NOZZLE DESIGN CONSIDERATIONS

In the design of the Solid Rocket Motor, the design of the nozzle is of critical importance. This document highlights the procedures taken in the design of the nozzle for the N-2 rocket motor.

The specifications for the N-2 rocket motor were as follows;

1. Fuel casing outer diameter → 56 mm
2. Fuel to be used → KNSB (Potassium Nitrate + Sorbitol)

Tools Used

1. OpenMotor
2. Casing.xls
3. SRM.xls

Procedure

1. Using the excel sheet **casing.xls**, we get the Design pressure for the rocket motor casing as well as the burst pressure.

Design and Burst Pressures for Rocket Motor Casing

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

Casing Dimensions and Design Factors

Do =	56	in. (mm)	Diameter, outside
t =	2	in. (mm)	wall thickness
S_D =	2.5		Design Safety factor

The values for the outer diameter and thickness of the proposed casing are input, in mm. The safety factor being 2.5

The material properties are also input in the following sections. N-2 utilizes 7075 aluminum alloy for the fabrication of the casing, the values are input in the sections below.

Material Properties

Fty =	430	ksi (MPa)	Yield Strength
Ftu =	510	ksi (MPa)	Ultimate Strength
E =	71700	Msi (MPa)	Modulus of Elasticity
ν =	0.33		Poisson Ratio
β =	0.843		Fty/Ftu
B =	1.322		Burst factor

The tool computes the design and burst pressures that can be handled by the casing with the given dimensions. The results are presented below;

Design and Burst Pressures

P_D =	**12286**	psi (kPa)	**Design pressure**
P_U =	**40610**	psi (kPa)	**Burst pressure**
S_U =	**3.31**		**Burst Safety Factor**

The design pressure is 12 MPa.

However, the initial design was done using 6063 aluminum which was not locally available. Using 6063 aluminum yielded a Design pressure of 2 MPa.

This value of pressure was used since it still lies way below the design pressure of 7075 aluminum, i.e., 12 MPa.

The value of interest is the design pressure → **2MPa.** (Remember to use the design pressure obtained from the tool casing.xls)

2. Using the excel workbook **SRM.xls**, we get the design of the nozzle as follows.
   In the first sheet within the workbook, **Data and Kn,** the values for Outer grain diameter, core diameter, number of grain segments, segment lengths, type of fuel, inhibited surfaces are input according to the design parameters.
   The target maximum pressure is also input in psi.
   The values were input as shown below;

Hint! To directly convert inches to mm, simply type =25.4**number*

Motor chamber:				
	Dc	52	mm	Chamber diameter (inside)
	Lc	200.0	mm	Chamber length (inside)
	Vc	424743	mm^3	Chamber volume (empty)
Propellant grain:				
	Propellant type	KNSB fine	*select*	*See Note [1] below*
	Do	50.00	mm	Outer diameter (initial)
	do	19	mm	Core diameter (initial)
	Lo	100.00	mm	Segment length (initial)
	N	2		Number of segments
	Outer surface:	Inhibited	*select*	
	Core surface:	Exposed	*select*	
	Ends surface:	Exposed	*select*	
	Lgo	200	mm	Grain length (initial)
	Vg	335993	mm^3	Grain volume (initial)
	V_ℓ	0.791		Volumetric loading fraction
	ρ'_{grain}	1.841	g/cm^3	Grain ideal density
		0.95		Density ratio (actual/ideal)
	ρ_{grain}	1.749	g/cm^3	Grain actual density
	m_{grain}	0.588	kg.	Grain mass (initial)
	Abeo	6720	mm^2	End burning area (initial)
	Abco	11938	mm^2	Core burning area (initial)
	Abso	0	mm^2	Outer surface burning area (initial)

The target maximum pressure is also input in psi.

	Abo	[illegible]	mm	Total burning area (initial)
Target MEOP:		300 psi	*select*	Maximum chamber pressure (target)
Kn max:		172		Ratio of Burning area / throat area (max)
Nozzle:	Ato	132	mm^2	Throat cross-section area (initial)
	Dto	**12.955**	mm	**Throat diameter** (initial)
	e	0.0	mm	Nozzle erosion
	Dtf	12.96	mm	Throat diameter (final)

The solve button is clicked, then proceed to the next stage. (The next sheet, titled **Pressure**)

3. In the Pressure sheet, click Solve 2 followed by Solve 3 then proceed to the next sheet, titled **Performance**

4. In the Performance sheet, the nozzle efficiency and the nozzle expansion ratio are set. Optimum values for the Nozzle expansion ratio are given and a suitable value for the nozzle expansion ratio can be selected bearing this in mind.

k	1.042	Ratio of specific heats, 2-ph. flow
η noz	0.85	Nozzle efficiency
Ae/At	6.25	Nozzle expansion ratio (initial)
Patm	0.101 MPa	Ambient pressure
Ato	131.8 mm^2	Throat cross-section area (initial)
Ae	823.8 mm^2	Nozzle exit cross-section area
Meo	2.815 0.00	Mach No. at nozzle exit (initial)
Mef	2.815 0.00	Mach No. at nozzle exit (final)
De	32.39 mm	Nozzle exit diameter
Ae/At opt	5.026	Optimum Nozzle expansion ratio at Po max
Ae/At opt	4.562	Avg. optimum nozzle expansion ratio
w f	0.621	Web fraction
CFmax	1.265	Thrust coefficient, maximum
F max	377 N.	Maximum thrust
I t	684 N-sec.	Total impulse
Isp	118.6 sec.	Specific impulse, delivered
Class:	J	Motor classification

Values for the optimum nozzle expansion ratio at Po max and the average optimum nozzle expansion ratio. These values are computed for the specific fuel we have been designing. In this case, the value 6.25 is selected. 6.25 is arbitrarily selected since it lies close to the optimum values provided. Any value around the given optimum values can be used.

5. Once this is done, click the **Solve (4)** button and proceed to the next excel sheet, titled

Nozzle Design.
Here, the convergence and divergence half angles are selected within some allowable limits. In our case, the following angles were selected.

Nozzle Design

beta	35.0	degrees	Nozzle convergence half-angle
alpha	15.0	degrees	Nozzle divergence half-angle

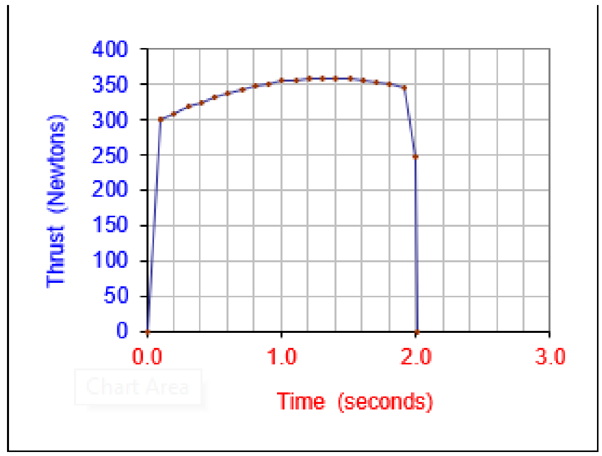
				Reference worksheets:
Dc	52	mm	Chamber inside diameter	*Data and Kn*
Dt	12.96	mm	Nozzle throat diameter	*Data and Kn*
De	32.39	mm	Nozzle exit diameter	*Performance*
De opt	27.67	mm	Optimum nozzle exit diameter	*Performance*
Lc	**27.88**	mm	**Convergence length**	
Ld	**36.26**	mm	**Divergence length**	
Lo	**64.14**	mm	**Overall length**	

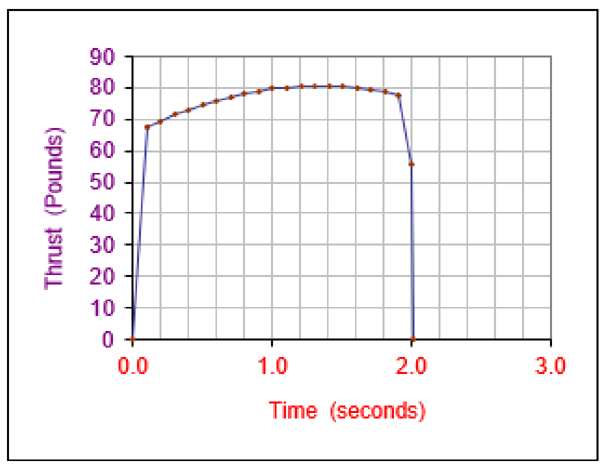
6. The final output of the rocket motor is then displayed in the next sheet, titled **Output**
   This is shown below;

Example Rocket Motor utilizing KNSB propellant.		
Grain mass	**0.588**	kg.
	1.295	lb.
Total impulse	**683.6**	N-sec.
	153.7	lb-sec.
Average thrust	**338.9**	N.
	76.2	lb.
Thrust time	**2.017**	sec.
Specific Impulse	**118.6**	sec.
Motor Classification	**J 339**	

Thrust-time data [see note 1]
Time step **0.0996** sec. [see note2]

Data pt.	Time (sec.)	Thrust (N.)	Thrust (lb.)
1	0.000	0	0
2	0.105	300	67
3	0.107	300	68
4	0.205	309	70
5	0.306	317	71
6	0.406	325	73
7	0.506	332	75
8	0.607	338	76
9	0.707	343	77
10	0.807	348	78
11	0.908	351	79
12	1.008	354	80
13	1.108	357	80
14	1.209	358	80
15	1.309	359	81
16	1.410	358	81
17	1.510	357	80
18	1.610	356	80
19	1.711	353	79
20	1.811	350	79
21	1.912	346	78
22	2.000	248	56
23	2.017	0	0





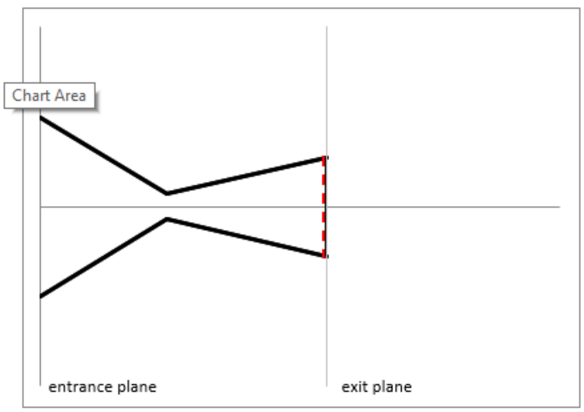
From Section (5) above, the nozzle parameters can be obtained.

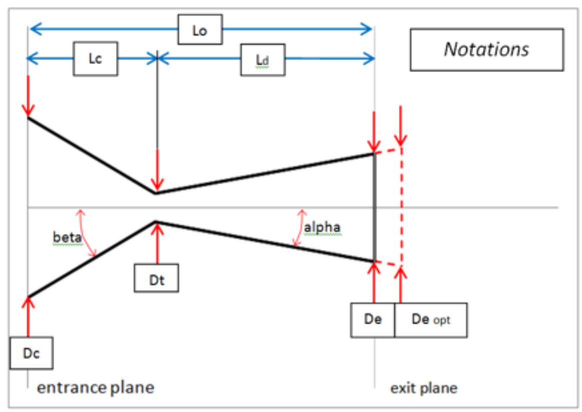
The section included the parameters to be used for the nozzle fabrication.

These parameters are listed below.

Nozzle Design

beta	35.0	degrees	Nozzle convergence half-angle	
alpha	15.0	degrees	Nozzle divergence half-angle	
				Reference worksheets:
Dc	52	mm	Chamber inside diameter	*Data and Kn*
Dt	12.96	mm	Nozzle throat diameter	*Data and Kn*
De	32.39	mm	Nozzle exit diameter	*Performance*
De opt	27.67	mm	Optimum nozzle exit diameter	*Performance*
Lc	**27.88**	mm	**Convergence length**	
Ld	**36.26**	mm	**Divergence length**	
Lo	**64.14**	mm	**Overall length**	

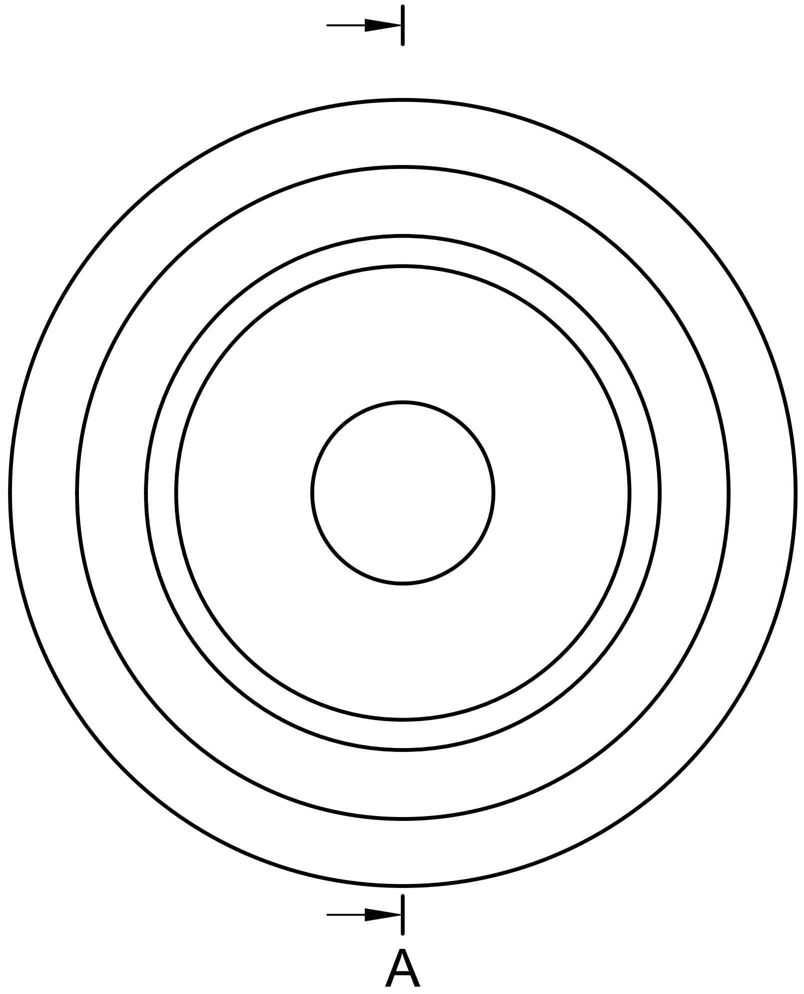


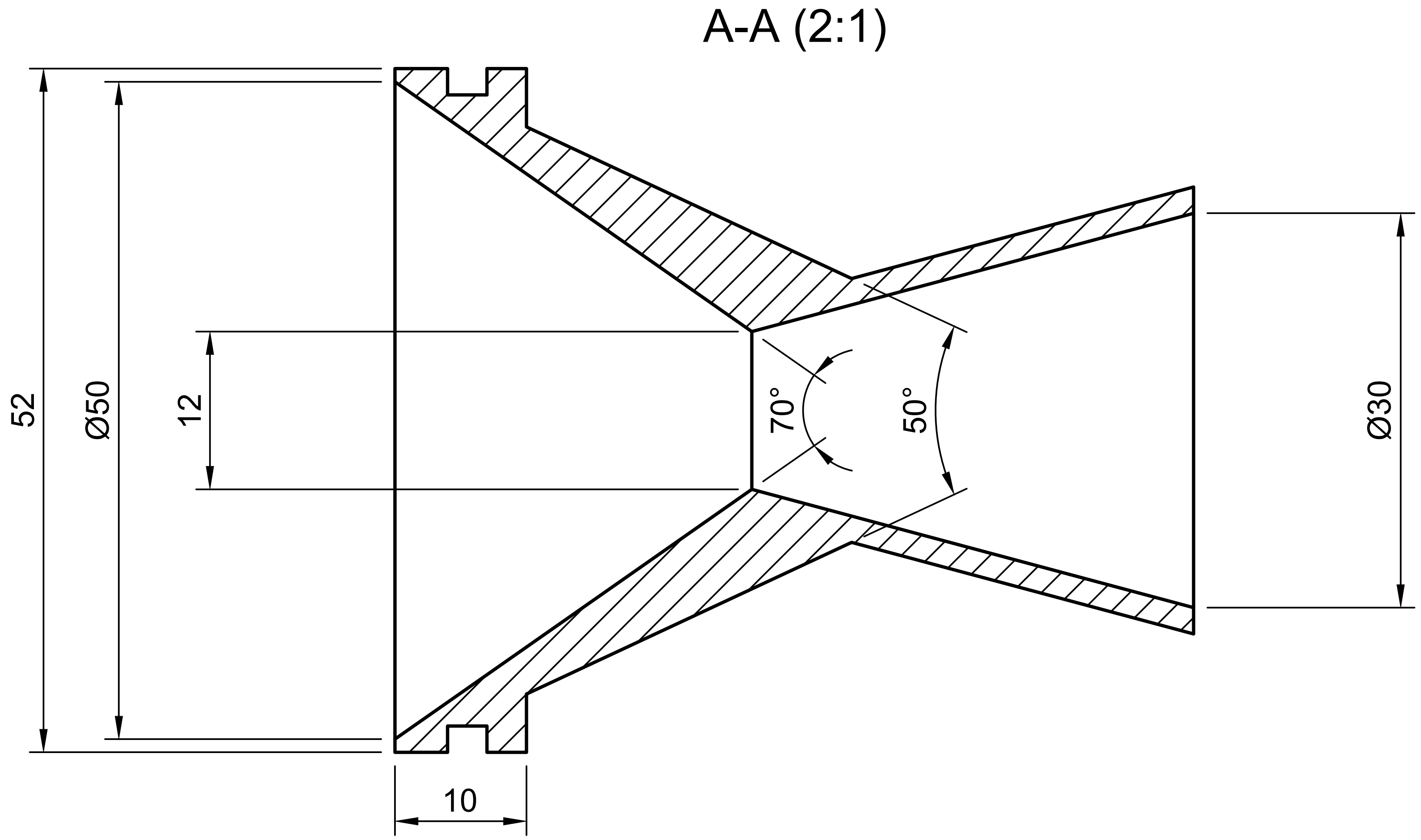


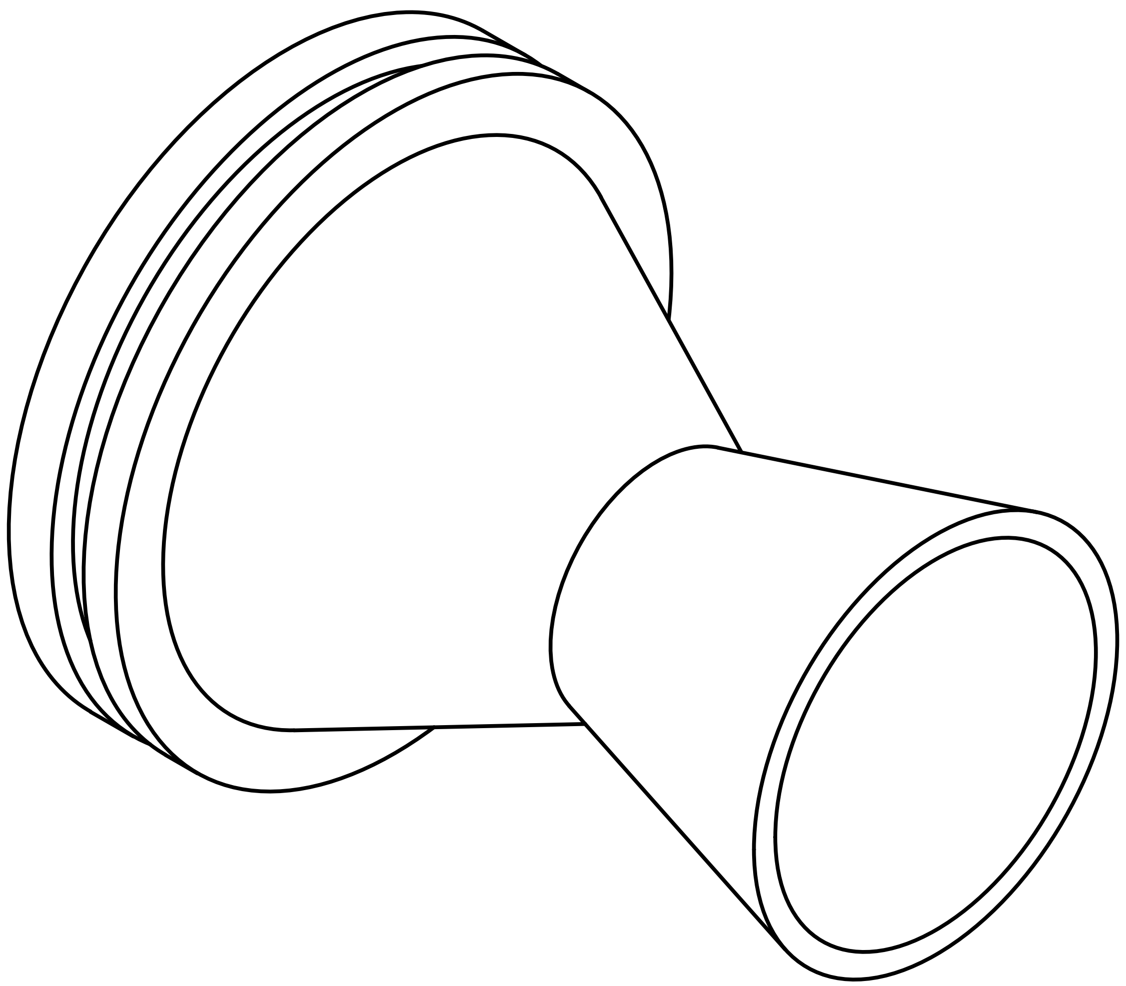
These values are used to design the nozzle.

OpenMotor is used to verify all these values and further optimize the nozzle if need be.

The Nozzle Engineering drawing is attached below







Dept.	Technical reference	Created by	Approved by		
		Washington Kamadi 3/8/2022			
		Document type	Document status		
		Title: Optimum Nozzle v3	DWG No.		
			Rev.	Date of issue	Sheet: 1/1