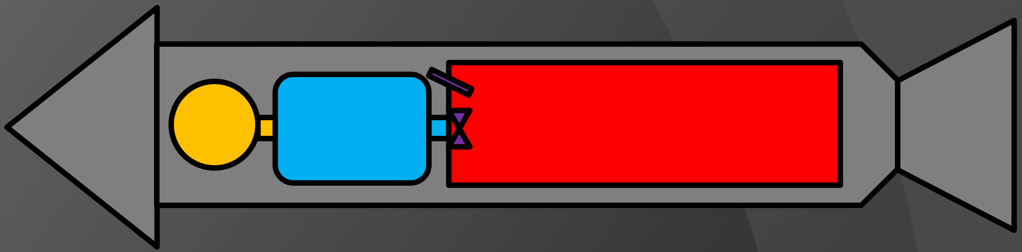
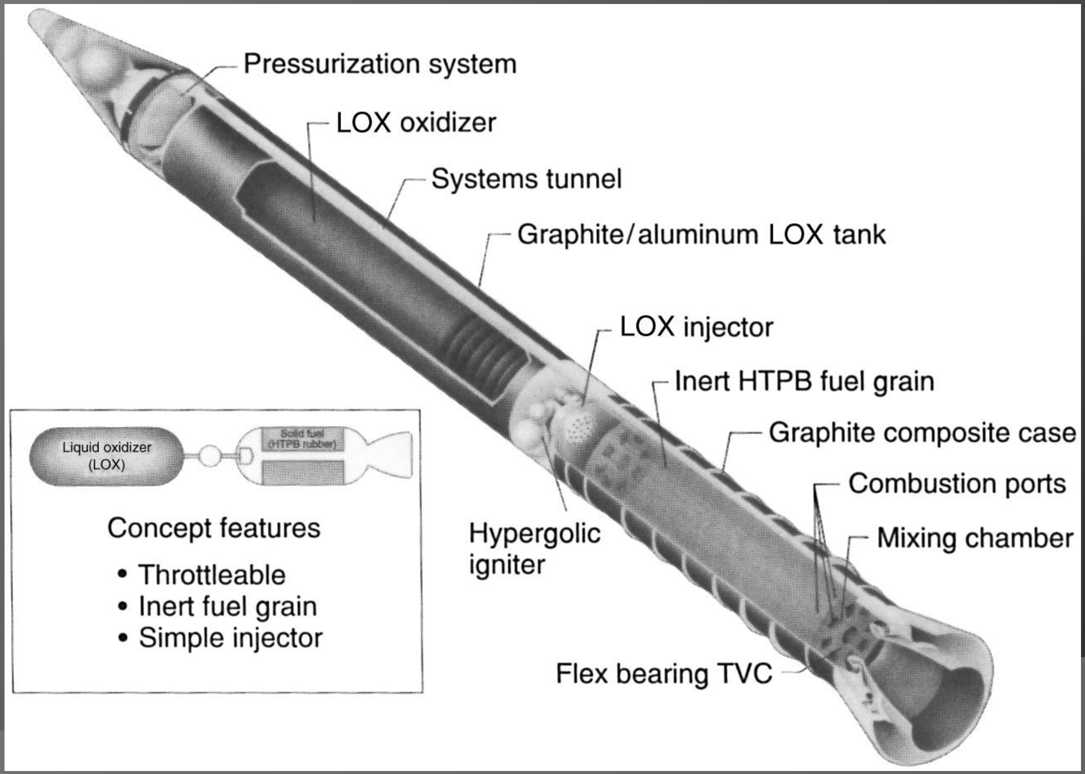
Hybrid Propellant Fundamentals

2/6/2015

Hybrid Rocket Design

- Oxidizer Pressurization System
- Oxidizer
- Injector
- Solid Fuel Grain
- Combustion Ports
- Mixing Chamber



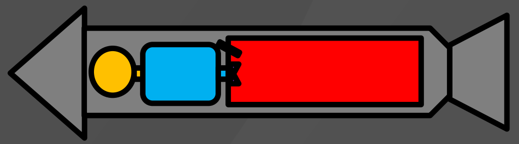


<u>Alternate Configurations</u>

- Inverse
- Mixed Hybrid

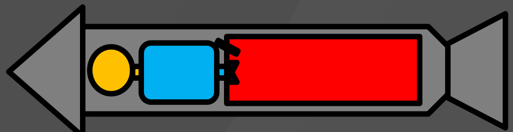
Advantages of Hybrid Rockets

1. Enhanced safety from explosion or detonation during fabrication, storage, and operation
2. Start-stop-restart capabilities
3. The ability to smoothly change thrust over wide range on demand
4. Higher specific impulse than solid rocket motors and higher density-specific impulse than liquid bipropellant engines
5. Relative simplicity which may translate into low overall system cost compared to liquids



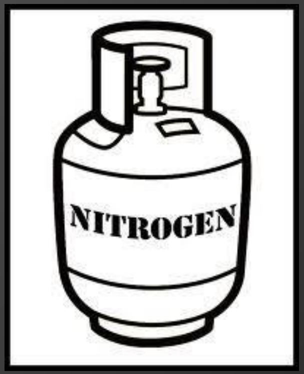
Disadvantages of Hybrid Rockets

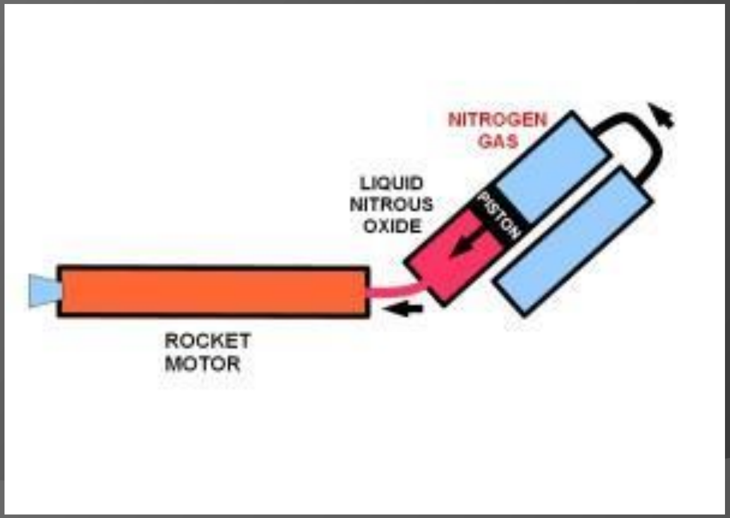
1. Mixture ratio and hence specific impulse may vary during steady-state operation
2. relatively complicated fuel geometries with significant unavoidable fuel residues at end of burn, which somewhat reduces the mass fraction and can vary if there is random throttling
3. Prone to large-amplitude, low-frequency pressure fluctuation
4. relatively complicated internal motor ballistics resulting in incomplete description, both of regression rates of the fuel and of motor-scaling effects, affecting the design of the large hybrid system.

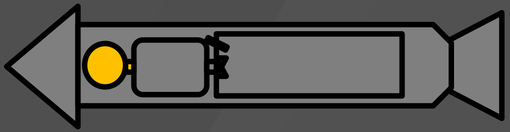


Oxidizer Pressurization System

- Several Methods
  - Self Pressurizing Liquid (N_2O)
  - Pushing with an Inert Gas
  - Piston/Bladder Configuration prevents inert gas from mixing with oxidizer







“Chugging”

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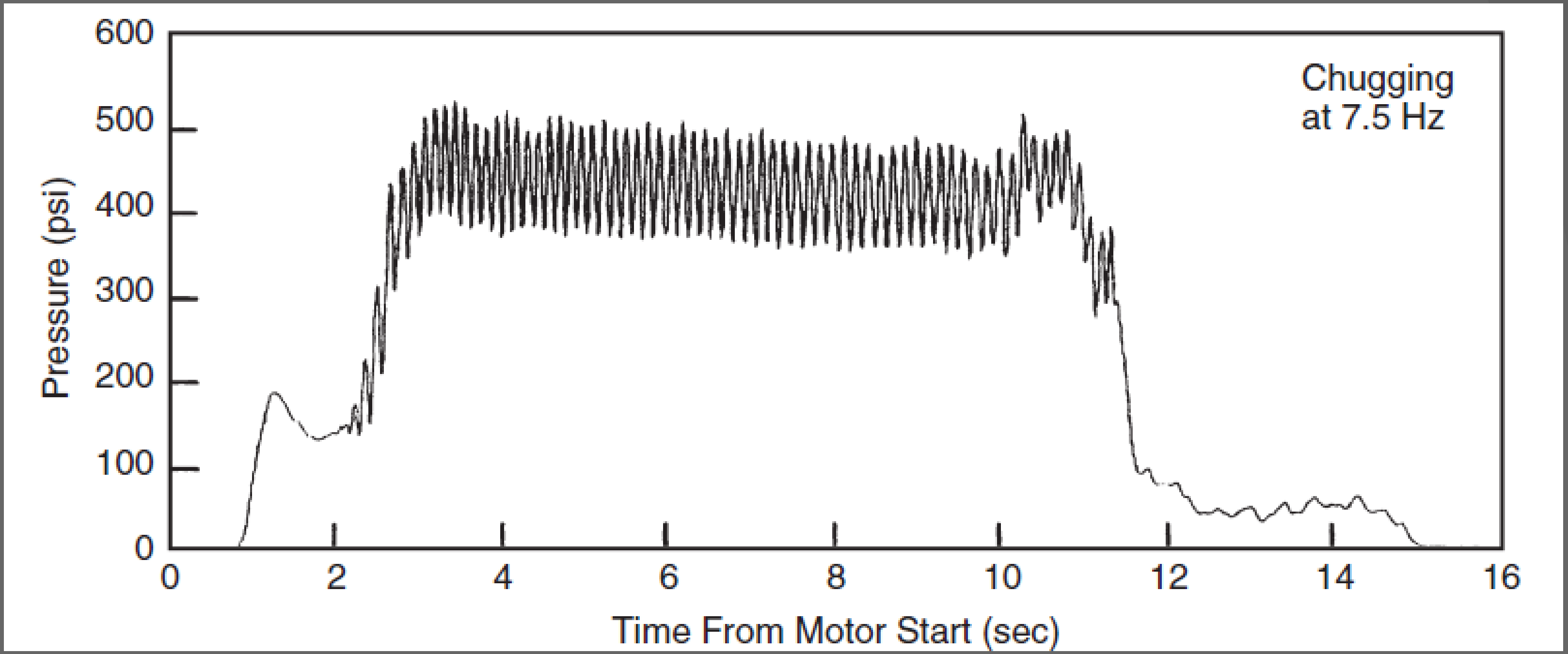
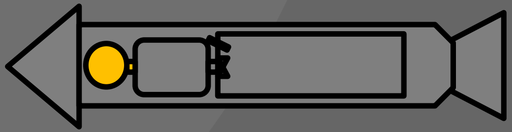
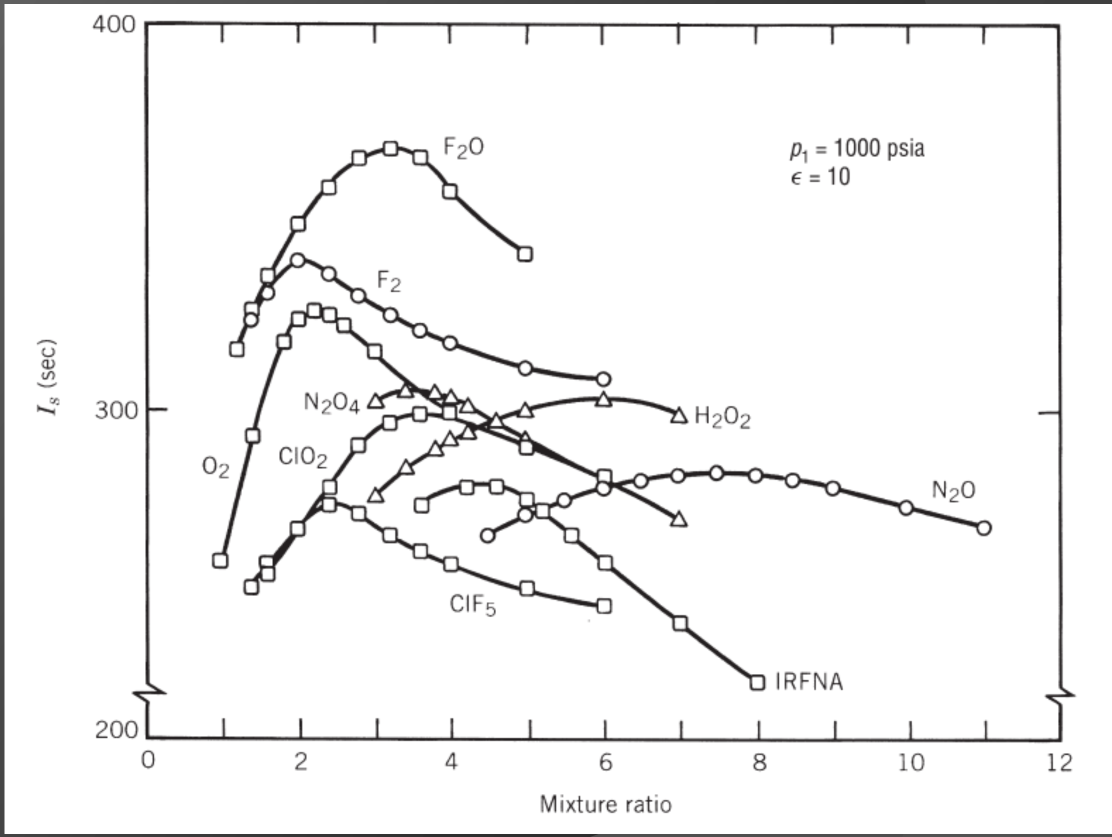


- Pressure Oscillations caused by compressible flow and two phase flow in feed lines.
- Ways to avoid:
  - Increasing injector pressure drop
  - Eliminating sources of compressibility



Oxidizer

- Varying Specific Impulses
- Higher Energy Oxidizers are extremely Toxic
- Either non-cryogenic (storable) liquid or cryogenic liquid



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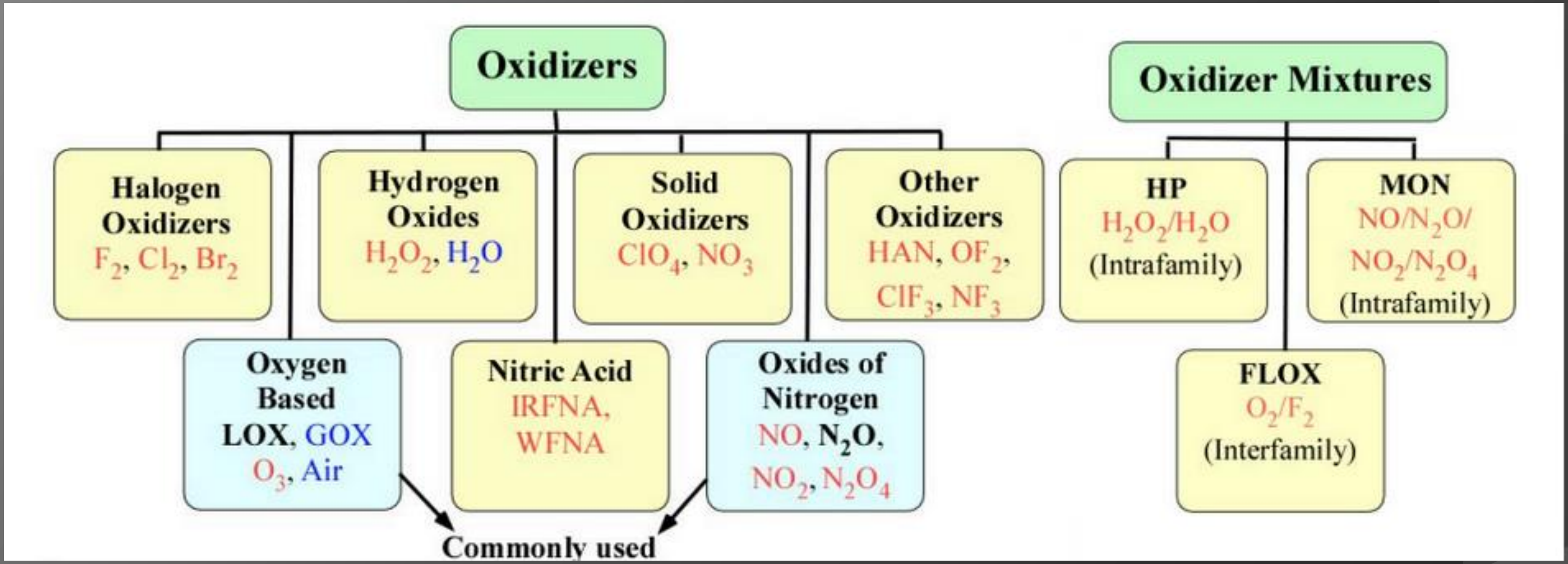
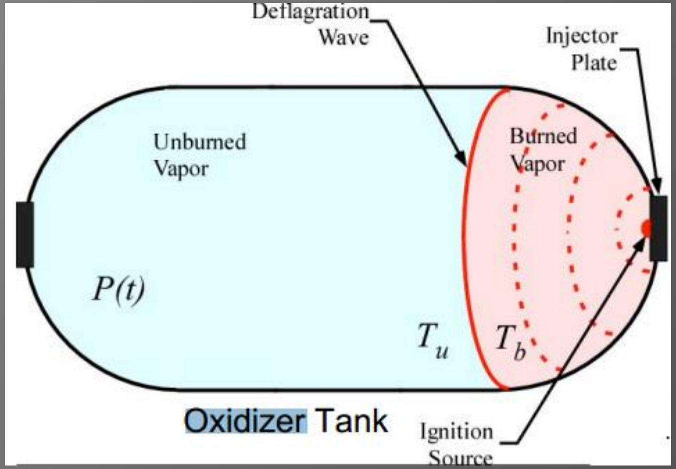
Oxidizer



Oxidizers
Oxidizer Mixtures
Halogen Oxidizers F_2, Cl_2, Br_2
Hydrogen Oxides H_2O_2, H_2O
Solid Oxidizers ClO_4, NO_3
Other Oxidizers HAN, OF_2, ClF_3, NF_3
HP H_2O_2/H_2O (Intrafamily)
MON $NO/N_2O/$ NO_2/N_2O_4 (Intrafamily)
Oxygen Based LOX, GOX O_3, Air
Nitric Acid IRFNA, WFNA
Oxides of Nitrogen NO, N_2O, NO_2, N_2O_4
FLOX O_2/F_2 (Interfamily)
Commonly used

N2O Decomposition Hazard



- Largest hazard is in the oxidizer tank during vapor phase combustion
- Hot injector plate

Risk Mitigation

- Supercharge with inert gas (He)
- Incorporate a burst disc

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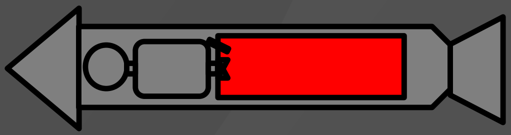
Combustion Ports

Single circular port geometry:

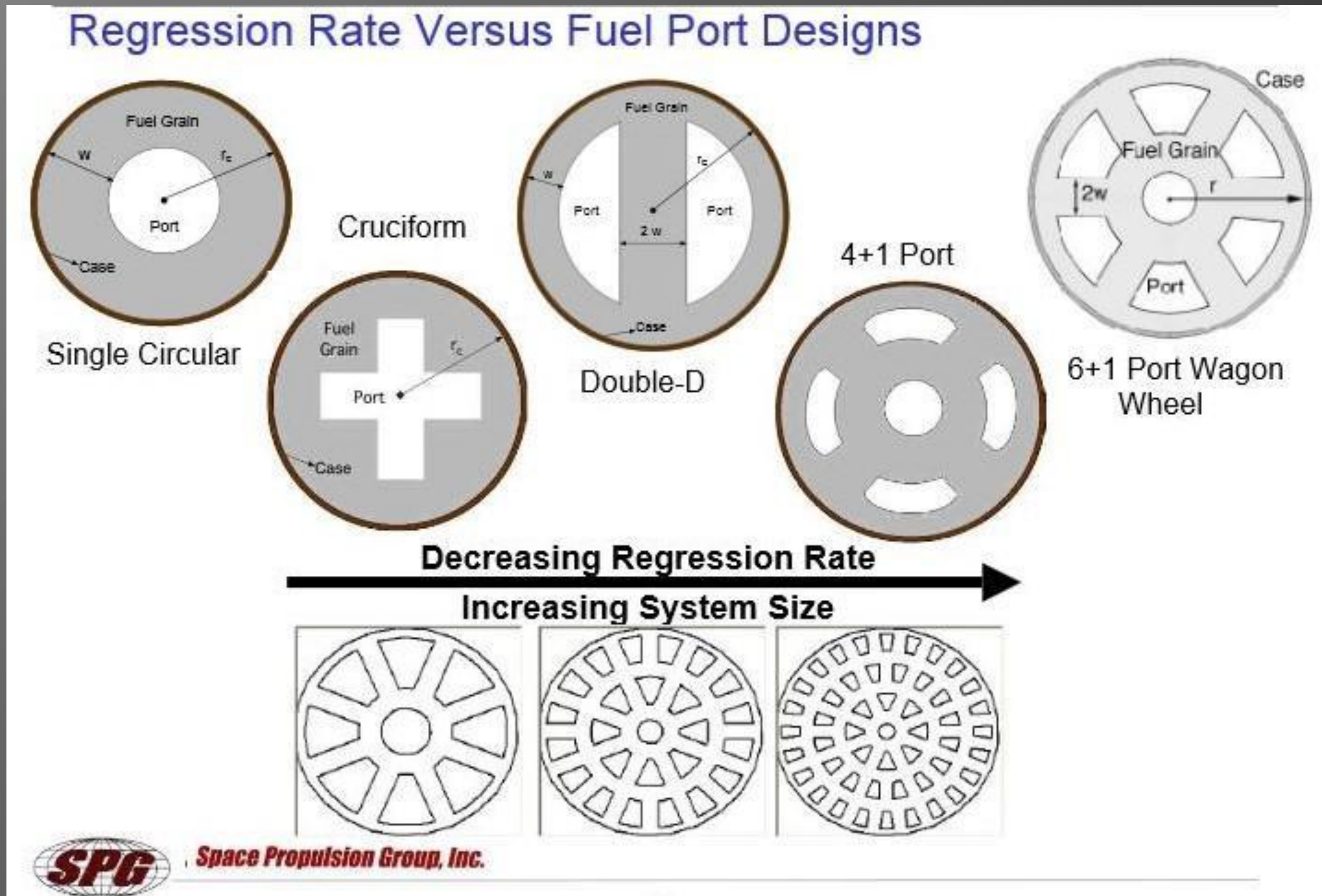
- Easy to manufacture
- High volumetric efficiency
- simplifies design
- only one injector necessary

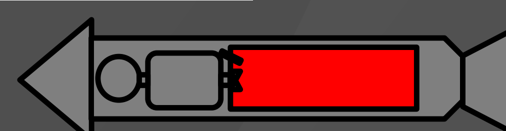
Multiple port geometries:

- require multiple oxidizer injectors
- increases regression rate
- decreases overall length of combustion chamber

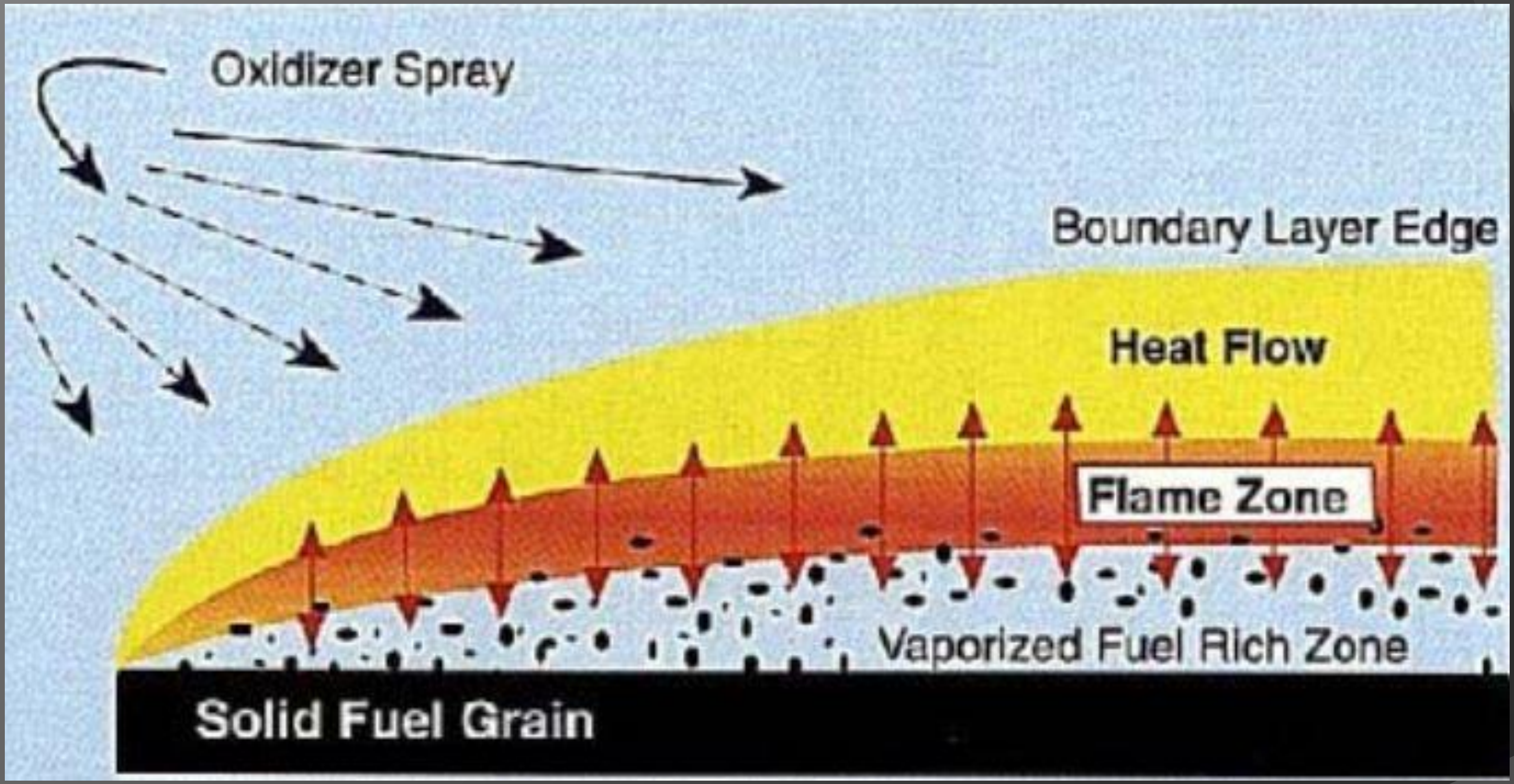


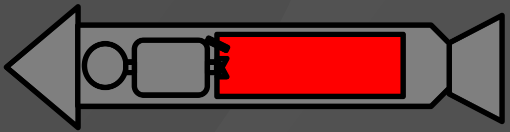
Combustion Ports



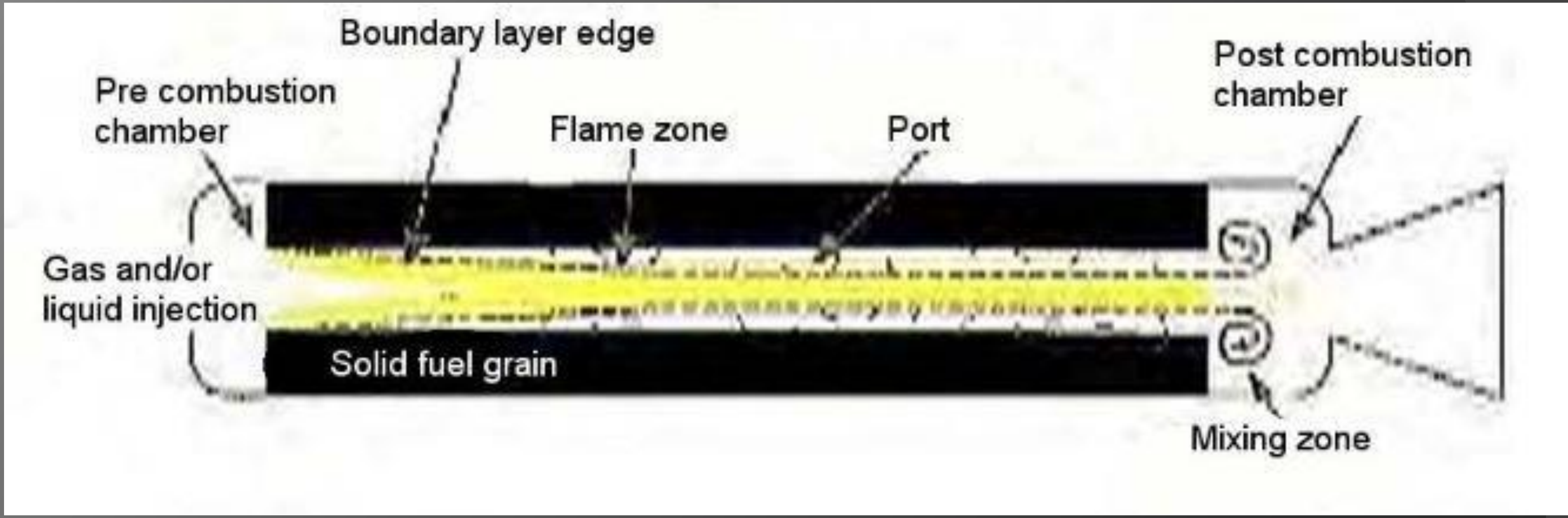


Fuel Mixture Zone





Fuel Mixture Zone

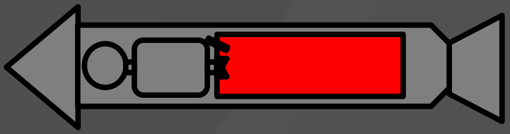


Pre combustion chamber:

- gives time for oxidizer to vaporize
- allows more even mixing of oxidizer before passing over fuel grain
- allows for hot gas recirculation

Post combustion chamber:

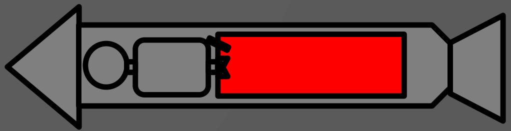
- unburned oxidizer/fuel are allowed time to mix and combust in post combustion chamber, using fuel more efficiently



Approaches for High Regression Rate

Technique	Fundamental Principle	Shortcoming
Add oxidizing agents self - decomposing materials	Increase heat transfer by introducing surface reactions	∞ Reduced safety ∞ Pressure dependency
Add metal particles (micron -sized)	Increased radiative heat transfer	∞ Limited improvement ∞ Pressure dependency
Add metal particles (nano -sized)	Increased radiative heat transfer	∞ High cost ∞ Tricky processing
Use Swirl Injection	Increased local mass flux	∞ Increased complexity ∞ Scaling?

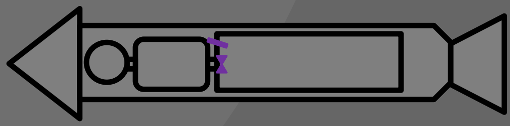
All based on increasing heat transfer to fuel surface



Injector

There are two methods of injection

- Direct injection into the fuel grain port
- Injection into a pre-combustion chamber
- Direct injection into the fuel grain port is the best approach when using a single circular port geometry



Injector

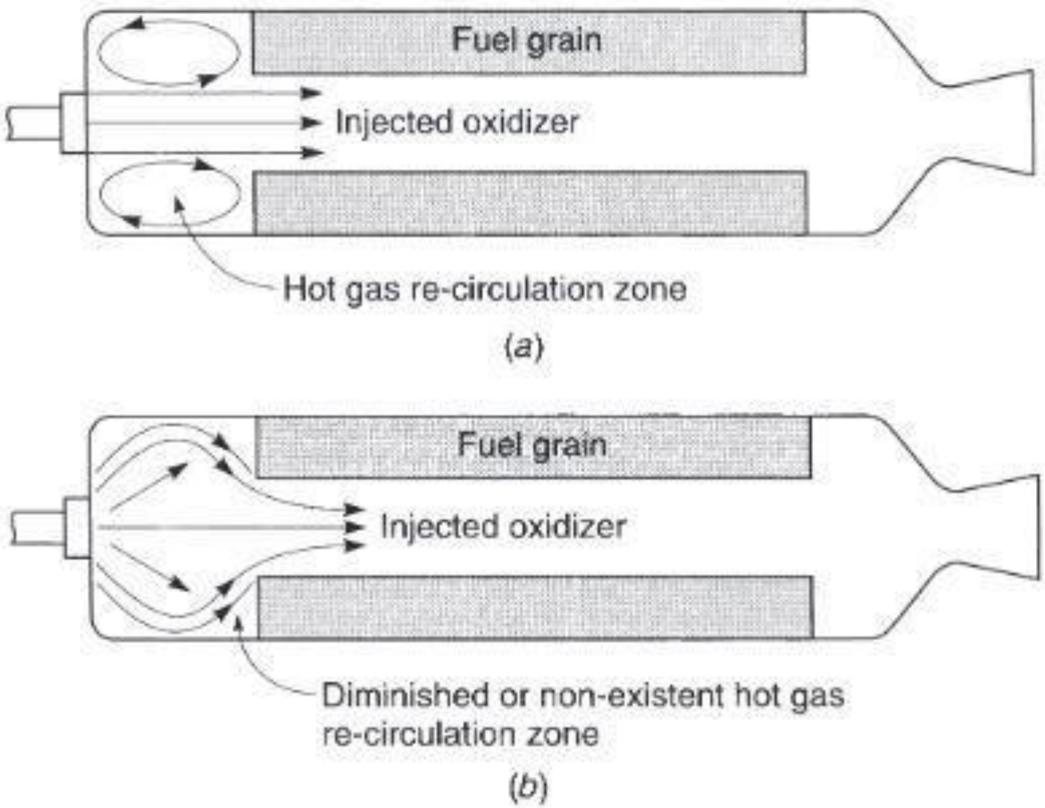
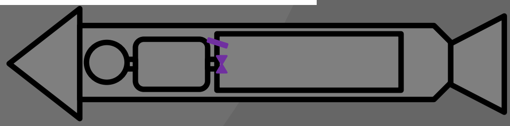
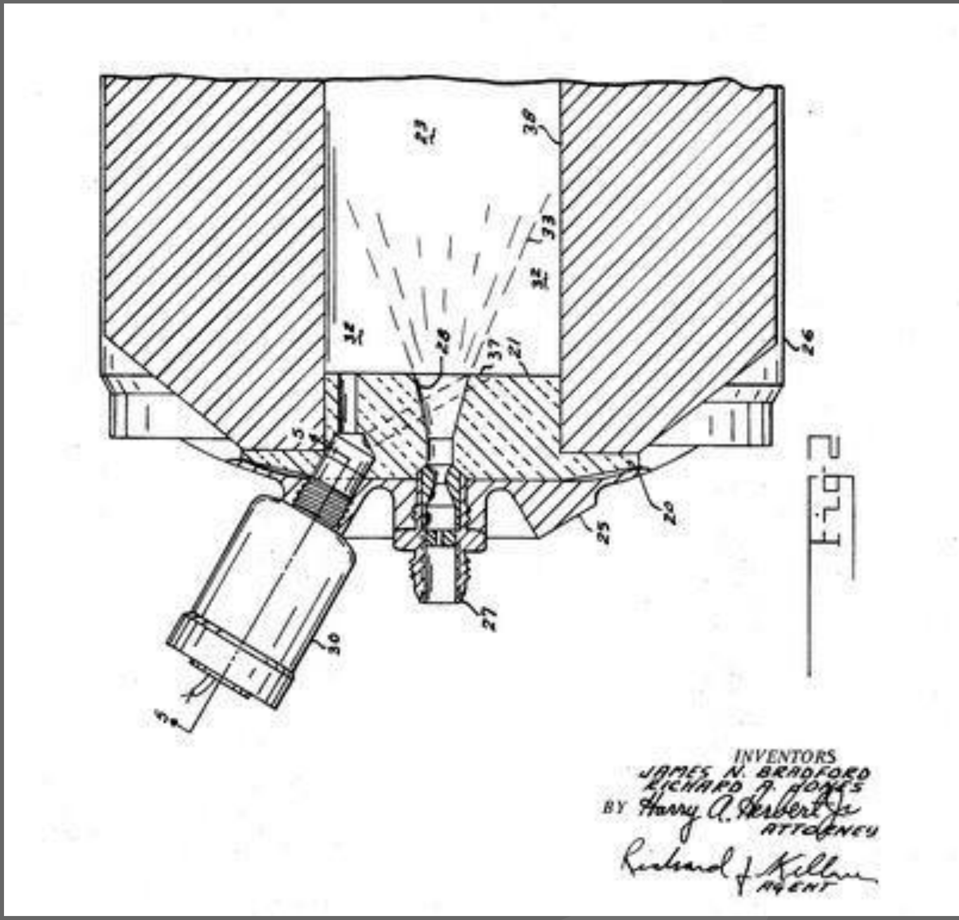


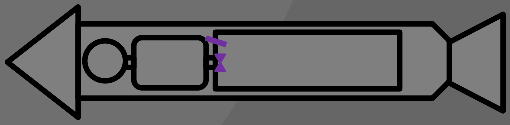
FIGURE 16–12. (*a*) Axial injection of oxidizer results in a strong hot gas flow recirculation zone at the fuel grain leading edge, producing stable combustion. (*b*) Conical injection of oxidizer can produce a weak or nonexistent hot gas flow recirculation zone at the fuel grain leading edge, resulting in unstable combustion.



Igniter

- Ignited by source of heat
- Oxidizer fully spreads ignition
- Typically used with hypergolic fluid
- Ex. TEA - TEB used in Atlas and Delta launch vehicles
- Smaller motors = passing current through steel wool





Formulas! (Performance Analysis)

- Conservation of Mass

$$\dot{m}_o + \dot{m}_f = \dot{m}_n + \dot{m}_a$$

$$\dot{m}_a = \frac{d(\rho_c V_c)}{dt}$$

$$\dot{m}_f = \rho_f A_b \dot{r}$$

$$\dot{r} = a G_o^n$$

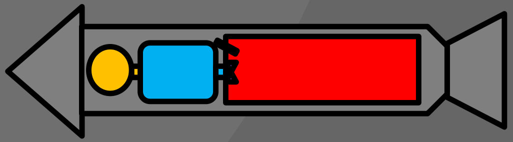
$$\dot{m}_n = \frac{P_c A_t}{c^*_{exp}}$$

$$G_o = \frac{\dot{m}_o}{A_p}$$

$$C_F = \sqrt{\frac{2\gamma^2}{(\gamma-1)}\left(\frac{2}{(\gamma+1)}\right)^{\frac{(\gamma+1)}{(\gamma-1)}}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{(\gamma-1)}{\gamma}}\right]} + \frac{(P_e - P_a)}{P_c}\frac{A_e}{A_t}$$

$$\frac{dP_c}{dt} = \left[\dot{m}_o + (\rho_f - \rho_c) A_b a G_o^n - \frac{P_c A_t}{c^*_{exp}}\right]\frac{RT_c}{V_c}$$

THRUST!! $F = C_F P_c A_t$

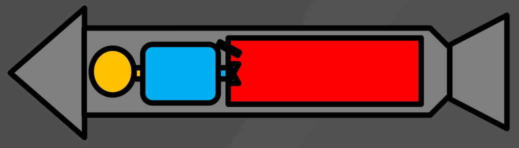


Regression Rate

$$\dot{r} = 0.036 \frac{G^{0.8}}{\rho_f} \left(\frac{\mu}{x}\right)^{0.2} \beta^{0.23}$$

$$\dot{r} = a \left(\frac{\dot{m}_o}{\pi R^2}\right)^n$$

- Turbulent Flow Regime
- Common Rates: .05 - .2 inches/sec
- Common N-Values: .4 - .7



Summary/Design Goals

- Smooth Oxidizer Flow vs. Ease of Installation/Use
- Simpler Fuel Grain Geometry -> Easier to Manufacture/Less Costly
- Simple Geometry -> Fewer Injectors
- Large Pressure Drop Across Injector
- Igniter -> Testing Needed
- Generally Turbulent Flow Means Empirical Relationship -> TESTING!!!!
- Share Purchasing Info