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Engine Nozzle Requirements

- Accelerate flow with
  - minimum p_o loss
  - low noise
- Sized to pass max required $\dot{m}_{corr}$
- Mix core and bypass streams (if turbofan with mixed nozzle)
- Allow for thrust reversing
- High performance
  - allow for thrust vectoring
  - permit afterburner operation without affecting main engine operation ($\Rightarrow$ variable area nozzle)
- Minimal cost, weight, drag
- Long life, good reliability, low maintenance

Pratt and Whitney

GE

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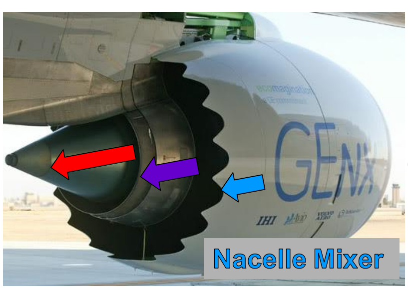
Nozzle Mixing

- Lobed or chevron features often used to rapidly mix
  - core and bypass flow
  - nozzle exhaust and ambient air (flowing around nacelle)
- Can improve thrust and lower engine noise
  - noise scales nonlinearly with peak jet velocity (shear layers)



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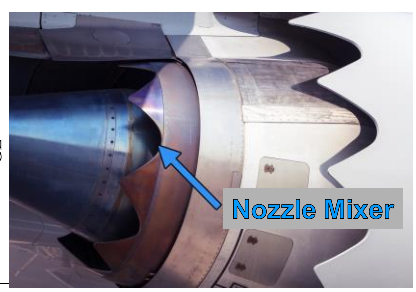

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Converging vs. C-D Nozzles

- Converging nozzles for subsonic aircraft with nozzle pressure ratio $p_o/p_a \lesssim 4$
  - may be choked, but C-D not justified
- Converging-diverging nozzles for supersonic, high speed subsonic with afterburning
  - require variable geometry

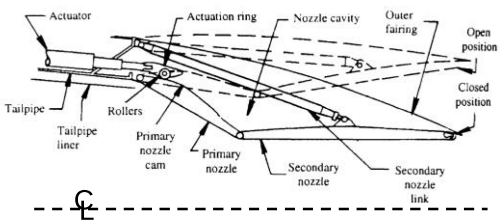

Figure 10-52 from Mattingly, *Elements Gas Turbine Propulsion*

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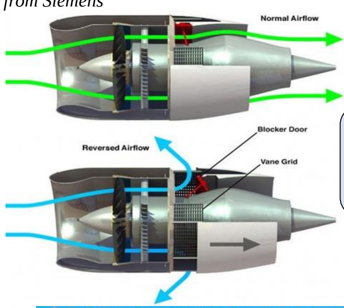
Thrust Reversers

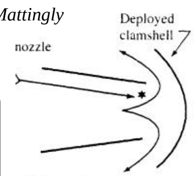
from Siemens



$$\frac{\tau}{\dot{m}_a} \sim -u \rightarrow -(u_e + u)$$

$$90 \rightarrow 180°$$

from Mattingly



airliners.net

FAA.gov

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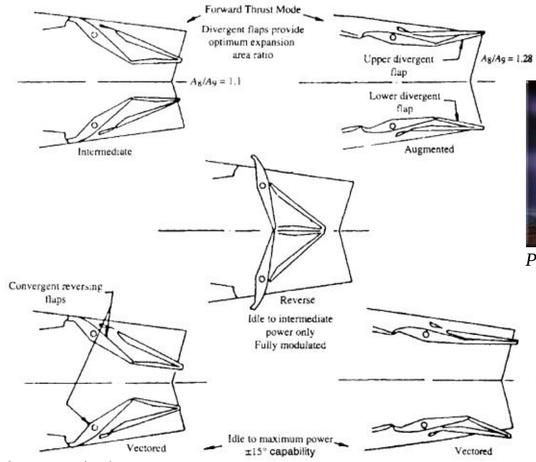
Thrust Vectoring



from Mattingly
FIGURE 10-58
Typical two-dimensional thrust vectoring nozzle with thrust reversing (Ref. 61).

Pratt and Whitney

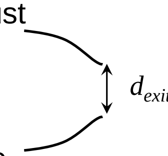
quora.com

Nozzle Sizing

- For converging nozzles, nozzle exit area must be large enough to pass required mass flowrate

  $$A_{exit} = \dot{m}_{corr,\max}\, fn(\gamma, MW, M_{exit})$$

  – for turbojets, low bypass turbofans nozzle likely choked
    - $M_{exit} = 1$



- For C-D nozzles
  – similar approach for sizing throat ($M_{th} = 1$)
  – exit area to achieve near $p_e = p_a$