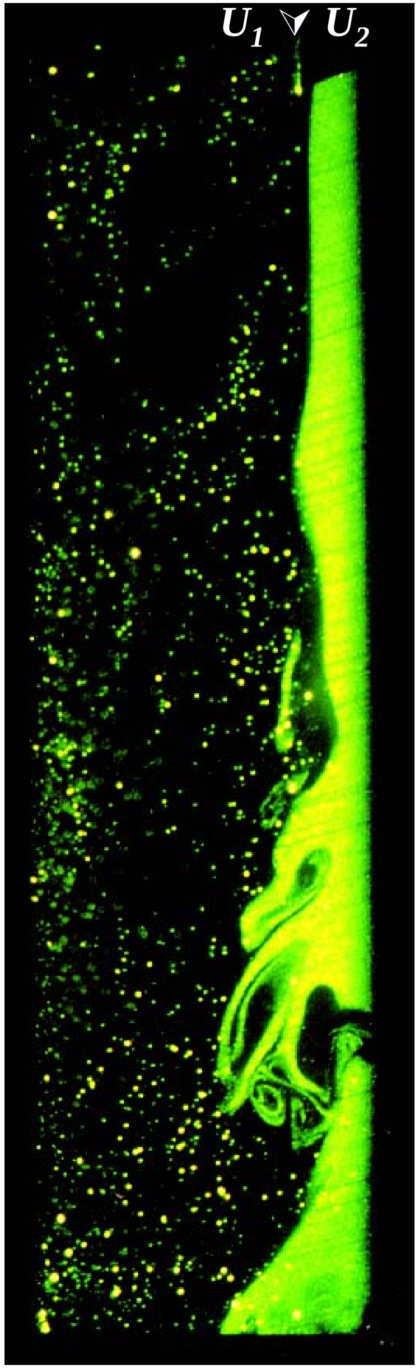

VON KÁRMÁN INSTITUTE FOR FLUID DYNAMICS
Environmental and Applied Fluid Dynamics Department

Final Public Presentation on 26th/06/2000

Experimental Investigation on Turbulence Modification by Particles in Shear Layer Flow Using L-6 Twin-Jet Wind Tunnel

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VKI-DC 1999/2000

supervisor: Prof. J-M. BUCHLIN
advisor: L. ZIMMER

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Contents

- **Introduction**, **Background**, **Objectives**
- **Upgrade of the Experimental Apparatus** /L-6 wind tunnel + spray/
- **Various Applied Measurement Techniques**
  - for single-phase flow /Prandtl tube, Heated Sphere Probe, PIV, PTVS/
  - for two-phase flow → particulate phase /PDA/
    → carrier gas phase /PTVS/
- **Typical Results**
  - Flow Visualization
  - Single-phase and two-phase flow measurements
- **Physical Modeling of Turbulence Modification**
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Introduction

- **Industrial importance** of two-phase flows /polydispersed particulate phase/
- **Weak point** is the modeling of *particle - turbulence interaction*
- **Lack** of *physical models*, **lack** of *experimental data*
- **"New" measurement techniques** - to obtain detailed *information on both phases* in particle laden flows

Background at VKI

- **Design** of L-6 wind tunnel for mixing layer study by [Borrego, 1981]
- **Particle Tracking Velocimetry and Sizing** /PTVS/ by [Zimmer, 1998]
- **Direct Numerical Simulation** /DNS/ by P. Rambaud

Objectives

⌘ **Set-Up an Experimental Apparatus** for Two-Phase Flow

⌘ **Perform Measurements** in Single-Phase and Two-Phase Flow to *characterize* the flow field of the *particulate phase* and the *carrier phase*

⌘ **Extract the Information** about the Carrier Gas Flow Turbulence Field

⌘ **Qualify the T.I. Modification** by the Analysis of the Results

⌘ **Contribute to Physical Modeling** of Turbulence Modification by Particles

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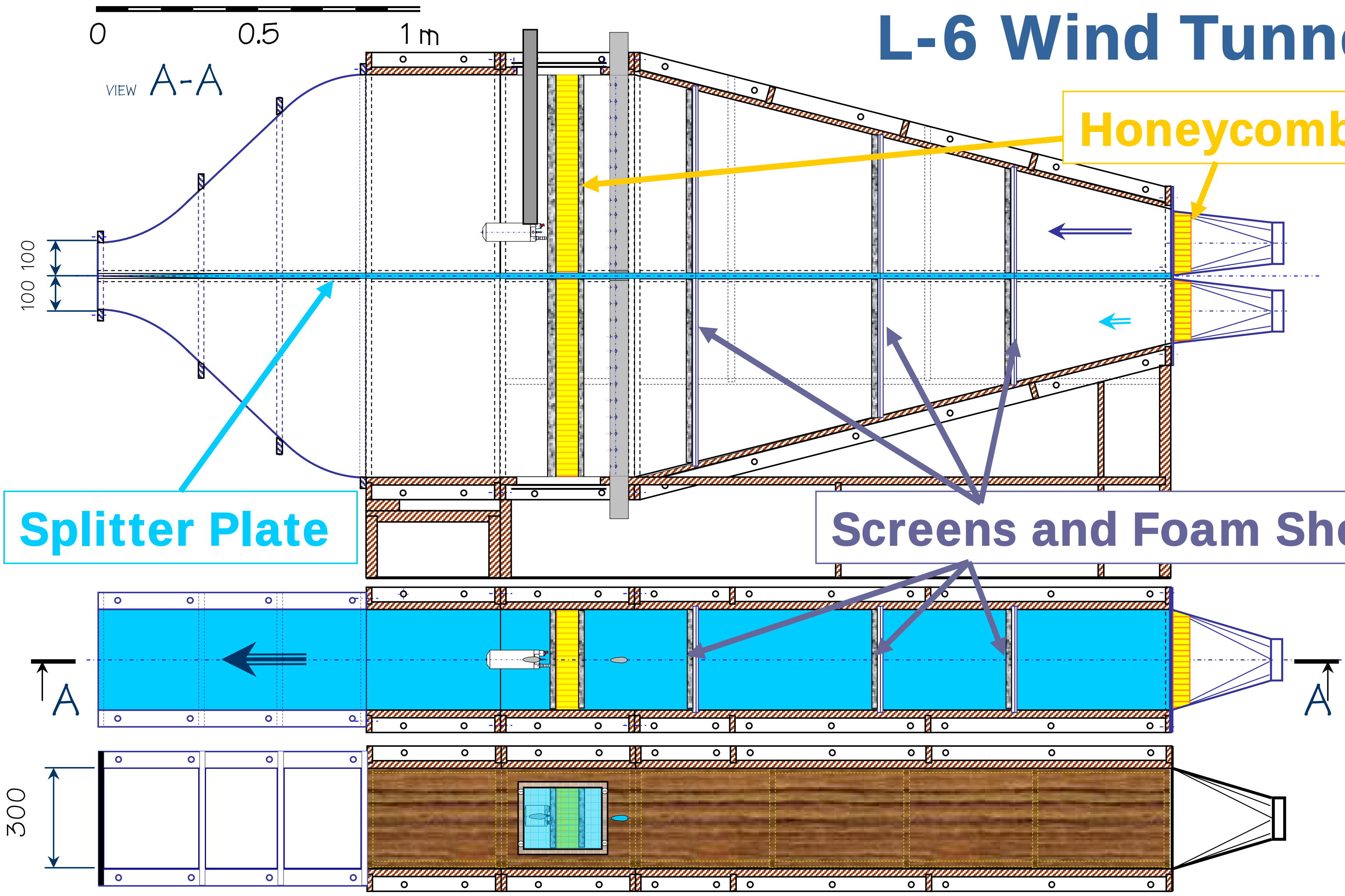
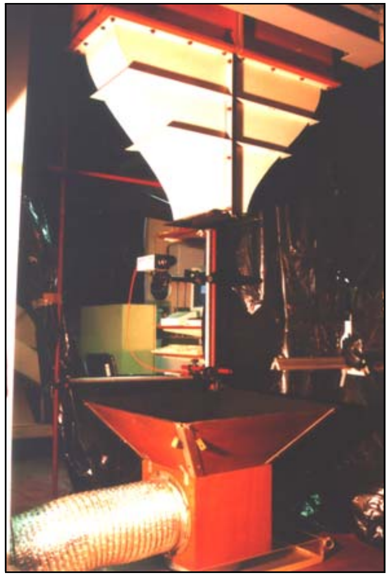
L-6 Wind Tunnel

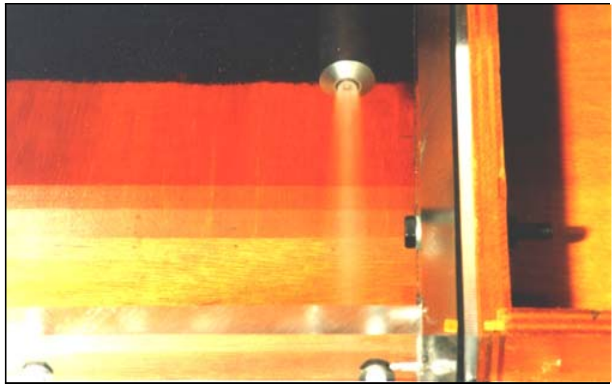


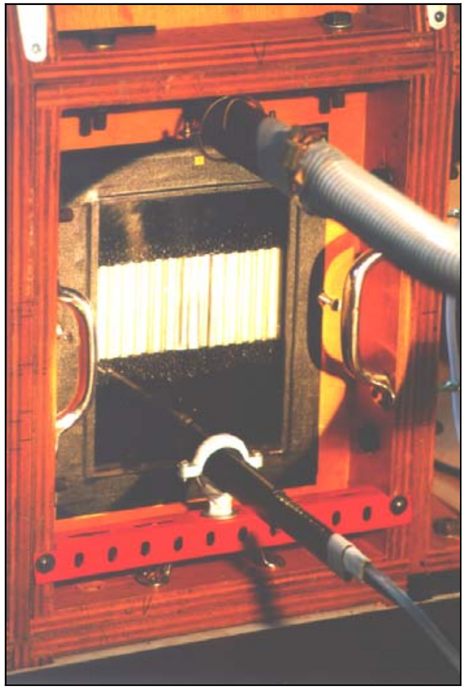
L-6 Wind Tunnel

Vertical Arrangement
Downward Twin-Jet Flow

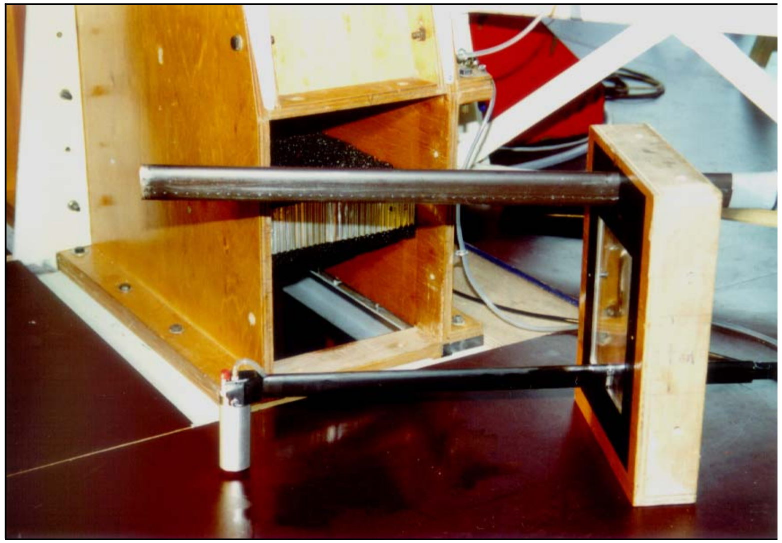
Twin-Jet Nozzle
1/6 Contraction Ratio

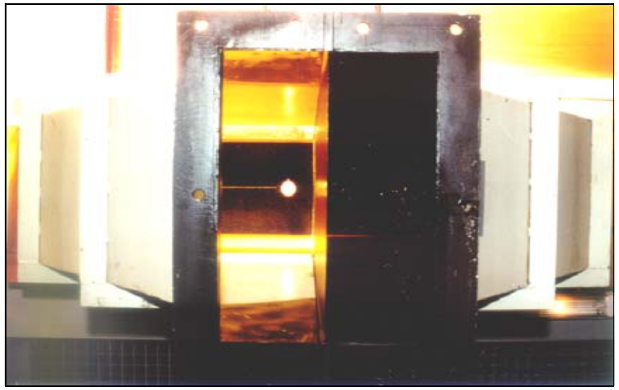


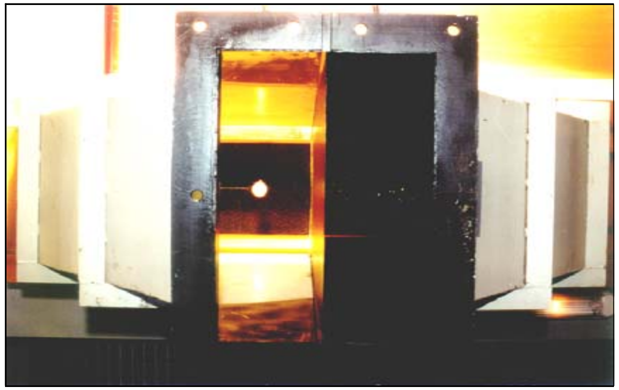




L-6 wind tunnel
upgrade and **supplementation** with **spray facility** and **smoke injection & suction units**





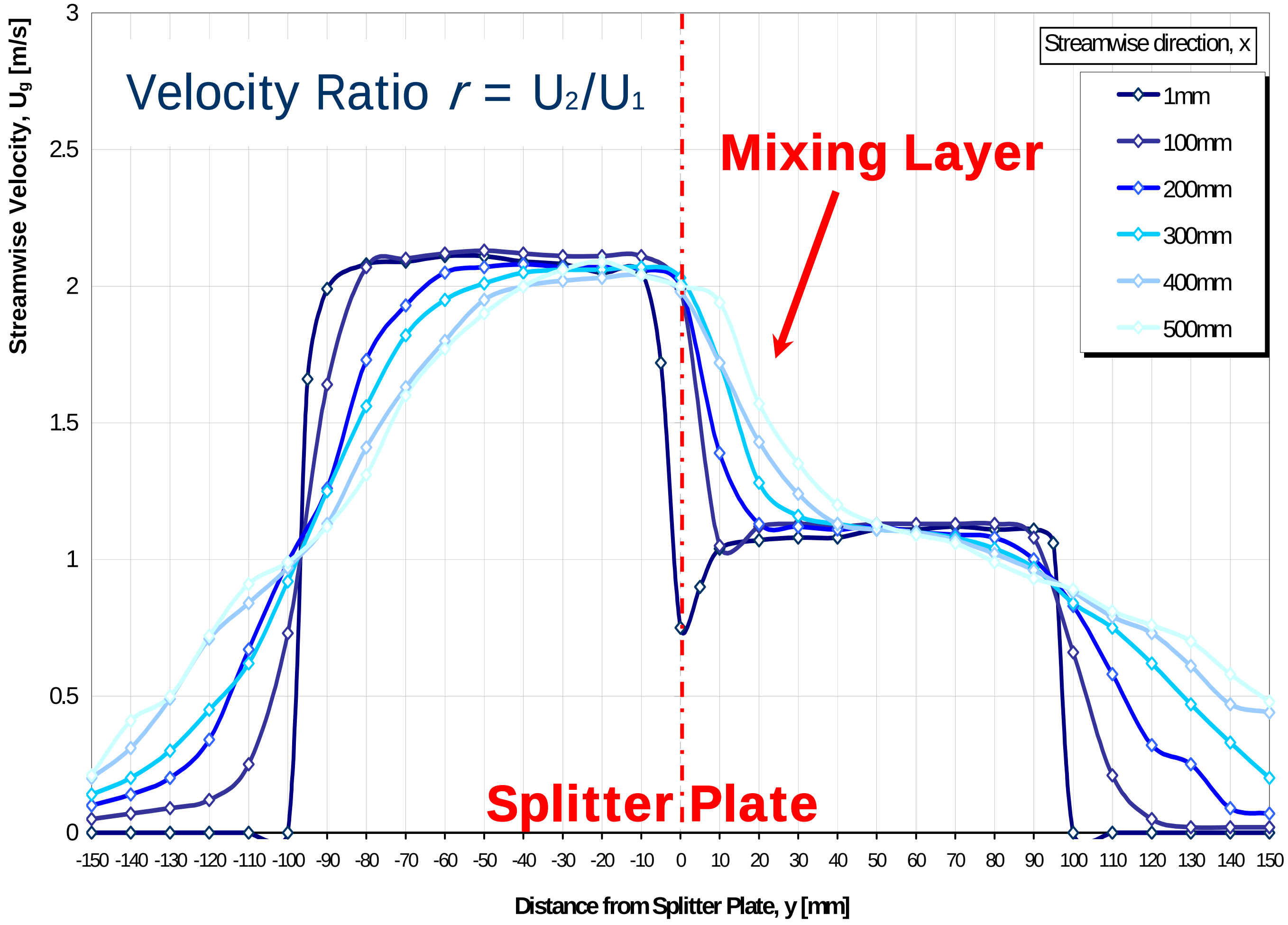


Velocity Profile Measurements with Heated Sphere Probe

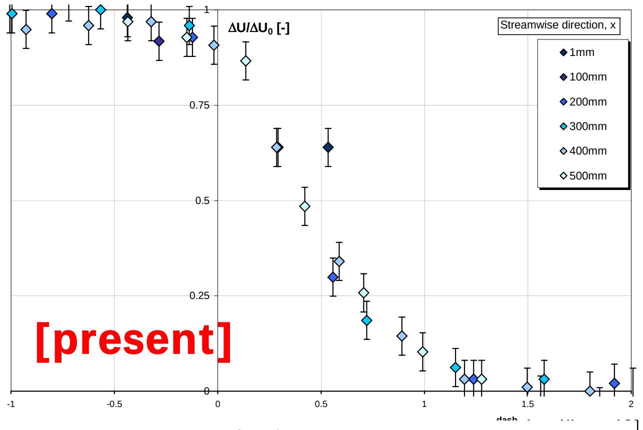
Single Phase Flow

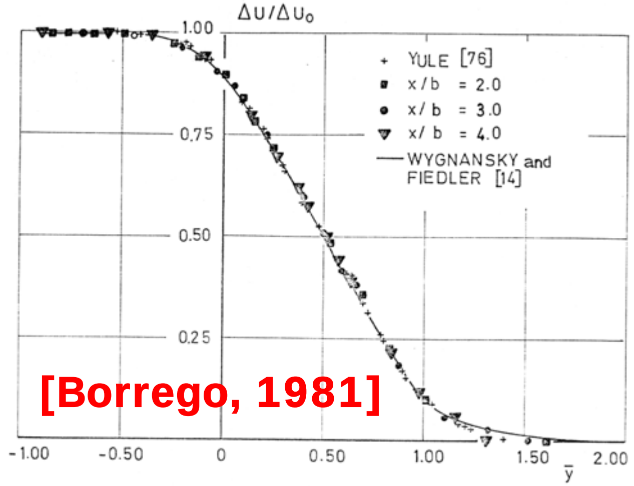
Velocity Profiles of Single Gas Phase

/ U_1=2m/s, U_2=1m/s, λ=0.33, Tetsoterm control measurements Test4 /



Non-dimensional Plot





Measurement Techniques

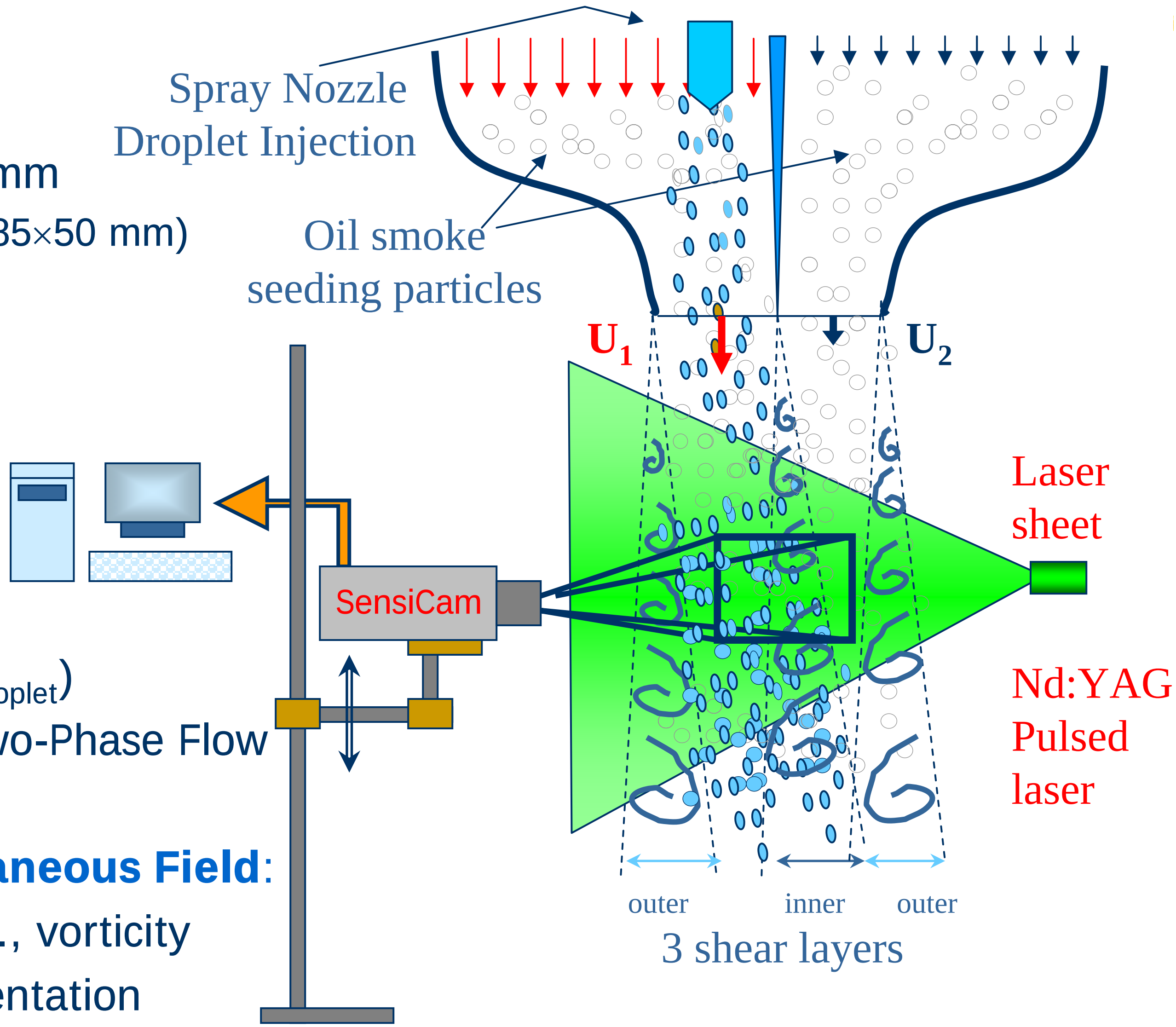
PARTICLE IMAGING VELOCIMETRY

PIV /single-phase flow/

- new PCO camera + NIKKOR 35mm
  - Image size: 1280×768 pixel (≈ 85×50 mm)
- Nd:YAG pulsed laser /6W/
  - f_s=10Hz
- Calibration Table [pixel/mm]
- Positioning system
- SensiCam acquisition software

PTVS /two-phase flow/

- Size Discriminating ($d_{seeding}$ « $d_{droplet}$)
- Gas Phase Flow Field Data in Two-Phase Flow



Post-processing of the Instantaneous Field:

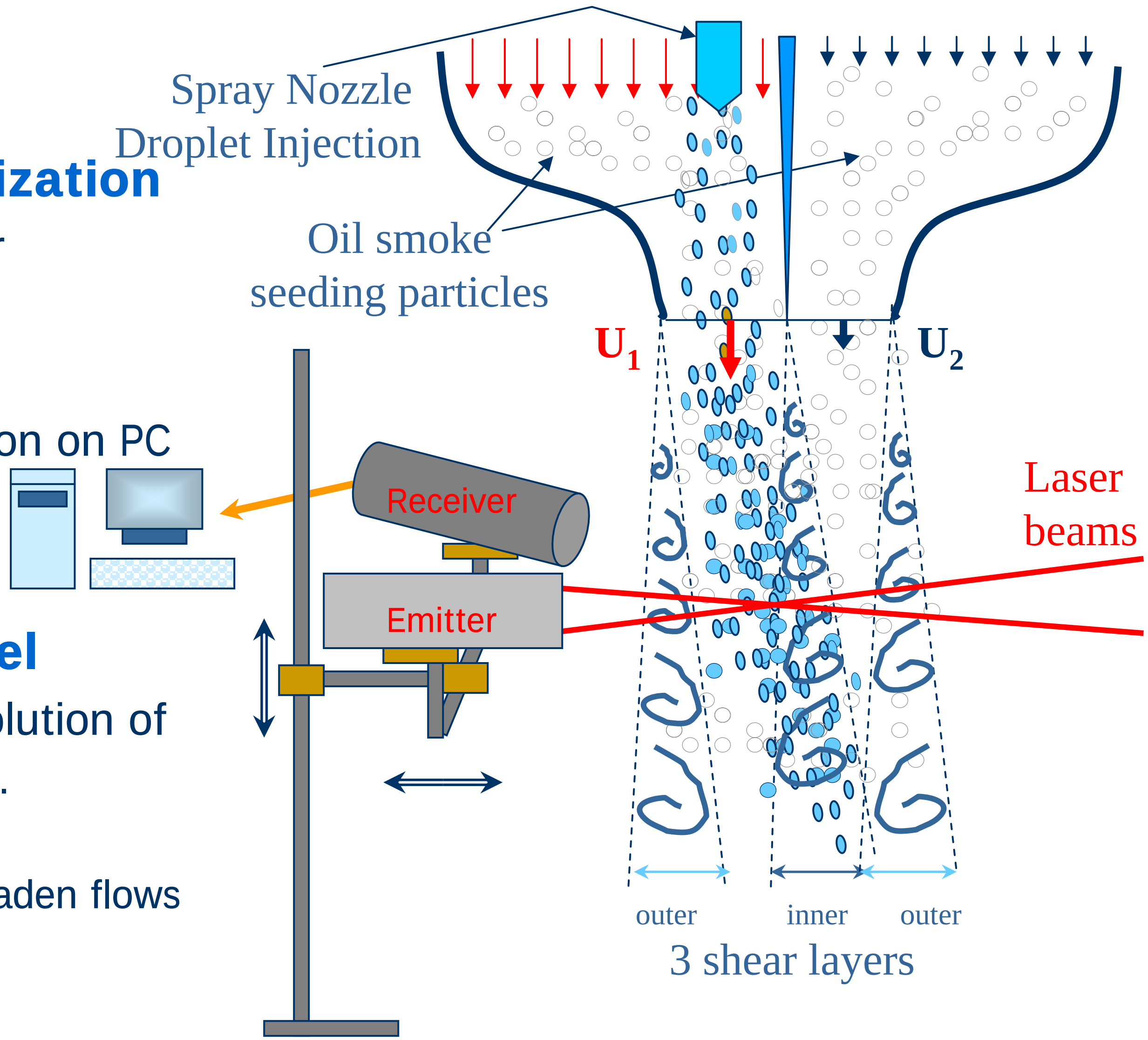
- Matlab for mean, u',v', RMS, T.I., vorticity
- TecPlot for calibration and presentation

PHASE DOPPLER ANEMOMETRY

Measurement Techniques

Particulate Phase Characterization

⌘ PDA Emitter: 15mW He-Ne laser
⌘ Positioning System for PDA
⌘ [mm] Positioning Table
⌘ Aerometrics PDPA data acquisition on PC



Data Post-Processing in Excel

⌘ Streamwise and Transversal evolution of
- droplet mean velocity, RMS, T.I.
- d_p droplet diameter distribution
- α_p volume ratio of liquid-air in laden flows

Turbulence Modification

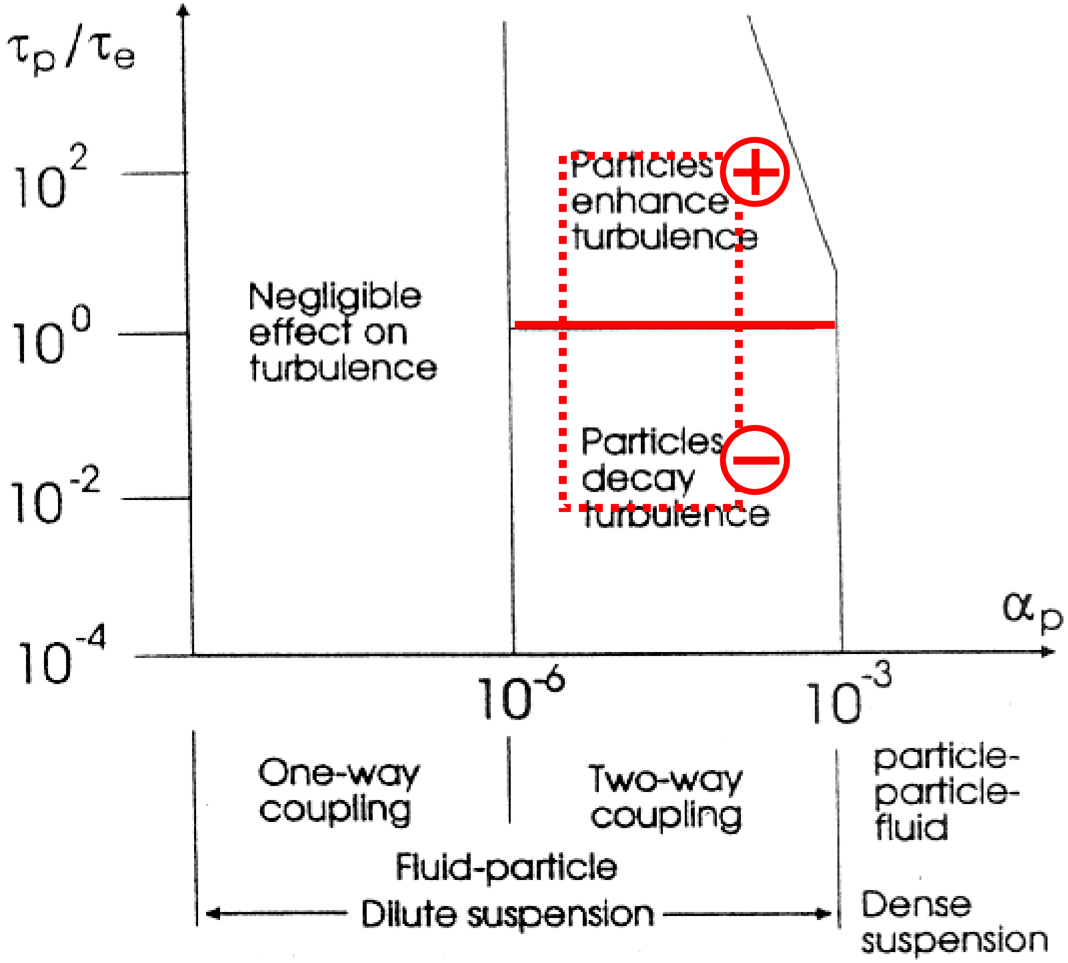
? QUESTION ?

Which Droplet (d_p) is Responsible for Turbulence Attenuation / Augmentation?

	DROPLET	**AIR**	RATIO
characteristic length scale:	d_p	l_e	d_p / l_e
characteristic time scale:	$\tau_p = \rho d^2 / 18\mu$	$\tau_e = 2\, l_e / \Delta U$	St_p

[Elghobashi, 1994]

Turbulence Modulation Map



$\alpha_p = 10^{-4} \div 10^{-5}$ $St_p = 10^{-2} \div 10^2$

Effect of **characteristic time scale ratio** on turbulence modification:

Map for particle-turbulence modulation ("*rough guide*")

Stokes number:

$$St_p = \frac{\tau_p}{\tau_e} = f(\alpha_p)$$

$\tau_p = \rho d_p^2 / 18\mu$ particle response time

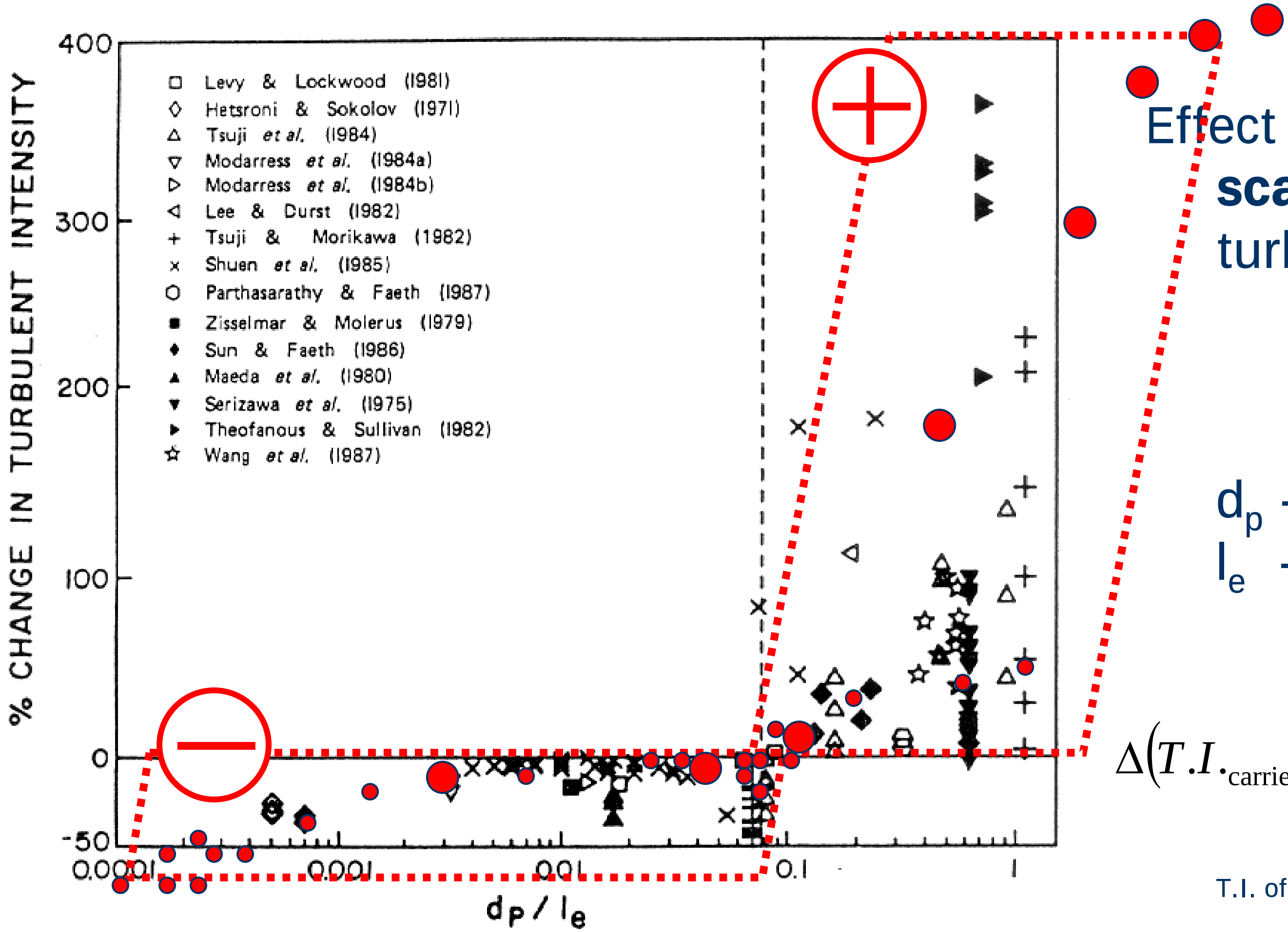
$\tau_e = 2\, l_e / \Delta U$ fluid time scale

α_p : particulate phase volume ratio

graph from [Elghobashi, 1994]
in [Crowe et al., 1996] *in Annu. Rev. Fluid. Mech.* Vol.**28**. pp.11-43.

[Gore and Crowe, 1989]

Turbulence Modulation Map



Effect of **characteristic length scale ratio** on modulating turbulent intensity:

$$\Delta(\text{T.I.}) = f\,(d_p/l_e)$$

d_p - particle diameter

l_e - fluid length scale
(integral length scale or characteristic length of the most energetic eddy)

$$\Delta\left(T.I._{\text{carrier phase}}\right) = \frac{T.I._{\text{two-phase}} - T.I._{\text{single-phase}}}{T.I._{\text{single-phase}}}$$

T.I. of the fluid based on PIV and PTVS velocity meas.

Mixing Layer: ⊖ **negative** rel. change (- 90%)

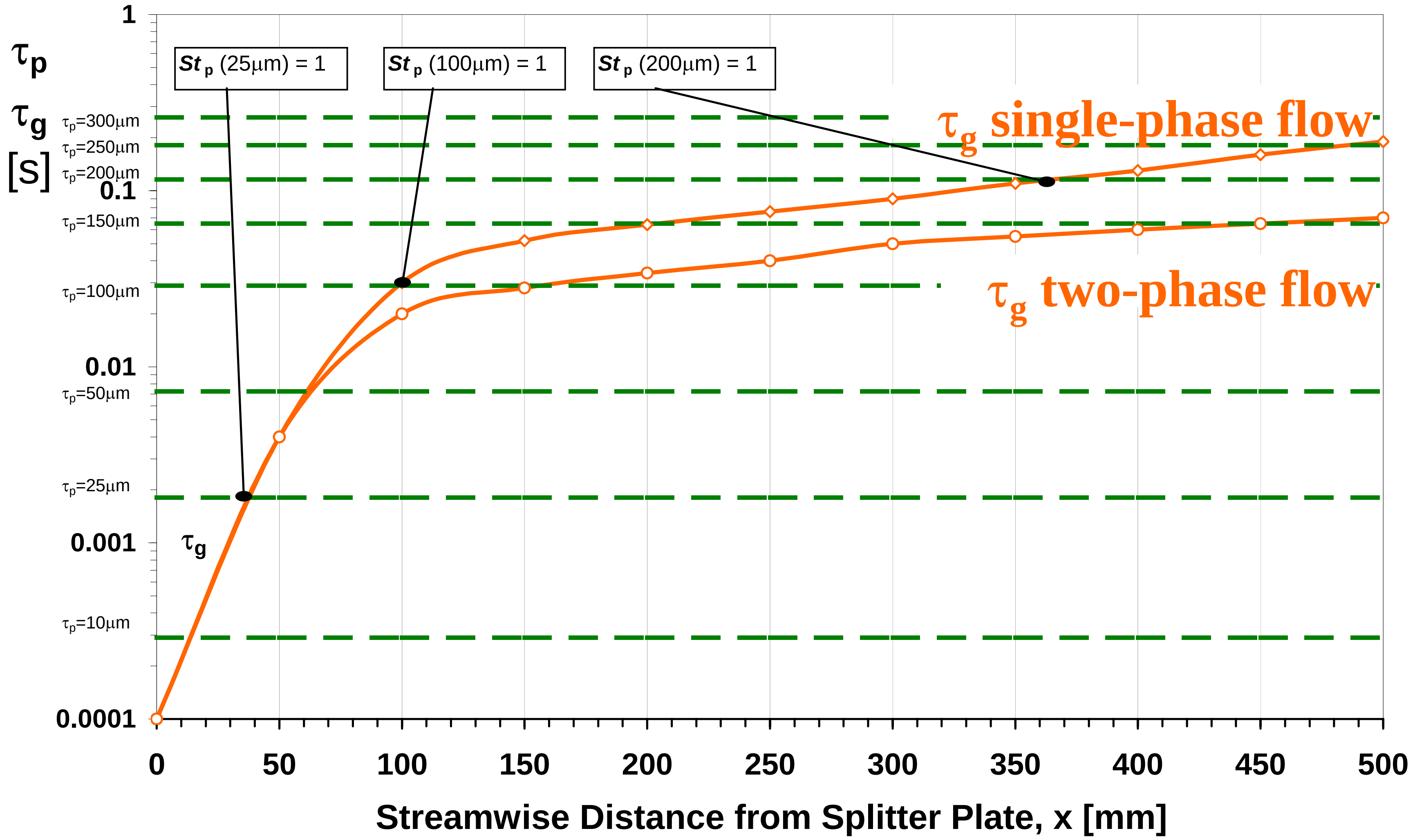
Main Flow: ⊕ **positive** rel. change (+1500%)

graph from [Gore and Crowe, 1989]
in Int. J. Multiphase Flow Vol.**15**. No.2, pp.279-285.

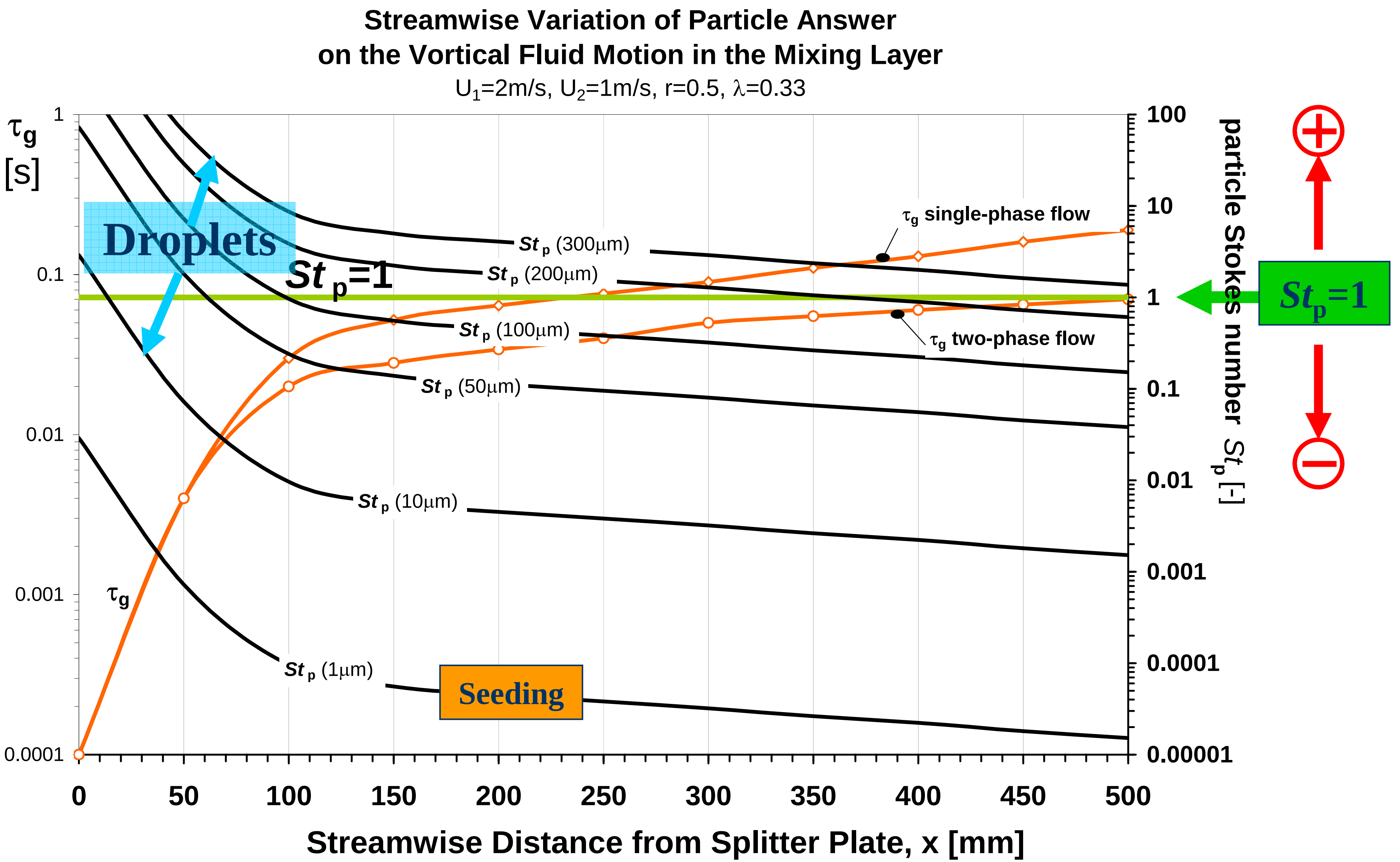
Physical Modeling

Streamwise Variation of Characteristic Time Scales in the Mixing Layer Flow

U_1=2m/s, U_2=1m/s, r=0.5, λ=0.33



Physical Modeling



Future Recommendations

- **100 instantaneous image** are **not sufficient enough** for clear statistics, but it is still limited by the available computational **memory** (Gbytes!)
- Importance of **both** characteristic **scale ratios**:
  - **time scales**: τ_g fluid, τ_p particle, (St_p Stokes number)
  - **length scales**: d_p , l_g
- **Avoid** particle **collision**! (e.g. solid particles)
- Highly recommended to use **monodisperse particulate phase** for academic studies
- **Discrimination** of particles based on fluorescence
- Using the **proposed particle Stokes number evolution graph**
- **More precise** positioning system and blower regulator is needed

Conclusion

- **Upgraded experimental apparatus is available** for further two-phase flow study in a mixing layer of twin-stream downward jet flow

- **Combination of various non-intrusive measurement techniques** (PDA, PIV, PTVS) for **Single-Phase** and **Two-Phase** Flow Measurements:
  - three different velocity ratio was examined
  - data processing and comparing results: time consuming!

- **Developing Mixing Layer** Flow and **Polydispersed Particulate Phase Highly Complex** turbulence modification **phenomena!**

- **Experimental results confirmed** the **importance** of **both characteristic** time and length **scale ratios**

- **Contribution** to the **physical modeling** with the proposed **particle Stokes number streamwise evolution** graph

Thank you for your attention!