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Flow through Nozzle in Sudden Expansion in Cylindrical Ducts with Area Ratio 2.89 at Mach 2.4: A Fuzzy Logic Approach

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Abstract—**In this paper the analysis of flow at Mach number 2.4 has been done with fuzzy logic approach to have smooth flow in the duct. Here there are three primary pressure ratio chosen for the enlarged duct, 2.10, 2.65 and 3.48. The area ratio is taken as 2.89. The study is analyzed for length to diameter ratio of 1.24 and 6. The nozzle used is a conical one with Mach number 2.4 at exit. The analysis based on fuzzy logic theory indicates that the length to diameter ratio of 4 is sufficient for smooth flow development keeping in view all the three parameters like base pressure, wall static pressure and total pressure loss.**

Index Terms—**area ratio, base pressure, conical nozzle, Mach number.**

NOTATION

A_r Area ratio defined as the ratio of enlarged duct area to the nozzle exit area.
ASR1 Models with cavity aspect ratio 1.
ASR2 Models with cavity aspect ratio 2.
D Diameter of enlarged duct.
P_a Ambient atmospheric pressure.
P_b Non-dimensional base pressure
P_{01} Stagnation pressure in the settling chamber, also called primary pressure.
L Length of enlarged duct.
M Mach number at the nozzle exit.
ST Represents enlarged duct without cavities.
R_eReinhold's number

I. Introduction

Soft computing is an emerging approach to computing which parallels the remarkable ability of the human mind to reason and learn in an environment of uncertainty and imprecision. Soft computing consists of several computing paradigms, including neural networks, fuzzy set theory, approximate reasoning, and derivative- free optimization methods such as genetic algorithms and simulated annealing. For learning and adaptation, soft computing requires extensive computation. In this sense, soft computing shares the same characteristics as computational intelligence. In general, soft computing does not perform much symbolic manipulation, so we can view it as a new discipline that complements conventional artificial intelligence approaches, and vice versa. Unlike conventional algorithms, soft computing methodologies are tolerant of imprecision, uncertainty and partial truth. Soft computing techniques do not suffer from the brittleness and inflexibility of standard algorithmic approaches. Fuzzy set theory, neural networks; genetic algorithms form the part of soft computing apart from many other techniques. Fuzzy set theory derives its motivation from approximate reasoning. Neural networks get their motivation from biological nervous systems. Genetic algorithms are based on the nature's law of the "survival of the fittest". There has been a spurt of activities to integrate these techniques.

II. Literature Review

In today's scenario the study about the abrupt expansion of the jet of gas is of general interest in a variety of flow systems. In most of the cases the enlarged duct used has a smooth continuous inner surface and makes use of the low base pressure that results due to the sudden relaxation of the shear layer from the inlet passage at the entry to the sudden enlargement. The base pressure and the flow field downstream of the base are dictated by the vortex dynamics triggered by the sudden expansion of the flow in the enlarged duct. There are also cases wherein the experiments on sudden expansion are conducted in a straight duct and some in straight duct with cavities. Our present study is about the optimization of the length to diameter ratio (L/D) of the straight duct in the absence of cavities with the help of a soft computing methodology, 'the Fuzzy Sets'. This work deals upon the effect of base pressure, pressure loss and wall static pressure individually. Some of the works, which are directly related to the present work, are the following. The effect of boundary layer on sonic flow through an abrupt cross-sectional area was experimentally studied by Wick [1]. He observed that the pressure in the corner of expansion was related to the type and thickness of boundary layer at the corner of inspection. He considered boundary layer as the source of fluid for corner flow. Korst [2] investigated the problem of base pressure in transonic and supersonic flow, for the case in which the flow approaching the base is sonic or supersonic after the wake. He devised a physical flow model based on the concept of introduction between the dissipative shear flow and the adjacent free streams and the conservation of mass in the wake. These results agreed closely with the experimental data of Wick. Hall and Orme [3] studied compressible flow through a sudden enlargement in a pipe both theoretically and experimentally and showed a good arrangement between theoretical and experimental results. They developed a theory to predict Mach number in a downstream location of sudden enlargement of known values of Mach number at the exit of the inlet tube, with compressible flow assumptions; they also assumed that the pressure across the face of the enlargement was equal to the static pressure in a small tube just before the enlargement. However these assumptions are far away from reality, since it is a well-established fact that the pressure across the face I the recirculation region, namely the base pressure, is very different from the pressure in the smaller tube just before the enlargement. They studied the problem with a range of Mach numbers from 0 to 1. Cherdon et al. [4] studied symmetric flow and instabilities in symmetric ducts with sudden expansion. Asymmetric flows were caused by the disturbance generated at the edge of the expansion and amplified in the shear layers. The spectral distribution on the fluctuation in velocity is quantitatively related to the dimension of the two unequal regions of flow recirculation. They showed that the intensity of fluctuating energy in the low Reynolds numbers could be larger than the corresponding turbulent flow. Brady and Acrivos [5] studied cavity laminar flows at moderate Reynolds number. They suggested that the similarity solutions should be reviewed with caution because they might not represent real flow once a critical Reynolds number was exceeded. The flow field in a suddenly enlarged combustion chamber was studied experimentally by Yang and Yu [6]. The combustion chamber consisted of circular Plexiglas with a suddenly enlarged section followed by a nozzle. The Reynolds number based o the inlet duct diameter and center velocity was 64,000. The wall pressure measurement was carried out with laser Doppler anemometer. Detailed profiles of main velocities of turbulent intensities, turbulent shear stresses and wall pressure distribution were developed. The dividing stream line, reattachment point and the magnitudes of the mean kinetic energy and turbulent kinetic were also determined. The authors observed that the laser Doppler anemometer with a frequency shifter was a useful instrument for measuring reverse flow fields especially for the highly turbulent flow field encountered in the study. Measurements from a conventional hot ire anemometer might present considerable error. Raghunathan and Mabey [7] studied passive shock wave/boundary layer control on a wall-mounted model. They evaluated the effects of orientation, normal forward facing and backward facing. The porosity used was 1.6%. Their measurement included static and dynamic pressure on the model surface and wake traverse. They had visualized the field with shadowgraphs. The forward facing holes located around shock position showed an appreciable decrease in drag compared with solid surface model. Raghunathan [8] studied pressure fluctuation with positive shock position showed an appreciable decrease in drag compared with solid surface model. Raghunathan [9] also studied pressure fluctuation. with passive shock/ boundary layer control and found that the forward facing holes configuration with a porosity of 1-2% produces maximum drag reduction. Wilcox Jr. [10] studied the passive venture system for modifying cavity flow fields at supersonic speed. Experimentally he showed that a passive venting system could be employed to control cavity flow field at supersonic speed, specifically the passive venting system had been used to extend the L/H value before the onset value of high drag producing closed cavity flow. In his experiment the porous flow eliminated the large drag increase for L/H >12. There is tremendous increase in drag coefficient for L/H > 12 but for porous flow having more diameters the decrease in drag coefficient is comparatively very less with the floor having fewer diameters. Tanner [11] studied base cavity at angle of incident. He concluded that the base cavity could increase the base pressure and thus decrease the base drag in axi-symmetric flow. He varied the angle of incident from 0 to 25 degrees. At alpha = 2 degree he found that the maximum drag decreased. Rathakrishnan et al. [12] studied the influence of cavities on suddenly expanded flow fields experimentally. Based on their study of air flow through a convergent axi-symmetric nozzle expanding suddenly into a annular circular parallel shroud with annular cavities, they concluded that smoothening effect by the cavities on the main flow field in the enlarged duct was well pronounced for the large ducts and the cavity aspect ratio has a significant effect on the flow field as well as on the base pressure. The results showed that increase in cavity aspect ratio from 2 to 3 results in base pressure, but for increase in aspect ratio from 3 to 4, the base pressure goes up. The effectiveness of a passive device for axi-symmetric base drag reduction at Mach 2 was studied by vishwanath and patil [13]. The device examined included primary base cavities and ventilated cavities. Their results showed that the ventilated cavities offered significant base drag reduction. They found 50% increase in base pressure and 3-5% net drag reduction at supersonic Mach number body of revolution. Kruiswtk and Dutton [14] studied the effects of base cavities on subsonic near wake flow. They experimentally investigated the effects of the base cavity on the near wake flow field of a slender two-dimensional body in the subsonic speed range. Their basic configurations were studied and compared were a blunt base, a shallow rectangular cavity base of depth equal to ½ of the base height and a deep rectangular cavity base of depth equal to base height. Schlieren photographs revealed that the basic qualitative structure of the vortex street was unmodified by the presence of base cavity. The weaker vortex street yielded higher pressure in the near wake for the cavity base, increase in the base pressure coefficient of the order 10-14% and increase in the shedding frequencies of the order of 4-6% relative to the blunt based configuration. Air flow from a mach 1.74 convergent-divergent axi-symmetric nozzle expanded suddenly into circular duct of larger cross-sectional area, provided with annular rectangular cavities, was studied experimentally by Pandey, K.M. and Rathakrishnan E. [15], focusing attention to the base pressure, and the flow development in the enlarged duct. It was found that the pressure is strongly influenced by the expansion level at the nozzle exit, the area ratio of the passage, the L/D ratio of the enlarged duct. For low area ratio, the annular cavities result in increase in the base pressure. Also, the cavity aspect ratio influences the base pressure significantly for low area ratio.

Supersonic jet flow from convergent divergent nozzle with method of characteristics contour expanding suddenly into circular pipes with and without annular cavities was experimentally investigated by Pandey, K.M. [16], for Mach number 1.74. Attention was focused on variation of non dimensional base pressure and oscillations of base pressure. It was observed that the base flow is wave dominated for L/D ratio up to 4 only with mild oscillations. It was observed that increasing L/D ratio beyond 6 does not have any effect on the base pressure and the base pressure is minimum for models without cavity and maximum for the models with cavities of aspect ratio 2. Flow from nozzles expanding suddenly into circular pipes with and without annular cavities was experimentally investigated by Pandey, K.M., [17] for Mach number range of 1.00 – 2.75. The base pressure was found increasing with increasing Mach number's as expected for supersonic Mach numbers. The effect of aspect ratio on base pressure is only marginal for supersonic Mach number's. Flow from nozzles expanding suddenly into circular pipes with and without annular cavities was experimentally investigated by Pandey, K.M. [18], for a Mach number range of 0.60 to 2.75. The pressure loss was found increasing with increasing mach numbers. Total pressure loss increases with increase in Mach number, primary pressure ratio, area ratio and L/D ratio. In supersonic regime pressure loss increases for models with cavities aspect ratio 1 and decreases for models with cavity aspect ratio 2 for L/D ratio up to 4. Airflow from convergent axi-symmetric nozzle expanded suddenly into circular duct of larger cross-sectional area was studied experimentally, by Pandey, K.M., Khan, S.A., and Rathakrishnan E. [19]. They focused their attention on base pressure, the flow development in the enlarged duct and the pressure loss. It was found that the base pressure is strongly influenced by the parameter viz. the nozzle exit mach no, the area ratio of the passage, the length to diameter ratio of the enlarged duct. The base pressure decreases with increase in Mach number. The base pressure was found to be smooth and without oscillation in the Mach number range of 0.6- 1.0. Dixit and Dixit [20] applied Fuzzy Set theory in Scheduling of a tandem cold- rolling mill. This gives a clear concept of using a fuzzy set theory in various fields of interest. They have worked on optimizing the power consumed and maximum reliability together by considering the various constraints like, interring stand tensions, rolling speed, and rolling pressure and forces, and thickness of the strip at exit of each stand. Even though all those parameters where considered to be related to power consumed they were all assumed constant for a particular speed and particular inter stand thickness. In his procedure with experimental data available he calculated the optimal power for those data, by deriving a relation for power and reliability. Rathakrishnan [21] demonstrated that a control in the form of annular ribs could serve as an effective controller to control the base pressure for axi-symmetric sudden expansion of under expanded sonic flows. It was found that the rib, when placed at an appropriate location downstream of the base prevents the reverse flow through boundary layer into the base zone. This enables the free-shear layer expanding at the base to have its process delinked from influence of the reverse flow. The same principle is going to be applied in our project also. Dixit, Robi and Sharma [22] studied a systematic study for design of cold rolling mill. The design of a cold rolling mill is calculated by considering many factors like roll velocity, power, reliability, running cost, roll torque, and roll radius. With this paper we can learn a clear idea of creating a membership function for any criteria. Abburi and Dixit [23] together generated a knowledge-based system for predicting the surface roughness in turning process. In which they generated IF-THEN rules using Fuzzy set theory. Soft computing-based techniques are used to impart capabilities. Pandey, K.M, and Rathakrishnan E. [24, 25] studied on flow characteristics of a subsonic, sonic and as well as supersonic flow through a circular duct provided with annular ducts. The experiment was conducted on various pressure ratios and area ratios. The base pressure, pressure loss and wall static pressure was calculated and they studied the effects caused on the circular ducts. They found that the flow was not attached for small L/D wherein the flow showed oscillatory pressure in a large L/D and moreover losses increased as the size of the L/D increased. During the introduction of the cavities the oscillations of pressure was suppressed for higher L/D ratios but the flow remains detached at smaller L/D ratios. R.Jagannath, N.G.Naresh and K.M. Pandey worked on pressure loss in sudden expansion in flow through nozzle: a fuzzy logic approach [26]. In this paper pressure loss in suddenly expanded ducts is studied with the help of fuzzy logic as a tool. It is observed that minimum pressure loss takes place when the length to diameter ratio is one and it is seen that the results given by fuzzy logic formulation are very logical and it can be used for qualitative analysis of fluid flow in flow through nozzles in sudden expansion. To make the problem simpler the linear function is considered throughout the methodology. We were provided with data, which were collected from the experiment conducted by Pandey K.M. at I.I.T. Kanpur [15]. Moreover, in spite of the flow being supersonic the effects of shock are not being considered. In this paper the main objective is to find the desired L/D ratio for smooth flow development keeping in view all the three parameters like base pressure, wall static pressure and total pressure loss.

III. Methodology in Fuzzy

FIS stands for Fuzzy Inference **S**ystem. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox (available with MATLAB environment): Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani type of Fuzzy Inference System is developed for this problem. Both command line as well as GUI (Graphical User Interface) based tools is available in MATLAB. The GUI window is invoked by *fuzzy* command. The antecedent (input variables viz. Base Pressure, Pressure

Loss and Wall Static pressure Variation) and the consequent (output variable viz. L/D ratio and pressure ratio) are identified and set into the FIS with the help of Add Variable GUI. The next task is to set Membership Function(s) in each of the variable(s) both input and output. This is done by Membership Function Editor GUI. The required number and type of MF is set accordingly so that the desired MF takes a desired portion of the input i.e. to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In the Fuzzy Logic Toolbox, the input is always a crisp numerical value limited to the universe of discourse of the input variable (in this case the interval between 0 and 1) and the output is a fuzzy degree of membership in the qualifying linguistic set (always the interval between 0 and 1). The shape of the MF can be changed by mouse or setting parameters for that particular MF.

IV. Results and Discussions

The effect of Base Pressure in the fluid flow is studied from the experiment conducted by Pandey K.M. [15]. It is inferred from their experiment that, low base pressure is desirable, as the flow tends to remain attached because of low base pressure or low wake. Hence this concept is considered in Fuzzy logic for determining the membership function. As we desire that Base pressure to be low, we assume a membership function 1 to the lowest possible Base Pressure. As our experimental data are calculated by considering non-dimensional ratios, i.e. Base Pressure is the ratio of Base pressure and ambient pressure in order to make the quantity dimensionless. The lowest possible base pressure ratio is 0.00 which can be attained at very high mach numbers. Hence by considering those criteria into factor the membership function 1 is assumed for a base pressure ratio of 0.00. Similarly the maximum possible base pressure ratio i.e. base pressure ratio 1 is given a membership function 0 as it is the most undesirable characteristics. Hence this assumption holds true for all the nozzles. It is obvious that, low pressure loss is desirable, as to attain maximum flow efficiency. Hence this concept is considered in Fuzzy logic for determining the membership function. As we desire that pressure loss to be low, we assume a membership function 1 to be the lowest possible Pressure loss. Theoretically lowest possible pressure loss is 0.00. Hence by considering those criteria into factor the membership function 1 is assumed for a pressure loss of 0.00. Similarly the maximum possible pressure loss as per experimental data is given the membership function as 0. Similarly low wall static pressure variation is desirable, as to attain smooth flow. Hence this concept is considered in Fuzzy logic for determining the membership function. As we desire that wall static pressure variation to be low, we assume a membership function 1 to be the lowest possible wall static Pressure variation. The lowest possible wall static pressure variation is 0.00 which is given the membership function as 1. Similarly the maximum possible wall static pressure variation as per experimental data is assigned membership function as 0. The various membership functions are shown below for input and output variables.

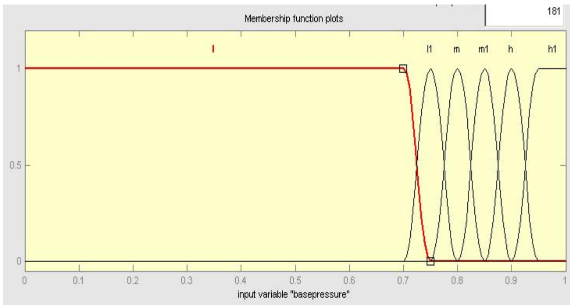

Fig.1 Membership functions for input variable "Base pressure"

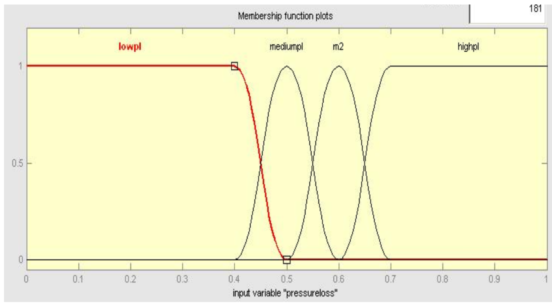

Fig.2 Membership functions for input variable "Pressure Loss"

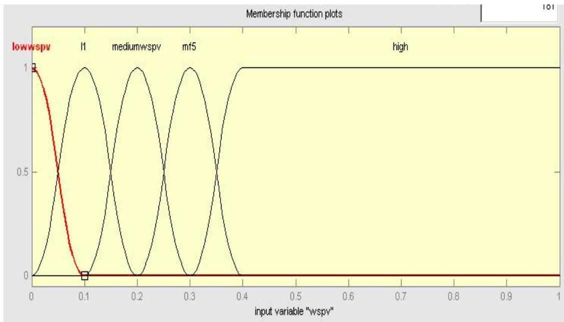

Figure 3 Membership functions for input variable "Wall Static pressure Variation"

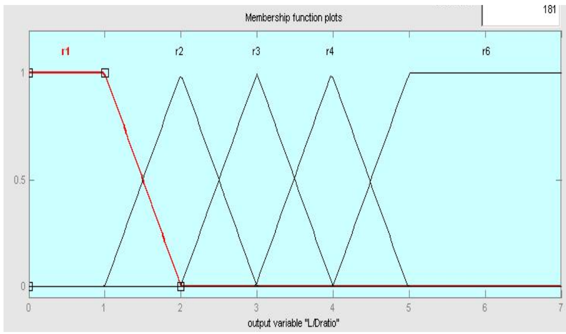

Fig. 4 Membership functions for output variable "L/D Ratio"

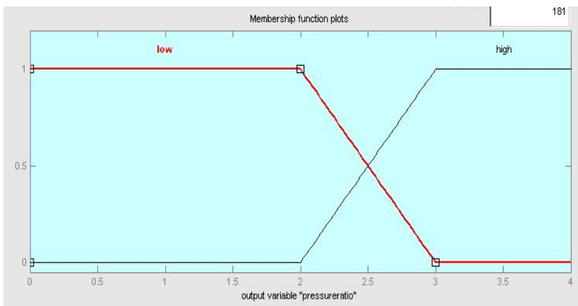

Fig.5 Membership functions for output variable "PressureRatio"

A detailed description of the variables and membership function specification is listed in table 1

TABLE-I MEMBERSHIP FUNCTION SPECIFICATIONS

Variable	Membership Function Specifications		
	Name	Type	Parameters
Base pressure	l (Very Low)	zmf	[0 .70 .75]
	l_1 (Low)	pimf	[.70 .75 .80]
	m (medium)	pimf	[.75 .80 .85]
	m_1(medium)	pimf	[.80 .85 .90]
	h (high)	pimf	[.85 .90 .95]
	h_1 (Higher)	sigmf	[.90 .95 1.0]
Pressure Loss	lowpl	zmf	[0 .4 .5]
	mediumpl	pimf	[.4 .5 .6]
	m2 (medium)	pimf	[.5 .6 .7]
	highpl	sigmf	[.6 .7 1.0]
Wall Static Pressure Variation	lowwspv	zmf	[0 0 .1]
	l1 (low)	pimf	[0 .1 .2]
	mediumwspv	pimf	[.1 .2 .3]
	mf5 (medium)	pimf	[.2 .3 .4]
	high	sigmf	[.3 .4 1.0]
L/D Ratio	r1	trapmf	[0 0 1 2]
	r2	trimf	[1 2 3]
	r3	trimf	[2 3 4]
	r4	trimf	[3 4 5]
	r6	trapmf	[4 5 6 6]
Pressure Ratio	low	trapmf	[0 0 2 3]
	high	trapmf	[2 3 4 4]

The most important part of the FIS is the IF-THEN rules which form the basis of FIS. Rules are set using Rule Editor GUI. The pure fuzzy logic system is the system where the fuzzy rule base consists of a collection of fuzzy IF–THEN rules, and the fuzzy inference engine uses these fuzzy IF–THEN rules to determine a mapping from fuzzy sets in the input universe of discourse $U \subset R_n$ to fuzzy sets in the output universe of discourse $V \subset R$ based on fuzzy logic principles.Since decisions are based on the testing of all of the rules in an FIS, the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the fifth and final step, defuzzification. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number, obtained by defuzzification. A list of If-Then rule is provided in table 2.

TABLE - II RULES DEFINITION

Rule No.	Rule Definition	Rule Wt
1	IF *Base pressure* is **h1** AND *Pressure Loss* is **lowpl** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r1** AND *Pressure Ratio* is **low**	1
2	IF *Base pressure* is **h** AND *Pressure Loss* is **mediumpl** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r2** AND *Pressure Ratio* is **low**	1
3	IF *Base pressure* is **m** AND *Pressure Loss* is **highpl** AND *Wall Static Pressure Variation* is **mediumwspv** THEN *L/D* is **r4** AND *Pressure Ratio* is **low**	1
4	IF *Base pressure* is **h1** AND *Pressure Loss* is **mediumpl** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r1** AND *Pressure Ratio* is **high**	1
5	IF *Base pressure* is **m** AND *Pressure Loss* is **mediumpl** AND *Wall Static Pressure Variation* is **mediumwspv** THEN *L/D* is **r2** AND *Pressure Ratio* is **high**	1
6	IF *Base pressure* is **l1** AND *Pressure Loss* is **m2** AND *Wall Static Pressure Variation* is **mf5** THEN *L/D* is **r4** AND *Pressure Ratio* is **high**	1
7	IF *Base pressure* is **l** AND *Pressure Loss* is **m2** AND *Wall Static Pressure Variation* is **mf5** THEN *L/D* is **r6** AND *Pressure Ratio* is **high**	1
8	IF *Base pressure* is **h** AND *Pressure Loss* is **m2** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r1** AND *Pressure Ratio* is **high**	1
9	IF *Base pressure* is **m** AND *Pressure Loss* is **m2** AND *Wall Static Pressure Variation* is **mediumwspv** THEN *L/D* is **r2** AND *Pressure Ratio* is **high**	1
10	IF *Base pressure* is **l** AND *Pressure Loss* is **highpl** AND *Wall Static Pressure Variation* is **mf5** THEN *L/D* is **r4** AND *Pressure Ratio* is **high**	1
11	IF *Base pressure* is **l** AND *Pressure Loss* is **highpl** AND *Wall Static Pressure Variation* is **high** THEN *L/D* is **r6** AND *Pressure Ratio* is **high**	1
12	IF *Base pressure* is **h1** AND *Pressure Loss* is **mediumpl** AND *Wall Static Pressure Variation* is **lowwapv** THEN *L/D* is **r1** AND *Pressure Ratio* is **low**	1
13	IF *Base pressure* is **h** AND *Pressure Loss* is **lowpl** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r2** AND *Pressure Ratio* is **low**	1
14	IF *Base pressure* is **h** AND *Pressure Loss* is **mediumpl** AND *Wall Static Pressure Variation* is **mediumwspv** THEN *L/D* is **r4** AND *Pressure Ratio* is **low**	1
15	IF *Base pressure* is **h** AND *Pressure Loss* is **mediumpl** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r6** AND *Pressure Ratio* is **low**	1
16	IF *Base pressure* is **h1** AND *Pressure Loss* is **m2** AND *Wall Static Pressure Variation* is **lowwspv** THEN *L/D* is **r1** AND *Pressure Ratio* is **high**	1
17	IF *Base pressure* is **h** AND *Pressure Loss* is **m2** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r2** AND *Pressure Ratio* is **high**	1
18	IF *Base pressure* is **m1** AND *Pressure Loss* is **m2** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r4** AND *Pressure Ratio* is **high**	1
19	IF *Base pressure* is **h** AND *Pressure Loss* is **highpl** AND *Wall Static Pressure Variation* is **l1** THEN *L/D* is **r1** AND *Pressure Ratio* is **high**	1
20	IF *Base pressure* is **m** AND *Pressure Loss* is **highpl** AND *Wall Static Pressure Variation* is **mediumwspv** THEN *L/D* is **r4** AND *Pressure Ratio* is **high**	1

V. CONCLUSION

The present work has been taken up with the objective of obtaining suitable L/D ratio which can produce smooth flow through a suddenly expanded duct with minimum total pressure loss. The objective is achieved using Fuzzy Inference System (Mat lab). FIS concept in the optimization of L/D ratio proves to be a powerful tool in achieving effective flow through minimum duct length. It aims at reaching the optimal configuration with simple methodology which in this study comes out to be L/D=3.71, and it can be taken as 4 and Pressure Ratio 2.68 for Mach number 2.4 and L/D=3.85 and again it can be taken as 4 and Pressure Ratio 2.84 for Mach number 2.75. This objective of evaluating the best possible L/D ratio has already been obtained earlier experimentally which is L/D=4 for both cases by other researchers mentioned in literature review part. Though we have obtained a logically derived optimum L/D ratio, it shows some variation with the experimentally arrived results. This variation can be well explained by considering the difference in approaches in obtaining the result. In experimental case the researcher used only four sets of configuration i.e. varying L/D ratio through 1, 2, 4 and 6. Through their knowledge and experience, they concluded the results. But in this study, the use of computer has given the opportunity of applying the previous knowledge to obtain results, which can be and is a fractional value, closer to the experimental one. As per the results obtained through Fuzzy Inference System, lt has been thoroughly discussed in the 'Results and Discussion' section. From the discussion, it can be concluded that the presence of ducts with L/D ratio below 4 is of no use as the jet does not get attached.

APPENDIX

BASE PRESSURE DATA FOR MACH 2.4 AND AREA RATIO 2.89

TABLE-I BASE PRESSURE RATIO – 2.10

L/D	ST
1	0.92
2	0.81
4	0.74
6	0.74

TABLE-II BASE PRESSURE RATIO – 2.38

L/D	ST
1	0.92
2	0.76
4	0.67
6	0.67

TABLE-III BASE PRESSURE RATIO – 2.65

L/D	ST
1	0.91
2	0.75
4	0.62
6	0.62

TABLE-IV BASE PRESSURE RATIO – 2.93

L/D	ST
1	0.92
2	0.75
4	0.59
6	0.56

TABLE-V BASE PRESSURE RATIO – 3.48

L/D	ST
1	0.92
2	0.74
4	0.52
6	0.42

1) Total Pressure Loss Data For Mach 2.4 And Area Ratio 2.89

TABLE-VI TOTAL PRESSURE LOSS AT PRESSURE RATIO – 2.10

L/D	ST
1	39.3
2	49.77
4	50.34
6	50.7

TABLE-VII TOTAL PRESSURE LOSS AT PRESSURE RATIO – 2.65

L/D	ST
1	47.54
2	59.06
4	59.8
6	62.2

TABLE-VIII TOTAL PRESSURE LOSS AT PRESSURE RATIO – 3.48

L/D	ST
1	58.17
2	40.37
4	65.7
6	67.91

[All experimental data are taken from Ph.D. thesis of Pandey, K.M., 1994, Studies on flow through nozzles with sudden expansion, Department of Mechanical Engineering, IIT Kanpur, India for the purpose of nanalysis.]

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