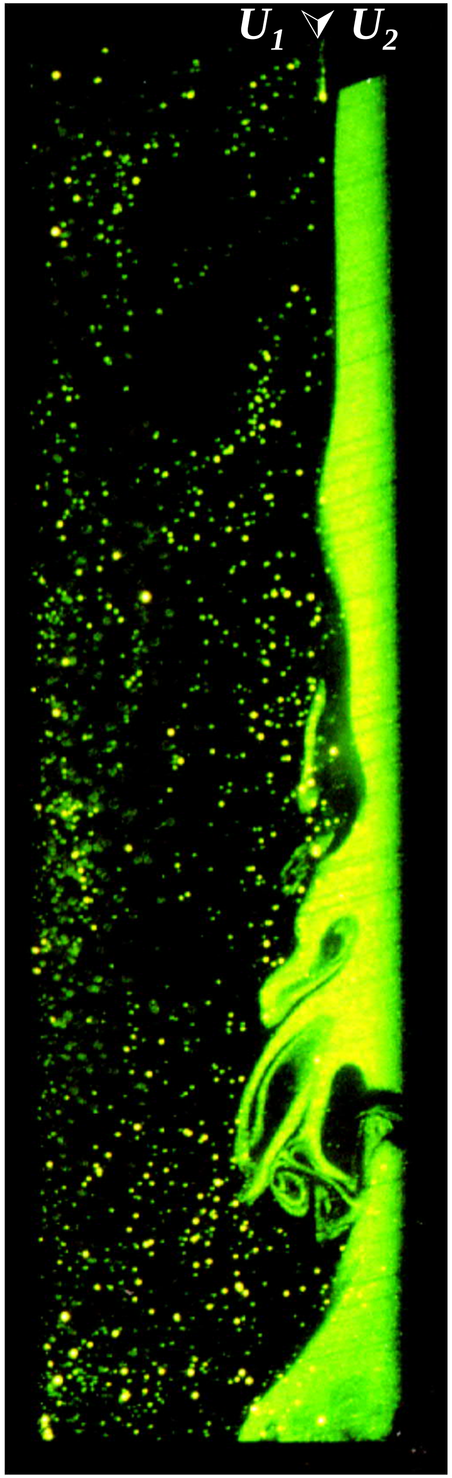

VON KÁRMÁN INSTITUTE FOR FLUID DYNAMICS
Environmental and Applied Fluid Dynamics Department

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
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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
  - Particle - turbulence modulation map, “rough guide” of [Elghobashi, 1994]
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- Future Recommendations
- Conclusions

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

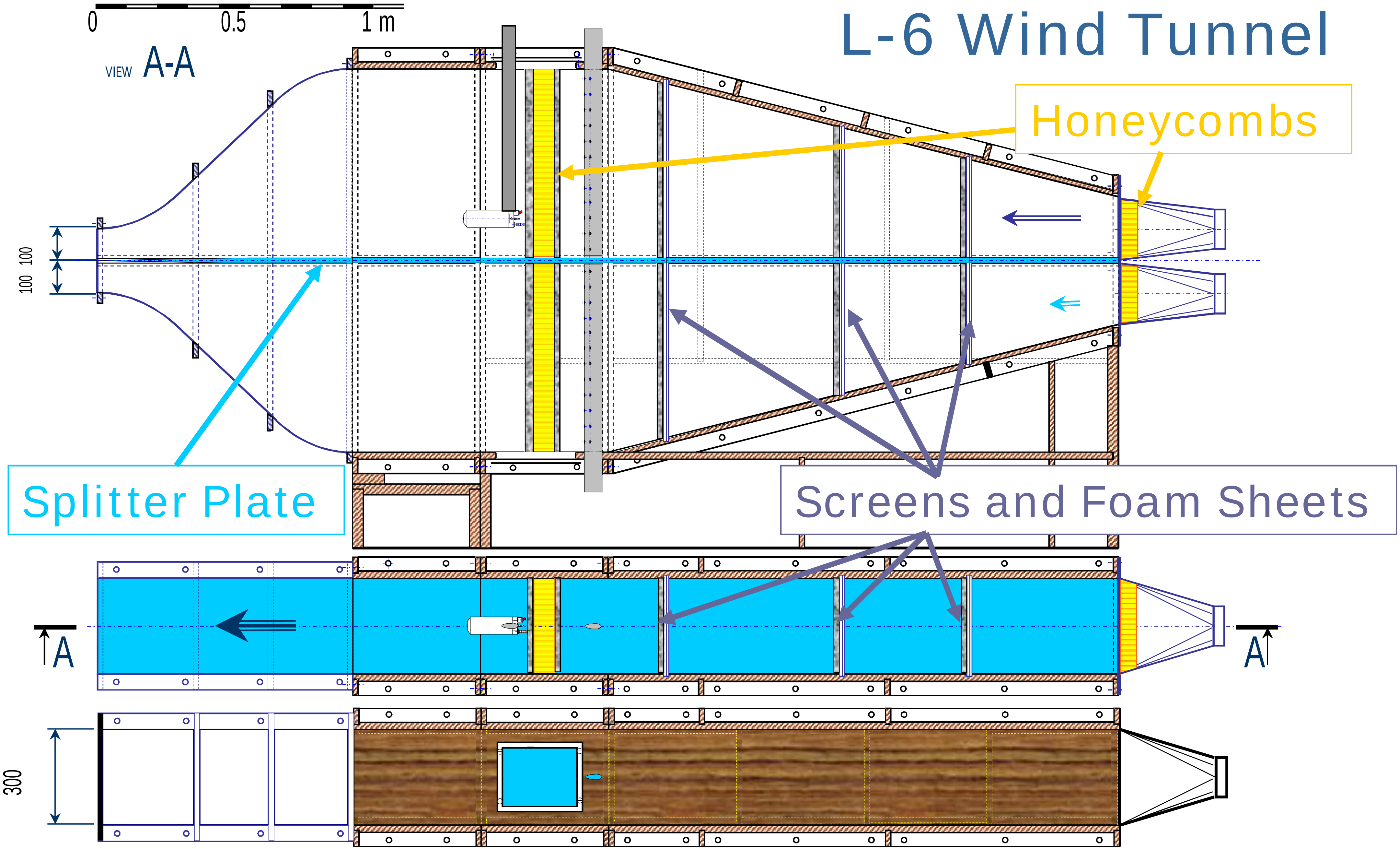
Background at VKI

- 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

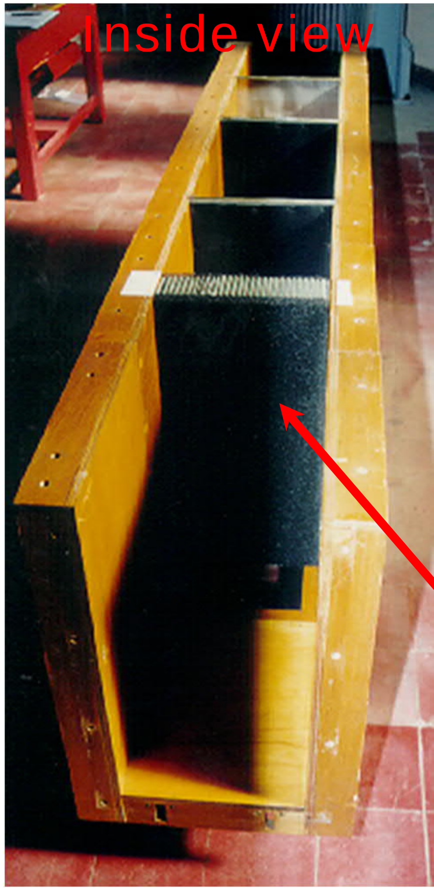
- Set-Up an Experimental Apparatus for Two-Phase Flow
- Perform Measurements in Single-Phase and Two-Phase Flow to characterize the flow field of the particulate phase and the carrier phase
- Extract the Information about the Carrier Gas Flow Turbulence Field
- Qualify the T.I. Modification by the Analysis of the Results
- Contribute to Physical Modeling of Turbulence Modification by Particles

L-6 Wind Tunnel

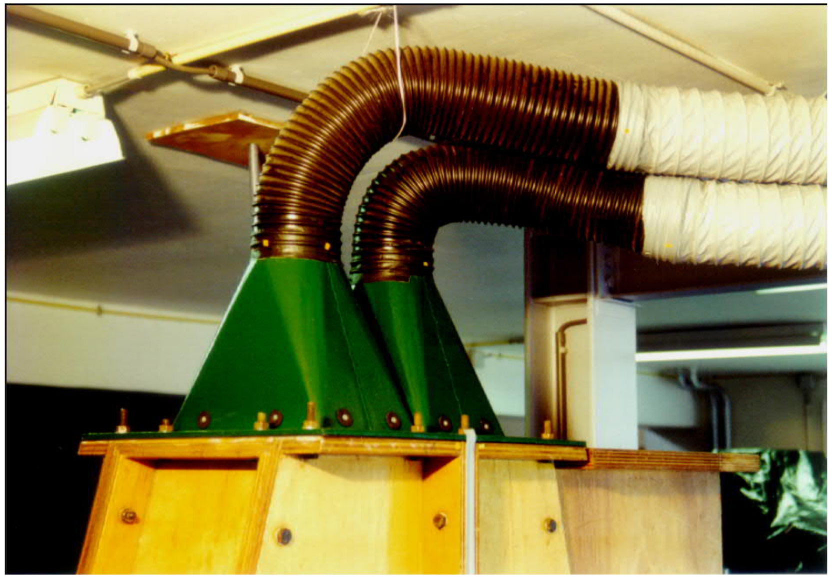


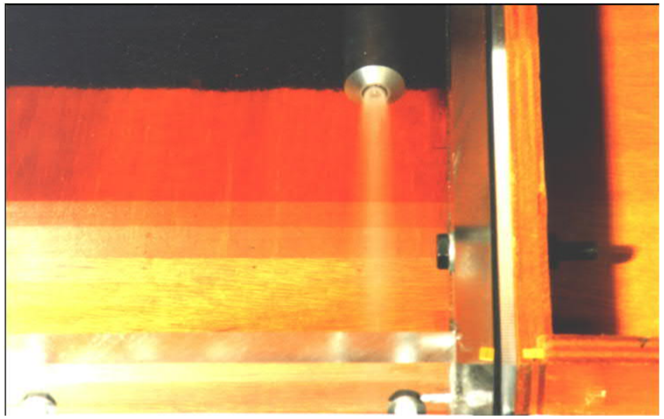
L-6 Wind Tunnel

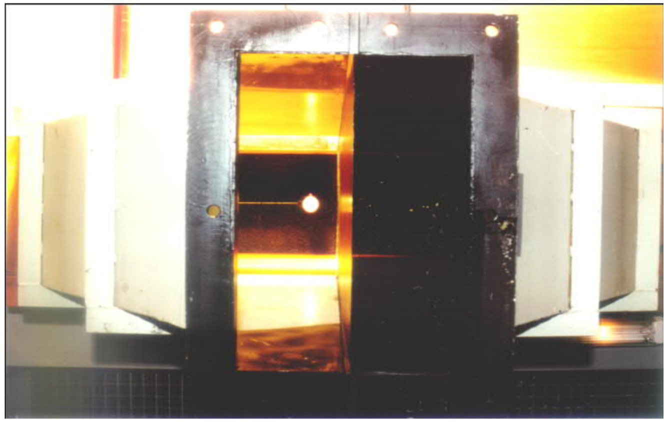
Vertical Arrangement
Downward Twin-Jet Flow

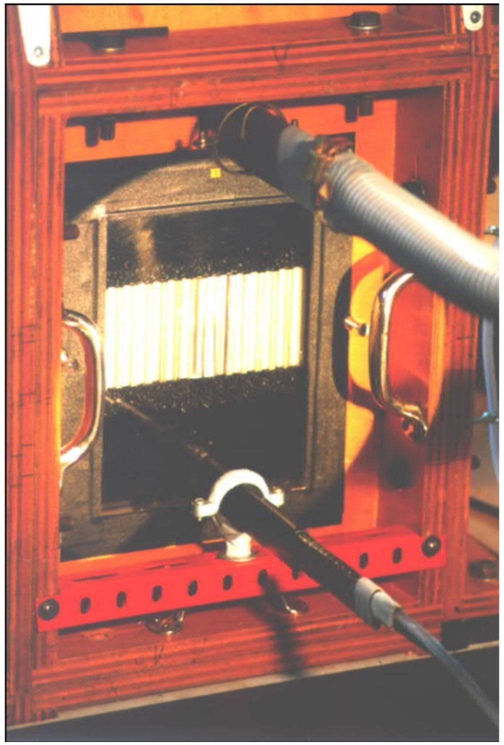


Twin-Jet Nozzle
1/6 Contraction Ratio

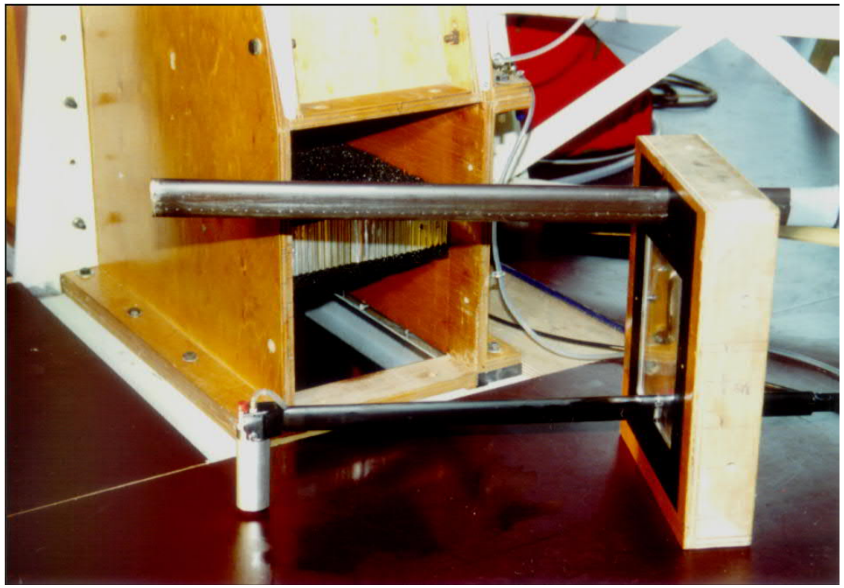


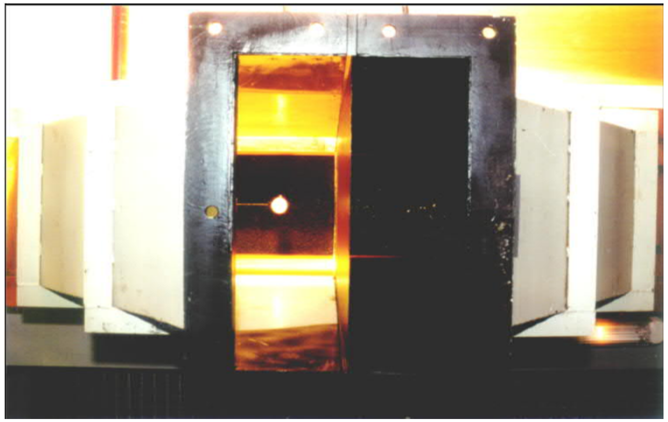






L-6 wind tunnel
upgrade and supplementation with spray facility and smoke injection & suction units





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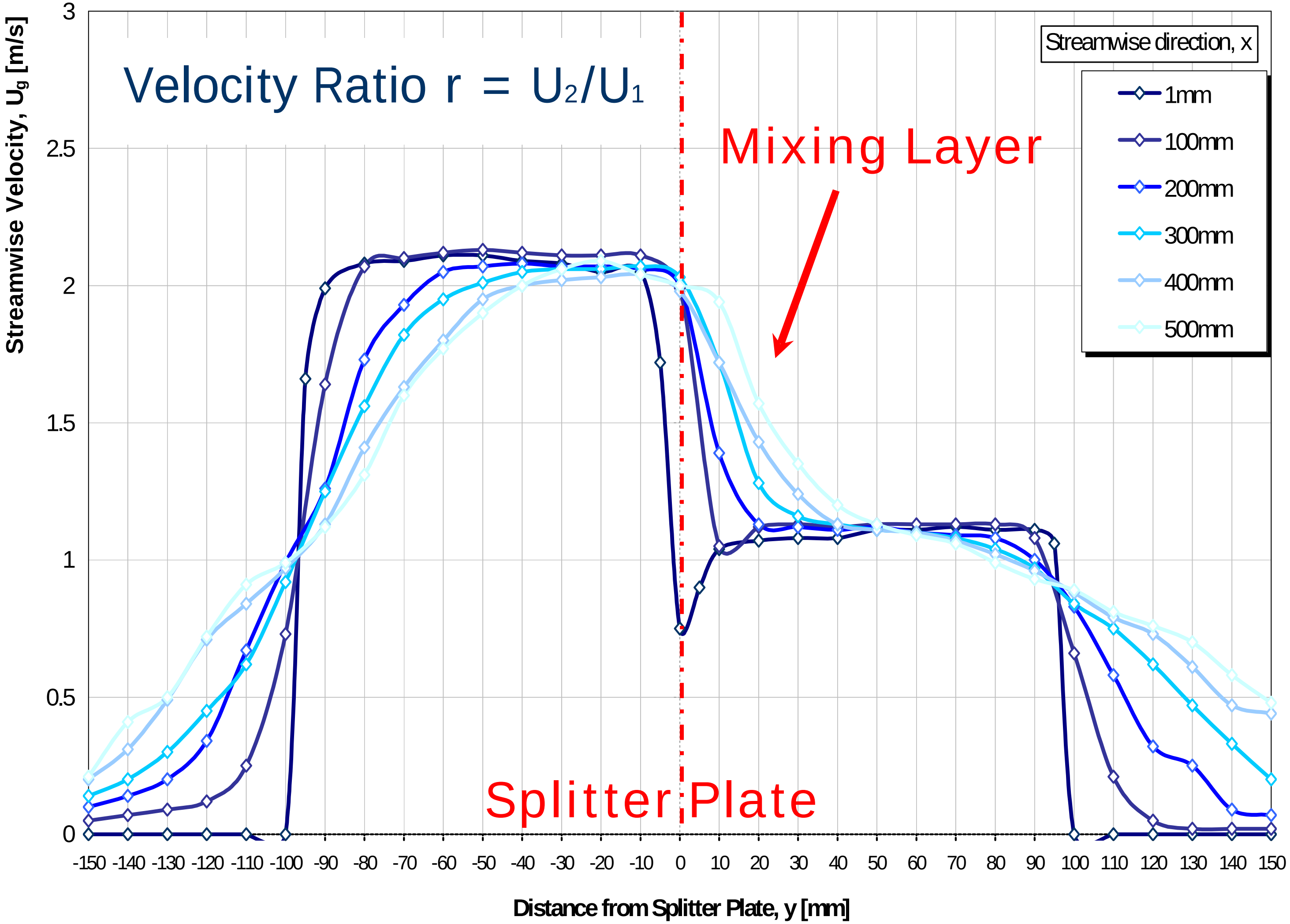
Velocity Profile Measurements with Heated Sphere Probe

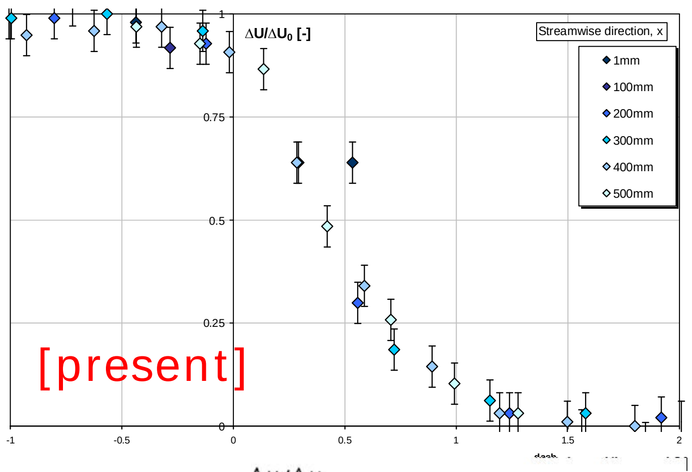
Single Phase Flow

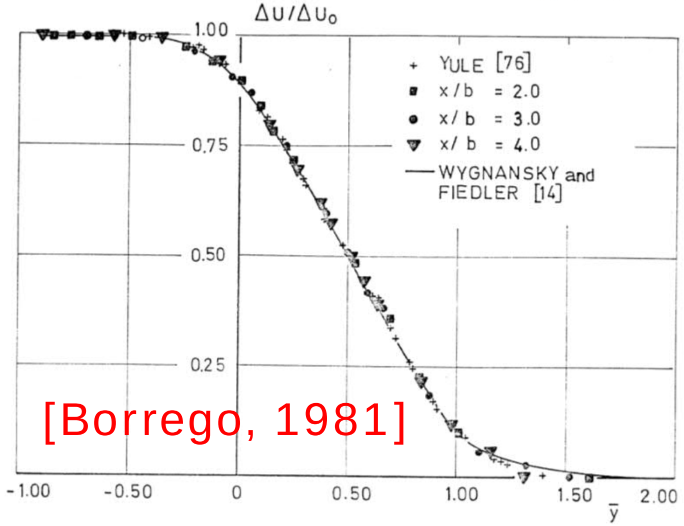
Velocity Profiles of Single Gas Phase

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



Non-dimensional Plot





Measurement Techniques

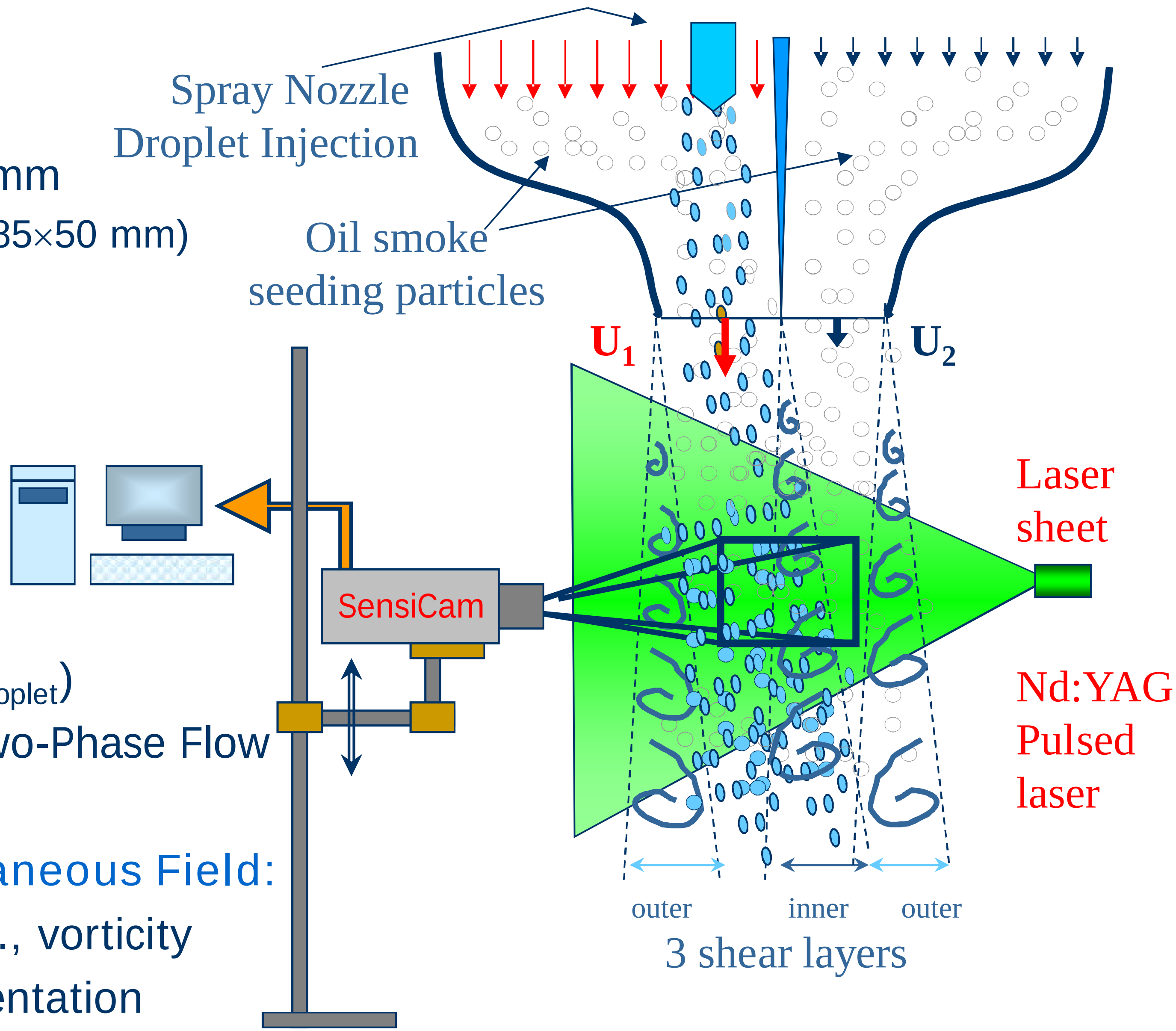
PARTICLE IMAGING VELOCIMETRY

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 ($d_{seeding} \ll d_{droplet}$)
- Gas Phase Flow Field Data in Two-Phase Flow



Post-processing of the Instantaneous Field:

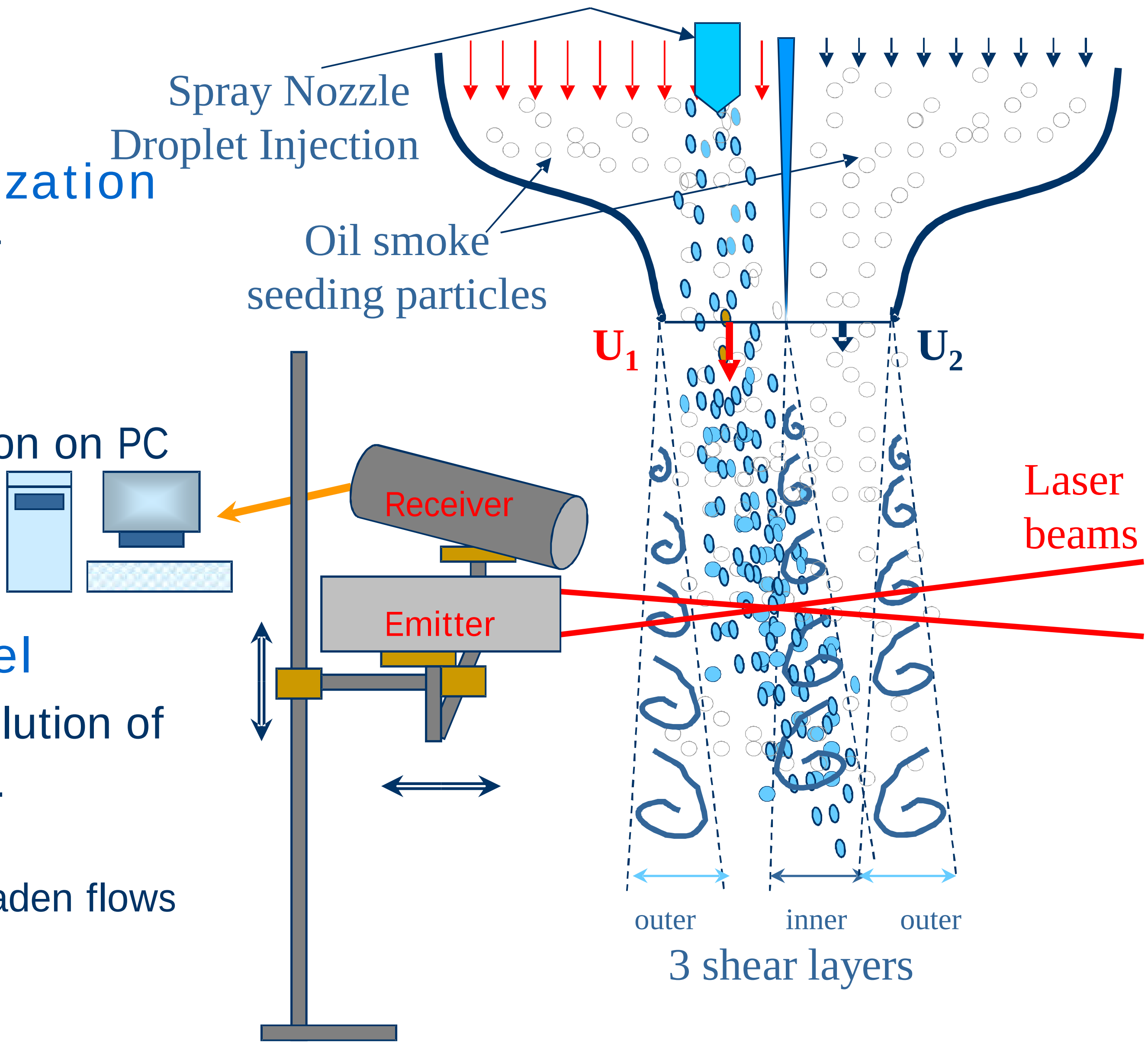
- Matlab for mean, u',v', RMS, T.I., vorticity
- TecPlot for calibration and presentation

Measurement Techniques

PHASE DOPPLER ANEMOMETRY

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

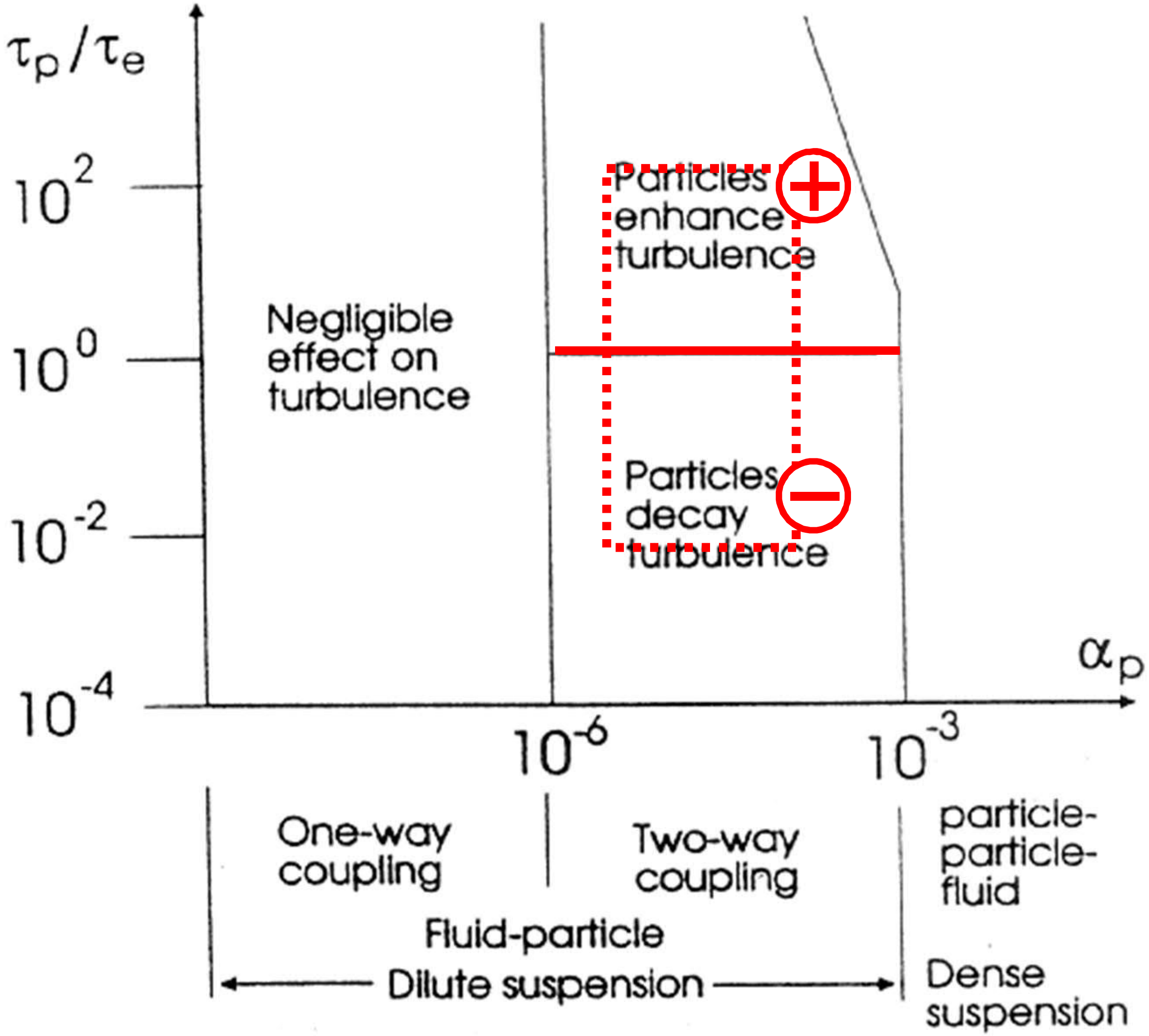
? QUESTION ?

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:

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

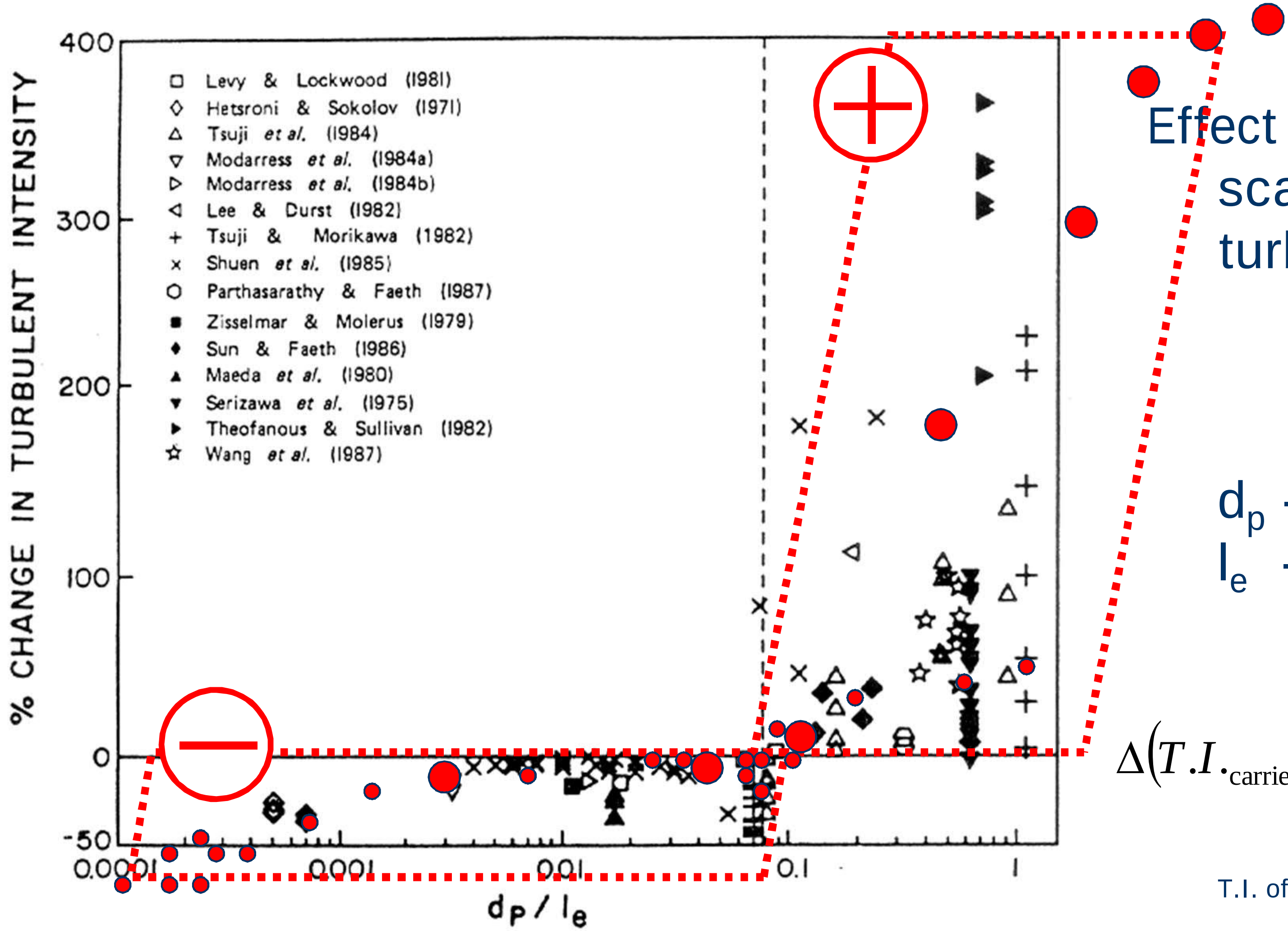
$\tau_p = \rho d_p^2 / 18\mu$ particle response time

$\tau_e = 2\, l_e / \Delta U$ 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:

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

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%)

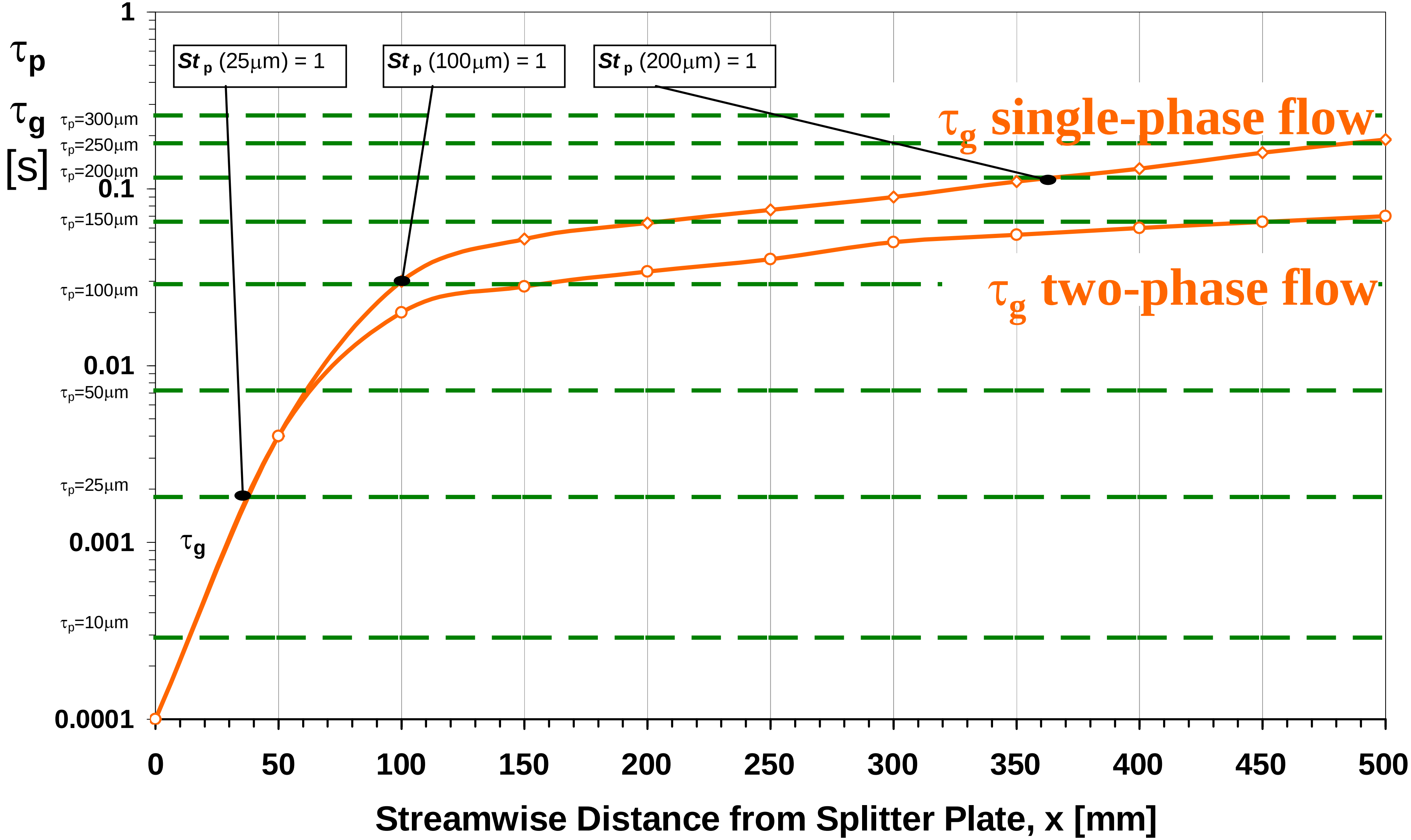
Main Flow: ⊕ **positive** rel. change (+1500%)

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

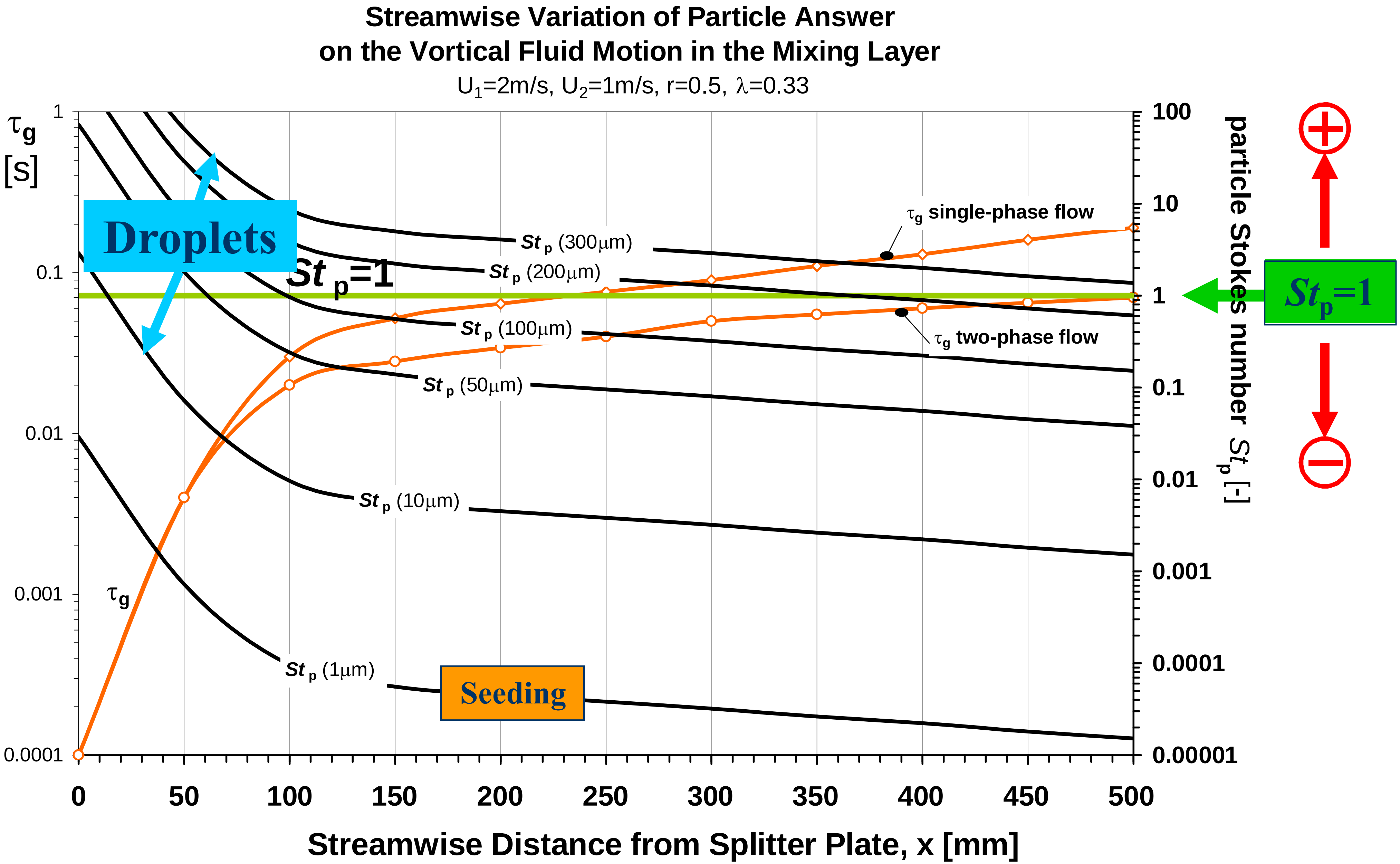
Physical Modeling

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!