Bursting of Laminar Separation Bubbles

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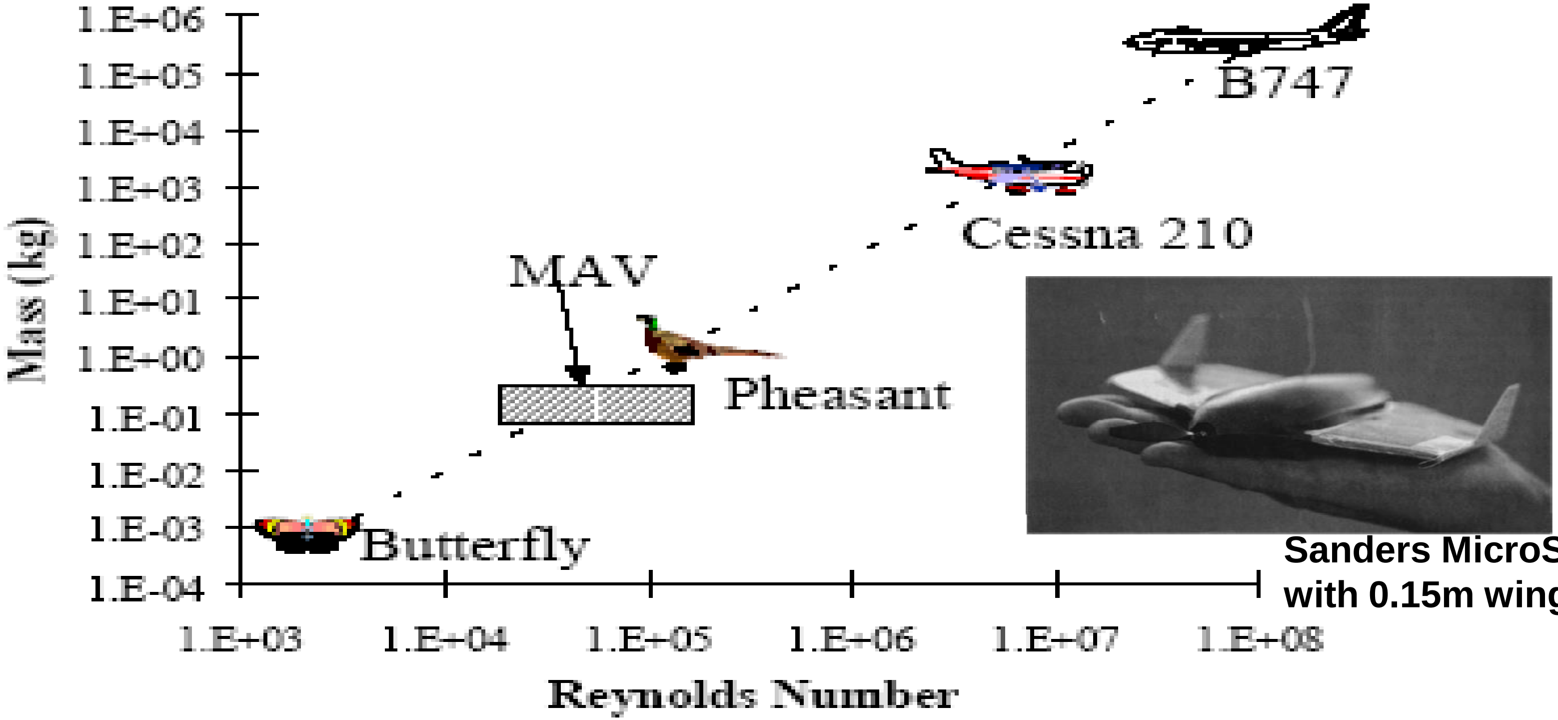
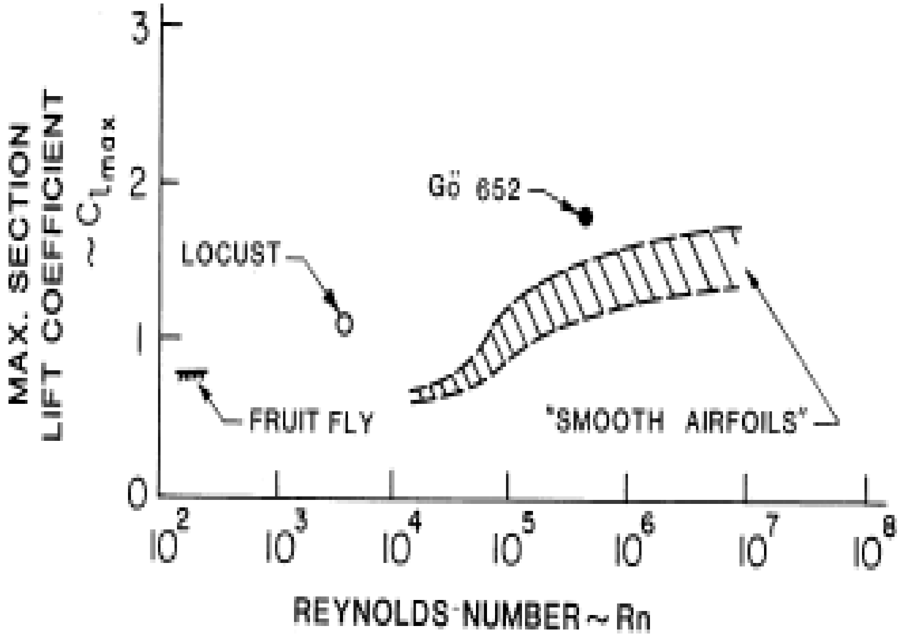
Acknowledgements

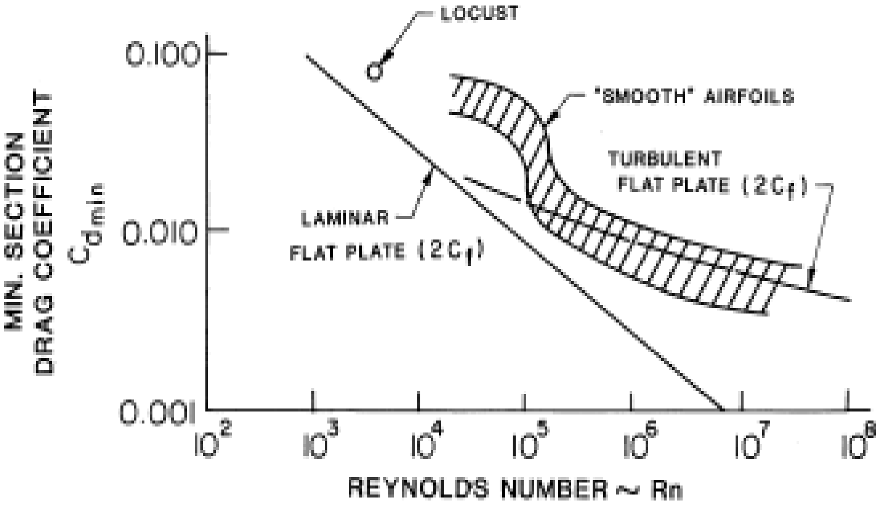
Abhijit Mitra

The MAV/Drone Connection



Sanders MicroSTAR with 0.15m wingspan

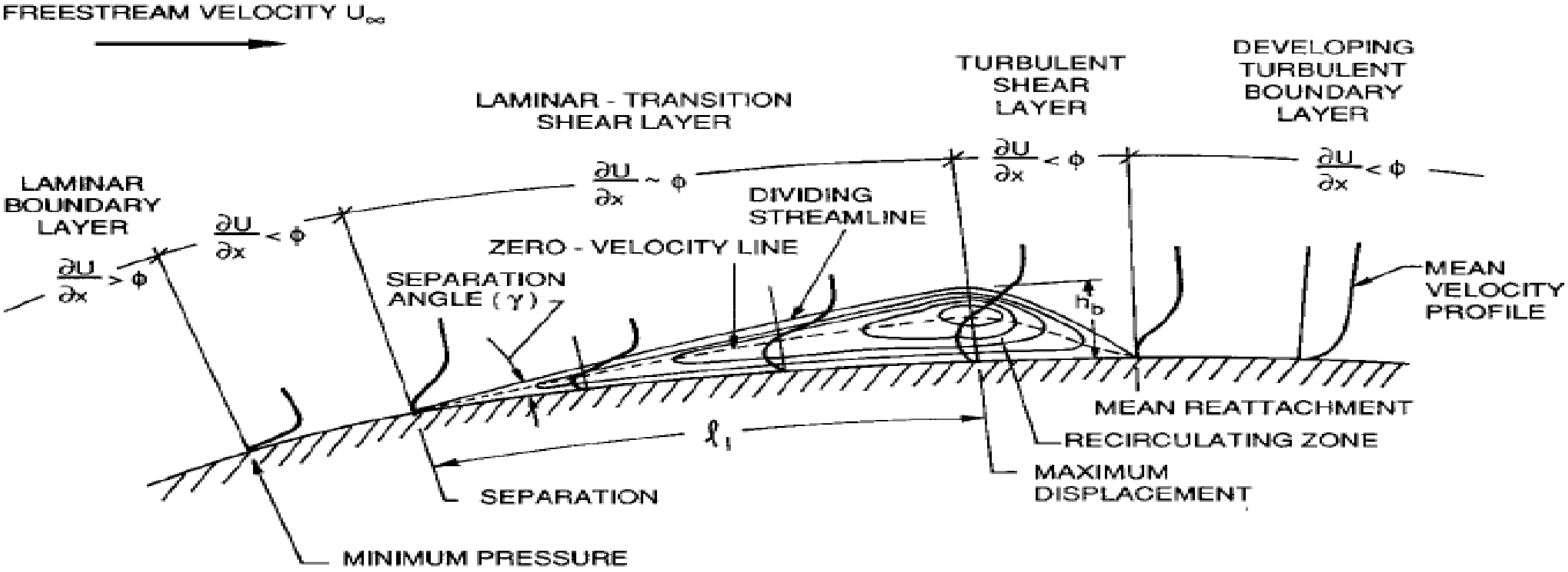




In the Reynolds Number range of Re~10^5 lift drops and drag rises drastically.

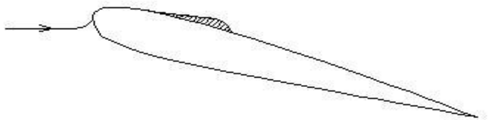
Culprit : Laminar Separation Bubble

Laminar Separation Bubble : A schematic

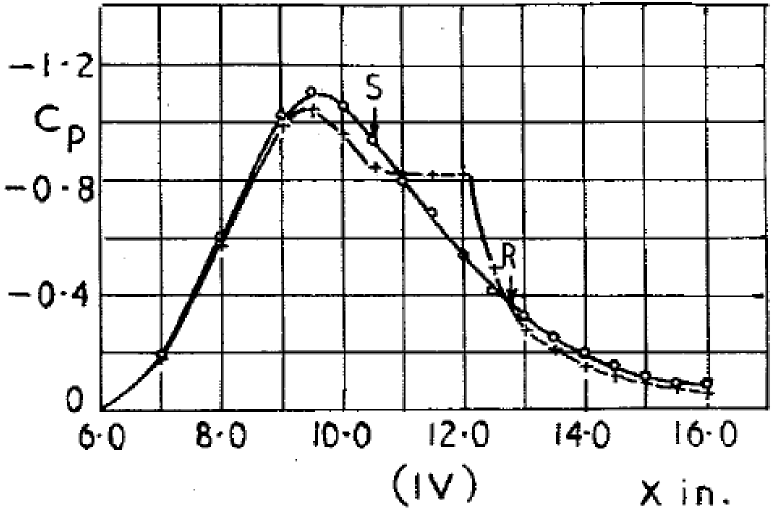


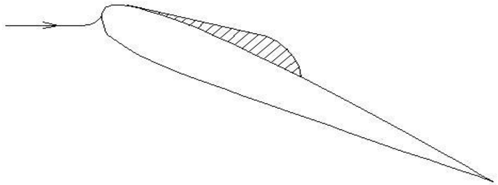
"... with a change in incidence or speed the shear layer may fail to reattach and the 'short' bubble may burst to form either a long bubble, or an unattached free shear layer. " Gaster (1967)

Bubble Bursting characterised by a sharp loss in lift

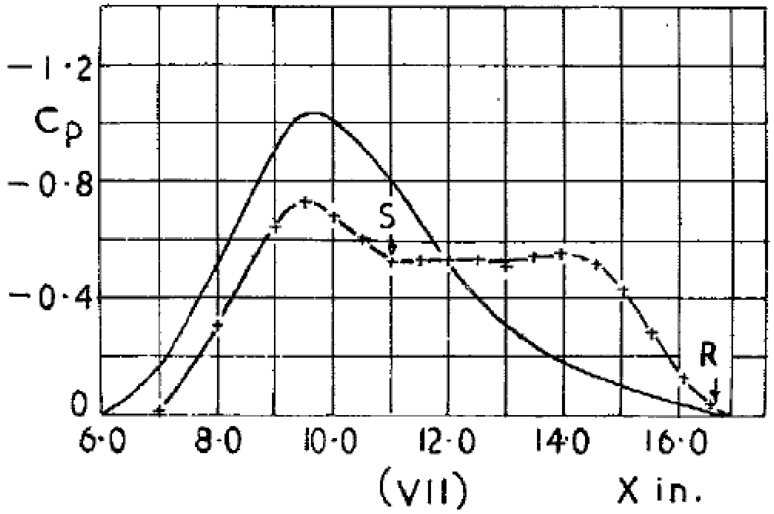


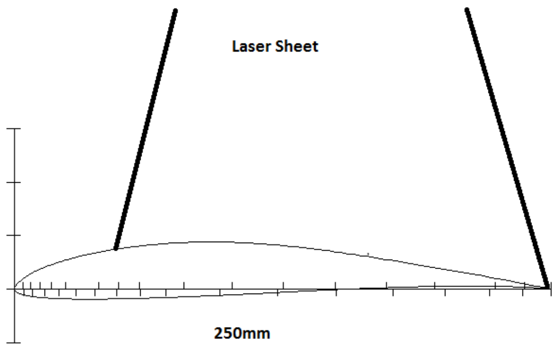
Short Bubble





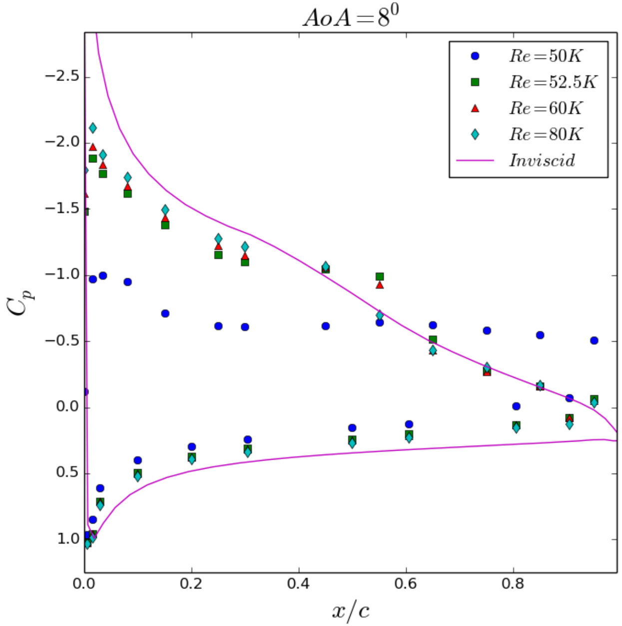
Long Bubble

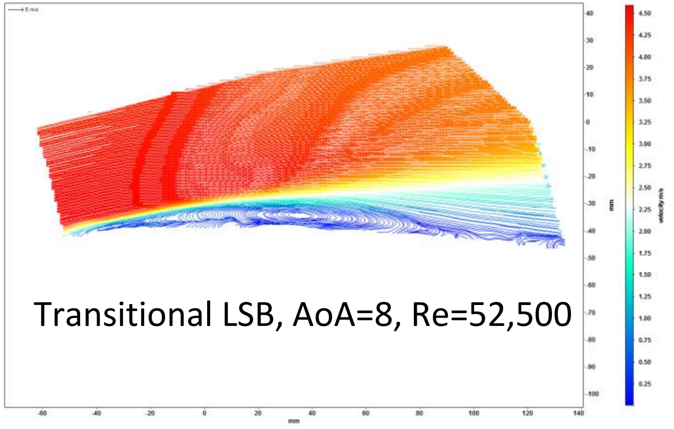




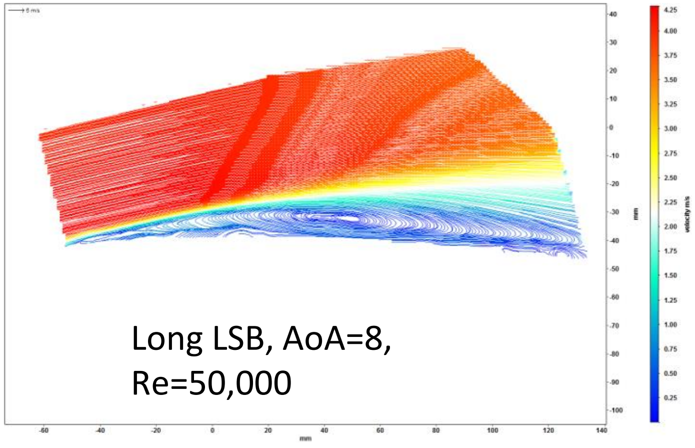
Side-view PIV arrangement

Pressure distribution :short/Long/Transitional bubbles

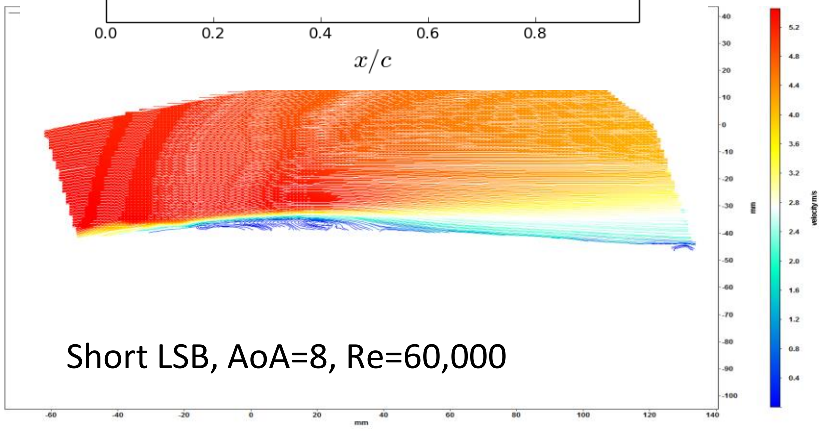




Transitional LSB, AoA=8, Re=52,500



Long LSB, AoA=8, Re=50,000



Short LSB, AoA=8, Re=60,000

Parameters for the prediction of bursting

Existing parameters

$$P_G = \frac{{\theta_s}^2}{\nu}\frac{(\Delta U)_{inv}}{\Delta x} \quad \text{and} \quad Re_{\theta_s}$$

Gaster(1967)

$$P_{DCR} = \frac{h^2}{\nu}\left(\frac{\Delta U}{\Delta x}\right)_{LSB} < -28 \qquad P_{DCR} \approx \frac{Vh}{\nu}$$

Diwan,Chetan and Ramesh(2007)

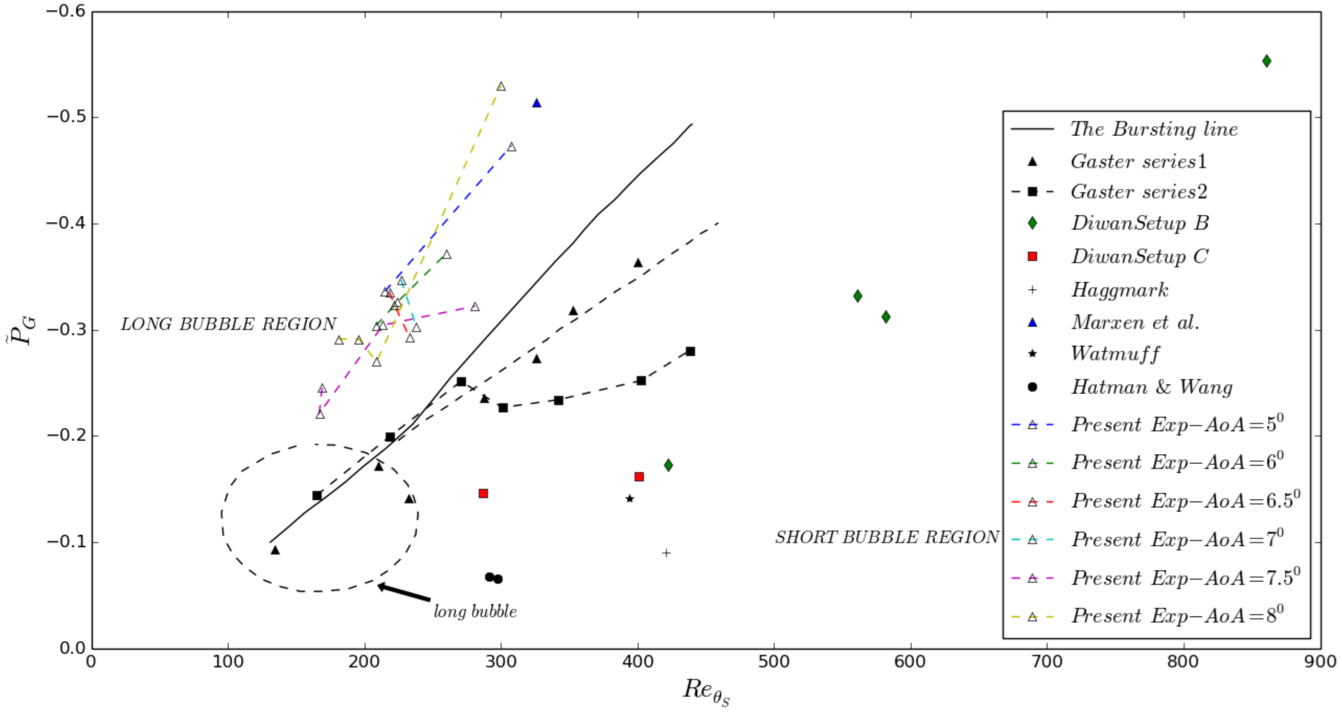
Modified Crabtree's parameter proposed (Abhijit Mitra PhD Thesis)

$$\tilde{\sigma} = \frac{P_R - P_S}{\frac{1}{2}\rho {U_a}^2} = 2\frac{\Delta U}{U_a} = -2\frac{P_{DCR}}{AR \cdot Re_{ah}}$$

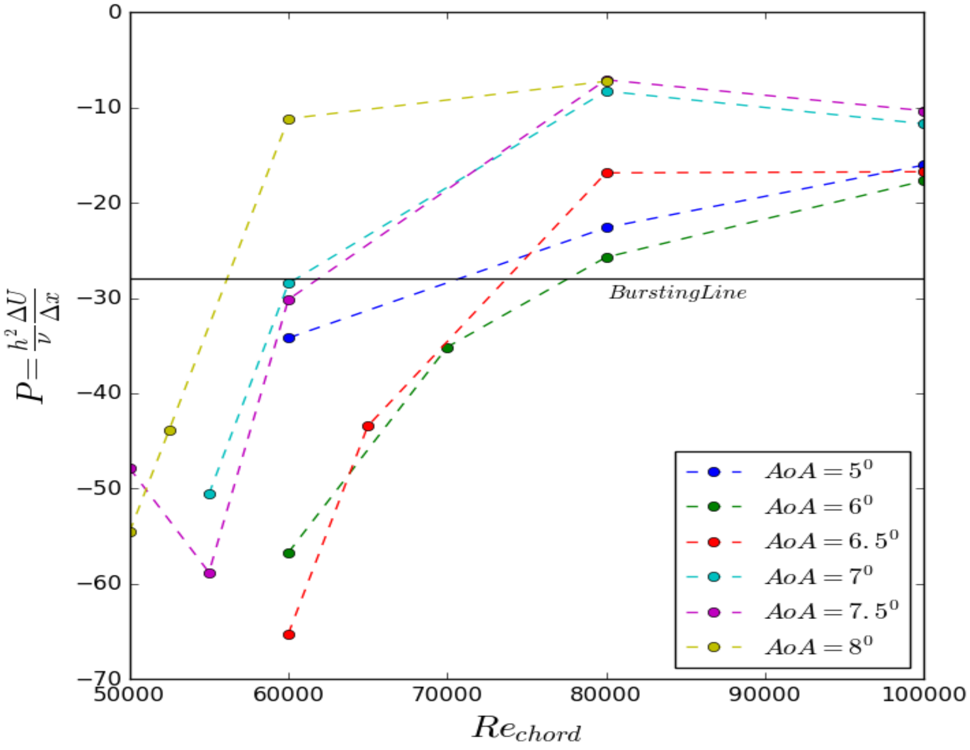
An Empirical Criterion for bursting,

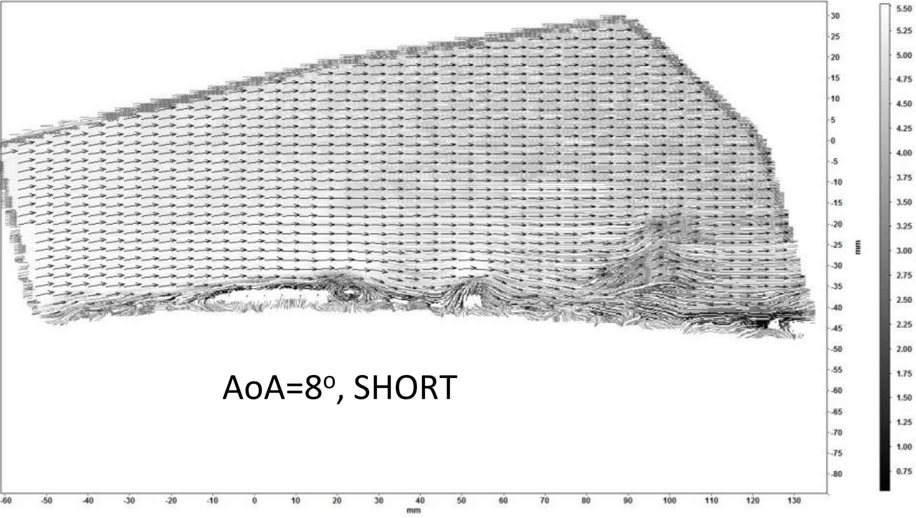
$$U_R \approx 0.87 U_S$$

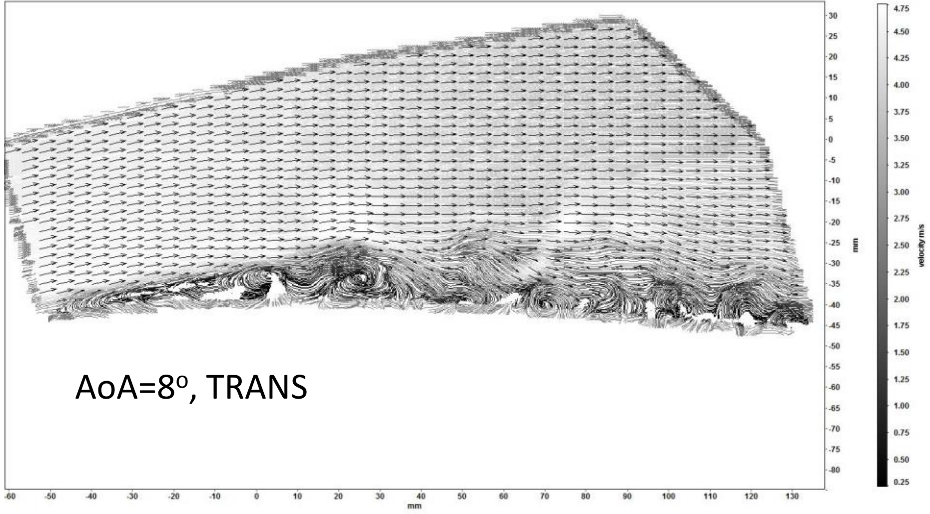
Gaster's parameter

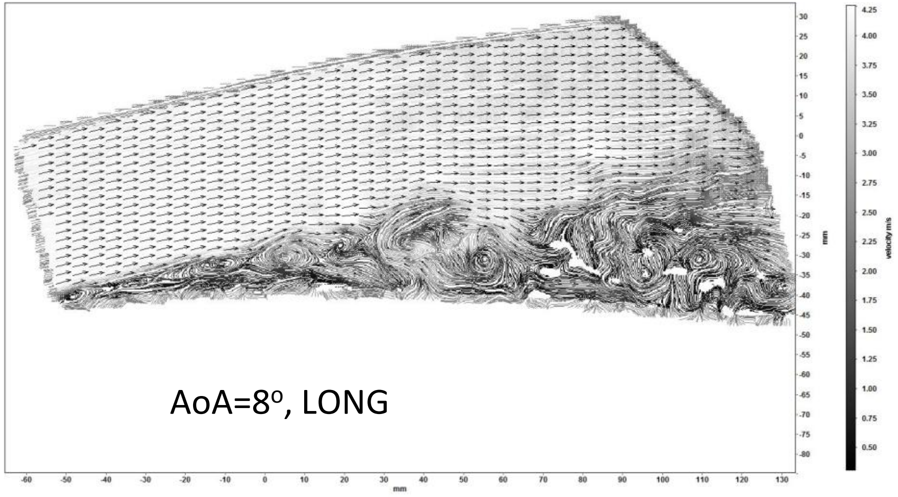


P_{DCR} evaluated for the present cases

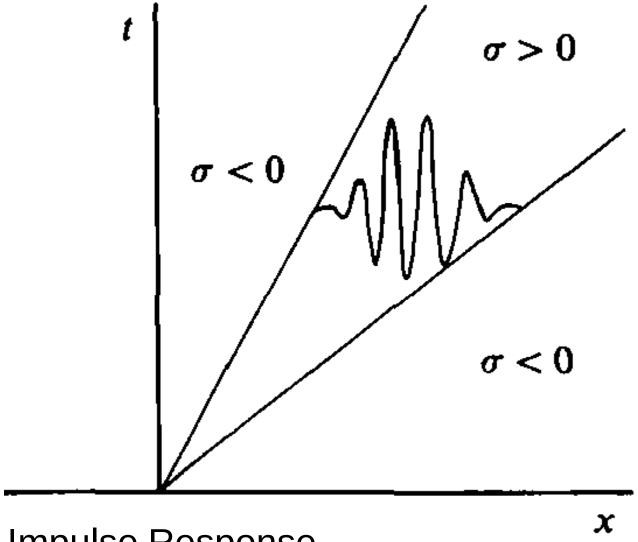


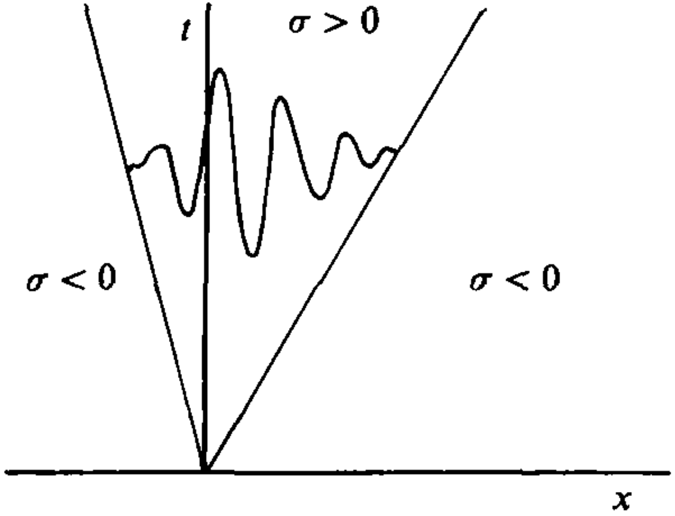

AoA=8o, SHORT
mm
velocity m/s


AoA=8o, TRANS
mm
velocity m/s


AoA=8o, LONG
mm
velocity m/s

What causes Bursting?





Impulse Response

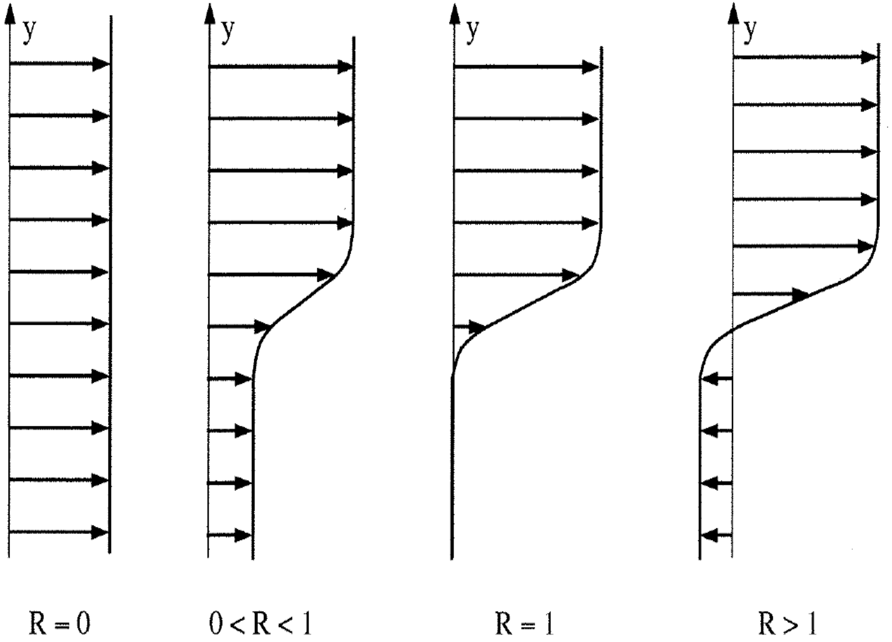
If the wave packet grows as it convects downstream : Convective Instability

If the wave packet grows at the same location without getting convected away : Absolute Instability

Bursting : Switch from Convective to Absolute Instability?

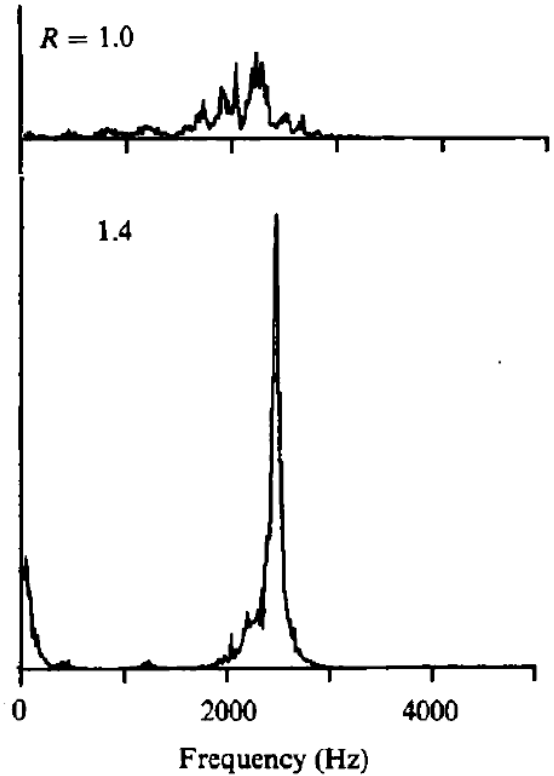
Convective /Absolute Instability in a free Shear Layer

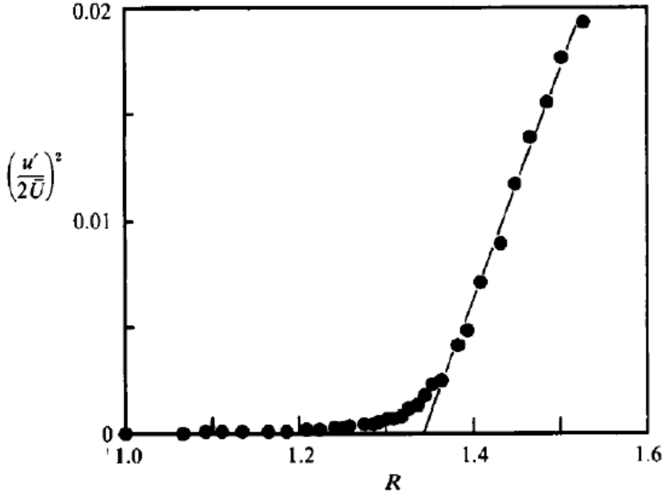
$$R \equiv \frac{U_1 - U_2}{U_1 + U_2} = \frac{\Delta U}{2\bar{U}}$$



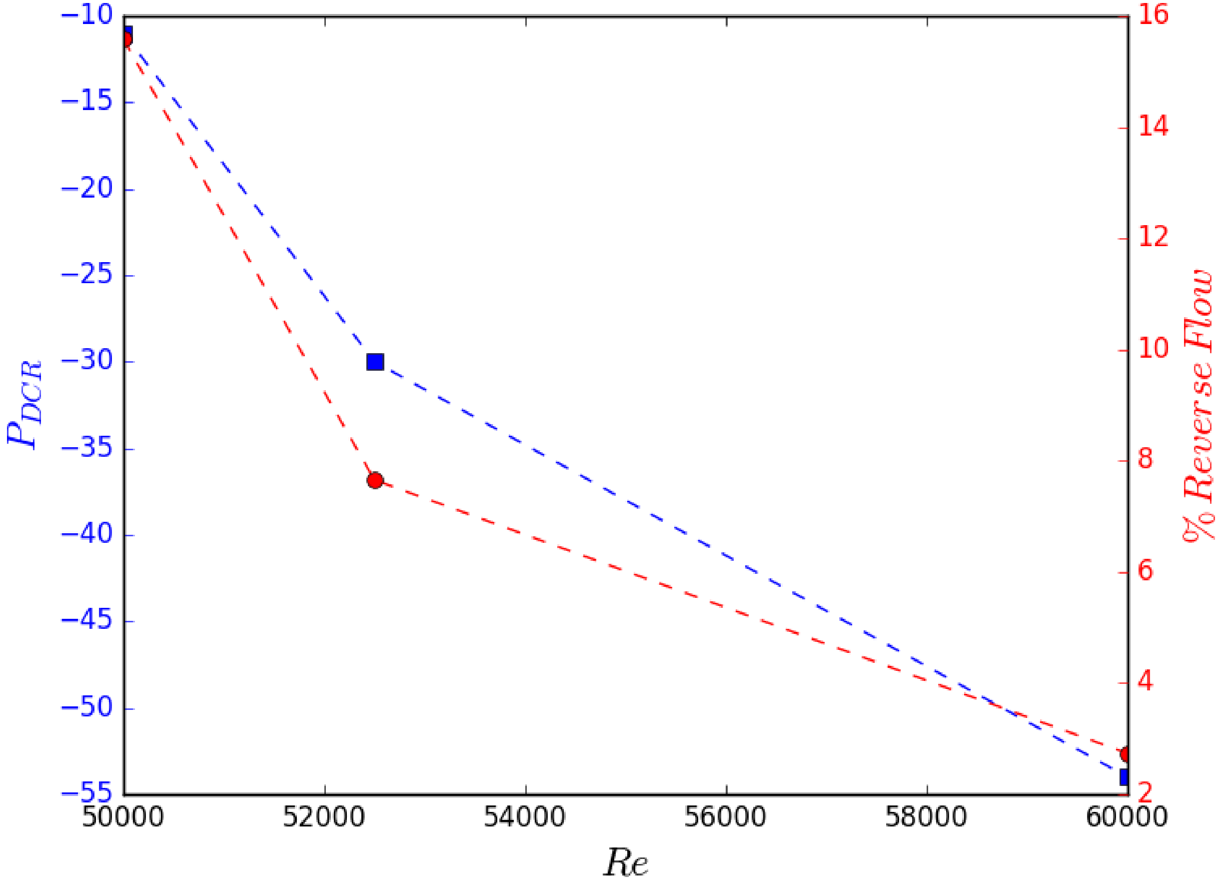
R=1.34 or when counter flow is about 14% of Forward Flow : Absolute Instability Onset

Amplifier to Oscillator Switch in Mixing Layers



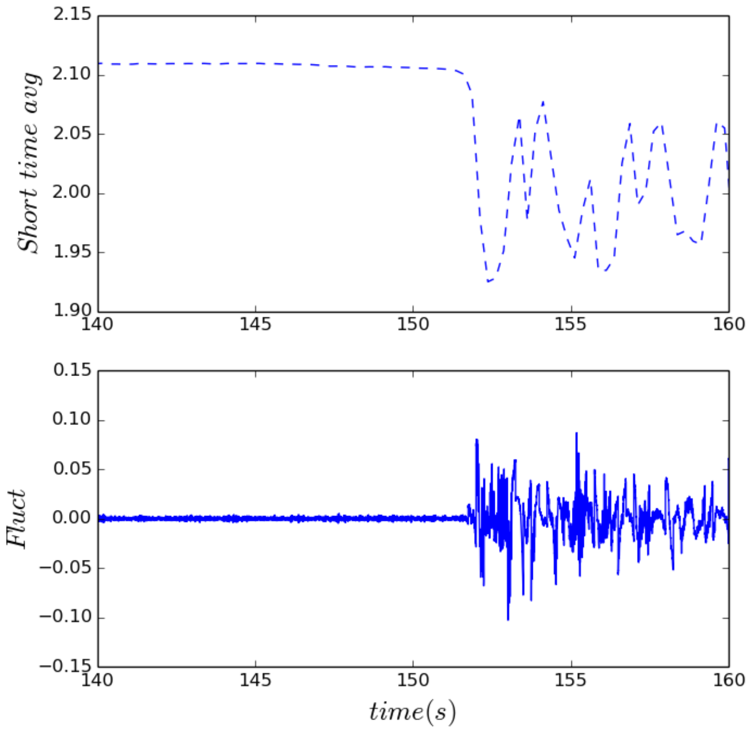


Strykowski & Niccum (1991)

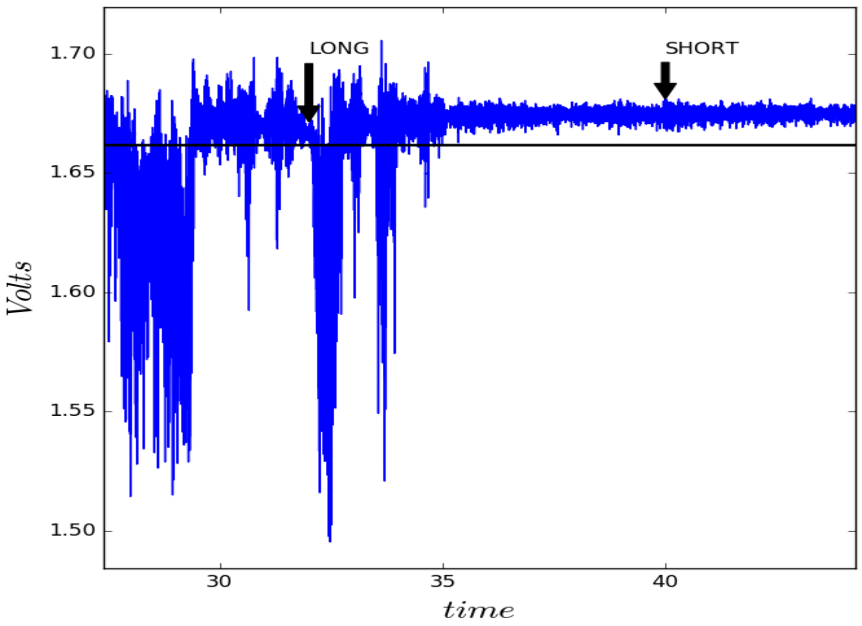


−10
−15
−20
−25
−30
−35
−40
−45
−50
−55
P_{DCR}
16
14
12
10
8
6
4
2
% Reverse Flow
50000
52000
54000
56000
58000
60000
Re

The transition from short to long and vice-versa
(Occuring via natural disturbance)

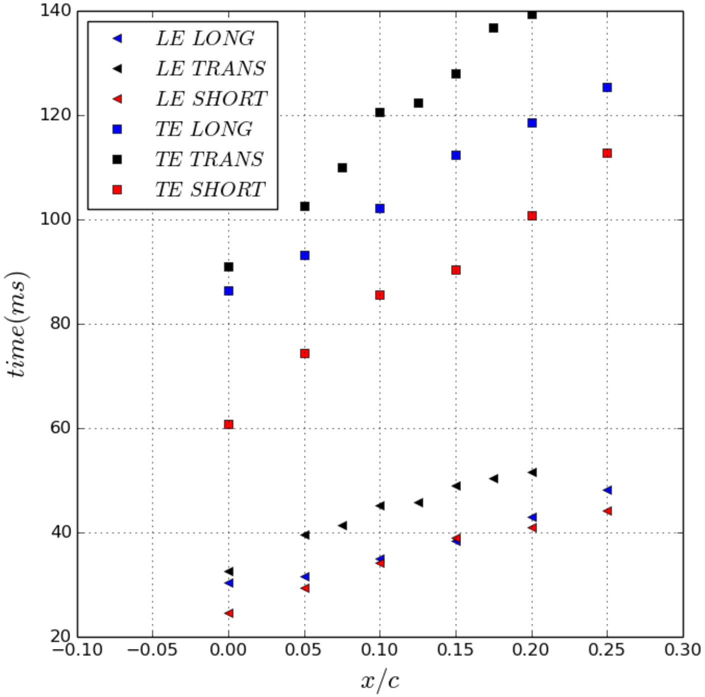


Short to long



Long to short

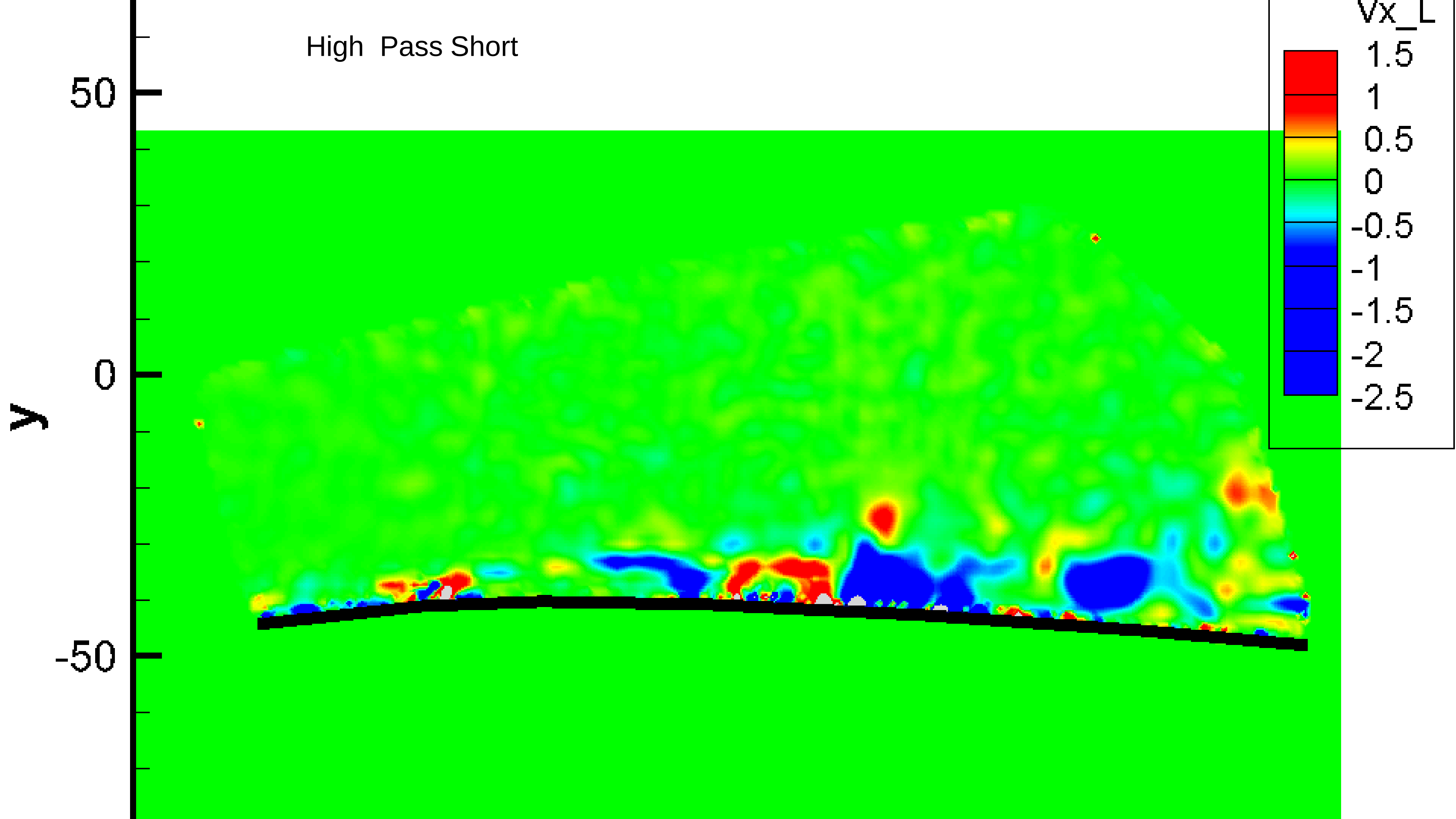
Absolute/convective nature of instability near bursting



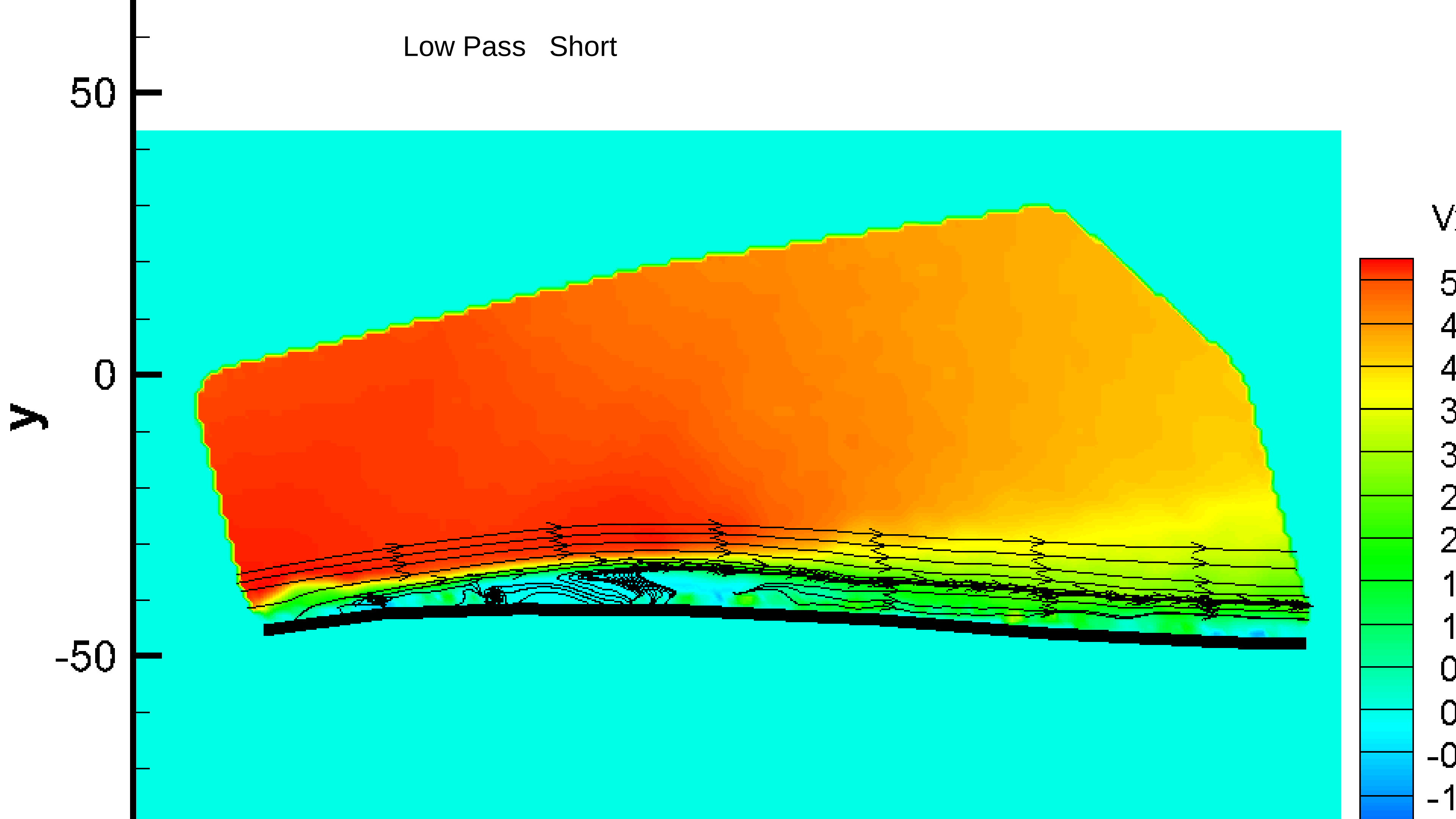
The impulse forcing x-t diagram at AoA=8°

Some movies from PIV

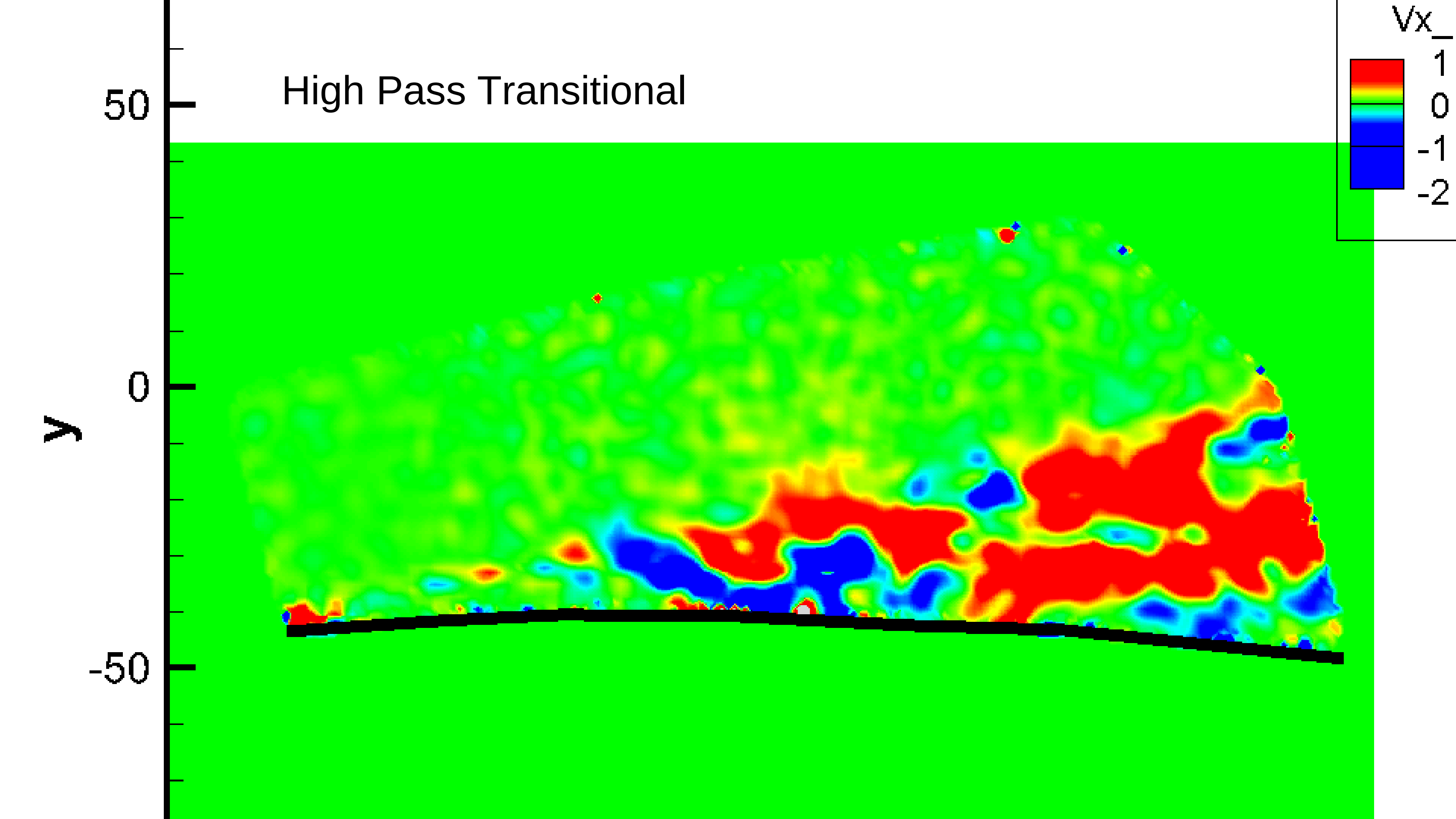
- Time resolved velocity data from PIV



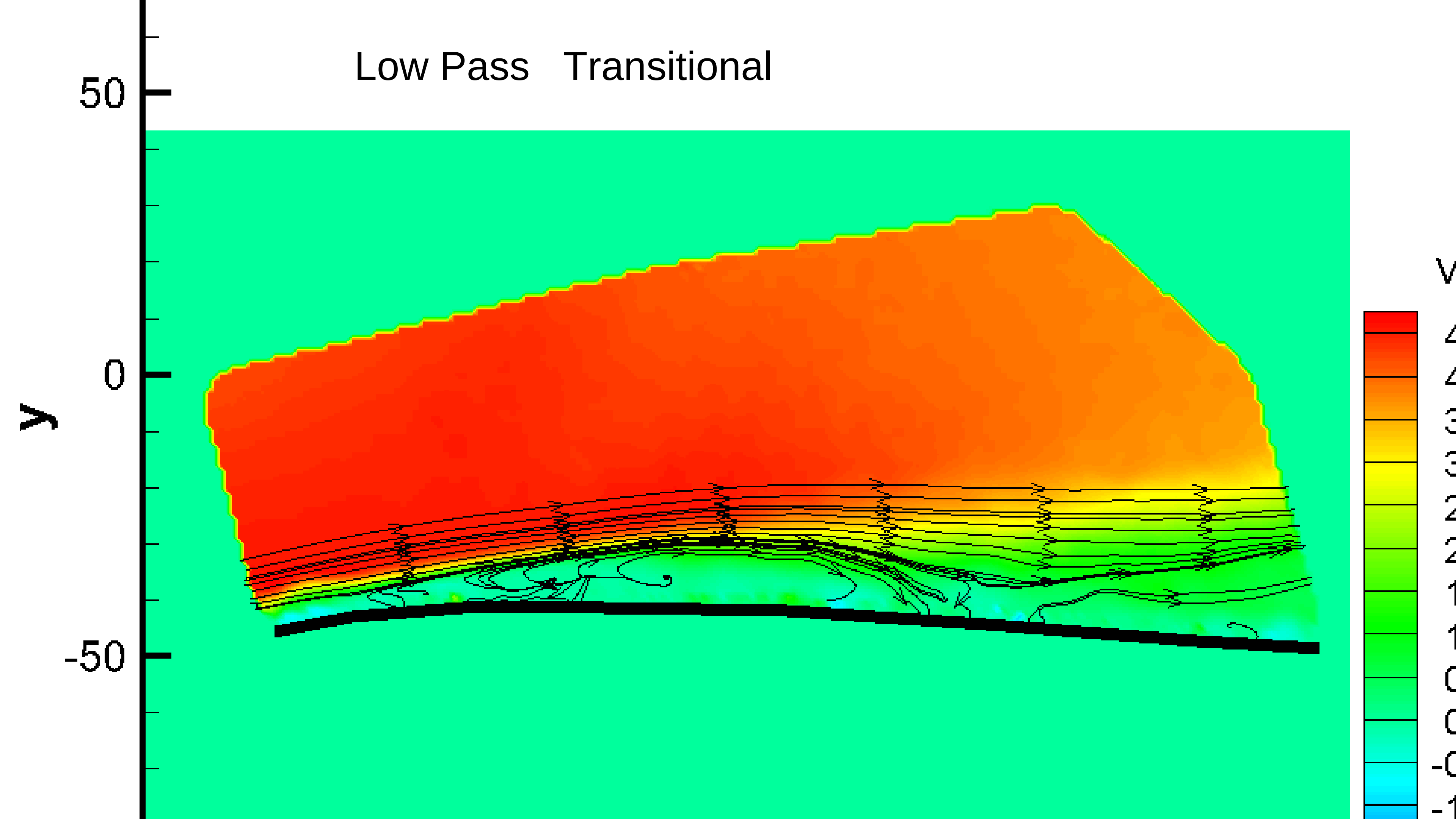
High Pass Short
50
0
-50
y
Vx_L
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5



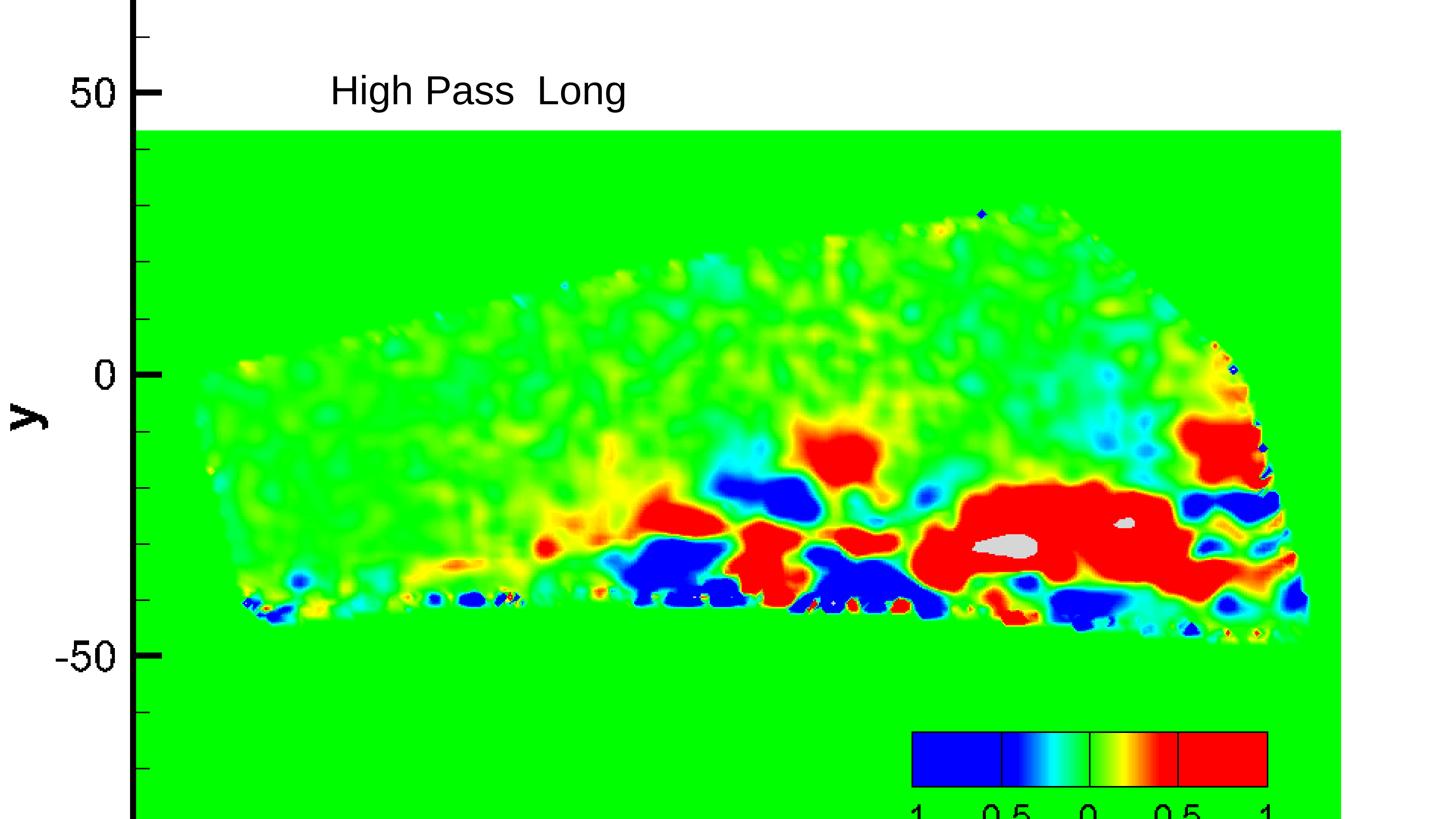
Low Pass Short
50
0
-50
y
V

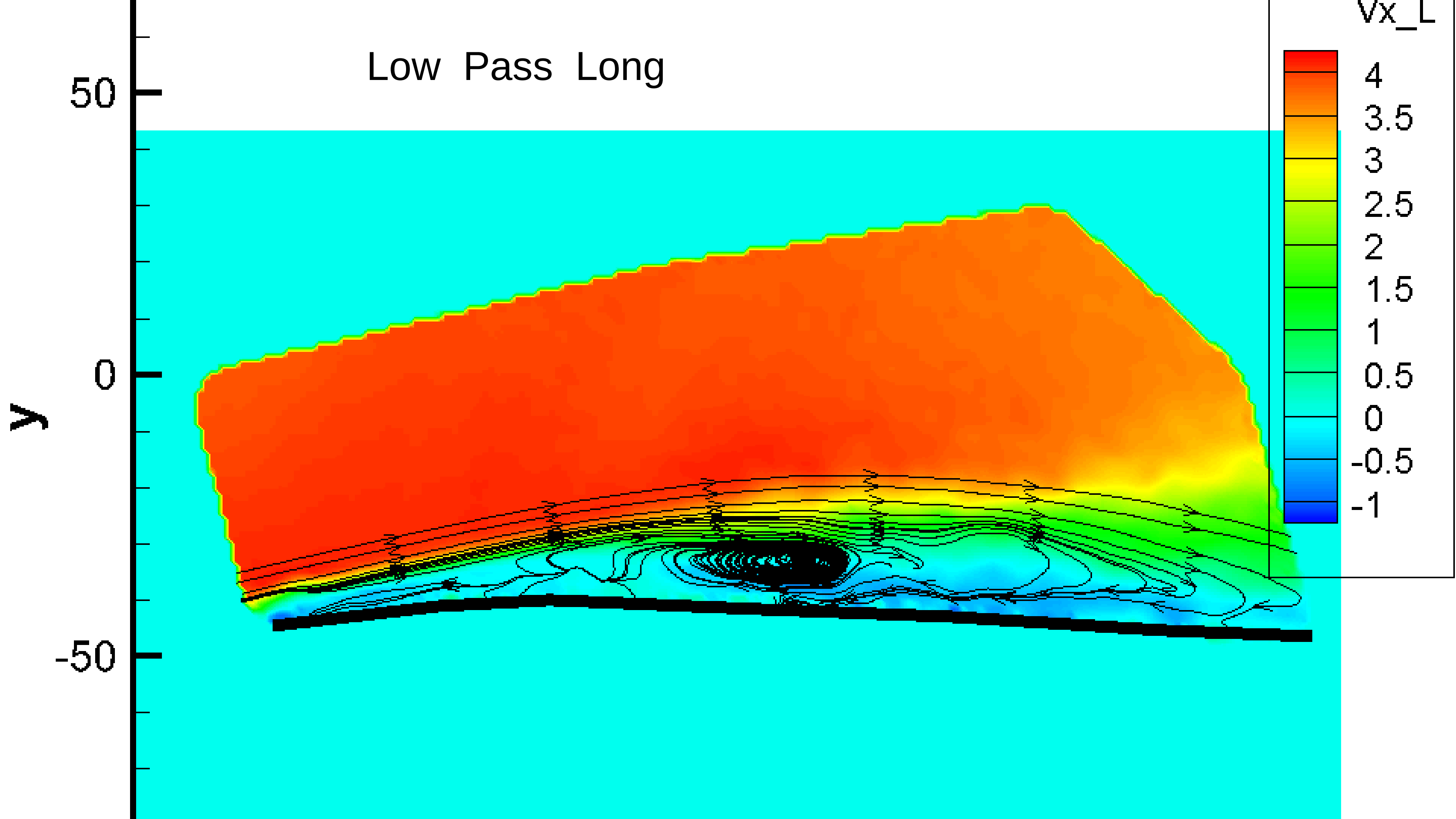


High Pass Transitional
50
0
-50
y
Vx_
1
0
-1
-2



Low Pass Transitional
50
0
-50
y


High Pass Long
50
0
-50
y
-1
-0.5
0
0.5
1



Low Pass Long
Vx_L
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
y
50
0
-50

Absolute/convective connection to low/high frequency content.

- The low frequency part component of the time-series seems to behave as a global oscillator, whereas the high frequency part behaves as a convective amplifier.
- The transitional and the long bubble cases show a high energy content for frequencies lower than 5Hz, which is absent, or very low, in the short case.

Observations

- Transitional Bubble not fully Absolutely unstable. Only part time

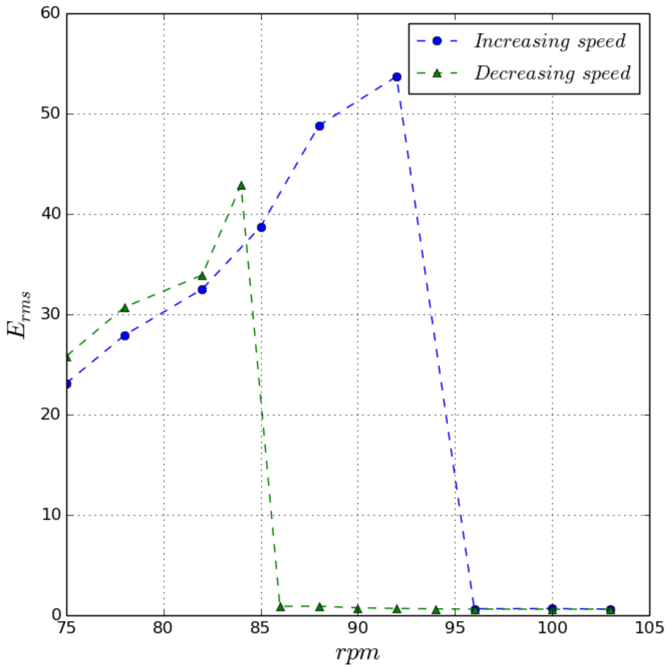
Fasel 2006 DNS showed the same

Whether Short Long or Transitional bubble, they seem to have oscillator and amplifier charactersitics in different proportions of time.

Variation of RMS amplitude with Re (Speed)

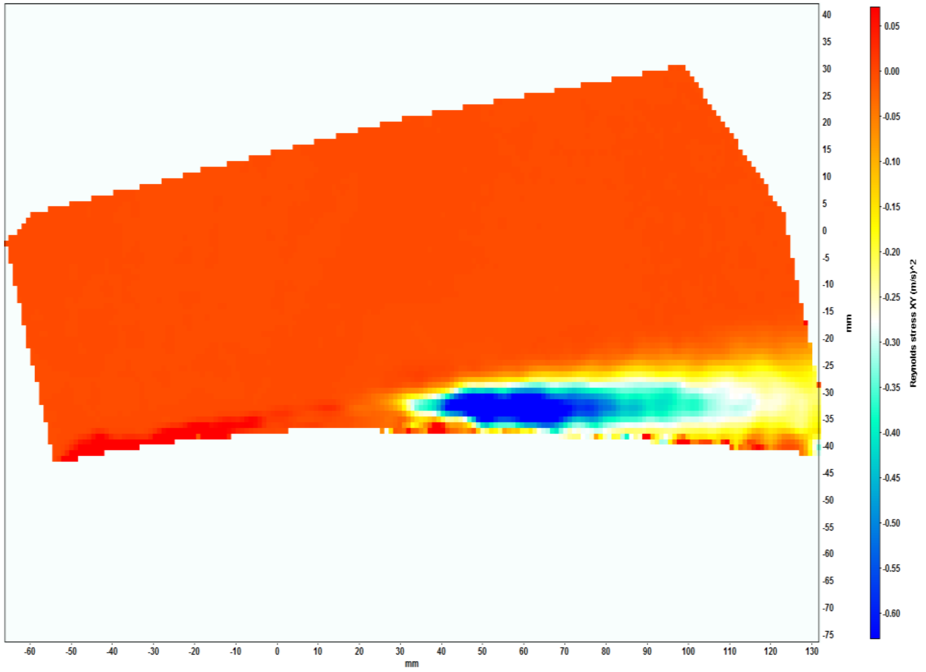
- The long to short transition happens at 96rpm, whereas the short to long happens at 85rpm –Hysteresis

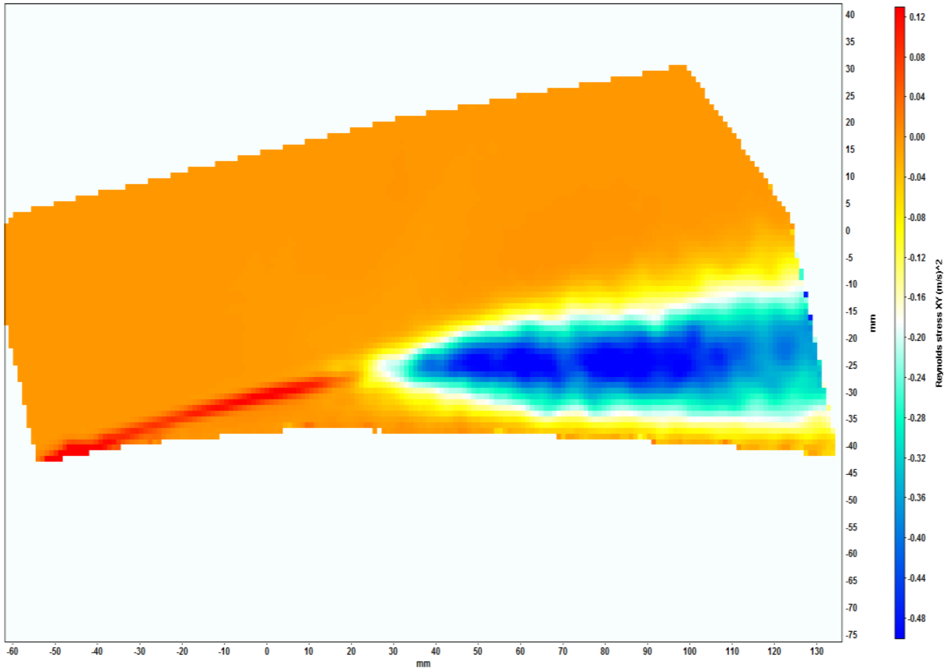
- Bifurcation from a subcritical to Supercritical? Perhaps not!



Reynolds shear stress <u’v’>

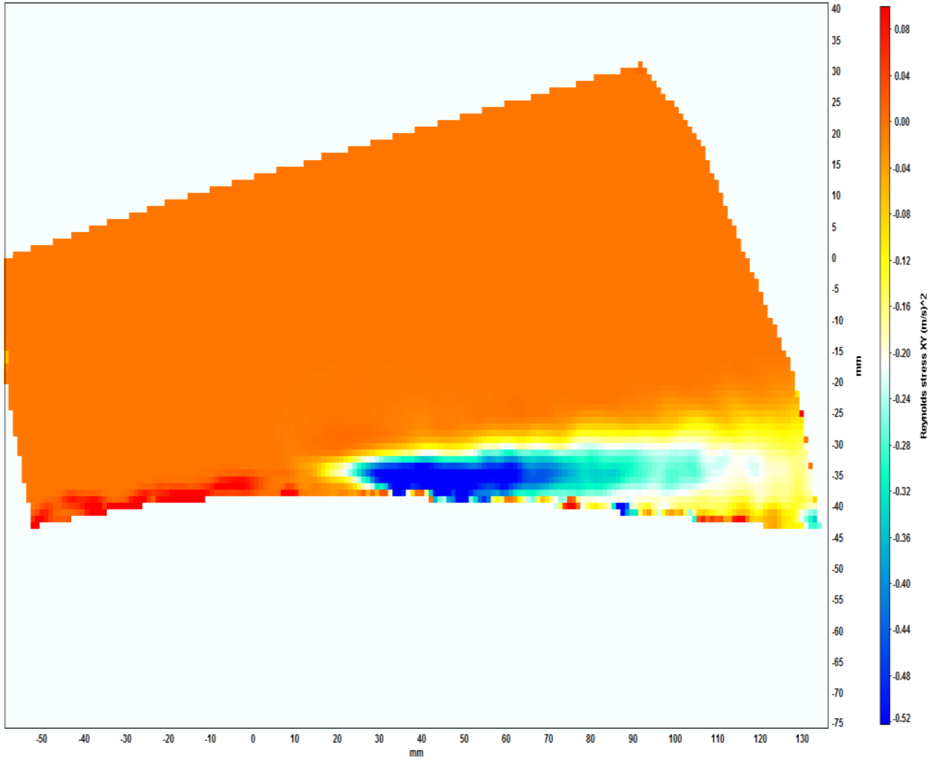
Indicative of Negative production of TKE in LSBs

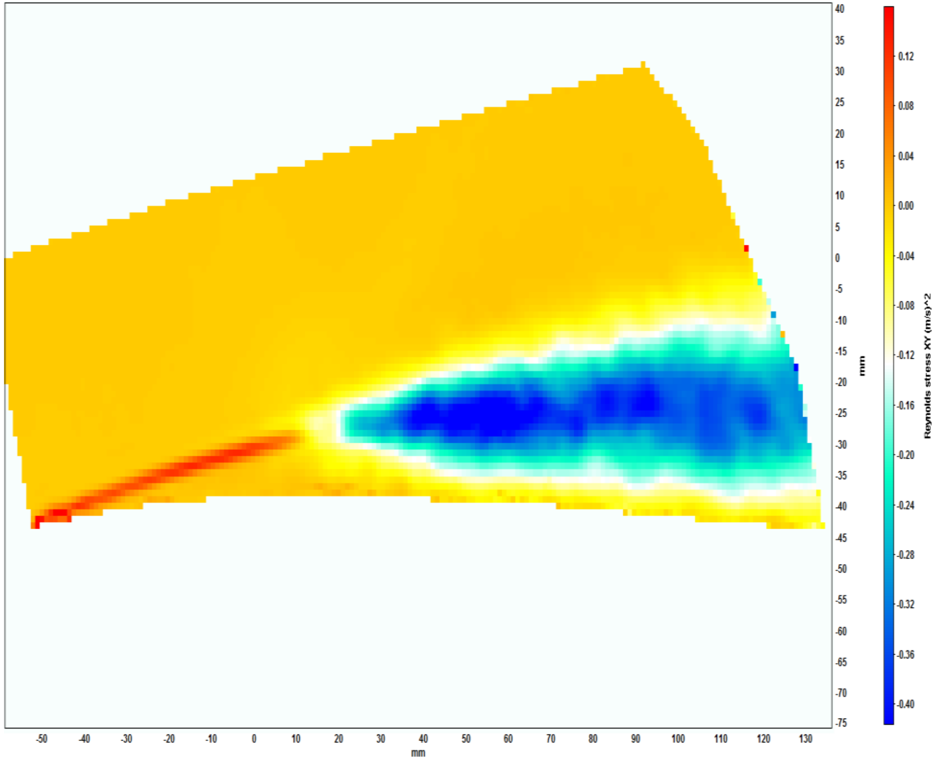




The Reynolds shear stress

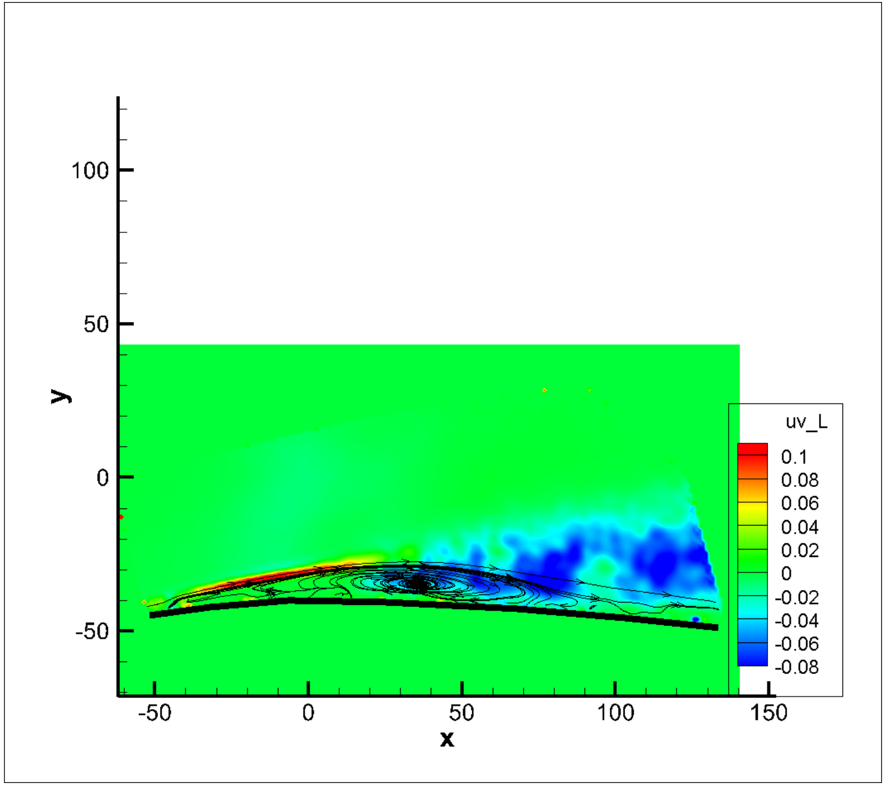
Indicative of Negative production of TKE in LSBs

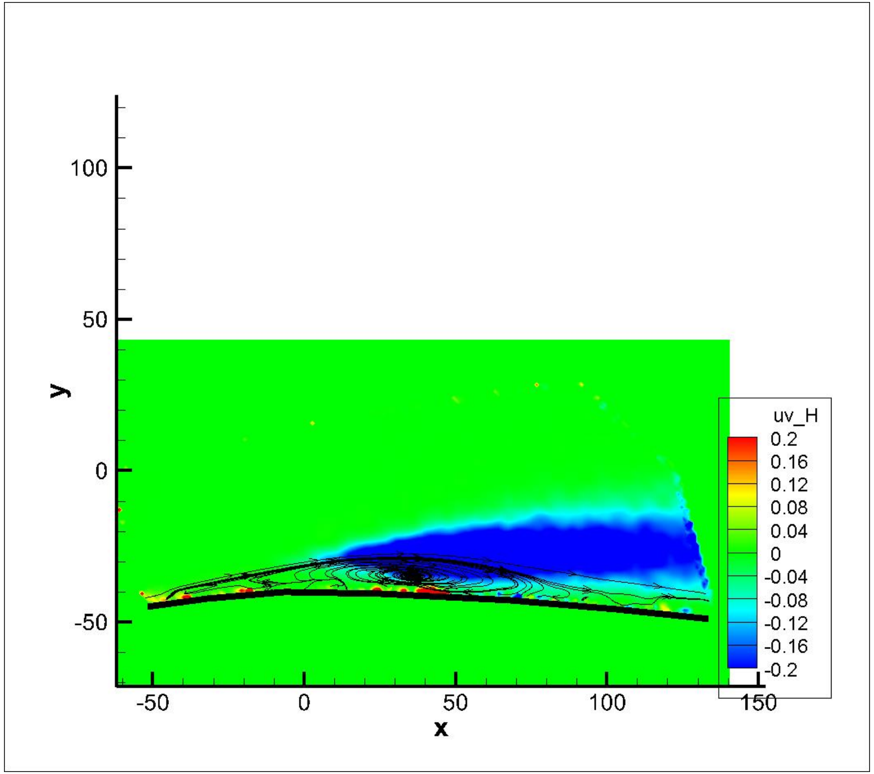




Reynolds shear stress

High and low frequency components[TRANS]



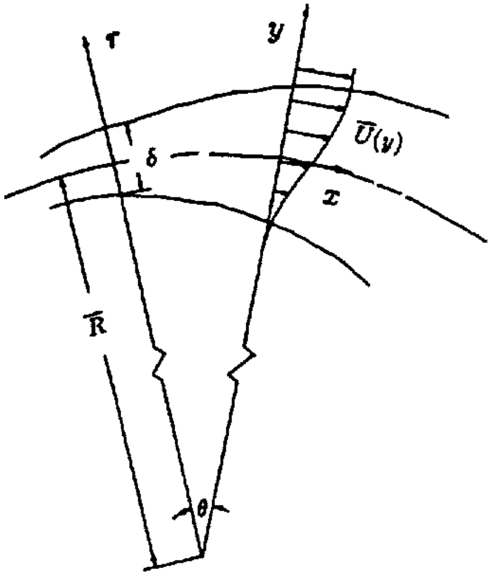


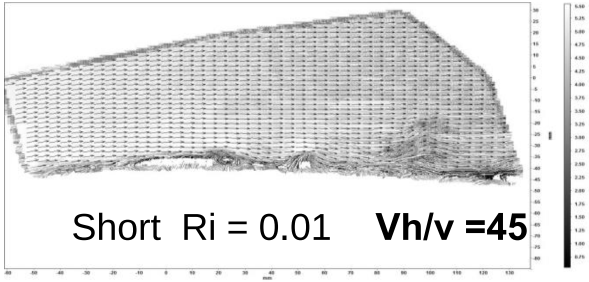
Stability of Curved Shear Layers

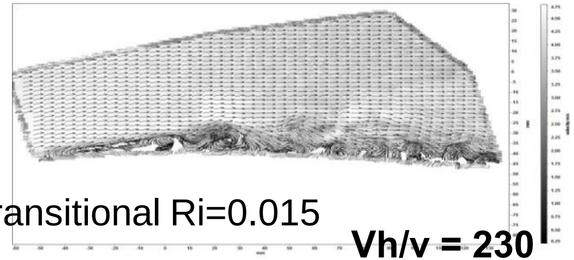
Curvature Richardson Number

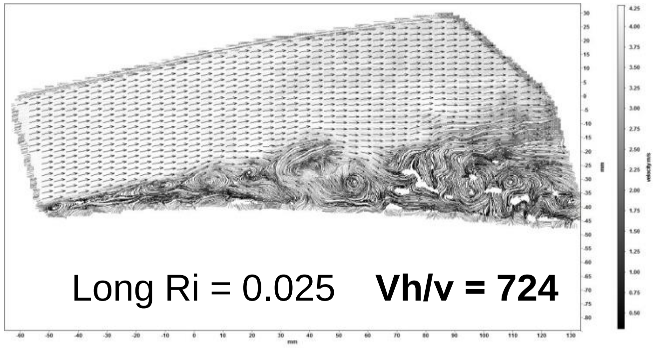
$$Ri = \frac{2U / R}{\left(\frac{dU}{dy} + \frac{U}{R}\right)}$$

Liu (PoF 1993)
If Ri > 0 curvature stabilising
If Ri < 0 curvature destabilising




Short Ri = 0.01 **Vh/v =45**


Transitional Ri=0.015 **Vh/v = 230**


Long Ri = 0.025 **Vh/v = 724**

Summary

- Laminar Separation Bubble Bursting Characterised by a single Parameter
- Connection of Bursting to a switch from convective to absolute instability explored
- Oscillator behaviour (Absolute Instability) and Amplifier Behaviour (Convective Instability) [resent in all three cases in varying measures. Time Sharing
- Longish Bubbles associated with Negative Production of Kinetic Energy and hence bubble finds difficult to reattach (a runaway effect)