ROCKET PROPULSION CAPSTONE

TEAM #3

REMY DASHER, SHANNON COMSTOCK, GRACE MORRIS AND ANDREW KING

DESIGN REQUIREMENTS SUMMARY

Customer Requirements

"Sturdy Test Stand" (Remy)

•CR1: Precisely records the motors' downward force for motors of sizes 38 to 75 millimeters.

Functionality

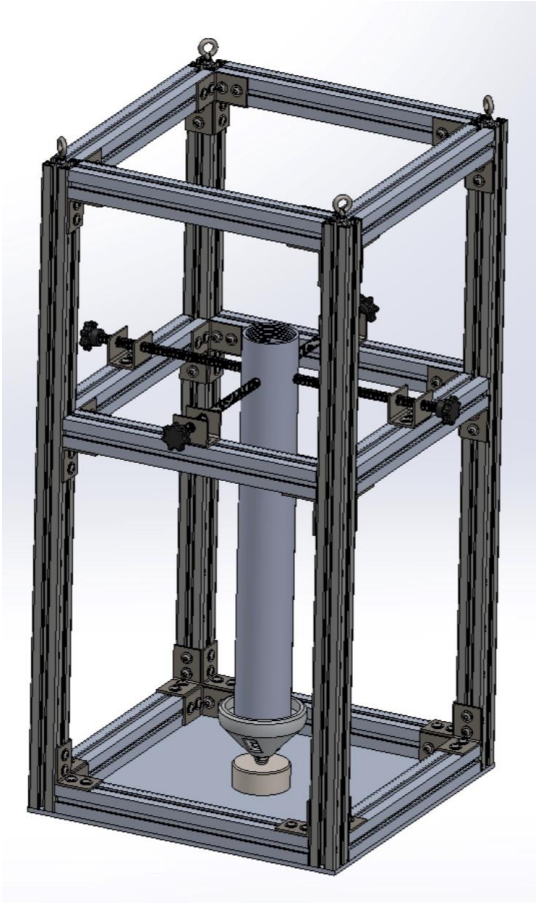
•CR2: Optimize and test a unique ammonium perchlorate propellant formula.

•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.



Scalable (Shannon)

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

Timely Completion

•CR7: 75mm motor successfully launched by the end of April 2024

Low Cost

CR8: $2000 budget 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.

DESIGN REQUIREMENTS SUMMARY

Engineering Requirements

Test Stand: (Grace)

•ER1A: lightweight (< 60 lbs).

•ER1B: Must accommodate motor sizes ranging from 38 to 75 millimeters diameter and 10 to 30 inches height.

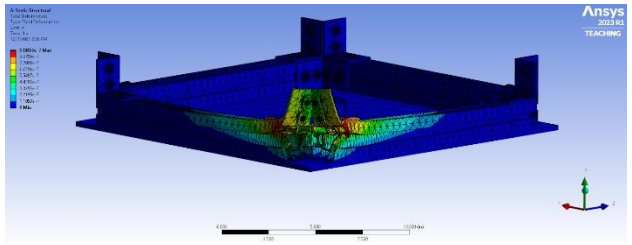
•ER1C: Capable of securely mounting motors.

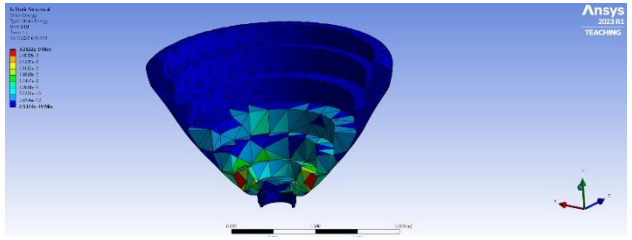
•ER1D: Must collect data during testing, such as thrust (up to 287.8 lbf), temperature (up to 500 degrees F) and pressure sensors (up to 1500 psi).

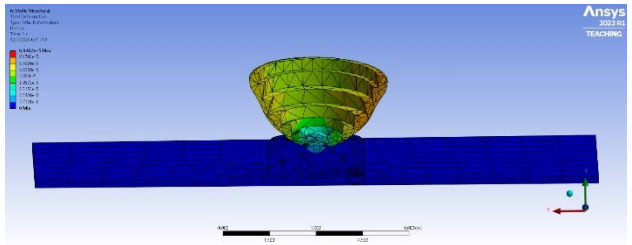
Propellant Formula:

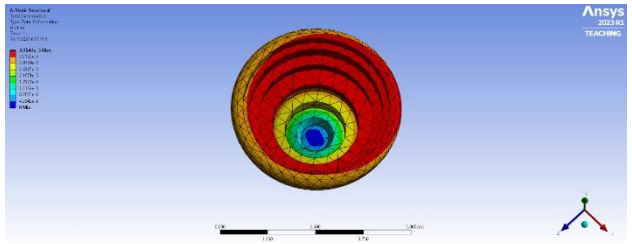
•ER2A: Optimized to have the highest thrust and impulse output (as close to 287.8 lbf and 5120 Newton seconds as possible)

•ER2B: Final formula must be tested in grain sizes of 54- and 75-mm motors









Motor Casing and Bulkheads: (Andrew)

•ER3A: Must be within tolerance ± 0.1mm of 0.1mm of 75 mm

•ER3B: The bulkheads must be made for 54- and 75-mm motors and incorporate at least two O-Rings and 1 snap-ring

•ER3C: Withstand 1500 psi with a factor of safety of 1.5 (for a total pressure rating of 2250 psi).

Nozzle:

•ER4A: 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.

EXPERIMENTAL PROCEDURES

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

Shannon

TOP LEVEL TESTING SUMMARY

Table 1. Test Summary Table

Experiment	Engineering Requirements	Customer Requirements
1	ER1: A, B, C and D (Test Stand Functionality)	CR1, CR8, CR9 (Size, Cost, Safety)
2	ER1: A, B, C and D (Test Stand Functionality)	CR1, CR8, CR9 (Size, Cost, Safety)
3	ER1: A, B, C and D (Test Stand Functionality) ER2: A, B (Propellant Formulation) ER3: B (Bulkhead Sizing)	CR1, CR2, CR6, CR8, CR9 (Size, Optimization, Testing, Cost, Safety)
4	ER1: A, B, C and D (Test Stand Functionality) ER2: A (Propellant Optimization) ER3: B (Bulkhead Sizing) ER4: A, B (Nozzle Design)	CR1, CR2, CR6, CR8, CR9 (Size, Optimization, Testing, Cost, Safety)
5A	ER1: A, B, C and D (Test Stand Functionality) ER2: A, B (Propellant Formulation) ER3: A, B, C (Bulkhead Design) ER4: A, B (Nozzle Design)	CR1, CR2, CR6, CR3, CR5, CR7, CR8, CR9 (Size, Optimization, Testing, Launching, Cost, Safety)
5B	ER1: A, B, C and D (Test Stand Functionality) ER2: A, B (Propellant Formulation) ER3: A, B, C (Bulkhead Design) ER4: A, B (Nozzle Design)	CR1, CR2, CR6, CR3, CR4, CR7, CR5, CR8, CR9 (Size, Optimization, Testing, Launching, Cost, Safety)

Grace

DETAILED TESTING PLANS (TEST/EXPERIMENT SUMMARY)

- Experiment 1: Known Thrust Curve Apogee 38 mm Motor Testing
  - Is the equipment on the test stand functioning and calibrated correctly?
    - Equipment: Test Stand, Rocket Motor, Electronics Box, Safety Checklist, Fire Extinguisher
    - Variable: Force in the Z-Direction
- Experiment 2: Disposable Casing Don White Propellant Formula 38 mm Testing
  - Is the casting process producing good motors?
    - Equipment: Test Stand, Rocket Motor, Electronics Box, Safety Checklist, Fire Extinguisher
    - Variable: Force in the Z-Direction
- Experiment 3: Disposable Casing Experimental Propellant Formula's 54 mm Testing
  - Is the test stand functioning for larger motors?
    - Equipment: Test Stand, Rocket Motor, Electronics Box, Safety Checklist, Fire Extinguisher
    - Variable: Force in the Z-Direction, Internal Pressure
    - Calculate: Thrust curve, Max altitude

Experiment 4: Reusable Casing 54 mm Final Formula Determination Testing

Which formula do we use?

-Equipment: Test Stand, Rocket Motor, Electronics Box, Safety Checklist, Fire Extinguisher

-Variable: Force in the Z-Direction, Internal Pressure

-Calculate: Thrust curve, Max altitude

Experiment 5A: Final Propellant Formula 75 mm Motor Testing

Is the 75 mm Motor functioning for final launch?

-Equipment: Test Stand, Rocket Motor, Electronics Box, Safety Checklist, Fire Extinguisher

-Variable: Force in the Z-Direction, Internal Pressure

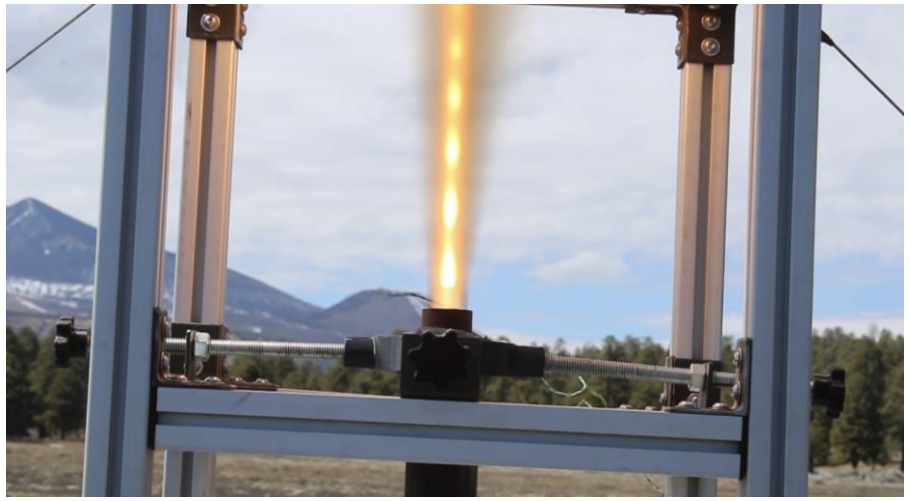
-Calculate: Thrust curve, Max altitude, Thrust to weight ratio

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

Grace

DETAILED TESTING PLANS (PROCEDURE)

- Experiment 1: Known Thrust Curve Apogee 38 mm Motor Testing
  - Ensure proper setup of test stand and electronics (don't connect igniter until ready to leave test stand)
  - Once at a safe distance, fire the motor
  - Approach if safe, and download thrust data
  - Compare recorded thrust data to the motor manufacturer's provided data.
- Experiment 2: Disposable Casing Don White Propellant Formula 38 mm Testing
  - Set up motor and test stand per the safety checklist's instructions
  - Fire the motor of Don White Propellant
  - Compare collected data to that expected of the don white formula (If they match, then move to next round testing)
- Experiment 3: Disposable Casing Experimental Propellant Formula's 54 mm Testing
  - Prepare for testing as the safety checklist lays it out
  - Fire one motor in the disposable motor casing
  - If successful, move on to final formula determination testing
- Experiment 4: Reusable Casing 54 mm Final Formula Determination Testing
  - Prepare for testing as the safety checklist lays it out
  - Fire one motor of each custom propellant
- Experiment 5A: Final Propellant Formula 75 mm Motor Testing
  - Prepare motor and test stand according to the 75mm motor testing safety checklist
  - If testing goes according to plan and the motor is deemed safe, then the team is ready to launch in the rocket
- Experiment 5B: Depending on Results of 5A, Option for Another 75 mm Motor Testing if Needed



Andrew

DETAILED TESTING PLANS (RESULTS)

Results Goals

Determine the Mach number at the nozzle exit:

Experimental / Simulation Data:

- Chamber Pressure (P_t) = 210psi
- Pressure at Exit (P_e) = 11.33psi
- Specific Heat Ratio (gamma) = 1.25

$$\frac{p_e}{p_c} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$

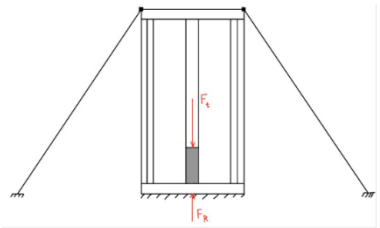
$$M = \sqrt{\left(\frac{2}{\gamma - 1}\right)\left(\frac{p_t}{p_e}\right)^{\frac{\gamma - 1}{\gamma}} - 1}$$

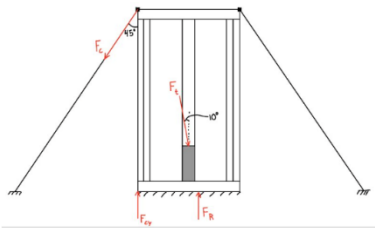
- Exit Mach, M = 3.65
- This tells us that the nozzle achieved choked flow, which is what we want

Determine the performance of the propellant based on the thrust and impulse:

- Expected impulse of less than 5120 N-sec
- Expected burn time of approx. 4 seconds
- For a 38 mm motor, we can expect 1280 N

$$I = F_t * t$$
$$F_t = \frac{I}{t}$$
$$F_x = F_t * \cos(\theta)$$





Given:
Impulse (I) = 5120.00 N-sec
Burn Time (t) = 4 sec
Angle = 10 degrees

(Assume frictionless surface)

Solution:

	Case A	Case B
	1280.00 N	1280.00 N
	1280.00 N	1260.55 N
	-	314.34 N
	-	222.27 N

Andrew
10/9
Rocket Propulsion Team 3

Andrew

Table 2. Customer Requirements Met

SPECIFICATION SHEET PREPARATION CUSTOMER REQUIREMENTS

Customer Requirements	CR Met? (Y/N)	Client Acceptable?
CR1- Measure Force	YES	YES
CR2- Optimize Formula	YES	YES
CR3- Design Casing	YES	YES
CR4- Design Nozzle	YES	YES
CR5- Altitude	--	YES
CR6- Test Multiple Sizes	YES	YES
CR7- Launch in April	YES	YES
CR8- Stay in Budget	YES	YES
CR9- Safety	YES	YES

•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.

•CR7: 75mm motor successfully launched by the end of April 2024

Shannon

SPECIFICATION SHEET PREPARATION ENGINEERING REQUIREMENTS

Table 3. Specification Sheet ER's

Engineering Requirements	Target	Tolerance	Measured	ER Met? (Y/N)	Client Acceptable?
ER1A-Lightweight Test Stand	<60 lbs	+ 5 lbs	45 lbs	YES	YES
ER1B- Accommodate Size Ranges	Dia: 38-75mm Length: 10-30in	Dia: +0.00/-0.05mm Length: -5/+10in	Dia: 38-75mm Length: 5-40in	YES	YES
ER1C- Securely Hold Motor	Runout <1mm	+0.00/-0.10mm	0.75mm	YES	YES
ER1D- Collects Data	300lb (136kg)	<= 1102.3lb (500kg)	287.8lb	YES	YES
ER2A- Optimized Propellant	5120 Ns	<5120Ns (Tripoli L2)	Experimental	YES	YES
ER2B- Propellant Tested in Multiple Sizes	5120 Ns	<5120Ns (Tripoli L2)	Experimental	YES	YES
ER3A-Casing Fit	75mm	+/- 0.1mm	0.01mm	YES	YES
ER3B- Use O-RIngs and Snap RIngs	54 & 75mm Bulkheads	+0.00/-0.010mm	54.90/74.90mm	YES	YES
ER3C- FOS on Bulkhead	<1000 psi	<=1.5 FOS	2.3 FOS @ 1000 psi	YES	YES
ER4A- Use CFD	Ensuring Choked Flow	M=1 +/-0.00	M=1 (CFD Analysis)	YES	YES
ER4B- Test Nozzle	2 Motor Tests	+1 Motor / -0 Motor	2 Motors	YES	YES

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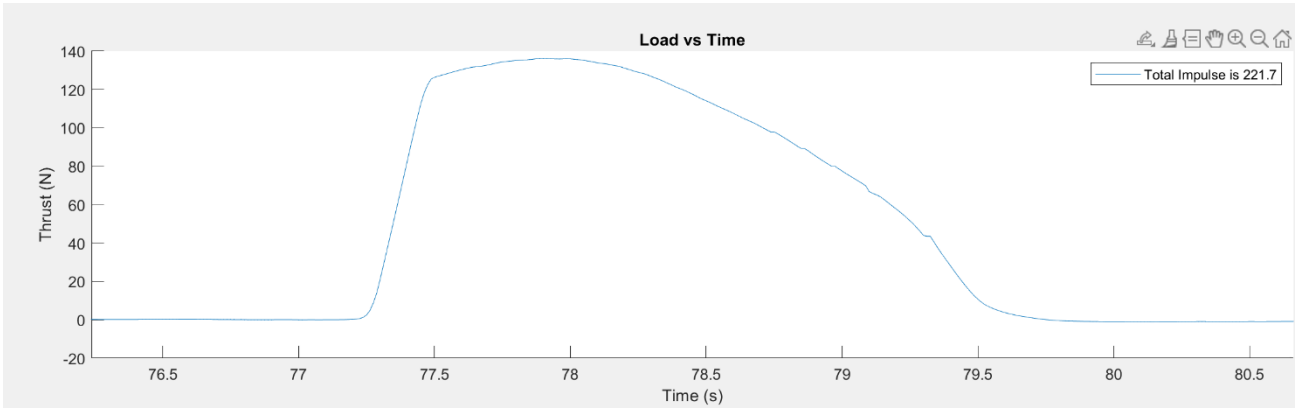
		Technical Requirements						
Customer Needs	Customer Weights	Reach minimum altitude	Stay within Budget for the Project	Dimensions meet constraints of rocket size	Stand withstands impulse of rocket testing	Meet Minimum Thrust to Weight Ratio Set by Tripoli	Complete final launch by march 2024	Non-Ferrous 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

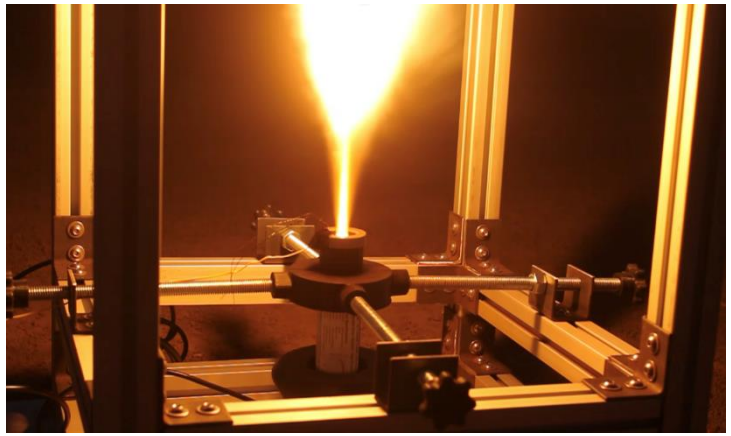
- Majority of testing is to ensure we meet minimum altitude requirement
- Testing and simulation results are submitted to launch site so that we get approval for launch

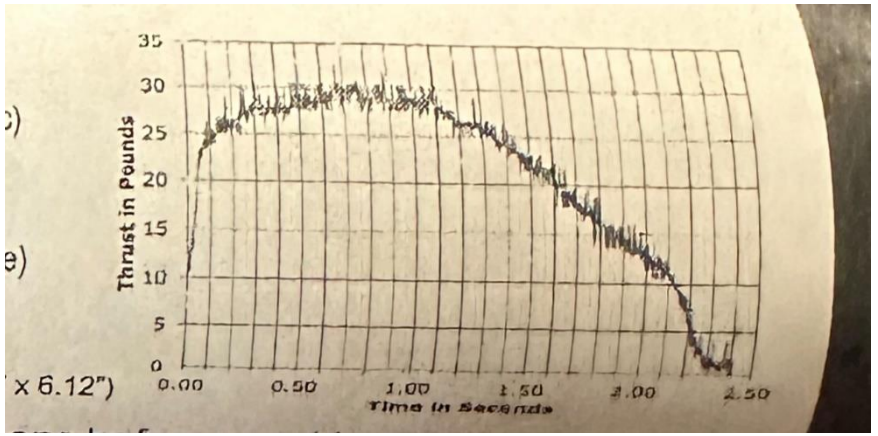
Grace

EXPERIMENT 1 (SUCCESS ☺)

38 mm Known Thrust Curve Results



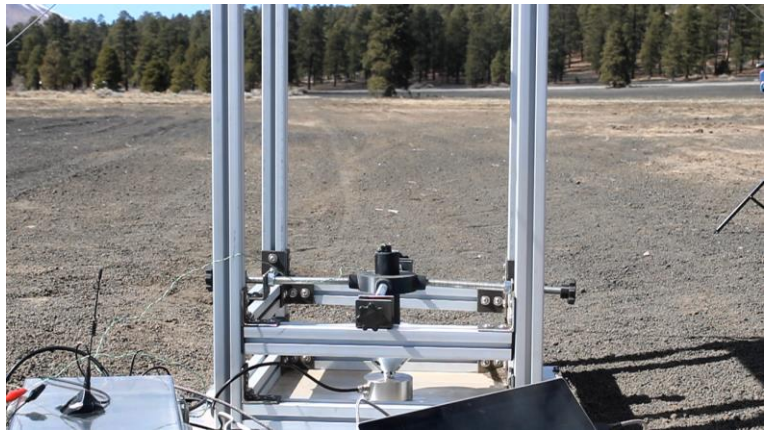


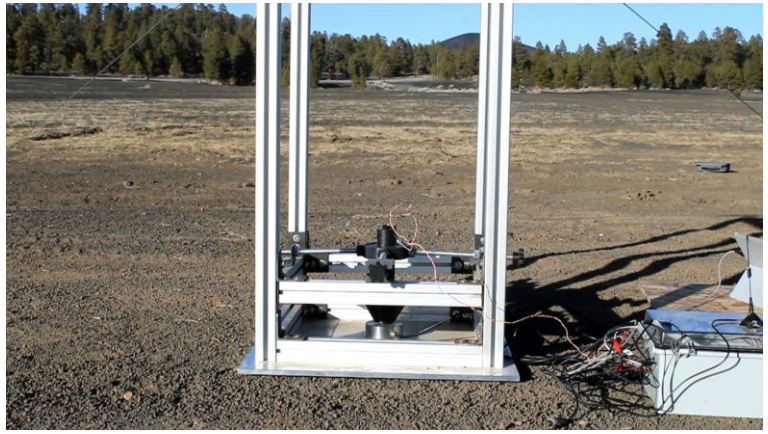


Andrew

EXPERIMENT 2

TRIALS 1 AND 2 (FAILURES ☹)

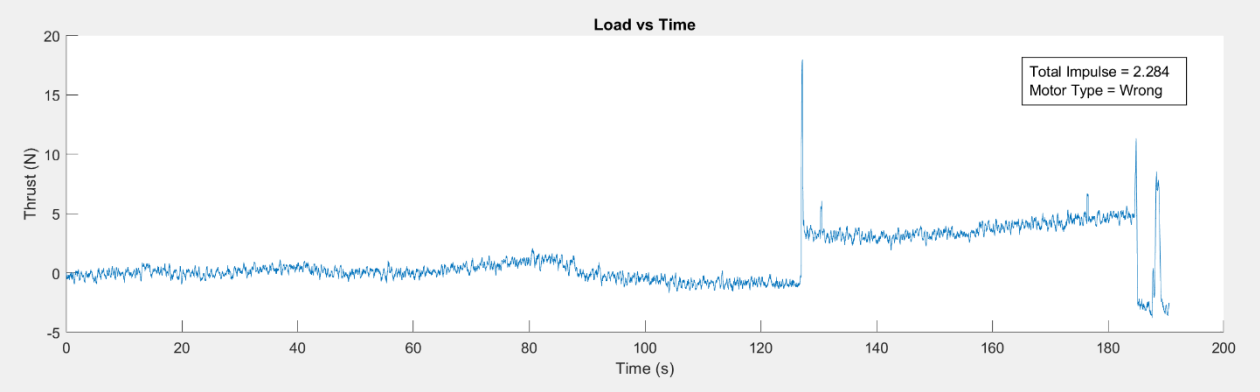


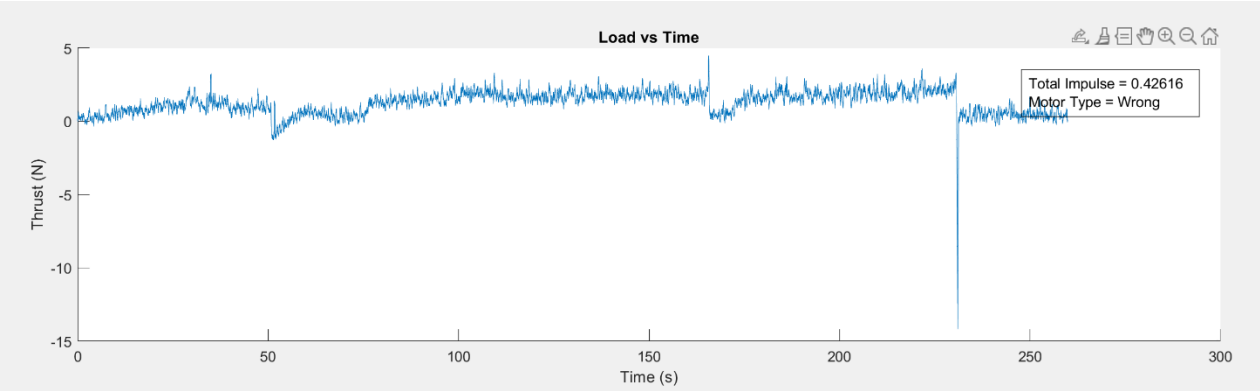


Remy

EXPERIMENT 2:

RESULTS FROM FAILED 38 MM DON WHITE FORMULA





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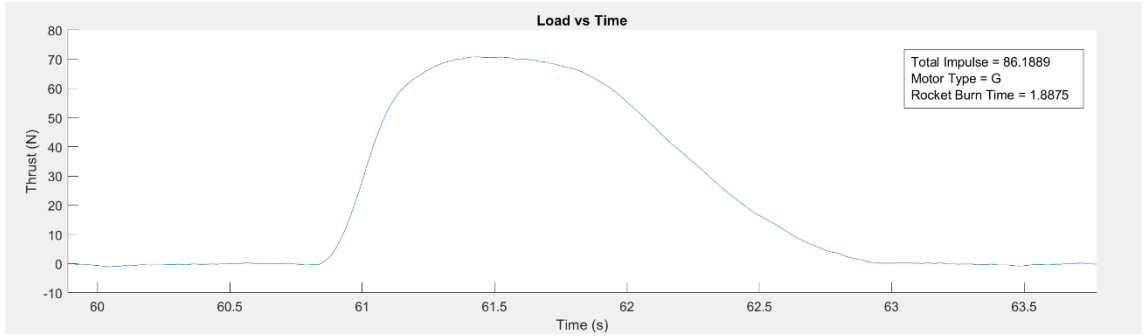
EXPERIMENT 2 TRIAL 3

38 MM DON WHITE FORMULA (SUCCESS ☺)



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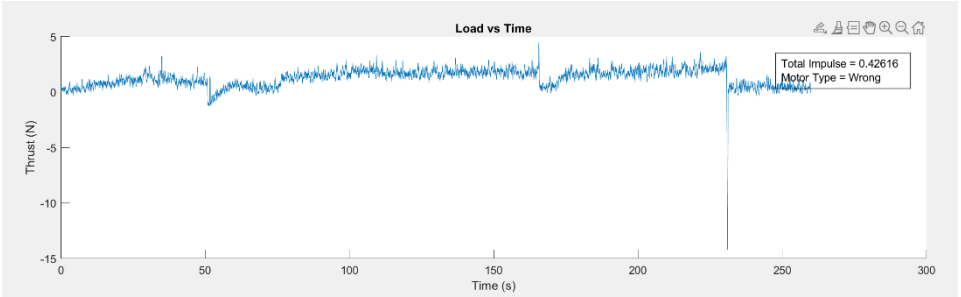
EXPERIMENT 3 TRIAL 1

54MM MOTOR TESTING (FAILURE ☹)

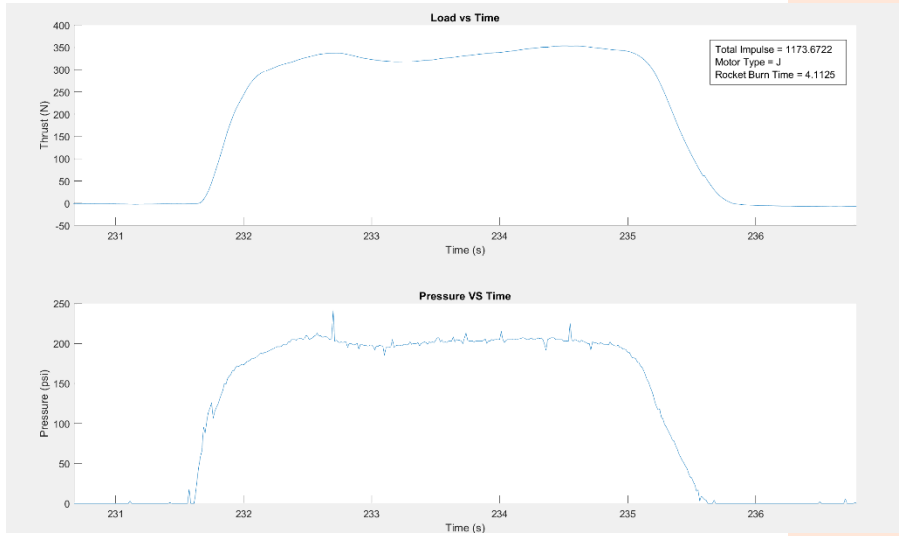


Shannon

EXPERIMENT 4

TRIAL 1(SUCCESS!! ☺☺☺)

54 MM MOTOR UNIQUE AP TEST



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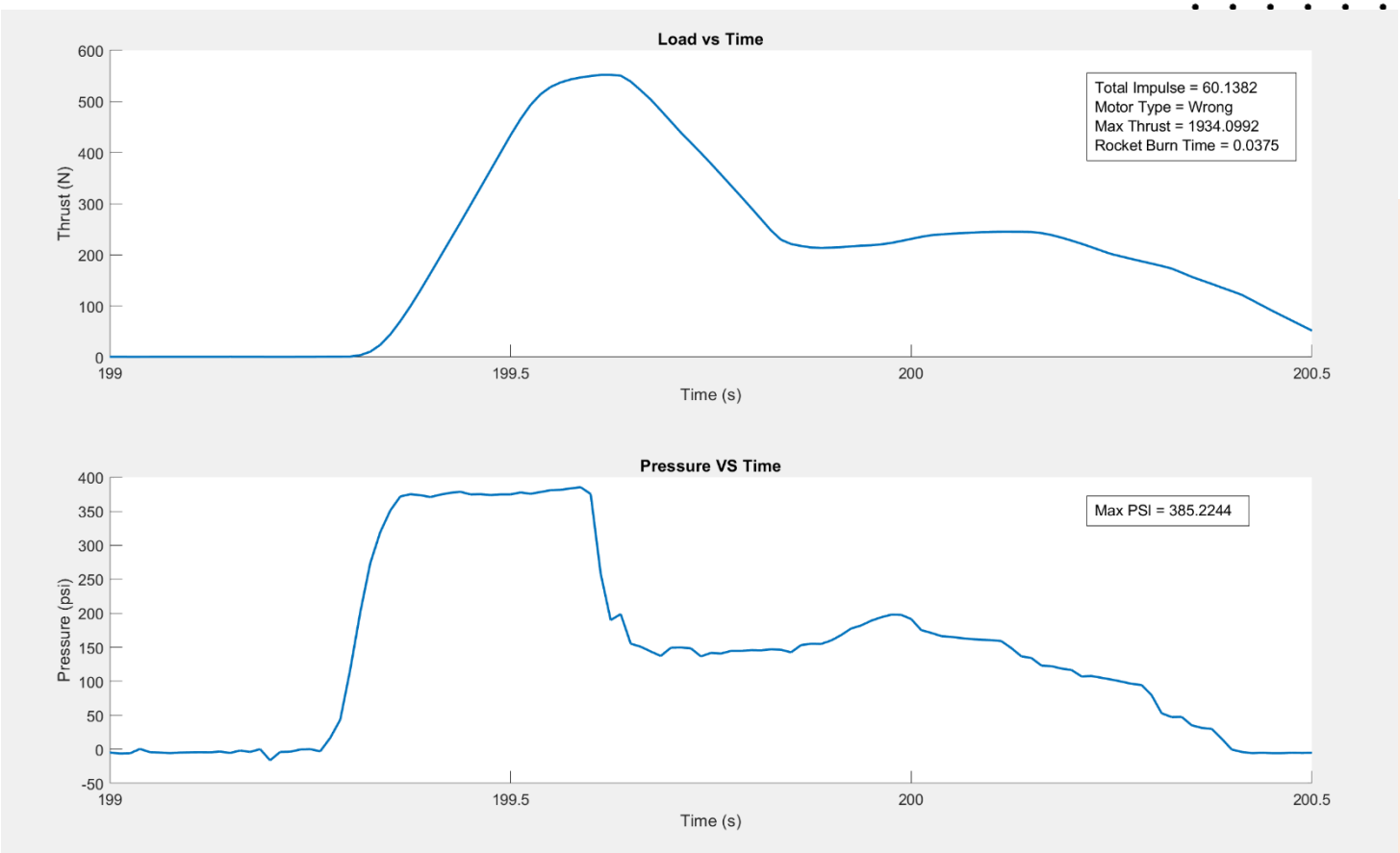
EXPERIMENT 4:
54 MM MOTOR NOZZLE (SUCCESS!)

Andrew

EXPERIMENT 4 TRIAL 2 (FAILURE ☹☹)

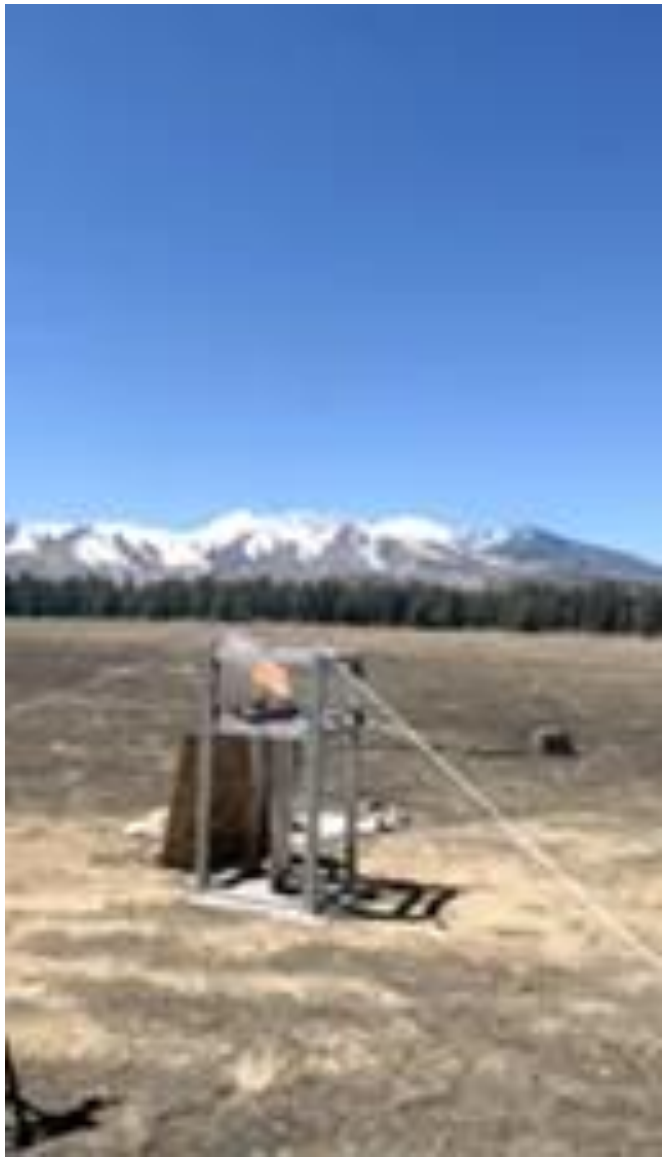
54 MM MOTOR UNIQUE AP TEST



Remy

EXPERIMENT 5A

75 MM MOTOR TEST



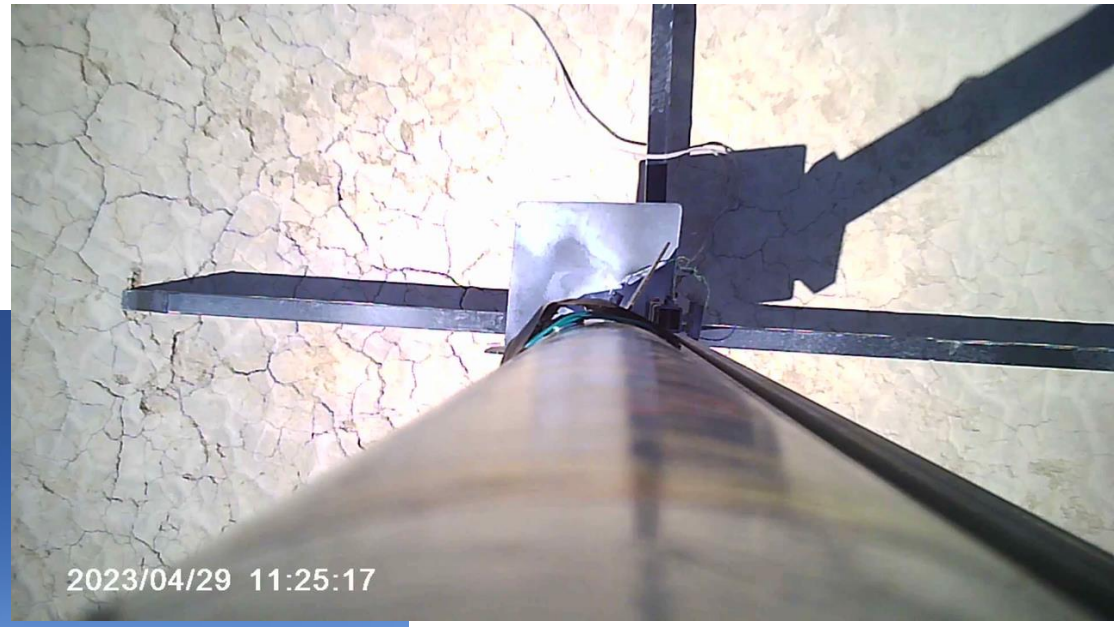
Remy

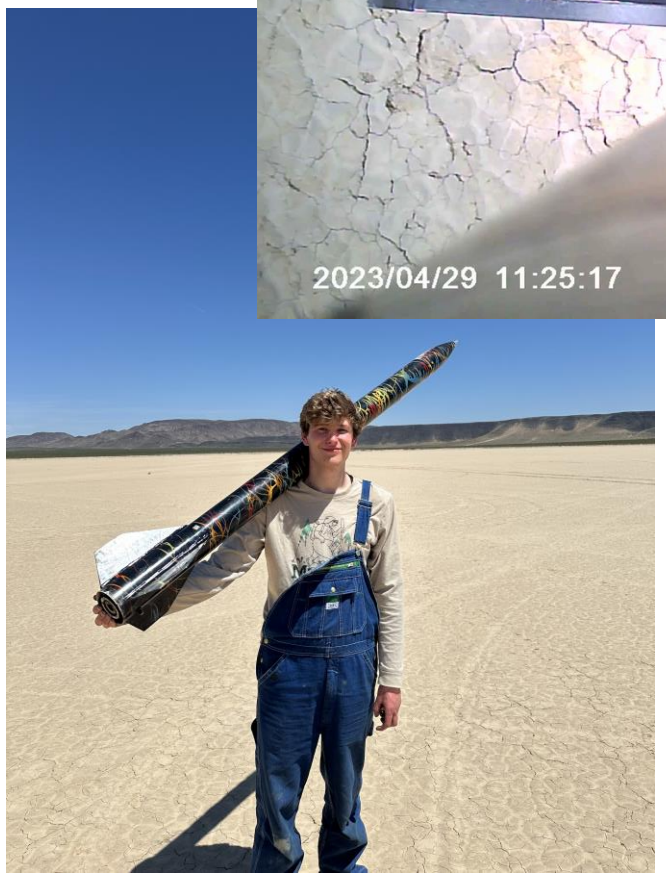
EXPERIMENT 5B

75 MM MOTOR TEST- ATTEMPT 2

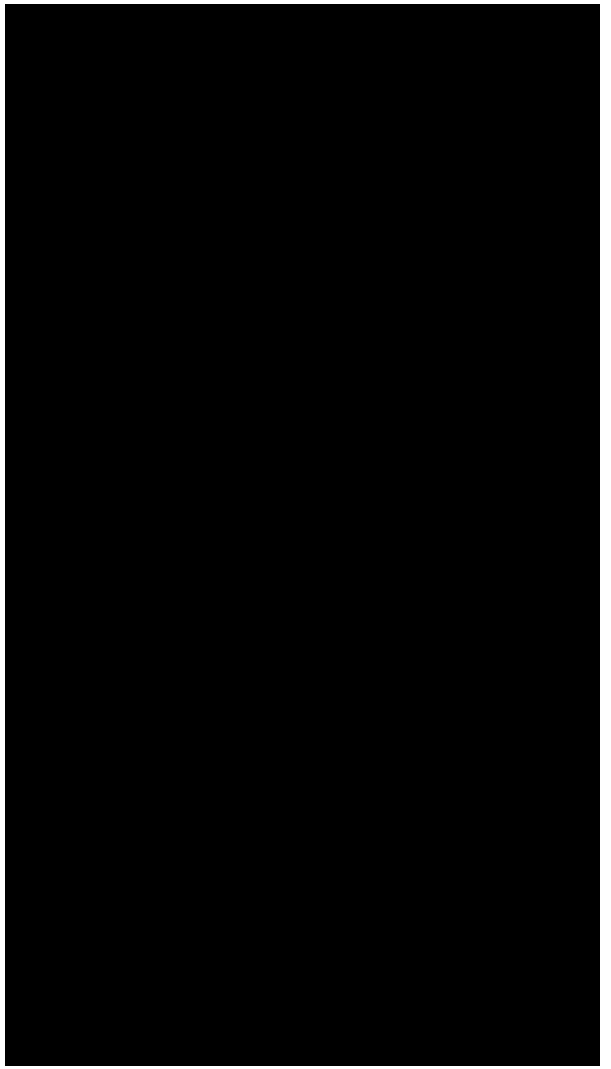
Remy

FINAL LAUNCH





54 MM MOTOR LAUNCH – CLIENT APPROVED



Grace

NEXT STEPS

- This week: Create new bulkheads, drill radial bolts, and test again mid-week.

Shannon

ANY QUESTIONS?