SNS COLLEGE OF TECHNOLOGY

(An Autonomous Institution)

COIMBATORE–35

DEPARTMENT OF AEROSPACE ENGINEERING

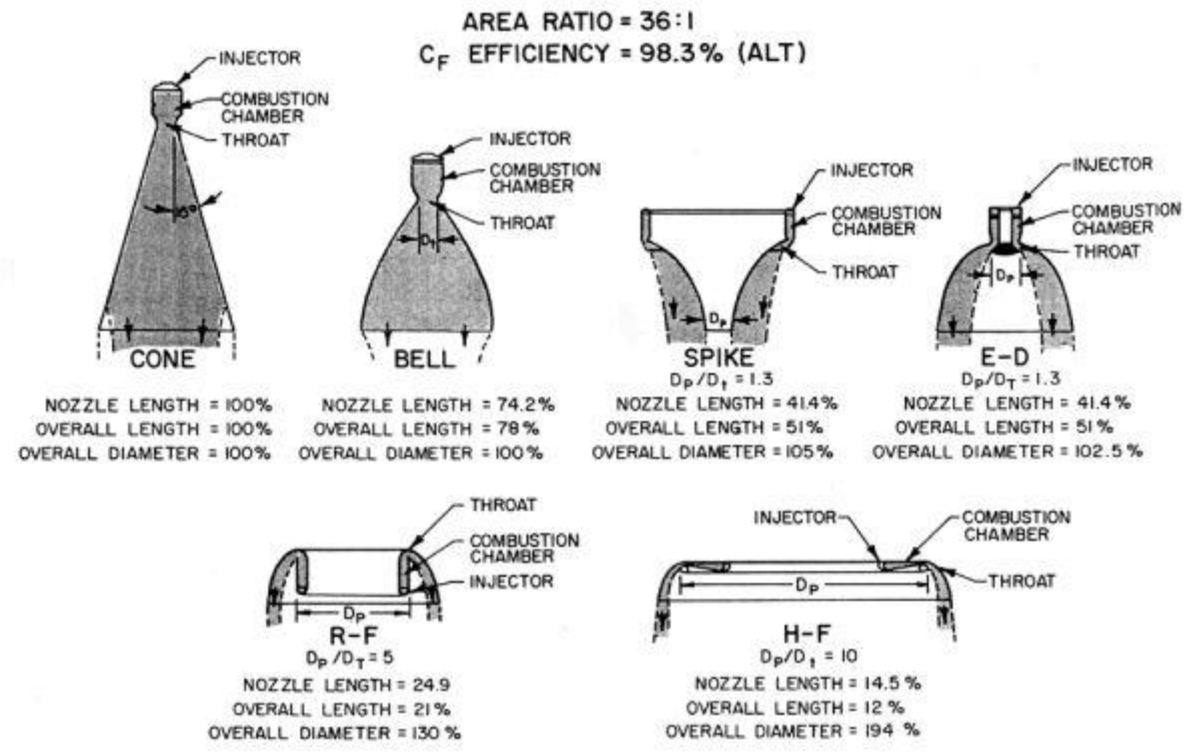
SPACE PROPULSION – ROCKET NOZZLE CLASSIFICATION

A rocket engine uses a nozzle to accelerate hot exhaust to produce thrust as described by Newton's third law of motion. The amount of thrust produced by the engine depends on the mass flow rate through the engine, the exit velocity of the flow, and the pressure at the exit of the engine. The value of these three flow variables are all determined by the rocket nozzle design.

Not all rocket nozzles are alike, and the shape selected usually depends on the application. This section discusses the basic characteristics of the major classes of nozzles used today.

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 diveregence tapers off further downstream. Near the nozzle exit, the diveregence 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.

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

Another parameter particular to this type of nozzle is the annular diameter ratio, D_p / D_t, or the ratio of the centerbody 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.

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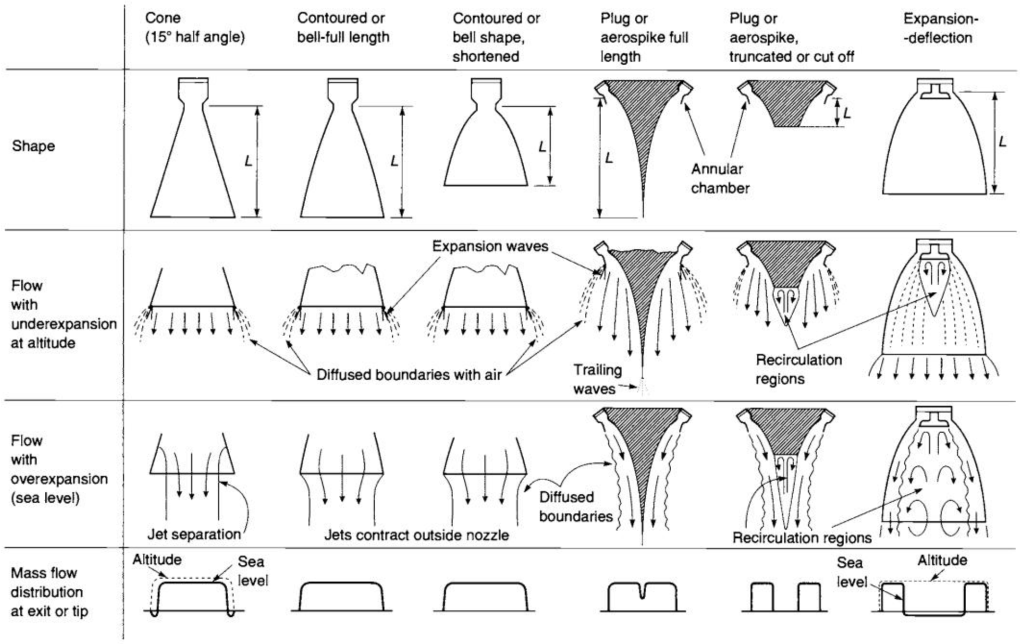

FIGURE 3–12. Simplified diagrams of several different nozzle configurations and their flow effects.