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Measurement, Analysis, and Reduction of Noise Produced by an Agricultural Tractor

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MEASUREMENT, ANALYSIS, AND REDUCTION OF NOISE PRODUCED BY AN AGRICULTURAL TRACTOR

BY

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MEASUREMENT, ANALYSIS, AND REDUCTION OF NOISE

PRODUCED BY AN AGRICULTURAL TRACTOR

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Major Department Date

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INTRODUCTION

Noise is a result of man's advanced technology in the design and application of agricultural machines. Excessive noise results in increased stress on the operator and the possibility of permanent hearing loss. Hearing audiograms conducted on incoming freshmen by the Speech and Hearing Center at South Dakota State University have indicated a loss of hearing above the national average. Further analysis showed that the incidence of hearing loss was among individuals who had worked in a noisy environment, such as farming or construction work.

Cooperative research by manufacturers of tractors, cabs, and soundproofing materials, together with universities is being conducted to find solutions to the problem of high noise levels. Tractor cabs are becoming more popular as operators become aware of the advantages of operation in controlled environments. However, with the reported increased noise levels in present tractor cabs, it is questionable whether the benefits are worth the danger of permanent hearing loss. Attempts have been made to reduce noise in cabs by insulating the ceiling, using rubber floor mats, and using vibration isolation mounts. It appears that additional improvement is still needed in noise reduction for tractors with and without cabs.

PURPOSE AND OBJECTIVES

Agricultural tractor noise has become an increasing concern of farmers, tractor and cab manufacturers, research engineers, and medical doctors. Requests from farmers concerned with reducing the noise levels in tractor cabs are being received at the Agricultural Engineering Department at South Dakota State University. The purpose of this study was to find suitable solutions to the problem of excessive noise produced by agricultural tractors.

The objectives of this study were:

1. To develop noise reduction treatments for an agricultural tractor.
2. To evaluate the treatments on the basis of total loudness at the position of a seated operator's head.
3. To evaluate the treatments on the basis of a noise exposure criteria to determine if noise reduction was adequate for continuous exposure situations.

REVIEW OF LITERATURE

With the increased use of cabs for agricultural tractors, operators have become increasingly aware of the need for improved noise control. Studies involving the effect of noise on operator performance and efficiency have been conducted and noise exposure criteria developed. However, the area of noise reduction and noise control of agricultural tractors is just beginning to be emphasized.

Effect of Noise on Operator

In 1958 Lierle and Reger (9) made a two-part study of the effect of tractor noise on auditory sensitivity. The first part consisted of making sound pressure level measurements at a location six inches from each ear of a seated operator. Eleven tractors were tested under actual load conditions in the field. The range of sound pressure levels was from 88 to 102.5 decibels for the 300-600 cycle per second octave band and 85 to 98 decibels for the 600-1200 cycle per second octave band. These levels were above the noise exposure criteria level of 85 decibels that was being used at that time. The second part of the study consisted of obtaining audiograms of 80 full time tractor operators. Results indicated that generally operators had some hearing loss above 1000 cycles per second with the greatest loss at 4000 cycles per second. It was concluded that tractor noise was sufficiently high to cause hearing loss in individuals with sensitive ears if exposed over an extended period of time.

Glorig (4) in 1961 discussed the history and effect of noise exposure and a tentative hearing conservation limit. He stated that there were four major factors of noise exposure that could contribute to hearing loss. These four factors were:

"1. The overall noise level

2. The frequency composition or spectrum of the noise

3. The duration and time distribution of the noise exposure during a typical work day

4. The total duration of noise exposure during an expected work life."

He believed that intermittent exposure to noise was less damaging than continuous exposure even if the sound pressure level was higher.

In another publication Glorig (5) discussed damage risk criteria. He divided noise exposure into three types, dependent upon the time involved. These three types were:

"1. Continuous steady noise that is on for 5 hours or more per day, 5 days a week, for many years

2. Continuous steady noise that is on for less than 5 hours per day, for 5 days a week, for many years

3. Steady noise that is intermittently on during the day for 5 days a week, for many years."

Steady noise was defined as noise that does not have any noticeable sharp changes in level. It was necessary to propose separate damage risk criteria for each type of noise exposure because the effects vary with the exposure time and level.

A Guide for Conservation of Hearing in Noise (12) was published to help industry determine when hearing conservation measures should be initiated; and if needed, how to organize and conduct a practical hearing conservation program. Guidelines were proposed for establishing standards for preventing hearing loss in the majority of exposed persons. These recommended standards have been proposed by the International Organization for Standardization.

Huang and Suggs (7) in 1957 studied the relation between tractor noise and operator performance. In their study four late-model, gasoline tractors were selected for making noise measurements. Stevens' (11) procedure was used to calculate the total loudness. The loudest noise producing tractor was selected for laboratory tests on operator performance. The noise was recorded and reproduced in a test chamber where operator performance tests consisting of mental tasks of addition and subtraction and tracking tasks to determine steering ability were conducted. Results of the tractor noise study indicated that design improvements in minimizing noise sources in tractors are needed. Tractor noise at full load was in the range of 101 to 109 decibels at the operator's ear. The study also indicated that noise levels had little effect on problem solving and steering tasks. However, noise level changes and exposure time did have a significant effect on tracking performance.

Measurement of Noise

In 1961 Stevens (11) presented a procedure for calculating the loudness of a complex sound. This was a revised procedure from the one first presented in 1956. The purpose was to provide a method by which complex sounds of diverse levels and spectra could be arranged on a scale of subjective magnitude. The revised procedure was easy to apply and agreed with actual measurements of loudness. It was an attempt to describe the judgments of typical human beings listening to a complex sound.

Jensen (8) in 1965 measured the sound pressure level of 21 tractors at the location of a seated operator's ear. Measurements were made with the tractor pulling three-fourths of maximum drawbar load in the working gear nearest four and one-half miles per hour. Stevens' Mark VI method was used to convert the sound pressure level in octave bands to total loudness in sones. Comparing the loudness of these 21 tractors and loudness of the 11 tractors tested in 1957 by Lierle and Reger, Jensen found that the two groups were essentially equal, even though horsepower had approximately doubled. Jensen believed that

> "high tractor noise levels are due not to the difficulty of reducing them, but to custom and customer expectations. The public mind seems to identify power with noise, and this identification influences marketability."

In 1963 the American Standards Association (1) proposed a standard procedure for the computation of loudness of noise. This method was based upon Stevens' procedure.

Chisholm (2) in 1967 developed techniques for characterizing the noise produced by an agricultural tractor in terms of the acoustic power and directivity. The directivity indices of the Ford 3000 gasoline tractor he used indicated that as much as 41 times the acoustic power was radiated in one direction as in another. He also found that about two-thirds of the total acoustic power was in the frequency range of 36 to 140 cycles per second. Chisholm's procedure could be used to select the location that would be quietest for an operator of an agricultural machine. The acoustic directivities would be determined and from these the best location would be selected.

Noise Reduction

In 1966 Rowley (10) discussed the source, level, and control of agricultural tractor noise. He divided the total noise from a tractor into four parts: exhaust, mechanical, fan, and intake. Noise tests were run on two 1965 diesel tractors and the four sources isolated to determine which contributed the most noise. Exhaust noise was the major source followed by fan, mechanical, and intake noise. Rowley mentioned three effective noise control methods applicable to an agricultural tractor. The first was distance between the operator and noise source. He found that with the air intake and fan mounted close to the front of the tractor these sources of noise were minimized. The second noise control was physical barriers placed between the noise source and operator. The third noise control method was directing the noise away from the operator. An example would be placing an extension on a muffler to raise the exhaust outlet. Rowley concluded that on some tractors decreasing exhaust noise only would not reduce noise to acceptable levels.

Egging (3) discussed the need for operator protection and fatigue reducing features in the design of cabs for agricultural tractors. He believed that a properly installed cab should prevent a tractor from completely turning over and thus protect the operator. To test the strength of cabs he suggested that tractors with cabs installed should be overturned. Egging emphasized that tractor and cab designers need to work together to meet the demands of tractor operators for greater safety and comfort.

THEORY

Basic Terminology

Noise is, by definition, unwanted sound. Sound can be defined first, as a variation in pressure in an elastic medium, such as air; and second, as the auditory sensation caused by the variation in pressure. The fluctuation in pressure is called sound pressure and is measured in units of microbars, a microbar being one dyne per square centimeter or approximately one-millionth of an atmosphere. Because of the wide range of sound pressure, about 0.0002 to 200 microbars, a term known as the sound pressure level is used. The sound pressure level is measured in decibels. The decibel represents a relative quantity based on the logarithmic ratio of the sound level to some reference or zero level. This reference quantity is normally 0.0002 microbars and can be referred to as zero decibels. It is also the level of the weakest sound that can be heard by a person with good hearing. The sound pressure level, L_p, in decibels is given by the following formula:

$$L_p = 20 \log_{10} \frac{p}{p_o}$$

where: L_p = sound pressure level in decibels referred to p_o

p = sound pressure in microbars

p_o = reference sound pressure (0.0002 microbars)

In order to compare noise reduction treatments, a single value of loudness is needed. This can be obtained by finding the total loudness as prescribed by Stevens' (11) method. The loudness of a sound indicates the subjective response of normal observers exposed to the sound. It pertains only to the magnitude of the auditory sensation a person experiences. Loudness cannot be measured directly with an instrument, but the sound pressure level can and this is used to calculate the total loudness in sones. Loudness values in sones are linear. A noise source that has a sones value twice that of another source would be judged by a normal observer to be twice as loud. Because of this characteristic it is possible to judge the effect of noise reduction treatments and to be able to explain the effects to a tractor operator.

The young human ear can hear between the frequencies of 20 and 20,000 cycles per second. However, the ear is more sensitive between the frequencies of 1000 and 4000 cycles per second. As a person becomes older his hearing ability may diminish in the higher frequency range. This is not noticed because the frequencies associated with man's hearing for speech are in the range from 500 to 2000 cycles per second. Hearing loss from exposure to noise depends upon the noise levels and the time of exposure. As mentioned previously, Glorig divided noise exposure into three kinds, dependent upon the time involved. The first one was continuous steady noise that is on for five hours or more per day, for five days a week, for many years. The International Organization for Standardization has recommended standards for each of the three noise exposure types. A modified form of the first proposed standard was used for this investigation.

The brief form of the proposed standard presented in the Guide for Conservation of Hearing in Noise (12) is given below:

> "When the exposure to broad-band noise is habitual and the noise continuous during the working day (5 or more hours) the average of the levels at 300-600, 600-1200, and 1200-2400 cycles per second should not exceed 85 dB. If this average exceeds 85 dB, hearing conservation measures should be initiated."

The octave bands of 300-600, 600-1200, and 1200-2400 cycles per second are not generally used at the present time in making sound measurements. The octave bands now used by most investigators are 250-500, 500-1000, and 1000-2000 cycles per second. For this study the sound pressure level was measured for one-third octave bands. The center frequencies of the one-third octave bands which are approximately in the same range as those in the International Organization for Standardization recommendation are 315, 400, and 500; 630, 800, and 1000; and 1250, 1600, and 2000 cycles per second. The range of frequencies corresponding to these center frequencies are 281-561, 561-1122, and 1122-2245 cycles per second.

Experimental Design

The experiment was set up as a factorial design. Three load conditions were applied to all combinations of five exhaust control methods and six arrangements of a tractor, commercial cab, and soundproofing, making a total of ninety treatments.

The tractor, commercial cab, and soundproofing were combined to form the six arrangements listed below.

A1. Unaltered tractor

A2. Tractor plus cab

A3. Tractor plus insulated cab

A4. Insulated tractor plus insulated cab

A5. Insulated tractor plus cab

A6. Insulated tractor

Arrangement A1 was chosen because it is the type of unit commonly used for agricultural power requirements. It was used as the basic unit for all the arrangements selected for the study. A2 was chosen to determine the effect of placing a commercial cab on an agricultural tractor. The cab was installed as obtained from the manufacturer. A3 was selected to determine the effect of soundproofing the cab to reduce the noise level. The inside of the cab was insulated on all exposed metal areas. Two layers of insulation were placed on the floor of the cab and platform of the tractor, and a rubber mat furnished with the cab was placed over the insulation. The ceiling of the cab was covered with one inch foam plastic insulation by the manufacturer. The one inch fiberglas insulation was placed over the foam insulation. For arrangement A4 the tractor was insulated by placing the insulation under the hood and on the fire wall to attempt to reduce the noise reaching the operator from the tractor engine. A5 and A6 were chosen to determine the effect of insulating the tractor with a non-insulated cab and without a cab. Pictures of arrangements A2, A3, and A6 are shown in Figures 1, 2, and 3.

The five exhaust control methods were:

E1. Factory replacement muffler

E2. Burgess-Manning exhaust snubber

E3. Factory replacement muffler at a 45° angle

E4. Burgess-Manning exhaust snubber at a 45° angle

E5. Factory replacement muffler with a two-foot extension

Method E1 was selected because it is the type of exhaust control used as standard equipment on most agricultural tractors. The Burgess-Manning exhaust snubber (E2) is used as a silencer on large industrial engines and was selected for this study to determine its feasibility for use on an agricultural tractor. Methods E3, E4, and E5 were selected to determine the effect of increasing the distance between the operator and the exhaust outlet. The 45° angle was obtained by placing the muffler and snubber at 45° from the vertical position and 45° from the direction of travel of the tractor. Pipe fittings were used to connect the muffler and snubber to the exhaust manifold pipe. Pictures of the exhaust control methods are shown in Figures 4, 5, 6, 7, and 8.

The three load conditions applied to the tractor engine with a power take-off dynamometer were:

L1. No Load; 1900 rpm

L2. 75% Load; 1900 rpm

L3. 65% Load; 1700 rpm

Figure 1. Uninsulated Tractor Cab

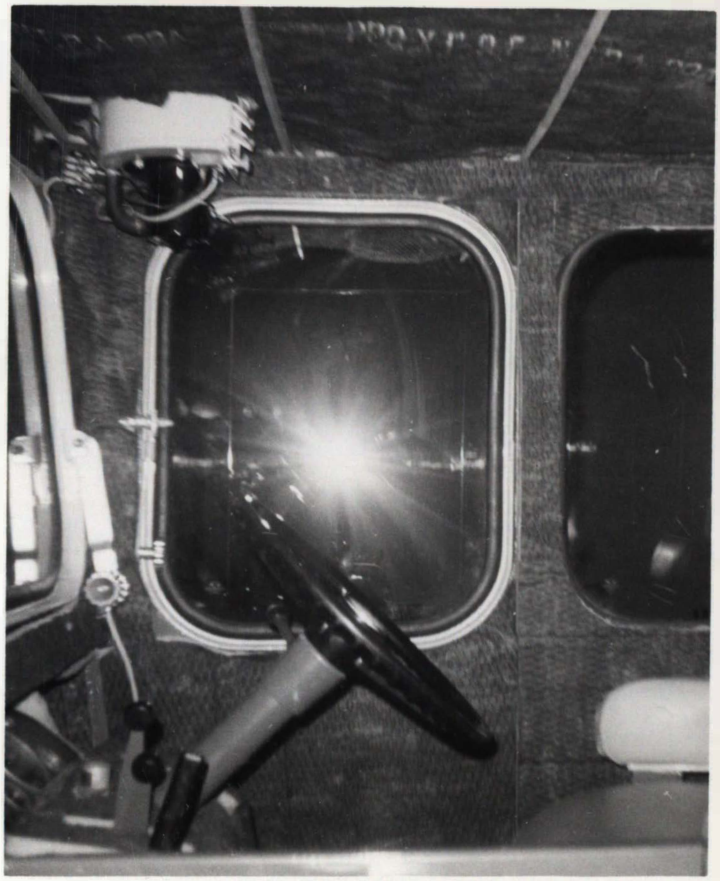


Figure 2. Insulated Tractor Cab

Figure 3. Insulated Tractor

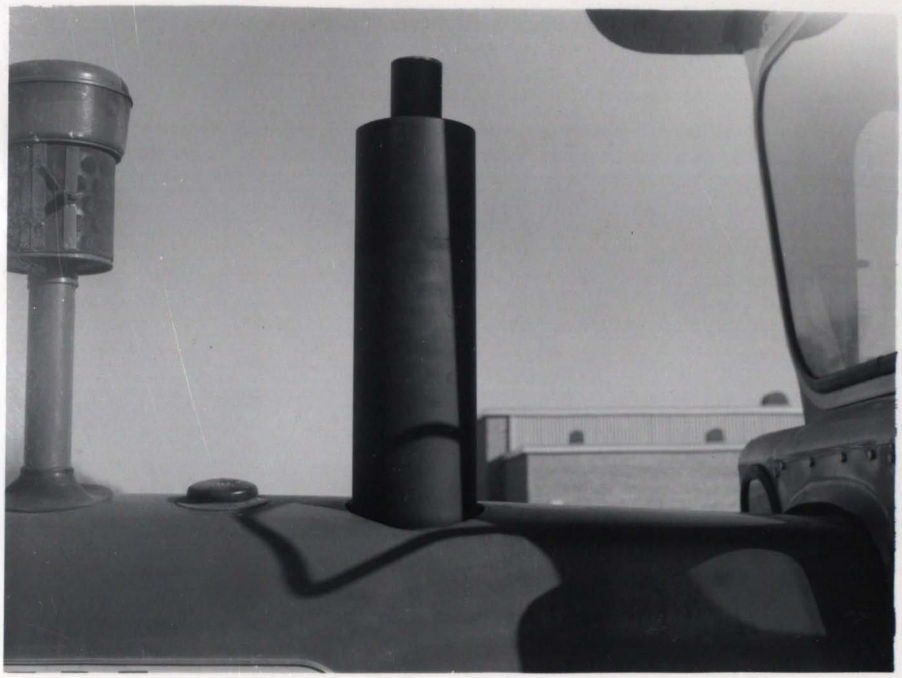


Figure 4. Factory Replacement Muffler

Figure 5. Burgess-Manning Exhaust Snubber

Figure 6. Factory Replacement Muffler at a 45^{o} Angle

Figure 7. Burgess-Manning Exhaust Snubber at a 45^{o} Angle

Figure 8. Factory Replacement Muffler with a Two-Foot Extension

Load condition L1 was chosen as a control. L2 and L3 were selected on the basis of similarity to engine load conditions encountered in the field. The horsepower at 75% and 65% load was calculated from the horsepower at standard power take-off speed as given in the Nebraska Tractor Test (13).

The notation used to represent a tractor, cab, and soundproofing arrangement (A); an exhaust control method (E); and a load condition (L) consisted of the letters A, E, and L followed by the appropriate Arabic numeral as listed previously. As an example, A1-E1-L1 represents an unaltered tractor with a factory replacement muffler and the tractor engine subjected to no load and 1900 rpm.

A load applied to the tractor engine with the power take-off dynamometer may not have the same effect as a load applied to the drawbar, such as in a field situation. The tractor was stationary for this study and therefore the effect of the transmission for different forward speeds as a noise source was not determined. It is possible that the transmission noise has an even greater effect with the use of cabs on tractors. The cab may act as an echo chamber and actually increase the noise level at the position of an operator's head. The dynamometer is also a possible noise source that would not be present if the load were applied to the drawbar of the tractor.

Stevens' Method for Loudness

The sound pressure level for one-third octave bands was recorded at the position of a seated operator's head for the frequency range from 40 through 5000 cycles per second. Three observations were made for each load condition. The sound pressure level values for each observation were converted to total loudness by Stevens' method as shown below:

1. Enter the geometric mean frequency of each band in the abscissa of Figure 13 in the Appendix. Then from the band level (ordinate of Figure 13) determine the loudness index of each band.
2. Find the total loudness, S_t, by means of the formula

$$S_t = I_m + F(\Sigma I - I_m)$$

where I_m is the largest of the loudness indexes and ΣI is the sum of the loudness indexes of all the bands. The value of the factor F is 0.15 for one-third octaves.

An analysis of variance was made for a factorial design using the values of total loudness. F tests were used to test for significance at the one-percent level. Orthogonal comparisons were made to determine where the differences between treatments were located.

Noise Exposure Criteria

To determine whether the noise reduction treatments developed were adequate for continuous exposure situations, a noise exposure criteria was used. This criteria consisted of comparing a mean sound pressure level to 85 decibels. Values above 85 decibels indicated that hearing conservation measures should be initiated. The procedure used for finding the mean sound pressure level to compare with the 85 decibel level is presented below:

1. Average the three observations of sound pressure level for each load condition at the band center frequencies of 315, 400, 500, 630, 800, 1000, 1250, 1600, and 2000 cycles per second.
2. Divide the nine band center frequencies into three groups and combine the sound pressure levels of the three center frequencies in each group.
3. Average the three combined sound pressure levels to obtain a single value of sound pressure level for each load condition.
4. Compare the average sound pressure level for each load with the 85 decibel level suggested in the <u>Guide for Conservation of Hearing in Noise</u> (12).

APPARATUS AND EQUIPMENT

A John Deere 3010 gasoline tractor was used as the noise source for the study. A cab, manufactured by The Egging Company, Gurley, Nebraska, was obtained for the tractor. A factory replacement muffler and a Burgess-Manning exhaust snubber were used as two types of exhaust controls. The exhaust snubber was obtained from the Burgess-Manning Company, Dallas, Texas. A modification of the factory replacement muffler was obtained by placing a two-foot extension on the muffler outlet. One inch thick Johns-Mannville Micro-Coustic fiberglas insulation was used for all soundproofing. The insulation was bonded to the metal with 3M Spray Trim adhesive. A portable power take-off dynamometer, shown in Figure 9, was used to apply the load to the tractor engine.

Equipment manufactured by the General Radio Company was used to measure and record the sound pressure level. This equipment consisted of a tripod, microphone (Type 1560-P5), preamplifier (Type 1560-P40), one-third octave band analyzer (Type 1564-A), and graphic level recorder (Type 1521-B). The sound was picked up by the microphone, amplified by the preamplifier to counteract cable loss, and transmitted to the analyzer. The analyzer filtered the sound with respect to frequency, and the graphic level recorder plotted the frequency versus sound pressure level. The tripod and microphone are shown in test position in Figure 10.

Figure 9. Dynamometer Used for Loading Tractor Engine

Figure 10. Tripod and Microphone in Measuring Position

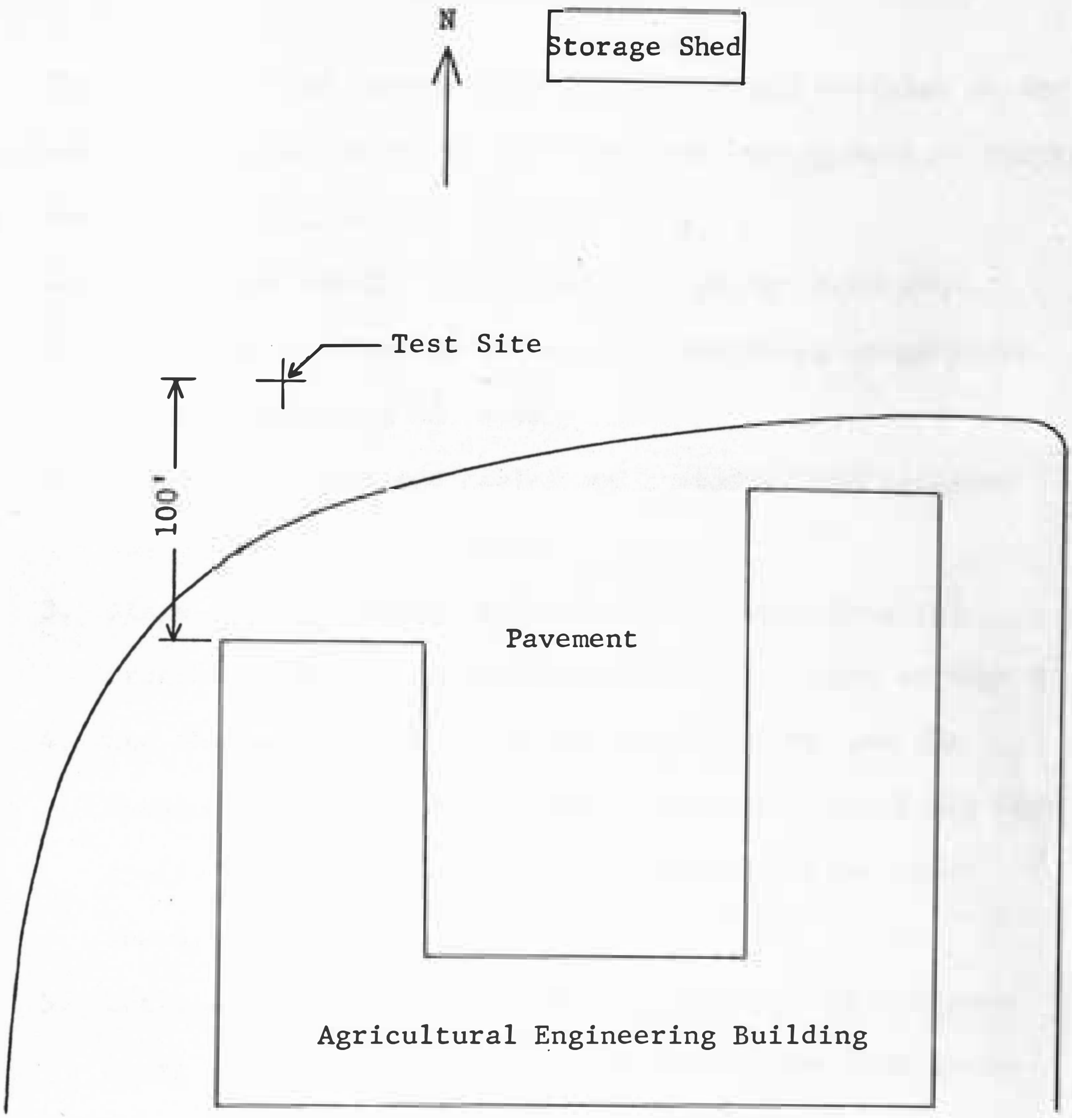


Figure 11. Plan View of Test Area

TEST PROCEDURE

The procedure for taking sound pressure level readings at the position of a seated operator's head for each arrangement of tractor, cab, and soundproofing was as follows:

1. Locate the tractor and dynamometer at the test site. Allow the tractor engine to reach operating temperature before conducting the test.
2. Connect the required cables and calibrate the analyzer and graphic level recorder.
3. Place the appropriate exhaust control method on the tractor. These were tested in the order shown on page 13.
4. Set the tractor engine at the desired speed and the dynamometer at the proper load. The load conditions were applied for each exhaust control method in the order shown on page 13.
5. Activate the instruments and record the sound pressure level for the frequency range of 40 through 5000 cycles per second. This step was repeated three times to obtain three observations for each load condition.
6. Repeat Steps 3, 4, and 5 for each of the five exhaust control methods.

All tests were conducted on days when the average wind velocity was less than nine miles per hour. Safety precautions were observed for all tests.

PRESENTATION AND ANALYSIS OF DATA

The total loudness in sones for the ninety treatments of three load conditions applied to all combinations of five exhaust control methods and six arrangements of a tractor, commercial cab, and soundproofing is presented in Table I. These values were calculated from the sound pressure level in decibels by Stevens' method for calculating loudness.

The analysis of variance for the data in Table I is presented in Table II. The data was punched on cards and the IBM 360 computer was used to calculate the analysis of variance for the factorial design used in this study.

Treatment totals are presented in Table III. Orthogonal comparisons calculated from the treatment totals in Table III are given in Table IV.

Table V presents, for each combination and load condition, the mean sound pressure level used to compare with the 85 decibel level suggested in the _Guide for Conservation of Hearing in Noise_ (12).

A sample of the plot obtained on the graphic level recorder is shown in Figure 12.

Sample calculations for total loudness and mean sound pressure level are presented in the Appendix.

Table I. Total Loudness (Sones)

Combi-nations	Load								
	L1 Observations			L2 Observations			L3 Observations		
	1	2	3	1	2	3	1	2	3
A1-E1	62.89	62.96	63.12	93.29	92.72	91.77	107.38	106.08	98.63
A1-E2	42.35	42.42	42.25	67.72	68.91	69.15	107.65	107.19	104.42
A1-E3	52.94	53.74	54.80	82.31	83.98	84.49	109.55	106.18	108.59
A1-E4	40.86	40.78	41.31	62.70	63.87	62.46	98.40	105.01	97.94
A1-E5	49.26	49.54	49.90	91.16	89.80	88.84	110.12	106.84	108.64
A2-E1	108.80	106.06	106.36	148.75	149.00	152.14	100.02	102.52	103.88
A2-E2	75.51	75.25	74.52	115.50	116.08	118.86	99.68	99.88	100.24
A2-E3	100.57	102.74	101.91	143.93	143.87	147.02	91.76	91.96	93.22
A2-E4	74.32	74.35	74.26	108.12	109.60	110.32	90.35	91.88	91.24
A2-E5	77.45	75.78	76.56	116.56	119.44	119.52	91.93	90.82	90.37
A3-E1	61.83	62.02	62.73	76.06	76.57	76.72	68.12	67.06	65.62
A3-E2	47.94	48.15	47.56	64.02	65.73	64.95	56.98	56.99	56.81
A3-E3	56.59	57.14	57.93	80.50	80.33	81.05	66.29	66.13	66.56
A3-E4	47.79	47.40	46.87	60.63	64.34	64.40	58.44	55.70	56.14
A3-E5	48.64	49.15	48.17	77.15	79.87	76.57	61.62	61.45	63.84
A4-E1	55.47	55.42	55.81	74.20	74.41	77.21	67.73	66.67	67.94
A4-E2	43.58	44.17	43.79	73.68	72.67	72.77	59.49	58.60	58.43
A4-E3	57.73	58.69	58.14	82.49	82.51	83.03	64.25	63.81	62.90
A4-E4	47.33	47.63	46.32	65.14	68.62	68.75	61.65	60.01	59.85
A4-E5	45.62	46.43	47.07	55.18	55.54	55.76	48.28	49.18	49.24
A5-E1	75.64	73.10	73.94	105.63	108.52	109.68	76.78	77.10	78.54
A5-E2	60.51	60.06	60.59	82.48	83.15	85.91	76.95	75.91	76.55
A5-E3	73.19	75.88	78.83	112.79	112.76	115.97	83.59	83.15	79.98
A5-E4	62.44	62.34	63.70	82.74	85.57	86.57	85.81	84.11	83.75
A5-E5	63.05	63.17	63.77	89.68	90.38	93.35	79.29	81.19	79.07
A6-E1	61.78	58.75	57.06	95.77	96.15	95.44	113.61	116.32	111.96
A6-E2	40.34	39.87	40.57	65.13	65.02	65.52	100.65	98.46	99.16
A6-E3	49.19	50.12	50.78	82.27	79.54	80.86	92.71	88.99	92.69
A6-E4	37.66	37.08	40.74	62.59	65.00	65.65	94.13	84.77	87.04
A6-E5	48.47	47.71	48.07	92.29	93.64	93.85	111.86	110.51	105.89

Table II. Analysis of Variance

Source	d.f.	S.S.	M.S.	F
Arrangements, A	5	54,491.36	10,898.27	4,892.60**
Exhaust, E	4	11,554.59	2,888.65	1,296.81**
Load, L	2	43,837.92	21,918.96	9,840.16**
AE	20	5,030.92	251.55	112.93**
AL	10	27,638.98	2,763.90	1,240.81**
EL	8	2,993.93	374.24	168.01**
AEL	40	2,862.24	71.56	32.12**
Error	180	400.95	2.23	
Total	269	148,810.89		

**Significant at the one-percent level.

Table III. Treatment Totals (Sones)

Arrangements	Load	Exhaust Control Methods					Totals
		E1	E2	E3	E4	E5	
A1	L1	188.97	127.02	161.48	122.95	148.70	749.12
	L2	277.78	205.78	250.78	189.03	269.80	1193.17
	L3	312.09	319.26	324.32	301.35	325.60	1582.62
	Total Load	778.84	652.06	736.58	613.33	744.10	3524.91
A2	L1	321.22	225.28	305.22	222.93	229.79	1304.44
	L2	449.89	350.44	434.82	328.04	355.52	1918.71
	L3	306.42	299.80	276.94	273.47	273.12	1429.75
	Total Load	1077.53	875.52	1016.98	824.44	858.43	4652.90
A3	L1	186.58	143.65	171.66	142.06	145.96	789.91
	L2	229.35	194.70	242.38	189.37	233.59	1089.39
	L3	200.80	170.78	198.98	170.28	186.91	927.75
	Total Load	616.73	509.13	613.02	501.71	566.46	2807.05
A4	L1	166.70	131.54	174.56	141.28	139.12	753.20
	L2	225.82	219.12	248.03	202.51	166.48	1061.96
	L3	202.34	176.52	190.96	181.51	146.70	898.03
	Total Load	594.86	527.18	613.55	525.30	452.30	2713.19
A5	L1	222.68	181.16	227.90	188.48	189.99	1010.21
	L2	323.83	251.54	341.52	254.88	273.41	1445.18
	L3	232.42	229.41	246.72	253.67	239.55	1201.77
	Total Load	778.93	662.11	816.14	697.03	702.95	3657.16
A6	L1	177.59	120.78	150.09	115.48	144.25	708.19
	L2	287.36	195.67	242.67	193.24	279.78	1198.72
	L3	341.89	298.27	274.39	265.94	328.26	1508.75
	Total Load	806.84	614.72	667.15	574.66	752.29	3415.66
Totals	Total Load 1	1263.74	929.43	1190.91	933.18	997.81	5315.07
	Total Load 2	1794.03	1417.25	1760.20	1357.07	1578.58	7907.13
	Total Load 3	1595.96	1494.04	1512.31	1446.22	1500.14	7548.67
	Total Load	4653.73	3840.72	4463.42	3736.47	4076.53	20770.87

Table IV. Orthogonal Comparisons

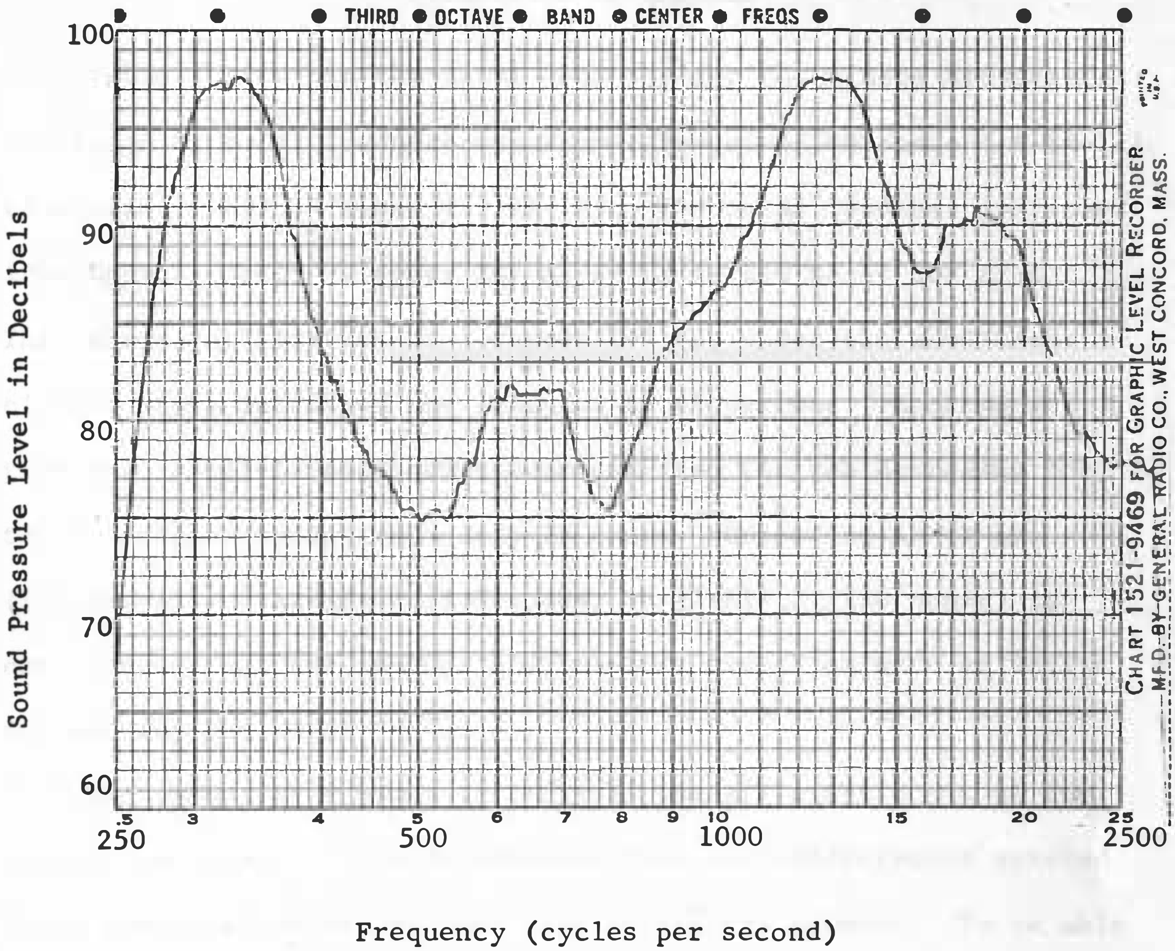
Source and Comparison	d. f.	S. S.	F
Arrangements	5	54,491	
*A2 vs. A3	1	37,857	16,976**
*A4 vs. A5	1	9,901	4,440**
*A1,A2,A3 vs. A4,A5,A6	1	5,323	2,387**
A1 vs. A2,A3	1	623	279**
A6 vs. A4,A5	1	787	353**
Arrangements	5	54,491	
*A1 vs. A2	1	14,137	6,339**
*A3 vs. A4	1	98	44**
A1,A2,A6 vs. A3,A4,A5	1	21,620	9,695**
A5 vs. A3,A4	1	11,921	5,346**
A6 vs. A1,A2	1	6,715	3,011**
Exhaust	4	11,555	
*E1,E3 vs. E2,E4	1	10,979	4,923**
*E1 vs. E3	1	335	150**
*E2 vs. E4	1	101	45**
E1,E2,E3,E4 vs. E5	1	140	63**
Exhaust	4	11,555	
*E1,E5 vs. E2,E4	1	6,155	2,760**
*E1 vs. E5	1	3,085	1,383**
*E2 vs. E4	1	101	45**
E1,E2,E4,E5 vs. E3	1	2,214	993**
Load	2	43,838	
*L1 vs. L2,L3	1	43,124	19,338**
*L2 vs. L3	1	714	320**

The error term of Table II was used for all F-tests.
*Comparisons of interest
**Significant at the one-percent level

Table V. Mean Sound Pressure Level in Decibels for the Frequency Range of 281 through 2245 Cycles Per Second

Combi-nations	Load		
	L1	L2	L3
A1-E1	80.5*	88.2	90.6
A1-E2	79.6*	87.1	91.2
A1-E3	80.6*	88.5	91.8
A1-E4	79.6*	86.4	90.7
A1-E5	81.3*	88.1	91.3
A2-E1	88.1	94.1	92.6
A2-E2	88.0	94.2	92.9
A2-E3	88.0	93.7	91.8
A2-E4	86.8	93.6	91.2
A2-E5	87.1	94.4	91.4
A3-E1	77.6*	84.3*	81.5*
A3-E2	76.0*	81.7*	81.1*
A3-E3	75.5*	80.8*	81.3*
A3-E4	76.2*	81.9*	80.3*
A3-E5	78.0*	84.5*	83.2*
A4-E1	76.2*	81.9*	81.7*
A4-E2	75.7*	81.8*	81.9*
A4-E3	75.6*	81.6*	81.7*
A4-E4	75.7*	81.9*	81.6*
A4-E5	75.7*	81.4*	80.7*
A5-E1	84.0*	90.0	88.3
A5-E2	84.3*	89.1	88.9
A5-E3	83.9*	90.6	89.7
A5-E4	84.5*	90.3	89.6
A5-E5	84.0*	89.9	89.3
A6-E1	79.9*	87.7	91.9
A6-E2	78.7*	85.7	90.3
A6-E3	78.8*	86.4	89.2
A6-E4	78.1*	86.8	88.9
A6-E5	80.4*	87.7	91.0

*Values less than 85 db. Indicates noise reduction was adequate.



Notes: 1. This plot represents sound pressure levels for treatment combination A3-E2, with engine at 75% load and 1900 rpm.

2. Writing speed was 3 inches/second.

3. Chart speed was 7.5 inches/minute.

Figure 12. Sample of Plot Obtained on Graphic Level Recorder

DISCUSSION OF RESULTS

Table I presents the total loudness for the ninety treatments. The range of total loudness was from a low of 37.08 sones (A6-E4-L1) to a high of 152.14 sones (A2-E1-L2). The total loudness increased from approximately 92 sones for A1-E1-L2 to 150 sones for A2-E1-L2. This shows installation of a commercial cab under the conditions of this study increased the loudness by 61 percent. Looking at treatment A3-E1-L2 shows that soundproofing the cab decreased the total loudness to approximately 76 sones. Comparing A2-E2-L2 (116 sones) and A2-E5-L2 (118 sones) to A2-E1-L2 (150 sones) it can be seen that the snubber and two-foot extension were effective in reducing the total loudness.

The values of F given in Table II are all significant at the one-percent level. This is evidence that real differences existed among treatment means and that interaction was present. To be able to specify a certain exhaust control method, an arrangement of tractor, cab, and soundproofing must be chosen first and vice versa. The small error term used as the denominator of all F-tests indicates that there was little variation between the three observations within each load condition.

Table III can be used to compare various treatment totals. The increase in loudness from arrangement A1 (3524.91) to A2 (4652.90) confirms that a commercial tractor cab was noisy. The decrease in loudness from arrangement A2 (4652.90) to A3 (2807.05) indicates that insulating the cab was effective in reducing the noise level. Insulating the tractor did not reduce the noise level appreciably as shown by the totals for A1 (3524.91) and A3 (2807.05) compared to A6 (3415.66) and A4 (2713.19) respectively. Comparing the totals in Table III for the exhaust control methods, it is apparent that the snubber at a 45^{o} angle (3736.47) reduced the noise level the most. However, due to the small difference between E2 (3840.72) and E4 (3736.47), the vertical snubber was the most practical. The factory replacement muffler with a two-foot extension was effective in combination with the tractor cab, as shown by the reduction from A2-E1 (1077.53) to A2-E5 (858.43).

Table IV shows that all orthogonal comparisons made were significant at the one-percent level. Not all comparisons are of interest but were necessary to complete each set of comparisons. Two sets of comparisons were calculated for the arrangements and exhaust sources to be able to include all comparisons of interest. The noise levels for A3 and A4 were significantly lower than for A2 and A5 respectively, indicating the desirability of insulating the cab. Although A1, A2, A3 vs. A4, A5, A6 and A3 vs. A4 were statistically significant, inspection of the totals (from Table III, 10,984.96 vs. 9,786.01 and 2807.05 vs. 2713.19) reveals that insulation of the tractor was relatively ineffective. A2 tested significantly higher than A1 and confirms, as does Table III, that mounting a commercial cab on a tractor increases noise levels appreciably.

E1, E3 vs. E2, E4 and E1, E5 vs. E2, E4 tested significantly different indicating the effectiveness of the snubber as compared to the factory replacement muffler. Although E1 vs. E3 and E2 vs. E4 were statistically significant, comparison of the totals from Table III (4653.73 vs. 4463.42 and 3840.72 vs. 3736.47) reveals that placing the muffler and snubber at a 45^{o} angle was relatively ineffective. E5 tested significantly lower than E1, as was verified by the totals in Table III.

Both load comparisons tested significantly different; but looking at Table III, there is little difference between L2 and L3 (7907.13 and 7548.67). The total for L1 was less (5315.07), as would be expected, because the engine was under no load.

Table V presents the mean sound pressure level used to compare with the level of 85 decibels as proposed by the International Organization for Standardization. A tabular value less than 85 decibels can be considered as acceptable. These values were calculated for the frequency ranges of 281-561, 561-1122, and 1122-2245 cycles per second. The proposed standard applies only to exposure to steady noise and not exposure to impulsive noise, such as a sonic boom. It also applies to noise that is continuous, that is, exposure for five or more hours per day, five days a week, for many years. This represents the most severe situation. Most agricultural tractor operators probably do not operate under the severe conditions above, but noise reduction to the 85 decibel level would indicate effective control.

The treatments below the 85 decibel level were A3-E1-L1 through A4-E5-L3. The other arrangements; A1, A2, A5, and A6; need further noise reduction to be safe for continuous exposure operations.

CONCLUSIONS

The following conclusions were drawn from this investigation:

1. The sound pressure level produced by the agricultural tractor used in this study was sufficient (from Table V, A1-E1-L2 = 88.2 decibels) to cause hearing damage for periods of continuous exposure for the criteria used.
2. The noise level at the position of a seated operator's head was increased considerably (from Table III, A1 = 3524.91 and A2 = 4652.90) by placing a cab on the tractor.
3. The noise level was effectively reduced in the tractor cab by the application of soundproofing material (from Table III, A2 = 4652.90 and A3 = 2807.05).
4. Insulation of the tractor was not an effective method of reducing the noise level (from Table III, A1 = 3524.91 and A6 = 3415.66).
5. Mufflers of larger volume, such as the snubber used in this study, are effective noise suppressors (from Table III, E1 = 4653.73 and E2 = 3840.72). Tractor manufacturers could equip tractors with more effective noise reducing mufflers.
6. The two-foot extension added to the factory replacement muffler was effective when used on the tractor with an insulated and noninsulated cab (from Table III, A2-E1 = 1077.53 and A2-E5 = 858.43).

7. Arrangements A3 (tractor plus insulated cab) and A4 (insulated tractor plus insulated cab) were found to have a mean sound pressure level for the frequency range of 281 through 2245 cycles per second below 85 decibels. These arrangements were considered acceptable for continuous exposure operations according to the noise-exposure criteria used for this study.

SUMMARY

Various noise reduction treatments were applied to an agricultural tractor and evaluated on the basis of total loudness at the position of a seated operator's head. Three load conditions were applied to all combinations of five exhaust control methods and six arrangements of tractor, cab, and soundproofing, forming a factorial design. The sound pressure level for one-third octave bands was recorded for the frequency range from 40 through 5000 cycles per second. The total loudness was computed by Stevens' Mark VI procedure.

The analysis of variance of the total loudness values in Table I showed that all treatments were significantly different at the one-percent level. This does not mean that all treatments were of practical value or merit application in field situations. The results indicate that for the tractor and cab tested the total loudness was considerably greater for a tractor with a cab as furnished by the manufacturer (from Table I, A1-E1-L2 = 92 sones and A2-E1-L2 = 150 sones). After additional insulation was added to the cab, the total loudness was reduced by about one-half of its former value (A3-E1-L2 = 76 sones).

To determine whether noise reduction was adequate, a noise-exposure criteria was used. This consisted of comparing the mean sound pressure level of the three frequency ranges 281-561, 561-1122, and 1122-2245 cycles per second to 85 decibels. If the average exceeded 85 decibels, it indicated that greater noise reduction was needed in order to conserve hearing for continuous exposure situations. Results of this comparison indicate that the arrangements A3 and A4, tractor plus insulated cab and insulated tractor plus insulated cab, are the only two that have a mean sound pressure level less than 85 decibels for all three loading conditions.

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APPENDIX

SAMPLE CALCULATIONS

Total Loudness

Tables VI, VII, and VIII present the sound pressure level as read from the chart paper of the graphic level recorder for combination A1-E1, the tractor with a factory replacement muffler. An example of Stevens' procedure for calculating the total loudness in sones for observation one, load condition one, and combination A1-E1 is presented below:

Step 1. The loudness index, I, of each one-third octave band, also presented in Tables VI, VII, and VIII, is found from Figure 13. The band center frequency is entered in the abscissa and the sound pressure level in the ordinate of Figure 13, to determine the loudness index.

Step 2. The total loudness, S_t, is found by means of the following formula:

$$S_t = I_m + F(\Sigma I - I_m)$$

where: I_m = greatest of loudness indexes

$= 25.6$

ΣI = sum of loudness indexes of all bands

$= 274.2$

$F = 0.15$ (for one-third octave bands)

$$S_t = 25.6 + 0.15\ (274.2 - 25.6)$$

$$\underline{\underline{S_t = 62.89 \text{ sones}}}$$

Mean Sound Pressure Level

Table IX presents the data used for calculating the mean sound pressure level for combination A1-E1. An example of the procedure used to calculate the mean sound pressure level for combination A1-E1, load condition one, is presented below:

Step 1. Average the three observations of sound pressure level found in Table VI for the band center frequencies of 315, 400, 500, 630, 800, 1000, 1250, 1600, and 2000 cycles per second.

Step 2. Combine the sound pressure levels for the three groups; 315,400, and 500; 630, 800, and 1000; and 1250, 1600, and 2000 cycles per second, to give three sound pressure levels. Decibels are combined on an energy basis, not added directly. If two levels of 80 decibels are to be combined, the result is 83 decibels, not 160 decibels.

Step 3. The three combined sound pressure levels of 85.3, 78.5, and 77.6 are averaged to obtain 80.5 decibels. This is the mean sound pressure level used to compare with the 85 decibel level.

Table VI. Total Loudness for Combination A1-E1, Load Condition L1

Band Center Frequency (cps)	Observations					
	1		2		3	
	SPL	I	SPL	I	SPL	I
40	71.0	2.6	71.0	2.6	70.5	2.5
50	76.5	4.5	75.0	4.0	75.0	4.0
63	90.5	14.2	89.0	12.6	89.5	13.1
80	85.5	11.3	86.0	11.7	85.5	11.2
100	83.0	10.3	84.5	11.5	85.0	11.8
125	93.0	21.4	92.0	20.0	92.0	20.0
160	90.0	18.7	91.0	20.0	91.0	20.0
200	93.5	25.6	94.0	26.5	94.0	26.5
250	86.5	17.0	87.0	17.5	87.0	17.5
315	81.5	13.1	81.5	13.1	81.5	13.1
400	81.0	13.5	81.5	14.0	81.5	14.0
500	78.0	11.8	78.0	11.8	78.0	11.8
630	79.0	13.5	77.0	11.8	76.0	11.1
800	73.5	10.2	72.5	9.6	73.5	10.2
1000	72.0	9.9	71.0	9.3	71.5	9.6
1250	73.5	11.5	72.5	10.8	73.0	11.1
1600	74.0	12.6	73.0	11.8	73.0	11.8
2000	72.0	11.8	72.0	11.8	72.0	11.8
2500	71.0	11.8	70.5	11.5	71.0	11.8
3150	67.0	9.9	66.5	9.6	66.5	9.6
4000	67.0	10.5	65.0	9.3	65.0	9.3
5000	62.5	8.5	63.0	8.8	63.0	8.8
Sum of Loudness Indexes, ΣI		274.2		269.6		270.6
Total Loudness S_t, Sones	62.89		62.96		63.12	

Table VII. Total Loudness for Combination A1-E1, Load Condition L2

Band Center Frequency (cps)	Observations 1		2		3	
	SPL	I	SPL	I	SPL	I
40	78.0	4.3	77.5	4.2	77.5	4.2
50	86.5	9.1	86.0	8.8	86.0	8.8
63	104.0	38.0	104.0	38.0	103.5	36.6
80	96.0	23.0	95.5	22.2	96.0	23.0
100	85.0	11.8	84.5	11.5	85.0	11.8
125	95.5	25.6	95.0	24.7	95.0	24.7
160	90.0	18.7	89.5	18.8	90.0	18.7
200	92.0	23.0	91.0	21.4	90.5	20.7
250	89.5	20.7	20.0	20.0	90.0	21.4
315	86.0	17.5	85.5	17.0	86.0	17.5
400	84.0	16.4	84.0	16.4	84.0	16.4
500	83.0	16.4	83.0	16.4	84.0	17.5
630	85.5	20.7	86.5	22.2	84.5	19.3
800	81.0	16.4	81.0	16.4	81.0	16.4
1000	80.0	16.4	80.5	17.0	80.5	17.0
1250	80.0	17.5	80.0	17.5	81.0	18.7
1600	84.0	24.7	83.5	23.9	84.0	24.7
2000	80.0	20.0	80.5	20.7	80.5	20.7
2500	78.0	18.7	76.5	17.0	77.0	17.5
3150	73.5	14.9	73.5	14.9	73.5	14.9
4000	74.0	16.4	75.0	17.5	75.0	17.5
5000	73.0	16.4	73.5	17.0	73.0	16.4
Sum of Loudness Indexes, ΣI	406.6		402.8		404.4	
Total Loudness S_t, Sones	93.29		92.72		91.77	

Table VIII. Total Loudness for Combination A1-E1, Load Condition L3

Band Center Frequency (cps)	Observations 1		2		3	
	SPL	I	SPL	I	SPL	I
40	78.0	4.3	79.0	4.7	80.0	5.0
50	94.0	16.0	84.5	16.7	95.0	17.3
63	96.0	21.4	96.0	21.4	95.5	20.7
80	83.5	9.8	83.0	9.4	83.0	9.4
100	96.5	25.6	96.5	25.6	96.5	25.6
125	98.5	31.7	98.0	30.5	98.0	30.5
160	95.0	26.5	95.0	26.5	94.5	25.6
200	90.0	20.0	90.0	20.0	89.5	19.3
250	87.0	17.5	87.0	17.5	87.0	17.5
315	86.5	18.1	87.5	19.3	87.5	19.3
400	86.0	18.7	86.0	18.7	85.0	17.5
500	98.5	50.0	98.0	48.0	96.0	41.0
630	85.5	20.7	85.5	20.7	84.5	19.3
800	80.0	15.3	79.5	14.9	80.0	15.3
1000	79.5	15.9	80.0	16.4	80.0	16.4
1250	82.5	20.7	82.5	20.7	82.5	20.7
1600	81.5	20.7	83.0	23.0	82.0	21.4
2000	80.0	20.0	79.5	19.3	80.0	20.0
2500	75.0	15.3	75.5	15.9	75.5	15.9
3150	71.5	13.1	71.5	13.1	72.0	13.5
4000	73.5	15.9	74.5	17.0	74.5	17.0
5000	72.0	15.3	72.5	15.9	73.5	17.0
Sum of Loudness Indexes, ΣI		432.5		435.2		425.2
Total Loudness S_t, Sones	107.38		106.08		98.63	

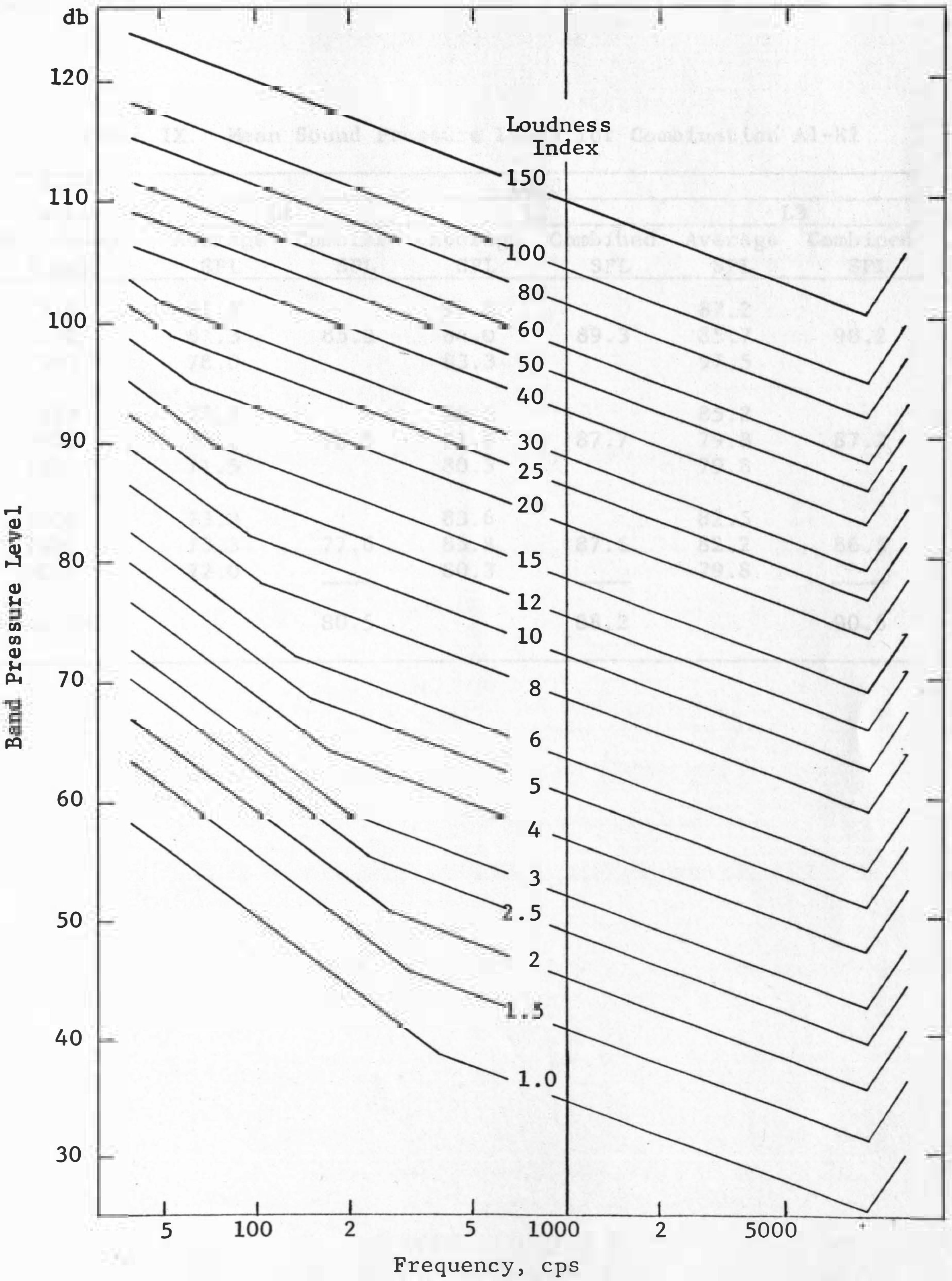


Figure 13. Contours of Equal-Loudness Index (1)

Table IX. Mean Sound Pressure Level for Combination A1-E1

Band Center Frequency (cps)	Load					
	L1		L2		L3	
	Average SPL	Combined SPL	Average SPL	Combined SPL	Average SPL	Combined SPL
315	81.5		85.8		87.2	
400	81.3	85.3	84.0	89.3	85.7	98.2
500	78.0		83.3		97.5	
630	77.3		85.5		85.2	
800	73.2	78.5	81.0	87.7	79.8	87.2
1000	71.5		80.3		79.8	
1250	73.0		83.6		82.5	
1600	73.3	77.6	83.8	87.6	82.2	86.5
2000	72.0		80.3		79.8	
Mean SPL		80.5		88.2		90.6

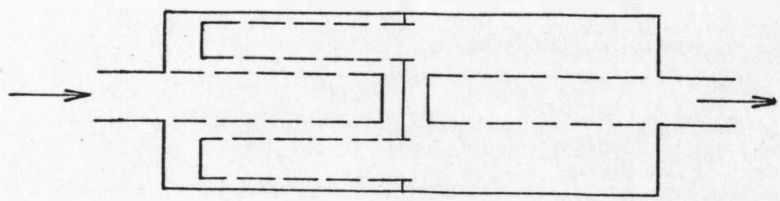
TRACTOR SPECIFICATIONS

Nebraska Tractor Test 763-John Deere 3010 Gasoline

Year	1960
Number of cylinders	4
Bore	4 inches
Stroke	4 inches
Displacement	201 cubic inches
Compression ratio	7.5 : 1
Rated speed	2200 rpm
Standard power take-off speed	1000 rpm
Horsepower at standard PTO speed	50.54 hp
Engine speed at standard PTO speed	1866 rpm

BURGESS-MANNING SNUBBER SPECIFICATIONS

Catalog Number	BMA-2½
Length	27 inches
Diameter	10 inches
Volume	2120 cubic inches



FACTORY REPLACEMENT MUFFLER SPECIFICATIONS

Length	21 inches
Diameter	6 inches
Volume	595 cubic inches