NOISE FROM A ROTARY LAWN MOWER

by

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Submitted in Partial Fulfillment

of the Requirements for the

Degree of Bachelor of Science

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

February, 1972

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Department of Mechanical Engineering, January 21, 1972

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ABSTRACT

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Annoyance and other adverse effects of a power lawn mower are considered. An octave band analysis and a directivity pattern for the noise produced by a 3.5 horsepower, 4-cycle, 22 inch, push type, rotary lawn mower are presented. Experiments confirmed that a simple muffler modification would not significantly reduce measured noise output. A general overview of research on lawn mower noise is given.

ACKNOWLEDGEMENT

The author would like to thank his thesis advisor, Professor A.D. Pierce, for his helpful advice and assistance in formulating, researching, planning, and executing this project. Also of great help were Mr. A. Rinsky, Mr. R. Liu, and the staff of the Mechanical Engineering Department.

Several men from outside M.I.T. were kind enough to contribute pertinent information: Mr. K.A. Finder, Director of Engineering and Product Safsty for the Toro Company; Mr. R.T. Bennett, Product Development Engineer for the Farm and Equipment Division of the International Harvester Company; Professor L.L. Faulkner of the Ohio State University Department of Mechanical Engineering.

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I BACKGROUND

Introduction

The lawn mower is familiar to every home owner. If not affluent enough to hire someone else to do it, the family gardener will spend many a summer Saturday cutting the grass. Unfortunately this involves more than the inconvenience of leisure time lost by the gardener. He, his family, and neighbors must endure the noise created by the lawn mower.

Two types of noise effects are known: "Auditory" effects consisting of temporary and permanent hearing loss; and "non-auditory" effects, such as annoyance, interference with speech communication, and possible decreased performance of exposed subjects [1].[1] These aspects are here considered in more detail.

Annoyance

There are trends toward the development of high density housing, for large numbers of people at low cost, in a suburban environment. Economic use of small plots of ground will demand a high concentration of individual homes.

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[1] Numbers in brackets, [], designate references at the end of this paper.

Students at the University of Hartford have concluded that the 100 PNdB which a simulated subject typically receives when one of his neighbors is cutting his lawn, and the up to 106 PNdB when three are, "could seriously affect the comfortable living of highly developed suburban areas"[2].

Most municipalities have ordinances which require power equipment to have an adequate muffler and prohibit loud and unusual noises which "disturb the peace"[3]. The interpretation of these subjectively worded laws is usually ambiguous and therefore the laws are often ineffective.[2]

It is becoming increasingly more common, however, for local government to take a scientific approach to noise limitation. Recently enacted ordinances specify the method of measurement, allowable sound pressure levels, and enforcement procedures. It should be noted that these new laws typically regulate a wide range of equipment, though each class of device may be subject to different requirements. Figure 1 (extracted from Lindsley[4]) shows some of the ultimate requirements of the Chicago noise ordinance which became effective on July 1, 1971. In

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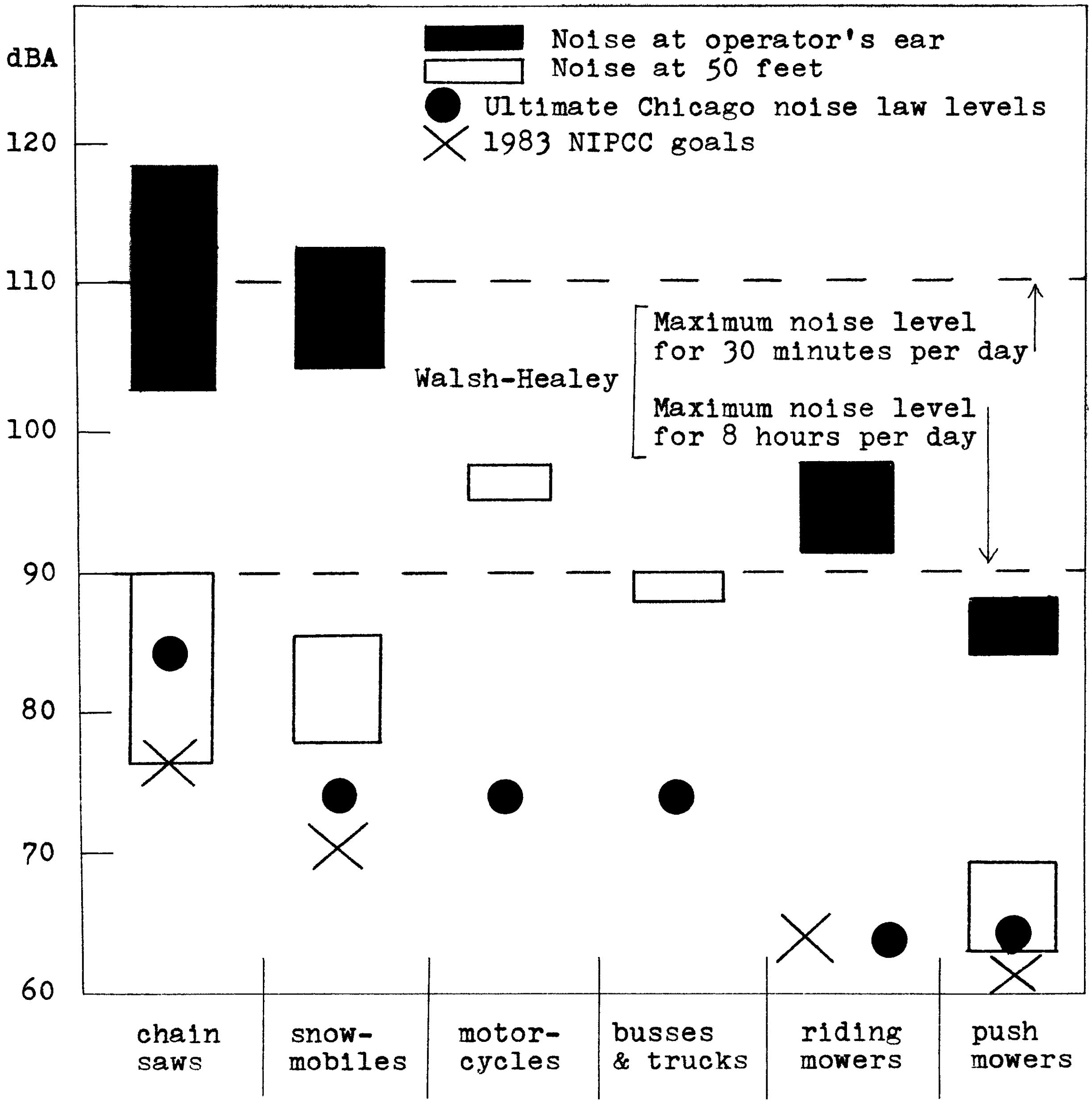
[2]A personal experience may be of some interest. Several years ago the author's father was reprimanded for cutting our lawn on a Sunday afternoon. The police officer noted that he was disturbing the peace and working on the day of rest, both violations of the (local) law. Evidently one of our neighbors felt sufficiently harassed by the noise to make a complaint. The authorities obliged him as best they could.



<u>Figure 1</u>. SMALL ENGINE NOISE LEVELS Comparative noise levels of commonly used power equipment are shown relative to federal limits set by Walsh-Healey industrial noise law. Also given are the ultimate limits set by Chicago, Ill. noise law, which provides for gradual reduction of limits beginning July, 1971, and the 1983 goals set by the National Industrial Pollution Control Council. (Based on information from Cushman Div., Outboard Marine Corp. Extracted from Lindsley[4].)

this ordinance the City of Chicago requires that under the test conditions specified in SAE Standard J952 and SAE Recommended Practice J184, the noise measured 50 feet from lawn mowers "manufactured: after January, 1972 (not exceed) 74 dBA; after January, 1975, 70 dBA; after January, 1978, 65 dBA"[5]. No one is permitted to sell or offer for sale within the city a device which does not conform to the standards set by the law.

A similar federal law is being considered by Congress and may soon be enacted [6].

Hearing Loss

It has been established that exposure to loud sound can cause first temporary, then permanent, hearing loss [7]. This hearing damage is usually expressed as an increase in the subject's threshold of hearing. The magnitude of a threshold shift varies according to the intensity of the sound, its duration, and its spectral distribution, as well as the duration of periods of rest between exposures. Individuals seem to vary in susceptibility to a given noise. Also there appear to be no sharp breaks in the functional relationships between threshold shift and noise exposure, at least for extended exposure to noises produced by industry today. [7].

Federal law (the Walsh-Healey Public Contracts Act of 1969 [8]) sets standards designed to protect industrial workers from occupational deafness. These Walsh-Healey are generally respected as the most realistic damage risk criteria available. Figure 1 illustrates two of the standards. It should be noted, however, that occupational deafness concerns the ability of employees to understand speech - not, for example, ability to appreciate high-fidelity music. The nature of speech is such that only the threshold shift in the frequency range 500 to 2000 Hz. is important [7].

Effects on Human Performance

Noise may have an adverse effect on human behavior. However, no effect on efficiency in performance of routine tasks has yet been found with noise levels below 90 dBA, though annoyance and inhibitation of speech communication may be present [9]. Since a noise level above 90 dBA is normally found only quite near a power mower, this section will consider the operator's response to it.

Broadbent[9] concludes that: "In general the effects on health of efficiency from noise seem to be somewhat slighter than is often thought." Mental attitude, however, is closely related to the effeciency of a subject exposed to high noise levels. One who expects his effeciency to be impaired by noise invariably finds that it is [9]. Many mower operators equate high noise output with high power and will run their machine at a higher speed than necessary for efficient grass cutting [10]. This excessive noise would seem to have little effect on such an operator;

his psychological condition protects him. It ought to be noted, however, that the noise may prevent the operator from hearing the shouts of a bystander attempting to caution him against a hazzard.

Fatigue is sometime associated with lawn mower operation. Fatigue is generally the result of vibration rather than sound[10, 11]. It is a phenomenon difficult to define and harder to measure. However, when present, fatigue can lead to mistakes and errors in judgement, even when overall efficiency in performing a task does not appear affected [11]. Such a situation is potentially dangerous, both to the operator and bystanders.

Manufacturer Initiative

Lawn mower manufacturers are recognizing definite incentives for quieting their product. An increasing body of new laws demand it; public outcry against noise pollution recommends it. [4]

The Leisure Sub-Council of the National Industrial Pollution Control Council (NIPCC), a joint effort of industry and the U.S. Department of Commerce, has made its own recommendations on ways to go about quieting power equipment. NIPCC suggests goals which it feels are reasonable[3]; Figure 1 shows the long range goals proposed.

[3] See [12].

Individual manufacturers recognize the problem and are concerned. In fairness it should be noted that frequently the mower and its engine are made by different companies. This tends to slow progress in noise reduction since both mower and engine contribute jointly to the problem. [13,14]

It is a commonly expressed opinion that unpleasantness is a quality of the environment distinct from effects on health or ability to do work. Much of our civilization is based on the assumption that it is worth doing more to the environment than merely securing survival. Reduction of annoyance, like the pursuit of happiness, is not necessarily an ignoble end.

II SOURCES OF LAWN MOWER NOISE

The Combustion Process

The combustion process, as a source of noise, includes the intake and exhaust of combustion materials in addition to the actual firing of the cylinder. Rowley[1] explains that intake and exhaust noise is created by high velocity gases moving through valve porting - the flow being caused by the pressure differential across the port. These high velocities are quickly dissipated in the manifold and piping; some of the energy, however, is transformed into a pressure wave, which is propagated as a sound wave superimposed on a much slower on a much slower throughput gas flow to atmosphere.

By this theory, any design factor which increases the gas velocity through the porting, or improves coupling between the cylinder and manifold (volume flow), will increase noise. Rowley[1] expresses this in the formula:

$$W \propto \frac{A_v V_p C_b P_c}{C_s}$$

where: W = acoustic power output

A_v = valve area

V_p = piston velocity

C_b = cylinder bore

P_c = cylinder pressure with valve open

C_s = cylinder stroke

Vibration

This is a two part problem. Cylinder firing and unbalanced rotating parts may excite vibrations in large sheet metal parts, such as the engine and blade housings, which then displace air and generate sound. Faulkner[15] reports that by simply placing his hand on the vibrating fender of a riding mower, he could achieve a 3 dBA reduction in noise, as measured at the operator's ear position. In general, vibrations of this type can be effectively reduced by a simple redesign of the offending part, or eliminated by removing the part entirely.

Vibration of the block itself is the other problem; redesign is costly and not simple. Cylinder firing is one source of engine vibration. Lindsley[4] reports that noise from the physical deflection of the engine cylinder head and associated parts is related to the size of the engine bore by:

$$SPL \propto (C_b)^3$$

where: SPL = observed sound pressure level

C_b = cylinder bore

There are indications that aluminum engines tend to be noisier than cast iron ones [13].

Another cause of this engine vibration is the inherent reciprocating unbalance of a single cylinder engine. The engine follows Newton's laws: If the piston is accelerated downward, the engine frame is accelerated upward so that the center of gravity of the entire assembly remains fixed [16]. This motion will in turn displace air and generate sound.

A third source of engine vibration is crankshaft unbalance. Most lawn mower engines are statically balanced, but because of expense involved are not dynamically balanced. The rotating system will cause casing vibration and noise in the same manner as the reciprocating one. Faulkner[15] reports that a dynamically balanced 8 horsepower engine was 4 dBA quieter than a similar non-dynamically balanced engine, when measured at the operator's ear position on a riding type mower. He also reports the engine is twelve dollars more expensive.

Bearing Noise

Good bearings are generally not a source of objectionable noise[19]. However, bearing noise may become noticeable if a rotating part is out of balance. If a bearing is overloaded by this unbalance, any number of objectionable sounds may be generated before the bearing eventually fails. Reference 19 contains a more complete treatment of bearing noise.

Blade Noise

The revolving cutting blade is a source of aerodynamic fan noise. U.S.A. Standard Safety Specifications for Power Lawn Mowers specify that the maximum blade tip speed be less than 19,000 ft/min. This is primarily to reduce the hazzard from thrown objects [17], but it also tends to limit fan noise.

The blade can be modeled as a centrifugal fan which produces both blade and vortex noise. Every time a blade tip passes a given point, the air at that point receives an impulse. The repetition of this impulse (twice the engine speed for most rotary mowers) determines the fundamental tone of this type of noise. Air flow separation which creates eddy flow, and Von Karman vortex shedding are responsible for broad-band noise. This is because the separations are random in size and point of release. [18]

Goldman and Maling (reported in [18]) suggest fan noise is separable into two parts: one associated with the developed static head, and the other associated with flow capacity. For an idealized lawn mower blade, this equation for the total radiated acoustic power output would take the form:

$$W = \frac{C_1 H^3}{\alpha} + \frac{C_2 d^3 s^5}{\alpha^4}$$

where: W = overall acoustic power radiated

H = static pressure at the grass outlet

d = total blade length

s = speed (r.p.m.) of blade

α = aspect ratio (the ratio of blade length to its width in the plane perpendicular to its rotation)

and C_1 and C_2 are experimentally determined constants which vary for different sized fans [18]. This author has not seen any typical values suggested for a lawn mower.

The acoustic power generated is not easily converted to a sound pressure level observed, because much of the power is radiated or reflected into the ground.

III EXPERIMENTAL WORK

Apparatus

All experiments done during the course of this investigation were performed on a new 22 inch "Maverick"[4] rotary lawn mower. Figures 2 and 3 are photographs of this device. It comes equipped with a 3.5 horsepower, 4-cycle Briggs and Stratton engine. The engine speed at full throttle was found to be 2780 r.p.m.; this was measured with a strobe.

A Brüel and Kjaer type 2203/1613 precision sound level meter and octave filter set, fitted with a 1-inch condenser microphone, was used to make sound pressure level measurements. A wind screen was not available, so care was taken to make outside measurements on calm days.

Test Site

Measurements were taken in M.I.T.'s Great Court. Figure 4 shows the location. The grass surface was generally soggy on the days when measurements were taken. Typical levels of the ambient noise at the test site are

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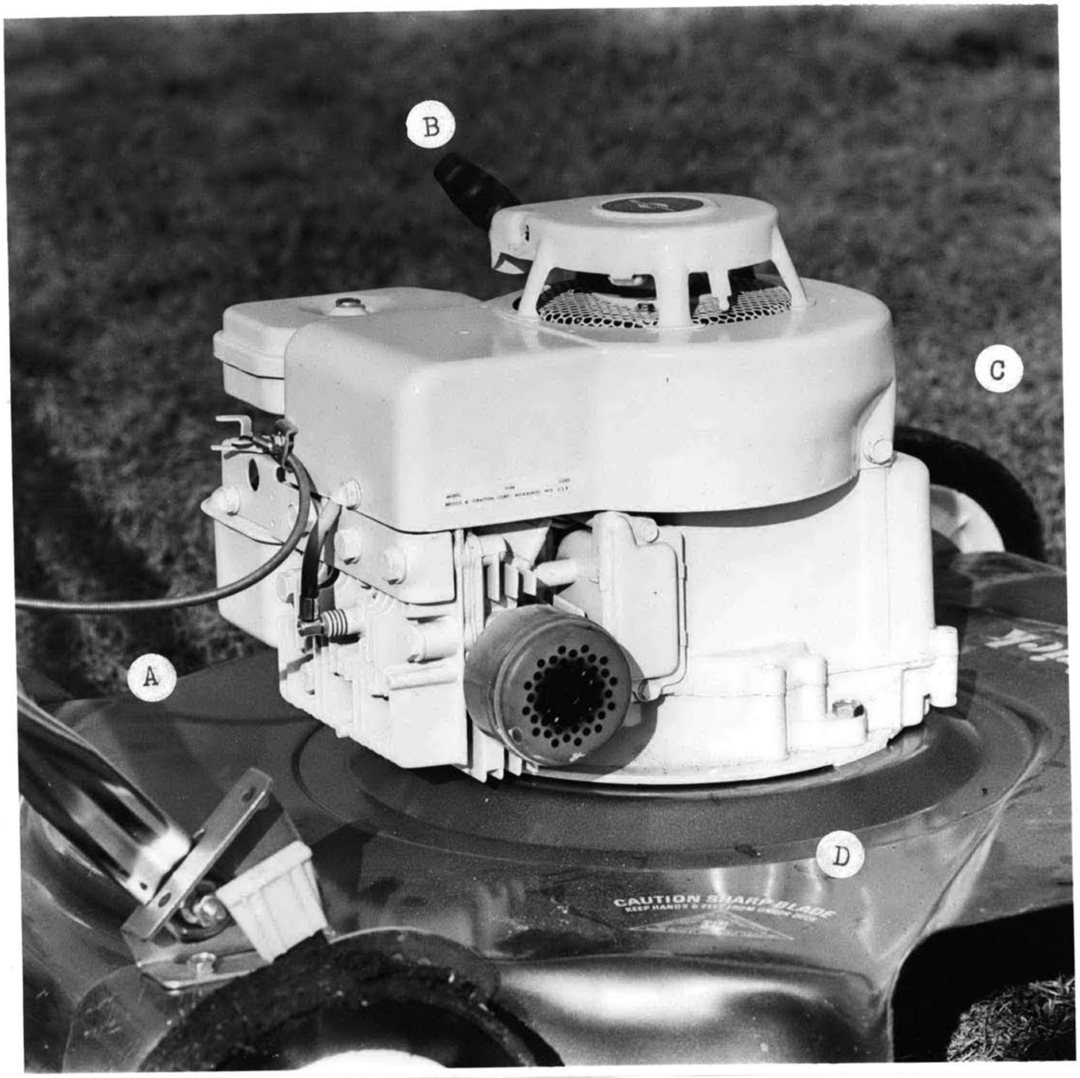
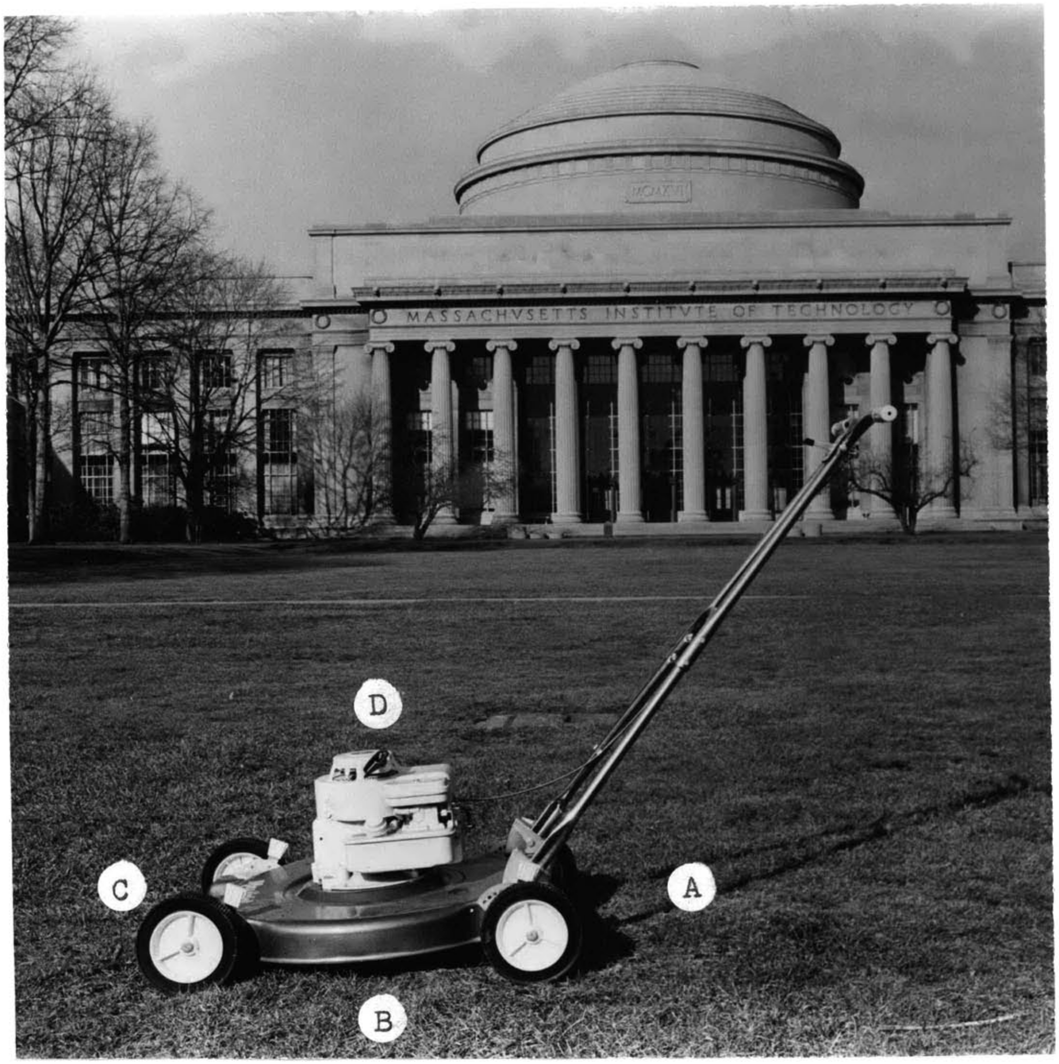
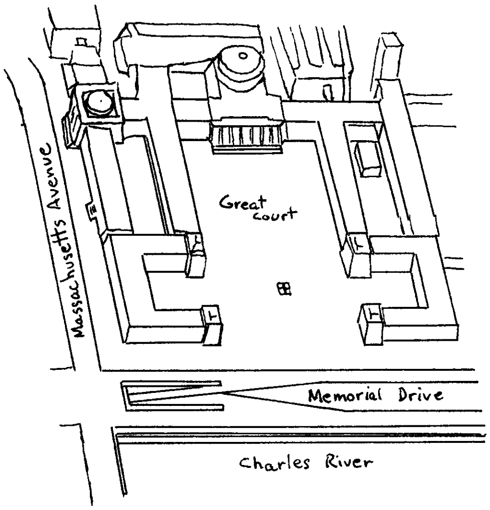
[4] General Leisure Products Corporation, lawn mower model number A1006.



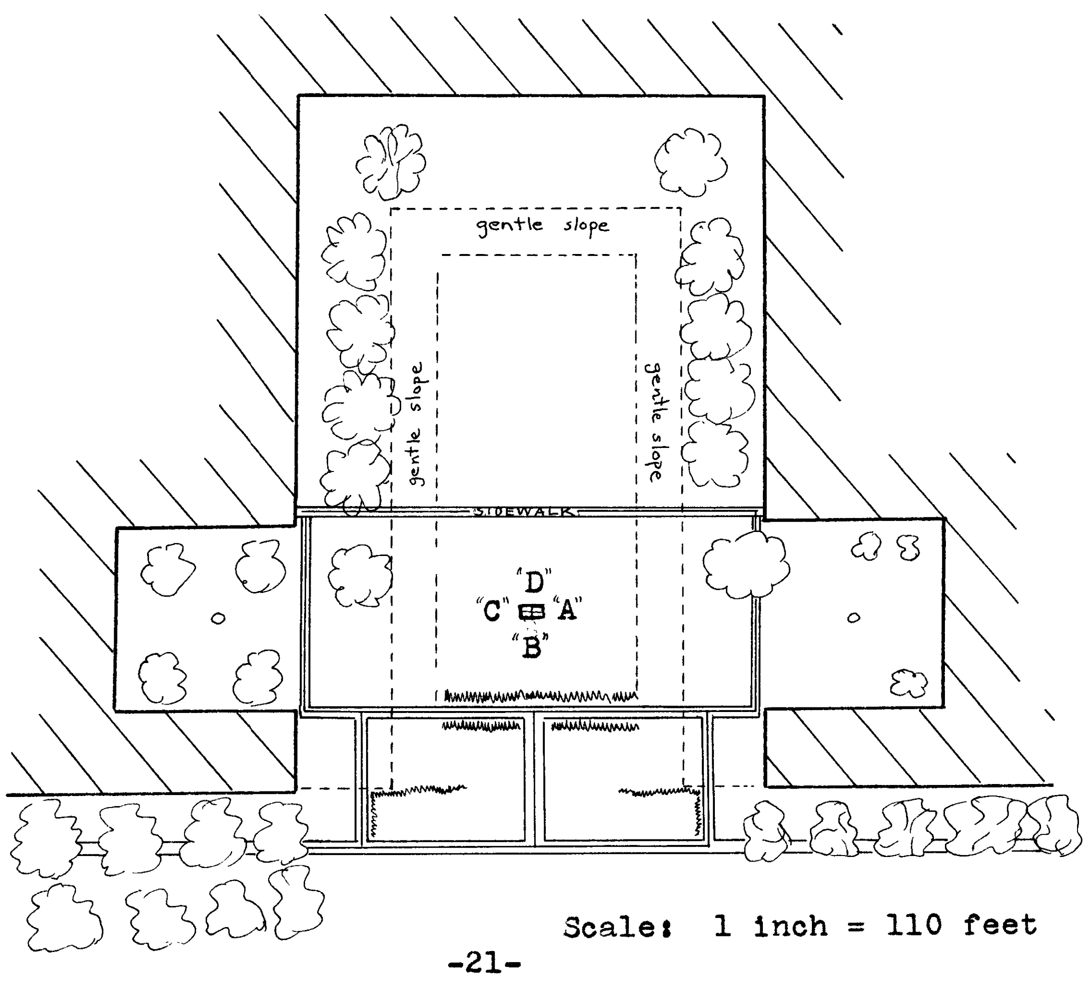
<u>Figure 2</u> THE LAWN MOWER is shown here close-up. This is a 22 inch "Maverick" rotary mower. It comes equipped with a 3.5 horsepower, 4-cycle, Briggs and Stratton engine. Note the details of the exhaust and cooling systems. (Letter lables are part of the system used to designate the position from which sound pressure levels were taken.)



<u>Figure 3</u> THE LAWN MOWER on the test site IN THE GREAT COURT. This is the orientation used during all reported experiments. Note letter position lables.



<u>Figure 4</u> TWO VIEWS OF THE TEST SITE (⊞) in the M.I.T. Great Court. Note the letter designation of positions from which sound pressure level measurements were made. Mower was consistently oriented at the site as shown in Fig. 3. The gentle slope shown in lower drawing has a total height of 30 inches.



Scale: 1 inch = 110 feet

given in Appendix I. Figures 2, 3, and 4 illustrate the system of lables used to designate the position from which measurements were taken. The mower was consistently oriented in the Great Court as shown in Figure 3.

Experiments and Discussion

The first experiment was to obtain a directional pattern of the noise from the lawn mower. The engine was set at full throttle and the sound level meter, six inches above the ground plane, was moved away from the mower until a desired A-weighted sound pressure level was indicated. This distance was measured and recorded. Figure 5 is a plot of the results, which are also tabulated in Appendix II. It is apparant that the noise distribution is fairly omnidirectional.

Next, A-weighted sound pressure levels were measured at the operator's ear position, following the procedure of SAE Standard J919a (Measurement of Sound Level at Operator's Station). A-weighted sound pressure levels were also measured 50 feet from the mower, following the procedure of SAE Standard J952b (Sound Levels for Engine Powered Equipment). A correction was applied to these measured values to separate the lawn mower noise from the ambient noise, which was less than the required 10 dBA below the lawn mower noise in some cases. Figure 6 is a tabulation of the results of these two experiments.

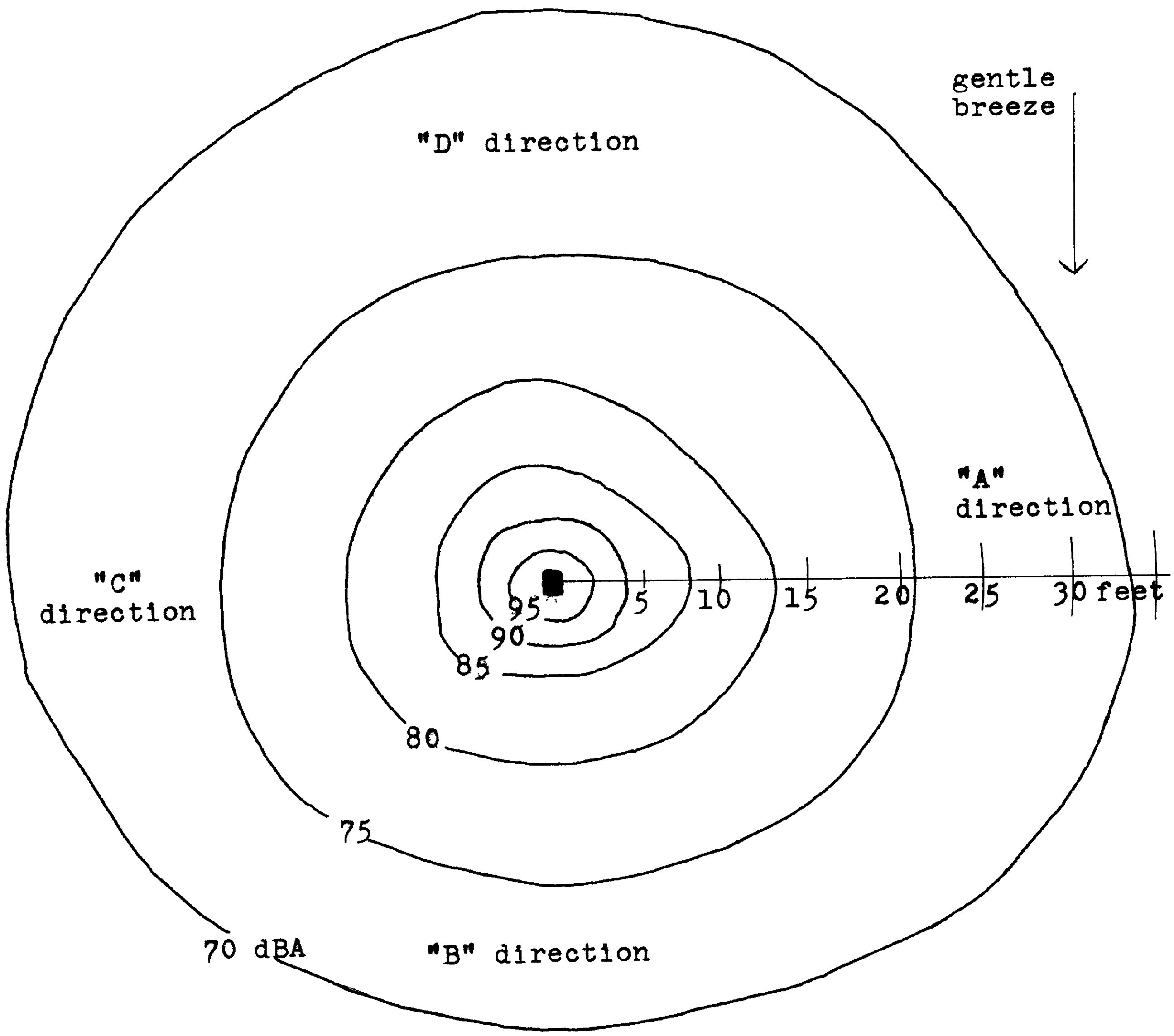


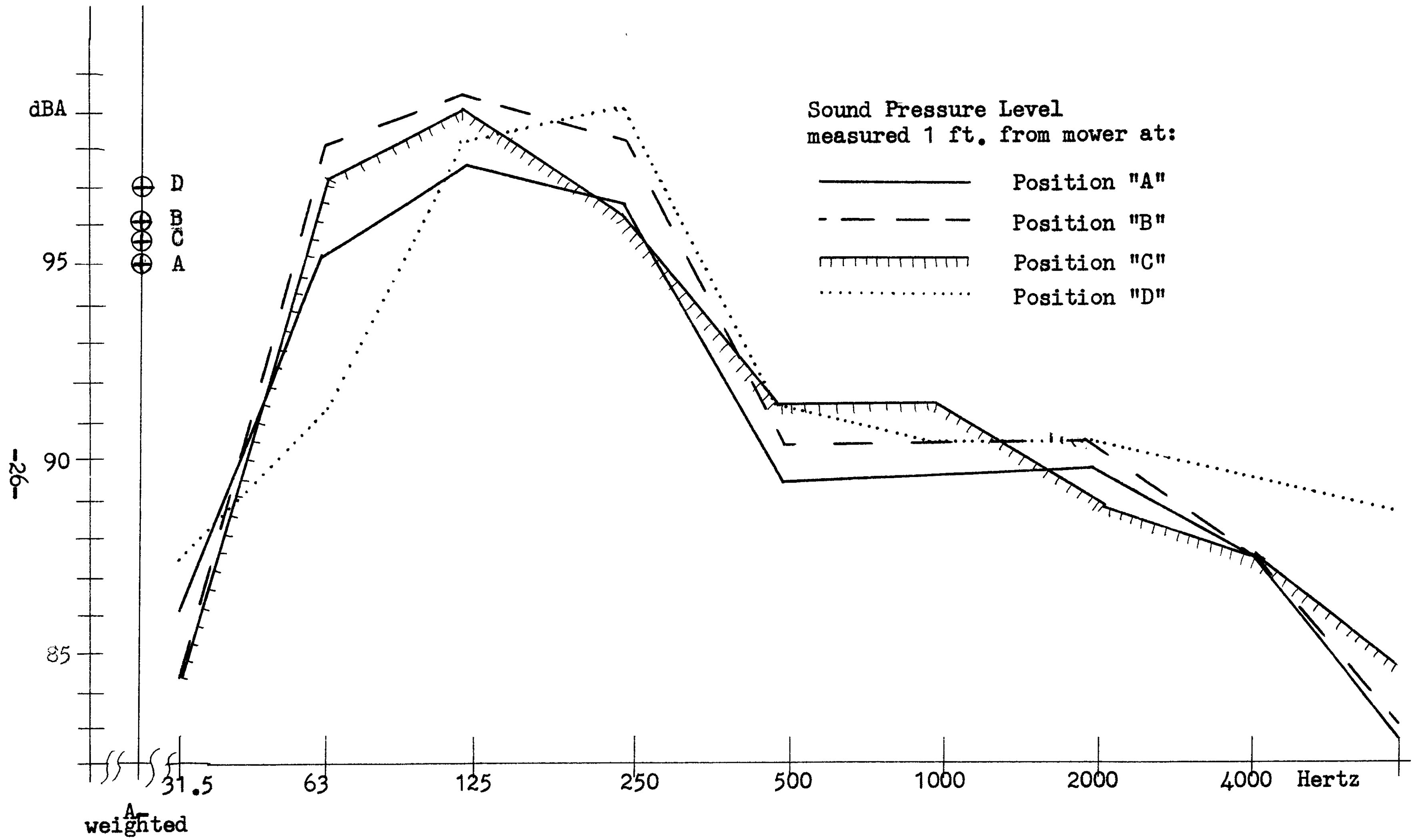
Figure 5 DIRECTIVITY PATTERN of noise from the lawn mower. The origin of this plot coincides with the axis of blade rotation. This figure was constructed from the data tabulated in Appendix II. Note that the exhaust and grass outlets are in the "D" direction; engine cooling fins face "A" direction.

SOUND PRESSURE LEVELS	
position	level
operator's ear	88.5 dBA
"A", 50 ft.	65 dBA
"B", 50 ft.	66.5 dBA
"C", 50 ft.	64.5 dBA
"D", 50 ft.	65 dBA

Figure 6 SOUND PRESSURE LEVELS AT OPERATOR'S EAR AND 50 FEET from lawn mower; measured following SAE Standard J919a and J952b, with appropriate corrections for ambient noise.

The third experiment was to obtain an octave analysis of the lawn mower noise. The sound level meter was placed one foot from the nearest edge of the mower housing, six inches above the ground plane. A-weighted and octave band sound pressure levels were measured and recorded for each of the mower's four sides. These data are plotted in Fig. 7, and tabulated in Appendix III. Note that there is a noise peak in the 125 Hz band. This could be due to a 92 Hz element, which is twice the engine speed of 46 Hz (2780 r.p.m.). Ninety-two Hz is the fundamental frequency of reciprocating unbalance impulses, as well as the rotating blade tip passage frequency. Note also that the noise peak on the exhaust and grass outlet side ("D") is at a slightly higher frequency.

A final experiment concerned exhaust noise. The muffler was removed and the spectral analysis repeated on the exhaust ("D") side. Next a 20 foot length of one-half inch pipe was attached to the exhaust port (in the usual place of the muffler), and the exhaust and its associated noise were conducted away from the immediate test site. Again an octave analysis was made. The results of these measurements, along with the analogous plot from Figure 7, are plotted in Figure 8. It should be noted that to the ear there was a quite discernable change in noise with each modification. The muffler tended to smooth out the harshness of the firing frequency, and isolation of the exhaust removed it. Due to this, the mower seemed quieter than would seem implied by the small change in A-weighted



<u>Figure 7</u> SOUND PRESSURE LEVELS OF OCTAVE BANDS measured one foot from nearest edge of mower. A-weighted levels are also given.

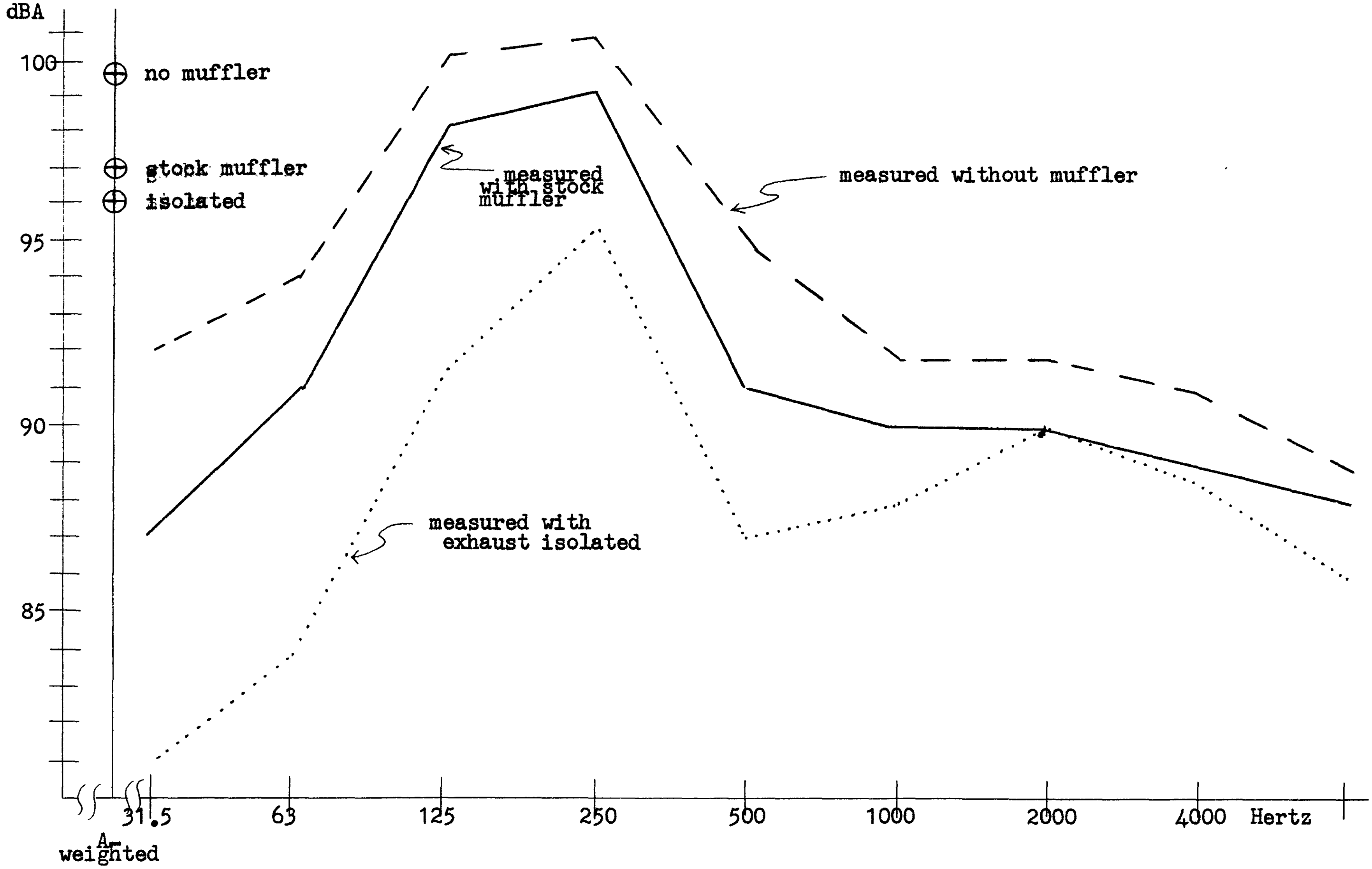


Figure 8 OCTAVE BAND SOUND PRESSURE LEVEL FOR DIFFERENT DEGREES OF EXHAUST MUFFLING, measured 1 foot from exhaust side ("D") of mower.

levels. Faulkner[15] has reported a similar observation for an 8.5 horsepower riding mower, with the mower attachment removed. He heard a large difference in noise level, while measuring only a 2 dBA reduction in sound pressure level at the operator's ear position, when an "ideal" muffler was substituted for the stock one.

General Observations

The engine speed at which the mower is operated has a large effect on subjectively perceived noise. This effect was more pronounced with the exhaust isolated. While an improved muffler would apparantly not help the mower at full power meet the Chicago noise ordinance specifications, it could be helpful in other situations.

Simple vibrations of large surfaces do not appear to be a major source of noise. The experimenter placed his gloved hand at several locations on the engine and mower housing. This damping would be expected to reduce natural vibrations of these surfaces, though not necessarily forced vibrations. No audible difference in noise level was heard when the damping was applied.

Fan noise from the blade was subjectively judged to increase with engine speed (an expected result). Fan noise is a rather distinct sound and was not difficult for the experimenter to distinguish, especially with the exhaust isolated.

Suggestions

Since manual damping of the large mower surfaces did not affect noise output, the problem of forced vibrations needs to be considered in more detail. Radiation from smaller surfaces, such as the engine cooling fins, should also be considered. Forced vibrations in this area might be responsible for some noise.

Alternative engine designs ought to be considered. Counterbalanced or two cylinder engines should be evaluated for bulk, weight, and monetary costs to achieve noise reduction.

An improved muffler on a larger engine might reduce noise output under "normal" operation. This should be investigated along with methods to prevent the unnecessary utilization of the additional power which would be available.

Alternative blade designs need to be evaluated. With careful redesign, fan noise could probably be reduced without sacrificing cutting performance.

IV CONCLUSIONS

There is a growing need for a quiet lawn mower. Public outrage at noise pollution, as manifest by recently enacted local noise-limitation ordinances, demands its development.

Quieting a lawn mower is not a matter of simply attaching a more efficient muffler. This experimenter has found that a perfect muffler could effect only a 1 dBA reduction in the sound pressure level measured 1 foot from the exhaust outlet of a "typical" push-type rotary mower.

There is apparently no simple way to build a quiet power mower, though much research still needs to be done in this area. Manufacturers are aware of the problem, but will require time to develop a quiet lawn mower. Any decrease in noise output will probably cost in terms of weight, bulk, and simplicity, as well as dollars.

APPENDIX I

Typical ambient sound pressure levels at the test site:

	POSITION							
	"A"		"B"		"C"		"D"	
	1 ft	50 ft	1 ft	50 ft	1 ft	50 ft	1 ft	50 ft
A-weighted	68	58	62	56	57	58	61	58
31.5 band	68	69	72	71	72	71	74	70
63 band	69	68	72	68	70	70	74	74
125 band	66	67	69	64	69	66	70	66
250 band	62	61	64	62	62	58	64	62
500 band	54	55	50	54	55	52	58	54
1000 band	47	50	48	50	46	50	49	49
2000 band	42	45	44	48	46	46	46	46
4000 band	34	36	34	42	34	36	38	38

These measurements were made at 11:oo AM on January lo, 1972. The weather was sunny and quite warm (50°) and the air was still. The values presented are averages; fluctuations up to 10 dB were observed.

APPENDIX II

The directivity pattern (Figure 5) was developed from these measurements:

	Distance at Level					
Position	95 dBA	90 dBA	85 dBA	80 dBA	75 dBA	70 dBA
A	2' 4"	3' 8"	6' 10"	11' 5"	18' 11"	33' 1"
AB	2' 4"	4' 4"	6' 5"	11' 9"	20' 6"	32' 0"
B	2' 5"	4' 8"	8' 2"	13' 6"	21' 2"	34' 0"
BC	2' 4"	4' 3"	6' 9"	11' 5"	19' 1"	29' 0"
C	2' 0"	3' 9"	6' 7"	10' 7"	17' 3"	25' 10"
CD	2' 4"	4' 6"	7' 6"	12' 4"	19' 7"	28' 8"
D	2' 8"	4' 2"	6' 11"	12' 1"	19' 3"	31' 6"
DA	2' 4"	4' 1"	7' 1"	11' 10"	19' 1"	32' 2"

Distances are measured from the center of rotation of the cutting blade. These data are plotted in Figure 5.

APPENDIX III

The octave analysis at one foot from the nearest edge of the mower had these results:

	Level at Position:			
	A	B	C	D
A-weighted	95	96.5	95.5	97
31.5 octave	84	84	86	87
63 octave	97	98	95	91
125 octave	99	99.5	97.5	98
250 octave	96	98	96.5	99
500 octave	91	90	89	91
1000 octave	91	90	89.	90
2000 octave	88.5	90	89.5	90
4000 octave	87	87	87	89

These levels are plotted in Figure 7.

APPENDIX IV

A comparison of the lawn mower noise created under different degrees of exhaust muffling:

	Sound Pressure Level with:		
	exhaust isolated	stock muffler	no muffler
A-weighted	96	97	99.5
31.5 octave	81	87	92
63 octave	84	91	94
125 octave	91.5	98	100
250 octave	95.5	99	100.5
500 Octave	87	91	95
1000 octave	88	90	92
2000 octave	90	90	92
4000 octave	88.5	89	91

These levels are plotted in Figure 8.

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