Rocket Nozzle Thrust

- Internal expansion (converging-diverging) nozzles with fixed $A_e/A_t$ have ~isentropic expansion (no shocks) for only one value of $p_a/p_o$ ($p_e=p_a$)

- Problem for rocket nozzles in launch vehicles
  - large change in $p_a$ with altitude
  - only get near optimum thrust for small range of $p_a$ ($p_e \approx p_a$)
  - bigger thrust loss when overexpanded (low altitude)
Unconfined Expansion Nozzles

• Alternate approach
  – nozzle geometries where expansion is controlled more by ambient pressure rather than nozzle walls

• Plug/Spike nozzle
  – flow expands along contoured centerbody
  – external outer wall ends at (approx.) throat
  – design condition \( (p_{a,\text{design}}) \), expansion waves intersect centerbody tip, \(~1\text{-d flow}\)

1st use: Me 262 WW II turbojet
Plug Nozzle: Off-Design Operation

• Expansion controlled by $p_a$, not by nozzle walls

• $p_a < p_{a,\text{design}}$ (underexpanded)
  – $p_{\text{tip}} = p_{a,\text{design}}$, keeps expanding
  – no shocks, slight flow misalignment

• $p_a > p_{a,\text{design}}$ (overexpanded)
  – $p = p_a$ before plug ends
  – weak shocks and expansions downstream
  – better than CD in “overexpanded” case

• Problem: keeping spike/plug cool
Aerospike Nozzle

- Cut-off end of plug/spike
  - flat ended plug
- Flow lower temperature (coolant) through plug
  - cools plug and prevents recirculation in plug wake
  - inner flow “takes the place” of the rest of the plug
- Linear Aerospike engine
  - uses modular arrays of combustors to form 2-d aerospike

From Hill and Peterson (4451 text)

Lockheed-VentureStar test (2001)