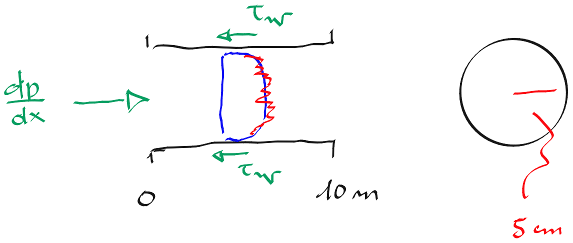
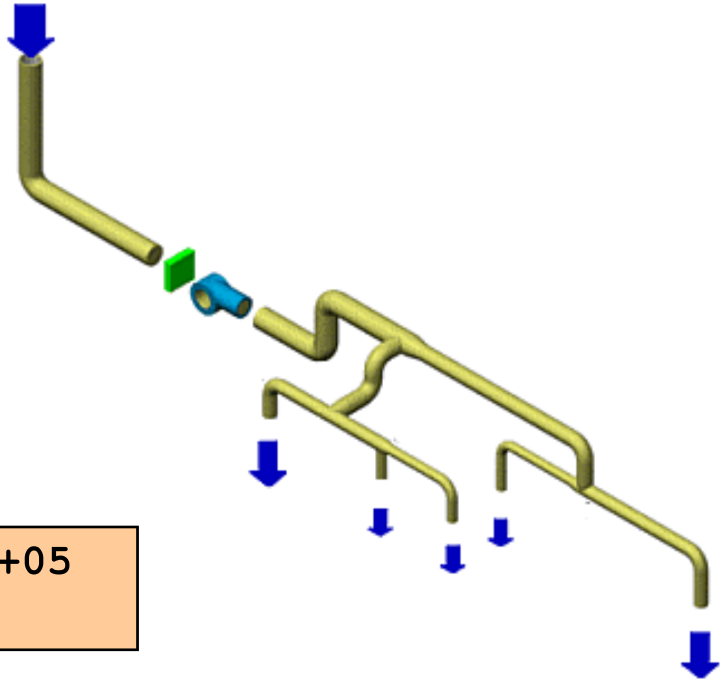
Ils savent même pas calculer les pertes de charges dans un tuyau !



Re = 1.67e+05



De l'air…

$$\overbrace{101\,325\ [Pa]}^{\text{PRESSION}}$$

$$\rho = \frac{p}{R_* \, T}$$

293 [K]

$$R/M$$

$$\underbrace{8.314 \qquad 2{,}99\ 10^{-2}}_{287{,}1\ [J/kg\ K]}$$

$$\boxed{\begin{array}{l} \rho = 1{,}204\ [kg/m^3] \\ \nu = \dfrac{\mu}{\rho} = 1{,}5\ 10^{-5}\ [m^2/s] \end{array}}$$

Propriétés matérielles de l'air
à pression atmosphérique
et à une température de 20° Celsius

μ	$1.81\ 10^{-5}$	$N\ s\ m^{-2}$
k	$2.57\ 10^{-2}$	$W\ m^{-1}\ K^{-1}$
c_p	$1.00\ 10^{3}$	$J\ kg^{-1}\ K^{-1}$
M	$2.90\ 10^{-2}$	$kg\ mole^{-1}$
R	8.314	$J\ mole^{-1}\ K^{-1}$

Estimer le problème !

$$Re = \frac{\overset{50\ m/s}{\bar{v}_m}\ \overset{5\ 10^{-2}\ m}{D}}{\underset{1,5\ 10^{-5}\ m^2/s}{\nu}}$$

$166\ 609 \simeq 1,7\ 10^5$

TURBULENT !

$$Pr = \frac{\nu}{\alpha} = \frac{\mu c_p}{k} = 0,7$$

$$Ma = \frac{\bar{v}_m}{\sqrt{\gamma R_* \bar{T}_m}} = 0,14$$

LES EFFETS COMPRESSIBLES SEMBLENT MODESTES

$$Ec = \frac{\bar{v}_m^{\,2}}{c_p(\underset{20°C}{\bar{T}_m} - \underset{10°C}{\bar{T}_w})} = 0,25$$

$$\left.\begin{aligned} Ec &= 0,25 \\ Ec\,Pr &= 0,176 \end{aligned}\right. \ll 1$$

DISSIPATION VISQUEUSE FAIBLE MAIS PAS TOTALEMENT NEGLIGEABLE

```
nu          =  1.50e-05  [m2/s]
rho         =  1.21e+00  [kg/m3]
Re          =  1.67e+05
Pr          =  7.04e-01
Ec          =  2.50e-01
Ec Pr       =  1.76e-01
Ma          =  1.46e-01
```

Nusselt

$$Nu = \frac{q_w}{k \Delta T / D}$$

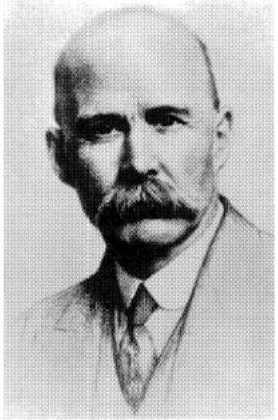
$$\frac{\rho D \bar{u}_m}{\mu} \qquad \frac{\mu c_p}{k}$$

$$Nu = \frac{q_w \; D}{k \cancel{\Delta T}} \; \frac{\rho c \bar{u}_m \cancel{\Delta T}}{\rho c \bar{u}_m \Delta T} = \overbrace{\frac{q_w}{\rho c \bar{u}_m \Delta T}}^{St} \; \overbrace{\frac{D \bar{u}_m \rho c}{k}}^{Pe = Re \, Pr}$$

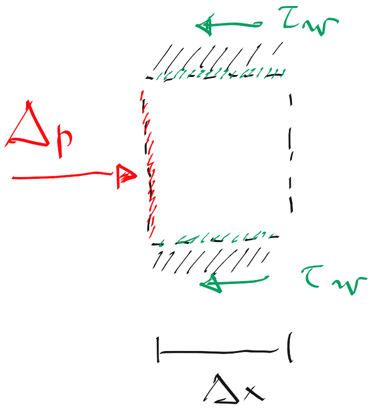
$$Nu = St \; Re \; Pr$$

$$St = \frac{q_w}{\rho c \bar{u}_m \Delta T}$$

Stanton



Faire avancer un fluide dans un tuyau !



$$\Delta p \, \cancel{\pi} R^{\cancel{2}} = \tau_w \, 2 \cancel{\pi} \cancel{R} \, \Delta x$$

$$\downarrow$$

$$2\tau_w = \frac{dp}{dx}$$

$$\boxed{\begin{aligned} C_f &= \frac{\tau_w}{\rho \bar{u}_m^2/2} \\ \lambda &= \frac{dp/dx}{\rho \bar{u}_m/D} \end{aligned}}$$

$$\boxed{4C_f = \lambda}$$

Tuyau lisse

$$\frac{1}{\sqrt{\lambda}} = -2\ \log_{10}\left(\frac{2.51}{Re_D}\ \frac{1}{\sqrt{\lambda}} + \frac{1}{3.71}\ \frac{\epsilon}{2R}\right)$$

$$St = \frac{\lambda}{8}\left(1+13\left(Pr^{2/3}-1\right)\sqrt{\frac{\lambda}{8}}\right)^{-1}$$

$\varepsilon = 0$

$\lambda = 1{,}61\ 10^{-2}$

$St = 2{,}31\ 10^{-3}$

```
===== Smooth pipe ==================================
Lambda               =  1.621e-02
St                   =  2.308e-03
Nu                   =  2.708e+02
Pressure difference  =  4.889e-01 [bar]
Pressure gradient    =  4.889e-03 [bar/m]
Heat flux density    =  1.392e+03 [Watt/m2]
Heat transfer coeff  =  1.392e+02 [Watt/m2K]
```

Tuyau rugueux

$\varepsilon = 1/2$ mm

$$\frac{1}{\sqrt{\lambda}} = -2 \log_{10}\left(\frac{2.51}{Re_D}\frac{1}{\sqrt{\lambda}} + \frac{1}{3.71}\frac{\epsilon}{2R}\right)$$

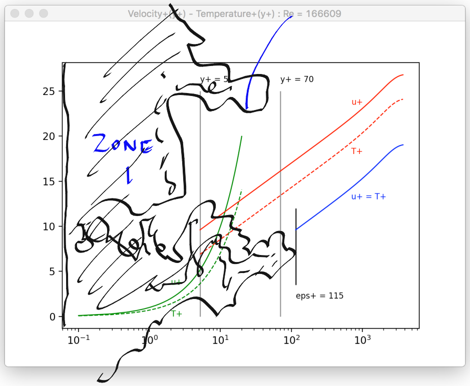
$$St = \frac{\lambda}{8}\left(1 + 13\left(Pr^{2/3} - 1\right)\sqrt{\frac{\lambda}{8}}\right)^{-1}$$

$\lambda = 3,82 \; 10^{-2}$

$St = \frac{\lambda}{8} = 4,78 \; 10^{-3}$

$\varepsilon^{+} = 115$

ZONE II



```
===== Rough pipe === epsilon =  5.00e-04 ===========
Epsilon_+           =  1.152e+02
Lambda              =  3.823e-02
St                  =  4.779e-03
Nu                  =  5.608e+02
Pressure difference =  1.153e+00 [bar]
Pressure gradient   =  1.153e-02 [bar/m]
Heat flux density   =  2.882e+03 [Watt/m2]
Heat transfer coeff =  2.882e+02 [Watt/m2K]
```

Laminaire virtuel

$\lambda = \frac{64}{Re} = 3{,}84\ 10^{-4}$

$St = 6{,}07\ 10^{-5}$

$Nu = 7{,}12$

$Nu = 9{,}6 \ldots\ldots 3{,}66$

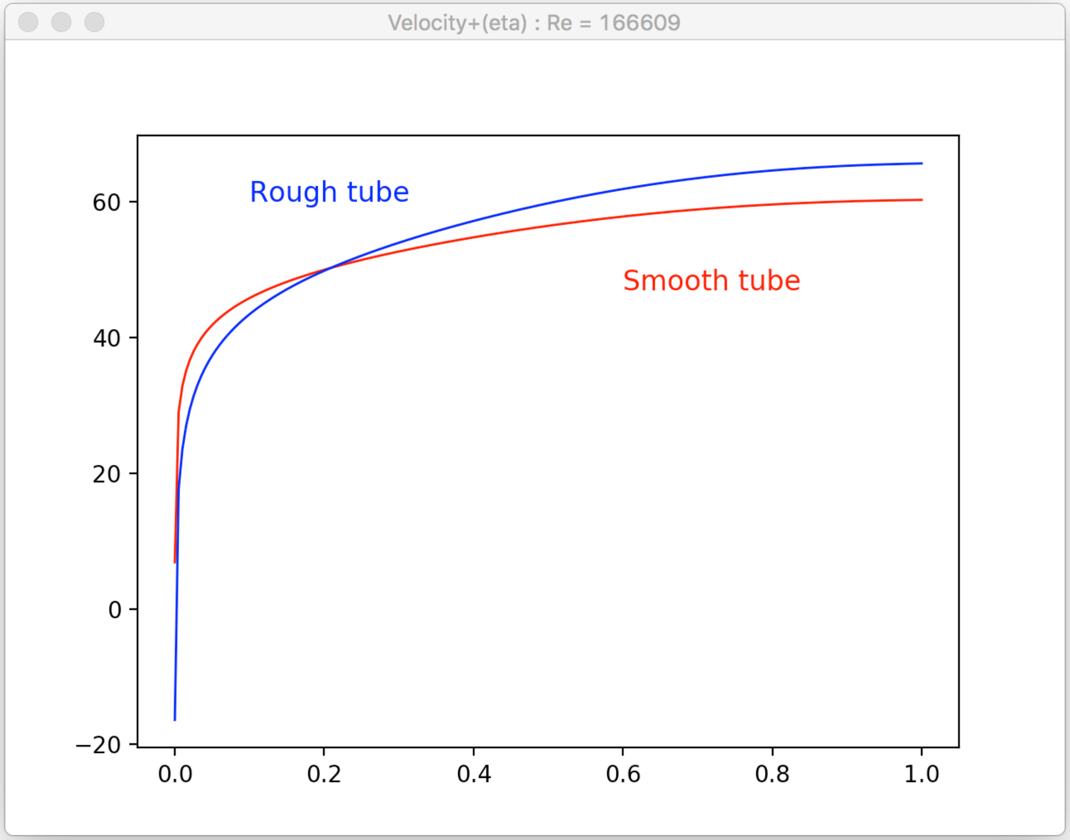
SUMMARY :-)

	TURBULENT RUGUEUX	TURB LISSE	LAMINAIRE
λ	$4\ 10^{-2}$	$2\ 10^{-2}$	$4\ 10^{-4}$
Nu	561	271	3... 9

C'EST
LE PRIX
A PAYER

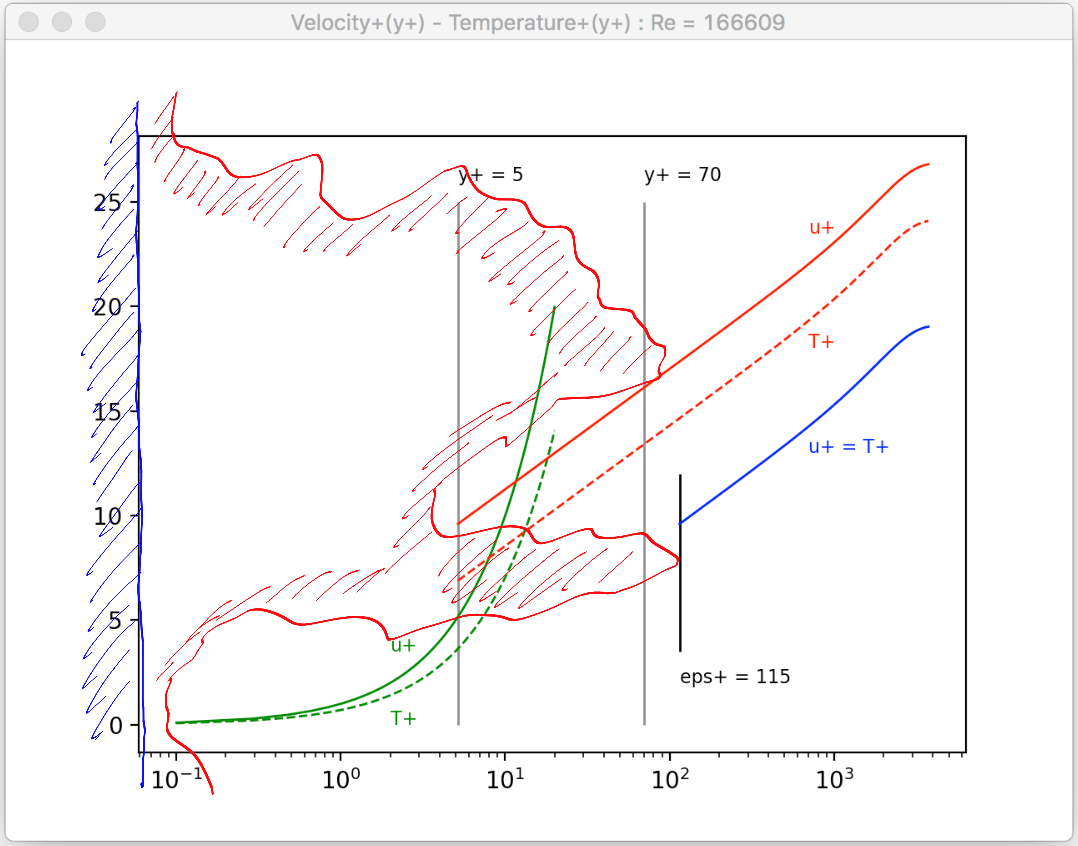
```
===== Virtual laminar pipe ==========================
Epsilon_+             =  1.152e+02
Lambda                =  3.841e-04
St                    =  6.066e-05
Nu                    =  7.118e+00
Pressure difference =  1.158e-02 [bar]
Pressure gradient   =  1.158e-04 [bar/m]
Heat flux density   =  3.658e+01 [Watt/m2]
Heat transfer coeff =  3.658e+00 [Watt/m2K]
```

Dessiner le problème



```
===== Profil logarithmique ========= kappa =  0.4000 et C =  5.5000
===== Correction de Coles ========== alpha =  1.3500 et D =  1.0000
==== Approximated mean velocity (smooth) :  54.3 [m/s]
==== Approximated mean velocity (rough)  :  56.4 [m/s]
```

Près de la paroi…



$\mathrm{Pr}_{turb} = 1$

$$0 = \frac{d}{dy}\left(\bar{q} + \bar{q}^t\right)$$

$$\boxed{\underbrace{\bar{q}(y)}_{= -k \frac{d\bar{T}}{dy}} + \underbrace{\bar{q}^t(y)}_{= -k^t \frac{d\bar{T}}{dy}} = \bar{q}_w \left(1 - y/R\right)}$$

$$\boxed{-\alpha \frac{d\bar{T}}{dy} \underbrace{- \alpha^t \frac{d\bar{T}}{dy}}_{\text{NEGLIGE}} = \frac{\bar{q}_w}{\rho c}\left(1 - \overset{\simeq 0}{y/R}\right)}$$

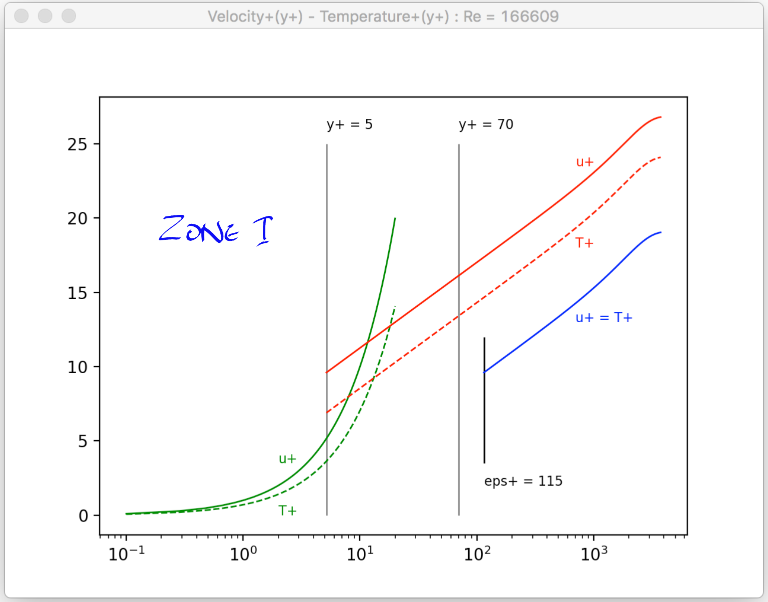
ZONE
À DOMINANCE
LAMINAIRE

$$y/R \ll 1$$

$$\bar{T}_w - \bar{T}(y) = \frac{1}{\alpha \rho c} \bar{q}_w \, y$$

$$= \underbrace{\frac{\nu}{\alpha}}_{P_r} \underbrace{\frac{\bar{q}_w}{\rho c \, \bar{u}_\tau}}_{T_\tau} \underbrace{\frac{\bar{u}_\tau y}{\nu}}_{y^+}$$

$$\boxed{\begin{aligned} \bar{T}^+ &= P_r \, y^+ \\ &= P_r \, u^+ \end{aligned}}$$



Velocity+(y+) - Temperature+(y+) : Re = 166609

$$\mathrm{Pr}_{\mathrm{turb}} = 1$$

$$\boxed{\underbrace{-\alpha \frac{d\bar{T}}{dy}}_{\text{NEGLIGE}} - \underbrace{\alpha^t}_{\nu^t(y)} \frac{d\bar{T}}{dy} = \frac{q_w}{\rho c}\left(1 - y/R\right)}$$

ZONE
A DOMINANCE
TURBULENTE

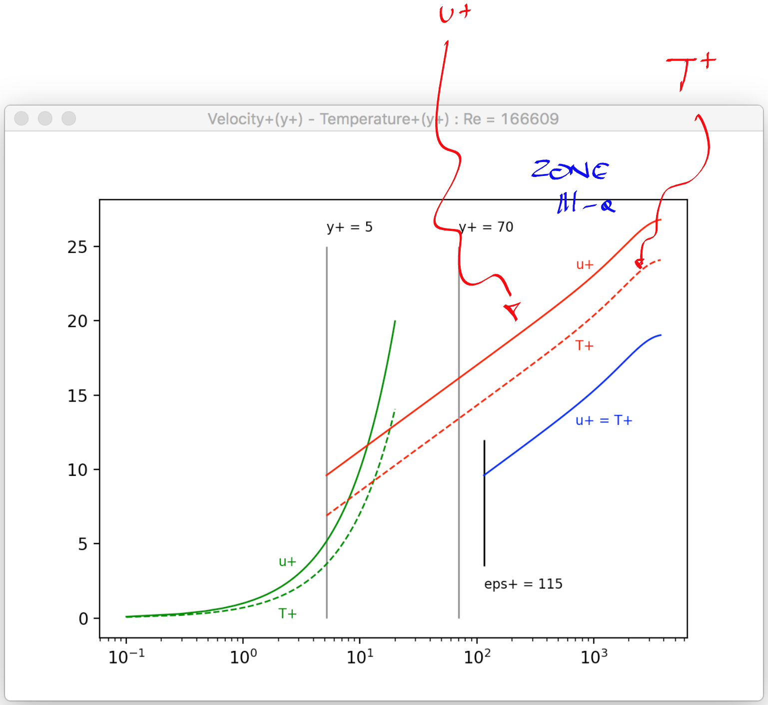
$$\underbrace{\nu^t(y)}_{\kappa y \bar{u}_\tau \left(\cancel{1 - y/R}\right)} \frac{d\bar{T}}{dy} = \frac{\bar{q}_w}{\rho c}\left(\cancel{1 - \frac{y}{R}}\right)$$

$$\boxed{\bar{T}^+ = \frac{1}{\kappa}\log\left(\bar{y}^+\right) + A}$$

FONCTION
DE Pr :-)

CAS
RUGUEUX

$$\boxed{\bar{T}^+ = \frac{1}{\kappa}\log\left(\frac{y}{\varepsilon}\right) + B}$$



Velocity+(y+) - Temperature+(y+) : Re = 166609

Est-ce un modèle réaliste ?

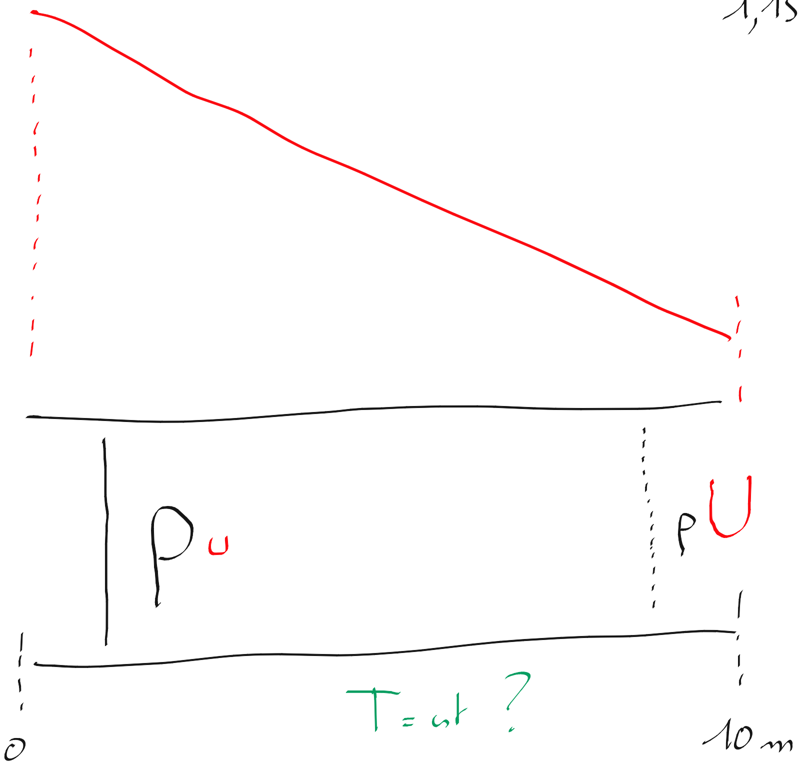
LISSE

$\Delta p = 0{,}49$ [bar]

$1{,}15$ [bar]

RUGUEUX

$$\rho = \frac{p}{RT}$$



$p = p_{atm}$:-)

$T = ct$?

SITUATION ADIABATIQUE !