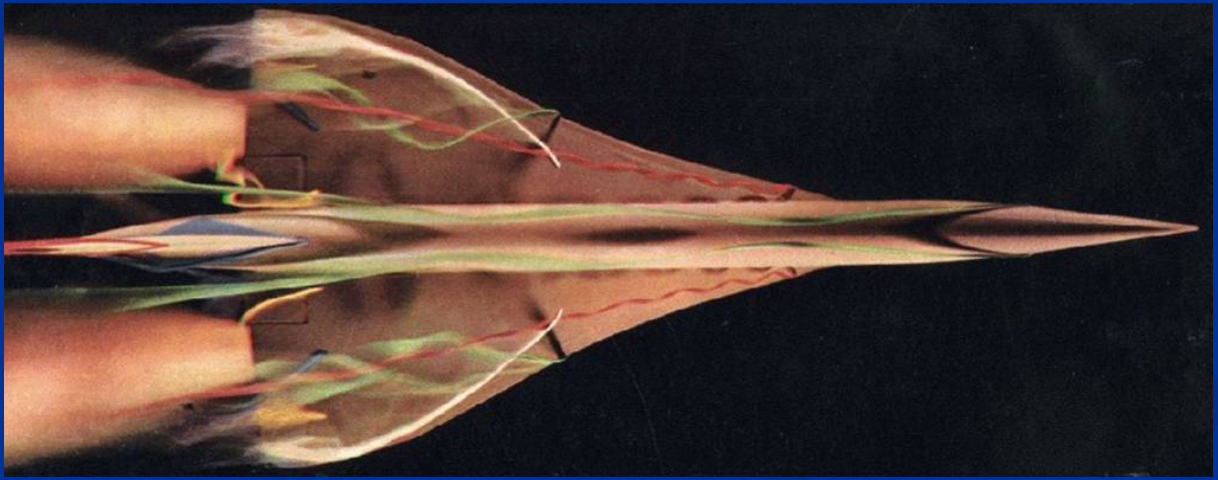
DELTA WING AERODYNAMICS – Requirements from CFD and experiments



I Gursul (University of Bath),
M. Allan and K. Badcock (University of Glasgow)

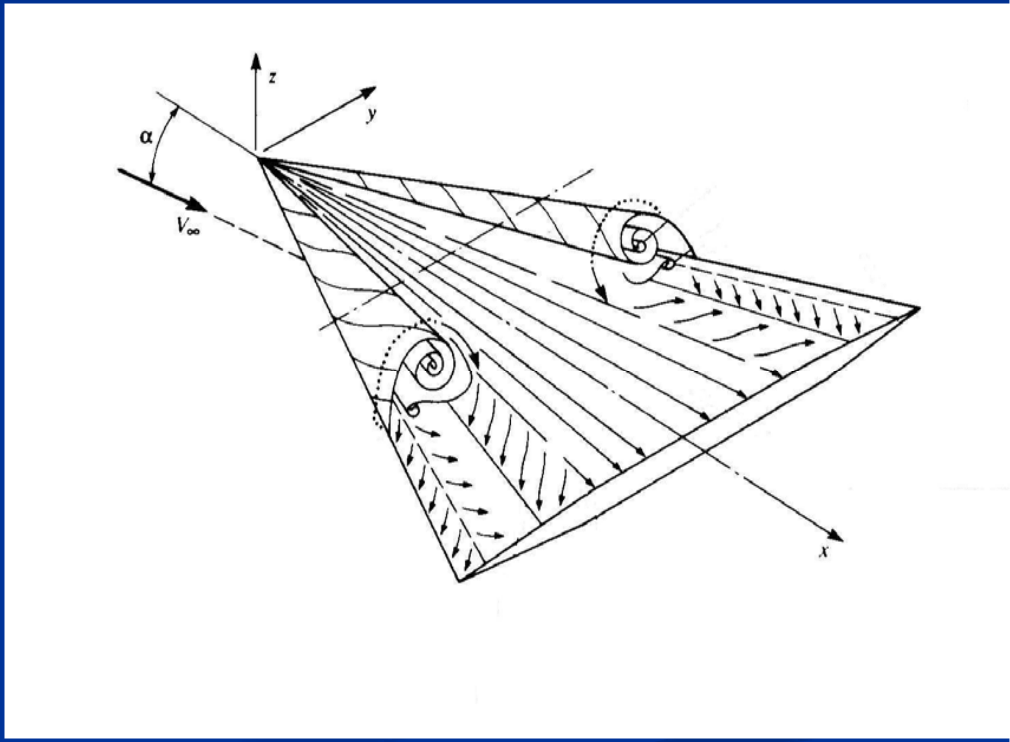
Integrating CFD and Experiments, Sept 8-9 2003, Glasgow, UK.

Overview

- Brief introduction to delta wing aerodynamics
- Issues and challenges
  - Vortex breakdown
  - Shear layer instabilities
  - Vortex breakdown interaction
  - Non-slender vortices
  - Manoeuvring wing vortices
  - Fluid / structure interaction
  - Multiple vortices
  - Alternative planforms
- Requirements from experiments and CFD

Properties of delta wing leading edge vortices

- Flow separates at low angle of attack
- Stable vortices produce increased lift and induced drag
- Secondary vortices form beneath primaries
- Core velocities reach up to 3.5 U_∞ (jet like velocity profile)



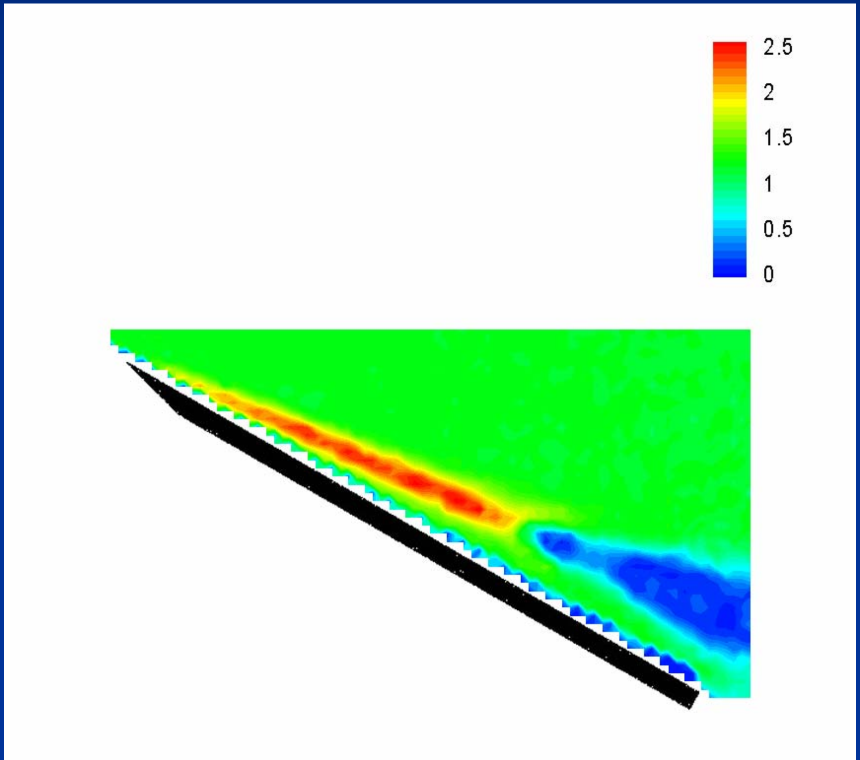
Vortex breakdown

Dryden Flight Research Center EC89-0096-206 Photographed 1989
F-18 HARV smoke and tuft flow visualization. Angle of Attack = 20 deg. NASA photo.

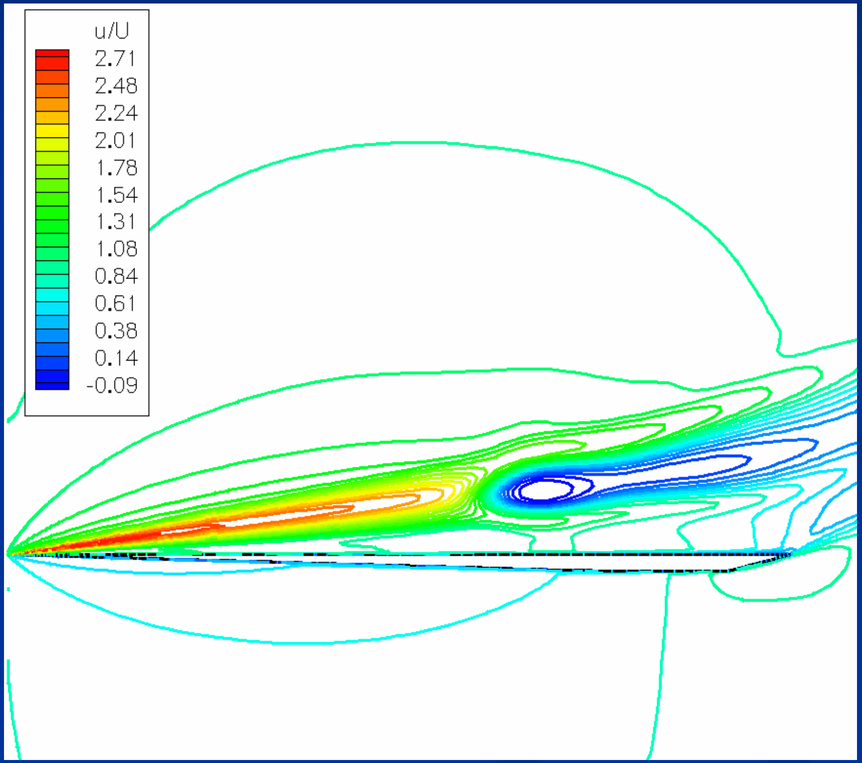
Character of vortex breakdown

- Associated with flow stagnation along vortex axis
- Core kinks and forms spiral of opposite sense to core rotation (**spiral breakdown**) or forms a recirculation region behind stagnation point (**bubble breakdown**)
- Downstream of breakdown flow turns into full scale turbulence
- Dominant frequencies present in breakdown region (associated with spiral breakdown)
- Loss in lift and sharp change in pitching moment
- Reynolds number independent
- **Sensitive to external influences**

Vortex breakdown (1)

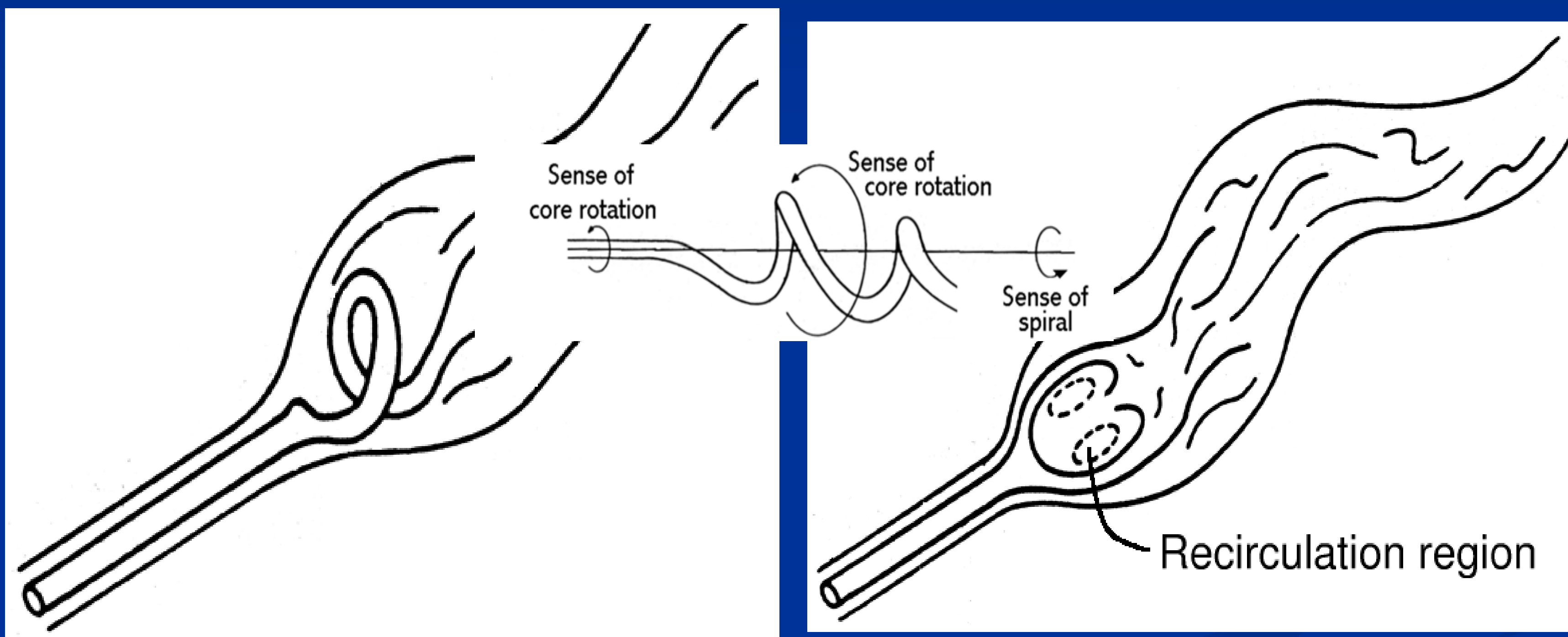


Time averaged PIV results
Magnitude of velocity
showing structure of breakdown



Steady state computation
Velocity contours
showing structure of vortex breakdown

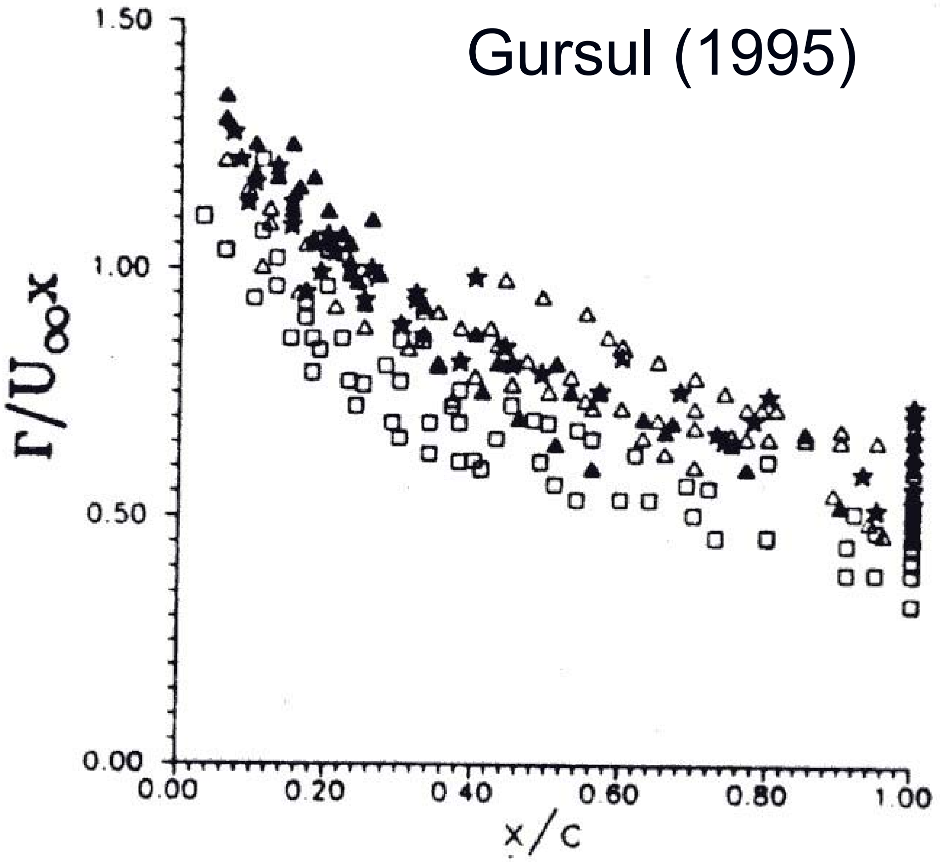
Vortex Breakdown (2)

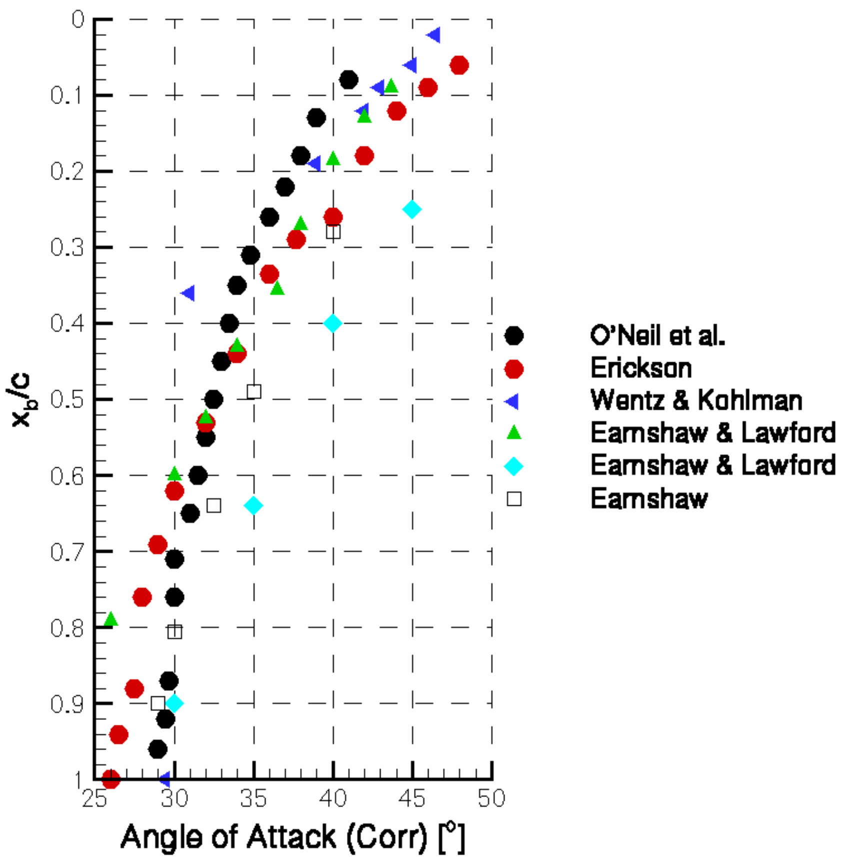


Spiral vortex breakdown

Bubble vortex breakdown

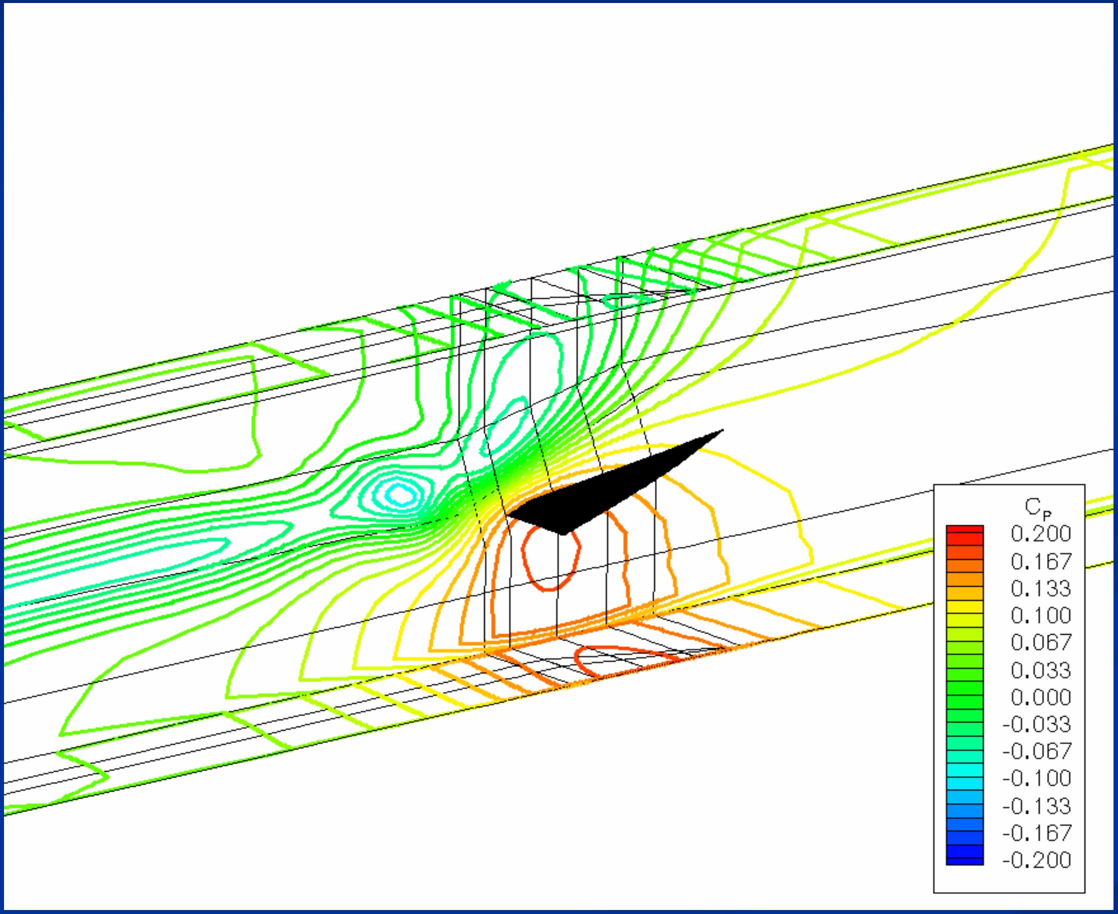
Breakdown location scatter





Large scatter in breakdown locations –
possibly due to geometry or test facilities

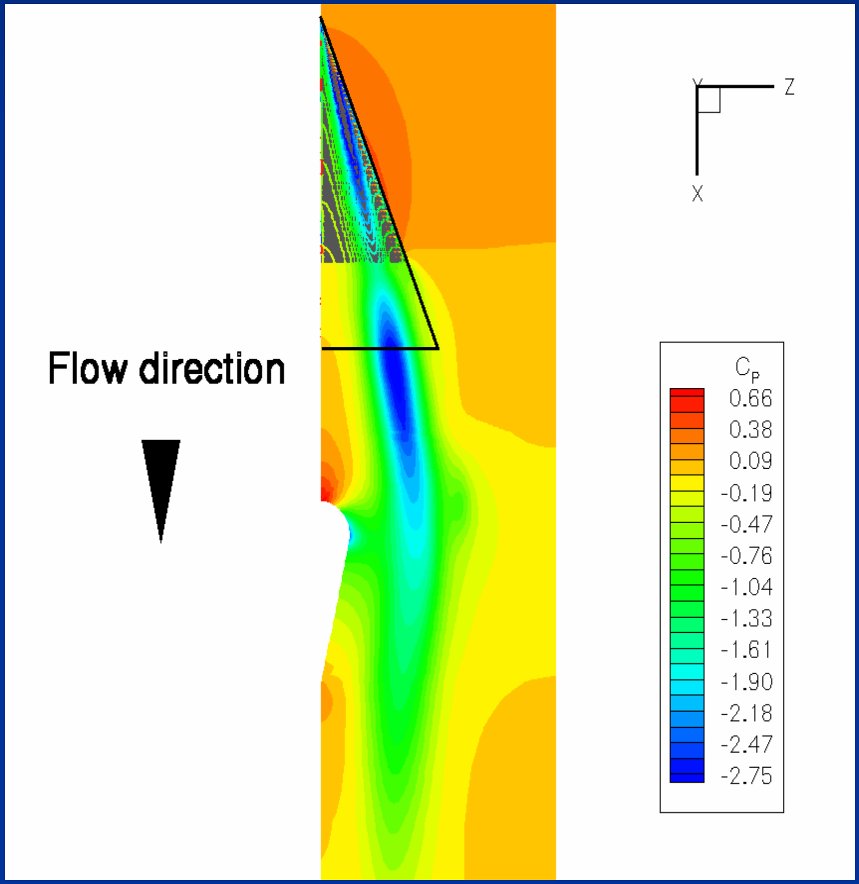
Test facility interference (1)

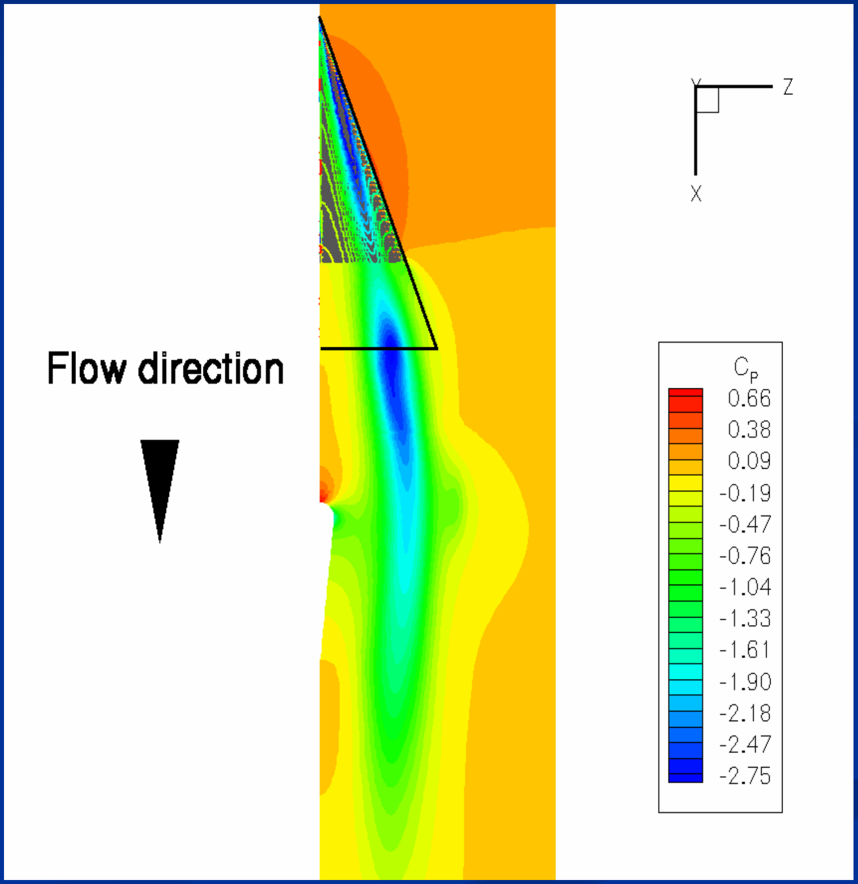


Allan *et al*. (2002)

Test facility interference (2)

Allan *et al*. (2003)

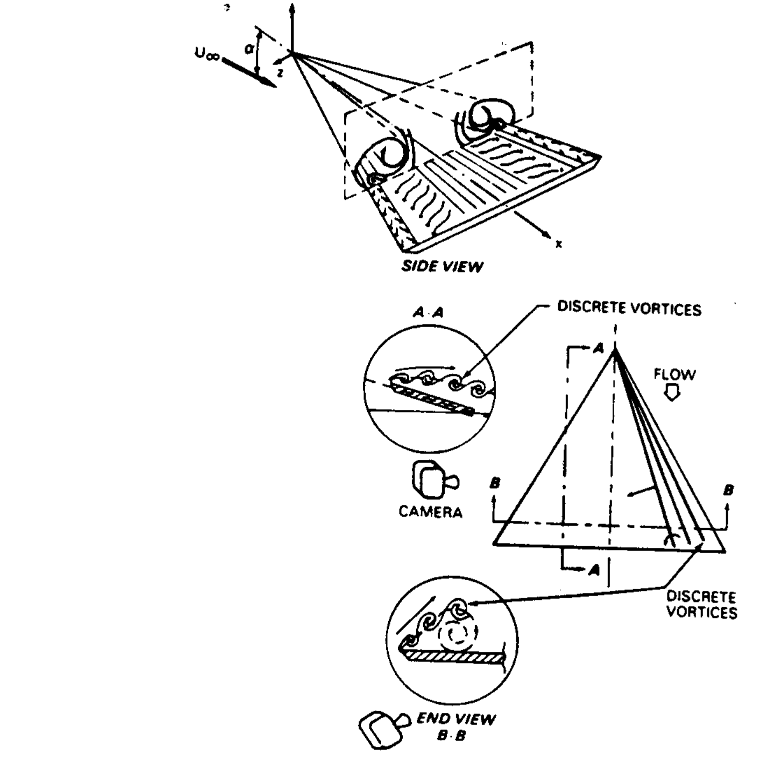




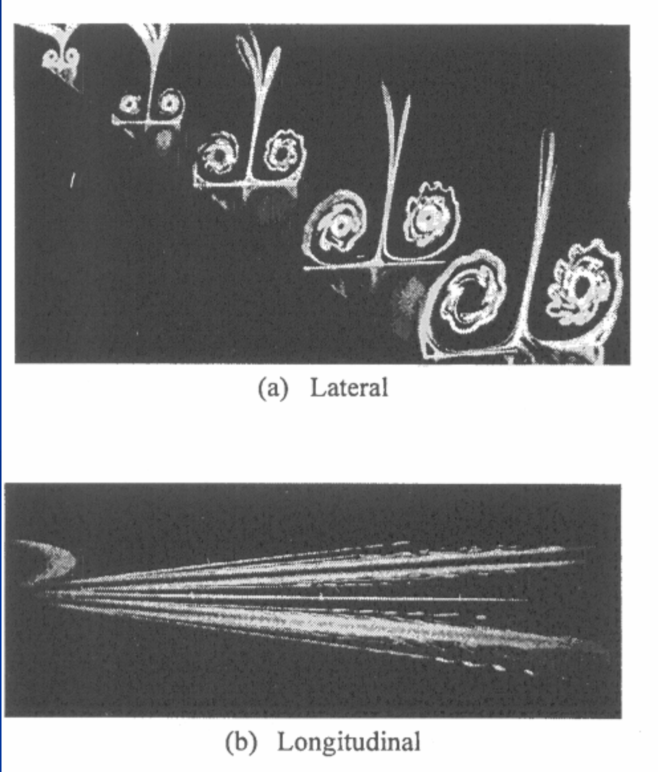
FAB 12% X_{BD} = 81 %c_r

FAB 6% X_{BD} = 73.8 %c_r

Shear layer instabilities (1)



Gad-El-Hak and Blackwelder (1985)



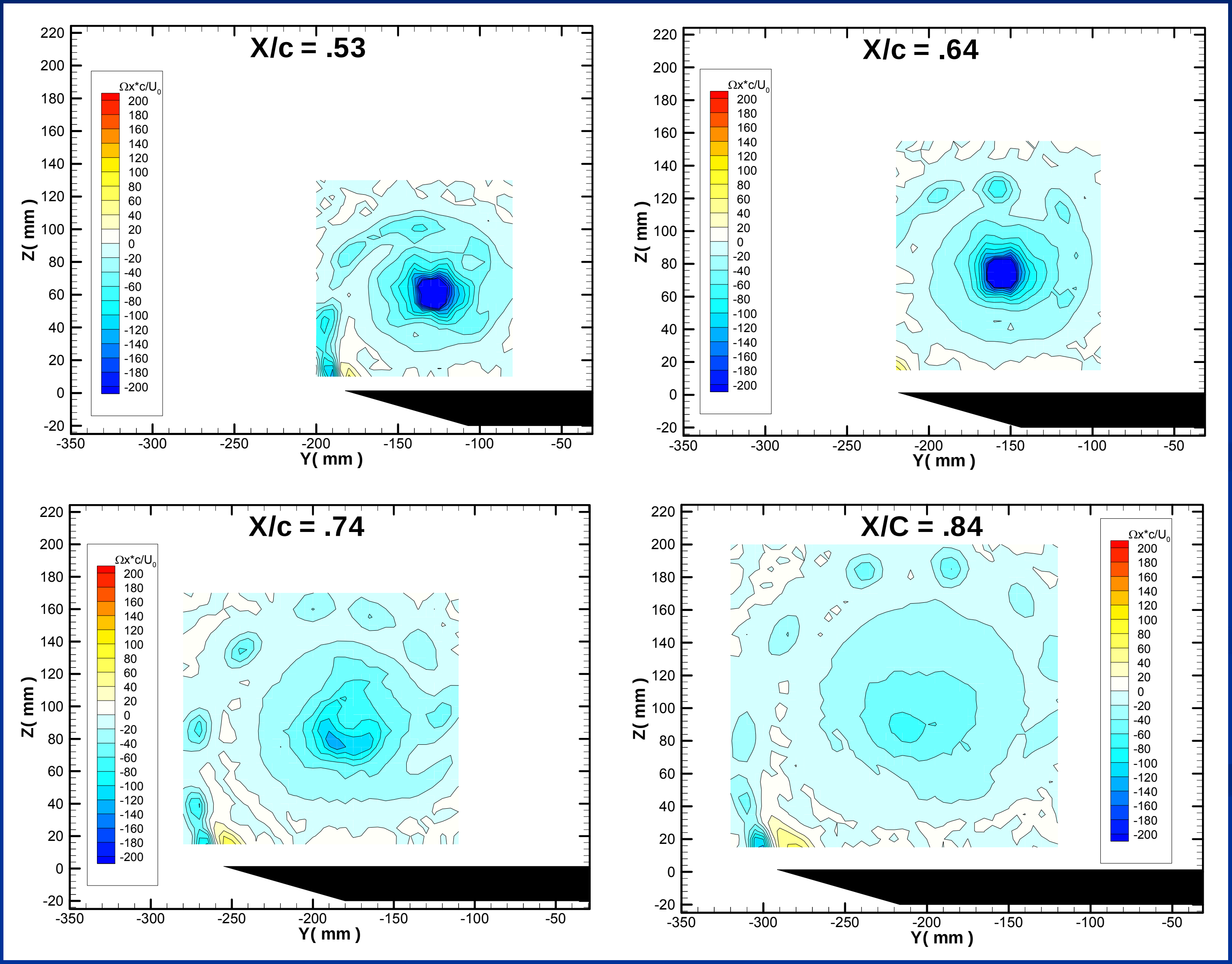
(a) Lateral

(b) Longitudinal

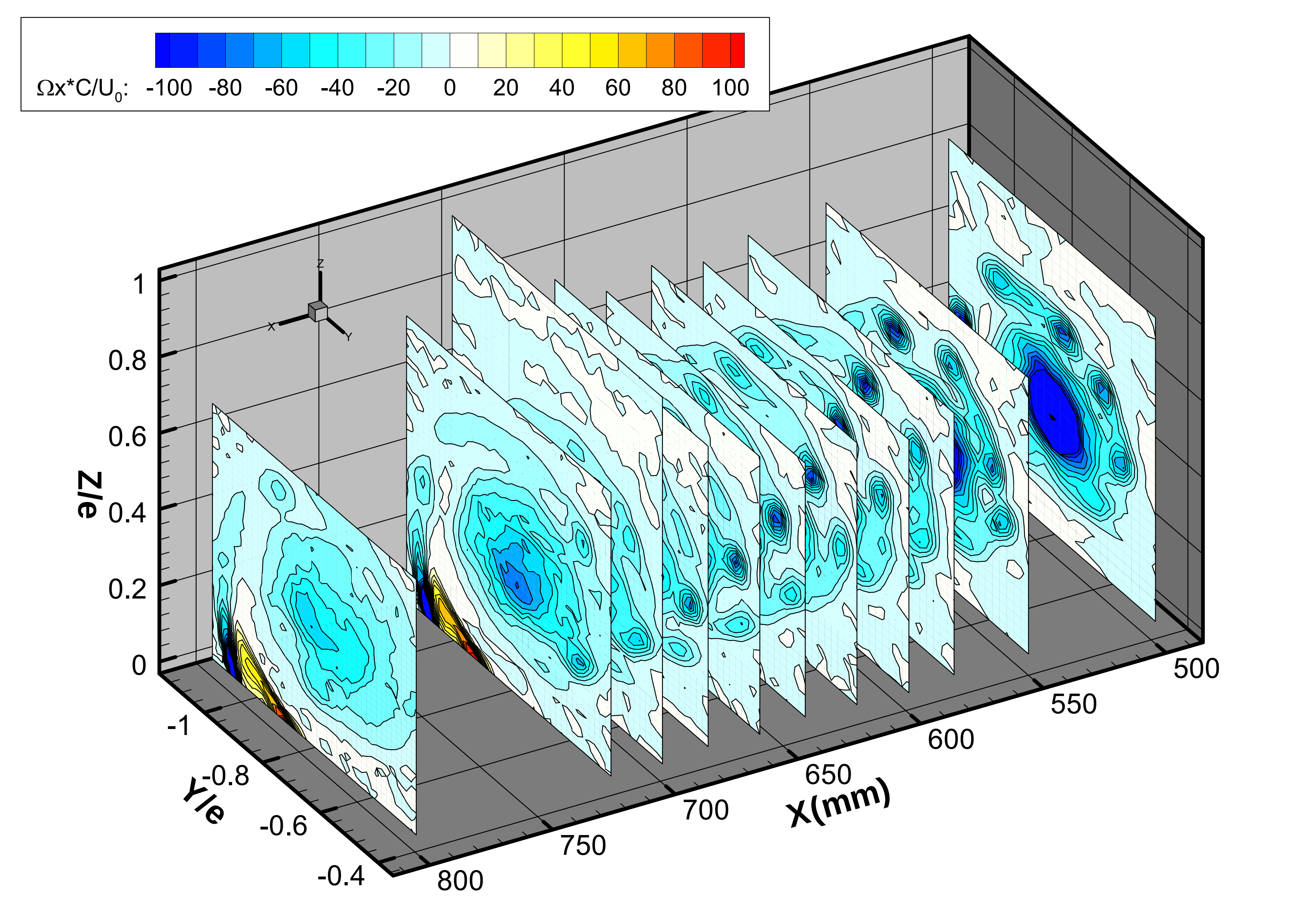
Payne *et. al.* (1988)

Shear layer instabilities (2)

A. Mitchell *et al.* (2001)



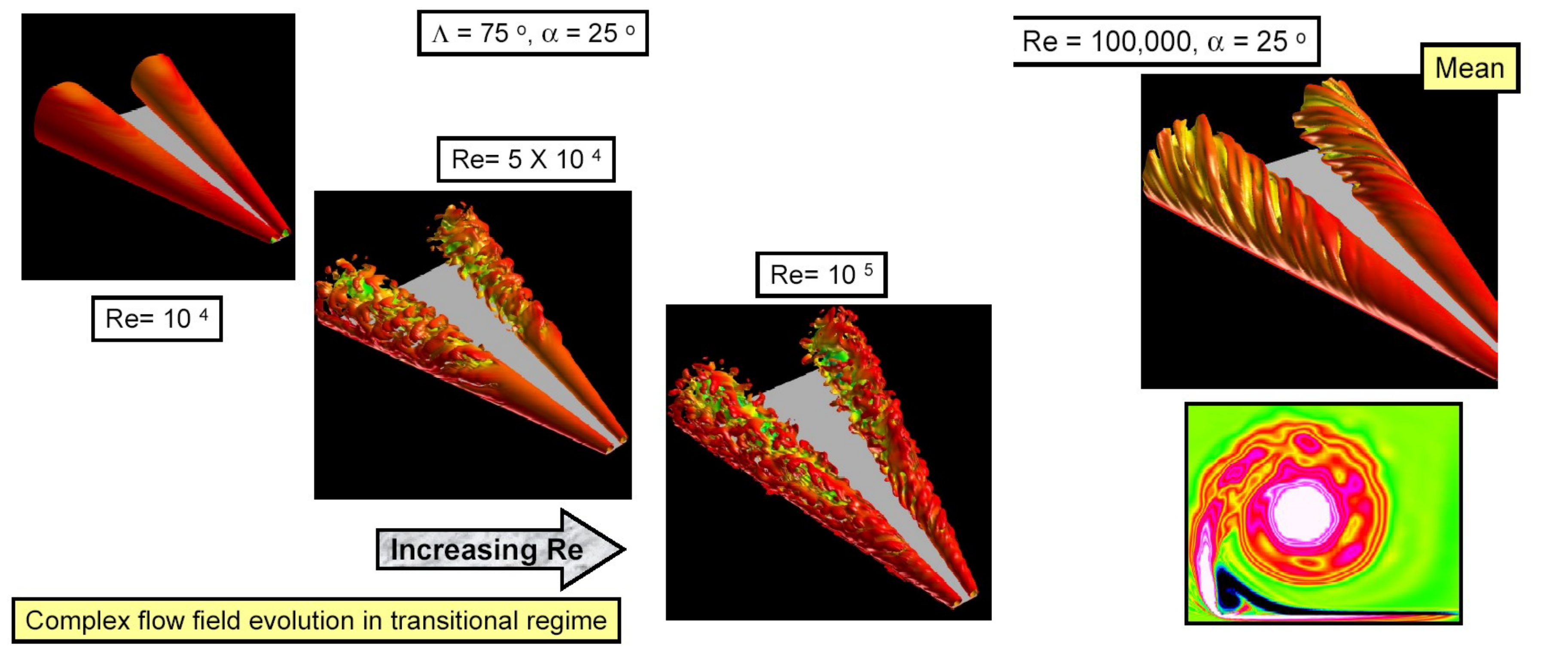
Shear layer instabilities (3)



A. Mitchell *et al.* (2001)

Shear layer instabilities (4)

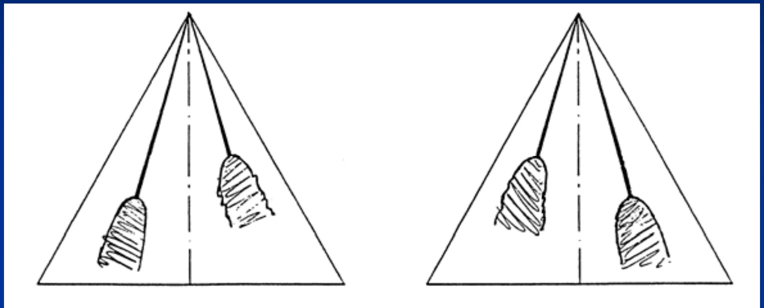
M. Visbal (2002)

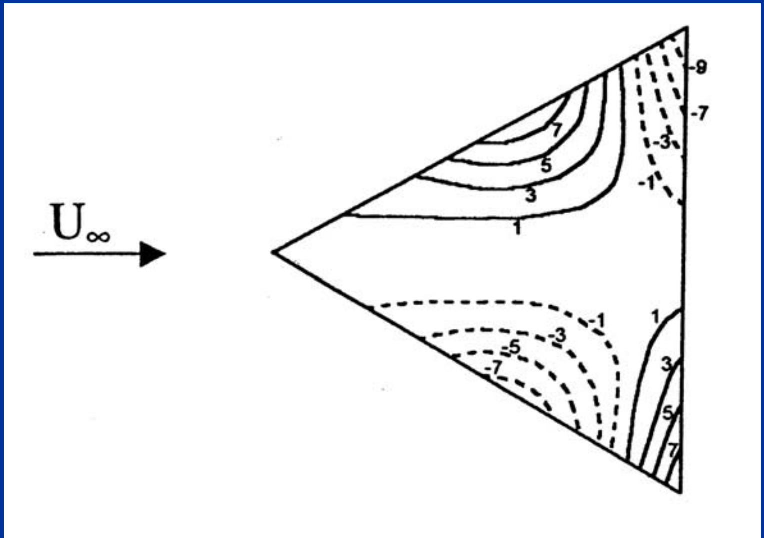


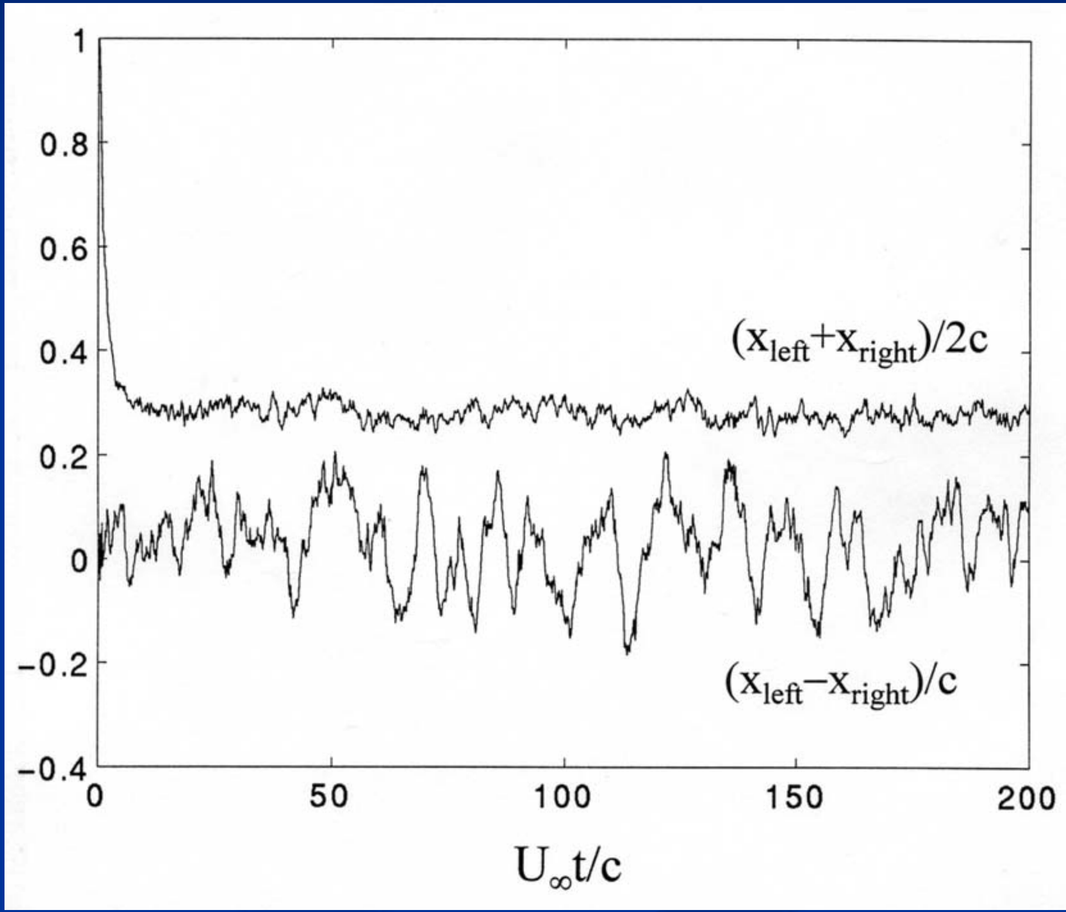
Instantaneous flow fields showing transition process with increasing Reynolds number

Time averaged flow structure

Vortex breakdown interactions





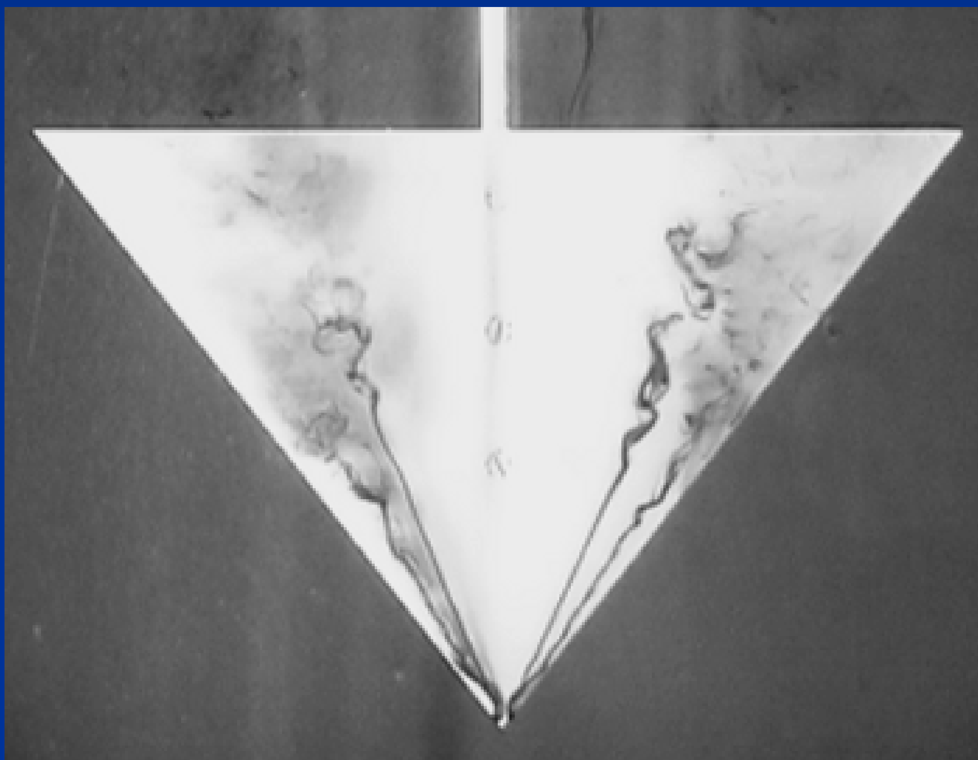


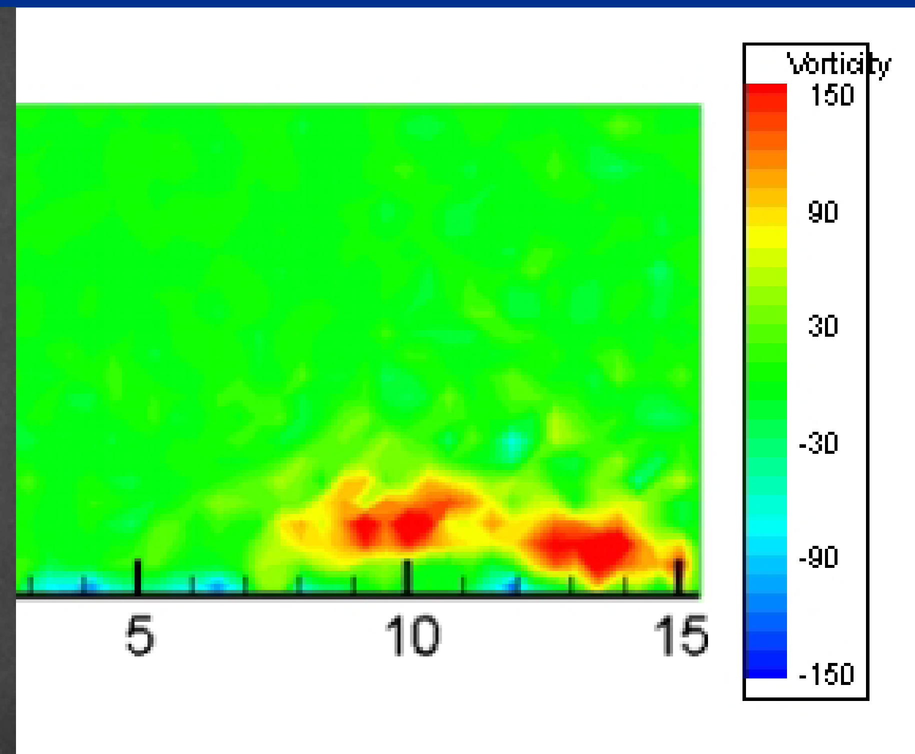
Gray *et al.* (2003)

Menke *et al.* (1999)

Non-slender vortices

Dual vortex system

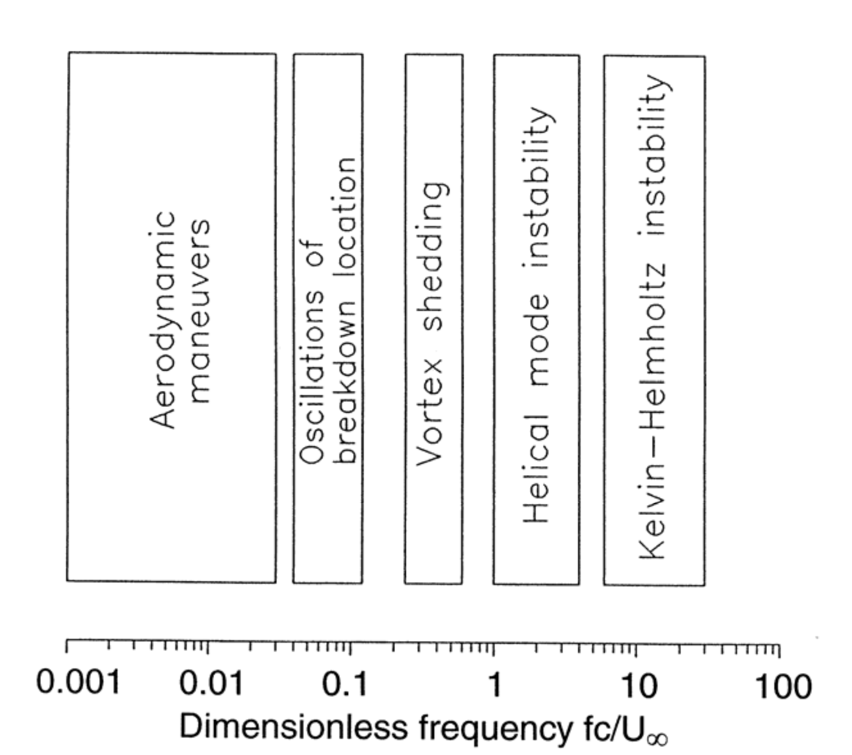




$\Lambda = 50^o$ Taylor *et al.* (2003)

Manoeuvring delta wings (1)

- Dynamic response of vortices and breakdown important
  - UAVs expected to have high manoeuvre rates (up to 30g envisaged)
  - Frequencies of motion may couple with vortex instabilities

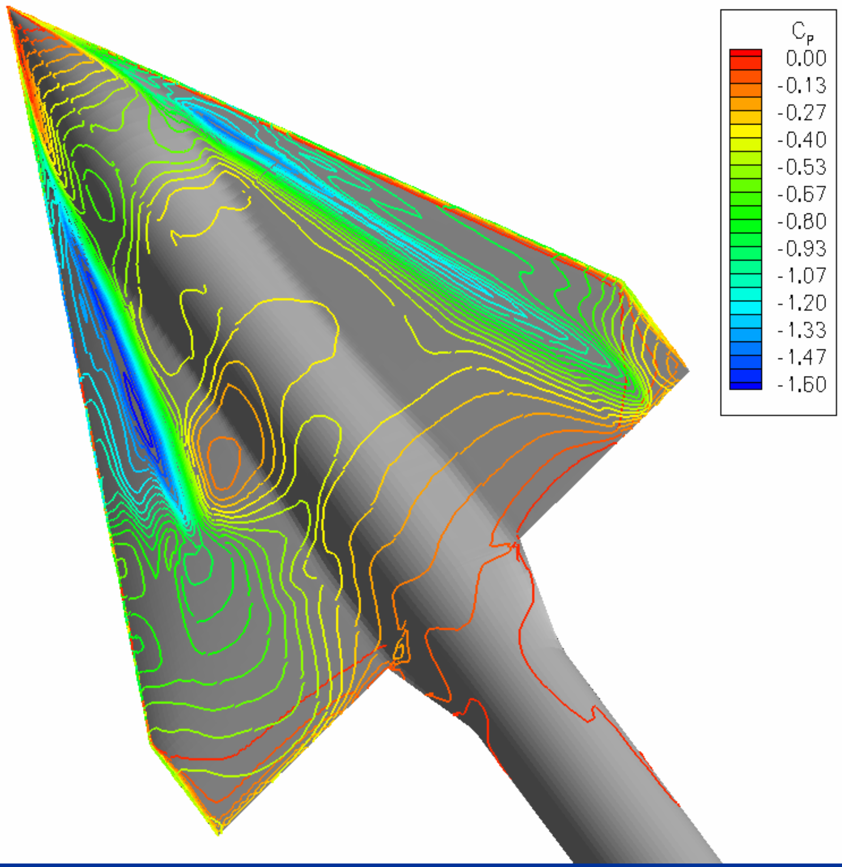


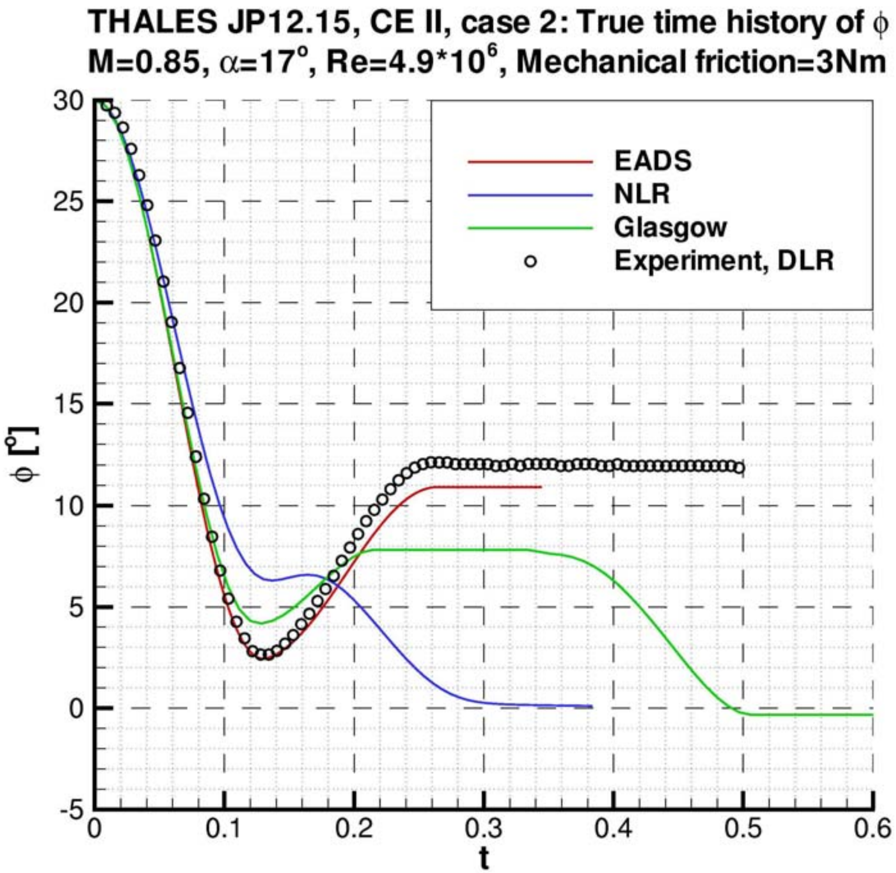
Menke *et al.* (1999)

Manoeuvring delta wings (2)

- Hysteresis effects present (especially with vortex breakdown) for pitch, roll, and yaw motion
    - Hysteresis in loads and moments as well as breakdown locations
    - Not well understood
    - CFD suggests PG delays along vortex axis important
- Hysteresis present for non-manoeuvering wings
  - Static hysteresis
  - Hysteresis due to flap / rudder deflections
  - Indicates motion induced rates are not solely producing hysteresis effects

Manoeuvring delta wings (3)

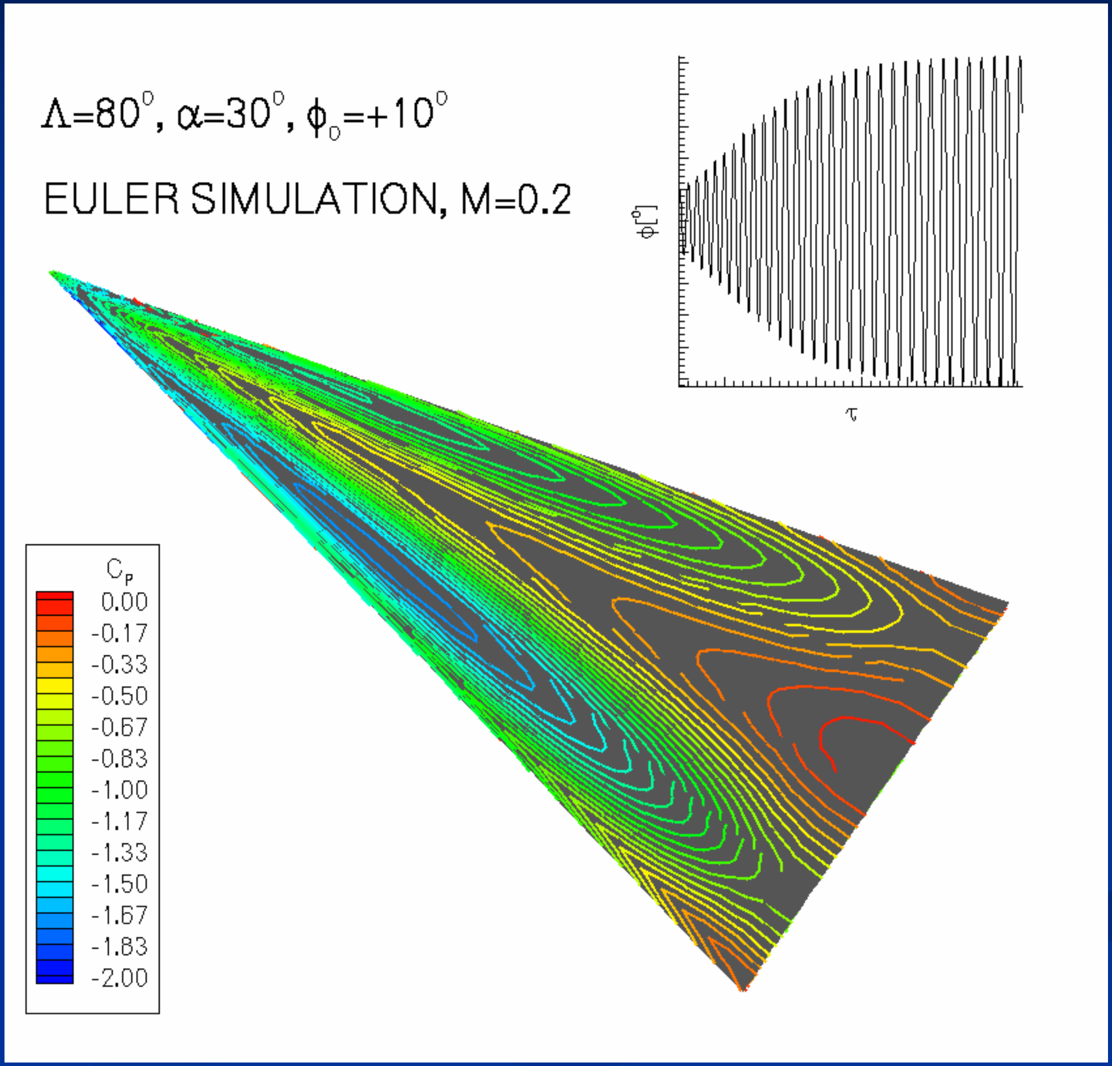




Free-to-roll cases – including bearing friction effects

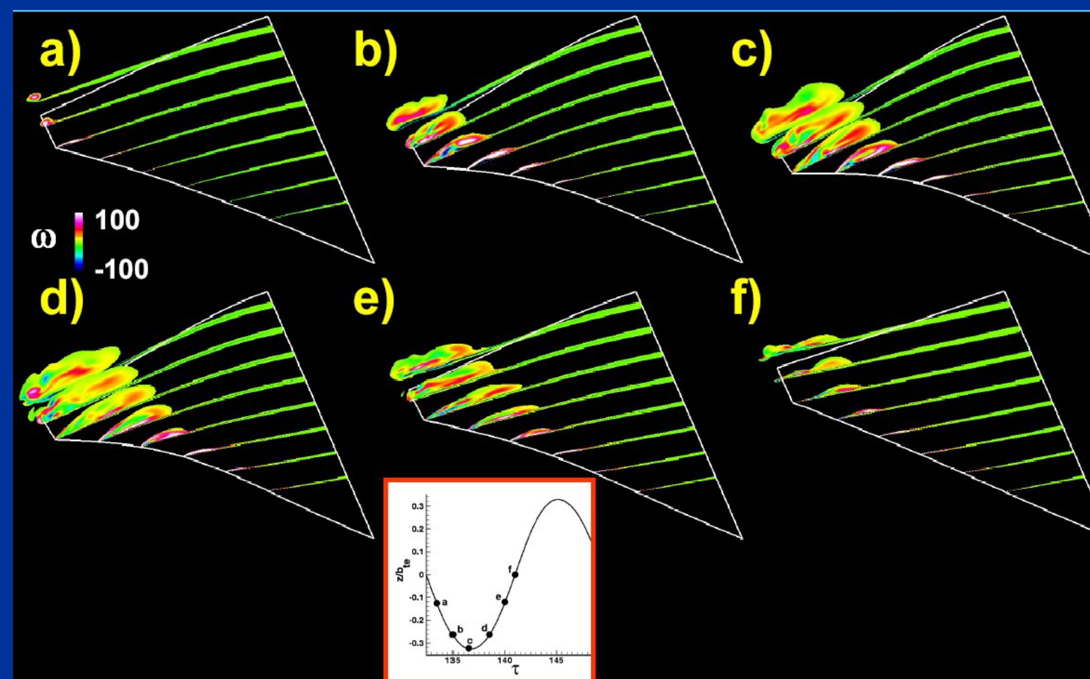
Manoeuvring delta wings (4)

Limit Cycle Oscillations (Wing rock) - Slender and non-slender wings



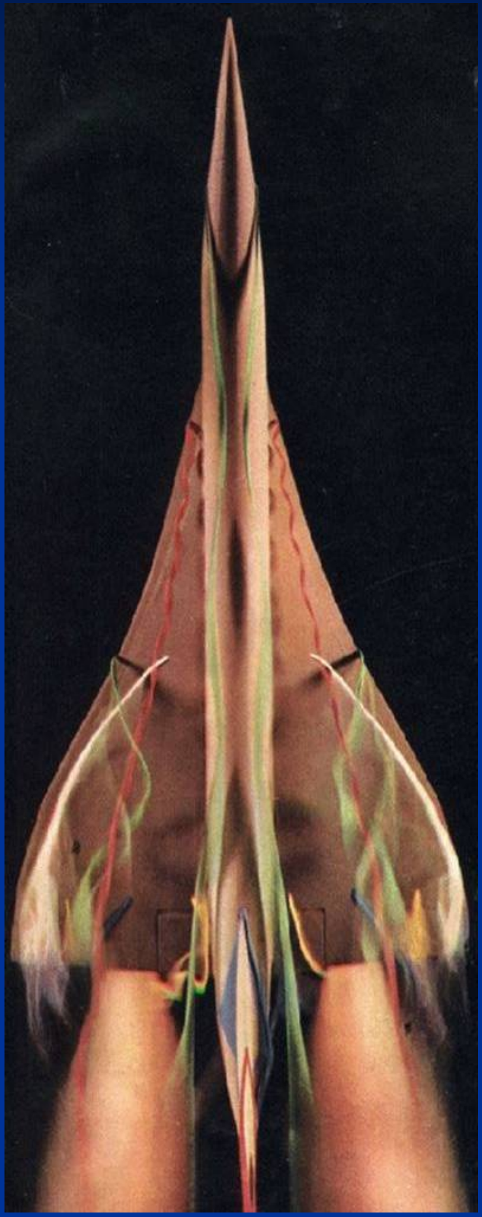
Fluid / structure interaction

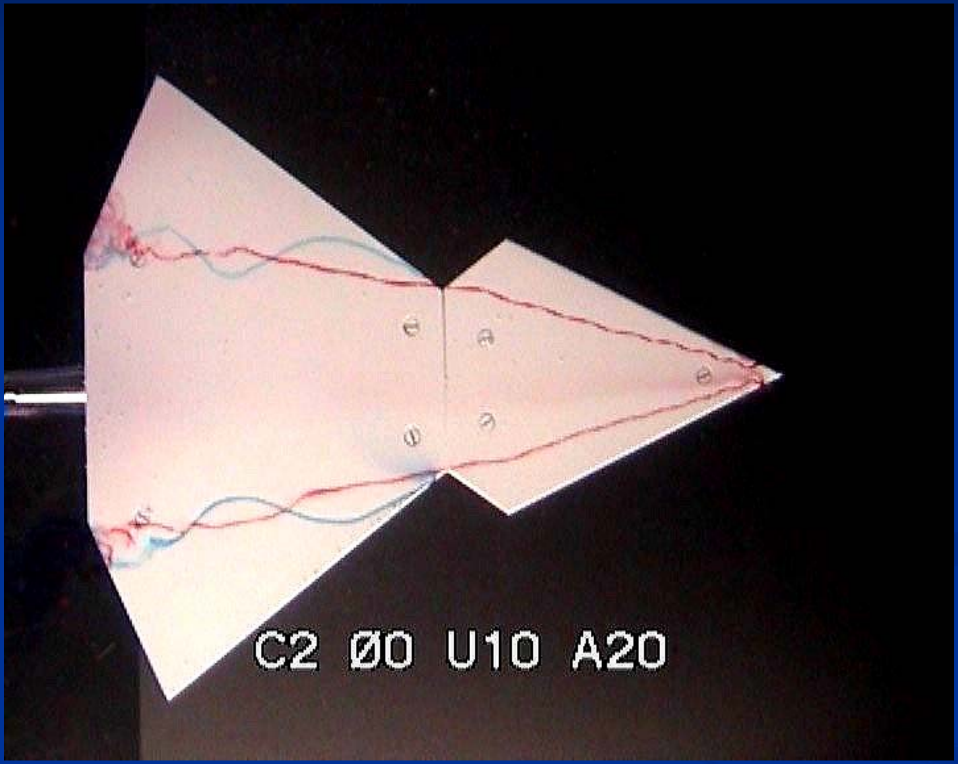
Unsteady vortex / structure interactions



Gordnier (2002)

Multiple vortices



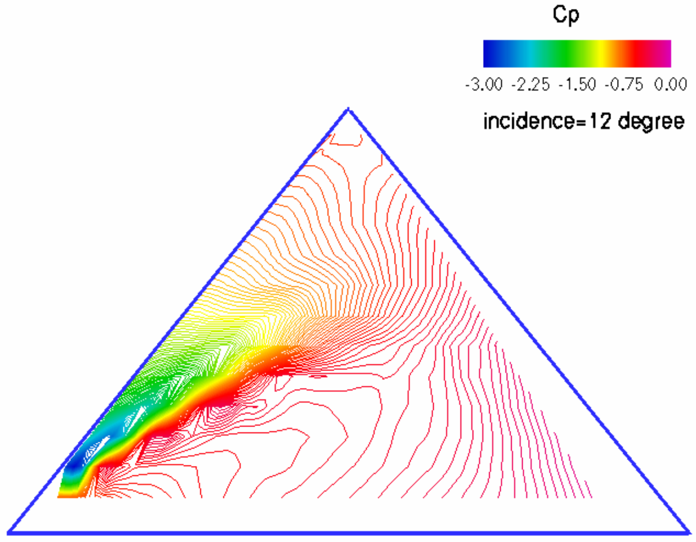


- Unsteady vortex interactions
- Complex flow patterns
- Coiling up and merging
- Breakdown

Alternative planforms

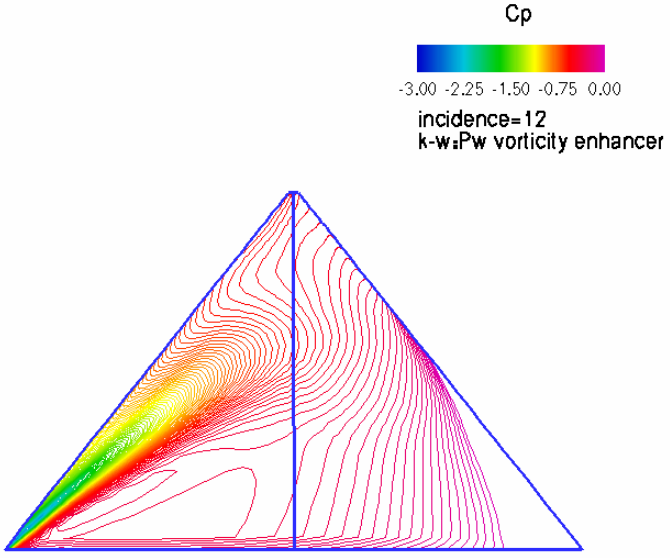
Diamond wings / Lambda wings for example

Experiment



Lynn *et al.* (1998)

CFD



Qiang (2003)

Summary - Requirements from experiments

- After 4 decades of research many experimentally observed phenomena poorly understood
  - Vortex breakdown, shear layer instabilities, hysteresis effects, multiple vortices, high rate manoeuvres
- Limitations
  - Measurement techniques available and data which can be acquired in a given time
  - Test facility restrictions
  - Cost

Summary - Requirements from CFD (1)

- Static test data
  - Complete data sets
    - Generally only one or two of flow vis / surface pressure / flowfield data / load data
  - Better description of test conditions
    - Tunnel geometries, support geometries, measurement equipment
  - More detailed flowfield data
    - Higher fidelity modelling is requiring more and more detailed flowfield data for validation
  - Validation of tunnel interference effects
    - Improved correction techniques

Summary - Requirements from CFD (2)

- Dynamic testing
  - Complete data sets
    - Force data / Breakdown location data / Surface pressure data / Flow vis / Flowfield data
  - Better understanding of support friction effects
  - Details of test facility interference sources
    - Improved correction techniques
  - Multiple DOF tests

The end.