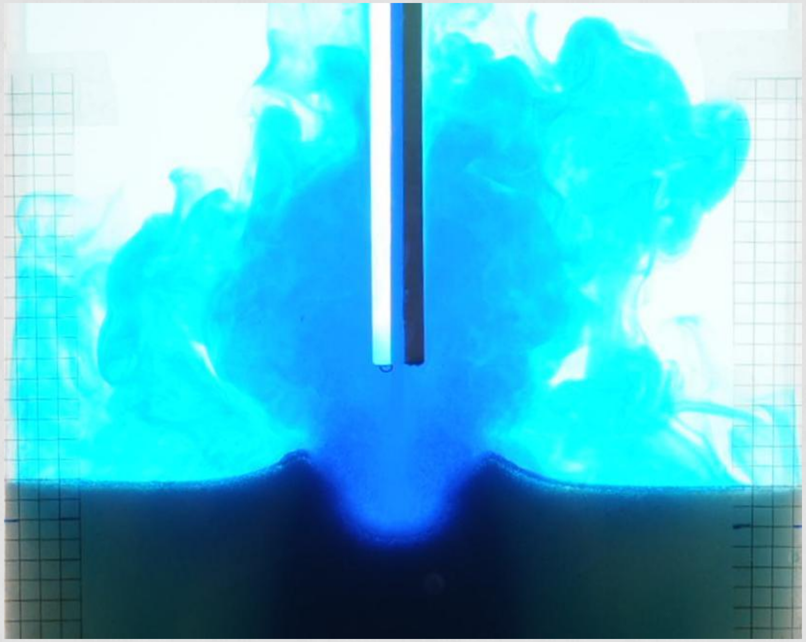
EROSION THRESHOLD OF A WATER IMMERSED GRANULAR BED BY A NORMAL WATER JET



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Laboratoire FAST, Orsay

FRANCE

ICSE 2012, Paris, August the 30th

EROSION BY JETS

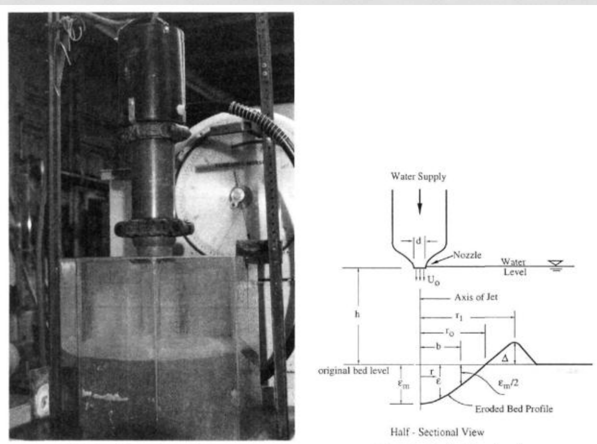


Fig. 1a. Experimental set-up. Fig. 1b. Definition sketch.

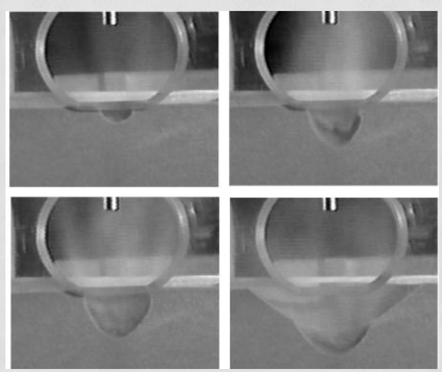
University of Alberta, Canada: Rajaratnam et *al.*

- Civil Engineering
- Many types of jets on grain beds

Figure 2. View of apparatus set-up *in situ*.

U.S. Departement of Agriculture: Hanson *et al*.

- Use in Civil Engineering
- Jet erosion Test on soils


Crater evolution as a function of time

NASA: Metzger *et al.*, *Journal of Aerospace Engineering* and *Soft condensed matter,* 2009

- Air jets on grain beds
- Lift-off/landing of rockets

EROSION BY VORTEX RINGS

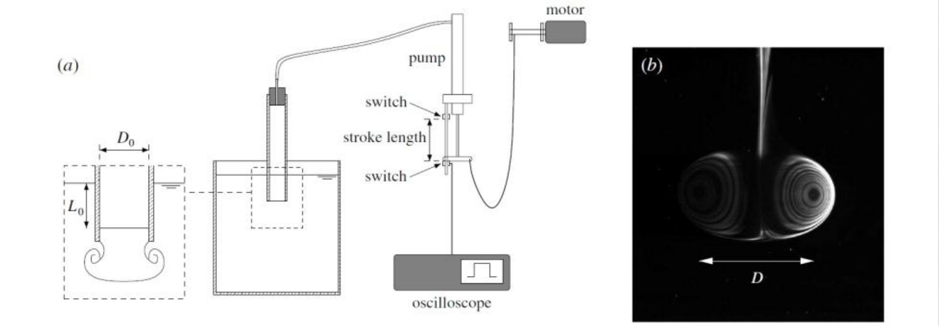


FIG. 1. (a) Schematic showing the system used to generate the vortex rings. The inset shows the slug length L_0, defined as the depth of fluid ejected from the orifice. (b) Image of an illuminated vortex-ring cross section illustrating how the ring diameter D is defined. The ring shown is fully formed with L_0/D_0 =0.9, D=4.0 cm, and Re=3700.

University of Cambridge, U.K.: Bethke *et al.*, *Physics of Fluids*, 2009 and 2012

Study of the critical conditions for particle resuspension and crater characteristics.

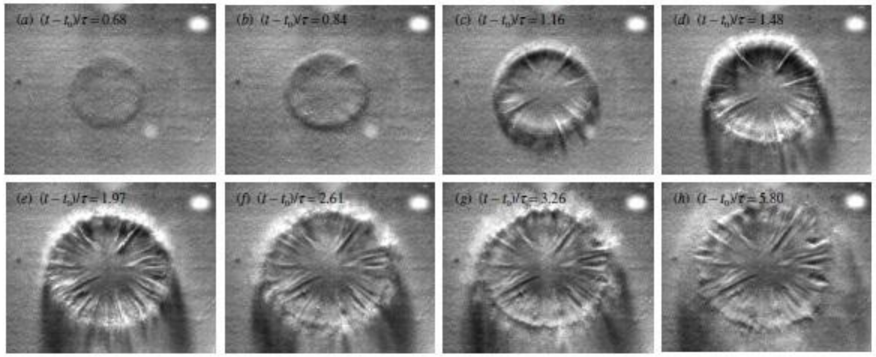


FIG. 7. Sequence of images showing an impact with d=150 μm (type B), $\theta=\theta_c$=6.2 D=5.0 cm, τ=0.106 s, and Re=11 800. Corresponding dimensionless times are included at the top of each frame. The images were taken viewing down onto the bed surface at an angle of approximately 10° to the vertical, illuminated by a light source directed across the layer surface.

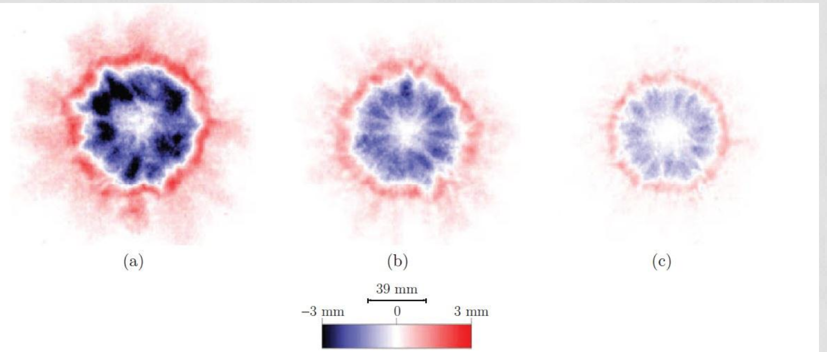
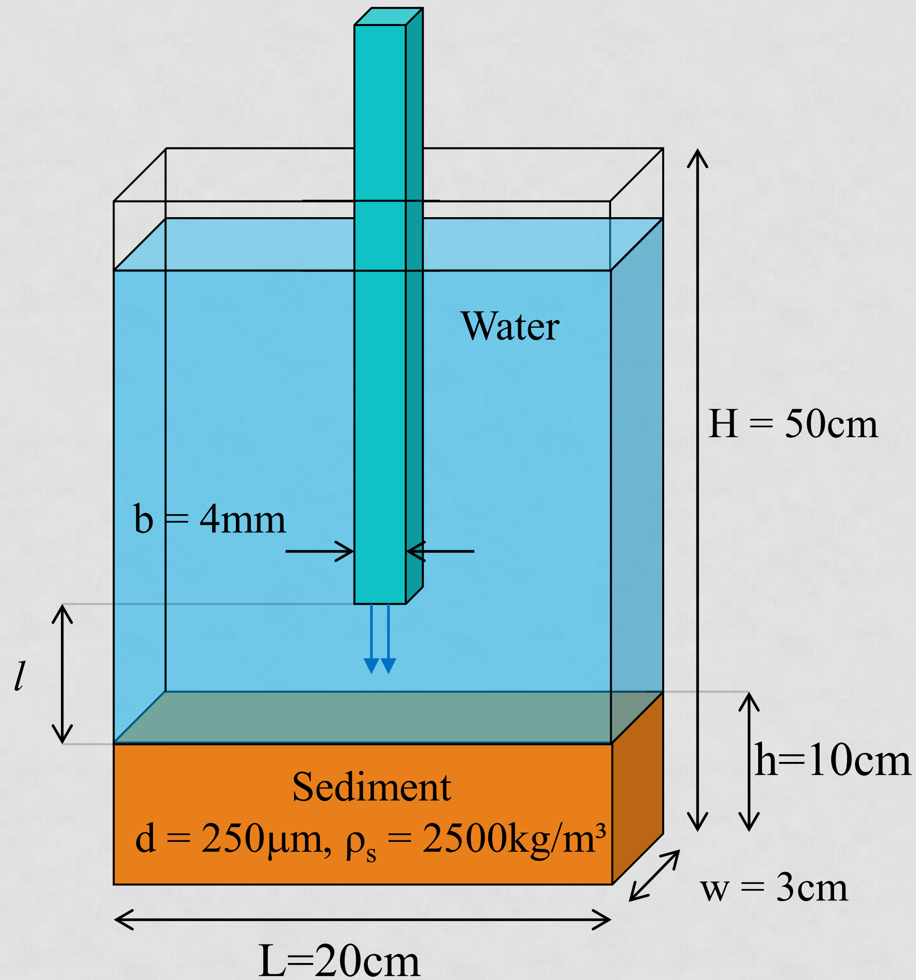


FIG. 10. Light attenuation images of craters on a 250 μm particle layer. The velocity of the vortex rings (L_s = 70 mm) was (a) $U \approx 709$ mm/s $\approx 7.3U_r$, (b) $U \approx 518$ mm/s $\approx 5.3U_r$ and (c) $U \approx 280$ mm/s $\approx 2.9U_r$.

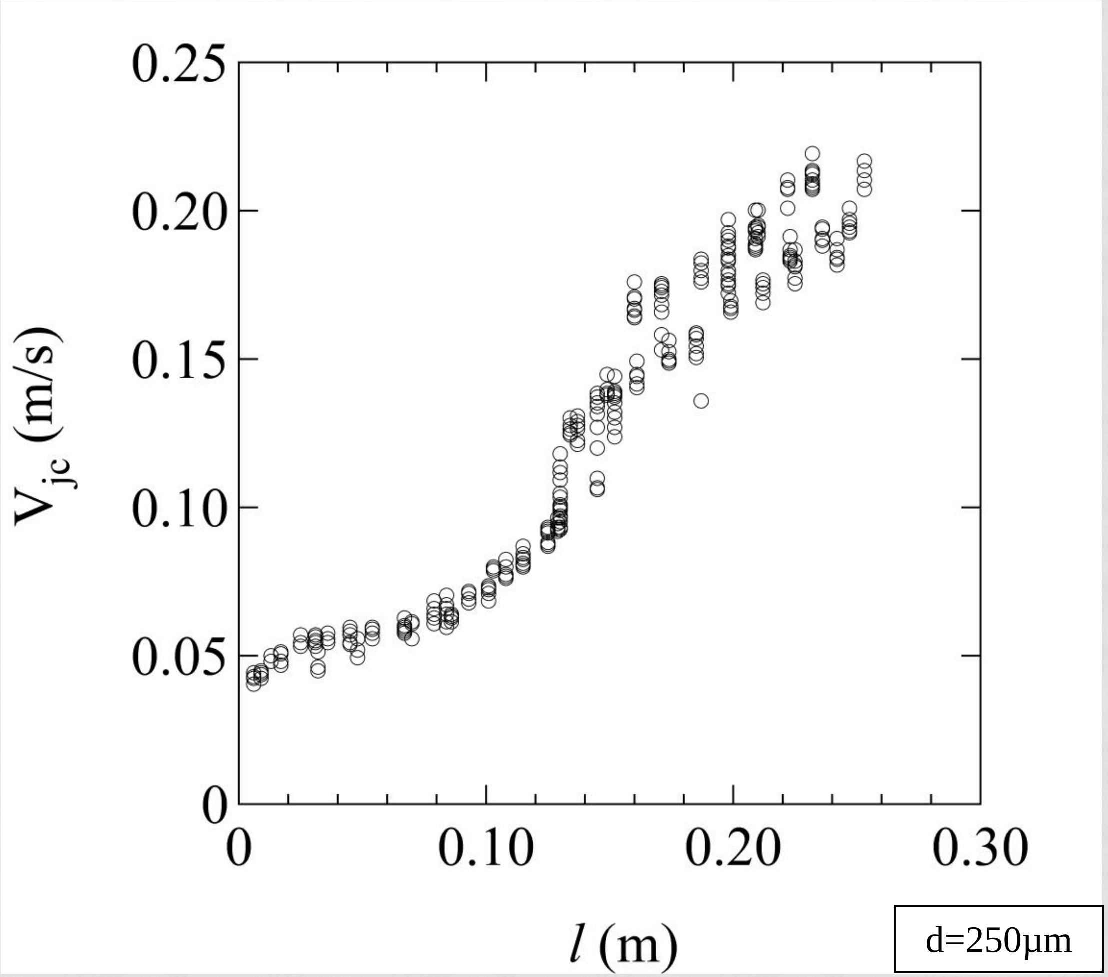
EXPERIMENTAL SETUP

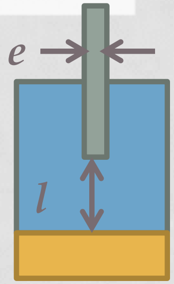


- Jet = sheet of 4 mm thickness
- $0{,}5 \leq l \leq 35$ cm
- Bi-dimensional setup:
  jet width ≈ tank width

Measurement of the mean jet velocity V_j at erosion threshold, as a function of the distance l

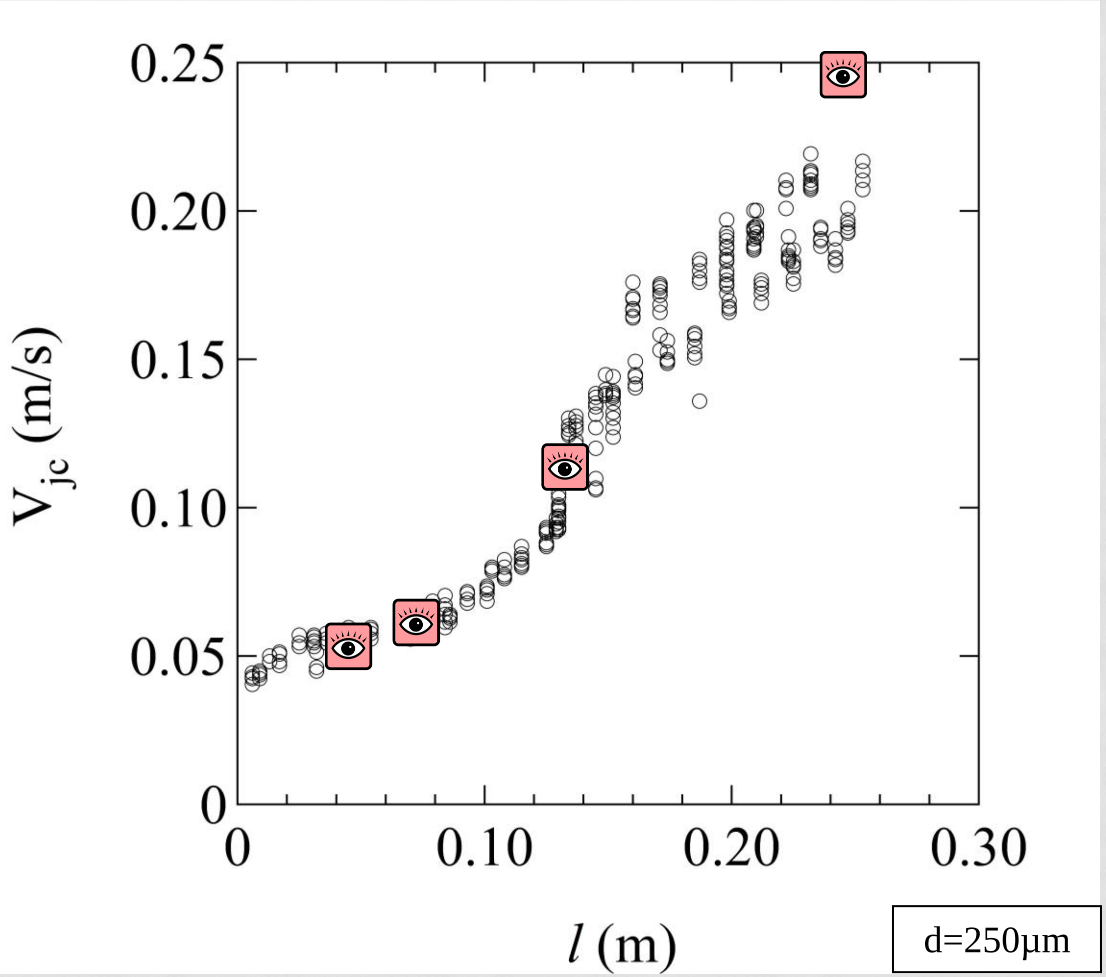
EROSION THRESHOLD

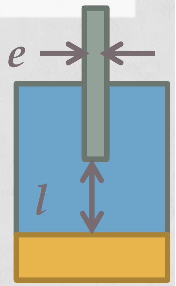




- Increase of V_j with l at threshold
- Non-uniform evolution

EROSION THRESHOLD

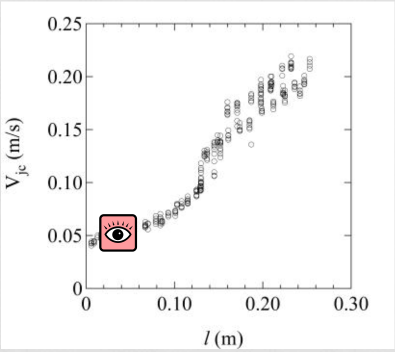


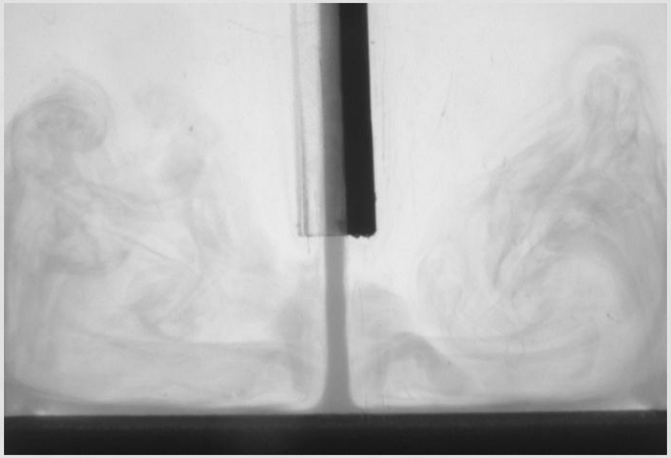


- Increase of V_j with l at threshold
- Non-uniform evolution

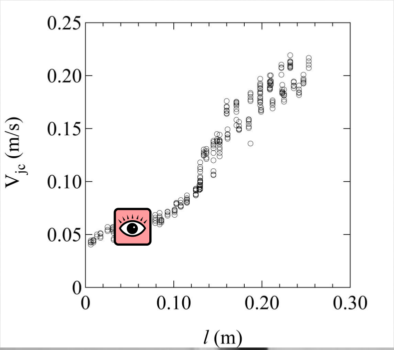
Flow visualisation with dye

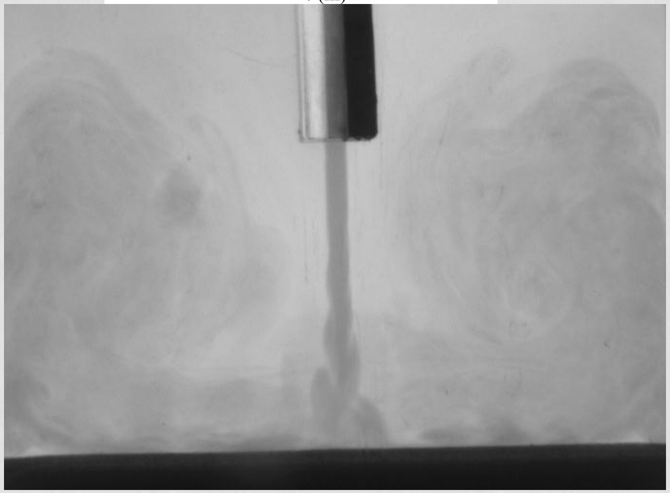
JET VISUALISATION AT THRESHOLD





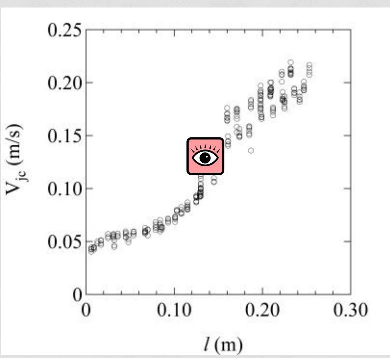
$l = 3{,}4$ cm
$V_j = 0{,}056\ \mathrm{m.s^{-1}}$
Rectilinear laminar jet

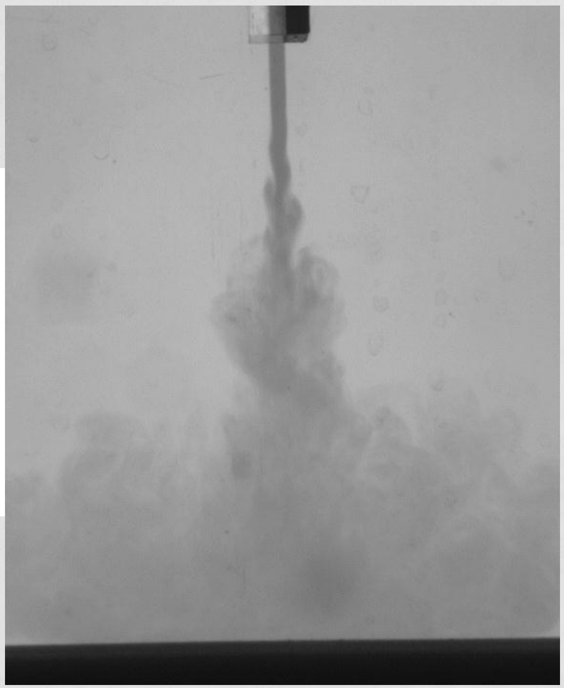




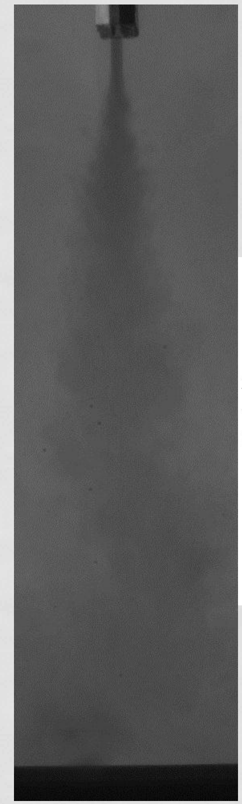
$l = 5{,}6$ cm
$V_j = 0{,}070\ \mathrm{m.s^{-1}}$
Oscillating jet

JET VISUALISATION AT THRESHOLD

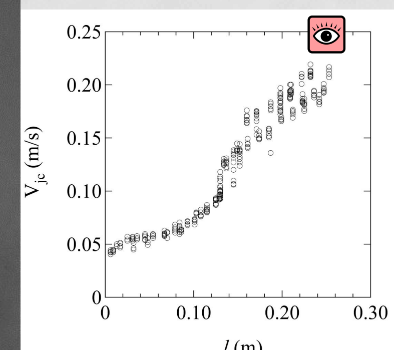




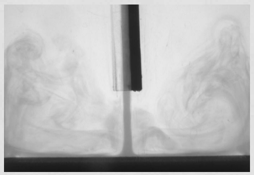
$l = 13{,}5$ cm
$V_j = 0{,}134\ \mathrm{m.s^{-1}}$
Mixed jet



$l = 25$ cm
$V_j = 0{,}261\ \mathrm{m.s^{-1}}$
Turbulent jet

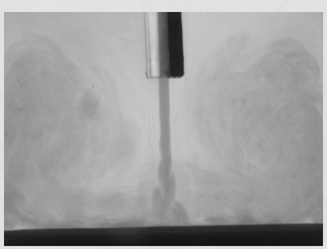


JET VISUALISATION AT THRESHOLD

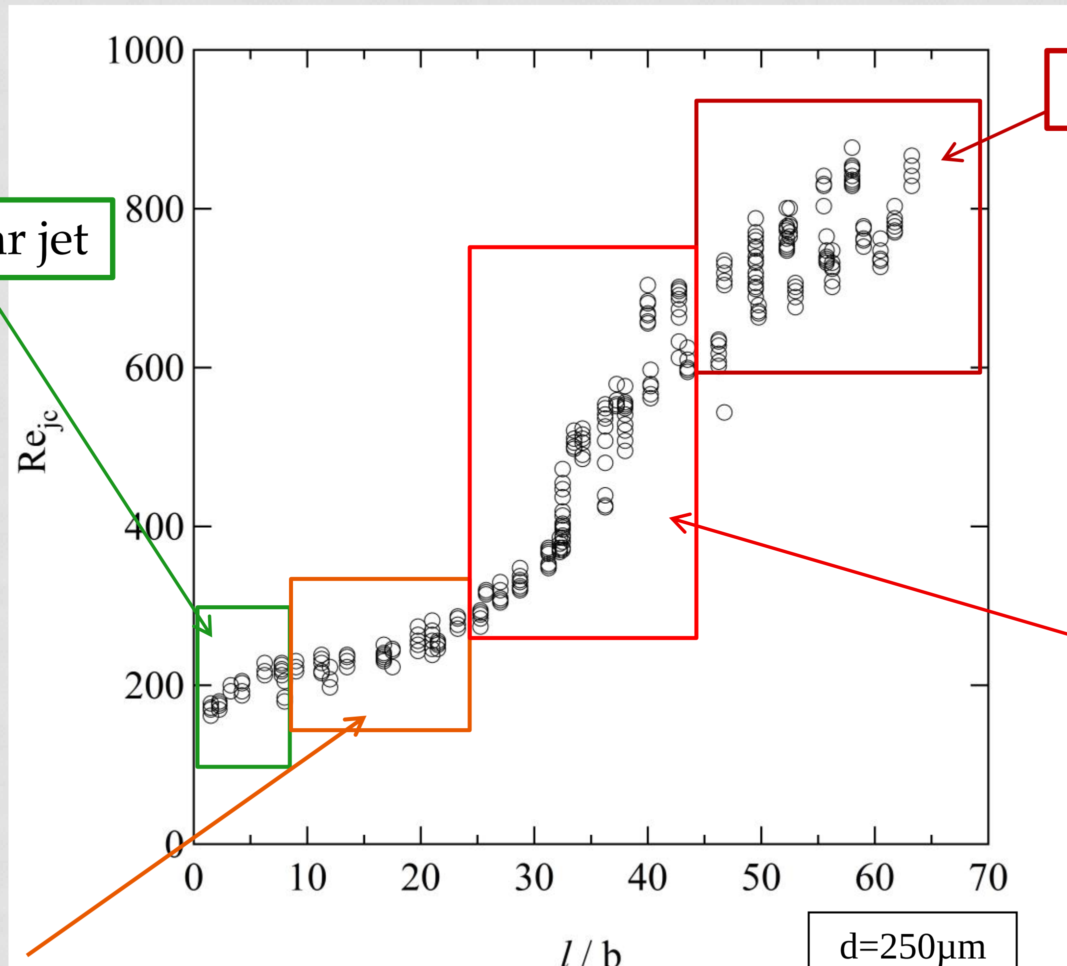


Rectilinear laminar jet

$$Re_j = \frac{V_j b}{\nu}$$



Oscillating jet

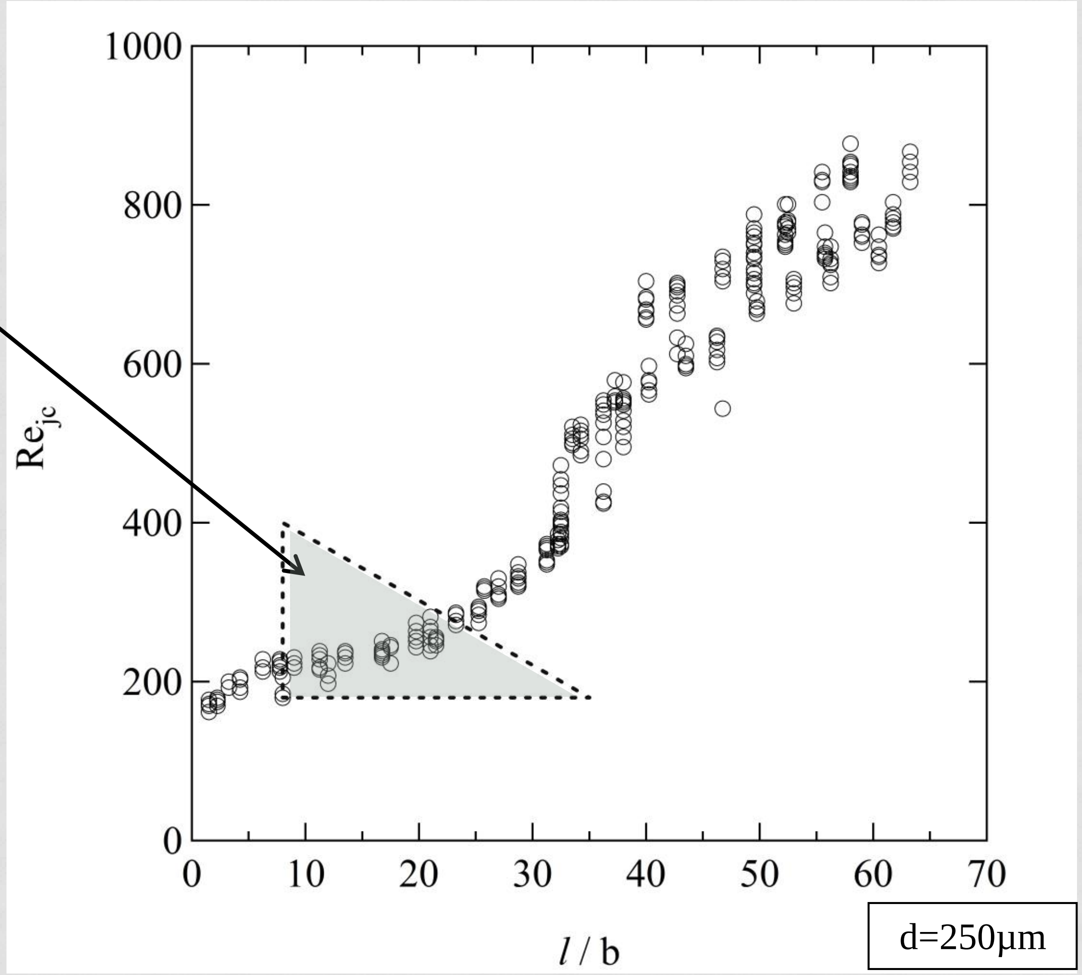


Turbulent jet

Mixed jet

JET VISUALISATION AT THRESHOLD

Locked regime: the jet sees the confinement.

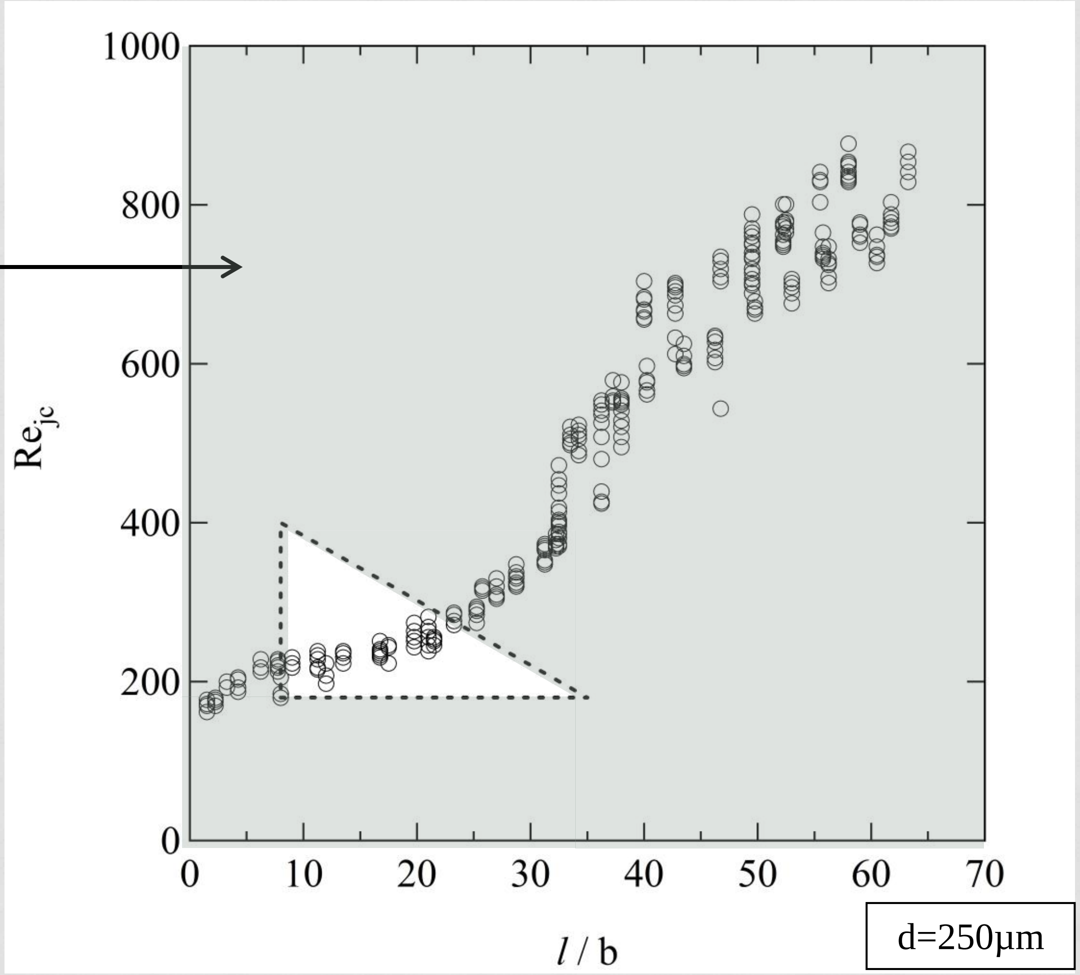


PMMH, ESPCI, Schlumberger in Paris:

Maurel et *al.*, *Physical Review E*, 1996

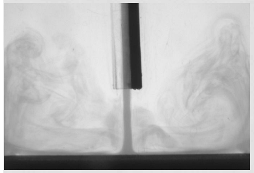
JET VISUALISATION AT THRESHOLD

Free jet

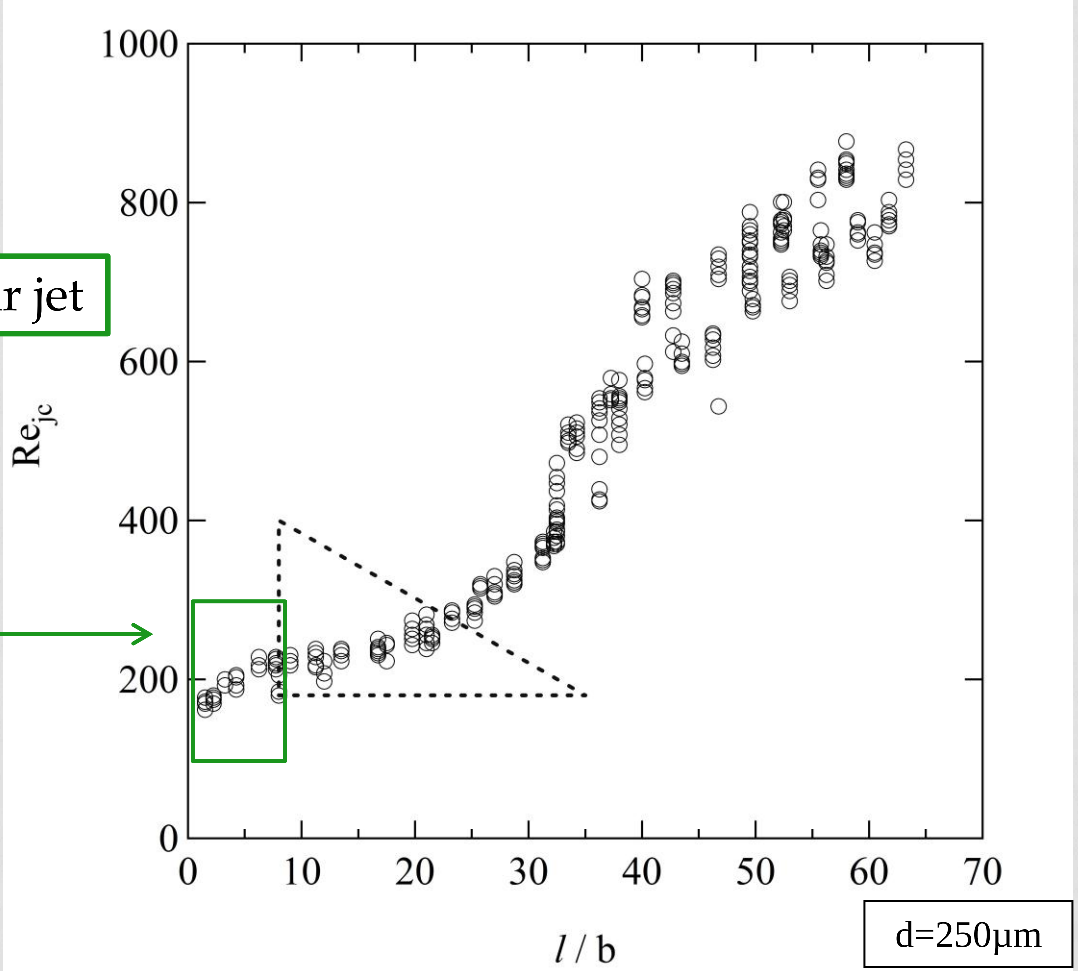


Maurel et *al.*, *Physical Review E*, 1996

JET VISUALISATION AT THRESHOLD



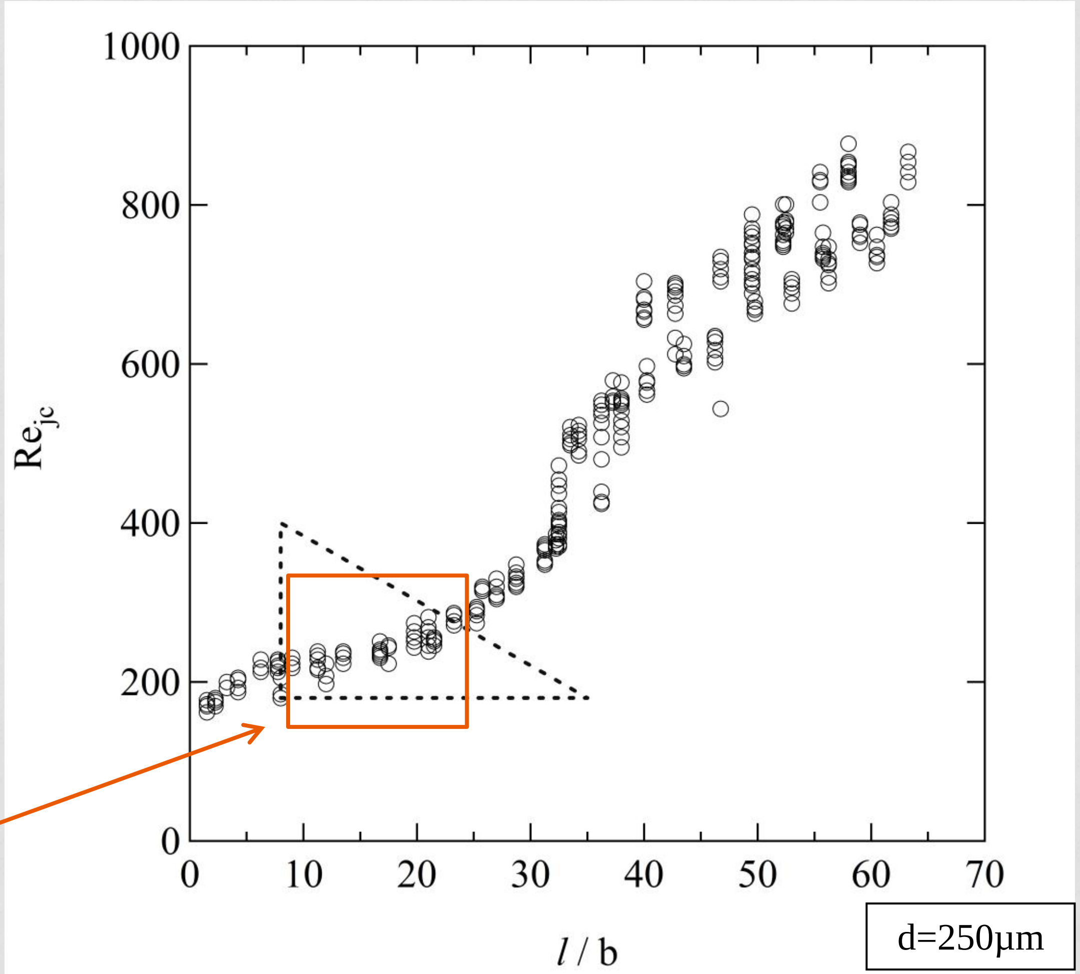
Rectilinear laminar jet



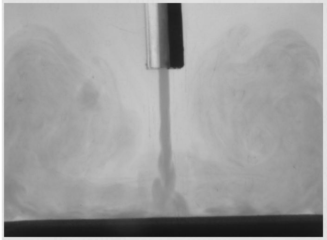
d=250µm

Maurel et *al.*, *Physical Review E*, 1996

JET VISUALISATION AT THRESHOLD

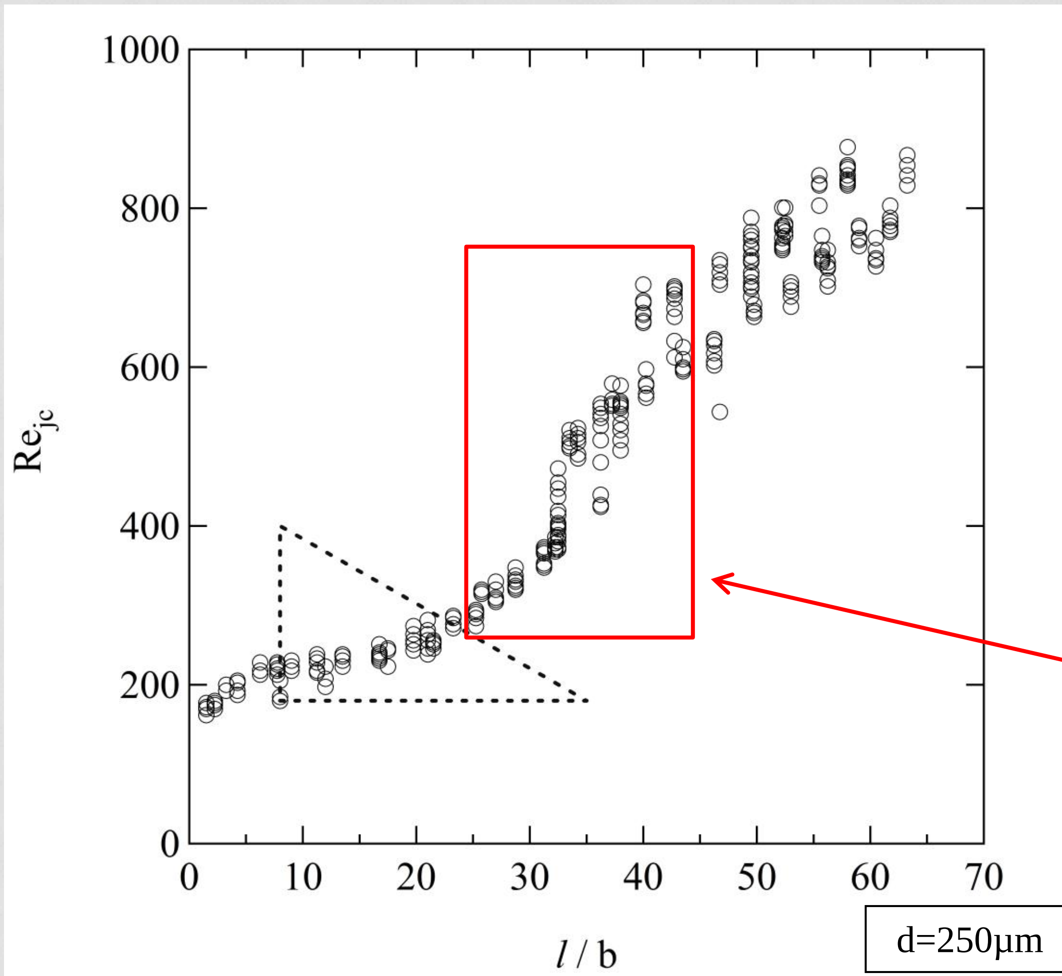


Maurel et *al.*, *Physical Review E*, 1996



Oscillating jet

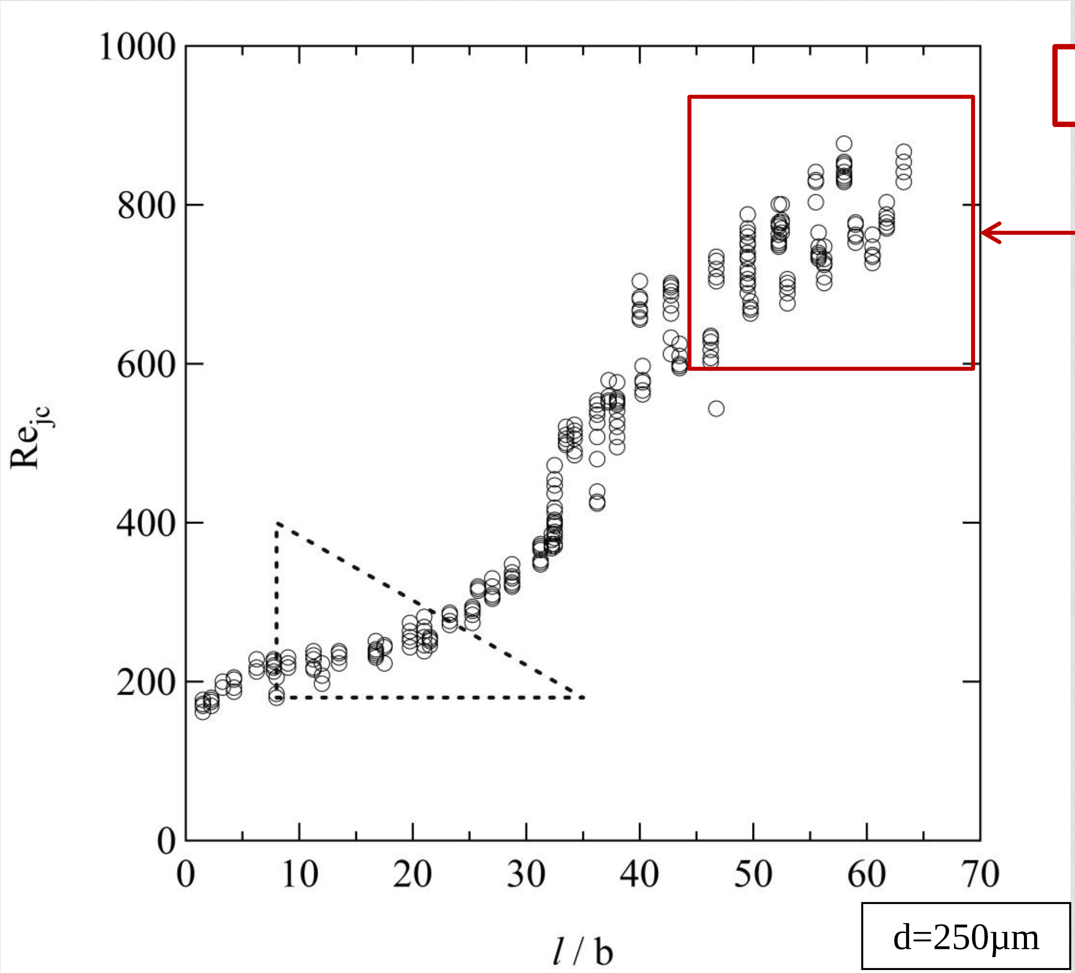
JET VISUALISATION AT THRESHOLD



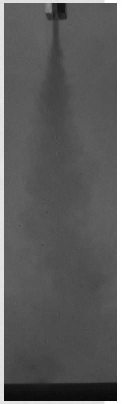
Maurel et *al.*, *Physical Review E*, 1996

Mixed jet

JET VISUALISATION AT THRESHOLD

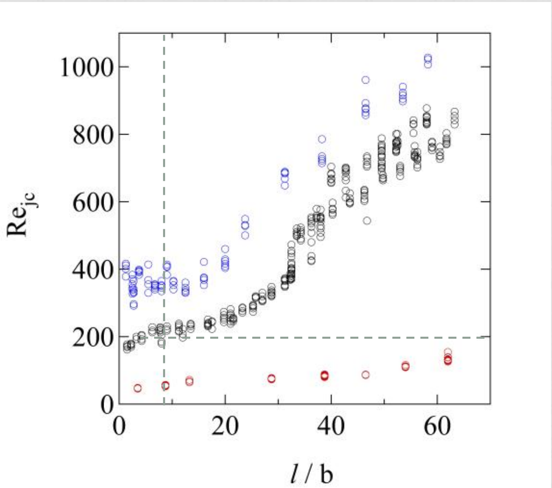


Turbulent jet



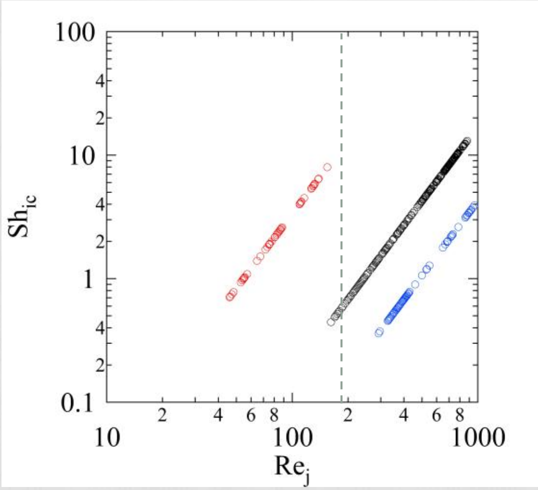
Maurel et *al.*, *Physical Review E*, 1996

EROSION PARAMETERS



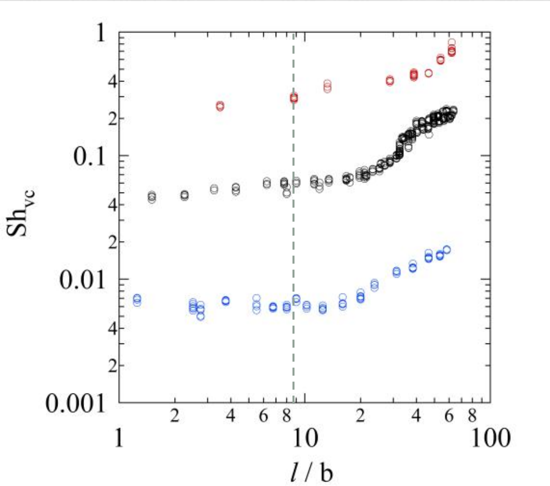
3 parameters:
- l/b for jet confinement
- Re_j for jet hydrodynamics
- Sh for sediment erosion

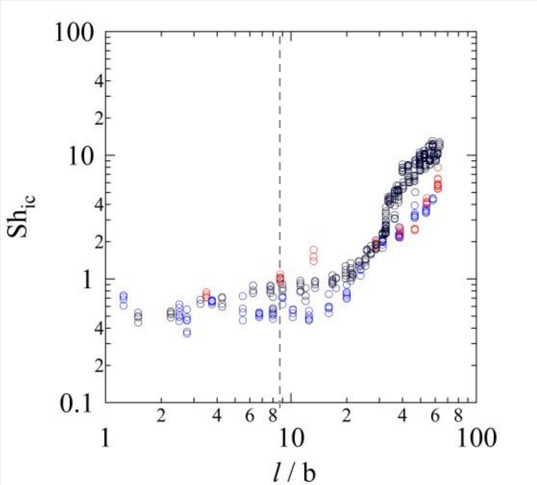
	d = 250 μm	d = 1 mm
$\nu = 1.10^{-6} m^2 s^{-1}$	○	○
$\nu = 4.10^{-6} m^2 s^{-1}$	○	



Viscous Shields

$$Sh_\nu = \frac{\mu V_j}{\Delta\rho g d^2}$$





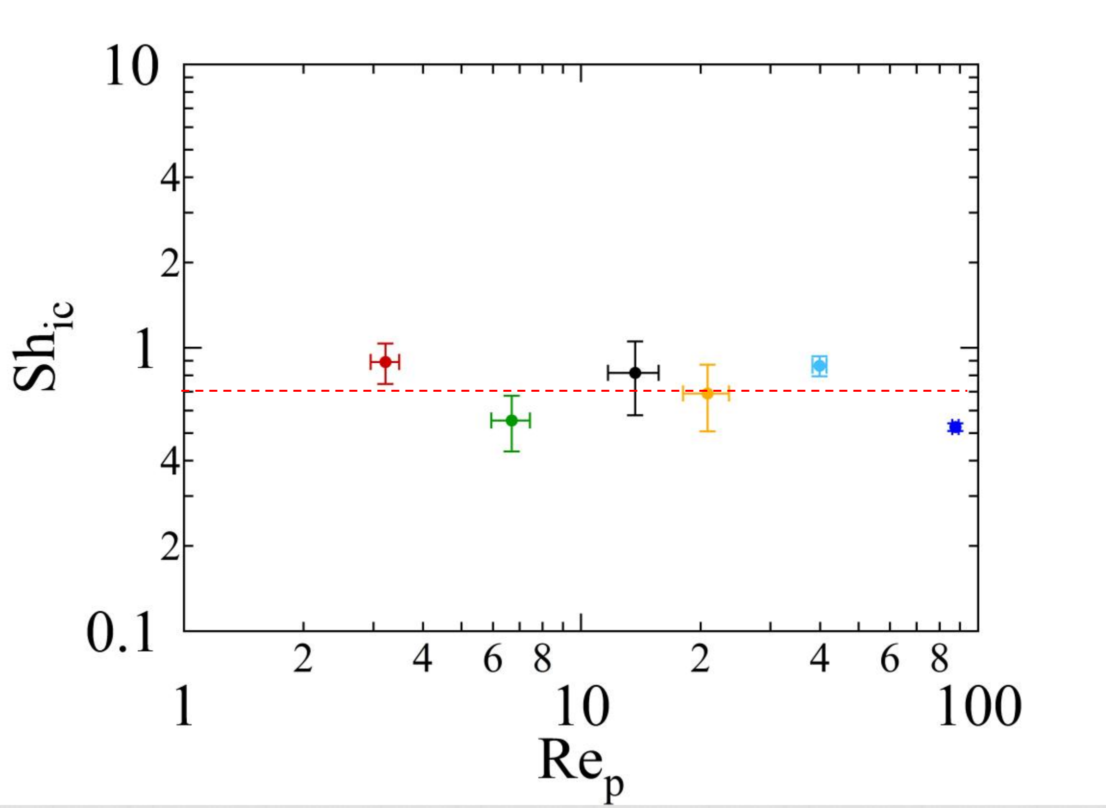
Inertial Shields

$$Sh_i = \frac{\rho V_j^2}{\Delta\rho g d}$$

INERTIAL REGIME

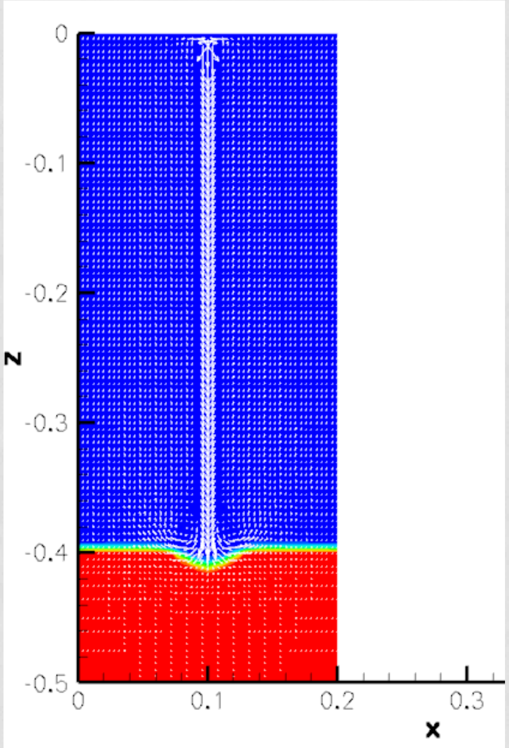
	$d = 250$ µm	$d = 350$ µm	$d = 500$ µm	$d = 1$ mm
$\nu = 1\,.10^{-6}\text{m}^2\text{s}^{-1}$	●	●	●	●
$\nu = 1{,}6\,.10^{-6}\text{m}^2\text{s}^{-1}$	●			
$\nu = 4\,.10^{-6}\text{m}^2\text{s}^{-1}$	●			

$$\mathrm{Sh}_i = \frac{\rho V_j^2}{\Delta\rho g d} \qquad \mathrm{Re}_p = \frac{V_j d}{\nu}$$



- Threshold measurements at $l/b \approx 5$
- Constant Sh_i in the inertial regime $\mathrm{Re}_p > 1$

CONCLUSIONS AND PERSPECTIVES



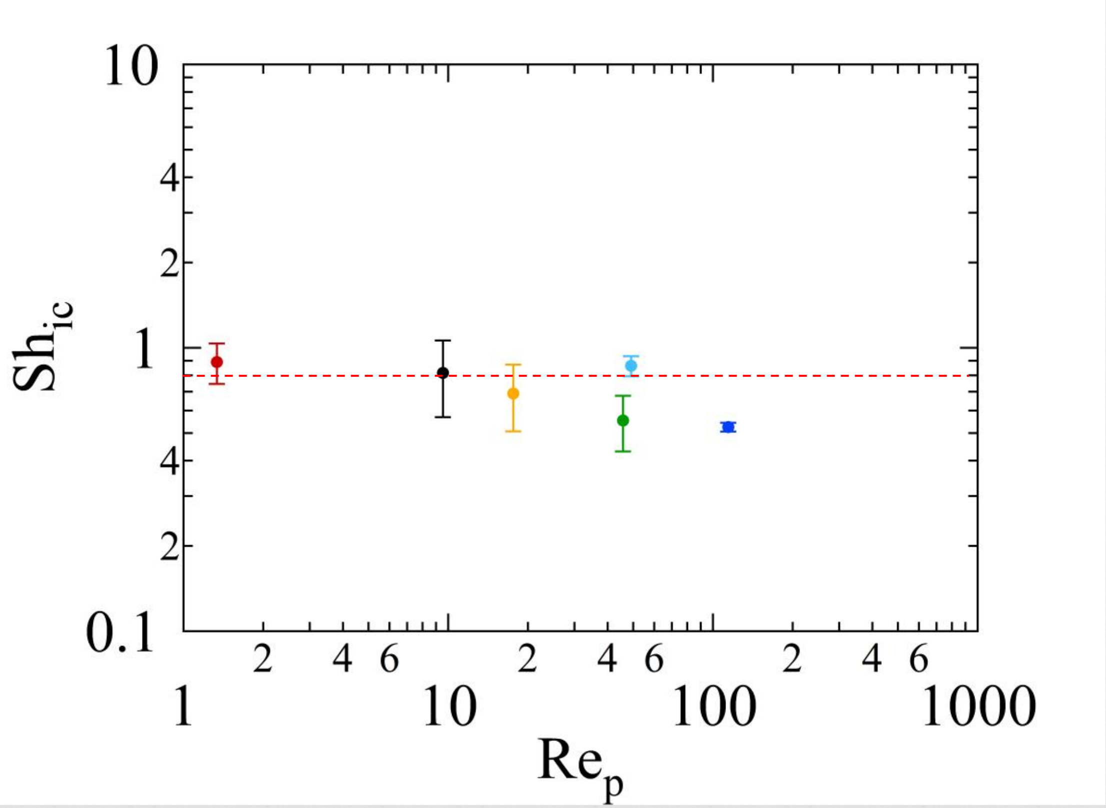
- Detailed study of erosion threshold

- Collaboration with **LHSV** lab
(D. Nguyen, F. Levy, J-S. Finck et D. Pham-Van-Bang**)** on a numerical model**.**

- Crater formation above threshold.

INERTIAL REGIME

	$d = 250$ µm	$d = 350$ µm	$d = 500$ µm	$d = 1$ mm
$\nu = 1\,.10^{-6}\mathrm{m^2s^{-1}}$	● (black)	● (yellow)	● (light blue)	● (dark blue)
$\nu = 1{,}6\,.10^{-6}\mathrm{m^2s^{-1}}$	● (green)			
$\nu = 4\,.10^{-6}\mathrm{m^2s^{-1}}$	● (red)			



$$\mathrm{Sh}_i = \frac{\rho V_j^2}{\Delta\rho g d} \qquad \mathrm{Re}_s = \frac{V_{sed} d}{\nu}$$

$$V_{sed} = \sqrt{\frac{3}{2}\frac{\Delta\rho g d}{C_D \rho}}$$

$$C_D = \frac{24}{Re_p}\left(1 + 0{,}15 Re_p\right)^{0{,}687}$$

$$Re_p = \frac{V_j d}{\nu}$$

Threshold measures at $l/b \approx 5$

Constant Sh_i in the inertial regime $\mathrm{Re}_p > 1$

INFLUENCE OF CELL WIDTH