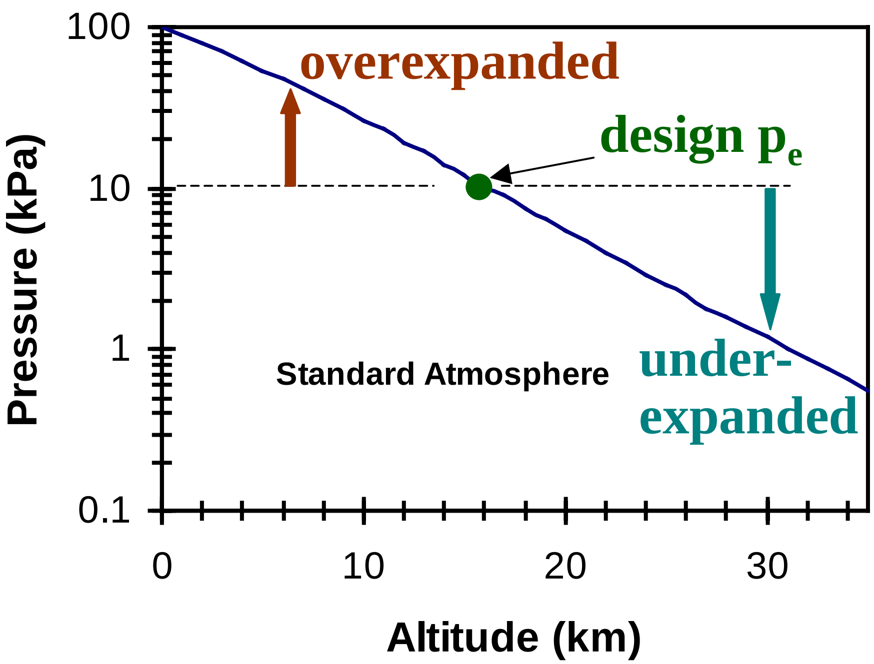
Rocket Nozzle Thrust

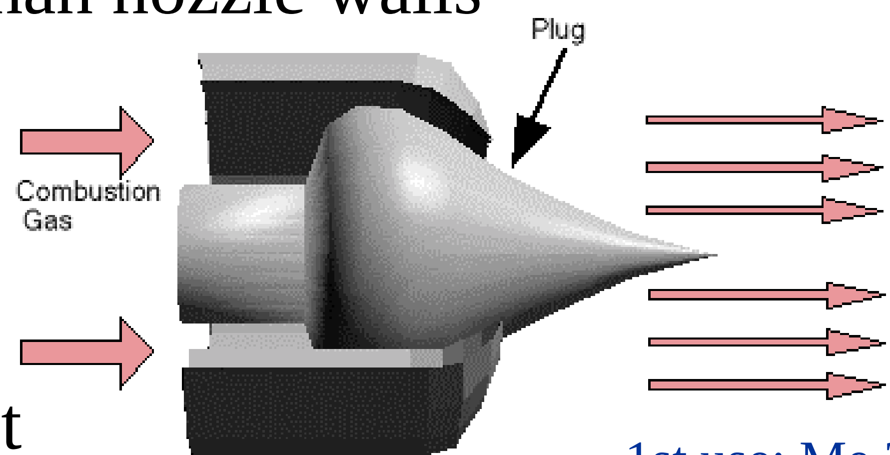
- Internal expansion (converging-diverging) nozzles *with fixed* A_e/A_t have ~isentropic expansion (no shocks) for only one value of p_a/p_o ($p_e=p_a$)
- Problem for rocket nozzles in launch vehicles

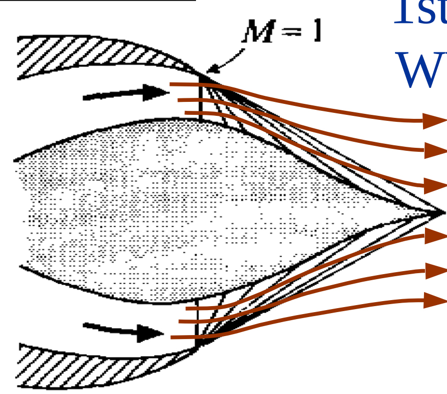


  - large change in p_a with altitude
  - only get near optimum thrust for small range of p_a ($p_e \approx p_a$)
  - bigger thrust loss when overexpanded(low altitude)

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 ($p_{a,design}$), expansion waves intersect centerbody tip, ~1-d flow

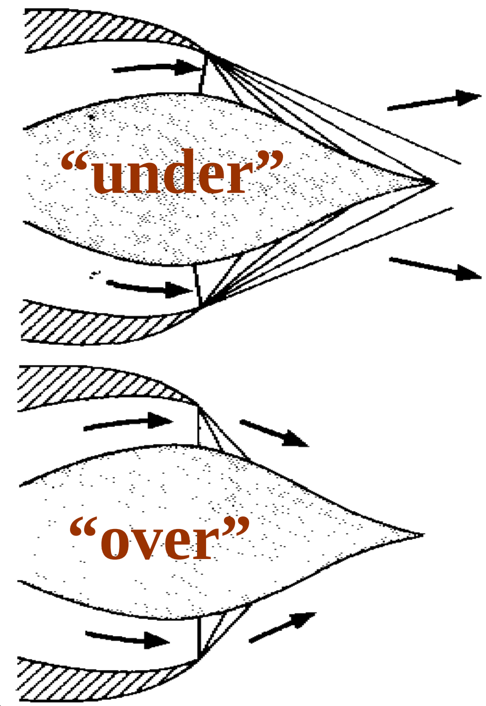


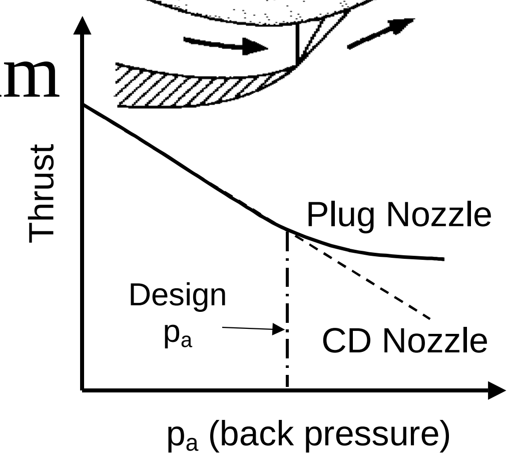


1st use: Me 262 WW II turbojet

Plug Nozzle: Off-Design Operation

- Expansion controlled by p_a, not by nozzle walls
- $p_a < p_{a,design}$ (underexpanded)
  - – $p_{tip} = p_{a,design}$, keeps expanding
  - – no shocks, slight flow misalignment
- $p_a > p_{a,design}$ (overexpanded)
  - – $p = p_a$ before plug ends
  - – ***weak*** shocks and expansions downstream
  - – better than CD in "overexpanded" case
- Problem: keeping spike/plug cool

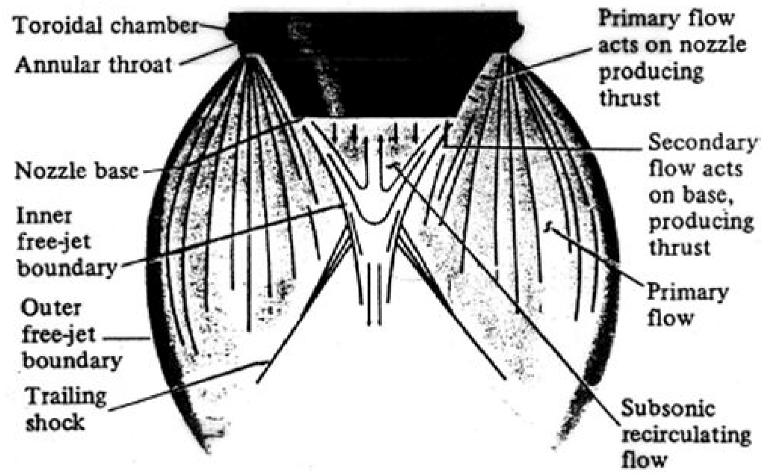




Aerospike Nozzle

- 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)