NAKUJA PROJECT
DESIGN.MAKE.LAUNCH

N-3.5 ROCKET LAUNCH (2024)

SOLID PROPULSION: TECHNICAL REPORT.

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Interstellar innovators, ready to defy gravity!

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1. INTRODUCTION.

This technical report constitutes the works accomplished by the Nakuja Project Solid propulsion team driving towards the aim of developing and launching the N3.5 rocket to an apogee of 1.6 KM in collaboration with other teams within Nakuja Project; Recovery team, Airframe team and liquid propulsion team.

In solid rocket motors (SRMs) the propellant to be burned is contained within the combustion chamber or casing. The solid propellant charge is called the grain, and it contains all the chemical elements for complete burning. Once ignited, it burns smoothly at a predetermined rate on all the internal surfaces of the grain.

The basic components of a solid rocket motor are:

- Motor Casing - The cylindrical outer housing that contains the propellant.
- Propellant - The chemical mixture serving as the motor's fuel.
- Nozzle- Attached to one end of the casing, it regulates the exhaust gases, converting high-pressure gas into high-velocity exhaust and directing it to produce thrust.
- Igniter- Activated by a microcontroller signal, it ignites the propellant.
- Bulkhead- It is attached at the opposite end of the motor casing. It seals the motor.

The design of these components was achieved through a combination of analytical methods, including mathematical calculations, software simulations, static firing tests, and iterative optimization based on test results.

2. PRE-LAUNCH PREPARATIONS.

2.1. Solid Rocket Motor Design and Fabrication.

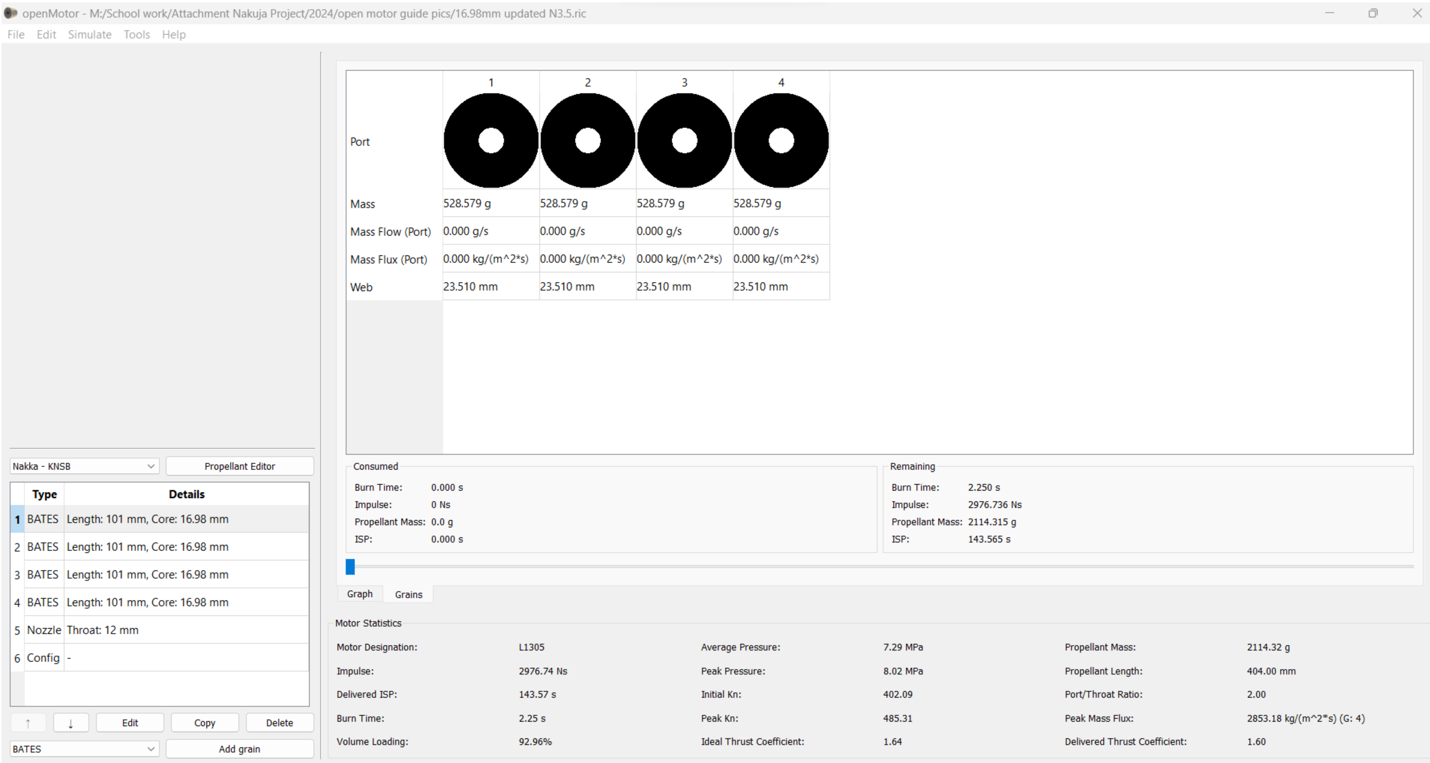
2.1.1. Propellant.

The propellant used for this rocket launch is a solid propellant composed of Potassium Nitrate/Sorbitol (KNSB). With a history of experimentation and launches using KNSB propellant-powered rockets in N2 and N3 under the Nakuja Project, the team selected Potassium Nitrate/Sorbitol (KNSB) as the preferred solid propellant for this mission.

Sorbitol, an artificial sweetener, is very similar in appearance and physical characteristics to sugars like sucrose and dextrose, but it is not a carbohydrate. Instead, sorbitol is a hexahydric alcohol, or an "alcohol sugar," with the chemical formula $C_6H_{14}O_6$. It is widely used in various industries due to its unique properties.

The standard formulation of KNSB propellant is 65% potassium nitrate (KN), which serves as the oxidizer, and 35% sorbitol (SB), which functions as both the fuel and binder. This ratio of oxidizer to fuel mass represents a practical upper limit for "solids" loading of a sugar binder, while maintaining good performance and burn rate characteristics. A higher O/F ratio, and thus higher "solids" loading, may give slightly enhanced performance, but leads to a thicker consistency of the melted mixture (slurry). This makes casting more difficult. The effect of using a lower O/F ratio is reduced performance and a slower burning rate. However, the slurry has a thinner consistency, which makes casting a bit easier.

Open motor Simulation.



Calculations.

Using a grain with 16.98mm diameter port:

Simulated mass of 1 grain= 529g

15% allowance for waste:

$$Total\ mass\ of\ constituents = 1.15 \times 529 = \mathbf{608.4g}$$

Taking ratio of KNO_3: Sorbitol = 65: 35

Mass of KNO_3: 0.65×608.4g = **395.46g.**

Mass of solid sorbitol : 0.35×608.4 = **212.94g.**

Liquid Sorbitol contains 70% sorbitol.

Mass of liquid sorbitol to be measured:

$$\frac{100 \times 212.94}{70} = \mathbf{304.2g}$$

Mass of iron (iii) oxide =1% total mass

$$= 0.01 \times 608.4 = \mathbf{6.084g}$$

One grain measurement.

ELEMENT	MASS (g)
POTASSIUM NITRATE	395.46
SORBITOL	304.2
IRON(iii) OXIDE	6.084

Cooking Grains procedure.

Step 1: Weighing of ingredients.

Step 2: Preheating sorbitol.

Step 3: Cooking the chemical mixture.

Step 4: Casting in mold

Step 5: Extracting core rod, removal of grain from casting tool, weighing grain.

Step 6: Storage of grains using silica gel and zip lock bags in an airtight container.

2.1.2. Nozzle.

The primary function of a nozzle in a rocket is to channel and accelerate the combustion products produced by the burning propellant to maximize the exhaust velocity at the exit, ideally reaching supersonic speeds. The nozzle design chosen for this application is the familiar rocket nozzle, also known as a convergent-divergent or de Laval nozzle. This nozzle achieves supersonic flow through its specific geometric profile.

The goal of rocket nozzle design is to accelerate the combustion products to the highest possible exit velocity. This is accomplished by shaping the nozzle to create an isentropic flow—a flow that depends only on the cross-sectional area and is both frictionless and adiabatic (with no heat loss). To achieve nearly isentropic flow in a real nozzle, it is crucial to minimize frictional effects, flow disturbances, and conditions that could lead to shock losses. Additionally, reducing heat transfer losses is important to maintain the desired flow properties.

By ensuring these conditions, the nozzle design allows the flow properties to be primarily influenced by the changing cross-sectional area as the combustion gases move through the nozzle, thereby achieving efficient acceleration and maximizing exhaust velocity.

AISI 1018 mild/low carbon steel was selected as the nozzle material due to its excellent weldability, good toughness, strength, and ductility. It produces a uniform and harder case, making it ideal for carburized parts. Additionally, AISI 1018 offers improved machining characteristics and Brinell hardness, providing a good balance of mechanical properties. Its toughness and relative affordability make it a widely used material for various applications.

Chemical Composition

Element	Carbon	Silicon	Manganese	Sulphur	Phosphorus
Content (%)	0.16 - 0.24	0.10 - 0.40	0.50 - 0.90	0.05 Max	0.05 Max

$$Port \ \ to\, Throat\ ratio = \frac{cross - section\ area\ of\ port}{cross - section\ area\ of\ throat}$$

$$= \frac{(D_p^2)}{(D_t^2)}$$

Diameter of throat = 12mm

Using Port to Throat ratio = 2

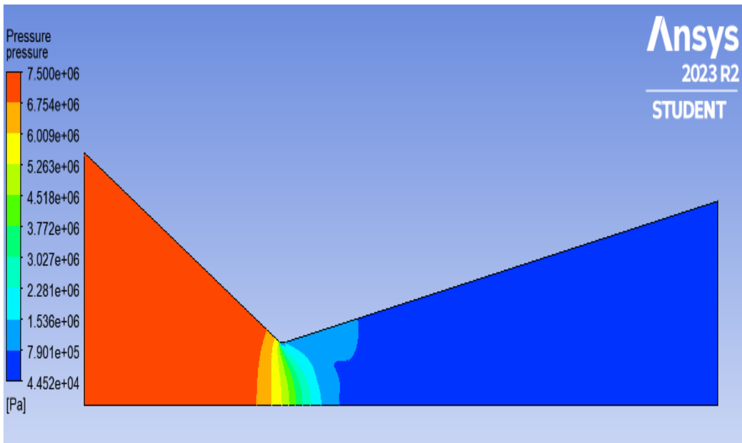
$$D_p^2 = \text{port to throat ratio} \times D_t^2$$

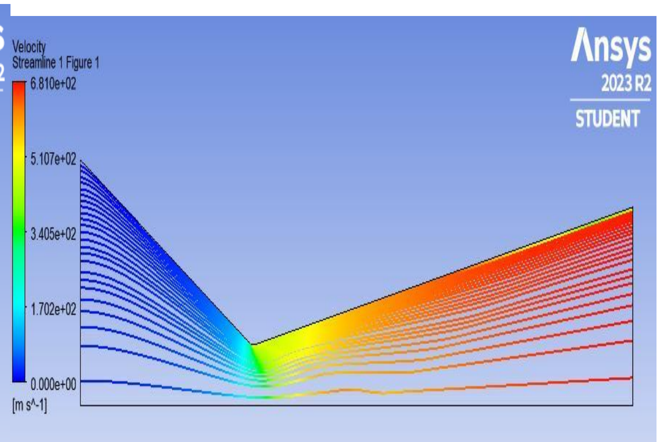
$$D_p^2 = 2 \times 12^2$$

$$D_p = 16.970 \text{ mm}$$

Approximately $D_p = 17$mm

Ansys simulation.





BOUNDARY CONDITIONS:

Inlet-7.5Mpa gauge

Outlet-101.325KPa(atmospheric).

FINDINGS
The flow of gas at outlet increased to supersonic speed (Mach>1).
The design of the nozzle is okay

Machining of Nozzle.

Cutting the workpiece

Facing

Drilling

Turning

Boring

Machined Nozzles

2.1.3. Casing.

The casing for the solid rocket motor was made from mild steel SCH40 pipe, chosen for its balance of tensile strength, thermal resistance, and cost-effectiveness. Mild steel offers good tensile strength, typically ranging from 400 to 550 MPa, which allows it to withstand the high pressures generated during combustion. Although it has moderate thermal resistance and is not inherently corrosion-resistant, with proper treatment and in controlled environments, mild steel is a suitable material for rocket motor casings.

The design of the casing took into account both the design pressure and burst pressure to ensure that the casing could safely contain the combustion gases and handle any pressure spikes. It was also engineered to withstand both static loads, such as steady-state forces during operation, and dynamic loads, like those experienced during ignition and combustion, ensuring structural integrity throughout the motor’s operation.

A thermal analysis of the casing focused on its ability to manage the heat generated during combustion, with considerations for heat dissipation and thermal expansion to prevent localized overheating or thermal stress. Quality control measures, including dimensional inspection, material testing, and pressure testing, were implemented to ensure the casing met all design specifications. The casing was also carefully integrated with other components of the rocket motor, such as the nozzle, propellant grain, and igniter, using secure attachment methods and O-rings for sealing to prevent leaks and ensure proper alignment, which is crucial for optimal performance and safety.

Calculation of casing thickness.

Considering design pressure:

$$P_D = \frac{2tF_{ty}}{D_0 S_D} \quad \text{.........} \ (1)$$

where:

$\boldsymbol{F_{ty}}$**- Yield strength.**

$\boldsymbol{P_D}$ **– Design Pressure**

t – thickness

$\boldsymbol{D_O}$ ***- Outer diameter***

$\boldsymbol{S_D}$ ***- Safety factor***

From equation (1)

$$t = \frac{P_D D_0 S_D}{2F_{ty}}$$

For:

P_D = *8.02 Mpa*

D_O= *73mm*

S_D= *1.87*

F_{ty}= *220MPa*

$$t = \frac{8.02 \times 73 \times 1.87}{2 \times 220}$$

= 2.488 mm

t =2.5mm

Thus D_{outer} = 73mm

D_{inner} = 68mm

t = 2.5mm

- Considering Burst pressure:

For the thickness 2.5mm:

$$P_V = \frac{2tF_{ty}B}{D_0}$$

where**:**

F_{ty}- Yield strength.

P_V – Burst Pressure

t – thickness

D_O* - *Outer diameter

B – Burst Factor

- For:

t= 2.5mm

D_O= 73mm

B= 1.726

F_{ty}= 220MPa

$$P_V = \frac{2 \times 2.5 \times 220 \times 1.726}{73}$$

= 26.0082MPa

=26MPa

Outer Diameter	73	mm						
Motor length	500	mm						
Density	7.87E-06	kg/mm3						
	Thick-ness [mm]	Thick-ness [in]	Design pressure [kPa]	Burst pressure [kPa]	Simulated Peak pressure (Open Motor) [kPa]	Simulated Peak pressure (Open Motor) [MPa]	Inner diameter [mm]	Total casing weight [kg]
N-3.5 ->	2.5	0.0984	8020	26000	1163.2	8.02	68	2.17883195
N-3 ->	2	0.0787	1134	3188	1450.38	10	69	1.75542773
	1.9	0.0748	1078	3029			69.2	1.67000515
	1.8	0.0709	1021	2869			69.4	1.58433533
	1.7	0.0669	964	2710			69.6	1.49841827
N-2 ->	1.65	0.065	936	2630			69.7	1.45536703

Design and Burst Pressures for Rocket Motor Casing

[Input data in blue text. English or (SI) units]

Casing Dimensions and Design Factors

Do =	2.874	in. (mm)	Diameter, outside
t =	0.098	in. (mm)	wall thickness
S_D =	1.87		Design Safety factor

Material Properties

Fty =	35	ksi (MPa)	Yield Strength
Ftu =	58	ksi (MPa)	Ultimate Strength
E =	29	Msi (MPa)	Modulus of Elasticity
ν =	0.29		Poisson Ratio
β =	0.603		Fty/Ftu
B =	1.726		Burst factor

Design and Burst Pressures

P_D =	1282	psi (kPa)	**Design pressure**
P_U =	4137	psi (kPa)	**Burst pressure**
S_U =	3.23		**Burst Safety Factor**

https://www.nakka-rocketry.net/softw.html

Machining of Casing.

- Drilled holes using 6mm diameter drill bit
- First tapped using M7 taps
- Finished with tapping using M8 taps

T= 2.5mm

Dout = 73mm

Din = 68mm

L = 500mm

2.1.4. Bulkhead.

The bulkhead was constructed from Aluminum Grade 6063, a low to medium strength aluminum alloy renowned for its excellent corrosion resistance, high surface finish, and versatility in forming complex shapes. This alloy, commonly used in architectural applications, is available in various temper conditions, with T6 providing high strength and T4 offering good formability. For the bulkhead, these properties ensure it can withstand the high-pressure forces exerted by the combustion gases while effectively sealing the forward end of the motor. To prevent gas leakage, O-rings were employed, ensuring a secure seal.

Thermal management was addressed by using casting sand as an insulator, which prevents direct contact between the igniter, the topmost grain, and the bulkhead. This insulation minimizes heat transfer and protects the bulkhead from thermal damage, maintaining its structural integrity throughout the motor's operation.

Integration with other components, such as the nozzle and propellant grain, was carefully managed to ensure proper alignment and secure attachment. This careful integration prevents misalignment and mechanical failures, which is crucial for the reliable and safe operation of the rocket motor. The bulkhead's design and assembly were optimized to ensure that it supports the overall functionality and performance of the rocket system.

Chemical Properties

Element	Manganese (Mn)	Iron (Fe)	Magnesium (Mg)	Silicon (Si)	Zinc (Zn)	Copper (Cu)	Aluminium (Al)
% Present	0.0 - 0.10	0.0 - 0.35	0.45 - 0.90	0.20 - 0.60	0.0 - 0.10	0.0 - 0.10	Balance

Machining of Bulkhead.

Cutting Workpiece.

Bulkhead with O-rings

2.1.5. Bolts.

Mild steel M8 bolts were chosen for the rocket motor assembly due to their strength and reliability in securing various components. These bolts, with a nominal diameter of 8 mm, offer a good balance of tensile strength, ductility, and cost-effectiveness. Typically, mild steel M8 bolts have a tensile strength ranging from 400 to 550 MPa, making them well-suited for handling the mechanical loads and stresses encountered in rocket motor applications. Their strength ensures they can withstand the high-pressure and high-stress conditions experienced during operation, providing secure and dependable connections between the bulkhead and other critical components.

calculations.

The maximum pressure (P_{Max})as simulated in open motor was **8.02Mpa**.

$$P_{Max} = 8.02Mpa$$

The pressure force (F_P):

$$F_P = P_{Max} \times Cross\ sectional\ area$$

Inside diameter(d) = 68mm

$$F_P = 8.02 \times \frac{\pi}{4} \times 68^2 = 29126.08N$$

M8 Bolt cross-section area= 50.265mm^2

Force acting on each bolt:

$$F_B = \frac{F_P}{n}, \ \textit{Where n= number of bolts}$$

Using **8** M8 Bolts:

$$F_B = \frac{29126.08}{8} = 3640.76N$$

The shear stress (τ) acting on each bolt

$$\tau = \frac{F_B}{bolt\ x{-}area}$$

$$\therefore \ \tau = \frac{3640.76N}{50.265mm^2} = 72.431\ N/mm^2$$

The **yield strength** of mild steel bolt is 250N/mm^2.

Using **von misses yield criterion** to calculate the maximum shear stress:

$$\tau_{Max} = 0.58\sigma_{yield}$$

$$\tau_{Max=0.58\times250=145N/mm^2}$$

Using a safety factor of 1.5:

$$Maximum\ allowable\ shear\ stress = \frac{145}{1.5} = \mathbf{96.67N/mm^2}$$

72.431 < 96.67

BOLTS SHEAR STRESS CALCULATIONS

	Bolt diameter	No. of bolts	CSA (per bolt)	Force per bolt	Shear stress(per bolt)
M6	6	6	28.27433388	4854.34708	171.6874074
		8		3640.76031	128.7655556
M8	8	6	50.272	4854.34708	96.56164625
		8		3640.76031	72.42123469
M10	10	6	78.55	4854.34708	61.7994536
		8		3640.76031	46.3495902

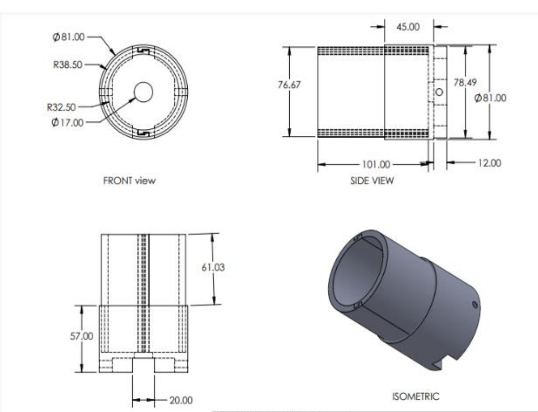
Pipe diameter	68
Tube Pressure(Max)	8.02
Yield stress(Mild steel)	250
Safety factor	1.5
CSA(tube)	3631.681108
Force on tube(max)	29126.08248
shear stress(Max)	145
Bolt Shear stress(allowable)	96.66666667

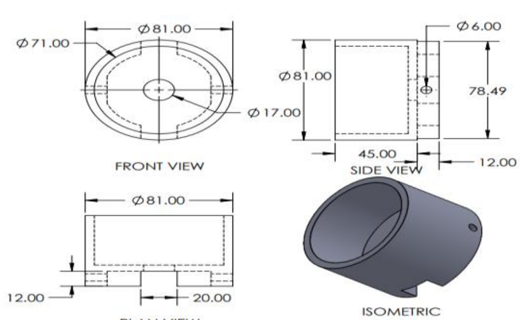
NB: CSA means cross section area
RESULTS: 72.4212Pa < 96.67Pa
INFERENCE: MINIMUM BOLT DIAMETER = M8
NO. OF BOLTS = 8

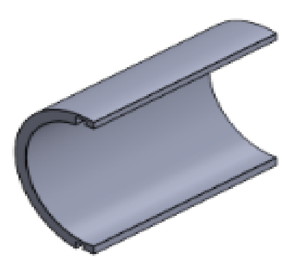
2.2. Casting tools.

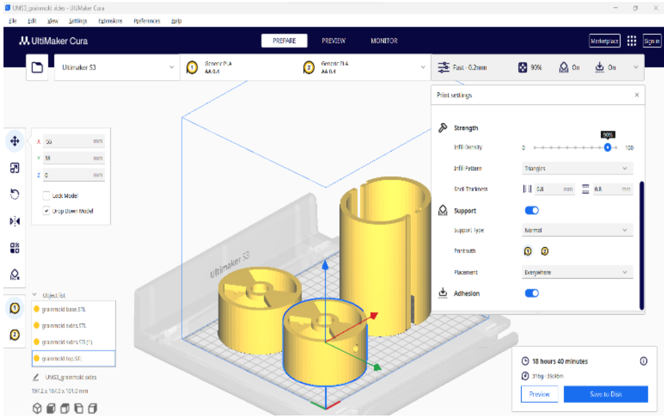
The casting tools serve a crucial function in the rocket motor assembly process. They are used to shape the molten propellant into the desired form This process shapes the propellant into the specific configuration needed for the rocket, which, in this case, was a Bates grain pattern. Essentially, the casting tools help create the exact shape of the propellant needed to ensure the rocket motor performs as intended.

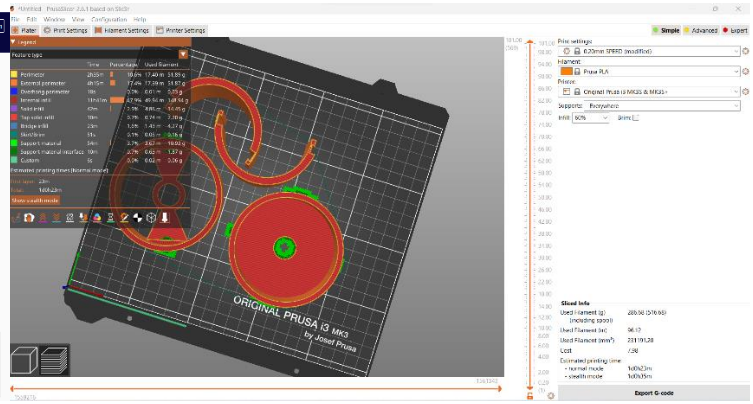
Design.











- Slicing for ultimaker done in Cura and for Prusa done in Prusa.

2.3. Igniter.

Ignition powder. (Black powder)

80% POTASSIUM NITRATE
20 % CHARCOAL

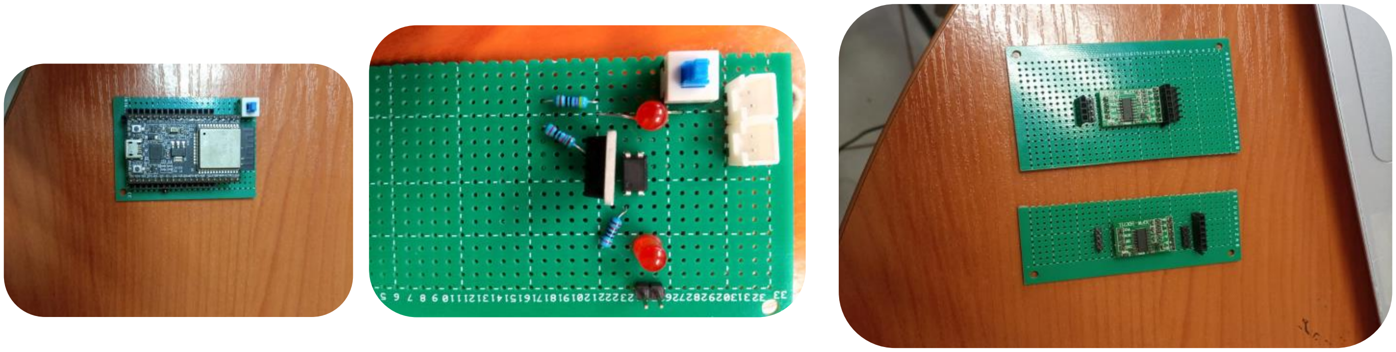
IGNITERS.

2.4. Ignition Circuit.

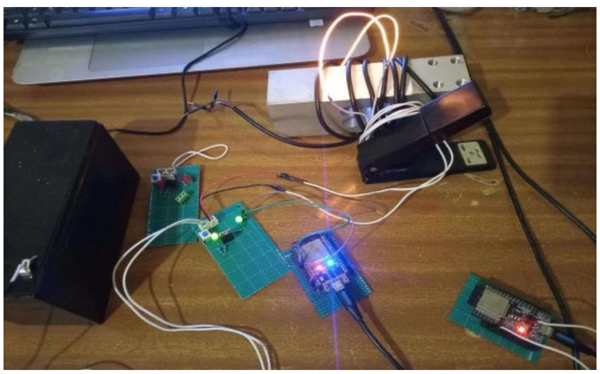
The ignition circuit section is a critical component of the rocket motor system, responsible for initiating the combustion process. The ignition circuit's primary role is to provide a reliable and precise mechanism for igniting the propellant, ensuring that the rocket motor functions as intended. There are two iterations of this circuit, each reflecting advancements in design and performance.

Iterations.

N3.5IgnCctV1.

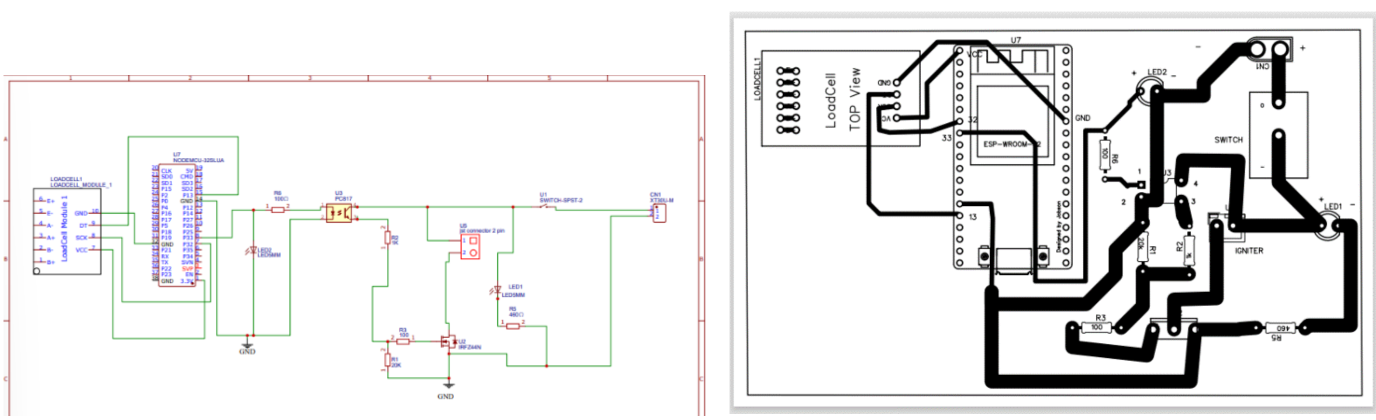


Trigger module, Ignition circuit module, loadcell module.

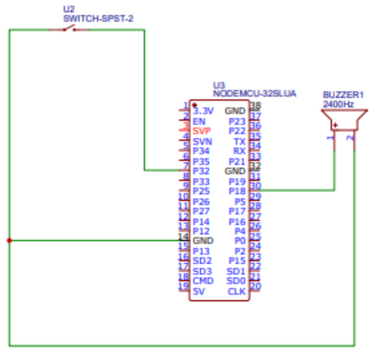


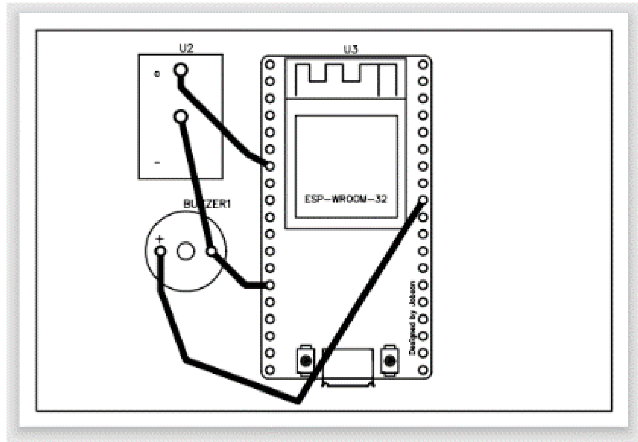
Testing of Ignition System.

N3.5IgnCctV2.

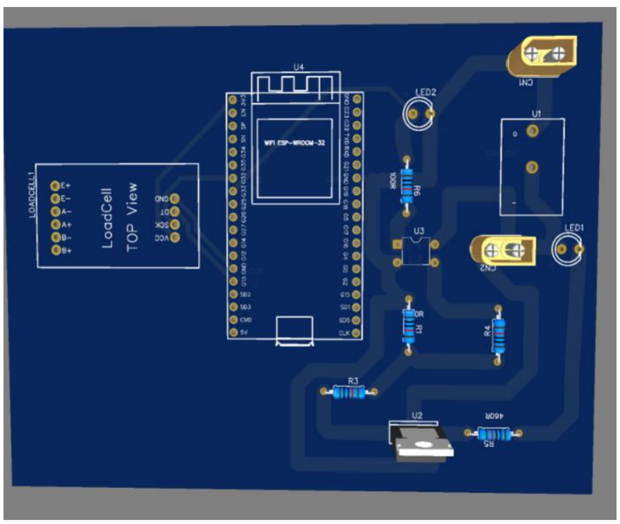


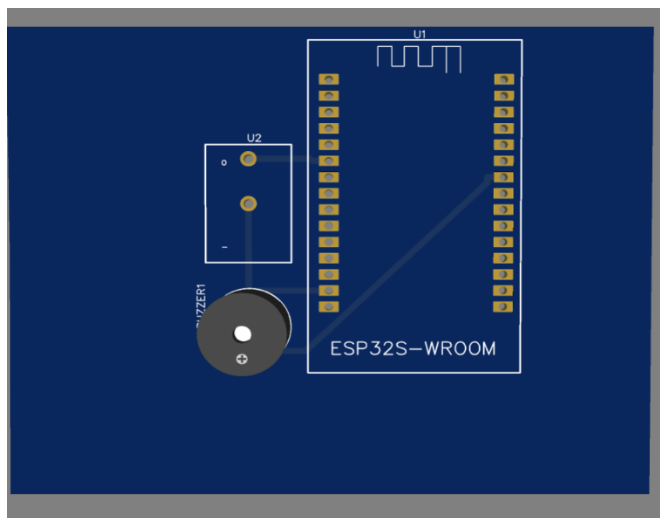
Ignition circuit module.





Trigger module.

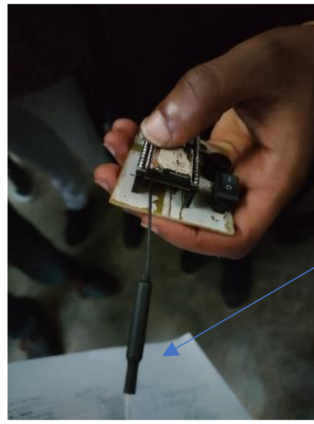




Ignition circuit module PCB.

Trigger module PCB.

The first iteration, Version 1, employed a protoboard for component assembly and used the internal antenna of the ESP32-WROOM module for wireless communication. In contrast, Version 2 featured a more refined design with components soldered onto printed circuit boards (PCBs) and utilized an external 2.4 GHz antenna on the ESP32 for enhanced signal strength and reliability. Both versions utilize the ESP-NOW protocol for wireless communication, a low-power, peer-to-peer protocol that enables efficient and reliable data transfer between the trigger module and the ignition circuit module. This protocol facilitates seamless communication between the two modules, essential for coordinating the ignition process.



WIFI 2.4 GHz Antenna.

Ignition system set-up during launch.

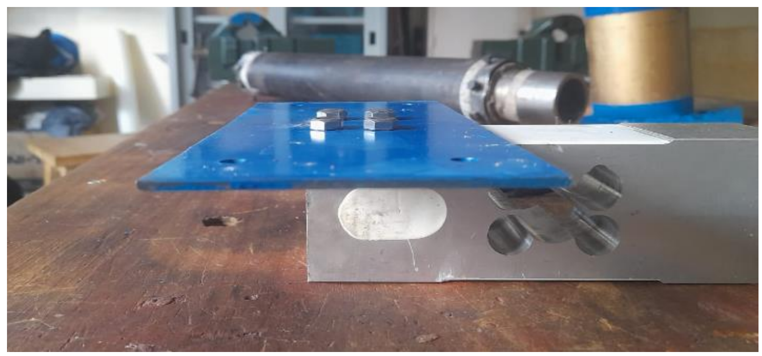
2.5. Motor Holder.

The motor holder is a crucial component designed to securely position the rocket motor on the loadcell during static tests. Initial attempts to fabricate the motor holder using PLA (Polylactic Acid) and aluminum encountered significant issues. The PLA motor holder proved inadequate due to its inability to withstand the mechanical stresses and thermal conditions experienced during testing. Similarly, the aluminum holder, made from a 2 mm thick rolled sheet joined to a circular base using epoxy, failed due to insufficient structural integrity under the load and stress conditions.

To address these failures, the design was revised, and a motor holder was fabricated from mild steel. This final design utilized a 2 mm thick rolled mild steel sheet, which was welded to a circular base. The mild steel construction provided superior strength and durability compared to PLA and aluminum, successfully withstanding the mechanical stresses and ensuring stable and reliable support for the motor during static tests. This transition to a more robust material and construction method demonstrated a significant improvement in performance and reliability for the motor holder.

PLA and Aluminum Motor Holder.


Mild steel motor holder.



Drilling and assembly to loadcell.

2.6. Motor Assembly.

The motor assembly process involves the meticulous integration of several key components to ensure optimal performance and reliability. The assembly process begins with fitting O-rings onto both the nozzle and bulkhead. These O-rings are crucial for ensuring a secure and airtight seal, which prevents any gas leakage during operation. Following this, precise drilling of holes is carried out on the nozzle, bulkhead, and casing to facilitate the attachment of components. Once the holes are drilled, they are tapped on the nozzle and bulkhead to accommodate the bolts that will secure these parts to the casing.

With the holes tapped, the bulkhead is installed into the casing and fastened in place using high-strength bolts. To further ensure thermal protection and prevent heat damage, casting sand is added around the bulkhead. This sand serves as an insulating shield, protecting the bulkhead from the intense heat generated during combustion.

Next, the propellant, which has been cast into a Bates grain configuration to achieve the desired burn characteristics, is prepared. The igniter is carefully loaded into the propellant, ensuring that it is correctly positioned to initiate combustion. The propellant, along with the igniter, is then loaded into the casing through the open end of the nozzle.

Once the propellant is in place, the nozzle is installed onto the casing and securely bolted, completing the assembly of the motor. Finally, the ignition circuit is set up and tested to verify its functionality ensuring that the ignition system operates as intended.

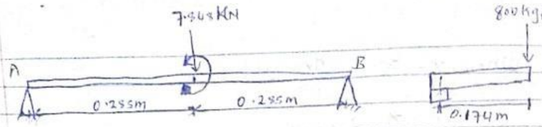


Drilling of Casing and Nozzle. Fitting of O-Rings. Loading of igniter into the propellant.

2.7. Test stand.

A test stand is a specialized structure used to conduct static tests of rocket motors. Its primary function is to securely hold the rocket motor in place while allowing for the controlled measurement and analysis of various performance parameters, such as thrust, pressure, and burn rate. During a static test, the rocket motor is ignited while restrained on the test stand, which measures the motor's performance under simulated flight conditions. By using a test stand, one can identify potential issues, validate design specifications, and ensure that the motor operates safely and effectively before it is used in an actual rocket launch. This testing process is essential for refining motor designs and verifying their performance to achieve successful rocket missions.

Calculations.



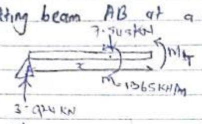
$R_A = R_B = \frac{7.545}{2} = 3.924\ KN$

$500\ Kgf = 500 \times 9.81 = 7.545\ KN$

Moment due to thrust acting on loadcell.

$M = 7.545 \times 0.174 = \cancel{1.30152\ KN/m}$
$= 1.365\ KN/m$

Cutting beam AB at a distance x from A



$M_T = 3.924x + 7.545(x - 0.285) - 1.365$

$-\frac{M}{IE} = \frac{d^2v}{dx^2}$

$IE\frac{d^2v}{dx^2} = -M = -3.924x - 7.545(x - 0.285) + 1.365$

$IE\frac{d^2v}{dx^2} = -11.772x + 3.6017$ (1)

$IE\frac{dv}{dx} = \frac{-11.772x^2}{2} + 3.6017x + C_1$ (2)

$IEV = \frac{-11.772x^3}{6} + \frac{3.6017x^2}{2} + C_1x + C_2$ (3)

When $x = 0$, $V = 0$
so $C_2 = 0$

When $x = \frac{L}{2}$, $\frac{dv}{dx} = 0$

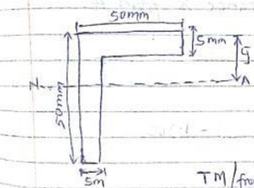
$x = \frac{L}{2} = 0.285m$

$C_1 = -0.5434$

Substituting in eqn. (3)

$IEV = -1.962x^3 + 1.80085x^2 + 0.5434x$

Using angleline (50×50×5mm)



TM/from top.

$((50\times5)+(45\times5))\bar{y} = (50\times5\times2.5) + (45\times5\times27.5)$

$\bar{y} = 14.34mm$ from top.

$I_{zz} = \left(\frac{50\times5^3}{12} + 50\times5\times11.84^2\right) + \left(\frac{9.34^3\times5}{12} + 9.34\times5\times4.67^2\right)$
$+ \left(\frac{35.66^3\times5}{12} + 35.66\times5\times17.83^2\right)$

$I_{zz} = 112502.7433\ mm^4$

Using E of mild steel = 200 GPa.

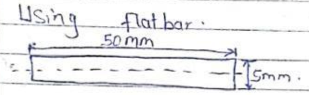
V_{max} occurs at $x = \frac{L}{2} = 0.285m$.

$IEV = -1.962(0.285^3) + 1.80085(0.285^2) - 0.5434(0.285)$

$V = \frac{-0.05449}{200\times10^9 \times 112502.7433\times10^{-12}}$

$V = -2.4217\times10^{-6}m$
$= 2.4217\times10^{-3}mm.$

Using flat bar.



$I_{zz} = \left(\frac{50\times5^3}{12}\right)$
$= 520.833\ mm^4$

$IEV = -0.05449$

$V = \frac{-0.05449}{200\times10^9 \times 520.833\times10^{-12}}$

$V = -5.2704\times10^{-4}m$
$= -0.52704mm.$

Calculation of the angle line bar supporting loadcell on the test stand.

L-Shaped bar can withstand more force and moment than the flat bar *(minimum deflection on L-shaped)*

L-shaped bars used to reinforce the load cell support. Pegs for test stand support.

Welding of test stand.

2.8. Testing.

Testing is a critical phase in the development and validation of solid rocket motors, focusing on assessing performance and ensuring safety. In solid motor testing, static tests are particularly significant. These tests involve igniting the rocket motor while it is securely mounted on a test stand, rather than during flight. The primary goal is to measure key performance parameters such as thrust, burn rate, and combustion stability.

Static tests provide valuable data on how the motor behaves under controlled conditions, allowing engineers to evaluate the motor's efficiency and reliability. They help identify any design flaws or operational issues before the motor is used in an actual launch. During a static test, one can expect to gather detailed information about the motor's thrust output, pressure profiles, and overall performance characteristics.

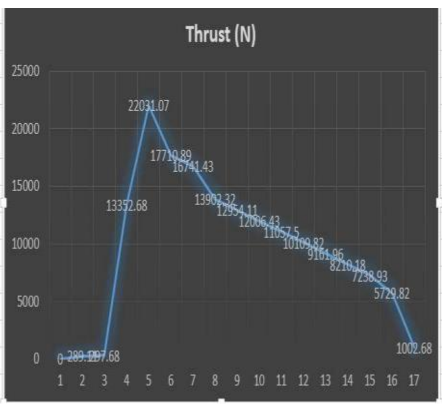
Safety is paramount during static tests. Due to the high-energy nature of rocket motors, stringent safety procedures are essential to protect personnel and equipment. This includes maintaining a safe distance from the test stand, using protective barriers, and ensuring that all safety protocols are followed rigorously. Proper handling and preparation, as outlined by experts such as Richard Nakka and other rocketry enthusiasts, are crucial for minimizing risks and ensuring a successful and safe testing process.

Loadcell calibration.

A known mass is used to calibrate the load cell. This process was repeated during each static test preparation.



STATIC TEST. 23-02-2024

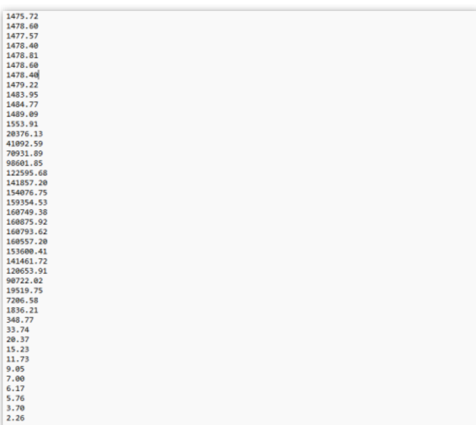


- A maximum thrust of 22.031kgf(216N).
- Failure of the loadcell support at 216N??



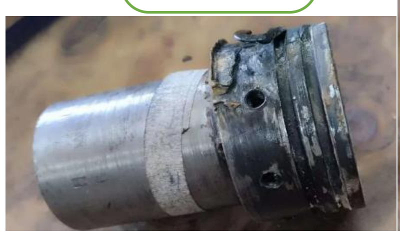
GOOD CONDITION	**DAMAGED**
BULKHEAD AND ITS O-RINGS	NOZZLE O-RINGS
NOZZLE	MOTOR HOLDER (PLA)
MOTOR CASING	
BOLTS	

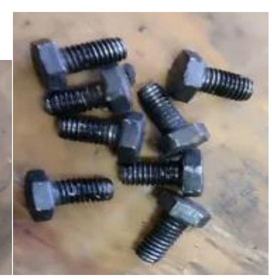
STATIC TEST. 21-03-2024



```
1475.72
1478.60
1477.57
1478.40
1478.81
1478.60
1478.40
1479.22
1483.95
1484.77
1489.09
1553.91
20376.13
41092.59
70931.89
98601.85
122595.68
141857.20
154076.75
159354.53
160749.38
160875.92
160793.62
160557.20
153600.41
141461.72
120653.91
90722.02
19519.75
7206.58
1836.21
348.77
33.74
20.37
15.23
11.73
9.05
7.00
6.17
5.76
3.70
2.26
```

Nozzle O-rings destroyed





All metallic components intact

Bulkhead O-rings intact

- Approximated burn time: 1.5 seconds
- Data points: 30
- Sampling time = $\frac{Burn\ time(Seconds)}{Number\ of\ data\ points}$

$$=\frac{1.5}{30}$$

= 0.05 Seconds

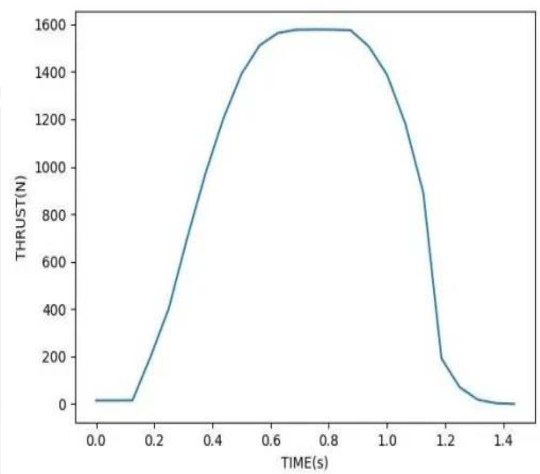
- Burn time: 1.5 seconds.
- Given thrust: 160kgf
- The rocket motor based on the calculated impulse

of 1220.74Ns lies within class J (640-1280Ns) of SRM

- Total Impulse = Area under the graph
  - $= \Delta t(\sum_{t=0}^{t=1.5} F) =$
  - $=1220.74Ns$

$$I_t = \Delta t \left(F_1 + F_2 + F_3 + \ldots\right)$$

Simulated thrust Curve vs actual thrust curve.



After repair

Before repair

STATIC TEST. 12-04-2024

Test 1.

SRM with Airframe.

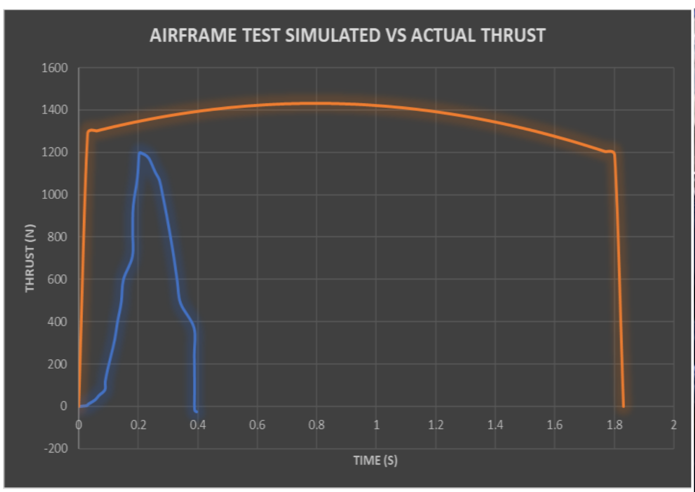



Drilling of casing and airframe.

- Airframe and motor casing successfully assembled together.

mass of propellant: 2056g

total mass of SRM 5920g




Collapsed Motor.

- Minimum thickness was discovered at the point of failure.
- **MOTOR CASING'S MINIMUM THICKNESS** = 0.67mm

STANDARD DIMENSIONS

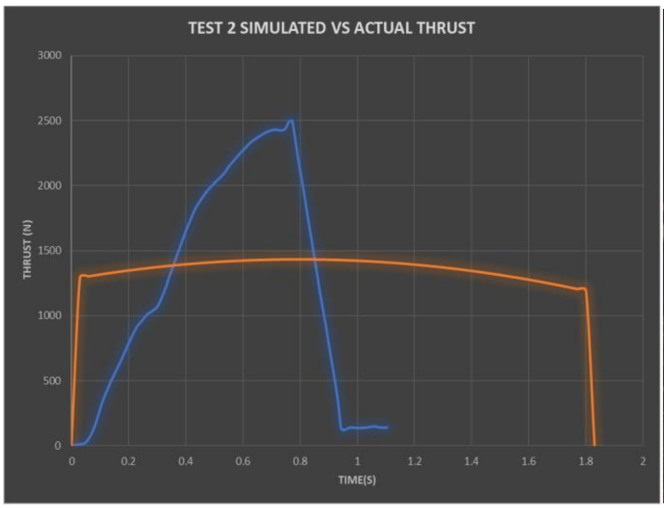
NAME	DIMENSION
D(outer)	73
D(inner)	69
Thickness	2

Test 2.

SRM only.

mass of propellant: 2022g

total mass of SRM 5749g



IMPULSE ACTUAL =1355.4Ns

Melted casing at one region. Nozzle ejected and bolts sheared.

STATIC TEST. 25-04-2024

The static fire test was aimed at checking the improvement of the new grains and the strength of the 2,5mm thick motor casing.

total mass of SRM 5749g

maximum thrust :407kgf

or 3992.67N

3. LAUNCH SUMMARY.

POST-LAUNCH ANALYSIS.

Summary of SRM Performance.

- Alpha- Mounted on Backup rocket.
- Beta- optimum performance, motor intact after launch and recovery.
- Charlie- optimum performance, motor intact after launch and recovery.
- Delta- optimum performance, motor intact after launch and recovery.

ALPHA

Backup rocket

Mass: 6953 g

Ziplock with silica.

Ignition System.

BETA

Mass: 7400 g

Mounting on the launch pad.

motor intact after launch and recovery.

CHARLIE.

Mass: 6934 g.

Mounting CHARLIE on the launch Pad.

DELTA.

Mass: 5848 g.

motor intact after launch and recovery.

4. RECOMMENDATIONS.

- Implementation of safety interlocks.
- Implementation of sensors to enhance monitoring and data driven analysis of rocket performance.
- Integration of Audio and visual feedback mechanisms for warning and safety.
- Improve Wireless communication range.

5. CONCLUSION.

The N3.5 rocket launch under the Nakuja Project successfully demonstrated the integration of solid rocket motor (SRM) technology using Potassium Nitrate/Sorbitol (KNSB) as the propellant. Critical components, including the motor casing, bulkhead, nozzle, and ignition system, were carefully designed and rigorously tested to ensure optimal performance and safety. The comprehensive static tests provided essential data on thrust, burn rates, and grain preparation, leading to the successful recovery and intact performance of motors Alpha, Beta, Charlie, and Delta. This progress marks a significant step toward achieving the mission's objective of reaching a 1.6 KM apogee.

6. ACKNOWLEDGEMENT.

This project was supported by the AFRICA-ai-JAPAN project (JICA). The Solid Propulsion team would like to extend our gratitude to Jomo Kenyatta University of Agriculture and Technology for providing the research facility and the technical support. We would also like to thank the Kenya Space Agency (KSA) for their collaboration. Lastly, to our colleagues and peers for their valuable feedback and engaging discussions that significantly enriched the research and development of the N3.5 Rocket. We hope that the findings presented here contribute to future advancements in space science technology research in Kenya and inspire further investigations that will lead to remarkable breakthroughs in the future.