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]

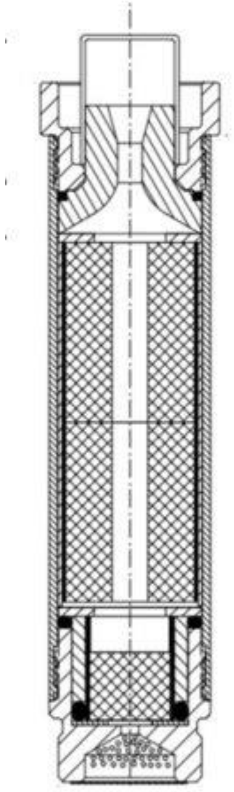


Figure 2: Propulsion section cut
Source: Solid Propulsion Development [2]

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

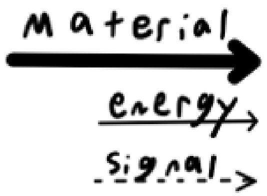
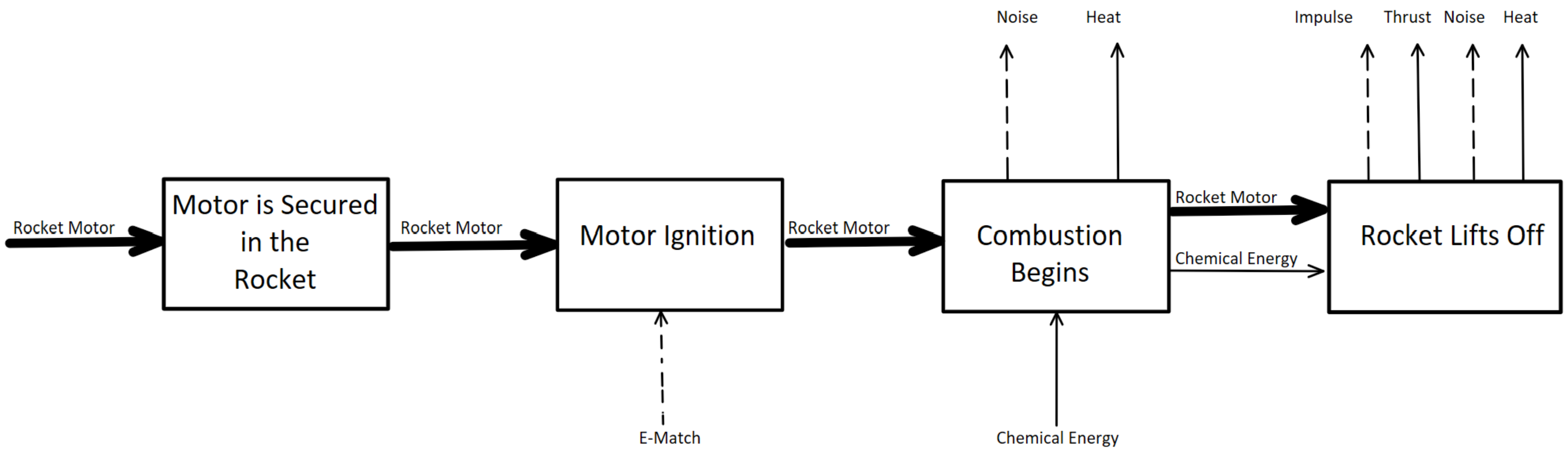


Figure 4: Propulsion Test
Source: Space News [4]



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BLACK BOX MODEL: TEST STAND

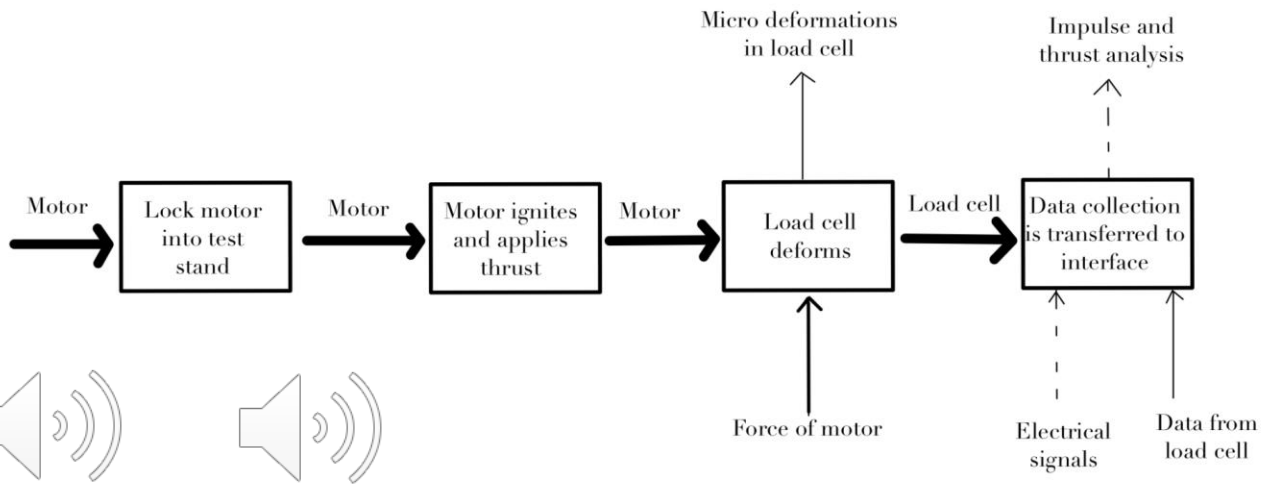
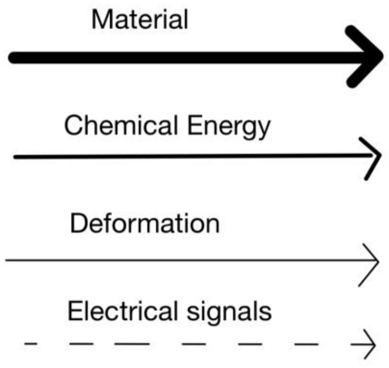


Figure 5: Test Stand
Source: Mobile Test Stand [5]



CONCEPT GENERATION: PROPELLANT FORMULATION

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

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

Percent By Weight	Component
60%	Ammonium Perchlorate
25%	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

$$\underbrace{ClH_4NO_4}_{\text{AP}} + AL + \underbrace{C_{200}H_{302}O_2 + H_{38}C_{19}O_2}_{\text{Binder}} \rightarrow \underbrace{H_2 + CO + HCl + H_2O + N_2 + Al_2O_3 + CO_2 + H}_{\text{Main Products}}$$

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

Equation 1: Exhaust Velocity Equation [11]

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

Equation 2: Specific Impulse Equation [11]

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

ProPepMain

File Options Multiple Runs Notes About

Propellant Formulation | Grain Information | Test Burns | Compute A & N

Ingredients

Name: Concept 1

Ingredient	Weight (gr)
AMMONIUM PERCHLORATE	70.00
ALUMINUM (PURE CRYSTALINE)	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
Total Wt. (grams)	100.00

Operating Conditions

Temp. of Ingredients (K): 298

Chamber Pressure (PSI): 1000

Exhaust Pressure (PSI): 14.70

☐ 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

Results

Copy Results to a File | Copy Results to Clipboard

```
 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 CRYSTALINE)    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
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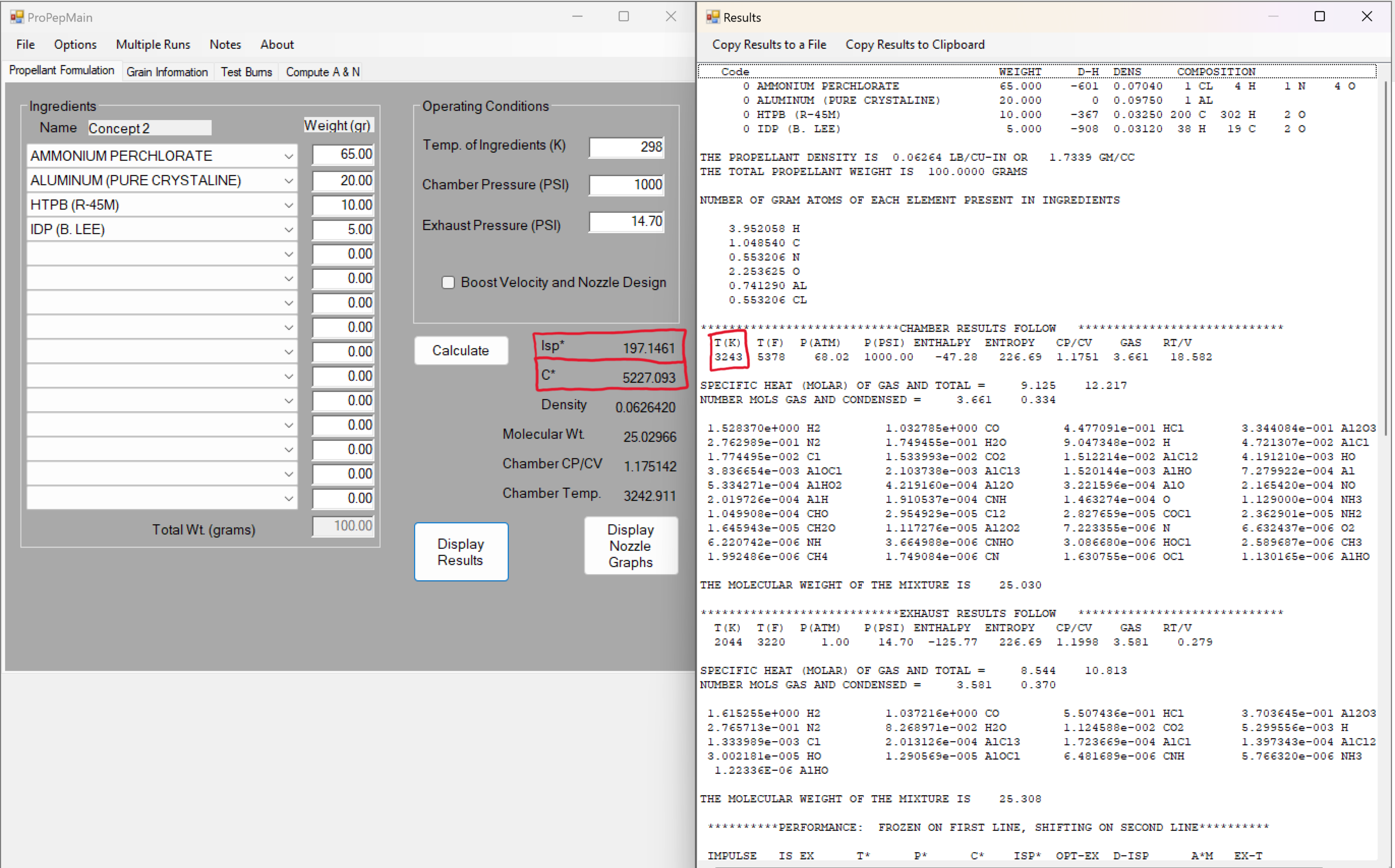

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pellant Formulation | Grain Information | Test Burns | Compute A & N

Ingredients

Name: Concept 3

Ingredient	Weight (gr)
AMMONIUM PERCHLORATE	60.00
ALUMINUM (PURE CRYSTALINE)	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
Total Wt. (grams)	100.00

Operating Conditions

Temp. of Ingredients (K): 298

Chamber Pressure (PSI): 1000

Exhaust Pressure (PSI): 14.70

☐ 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 CRYSTALINE)           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 CNCl

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*********
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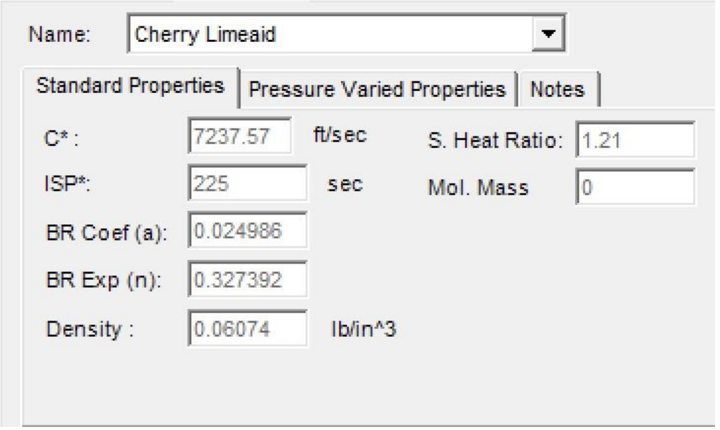
CONCEPT EVALUATION: PROPELLANT FORMULATION

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

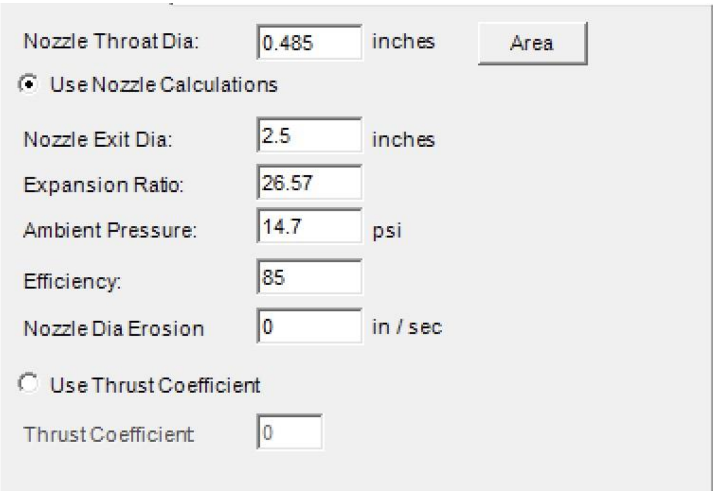
- The Datum is an average of all formulas used for similar projects

CONCEPT GENERATION: PROPELLANT GEOMETRY: BURNSIM DATA



Propellant Properties Used:

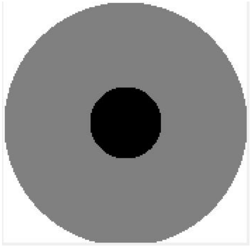
"Cherry Limeade" formulation created by MIT. [1]



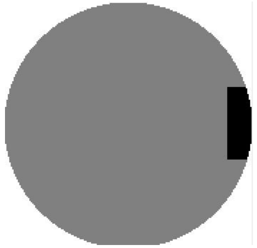
Nozzle Properties Used:

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

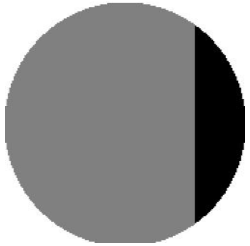
CONCEPT GENERATION: PROPELLANT GEOMETRY DEFINITIONS



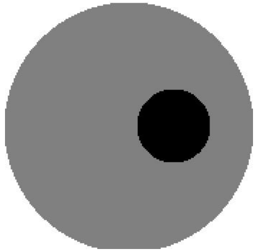
BATES Grain



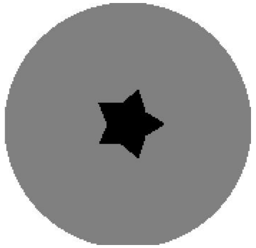
C-Slot Grain



D-Grain

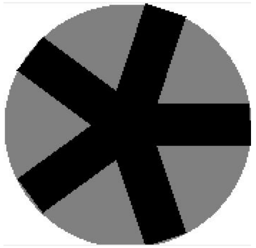


Moon Grain



Star Grain

X-Core Grain



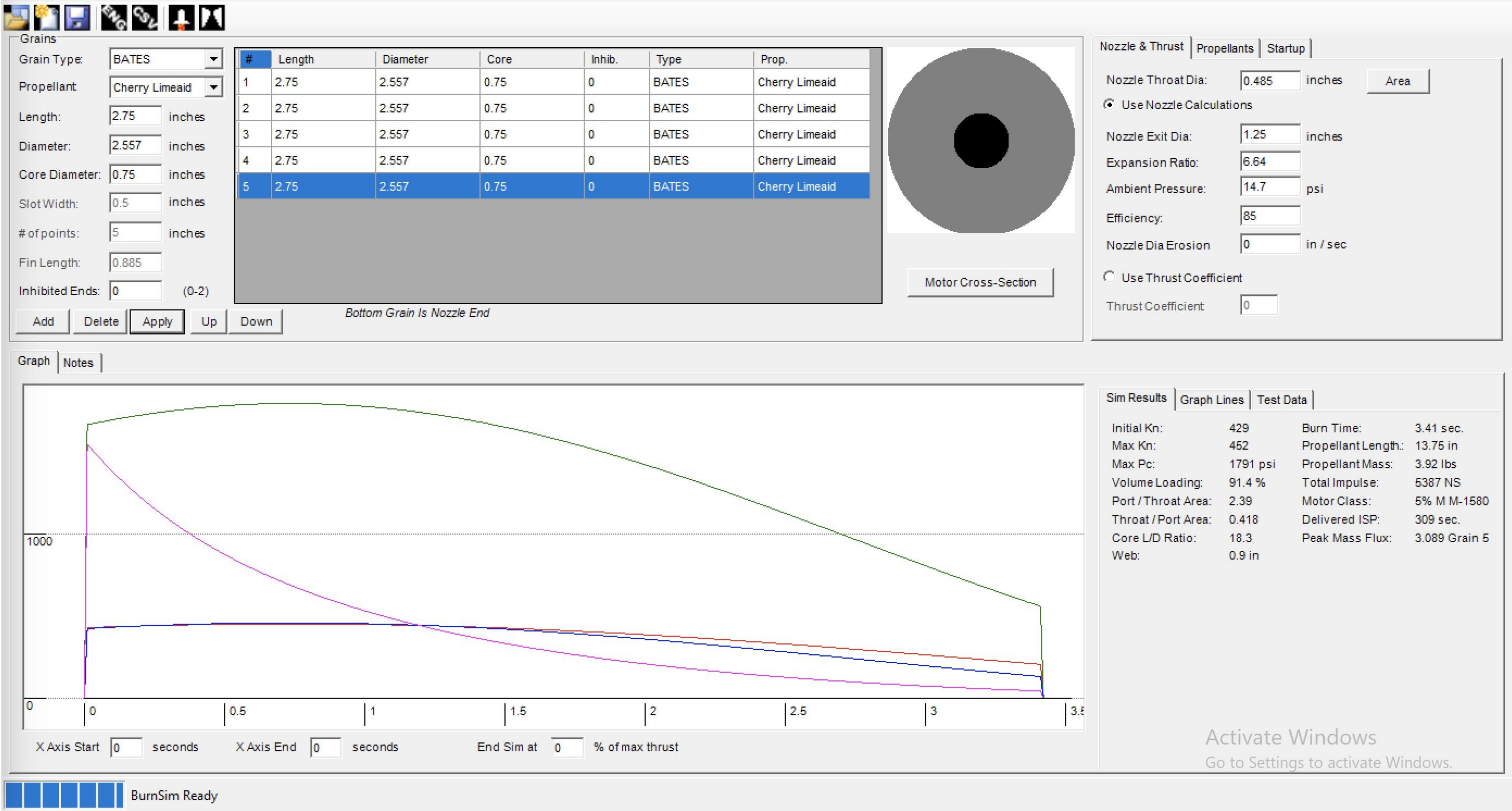
Finocyl Grain

Figure 6.

Figure 7.

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

ENGINEERING CALCULATIONS: PROPELLANT GRAIN GEOMETRIES I



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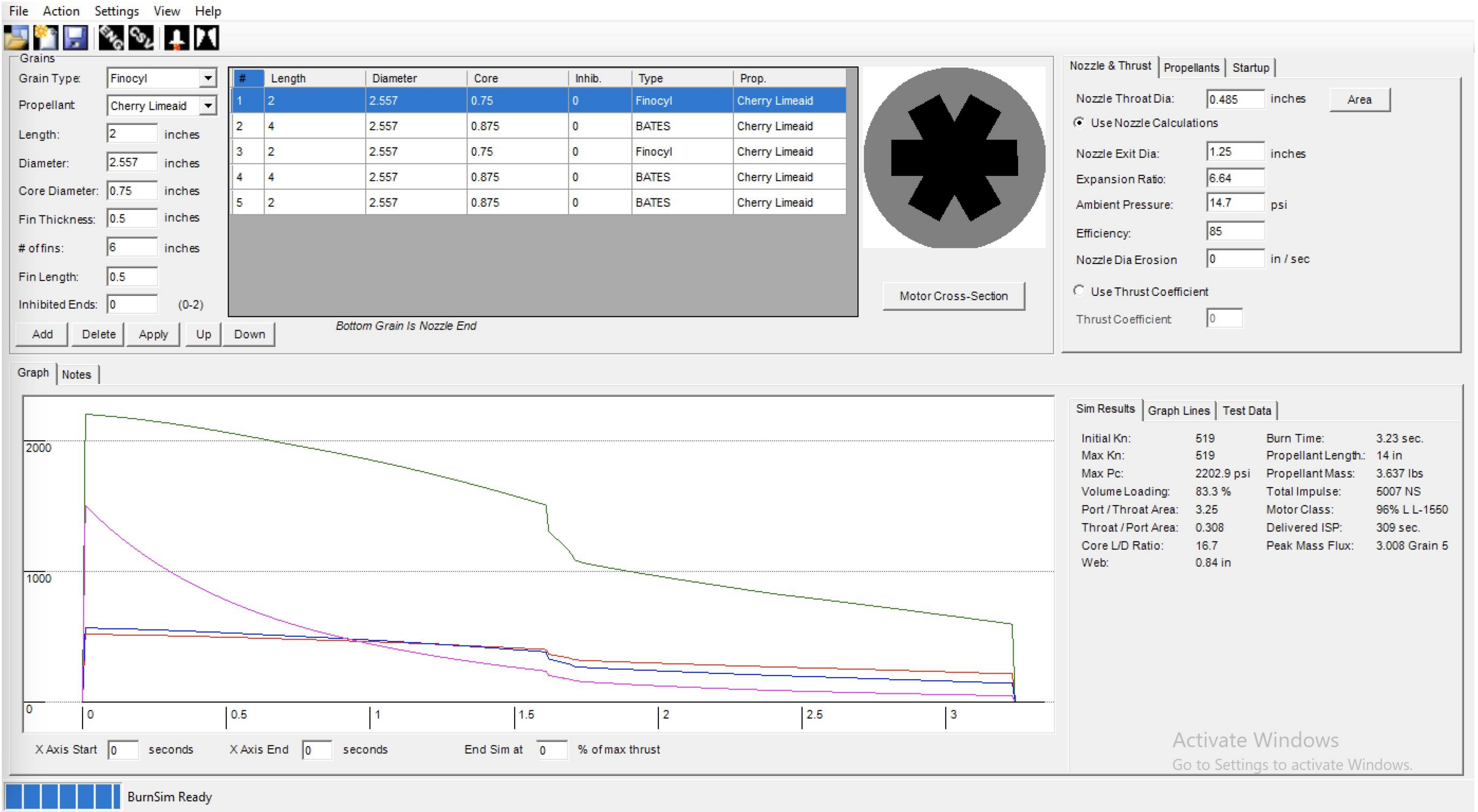
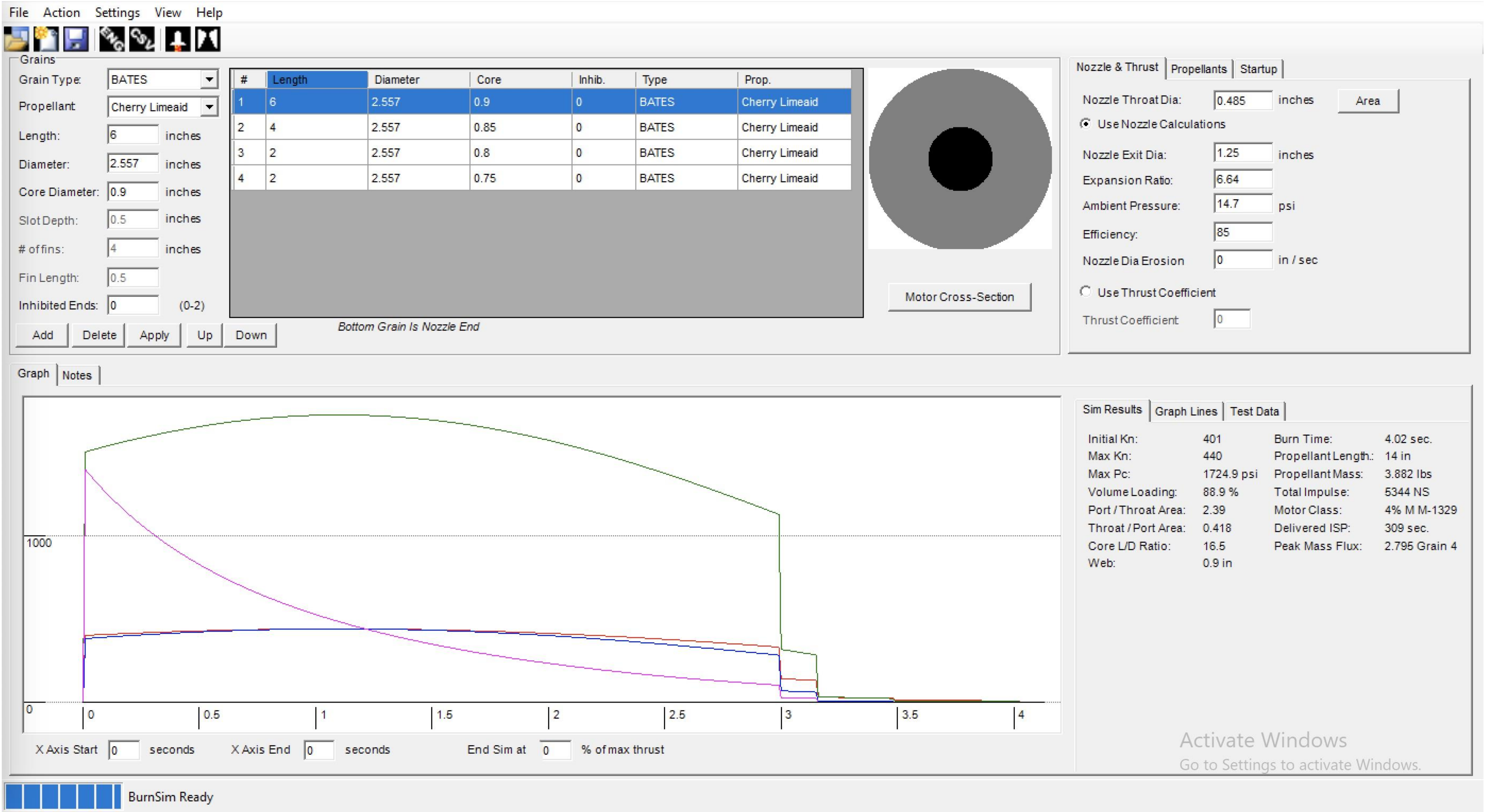
ENGINEERING CALCULATIONS: PROPELLANT GRAIN GEOMETRIES 2



ENGINEERING CALCULATIONS: PROPELLANT GRAIN GEOMETRIES 3



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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.

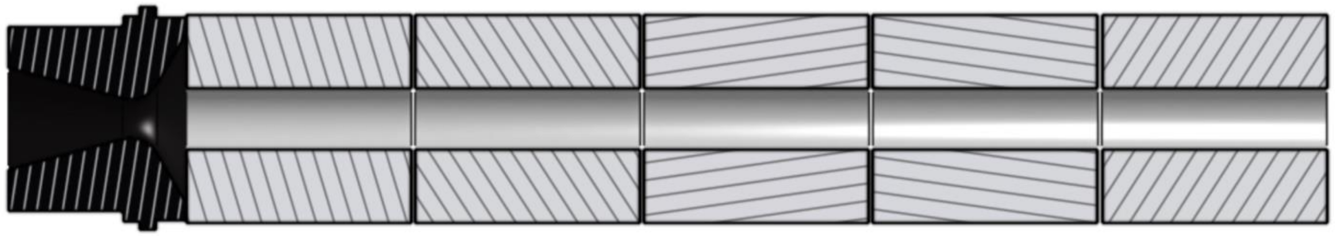
* - Ideal Measures
** - Non-Ideal Measures

CONCEPT SELECTION: PROPELLANT GEOMETRY

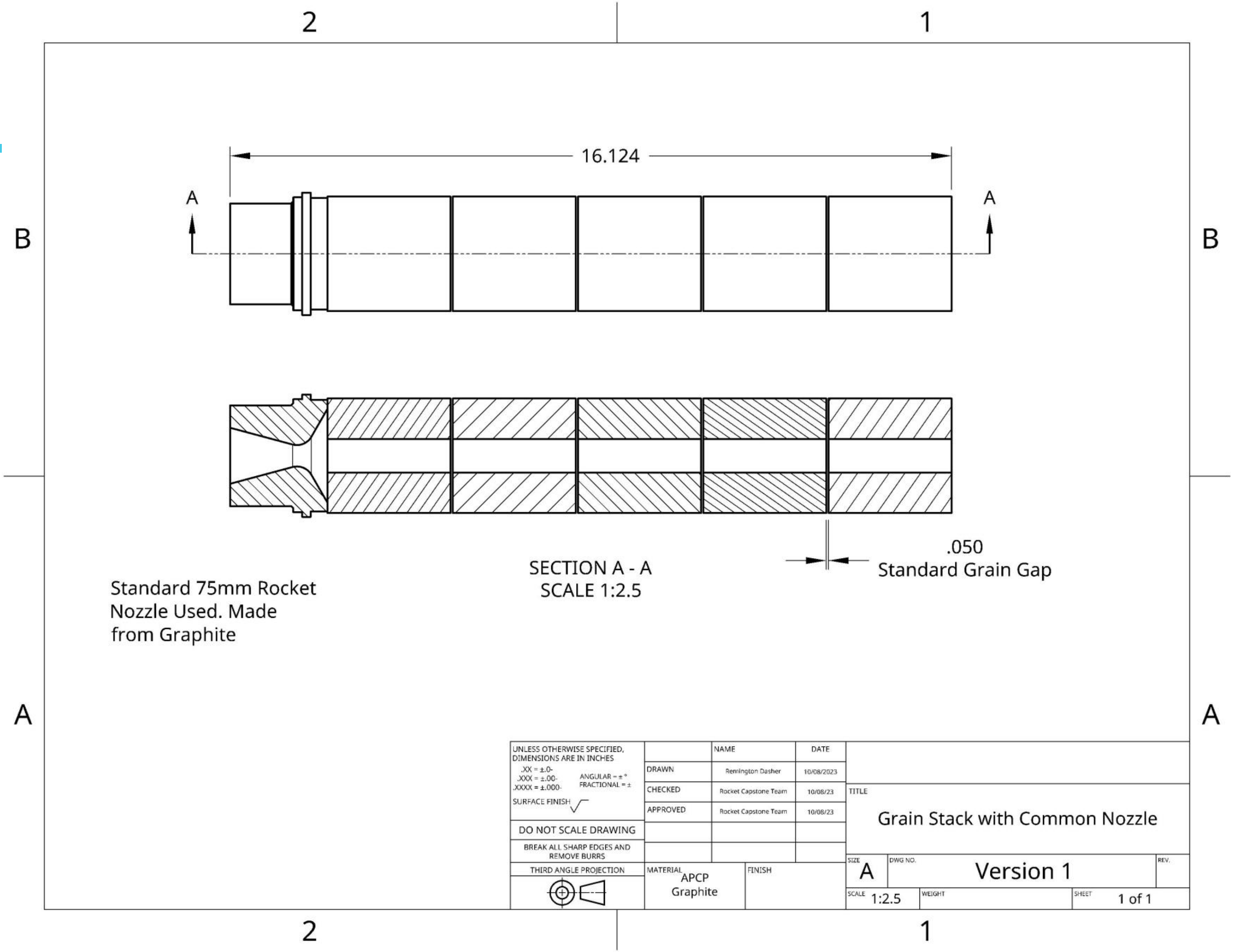
		Option 1	Option 2	Option 3	Option 4
Criteria	**Weight**	Competition Motor	Uniform Concentric	Variying Geometries	Non-Uniform Concentric
Reach minimum altitude	3	DATUM	+	-	+
Stay within Budget for the Project	2		+	-	--
Dimensions meet constraints of rocket size	3		+	+	+
Stand withstands impulse of rocket 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.



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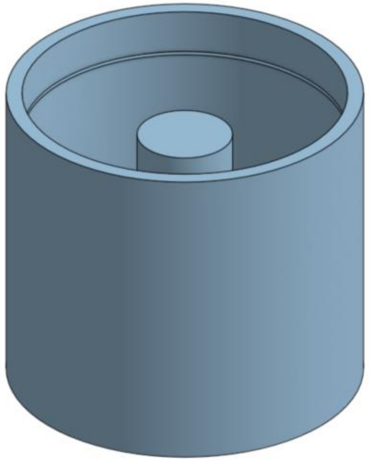
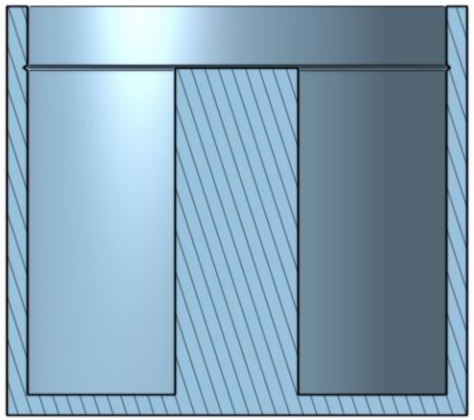
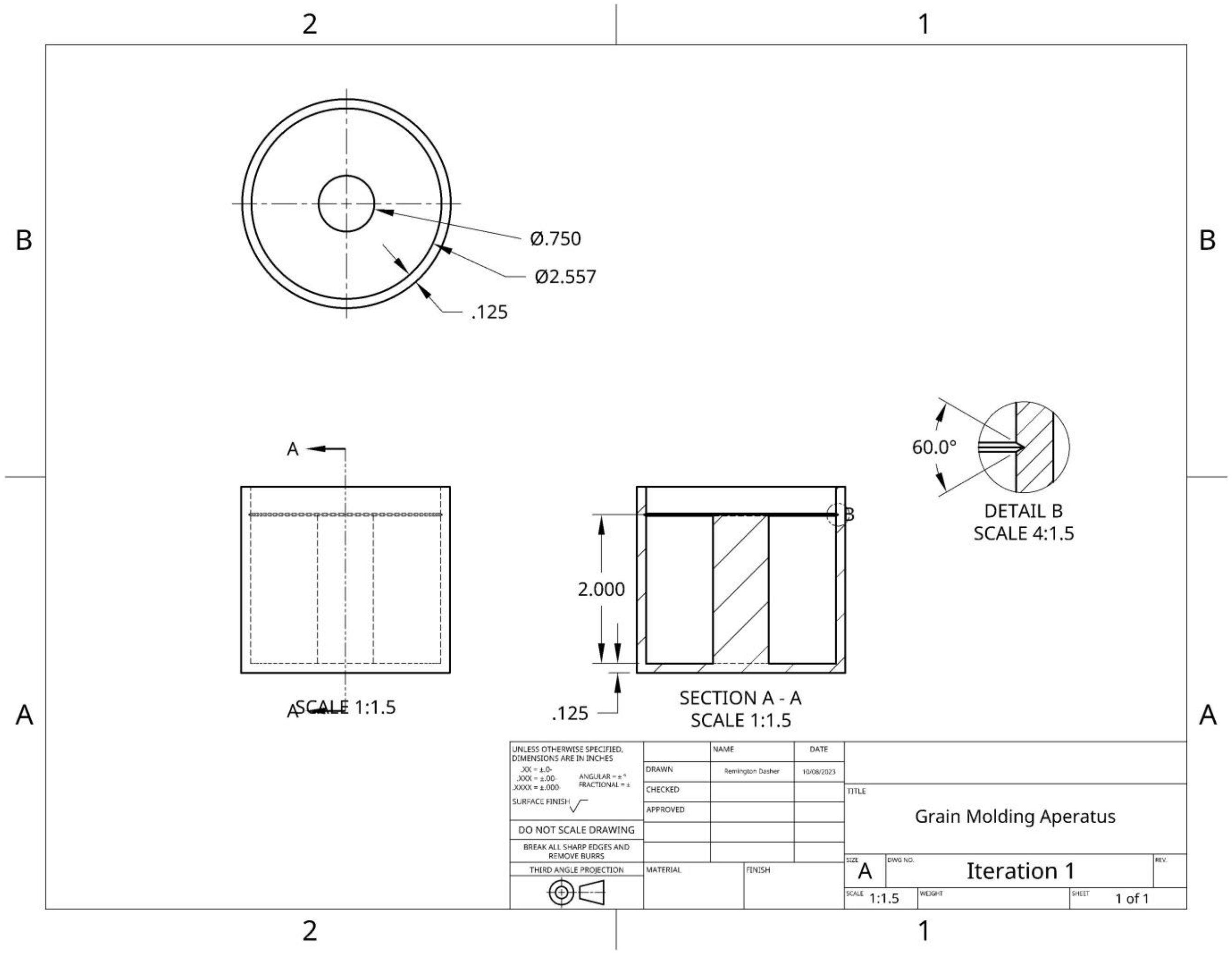
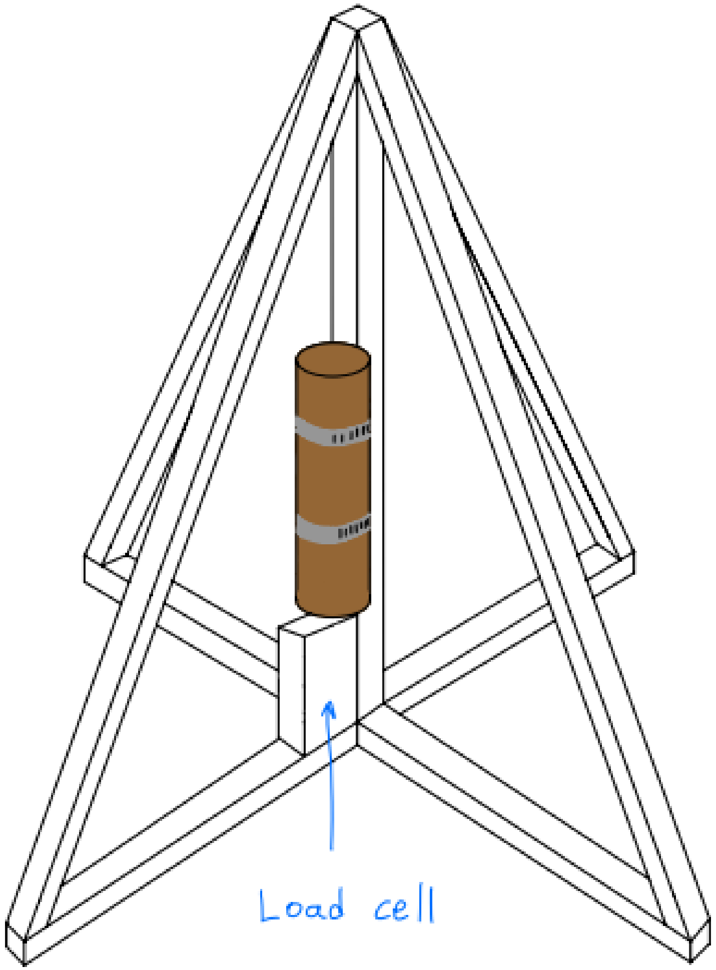
CAD MODEL (PROPELLANT GRAIN MOLDING APPARATUS







CONCEPT GENERATION ~ VERTICAL TEST STAND DESIGN 1



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 1

Equations:

$$I = F_t * t$$

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

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

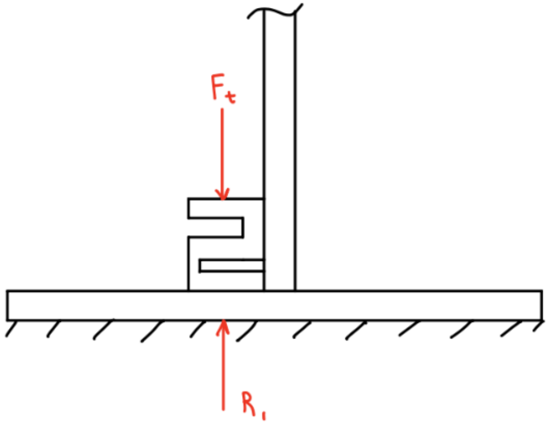
$$F_{fs} = F_R * \mu$$

Given:

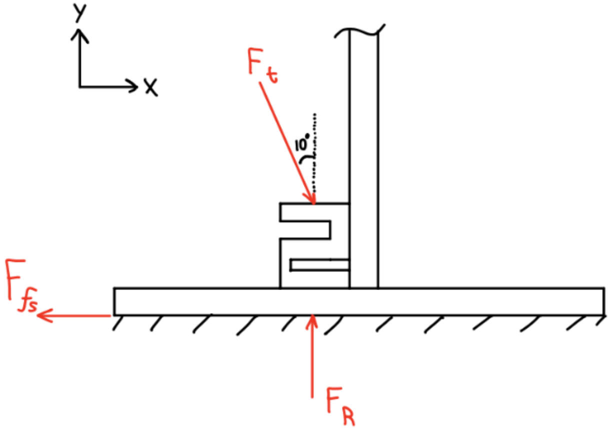
Impulse (I) = 5120.00 N-sec
Burn Time (t) = 4 sec
Gravitational Acceleration (g) = 9.80665 m/s^2
Coefficient of Static Friction (μ) = 0.56

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

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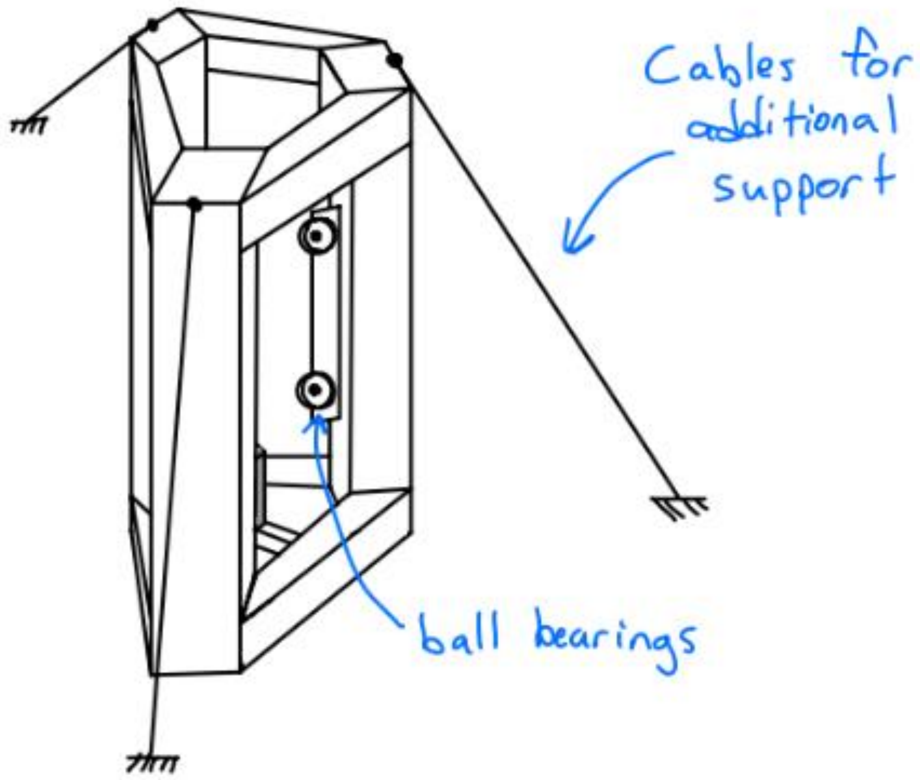
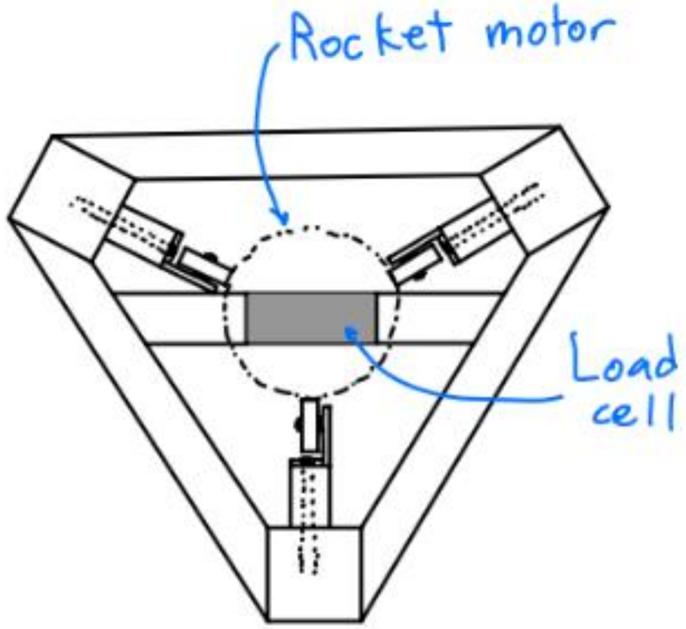
CONCEPT GENERATION ~ VERTICAL TEST STAND DESIGN 2





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:

$$I = F_t * t$$

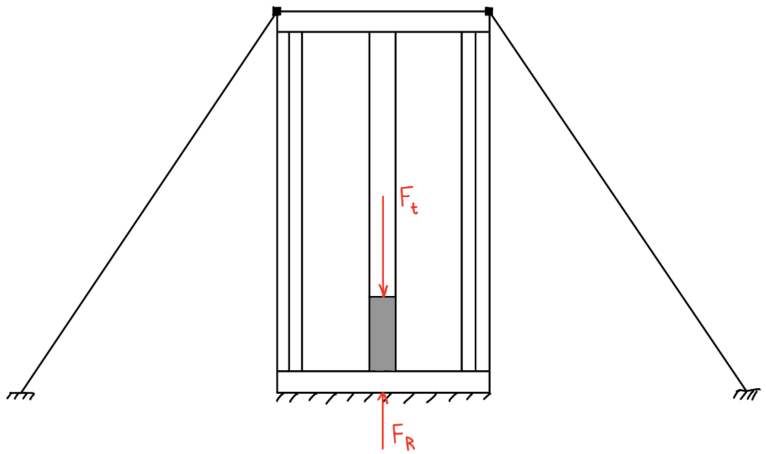
$$F_t = \frac{I}{t}$$

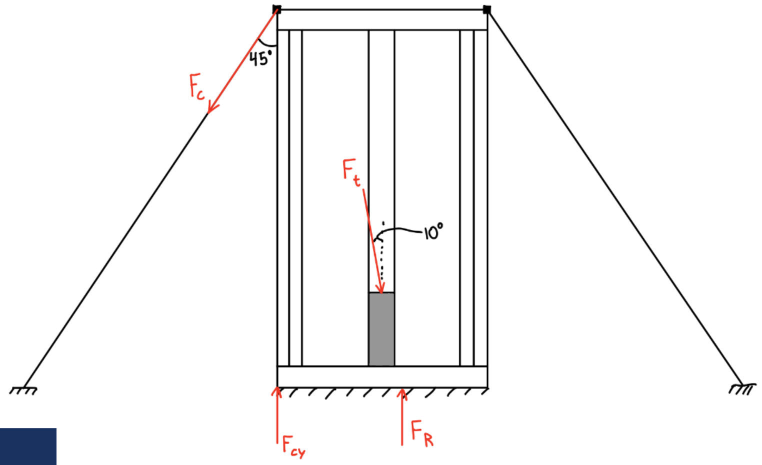
$$F_x = F_t * \cos(\theta)$$

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

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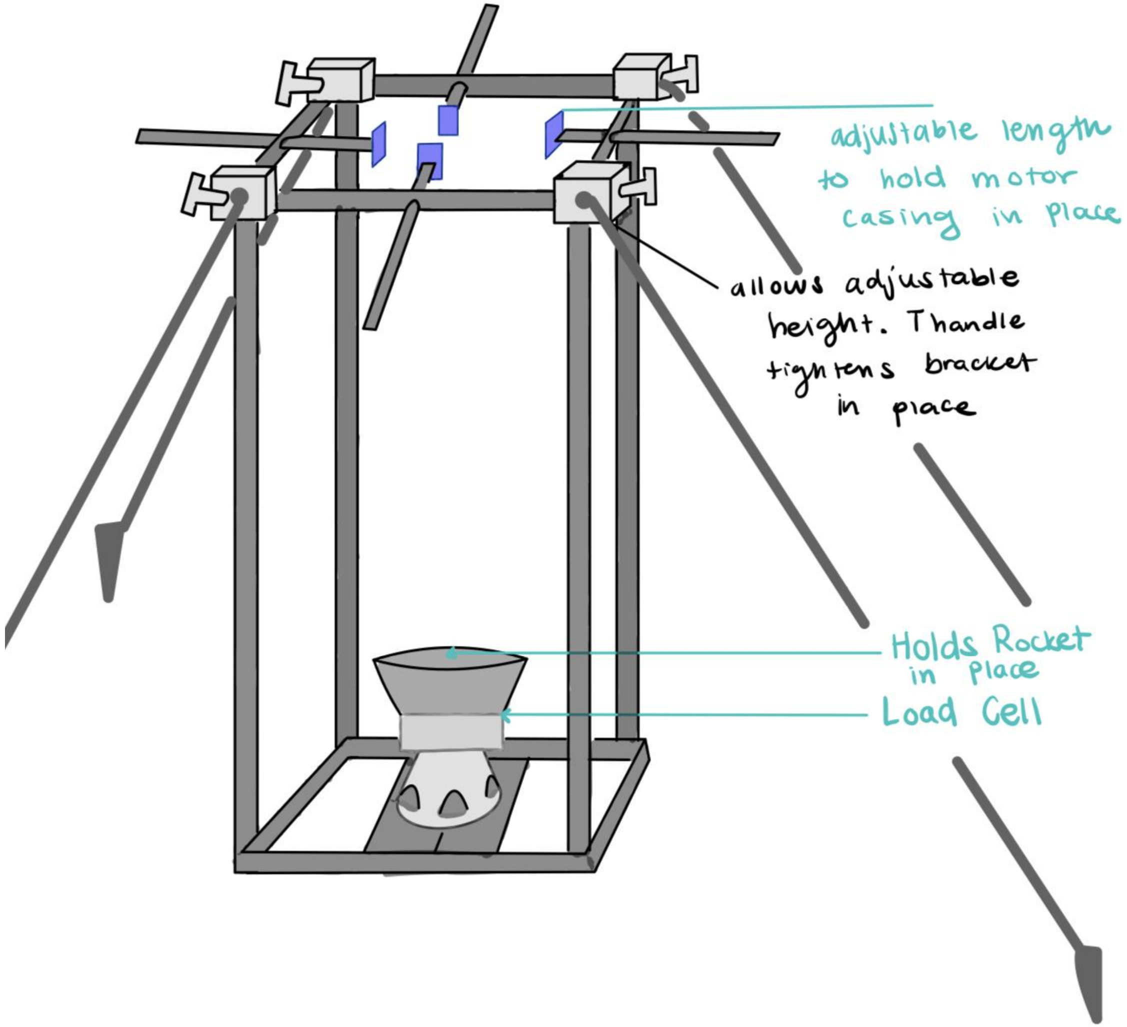
CONCEPT GENERATION ~ VERTICAL TEST STAND DESIGN 3



Design Features:

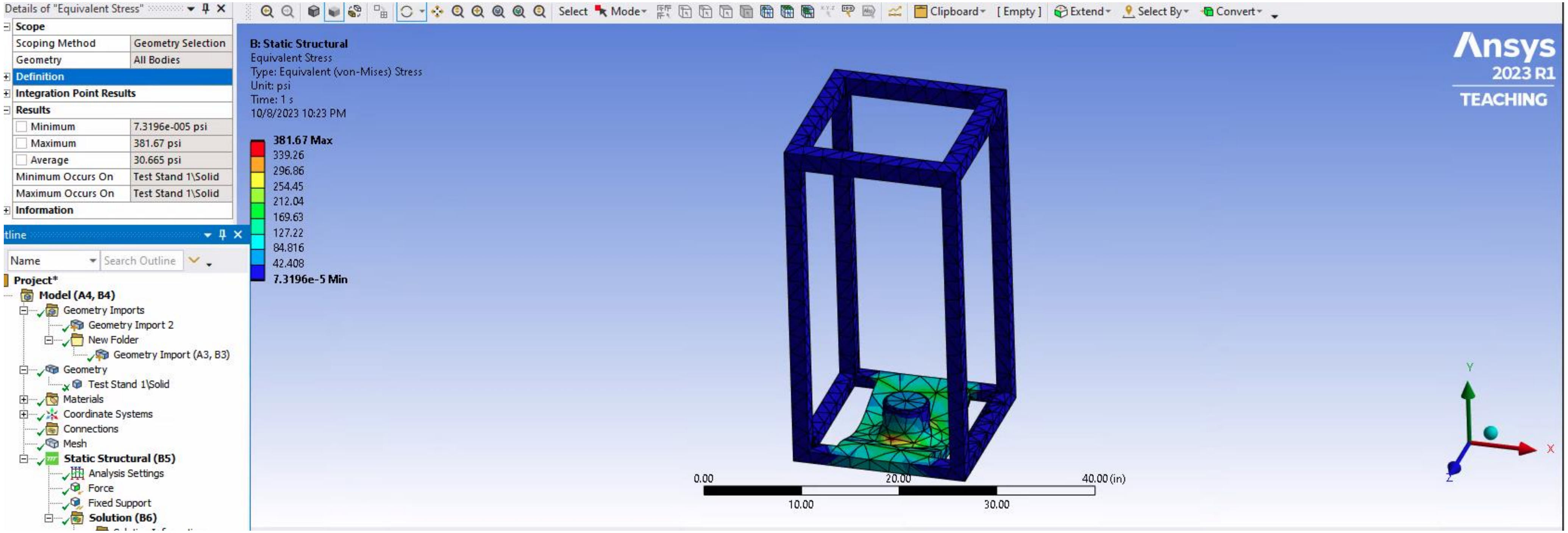
- Securely holds load cell
- Forces are distributed into ground
- Attaches at multiple points
- Points of contact are low friction
- Adjustable top allow for different diameters and heights
- Simple to build
- Structurally stable

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:
  - 381.7psi * 1.5 = 572.6 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

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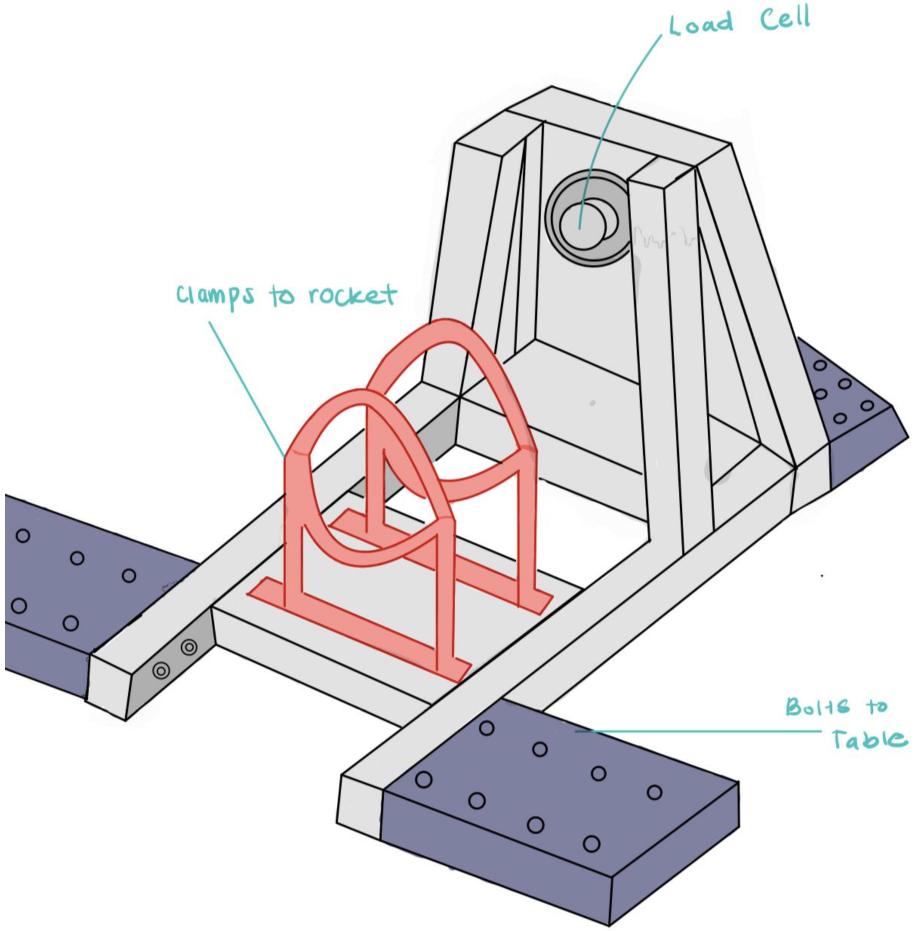
CONCEPT GENERATION ~ HORIZONTAL TEST STAND 1



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 1

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

Where 4 seconds is the approximate burn time

$+ \sum M_D = 0$

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

$(R_1)(18in) - (287.8lbf)(9in) - (287.8lbf)(4in) = 0$

$R_1 = 204.9lbf$ ↓

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

$R_{Dy} = 204.9lbf$

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

$R_{Dx} = 287.8lbf$ ↑

$+ \sum M_B = 0$

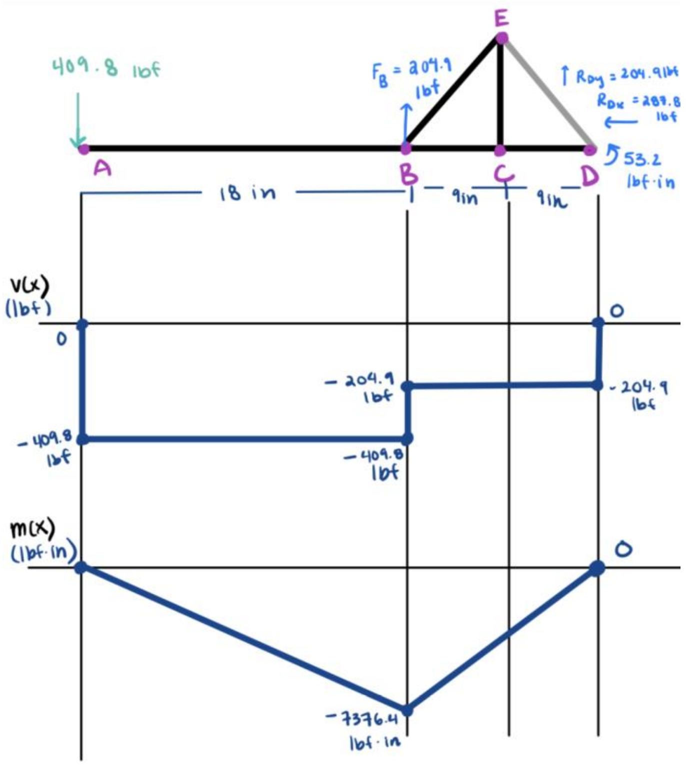
$-(287.8lbf)(9in) - (287.8lbf)(4in) + M_D + (204.9lbf)(18in) = 0$

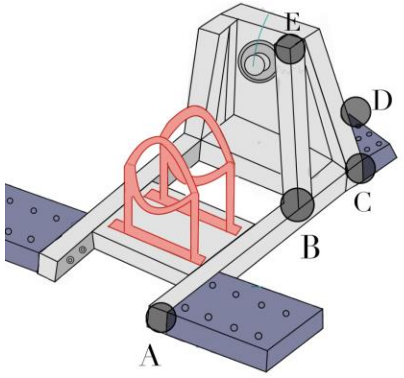
$M_D = 53.2\ lbf * in$

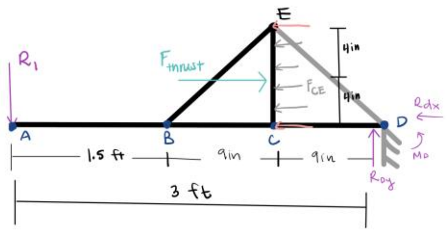
$-R_{Ay} + R_{Dy} + F_B = 0$

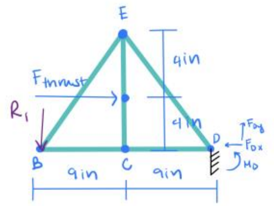
$-R_{Ay} + 204.9lbf + 2 - 4.9lbf = 0$

$R_{Ay} = 409.8lbf$









- 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 lbf * 1.5 =614.7 lbf

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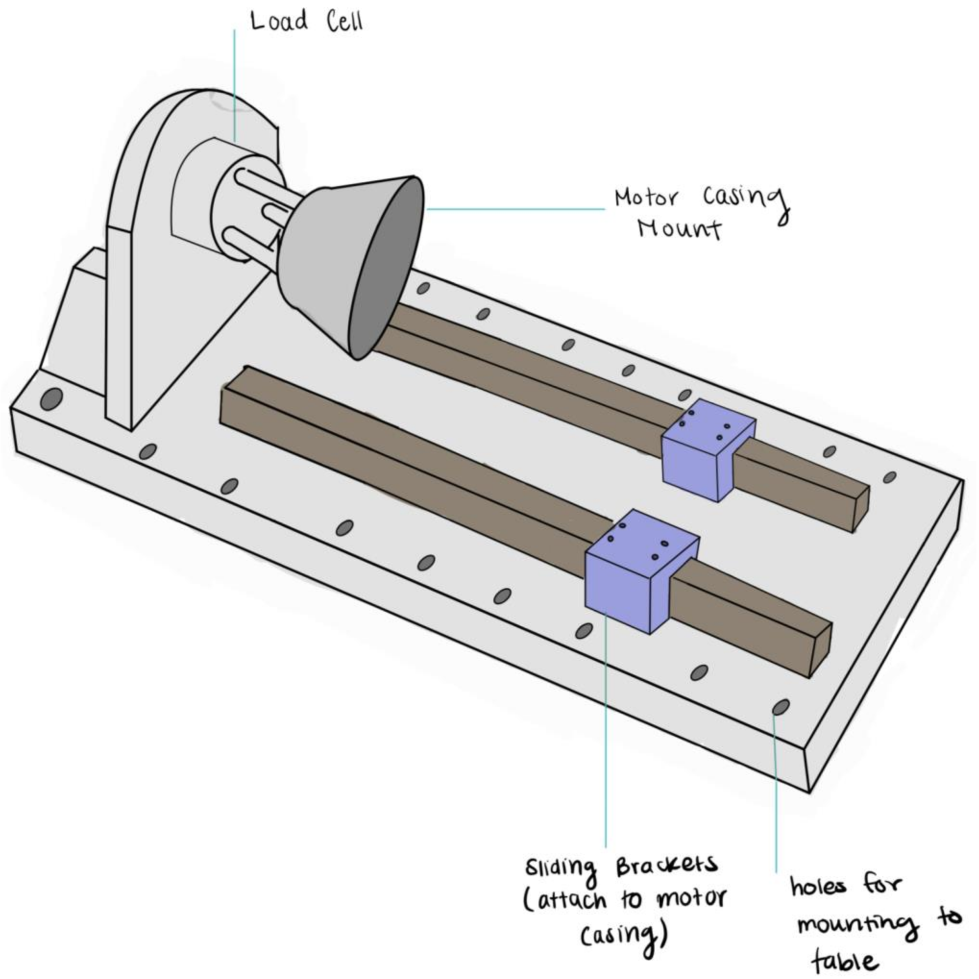
CONCEPT GENERATION ~ HORIZONTAL TEST STAND 2



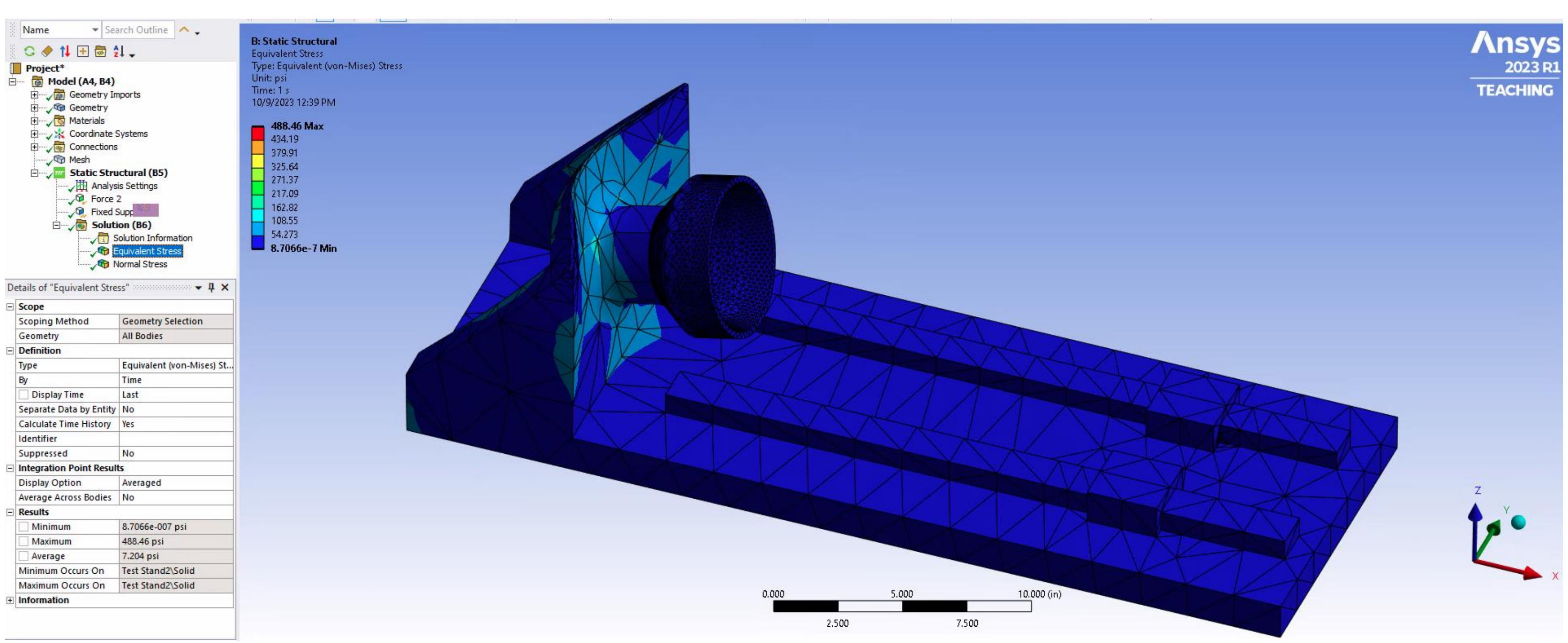
Design Features:

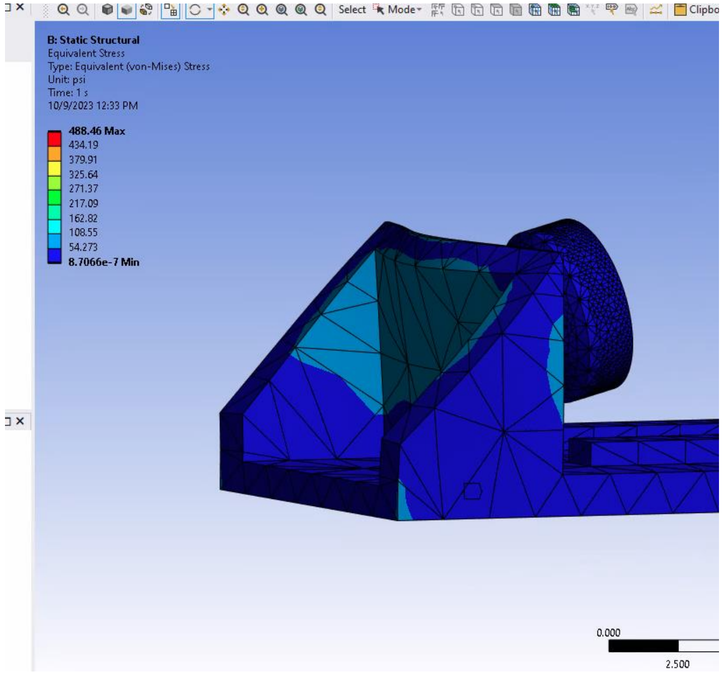
- Friction is negligible
- Gravity is negligible
- Simple to build
- Cost efficient

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:
  - 488.5psi * 1.5 = 732.8 psi
  - Must design back plate to withstand 732.8 psi

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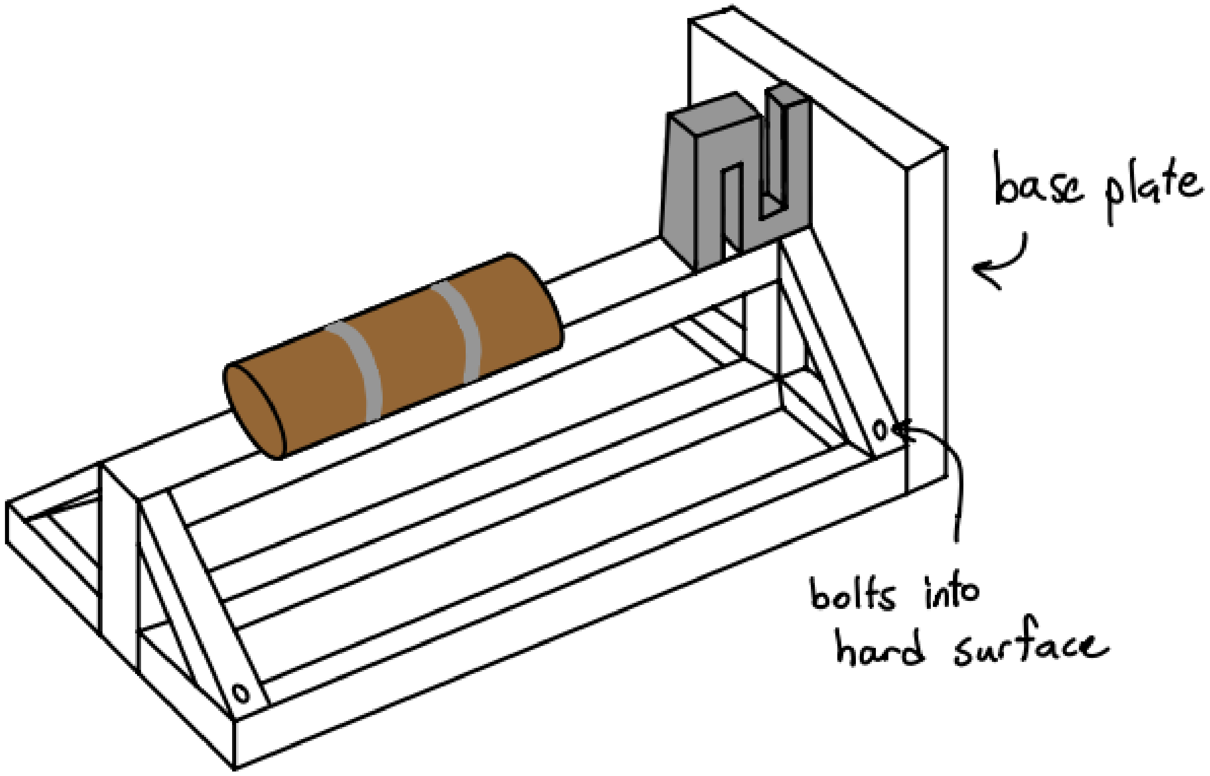
CONCEPT GENERATION ~ HORIZONTAL TEST STAND DESIGN 3



Design Features:

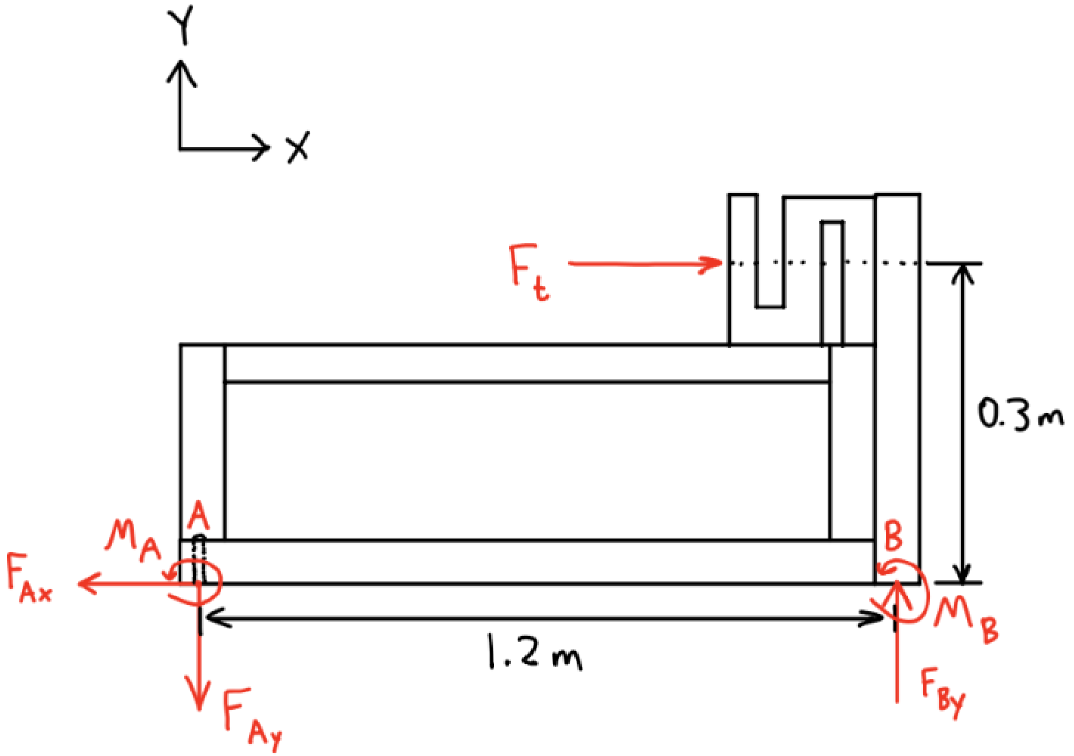
- Motor is mounted to linear bearing
- Easy to build, yet rigid structure using aluminum extrusion
- Base plate to provide support to load cell

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:

$$I = F_t * t$$

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

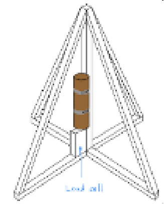
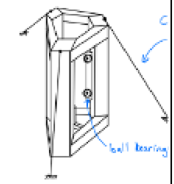
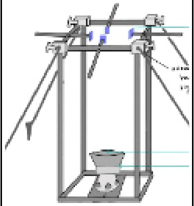
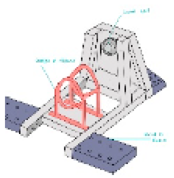
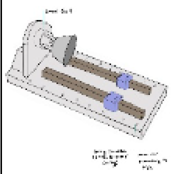
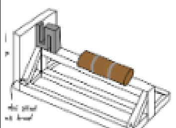
$$\sum M = 0$$

$$\sum F_x = 0$$

$$\sum F_y = 0$$

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		0	0	0	0	0	0
Stay within Budget for the Project	2		+++	++	+	-	-	0
Dimensions meet constraints of rocket size	3	D	---	++	+++	--	0	+++
Stand withstands impulse of rocket testing	2	A	--	+	++	+++	++	+
Meet Minimum Thrust to Weight Ratio Set by Tripoli	3	T	0	0	0	0	0	0
Complete final launch by march 2024	2	U	0	0	0	0	0	0
Non-Ferrous, Ductile Casings	3	M	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

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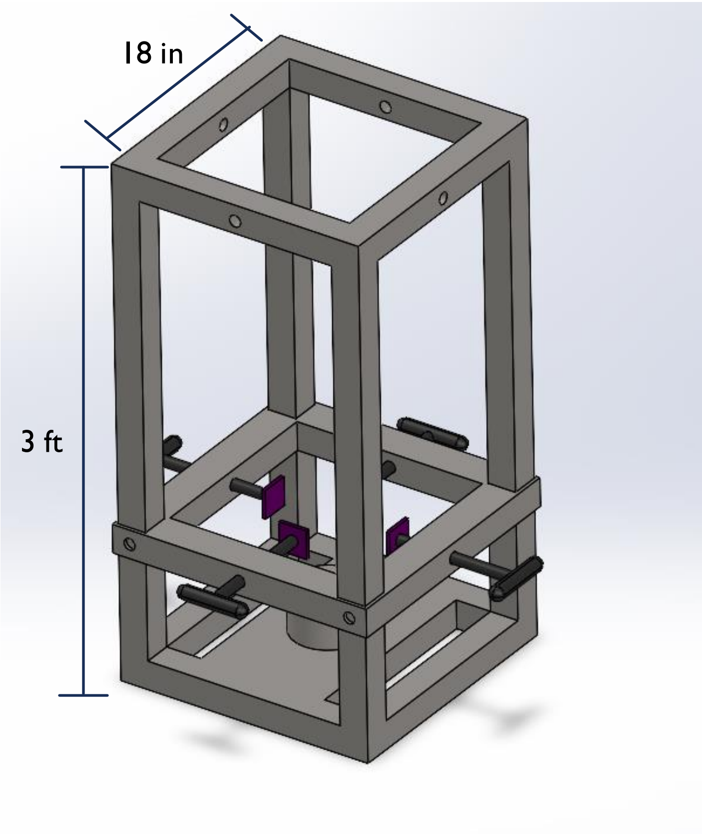
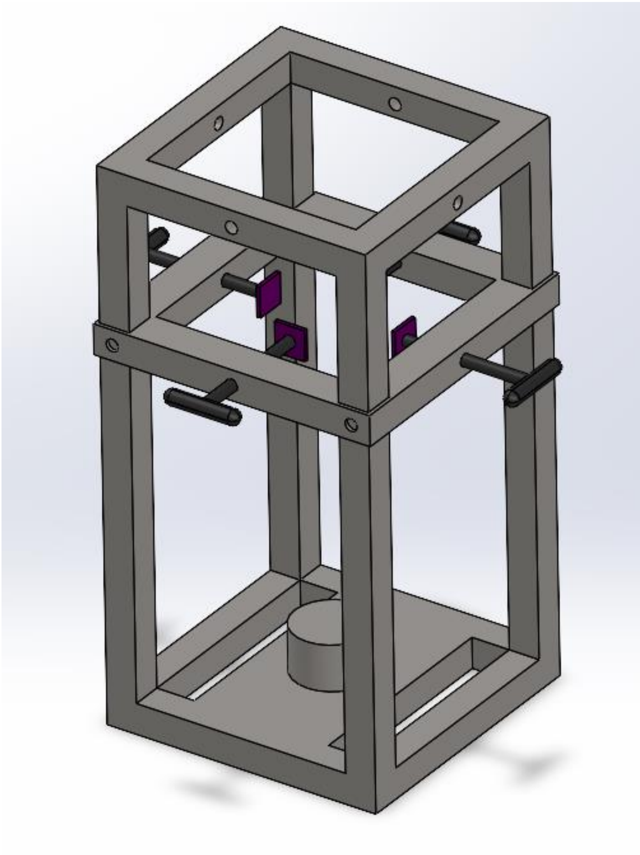
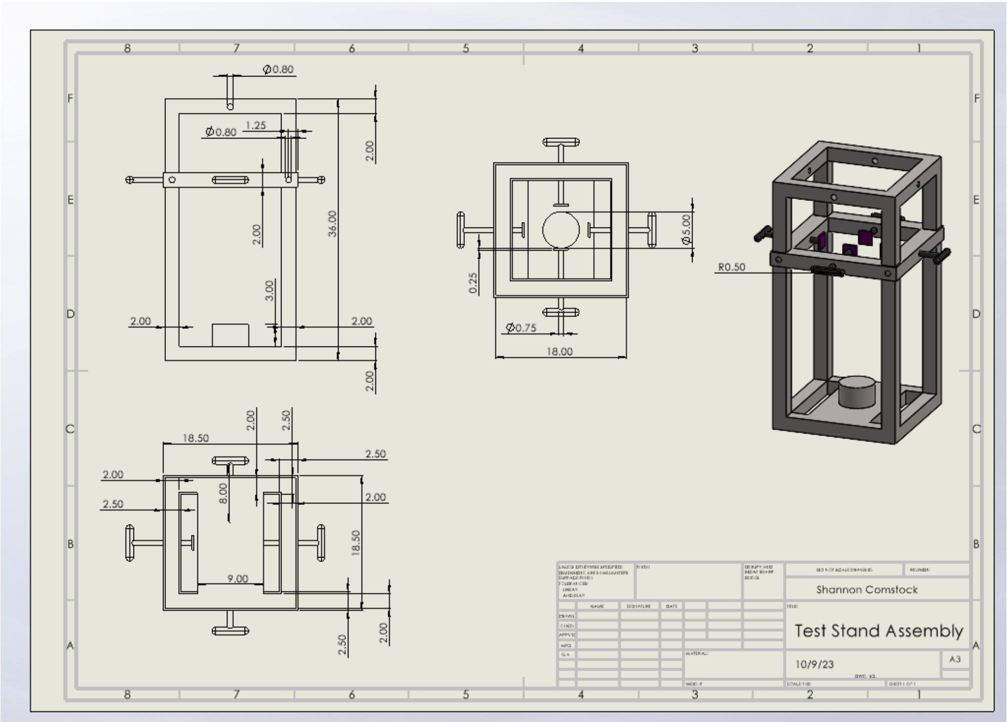
CONCEPT SELECTION: TEST STAND CAD MODEL



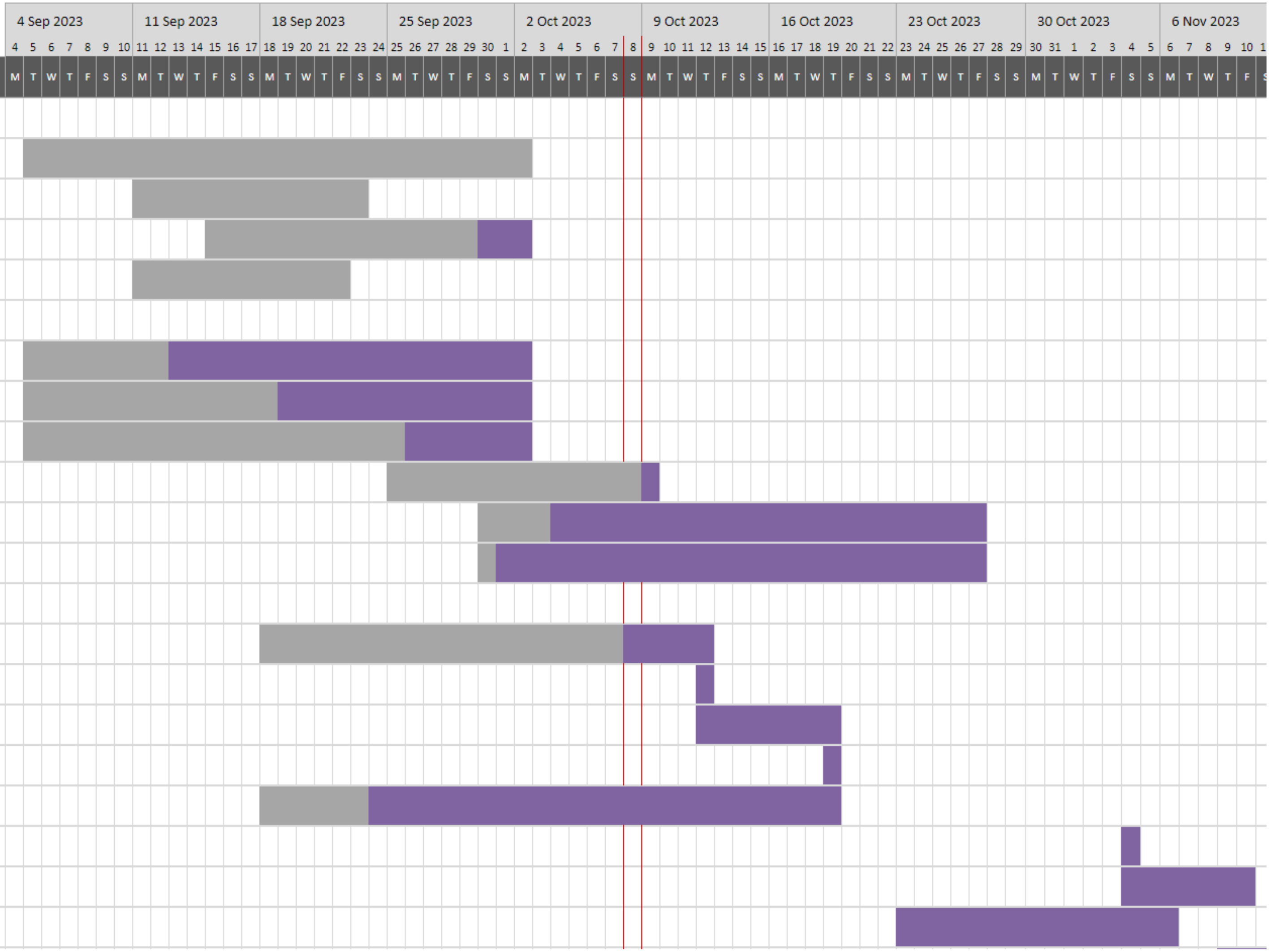




SCHEDULE

Project Start:	09/04/23	05/06/24
Display Week:	1	

PROGRESS	PROGRESS	START	END	Focal
Project Plan				
Develop Project Plan	100%	09/05/23	10/02/23	
Develop Project Schedule	100%	09/11/23	09/23/23	
Develop Project Budget	85%	09/15/23	10/02/23	
Develop and Complete Presentation 1	100%	09/11/23	09/22/23	
Research				
Nozzle	30%	09/05/23	10/02/23	
Propellant	50%	09/05/23	10/02/23	
Test Stand	75%	09/05/23	10/02/23	
Presentation 2	95%	09/25/23	10/09/23	10/13/23
Report 1	15%	09/30/23	10/27/23	10/27/23
Website Check	5%	09/30/23	10/27/23	10/27/23
Design and Build				
Initial Design	80%	09/18/23	10/12/23	
Initial Design Review	0%	10/12/23	10/12/23	
Re-Design and Modify 1	0%	10/12/23	10/19/23	
Design Approval 1	0%	10/19/23	10/19/23	
Create BOM	20%	09/18/23	10/19/23	
Test 1	0%	11/04/23	11/04/23	
1st Protoype Paper	0%	11/04/23	11/10/23	
Presentation 3	0%	10/23/23	11/06/23	10/10/23



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

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 extrustion 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 (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 - K616,” 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=iTzKEmW2s-k (accessed Oct. 7, 2023).

RESEARCH CITATIONS

- [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?