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IMPROVED CALCULATION METHODS FOR ASSESSING ENGINE TEST NOISE

O. Zaporozhets*, V. Tokarev*, K. Attenborough**

* Kyiv International University of Civil Aviation, 1, Cosmonaut Komarov Prospect, 03058, Kyiv, Ukraine

** School of Engineering, University of Hull, Hull, HU6 7RX, HU6 7RX, Hull, United Kingdom

Tel.: 380-44-4849212 / Fax: 380-44-4883027 / Email: zap@elan-ua.net

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ABSTRACT

Engine testing can give rise to many complaints around airports. In the absence of barriers, the main influence on propagation from an engine test is ground effect − the influence of interference between direct and reflected sound waves. Three methods of predicting ground effect are compared with each other and with some data for aircraft engine noise at run-up. All techniques allow consideration of the different types of ground cover, including mixed covering, that are usually found inside and outside airports. Also it is possible to consider the influence of various types of source components including monopole, dipole or quadrupole.

1 - INTRODUCTION

The main approach used for aircraft engine noise assessment (for airplane on the ground, when the height of noise source is equal to the height of engine installation, or for aircraft engine testing facilities, for which the height is usually equal to 4-5 m) by current methods is to consider the noise directivity pattern for appropriate type and mode of the engine. Similar to it is the approach, which uses Noise-Power-Distance-relationships for particular type of engine and/or aircraft also. Both of them need for adjustment due to the influence of few effects like sound wave divergence, air absorption, interference and/or diffraction, etc. It is obvious to expect that sound wave interference for that ground-to-ground cases of noise propagation is much stronger than for air-to-ground propagation cases.

Today there are many kinds of approximations are used worldwide for sound interference effect assessment. First of all the recommendations of standard ISO 9613/2 must be mentioned as a general tool. Particularly for aircraft noise level calculations the SAE 1751 standard is used mostly, for example − in FAA INM or in previous USSR method and current Ukrainian one (realized in software ISOBELL'a). Another well-known approximation is used in UK method for aircraft noise assessment and the differences between the results of calculations using SAE/ICAO and UK approximations along the equal sound propagation paths may change between the -3.5…+1.5 dB.

2 - SOME OBVIOUS RESULTS

Interference ("ground") effect assessment approximations, mentioned above, reflect the general conditions of aircraft noise (AN) calculations: unfavourable sound propagation conditions without consideration of the type of noise source (engine type and mode, direction of noise propagation, etc). Preliminary results of analysis of measurement data of noise generated by aircraft on the ground are following:

- AN measurements frequently provided in a spectrum domain (1/3-octave is preferable) and then the results can be recalculated in a form of noise indexes of any kind;
- AN assessment (calculated or/and measured) provided for real noise source spectrum in accordance with engine mode and directivity angle;

- AN assessment at a point of noise control takes into a count impedance characteristics (type of covering) of the reflecting surfaces under consideration;
- Type of covering of the reflecting surfaces may change along the sound propagation path influencing on the ground effect adjustment to the level at a point of noise control;
- Type of noise source may influence on propagation effects, as it was shown by comparison between the propagation adjustments derived for inlet and outlet directions even for the same type of the engine.

To meet the strict current requirements for AN calculations is possible with accurate implementation of models and methods for particular parts of AN assessment. For example, for assessment of generation effect of an aircraft of any type is derived from the noise matrices and the value of each component of the matrices is defined by contributions of all particular noise sources and transfer function [1]. Transfer function is the solution of identification task derived with flight or engine testing data obtained from noise certification results thus providing highest accuracy of the model.

There are many models and methods were developed for "ground effect" assessment provided the calculation in 1/3-octave frequency domain that is coincide the model of noise generation. They include the influence of surface impedance in relation to the type of the surface covering and its characteristics. Few of these models were examined for use in aircraft engine noise assessments and one of them was derived specially for this case.

3 - ONE BASIC CASE OF GROUND EFFECT ASSESSMENT

In a case of finite impedance reflecting surface the displacements of sound-wave phase and amplitude are observed between descriptions of straight and reflected waves, which form a complicated interference picture − depletion or enhancement of sound pressure levels in separate bands of frequency spectrum. Computation of sound-waves interference influence on noise parameters in a sound receiving point for separate frequency bands can be performed in a form of transmission loss or by formula [5]:

$$\Delta L_{INT} = 10\lg\left\{1 + S^2\left|Q\right|^2 + 2S\left|Q\right|\left[\sin\left(\alpha\cdot dR/\lambda\right)/\left(\alpha\cdot dR/\lambda\right)\right]\cos\left(\beta\cdot dR/\lambda+\delta\right)\right\} \tag{1}$$

where S=R_1/R_2, dR=$(R_2 - R_1)$, R_1, R_2 − direct and reflecting path distances, $\alpha = \pi\left(df/f_i\right)$, df − width of frequency band, f_i − central frequency of the band, λ − wave length, $\beta = 2\pi\left[1+\left(df/f_i\right)^2/4\right]^{1/2}$, for 1/3-octave bands α=0,725, β=6,325.

A reflection coefficient in (1) conforms to conditions of spherical wave, therefore it must be represented in accordance with expressions

$$Q = Q_p + \left(1 - Q_p\right)F\left(p_e\right) \tag{2}$$

where plane reflection coefficient Q_p used in a form:

$$Q_p = \frac{Z\sin\psi - 1}{Z\sin\psi + 1} = \frac{\beta - \cos\Theta}{\beta + \cos\Theta} \tag{3}$$

$F(p_e)$ is *boundary loss* function for "*numerical distance*" p_e (factor of boundary losses is a result of interaction between distorted wave surface with flat reflecting surface):

$$F\left(p_e\right) = 1 + ip_e^{1/2}\exp\left(-p_e\right)\mathrm{erfc}\left(-ip_e\right)\ ;\ p_e = \left(\frac{ikR_2}{2}\right)^{1/2}\left[\beta + \cos\theta\right] \tag{4}$$

The algorithm (1-4) was designed grounding on a solution have been derived in [3]. Impedance Z can be calculated with known formula by Delany M.E., Bazley E.N. [4] or by one of Attenborough K. approaches. The efficiency of the algorithm is recognized anywhere and for example realized in [5]. In fig. 1 the results of its use are shown in comparison with measurement data [6] for engine testing facility with various covering of the ground surface.

4 - INFLUENCE OF PHYSICAL NOISE SOURCE

Results of calculation for arbitrarily oriented dipole, provided with K.M.Li, S.Taherzadeh & K.Attenborough [3] models, sufficiently different from monopole source shown above. Preliminary analysis have been performed for "ground attenuation" of noise produced by D30-KP engine in a direction of maximum fan noise generation. Comparison via assessment of sum of least squares for four groups of data: 1)

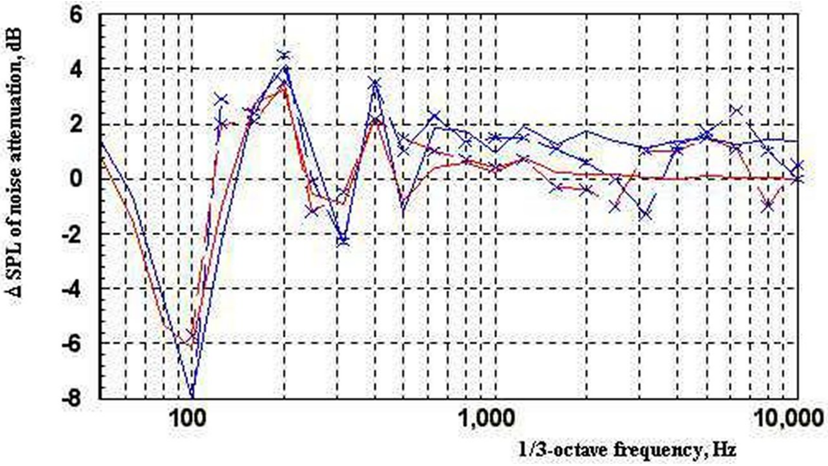

Figure 1: Comparison of calculated and measured "ground effects" for engine testing facility with concrete (blue) and foam lining (red) covering of the ground surface.

Calculations for dipole above the concrete and Measurements; 2) Calculations for monopole above the concrete – Measurements; 3) Calculations for dipole above the soil – Measurements; 4) Calculations for monopole above the soil – Measurements; provides the best features for grouping – Calculations for dipole above the concrete and Measurements. Thus the physical type of acoustic source may be sufficient for modeling and assessment of "ground attenuation".

5 - INFLUENCE OF DISCONTINUITY POINT ON GROUND EFFECT

For aircraft noise assessment inside aerodrome zone there is a common situation that various covering of ground surface are existed, thus sound wave may propagates along the surface with changed impedance of its covering. Transition intervals are observed for that at "ground effects". For the group of prop-turbine engines the data are shown in fig. 2. The intersection of two direct lines in fig. 2 defines the transition interval in relationship. There is a reason to analyze the model of "ground attenuation" in presence of point of impedance discontinuity for aircraft noise calculations.

Preliminary the influence of impedance discontinuity of the reflecting surface on ground effect of sound propagation have been made using the simple approach of de Jong [4], which suppose that the point of discontinuity works like a point of sound diffraction.

More accurate analysis of the impedance discontinuity influence can be done using more scientifically strict model. For this need the Wiener-Hopf technique have been used for the solving sound propagation equations. The useful advantage of derived model comparing with de Jong model that it provides the separation between the influence of discontinuity point and interference effect. Solutions were received for monopole and dipole noise sources.

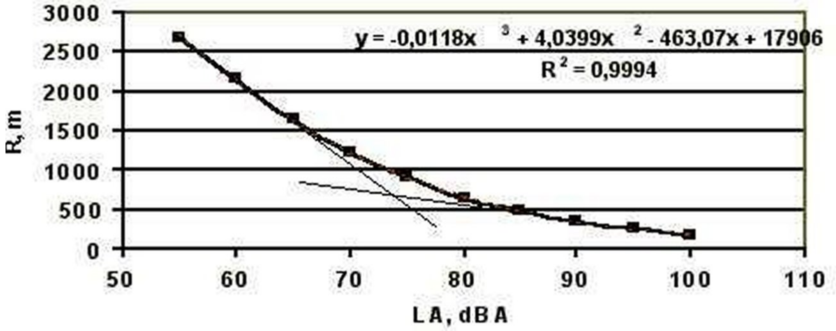

Figure 2: Distance-to-noise level relationship for prop-turbine engine for directivity angle 80° from the engine inlet.

For example, for one of the considered calculation schemes the total solution for the field of dipole noise sources over mixed impedance plane was derived as following:

$$p_t = -\frac{k\sin\left(\theta+\gamma_d\right)}{4}H_0^{(1)}\left(kR\right) - \frac{k\sin\left(\theta'-\gamma_d\right)}{4}H_0^{(1)}\left(kR'\right) + p_1 + p_2 \tag{5}$$

where p_1, p_2 - can be written in form:

$$p_1 = -\frac{i\beta_2\sin\left(\theta_0+\gamma_d\right)\exp\left[ik\left(r+r_0\right)\right]N_-\left(k\cos\theta_0\right)}{4\pi\sqrt{r_0 r}\left(\cos\theta+\cos\theta_0\right)K_{1-}\left(-k\cos\theta\right)K_{2+}\left(-k\cos\theta\right)} \text{ for } \theta+\theta_0>\pi$$
$$p_2 = -\frac{i\beta_1\sin\left(\theta_0+\gamma_d\right)\exp\left[ik\left(r+r_0\right)\right]N_+\left(k\cos\theta_0\right)}{4\pi\sqrt{r_0 r}\left(\cos\theta+\cos\theta_0\right)K_{1-}\left(-k\cos\theta\right)K_{2+}\left(-k\cos\theta\right)} \text{ for } \theta+\theta_0<\pi$$
$$x_0 = r_0\cos\theta_0,\ z_0 = r_0\sin\theta_0,\ x = r\cos\theta,\ z = r\text{s in}\theta$$
$$0<\theta<\pi,\ 0<\theta_0<\pi;\ \theta+\theta_0\neq\pi$$

First two parts in (5) are the direct and reflected sound waves, p_1, p_2 - influence of discontinuity point in accordance with its location relatively the source and receiver.
Analysis of the calculation results shows that if the reflection point follows closely to discontinuity point the influence of it grows up. Along the path above the soft covering the influence is greater (the influence from hard surface on soft surface) than the path above the hard covering (the influence from soft surface on hard surface).

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