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VIBROACOUSTICS OF NEW GENERATION AVIATION ENGINES AND FLIGHT SAFETY

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ABSTRACT

Application of super-high by-pass engines provides a significant increasing of fuel efficiency that has become a requirement for new generation engines in crisis and high oil prices maintenance. Servicing of a huge long-haul aircraft park (25000) is required to reduce the engine maintenance costs that cause the trend to pass from 4-engine to 2-engine power plants of larger thrust. Both directions of power plants development lead to increasing of fan diameter and the formation of shock waves at supersonic speed of blade tips.

Operating experience of new generation engines has show that substantial noise redistribution occurs. While jet noise has been reduced dramatically, the engine still remains the basic source of noise, but now it is fan noise in both forward and backward hemispheres. In the forward hemisphere, beside the discrete components at fan blade frequency, long row of discrete components has been observed around the principal blade frequencies as result of shockwave influence (Shivashankara B.,2002). This phenomenon is called *buzz-saw noise*.

Studies on the generation of buzz-noise have been published by several authors (Philpot M.G., Morfey C.L. and Fisher M.J.) since the 1970s, with the introduction of higher bypass ratio aircraft engines. The pressure signature associated with an ideal fan, consisting of precisely identical rotor blades in a uniform flow, will be a regular sawtooth. The frequency spectrum of an irregular sawtooth now contains energy distributed amongst harmonics based on the engine rotation frequency fan (McAlpin A. and Fisher M, 2001).

One of the necessary measures to control shockwaves is reducing the fan shaft speed.
Today we are on the next stage of engines development – the transition to super-high by-pass engines (m=10…13). It makes turbofan engine similar to turboprop, especially in case of gearbox scheme application and concept of “open rotor”.

Vibration spectrum of turbofan engines, especially the extra large by-pass ratio, greatly extended due to fan rotor low speed (especially in the case of using the gearbox) that will determine the character of the vibration process on the engine housing.

These components will determine the spectrum of power plant dynamic effect transferred via mounting assembly (engine attachments) on airframe structure. This spectrum is re-radiated into the cabin in the form of structural noise.

An airframe typically possesses dozens of oscillation modes in the low-frequency spectrum part**.** The interaction of some of them with the perturbing action of the power plant via mount attachment may lead to the generation of high-level low-frequency noise components in the pressurized cabin, including infrasound (Baklanov V, 2011).

Investigations of the Portuguese Medical Centre (Alves-Pereira at al., 2001) point out the increased level of infrasound components in crew cabin with regard to passenger cabin in modern airplanes. These components arise both due to the exciting impact of oncoming flow and to the effect of power plant – airframe interaction mentioned above. These data cause anxiety due to possible increase of these components when switching to high by-pass ratio engines.

New experimental researches make it reasonable to claim the low-frequency noise (31 Hz octave band and especially infrasonic range within 8 and 16 Hz octave bands) to be professionally harmful factor, influencing human health. This is connected with the fact that the frequencies of many internal organs are in the infrasonic range. There is also evidence of changes in the pericardial tissue bundle under the influence of infrasound .low-frequency of noise infrasonic range on the nature of its actions are similar to the effect of vibration, as well as having a direct impact on the system of the cranial nerves.

Therefore, the allowed infrasound levels at the places of operators (example, aircraft crew), who perform tasks of different mental and emotional tension, are proposed to be lowered.
There are no obligatory international standards limiting internal noise in cabins of airplanes today. Execution of those or other conditions on noise (according to national standards) is a parameter of competitiveness of manufacturers or airlines. The noise level in a cabin of pilots is fixed by the manufacturer in view of opinion of large airlines that covenant with trade union of pilots.
Selecting power plant for new generation aircraft should include the development of high performance vibration protection system of crew and passengers to ensure crew's comfort and flight safety.

Keywords: engine, vibrating spectrum, infrasound components, human health.

INTRODUCTION

Operating experience of new generation engines has shown, that substantial noise redistribution occurs. While jet noise has been reduced dramatically, the engine still remains the basic source of noise, but now it is fan noise in both forward and backward hemispheres. In the forward hemisphere, beside the discrete components at fan blade frequency, long row of discrete components has been observed around the principal blade frequencies as result of shockwave influence. This phenomenon -"buzz-saw noise" is called (Fig.1).

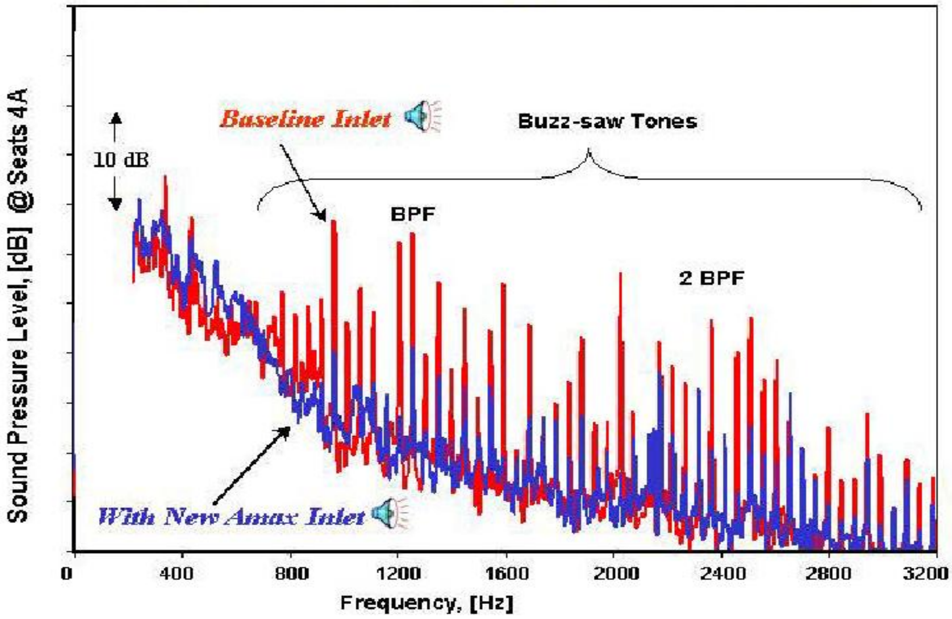

Fig. 1 Buzz-saw noise decrease in B-777 cabin (Shivashankara B., 2002)

Studies on the generation of buzz-noise have been published by several authors (Philpot M.G., Morfey C.L. and Fisher M.J.) since the 1970s, with the introduction of higher bypass ratio aircraft engines. The pressure signature associated with an ideal fan, consisting of precisely identical rotor blades in a uniform flow, will be a regular sawtooth. The frequency spectrum of an irregular sawtooth now contains energy distributed amongst harmonics based on the engine rotation frequency fan (McAlpin A. and Fisher M, 2001).

Buzz-saw noise is one part (high-frequency region) of the spectrum of noise expected in the pressurized cabin of new generation engines with extra high bypass ratio. The other part of the spectrum is the low-frequency region, which includes rotor frequencies of the three shafts and duct low frequency components has not been shown in Fig.1.

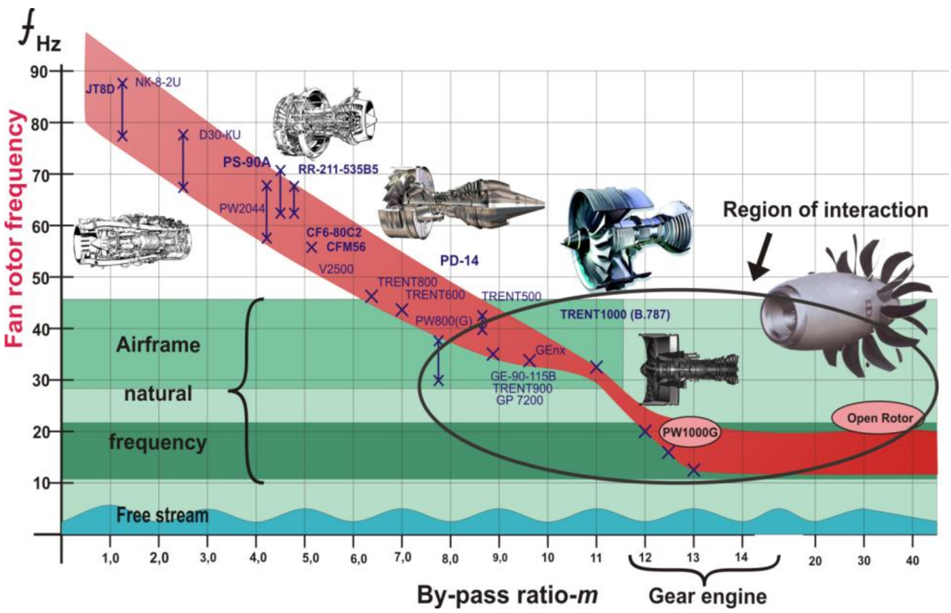

Fig. 2 Change of frequency of rotation of fan shaft at degree increase by-pass ratio of engines

One of the necessary measures to control shockwaves is reducing the fan shaft speed.
Vibration spectrum of turbofan engines, especially the extra large by-pass ratio, greatly extended due to fan rotor low speed (especially in the case of using the gearbox) that will determine the character of the vibration process on the engine housing (Fig.2).
An airframe typically possesses dozens of oscillation modes in the low-frequency spectrum part. The interaction of some of them with the perturbing action of the power plant via mounting attachment may lead to the generation of high-level low-frequency noise components in the pressurized cabin, including infrasound (Baklanov V, 2011).
These components will determine the spectrum of power plant dynamic effect transferred via mounting assembly (engine attachments) on airframe structure. This spectrum is re-radiated into the cabin in the form of structural noise.
It was confirmed investigations of the Portuguese Medical Centre point out the increased level of infrasound components in crew cabin in modern airplane (Fig.3).
Horizontal upper limits (red) for a range of infrasound - levels set by sanitary standards (Ministry of health of the Russian Federation, 1997) for works of different degree of emotional intensity.
Levels measured noise in the infrasound range approaching the maximum acceptable.

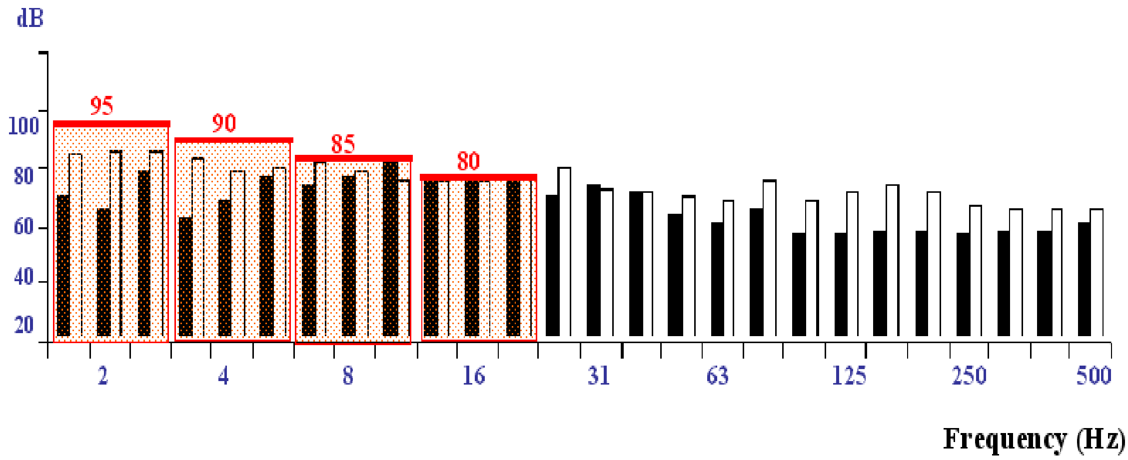

Fig. 3 Comparison spectrum of noise in the cockpit A340 (black) and the underground (white)

These components arise both due to the exciting impact of oncoming flow and to the effect of power plant – airframe interaction mentioned above. These data cause anxiety due to possible increase of these components when switching to high by-pass ratio engines.
New experimental researches make it reasonable to claim the low-frequency noise (31 Hz octave band and especially infrasonic range within 8 and 16 Hz octave bands) to be professionally harmful factor, influencing human health (Fig.4). This is connected with the fact that the frequencies of many internal organs are in the infrasonic range (Table 1).

Table 1 Natural frequencies of human internal organs

Head:	25 Hz
Legs:	2…20 Hz
Arms:	16…30 Hz
Eye ball:	30…80 Hz
Chest wall:	60 Hz
Spinal column	50…200 Hz

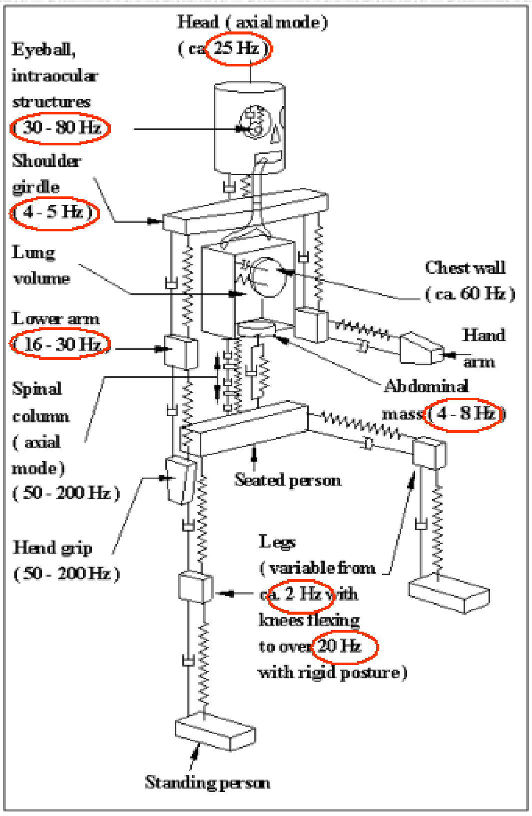

Fig. 4 Dynamic model human (Per V.Bruel,1988)

First (T. Matoba, 1983) reported the observation of pericardial thickening in noise workers. There is also evidence of changes in the pericardial tissue bundle under the influence of infrasound (Castelo Branco N. A. A , Alves-Pereira M., 2004). Statistics research of Portuguese Medical Center show that pilots are loosening the pericardium and its thickness is bigger in two to four times than the normal (Table 2).

Table 2 Summary of VAD patients' data

Occupation	Age	Pericardial Thickness (mm)*
Aircraft Technician	32	1.35
Aircraft Pilot	37	2.04
Aircraft Pilot	39	1.22
Aircraft Pilot	41	2.19
Aircraft Pilot	44	2.23
Helicopter Pilot	48	1.40
Aircraft Technician	51	1.60
Truck Driver	52	1.67
Helicopter Pilot	53	1.03
Helicopter Pilot	57	2.02
Helicopter Pilot	60	1.06
Aircraft Technician	62	1.09

Normal: <0.5mm

Low-frequency noises of infrasonic range on the nature of its actions are similar to the effect of vibration, as well as having a direct impact on the system of the cranial nerves.

Therefore, the allowed infrasound levels at the places of operators (example, aircraft crew), who perform tasks of different mental and emotional tension, are proposed to be lowered. There are no obligatory international standards limiting internal noise in cabins of airplanes today. Execution of those or other conditions on noise (according to national standards) is a parameter of competitiveness of manufacturers or airlines. The noise level in a cabin of pilots is fixed by the manufacturer in view of opinion of large airlines that covenant with trade union of pilots.

RESULTS AND CONCLUSIONS

Today we are on the next stage of engines development – the transition to super-high by-pass engines (m=10…15). It makes turbofan engine similar to turboprop, especially in case of gearbox scheme application and concept of "open rotor".

The necessity of new vibration isolation mounting relates with: 1) extension of vibration spectrum of modern engines and its tendency to shift towards the low-frequency region; 2) insufficient efficiency of existing vibration protection, developed on basis of out-of-date computation models, especially in the low-frequency region; 3) change of dynamic characteristics of airframe and engine bodies at attachment points with the increase of engines by-pass ratio.

The long-term investigations directed to dynamical characteristics definition for engine bodies (different by-pass ratio) and airframe constructions of aircraft allow to significantly specify calculation models of modern aircraft constructions in engine's rotor frequency range. And it allows todetermine tendency of engine's dynamical characteristics variation with by-pass ratio increasing. The obtained characteristics and algorithms have allowed to calculate the expected noise due to vibration impact of engine (Baklanov V.,2012).

The comparison of the expected noise and the experimental data yields both a good convergence of fan rotor harmonic level and a possibility of high-intensity low-frequency components generation at the operation level of engine vibration (Fig.5).

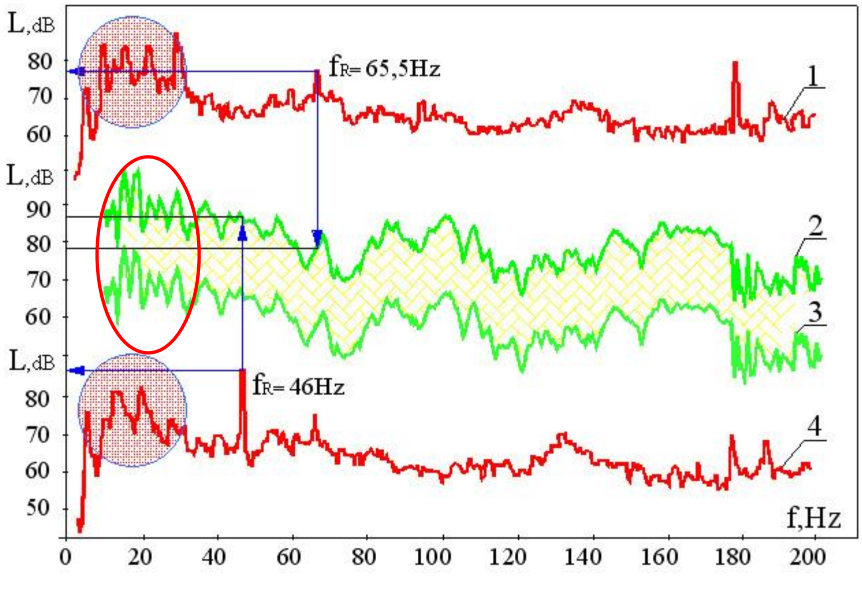

Fig.5 The comparison of experimental and prediction data of the structure-borne sound in aircraft cabin.
1, 4 – experimental data V_E=10mm/s.
2, 3 – prediction data V_E=10mm/s, V_E=1mm/s accordingly.

On decreasing of fan noise the low-frequency discrete components will be determine the acoustical climate in the cabin.
It was confirmed by new investigations on an airplane-demonstrator QTD2 (B-777 with GE90-115V engines, bypass ratio is equal to 9), where low-frequency components are risen in the total spectrum over 30-40 dB (Nesbitt E. and Yu Jia, 2006), Fig.5.

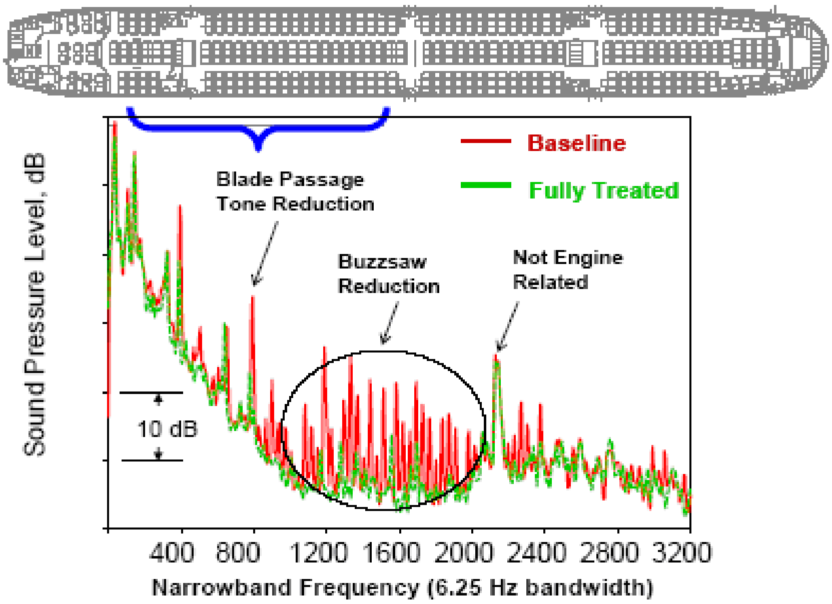

Fig.5 Forward cabin interior noise (Nesbitt E. and Yu Jia , 2006)

Selecting power plant for new generation aircraft should include the development of high performance vibration protection system of crew and passengers to ensure crew's comfort and flight safety.

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