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NOISE AT SUPERSONIC JET INTERACTION WITH A DEFLECTOR

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Abstract. Analysis and generalization of experimental data on unsteady surface pressures and outer broadband acoustic field generated at supersonic jet impingement on an inclined surface are presented. At least four independent regions of noise generation for the system "jet + inclined deflector" exist: region of undisturbed jet between nozzle exit and deflector, strong interaction region (region of direct jet impingement and flow), jet spreading over deflector surface and the deflector as a reflector of acoustic radiation. Integral acoustic power of noise radiated by the system “jet - deflector”, inputs of different regions of noise generation into the integral acoustic power, and, by analogy with acoustics of free jets, acoustic efficiency of the system “jet- obstacle” are estimated for different supersonic gas jets interacting with normal flat plate and with two-slope gas deflector mounted on the flat plate in the frame of semi-empirical technique

1. INTRODUCTION

Studies on acoustic environment resulting from subsonic and supersonic jets interaction with a deflector have been carried out during many years. Paper[1] contains a thorough review and bibliography on early investigations and includes a semi-empirical method for predicting acoustic environment resulting from supersonic jet interaction with a deflector based on a model of "free jet deflection". The jet itself (from a nozzle exit to the deflector), jet spreading over the deflector (it has the same characteristics as free jet), and noise reflection from the deflector are considered to be sources of noise generation. Analysis of later works on this subject and refinement of the above model are presented in papers[2,3]. But such approach does not always agree with experimental data since, firstly, it does not take into consideration all regions of noise generation on the deflector and, secondly, there is a problem with an assignment of characteristic scales for acoustic sources distributions which represent noise generation regions[2-4].

Detailed analysis of noise generation regions in the case of jet interaction with a flat plate deflector is given in papers[5,6]. It is shown that broadband acoustic field induced by an interaction of supersonic jet with normal flat obstacle essentially differs from acoustic field caused by free exhausting jet.

Numerous experimental investigations have revealed that:

- Acoustical efficiency (ratio the sound power to the jet mechanical power) of the system "jet + flat obstacle" may account for 30 ÷ 150% of the acoustical efficiency of the free jet depending on the distance $\hat{H} = H/D_a$ between nozzle exit and deflector, D_a – nozzle exit diameter. Maximum value is reached at $\hat{H}$ = 10 -20.

- Schlieren flow visualization shows that there is an intensive acoustic radiation from region of direct jet impact (jet "spot"). For relatively small $\hat{H}$ this radiation predominates over acoustic radiation from jet itself.

- Measurements of normalized space - time correlation coefficients show that a noticeable correlation between a point in acoustic field and points on the obstacle surface is observed only for the points located immediately in the region of direct jet impact.

- Characteristics of sound pressure in the acoustic field upwards nozzle exit measured with shielding of the jet spreading over the obstacle by screens having holes with diameters $d \leq 2.5 \div 3.0D$ (D - jet diameter at the section of interaction with the deflector) are practically the same as without shielding.

- OASPL L_Σ in the outside acoustic field for $\hat{H} \approx 0.5 \div 20$ are proportional to the maximum of overall level of pressure fluctuation on obstacle surface in the region of direct jet impact (jet "spot") which depends on gasdynamic parameters of the jet and a distance between nozzle exit and obstacle.

- One third octave spectra of acoustic pressure $L_{1/3}(f)$ induced in outside acoustic field by the jet "spot" region may be found from universal empirical relation $L_{1/3}(f) - L_\Sigma = F(Sh/Sh_{max})$, $Sh = fD_j/u_j$, $Sh_{max} = K(R/D_j,, \varphi, a_\infty/a_j)$. Here: f - frequency, a_∞ - speed of sound in ambient environment, (R, φ) – polar coordinates of observation point with the origin in critical point on the obstacle surface.

Therefore the interaction of the jet with flat deflector results in appearing of additional region of noise generation. The following regions of noise generation may be highlighted: undisturbed jet region from nozzle cut to the obstacle, jet "spot" on the obstacle, the obstacle as a reflector of acoustic radiation. As concern acoustic radiation from spreading jet experimental data shows that it can be neglected due to very quick decay of this wall radial jet. The contribution of each source noise in the integral acoustic field induced by a system "jet + flat obstacle" varies with a distance between nozzle exit and obstacle.

This paper deals with the analysis of peculiar properties of noise generation for typical case of jet interaction at launch vehicle lift-off - jet interaction with inclined jet deflector.

2. EXPERIMENTAL DATA ANALYSIS

Fig.1 illustrates influence of jet deflector shape on overall sound pressure level (OASPL) L_Σ and 1/3-octave sound pressure spectrum $L_{1/3}(f)$ in the point located at the distance about $0.5D_a$ upstream nozzle exit. A difference $\Delta L_\Sigma = L_\Sigma(\hat{H}) - L_\Sigma(\hat{H} = \infty)$ is plotted against $\hat{H} = H/D_a$, H is a distance between the nozzle exit and the plate, $\hat{H} = \infty$ corresponds to free jet (there is no deflector), M_a - Mach number at the nozzle exit, T_0 – jet stagnation temperature, n - a ratio of static pressure at nozzle exit to ambient pressure, D_a - nozzle exit diameter. For any considered case the most value of OASPL

L_Σ is observed when the nozzle is positioned near the deflector, with $\hat{H}$ increasing OASPL falls and tends to the value for free jet, maximum values of OASPL corresponds to normal jet impingement. The presence of a gas deflector on the plate decreases noticeably low frequency spectral components. Presented data corresponds to relatively small values of $\hat{H}$. Since acoustic radiation from free jet portion between the nozzle and the deflector in this case is relatively small so considerable variation of noise characteristics for different gas deflectors can't be explained by sound reflection and it is connected with difference in noise generation in flow over gas deflector surface. The difference of flow over conical axisymmetric deflector and single slope "plane" deflector is evident.

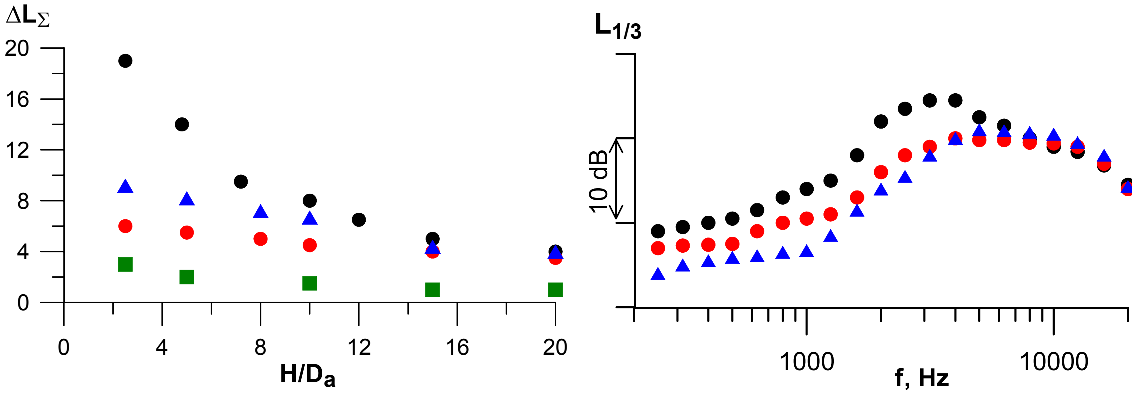


Figure 1. The influence of jet deflector shape on overall sound pressure level and 1/3-octave sound pressure spectrum ($M_a = 3{,}5$; $n = 1{,}0$; $T_o = 300K$)
● - plate; ■- inclined plate; ▲ - two-slope deflector; ● - conical deflector

Typical distributions of static pressure P and rms levels of pressure fluctuations $\hat{H}$ along single slope deflector surface when jet impinging are presented in Fig.2. As for normal jet impingement on a flat plate[5,6] two main regions of flow can be distinguished: a zone of direct jet impingement and flow turn (region of strong interaction), where pressure fluctuation on the surface is very high, and a zone of spreading wall jet with gradually decreasing pressure fluctuations. As distinct from normal flat plate case due to lower jet interaction intensity region of strong interaction is more extended and spreading wall jet is more long-range.

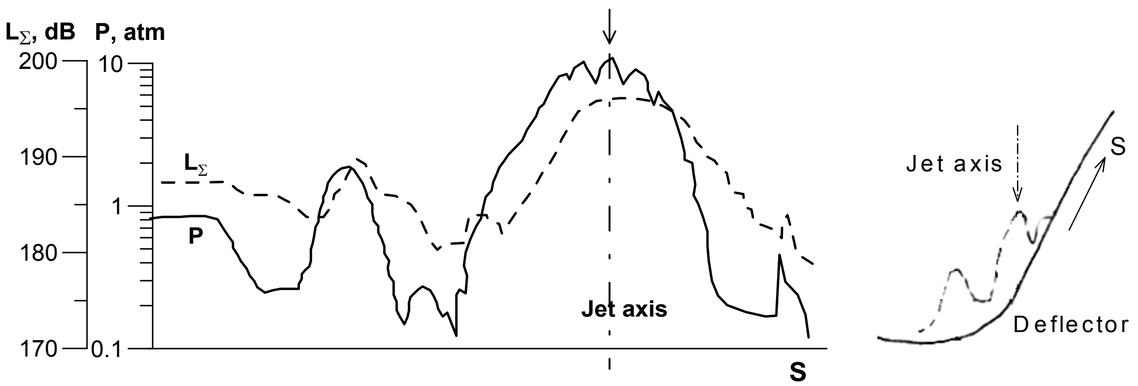


Figure 2. Typical distributions of static pressure P and rms levels of pressure fluctuations L_Σ. along generatrix of single slope deflector surface ($M_a = 3{,}0$; $n = 0{,}9$; $T_o = 300K$, H/D_a=6,3)

Interaction intensity may be described by a ratio $\sigma_\Sigma / \sigma_{\Sigma(90°)}$ where σ_Σ - rms value of pressure fluctuation in the point of jet axis intersection with a surface of inclined deflector, $\sigma_{\Sigma(90°)}$ - rms value of pressure fluctuation in the point of jet axis intersection with a normal flat plate, α - deflector inclination angle (Fig.3).

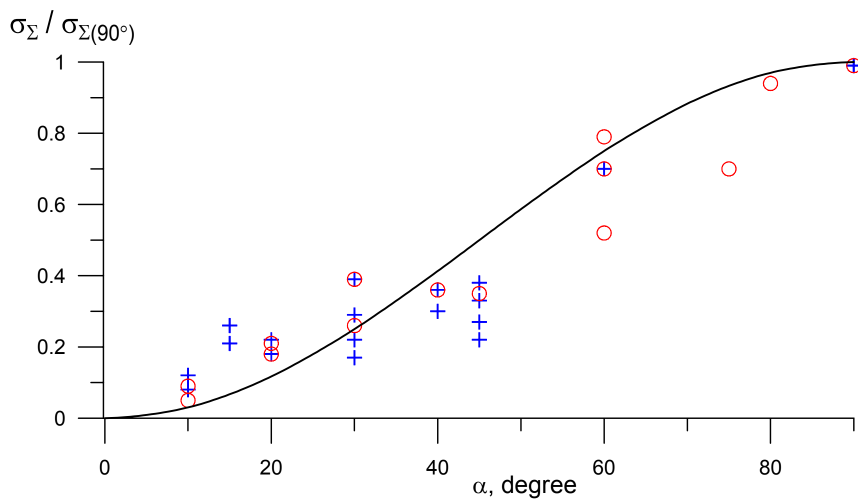


Figure 3. Jet interaction intensity

— $\sigma_\Sigma / \sigma_{\Sigma(90°)} = \sin^2\alpha$; + - H/D_a = 12-30; ○ - H/D_a = 6-10

Measurements of normalized space - time correlation coefficients R, presented in Fig.4, show that a noticeable correlation between a point in acoustic field and points on the single slope deflector surface is observed not only for points located immediately in the region of direct jet impingement (as for normal flat deflector) but for region of flow turn. This fact and results of optical investigations have shown that there is an intensive acoustic radiation from the region of strong interaction. At some distance from inclined deflector surface the radiation may be considered as spherical.

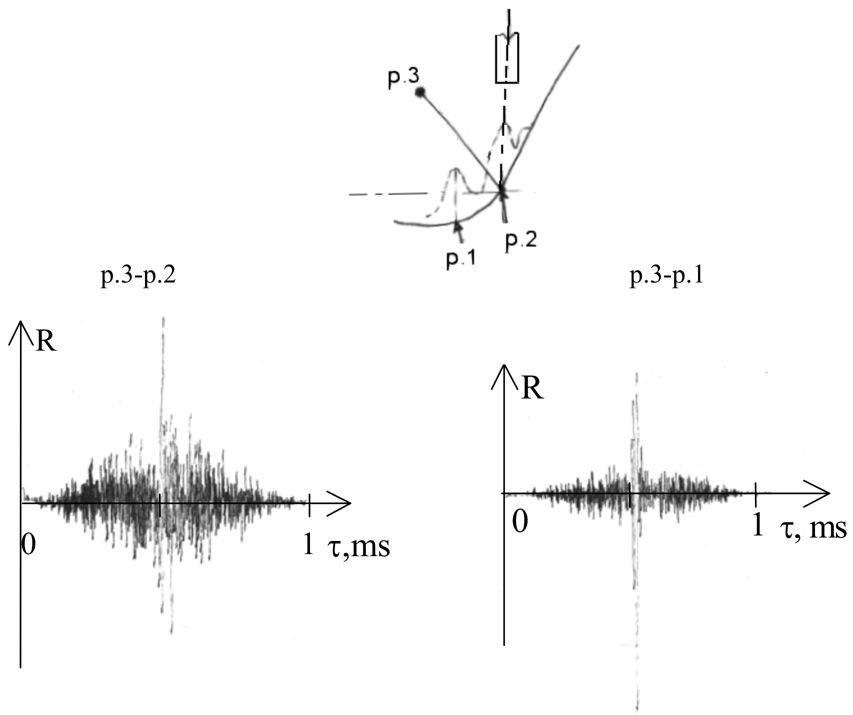
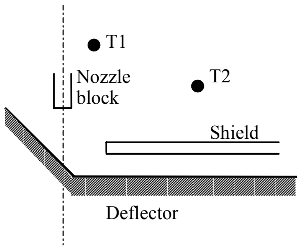


Figure 4. Measurements of normalized space - time correlation coefficient

Fig.5 presents typical result of investigations on shielding of acoustic field generated by jet spreading over deflector. Quantity $\Delta L_{1/3}$ is a difference of 1/3-octave spectra in tests with and without shield. The data indicate that acoustic radiation from spreading jet is a considerable as distinct from the case of jet interaction with a normal plate[5, 6].



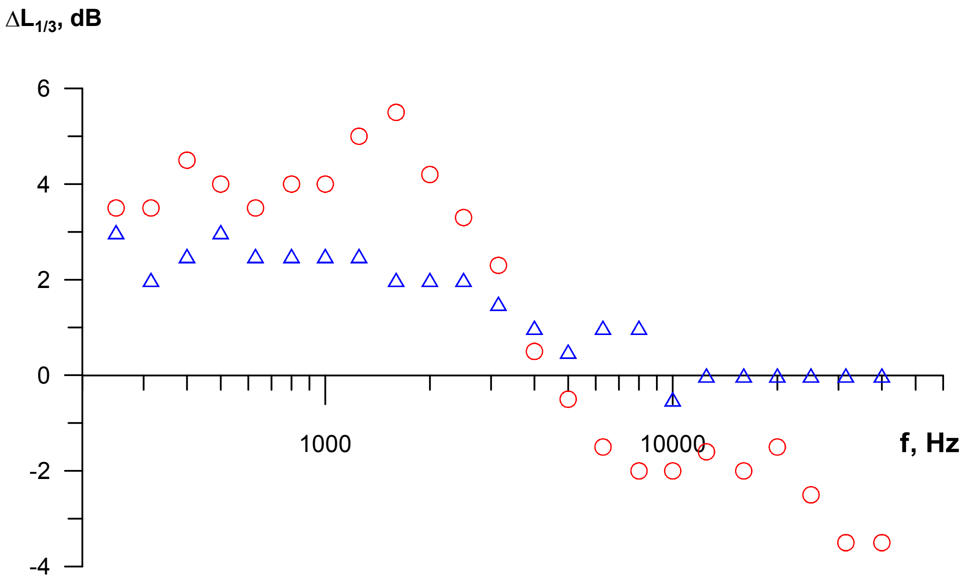


Figure 5. Dependency $\Delta L_{1/3}$ against jet acoustic radiation frequency f
(○ – in point T1, △- in point T2); $M_a = 3{,}2$; $n = 1.0$; $T_o = 2200K$; $H/D_a = 4{,}0$

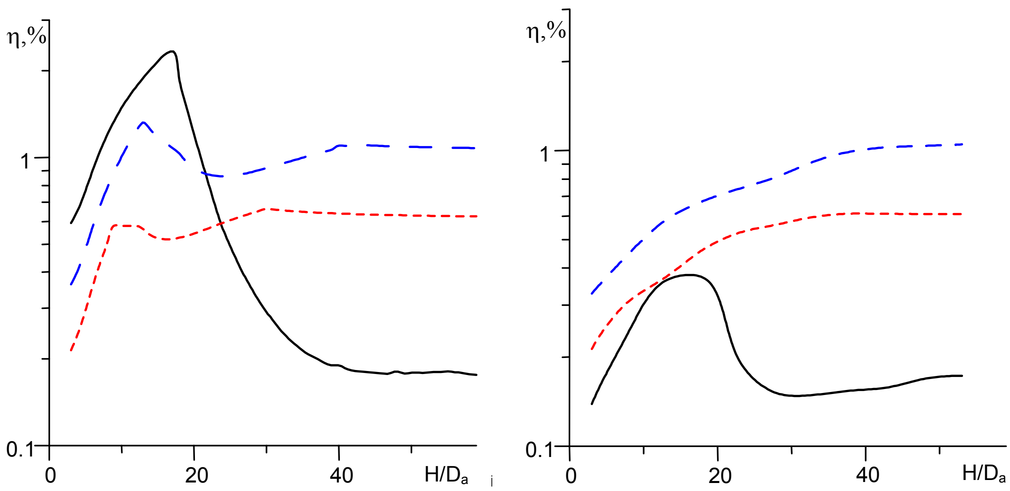
3. ACOUSTIC MODEL OF SUPERSONIC JET INTERACTION WITH A DEFLECTOR MOUNTED ON A FLAT PLATE

Experimental investigations carried out in a wide variation range of supersonic jet parameters with various values of the deflectors parameters, jet lateral displacements, and a distance from the nozzle exit to the deflector have shown that in the contrary to the case of simple flat plate deflector the noise generation region on the deflector and flat plate is rather extended. It is necessary to separate the region of jet impingement with the deflector (the region of strong interaction) and the jet spreading over the deflector and flat plate surface. So four independent regions of noise generation exist: undisturbed jet from nozzle exit to a deflector, region of strong interaction between jet and deflector, the jet spreading over deflector and flat plate, deflector and flat plate surfaces as reflectors of acoustic radiation.

The acoustic model uses a superposition of contributions from different noise generation regions. The contribution of each source of noise into integral acoustic field varies with a distance between a nozzle and a gas deflector and with transverse displacement of a nozzle with respect to deflector. Each noise generation region is represented by a system of independent acoustical sources with prescribed acoustic power and spectrum of acoustic radiation. Spectral characteristics of resultant acoustical field and overall sound pressure levels are determined by summation of inputs from each source using geometrical acoustics approach. Acoustical characteristics of sources are determined by the generalization of numerous experimental data. General scheme of calculations and acoustical characteristics of sources are presented in paper[7].

As distinct from interaction model described in papers[1, 2], in the present interaction model parameters of acoustic sources are prescribed independently, and their values are defined by jet thermodynamics, the deflector geometry and a distance between the latter and the nozzle exit. Thus integral acoustic power of noise radiated by the system “jet - deflector”, inputs of different regions of noise generation into the integral acoustic power, and, by analogy with acoustics of free jets, acoustic efficiency of the system “jet- obstacle” have been estimated for different supersonic gas jets interacting with normal flat plate and with two-slope gas deflector mounted on the flat plate

Variation of acoustic efficiency for the system “jet – deflector” $\eta = W_a/W_{mech}$ with a distance between nozzle exit and deflector is shown in Fig.6 (W_a – integral acoustic power of noise radiated by the system, W_{mech} - jet mechanical power, H/D_a- the distance between the nozzle exit and obstacle).



a) b)

Figure 6. Acoustic efficiency of the system "jet-deflector" (M_a=3.0)
a) normal plate, b) double-slope deflector
—— - *To* = 300K, γ = 1.4; – – – - *To* = 1030K, γ = 1.4; - - - - - *To* = 2500K, γ = 1.25

Input of different region of noise generation into integral acoustic power of the system is illustrated by calculation results in Fig.7. Here W_j – acoustic power of noise generated by undisturbed jet region including its reflection from deflector, W_{sj} – acoustic power of noise generated by the jet spreading over the obstacle including its reflection from two-slope deflector, W_{int} – acoustic power of noise generated by strong interaction region, W_a – integral acoustic power of the system.

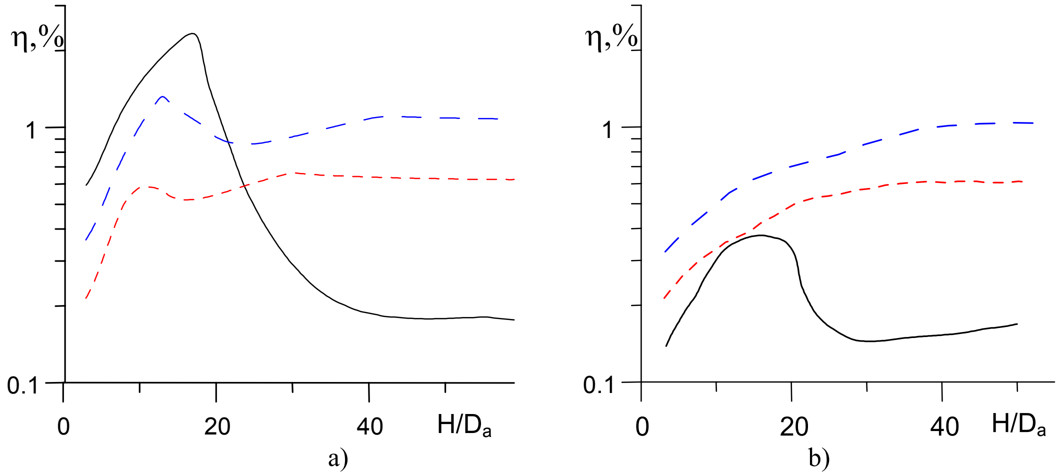


Figure 7. Input of different regions of noise generation (T_o = 2500K; γ = 1.25; M_a = 3.0)
a) normal plate, b) double-slope deflector
—— W_j / W_a – – – W_{sj} / W_a ------ W_{int} / W_a

It follows from the presented data that for discussed acoustic model of interaction the noise generated by system "jet - deflector" depends significantly on the jet parameters and the deflector geometry, unlike models presented in papers[1, 2].

4. CONCLUSIONS

By experimental evidence it is shown that the region of direct jet impingement on an inclined deflector, the same as for normal flat deflector, is an independent source of very intensive acoustic radiation which dominates at relatively small distances between nozzle and deflector.

Unlike the case of jet interaction with a normal flat deflector, acoustic radiation of the jet spreading over deflector and flat plate gives a considerable input into generated acoustic field.

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