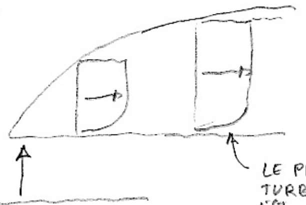
EX 23

$$\boxed{Re = 10^9} \;!!$$

1



$\nu = 10^{-6}\ [m^2/s]$
EAU (-)

LE PROFIL TURBULENT EST PLUS PLEIN !

$$\boxed{\begin{array}{l} x_{CR} = 0{,}005 \,! \\ Re_{CR} = \dfrac{Ux}{\nu} = 54000 \end{array}}$$

2

3

$$C_f = \frac{\overline{\tau}_w}{\rho \overline{U}_e^2/2}$$

$$\boxed{\overline{U}_\tau^2 = \frac{\overline{\tau}_w}{\rho}}$$

$$C_f = \frac{2\,\overline{U}_\tau^2}{\overline{U}_e^2}$$

$$\boxed{\sqrt{\frac{C_f}{2}} = \frac{\overline{U}_\tau}{\overline{U}_e}}$$

4

$$\sqrt{\frac{2}{C_f}} = \frac{\overline{U}_e}{\overline{U}_\tau} = \frac{1}{\varkappa} \log \left[\overbrace{\underbrace{\frac{\delta\, \overline{U}_\tau}{\nu}}}^{\delta^+} \right] + C + G(1)$$

$$\frac{\delta \overline{U}_e}{\nu} \frac{\overline{U}_\tau}{\overline{U}_e} = Re_\delta \sqrt{\frac{C_f}{2}}$$

$$\sqrt{\frac{2}{C_f}} = -\frac{1}{\varkappa} \log\left[\frac{1}{Re_\delta}\sqrt{\frac{2}{C_f}}\right] + \frac{1}{\varkappa}\log\left[\exp(\varkappa(C+G(1))\right]$$

$$= \underbrace{-\frac{1}{\varkappa}}_{a} \log\left[\underbrace{\exp(-\varkappa(C+G(1))}_{b} \frac{1}{Re_\delta}\sqrt{\frac{2}{C_f}}\right]$$

5

$$\boxed{\begin{array}{l} a = \dfrac{1}{\varkappa} \\ b \simeq 1/22 \end{array}}$$

6

$$\int_0^h \overline{U}\frac{\partial \overline{U}}{\partial x} + \underbrace{\int_0^h \overline{V}\frac{\partial \overline{U}}{\partial y}} = \underbrace{\int_0^h \frac{\partial}{\partial y}(\overline{\tau}+\tau^t)\, dy}_{-\overline{\tau}_\omega/\rho}$$

$h \gg \delta$!!

$$\underbrace{-\int_0^h \int_0^y \frac{\partial \overline{U}}{\partial x} d\eta \frac{\partial \overline{U}}{\partial y} dy}$$

$$-\int_0^h \overline{U}_e \frac{\partial \overline{U}}{\partial x} + \int_0^h \overline{U}\frac{\partial \overline{U}}{\partial x}$$

$$\int_0^h \underbrace{2\overline{U}\frac{\partial \overline{U}}{\partial x} - \overline{U}_e \frac{\partial \overline{U}}{\partial x}}\, dy = -\overline{\tau}_w\, \rho$$

$$\underbrace{\frac{\partial}{\partial x}(\overline{U}(\overline{U}-\overline{U}_e)\, dy}$$

$$\overline{U}_e^2 \frac{d\Theta}{dx}$$

ON AVAIT DEJA VU CELA !!!

EQUATION INTEGRALE DE VON KARMAN.

$$\boxed{\frac{d\Theta}{dx} = \frac{\overline{\tau}_w}{\rho \overline{U}_e^2}}$$

7

$\alpha = 1/n$

$$\Theta = \delta \int_0^1 \eta^\alpha (1-\eta^\alpha)\, d\eta$$

$$= \delta \left[\underbrace{\frac{\eta^{\alpha+1}}{\alpha+1} - \frac{\eta^{2\alpha+1}}{2\alpha+1}} \right]_0^1$$

$$= \frac{\alpha}{(\alpha+1)(2\alpha+1)}$$

$$= \frac{n}{(n+1)(n+2)}$$

$$\boxed{\frac{\Theta}{\delta} = \frac{7}{72}}$$

8

$$\underbrace{\frac{d\theta}{dx}(x)}_{\frac{7}{72}\,\delta'(x)} = \underbrace{\frac{\tau_w(x)}{\rho\, \bar U_e^2}}_{\frac{C_f(x)}{2} \simeq \frac{1}{100}\, \underbrace{Re_\delta^{-1/6}(x)}_{[\delta(x)]^{-1/6} \left[\frac{\bar U_e}{\nu}\right]^{-1/6}}}$$

9

$$\delta'(x)\,[\delta(x)]^{1/6} = \frac{72}{700}\left[\frac{\bar U_e}{\nu}\right]^{-1/6}$$

$$\frac{6}{7}\,[\delta(x)]^{7/6} = \frac{72}{700} \times \left[\frac{\bar U_e}{\nu}\right]^{-1/6}$$

$$\left[\frac{\delta(x)}{x}\right]^{7/6} = \frac{72}{600}\left[\frac{\bar U_e\, x}{\nu}\right]^{-1/6}$$

$$\boxed{\delta(x) = x \underbrace{\left[\frac{72}{600}\right]^{6/7}\left[\frac{1}{Re(x)}\right]^{1/7}}_{0{,}162\,[Re(x)]^{-1/7}}}$$

$$C_f(x) = 2\,\frac{d\theta}{dx} = \underbrace{\frac{14}{72}\,0{,}162}_{0{,}0316}\left[\frac{\bar U_e}{\nu}\right]^{-1/7} \underbrace{\frac{d}{dx}\left[x^{6/7}\right]}_{\frac{6}{7}\,x^{-1/7}}$$

$$\frac{6}{7}\,[Re(x)]^{-1/7}$$

$$\boxed{\begin{array}{l} C_f = 0{,}0271\,[Re]^{-1/7} \\ C_{f,m} = \dfrac{2\theta}{x} = \underbrace{\dfrac{14}{72}\,0{,}162}_{0{,}0316}\,[Re]^{-1/7} \end{array}}$$

10

$$F_{DRAG} = \underbrace{bL}_{2\,10^3}\ \frac{1}{2}\,\underbrace{\rho}_{10^3}\ \underbrace{\bar U_e^2}_{10^2}\ \underbrace{C_{f,m}(L)}_{\substack{1{,}63\,10^{-3} \\ 1{,}637\,10^{-3}}}$$

AVEC $0{,}0316\ Re^{-1/7}$

AVEC FORMULE DE WHITES :-)

$$F_{DRAG} = 1{,}637\ 10^5\ [N]$$
$$P = 1{,}637\ 10^6\ [Watt]$$

C'EST CON LES BATEAUX

PAS LISSES !

11 $\boxed{\text{CAS RUGUEUX}}$

$$C_{f,m}(L) = 3{,}593\ 10^{-3}$$
$$F_{DRAG} = 3{,}593\ 10^5\ [N]$$
$$P = 3{,}593\ 10^6\ [Watt]$$

C'EST DEUX FOIS PLUS QUE LE CAS LISSE !!

$\boxed{6}$

$\boxed{\text{SOLUTION ALTERNATIVE}}$

$$\int_0^{S(x)} u\frac{\partial u}{\partial x}\,dy + \underbrace{\int_0^{S(x)} v\frac{\partial u}{\partial y}} = \underbrace{\int_0^{S(x)} \frac{1}{\rho}\frac{\partial \tau}{\partial y}\,dy}_{-\frac{\tau_w}{\rho}}$$

$\boxed{\text{INTEGRALE PAR PARTIES}}$

$$\underbrace{\int_0^{S(x)} \frac{\partial}{\partial y}(vu)} - \underbrace{\int_0^{S(x)} u\frac{\partial v}{\partial y}}$$

$\boxed{\text{CAR } \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0}$

$$= \left[vu\right]_0^{S(x)} \qquad = \int_0^{S(x)} -u\frac{\partial u}{\partial x}$$

$$= \bar{U}_e\, v(S(x))$$

$\boxed{\text{CAR } \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0}$

$$= \bar{U}_e \int_0^{S(x)} \frac{\partial v}{\partial y}\,dy$$

$$= \bar{U}_e \int_0^{S(x)} -\frac{\partial u}{\partial x}$$

$$\int_0^{S(x)} \underbrace{2u\frac{\partial u}{\partial x} - u_e\frac{\partial u}{\partial x}}_{\frac{\partial}{\partial x}\left(u(u-u_e)\right)}\,dy = -\frac{d}{dx}\Theta\ \bar{U}_e^{\,2}$$

$$\boxed{\frac{d\Theta}{dx} = \frac{\tau_w}{\rho\,\bar{U}_e^{2}}}$$

BONUS : QUID SI u_e N'EST PAS CONSTANT !

$u_e(x)\ldots$

→ COURS ECOULEMENTS EXTERNES