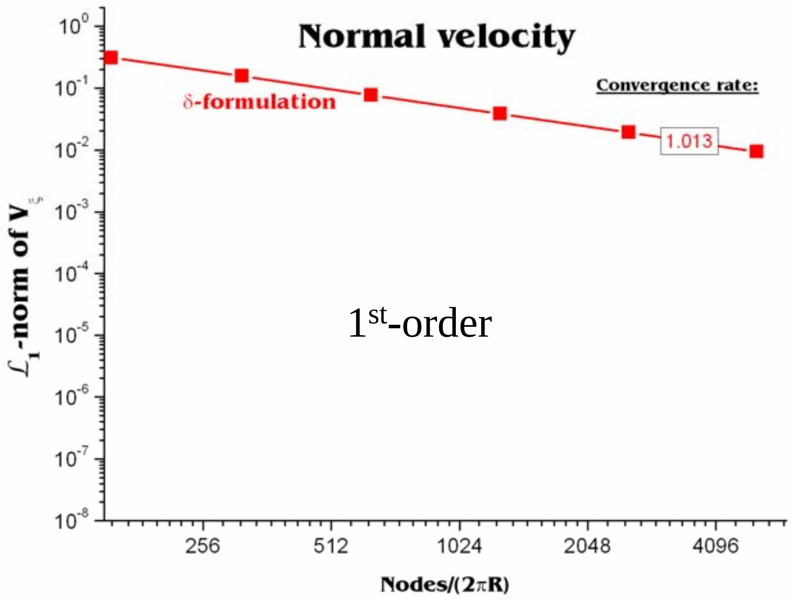


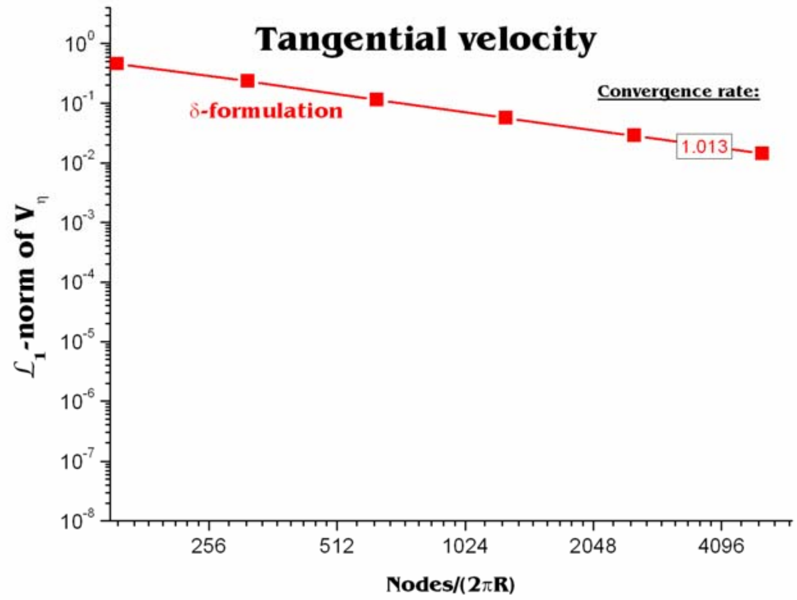


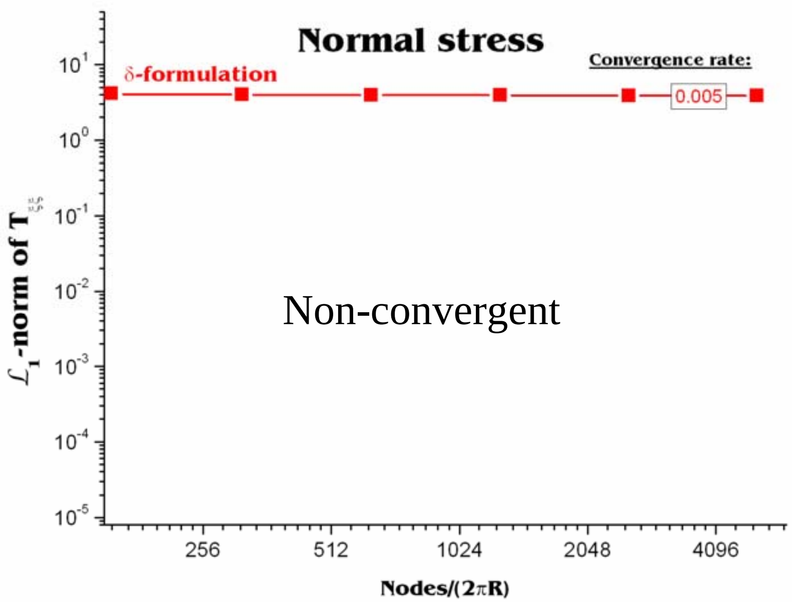


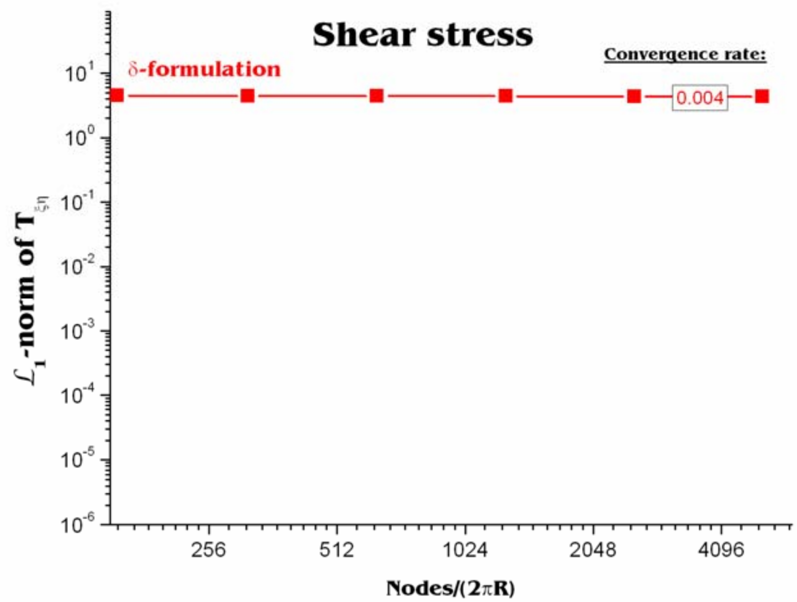
Grid convergence test

$\langle \mu \rangle = 25$
$\sigma = 1$









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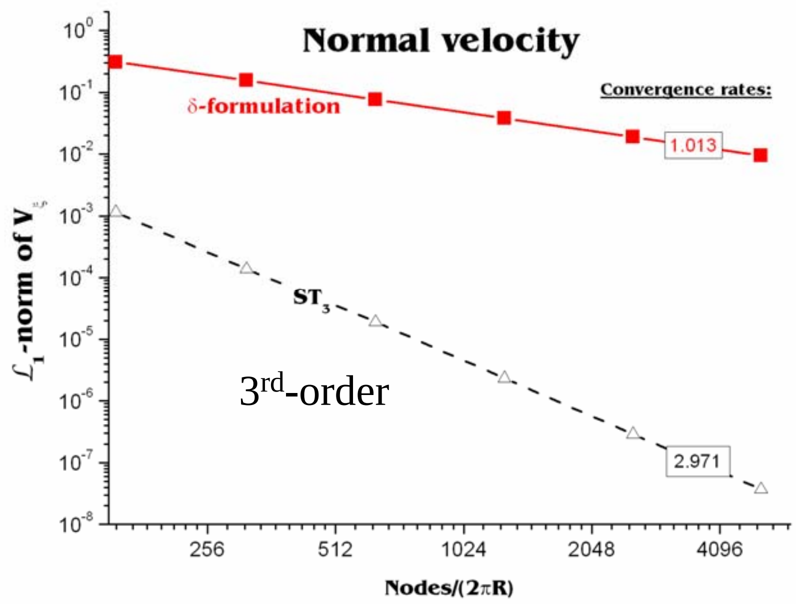
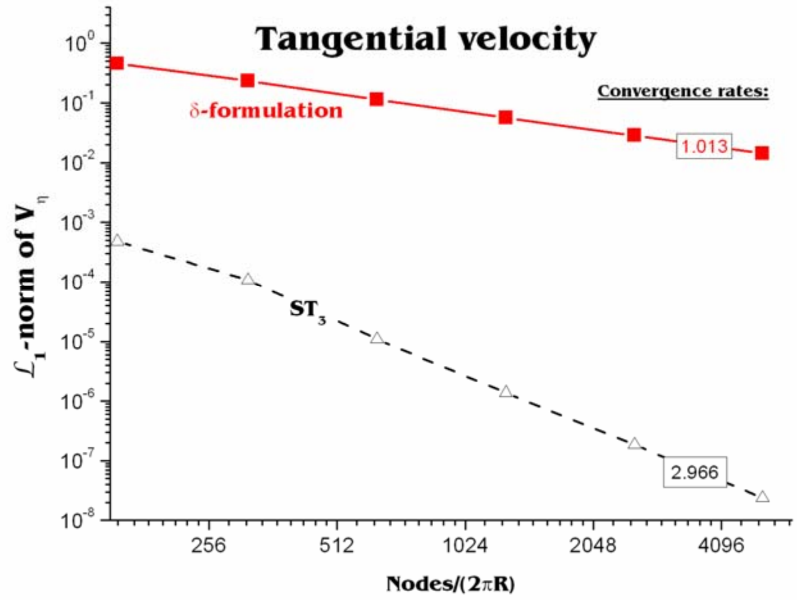
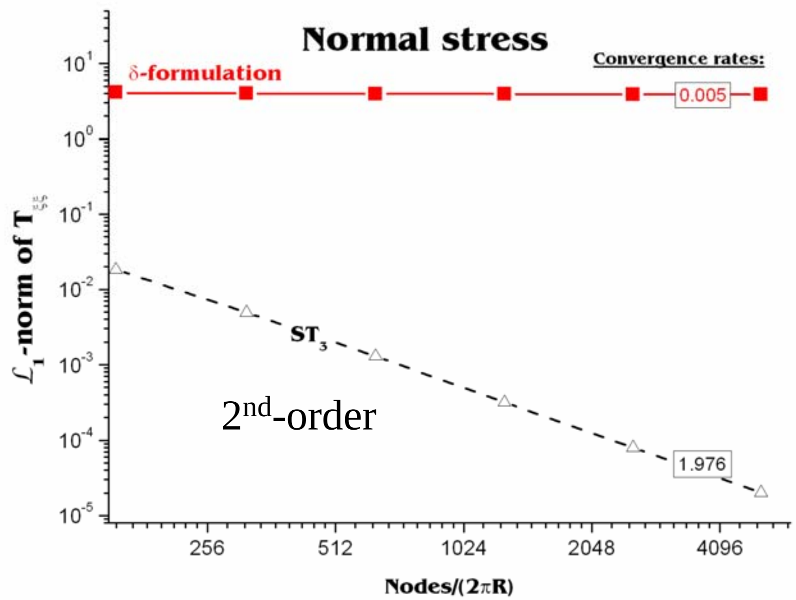
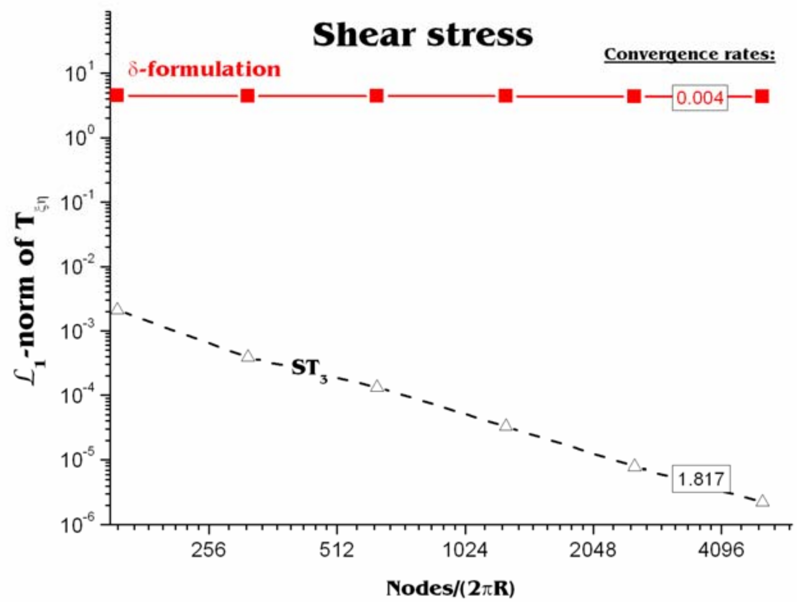
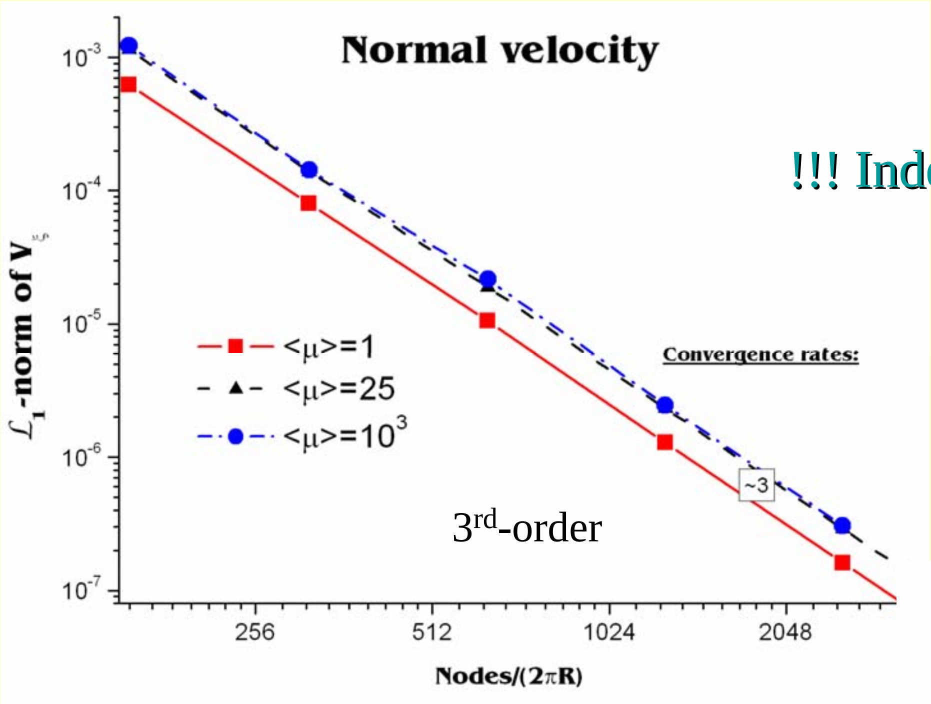




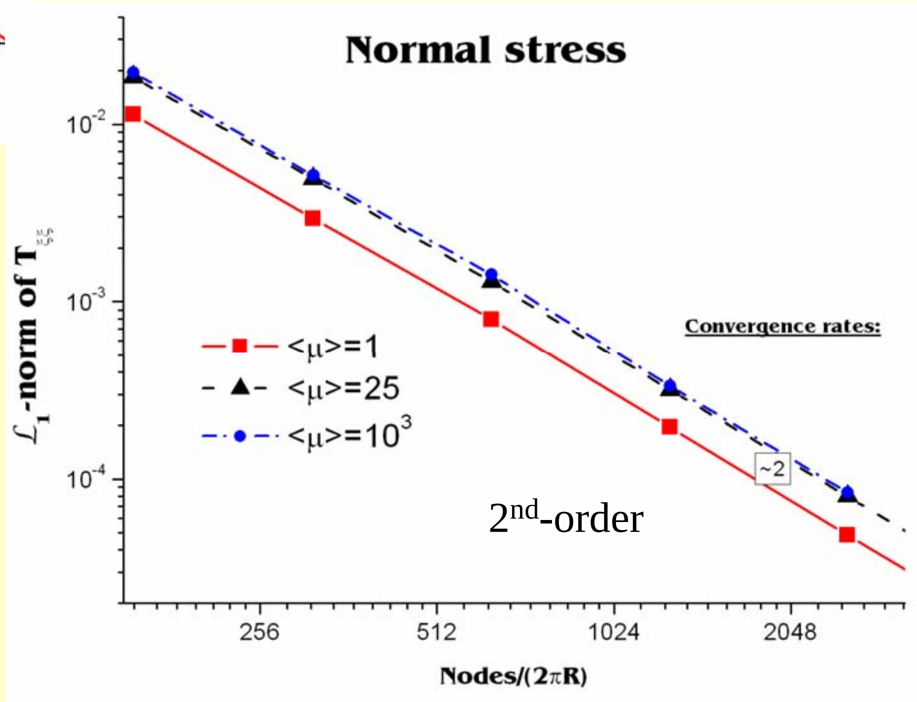




Grid convergence test



!!! Independent of viscosity ratio !!!



Major Results

- On Data Base development we have proven all aspects of the experimental technique and begun Production Runs (well ahead of schedule),
- We have shown experimentally that VE drops can survive intact at We~ 4,000! Or $1/2\rho v^2 = 2\ 10^5$!
- We developed a theoretical understanding of the mechanisms for Newtonian/Viscous liquid breakup over the whole range of regimes, unified all data, and corrected major, long-standing misconceptions,
- On DNS we achieved the sharp treatment of interfaces, and established capability to compute instabilities on shocked, high acoustic impedance mismatch interfaces.