# SNS COLLEGE OF TECHNOLOGY

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## DEPARTMENT OF AEROSPACE ENGINEERING

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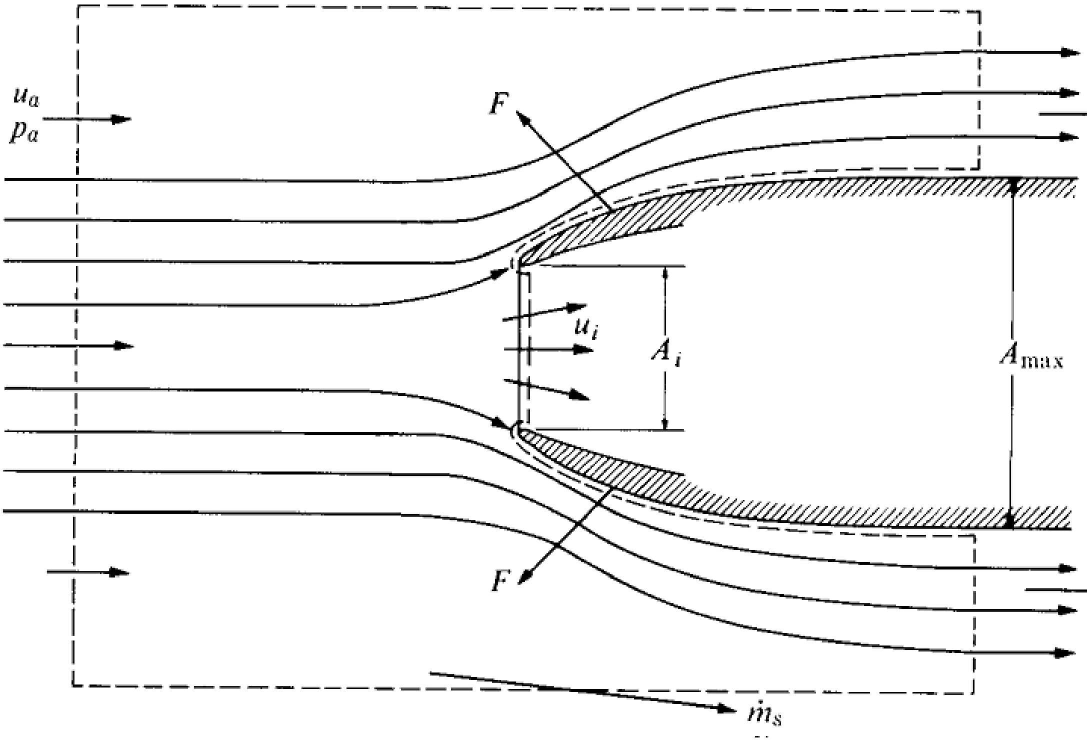
| Course | : | **23ASB201 - Aerospace Propulsion** | | | |

## UNIT II - JET ENGINE INTAKES AND EXHAUST NOZZLES

## Calculations on Area Ratios and Thrust Reversal Scenarios

### Relation for minimum area ratio (Amax/Ai) in terms of external deceleration (Ui/Ua)



Let $A_{max}$ = Maximum area cross section of the inlet

$A_i$ = Minimum area cross section of inlet

$u_a$ = upstream or flight velocity

$u_i$ = velocity inside inlet.

The net momentum flux out of the control volume

$$F = \dot{m}_i u_i + \dot{m}_s u_a - \dot{m}_e u_a \quad \text{—} ①$$

$$F = \rho u_i^2 A_i + \dot{m}_s u_a - \rho u_2^2 A_{max} \quad \text{—} ②$$

From continuity the side flow rate

$$\dot{m}_s = \rho u_a A_{max} - \rho u_i A_i \quad \text{—} ③$$

$\dot{m} = \frac{m}{t}$

$= \rho A \frac{l}{t}$

$\boxed{\dot{m} = \rho A V}$

3 in 2 $\Longrightarrow$

$$F = \rho u_i^2 A_i + \rho u_a^2 A_{max} - \rho u_i u_a A_i - \rho u_a^2 A_{max}$$

$$\rho u_i^2 A_i - \rho u_i u_a A_i$$

$$F_s = \rho A_i (u_i^2 - u_i u_a) \quad \text{—} ④$$

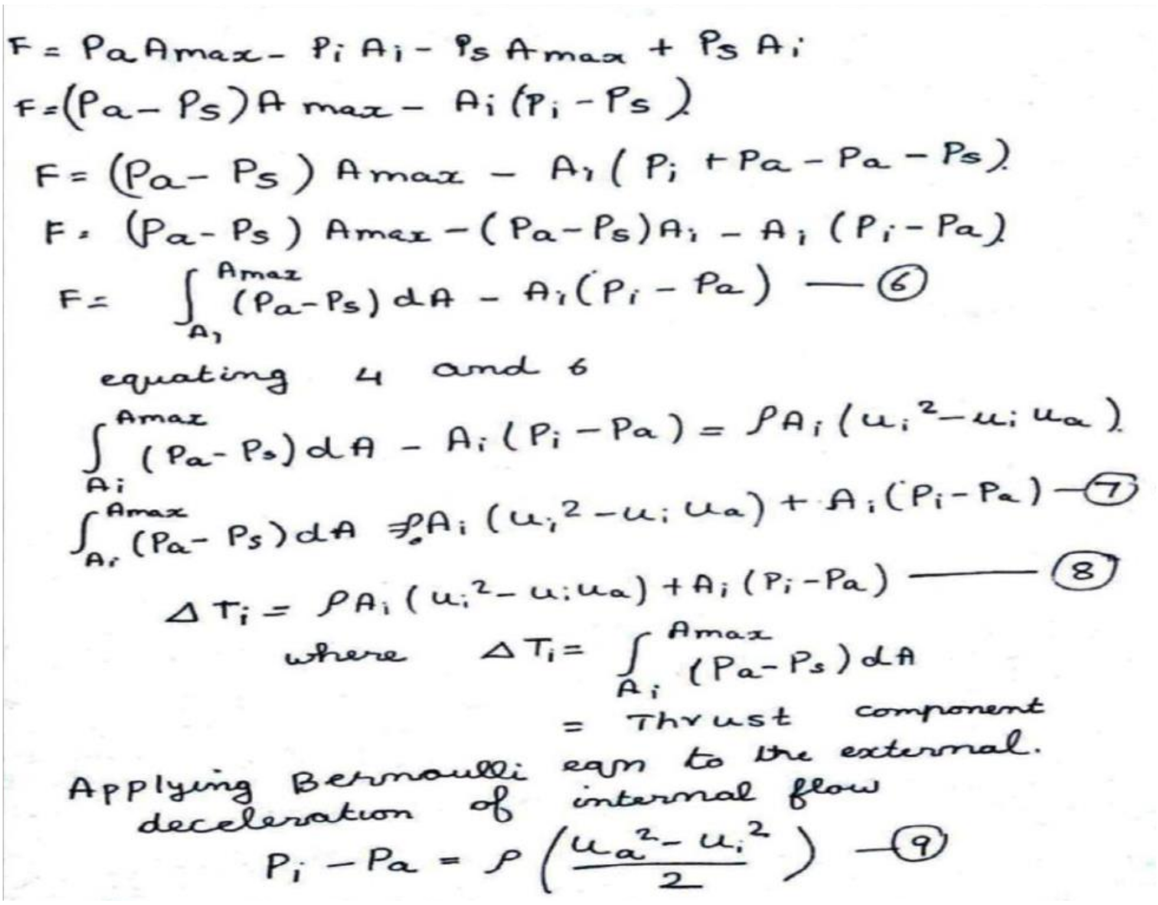
Let $P_s$ = Pressure on surface.

$P_1$ = Pressure at inlet

$P_a$ = Pressure at exit

The total Force

$$F_s = P_a A_{max} - P_i A_i - \int_{A_i}^{A_{max}} P_s \, dA \quad \text{—} ⑤$$



$$F = P_a A_{max} - P_i A_i - P_s A_{max} + P_s A_i$$

$$F = (P_a - P_s) A_{max} - A_i (P_i - P_s)$$

$$F = (P_a - P_s) A_{max} - A_1 (P_i + P_a - P_a - P_s)$$

$$F = (P_a - P_s) A_{max} - (P_a - P_s) A_i - A_i (P_i - P_a)$$

$$F = \int_{A_1}^{A_{max}} (P_a - P_s)\, dA - A_1 (P_i - P_a) \quad — ⑥$$

equating 4 and 6

$$\int_{A_i}^{A_{max}} (P_a - P_s)\, dA - A_i (P_i - P_a) = \rho A_i (u_i^2 - u_i u_a)$$

$$\int_{A_1}^{A_{max}} (P_a - P_s)\, dA = \rho A_i (u_i^2 - u_i u_a) + A_i (P_i - P_a) \quad — ⑦$$

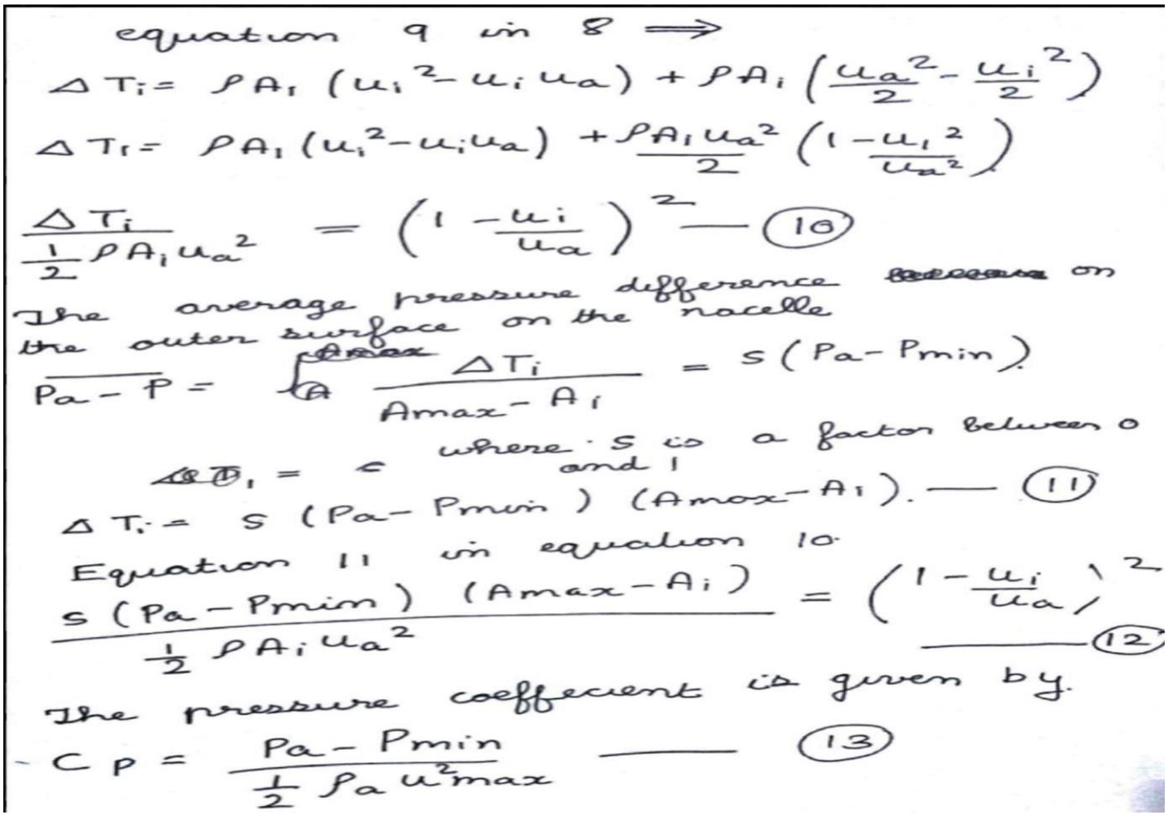
$$\Delta T_i = \rho A_i (u_i^2 - u_i u_a) + A_i (P_i - P_a) \quad —— ⑧$$

where $\Delta T_i = \int_{A_i}^{A_{max}} (P_a - P_s)\, dA$

= Thrust component

Applying Bernoulli eqn to the external. deceleration of internal flow

$$P_i - P_a = \rho \left( \frac{u_a^2 - u_i^2}{2} \right) \quad — ⑨$$



equation 9 in 8 ⟹

$$\Delta T_i = \rho A_1 (u_i^2 - u_i u_a) + \rho A_i \left( \frac{u_a^2}{2} - \frac{u_i^2}{2} \right)$$

$$\Delta T_1 = \rho A_1 (u_i^2 - u_i u_a) + \frac{\rho A_1 u_a^2}{2} \left( 1 - \frac{u_1^2}{u_a^2} \right)$$

$$\frac{\Delta T_i}{\frac{1}{2} \rho A_i u_a^2} = \left( 1 - \frac{u_i}{u_a} \right)^2 \quad —— ⑩$$

The average pressure difference on the outer surface on the nacelle

$$\overline{P_a - P} = \int_{A}^{\cancel{A_{max}}} \frac{\Delta T_i}{A_{max} - A_i} = s (P_a - P_{min})$$

where s is a factor between 0 and 1

~~$\Delta T_1$~~ $=$ c

$$\Delta T_i = s (P_a - P_{min}) (A_{max} - A_1). \quad —— ⑪$$

Equation 11 in equation 10

$$\frac{s (P_a - P_{min}) (A_{max} - A_i)}{\frac{1}{2} \rho A_i u_a^2} = \left( 1 - \frac{u_i}{u_a} \right)^2 \quad —— ⑫$$

The pressure coeffecient is given by.

$$-C_P = \frac{P_a - P_{min}}{\frac{1}{2} \rho_a u_{max}^2} \quad —— ⑬$$

Equation 13 in equation 12 →

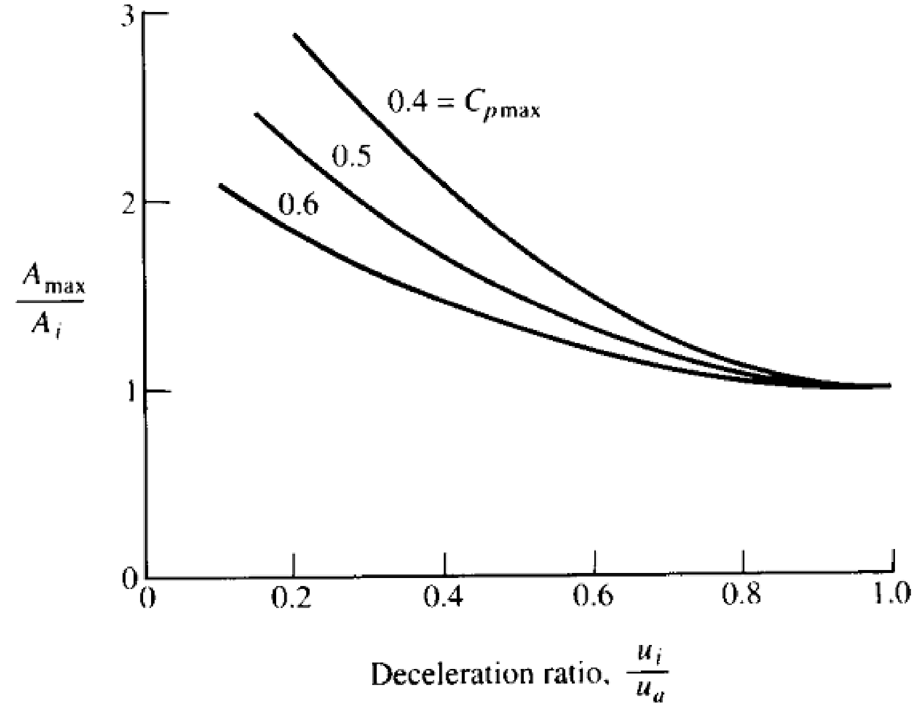
$$\frac{S C_p \left(\frac{A_{max}}{A_i} - 1\right)}{\frac{u_a^2}{u_{max}^2}} = \left(1 - \frac{u_i}{u_a}\right)^2$$

$$\frac{A_{max}}{A_i} - 1 = \frac{\left(1 - \frac{u_i}{u_a}\right)^2 \left(\frac{u_a}{u_{max}}\right)^2}{S C_p}$$

$$\frac{A_{max}}{A_i} - 1 = \frac{\left(1 - \frac{u_i}{u_a}\right)^2}{S C_p \left(\frac{u_{max}}{u_a}\right)^2}.$$

$$\boxed{\frac{A_{max}}{A_1} = 1 + \frac{\left(1 - \frac{u_i}{u_a}\right)^2}{S C_p \left(\frac{u_{max}}{u_a}\right)^2}.}$$

The main point here is that the larger the external deceleration (i.e., the smaller the value of Ui/Ua), the larger must be the size of the nacelle if one is to prevent excessive drag. Even in the absence of separation, the larger the nacelle, the larger the aerodynamic drag on it. But if the external deceleration is modest (e.g., U/ISa > 0.8), its effect on minimum nacelle size is quite small.



It shows that the performance of an inlet depends on the pressure gradient on both internal and external surfaces. The external pressure rise is fixed by the external compression and the ratio, Amax/Ai, of maximum area to inlet area. The internal pressure rise depends on the reduction of velocity between entry to the inlet diffuser and entry to the compressor (or burner, for a ramjet). The nacelle size required for low drag can be quite strongly dependent on the degree of external deceleration.

### Thrust Reversers

Based on the type of engine, the conventional kind of reverse system is built into the engine nacelle or at the end of the engine. The main function of the thrust reverser is to redirect the airflow to generate the reverse engine thrust. The thrust reverse system is applied immediately when the aircraft lands on the runway. The thrust reverse force is generated by the redirection of the airflow through the thrust system. In this case, the thrust reverser reaches its highest value at high speed, but the wheel brakes are restricted by the high velocity. As the airplane speed slows down, the thrust reverse force also decreases.

***Types of Thrust Reverses:***

- Clamshell door system is used for turbojet engine;
- Bucket target system is suited for low bypass ratio (BPR) engines,
- Cold stream reverser system is designed for high bypass ratio turbofan engine.

**Clamshell door system:** forward position, which means the exhaust airflow is not guided by this reverser system. The doors situated before the end of the engine compose the convergent part of the convergent-divergent nozzle. When the pilot selects the reverse thrust, the two doors actuated by the pneumatic system rotate to the convergent area of the nozzle and form a cone-shaped space, closing the exit of the convergent duct. Meanwhile, the hot gas is directed by the cascade vanes located outside of the engine. The airflow passed through the cascade vanes generates the opposing thrust.

**Bucket target system:** The bucket door thrust reverser designed at the end of the nozzle is made up of a divergent part of the convergent-divergent nozzle during the flaying situation The buck door thrust reverser is actuated by the hydraulic system. It is also constructed by two doors actuated by a pushrod system. In the reverse thrust position, these two doors turn to the end of the engine to deflect airflow, which comes from the bypass and core engine.

**Cold stream reverser system:** Cold stream reverser system is used for high bypass ratio turbofan engines. In this case, only the bypass airflow accelerated by the fan is guided forward of the aircraft because the main part of the propulsive force is created by the bypass airflow. There are two types of cold stream reverser systems.

- cascade reverser,
- pivoting reverser.

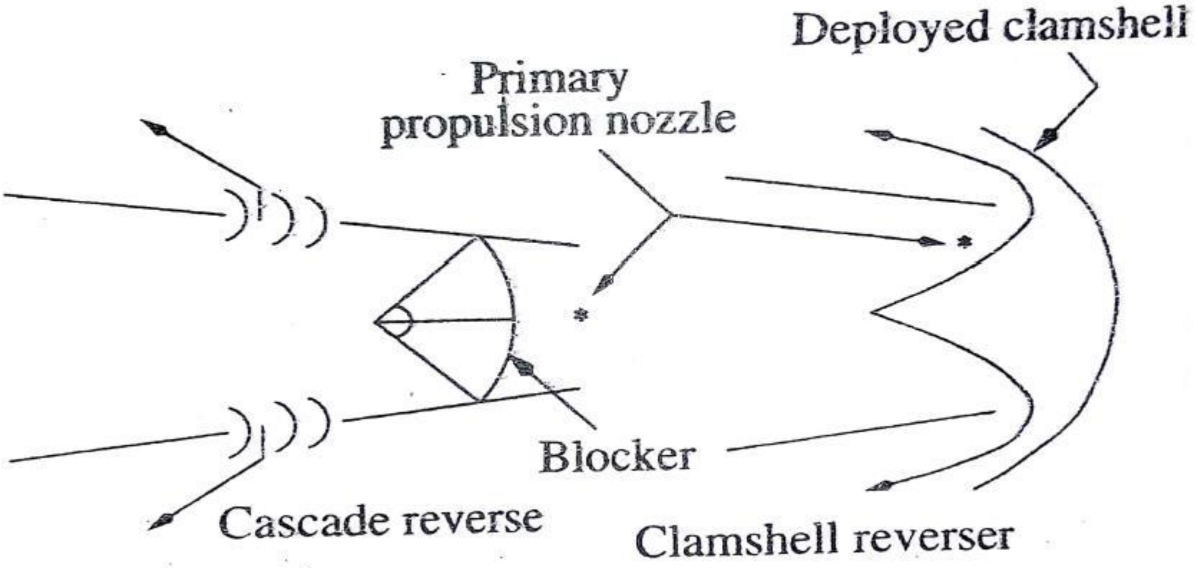


Fig. 13.12 Thrust reversers

**Thrust Vectors**

Thrust vectoring is a technique whereby the orientation of the primary exhaust jet from a propulsive unit is varied to provide useful aircraft control moments.

- Mechanical thrust vectoring is achieved by mechanically deflecting the exhaust flow of an aircraft using some sort of physical object changes in nozzle geometry. This is usually achieved using various nozzles or vanes.

- On the other hand, fluidic thrust vectoring systems use a secondary air jet to control the direction of the primary jet. Fluidic control in exhaust nozzles includes throat area, expansion ratio, and thrust vector angle.

***Mechanical Thrust Vectoring Methods***

- **Flaps:** Flaps deflect the engine's flow in much the same way as wing flaps deflect the external air flow see figure (15 a). This type of system introduces a thrust loss of approximately 3-6% when vectored to 90 degrees. The vectoring flaps can also be external to the nozzle as a part of the wing flap.

- **Bucket:** The bucket thrust vectoring mechanism is similar to the commonly used clamshell thrust reverser see figure(15 b). The great advantage of this concept is that the force is transmitted through the hinge line of the bucket, meaning actuators can be reasonably small. Another advantage of this system is that the turning surface can be made very efficient. This method can be used to create 90-degree vectoring with about 2-3% thrust loss.
- **Axisymmetric:** In this type of nozzle (figure 15 c), the tailpipe is broken along slanted lines into three pieces, as shown. The three pieces are connected with circular rotating ring bearings so that the middle (shaded) piece can be rotated about its longitudinal axis while the other parts remain un-rotated. This causes the middle and end parts of the nozzle to vector thrust downward. This vectoring nozzle has a 3-5% thrust loss when vectoring at 90 degrees.

- **Ventral:** The ventral nozzle (figure 15 d ) is simply a hole in the bottom of the tailpipe leading to a downward-facing nozzle. The normal exhaust opening is blocked by some sort of valve. These valves can be used easily on aircraft with afterburners because they can be placed upstream of the afterburner. These ventral nozzles can help solve the balance problem of VTOL aircraft. The ventral nozzle has a thrust loss of 3-6% when vectored to 90 degrees.

- **Elbow Nozzle:** This type of nozzle is used on the AV-8 Harrier. The elbow nozzle is simple and lightweight and doesn’t require much actuating force. A disadvantage of this design is the fact that the flow is always being turned through a total of 180 degrees, even in forward flight. Because the flow is always being turned, this nozzle type suffers 6-8% thrust loss at all times. All the other types of vectoring nozzle only impose a thrust loss during vertical flight.