COLLEGE OF ENGINEERING

Chemical, Biological & Environmental Engineering

HYBRID ROCKET FUEL DEVELOPMENT

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Opportunity

The hybrid rocket team at OSU requires an effective fuel for use in its hybrid rocket.

Objective

- Formulate and test five to ten solid fuel compositions and collect thrust and impulse data
- Select one full-scale fuel grain for the full-scale rocket based on composition performance

Background

Hybrid Rocket Main Sections:

- Oxidizer: Liquid nitrous oxide (N_2O) is a self-pressurizing oxidizer for hybrid rockets
- Fuel grain: A solid, wax-based material that reacts with NO_2 to produce thrust
- Nozzle: Products of the reaction are propelled quickly as exhaust

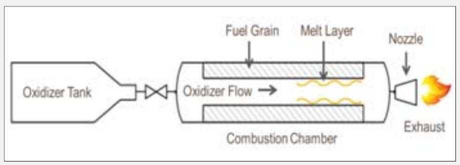


Figure 1. Basic components of a hybrid rocket. Oxidizer flows through the combustion chamber, reacts with the fuel grain, and exits through the nozzle.

Fuel Grain Components:

- Paraffin: Wax that produces a "melt layer," increasing burn rate (Figure 2)
- Lithium aluminum hydride ($LiAlH_4$): Strong reducing agent used to increase thrust
- Aluminum powder (Al): Energetic additive currently used in OSU hybrid fuels
- Ethylene-vinyl acetate copolymer (EVA): increases viscosity and ensures all fuel burns in the combustion chamber

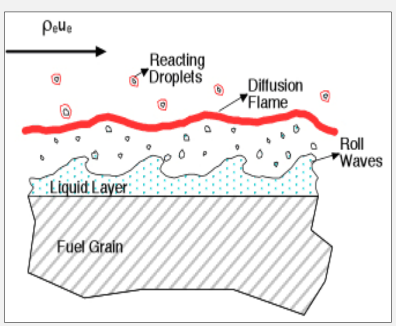


Figure 2. The melt layer, or liquid layer, produces droplets that increase the surface area of the fuel grain.

Chemistry Background

Each fuel component forms products upon reaction with nitrous oxide. Reactions for aluminum, lithium aluminum hydride, paraffin, and ethylene-vinyl acetate copolymer are:

$$2Al + 3N_2O \rightarrow Al_2O_3 + 3N_2$$

$$2LiAlH_4 + 8N_2O \rightarrow 8N_2 + 3H_2O + Al_2O_3 + 2LiOH$$

$$C_{31}H_{64} + 94N_2O \rightarrow 31CO_2 + 32H_2O + 94N_2$$

$$C_{22}O_2H_{42} + 63N_2O \rightarrow 22CO_2 + 21H_2O + 63N_2$$

Energies of reaction can be calculated using enthalpies of formation:

$$H_{RXN} = \sum \Delta_f H^o{}_{Products} - \sum \Delta_f H^o{}_{Reactants}$$

Compound	ΔH_f (kJ/mole)
N_2O (g)	81.6
Al (s)	0
$LiAlH_4$ (s)	-116.3
Paraffin (s)	-1588.4
EVA_{10} (s)	-881.3
N_2 (g)	0
H_2O (g)	-241.8
Al_2O_3 (s)	-1675.7
LiOH (s)	-484.9
CO_2 (g)	-393.5

The following energies of reaction were calculated for each fuel component:

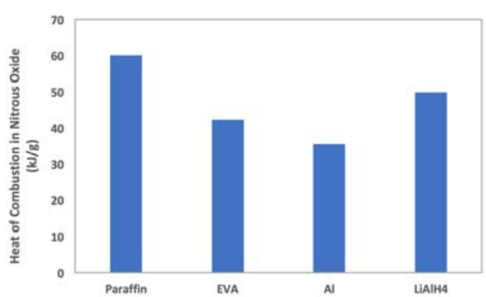


Figure 3. Paraffin wax shows the greatest energy of reaction with the oxidizer, followed by $LiAlH_4$. Both are key components of the fuel grain.

Materials and Methods

Fuel grains cylinders five inches long with one inch inner diameters were made. Paraffin was used as the main component with either 5μm aluminum powder added or lithium aluminum hydride, $LiAlH_4$. Ethylene-vinyl acetate, EVA, was also added to increase viscosity. Fuel compositions are below:

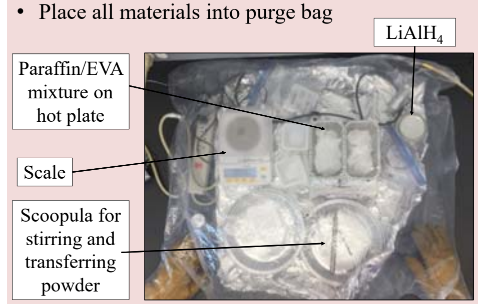
Paraffin	EVA	Aluminum	$LiAlH_4$
100	0	0	0
75	5	20	0
70	10	20	0
65	15	20	0
60	20	20	0
90	10	0	5
85	10	0	10
80	10	0	15
75	10	0	20

Adding aluminum:

- Weigh individual components
- Melt paraffin/EVA mixture in baking tin
- Remove from heat
- Add 5μm aluminum powder and stir
- Allow mixture to cool and solidify

Adding $LiAlH_4$:

- Weigh paraffin/EVA
- Place all materials into purge bag



- Fill purge bag with nitrogen
- Weigh $LiAlH_4$ in purge bag
- Melt paraffin/EVA mixture
- Remove from heat
- Allow mixture to cool below 100°C
- Add $LiAlH_4$ to molten mixture
- Allow to cool and solidify
- Neutralize excess $LiAlH_4$ with ethyl acetate
- Remove all items from purge bag

Testing Fuel Grains

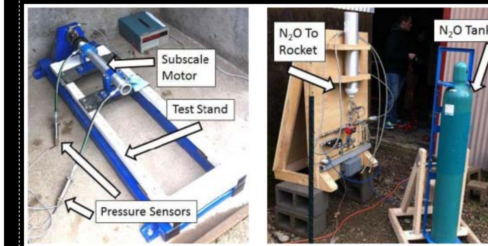


Figure 4. The fuel grains will be tested on a subscale motor at the OSU Propulsion Lab on the test stand above.

Collect:

- Thrust (N) vs. time (s) data
- Impulse (N·s) data: integral of thrust over time
- Specific impulse (N·s)/kg: impulse per unit of fuel

Determine:

- Fuel composition with highest specific impulse
- EVA composition with highest specific impulse and most fuel burned
- Energy efficiency compared to theoretical energy calculations

Conclusions To Date

Compositions of lithium aluminum hydride and ethylene-vinyl acetate in a paraffin wax fuel base will be tested on a subscale motor. Lithium aluminum hydride compositions have a higher energy content per mass than aluminum compositions.

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