GLASGOW 2003
INTEGRATING CFD AND EXPERIMENT

A Detailed CFD and Experimental Investigation of a Benchmark Turbulent Backward Facing Step Flow

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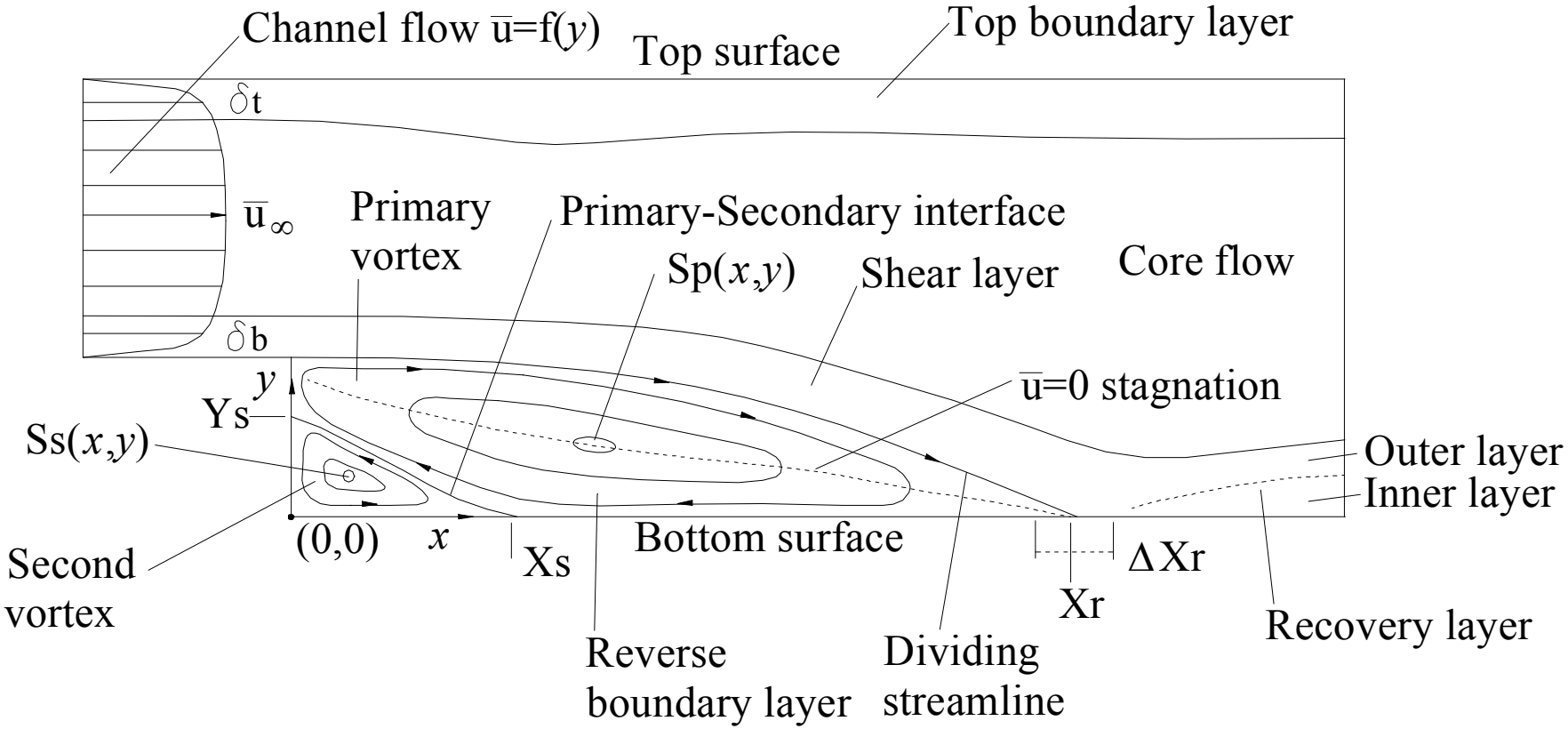
INTRODUCTION

- Turbulent Backward Facing Step - benchmark flow
- Compare Particle Image Velocimetry (PIV) and CFD
- Not just to check CFD
- Rather to use the best of each
- What is the best of each? - first steps

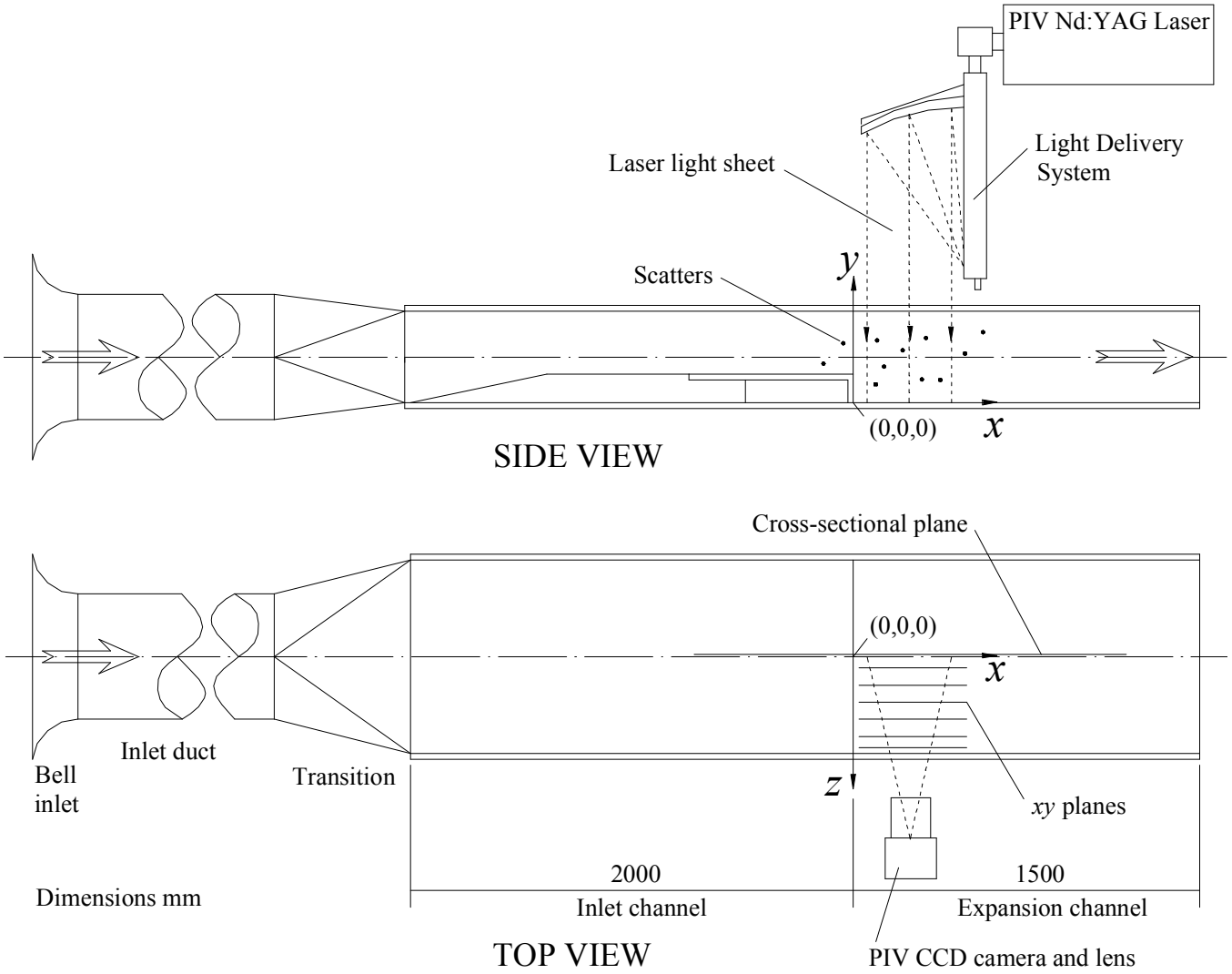
TURBULENT BACKWARD FACING STEP

- Mean flow structures
- Characteristic lines and points
- Wide velocity, turbulence range
- Good CFD and PIV test



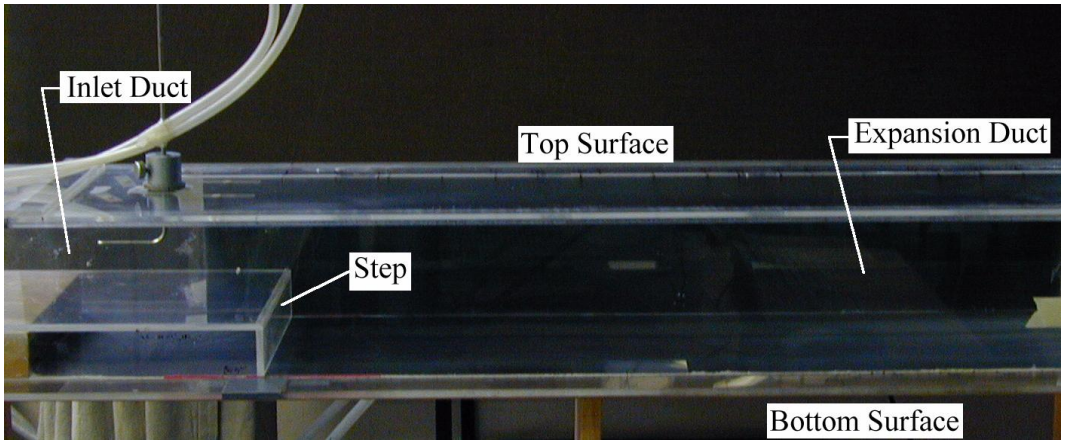
EXPERIMENTAL TEST RIG

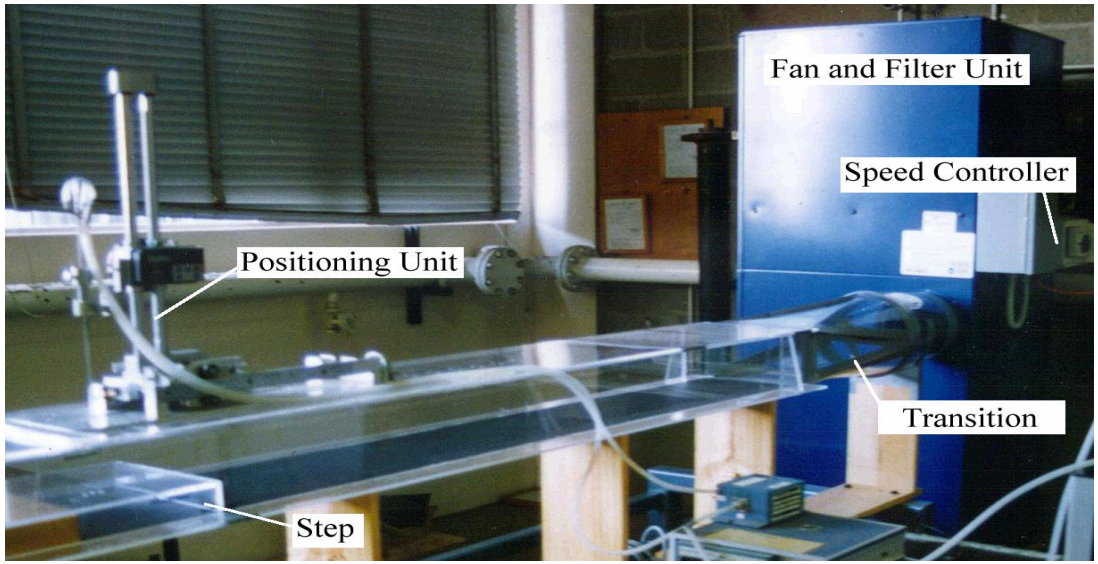
- Dimensions and PIV access



EXPERIMENTAL TEST RIG

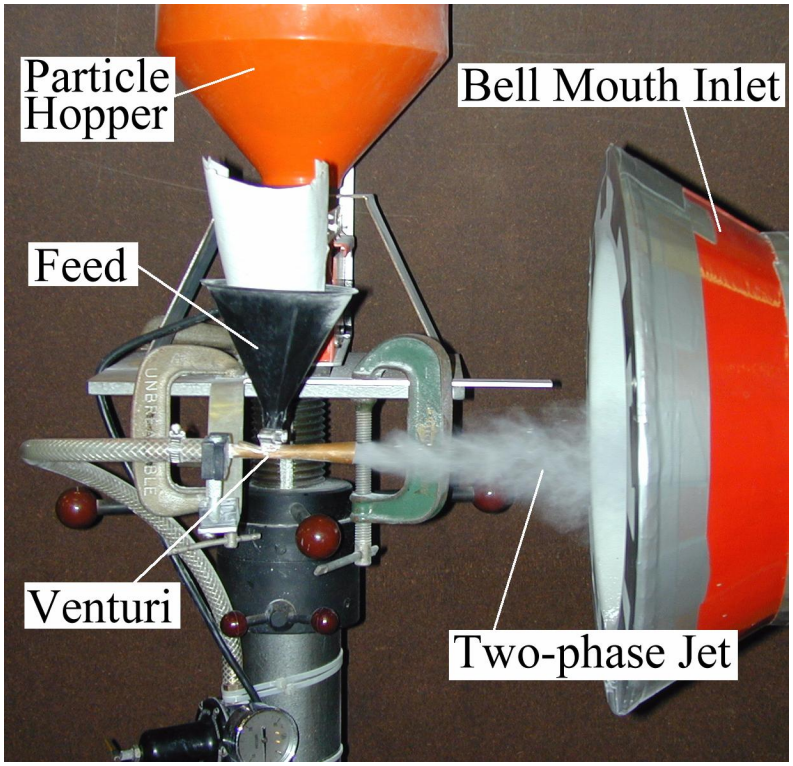
- Clear acrylic – light access
- Low reflection base
- Full side view

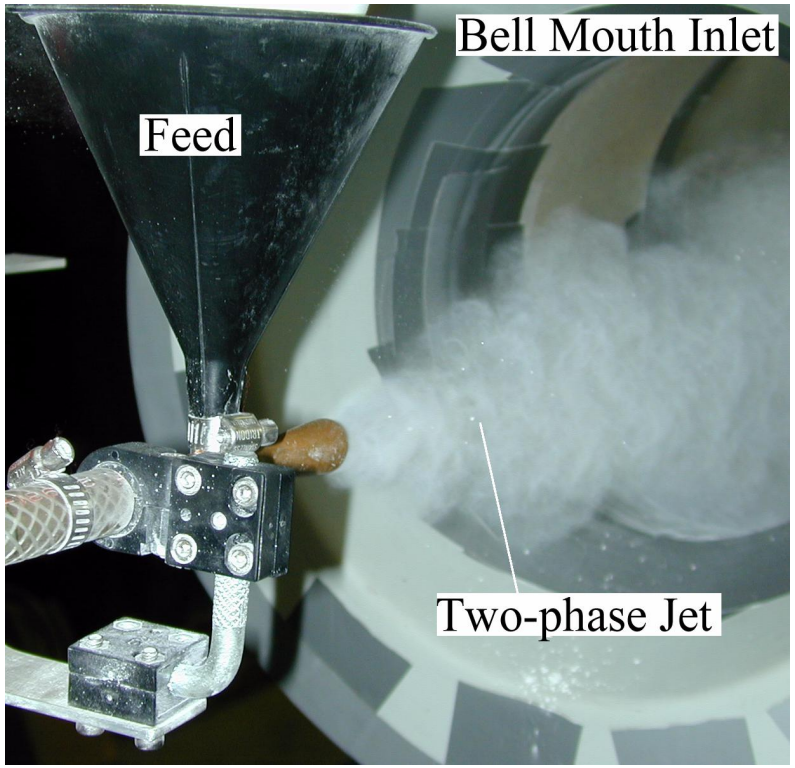




EXPERIMENTAL TEST RIG

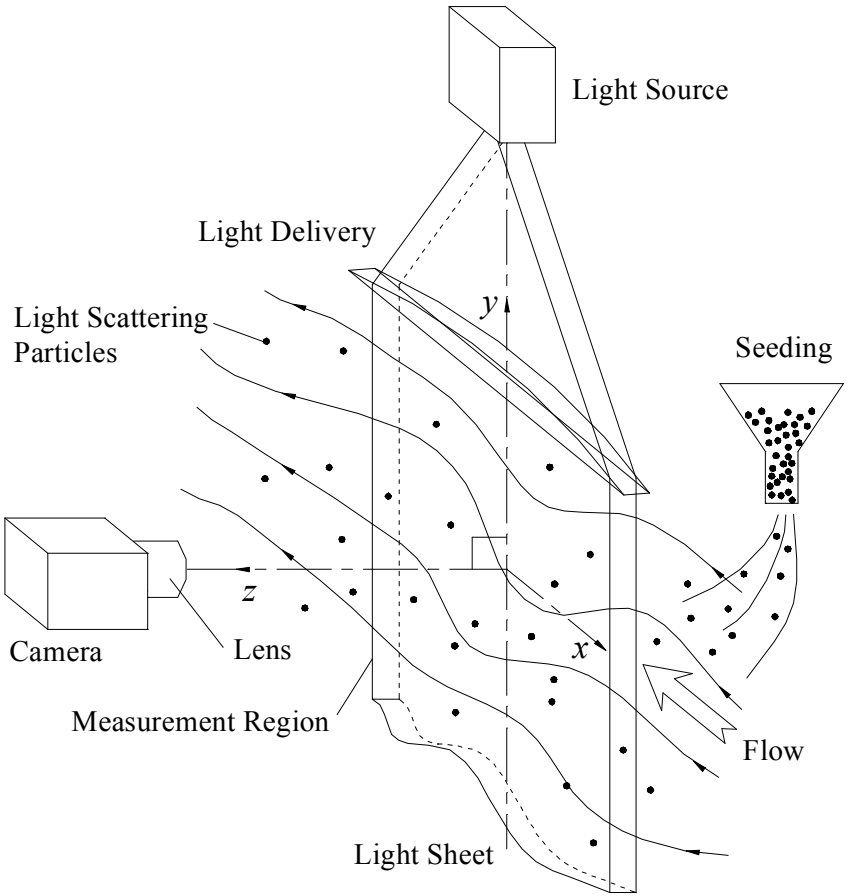
- High density PIV seeding – critical
- Particle – hollow polymer spheres
- Venturi jet seeder well upstream



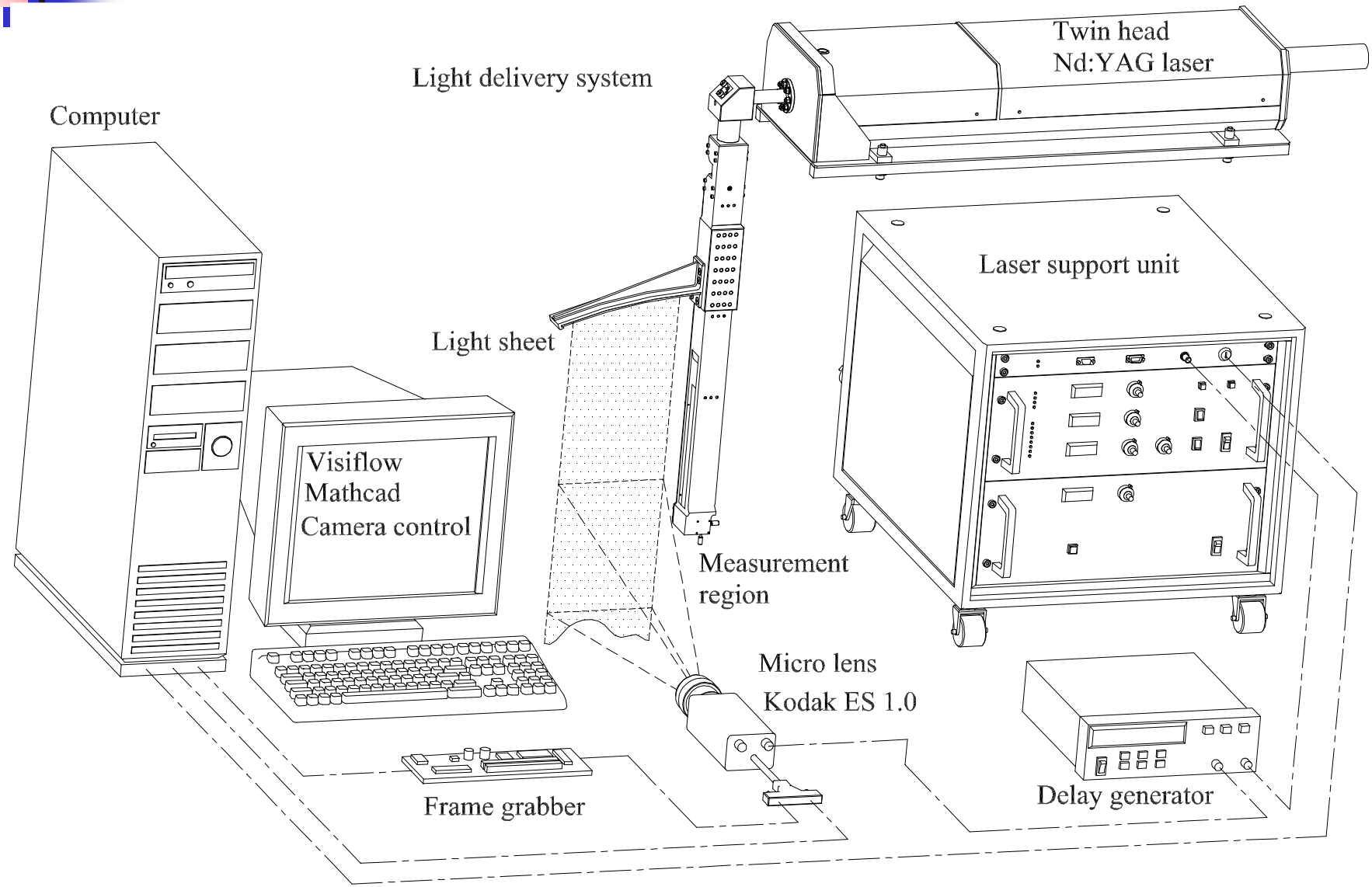


HIGH RESOLUTION PIV

- Basic 2D arrangement
- Mean flow aligned in light sheet
- Camera perpendicular to light sheet

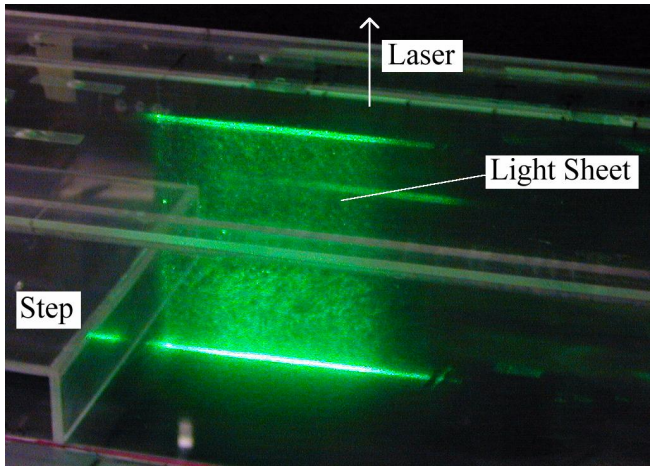


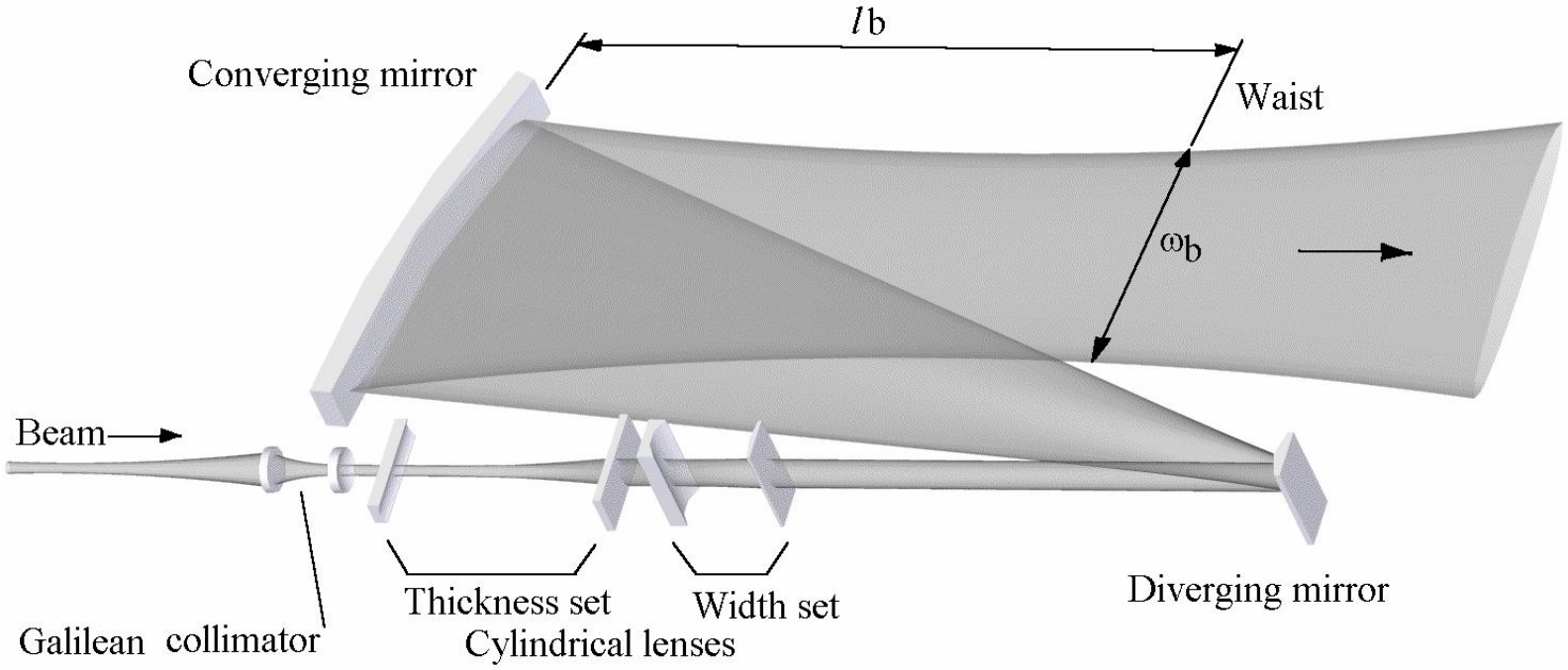
HIGH RESOLUTION PIV



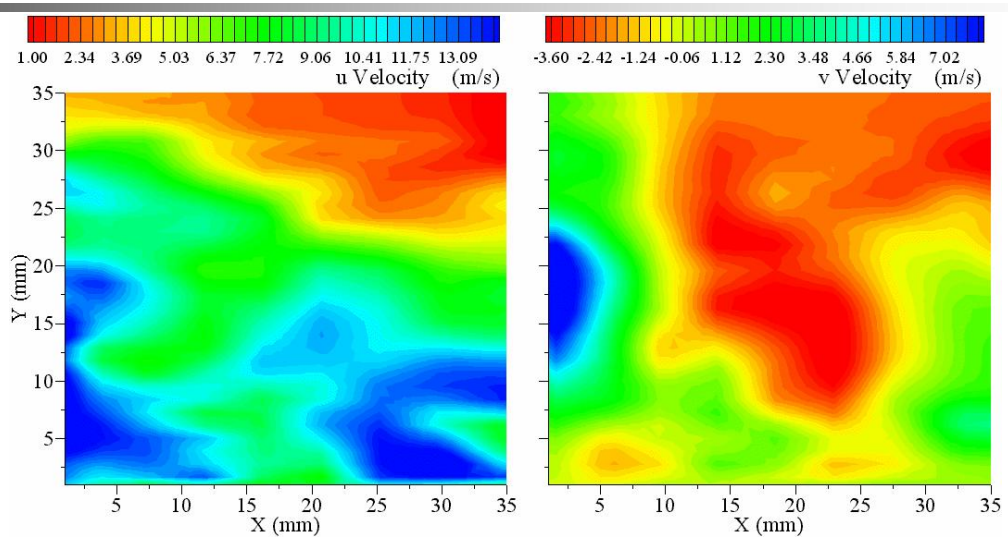
HIGH RESOLUTION PIV

- Constant intensity light sheet
- Adjustable width and thickness

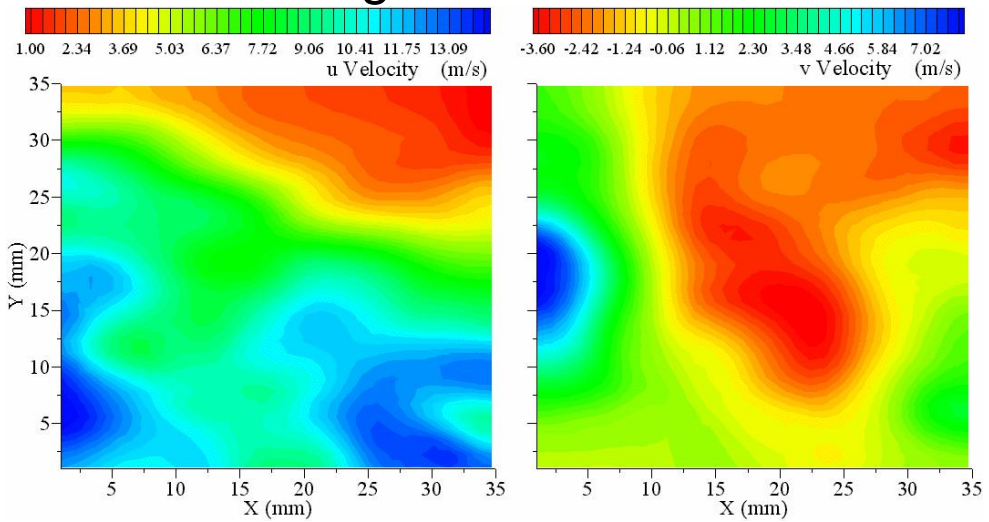




PIV VERIFICATION USING CFD



- Contours From Standard PIV Images of Okamoto and Watanabe (1999)



- Contours From a PIV Analysis of the Standard PIV Images

PURPOSE OF CFD

- Not only to validate CFD against experiment
- But to reveal greater detail about phenomena
- And supplement experimental results
- Make full use of the reliability of modern CFD

CFD APPROACH

- 2D RANS finite volume (Fluent)
- RNG k-$\in$, RSM turbulence closure (literature)
- Second order interpolation
- Ambient and boundary conditions – use experimental

CFD VERIFICATION ASSESSMENT

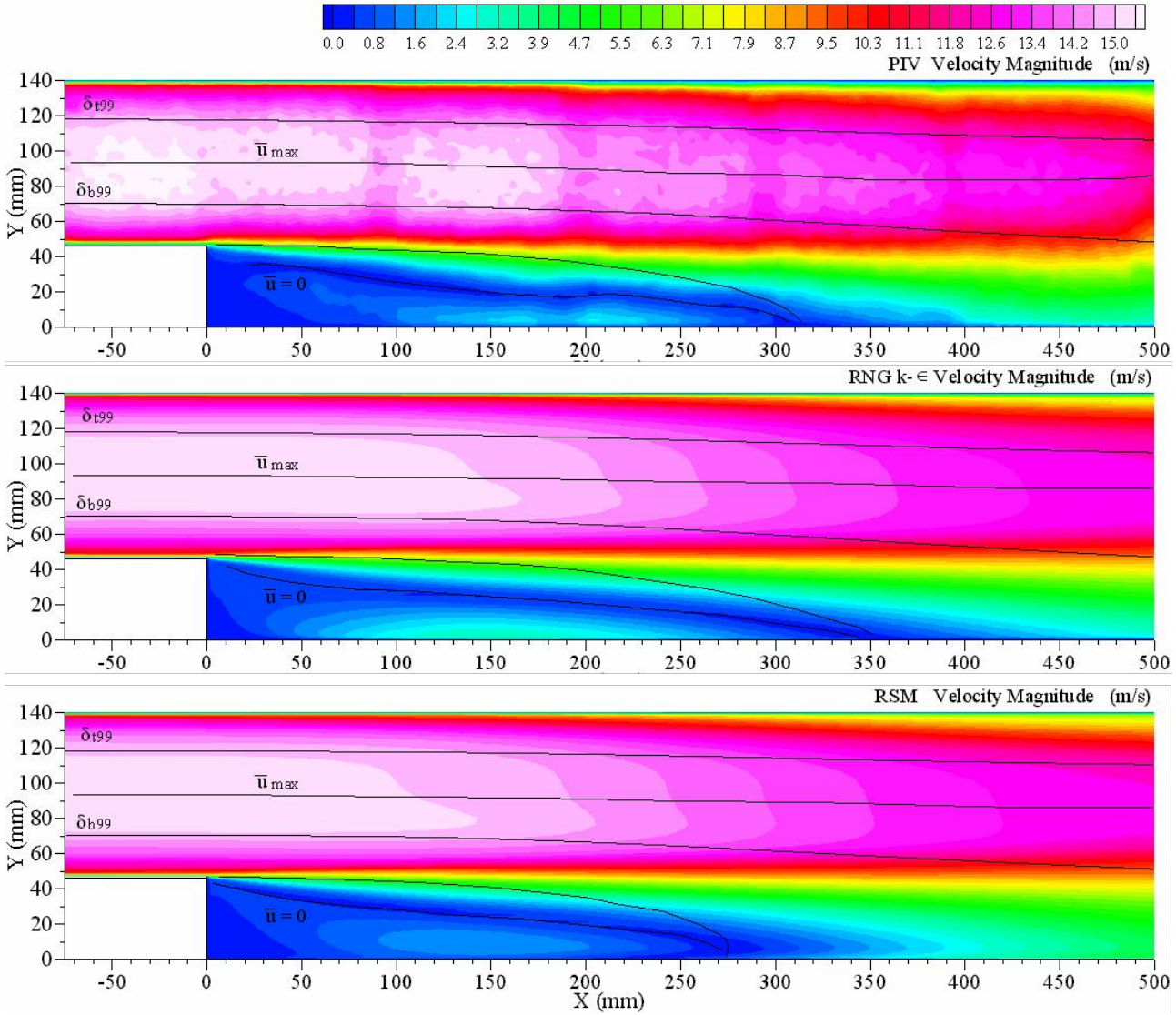
- Key functionals Xr, Xs, Ys, Sp, Ss, Lift, Drag
- Grid convergence – literature 200 cells vertical
- Iterative convergence
- 3D vs 2D – same grid resolution
  - 3% on Xr
- Turbulence modeling, is code correct?
  - commercial code

CFD AND PIV COMPARISON

- Many quality CFD and Experimental data sets
- Most missing complete boundary conditions
  - not previously required
- Perform both CFD and PIV myself
  - “exactly equivalent”
- Work in raw variables u, v, Vmag
  - less need to non-dimensionalise
- Contours – variation
- Streamlines - direction

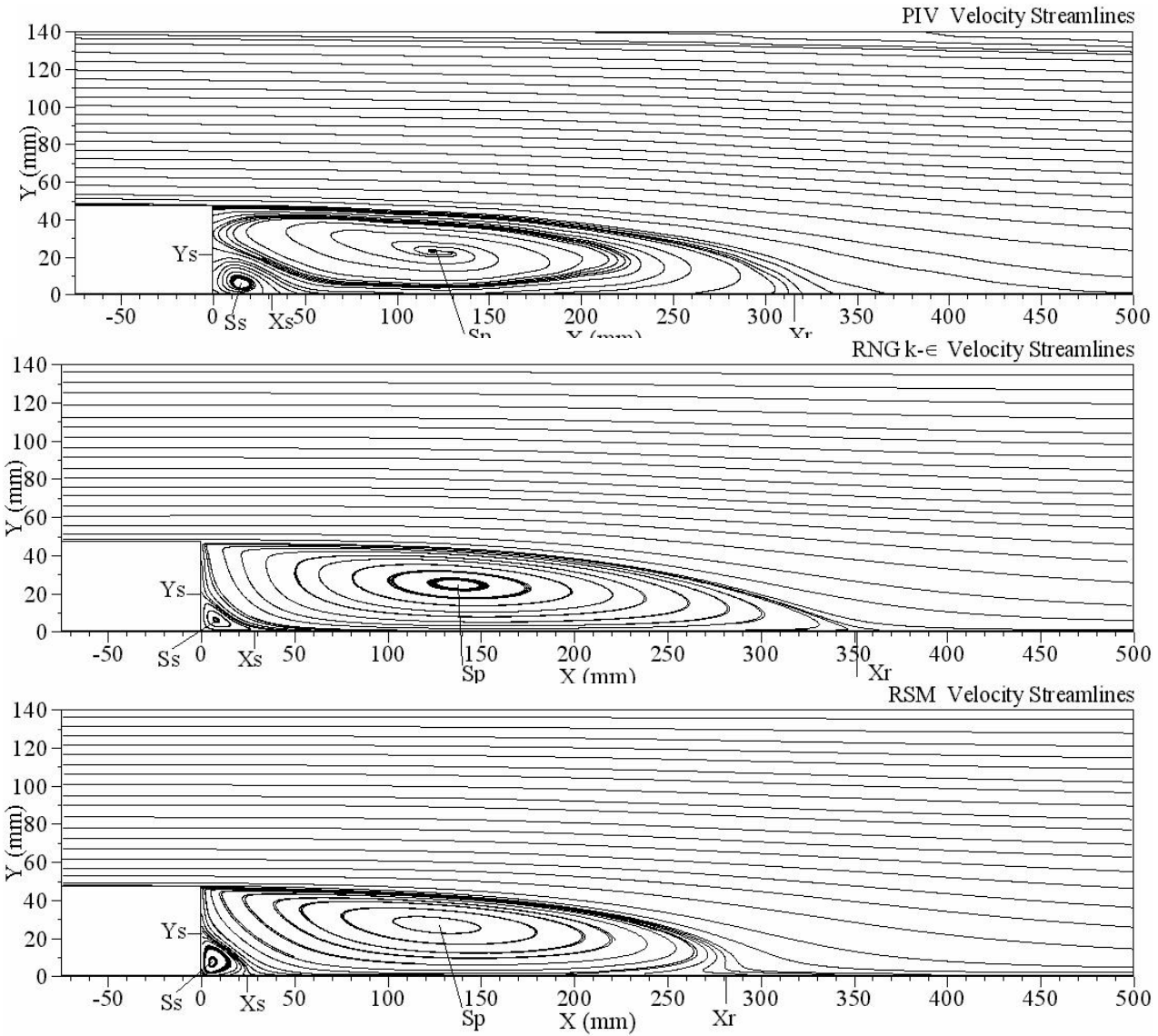
MEAN VELOCITY MAGNITUDE

- Velocity Mag. in CS Plane, (top) PIV, (mid.) RNG k-∈, (bot.) RSM



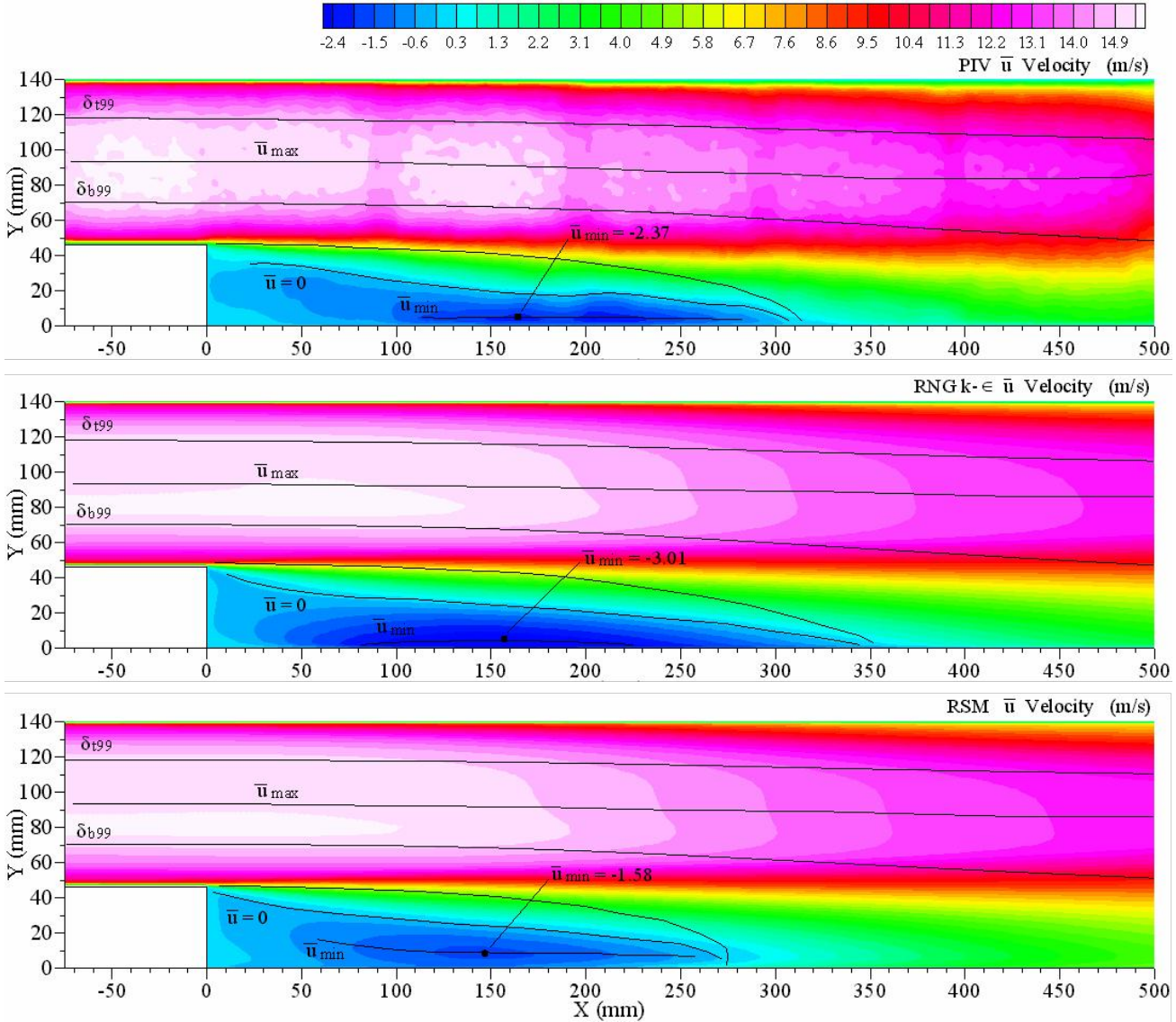
STREAMLINES

- Streamlines in CS Plane, (top) PIV, (mid.) RNG k-∈, (bot.) RSM



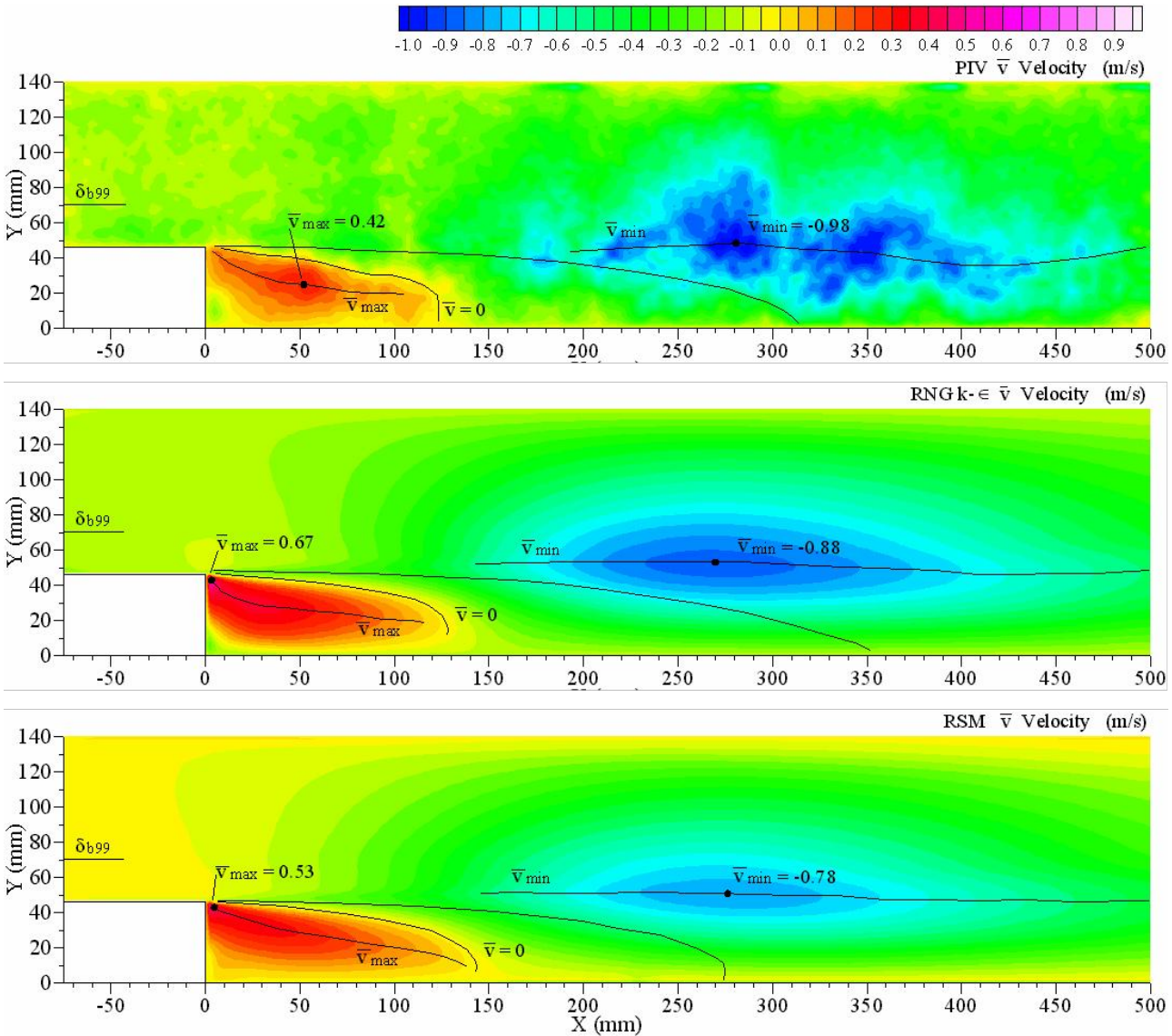
U HORIZONTAL VELOCITY

Mean Horizontal Velocity in CS Plane, (top) PIV, (mid.) RNG k-∈, (bot.) RSM



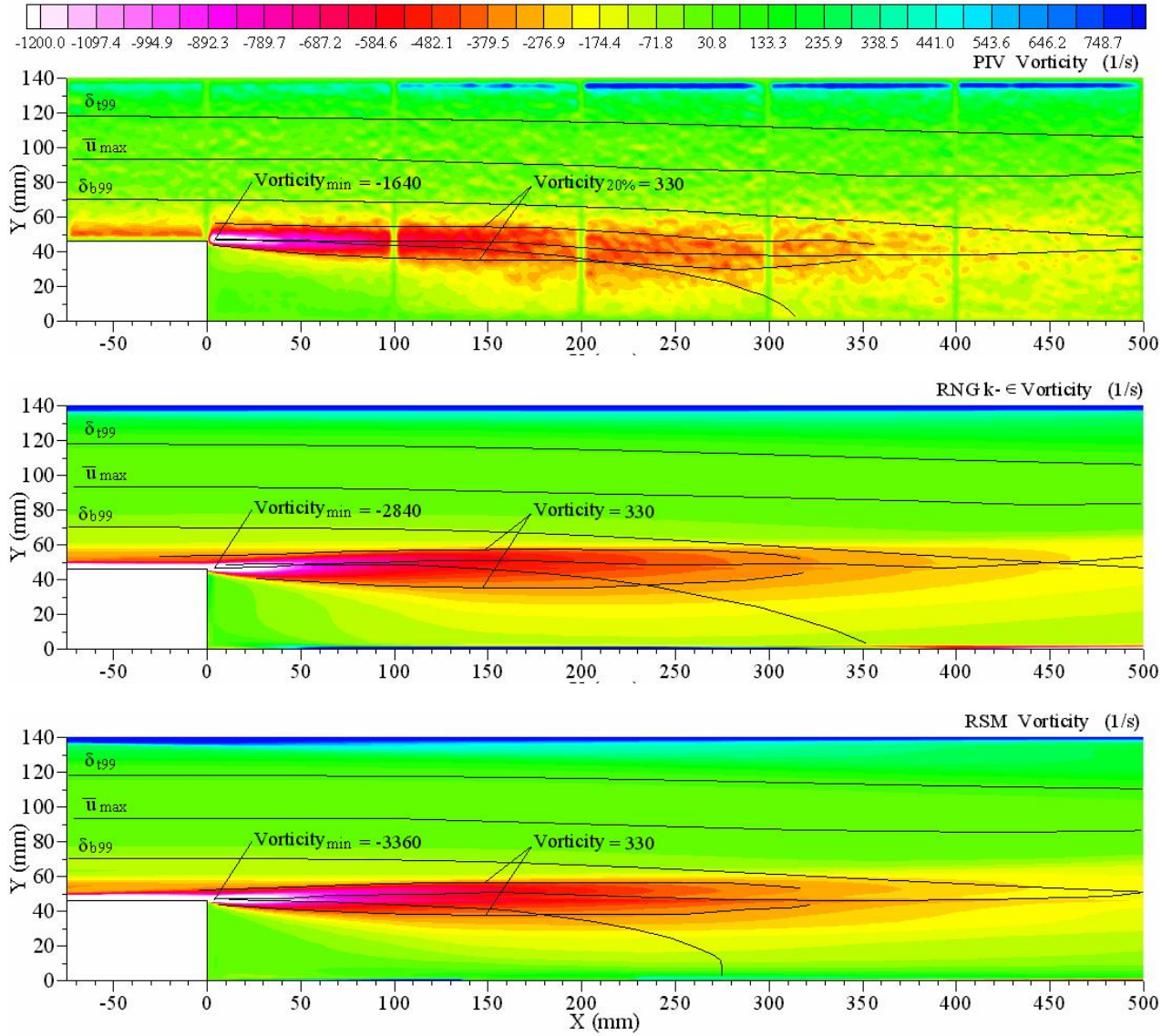
V VERTICAL VELOCITY

- Mean Vertical Velocity in CS Plane, (top) PIV, (mid.) RNG k-∈, (bot.) RSM



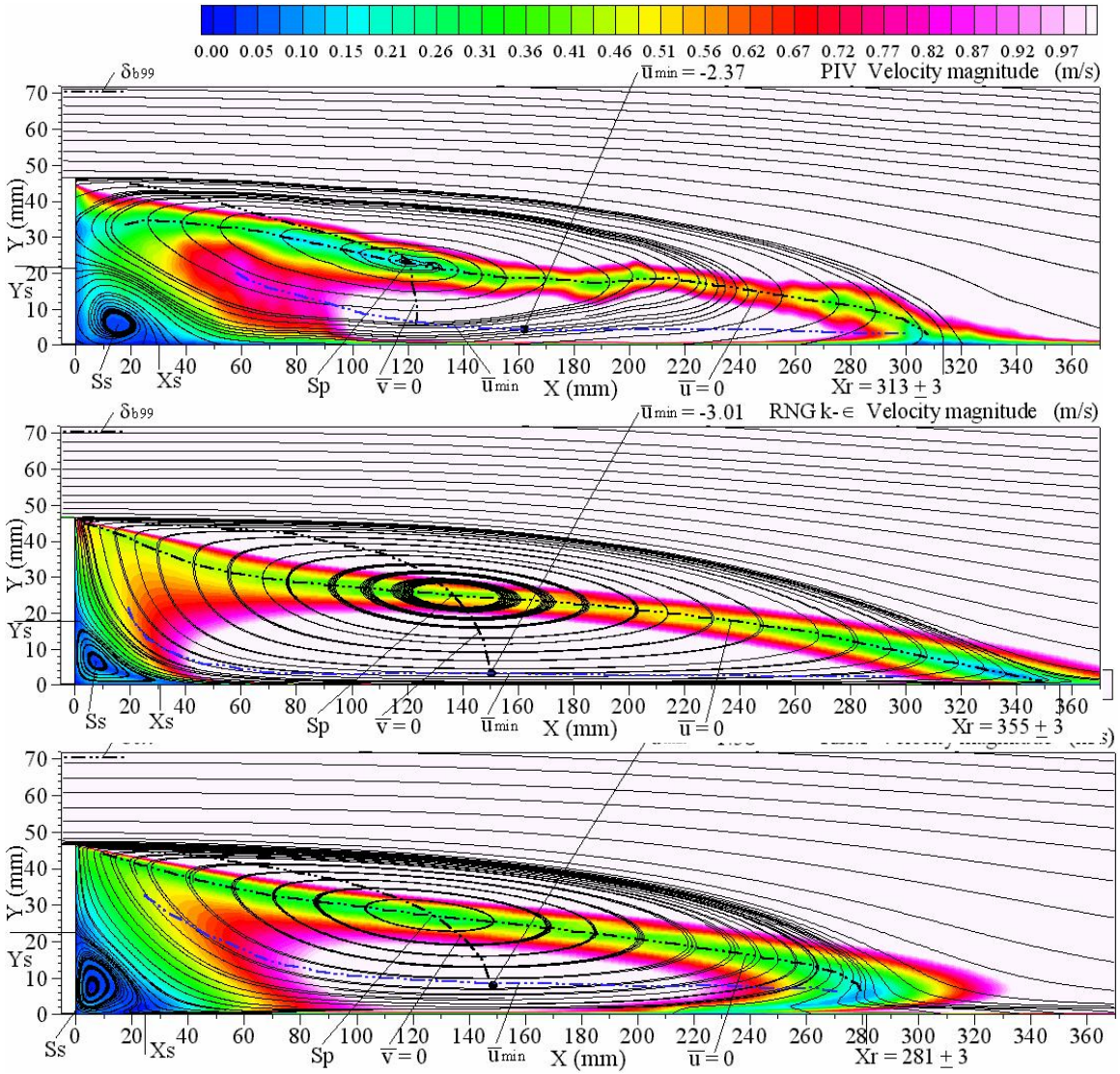
VORTICITY

- Vorticity Mag. in CS Plane, (top) PIV, (mid.) RNG k-∈, (bot.) RSM



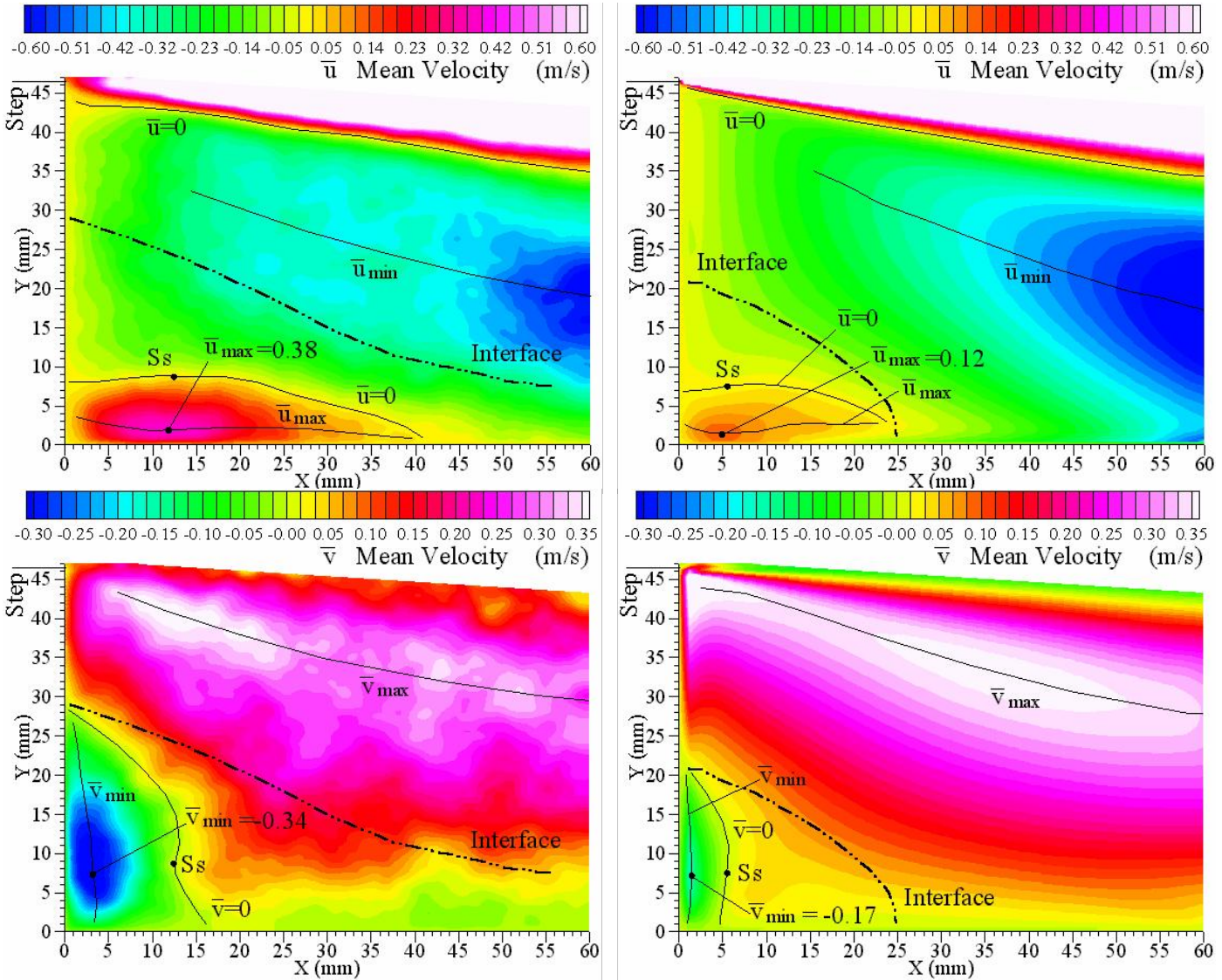
VELOCITY MAGNITUDE AND STREAMLINES BEHIND STEP

- Characteristic Lines in CS Plane, (top) PIV, (mid.) RNG k-∈, (bot.) RSM



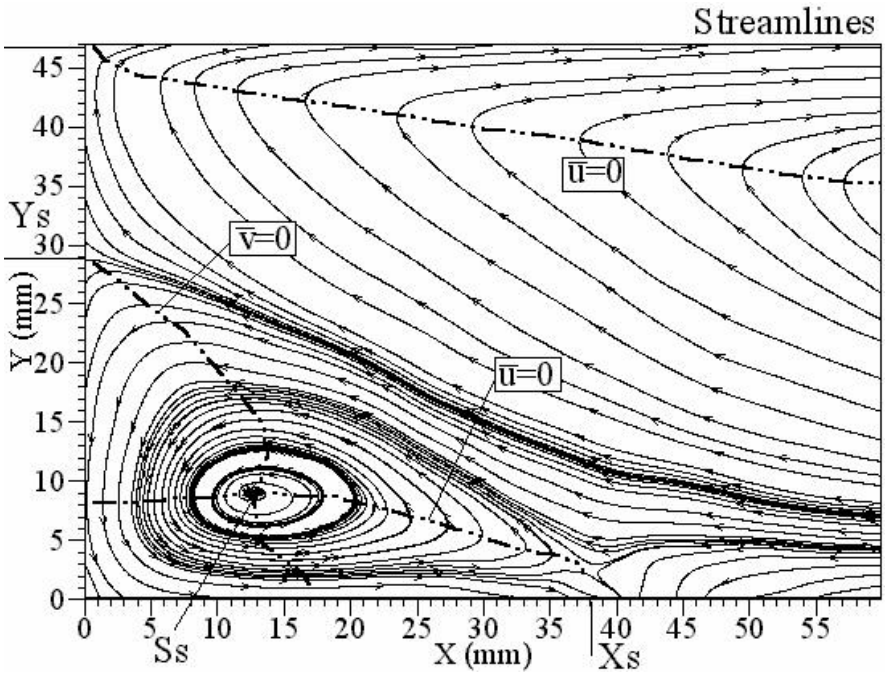
FOCUSED BEHIND STEP

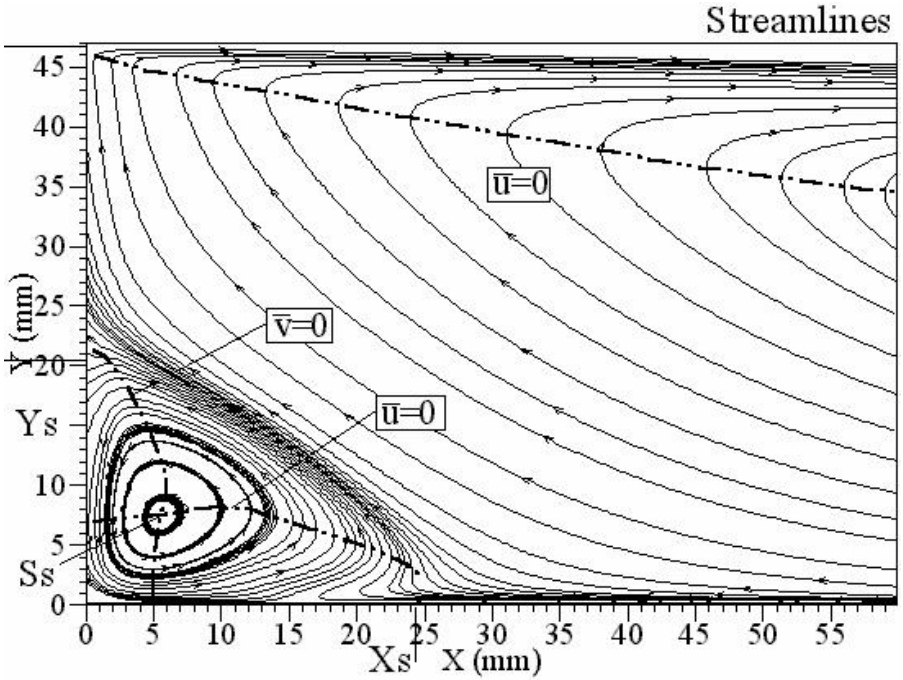
Mean Velocities in CS Plane, (left) PIV, (right) RSM t_p=70 μs



FOCUSED BEHIND STEP

- Streamlines in CS Plane, (left) PIV, (right) RSM, t_p=70 μs





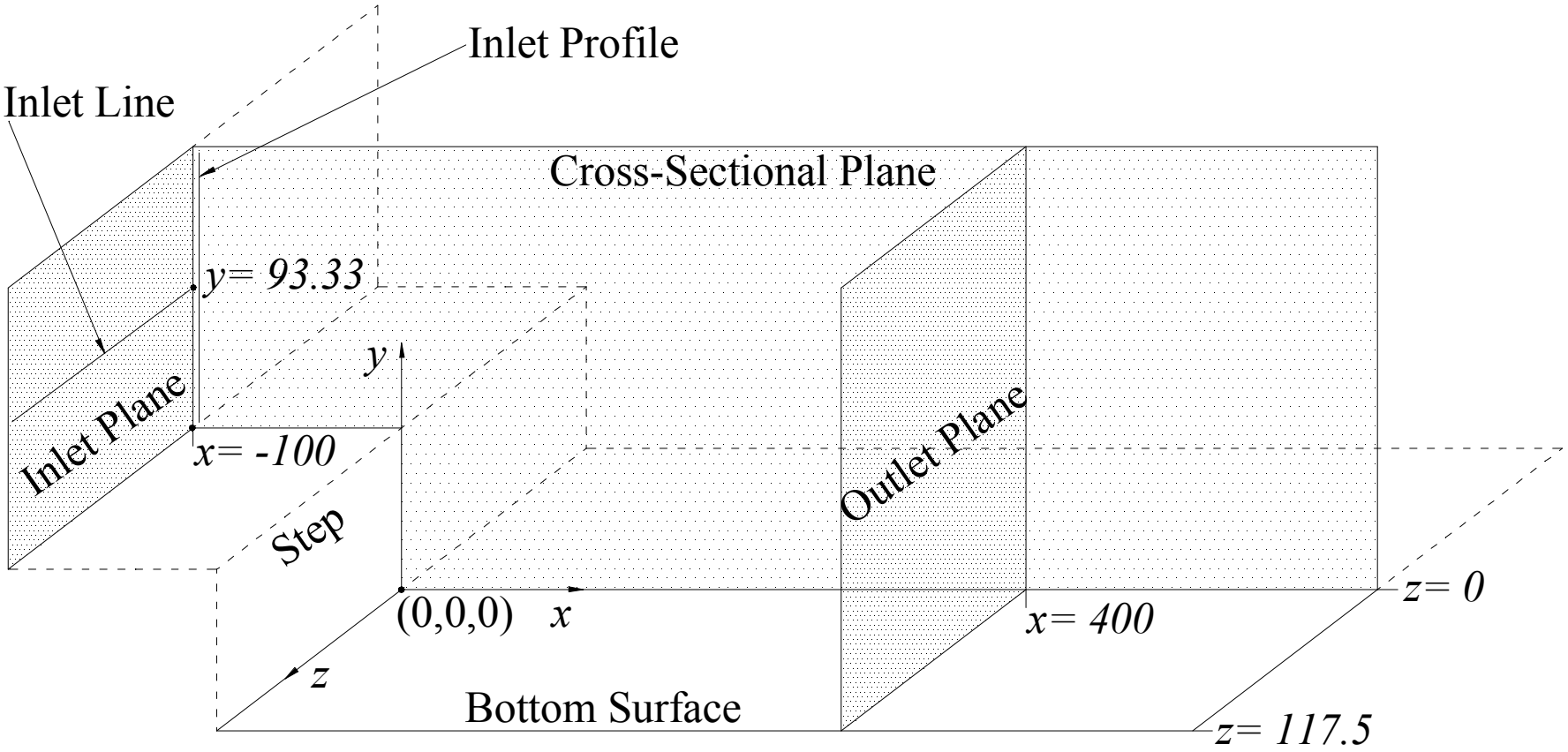
CONCLUSIONS

- CFD and PIV reveal detailed flow structure
- "Exactly Equivalent" simultaneous CFD and PIV
  - Highlights limitations in each
  - Improves confidence in results
- Essential complimentary techniques

FUTURE DIRECTIONS

- CFD should be first part of any PIV?
- Unsteady 3D CFD PIV (TR PIV, stereoscopic)
- Total integration of CFD PIV
  - PIV modifies turbulence closure model throughout
  - CFD error checks PIV and fills in error regions
  - mathematically rigorous

PLANES OF INTEREST



HIGH RESOLUTION PIV

- Basic sub-systems
- Optimise performance of each