SOLID PROPULSION PROGRESS REPORT: WEEKS 1 & 2

Week 1 Objectives

- Orientation
- Go through the theory of solid motors
- Help in N3.5 launch preparation
- Understand N3.5 propulsion system

Tasks completed in week 1

- Attending orientation meetings
- Reading solid motor theory - Richard Nakka
- Helped N3.5 team prepare for launch
- Installation and training on necessary software - Solidworks, Open Motor, Ansys, etc
- Solid propulsion system characterization for N3.5

Week 2 Objectives

- Benchmarking solid motor designs
- Estimation of required impulse for target apogee
- Casing Design
- Design of grains and nozzle parameters using Open Motor
- Ansys Simulation of flow through nozzle
- Design of grain casting tools
- Improvements and SA Cup Requirements
- Design of Casting Tools

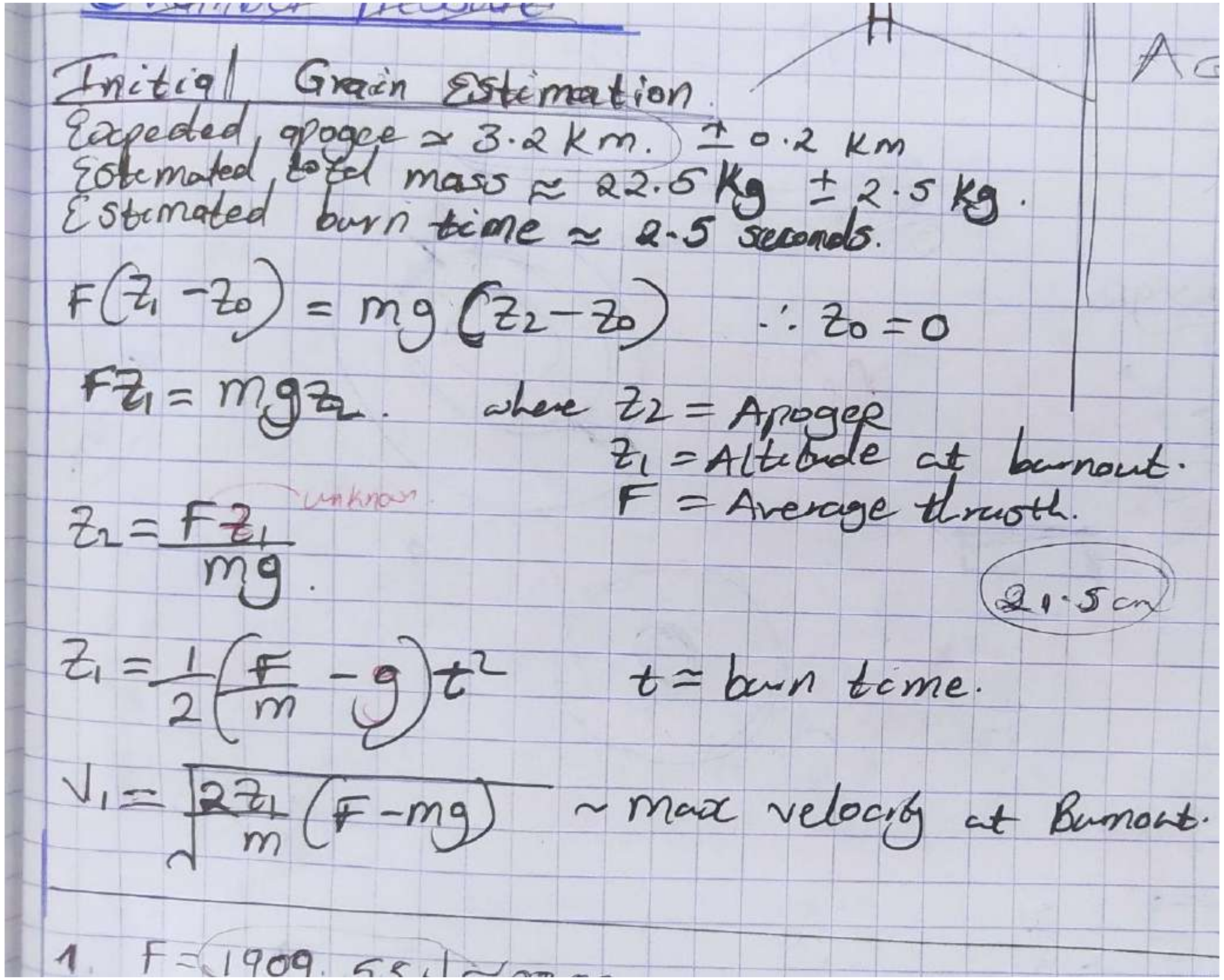
Tasks Completed in week 2

Benchmarking of SRM designs

		GRAINS					Nozzle					CASING	
University	Name of Rocket	Propellant	Number of grains	Outside diameter D (mm)	Core diameter,d (mm)	Length, L (mm)	Exit diameter (mm)	Throat length (mm)	Throat diameter (mm)	Half divergence angle (deg)	Half convergence angle (deg)	Outside Diameter (mm)	Thickness (mm)
JKUAT	Nakuja N3.5	KNSB	4	64	16.98	101	42	1	12	12	32.3		2.5
West Virginia University	Wild and Wonderful II	APCP	5	82.423	34.925	134.95	47.625		23.83			98	
Universidade de São Paulo - USP	Imperius Project	KNSB 65-35	5	94	32	156	67		22.8	15	30	110.7	4.22
University of Nevada	SEDS UNLY	APCP	4	75	-	155.25							
University of Maryland	Project Karkinos	Terple Nebula	6	98	38	152						107.8	4.6
University of Florida	TropoGator	APCP		98								98	

Impulse estimation

Utilization of work-energy equations



Initial Grain Estimation

Expected apogee ≈ 3.2 km. ± 0.2 km

Estimated total mass ≈ 22.5 Kg ± 2.5 kg.

Estimated burn time ≈ 2.5 seconds.

$$F(z_1 - z_0) = mg(z_2 - z_0) \quad \therefore z_0 = 0$$

$$F z_1 = m g z_2.$$

where z_2 = Apogee

z_1 = Altitude at burnout.

F = Average thrust.

$$z_2 = \frac{F z_1}{mg}.$$

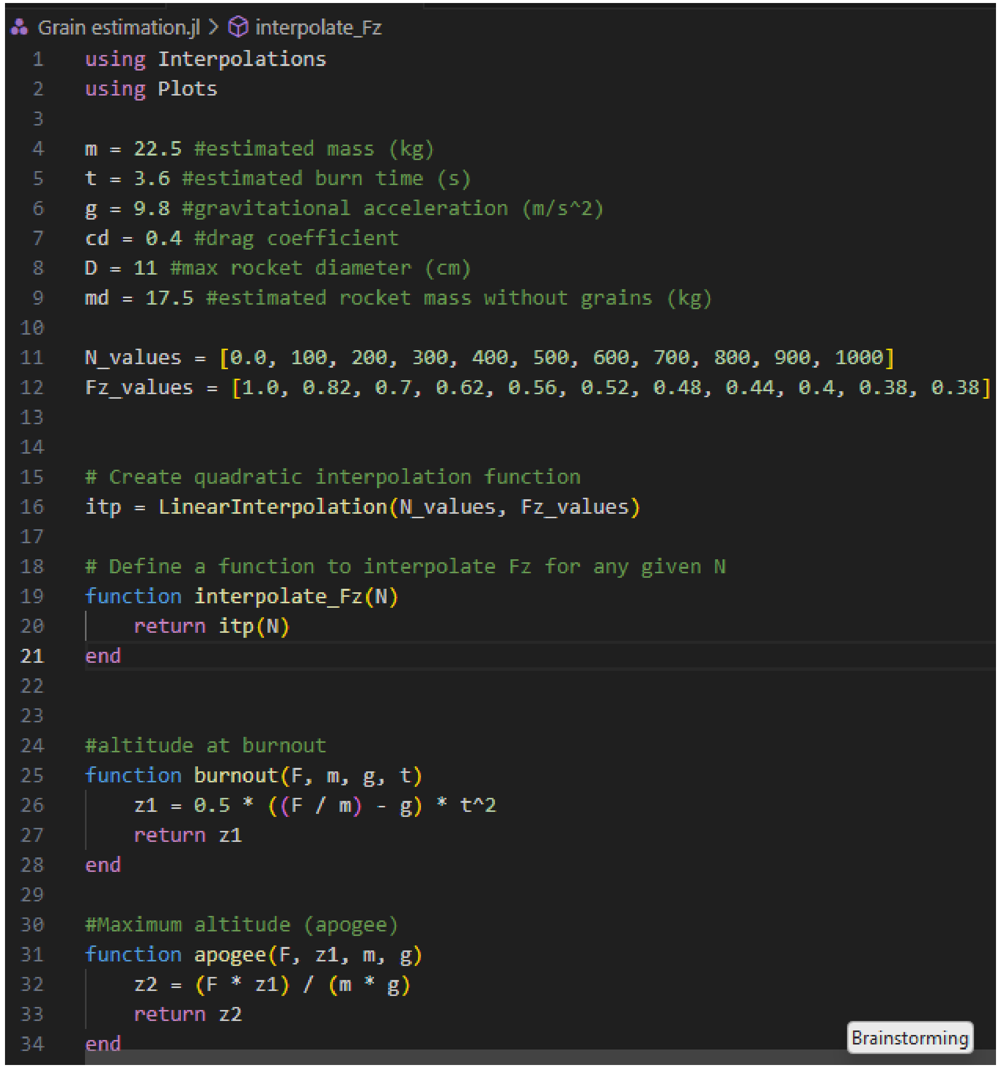
unknown

21.5 cm

$$z_1 = \frac{1}{2}\left(\frac{F}{m} - g\right)t^2 \qquad t = \text{burn time}.$$

$$V_1 = \sqrt{\frac{2z_1}{m}(F - mg)} \sim \text{max velocity at Burnout}.$$

1. F = 1909. 55...



Grain estimation.jl > interpolate_Fz

```julia
using Interpolations
using Plots

m = 22.5 #estimated mass (kg)
t = 3.6 #estimated burn time (s)
g = 9.8 #gravitational acceleration (m/s^2)
cd = 0.4 #drag coefficient
D = 11 #max rocket diameter (cm)
md = 17.5 #estimated rocket mass without grains (kg)

N_values = [0.0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000]
Fz_values = [1.0, 0.82, 0.7, 0.62, 0.56, 0.52, 0.48, 0.44, 0.4, 0.38, 0.38]


# Create quadratic interpolation function
itp = LinearInterpolation(N_values, Fz_values)

# Define a function to interpolate Fz for any given N
function interpolate_Fz(N)
    return itp(N)
end


#altitude at burnout
function burnout(F, m, g, t)
    z1 = 0.5 * ((F / m) - g) * t^2
    return z1
end

#Maximum altitude (apogee)
function apogee(F, z1, m, g)
    z2 = (F * z1) / (m * g)
    return z2
end
```

Apogee Estimation Results

```
Iteration80.0
Thrust: 2000
Altitude at burnout: 512.496
Maximum altitude (apogee): 3163.933399184551
velocity at burnout v1: 284.71999999999997
Drag influence number N: 224.20395168914283


Iteration81.0
Thrust: 2025
Altitude at burnout: 519.696
Maximum altitude (apogee): 3224.2658809073023
velocity at burnout v1: 288.72
Drag influence number N: 230.54783648914292


Iteration82.0
Thrust: 2050
Altitude at burnout: 526.8960000000001
Maximum altitude (apogee): 3284.0852572420786
velocity at burnout v1: 292.72
Drag influence number N: 236.9802241462858
```

Burn time (estimate) = 3.6 s

Avg thrust required = 2025 N

Impulse required = 7290 Ns

Casing Design

Design and Burst Pressures for Rocket Motor Casing

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

Casing Dimensions and Design Factors

Do =	100	in. (mm)	Diameter, outside
t =	5	in. (mm)	wall thickness
S_D =	2		Design Safety factor

Material Properties

Fty =	210	ksi (MPa)	Yield Strength
Ftu =	240	ksi (MPa)	Ultimate Strength
E =	68900	Msi (MPa)	Modulus of Elasticity
ν =	0.33		Poisson Ratio
β =	0.875		Fty/Ftu
B =	1.284		Burst factor

Design and Burst Pressures

P_D =	10500	psi (kPa)	**Design pressure**
P_U =	26955	psi (kPa)	**Burst pressure**
S_U =	2.57		**Burst Safety Factor**

Elastic Deformation under Pressure *

Aluminum 6063 T6

Casing

Material: Aluminum 6063 T6
Supplier: Keps Metal.
Yield strength F_{ty}: 210 MPa.
Ultimate strength F_{tu} = 240 MPa.
E = 68900 MPa.
μ = 0.33.

D_o (outside diameter) = 100 mm
thickness, t = 5 mm.

Design Pressure, $P_D = 2\dfrac{t F_{ty}}{D_o S_D}$

S_D (Design safety factor) = 2.

Burst Factor, B = 1.284.

$\beta = \dfrac{F_{ty}}{F_{tu}} = 0.874$

$P_D = \dfrac{2\times 5\times 210}{100\times 1.284} = 16.35$ MPa

Burst Pressure, $P_u = \dfrac{2\times t\, F_{ty}}{D_o} \cdot B$

$= \dfrac{2\times 5}{100}\times 240\times 1.284 = 30.82$ MPa

[illegible]

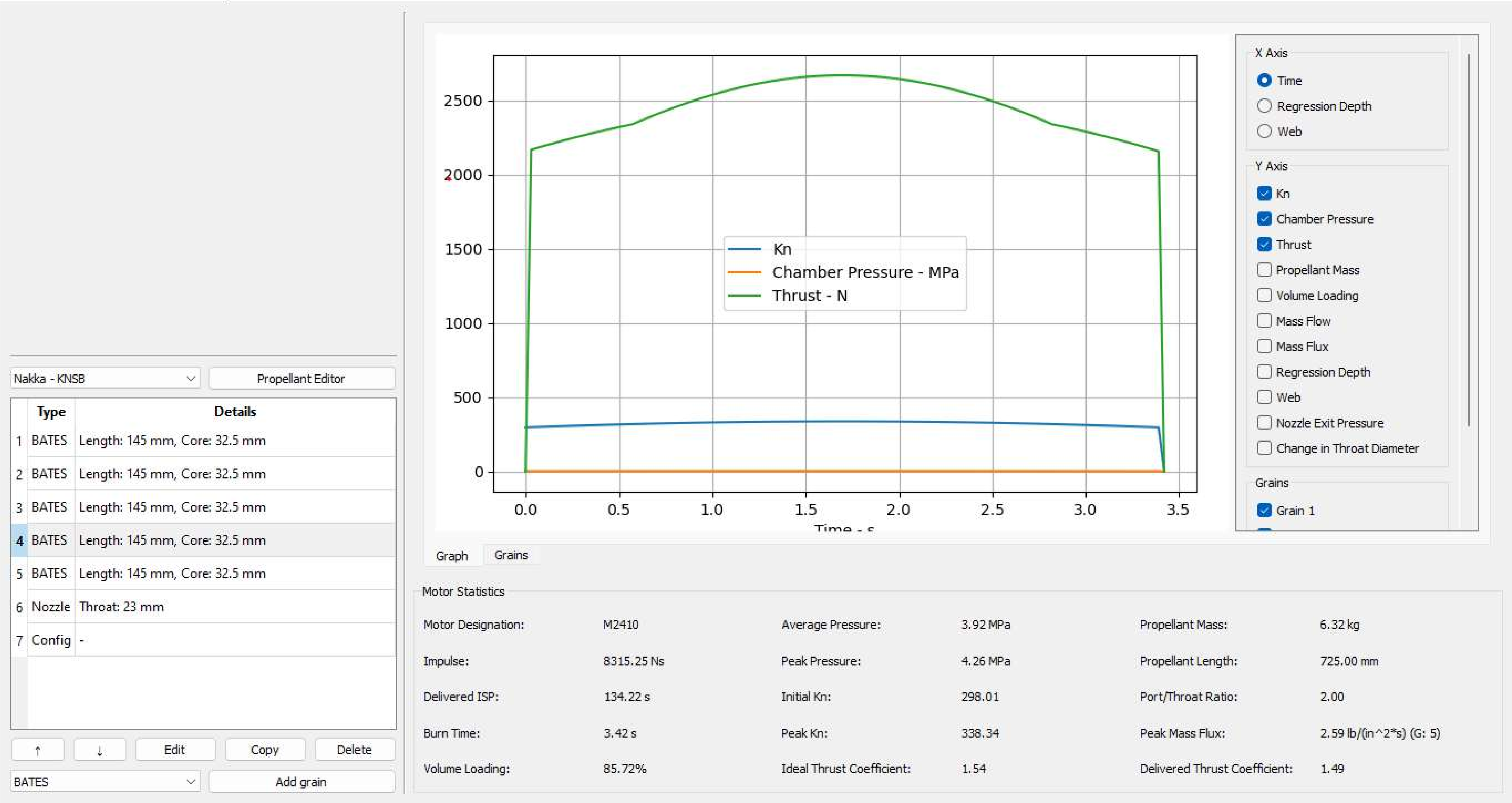
$P_D = 10500$ kPa $\therefore$ $10.5 = \dfrac{2\times t\times 210}{100\times 1.284}$

$\therefore t = 3.21$ mm.

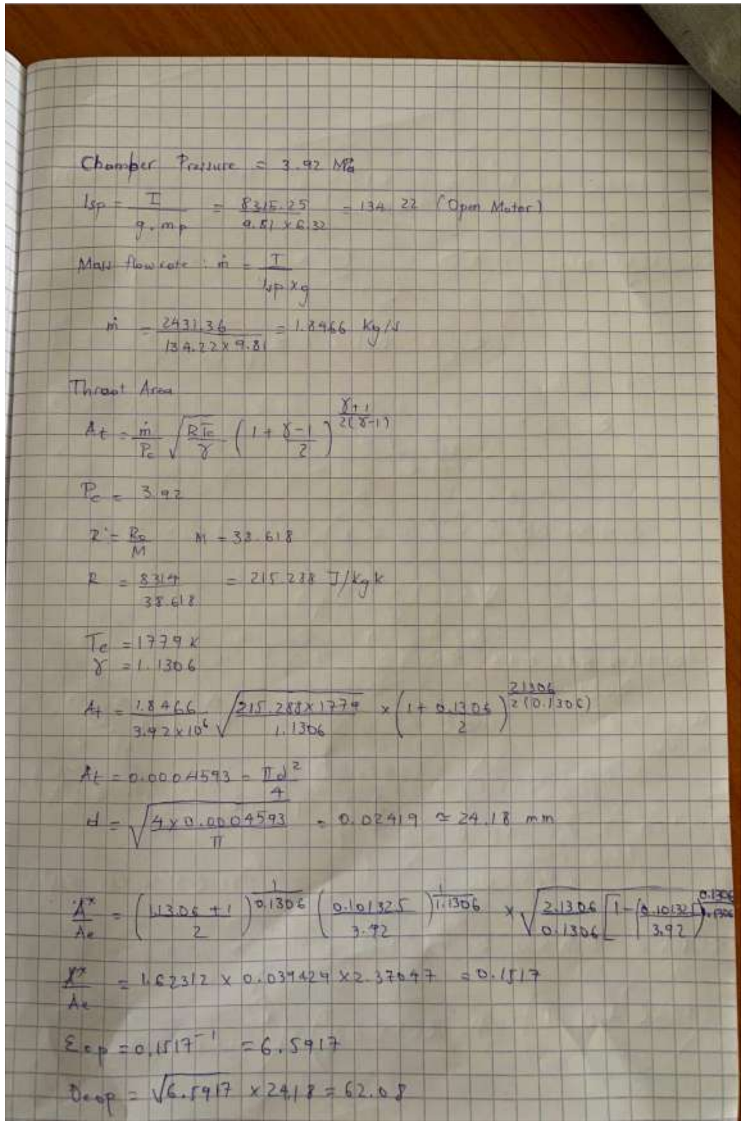
$P_u = 26955$ kPa $\therefore$ $26.96 = \dfrac{2\times t\times 240\times 1.284}{100}$

$\therefore t = 4.37$ mm

Design of Grains and Nozzle Parameters

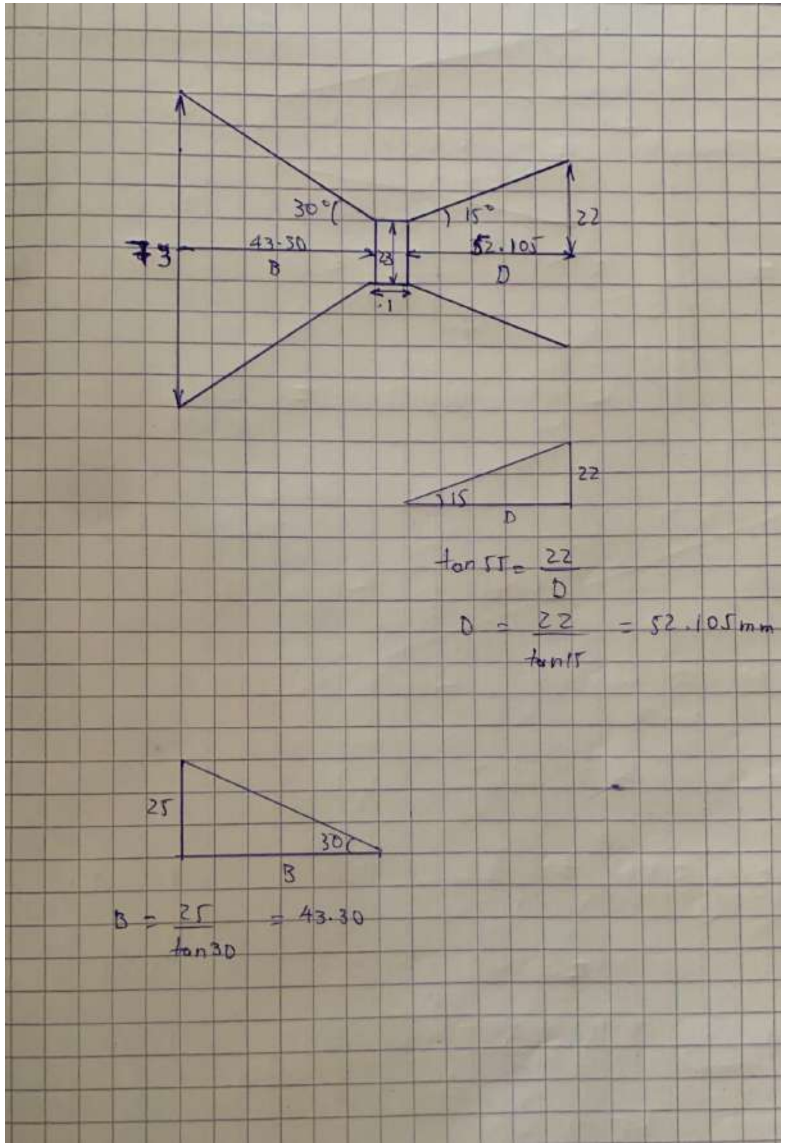


Design of Grains and Nozzle Parameters




```
Code                          WEIGHT    D-H  DENS     COMPOSITION
  0 SUCROSE (TABLE SUGAR)        2212.000  -1550  0.05740  22 H   12 C   11 O
  0 POTASSIUM NITRATE            4108.000  -1167  0.07670   1 N    3 O    1 K

THE PROPELLANT DENSITY IS  0.06862 LB/CU-IN OR   1.8995 GM/CC
THE TOTAL PROPELLANT WEIGHT IS 6320.0000 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

 142.164400 H
  77.544200 C
  40.629820 N
 192.971600 O
  40.629820 K

******************************CHAMBER RESULTS FOLLOW    ******************************
 T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV    GAS   RT/V
 1703  2606    38.71    569.00 -8222.64 10660.18  1.1349151.569    0.255

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL =    10.511    14.861
NUMBER MOLS GAS AND CONDENSED =   151.569    18.878

 5.000043e+001 H2O       3.368403e+001 CO        2.497893e+001 CO2       2.031121e+001 N2
 1.972611e+001 H2        1.887710e+001 K2CO3*    2.665177e+000 KHO       1.788783e-001 K
 1.427333e-002 K2H2O2    3.709072e-003 NH3       1.329761e-003 H         1.161684e-003 KH
 5.974830e-004 KCN       1.795201e-004 HO        1.630892e-004 CH4       1.250677e-004 CH2O
 0.000119285 CNH

THE MOLECULAR WEIGHT OF THE MIXTURE IS    37.079
```

Design of Grains and Nozzle Parameters



Motor dimensions estimation

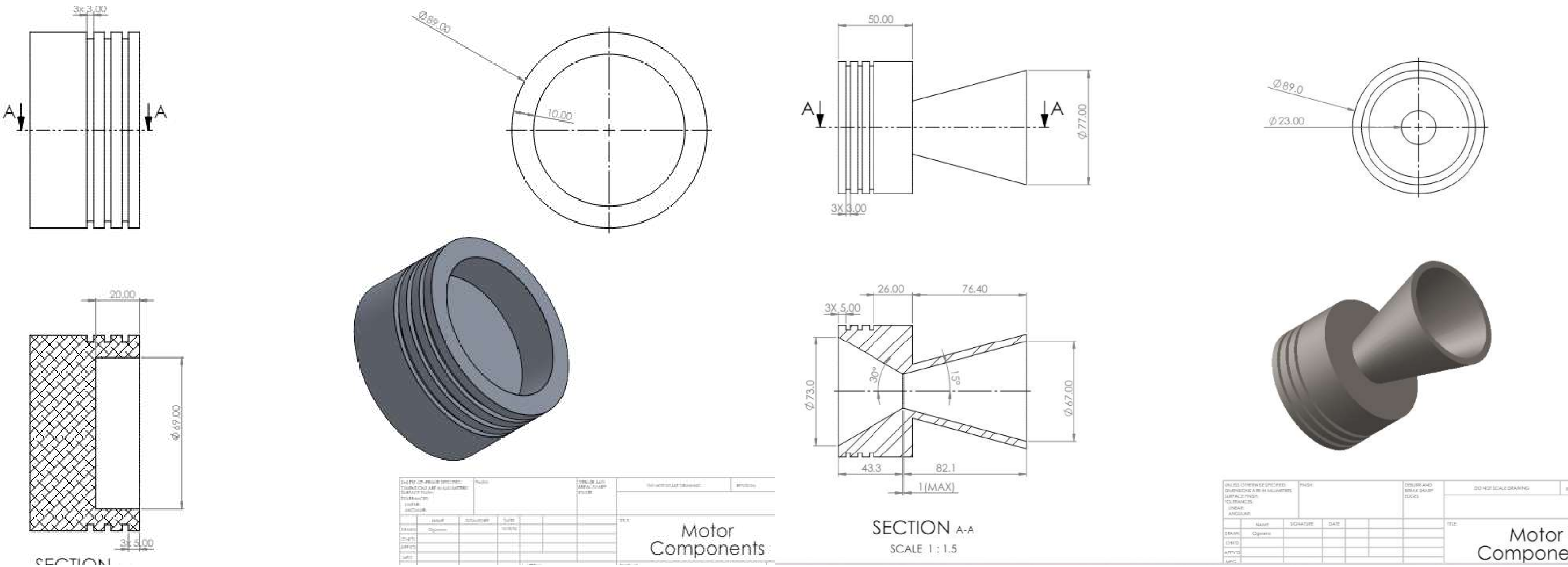
GRAIN SIZING				
Propellant	**Number of grains**	**Outside diameter(mm)**	**Core diameter(mm)**	**Length L = 1.5D+0.5d**
KNSB	5	86	32.5	145.25

CASING SIZING			
Material	**Outer diameter(mm)**	**Inner diameter(mm)**	**Length**
Aluminum 6063 T6	100	90	825

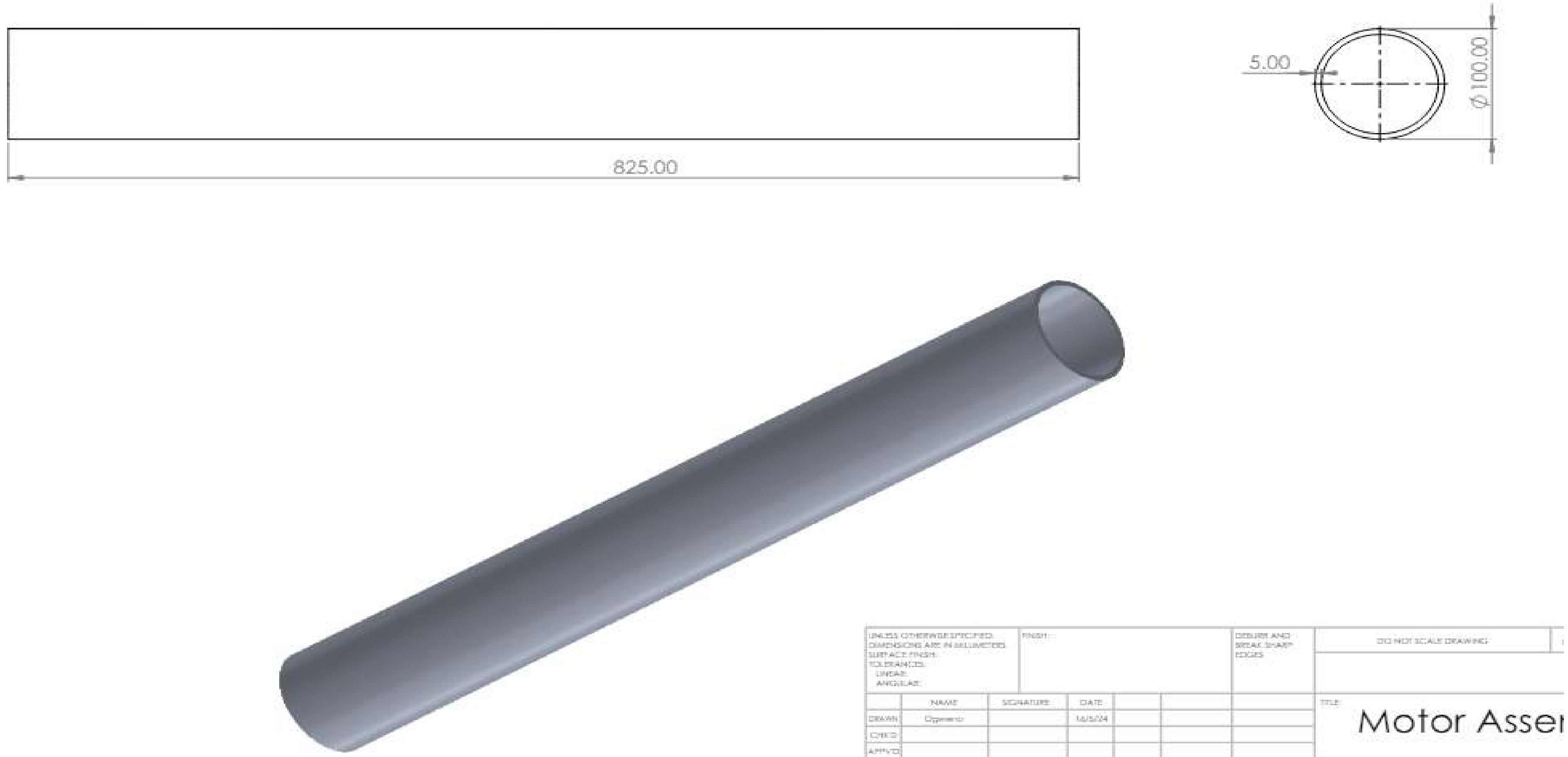
BULKHEAD SIZING		
Material	**Outer diameter(mm)**	**Length**
Aluminum 6063 T6	89	50

NOZZLE SIZING					
Material	Outside diameter	Throat diameter	Exit diameter	Divergence half-angle	Convergence half angle
Mild Steel	89	23	67	15	30

Bulkhead and Nozzle drawing



Casing drawing



Recommendations on N3.5 and SA Cup Requirements

Recommendations

- Measuring chamber pressure and temperature
- Measuring casing temperature
- Redesign of test stand
- Long storage and drying of grains

SA Cup Requirements

SA Cup Requirements - Google Docs

Challenges

- Simulation softwares
- Unergonomic seats

Next Week’s Objectives

- Nozzle simulation (Ansys) and characterization
- Coming up with a components budget
- Procurements of casing, nozzle and bulkhead materials
- Test stand design
- Research on grain storage
- Design and 3D printing of Casting tools


THANK
YOU
iStock
Credit: Andres Victorero
1327139263