NAU Rocket Propulsion Capstone Team #3

Shannon Comstock, Remy Dasher, Andrew King, Grace Morris

PROJECT DESCRIPTION

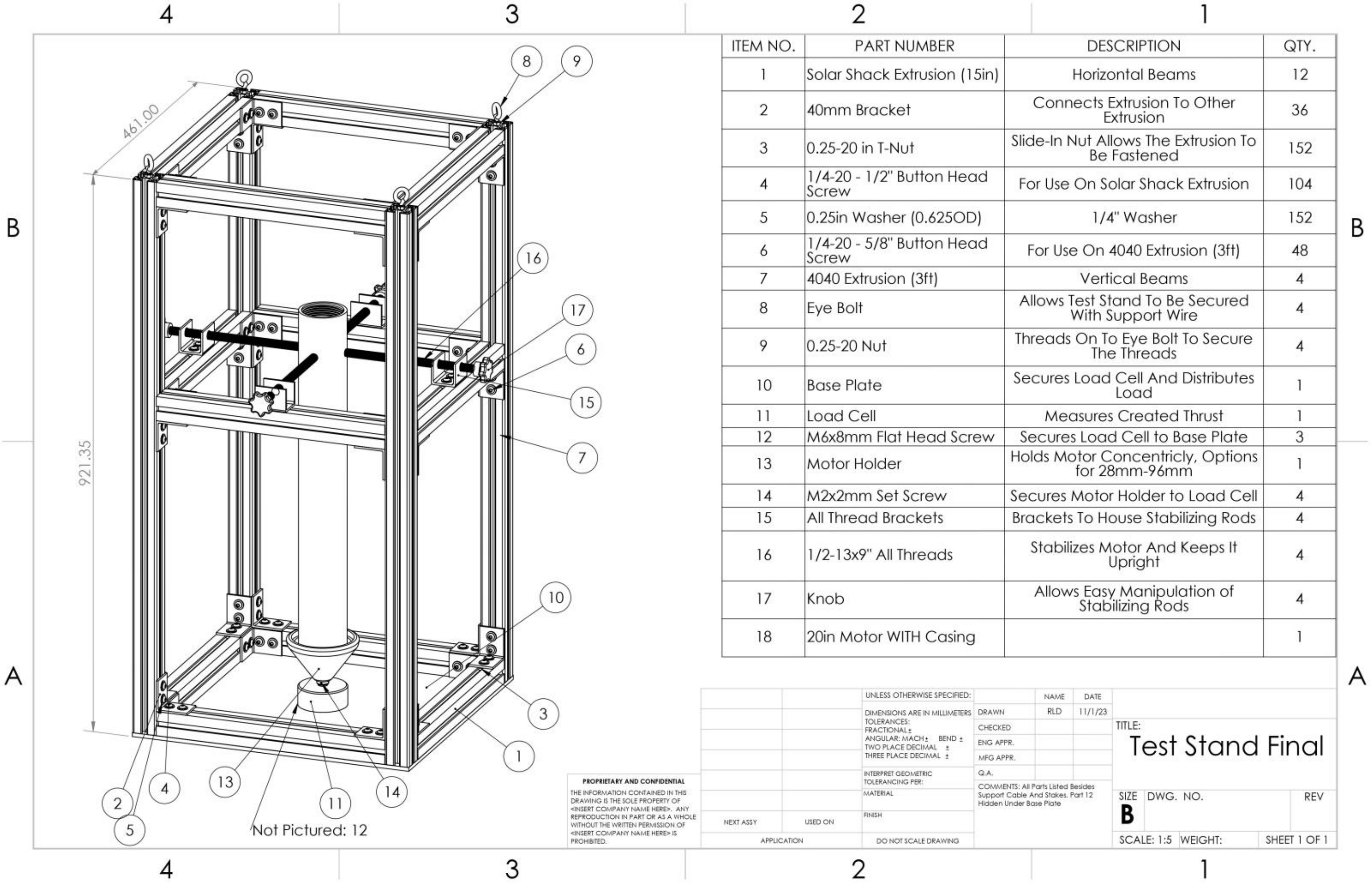
Build a propulsion system for a high-power level 2 rocket:

- Develop a unique Ammonium Perchlorate Composite Propellant (APCP) formula
  - working with mentor(s)
  - using software simulators
- Design and build a rocket test stand (currently in build stage)
  - Work with EE team to input thrust and impulse data
- Have at least two motor testing's small scale 38 and 54 mm
- Impulse must not exceed 5120 Newton-seconds
- Optimize propellant formula
- Design and build a motor casing for final 75 mm
- Build a final 75mm diameter rocket motor to launch in March 2024

Figure 1: Level 2 Rocket
Source: Apogee Components [1]

DESIGN DESCRIPTION: TEST STAND

- Rocket motor is locked into motor holder (#13)
- Sliding extrusion bars are moved to just below the nozzle
- Tighten knobs (#17) such that the threaded bar (#16) applies pressure to motor from all sides
- Attach cables to hooks at top of test stand (#8) and use stakes to secure the cables in ground
- Ensure motor is locked in place and load cell (#11) is secure



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Solar Shack Extrusion (15in)	Horizontal Beams	12
2	40mm Bracket	Connects Extrusion To Other Extrusion	36
3	0.25-20 in T-Nut	Slide-In Nut Allows The Extrusion To Be Fastened	152
4	1/4-20 - 1/2" Button Head Screw	For Use On Solar Shack Extrusion	104
5	0.25in Washer (0.625OD)	1/4" Washer	152
6	1/4-20 - 5/8" Button Head Screw	For Use On 4040 Extrusion (3ft)	48
7	4040 Extrusion (3ft)	Vertical Beams	4
8	Eye Bolt	Allows Test Stand To Be Secured With Support Wire	4
9	0.25-20 Nut	Threads On To Eye Bolt To Secure The Threads	4
10	Base Plate	Secures Load Cell And Distributes Load	1
11	Load Cell	Measures Created Thrust	1
12	M6x8mm Flat Head Screw	Secures Load Cell to Base Plate	3
13	Motor Holder	Holds Motor Concentricly, Options for 28mm-96mm	1
14	M2x2mm Set Screw	Secures Motor Holder to Load Cell	4
15	All Thread Brackets	Brackets To House Stabilizing Rods	4
16	1/2-13x9" All Threads	Stabilizes Motor And Keeps It Upright	4
17	Knob	Allows Easy Manipulation of Stabilizing Rods	4
18	20in Motor WITH Casing		1

Figure 2: Engineering Drawing Test Stand

DESIGN DESCRIPTION: MOTOR

- The motor features three major components:
  - Propellant (#1)
  - Casting Tubes (#2)
  - Liners (#3)
- The propellant will be cast into individual casting tubes
- Multiple grains: casting tubes with propellant grains inside slide into the liner
- The liner with the grains inside makes the motor which slides into the casing

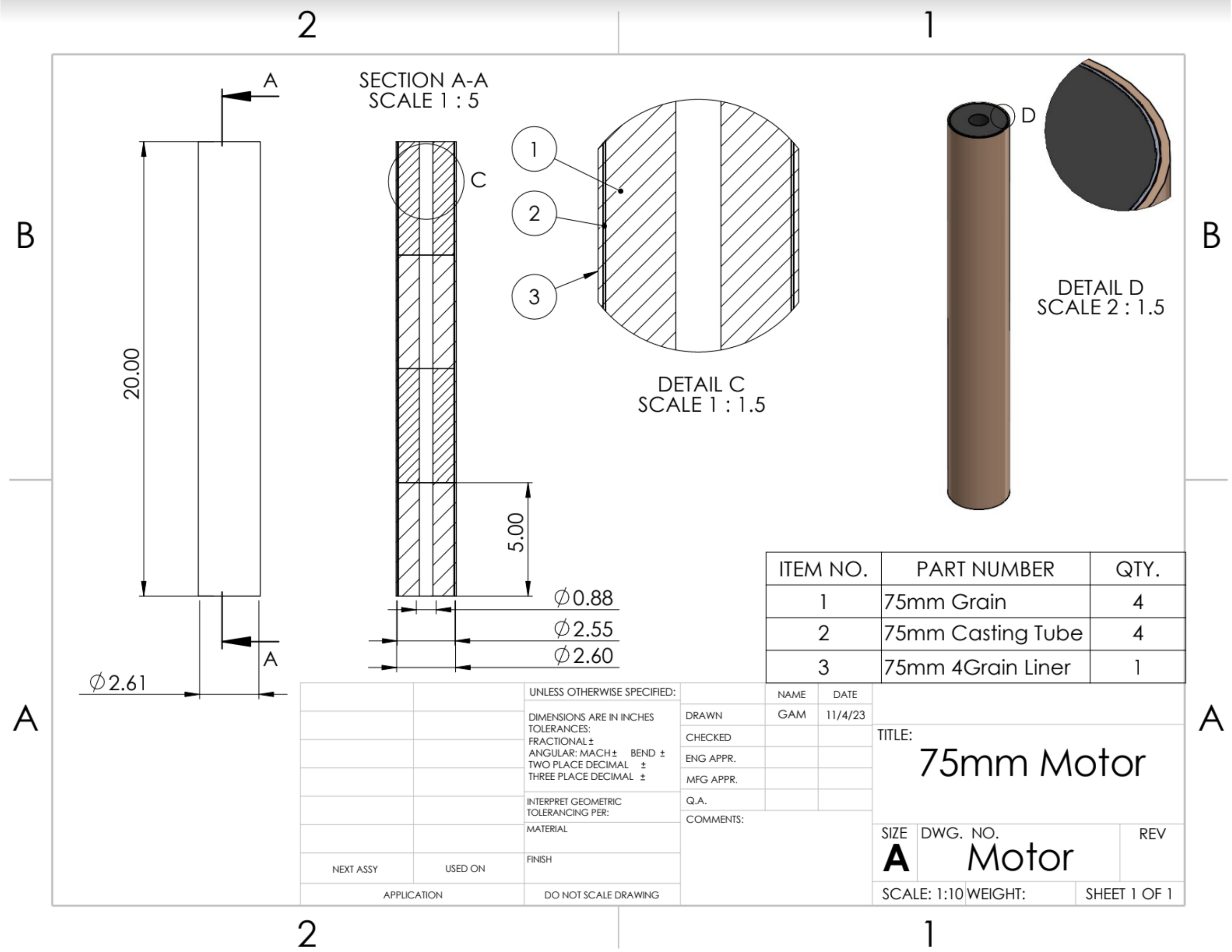


Figure 3: Engineering Drawing Motor

DESIGN DESCRIPTION: MOTOR CASING

- Precise dimensions ensure a secure placement of the motor and lining
- Provides an attachment point for the bulkhead at the top of the casing
- Outer diameter matches the inner diameter of the rocket body for added stability
- Features a threaded connection for securing the nozzle onto the motor casing

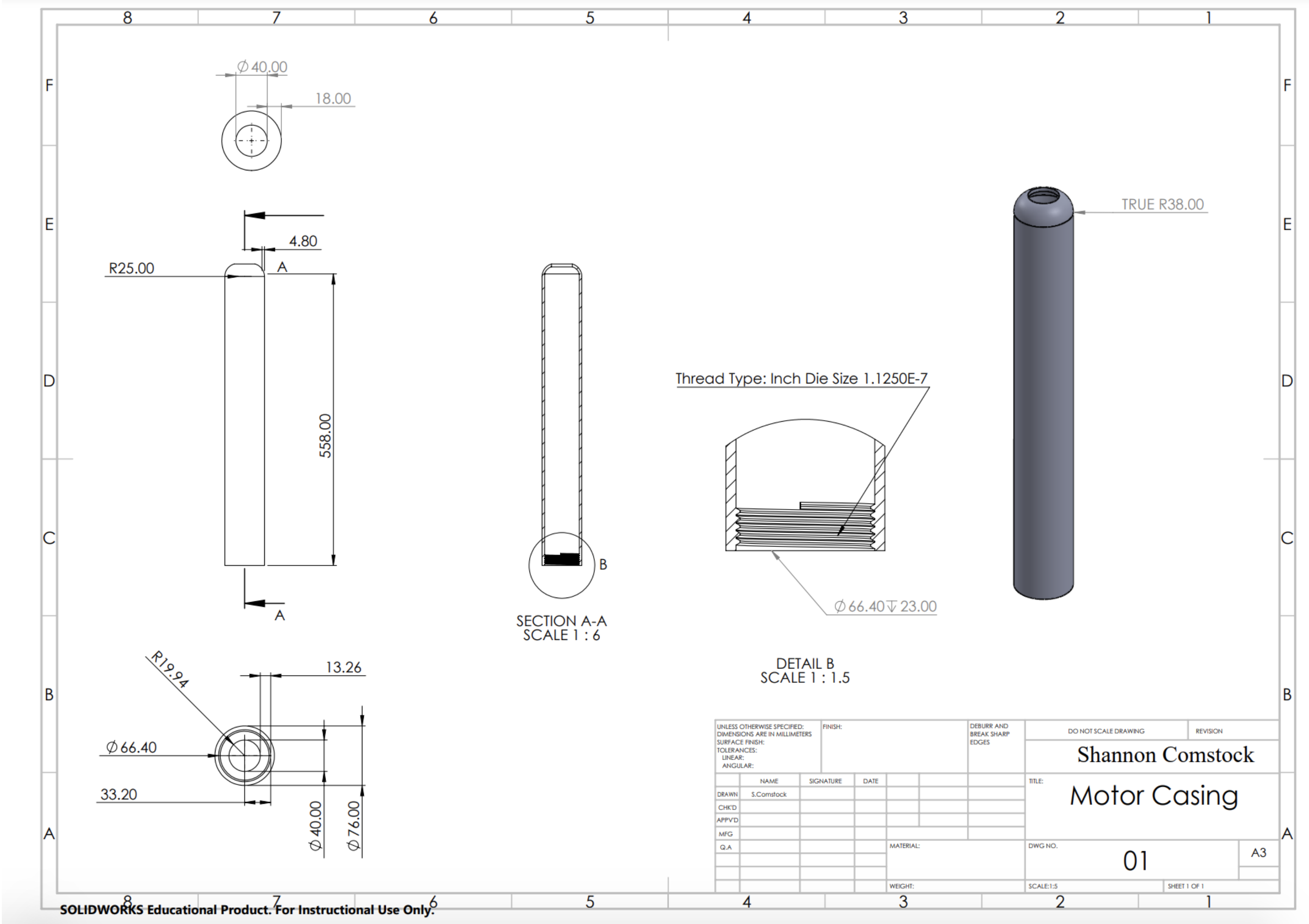
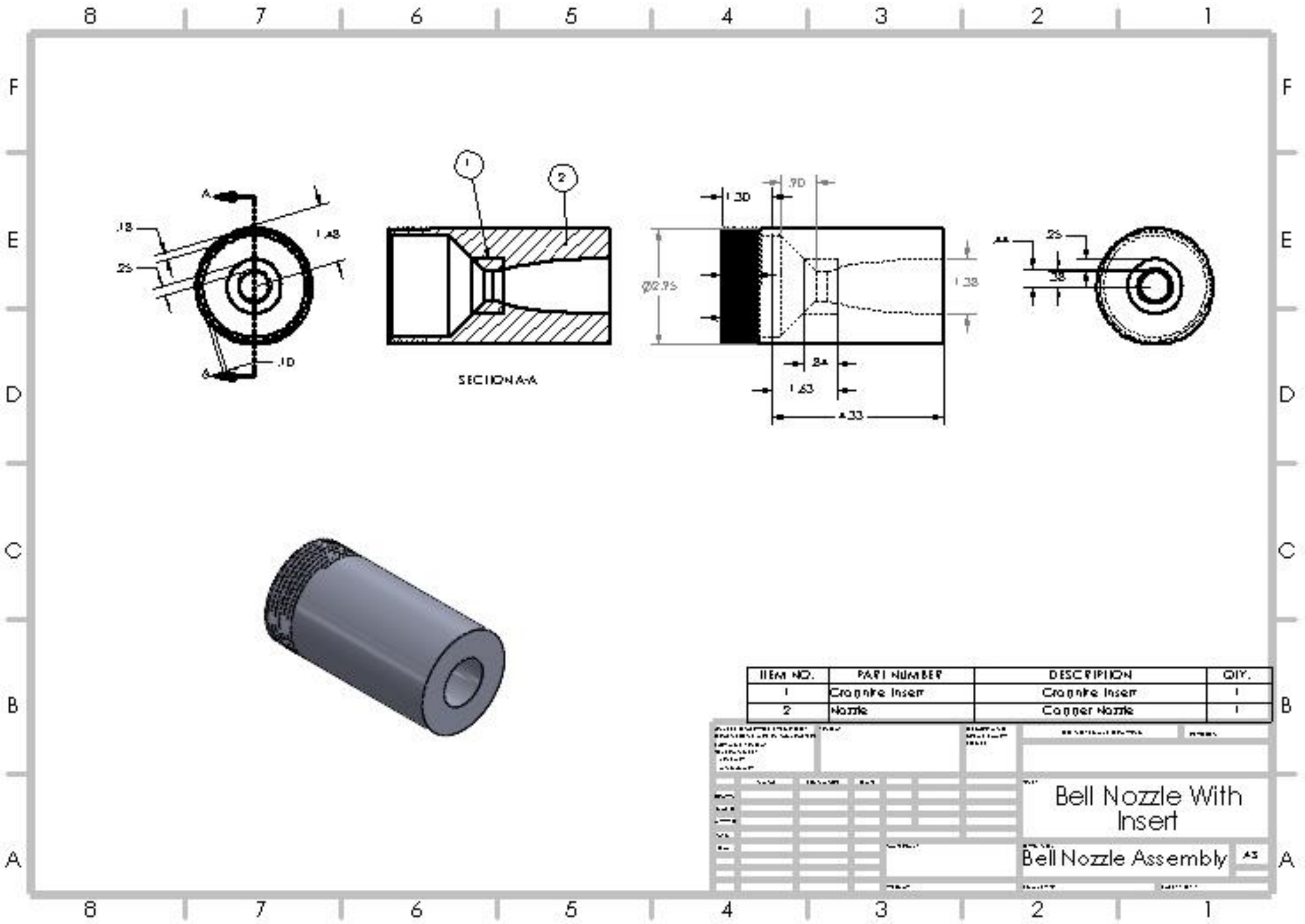


Figure 4: Engineering Drawing Motor Casing

DESIGN DESCRIPTION: NOZZLE

- Graphite insert at throat to prevent erosion of copper nozzle
- Copper converging/diverging nozzle with parabolic curve generated using method of characteristics program
- Threads securely into motor casing



Andrew
11/6/23
Rocket Propulsion Team 3

CUSTOMER REQUIREMENTS

Customer Requirements are critical because the team must prioritize these to fulfil the needs of the end user

- Functionality – Results must function to the end user's major needs.
- Cost-Efficient – Must stay within the given budget and be replicable for future club members
- Scale-able - Able to apply small-scale tests to full scale ones.
- Test Stand - Must be able to withstand up to L-Class motors (MAX 5120 Newton-Seconds)
- Tripoli Rocketry Association Safety Standards Compliant – Stay within known safety standards
- Completion in timely manner – Client needs the final product ready for the student launch

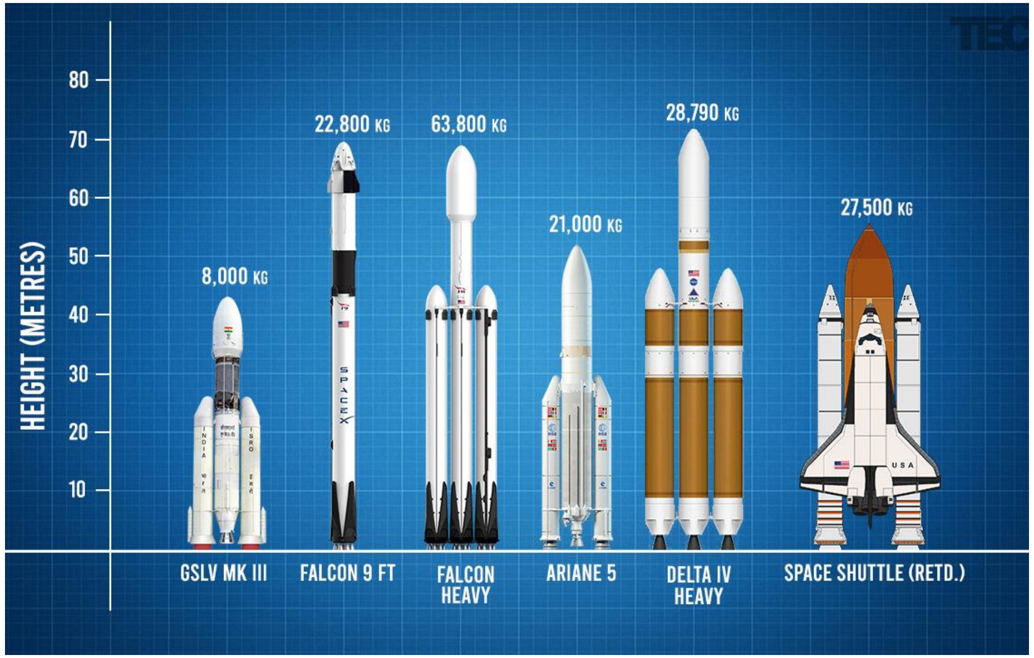


Figure 6: Rocket History Heights
Source: First Post Chandraayan 2 Landing [3]

ENGINEERING REQUIREMENTS

Engineering Requirements allow us to quantify our customers product requirements

- Completing Within Budget – Must stay within client's budget ($2000); able to fundraise more
- Test Stand Accepting of Sub/Full-Scale motors – Stand must accept any size motors (up to 75mm)
- 5120 Newton Second Impulse – Test stand must be rated to withstand the limits of Level 2 impulses
- Thrust-to-Weight Ratio – Must be within the thrust-weight ratio set by Tripoli Rocketry Association
- Timely Completion – Must be tested and completed by February-March for the student launch
- Ductile, Non-Ferus Casing – Must be housed correctly to make sure possible fragments or sparks are avoided

Figure 7: Rocket Motor Test Stand
Source: BPS Space YouTube [4]

QFD

- New technical requirements break down the safety to be more specific
- New customer requirements to account for the cost of the project.

System QFD

Project:	**Rocket Club CAPSTONE**
Date:	10/21/23

Legend	
A	Aerocon
B	FUTEK
C	Richard Nakka's
D	75/1280 Motor
E	M1350W
F	L875DM

	Reach minimum altitude	Stay within Budget for the Project	Dimensions meet constraints of rocket size	Stand withstands impulse of rocket testing	Meet Minimum Thrust to Weight Ratio Set by Tripoli	Complete final launch by march 2024
Reach minimum altitude						
Stay within Budget for the Project	0					
Dimensions meet constraints of rocket size	9	0				
Stand withstands impulse of rocket testing	3	0	3			
Meet Minimum Thrust to Weight Ratio Set by Tripoli	9	3	6	6		
Complete final launch by march 2024	3	3	3	3	3	
Non-Ferrous Ductile Casing	3	0	3	3	6	3

Customer Needs	**Customer Weights**	Reach minimum altitude	Stay within Budget for the Project	Dimensions meet constraints of rocket size	Stand withstands impulse of rocket testing	Meet Minimum Thrust to Weight Ratio Set by Tripoli	Complete final launch by march 2024	Non-Ferrous Ductile Casing	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
		Technical Requirements							**Customer Opinion Survey**				
Functionality	4	9	3	6	9	3	3	3		A B C	F	E	D
Low Cost	4	0	9	3	0	6	3	0	B E F		D	A	C
Scalable	3	3	3	9	6	6	3	3		C		A B	D E F
Sturdy Test Stand	4	3	3	6	9	3	3	3	C D E F	A			B
Comply with Tripoli Rocketry Association safety standards	5	3	3	6	6	9	3	9	C	A D	E		B F
Timely Completion	3	3	3	3	3	3	9	3	B	C	A D E F		
Technical Requirement Units		km	$	mm	N-s	N/N	Months	Y/N					
Technical Requirement Targets		10	2000	75	5120	5:1	3	Y					
Absolute Technical Importance		81	57	114	129	96	75	87					
Relative Technical Importance		4	3	5	5	5	4	5					

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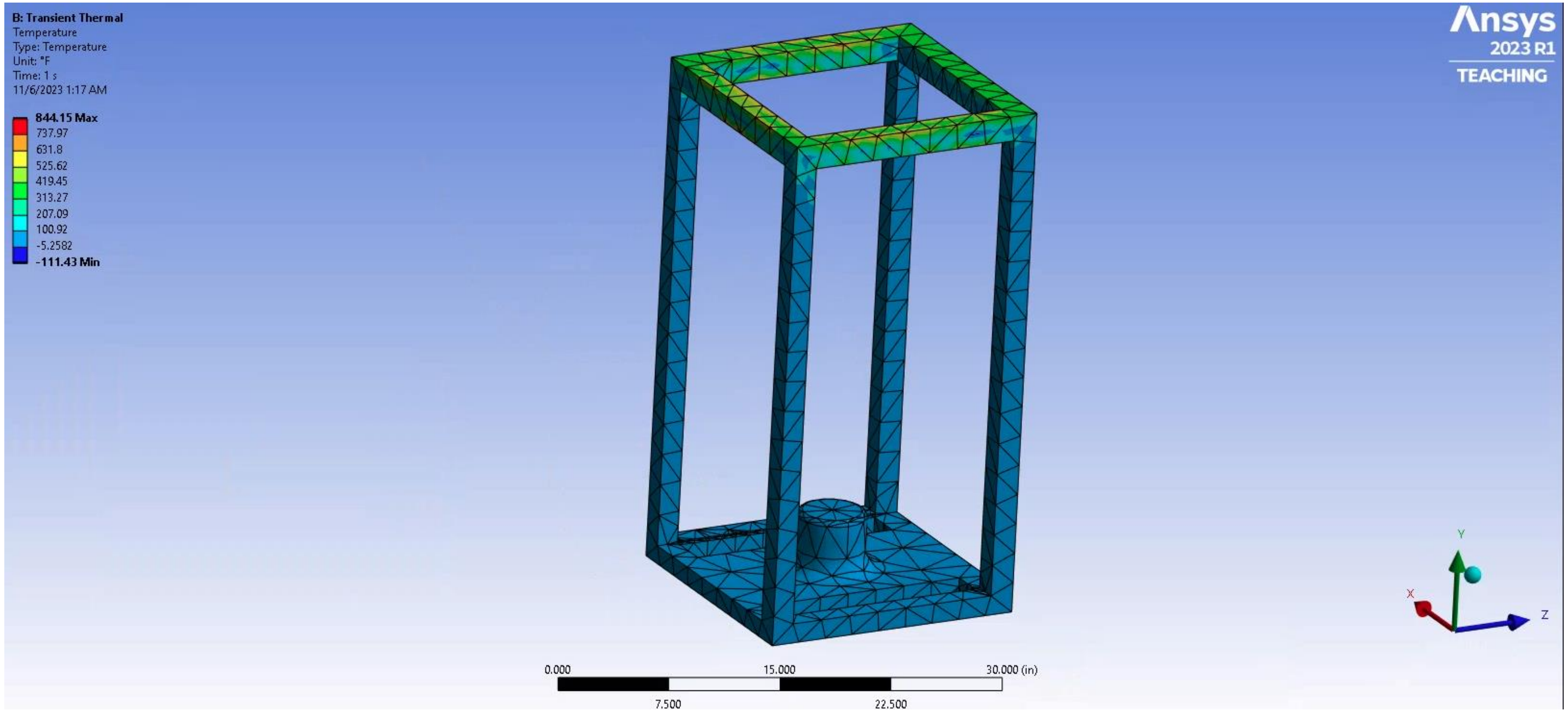
QFD

- Each ER correlates strongly to at least one customer need
- The test stand has the highest technical importance
    - Sturdy = Safer
    - Allows us to quickly iterate propellant

		Technical Requirements						
Customer Needs	Customer Weights	Reach minimum altitude	Stay within Budget for the Project	Dimensions meet constraints of rocket size	Stand withstands impulse of rocket testing	Meet Minimum Thrust to Weight Ratio Set by Tripoli	Complete final launch by march 2024	Non-Ferrous Ductile Casing
Functionality	4	9	3	6	9	3	3	3
Low Cost	4	0	9	3	0	6	3	0
Scalable	3	3	3	9	6	6	3	3
Sturdy Test Stand	4	3	3	6	9	3	3	3
Comply with Tripoli Rocketry Association safety standards	5	3	3	6	6	9	3	9
Timely Completion	3	3	3	3	3	3	9	3
Technical Requirement Units		km	$	mm	N-s	N/N	Months	Y/N
Technical Requirement Targets		10	2000	75	5120	5;1	3	Y
Absolute Technical Importance		81	57	114	129	96	75	87

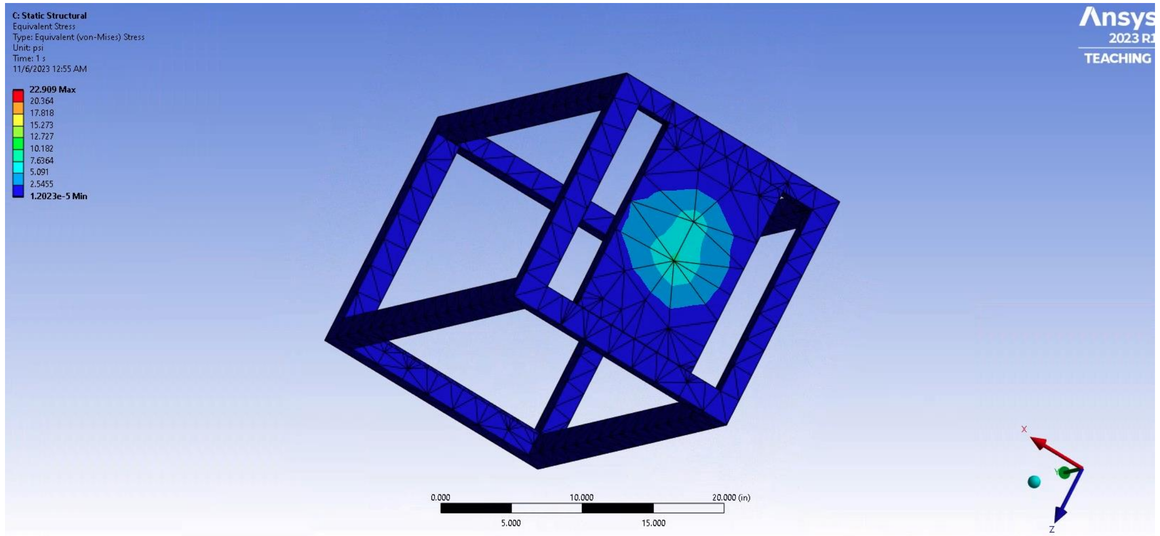
ENGINEERING CALCULATIONS: TEST STAND

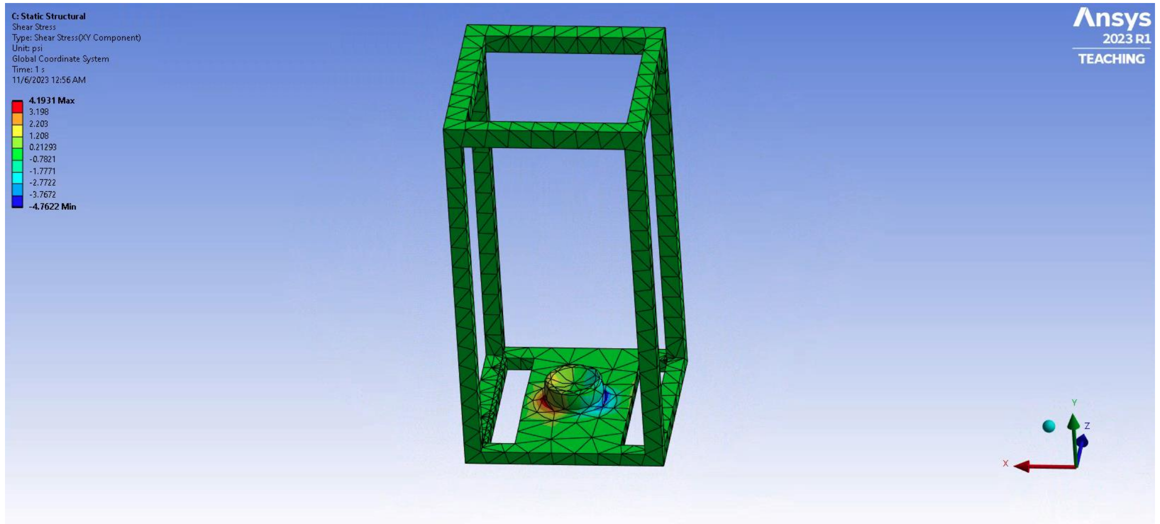
- By applying a heat flux of $230\ x\ 10^4\ W/m^2$ directly to the upper frame
- Max temperature is 844.15 degrees F
- Aluminum can warp at 400 degrees F
- Steel can warp at 1500 degrees F
- The aluminum extrusion should be wrapped in thermal shielding to prevent damage



ENGINEERING CALCULATIONS: TEST STAND

- Stresses dissipate quickly
- Mitigates system parts which experience stress
- Shows how the forces stay local to base plate
- Max normal stress is 22.9 psi, causing minimal fatigue
- Max shear stress is 4.19 psi due to pressure from load cell on the plate
- This small of a shear stress and normal stress over the approximate 4 second intervals of motor testing won't impact the structural integrity.





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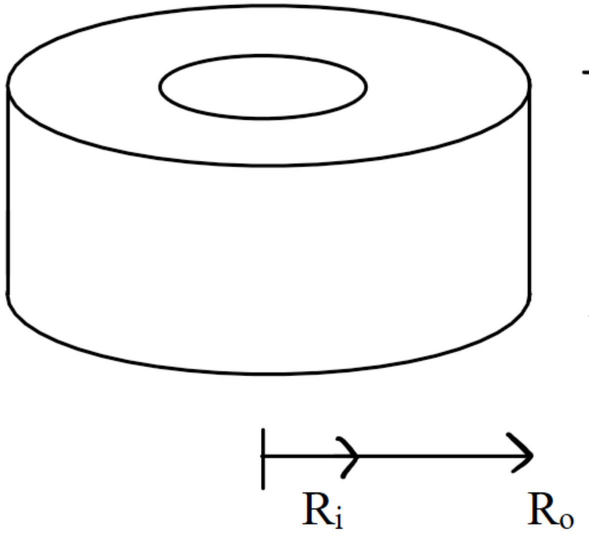
ENGINEERING CALCULATIONS: PROPELLANT

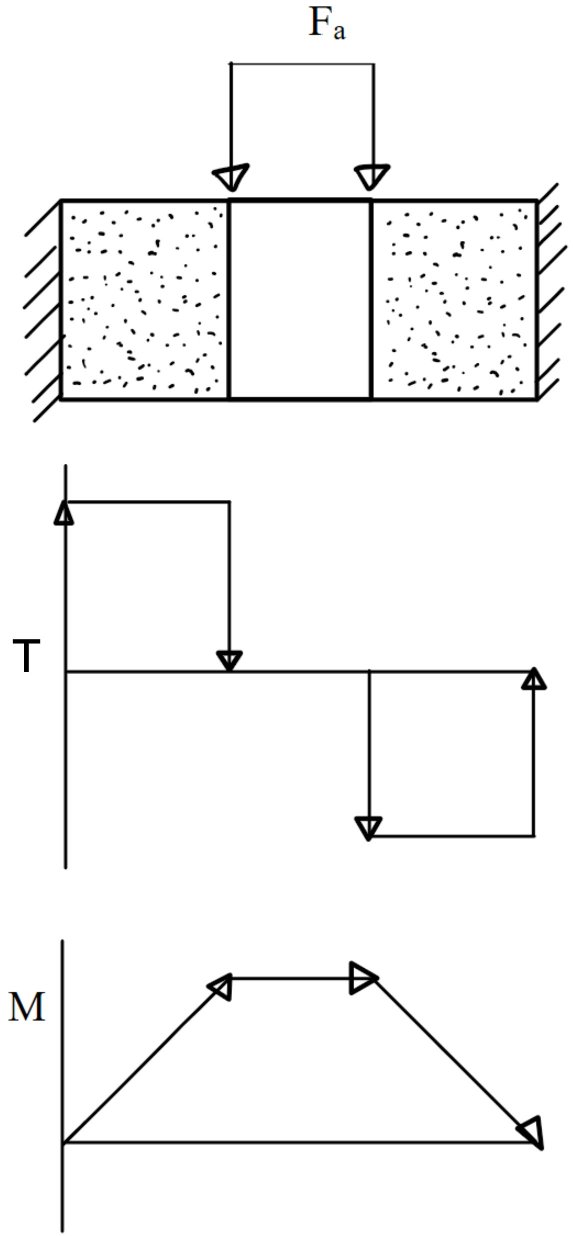


T= F/A

T= Fa/ (h* 2 *Pi*r)

Tmax= FS* Fa/ (h* 2*Pi*Ri)

Tmax= (Fa/ (h* Ri)) * (0.75/Pi)



Tmax= (1245.5 N/ (0.1143 m* .0111125 m)) * (0.75/Pi)= 234097.6846 pa

Tmax~ 0.5*Tensile

Tensile= 0.468195 Mpa

Tensile Actual~ 1.5 Mpa [2]

For a 35 mm motor
Ri= 7/16 in
h= 4.5 in
Fa~ 280 lbf

ENGINEERING CALCULATIONS: MOTOR CASING (REMY)

[2] MATLAB logo,
Source: wikipedia.org

MATLAB is used for the primary calculations.

- Ease of use
- Quick calculations given a small material change
- Concise and readable

These are the major factors we must consider to make sure our casing is successful and retains the high pressures and temperatures that are experienced:

- Hoop Stress
- Axial (Longitudinal) Stress
- Overall Material Selection

Figure 8: Rocket Motor Casing Various Sizes
Source: Sunward Hardware Casing [5]

ENGINEERING CALCULATIONS: MOTOR CASING (REMY)

Hoop Stress: The stresses acting on the circumference of a pressurized cylinder

First, we must analyze which equation we must use (Thick/Thin Walled)

$$\frac{r}{t} \geq 10$$

Thick Walled:

$$\sigma_r = \frac{r_i^2 p_i}{r_o^2 - r_i^2}\left(1 - \frac{r_o^2}{r^2}\right)$$

Thin Walled:

$$= \frac{p_i d_i}{2t}$$

```
% Thick/Thin Walled Calc (Despite Thickness Ratio)
Casing_Pressure_Thin = (4*FOS_Yield_Strength*Casing_Thick)/Casing_ID_in; % Internal Casing Pressure [psi] (Thin Walled)
Casing_Pressure_Thick = ((FOS_Yield_Strength/(1+((Casing_OR_in^2)/(Casing_IR_in^2))))*((Casing_OR_in^2)-(Casing_IR_in^2)))/Casing_IR_in^2; % Internal Casing Press

if Thick_Ratio >= 10
    Allowable_Casing_Pressure = ((FOS_Yield_Strength/(1+((Casing_OR_in^2)/(Casing_IR_in^2))))*((Casing_OR_in^2)-(Casing_IR_in^2)))/Casing_IR_in^2 % Allowable Inte
else
    Allowable_Casing_Pressure = (2*FOS_Yield_Strength*Casing_Thick)/Casing_ID_in % Allowable Internal Casing Pressure [psi] (Thin Walled)
end
```

Equations from Shigleys Mechanical Engineering Design Textbook [1]

ENGINEERING CALCULATIONS: MOTOR CASING (REMY)

Axial Stress: The stresses acting on the end caps of the cylinder

Thick Walled:

$$\sigma_l = \frac{p_i r_i^2}{r_o^2 - r_i^2}$$

Thin Walled:

$$\sigma_l = \frac{p_i d_i}{4t}$$

Equations from
Shigleys Mechanical Engineering
Design Textbook [1]

```
% Thick/Thin Walled Calc (Despite Thickness Ratio)
Bulkhead_Pressure_Thin = ((4*FOS_Yield_Strength*Casing_Thick)/Casing_ID_in); % Bulkhead Pressure [psi] (Thin Walled)
BulkHead_Pressure_Thick = ((FOS_Yield_Strength*((Casing_OR_in^2)-(Casing_IR_in^2)))/(Casing_IR_in^2)); % Bulkhead Pressure [psi] (Thick Walled)

if Thick_Ratio >= 10
    Allowable_Bulkhead_Pressure = ((FOS_Yield_Strength*((Casing_OR_in^2)-(Casing_IR_in^2)))/(Casing_IR_in^2)) % Allowable Bulkhead Pressure [psi] (Thick Walled)
else
    Allowable_BulkHead_Pressure = ((4*FOS_Yield_Strength*Casing_Thick)/Casing_ID_in) % Allowable Bulkhead Pressure [psi] (Thin Walled)
end
```

ENGINEERING CALCULATIONS: NOZZLE

Method of Characteristics (MOC)

- Computes the minimum-length, ideal curve of an axisymmetric nozzle.

The Characteristic mesh is calculated with solving for the compatibility equations for an inviscid, irrotational, axisymmetric supersonic flow:

$$d\theta = \mp\sqrt{M^2 - 1}\,\frac{dV}{V} \pm \frac{1}{\sqrt{M^2 - 1} + \cot(\theta)}\,\frac{dr}{r}$$

When substituting the differential of the Prandtl-Meyer function, *dv*, the final compatibility equations are as follows:

$$d(\theta + \nu) = \frac{1}{\sqrt{M^2 - 1} - \cot(\theta)}\,\frac{dr}{r} \quad \text{(along a C- characteristic)}$$

$$d(\theta - \nu) = -\frac{1}{\sqrt{M^2 - 1} + \cot(\theta)}\,\frac{dr}{r} \quad \text{(along a C+ characteristic)}$$

The MATLAB program requires user input for the estimated exit Mach number (M_e), the heat capacity ratio (γ)

```
mach_exit= 3 ; %estimated exit mach number
gamma= 5/3 - 1.667 ; %heat capacity ratio (perfect gas)
N_lin= 20 ; %linear kernel
N_comp= 5 ; %compressed kernel - set 1 for uncompressed kernel
index_comp= 5 ; %compression exponent
th= 1e-7 ; %tolerance
AR= 1 ; %aspect ratio for the transition region
```

The equations are as follows:

Exit Mach Number:

$$c_p - c_v = \frac{R}{J}$$

$$M_e = \frac{V_e}{\sqrt{\gamma R T_e}} \qquad \gamma = \frac{c_p}{c_v} \qquad c_p = \frac{\gamma R}{(\gamma - 1)\,J}$$

Where,

$\theta =$ deflection angle

$M =$ Initial Mach number of supersonic flow

$M_e =$ Mach number at nozzle exit

$\nu =$ Prandtl-Meyer function

ENGINEERING VALIDATION: TEST STAND

- Critical Modes of Failure
  - Top extrusion bars experience temperature deformation
  - Bottom extrusion bars experience force deformation
- Mitigation of Potential Failures:
  - Coating/ wrapping extrusion top bar with thermal shield
  - Simulate different ways of connecting load cell plate to extrusion bar
- Risk Trade Off Analysis:
  - Ansys static structural and thermal simulations
- Testing Procedures
  - Burning motors on the test stand
  - Checking for deformations of parts
  - Checking bolts for loosening
- Required Equipment
  - Safety glasses, test stand, rocket motor, safety barrier
  - Large open area with little to no vegetation

Product Name: Motor Test Stand
System Name: Motor Testing
Subsystem Name: Thrust and Impulse Analysis
Component Name: Test Stand

Development Team: Shannon Comstock, Remy Dasher, Andrew King, Grace Morris

Page No of
FMEA Number
Date 11/1/2023

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Top Brackets	Temperature Deformation	Top extrusion bars and brackets will loosen due to expansion from motor exhaust heat, decreasing the structural interity over time	3	Motor exhaust reaches high temperature	4	Maintenance requirement to tighten all bolts	2	24	None
	Thermal Fatigue from the expansion and contraction from the exhaust heat on the brackets	Crack propogations can cause brackets to fail, decreasing the structural integrity	4	Motor exhaust reaches high temperature	2	Coat/ cover the parts exposed to heat with thermal sheilding	3	24	None
Bottom Brackets	Force Deformation	The brackets warp causing the structural integrity to decrease.	2	Impact loading from thrust force	2	Designed to withstand max loading	3	12	None
Top Extrusion Bars	Temperature Deformation	The aluminum extrusion warps from heat exposure, causing structure to deform and potentially effect grip on motor	6	Motor exhaust reaches high temperature	5	Coat/ cover the parts exposed to heat with thermal sheilding	4	120	Simulate thermal analysis of these components and detemrine if design needs to be altered
	Thermal Fatigue from the expansion and contraction from the exhaust heat	The aluminum extrusion fractures/ fails, causing motor to lack support in its fixed position	3	Motor exhaust reaches high temperature	2	Coat/ cover the parts exposed to heat with thermal sheilding	3	18	None
Bottom Extrusion Bars	Force Deformation	Instability in motor mounting during testing may cause motor to become disloged and become a projectile	9	Impact loacing from thrust force	4	Designed to withstand max loading	5	180	Simulate structural analysis of these components and determine if design needs to be altered
Bolts	Force deformation (Shearing)	Bolts shear during testing, potentially causing bracket to be unsupported	4	Impact loacing from thrust force	5	Designed to withstand max loading	4	80	None
	Force Deformation (Normal Stress)	Bolts buckle from compressive stress causing lack in structural integrity	4	Impact loacing from thrust force	5	Designed to withstand max loading	3	60	None
	Temperature Deformation	Bolts come loose from the structure, causing instability, potentially lack of support for motor	4	Motor exhaust reaches high temperature	2	Maintenance requirement to tighten all bolts	2	16	None
	Thermal Fatigue from the expansion and contraction from the exhaust heat	Bolts crack during tesing, decreasing structural integrity	2	Motor exhaust reaches high temperature	2	Coat/ cover the parts exposed to heat with thermal sheilding	2	8	None
T-Nuts	Force Deformation (Normal Stress)	Loosens from bolts, compromising the strength of the brackets hold on the extrusion	2	Impact loacing from thrust force	1	Maintenance requirement to tighten all bolts	2	4	None

Product Name: Motor Test Stand		Development Team: Shannon Comstock, Remy Dasher, Andrew King, Grace Morris	Page No of
System Name: Motor Testing			FMEA Number
Subsystem Name: Thrust and Impulse Analysis			Date 11/1/2023
Component Name:	Test Stand		

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
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T-Nuts	Force Deformation (Normal Stress)	Loosens from bolts, compromising the strength of the brackets hold on the extrusion	2	Impact loacing from thrust force	1	Maintenance requirement to tighten all bolts	2	4	None

ENGINEERING VALIDATION: PROPELLANT

- Critical Modes of Failure
  - Propellant grains experiencing Force deformation
  - Propellant grains having accelerated burn rate
- Mitigation of Potential Failures:
  - Multiple team members check the hardness of grains
  - Manufacturing the grains with the use of a shake table
- Testing Procedures
  - Measure hardness
  - Weighing grains
  - Measuring the volume of grains
- Required Equipment
  - Hardness tester
  - Scale and calipers
  - PPE

Product Name		Development team: Shannon, Remy, Andrew, Grace				Page No of			
System Name						FMEA Number			
Subsystem Name						Date 11/3/23			
Component Name	Motor								
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Propellant Grain	Force Deformation	Propellant falls out of rocket either before or during combustion depending on severity, this leads to unsafe conditions for spectators and decreased altitude performance	9	Incorrect propellant formulation; Propellant is not fully cured	4	Hardness checks	2	72	Two or more team members should look over the grains prior to launch
	Accelerated Burn Rate	Pressure builds and the rocket explodes, or the fuel burns too fast and decreases altitude performance	10	Propellent contains voids due to errors in manufacturing processes	3	Density checks	2	60	Include a shake table in manufacture to reduce size and occurrence of voids
	Decelerated Burn Rate	Minimum thrust-to-weight ration is not meet and rocket can not lift off	7	Incorrect propellant formula	7	Iterative formula testing and analysis	1	49	Double check final iterations with a mentor prior to launch
Casting Tubes	Inconsistent Part Quality	The propellant grain does not fit properly in the liner and needs to be trimmed down	2	Casting tube is ripped during manufacturing	1	Rough quality control of incoming parts	2	4	None
Motor Liners	Inconsistent Part Quality	The motor does not fit properly in the casing	6	Incorrect Tolerances	1	Rough quality control of incoming parts	2	12	None
E-Match	Short Circuit	Ignition would fail and nothing would happen	5	Manufacturer error	1	Rough quality control of incoming parts	6	30	None

Product Name		Development team: Shannon, Remy, Andrew, Grace					Page No of		
System Name							FMEA Number		
Subsystem Name							Date 11/3/23		
Component Name	Motor								
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Casting Tubes	Inconsistent Part Quality	The propellant grain does not fit properly in the liner and needs to be trimmed down	2	Casting tube is ripped during manufacturing	1	Rough quality control of incoming parts	2	4	None
Motor Liners	Inconsistent Part Quality	The motor does not fit properly in the casing	6	Incorrect Tolerances	1	Rough quality control of incoming parts	2	12	None
E-Matich	Short Circuit	Ignition would fail and nothing would happen	5	Manufacturer error	1	Rough quality control of incoming parts	6	30	None

ENGINEERING VALIDATION: MOTOR CASING

- Critical Modes of Failure
  - Aluminum casing experiencing a rupture which destroys the casing and is a safety hazard
- Mitigation of Potential Failures:
  - Ensure uniform thicknesses and looking for material imperfections
  - Ensure grains are free of voids or pits
- Risk Trade Off Analysis:
  - Ensuring tubing is uniform and free of pitting and other manufacturing defects
- Testing Procedures
  - Attempt a hydrostatic test with the casing to make sure it can withstand experienced pressures
- Required Equipment
  - Micrometer

Product Name	NAU Rocket Capstone	Development Team: Shannon Comstock, Remington Dasher, Andrew King, Grace Morris
System Name		
Subsystem Name		
Component Name	Motor Casing	

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Aluminum Casing	Casing rupture	Explosive decompression caused by rapid gas fluxuation	10	Voids in propellant grains, inconsistant aluminum rounds, incorrect milling	5	Grain analysis, Aluminum checks	4	200	Assign 1-2 teammembers to analyze each grain for voids, make sure during milling that aluminum is sound
Bulkheads	Bulkhead rupture	Rapid decompression which causes harm to the casing	4	Incorrectly machined parts, Faulty O-rings	3	Consistant dimension checks during machining	3	36	Make sure that consistant checks on the bulkhead dimensions are done, ensuring o-rings are consistant
0	Radial Bolt Failure	Destroys casing and bulkhead is no longer secure	5	Impropper bolt selection	4	Load analysis of the bulkead/casing interaction	4	80	Ensure that the load analysis gives accurate results to ensure proper bolt selection
0	Pressure Transducer Thread Failure	Destroys bulkhead and pressure transducer	3	Incorrect thread tapping, teflon tape use	4	Ensuring threads are fully cut	2	24	Make sure with machine shop managers that threads are adequetly cut
Nozzle	Nozzle Improperly Secured	Nozzle unseats or falls out which would ruin compression and thrust	5	Incorrect seating, loose nozzle fit	3	Move the nozzle and look out for any slop or other signs of incorrect seating	1	15	Prepare an accurate CAD model to make sure nozzle seats correctly

Product Name	NAU Rocket Capstone	Development Team: Shannon Comstock, Remington Dasher, Andrew King, Grace Morris
System Name		
Subsystem Name		
Component Name	Motor Casing	

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
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ENGINEERING VALIDATION: NOZZLE

- Critical Modes of Failure
  - Cross sectional area of throat is too small, causing over pressurization of motor casing
  - Diverges too quickly, causing flow separation and subsequent side-loading forces
  - Temperature deformation
- Mitigation of Potential Failures:
  - Quality assurance checks on O-rings
  - Measure nozzle geometry with micrometers after manufacture
  - Run simulations with MOC, CFD, FEA
- Testing Procedures
  - Simulation software
  - Small scale experimental tests
- Required Equipment
  - Lathe
  - Micrometers or calipers
  - Manual Press

Product Name	NAU Rocket Club Capstone	Development Team: Shannon Comstock, Remington Dasher, Andrew King, Grace Morris	Page No of
System Name	Carbon Rocket		FMEA Number
Subsystem Name	Propulsion Subsystem		Date: 11/3/2023
Component Name	75mm Rocket Nozzle		

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
graphite insert for throat	Overpressurization of motor casing - Ductile Fracture	Explosion of motor casing, mounting points of nozzle are sheared off	10	Cross-sectional area of throat is too small	3	Measure precise throat diameter with micrometers	1	30	Pay special attention during design process, and ensure the insert has been machined to the correct diameter
	Throat area experiences extreme erosion	Decreased thrust performance	5	High temp. exhaust, abrasive granules present in exhaust gas	4	Simulations, and small scale experimental burn	3	60	Pick isotropic graphite, pick low-temperature propellant.
	Mechanical vailure via crack propogation	Fracturing of graphite insert, rapid decrease in thrust	8	Thermal expansion	2	Ensure proper fitting, and FEA simulations	3	48	Choose temperature resistant graphite, and consider adding insulation to reduce thermal expansion. Ensure the diameter is the same as the height of the insert
	Insert is ejected out of nozzle due to force of exhaust gas	The insert becomes a high-velocity projectile and the rest of the propulsion assembly may fail	10	If the step-down that holds the insert in place is too weak	1	Perform FEA on parts to ensure required strenth	2	20	geometry, precicely machine graphite for a press-fit, Heat up metal nozzle during press fit.
Converging-Diverging nozzle	Ductile failure of diverging section	Explosion of motor casing, rapid decrease in thrust	10	Nozzle diverges at too steep of an angle and the flow separation causes inintentional side-loading	2	CFD simulations in Ansys, and small scale test firings	2	40	Pay special attention during design process, and ensure the nozzle has been machined correctly
			9	The extreme temperatures weakens the design	3	Heat transfer simulations and hand calculations	2	54	Select nozzle material that has a high thermal conductivity and is resistant to melting
O-ring Seals	Force and/or temperature deformation	Increased likelihood of catastrophic motor failure, decrease in thrust performance, components that are not meant to experience extreme temperature will be affected by the escape of exhaust	10	Incorrectly sized O-rings; too small	2	ensure proper O-ring groove dimensions with calipers or micrometer	1	20	Choose temperature resistant o-rings or implement additional insulation
			10	Incorrect installation	3	Compare attached O-ring Diameter with inner diameter of casing	1	30	Ensure that the O-rings fit securely in the machined grooves in nozzle fitting
	Chemical and thermally induced corrosion	Chamber pressure will escape and have catastophic effects on motor and rocket parts	10	Manufacturer defect; did not cure properly in factory	1	Elastic strength tests	1	10	Implement quality assurance plan guring motor assembly

Product Name	NAU Rocket Club Capstone	Development Team: Shannon Comstock, Remington Dasher, Andrew King, Grace Morris				Page No of			
System Name	Carbon Rocket					FMEA Number			
Subsystem Name	Propulsion Subsystem					Date: 11/3/2023			
Component Name	75mm Rocket Nozzle								
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
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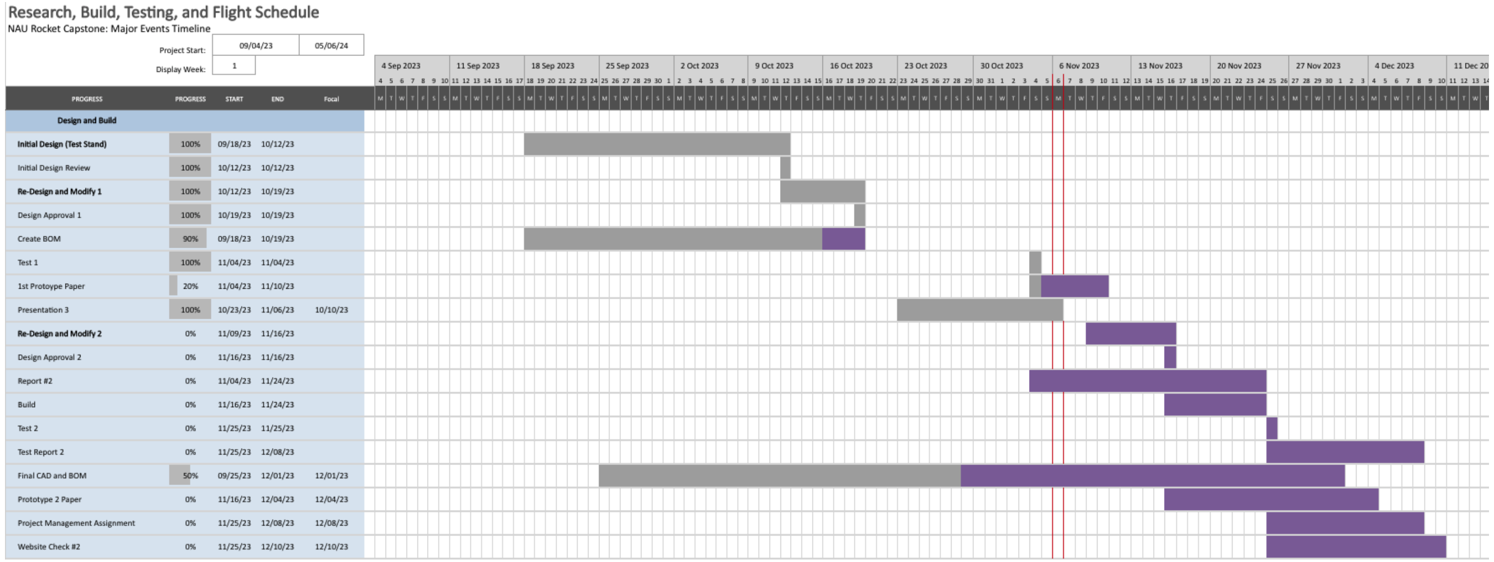
UPDATED BUDGET

Actual Expenses To-Date		
Subsystem	Products Needed	Amount
Nozzle		
Casing		
Test Stand	Aluminum Extrusion	156.5
	Angle Iron	30.82
	T-Nuts	81.56
	Screws	45.03
	Washer	32.93
Test Stand Electronics		
Test Rocket Motors	Aluminum Powder	29.41
	Binders	27.75
	Additives	71.62
	Liners	66.95
	Casting Materals	154.1
75mm Final Motor		
PPE	Gloves	24
		696.67

0		Expected Expenses		
Source	Amount	Subsystem	Products Needed	Amount
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

CURRENT SCHEDULE AND PROGRESS



Research, Build, Testing, and Flight Schedule

NAU Rocket Capstone: Major Events Timeline

Project Start: 09/04/23 05/06/24

Display Week: 1

PROGRESS	PROGRESS	START	END	Focal
Design and Build				
Initial Design (Test Stand)	100%	09/18/23	10/12/23	
Initial Design Review	100%	10/12/23	10/12/23	
Re-Design and Modify 1	100%	10/12/23	10/19/23	
Design Approval 1	100%	10/19/23	10/19/23	
Create BOM	90%	09/18/23	10/19/23	
Test 1	100%	11/04/23	11/04/23	
1st Protoype Paper	20%	11/04/23	11/10/23	
Presentation 3	100%	10/23/23	11/06/23	10/10/23
Re-Design and Modify 2	0%	11/09/23	11/16/23	
Design Approval 2	0%	11/16/23	11/16/23	
Report #2	0%	11/04/23	11/24/23	
Build	0%	11/16/23	11/24/23	
Test 2	0%	11/25/23	11/25/23	
Test Report 2	0%	11/25/23	12/08/23	
Final CAD and BOM	50%	09/25/23	12/01/23	12/01/23
Prototype 2 Paper	0%	11/16/23	12/04/23	12/04/23
Project Management Assignment	0%	11/25/23	12/08/23	12/08/23
Website Check #2	0%	11/25/23	12/10/23	12/10/23

Shannon
11/6/23
Rocket
Propulsion
Team 3

SPRING SCHEDULE GANTT CHART PART 1

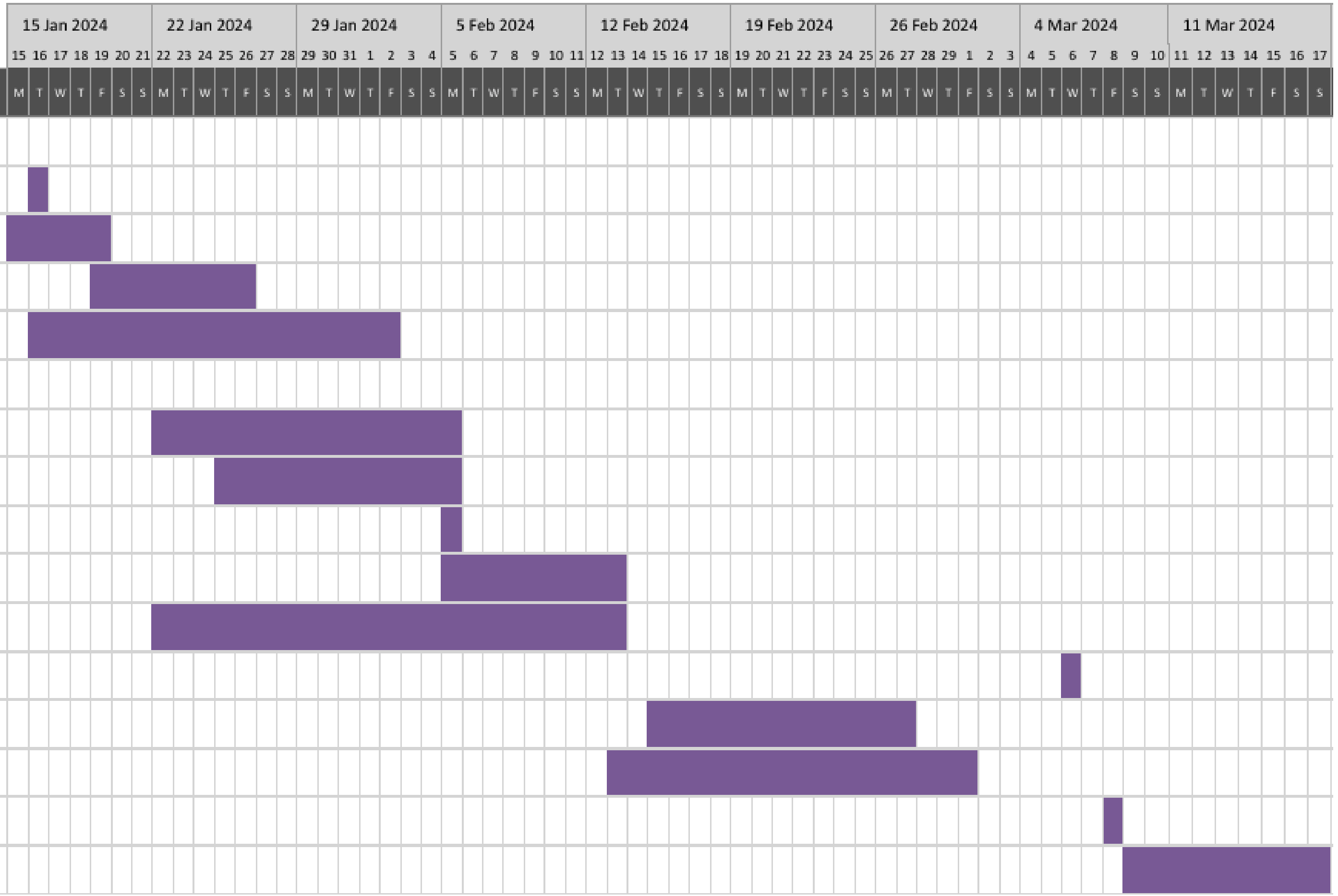
Spring Semester Tentative Schedule

NAU Rocket Capstone: Major Events Timeline

Project Start: 01/16/24 | 05/15/24

Display Week: 1

PROGRESS	PROGRESS	START	END	Focal
Semester Kick Off				
Spring Kickoff Meeting	0%	01/16/24	01/16/24	
Project Management Assignment	0%	01/15/24	01/19/24	
Engineering Model Summary Assignmeny	0%	01/19/24	01/26/24	
Self Learning/ Individual Analysis Assignme	0%	01/16/24	02/02/24	
Final Build Phase 1				
Have all Parts Ordered for 75mm Motor	0%	01/22/24	02/05/24	
Build final test motor 54 mm	0%	01/25/24	02/05/24	
Launch 54mm test motor	0%	02/05/24	02/05/24	
Hardware Status Update	0%	02/05/24	02/13/24	
At Least 33% Built	0%	01/22/24	02/13/24	
UGRADS Registration	0%	03/06/24	03/06/24	
Website Check #1	0%	02/15/24	02/27/24	02/27/24
Hardware Status Update (at least 67% Built	0%	02/13/24	03/01/24	
Final 75mm Motor Launch!!!	0%	03/08/24	03/08/24	
Spring Break	0%	03/09/24	03/17/24	



Shannon
11/6/23
Rocket Propulsion Team 3

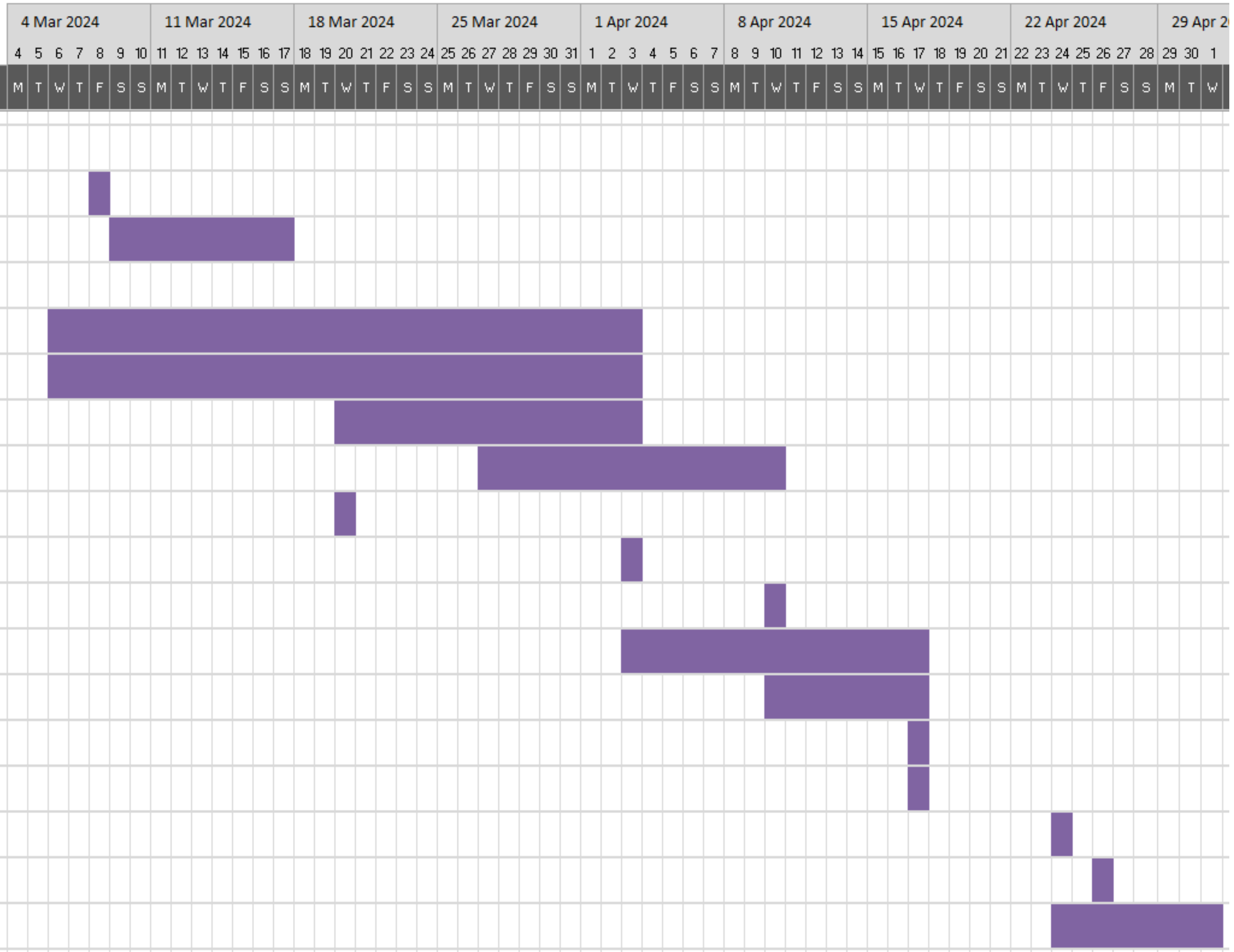
SPRING SCHEDULE GANTT CHART PART 2

Spring Semester Tentative Schedule

NAU Rocket Capstone: Major Events Timeline

Project Start:	01/16/24	05/15/24
Display Week:	8	

PROGRESS	PROGRESS	START	END	Focal
Hardware Status Update (at least 67% Built)	0%	02/13/24	03/01/24	
Final 75mm Motor Launch!!!	0%	03/08/24	03/08/24	
Spring Break	0%	03/09/24	03/17/24	
Final Build Phase 2				
Testing Plan	0%	03/06/24	04/03/24	
Hardware Status, 100% Built	0%	03/06/24	04/03/24	
Final CAD Packet	0%	03/20/24	04/03/24	
Final Poster & PPT	0%	03/27/24	04/10/24	
Staff Meeting	0%	03/20/24	03/20/24	
Staff Meeting	0%	04/03/24	04/03/24	
Initial Testing Results	0%	04/10/24	04/10/24	
Final Report	0%	04/03/24	04/17/24	
Final Website Check	0%	04/10/24	04/17/24	
Product Demo	0%	04/17/24	04/17/24	
Final Testing Results	0%	04/17/24	04/17/24	
Practice Presentations In Class	0%	04/24/24	04/24/24	
Symposium -on Friday	0%	04/26/24	04/26/24	
Client Handoff	0%	04/24/24	05/01/24	05/01/24



THANK YOU!

QUESTIONS?

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