DEPARTMENT OF AEROSPACE ENGINEERING

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Course	:	**23ASB201 - Aerospace Propulsion**			

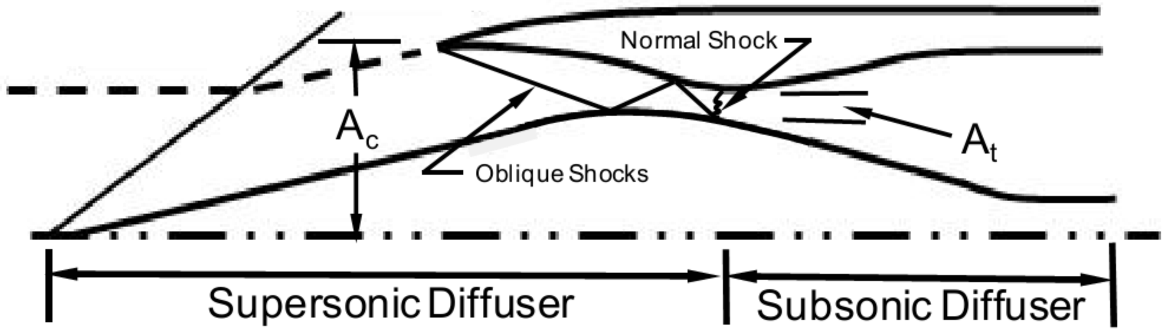
UNIT II - JET ENGINE INTAKES AND EXHAUST NOZZLES

Supersonic Inlet Starting Problems and Solutions

Supersonic Inlets

The supersonic inlet is required to provide the proper quantity and uniformity of air to the engine over a wider range of flight conditions than the subsonic inlet. In addition, the nature of supersonic flow makes this inlet more difficult to design and integrate into the airframe. In supersonic flight, the flow is decelerated by shock waves that can produce a total pressure loss much greater than, and in addition to, the boundary-layer losses.

Working Principle of Supersonic Inlets:

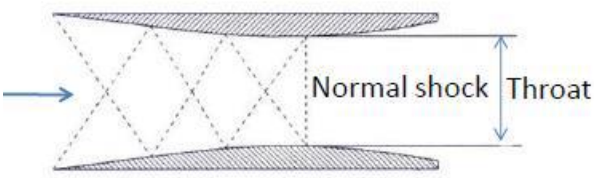


A supersonic inlet is made up of two distinct parts. First, the flow is compressed supersonically from the velocity of the flight vehicle or, in other words, the free stream Mach number. This is done by reducing the flow area as the flow proceeds downstream. In this region, the flow velocity is reduced through a series of compression waves and/or oblique shocks. Flow velocity is reduced to a minimum speed at the duct minimum area, called the throat of the inlet, where the flow approaches sonic velocity or a Mach number of one. At this point, the flow Mach number will be reduced from supersonic, above one, to subsonic, below one, through a normal shock. This begins the second part of the inlet, the subsonic diffuser. In this region, the velocity is reduced as the flow area is increased. The result of this process is conditioned air, smooth, subsonic air at high pressure, which is then delivered to the engine.

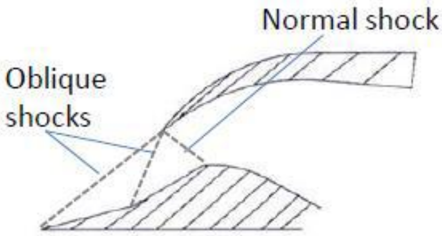
Supersonic Inlet Types:

Internal compression inlet: The internal compression inlet shown in Figure achieves compression through a series of internal oblique shock waves followed by a terminal normal shock positioned downstream of the throat (its stable location). This type of inlet requires a variable throat area to allow the inlet to swallow the normal shock (during starting). Fast reaction bypass doors are also required downstream of the throat to permit proper positioning of the normal shock under varying flight and engine conditions.

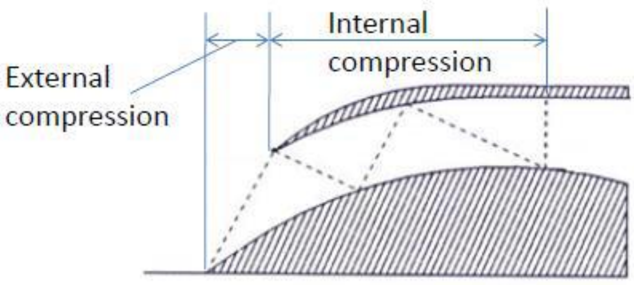
External compression inlet: The compression of the external compression inlet is achieved through either one or a series of oblique shocks followed by a normal shock or simply through one normal shock.



Internal compression intake



External compression intake



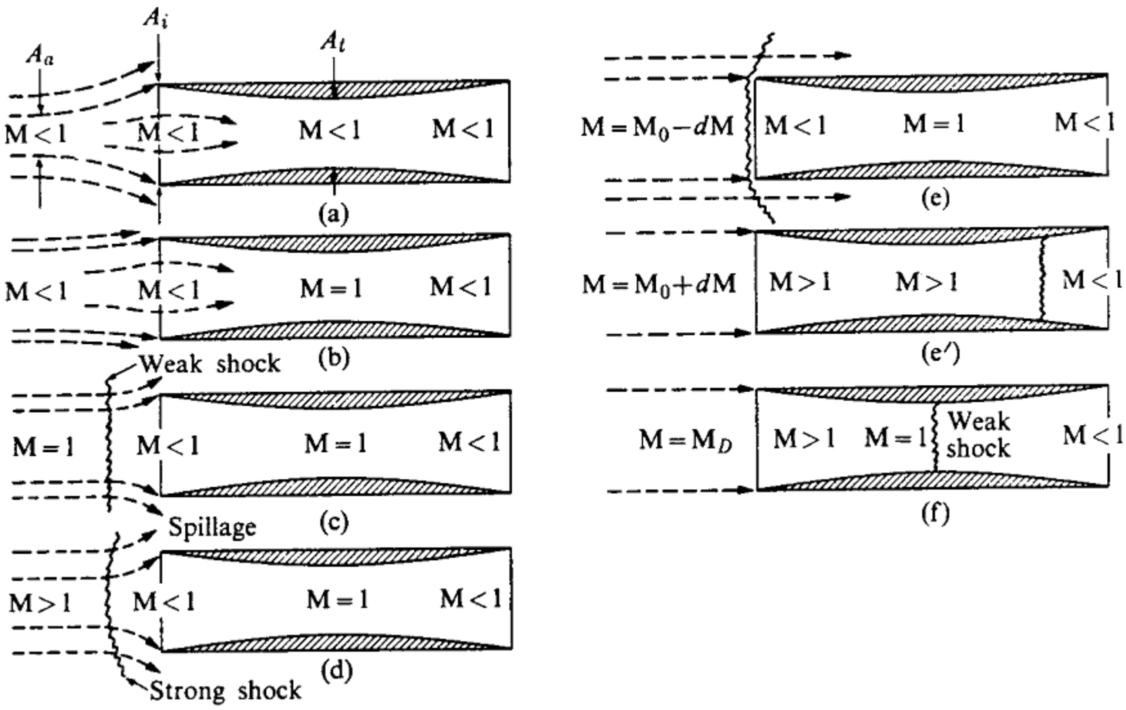
Mixed compression intake

Mixed compression inlet: At flight Mach numbers above 2.5, the mixed compression inlet is used to obtain an acceptable total pressure ratio (by utilizing the required number of oblique shocks) while obtaining acceptable cowl drag. The mixed compression inlet is more complex, heavier, and costlier than the external compression inlet. The typically mixed compression inlet achieves compression through the external oblique shocks, the internal reflected oblique shocks and the terminal normal shock. The ideal location of the normal shock is just downstream of the inlet throat to minimize total pressure loss while maintaining a stable operating location for this shock. Similar to the internal compression inlet, the mixed compression inlet requires both fast-reacting bypass doors (to maintain the normal shock in a stable location) and a variable throat area.

The supersonic inlet must have the following characteristics:

- Provide adequate subsonic performance
- Good pressure distribution at the compressor inlet
- High-pressure recovery ratios, and
- Must be able to operate efficiently at all ambient pressures and temperatures during takeoff, subsonic flight, as well as its supersonic design condition.

Starting of an intake (Successive steps in the acceleration and overspeeding of a one-dimensional supersonic inlet)

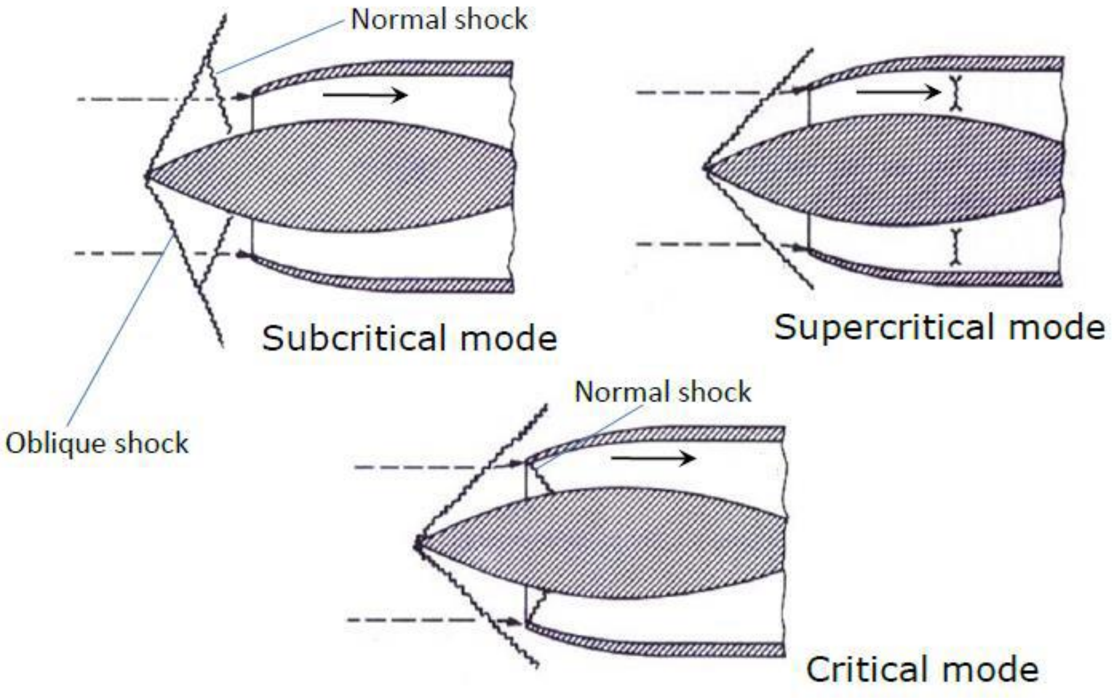


Condition (a) illustrates low subsonic speed operation, for which the inlet is not choked. In **Condition (b**), though the flight velocity is still subsonic, the flow is assumed to be accelerated to the sonic velocity at the minimum area At, and the inlet mass flow rate is limited by the choking condition at At. Once the shock is established, the flow entering the inlet is no longer isentropic. Hence, when the design Mach number of the aircraft is first reached, as at **condition (d**), the "reversed isentropic nozzle" mass flow cannot pass through the throat area At. At the

Design Mach number, the inlet is capable of ingesting the entire incident mass flow without spillage. The shock position will be just on the lip of the inlet, as in **condition (e)**, and a slight increment in speed, as in **condition (e'),** will cause the shock to enter the convergence. Since a shock cannot attain a stable position within the convergence, it will move quickly downstream to come to rest within the divergence at a position determined by downstream conditions. Having thus attained isentropic flow in the inlet, the Mach number may be reduced from M0 to MD, as at **condition (f).** At exactly the design speed, the throat Mach number would be just unity and isentropic deceleration from supersonic to sub-sonic flow would exist. Even for this simplified model, however, this condition.

Modes of operation of an external compression intake

External compression intakes complete the supersonic diffusion outside the covered portion of the intake. These intakes usually have one or more oblique shocks followed by a normal shock.



Depending upon the location of these shocks, the intake may operate in subcritical, critical, or supercritical modes.

Subcritical:

- At Mach numbers below the design value.
- The normal shock occurs ahead of the cowl lip.
- High external drag due to spillage.

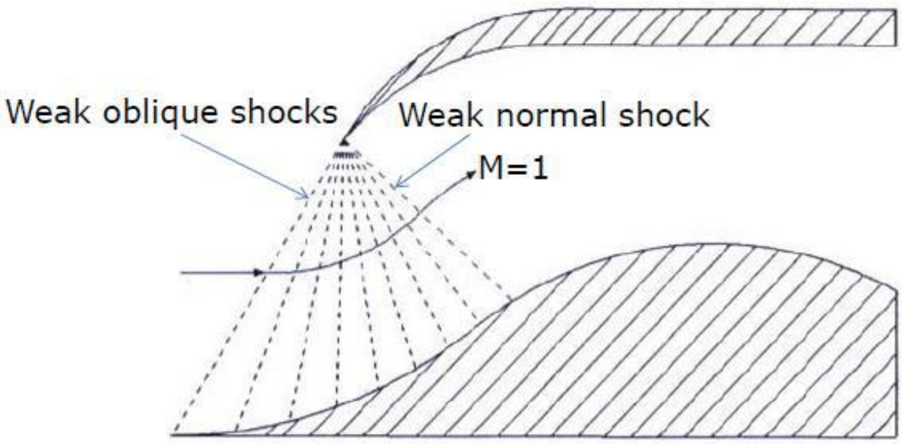
Supercritical:

- Occurs at the same mass flow as a critical mode
- Higher losses as the normal shock occurs in a region of higher Mach number.

Critical:

- Design point operation.
- The normal shock is located exactly at the cowl lip.

Total pressure losses are highest in the case of a diffuser with a single normal shock. Several oblique shocks followed by a normal shock would lead to lower total pressure losses. Oblique shocks are generated using steps in the Centre body. A diffuser with a smoothly contoured center body may have infinite oblique shocks: Isentropic external diffuser.



Isentropic external diffuser

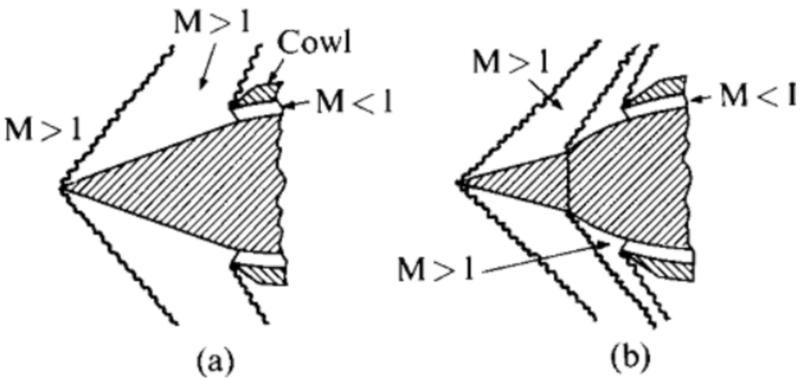
External Deceleration

External deceleration must occur upstream of the inlet plane to reduce the Mach number of the normal shock to a suitable value. The simplest and most practical external deceleration mechanism is an oblique shock or, in some cases, a series of oblique shocks. Though such shocks are not isentropic, the stagnation pressure loss in reaching subsonic velocity through a series of oblique shocks followed by a normal shock is less than that accompanying a single normal shock at the flight velocity. The losses decrease as the number of oblique shocks increases, especially at high flight Mach numbers.

In the external compression process, shocks and boundary layers may interact strongly, so it is highly desirable to locate the oblique shocks at points where boundary layers are absent The shape, size, and number of the oblique planes influence the normal shocks.

Considering the typical single oblique shock system and the double oblique shock systems. The double shock systems theoretically give better performance. If the deceleration had been achieved by a single normal shock, the overall stagnation pressure ratio would have been only 0.33. However, in the case of double oblique shock systems, the overall stagnation pressure ratio would have been only 0.875. The following figure provides an ideal geometry to achieve low losses while at the same time avoiding the starting problems of internal convergence.

However, several practical difficulties would be encountered in the operation of such an inlet. This geometry, like that of the isentropic internal flow diffuser, would function properly at only one Mach number, and performance would be very sensitive to the angle of attack. Furthermore, the boundary layer along the curved surface, unlike that along plane or conical surfaces, would be subject to a high adverse pressure gradient, which might cause separation. Finally, for high flight Mach numbers, it would be necessary that the flow turns through large angles before reaching sonic velocity.

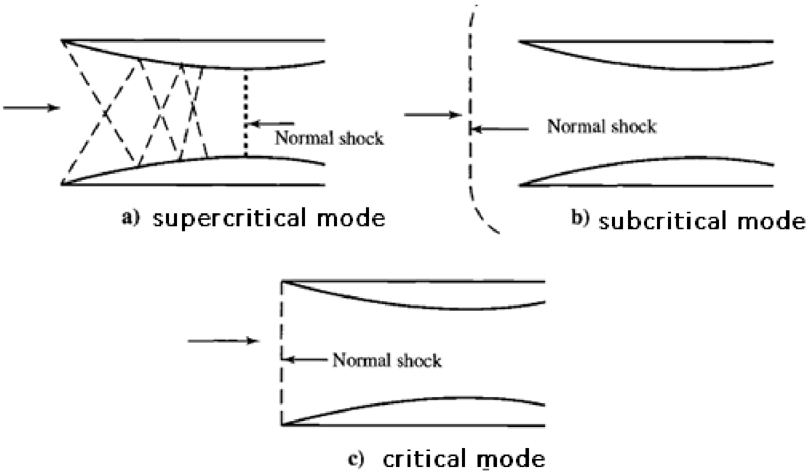


The Flow Stability Problem

Consider a fixed geometry inlet designed for shock-free operation at Compressible internal flow. At supersonic Mach numbers below the design value, the inlet cannot pass the flow in the upstream stream tube, and the excess must be diverted around the inlet. A shock, therefore, stands in front of the inlet, as in Figure (a). This mode is known as subcritical mode.

As the Mach number is increased towards MD, the corrected flow per unit area of the incoming stream decreases, reducing the flow that must be spilled around the inlet and allowing the shock to move closer to the inlet. At the design Mach number, the shock will sit on the inlet lip. In this position, it is unstable because a small perturbation that moves it into the inlet causes a decrease in shock Mach number, this mode is known as Critical mode.

With achieving shock swallowing in the diffuser, the consequence of the transient is shock motion through the throat to a downstream position determined by the variable nozzle. To achieve the best recovery, the nozzle is adjusted to position the shock at the throat. The model is known as supercritical Mode.



Typical Modes of Inlet operation