Georgia Tech

Ramblin' Rocket Club

Liquid Rocket Propulsion

Types of Rocket Propulsion

- Solid
  - Fuel and oxidizer coexist in a solid matrix
- Liquid
  - Fluid (liquid or gas) propellants stored separately
  - Propellants routed to a combustion chamber to react
- Hybrid
  - Combines elements of solid and liquid propulsion
  - Fluid oxidizer injected into solid fuel grain

Why Liquid Propulsion?

- Generally better performance
- Control
  - Ability to throttle
  - Ability to shutdown (and restart)
  - Improved thrust vectoring
- Safety (isolate and stop failures)
- Reusability
  - Allows for each engine to be tested before use

History of Liquid Propulsion

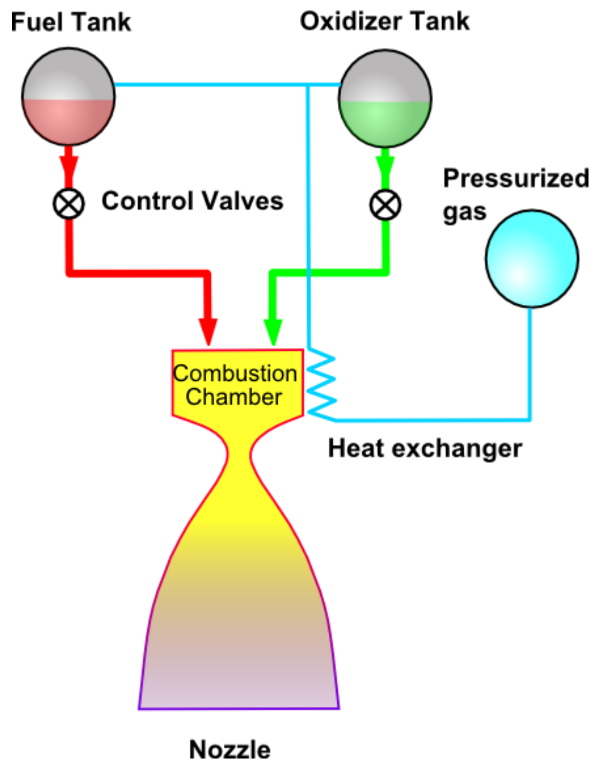
- Liquid propellant engines pioneered by Pedro Paulet in 19th century
- Robert Goddard flies first liquid propellant engine (LOX/gasoline) March 16, 1926 in Auburn, MA
- V-2 (LOX/ethanol) developed in the 1930s
- Early proponents of liquid propulsion include Tsiolkovsky, Goddard, and Oberth

Engine Cycles

- Propellants not burned the same place they are stored (like solids are)
- Must have a way to transport propellants from tanks to combustor(s)
- Methods of moving propellant vary in cost, complexity, weight, and performance
- Many different cycles and variations of cycles, but can be classified in four main categories

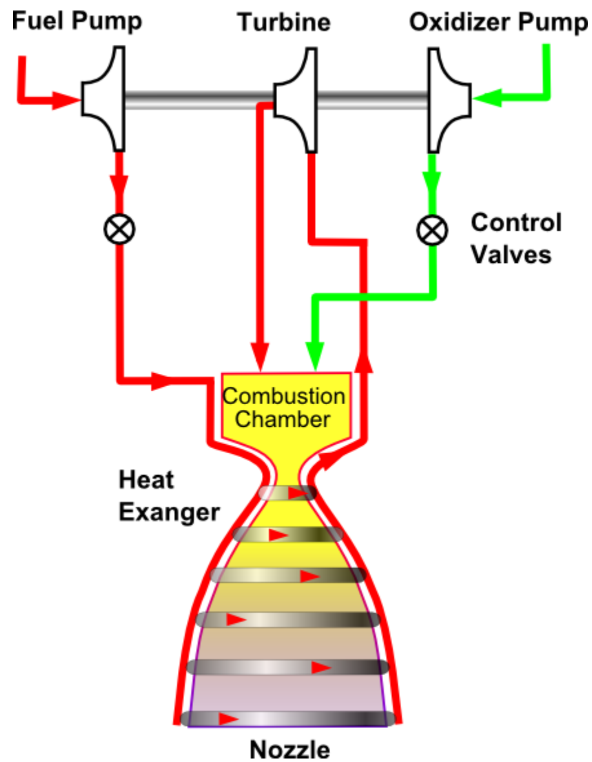
Engine Cycles – Pressure Fed

- Simplest cycle for rocket propulsion
- Relies on a pressurant to force propellant from the tanks to the combustor
- Thrust-limited due to the size of the pressurant tank
- Shuttle OMS, AJ-10 (Delta II), Kestrel (Falcon 1), Apollo LM Descent engine



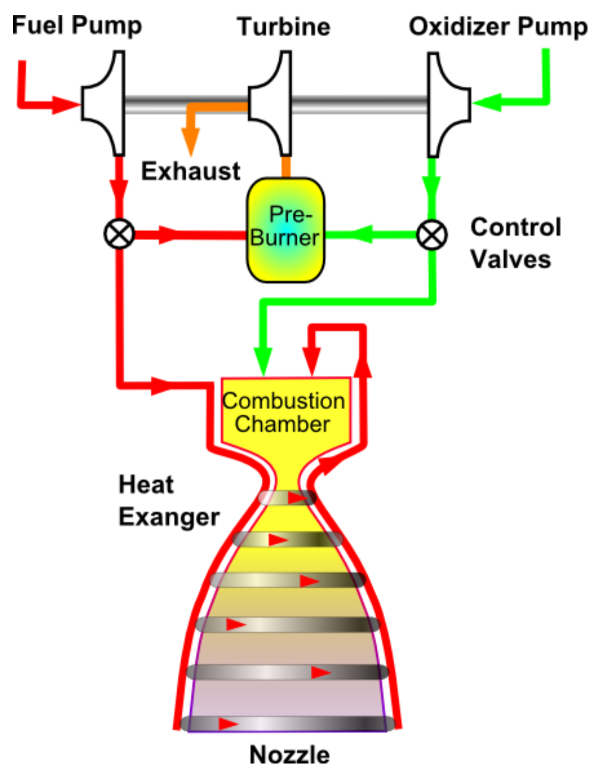
Engine Cycles – Expander

- Relies on a turbopump to force propellants from tanks to the combustor
- Tanks kept at lower pressures
- Fuel heated via regenerative cooling process and passed through turbine to drive pumps
- Thrust-limited due to square-cube rule (heat transfer)
- RL10 (Delta IV, Atlas V), LE-5B (H-IIA, H-IIB)



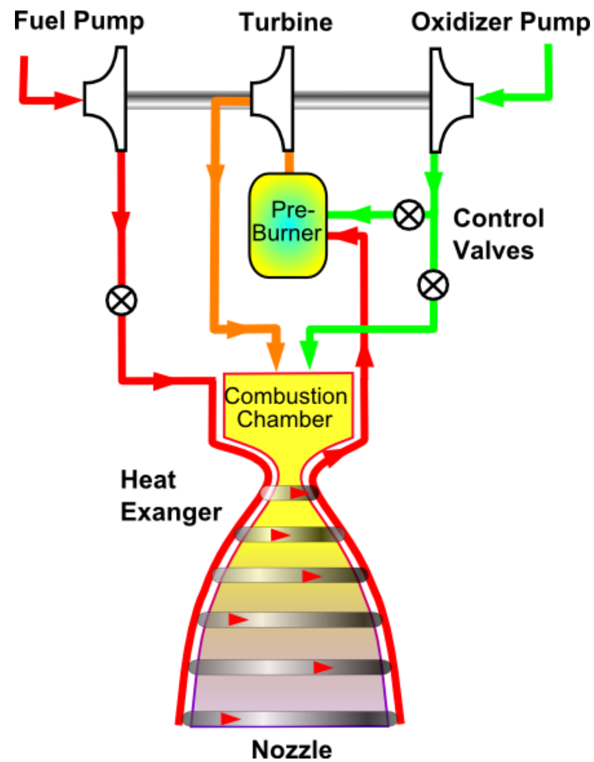
Engine Cycles – Gas Generator

- Relies on a turbopump to force propellants from tanks to the combustor
- Tanks kept at lower pressures
- Some propellant burned, passed through turbine to drive pumps, and dumped overboard
- Most common engine cycle
- Merlin (Falcon 9), RS-68 (Delta IV), J-2X (SLS), F-1 (Saturn V)



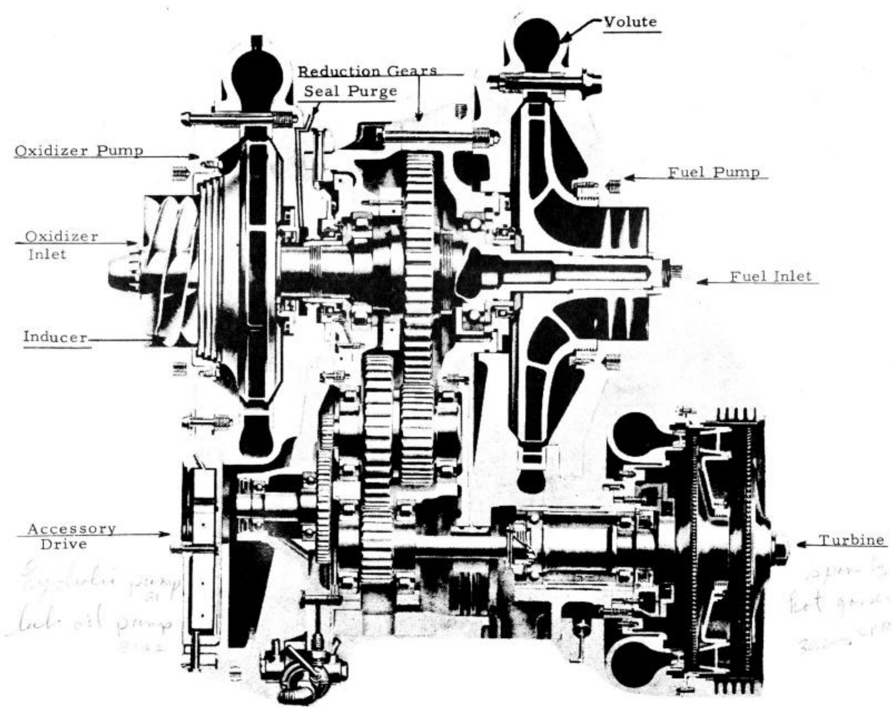
Engine Cycles – Staged Combustion

- Relies on a turbopump to force propellants from tanks to the combustor
- Tanks kept at lower pressures
- Some propellant burned, passed through turbine to drive pumps, and injected into combustor
- Most efficient engine cycle
- SSME, NK-33/AJ-26 (N-1, Antares), RD-180 (Atlas V), Raptor (MCT?), BE-4 (Freedom/Eagle/GalaxyOne)



Turbopumps

- Hot gas passes through a turbine to produce power
- Power generated by turbine used to drive pump(s) or compressor(s)
- Pumps/compressors add pressure to fluid propellants
- Turbopumps used to get sufficient mass flow rate to produce thrust



Regenerative Cooling

- Common method for cooling rocket engines
- Coolant flows over back side of the chamber to convectively cool the rocket engine
- Coolant with heat input from cooling the liner is injected into the chamber as a propellant
- Fuel is typically the coolant

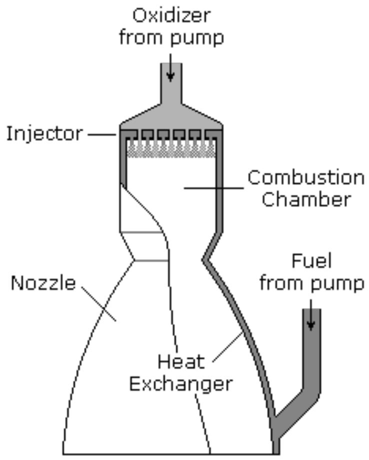
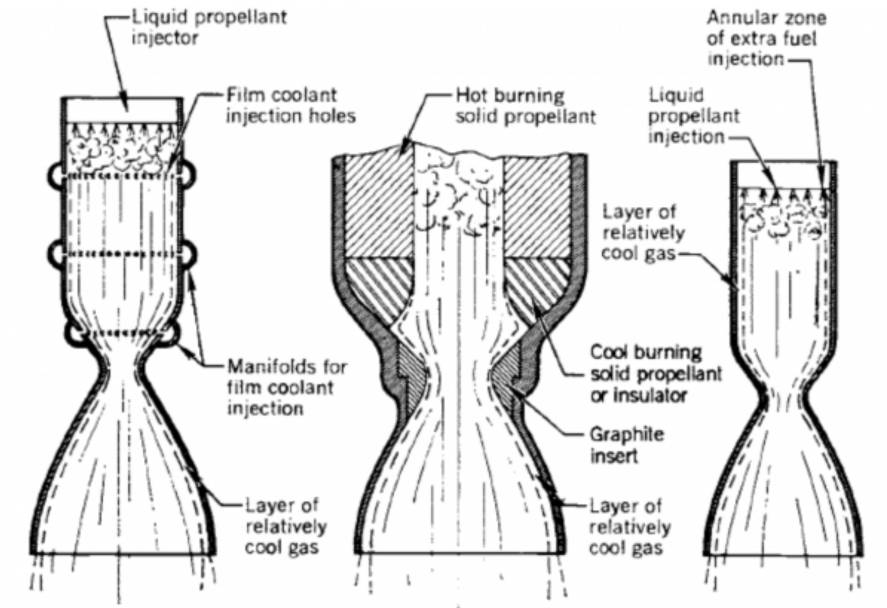


Fig. 1.12 - REGENERATIVE COOLING

Film Cooling

- Injects a thin film of coolant or propellant at the injector periphery near chamber wall
  - Typically uses the fuel or a fuel-rich mixture
- Typically used in high heat flux regions
- Often used in concert with regenerative cooling

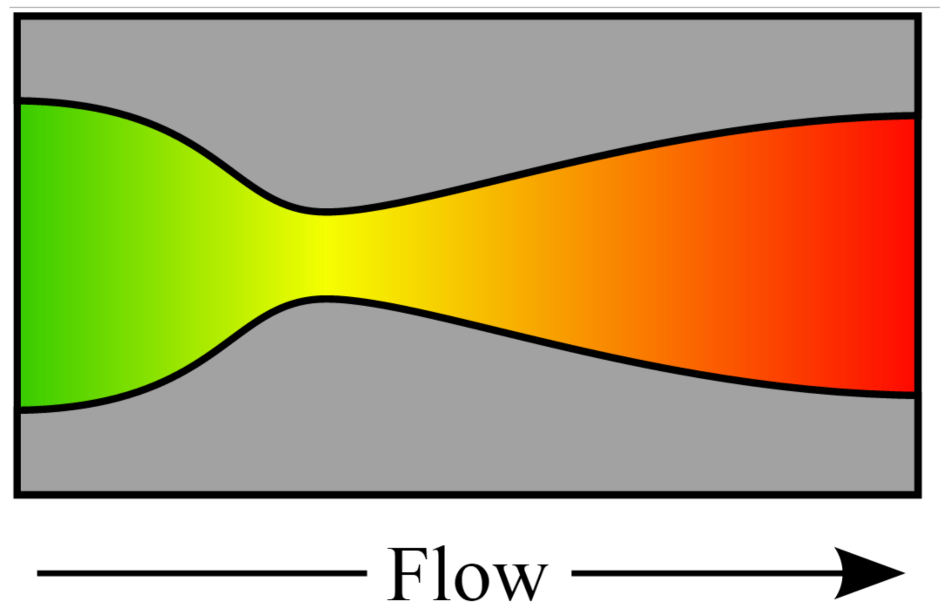


Liquid Propellants

- Hypergols
  - Includes hydrazine, MMH, UDMH fuels and NTO, RFNA, WFNA, IRFNA oxidizers
  - Ignites on contact with each other
  - Toxic and moderately low-efficiency
- LOX/hydrocarbons
  - Most common class of propellants used (LOX/RP-1)
- LOX/LH2
  - Most efficient propellants available
  - Requires large bulky tanks and special materials due to hydrogen environment embrittlement

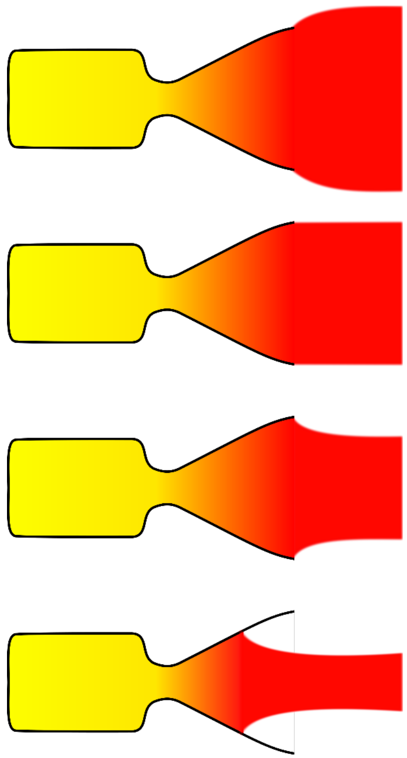
Physics of Propulsion

- Propellant is burned in a combustion chamber, releasing large volumes of hot gases
- Combustion exhaust accelerated through converging-diverging nozzle to supersonic speeds
- High exit velocity creates large thrust and high efficiency
- Conservation of momentum



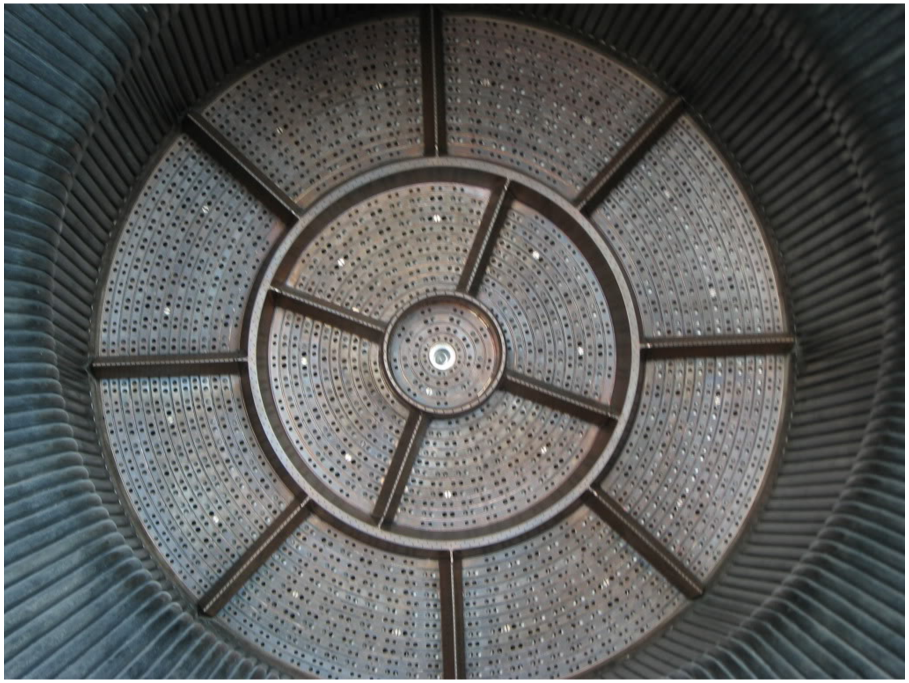
Nozzle Expansion

- Overexpansion
  - Pressure at nozzle exit less than atmospheric pressure
  - Plume relatively contracts
- Underexpansion
  - Pressure at nozzle exit greater thanatmospheric pressure
  - Plume relatively expands
- Ideally expanded
  - Pressure at nozzle exit equal to atmospheric pressure
  - Plume relatively straight
- Static nozzles can only be ideally expanded at one altitude



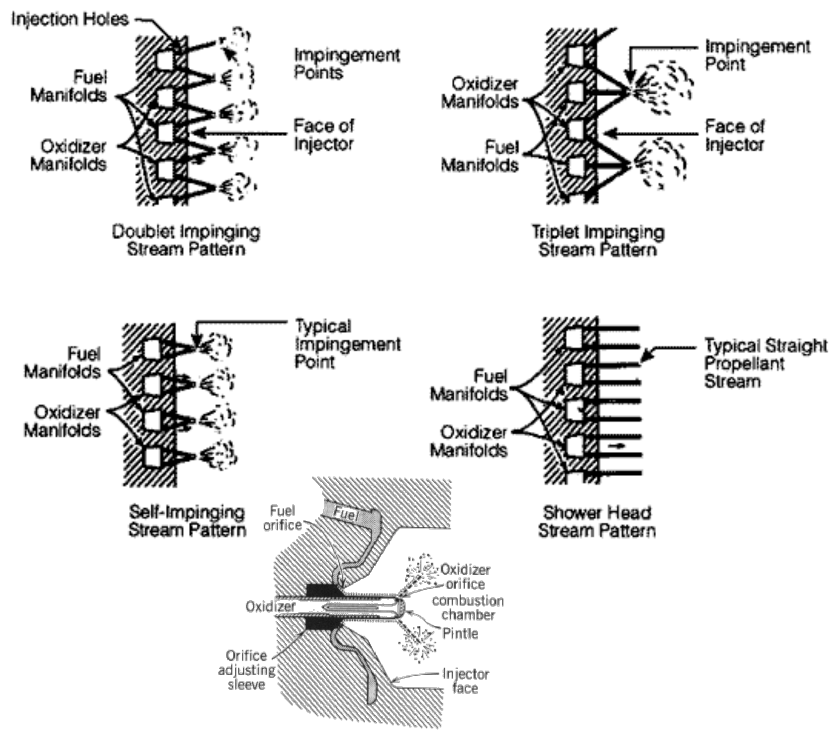
Injectors

- Design crucial to ensure mass flow delivery
- Must promote good mixing of propellants for stability
- Must sufficiently atomize propellant to promote complete combustion
- Baffles, acoustic cavities used to enhance stability



Injectors

- Many different designs for injectors, each with different physics
- Showerhead
- Impinging (like-on-like, unlike, doublets, triplets)
- Coaxial
- Pintle



Performance Metrics

- Thrust
  - Ideally, $T = \dot{m} v_e$ or $T = \dot{m} g_0 I_{sp}$
- Specific impulse (Isp)
  - "MPG" measurement for rocket engines

$$I_{sp} = \frac{T}{\dot{m} g_0}$$

  - Ranges from 275-400 s depending on propellant and cycle
- Characteristic velocity (c*)
  - Measure of the energy available from the combustion process

$$c^* = \frac{p_c A^*}{\dot{m}}$$

Common Issues

- Reliability
  - Moving parts, especially turbomachinery
  - Part count
  - Extreme environments (hot and cold)
- Combustion stability
- Decreased density Isp
- Cost (especially from development)

Additional Resources

- *Rocket Propulsion Elements*, by G. Sutton
- *Modern Engineering for Design of Liquid Propellant Rocket Engines*, by D. Huzel and D. Huang
- *Liquid Rocket Thrust Chambers*, by V. Yang et al
- http://www.braeunig.us/space/propuls.htm