AE-705: Introduction to Flight

Viscous Flow, Reynolds Number
&
Boundary Layers

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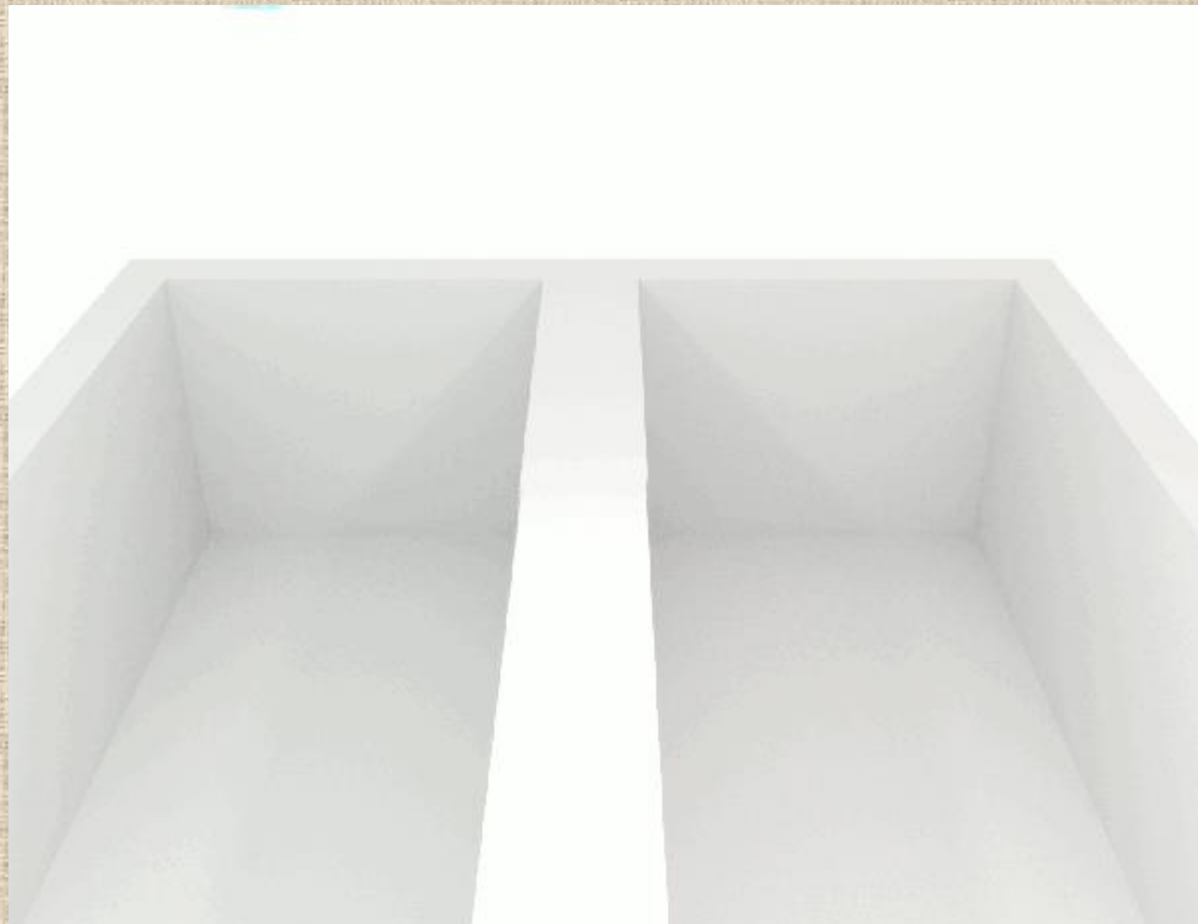
CONTENTS

Lets start with a simple experiment


THICK & THIN

?



https://en.wikipedia.org/wiki/Viscosity#/media/File:Viscosities.gif

Which one is thicker ??

Viscosity

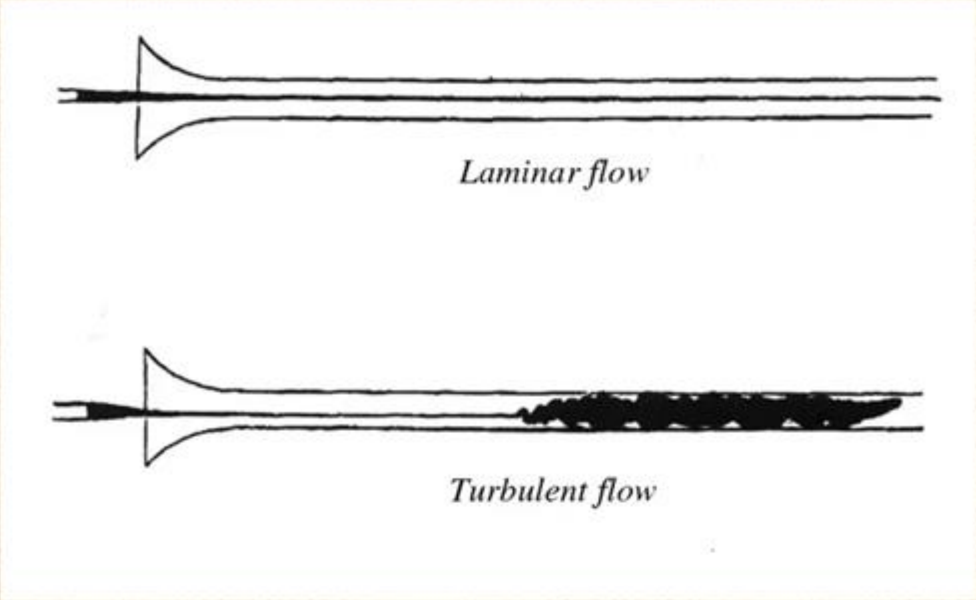
- Resistance to relative motion (friction???)
- Thicker ➔ Higher Viscosity
- Higher Viscosity ➔ [Lower flow rate]

- Are gases viscous too??

Well, Good to know about viscosity! Let us calculate the pressure using Bernoulli's principle

Oye! Go and read my assumptions

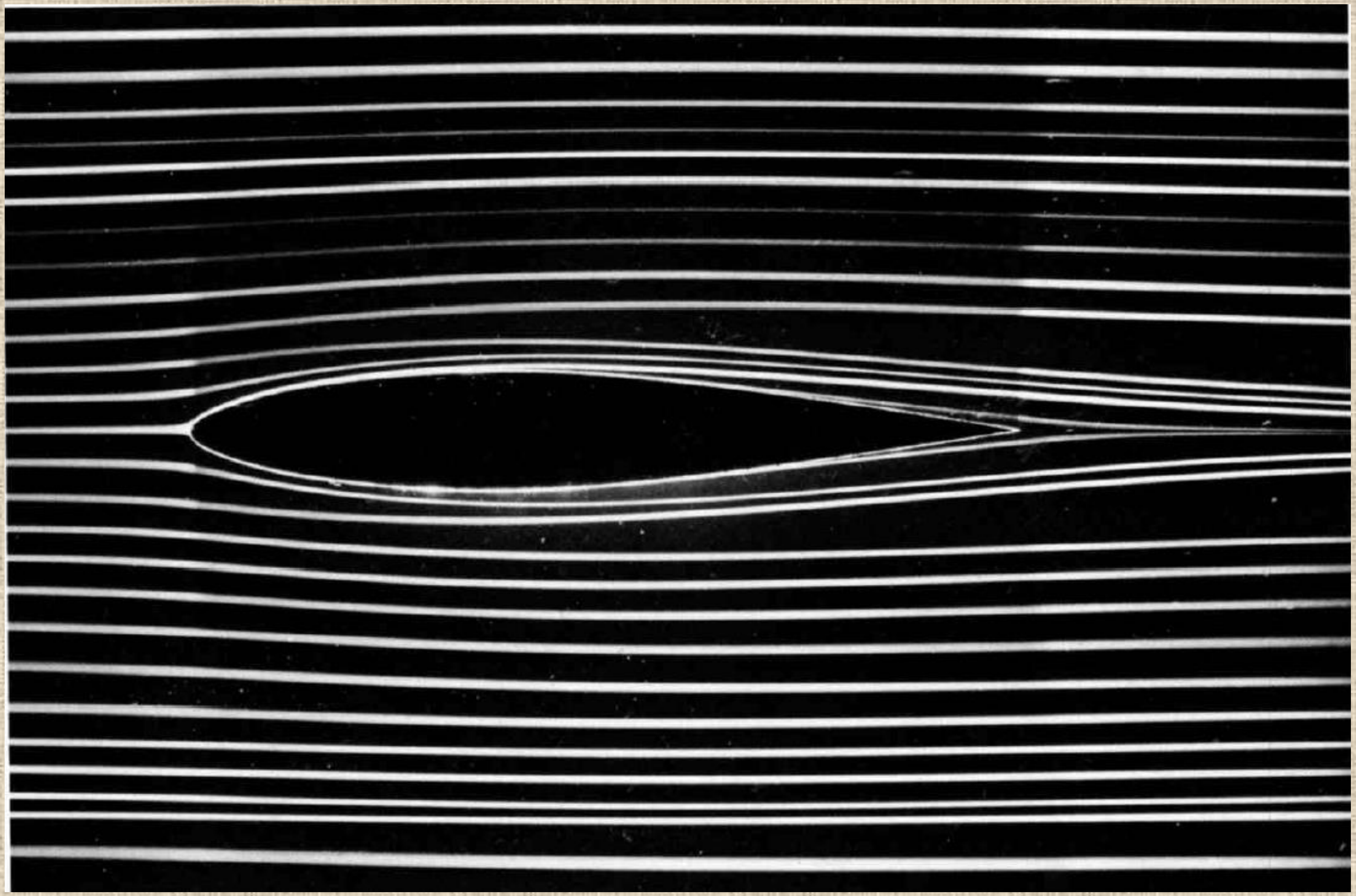
Flow in a pipe



https://www.quora.com/What-is-a-fully-developed-laminar-and-turbulent-flow

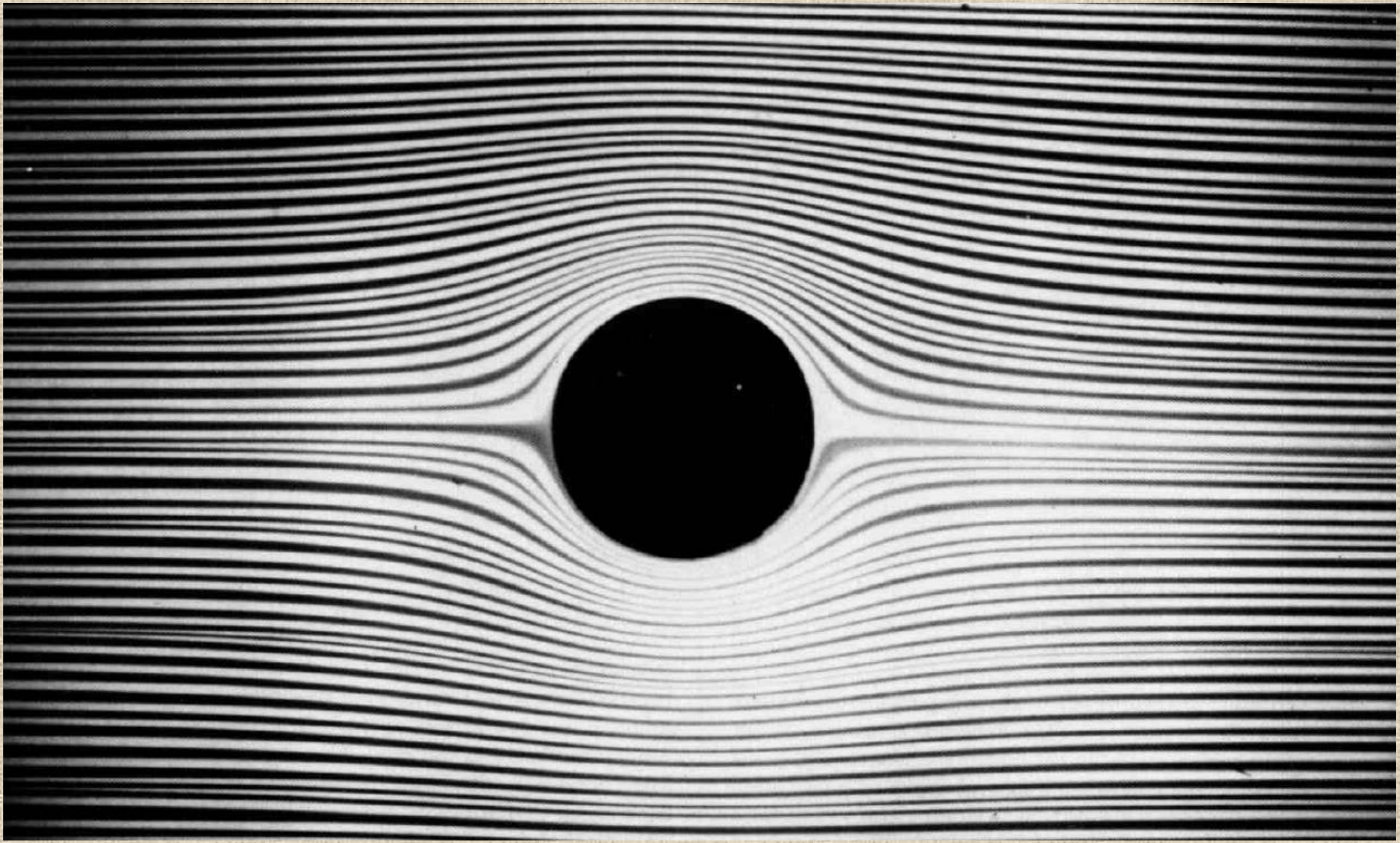
What about external flows? Can we have Laminar flow over aeroplane wings?

Laminar flow over a wing cross section



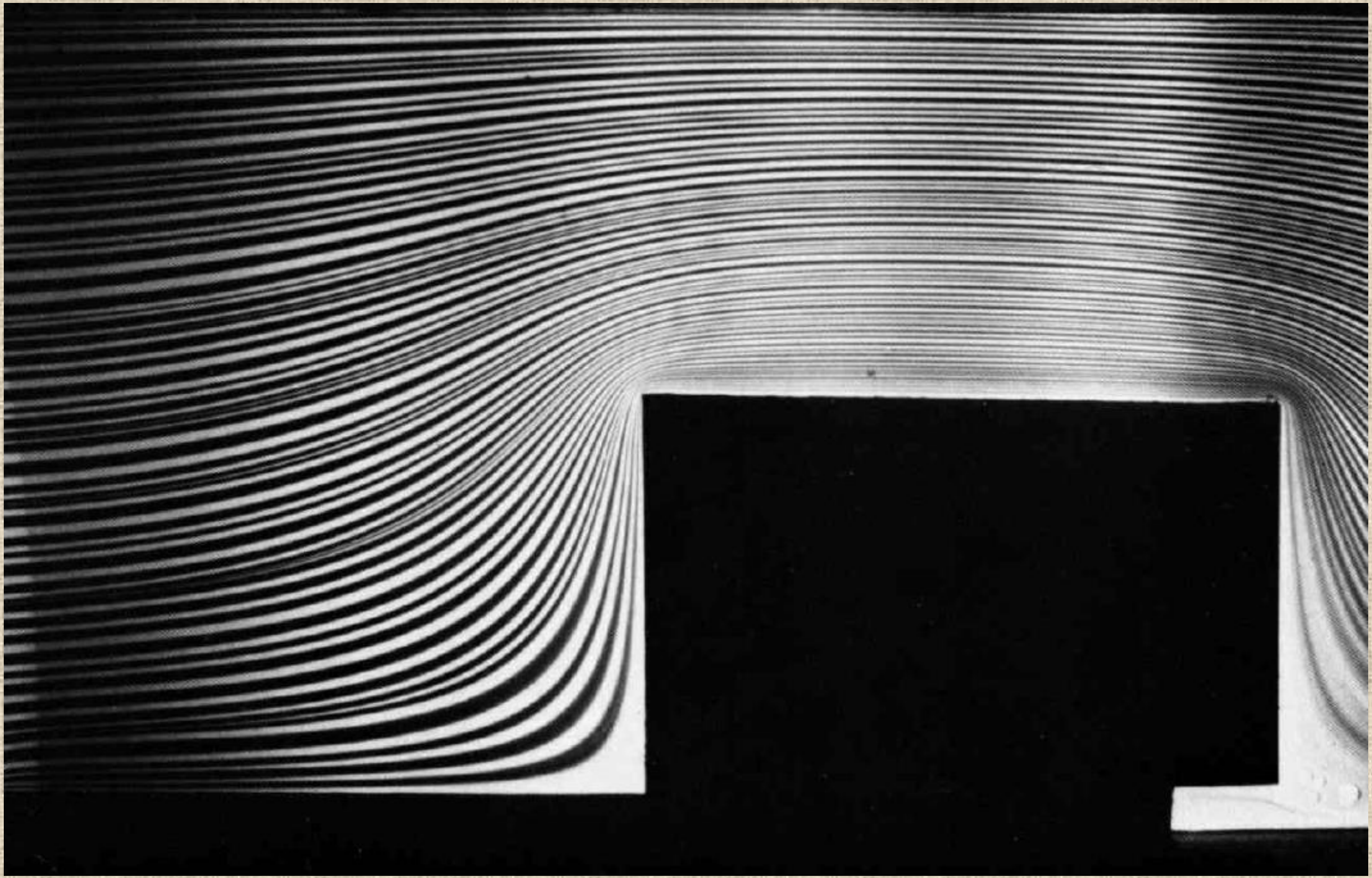
Source : **

Laminar flow over cylinder



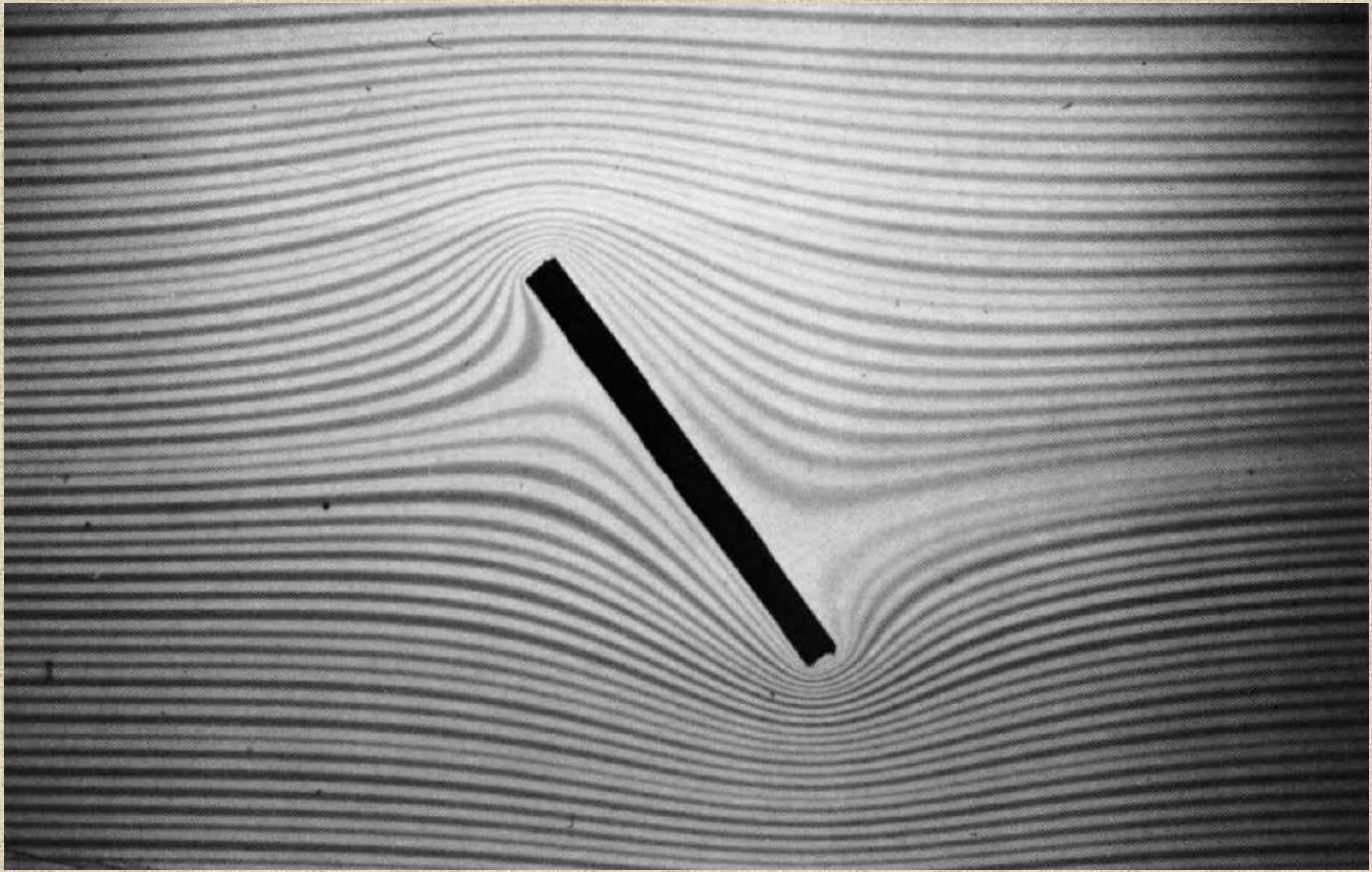
Source : **

Laminar flow over a rectangular block



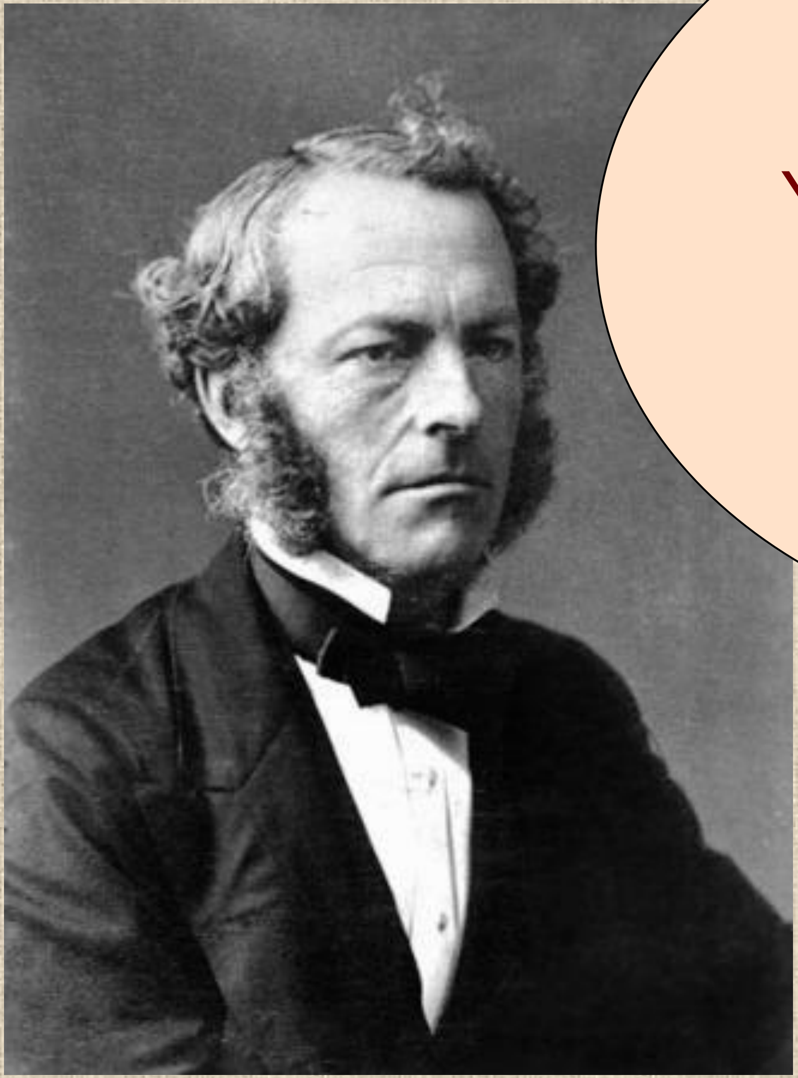
Source : **

Laminar flow over a flat plate



Source : **

Can we predict when would a Laminar flow becomes Turbulent?



I have made some efforts to study this. You will learn most of my theories later !!

Who am I ?

A Short Quiz

Who is this famous scientist?

a) Ludwig Prandtl

b) George Gabriel Stokes

c) Osborne Reynolds

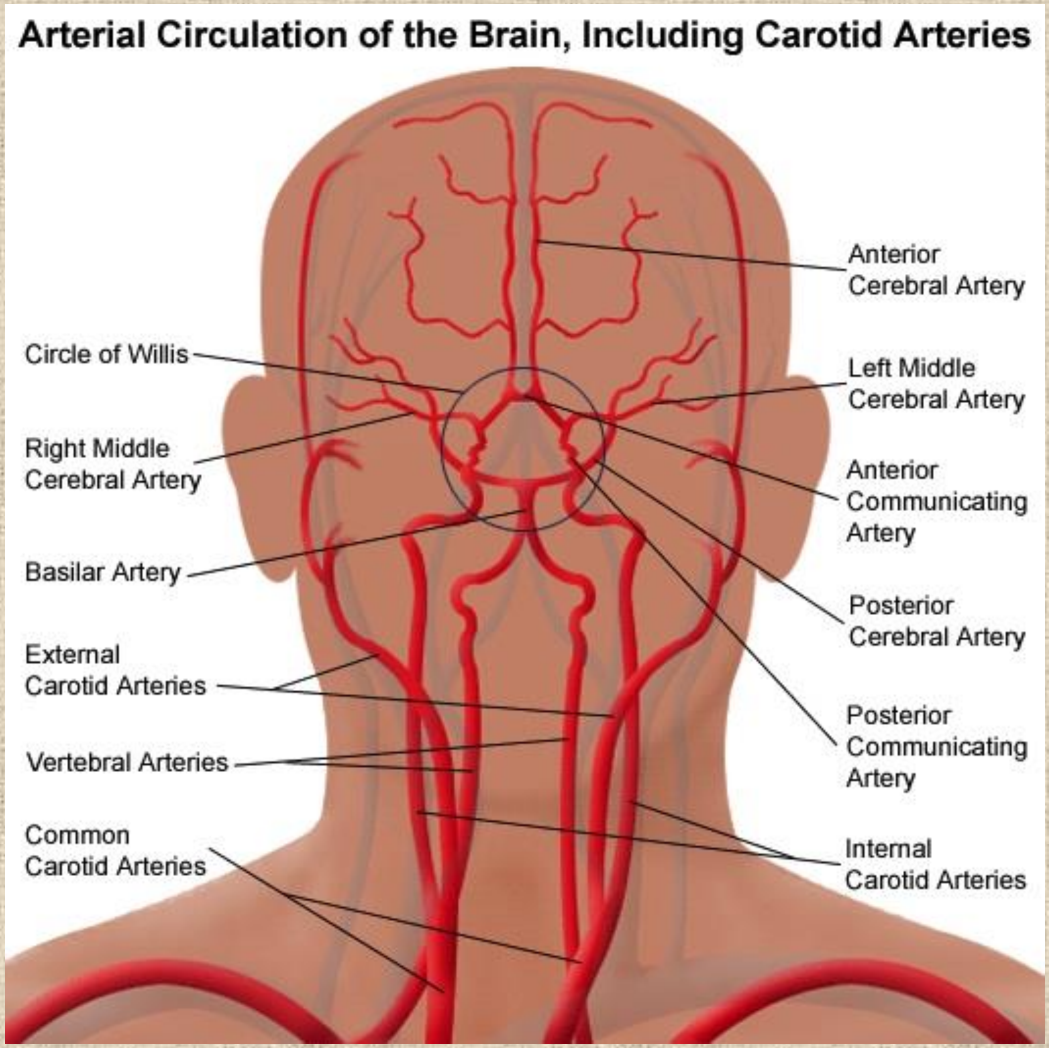
d) Arnold Sommerfeld

Can you answer ?

https://en.wikipedia.org/wiki/Sir_George_Stokes,_1st_Baronet#/media/File:Ggstokes.jpg

Reynolds Number:

- Re No = $\dfrac{\text{Inertial force}}{\text{Viscous force}} = \dfrac{\rho V L}{\mu}$
- Transition Re No → Critical Reynolds No
- Critical Re No for Internal flow → 3000 - 5000
- For external flow → 300000 – 500000
- Best measure to compare flows
- Re No ↑ Laminar nature ↓



http://www.neuroems.com/2014/03/15/blood-flow-through-the-brain-pt-1-overview/

Re No : 100

Re No ~ 4 million

https://breakingmuscle.com/fitness/7-essential-swimming-tips-for-even-the-strongest-athletes

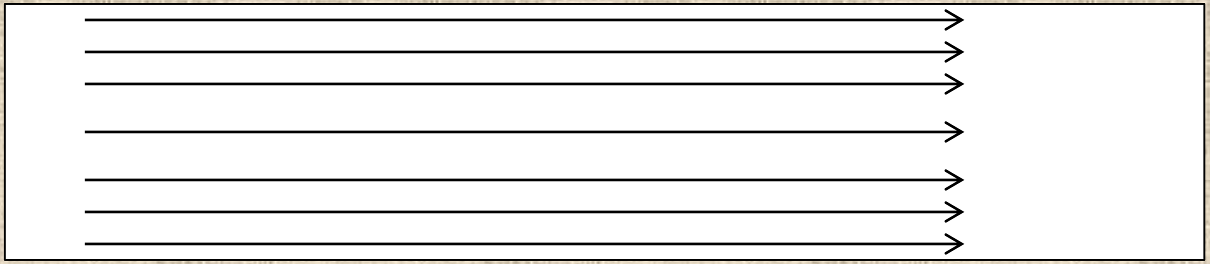
Re No ~ 10^9

http://www.cruisecritic.co.uk/news/news.cfm?ID=7096

Can you name this Ship ?

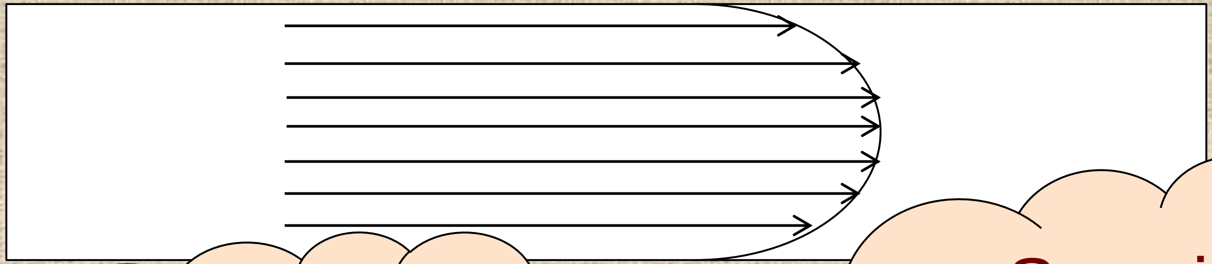
What happens when Re No is 2900 in a pipe? Will it be purely Laminar?

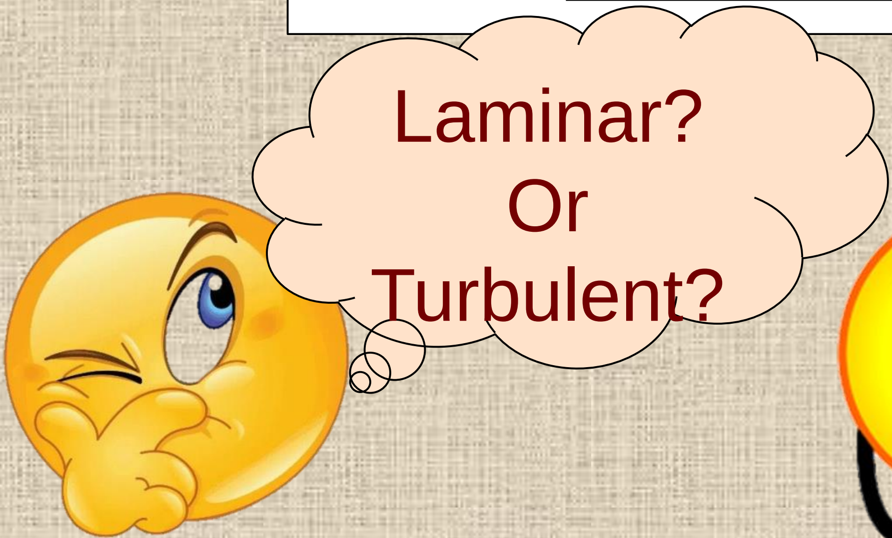
We usually compare the order of magnitude

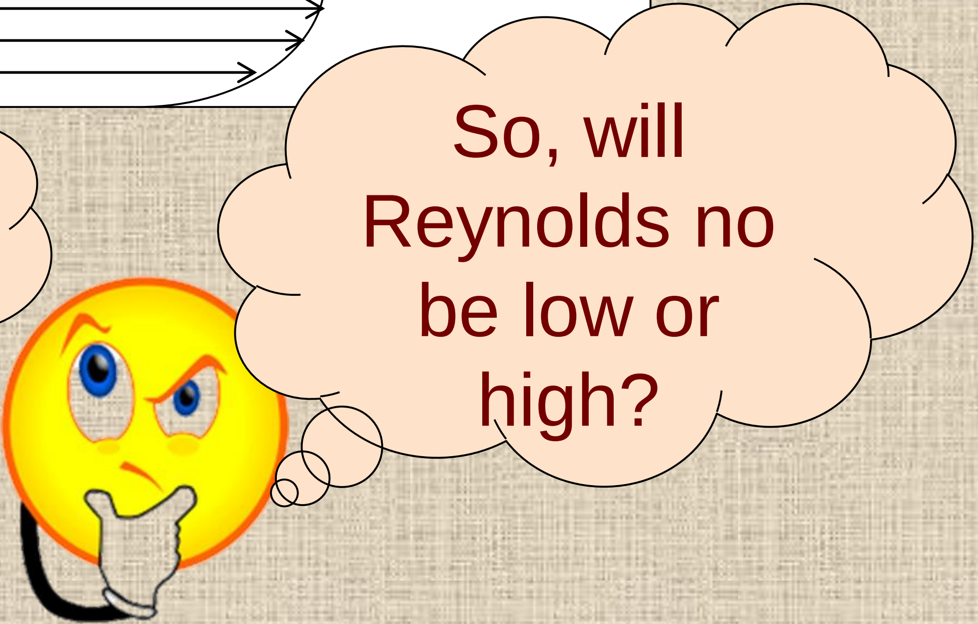


This is non-viscous flow in a pipe

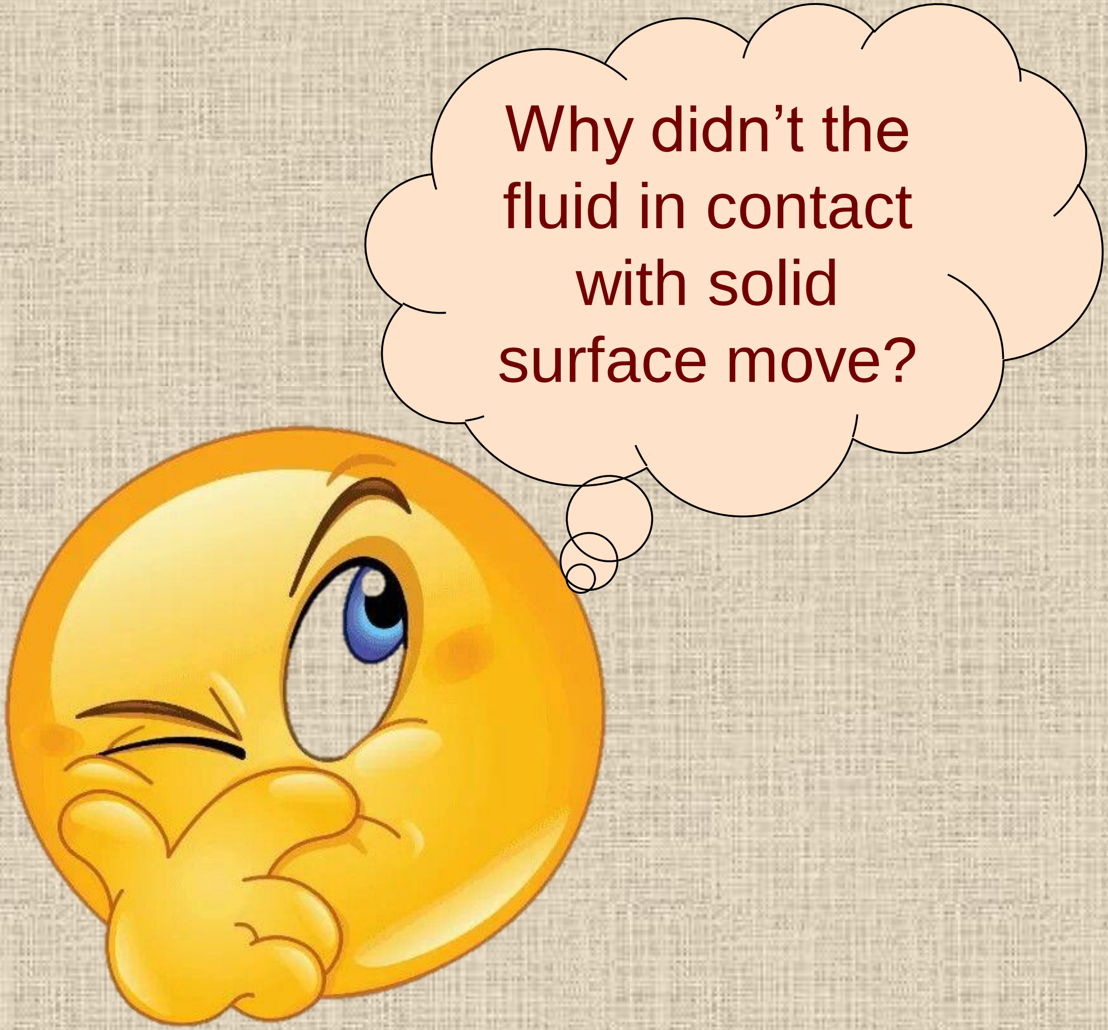
What would be the case with viscosity?



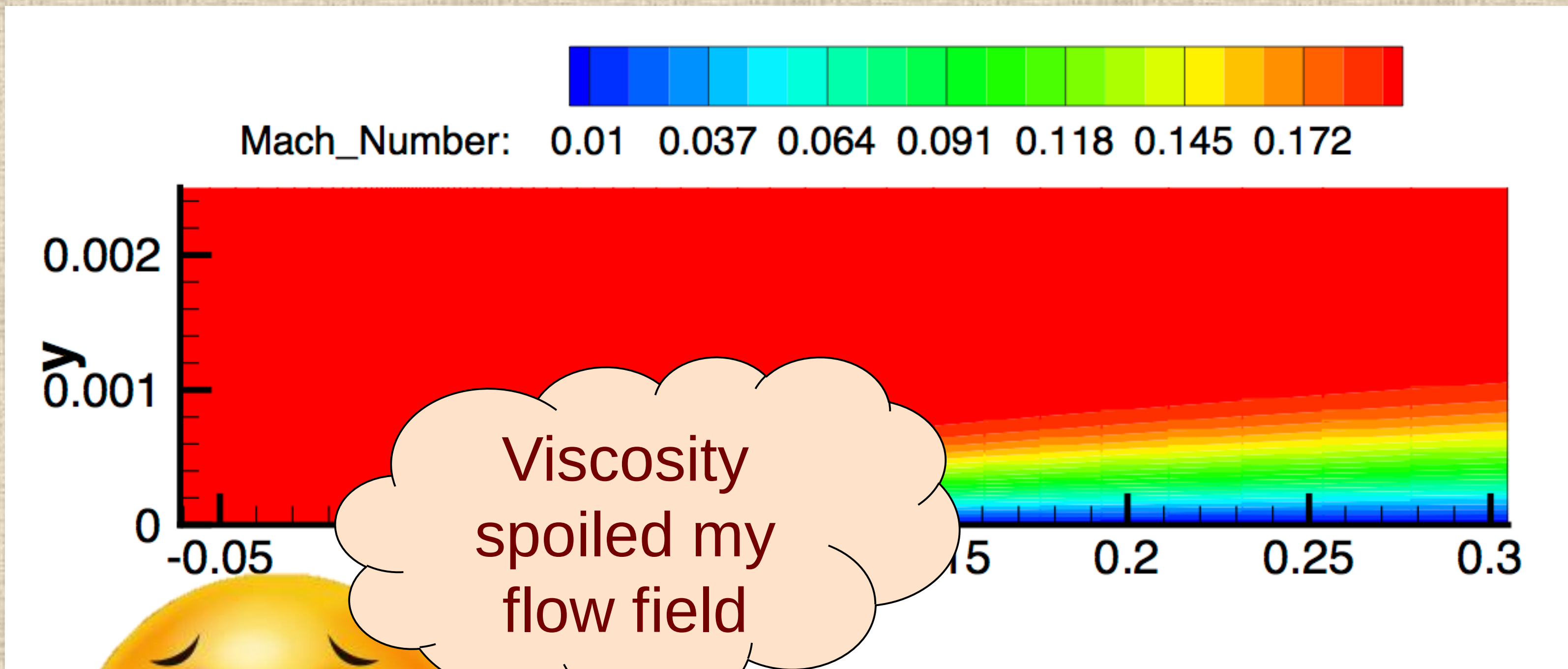




Viscous flow over a solid surface

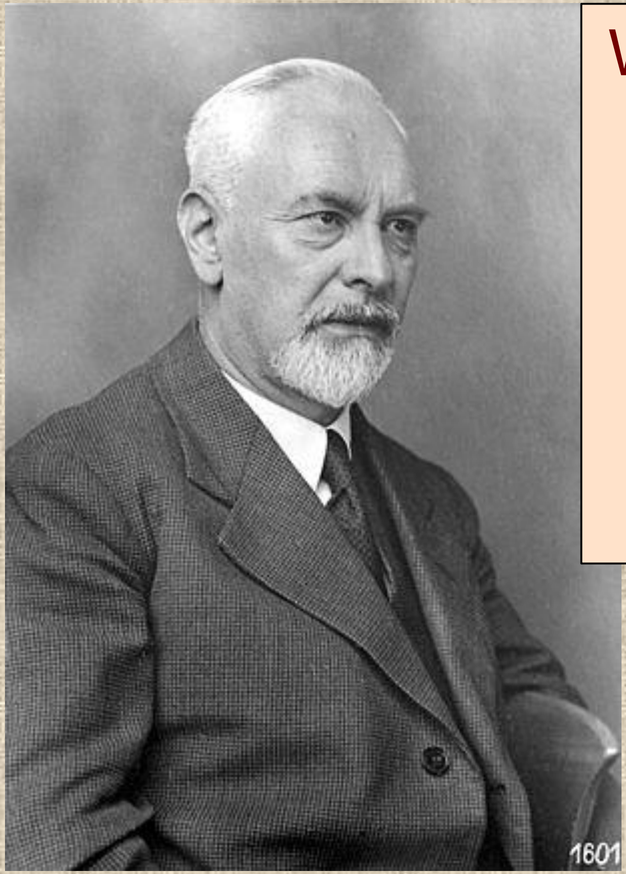


Viscous flow over [flat plate]



Viscosity spoiled my flow field

htt… github… /su… de/SU2/wiki/Laminar-Flat-Plate



https://en.wikipedia.org/wiki/Boundary_layer

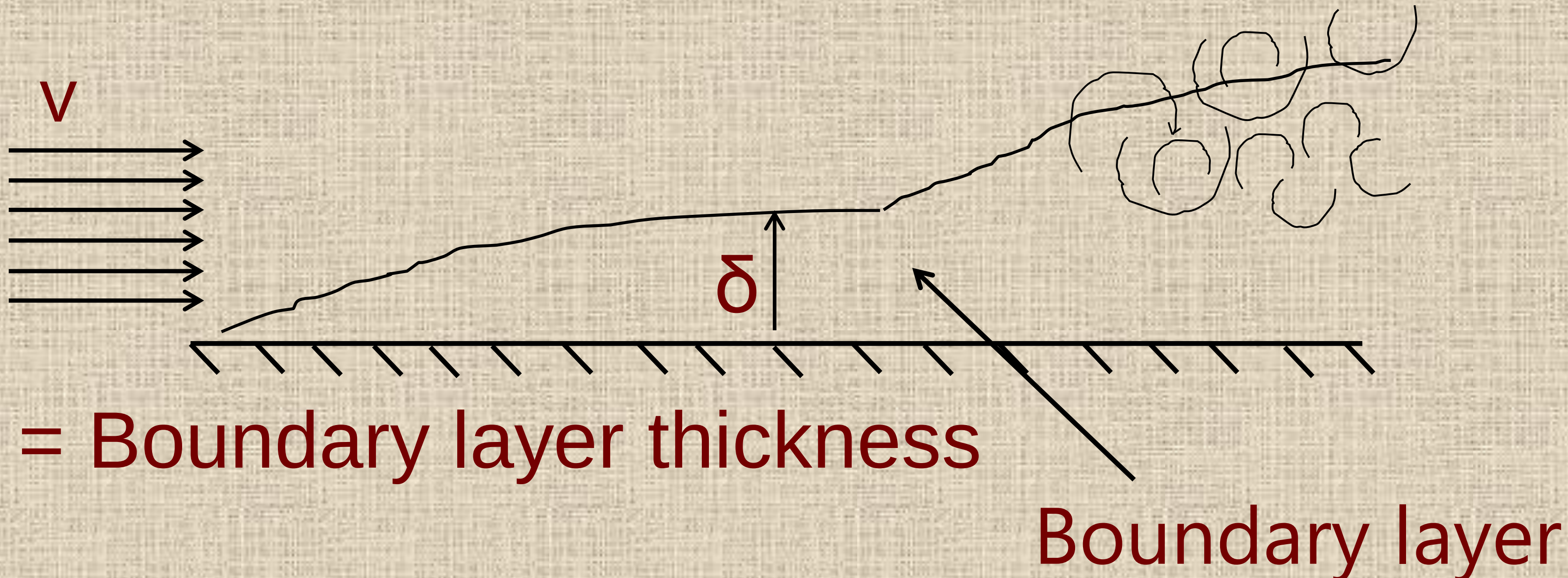
Why don’t you split the domain in 2 regions ?

One where viscous effects are significant

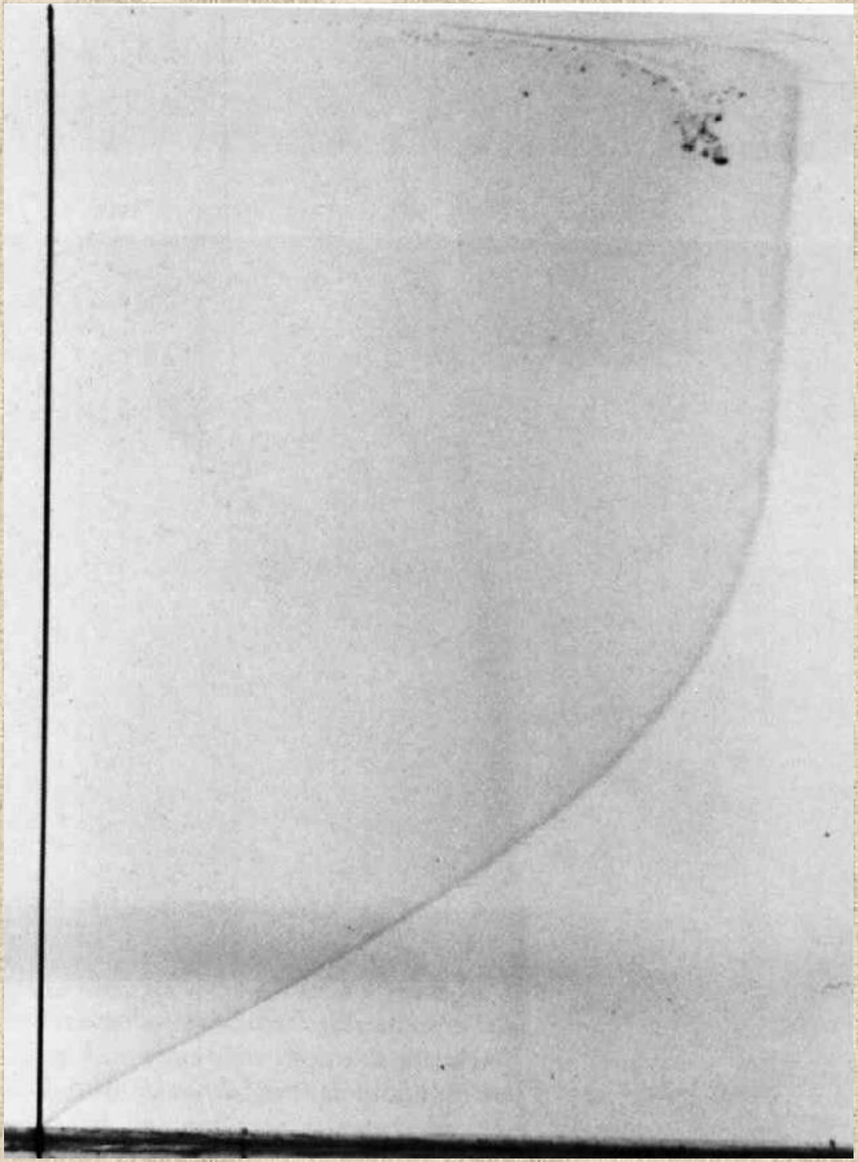
Another with negligible viscous effects?

Boundary Layer

- First defined by the Father of Aerodynamics
- Edge of BL – 99% of Freestream velocity

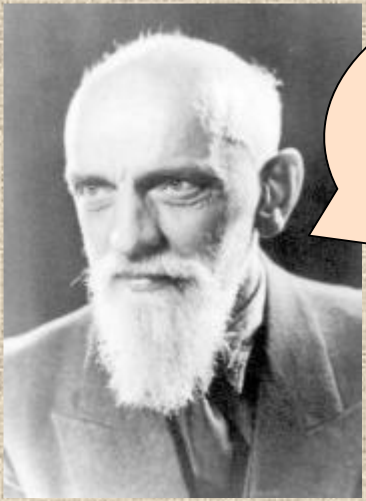


δ = Boundary layer thickness

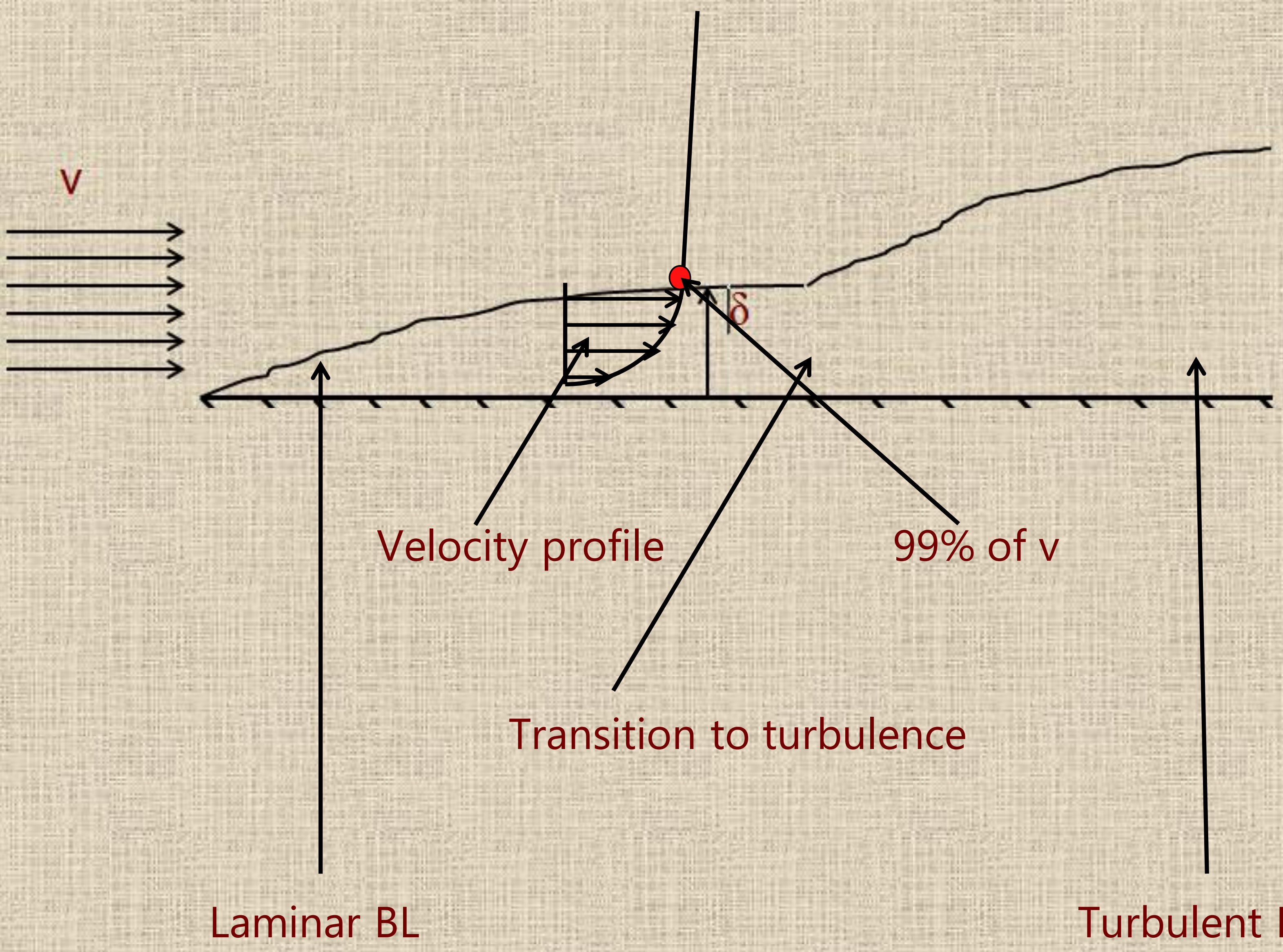


Source **

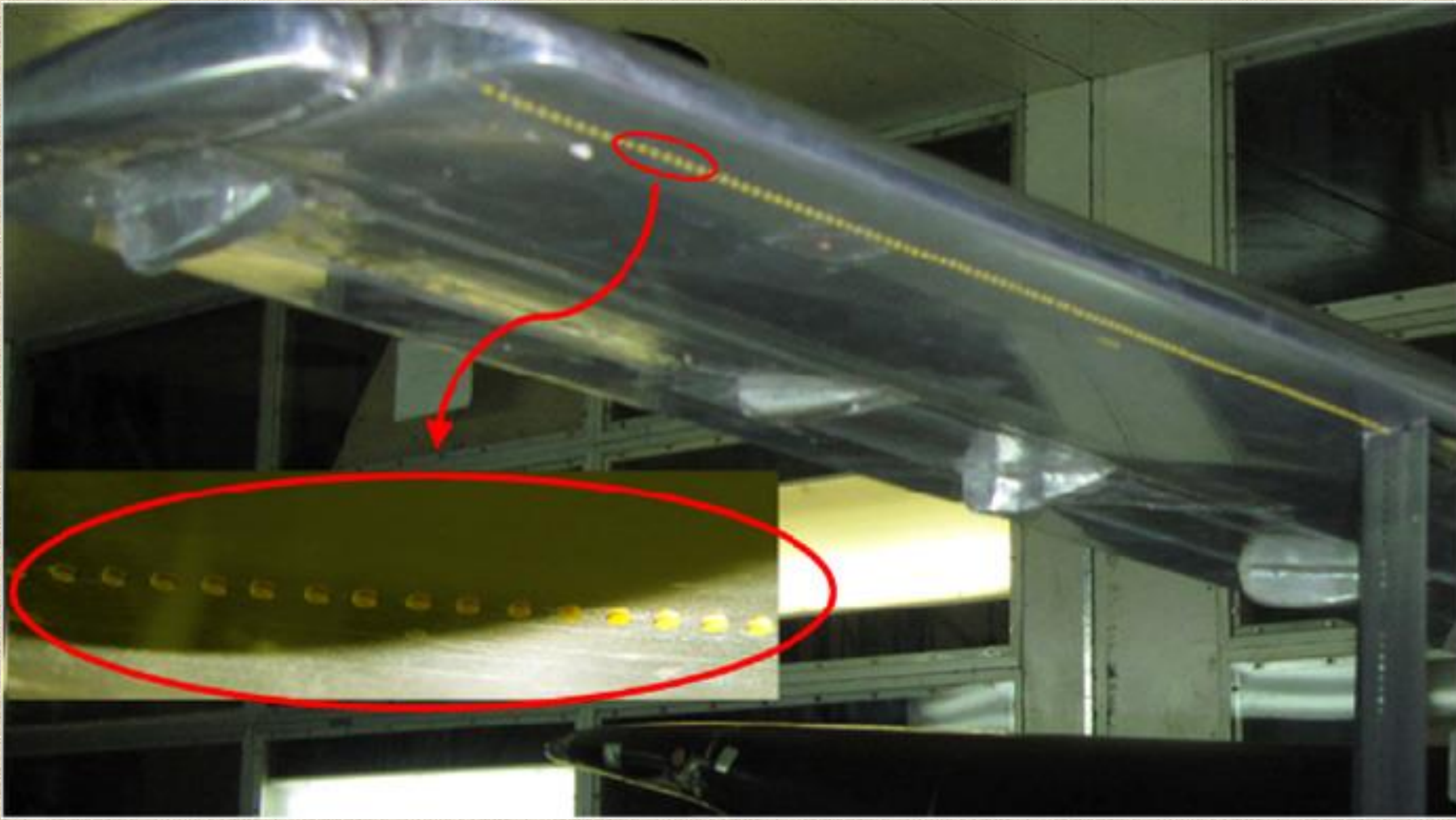
I observed
it first !
Who am I ?



I formulated
it first !
Who am I ?


v
δ
Velocity profile
99% of v
Transition to turbulence
Laminar BL
Turbulent BL

Transition Strips in WT Testing



M Mirzaei, MH Karimi, MA Vaziri, An investigation of a tactical cargo aircraft aft body drag reduction based on CFD analysis and wind tunnel tests, Aerospace Science and Technology, 2012

Transition Strips in WT Testing

with 2 degrees increments. The experiments were performed at a Mach number of 0.2 that covers dominant phases of the real flight conditions. Regarding to scaling of the models, Reynolds numbers of the aircraft and the models were not similar. In fact, Reynolds number (based on wing main chord length) of the test cases was 1.2 × 106 whereas the flight Reynolds number was 13 × 106. Since the dependency of the drag coefficient on the Reynolds number in a fully turbulent flow is weak, this difference does not influence the accuracy of the test results. The location of the transition region has essential effects on the drag coefficient. This location was controlled using trip strips at the wing leading edge (10% of chord) and at the nose (50% of maximum diameter of the body). The size of the trip strips was 0.0101 inch in height. Fig. 4 shows the position of the trip strips on the leading edge of the wing.

M Mirzaei, MH Karimi, MA Vaziri, An investigation of a tactical cargo aircraft aft body drag reduction based on CFD analysis and wind tunnel tests, Aerospace Science and Technology, 2012

Sometimes, transition strips don't work !

XL Wang, GY Fu, DP Duan, XX Shan, Experimental Investigations on Aerodynamic Characteristics of the ZHIYUAN-1 Airship, Technical Note, Journal of Aircraft, 2010,

Experiment v/s Numerical Simulation

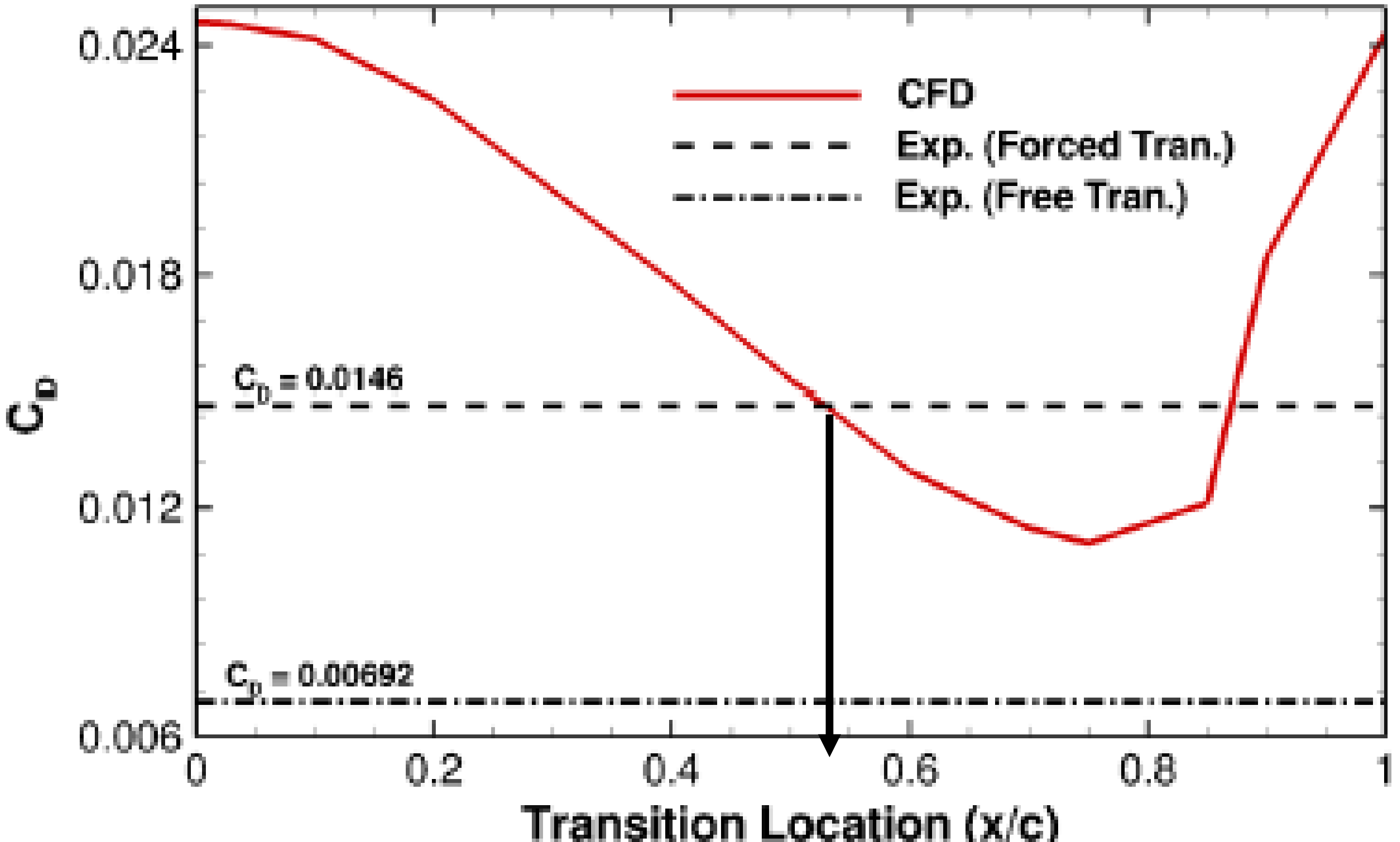
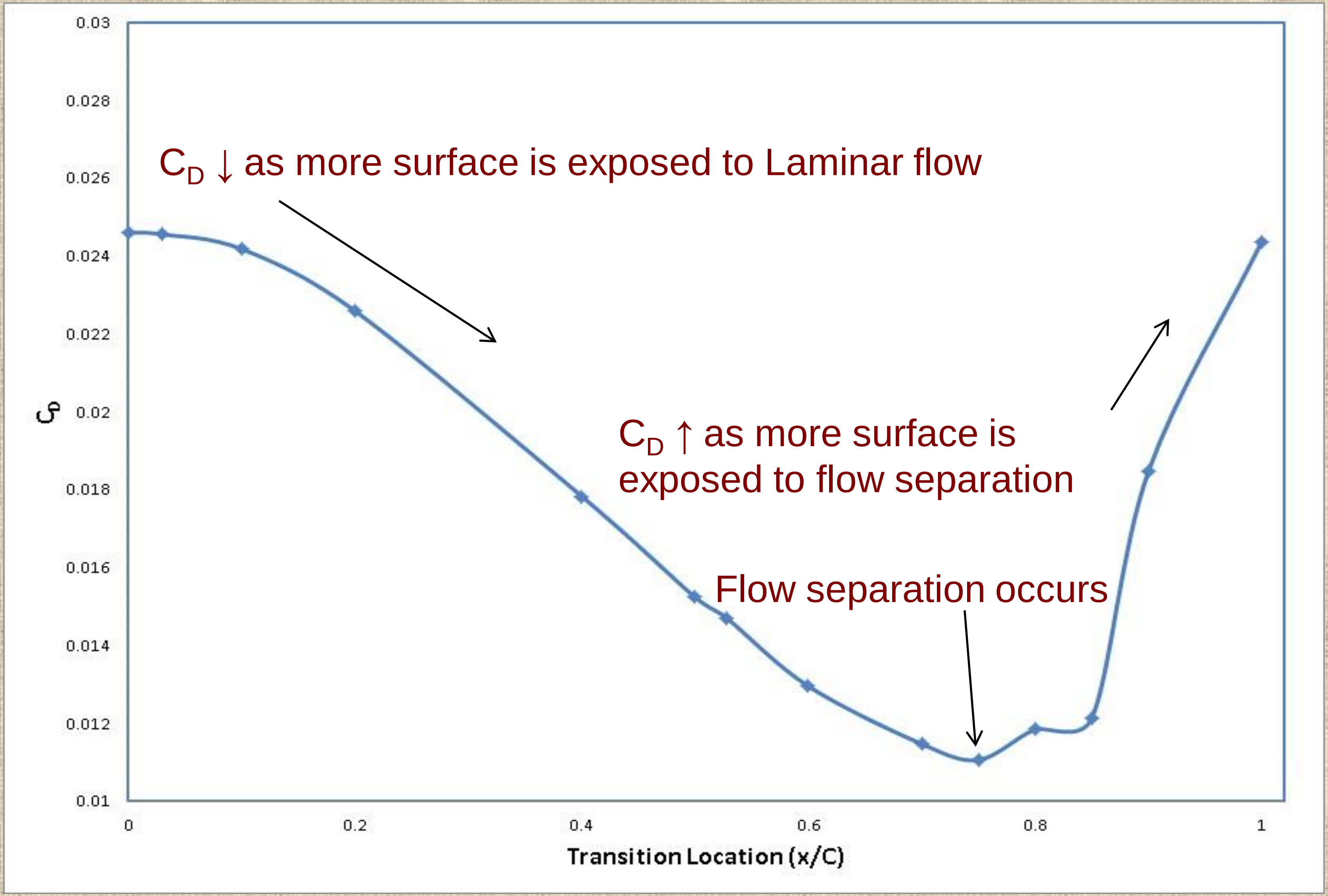


Fig. 3 Variation in the computed drag coefficient at zero angle of attack in RANS simulations with different x/c.

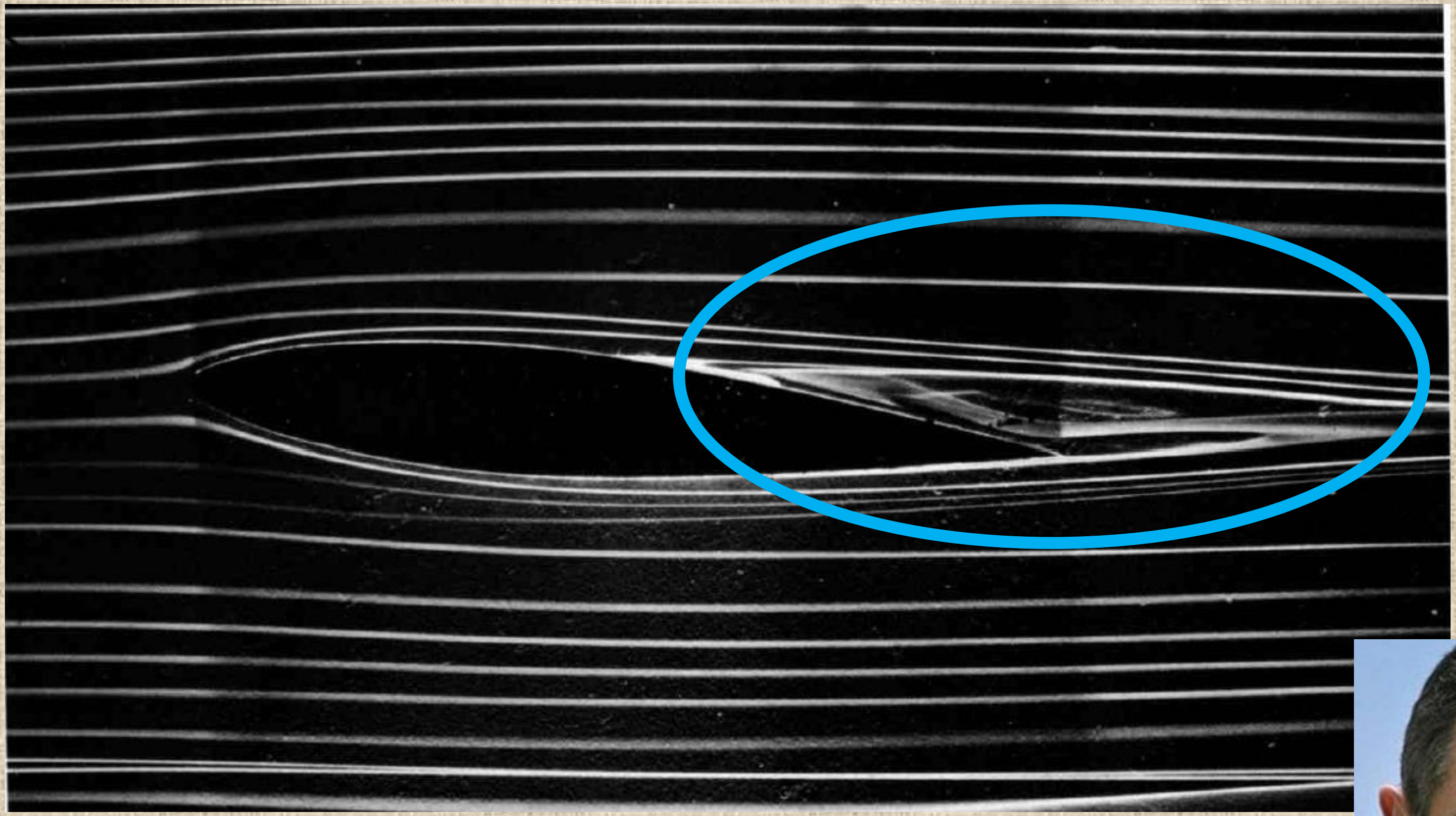
S. Suman, S. Lakshmipathy, R. S. Pant, Evaluation of the assumed-transition-point criterion in context of RANS simulations around Lighter-Than-Air vehicles, Journal of Aircraft, **50**(2), 2013

Effect of Transition Location



S. Suman, S. Lakshmipathy, R. S. Pant, Evaluation of the assumed-transition-point criterion in context of RANS simulations around Lighter-Than-Air vehicles, Journal of Aircraft, **50**(2), 2013

Real flow field



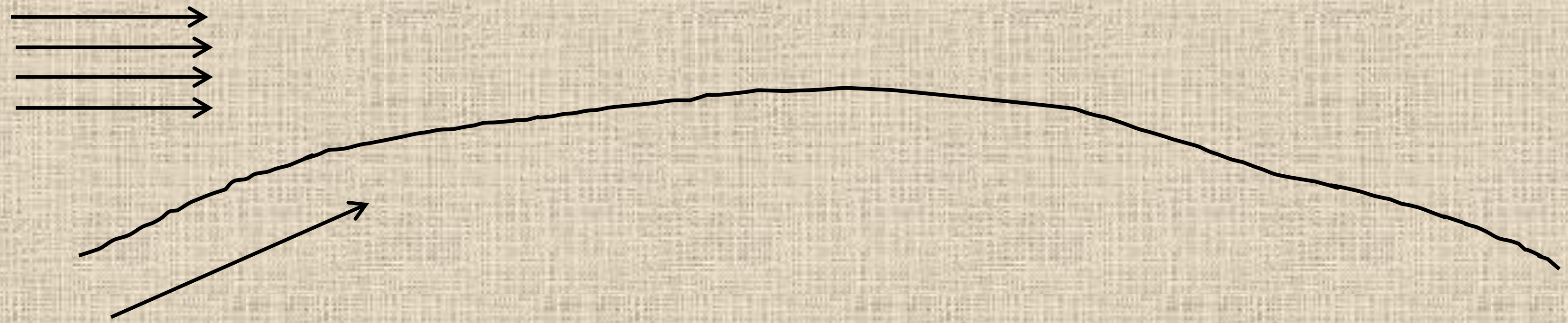
Source **

Video source : NIT Suratkal

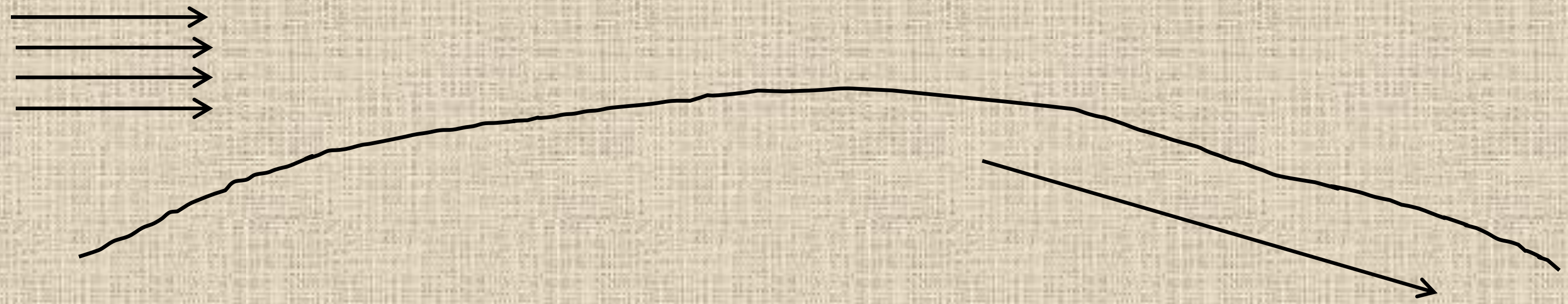
?

Flow separation

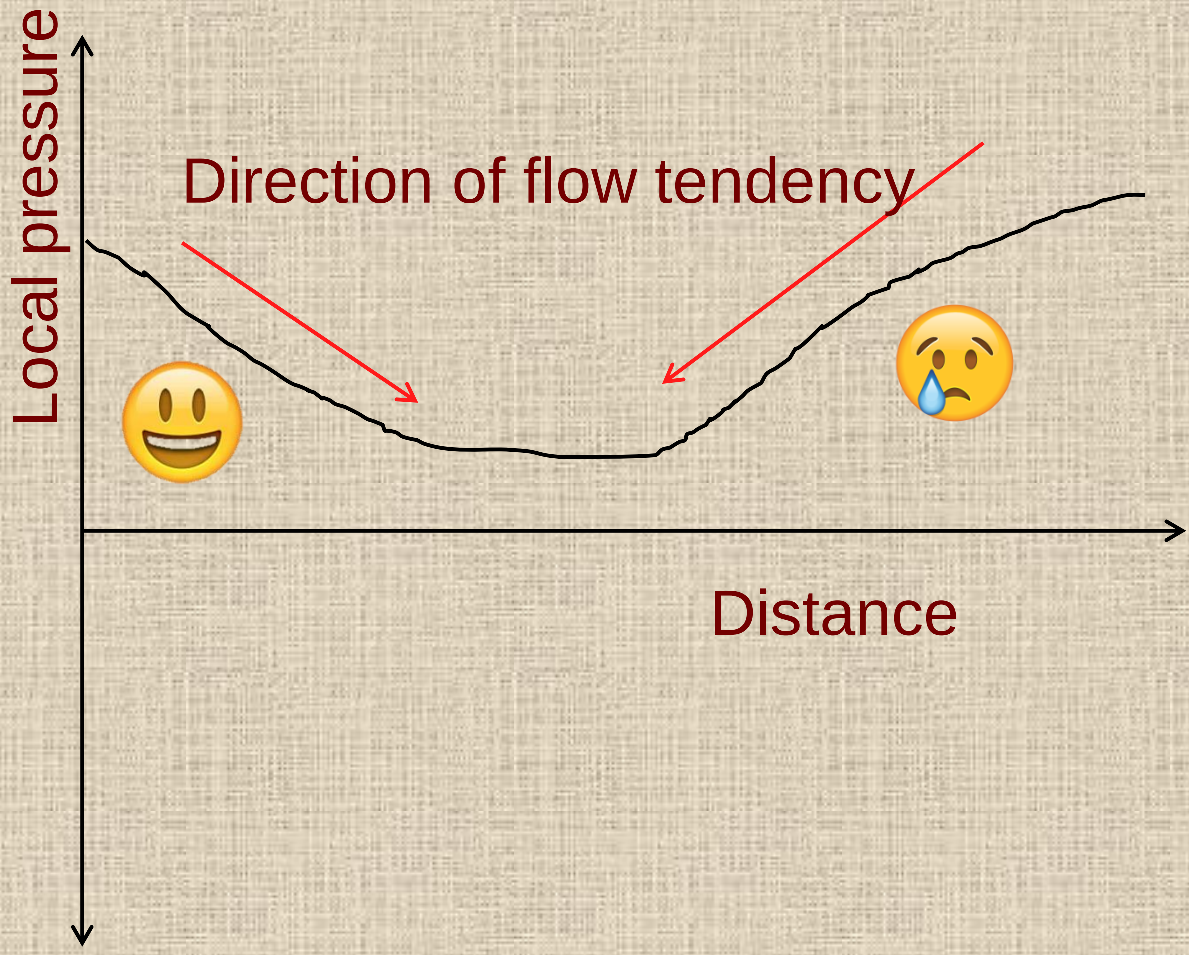
- ❑ Viscous flow phenomenon
- ❑ “Adverse pressure gradient” ?

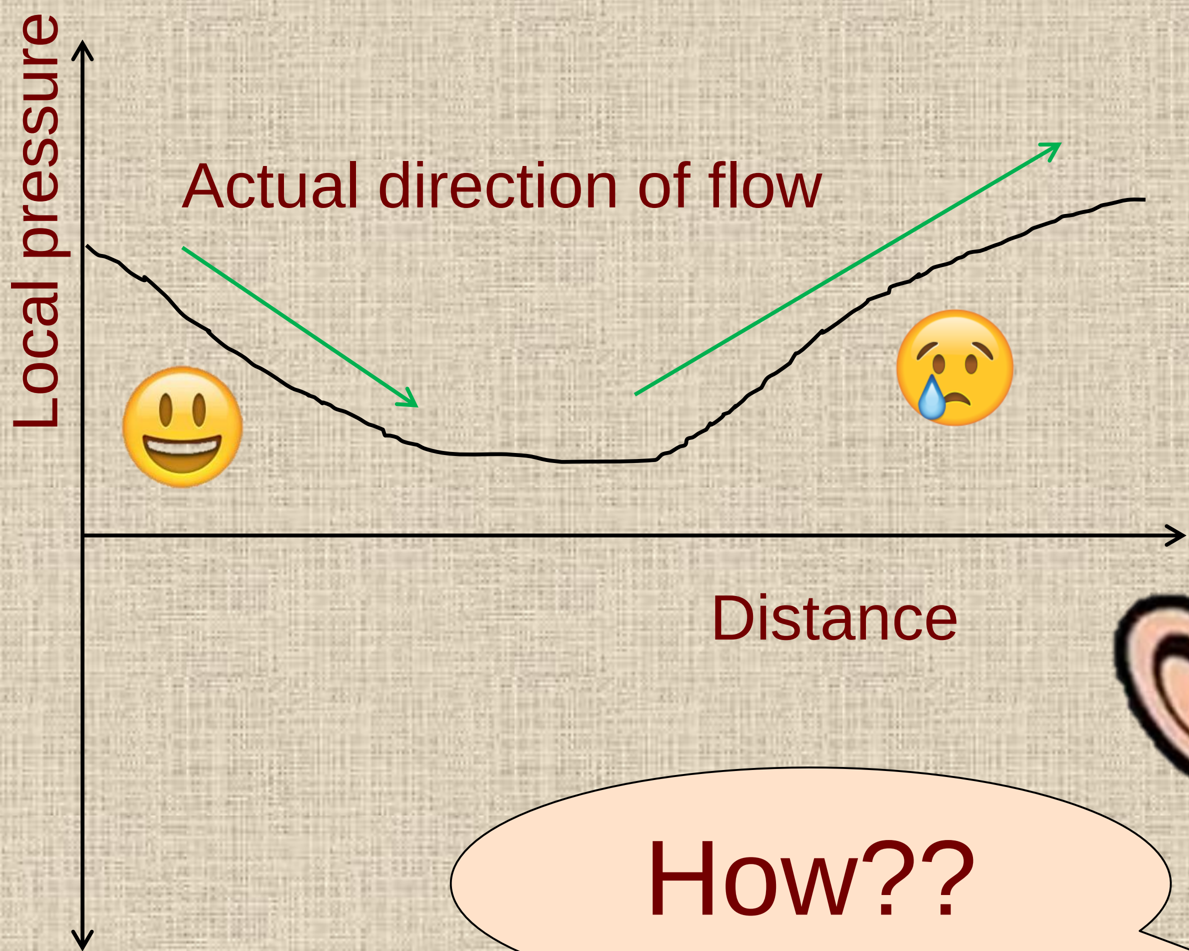


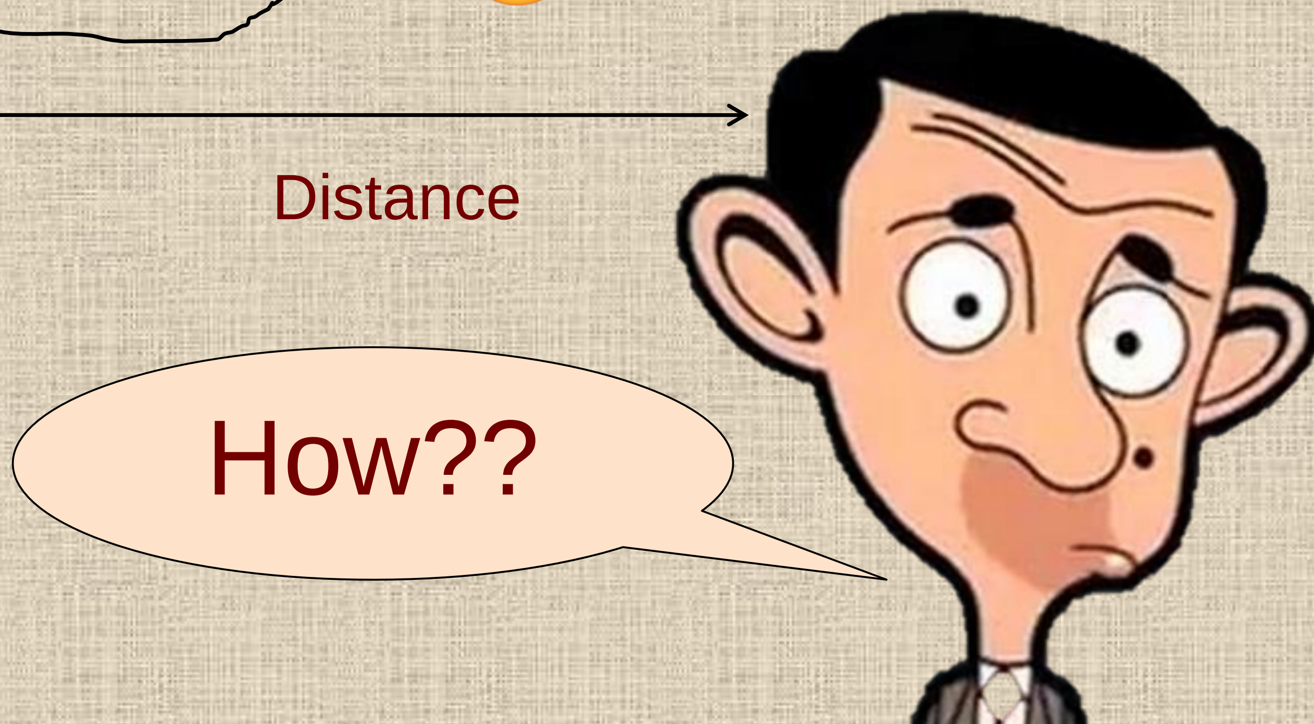
Pressure decreases → favourable pressure gradient



Pressure increases → unfavourable pressure gradient


Local pressure
Direction of flow tendency
Distance


Local pressure
Actual direction of flow
Distance


How??

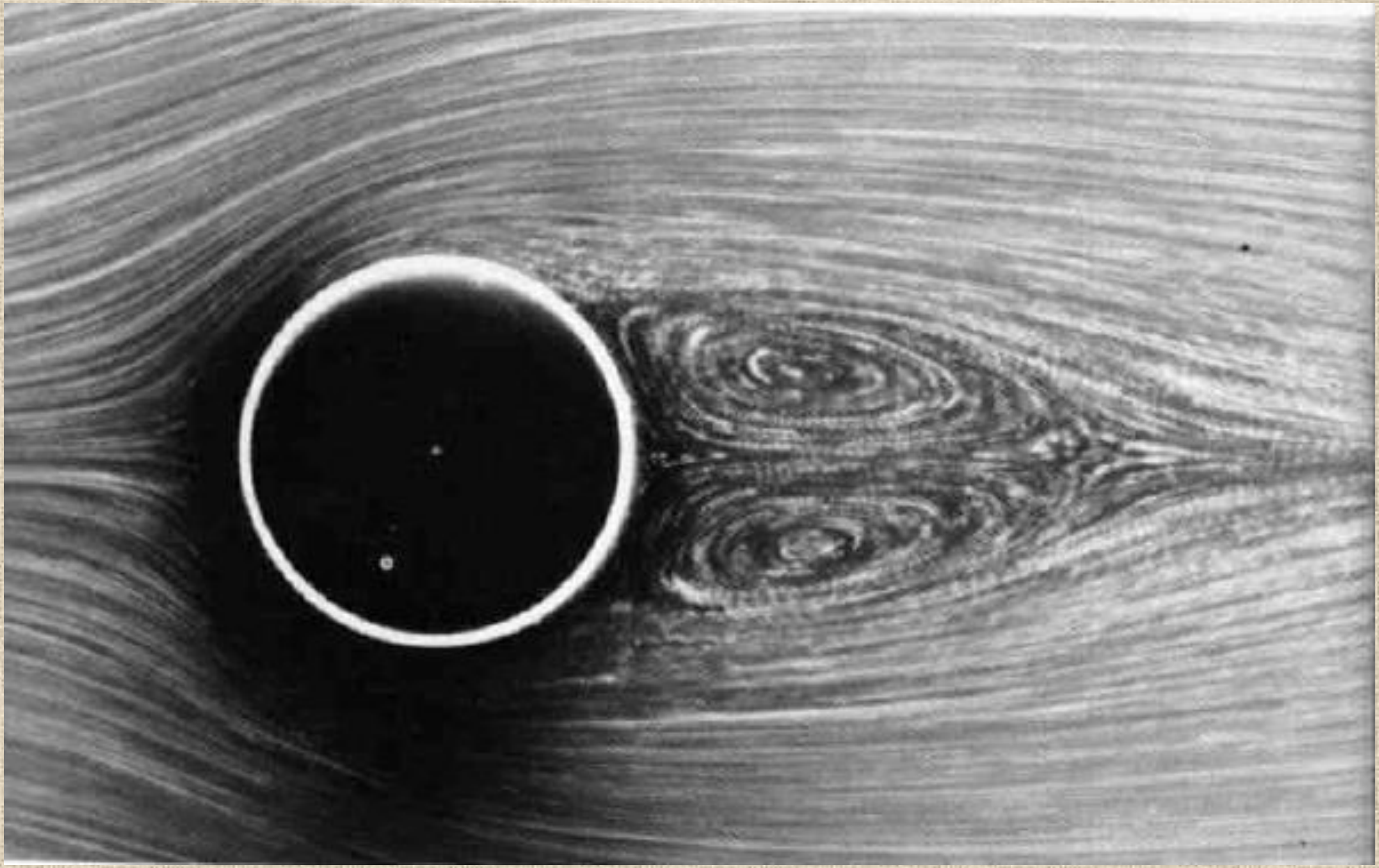
Because flow has momentum which drives the flow against pressure gradient

But flow near the solid surface already lost most of its momentum!!

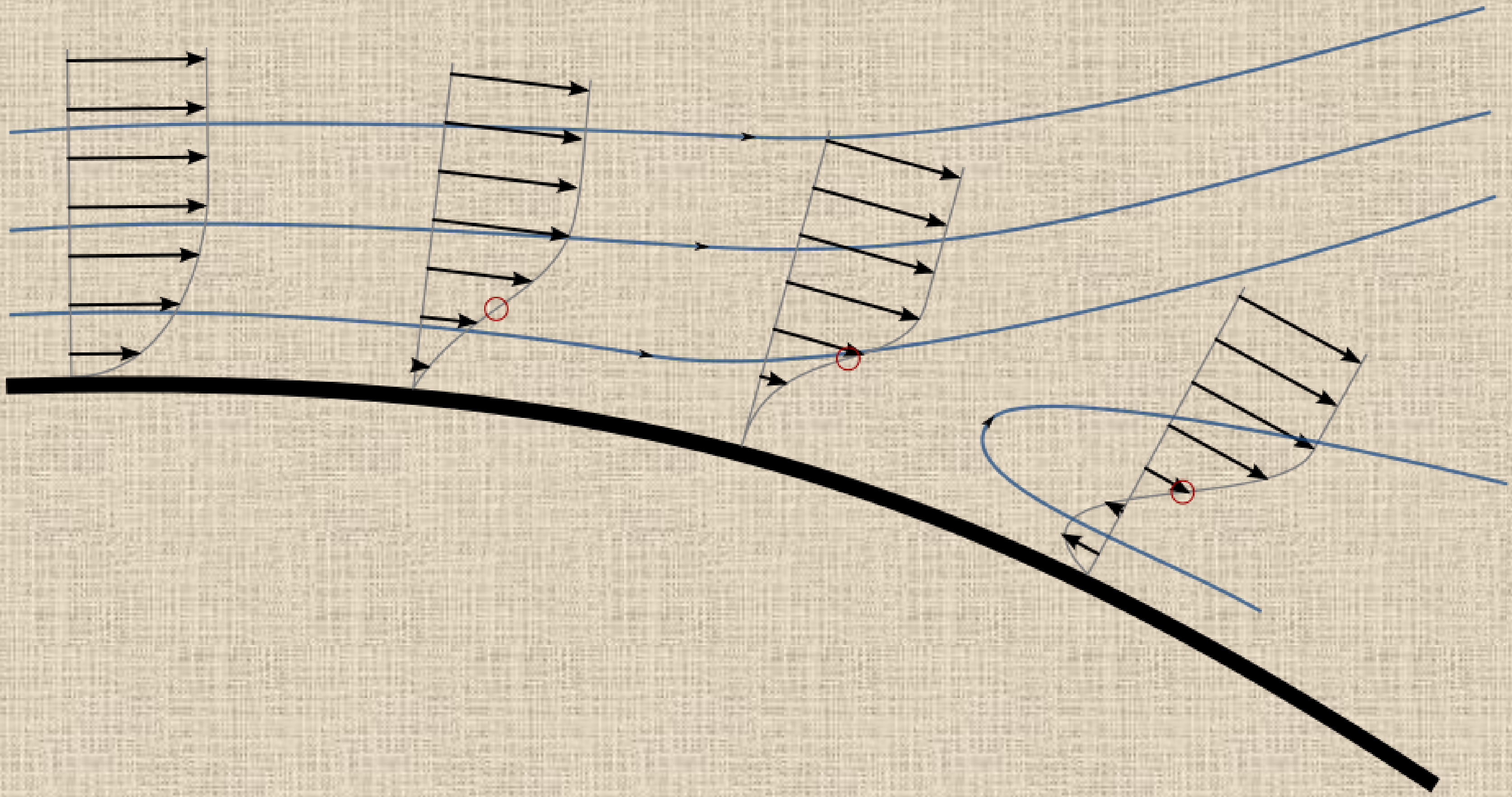
So, guess what happens!!

What is happening in the separated flow region?

Reversed Flow



Source **

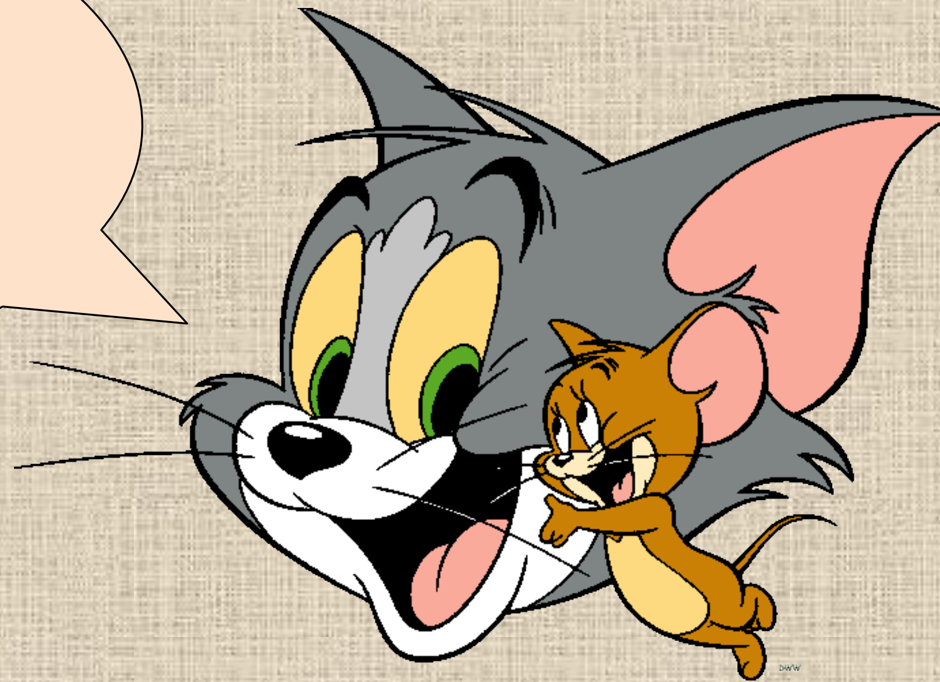


https://en.wikipedia.org/wiki/Flow_separation

Can you answer why is there a reversal of flow?

Clue:
pressure gradient

HOMEWORK:
Flow Separation
and Recirculation



Is laminar BL separation similar to turbulent BL separation?

Turbulent BL delays separation – higher momentum

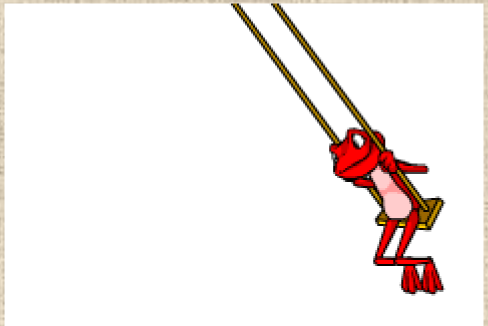

Tired?

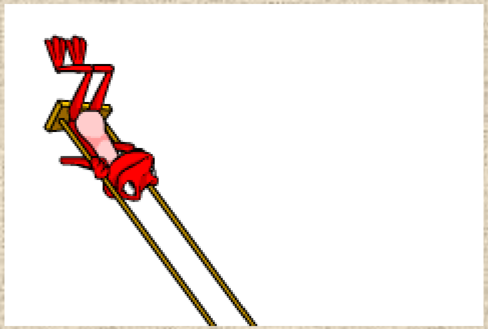
Let us watch [cricket!!]

SWING

and

REVERSE SWING?






Let us talk about Golf!
INKING: HELENE HUNTER
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Why so many [dimples?]

What we have learnt till now?

- ❑ Viscous flow
- ❑ Types of flow – Laminar & Turbulent
- ❑ Transition
- ❑ Reynolds no – effects
- ❑ Boundary layer
- ❑ Separation

QUESTIONS??