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Orifice Inlet효과에 의한 이젝터 성능에 관한 수치해석적 연구

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Numerical Investigation of the Effects of an Orifice Inlet on the Performance of an Ejector

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ABSTRACT

Supersonic ejectors are simple mechanical components, which generally perform mixing and/or recompression of two fluid streams. Ejectors have found many applications in engineering. In aerospace engineering, they are used for altitude testing of a propulsion system by reducing the pressure of a test chamber. It is composed of three major sections: a vacuum test chamber, a propulsive nozzle, and a supersonic exhaust diffuser. This paper aims at the improvement of ejector-diffuser performance by focusing attention on reducing exhaust back flow into the test chamber, since alteration of the backflow or recirculation pattern appears as one of the potential means of significantly improving low supersonic ejector-diffuser performance. The simplest backflow-reduction device was an orifice plate at the duct inlet, which would pass the jet and entrained fluid but impede the movement of fluid upstream along the wall. Results clearly showed that the performance of ejector-diffuser system was improved for certain a range of system pressure ratios, where as there was no appreciable transition in the performance for lower pressure ratios and the orifice plate was detrimental to the ejector performance for higher pressure ratios. It is found that an appropriately sized orifice system should produce considerable improvement in the ejector-diffuser performance in the intended range of pressure ratios.

Key Words: Compressible Flow (압축성 유동), Internal Flow (내부 유동), Mach Number(마하수), ejector

NOMENCLATURE

D - diameter
θ - Prandtl-Meyer expansion angle
L - length of diffuser
M - Mach number
P - pressure
T - Temperature
x - axial location of orifice
γ - heat capacity ratio

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Suffixes
n,o,p - nozzle, orifice, diffuser
a,e,t - alitude, exhaust, total

1. Introduction

Supersonic ejectors are simple mechanical components, which generally perform mixing and/or recompression of two fluid streams. Ejectors have found many applications in engineering. In aerospace engineering, they are used for altitude testing of a propulsion system by reducing the pressure of a test chamber. It is composed of three major sections: a vacuum test chamber, a propulsive nozzle, and a supersonic exhaust diffuser. The fluid with highest total energy is the primary stream, while the other, with the lowest total energy is the secondary stream. The ejector system entrains the secondary flow through a shear action generated by the primary jet. When it is used to create high-vacuum levels in the secondary chamber, such as those required in high-altitude simulation tests, this is done by dragging mass from a finite secondary chamber often called as zero-secondary flow ejector (fig.1). The efficiency of such an ejector system is relatively very low, compared to other fluid transport devices driven mainly by normal forces [2]. However, its major advantage is in a simple structure with no moving parts, and it can not only compress and transport a large amount of fluid with a small driving energy, but also needs little maintenance. For these reasons, the ejector system has been extensively utilized for the thrust augmentation of V/STOL [3-4], high-altitude simulation facility [5], combustion facility [6], refrigeration system [7], natural gas generation [8], fuel cells [9], noise-control facility [10], etc.

This paper aims at the improvement of ejector-diffuser performance by focusing attention on reducing exhaust back flow into the test chamber, since alteration of the backflow or recirculation pattern appears as one of the potential means of significantly improving low supersonic ejector-diffuser performance. The simplest backflow-reduction device was an orifice plate at the duct inlet, which would pass the jet and entrained fluid but impede the movement of fluid upstream along the wall.

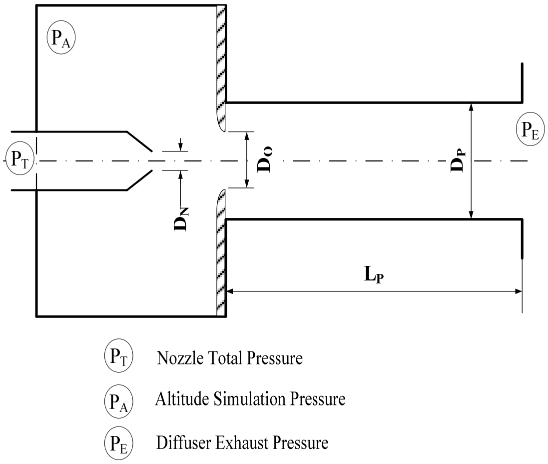

Fig.1 Schematic of vacuum ejector with inlet orifice

2. Orifice Plate Installation

The axial position of the orifice plate from the nozzle exit was estimated by assuming Prandtl-Meyer expansion from the nozzle. The orifice plate should pass completely the supersonic primary jet and entrained fluid while isolating the altitude chamber from the down stream conditions (fig.2). Owing to such shielding effect, the evacuation process is no longer affected by the ambient state, and hence the performance of the vacuum ejector system can be increased.

The primary jet and the entrained secondary jet should pass through the orifice. For the ejector with orifice system to be effective the orifice in no way should obstruct the flow of primary jet. The orifice is expected to be effective until the expanding primary jet just touches the orifice plate tip. Hence, axial position of orifice plate is a governing parameter as well as orifice size. For the present analysis, the axial position is estimated by using PM-expansion theory for an established NPR and orifice size. Although many different axial positions of orifice are possible for different NPR values, the orifice plate was placed close to the primary nozzle (using a higher NPR) with the sole intension of avoiding taking into consideration the jet curvature and hence closely follows the PM theory. Mach number at the nozzle exit is found by assuming a nozzle pressure ratio (NPR).

$$NPR = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$

The axial position, x was estimated to be 6mm from the primary nozzle exit for NPR=17.0, D_O/D_N = 1.56 with PM expansion angle(θ) of 40^0, which is calculated using the relation

$$\theta = \left(\frac{\gamma+1}{\gamma-1}\right)^{1/2} \tan^{-1}\left[\frac{\gamma-1}{\gamma+1}\left(M^2-1\right)\right]^{1/2} - \tan^{-1}\left[\left(M^2-1\right)\right]^{1/2}$$

This θ is the angle, measured from the flow direction where M = 1(primary nozzle throat), through which the flow has been turned (by an isentropic process) to reach the Mach number at the nozzle exit position.

Good agreements were found between the PM expansion angle and the actual jet turning angle, suggesting that the under-expanded axi-symmetric free-jet from the nozzle was essentially inviscid. The flows are purely laminar with no turbulence practically, inside the altitude chamber. But downstream of the nozzle choice of the turbulence model plays an important role for correctly predicting the turbulent internal flows under zero-pumping conditions.

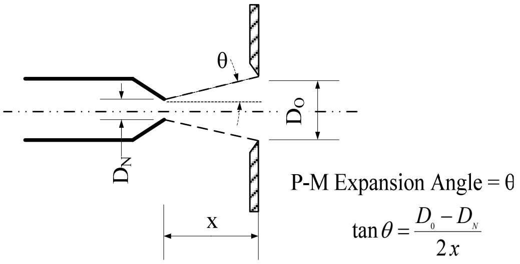

Fig. 2. Prandtl-Meyer expansion at nozzle exit

3. Computational Methodology

The governing equations are discretized using a control volume technique. Sst-kω turbulence model is best suited to predict the shock phase, strength and the mean line of pressure recovery; also it has further shown better performance in term of stream mixing. Axi-symmetric coupled implicit solver is chosen with sst-kω turbulence model for the steady simulations. Simulations were done with a single convergent nozzle of diameter 19mm with Duct-to-nozzle area ratios of 5.5 and duct length-to-diameter ratios of 5.4 with orifice plate of diameter 28mm placed at an axial distance of 6mm from nozzle exit. Schematic of vacuum ejector system with orifice plate along with the boundary conditions are shown in fig.(3).

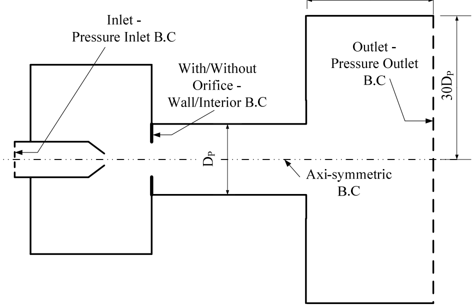

Fig. 3. Schematic of vacuum ejector with boundary conditions.

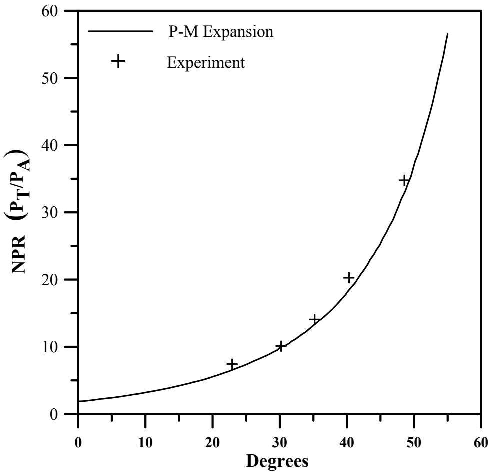

Fig. 4. Correlation between PM expansion and experiment

4. Results and Discussion

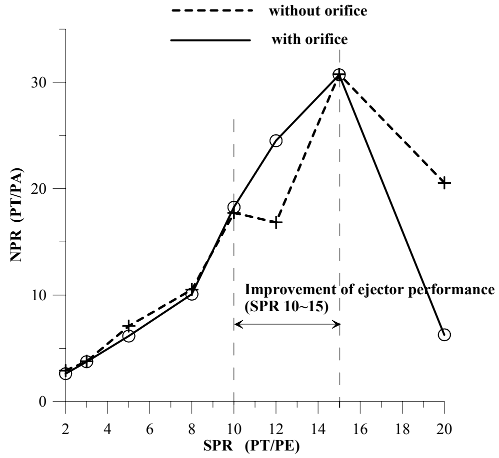

Fig. 5. Effect of inlet orifice plate on performance of straight-duct diffuser.

For low pressure ratio, the effect of orifice is barely noticeable. Both the primary jet and entrained secondary jet are passed by the orifice. It can be seen that for SPR from 10 to 15, ejector performance is increased. At pressure ratio of 10.0 the diffuser is started. The expanding sonic line attaches firmly to the diffuser wall, thus isolating the altitude simulation chamber from downstream conditions. No recirculation is observed at the inlet of the straight exhaust duct.

Maximum performance increase is for SPR=12.0. At pressure ratio of 12.0 a strong recirculation is formed at the inlet of the straight duct, due to this the entrainment is affected, hence the performance is decreased. Installation of orifice plate will shield this recirculation from the secondary fluid and hence entrainment increases for the latter case as can be seen from fig.6.

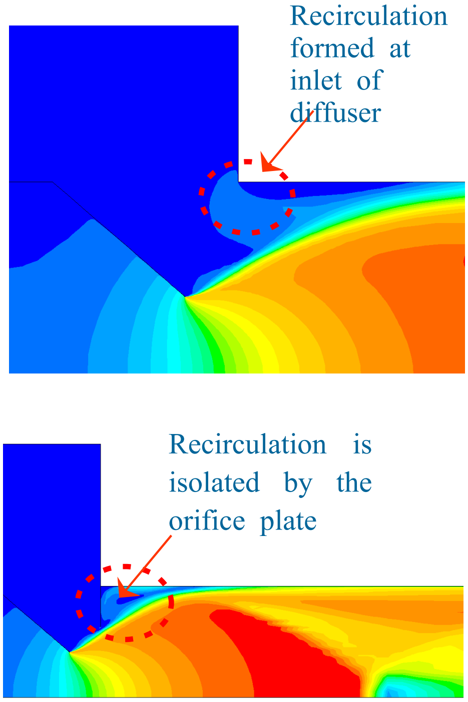

Fig. 6. Velocity vector and contour plot for vacuum ejector without/with inlet orifice

5. CONCLUSIONS

Results clearly showed that the performance of ejector system was improved for certain a range of system pressure ratios, where as there was no appreciable transition in the performance for lower pressure ratios and the orifice plate was detrimental to the ejector performance for higher pressure ratios. It is found that an appropriately sized orifice system should produce considerable improvement in the ejector-diffuser performance in the intended range of pressure ratios.

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