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Short Communication

Effect of primary jet excitation on the performance of an ejector

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Abstract

Experiments were conducted on an ejector with its plane primary jet excited by a small oscillating flap placed in the potential core region. Excitation did increase the spread of the jet as well as local mixing inside a straight rectangular ejector duct; however, there was negligible improvement in the induced mass flow as well as in thrust. On the other hand, with a diffuser attached to the rectangular duct, there was significant enhancement in ejector thrust on account of the improvement in the quality of the flow in the diffuser due to jet excitation.

Key words: Ejector, oscillating flap, induced mass flow, jet excitation.

1. Introduction

In the past two dacades, ejector technology has assumed considerable importance on account of its application to air-borne vehicles[1,2]. Thrust augmentation of a jet using an ejector could be profitably employed in the vertical take-off and landing operations of an aircraft. Special wing configurations are already being developed for the above purpose[2].

The performance of an ejector depends on many parameters, namely, the inlet area to the primary nozzle area ratio, the turbulent mixing and the diffuser efficiency. Using appropriate boundary conditions and assuming complete mixing, the overall performance of an ejector could be estimated[3]. However, ideal conditions are rarely achieved due to various constraints encountered in practice. For many practical applications, the size of the ejector is restricted especially in its length. In such designs wide angle diffusers have to be used which are very susceptible to flow separation. Incomplete mixing due to short length of the duct also adversely affects the performance of the ejector. Considerable attention has been paid in recent years to these problems and the outcome of the research is the development of hypermixing nozzle[4], the rotary flow augmentor[5] and the Alperin jet diffuser ejector[6]. In all these devices, emphasis is laid on increasing turbulent mixing. Alperin, in addition to mixing, employs tangential blowing to enhance diffuser efficiency.

Recent experiments on unsteady jets have indicated that the mixing characteristics of a jet could be enhanced in a simple manner by exciting the flow with a tiny oscillating flap placed in its potential core region[7,8]. Significant increase in the spread of the jet as well as in the entrainment of the surrounding fluid could be achieved using this method which requires only a small amount of input energy for excitation, compared to the kinetic energy of the issuing jet. It is envisaged that the above technique could be employed in an ejector system, in a beneficial manner. The aim of the present experiment is towards this goal.

2. Experimental set-up

The details of the ejector set-up are shown in fig.1. The primary jet assembly consisted of a large cylindrical settling chamber of 10 cm dia and 20 cm length which was attached to a straight nozzle of 20 × 0.9 cm opening. It was enclosed in a shroud with a converging section followed by a short length of parallel duct and a diffuser. The span of the ejector was 20 cm. Two sets of diffusers were employed in this experiment: (a) 61 cm long diffuser whose half-angle (θ) could be varied from 0 to 30° (short diffuser) and (b) a pair of fixed angle diffusers 4.5° and 7°, each 124 cm long.

The ejector shroud was mounted in a cradle like fashion using a four-bar parallelogram suspension system while the main jet was independently attached to a cantilever strut firmly fixed to the ground. A sensitive transducer was used to measure the displacement of the shroud which was proportional to the horizontal force acting on it. The thrust of the primary jet was measured directly using a load cell. A number of static pressure holes were provided at suitable intervals all along the length of the ejector and were connected

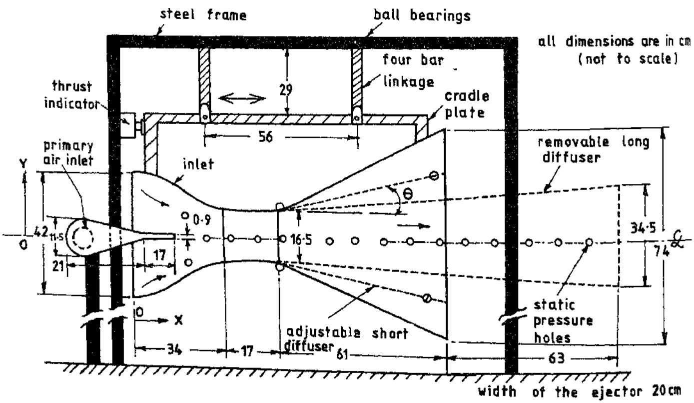

FIG 1. Ejector test rig mounted on cradle.

to a multitube water manometer. The mean velocity profiles were measured employing a pitot rake.

The jet was excited by the self-induced oscillations of a 1 mm thick, 6 mm wide elastic membrane of rubberised cloth stretched along the entire length of the nozzle and placed at a distance of 5 mm downstream of the exit. By adjusting the tension of the membrane, the oscillating frequency of the membrane could be varied to some extent. In the present experiment, the amplitude and frequency of the oscillations were 4 mm and 62 Hz respectively.

3. Results

In all the experiments, the jet was operated at a total pressure (P_O) of 0.35 kg/cm^2 gauge. For this condition, the thrust of the jet (T_1) was 2.7 Newton and the exit velocity of the jet was 190 m/sec.

The first set of experiments were carried out with the short diffuser whose half-angle could be varied from 0 to 30°. For $\theta = 0°$ without jet excitation, the velocity profile at the exit ($x = 51$ cm) of the diffuser was symmetric, with respect to $y = 0$; however, it was far from being uniform (fig. 2), the velocity at the centre was 45 m/sec. With increase in diffuser angle to $\theta = 2.3°$ the flow exhibited tendency towards incipient separation as can be seen from the mean velocity profiles (fig. 3). A further increase in θ to 6.3°, resulted in the flow attaching to one side of the diffuser, the mean velocity profile exhibiting a high degree of asymmetry (fig. 4).

The thrust exerted by the ejector with the short diffuser was measured for four values of θ namely 0°, 2.3°, 4.0° and 6.3° with the jet in the steady state (fig. 3). For $\theta = 0°$, the

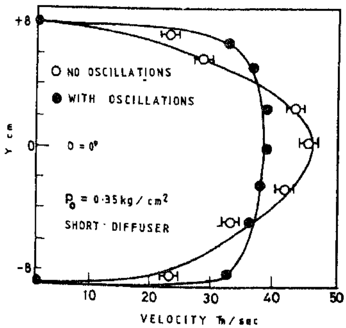

Fig 2. Mean velocity profiles at the exit of the diffuser $\theta = 0°$.

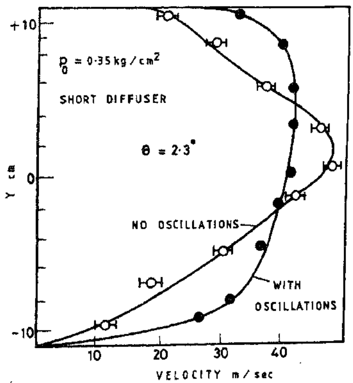

Fig 3. Mean velocity profiles at the exit of the diffuser ($\theta = 2.3°$).

thrust augmentation ratio (ϕ) was 1.40. A maximum of $\phi = 1.50$ was obtained for $\theta = 4°$. Beyond this angle, there was a decrease in ϕ.

With the introduction of the flap in the system, the oscillations produced by it, had marked effect on the diffuser flow. This effect was found to be nearly independent of the frequency of flapping (f) as well as the amplitude of oscillations (S) provided f and S were above 15 Hz and 2 mm respectively. In all the experiments in the present investigation, $f = 62$ Hz and $S = 4$mm. For $\theta = 0°$, there was no increase in the value of ϕ when excitation was introduced. However, the mean velocity profile at the exit became nearly uniform with a centre velocity of 36 m/sec, different from that observed with a steady jet (fig. 2). A somewhat similar trend was noticeable for the case of $\theta = 2.3°$ (fig. 3). The thrust augmentation ratio for the above angle increased to 1.65. In the case of $\theta = 6.3°$, excitation of the main jet did increase ϕ; however, the value was not higher than for $\theta = 2.3°$ and the mean velocity profiles at the exit of the diffuser were somewhat unsymmetrical but significantly improved over the skewed profile of the unexcited flow.

Experiments with the longer diffusers showed more favourable results (fig. 5). The mean velocity distribution at the exit of the diffuser with $\theta = 4.5°$ is shown in fig. 6. Reliable pitot survey could not be made for $\theta = 7°$ due to large fluctuations in the static pressure readings. For the case of $\theta = 4.5°$, the values of ϕ with and without excitation were 1.52 and 1.8 respectively (fig. 5). The corresponding values of ϕ for the 7° diffuser were 1.1 and 1.81.

For the straight diffuser ($\theta = 0°$) the ratio of the induced mass flow to that of the primary jet (m) was about 5.8 for the steady jet and it was the same even for the case with excitation. The values of m for the short diffuser ($\theta = 2.3°$), with and without excitation, were 5.51 and 8.26 respectively. The corresponding values of m for the long diffuser ($\theta = 4.4°$) were 7.5 and 9.4. In all these experiments, the mass flow rate of the primary jet was 0.554 kg/sec.

4. Discussion

The results of the above experiments clearly indicate that an excited primary jet in an ejector system tends to smoothen the velocity gradients in the flow more rapidly than that when the jet is steady. This trend can be clearly seen in the case $\theta = 0°$. There is no doubt that this effect is due to mixing but it is purely local and with this type of mixing, it is unable to induce more mass into the ejector system. An examination of the total momentum flux across the duct for $\theta = 0°$ revealed that it remained the same whether the jet was excited or not. This trend is in conformity with the observations made earlier by Badri Narayanan and Poddar[9]. It is well known that the large scale turbulence structures or vortices in the jet are responsible for inducing flow through mixing. However, in the present case, this concept does not seem to hold good. Since our present day knowledge on the structure of the excited jet is extremely limited it is futile to speculate reasons for the above observation. Perhaps not only the existence of large vortices, but also their orientation plays a role in the induction process.

In the case of the ejector with diffuser, the enhancement in the induced flow as well as

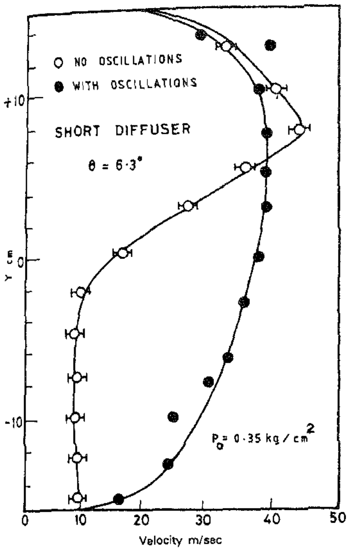

Fig 4. Mean velocity profiles at the exit of the diffuser ($\theta = 6.3°$).

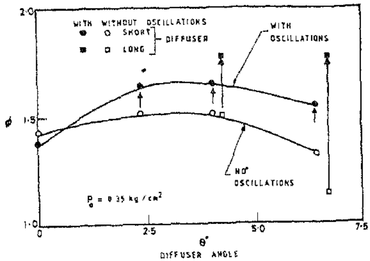

Fig. 5. Effect of oscillations on thrust augmentation.

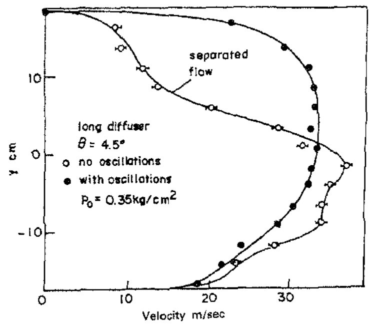

Fig 6. Mean velocity profiles at the downstream end of the diffuser.

the increase in the ejector thrust are solely due to improvement in diffuser efficiency. The excitation of the jet had profound influence on the quality of flow in the diffuser. In the case of the short diffuser with a half-angle of 6.3°, flow separation was suppressed when the jet was excited (fig. 4) resulting in the recovery of the thrust (fig. 5). This trend is in conformity with the observations made by Viets[10] on diffuser flow with oscillating jets. Similar results were observed with the long diffuser (fig. 6). However, for $\theta > 6.3°$ excitation could not suppress separation; hence there was a rapid deterioration in the overall performance of the ejector.

5. Conclusions

1) Flap excited jet enhanced local mixing of the flow in a straight ejector; however, its direct influence on entrainment and augmentation in thrust was negligible.

2) Excitation of the jet improved the quality of the flow in the diffuser by suppressing flow separation which eventually resulted in favourable thrust augmentation.

Acknowledgement

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Nomenclature

x : Longitudinal distance from the inlet of the ejector shroud; $x = 0$ at the inlet
y : Coordinate perpendicular to x axis; $y = 0$ along the centre line of the ejector
U : Mean velocity
u : Average velocity
m : Induced rate of mass flow/rate of mass flow of the primary jet
T_1 : Thrust of the jet
T_2 : Thrust of the ejector
ϕ : Thrust augmentation ratio $= (T_1 + T_2)/T_1$
θ : Diffuser half angle
S : Amplitude of oscillation (peak to peak)

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