



DESIGN , FABRICATION AND FLOW VISUALIZATION OF A BLOW DOWN SUPERSONIC WIND TUNNEL

R.Ajay Kishore¹, G.M.Deepak Venkataramana², V.Sriram³, N.Tamilmani⁴.

^{1,2,3,4}-Student, Department of Aeronautical Engineering, KCG College of Technology,
Chennai 600097, India

ABSTRACT

The report deals with the design, fabrication and visualization of a miniature two dimensional wind tunnel having the minimum possible length for the divergent portion and visualizes the shock patterns using shadowgraph. The short nozzles also called as “sharp throat nozzles” are widely used in space launching rockets and missiles technology. The specialty of these nozzles is that the flow is made to expand fully at the throat so that the length of the divergent portion is reduced. This reduction in length reduces the weight of the nozzle which plays the main role in the performance and efficiency of rockets and missiles. The contour nozzle used for this experiment has design Mach number 2.0. The contour of the divergent portion has been designed by the method of characteristics using MATLAB and fabricated using Vertical Machining. The contraction portion has been designed by the Bell and Mehta’s Fifth degree Polynomial using MATLAB. The flow pattern at the exit of the nozzle is captured by using shadowgraph system.

Keywords- Supersonic, nozzle, design, fabrication, contour, shadowgraph

Introduction

Supersonic nozzle is a passage used to transform pressure energy into kinetic energy and delivering flow at supersonic speeds. It needs a combination of convergent and divergent nozzle (C-D or De Laval Nozzles). To deliver a supersonic flow at the desired Mach number, the flow should be wave free and parallel. An improper contour results in the formation of finite shocks inside the nozzle by coalescence of weak waves and can prevent a uniform flow. The Method of Characteristics (MOC) provides a technique for properly designing the

contour of the supersonic nozzle. In applications like rockets and missiles, nozzles are comparatively shorter than in the wind tunnels. In wind tunnel they have a smooth, gradually expanded divergent portion for delivering a high-quality, uniform flow required in the test section which is done in order to minimize weight. In such cases the expansion portion of the nozzle is shrunk to a point, and the expansion takes place through a centered Prandtl-Meyer wave emanating from a sharp-corner throat called as “sharp-throat characteristics nozzle” or “short nozzles”.

In the literature, a lot of experimental, theoretical and analytical studies on the flow through supersonic nozzles can be found. Among them Jay Pascual made the initial and basic calculations[1]. The design and fabrication of a indraft supersonic tunnel with a run time of atleast 2 minutes and optical access for the test section of the tunnel was done by Peter Moore[2]. The report details the process of determining critical dimensions (throat area and expansion ratio), estimating the attainable test duration, and design of a supersonic nozzle to minimize shocks in the test section.

Prof. Alberto Guardone [3] in collaboration with the University of Glasgow designed a small intermittent transonic wind tunnel. The study has been focused on an innovative Mach number regulation system based on a combined use of a test section shaped wall and a wedge before the diffuser. A numerical model has been then validated with reference to experimental results obtained in a similar facility. The efficiency of the new chocking system, compared to the existing ones, has been demonstrated by the simulations. Dimitri Papamoschou[4] made investigation of supersonic nozzle flow separation with the help of Schlieren set up. The flow lasted for almost 15 secs.

The computational anlysis was done by E.M.S Ekanayake[5] in Flow simulation of a two dimensional rectangular supersonic convergent divergent nozzle with two different exit to throat area ratios, at different angles and at different Nozzle pressure ratio's.

Design of Supersonic Wind Tunnel

A 2-D Supersonic Wind tunnel designed for Mach number 2.0 is used as the experimental model and the same has been used to perform the Shockwave studies. This tunnel includes the design of diffuser, settling chamber and the convergent divergent nozzle.

Design of Supersonic nozzle

A convergent – divergent nozzle designed for Mach number 2.0 and to have shock free flow in the divergent part is fabricated .To have a shock free flow the nozzle pressure ratio is to be maintained at 0.1278.

Design of convergent portion

The contraction, from supply section to the throat, must be in such a shape that the air is uniformly accelerated and to ensure that the pressure decreases monotonically without any adverse pressure gradient or accrues of separation. This can be achieved by changing the curve smoothly.

Area ratio method was followed to design the convergent portion.Using isentropic relations the throat area and the inlet area ,for an outlet area of 400mm^2 and mach no. 2, was determined as 237mm^2 and 2000mm^2 respectively. In order to keep the Tunnel as 2-D the width of the entire setup was determined to be 20 mm.Now by excluding the width the height at the throat and the inlet was obtained as 11.8mm and 100mm respectively.

The length and the curve for the convergent section was obtained using Bell and Mehta 5th degree polynomial.A MATLAB code was written for obtaining the curve using the polynomial.The length was fixed by trial and error method by keeping a number of length / heighth ratio's.It was later seen that the subsonic flow was uniform and streamlined for the ratio's 0.8 to 1.45.Based on this a ratio of 1.43 was chosen and the length obtained was 143mm.

The convergent portion of the nozzle before the throat was kept straight for a length of 3mm, in order to aid in expansion at the corner of the throat.

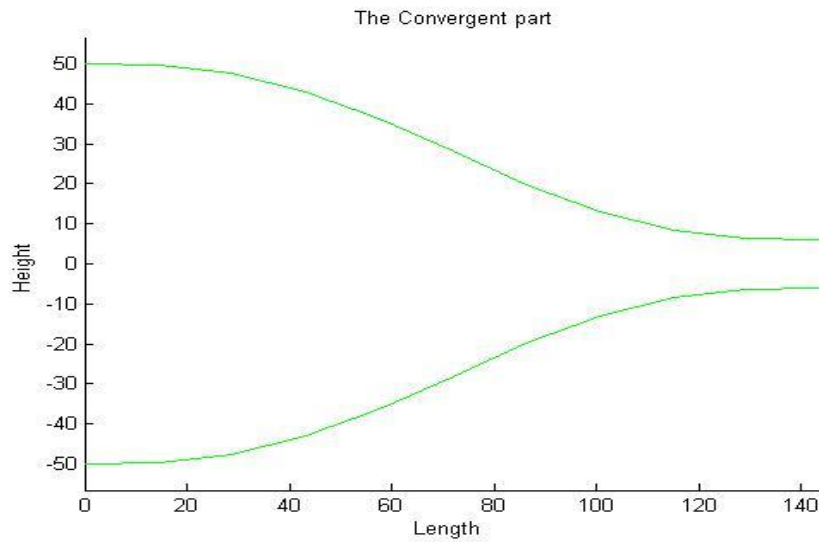


Fig. 1 : Design of convergent portion

Table 1: Convergent Portion X and Y Values

X Values in mm	Y values in mm
0	50
14.3	49.6225
28.6	47.44573
42.9	42.80817
57.2	36.0009
71.5	27.95
85.8	19.8991
100.1	13.09183
114.4	8.45427
128.7	6.2775
143	5.9

Design of Contour Nozzle Divergent Portion

The method of characteristics provides a technique for properly designing the contour of supersonic nozzle for shock-free, isentropic flow, taking into account the multidimensional flow inside the duct and the minimum length factor of the nozzle. The length of this nozzle obtained was the minimum length possible for shock-free, isentropic flow.

The region-to-region 2D inviscid MOC was employed for designing the contour of the divergent portion for a sharp-cornered nozzle. The boundary layer correction was also considered. The contours for the divergent portion had been designed using the codes written in MATLAB which had been verified with the values of the design of a contour nozzle by Dr.E.Rathakrishnan[6].

The code written in MATLAB obtains inlet mach no. , outlet mach no. , test section area ,gamma and the difference between the mach lines from the user and gives the output with X and Y axes values of contour with the area ratio, mach no. , the Prandtl Meyer value at each and every point locations.

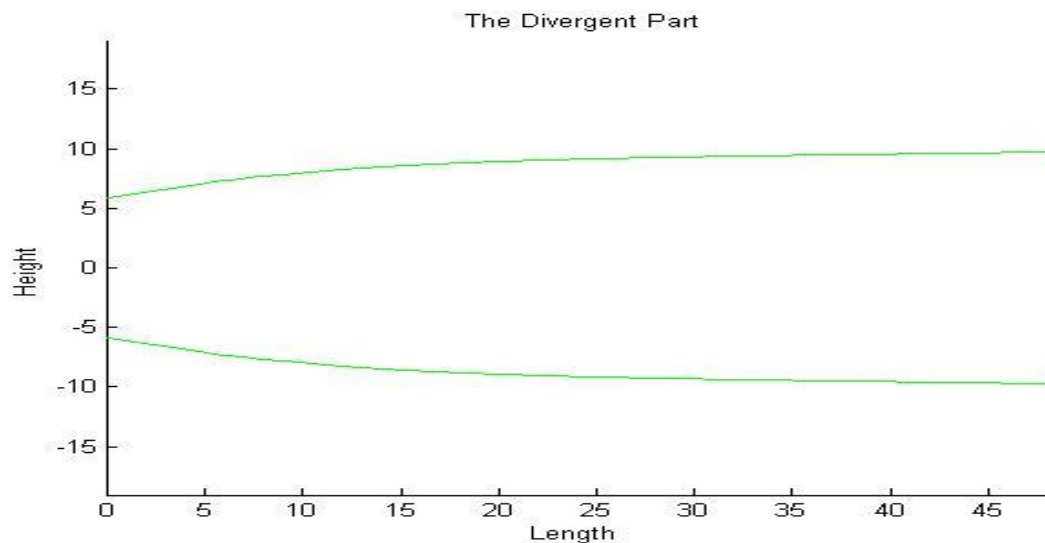


Fig. 2 : Design of divergent portion

Table 2: Divergent portion X and Y values

X Value in mm	Y value in mm
0	5.924
5.22754	7.149134
5.348873	7.177146
6.067264	7.329845
6.898859	7.491491
7.868447	7.662455
9.009311	7.84315
10.367476	8.034028
12.009004	8.235582
14.033361	8.448351
16.600166	8.672917
19.989378	8.909914
24.76179	9.160025
32.320794	9.423992
48.282943	9.702612
55	10

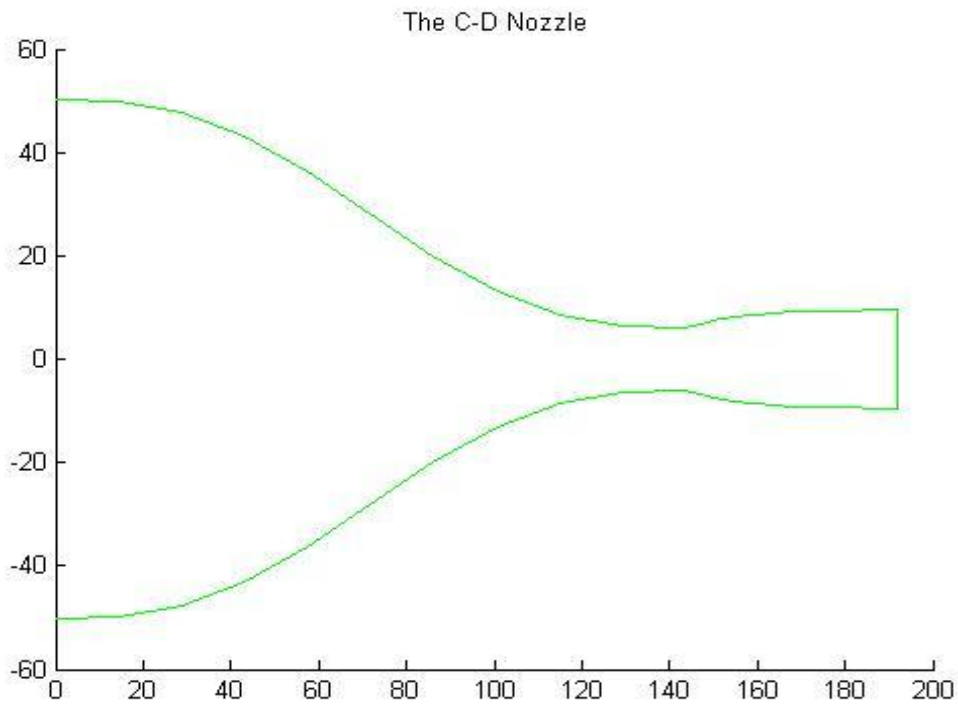


Fig. 3 : Design of contour nozzle

Analysis of Contour Nozzle :

In order to validate the design CFD analysis is done on the contour nozzle using Fluent14.0 software and the following comparisons and results are obtained.

General	Solver type: Density based, 2D ,planar
Models	Energy equation :ON, Viscous model k-ε model, Realizable, enhanced wall treatment.
Materials	Density :ideal gas $C_p=1006.43 \text{ J/Kg-K}$ Viscosity = $1.784e^{-5} \text{ Kg/m s}$ thermal conductivity= 0.0242 W/Mk Molecular weight= 28.966 Kg/Kgmol
Boundary Conditions	Inlet pressure =8 bar Inlet temperature= 303K Outlet pressure=1.2bar Outlet temperature=168K
Solution controls	Courant number=5
Solution initialization	Compute from :inlet

The comparison between theoretical and analytical values were given below

Section of nozzle	A/A*	Pressure		Temperature		Mach no.	
		Theoretical	Analytical	Theoretical	Analytical	Theoretical	Analytical
Convergent	7.26	8	7.6	303	295	0.08	0.06
Throat	1	4.22	3.7	253	239	1	1
Outlet	1.68	1.02	0.86	168	160	2	2.00

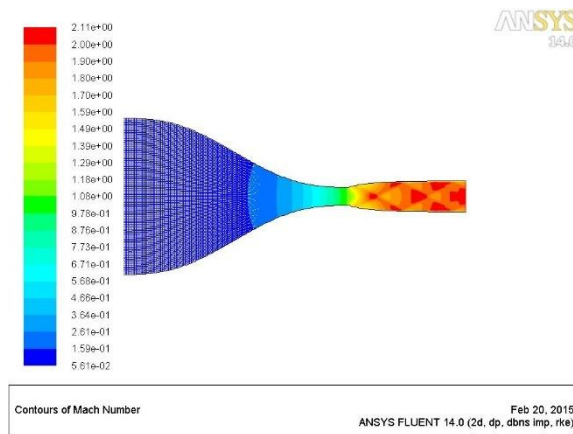


Figure 4 Contours of Mach number

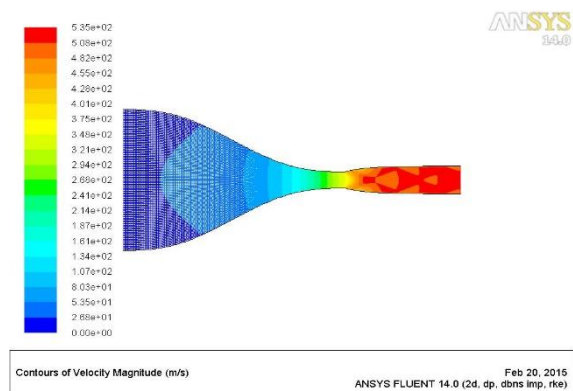


Figure 5 Contours of Velocity Magnitude (m/s)

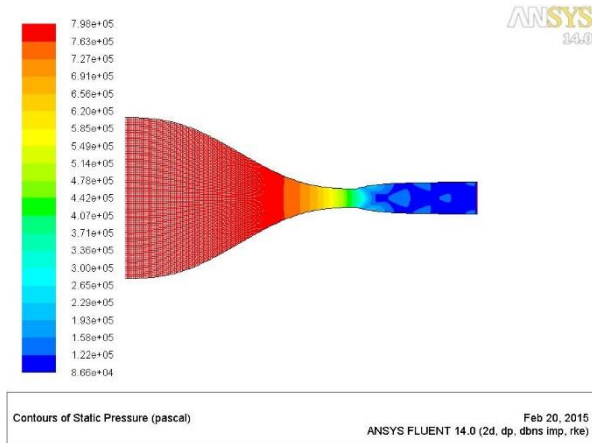


Figure 6 Contours of Velocity Magnitude (m/s)

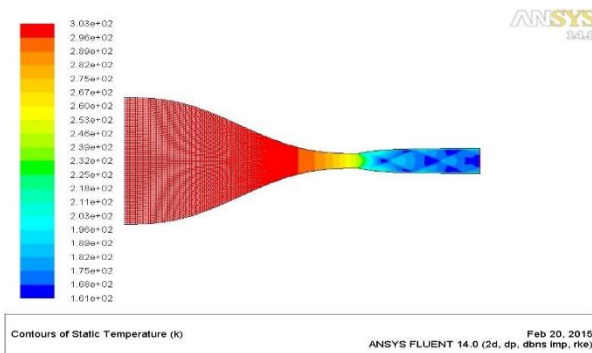


Figure 7 Contours of Static Temperature (k)

Fabrication of Nozzle

The 2-D design of the nozzle is used in the Vertical Machining system and the codes for the machining is generated.

The material used is Aluminum 6061 for the nozzle part. The machining is done on two Aluminum bars of 20 mm in width, thereby maintaining the width of the setup.

Then machined pieces are then placed apart from each other in such a way that the required heights at the inlet, throat and the outlet are obtained.



Figure 1 C-D Nozzle Front view



Figure 9 Surface finish of C-D Nozzle

Experimental Set-up

Air supply system:

An air compressor with a maximum range of 12 atmospheres (175 psi) was used as the air supplier. In order to increase the run time a reservoir of 0.6m³ was added to the air supply system.

Diffuser:

Basically, diffuser is a passage in which the flow will decelerate. Designing of the diffuser was most difficult and important. In order to have a proper flow into the settling chamber for maintaining the stagnation pressure, for the prevention of the losses and to maintain the setup to be 2-D, two diffusers are made.

The first diffuser is done to change the circular section to a square section and this change is done gradually in order to maintain the proper flow.

The second diffuser is a square to rectangular section diffuser which acts as a normal diffuser.

Settling Chamber:

The section area of the settling chamber is designed by evaluating the flow velocity in it in order to avoid big losses of pressure. The settling chamber is of rectangular cross section of 100mm*20mm over a length of 250mm.

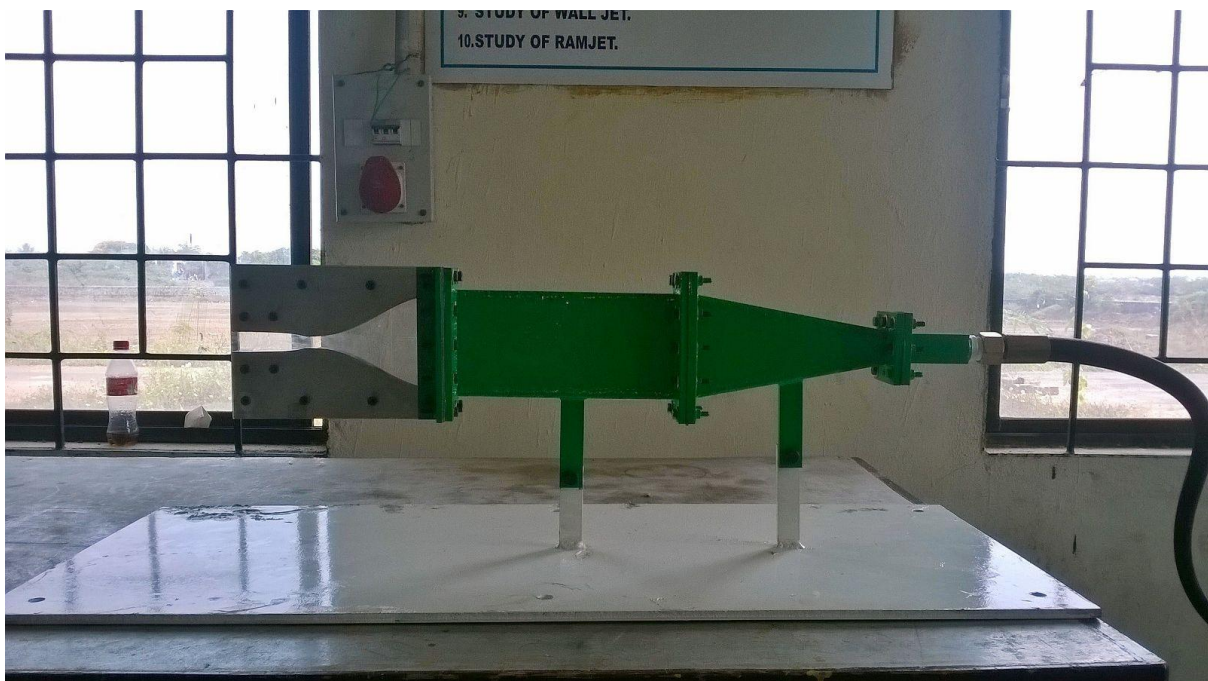


Figure 10 Supersonic Wind tunnel

Visualization Technique:

The shadowgraph technique is used to visualization the shocks clearly due to the pressure difference between the exit pressure and the atmospheric pressure. In the current work,

Mercury vapor lamp was used as the source of light for the shadowgraph setup since it is very powerful and provides parallel beam of light.

Experimental Procedure

The 2-D miniature supersonic wind tunnel was setup as shown in the fig 10. In order to capture the shock propagation starting from the divergent portion of the nozzle, it was mandatory to make the sides of the nozzle as transparent. At the same time it has to withstand the pressure therefore plexi glass was used.

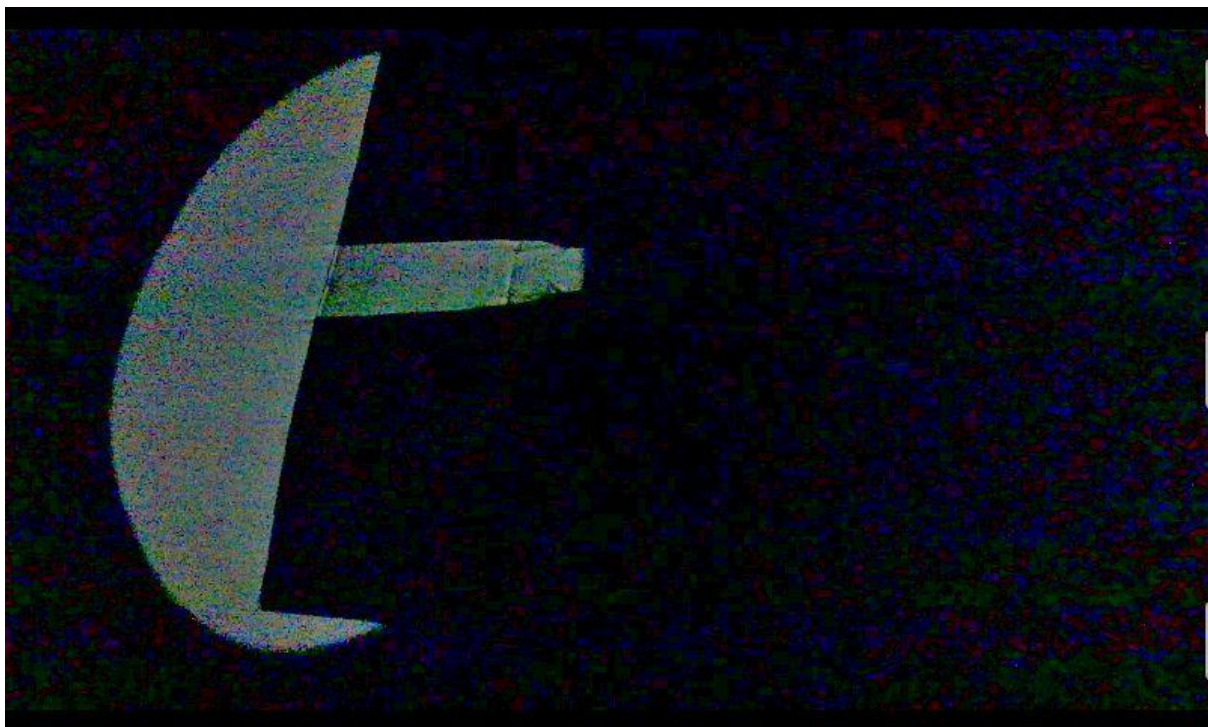


Figure 11 Shock wave visualization [NPR 4]

Conclusion

Thus a supersonic wind tunnel was fabricated as per the design characteristics and flow visualization was done using shadowgraph technique. This could be extended by designing a second throat thereby decreasing the inlet pressure, measuring the wall pressure in the nozzle part, etc apart from these few more tests can be done in this tunnel thereby making a perfect miniature super sonic wind tunnel.

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