LITERATURE SURVEY ON NOZZLE THROAT ANALYSIS

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ABSTRACT

The current study of the nozzle is based on the axisymmetric de level nozzle. To improve the performance in high-speed application, nozzle keeps a special status. In the present, work our focus to study the recent development and past data of nozzle development. In high-speed nozzle application stagnation properties plays important role and they are the deciding factor for the under expansion, over expansion and optimum expansion. This work also compares the practical importance of real nozzle and isentropic nozzle.

Keyword: - *Nozzle1, Axisymmetric 2, Shock Waves 3, and Rockets 4.*

1. INTRODUCTION

A nozzle (from nose, meaning 'small spout') is a tube of varying cross-sectional area (usually axisymmetric) aiming at increasing the speed of an outflow, and controlling its direction and shape. Nozzle flow always generates forces associated to the change in flow momentum, as we can feel by handholding a hose and opening the tap. In the simplest case of a rocket nozzle, relative motion is created by ejecting mass from a chamber backwards through the nozzle, with the reaction forces acting mainly on the opposite chamber wall, with a small contribution from nozzle walls. As important as the propeller is to shaft-engine propulsions, so it is the nozzle to jet propulsion, since it is in the nozzle that thermal energy (or any other kind of high-pressure energy source) transforms into kinetic energy of the exhaust, and its associated linear momentum producing thrust. The flow in a nozzle is very rapid (and thus adiabatic to a first approximation), and with very little frictional loses (because the flow is nearly one-dimensional, with a favorable pressure gradient except if shock waves form, and nozzles are relatively short), so that the isentropic model all along the nozzle is good enough for preliminary design. The nozzle is said to begin where the chamber diameter begins to decrease (by the way, we assume the nozzle is axisymmetric, i.e. with circular cross-sections, in spite that rectangular cross-sections, said two-dimensional nozzles, are sometimes used, particularly for their ease of direction ability). The meridian nozzle shape is irrelevant with the 1D isentropic models; the flow is only dependent on cross-section area ratios. Real nozzle flow departs from ideal (isentropic) flow on two aspects:

1.1 Non-adiabatic effects.

There is a kind of heat addition by non-equilibrium radical-species recombination, and a heat removal by cooling the walls to keep the strength of materials in long-duration rockets (e.g. operating temperature of cryogenic SR-25 rockets used in Space Shuttle is 3250 K, above steel vaporization temperature of 3100 K, not just melting, at 1700 K). Short-duration rockets (e.g. solid rockets) are not actively cooled but rely on ablation; however, the nozzle-throat diameter cannot let widen too much, and reinforced materials (e.g. carbon, silica) are used in the throat region.

1.2 Viscous dissipation

There is viscous dissipation within the boundary layer, and erosion of the walls, what can be critical if the erosion widens the throat cross-section, greatly reducing exit-area ratio and consequently thrust. Axial exit speed is lower than calculated with the one-dimensional exit speed, when radial outflow is accounted for.

2. LITERATURE SURVEY

The early studies of transonic two-dimensional and axisymmetric flow involve velocity perturbations about the sonic velocity. The continuity equation can be re-written in terms of a velocity perturbation potential and its partial derivatives. Meyer (12) first obtained a solution to this equation by expanding the perturbation potential in a power series and assuming a linear velocity distribution along the nozzle axis. Light hill (13) made use of the series solution to make a qualitative analysis of the behavior of the flow near the sonic line. The method can be applied conveniently only to the indirect (or design) problem. That is, the flow field is developed dependent upon the assumed centerline velocity distribution. Any streamline may be a wall and, therefore, once the solution is obtained, the flow field for the streamline contour produced is known. Application of the method to the direct (or performance) problem is cumbersome and time-consuming because the centerline velocity distributions, which will produce a given wall, contour is not known.

Taylor (14) and Hooker (15) respectively first solved the direct problem for symmetric two-dimensional and axisymmetric flow. Using a double power series, Taylor evaluated the velocity perturbation potential up to and including fourth order terms. This involved the simultaneous solution of eight equations for the eight unknown series coefficients.

The perturbation solutions are fundamental in their approach. The evaluation, however, of a double power series expansion for the general equations of motion is a major effort even for the simple case of a linear axial velocity distribution. The complexity cannot be justified, especially when the method cannot be conveniently utilized for performance analysis of nozzles. To overcome this drawback various authors have simplified the equations of motion and obtained approximate solutions for transonic flow in a nozzle.

Sauer (8) was the first to make a major simplification to the equations of motion. He wrote the governing equations in terms of the velocity perturbation potential. Then noting that several of the terms approached zero near the throat, he retained only the first order factors in these terms. This produced a series solution, which was the first three terms of Meyer's solution. The technique was found to be applicable for nozzles with low inlet cone angles only. Several attempts have, therefore, been made to improve Sauer! s original solution. Yur'ev (16) obtained a solution by including an extra term and Sims (17) expanded the power series solution to five terms. Mendelson (18) extended Meyer's power series solution by formulating recurrence relationships for the general series coefficients in terms of the velocity distribution specified along the nozzle axis. In-all these cases no substantial improvement was made in accuracy over Sauer’s original solution.

Oswatitsch and Rothstein (19) in an effort to eliminate the need to specify the axial velocity distribution developed an iterative solution based on successive approximations to the flow field. Although Oswatitsch (20) later showed that, the numerical technique was unstable when applied to nozzles with steep inlet cone angles, their work became the basis for many investigators.

The most significant factor that influences the transonic flow pattern is the wall radius curvature in the throat region. Realizing this, Hall (21) produced a. technique for symmetric nozzles. Using a perturbation technique, he wrote the series expansion in inverse powers of Rt, the ratio of throat radius of curvature to throat radius. Subsequent studies typified by the works of Moore and Hall (22) and Quan and Kliegal (23) have extended Hall's original solution to two-dimensional and annular nozzles with arbitrary profiles and dual gas flows. The solutions have shown favorable results, however, only for slender nozzles ($Q ^ 30°, Rt ^ 1.5). Increase the accuracy of the method for R_t less than one, Kliegel and Levine (24) reformulated the series expansion to inverse powers of (R^ +1). The method solved only the transonic flow region. The interdependency of subsonic and transonic solutions was not taken into account.

The streamline procedure developed first by Friedrichs (25, 26) is an attempt to improve on the perturbation methods. The procedure utilizes the full nonlinear partial differential equations of motion for Inviscid, irrotational, isentropic transonic nozzle flow. The equation of continuity for steady, axisymmetric flow is expressed in terms of the stream function and the velocity potential. A transformation is then made using the velocity distribution along the nozzle axis. The resulting system of partial differential equations is then solved by a series expansion of the stream function. The method determines the flow field in both the subsonic and supersonic regions.

The streamline procedure has been adapted to the two-dimensional problem by Liepman (27). Gray (28) generalized the technique to allow any curve in axisymmetric or two-dimensional flow to be selected as the reference line along which the velocity distribution is specified. Hopkins and Hill (29, 30) and Thompson (31) have utilized the method in the study of asymmetric, two-dimensional annular plug, expansion-deflection type nozzles and two-dimensional curved channels.

Other procedures using a streamline technique have been formulated which numerically iterate the equations of motion across the flow field. The results of iteration are used to approximate the partial derivatives in the axial direction for the next iteration. Utilizing a given velocity distribution along the axis Pirumov (32) constructed the transonic solution in a converging-diverging nozzle. Zupnik and Nilson (33) generalized the approach to solve the direct problem in two-dimensional and axisymmetric nozzles.

3. PROBLEM IDENTIFICATION

A solution is needed for two-dimensional isentropic flow, which is valid throughout a supersonic nozzle. The literature reveals that such a solution is virtually non-existent (1). The reason lies in the varying mathematical character of the equations describing the flow through the nozzle. The equations for subsonic, sonic, and supersonic flow are elliptic, parabolic, and hyperbolic respectively. Existing studies, therefore, usually entail analysis in three different flow regions; namely, the subsonic or convergent region, the transonic or throat region, and the supersonic or divergent region

3. CONCLUSION

The problem then, is to develop a two-dimensional solution technique for the subsonic-transonic region of a conical converging-diverging nozzle with a steeply inclined entrance cone and a tight throat contour. This solution can then provide the boundary conditions necessary for the solution of the supersonic region by the method of characteristics.

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