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NOISE ATTENUATION ASSOCIATED WITH USING EJECTORS

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ABSTRACT. The ejectors are developed and used for gas turbine engines, to generate effective exhaust noise attenuation without losing engine thrust, but even if possible with thrust increase. Also ejectors are used for subsonic rocket propelled vehicles as thrust augmenting devices, as result of increasing their propulsive efficiency. In this paper, a combined numerical and experimental study is conducted to establish an optimum design of compressible subsonic air ejector as a thrust augmentor and noise attenuator. The theoretical solution of the flow through the exhaust system with ejectors is done numerically by using "Fluent 6.1" package. The package solved the steady 2-D compressible viscous flow by using the finite volume technique. While the experimental measurement of the flow field of the considered problem is done by using Particle Image Velocimetry (PIV) technique. The obtained results help to understand the flow behavior and the physical phenomena occurring in the flow through ejectors, and give optimum design of exhaust ejector to give optimum thrust augmentation and optimum design to give optimum noise attenuation.

KEYWORDS: Jet mixing flow; Two-dimension flow; Ejectors and noise attenuation.

NOMENCLATURE

AR_D	Diffuser area ratio, $=(D_D/D_E)^2$	V'_P	Nozzle exit average jet velocity without ejector, (m/s)
AR_E	Ejector area ratio, $= (D_E/D_N)^2$	$\dot{m}_{Ee}$	Air mass flowrate at ejector exit, (kg/s)
D_E	Ejector diameter, (m)	$\dot{m}_P$	Primary air mass flowrate, (kg/s)
D_D	Diffuser exit diameter, (m)	$\dot{m}_S$	Secondary air mass flowrate, (kg/s)
D_N	Nozzle exit diameter, (m)	$p_{atm.}$	Ambient pressure, (Pa)
L_E	Ejector length, (m)	p_E	Static pressure at ejector entrance, (Pa)
L_S	Nozzle axial position with respect to ejector entry, (m)	p_{op}	Total pressure of primary air, (Pa)
M	Mach number	$p_{op}/p_{atm.}$	Nozzle pressure ratio
U(X)	The center line velocity of the jet at any position downstream, (m/s)	T_P	Total temperature of primary air, (K)
U(0)	The center line velocity at the jet nozzle exit, (m/s)	V_P	Nozzle exit average jet velocity with ejector, (m/s)
V_{Ee}	Mixed air velocity at ejector exit, (m/s)	X	Axial position, (m)

1. INTRODUCTION

Ejector is a fluid dynamic pump with no moving parts. Fig. 1 is a schematic drawing of an ejector. The ejector system configuration consists mainly of four parts, namely, the primary nozzle, inlet section, mixing section, and diffuser. In the ejector, the kinetic energy of the primary driving fluid is used to create a low pressure region entraining the secondary fluid stream. Mixing of the two fluid streams occurs in the mixing chamber of the ejector and the resultant fluid mixture is compressed down-stream out in the diffuser. The resulting exhaust jet has a higher flow rate and a lower velocity than the original primary flow. Such ejector systems can provide thrust augmentation, jet noise reduction, IR (infrared) suppression, and exhaust cooling on jet engines. The interest with the ejectors stems from their application to propulsive machines like jet engines. They have the capacity to increase thrust, since they increase the mass flow in the jet and reducing the jet noise, since they lower the jet velocity. The ejector advantages lie in its simplicity, ease of operation and rugged construction, having no moving parts and requiring little maintenance, and it has a long service life. Many types of nozzles are used with ejector; the famous types are conventional nozzles, hypermixing nozzles (Goethert B. H. [1]) and lobed nozzles (O'Sullivan M.N. [2]).

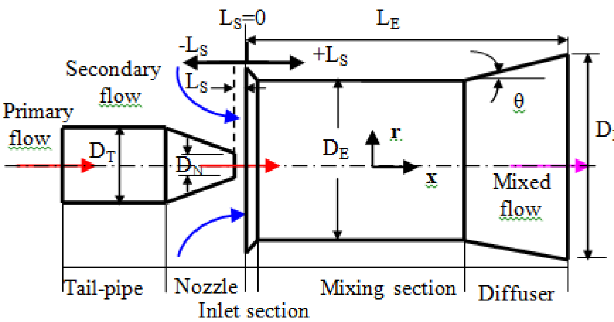


Fig. 1. Fig. 1 Definition of ejector geometry with conventional nozzle.

The conventional nozzle is a nozzle of conventional shape, with circular or rectangular shape at exit, in which the exhaust flow (primary jet) is parallel to centerline of nozzle. Viscous forces are generated in the mixing region of the primary jet and transfer the flow energy from the primary fluid to the secondary fluid. There have been several previous investigations into these phenomena. The one-dimensional analysis of an ejector flow was intensively studied by Keenan and Neumann [3] for compressible flow and Von Karman [4] for incompressible flows. The interest in these devices stems from their application to propulsive machines like jet engines. They have the capacity to increase thrust, since they increase the mass flow in the jet. Recent reviews by Quinn [5], and Porter et al. [6], Bevilaqua [7] gave accounts of the various advances made in the analysis of thrust-augmenting ejectors. A compressible flow analysis of the flow through a thrust augmenting ejector has been described by Alperin and Wu [8 and 9]. They presented the results of an investigation of the performance of thrust augmenting ejectors operating in and with compressible gases and utilizing energy from the discharge of conventional gas generators. The circulation theory of aircraft lift was applied to calculate the static performance for thrust augmenting ejector by Bevilaqua, P.M. [10]. Fisher, S.A. and Irvine, R.D. [11], investigated the effect of applying axisymmetric ejector with a constant area mixing tube followed by a diffuser on the increase of static rocket thrust which can be achieved by air augmentation. EL-Banna, R.A.M [12], study the effect of a diffuser on thrust-augmenting ratio for subsonic conventional ejector. Whitley, N. et al. [13] conducted a theoretical analysis of the compressible flow through a constant-area jet-engine ejector in which a primary jet mixes with ambient fluid from a uniform free stream. Due to the assumptions made, the analysis provides idealized values for the thrust-augmentation ratio and the mass flux entrainment factor. Raman and Taghavi [14] provide a detailed experimental evaluation of rectangular multi-element jet mixer-ejector nozzle, the obtained results showed that the ejector configuration that produced the maximum entrainment ratio also exhibited the lowest wall pressures in the inlet region and higher thrust augmenting. Also, their data includes details of acoustics of mixer-ejector that are important for jet exhaust noise suppression. An experimental and numerical calculation were performed on the flow field of a model ejector ramjet configuration to investigate fundamental fluid dynamic aspects of its shear and mixing effect by Okai, et al. [15]. Aissa, W.A., [16 and 17] performed an experimental and analytical analysis of the effects of cylindrical length on the mass flow ratio and wall pressure distribution of an ejector at low primary to secondary stagnation pressure ratios.

Kabeel et al. [18] conducted an experimental study to determine the ideal compressible subsonic air ejector design for use as an IR suppression tool. Using the Particle Image Velocimetry (PIV) technique, the flow field of the problem under consideration is experimentally measured. The experimental study showed that, the optimum exhaust mixed air temperature is achieved for an ejector with length-to-diameter ratio of LE/DE = 7, the axial position of primary nozzle relative to the ejector inlet LS = - 0.5 DE and mixing suction to nozzle exit area ratio ARE = 36. At this optimum exhaust mixed air temperature;

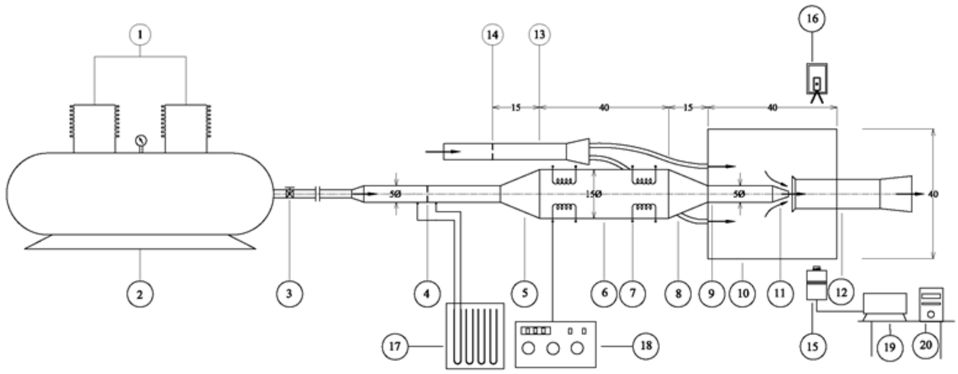
the emissive power is suppressed to 330 %.in addition, the exhaust mixed air temperature reduces by 40% about no ejector case. In order to increase pumping performance and augment thrust, ejector nozzles have been developed in conjunction with unique mixer nozzles [19]. Since increasing the mixing capacity of the primary nozzle is essential to enhancing the ejector's performance, this capacity is examined using both computational and experimental techniques. The primary uses of very small turbojet engines outside of model aircraft propulsion are in military reconnaissance and target drones such as the Airbus Do-DT-25.Consequently, due to their low overall efficiency (5–10%) and requirement for aircraft integration, relatively tiny turbojet engines need to be updated [20]. Higher turbine inlet temperatures and pressure ratios are needed to boost thermal efficiency.

A problem which greatly strains the operation of the ejector concept is the mixing of the primary and secondary streams. If this mixing is incomplete, thrust augmentation suffers and various loss mechanisms emerge. It is necessary to achieve this mixing in as short a distance as possible in order to minimize the size and weight penalty caused by the engine.

The previous literatures have not obtained the optimum configurations of exhaust ejectors to give optimum thrust augmentation and or optimum noise suppression based on the effect of the variation of all geometrical and operational parameters. So that, the aim of this paper is to determine the optimum configurations of exhaust ejectors to give optimum thrust augmentation ratio and optimum noise reduction. The design of ejectors is a complex problem; many geometrical and operational parameters can affect ejector performance. These factors include: ejector length-to-diameter ratios (L_E/D_E), ejector area ratio (AR_E), diffuser area ratio (AR_D), half-divergence angle of the diffuser (θ), nozzle pressure ratio ($p_{op}/p_{atm.}$), total temperature of primary air (T_P) and the axial position of primary nozzle relative to the ejector entry (L_S).

2. THE EXPERIMENTAL TEST RIG

The experimental investigation was conducted using an open aerodynamic circuit. The experimental test rig is shown schematically in Fig. 2. The experimental facility consists of two reciprocating compressors which compress air to air tank. Each compressor is driven by an electric-motor having an output power of 7.5 kW. The air comes from the tank to the settling pipe through compressed air line. The primary air mass flow rate is ($\dot{m}_P$) controlled using a valve fitted downstream of tank, whereas it is measured by orifice meter mounted within the settling pipe. The settling pipe was connected to a settling chamber through a divergent section. The settling chamber supports the heaters and screens. Each heater is a cylindrical shape bar of diameter 6 mm and one-meter length generates a thermal power about 1 kW. The settling chamber is connected to a tail pipe through a convergent section. The air from the settling chamber flows to the convergent nozzle via a tail pipe. The K-type thermocouple is supported in the first of tail pipe wall to measure the total temperature of the primary air. The air flowing through the nozzle is exhausted to ejector and finally into the atmosphere.



1-Reciprocating compressors	5- Divergent section	9 - Tail pipe	13- Secondary flow pipe	17- Manometers
2- Air pressure tank	6- Settling chamber	10- Entry chamber	14- Secondary orifice	18-Control panel
3- Control valve	7- Heaters	11- Nozzle	15- CCD Camera	19-Monitor
4- Primary orifice	8- Convergent section	12- Ejector	16-Laser power supply	20- CPU

Fig. 2. Fig. 2 Experimental test rig.

Two Pitot-static tube are used whereas the first mounted upstream of nozzle (mid of the tail pipe) to measure the total pressure. The second Pitot-static tube is located at the centerline of the exit nozzle, to measure the velocity and static pressure of primary air. The used Pitot-static tubes are calibrated with standard Pitot-static tube. The primary jet of air entrains additional air from the surroundings and discharges the mixture of primary jet and entrained air (secondary air) through the ejector to the atmosphere. For determination of the secondary air mass flow rate, the tail pipe, nozzle and entrance part of ejector are mounted inside entry chamber, which is a box made of Perspex. The secondary air is drawn from four holes in upstream side of entry chamber. These holes are symmetrical with respect to the tail pipe and connected to a secondary flow pipe via four tubes. The mass flow rate of the secondary flow ($\dot{m}_S$) is measured by orifice meter mounted within secondary flow pipe. The air flow field through the ejector is measured in meridonal plane using Particle Image Velocimetry (PIV).

An experimental and numerical investigation of the effect of geometrical and operational parameters variations on the thrust augmentation ratio (φ) and noise attenuation of ejector with and without diffuser is presented. The ejectors are made of transparent Perspex in order to measure the air flowfield from out side surface of the ejectors using PIV. Ejectors have cylindrical mixing sections of length-to-diameter ratios (L_E/D_E) is varied from 2 to 13, ejector area ratio (AR_E) from 11 to 75, diffuser area ratio (AR_D) varied from 1.3 to 2 and half-divergence angle (θ) of diffuser varied from 4 to 8 degrees. The casing of the tested diffusers was fabricated from a single transparent Perspex sheet by rolling it around a wooden conical section having the required dimensions. Convergent nozzle with 50 mm length and has area ratio 11.1 is used. The series of computations and experiments are repeated for nozzle pressure ratio ($p_{op}/p_{atm.}$) varying from 1.1 to 1.8. The axial position of primary nozzle relative to the ejector inlet (L_S) varied from - 2 D_E (the nozzle outside the ejector) to 2 D_E (the nozzle inside the ejector) and total temperature of primary jet (T_P) varying from 300 to 500 K. Thrust augmentation ratio (φ) is the ratio of the thrust of the ejector to the thrust of the baseline primary nozzle expanded to ambient pressure, Refs. [8], [9], [12] and [13], $\varphi = \left[\frac{\dot{m}_{Ee} V_{Ee}}{\dot{m}_P V_P'}\right]$, Where,

$\dot{m}_{Ee}$= Air mass flowrate at ejector exit, (kg/s), $= \dot{m}_P + \dot{m}_S$

V_P' = Nozzle exit average jet velocity without ejector, (m/s)

V_P = Nozzle exit average jet velocity with ejector, (m/s).

The noise generated is measured with a precision integration sound level meter type 2236, Bruel & Kjaer. In the presence of ejector there are two major noise sources, the first is jet mixing noise at the ejector inlet and a second one behind the exit of the ejector, so that a 10 mm microphone is moved in a circular path with a radius of 1 meter from the center of the exit plane of the primary nozzle, in horizontal plane containing the nozzle center line. The overall sound pressure levels are measured at four locations, and the mean value is calculated which represents the overall sound pressure level. As a note all noise measurements are conducted without entry chamber, where it causes damping for mixing noise and give uncorrected value for sound level meter. The sound level meter is calibrated with sound level calibrator type 4231.

3. NUMERICAL SOLUTION

3.1. SOLVER

The two-dimensional steady turbulent compressible flowfild in the ejector is governed by continuity, momentum and an energy equation together with the application of the turbulence standard k-ε model. After setting up the governing equations, which describe the ejector air flow, a numerical model is used to change it into a set of algebraic equations. Then, the computational fluid dynamics method using a packaged "Fluent 6.1" is used based on the "SIMPLE" technique introduction by Patanker [22].

3.2. BOUNDARY CONDITIONS

The boundary conditions at the flow inlet are the prescribed total pressure and total temperature for both primary and secondary flows. At the diffuser exit plane, the static pressure was specified. In addition, zero temperature gradient is considered at diffuser exit plan. This means that the pressure ratios are specified prior to calculation and the mass flow rate is determined by solver. Walls are treated as no-slip condition. The wall has a fluid on each side, it is called a ``two-sided wall'', to couple the two sides of the wall no additional thermal boundary conditions are required, because the solver will calculate heat transfer directly from the solution in the adjacent cells. The wall flow field governing equations are a collection of semi-empirical formulas and functions that in effect ``bridge'' or ``link'' the solution variables at the near-wall cells and the corresponding quantities on the wall. The wall functions comprise: laws-of-the-wall for mean velocity and temperature (or other scalars) and formulas for near-wall turbulent quantities. The standard wall functions are based on the proposal of Launder and Spalding [23].

3.3. Model Validation

The validity of the model is verified by comparing results obtained in the present work with corresponding experimental results reported by data of Carletti et. al. [21] is shown in Fig. 3. Where, The vertical axis shows the center line velocity of the jet flow at any position downstream (U(X)) normalized by the center line nozzle exit velocity (U(0)). The horizontal axis represents the distance downstream of the jet nozzle normalized by the diameter of nozzle (D_N).

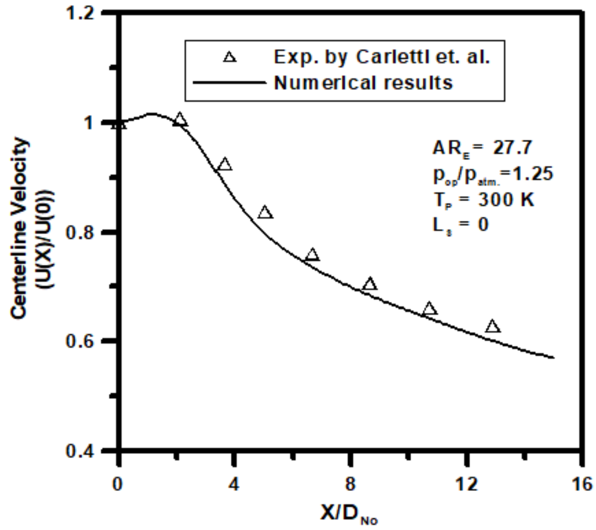


Fig. 3. Comparison between the predict centerline velocity and the exp. data by Carletti et. al. [24].

4. Results and Discussion

In the following section, the results noise attenuation at different operating parameters: nozzle total to static pressure ratio, total temperature of primary air, nozzle axial position with respect to ejector entry section L_S and ejector configuration are presented. These results included the numerically calculated results and measured PIV velocity vectors map which connects with calculated contours of velocity magnitude. Also, the results included the measured noise attenuation due to ejector application.

4.1. Effect of Ejector with Diffuser on Noise Reduction.

Diffusers are widely used to slow down a mean flow, converting its kinetic energy into pressure energy. So that the flow is more uniform at ejector exit in the presence of diffuser and the noise reduction of the ejector is better. The noise reduction increases by 2.5 dB due to presence of diffusers at $p_{op}/p_{atm.}$= 1.1. As shown in table 2, the ejector with AR_E = 36, L_E/D_E= 9, AR_D=1.8, and θ=4° has the best overall noise suppression which is about 5 dB at $p_{op}/p_{atm.}$= 1.5. The mean value of turbulence kinetic energy at ejector exit for different diffuser area ratios are presented in table 5.

The center line velocity decay is increasing if a diffuser is fixed behind the mixing duct. Also, the diffusers increasing entrained mass flow rate. Fig. 4 is illustrated the effect of diffuser area ratio on exit center line velocity at half-divergence angle θ = 4° of the diffuser, AR_E= 22, L_E/D_E =7, $p_{op}/p_{atm.}$=1.5. The results indicate that, the best center line velocity decay was obtained at diffuser area ratio AR_D=1.8, half-divergence angle θ = 4° and L_E/D_E= 9, under this condition an exit center line velocity decreases by 8 % about no diffuser case. On the other hand, an increase in AR_D decrease the energy transfer efficiency, EL-Banna, R.A.M [12], so that the exit center line velocity increase when AR_D> 1.8.

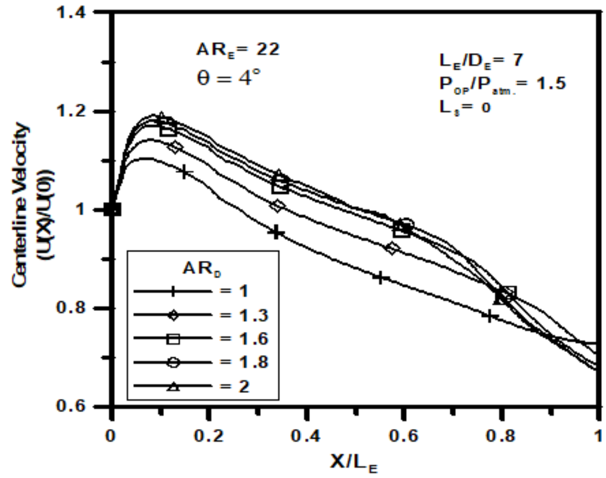


Fig. 4. Effect of AR_D on centerline velocity decay for AR_E =22 and L_E/D_E =7 at θ = 4

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Table 1. Noise reduction (dB) for various ejector geometries at $p_{op}/p_{atm.}$= 1.5, T_P= 300 K and L_S= 0.

AR_E	L_E/D_E	Noise reduction dB									
		AR_D=1	**AR_D=1.3**			**AR_D=1.6**			**AR_D=1.8**		
		θ=0	**$\theta=4^0$**	**6^0**	**8^0**	**$\theta=4^0$**	**6^0**	**8^0**	**$\theta=4^0$**	**6^0**	**8^0**
	3	-0.5	-0.3	0.2	0.2	-	-	-	-	-	-
	5	0.5	0.7	1	0.9	1.0	0.9	0.9	1.3	1.2	1.0
11	7	1	1.3	1.2	1.2	2.5	2.2	2	2.8	2.5	2.4
	9	**1.4**	2.2	2.0	1.9	3	2.8	2.7	3.2	3.1	3.1
	11	1.3	2.3	2.1	2.1	3.2	3.1	3	3.3	3.2	3.2
	3	0.2	0.4	0.7	0.5	-	-	-	-	-	-
	5	1	1.5	1.6	1.2	2.3	2.2	2.1	2.7	2.4	2.3
22	7	1.9	2.4	2.2	2.1	3.6	3.4	3.1	3.7	3.5	3.3
	9	**2.7**	3.3	3.0	2.9	4.1	4	3.9	4.4	4.3	4
	11	2.6	3.5	3.3	3.2	4.3	4.1	4	4.6	4.3	4.2
	3	0.3	0.55	0.8	0.6	-	-	-	-	-	-
	5	1.2	2.6	2.8	2.7	2.8	2.5	2.4	3	2.8	2.8
36	7	2.2	3.2	3.8	3.6	3.8	3.6	3.4	4.2	3.9	3.6
	9	**3.3**	3.9	4.8	4.4	4.6	4.4	4.2	**5**	4.8	4.6
	11	3.2	3.8	4.8	4.6	4.5	4.2	4.1	4.9	4.8	4.5
	3	0.3	0.6	0.9	0.5	-	-	-	-	-	-
	5	1.2	2.5	2.7	2.6	2.9	2.7	2.5	3	2.7	2.6
54	7	2.1	3.1	3.8	3.5	3.7	3.6	3.2	4.1	3.8	3.5
	9	**3.2**	3.8	4.7	4.5	4.5	4.4	4.1	4.8	4.7	4.6
	11	3.2	3.7	4.6	4.4	4.4	4.3	4.1	4.7	4.7	4.4

4.2. EFFECT OF AXIAL POSITION OF PRIMARY NOZZLE (L_S) ON NOISE REDUCTION.

The axial distance of primary nozzle relative to the ejector entrance (L_S) is varied from – $2D_E$ to $2D_E$. Fig. 5 shows the effect of varying the axial position of the primary nozzle relative to the ejector entrance, for AR_E= 36 at a fixed nozzle pressure ratio of 1.5, on the sound pressure reduction. From this figure the noise reduction depends on the position of the nozzle exit with respect to the ejector entrance, it can be seen that the sound pressure reduction increases when the nozzle is inside the ejector and the level of noise increases when the nozzle out side the ejector. The best overall noise suppression occurred at L_S=0.75D_E, the noise reduction increased by 2 dB in case L_S = 0.75 D_E compared to L_S = 0 at AR_E= 36, L_E /D_E= 9 AR_D=1.8, and θ =4^o. When L_S has positive value (the nozzle inside the ejector) the inlet area of ejector becomes smaller and causes drop in entrainment air mass flow rate, as results the turbulence kinetic energy is minimum at ejector inlet, and consequently the mixing noise becomes minimum. While for the nozzle located outside ejector the mixing noise becomes larger which leads to higher noise.

Fig. 6 illustrate the effect of varying the axial position of primary nozzle relative to the ejector inlet (L_S) on center line velocity for ejector have AR_E=36, L_E/D_E=5 at $p_{op}/p_{atm.}$=1.5. It can be observed from Fig. 6 that, the exit center line velocity increases when the nozzle is outside the ejector (-Ls). While, in Fig. 7, the result can be generalized in this way, the center line exit velocity decreases slowly with increasing the distance (the nozzle inside the ejector) up to Ls = 0.75D_E, there after center line exit velocity increases with increase in positive axial distance. Fig. 8 shows the effect of ejector position on turbulence kinetic energy at exit of ejector has area ratio AR_E= 36 and at different axial position.

4.3. EFFECT OF TOTAL TEMPERATURE OF PRIMARY AIR ON NOISE REDUCTION.

The ejector entrains cold secondary air to mix with a hot fast primary stream to reduce the velocity of the jet leaving the ejector. This reduction in jet velocity decreases the intensity of the turbulent mixing process between the exhaust jet and ambient air and thereby reduces the generated noise. From sound level meter measurements, the noise reduction of the ejectors grows significantly with increase of the total temperature of the primary flow T_P (in the present experimental work from 300 K to 400 and 450 K), the same results was previously obtained by Goethert, B. [1] and Raman, G. and Taghavi, R. [14]. With increase of ejector length, temperature and presence of the diffusers, a steady increase of the noise reduction to the maximum of 8.1 dB, that's for the ejector with $AR_E = 36$, $L_E/D_E = 9$, $AR_D=1.8$, $\theta= 4^o$, $L_S= 0.75D_E$ and at T= 450 K. On the other hand, the influence of the flow temperature at constant nozzle pressure ratio can be attributed the higher exhaust velocities and increase the total entrained air.

Figure 8 shows the effect of total temperature of primary air on center line velocity at $AR_E = 22$. From this figure the center line velocity decay of the ejector decreases with increasing the total temperature of the air. Where, the influence of the flow temperature at constant nozzle pressure ratio attributes the higher exhaust velocities and increase the total entrained air. The results indicate that, when air temperature 300 K the exit center line velocity decreases by 16% about jet velocity, but decreases by 21% when air temperature 450 K, that at $AR_E=36$, $L_E/D_E=9$, $L_S=0$ and $p_{op}/p_{atm.}=1.5$.

4.4. EFFECT OF NOZZLE PRESSURE RATIO (POP/PATM.) ON NOISE REDUCTION

The sound level mater is used to study the effect of nozzle pressure ratio on the noise reduction and the measurements. The results of noise reduction show that, the noise suppression decreases with the nozzle pressure ratio increase due to jet velocity increase. The noise reduction decreases from 7.5 dB to 3.4 dB between $p_{op}/p_{atm.}=1.1$ and 1.6, at $AR_E=36$, $L_E/D_E = 9$, $L_S=0$, $\theta = 6$, $AR_D=1.8$ and T=300 K. Since, with increasing the jet velocity the time is not enough for complete mixing of the secondary and primary flow to reach more uniform flow.

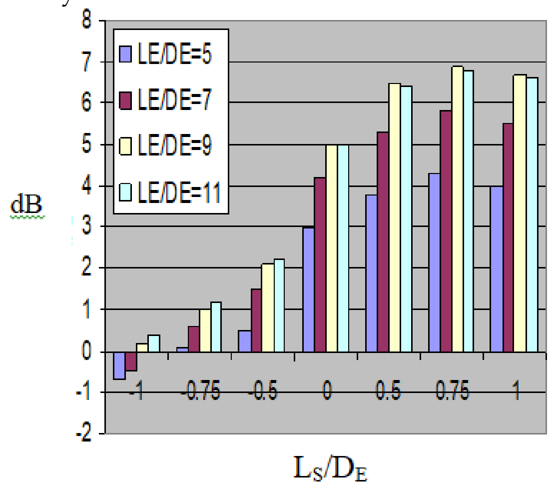

Fig. 5. Fig. 5 Noise reduction (dB) for $AR_E=36$ at different L_S, $AR_D=1.8$ and $\theta= 4^o$.

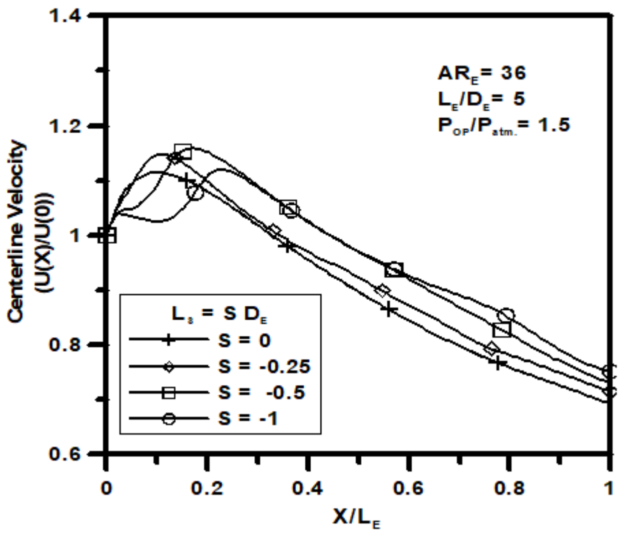

Fig. 6. Effect of $-L_S$ on center line velocity for $AR_E = 36$ and $L_E/D_E= 5$.

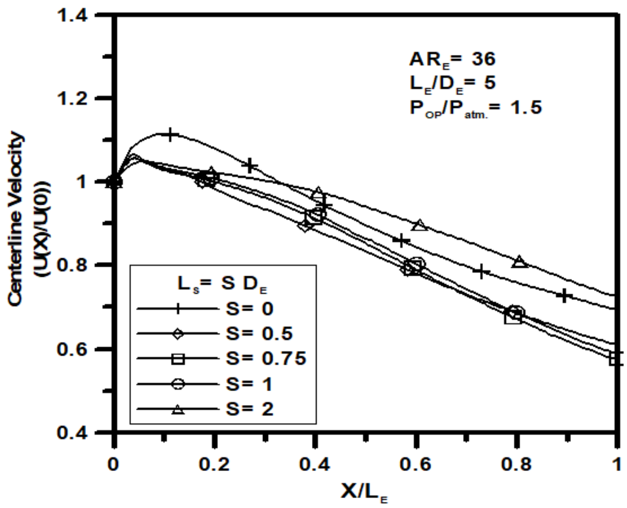

Fig. 7. Effect $+L_S$ on center line velocity for $AR_E = 36$ and $L_E/D_E= 5$.

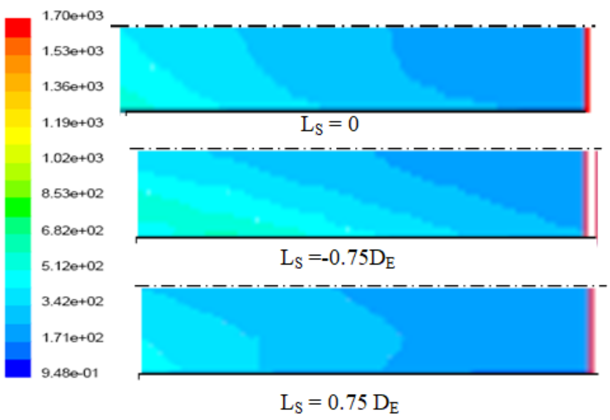

Fig. 8. Measured turbulence kinetic energy(m^2/s^2) for $AR_E = 36$, $L_E/D_E=7$ and different L_S at ejector exit (half section)

5. CONCLUSIONS

The numerical and experimental studies are conducted to establish an optimum design of subsonic air ejectors to give optimum noise reduction. The following results at total temperature of primary air T_P=500 K and nozzle pressure ratio $p_{op}/p_{atm.}$=1.5 are obtained:-

1- Combination of noise, turbulence intensity, centerline velocity and flowfiled to explain nature of flowfiled.

2- Selection of the ejector configuration according to object (optimization):

- The optimum noise attenuation is achieved for an ejector with length-to-diameter ratio L_E/D_E = 9, ejector area ratio AR_E = 36, diffuser area ratio AR_D = 1.8, half-divergence angle θ = 4^0 of the diffuser and the axial position of nozzle relative to the ejector inlet L_S = 0.75D_E (the nozzle inside the ejector).
- Depending upon the major objectives of the ejector application, a design for optimum r for noise attenuation must be selected. If both thrust increase and noise attenuation are equally important, an ejector with L_E/D_E = 7, AR_E = 22, AR_D = 1.6, θ = 4^0 and L_S = 0 is the optimum and the reduction of the exhaust noise was found to increase to 4.8 dB.

3- At ejector having length-to-diameter ratio 2.5 noise reduction about 0.3 dB, so that length-to-diameter ratio must be between $3 \leq L_E/D_E \leq 9$ in any case.

4- Developing numerical solution flow through ejectors with selector of suitable boundary condition, which validated by experiment and other researcher experiments whereas good coincidences exist.

6. FUTURE SCOPES

Based on the findings of the current study, it is concluded that the new techniques might be used to improve ejectors performance, such as:

1- Determine the exhaust temperature at various design conditions.

2- Determine the best state for a higher thrust augmentation..

REFERENCES

[1] Goethert, B., "Noise Attenuation and Associated Thrust Increase of Turbojet Engine through Hyper-Mixing Ejector Shrouds", 5th International Symposium on Air Breathing Engine, ISABE 81, India, pp. 17.1-17.11, 1981.

[2] O'Sullivan, M.N., "A Computational Study of Viscous Effects on Lobed Mixer Flow Features and Performance", manuscript in preparation, 1993.

[3] Keenan, J.H., and Neumann, E.P., "A Simple Air Ejector", Journal of Applied Mechanics, 9, A75-AS1, 1942.

[4] Von Karman, T., "Theoretical Remarks on Thrust Augmentation", In Contributions to Applied Mechanics (Reissner AnniversaryVolume), pp. 461-468, 1949.

[5] Quinn, B., " Thrust Augmenting Ejectors", A Review of the Application of Jet Mechanics to V/STOL Aircraft Propulsion, AGARD CPP-308, 19.1-19.14, 1981.

[6] Porter, J.L., Sqnyers, R.A., and Nagaraja, K.S., "An Overview of Ejector Theory", AIAA Paper No. 81-1678, 1981.

[7] Bevilaqua, P.M., "Advances in Ejector Thrust Augmentation", In Recent Advances in Aerodynamics, Springer-Verlag, New York, pp. 375-405, 1985.

[8] Alperin, M. and Wu, J. J., "Thrust Augmenting Ejectors, Part I" AIAA Journal, Vol. 21, No. 10, October 1983, pp. 1428-1436.

[9] Alperin, M. and Wu, J. J., "Thrust Augmenting Ejectors, Part II" AIAA Journal, Vol. 21, No. 12, , pp. 1428-1436, December 1983.

[10] Bevilaqua, P.M., "Lifting Surface Theory for Thrust Augmenting Ejectors" AIAA Journal, Vol. 16, No. 5, May 1978, pp. 475-481.

[11] Fisher, S.A. and Irvine, R.D., "Air Augmentation of Rocket for Low Speed Application," 5th ISABE 81, INDIA, pp.26.1-26.8. 1981.

[12] EL-Banna, R.A.M, "New Concepts in Thrust Augmentor Ejectors", SECOND A.S.A.T. Conference, Cairo-Egypt, 21-23 April 1987.

[13] Whitley, N., Krothapalli, A. and Van Dommelen, L. "A Determinate Model of Thrust-Augmenting Ejectors", Theoretical and Computational Fluid Dynamics, 8:37-55, 1996.

[14] Raman, G. and Taghavi, R., "Aeroacoustic Characteristics of a Rectangular Multi-Element Supersonic Jet Mixer-Ejector Nozzle", Journal of Sound and Vibration 207(2), 227-247, 1997.

[15] Okai, K., Taguchi, H. and Futamura, H., "Experimental and Numerical Investigations of Ejector and Mixing Effects in a Model Ejector Ramjet Configuration", ISABE 2003-1230.

[16] Aissa, W.A., "Effect of Throat Length on the Performance of an Air Ejector", ISABE 2003-1121.

[17] Aissa, W.A., "Experimental and Analytical Investigation of an Air Jet Ejector", Mansoura 4th International Engineering Conference, Sharm El-Shiekh, Egypt, pp. 171-176, April 20-22, 2004.

[18] A.E. Kabeel, A.M. El-Zahaby, E.A. El-Shenawy, A.I. Bakry, Z.M. Omara. The infrared suppression and cooling by utilizing ejectors. Contemporary Technology and Applied Engineering (JCTAE), 1(1), 2022, 82-88. DOI: 10.21608/JCTAE.2022.160264.1010.

[19] Schmidt R., A Hupfer. Design and numerical simulation of ejector nozzles for very small turbojet engines. CEAS Aeronautical Journal 2021. https://doi.org/10.1007/s13272-021-00537-3.

[20] A. Hupfer, Hirndorf, D. Investigation of parameters affecting thermodynamic cycle of very small jet engines. In: Proceedings of 15th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery (ISROMAC-15), Honolulu (2014)

[21] Patankar, S. V., "Numerical Heat Transfer and Fluid Flow", Hemisphere Publishing Company, New York, 1980.

[22] Launder, B. E. and Spalding, D. B., "The Numerical Computation of Turbulent Flows", Computer Methods in Applied Mechanics and Engineering, 3:269-289, 1974.

[23] Binder, G. and Didelle, H., "Improvement of Ejector Thrust Augmentation by Pulsating or Flapping Jets", published by BHRA Fluid Engineering, Cranfield, Bedford, England. March,1985.

[24] Carletti, M., Rogers, C.B. and Parekh, D.E., "Use of Streamwise Vorticity to Increase Mass Entrainment in a Cylindrical Ejector", AIAA Journal, Vol. 33, No. 9, pp. 1641-1645, Sept. 1995.