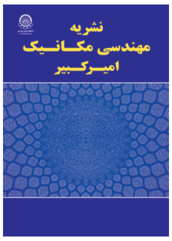

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Hypersonic Wind Tunnel Diffuser Design Based on Numerical Analysis of Flow Field

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ABSTRACT: The design of a fixed geometry hypersonic wind tunnel diffuser is presented for Mach numbers of 5, 6 and 7. The design is based on the development cost reduction and minimizing the pressure ratio for stable flow in test section. The conceptual design is done based on statistical nondimensional geometrical data of existing hypersonic wind tunnels. In the preliminary design, the optimum value of each geometrical parameter is determined by using computational fluid dynamics. The diffuser isentropic efficiency is used as the design criterion. Finally, the geometry with the highest possible efficiency is obtained for highest tunnel run time.

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1- Introduction

The diffuser recovers fluid static pressure from kinetic energy of the fluid flow. In hypersonic wind tunnels, this is achieved by using the combination of a convergent duct followed by a throat and then by a divergent duct. In convergent section, the pressure recovery is achieved by oblique shock waves that have lower total pressure loss compared to normal shock waves. In the throat, the reflection of oblique shock waves is continued and finally a subsonic flow is achieved after a weak normal shock wave in the divergent section. In another word, in the last section of the diffuser, the flow becomes fully compressed and static pressure is increased and in the diffuser output section, the total pressure is approximately equal to the ambient pressure.

Because of the complexity of the flow in hypersonic wind tunnel diffuser, there are a few references in the literature [1-3]. Following this complexity, the analytical relations and engineering codes cannot accurately predict the flow characteristics in the diffuser. Nowadays, the Computational Fluid Dynamics (CFD) is one of the best tools to analyze the flow in the hypersonic wind tunnel diffuser.

In the present work, at first, the basic dimensions of diffuser are obtained by using the collection of statistical geometric data of the existing hypersonic wind tunnels. Then the geometrical parameter optimization is done by using CFD.

Because of the lack of boundary conditions and for accurate solution, in the present research as shown in Fig. 1, the total wind tunnel circuit from nozzle to diffuser is modelled.

The axisymmetric basic configuration is modelled and then by fractional change in diffuser geometrical parameters, the optimum values of each parameter is achieved. The diffuser isentropic efficiency is used as the design criterion of diffuser geometrical parameters.

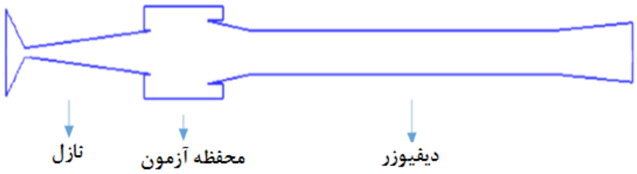

Figure 1. The wind tunnel components modelled in the present research

2- Equations

Navier-Stokes equations are solved to simulate the flow in the wind tunnel circuit from nozzle to diffuser by using the k-ω SST as the turbulence model [5].

Isentropic diffuser efficiency is used to evaluate the performance of the diffuser as follow:

$$\eta_i = \frac{2}{\gamma - 1} \cdot \frac{1}{M_1^2} \cdot \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \qquad (1)$$

A complete grid independency test is done and the final grid is selected based on the solutions accuracy. In the selected grid, the y^+ value on the diffuser walls is always less than 1.5.

3- Conceptual Design Based on Statistical Studies

In the process of statistical study, data from references [5-13] are used.

According to the design requirements [14], the diffuser inlet diameter is 725 mm. Therefore, all parameters become dimensionless based on the diameter of the diffuser inlet.

Primary diffuser dimensions, according to statistical process

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Corresponding author, E-mail: mhadidoolabi@mut.ac.ir are presented in Table 1.

Table 1. Initial designed diffuser dimensions (in mm)

Mach	d_1	l_1	d_2	l_2	d_3	l_3
5	725	690.78	500.468	4823.4	683.17	1243.6
6	725	823.6	495.465	5074.2	671.2	1365.75
7	725	956.42	490.46	5324.98	659.24	1487.92

4- Diffuser Design on Basis of Parametric Study and Numerical Analysis

By changing any components of the diffuser as shown in Fig. 2, changes in the efficiency of the diffuser is obtained respectively. Final dimensions of diffuser are shown in Table 2.

Figure 2. The introduction of the components being designed diffuser

Table 2. Final dimensions of diffuser (in mm) in Mach number of 5, 6 and7

Mach	d_1	l_1	d_2	l_2	d_3	l_3
5	725	690.78	500.468	4823.4	683.17	1243.6
6	725	823.6	495.465	5074.2	671.2	1365.75
7	725	956.42	490.46	5324.98	659.24	1487.92

5- The ultimate performance in a maximum reduction in the pressure diffuser

Variation of pressure ratio associated as a function of diffuser efficiency is presented in Tables 3 to 5.

Table 3. Effect of pressure ratio on efficiency at Mach number 5

Pressure ratio	Efficiency	Percent of efficiency change
40	0.2981488	0
22	0.3332409	11.7699
18	0.3503466	17.5073
17.5	0.3543681	18.8561
17	Shock in Test Section	------

Table 4. Pressure ratio in a tapered nozzle with Mach number of 6

Pressure ratio	Efficiency	Percent of efficiency change
130	0.24679	0
80	0.23801	-3.55663
50.00	0.26492	7.34648
40	0.28360	14.9141
38.00	0.28956	17.3313
35.00	Shock in Test Section	-------

Table 5. Effect of pressure ratio on efficiency at Mach number 7

Pressure ratio	Efficiency	Percent of efficiency change
290	0.218400977	0
140	0.212630158	-2.642304745
70.00	0.251896176	15.33656089
65	0.259257323	18.70703444
60.00	Shock in Test Section	--

6- Conclusions

Simultaneous use of statistical information, analysis of the flow using CFD, geometry correction and determining efficiency at every stage is the perfect solution for achieving maximum diffuser efficiency. By using this process the geometry of a diffuser is designed for Mach numbers of 5, 6 and 7. Mach contours are shown in Figs. 3 and 4, respectively.

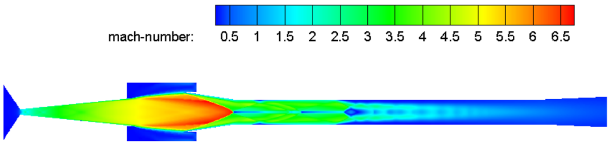

Figure 3. Mach contour in designed wind tunnel for Mach number 5 in the pressure ratio of 17.5

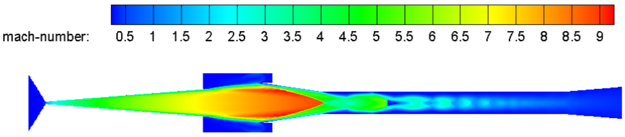

Figure 4. Mach contour in designed wind tunnel for Mach number 5 in the pressure ratio of 17.5

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