ICAS-96-4.1 (R)

CIVIL AIRCRAFT AND THEIR NOISE IMPACT ON THE ENVIRONMENT OF THE ATHENS - SPATA AIRPORT

N.J. Yiparakis and G. Lambrianidis

Introduction

The paper presented pertains to a model of noise emission from civilian aircraft (a/c) and the environmental impact they have in the the vicinity of the Spata airport currently under construction.

A 3000 ft high Ymittos mountain separates the rural area of Spata from the densely populated city of Athens in the west. In the east is the Aegean sea. The proposed runway orientation (04-22) is such so as to not only take advantage of the prevailing winds which have a NNE direction, but in addition to handle the increased future air traffic at a minimum noise pollution level.

Intended to provide a method of estimating actual noise values as a decision making and support system, the above model is to be used as a simple prediction tool for noise emission and is designed for both propeller and jet airplanes.

Propeller aircraft

This paper section aims at predicting the emitted noise level of propeller a/c either of constant or of variable pitch. (Notice that helicopter noise is not predicted by the aforementioned model because of significant deviations from actual values due to the phenomenon of rotor downwash). Typical examples of a/c of this type that will be soon operating from Spata airport are Dornier 228, ATR 72 or ATR 42, as well as a number of general aviation turboprop or piston engine airplanes such as the Beechcraft King Air BE20, Pipers, Cessnas etc.

Input parameters used in the development of the logistic model employed here -- regardless of airplane make and model -- were the following:

- Ambient temperature, (K)
- Wind velocity, (m/s)
- Aerodynamic power, (kW)
- Rotor diameter, (m)
- Rotational speed, (rad/s)
- Distance from observer, (m)
- Source orientation with respect to observer, (°)

The overall noise level from a multi-engine propeller a/c due to the simultaneous operation of all of its engines can be calculated by the logarithmic addition of its individual engines' noise emission at the receiver's position. As an example, if the A-filtered noise levels for a four engine propeller a/c (allowing for atmospheric attenuation) are as shown below, then the overall sound pressure level from all four propellers spinning simultaneously will be as follows:

$$\text{Propeller No.1} = 91\ \text{dB(A)} = Lp1 \Rightarrow$$
$$\Rightarrow 10^{(Lp1/10)} = 1\ 258\ 925\ 412$$
$$\text{Propeller No.2} = 92\ \text{dB(A)} = Lp2 \Rightarrow$$
$$\Rightarrow 10^{(Lp2/10)} = 1\ 584\ 893\ 192$$
$$\text{Propeller No.3} = 89\ \text{dB(A)} = Lp3 \Rightarrow$$
$$\Rightarrow 10^{(Lp3/10)} = 794\ 328\ 235$$
$$\text{Propeller No.4} = 90\ \text{dB(A)} = Lp4 \Rightarrow$$
$$\Rightarrow 10^{(Lp4/10)} = 1\ 000\ 000\ 000$$

$$\Rightarrow \sum_{N=1}^{4} \{10^{(LpN/10)}\} = 4\ 638\ 146\ 839$$

$$\text{Overall Sound Pressure Level} = 10*\text{Log}\left(\sum_{N=1}^{4} \{10^{(LpN/10)}\}\right) =$$
$$= 10*\text{Log}[4\ 638\ 146\ 839] = 97\ \text{dB(A)}$$

Aerodynamic Models

There are two commonly accepted aerodynamic models, according to which propeller blades can be analyzed, namely the Central Flow and the Vortex. The former is quite consistent with the latter but the Vortex is much more precise.(1)

The essential difference between them is that, while in the Central Flow model a propeller is considered as a solid circular actuator disk perpendicularly placed to its axis within a tubular air stream of equal radius, in the Vortex model each blade of the propeller is examined as a separate entity.

For example, under the latter, there are distinct trailing vortex sheets in the shape of helicoidal surfaces that roll up into as many vortices as the number of blades and into one central hub-vortex equal in strength to the sum of the tip vortices.

It is interesting to note that for the highest blade efficiency and lowest air stream disturbances and consenquently for the lowest aerodynamic noise, we tackle the problem from two different directions opposed to each other. Since the blades experience frictional losses due to air viscosity, we must minimize these losses by operating at pitch angles equal to 45° minus half the angle whose tangent is the (lift/drag) ratio of the blade in two dimensions.(2) In other words, we need small tip-speed ratios. We also require that the solidity of the blades be high and operate at high Reynolds numbers which correspond to low skin friction.

When the induced losses however are considered, the number of blades and tip-speed ratio must be increased so that the minute vortices produced from the blades may be closely spaced and rotate perpendicularly to the turbine axis. The objective is to make the velocity slipstream more uniform and thus blades of low solidity are needed.

Summarizing, when an attempt is made to minimize induced losses due to the vorticity of the slipstream, the blades must be slender, numerous and of high tip-speed ratio. When an attempt is made to minimize frictional losses, the blades should be few, of high solidity and low tip-speed ratio. Clearly a compromise between the two approaches yields optimum results with respect to minimum noise emission.

In terms of distance between the noise emitted by the source and the sound level perceived by the observer at the point where the observer is the noise emission is divided into two groups:

1. Far-Field noise and
2. Near-Field Noise.

1. The Far-Field noise is at a distance greater than one blade diameter from the blade tip.(3) It can be estimated by using Figures 1 through 4. In fact it is a simple additive procedure which permits an engineer using even a pocket calculator to find an accurate result on site. More specifically, the prediction model comprises the following step by step procedure:

- Calculate the rotational tip Mach number, i.e., $M_{rotation} = \pi * n * D / V_a$ where n = rounds per second, D = rotor diameter, V_a = local speed of sound, where $V_a = \sqrt{\gamma_{air} R_{air} T}$ with $\gamma_{air}=1.4$, $R_{air}=288$ J/(kg)(K), T=ambient temperature.

- Based on the power input to the propeller and its rotational speed, obtain the partial sound level FL1 from Fig.1.

- Find the adjustment FL2 for diameter and number of blades from Fig.2.

- To account for atmospheric absorption and spherical spreading of sound find FL3 from Fig.3.

- Obtain the correction DI for the directivity pattern from Fig.4, where azimuth angle $\theta = 0$ degrees is on the blade rotor axis in the forward direction.

Overall sound pressure level = FL1 + FL2 + FL3 + DI, dB

To calculate A-weighted sound pressure level in dB(A), subtract 14 dB from the total sum, as per the Hamilton Standard report PDP 6101 A of United Aircraft Corporation. Note that the helical tip Mach number needed can be calculated by the following equation:

$$M_{tip} = M_{\infty} \sqrt{[1 + (\pi / j)^2]},$$

where j = advance ratio = 1/(tip speed ratio)

2. The Near-Field noise is the noise perceived at a distance within one rotor diameter from the blade tip. Mainly used for assessing accoustic fatigue potential of the propeller structure, this information is not included in the present prediction model, as it does not have any environmental impact.

In general, propeller noise originates from two sources:

1. Rotational noise and
2. Vortex noise.

1. Rotational noise describes all sound which has discreet frequencies occurring at harmonic of the propeller blade passage frequency, i.e., the number of the blades multiplied by the rotational frequency. It is generated because of the oscillatory pressure field acting on the air at a fixed point near the rotor disk. The noise level is maximum in the plane of rotation and increases with absorbed power, increased diameter, fewer blades and with increased tip speed.

2. Vortex noise (or broad band noise) describes the sound produced by the unsteady pressure field associated with vortices shed from the trailing edge (TE) and tips of the blades, as well as those associated with turbulence effects in the air stream. It is for this reason that curvature to the TE rather than designing it completely sharp (e.g., Clark-Y airfoil sections) control emanating vortices.

The vortex shedding frequency is a function of the flow velocity. Notice that for a rotating blade the sectional velocity is different along the blade span, resulting in a broad band of shedding frequencies. Since the noise level is proportional to the sixth power of the section velocity, it follows that the frequencies associated with the tip section tend to be of the greatest amplitude. Therefore, to reduce vortex noise tip speed should be reduced. To make up for the lost power extracted, the blade area must be increased. However, increasing the blade area will affect blade structural design and will have a negative impact on blade efficiency.

Evidently, a quiet and at the same time aerodynamically efficient propeller requires a meticulously detailed design. In the current decade it is not uncommon to encounter the "prop-fan" type of propellers. Having a shape similar to that of an umbrella, these propellers aim at reducing noise by essentially lowering their helical tip Mach number.

Jet aircraft

Due to the more stringent noise criteria of the current decade, most jet aircraft use turbofan engines ranging in their

Bypass Ratio (BPR) values from of 2 to 8. Typical examples of a/c in this class that will be operating from the Spata airport are Boeing B747-200, B737-400, B757-200, B767-200, McDonnell Douglas DC10-30, MD-11, DC8-60, Airbus A300, A310, Illushin IL62 and IL86, Tupolev TU34 and TU54, British Aerospace Bae1-11 etc.

Unlike the propeller section of the logistic model, however, the jet section is tailored around the individual noise characteristics according to airplane make and model. In other words, for a Boeing 737-300 having CFM56-3 engines, the model is based on actual measurements at various power settings, e.g., idle power, take-off power etc. Families of curves called "isoacoustics" reflect those actual measurements.(4) A typical example is shown in Figure 5. When isoacoustics for a given power setting of a particular jet are curve-fit, analytical relations of noise emissions vs distance and observation angle are generated. The process is repeated for other types of engines such as Pratt & Whitney JT9D-70 or RB-211 and thus this section of the logistic model is obtained. Independent parameters used here were:

- Distance of source from observer, (m) and
- Angle between source and observer, (°)

Principles of noise attenuation

Sound waves generated by an aircraft are perceived by an observer through a process that it is quite complex. In general, the overall sound level increases and subsequently decreases again depending on the duration of the aircraft passage through the observer's location.

During that process, not only does the frequency of the emitted sound waves change (Doppler effect), but the frequency spectrum of the aircraft's engines is constantly changing due to sound propagation phenomena within the atmosphere, along the entire path from the source to the observer. A characteristic example of worst case pollution is shown in Figure 6, i.e., the take-off phase of a departing a/c. Notice that due to noise abatement, power is reduced at a height Above Ground Level (AGL) of 1500 ft (450 m).

In general, a/c sound propagation comprises:

1. Spherical spreading
2. Atmospheric absorption and
3. Additional attenuation.

1. Spherical spreading of sound waves is best described by the law of "the inverse of the distance squared", or alternatively, when doubling the distance between source and observer, the sound level decreases by 6 dB.

2. Atmospheric absorption is due to excitation of the air molecules. The magnitude of this absorption is directly proportional to the square of the frequency and varies linearly with the distance. Typically, only frequencies higher than 500 Hz and distances in excess of 1000 m are significant.

As the mechanism of atmospheric absorption is of a molecular resonance type, it sharply varies in proportion to the water content of the air and consequently to the relative humidity and temperature. It is for this reason that aircraft noise levels are normalized at 15°C and 70% relative humidity. In the case of aircraft, when the distance is doubled, there is an approximate further noise reduction by 2 dB. This phenomenon is usually reflected in data tables issued by the U.S. Society of Automotive Engineers (SAE APR 866A, 1975), which resulted from the compilation of actual measurements of aircraft, as analyzed in relation with the relevant parameters.

3. Additional attenuation which is the cause of all other noise reduction phenomena, except for the spherical dispersion or atmospheric absorption. Such additional attenuation principally depends on the absorptive capacity of the terrain surface and, as a consequence, it has the tendency of increasing in all the cases when the a/c sound waves reach the observer from a long distance, while the elevation angle is small and typically less than 15°. The phenomenon of this additional attenuation is usually reflected in data tables issued by the U.S. Society of Automotive Engineers (SAE AIR 1751, 1981), which applies in the case of "soft" terrain surface, such as courts with low grass or similar vegetation. These data have been determined by a series of actual measuremnts, where the differences amongst the sound spectra result from the comparison of values of flight path lying above the observer at a given minimum aircraft oblique approach versus the corresponding values of the flight path lying directly above the observer.

As an approximation, when the noise level is expressed in dB(A) terms of the value of maximum noise pollution of an overflying aircraft, we can add 2dB when the distance is doubled for an almost horizontal sound transmission, while we should reduce this modification to 1 dB only for an aircraft elevation angle of 7.5° and to 0 dB for 15° or higher elevation angles.

CONCLUSIONS

The model presented is quite accurate, in vew of the fact that the propeller section does not deviate from actual values by more than 2 dB, i.e., hardly audible by the human ear.

Regarding the jet section, the model is reliable as long as the ambient air conditions are considered to be normal at a a temperature value of 15° C and a relative humidity of 70%. In order to design a more complete model, capable of predicting jet aircraft noise emissions under various atmospheric conditions, further investigation is needed.

This is a simple model which can be used as a prediction tool for estimating the noise pollution in the area of Spata International airport.

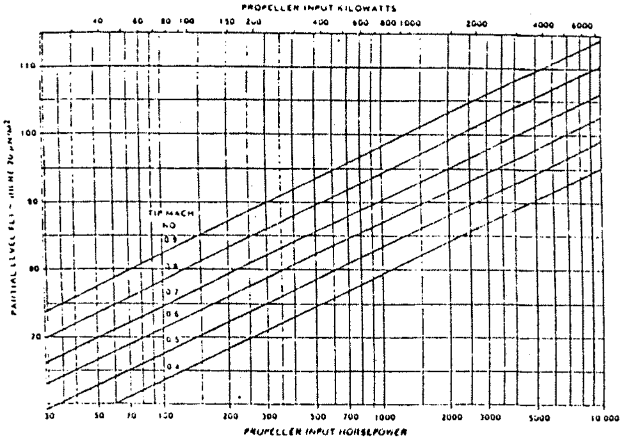
REFERENCES

1. Lan Chuan-Tau E., Roskam Jan : "Airplane Aerodynamics and Performance", University of Kansas, Roskam Aviation Corporation 1981.

2. Larrabbee, E. (1980). The Screw Propeller", Scientific American, 243 (1), 134-148

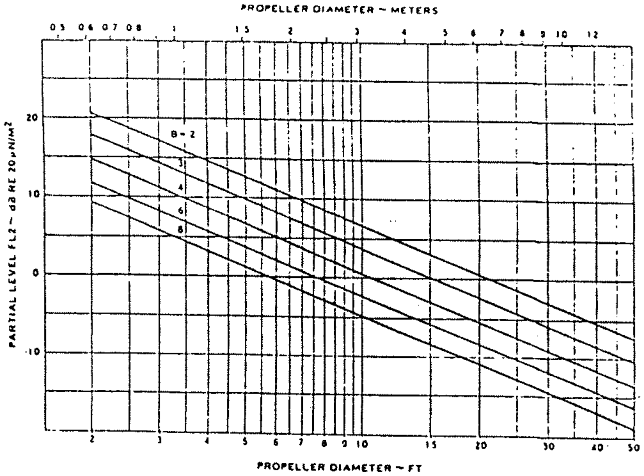
3. "Prediction Procedure for Near-Field and Far-Field Propeller Noise", Aerospace Report 1407, Society of Automotive Engineers Inc., 1977.

4. Boeing 737-300 isoacoustics of take-off power corresponding to CFM56 engines.



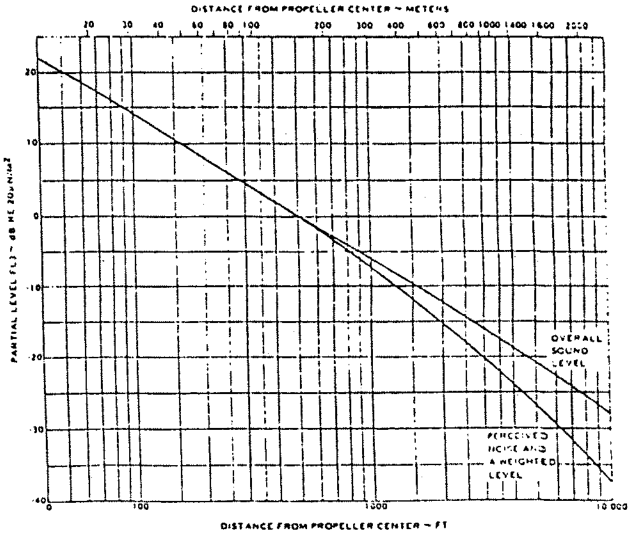
FAR FIELD PARTIAL LEVEL BASED ON POWER AND TIP SPEED

FIGURE 1



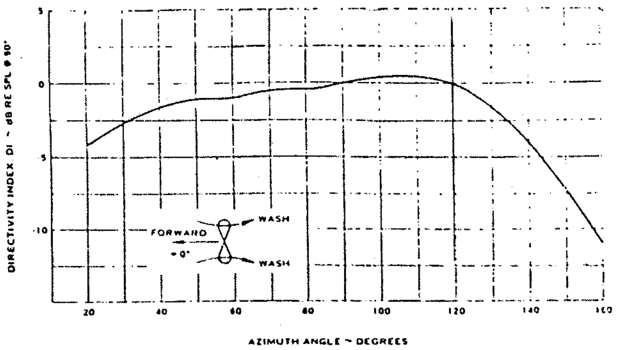
FAR FIELD PARTIAL NOISE BASED ON BLADE COUNT AND ROTOR DIAMETER

FIGURE 2



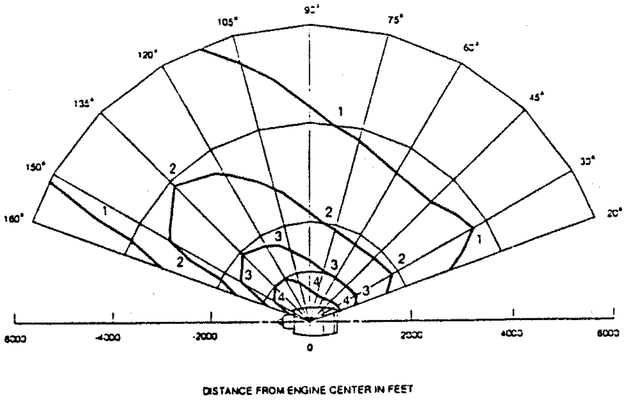
ATMOSPHERIC ABSORPTION AND SPHERICAL SPREADING OF SOUND

FIGURE 3



DIRECTIVITY INDEX

FIGURE 4

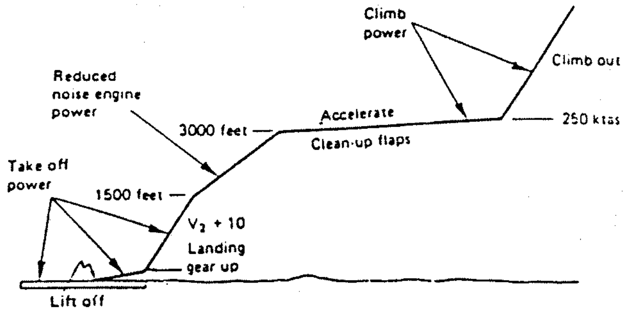


dBA
1 - 40
2 - 50
3 - 60
4 - 70

ONE CFM56-3 ENGINE OPERATING
IDLE POWER (1535 RPM N1)
77 DEGREES FAHRENHEIT
70% RELATIVE HUMIDITY
±5 DBA TOLERANCE

ENGINE NOISE ISOACOUSTICS (dBA)

FIGURE 5



TYPICAL DEPARTURE PROFILE FOR NOISE ABATEMENT

FIGURE 6