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# Engineering Measures for Noise Abatement of Mine Vent Fans and Ductwork

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## ABSTRACT

Mine ventilation fans and their attached ductwork were identified as major noise sources in the underground coal mining environment. The sound intensity levels of two ventilation fans from the subject coal mine were measured and compared. The two fans were 34-inch diameter ventilation fan in both refurbished and worn conditions. The intensity levels of the worn unit yielded levels 10 to 30 dBA higher than those of the refurbished fan. It was also found that the unlined fiberglass ducts had little noise attenuation. In addition, they were acting as a noise source along their entire path and re-radiating the fan noise significant distances from the unit. In an attempt to predict the effectiveness of noise reduction techniques in the system, a model of the duct has been modeled using the statistical energy analysis (AutoSEA2) software. By changing the physical properties of the duct (i.e. adding insulation) via the model, predictions were made regarding noise reduction. Cost effective and viable physical noise reduction techniques for the system can then be ensured prior to implementation. In the future, these characteristics can be used to model the duct as a noise source in larger simulations.

## 1. INTRODUCTION

The federal Mine Safety and Health Administration (MSHA) issued new hearing health standards in 1999 that require underground miners be exposed to constant noise levels of no more than 90 dBA per 8-hour shift [1]. If miners are exposed to an average sound level of 85 dBA or more over an eight-hour period, they must be enrolled in a hearing protection program. Prior research and practical experience demonstrate that there are numerous important sources of noise in a mine. Most of the noise sources in the underground mining environment are individual/discrete pieces of equipment. Examples are continuous mining machines, bolters, drills, and construction equipment such as skid drivers, forklifts, or haul trucks (many of these types of machines are underground versions, designed specifically for use in a mine). The Noise Group of the Western Mining Resource Center (WMRC) currently focuses on a single significant noise source, underground ventilation equipment. Its acoustical impact is twofold. First, very powerful fans (often powered by 100 HP motors) create extreme but localized noise. Second, extensive ductwork carries and distributes much of this noise, acting as a line source and driving levels above the 85-dBA threshold along its entire length. Noise reduction measures are being explored for ventilation equipment, along with computer modeling techniques that can be used to predict their effectiveness. A statistical energy analysis model is being developed using AutoSEA2 software, from Vibro-Acoustic Sciences Inc. to simulate noise propagation through a section of typical underground ductwork. Data from above ground measurements of typical ventilation equipment is being used to verify the model's accuracy. Future above ground measurements can be used to verify the model's predictions regarding effectiveness of noise abatement measures before they are implemented in an underground situation.

## 2. 90 dBA RESTRICTION; 85 dBA THRESHOLD

The September 9, 1999 MSHA news release (No. 99-0909) quotes Davitt McAteer, Assistant Secretary of Labor for mine safety and health, as saying, "Physicians and hearing specialists recognize that workers' hearing is adversely affected by noise exposures at or over 85 dBA. We recognize that this rule will not prevent all cases of hearing loss. We also understand that in some circumstances it is not now technologically or economically feasible to reduce noise levels to 90 dBA. But we plan to work with the mining community in the years ahead to develop new technologies for lowering miners' exposure to hazardous noise."

The MSHA requirements include these guidelines:

- Mine operators are required to use all feasible engineering and administrative controls to reduce miners' noise exposure to the permissible exposure level (PEL), which is an eight-hour time-weighted average (TWA<sub>8</sub>) of 90 dBA. Hearing protectors are not permitted in lieu of such controls.
- Miners exposed to 50- 99% of the PEL (TWA<sub>8</sub> at 85 dBA), are at the "action level" This classification requires the mine operators to: enroll the impacted miners in a hearing conservation program, provide hearing protection to the miner, and ensure the miner wears his hearing protection if he has a standard threshold shift or if it will be longer than six months before he receives a baseline audiogram.
- If a miner is in an environment that exceeds the PEL: he must be provided with hearing protection, the mine operator must ensure that it is used, and the miner must be enrolled in a hearing conservation program.
- A miner in an environment that exceeds a TWA<sub>8</sub> of 105 dBA must wear dual hearing protection.
- No miner can be exposed to noise levels exceeding 115 dBA

The goal of the WMRC Noise Group is to find methods to bring as many areas in the underground mine environment under the 'action level' of 85 dBA. At this level the miners are exposed to a safe level of noise and no additional action is required of mine operators.

## 3. FAN UNIT

Measurements were made of two fan units at the Spendrup Fan Company's facilities in Grand Junction, Colorado. Spendrup is a fan manufacturer and refurbisher for the mining industry. The first unit was a 34-inch diameter vent fan recently refurbished for a Colorado coalmine. The unit had been fitted with new motors, fan blades and restored inlet and outlet silencers. The fan body was a single-wall, solid-steel construction welded to a skid. At the time of testing, the impact cage was removed. During evaluation, the fan was fitted with a 30°-inlet elbow and four sections of rigid fiberglass duct (Figures 9 and 10).

Intensity measurements were taken at the centerlines of the major fan while the fan was operating normally. It was assumed that the radiated sound energy was symmetric about the long axis and therefore a single point represented a circumferential band of energy. The sound intensity level for each band is shown in Figure 1.

The data indicates that the strongest single source within the system is the blades at the fan plane. At this location, levels are up to 14 dB louder than other sections of the unit. Other highly energized locations are the motor sections on either side of the fan plane. This information could prove helpful in future abatement measures because an enclosure or similar noise control measure could be limited to a relatively small section of the fan rather than applied to the entire unit.

The second available sample was a similar fan unit from the same coalmine, but operating before a professional rebuild. Initial assesment of the fan's condition indicated that it may have lost one of its motor bearings and the fan blade tolerance of 1/8 inch for new fans had been eroded to 3 or 4 inches by wear under heavy use.

The unit was similar in that it was single-wall steel construction welded to a steel skid. However, it had an impact cage installed and that no ductwork was attached to the fan inlet.

Another set of sound intensity measurements was obtained for the second, worn unit. Although the trends in energy content were similar to the rebuilt unit, the intensity levels were from 10 to 30 dBA higher. Average intensity levels were 108 dBA, or about 30 dBA above the acceptable exposure levels for an operator at a reasonable distance from the fan.

In the second test unit (Figure 2), the controlling sources were: the outlet face, the downstream motor noise radiating from the fan body, and the fan inlet face. Observation of the other subsystem noise levels indicates that the energy from the inlet and outlet faces is driven by motor 2 as well. It is evident from the measurements that motor 2 is the unit with a noisy bearing.

This data indicates that through the normal life cycle of a fan, its contribution to miner noise exposure may increase by as much as 20 to 30 dBA. Later discussions with miners from the company that owned both units confirmed that the refurbishment process tends to have a very noticeable effect on the perceived noise levels generated by fan units. It is clear from both anecdotal and experimental information that regular maintenance of the fan units can contribute largely to noise control in areas near to the fan unit itself.

#### **4. DUCTWORK**

The Spondrup measurements indicate (Figure 1) that while the fiberglass duct is quite efficient as a guide for directing airflow, it is a poor barrier to noise. Energy 'breakout' occurs along the entire length of the duct creating an important and detrimental line noise source. Another important detail that the data illustrates is the lack of sound attenuation along the length of the duct. This is demonstrated by the final intensity measurement point for the mock-up system at the mouth of the inlet. At this location, after four sections of fiberglass duct, the levels were 90 dBA, higher than the MSHA allowed levels. Levels of this order indicate that there is very little noise reduction taking place as the sound travels down the duct. This suggests that the majority of the fan noise can be transported to the mining face through the duct, exposing operators to near-source levels.

Unlike most noise sources in the underground environment, ventilation ducts can become controlling contributors along hundreds of feet of tunnel. Typical lengths for ducts in the mine visited were 200 to 300 feet. Any length of tunnel through which a duct passes is most likely in violation of the 90-dBA limit and almost certainly exceeds the 85-dBA threshold. This creates large sections of work area where miners are reliant on personal protective equipment (PPE) to safeguard their hearing. In areas that are far from any significant noise source other than the duct, it is less likely that PPE will be used by miners who may see the duct noise as more of an annoyance than a threat to their hearing.

Because the sound energy transported by the duct originates at one end, it is possible to reduce the sound level throughout the duct with measures taken near the fan unit. If the sound pressure level (SPL) of the air inside the duct at a particular distance from the fan unit is shown to be 85 dBA, it is reasonable to assume that nowhere upstream from the point (the air stream flows toward the fan with sound traveling in the opposite direction) will the noise level will be greater. This means that it may be possible to engineer a solution that will allow mines to maintain their current stocks of ductwork while still bringing portions of tunnel acoustically controlled by ducts below the 85 dBA target.

A proposed solution is the addition of a liner to the first few sections of ductwork after the fan unit. Most likely made of fiber glass, the linings would be relatively inexpensive, easy to install, and unaffected by the dirty mine environment. If the breakout levels from the duct could be reduced to 85 dBA or less after only a few lined sections, the entire remaining length of duct would then be brought into compliance.

In the near future another set of measurements will be taken of a fan unit at the Spondrup facilities. A fan will be assembled with a number of duct sections, as before, and a similar battery of level checks will be conducted. A few sections of duct will then be fitted with an acoustical duct lining produced by Johns Manville Corporation. Another set of measurements will be taken and a direct assessment of the lining's effectiveness can then be made. Conclusions drawn from this experiment should be true for any length of duct that may be attached after the lined sections.

## 5. AUTOSEA2 MODEL

To extend the results and predictions of these tests, statistical energy analysis (SEA) computer modeling of underground ventilation equipment was employed. A model will attempt to predict the outcome of the future test data (Figure 11). The model is derived from the March 2002 experimental data and makes a good approximation of its results. The model simulates four 24-inch diameter, 96-inch length fiberglass ducts, along with their internal acoustic cavities. The cavities are interconnected with no transmission loss. Intensity data taken from the inlet side of the original experimental arrangement was determined to be the closest available picture of the noise spectrum introduced to the duct by the fan unit. An acoustic source modeled after this data was attached to the first cavity in the model to serve as the driving source.

As is evident in Figures 3 and 4, the frequency distribution of the noise level as it propagates along the duct remains similar between the original data and the computer model. The computer model shows a high frequency roll-off that differs from the original data, but otherwise the curves demonstrate very similar trends. The reason for the high frequency roll-off has been attributed to over prediction of air absorption constants in the model.

The original data shows an attenuation of 4 dBA from the first to second section of duct. This is very similar to the 5 dBA displayed by the computer model. From the second to third sections and from the third to fourth sections, the reductions in the original data are reduced and even reversed. It is believed that these levels were influenced by the noise escaping from the duct inlet, which was measured at 92.4 dBA. Measurements taken nearer the duct inlet displayed greater influence from escaping noise. The computer model, which does not account for noise detectable on the outside of the shell originating from the duct inlet, showed a steady attenuation of about 5 dBA per duct section. This seems to be a reasonable approximation of conditions that would exist in the first few sections of a duct several hundred feet long, where noise from the duct inlet could not influence measurements being taken near its early sections.

With the model established as a reasonable representation of real-world conditions, sections of the duct were then modeled with a 1-inch thick fiber glass lining. The ability of the treatment to absorb noise (absorption coefficient,  $\alpha$ ) with respect to frequency is detailed in Figure 5. Three separate simulations were run, each with an additional section of duct modeled with 100% coverage of its inside area by the noise treatment.

With one 96-inch section covered in treatment, the noise level at the fourth section of duct was reduced by nearly 5 dBA from 72.0 to 67.1. A reduction from 82.3 to 77.8 dBA was detected in the second section (the section immediately following the lining) from the unlined to the lined model (Figure 6).

With two sections covered, levels at the fourth section were further reduced to 63.5. The level at the third section was reduced from 77.2 dBA in the unlined model to 68.9 in the model with 2 lined sections (Figure 7).

Adding lining to the third section (a total of 288 linear inches, or 6912 square inches of surface area) produced a noise level of 60.2 in the fourth duct, or a reduction of 12 dBA from the original, unlined model (Figure 8).

## 6. CONCLUSIONS

Mine vent fans and ductwork have been established as major sources of noise in the underground mine environment, both from experimental data and experience from operators. Above ground tests of a worn, but functioning unit show levels approaching 110 dBA, which is well into the range requiring dual hearing protection as outlined by MSHA. Above ground tests and miner testimony show that a significant amount of sound energy is transmitted from a fan through its attached ductwork, releasing noise along its entire length and finally producing noise levels near the duct inlet similar to those of the original source.

It has been shown through measurements of two similar fan units, one worn and one recently refurbished, that maintenance of a fan unit can help to greatly reduce the amount of noise it produces. Future, long-term experiments are planned to show the rate at which the condition and/or noise produced by a fan changes after a refurbishment. Such experiments may help to devise preventative maintenance routines for mine operators to apply to their fan units.

A computer model has been developed to simulate the behavior of a section of typical ductwork to an acceptable accuracy. Noise control treatments to the computer model show promising results in terms of reducing the level of 'breakout' noise from ducts below the 85 dBA threshold outlined by MSHA. Achieving this reduction is especially important with ducts because they occupy long sections of underground tunnels and can drive large work areas into 'action levels' or above permissible exposure levels. Additional physical data will be collected that will help to determine the accuracy of the model's results. If a reasonable correlation still exists, noise treatment material will be installed and tested in a typical operating environment.

SEA models of ductwork can eventually be used to model ducts as noise sources in larger simulations, which may include models of tunnel walls and additional mining equipment. Typical equipment configurations can be tested in such models to help determine what actions may be possible to meet the guidelines laid out by MSHA in September of 1999.

## **7. ACKNOWLEDGEMENTS**

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## **REFERENCES**

1. *New Standards Add Protections For Miners Exposed to Noise*. MSHA News Release No. 99-0909: September 1999 (Mine Safety and Health Administration – USDOL).

Figure 1: A-Weighted Intensity Data Along Fan Axis (Worn)

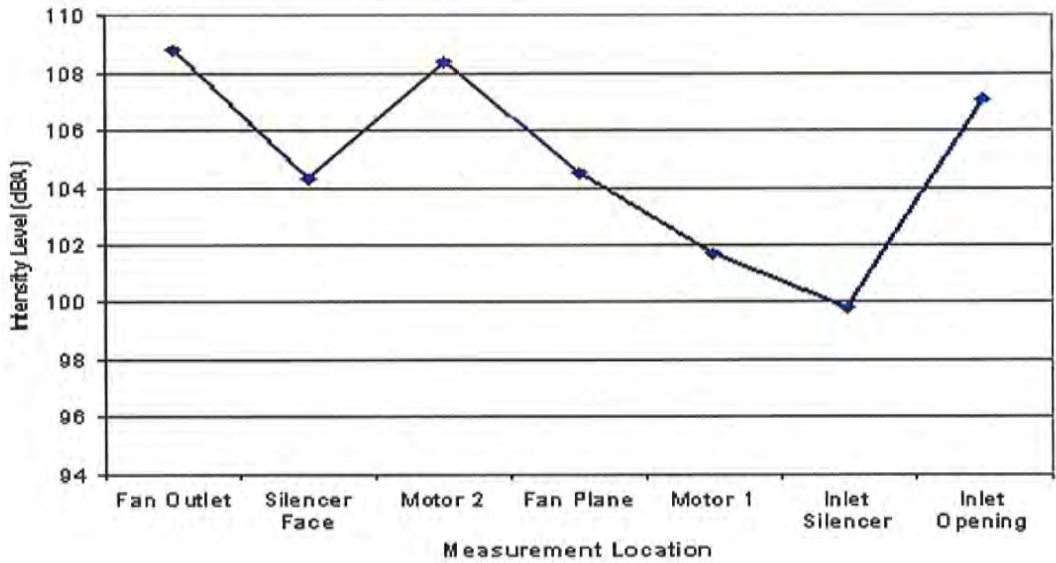


Figure 2: A-Weighted Intensity Data Along Fan Axis (Rebuilt)

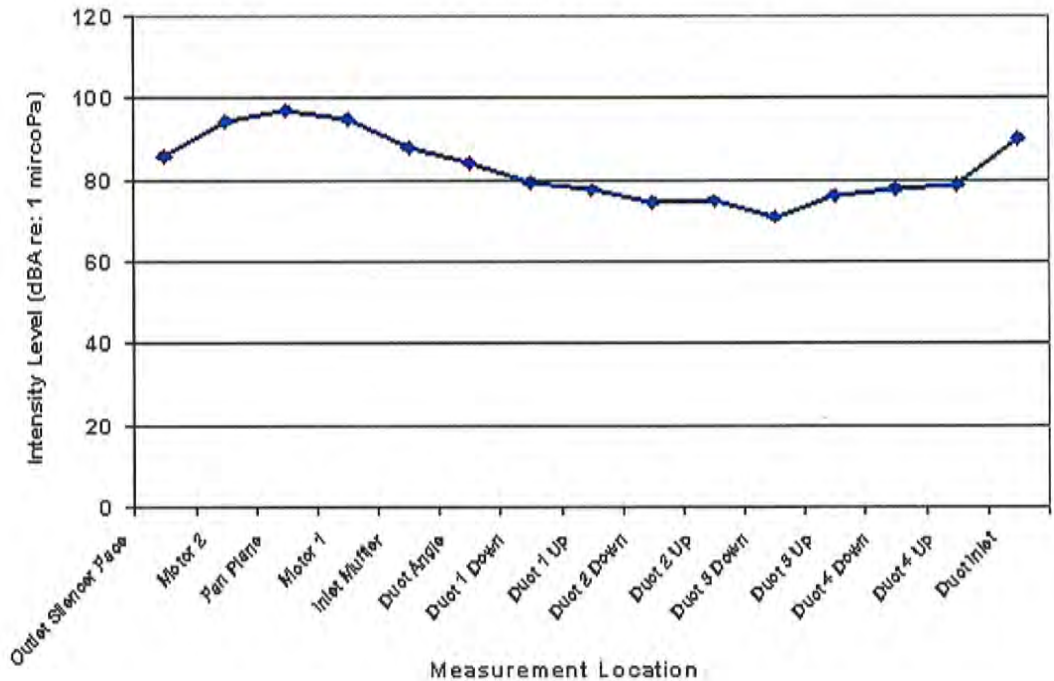


Figure 3: Measured Data 3/02

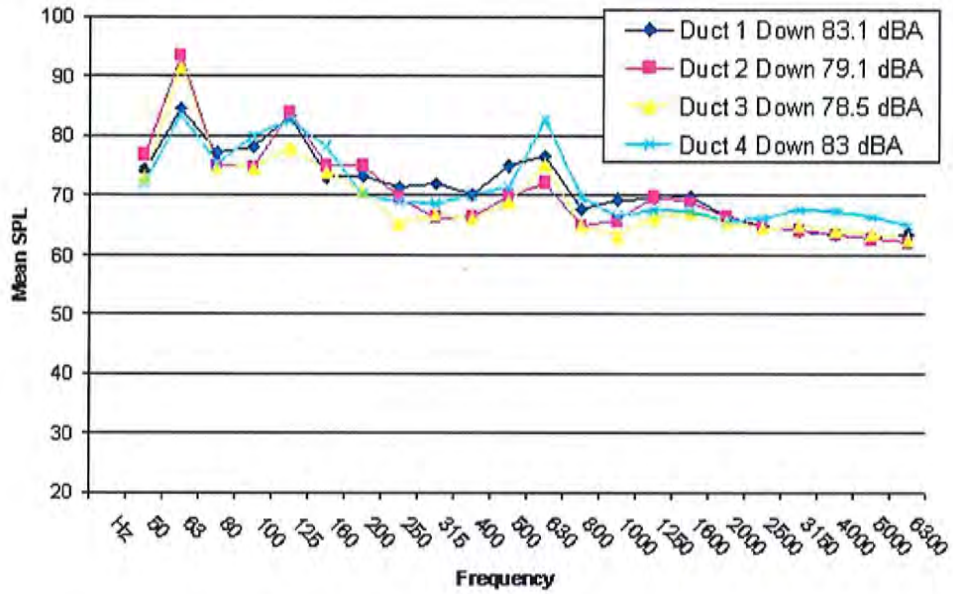


Figure 4: Model Data, No Insulation Applied

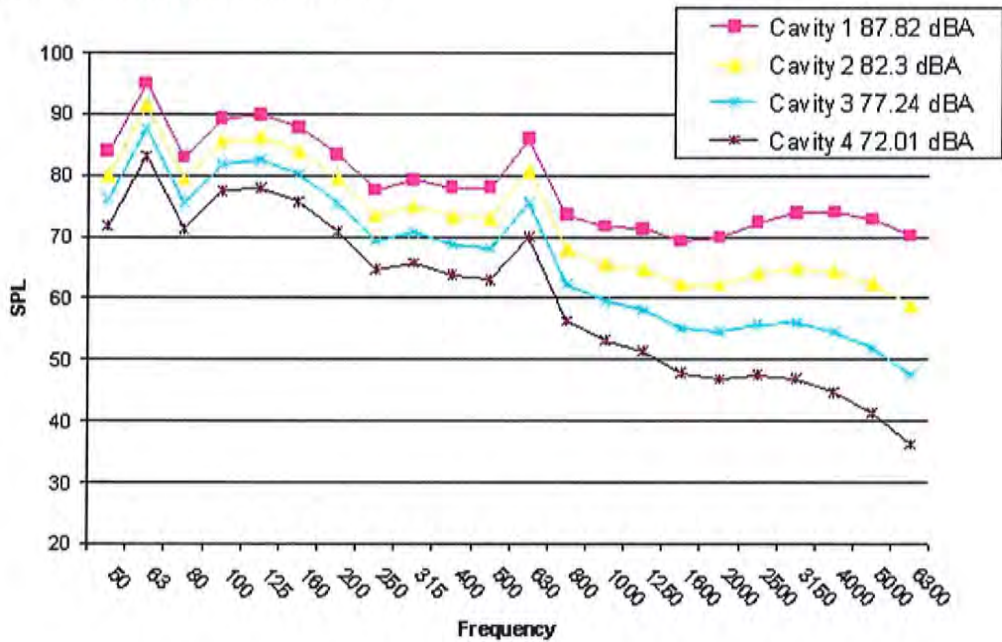


Figure 5: Treatment Absorption Data

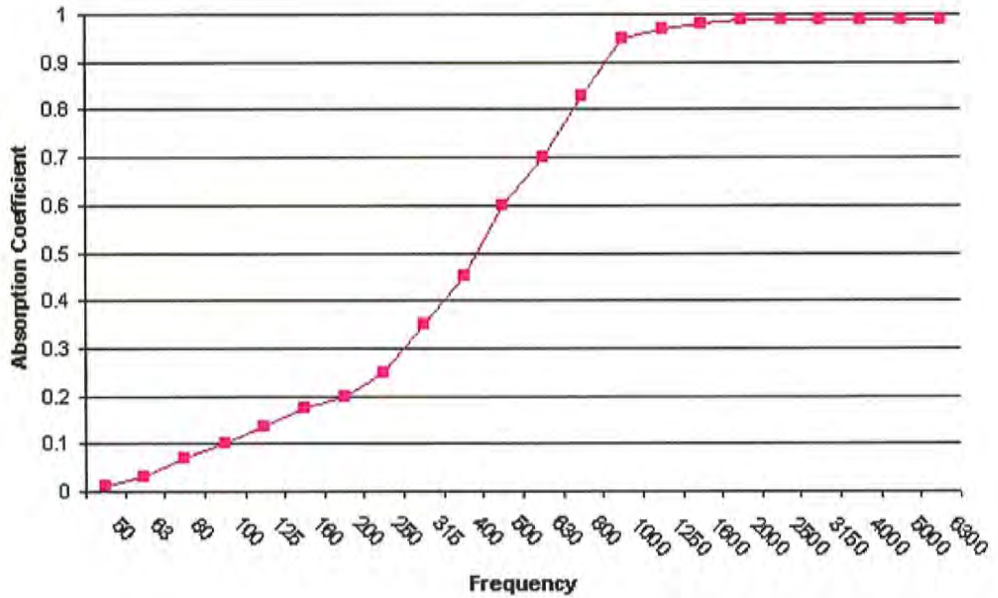


Figure 6: Model Data with One Insulated Section

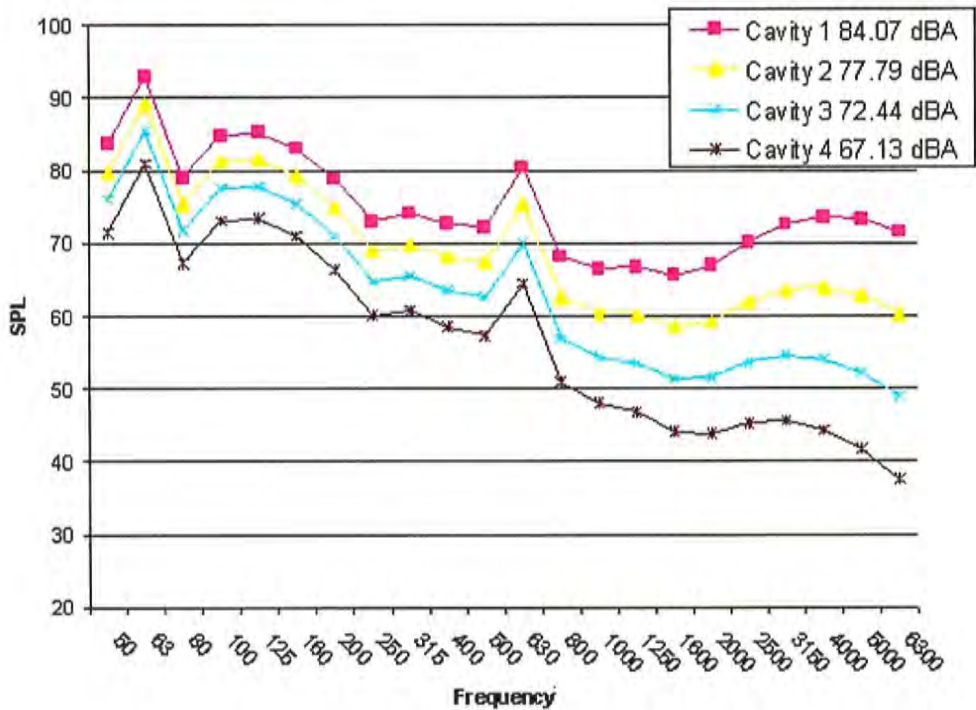


Figure 7: Model Data with Two Insulated Sections

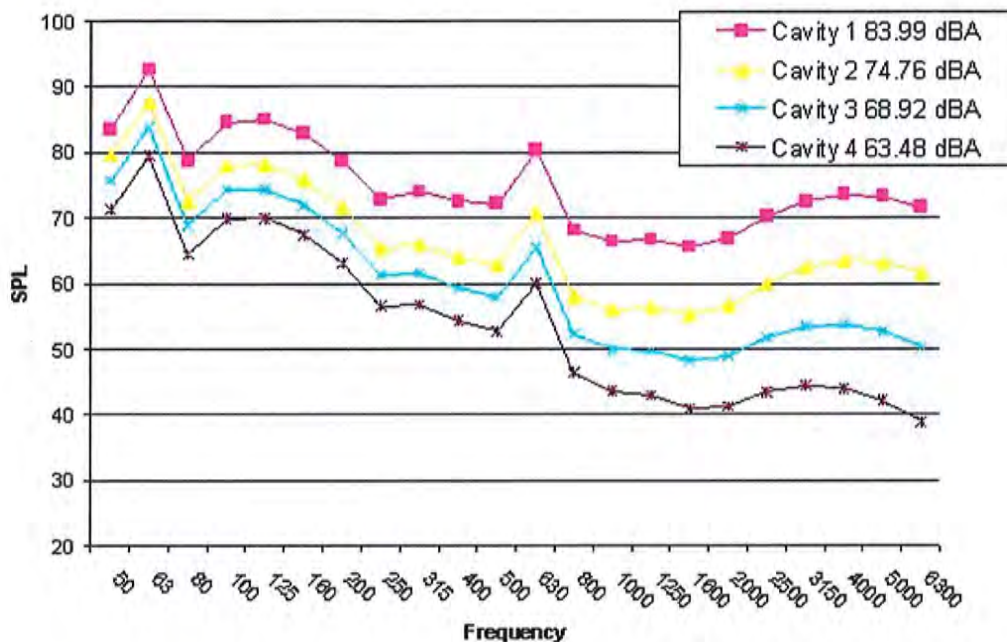
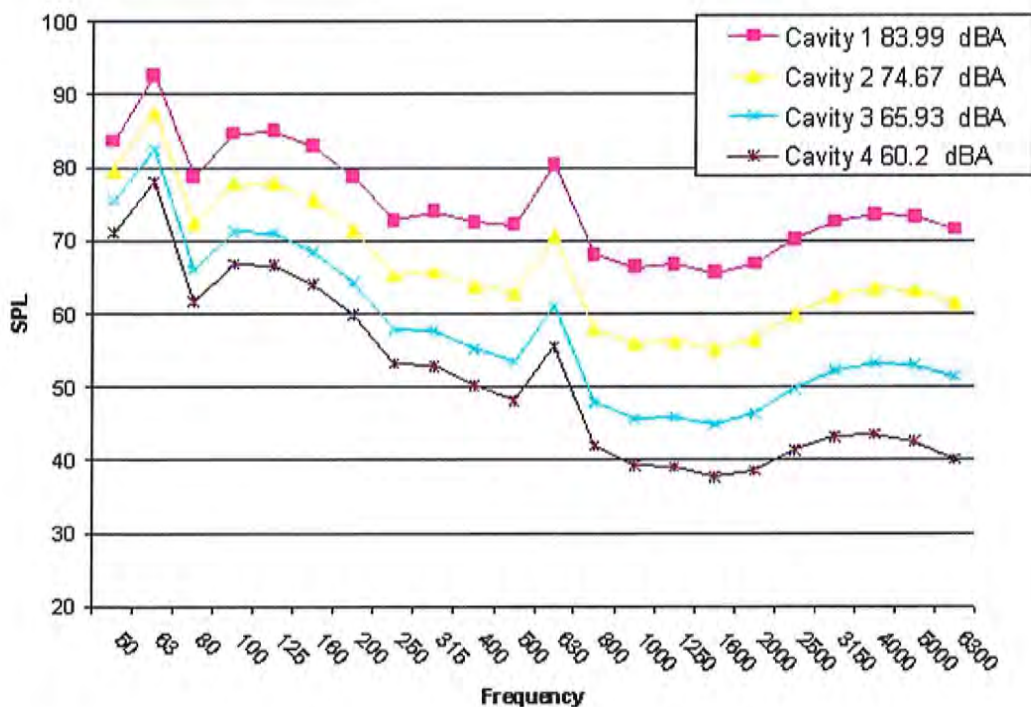


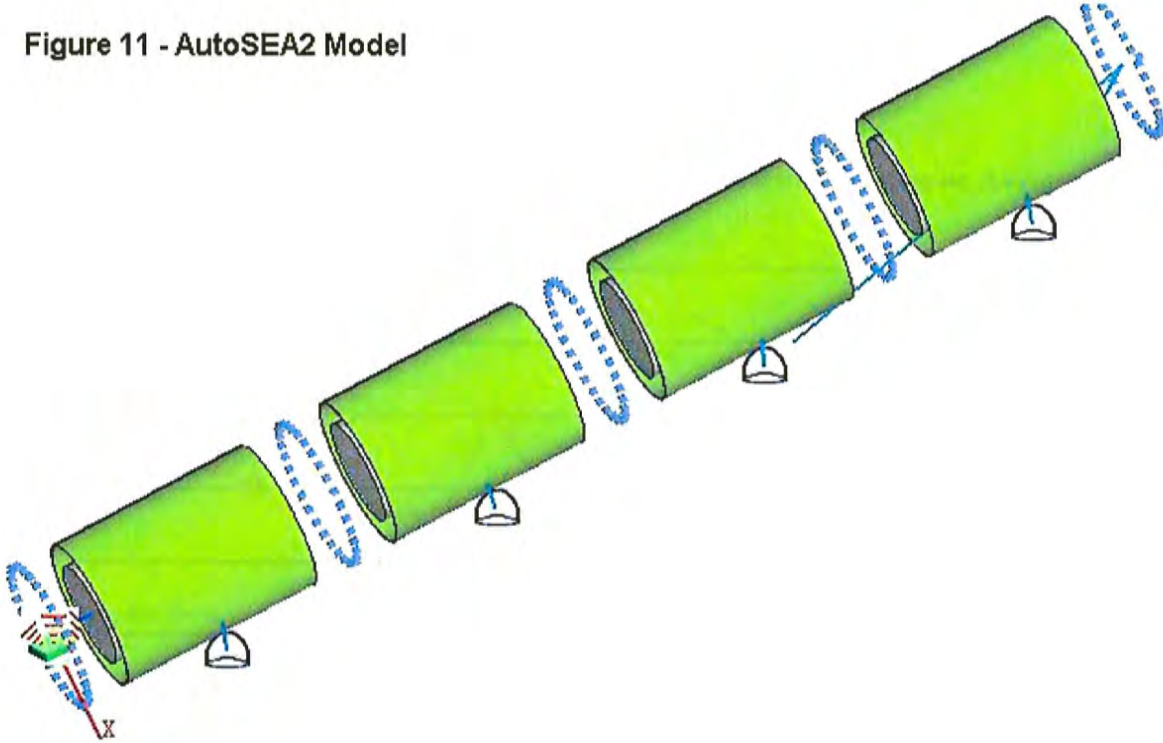
Figure 8: Model Data with Three Lined Sections



Figures 9 and 10 - Fan and Ductwork from March 2002 Experiment



Figure 11 - AutoSEA2 Model



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**Foreword**

**Table of Contents**

**Author Index**

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