## The Air Inlet and its effect on turbo compressors

The air inlet is required to deliver air into the fan and or Core compressor. The mean pressure recovery only effects the compressor speed and has no significant effect on the compressor stability margin. The non uniform flow induced in the inlet by viscous effects and non uniform shocks have a major effect on compressor stability.

The lecture aims to examine the flight envelope within which the inlet compressor combination must work stabily. It then discusses the nature of the inlet flow at extremes of the envelope. The scaling laws for inlets at points on the envelope. The mutual effect of the inlet flow and the compressor, this leads to the concept of the parallel compressor theory and the inlets effect on compressor stability. The main examples are taken from civil pod inlets but S ducts and military inlets are examined; mention is made of other destabilising features of the engine installation. Finally a brief introduction is made to other compressor destabilising features.

## Engine Aircraft Operating Envelope

Figure 1 shows the inlet centre line/flow angle as a function of aircraft Mach number for a large transport aircraft, it includes ground operations, winds from the side; high incidence operation at low aircraft flight speed take off/landing/wave off and cruise operation in turbulence. Figures 2 and 3 show typical results for an inlet at low speed high incidence and ground operation with a cross wind. Figure 3 shows the pattern of inlet total pressure at a number of operating points. The Distortion Parameter DC60 is defined as:

$$\frac{\text{Mean total Pressure in Worst } 60^\circ \text{ segment} - \text{Mean total Pressure}}{\text{Inlet Dynamic Head}}$$

It measures the circumferential mean flow distortion. As described in Appendix 1, the average pressure loss in the inlet does not affect stability. Figure 3 shows that typically the distortion only occupies 120° or so, the rest of the flow is essentially clean for this typical large transport aircraft.

Figure 3 shows that the distortion falls as engine massflow increases then rises again; this is due to there being two mechanisms viscous separation at low speed decreasing as the flight speed to inlet flow speed decreases and shock induced separation at high inlet mass flows.

## Inlet Loading

There are two elements of inlet loading, low speed loading that induces viscous separation and shock induced loss at high mass flows. Figure 4 shows the pressure recovery against inlet mass flow for several model inlets ground running with no external air speed. It can be seen that as flow is increased the lower contraction ratio inlets rapidly increase in loss.

Contraction ratio is the area inside the high light plane/throat area as shown in Figure 5. High contraction Ratio Inlets have higher mass flows before shock induced separation. Appendix 2 describes a simple theory that relates the mean velocity over the inlet lip to the contraction ratio and throat Mach numbers. For a given throat Mach number the smaller the contraction ratio the greater the mean Mach number over the lip. Modern CFD methods can of course calculate the effect but not explain it. The extension of the simple theory in Appendix 3 allows for forward speed and cross velocity; superimposing the effect of inlet contraction forward speed and cross flow leads to a criteria that inlet separation at low speed is controlled by the limiting diffusion of the mean velocity around the inlet tip to the mean velocity in the inlet throat. Based on this criteria inlet separation can be estimated as a function of inlet geometry and flow and flight speed and incidence.

Figure 6 shows the correlated and measured reattachment points for low contraction inlets as a function of forward speed.

Figure 7 shows the general criteria, the data is all from inlet models of around 0.25 metres in diameter of 2:1 aspect ratio ellipse inlet lips and is not valid for other shapes or larger inlets modern CFD methods are capable of handling this problem far better than any correlation.

Figure 9 shows a correlation of distortion as a function of the flight condition minus the flight condition when the inlet separates.

The distortion coefficient used in this analysis is a time average value but since the inlet is separating which is an unsteady process the distortion coefficient varies in time as the separation grows and falls. Results of typical tests are shown in Figure 10. These shows that the peak value of DC60 is over twice the time average value for a variety of inlets.

## Interaction between Inlet and Compressor

Between the inlet and the compressor there are genuine interactions. The compressor reduces the inlet total pressure distortion the inlet can destabilise the compressor. The first feature is shown in Figure 11 where an experiment measuring the distortion created by an inlet includes a close or remote coupled fan. The distortion is close to being halved when the inlet and fan are close coupled. This effect can be emulated by either a gauze or rods forming a coarse mesh. The pressure rise/flow pressure drop/flow characteristics cause the velocity in the distorted/reported region to increase and reduce the extent of the separation. The consequences of of this is that part of the compressor works harder than the rest. This interaction can be seen in figure 12 as a reduction in compressor surge line. The intake limitation is therefore the distortion that causes the compressor to surge/stall.