0.1 Inlets

0.1.1 Characteristics of a jet engine

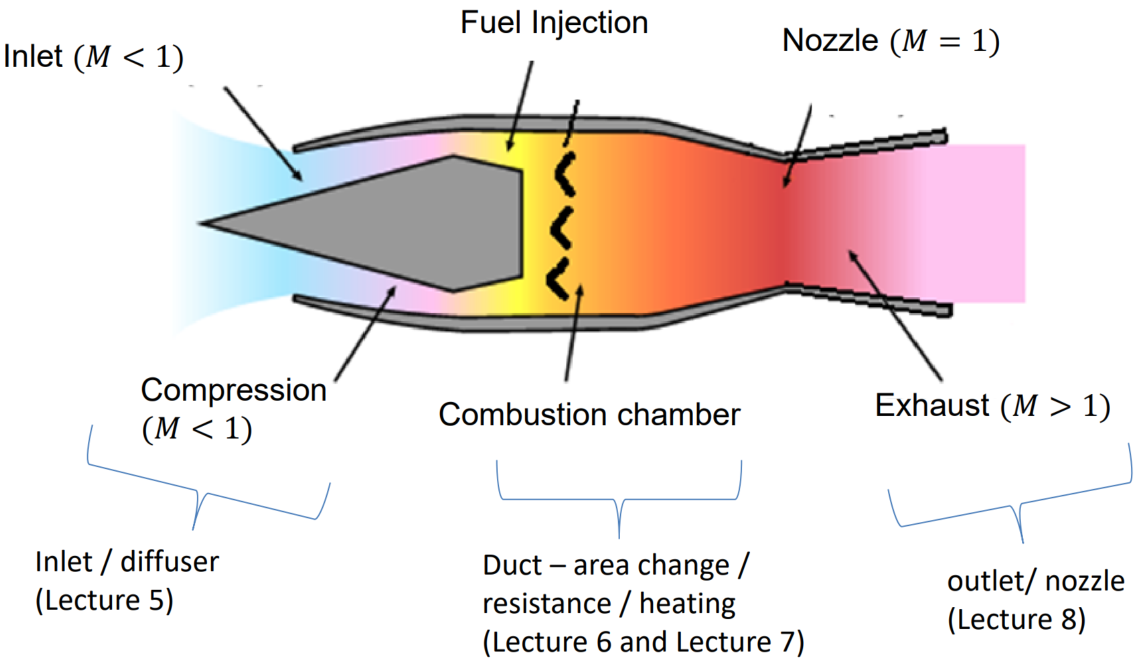

Figure 1: Components of a jet engine.

0.1.2 Thrust from a jet/turbine

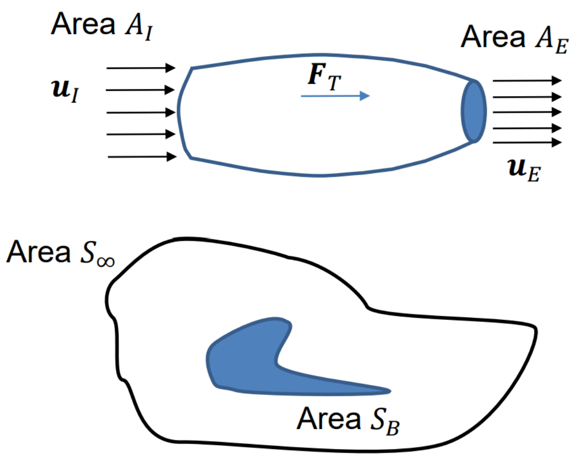

Figure 2: Inlet areas.

The thrust force on a body is determined by the integrated (pressure) force over its surface S_B:

$$\underline{F}_T = \int_{S_B} (p\underline{\hat{n}})\,\mathrm{d}S \tag{1}$$

From the conservation of momentum, the force can be expressed in terms of integrals over S_∞ and S_B:

$$\underline{F}_T = -\int_{S_\infty} (p\underline{\hat{n}})\,\mathrm{d}S + \int_{S_B+S_\infty} \left(\rho\left(\underline{u}\cdot\underline{\hat{n}}\right)\underline{u}\right)\mathrm{d}S \tag{2}$$

Taking a control surface that envelopes the body:

$$\underline{F}_T \cdot \underline{\hat{x}} = A_E p_E - A_1 p_1 + \dot{m}\left(u_E - u_1\right) \tag{3}$$

0.1.3 Purpose of an inlet

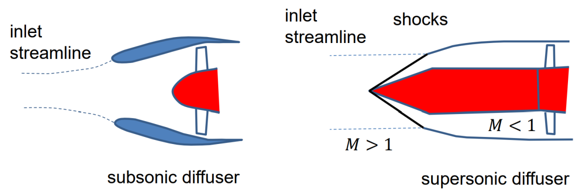

Figure 3: Inlet streamlines with various diffusers.

There are two requirements:

1. Efficiency of engine depends on reducing losses (such as loss of stagnation pressure)
2. Provide the required inlet mass flow (there are constraints to this). This is limited by choking of the inlet.

0.1.4 What do they look like?

Figure 4: Subsonic inlet.

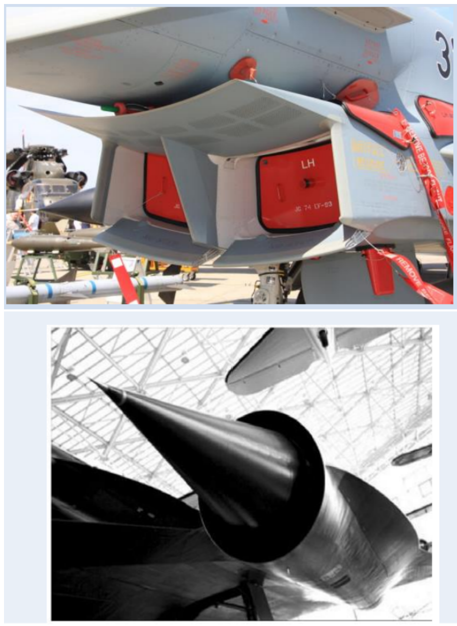

Figure 5: Supersonic inlets.

Modern jets are turbofans. This consists of a low speed fan and an inner high speed compressor. This is preferred because of the lower exhaust speed that is more efficient and gives rise to less noise.

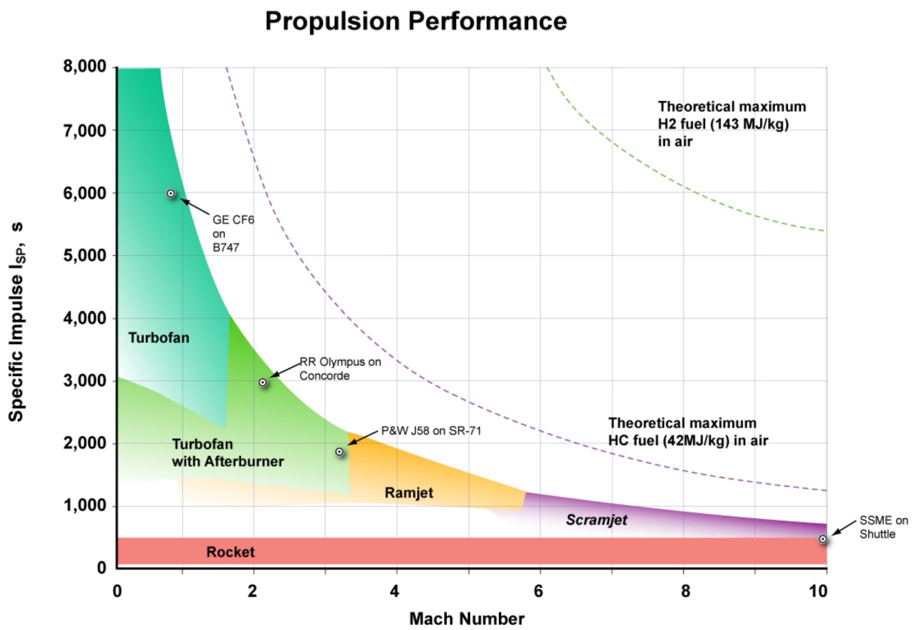

Figure 6: Graph to show propulsion performance for different inlet types.

Thrust divided by rate at which mass of propellant is consumed $\dfrac{F_T}{\dot{m}}$.

0.2 Jet engines

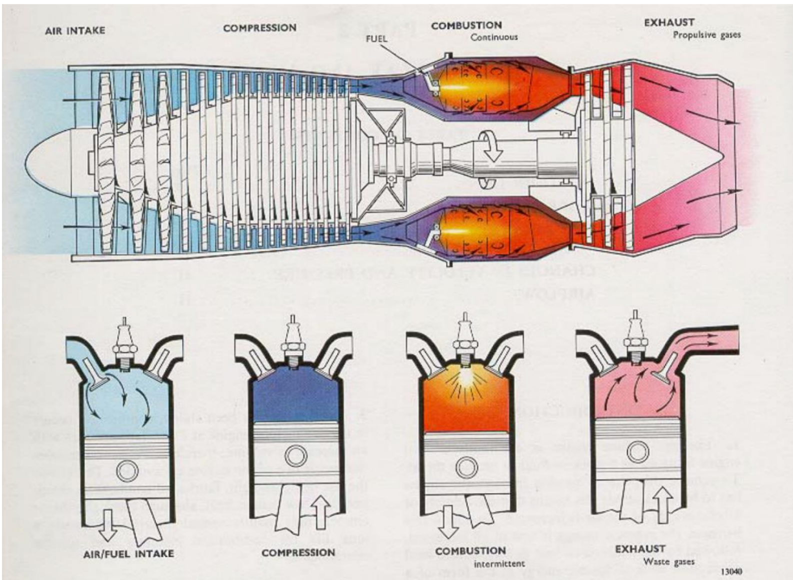

Figure 7: Jet engine.

In the first half - need high pressure, in the second half - need high velocity. There are four main components to a jet engine:

1. Inlet
2. Compression
3. Combustion

4. Exhaust

Thrust:

1. Exhaust gas
2. Pushing the flow

0.2.1 Ramjet

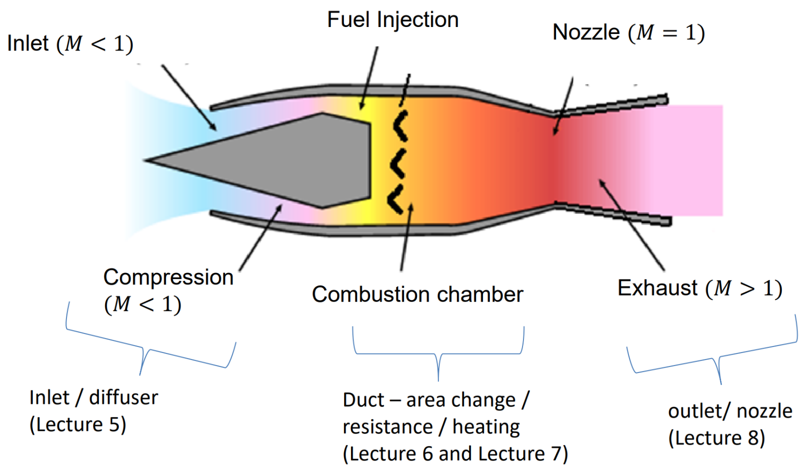

Figure 8: Ramjet.

This is a form of airbreathing jet engine that uses the engine's forward motion to compress incoming air without an axial compressor. Ramjets work most efficiently at supersonic speeds, around Mach 3 and can operate up to speeds of Mach 6 ($7350\,\mathrm{km\,h^{-1}}$).

0.2.2 Scramjet

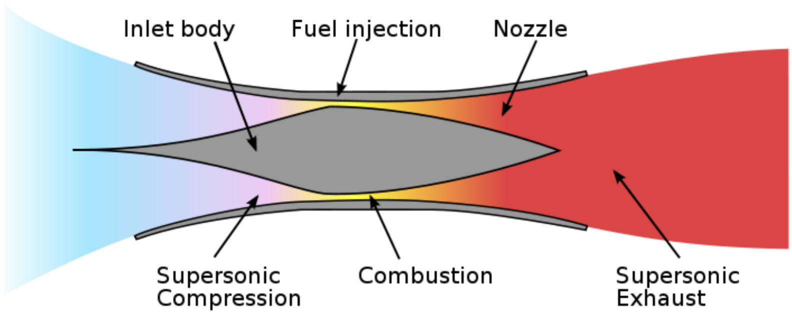

Figure 9: Scramjet.

This consists of a converging inlet, where incoming air is compressed; a combustor, where gaseous fuel is burned with atmospheric oxygen to produce heat. There is a diverging nozzle, where the heated air is accelerated to produce thrust. The flow is supersonic through the entire flow. The thrust is:

$$F = \dot{m}\,(V_2 - V_1) \tag{4}$$

Increasing pressure of airflow increases the potential energy. Increasing velocity increases kinetic energy. The purpose of the inlet, compressor and exhaust is to convert potential energy to kinetic energy.

0.3 Inlet types

0.3.1 Subsonic

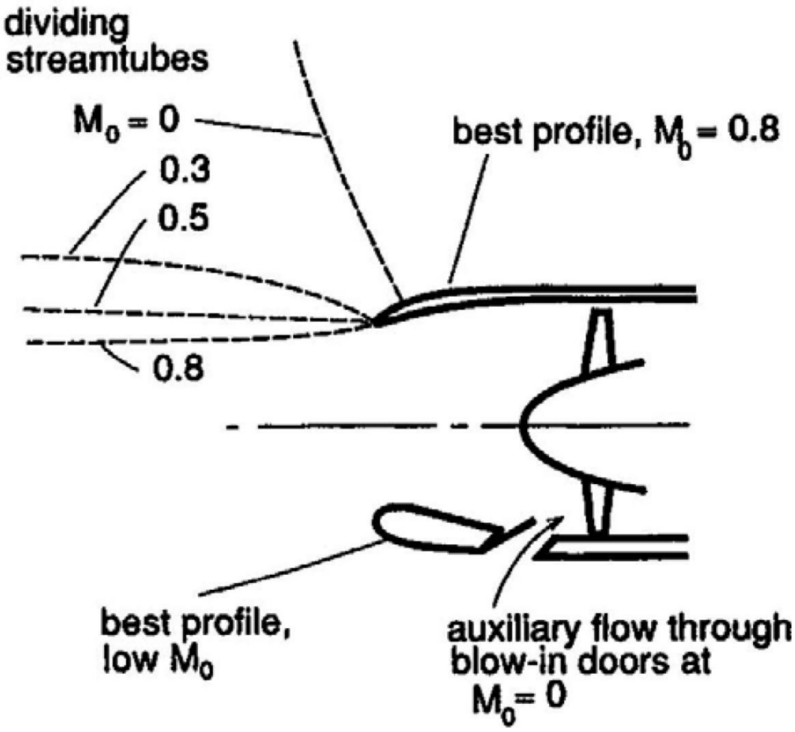

Figure 10: Subsonic inlet profile.

0.3.2 Supersonic inlets

An inlet for a supersonic aircraft, on the other hand, has a relatively sharp lip. The inlet lip is sharpened to minimise the performance losses from shock waves that occur during supersonic flight. For a supersonic aircraft, the inlet must slow the flow down to **subsonic** speeds before the air reaches the compressor.

0.4 Simple normal shock inflow

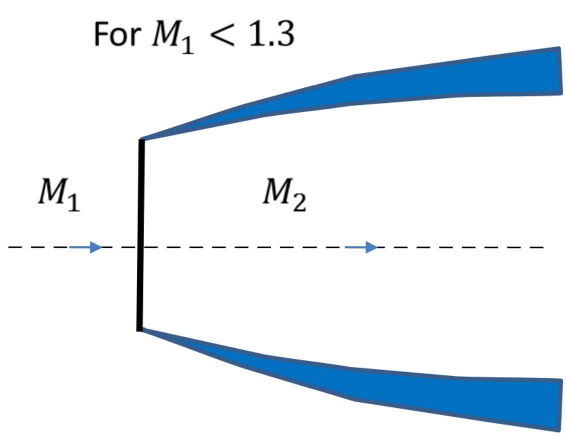

Figure 11: Simple normal shock inflow.

Relationship between flow properties upstream and downstream of shock:

$$M_2^2 = \frac{1 + \frac{1}{2}(\gamma - 1) M_1^2}{\gamma M_1^2 - \frac{1}{2}(\gamma - 1)} \tag{5}$$

$$\frac{p_2}{p_1} = 1 + \frac{2\gamma}{\gamma + 1}\left(M_1^2 - 1\right) \tag{6}$$

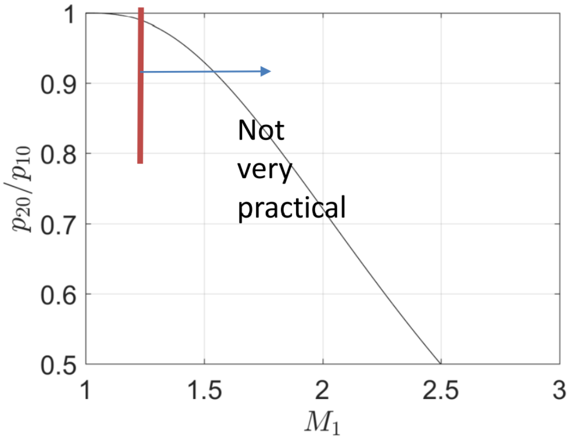

Figure 12: Graph to show ratio of stagnation pressure vs Mach number.

Ratio of stagnation pressure downstream to upstream of normal shock:

$$\frac{p_{10}}{p_{20}} = \left(\frac{2\gamma M_1^2}{\gamma + 1} - \frac{\gamma - 1}{\gamma + 1}\right)^{\frac{1}{\gamma - 1}} \left(\frac{(\gamma - 1) M_1^2 + 2}{(\gamma + 1) M_1^2}\right)^{\frac{\gamma}{\gamma - 1}} \tag{7}$$

0.5 Basic concept - reflection of shock at wall

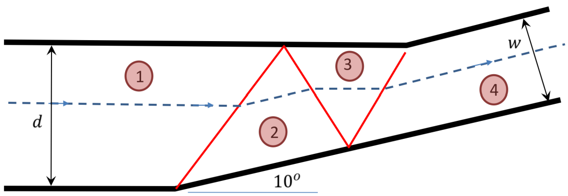

Figure 13: Diagram of shock at wall.

Example from Problem Sheet 2. The inlet Mach number is $M_1 = 2.8$. For a turning angle of 10°, calculate the width of the duct (w) in terms of the inlet width d, given that the shock cancels out at the corner.

Region 1	Region 2	Region 3	Region 4
$M_1 = 2.8$	$M_2 = 2.34$	$M_3 = 1.94$	$M_4 = 1.58$
	$\zeta_2 = *$	$\zeta_3 = *$	$\zeta_4 = *$
	$\frac{p_2}{p_1} = 2.0$	$\frac{p_3}{p_2} = 1.82$	$\frac{p_4}{p_3} = 1.*$

Table 1: Mach numbers in different regions.

0.6 External vs internal compression

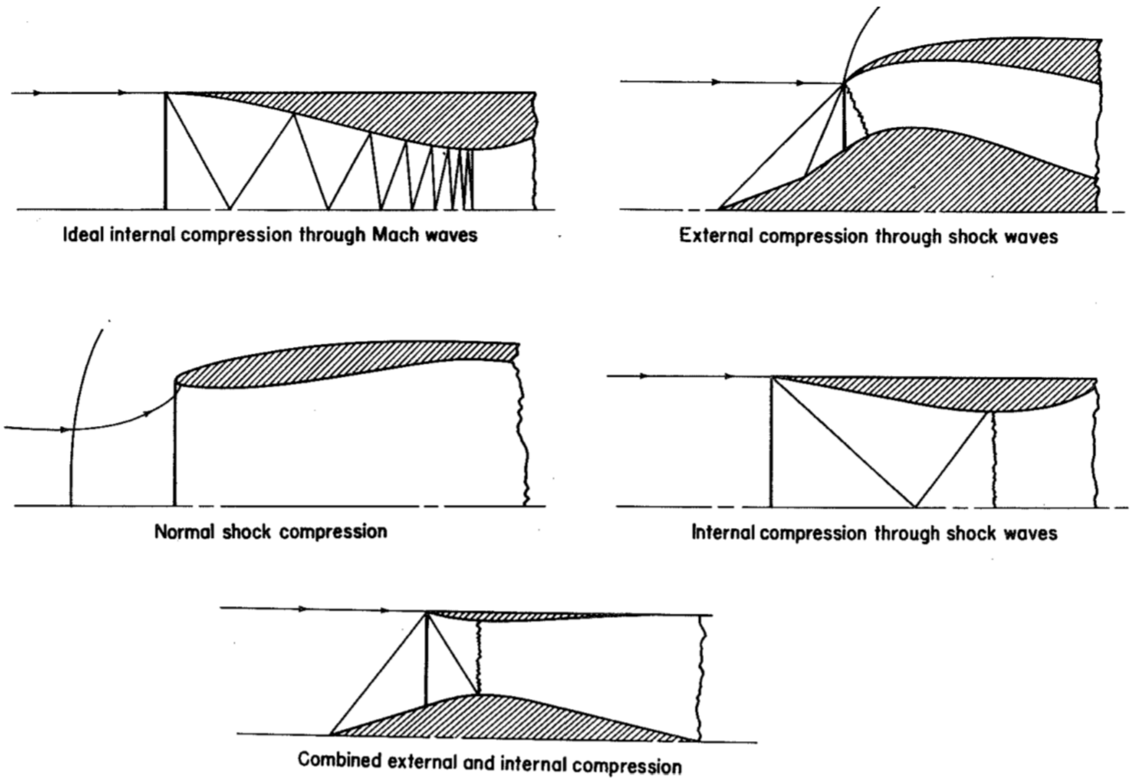

Figure 14: External vs internal compression.

0.7 Strategy for increasing stagnation pressure

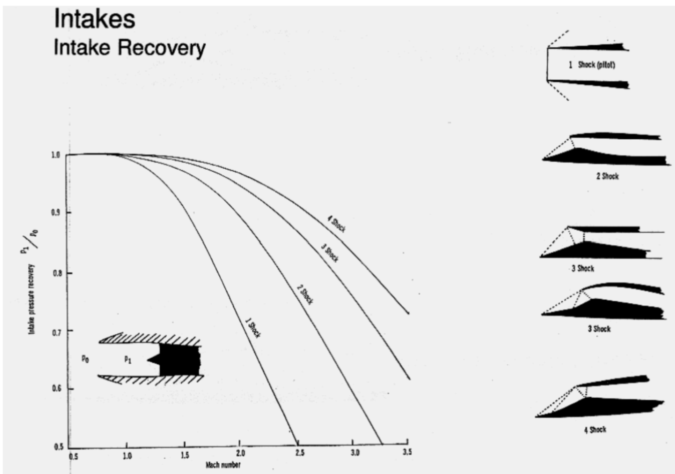

Figure 15: Intake recovery graph.

To increase the stagnation pressure after the compression stage, it is useful to compress the flow with a series of external and internal shocks. This shows the stagnation pressure ratio due to a series of shocks which are of equal strength. Equal strength means that:

$$\frac{p_2}{p_1} = \frac{p_3}{p_2} = \frac{p_4}{p_3} = ... \tag{8}$$

0.7.1 Optimal choice

The shocks are set up so that they tend to meet at the edge of the cowl. This is to:

1. minimise spillage
2. minimise buzz - oscillations in the inlet
3. minimise loss of stagnation pressure

We tend to ensure that the ratio of stagnation pressure across the shocks is the same (i.e. they have the same strength).

0.8 Oblique diffusers

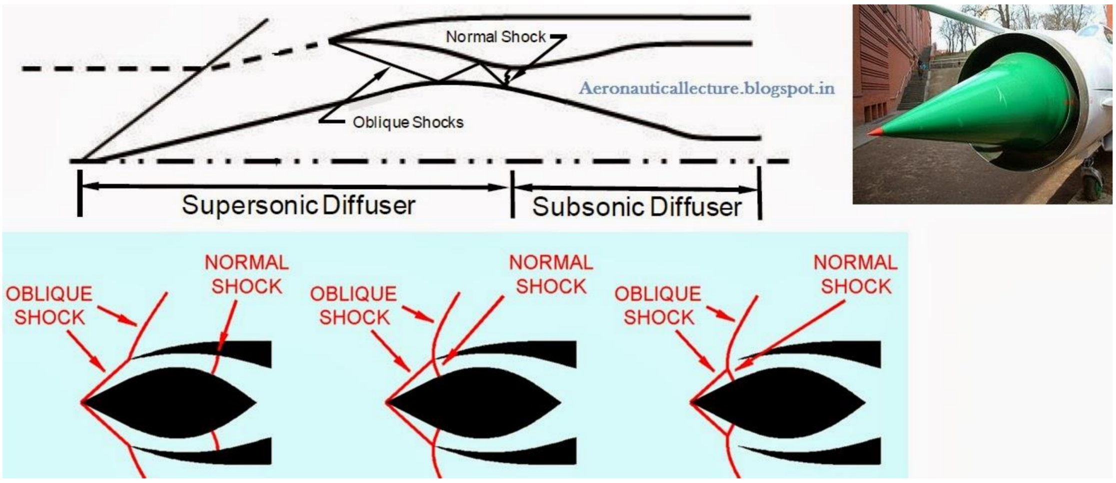

Figure 16: Oblique diffusers.

0.8.1 Adaptation

A movable cone called a 'spike' is used. For subsonic flow, the spike is pushed forward. When the aircraft accelerated past Mach 1.6, an internal jackscrew moved the spike up 66 cm inwards, directed by an analog air inlet computer that took into account pitot-static system, pitch, roll, yaw and angle of attack. Moving the spike tip drew the shock wave riding on it closer to the inlet cowling until it touched just slightly inside the cowling.