FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

An Influence of SST-2 Mixer-Ejector Nozzle Elements Variations on Its Aerodynamic and Acoustic Characteristics

Sergey Ju. Krasheninnikov, Alexey K. Mironov
Central Institute of Aviation Motors (CIAM), Russia
Eugeni V. Pavlyukov, Vladimir K. Jitenev, Andrey V. Shenkin
Central Aerogydrodynamic Institute (TsAGI), Russia

ABSTRACT

In earlier work of CIAM/TsAGI/SNECMA the acoustic and aerodynamic characteristics of 2-D mixer-ejector models, which could be prototype of real variable nozzle for future supersonic aircraft, were experimentally investigated. It was shown that 2-D mixer-ejector can give about 10 EPNdB noise reduction in take-off and flight over check points. Its efficiency is not worse than for conventional noise suppressors - about 3÷4.5PNdB per 1% thrust loss at static conditions. In the present work the possibility of the increasing of the efficiency of the previously designed mixer-ejector by means of variation of its elements was studied. The results of the investigation of the influence of auxiliary slots and acoustic lining at ejector walls on mixer-ejector acoustic and thrust performances are presented. The flow structure and its influence on mixer-ejector acoustic characteristics was also studied.

INTRODUCTION

The jet noise is an important problem in the designing of advanced engine for future supersonic civil aircraft. The needed jet noise suppression for low by-pass engine is 12-14EPNdB[1,2]. One of the ways of solving this problem is application of mechanical suppressors[3].

The researches[1,2] showed that 2-D mixer-ejector (with length to equivalent nozzle diameter ratio = 3.5) can give up to 12 EPNdB noise reduction in take-off and flight check points. Its efficiency is not worse than for conventional axisymmetric noise suppressors[4] - about 3÷4.5PNdB per 1% thrust loss at static conditions. The experimental results clarify the influence of separate suppressor's elements on its performances and give an opportunity to define the ways of modification the mixer-ejector scheme for improving its acoustic and thrust characteristics. The main reasons of decreasing the acoustic efficiency of real mixer-ejector comparing to ideal one are non-uniformity of the flow at the real ejector exit and partial re-radiation of acoustic energy from ejector volume. It was shown that for ejection coefficient equaled 1.8 the difference between ideal and real jet noise suppression is about

10dB. The improving of the thrust performances of mixer-ejector could give the increasing of its efficiency also. For example, estimations show that the removing of plug from lobed nozzle can reduce the thrust losses by 1÷1.5%.

The goal of the present work is to investigate the possibility of the increasing of the efficiency of the previously designed mixer-ejector by means of variation of its elements. The flow structure and its influence on mixer-ejector acoustic performances were also studied.

The next variations of constructive elements were investigated:

- additional slots in the ejector walls for intensification of the mixing processes within ejector;
- additional acoustic lining at ejector walls for increasing the absorption of the sound generated by high-speed part of a jet;
- models with and without plane central body (plug) within multi-lobe nozzle;
- shifting the upper and lower lobes relatively to each other (the plane symmetry of the mixing nozzle).

The influence of lobe shape on flow field in a jet was also studied.

The model experimental data were used to calculate the noise suppressor efficiency in Effective Perceived Noise Level (EPNL). Experiments show, that the variation of a mixer-ejector configuration can give additional noise reduction about 1EPNdB.

THE DESCRIPTION OF FACILITY, MODELS AND EXPERIMENTAL PROCEDURE.

The models were simultaneously tested at CIAM open acoustic test bench C17-A4 and at TsAGI aerodynamic facility TPD-TR wind tunnel[1]. The nozzle pressure ratio (NPR) was varied from 1.7 to 4. In acoustic tests heated jets were studied (T^*=300÷660K), in the aerodynamic tests only the cold jets were investigated. Before each acoustic experiment, characteristics of round nozzle of equivalent diameter at the same regimes were measured to reduce possible errors. During aerodynamic research, test models were set in an Eiffel chamber. For the present series of tests the models were installed on the axisymmetric support with a one-component force balance. Along with the thrust measurements the total pressure fields in the exhaust jet in the upstream area of mixing and at the ejector exit were determined. The movable rake with 26 pitot tubes was used. The experiments were carried out at static conditions. All acoustic measurements were made in the side opposite to lobes of mixer-ejector.

The configurations of models are shown in fig.1. These configurations are corresponded the take-off position of noise reduction nozzle. Basic configuration, investigated in previous works[1,2], have the plugged nozzle with 4 rectangular lobes and ejector of rectangular cross-section (fig.1a). In acoustic tests the two walls of ejector opposite to the lobes were covered by acoustic lining. The models for acoustic and aerodynamic tests were manufactured separately. The sizes of acoustic models were two times larger then aerodynamic models. The equivalent nozzle throat diameters were D_{eq}=92.4mm and D_{eq}=46.2mm for acoustic and aerodynamic models respectively. The inner sizes of acoustic and aerodynamic models were similar. All nozzles were convergent, the critical section was situated at the cold lobes edge station.

In the first modification of the basic model ejector had an longitudinal auxiliary inlets arranged between the jets issuing from lobed nozzle (fig.1b). The area of the auxiliary inlets was about 4% of the ejector internal surface area. The second modification was the installation the additional acoustic treatment at the side ejector walls: fig.1c. In next two variations of construction the plug was removed from the nozzle (fig.1d,e). The lobes was shifted to nozzle centerline, thus the critical section area was the same as in the plugged nozzles. In the last configuration of the model (fig.1e) upper and lower lobes were shifted relatively to each other.

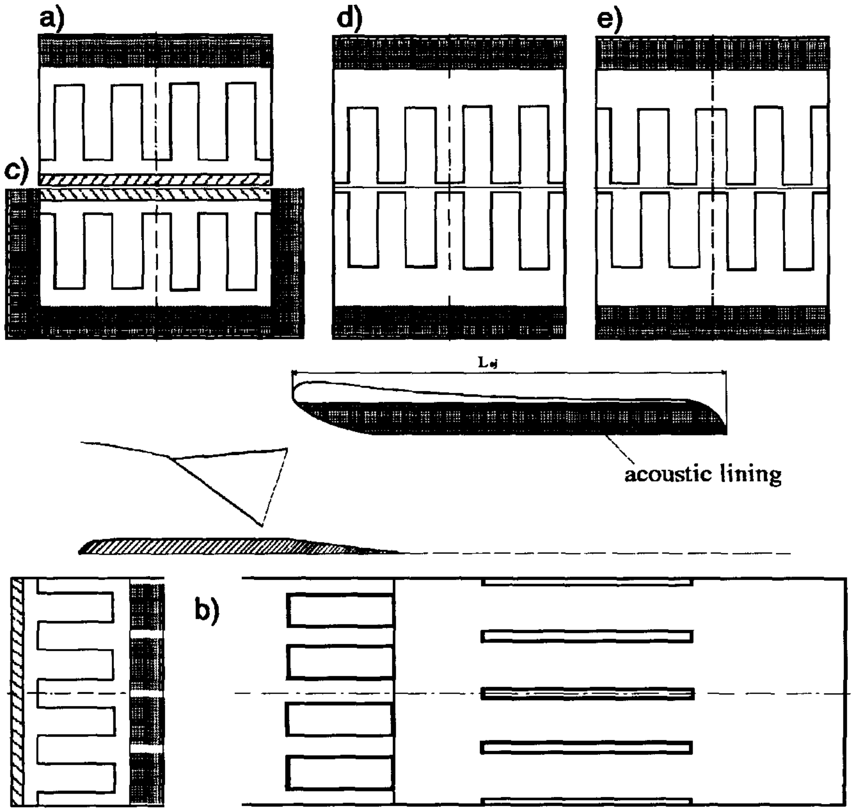
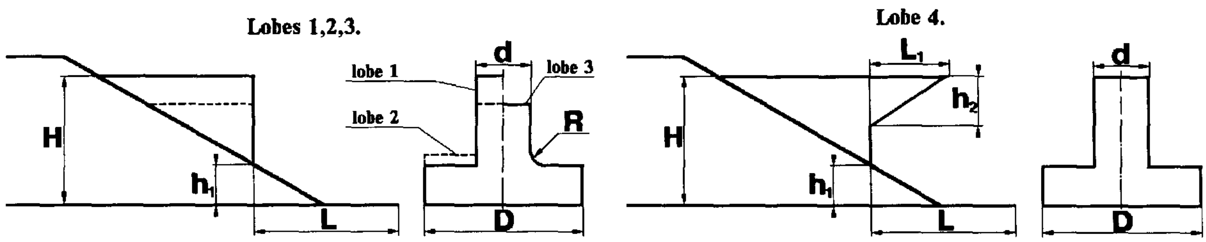


Fig.1. Configuration of the mixer-ejector models.



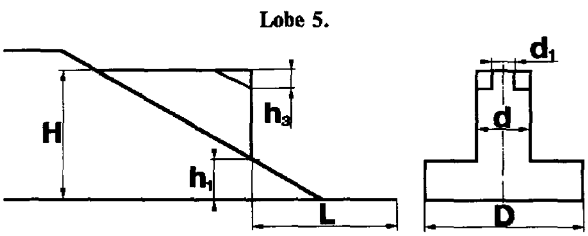


Table 1

Lobe	h_1	h_2	h_3	d	d_1	H	L_1	D	L	R
Lobe 1	11.4	–	–	30.7	–	74.0	–	67	79	–
Lobe 2	22.7	–	–	30.7	–	60.6	–	67	79	–
Lobe 3	22.7	–	–	30.7	–	60.6	–	67	79	10
Lobe 4	11.4	29	–	30.7	–	74.0	29	67	79	–
Lobe 5	20.3	–	16	30.7	12.5	74.0	–	67	79	–

Fig.2. Models of single lobes.

To determine the influence of lobe shape on the mixing processes five isolated lobes were aerodynamically tested. Its configuration is shown in the fig.2. The lobe 1 has the same shape as in the basic model (fig1.a). The lobe 2 has different height to width ratio. The lobe 3 differs from the lobe 2 by the rounded corner. The lobe 4 has an extended upper wall. The lobe 5 has a complementary "minilobe" at the upper part of the basic lobe. The geometrical sizes of the lobes are given in the table 1 in millimeters. Detailed description of single lobe geometry is given in the work[5].

EXPERIMENTAL RESULTS.

Models of single lobe. The earlier investigation[1] shows the strong influence of nozzle geometry on the flow structure. For the better understanding of the mixing processes within ejector the study of the flow field after isolated lobes was undertaken. The results of the total pressure measurements at distance of 89 mm from the lobe exit are presented in Fig.3. The data are shown in non-dimensional form: $\langle P \rangle = (P_{t,j}-P_a)/(P_{t,n}-P_a)$. (Here, $P_{t,n}$ - total pressure at the nozzle entry, P_a - ambient static pressure, $P_{t,j}$- pitot pressure in the jet). All the lobes have an identical footing width D and an identical width d of the cylindrical part. Therefore, the major parameters influencing on the thrust losses and flow field are the height of the passage under the convergent part of the lobe (h_l) and the corner rounding circle radius (R).

Analysis of test results in fig.3 shows that the transverse flows in the subsonic part of the nozzle which are directed from the converging part of the lobe towards the center produce the stream bend near the corner. It should be noted, that the ratio of heights of the converging and cylindrical parts of the lobe (h_l and H) is the governing parameter which is determined the jet cross section shape in the mixing area. Lobes 1 and 4 form the jet at the upper part of the lobe; the lobe 2 divides the jet into two jets nearly equal in their size; the rounding of the internal corner of lobe 3 has a little influence on the jet shape. Compared to the lobe 1, the flap with the lobe 4 deflects the jet down. The mini-lobe in the upper part of the "big" lobe 5 forms the jet that flows from the lower part of the lobe, because of the increase in static pressure in the subsonic part of the lobe in the mini-lobe location domain.

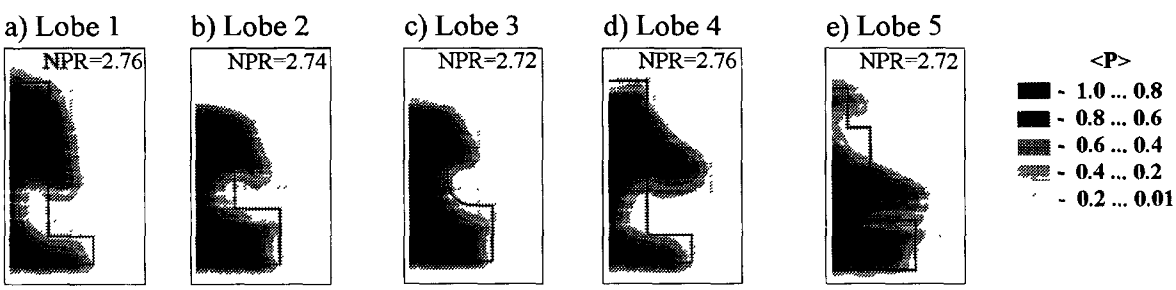


Fig.3 Pitot pressure downstream of a single lobes.

Thrust measurements show that increasing of the h_l from 11.4 (lobe 1) to 22.7 mm (lobe 2) decreases the thrust losses from 3.5% to 2% for NPR=2. Rounding the corner (lobe 3) reduces the thrust losses down to 1% of the ideal nozzle thrust. Thrust losses of the lobe 4 are less by 0.3%÷0.5% comparing to corresponding values for the lobe 1. Comparison of the thrust losses of lobe 2 (h_l=22.7 mm) and the lobe 5 (h_l=20.3 mm) shows that mini-lobe in the upper part of the basic lobe has a little influence on the thrust performance.

The experiments show that vortical wisps, stalled from lobes edges, play the main role in mixing processes. The structure of jet exhausting from the corrugated nozzle can be essentially changed by slight variation of the lobe shape. An optimal shape of the lobes can be chosen only after acoustic measurements on complete models of the mixer-ejector nozzle.

Auxiliary inlets in the ejector walls. As it was mentioned above, the non-uniformity of the flow at the ejector exit is one of main reasons of decreasing the acoustic efficiency of real mixer-ejector.

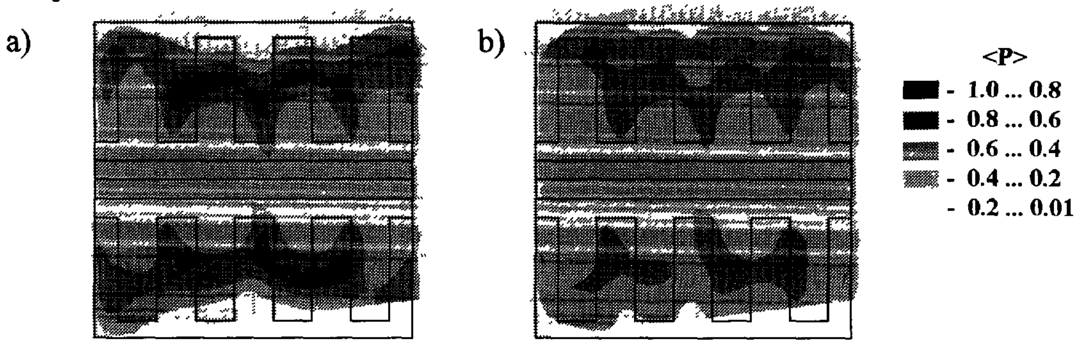


Fig.4 Pitot pressure in jet downstream ejector exit section.

In fig.4 the total pressure contours at the ejector exit are plotted. (Fig.4a - basic model with basic ejector, 4b- basic model with ejector with auxiliary slots). Data were obtained for NPR about 2.7. In the fig.4a the small jets from mixer lobes are evident with high pressure spots. The using of auxiliary slots makes the pressure distribution at the ejector exit more uniform (fig.4b). The static pressure within the ejector becomes more uniform too (see fig.5). The minimum static pressure (P_s/P_a) in the ejector with auxiliary inlets is 0.84-0.88, instead of value 0.6-0.7 for the basic ejector. Fig.6 shows thrust losses of the 2D mixer/ejector. The auxiliary inlets increase the thrust losses by 0.2%-1.0% for the NPR from 2.5 to 3.5. It is connected with increasing of static pressure in the ejector entrance and corresponding decreasing of the additional thrust applied to the ejector leading edge (see Fig.5).

	Lobes	Auxiliary inlets	NPR
●	1	without	2.77
■	5	without	2.73
○	1	with	2.71
□	5	with	2.71

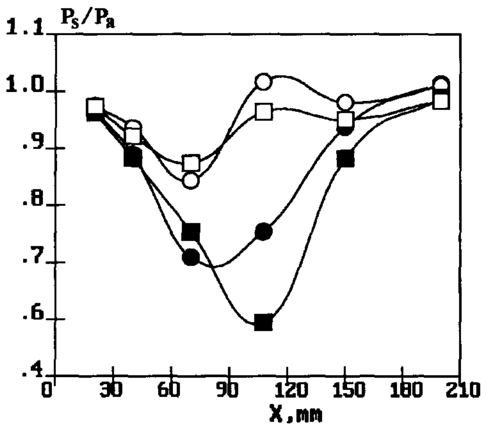


Fig.5 Static pressure along ejector.

	Lobes	Auxiliary inlets
●	1	without
○	5	without
■	1	with
□	5	with

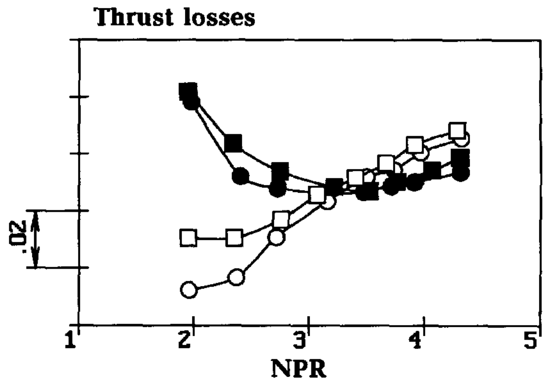
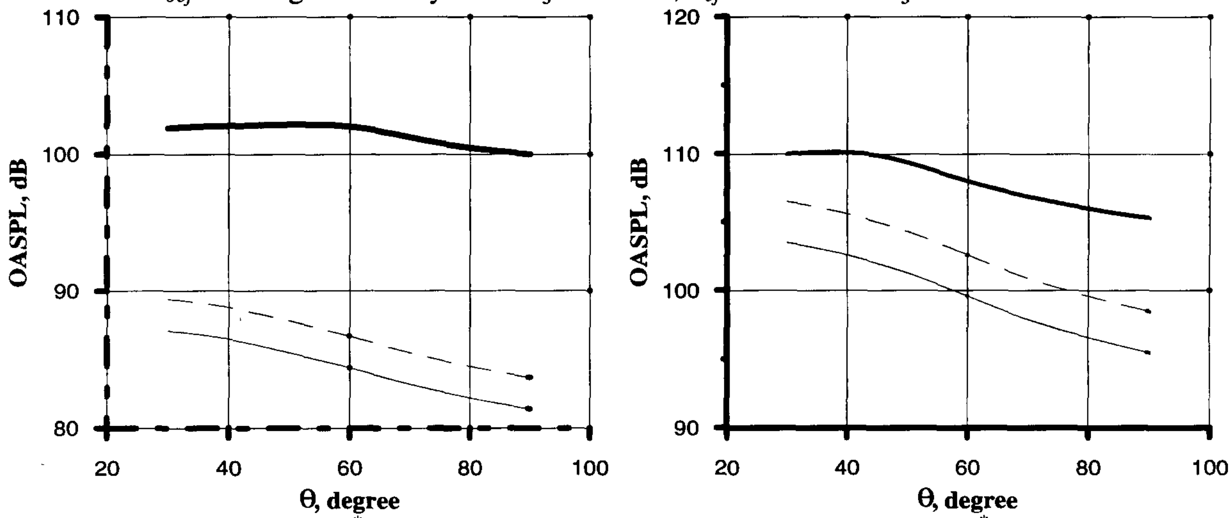


Fig.6 Thrust losses in 2D-mixer/ejector.

The total pressure measurements give an opportunity to calculate the velocity field at the ejector exit and to estimate the influence of non-uniformity of the exhaust jet on the mixer-ejector common noise. The calculation of flow field, made under assumption of equality of static and ambient pressure for basic model, shows that within traces of little jets issuing from mixer the velocity can be 1.3-1.4 times greater than average velocity at ejector edge. So far as pitot tubes measurements cannot give the pulsation characteristics of the flow, the estimations of the non-uniform exhaust jet were made in a simple way using Lighthill's theory. The jet issuing from ejector was approximated as a number of elementary jets with area dS and it was supposed, that the acoustic energy of the each jet is proportional to $U^8(y,z)dS$. In this case the difference between noise levels of the non-uniform and fully mixed jet can be estimated as:

$$\Delta L = 10\log(\iint_{Sej} U^8(y,z)dydz \Big/ U^8_{oej} S_{ej})$$

here U_{0ej} - averaged velocity at the ejector exit, S_{ej} - area of the ejector exit.



a). NPR=1.7, T^*=300K b). NPR=2.4, T^*=300K

Fig.7. Noise patterns of uniform and non-uniform jet issuing from ejector.
------ non-uniform jet; —— fully mixed jet; ▬▬ mixer-ejector (experiment)

If the local velocities are not strongly differ from average velocity one can suppose that noise patterns of non-uniform and uniform jets will be similar. Thus noise patterns of non-uniform jet can be estimated in this way: first, jet noise of fully mixed jet should be calculated for U_{0ej} and S_{ej} (in the present work it was made using procedure[6]), second, the ΔL should be added to calculated results. This method was tested on well-known case of co-axial jets and gave a good agreement with experimental data for internal/external velocity ratio 0.5-1.5.

The results of calculation of jet noise patterns are presented in the fig.7 (here OASPL is overall sound pressure level, ϑ is angle to jet axis, $\vartheta=0^\circ$ corresponds to stream direction). In this figure the experimental mixer-ejector noise patterns are plotted also. The difference between uniform and non-uniform jet noise levels equals 2.5÷3dB. The data show that when NPR is low (fig.5a) the noise levels of mixer-ejector are essentially greater than noise level of a jet issuing from ejector. In this case, the improving of exhaust jet uniformity cannot give any additional effect in the noise reduction. When NPR is high (fig.7b) the exhaust jet noise contributes a considerable part into common noise of mixer ejector. In this case, if the velocity distribution at ejector exit is uniform it can give additional noise reduction. The estimation derived from data in the fig.7 shows that for NPR=1.7 the maximal additional noise reduction can be about 0.2-0.25dB, for NPR=2.4 - 0.5-1.3dB.

The auxiliary inlets in the ejector wall make the flow more uniform and it leads to decreasing of noise. On the other hand the sound generated by high speed initial region of a jet can propagate through the inlets and it leads to increasing of common noise of mixer-ejector system. The noise spectra of mixer-ejector with and without additional slots are presented in the fig.8 (here SPL is sound pressure levels in 1/3-octave band, Sh is Strouhal number, defined by equivalent diameter of lobed nozzle and jet velocity). This data show that propagation of sound through the slots have a greater effect on the common noise than uniformity of the flow. It should be noted, that the increasing of mixer- ejector noise connected with sound emission through slots is partially compensated by uniforming of flow profiles at the ejector exit at high NPR (see fig.8a), apparently, in case of subsonic NPR the compensation does not take place (the data in the fig.7 confirm it) and SPL for slotted ejector are higher than for basic model for all frequency range (fig.8a,b).

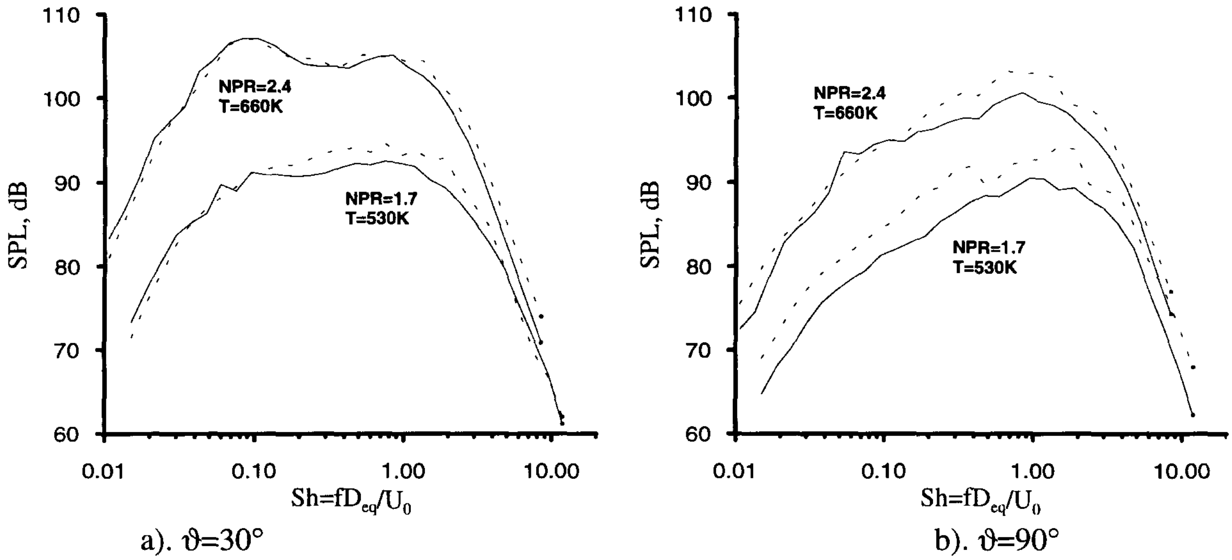


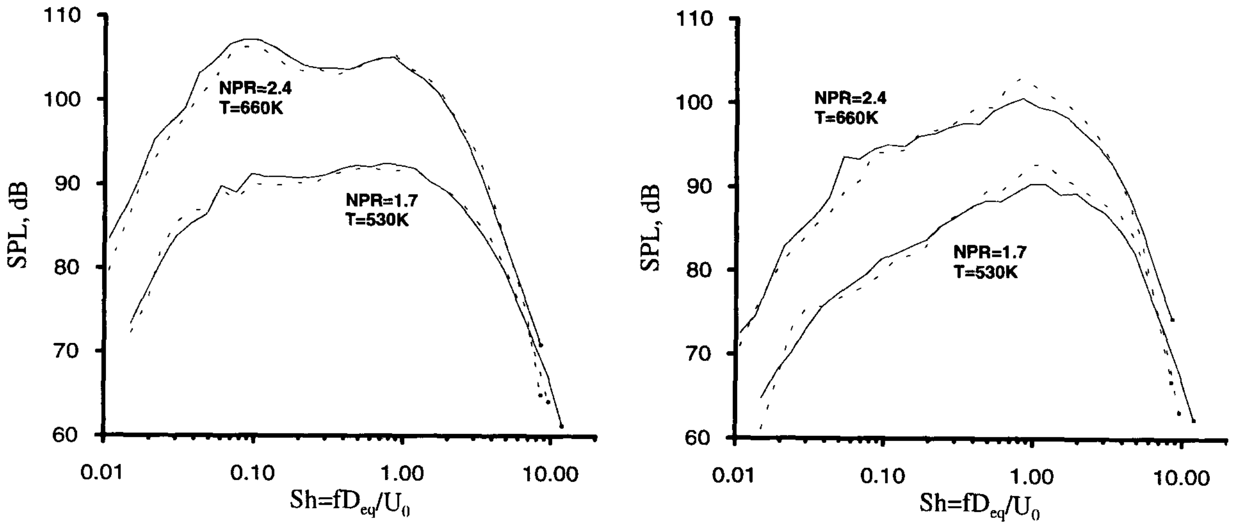
Fig.8. Comparison of the basic model and model with auxiliary slots in the ejector walls.
------ ejector with auxiliary inlets; —— basic mixer-ejector

The ejector with all walls acoustically treated. The additional treatment of ejector walls gives a little effect on the noise reduction (fig.9). It is necessary to notice, that measurements were conducted only in the plane parallel to additional treatment. In analogous studies of influence of the central body treatment[2] the effect was obtained only in the plane perpendicular to acoustic lining (about 2dB additional noise reduction). At high angles to jet axis the additional treatment can give a slight increasing of the mixer-ejector noise (fig.9.b). It is probably connected with interaction with high speed jet with acoustic treatment.

The influence of central body. The removing of the plug from the mixer gives the increasing of 'main jet maximum' in the noise spectra (fig.10) It can be seen at all NPR and all angles to the jet axis SPL in the intermediate frequency ranges for plugged nozzle is lower than for nozzles without central body. Shifting the lobes in the mixing nozzle (fig.1e) leads to the decreasing of the spectra at the high frequencies.

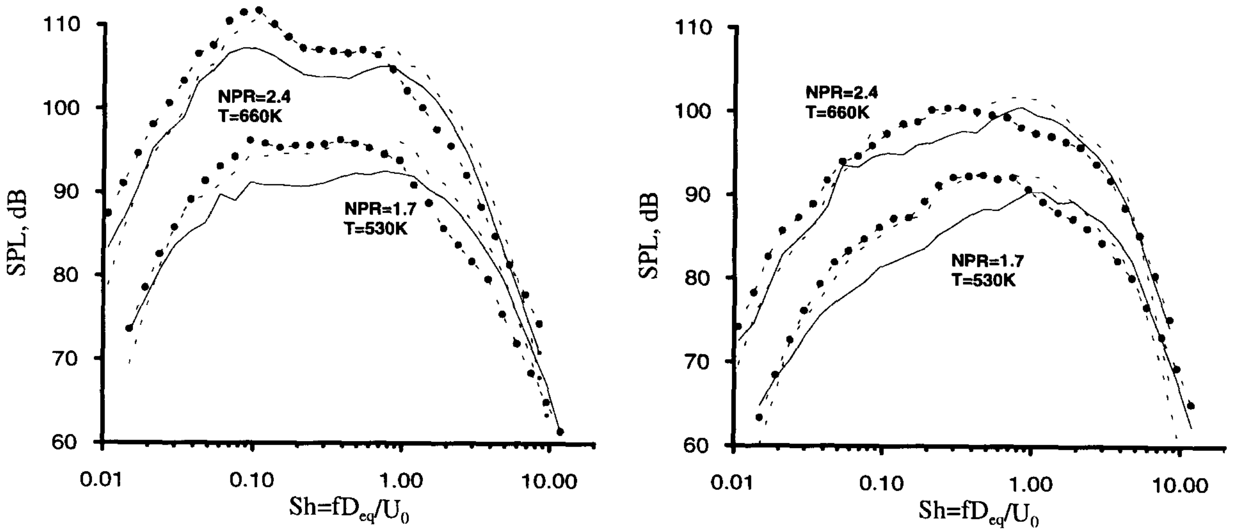
DISCUSSION

The model experimental data could be used to calculate the noise suppressor efficiency in Effective Perceived Noise Level (EPNL). It was supposed that aircraft have 4 engines and its take-off weight is about 350T. The EPNL calculation procedure is described in works[1,2]. The differences between researched model (fig.1b-1e) EPNL and basic model (fig.1a) EPNL are cited in the table 2 for side-line check point. The sign "+" means that the noise increases comparing to basic model, "-" - noise decreases. Data in the table 2 show that practically all studied variations of constructive parameters of mixer-ejector, except the additional acoustic treatment of the ejector walls, led to worsening of the acoustic efficiency of the system. The additional acoustic treatment gave about 1EPNdB additional noise reduction.



a). ϑ=30° b). ϑ=90°

Fig.9. An influence of additional acoustic treatment of ejector walls.
------ all side lined ejector; —— basic mixer-ejector



a). ϑ=30° b). ϑ=90°

Fig.10. An influence of central body on acoustic performances.
---- basic model without plug; -•-•- basic model without plug with shifted lobes; —— basic mixer-ejector

Table 2. Take-off (side line) check point.

Regime parameters	Auxiliary inlets	Additional acoustic treatment	Nozzles without plug	
			basic model	shifted lobes
NPR=1.7, T=530K	+3.0	-1.1	+0.2	
NPR=2.4, T=660K	+2.1	-0.1	+1.7	+1.3
NPR=2.8, T=700K		-0.8	+1.3	

The EPNL calculations show that the basic configuration studied in the previous works was close to optimum for constructive restrictions imposed on the model geometry[1,2] (number of lobes, length and width of ejector, critical area of the nozzle, etc.) and slight variations of mixer-ejector elements, apparently, will not give an essential improvement of mixer-ejector acoustic performances. Only the considerable changes in the mixer-ejector construction (i.g. increasing of the number of lobes, changing of system proportions, etc.) can give essential increasing of noise reduction comparing to the basic model.

ACKNOWLEDGMENT

The present work was carried out within the project # 200 sponsored by the International Science and Technology Center (ISTC).

REFERENCES

1. S.Ju.Krasheninnikov, A.K.Mironov, E.V. Pavlyukov, V.K. Jitenev, J. Julliard, E. Maingre. An experimental study of 2-D mixer-ejector nozzle noise and thrust characteristics. AIAA Paper No. 96-1668, 1996.
2. S.Ju.Krasheninnikov, A.K.Mironov, V.Iv.Vasiliev, E.V.Pavlyukov, V.K.Jitenev, M.Goutines, J.Julliard, E. Maingre, H.Joubert. An model study of acoustic efficiency of the 2-D mixer/ejector nozzle for jet noise suppression. Fourth international congress on sound and vibration. St. Peterburg 1996.
3. W.K.Lord, C.W.Jones, A.M.Stern, V.L.Head, E.A.Krejsa. Mixer Ejector Nozzle for Jet Noise Suppression. AIAA 90-1909, 1990, 19 p.
4. Brooks J.R., McKinnon R.A., Johnson E.S. Results from Flight Noise Tests on a Viper Turbojet fitted with Ejector/Suppressor Nozzle Systems. Douglas Paper 6961, 1980.
5. M.A.Nukhtikov, V.K.Jitenev, A.V.Shenkin. Experimental Investigation of Thrust Performance and Mixing Processes in A 2d-Mixer/Ejector Nozzle. Second Seminar on Recent Research And Design Progress in Aeronautical Engineering and Its Influence on Education. Warsaw University of Technology. Warsaw, 25-27 November, 1996.
6. Gas turbine jet noise prediction - SAE Committee Correspondence, 1975.