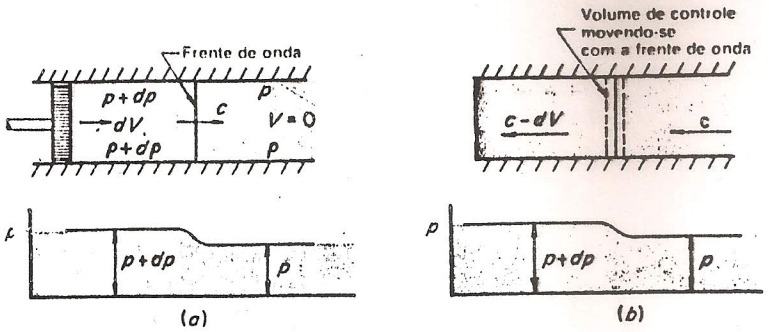
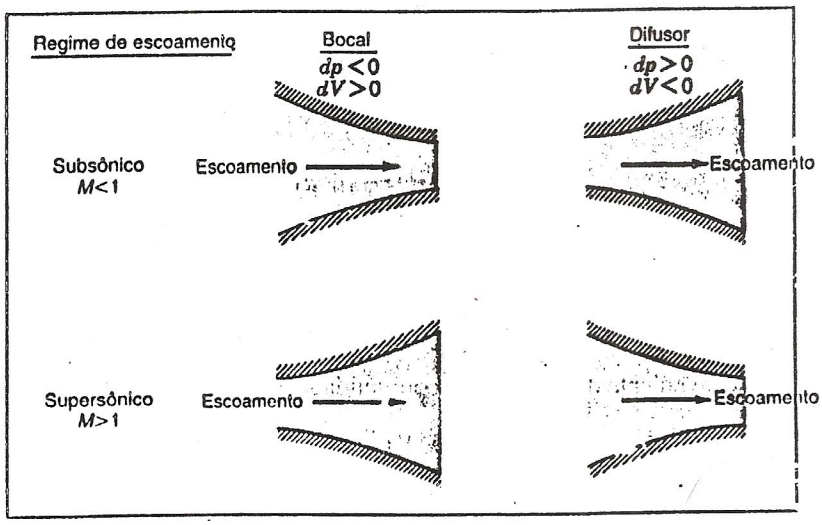
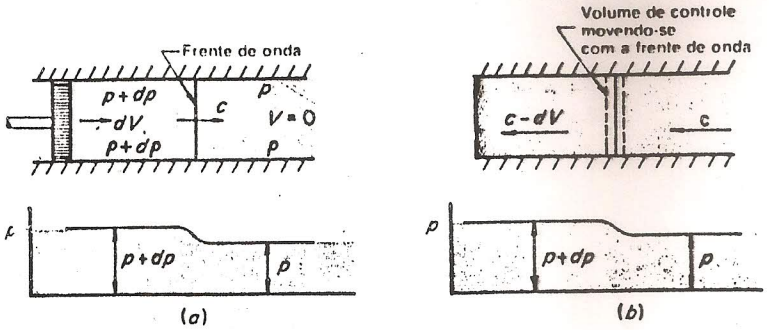
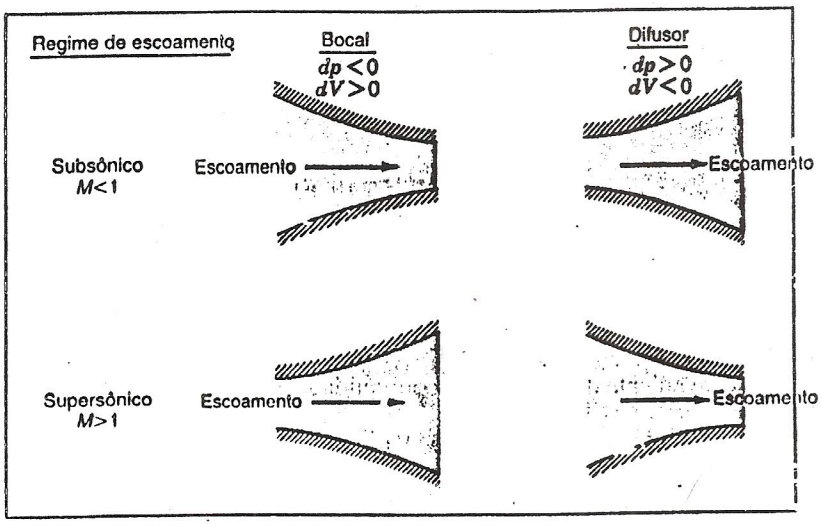
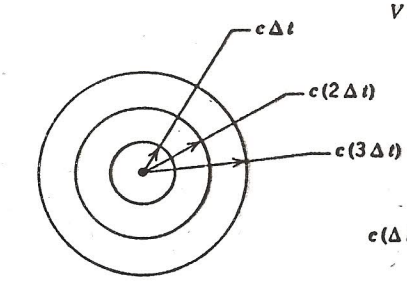

Frente de onda
p+dp
dV
p+dp
c
p
V=0
p
p+dp
p
(a)
Volume de controle
movendo-se
com a frente de onda
c-dV
c
p
p+dp
p
(b)

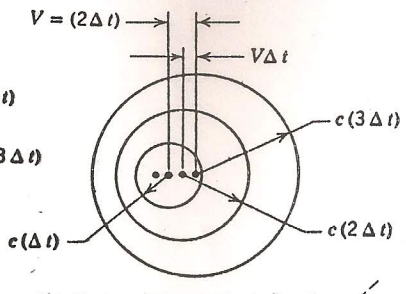

Regime de escoamento
Bocal
dp<0
dV>0
Difusor
dp>0
dV<0
Subsônico
M<1
Escoamento
Escoamento
Supersônico
M>1
Escoamento
Escoamento


Frente de onda
p+dp
dV
p+dp
c
p
V=0
p
p
p+dp
p
(a)
Volume de controle
movendo-se
com a frente de onda
c-dV
c
p
p+dp
p
(b)

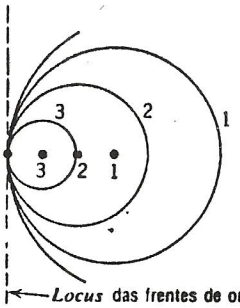

Regime de escoamento
Bocal
dp<0
dV>0
Difusor
dp>0
dV<0
Subsônico
M<1
Escoamento
Escoamento
Supersônico
M>1
Escoamento
Escoamento



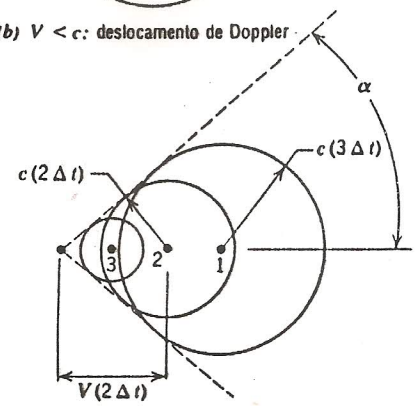
(a) $V = 0$: fonte estacionária



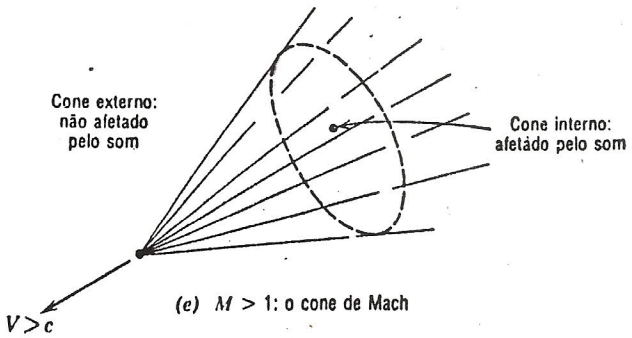
(b) $V < c$: deslocamento de Doppler



(c) $V = c$



(d) $V > c$: movimento supersônico



(e) $M > 1$: o cone de Mach

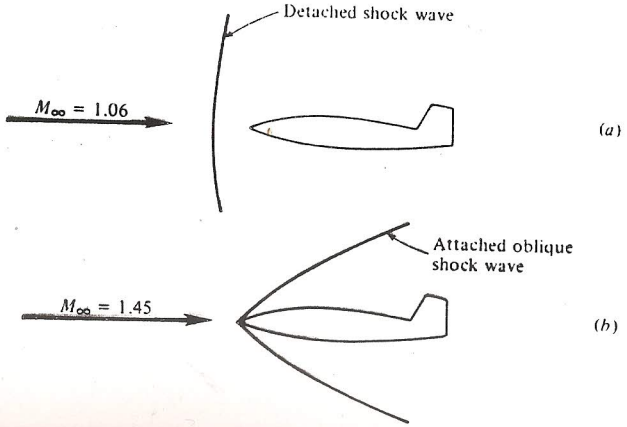


FIGURE 3.1
Attached and detached shock waves on a supersonic vehicle.

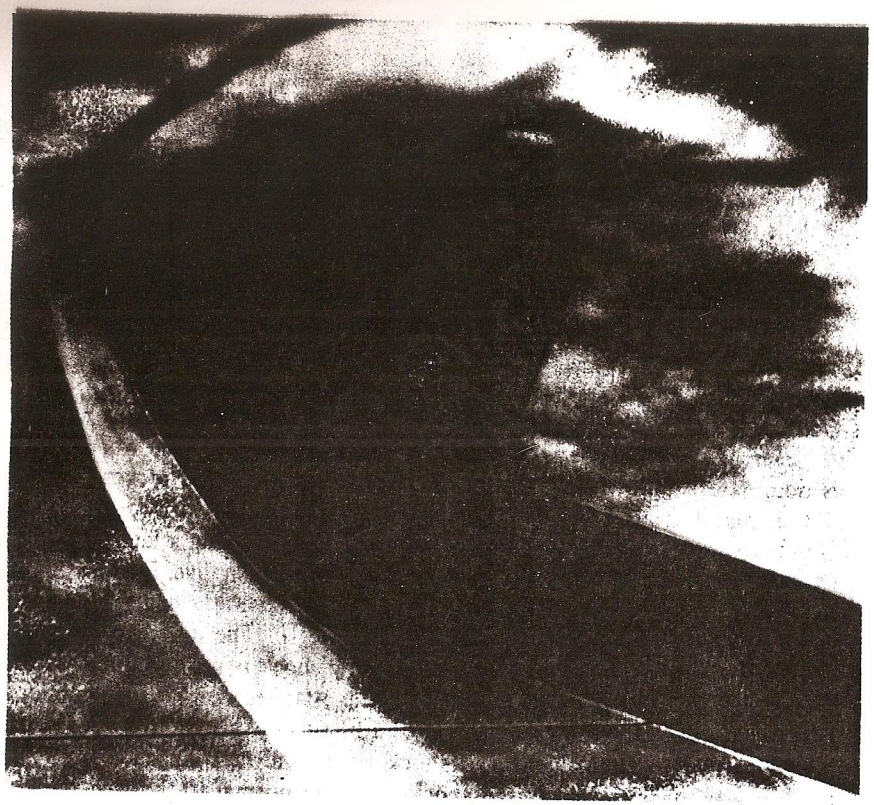


FIGURE 3.2*a*
Shock wave on the Apollo command module. Wind tunnel model at $\alpha = 33°$ in the NASA Langley Mach 8 variable-density wind tunnel ion air. (*Courtesy of the NASA Langley Research Center.*)

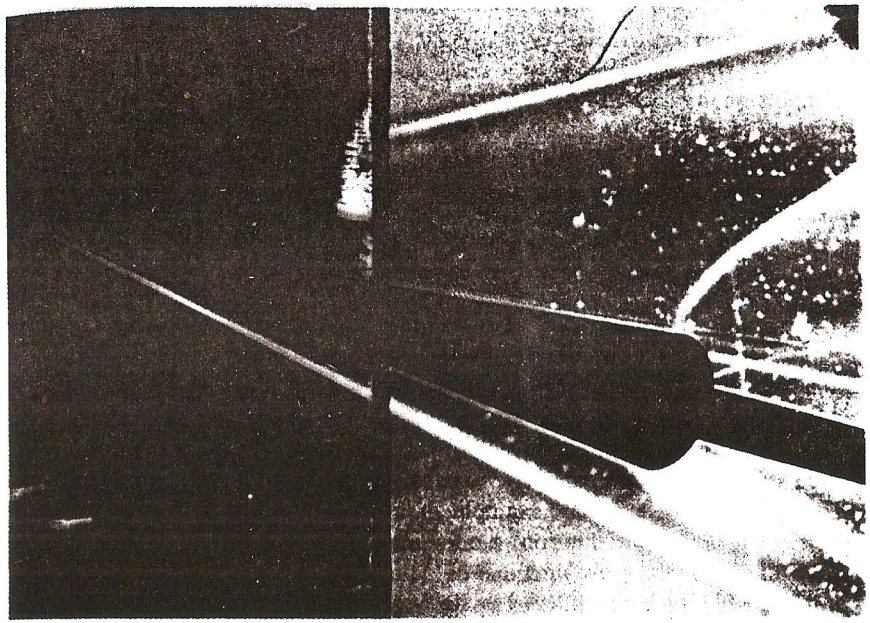


FIGURE 3.2*b*
Shock waves on a sharp-nosed slender cone at angle of attack. (*Courtesy of the Naval Surface Weapons Center, White Oak, MD.*)

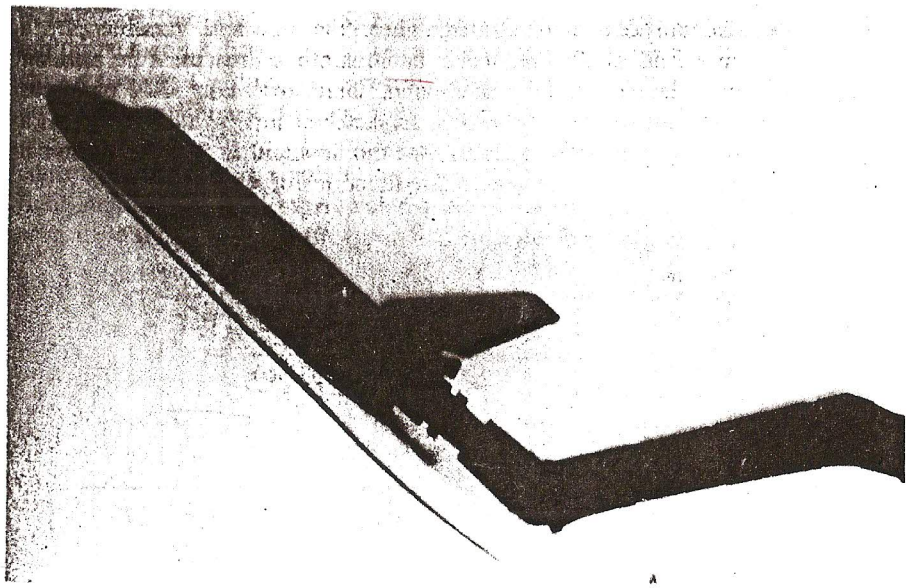
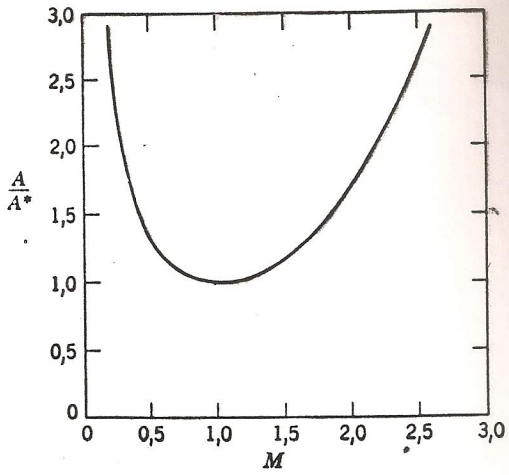
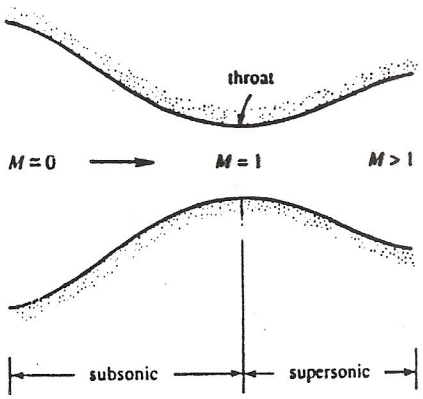
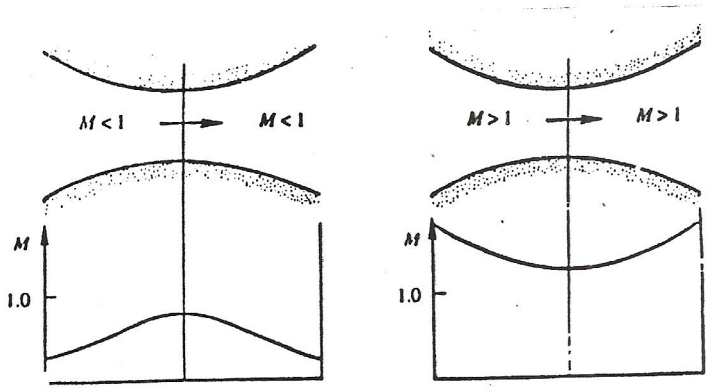
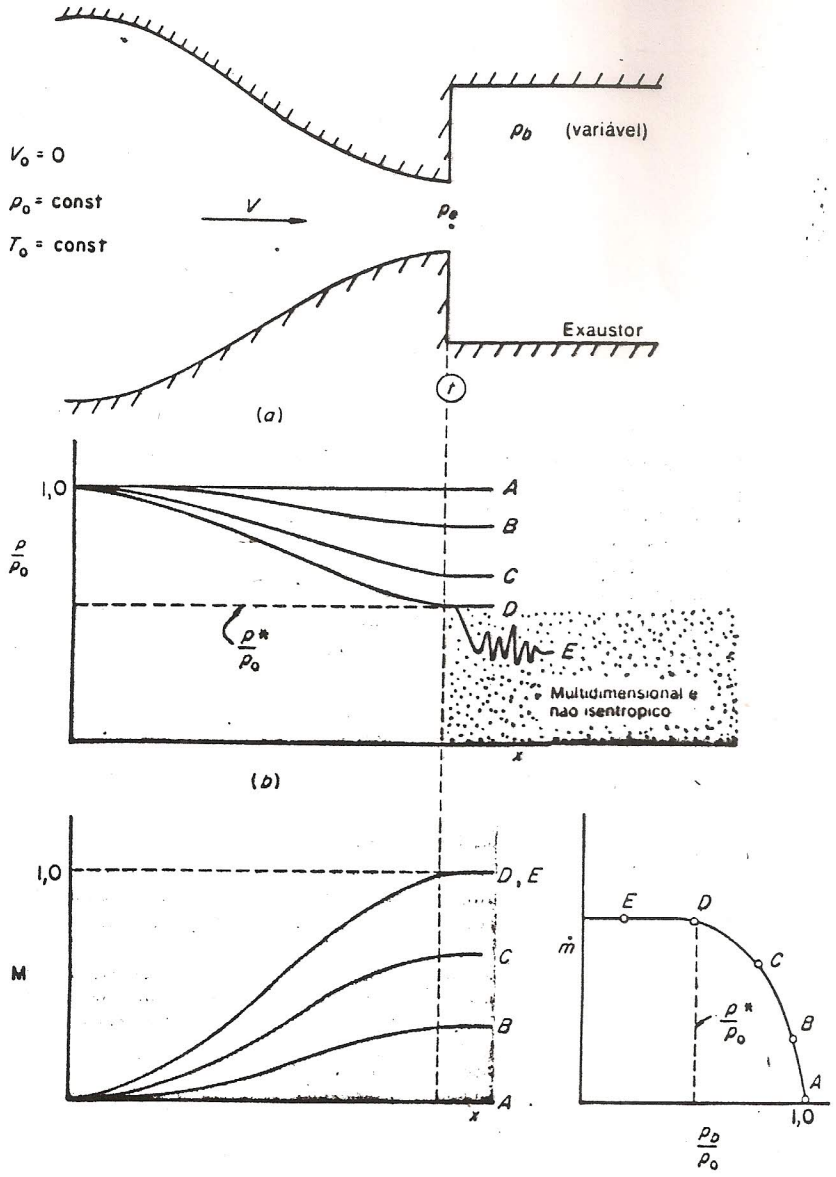


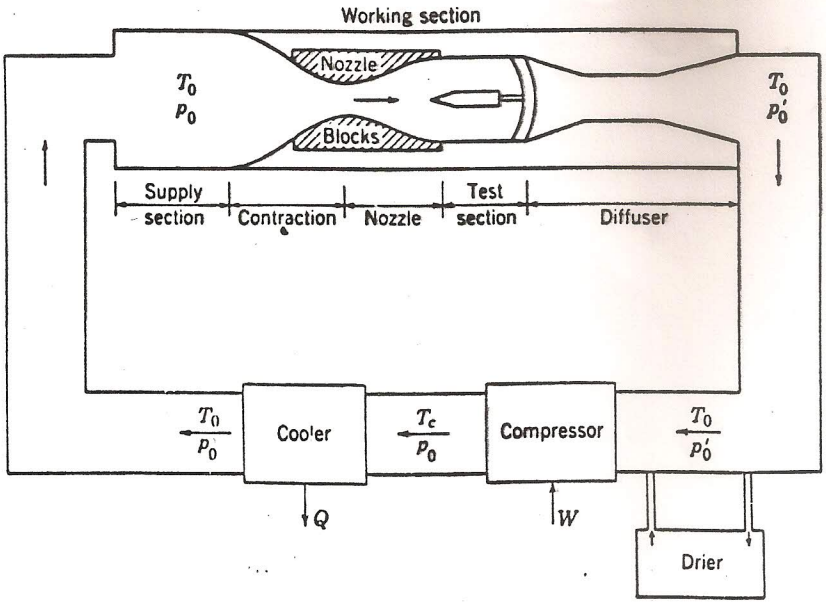
FIGURE 3.2*c*
Shock wave on a wind tunnel model of the space shuttle. (*Courtesy of the NASA Langley Research Center.*)

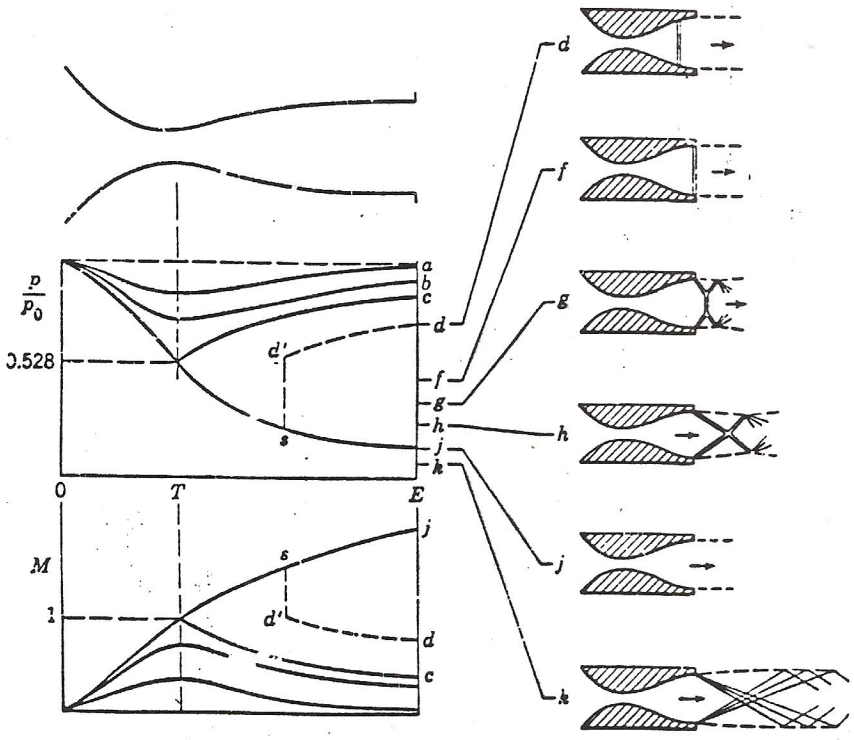

3,0
2,5
2,0
1,5
1,0
0,5
0
$\frac{A}{A^*}$
0
0,5
1,0
1,5
2,0
2,5
3,0
M

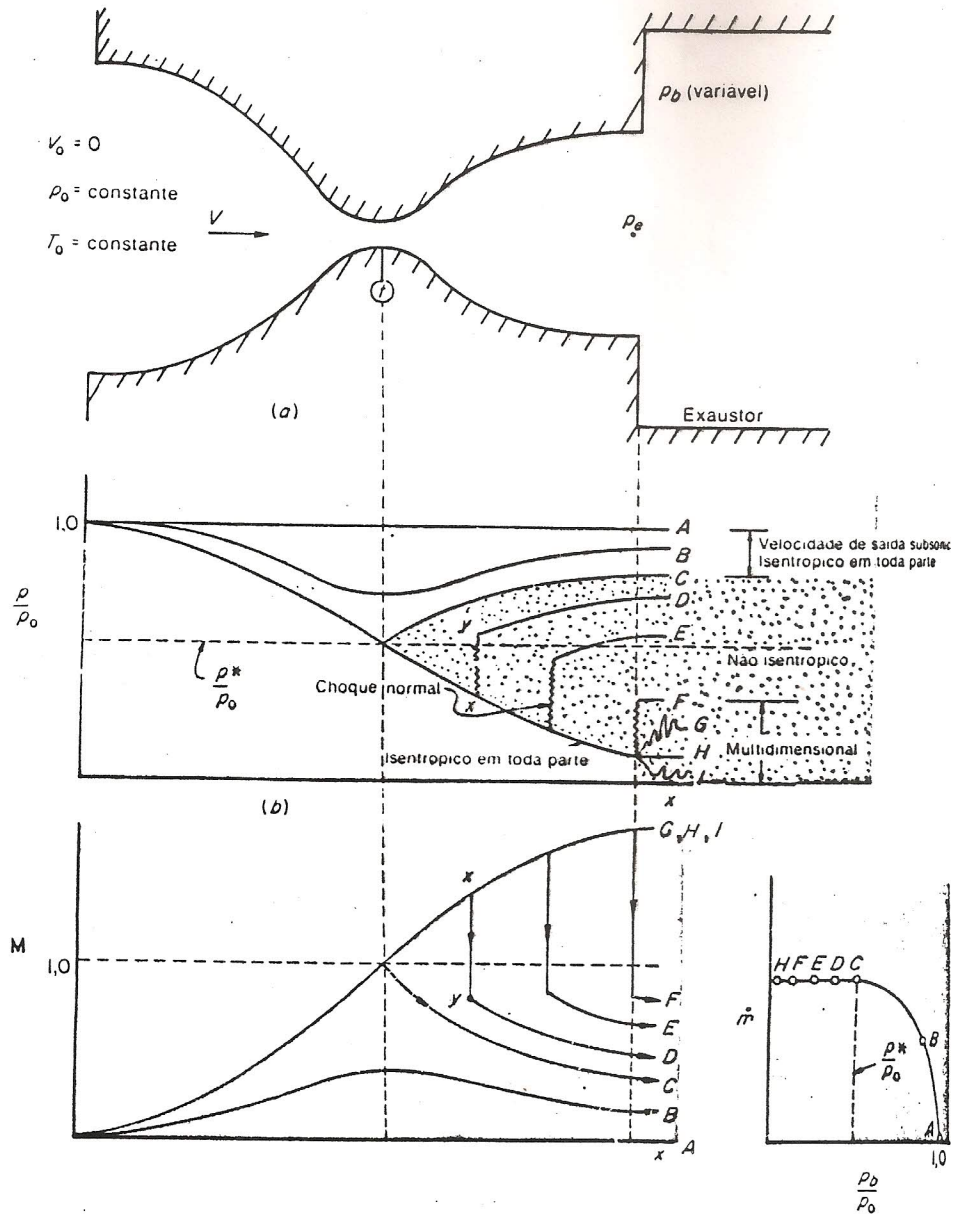

throat
M = 0
M = 1
M > 1
subsonic
supersonic


M < 1
M < 1
M
1.0
M > 1
M > 1
M
1.0


$V_0 = 0$
ρ_0 = const
T_0 = const
V
p_b (variável)
p_e
Exaustor
1
(a)
1,0
A
B
C
D
E
$\frac{\rho}{\rho_0}$
$\frac{\rho^*}{\rho_0}$
Multidimensional e não isentrópico
x
(b)
1,0
D, E
C
B
A
M
x
E
D
C
B
A
$\dot{m}$
$\frac{\rho^*}{\rho_0}$
1,0
$\frac{p_b}{p_0}$


Working section
Nozzle
Blocks
T_0
p_0
T_0
p_0'
Supply section
Contraction
Nozzle
Test section
Diffuser
T_0
p_0
Cooler
T_c
p_0
Compressor
T_0
p_0'
Q
W
Drier


$\frac{p}{p_0}$
0.528
a
b
c
d
d'
f
g
h
j
k
s
0
T
E
M
1
d
f
g
h
j
k


p_b (variável)
$V_0 = 0$
ρ_0 = constante
T_0 = constante
V
p_e
(a)
Exaustor
1,0
A
B
C
D
E
F
G
H
Velocidade de saída subsônic
Isentrópico em toda parte
$\frac{\rho}{\rho_0}$
$\frac{\rho^*}{\rho_0}$
Choque normal
Não isentrópico
Multidimensional
Isentrópico em toda parte
x
y
(b)
M
1,0
G, H, I
F
E
D
C
B
A
$\dot{m}$
H F E D C
B
A
1,0
$\frac{p_b}{p_0}$