FINAL DESIGN REVIEW
SOLID FUEL DESIGN AND PERFORMANCE

CALIFORNIA STATE UNIVERSITY LOS ANGELES

MAY 6, 2021

ADVISOR: JEFFREY SANTNER
CLIENT: CSULA EAGLE ROCKETRY TEAM

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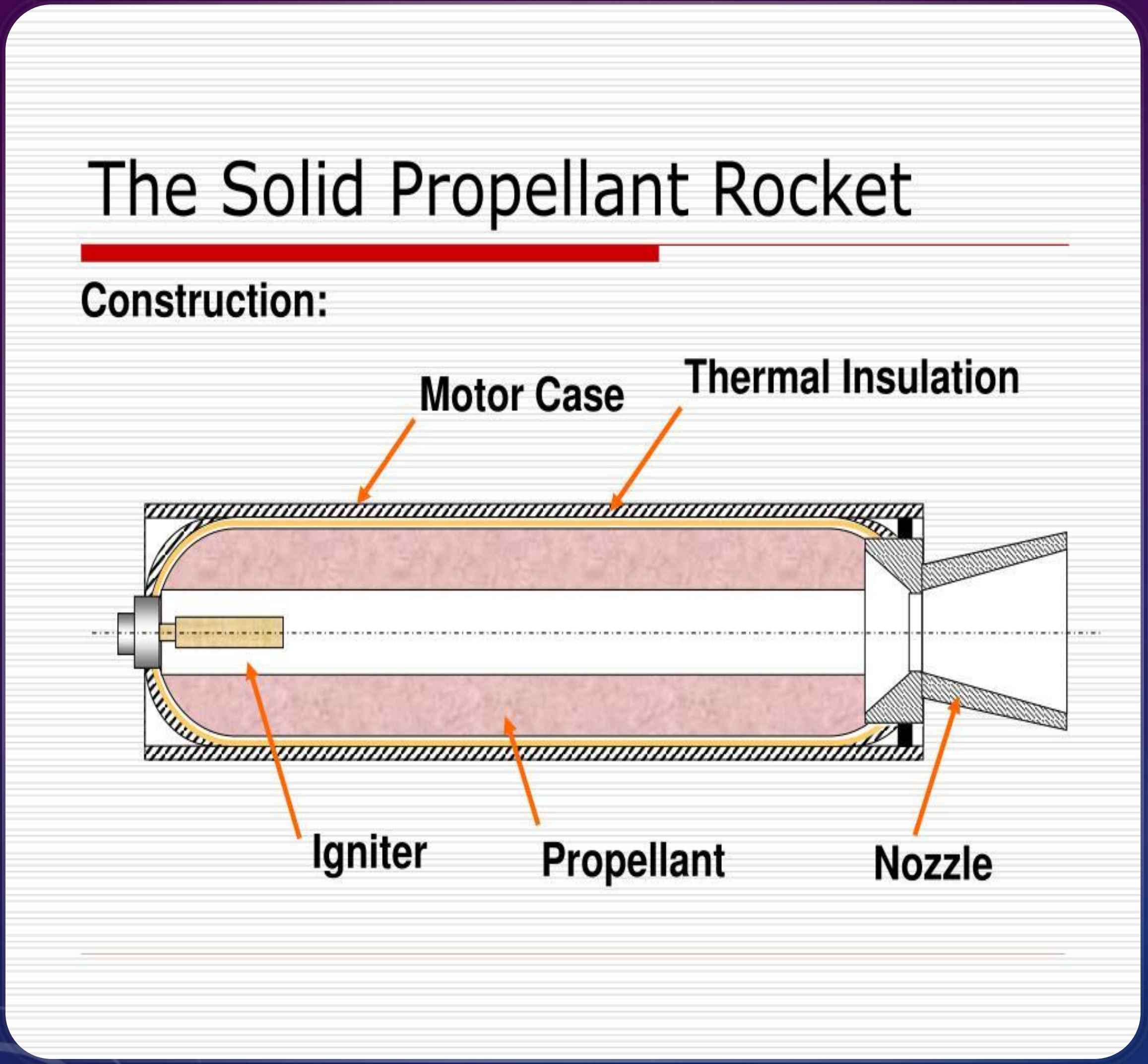
AGENDA

1. Background
2. Fuel Team | Jennifer & Jana
    - Composition of solid fuel
    - Fabrication Process
    - Results from simulation software
3. Test Stand & Fuselage Team | Aldo, Jacquelyn, and Steven
    - Test stand design and manufacturing process
    - Data Acquisition and ignition system
    - Fuselage design and manufacturing process
4. Future Work
5. Conclusion



BACKGROUND

- Solid Rocket Motor: Solid propellant (fuel/oxidizer), motor casing, nozzle & igniter
- The Chinese developed and used for warfare in 13th century
- Presently used in military armaments, model rockets & solid rocket boosters
- NASA SRB 1st solid propellant rocket used for primary propulsion on a vehicle used for human space flight [1], [2]

PROBLEM

REQUIREMENTS

- Improve Eagle Rocketry solid fuel propellant
- Make several fuel recipes for non-destructive testing
- Determine manufacturing process that best fits our situation
- Design a reliable, reusable and safe fuselage & test stand
- Design a data collection system to measure thrust & burn rate
- Create and implement an ignition system to ignite the rocket fuel

DELIVERABLES

Fuel Team

- Understanding of solid fuel
- Create 5 or more recipes depending on variables being tested
- Determine manufacturing methods
- Nondestructive testing
- Run software simulations

Test Stand & Fuselage Team

- Design a safe and secure stand
- Design the fuselage to be reusable
- Improve original design of the fuselage to fit a factor of safety
- Create an ignition system that simultaneously collects thrust and burn time during testing
- Hydrostatic & static fire test’s

SOLID FUEL

JENNIFER RIVELLO

JANA RAMIREZ

ALDO SOLIS

TYPES OF COMPOSITE SOLID FUEL

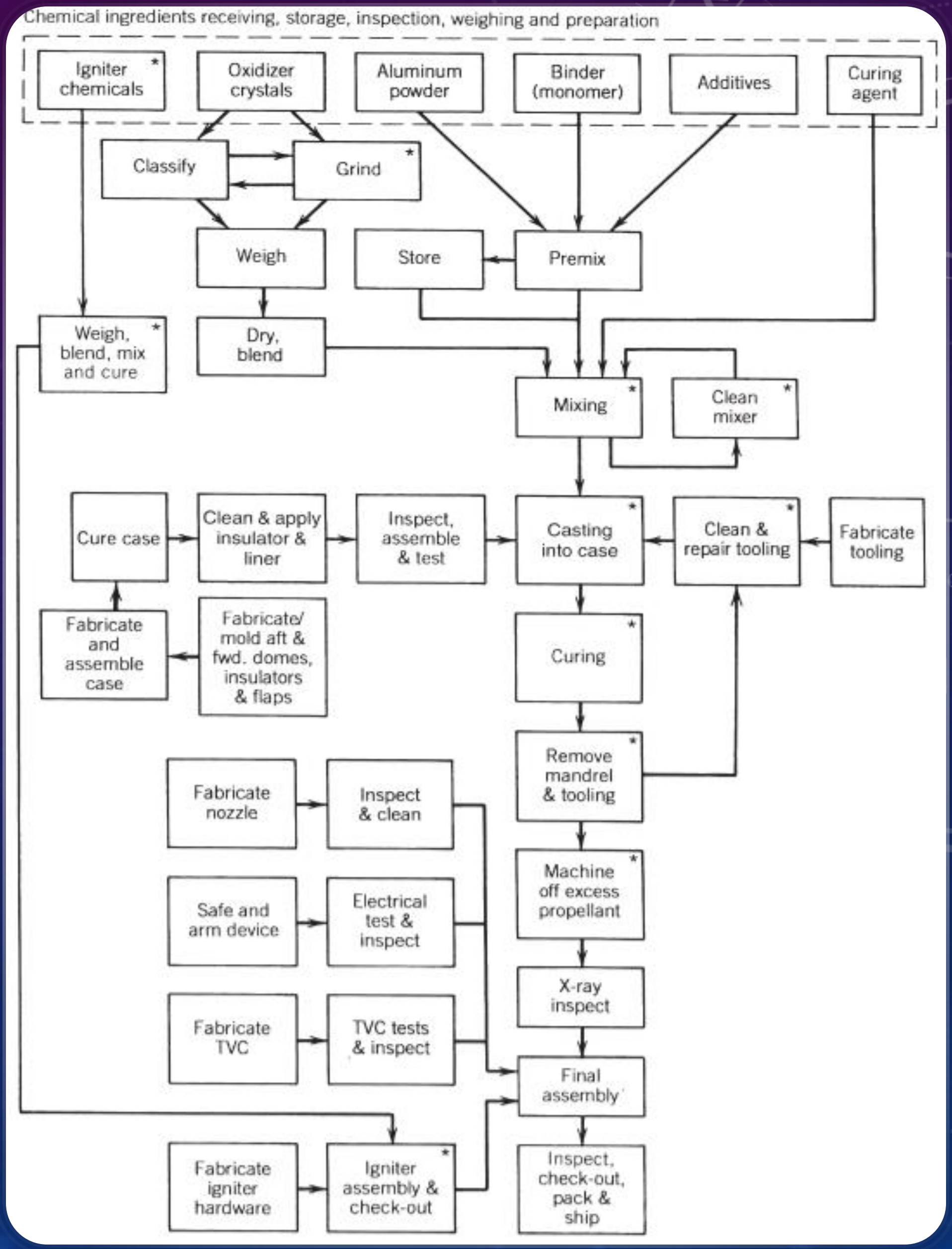
- Two different types
  - Aluminum Powered
    - Fuel is aluminum powder
    - Oxidant is Ammonium Perchlorate
  - Black Powder Rocket
    - Fuel is Carbon
    - Oxidant is Potassium Nitrate

MANUFACTURING SOLID FUEL

- Free-standing grains for cartridge loading
- Process takes a few days
- Fuel case mold will be cardboard
- Done under a fume hood, in vacuum to remove air and other gases

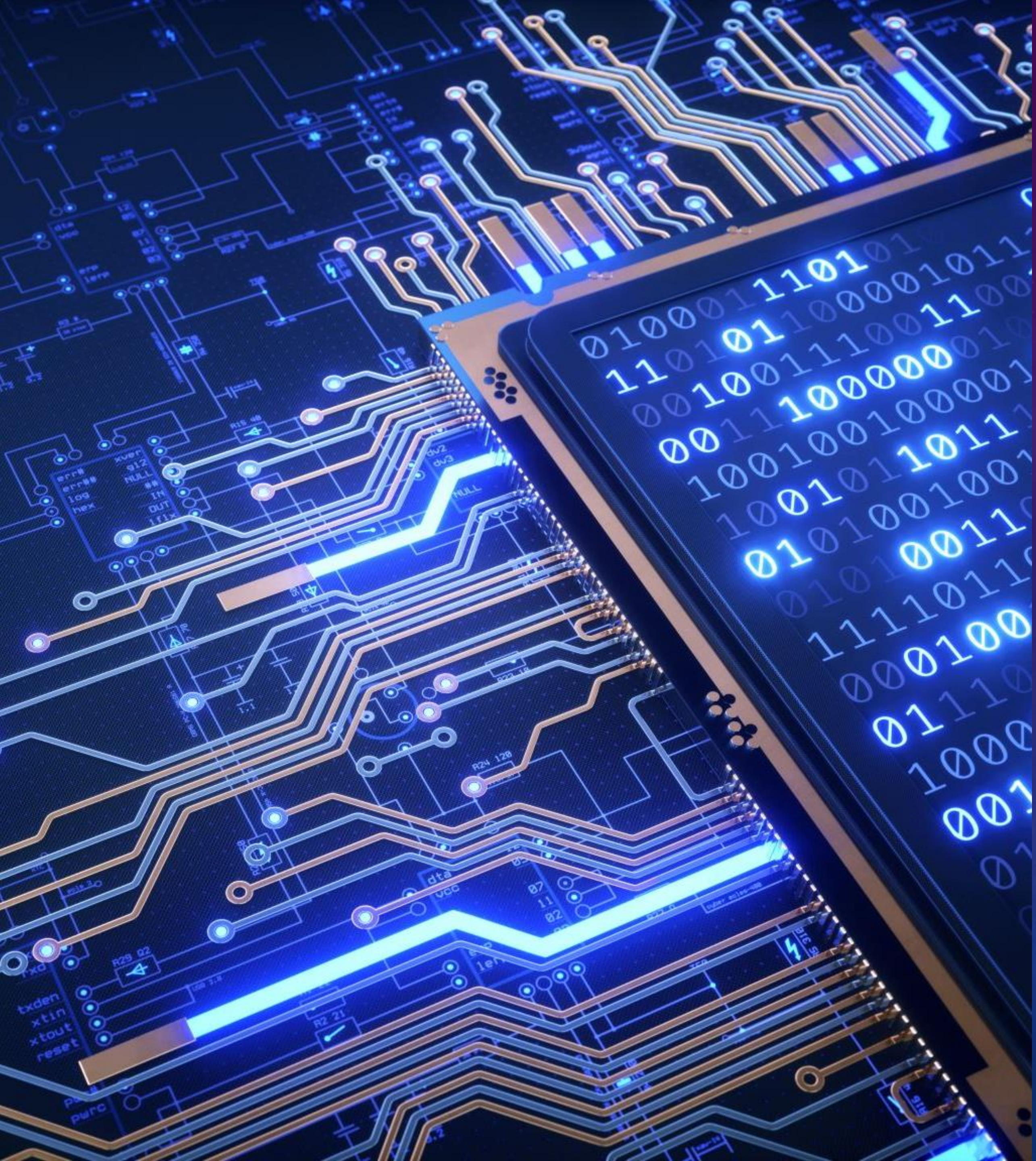
GENERAL PROCEDURE

- Mixing
  - Premix in a standing mixer, vary mixing times to test outcomes
  - Mix to an extrudable dough consistency
- Casting
  - Pour propellant into mold



GENERAL PROCEDURE CONTINUED

- Curing
  - Cure in a fume hood and store in a room for 1-2 days around 80 F.
  - Curing in vacuum is best to rid the fuel of bubbles and voids.
- An important objective in processing is to produce a propellant grain free of cracks, low-density areas, voids, or other flaws.



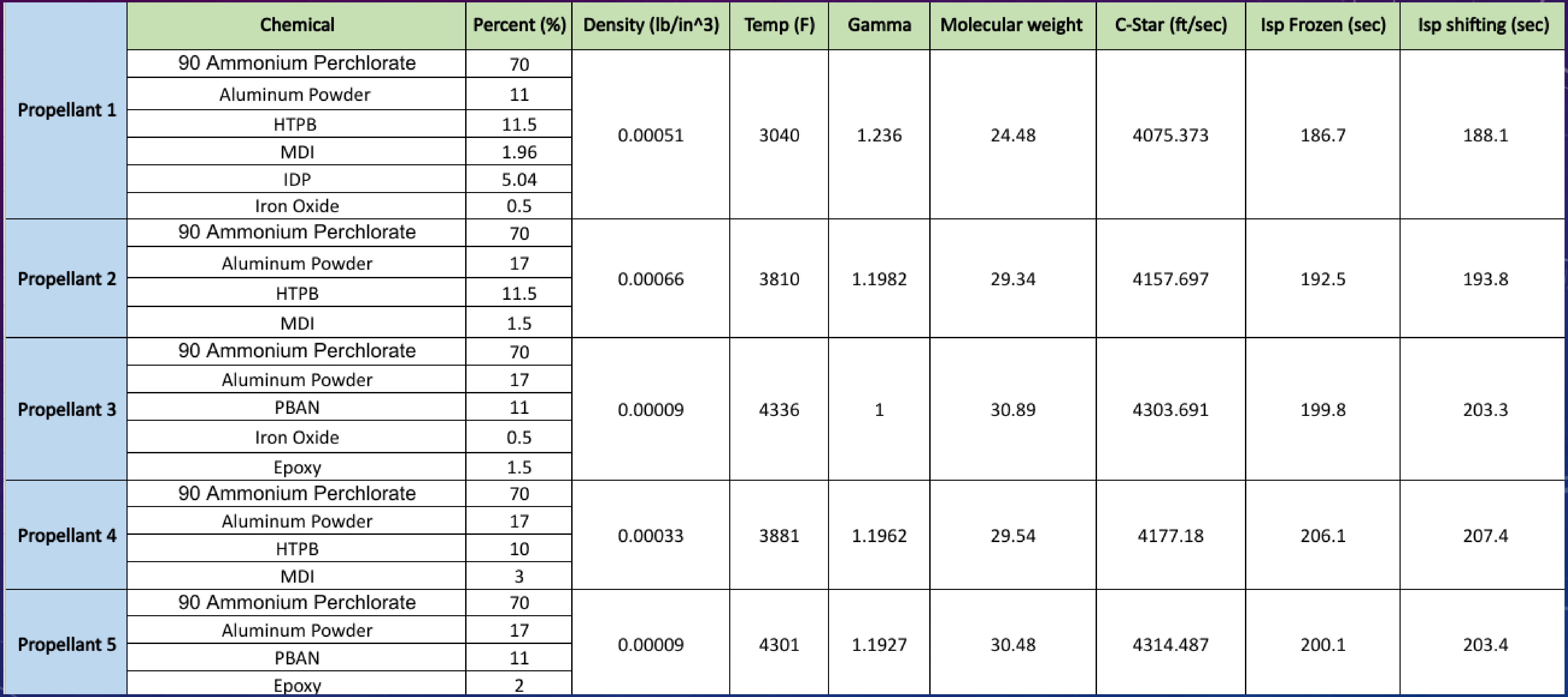
SIMULATION SOFTWARE

- Searched for a simulation software for solid fuels
- CHEM Thermochemistry Software
    - Able to simulate our solid propellants
    - Output values such as c-star, flame temperature, and density
- ChemKin
    - Used software to determine adiabatic flame temperature and equilibrium pressure
    - Compared results to simulation software

FUEL FORMULAS

		Mass Fractions of Each Chemical Ingredient (%)				
Chemical	**Purpose**	**Fuel 1**	**Fuel 2**	**Fuel 3**	**Fuel 4**	**Fuel 5**
Ammonium Perchlorate (AP)	Crystal Oxidizer	70	70	70	70	70
Aluminum Powder	Metal Fuel	11	17	17	17	17
Hydroxyl-Terminated Polybutadiene (HTPB)	Binder	11.5	11.5	0	10	0
Polybutadiene Acrylonitrile (PBAN)	Binder	0	0	11	0	11
Liquid Polyisocyanate (MDI)	Curing Agent	1.96	1.5	0	3	0
Epoxy Resin	Curing Agent	0	0	1.5	0	2
Iron (II) Oxide	Burn Rate Modifier	0.5	0	0.5	0	0
Isodecyl Pelargonate (IDP)	Plasticizer	5.04	0	0	0	0

CHEM THERMOCHEMISTRY SIMULATION RESULTS



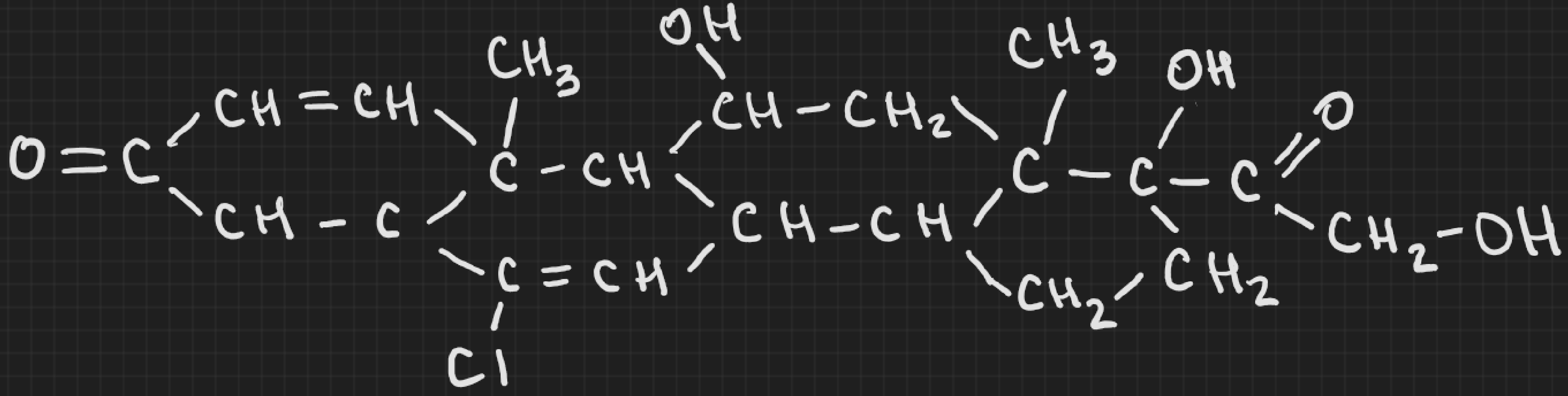
	Chemical	Percent (%)	Density (lb/in^3)	Temp (F)	Gamma	Molecular weight	C-Star (ft/sec)	Isp Frozen (sec)	Isp shifting (sec)
Propellant 1	90 Ammonium Perchlorate	70	0.00051	3040	1.236	24.48	4075.373	186.7	188.1
	Aluminum Powder	11							
	HTPB	11.5							
	MDI	1.96							
	IDP	5.04							
	Iron Oxide	0.5							
Propellant 2	90 Ammonium Perchlorate	70	0.00066	3810	1.1982	29.34	4157.697	192.5	193.8
	Aluminum Powder	17							
	HTPB	11.5							
	MDI	1.5							
Propellant 3	90 Ammonium Perchlorate	70	0.00009	4336	1	30.89	4303.691	199.8	203.3
	Aluminum Powder	17							
	PBAN	11							
	Iron Oxide	0.5							
	Epoxy	1.5							
Propellant 4	90 Ammonium Perchlorate	70	0.00033	3881	1.1962	29.54	4177.18	206.1	207.4
	Aluminum Powder	17							
	HTPB	10							
	MDI	3							
Propellant 5	90 Ammonium Perchlorate	70	0.00009	4301	1.1927	30.48	4314.487	200.1	203.4
	Aluminum Powder	17							
	PBAN	11							
	Epoxy	2							

USING CHEMKIN

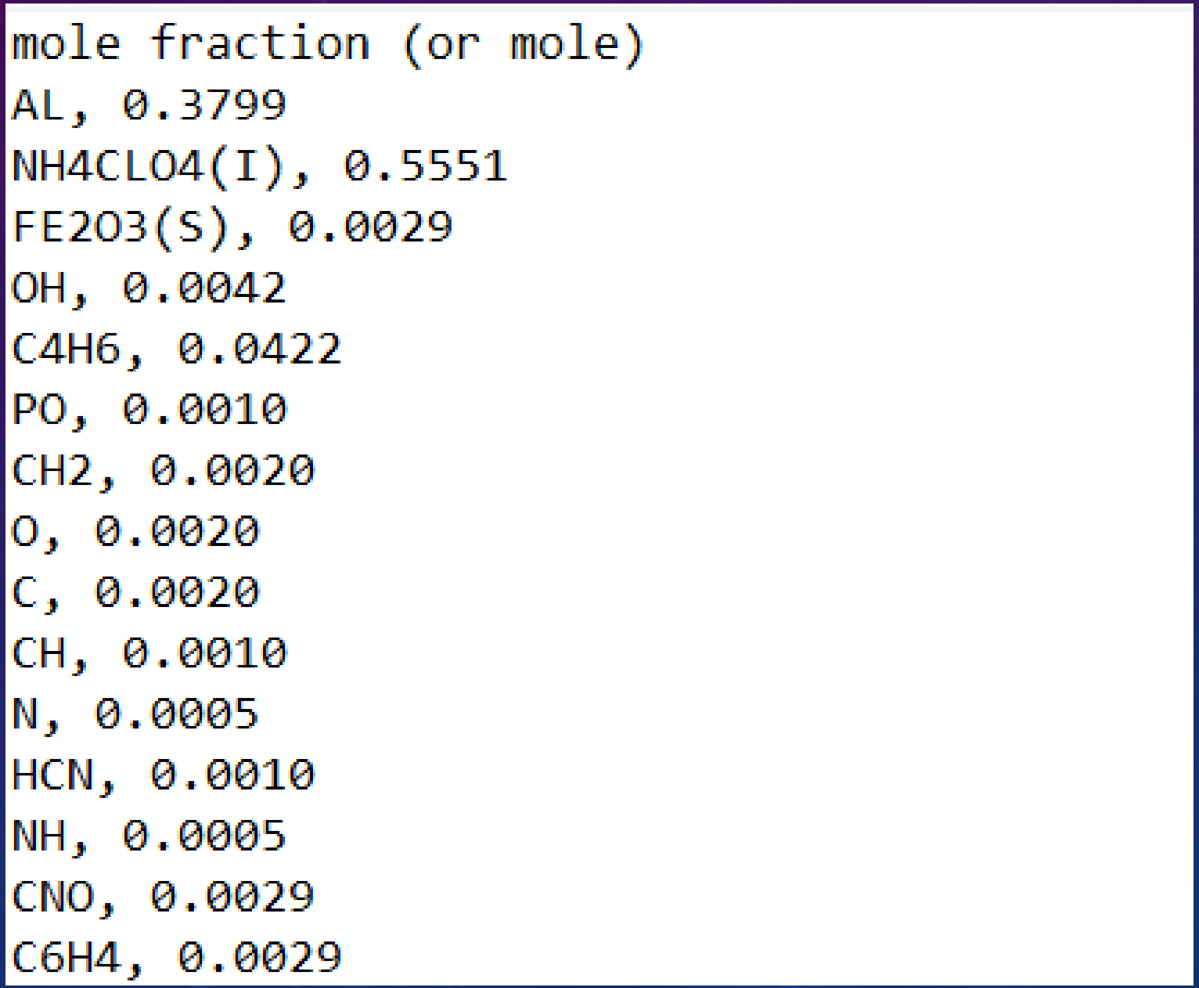
- Thermodynamic data not available for HTPB, PBAN, MDI, Epoxy, and IDP
    - These chemicals had to be broken down into smaller species whose data were available
- Assumed initial conditions and guessed equilibrium conditions
    - Initial: 300 K (~ room temperature); equilibrium: (1500 K)
    - Initial: atmospheric pressure (14.7 PSI); equilibrium: (1000 psi)
- Molar fraction of each chemical species imported through a text file

EPOXY RESIN

Epoxy - $(CH)_8(CH_2)_4(CH_3)_2(OH)_3(CCl)C_6O_2$



MOLAR FRACTION INPUT FILE



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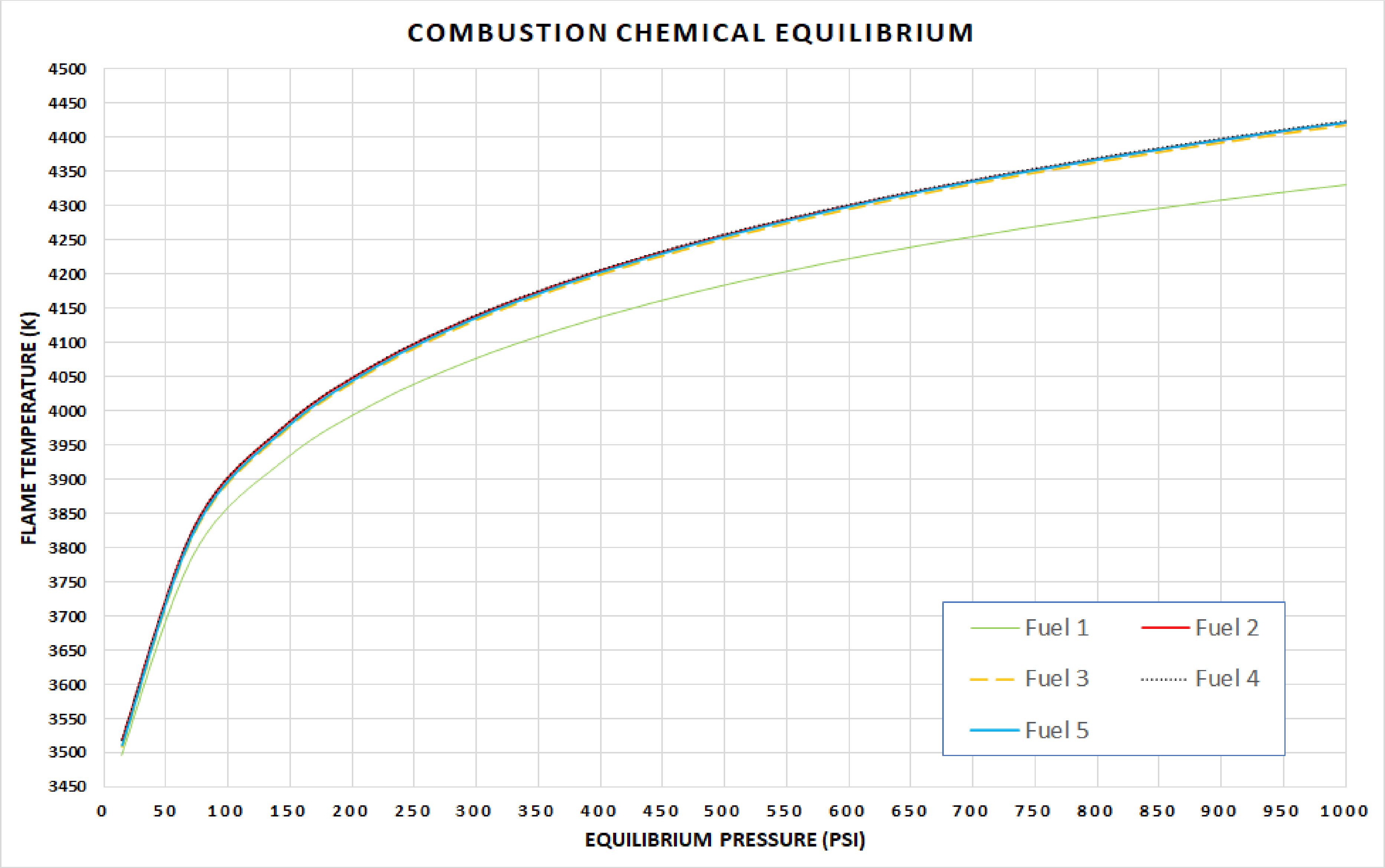
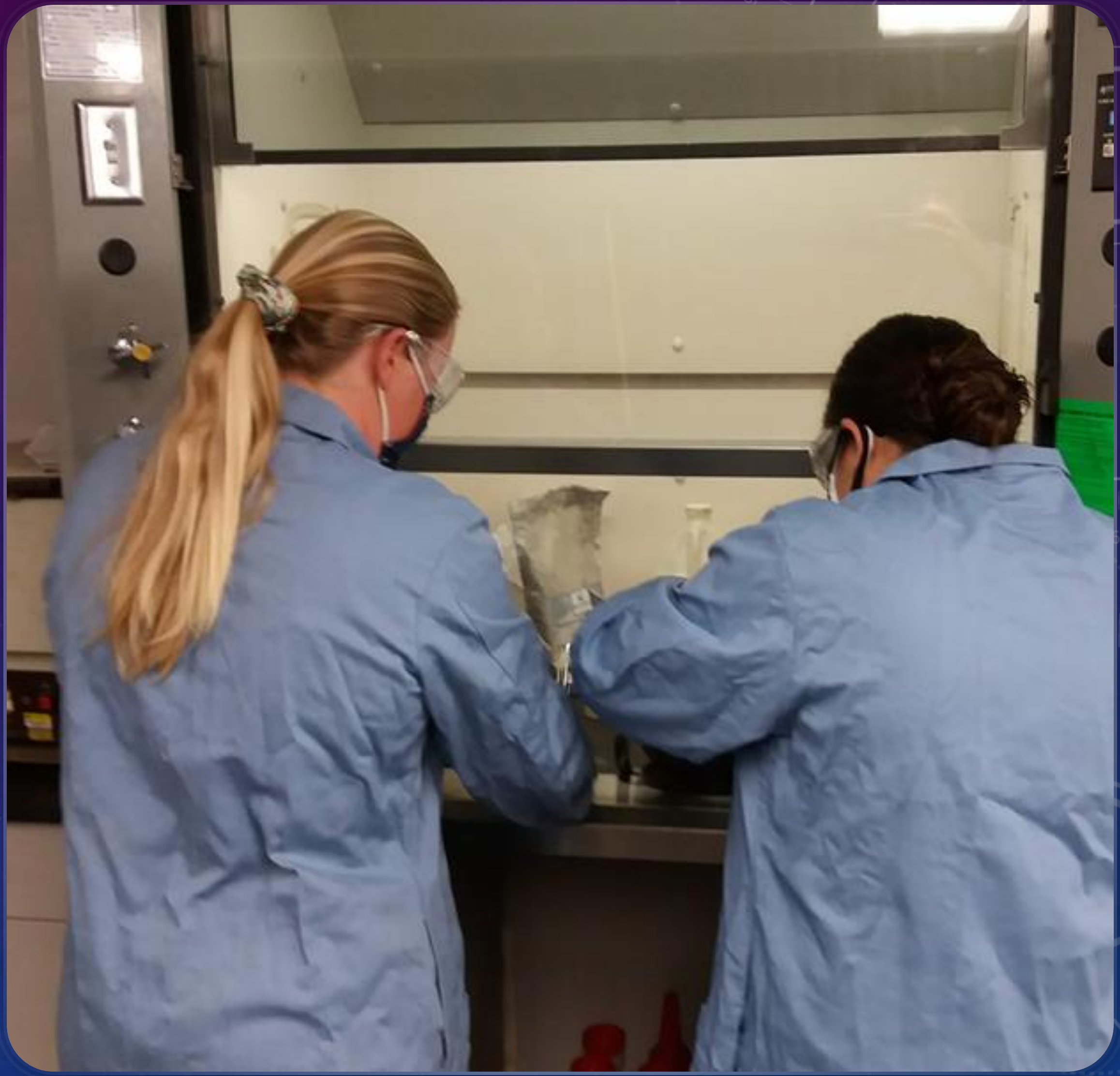
mole fraction (or mole)
AL, 0.3799
NH4CLO4(I), 0.5551
FE2O3(S), 0.0029
OH, 0.0042
C4H6, 0.0422
PO, 0.0010
CH2, 0.0020
O, 0.0020
C, 0.0020
CH, 0.0010
N, 0.0005
HCN, 0.0010
NH, 0.0005
CNO, 0.0029
C6H4, 0.0029
```

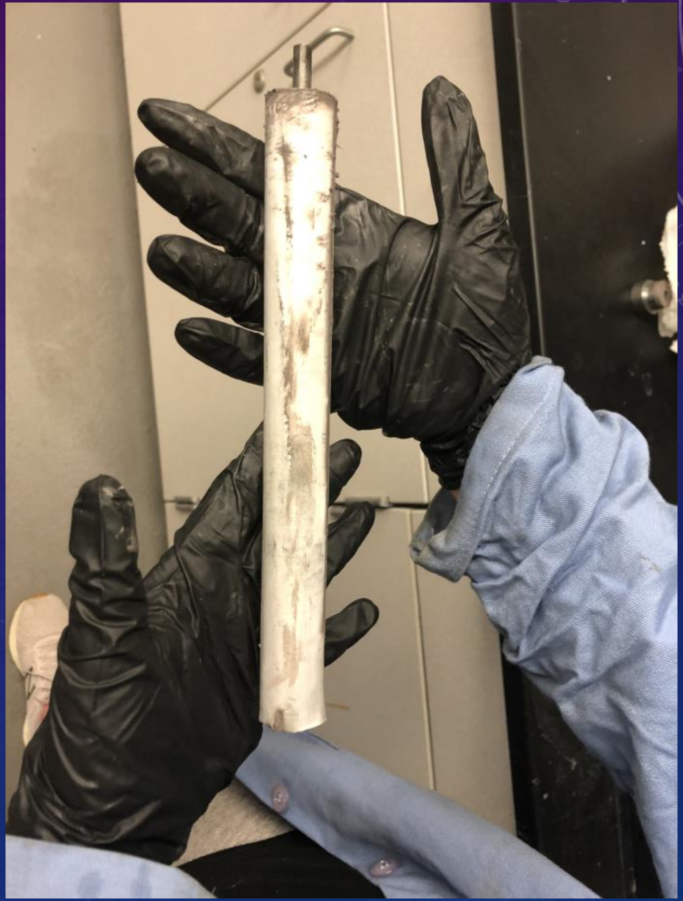
CHEMKIN SIMULATION RESULTS



ON CAMPUS

- It was decided to manufacture fuel 1 and 2 because we wanted to use iron oxide in one of them.
- Each chemical was weighed on a digital scale.
- Dry ingredients were mixed first, then wet ingredients were added to the dry mixture.
- It was mixed to a dough consistency, and then poured into the fuel mold.





TEST STAND & FUSELAGE TEAM

STEVEN MORA
JACQUELYN RADER
ALDO SOLIS

TEST STAND

TEST STAND

- Purpose: provide a structure to safely ignite the rocket and measure its static thrust
- Design and manufacture a reliable and reusable test stand

ROCKET TEST STAND DESIGN

Rocket Motor Housing

- 12" Threaded Aluminum Pipe
- OD = 1.315" & ID = 1.25"

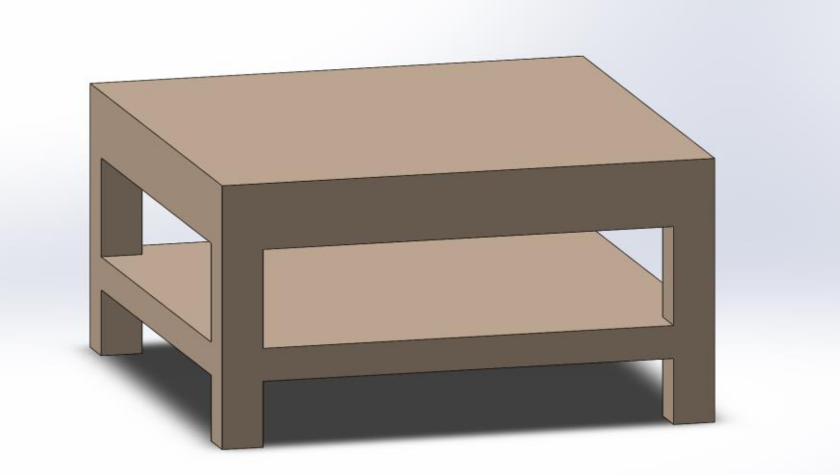
Base for Housing

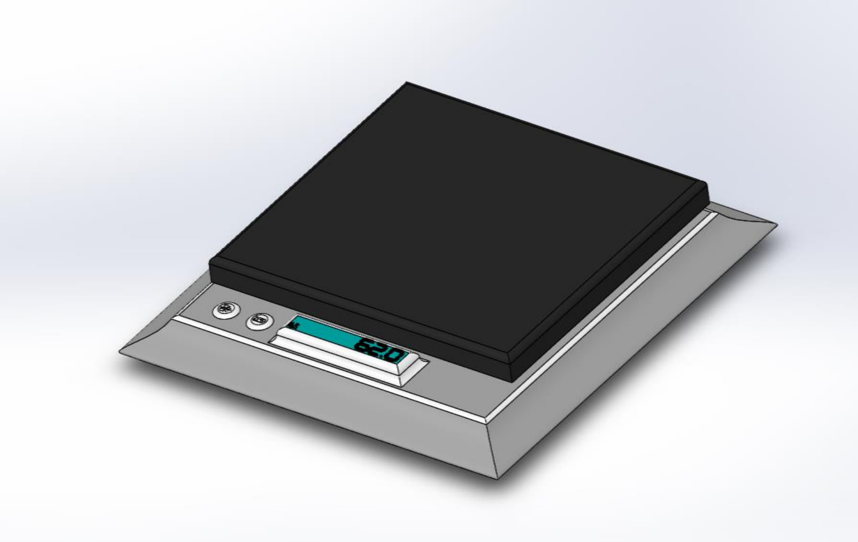
- Threaded Aluminum Pipe Flange
- OD = 4.25"

ROCKET TEST STAND DESIGN

Table

- 12" x 12" x 6" wooden table
- Top level – rocket motor housing
- Lower level – digital weight scale

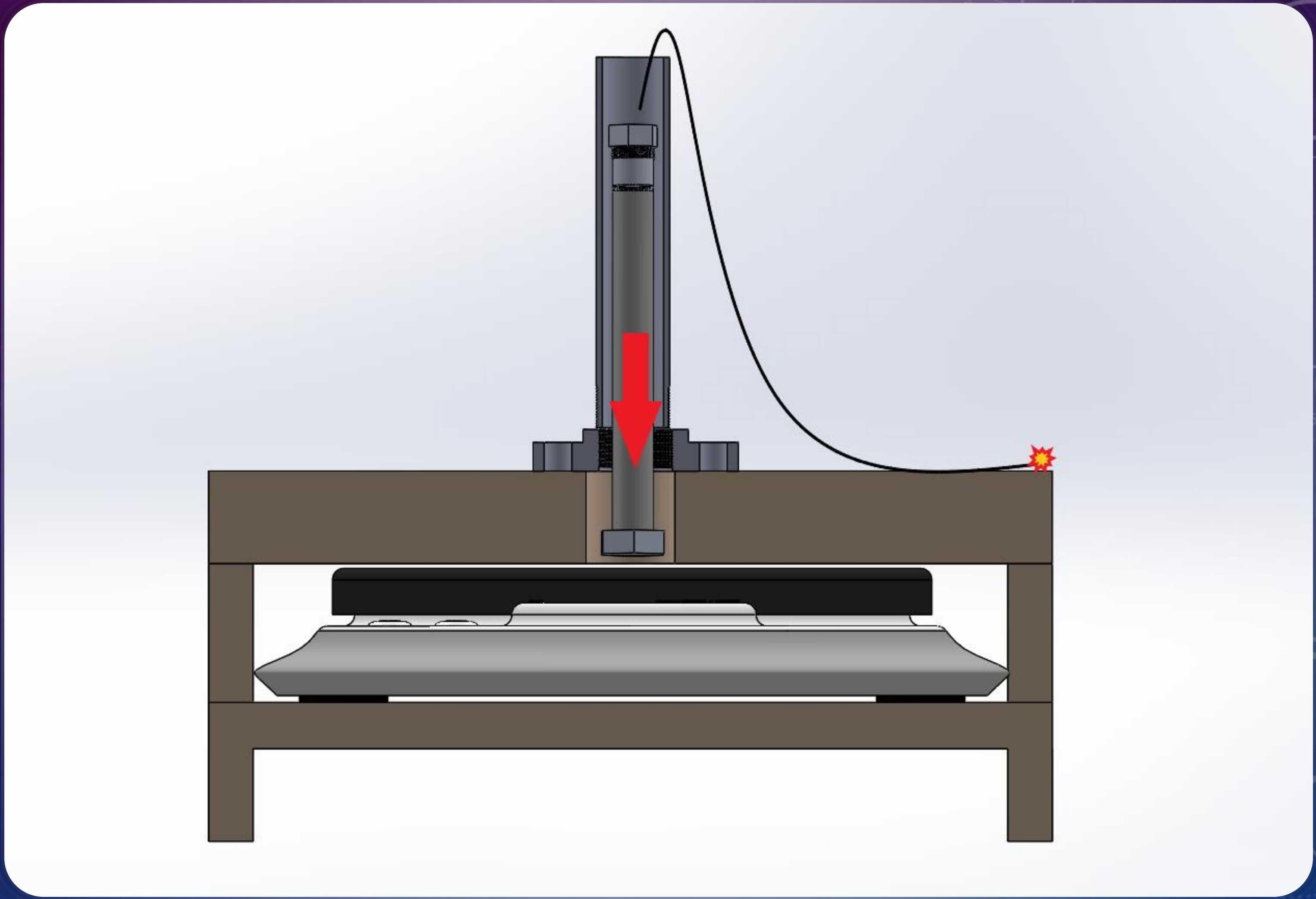




Digital Weight Scale

- 70lb capacity (expected 30-45lbf of thrust)
- Estimated size of 12" x 12" x 3"

TEST STAND ASSEMBLY



THRUST & IGNITION

THRUST MEASURING SYSTEM

- A scale will be used to record the amount of force the rocket produces.
- A camera will record the force in real time
- Goal is to plot thrust vs time to find optimal chemical composition of solid fuel recipes

IGNITION SYSTEM

Materials:

Nichrome wire

Masking tape

Aero gloss

Paper clip

scissors

Wrap nichrome wire around paper clip

Secure shape with masking tape

Cover tip in aero gloss to create insulation

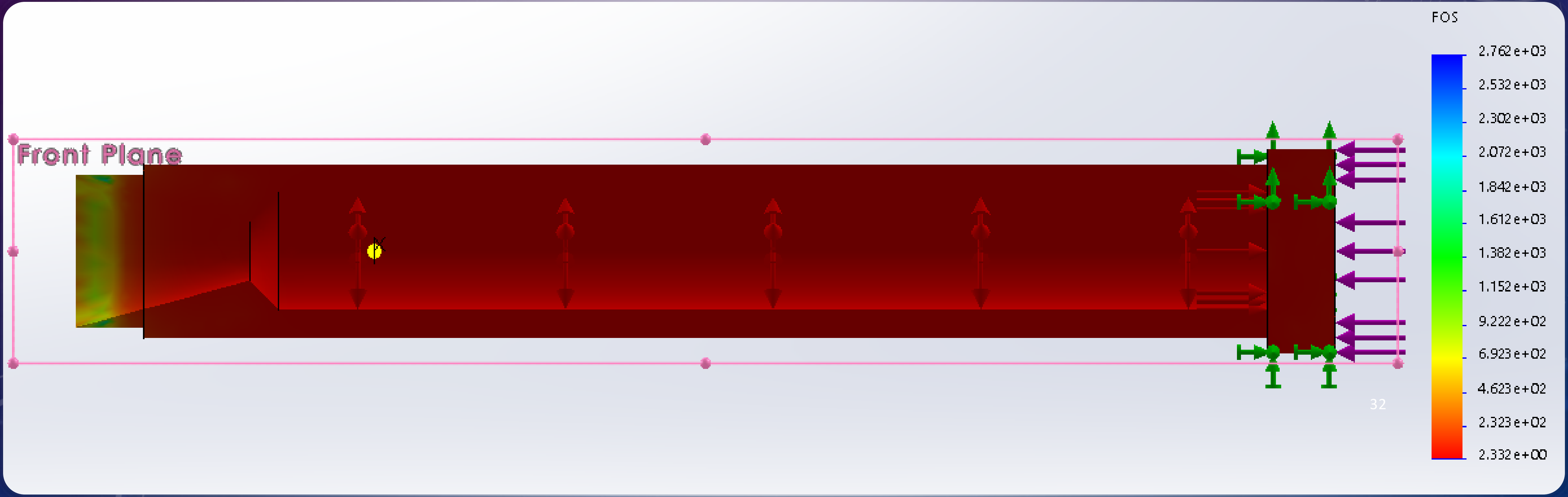
Place wiring in nozzle and secure with tissue

- Goal is to have a protruding wire long enough for safe ignition

FUSELAGE ASSEMBLY

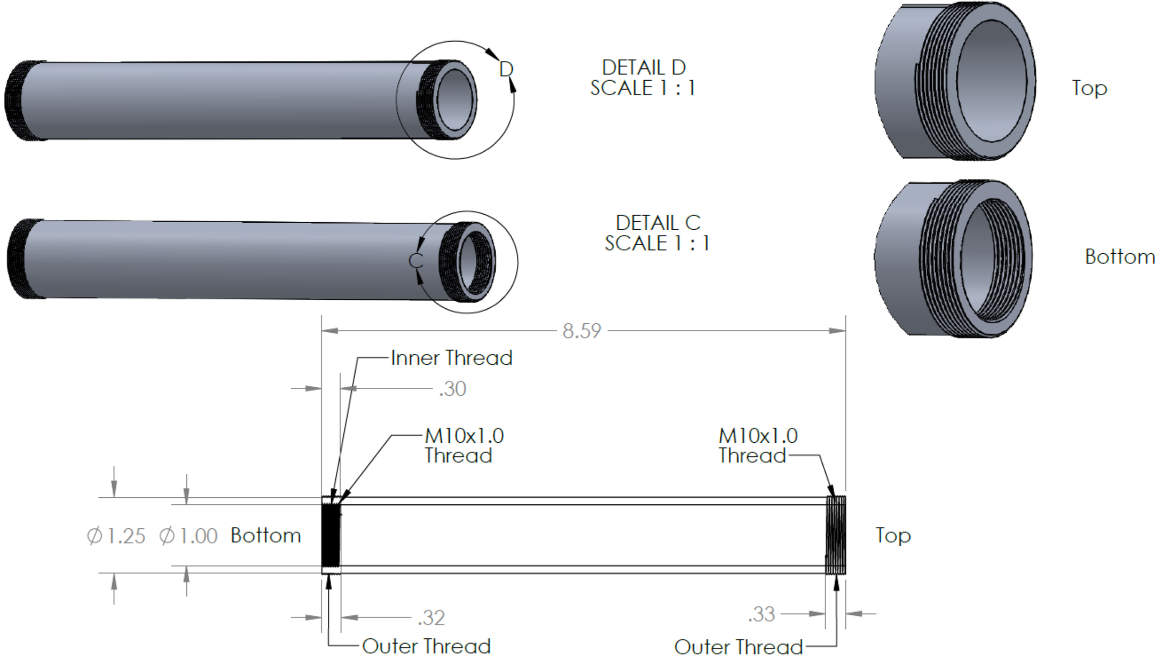
FUSELAGE ANALYSIS

- SolidWorks: Static Pressure Test | Pressure: 1000 Psi| Force: 100 lbf | Fixed End: Top Nose



FUSELAGE

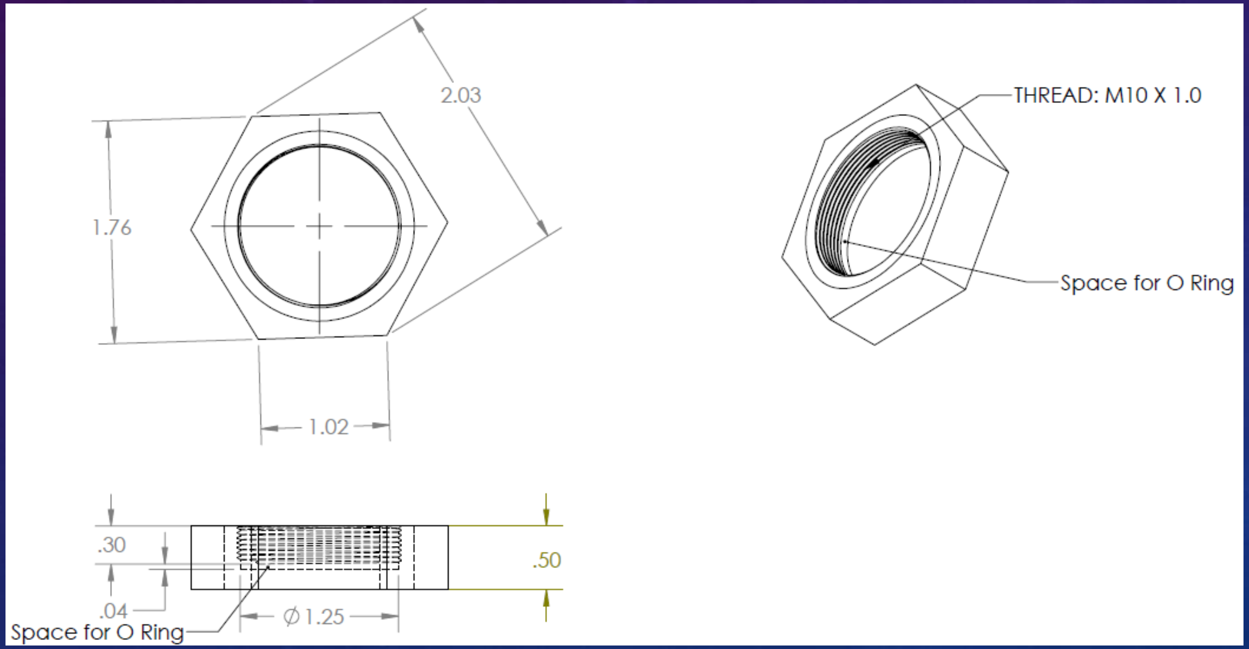
Design



Product

BULKHEAD

Design



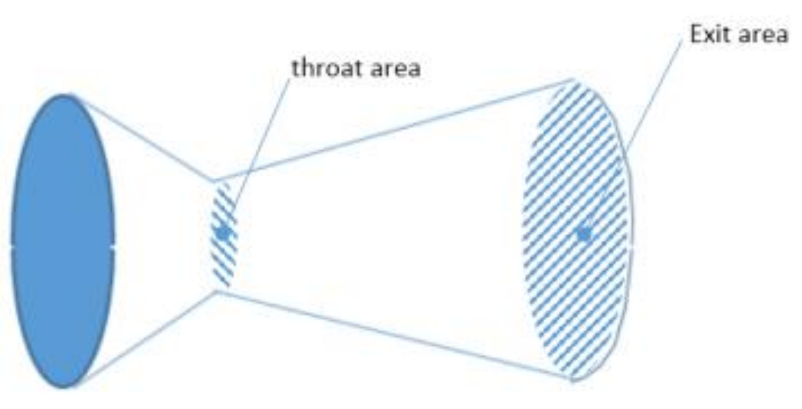
Product


Bulkhead

NOZZLE GEOMETRY

- **Optimum Expansion Ratio**

$$\frac{A_{Throat}}{A_{exit}} = \left(\frac{k+1}{2}\right)^{\frac{1}{k-1}} \left(\frac{P_e}{P_o}\right)^{\frac{1}{k}} \sqrt{\left(\frac{k+1}{k-1}\right)\left[1-\left(\frac{P_e}{P_o}\right)^{\frac{k-1}{k}}\right]}$$



- **Assumptions**
  - *K : ratio of specific heats = 1*
  - *Pe = 1 atm*
  - *Po = 64 atm*

- **Result**
- Optimum Expansion Ratio$= \frac{A_{exit}}{A_{Throat}} = \frac{1}{\frac{A_{Throat}}{A_{exit}}}$ = 7.3127

NOZZLE GEOMETRY

- *Nozzle Exit Diameter*

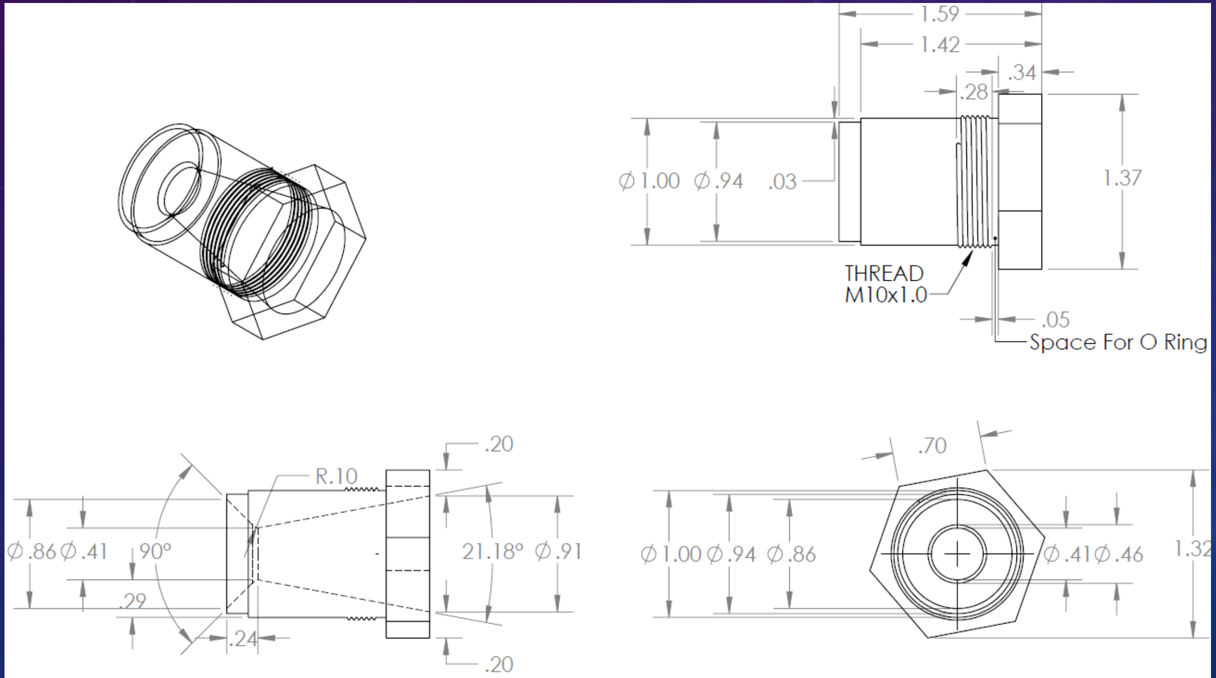
$$D_{exit} = \sqrt{\frac{4\left(\frac{A_{exit}}{A_{Throat}}\right)A_{Throat}}{\pi}}$$

- $D_{throat} = .40\ inches$
- $\frac{A_{exit}}{A_{Throat}}$ = 5
- A_{Throat} = .130 inches

- Result
- $D_{exit} =$ .9099 inches

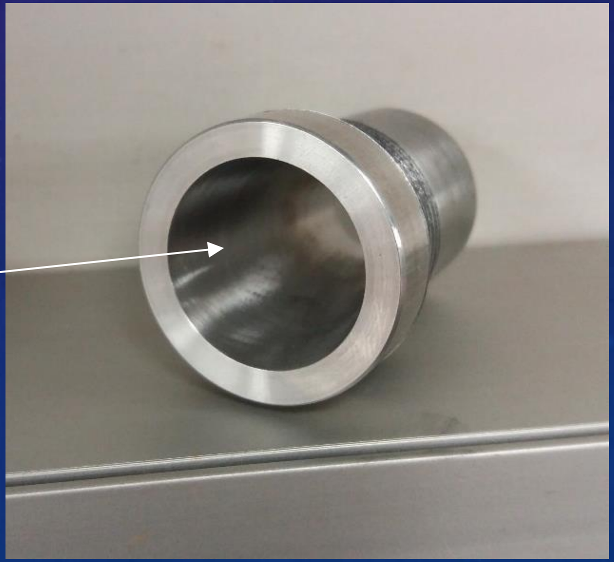
NOZZLE

Design



Product


Converging


Diverging

FUTURE WORK

- Hydrostatic Test | Week Of May 3rd
- Static Fire Test | Week Of May 3rd or May 10th
- Data Analysis | Week of May 12th
- Results & Discussion | Week of May 12th

CONCLUSION

Requirements	**Completed**	**Planned**
Make 3 Fuel Recipes	✓	🛠
Develop Fuel Manufacturing Process	✓	
Safe, Reusable & Reliable Test Stand	✓	
Safe, Reusable & Reliable Fuselage		🛠
Data Collection system	✓	
Ignition System	✓	

ACKNOWLEDGMENTS

- Dr. Jeffrey S. Santner | Senior Design Advisor
- Blake Cortis | ECST Machine Shop Instructor
- Jonathan Cervantes | Student Shop Supervisor
- Amy Moore | Eagle Rocketry Liaison
- Steve | Material Supplier

REFERENCES

- [1] Sutton, G. P., "History of Liquid-Propellant Rocket Engines in Russia, Formerly the Soviet Union." *Journal of Propulsion and Power* 19 (2003): 1008-1037.
- [2] Zak, A., "Did the Soviets Actually Build a Better Space Shuttle?" Popular Mechanics, 19 November 2013, [Online] Available: https://www.popularmechanics.com/space/rockets/a9763/did-the-soviets-actually-build-a-better-space-shuttle-16176311/. [Accessed: 24 April 2021]
- Future work slide – static fire test picture. https://www.youtube.com/watch?v=-yq1EmTkBCs
- Future work slide – hydrostatic test picture. https://www.builders.ph/-hydrostatic-test-pump-philippines/
- Igniter System Slide- https://makezine.com/projects/model-rocket-igniters/

THANK YOU!