Jet Aircraft Propulsion

Prof. Bhaskar Roy, Prof. A M Pradeep
Department of Aerospace Engineering,
IIT Bombay

Lect-28

In this lecture...

- Performance of intakes
  - Performance parameters
  - Sources of losses
  - Starting problem in supersonic intakes
  - Modes of operation of an external compression intake

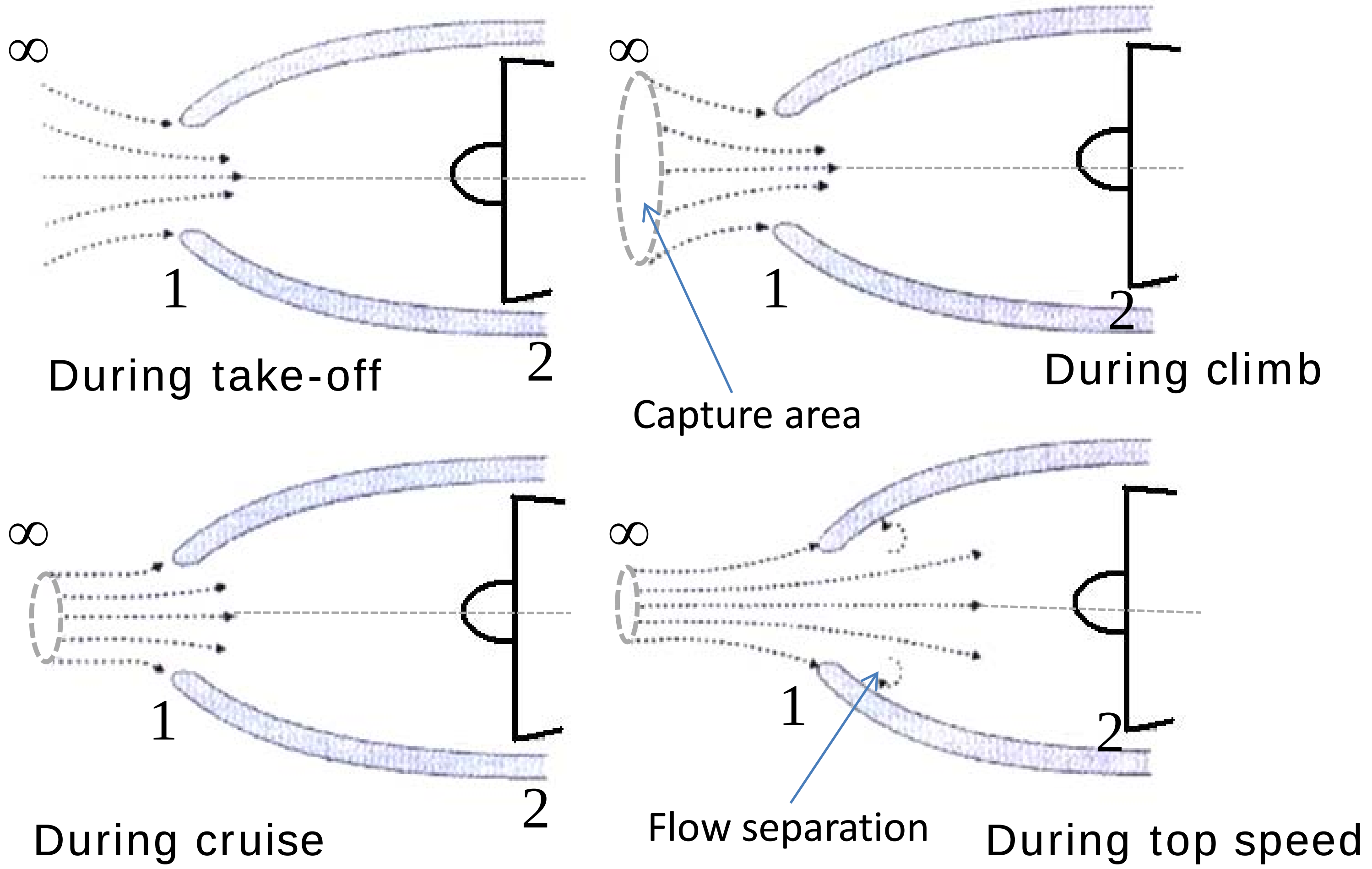
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Intake performance

- Intake operation varies tremendously over the operating range of the engine.
- During take-off the engine requires high mass flow, but is operating at a lower speed.
- A typical fixed geometry intake may have problems delivering this mass flow.
- The intake design must ensure that under these extreme operating conditions too the intake performance is not drastically affected.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance



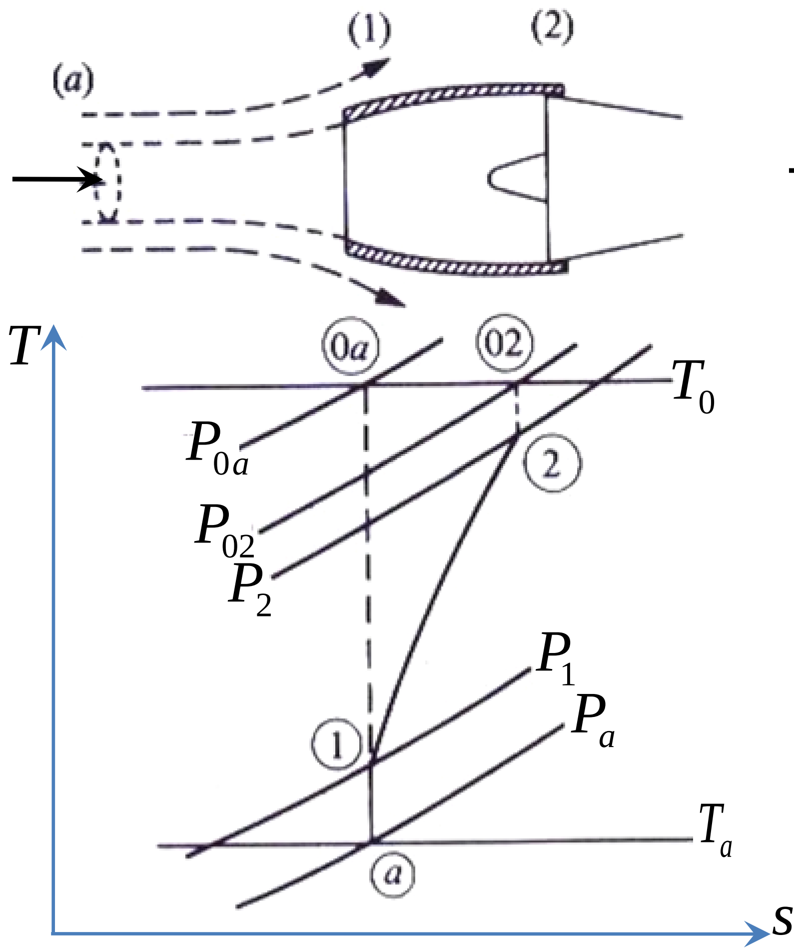
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance

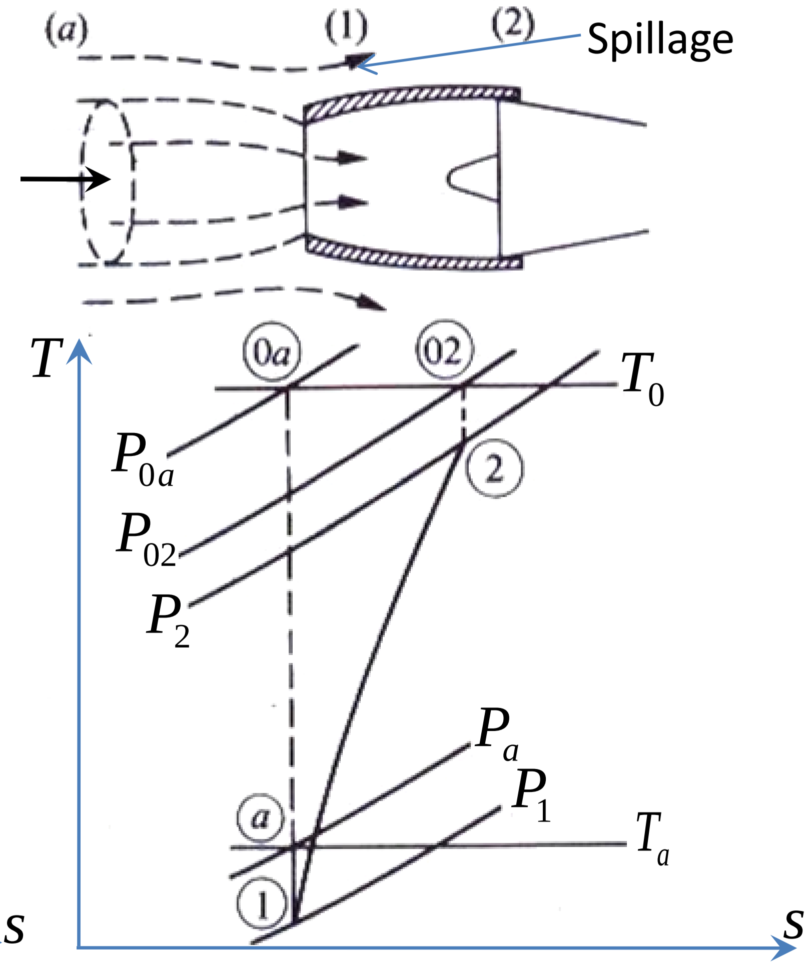
- The compression in a subsonic intake consists of two components:
  - Pre-entry compression or external compression
  - Internal compression or the compression in the diffuser
- Pre-entry compression is always isentropic, whereas internal compression is not.
- However trying to maximize pre-entry compression may result in boundary layer separation within the internal compression.
- Designers try to optimize between external and internal compression.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance



High speed/low mass flow



Low speed/high mass flow

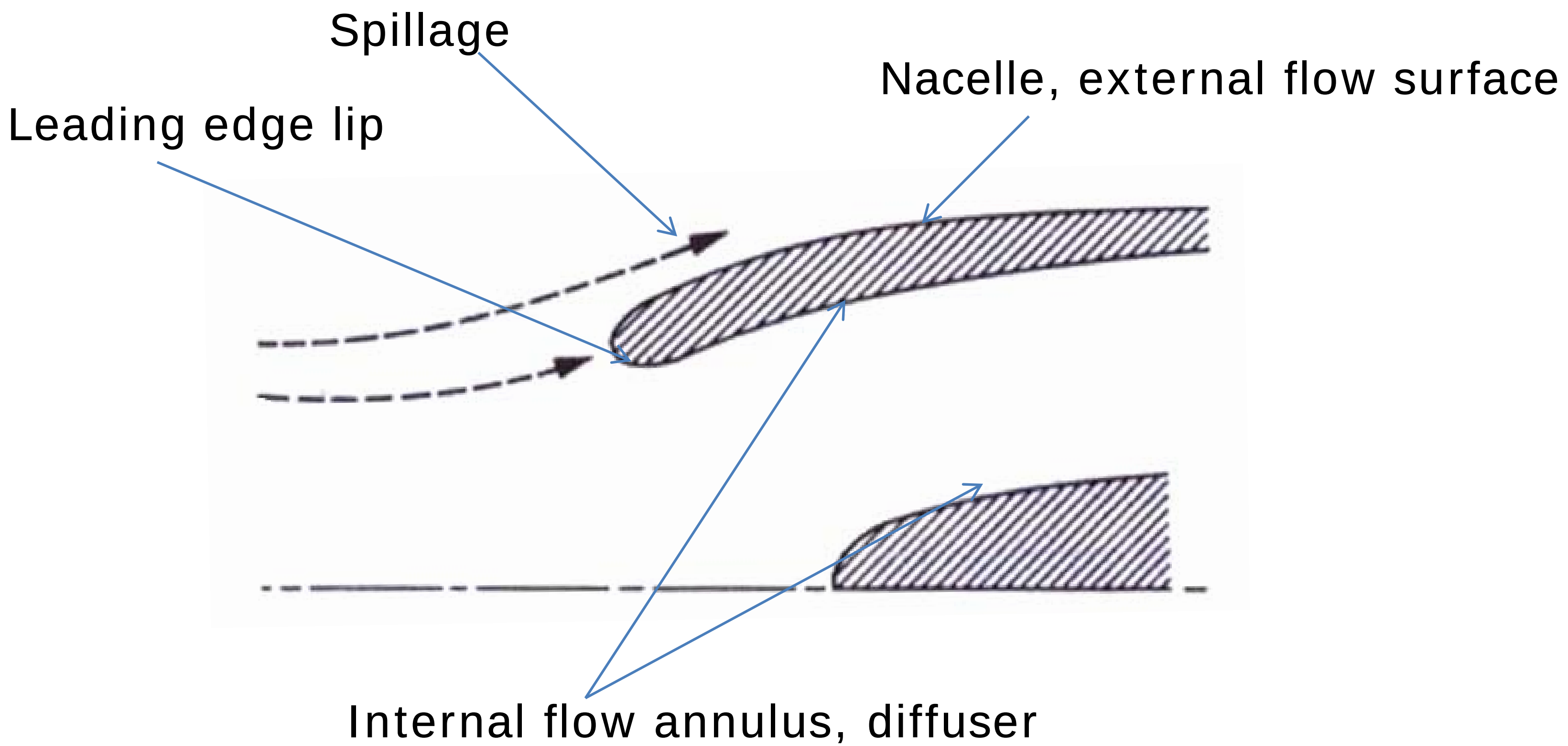
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance

- Flow separation can get initiated at three possible locations
  - External to the intake on the nacelle
  - Within the diffuser internal surface
  - On the centerbody or the hub
- Separation on the nacelle would lead to increase in overall drag of the aircraft
- Separation within the diffuser geometry may lead to higher stagnation pressure losses and therefore lower diffuser efficiency.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance



Possible regions of flow separation

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance

- Spillage:
  - Occurs when the incoming streamtube (capture area) is different from the intake entry area
  - Leads to increased drag
  - May also lead to separation on the cowl
- External deceleration (pre-entry compression) devoid of losses
  - Sensitive to operating condition
- Trade-off between external and internal deceleration

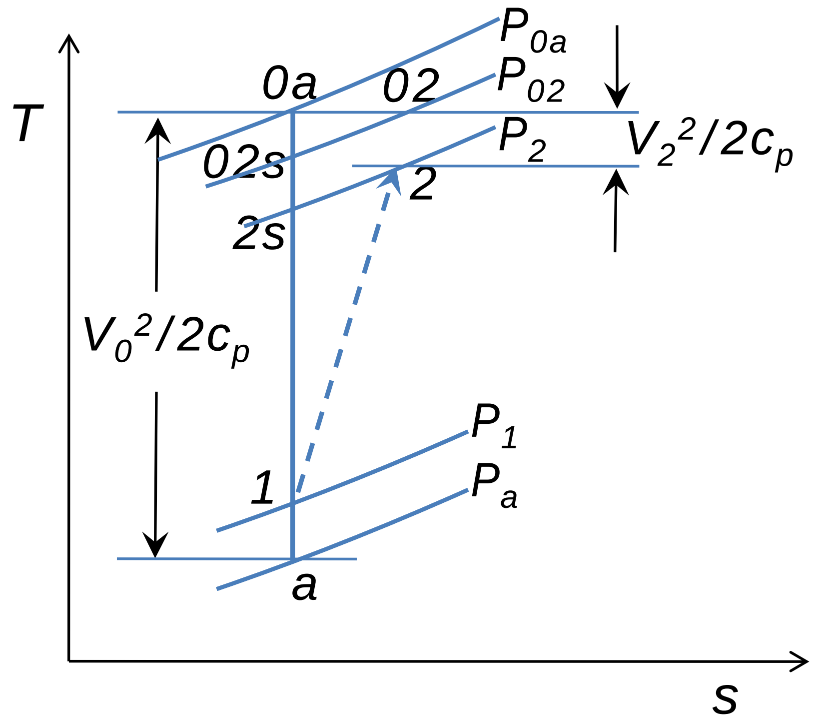
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Intake performance

- Performance of intakes (subsonic as well as supersonic) are evaluated using the following:
  - Isentropic efficiency
  - Stagnation pressure ratio or pressure recovery
  - Distortion coefficient

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance



Isentropic efficiency

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance

- Isentropic efficiency, η_d, of the diffuser is

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

- Stagnation pressure ratio or pressure recovery is the ratio of the outlet stagnation pressure to the inlet stagnation pressure:

$$\pi_d = P_{02} / P_{0a}$$

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance

- Isentropic efficiency can be related to the total pressure ratio (π_d) and Mach number

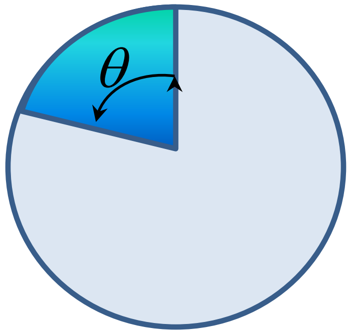
$$\eta_d = \frac{\left(1 + \frac{\gamma - 1}{2} M^2\right) \pi_d^{(\gamma-1)/\gamma} - 1}{\left[(\gamma - 1)/2\right] M^2}$$

- Distortion coefficient is a measure of the intake exit flow non-uniformity.
- There are several definitions for distortion coefficient.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance

- One of the most commonly used definitions is DC_θ



$$DC_\theta = \frac{\overline{P}_{02} - \overline{P}_{02\theta\min}}{1/2\rho V_\infty^2}$$

$\overline{P}_{o2}$ is the average outlet stagation pressure

$\overline{P}_{02\theta\min}$ is the average outlet stagnation pressure is sector where stagnation pressure is minimum

$1/2\rho V_\infty^2$ is the inlet dynamic pressure

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Subsonic intake performance

- Based on the sector angle chosen, there are different ways of defining distortion coefficient.
- The sector angle that is most commonly used is 60^o and therefore the distortion coefficient is DC_{60}.
- Other angles like 45^o and 90^o are also sometimes used.

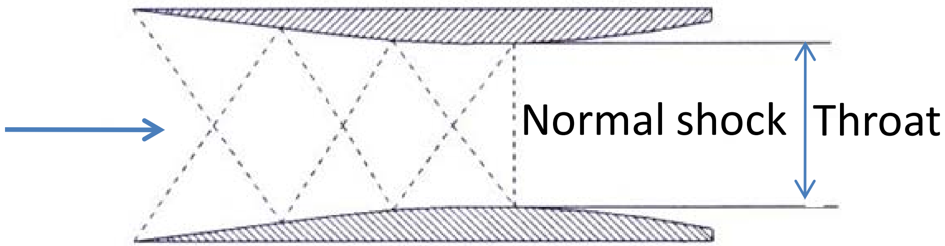
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Supersonic intakes

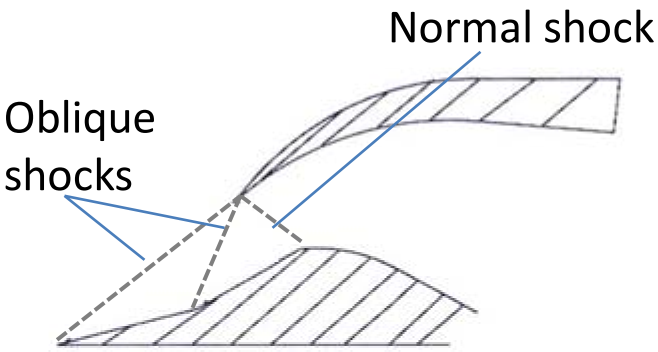
- Internal, external or mixed compression
  - Depending upon the location of the shocks
  - Internal compression intakes have shocks that are located within the intake geometry
  - External compression intakes have shocks located outside the intake
  - Mixed compression intakes have shock that are located within as well as outside the intake geometry.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

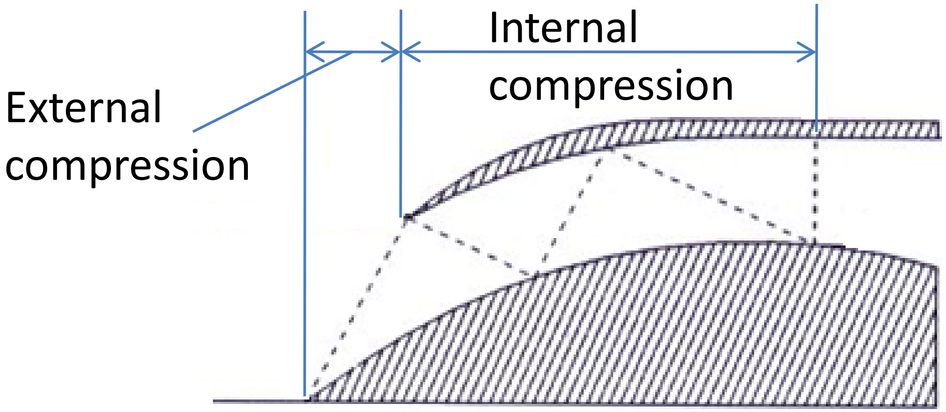
Supersonic intakes



Internal compression intake



External compression intake



Mixed compression intake

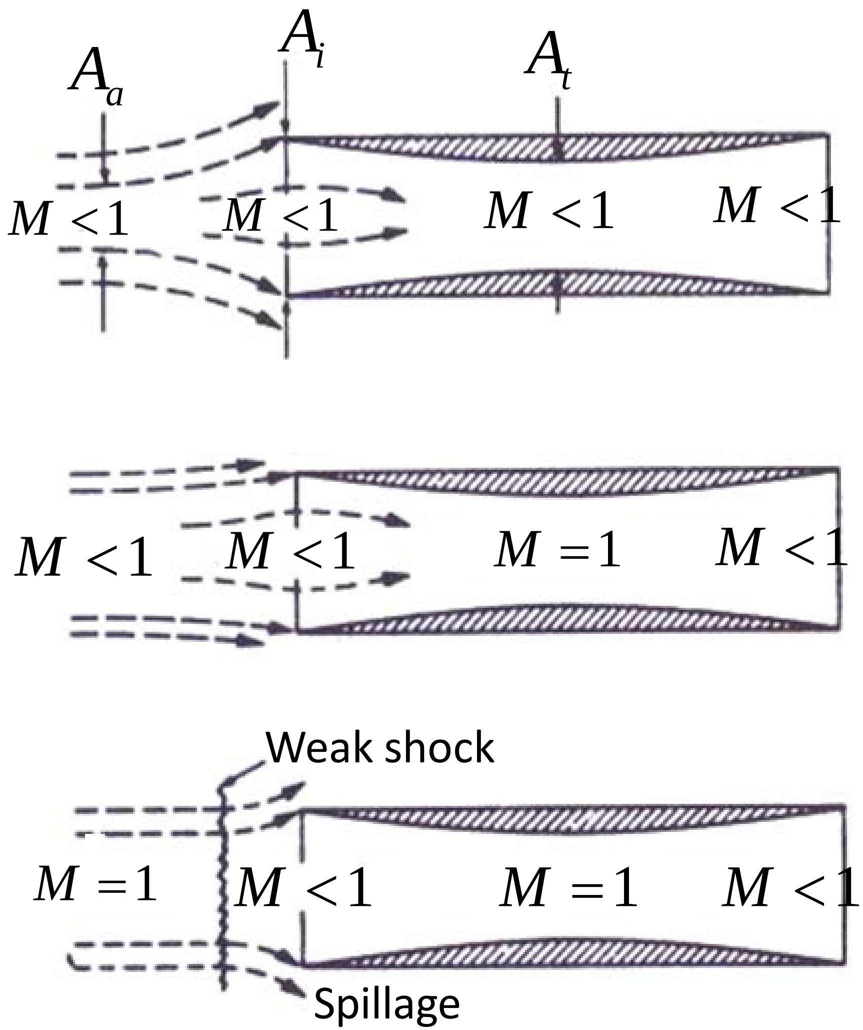
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Supersonic intake performance

- Supersonic diffusers are characterised by the presence of shocks.
- However before the intake operates in a supersonic flow, it must pass through the subsonic flow regime.
- In some types of supersonic intakes, establishing a shock system with minimal losses is not easy.
- The process of establishing a stable shock system is referred to as Starting of an intake.

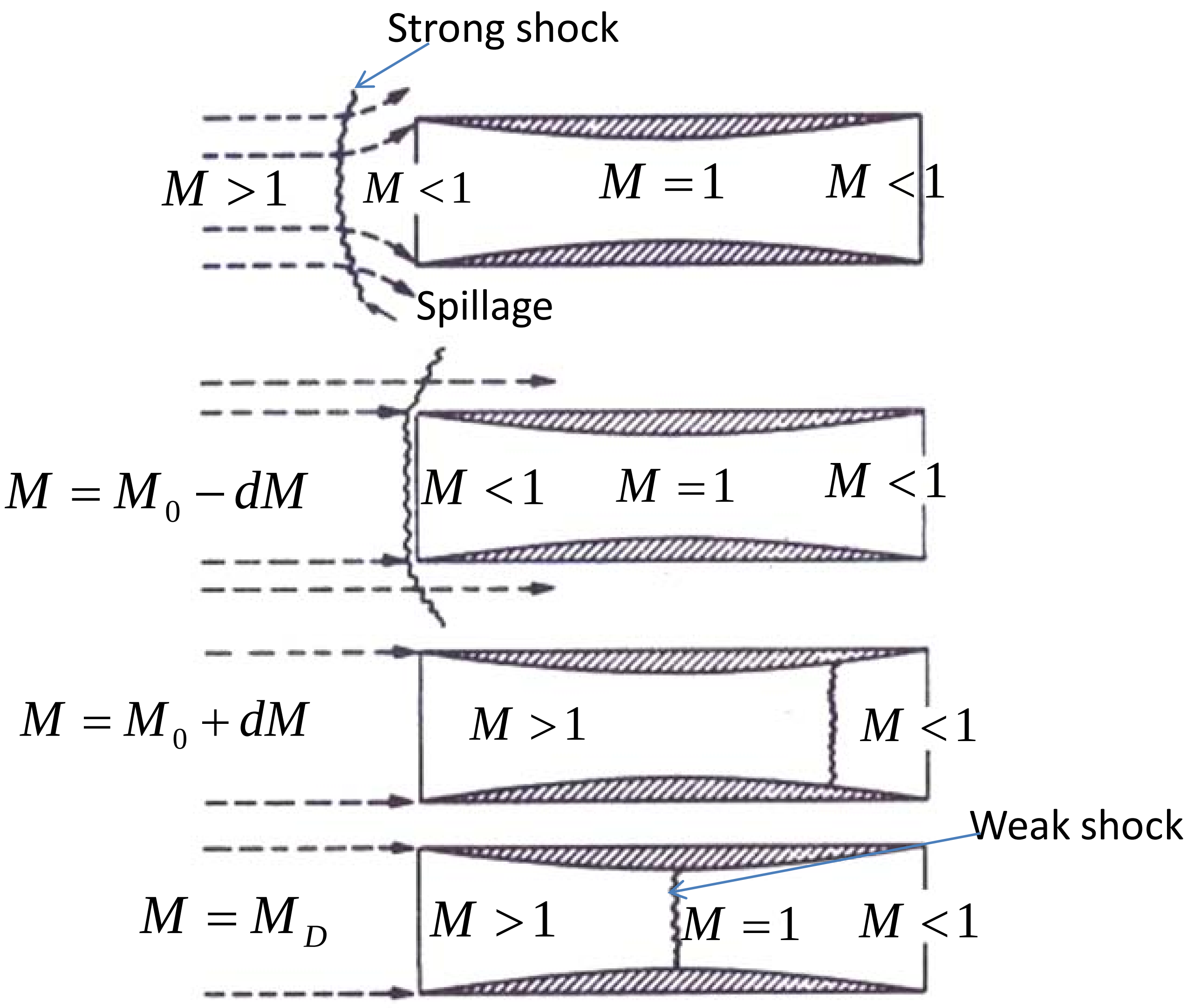
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Starting of an intake



Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Starting of an intake



Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Supersonic intake performance

- 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.

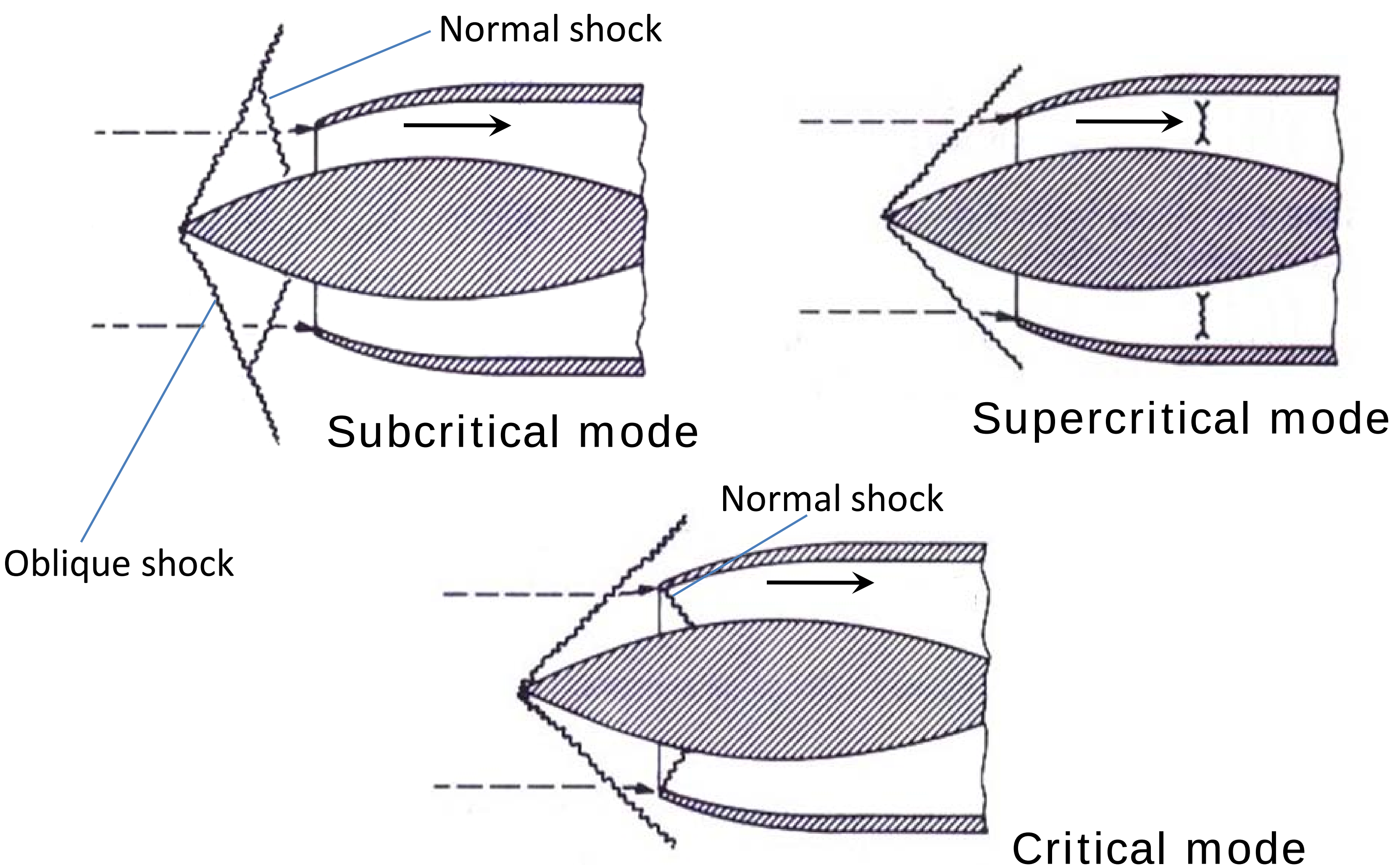
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Supersonic intake performance

- 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 same mass flow as 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.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Supersonic intake performance



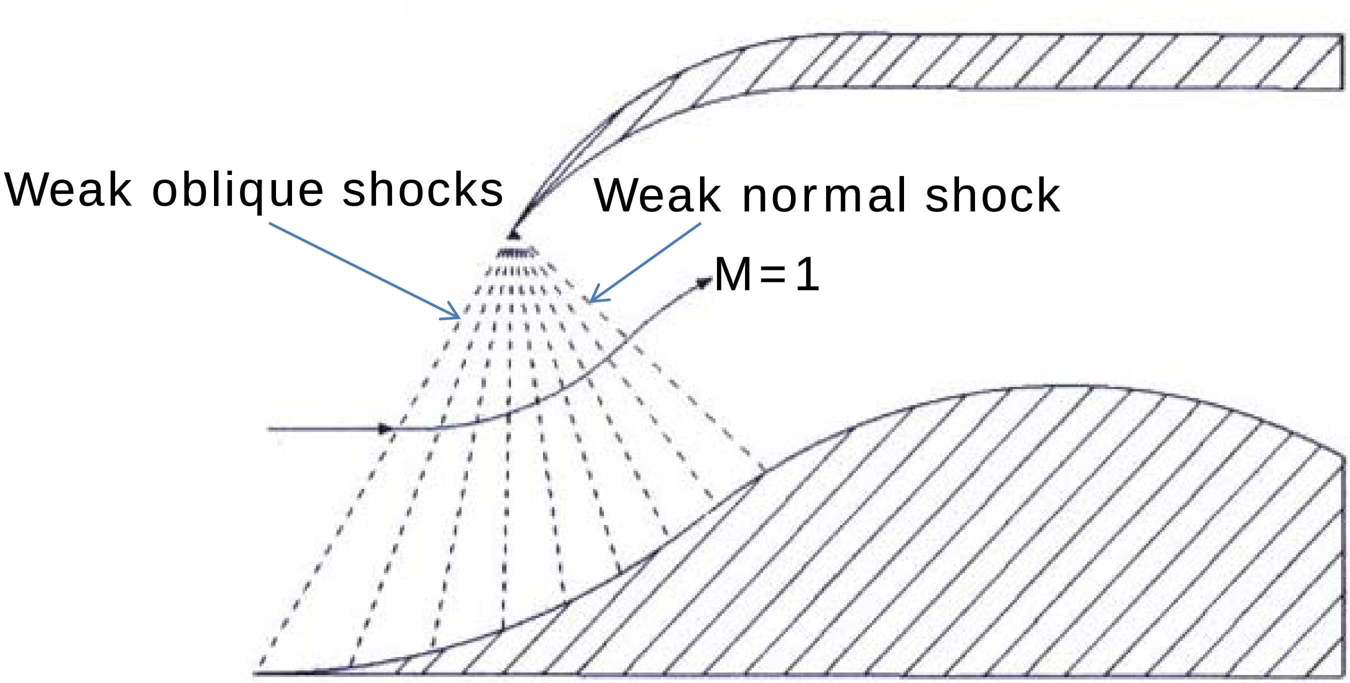
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Supersonic intake performance

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

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Supersonic intake performance



Isentropic external diffuser

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

In this lecture...

- Performance of intakes
  - Performance parameters
  - Sources of losses
  - Starting problem in supersonic intakes
  - Modes of operation of an external compression intake

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

In the next lecture...

- Nozzle:
  - fixed and variable geometry nozzles

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay