Fluid Propellant Selection

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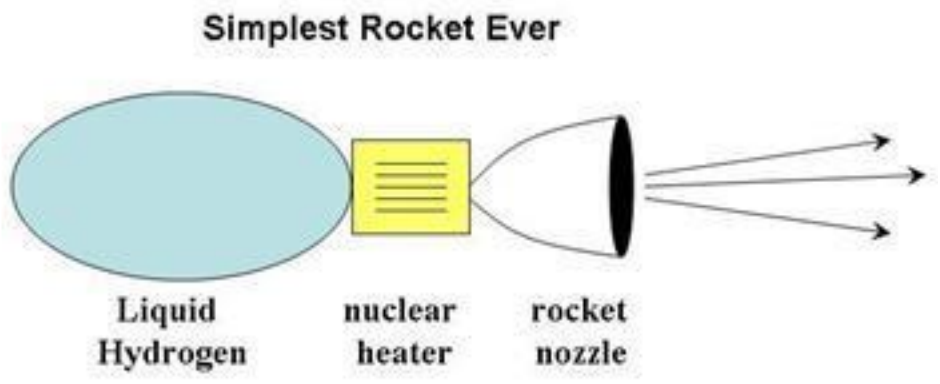
How to Select Fluid Propellants

1. Pertinent Propellant Properties
2. Elimination Round
3. Propellant Comparison
4. Final Decision/Future Plans



http://www.neofuel.com/inhabit/inhabit.htm

Falcon Heavy

Oxidizer/Fuel

- Liquid OXygen (LOX) and Rocket Propellant-1 (RP-1)
- RP-1 is highly refined kerosene
- Most common oxidizer/propellant combination

Details

- Most powerful operational rocket (*only Saturn V more powerful*)
- First stage uses three Falcon 9 cores (*27 Merlin Engines*)
- Newest rocket in use by SpaceX (first launch sometime this year)
- Falcon Heavy animation: (https://www.youtube.com/watch?v=4Ca6x4QbpoM)

http://www.spacex.com/falcon-heavy

Ideal Fuel/Oxidizer

- **Low Freezing Point:** Allows rocket to operate in cold weather
- **High Specific Gravity:** Denser propellants provide larger mass per volume

$\boldsymbol{\rho}_{av}$ = average density $\boldsymbol{\rho}_{o}$ = density of oxidizer $\boldsymbol{\rho}_{f}$ = density of fuel (7-2)
r = oxidizer per fuel mixture ratio

$$\rho_{av} = \frac{\rho_o * \rho_f * r + \rho_o * \rho_f}{\rho_f * r + \rho_o}$$

- **Good Stability:** No chemical deterioration/decomposition while in storage
- **Heat Transfer Properties:** High Specific heat, high thermal conductivity, and high boiling or decomposition temperature (Section 8.5)
- **Small Temperature Variation of Physical Properties:** It is difficult to predict your system with large property difference with temperature changes
- **(Optional) Adequate Pumping Properties:** Low vapor pressure propellants allow for more effective pump designs; lower viscosity propellants are easier to pump

Propellant Properties

- **Economic Factors:** Availability & Cost of Propellants
- **Performance of Propellants:** Propellants can be compared on the basis of:

Specific Impulse (I_{sp}) (2-6)

$$I_{sp} = \frac{F}{\dot{m} * g_0}$$

Exhaust Velocity (v_e) (2-17)

$$v_e = I_{sp} * g_0$$

Characteristic Velocity (c*) (2-18)

$$c^* = \frac{p_1 * A_t}{\dot{m}}$$

F: Thrust Force

g_0: Gravity Constant

m(dot): Mass Flow Rate of Propellant

p_1: Chamber Pressure

A_t: Area at Throat

Other engine parameters: (f[illegible]nance parameters (Ch 4), chemical combination parameters (Ch 5), etc.)

Possible Propellant Hazards

- **Common Physical Hazards:**

Corrosion: Certain propellants can corrode when exposed to certain materials and produce a gaseous reaction product that can damage parts of the rocket

Explosion Hazards: Some propellants are unstable and will detonate under certain conditions of impurities, temperatures, and shock. Others may detonate immediately when exposed to an oxidizer

Fire Hazards: Many oxidizers will start a chemical reaction with organic compounds and/or exposed to air

Material Compatibility: Several propellants have only specific materials that can house the propellants properly

Health Hazards: Many propellants are poisonous in gaseous/liquid form on their own while others are harmful when reacting with an oxidizer; all above hazards can also cause harm if handled improperly

Elimination Process

- No toxic propellants
  - “Toxic propellants would require breathing apparatus, special storage and transport infrastructure, extensive personal protective equipment, etc.” - IREC Rules
- Cryogenic propellants
- Expensive/inaccessible
- Poor properties (melting/boiling point, corrosive, low energy density)
- Environmental concerns

Eliminated Propellants

- Hydrazine (all types)
  - Highly hazardous, violates competition rules
  - Toxic, spontaneous ignition in air, carcinogenic
  - High freezing point (34 F)
- Liquid Fluorine
  - Highly toxic, Highly reactive
  - Produces Hydrofluoric acid
- Liquid Hydrogen
  - Low boiling point (-423.2 F)
  - Expensive
  - Low shelf life

Eliminated Propellants Cont.

- Nitrogen Tetroxide
  - Used as Hydrazine oxidizer
  - Form strong acidic compounds when mixed with water
  - Highly toxic, carcinogenic
- Methane
  - Low boiling point (- 258.7 F)
  - Low flash point (- 306 F)
  - Small gap between boiling and freezing

Proton-M

- Russian made
- Hydrazine (UDMH)
- Nitrogen Tetroxide
- Reported to cause acidic rain after launch
- 115 launches, 9 failures
- May 14, 2012, failure 17 seconds after launch in Kazakhstan
- Created toxic cloud comprised of unspent fuel

Marder, Jenny. "Russian Rocket Explosion Releases Toxic Fuel Cloud." *PBS.com*. PBS, 3 July 2013. Web.

Top three fuels

Ethanol

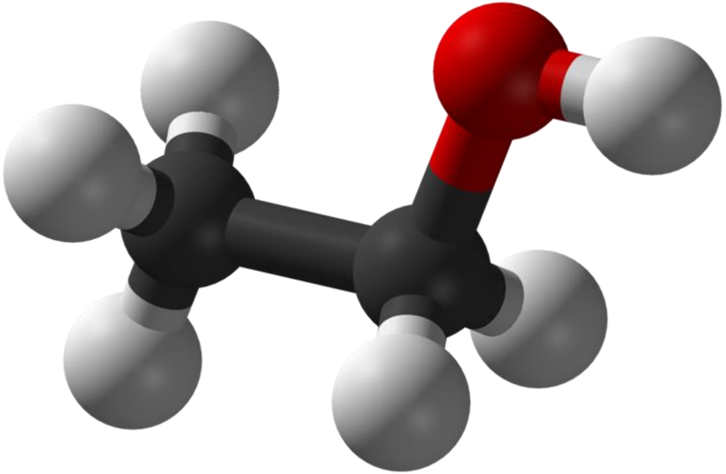
Kerosene

Gasoline

Ethanol

$C_2H_5OH + 3O_2 \text{ --> } 2CO_2 + 3H_2O$; $-\Delta H_c = 1236$ kJ/mol

Density: 0.789 g/cm^3
Melting Point: −114 °C
Flash Point: 16 °C
Specific Heat: 2.438 J/(g K)



http://en.wikipedia.org/wiki/File:Ethanol-3D-balls.png

V-2

LOX/Ethanol

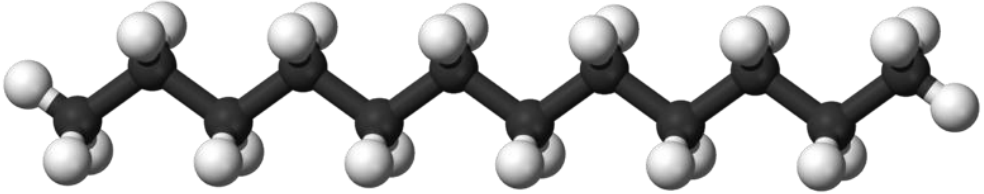
Led to development of PGM-11 Redstone

http://en.wikipedia.org/wiki/File:Fus%C3%A9e_V2.jpg

Kerosene

$2\ C_{12}H_{26}(l) + 37\ O_2(g) \rightarrow 24\ CO_2(g) + 26\ H_2O(g)$; $-\Delta H^\circ = 6{,}779$ kJ/mol (Approximate reaction)

Density: 0.81 g/cm^3
Melting Point: −43 °C
Flash Point: 58 °C
Specific Heat: 2.01 J/(g K)



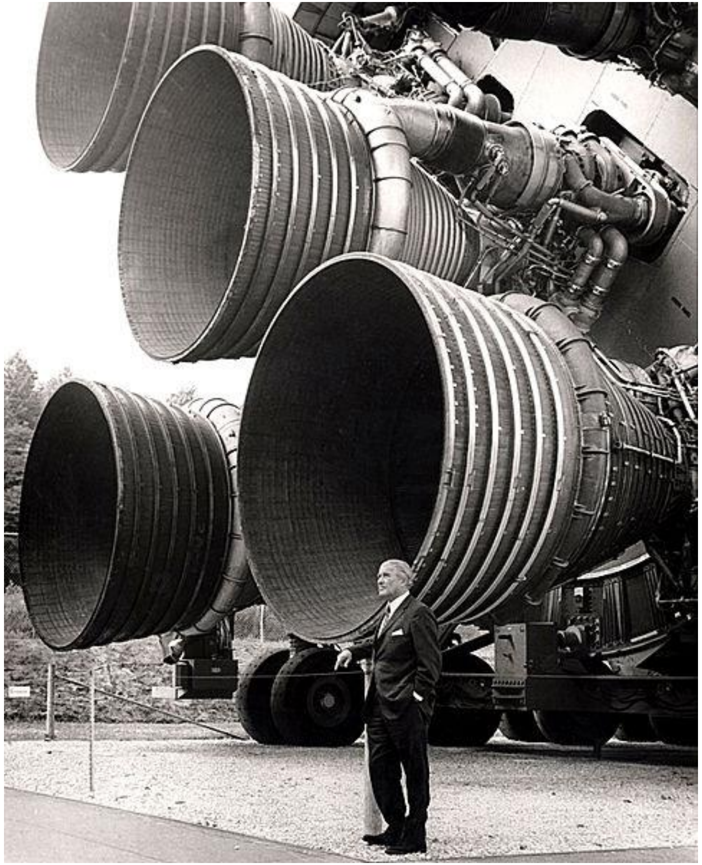
http://en.wikipedia.org/wiki/File:Dodecane-3D-balls-B.png

Rocketdyne F-1

Saturn V First Stage

LOX/Kerosene (RP-1)

Most powerful single-chamber liquid-fueled rocket engine ever developed

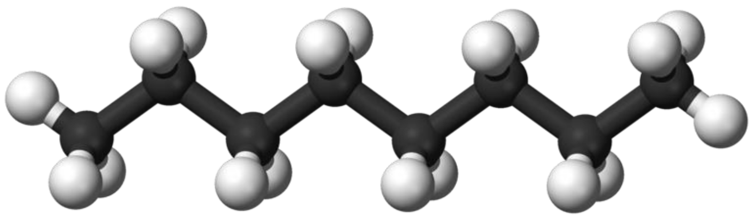


http://en.wikipedia.org/wiki/File:S-IC_engines_and_Von_Braun.jpg

Gasoline

$2\ C_8H_{18} + 25\ O_2 = 18\ H_2O + 16\ CO_2$; $-\Delta H^\circ = 5{,}074.9$kJ/mol

Density: 0.81 g/cm^3
Melting Point: −43 °C
Flash Point: 58 °C
Specific Heat: 2.22 J/(g K)



http://en.wikipedia.org/wiki/File:Octane-3D-balls-B.png

Nell

First liquid propellant rocket

LOX/Gasoline

http://en.wikipedia.org/wiki/File:Goddard_and_Rocket.jpg

Top three oxidizers

Hydrogen Peroxide

Gaseous Oxygen

Liquid Oxygen

Fuel Property Comparison

Fuel	ρ (g/cm³)	μ (Pa*s)	Flash (℃)	Auto (℃)	Boiling (℃)
Ethanol	0.789	0.001074	8.889	363	78
Kerosene	0.82	0.00075	43.33	220	177-187
Gasoline	0.726	0.0004	-42.8	257	26

Fuel Performance Comparison

Fuel	ΔH_c (kJ/mol)	r	c (m/s)*	F (N)*	Is (s)*
Ethanol	1236	2.1	3480.9	10791	354.8
Kerosene	6779	3.5	3442.2	15490	350.8
Gasoline	5075	3.2	3921.5	16471	399.7

* calculated based on a 1 kg/s mass flow rate of fuel
with η_c= 1, η_{int}= 0.7, η_p= 1

Final fuel selection

Fuel: Ethanol C_2H_5OH

- -Potential biofuel
- -low mixture ratio
- -good specific impulse

Oxidizer: Gaseous Oxygen O_2

- -easy to obtain and store
- -can be pressurized
- -does not decompose

History

Viking Sounding Rockets

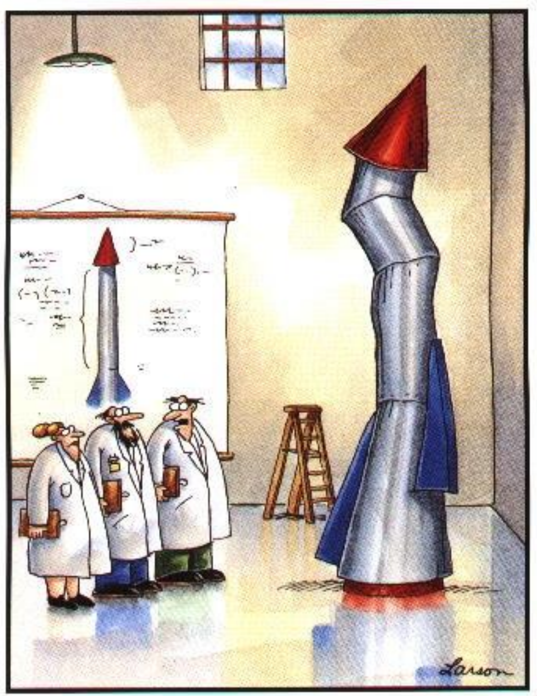
http://en.wikipedia.org/wiki/Viking_%28rocket%29

XS-1

http://www.aerospaceweb.org/aircraft/research/x1/

Summary and Next Steps

1. Fuel Selection
2. System Selection
3. Maths
4. Combine math
5. Try and connect the math to reality



"It's time we face reality, my friends. ...
We're not exactly rocket scientists."

http://imgarcade.com/1/science-comic-larson/