EXPERIMENTAL INVESTIGATION OF ACOUSTIC EFFICIENCY OF CHEVRON NOZZLES FOR HIGH BY-PASS AVIATION ENGINE.

Alexey Mironov, Sergey Krasheninnikov, Vladimir Maslov

Central Institute of Aviation Motors (CIAM), Aviamotornaja, 2, 111116, Moscow, Russia
email:akomir@mail.ru

Acoustic characteristics of jet after high by-pass ratio chevron nozzle assembled with pylon and wing were experimentally investigated. The model nozzle was a prototype of exhaust system of advanced civil aviation engine with high (about 12) by-pass ratio. Experiments were carried out on small scaled models, scaling factor was approximately 1:60 in relation to actual aviation engines. The main parameters of real two-stream exhaust nozzle (total pressures and temperatures) were modeled during experiments. Experiments were conducted as under static conditions as under modeling of external stream (M_e=0.28). The diameter of external flow nozzle was equal to 100 mm. Chevrons was installed on outer nozzle only. The jet noise patterns and spectra were measured at different azimuthal angles. It was shown that chevrons decrease overall jet noise on 1-1.5 dB at static conditions and on 0.5-1 dB under presence of external flow. It should be noted that proposed configuration of chevron nozzle did not generate excess high frequency noise (so-called “high frequency penalty”). Obtained experimental data were used to estimate the efficiency of chevrons in Effective Perceived Noise Level in EPNdB.
Keywords: aircraft noise, exhaust nozzle, turbulent jet, chevron nozzle

1. Introduction

Intensive studies of chevron nozzles for jet noise reduction have been conducted since 2000 ([1-6]. Both single stream [2, 4, 6] and by-pass [1, 3, 5] models of aviation engine exhausting nozzles were investigated. The typical transformation of 1/3-d octave spectra in acoustic field of jets after single stream chevron nozzles taken from [4] is presented in the fig.1. Here NPR – nozzle pressure ratio, T – total temperature, ϑ - observation angle relative to jet axis, α chevron inclination angle, SPL – sound pressure level.

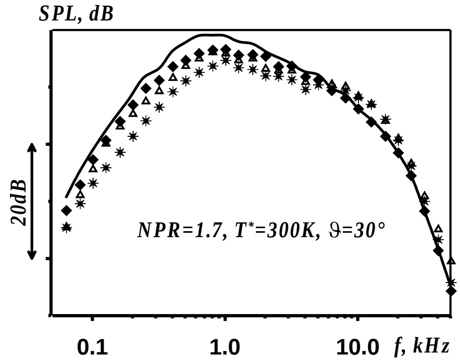

Figure 1. Jet noise spectra (— - round nozzle, ◆ - α=6°, ▲ - α=22°, ∗ - α=38°)

Data in the fig.1 show that under the small inclination angles (α) chevrons influence only on low and middle frequency part of the spectra. There are no visible changes of the spectra at high frequency comparing to reference nozzle. The greatest reduction of SPL is occurred near the maximum of spectra and reaches 3-4dB at low angles of observation (ϑ). Increasing of the inclination angle (α) leads to further reducing sound pressure levels at low and middle frequencies. However this reducing is accompanied with growth of high frequency part of the noise spectra (so-called, “high-frequency penalties” [6]). Analogous effects were pointed out in other works.

Analysis given in [4, 5] shows that longitudinal vorticity created near nozzle exit plane by chevrons plays main role in efficiency decreasing of acoustic radiation of a jet.

When assembling the engine with airframe the deformation of the exhaust jet is occurred due to its interaction with the elements of the frame - pylon, wing, flaps. The jet flow becomes asymmetric, respectively its acoustic field becomes non-uniform also. The reflection of sound from the wing surface amplifies these effects. Moreover, there may appear the additional noise sources associated with the boundary vortexes formed in the flow around the flap.

It is known, that jet after nozzle assembled with pylon has acoustic azimuthal non-uniformity about 1-2 dB [7]. The presence of a wing sharply amplifies this irregularity. Azimuthal non-uniformity of jet acoustic field can gain value 7-9 dB when external flow is presented. The detailed analysis of jet-flaps-interaction (JFI) is given in [8-9].

JFI effects and external flow affect the noise reduction when using chevron nozzles. The acoustic efficiency of chevrons application can be increased as it happens in the interaction of the jet with pylon in the absence of wing. In this case chevrons decrease azimuth non-uniformity of jet acoustic field and significantly reduce noise at the side of pylon. However in the literature there are some cases when at static condition chevrons decrease jet noise and at flight simulation they lead to overall noise amplification [10]. That is why the investigations of chevron influence on jet noise under full conditions (pylon, wing, flaps, and external flow) have a great interest.

The main purpose of presented research is the experimental investigation of the efficiency of application of chevron nozzles for high by-pass (BPR≈12) aviation engine. Model of nozzle of perspective high by-pass ratio engine in combination with pylon and wing was used. Experiments were carried both at static conditions and at the simulation of flight conditions - external flow.

2. Experimental set-up.

The experiments were performed at U-389 facility in CIAM. This facility was build up for modeling of co-axial jet of modern aviation engine. Central, high pressure compressor station was used to supply air to the co-axial nozzles. A low pressure centrifugal fan was used to supply air for the external airflow. Thermocouples and Pitot probes for controlling of test regimes were installed inside of all flow ducts.

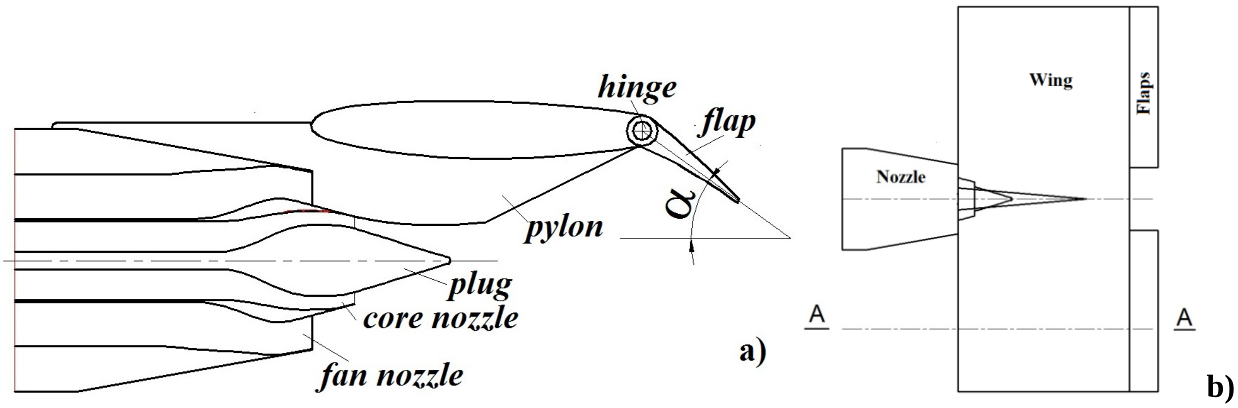

Figure 2. Scheme of model.

The schemes of investigated model are shown in the fig. 2. The bypass nozzle and pylon geometry presented in the fig. 2a-b were described in detail in previous work [7]. The characteristic diameter of fan nozzle was equal D_f=34 mm.

The shape of wing is very close to wing geometry from DLRF6 from AIAA Drag Prediction Workshop [11]. The front edge of the wing is located in the shear plane of fan nozzle. The flaps was fastened to the wing with a help of a hinges. Swing joint easily allow to adjust flap angle (α) continuously from α=0° to α=30°. In current work the flaps was installed at angle 20°. It is typical angle for take-off. Model has a gap between flaps (see fig. 2b). The width of a gap is equal $W=\Delta Y/Df$ =0.92. In present work the chevrons on the external nozzle was studied only. The relative length of chevron was L/D_f =0.2. Chevrons were placed uniformly; angle between adjacent chevrons was equal 30°. Scheme of the chevron nozzle is shown in the fig.3.

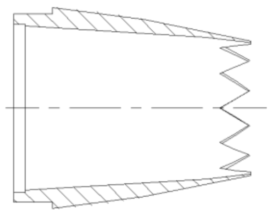

Figure 3. Nozzle scheme.

Measurements were conducted under next flow parameters: NPR_c =1.28, T_c =815K, U_c= 335m/s, NPR_f =1.5, T_f =310K, U_f=261.1m/s. Me=0.28 (“Take-off” regime). Here Me is Mach number of external airflow. Subscript “c” corresponds to core nozzle (internal duct), “f” – to fan nozzle. The nozzle bypass ratio (BPR) at take-off regime was about 12.3.

Sound pressure levels in 1/3-octave bands (SPL) were measured using 1/4″ G.R.A.S.S. microphones. High-frequency correction was performed according to microphone frequency response. The frequency range of measurements was from 500 Hz up to 100 kHz. At characteristic jet flow parameters it corresponds to Strouhal numbers 0.05-10. This is enough for an accurate measurement of overall sound pressure levels (OASPL). The microphone was placed at a distance $R/D_f \approx 20$ from the model exit at different polar angles (θ=0÷90°) relatively to jet axis and three azimuth angles (Φ=180°, 45° and 90°). Scheme of measures is shown in the fig. 4.

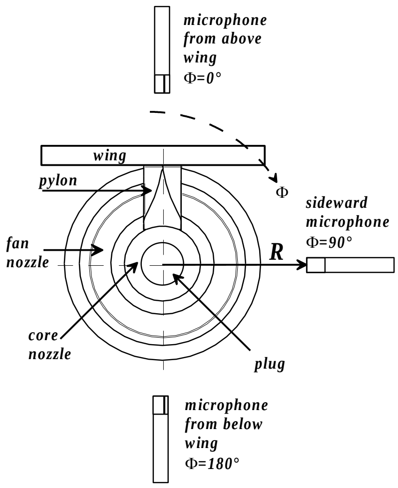

Fig.4. Scheme of measurements

Specially conducted verification of acoustic measurements shows that experimental data obtained at relatively small U-389 facility are in a good agreement (in limits within 1-1.5dB) with known results of acoustic measurements performed at large scale models. Detailed results of verification are described in [7].

3. Experimental results.

In the fig. 5 the data, obtained in present investigation are compared with results [12].

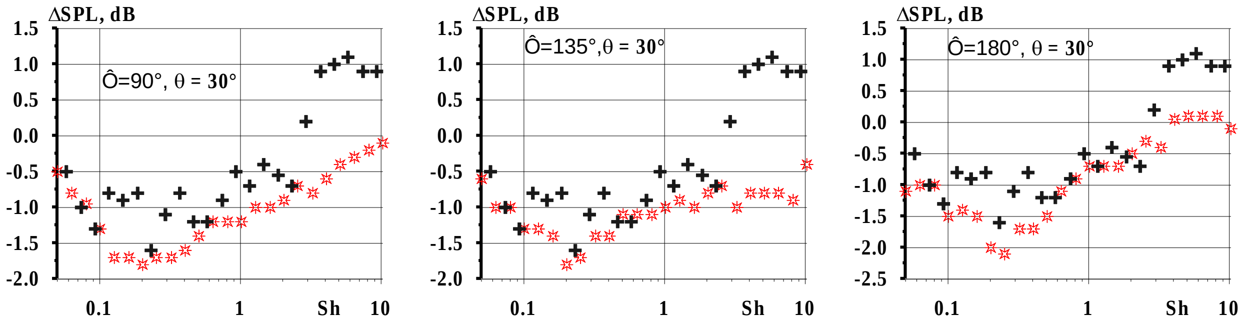

Figure 5. Difference of 1/3-d octave spectra in acoustic field of jets after chevron and round nozzles. Static condition. ∗ - present work, + - [12] large scale model without wing.

In both cases the external flow is absent. The working conditions and nozzle contours are practically identical. The differences in experiments are in model scale (in [12] model is four times bigger) and in the absence of the wing in experiments [12]. Data are presented for angle θ=30° - maximum of overall jet acoustic radiation throughout noise pattern. The Strouhal number was calculated using fan nozzle diameter and “fully mixed jet” velocity. Negative data are corresponding to noise reduction, positive – to amplification (high frequency penalties). It can be seen that in both cases chevrons reduce jet noise near maximum of spectra on the value about 1-.1.5 dB. However in present investigation “high frequency penalties” were not detected in contrast to results in [12]. It should be noted that this fact have a place for all experimental results obtained in preset work independently of presence or absence of external flow. It could possibly connect with reducing of additional noise of jet flaps interaction under using of chevron nozzle.

Special series of experiments was carried out to allocate the jet noise from common acoustic radiation of model (fig. 2). For these purpose the measurements of spectra of the pure jet of external flow only (without of nozzle-pylon-wing model) and spectra of external flow when the model was installed in the facility, but pressure was not fed to the nozzle, were carried out. The results of measurements below the wing are plotted in the fig. 6. Here no correction of microphone frequency response was made. (These experiments were conducted without chevrons in the methodological purpose only).

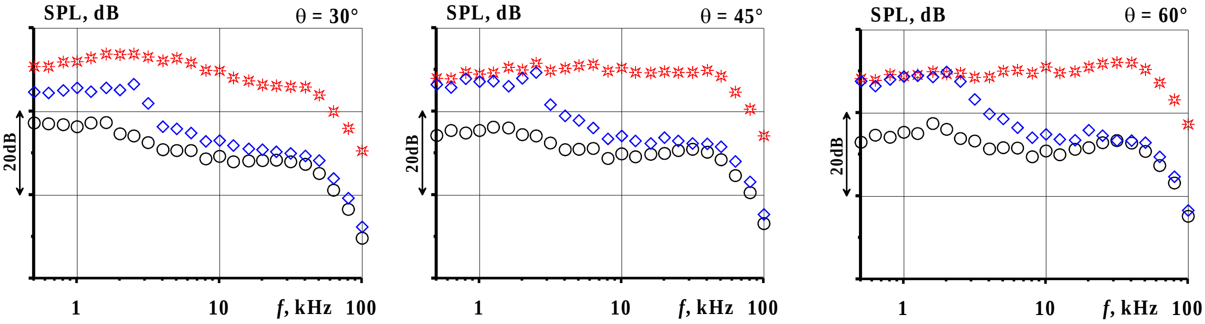

Figure 6. 1/3-d octave spectra. Φ=180°.* jet with external flow, ◇ - noise of model blowing, ○ - external flow only.

Distinctly seen, that at small observation angles (θ<45°) jet noise (including jet flaps interaction) is dominated above the rest noise sources in a whole frequency diapason. At θ>45° the noise of model blowing is a main source of acoustic radiation at frequencies below 3 kHz (Sh<0.3). Analogous data were obtained for azimuth angles Φ=135° and 90°. That is why we cannot expect any influence of chevrons at these angles and frequencies at flight condition (the presence of external blowing). Next pictures are confirmed this statement.

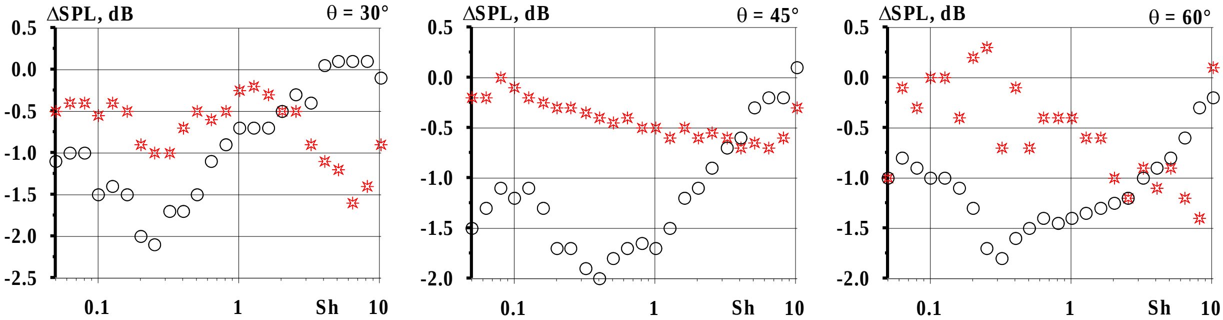

Figure 7. Difference of 1/3-d octave spectra in acoustic field of jets after chevron and round nozzles (Complete model with pylon, wing and flaps).

○ - static condition. ∗ - flight condition. Φ=180° (below the wing)

In the fig. 7 the influence of chevron nozzle on jet noise at static and flight conditions are shown.

As it was expected the noise reduction by chevrons at low frequencies under flight condition is minimal in contrast to static measurements. However at high frequencies the acoustic efficiency of chevrons occurs greater in the presence of external flow. As it mentioned above it can be connected with reducing of additional noise of jet flaps interaction.

Table 1. Efficiency of chevron nozzle in EPNdB

ΔEPNL, Φ=180°		ΔEPNL, Φ=90°		ΔEPNL, Φ=135°	
static condition	flight condition	static condition	flight condition	static condition	flight condition
-0.92	-0.87	-1.09	-1.00	-0.87	-1.13

In the table 1 the results of efficiency of chevron nozzle in EPNdB are presented. Detailed procedure of ΔEPNL calculations on the base of experimental data are given in [13].

When calculated Perceived Noise Levels the high frequencies SPL are considered with greater weight coefficients [14]. That is why estimation of EPNL reduction, based on present experimental data, due to chevrons gave the approximately the same results for static and flight conditions. It can be seen that instead of differences of spectra transformation under of static and flight conditions (fig. 7) the overall results of noise reduction in EPNdB is approximately the same.

CONCLUSIONS

Acoustic characteristics of jet after high by-pass ratio chevron nozzle assembled with pylon and wing were experimentally investigated. The model nozzle was a prototype of exhaust system of advanced civil aviation engine with high (about 12) by-pass ratio.

Experimental results show that chevrons reduce overall jet noise by 1-1.5 dB at static condition and by 0.5-1 dB at flight simulation. Without external flow chevrons suppress jet noise in the region of spectra maximum by value about 2 dB. When using chevron nozzle of investigated configuration there is no noticeable noise amplification at high frequency observed. The “high frequency penalties” are practically absent.

Under modelling of the flight condition no pronounced noise reduction in the area of spectra maximum is occurred. On other side in contrast to static conditions chevrons noticeably suppress jet noise at high frequencies – by 1.5 - 2 dB. This is apparently due to fact that in the presence of external flow the additional noise sources connected with JFI are appeared. Chevrons modify flow structure and suppress this noise.

One of the main questions of this study is: how accurately can we transfer model data to real conditions. Here two factors are essential: the influence of model scale and feature of wing and flaps design. The comparison of results obtained for models of different scale (fig. 5) confirms the possibility of using of Strouhal number for converting experimental data from present work to full-scale conditions. Construction features of model have a strong influence on results of experiments.

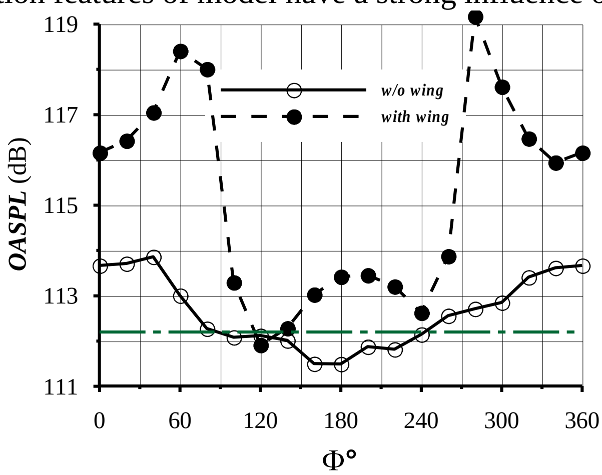

Figure 8. Azimuthal non-uniformity of jet acoustic field [7].

The jet-flaps-interaction can give 7-9 dB of azimuthal non-uniformity of jet acoustic field. The typical dependence of total jet noise from azimuth angle taken from [7] is presented in the fig. 8. Overall sound pressure levels of axisimmetric by-pass jet (without pylon and wing) are shown in the fig. 8 with dash-dot line. Empty circles correspond to nozzle with pylon, filled – to the nozzle with pylon and wing. It can be seen, that below the wing (Φ=120°-240°) the dependence of OASPL from azimuth angle is not so strong (in limits ≈ 1dB). From the side of the wing (Φ=60°-120°) a large gradient of this dependence is occurred. The form of OASPL curve depends on wing shape, flap inclination angle and polar angle (θ). However, it should be mentioned that the main features of this curve (low gradient below wing and large gradient at the side) remain the same. At the same time effect of chevrons can be various in dependence on azimuth angle (especially in the zone of large gradient) and positional relationship of nozzle and wing. To all appearances the differences of these factors are the main reason for dissimilarity between result of presented report and work [10] where chevrons under external flow conditions gave noise amplification.

In this way the results of presented work can be applied to the real conditions only if configuration of chevron nozzle, wing and flaps shape, wing-nozzle arrangement are close to investigated model.

ACKNOWLEDGMENT

The present work was supported by the project RFFI # 17_01_00213_a.

REFERENCES

1 Janardan B., Hoff G., W. Barter J., Martens S., Gliebe P., Mengle V., Dalton W. AST Critical Propulsion and Noise Reduction Technologies for Future Commercial Subsonic Engines Separate-Flow Exhaust System Noise Reduction Concept Evaluation. *NASA/CR—2000-210039*, 2000.

2 Krasheninnikov S.Yu., Mironov A.K., Pavlyukov E.V., Jitenev V.K. An investigation of possibility of turbo engine exhaust jet noise reduction using chevron nozzles. *Proceedings of the 6th Intrnational Symposium "Transport Noise and Vibration"*, St. Peterburg, Russia, 3-5 June 2002. Published by EEAA p.7.

3 Saiyed Naseem H., Mikkelsen Kevin L., Bridges James E. Acoustics and Thrust of Quiet Separate-Flow High-Bypas-Ratio Nozzles. *AIAA Journal*, Vol.41, No. 3, March 2003, p.372-378.

4 Krasheninnikov S.Yu., Mironov A.K. Effect of the Streamwise Component of Vorticity Formed in a Turbulent Jet Source on the Acoustic Characteristics of a Jet. Fluid Dynamics, Vol. 38, No. 5, 2003, pp. 698-711.

5 Krasheninnikov S.Yu., Mironov A.K. Experimental investigation of chevrons influence on the noise of co-axial jets. *Proceedings of the 11th International Congress on Sound and Vibration*, St. Peterburg, Russia, 5-8 July 2004. Published by IIAV p.8.

6 Bridges, J., Brown, C. Parametric Testing of Chevrons on Single Flow Hot Jets," AIAA 2004-2824, 2004.

7 Lyubimov D., Maslov V., Mironov A., Secundov A., Zakharov D. Experimental and numerical investigation of jet flap interaction effects. *International journal of aeroacoustics*, Vol.13, No.3&4, pp.275-302, 2013.

8 Mengle V., Brusniak L., Elkoby R, Thomas R. Reducing Propulsion Airframe Aeroacoustic Interactions with Uniquely Chevrons: 3. Jet-Flap Interaction. *AIAA 2006-2435*.

9 V. Mengle. The Effect of Nozzle-to-Wing Gulley Height on Jet Flow Attachment to the Wing and Jet-Flap Interaction Noise. *AIAA 2011-2705*.

10 Victor Kopiev, Investigations of jet-flap interaction noise in tsagi. *Proceedings of the 22nd International Congress on Sound and Vibration*, Florence,l Italy, 12-16 July 2015, pp. 7.

11 Brodersen O., St¨urmer A. Drag Prediction of Engine–Airframe Interference Effects Using Unstructured Navier–Stokes Calculations. *AIAA 2001–2414*.

12 Mironov A, Krasheninnikov S. An Influence of Pylon Shape on Jet Noise and Flow-Field. *Proceedings of the 18th International Congress on Sound and Vibration*, Rio de Janeiro, Brazil, 10–14 July, (2011). v.2, P. 1050-1056.

13 Krasheninnikov S., Mironov A., Paulukov E., Shenkin A., Zitenev V.. Mixer-Ejector Nozzles, Acoustic and Thrust Characteristics. *International journal of aeroacoustics*, Vol. 4, No.3+4, pp.267-288 (2005).

14 International Civil Aviation Organization. International standards and recommended practices. Aircraft noise. Annex 16 to Convention on International Civil Aviation. Fourth Edition. July 2005.