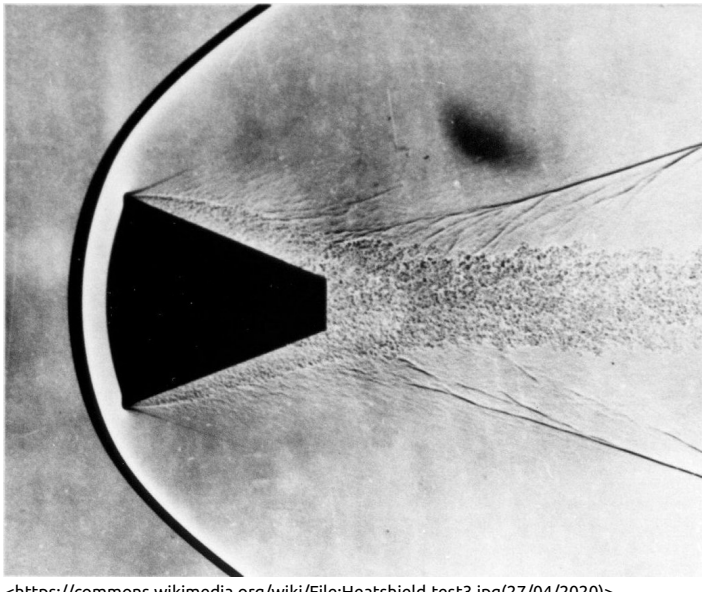
ESCOAMENTO COMPRESSÍVEL

EXERCÍCIO

PROPRIEDADES APÓS CHOQUE NORMAL

Uma onde de choque normal ocorre na seção de testes de um túnel de ventos supersônico. A montante da onda M_1=3, P_1=0,5atm e T_1=200K. Encontre Mach, pressão, temperatura e massa específica após o choque.



<https://commons.wikimedia.org/wiki/File:Heatshield-test3.jpg(27/04/2020)>

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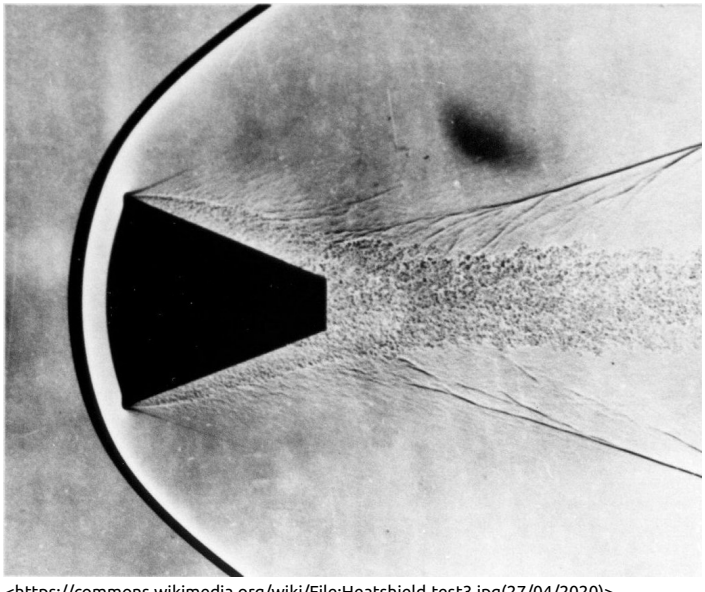

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EXERCÍCIO

PROPRIEDADES APÓS CHOQUE NORMAL

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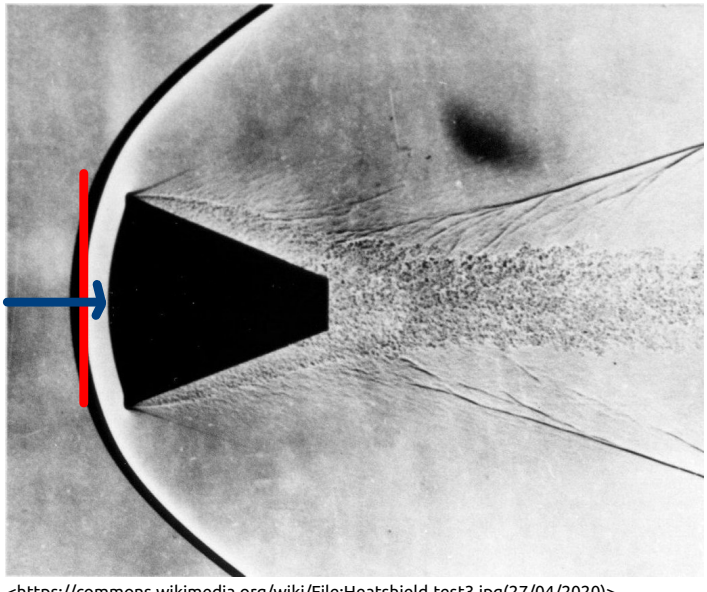

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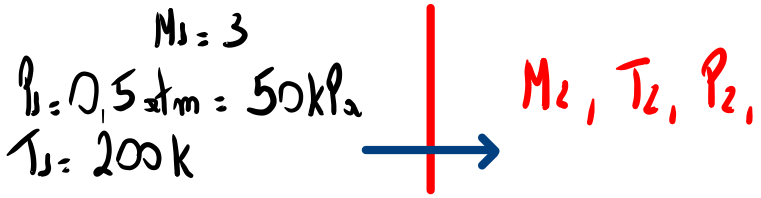
Uma onde de choque normal ocorre na seção de testes de um túnel de ventos supersônico. A montante da onda $M_1=3$, $P_1=0,5atm$ e $T_1=200K$. Encontre Mach, pressão, temperatura e massa específica após o choque.



ρ_2

Ar $\begin{cases} k = 1,4 \\ R = 287 \frac{J}{kg\,K} \end{cases}$

$$P_1 = \rho_1 R T_1$$

$$\rho_1 = \frac{50.10^3\ \rho_2}{287 \frac{J}{kg\,K} \cdot 200\,K}$$

$$\rho_1 = 0,87108\ kg/m^3$$

Formulário

Gráficos

Calculadora Online

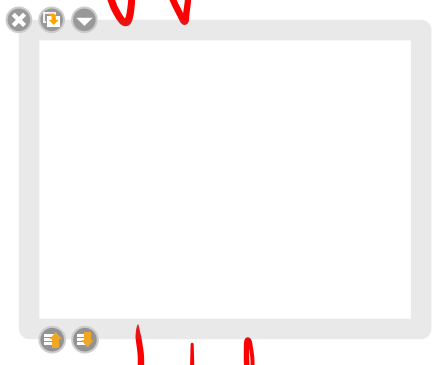
$$M_2^2 = \frac{1+[\frac{k-1}{2}]M_1^2}{kM_1^2 - \frac{k-1}{2}}$$

$$\frac{\rho_2}{\rho_1} = \frac{V_1}{V_2} = \frac{(k+1)M_1^2}{2+(k-1)M_1^2}$$

$$\frac{P_2}{P_1} = 1 + \frac{2k}{k+1}(M_1^2 - 1)$$

$$\frac{T_2}{T_1} = \frac{h_2}{h_1} = \left[1 + \frac{2k}{k+1}(M_1^2 - 1)\right]\left[\frac{2+(k-1)M_1^2}{(k+1)M_1^2}\right]$$

$$s_2 - s_1 = -R\ln\frac{P_{o2}}{P_{o1}}$$



Tabelas

Tabela 1.2 – Tabela para Choque Normal. $k = 1,4$

M_1	M_2	$\frac{\rho_2}{\rho_1}$	$\frac{P_2}{P_1}$	$\frac{T_2}{T_1}$	ds	$\frac{P_{o2}}{P_{o1}}$	$\frac{P_{o2}}{P_1}$
1,00	1,000000	1,000000	1,000000	1,000000	0,000000	1,000000	1,892929
1,02	0,980519	1,033441	1,047133	1,013249	0,000003	0,999990	1,937897
1,04	0,962025	1,067088	1,095200	1,026345	0,000022	0,999923	1,984423
1,06	0,944445	1,100921	1,144200	1,039312	0,000072	0,999751	2,032453
1,08	0,927713	1,134925	1,194133	1,052170	0,000163	0,999431	2,081942
1,10	0,911770	1,169082	1,245000	1,064938	0,000308	0,998928	2,132847
1,12	0,896563	1,203377	1,296800	1,077634	0,000513	0,998213	2,185134
1,14	0,882042	1,237793	1,349533	1,090274	0,000787	0,997261	2,238769
1,16	0,868162	1,272315	1,403200	1,102872	0,001135	0,996052	2,293725
1,18	0,854884	1,306927	1,457800	1,115441	0,001563	0,994569	2,349977
1,20	0,842170	1,341615	1,513333	1,127994	0,002074	0,992798	2,407502
1,22	0,829986	1,376364	1,569800	1,140541	0,002673	0,990731	2,466280
1,24	0,818301	1,411160	1,627200	1,153094	0,003361	0,988359	2,526294
1,26	0,807085	1,445989	1,685533	1,165661	0,004140	0,985677	2,587527
1,28	0,796312	1,480839	1,744800	1,178251	0,005014	0,982682	2,649964
1,30	0,785957	1,515695	1,805000	1,190873	0,005982	0,979374	2,713594

http://www.dept.aoe.vt.edu/~devenpor/aoe3114/calc.html

Formulário

MACH

Gráfico

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

$$M_2' = \frac{1 + \frac{(1,4-1)}{2} \cdot 3'^2}{1,4 \cdot 3'^2 - \frac{(1,4-1)}{2}}$$

$$M_2 = 0,475$$

PRESSÃO

Formulário

Gráfico

$$\frac{P_2}{P_1} = 1 + \frac{2k}{k+1}\left(M_1^2 - 1\right)$$

$$\frac{P_2}{P_1} = 1 + \frac{2 \cdot 1{,}4}{1{,}4 + 1}\left(3^2 - 1\right)$$

$$\frac{P_2}{P_1} = 10{,}33$$

$$P_2 = 5{,}165 \text{ atm}$$

Massa Específica

Formulário

Gráfico

$$\frac{\rho_2}{\rho_1} = \frac{(k+1)M_1'}{2+(k-1)M_1'}$$

$$\frac{\rho_2}{\rho_1} = \frac{(1{,}4+1)\cdot 3'}{2+(1{,}4-1)\cdot 3'}$$

$$\frac{\rho_2}{\rho_1} = 3{,}8571$$

$$\rho_2 = 3{,}3538 \ \frac{kg}{m^3}$$

TEMPERATURA

Formulário

$$P = \rho R T \rightarrow T = \frac{P}{\rho R}$$

$$\frac{T_2}{P_2} = \frac{P_2}{\rho_2 \cdot R} \cdot \frac{\rho_1 R}{P_1} \rightarrow \frac{T_2}{T_1} = \frac{P_2}{P_1} \cdot \frac{\rho_1}{\rho_2}$$

$$\frac{T_2}{T_1} = \left[1 + \frac{2k}{k+1}\left(M_1^2 - 1\right)\right]\left[\frac{2 + (k-1)M_1^2}{(k+1)M_1^2}\right]$$

$$\frac{T_2}{T_1} = 10{,}33 \cdot \frac{1}{3{,}8571}$$

$$\frac{T_2}{T_1} = 2{,}6795$$

$$T_2 = 535{,}8\ K$$

Gráfico

Propriedades de Estagnação e Críticas

$M_1 = 3$	$M_2 = 0{,}475$
$P_1 = 0{,}5\ atm$	$P_2 = 5{,}165\ atm$
$T_1 = 200\ k$	$T_2 = 535{,}8\ k$

T_{01}, P_{01} ← → T_{02}, P_{02}

T_1^*, P_1^* $\qquad$ T_2^*, P_2^*

$$\frac{T_0}{T} = \left(\frac{P_0}{P}\right)^{\frac{k-1}{k}} = \left(\frac{\rho_0}{\rho}\right)^{k-1}$$

$$\frac{T_0}{T^*} = \left(\frac{P_0}{P^*}\right)^{\frac{k-1}{k}} = \left(\frac{\rho_0}{\rho^*}\right)^{k-1}$$

Propriedades de Estagnação e Críticas

$M_1 = 3$ | $M_2 = 0{,}475$

$P_1 = 0{,}5\ atm$ | $P_2 = 5{,}165\ atm$

$T_1 = 200\ k$ | $T_2 = 535{,}8\ k$

$$\frac{T_{01}}{T_1} = 1 + \frac{k-1}{2} M_1^2 \rightarrow \frac{T_{01}}{T_1} = 2{,}8 \rightarrow T_{01} = 560\ k$$

$$\frac{P_{01}}{P_1} = \left(\frac{T_{01}}{T_1}\right)^{k/k-1} \rightarrow \frac{P_{01}}{P_1} = 2{,}8^{3{,}5} = 36{,}73 \rightarrow P_{01} = 18{,}36\ atm$$

$$\frac{\rho_{01}}{\rho_1} = \left(\frac{T_{01}}{T_1}\right)^{1/k-1} = 13{,}1188 \rightarrow \rho_{01} = 11{,}427\ kg/m^3$$

Propriedades de Estagnação e Críticas

$M_1 = 3$	$M_2 = 0{,}475$
$p_1 = 0{,}5\ atm$	$p_2 = 5{,}165\ atm$
$T_1 = 200\ k$	$T_2 = 535{,}8\ k$

$$\frac{T_{01}}{T_1^*} = \frac{k+1}{2} \Rightarrow T_1^* = 466{,}67\ k$$

$$\frac{p_{01}}{p_1^*} = \left(\frac{T_{01}}{T_1^*}\right)^{k/k-1} \rightarrow p_1^* = 3{,}7\ atm$$

$$\frac{\rho_{01}}{\rho_1^*} = \left(\frac{T_{01}}{T_1^*}\right)^{1/k-1} \rightarrow \frac{\rho_{01}}{\rho_1^*} = 3{,}57144 \rightarrow \rho_1^* = 7{,}2440\ \frac{kg}{m^3}$$

Propriedades de Estagnação e Críticas

$M_1 = 3$
$p_1 = 0{,}5\ atm$
$T_1 = 200\ k$

$M_2 = 0{,}475$
$p_2 = 5{,}165\ atm$
$T_2 = 535{,}8\ k$

$\rho_2 = 3{,}3588\ kg/m^3$

$$\frac{T_{o2}}{T_2} = 1 + \frac{k-1}{2} M_2^2 \rightarrow \frac{T_{o2}}{T_2} = 1{,}045125 \rightarrow T_{o2} = 560k$$

$$\frac{p_{o2}}{p_2} = \left(\frac{T_{o2}}{T_2}\right)^{k/k-1} \rightarrow \frac{p_{o2}}{p_2} = 1{,}045125^{3{,}5} = 1{,}167 \rightarrow p_{o2} = 6{,}03\ atm$$

$$\frac{\rho_{o2}}{\rho_2} = \left(\frac{T_{o2}}{T_2}\right)^{1/k-1} \rightarrow \frac{\rho_{o2}}{\rho_2} = 1{,}1168 \rightarrow \rho_{o2} = 3{,}751\ kg/m^3$$

Propriedades de Estagnação e Críticas

$M_1 = 3$
$p_1 = 0{,}5\ atm$
$T_1 = 200\ K$

$M_2 = 0{,}475$
$p_2 = 5{,}165\ atm$
$T_2 = 535{,}8\ K$

$\rho_2 = 3{,}3588\ kg/m^3$

$$\frac{T_{02}}{T_2^*} = \frac{k+1}{2} \Rightarrow T_2^* = 466{,}67\ K = T_1^*$$

$$\frac{p_{02}}{p_2^*} = \left(\frac{T_{02}}{T_2^*}\right)^{k/k-1} \Rightarrow p_2^* = 3{,}18\ atm$$

$$\frac{\rho_{02}}{\rho_2^*} = \left(\frac{T_{02}}{T_2^*}\right)^{1/k-1} \Rightarrow \frac{\rho_{02}}{\rho_2^*} = 1{,}57144 \Rightarrow \rho_2^* = 2{,}3773\ \frac{kg}{m^3}$$

$$ds = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

ou

$$s_{2^0} - s_{1^0} = s_2 - s_1$$

$$\rightsquigarrow ds = c_p \ln\left(\frac{T_{2^0}}{T_{1^0}}\right) - R \ln\left(\frac{P_{02}}{P_{01}}\right) \rightsquigarrow ds = -R \ln\left(\frac{P_{02}}{P_{01}}\right)$$

+ $ds = 1{,}0045 \frac{kJ}{kg\,K} \ln\left(\frac{535{,}8}{200}\right) - 0{,}287 \frac{kJ}{kg\,K} \ln\left(\frac{5{,}1965}{0{,}5}\right) \rightsquigarrow ds = 0{,}3197 \frac{kJ}{K}$

+ $ds = -0{,}287 \frac{kJ}{kg\,K} \ln\left(\frac{603}{18{,}36}\right) \rightsquigarrow ds = 0{,}3196 \frac{kJ}{K}$

Tabela 1.2 – Continuação da página anterior

M_1	M_2	$\frac{\rho_2}{\rho_1}$	$\frac{P_2}{P_1}$	$\frac{T_2}{T_1}$	ds	$\frac{P_{02}}{P_{01}}$	$\frac{P_{02}}{P_1}$
2,00	0,577350	2,666667	4,500000	1,687500	0,093933	0,720874	5,640441
2,02	0,573972	2,696181	4,593800	1,703817	0,097678	0,711527	5,743330
2,04	0,570679	2,725463	4,688533	1,720271	0,101473	0,702180	5,847268
2,06	0,567467	2,754511	4,784200	1,736860	0,105317	0,692839	5,952256
2,08	0,564334	2,783325	4,880800	1,753586	0,109207	0,683512	6,058292
2,10	0,561277	2,811902	4,978333	1,770450	0,113142	0,674203	6,165375
2,12	0,558294	2,840243	5,076800	1,787453	0,117122	0,664919	6,273505
2,14	0,555383	2,868345	5,176200	1,804594	0,121144	0,655666	6,382681
2,16	0,552541	2,896209	5,276533	1,821876	0,125208	0,646447	6,492903
2,18	0,549766	2,923834	5,377800	1,839297	0,129312	0,637269	6,604169
2,20	0,547056	2,951220	5,480000	1,856860	0,133454	0,628136	6,716480
2,22	0,544409	2,978365	5,583133	1,874563	0,137635	0,619053	6,829835
2,24	0,541822	3,005271	5,687200	1,892409	0,141852	0,610023	6,944232
2,26	0,539295	3,031936	5,792200	1,910397	0,146105	0,601051	7,059673
2,28	0,536825	3,058362	5,898133	1,928527	0,150391	0,592140	7,176155
2,30	0,534411	3,084548	6,005000	1,946801	0,154711	0,583295	7,293680
2,32	0,532051	3,110495	6,112800	1,965218	0,159063	0,574517	7,412245
2,34	0,529743	3,136202	6,221533	1,983779	0,163446	0,565810	7,531852
2,36	0,527486	3,161671	6,331200	2,002485	0,167858	0,557177	7,652499
2,38	0,525278	3,186902	6,441800	2,021336	0,172299	0,548621	7,774187
2,40	0,523118	3,211896	6,553333	2,040332	0,176767	0,540144	7,896914
2,42	0,521004	3,236653	6,665800	2,059473	0,181265	0,531748	8,020681
2,44	0,518936	3,261174	6,779200	2,078760	0,185787	0,523435	8,145487
2,46	0,516911	3,285461	6,893533	2,098194	0,190334	0,515208	8,271331
2,48	0,514929	3,309514	7,008800	2,117773	0,194905	0,507067	8,398214
2,50	0,512989	3,333333	7,125000	2,137500	0,199499	0,499015	8,526136
2,52	0,511089	3,356921	7,242133	2,157374	0,204116	0,491052	8,655095
2,54	0,509228	3,380279	7,360200	2,177394	0,208754	0,483181	8,785092
2,56	0,507406	3,403407	7,479200	2,197563	0,213412	0,475402	8,916127
2,58	0,505620	3,426307	7,599133	2,217879	0,218090	0,467715	9,048199
2,60	0,503871	3,448980	7,720000	2,238343	0,222787	0,460123	9,181308
2,62	0,502157	3,471427	7,841800	2,258956	0,227502	0,452625	9,315453
2,64	0,500477	3,493651	7,964533	2,279717	0,232235	0,445223	9,450636
2,66	0,498830	3,515651	8,088200	2,300626	0,236984	0,437916	9,586854
2,68	0,497216	3,537431	8,212800	2,321685	0,241749	0,430705	9,724109
2,70	0,495634	3,558991	8,338333	2,342892	0,246530	0,423590	9,862399
2,72	0,494082	3,580333	8,464800	2,364249	0,251325	0,416572	10,001726
2,74	0,492560	3,601458	8,592200	2,385756	0,256133	0,409650	10,142088
2,76	0,491068	3,622369	8,720533	2,407412	0,260955	0,402825	10,283485
2,78	0,489604	3,643066	8,849800	2,429218	0,265790	0,396096	10,425918
2,80	0,488167	3,663551	8,980000	2,451173	0,270636	0,389464	10,569386
2,82	0,486758	3,683827	9,111133	2,473279	0,275494	0,382927	10,713888
2,84	0,485376	3,703894	9,243200	2,495536	0,280363	0,376486	10,859426
2,86	0,484019	3,723755	9,376200	2,517942	0,285241	0,370141	11,005998
2,88	0,482687	3,743411	9,510133	2,540500	0,290130	0,363890	11,153605
2,90	0,481380	3,762864	9,645000	2,563207	0,295027	0,357733	11,302246
2,92	0,480096	3,782115	9,780800	2,586066	0,299933	0,351670	11,451922
2,94	0,478836	3,801167	9,917533	2,609076	0,304846	0,345701	11,602632
2,96	0,477599	3,820021	10,055200	2,632237	0,309767	0,339823	11,754375
2,98	0,476384	3,838679	10,193800	2,655549	0,314696	0,334038	11,907153
3,00	0,475191	3,857143	10,333333	2,679012	0,319630	0,328344	12,060965

TABELA PARA CHOQUE NORMAL!

$M_1 = 3$

Equação

$M_2 = 0,475191$ (0,4752)

$\frac{\rho_2}{\rho_1} = 3,857143$ (3,8571)

$\frac{P_2}{P_1} = 10,333$ (10,33)

$\frac{T_2}{T_1} = 2,679012$ (2,6790)

$ds = 0,319630$ (0,31931)

$\frac{P_{02}}{P_1} = 12,060365$ $\left(\frac{6,03}{0,5} = 12,06\right)$

Propriedades de Estagnação 1

$M_1 = 3$ | $M_2 = 0{,}475$

$P_1 = 0{,}5\ atm$ | $P_2 = 5{,}165\ atm$

$T_1 = 200\ k$ | $T_2 = 535{,}8\ k$

Tabela 1.1 – Tabela para escoamento Isoentrópico. $k = 1{,}4$

M	$\frac{T_o}{T}$	$\frac{P_o}{P}$	$\frac{\rho_o}{\rho}$
2,02	1,816080000	8,071837587	4,444648686
2,04	1,832320000	8,327307979	4,544679957
2,06	1,848720000	8,591104239	4,647055389
2,08	1,865280000	8,863476911	4,751821127
2,10	1,882000000	9,144683243	4,859024040
2,12	1,898880000	9,434987325	4,968711727
2,14	1,915920000	9,734660242	5,080932524
2,90	2,682000000	31,594079549	11,780044575
2,92	2,705280000	32,564377179	12,037340748
2,94	2,728720000	33,562662760	12,299782594
2,96	2,752320000	34,589655845	12,567454309
2,98	2,776080000	35,646091744	12,840441106
3,00	2,800000000	36,732721805	13,118829216
3,02	2,824080000	37,850313686	13,402705903

Continua na página posterior

$\frac{T_{o1}}{T_1} = 2{,}8$ (2,8)

$\frac{P_{o1}}{P_1} = 36{,}7321\,21805$ (36,73)

$\frac{\rho_{o1}}{\rho_1} = 13{,}1188$ (13,1188)

Propriedades Criticas 1

$M_1 = 3$ | $M_2 = 0{,}475$

$P_1 = 0{,}5\ atm$ | $P_2 = 5{,}165\ atm$

$T_1 = 200\ k$ | $T_2 = 535{,}8\ k$

Tabela 1.1 – Tabela para escoamento Isoentrópico. $k = 1{,}4$

M	$\frac{T_o}{T}$	$\frac{P_o}{P}$	$\frac{\rho_o}{\rho}$
1,00	1,200000000	1,892929159	1,577440966
1,02	1,208080000	1,937915922	1,604128801
1,04	1,216320000	1,984574779	1,631622253
1,06	1,224720000	2,032960007	1,659938604
1,08	1,233280000	2,083127778	1,689095565
1,10	1,242000000	2,135136208	1,719111279

$\frac{T_{o1}}{T_1^*} = 1{,}2$ $\quad \frac{T_o}{T^*} = \frac{k+1}{2} = 1{,}2$

$\frac{P_{o1}}{P_1^*} = 1{,}893\,23\,23\,153$ $\quad \left(\frac{18{,}36}{9{,}7} = 1{,}893\,783\right)$

$\frac{\rho_{o1}}{\rho_1^*} = 1{,}577\,440\,966$ ✓

Propriedades de Estagnação 2

$M_1 = 3$ | $M_2 = 0{,}475$

$P_1 = 0{,}5\ atm$ | $P_2 = 5{,}165\ atm$

$T_1 = 200\ k$ | $T_2 = 535{,}8\ k$

Tabela 1.1 – Tabela para escoamento Isoentrópico. $k = 1{,}4$

M	$\frac{T_o}{T}$	$\frac{P_o}{P}$	$\frac{\rho_o}{\rho}$
0,00	1,000000000	1,000000000	1,000000000
0,02	1,000080000	1,000280028	1,000200012
0,04	1,000320000	1,001120448	1,000800192
0,06	1,000720000	1,002522269	1,001800972
0,08	1,001280000	1,004487173	1,003203073
0,10	1,002000000	1,007017518	1,005007502
0,12	1,002880000	1,010116340	1,007215559
0,14	1,003920000	1,013787360	1,009828831
0,16	1,005120000	1,018034982	1,012849194
0,18	1,006480000	1,022864304	1,016278817
0,20	1,008000000	1,028281121	1,020120160
0,22	1,009680000	1,034291935	1,024375975
0,24	1,011520000	1,040903957	1,029049309
0,26	1,013520000	1,048125123	1,034143503
0,28	1,015680000	1,055964098	1,039662194
0,30	1,018000000	1,064430286	1,045609318
0,32	1,020480000	1,073533846	1,051989110
0,34	1,023120000	1,083285700	1,058806103
0,36	1,025920000	1,093697545	1,066065136
0,38	1,028880000	1,104781869	1,073771352
0,40	1,032000000	1,116551966	1,081930199
0,42	1,035280000	1,129021948	1,090547435
0,44	1,038720000	1,142206766	1,099629126
0,46	1,042320000	1,156122222	1,109181654
0,48	1,046080000	1,170784991	1,119211715

M			
0,46	1,04232	1,156122	1,109381654
0,475	T_{o_2}/T_2	P_{o_2}/P_2	ρ_{o_2}/ρ_2
0,48	1,04608	1,170784991	1,119211715

$\frac{T_{o_2}}{T_2} = 1{,}0442$ $(1{,}045325)$

$\frac{P_{o_2}}{P_2} = 1{,}1634$ $(1{,}167)$

$\frac{\rho_{o_2}}{\rho_2} = 1{,}1142$ $(1{,}1167)$

Propriedades Criticas 2

$M_1 = 3$	$M_2 = 0,475$
$P_1 = 0,5\ atm$	$P_2 = 5,165\ atm$
$T_1 = 200\ k$	$T_2 = 535,8k$

Tabela 1.1 – Tabela para escoamento Isoentrópico. $k = 1,4$

M	$\frac{T_o}{T}$	$\frac{P_o}{P}$	$\frac{\rho_o}{\rho}$
1,00	1,200000000	1,892929159	1,577440966
1,02	1,208080000	1,937915922	1,604128801
1,04	1,216320000	1,984574779	1,631622253
1,06	1,224720000	2,032960007	1,659938604
1,08	1,233280000	2,083127778	1,689095565
1,10	1,242000000	2,135136208	1,719111279

$\frac{T_{o2}}{T_2} = 1,2 \quad \left(\frac{560}{466,67} = 1,2\right)$

$\frac{P_{o2}}{P_2} = 1,892929153 \quad \left(\frac{6,03}{3,18} = 1,896226\right)$

CALCULADORA ONLINE $M_1 = 3$

$M_2 = 0,475193$ $(0,475)$

$\frac{p_2}{p_1} = 3,857143$ $(3,8571)$

$\frac{p_2}{p_1} = 30,333$ $(30,33)$

$\frac{T_2}{T_1} = 2,679312$ $(2,6790)$

$ds = 0,31963$ $(0,3196)$

$\frac{p_{02}}{p_1} = 12,060365$ $\left(\frac{6,03}{0,5} = 12,06\right)$

Propriedades de Estagnação e Críticas I

$M_3 = 3$ | $M_2 = 0{,}475$

$P_3 = 0{,}5\ atm$ | $P_2 = 5{,}165\ atm$

$T_1 = 200\ K$ | $T_2 = 535{,}8\ K$

$$\frac{T_{01}}{T_1} = 2{,}8 \rightsquigarrow \frac{T_1}{T_{01}} = 0{,}35714$$

$$\frac{P_{01}}{P_1} = 36{,}73 \rightsquigarrow \frac{P_1}{P_{01}} = 0{,}02722$$

$$\frac{P_1}{P_1^*} = 0{,}0515325 \rightarrow P_1^* = 3{,}10\ atm$$

$$\frac{T_1}{T_1^*} = 0{,}42851142 \rightarrow T_1^* = 466{,}17\ K$$

Propriedades de Estagnação e Críticas 2

$M_1 = 3$	$M_2 = 0{,}475$
$p_1 = 0{,}5\ atm$	$p_2 = 5{,}165\ atm$
$T_1 = 200\ k$	$T_2 = 535{,}8\ k$

Compressible Aerodynamics ***Calculator*** 3.0

What's this? .....Smartphone Version (1/31/11)...HP Prime version (8/25/14)...Recently added ..... Other Java

Isentropic Flow Relations Perfect Gas, Gamma = 1.4, angles in degrees.

INPUT: Mach number = 0.475 Calculate

Mach number=	0.475	**Mach angle=**		**P-M angle=**			
p/p0=	0.85686257	**rho/rho0=**	0.89552849	**T/T0=**	0.95682334		
p/p*=	1.62198014	**rho/rho*=**	1.41264333	**T/T*=**	1.14818801	**A/A*=**	1.39080858

Normal Shock Relations Perfect Gas, Gamma = 1.4

INPUT: M1 = 2.0 Calculate

M1=		**M2=**		**p02/p01=**		**p1/p02=**	
p2/p1=		**rho2/rho1=**		**T2/T1=**			

$$\frac{T_{02}}{T_2} = 1{,}045115 \rightsquigarrow \frac{T_2}{T_{02}} = 0{,}9568233$$

$$\frac{p_{02}}{p_2} = 1{,}167 \rightsquigarrow \frac{p_2}{p_{02}} = 0{,}856898\ldots$$

$M_1 = 3$ | $M_2 = 0{,}475$

$P_1 = 0{,}5\ atm$ | $P_2 = 5{,}165\ atm$

$T_1 = 200\ K$ | $T_2 = 535{,}8\ K$

$T_{01} = 560\ K$ | $T_{02} = 560\ K$

$P_{01} = 18{,}36\ atm$ | $P_{02} = 4{,}03\ atm$

$\rho_{01} = 11{,}427\ kg/m^3$ | $\rho_{02} = 3{,}751\ kg/m^3$

$T_1^* = 466{,}67\ K$ | $T_2^* = 466{,}67\ K$

$P_1^* = 9{,}7\ atm$ | $P_2^* = 3{,}18\ atm$

$\rho_1^* = 7{,}245\ kg/m^3$ | $\rho_2^* = 2{,}3779\ kg/m^3$

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