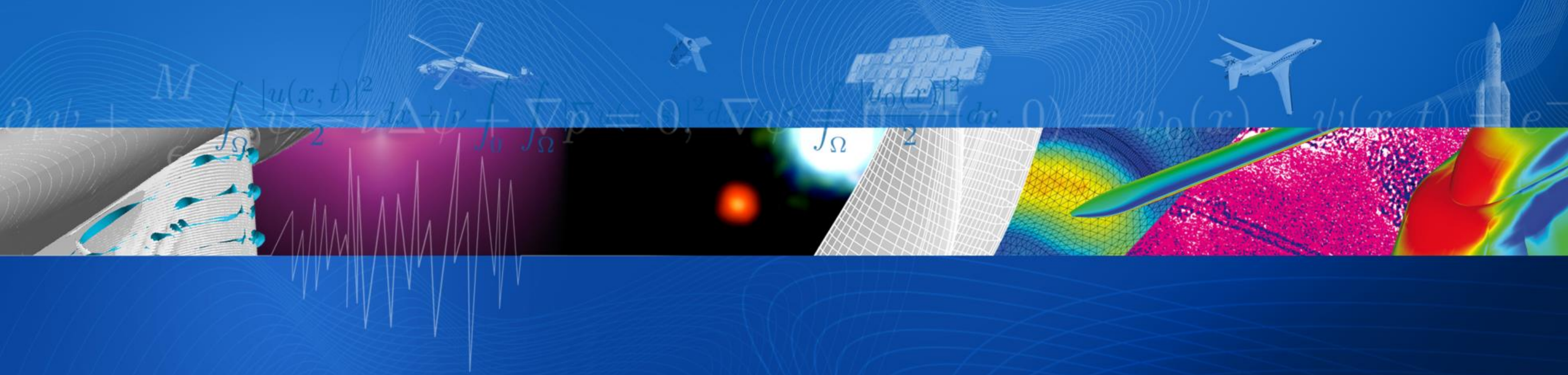


ONERA

THE FRENCH AEROSPACE LAB

www.onera.fr

Research on Wake Vortices at ONERA

V. Brion

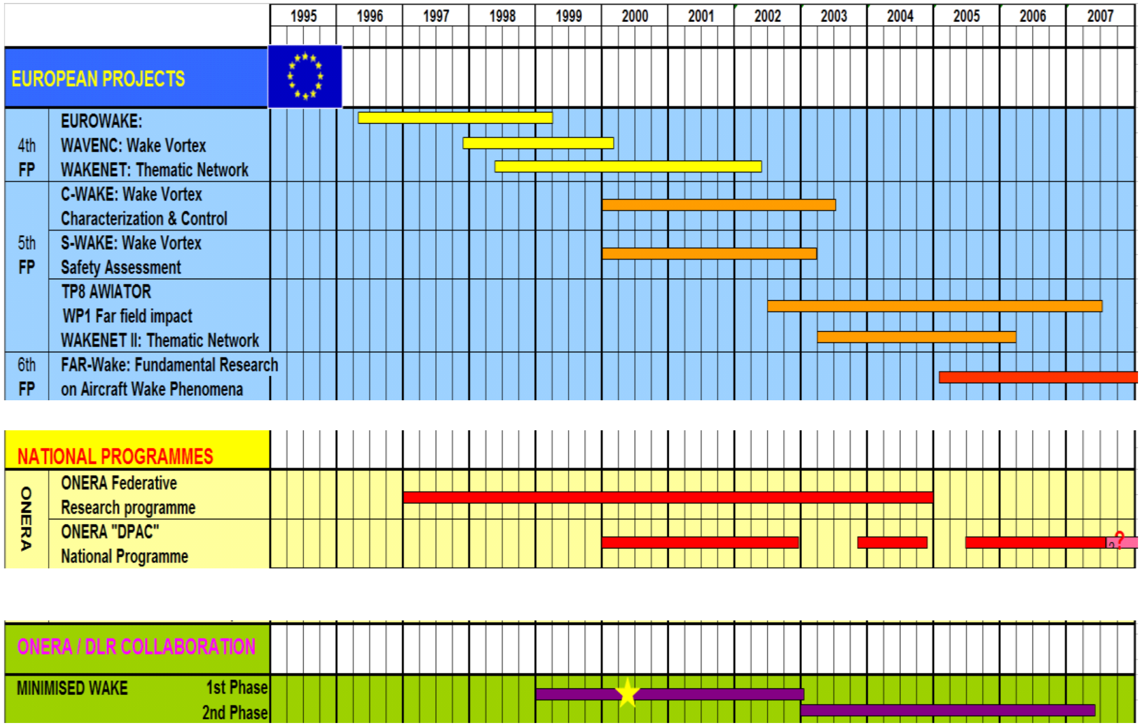
Dept of Fundamental and Experimental Aerodynamics (DAFE)

ONERA Meudon, France

Future Sky meeting, TU Braunschweig, 8 June 2016

Theme « Dynamics of Wake vortices » at ONERA

sources : E. Coustols, L. Jacquin

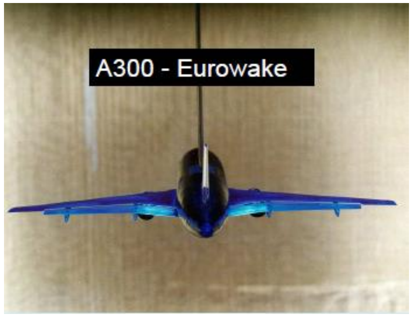


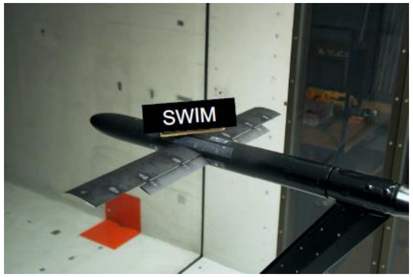
F2 WT
A300 type model
Flap setting
SWIM

Catapult
B20, end effects
theory

theory

F2 WT, LES





Since 2007

- DOCTOR internal project on radar/lidar measurements of WV & models (2010-2012)
- A couple of PhDs
- Wakenet meetings

ONERA internal map of WV related activities

DEMR (Radar)

- Involved in Doctor project
- Investigated WV radar measurement in presence of rain

DOTA (Lidar)

- Lidar design & development
- WV, EDR monitoring

DMAE (Fluid Dynamics & Energetics)

- Project management
- Experiments (WT, water tunnel)
- Ground effect
- Parabolized Navier-Stokes

DEFA (Energetics)

- Contrails
- RANS, LES
- Thermodynamics, microphysics and chemistry

DCSD (Flight Mechanics & Systems)

- B10, B20 facilities
- Severity of encounter metrics

DAAP (Applied Aerodynamics)

- Panel methods
- Vorticity confinement

DCPS (Design & Performance of Systems)

- IESTA air trafic simulator

DAFE (Fluid Dynamics)

- Vortex Dynamics
- Simulation, theory, experiment

Research at DAFE (Dpt Fundamental & Exp. Aerodynamics)

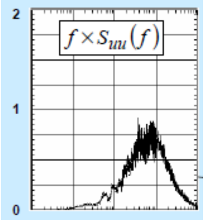
Research threads

- Single vortex, pair, 4-vortex systems
- merging, meandering
- Jet / wake interaction, contrails
- DNS, LES
- Theory (stability)
- Wind tunnel experiments

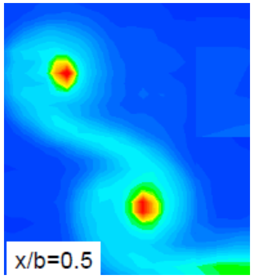
Motivations

- Physics
- WV mitigation
  - 4 vortex systems
  - Crow instability

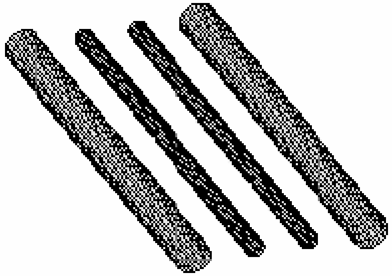
meandering



merging



4-vortex



On-going projects

PHYWAKE project

funded by DGAC (French Civil Aviation), 2015 → 2019

Several departements (DOTA, DAAP, DEFA and DAFE) involved

Dedicated to WV

- Flow physics
- Measurements (Lidar/Radar)
- Mitigation
- 1D modelling

Motivation

- Trafic security
- Contrails

On-going projects

SESAR H2020

ONERA is third party behind DGAC (French Civil Aviation)

Involved in

- PJ13
- **PJ2.1 « runway throughput »**
- PJ8.1
- PJCI -04

Period 2017-19

Presentation outline – WV research over the past 5 years

Motivations

- WV mitigation using the Crow instability
- WV measurements

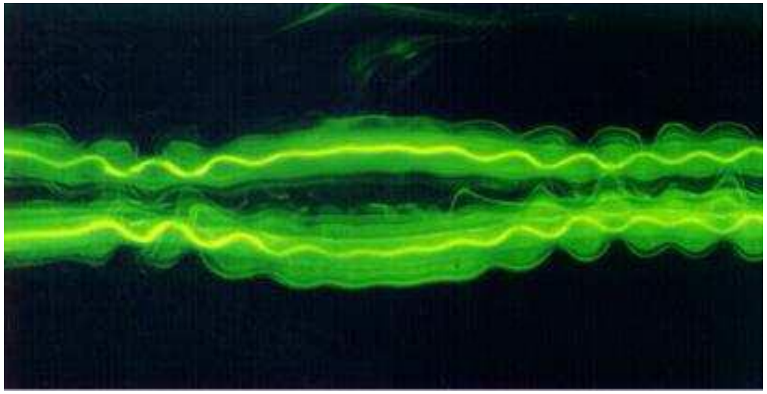
Items presented

- Observing vortex pair instabilities in a wind tunnel
- Optimal perturbation in vortices (H. Johnson Phd)
- Radar Detection in clear air (Doctor project)

Vortex pair instabilities, a wind tunnel experiment using high speed stereo PIV

Short and long-wave instabilities in vortex pairs

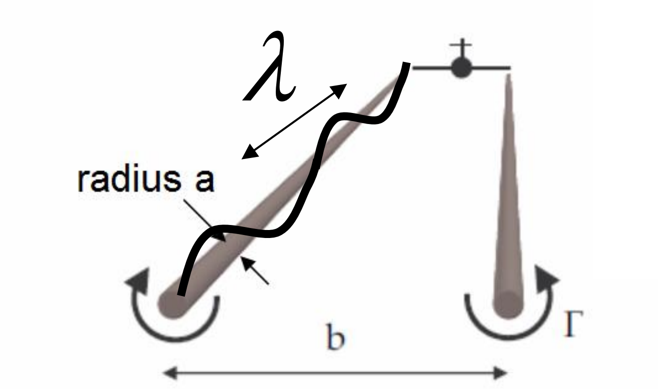
long wavelength kb~1 : Crow



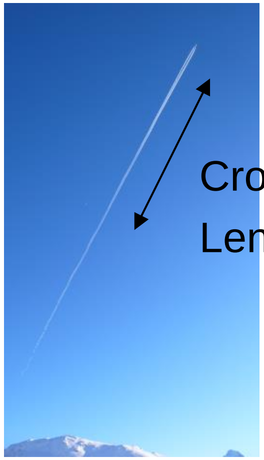
source : Leweke and Williamson 1998

short wavelength ka ~1: Widnall

$$k = \frac{2\pi}{\lambda}$$



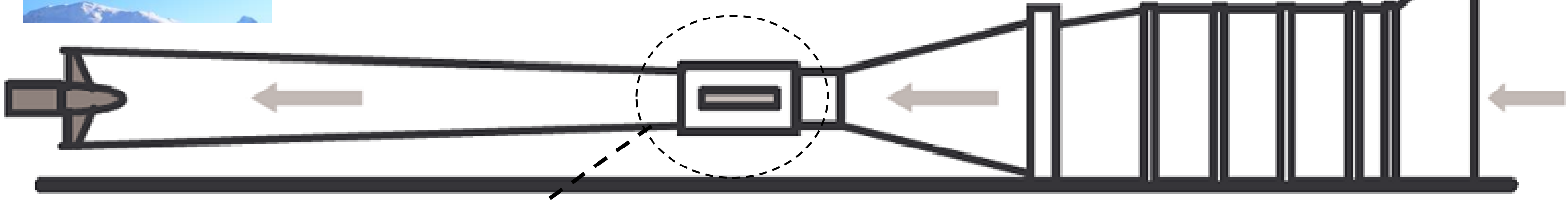
Spatial requirements on wake development

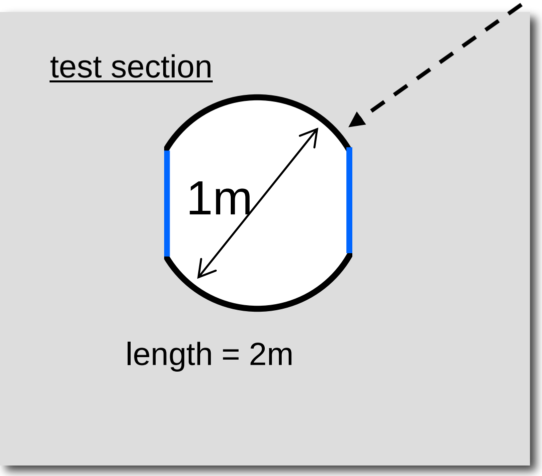


Crow instabilities is slow

Length required for the development of the instabilities is ~ 100 wing spans

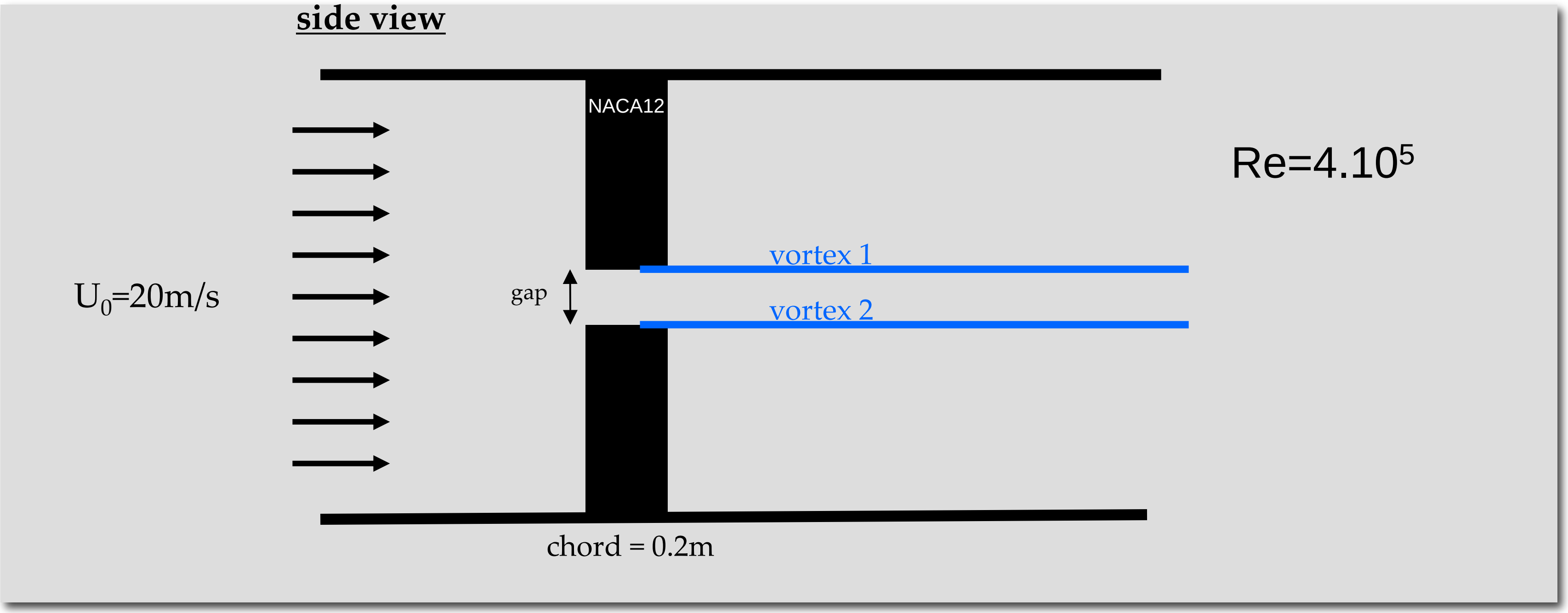
S2L Wind Tunnel Eiffel type





→ Obtain Crow in the length of the test section ?

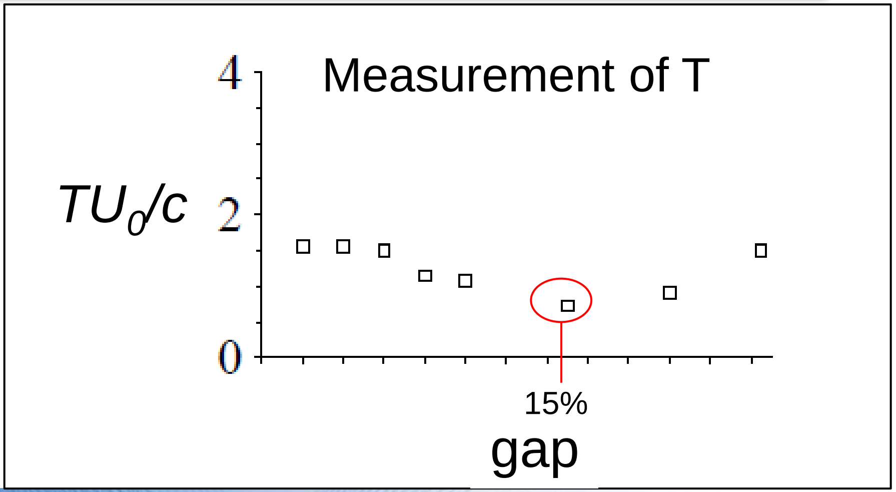
Experimental setup



Crow time

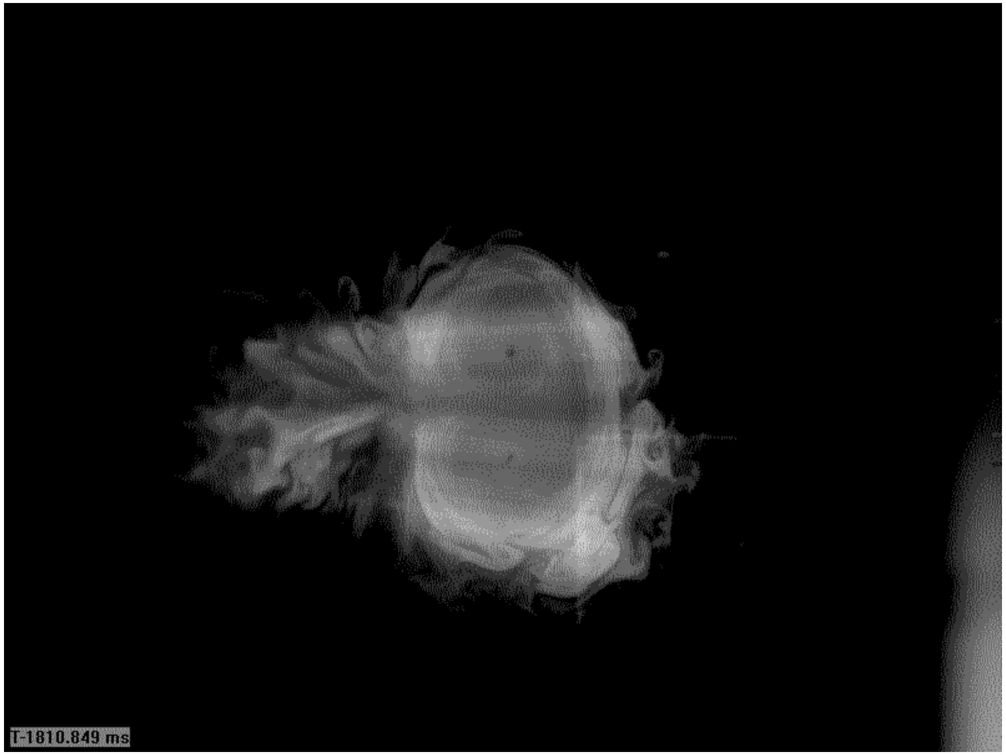
$$T = \frac{2\pi b^2}{\Gamma}$$

➔ Choose the gap to reduce T, so reduce b and maintain a strong Γ

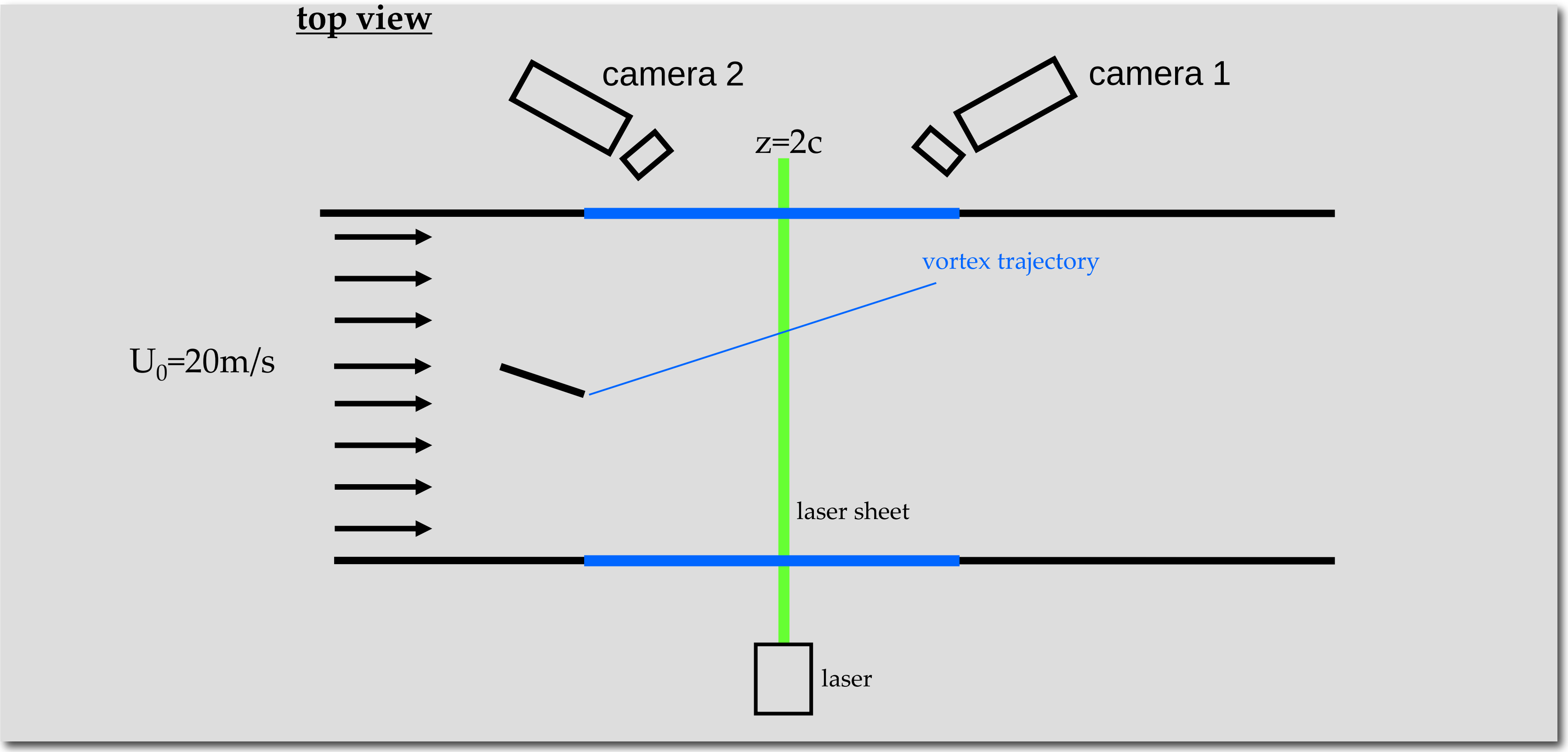


Literature : Pailhas 2000, Devenport JFM 1997, Heyes 2004

Flow field visualized by smoke



High speed PIV setup

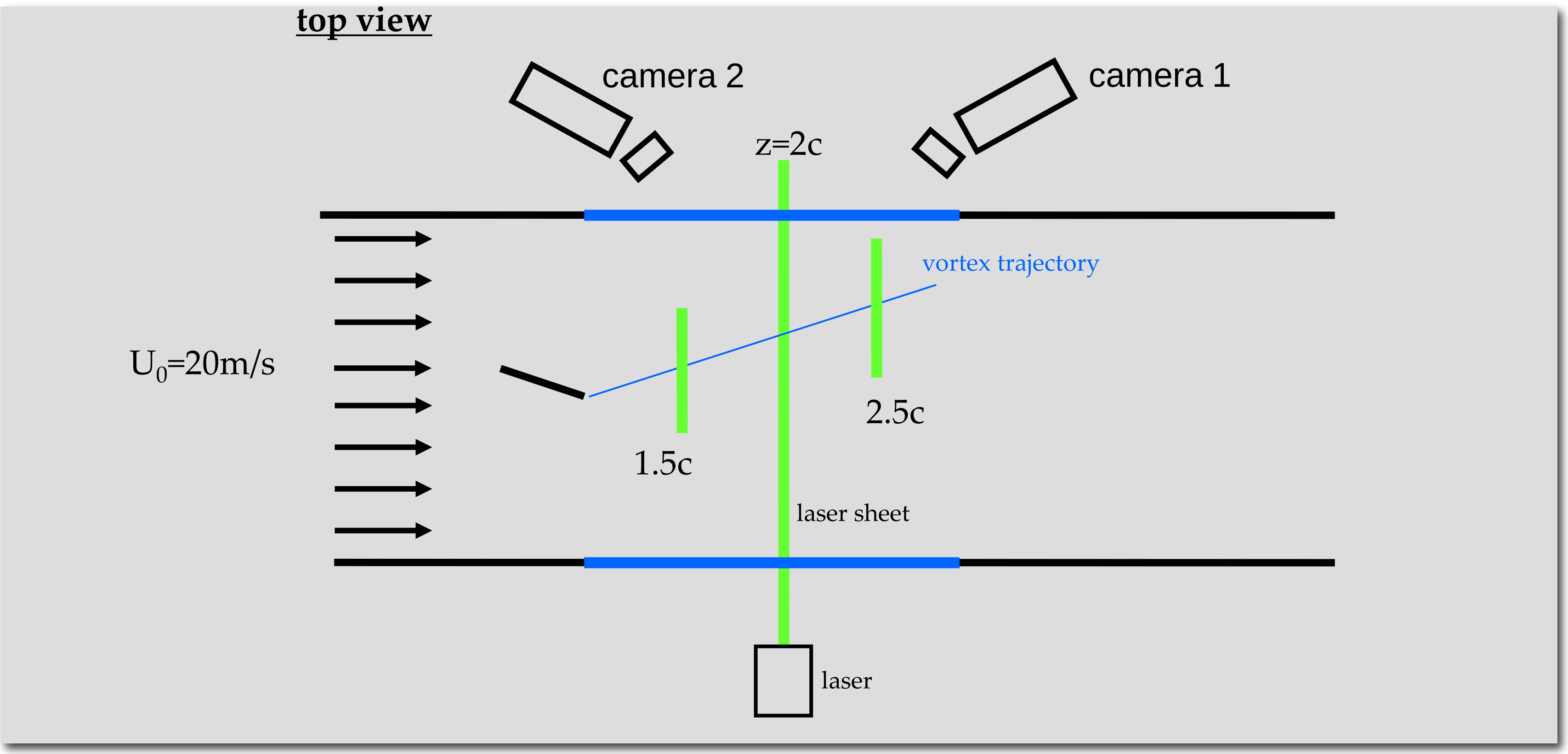


Time resolved stereoscopic PIV f=3kHz

Posttreatment based on in-house code FolkiPIV*

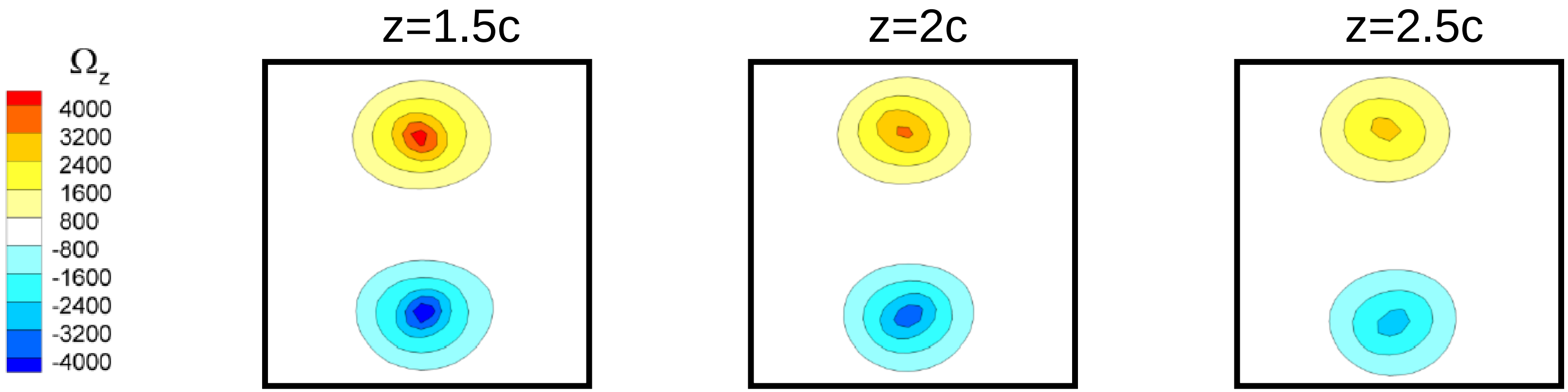
*Champagnat et al. 2010

High speed PIV setup



3 measurement planes : 1.5c ; 2c ; 2.5c

Mean flow

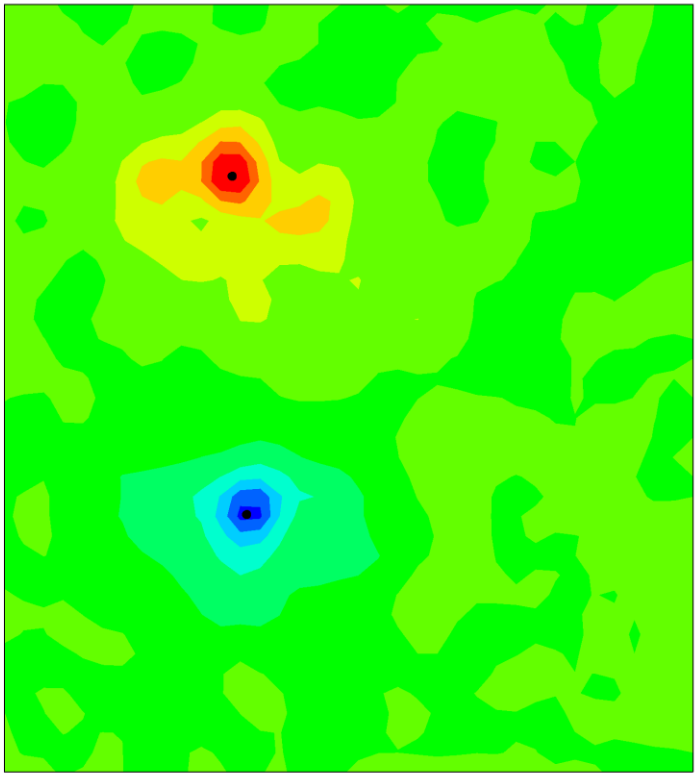


axial vorticity field

Longitudinal evolution of the vortex properties

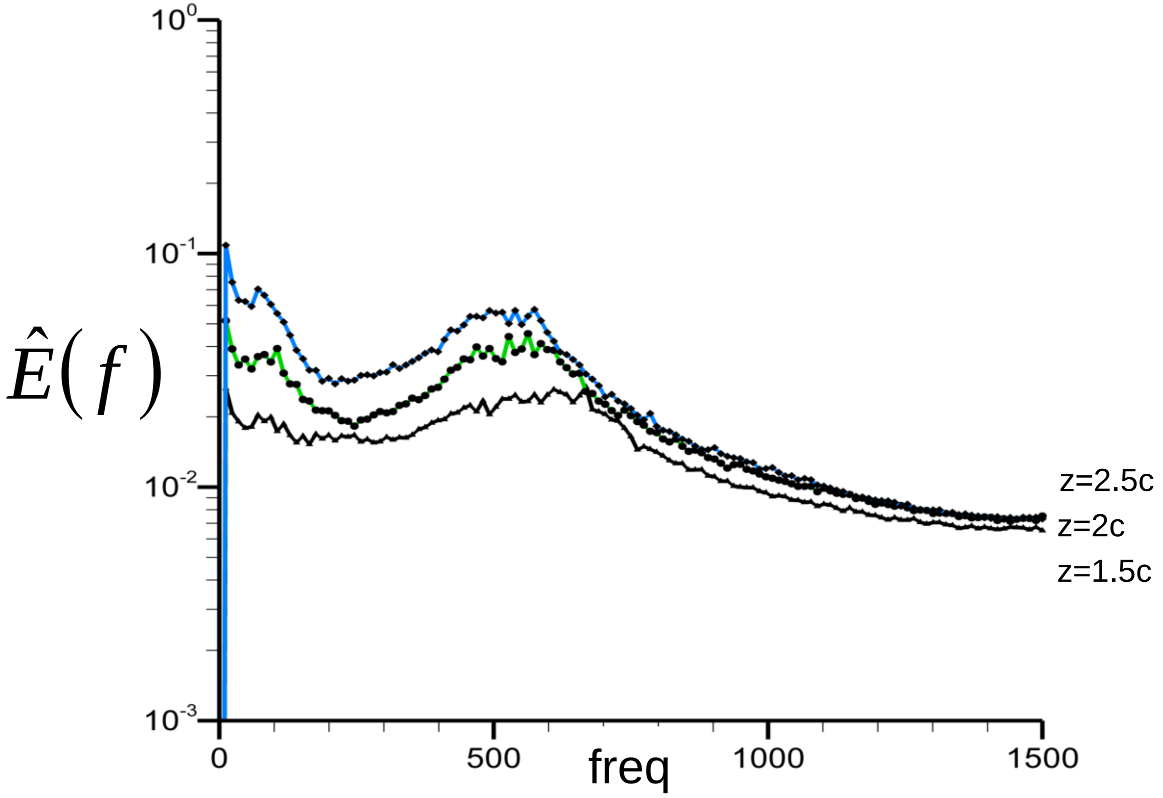
	Position	$z = 1.5c$	$z = 2c$	$z = 2.5c$
circulation	Γ (m^2/s)	1.37	1.33	1.22
vortex radius	a (mm)	13.5	14.5	15.3
vortex separation	b (mm)	38.4	40.5	42.3
aspect ratio	a/b	0.35	0.36	0.36

INSTANTANEOUS FLOW FIELD

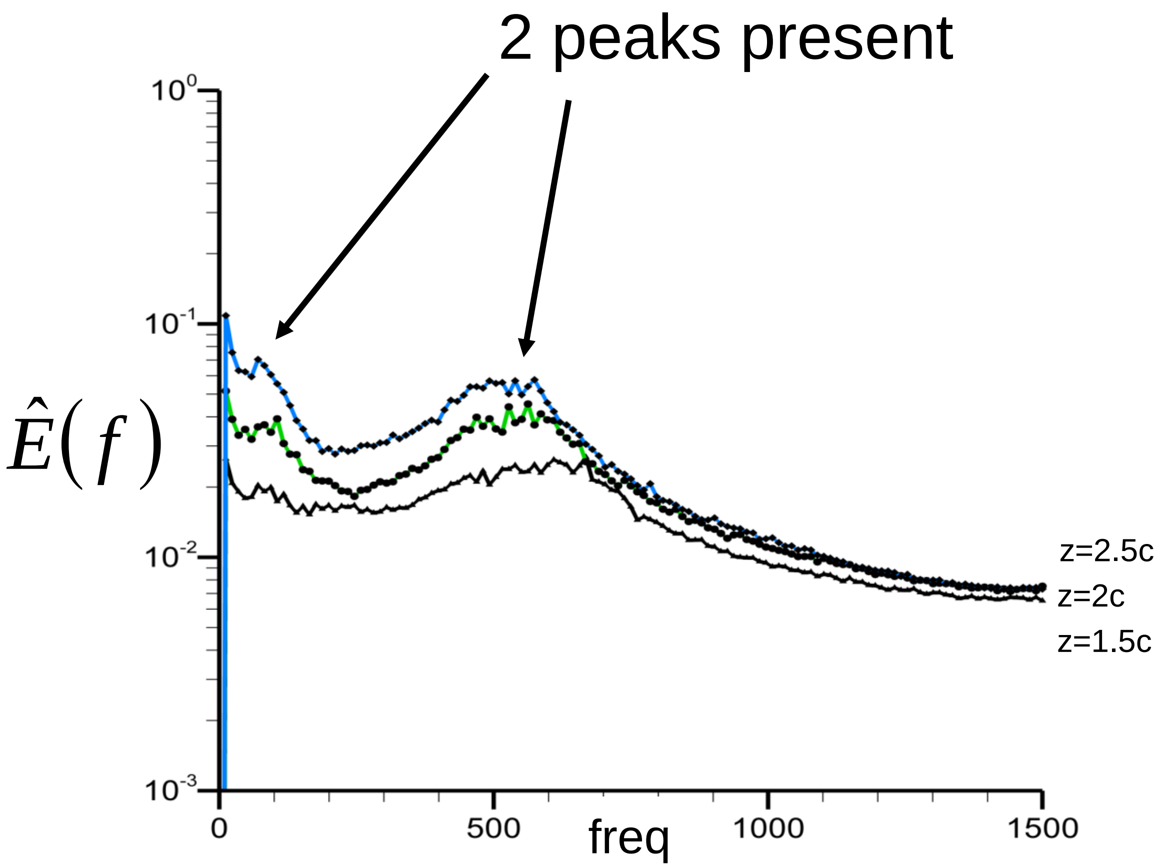


Unsteadiness : evolution of the kinetic energy

$$E(t,z) = 0.5\int_V \left\|\underline{u}(t,z)\right\|^2 dx \xrightarrow{\text{FFT}} \hat{E}(f,z)$$



Unsteadiness : evolution of the kinetic energy


2 peaks present

Wavelength

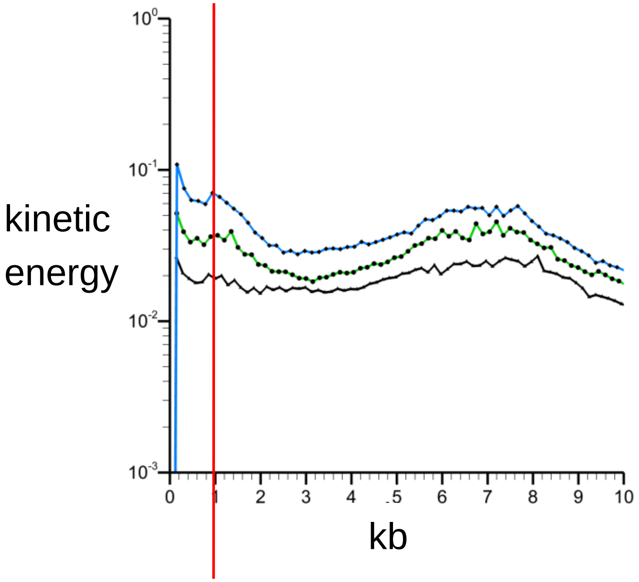
frequency to wavelength ➔ Taylor hypothesis

$$k = \frac{2\pi f}{U_0}$$

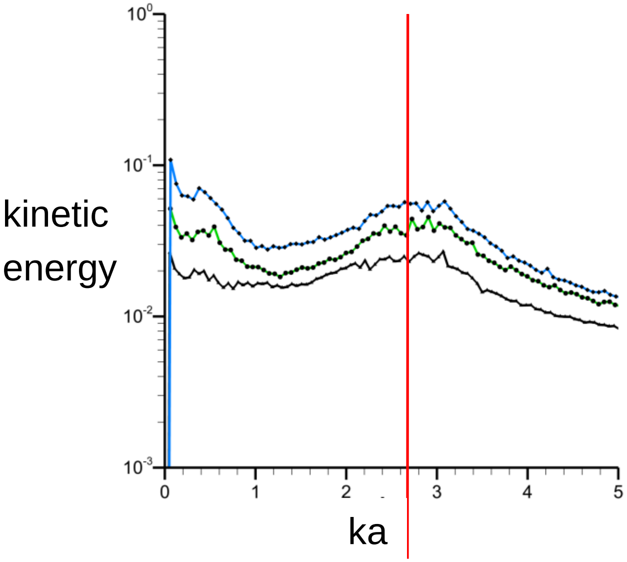
(convective instability – see Fabre et al. 2000)

normalize on separation "b"

normalize on radius "a"



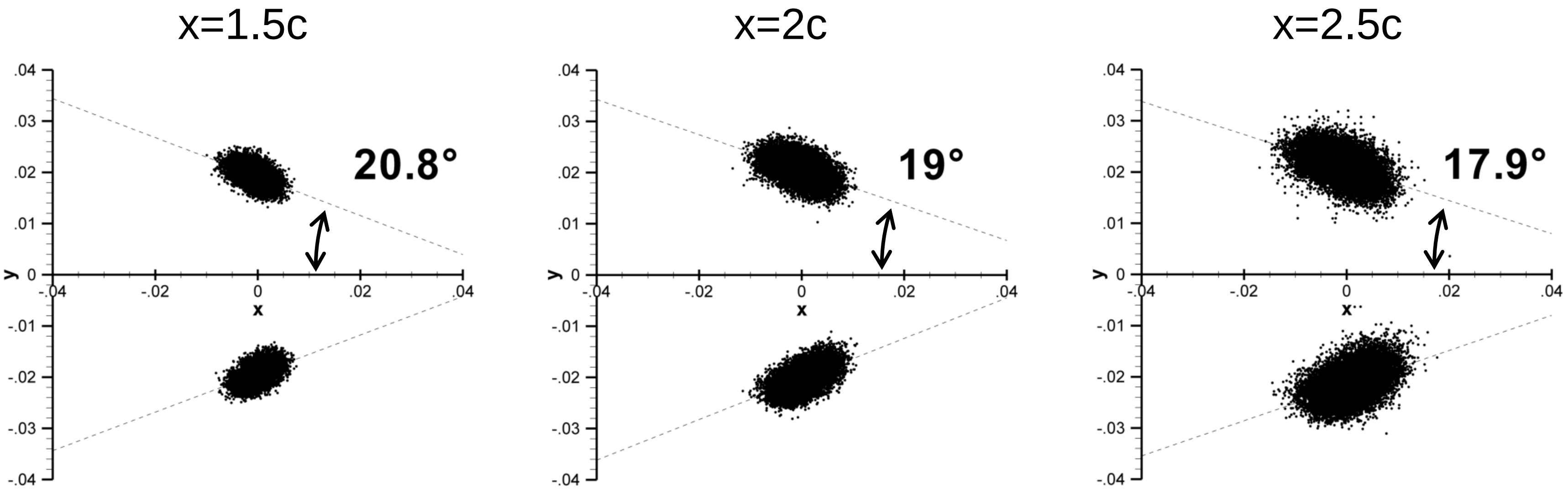
kb ~ 1



ka ~ 2.7

Crow & Widnall compatible !

Scatter plot of the vortex centers


x=1.5c

x=2c

x=2.5c

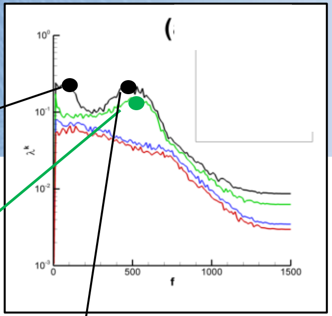
1 / Preferred orientation ~20°

2 / Symmetric about center line

3 / Amplification

POD modes

Vorticity fields



Crow peak

Widnall peak

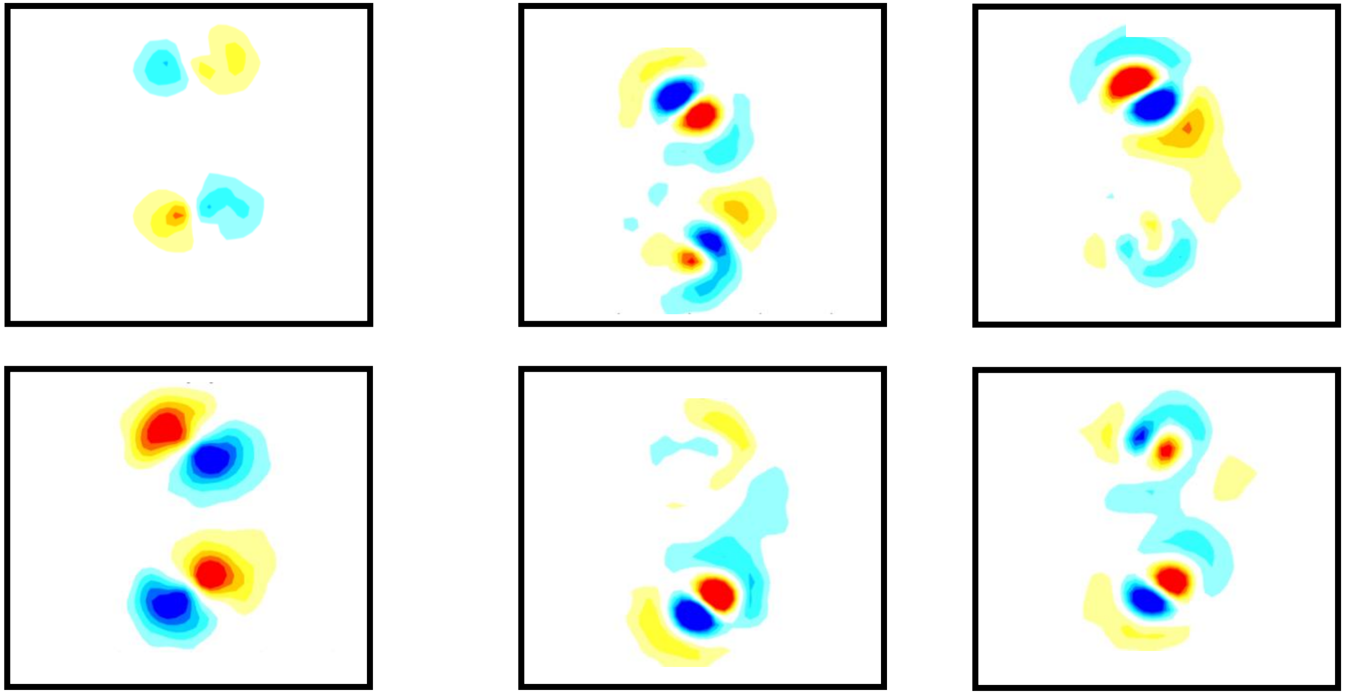
SYMMETRIC

SYMMETRIC

ANTISYMMETRIC

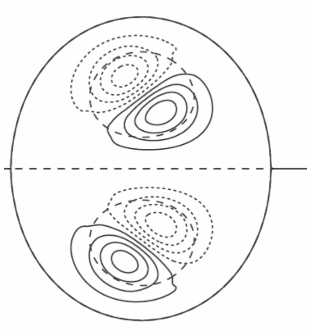
Real part

Imaginary part

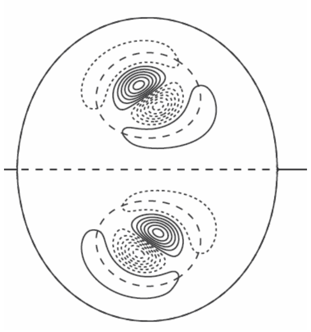


Comparison to theory

Theory

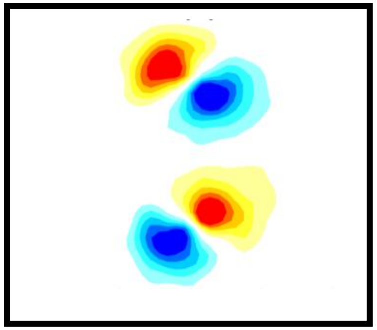


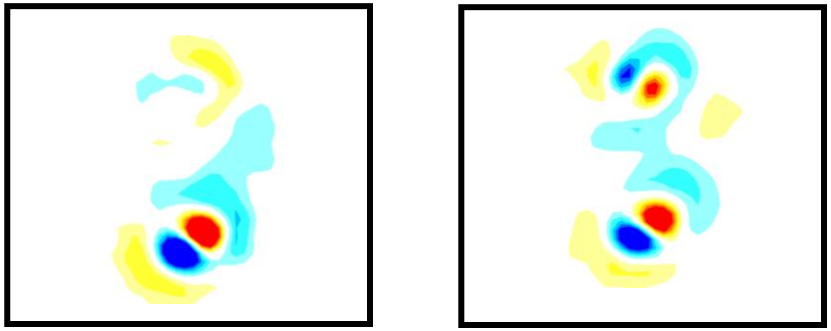
Crow



Widnall S

Present experiment





OPTIMAL PERTURBATION

A way to mitigate vortices

- Valid for stable or weakly unstable systems (such as Crow)
- Transient growth mechanisms may lead to by-pass and early turbulence

OPTIMAL PERTURBATION

Objective : Find the maximum of kinetic energy E_T at time T where $\mathrm{E} =< q', Bq' >$ and $<.,.>$ s.p.

$q' = (\boldsymbol{u}', p')$ is the perturbation state vector and $B = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$

Constraints : Navier-Stokes equations + bound. cond.

➔ **Lagrangian approach**

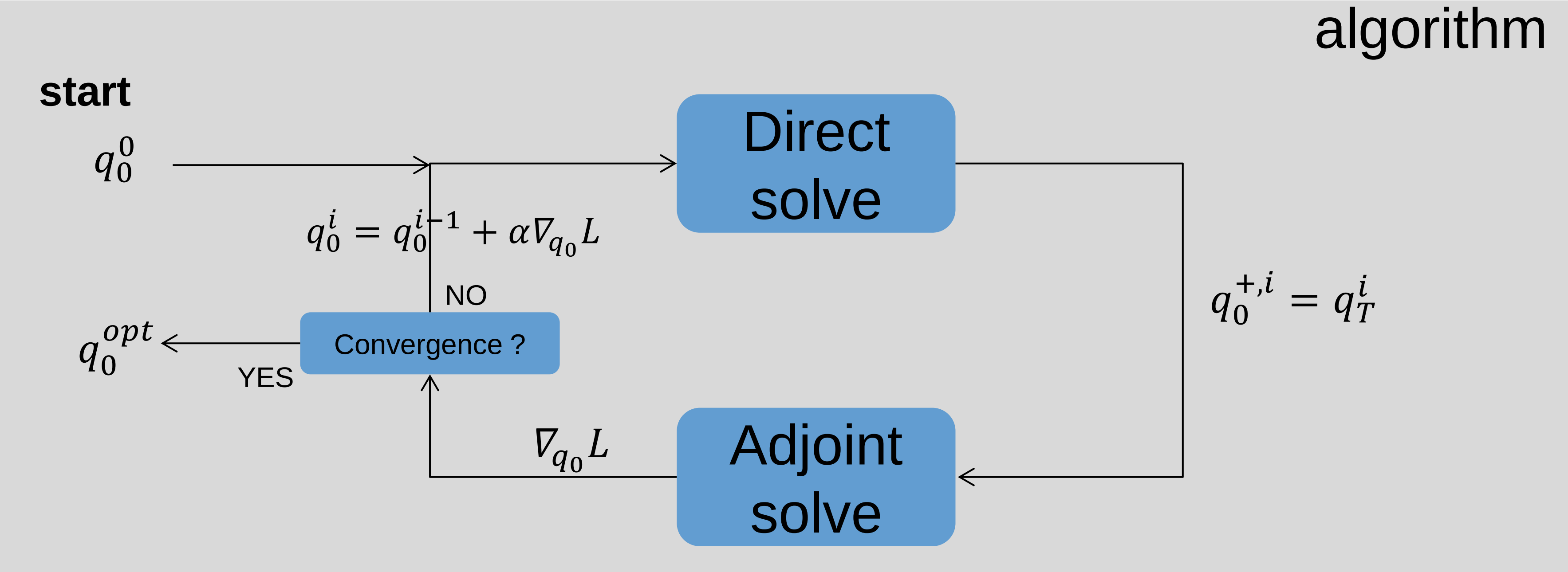
$$L(q_0, q, q^+) = \frac{E_T}{E_0} - (q^+, NS(q))$$

where $(a, b) = \int_0^T < a, b > dt$

OPTIMAL PERTURBATION

→ **Optimal : find** ${q'}_0$ such that $\frac{\partial L}{\partial {q'}_0} = 0$ by an iterative approach

→ Impose $|{q'}_0| = E_0$ in the process



algorithm

start

q_0^0

Direct solve

$q_0^i = q_0^{i-1} + \alpha \nabla_{q_0} L$

NO

q_0^{opt}

Convergence ?

YES

$q_0^{+,i} = q_T^i$

$\nabla_{q_0} L$

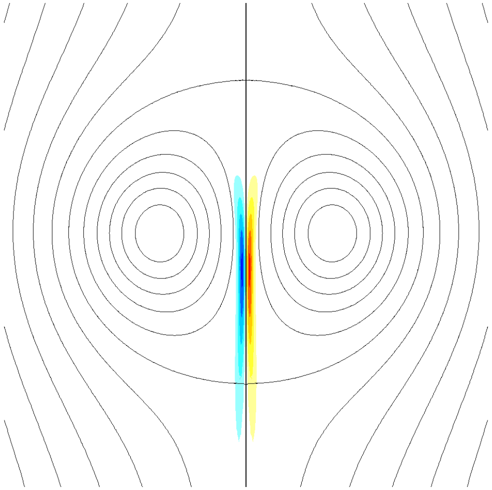
Adjoint solve

APPLICATION TO VORTICES

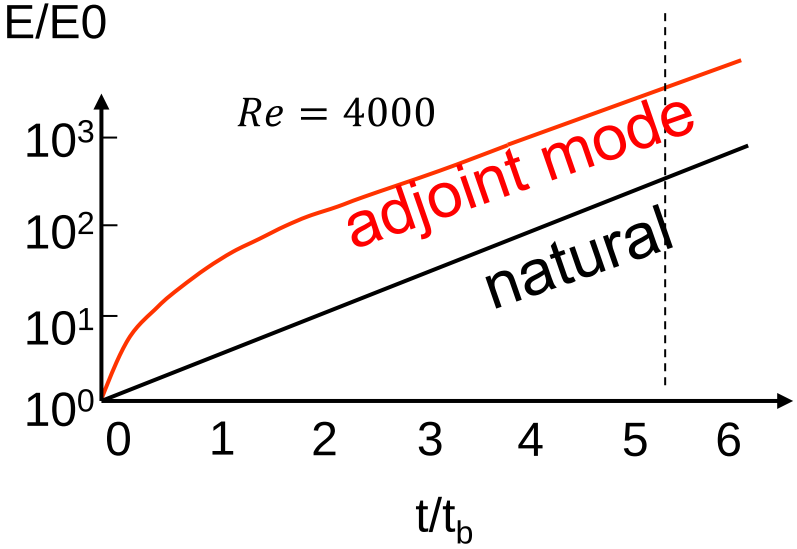
Background

- Linear optimal perturbation to a **single vortex** (Antkowiak 2004, Pradeep 2006, Heaton 2007)
- Linear opt. pert. to a **vortex pair** (Brion 2007, Donnadieu 2009)

Crow optimal (adjoint)



$$t_b = \frac{2\pi b^2}{\Gamma}$$



LINEAR OPTIMAL WITH FINITE AMPLITUDE

A first step toward non linear optimization (Wakenet 2015)

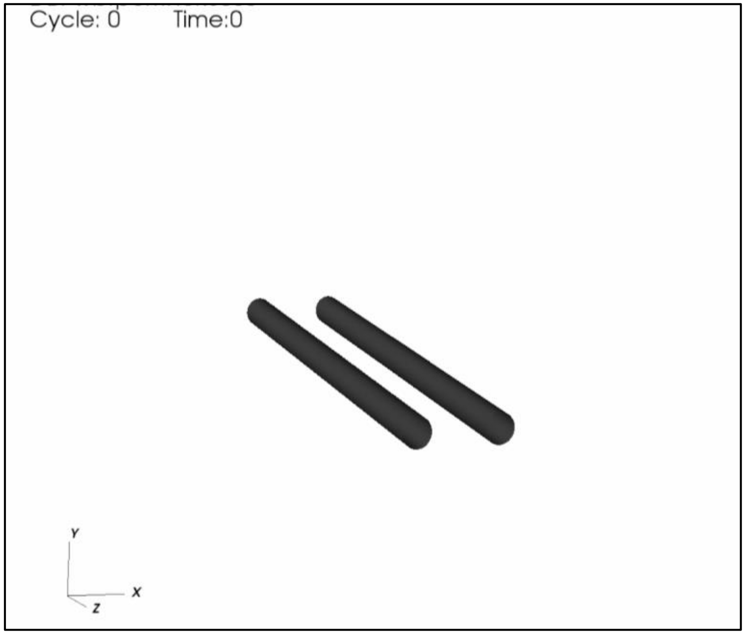
Baseflow + $\boxed{\mathcal{E}}$ Linear optimal

H. Johnson PhD

Effect of initial amplitude ϵ ?

→ DNS simulations with increasing ϵ

$\epsilon = 10^{-3}$



Re=1000

INFLUENCE OF ϵ ON THE DYNAMICS AFTER LINKING

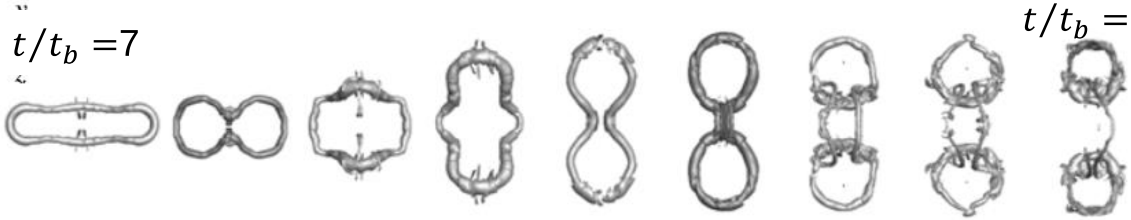
$\epsilon = 10^{-3}$

$t/t_b = 13$

$t/t_b = 26$

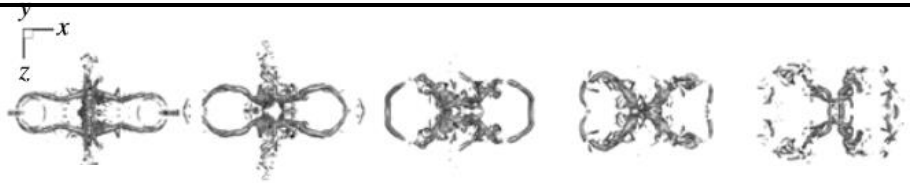
$\epsilon = 10^{-2}$

$t/t_b = 7$



$t/t_b = 16$

$\epsilon = 3.10^{-2}$



$t/t_b = 7$

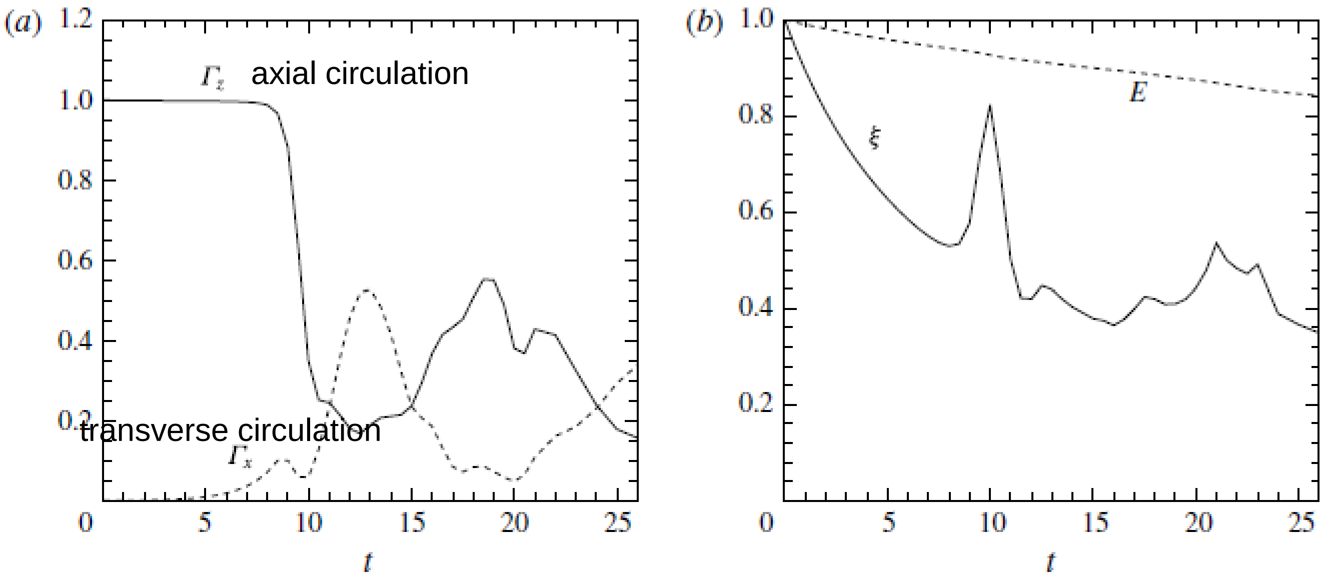
$t/t_b = 12$

→ Strong sensitivity to initial amplitude

→ Persistence of the ring state for small ϵ

→ Largest ϵ produces a pre-turbulent state rapidly (t=12 vs. t>26)

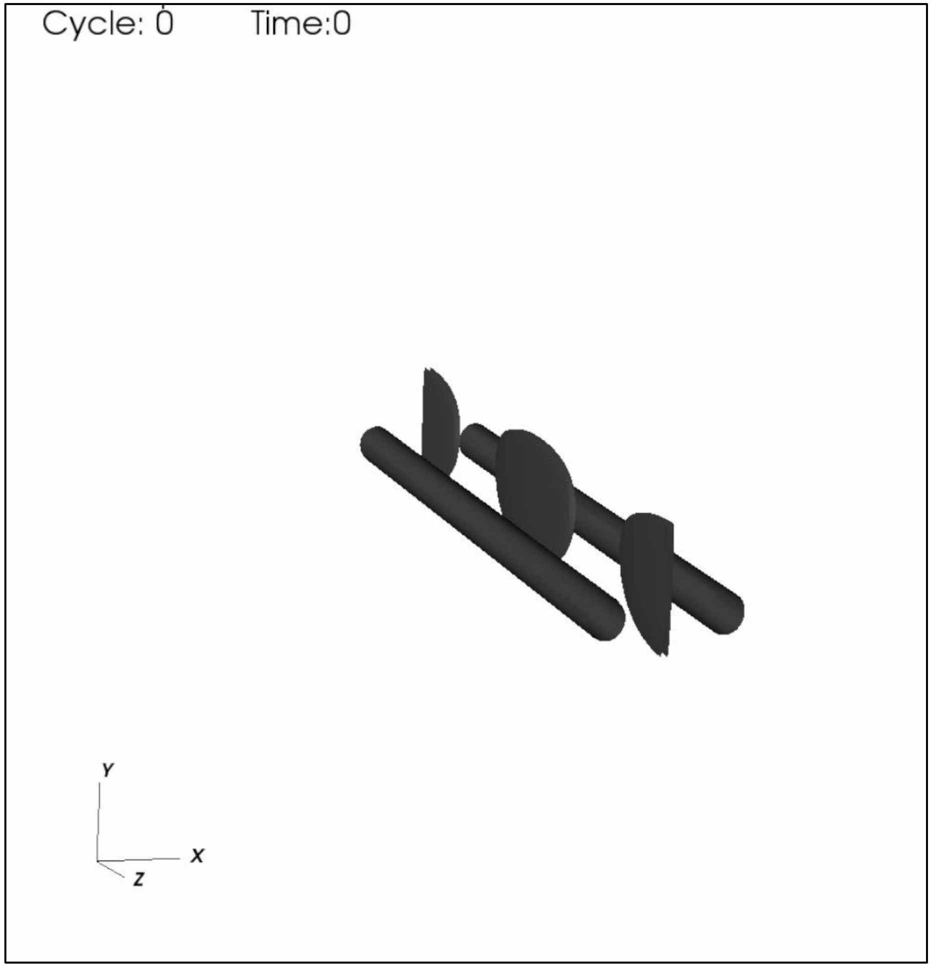
PERIODIC RING STATE DYNAMICS



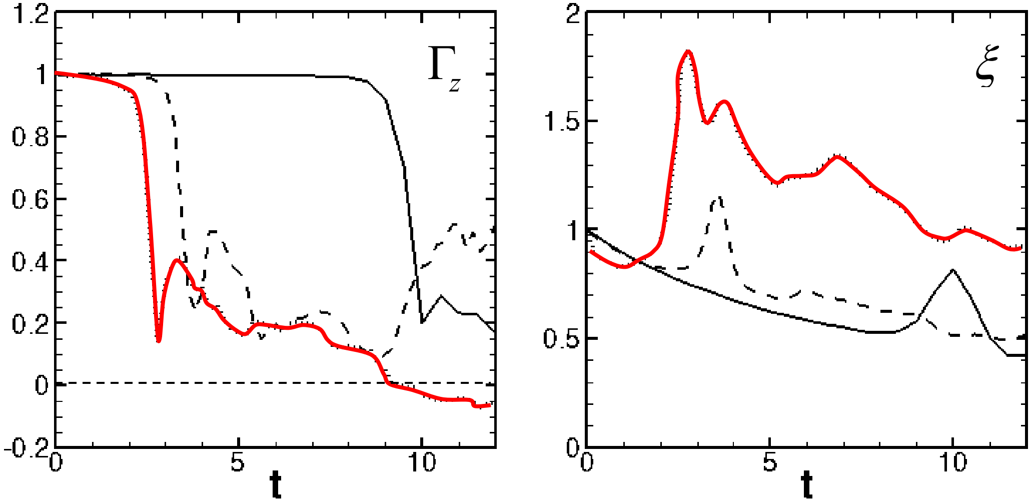
ref. Arms & Hama (1965).

- Vorticity exchange Γ_x vs. Γ_z
- Low decrease of kinetic energy

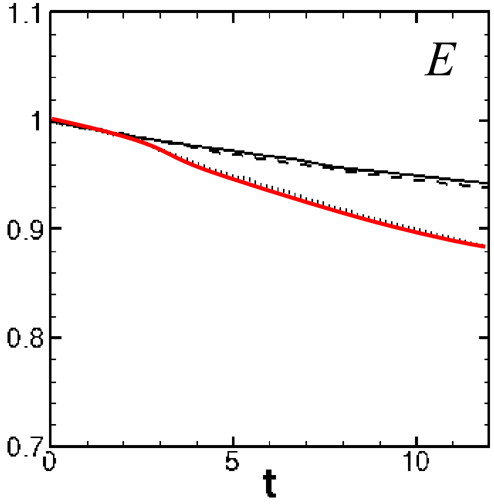
EFFECT OF $\epsilon = 3.10^{-2}$



EFFECT OF $\epsilon = 3.10^{-2}$



$$\frac{dE}{dt} = \int_V \xi \, dV$$

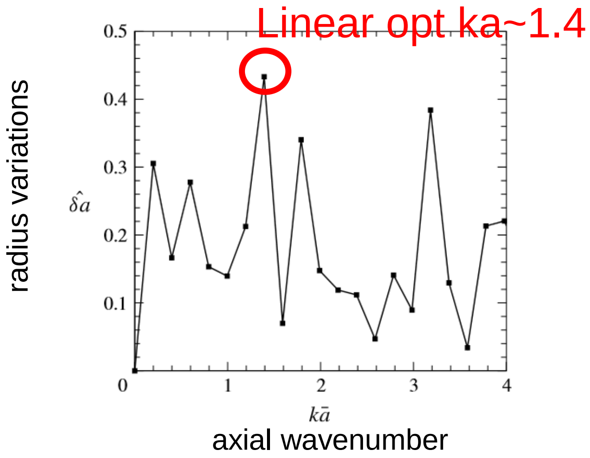


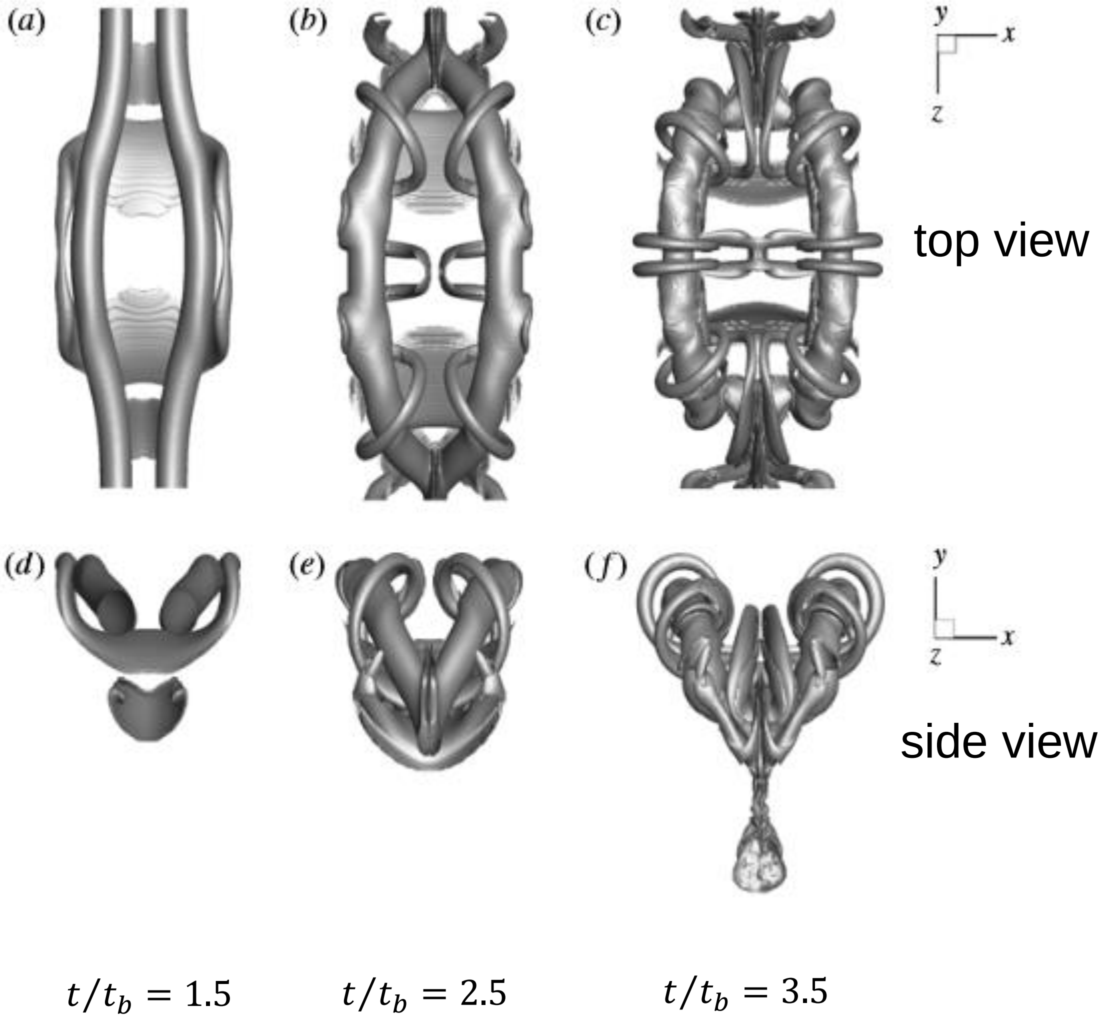
- Linking accelerated
- Ring state dynamics prevented
- Higher dissipation due to turbulent small scales
- **Accelerated decay**

PHYSICAL MECHANISM

$\epsilon = 3.10^{-2}$ is the threshold for the persistance of the perturbation around the vortex cores

This external perturbation likely promotes transient in the cores (Antkowiak 2004)



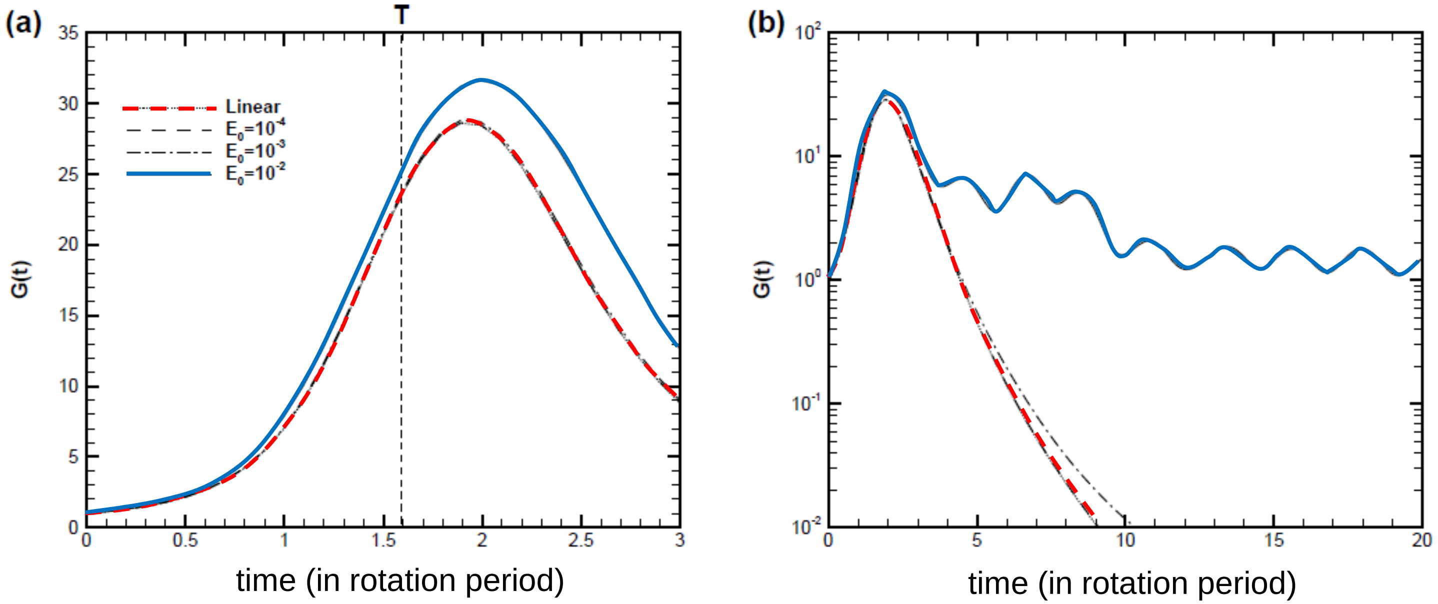


NON-LINEAR OPTIMIZATION

Previous analysis shows that non-linear effects clearly have potential in 3-D

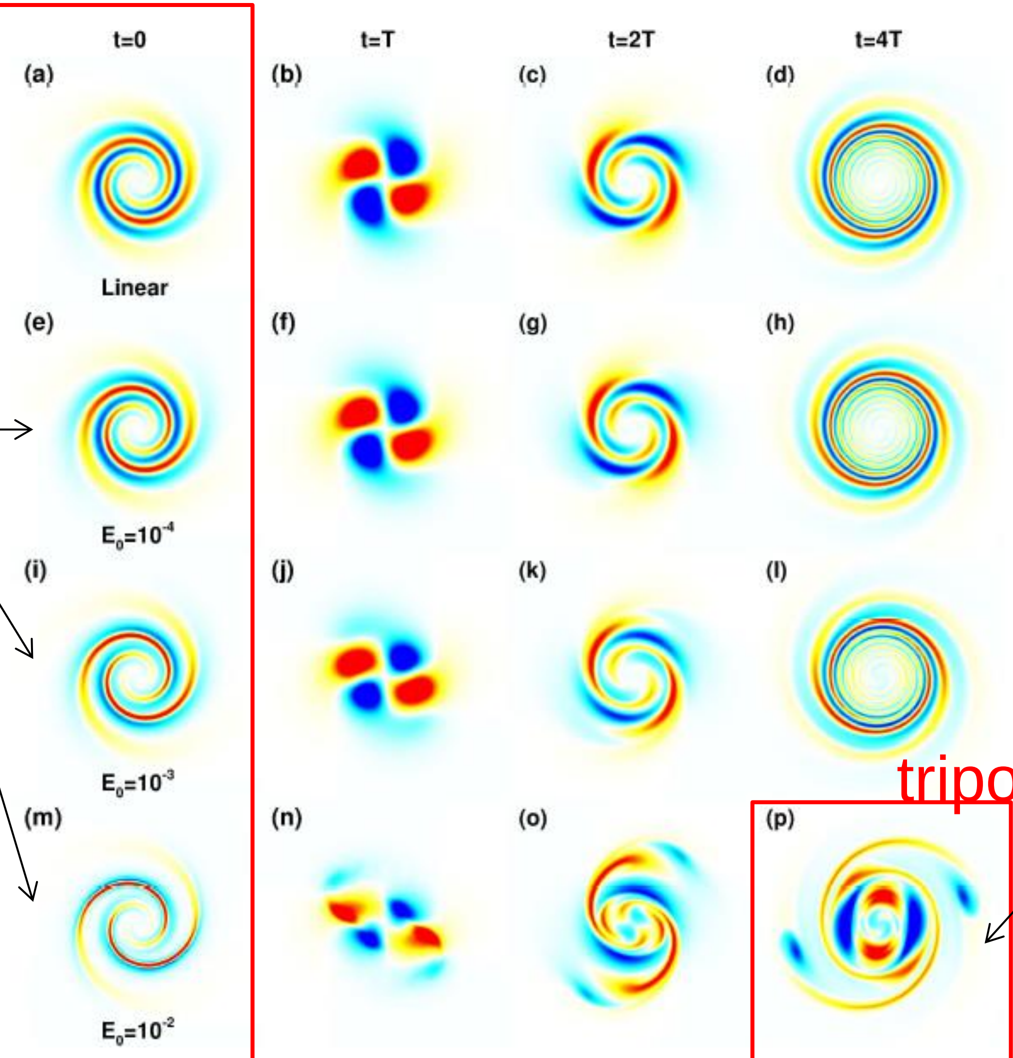
The method has first been developped for 2-D perturbations to a single vortex following Bisanti 2014

→ Case of the Lamb-Oseen vortex, at Re=1000



NON-LINEAR OPT. OF THE LAMB-OSEEN VORTEX IN 2-D

Optimal initial



tripole

perturbation gets more localized with increasing ϵ

Bifurcation occurs (tripole) for sufficient initial amplitude

CASE OF 3-D PERTURBATION TO A SINGLE VORTEX

Linear

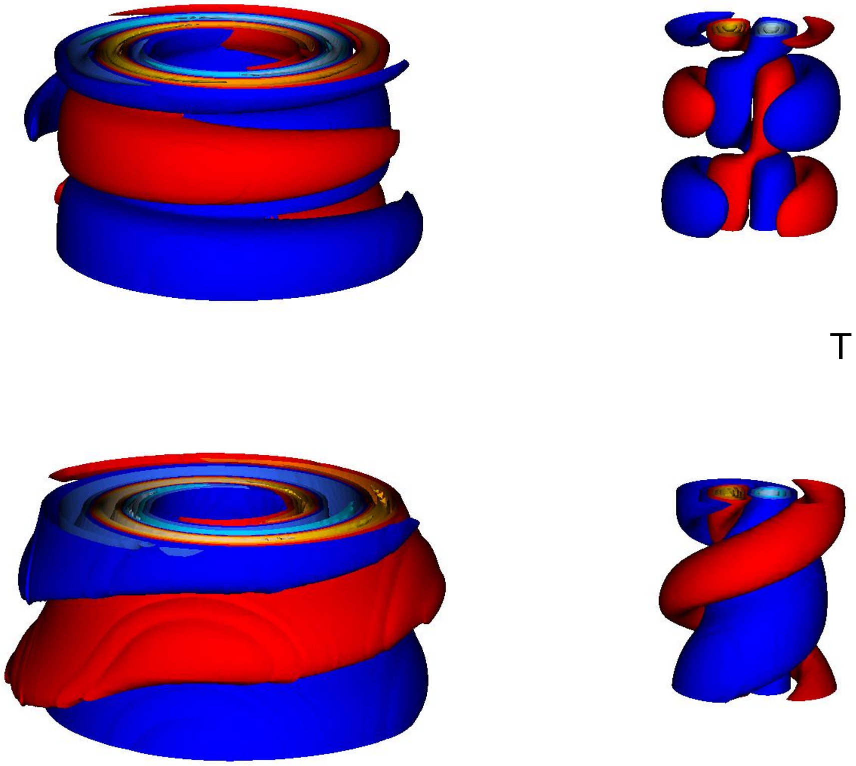
$E_0 = 10^{-4}$

$G(T) = 57$

Non-linear

$E_0 = 10^{-2}$

$G(T) = 48$



ka = 1.4
T = 12.6 (rotation times)
Re = 500