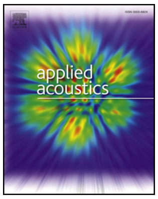
Applied Acoustics 138 (2018) 156–162

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust



Decontamination of acoustic measurement with critical point noise detection

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ARTICLE INFO

Keywords:
Noise
Decontamination
Directivity

ABSTRACT

Extraneous noise often contaminates acoustic flyover. A new method for detecting the presence of ambient acoustic noise in measurements has been developed that overcomes limitations of legacy methods. Critical Point Noise Detection (CPND) improves acoustic source construction accuracy through selecting the highest number of valid data points. CPND applies the fundamental theorem of Calculus to locate critical points of Cartesian coordinate time history traces on the surface of a fixed radius sphere circumscribed around the acoustic source. An example acoustic surface created from a measurement of a UH-1 Iroquois aircraft demonstrates the validity of CPND. The validation shows CPND successfully removes contaminated measurements from the UH-1 directivity pattern. CPND possesses advantages in the quantity of data for individual frequencies, replicability, and processing automation.

1. Introduction

Extraneous noise not emitted from the test acoustic source frequently contaminates acoustic measurements. This is observed in a wide variety of situations, such as measurement of interior aircraft cabin noise [1] and measurements made using microphones near the ground [2]. For acoustic directivity construction, the extraneous noise is typically the electro-acoustic noise floor of the measurement system. This is a combination of the transducer and acquisition system electrical noise floor and the ambient noise inherent in the measurement location.

One way this extraneous noise influences measurements is by reducing the signal-to-noise ratio between the acoustic noise floor and desired signal. Another source of extraneous noise during data collection is biological noise. As is mentioned in other research, extraneous noise is also observed when acoustic sources are present in a transient manner, like road noise near the acoustic measurements, or additional aircraft in the vicinity of the measurement site [3].

Interest in directivity patterns exist in general propagation [4] and the study of the directional nature of rotorcraft [5–10]. However, community noise requires higher fidelity full-scale representation of aircraft directivity. Two full-scale 3-D community noise directivity pattern models are proposed: the Rotorcraft Noise Model (RNM) [11,12], and the series decomposition model from the Swiss Federal Laboratories (EMPA) [3]. Both models use simple rules to identify potential contaminants from extraneous noise. Both construction methods de-propagate measured sound pressure levels along paths to a fixed radius sphere around the test vehicle. One interpolates these source levels into a regular grid [13]; the other decomposes the surface into a series expansion of spherical harmonics [3,14,15].

The Rotorcraft Noise Model (RNM) [12,13,16] implements the 3-D interpolated directivity pattern. This method requires a noise floor or ambient acoustic level to compare with measured levels. Details of the implementation within RNM and the source construction model, the Acoustic Repropagation Technique [13] (ART), are minimal. In Section 4.1.3 of the RNM manual [17], the signal-to-noise noise floor method (NFM) is presented. The manual states that NFM discards any measurement that does not exceed the acoustic noise floor plus a fixed signal-to-noise ratio (SNR). A similar method to remove contaminated data is suggested by an ANSI standard [18], but again details of the implementation are limited.

Regardless of exclusion of a single frequency or the entire spectrum, NFM requires the definition of the ambient noise spectrum. The timing of the acoustic ambient measurement can significantly influence testing schedules and resulting data analysis. During a typical test activity, the acoustic ambient does vary. Ambient measurements at the beginning and end of a test may not be sufficient to capture variations, which can occur during a test. However, the collection of acoustic ambient data between passes requires the aircraft to leave the test area so that it is not audible, but determining audibility is one of the purposes of acoustic characterization. The effective implementation of NFM

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https://doi.org/10.1016/j.apacoust.2018.03.030
Received 21 April 2017; Received in revised form 22 March 2018; Accepted 27 March 2018
0003-682X/ Published by Elsevier Ltd.

requires definition of a sound pressure level trace that is significantly complicated to measure.

EMPA is developing a different construction method based on series expansion of spherical harmonics. During a measurement to analyze the efficacy of this construction method, EMPA measured a number of aircraft over-flights containing acoustic noise contaminants [3] such as highway noise and additional aircraft in the vicinity of the measurement array. EMPA researchers employ a subjective quality metric (SQM) which is significantly problematic because it requires human experimenters to examine the spectral levels. Field notes, recollections and data analyses are combined to define SQM for each spectrum which varies from one (highly contaminated) to six (highly uncontaminated). EMPA defines the inclusion criteria as SQM values between four and six. However, SQM does not discriminate between specific frequencies.

To simplify and address limitations of these legacy methods, a new method called Critical Point Noise Detection (CPND), based upon the fundamental theorem of Calculus, is proposed. CPND uses the critical points of Cartesian coordinate trace time histories to locate the electro-acoustic noise floor of the acoustic measurement. Through CPND, the acoustic noise floor of a UH-1 helicopter acoustic measurement is determined. CPND takes input parameters that are independent of geographic location and observer notes. It is numeric, and requires no human examination. CPND determines the value of the electro-acoustic ambient noise from the measurements used to construct the directivity pattern. This produces an ambient definition that is more time synchronized with measurements than the NFM method. This paper shows CPND successfully removes acoustic noise floor contaminates due to the electro-acoustic noise floor and maintains the highest number of valid data points for each frequency when compared to the legacy methods.

2. Critical point noise detection

2.1. Definition of coordinate traces

RNM and EMPA source construction methods determine the location where emitted sound path crosses a fixed radius sphere [3,12]. CPND uses the body coordinate system [19] (Fig. 1) and vector transformations through Canonical Euler rotation matrices to define the acoustic emission sites. The spherical angles are relative to the rotated Cartesian coordinate unit vectors shown in Fig. 1.

Given a vector pointing from the center of the reference Cartesian system to the source (v_{src}) and a similar vector pointing to the receiver (v_{rec}) the vector pointing from the source to the receiver is determined in the rotated coordinate system with Eq. (1):

$$v = R_x(\mu)R_y(\rho)R_z(\gamma)R_z(-\pi/2)R_x(\pi)(v_{rec}-v_{src}), \tag{1}$$

where μ, ρ, and γ are the Euler rotation angles of the aircraft in the body coordinate system and the R_i are the canonical Euler rotation matrices [20]. The Euler rotation angles are also the orientation angles yaw/heading (γ), pitch (ρ) and roll (μ).

The spherical acoustic emission angles are equivalent to the spherical polar and elevation angles, and are determined from the canonical transforms:

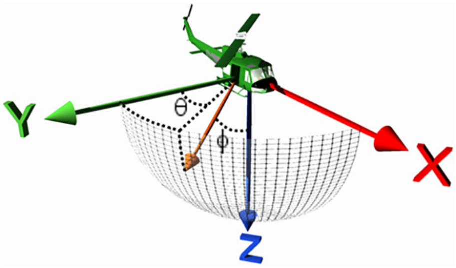

Fig. 1. Definition of the Cartesian coordinates in the body system that is used to define the axes for the decontamination.

$$\theta = \tan^{-1}\frac{v_2}{v_1} \tag{2}$$

$$\varphi = \cos^{-1}\frac{v_3}{\rho} \tag{3}$$

where $\rho = \sqrt{\sum v_i^2}$ and v_i are the Cartesian coordinates of the vector determined with Eq. (1). These emission angles are logged for each point in the flight track, and for each receiver in the measurement array. The acoustic arrival time is determined with Eq. (4), where c is the adiabatic speed of sound during data collection.

$$t_{arrival} = t_{track} + \rho/c \tag{4}$$

Spherical coordinates are transformed back to Cartesian coordinates for application of CPND. The transform is accomplished with canonical transform equations, but this time the spherical radial value is replaced with the sound pressure level at the directivity surface for a specific frequency.

2.2. Critical point decontamination

Both NFM and SQM potentially reduce the amount of data points within the surface definition and may remove all elements of a spectrum when a single frequency element is contaminated. The goal of CPND is to provide a mathematical method to remove individual frequency content independent of human observation and intervention while maintaining the maximum quantity of valid data.

Three parts of the acoustic directivity pattern require the most valid data points. Because the angle changes so rapidly, directivity under the aircraft must be sampled at a higher density. This is typically accomplished with the inclusion of microphones on the flight path [21,22], as suggested by the ANSI standard [18]. Due to the typical array used in characterization [3,21,22,18], the nose and tail of the directivity pattern are also difficult to quantify. During the de-propagation stage [3,21,23] of source construction, when the electro-acoustic noise floor is de-propagated. This causes a large protrusion on the noise and tail that is an artifact of the de-propagation and the measurement array not the acoustic emissions of the test aircraft. Inclusion of this increases the error and uncertainty of the measurement, and can produce erroneous results from the interpolation and curve fitting. The removal of the electro-acoustic noise floor limits the inclusion of these de-propagated levels.

The following steps define the CPND algorithm:

(1) Determine the emission locations on a fixed radius sphere (Eqs. (1)-(4));
(2) De-propagate measured levels[3,11–14];
(3) Determine the discrete first differential of the Cartesian x-coordinate time history;
(4) Determine the discrete second derivative of the Cartesian x-coordinate time history;
(5) Find the minimum of the first derivative;
(6) Find the last inflection point of the first derivative before the minimum from Step 5;
(7) Find the first inflection point of the first derivative after the minimum from Step 5.

Additional details of each of step are provided in the following sections.

2.2.1. Determine emission locations

Exposition of CPND's steps uses a numeric simulation. The simulation uses a monochromatic monopole flown at a constant 250 foot above ground level. A virtual receiver is 300 feet offset from the source track. Using Eqs. 1–3, the emissions locations cross a 100-foot sphere at