

**NORTH CAROLINA SCIENCE AND TECHNOLOGY RESEARCH CENTER**  
A UNIT OF THE DEPARTMENT OF NATURAL AND ECONOMIC RESOURCES

**INDUSTRIAL NOISE CONTROL: Some Case Histories**

**Volume I**

STR-504

RESEARCH TRIANGLE PARK, NORTH CAROLINA 27709

**INDUSTRIAL NOISE CONTROL: SOME CASE HISTORIES VOL. I**

**Prepared by**

**Dr. Franklin D. Hart  
Director of the Center for Acoustical Studies  
North Carolina State University**

**Mr. C. Leon Neal  
North Carolina Science and Technology Research Center**

**Dr. F. O. Smetana, Professor  
Department of Mechanical & Aerospace Engineering  
North Carolina State University**

**August 1974**

## TABLE OF CONTENTS

	<u>Page Number</u>
Introduction	
Corrugating Steel Stock	1
Quiet Stock Tube for Automatic Screw Machines	3
Ejector Chutes for Metallic Objects	5
Air Ejection Nozzles	8
Air Compressor Intake Pipe	10
Paper Shredder	12
Gasoline-Powered Golf Cart	15
Riveting Hammer	18
Vibratory Parts Feeder	21
Conveyor Line	23
Automatic Lathe	25
Wind Tunnel	27

## INDUSTRIAL NOISE CONTROL: SOME CASE HISTORIES VOL. I

### Introduction

What we know as "Noise" is always produced during manufacturing, processing, or materials handling operations; in fact, noise develops anytime a significant number of people congregate in one place. Such noise used to be regarded as a mark of economic well-being. Lately, however, a number of forces, which, individually, would not have been decisive, have coalesced to demand amelioration of environmental noise. Among these are (1) an unprecedented general affluence, (2) a more concentrated, more mechanized population, (3) an understanding of the means to reduce noise, and (4) demonstration of the causal relationship between noise and hearing loss. These pressures led to the passage of sweeping Federal legislation requiring that workers be protected from noise hazardous to their hearing, to community noise abatement rules, to lawsuits asking for injunctive relief from "noise pollution," and to increased customer sensitivity to noise emanating from the products they buy. As a result there is unprecedented interest in muting the sound of industrial processes and products.

Unfortunately, because the principles of noise control are not yet among the working tools of most middle and upper level industrial supervisors, many inadequate noise remedies are purchased at highly inflated prices. It would be unreasonable, however, to expect that most such supervisors would be able to take the time needed to become familiar with acoustic formalism from their regular duties. This collection of solutions to industrial noise problems has therefore been assembled with the hope that busy supervisors will be able to acquire a general sense of how such problems are analyzed and solved. Then from their personal knowledge of hardware fabrication costs they should be able to arrive at an approximate cost for solving similar or related problems in their own environments.

Each problem is described in relatively simple terms, with noise measurements where available. The solution is then given, often with explanatory figures. Where the solution rationale is not so obvious an explanatory paragraph is usually appended. As a preface to these solutions, a short exposition is provided below of some of the guiding concepts used by noise control engineers in devising their solutions.

The concept for this publication originated with Dr. Franklin D. Hart, Director of the Center for Acoustical Studies at North Carolina State University, who prepared many of the solution descriptions presented here. Mr. C. Leon Neal of the NC/STRC staff prepared the remainder with the exception of the wind tunnel discussion. Ms. Sylvia Sanders of the

NC/STRC technical staff prepared the sketches and graphs. Dr. F. O. Smetana contributed his solution to the wind tunnel noise problem and edited the entire report.

If a collection of this type proves popular, additional volumes will be prepared.

## CONCEPTS IN NOISE CONTROL

In simplest terms there are three means by which noise can be prevented from inflicting hearing damage:

(1) The hearer can be provided with protective devices to keep the sound waves from entering the ear.

(2) The sound waves generated by a noise source can be absorbed or deflected prior to their reaching the ears of the hearer.

(3) The noise generating ability of the source can be reduced through redesign.

The first means is generally the least expensive; the last means is the most expensive when applied to an existing situation. Unfortunately, insuring the proper wearing of protective devices by all affected employees requires constant, intensive supervision because most such devices become uncomfortable to wear (after a while at least) and because noise-induced hearing loss is progressive and therefore not readily apparent to the hearer over short periods of time. For this reason redesign for lower noise output is usually a more satisfactory permanent solution.

What we perceive as noise is the arrival at our ears of a moderate-to-high amplitude fluctuation in the local air pressure. Plotted against time, this fluctuation is usually very irregular. To devise effective noise controls it is, of course, helpful to know as much of the nature of the noise as possible. The more knowledge one has, the more avenues of attack one may use. One way to learn quite a bit is to measure these pressure fluctuations accurately and then attempt to represent them by a sum of simple waves, each having a unique frequency, amplitude, and phase relationship. Isolating the dominant waves in a noise pattern through this means frequently enables one to identify the noise source in the machine; for example, one which occurs at a period corresponding with the rotation of a particular shaft or one which results from gear teeth striking an object so many times per second.

There are devices on the market which employ narrow-pass-band electrical filters operating on the output of noise-sensing microphones to determine the amount of acoustical energy present in narrow frequency bands of the noise. By scanning the entire audible range of frequencies one can get quite a good picture of the constituent simple waves in the noise. Even better results can be obtained by analyzing the noise signal mathematically using a digital computer.

Once the noise source is identified one can proceed to try to reduce its strength or at least absorb its output. The means by which one would absorb acoustical radiation depend principally upon the frequency and intensity of the noise. Since the ear is most sensitive at frequencies around 1000 Hz more attention must be given to this area although there can be problems with high intensity radiation at ultrasonic frequencies as well as at sub-audible frequencies. In the latter case individuals become quite nauseated when exposed to such radiation because their internal organs are excited to resonance.

Acoustic energy can be likened to flowing water or electric current. To attenuate an electric current one may use either resistive or reactive means. In water flow, a fine mesh screen represents a resistance, while a diaphragm with one face in contact with the water and the other with a fixed volume of gas might represent a reactance. The ability of a material to act as an acoustic damper must depend upon its physical size in relation to an acoustical wave length as well as to its natural lack of "springiness." Thus a given thickness of fiberglass will be more effective at damping higher frequencies than low. It is, in effect, a frequency-sensitive resistance.

Usually materials can absorb a given amount of acoustic energy per pound, the amount being dependent upon the material and the frequency. The damping capability is usually poorest at low frequencies so that for these conditions heavy weights, commonly sheets of lead, layers of sand, or tar-like materials are required. This is one reason why luxury automobiles are considerably heavier than their cheaper (and noisier) counterparts which use the same basic body shell.

Reactive attenuation depends for its effectiveness on one's being able to add a 180 out-of-phase component to a pressure wave. Inherently this mechanism limits the effectiveness of a single device to a narrow band of frequencies.

Reduction of noise source strength requires an understanding of the way noise is generated and a search for an alternate means of performing

the task which produces less noise. This is probably best explained by an example. Consider a planer for smoothing wooden boards. The cutter usually consists of a cylinder into which are set four knives running parallel to axis of the cylinder. The board is struck successively by each of the four knives. It can be shown theoretically that the noise produced in this operation results from a vibration of the board and is proportional to the instantaneous rate of work being done on the board in removing a layer of shavings. Note that the entire knife blade strikes the board at one time, removes some wood, and then leaves the surface -- a very large instantaneous action having a relatively low average over time. Thus, the solution to this problem is to use a higher average rate and a lower instantaneous rate of wood removal by canting the blades so that the wood removal occurs only on a line across the board but continues as the cutter turns. In addition, one can make the noise less objectionable by increasing the number of knives so that less wood is removed by each knife and the noise generated occurs at a higher -- and therefore usually less audible -- frequency.

From the foregoing it should be apparent that one way to decrease the noise levels associated with forging, stamping, punching, or weaving operations is to find ways to apply the force more gradually and more continuously. Another, although more difficult, way to reduce noise output is to restrain the work piece from vibrating. This is because a vibrating work piece acts as a loud speaker, moving a mass of air and setting up a pressure wave which we sense as noise. Since all materials are elastic to some degree it is very difficult to suppress all motions of the work piece.

One drastic solution is to perform such operations as forging in a near vacuum. Then the vibrating work piece has little air to move and can therefore generate little noise.

## CORRUGATING STEEL STOCK

**Problem Statement:** Figures 1 and 2 illustrate an operation for corrugating steel stock. The stock is fed through the corrugating rolls at speeds of about 80 ft/min. The action of the corrugating rolls produced vibration in the sheet stock and since the supply end was practically undamped, excessive sound radiation occurred. The noise level produced is shown in Figure 3.

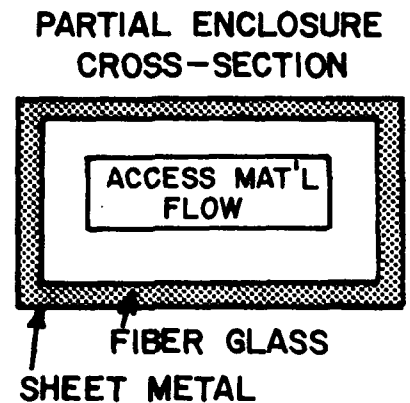


Figure 1. *Partial Stock Enclosure for Reducing Radiated Sound*

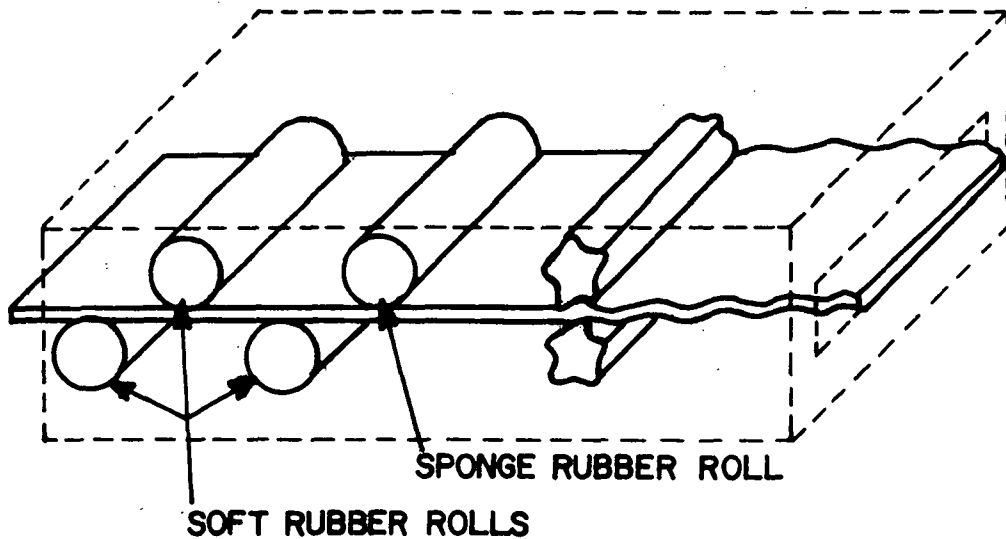


Figure 2. *Corrugating Rollers*

**Problem Solution:** Soft rubber rolls were placed on the in-feed side to prevent vibration from propagation along the stock and resulting in sound radiation. This procedure reduced the total effective surface



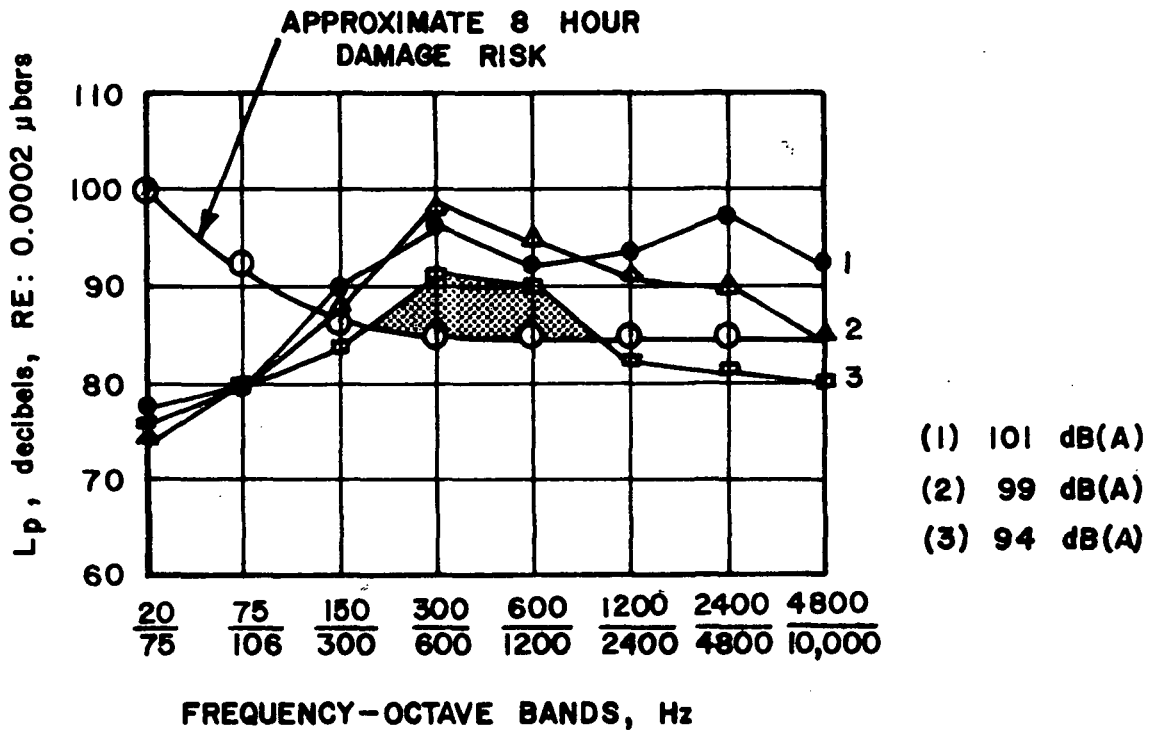


Figure 3. *Before and After Noise Levels*

contributing to sound radiation. The effect on noise of the procedure is shown as curve (2) of Figure 3. A partial enclosure was used to surround the roller assembly area which was then the area of greatest sound radiation. The partial enclosure provided additional reduction as illustrated by curve (3) of Figure 3.

Solution Source: This solution was presented by C. L. Coyne in the March, 1958 issue of NOISE CONTROL, p. 116.

## QUIET STOCK TUBE FOR AUTOMATIC SCREW MACHINES

**Problem Statement:** In automatic screw machines, metal stock tubes are used to contain stock which is rotated at speeds of 4000 RPM and greater. When plain stock tubes are used, the vibration caused by inter-action of the stock with the stock tube resulted in excessive sound radiation. Noise levels are affected by the size and shape of the stock and speed of rotation. One example is illustrated in Figure 4.

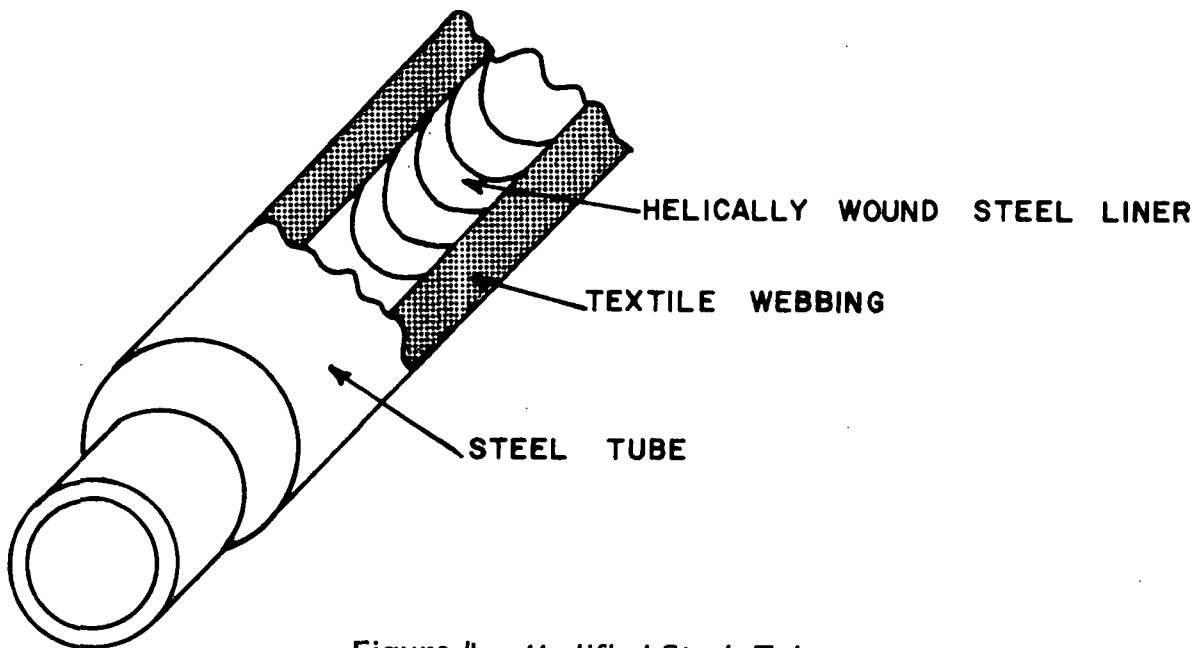


Figure 4. *Modified Stock Tube*

**Problem Solution:** The solution is illustrated in the figure and represents a modification of the plain stock tube. It is constructed of a helically wound inner liner, a fibrous filler (textile webbing) and the outer steel tube. The fibrous filler isolates the outer tube from the inner liner which is in contact with the rotating stock and absorbs vibratory energy from the inner liner before it is radiated into acoustic energy. The liner, being helically wound, has better interaction with the fibrous material which aids in attenuation.

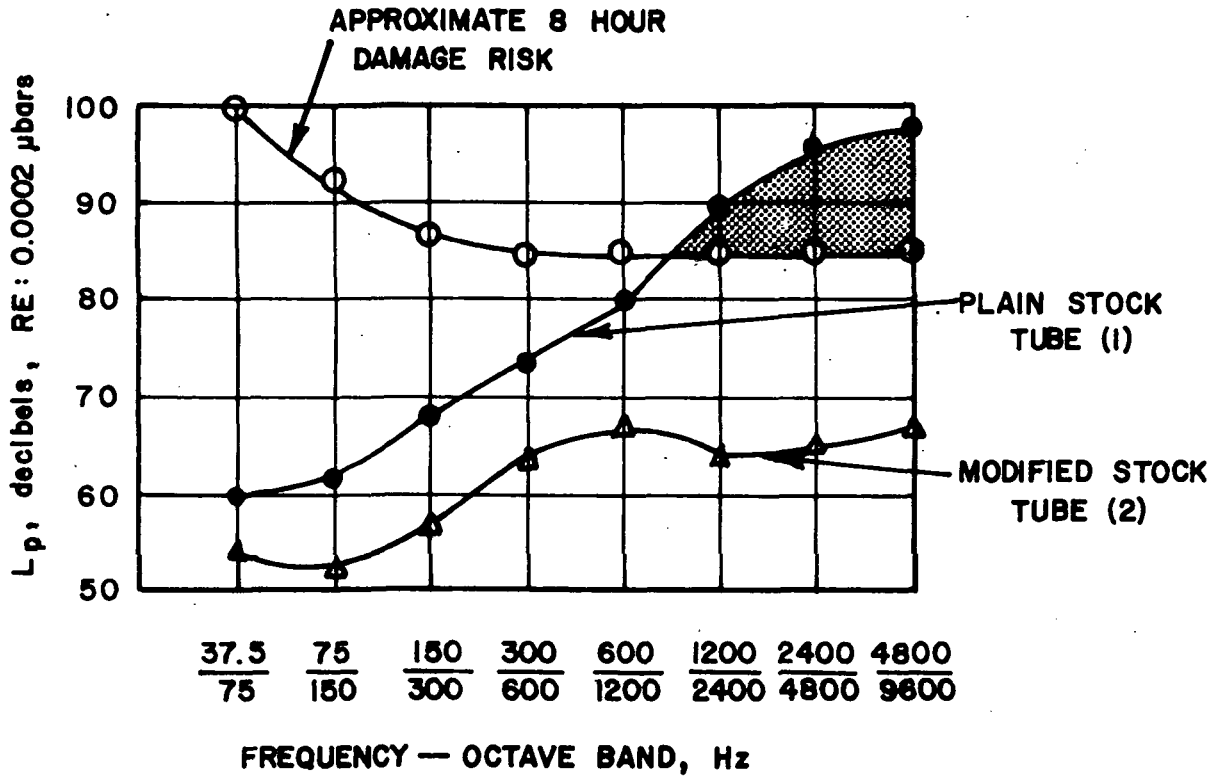


Figure 5. Noise Levels Produced by Plain and Modified Stock Tubes

Solution Source: The solution presentation based on an article by B. J. Schweitzer in the March, 1956 issue of NOISE CONTROL, p. 14. The quiet stock tube illustrated was produced under patent in 1956 by the Corlett-Turner Co., Chicago, Illinois.

## EJECTOR CHUTES FOR METALLIC OBJECTS

**Problem Statement:** Smaller metallic parts are ejected onto the chute as illustrated in Figure 6. The tumbling parts cause impact noise and induce vibration of the metallic chute resulting in sound radiation. While the noise from such an arrangement conveying 30-caliber cartridge cases was not extremely high, the principles employed in its solution apply equally well to situations wherein the noise levels produced are more intense.

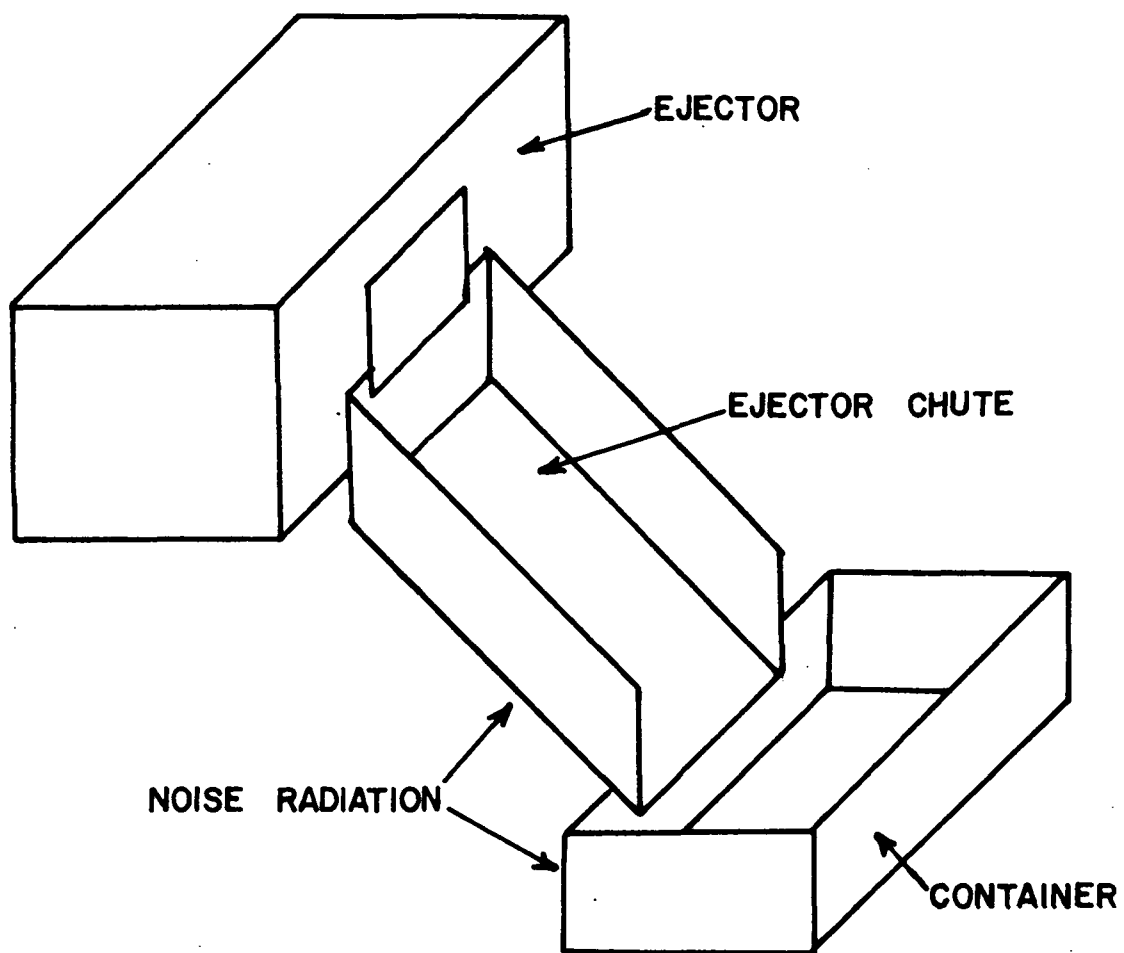


Figure 6. *Ejector Chute*

### CHUTE CROSS-SECTION

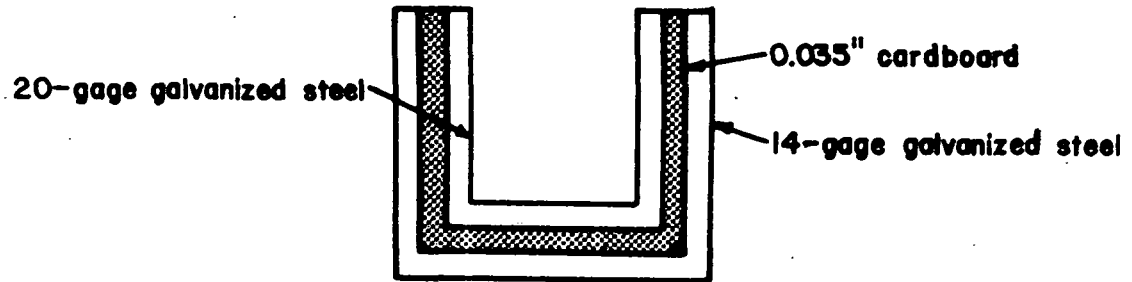


Figure 7. Cross-Section of Treated Ejector Chute

**Problem Solution:** A sandwich was constructed using the original 14-gage steel bottom of the chute, a middle layer of 0.035 in. thick cardboard, and a top plate of 20-gage galvanized steel. The fibrous cardboard provides damping and vibration isolation with attendant noise reduction as noted by

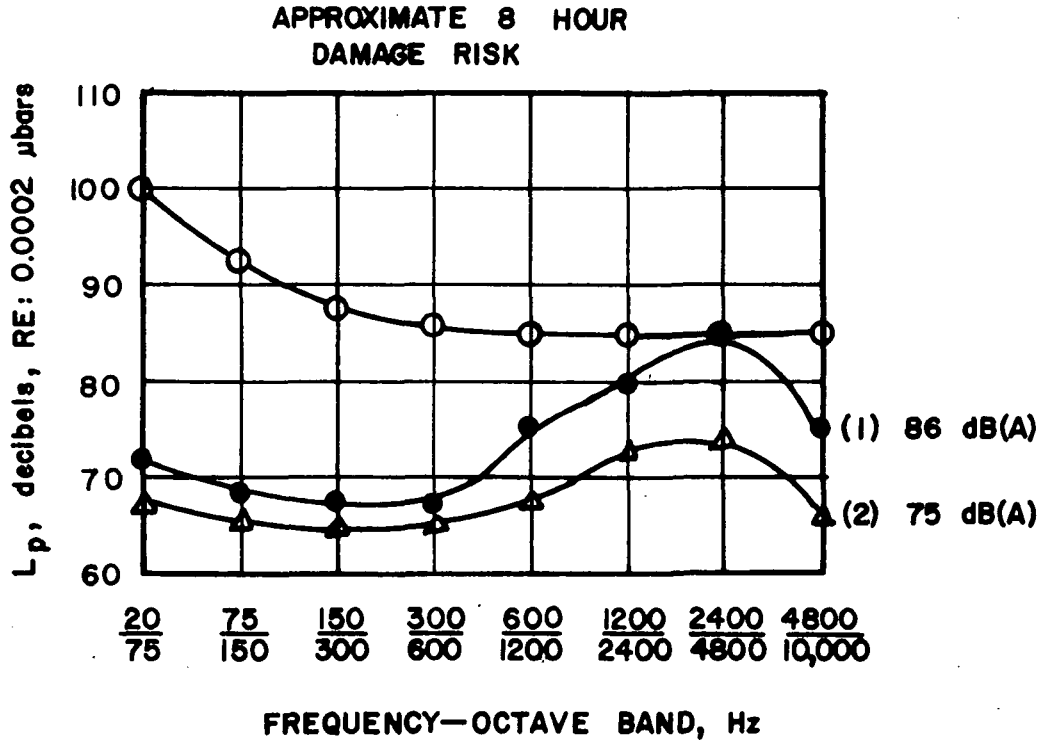


Figure 8. Noise Levels of Ejector Chutes Before and After Treatment

comparing curves (1) and (2) in Figure 8 above. A sandwich constructed in this way can be held in place with several rigid connections without serious loss in efficiency. It is noted that the chute could be capped with an acoustically treated cover to provide additional noise reduction where required. In cases where the containers or tote boxes radiate noise due to vibration of the objects, a treatment similar to that used for the chute would be effective. For these applications, other fibrous filler materials such as felt or asbestos could also be used.

Solution Source: This presentation is based on an article by A. L. Cudworth in the January, 1959 issue of NOISE CONTROL, p. 40.

## AIR EJECTION NOZZLES

**Problem Statement:** In many cleaning, drying, and ejection processes, high velocity air from small openings is employed and is a source of intense noise. The nozzle (Figure 9) was used in a can drying process where it was important to have the air stream distributed over a relatively large area.

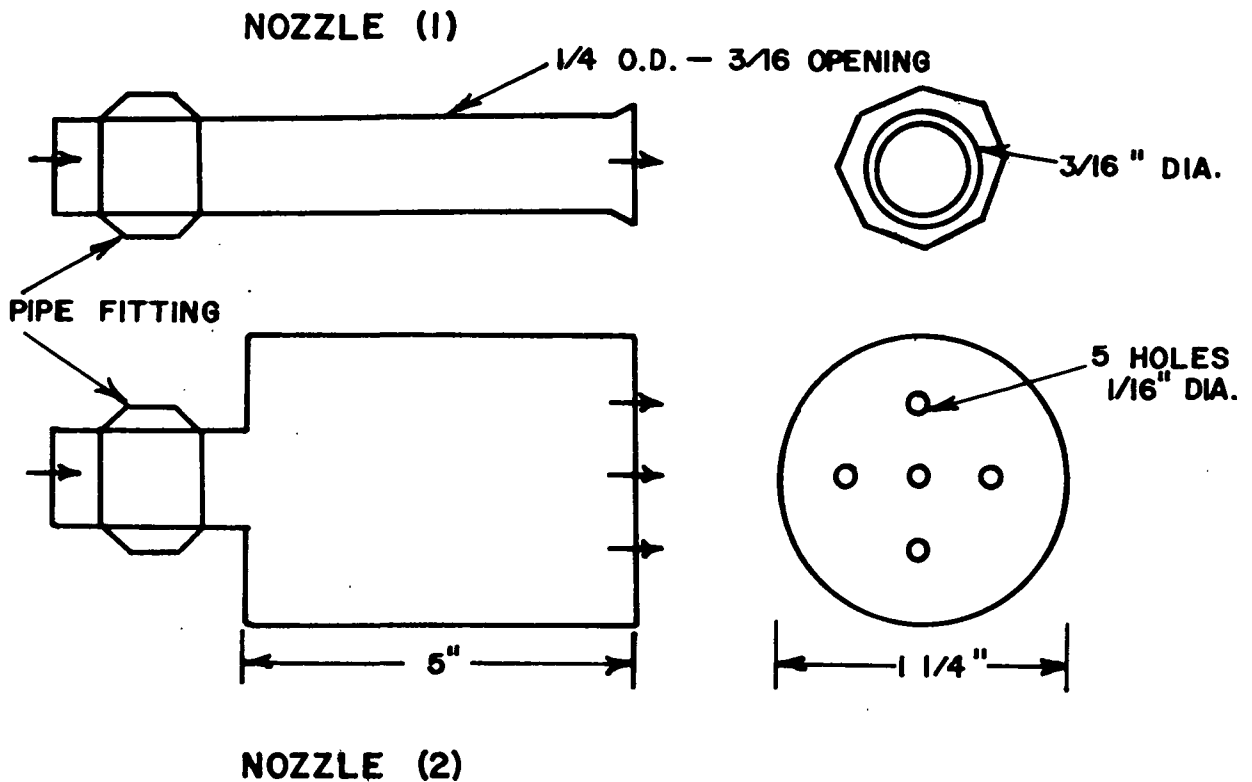


Figure 9. Air Ejection Nozzle

**Problem Solution:** Jet noise depends on jet diameter and exit jet stream velocity with the sound energy concentrated at the higher frequencies for small, high velocity jets. The solution entailed replacing the high velocity nozzle (1) with two lower velocity nozzles (2). The single nozzle required higher velocity for the same area coverage. The noise produced from a flared fitting  $1/4$  inc. copper tube ( $3/16$  in. nozzle diameter) is shown in Figure 10. The combination of smaller diameter

openings and lower velocity produced the reduction noted in curve (2) of the figure.

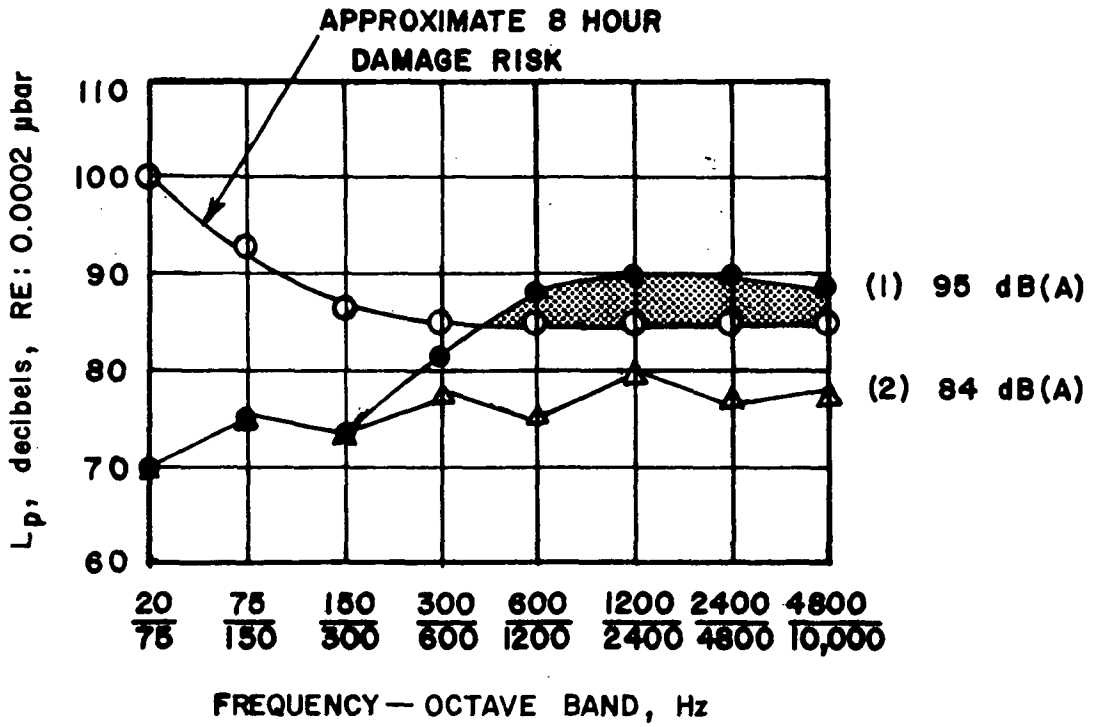


Figure 10. *Ejection Noise Levels Before and After Nozzle Modification*

Solution Source: This solution presentation is based on an article by A. L. Cudworth in the January, 1959 issue of NOISE CONTROL, p. 41.



## AIR COMPRESSOR INTAKE PIPE

**Problem Statement:** A 24 in. diameter, 49 ft. high air intake pipe for a 9000-hp air compressor was protected from rain and other environmental elements by an open-bottomed house (Figure 11). Sound was reflected back to the ground and near the bottom edge of the enclosure an intense noise spectrum was produced, see Figure 12.

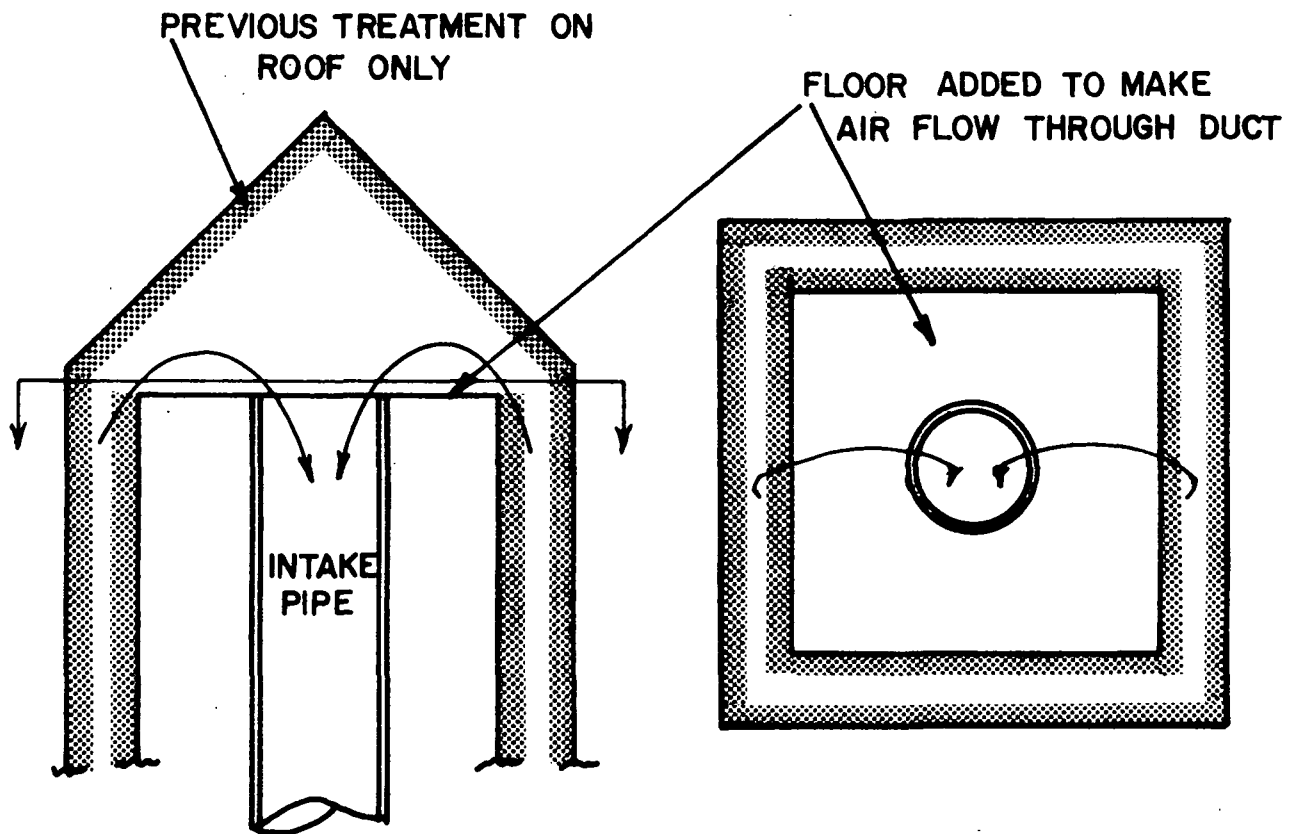


Figure 11. *Silenced Air Compressor Intake Pipe*

**Problem Solution:** As shown in the elevation view, a dissipative muffler was constructed by making an inner structure lined with 2 in. thick fiber glass. Intake air was forced to flow through the constructed duct by adding a floor which connects the inner wall with the intake pipe. Noise

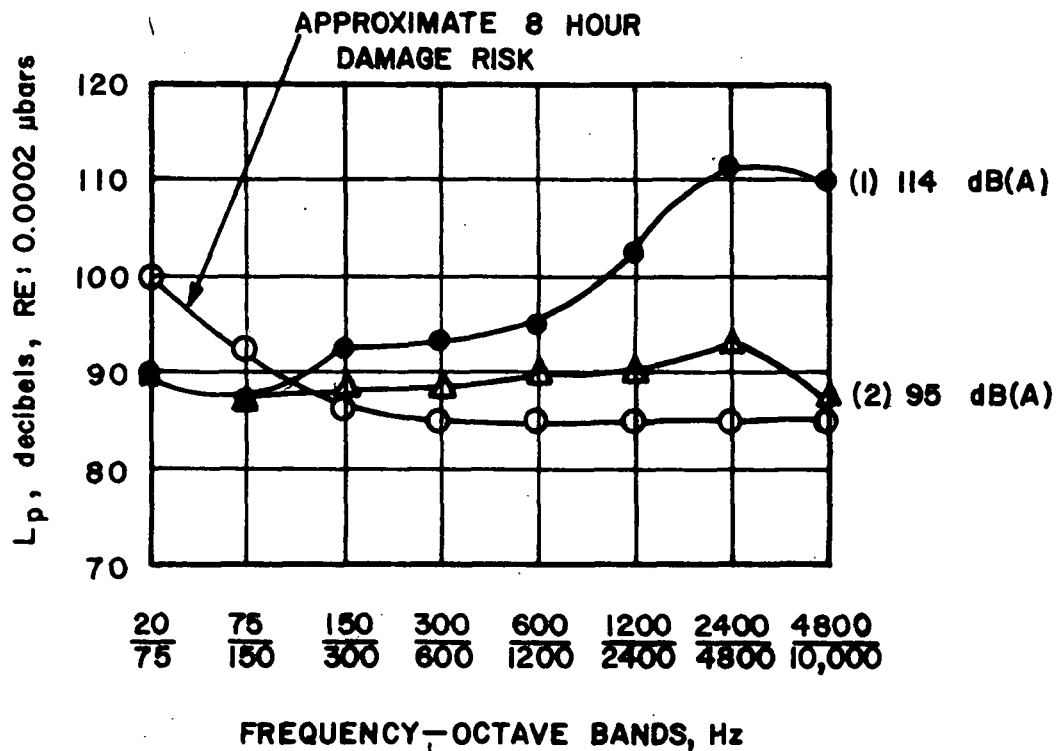


Figure 12. *Noise Levels Produced by Compressor Intake Pipe Before and After Treatment*

radiating from the pipe opening is attenuated by the turn and the lined duct as it propagates through the duct towards the ground. The degree of attenuation is seen by comparing curves (1) and (2) in Figure 12.

Solution Source This solution presentation is based on an article by A. L. Cudworth in the January, 1959 issue of NOISE CONTROL, p. 43.

## PAPER SHREDDER

**Problem Statement:** A device for shredding scrap cards and strip stock is illustrated in Figure 13. The shredding disk is 30 in. in diameter, and produces a shearing cut frequency of 3600 RPM with four knife blades

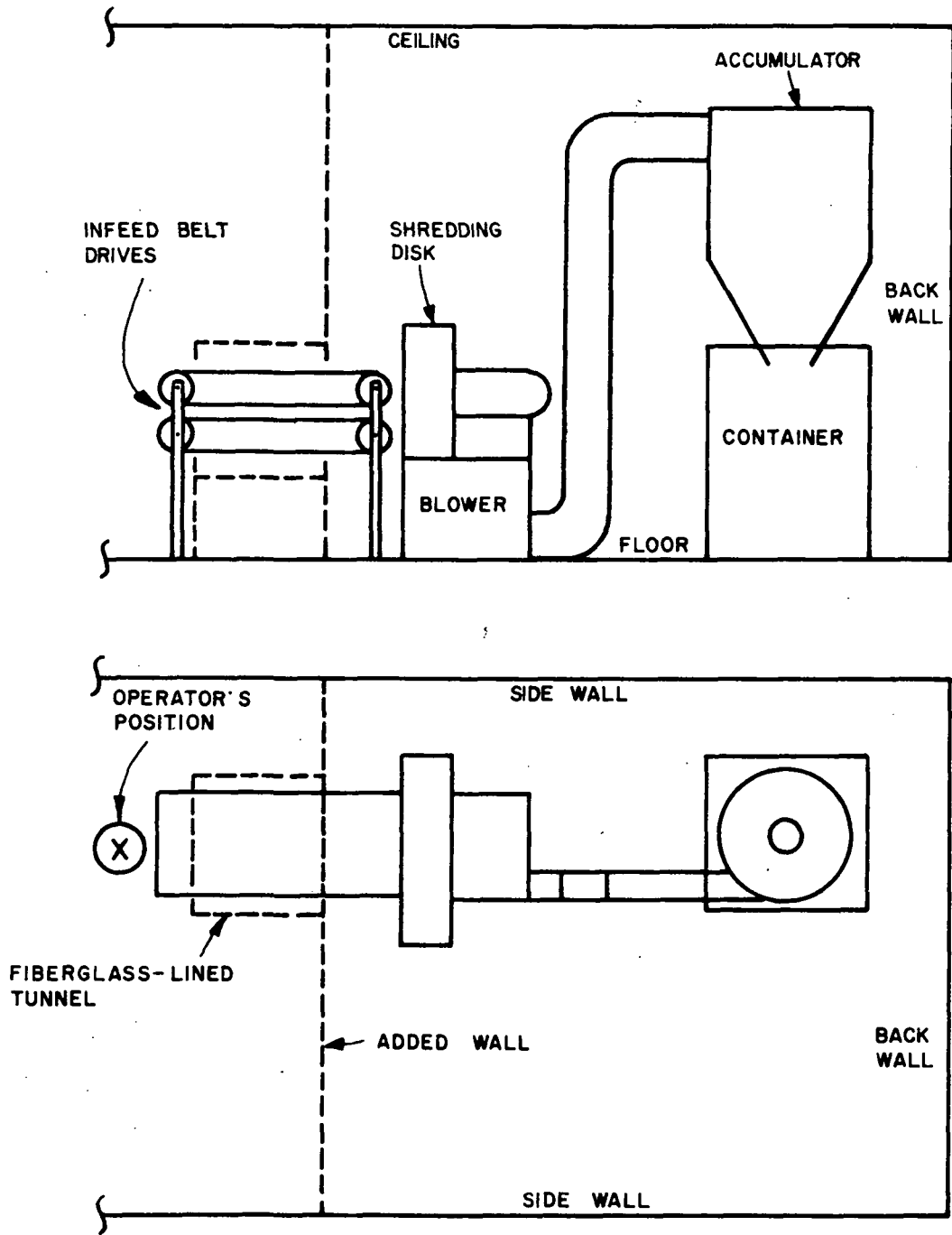


Figure 13. *Acoustically Treated Paper Shredder*

equally spaced on the disk. Material is fed to the shredding disk by top and bottom endless belt drives and the shredded paper is fed into a container. While the absolute values of noise levels is not given in the spectrum, exposure at the operator's position was considered to be excessive.

**Problem Solution:** Since the shredding machine was already enclosed on three sides by concrete, brick, and glass walls, a fourth wall was added to form an enclosure. The added wall was constructed using the double wall procedure and consisted of staggered 2" x 4" studding on 2" x 6" face and header plates and covered with 3/8 in. gypsum wall board. A 1/4 in. double glass viewing window was placed in the wall directly above the infeed drive unit. An access door, 44 in. wide by 7 ft. high, was covered on both sides with 3/8 in. gypsum wall board (for additional noise attenuation) and provided with sponge rubber gasket seals at the top and on each side. The infeed belt drive assembly protruded through the wall and was capped by a 1 ft. long tunnel lined with acoustical absorbing material to provide attenuation for noise escaping through the access hole.

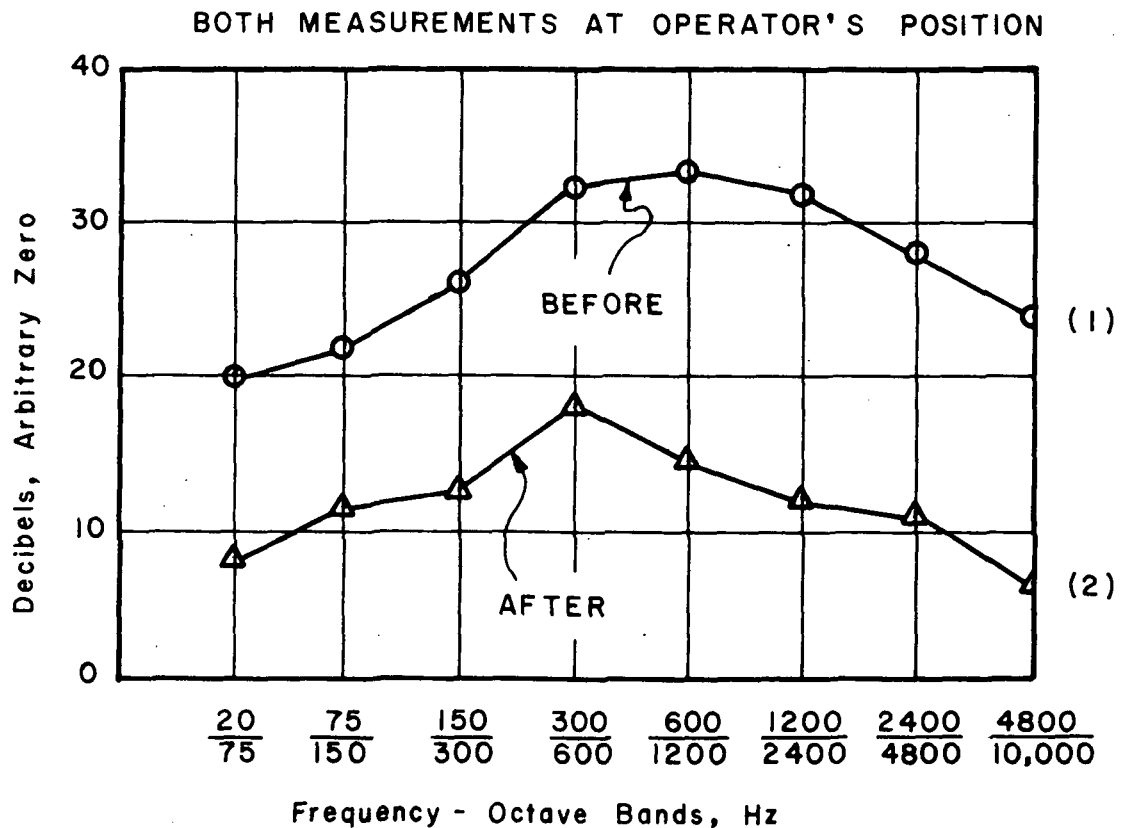


Figure 14. Paper Shredder Noise Levels Before and After Treatment

Fiberglass panels were placed on the inside walls of the enclosure with additional panels suspended from the ceiling to prevent reverberation build up inside the room. The overall attenuation achieved by the enclosure measured at the operator's position is shown in Figure 14.

Solution Source: This solution presentation is based on an article by John R. Engstrom appearing in the March, 1956 issue of NOISE CONTROL, p. 20.

## GASOLINE-POWERED GOLF CART

**Problem Statement:** A manufacturer of gasoline-powered golf carts had an acoustically untreated model which produced a noise level of 98dba with a peak of 100 db at 250 hertz at the rider's ear level. By use of improved engine isolation mounts, a new muffler design, flexible rubber air intake, and some fiberglass treatment of the body a level of 84 dba with a peak of 86 db at 250 hertz at the rider's ear was achieved (98 db - 250 Hz at ground level at rear wheels). The prime competitor of this manufacturer had a model which produced only 80 dba at ear level and the firm's distributors and dealers advised them that they could not write orders for new model carts unless they were below the 80 dba noise level at the rider's ear level.

**Problem Solution:** Because the floor of the cart must be left open for cooling, it was necessary to use a type of acoustic reflecting and absorbing material. Representatives of Consolidated Kinetics aided in the solution and all products used were Ferro Cousti-Products.

The acoustical treatment developed involved:

1. Replacement of fiberglass insulation on engine box (front and sides) and the bottom of the seat cushion with Ferro Cousti-Composite 10-100 held by 1/2" foam bonded to the surface as shown in figure 15.

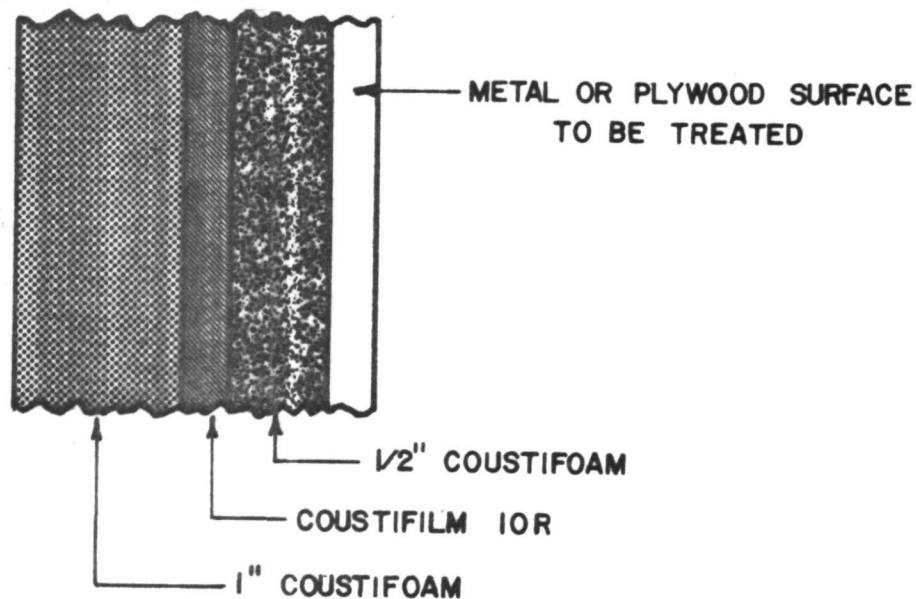
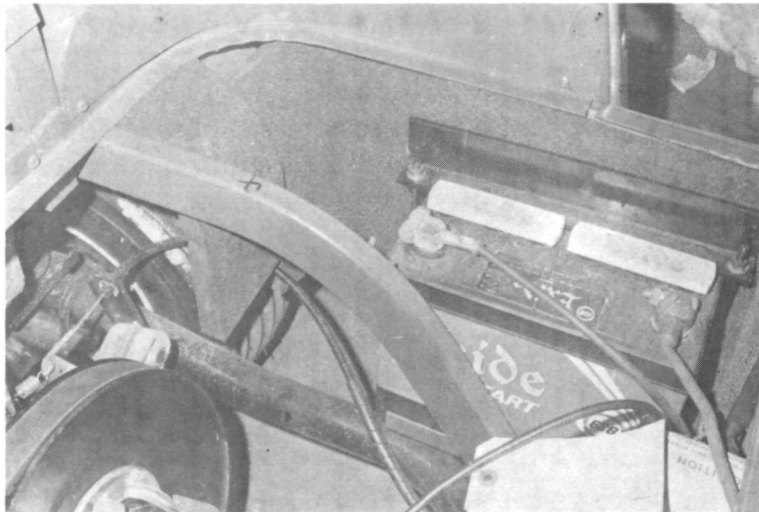


Figure 15. *Acoustical Treatment for Engine Compartment*

2. Treatment of rear fenders, front of gas tank, and forward side of golf bag rack panel with 1" coustifoam.

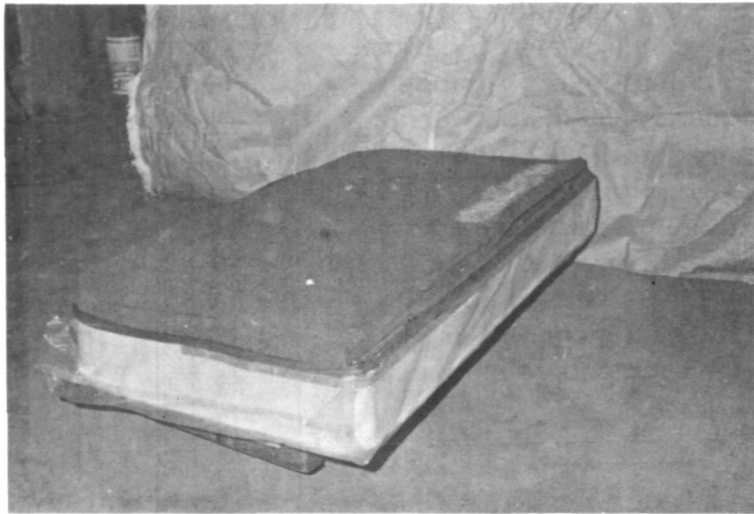
The total cost of the material used for treatment was \$39.00 and the noise level was reduced to 75 dba at ear level (86 dba at ground level/ rear wheel). This was an overall reduction of approximately 11 dba and placed the cart in a favorable position relative to the chief competing brand.

Pictures of the treated engine compartment and seat cushion follow.



#### INSIDE ENGINE COMPARTMENT

Showing Cousti-Composite 10-100 on side and front of engine compartment. Coustifoam on fender.



### **SEAT CUSHION**

**Cousti-Composite 10-100 adhered to underside.**

**Applications:** Similar principles can be applied to lawn mowers, snow-mobiles, factory vehicles, etc. which have small gasoline engines.

**Solution Source:** Company literature Ferro Corporation, Eastern Composites Division, Norwalk, Connecticut.



## RIVETING HAMMER

**Problem Statement:** Riveting hammers are a common source of excessive noise exposure. The type presented here (Fig. 16) has a continuously running motor with a hammer, eccentrically driven, that is actuated by a foot-operated clutch lever. Its operating frequency varies between a few hundred and 3000 blows per minute. The figures illustrate the relative noise spectrum and the treatment provided. The spectrum levels presented (Fig. 18) are the maximum values recorded for each octave band.

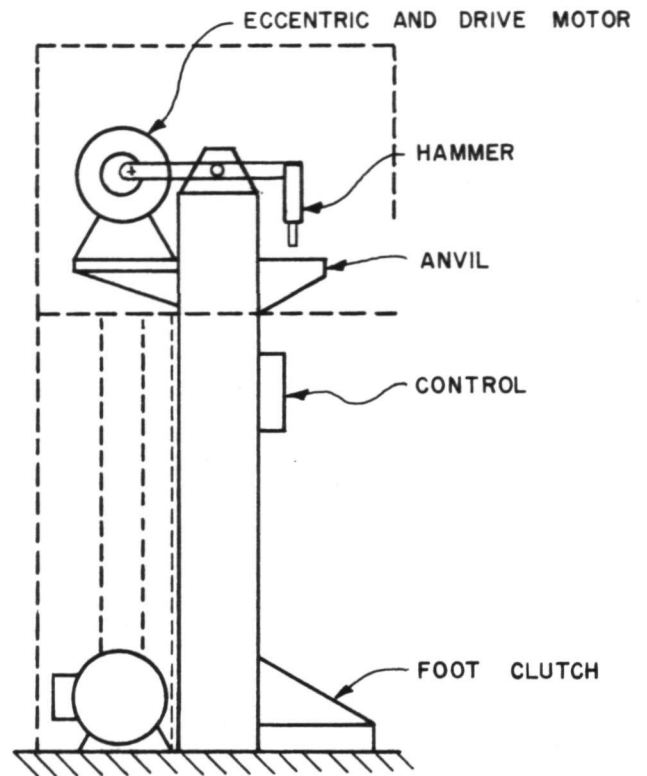


Figure 16. *Riveting Hammer*

**Problem Solution:** A partial enclosure with absorbing material inside, fitted around the motor and impact area is illustrated in Figure 17. It is, in effect, a box with a plexiglass front cover leaving the minimum gap required for access to the anvil area. Since the ear level is above the gap area, no direct path exists between the noise source (impact area) and the ear. All interior surfaces are lined with absorbing material and covered with perforated metal. The enclosure has independent support and is not attached directly to the riveting machine. The noise reduction provided by an enclosure of the type illustrated is shown in the spectrum figure.

1. Removable section for adjusting anvil - 1/2" plywood, sound absorbing felt, perforated metal covering - 4600 holes per sq. ft., 0.068 in. dia.
2. Plywood, sound absorbing felt, perforated metal covering.
3. Plywood, fiberglass, perforated metal covering.
4. Metal shield.
5. Plexiglass shield to reflect sound back into absorbing interior and provide good vision. It is attached to front so that it can be adjusted in vertical direction.
6. Top cover is hinged so top can be lifted up to provide access to motor and drive assembly for maintenance, adjustments, etc.
7. Support structure for partial enclosure around motor, hammer, and anvil area.

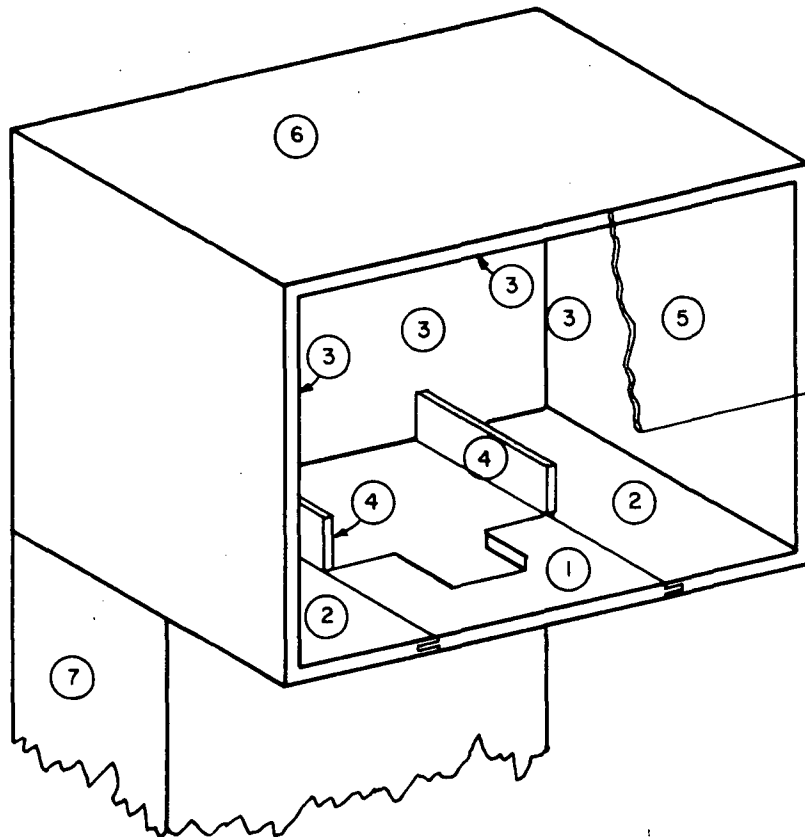


Figure 17. *Sound-Absorbing Enclosure*

BOTH MEASUREMENTS AT OPERATOR'S POSITION

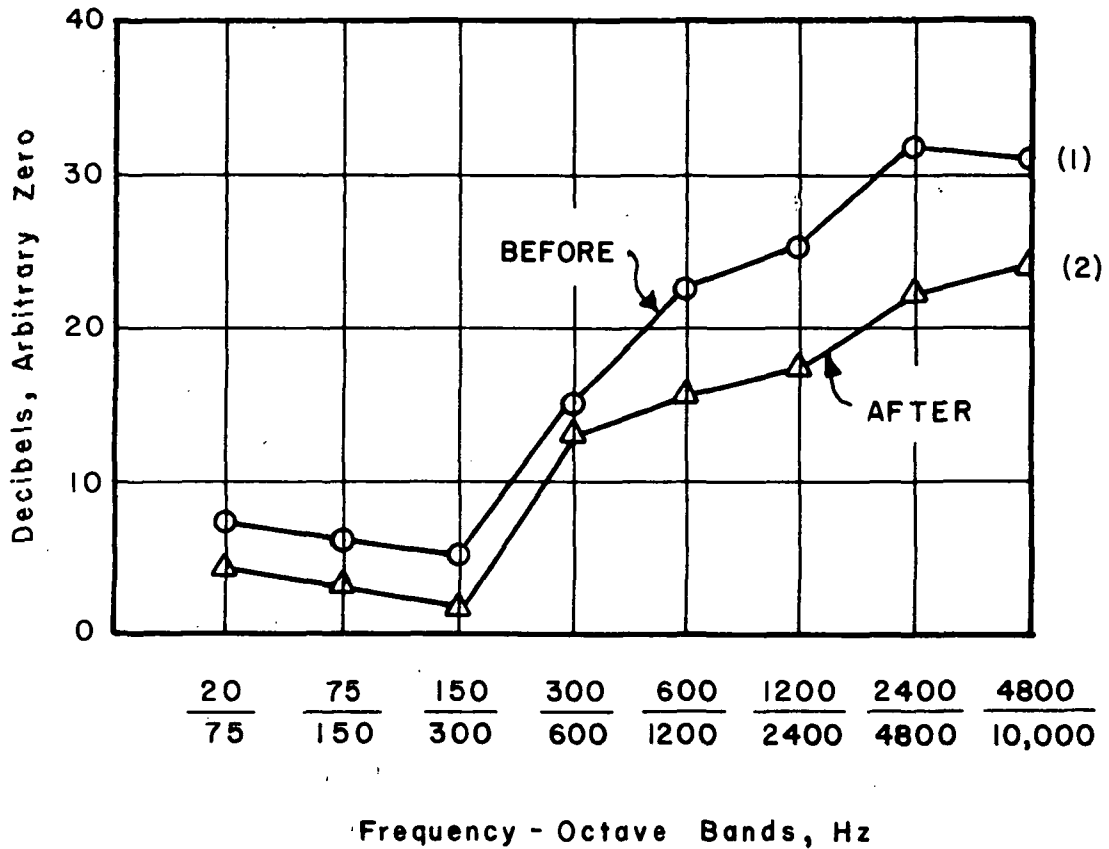


Figure 18. *Before and After Acoustical Treatment Noise Spectra for Riveting Hammer*

**Solution Source:** The presentation is based on an article by John R. Engstrom in the March, 1956 issue of NOISE CONTROL, p. 18. The description of the enclosure has been modified to provide more detail.

## VIBRATORY PARTS FEEDER

**Problem Statement:** A common noise source in manufacturing plants is a vibratory parts feeder. This device is a large metal bowl mounted on a vibrating base. Randomly oriented parts are placed in the bowl and the vibrations cause the parts to follow a prescribed path. The path is such that only correctly oriented parts can exit from the bowl.

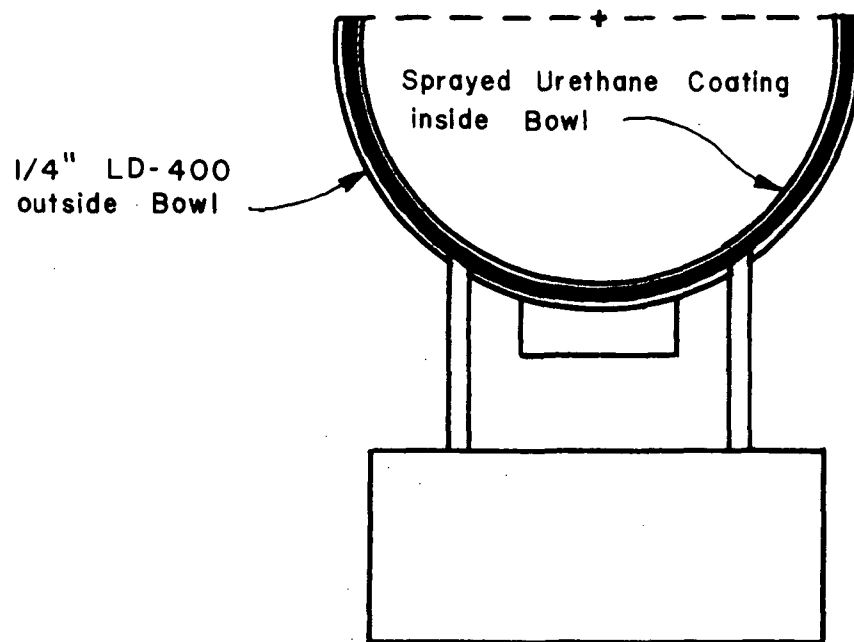


Figure 19. *Acoustical Treatment of Bowl*

The noise of this machine comes from the bowl, the parts impacting the bowl, and the parts impacting each other. The noise of the bowl itself is usually a small portion of the overall noise except in the case of a fabricated steel bowl. For a fabricated steel bowl the substitution of a bowl of different material may have a large noise reduction effect.

The particular problem cited below involved a 30-inch diameter aluminum bowl.

**Problem Solution:** The method used to reduce the noise of this vibratory feeder involved:

- (1) Polyurethane coating on the inside of the bowl (See Figure 19);

(2) Damping material (1/4 inch LD-400) on the outside of the bowl;

(3) Acoustically treated hood over the bowl.

The total reduction using these three treatments was 8 dba (Figure 20).

Solution Source: Glenn E. Warnaka, H. T. Miller and J. M. Zalos, "Structural Damping as a Technique for Industrial Noise Control," American Industrial Hygiene Association Journal, January, 1972, p.1-11.

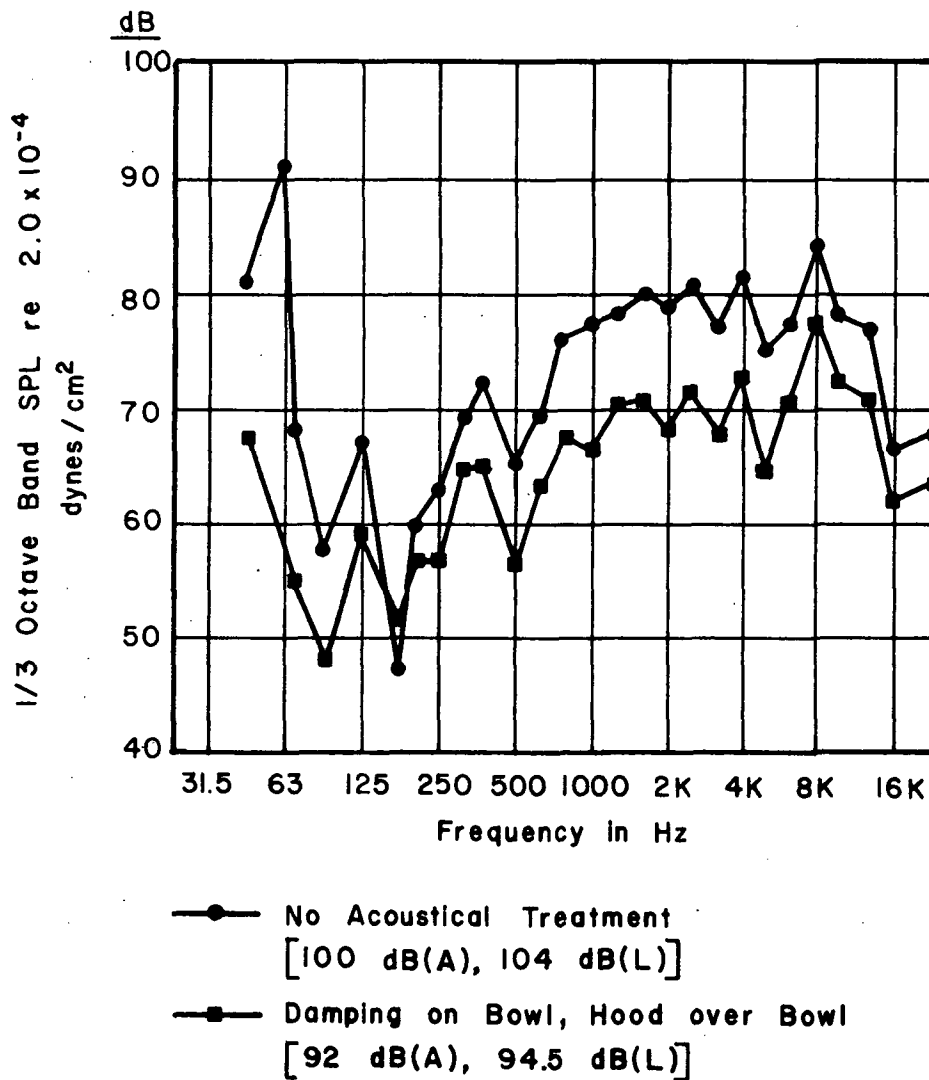


Figure 20. Noise Spectra of Bowl Before and After Acoustical Treatment

## CONVEYOR LINE

**Problem Statement:** The problem involved a conveyor line which removed metal parts from a large industrial dryer. The exit chute was constructed of heavy gauge steel and the material leaving the dryer was ejected at high velocity. The impact of the ejected parts against the chute produced a high noise level. Operating personnel are not continuously in the area; however, servicemen working on machines are often in the area.

**Problem Solution:** The solution to this problem involved the application of damping material to the outside of the chute. The material selected was LD 400 damping material manufactured by Lord Manufacturing Company. The thickness used was 0.125". (Figure 21)

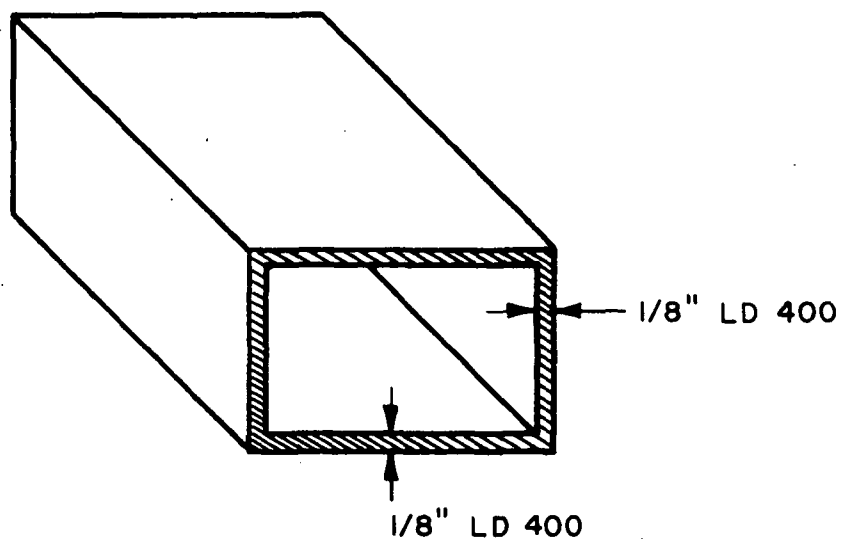


Figure 21. *Acoustical Treatment of chute*

As seen in Figure 22, the reduction was 5 to 6 db in all frequencies bands. This reduced the noise level sufficiently for the workmen to service the machines within permissible noise exposure limits.

**Solution Source:** Glenn E. Warnaka, H. T. Miller, and J. M. Falos, "Structural Damping as a Technique for Industrial Noise Control," *American Industrial Hygiene Association Journal*, January, 1972, p. 1-11.

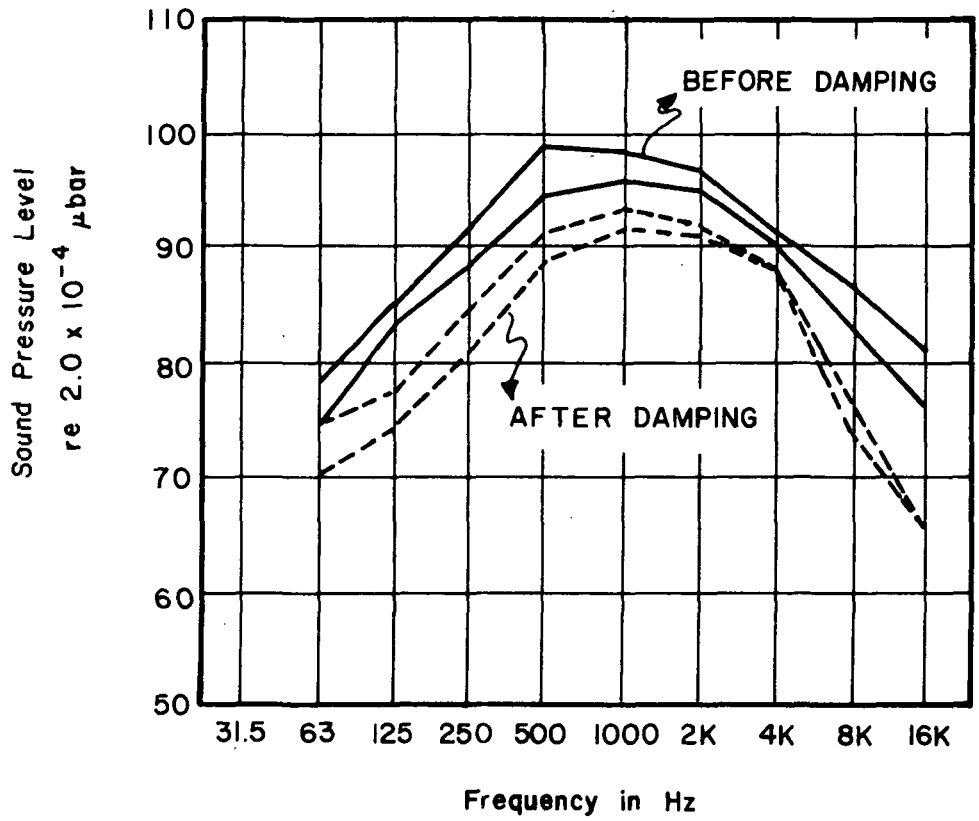


Figure 22. *Noise Spectra of Chute Before and After Acoustical Treatment*

## AUTOMATIC LATHE

**Problem Statement:** In a facility with bar automatic lathes the noise is frequently in the range of 96-110 dba. The lathes may be single spindle machines; however, they are often multi-spindle (6) machines. The

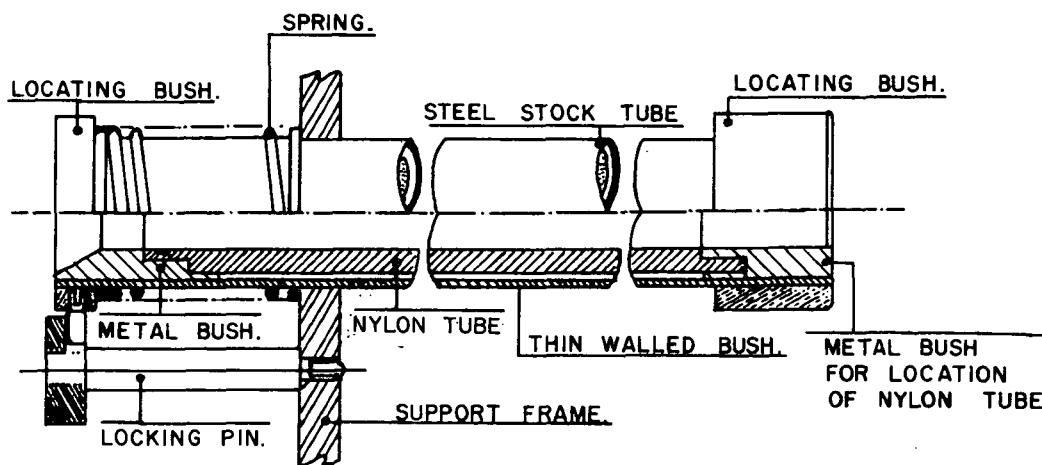


Figure 23. Stock Tube with Acoustical Liner

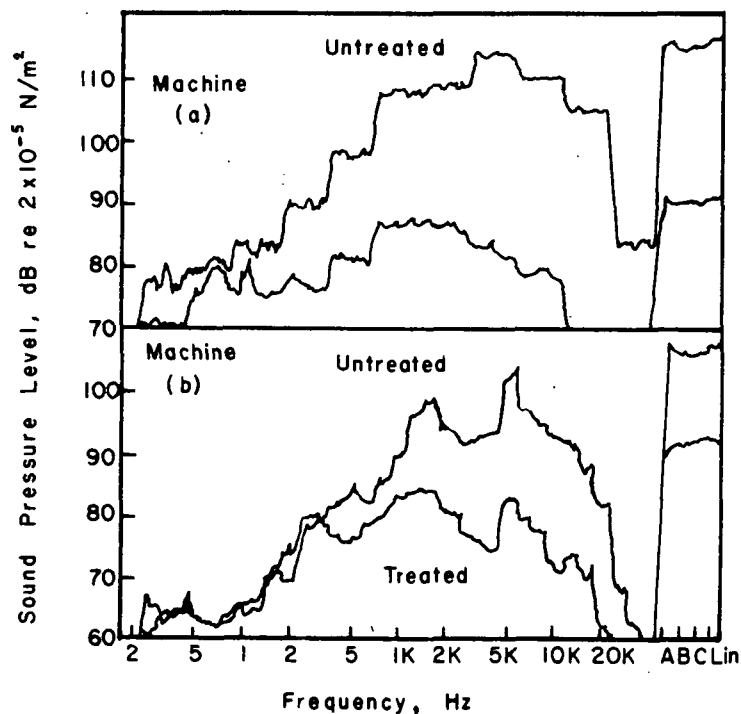


Figure 24. Effect of Stock Tube Lining on Machine Noise



noise observed in a lathe factory is typically a general noise with a superimposed characteristic noise produced by the rattling of stock bars against the feed guide tubes. This noise is especially noticeable when hexagonal bars are rotated at high spindle speeds. In the paper upon which this example is based, a solution is sought to the noise produced by the bar stock in the feed guide tubes.

Problem Solution: The solution was to machine and fit nylon tubes inside each of the steel stock tubes as shown in Figure 23.

In addition, a lightly spring-loaded canvas strap was fitted around the set of tubes to prevent the tubes themselves from generating noise. Before and after noise measurements are given (Figure 24) for two different machines. The two examples show that the machines differ due to age and condition; however, the treatment was effective for each machine.

The overall reduction for machine A was 25 dba and for machine B, it was about 15 dba.

Solution Source: G. L. Lee and D. J. Smith, "The Control of Noise Produced by Bar Automatic Lathes," *Annals Occupational Hygiene*, Vol. 14, pp. 337-343, 1971.

## WIND TUNNEL

Problem Statement: Two large Roots pumps (size 2060) are used to power an induction wind tunnel (Figure 25). Each is turned at 360 RPM by a 150 HP electric motor. Total air flow rate into the pumps in this configuration is 17,500 cfm. Minimum permissible pump suction pressure is 10.7 psia and maximum discharge pressure is approximately atmospheric. The pumps (weight about 15,000 lbs. each) are bolted directly to an 8" concrete floor. The wind tunnel inlet and discharge line consist largely of 1/8" thick wall steel pipe up to 30" diameter and are bolted directly to the pumps. These lines are suspended by strap hangers from the building structure, either floor or ceiling. The noise from the operation of this wind tunnel made attending personnel ill after only a few minutes exposure, shook the entire academic building in which it was located, and in general made other activity in the building and its environs impossible. The measured noise spectrum in the vicinity of the tunnel exhaust exceeded 120 db with the intensity highest at the lowest measured frequency. Indications are that it reached a maximum at about 12 Hz.

Restrictions on Solutions: Mufflers that restrict the air flow significantly cannot be used because the pressure limits of the Roots pumps will then be exceeded. Cost of sound controls have to be absorbed by a research project which is not budgeted for this purpose. Plumbing on the suction side of the pumps must be vacuum tight for satisfactory tunnel operation. Suction side plumbing for the most part cannot be lined internally because of the deleterious effect on flow quality.

Problem Solution: The solution to the noise problem was arrived at progressively through a series of treatments. The first item applied to the system is shown in Figure 29. This was effective at the lowest frequencies as had been expected. The device shown in Figure 30 was then added with moderate success. This was followed by that shown in Figure 28. A small additional reduction in noise level was obtained. Finally, satisfactory exhaust line quieting was achieved through the addition of the device shown in Figure 31. Suspension of the exhaust duct from the building floor was accomplished as shown in Figure 32.

Inlet side quieting was achieved by the treatments depicted in Figures 26 and 27.

Solution Rationale: A Roots pump consists of two tightly-fitting figure-eight lobes geared together with the major axes of the lobes at  $90^\circ$  to one another. Every revolution of the shaft results in the application of two sharp pressure pulses to the air flow in the exhaust duct. With the pumps running at 360 RPM (6 RPS) there is applied to the steady state flow a rather distorted sine wave modulation having a fundamental frequency of about 12 Hz. Energy at this frequency is very difficult to attenuate by dissipative means. Another way of saying this is that it requires a large amount of damping material such as fiberglass, lead, mastic, etc. to absorb significant energy at these frequencies. Further, the use of these materials in sufficient quantities to be effective will result in excessive pressure drops in the system. Reactive attenuators have the disadvantage that they operate only over a narrow band of frequencies. Unfortunately, square waves such as those produced by Roots pumps have a large harmonic content so that a side branch resonator tuned to 12 Hz. will attenuate only the fundamental tone in the exhaust flow. But since reactive attenuators cause little or no pressure drop one has little choice but to use them for the attenuation of low frequency noise in this application.

Two such attenuators were constructed and installed and the noise spectrum measured. Significant improvement was noted. The spectrum indicated other likely frequencies below 400 Hz where this type of attenuation might be effective, the most prominent being at 250 Hz. An additional resonator tuned for this frequency was added but the benefit was not very large.

The higher frequency noise which was more "white" in nature seemed to require dissipative mufflers to attenuate it adequately. Accordingly, first the smaller in-line dissipative muffler and then the larger one were installed. These, in conjunction with the cones installed to inhibit the development of standing waves in the exhaust duct, and the use of canvas isolators in a section of duct brought the exhaust noise level to within the desired range.

The treatment of the inlet plumbing is quite conventional: wrapping of the duct externally with absorbent materials to attenuate noise and prevent radiation from the duct. In the low speed areas of the inlet duct, the acoustical treatment is applied internally.

Solution Source: Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, North Carolina 27607

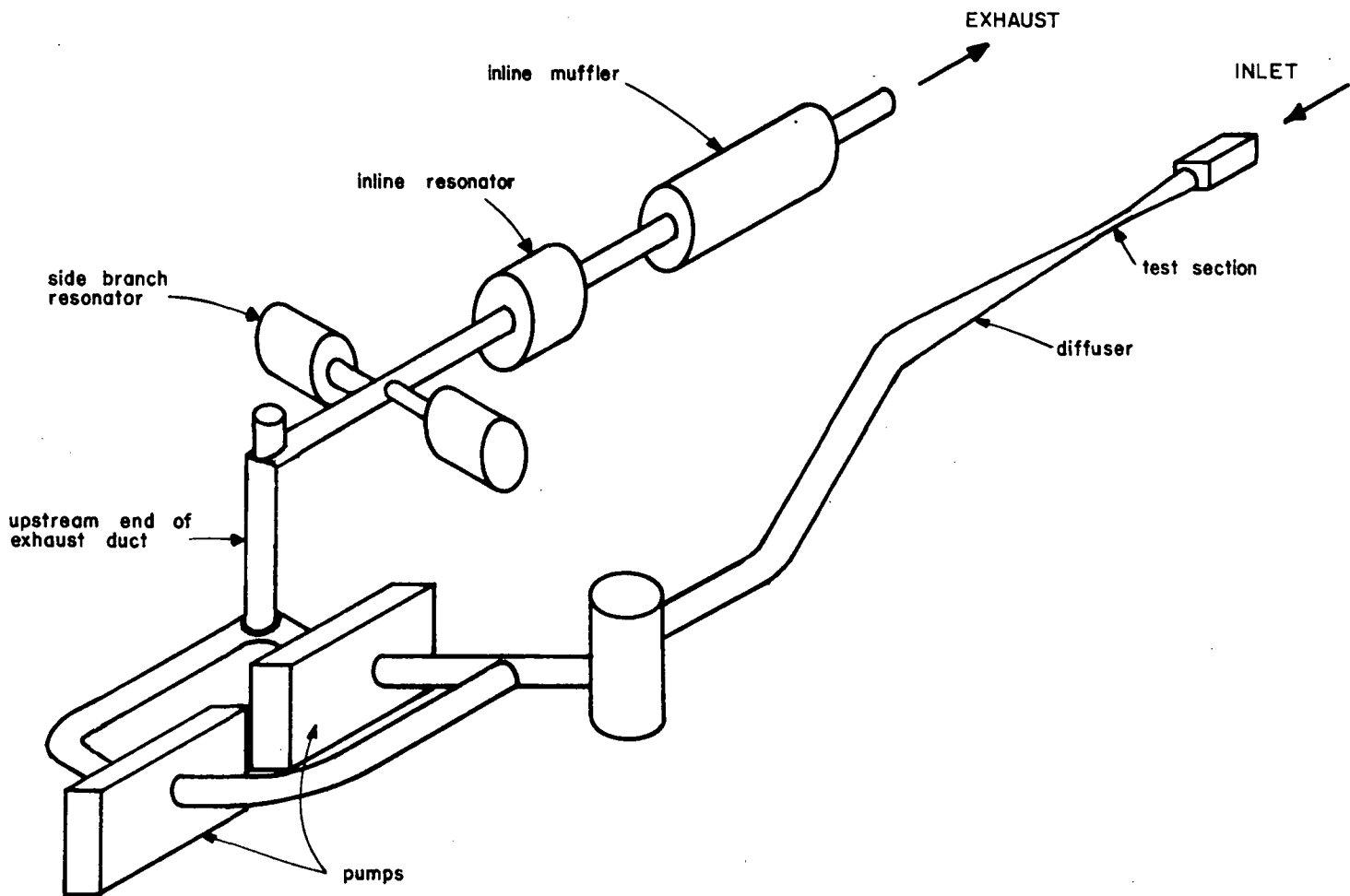


Figure 25. *Layout of Tunnel Components*

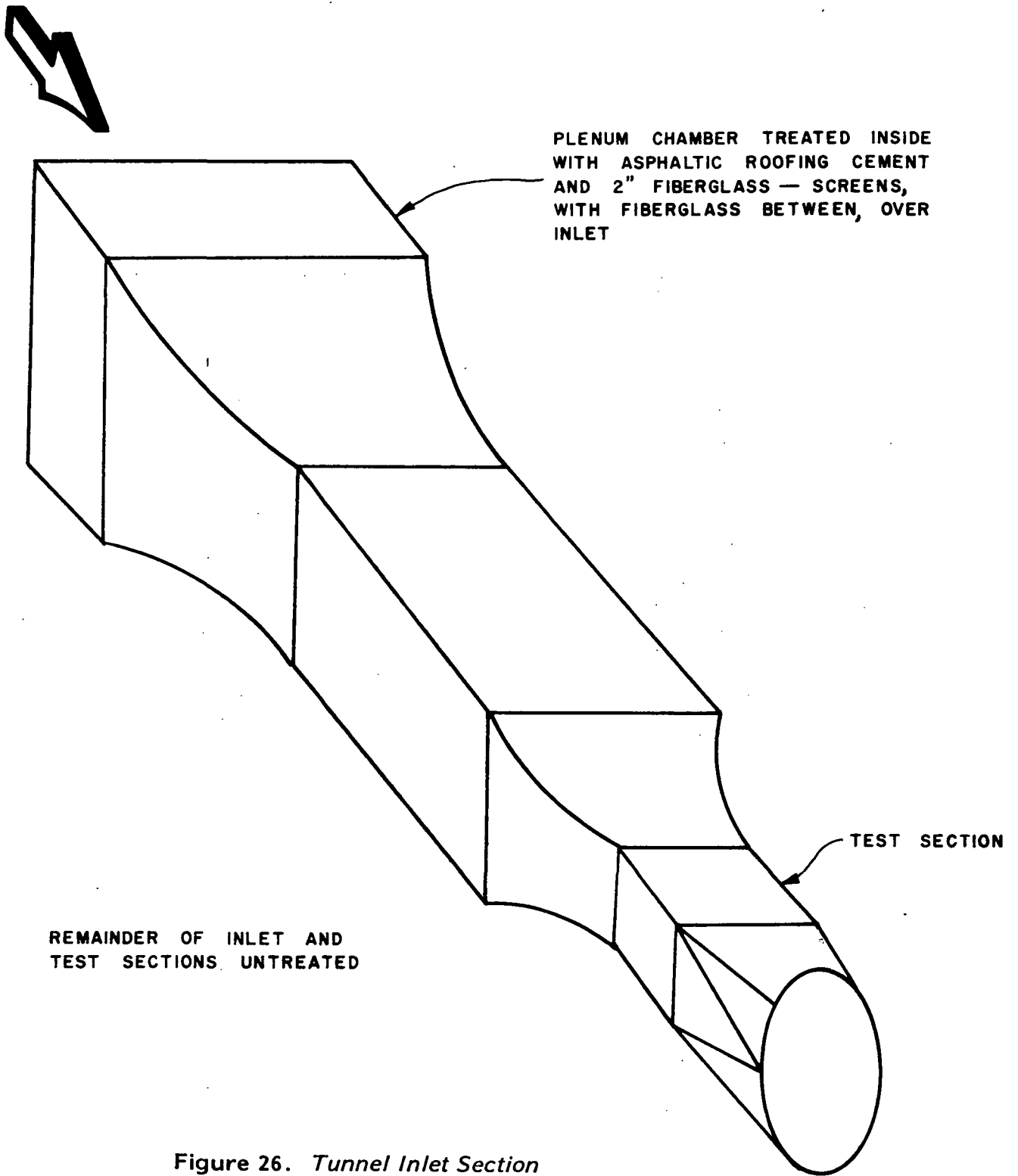


Figure 26. Tunnel Inlet Section

EXTERIOR COATED WITH ASPHALTIC  
ROOFING CEMENT, FIBERGLASS, AND  
WRAPPED WITH MUSLIN SHEETING

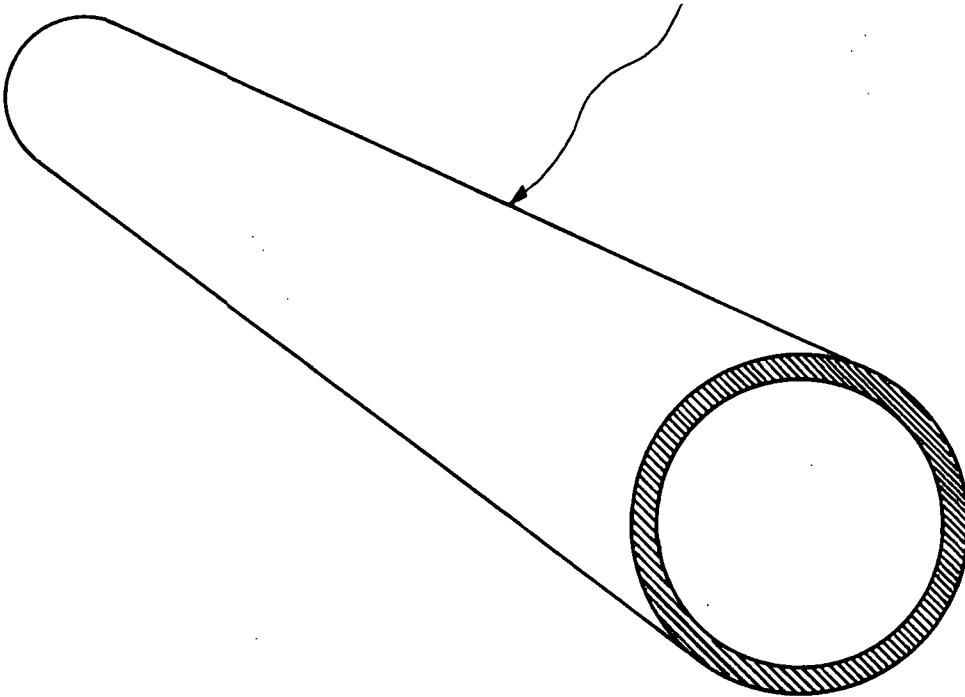


Figure 27. *Wind Tunnel Diffuser*

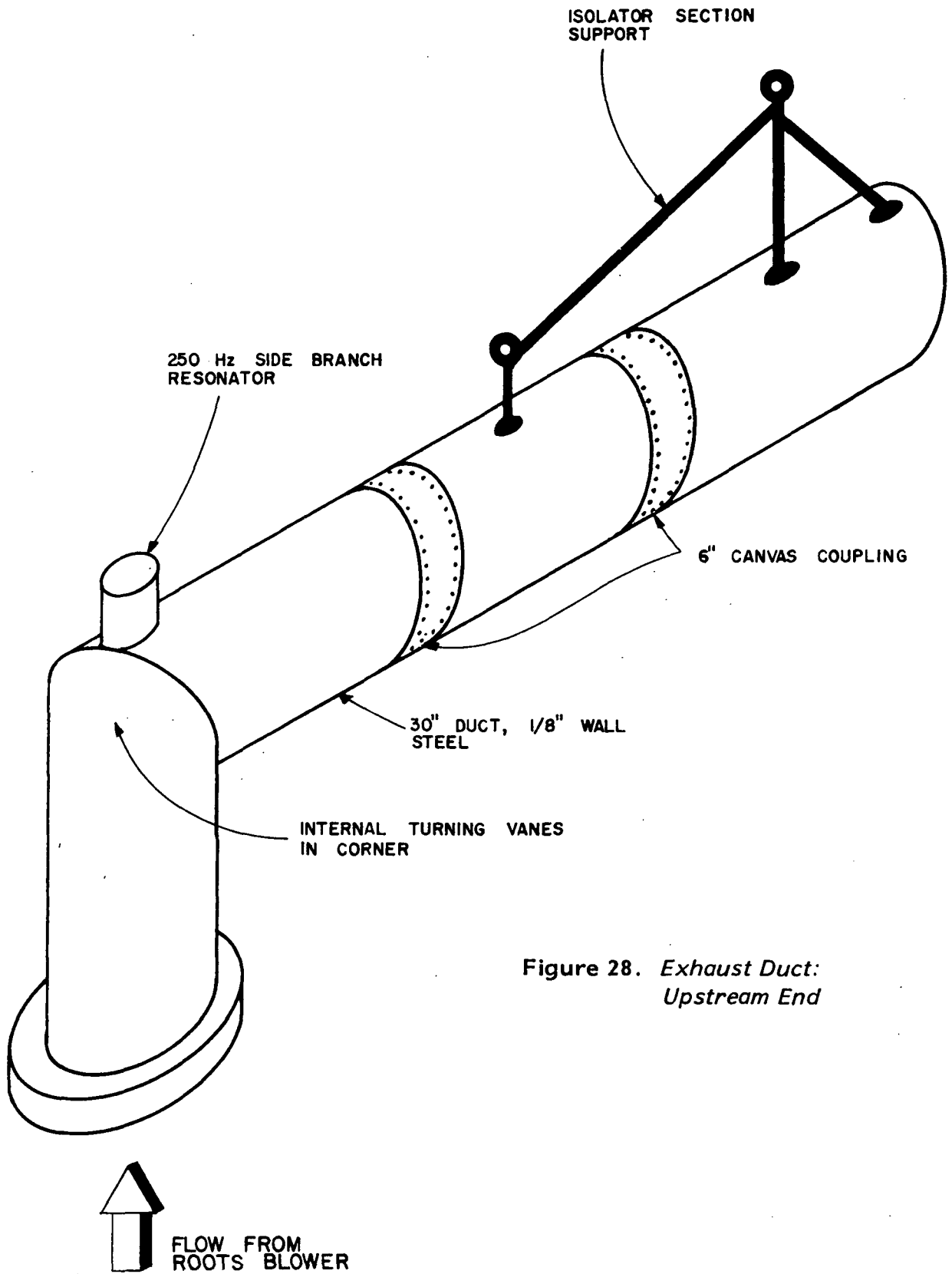


Figure 28. *Exhaust Duct: Upstream End*

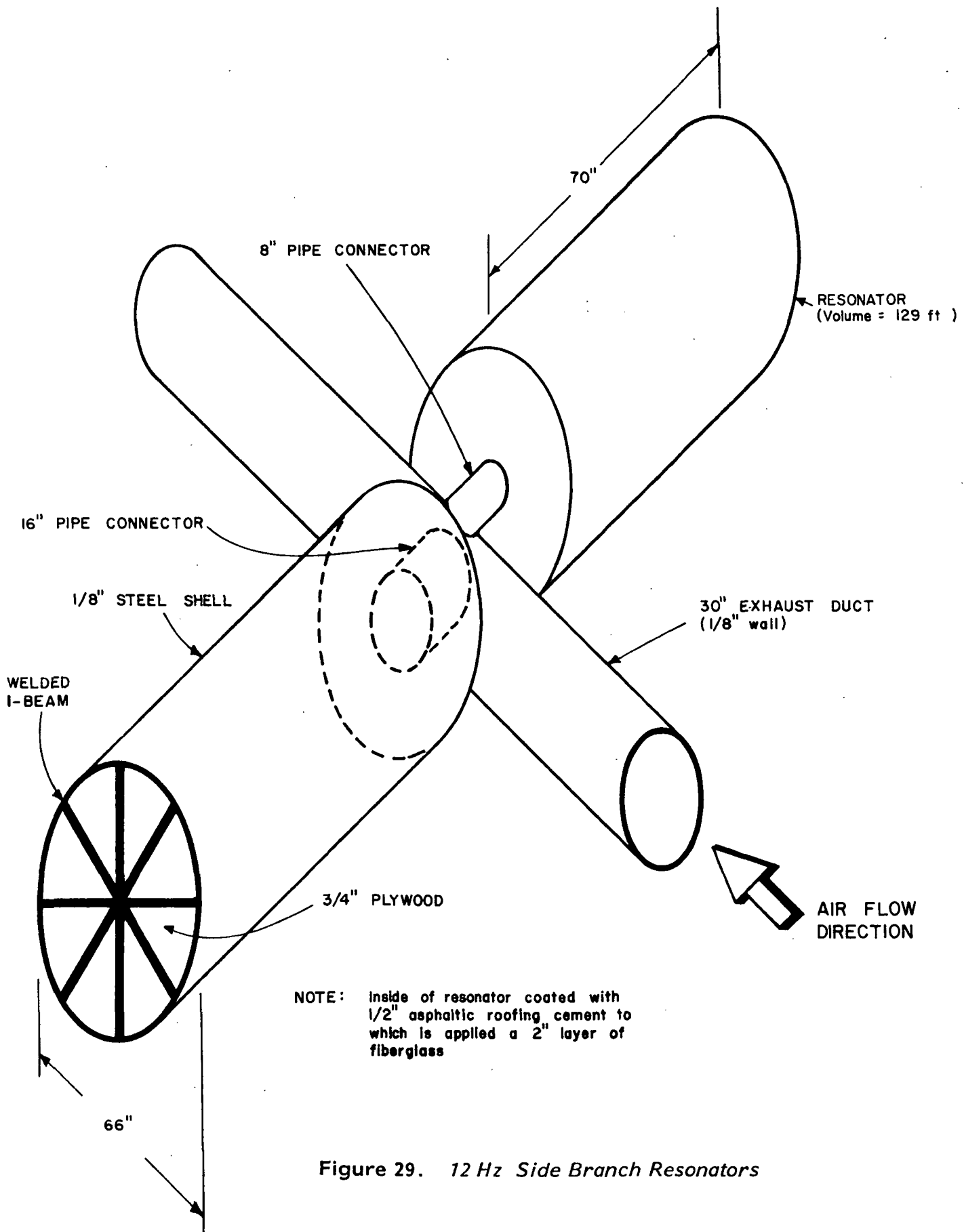


Figure 29. 12 Hz Side Branch Resonators



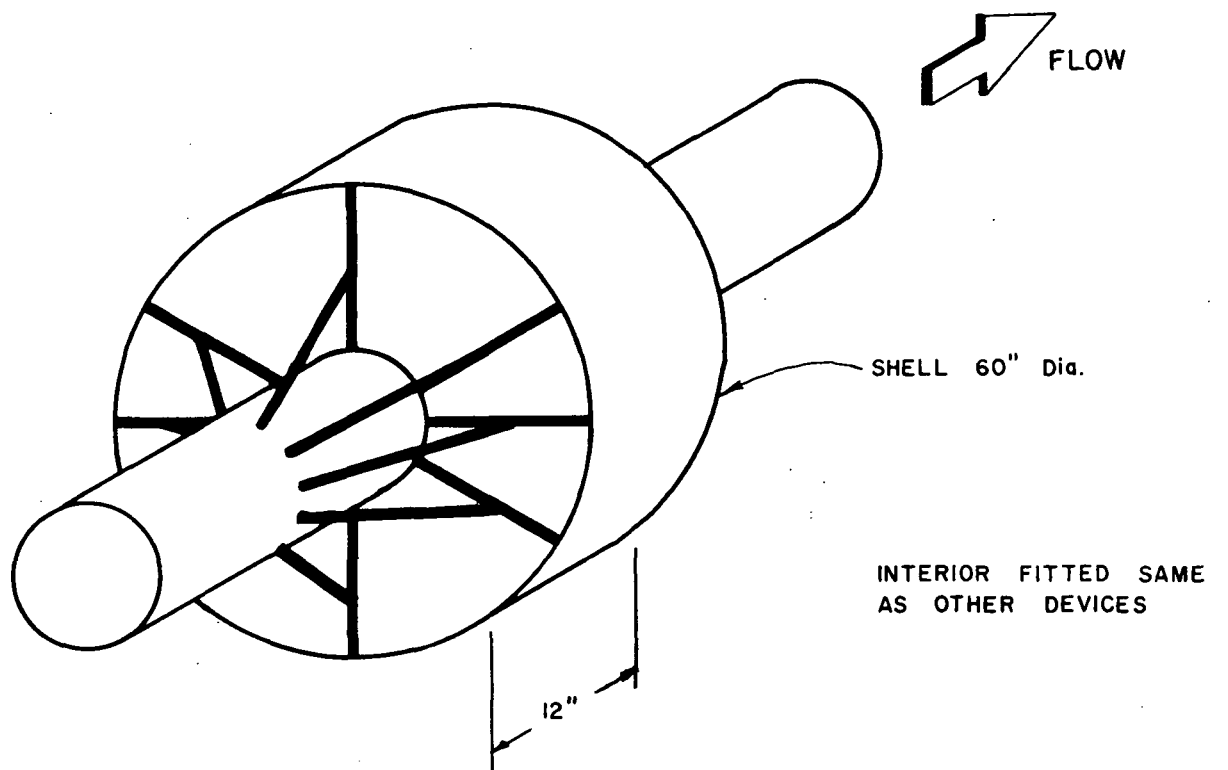


Figure 30. *Inline Resonator*

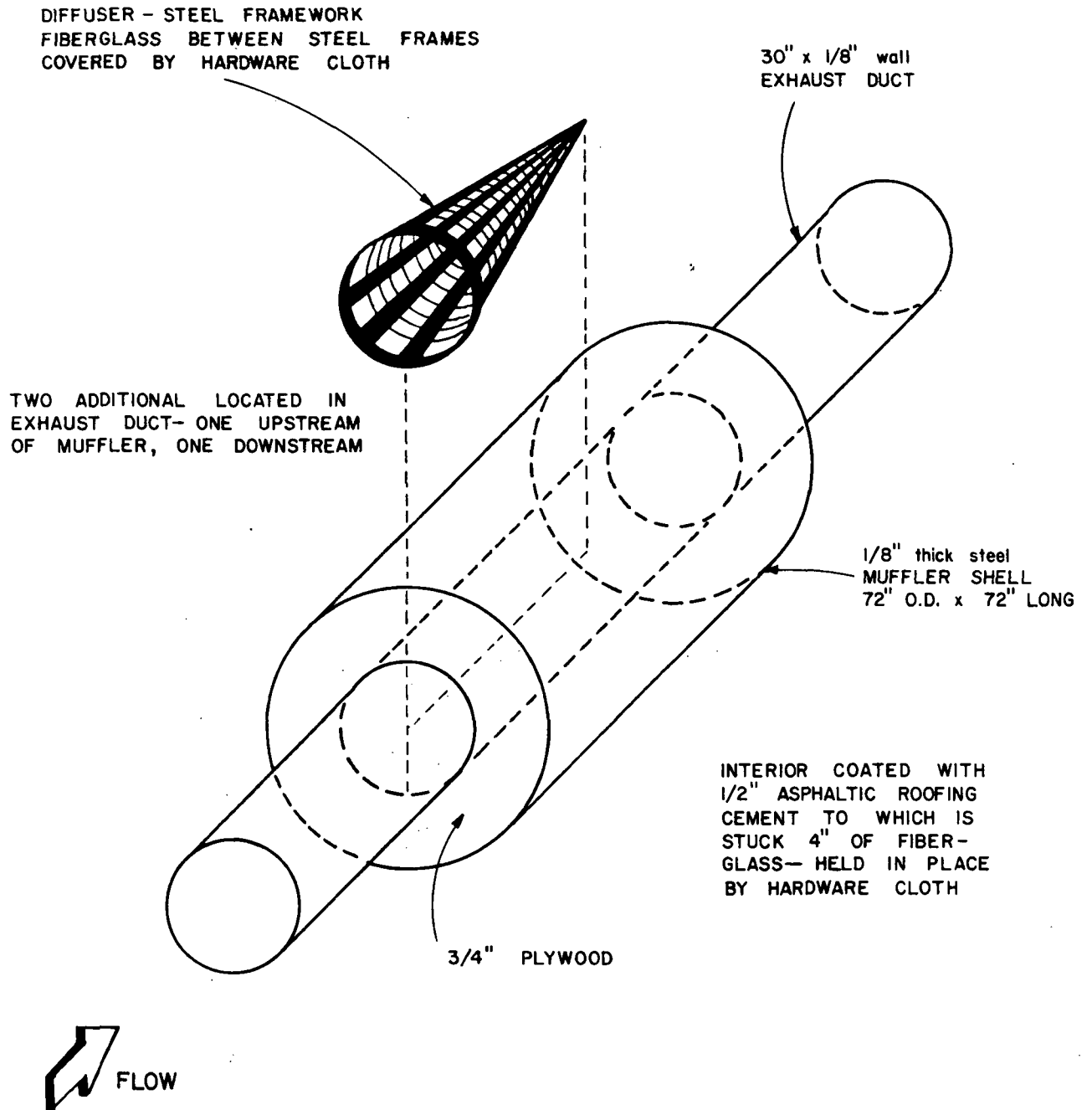


Figure 31. *Inline Muffler*

DUCT SUPPORT STRAP: 4" x 1/16" BOLTED TO COLUMN. DUCT NOT FIXED TO STRAP

COLUMN: 3" STEEL PIPE

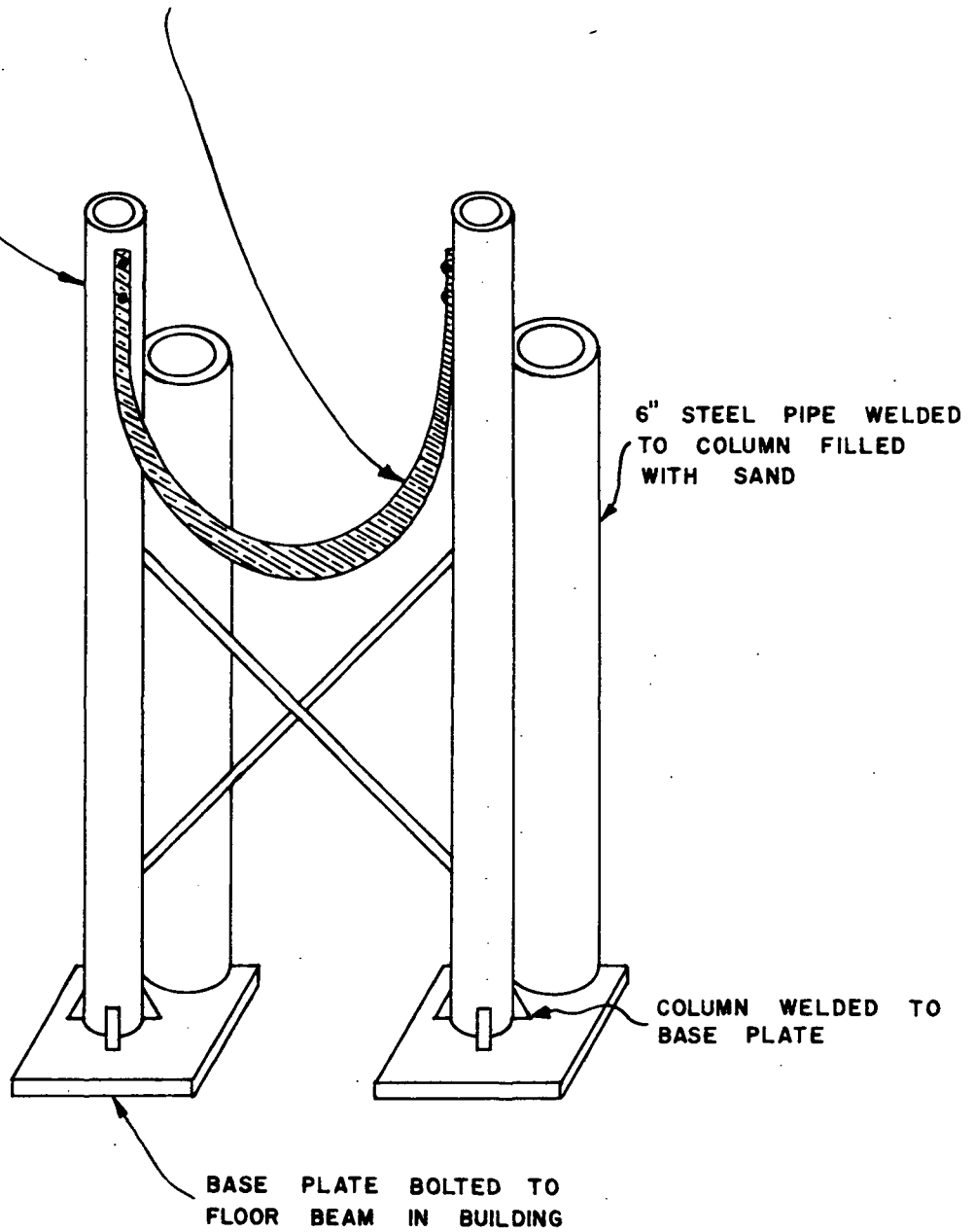


Figure 32. Exhaust Duct Support