ANALYSIS OF SD OF 3D NOZZLE DESIGN IN CFD

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Abstract—* *The standard deviation of the three dimensional nozzle designs were compared to their respective 2D standard deviations to get the best design which produces more uniform mach number of the ideal gas that comes out. The standard deviation of the nozzle model 3 is the least. But comparing to 3 dimensional nozzles model 2 has significant reduction in standard deviation, approximately 31% reduction. Hence it was concluded that the nozzle model 8 which was designed for producing Mach number 3 was the most efficient nozzle which produces maximum uniformity at the nozzle exit.

Index Terms—Mach number, Nozzle Model 8, Nozzle Throat

I. INTRODUCTION

A gas turbine is a rotating machine that uses the action of fluid to produce work. In gas turbine a pressurized, high temperature gas is the driving force. For electrical power generation and marine applications, it is generally called a power turbine. For aviation purposes, it is usually called a gas generator. One of the reasons that gas turbine engines are widely used to power aircraft is they are light and compact and have a high power-to-weight ratio. Gas turbines are used to power aircrafts, helicopters, trains, ships, electrical generators, or even tanks.

Inlet Compressor Shaft Burner Turbine Nozzle

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in-between. Fresh atmospheric air flows through a compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor and other devices such as an electric generator that may be coupled to the shaft. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity. The purpose of the gas turbine determines

the design so that the most desirable energy form is maximized.

A nozzle is a device designed to control the characteristics of a fluid flow (especially to increase velocity). A nozzle is often a pipe or tube of varying cross sectional area. Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them. In a nozzle velocity of fluid increases on the expense of its pressure energy.

A propelling nozzle converts a gas turbine into a jet engine. Energy available in the gas turbine exhaust is converted into a high speed propelling jet by the nozzle. Turbofan engines may have an additional and separate propelling nozzle which produces a high speed propelling jet from the energy in the air that has passed through the fan.

Propelling nozzles may have a fixed geometry, or they may have variable geometry to give different exit areas to control the operation of the engine when equipped with an afterburner or a reheat system. When afterburning engines are equipped with a C-D nozzle the throat area is variable. Nozzles for supersonic flight speeds, at which high nozzle pressure ratios are generated, also have variable area divergent sections.

A nozzle operates by using its narrowest part, or 'throat', to increase pressure within the engine by constricting airflow, usually until the flow chokes, then expanding the exhaust stream to, or near to, atmospheric pressure, while forming it into a high speed jet to propel the vehicle. The fundamental concept in which a nozzle works is continuity equation. Mass is conserved in the whole process.

The energy to accelerate the stream comes from the temperature and pressure of the gas. The gas expands adiabatically with low losses and hence high efficiency. The gas accelerates to a final exit velocity which depends on the pressure and temperature at entry to the nozzle, the ambient pressure it exhausts to, and the efficiency of the expansion. Christo Ananth et al. [4] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

Air breathing engines create forward thrust on the airframe by imparting a net rearward momentum to the air by producing a jet of exhaust gas which has a speed that exceeds that of the aircraft with a help of a nozzle.

II. EXISTING SYSTEM

In [1], some experiments in which planar laser induced fluorescence (PLIF) of nitric oxide (NO) was used to measure vibrational and rotational temperatures. The experiments took place in a small shock-tunnel facility, which is an impulse facility that can generate the pressures and stagnation enthalpies required for simulation of hypersonic atmospheric re-entry flows. Good agreement between measured rotational temperature and a non-equilibrium one-dimensional nozzle calculation was demonstrated. The measured vibrational temperatures were higher than the computed value, although they exhibited the expected vibrational freezing behaviour. This disagreement was attributed to non-linearities in the imaging system and non-uniformity in the flow. The non-uniformities were assumed to be due to contamination by driver gas and were found in 32% of the images.

[2] showed that moderate non-uniformities in the flow properties leaving the combustor and entering a supersonic nozzle had effect on thrust produced by the nozzle. Later, Doty et al. studied non-uniform profiles which were more severe and consequently had more influence on nozzle performance. Christo Ananth et al. [4] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

III. PROPOSED SYSTEM

In order to create the nozzle shapes, first the design parameters are to be considered. In this project nozzle shapes are optimized for mach numbers 2, 3 & 4. Hence 4 design shapes are created for each Mach number, totally 12 nozzle designs. The nozzle type designed in this project is conical type. Considering the A/A* ratios mach number 2 & 3 from the isentropic flow of perfect gas tables, the range in which the nozzle design parameters vary are given below (Table 4.1).

TABLE I
RANGE OF INPUT DESIGN PARAMETERS

INPUTS	RANGE OF VALUES
x- location of the inlet (Xi)	-19 to -2 m
x- location of the exit (Xe)	2 to 140 m
nozzle inlet radius (Ri)	1.5 to 2 m
nozzle exit radius (Re)	1.5 to 11 m
nozzle inlet wall slope (alpha_i)	-14 to -3 °
nozzle exit wall slope (alpha_e)	3 to 15°
nozzle throat radius (Rt)	1m

The data in Table I gives the range of input design parameters of the nozzle to be designed and optimized. The location of inlet from the throat varies from 2 to 19 m. The location of outlet from the throat varies from 2 to 140 m. The length of the nozzle depends upon the convergent and divergent section angles. The nozzle inlet radius varies from 1.5 to 2 m. The nozzle exit radius varies from 1.5 to 11 m. The inlet & exit radius depends upon the A/A* ratio for each Mach number. The nozzle inlet wall slope varies from -14 to -3 °. The nozzle exit wall slope varies from 3 to 15°. The nozzle throat radius is fixed as 1m. These input parameters are represented in the below Fig.1.

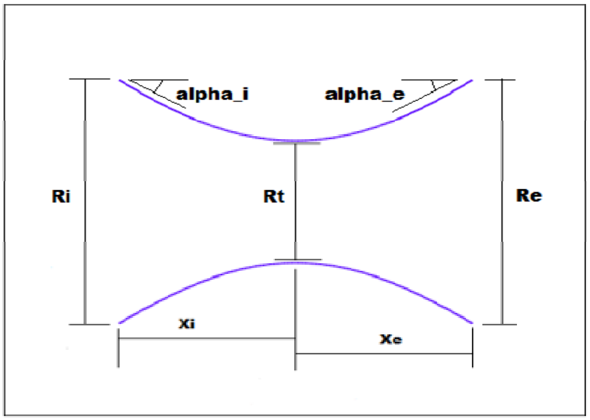

Fig.1. Representation of Input Parameters

The solution is initialized to compute from the domain inlet. And the maximum number of iteration needed to get the solution converged is set. The maximum number of iteration set in this work is 100000 iterations. Then the Ansys-Fluent is allowed to calculate the solutions by iteration process. All the 12 models were solved for the solutions and results were saved. An example of convergence history is shown in Fig.2. below.

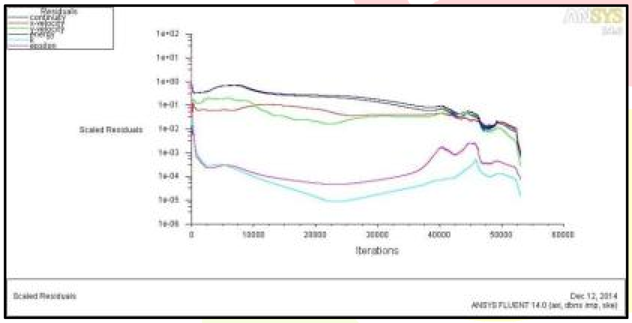

Fig.2. Convergence History

Now the plots were carefully analysed for all the 12 nozzle design for various Mach numbers, it was observed that there was significant variation in Mach number as the flow nears the wall of the nozzle. So in order to obtain a nozzle design which has more uniformity of Mach number at the exit, it was decided to find the standard deviation of the mach numbers at the exit. Christo Ananth et al. [5] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

TABLE II
MACH NUMBER STANDARD DEVIATION

DESIGN No.	MACH NUMBER	AVERAGE MACH NUMBER	SD
1	2	2.16	0.1084
2	2	2.25	0.0523
3	2	2.19	0.0489
4	2	2.17	0.0589
5	3	3.05	0.3425
6	3	3.16	0.2542
7	3	3.19	0.2169
8	3	3.22	0.2121
9	4	3.49	0.7981
10	4	3.17	1.0295
11	4	3.35	0.9996
12	4	3.43	0.9782

In statistics, the standard deviation (SD) is a measure that is used to quantify the amount of variation or dispersion of a set of data values. A standard deviation close to 0 indicates that the data points tend to be very close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values. It is represented by the Greek letter sigma (σ). Table 5.1 shows the SD of mach numbers of all the 12 nozzle designs.

From the Table II, it was observed that all the nozzle designs produced Mach numbers slightly greater than their design mach number. An approximate error of 10% was found. It was also observed that as the mach number increased from 2 to 4 the values of standard deviation too increased. Even though the standard deviations had significant values, in order to get an efficient nozzle a design was choose among which had the least standard deviation. Christo Ananth et al. [5] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

From the Table II it was observed that for Mach number 2, design 3 had the least SD value of 0.0489 which is near to zero. Hence it would produce a more uniform mach number at the exit. Similarly it was observed that for Mach number 3, design 8 had the least SD value of 0.2121 which is slightly above zero. Hence it was known that design 8 produced more uniform mach number at exit among the other designs. Moreover it was also observed that for Mach number 4, the values of SD started to deviate a lot, however design 9 had the least SD value of 0.7981 among others which is close to zero.

Hence it was concluded that designs 3, 8, 9 was producing more uniformity at the exit. In order to verify the results even more for accuracy, it was planned to develop these three designs in 3D and then again simulate them to get the mach number solutions. This is discussed in the next chapter.

IV. CONCLUSION

The standard deviation of the three dimensional nozzle designs were compared to their respective 2D standard deviations to get the best design which produces more uniform mach number of the ideal gas that comes out. The standard deviation of the nozzle model 3 is the least. But comparing to 3 dimensional nozzles model 2 has significant reduction in standard deviation, approximately 31% reduction. Hence it was concluded that the nozzle model 8 which was designed for producing Mach number 3 was the most efficient nozzle which produces maximum uniformity at the nozzle exit.

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