DEPARTMENT OF AEROSPACE ENGINEERING

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Year & Branch	:	**II AEROSPACE**	Semester	:	**IV**
Course	:	**23ASB201 - Aerospace Propulsion**			

UNIT II - JET ENGINE INTAKES AND EXHAUST NOZZLES

Explore Subsonic Inlet Stall and Diffuser Performance

Subsonic (pitot type) intakes

The most common type of subsonic intake is the Pitot intake. Pitot intakes make the best use of the ram effect due to forward motion. These intakes also suffer the minimum loss of ram pressure during changes in altitude. However, these intakes are primarily for subsonic operations.

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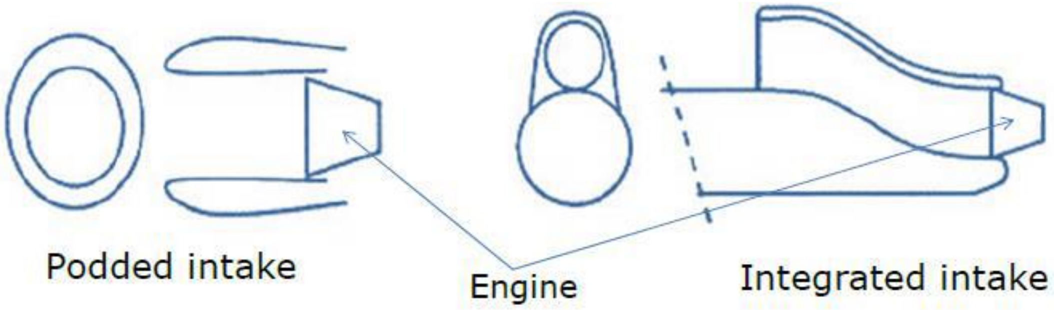
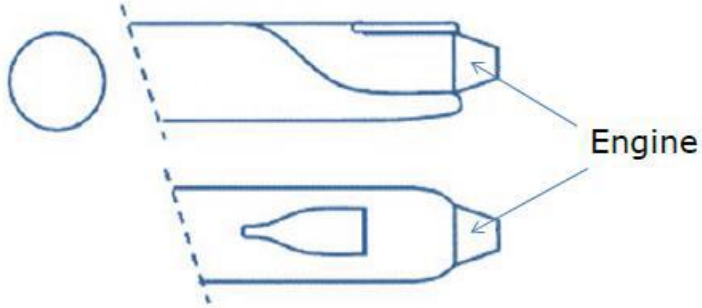
- Podded intakes
- Integrated intakes
- Flush intakes

Podded intakes are commonly used in transport aircraft (civil or military). Integrated intakes are used in combat aircraft. Flush intakes are used in missiles.





Submerged or flush intake

Podded intakes: Usually, the friction losses in podded intakes are insignificant. Flow separation may drastically affect the performance. The leading edge of the intake captures a certain stream tube and then divides this stream into internal flow and external flow. The design of the duct must be such that it preserves good aerodynamics of the airframe and an internal flow with minimal loss.

Integrated and flush intakes: For integrated intakes, the internal flow problems are of concern. The duct is usually longer and with bend(s). The aircraft fuselage ahead of the intake feeds a boundary layer into the intake. The curvature of the intake also leads to the generation of secondary flows, leading to flow distortion. Flush intakes are used in missiles as these can be easily accommodated into missile airframes as well as for canister launching.

Internal flow, stall in subsonic inlets, and Boundary layer Separation (subsonic inlet with typical streamline patterns)

Depending on the flight speed and the mass flow demanded by the engine, the inlet may have to operate with a wide range of incident stream conditions. The Figure shows the streamline patterns for two typical subsonic conditions and the corresponding thermodynamic path of an "average" fluid particle.

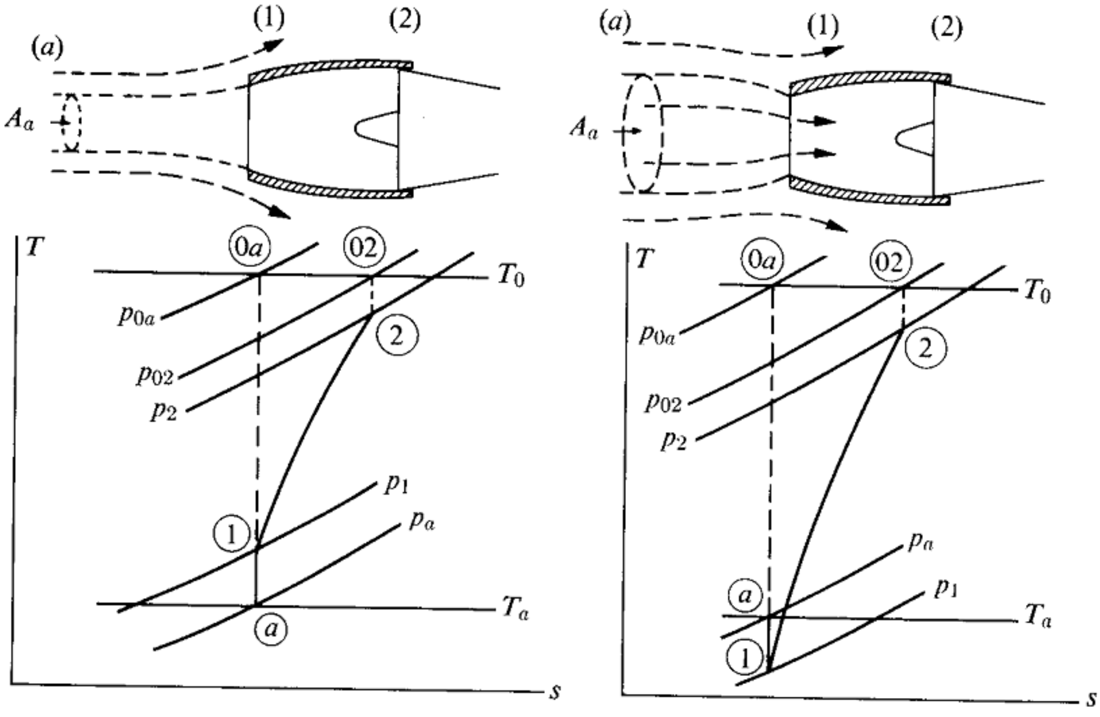
During level cruise, the streamline pattern may include some deceleration of the entering fluid External to the inlet plane and hence low mass flow rate[Fig. a]. During low-speed high-thrust operation (e.g., during takeoff and climb), the same engine will demand more mass flow, and the streamline pattern may resemble Fig. b, which illustrates the external acceleration of the stream near the inlet.

For given air velocities, external acceleration raises the inlet velocity and lowers the inlet pressure, thereby increasing the internal pressure rise across the diffuser. If this pressure increase is too large, the diffuser may stall because of boundary layer separation; stalling usually reduces the stagnation pressure of the stream as a whole.

Conversely, external deceleration requires less internal pressure rise and, hence, a less severe loading of the boundary layer.

Therefore, the inlet area is often chosen to minimize external acceleration during takeoff, with the result that external deceleration occurs during level-cruise operation. Under these conditions, the "upstream capture area" Aa is less than the inlet area A1, and some flow is "spilled over" the inlet, accelerating as it passes over the outer surface.

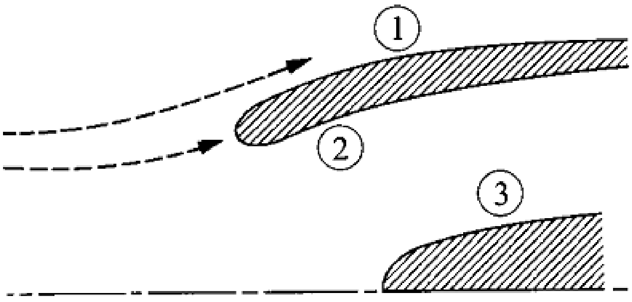
In the actual engine inlet, separation can take place in any of the three zones shown in the figure below.



(a) High speed or low mass flow

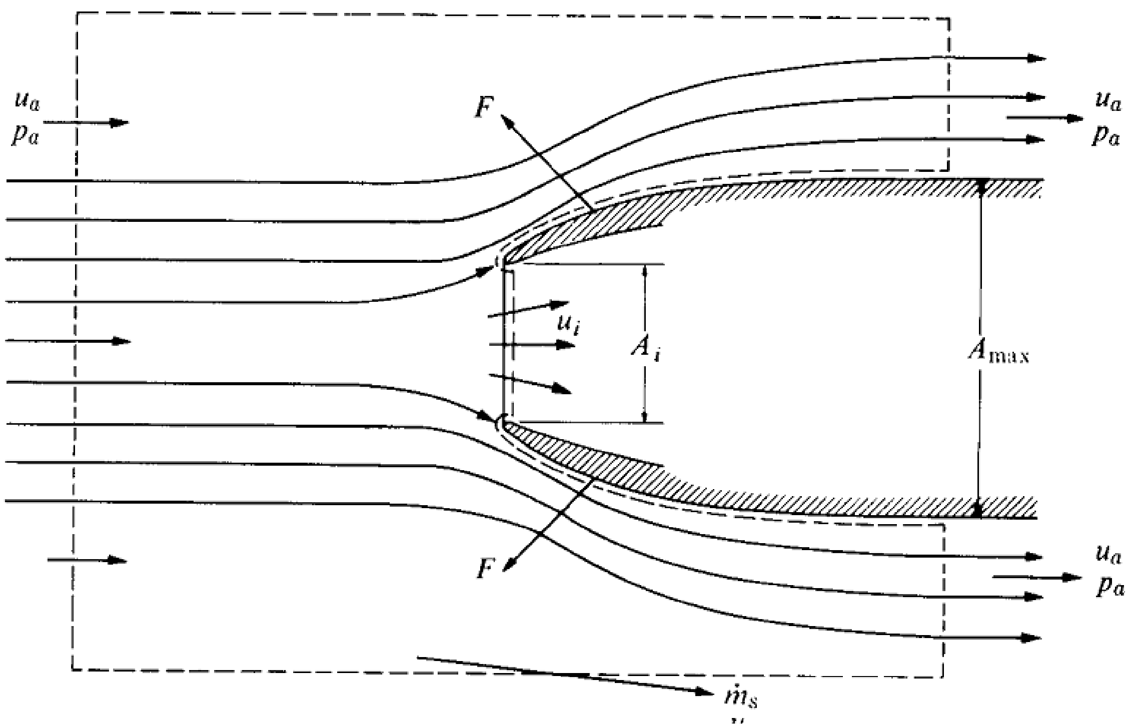
(b) Low speed or high mass flow

Separation of the external flow in zone 1 may result from local high velocities and subsequent deceleration over the outer surface. Separation on the internal surfaces may take place in either zone 2 or zone 3, depending on the geometry of the duct and the operating conditions. Zone 3 may be the scene of quite large adverse pressure gradients since the flow accelerates around the nose of the center body and then decelerates as the curvature decreases.



Major features of external flow near a subsonic inlet

Figure shows a typical streamline pattern for large external deceleration. In flowing over the lip of the inlet, the external flow is accelerated to high velocity, much as the flow is accelerated over the suction surface of an airfoil. This high velocity and the accompanying low pressure can adversely affect the boundary layer flow in two ways:

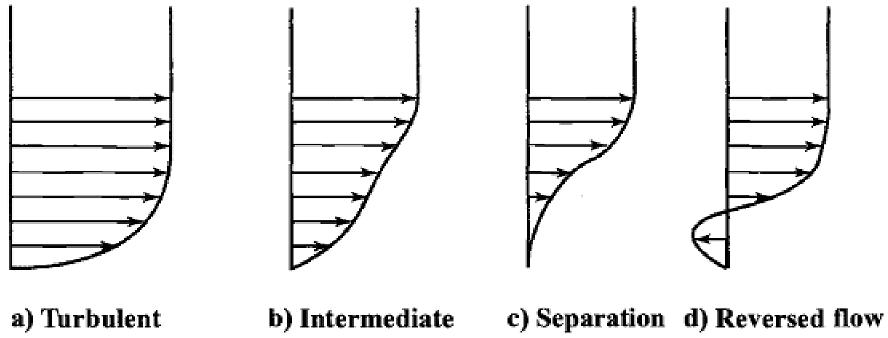


For entirely subsonic flow, the low-pressure region must be followed by a region of rising pressure in which the boundary layer may separate. Hence, one might expect a limiting low-pressure Pmin or, equivalently, a maximum local velocity Umax, beyond which boundary layer separation can be expected downstream.

For higher flight velocities (or higher local accelerations), partially supersonic flow can occur. Local supersonic regions usually end abruptly in a shock, and the shock-wall intersection may cause boundary layer separation. One might expect a limiting local Mach number that should not be exceeded.

Diffuser

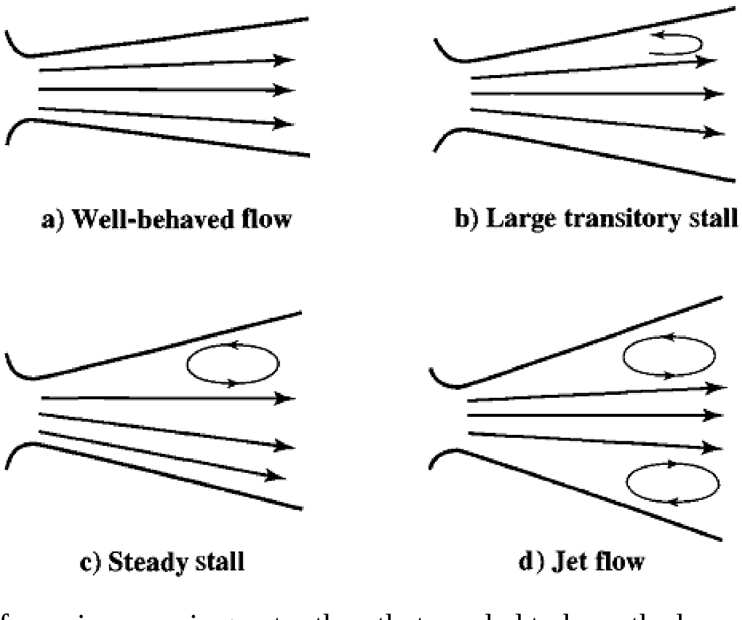
The flow within the inlet is required to undergo diffusion in a divergent duct. This reduction in flow velocity creates an increase in static pressure that interacts with the boundary layer. If the pressure rise due to diffusion occurs more rapidly than turbulent mixing can reenergize the boundary layer, the boundary layer will assume the configurations shown in Fig.



t Propulsion

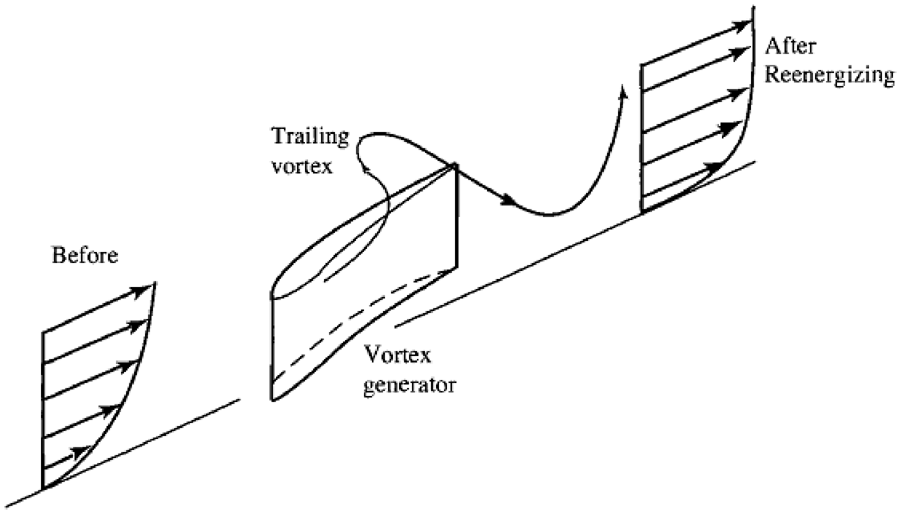
Inlets & Nozzles

The rate of area increase in a diffuser has a direct effect on the behavior of flow in the diffuser, as shown in Fig.



If the rate of area increase is greater than that needed to keep the boundary layer energized and attached, the flow may be characterized by unsteady zones of stall. The turbulent mixing is no longer able to overcome the pressure forces at all points in the flow, and local separation occurs at some points. The total pressure decreases markedly due to the irreversible mixing of a fairly large portion of low-velocity fluid with the main flow. If the diffuser walls diverge rapidly, the flow will separate and behave much like a jet, as shown in Fig d. The rate of area increase without stall for a diffuser depends on the characteristics of the flow at the entrance and on the length of the divergent section

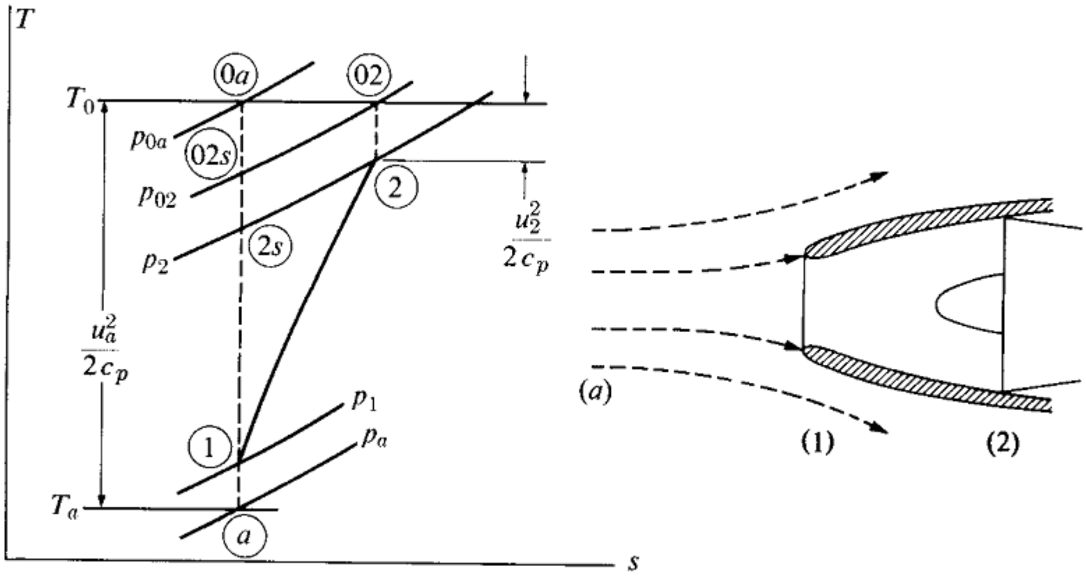
Use of vortex generators as a mechanical mixing device to supplement the turbulent mixing:



In the presence of an adverse pressure gradient (static pressure increasing in the direction of flow), boundary layers tend to separate when the boundary layer is not reenergized rapidly enough by turbulent mixing. Taylor proposed the use of vortex generators as a mechanical mixing device to supplement the turbulent mixing. If vortices are generated by vortex generators in pairs, regions of inflow and outflow exist. These carry high-energy air into the boundary layer and low-energy air out. The figure shows how vortex generators reenergize a boundary layer.

By using vortex generators together with a short, wide-angle diffuser, it may be possible to have a lower total pressure loss than with a long diffuser without vortex generators. Here, the reduced skin friction losses associated with flow separation are traded against vortex losses. The use of shorter diffusers may reduce weight and facilitate engine installation.

Subsonic Diffuser Performance and its Efficiency



Isentropic efficiency: we can define the isentropic efficiency of a diffuser in this form

$$\eta_d = \frac{h_{02s} - h_a}{h_{0a} - h_a}$$

$$= \frac{T_{02s} - T_a}{T_{0a} - T_a}$$

$$= \frac{\frac{T_{02s}}{T_a} - 1}{\frac{T_{0a}}{T_a} - 1} \quad \text{— (1)}$$

But $\frac{T_{02s}}{T_a} = \left(\frac{P_{02}}{P_a}\right)^{\frac{\gamma-1}{\gamma}}$ — (2)

$\frac{T_{02}}{T_a} = 1 + \frac{\gamma-1}{2} M^2$ — (3)

3 in 1 $\Longrightarrow$

$$\eta_d = \frac{\left(\frac{P_{02}}{P_a}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\left(\frac{\gamma-1}{2}\right) M^2}.$$

$$\eta_d = \frac{h_{o2s} - h_a}{h_{oa} - h_a}$$

$$= \frac{T_{o2s} - T_a}{T_{oa} - T_a}$$

$$= \frac{\frac{T_{o2s}}{T_a} - 1}{\frac{T_{oa}}{T_a} - 1} \quad \text{—— (1)}$$

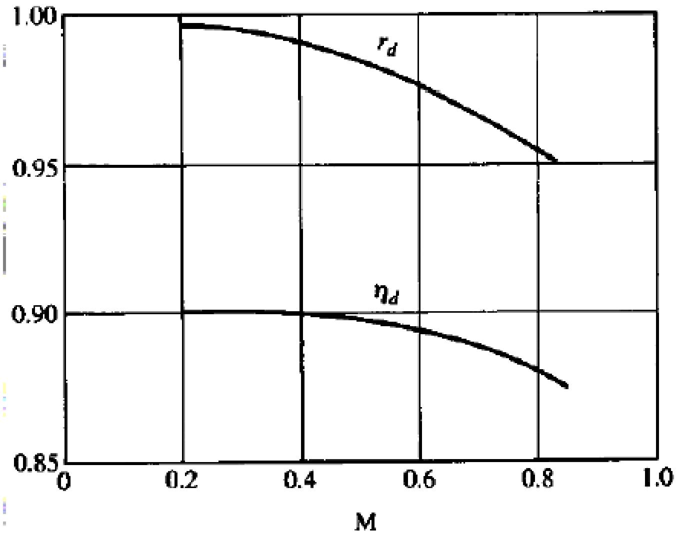
But $\frac{T_{o2s}}{T_a} = \left(\frac{P_{o2}}{P_a}\right)^{\frac{\gamma-1}{\gamma}}$ —(2)

$\frac{T_{o2}}{T_a} = 1 + \frac{\gamma-1}{2} M^2$ —(3)

3 in 1 $\Longrightarrow$

$$\eta_d = \frac{\left(\frac{P_{o2}}{P_a}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\left(\frac{\gamma-1}{2}\right) M^2}.$$

subsonic diffuser performance is shown as

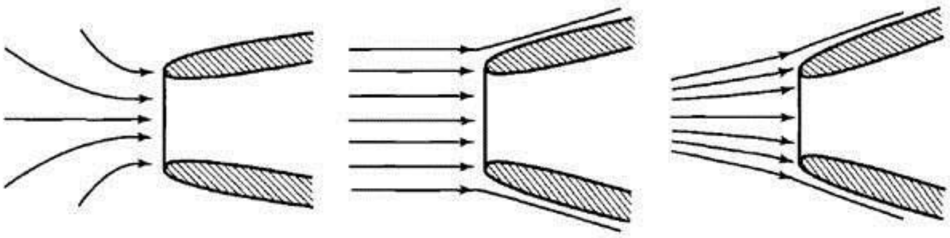


Typical subsonic diffuser performance; $\gamma = 1.4$.

The operation of subsonic inlets under various flow speed

Most subsonic aircraft have their engines placed in nacelles; thus, in this section, we do not deal with the inlet alone but include the nacelle at subsonic Mach numbers. The cross-section of a typical subsonic inlet and its geometric parameters are shown in Fig. The inlet area A1 is based on the flow cross-section at the inlet highlight. Because the subsonic inlet can draw in airflow whose free stream area A0 is larger than the inlet area A1, variable inlet geometry is not required (except sometimes blow-in doors or auxiliary inlets are used to reduce installation drag during takeoff). The material in this section on subsonic inlets is based on a fixed-geometry inlet.

The operating conditions of an inlet depend on the flight velocity and mass flow demanded by the engine. Figure 10.2 shows the streamline pattern for three typical subsonic conditions. Figure 10.2a shows the acceleration of the fluid external to the inlet that will occur when the inlet operates at a velocity lower than the design value or a mass flow higher than the design value.



a) Static operation (or insufficient air for engine)

b) Low-speed operation (correct engine air)

c) High-speed operation (more air than the engine needs)

Fig. 10.2 Typical streamline patterns for subsonic inlet (Ref. 55).

Figure 10.2c shows the deceleration of the fluid external to the inlet that will occur at a velocity higher than design or a mass flow lower than design.