Transition from Laminar to Turbulent Flow

- Flow in pipes

Reynolds experiment

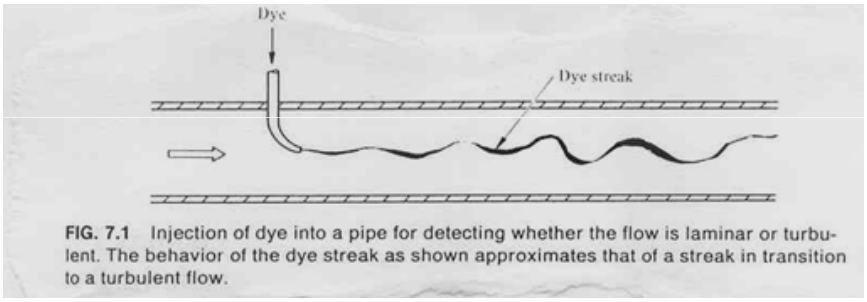
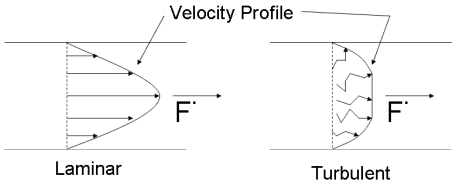


FIG. 7.1 Injection of dye into a pipe for detecting whether the flow is laminar or turbulent. The behavior of the dye streak as shown approximates that of a streak in transition to a turbulent flow.



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Reynolds experiment

Masters of Mechanical Engineering

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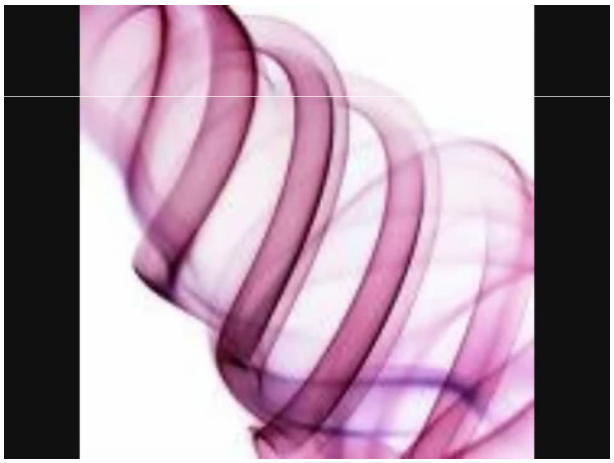

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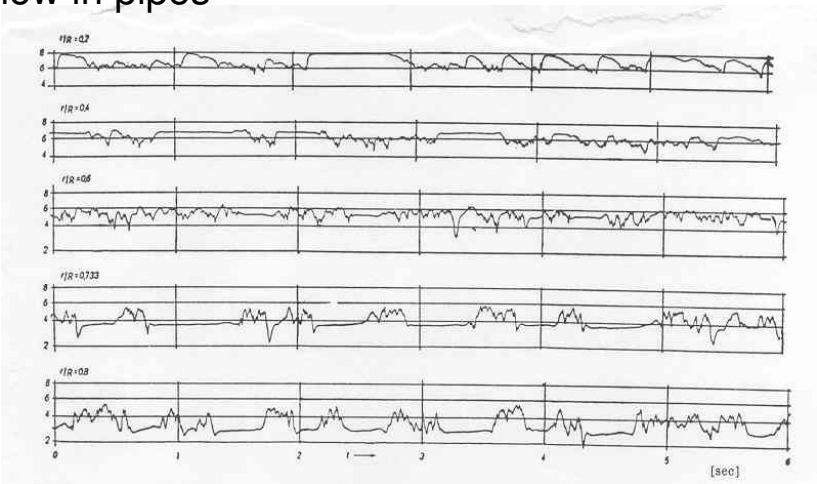

Fig. 16.2. Variation of flow velocity in a pipe in the transition range at different distances r from pipe axis, as measured by J. Rotta [75]

Reynolds number $R = \bar{w}d/\nu = 2550$; axial distance $x/d = 322$; $\bar{w} = 4{\cdot}27$ m/sec ($= 14{\cdot}0$ ft/sec); velocities given in m/sec. These velocity plots, obtained with the aid of a hot-wire anemometer, demonstrate the intermittent nature of the flow in that periods of laminar and turbulent flow succeed each other in time

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Transition from Laminar to Turbulent Flow

- Transition in boundary-layers

Parameters that affect transition

- Pressure gradient
- Wall roughness
- Outer flow turbulence

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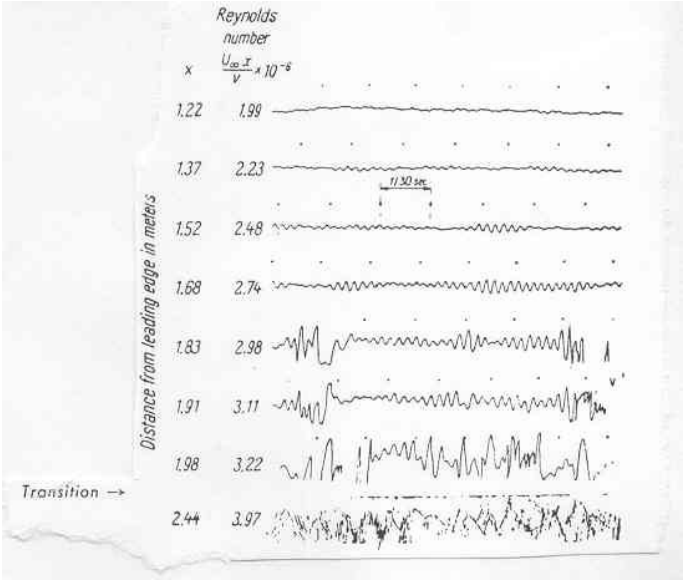
Transition from Laminar to Turbulent Flow

- Transition in boundary-layers

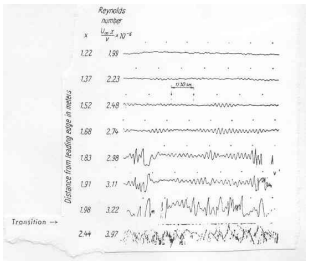


Critical Reynolds number

Transition Reynolds number

Transition from Laminar to Turbulent Flow

- Different stages of boundary-layer transition



1. Two dimensional instabilities of the boundary-layer profile. Tollmien-Schlichting waves
2. Three-dimensional introduced by secondary perturbations
3. Start of aleatory turbulent eruptions
4. "Fully-turbulent" flow

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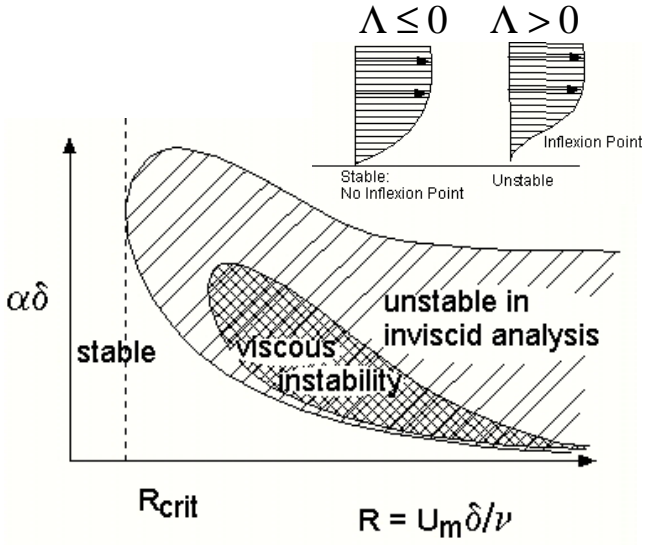
Transition from Laminar to Turbulent Flow

- Transition in boundary-layers

Neutral stability of boundary-layer velocity profile



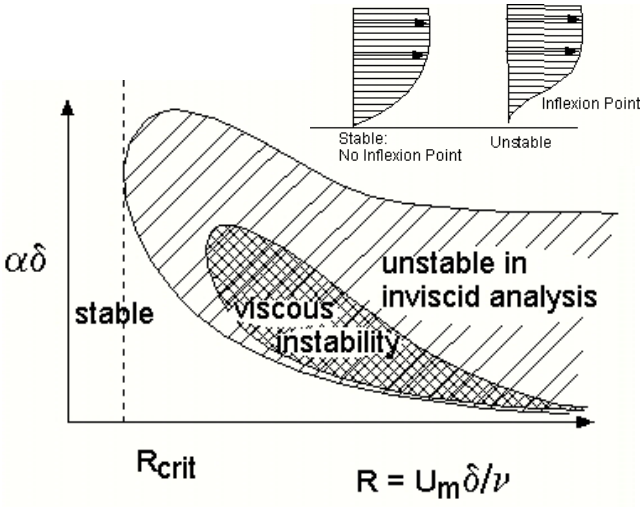
- α is the wavenumber of the perturbation (wavelength $= \frac{2\pi}{\alpha}$)
- R_{crit} is the minimum Reynolds number of the line that divides the stable and unstable regions of the diagram
- R_{trans} is the Reynolds number where the turbulent flow regime starts $R_{trans} > R_{crit}$

Transition from Laminar to Turbulent Flow

- Transition in boundary-layers

Neutral stability of boundary-layer velocity profile

$\Lambda \leq 0 \quad \Lambda > 0$



Profile without inflection point

$R_e \to \infty \Rightarrow \alpha \to 0$

Viscous instability

Profile with inflection point

$R_e \to \infty \Rightarrow \alpha \to \alpha_\infty$

Inviscid instability

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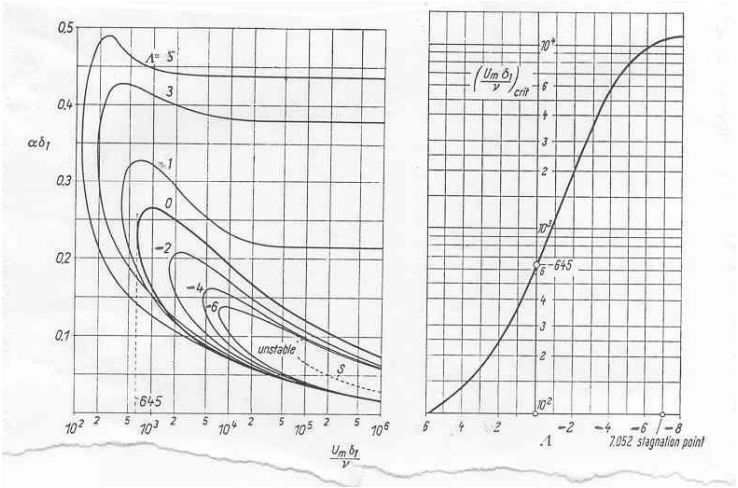
Transition from Laminar to Turbulent Flow

- Transition in boundary-layers



$$\Lambda = -\frac{\delta^2}{\nu}\frac{dU_e}{dx}$$

- Adverse pressure gradient, $\Lambda>0$, favours transition
- Favourable pressure gradient, $\Lambda<0$, makes transition hardest

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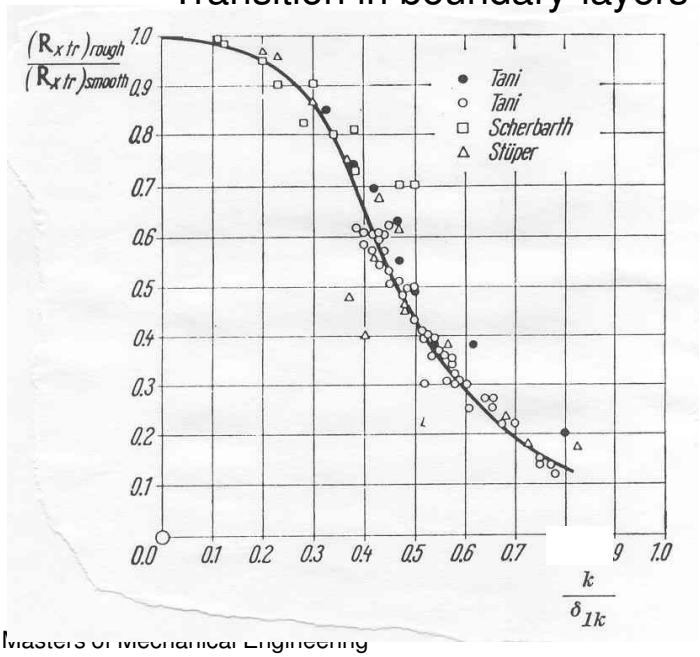
Transition from Laminar to Turbulent Flow

- Transition in boundary-layers



Effect of roughness on the transition Reynolds number of a flat plate boundary-layer (zero pressure gradient)

- The increase of the roughness height favours transition

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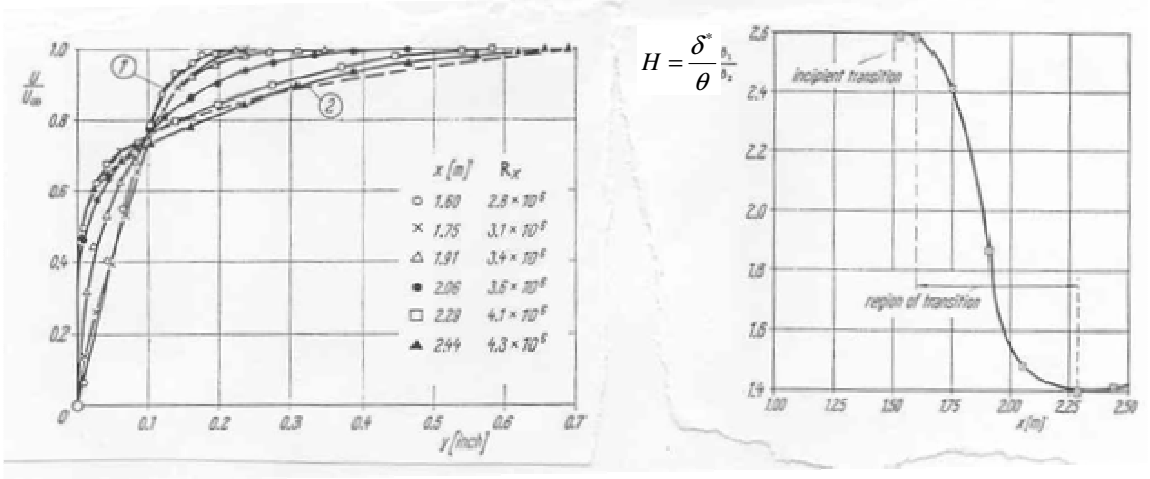
Transition from Laminar to Turbulent Flow

- Transition in boundary-layers

Change of the velocity profile



Transition from Laminar to Turbulent Flow

- Transition in boundary-layers

Change of the velocity profile

- The shape factor, H, diminishes
- The momentum thickness, θ, remains approximately constant, if $x_{crit} \simeq x_{trans}$
- The displacement thickness, δ^*, diminishes
- The skin friction coefficient, C_f, increases
- Empirical correlation to determine H at the end of transition to turbulent flow

$$H = \frac{1{,}4754}{\log_{10}\left(R_{e\theta_{trans}}\right)} + 0{,}9698$$

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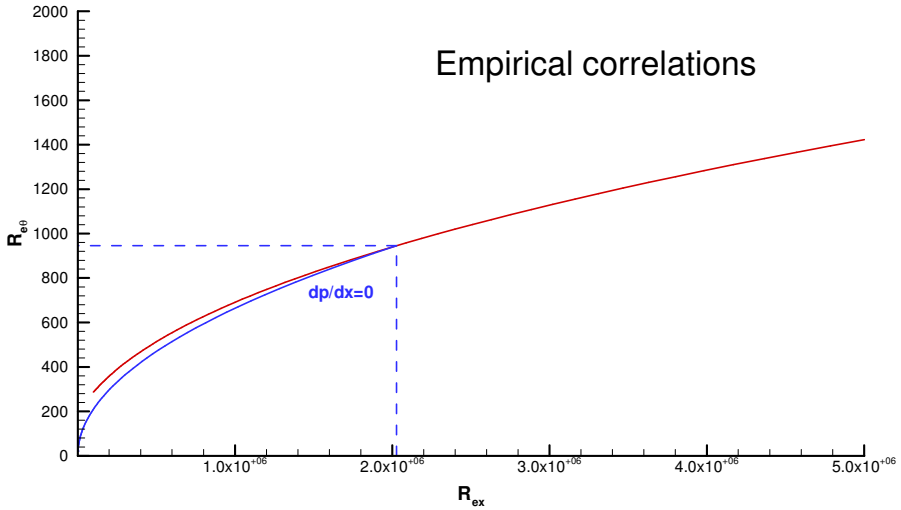
Empirical correlations

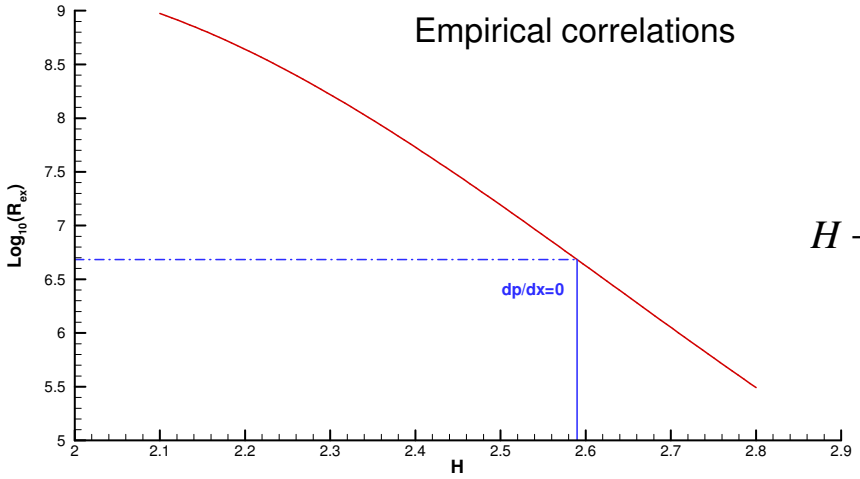


Cebeci & Smith

$$R_{e\theta} = 1{,}174\left(1 + \frac{22400}{R_{ex}}\right)R_{ex}^{0{,}46} \quad \text{with} \quad 10^5 < R_{ex} < 4\times10^7$$

Transition from Laminar to Turbulent Flow

- Transition in boundary-layers



$$\log_{10}(R_{ex}) = -40{,}4557 + 64{,}8066H - 26{,}7538H^2 + 3{,}3819H^3 \quad \text{with} \quad 2.1 < H < 2.8$$