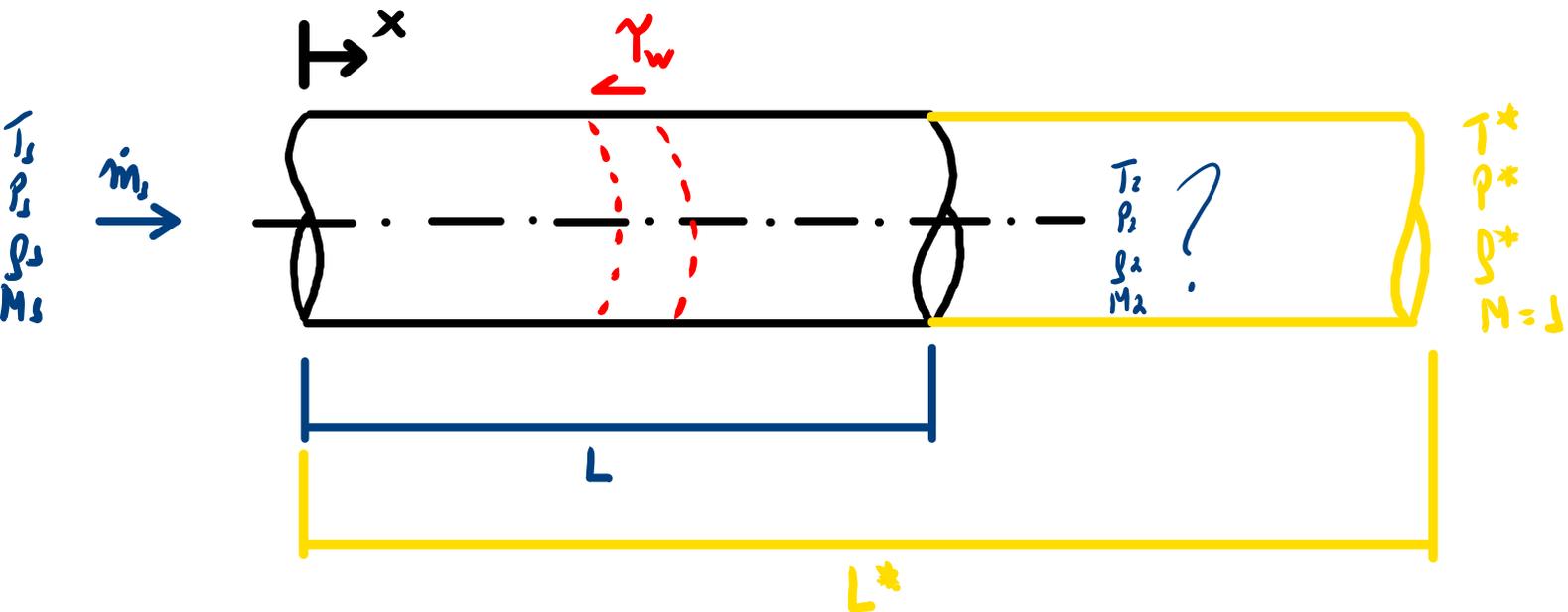


ESCOAMENTO DE FANNO

Condição Sônica

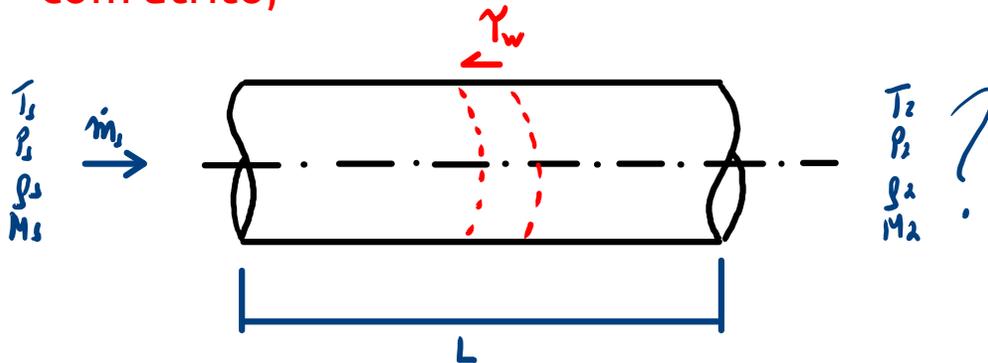


ESCOAMENTO COMPRESSÍVEL

ESCOAMENTO DE FANNO

Escoamento de Fanno se refere a um escoamento:

- * unidimensional;
- * em regime permanente;
- * adiabático;
- * através de um duto de área constante;
- * com atrito;



Hipóteses

- * unidimensional;
- * em regime permanente;
- * adiabático;
- * através de um duto de área constante;
- * com atrito;

Equações governantes

Continuidade

$$\rho_1 V_1 = \rho_2 V_2$$

Momento $\frac{D(m\vec{v})}{Dt} = \frac{d}{dt} \int_{vc} \rho \vec{v} dV + \int_{sc} (\rho \vec{v} \cdot d\vec{A}) \vec{v} = \Sigma \vec{F} = - \int_{sc} p d\vec{A} - \int_{sc} \vec{\tau} d\vec{A}$

Energia $\frac{DE}{Dt} = \frac{d}{dt} \int_{vc} \rho e dV + \int_{sc} e (\rho \vec{v} \cdot d\vec{A}) = \dot{Q} + \dot{W} = - \int_{sc} p d\vec{A} \cdot \vec{v} - \int_{sc} \vec{\tau} d\vec{A} \cdot \vec{v}$

$$p = \rho R T \quad h = c_p T \quad c_p = k R T = k \frac{p}{\rho}$$

$$W = \vec{F} \cdot \frac{d\vec{r}}{dt} = \vec{F} \cdot \vec{V}$$

$$\int_{x_1}^{x_2} \frac{4 \downarrow dx}{D} = \left[-\frac{1}{kM^2} - \frac{k+1}{2k} \ln \left(\frac{M^2}{1 + \frac{k-1}{2} M^2} \right) \right]_{M_1}^{M_2}$$

$b > 0 \Rightarrow$ Coeficiente de atrito médio

$$\bar{\downarrow} = \frac{1}{(x_2 - x_1)} \int_{x_1}^{x_2} \downarrow dx$$

$$\int_{x_1}^{x_2} \frac{4 \downarrow dx}{D} \Rightarrow \frac{4 \bar{\downarrow}}{D} (x_2 - x_1) > 0$$

FUNÇÃO DE FANNO $F(M) = \frac{1}{kM^2} + \frac{k+1}{2k} \ln \left(\frac{M^2}{1 + \frac{k-1}{2} M^2} \right)$

$$\frac{4 \bar{\downarrow} (x_2 - x_1)}{D} = F(M_1) - F(M_2) > 0$$

FUNÇÃO DE FANNO $F(M) = \frac{1}{kM^2} + \frac{k+1}{2k} \ln \left(\frac{M^2}{1 + \frac{k-1}{2} M^2} \right)$

$$F(M_1) > F(M_2)$$



SE M_1 subsônico

$$M_2 > M_1$$

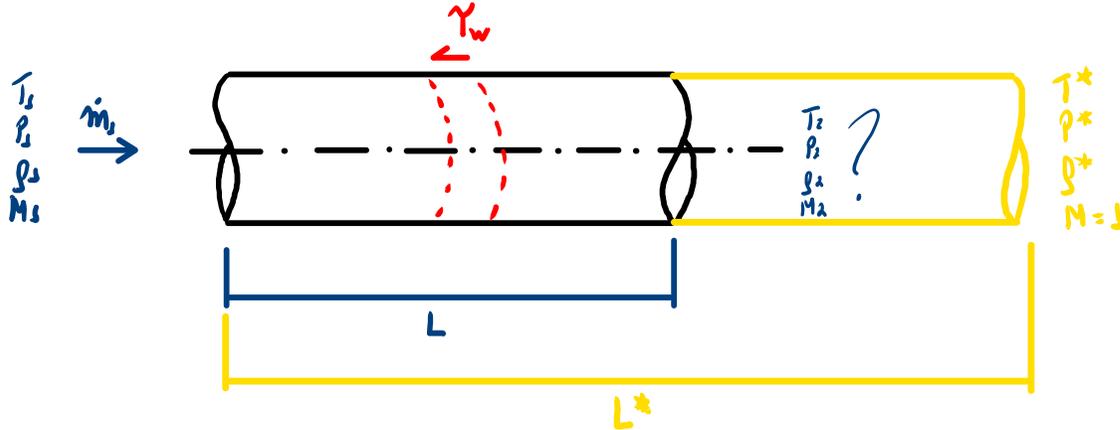
SE M_1 supersônico

$$M_2 < M_1$$

Condição sônica em Escorrimto de Fanno

Escorrimto pode ser levado a Mach 1 se $L = L^*$

• subsônico a uma • supersônico decelera



$$\int_{x_1}^{x_2} \frac{4f dx}{D} = \left[-\frac{1}{kM^2} - \frac{k+1}{2k} \ln \left(\frac{M^2}{1 + \frac{k-1}{2} M^2} \right) \right]_{M_1}^{M_2}$$

$x_2 - x_1 = L^* \rightarrow M_2 = 1$

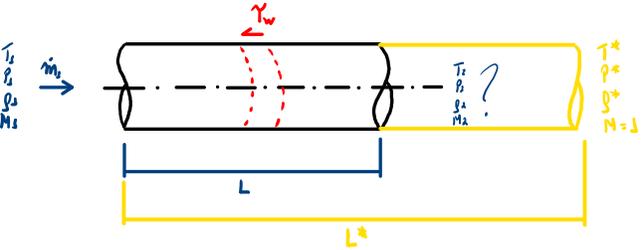
$$\int_{x_1}^{x_2} \frac{y \, dx}{D} = \left[-\frac{1}{kM^2} - \frac{k+1}{2k} \ln \left(\frac{M^2}{1 + \frac{k-1}{2} M^2} \right) \right]_{M_1}^{M_2}$$

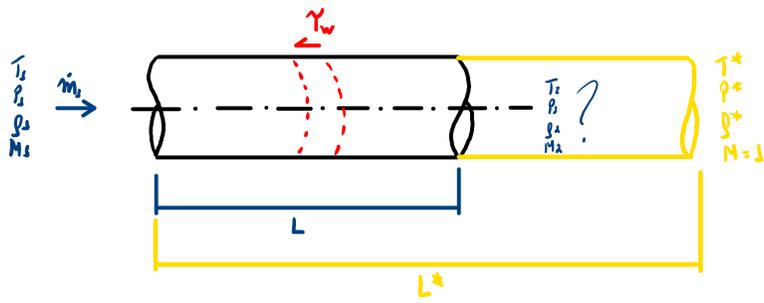
$$\frac{y \, L^*}{D} = \left[-\frac{1}{k} - \frac{k+1}{2k} \ln \left(\frac{1}{1 + (k-1)/2} \right) \right] - \left[-\frac{1}{kM_2^2} - \frac{k+1}{2k} \ln \left(\frac{M_2^2}{1 + 0,5(k-1)M_2^2} \right) \right]$$

LADO DIREITO → SO DEPENDE
DE "M₂" E "k" !

$$L^* = F(M_2)$$

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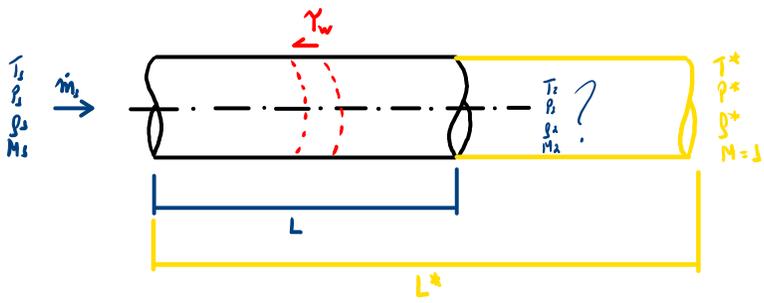
$$\frac{T_2}{T_1} = \frac{2 + (k-1)M_1^2}{2 + (k-1)M_2^2}$$

$$\frac{T^*}{T} = \frac{2 + (k-1)M^2}{k+1}$$

$M < 1 \quad T^* < T$

$M > 1 \quad T^* > T$

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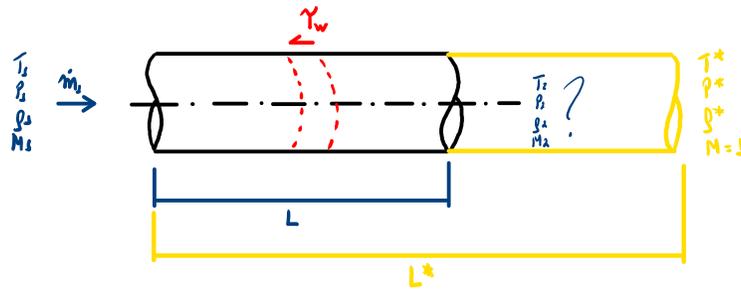
$$\frac{p_2}{p_1} = \frac{M_1}{M_2} \left[\frac{2 + (k-1)M_1^2}{2 + (k-1)M_2^2} \right]^{1/2}$$

$$\frac{p^*}{p} = M \left[\frac{2 + (k-1)M^2}{k+1} \right]^{1/2}$$

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$$M < 1 \quad p^* < p$$

$$M > 1 \quad p^* > p$$



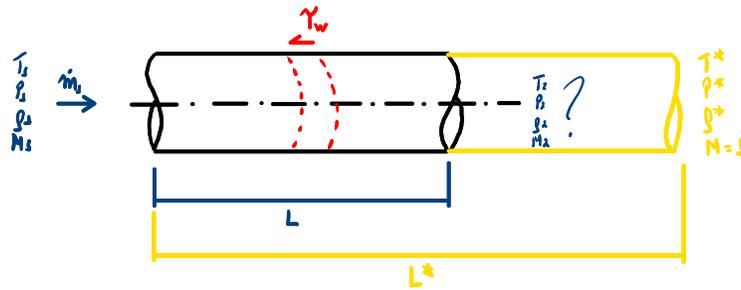
$$\frac{P_2}{S_1} = \frac{M_1}{M_2} \left[\frac{2 + (k-J) M_1^2}{2 + (k-J) M_2^2} \right]^{-1/2}$$

$$\frac{P^*}{S} = M \left[\frac{2 + (k-J) M^2}{k+J} \right]^{-1/2}$$

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$$M < 1 \rightarrow P^* < S$$

$$M > 1 \rightarrow P^* > S$$



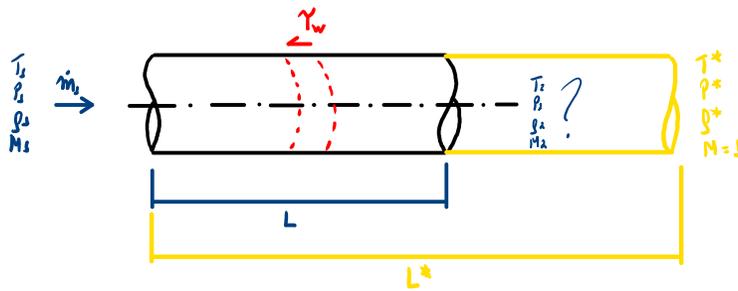
$$\frac{\rho_2}{\rho_1} = \frac{M_1}{M_2} \left[\frac{2 + (k-1)M_1^2}{2 + (k-1)M_2^2} \right]^{-1/2}$$

$$\frac{\rho^*}{\rho} = M \left[\frac{2 + (k-1)M^2}{k+1} \right]^{-1/2}$$

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$$M < 1 \rightarrow \rho^* < \rho$$

$$M > 1 \rightarrow \rho^* > \rho$$

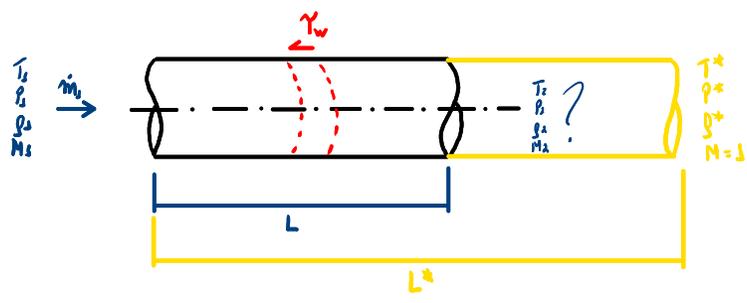


$$\frac{p_2}{p_{01}} = \frac{M_1}{M_2} \left[\frac{2 + (k-1)M_2^2}{2 + (k-1)M_1^2} \right]^{\frac{(k+1)}{2(k-1)}}$$

$$\frac{p_{0^*}}{p_0} = M \left[\frac{k+1}{2 + (k-1)M^2} \right]^{\frac{(k+1)}{2(k-1)}}$$

$$p_{0^*} \leq p_0$$

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$$\frac{p_2}{p_{01}} = \frac{M_1}{M_2} \left[\frac{2 + (k-1)M_2^2}{2 + (k-1)M_1^2} \right]^{\frac{(k+1)}{2(k-1)}}$$

$$\frac{p_{0^*}}{p_0} = M \left[\frac{k+1}{2 + (k-1)M^2} \right]^{\frac{(k+1)}{2(k-1)}}$$

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$$p_{0^*} \leq p_0$$

Tabela 1.4 – Tabela para escoamento unidimensional com atrito. $k = 1,4$

M	$\frac{T}{T^*}$	$\frac{P}{P^*}$	$\frac{\rho}{\rho^*}$	$\frac{P_0}{P_0^*}$	$\frac{4fL^*}{D}$
0,02	1,19990	54,77006	45,64537	28,94213	1778,44988
0,04	1,19962	27,38175	22,82542	14,48149	440,35221
0,06	1,19914	18,25085	15,21999	9,66591	193,03108
0,08	1,19847	13,68431	11,41819	7,26161	106,71822
0,1	1,19760	10,94351	9,13783	5,82183	66,92156
0,12	1,19655	9,11559	7,61820	4,86432	45,40796
0,14	1,19531	7,80932	6,53327	4,18240	32,51131
0,16	1,19389	6,82907	5,72003	3,67274	24,19783
0,18	1,19227	6,06618	5,08791	3,27793	18,54265
0,2	1,19048	5,45545	4,58258	2,96352	14,53327
0,22	1,18850	4,95537	4,16945	2,70760	11,59605
0,24	1,18633	4,53829	3,82548	2,49556	9,38648
0,26	1,18399	4,18505	3,53470	2,31729	7,68757
0,28	1,18147	3,88199	3,28571	2,16555	6,35721
0,3	1,17878	3,61906	3,07017	2,03507	5,29925
0,32	1,17592	3,38874	2,88179	1,92185	4,44674
4,86	0,20965	0,09421	0,44939	22,33061	0,68717
4,88	0,20823	0,09351	0,44907	22,69631	0,68814
4,9	0,20683	0,09281	0,44875	23,06712	0,68911
4,92	0,20543	0,09212	0,44843	23,44311	0,69007
4,94	0,20406	0,09144	0,44812	23,82434	0,69102
4,96	0,20269	0,09077	0,44782	24,21086	0,69196
4,98	0,20134	0,09010	0,44751	24,60272	0,69288
5	0,20000	0,08944	0,44721	25,00000	0,69380

The logo consists of a large yellow circle centered on a red background. Inside the circle, the text "CIÊNCIAS TÉRMICAS" is written in a bold, white, sans-serif font, with "CIÊNCIAS" on the top line and "TÉRMICAS" on the bottom line. Below this, ".com" is written in a smaller, white, sans-serif font.

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