Subsonic Inlets - Goals

- **Produce desired Mach number at diffuser exit**
  - e.g., \( M_{\text{exit}} \sim 0.4-0.6 \)
  - requirement based on fan or compressor inlet considerations

- **Minimize \( p_0 \) losses**
  - external: drag
  - internal: e.g., avoid boundary layer separation

- **Create “uniform” flow at diffuser exit**
  - inlet “distortions” can lead to reduced performance and operability problems (oscillations)

Subsonic Inlet: External Flow Cases

- **Accelerating inflow** (high thrust, low \( u_{\text{flight}} \))
  - \( \dot{m}_a > \dot{m}_{\text{tube}} \)
  - Engine draws in more air than “coming towards it” \( (p_{\text{inlet}} < p_a) \)
Subsonic Inlet: External Flow Cases

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

- Air must divert around engine, \( (p_{inlet} > p_a) \)

Inlet Sizing: Throat Diameter

- Limit inlet (throat) \( M \), e.g., \( M < 0.75\text{-}0.8 \) at worst case operating point
  - a margin to prevent choking inlet
    - reduced \( \dot{m}_a \) would lower engine thrust

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

\[
\dot{m}_{required} = \frac{p_o}{\sqrt{T_o}} A_{MMP}(\gamma, MW, M_{inlet}) = \frac{p_o}{\sqrt{T_o}} A_{MMP}(1.4, 28.97, 0.75 - 0.8)
\]

- For cylindrical inlet (w/ \( M_{inlet}=0.8 \))

\[
\begin{align*}
\text{(V.1a)} d_{inlet} &= \left[ \dot{m}_{required} \frac{4 \sqrt{T_o}}{\pi p_o 0.6595} \right]^{1/2} \\
\text{(V.1b)} d_{inlet} &= 0.07413 \sqrt{\dot{m}_{c,max} \frac{m^3 s^{-2/3}}{k^2 g^{-1/3}}} = 0.1636 \sqrt{\dot{m}_{c,max} \frac{ft^3 s^{-2/3}}{lbm^2 s^2}} \\
\end{align*}
\]

\( T_{ref} = 288.2 \text{K} \)
\( p_{ref} = 101.3 \text{kPa} \)

\( T_{ref} = 518.7 \text{R} \)
\( p_{ref} = 14.7 \text{psi} \)
Engine Mass Flow Requirements

- How to find maximum (worst case) corrected mass flow rate?
- Use engine performance calculations to determine engine mass flow rate throughout flight envelope
  - takeoff, climb, cruise, descent, landing
- Engine should already be sized to meet thrust requirements
  - maximum thrust requirement typically occurs at takeoff (TO), so TO usually has maximum $\dot{m}_a$
  - but lower pressure at high altitude can make it max required corrected mass flowrate
    - @ 35 kft, $p_a < 0.25$ atm

Exit Sizing: Maximum Diameter

- Area ratio of inlet determines exit Mach number
  - $M_{exit} = f \left( \frac{A_{exit}}{A_{inlet}}, M_{inlet} \right) \Rightarrow d_{max}/d_{inlet}$
    - e.g., $M_{inlet} = 0.75, M_{exit} = 0.5 \Rightarrow d_{max}/d_{inlet} = 1.12$
- Fan or compressor will have design inlet Mach number
  - modern turbofans allow for relatively high inlet Mach numbers
  - so only small amount of diffusion required (except at high $M_\infty$)
  - inlet still required to minimize distortions
Pressure Loss

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

![Graph showing corrected engine airflow percentage.]

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

Internal Flow Separation

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

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

\( (V.3) \)
External Nacelle Flow

- Typically external flow decelerates approaching inlet
- Flow then accelerates around nacelle forebody
- Produces drag
- Separation can also occur near inlet lip where velocity reduced (adverse p gradient)

Inlet Sizing Summary

- Inlet area tradeoff
  - \( d_{inlet} \) sized to pass maximum required flowrate
  - larger inlet requires more external decel. and nacelle drag at cruise conditions
- \( d_{max} / L \) tradeoff
  - small value reduces internal flow separation
  - large value reduces boundary layer losses
Noise Suppression

- Modern inlets for high bypass turbofans typically have acoustic liners to absorb/suppress noise fan noise before it can leave inlet upstream or propagate downstream.
- Commonly employ composite structures based on Helmholtz resonators tuned to absorb specific sound frequencies.

Rolls-Royce
dlnstalled in a honeycomb core
perforated front panel
back panel
DLR