Rocket Engine Performance Report (200N)

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Abstract

This report presents the complete performance calculation workflow for a small liquid rocket engine using ethanol and gaseous oxygen (GOX). Calculations include propellant flow distribution, nozzle sizing, combustion chamber geometry, and injector orifice sizing. All results are based on standard rocket propulsion equations. All input parameters are derived from calculations performed by NASA Chemical Equilibrium Analysis (CEA).

Contents

1 Input Parameters

1.1 Base Engine Parameters

Table 1: Base Engine Design Parameters

Parameter	Symbol	Value
Thrust	F	200.0000 N
Chamber pressure	P_c	1 800 000.0000 Pa
O/F mass ratio	O/F	1.60
Effective exhaust velocity	c	2293.0000 m/s
Characteristic velocity	c^*	1732.1000 m/s
Expansion ratio	$\epsilon = A_e/A_t$	3.6500
Standard gravity	g_0	9.81 m/s^2

2 Basic Performance Calculations

2.1 Specific Impulse

$$I_{sp} = \frac{c}{g_0} \tag{1}$$

$$I_{sp} = \frac{2293.0000\,\mathrm{m/s}}{9.81\,\mathrm{m/s^2}} = 233.741\,\mathrm{s} \tag{2}$$

2.2 Propellant Mass Flow Rates

Total mass flow rate:

$$\dot{m}_{\mathrm{total}} = \frac{F}{c} = 0.0872\,\mathrm{kg/s} \tag{3}$$

Fuel and oxidizer flow rates (given O/F = OF):

$$\dot{m}_{\mathrm{fuel}} = 0.0335\,\mathrm{kg/s} \tag{4}$$

$$\dot{m}_{\mathrm{oxidizer}} = 0.0537\,\mathrm{kg/s} \tag{5}$$

3 Nozzle Design

3.1 Throat Area and Diameter

Throat area from characteristic velocity:

$$A_t = \frac{c^* \cdot \dot{m}_{\mathrm{total}}}{P_c} \tag{6}$$

$$A_t = \frac{c^* \cdot \dot{m}_{\mathrm{total}}}{P_c} = \frac{1732.1000\,\mathrm{m/s} \times 0.0872\,\mathrm{kg/s}}{1\,800\,000.0000\,\mathrm{Pa}} = 8.393\,177 \cdot 10^{-5}\,\mathrm{m^2}$$

$$d_t = 2\sqrt{\frac{A_t}{\pi}} = 2\sqrt{\frac{8.393\,177 \cdot 10^{-5}\,\mathrm{m^2}}{\pi}} \approx 10.34\,\mathrm{mm}$$

Throat diameter:

$$d_t = 2\sqrt{\frac{A_t}{\pi}} \approx 10.34\,\mathrm{mm} \tag{7}$$

3.2 Exit Area and Diameter

$$d_e = A_t \times \epsilon = 3.063\,510 \cdot 10^{-4}\,\mathrm{m}^2 \tag{8}$$

$$d_e = 2\sqrt{\frac{A_e}{\pi}} \approx 19.75\,\mathrm{mm} \tag{9}$$

4 Combustion Chamber Design

4.1 Characteristic Length

Selected value: $L^* = 1.500\,000\,\mathrm{m}$ (typical for small pressure-fed engines). Chamber volume:

$$V_c = L^* \times A_t = 1.500\,000\,\mathrm{m} \times 8.393\,177 \cdot 10^{-5}\,\mathrm{m}^2 = 0.0001\,\mathrm{m}^3 \approx 126\,\mathrm{cm}^3 \tag{10}$$

$$V_c = L^* \times A_t = 1.500\,000\,\mathrm{m} \times 8.393\,177 \cdot 10^{-5}\,\mathrm{m}^2 = 0.0001\,\mathrm{m}^3$$

4.2 Chamber Geometry for Different Contraction Ratios

Table 2: Combustion chamber dimensions for various A_c/A_t contraction ratios ($L^* = 1.500\,000\,\mathrm{m}$)

A_c/A_t	A_c (cm^2)	d_c (mm)	H_c (mm)	V_c (cm^3)
3	2.52	17.9	500	126
4	3.36	20.7	375	126
5	4.20	23.1	300	126
6	5.04	25.3	250	126
7	5.88	27.4	214	126
8	6.71	29.2	188	126
9	7.55	31.0	167	126
10	8.39	32.7	150	126
11	9.23	34.3	136	126
12	10.07	35.8	125	126
13	10.91	37.3	115	126
14	11.75	38.7	107	126
15	12.59	40.0	100	126
16	13.43	41.4	94	126
17	14.27	42.6	88	126
18	15.11	43.9	83	126
19	15.95	45.1	79	126
20	16.79	46.2	75	126
21	17.63	47.4	71	126
22	18.46	48.5	68	126

5 Chemical Reactions

The primary combustion reaction (stoichiometric with ethanol fuel) is:

$$C_2H_5OH + 3\,O_2 \rightarrow 2\,CO_2 + 3\,H_2O \tag{11}$$

Molar masses and specific gas constants used for injector/thermodynamic estimates:

- Ethanol: molar mass $M_{\text{ethanol}} = 46.070$ g/mol, specific gas constant $R_{\text{ethanol}} =$ 123.0000 J/kgK.
- Oxygen (O_2): molar mass $M_{\text{O2}} = 31.998$ g/mol, specific gas constant $R_{\text{O2}} =$ 259.8000 J/kgK.

The specific gas constant is computed from the universal gas constant R_u as:

$$R = \frac{R_u}{M} \quad \text{with } M \text{ in kg/mol.} \tag{12}$$

6 Injector Design

Injection Density Calculation

For gaseous propellants at subsonic conditions:

$$\rho_{\text{inj}} = \frac{P_{\text{inj}}}{R \cdot T_{\text{inj}}} \tag{13}$$

where:

$$\rho_{\text{ethanol}} = \frac{2\,160\,000.0000\,\text{Pa}}{123.0000\,\text{J/kgK} \times 775.2700\,\text{K}} = 22.6514\,\text{kg/m}^3 \tag{14}$$

$$\rho_{\text{GOX}} = \frac{2\,340\,000.0000\,\text{Pa}}{259.8000\,\text{J/kgK} \times 293.1500\,\text{K}} = 30.7246\,\text{kg/m}^3 \tag{15}$$

6.1 Ethanol Injector

Table 3: Ethanol Injector Input Parameters

Parameter	Symbol	Value
Injection temperature	T_{inj}	775.2700 K
Injection density	ρ_{inj}	22.6514 kg/m^3
Pressure drop	ΔP	360 000.0000 Pa
Injection pressure	P_{inj}	2 160 000.0000 Pa
Discharge coefficient	C_d	0.60
Specific heat ratio	γ	1.130
Y-factor (compressibility)	Y	0.940

Using Y-corrected subsonic formula: $A = \dot{m}/(Y C_d \sqrt{2\rho\Delta P})$

$$A_{o,\text{total}} = \frac{\dot{m}_{\text{fuel}}}{Y_{\text{eth}}\, C_d \sqrt{2\rho\Delta P}} \tag{16}$$

$$A_{o,\text{total}} = \frac{\dot{m}_{\text{fuel}}}{Y_{\text{eth}}\, C_d \sqrt{2\rho\Delta P}} = \frac{0.0335\,\text{kg/s}}{0.940\; 0.60\; \sqrt{2\; 22.6514\,\text{kg/m}^3\; 360\,000.0000\,\text{Pa}}} = 1.473\,593{\cdot}10^{-5}\,\text{m}^2$$

$$A_{o,\text{total}} \approx 14.74\,\text{mm}^2 \quad \rightarrow \quad d_o = 2\sqrt{\frac{A_{o,\text{total}}}{\pi}} \approx 4.33\,\text{mm}$$

Equivalent single orifice diameter:

$$d_o = 2\sqrt{\frac{A_{o,\text{total}}}{\pi}} \approx 4.33\,\text{mm} \tag{17}$$

6.2 GOX Injector

Table 4: GOX Injector Input Parameters

Parameter	Symbol	Value
Injection temperature	T_{inj}	293.1500 K
Injection density	ρ_{inj}	30.7246 kg/m^3
Pressure drop	ΔP	540 000.0000 Pa
Injection pressure	P_{inj}	2 340 000.0000 Pa
Discharge coefficient	C_d	0.60
Specific heat ratio	γ	1.400
Y-factor (compressibility)	Y	0.932
Number of orifices	n	8

Using Y-corrected subsonic formula: $A = \dot{m}/(Y C_d \sqrt{2\rho\Delta P})$

$$A_{o,\text{total}} = \frac{\dot{m}_{\text{oxidizer}}}{Y_{\text{GOX}}\, C_d \sqrt{2\rho\Delta P}} \tag{18}$$

$$A_{o,\text{total}} = \frac{\dot{m}_{\text{oxidizer}}}{Y_{\text{GOX}}\, C_d \sqrt{2\rho\Delta P}} = \frac{0.0537\,\text{kg/s}}{0.932\; 0.60\; \sqrt{2\; 30.7246\,\text{kg/m}^3\; 540\,000.0000\,\text{Pa}}} = 1.665\,542{\cdot}10^{-5}\,\text{m}^2$$

$$A_{o,\text{total}} \approx 16.66\,\text{mm}^2$$

For 8 orifices, per-orifice dimensions:

$$A_{o,\text{each}} \approx 2.08\,\text{mm}^2 \qquad d_{o,\text{each}} = 2\sqrt{\frac{A_{o,\text{each}}}{\pi}} \approx 1.63\,\text{mm} \tag{19}$$

7 Design Summary

- Thrust: 200.0000 N
- Specific impulse: 233.741 s
- O/F ratio: 1.60
- Total mass flow: 0.0872 kg/s
- Throat diameter: 10.34 mm
- Exit diameter: 19.75 mm
- L^*: 1.500 000 m