Fluid Propellant Fundamentals

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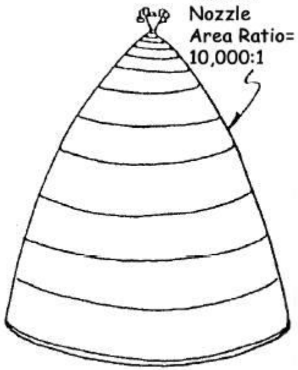
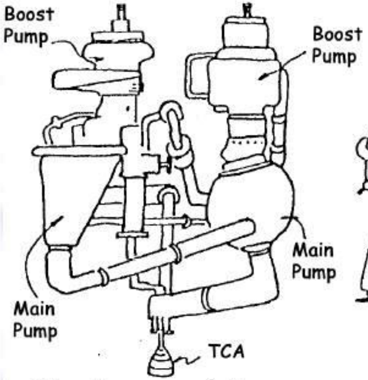
The "Dream" Design Liquid Rocket Engine

(as viewed by various groups)

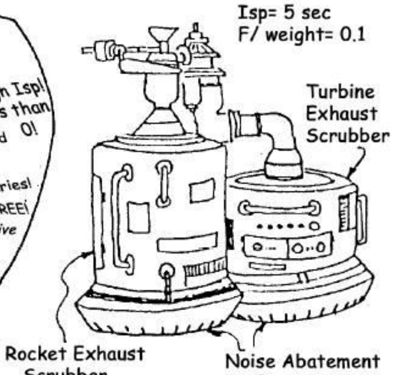


Performance Analysis

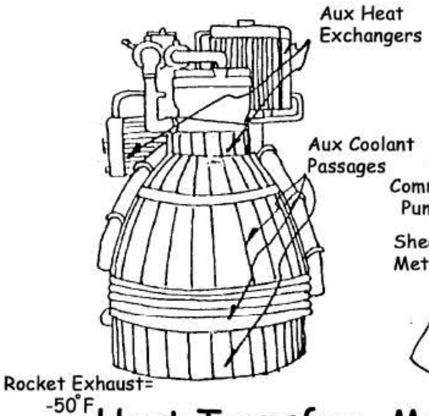


Turbomachinery Design

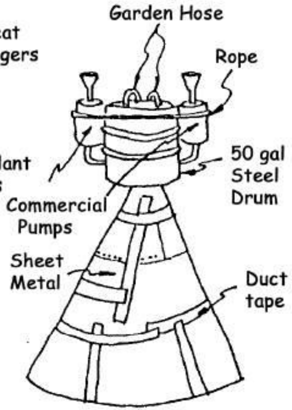
Marketing



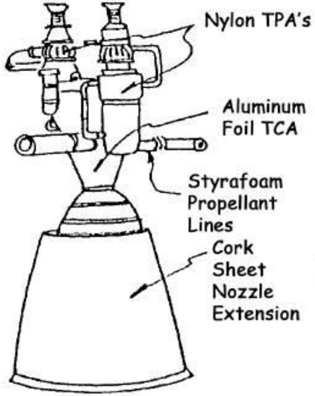
OSHA



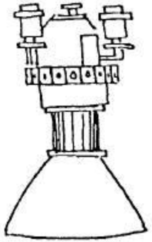
Heat Transfer Analysis



Manufacturing



Weight Evaluation



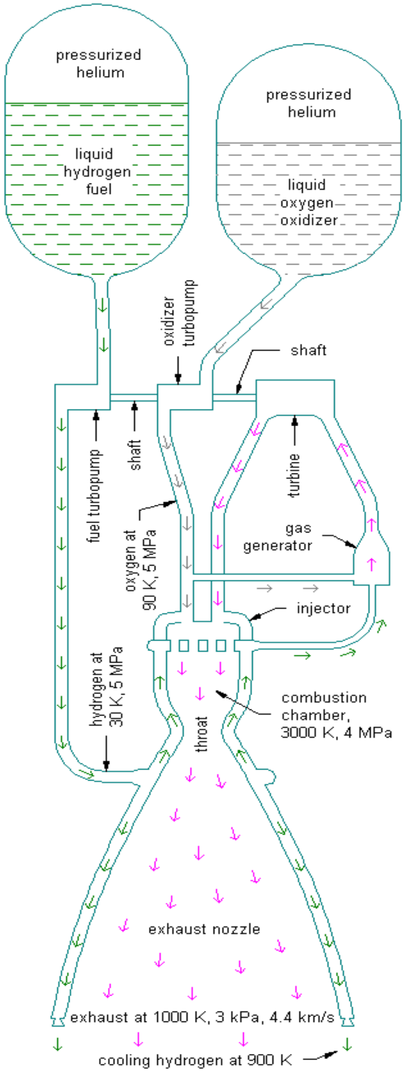
Design Description

Thrust:	50,000 lbf $\pm$ 150,000lbf
Weight:	1,000 lbm $\pm$ 3500 lbm
Isp:	450 $\pm$ 800 sec
Length:	75 $\pm$ 200 in.

Preliminary Design

Major Design Considerations

- Heat Transfer
- Thrust/Weight
- System Level Performance
- Reliability and Safety
- Feasibility in Manufacturing

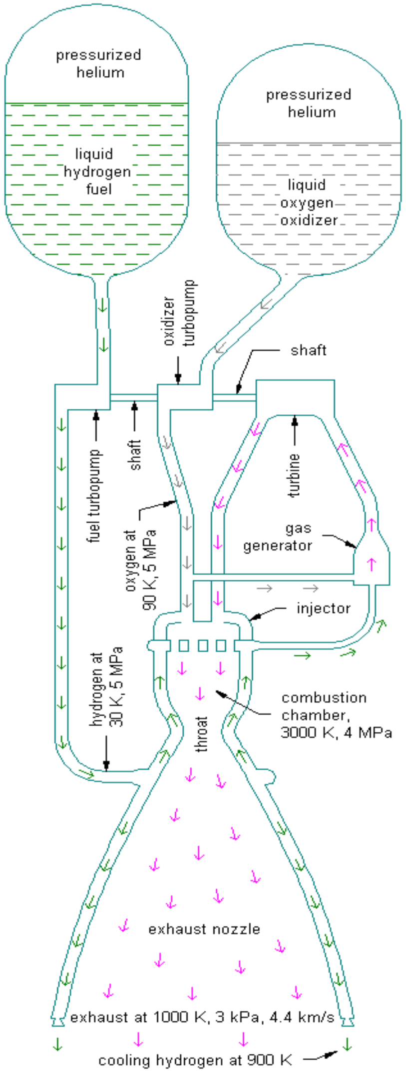


Major Design Considerations

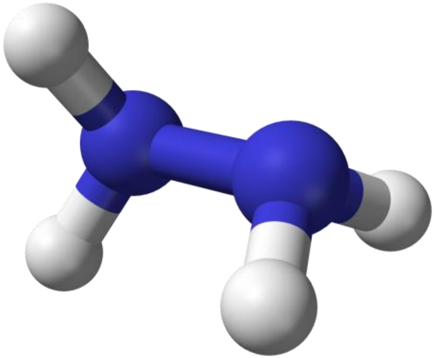
Table 1-3 Actual ranges of liquid-propellant rocket engine parameters.

Gas temperature T, R°	4000 to 7000
Nozzle stagnation pressure Pc_{ns}, psia	10-2500
Molecular weight M	.2 to 30
Gas constant R	.51.5 to 772
Gas flow Mach number M	.0 to 4.5
Specific heat ratio γ	1.13 to 1.66
Nozzle expansion area ratio ε	3.5 to 100
Nozzle contraction area ratio εc	1.3 to 6
Thrust coefficient C_f	1.3 to 2.0
Characteristic velocity c*, ft/s	.3000-8000
Effective exhaust velocity c, ft/s	4000-12,000
Specific impulse (vacuum) I_s, s	150-480

Huzel, Dieter, and David Huang. "Introduction." *Modern Engineering for Design of Liquid-Propellant Rocket Engines*. Vol. 147. Washington D.C.: AIAA, 1992. 7-22. Print.



Propellants



Types of fuel systems

- Monopropellent
- Bipropellent

Types of Propellants

- Cold gas
- Cryogenic
- Storable
- Gelled

Mixture Characteristics

$$r = \frac{\dot{m}_{oxidizer}}{\dot{m}_{fuel}}$$

$$\dot{m} = \dot{m}_{oxidizer} + \dot{m}_{fuel} = \frac{F}{c}$$

$$v_2 = \sqrt{\frac{2k}{k-1}\frac{R'T_1}{\mathfrak{M}}\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}\right]}$$

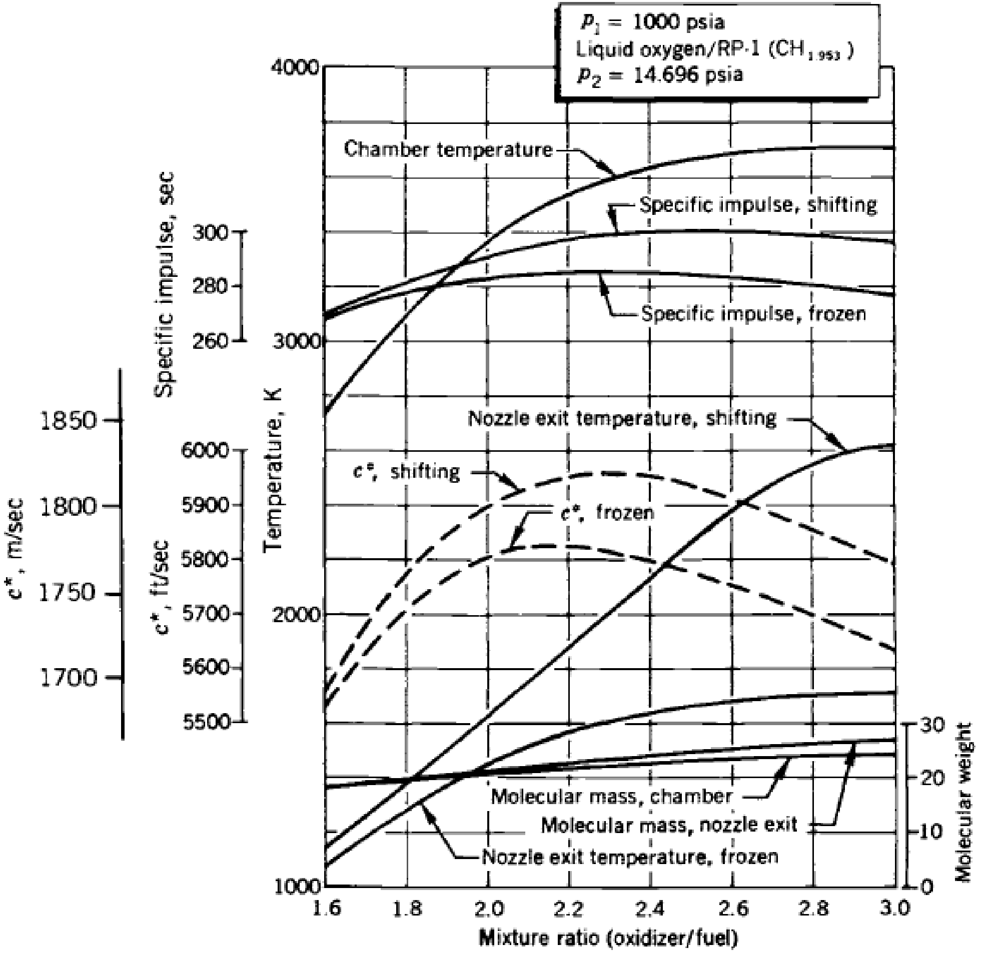


FIGURE 5–1. Calculated performance analysis of liquid oxygen and hydrocarbon fuel as a function of mixture ratio.

Propellent Hazards

- Corrosion
- Explosion
- Fire
- Toxicity
- Material Compatibility

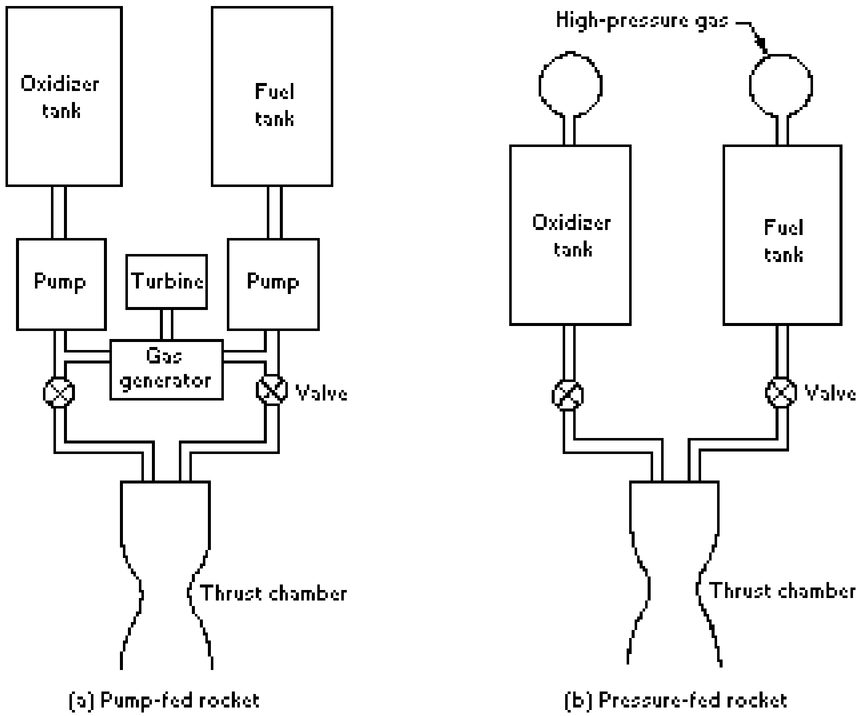
Toxic

Physical Properties

- Freezing Point
- Specific Gravity
- Stability
- Specific Heat
- Thermal Conductivity
- Vapor Pressure
- Viscosity
- Hypergolic

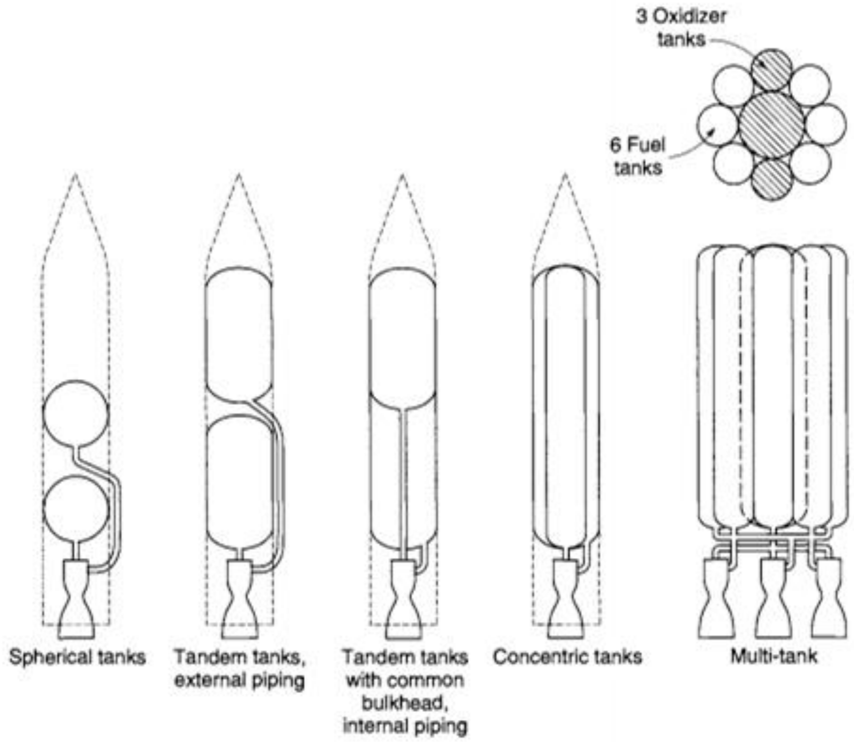
Feed Systems

- Turbopump
- Pressurized
- Low Pressure Tanks
- High Pressure Tanks



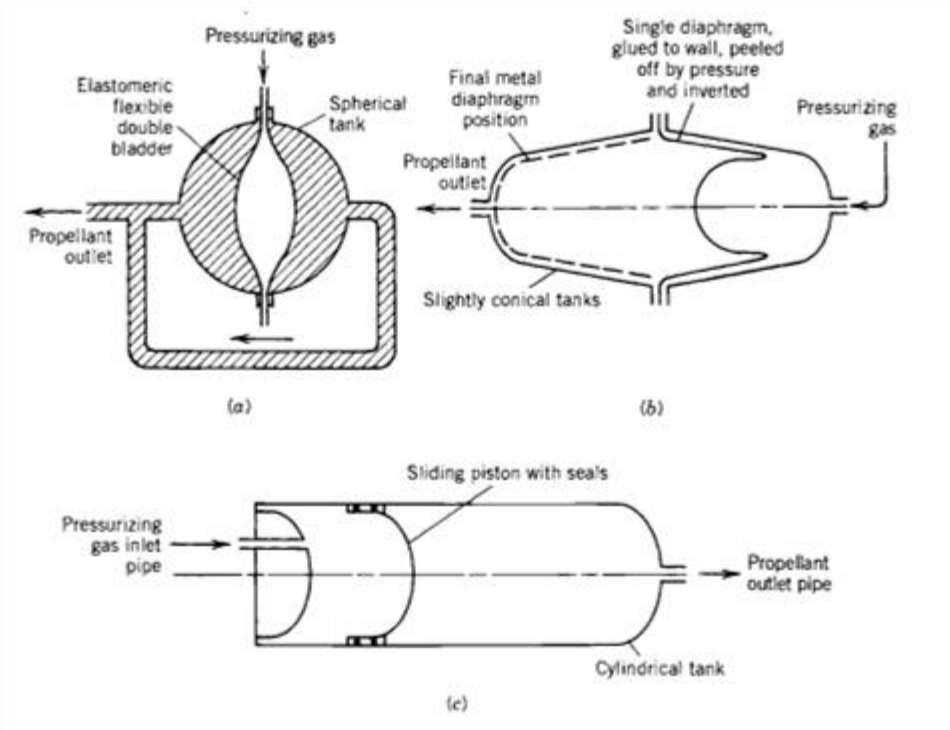
Tank Layouts

- Multiple Tanks
- CG concerns



Fuel orientation inside tanks

- Sloshing
- Zero-G, Side Acceleration
- Vortexing
- Expulsion Efficiency



TurboPumps

Concept	Performance	Life	Wt	Potential Benefits	Potential Drawbacks	Features
Staged combustion cycle	x			High P_c, high performance	Higher development cost	Maximum performance; eliminates secondary flow losses; maximum energy available to turbines; severe turbine environment; high pump pressures
Gas generator cycle		x	x	Simplicity, lower development cost	Lower performance	Simple system; components independent; parallel turbine and chamber flows; easy to develop/test
Expander cycle	x	x		Good performance, good turbine environment	Power limited	Benign turbine environment; topping cycle for high performance; no secondary flow stream; limited to relatively low thrust levels unless multiple chambers used

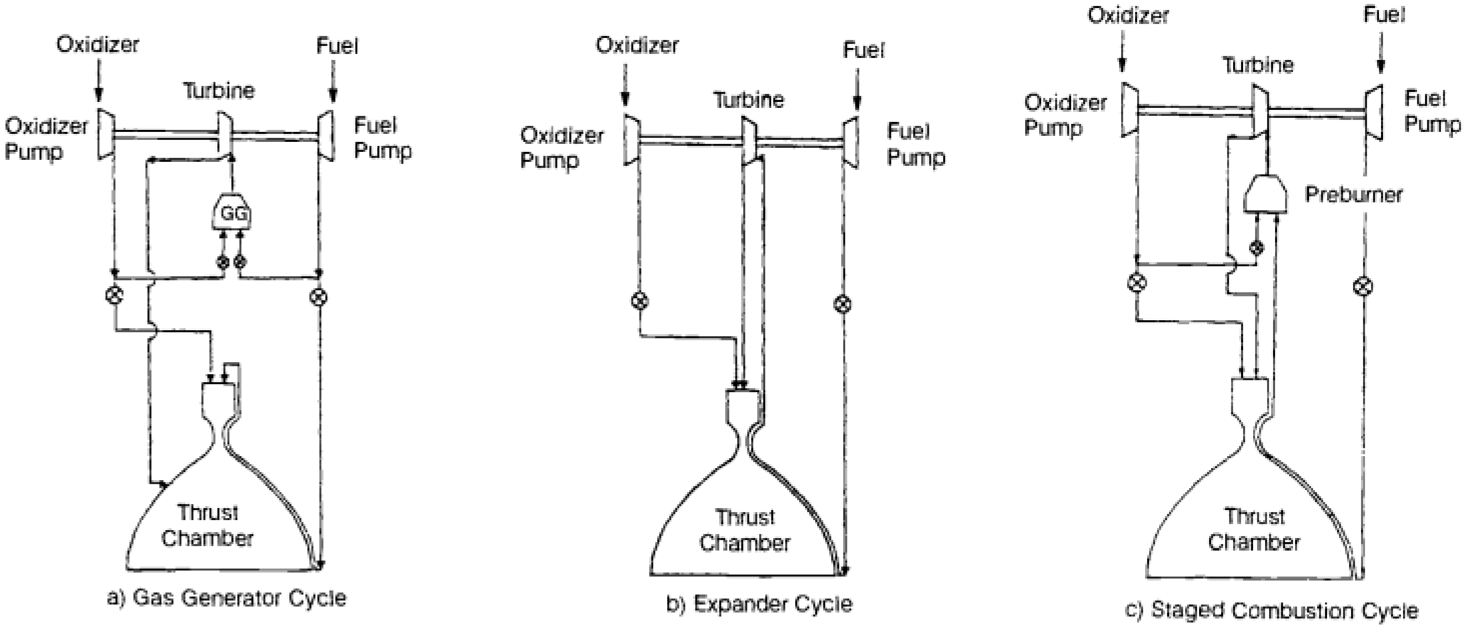
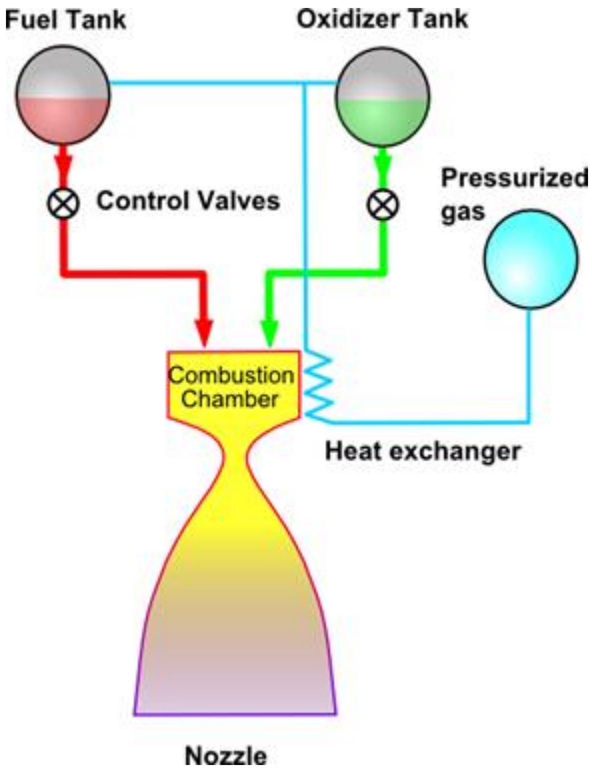


Fig. 2-9 Basic cycles for pump-fed liquid-propellant engines.

Huzel, Dieter, and David Huang. "Introduction." *Modern Engineering for Design of Liquid-Propellant Rocket Engines*. Vol. 147. Washington D.C.: AIAA, 1992. 35. Print.

Gas Pressure

- High pressure gas
- Simple
- Control propellant discharge
- Reliable
- Elements: tank, stating valve, pressure regulator, propellant and feed line

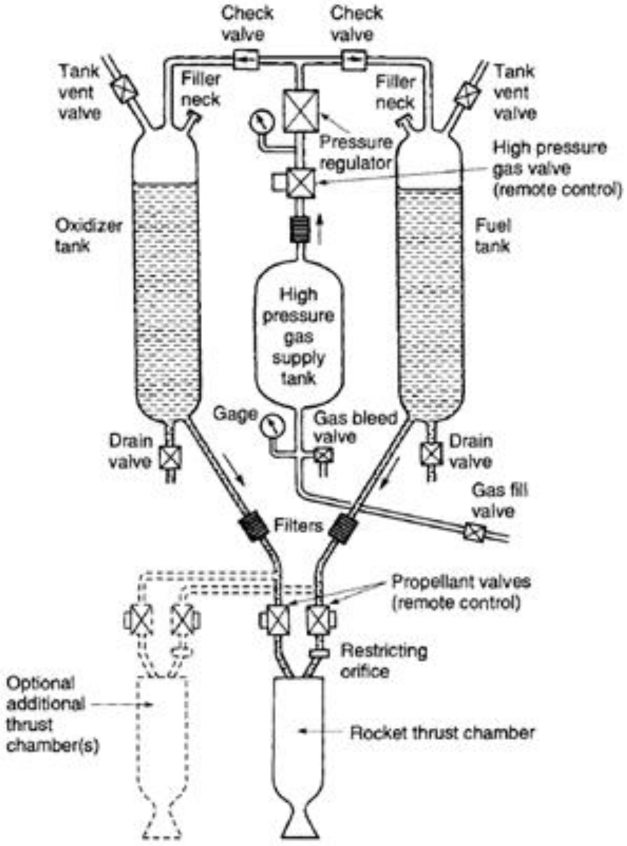


Components of feed system

- Draining provisions,

check valves,

filters, etc.



Disadvantages of gas feed systems

- limits in combustion chamber pressure
- thicker and heavier tanks
- used in higher stages
- freeze a propellant
- decrease tank pressures
- damage components not designed for low temperature

Features

- Enhance safety
- Provide control
- Enhance reliability
- Provide for reusability
- Enable effective propellant utilization

Comparing types of pressurized gas

Regulated pressure

- Stays constant
- Needs more components
- Constant trust, Is, and r
- Better control mixture
- Complex, shorter burning time

Blowdown

- Decreases as propellant is consumed
- Large volume (heavier)
- Simpler system
- Thrust decreases
- Higher residue
- Lower Is at the end of burning time

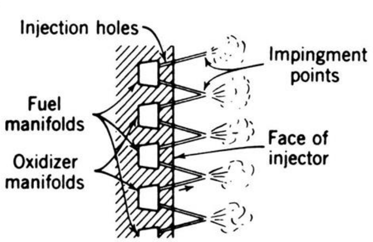
apollo lunar module


Space Shuttle OMS/RCs Pod

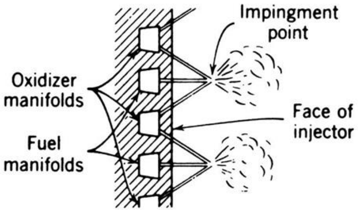

AJ-10

Delta II

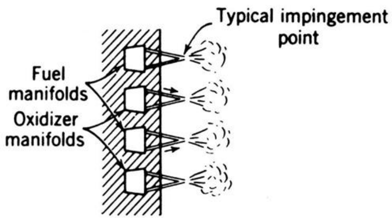
Injectors



Doublet impinging stream pattern



Triplet impinging stream pattern



Self-impinging stream pattern

Type of Injectors:

1. Doublet impinging stream pattern
2. Self-impinging stream pattern
3. Shower head stream pattern
4. Premixing type
5. Splash plate pattern

Things to consider for our design:

Fuel ratios

Velocity of fuel

Combustion Chamber

Definition: A CC is that part of an internal combustion engine in which the fuel/air mix is burned.

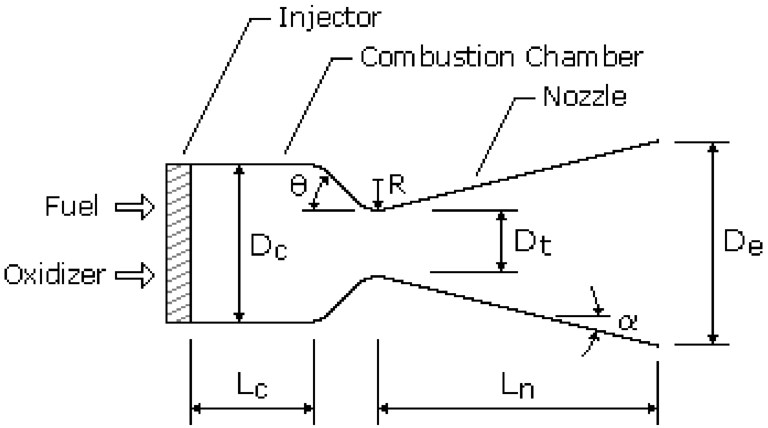


Figure 1.4

http://www.braeunig.us/space/pics/fig1-04.gif

Combustion Chamber

Things need consideration:

1. Volume and Size
2. Propellant Combination
3. Chamber Pressure
4. Nozzle area ratio
5. Feed system, using pumps or pressurized tanks
6. Thrust level

Nozzle

Nozzle Inlet
Nozzle Throat Area

Things to consider:
Ideal Nozzle Theory

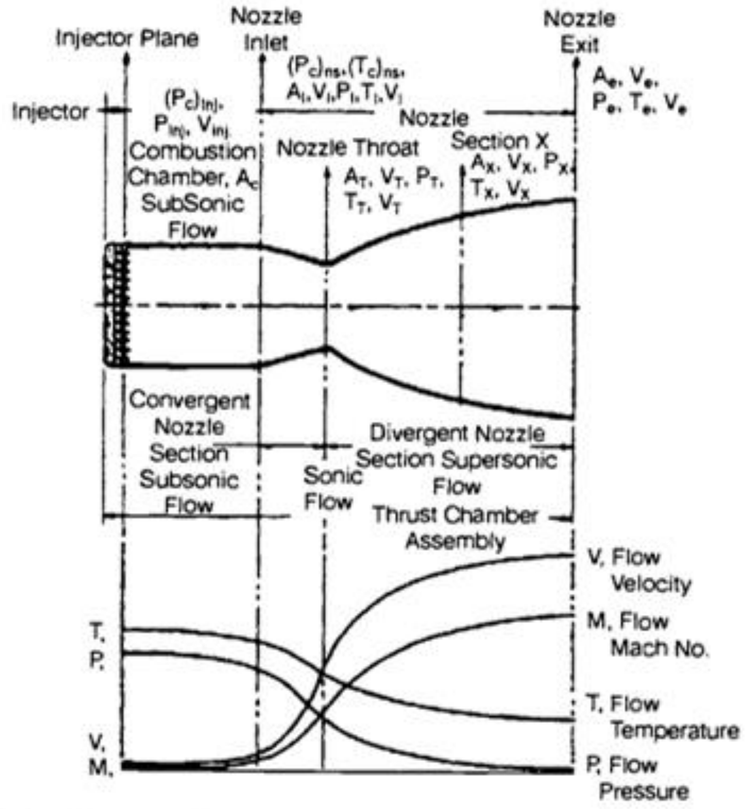


Fig. 1-9 Gas flow within liquid-propellant-rocket thrust chamber.

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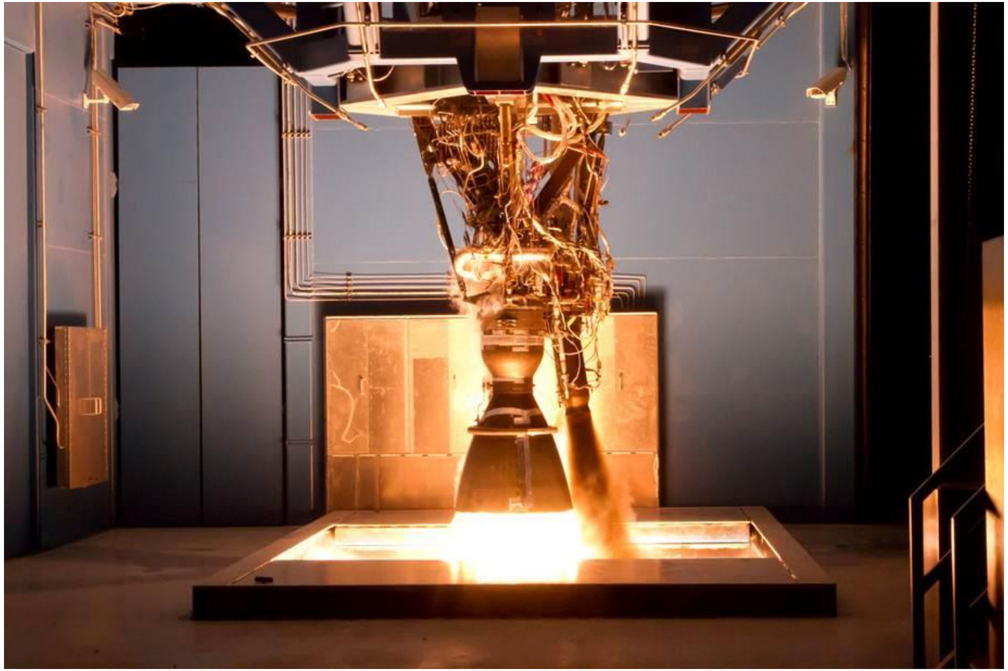
Nozzle

Real world Rocket Engine
Melin Specs:
654-716 kilonewtons of thrust
Thrust to weight 150+
9 Merlin Engines currently on Falcon 9



Spacex Merlin Engine

VALVES, LINES, & ENGINE SUPPORT STRUCTURE

Intro to Valves & Lines

Valves

- Control the flow of fluids

Lines

- Transport fluids to components

Valves and lines need to be reliable, lightweight, leak-proof, and able to withstand significant vibrations and loud noises.

Valves and lines should be tested for leaks and performance prior to use.

Types of Valves

Isolation Valves

- Isolate a portion of the propulsion system when shut

Latch Valves

- Briefly require power to open or close
- Once open or closed, no power is needed

Burst Diaphragm

- Circular disk that blocks a line
- Designed to burst at certain pressures.

Pressure Regulators

- regulate discharge pressure
- Use piston, diaphragm, or electromagnet to throttle flow

Isolation Valve

Latch Valve

Pressure Regulator

Burst Diaphragm

Gaskets

- Gasket compatibility with corrosive fluids

Lines

Material

- Metal

Connections

- Fittings or Welds

Flexibility

- Necessary for gimballed thrust chambers
- Probably not needed for our designs

Durability

- Withstand Vibrations and thermal expansion

Line Filters

- To prevent particles and debris (from burst diaphragm/other) from blocking valves or injection holes

Engine Support Structure

Support Structure

- Transmits the thrust force to the vehicle
- Many forms of support structures
- In large engines the thrust chamber is used for the support structure
- Turbo pump, control boxes, or gimbal actuators are attached to it

Our Structure

- Most likely welded skeletal structure and sheet metal assembly
- All components are mounted directly to the skeletal structure
- Sheet metal will enclose all components

Rocket Support Frame Example