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Explicit formulas for the calculation of regenerated noise in ducts

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Abstract [27] In analyzing mechanical services systems in facilities requiring low noise levels including theatres, concert halls and film studios, the major source of noise is generally not fan noise but flow-induced noise produced within the duct system by fittings and control elements. For the review of a major new concert hall, the analysis required the estimation of noise generated by fittings such as rectangular bends, radius bends, branches, dampers and straight ducts.

A review of the literature published by various research organizations since the 1970's indicated a number of test reports that could be used to develop standardized formulas for prediction. It appears that a number of prediction methodologies significantly err in estimating the fitting-regenerated sound power. Using newly obtained information including unpublished data on radius bends, a full suite of complementary noise prediction algorithms was prepared which enabled the overall sound power and spectrum of a particular fitting to be determined. These formulas are consistent with the regenerated noise predictions published by SMACNA, NEBB or ASHRAE but are presented in a form suitable for use in spreadsheets.

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1. INTRODUCTION

The new Esplanade -Theatres on the Bay Concert Hall and Lyric Theatre in Singapore has had the prime mechanical services systems noise analyzed by a new computer based software program that greatly simplifies and enhances the analysis. This program provides comprehensive results in a simple-to-evaluate format and predicts regenerated noise within the system by key duct elements. A review of the program output enables rapid identification and resolution of ductborne noise problems.

2. BACKGROUND

The regenerated (or "self") noise produced by dampers, fittings, grilles, registers, fans, VAV boxes and attenuators is generally well documented by manufacturers. However the prediction of noise at branches, bends, elbows and in straight duct is not well presented. Very few reliable prediction data exists.

Apart from methodologies presented in ASHRAE Systems 1980[1] and the SMACNA Handbook[2] there has been no evaluation or review of literature and published data. As part of the validation process during the development of the above mentioned software, a review of available prediction methods was conducted.

This paper summarizes the available methods and presents algorithms for their use rather than graphical tools or nomograms. A comparison of the available methods is also presented. Validation of the prediction is discussed in another paper at Inter Noise 2004.

3. GENERALIZED RESULTS

Air flow noise in ducts, where good flow conditions exist, will change dramatically if the entry conditions or turbulence changes. Most acoustic design is based on velocity guidelines that depend on duct location and which are used for duct sizing and hence minimal noise generation. These guidelines are empirical with no basis other than conservative past experience. With this approach there is no opportunity for duct optimization or problem identification and rectification.

At present there is no agreed method for taking the turbulence into account, other than derivations from basic theory. In an ideal scenario the flow noise is a function of velocity, cross sectional area, the Strouhal number, and pressure drop. From the knowledge that the regenerated sound power W, is related to the duct area and velocity by $W = KAV^6$, the generalized form of the required relationship is given by Murray Mason of ACADS[3] and others as follows:

$$Lw = Fg + 10\log A + 10\log b + 50\log V + 10\log f,\ dB \ \ldots\ldots\ldots\ldots.(1)$$ where:

Fg = spectrum correction term related to the fitting and modified Strouhal number S_N.
$S_N = fdBe/V$, dimensionless
Be = friction term related to pressure drop dynamic loss factor, k
A = upstream duct area, m^2
b = characteristic dimension, mm(width, diameter etc)
V = velocity, m/s
f = frequency Hz

Based on the available published data, test results and publications referred to above all predictions can be presented in this format. Not all published predictions are consistent but can be compared and validated using this procedure.

4. NOISE GENERATED AT RADIUSED BENDS

Noise from bends will depend on the radius of the bend, the geometry (circular or square/rectangular) and whether (in rectangular bends) turning vanes are fitted or not.

Until recently no published literature relating to circular radiused bends existed. Works conducted for WS Atkins by Waddington and Oldham[4] has enabled a prediction method to be developed. This method is currently only available for bends where R=1.5D - the most common type of bend particularly in low noise situations. More research is required for the method to be extended to bends of longer or shorter radius. The sound power is given by the following, where the terms as described above still apply.

$$Lw = Fg + 10\log A + 10\log (b/1000) + 50\log (V/Be) + 10\log(f/63),\ dB \quad (2)$$

Fg for circular radiused bends is obtained by reference to Figure 1. In this case b is the duct diameter. This method has also been used, without validation, for radiused rectangular bends without vanes, in the absence of any other data. In this case b=vA (area).

5. NOISE GENERATED AT MITRE BENDS WITHOUT TURNING VANES

The pioneering results from Bullock and Brockmeyer have been published in ASHRAE 1980 and 1987[5] and can be presented in the format of (1) above. There are no other known prediction methods for calculating noise from mitre bends (elbows) without turning vanes. This method originally published in ASHRAE 1980[1] shows the effect of aspect ratio, and is no longer included in the handbook. Another method derived from Brockmeyer is presented in the SMACNA Handbook.[2] The sound power of mitre elbows without vanes is given by:

$$Lw = Fg + 10\log A + 10\log(b/1000) + 50\log(V/Be) + 10\log(f/63) - 6, \text{ dB} \quad (3)$$

Fg for mitre bends without turning vanes is given in Figure 2.

6. NOISE GENERATED AT MITRE BENDS WITH TURNING VANES

In 1975, P Holmes of BSRIA published a paper on the noise generated by mitre bends with turning vanes[6]. The relationship below is based on that paper. Although no details of the turning vanes was given by Holmes the prediction can be regarded as accurate conservatively agreeing with ASHRAE 1980 [1] by 4dB. The differences can be attributed to lack of information regarding the turning vanes geometry.

$$Lw = Fg + 10\log A + 10\log(b/1000) + 50\log(V/Be) + 10\log(f/63), \text{ dB} \quad (4)$$

Fg for mitre bends with turning vanes is obtained by reference to Figure 3.

7. NOISE GENERATED AT BRANCH TAKE OFFS

ASHRAE 1980[1] & 1987[5] present graphical and mathematical prediction methods, the latter being consistent with the method in the SMACNA Handbook. The method allows both the branch and downstream sound power to be calculated. In algorithm format this is given by:

$$Lw = Fg + 10\log A + 10\log(b/1000) + 25\log(V/Be) + 10\log(f/63) - 2, \text{ dB} \quad (5)$$

Fg for a branch take off is obtained by reference to Figure 4. Subsequent issues of ASHRAE have deleted this prediction method presumably for lack of space, and the 1987 method predicts slightly lower sound power levels than the earlier publication.

8. NOISE GENERATED IN STRAIGHT DUCTS

SRL in Noise control for Mechanical Services[7] published noise data for flow in straight ducts. When this data is normalized the Strouhal number relationship can be established which then enables Fg to be calculated. Within the range of velocities below 25m/s the regenerated sound power can be predicted from:

$$Lw = Fg + 10\log A + 10\log(b/1000) + 50\log(V) + 10\log(f/63), \text{ dB} \quad (6)$$

Fg for straight ducts is obtained by reference to Figure 5.

9. SUMMARY

A comparison of the predictions indicates some differences:

Table 1
Summary of prediction methodologies

Fitting type	1. Modified ACADS	2. ASHRAE 87	3. SMACNA H'book
Radiused bend	preferred method	non given	non given
Mitre bend with vanes	over predicts by 4 dB*	preferred method	based on (2)
Mitre bend no vanes	agrees with (2)	deleted after 87 issue	based on (2)
Branch ("T" or "X")	within 2dB of (2)	derived from Bullock	under predicts by 8dB
Straight duct	preferred method	non given	non given

*assuming a given turning vane geometry

10. CONCLUSION

There is very little published data on regenerated noise in fittings. A review of the available prediction methods has been summarized and is now available with algorithms suitable for use in prediction software or spreadsheets.

Comparison with ASHRAE and SMACNA, the two most commonly used references, indicates most methods are derived from only a very few sources. Some of these date back to the early 1970's with little new published test data. In some cases the data has been adjusted resulting in discrepancies in the various published methods.

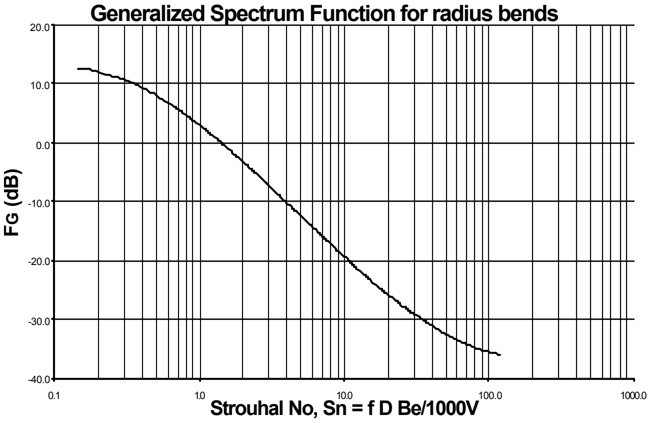
The actual noise generation is highly sensitive to turbulence and interaction between fitting must play a significant role is generating excessive noise. In addition the aspect ratio of rectangular ducts is a factor but its influence is generally unknown.

Given that regenerated noise may be sensitive to duct parameters and construction additional testing and research in high quality laboratories is recommended to further improve the available knowledge. At present the accuracy of the prediction methods can be no more than 3-4dBA and then only for best case flow conditions

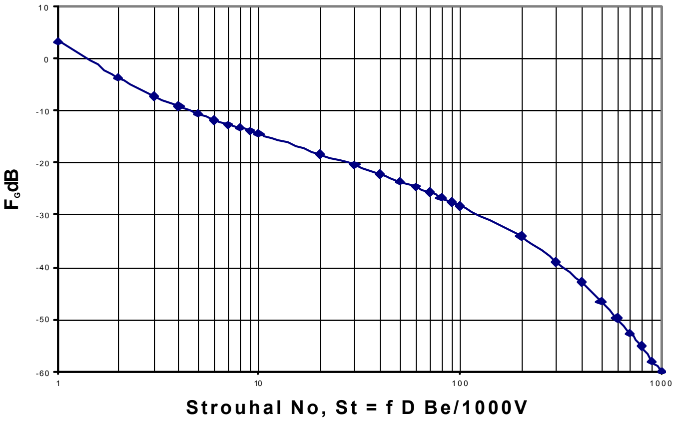
11. REFERENCES

[1]. ASHRAE: Systems Handbook 1980; [2]. SMACNA: HVAC Systems Duct Design 1990; [3]. Murray Mason, ACADS Design Manual; [4]. W A Oldham: Private communication and IOA Proceedings Vol 22(2), 2000 (with Waddington); [5]. ASHRAE: Systems and Applications Handbook 1987; [6]. PA Holmes BSRIA 1975; [7]. SRL: Noise control in Mechanical Services.

Generalized Spectrum Function for radius bends



Generalised Spectrum Function for rectangular mitre bends



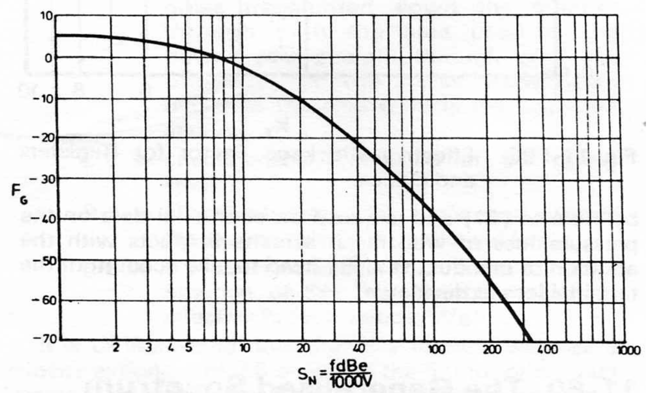


Fig. 11-60A Generalised Spectrum Function for Mitre Bends with Turning Vanes

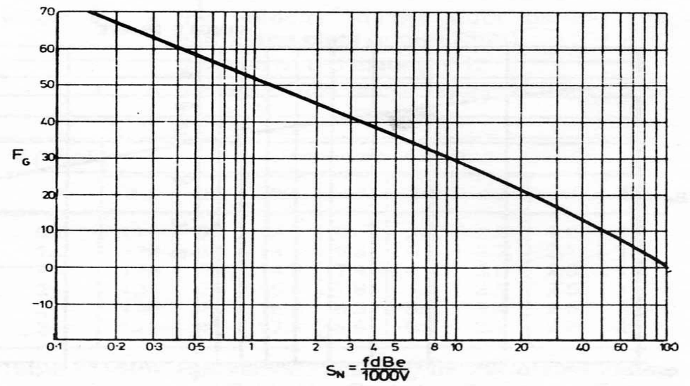
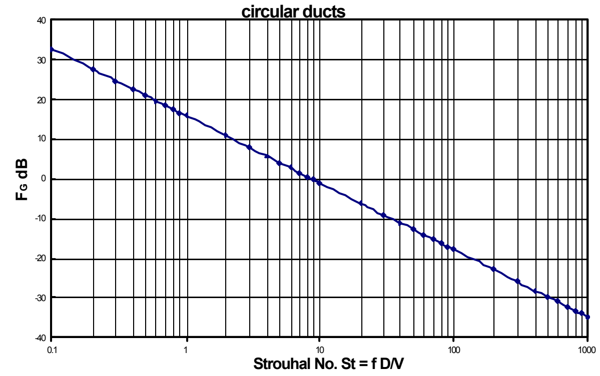


Fig. 11-60F Generalised Spectrum Function for 90° Sharp Take-Off Divided Flow Fittings

Generalized Spectrum Function for straight rectangular and circular ducts



Legend:
Top Left; Figure 1
Top Right; Figure 2
Above left; Figure 3
Above Right; Figure 4
Left; Figure 5