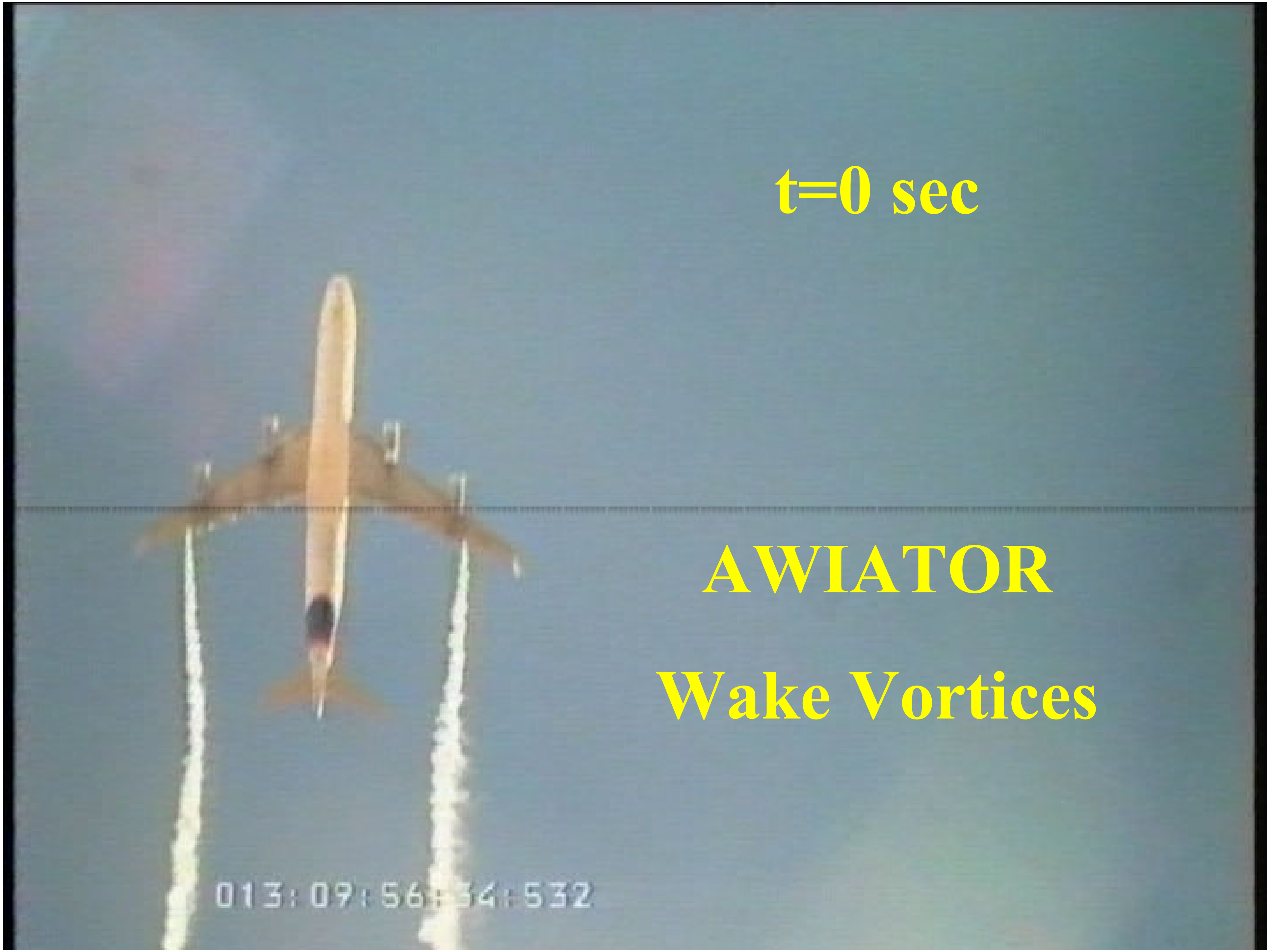
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AWIATOR
Wake Vortices
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WakeNet Europe
Workshop 2007

AWIATOR

Task 1.1: Wake Vortex

Wake alleviation by design

Anton de Bruin (NLR)

on behalf of Awiator Task11 partners:
Airbus, DLR, ONERA, NLR, CERFACS, UCL, TUM, IRPHE, IST

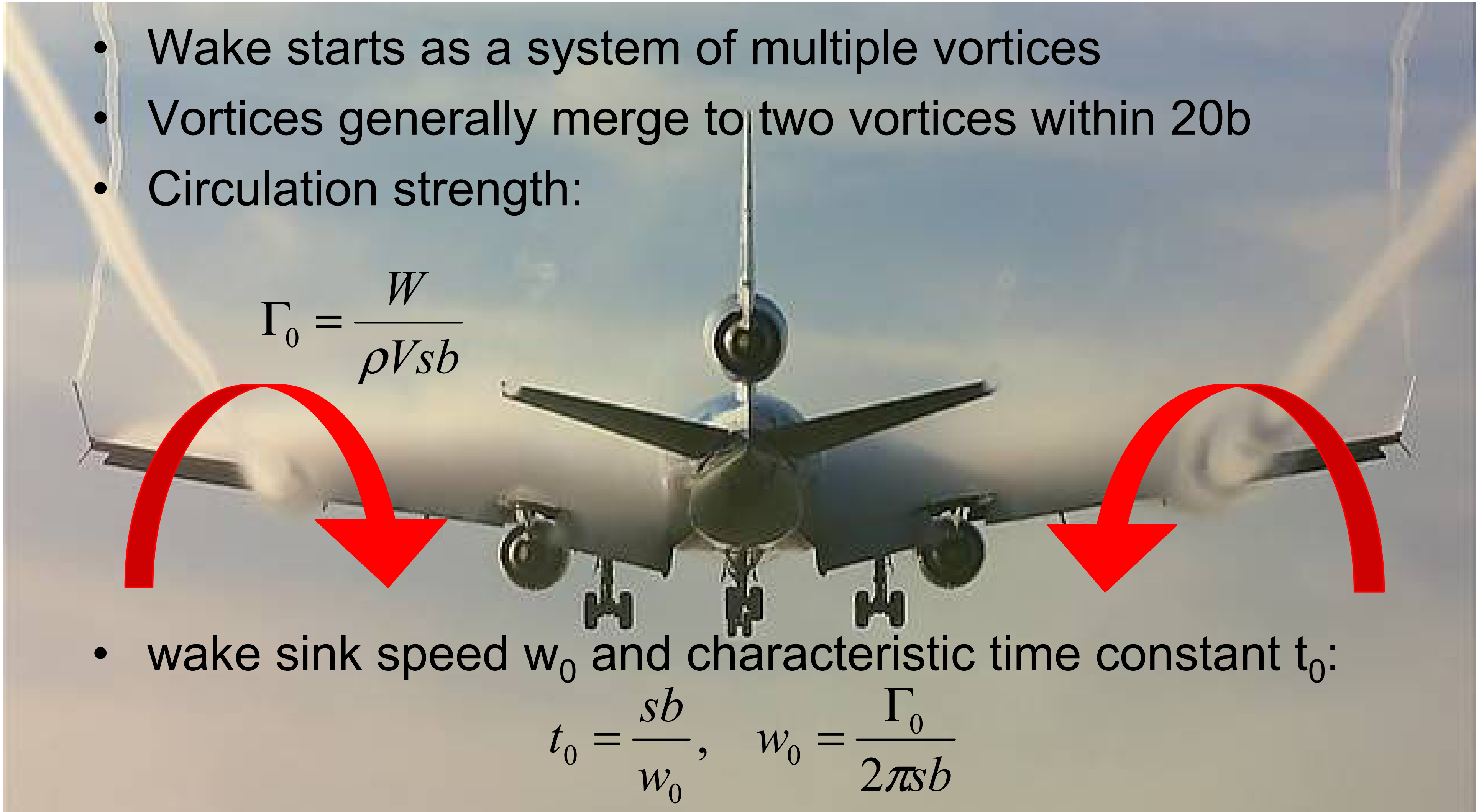
Awiator (July 2002-July 2007), Wake Vortex Alleviation Task,

Successor of former Eurowake and C-Wake projects

- ✓ Develop and test High lift wing designs for A340 landing configuration (C_L=1.4) with alleviated wake characteristics
- ✓ Develop and validate CFD methods to design for more benign wakes
- ✓ Develop and apply sub-scale test procedures to select promising configurations
- ✓ Develop measuring techniques to assess the wake characteristics in real flight
- ✓ Perform Flight Testing with selected wing configurations
- Analyse the results (in progress until June 2007)

Introduction

Definition of some key parameters



- Wake starts as a system of multiple vortices
- Vortices generally merge to two vortices within 20b
- Circulation strength:

$$\Gamma_0 = \frac{W}{\rho V s b}$$

- wake sink speed w_0 and characteristic time constant t_0:

$$t_0 = \frac{sb}{w_0}, \quad w_0 = \frac{\Gamma_0}{2\pi s b}$$

Methods to enhance Crow instability in two vortex systems

Initial vortex strength

- $\Gamma \sim W / b_0$

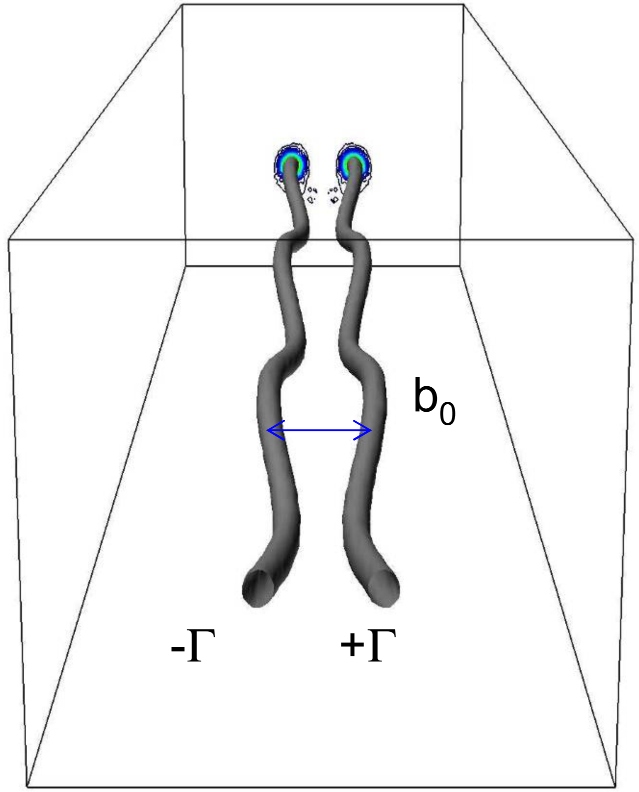
Generic wake decay mode: Crow instability

- Perturbations amplify in the form:
  $A(t) = A_0 \exp(\sigma t)$
- The instability has a growth rate
  $\sigma = K_C \cdot \Gamma/(2\pi b_0^2)$
  $\sim W / b_0^3$

Instability efficiency increased through aircraft modification

- Decrease of b_0 (inboard loading: more effective inboard flap or outboard de-loading
- Increase of A_0 : active wake excitation at frequency $f \approx V/(5b_0)$

Crow instability

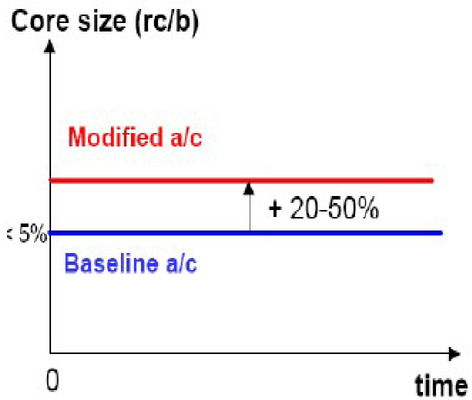


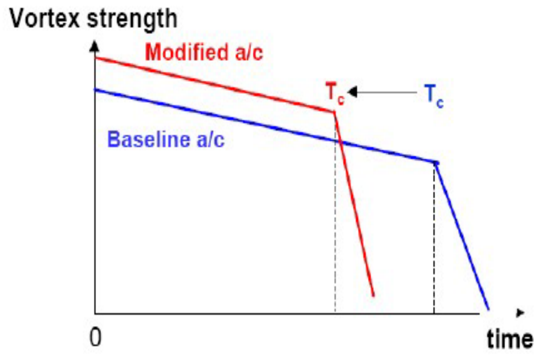
Other methods to enhance wake decay

Design for dedicated multi-vortex systems, to:

- promote long wavelength instabilities (including Crow type)
- promote vorticity annihilation across the wake symmetry plane
- promote 3D interaction between vortices to enhance vortex diffusion (short + long-wavelength instabilities, e.g. Ω-loops)

- **Method should work, independent of atmospheric turbulence conditions**

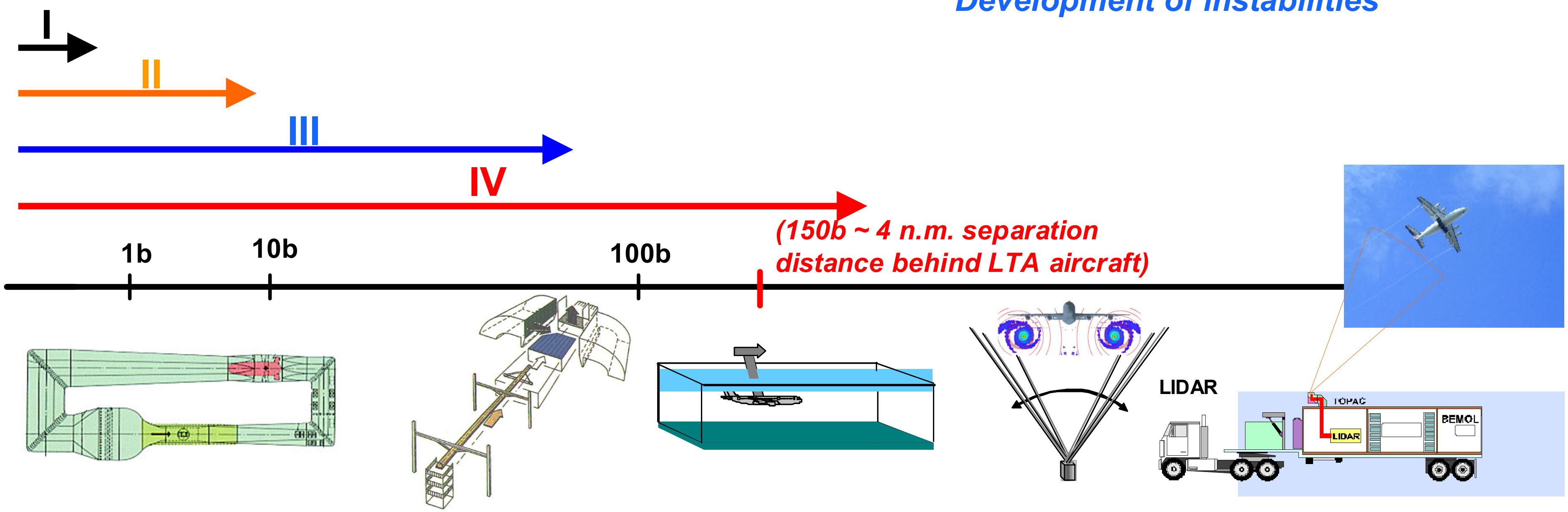




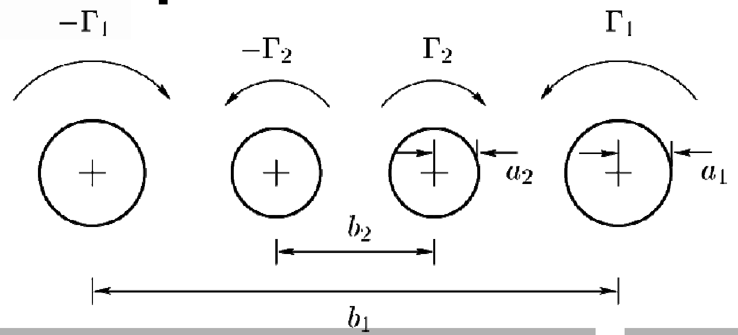
Required testing and CFD capabilities

Vortex field: generally split in <u>four</u> regions

- **<u>Region I</u>: Near-wake field** (few wing chord lengths) — *Vortex formation*
- **<u>Region II</u>: Extended near-wake field** (~10 b) — *Vortex roll-up & merging*
- **<u>Region III</u>: Mid-wake field** (→ ~80-100b) — *Vortex drift - instabilities appearance*
- **<u>Region IV</u>: Far-wake field** (> 100 b) — *Vortex collapse, disperse*
  Development of instabilities

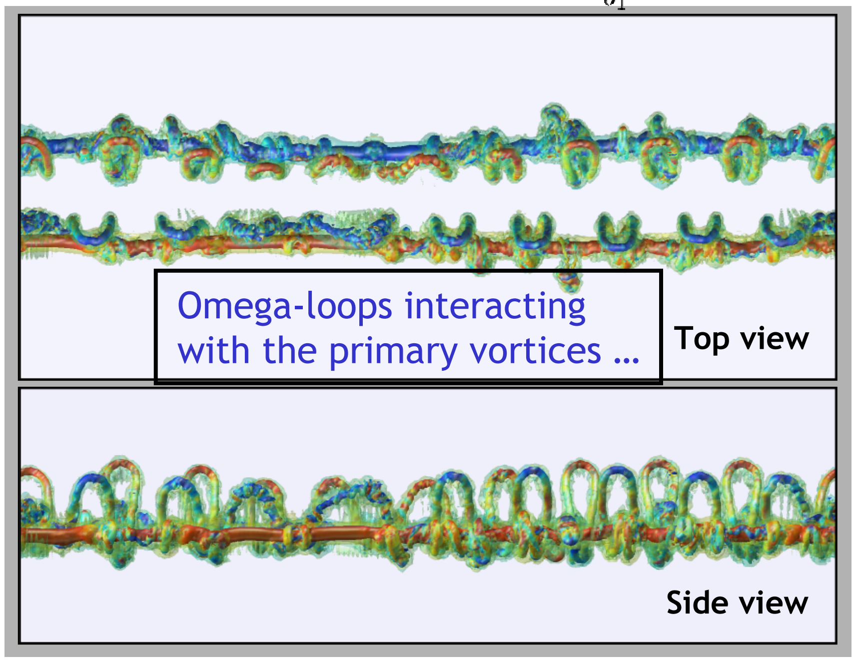


Numerical simulations (e.g. LES)
Computation of a 4-vortex system



$$\frac{\Gamma_2}{\Gamma_1} = -0.37 \qquad \frac{b_2}{b_1} = 0.484$$

$$\frac{a_1}{b_1} = 0.065 \qquad \frac{a_2}{a_1} = 0.54$$



LES simulations (UCL, CERFACS, DLR):

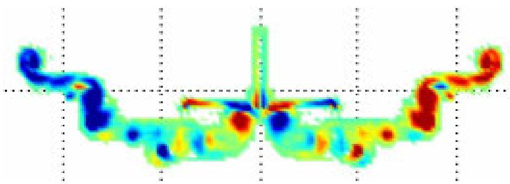
- increase physical understanding
- select promising configurations

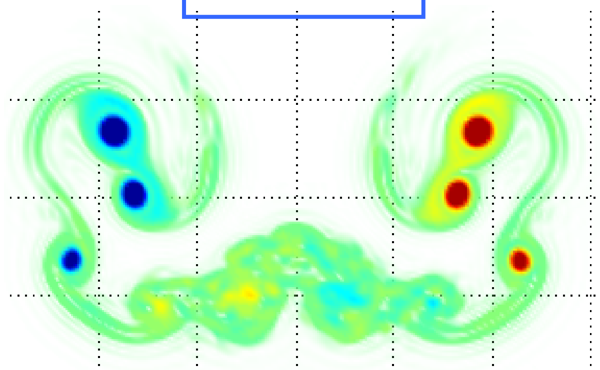
LES results compared with experiment (vorticity fields)

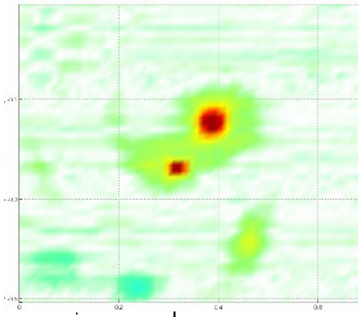
x/b= 0.5

x/b= 6.5

Baseline



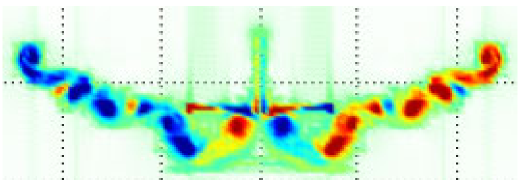


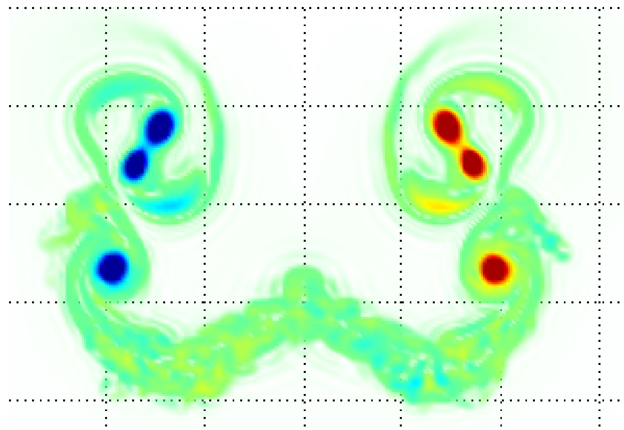


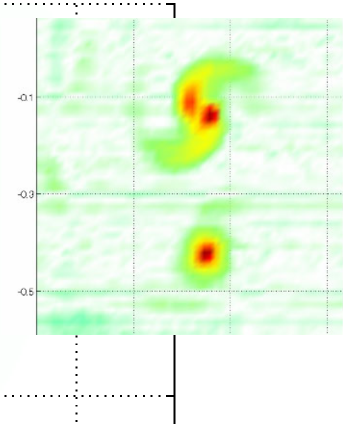
Initial conditions (from EXP)

LES simulations (UCL)

EXP (DNW-LLF)



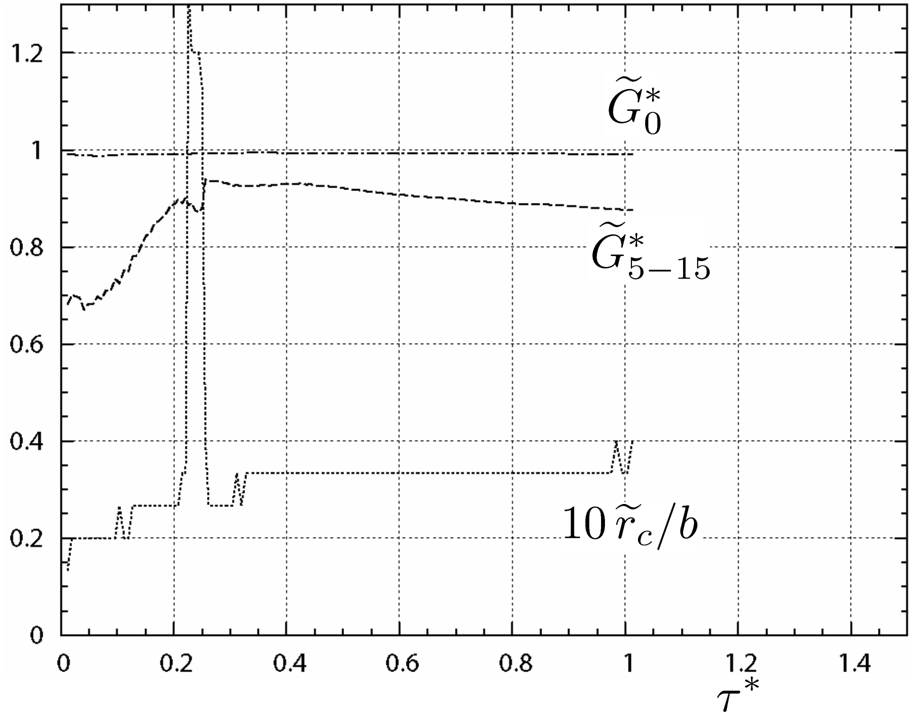




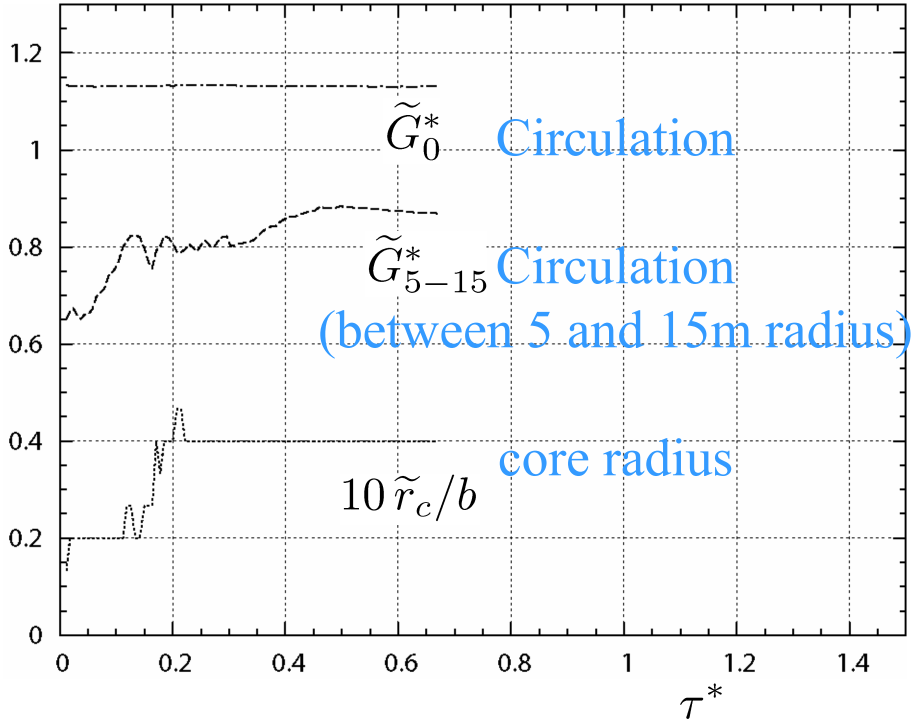
DFS 32/10

LES results: Comparison Baseline and DFS 32/10

Baseline 26/26

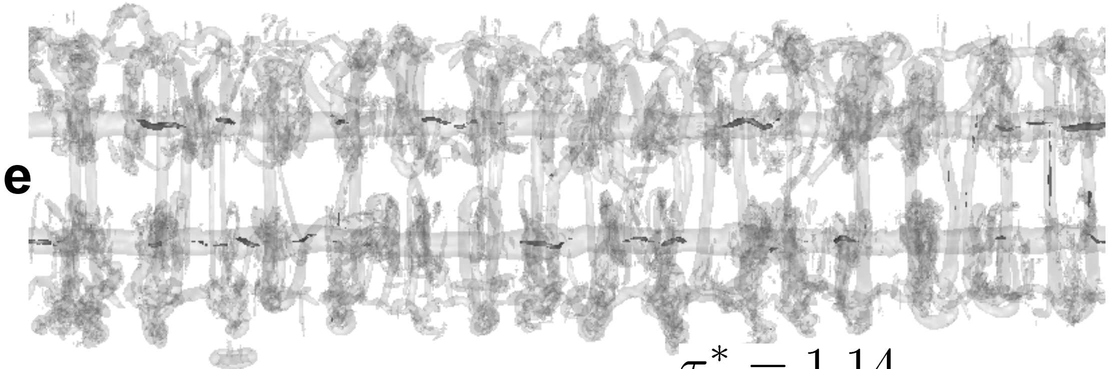


DFS 32/10



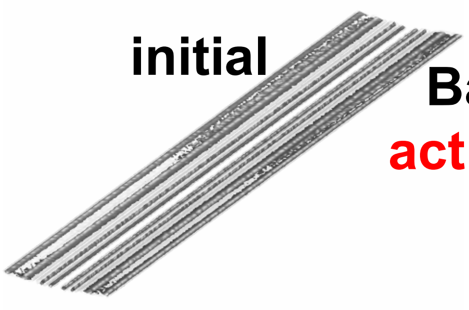
LES: simulation of active control

Baseline

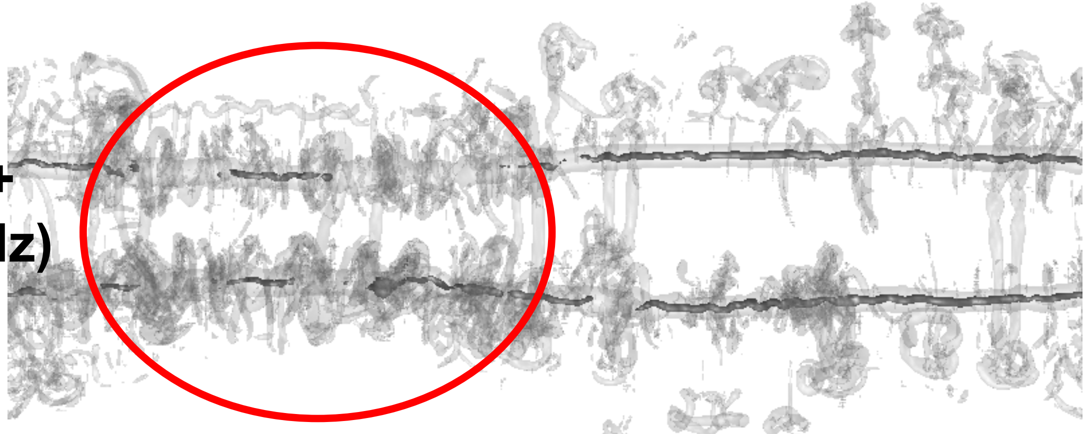


$\tau^* = 1.14$

initial



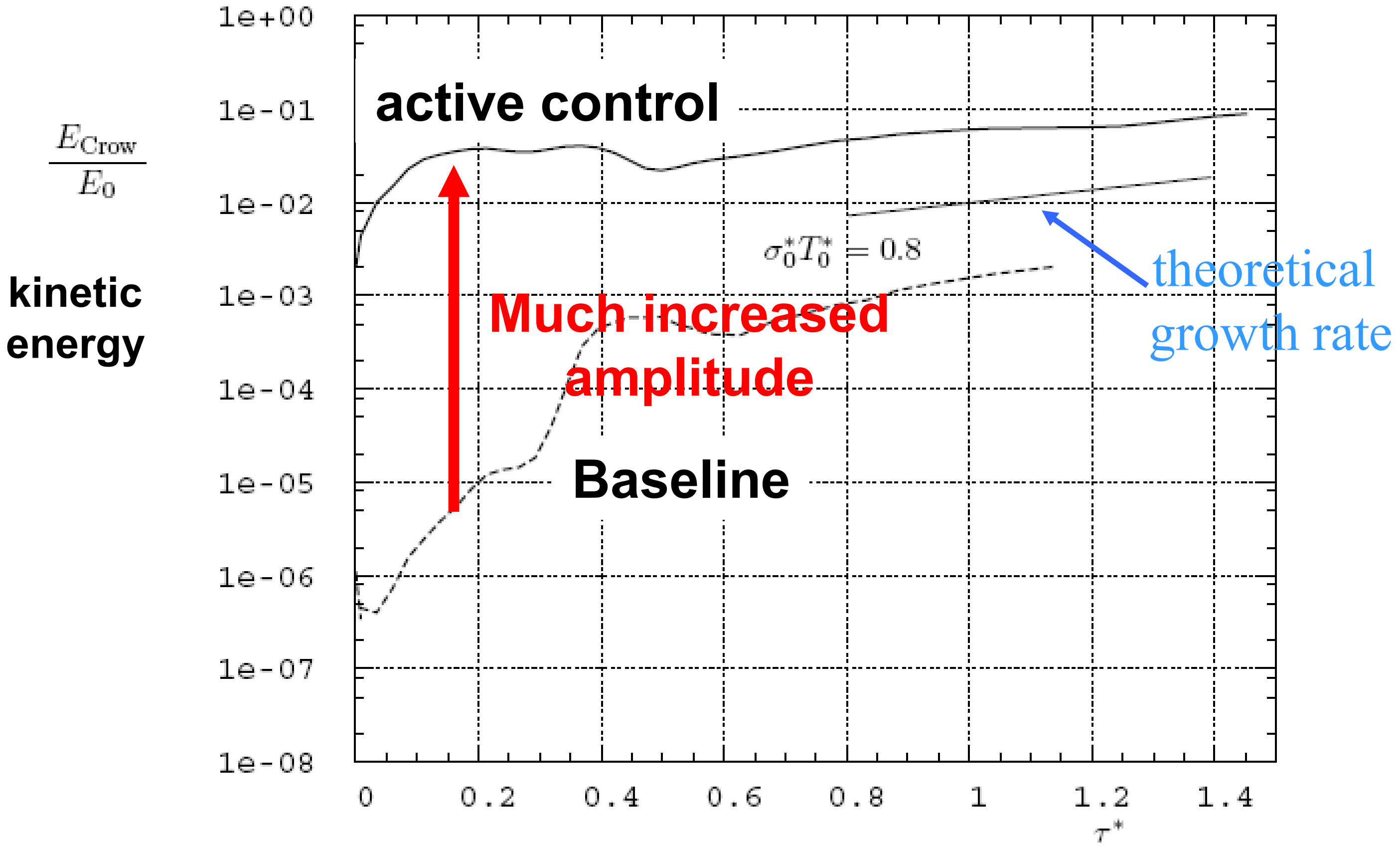
Baseline + active (0.2Hz) control



$\tau^* = 1.45$

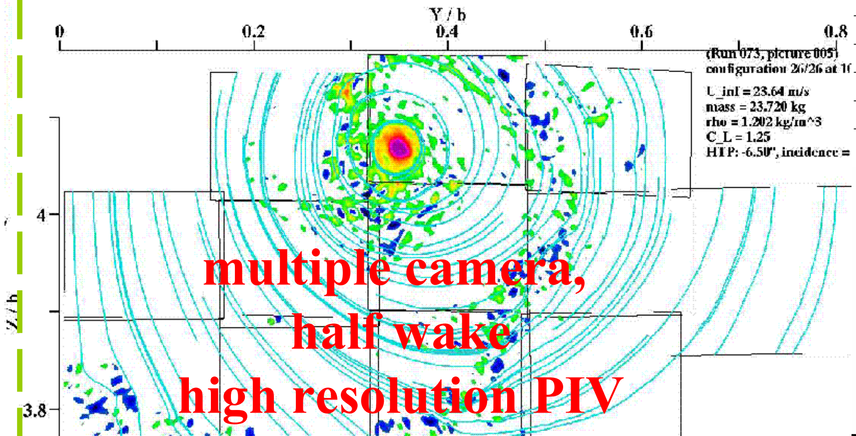
LES simulation of Crow mode (UCL)

comparison baseline + active control

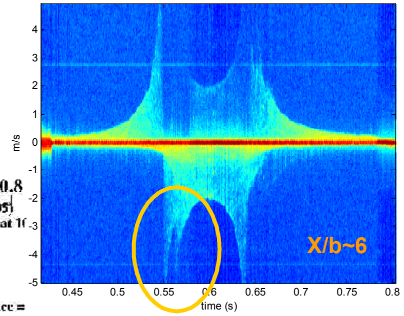


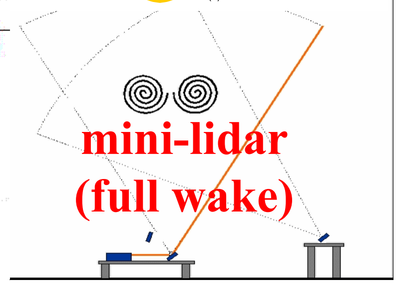
Summary of test facilities/ techniques used

near wake, 5-hole probes
(e.g. span -loading)

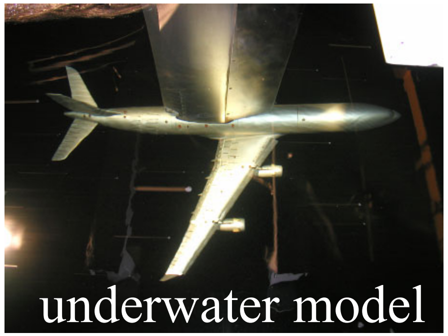


multiple camera,
half wake
high resolution PIV

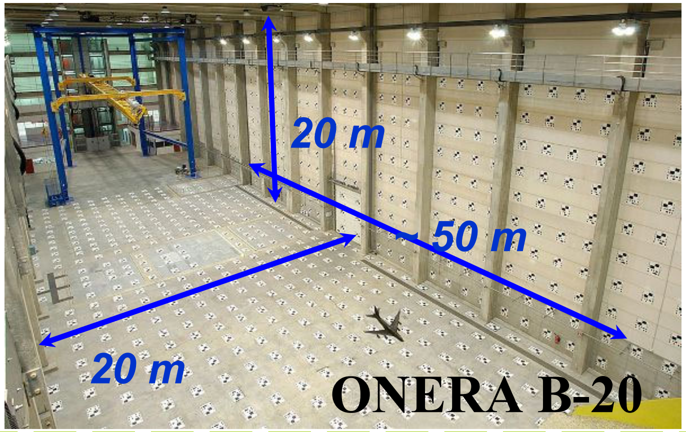


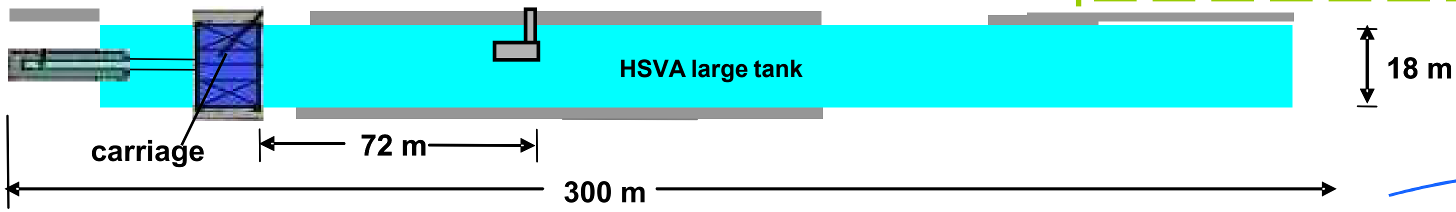


mini-lidar
(full wake)



single camera,
half wake
low resolution PIV





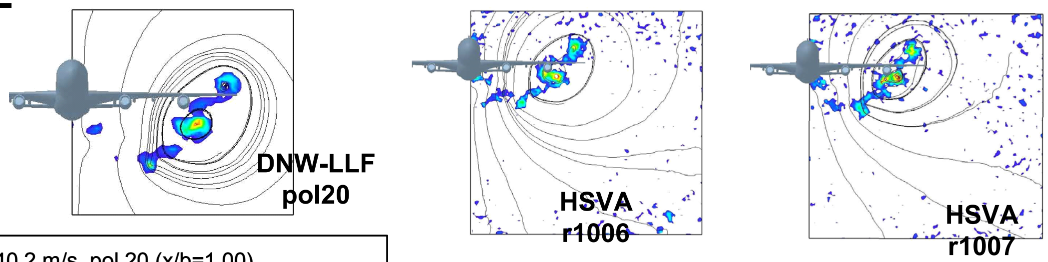
Experiments: cross checks

DNW-LLF windtunnel and HSVA towing tank

- Same model but different measurement techniques: PIV at HSVA, 5-hole at DNW-LLF

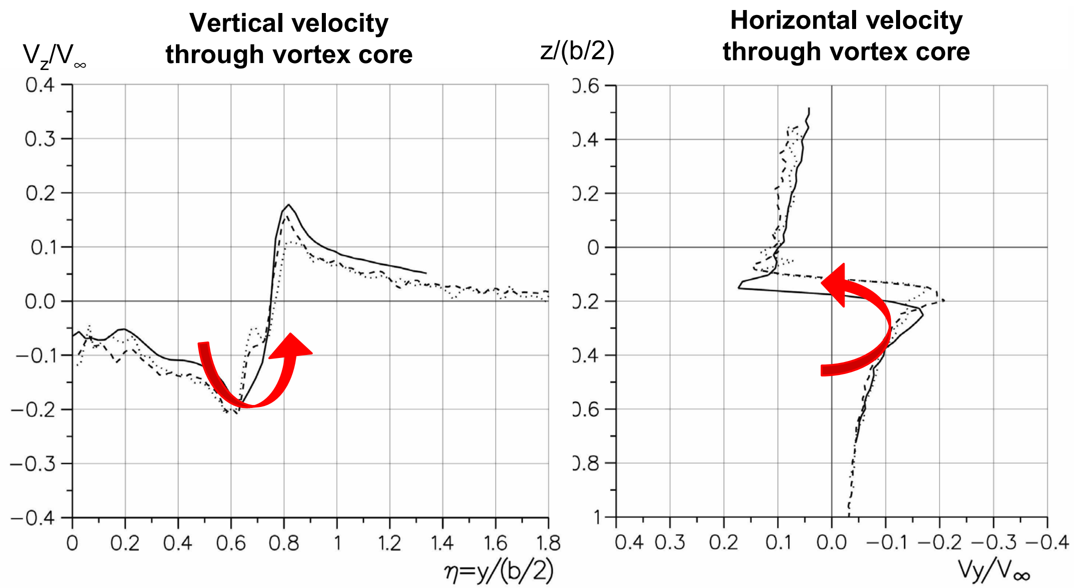
Full model

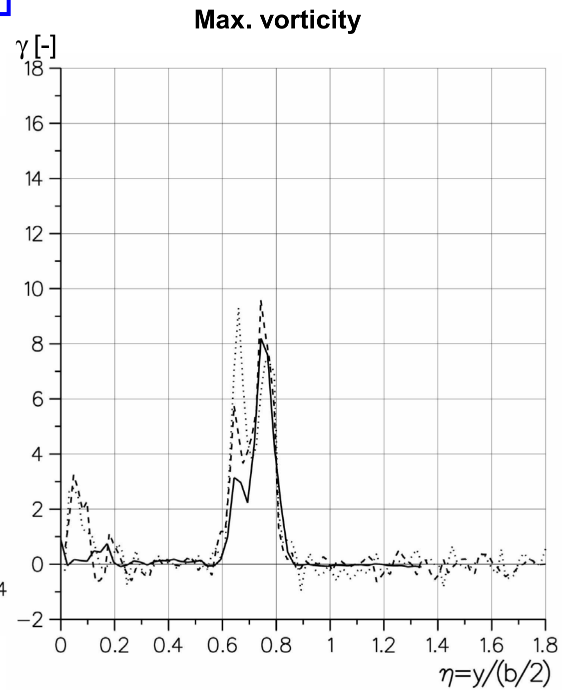
Model: E4, scale: 1:48
flap 26/26°, slat 19.6/23/23°
aileron 5°, HTP –5.5°
u/c off



——	DNW, α= 9.05, C_L=1.40, V=40.2 m/s, pol 20 (x/b=1.00)
- - - -	HSVA, α= 9.12, C_L=1.39, V=3.0 m/s, run 1006 (x/b=1.05)
········	HSVA, α= 9.09, C_L=1.39, V=3.0 m/s, run 1007 (x/b=1.25)

x/b=1.00

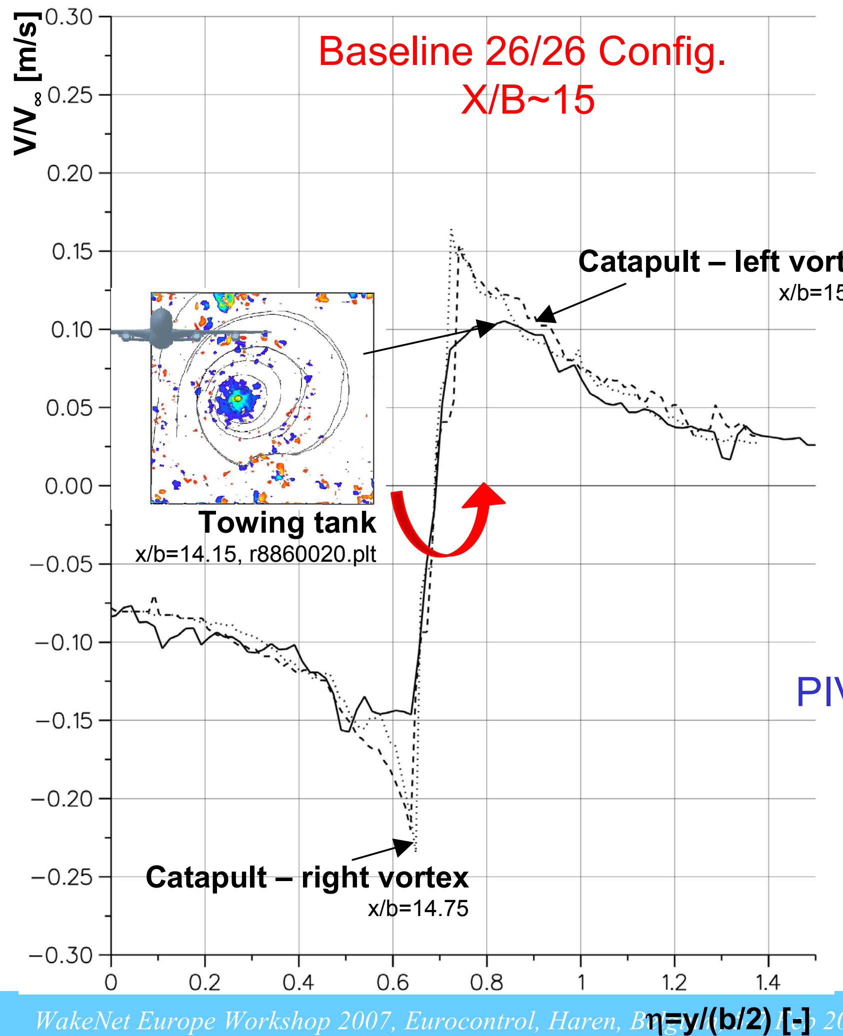


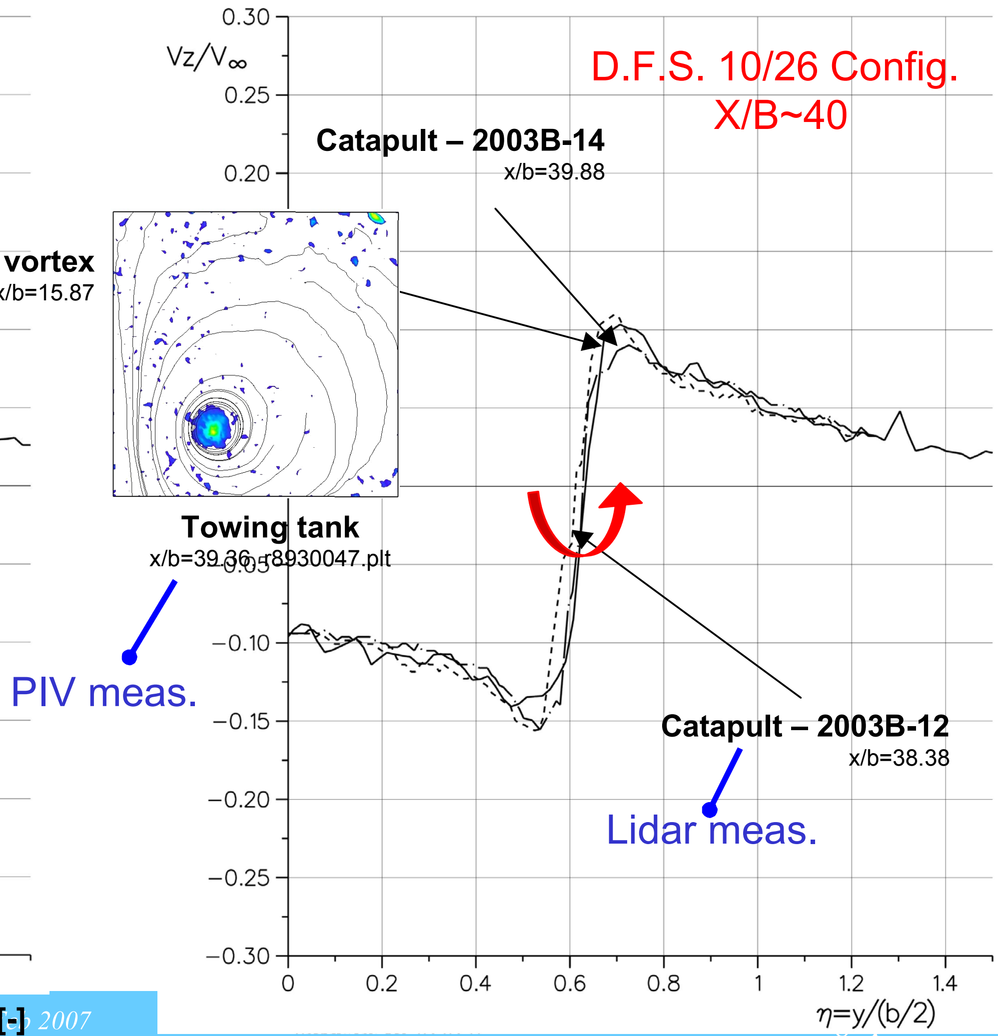


Cross-checks between facilities

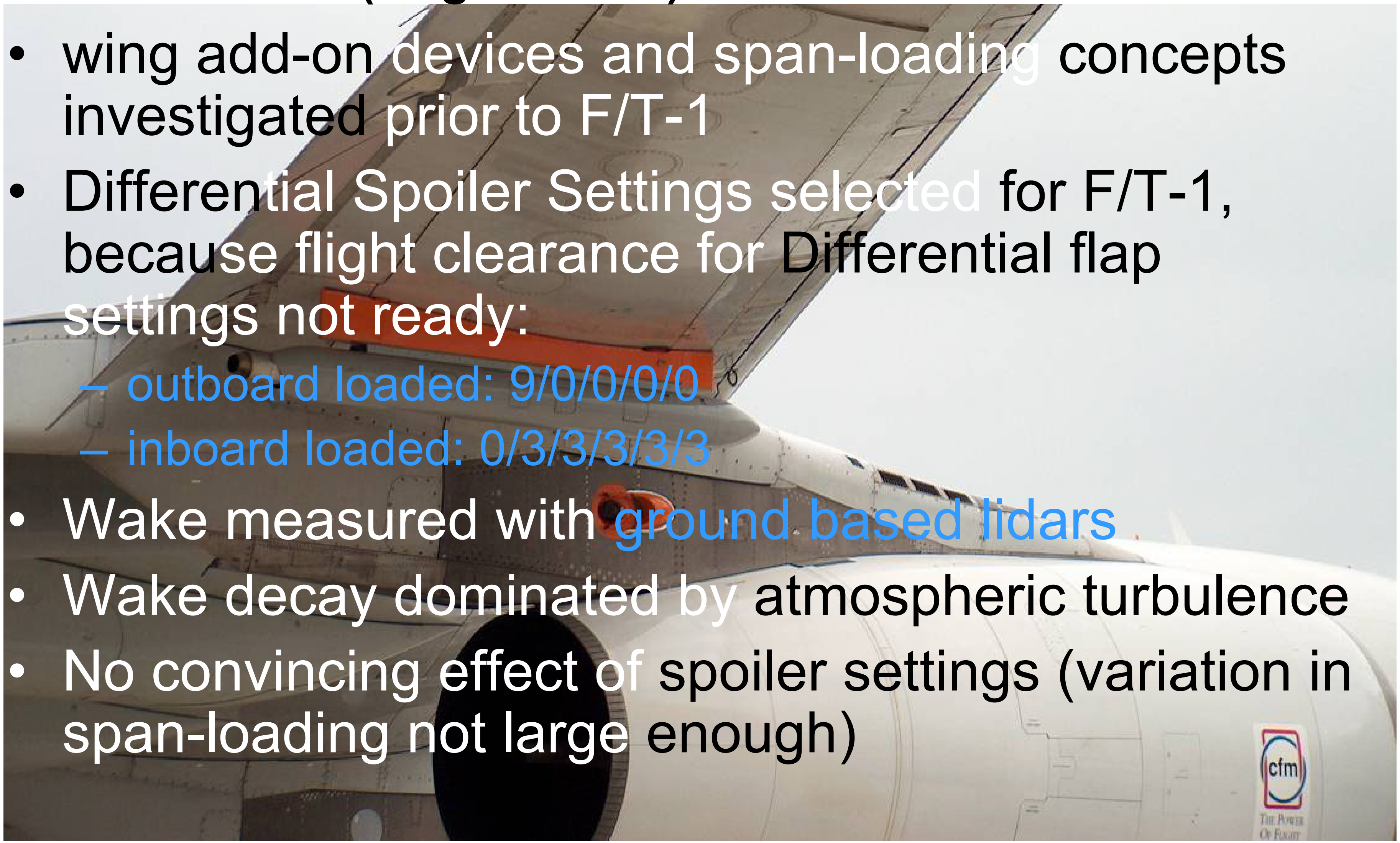
HSVA Towing Tank & B20 Catapult

- ☐ Different flap settings and different meas. techniques





Selected configurations for F/T-1 (August 2003)



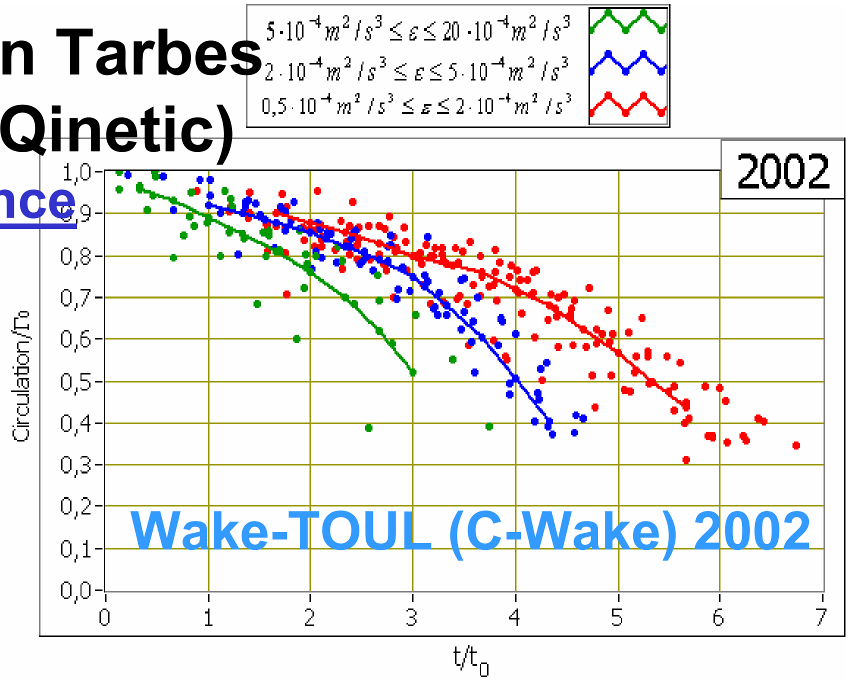
- wing add-on devices and span-loading concepts investigated prior to F/T-1
- Differential Spoiler Settings selected for F/T-1, because flight clearance for Differential flap settings not ready:
  - outboard loaded: 9/0/0/0/0
  - inboard loaded: 0/3/3/3/3/3
- Wake measured with ground based lidars
- Wake decay dominated by atmospheric turbulence
- No convincing effect of spoiler settings (variation in span-loading not large enough)

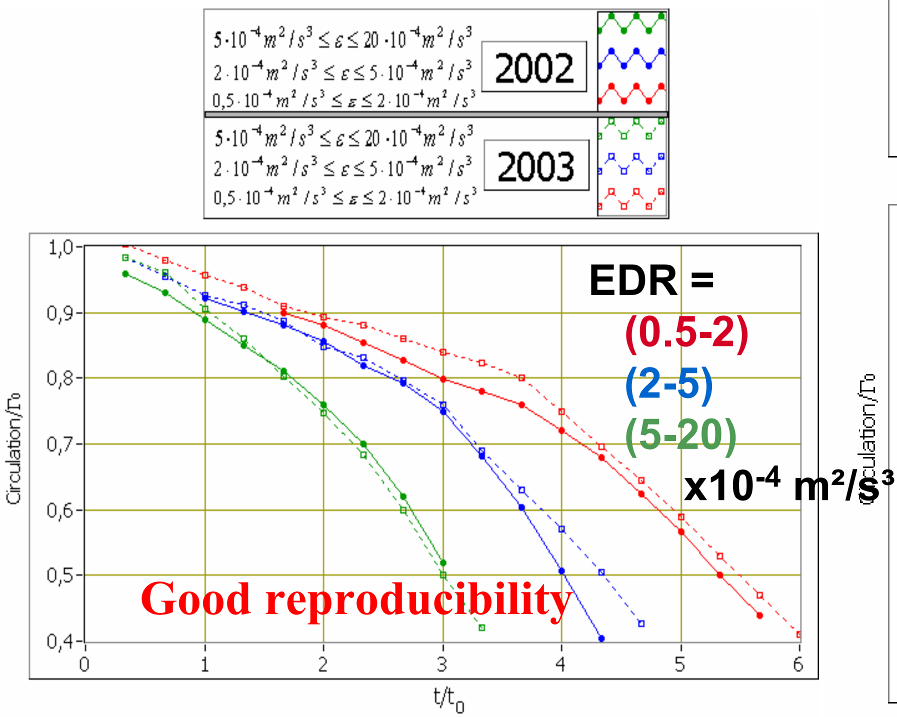
Lidar measurements of aircraft wake vortices in Tarbes (DLR, ONERA, Qinetic)

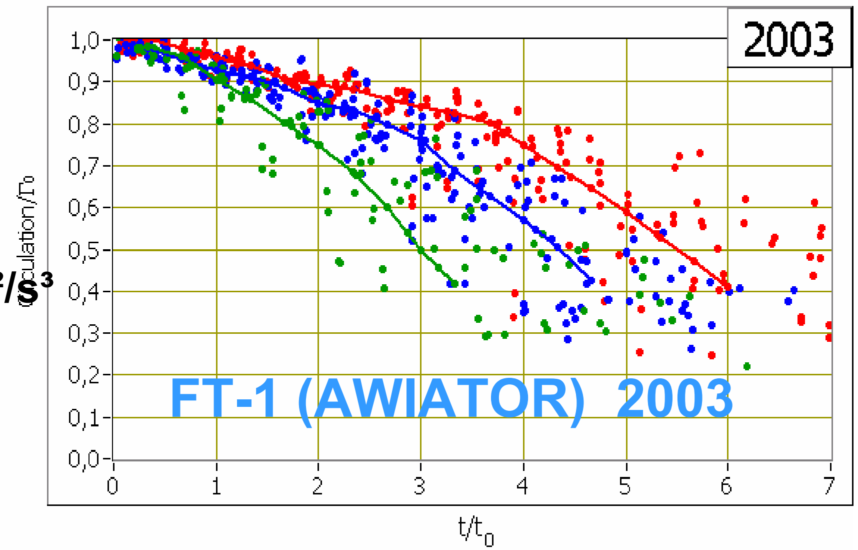
Influence of atmospheric turbulence on vortex decay

circulation vs. time

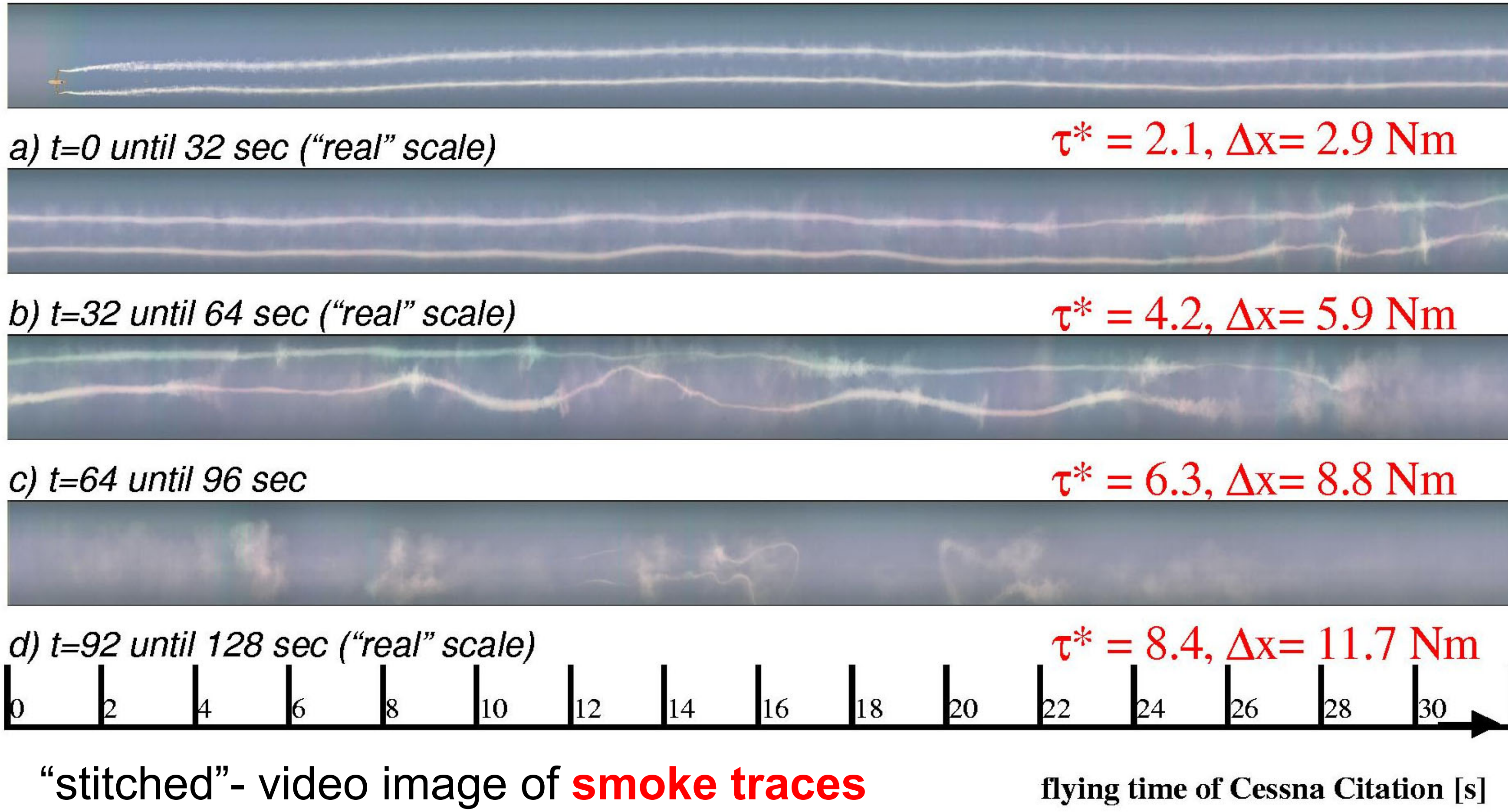
Köpp, Smalikho, Rahm







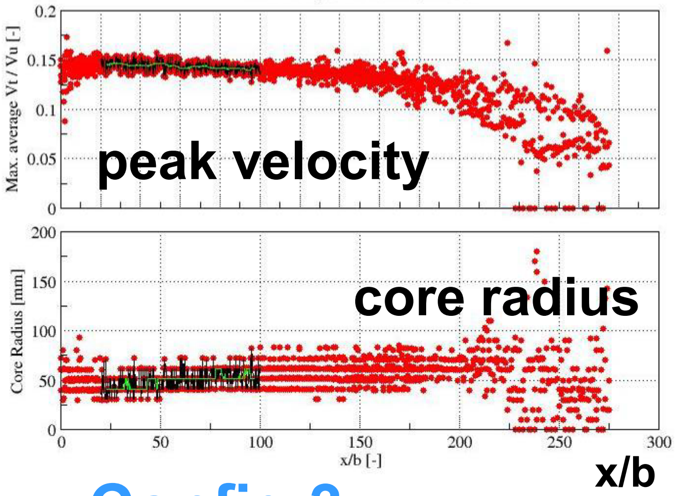
"stitched" video sequence taken from NLR's Cessna Citation a/c (F/T-1, August 29, 2003)



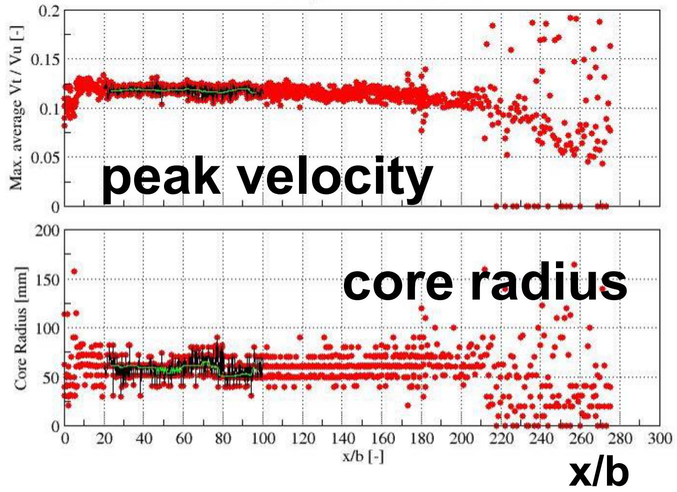
- "stitched"- video image of **smoke traces**
- A340 (FL90) with 2 smoke generators, passing NLR Citation (FL75)
- No noticeable differences between the configurations

Results from HSVA water-tank tests
Selected cases for F/T-2 only

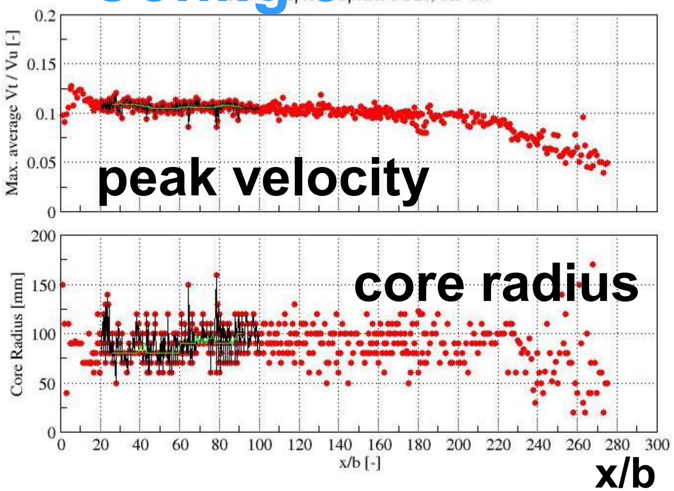
Baseline



DFS 32/10



Config 3



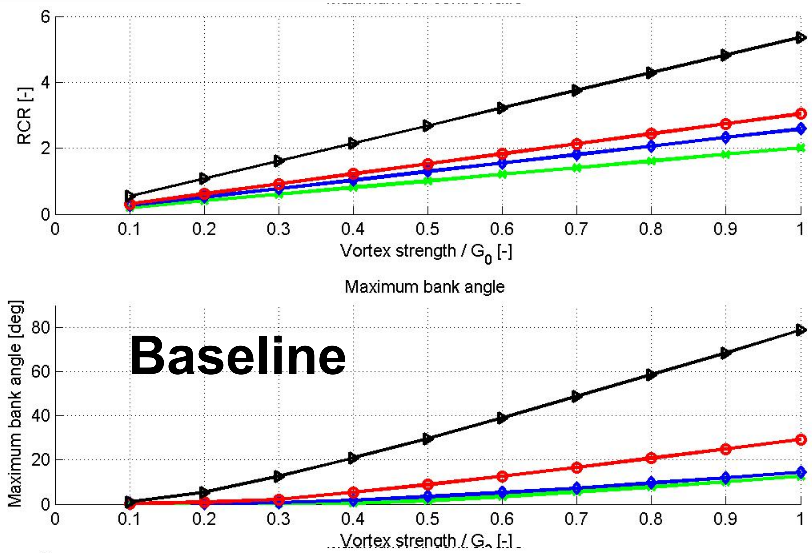
Config 4

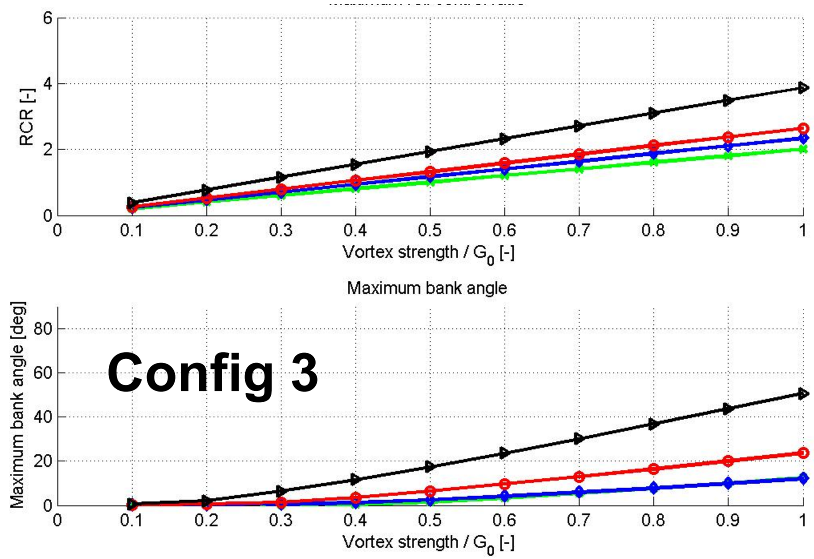
Active control

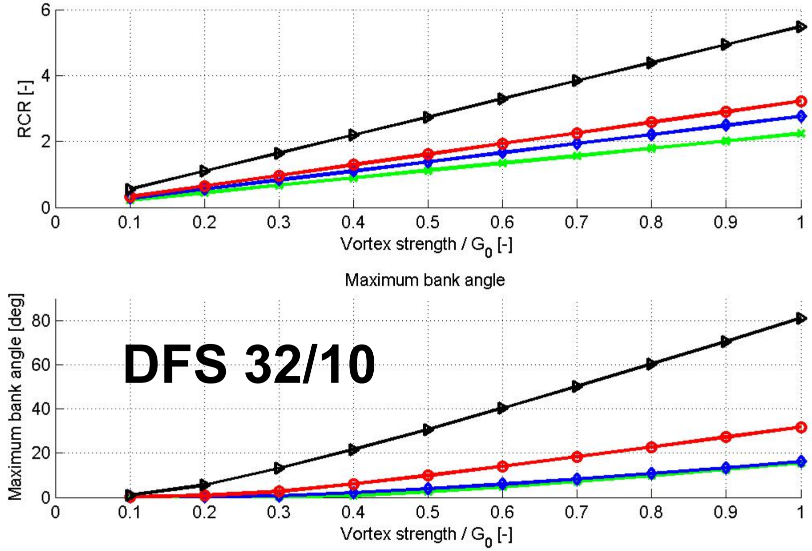
NO experiments

(LES simulations + F/T only)

Initial assessment of encounter severity (worst case condition)





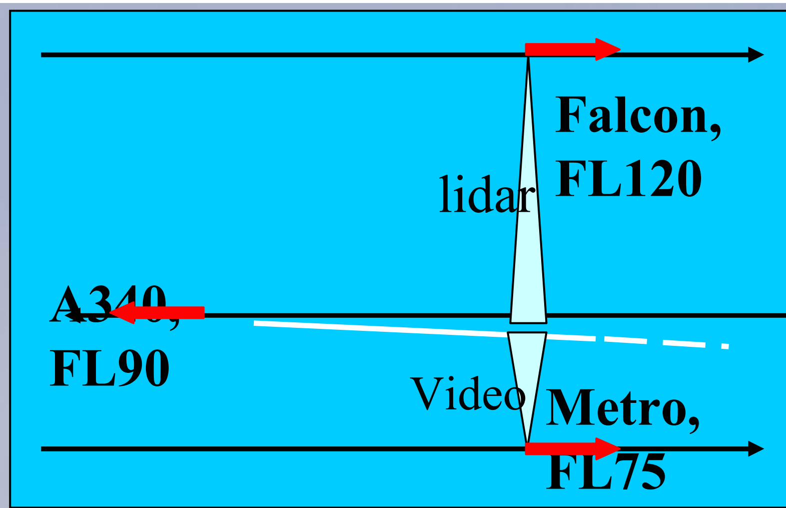


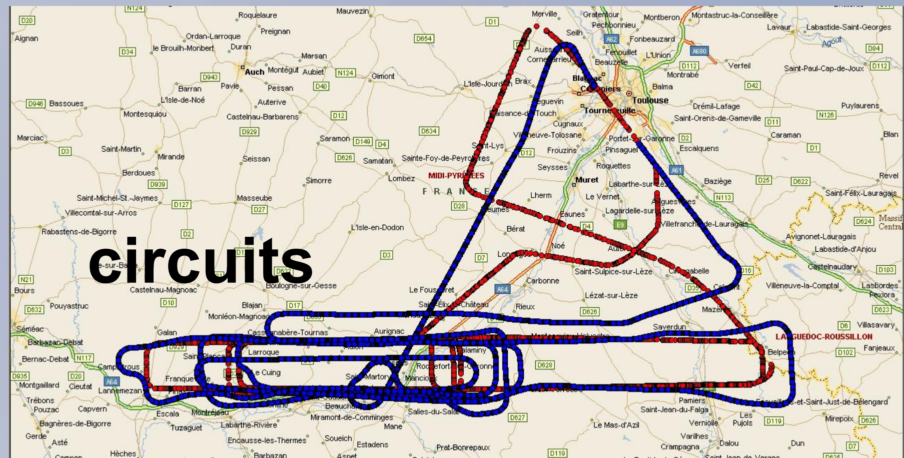
Selected configurations for F/T-2
(November 9 and 15, 2006)

- **New selected (practical) span-loading concepts:**
  - Baseline (flap settings 26/26)
  - DFS 32/10 (inboard loaded, flaps rigged during entire flight)
  - Config 3 (-)
  - Config 4 (active control of Crow instabilities)
- **Following successful try-out tests + applications for A380 with on-board pulsed lidar (DLR-Falcon)**
- **Onboard lidar (DLR-Falcon) + flow visu (NLR Metro) was selected for F/T-2**
- **Enabled much more efficient F/T than in F/T-1**
- **Nov 9, DFS 32/10 tested in low turbulence**
- **Nov 15, all other configurations tested in 3 flights** (unfortunately at medium turbulence conditions)

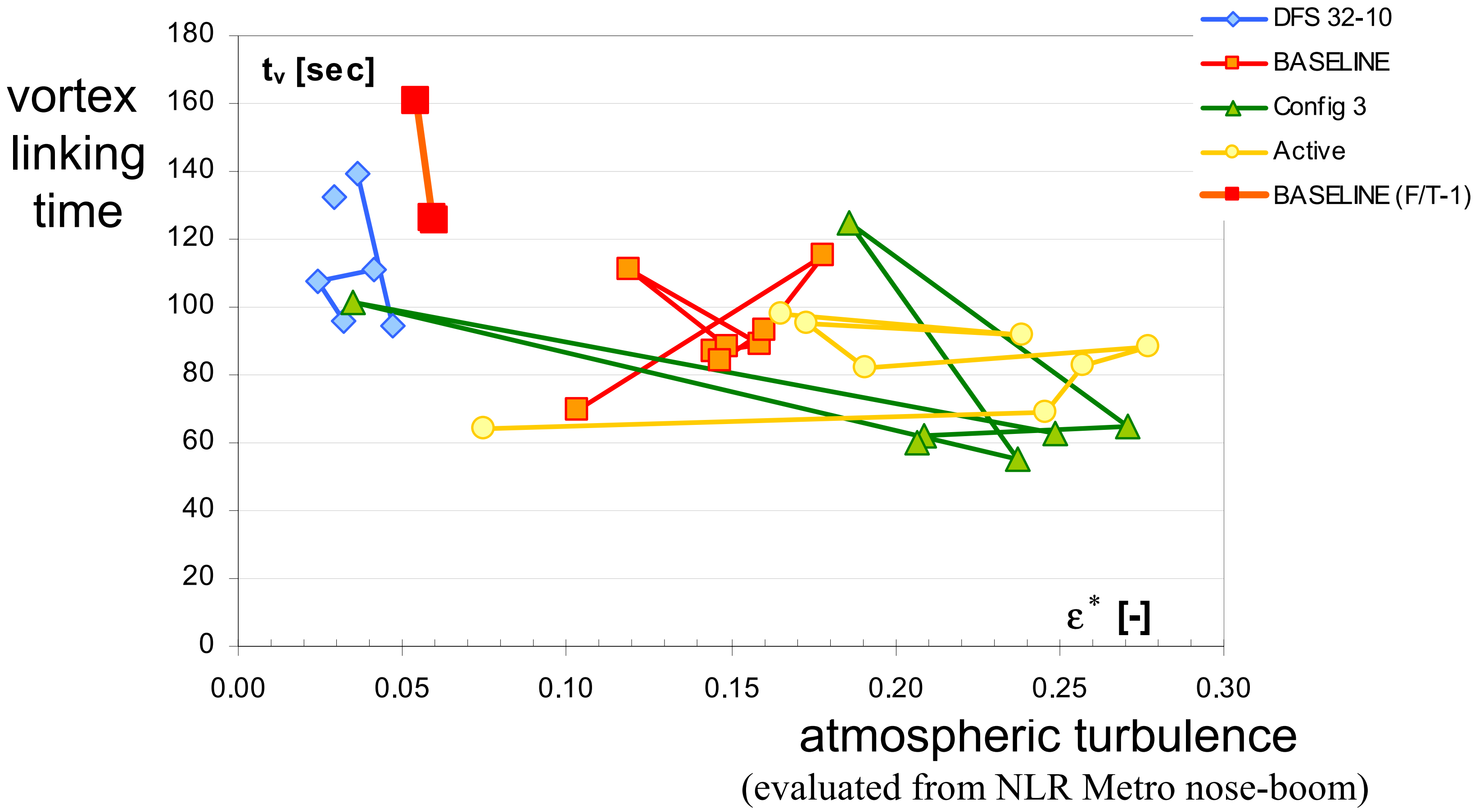
F/T-2 test procedure

picture taken from cockpit window
of NLR Metro during A340 passage

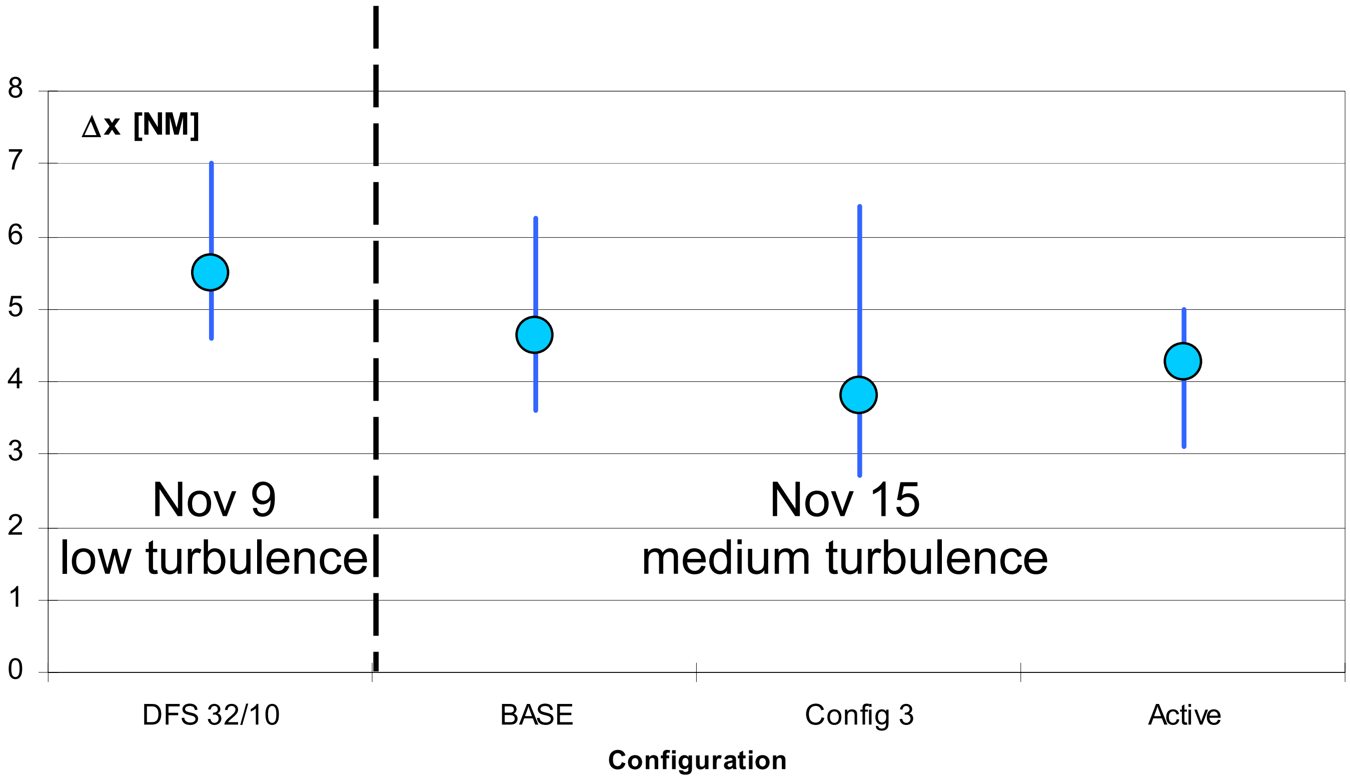




F/T-2: Flow visualisation results (NLR)



F/T-2: Flow visualisation results (NLR)



Observed wake distance behind A340 for the first vortex linking

Concluding remarks

- LES methods helpful to define promising configs.
- Windtunnel necessary to characterise near wake
- Catapult + towing tank technique applicable for wake research up to x/b=100
- On-board lidar technique was developed in Awiator
- On-board technique was used in F/T-2 (and for A380)
- Valuable technique to classify in flight wake characteristics, especially when seeded with smoke
- Atmospheric turbulence and stratification plays a major role in wake decay and should be measured along with the wake measurements

Concluding remarks

- In low turbulence DFS 32/10 shows earlier vortex linking than baseline configuration
- In higher turbulence, Config 3 and 4 show only weak benefit (compared to baseline)
- Full analysis of (lidar) results is still needed
- too early to draw definite conclusions on configuration effects on decay and safety
- Initial safety assessment (NLR, in progress) shows that for worst case condition (no decay) config 3 has a favourable effect for the smallest follower aircraft (a small turboprop) only

Questions ?

Wake video footage during landing phase of A340

remaining smoke released
to visualise the wake in ground effect
for FAR-Wake project