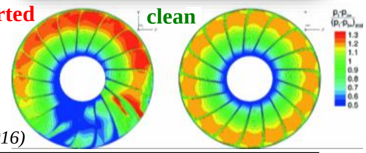
Subsonic Inlets - Goals

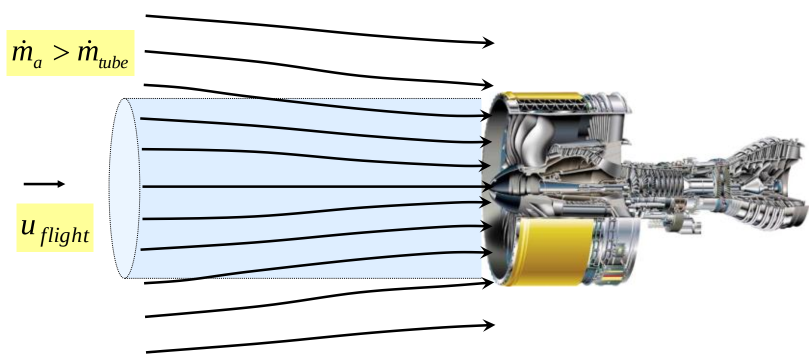
- **Produce desired Mach number at diffuser exit**
  - e.g., M_{exit} ~ 0.4–0.6
  - requirement based on fan or compressor inlet considerations
- **Minimize p_o losses**
  - external: drag
  - internal: e.g., avoid boundary layer separation
- **Create "uniform" flow at diffuser exit**
  - inlet "distortions" can lead to reduced performance and operability problems (oscillations)



Theune et al., Springer (2016)

Subsonic Inlet: External Flow Cases

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



- Engine draws in more air than "coming towards it" ($p_{inlet} < p_a$)

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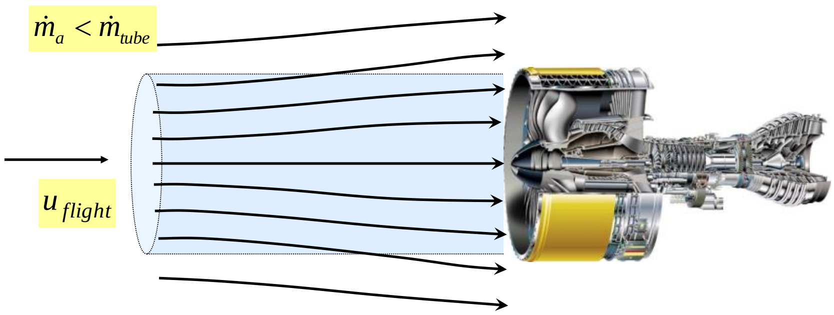
Subsonic Inlet: External Flow Cases

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



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

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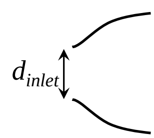
Inlet Sizing: Throat Diameter

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



$$\dot{m} = \frac{p_o}{\sqrt{RT_o}} A \underbrace{\sqrt{\gamma} M \left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{\gamma+1}{2(1-\gamma)}}}$$

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

- For cylindrical inlet (w/ M_{inlet}=0.8) ***corrected mass flowrate***

(V.1a) $$d_{inlet} = \left[\dot{m}_{required} \frac{4}{\pi} \frac{\sqrt{T_o}}{p_o} \frac{\sqrt{R}}{0.6595}\right]^{1/2}$$

(V.2) $$\dot{m}_c \equiv \dot{m} \frac{\sqrt{T_o/T_{ref}}}{p_o/p_{ref}}$$

T_{ref}=288.2K (518.7R)
p_{ref}=101.3kPa (14.70psi)

(V.1b) $$d_{inlet} = 0.07413\sqrt{\dot{m}_{c,\max}}\ ms^{1/2}/kg^{1/2} = 0.1636\sqrt{\dot{m}_{c,\max}}\ ft\, s^{1/2}/lb_m^{1/2}$$

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Engine Mass Flow Requirements

- How to find maximum (worst case) corrected mass flow rate?
- Use engine performance calculations to determine engine mass flowrate 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

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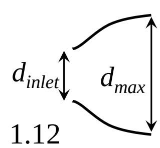
Exit Sizing: Maximum Diameter

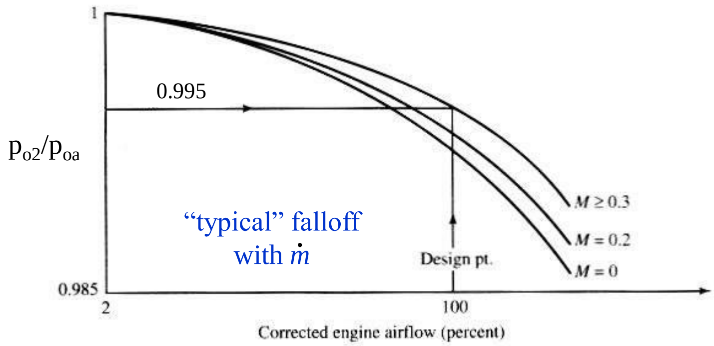
- Area ratio of inlet determines exit Mach number
  - $M_{exit} = f\left(A_{exit}/A_{inlet}, M_{inlet}\right) \Rightarrow d_{max}/d_{inlet}$
    - e.g., $M_{inlet} = 0.75$, $M_{exit} = 0.5 \Rightarrow d_{max}/d_{inlet} = 1.12$



- 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_∞)
  - inlet still required to minimize distortions

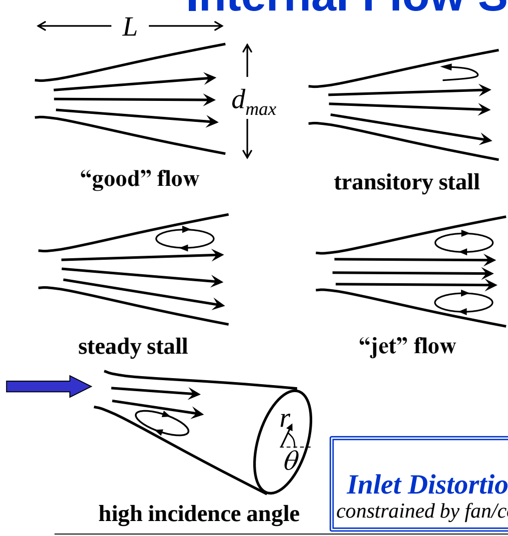
Pressure Loss

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



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 < *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

Inlet Distortion *constrained by fan/compressor* $= \dfrac{p_{o,\max} - p_{o,\min}}{p_{o,avg}}$ over (r,θ) **(V.3)**

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External Nacelle Flow

- Typically external flow decelerates approaching inlet

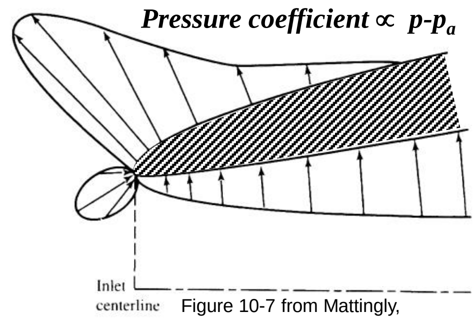
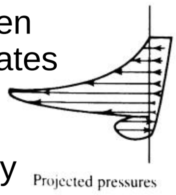


Figure 10-7 from Mattingly, *Elements of Gas Turbine Propulsion*

- Flow then accelerates around nacelle forebody



- Produces drag
- Separation can also occur near inlet lip where velocity reduced (adverse p gradient)

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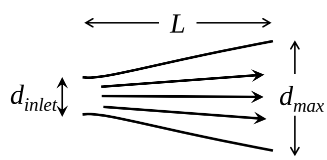
Inlet Sizing Summary

- **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