Chapter 10 Compressible Flow through Nozzles, Diffusers and Wind Tunnels

2019年12月20日 星期五 15:11

# Chapter 10 通过喷管、扩压器和风洞的可压缩流

## 10.1 引言P670

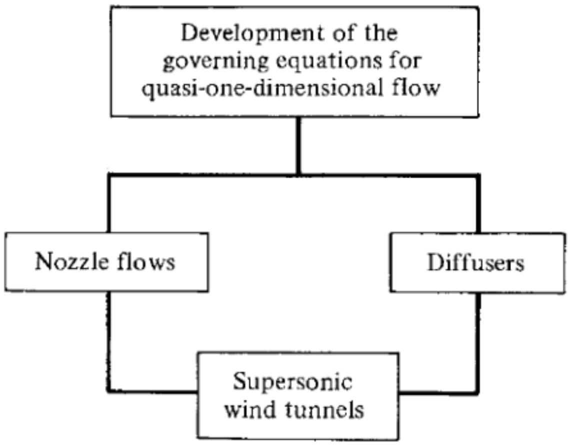



**Figure 10.5** Road map for Chapter 10.

## 10.2 准一维流动的控制方程P672

## 10.3 喷管流动P681

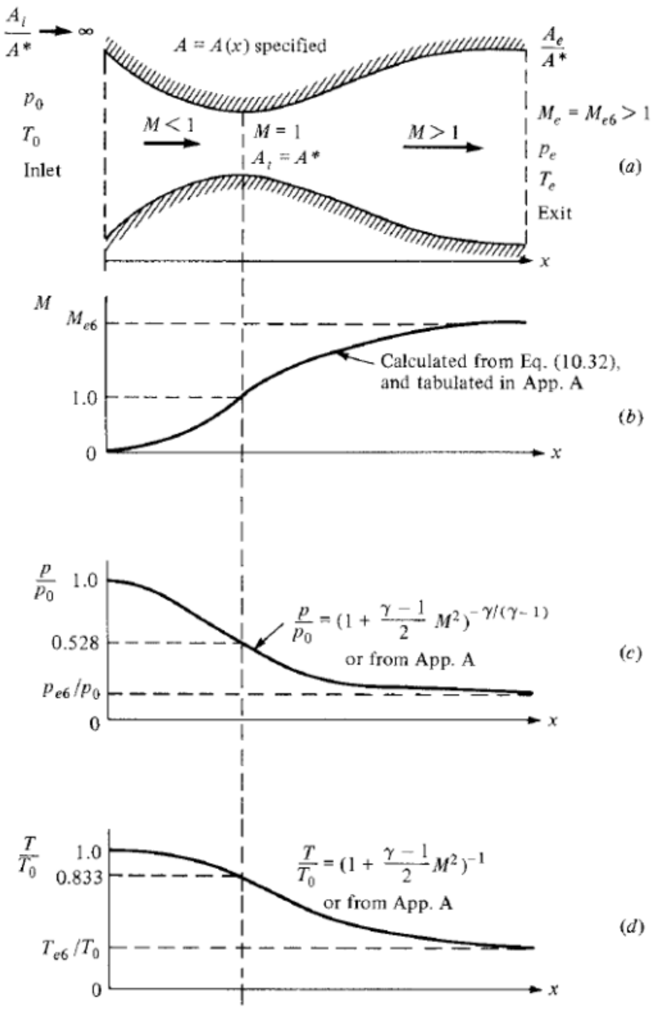
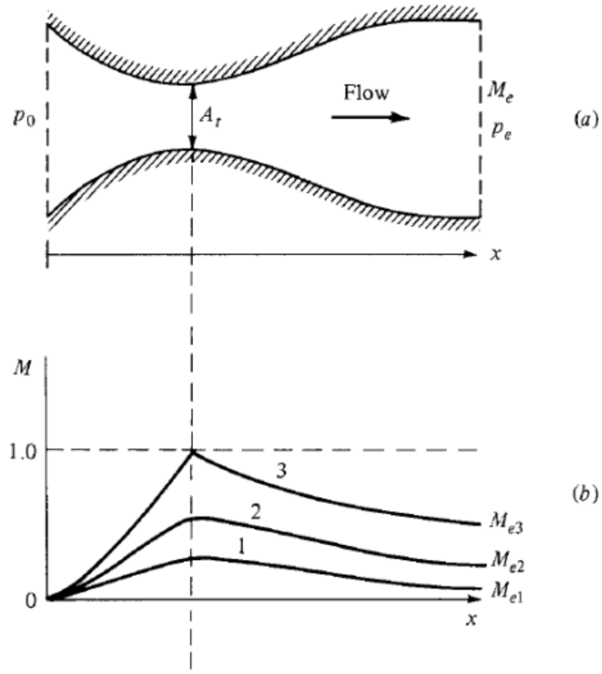
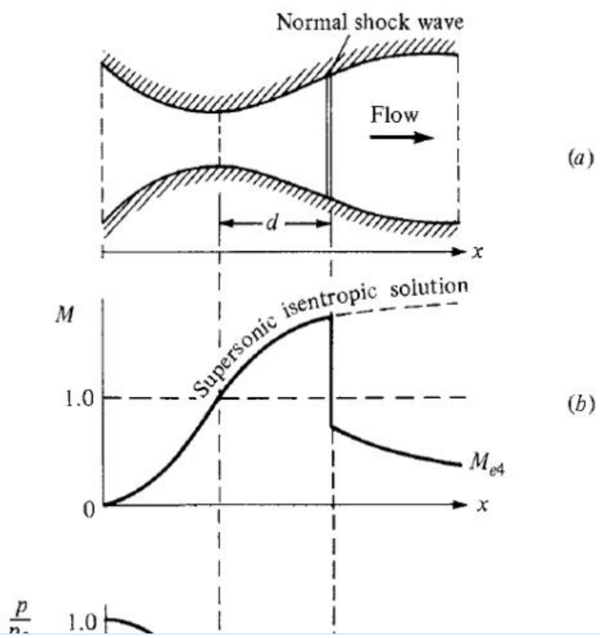



**Figure 10.12** Isentropic supersonic nozzle flow.



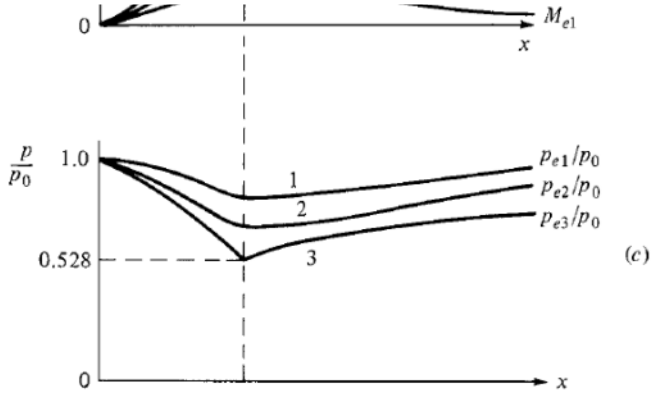



**Figure 10.13** Isentropic subsonic nozzle flow.

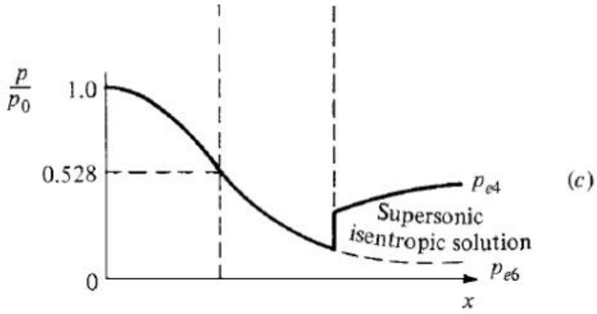



**Figure 10.15** Supersonic nozzle flow with a normal shock inside the nozzle.

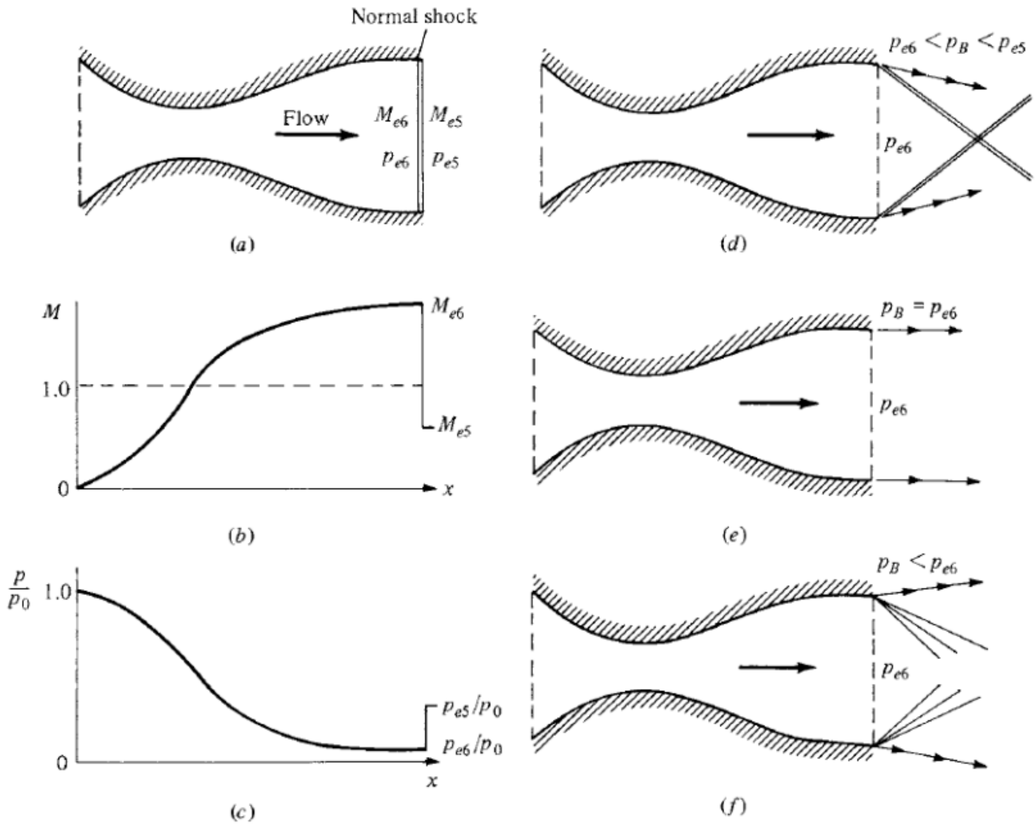



**Figure 10.16** Supersonic nozzle flows with waves at the nozzle exit: (*a*), (*b*), and (*c*) pertain to a normal shock at the exit, (*d*) overexpanded nozzle, (*e*) isentropic expansion to the back pressure equal to the exit pressure, (*f*) underexpanded nozzle.

## 10.3.1 更多关于质量流的讨论P695

# 10.4 扩压器P696

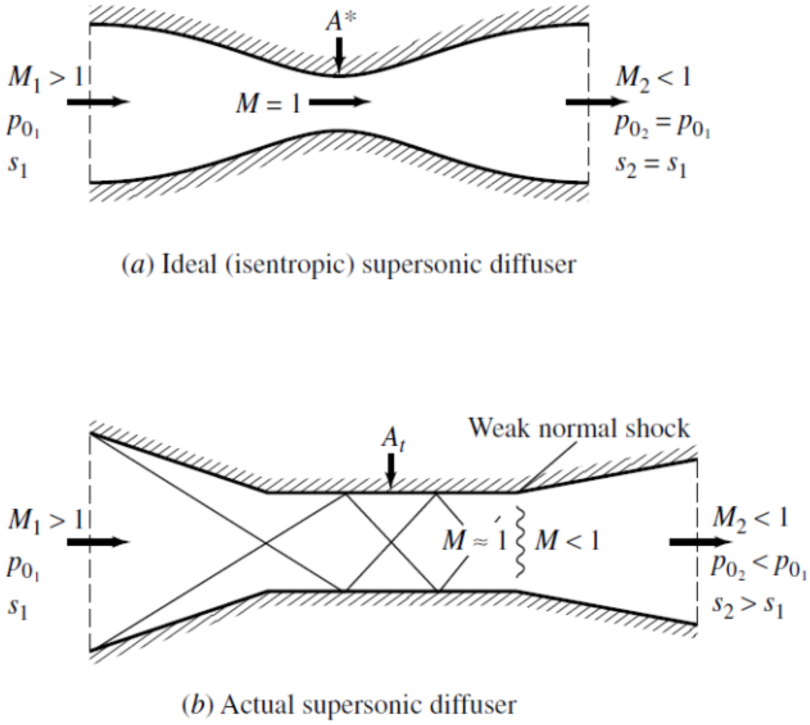



**Figure 10.17** The ideal (isentropic) diffuser compared with the actual situation.

# 10.5 超声速风洞P698

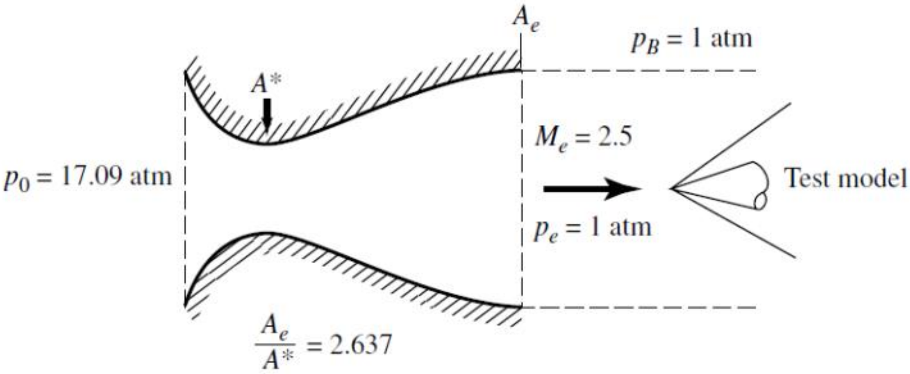



**Figure 10.18** Nozzle exhausting directly to the atmosphere.

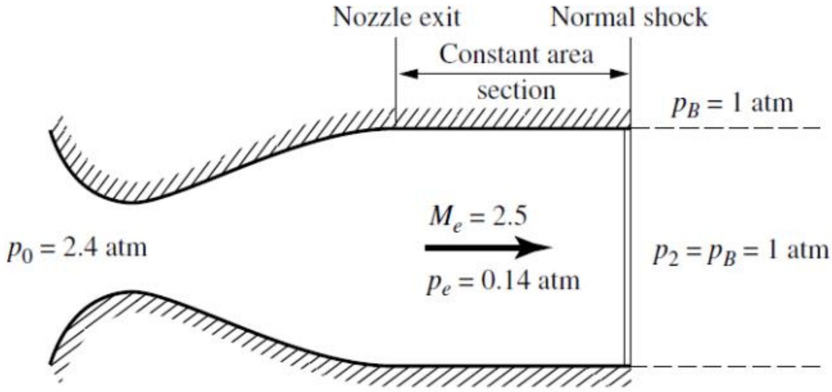



**Figure 10.19** Nozzle exhausting into a constant-area duct, where a normal shock stands at the exit of the duct.

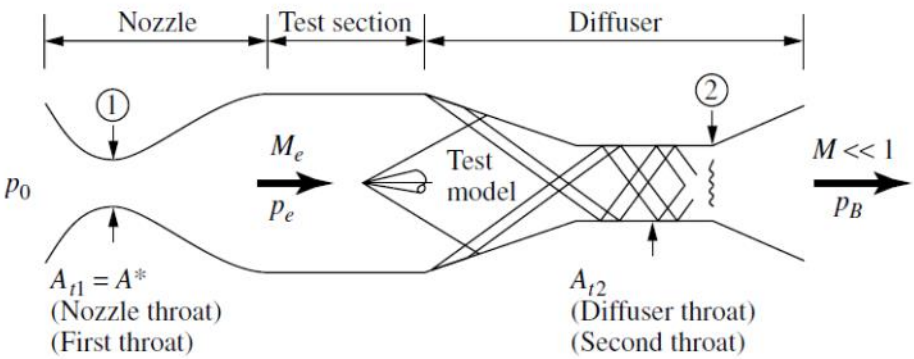



**Figure 10.20** Sketch of a supersonic wind tunnel.

## 10.6 粘性流动：喷管内的激波/边界层干扰P704

## 10.7 总结P706

Quasi-one-dimensional flow is an approximation to the actual three-dimensional flow in a variable-area duct; this approximation assumes that $p = p(x)$, $u = u(x)$, $T = T(x)$, etc., although the area varies as $A = A(x)$. Thus, we can visualize the quasi-one-dimensional results as giving the mean properties at a given station, averaged over the cross section. The quasi-one-dimensional flow assumption gives reasonable results for many internal flow problems; it is a "workhorse" in the everyday application of compressible flow. The governing equations for this are

*Continuity:*

$$\rho_1 u_1 A_1 = \rho_2 u_2 A_2 \tag{10.1}$$

*Momentum:*

$$p_1 A_1 + \rho_1 u_1^2 A_1 + \int_{A_1}^{A_2} p\, dA = p_2 A_2 + \rho_2 u_2^2 A_2 \tag{10.5}$$

*Energy:*

$$h_1 + \frac{u_1^2}{2} = h_2 + \frac{u_2^2}{2} \tag{10.9}$$

The area velocity relation

$$\frac{dA}{A} = (M^2 - 1)\frac{du}{u} \tag{10.25}$$

tells us that

1. To accelerate (decelerate) a subsonic flow, the area must decrease (increase).
2. To accelerate (decelerate) a supersonic flow, the area must increase (decrease).
3. Sonic flow can only occur at a throat or minimum area of the flow.

The isentropic flow of a calorically perfect gas through a nozzle is governed by the relation

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2}\left[\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{(\gamma+1)/(\gamma-1)} \tag{10.32}$$

This tells us that the Mach number in a duct is governed by the ratio of local duct area to the sonic throat area; moreover, for a given area ratio, there are two values of Mach number that satisfy Equation (10.32)—a subsonic value and a supersonic value.

For a given convergent-divergent duct, there is only one possible isentropic flow solution for supersonic flow; in contrast, there are an infinite number of subsonic isentropic solutions, each one associated with a different pressure ratio across the nozzle, $p_0/p_e = p_0/p_B$.

In a supersonic wind tunnel, the ratio of second throat area to first throat area should be approximately

$$\frac{A_{t,2}}{A_{t,1}} = \frac{p_{0,1}}{p_{0,2}} \tag{10.39}$$

If $A_{t,2}$ is reduced much below this value, the diffuser will choke and the tunnel will unstart.

## 10.8 作业题P707