Chaotic sedimentation of low-Re particles in a vertical channel.

Romuald Verjus

Sylvain Guillou Jean-Régis Angilella

LUSAC, Université de Caen Basse-Normandie (France)

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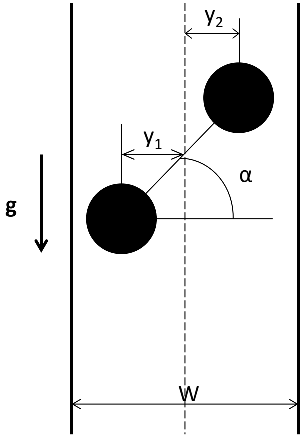
Chaotic sedimentation of low-Re particles in a vertical channel.

- Sedimentation of heavy particles in a vertical column : great interest in industry or natural science.

- Complex relation between sedimentation velocity and particle characteristics.

- Simplification : 2D circular particles.

Sedimentation of particle pairs



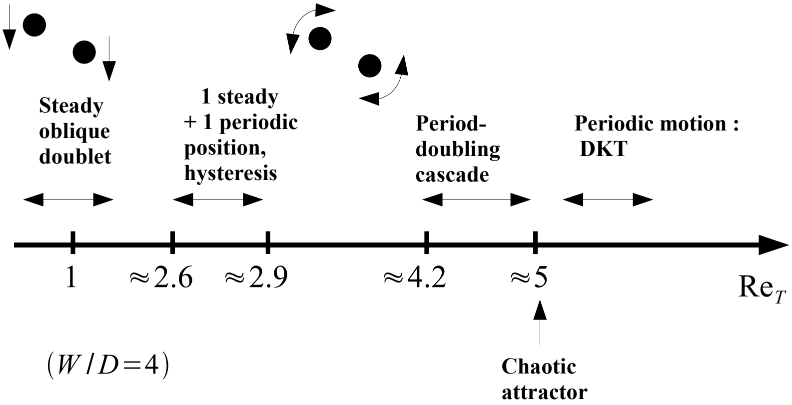
Particle/wall and particle/particle hydrodynamic interactions influence the sedimentation.

Sedimentation of particle pairs

Steady oblique doublet, $R_{eT} = 1.78$, $\frac{W}{D} = 8$ (Feng, Hu & Joseph 1994).

Sedimentation of particle pairs

... but sedimentation of pairs appears to be more complex (Aidun & Ding 2003) :



Sedimentation of particle pairs

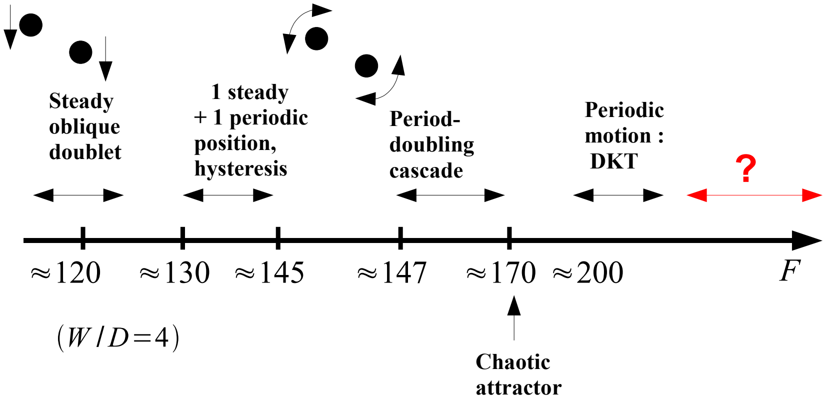
Question :

how does the pair sediment when one increases the weight of the inclusion ?

More inertial regimes

- Choice of the control parameter :

$F = \frac{\pi}{4}\frac{D^3 g}{\nu^2}(\frac{\rho_p}{\rho_f} - 1)$ (non-dim weight+buoyancy), rather than Re_T.



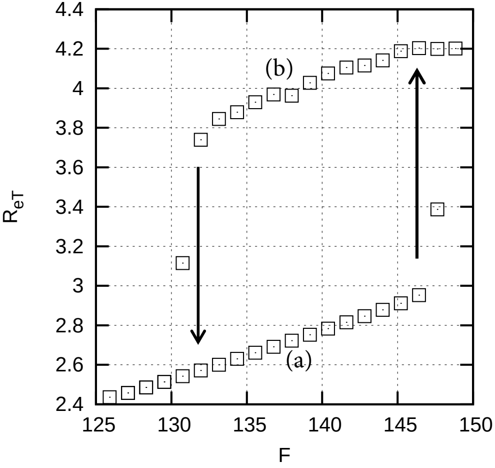
Numerical method

- DFFD : Direct Forcing Fictitious Domain Method (Yu & Shao 2007).

- Time stepping : fractional step method.

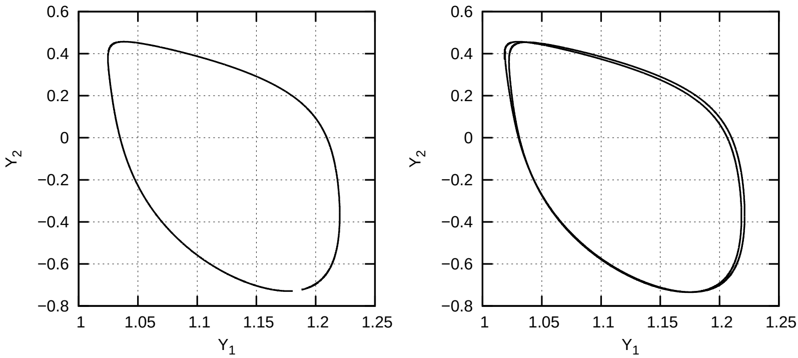
- Spatial discretization : staggered grid, 2nd order finite differences.

$130 < F < 145$: multiple stable states and hysteresis



(a) : steady oblique doublet, $\alpha \approx 30^o$. (b) : oscillating oblique doublet, $\alpha \approx 45^o$.
(See also Aidun & Ding 2003.)

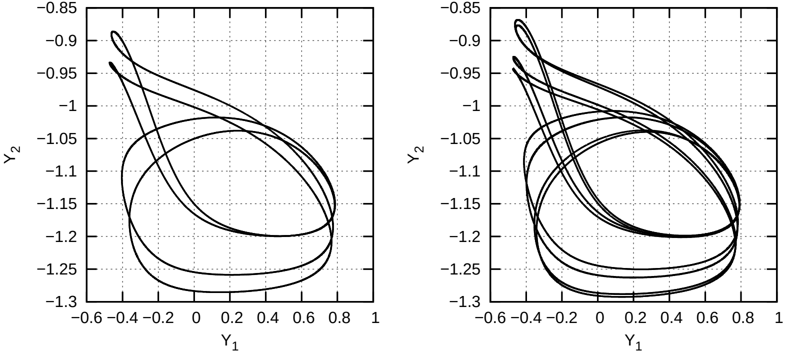
$147 < F < 200$: Period-doubling



Left : $F = 145.217$. Right : $F = 146.423$.

(Y_i = horizontal coordinate of particle i.)

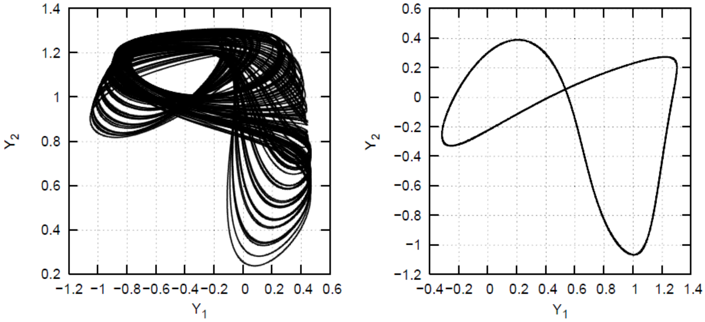
$147 < F < 200$: Period-doubling



Left : $F = 156.07$. Right : $F = 159.09$.

(Y_i = horizontal coordinate of particle i.)

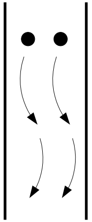
$F \sim 200$: Chaotic attractor (= Aidun & Ding 2003), and return to periodicity



$F = 197.68$ $F = 241.61$

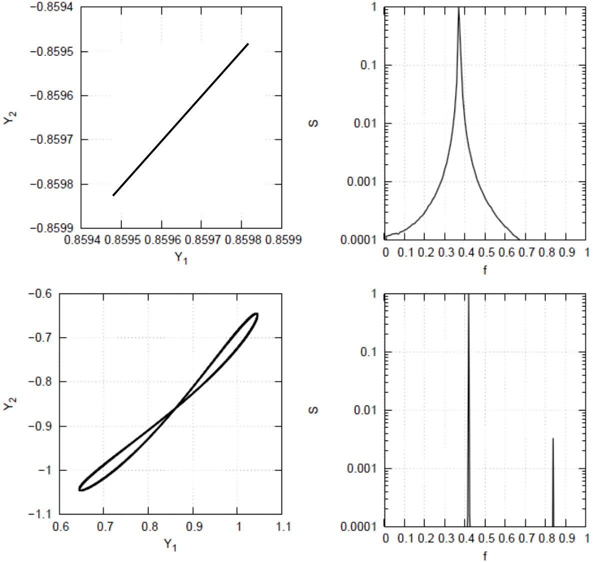
Larger weight : $400 < F < 510$

$F = 400$: DKT vanishes, and a horizontal periodic structure appears (frequency f_1).



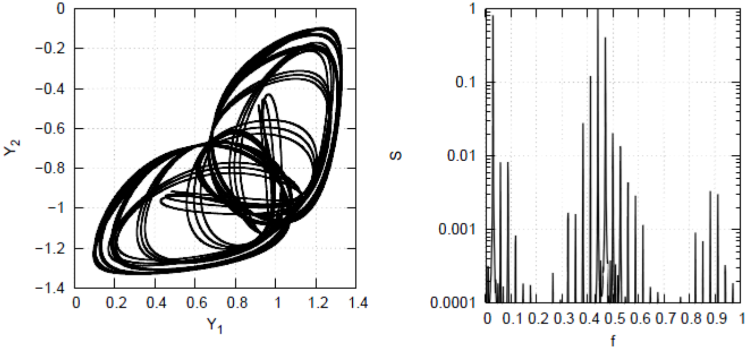
- Increasing F leads to the appearance of another frequency $f_2 \simeq 2f_1$.
- Increasing F to 500 does not change the ratio f_2/f_1, until a third frequency appears.

Larger weight : $400 < F < 510$



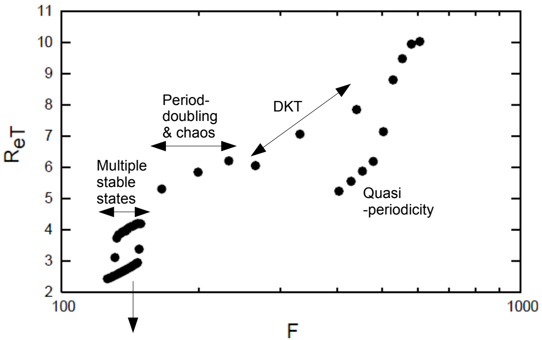
Upper Figs.: $F = 402.12$, lower: $F = 477.52$

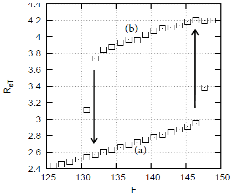
Larger weight : $400 < F < 510$



$F = 502.65$

Link between F and Re_T: global picture



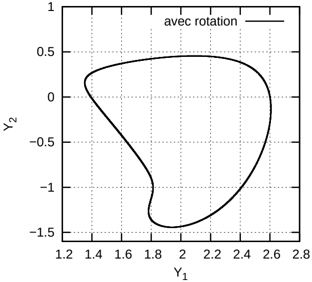


The effect of particle rotation

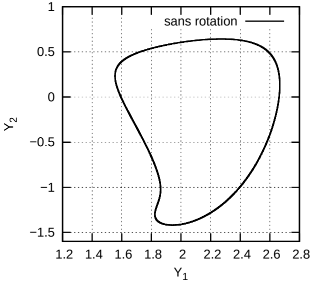
- The Magnus effect is claimed to be a key ingredient for the appearance of the various stable configurations.

- Simulations without rotation have been conducted, by blocking the rotational degree-of-freedom.

The effect of particle rotation



rotation allowed



no rotation

$F \simeq 130, \ Re_T = 2.5$

Conclusion

- In a confined environment, increasing the driving force does not necessarily result in an increase of the settling velocity.

- Complex sedimentation occurs, under the combined effect of particle/wall and particle/particle hydrodynamic interactions.

- Numerical results strongly suggest the existence of a quasiperiodic route to chaos at $F = O(400)$, leading to a new chaotic attractor.

- The intrinsic rotation of particles has little effect on the various regimes and bifurcations.