Numerical Simulations of the Late Stages of Transition to Turbulence

N. D. Sandham

Department of Aeronautical Engineering
Queen Mary and Westfield College
Mile End Road
London E1 4NS, UK

References:

Sandham and Kleiser, JFM **245** (1992).
Sandham and Adams, ETC 4 (1992). [M=2.0]
Adams and Kleiser, (1993). [M=4.5]

(1)

CLASSICAL TRANSITION PROCESS
(vibrating ribbon experiments)

- linear instability - TS waves
- secondary instability - Lambda vortices
  K-type (Klebanoff) or H-type (Herbert)
- ? - spikes, hairpins, tertiary instabilities
- turbulence

Objective:

- clarify phenomena and mechanisms in the late stages of the transition process

(2)

NUMERICAL SIMULATION

Gilbert (1988), Gilbert & Kleiser (1990)

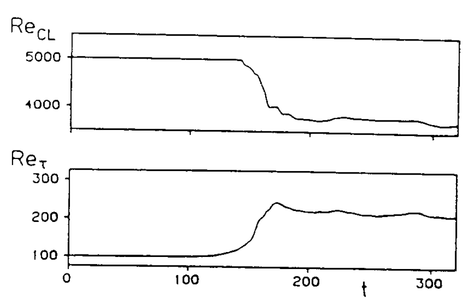
Overview

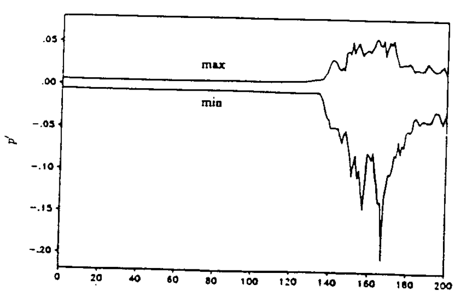
- plane channel flow geometry
- temporal development (periodic in x1, x2)
- 3d incompressible Navier-Stokes
  (no turbulence model)
- direct numerical simulation
  (spectral method)
- COMPLETE transition process simulated

Databases (constant Q, Re=5000)

- K-type transition
- H-type transition
- Mixed-type transition

(3) Initial condition TS wave (3%)
oblique waves (0.1%)





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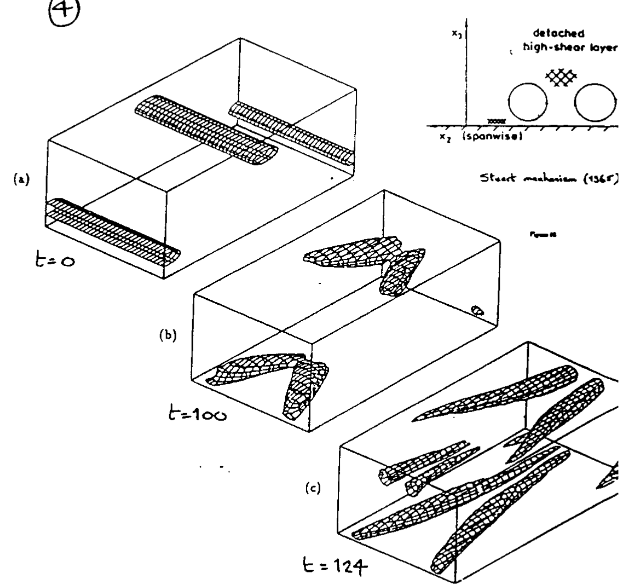
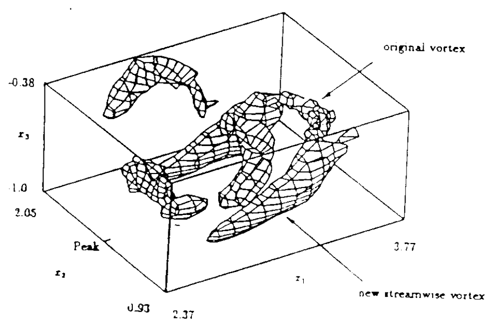


$$\Pi = \frac{\partial v_i}{\partial x_j}\frac{\partial v_j}{\partial x_i}$$

Figure 2

(13)



t = 156

Figure 14

(14)

Transition at M=2

1. Streamwise vortices
2. Decay and formation of new vortices
3. Vortex break-up

(see Sandham, Adams and Kleiser, 1994)

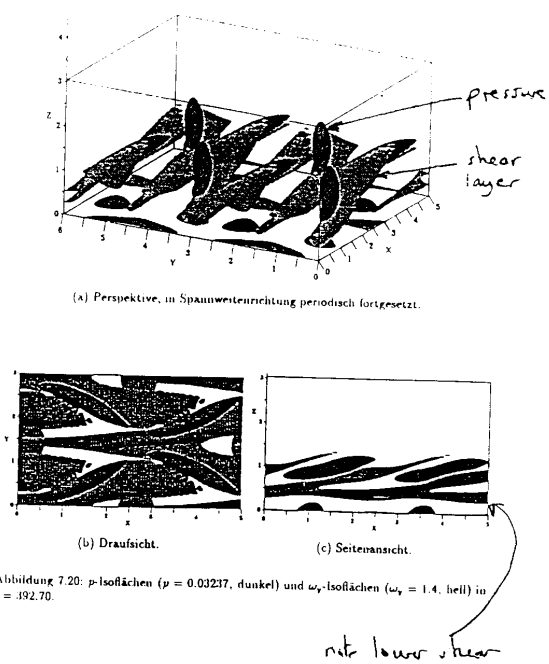
Transition at M=4.5

1. Mack mode of primary instability
2. Formation of Λ-vortices from random noise
3. Sonic layer important for Stuart mechanism
4. Lower shear layer develops first
5. Simulation results up to the beginnings of turbulence

Adams - dissertation (1993)
Adams and Kleiser (JFM, submitted)

(15)

M = 4.5



(a) Perspektive, in Spannweitenrichtung periodisch fortgesetzt.

(b) Draufsicht.

(c) Seitenansicht.

Abbildung 7.20: p-Isoflächen ($p = 0.03237$, dunkel) und ω_y-Isoflächen ($\omega_y = 1.4$, hell) in $t = 392.70$.

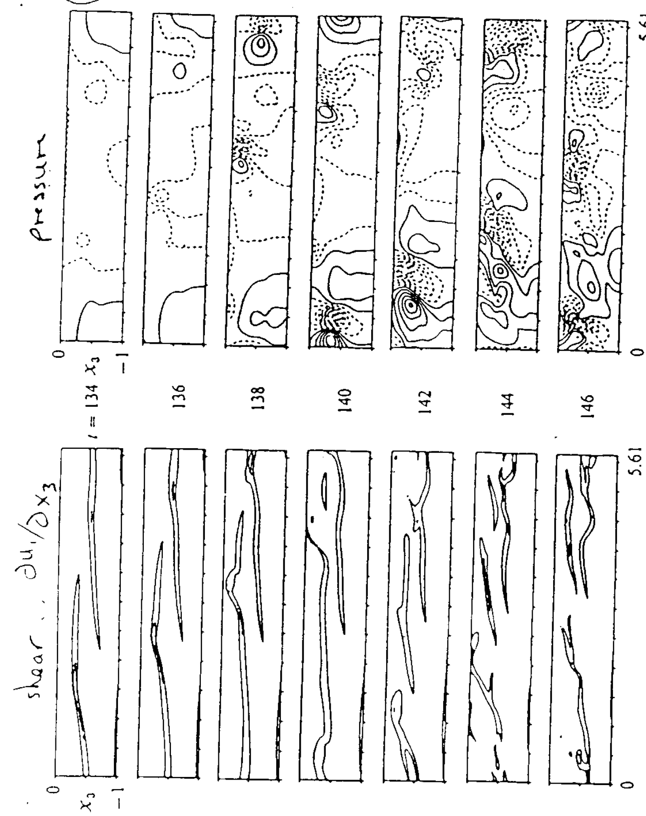
(16)

Outlook

Advantages of DNS:
- controlled disturbances
- full flowfield data

Future developments:
- more databases (esp. compressible, 3D)
- higher Re, larger computational domains
- (more) complex geometries

5



6

Late stages of transition to turbulence in channel flow

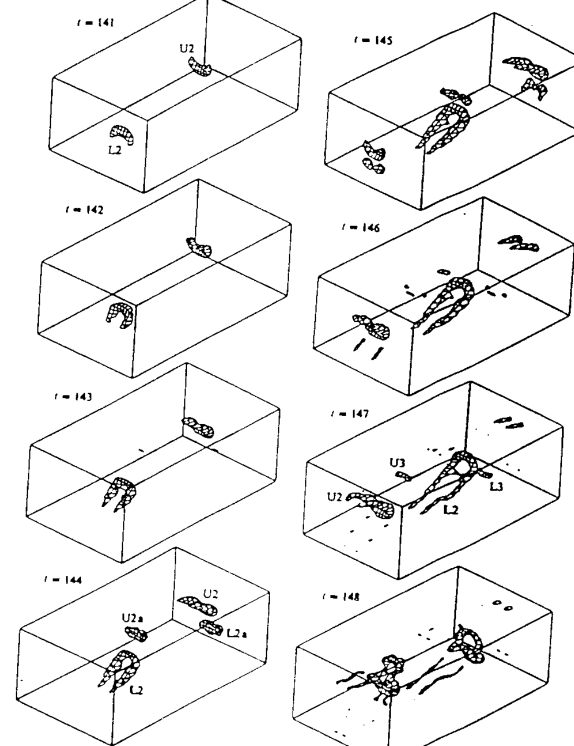


FIGURE 10. A time sequence of the pressure surface $p' = -0.025$ showing the three-dimensional evolution of the vortices that originate in the high-shear layer. Vortices L2 and U2 develop into pronounced hairpin vortices.

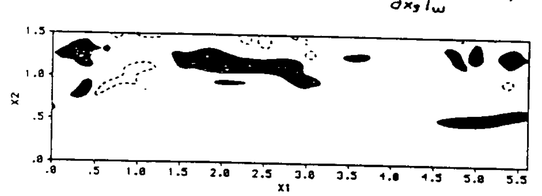
Sandham & Kleiser 1992

7

Streak development

t = 155

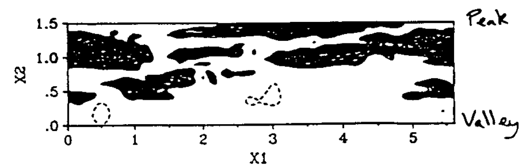
SHEAR ON WALL $\frac{\partial v_1}{\partial x_3}\Big|_w = 0, 10, 20$



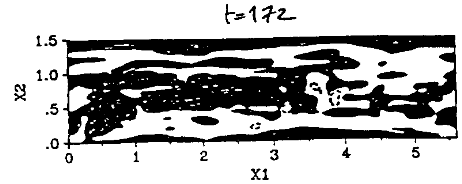
8

Wall Shear

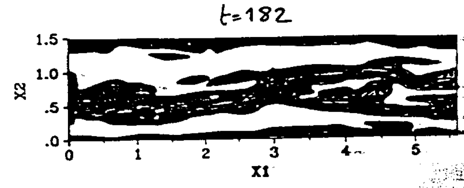
t=162



t=172

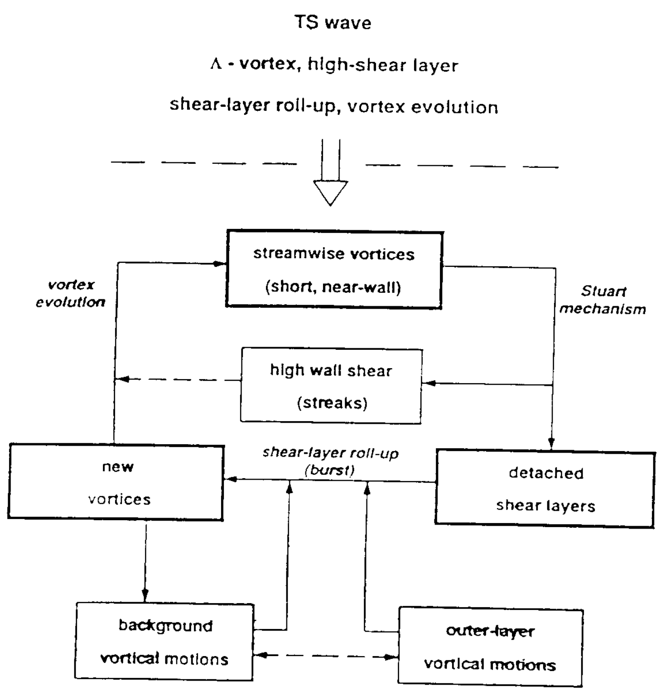


t=182



9

Development near-wall turbulence in the late stages of transition



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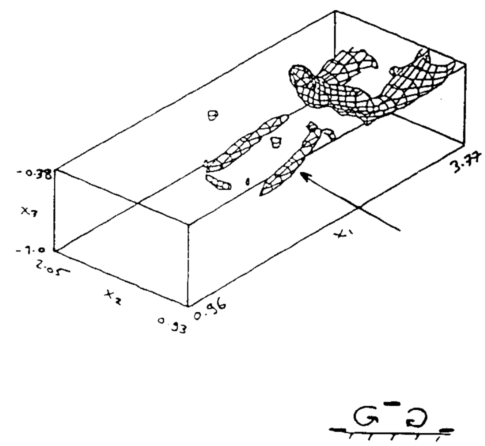
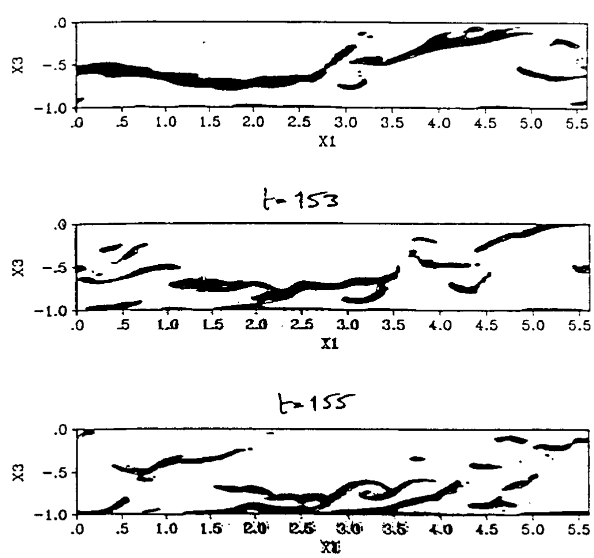
t=150



11

shear $\partial u_1/\partial x_3$

t=151



12

pressure