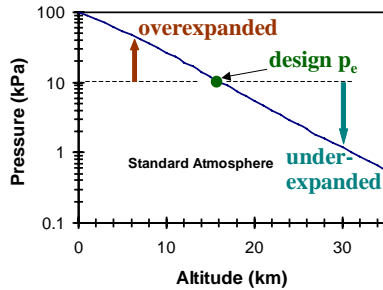


Rocket Nozzle Thrust

- 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



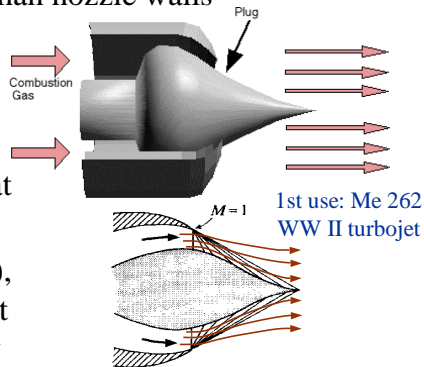
- large change in p_a with altitude
- only get near optimum thrust for small range of p_a ($p_e \approx p_a$)
- bigger thrust loss when overexpanded (low altitude)

Plug/Aerospoke Nozzles -1
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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

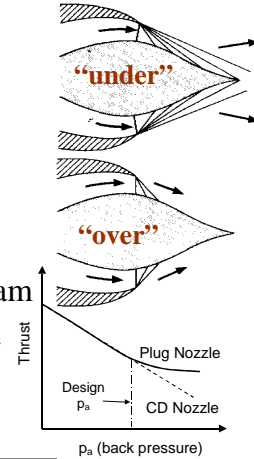


Plug/Aerospoke Nozzles -2
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Plug Nozzle: Off-Design Operation

- 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



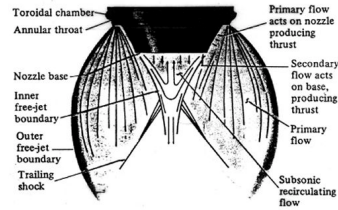
Plug/Aerospike Nozzles -3
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Aerospike Nozzle

- 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)

Plug/Aerospike Nozzles -4
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