DYNAMICS AND VIBRATION OF NEW GENERATION AVIATION ENGINES

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INTRODUCTION

Strategic development of new generation airplanes goes in a direction of the further decrease in noise, emissions and increase of fuel efficiency, where the defining role belongs to engines. The rapid development of engine allows re-engining of the most popular narrow-fuselage airplanes (type B737 and A320), occupying 80% of the park-haul aircraft and aircrafts of another popular class - B777 and A330.
The next 10 - 15 years we will have to deal with aircraft equipped with turbofan engines of high bypass ratio (8.5 - 12): Leap-1B, Leap-1A, PD-14, GE9X, TRENT 7000, TRENT 1000 TEN, XWB and family type PW1000G.

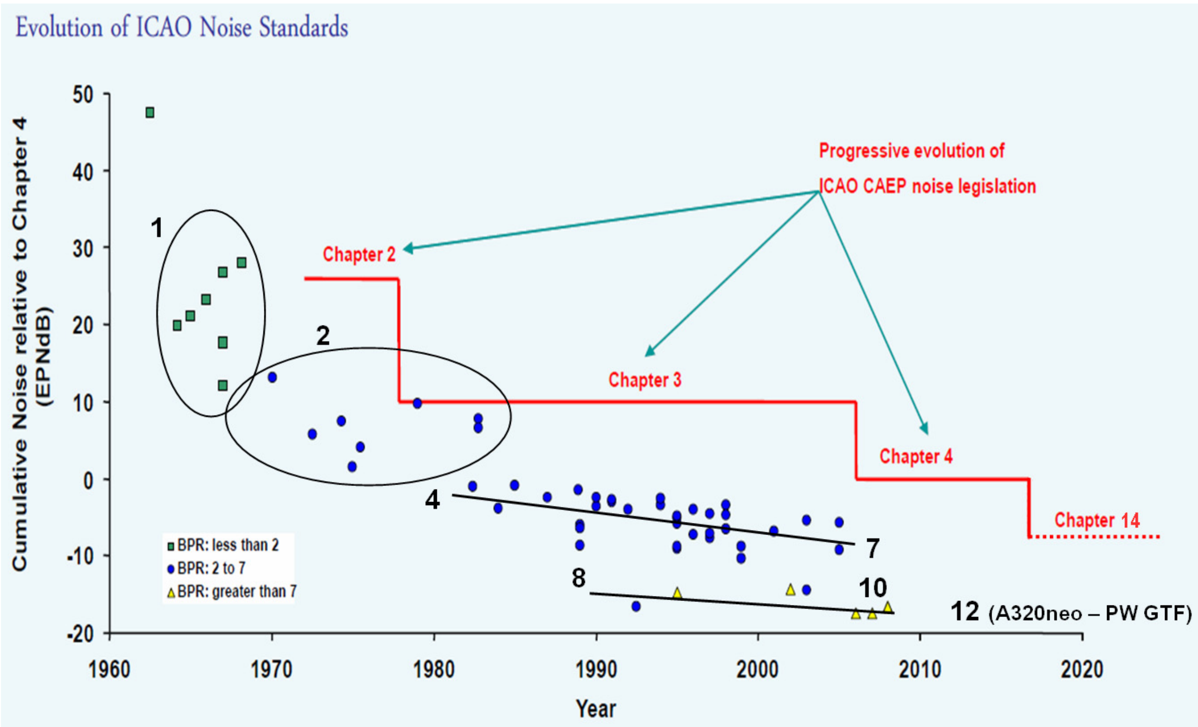

Fig.1. Evolution of ICAO Noise Standard.

Aircraft equipped with these engines, can successfully execute future noise standards in 2017 (Chapter 14), Fig.1, ensure the reduction of harmful emissions and increase of fuel efficiency, but this is accompanied by a significant change of dynamic characteristics and vibration engines.

INVESTIGATION

The long-term investigations directed to dynamical characteristics definition for engine bodies (different by-pass ratio) and airframe of aircraft allow to significantly specify calculation models of modern aircraft constructions in engine's rotor frequency range. And it allowed to determine tendency of engine's dynamical characteristics variation with by-pass ratio increasing. If by-pass ratio is increased up to estimated 8…12 we should expect that the upper boundary of rigid-body-like dynamic behavior of the engine does not exceed 10 Hz.

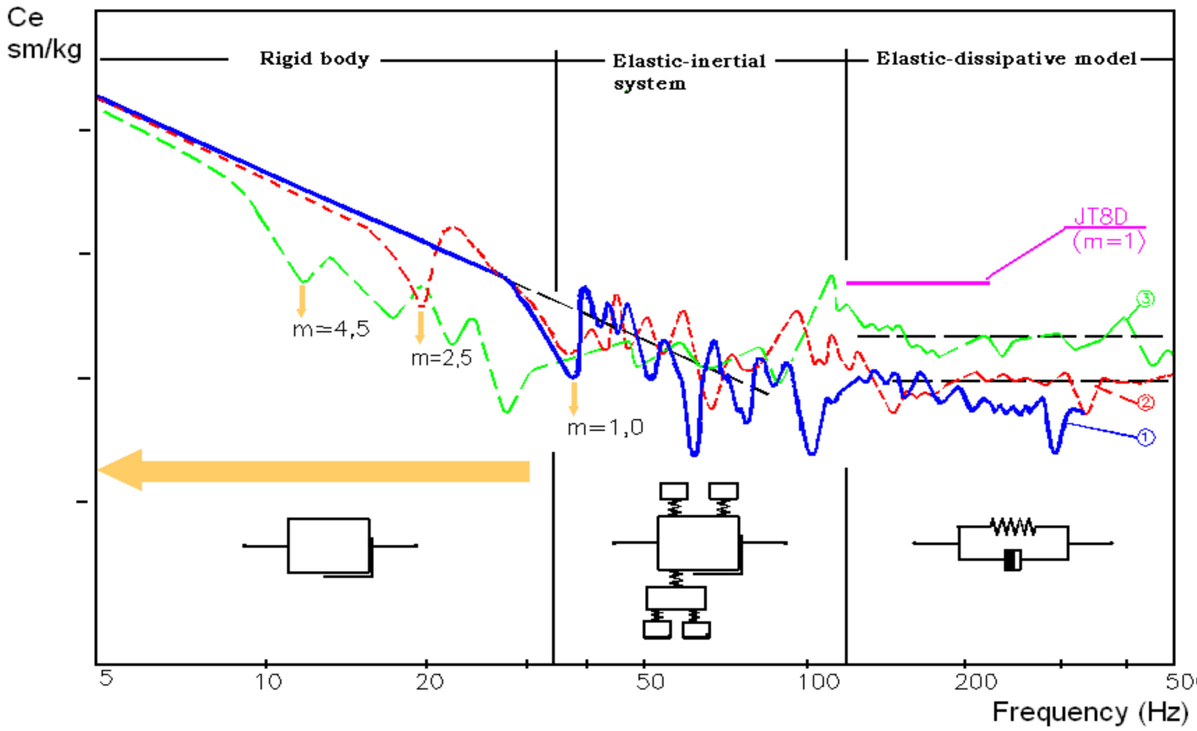

Fig.2. Dynamic compliances of engine body at attachment points
1 – m = 1; 2 – m = 2,5; 3 – m = 4,5.

A well-known impedance testing technique was used: for the determination of these characteristics: the structures were excited by an electrodynamics shaker while the harmonic input force amplitude was constant and its frequency was varying automatically within the studied range 10 ... 500 Hz [1].

The dynamic characteristics enabled to make the dynamic model for an aviation gas-turbine engine more precise, especially in the rotor frequency range [2].

Analysis of obtained data makes it possible to divide the frequency range of investigation into three sub-ranges characterized by certain dynamic behavior of the engine and consequently each of said ranges can be provided with its special mathematical model – simple and clear enough (fig.2).

Dynamic compliances of engine body at the attachment points has revealed that the body of engines with by-pass ratio (*m*) of 0.5…1.1 corresponds to the rigid body model for frequencies below 40 Hz, while for engines with by-pass ratio of 2.5…4.5 the upper boundary of the rigid body model behavior is shifted to 20 Hz.

It has been found out that at frequencies between 20…40 Hz and 120 Hz the engine body behaves as an elastic-inertial system with a large number of resonances of various damping degrees.
Identification of these resonances (by comparison of results of various researches) allowed to connect them with own frequencies of a number of elements of the engine (rotors, a box of the drives, the separate units fixed on the case) [3]
Within the frequency range 120…500 Hz the engine body corresponds to the model of elastic – dissipative element. The case of engine JT8D also corresponds to this model at the indicated frequency range [4].
Within a wide range of rotor frequencies the dynamic behavior of engine body corresponds to the model of elastic-inertial system or to an elastic-dissipative element. It differs substantially from the idealized rigid-body model of aircraft gas turbine engine both by the value of dynamic compliance module and by the type of dynamic behavior.
Increased bypass ratio engine not only leads to a considerable increase of acoustic power of the fan, but also a change in the spectrum of noise emitted from the front and rear hemispheres power plant.
But this direction of power plants development leads to increasing of fan diameter and formation of shock waves at supersonic speed of blade tips.
Interaction of shock waves with the fan wheel forms a series of discrete components of polyharmonic around the main frequencies of blades (the first and second harmonics), The distance between components of blade frequency are equal to shaft rotation frequency. This phenomenon is called "buzz-saw noise" (Fig. 3).

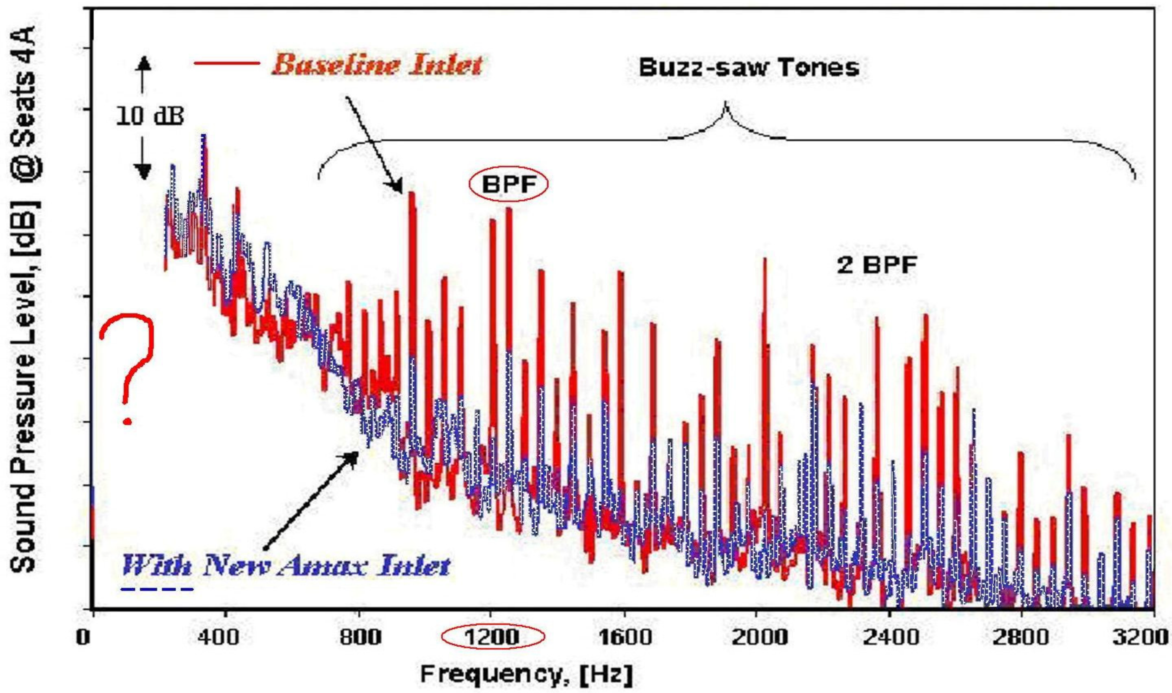

Fig.3. Spectrum interior noise of forward cabin aircraft-demonstrator QTD1

(B777 with engines TRENT 800, by-pass ratio – 6) [5].

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.4).

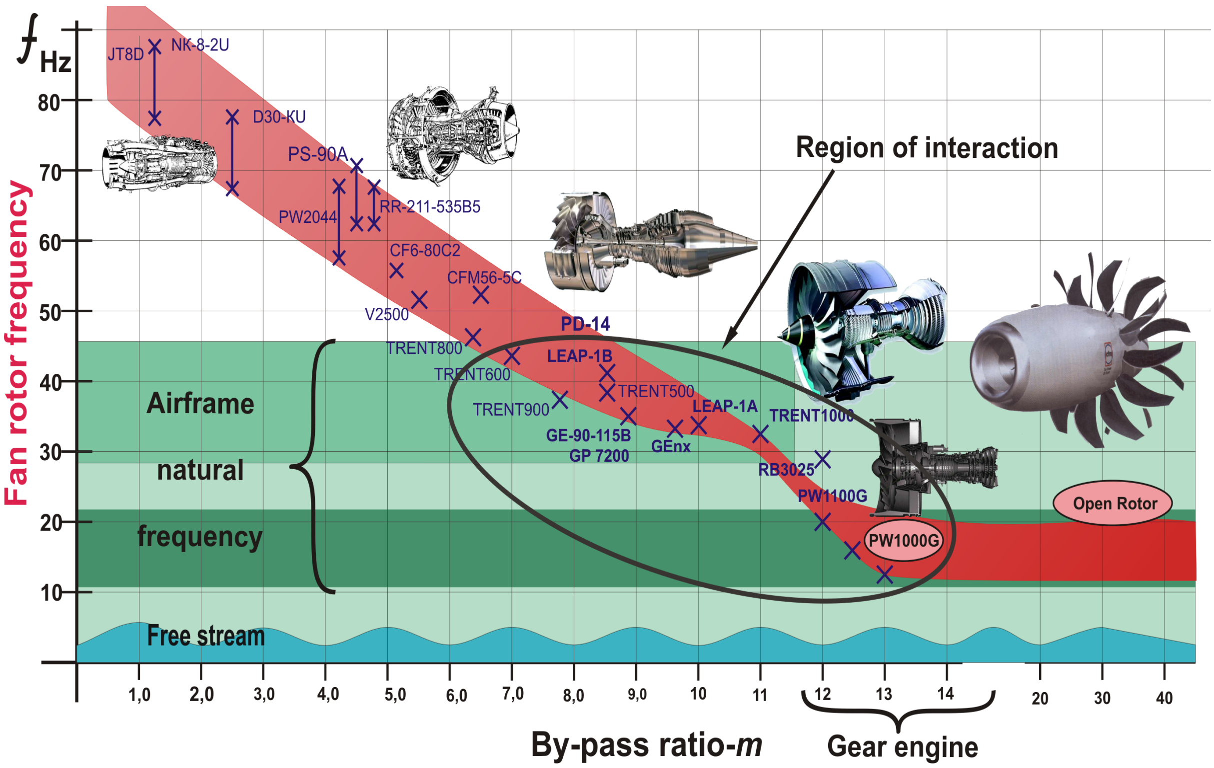

Fig.4.Change of frequency of fan shaft rotation at degree increase by-pass ratio of engines.

An airframe typically possesses dozens of oscillation modes in the low-frequency spectrum part (flexural and torsional oscillation of the fuselage, a wing, stabilizer and other constructional elements).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 [6].

Acoustic field of pressurized cabin is substantially changing with high by-pass ratio engines application. Increases significantly contribute to the vibroacoustic field of cabin structural noise caused by vibration impact engines.

It was confirmed by new investigations on an airplane-demonstrator QTD2 (B-777 300 ER with GE90-115B engines, bypass ratio – 8,7), where low-frequency components are risen in the total spectrum over 30-40 dB (Fig.5) .

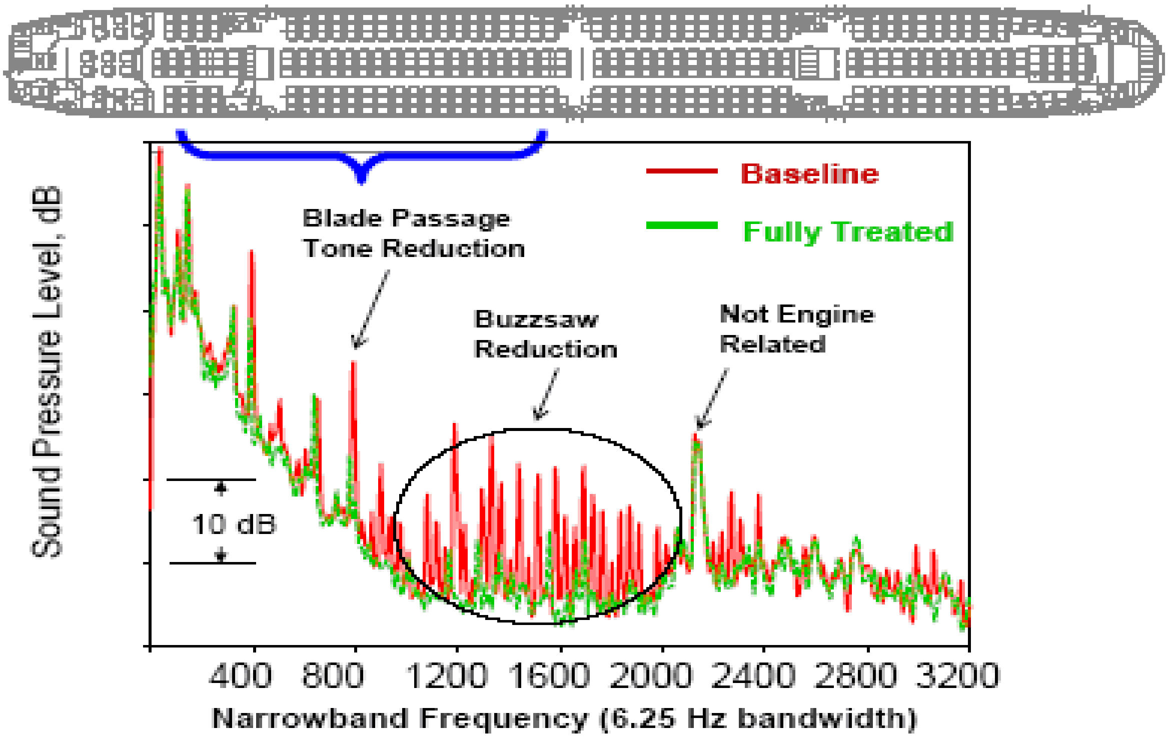

Fig.5. Spectrum interior noise (forward cabin) aircraft-demonstrator QTD2 [7].

Reducing the speed of the shaft and the number of fan blades significantly reduces the frequency of the first harmonic of the fan in the mid-frequency range (800 Hz for GE90-115B against 1200 Hz TRENT 800).
The level of these components is mainly defined by the conditions at the fan inlet (possibility to generate aerodynamic unbalance long fan blades).
All these components will determine the spectrum of power plant dynamic effect transferred via mounting assembly (engine attachments) on airframe structure. The expected level of structural noise (from engine vibration influence) in the cockpit increases significantly in the low-frequency part of the spectrum, which is confirmed by the calculation taking into account real characteristics of the transfer functions and dynamic compliances prototypes of engines and airframes, and measurements on the aircraft - demonstrator QTD2.

CONCLUSION

So the noise emitted from the engine air intakes high bypass ratio in the far field and the direction of the wall of the fuselage consists of multiple tones frequencies, which was also observed in the spectrum of the noise of the front passenger compartment of aircrafts - demonstrators QTD1 and QTD2.
Solving of community noise problems probably require shift in emphasis from traditional methods (installation of liners, which are required with a wide variety and increased height) on methods of noise control at the source (wide chord fan blades, blisc technology, actuators).

Solving problems of structural noise low-frequency part of the spectrum will require a new generation of engine mounts (probably with built low-frequency vibration isolation units or piezoelectric actuators).
Experience in operating aircraft with engines high bypass ratio shows that the level of low-frequency components structural noise in the cockpit crew may exceed the recommendations of sanitary norms and raise questions about safety, and we expect ahead second (Advance) and third (UltraFan) generations of geared engines and can be «Open rotor».

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