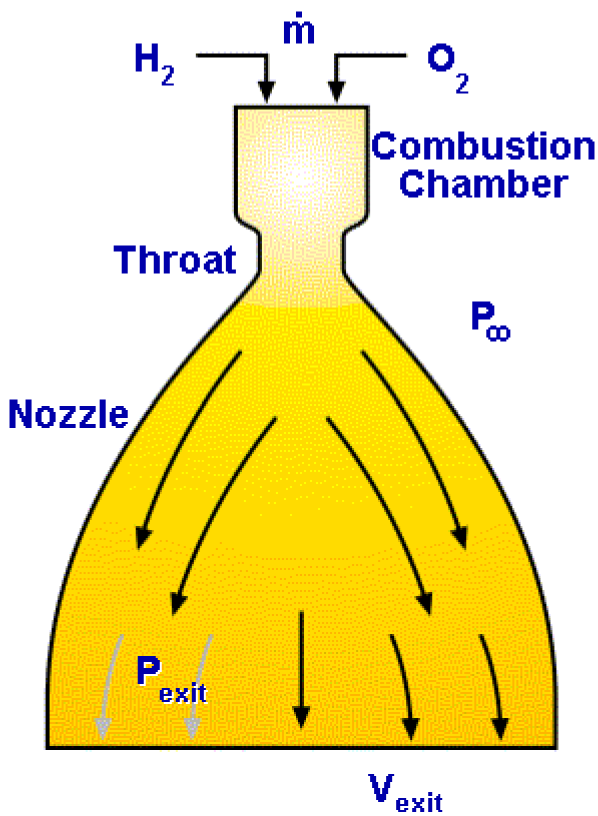
Rocket Nozzles

Purpose:

Simply put, the nozzle is the component of a rocket or air-breathing engine that produces thrust. This is accomplished by converting the thermal energy of the hot chamber gases into kinetic energy and directing that energy along the nozzle's axis, as illustrated below.



Simple representation of a rocket nozzle [from Rocketdyne, 1999]

Although simplified, this figure illustrates how a rocket nozzle works. The propellant is composed of a fuel, typically liquid hydrogen (H_2), and an oxidizer, typically liquid oxygen (O_2). The propellant is pumped into a combustion chamber at some rate $\dot{m}$ (mdot) where the fuel and oxidizer are mixed and burned. The exhaust gases from this process are pushed into the throat region of the nozzle. Since the throat is of less cross-sectional area than the rest of the engine, the gases are compressed to a high pressure. The nozzle itself gradually increases in cross-sectional area allowing the gases to expand. As the gases do so, they push against the walls of the nozzle creating thrust.

Mathematically, the ultimate purpose of the nozzle is to expand the gases as efficiently as possible so as to maximize the exit velocity (v_{exit}). This process will maximize the thrust (F) produced by the system since the two are directly related by the equation

$$F = \dot{m}\, v_{exit} + (p_{exit} - p_{\infty})\, A_{exit}$$

where

F = thrust force

$\dot{m}$ = mass flow rate

v_{exit} = exhaust gas velocity at the nozzle exit

p_{exit} = pressure of the exhaust gases at the nozzle exit

p_{∞} = ambient pressure of the atmosphere

A_{exit} = cross-sectional area of the nozzle exit

Expansion Area Ratio:

In theory, the only important parameter in rocket nozzle design is the expansion area ratio (ε), or the ratio of exit area (A_{exit}) to throat area (A_{throat}).

$$\varepsilon = \frac{A_{exit}}{A_{throat}}$$

Fixing all other variables (primarily the chamber pressure), there exists only one such ratio that optimizes overall system performance for a given altitude (or ambient pressure). However, a rocket typically does not travel at only one altitude. Thus, an engineer must be aware of the trajectory over which a rocket is to travel so that an expansion ratio that maximizes performance over a range of ambient pressures can be selected.

Nevertheless, other factors must also be considered that tend to alter the design from this expansion ratio-based optimum. Some of the issues designers must deal with are nozzle weight, length, manufacturability, cooling (heat transfer), and aerodynamic characteristics.