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DEPARTMENT OF AEROSPACE ENGINEERING

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UNIT I - FUNDAMENTALS OF ROCKET PROPULSION

Rocket Nozzle Classification

Nozzles:

The function of nozzle is

- To convert high-pressure, high-temperature energy (enthalpy) to kinetic energy. Thrust force is derived from this conversion process.
- To straighten the flow so that it exists in axial direction Because of the high temperatures that the nozzle experiences, materials used in nozzle construction are usually nickel-based alloys, titanium alloys or ceramic composites

Under-expanded Nozzles: If the nozzle exit pressure is greater than ambient pressure, the flow is considered as **under-expanded**.

- An **under-expanded nozzle** discharges the fluid at an exit pressure greater than the external pressure • The exit area is too small for optimum expansion.
- The expansion is incomplete.
- This condition occurs at altitudes higher than the design altitude.

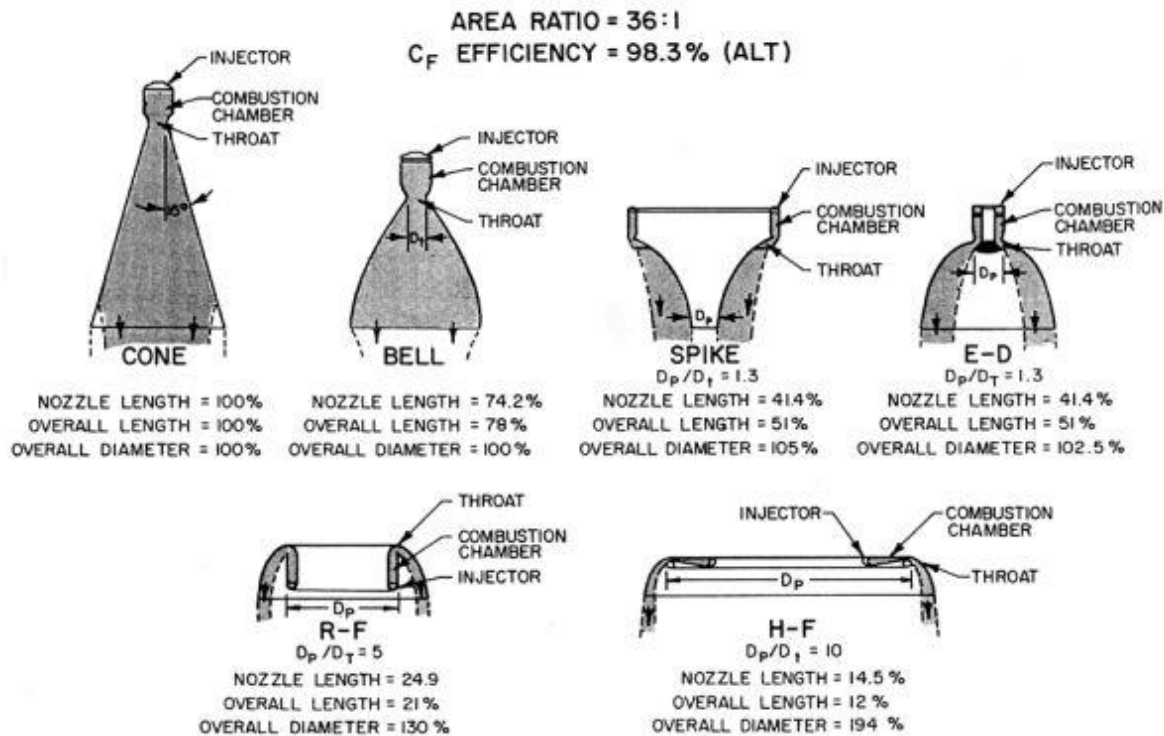
Over-Expanded Nozzle: If the exit pressure is lower than the ambient pressure, the flow is considered to be **over-expanded**.

- In an **over-expanded nozzle**, the fluid attains a lower exit pressure than the atmospheric pressure.
- The exit area at this condition is too large than the optimum area.
- This condition occurs when the nozzle operates at altitudes lower than the design altitude.

- Since the pressure inside the nozzle is lower than the outside pressure, there is possibility of flow separation due to adverse pressure gradient.

Nozzle Comparisons:

To date three major types of nozzles, the cone, the bell or contoured, and the annular or plug, have been employed. Each class satisfies the previously discussed design criteria to varying degrees. Examples of these nozzle types can be seen below.



Size comparison of optimal cone, bell, and radial nozzles for a given set of conditions [from Huzel and Huang, 1967]

Conical Nozzle:

The conical nozzle was used often in early rocket applications because of its simplicity and ease of construction. The cone gets its name from the fact that the walls diverge at a constant angle. A small angle produces greater thrust, because it maximizes the axial component of exit velocity and produces a high specific impulse (a measure of rocket efficiency). The penalty, however, is a longer and heavier nozzle that is more complex to build. At the other extreme, size and weight are minimized by a large nozzle wall angle. Unfortunately, large angles reduce performance at low altitude because the high ambient pressure causes overexpansion and flow separation.

Bell Nozzle:

The bell, the most commonly used nozzle shape, offers significant advantages over the conical nozzle, both in size and performance. Referring to the above figure, note that the bell consists of two sections. Near the throat, the nozzle diverges at a relatively large angle but the degree of divergence tapers off further downstream. Near the nozzle exit, the divergence angle is very small. In this way, the bell is a compromise between the two extremes of the conical nozzle since it minimizes weight while maximizing performance. The most important design issue is to contour the nozzle to avoid oblique shocks and maximize performance. However, we must remember that the final bell shape will only be the optimum at one particular altitude.

Annular Nozzles:

The annular nozzle, also sometimes known as the plug or "altitude-compensating" nozzle, is the least employed of those discussed due to its greater complexity. The term "annular" refers to the fact that combustion occurs along a ring, or annulus, around the base of the nozzle. "Plug" refers to the centerbody that blocks the flow from what would be the center portion of a traditional nozzle. "Altitude-compensating" is sometimes used to describe these nozzles since that is their primary advantage, a quality that will be further explored later.

Before describing the various forms of annular nozzles, it is useful to mention some key differences in design parameters from the conical or bell nozzles. The expansion area ratio for a traditional nozzle has already been discussed. When considering an annular nozzle, the area of the centerbody (A_{plug}) must also be taken into account.

$$\epsilon = \frac{A_{\text{exit}} - A_{\text{plug}}}{A_{\text{throat}}}$$

Another parameter particular to this type of nozzle is the annular diameter ratio, D_p / D_t , or the ratio of the center body diameter to that of the throat. The ratio is used as a measure of the nozzle geometry for comparison with other plug nozzle shapes. Typical values of this ratio appear in the above figure.