



ROCKET PROPULSION CAPSTONE TEAM #3

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PROJECT DESCRIPTION

Build a propulsion system for a high-power level 2 rocket:

- Develop a unique Ammonium Perchlorate Composite Propellant (APCP)
- Design and build a rocket test stand
 - Work with EE team to input thrust data
- Have at least two motor testing's small scale
- Develop a motor casing
- Optimize rocket motor
- Build a final 75mm diameter rocket motor to launch in March 2024



Figure 1: Rocket Launch
Source: High Power Rocketry [1]

PROJECT PURPOSE

- Research and develop new formulas for rocket propellants
- Build large scale motor such that NAU Rocket Club can follow our designs
- Design and build a test stand for NAU Rocket Club
- Assist in development of aerospike nozzle design
- Develop skills in the aerospace field



Figure 3: Test Stand
Source: Duluth Rocketry Team[3]

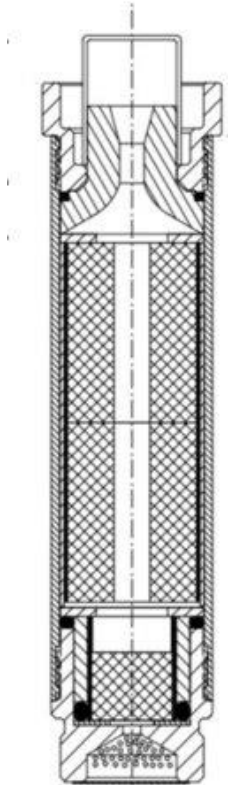


Figure 2: Propulsion
section cut
Source: Solid
Propulsion
Development [2]

Shannon
10/9
Rocket
Propulsion
Team 3



FUNDING AND STAKEHOLDERS



- Project funding is being provided by W.L. Gore & Associates
- Our primary client is NAU Rocket club
 - Our propulsion system will be improved upon and used in future club projects
 - Have interest in a unique propulsion system that may be scaled up in size
- Additional Stakeholder: Professor Carson Pete
 - Faculty advisor for the NAU Rocket club



NAU Rocket Club

BLACK BOX MODEL: ROCKET PROPULSION

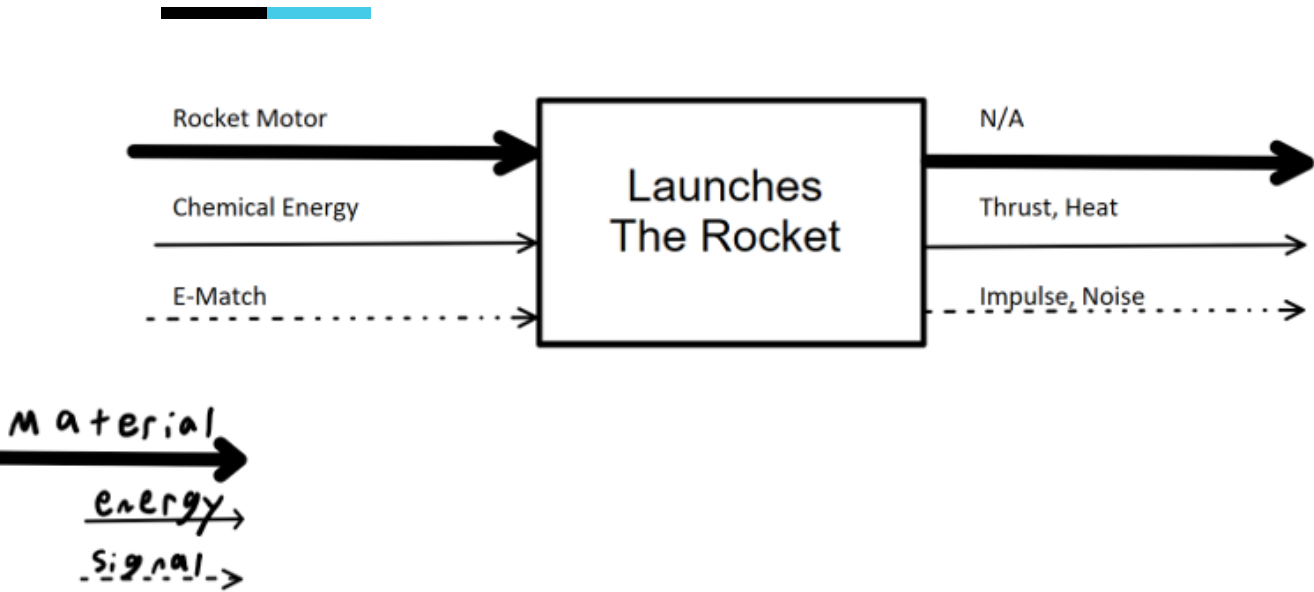
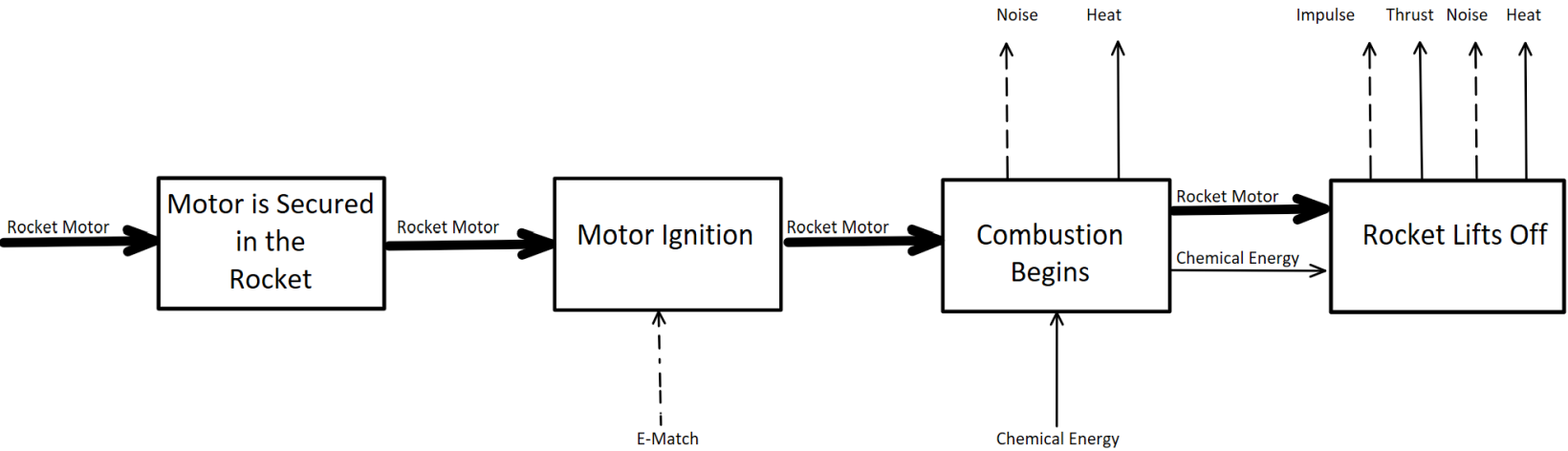


Figure 4: Propulsion Test
Source: Space News [4]



BLACK BOX MODEL: TEST STAND

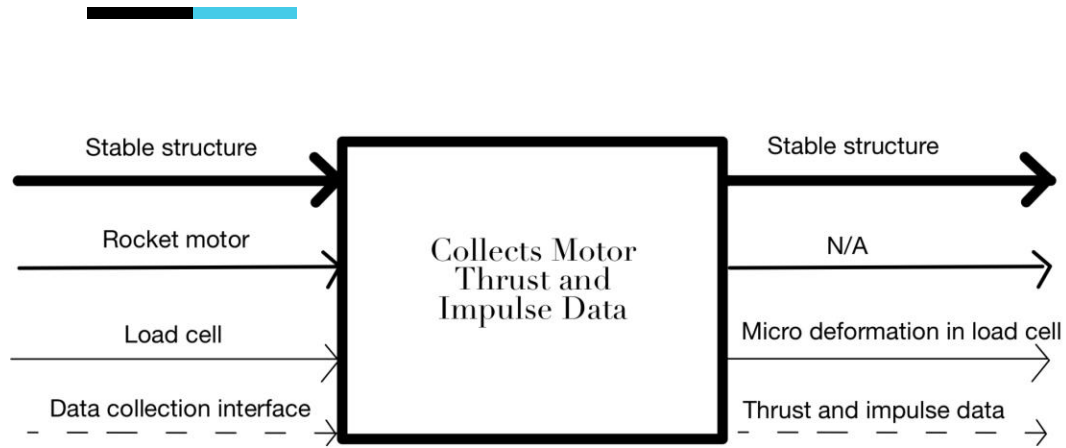
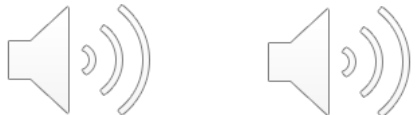
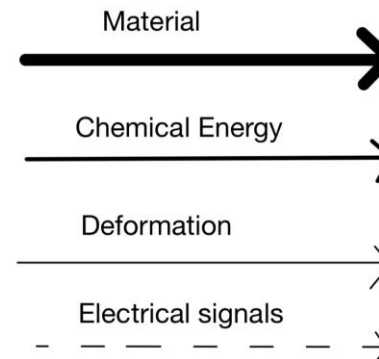
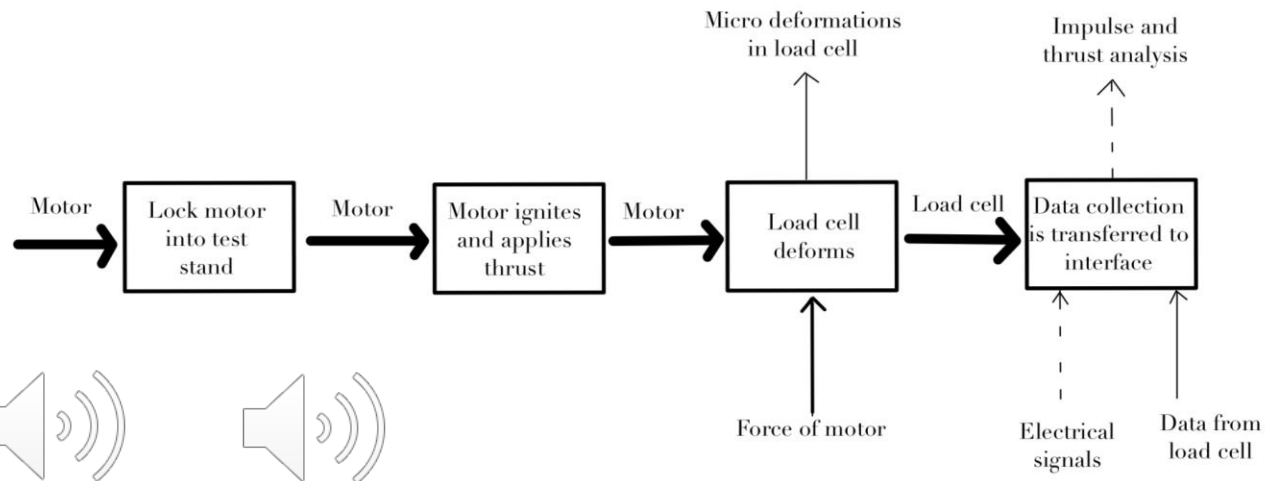


Figure 5: Test Stand
Source: Mobile Test Stand [5]



CONCEPT GENERATION: PROPELLANT FORMULATION

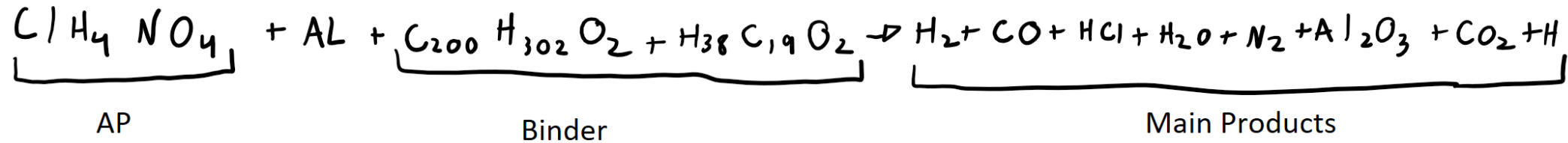
Percent By Weight	Component
70%	Ammonium Perchlorate
15%	Aluminum Powder
14%	Binder
1%	Additives

Percent By Weight	Component
60%	Ammonium Perchlorate
25%	Aluminum Powder
14%	Binder
1%	Additives

Percent By Weight	Component
65%	Ammonium Perchlorate
20%	Aluminum Powder
14%	Binder
1%	Additives

- All percentages align with the ranges found in our sources
- Generated by looking at percentages in sources and comparing and compromising between them

ENGINEERING CALCULATIONS: PROPELLENT FORMULATION



$$c^* = \sqrt{\frac{R'M T_0}{k \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}}$$

Equation 1: Exhaust Velocity Equation [11]

$$I_{sp} = \frac{1}{g} \sqrt{2 T_0 \left(\frac{R'}{M}\right) \left(\frac{k}{k-1}\right) \left[1 - \left(\frac{P_e}{P_0}\right)^{\frac{k-1}{k}}\right]}$$

Equation 2: Specific Impulse Equation [11]

- × ProPep will calculate these things for us
- × The governing equations are important

Ingredients

Name	Concept 1	Weight (gr)
AMMONIUM PERCHLORATE		70.00
ALUMINUM (PURE CRYSTALLINE)		15.00
HTPB (R-45M)		10.00
IDP (B. LEE)		5.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
Total Wt (grams)		100.00

Operating Conditions

Temp. of Ingredients (K)

Chamber Pressure (PSI)

Exhaust Pressure (PSI)

Boost Velocity and Nozzle Design

Calculate

Isp* 196.8531

C* 5195.499

Density 0.0618768

Molecular Wt 24.8083

Chamber CP/CV 1.183034

Chamber Temp. 3171.246

Display Results

Display Nozzle Graphs

Code	WEIGHT	D-H	DENS	COMPOSITION			
0 AMMONIUM PERCHLORATE	70.000	-601	0.07040	1 CL	4 H	1 N	4 O
0 ALUMINUM (PURE CRYSTALLINE)	15.000	0	0.09750	1 AL			
0 HTPB (R-45M)	10.000	-367	0.03250	200 C	302 H	2 O	
0 IDP (B. LEE)	5.000	-908	0.03120	38 H	19 C	2 O	

THE PROPELLANT DENSITY IS 0.06188 LB/CU-IN OR 1.7127 GM/CC

THE TOTAL PROPELLANT WEIGHT IS 100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

```

4.122274 H
1.048540 C
0.595760 N
2.423842 O
0.555967 AL
0.595760 CL
    
```

*****CHAMBER RESULTS FOLLOW *****

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V
3171	5249	68.02	1000.00	-50.28	231.97	1.1830	3.761	18.089

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL = 9.532 11.982

NUMBER MOLS GAS AND CONDENSED = 3.761 0.270

1.246371e+000 H2	9.960066e-001 CO	5.559186e-001 HCl	4.965642e-001 H2O
2.974772e-001 N2	2.702688e-001 Al2O3*	6.825920e-002 H	5.229062e-002 CO2
2.046359e-002 Cl	1.048451e-002 HO	7.426241e-003 AlCl	3.601167e-003 AlCl2
2.154777e-003 AlOCl	7.987877e-004 AlCl3	6.622673e-004 AlHO2	5.942881e-004 NO
5.341821e-004 AlHO	3.408601e-004 O	1.019973e-004 AlO	8.750231e-005 NH3
7.929526e-005 CHO	6.619562e-005 Al	5.393000e-005 O2	4.808235e-005 CNH
4.750404e-005 Cl2	3.268859e-005 COCl	1.871239e-005 Al2O	1.739327e-005 AlH
1.689252e-005 NH2	1.264216e-005 CH2O	1.064934e-005 HOCl	5.414812e-006 OCl
5.064441e-006 N	4.247003e-006 NH	3.168182e-006 CNHO	1.709902e-006 Al2O2
1.31962E-06 NHO			

THE MOLECULAR WEIGHT OF THE MIXTURE IS 24.808

*****EXHAUST RESULTS FOLLOW *****

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V
1813	2804	1.00	14.70	-126.99	231.97	1.2129	3.706	0.270

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL = 8.896 10.531

NUMBER MOLS GAS AND CONDENSED = 3.706 0.278

1.308273e+000 H2	9.617747e-001 CO	5.953732e-001 HCl	4.546825e-001 H2O
2.978508e-001 N2	2.779615e-001 Al2O3*	8.669350e-002 CO2	8.772871e-004 H
3.041119e-004 Cl	2.119714e-005 HO	6.440320e-006 AlCl3	6.384079e-006 NH3

THE MOLECULAR WEIGHT OF THE MIXTURE IS 25.101

*****PERFORMANCE: FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE*****

IMPULSE	IS	EX	T*	P*	C*	ISP*	OPT-EX	D-ISP	A*M	EX-T
252.1	1.1905	2895	38.52	5042.1			9.04	431.7	0.15675	1614
258.4	1.1348	2979	39.28	5195.5	196.9	9.47	442.5	0.16152		1813

Ingredients	
Name	Weight (gr)
AMMONIUM PERCHLORATE	65.00
ALUMINUM (PURE CRYSTALLINE)	20.00
HTPB (R-45M)	10.00
IDP (B. LEE)	5.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
Total Wt (grams)	100.00

Operating Conditions

Temp. of Ingredients (K)

Chamber Pressure (PSI)

Exhaust Pressure (PSI)

Boost Velocity and Nozzle Design

Calculate

Isp* 197.1461

C* 5227.093

Density 0.0626420

Molecular Wt 25.02966

Chamber CP/CV 1.175142

Chamber Temp. 3242.911

Display Results

Display Nozzle Graphs

Code	WEIGHT	D-H	DENS	COMPOSITION			
0 AMMONIUM PERCHLORATE	65.000	-601	0.07040	1 CL	4 H	1 N	4 O
0 ALUMINUM (PURE CRYSTALLINE)	20.000	0	0.09750	1 AL			
0 HTPB (R-45M)	10.000	-367	0.03250	200 C	302 H	2 O	
0 IDP (B. LEE)	5.000	-908	0.03120	38 H	19 C	2 O	

THE PROPELLANT DENSITY IS 0.06264 LB/CU-IN OR 1.7339 GM/CC
 THE TOTAL PROPELLANT WEIGHT IS 100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

3.952058	H
1.048540	C
0.553206	N
2.253625	O
0.741290	AL
0.553206	CL

*****CHAMBER RESULTS FOLLOW *****

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V
3243	5378	68.02	1000.00	-47.28	226.69	1.1751	3.661	18.582

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL = 9.125 12.217
 NUMBER MOLS GAS AND CONDENSED = 3.661 0.334

1.528370e+000	H2	1.032785e+000	CO	4.477091e-001	HCl	3.344084e-001	Al2O3
2.762989e-001	N2	1.749455e-001	H2O	9.047348e-002	H	4.721307e-002	AlCl
1.774495e-002	Cl	1.533993e-002	CO2	1.512214e-002	AlCl2	4.191210e-003	HO
3.836654e-003	AlOCl	2.103738e-003	AlCl3	1.520144e-003	AlHO	7.279922e-004	Al
5.334271e-004	AlHO2	4.219160e-004	Al2O	3.221596e-004	AlO	2.165420e-004	NO
2.019726e-004	AlH	1.910537e-004	CNH	1.463274e-004	O	1.129000e-004	NH3
1.049908e-004	CHO	2.954929e-005	Cl2	2.827659e-005	COC1	2.362901e-005	NH2
1.645943e-005	CH2O	1.117276e-005	Al2O2	7.223355e-006	N	6.632437e-006	O2
6.220742e-006	NH	3.664988e-006	CNHO	3.086680e-006	HOC1	2.589687e-006	CH3
1.992486e-006	CH4	1.749084e-006	CN	1.630755e-006	OCl	1.130165e-006	AlHO

THE MOLECULAR WEIGHT OF THE MIXTURE IS 25.030

*****EXHAUST RESULTS FOLLOW *****

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V
2044	3220	1.00	14.70	-125.77	226.69	1.1998	3.581	0.279

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL = 8.544 10.813
 NUMBER MOLS GAS AND CONDENSED = 3.581 0.370

1.615255e+000	H2	1.037216e+000	CO	5.507436e-001	HCl	3.703645e-001	Al2O3
2.765713e-001	N2	8.268971e-002	H2O	1.124588e-002	CO2	5.299556e-003	H
1.333989e-003	Cl	2.013126e-004	AlCl3	1.723669e-004	AlCl	1.397343e-004	AlCl2
3.002181e-005	HO	1.290869e-005	AlOCl	6.481689e-006	CNH	5.766320e-006	NH3
1.22336E-06	AlHO						

THE MOLECULAR WEIGHT OF THE MIXTURE IS 25.308

*****PERFORMANCE: FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE*****

IMPULSE	IS	EX	T*	P*	C*	ISP*	OPT-EX	D-ISP	A*M	EX-T
---------	----	----	----	----	----	------	--------	-------	-----	------

ProPepMain

File Options Multiple Runs Notes About

Propellant Formulation Grain Information Test Burns Compute A & N

Ingredients

Name	Concept 3	Weight (gr)
AMMONIUM PERCHLORATE		60.00
ALUMINUM (PURE CRYSTALLINE)		25.00
HTPB (R-45M)		10.00
IDP (B. LEE)		5.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
		0.00
Total Wt (grams)		100.00

Operating Conditions

Temp. of Ingredients (K)

Chamber Pressure (PSI)

Exhaust Pressure (PSI)

Boost Velocity and Nozzle Design

Calculate

Isp* 191.6704

C* 5080.634

Density 0.0634263

Molecular Wt. 25.44326

Chamber CP/CV 1.177161

Chamber Temp. 3122.51

Display Results

Display Nozzle Graphs

Results

Copy Results to a File Copy Results to Clipboard

Code	WEIGHT	D-H	DENS	COMPOSITION			
0 AMMONIUM PERCHLORATE	60.000	-601	0.07040	1 CL	4 H	1 N	4 O
0 ALUMINUM (PURE CRYSTALLINE)	25.000	0	0.09750	1 AL			
0 HTPB (R-45M)	10.000	-367	0.03250	200 C	302 H	2 O	
0 IDP (B. LEE)	5.000	-908	0.03120	38 H	19 C	2 O	

THE PROPELLANT DENSITY IS 0.06343 LB/CU-IN OR 1.7556 GM/CC
THE TOTAL PROPELLANT WEIGHT IS 100.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

3.781841 H
1.048540 C
0.510651 N
2.083408 O
0.926612 AL
0.510651 CL

*****CHAMBER RESULTS FOLLOW*****

T (K)	T (F)	P (ATM)	P (PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V
3123	5161	68.02	1000.00	-44.27	220.02	1.1772	3.600	18.896

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL = 8.976 12.093
NUMBER MOLS GAS AND CONDENSED = 3.600 0.330

1.714516e+000 H2	1.044524e+000 CO	3.304490e-001 Al2O3*	2.545694e-001 N2
2.166904e-001 HCl	2.036951e-001 AlCl	6.836099e-002 H	3.624560e-002 AlCl2
3.065577e-002 H2O	5.823047e-003 Cl	5.617128e-003 Al2O	4.500219e-003 Al
3.058705e-003 AlCl3	2.699320e-003 AlOCl	2.488410e-003 CO2	2.283812e-003 AlHO
1.481298e-003 AlH	1.269511e-003 CNH	4.556235e-004 HO	3.116133e-004 AlO
1.404961e-004 NH3	1.284496e-004 AlHO2	9.100935e-005 CHO	2.289523e-005 Al2O2
2.285815e-005 CH4	2.027340e-005 CH3	1.970394e-005 NO	1.968756e-005 NH2
1.909132e-005 CH2O	1.082862e-005 O	1.066566e-005 COCl	1.044298e-005 C2H2
7.135681e-006 CN	4.683940e-006 Cl2	3.725427e-006 CNHO	3.686930e-006 NH
3.445210e-006 N	2.722967e-006 Al2	1.756622e-006 CH2	1.231752e-006 AlHO
1.05752E-06 CNC1			

THE MOLECULAR WEIGHT OF THE MIXTURE IS 25.443

*****EXHAUST RESULTS FOLLOW*****

T (K)	T (F)	P (ATM)	P (PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V
1933	3020	1.00	14.70	-118.02	220.02	1.2023	3.500	0.286

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL = 8.588 10.747
NUMBER MOLS GAS AND CONDENSED = 3.500 0.347

1.809828e+000 H2	1.043073e+000 CO	3.466747e-001 Al2O3&	2.530821e-001 N2
1.530751e-001 HCl	1.463217e-001 AlCl	4.941271e-002 AlCl2	3.739645e-002 AlCl3
4.428411e-003 CNH	2.553673e-003 H	3.429885e-004 C2H2	2.557069e-004 CH4
1.617736e-004 Cl	1.419980e-004 H2O	3.997374e-005 Al	1.903442e-005 AlOCl
1.897238e-005 CO2	1.360842e-005 Al2O	9.378925e-006 AlH	8.917960e-006 CH3
8.0724E-06 NH3	8.0724E-06 NH3	8.0724E-06 NH3	

THE MOLECULAR WEIGHT OF THE MIXTURE IS 25.995

*****PERFORMANCE: FROZEN ON FIRST LINE. SHIFTING ON SECOND LINE*****

CONCEPT EVALUATION: PROPELLANT FORMULATION

Criteria	Weight	DATUM	Option 1	Option 2	Option 3
		73% AP	70% AP	65% AP	60% AP
Reach minimum altitude	3	D A T U M	+	++	-
Stay within Budget for the Project	2		+	+	++
Dimensions meet constraints of rocket size	3		0	0	0
Stand withstands impulse of rocket testing	1		-	--	+
Meet Minimum Thrust to Weight Ratio Set by Tripoli	3		-	-	--
Complete final launch by march 2024	2		0	0	0
Non-Ferrous, Ductile Casings	3		0	0	0
+			5	8	5
0		17	3	3	3
-			4	5	9
TOTAL		0	1	3	-4

- The Datum is an average of all formulas used for similar projects

CONCEPT GENERATION: PROPELLANT GEOMETRY: BURNSIM DATA

Name:

Standard Properties | Pressure Varied Properties | Notes

C* : ft/sec S. Heat Ratio:

ISP*: sec Mol. Mass

BR Coef (a):

BR Exp (n):

Density : lb/in³

Propellant Properties Used:

"Cherry Limeade" formulation created by MIT. [1]

Nozzle Throat Dia: inches

Use Nozzle Calculations

Nozzle Exit Dia: inches

Expansion Ratio:

Ambient Pressure: psi

Efficiency:

Nozzle Dia Erosion in / sec

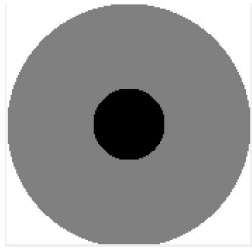
Use Thrust Coefficient

Thrust Coefficient

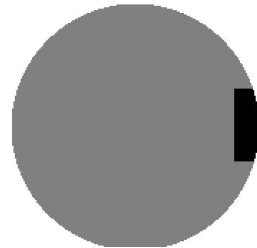
Nozzle Properties Used:

Standard un-drilled 75mm solid rocket motor nozzle. [2]

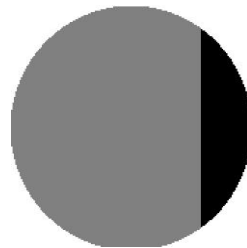
CONCEPT GENERATION: PROPELLANT GEOMETRY DEFINITIONS



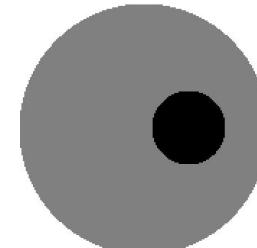
BATES Grain



C-Slot Grain



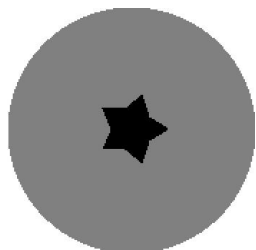
D-Grain



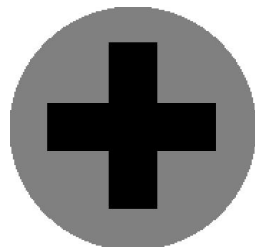
Moon Grain



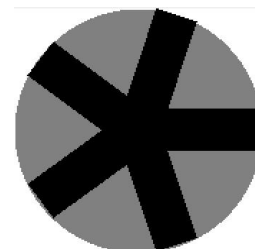
Figure 6.



Star Grain



X-Core Grain



Finocyl Grain



Figure 7.

Figures 6 and 7: Rocket Motor Grain
Source: K6r6 YouTube [6]

ENGINEERING CALCULATIONS: PROPELLANT GRAIN GEOMETRIES I

Grains

Grain Type: BATES

Propellant: Cherry Limeaid

Length: 2.75 inches

Diameter: 2.557 inches

Core Diameter: 0.75 inches

Slot Width: 0.5 inches

of points: 5 inches

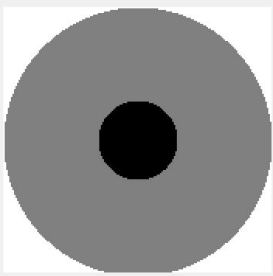
Fin Length: 0.885

Inhibited Ends: 0 (0-2)

Add Delete Apply Up Down

Bottom Grain Is Nozzle End

#	Length	Diameter	Core	Inhib.	Type	Prop.
1	2.75	2.557	0.75	0	BATES	Cherry Limeaid
2	2.75	2.557	0.75	0	BATES	Cherry Limeaid
3	2.75	2.557	0.75	0	BATES	Cherry Limeaid
4	2.75	2.557	0.75	0	BATES	Cherry Limeaid
5	2.75	2.557	0.75	0	BATES	Cherry Limeaid



Motor Cross-Section

Nozzle & Thrust | Propellants | Startup

Nozzle Throat Dia: 0.485 inches Area

Use Nozzle Calculations

Nozzle Exit Dia: 1.25 inches

Expansion Ratio: 6.64

Ambient Pressure: 14.7 psi

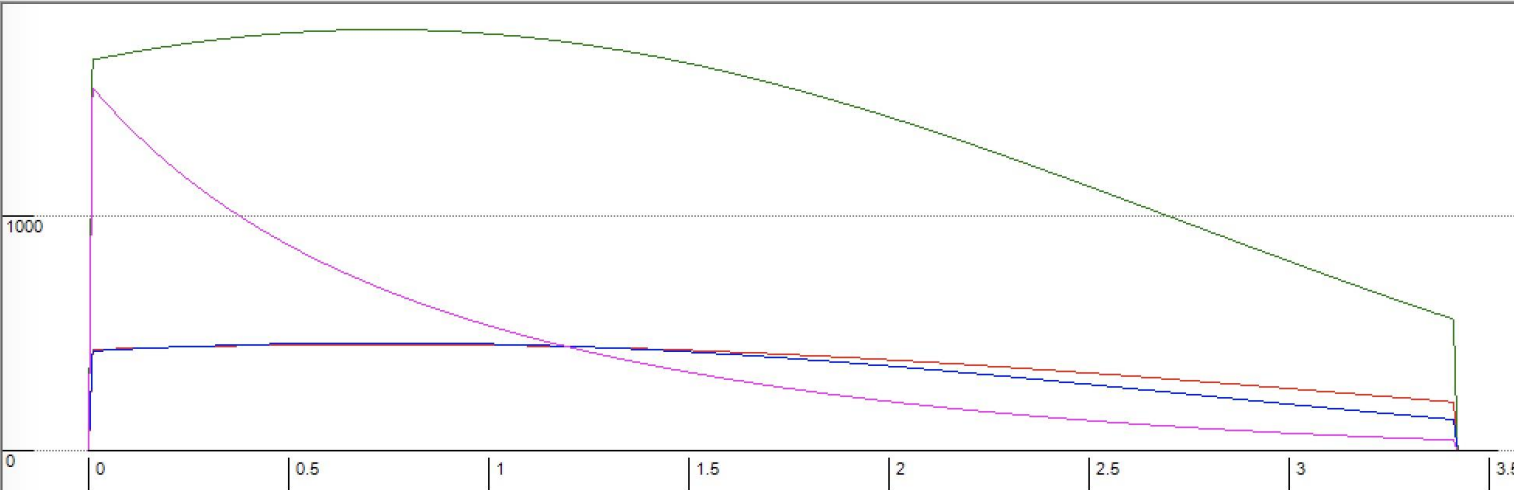
Efficiency: 85

Nozzle Dia Erosion: 0 in / sec

Use Thrust Coefficient

Thrust Coefficient: 0

Graph | Notes



X Axis Start 0 seconds X Axis End 0 seconds End Sim at 0 % of max thrust

Sim Results | Graph Lines | Test Data

Initial Kn:	429	Burn Time:	3.41 sec.
Max Kn:	452	Propellant Length:	13.75 in
Max Pc:	1791 psi	Propellant Mass:	3.92 lbs
Volume Loading:	91.4 %	Total Impulse:	5387 NS
Port / Throat Area:	2.39	Motor Class:	5% M M-1580
Throat / Port Area:	0.418	Delivered ISP:	309 sec.
Core L/D Ratio:	18.3	Peak Mass Flux:	3.089 Grain 5
Web:	0.9 in		

Activate Windows
Go to Settings to activate Windows.

ENGINEERING CALCULATIONS: PROPELLANT GRAIN GEOMETRIES 2

File Action Settings View Help

Grains

Grain Type: **Finocyl**

Propellant: **Cherry Limeaid**

Length: **2** inches

Diameter: **2.557** inches

Core Diameter: **0.75** inches

Fin Thickness: **0.5** inches

of fins: **6** inches

Fin Length: **0.5**

Inhibited Ends: **0** (0-2)

#	Length	Diameter	Core	Inhib.	Type	Prop.
1	2	2.557	0.75	0	Finocyl	Cherry Limeaid
2	4	2.557	0.875	0	BATES	Cherry Limeaid
3	2	2.557	0.75	0	Finocyl	Cherry Limeaid
4	4	2.557	0.875	0	BATES	Cherry Limeaid
5	2	2.557	0.875	0	BATES	Cherry Limeaid

Bottom Grain Is Nozzle End

Motor Cross-Section

Nozzle & Thrust | Propellants | Startup

Nozzle Throat Dia: **0.485** inches **Area**

Use Nozzle Calculations

Nozzle Exit Dia: **1.25** inches

Expansion Ratio: **6.64**

Ambient Pressure: **14.7** psi

Efficiency: **85**

Nozzle Dia Erosion: **0** in / sec

Use Thrust Coefficient

Thrust Coefficient: **0**

Graph | Notes

X Axis Start **0** seconds X Axis End **0** seconds End Sim at **0** % of max thrust

Sim Results | Graph Lines | Test Data

Initial Kn:	519	Burn Time:	3.23 sec.
Max Kn:	519	Propellant Length:	14 in
Max Pc:	2202.9 psi	Propellant Mass:	3.637 lbs
Volume Loading:	83.3 %	Total Impulse:	5007 NS
Port / Throat Area:	3.25	Motor Class:	96% L L-1550
Throat / Port Area:	0.308	Delivered ISP:	309 sec.
Core L/D Ratio:	16.7	Peak Mass Flux:	3.008 Grain 5
Web:	0.84 in		

Activate Windows
Go to Settings to activate Windows.

ENGINEERING CALCULATIONS: PROPELLANT GRAIN GEOMETRIES 3

File Action Settings View Help

Grains

Grain Type: BATES

Propellant: Cherry Limeaid

Length: 6 inches

Diameter: 2.557 inches

Core Diameter: 0.9 inches

Slot Depth: 0.5 inches

of fins: 4 inches

Fin Length: 0.5 inches

Inhibited Ends: 0 (0-2)

#	Length	Diameter	Core	Inhib.	Type	Prop.
1	6	2.557	0.9	0	BATES	Cherry Limeaid
2	4	2.557	0.85	0	BATES	Cherry Limeaid
3	2	2.557	0.8	0	BATES	Cherry Limeaid
4	2	2.557	0.75	0	BATES	Cherry Limeaid

Motor Cross-Section

Bottom Grain Is Nozzle End

Nozzle & Thrust | Propellants | Startup

Nozzle Throat Dia: 0.485 inches Area

Use Nozzle Calculations

Nozzle Exit Dia: 1.25 inches

Expansion Ratio: 6.64

Ambient Pressure: 14.7 psi

Efficiency: 85

Nozzle Dia Erosion: 0 in / sec

Use Thrust Coefficient

Thrust Coefficient: 0

Graph | Notes

Sim Results | Graph Lines | Test Data

Initial Kn:	401	Burn Time:	4.02 sec.
Max Kn:	440	Propellant Length:	14 in
Max Pc:	1724.9 psi	Propellant Mass:	3.882 lbs
Volume Loading:	88.9 %	Total Impulse:	5344 NS
Port / Throat Area:	2.39	Motor Class:	4% M M-1329
Throat / Port Area:	0.418	Delivered ISP:	309 sec.
Core L/D Ratio:	16.5	Peak Mass Flux:	2.795 Grain 4
Web:	0.9 in		

X Axis Start 0 seconds X Axis End 0 seconds End Sim at 0 % of max thrust

BurnSim Ready

Activate Windows
Go to Settings to activate Windows.

CONCEPT SELECTION: PROPELLANT GEOMETRY

Major Factors: Casing Pressure, Burn Time, Impulse, Propellant Mass, & Curve Characteristics

Concept 1: Properties	Concept 1: Results
Max Casing Pressure	1791 psi
Burn Time	3.41s
Total Impulse	5387 Ns *
Propellant Mass	3.92 lbs. **

Concept 2: Properties	Concept 2: Results
Max Casing Pressure	2202.9 psi **
Burn Time	3.23s m **
Total Impulse	5007 Ns **
Propellant Mass	3.637 lbs. *

Concept 3: Properties	Concept 3: Results
Max Casing Pressure	1724.9 psi *
Burn Time	4.02s *
Total Impulse	5344 Ns
Propellant Mass	3.882 lbs.

* - Ideal Measures
** - Non-Ideal Measures

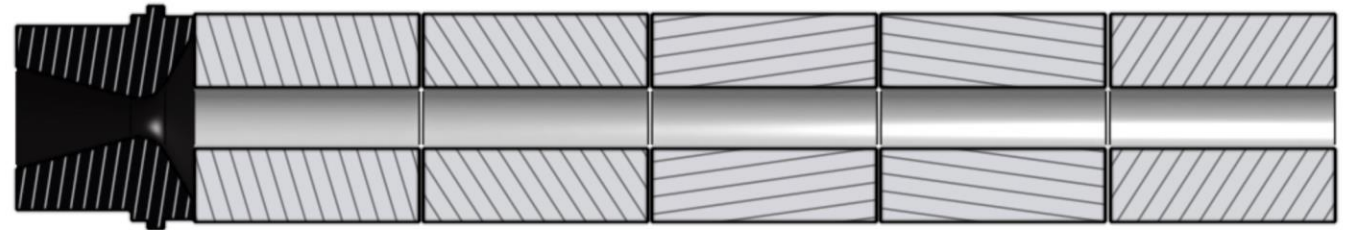
CONCEPT SELECTION: PROPELLANT GEOMETRY

		Option 1	Option 2	Option 3	Option 4
Criteria	Weight	Competition Motor	Uniform Concentric	Varying Geometries	Non-Uniform Concentric
Reach minimum altitude	3	D A T U M	+	-	+
Stay within Budget for the Project	2		+	-	--
Dimensions meet constraints of rocket size	3		+	+	+
Stand withstands impulse of rocket testing	1		-	+	0
Meet Minimum Thrust to Weight Ratio Set by Tripoli	3		+	-	++
Complete final launch by march 2024	2		-	-	+
Non-Ferrous, Ductile Casings	3		0	0	0
+			12	7	14
0		17	1	1	2
-			3	9	4
TOTAL		0	9	-2	10

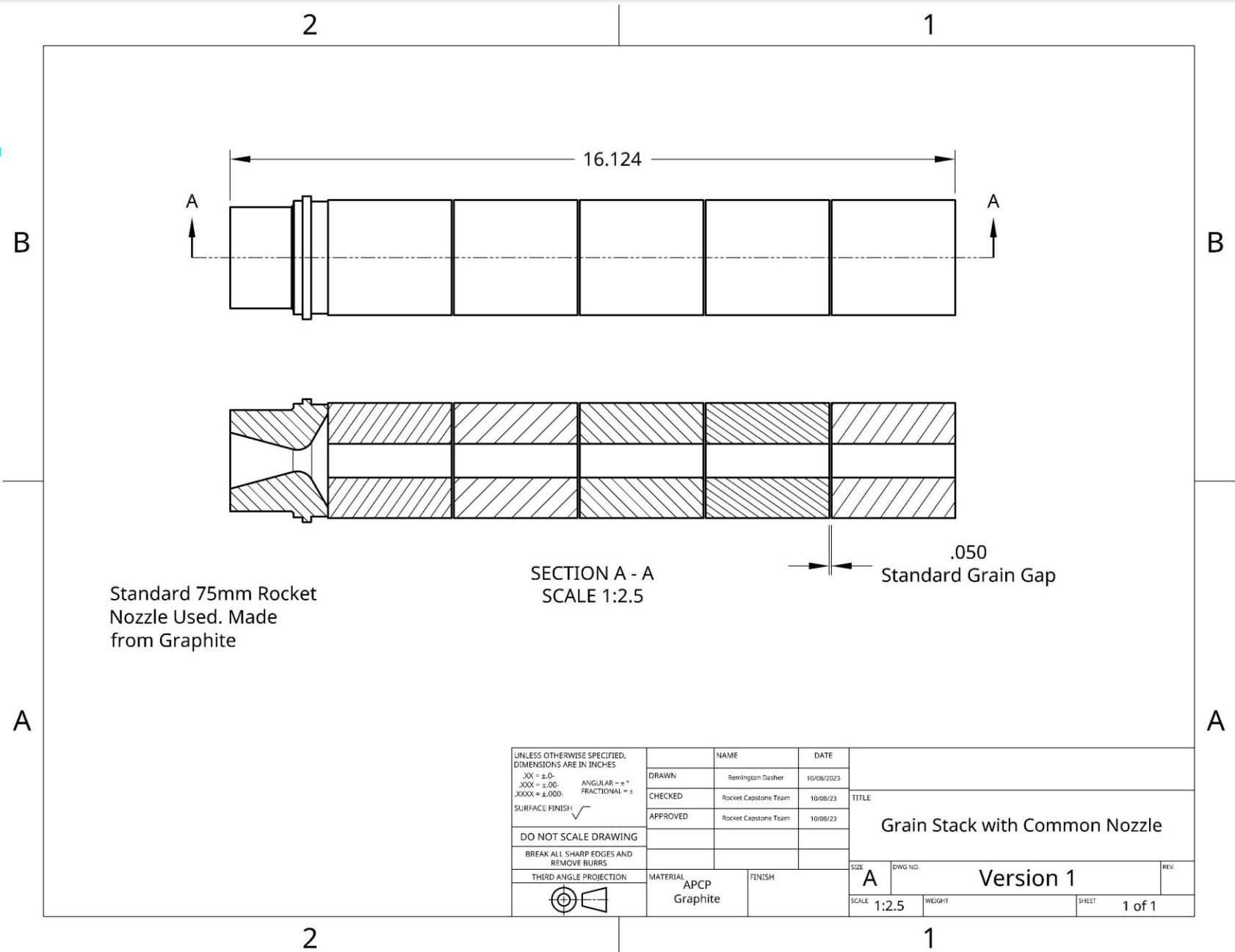
CAD MODELS



Isometric View of the grains arranged in firing form. The white parts are the grains and the black part is the graphite nozzle.



Section view of the firing form grain arrangement. Like we saw in the grain geometry concept selection, these are exactly what we expect to cast for our grains. An aluminum casing will slide over this arrangement with an insulation material under it.



UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES
.XX = ±.0-
.XXX = ±.00-
XXXX = ±.000-
ANGULAR = ±°
FRACTIONAL = ±

SURFACE FINISH: ✓

DO NOT SCALE DRAWING

BREAK ALL SHARP EDGES AND REMOVE BURRS

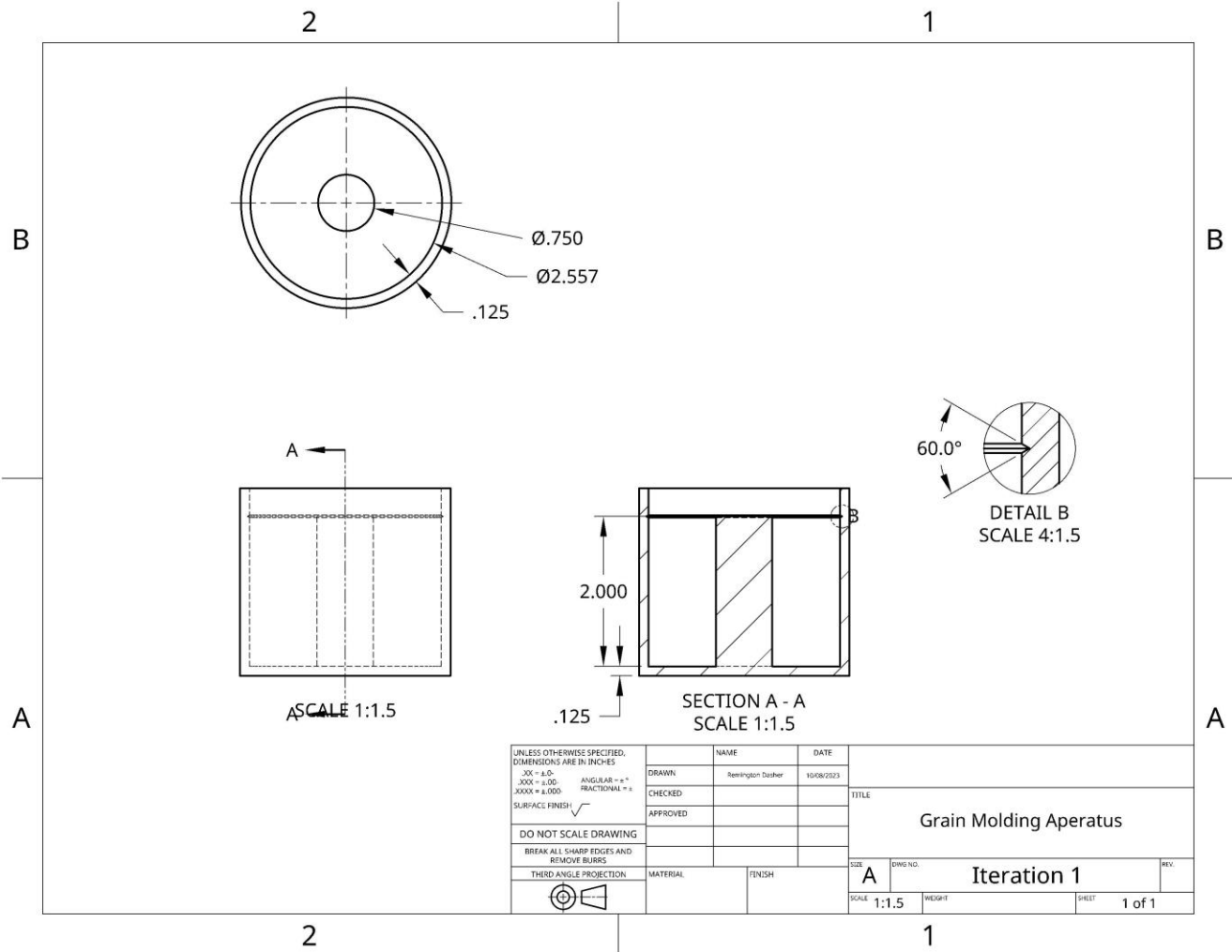
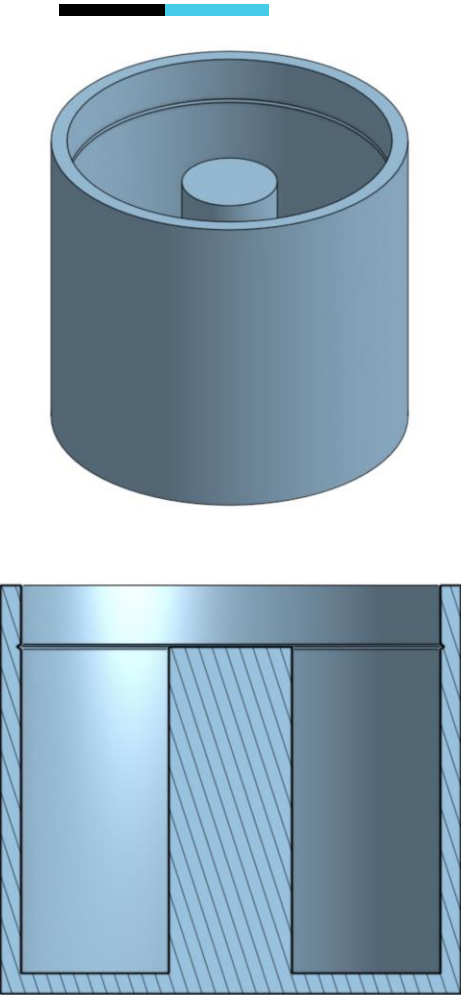
THIRD ANGLE PROJECTION



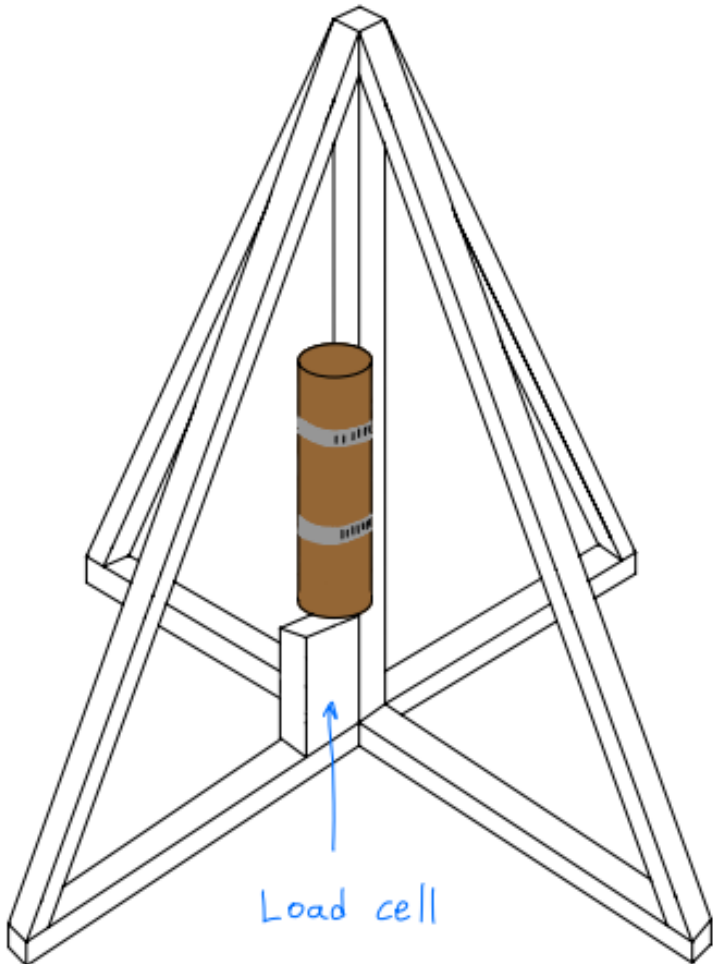
	NAME	DATE
DRAWN	Remington Dasher	10/08/2023
CHECKED	Rocket Capstone Team	10/08/23
APPROVED	Rocket Capstone Team	10/08/23
MATERIAL	APCP Graphite	FINISH

TITLE		
Grain Stack with Common Nozzle		
SIZE A	DWG NO. Version 1	REV.
SCALE 1:2.5	WEIGHT	SHEET 1 of 1

CAD MODEL (PROPELLANT GRAIN MOLDING APPARATUS)



CONCEPT GENERATION ~ VERTICAL TEST STAND DESIGN I



Design Features:

- Motor secured to vertical rail on a linear bearing
- Easy to build, simplistic design
- Build from aluminum extrusion, which we already have

Disadvantages:

- The exhaust gas directly impacts the frame
- The motor will apply moment force on the linear bearing, which increases friction

ENGINEERING CALCULATIONS ~ VERTICAL DESIGN I

Equations:

$$I = F_t * t$$

$$F_t = \frac{I}{t}$$

$$F_x = F_t * \cos(\theta)$$

$$F_{fs} = F_R * \mu$$

Given:

Impulse (I) = 5120.00 N-sec

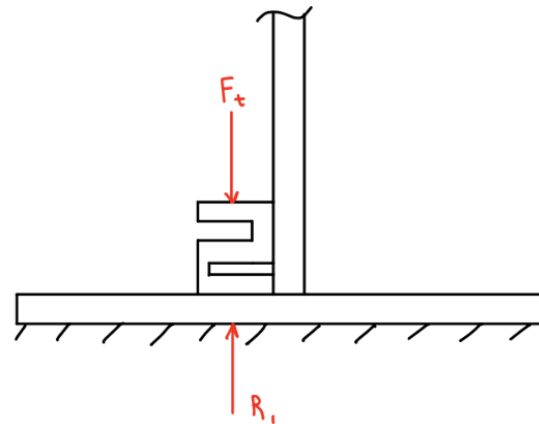
Burn Time (t) = 4 sec

Gravitational Acceleration (g) = 9.80665 m/s²

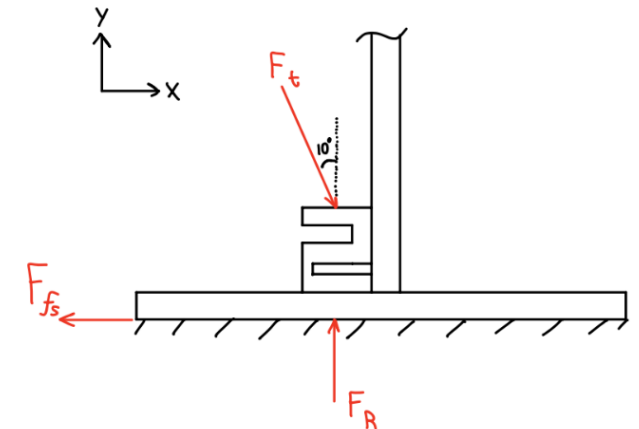
Coefficient of Static Friction (μ) = 0.56

Find:

Case A: Reaction Forces Present in an ideal motor test (perfectly vertical)



Case B: Reaction forces present in a scenario where motor is not perfectly mounted (10 degrees from vertical).

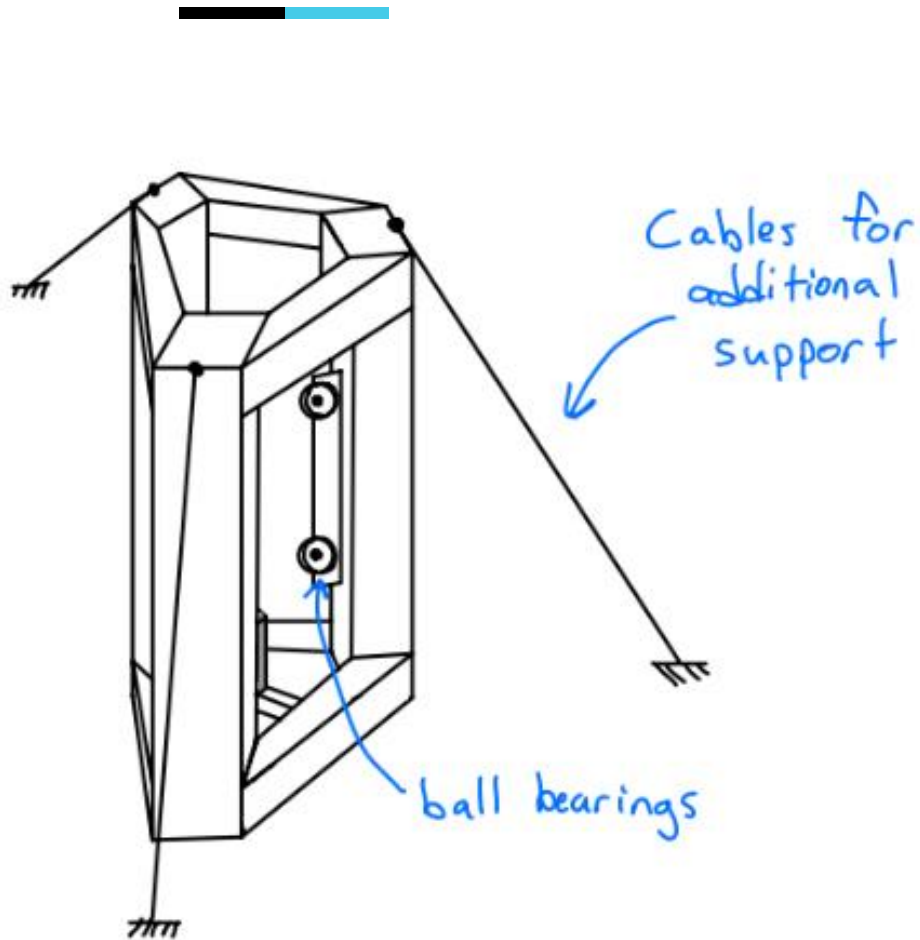


Solution:

	Case A	Case B
F_t	1280.00 N	1280.00 N
F_R	1280.00 N	1260.55 N
F_x	-	222.27 N
F_{fs}	-	-222.27 N

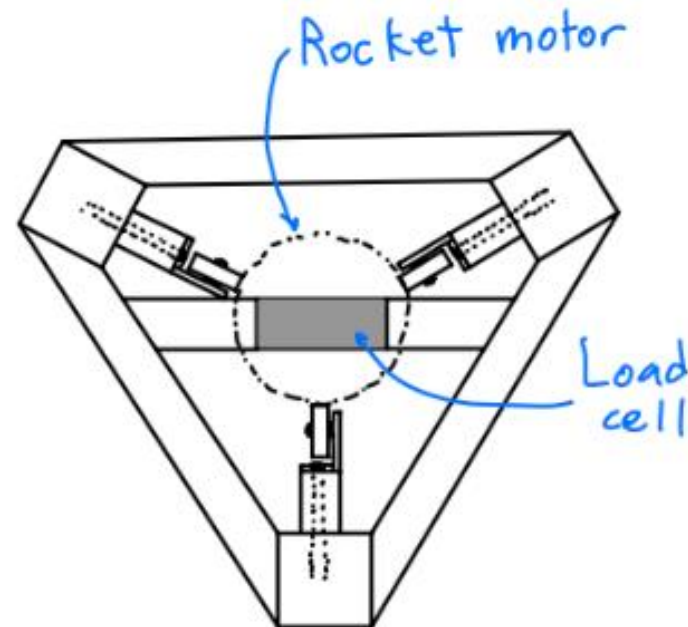
Coefficient of Static Friction (μ) must be greater than 0.176 to keep the design still

CONCEPT GENERATION ~ VERTICAL TEST STAND DESIGN 2



Design Features:

- Motor secured with 6 bearings
- Bearing mounts can be altered to secure multiple motor diameters



Disadvantages:

- Building would require differently sized extrusions
- Motor is held in place from 3 angles instead of 4

ENGINEERING CALCULATIONS ~ VERTICAL DESIGN

Equations:

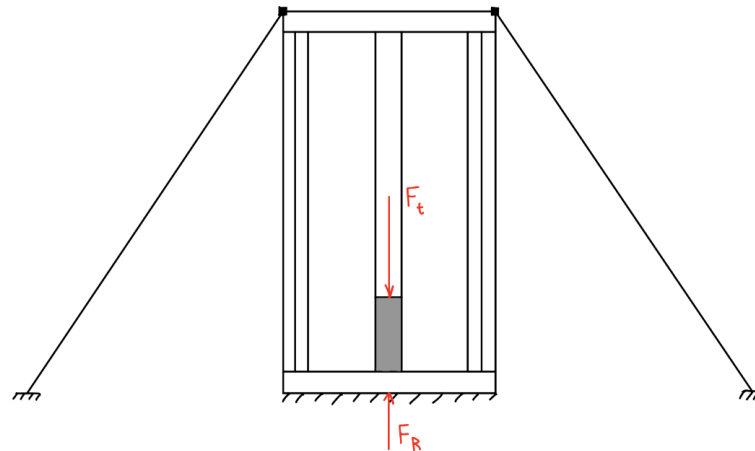
$$I = F_t * t$$

$$F_t = \frac{I}{t}$$

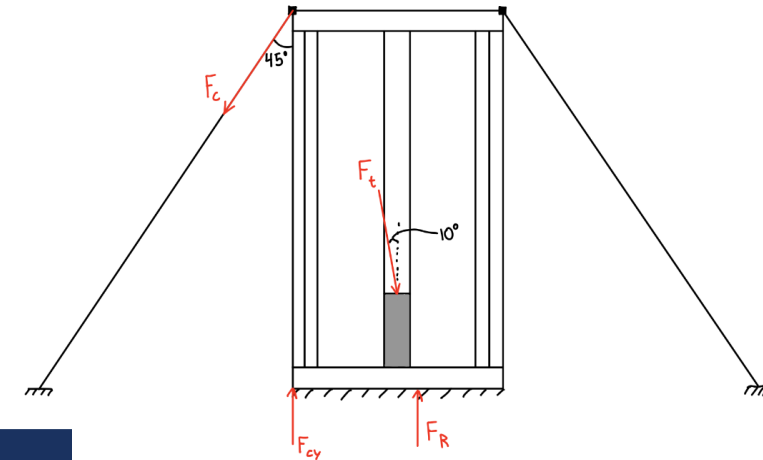
$$F_x = F_t * \cos(\theta)$$

Find:

Case A: Reaction Forces Present in an ideal motor test (perfectly vertical)



Case B: Reaction forces present in a scenario where motor is not perfectly mounted (10 degrees from vertical).



Given:

Impulse (I) = 5120.00 N-sec

Burn Time (t) = 4 sec

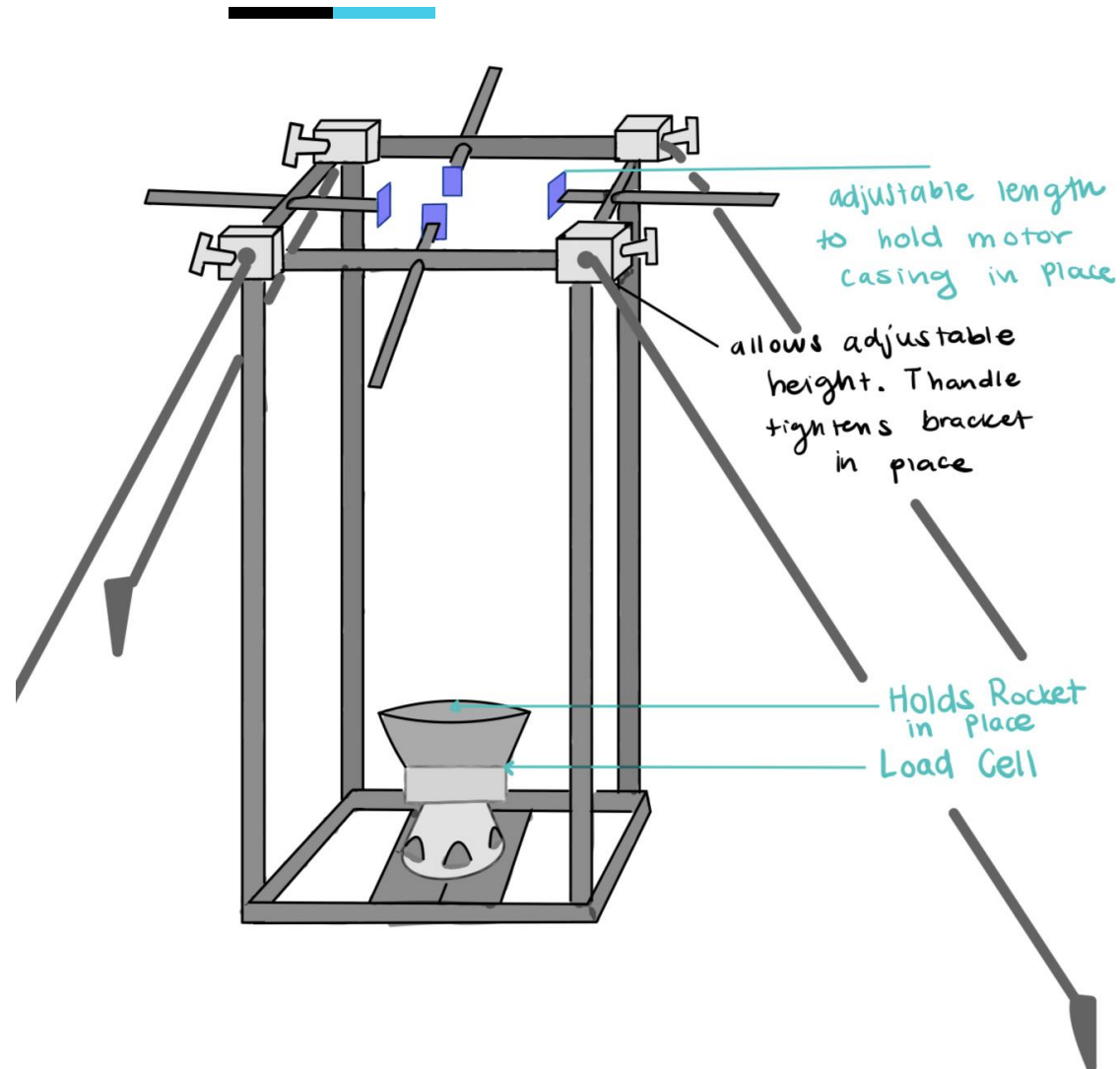
Angle = 10 degrees

(Assume frictionless surface)

Solution:

	Case A	Case B
F_t	1280.00 N	1280.00 N
F_R	1280.00 N	1260.55 N
F_c	-	314.34 N
F_{cy}	-	222.27 N

CONCEPT GENERATION ~ VERTICAL TEST STAND DESIGN 3



Design Features:

- Securely holds load cell
- Forces are distributed into ground
- Attaches at multiple points
- Points of contact are low friction
- Adjustable top allow for different diameters and heights
- Simple to build
- Structurally stable

Disadvantages:

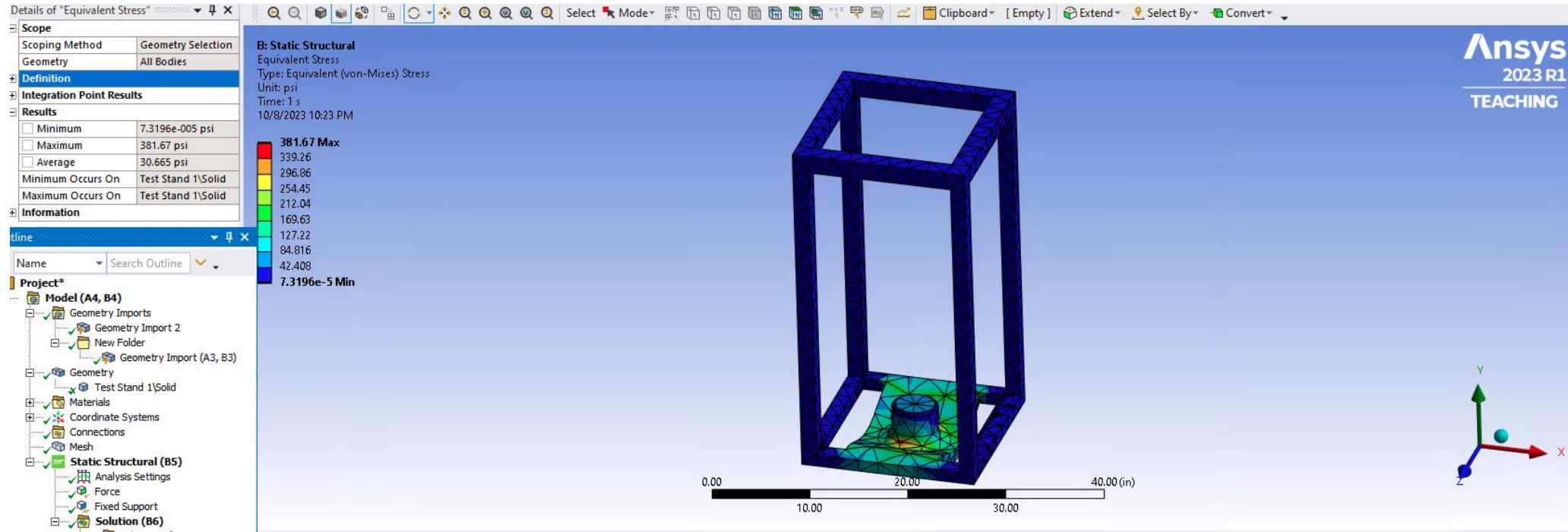
- Must account for gravity in calculations
- Must design and build specialty part to hold load cell



Figure 8: Propulsion Test
Source: BPS Space [7]



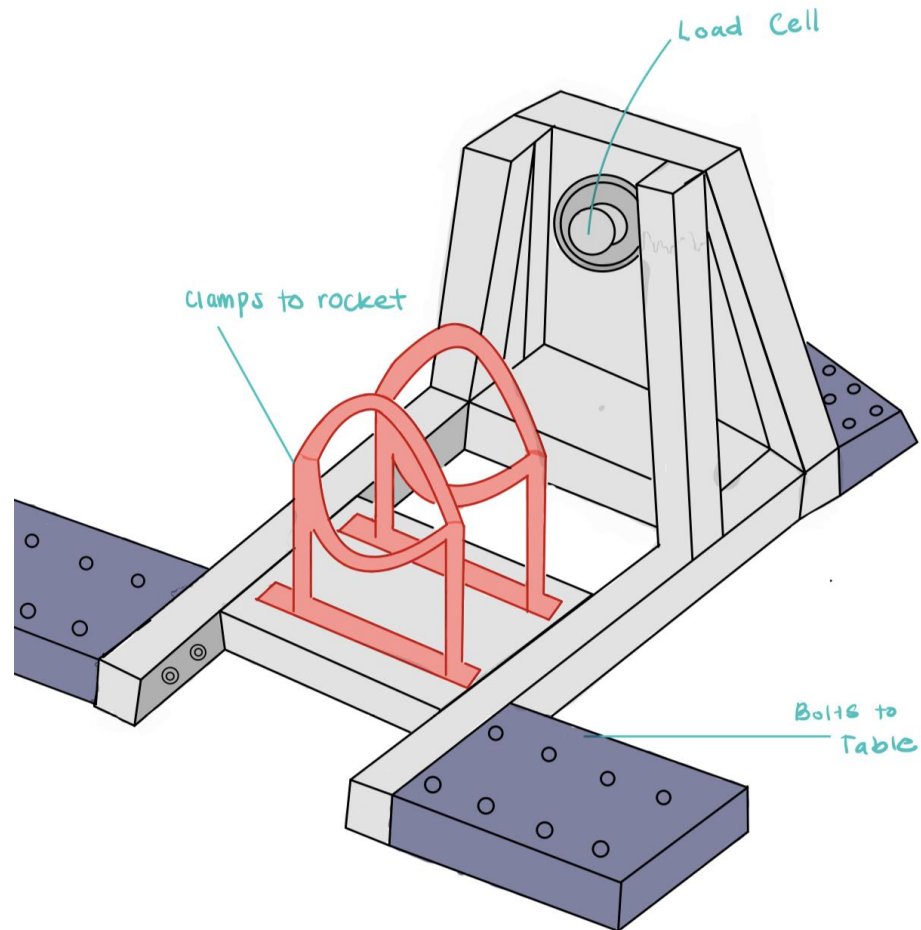
ENGINEERING CALCULATIONS ~ VERTICAL DESIGN 3



- × The maximum force applied to the load cell is 5120 N*s of impulse, or 287.8 lbf of thrust.
- × By applying this force in the -Y direction to the load cell:
 - + Largest stress is 381.7 psi
- × Must reinforce plate and load cell to support 381.7 psi * Factor of Safety
- × Assuming a F.O.S. of 1.5:
 - + $381.7\text{psi} * 1.5 = 572.6\text{ psi}$
- × Must design the load cell support structure and plate to withstand 572.6 psi
- × The thrust forces can dissipate through the ground once moving through the plate
 - + This allows the rest of the structure to not experience the forces of the motor, reducing modes of failure



CONCEPT GENERATION ~ HORIZONTAL TEST STAND I



Design Features:

- Mounting blocks to ensure stability
- Gravity is negligible
- Load cell is mounted to plate
- No need to build load cell holder
- Allows for all diameters

Disadvantages:

- Friction between clamps and motor
- Large forces on plate and supports
- Must be a certain height



ENGINEERING CALCULATIONS ~ HORIZONTAL DESIGN I

$$\text{Impulse} = 5120 \text{ N} \cdot \text{s} = (5120 \text{ N} \cdot \text{s}) \left(\frac{1}{4 \text{ s}} \right) \left(\frac{0.224808943 \text{ lbf}}{\text{N}} \right) = 287.76 \text{ lbf} \text{ (Thrust)}$$

Where 4 seconds is the approximate burn time

$$+ \sum M_D = 0$$

$$(R_1)(18 \text{ in}) - (F_{\text{Thrust}})(9 \text{ in}) - (F_{\text{Thrust}})(4 \text{ in}) = 0$$

$$(R_1)(18 \text{ in}) - (287.8 \text{ lbf})(9 \text{ in}) - (287.8 \text{ lbf})(4 \text{ in}) = 0$$

$$R_1 = 204.9 \text{ lbf} \downarrow$$

$$+ \sum F_y = -204.9 \text{ lbf} + R_{Dy} = 0$$

$$R_{Dy} = 204.9 \text{ lbf}$$

$$+ \sum F_x = 204.9 \text{ lbf} - R_{Dx} = 0$$

$$R_{Dx} = 287.8 \text{ lbf}$$

$$+ \sum M_B = 0$$

$$-(287.8 \text{ lbf})(9 \text{ in}) - (287.8 \text{ lbf})(4 \text{ in}) + M_D + (204.9 \text{ lbf})(18 \text{ in}) = 0$$

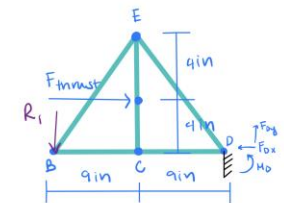
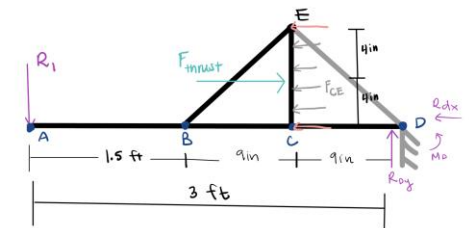
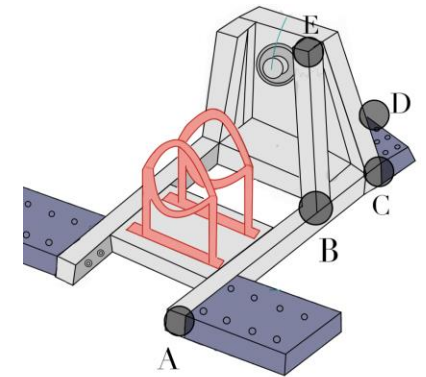
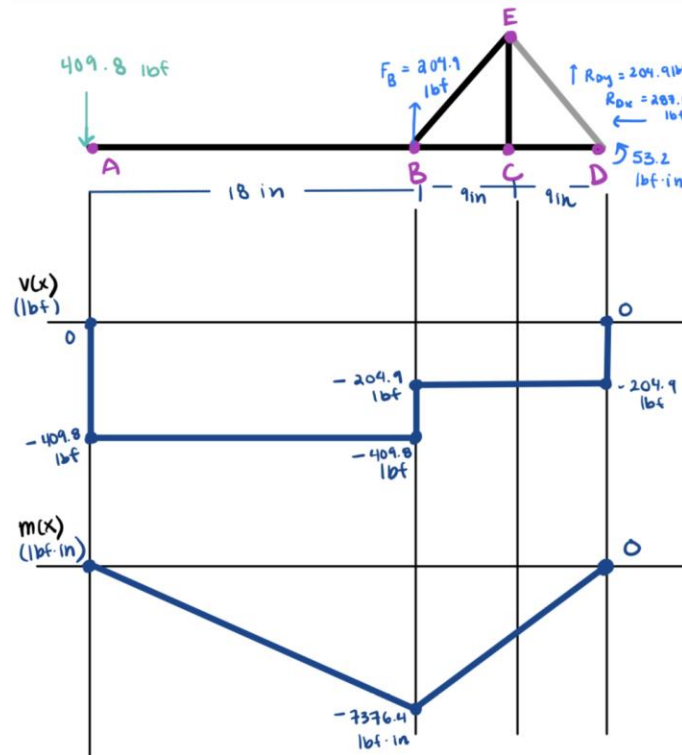
$$M_D = 53.2 \text{ lbf} \cdot \text{in}$$

$$-R_{Ay} + R_{Dy} + F_B = 0$$

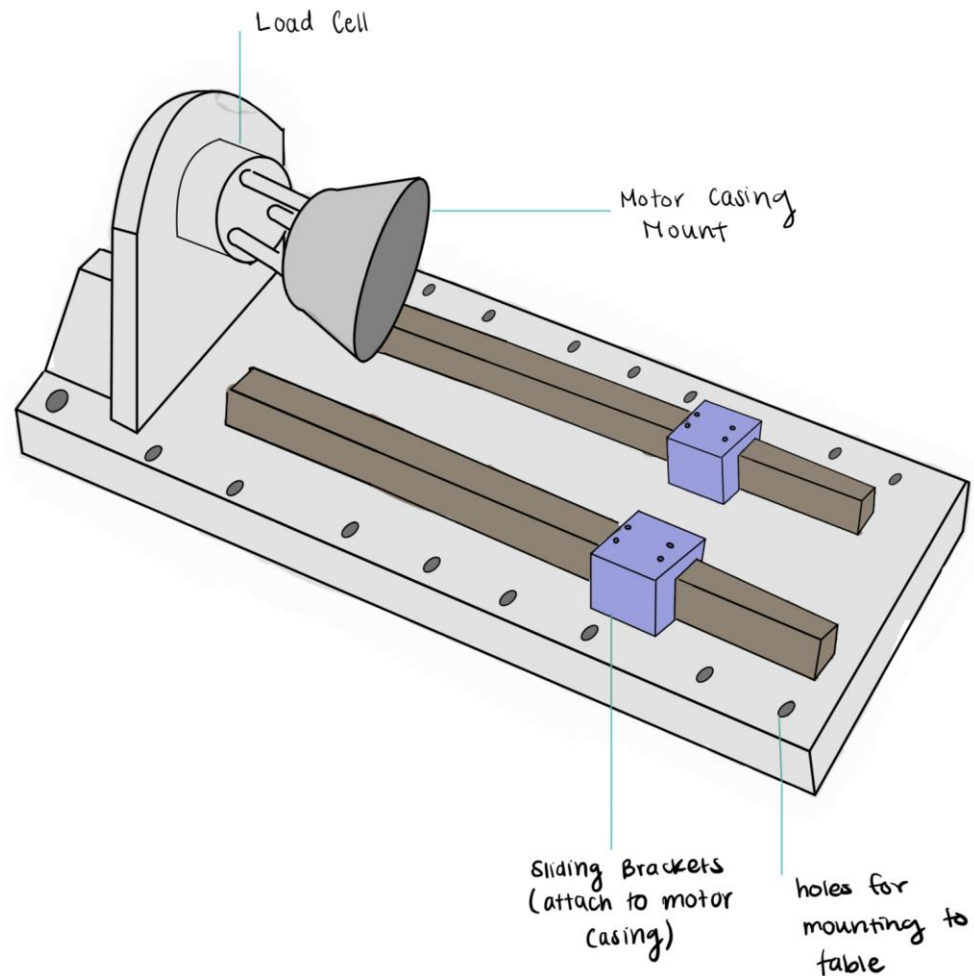
$$-R_{Ay} + 204.9 \text{ lbf} + 204.9 \text{ lbf} = 0$$

$$R_{Ay} = 409.8 \text{ lbf}$$

- Based on the shear force and bending moment diagram, the greatest stress will occur at point B. Therefore, this design may be more likely for failure since member EB would need to be greatly reinforced.
- The required design must account for max stress:
 - Assuming F.O.S = 1.5
 - $409.8 \text{ lbf} \cdot 1.5 = 614.7 \text{ lbf}$



CONCEPT GENERATION ~ HORIZONTAL TEST STAND 2



Design Features:

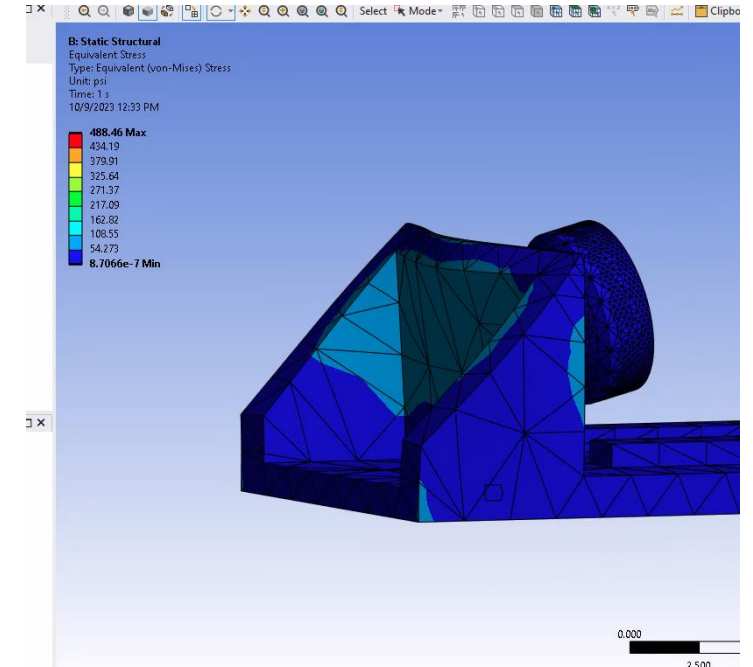
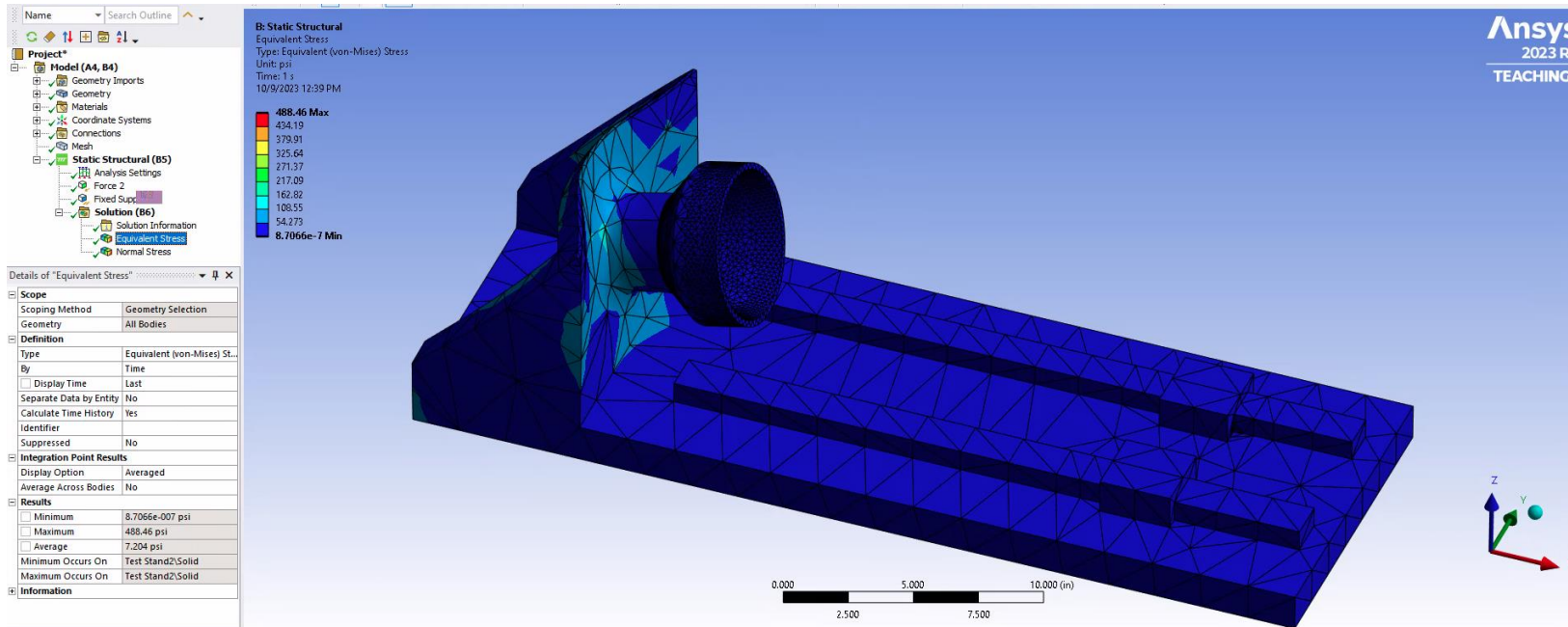
- Friction is negligible
- Gravity is negligible
- Simple to build
- Cost efficient

Disadvantages:

- Less contact with motor
- High stress points
- More likely to fail



ENGINEERING CALCULATIONS ~ HORIZONTAL DESIGN 2

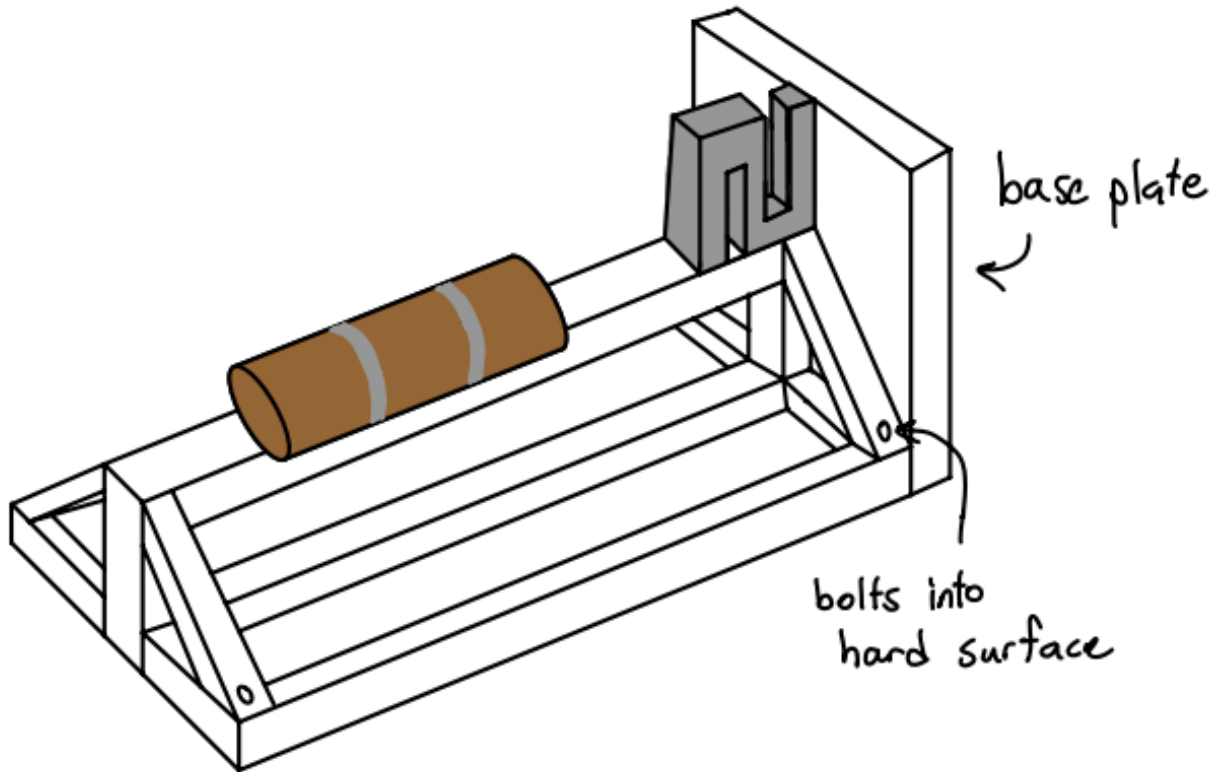


- Applying 287.8 lbf in the $-X$ direction to the motor casing mount:
 - Force max is 488.5 psi
 - Would require multiple steel plates supporting the back wall
 - More likely to failure
 - More likely for fatigue and deformation

- Assuming F.O.S of 1.5:
 - $488.5\text{psi} * 1.5 = 732.8\text{ psi}$
 - Must design back plate to withstand 732.8 psi



CONCEPT GENERATION ~ HORIZONTAL TEST STAND DESIGN 3



Design Features:

- Motor is mounted to linear bearing
- Easy to build, yet rigid structure using aluminum extrusion
- Base plate to provide support to load cell

Disadvantages:

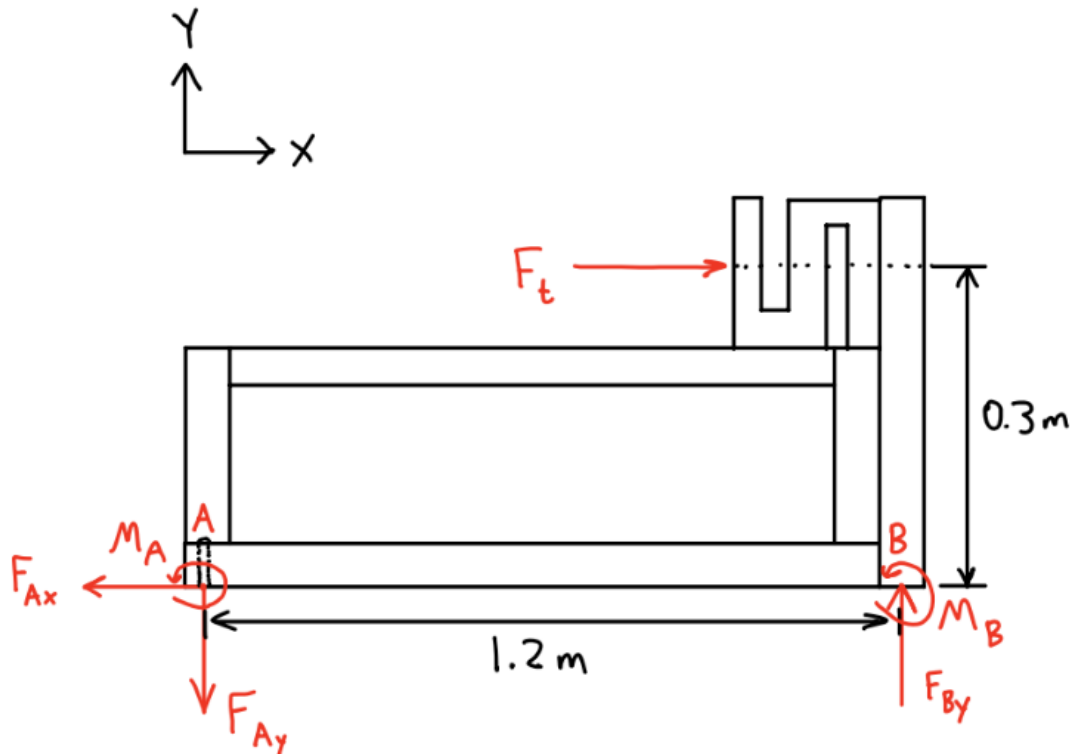
- Must be secured to a hard immovable surface
 - This would significantly increase our project cost
- The mounting bolts must be able to resist the thrust force

ENGINEERING CALCULATION ~ HORIZONTAL DESIGN 3

Given:

Impulse (I) = 5120.00 N-sec

Burn Time (t) = 4 sec



Equations:

$$I = F_t * t$$

$$F_t = \frac{I}{t}$$


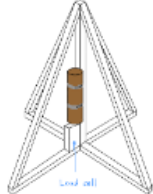
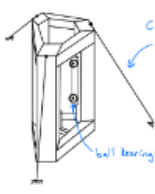
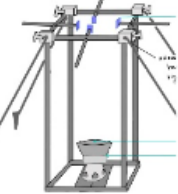
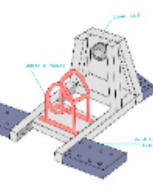
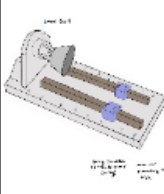
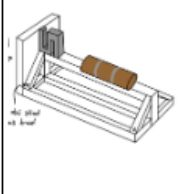
$$\sum M = 0$$

$$\sum F_x = 0$$

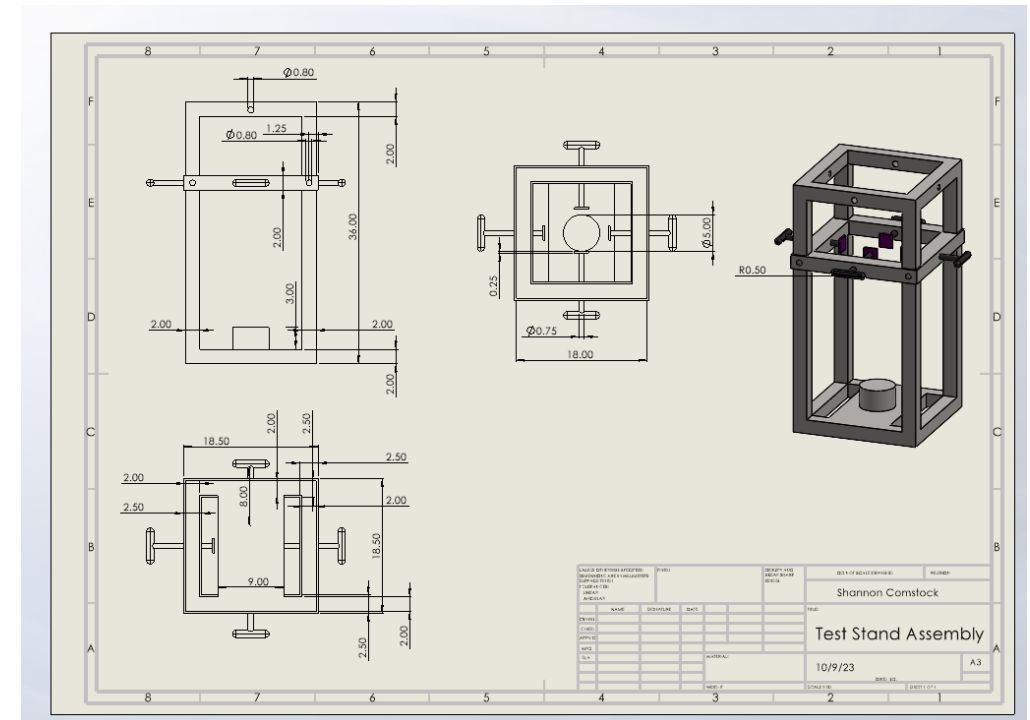
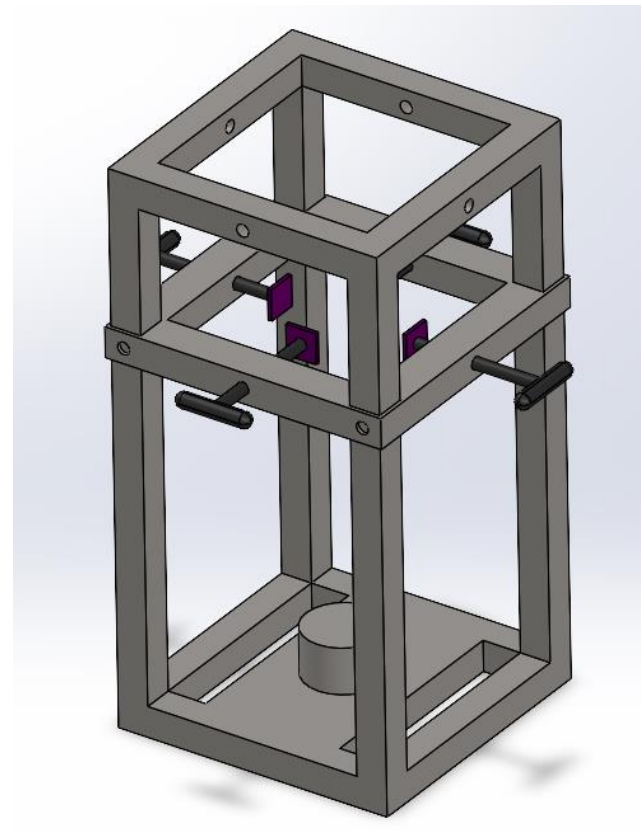
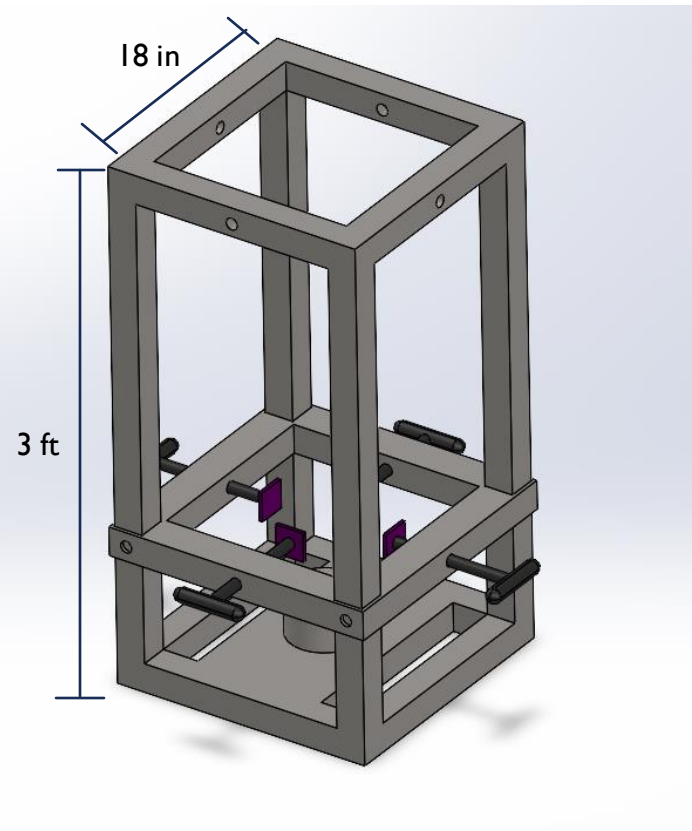
$$\sum F_y = 0$$

Force	Force (N)
F_t	1280
F_{Ax}	1280
F_{Ay}	320
F_{By}	320

CONCEPT EVALUATION

		DATUM	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Criteria	Weight							
Reach minimum altitude	2	D A T U M	0	0	0	0	0	0
Stay within Budget for the Project	2		+++	++	+	-	-	0
Dimensions meet constraints of rocket size	3		---	++	+++	--	0	+++
Stand withstands impulse of rocket testing	2		--	+	++	+++	++	+
Meet Minimum Thrust to Weight Ratio Set by Tripoli	3		0	0	0	0	0	0
Complete final launch by march 2024	2		0	0	0	0	0	0
Non-Ferrous, Ductile Casings	3		0	0	0	0	0	0
+			6	12	15	6	4	11
0		17	4	4	4	4	5	4
-			13	0	0	8	2	0
TOTAL		0	-7	12	15	-2	2	11

CONCEPT SELECTION: TEST STAND CAD MODEL



SCHEDULE

Project Start:

Display Week:

PROGRESS	PROGRESS	START	END	Focal	4 Sep 2023							11 Sep 2023							18 Sep 2023							25 Sep 2023							2 Oct 2023							9 Oct 2023							16 Oct 2023							23 Oct 2023							30 Oct 2023							6 Nov 2023						
					M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S
Project Plan																																																																										
Develop Project Plan	100%	09/05/23	10/02/23		[Gantt bar: 09/05/23 to 10/02/23]																																																																					
Develop Project Schedule	100%	09/11/23	09/23/23		[Gantt bar: 09/11/23 to 09/23/23]																																																																					
Develop Project Budget	85%	09/15/23	10/02/23		[Gantt bar: 09/15/23 to 10/02/23]																																																																					
Develop and Complete Presentation 1	100%	09/11/23	09/22/23		[Gantt bar: 09/11/23 to 09/22/23]																																																																					
Research																																																																										
Nozzle	30%	09/05/23	10/02/23		[Gantt bar: 09/05/23 to 10/02/23]																																																																					
Propellant	50%	09/05/23	10/02/23		[Gantt bar: 09/05/23 to 10/02/23]																																																																					
Test Stand	75%	09/05/23	10/02/23		[Gantt bar: 09/05/23 to 10/02/23]																																																																					
Presentation 2	95%	09/25/23	10/09/23	10/13/23	[Gantt bar: 09/25/23 to 10/09/23]																																																																					
Report 1	15%	09/30/23	10/27/23	10/27/23	[Gantt bar: 09/30/23 to 10/27/23]																																																																					
Website Check	5%	09/30/23	10/27/23	10/27/23	[Gantt bar: 09/30/23 to 10/27/23]																																																																					
Design and Build																																																																										
Initial Design	80%	09/18/23	10/12/23		[Gantt bar: 09/18/23 to 10/12/23]																																																																					
Initial Design Review	0%	10/12/23	10/12/23		[Gantt bar: 10/12/23 to 10/12/23]																																																																					
Re-Design and Modify 1	0%	10/12/23	10/19/23		[Gantt bar: 10/12/23 to 10/19/23]																																																																					
Design Approval 1	0%	10/19/23	10/19/23		[Gantt bar: 10/19/23 to 10/19/23]																																																																					
Create BOM	20%	09/18/23	10/19/23		[Gantt bar: 09/18/23 to 10/19/23]																																																																					
Test 1	0%	11/04/23	11/04/23		[Gantt bar: 11/04/23 to 11/04/23]																																																																					
1st Protoype Paper	0%	11/04/23	11/10/23		[Gantt bar: 11/04/23 to 11/10/23]																																																																					
Presentation 3	0%	10/23/23	11/06/23	10/10/23	[Gantt bar: 10/23/23 to 11/06/23]																																																																					

BUDGET



Income		Expected Expenses			Actual Expenses To-Date	
Source	Amount	Subsystem	Products Needed	Amount	Item Bought	Cost
Gore Fund	2000	Nozzle	Graphite	125		
Go Fund Me	350		Steel	150		
Undergrad Research	700		Lathe	450		
		Casing	Prototype Casings	25		
			Retaining Rings	40		
			Material for Final Casing	100		
		Test Stand	Steel Tubing	50		
			Aluminum Stock	50		
			Connectors	50		
			Bearings or Wheels	100		
EE Team	500	Test Stand Electronics	Load Cell	300		
			Arduino	50		
			Other EE Components	525		
		Test Rocket Motors	Ammonium Perchlorate	200		
			Aluminum Powder	100		
			Binder	150		
			Additives	75		
			Fuses	15		
		75mm Final Motor	Ammonium Perchlorate	250		
			Aluminum Powder	125		
			Binder	175		
			Additives	100		
			Fuses	15		
		PPE	Gloves	10		
			Eye Protection	5		
			Resperators	60		
Total	3550			3220		0

Note: all red funds can only be used for specific things

CURRENT BILL OF MATERIALS

Subsection	Material	Description / Justification	Quantity
Propellant	Ammonium Perchlorate	Oxidiser	1 Unit
	Aluminum Powder	Fuel	1 Unit
	Hydroxyl Terminated Polybutadiene (or other binder)	Propellant binder	1 Unit
	other additives depend on the properties of the specific propellant combination		1 Unit
	(show exact type of motor formula) Chris's rocket supply (research capstone teams rocket designs, other universities)		
Potential:	Fuse for lighting (Carsons fuses or E-matches)		1

Subsection	Material	Description / Justification	Quantity
Test Stand	Steel 16 gauge tubing for structure of stand		4
	20mm x 40mm aluminum extrusion for the rocket sled		2
	6mm eccenteic spacer for attaching gantry to rail		8
	Solid V-Wheel for proper sliding of the gantry sled		8
	Misc. Parts for assembly along with welding		variable
	Circular aluminum stock (4in diameter, foot long), For rocket motor clamps		1
Potential:	Load Cell (loadcell jeff has)		1
	Arduino		1
	EE Equipment for data collection		

CURRENT BILL OF MATERIALS: (CONTINUED)

Subsection	Material	Description / Justification	Quantity
Nozzle	Lathe	To machine graphite insert	1
	1018 Cold Finish Steel Round	(2 3/4" dia, 24" length), for full scale	1
	Isomolded Graphite Rod	(1.5" x 24"), to be machined into inserts f	1
	Isomolded Graphite Plate	(4"x4"x1") aerospike outer insert	1
	O-rings		

Subsection	Material	Description / Justification	Quantity
Casing	16-Series Aluminum Tubing; Inner Lining: Likely carbon fiber		1
	Prototype Casing (38mm small casing) (paper towel cardboard tube)		1
	75 mm Retaining Rings		2
	(look at DPS's casing)		

IMAGE CITATIONS

- [1] “High-power rocketry,” Wikipedia, [https://en.wikipedia.org/wiki/High-power_rocketry#/media/File:A_glorious_launch_of_my_Red_Mongoose_rocket_to_Mach_1.4_\(52387748282\).jpg](https://en.wikipedia.org/wiki/High-power_rocketry#/media/File:A_glorious_launch_of_my_Red_Mongoose_rocket_to_Mach_1.4_(52387748282).jpg) (accessed Sep. 17, 2023).
- [2] “APCP solid propulsion development,” Brandon Fallon, <https://brandonfallon.com/apcp-solid-propulsion-development/> (accessed Sep. 17, 2023).
- [3] J. Zimmer, “Launch rockets with the University of Minnesota Duluth Rocketry Team,” NASAs Minnesota Space Grant Consortium, <https://www.mnspacegrant.org/launch-rockets-with-umn-duluth/> (accessed Oct. 8, 2023).
- [4] S. Erwin, “Air Force’s rocket propulsion arm looking to invest in technologies for ‘responsive launch,’” SpaceNews, <https://spacenews.com/air-forces-rocket-propulsion-arm-looking-to-invest-in-technologies-for-responsive-launch/> (accessed Oct. 7, 2023).
- [5] “Mobile test stand,” Rice Eclipse, <http://eclipse.rice.edu/mobile-test-stand> (accessed Oct. 7, 2023).
- [6] “54/2000 aft finocyl - K6 I 6,” YouTube, <https://www.youtube.com/watch?app=desktop&v=bp4o7TBjRgA> (accessed Oct. 7, 2023).
- [7] “Building a rocket motor test stand - simplex EP 5,” YouTube, <https://www.youtube.com/watch?v=iTzKEmV2s-k> (accessed Oct. 7, 2023).

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- × [8] <https://brandonfallon.com/apcp-solid-propulsion-development/>
- × [9] https://www.rocketmotorparts.com/details/p1577809_20627885.aspx#:~:text=75mm%20Nozzle%2C%200.485%22%20Throat%20Summary&text=Dimensions%3A,2.730%22%20O.D.
- × [11] “Solid Rocket Motor Theory -- GUIPEP,” Richard Nakka’s Experimental Rocketry Site, https://www.nakka-rocketry.net/th_imp.html (accessed Oct. 12, 2023).



THANK YOU!

ANY QUESTIONS?