Nozzle Design

Introduction

A de-Laval nozzle designed for the Nakuja N4 rocket was simulated in Ansys Fluent Software and throat and exit characteristics of the flow were determined. The purpose of the nozzle is to accelerate the products of combustion thus trading pressure for velocity to maximise the thrust generated. Considerations for the expansion ratio, έ which is the ratio of the nozzle exit area, Ae to that of the nozzle throat area, At.

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The operating chamber pressure and Specific impulse were determined first using Open Motor,

$P_c = 4.26\ MPa$

$I_{sp} = 134.83\ s$

Mass Flowrate,

$$\dot{m} = \frac{I}{I_{sp} * g} = \frac{2431.36}{134.22*9.81} = 1.8466\ kg/s$$

Optimum throat area for sonic transition,

$$A_t = \frac{\dot{m}}{P_c} * \sqrt{\frac{R*T_c}{\gamma}} * \left(1 + \frac{\gamma-1}{2}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$$

The specific gas constant of the combustion mixture is determined by,

$R = \frac{Ro}{M}$ where, M is the molecular weight = 35.361 g/mol (from Proprep)

And R_o is the universal gas constant = 8.314 J/mol.K

$$R = \frac{8.314}{35.361*10^{-3}} = 235.1178\ J/Kg.K$$

Chamber static temperature during combustion,

$$T_c = 1595\,K$$

Ratio os specific heats,

$$\gamma = 1.1369 \text{ (from Proprep)}$$

Optimum throat diameter,

$$A_t = \frac{1.8466}{4.26*10^6} * \sqrt{\frac{235.1178*1595}{1.1369}} * \left(1 + \frac{1.1369-1}{2}\right)^{\frac{1.1369+1}{2(1.1369-1)}} = 4.17883 * 10^{-4}\,m^2$$

Throat diameter,

$$d = \sqrt{\frac{\left(4*4.17883*10^{-4}\right)}{\pi}} = 23.1\,mm$$

Optimum throat to exit area ratio,

$$\frac{A_t}{A_e} = \left(\frac{\gamma+1}{2}\right)^{\frac{1}{\gamma-1}} * \left(\frac{P_e}{P_c}\right)^{\frac{1}{\gamma}} * \sqrt{\left(\frac{\gamma+1}{\gamma-1}\right) * \left[1 - \left(\frac{P_e}{P_c}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

$$\frac{A_t}{A_e} = \left(\frac{1.1369+1}{2}\right)^{\frac{1}{1.1369-1}} * \left(\frac{101325}{4.26*10^6}\right)^{\frac{1}{1.1369}} * \sqrt{\left(\frac{1.1369+1}{1.1369-1}\right) * \left[1 - \left(\frac{101325}{4.26*10^6}\right)^{\frac{1.1369-1}{1.1369}}\right]} = 0.14395$$

Optimum expansion ratio,

$$\varepsilon_{opt} = \left(\frac{A_t}{A_e}\right)^{-1} = 0.14395^{-1} = 6.947$$

Exit diameter,

$$D_e = \sqrt{\varepsilon} * d = \sqrt{6.947} * 23.1 = 60.9\,mm \cong 61\,mm$$