Subsonic Inlets - Goals

- Produce desired diffuser exit Mach number
  - M~0.4-0.7
- Create “uniform” flow at diffuser exit
  - inlet “distortions” can lead to operability problems (oscillations) and performance loss
- Minimize $p_o$ losses
  - avoid boundary layer separation

Subsonic Inlet Flow Cases

- Accelerating inflow (high thrust, low $u_{flight}$)

\[ \dot{m}_a > \dot{m}_{labe} \]
Subsonic Inlet Flow Cases

- Decelerating inflow (low thrust, high \( u_{flight} \))

\[
\dot{m}_a < \dot{m}_{tube}
\]

\( u_{flight} \)

Inlet Sizing: Throat Diameter

- Limit inlet throat Mach number, \( M < 0.8 \)
  - margin to prevent choked inlet

\[
\dot{m} = \frac{p_o}{\sqrt{R}T_o} A \sqrt{\gamma M} \left( 1 + \frac{\gamma - 1}{2} M^2 \right)^{\frac{\gamma + 1}{2(\gamma - 1)}}
\]

\[
\dot{m}_{required} = \frac{p_o}{\sqrt{T_o}} \text{AMFP}(\gamma, M) = \frac{p_o}{\sqrt{T_o}} \text{AMFP}(1.4, 0.8)
\]

- For cylindrical inlet

\[
d_t = \left( \dot{m}_{required} \frac{4 \sqrt{T_o}}{\pi} \frac{\sqrt{R}}{p_o} 0.6595 \right)^{\frac{1}{2}}
\]

\[
d_t = 0.07413 \dot{m}_{c,\text{max}} \text{ms}^{\frac{3}{2}} / \text{kg}^{\frac{1}{2}} = 0.1636 \dot{m}_{c,\text{max}} \text{ft} \text{s}^{\frac{3}{2}} / \text{lbm}^{\frac{1}{2}}
\]

\( d_t \) corrected mass flowrate

\[
\dot{m}_c = \dot{m} \frac{T_o / T_{ref}}{P_o / P_{ref}}
\]

\( T_{ref} = 288.2 \text{K (518.7R)} \)

\( P_{ref} = 101.3 \text{kPa (14.7psi)} \)
Engine Mass Flow Requirements

- Use cycle performance calculations and engine thrust requirements to size inlet

Exit Sizing: Maximum Diameter

- Area ratio of inlet determines exit Mach number
  \[ M_{\text{exit}} = f \left( \frac{A_{\text{exit}}}{A^*} \right) \]

- Fan or compressor has maximum allowable inlet Mach number
  - modern turbofans allow for relatively high inlet Mach numbers
  - little diffusion required (except at high \( M_{\infty} \))
  - inlet still required to minimize distortions (described below)
**Pressure Loss**

- Internal pressure loss in diffuser depends on mass flow rate
  - standard \( r_d \), or \( \eta_d \) approach does not capture this

\[
\frac{p_{in}}{p_{oa}} = \begin{cases} 
0.995 & \text{at } M = 0.3 \\
0.985 & \text{at } M = 0.2 \\
0.95 & \text{at } M = 0.1 
\end{cases}
\]

"typical" falloff with \( \dot{m} \)

Corrected engine airflow (percent)

After Figure 10-3 from Mattingly, *Elements of Gas Turbine Propulsion*

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**Internal Flow Separation**

- Too high a rate of diffuser area increase leads to stall
  - \( \frac{d_{max}}{L} < \text{critical value} \)

- Boundary layer separates if adverse pressure gradient too large and not enough turbulent mixing with freestream to "energize" boundary layer

- High angle incidence can also lead to separation

\[
\text{Inlet Distortion} = \frac{p_{o,\text{max}} - p_{o,\text{min}}}{p_{o,\text{avg}}} \quad \text{over} \quad (r, \theta)
\]

"good" flow

transitory stall

steady stall

"jet" flow

high incidence angle

**AE4451 Propulsion**
External Nacelle Flow

- Typically external flow decelerates approaching inlet
- Flow then accelerates around nacelle forebody
- High velocity leads to friction drag
- Separation can also occur near lip where velocity reduced

\[ \text{Pressure coefficient } \propto p - p_a \]

Inlet Sizing Summary

- **Inlet area tradeoff**
  - \( d_t \) sized to pass maximum required flowrate
  - Larger inlet requires external decel. and nacelle drag at cruise conditions
- \( d_{\text{max}} / L \) tradeoff
  - Small value reduces internal flow separation
  - Large value reduces boundary layer losses

Figure 10-7 from Mattingly, *Elements of Gas Turbine Propulsion*