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NAU Rocket Capstone
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Finalized Testing Plan

Design Requirements Summary (10pts)

Customer Requirements

Sturdy Test Stand-

- CR1: Develop a rocket motor test stand which can precisely record the motors' downward force for motors of sizes 38 to 75 millimeters.

Functionality-

- CR2: Optimize and test a unique ammonium perchlorate propellant formula.
- CR3: Design and develop a 75 mm motor casing and bulkhead to fit inside the NAU Rocket Club's carbon-fiber rocket body.
- CR4: Design and develop an optimized, tested nozzle for the final 75 mm level 2, M-class motor.
- CR5: If the rocket does not reach an altitude of 30,000 feet during launch, define the class type motor and size required to reach 30,000 feet.
- Optimize the 75 mm motor to reach peak altitude during launch, preferably reaching a minimum of 15,000 feet.

Saleable-

- CR6: Build multiple 38-, 54- and 75-mm motors to be tested on the rocket motor test stand.

Timely Completion-

- CR7: Assemble a full 75 mm motor to be placed inside the carbon fiber rocket body to be successfully launched by the end of April 2024

Low Cost-

CR8: Must stay within the budget of $2000 provided by GORE and the additional fundraiser money.

Comply with Tripoli Rocketry Association Standards-

- CR9: Must incorporate safety standards such as distance from motors or rockets when testing and have an in-depth safety checklist written and followed for each test and launch.

Engineering Requirements

Test Stand:

- ER1A: Must be lightweight for carrying to testing locations (< 60 lbs).
- ER1B: Must accommodate motor sizes ranging from 38 to 75 millimeters diameter and 10 to 30 inches height.
- ER1C: Must be capable of securely mounting and testing the motors.
- ER1D: Must include necessary instrumentation for data collection during testing, such as thrust (up to 287.8 lbf), temperature (up to 500 degrees F) and pressure sensors (up to 1500 psi).

Propellant Formula

- ER2A: Must be optimized to have the highest thrust and impulse output, as close to 287.8 lbf and 5120 Newton seconds as possible.
- ER2B: Final formula must be tested in grain sizes of 54- and 75-mm motors to ensure the safety and reliability of the formula.

Motor Casing and Bulkheads

- ER3A: 75 mm motor casing outer diameter must be within tolerance ± 0.1mm of 0.1mm less than inner diameter of the rocket body to ensure a snug fit with the rocket body and prevent vibrations or components from moving during launch.

- ER3B: The bulkheads must be made for 54- and 75-mm motors and incorporate at least two O-Rings and 1 snap-ring to ensure stability within the motor casing during launch
- ER3C: Design the 75 mm motor casing to withstand 1500 psi with a factor of safety of 1.5 (for a total pressure rating of 2250 psi).

Nozzle

- ER4A: Design nozzle to optimize rockets thrust based on computational fluid dynamics principles.
- ER4B: Test nozzle design using the test 54 mm motors and their thrust curves using the same propellant formula for each trial.

Top Level Testing Summary (20pts)

Experiment 1: Known Thrust Curve Apogee 38 mm Motor Testing
Experiment 2: Disposable Casing Don White Propellant Formula 38 mm Testing
Experiment 3: Disposable Casing Experimental Propellant Formula's 54 mm Testing
Experiment 4: Reusable Casing 54 mm Final Formula Determination Testing
Experiment 5A: Final Propellant Formula 75 mm Motor Testing
Experiment 5B: Depending on Results of 5A, Option for Another 75 mm Motor Testing if Needed

Table 1. Test Summary Table

Experiment	Engineering Requirements	Customer Requirements
1	ER1: A, B, C and D	CR1, CR8, CR9
2	ER1: A, B, C and D	CR1, CR8, CR9
3	ER1: A, B, C and D ER2: A, B ER3: B	CR1, CR2, CR6, CR8, CR9
4	ER1: A, B, C and D ER2: A ER3: B ER4: A, B	CR1, CR2, CR6, CR8, CR9
5A	ER1: A, B, C and D ER2: A, B ER3: A, B, C ER4: A, B	CR1, CR2, CR6, CR3, CR5, CR7, CR8, CR9
5B	ER1: A, B, C and D ER2: A, B ER3: A, B, C ER4: A, B	CR1, CR2, CR6, CR3, CR4, CR7, CR5, CR8, CR9

Detailed Testing Plans (30pts)

Experiment 1: Known Thrust Curve - Apogee 38 mm Motor Testing

This experiment focuses on the test stand instruments, such as the load cell, and determining if the data collection method is accurate. Also, it will ensure that the test stand will hold the motors securely during testing and test its structural integrity. This is performed by using a 38 mm motor purchased through a professional rocketry source, called Apogee Rocketry, which includes a precise thrust curve for the motor. By testing this motor on the test stand and analyzing the data to obtain the thrust curve, we can confirm that the load cell and test stand are performing correctly if the thrust curves match.

Experiment 2: Disposable Casing Don White Propellant Formula 38 mm Testing

The second experiment is designed to test the propellant formulation procedure of the team by casting 38 mm motors of a well proven and tested propellant formula. This allows the team to see the propellant's performance to ensure the casting method does not have errors causing the propellant to malfunction when ignited. Additionally, it will test that the data collection procedure provides reliable data by analyzing if the thrust curves are very similar for the two motor testing's.

Experiment 3: Disposable Casing Experimental Propellant Formula’s 54 mm Testing

Experiment 3 is catered towards homing in on a propellant choice that best fits our engineering requirements. Specifically, reaching maximum apogee and thrust-to-weight ratio. This will be our first test of our own formulation of propellant which comparing against our other data, we can select the best propellant choice. Comparing thrust curves from other sized and available motors will let us determine if our propellant is superior to the existing propellant formulations.

Experiment 4: Reusable Casing 54 mm Final Formula Determination Testing

Experiment 4 will mostly focus on nozzle design and propellant casting techniques. Being able to reliably cast our motors is incredibly important for the success of the project and our total apogee. This disposable casing will also have a pressure transducer attached to it which will allow for further data collection and design of the final nozzle. Both the load and pressure data will allow us to make an informed decision about what formula, nozzle, and core diameter to use. We can also use this data to simulate the burn characteristics which will allow for idealized selections.

Experiment 5A: Final Propellant Formula 75 mm Motor Testing

Our final motor burn will tell us much about what our max apogee will be as well as any indications of pressure leaks or critical pressures. It is known that with a 1000 psi maximum casing pressure, the casing should have a factor of safety of 2.3. This test will determine if our snap ring design is adequate, and our O-ring selection is appropriate. Much analysis has been done in these two areas, but making sure the analysis stands up to the design is critical. Lastly, this test will underline the importance for safe testing and overall propellant grain design. If we see the pressure gets too high, we must adjust the grain core or nozzle throat diameter to reduce the internal pressure. We intend to stay above a factor of safety of 2.0 throughout the entirety of the experimental process.

Experiment 5B: Depending on Results of 5A, Option for Another 75 mm Motor Testing if Needed

This option is here in case we have a casing failure or need to test different nozzle throat or propellant grain core diameters. As said in the description of Experiment 5A, if we are seeing pressures that fall below our factor of safety of 2.0, adjustments to either or both diameters must be made. We will likely have more than one 75mm test, but this test is here just in case we need to do more than intended.

Equipment, isolated variables and procedure are laid out in Appendix A. This is our test stand static firing safety checklist and it highlights the importance of remaining safe during the testing as well as tabulating all required equipment to complete the testing. The safety checklist was amended from an earlier safety checklist submitted to the Tripoli Safety Community for the NAU Rocket Club's launch. The checklist also offers a safe distance table that is directly taken from the Tripoli Safety Code which allows us to remain a safe distance from the motor when testing. The results taken will determine our propellant, nozzle, and grain design selection which is why this testing procedure is so important.

In conclusion, this is a rather dangerous project which means safety is our upmost concern. Ensuring safe processes will allow us to continue our work without harm. Starting small and working up to our full scale is imperative to our project's success and safety. We have already begun propellant testing on the 38 mm motors and have learned from the mistakes made. This weekend, we intend to test our first motor with our own formulated propellant. This will show us if our process is correct and how we can better the formulation if needed. Once we get to the reusable motor casing, we can hone in on our nozzle design which will transfer over to the full-scale 75 mm test and final motor.

Specification Sheet Preparation (30pts)

To ensure that the team is progressing in a way that satisfies all of the client's requirements, the following tables were created (Table , and Table). So far, the team has met all of the major customer requirements thus far, but have not met all of the engineering requirements.

The reason for the team not having met all of the engineering requirements so far is due to the fact that our project is still in progress, and we do not know if certain aspects of our design will be successful until we teat them. Such cases are noted with "?" and are marked yellow in Table 2. For example, we will not know if our design can reach a minimum altitude of 10km until we can simulate the thrust curve gathered from the test stand in Rocksim. Until we are able to simulate the rocket's performance in Rocksim, we will not know if the design meets the requirement of having a minimum thrust to weight ratio of 5 to 1. This is a requirement for all rockets at any Tripoli launch site.

Despite not having met all engineering requirements yet, the team is on track to having them complete. Our client is confident in our progress and testing plan.

Table 2: Customer Requirement Check With Client

Customer Requirement (CR)	CR met?	Client Acceptable?
Project must satisfy all engineering requirements	no	Yes
Project fits within the alotted budget	Yes	Yes
Project is on time according to the most recent iteration of the Gantt Chart	Yes	Yes
Our design is scalable in size (38mm to 75mm)	Yes	Yes
Design and procedures comply with the safety standards established by Tripoli Rocketry Association	Yes	Yes

Table 3: Engineering Requirement Check With Client

Engineering Requirement (ER)	Target	Tolerance	Measured/Calculated Value	ER met?	Client Acceptable?
The rocket must reach a minimum altitude of 10 kilometers above ground level	10 km	±1km	N/A	?	Yes
Project fits within the alotted budget, plus fundraised money	$2,684	< $2,684	$2,668	Yes	Yes
Propulsion system meets constraints of motor mount tube in the rocket	75mm	75mm - 0.2mm	74.9mm	Yes	Yes
Test stand witstands the impulse of rocket testing	5120N-s	5120Ns - 500Ns	so far, only 234 N-s	Yes	Yes
Rocket meets minimum thrust-to-weight ratio set by Triopli Rocketry Association	5:1	> or = 5:1	N/A	?	Yes
Complete final launch by April 20th	Apr-24	+ 1 Week	N/A	?	Yes
Casing Material is Non-Ferrous and Ductile	Non-Ferrous and Ductile	none	It is Ductile and Non-Ferrous	Yes	Yes

QFD (10pts)

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

	Technical Requirements						
1	Reach minimum altitude						
	Stay within Budget for the Project	0					
2	Dimensions meet constraints of rocket size	9	0				
3	Stand withstands impulse of rocket testing	3	0	3			
4	Meet Minimum Thrust to Weight Ratio Set by Tripoli	9	3	6	6		
5	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
1	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
2	Scalable	3	3	3	9	6	6	3	3		C		A B	D E F
3	Sturdy Test Stand	4	3	3	6	9	3	3	3	C D E F	A			B
4	Comply with Tripoli Rocketry Association safety standards	5	3	3	6	6	9	3	9	C	A D	E		B F
5	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					

Image 1. QFD Displaying Corilation Between All CR and ER

Each customer need is linked to at least one technical requirement. The functionality customer requirement is directly correlated to the technical requirement to reach a minimum altitude of 10 km during the final launch. The project must be low-cost witch is quantified by staying within the $ 2,000 budget, this can be increased if the team does additional fundraising. The rocket must comply with Tripoli Rocketry Association safety standards. Two of these standards can be found in the technical reequipments. Firstly, the casing must be made of a non-ferrous ductile material which can be evaluated by looking at the material properties. The other safely standard is that the minimum thrust to weight ratio of five to one. The link between customer needs and technical requirements can be found by looking at figure 1. In figure 1 the section of the QFD where the customer needs rows and the technical requirements columns overlap; when the number in that section is high that means the two design criteria are strongly correlated, so a value of 9 means the two requirements are directly linked.

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Appendix A. Test Stand Safety Checklist

Test Stand Safety Checklist

Materials:

Test Stand	Ignitor	Ignition System	Electronics Box
Motor	Fire Extinguishers	Safety Glasses	Motor Holder
Motor Guide	Water	Shovel	Level (If Needed)

Air Temperature________ **Wind Speed**_________ **Gusting**_________ **Direction**_______

Air Humidity___________ **Barometric Pressure**___________________

- ❑ 1. Fill out air data and wind speeds to ensure safe operation
- ❑ 2. Set up the test stand in an area free from any brush or flammable debris
- ❑ 3. Adjust the gantry height to be around 3-4 inches from the nozzle end of the motor; secure the screws to lock into place
- ❑ 4. Ensure that the motor holder is correctly secured onto the load cell nipple. Use a level if necessary
- ❑ 5. Plug in the load cell wires into the electronics box
- ❑ 6. Place the motor through the motor guide on the gantry and slot into the correct motor holder ring
- ❑ 7. Plug in the pressure transducer and thread the wire through the motor holder. Plug into the electronics box
- ❑ 8. PRESS THE OFF BUTTON, SWITCH OFF THE IGNITION REMOTE, AND TAKE THE BATTERY OUT
- ❑ 9. Thread the ignitor through the electronics box (DO NOT CONNECT TO SYSTEM)
- ❑ 10. Thread the ignitor all the way down into the motor until it stops. Place tape on the top of the motor; out of the way of the nozzle
- ❑ 11. With fire extinguishers nearby and safety glasses on, secure the ignition wire into the electronics box
- ❑ 12. After all systems are ready, walk back to the distance given by the Tripoli Safety Standard (Table 1).

Table 1. Safety Data For Distance According to Max Impulse From Tripoli Safety Standard

Motor Designation	Total (MAX) Impulse (Nm)	Distance in Feet
A-G	0.01	100

H-J	160.01	100
K	1280.01	200
L	2560.01	300
M	**5120.01**	**500**
N	10240.01	1000

- ❑ 13. Put the battery back into the remote and switch on the ignition remote
- ❑ 14. Count down from five (5) to ensure everyone is ready and alert. Ignite
- ❑ 15. Keep an eye on the burn. If after the burn brush catches fire, rush to put it out using the fire extinguishers/water
- ❑ 16. After the burn has concluded, turn the ignition remote off, take out the battery, then approach the stand and take the motor out; being cautious of the motor heat