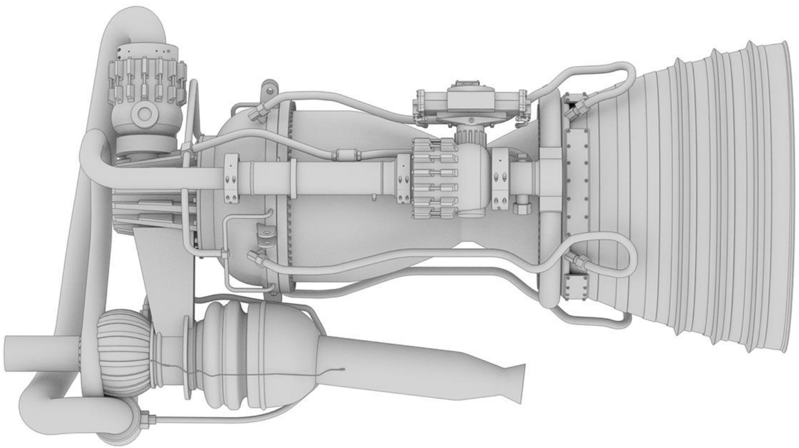

# Fuel and Oxidizer Feed Systems

Zachary Hein, Den Donahou, Andrew Doornink, Mack Bailey, John Fieler

# Design Selection Recap

Fuel Selection

**Fuel:** Ethanol $C_2H_5OH$

-Potential Biofuel

-Low mixture ratio with LOX

-Good specific impulse

-Easy to get

**Oxidizer:** Liquid Oxygen LOX

-Smaller tank needed (Compared to gaseous $O_2$)

-Can be pressurized

-Lowest oxidizer mixture ratio

-Provides Highest specific impulse

# Design Selection Recap

Thrust Chamber

**Thrust Chamber Selections**

- **Injector:** Like Impinging Doublet
- **Cooling System:** Regenerative Cooling
- **Thrust Chamber Material:** Haynes 230

# Design Selection Recap

## Thrust Chamber

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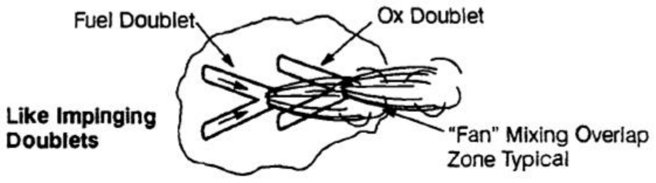


Fig. 4-57 Typical injector element types.

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.

# Design Selection Recap

## Thrust Chamber

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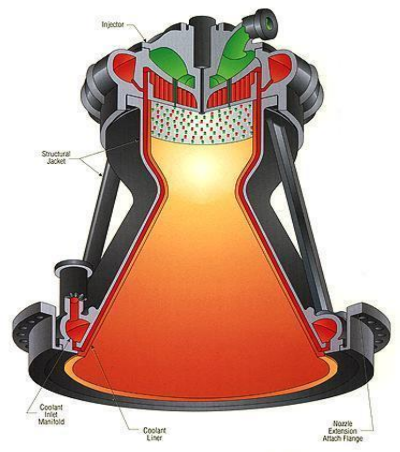
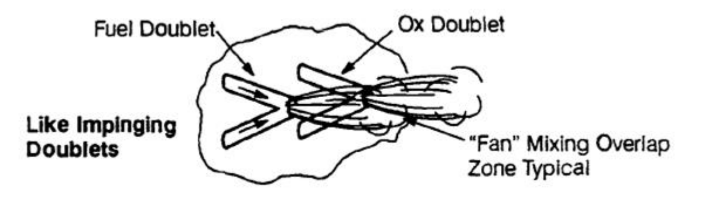



http://www.k-makris.gr/RocketTechnology/ThrustChamber/Thrust_Chamber.htm

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# Design Selection Recap

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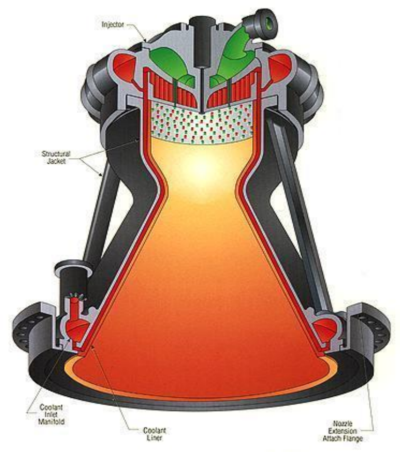
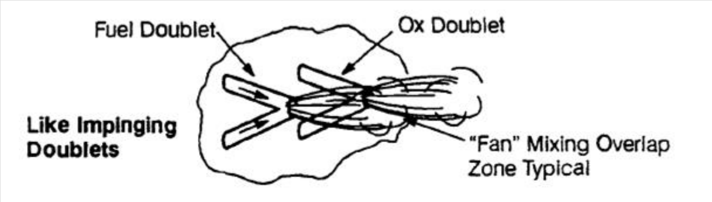



http://www.k-makris.gr/RocketTechnology/ThrustChamber/Thrust_Chamber.htm



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http://www.alibaba.com/product-detail/haynes-seamless-pipe_1715659362.html

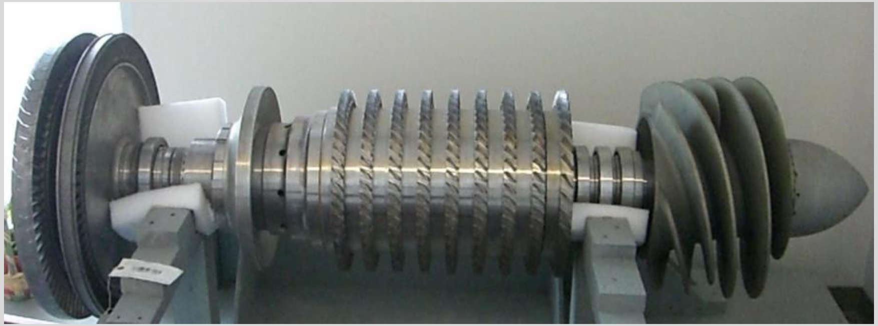
# Turbo Pump Basics

Turbo Pumps provide pressurization to gaseous fuel components to required pressures and mixture ratios.

Turbo Pump uses hot expanding gases to provide mechanical power to pressurize fuel components to required values over coming the back pressure of the combustion chamber.

Pump Types

- Single stage axial flow
- Single stage radial flow
- Multi stage radial flow



M1 rocket turbine http://history.nasa.gov/conghand/propulsn.htm

# Turbo Pump

## How They Provide Power

Gas generator cycle

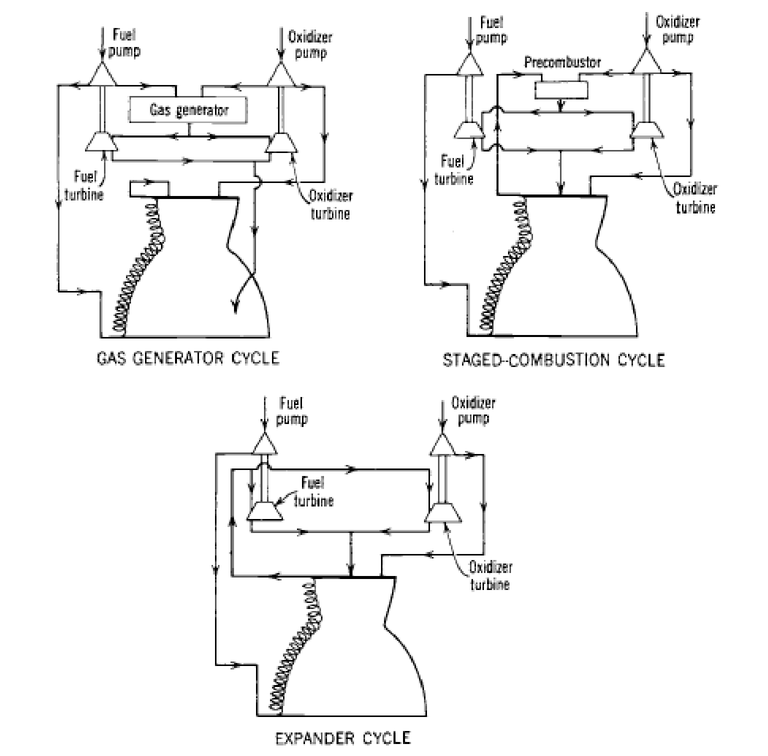
- Combusted fuel and oxidizer to create ho expanded gasses.

Pre Combustion cycle

- Very similar to gas generator system, but vents all leftover gases to top of combustion chamber.

Expander cycle

- Uses expansion of gasses from liquid to gaseous state to provide mechanical energy.



# Single Stage Axial Flow
## Turbopump

- Screw type single stage turbine with axial flow pump.

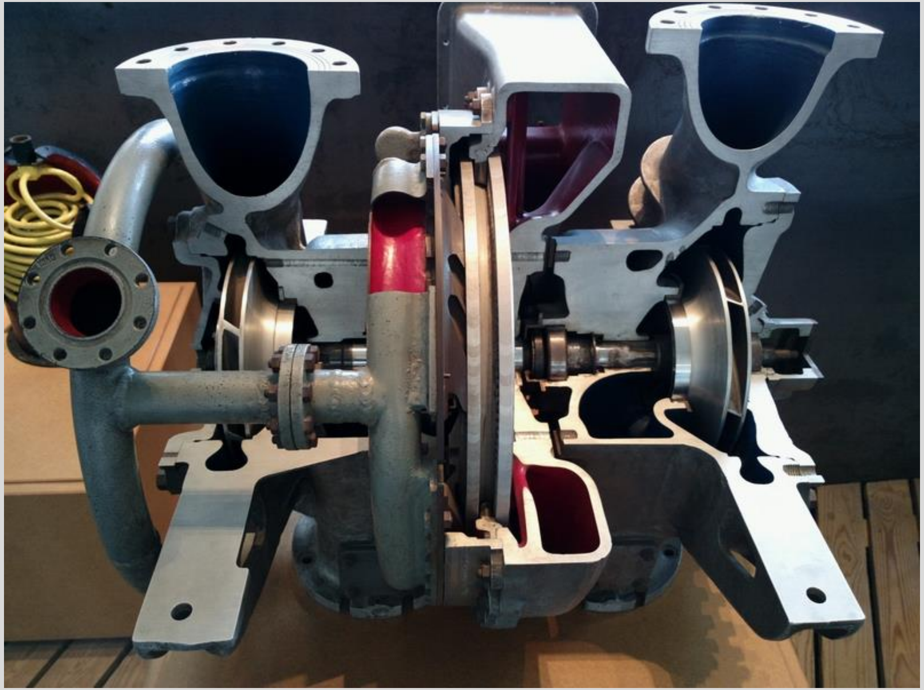
- Gas generator driven Mono propellant system.

http://www.conceptsnrec.com/Resources/Photo-Gallery/Pumps.aspx

# Single Stage Radial Flow

- Simplest design for mono or bi propellants
- Allows for high pressure fuel and oxidizer delivery
- Uses axial flow design very similar to turbos we see in cars.

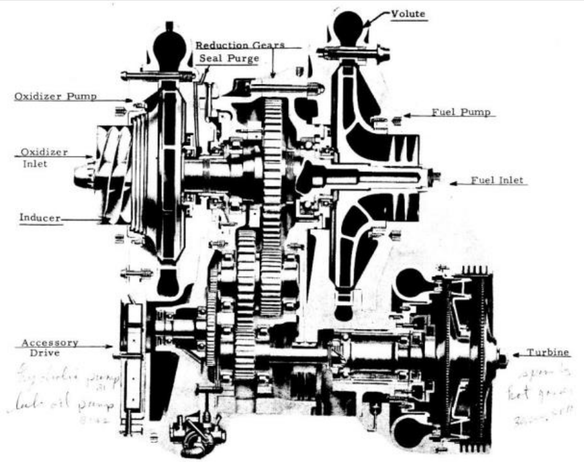
https://www.youtube.com/watch?v=Yn81Mr1vyUE

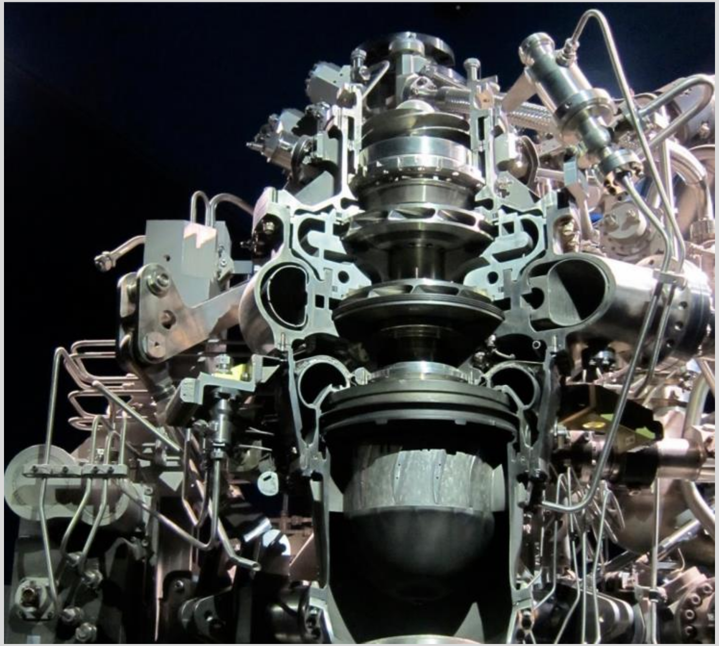


http://www.peter2000.co.uk/aviation/edcp/file-054.jpg

# Multi Stage Axial flow

- Generally connected to gear system to achieve higher pressures and used more often for oxidizer delivery.
- Has both axial flow turbine as well as radial turbines to transfer higher efficiencies.

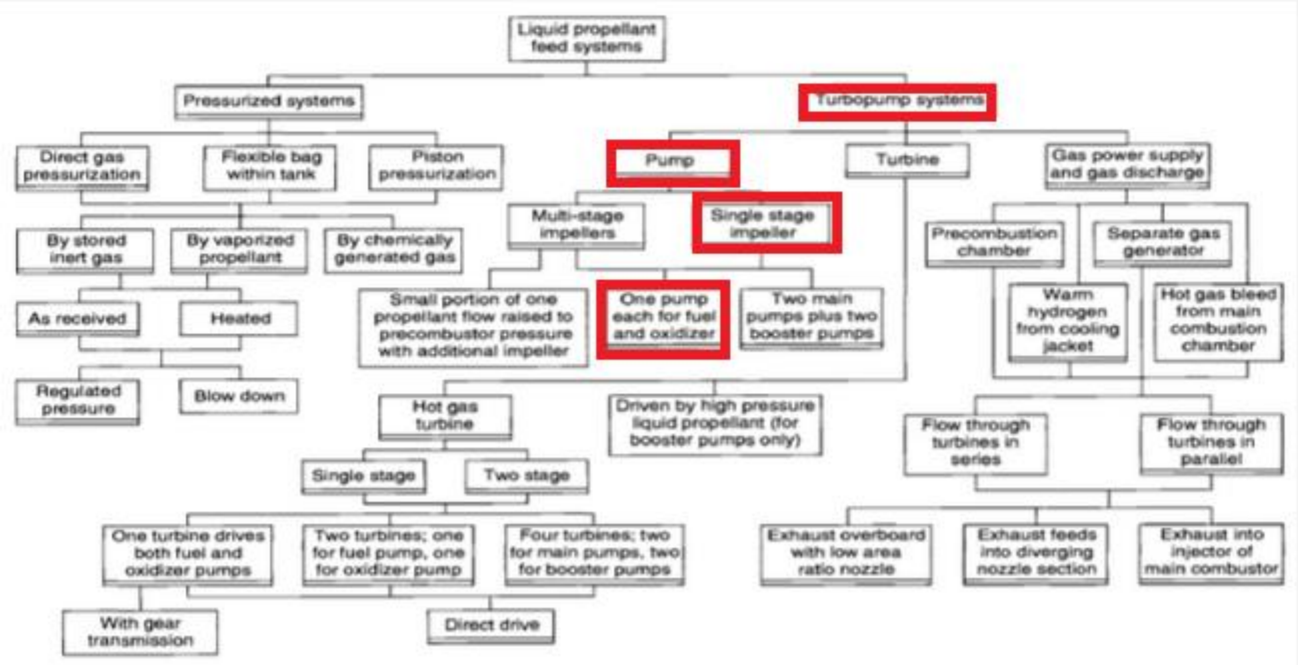


http://www.siloworld.net/579thSMS/SCHOOL/Booster%20Turbo%20Pump.jpg
http://i.imgur.com/8nvkPqg.jpg

# Turbo Pump Selection

- Decision of turbo system for us
- High pressure bi propellant system
- Turbo pump for each fuel and oxidizer



# Fuel and Oxidizer Feed Systems

## Pressurized Systems

- Primary designs for pressurized gas
  - Direct gas pressurization
  - Flexible bag in tank
  - Pressure from piston

- Three main considerations
  - Stored inert gas
  - Gas from chemical reaction
  - Vaporized from propellant

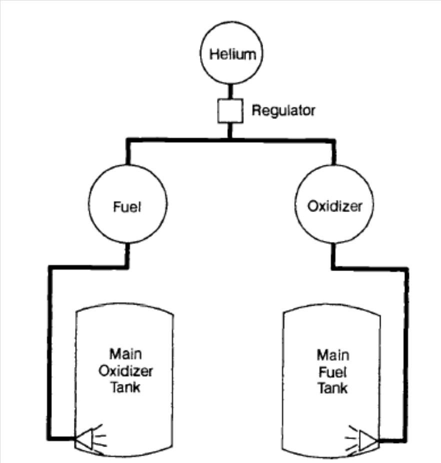
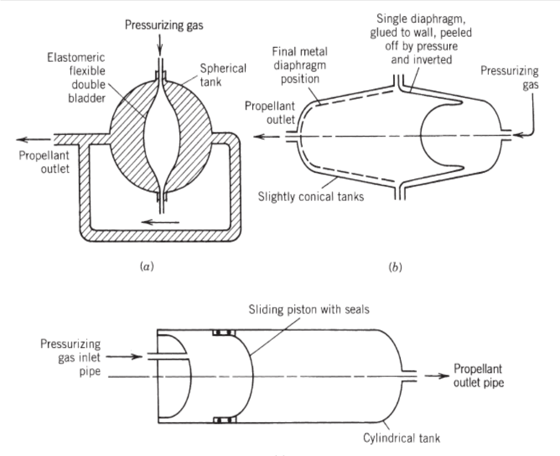


**Fig. 5-17 Main-propellant-tank dual direct-injection system.**

(Arbit)




(Sutton)

# Gas Pressure Feed Systems

## Gas Considerations

- Gas used:
  - High-Pressure Inert Gas
    - Nitrogen, Helium, Air
  - Heated High-Pressure Inert Gas
    - Heated using a heat exchanger to
    - lower inert mass
  - Self-pressurized, cryogenic propellant
  - Direct injection of hypergolic propellant
  - Chemical reaction

- Mass requirement factors:
  - Propellant evaporation
  - Gas solubility
  - Condensation
  - Changes in Gas Temperature
    - Sloshing, turbulence, component heat

$$m_0 = \frac{p_g m_0}{p_0} + \frac{p_p V_p}{R T_0} k = \frac{p_p V_p}{R T_0}\left(\frac{k}{1 - p_g/p_0}\right) \quad (6.7)$$

(Sutton)

# Fuel and Oxidizer Feed Systems

## Pressure Control

- Decision whether to alter pressurized gas temperature
- Analyze two fundamental design options
  - Remain as given
  - Heated reaction present

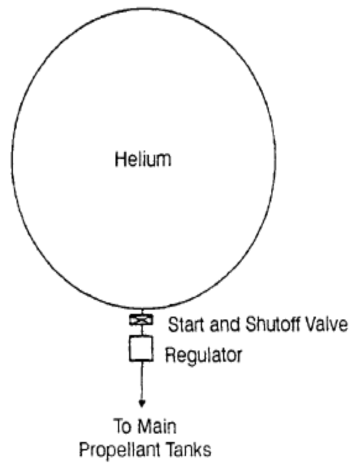



**Fig. 5-1 Helium pressurization system without heating.**

(Arbit)

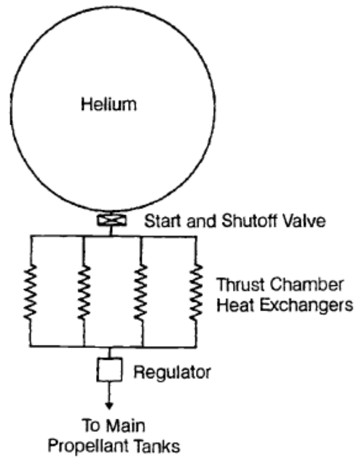



**Fig. 5-2 Helium pressurization system using thrust-chamber heat exchangers.**

(Arbit)

# Fuel and Oxidizer Feed Systems

## Overall Decision

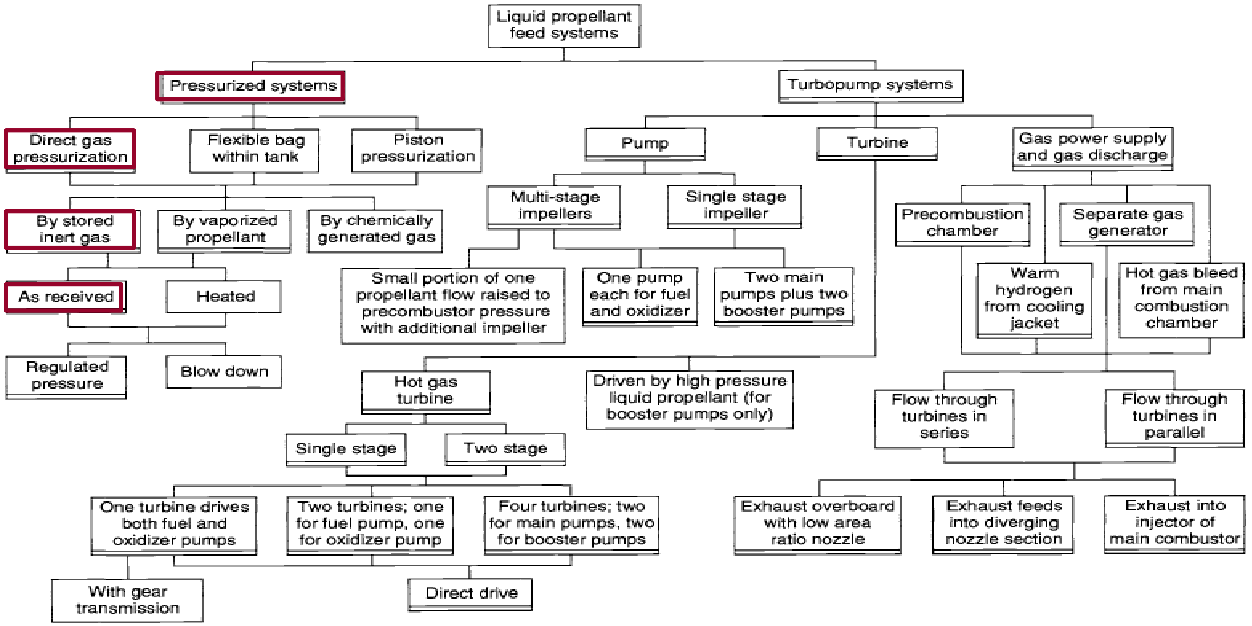



**FIGURE 6–2.** Design options of fed systems for liquid propellant rocket engines. The more common types are designated with a double line at the bottom of the box.

(Sutton)

# Gas Pressure Feed Systems

## Basic Concept

- High pressure gas is used to displace the propellant from its tanks, through lines and into the combustion chamber
- Characterized as being simpler but lower performance feed system
- Must use an inert gas as to not react with either the fuel or the oxidizer
- Flow can easily be turned on and off by actuating valves
- First feed system used in a fluid propellant rocket

# Gas Pressure Feed Systems

## Types of Pressure-Fed Systems

Gas Pressure Regulator

- Separate, high pressure gas tank
- Remotely actuated through a pressure regulator
- Propellants are displaced using the high pressure gas
- Easy control of mixture ratio, feed pressure
- Feed gas can be used to clear lines of excess propellants

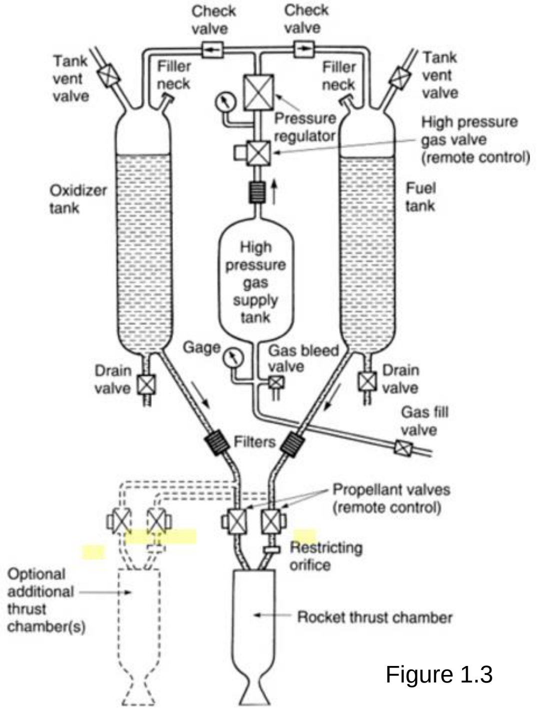


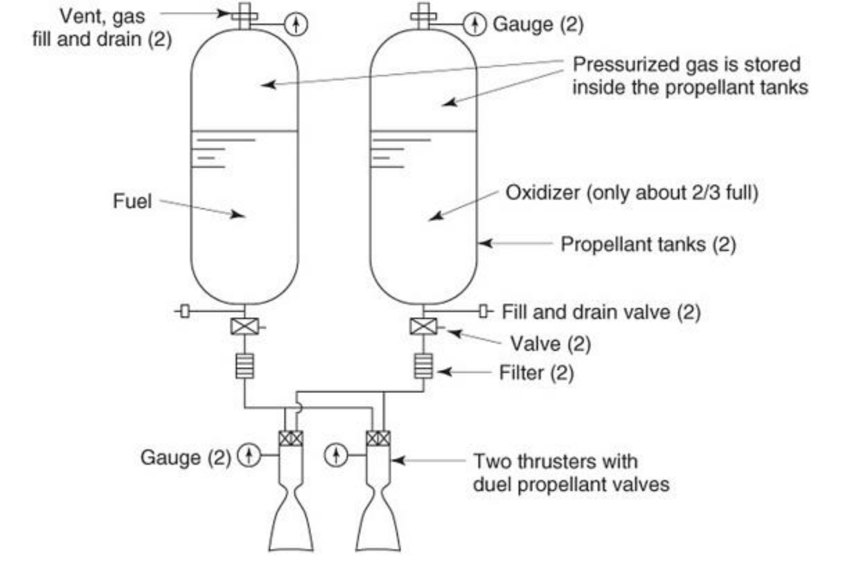

Figure 1.3

# Gas Pressure Feed Systems

## Types of Pressure-Fed Systems

Blow-down feed system

- Pressurized gas held within the propellant tanks
- Gas expands inside tank displacing propellant
- May be self pressurizing
- Requires larger, higher pressure propellant tanks
- Pressure decreases as tank empties



# Gas Pressure Feed Systems

## Comparison

| Type | Pressure Regulator | Blow-down |
|---|---|---|
| Advantages | Constant feed pressure | Simpler system |
| | Mixture ratio control | Less inert mass |
| Disadvantages | More complex system | Thrust decreases throughout burn |
| | Requires an additional high pressure gas tank | Less accurate mixture ratio |
| | Pressure can drop if not enough gas is stored | Must operate at a wider range of thrusts and mixture ratios |
| | Shorter burn time | Lower specific impulse at the end of burning |

# Fuel and Oxidizer Feed Systems

## Overall Decision

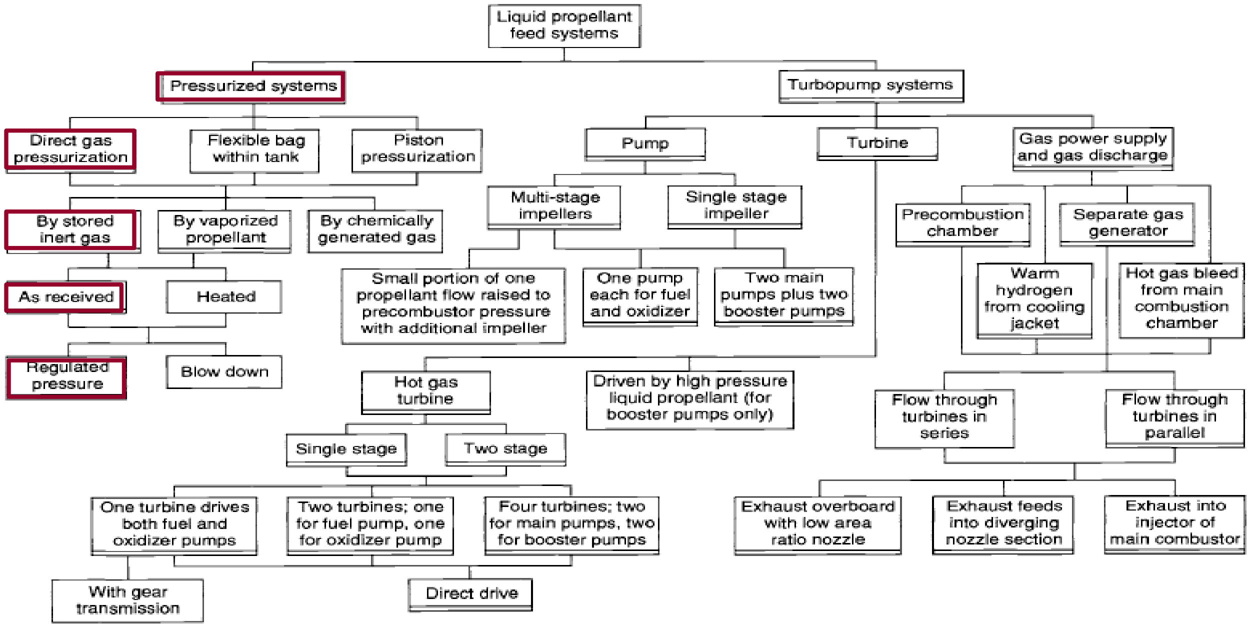



**FIGURE 6–2.** Design options of fed systems for liquid propellant rocket engines. The more common types are designated with a double line at the bottom of the box.

# Our System

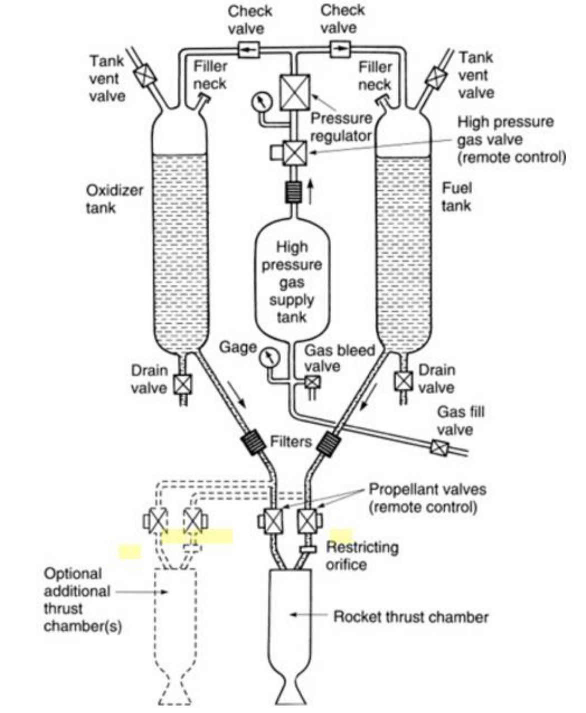
## Overall Design

Gas Pressure Regulator

- Mixture ratio control
- Constant Pressure

Helium

- Inert
- Won’t form a liquid liquid mixture with LOX

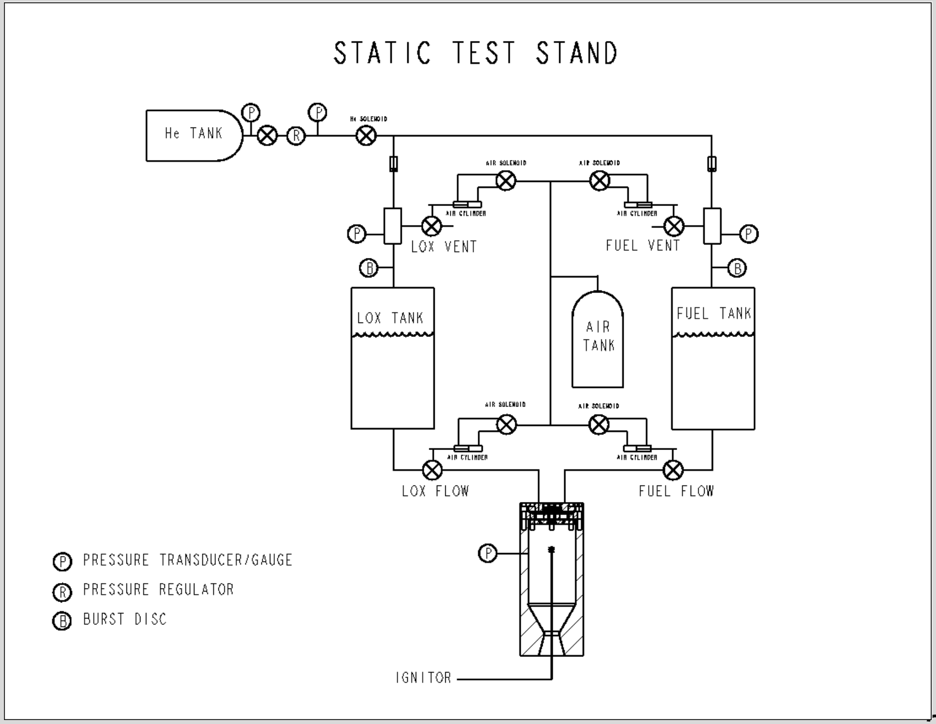


# Our System

## Example System

Roberts Rocket Project

- LOX/Kerosene
- 250 lbf Thrust
- Gas Pressure Regulator system




http://www.watzlavick.com/robert/rocket/testStand/index.html

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# Our System

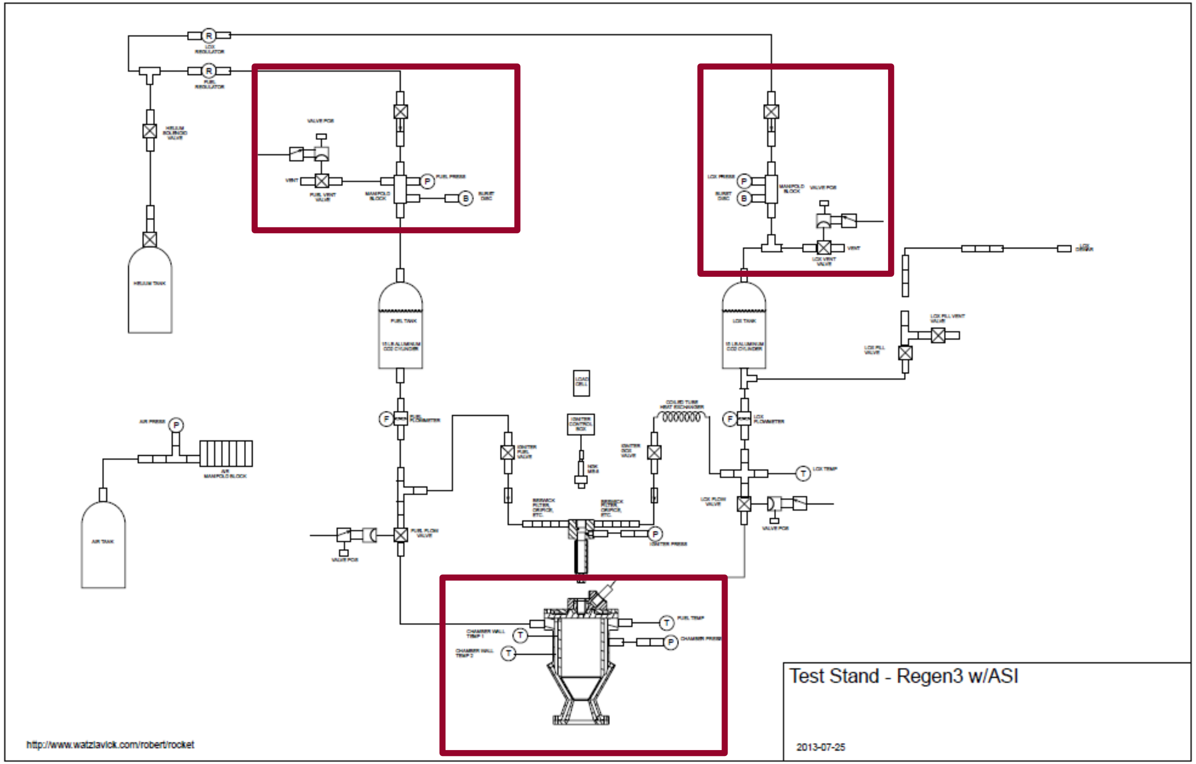
## Example System

Safety Systems

- Burst Disks
- Pressure Regulators
- Pressure Sensors
- Temperature Sensors

Actuators

- Solenoid Valves
- Pneumatic Pistons



# Our System

## Design

Piping

Tanks

Valves

# Our System

## Piping

Copper Tubing

- Easy to work with
- Easy to obtain
- Can be used with O2 and ethanol

Type K

- Highest pressure copper tubing

**TABLE 3a. Rated Internal Working Pressures for Copper Tube: TYPE K***

| Nominal Size, in | Annealed | | | | | | | Drawn** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S= 6000 psi 100 F | S= 5100 psi 150 F | S= 4900 psi 200 F | S= 4800 psi 250 F | S= 4700 psi 300 F | S= 4000 psi 350 F | S= 3000 psi 400 F | S= 10,300 psi 100 F | S= 10,300 psi 150 F | S= 10,300 psi 200 F | S= 10,300 psi 250 F | S= 10,000 psi 300 F | S= 9,700 psi 350 F | S= 9,400 psi 400 F |
| 1/4 | 1074 | 913 | 877 | 860 | 842 | 716 | 537 | 1850 | 1850 | 1850 | 1850 | 1796 | 1742 | 1688 |
| 3/8 | 1130 | 960 | 923 | 904 | 885 | 753 | 565 | 1946 | 1946 | 1946 | 1946 | 1889 | 1833 | 1776 |
| 1/2 | 891 | 758 | 728 | 713 | 698 | 594 | 446 | 1534 | 1534 | 1534 | 1534 | 1490 | 1445 | 1400 |
| 5/8 | 736 | 626 | 601 | 589 | 577 | 491 | 368 | 1266 | 1266 | 1266 | 1266 | 1229 | 1193 | 1156 |
| 3/4 | 852 | 724 | 696 | 682 | 668 | 568 | 426 | 1466 | 1466 | 1466 | 1466 | 1424 | 1381 | 1338 |
| 1 | 655 | 557 | 535 | 524 | 513 | 437 | 327 | 1126 | 1126 | 1126 | 1126 | 1093 | 1061 | 1028 |
| 1 1/4 | 532 | 452 | 434 | 425 | 416 | 354 | 266 | 914 | 914 | 914 | 914 | 888 | 861 | 834 |
| 1 1/2 | 494 | 420 | 404 | 396 | 387 | 330 | 247 | 850 | 850 | 850 | 850 | 825 | 801 | 776 |
| 2 | 435 | 370 | 355 | 348 | 341 | 290 | 217 | 747 | 747 | 747 | 747 | 726 | 704 | 682 |
| 2 1/2 | 398 | 338 | 325 | 319 | 312 | 265 | 199 | 684 | 684 | 684 | 684 | 664 | 644 | 624 |
| 3 | 385 | 328 | 315 | 308 | 302 | 257 | 193 | 662 | 662 | 662 | 662 | 643 | 624 | 604 |
| 3 1/2 | 366 | 311 | 299 | 293 | 286 | 244 | 183 | 628 | 628 | 628 | 628 | 610 | 592 | 573 |
| 4 | 360 | 306 | 294 | 288 | 282 | 240 | 180 | 618 | 618 | 618 | 618 | 600 | 582 | 564 |
| 5 | 345 | 293 | 281 | 276 | 270 | 230 | 172 | 592 | 592 | 592 | 592 | 575 | 557 | 540 |
| 6 | 346 | 295 | 283 | 277 | 271 | 231 | 173 | 595 | 595 | 595 | 595 | 578 | 560 | 543 |
| 8 | 369 | 314 | 301 | 295 | 289 | 246 | 184 | 634 | 634 | 634 | 634 | 615 | 597 | 578 |
| 10 | 369 | 314 | 301 | 295 | 289 | 246 | 184 | 634 | 634 | 634 | 634 | 615 | 597 | 578 |
| 12 | 370 | 314 | 302 | 296 | 290 | 247 | 185 | 635 | 635 | 635 | 635 | 617 | 598 | 580 |

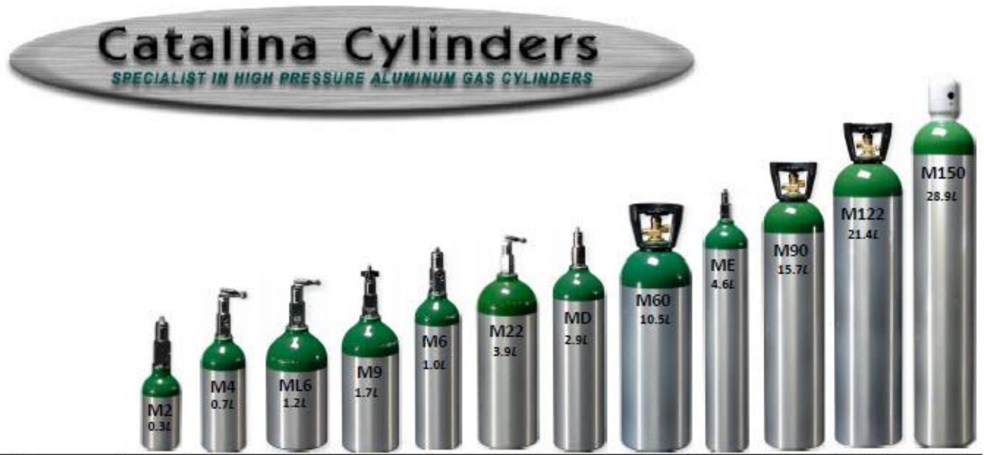
The Copper Tube Handbook - Copper Development Association (pg 25)

# Our System

## Tanks

LOX Tank

- Medical Oxygen Tank
- Size ME
- O2 Approved
- Custom Tank
- Needs 2 ports:
  Gas in
  O2 out




| Cylinders | | M2 | M4 | ML6 | M9 | M6 | M22 | MD | M60 | ME | M90 | M122 | M150 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Service Pressure (psi) | | 2216 | 2216 | 2015 | 2015 | 2216 | 2216 | 2015 | 2216 | 2015 | 2216 | 2216 | 2015 |
| Diameter | in | 2.5 | 3.21 | 4.38 | 4.38 | 3.21 | 5.25 | 4.38 | 7.25 | 4.38 | 7.25 | 8.0 | 8.00 |
| | mm | 63.5 | 81.5 | 111.3 | 111.3 | 81.5 | 133.4 | 111.3 | 184.2 | 111.3 | 184.2 | 203.2 | 203.2 |
| Length | in | 5.7 | 8.7 | 7.8 | 10.9 | 11.8 | 16.3 | 16.7 | 22.9 | 25.4 | 32.6 | 36.2 | 47.0 |
| | mm | 145 | 221 | 198 | 277 | 300 | 414 | 424 | 582 | 645 | 828 | 919 | 1194 |
| Weight | lbs | 0.7 | 1.7 | 2.9 | 3.7 | 2.3 | 8.0 | 5.4 | 22.3 | 7.8 | 30.3 | 39.5 | 48.8 |
| | kgs | 0.3 | 0.8 | 1.3 | 1.7 | 1.0 | 3.6 | 2.4 | 10.1 | 3.5 | 13.7 | 17.9 | 22.1 |
| Oxygen Capacity | cu ft | 1.5 | 4.0 | 6.0 | 9.0 | 6.0 | 22.0 | 15.0 | 60.0 | 24.0 | 90.0 | 122.0 | 150.0 |
| | liters | 42 | 113 | 170 | 255 | 170 | 623 | 425 | 1699 | 679 | 2549 | 3455 | 4248 |

http://www.southeastoxygen.com/medical-oxygen/cylinders/medical-oxygen-cylinder-size-m6.html

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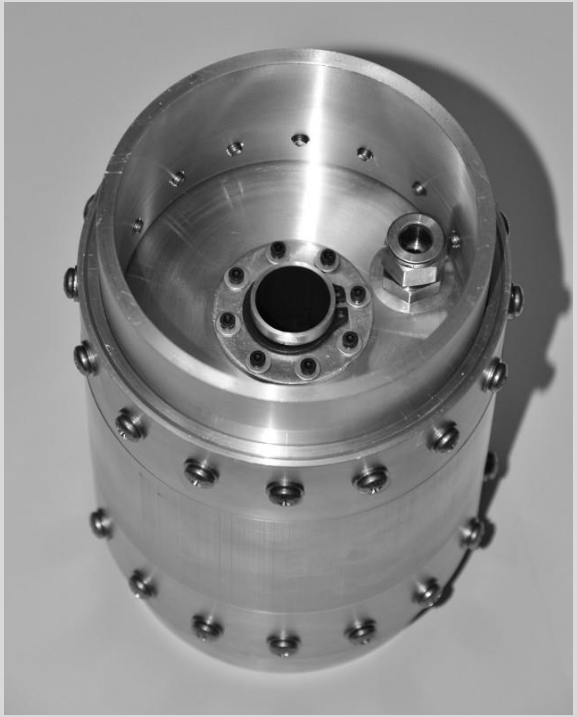
# Our System

## Tanks

Ethanol Tank

- Custom Aluminum Tank
- Fire Extinguisher?
- Does not need
  to be O2 Approved
- Needs two ports



http://www.watzlavick.com/robert/rocket/rocket1/photos/dsc_9168m.jpg

# Our System

## Tanks

Helium Tank

- Highest Pressure (10-30 MPa)
- Composite Materials (light weight)
- Does not need
  to be O2 Approved

http://www.ctgltd.com/key-technologies

# Our System

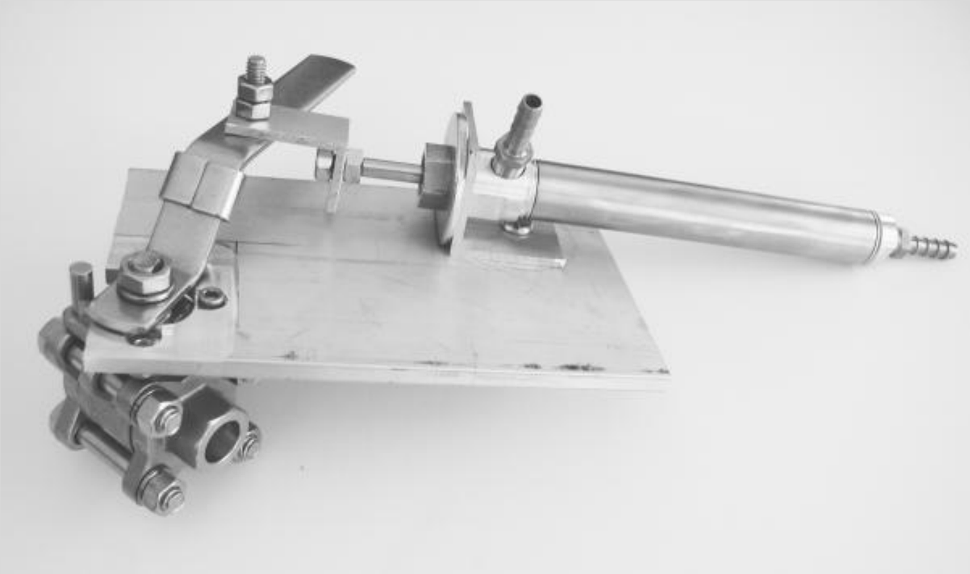
## Valves

Design Considerations

- High Pressure (Ethanol/LOX/Helium)
- Cryogenic (LOX)
- O2 Approved (LOX)

Swagelok

- High Pressure (Ethanol/Helium)



http://watzlavick.com/robert/rocket/testStand/airValvePic.jpg

# Our System

## Valves

Design Considerations

- High Pressure (Ethanol/LOW/Helium)
- Cryogenic (LOX)
- O2 Approved (LOX)

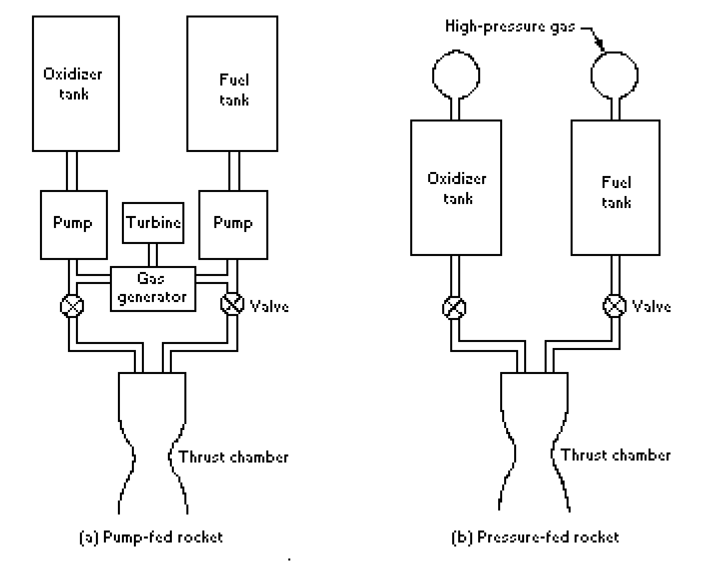
Cryogenic Ball Valves

https://www.bray.com/ball-valves/specialty-products/cryogenic

# Design Selection Recap

## Blowdown Gas

- Choice: Helium Gas
- - Inert Gas
  - - no liquid liquid mixture with oxygen $T_{sat\ atm} = 4$ K
- - Avoid Pumps and Turbo
- - Provides source for pneumatic actuators
  - - Readily available
  - - Does not form liquid-liquid mixture with LOX




http://history.nasa.gov/conghand/propulsn.htm

# Design Selection Recap

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- Choice: Helium Gas
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- - Avoid Pumps and Turbo
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    - - Readily available
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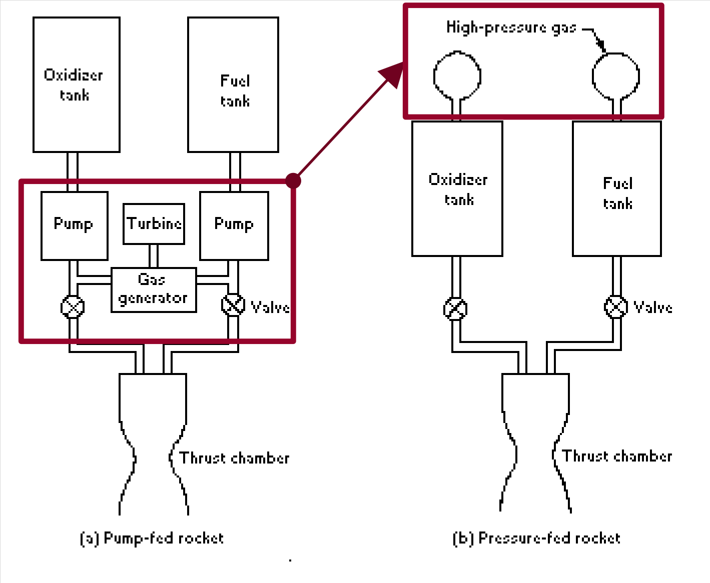


http://history.nasa.gov/conghand/propulsn.htm

# Summary

## Future Processes

Finalize Component Selection

- Tank Volumes
- Tank Pressures
- Flow Rates

Begin Part Selection and Manufacturing

- Compile data for overall system
- Choose optimal, cheapest parts