ISSN 1392-2114 ULTRAGARSAS, Nr.4(61). 2006.

Board monitoring of airplane noise levels based on engine's thermo-gasdynamic parameters

P. Zvanchuk, V. Labendik, V. Mukhin

Aviation Institute of Riga Technical University,
Lomonosov street 1, Bild. B, LV-1019, Riga, LATVIA, Phone: +371 7 089959, Fax. +371 7089990,
E-mail: vladlab@.junik.lv.

Abstract

The offered design procedure of acoustic characteristics Turbofan allows calculation of noise of the plane with use thermo-gasdynamic parameters measured for diagnostics of engines.

This technique can be used, for example, in the on board computer for monitoring by a crew of flying noise under a trajectory of rise - landing of the plane and, if necessary, partial correction of a trajectory of the flight from conditions of maintenance of the set norms on noise in three control points.

At ground processing of the flight information there is an opportunity to calculate isolines of the plane effective or equivalent noise levels in area of the concrete airport, even if there is no system which measures noises of planes in control points. The size of the area of a contour of equal equivalent noise level can be used at calculation of economic efficiency of those or other acoustic actions providing liberation of the area of the ground near to the airport from the emitted noise.

Key words: monitoring, parameters, engine.

Introduction

In connection with entrance in the European Community since January, 2006 due to more rigid norms of an effective level of perceived noise of planes in three control points corresponding to Chapter 4 ICAO (norms reduce on 8 EPNdB), there is a problem of operation of plane park with out-of-date engines. Planes with such engines are maintained at the airport "Riga ". For objective estimation of acoustic characteristics of subsonic planes in a real time mode directly on-board the plane at its rise and landing, a special semi-empirical method was developed by us based on updating of a technique [1]. As the basic sources of noise of planes with Turbofan are fans, turbines (turbofan) and jets [2], it is offered to estimate the noise Turbofan with the use of thermo-gasdynamic parameters, measured on-board for diagnostics of engines. It can be used, for example, in the on-board computer for monitoring and indicating a crew of a flying noise under a trajectory of rise - landing of the plane and, in case of need, a partial correction of a trajectory of the flight from conditions of maintenance of the set norms on noise in three control points. Besides that the presented information will allow to compare in disputable situations continuously emitted noise on-board to levels of the perceived noise of the plane, measured on the ground in three control points.

Design procedure of jet jets noise on determinations of the thermo-gasdynamic parameters

Let's consider definition of the jet noise Turbofan at the base distance 60 m.

Convenient initial expression for definition of a jet noise in PN dB for a range of speeds 300 m/c $\le Cc \le$ 750 m/c is the formula [3]:

$$PNL_0 = 20\lg\rho_j + 6\lg F_j + 88\lg C_j - 100\text{, PN dB.} \quad (1)$$

After substitution in the initial formula expressions of design quantities through measured on the engine along its flowing part the parameters $(T^*; P^*; n)$ used for diagnostics of its condition in flight, the expression for definition of the jet noise Turbofan with mixture is obtained:

$$PNL_j = 20\lg P_o + 24\left[\lg T_m^* + \frac{k-1}{k}\lg\pi_m^*\right] + 44\lg\left(\pi_m^{*\frac{k-1}{k}} - 1\right) = 20\lg P_o + 24\lg T_m^* + 24\frac{k-1}{k}\lg\pi_m^* + 44\lg\left(\pi_m^{*\frac{k-1}{k}} - 1\right) + Kj \text{ PN}\cdot\text{dB.} \quad (1a)$$

In this expression except of the measured quantities there are some parameters which for the concrete engine can be united into a constants, such as:

- R_m - gas constant of a mix;
- F_n - the area of a noncontrollable subsonic nozzle, which is constant for each type of the engine.

Then

$$K_j = Const = 24\lg R_m + 44\lg\frac{2k}{k-1} + 6\lg F_n - 100 + \Delta L_j$$

where: ΔL_j - adetement dependent on a construction of nozzle; $k = \frac{Cp_m / R_m}{Cp_m/(R_m - 1)}$ - parameter of an adiabatic curve of a gas mix on exhaust Turbofan; $Cp_m = \frac{Cp_1 + mCp_2}{1+m}$ - thermal capacity of a gas mix; $\rho_m = \frac{P_o}{R_m^* * T_m^*} * \pi_m^{*\frac{k_m - 1}{k_m}}$ is the density of a gas mix; P_o - external pressure.

As at the output from the short chamber of mixture of modern BTJE occur an incomplete mixture of gas jets, but fields of parameters of a stream at the output are not measured, we shall define parameters of a mix as at full mixture (T_m^*-temperature of a gas jet, π_m^*- a degree of expansion) on measures of stream parameters in contours on an input in the mixer. Thus the formulas edited in the program of the on-board computer, look like:

$$T_m^* = \frac{1.146 * T_I^* + mT_{II}^*}{1.146 * m},$$

where T_I^* and T_{II}^* - temperature of gas jets of the first and second contours accordingly; $m = \bar{F} * \sqrt{T_I^* / T_{II}^*}$ bypass degree;

$$P_m^* = \sigma_m^* \left(\frac{P_I^* + P_{II}^* \bar{F}}{1 + \bar{F}} \right),$$

where P_I^* and P_I^* are the pressure of the first and second contours accordingly; $\overline{F} = \frac{F_{II}}{F_I}$ - proportion of the areas of contours.

Design procedure method of turbofan noise on measured parameters

The basic formula for definition of the maximal linear level of the perceived noise of the one-stage fan in static conditions at the base distance 60m from a source looks like [4]:

$$PNL_f = 47{,}5\lg U_f + 7{,}5\lg G_f - 9{,}5 \text{ , PN dB} \qquad (2)$$

where U_f is the peripheral velocity, m/s; G_f is the air discharge, kg/s.

After transformations of the initial formula to expressions in the characteristic sizes and the measured on the engine parameters $(D_f; \pi_f^*; n_f)$ used for diagnostics, we obtain:

$$PNL_f = 47{,}5\lg n_f + 47{,}5\lg D_f + 47{,}5\lg \pi + $$
$$+ 7{,}5\lg a\pi_f^* - 9{,}5 = 47{,}5\lg n_f + 7{,}5\lg a\pi_f^* + K_f \quad \text{PN} \cdot \text{dB.} \qquad (2a)$$

Here $U_f = 2\pi R_f * n_f = \pi D_f * n_f$; $G_f = a * \pi_f^{*\,b}$, where D_f - fan diameter, m; n_f - revolutions of fan, r/m; π_f^* - compression ratio.

Then

$$K_f = Const = 47{,}5\lg D_f + 47{,}5\lg \pi - 9{,}5 + \Delta L_f .$$

At presence on the engine of constructive differences in a fan contour in comparison with base, and also sound-proof facings, in the formula is entered the total amendment ΔL_f.

In a technique [1] noise of the turbine is not taken into account, however at high parameters of modern engines it can appear in a back hemisphere, especial at descent on landing. The formula for definition of the maximal linear level of the perceived noise of turbine Turbofan in static conditions on the base distance 60 m from a source looks like [5]:

$$PNL_t = 40\lg \left[1 - \left(\frac{1}{\pi_t} \right)^{\frac{k-1}{k}} \right] - 20\lg U_t + $$
$$+ 10\lg F_{n1} + \Delta L_t + 164 \quad \text{PN} \cdot \text{dB.} \qquad (3)$$

Here U_t - peripheral velocity of the driving wheel of the last step of the turbine on external radius, m/s; $\pi_t = \frac{P_3^*}{P_4^*}$ - the general difference of pressure in the turbine; P_3^* - full pressure upon an entrance in the turbine; P_4^* - static pressure upon an exit from the turbine; F_n - the output area of nozzle of the BTJE internal contour, m^2 $\Delta L_t = PNL_t - L_t$ - the additive which is taking into account the frequency of the basic tone last (dominating over noise) steps of the turbine; it can be determined from the formula:

$$\Delta L_t = 16{,}4 - 0{,}48 f - 0{,}014 f^2 \text{, PN dB} \qquad (4)$$

Here f is the frequency of the basic tone of the turbine, kHz.

After transformations of the initial formula we obtain:

$$PNL_t = 40\lg \left(1 - \frac{1}{\pi_t^{\frac{k-1}{k}}} \right) - 20\lg n_t - K_t \text{, PN dB} \qquad (5)$$

where $K_t = \text{const} = \lfloor 20\lg d_t - 188{,}7 \rfloor$.

As well as in case of the fan, distribution of sound fluctuations from the turbine depends on geometrical characteristics of the channel behind the turbine. For cases when the estimation of noise in PN dB is required, the level of the perceived noise is defined with the help of a correlation [6]:

$$PNL = L_t + \Delta PNL \text{, PN dB} \qquad (6)$$

Spectral characteristics of noise of the turbine step are in dependence from power setting (take-off and landing) [6]:

$$L_t(f) = L + \Delta L \text{, PN dB} \qquad (7)$$

The amendment ΔL additive to a frequency spectrum is depending on power setting.

As the noise of the turbine and the noise of the fan are in the high-frequency range is possible to define influence of the noise of the turbine in a back hemisphere in static conditions at the base distance 60 m from a source using the formula of power addition:

$$\text{PNL}_{\text{TK}} = 10\lg \left[\text{antilg}\frac{\text{PNL}_1}{10} + \text{antilg}\frac{\text{PNL}_2}{10} \right] \text{ PN dB} \qquad (8)$$

Definition of total noise of a power-plant of the plane

Total noise of a power-plant (as a whole from sources) is obtained in the following order:

1. On a special curve (Fig. 1) define an increment PNL_{comb} - the additive to greater of values PNL of jets and the fan, depending from a difference of sizes PNL_{Σ} total noise of jets and PNL of fan.

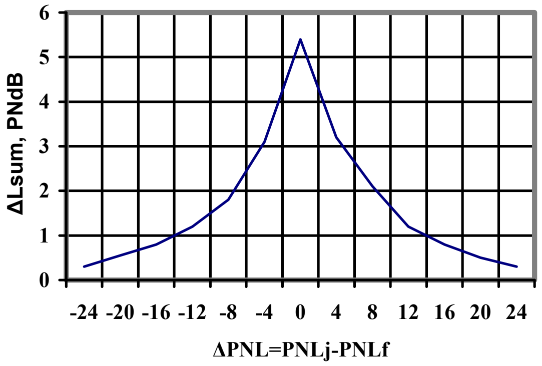

Fig.1. **Addition of noise of jets and the fan.**

2. The level of the perceived total noise of the engine (the combined noise of jets and the fan) at the base distance 60 m is calculated by addition ΔPNL_{comb} to greater of values PNL of jets and the fan.

3. Consider loss of noise of the engine which depends on the following factors [1]:

- distances of a noise source from a point of it perception (1);
- the corner formed by a sound beam and its projections on the ground (β˚);
- deviations of a sound beam from a direction of the maximal sounding (Θ ≠ Θ max.).

4. For definition in flight of noise of the power-plant, consisting from Z engines, it is necessary to the noise of the separate engine to add $\Delta L_z = 10 \lg Z$, then

$$PNL_{pp} = PNL_{en} + \Delta L_z = PNL_{en} + 10 \lg Z \,, \quad \text{PN dB} \qquad (9)$$

The effective level of the perceived noise of a power-plant and the plane as a whole is defined according to formulas presented in [1].

Calculation of an effective level of the perceived noise is possible to perform in the on-board computer using a specially developed program written in the programming language C++, developed on the basis of algorithms with use of the above-stated formulas.

At ground processing of the flight information there is an opportunity to calculate a contour of the plane of equal effective or equivalent noise levels in the district area of the concrete airport even if it there is no system which measures noise of planes in control points. The size of the area of a contour of equal equivalent noise level can be used for calculation of economic efficiency of those or other acoustic actions providing liberation of the area of the ground near to the airport from the emitted noise.

Conclusions

On the basis of transformations before used formulas of engineering calculation of noise Turbofan the new formulas of noise of sources Turbofan are obtained, expressed through the parameters, registered on the engine in flight for its diagnostics.

It will allow during take - off and landing of the plane with the help of the onboard computer to monitor the noise emitted by a plane and to compare it to measures of noises on the ground in control points in the area at the airport in which take - off and landing take place during each carried out flight.

References

1. **Клячкин А. Л., Лабендик В. П., Минеев О. Б.** Руководство по расчету шума самолета с ДТРД. Рига, РКИИГА. 1976. P. 99.
2. Снижение шума самолетов с реактивными двигателями. Под редакцией Мхитаряна А.М. Москва: Машиностроение. 1975. P.215.
3. **Бернард Д. Р. и др.** Комплекс акустических исследований ТРДД CFM-56. "Новое в зарубежном авиадвигателестроении". Москва: ЦИАМ. 1979. N 5.
4. **Башелл К. В.** Измерения и прогнозирование шума реактивной струи в полете. Э.-И. "Воздушный транспорт". 1976. No.39.
5. **Квитка В. Е.** Нормирование и снижение шума самолетов и вертолетов. Киев. 1980. P.206.
6. **Labendiks Vl., Zvančuks P.** Lidmašīnu projektēšanas ar gāzturbīnu dzinēju akustisko raksturlielumu prognozēšana. RTU Zinātniskie raksti, 6. sērija, "Mašīnzinātne un transports. Transports. Aviācijas transports", 12. sējums. Rīga, "RTU". 2003. Lpp.63-68. (ISSN 1407-8015). (latv.)
7. **Званчук П. Н., Лабендик В. П.** Методика оценки шума самолета с ТРДД под траекторией взлета-посадки по замеряемым в полете параметрам.. Тезисы докладов всероссийской НТК молодых ученых и специалистов «Проблемы создания перспективных авиационных двигателей», 27-30 сентября 2005. Россия, Москва. М.: ЦИАМ. 2005. P.157-158.

P. Zvančiuk, V. Labendik, V. Mukhin

Pusiau empirinė dvisrovių TRV akustinių charakteristikų skaičiavimo metodika

Reziumė

Pateiktoji dvisrovių TRV skaičiavimo metodika leidžia apskaičiuoti lėktuvo triukšmą pagal terminius dujų parametrus, naudojamus varikliams diagnozuoti.

Ši metodika, turint bortinį kompiuterį, gali būti panaudota kai lėktuvas kyla ar tupia ir esant reikalui matuoti 3 taškuose, keisti skrydžio trajektoriją pagal neleistiną triukšmo lygį.

Apdorojant antžeminę informaciją, galima nustatyti tam tikrų triukšmo lygių poveikio priemones ir sumažinti triukšmą skrydžio metu.

Received 05 06 2006