Qualitative and Quantitative Characterization of a Jet and Vortex Actuator

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Outline

- Motivation
- Construction of a JaVA Prototype
- Experimental Setup and Governing Parameters
- JaVA Visualization Results
- Extraction of Optical Flow Fields
- Conclusions & Outlook

Known & Open Issues

- Synthetic Jets
  - Operate over a range of amplitudes and frequencies
  - Don't need any external fluid (zero-net-mass flux system)
  - Add only negligible drag when the system is not actuated
- JaVA (Lachowicz *et al.*, Exp. Fluids, 1999)
  - All of the above
  + Very wide-spread flow-fields in still air (e.g. wall and free jets of different orientation, vortex flow, direct generation of vortices)
  - How does it work?
  - What potential applications ?

References

[1] Lachowicz, J. T., Yao, C., and Wlezien, R. W., 1999: *Flow Field Characterization of a Jet and Vortex Actuator*, Experiments in Fluids, Vol. 27, pp. 12-20

[2] Joslin, R.D., Lachowicz, J. T., and Yao, C., 1998: *DNS of Flow Induced by a Multi-Flow*, ASME paper Number FEDSM98-5302, ASME Fluid Engineering Meeting

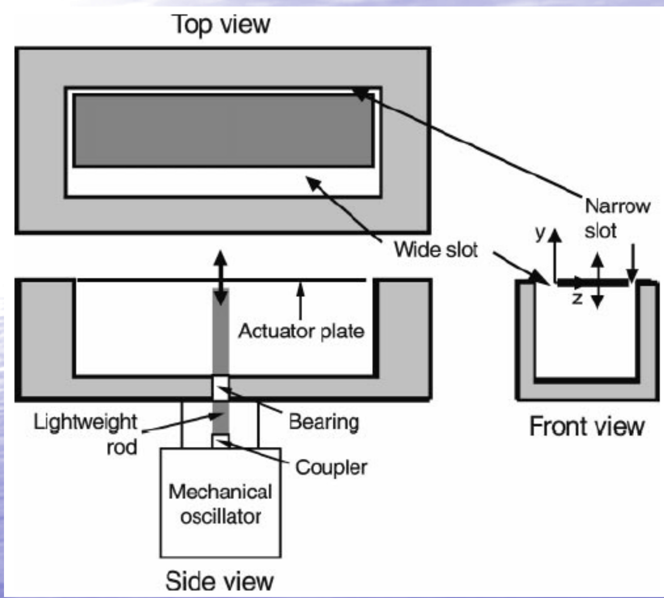
[3] Koumoutsakos, P., 1995: *Simulations of Vortex Generators*, Center for Turbulence Research, Annual Research Briefs, pp. 233-240

[4] Saddoughi, S.G., Koumoutsakos, P., Bradshaw, P., Mansour N.N., 1998: *Investigation of on demand vortex generators*, Center for Turbulence Research Manuscript No. 171, Stanford University

[5] Jacobson, S.C. and Reynolds, W.C., 1998: *Active control of stream wise vortices and streaks in boundary layers,* Journal of Fluid Mechanics **360**: 179-994

Basic Setup & Parameters

Lachowicz *et al.*, Exp. Fluids, 1999



Governing Parameters

- Actuator amplitude a [mm]
- Actuator width b [mm]
- Actuator frequency f [Hz]
- Characteristic velocity U [mm/s]
- Wide slot spacing w_w [mm]
- Narrow slot spacing w_n [mm]
- Kinematic viscosity υ [mm^2/s]

Non-dimensional governing parameters:

- $\pi_1 = Ub/\upsilon$
  - $\rightarrow \pi_1 = Re = 2\pi afb/\upsilon$
- $\pi_2 = U/bf$
- $\pi_3 = a/b$
  - $\rightarrow \pi_3 = f(\pi_1) = S_a = 2\pi a/b$
- $\pi_4 = g_n = w_n/b$
- $\pi_5 = g_w = w_w/b$

Results of Lachowicz *et al.*, Exp. Fluids, 1999

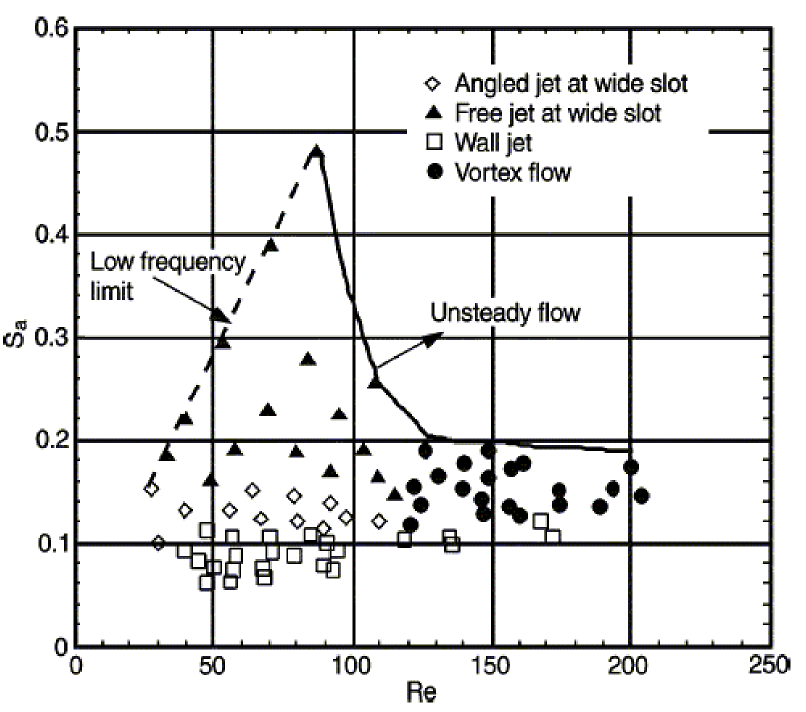


Fig. 9. Flow Regimes at $g_w = 0.099$

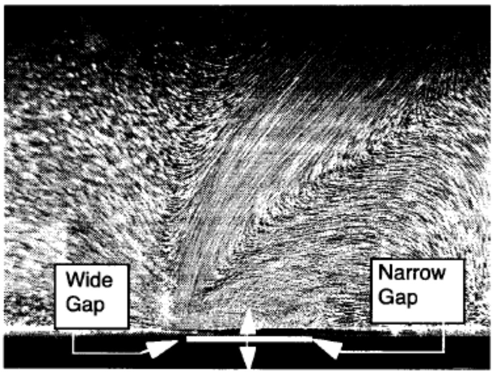


Figure 2. Angled jet at wide gap: f=70 Hz, g_r=3, S_a=0.13, Re=56

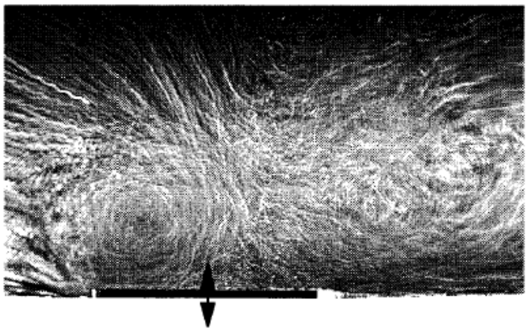


Figure 5. Vortex flow: f=190 Hz, g_r=3, S_a=0.13, Re=146

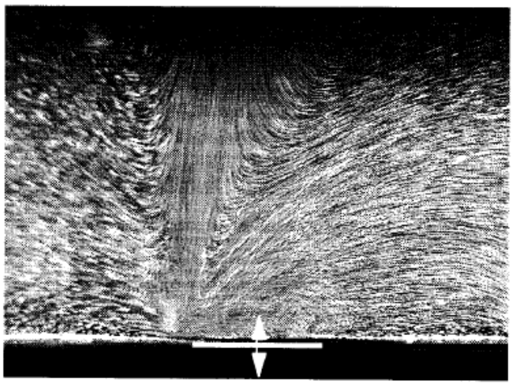


Figure 3. Jet at wide gap: f=70 Hz, g_r=3, S_a=0.19, Re=80

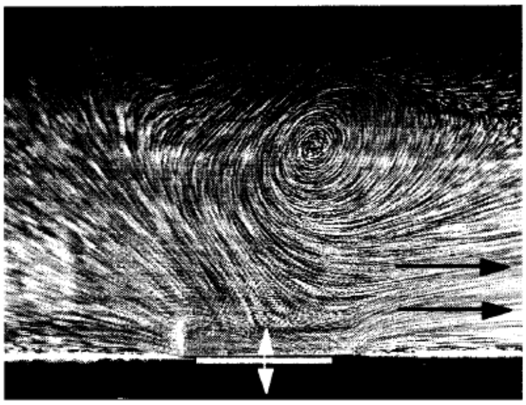
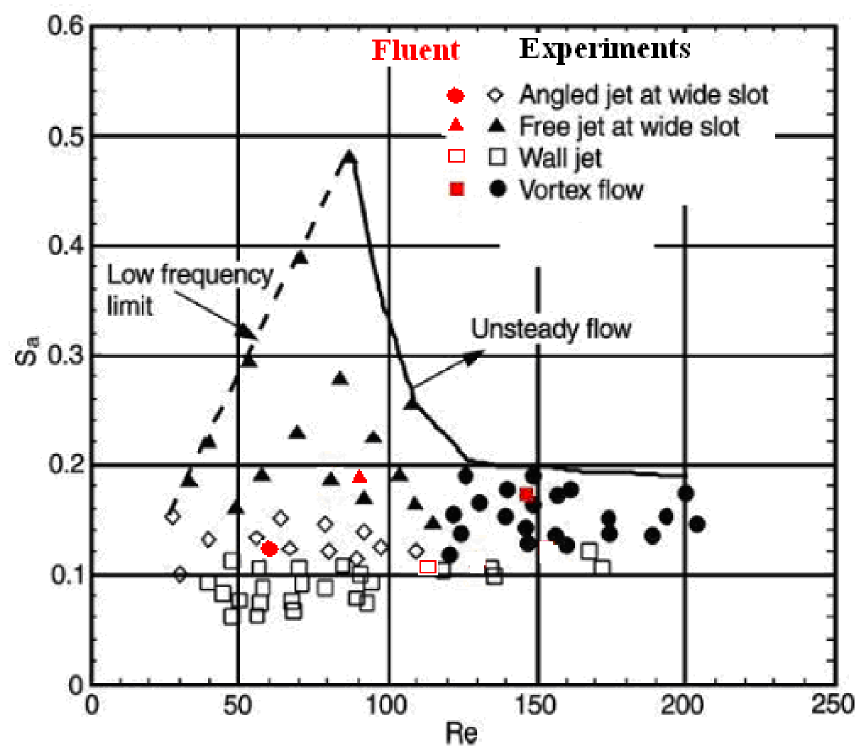
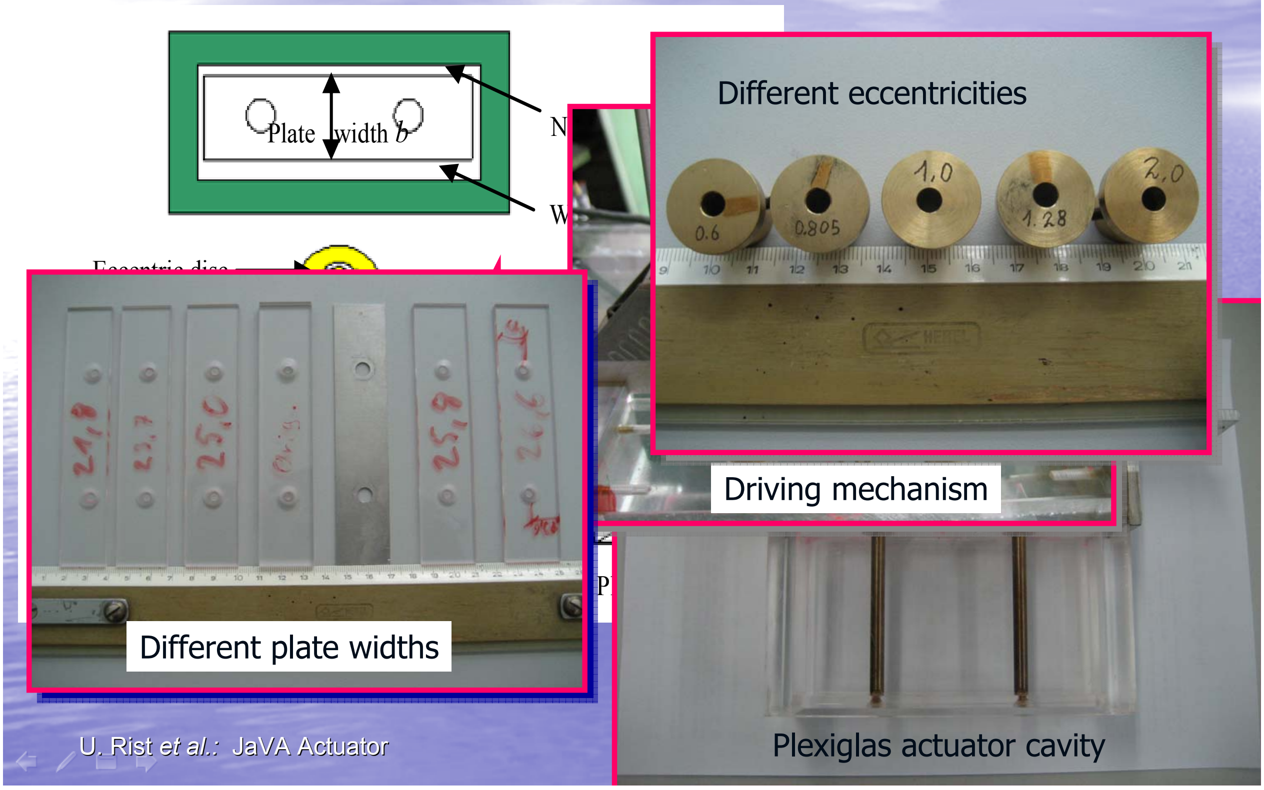


Figure 4. Horizontal flow: f=210 Hz, g_r=3, S_a=0.11, Re=134

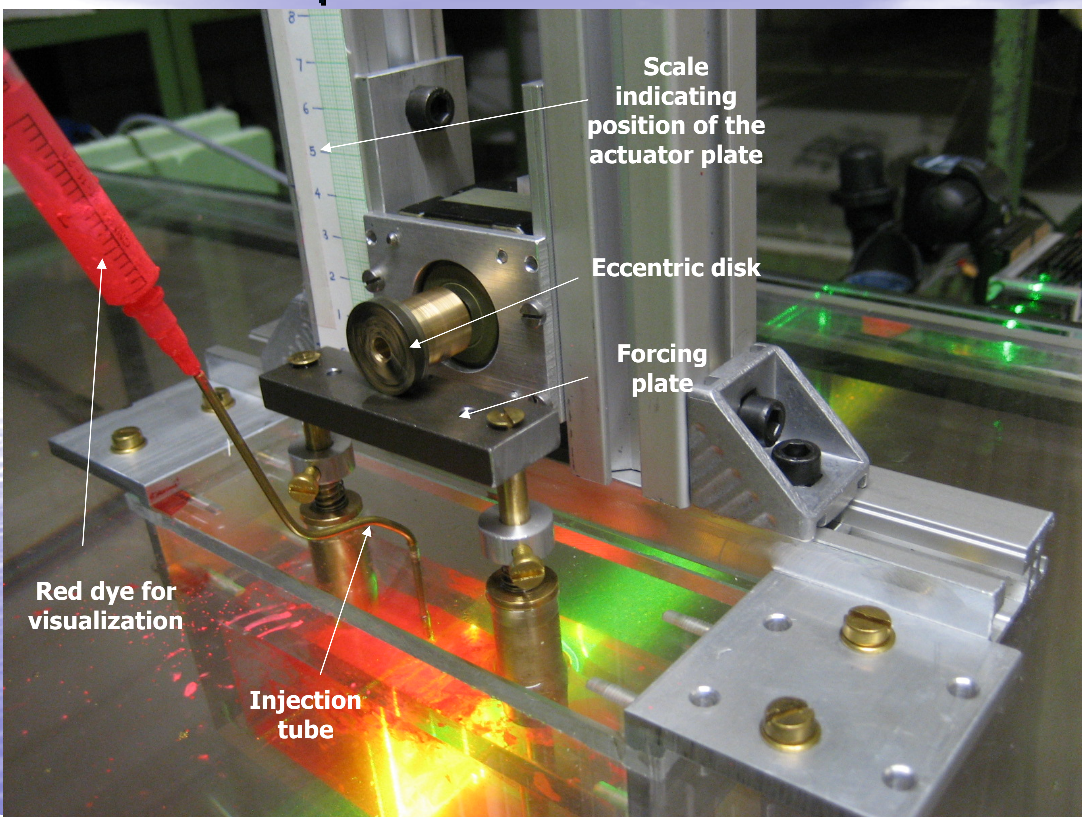
CFD Results of Rashad & Rist



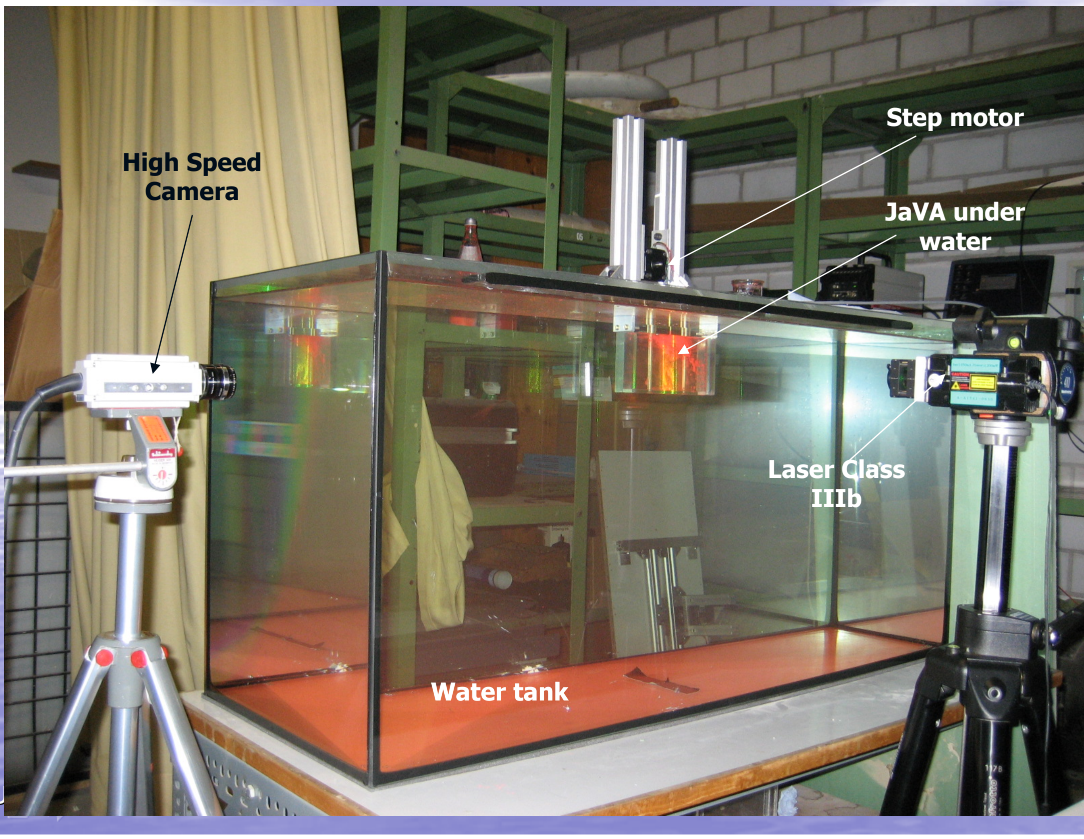
Construction of a JaVA for Experiments in Water



Operation of the JaVA

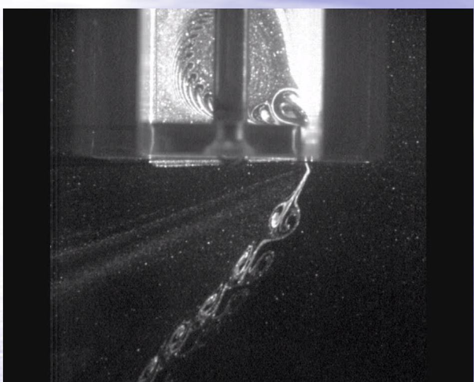


View of Experimental Setup

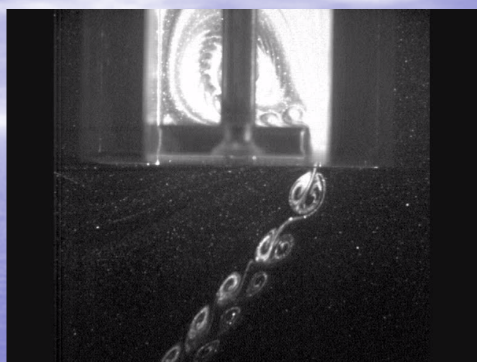


Effect of Reynolds Number

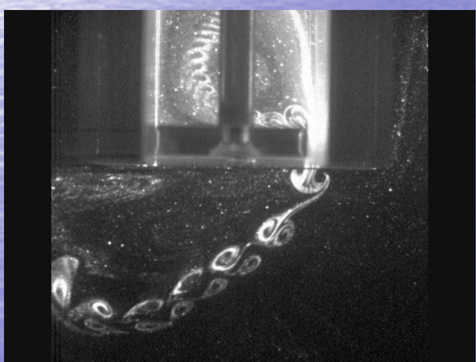
Re = 201
f = 1 Hz



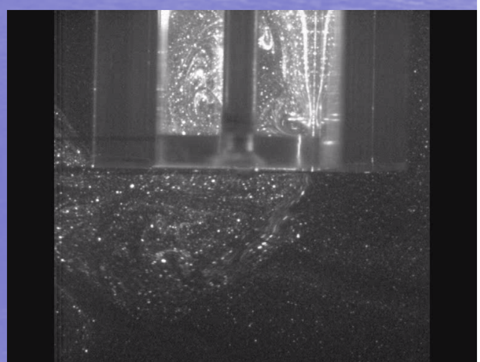
Re = 241
f = 1.2 Hz



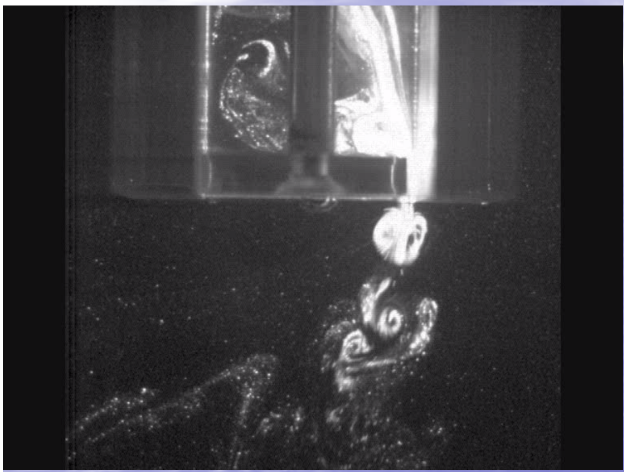
Re = 271
f = 1.35 Hz



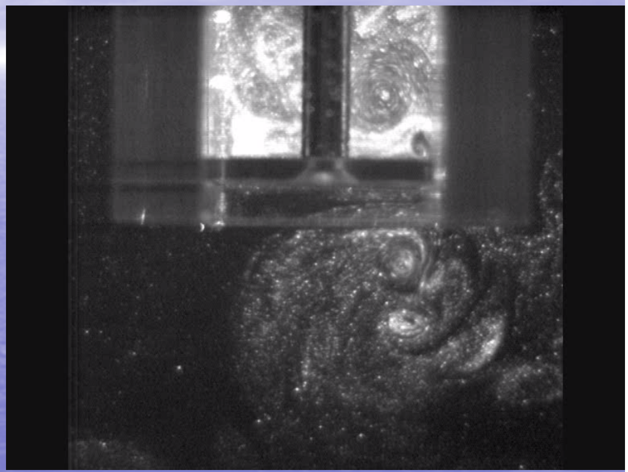
Re = 302
f = 1.5 Hz



Typical JaVA-induced Unsteady and Vortex Flows



Re = 402, S_a=0.32, g_w=0.1
(a = 1.28, b = 25, f = 2 Hz)



Re = 214, S_a=0.30, g_w=0.034
(a = 1.28, b = 26.6, f = 1 Hz)

Influence of Additional Parameters?

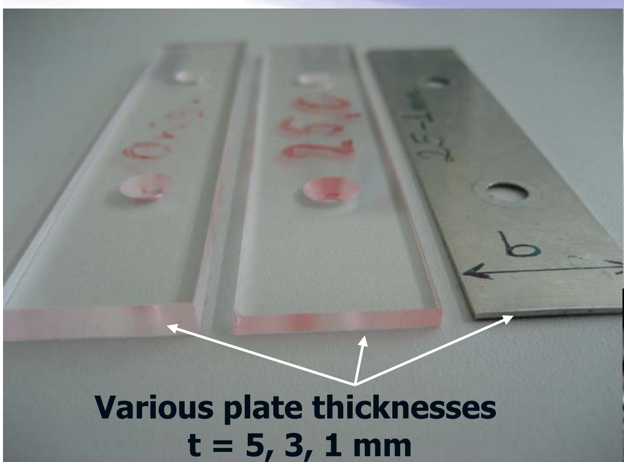
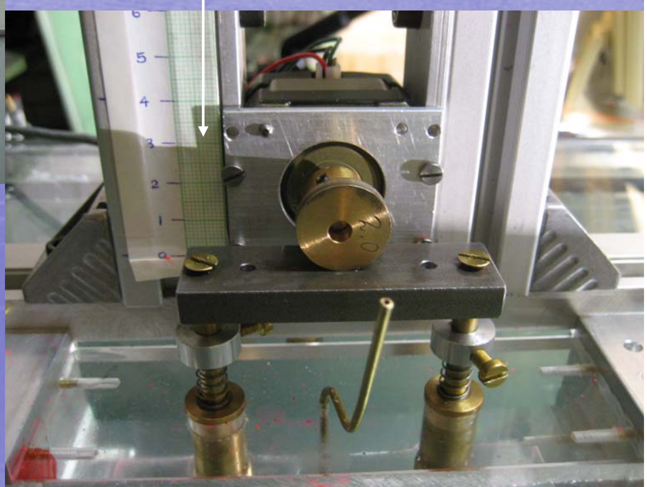
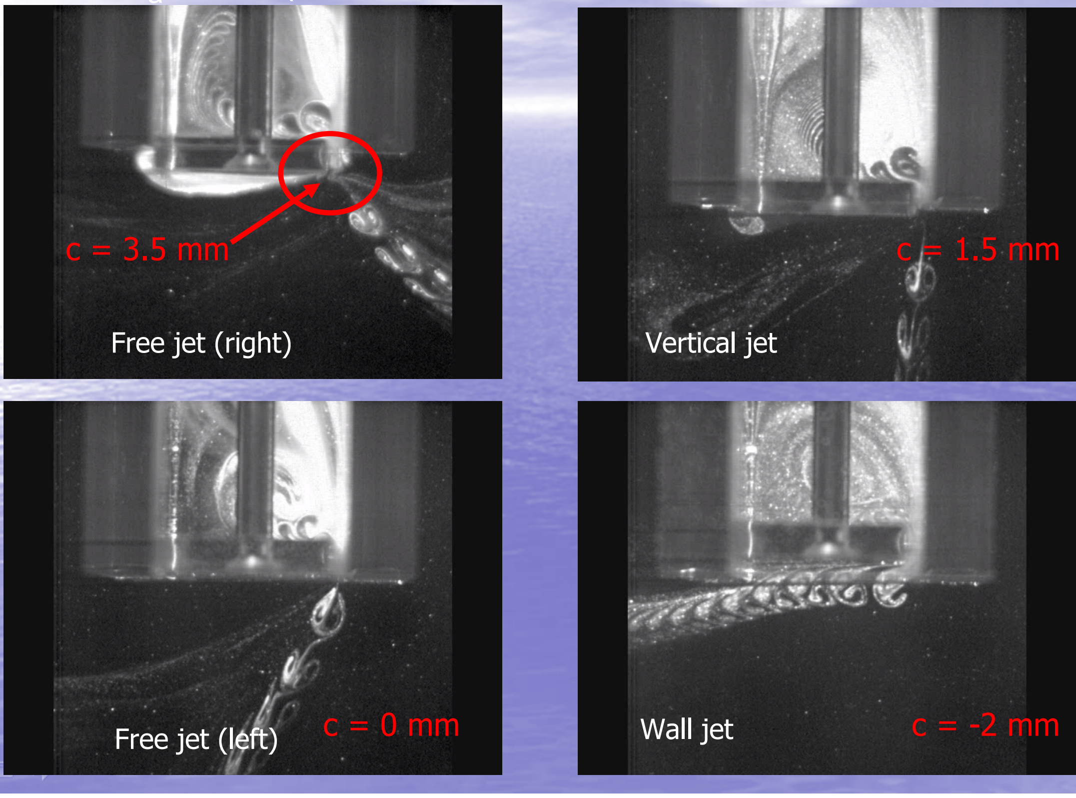


Plate mean position



Effect of Plate Mean Position

Re = 201, C_a=0.32 (a = 1.28, b = 25, f = 1 Hz, **c = -2,…,3.5 mm**)



Optical Flow Concept

Brightness change constraint. A common assumption on optical flow is that the image brightness $g(\boldsymbol{x}, t)$ at a point $\boldsymbol{x} = [x, y]^T$ at time t should only change because of motion. Thus, the total time derivative,

$$\frac{\mathrm{d}g}{\mathrm{d}t} = \frac{\partial g}{\partial x}\frac{\mathrm{d}x}{\mathrm{d}t} + \frac{\partial g}{\partial y}\frac{\mathrm{d}y}{\mathrm{d}t} + \frac{\partial g}{\partial t} \tag{10.1}$$

needs to equal zero. With the definitions $f_1 = \mathrm{d}x/\mathrm{d}t$ and $f_2 = \mathrm{d}y/\mathrm{d}t$, this directly yields the well-known *motion constraint equation* or *brightness change constraint equation*, BCCE [6]:

$$(\nabla g)^T \boldsymbol{f} + g_t = 0 \tag{10.2}$$

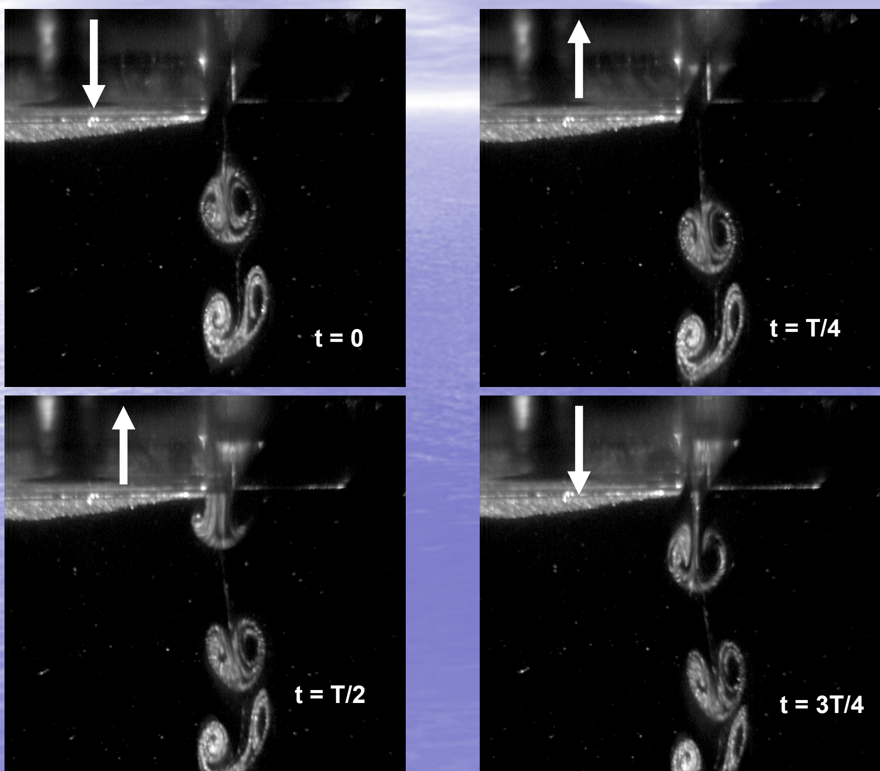
where $\boldsymbol{f} = [f_1, f_2]^T$ is the optical flow, ∇g defines the spatial gradient, and g_t denotes the partial time derivative $\partial g / \partial t$.

Optical Flow Concept

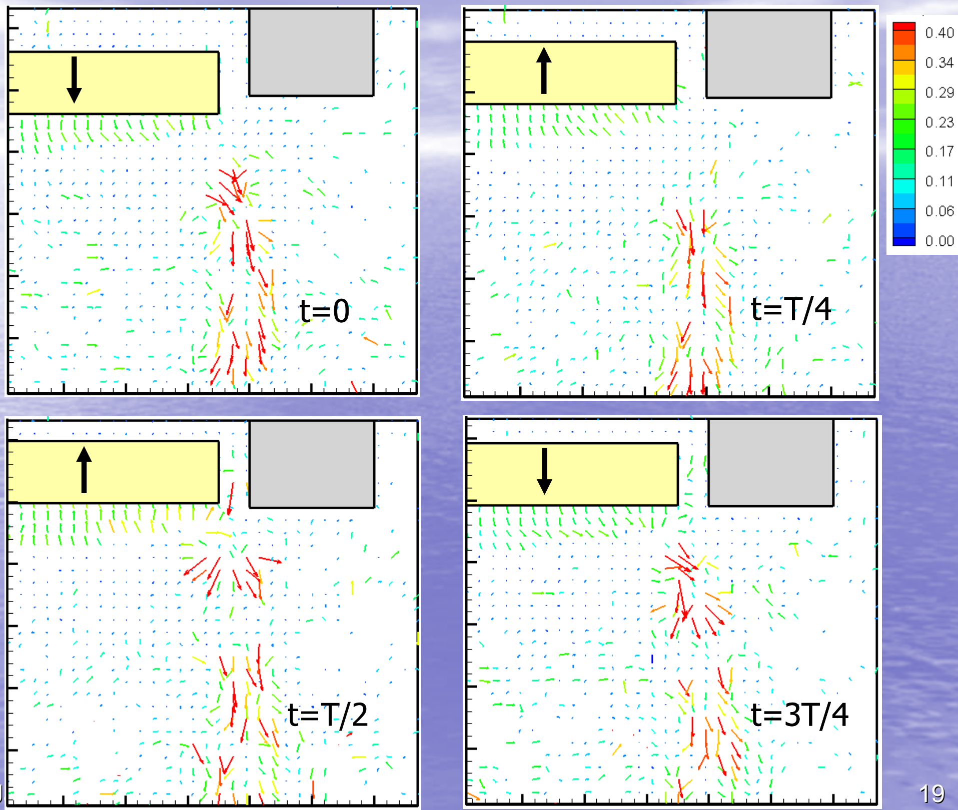
- Cannot be solved for a single point in the image, so some constraints are to be applied
- Assume that in a small neighborhood the velocity (optical flow) is constant
- Combining the pixels in the neighborhood we obtain an over determined system of equations
- Solve for $v_x = f_1$ and $v_y = f_2$ with the pseudo-inverse (based on least squares) method

Series of Snapshots from Movie

= 201, S_a=0.32 (a=1.28 mm, b=25 mm, f=1Hz, c=2 mm)

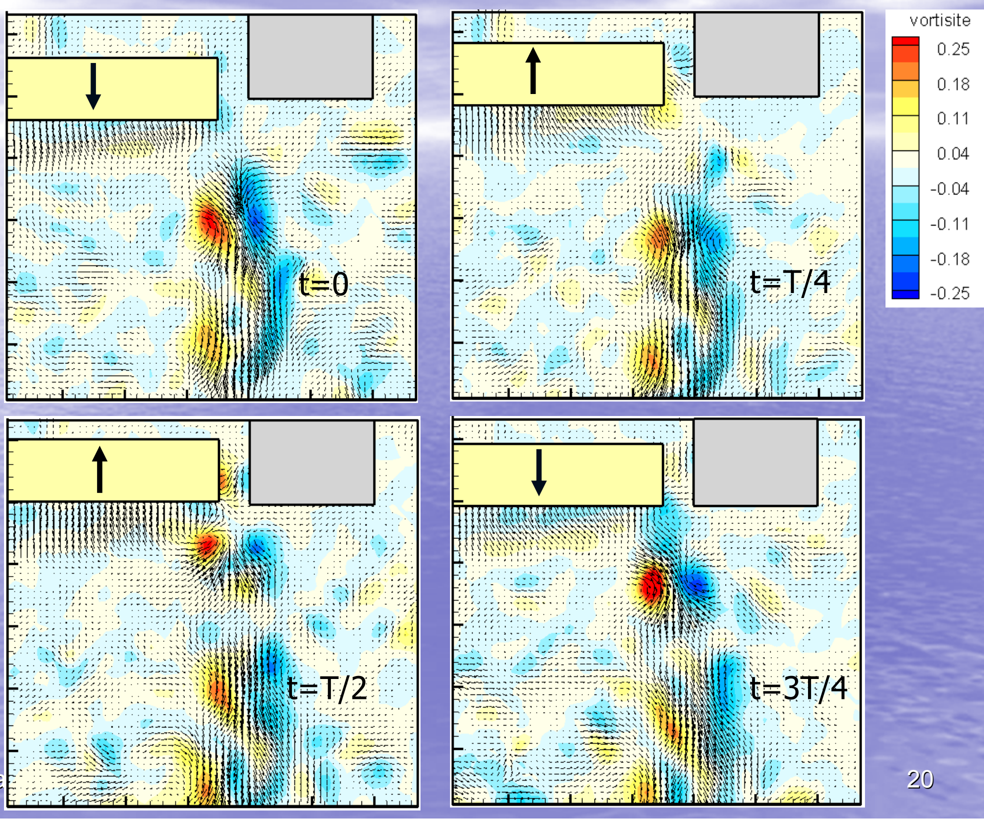


Extracted Flow Field



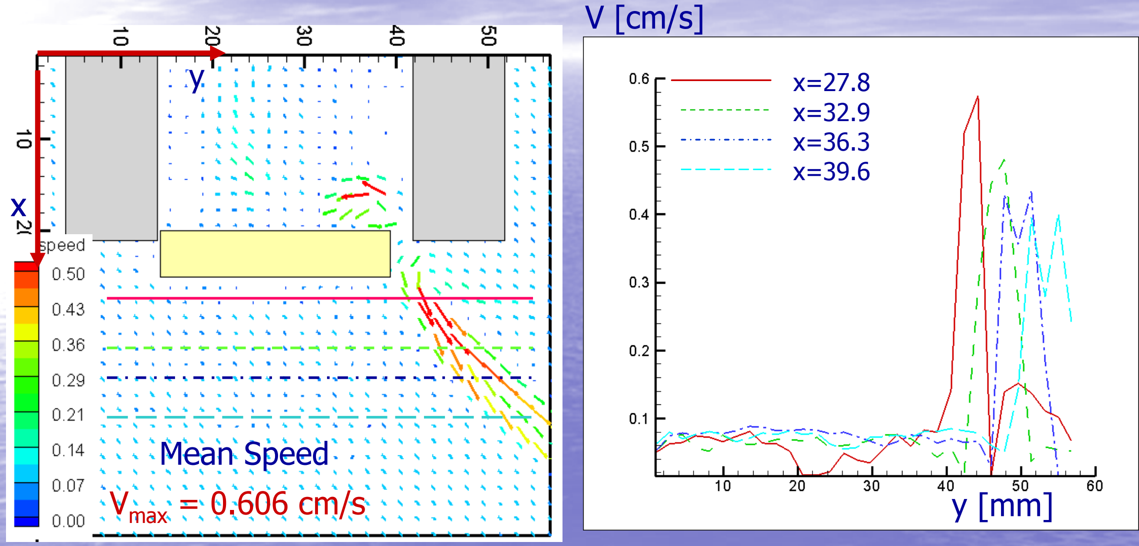
Instantaneous Vorticity Field

lution Enhancement and Smoothing of Optical Flow via Kriging



Averaged Flow Fields (1)

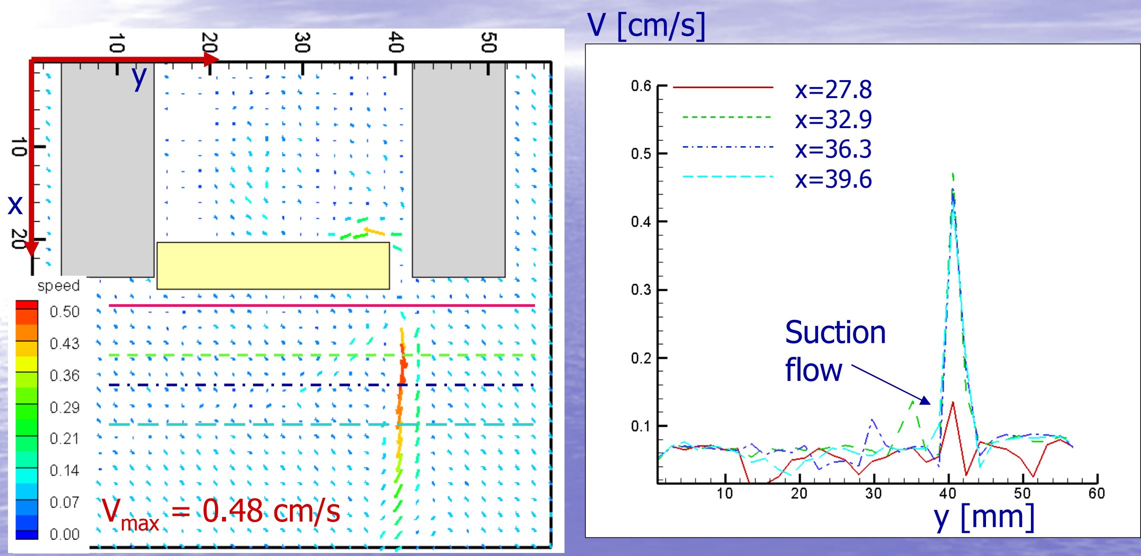
Re = 201, S_a=0.32 (a=1.28 mm / b=25 mm / f=1Hz / 3.5 mm)



Angled Jet to the Right

Averaged Flow Fields (2)

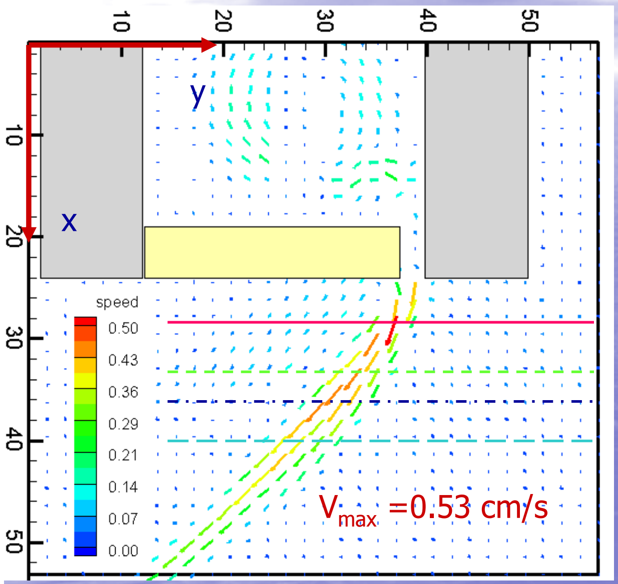
Re = 201, S_a=0.32 (a=1.28 mm / b=25 mm / f=1Hz / 2 mm)

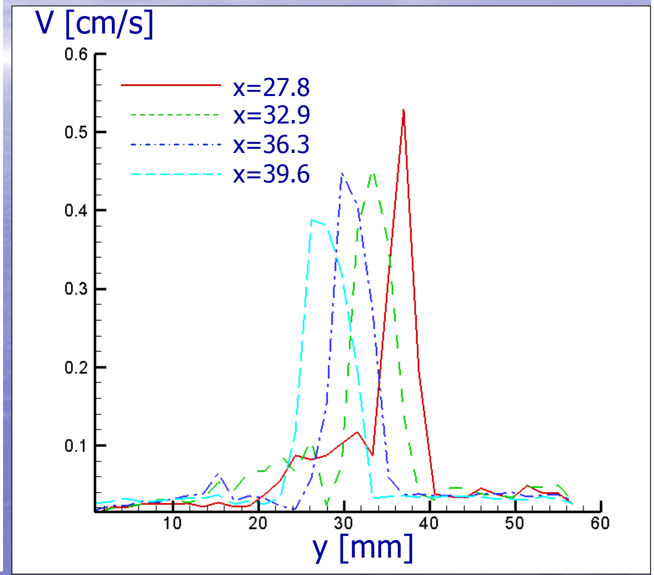


Free Vertical Jet

Averaged Flow Fields (3)

Re = 201, S_a=0.32 (a=1.28 mm / b=25 mm / f=1Hz / 0mm)

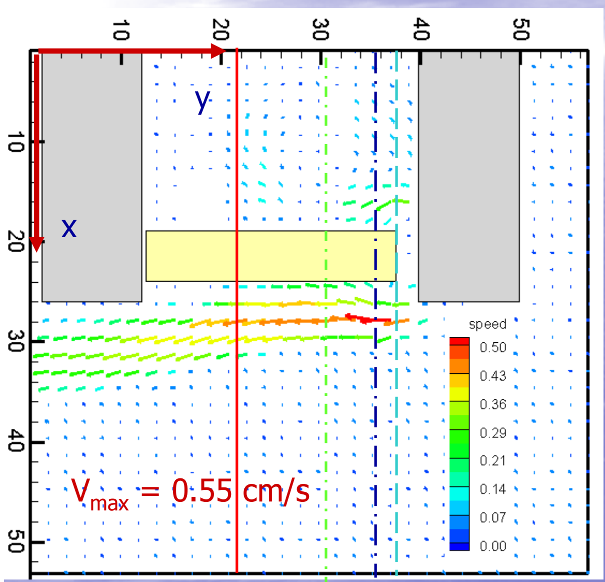


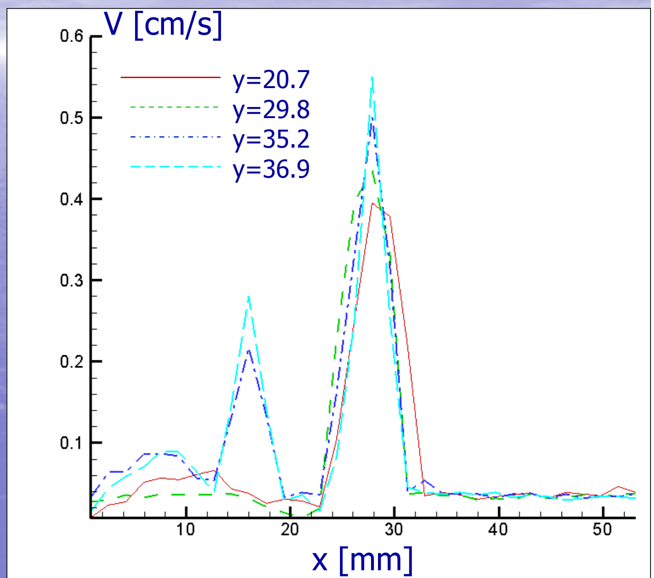


Angled Jet to the Left

Averaged Flow Fields (4)

Re = 201, S_a=0.32 (a=1.28 mm / b=25 mm / f=1Hz / -2 mm)





Wall Jet

Conclusions & Outlook

- Results of Lachowicz *et al.* repeated
- Parameters not documented by Lachowicz *et al.* are of influence
- Jet flows in various directions can be obtained by changing the mean position of the actuator plate
- Accurate quantitative data can be extracted via optical flow
- The typical JaVA-induced flows are also obtained via CFD simulations which give detailed information in the close proximity of the gaps
- Kriging and constraint interpolation techniques can be used for reconstruction, smoothing and enhancement of optical flow & PIV data
- Three-dimensional effects are confined to the ends of the JaVA for most flow types
- Preliminary results of JaVA mounted in a boundary layer look very promising