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# ABOUT AERODYNAMIC AUTOMOBILE LEAK NOISE

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## 1. INTRODUCTION

The leak noise is one of the types of aerodynamic noise. It arises in case of design's or manufacturing's defects of vehicle passenger compartment's seals (doors, windows, vent openings), as well as in case of not absolutely closed window. At car's movement with high speed the zones of low air pressure are formed on lateral sides of body. If the door's or window's seals do not keep such difference, the gap will be formed due to seal's deformations and the air flow will appear through this gap. The intensively ejecting air flow generates a specific noise that can be perceived very unpleasant. That is why it is important to know mechanism of this noise creature and of its transmission from the source to the passenger compartment.

## 2. LEAK NOISE RADIATION AND PROPAGATION

The researches of aerodynamic automobile noise might be carried out as in road condition, as during the wind tunnel tests. The tests in wind tunnel give more objective results because there is only noise connected to aerodynamic present during these tests.

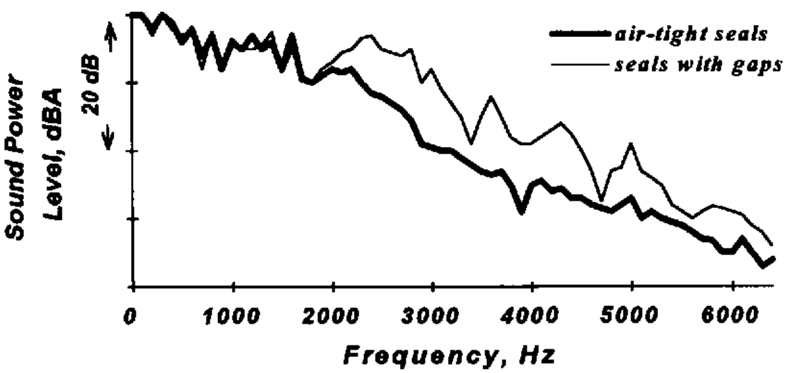


*Fig. 1*

In ideal case the aeroacoustic test in wind tunnel requires a "silent" air flow. We have carried out both types of the tests The work on research of leak noise was carried out on the automobile containing the side window seals with gaps. The figure 1 shows the spectra of interior noise received on car containing the side window seals with gaps as well as an absolutely air-tight car's passenger compartment. It is possible to see that tight closing of the window seals results to essential sound pressure reduction in frequent area 100-8000 Hz and especially in band 2000-3100 Hz. The absolutely closed window seals eliminate completely unpleasant whistling noise that was perceived subjectively in interior as inadmissible up to moment of its elimination.
From well-known aeroacoustic models, in reference to researching question, it is possible to consider a model of sound radiation of an ejecting gas stream. The model is based on fundamental theory of flow noise developed by Lighthill [1]. Considering a usual case, when a speed of vehicle increases up to 140 km/h, the velocities of the air flow ejecting from car do not exceed 0.1 Mach number.
It is theoretically established [2] that the sound power of ejecting stream in area of low Mach number ($P$) is defined as

$$P = k\frac{\rho_c^2 V^6 D^2}{\rho c^3},$$

where $k$ - const, $\rho_c$, $\rho$ - density of jet and air environment, $c$ - sound velocity, - velocity of ejecting stream, $D$ - reduced stream diameter.
The sound pressure levels in 1/1 octave band of 2.5 kHz as function of vehicle velocity are shown on figure 2. The experimental curve at figure 2 is a contribution of leak noise to internal car's noise. The velocity of air flow ejecting from car's interior made 21, 26, 31, 36 m/s while the car's speed was 80, 100, 120, 140 km/h accordingly. The thin direct line on figure 2 shows the dependence $L_p = 20\lg\frac{P}{P_0}$, where $P_0 = 20\cdot 10^{-6}\,Pa$, and $P = kV^6$, - velocity of ejecting air flow. I.e. leak noise sound power is proportionally to the sixth power of the air flow velocity ($V^6$) and thus the automobile leak noise is determined by theory for a low Mach number jet and it is described by sound source of a dipole type.

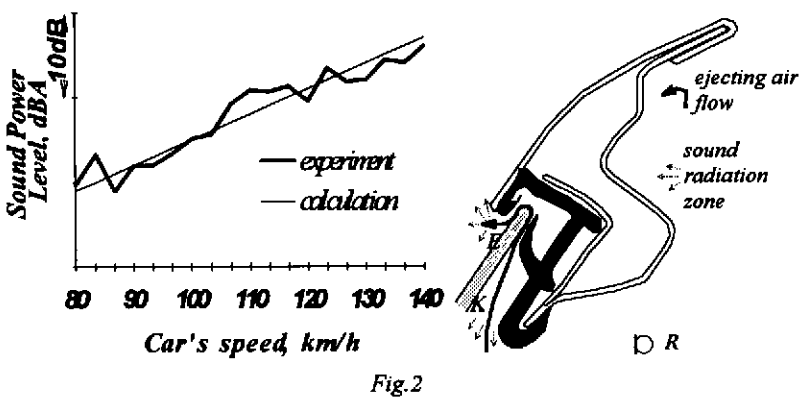


*Fig.2*

Let's consider a spectrum structure of leak noise. It is shown in [2], that the sound power spectrum of a jet is continuous. But a narrow-band spectrum of leak noise shown on figure 1 has a clear discrete character.

The discrete character of spectrum could be explained by presence of turbulization elements in jet's zone [2] as well as by resonances of acoustic resistance of the noise transmitting channel. The explanation basing on the second hypothesis consists following.

The simplified circuit of radiation and propagation of sound is represented on figure 2. The initial sound source is placed outside of car at the edge of seal's gap (E) and the sound energy is radiated in two directions: in an environment and in car's interior through the air acoustic channel EK to a sound pressure receiver R. The air acoustic channel is formed by gap between window glass and seal. Considering acoustic resistance $Z$ of the such air channel opened with two ends (EK) we find :

$$Z \sim \frac{\rho c}{s} tg(k l),$$

where $\rho c$ - acoustic impedance of air, $l$ - length of channel, $s$ - area of cross section of channel, $k$ - wave number, $k = \frac{2 \cdot \pi \cdot f}{c}$, $c$ - sound velocity, $f$ - frequency. The resonance will be observed at $Z = 0$, $tg(kl) = 0$ or $kl = \pi n$. Natural frequency of channel opened with both ends will be $f_r = \frac{c}{2l} \cdot n$, where $c$ - sound velocity, and $n = 1,2,3,\ldots$

The length of the air channel of tested car makes 0.07 m and consequently the first natural frequency of channel is equaled to 2400 Hz. This number coincides with the first amplitude peak in noise spectrum shown on figure 1.

The creation of exact mathematical model of insulation of untight seal in frequent area higher then first resonance has certain difficulties owning to very complex seal's design and, to the other hand , the determination of a such model is not urgent in view of essential preponderance sound pressure level just on frequency of the first resonance

$$f_r = \frac{c}{2l} \text{ Hz.}$$

## 3. POSSIBLE CONSTRUCTIVE DECISIONS DIRECTED TO LEAK NOISE REDUCTION

The wide spread decision enabling to eliminate the occurrence of this noise contains the increasing of depth of contact zone of seal and glass, and increasing of its contact effort. Another decision is introduction the duplicating element of the sealing (in most cases at the door's seals).

If such decision in case of constructive, layout, technological or other reasons is impossible, the other seal's design could be offered. This decision also could eliminate the appearance of leak noise in case of non absolutely closed window.

It is possible to offer window's seal element combined with integrated noise reduction construction in a kind of 1/4 wave resonator (variant 1) or Helmholtz resonator (variant 2), see figure 3, or design combining both these resonators. The 1/4 wave resonator could be included directly in seal's design using the seal's petal as labyrinth of appropriate depth with closed end. The 1/4 wave resonator could be filled by a noise absorbing material for expansion of an effective frequent area of resonator's work. As volume of Helmholtz resonator a closed cavity in the top of door's framework could be used. The cavity is communicated with gap between glass and seal by a zone of perforating holes making the resonator's throat..

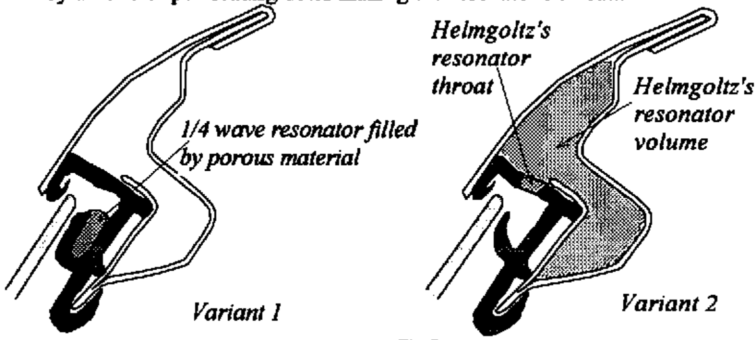


Fig.3

## 4. CONCLUSIONS

Proceed from received results, it is possible to determine main properties, characteristic for aerodynamic leak noise:

- The sound power radiated by an air flow running out from car (through the gaps of car's window seals) is proportional to the sixth power of the air flow velocity, and the sound source is a source of a dipole type. This result has a good correlation with theory of sound radiation of a low Mach number jet.
- The tones of leak noise spectrum are formed by acoustic resistance of transfer path from source to receiver (in researched case tones are formed by gap between seal and window glass).

For elimination of this type of noise, which can appear in case of the design or manufacturing failure as well as in case of not absolutely closed window, the construction of seal with integrated elements of 1/4 wave resonator or Helmholtz resonator can be used. A closed cavity in the top of door's framework might be used as a volume of the Helmholtz resonator's chamber.

**References**

1. Lighthill M.I. **On Sound Generated Aerodynamically. Part 1, General theory**. Proc. Roy. Soc., ser. A. vol. 211, N 1107, 1952, vol. 222, N1148, 1954.

2. Munin A.G., Kuznetsov V.M., **"Aerodinamicheskiye Istochniki Shuma,"** M, Mashinostroenie, 1981, 248 s. /in russ./