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A BROADBAND NOISE PREDICTION SCHEME FOR LOW-NOISE CENTRIFUGAL BLOWERS

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ABSTRACT

In this paper we outline a semi-empirical procedure for predicting the broadband sound power spectrum radiated by any member of a family of geometrically similar, centrifugal blowers. The prediction scheme is based on the use of a normalized sound power spectrum that is obtained by measuring the sound power radiated by *one* member of the blower family. In the present instance, a low-noise blower design has been identified by conducting a large scale parametric study of blower noise as a function of geometrical design parameters and operating point; the resulting optimum design served to define the geometrical parameters of the blower family considered here. The prediction procedure allows calculation of either 1/3-octave band spectral levels or overall A-weighted levels. In addition it is possible to calculate "noise surfaces," i.e., plots of A-weighted sound power level *versus* design parameters and operating condition; in this way it is easy to identify optimally quiet blower designs that satisfy specified pumping requirements. It has been found, for example, that large diameter impellers of relatively small width operating at low speeds tend to result in the lowest noise level at a given pumping requirement.

INTRODUCTION

"Sound laws" can be used to predict the *overall* sound power level radiated by centrifugal blowers when the power level of a geometrically similar reference blower is known [1]. In this paper we present a prediction scheme for blower noise *spectra* that is firmly based on an existing parametric representation of blower noise spectra. In particular, it will be shown that a parameterized spectral representation proposed by Maling [2] may be combined with measured reference data to yield noise predictions for a complete family of geometrically similar blowers. In addition, Maling's approach has been extended here to allow for impeller width variations in the scaling procedure. A key result of the present work is the definition of a noise surface that allows one to identify the low-noise blower designs that will meet a given pumping requirement.

DEVELOPMENT OF A NOISE PREDICTION SCHEME

The scheme presented here allows the prediction of the 1/3-octave band sound power levels in the frequency range 100 Hz to 10 kHz for various blowers having different geometries and operating speeds, but all fulfilling a specified pumping requirement (i.e., a particular combination of pressure and flowrate). As a result, the overall A-weighted sound power level can then be calculated and plotted *versus* the corresponding point of rating, ϕ, and the aspect ratio, α (impeller width over diameter), to produce a noise surface. The lowest noise level can then be identified along with the corresponding blower geometry and the required operating speed.

The scheme is based on measurements of the aerodynamic and acoustic performance of a low-noise reference blower that is treated as a representative member of a family of geometrically similar blowers. The aerodynamic data consist of a discrete set of operating points at which acoustical measurements were conducted using the reference blower. For each operating point, non-dimensionalized *generalized* flow and pressure coefficients, ϕ_g and ψ_g, were calculated according to equations (1) and (2) [2]:

$$\phi_g = \frac{Q}{\pi D^3 N \alpha}, \tag{1}$$

$$\psi_g = \frac{2p}{\rho(\pi DN)^2}, \tag{2}$$

where p and Q, respectively, denote pressure and flowrate at the corresponding operating point, ρ is the fluid density and D and N are the impeller diameter and speed, respectively. If such a normalization is applied to the performance curve of the reference blower, a universal head-flow curve is obtained that characterizes the aerodynamic performance of any blower in the family [2]. A point on this head-flow curve is called a point of rating. Note that the conventional definition of ϕ_g has been modified here to allow for the impeller aspect ratio under the assumption that the flowrate delivered by a centrifugal blower is proportional to its aspect ratio at a constant static pressure. An experimental verification of this assumption will be presented below. The measured acoustical data consist of 1/3-octave, unweighted sound power levels for the reference blower, L_{wr}, measured at the operating points defined above. From the levels measured at a particular operating point, i.e., point of rating, a normalized spectrum can be derived that is characteristic of the sound radiated by any blower in the family *operating at that point of rating*.

The equation that is used to derive the normalized spectrum has been proposed previously by Maling [2]: i.e.,

$$E = \rho c^2 D^3 M^3 \alpha g(\phi, s). \tag{3}$$

In this equation, E is the sound power/Hz radiated by the blower, c is the speed of sound in air, $M=\pi DN/c$ is the impeller tip speed Mach number, and $g(\phi,s)$ is the normalized spectrum expressed as a function of point of rating, ϕ, and dimensionless frequency, s ($s = f/N$). Note that Maling's equation has been modified to account for the impeller aspect ratio by the inclusion of the factor α. The assumed dependence on α implies that the radiated sound power is proportional to the impeller aspect ratio when both static pressure and air flow per unit width are constant. An experimental confirmation of this assumed dependence will be presented below.

From measurements using the reference blower, values of the normalized spectrum, $g(\phi_i,s_i)$, at the points of rating (ϕ_i) at which noise measurements have been made can easily be computed by calculating E from the measured power levels and solving equation (3) for $g(\phi_i,s_i)$. The values of s_i are calculated simply by dividing the 1/3-octave band center frequencies, f_c, by the blower speed at the point of rating being considered. To evaluate the normalized spectrum at points other than those measured, e.g., when a blower is run at a speed different than the reference blower, it is necessary to interpolate between or extrapolate from the measured data points. This can be achieved most easily by fitting a curve through $g(\phi_i,s_i)$ at each operating point. Since the sound power spectrum of a centrifugal blower tends to decrease by an almost constant number of decibels per decade of frequency, it is appropriate to fit a straight line to a doubly logarithmic presentation of $g(\phi_i,s_i)$ *versus* s_i.

Once the normalized spectra have been obtained at each point of rating, the impeller diameters, D_j, and speeds, N_j, can be calculated for a set of blowers that all satisfy a given pumping requirement (i.e., a particular combination of p and Q) but which have different aspect ratios and are operated at different points of rating (the points of rating at which measurements were made using the reference blower). At a fixed point of rating, equations (1) and (2) may be used to derive relations between the reference values of D and N and new values that satisfy a particular pumping requirement: i.e.,

$$D_j = D\left\{\frac{\alpha}{\alpha_j}\frac{Q_j}{Q}\left\{\frac{p}{p_j}\right\}^{1/2}\right\}^{1/2}, \tag{4}$$

$$N_j = N\frac{\alpha}{\alpha_j}\frac{D^3}{D_j^3}\frac{Q_j}{Q}, \tag{5}$$

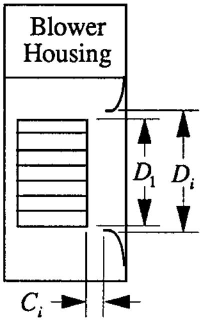
where the subscript j refers to the "new" blower geometry and the unsubscripted parameters are the reference values at a particular point of rating. In particular, note that the combination of p_j and Q_j fix the pumping requirement. The reference values of p and Q to be used in equations (4) and (5) obviously change depending on the operating point of the reference blower that is considered in this transformation. In addition, note that at each point of rating the aspect ratio of the new blower can be varied arbitrarily. Thus, at each operating point, pairs of impeller diameter and speed can be calculated for any given aspect ratio.

In this way ϕ_i and α_j fix the allowed values of D_j and N_j for a given pumping requirement. Given the value of N_j, it is straightforward to calculate values of s_j that correspond to standard 1/3-octave band center frequencies. The values of the normalized spectrum at these values of s_j for each point of rating may then be evaluated using the curve fits referred to above. Equation (3) can then be used to calculate the sound power per Hertz at each 1/3-octave band center frequency, from which, in turn, the 1/3-octave band sound power levels can be calculated. From the latter, the overall A-weighted sound power level may be computed. Finally, the noise levels calculated for different combinations of ϕ_i and α_j are then plotted *versus* these two parameters, the result being a noise surface.

EXPERIMENTAL RESULTS

The usefulness of the prediction scheme developed above is obviously dependent on the identification of a low-noise reference blower. An extensive experimental program has therefore been conducted in order to define the optimum values of several geometrical blower design parameters. In addition, it was necessary to verify experimentally the assumptions regarding impeller width that are implicit in the scaling procedure.

Reference Blower Data. To identify a low-noise blower design, the A-weighted sound power radiated by a family of mid-sized blowers (0.16 m impeller diameter) was studied as a function of several design parameters. The effect of each design parameter was isolated by conducting experiments in which only one design parameter at a time was changed. The design parameters varied in this study and their optimum values are summarized in Figure 1. Note, that the effects of all parameters were studied in combination with the two commercially available blade types: 'tablock' and 'bladestrip.' Tests conducted using the two blade types showed that the tablock design is quieter than the bladestrip at a given level of aerodynamic performance. For a complete description of the experimental procedure used to identify the optimum reference blower design, see references [3,4].



Design Parameters	**Optimum Values**	
	Tablock	Bladestrip
Expansion angle [deg]	8	8
Development angle [deg]	300	300
Cutoff Clearance	24 mm	24 mm
Radial Inlet Clearance (D_i / D_1)	1	1
Axial Inlet Clearance (C_i)	2.5 mm	7.5 mm

Figure 1. Blower design parameters and their optimum values.

The blower noise in each case was measured using the INCE plenum in a reverberation room as standardized in ANSI S12.11 1987 [5]. As noted above, the noise prediction scheme developed here is applicable *only* to the broadband aerodynamic noise generated by turbulent flow through the blower; it specifically does not apply to pure tones generated by blade-cutoff interaction (these have been studied extensively elsewhere, see, for example, references [6,7]) or to tones generated by the drive motor. Therefore, when measuring the reference acoustical data the pure tones were removed from the measured spectra. Since all the blowers tested were driven *directly* by a 4 pole, AC-motor, all discrete tones occured at harmonics of the motor shaft speed. As a result, a simple editing and interpolation procedure could be used to remove the tones from the sound power spectra. For more information on the tone removal, refer to reference [3].

The aerodynamic performance of each blower was measured using a flow test tank built according to AMCA standard 210-85 [8].

Experimental Verification of Scaling with Respect to Impeller Width. As noted previously, the conventional definition of the dimensionless flow coefficient, ϕ_g, has been modified in this paper to account for the effect of different impeller aspect ratios on the aerodynamic performance of centrifugal blowers. The modified definition reflects the assumption that the flowrate delivered by a blower is proportional to its aspect ratio at a constant static pressure. This assumption has been validated by making measurements with three blowers having different impeller widths but constant impeller diameters (thus resulting in α values of 0.227, 0.436, and 0.574). The performance curves before and after normalization are shown in Figure 2; it can be seen that the proposed normalization produces an acceptable collapse of the data.

Recall that the noise equation (3) has also been generalized to account for different aspect ratios in the family of geometrically similar blowers. It was assumed that the radiated sound power is proportional to the width of the impeller when both static pressure and air flow per unit width are constant. This assumption was experimentally validated by calculating the normalized spectra, $g(\phi_i,s_i)$, for three blowers having different aspect ratios, but operating at the same point of rating. As shown in Figure 3, the collapse of the spectral data is significantly improved by the normalization procedure, thus suggesting that the proposed α-dependence is reasonable.

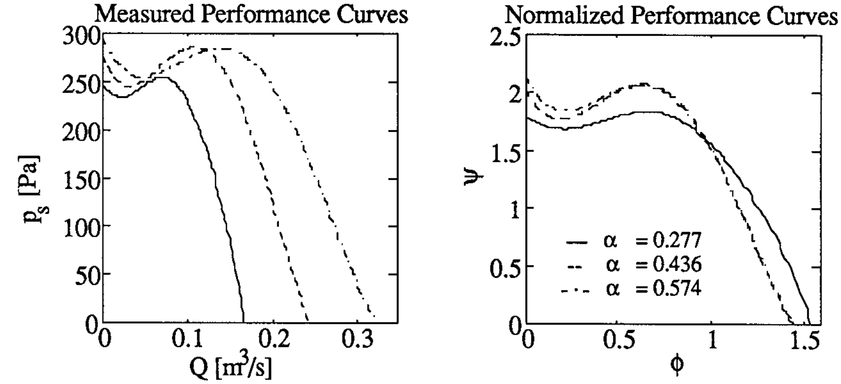


Figure 2. A comparison of measured and normalized performance curves.

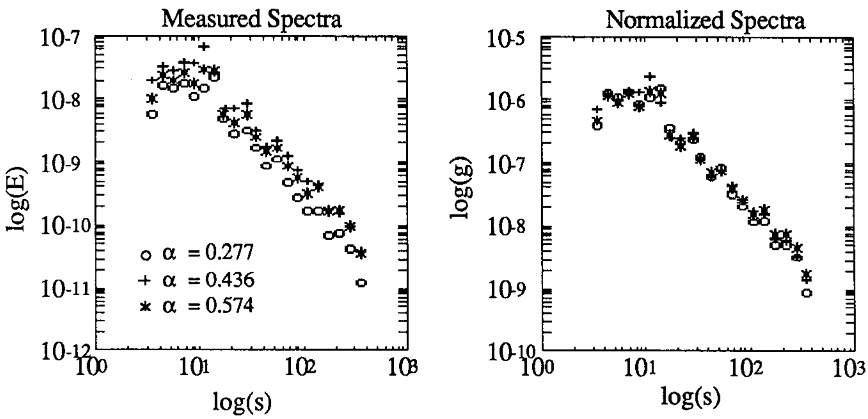


Figure 3. A comparison of measured and normalized blower spectra.

Calculation of Noise Surfaces. Perhaps the most important use of the procedure described here is as a tool to aid in designing low-noise blowers to meet particular pumping requirements. As described above, the predicted A-weighted sound power level of all blowers geometrically similar to the reference blower and that meet a specified pumping requirement may be plotted as a function of point of rating and aspect ratio. Curves of A-weighted level *versus* point of rating and either blower speed or impeller diameter can also be generated. An example of a typical noise surface based on the reference data presented above is shown in Figure 4. This surface was calculated for an operating point characterized by a pressure of 300 Pa and a flowrate of 0.25 m^3/s. It is clear from this example, that small aspect ratios are to be preferred from a noise point of view. More generally, studies of noise predictions for various pumping requirements have shown that a blower having a narrow, large diameter impeller running at low speed usually results in the lowest noise levels.

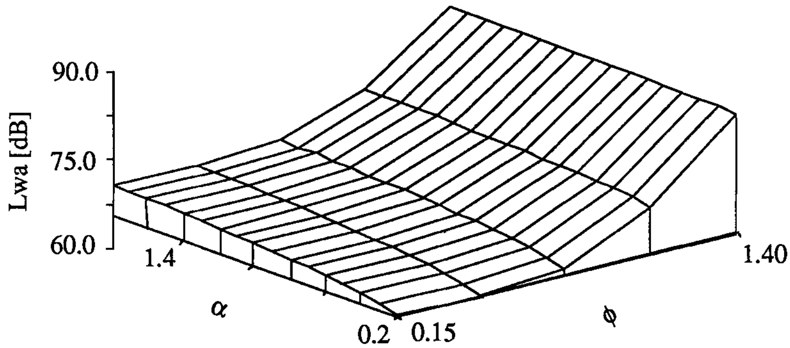


Figure 4. A typical noise surface based on the low-noise reference blower.

SUMMARY AND CONCLUSIONS

A technique has been developed that can be used to predict the 1/3-octave band sound power levels of centrifugal blowers. The predictions are based on measurements of aerodynamic and acoustical performance made using a low-noise reference blower. The design of such a blower was identified experimentally in a large scale study. Given a particular pumping requirement, the prediction scheme can also be used to identify the lowest noise blower from a family of geometrically similar blowers. Since the definitions for the dimensionless parameters flow and pressure coefficient were generalized along with the noise equation to allow for impeller width variations, the prediction scheme can also account for the effects of varying the impeller width.

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