Jet Aircraft Propulsion

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Lect-29

In this lecture...

- Nozzle:
  - Fixed and variable geometry nozzles
  - Functions of nozzles
  - Thrust vector control
  - Thrust reversal
  - Noise control

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Exhaust nozzles

- Nozzles form the exhaust system of gas turbine engines.
- It provides the thrust force required for all flight conditions.
- In turboprops, nozzles may generate part of the total thrust.
- Main components: tail pipe or tail cone and the exhaust duct.
- Nozzles could be either of fixed geometry or variable geometry configuration.

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Exhaust nozzles

- Besides generating thrust, nozzles have other functions too.
- Variable area nozzles are used for adjusting the exit area for different operating conditions of the engine.
- For thrust reversal: nozzle are deflected so as to generate a part of the thrust component in the forward direction resulting in braking.
- For thrust vectoring: vectoring the nozzles to carry out complex maneuvers.
- Exhaust noise control

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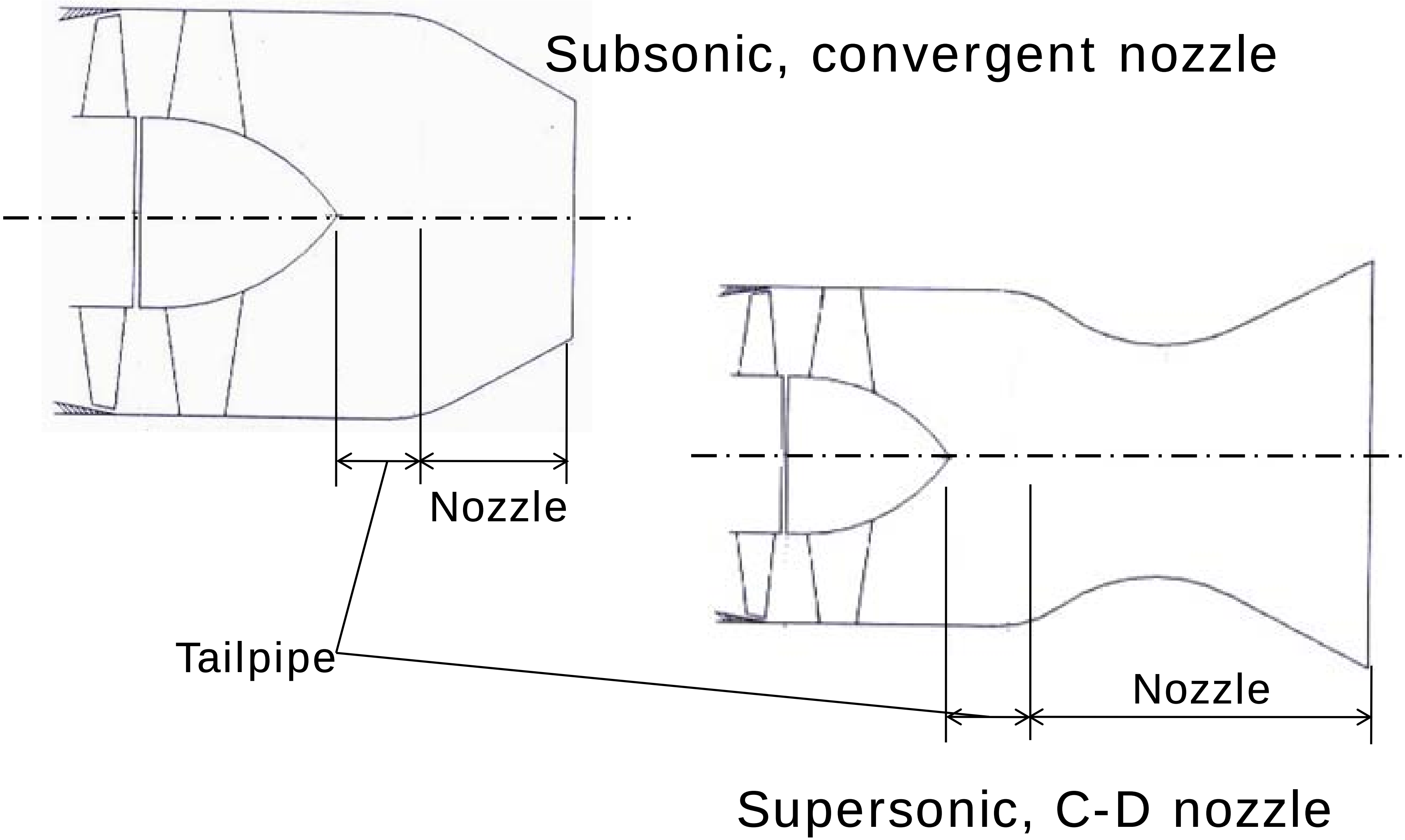
Exhaust nozzles: Fixed geometry



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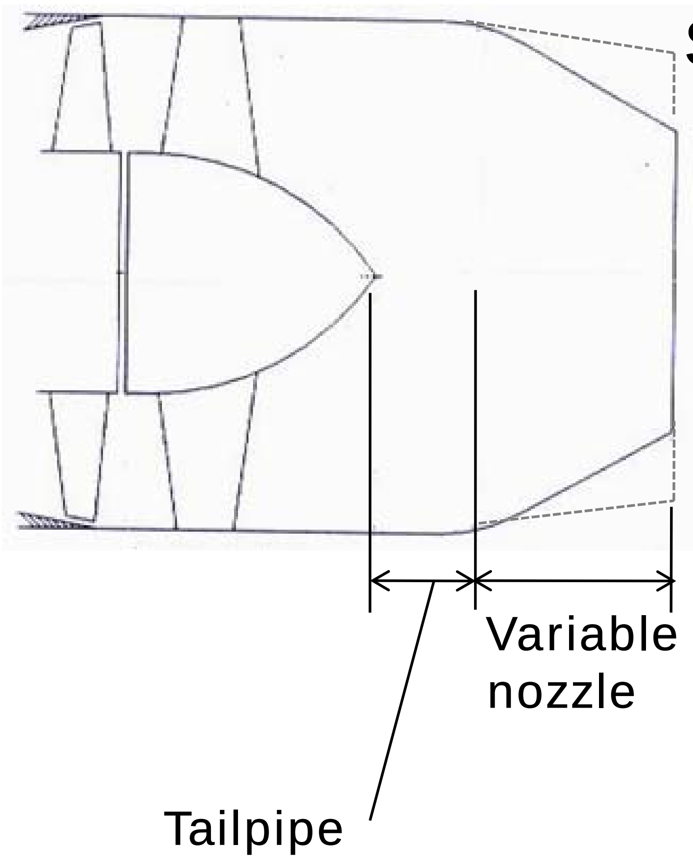
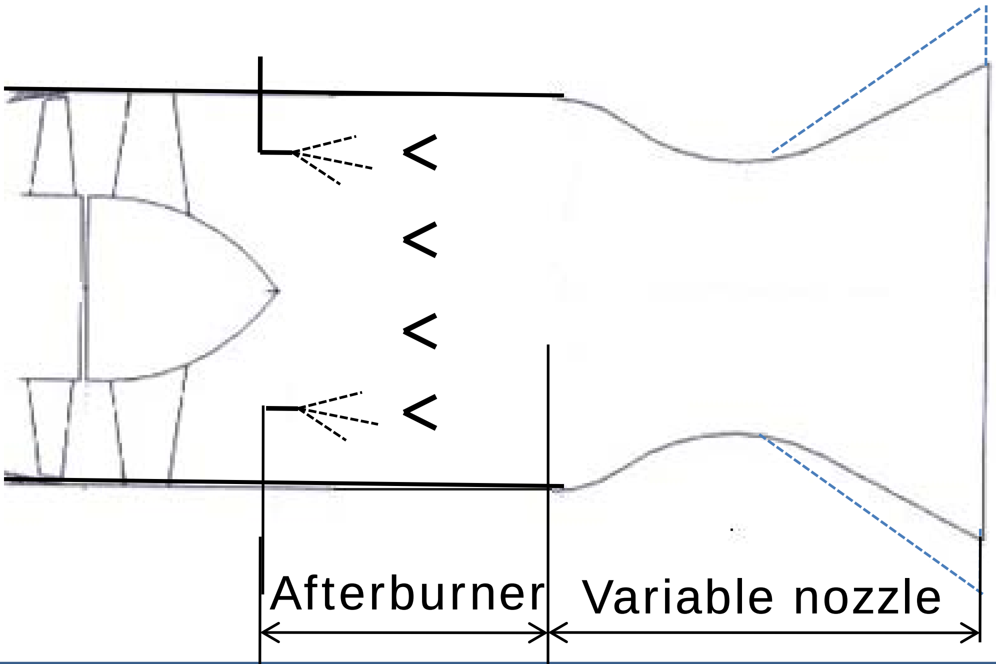
Exhaust nozzles: Variable geometry





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Exhaust nozzles

- Types of nozzles:
  - Convergent or Converging-diverging
  - Axisymmetric or two-dimensional
  - Fixed geometry or variable geometry
- Simplest is the fixed geometry convergent nozzle
  - Was used in subsonic commercial aircraft.
- Other nozzle geometries are complex and require sophisticated control mechanisms.

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Exhaust nozzles

- Nozzle must fulfill the following:
  - Be matched with other engine components
  - Provide optimum expansion ratio
  - Have minimum losses at design and off-design
  - Permit afterburner operation
  - Provide reversed thrust when necessary
  - Suppress jet noise and IR radiation
  - Provide necessary vectored thrust
  - Have minimal weight, cost and maintenance while satisfying the above.

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Exhaust nozzles

- Convergent nozzles are normally used in subsonic aircraft.
- These nozzles operate under choked condition, leading to incomplete expansion.
- This may lead to a pressure thrust.
- A C-D nozzle can expand fully to the ambient pressure and develop greater momentum thrust.
- However due to increased weight, geometric complexity and diameter, it is not used in subsonic transport aircraft.

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Variable geometry nozzles

- Variable area nozzles or adjustable nozzles are required for matched operation under all operating conditions.
- Three types of variable area nozzles are:
  - Central plug at nozzle outlet
  - Ejector type
  - Iris nozzle
- The Central plug is very similar to the spike of an intake.
- Unlike intake, the central plug causes external expansion fans.

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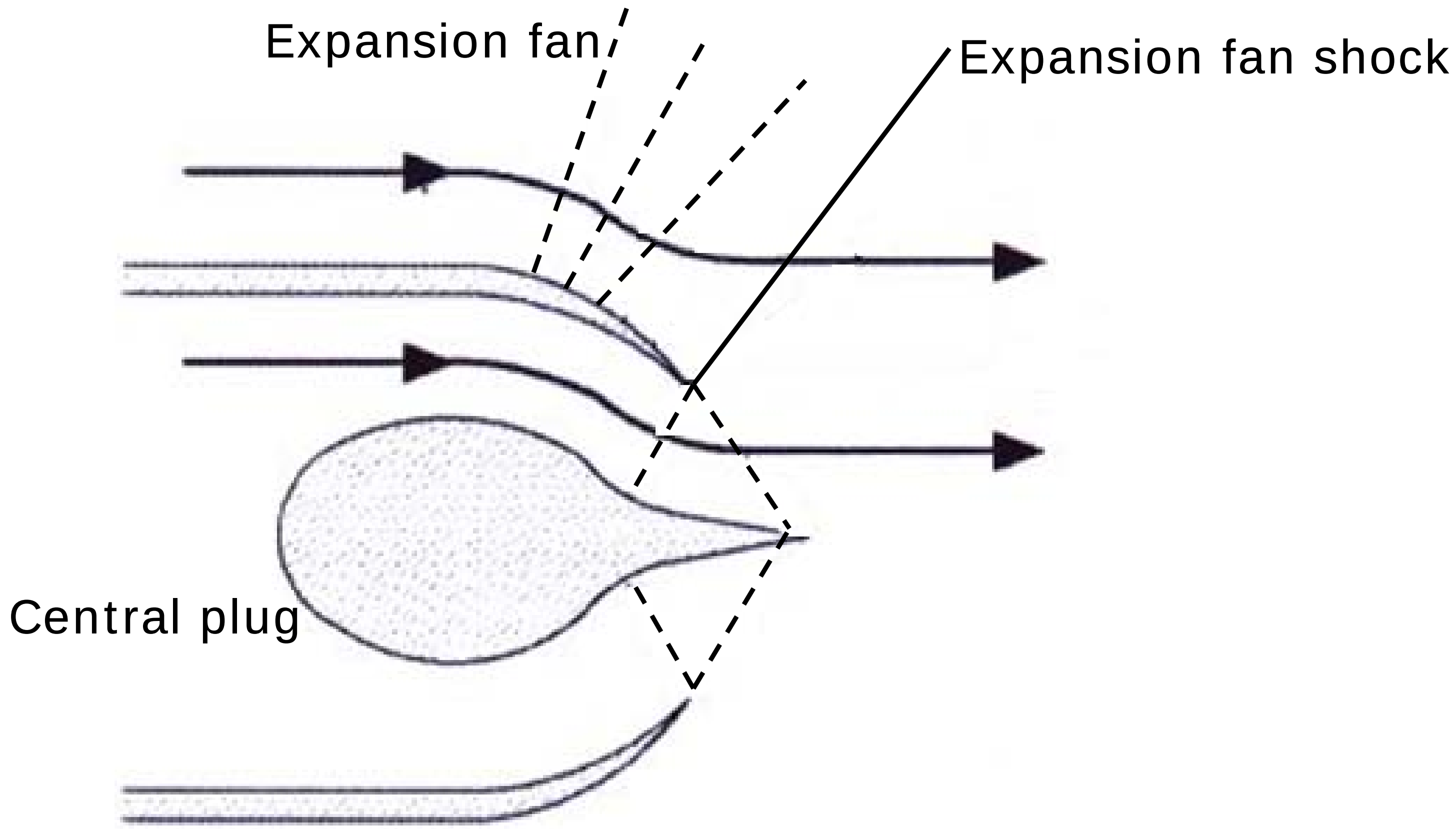
Central plug nozzles



Central plug at nozzle outlet

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Ejector type nozzles

- Ejector nozzle: creates an effective nozzle through a secondary airflow
- At subsonic speeds, the airflow constricts the exhaust to a convergent shape.
- As the speed increases, the two nozzles dilate and the two nozzles form a CD shape.
- Some configurations may also have a tertiary airflow.
- SR-71, Concorde, F-111 have used this type of nozzle.

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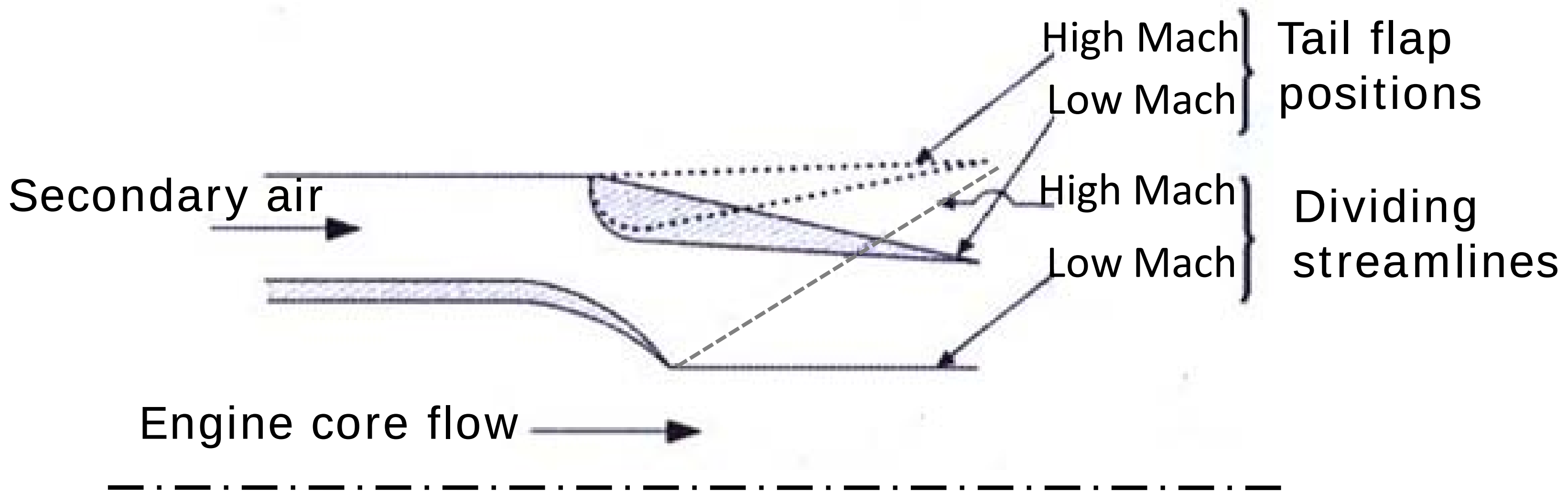
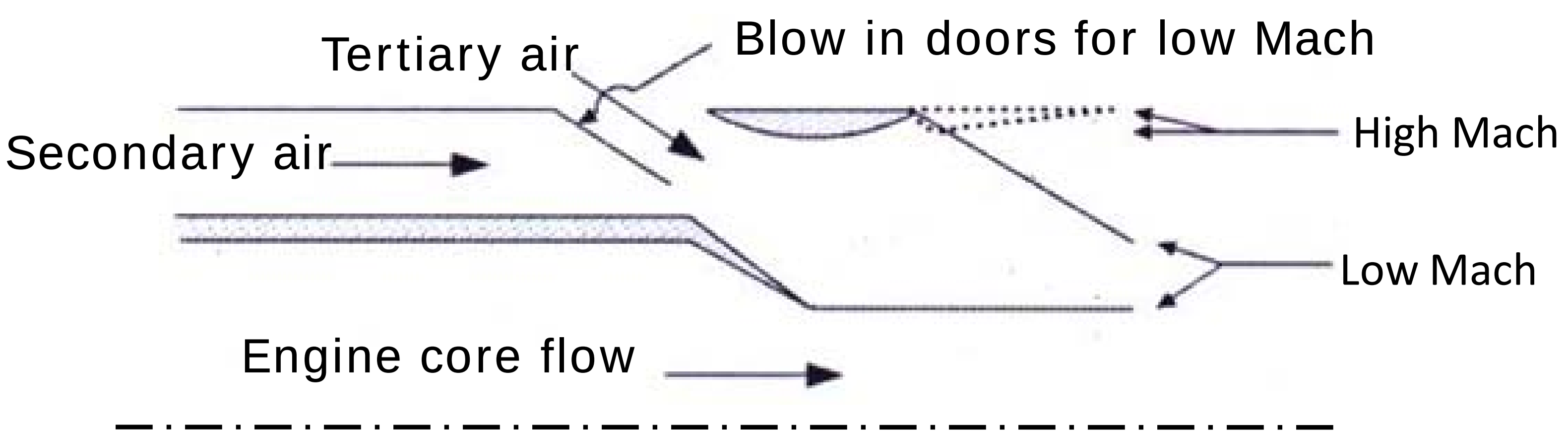
Ejector type nozzles





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Variable geometry nozzles

- Iris nozzle: uses overlapping, adjustable petals.
- More complicated than the ejector type nozzle.
- Offers significantly higher performance.
- Used in advanced military aircraft.
- Some of the modern aircraft also have iris nozzles that can be deflected to achieve vectored thrust.

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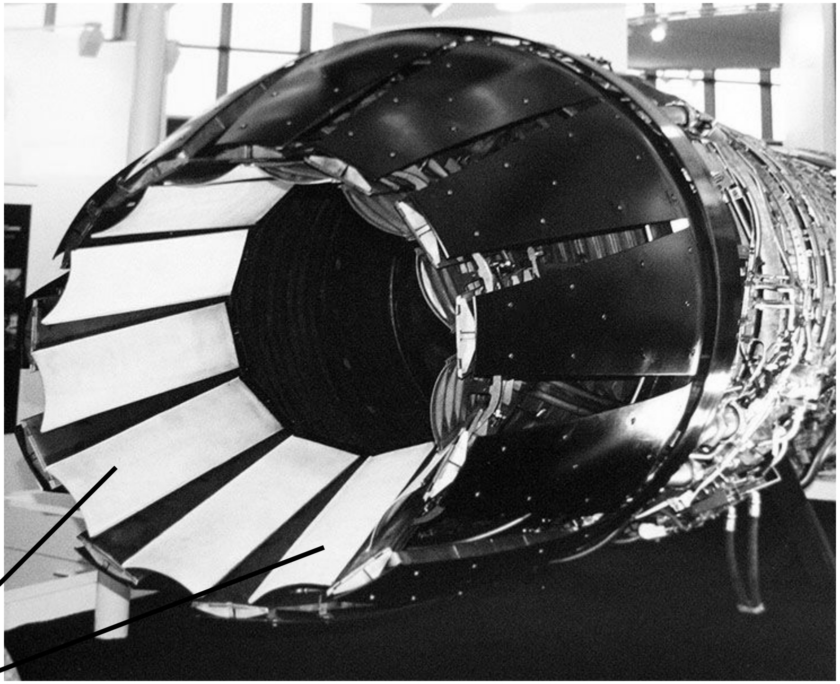
Iris type nozzles



Iris petals for variable geometry

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Thrust vectoring

- Directing the thrust in a direction other than that parallel to the vehicles' longitudinal axis.
- This allows the aircraft to undergo maneuvers that conventional control surfaces like ailerons or flaps cannot provide.
- Used in modern day combat aircraft.
- Provides exceptional agility and maneuvering capabilities.

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Thrust vectoring

- Thrust vectoring was originally developed as a means for V/STOL (Vertical or Short Take Off and Landing).
- Thrust vectored aircraft have better climb rates, besides extreme maneuvers.
- Most of the modern day combat aircraft have thrust vectoring.
- Some of the latest aircraft also have axisymmetric nozzle thrust vectoring.

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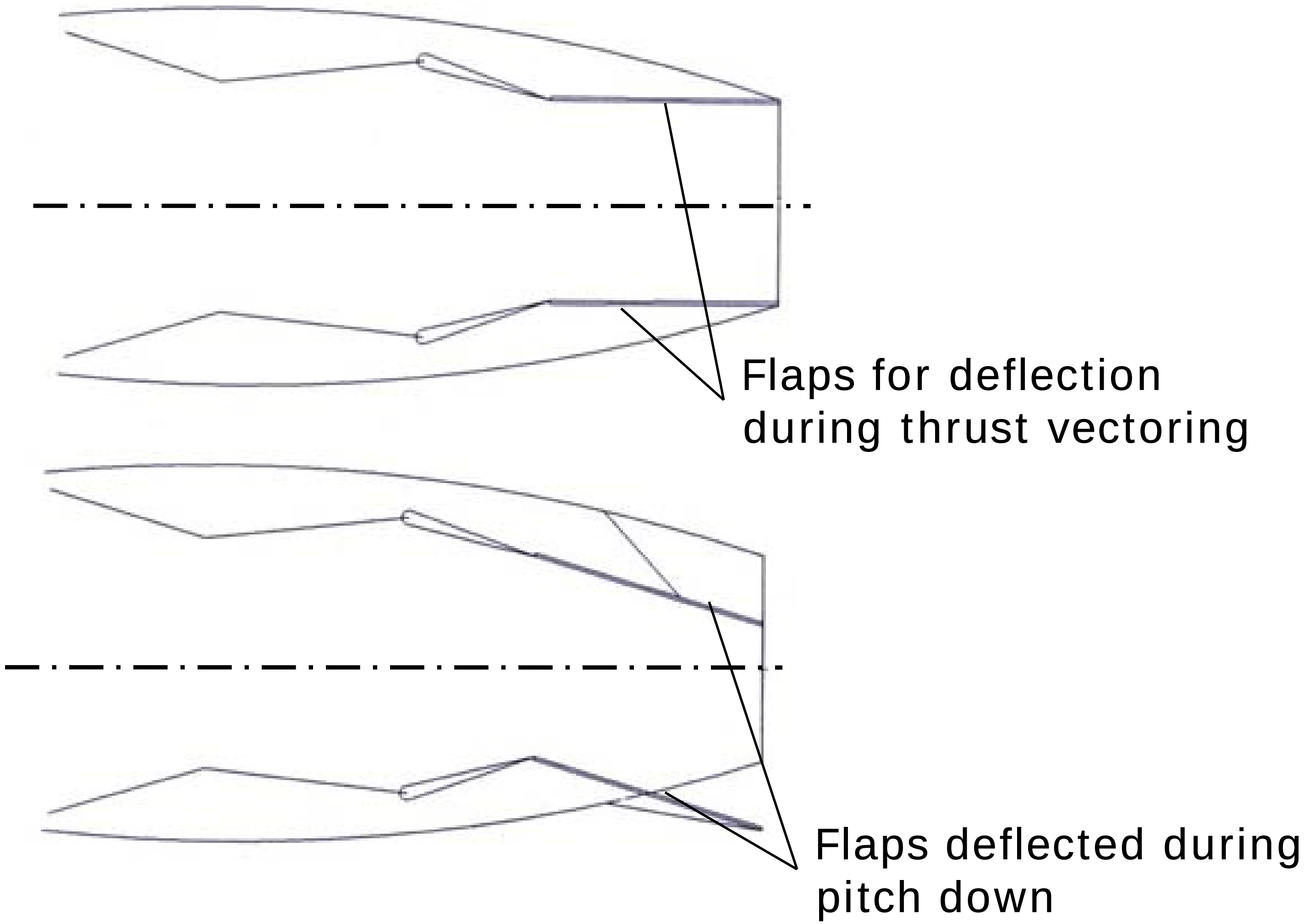
Thrust vectoring

- There are two types of thrust vector controls:
  - Mechanical control
  - Fluidic control
- Mechanical control involves deflecting the engine nozzle and thus physically alter the direction of thrust.
- Fluidic vectoring involves either injecting fluid or removing it from the boundary layer of the primary jet.

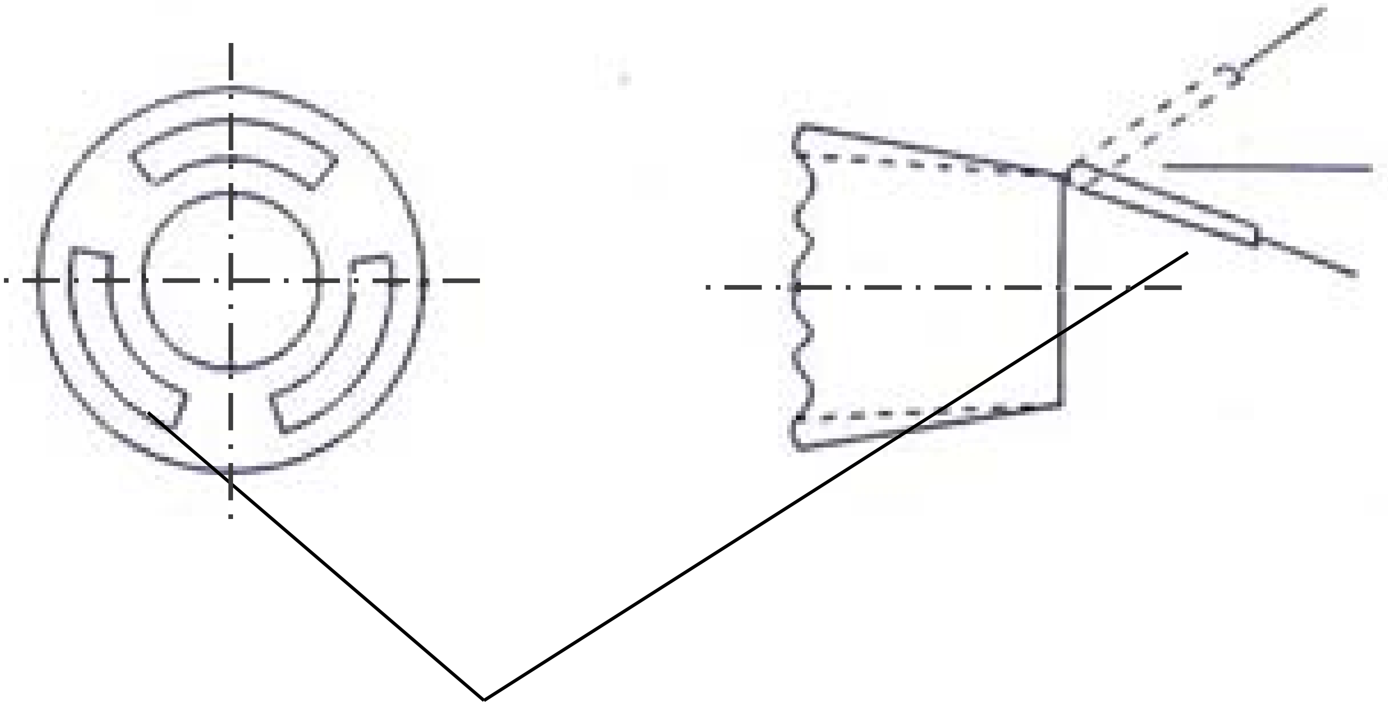
Thrust vectoring

- Mechanical vectoring system is heavier and complex.
- There are two types of mechanical thrust vectoring
  - Internal thrust vectoring
  - External thrust vectoring
- Internal thrust vectoring permits only pitch control.
- External thrust vectoring can be used for pitch and yaw controls.

Internal thrust vectoring



External thrust vectoring



Flaps or petals to be appropriately deployed to effect vectored thrust

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Thrust vectoring

- Fluidic thrust vectoring has been demonstrated successfully at a laboratory scale.
- This method has several advantages over the mechanical control.
- Main challenge lies in ensuring an effective control with a linear response.
- Other concepts like Shock thrust vector control, coflow and counter flow thrust vectoring concepts are also being pursued.

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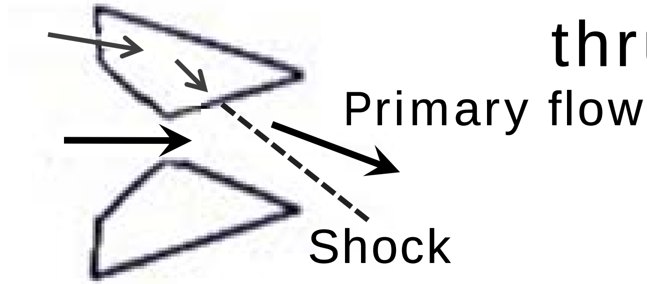
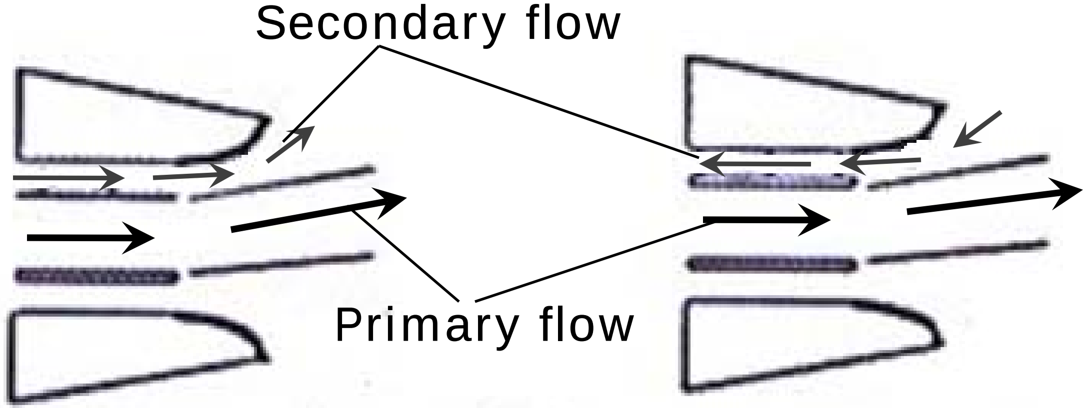
Fluidic thrust vectoring



Shock vector thrust vectoring



Co-flow and counter-flow thrust vectoring

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Thrust reversal

- With increasing size and loads of modern day aircraft, wheel brakes alone cannot brake and aircraft.
- Deflecting the exhaust stream to produce a component of reverse thrust will provide an additional braking mechanism.
- Most of the designs of thrust reversers have a discharge angle of about 45^o
- Therefore a component of the thrust will now have a forward direction and therefore contributes to braking.

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Thrust reversal

- There are three types of thrust reversal mechanisms that are used
  - Clamshell type
  - External bucket type
  - Blocker doors
- Clamshell type: is normally pneumatically operated system.
- When deployed, doors rotate and deflect the primary jet through vanes.
- These are normally used in non-afterburning engines.

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Thrust reversal

- Bucket type system uses bucket type doors to deflect the gas stream.
- In normal operation, the reverser door form part of the convergent divergent nozzle.
- Blocker doors are normally used in high bypass turbofans.
- The cold bypass flow is deflected through cascade vanes to achieve the required flow deflection.

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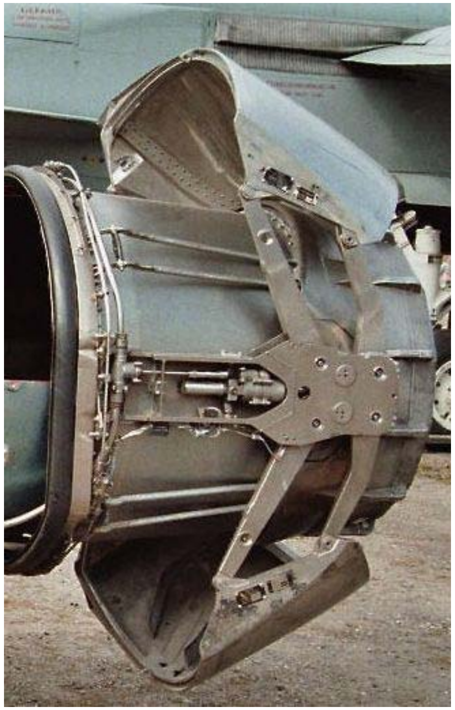
Thrust reversal



Bucket type thrust reverser

Clamshell type thrust reverser

Noise control

- Jet exhaust noise is a major contributor to the overall noise generated by an aircraft.
- Jet exhaust noise is caused by the turbulent mixing of the exhaust gases with the lower velocity ambient air.
- Nozzle geometry can significantly influence the exhaust noise characteristics.
- Better mixing between the jet exhaust and the ambient can be achieved by properly contouring the nozzle exit.
- Corrugations or lobes (multiple tubes) are some of the methods of achieving lower jet exhaust noise.

Noise control

Noise control using corrugations/serrations at the nozzle exit

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In the next lecture…

- Subsonic and supersonic nozzles
- Working of these nozzles
- Performance parameters for nozzles

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