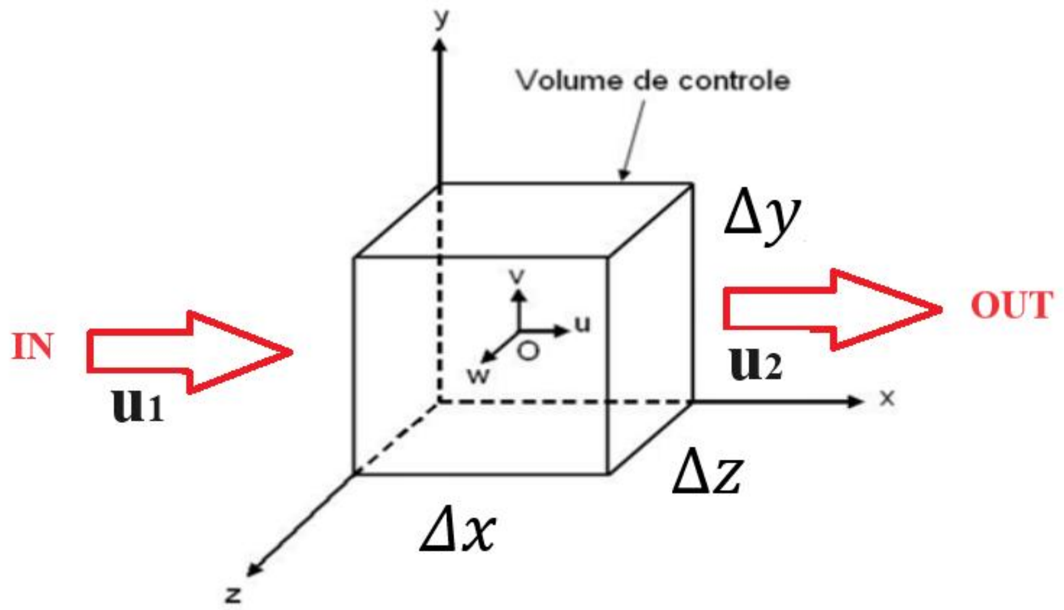
Leis de Conservação da Mecânica dos Fluidos aplicadas à Hidrodinâmica do Navio

I – Lei da Conservação de Massa

Vol . .

p τ - -

. . x 



p_{rxw} p_{l} p_{xer}

-

p $\tau x D$

x $\frac{}{w}$ D C -

p_{rxw} τ x D

p_{l} τ x D

- -

p_{xer} $\frac{p}{w}$ C $\frac{\tau}{w}$ - -

p_{rxw} p_{l} p_{xer}

$\tau \;\; x \;\; D \qquad \tau \;\; x \;\; D \qquad \frac{\tau}{w}$ - -

- -

$D \qquad D$ -

$\tau \;\; x \qquad \tau \;\; x$ - $\frac{\tau}{w}$ - -

$\tau \;\; x \qquad \tau \;\; x \qquad \tau x$

τx - $\frac{\tau}{w}$ - -

τx - C τy - C τz - $\frac{\tau}{w}$ - -

y z

- -

$\frac{\tau x}{} \;\; C\frac{\tau y}{C} \;\; C\frac{\tau z}{} \qquad \frac{\tau}{w}$

. $\frac{-}{-}$ $\frac{-}{-}$C

$$\frac{\tau x}{} \; C \frac{\tau y}{} \quad \frac{\tau z}{} \qquad \frac{\tau}{w}$$

$$\tau \qquad \frac{\tau}{w}$$

$$\frac{}{} \; C \frac{}{} \quad \frac{}{}$$

u, v e w *x, y e z*

$$\tau \quad - \quad g_D \qquad \frac{g}{gw} \qquad \tau C g \;_{ro}$$

$$\frac{\tau}{w}$$

$$\tau$$

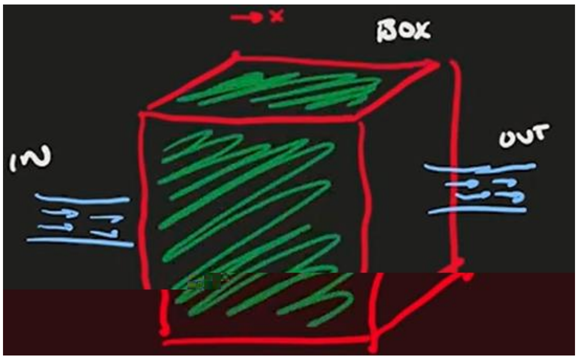
$$\frac{\tau x}{} \; C \frac{\tau y}{} \quad \frac{\tau z}{} \qquad \tau \; \frac{x}{} \; C \frac{y}{} \quad \frac{z}{}$$

$$\frac{x}{} \; C \frac{y}{} \quad \frac{z}{}$$

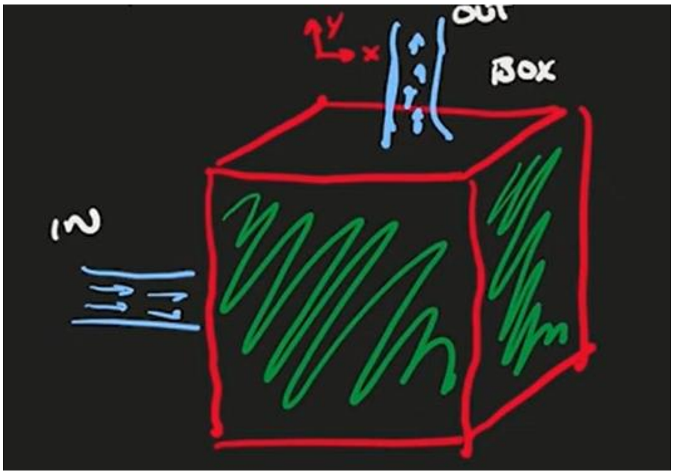
-

$\underline{x}$

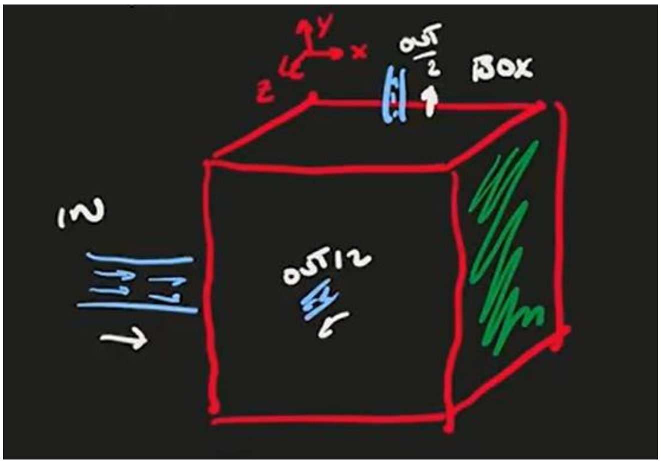
$\underline{y}$ $\underline{z}$



$\underline{x}$



C $\underline{x}$ C $\underline{y}$



$C\frac{x}{\ }$ $C\frac{y}{\ }$ $\frac{z}{\ }$

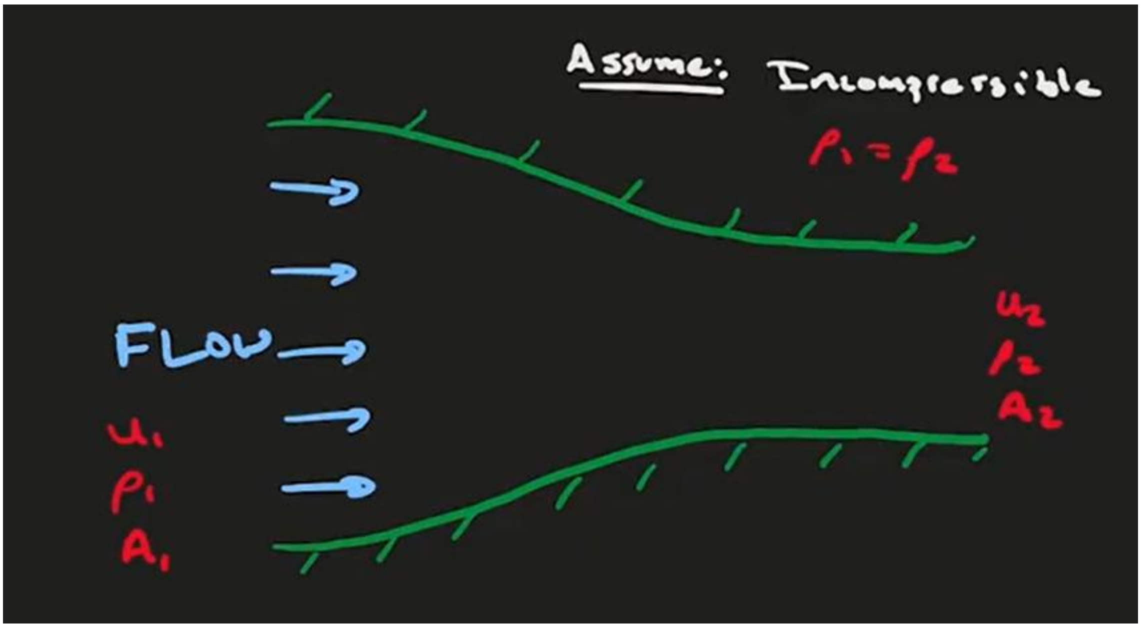
II – A lei de conservação da quantidade de movimento

$$\frac{p}{w} \quad C$$

A derivada material, derivada substantiva ou derivada total

$$\tau \frac{x}{w}$$

(u e u) τ *hGτ* *(A e A)*



$\tau \;\; x \;\; D \qquad \tau \;\; x \;\; D$

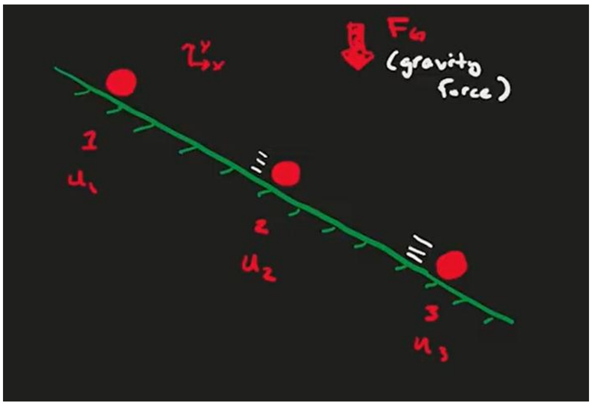
$\tau \qquad C\tau$

$x \;\; D \qquad x \;\; D$

$D \qquad D \qquad x \qquad x$

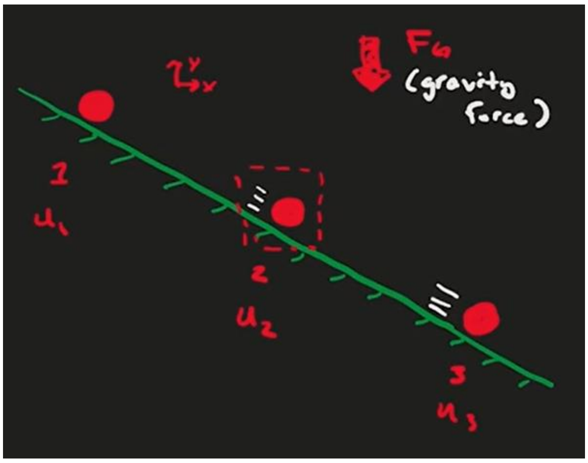
$\frac{x}{w}$

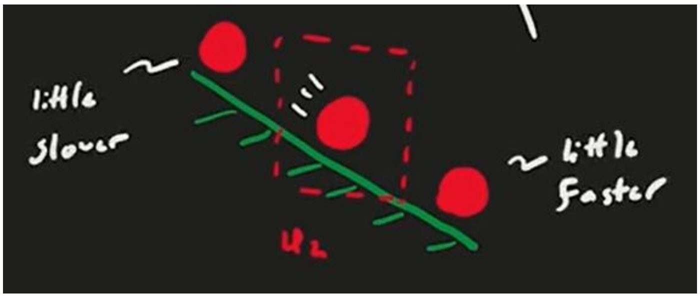
$\frac{x}{w}$



$x \qquad x \qquad x$


u
t
Δu
Δt
a = Δu / Δt


F_G
(gravity force)
1
u_1
2
u_2
3
u_3


little slower
little faster
u_2

$$\frac{x}{w} \quad \frac{x}{w}\frac{}{} \quad \frac{}{}\frac{x}{w} \quad x\frac{x}{}$$

$$\frac{x}{w} \quad \frac{x}{w}\frac{}{} \quad \frac{}{}\frac{x}{w} \quad y\frac{x}{}$$

C

$$d \quad \frac{x}{w} \quad x\frac{x}{} \quad y\frac{x}{} \quad z\frac{x}{}C$$

DvGdf hdhud hvGqdvGgluh hvĆdChĈdGvhu rGuhvs hf lydp hq hC

$d \qquad \frac{}{w} \quad x\frac{y}{} \quad y\frac{y}{} \quad z\frac{y}{}$C

C

$d \qquad \frac{z}{w} \quad x\frac{z}{} \quad y\frac{z}{} \quad z\frac{z}{}$C

C

dvrGrGhvfrdp hq rGvhmdGshup dqhq h.Chp vhC

C$\frac{x}{w}$ .C$\frac{y}{w}$ GhC$\frac{z}{w}$

Forças atuantes em um elemento fluido

$\frac{\frac{p}{o}}{w}$ C$\frac{}{o}$

$\frac{p}{ro} \quad \tau$

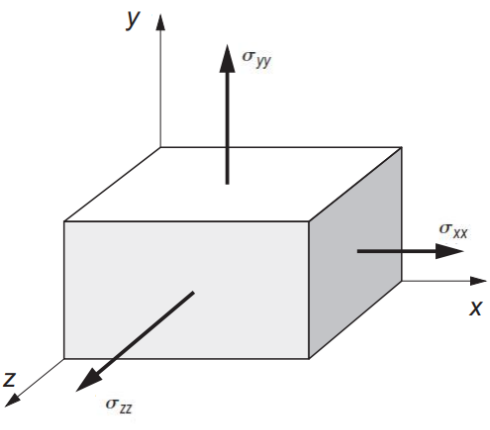
$\frac{\tau}{w}$ C$\frac{}{o}$

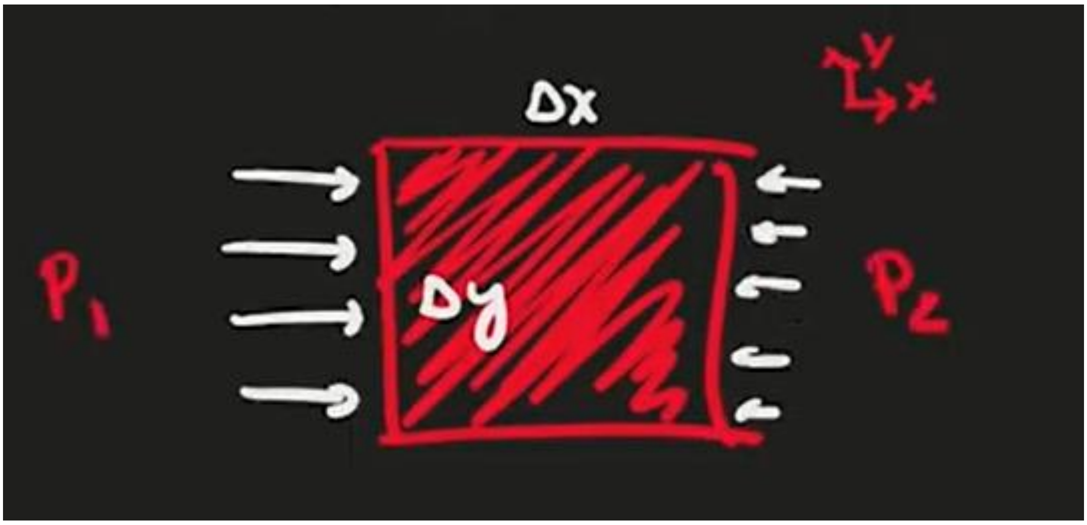
$\tau \frac{}{w}$ C$\frac{}{o}$

As forças normais ou de pressão

lm i

j





s C$\frac{}{D}$ Cs D

s D s D

D D

s s

s s s

s

$$\overline{} \quad \frac{s}{}$$

$$\frac{}{ro} \quad \frac{s}{}$$

$$\frac{}{ro} \quad \frac{s}{}$$

$$\frac{}{ro} \quad \frac{s}{}$$

$$\tau \frac{x}{w} \quad \frac{s}{}$$

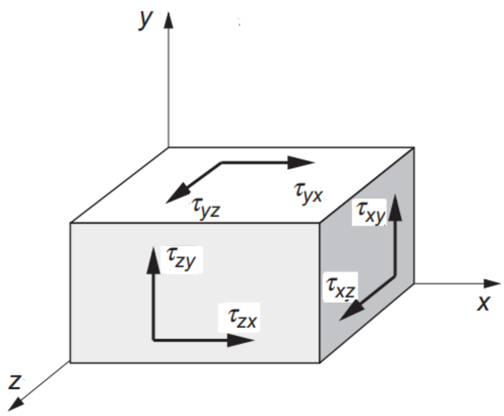
$$\tau \frac{y}{w} \quad \frac{s}{}$$

$$\tau \frac{z}{w} \quad \frac{s}{}$$

As forças tangenciais, também conhecidas como forças friccionais ou viscosas

lm

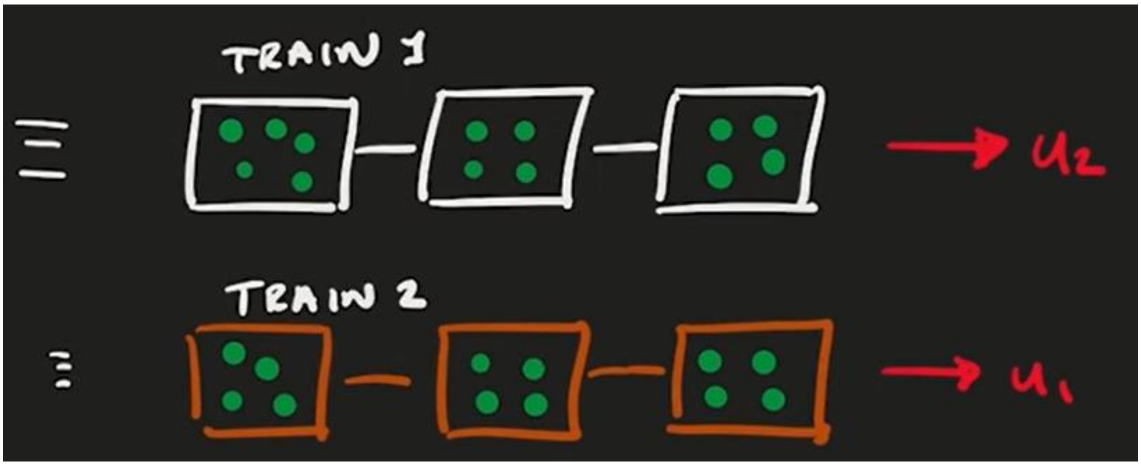
i *j*

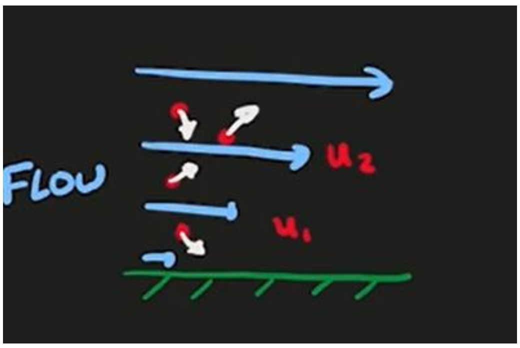


$x \quad x$

x

x





C_D $C\,D$

$\mathrm{C}\frac{}{D}$ $\frac{p}{D}\frac{x}{w}$

$\frac{x}{w}$

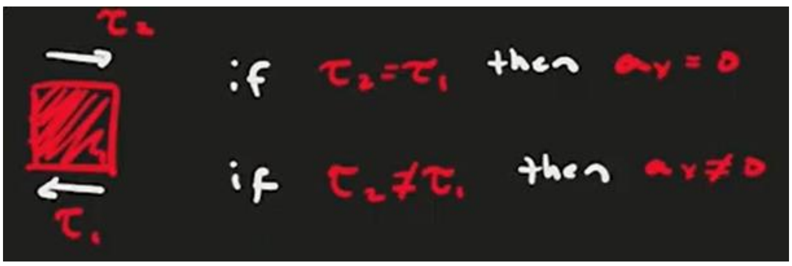
$\frac{x}{w}$ $\frac{x}{w}$ $\frac{x}{w}$

$\frac{p}{D}\frac{x}{w}$ $\frac{p}{D}\frac{}{w}\frac{x}{}$

$\frac{p}{D}\frac{}{w}$

$\frac{p}{D}\frac{}{w}$

$\frac{x}{}$



D D

D D

$\frac{x}{\ }$

$\frac{x}{\ }$ $\frac{x}{\ }$

$\frac{\ }{o}$ $\frac{x}{\ }$

$\frac{\ }{o}$ $\frac{x}{\ }$ $\frac{x}{\ }$ $\frac{x}{\ }$

$\tau \frac{x}{w}$ $\frac{s}{\ }$ $\frac{x}{\ }$ $\frac{x}{\ }$ $\frac{x}{\ }$

$$\tau \frac{y}{w} \quad \frac{s}{} \quad \frac{y}{} \quad \frac{y}{} \quad \frac{y}{}$$

$$\tau \frac{z}{w} \quad \frac{s}{} \quad \frac{z}{} \quad \frac{z}{} \quad \frac{z}{}$$

As forças de corpo

Cρ Cr

$$\overline{\qquad\qquad} \quad Cr$$

$$\tau \frac{x}{w} \quad \frac{s}{} \quad \frac{x}{} \quad \frac{x}{} \quad \frac{x}{} \quad \tau$$

$$\tau \frac{x}{w} \quad x\frac{x}{} \quad y\frac{x}{} \quad z\frac{x}{} \quad \frac{s}{} \quad \frac{x}{} \quad \frac{x}{} \quad \frac{x}{} \quad \tau \quad C$$

hCr up dCvlp lodu Cqdv Cgluh hvĆdChĈdCvhu rCuhvs hf lydp hq hC

$$\tau \frac{}{w} \quad x\frac{y}{} \quad y\frac{y}{} \quad z\frac{y}{} \quad \frac{s}{} \quad \frac{y}{} \quad \frac{y}{} \quad \frac{y}{} \quad \tau \quad C$$

C

$$\tau \frac{z}{w} \quad x\frac{z}{} \quad y\frac{z}{} \quad z\frac{z}{} \quad \frac{s}{} \quad \frac{z}{} \quad \frac{z}{} \quad \frac{z}{} \quad \tau \quad C$$

C

DvC u vCht xd hvCdflp dCfruuhvs rqghp CdCdp rvdC t x rCghCQdylhu V rnhv.Ct xhCqdC irup dCyh ruldC Cds uhvhq dgdCs ruC

τ —— s τ C
w

C

C CDChlCghCfrqvhuyd rCghChqhuj ldC

Srgh vhCglylgluCdChqhuj ldCghCxp Cvlv hp dChp Cgx dvCfodvvhvCglv lq dv-CdChqhuj ldC dup ddhqdgdChCdChqhuj ldChp C udqvl r-CDCs ulp hludChv Cuhodflr qdgdCgluh dp hq hC uhodflr qdgdCfr p CdCp dvvdCgr Cs u s ulr Cvlv hp d.ChChqyr oyhCdvChqhuj ldvCq huqd.Cflq lfdC hCs r hqfldoCdCvhj xqgdCfodvvhCvhCuhodflr qdCfr p CdChqhuj ldC ur f dgdChq uhCvlv hp dv.C lqf oxlqgr Cr Cf dor uChCr C ude ddkr-C r qvlghudqgr C CdChqhuj ldC r doCdup ddhqdgdCs ruCxp C vlv hp dCt xh.Cqxp Cq huydor Cghp Chp s r.Cuhf he hxCxp dCt xdq lgdghCghCf dor uC ChCh hf x r xC xp C ude ddkrC .CdCfr qvhuyd rCghvvhCvlv hp dC CudgxdlgdCd udy vCgdCh s uhvv r-C

C

DCh s uhvv rCdflp dC CdCs ulp hludChlCgdChup r glq p lf d-CC

q r.CdC d dCghCyduld rCgdChqhuj ldCs ruCxqlgdghCghC hp s rC C$\frac{g}{gw}$ .CdvC ur f dvCghC hqhuj ldChih xdgdvCfr p Cr Ch hulr uCvreCr up dCghCf dor uC$\frac{\mu}{gw}$ .ChCdCghC ude ddkr.C$\frac{g}{gw}$ Cuhvxo dqgr Chp -C

$$\frac{g}{gw} \quad C$$

Ct xhCvlj ql lf dCgldhuCt xhCdCd dCghChq udgd.Cs ruCxqlgdghCghChp s r.CghChqhuj ldC up lfdC hCp hf qlfdCqxp Cvlv hp dCp hqr vCdCfruuhvs rqghq hCd dCghCvd gdCghyhu Cj xdodu CdCd dC ghCdfxp xod rCghChqhuj ldCqr Cq hulr uCghvvhCp hvp r Cvlv hp dC

SdudCuhodflr qduChv hvCfr qfhl r vCdflp dCfr p CdCqr rCghCyr oxp hCghCfr q urdh.Chp s uhj d vhCr Cfr qfhl rCghCghqvlgdghCp vvlfdCghChqhuj ldCdup ddhqdgdCs horCvlv hp d.Ch-C

h

μ

p

$\frac{g}{gw}$ — w $h\tau$Çgy o $h\tau$ - gDÇ

p

h

p h

h

h $s\,uhvv\ r$ $ylv\ rvdv$

h

p

$s\,uhvv\ r$

gD

g $s\,uhvv\ r$ s - gD

$s\,uhvv\ r$ s - gD

$ylv\ rvdv$

$g \quad ylv\ rvdv \quad - \quad gD$

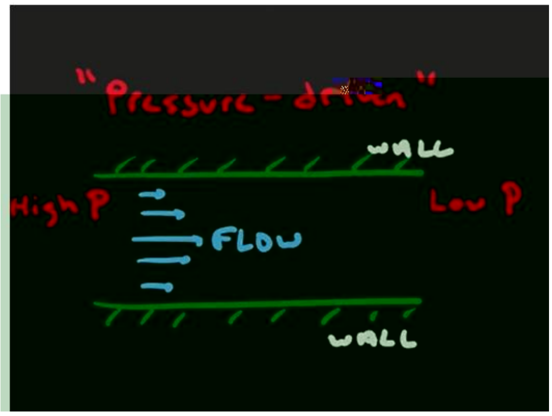
$ylv\ rvdv \quad - \quad gD$

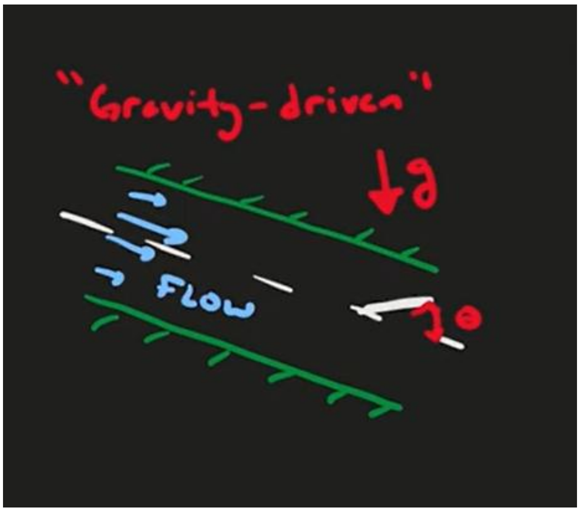
$_p \quad s \quad - \quad gD \quad - \quad gD$

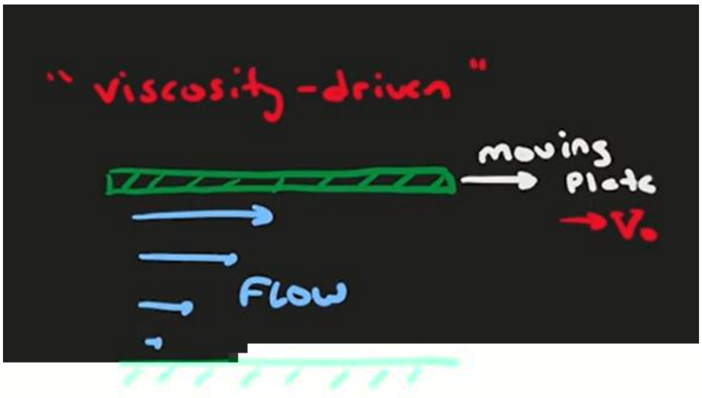
$\overline{\ \ }\ w \quad _{ro} \quad x \quad - \quad \tau Ҁgy \quad o \quad _V \quad x \quad - \quad s \quad - \quad gD$

Hipóteses comum na mecânica dos fluidos

Aplicações simples das leis de conservação de massa e de conservação de quantidade de movimento - Escoamentos laminares internos fechados


WALL
High P
FLOW
Low P
WALL

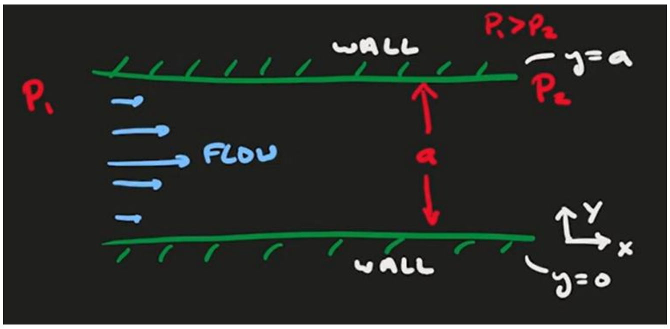




Escoamento plenamente desenvolvido dominado pelas forças de pressão

s s s s

d d



τ vw

$\frac{-}{w}$

$\frac{x}{}$

$\frac{-}{}$ z

τ

x 3 x d

Cz 3 z d

y 3 y d

$\frac{x}{}$ C$\frac{y}{}$ $\frac{z}{}$

$\frac{x}{}$ $\frac{z}{}$

$\frac{y}{}$

$\frac{y}{\quad} g \qquad y \qquad vw \quad F$

F

$x \quad _3 \qquad x \quad _d$

$x \quad _3 \quad -\frac{s}{} \qquad F \qquad F$

F

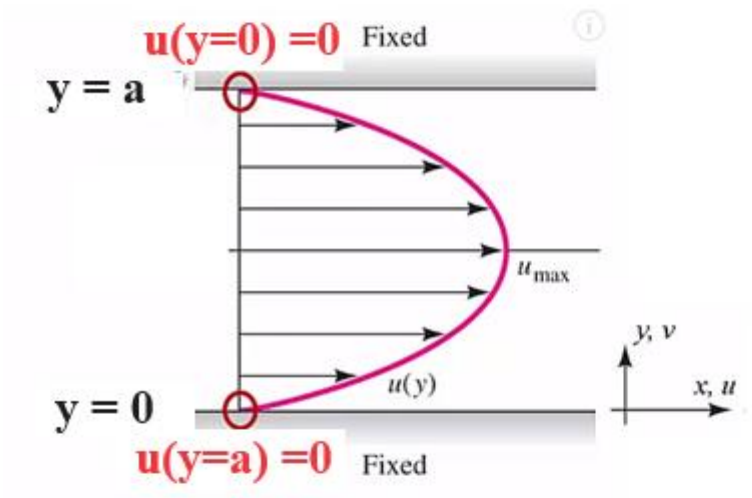
$x \quad _d \quad -\frac{s}{} d \qquad F \; d$

$F \qquad -\frac{s}{}\frac{d}{}$

$F \quad F$

$x \quad -\frac{s}{} \qquad -\frac{s}{}\frac{d}{}$

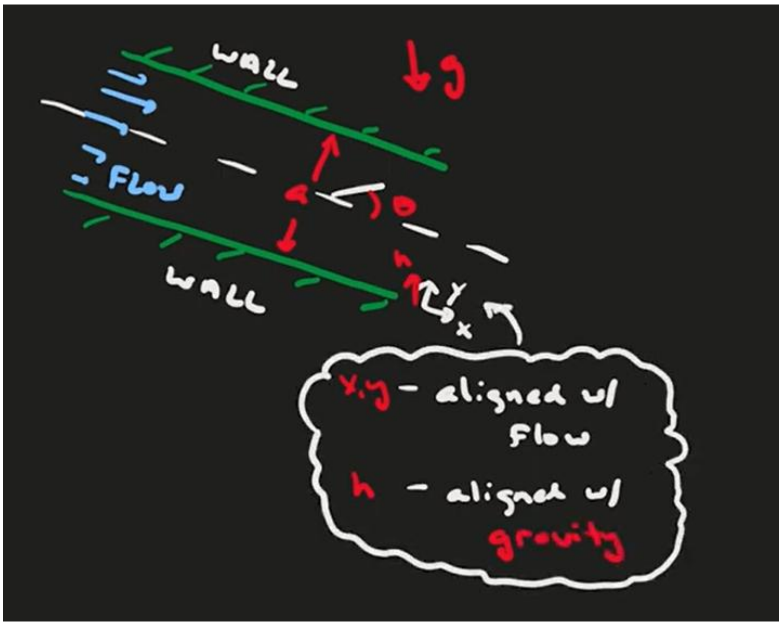
$x \quad -\frac{s}{} \qquad d$



Escoamento plenamente desenvolvido dominado pela força de corpo

d

d



τ vw

$\frac{-}{w}$

$\frac{x}{}$

$\frac{-}{}$ z

x 3 x d

Cz 3 z d

y 3 y d

$\frac{x}{}$ C$\frac{y}{}$ $\frac{z}{}$

$\frac{x}{}$ $\frac{z}{}$

$\frac{y}{}$

$\frac{y}{} g$ y vw F

y $_{3.d}$

F y

τ $\frac{x}{w}$ $x\frac{x}{}$ $y\frac{x}{}$ z $\frac{x}{}$ $\frac{s}{}$ $\frac{x}{}$ $\frac{x}{}$ $\frac{x}{}$ τ C

$\frac{x}{w}$

$x\frac{x}{}$ $x\frac{x}{}$

z $\frac{x}{}$ $\frac{x}{}$

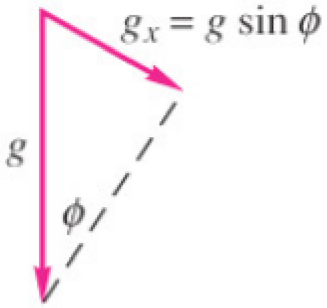
τ

y $y\frac{x}{}$

$\frac{s}{}$ $\frac{x}{}$ τ

$\frac{x}{}$ $\frac{s}{}$ τ

vlq



vlq $\frac{g}{g}$

$\frac{x}{\quad} \quad -\frac{s \quad \tau}{\quad} \qquad vw$

$\frac{x}{\quad} \quad -\frac{s \quad \tau}{\quad} \qquad F$

x

$x \quad -\frac{s \quad \tau}{\quad} \qquad F \qquad F$

$x \quad 3 \qquad x \quad d$

$x \quad 3 \quad -\frac{s \quad \tau j}{\quad} \qquad F \qquad F$

F

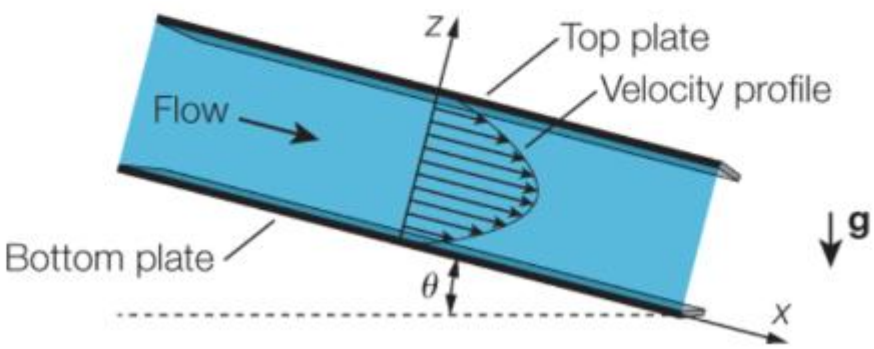
$x \quad _d \quad -\frac{s \quad \tau j}{} \frac{d}{} \quad F\ d$

$F \quad -\frac{s \quad \tau j}{} \frac{d}{}$

$F \quad F$

$x \quad \frac{}{} \frac{s \quad \tau}{} \quad -\frac{s \quad \tau}{} \frac{d}{}$

$x \quad \frac{}{} \frac{s \quad \tau}{} \quad d$



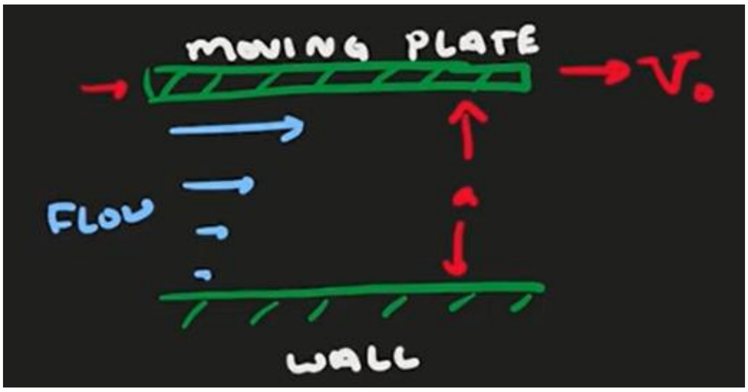
Escoamento plenamente desenvolvido dominado pelas forças friccionais

V s

s s s

d

d



τ vw

$\frac{-}{w}$

$\frac{x}{}$

$\frac{-}{}$ z

x 3 x d 3

Cz 3 z d

y 3 y d

$\frac{x}{}$ $C\frac{y}{}$ $\frac{z}{}$

$\frac{x}{}$ $\frac{z}{}$

$\frac{y}{}$

$\frac{y}{}g$ y vw F

y $_{3.d}$

F y

τ $\frac{x}{w}$ $x\frac{x}{}$ $y\frac{x}{}$ $z\frac{x}{}$ $\frac{s}{}$ $\frac{x}{}$ $\frac{x}{}$ $\frac{x}{}$ τ C

$\frac{x}{w}$

$x\frac{x}{}$ $x\frac{x}{}$

$z\frac{x}{}$ $\frac{x}{}$

τ

y $y\frac{x}{}$

$\frac{x}{}$

$\frac{x}{}$ F

x

x F F

x $_3$ x $_d$ $_3$

x $_3$ F F

F

x $_d$ F d $_3$

F $\frac{}{d}$

$x \quad \frac{3}{d} \qquad d$