# Flow Control

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## Flow Control

- Coherent structures and Turbulent boundary layers
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# Turbulent Boundary layers

# Coherent Structures

## Coherent Motions can be classed into 8 forms:

- Low-speed streaks
- Ejections of low-speed fluid outward from the wall
- Sweeps of high-speed fluid toward the wall
- Vortical structures of several proposed forms
- Strong internal shear layers in the wall zone
- Near wall pockets, observed as areas clear of marked fluid
- Backs: surfaces across which the streamwise velocity changes abruptly
- Large scale motions in the outer layers (superlayers and deep valleys of free stream fluid) [Kline and Robinson, 1990]

# near wall events

## bursting

- 50% of total shear stress generated in first 5% of boundary layer
- interaction between streamwise vortices causes low speed streaks
- low speed streak slowly migrates away form the wall but moves rapidly at $y^+12$ (bursting)

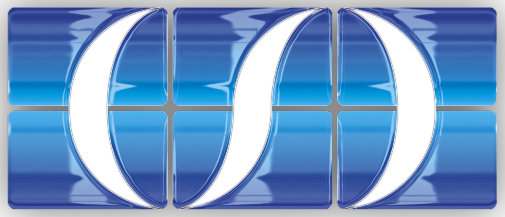
## intermediate structures

- Falco eddies - important link between the large structures and the near wall events
- pockets of non turbulent fluid from out of the wall
- Sloping shear layers between low-spped and high-speed fluid common

## outer structures

- large three dimensional eddies dominate the outer layer
- deep crevasses of high-speed potential fluid around the edges
- entrainment of high-speed fluid occurs

# Active blowing/sucking



# Choi 1994

## Choi 94:

In 1994, "Active turbulence control for drag reduction in wall bounded flows" by Choi et al, was published. it was the first research into an active closed loop system for flow control on a turbulent boundary layer

# V-Control

## The first set of experiments performed used Vcontrol:

- The intention was by manipulating the boundary conditions the sweeps and ejections could be suppressed
- The simulations were run on fractional step DNS code
- Course computational grid (32x65x32) at $re_c = 1800$ and finer grid (128x129x128) at $re_c = 3300$ were used
- The detection planes used were $y^+ = 5$, 10, 20 and 26

## other control methods investigated

- The best detection plane was at $y^+10$ producing a 25% drag reduction - (out-of-phase)
- 20% and 15% reductions for $v_{rms}$ and $2v_{rms}$ respectively using only 25% and 5% of the surface area being controlled respectively

# other control methods

## w-control

- w velocity was investigated - 30% reduction at $y^+10$ (out-of-phase)
- drag increased at a detection plane of $y^+20$
- in-phase control also gave a significant increase in drag

## u' and vw control

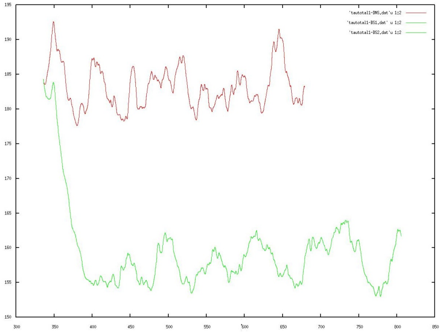
- u velocity - out-of-phase control produced increased drag
- u velocity - 10% reduction at $y^+10$ with in-phase control
- vw combined out-of-phase control (blowing/sucking at angles) - produced a 30% reduction
- combined control so effective that laminarization occurred in some cases

# control schemes 2

## schemes at the wall

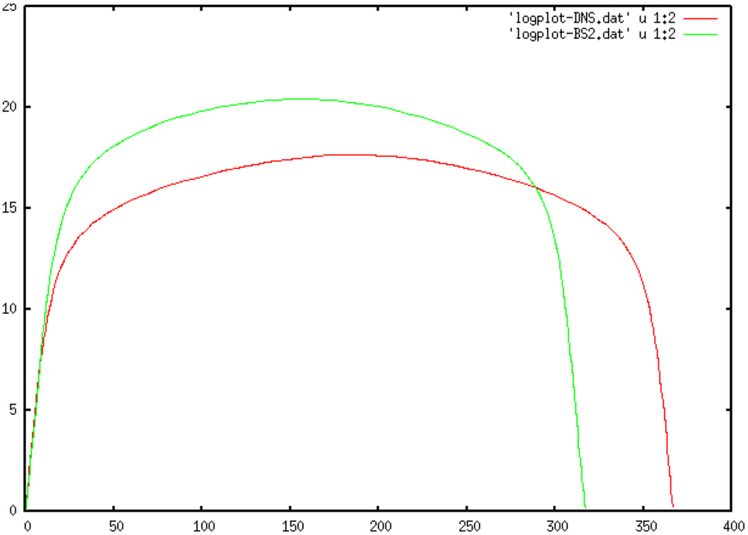
- Wall pressure has very little correlation with the v fluctuation at $y^+10$
- Very little improvement in correlation with the v fluctuation and downstream pressure
- streamwise velocity derivative $\frac{\partial u'}{\partial y}|_w$ slightly better with high-amplitude positive values likely to be associated with sweeps
- v control experiment based on $g_w = \left(\frac{\partial}{\partial z}\right)\frac{\partial w}{\partial y}|_w$ gave a 6% reduction

# $Re_\tau$



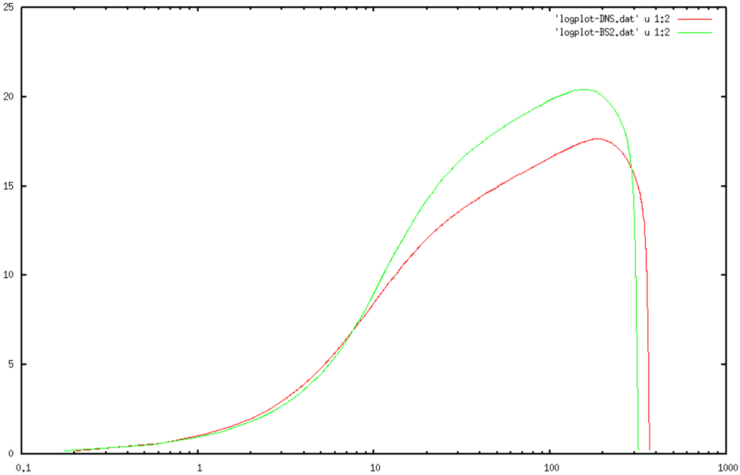

- no control - $Re_\tau = 183.2,\ C_f = 8.56X10^{-3}$
- control - $Re_\tau = 158.4,\ C_f = 6.4X10^{-3}$

# u+ against y+

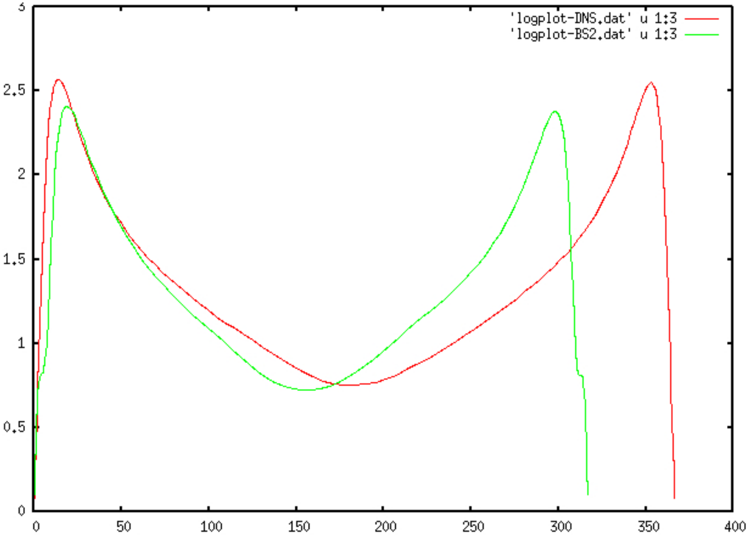


'logplot-DNS.dat' u 1:2
'logplot-BS2.dat' u 1:2
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400

# u+ against log y+



# u' against y+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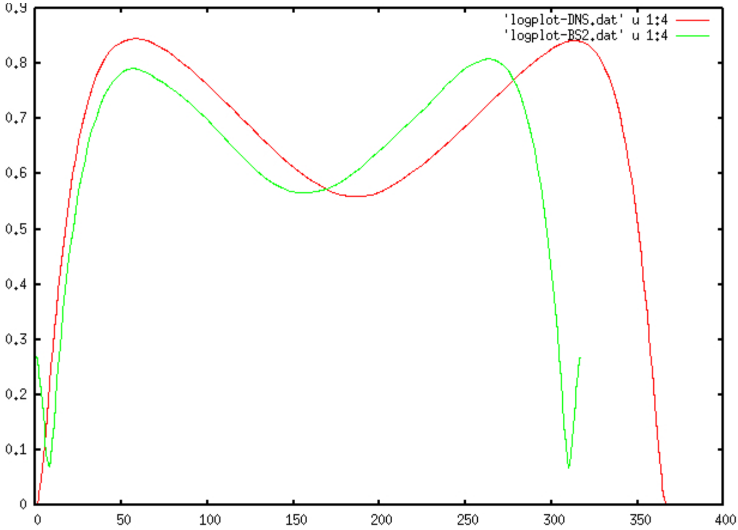
'logplot-BS2.dat' u 1:3
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
400

# u against y+



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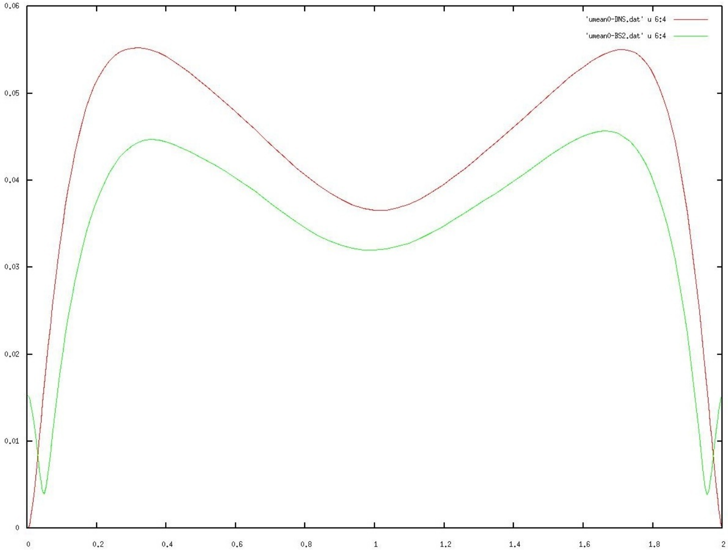
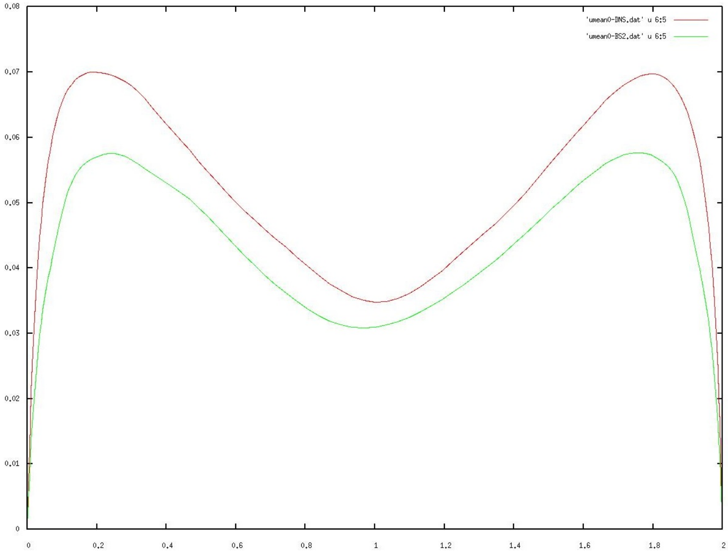
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400

# v' against y

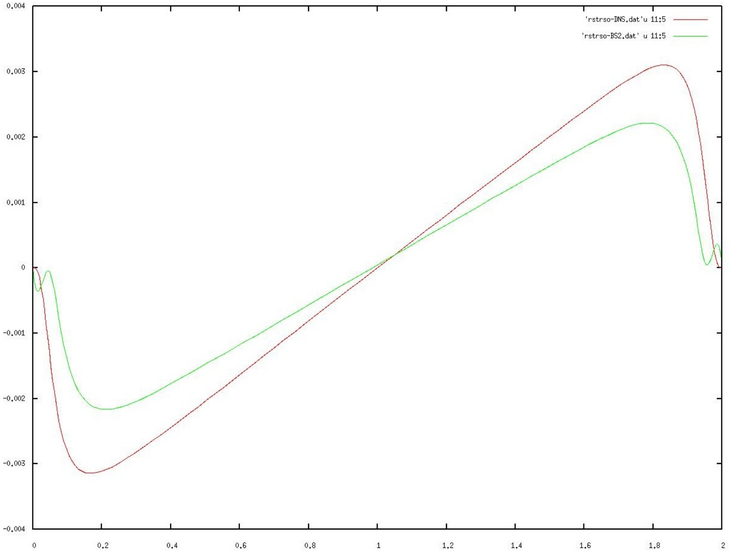


'umean0-DNS.dat' u 6:4
'umean0-BS2.dat' u 6:4
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

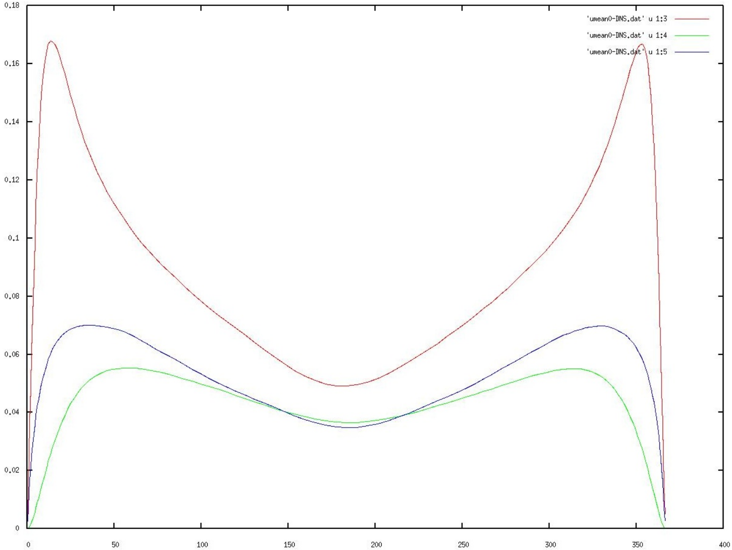
# w against y


'umean0-DNS.dat' u 6:5
'umean0-BS2.dat' u 6:5
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

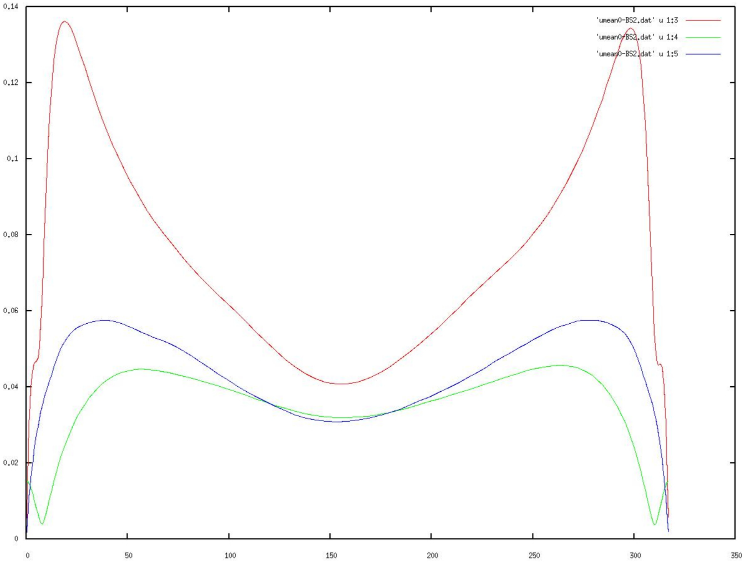
# shear stress against y



# normal velocity components



# manipulated flow velocity components



# Turbulence reduction

## turbulence statistics

- no control - $Re_\tau = 180$, $\frac{u_\tau}{U_m} = 0.064$ $C_f = 8.37X10^{-3}$
- v control - $Re_\tau = 158$, $\frac{u_\tau}{U_m} = 0.057$ $C_f = 6.4X10^{-3}$
- w control - $Re_\tau = 154$, $\frac{u_\tau}{U_m} = 0.055$ $C_f = 6.09X10^{-3}$

- an upward shift in the log law and an increase of the viscous sub layer thickness ere obtained
- An apparent outward shift of the controlled data, suggesting a displaced virtual origin of the boundary layer
- velocity, pressure, vorticity fluctuations and reynolds shear stress were significantly reduced through the channel
- streaky structures below $y^+ = 5$ were clearly diminished while the spacing between streaks above $y^+ = 5$ increased

# conclusions

## conclusions

- although simulations were conducted at low reynolds numbers, authors confident that a similiar effect would occur at higher reynolds numbers
- active control provided greater drag reduction that passive geometrical flow control methods
- drag is primarily reduced mainly be deterring the sweep motion
- stabilizaton of the streamwise vortices occurs - stabilizing and prevent thier lifting
- v-control altered the mutual interaction between the primary vortex pair and the secondary vorticity by preventing the lifting of the secondary vorticity

# Further Research

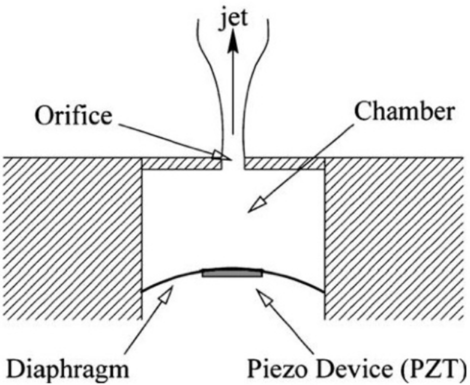
## Hammond et al

- detection plane at $y^+ = 15$ was found to be the optimum with a 25% reduction using out-of-phase v control
- virtual wall found to exist half way between detection plane and wall, where v fluctuation are almost zero
- at higher detection planes does not counter the streamwise vortices, failing to create a virtual wall, high momentum fluid can be drawn into the area between the detection plane and the wall

## lee

- used a neural network to correlate wall-shear stress to v velocities at $y^+ = 10$, 20% was achieved
- a simpler linear control scheme could potentially be used
- 35 fold energy saving to power used
- issues are numerous: - sensor density, actuation, time delay, energy losses and reynolds number

# Helmholtz Resonators




$$\frac{dp'}{dt} = -\frac{A}{V} p_e v$$

$$\frac{dv}{dt} = \frac{\lambda}{\rho_e l}(p' - p_i) + \frac{8}{\rho_e Re_\tau R^2} v$$