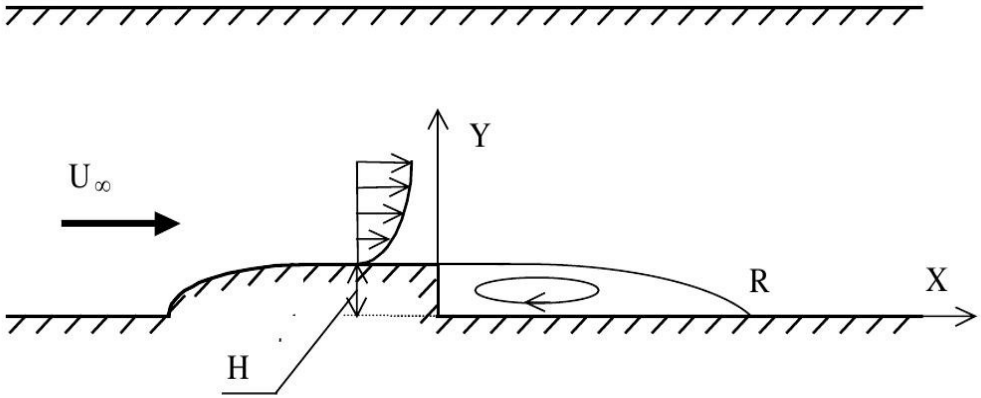
Unsteady Phenomena in Separated and Reattaching Flows: from Statistical Characteristics to Instantaneous Space-Time Fields

P.S.Zanko, A.Pollard, N.I.Mikheev

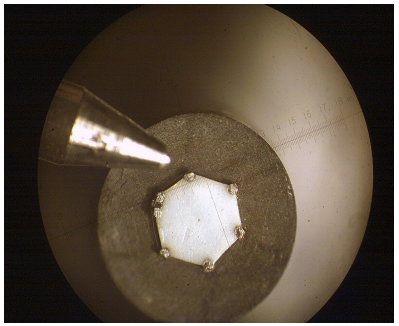
Motivation

And so these men of Hindustan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right
And all were in the wrong.

J.G.Saxe



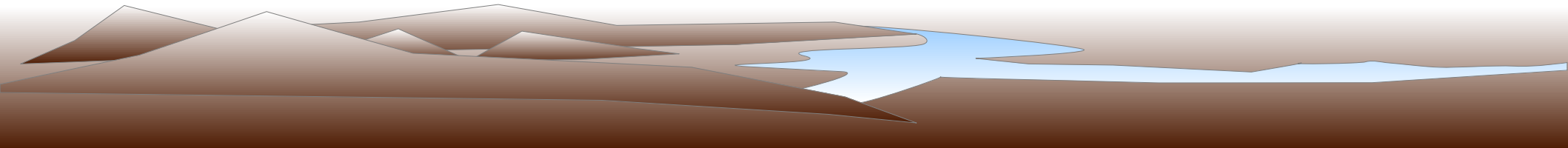
Flow behind backward-facing step



6-wire skin friction probe

Basic Facts

- The instantaneous reattachment point moves up- and downstream
- The pulsation of the reattachment point is closely connected with the so-called low-frequency “flapping” of the shear layer normal to the wall
- The recirculation region is not “continuous”, i.e. there can be blobs of forward flow reaching down to the wall inside it
- The reattachment is an essentially 3D phenomenon
- The underlying cause of the low-frequency pulsation in separated flows is not clear

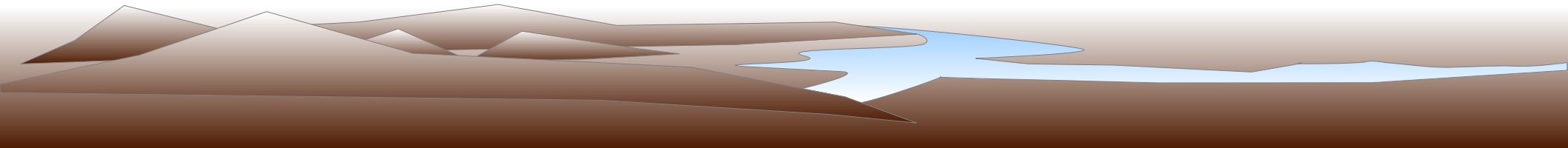


Qualitative Description
(Arnal-Friedrich, 1992)

- "... two of the eddies begin to merge in the shear layer.
- At the instant shown, the entrainment of fluid from the bubble prevails over the reinjection of fluid in the reattachment region.
- On the upstream side of the structure, fluid is being entrained from the backflow region into the shear layer.
- On the downstream side, positive velocity fluid from above the shear layer is being forced down into the recirculation region.

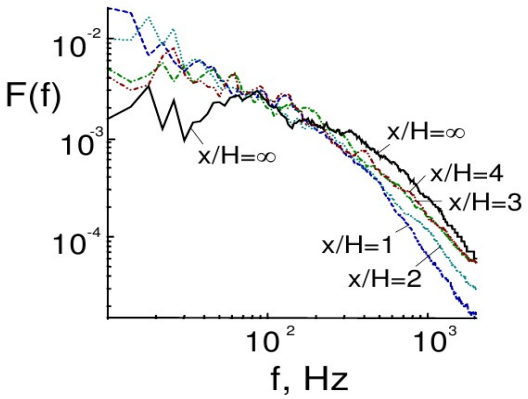
Qualitative Description

- This leads to a pinching of the separation bubble and shedding of fluid from the recirculation zone. Following this, the separation region becomes more contracted in size.
- The two eddies which have merged ... are shed from the shear layer and move downstream.
- The recirculation zone then gradually increases in size as the pressure within it increases.
- This expansion of the separation region leads to downstream movement of the instantaneous shear layer impingement point and causes the shear layer itself to move away from the recirculation zone”



Problem

U<0



Identification Criteria

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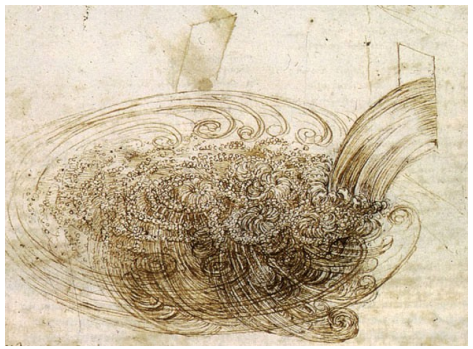


Quantitative Statistical Characteristics

Qualitative Description

With a «Little» Help from My Friends

Raiesi H., Piomelli U., Pollard A. Evaluation of Turbulence Models Using Direct Numerical and Large-Eddy Simulation Data. J. Fluids Eng. 2011, vol.133, 10 p.

Prof. Ugo Piomelli

Prof. Andrew Pollard

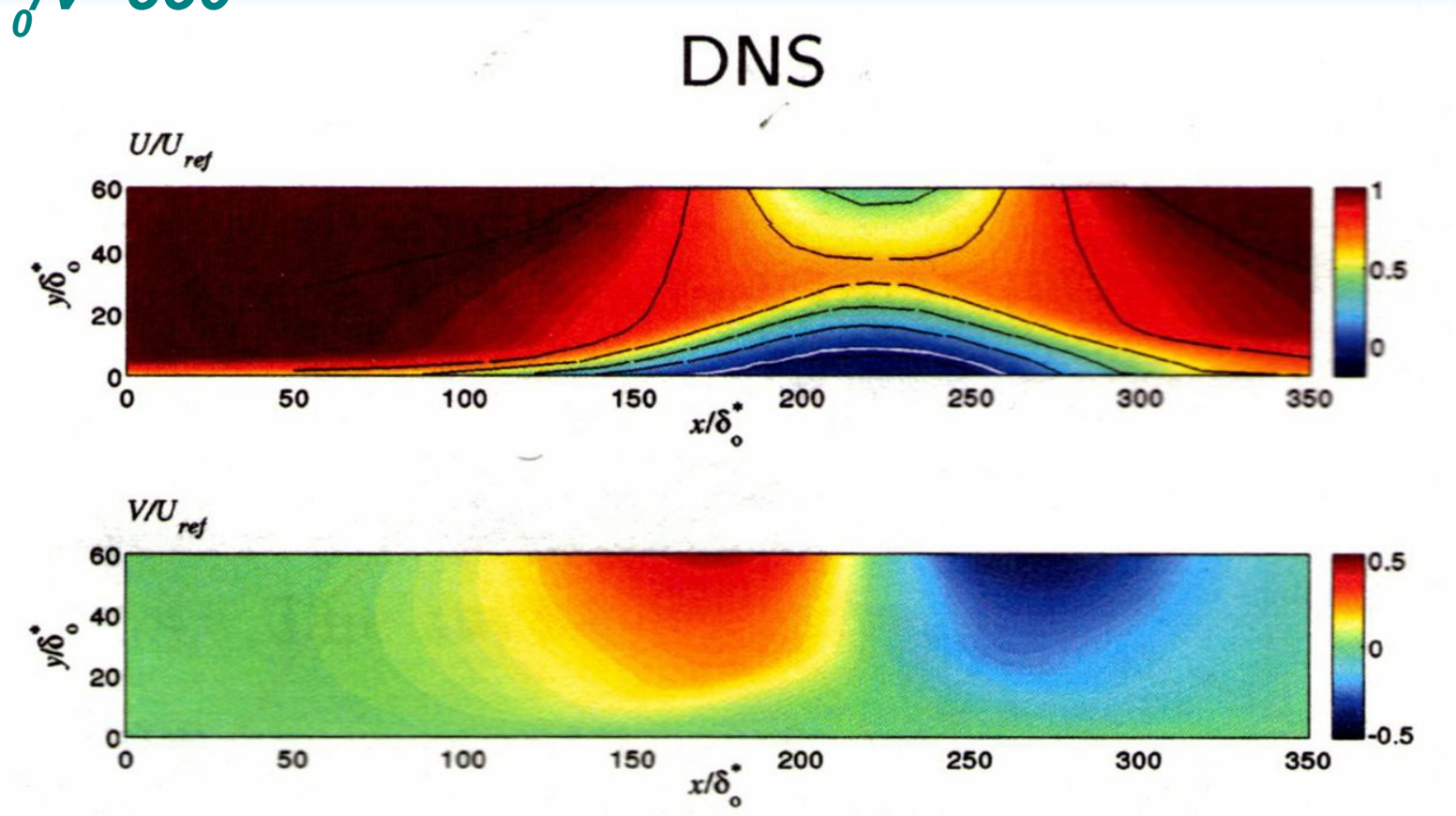
Dr. Hassan Raiesi

Queen's UNIVERSITY

Thank you so much!

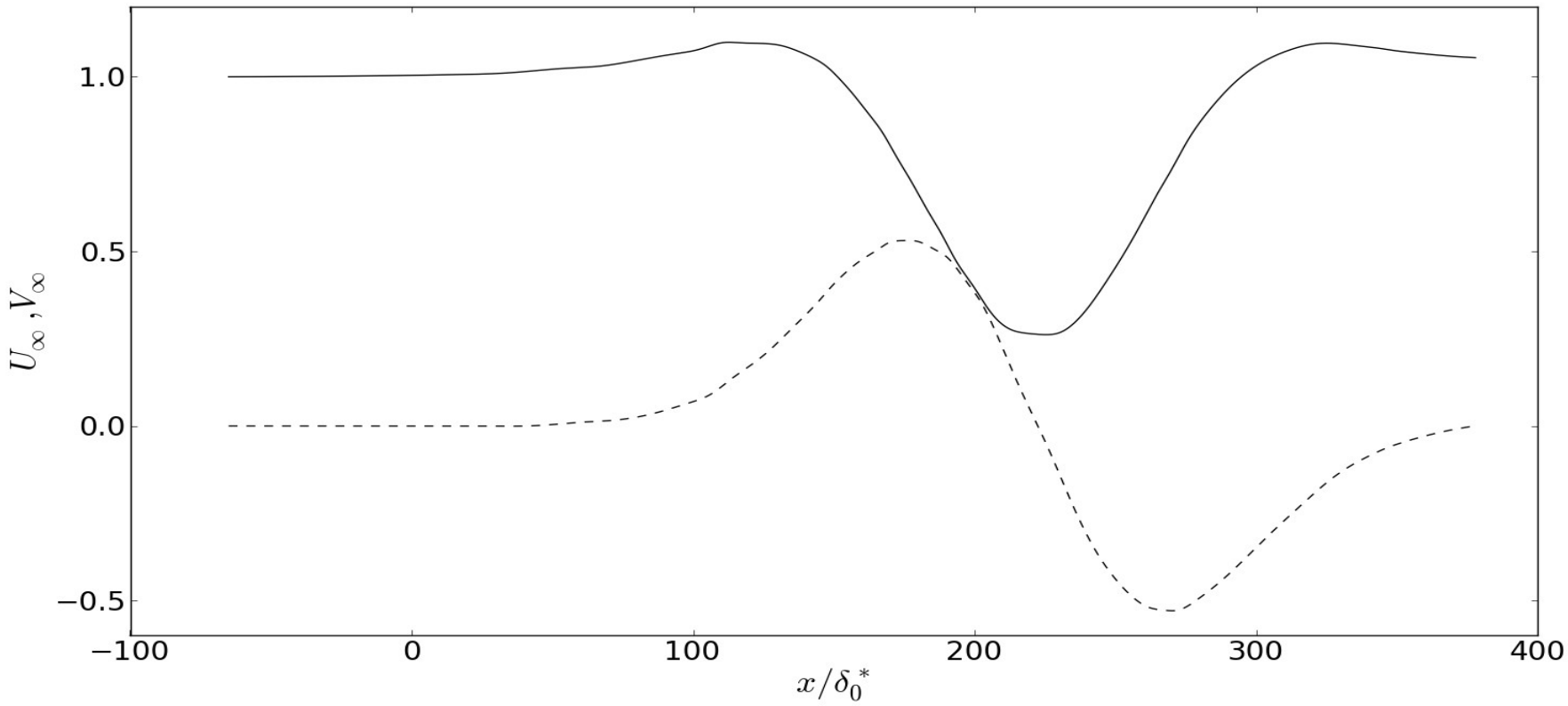
Separated Turbulent Boundary Layer on a Flat Plate

$Re^* = U_0 \delta^*_0 / \nu = 550$

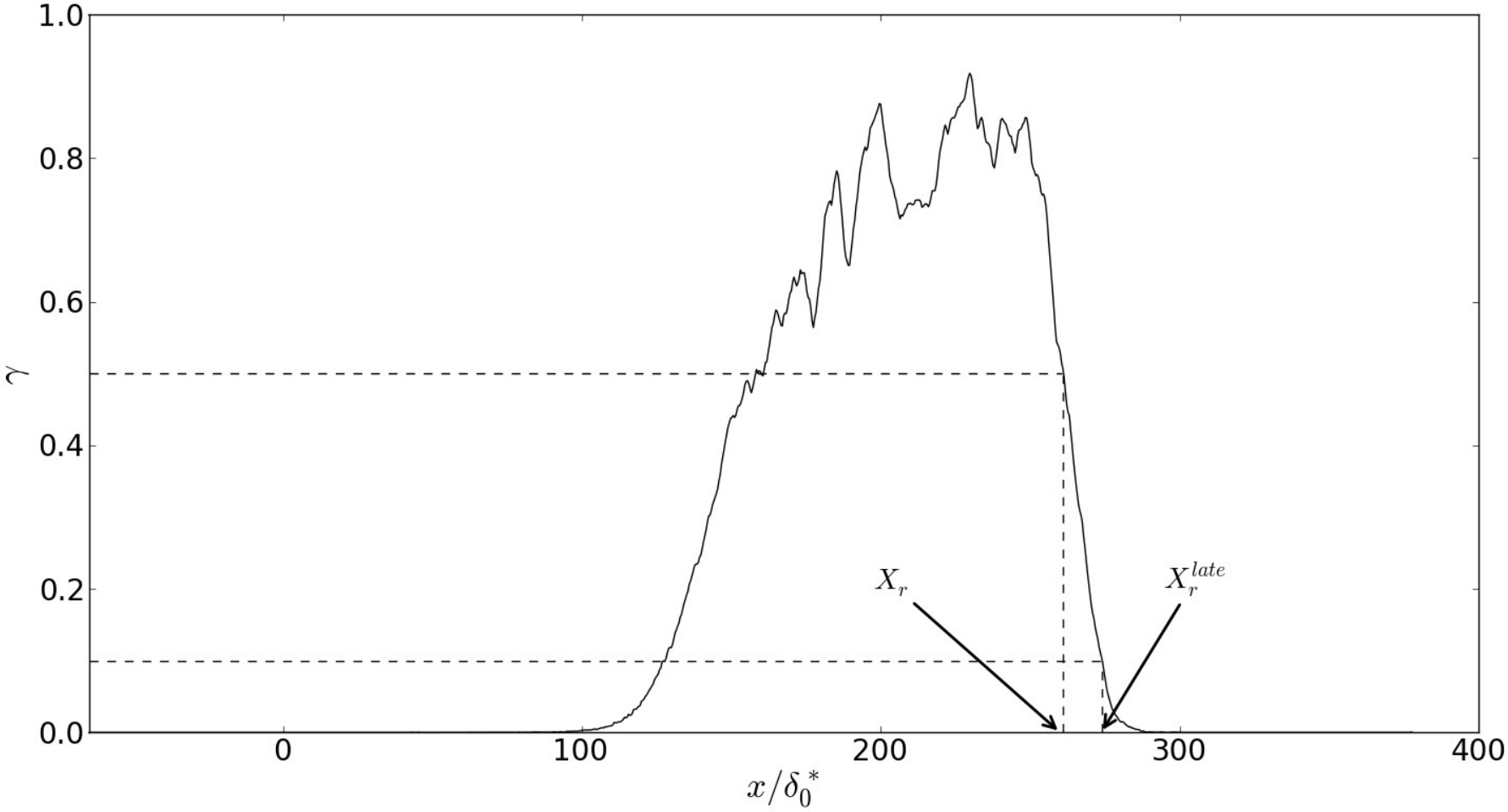


1024 x 192 x 192 grid points

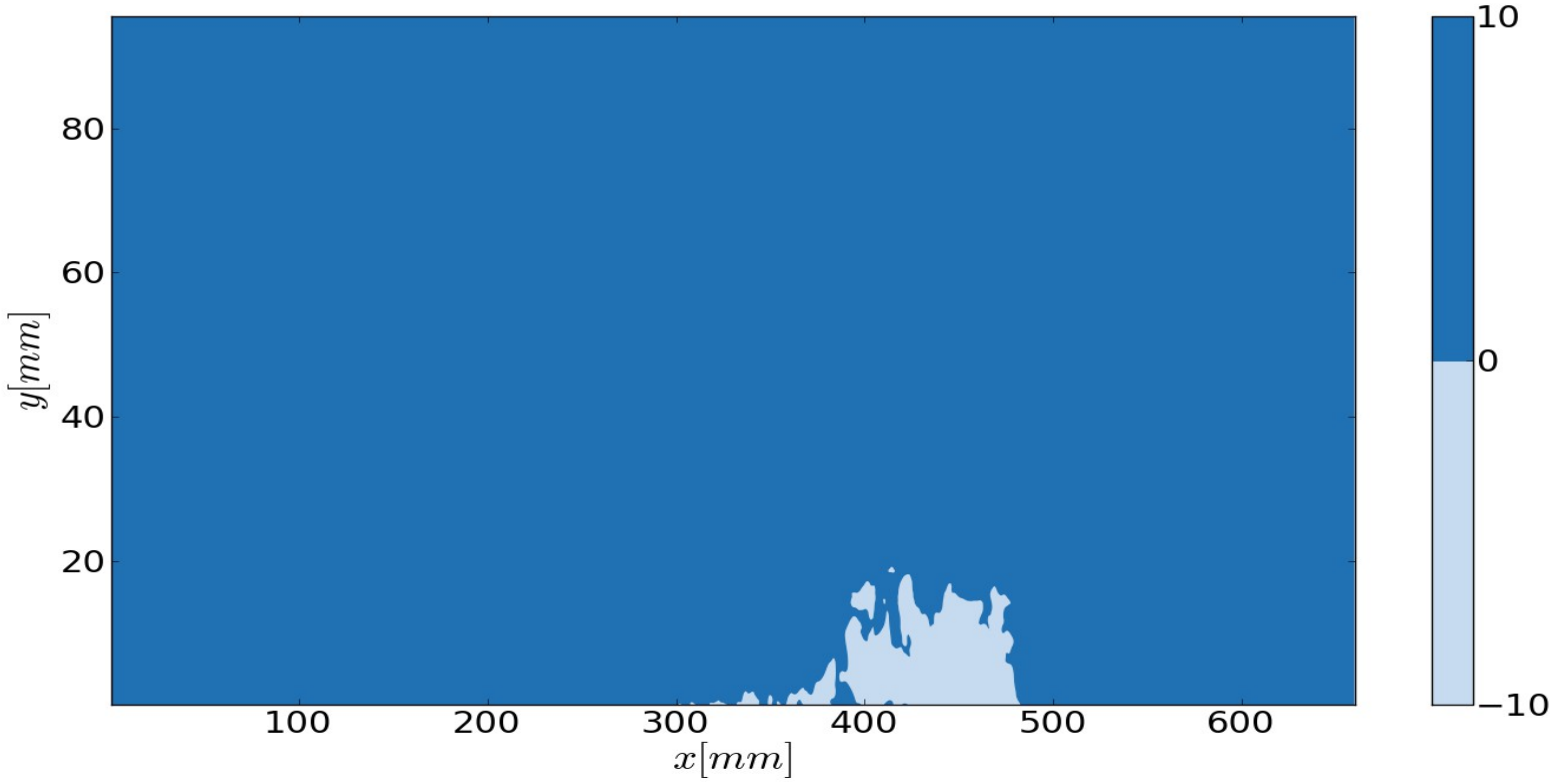
Free-Stream Parameters



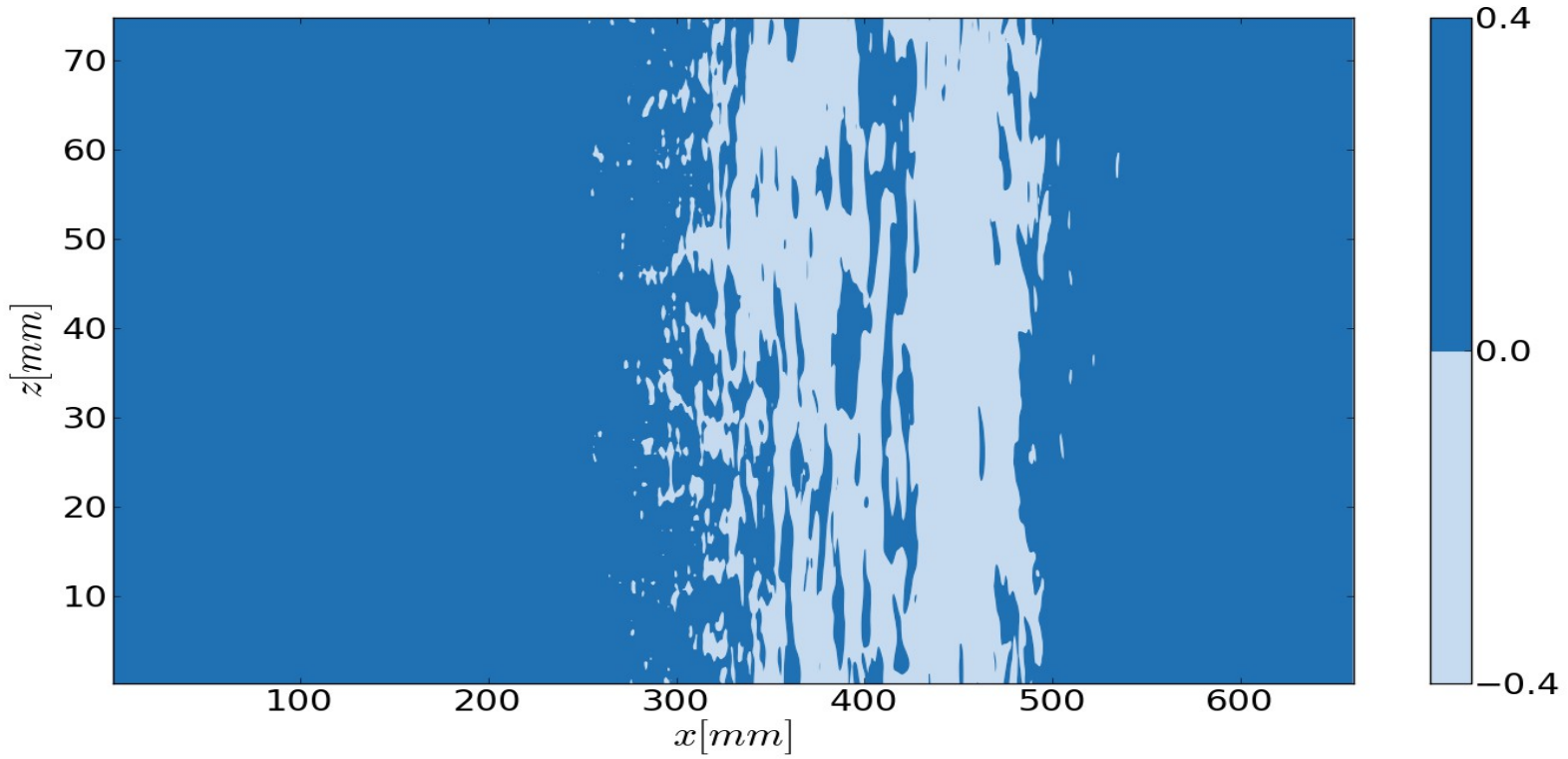
Probability of Reverse Flow



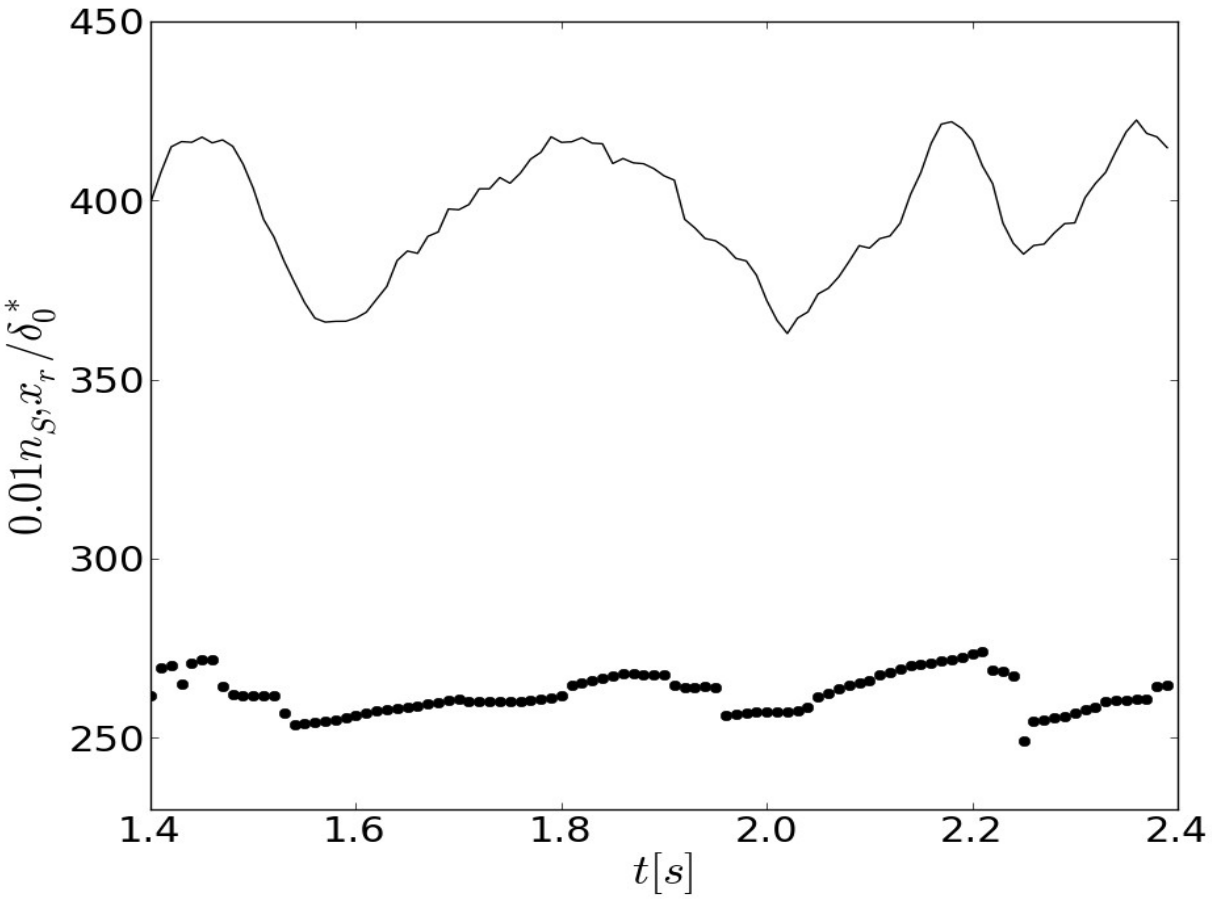
Time Evolution of Backflow Region ($z \approx 25\delta_0^*$)



Time Evolution of Skin Friction in Recirculation Region



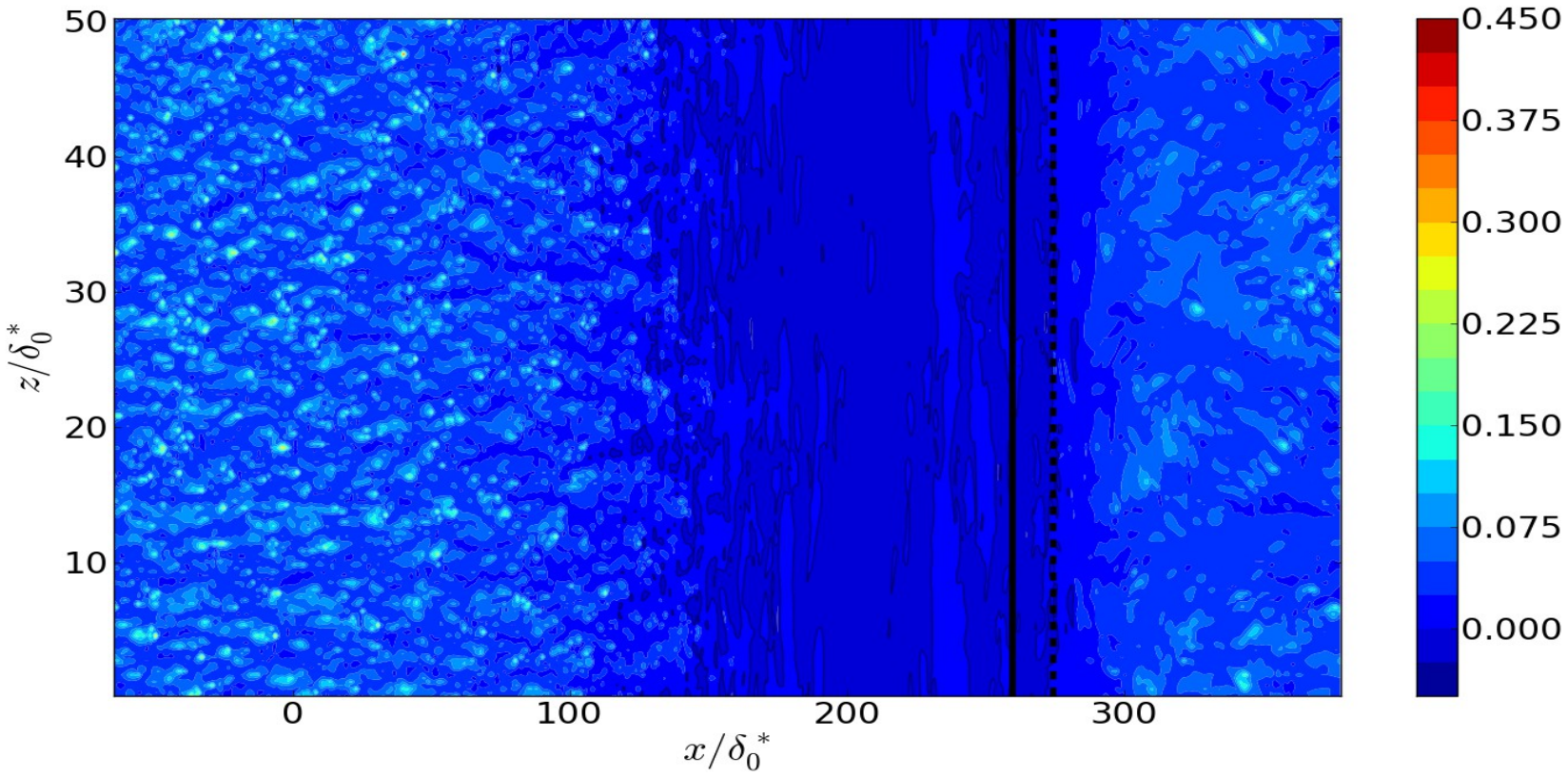
Time Evolution of Total Area of Backflow Region



n_s (——)

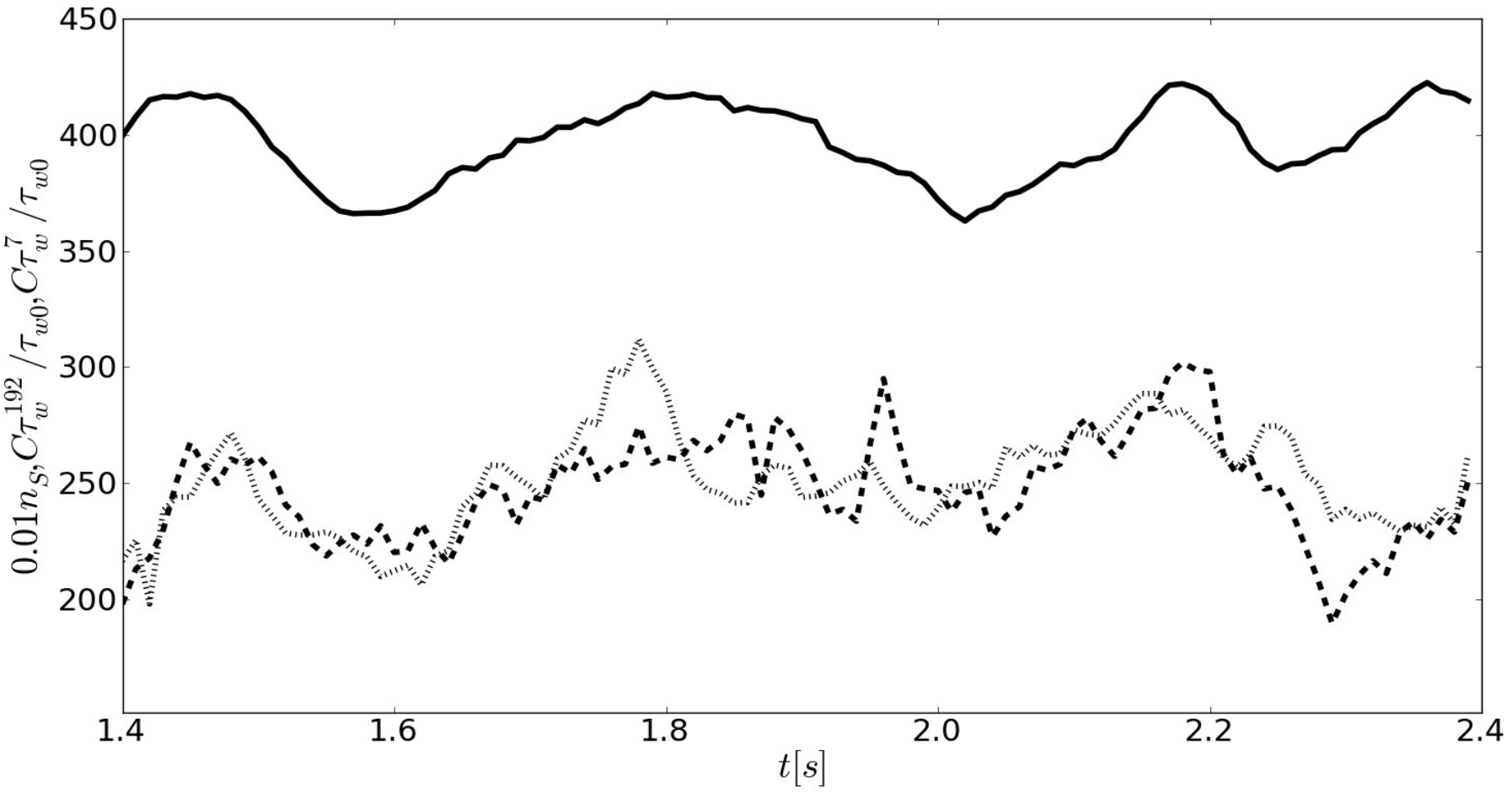
x_r/δ_0^* (•••••)

Instantaneous Skin Friction Field: Late Reattachment Event



mean reattachment line late reattachment line

Searching for Criterion



— total area of backflow region - - - $C\tau_w^{192}/\tau_{w0}$ ..... $C\tau_w^{7}/\tau_{w0}$ ***x/δ₀*=369.2***

Conclusions

- The dynamics of the backflow region in a separated turbulent flow is visualized using results of a direct numerical simulation.
- A new parameter for description of the non-stationary cycle in a separated flow is proposed - the total wall area occupied by the reverse flow. The time evolution of the parameter illustrates the non-stationary cycle in a very clear way, much better than the conventional pulsation of the instantaneous reattachment point.
- A local multipoint identification criterion for registering basic stages of the non-stationary cycle is presented.