Laminar to turbulent transition in separated boundary layer at elevated turbulence level

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Overview

Laminar - Turbulent transition

Laminar - Turbulent (LT) transition of boundary layer is multiple process.

- Natural transition, for low turbulence level in the free stream ($T < 1\%$). Initiated by Tollmien Schlichting (TS) waves. Typically exist in external flows like flow over airfoils.
- Bypass transition, for high turbulence level in the free stream $T > (0.5 - 1)\%$. Typically exist in turbomachinery flows.
- Transition in the separated boundary layer.

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Bypass type transition

Shear sheltering

The small-scale free stream disturbances are damped by the boundary layer shear.

Klebanoff modes

The longitudinal structures are produced inside the pseudo-laminar boundary layer.

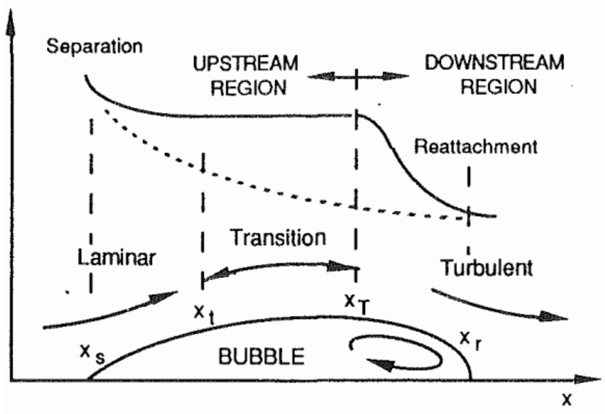
Turbulent spot

The small scale disturbances from the free stream impact the outer part of the boundary layer. This leads to secondary instability and turbulence breakdown.

Transition caused by separation

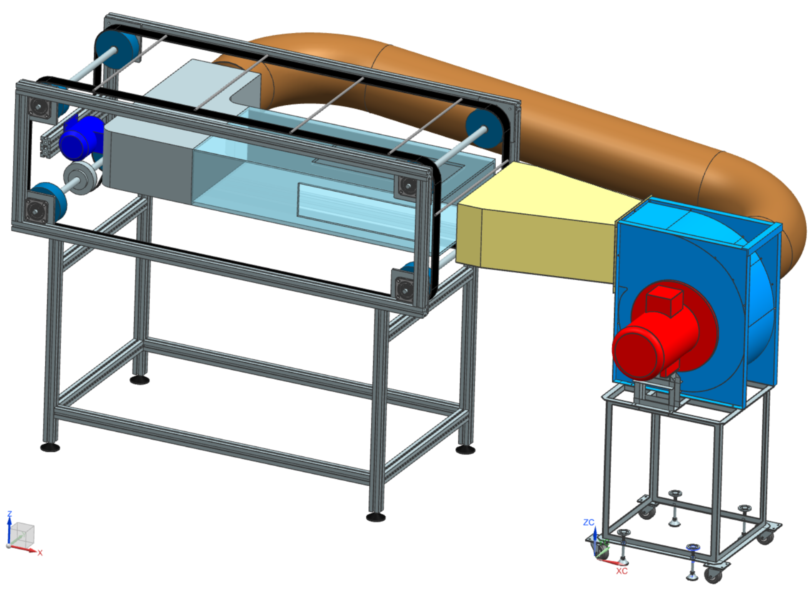
Separation with re-circulation

- **S**eparation point,
- **t**ransition starting point,
- final **T**ransition point,
- **r**eattachment.

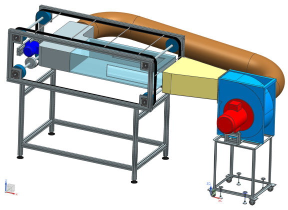


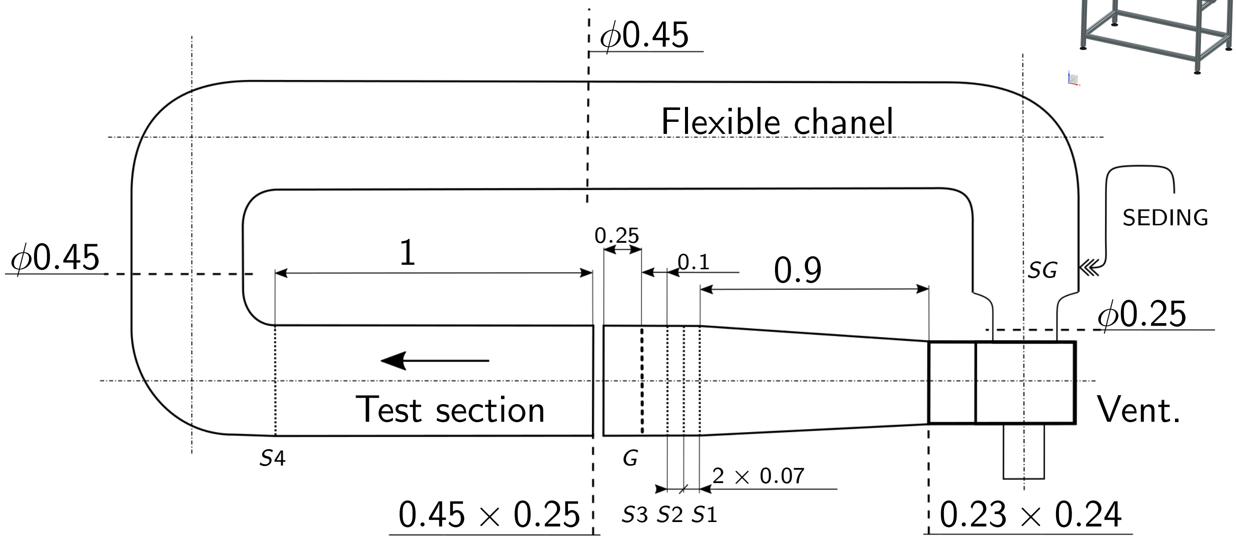
Robert Edward Mayle. The role of Laminar-Turbulent transition in gas turbine engines. *(1991)*

Experimental setup

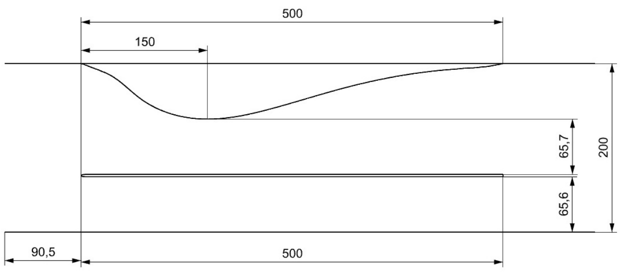


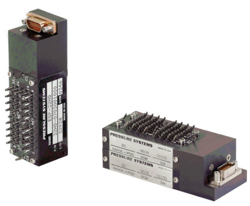
Experimental setup

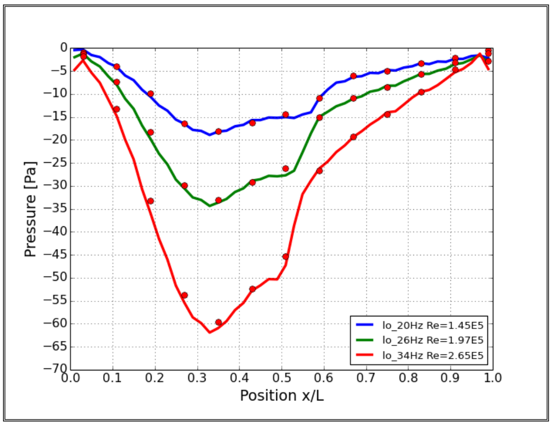




Model detail - Test section and pressure distributions

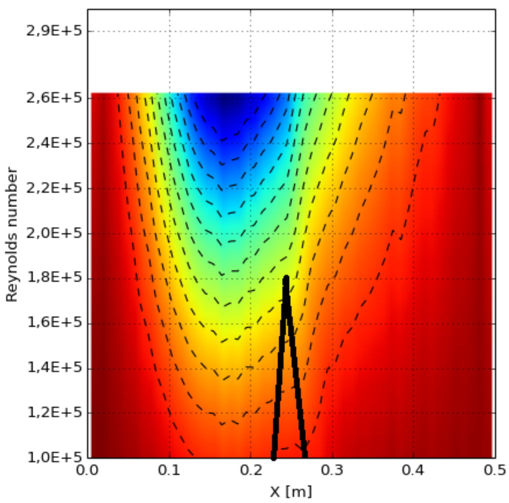




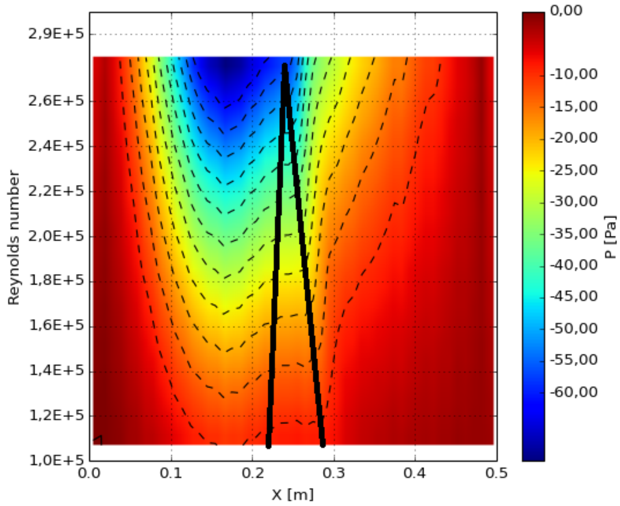


Pressure distribution along flat plate model.

Pressure distributions



With turbulence grid.



Without turbulence grid.

Constant Temperature Anemometer

- Dual channel probe - X-probe 55P61,
- Sampling 20kS/s & 16bit,
- FFT - Hamming window 1024s 50%ov.

Particle Image Velocity

- laser 15Hz & 200mJ,
- 2D PIV 2560×2048pix,
- area of interest - 211×21mm,
- correlation window - 4×4 & 50%ov.,
- $\triangle x \triangle y = 0.165$mm.

The challenges:

- correct setup of hardware (illumination and camera),
- correct setup of correlation (DaVis),
- correct post-processing of data.

PIV post-processing of data

input Vx, Vy, StdVx, StdVy, Avgeragekineticenergy, StandarddeviationofVx, StandarddeviationofVy, ReynoldsstressXY, ReynoldsstressXX, ReynoldsstressYY, TSSmax2D, Turbulentkineticenergy.

output $U_0,\ C_f,\ u_\tau,\ \delta,\ \delta^*,\ \theta,\ \delta^{***},\ Re_\theta,\ H_{12},\ H_{23},\ y_0,\ \frac{\partial u}{\partial y}|_{y_0},\ \frac{\partial u}{\partial y}|_{max},$

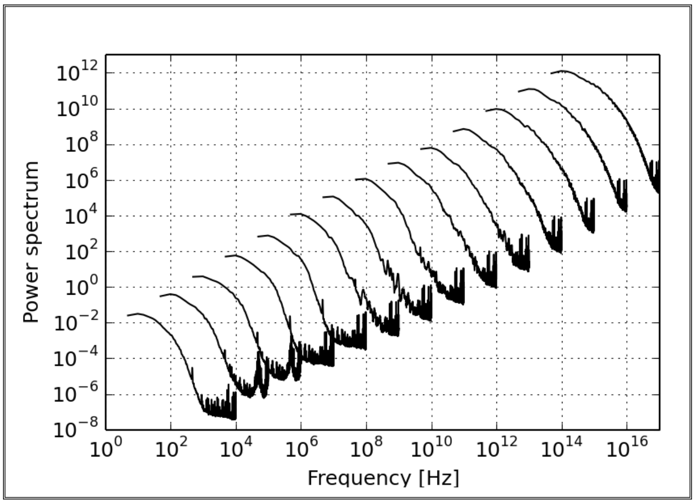
$zero_{point},\ poket_{point},\ inflection_{point},$

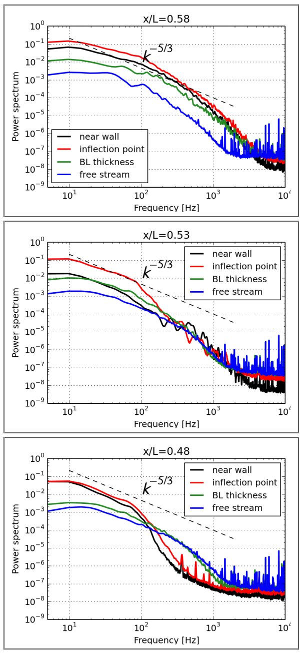
$Rxy_{max},\ \frac{Rxy_{max}}{{u_\tau}^2},\ TKE_{max},\ \frac{Rxy_{max}}{TKE_{max}}$

tests transition criteria: Mayle, Roberts&Yaras

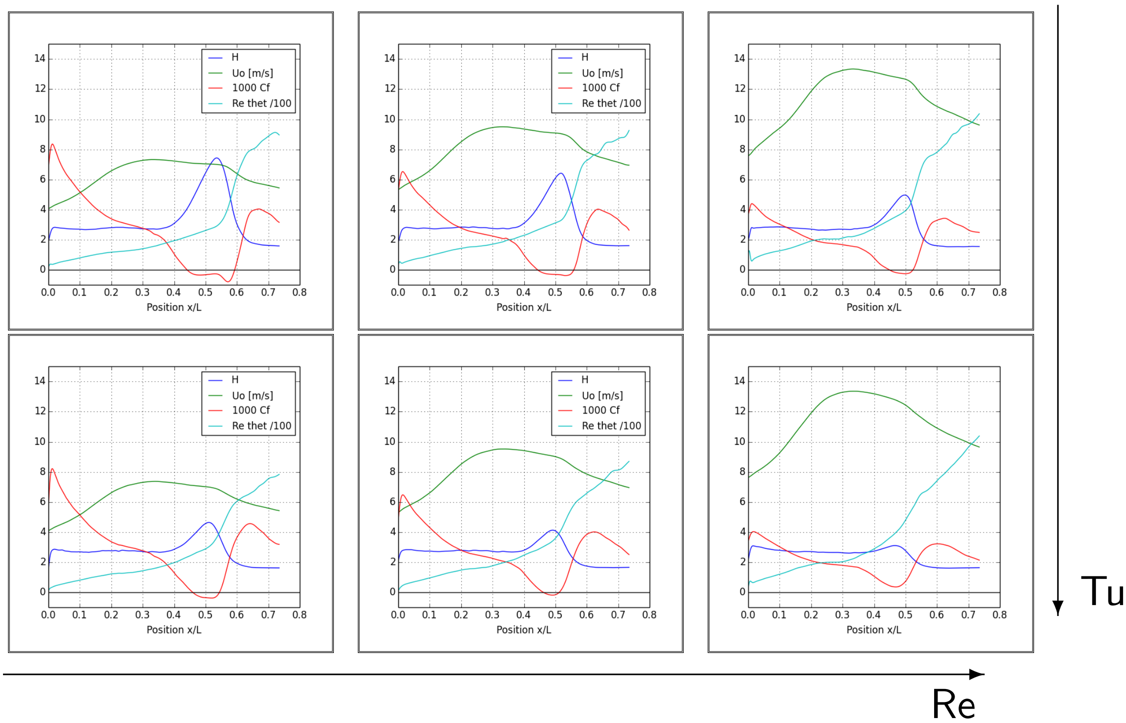
cond. $Re \in (1.0 - 2.5 \times 10^5),\ Tu \in (3.5\% - 5\%)$

CTA - energy growth

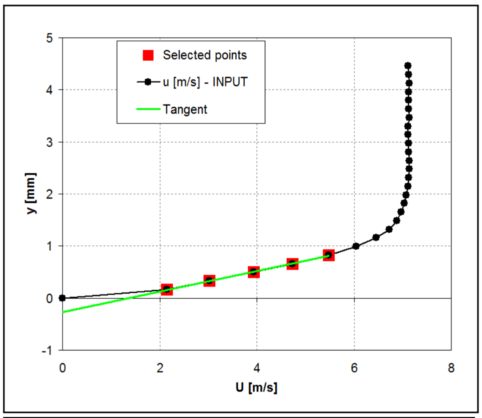


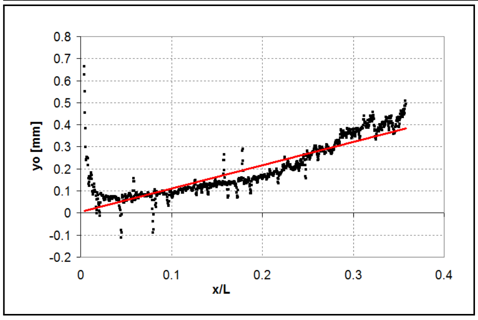


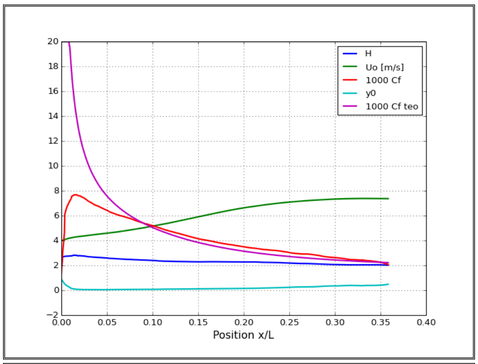
Profiles

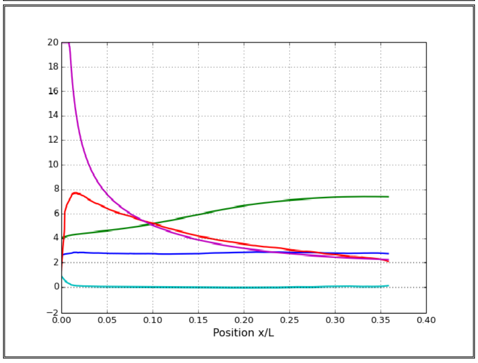


Wall detection and velocity profile shift - laminar case

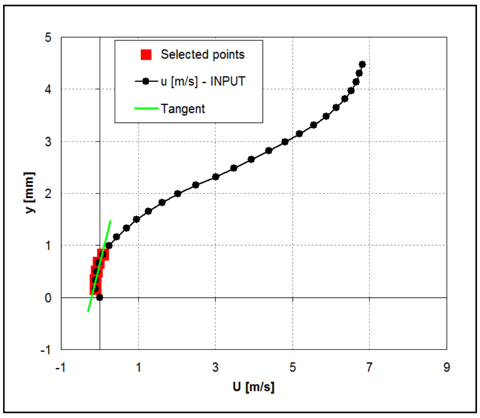


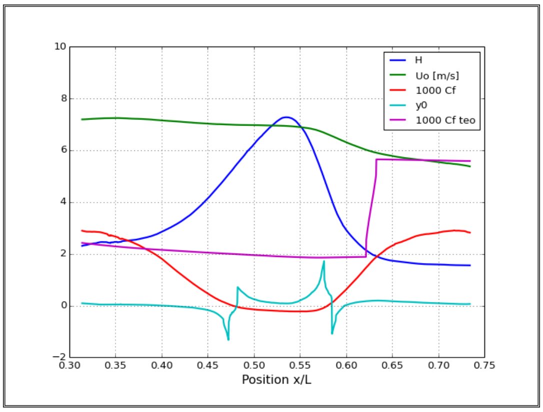






Wall detection and velocity profile shift - separation zone





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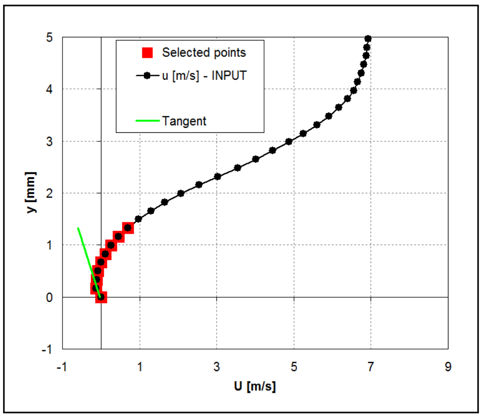
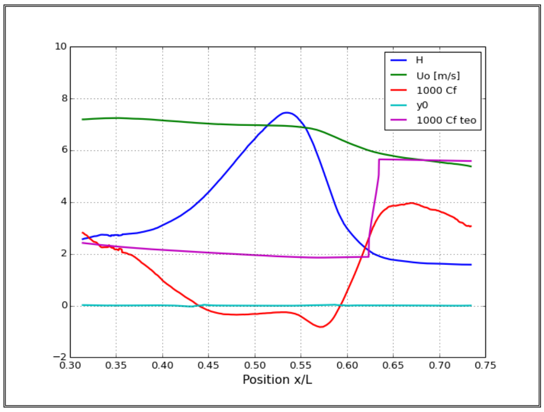
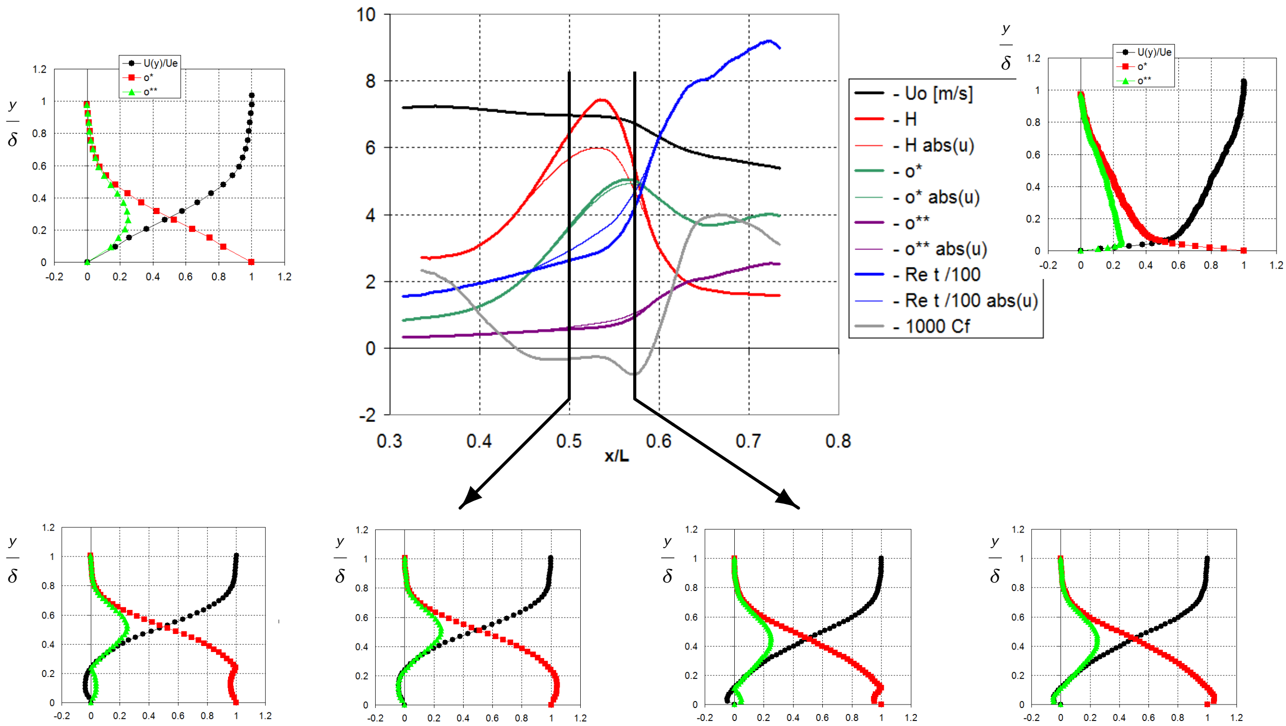




Integration of velocity profiles



Intermittency factor calculations I

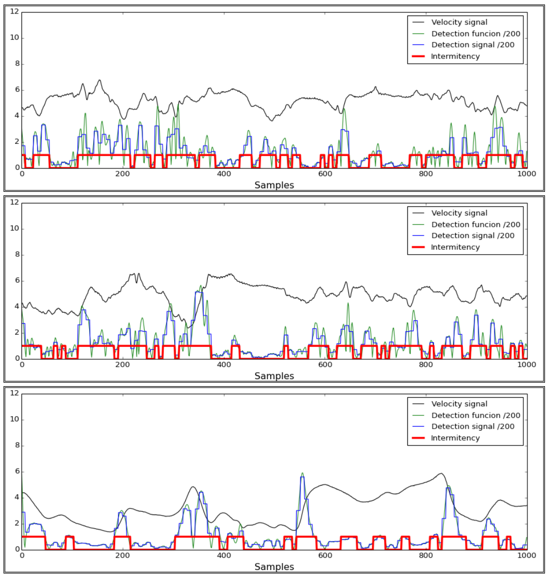
How to chose decision value where $\Gamma(t) = 1$

- Derivatives method

$$\left|\frac{du'}{dy}u'(t)\right|$$

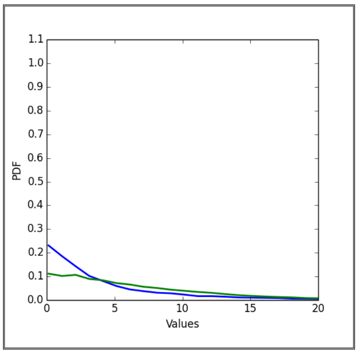
- Continues Wavelet Transform method

$$CTW(8, 1, u'(t), \Psi(t))$$

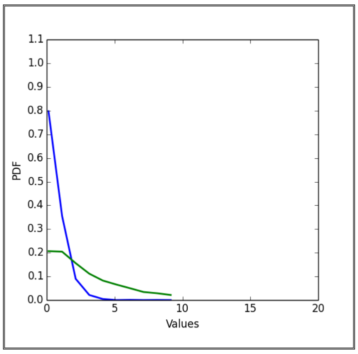


Intermittency factor calculations II

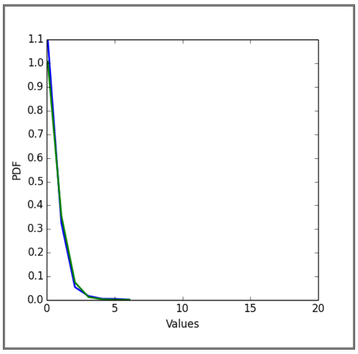
Decision value is representative for local velocity profile or for total field.



$x/L = 0.79$



$x/L = 0.58$



$x/L = 0.505$

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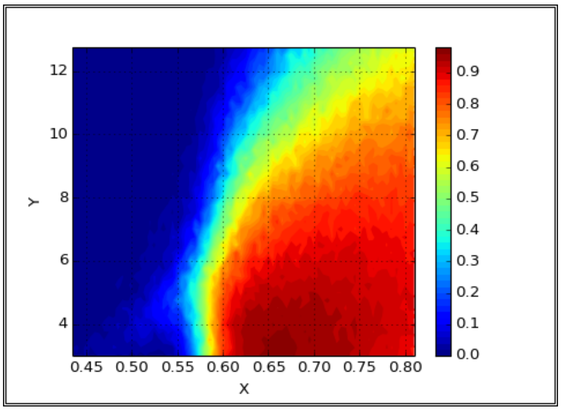
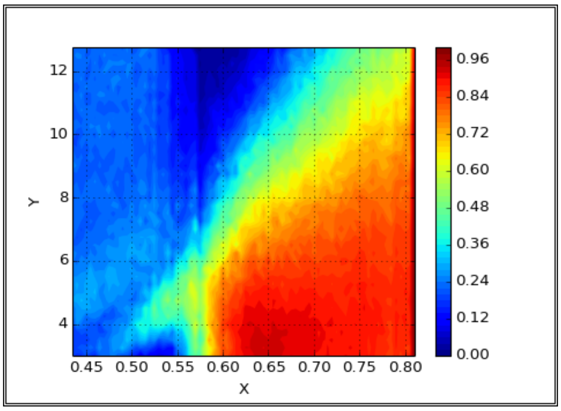
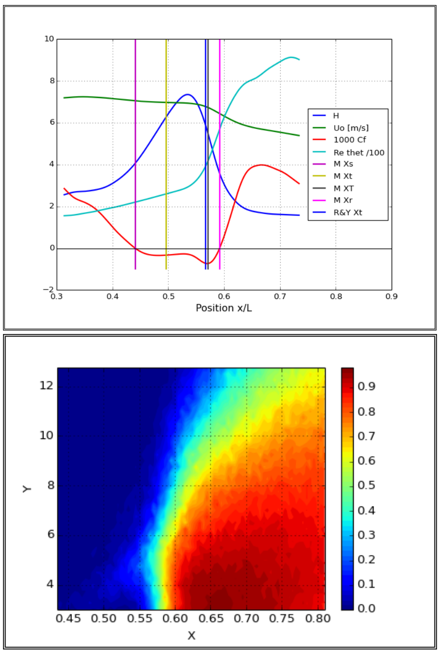


Global value.

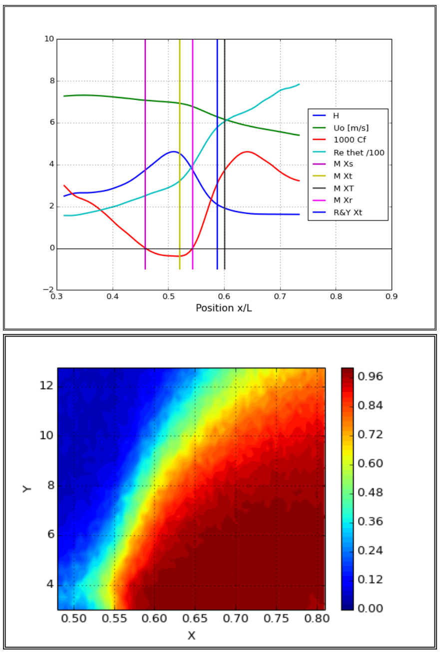


Local value.

Profiles



$Xt = 0.56$



$Xt = 0.5$

Conclusions

- Assumption of global threshold value for calculation of intermittent factor seams to be more reliable.
- Better agreement is obtained between reality and correlations by Mayle and Roberts for low turbulence case.
- Improvement by Roberts correlation is not sufficiently strong for case with high turbulence level.

Introduction
Research methods
Results
Data validation
Predictability of transition

The End

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