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Evaluation of Thrown Objects Tests for Proposed Safety Standard for Power Lawn Mowers

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Institute for Basic Standards
National Bureau of Standards
Washington, D. C. 20234

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Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

LIST OF TABLES

LIST OF FIGURES

CONTENTS

Page

EVALUATION OF THROWN OBJECTS TESTS FOR PROPOSED SAFETY STANDARD FOR POWER LAWN MOWERS

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ABSTRACT

An evaluation was made of thrown objects dispersion and penetration tests which have been developed for a proposed safety standard for power lawn mowers. To evaluate the proposed laboratory dispersion tests, supplementary outdoor dispersion tests were conducted on walk-behind lawn mowers in which actual grass cutting conditions were simulated. A description of these outdoor tests, a comparison of the outdoor and laboratory dispersion tests for a sample of walk-behind lawn mowers, and an evaluation of the proposed dispersion and penetration tests are given. The evaluation includes a theoretical discussion of the penetration of thrown objects which is related to experimental results in terms of the shape, size and velocity of the thrown projectiles.

Key Words: Dispersion tests; lawn mowers; penetration tests; power lawn mowers; safety standard; thrown objects tests.

1. INTRODUCTION

A Thrown Objects Test which has been developed for the Consumer Product Safety Commission (CPSC) for the Proposed Safety Standard for Power Lawn Mowers [1]* has been evaluated. The proposed test was developed by an Offeror for CPSC to evaluate the tendency of power rotary mowers to throw struck objects. During the development of the Thrown Objects Test, mower characteristics which were identified included: 1) dispersion, the spatial distribution of thrown objects; 2) penetration, a measure of kinetic energy which the mower imparts to a struck object; and 3) pickup, the relative tendency of mowers to lift and strike objects which are in their cutting path. Tests were only developed, however, to estimate the ability of a struck object to penetrate a specified target and to evaluate the dispersion, but not to measure pickup.

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*Figures in brackets refer to literature references given at the end of this report.

As outlined in the Rationale for Proposed Safety Standard [2], the test mower is suspended so that the horizontal plane of its blade is a few feet above a non-rebounding surface.* This procedure eliminates ricochets of objects off the "ground". The objects, which are nails or steel balls depending on the test, are forcibly injected upward into the path of the rotating blade. Since there is no supporting surface close enough to the blade, "ground" ricochets are thereby eliminated. This geometry also plainly eliminates from the test the "pickup" effect, i.e., variations from mower to mower in their ability to pick up objects placed on the "ground".

To evaluate the proposed laboratory dispersion tests, the National Bureau of Standards (NBS) conducted outdoor dispersion tests on walk-behind lawn mowers in which actual grass cutting conditions were simulated. A description of these outdoor tests, a comparison of the outdoor and laboratory dispersion tests for a sample of walk-behind mowers, and an evaluation of the dispersion and penetration thrown objects tests proposed by the Offeror are given in this report. Included in the evaluation is an analysis of the penetration by thrown objects which discusses such effects as the shape, size and velocity of the thrown projectiles and the effects of humidity on the target material.

It is assumed that the reader of this report is thoroughly familiar with the contents of References 1 and 2 which formed the basis for the investigation. Copies of these references may be obtained from the Consumer Product Safety Commission.

2. OUTDOOR DISPERSION TESTS

The general characteristics of the walk-behind mowers used in the evaluation program are given in Table 1. These mowers were purchased from normal retail stock. The models were chosen to represent many of the existing lawn mower design variables which were available during the late summer period of 1975. For the outdoor dispersion tests a portable target with wheels to move on rails along a grass surface was constructed. The test mower was centered in the target and attached to it by thin cables, as shown in Figure 1. Initial tests were conducted with the target stationary on the grass. Fifty sixpenny box nails were fed head first into the rotating blades through a hole in the top of the

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*For convenience, this surface is referred to as the "ground" in the Rationale for the proposed laboratory tests [2].

Table 1 - Lawn Mower Characteristics

Mower	Power	Measured Blade Tip Speed		Blade Cutting Width	
		ft/min	(m/s)	in	(m)
W1A	Electric	8 600	(43.7)	18.25	(0.46)
W2A*	Electric	15 400	(78.3)	18.62	(0.47)
W2B	Electric	15 200	(77.3)	18.62	(0.47)
W3*	Electric	18 600	(94.6)	18.00	(0.46)
W4A*	Gasoline	15 900	(80.8)	21.00	(0.53)
W4B	Gasoline	16 100	(81.8)	21.00	(0.53)
W5A	Gasoline	16 300	(82.8)	21.50	(0.55)
W7A*	Gasoline	17 800	(90.5)	23.75	(0.60)
Foreign	Gasoline	17 300	(87.9)	19.00	(0.48)
W7B**	Gasoline	12 700 (reduced throttle)	(64.6)	23.75	(0.60)

*Mowers tested on grass in addition to proposed dispersion tests.

**Penetration test for W7B was conducted at a reduced throttle. All other tests conducted with mowers at full throttle.

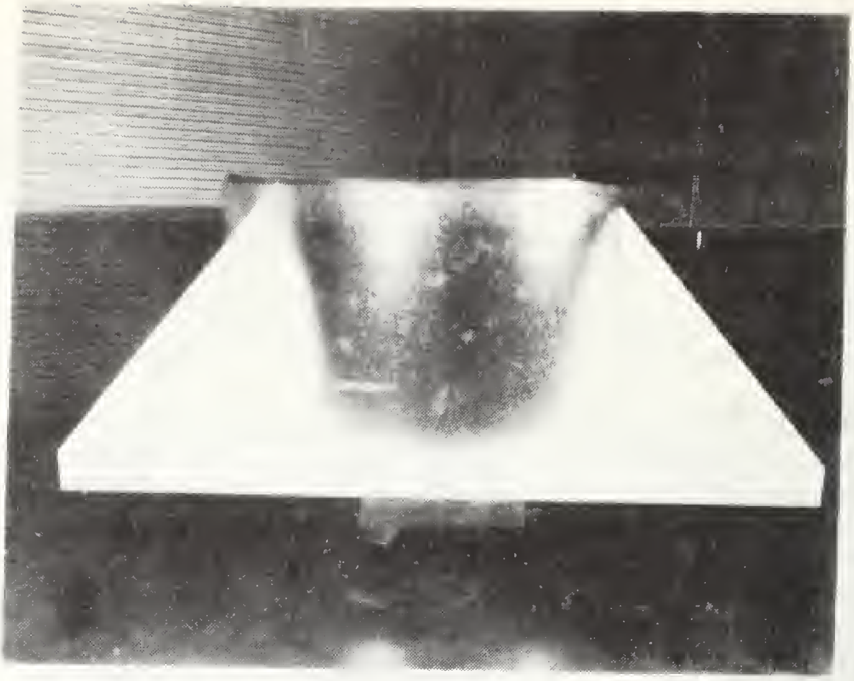

Figure 1a – PORTABLE TARGET DEVICE FOR OUTDOOR DISPERSION TESTS

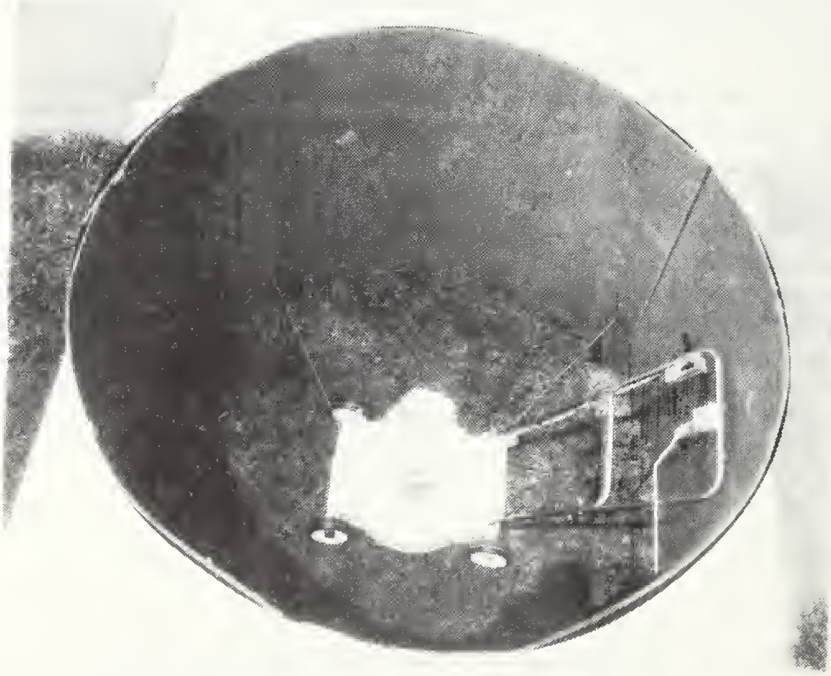

Figure 1b – LAWN MOWER ARRANGEMENT WITHIN PORTABLE TARGET mower deck.* This test was repeated, on a new grass surface, for each of the five lowest blade height settings. It was apparent that these tests were unrealistic, but they did indicate the relationship between blade height setting and the number of target hits and gave a general idea of the relative thrown object dispersion for the three gasoline-powered mowers tested.

A second set of dispersion tests was conducted in which the target was towed along rails with the mower, so that the mower wheels were always in contact with the ground. A small hole was cut in the front of the target and 50 nails were placed in line along the grass over which the mower-target assembly was moved. This test was repeated for each of the four lowest blade height settings for each of five lawn mowers. To enhance the pickup of the nails, which are relatively heavy with low surface area, small cubes of styrofoam plastic were attached by pushing the nail shank through the cubes up to the head surface. No systematic tests were made to optimize this technique, but this modification did improve the nail pickup.

The results of these tests clarified the relationship between blade height setting and the number of target hits which the initial tests had indicated. The "worst" blade height, i.e., the height of the blade giving the maximum number of target hits, is apparently determined by the combination of the housing design and lift properties of each mower. Specifically, the number of nails picked up and the number of target hits appeared to vary with the blade height setting differently for each of the mowers.

Having determined the "worst" blade height setting, additional tests were run on each mower at that setting. One hundred nails with the attached styrofoam material were picked up as in the previous test, the target hits were counted, and the test repeated. Most of the hits occurred in elevations one to three, with relatively few in the fourth elevation below the blade plane, the elevations being designated in five angular increments originating from the blade tip [1], as indicated in Table 2. It should be noted that elevation four intersects the ground and elevation five is not applicable to these tests. Scoring of the mowers for outdoor tests on grass was computed in the manner specified in Section 1205.21(s) of the proposed standard [1], shown in Table 2. The equations used were modified as required for the number of test projectiles used. It may appear to the casual observer that the introduction of a grass surface and the problems of nonuniform test surfaces, ricochets and other

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*The rationale for selecting nails for the dispersion tests is their resemblance to the most dangerous real-life thrown objects, pieces of wire [2].

Table 2 - Weighting Factors for Dispersion Tests for Walk-Behind Lawn Mowers

Zone* Elevation†	Front 90°	Right 105°	Operator 60°	Left 105°
1 (+45° to +30°)	1 3.4	6 12.1	11 100	16 12.1
2 (+30° to +15°)	2 3.1	7 10.9	12 90	17 10.9
3 (+15° to 0°)	3 2.4	8 8.5	13 70	18 8.5
4 (0° to -15°)	4 1.2	9 4.2	14 35	19 4.2
5 (-15° to -30°)	5 0.2	10 0.6	15 5	20 0.6

*Zones defined with respect to center of rotating blade [1].
†Elevations defined with respect to blade tip circle [1].

Note: The number in the corner of each box is the window number.

The equations for the dispersion test calculations for walk-behind mowers are:

Score for each test:

$$X = \sum_{i=1}^{20} \frac{H_i W_i}{300}$$

where $H_i W_i$ = number of hits times the weighting factor in window "i"

Standard deviation for each test:

$$S = \sqrt{\frac{\left(\sum_{i=1}^{20} H_i W_i^2\right) - 300\ X^2}{89{,}700}}$$

questions relating to actual grass cutting conditions could give misleading results. However, the results of this evaluation showed that: 1) none of the five tested lawn mowers unconditionally failed the acceptance criteria of the proposed standard, $\bar{X} < (2-R)$*, although one mower would have required retesting; and 2) the relative performance of the mowers was similar for the outdoor tests and the proposed mower tests. These results should not be construed as verifying the procedure of the proposed tests since only a limited number of tests were conducted on a small sample of mowers using one type of projectile, picked up at one location, and no replicate tests were performed on different samples of the models tested. The results suggest rather that the introduction of a grass or grass-like substrate which permits ricochets of objects may not be "a source of great confusion and error in the interpretation of test data" as stated in the Rationale of the Proposed Standard [2].

3. PROPOSED DISPERSION TESTS

For the evaluation of the proposed dispersion tests, a wooden weatherproof test chamber was constructed suitable for conducting the dispersion and the penetration tests on any of the walk-behind and most of the riding mowers in the test program. A photograph of the test chamber is shown in Figure 2. The mower in the figure is set up for a dispersion test.

In addition to the five walk-behind mowers tested outdoors, two other models were employed in the evaluation of the proposed dispersion tests [1]. The mower to be tested was first centered in the test chamber so that the horizontal plane of the blade tip circle was the required minimum distance of 32 in (81 cm) above the floor. The blade cutting height of the mower was adjusted to the setting closest to 2 in (51 mm) and the trailing shield was supported so that its position was the same as if the mower were placed on the ground. Energy absorbent material was placed under the mower after adjustment of the location of the nail injection tube.

To avoid problems with the tearing of large areas of the proposed dispersion test target material of 50 lb** kraft paper, which complicates the

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*$\bar{X}$ is the average of the scores for two tests and R is the average of the standard deviations $\bar{S}$ for two tests or 0.20, whichever is greater, for walk-behind mowers. Equations for X and S are given in Table 2.

**Paper and cardboard specifications referred to in this report are trade designations which have not yet been issued in metric equivalents. This is non-trivial since units vary from weight/ream, weight/standard sheet, to force/area bursting strength, and so forth.

Figure 2 – CHAMBER FOR EVALUATING PROPOSED THROWN OBJECTS TESTS (DISPERSION TEST ARRANGEMENT SHOWN)

scoring of nearby hits passing through the torn areas, a single layer of 350 lb cardboard specified for the penetration tests was used as the target. No comparative tests of localized damage between cardboard and kraft paper targets were made.

Dispersion tests were run for each of the mowers listed in Table 1. Tests were conducted with the grass bag attached as well as without the grass bag for all but the foreign made mower, which could only be used with a grass bag. Each of the mowers tested had average test scores, $\bar{X}$, which fell below the specified criteria (2-R) for unconditional acceptance, both with and without the grass bag [1]. Furthermore, all but mower W7A had test scores which fall below the criteria (1.6-R) specified for unconditional acceptance 24 months after the effective date of the proposed standard [1]. An additional dispersion test was conducted for W7A and it appears that this mower might fail the proposed retesting criteria for 24 months after effective date of the standard.

To compare the results of the proposed and outdoor dispersion tests, the ratio of the average test score to the unconditional acceptance criteria, $\bar{X}/(2\text{-R})$, was calculated. These values were plotted against the mower blade tip speed, which was based on a measurement of the maximum blade rotational speed. The resulting graph for the gasoline lawn mowers is shown in Figure 3.

As can be observed from this figure each of the gasoline powered mowers would be considered acceptable when evaluated by the proposed dispersion tests since the ratio for unconditional acceptance was always less than unity. The most obvious feature of the graph is the clear dependence of the test score to acceptance ratio on the mower blade tip speed. The mower having the highest blade tip speed was relatively worse in its dispersion characteristics than the other mowers tested. The same conclusions were reached when comparing the results of the electric powered mowers with each other.

4. PENETRATION TESTS

Penetration tests to evaluate the tendency of a thrown object to penetrate a target were conducted on six walk-behind mowers according to the proposed standard [1]. The setup for these tests is shown in Figure 4. The results of the tests are summarized in Table 3, where the results are listed in the order of increasing mower blade tip speed, a plot of which is given in Figure 5. It is clear from Figure 5 that the blade tip speed strongly influences the penetration characteristics for the mowers. The significance of the blade speed in thrown objects technology is documented in various sources, such as Reference 3 and in the following analysis where additional background information and references are given.

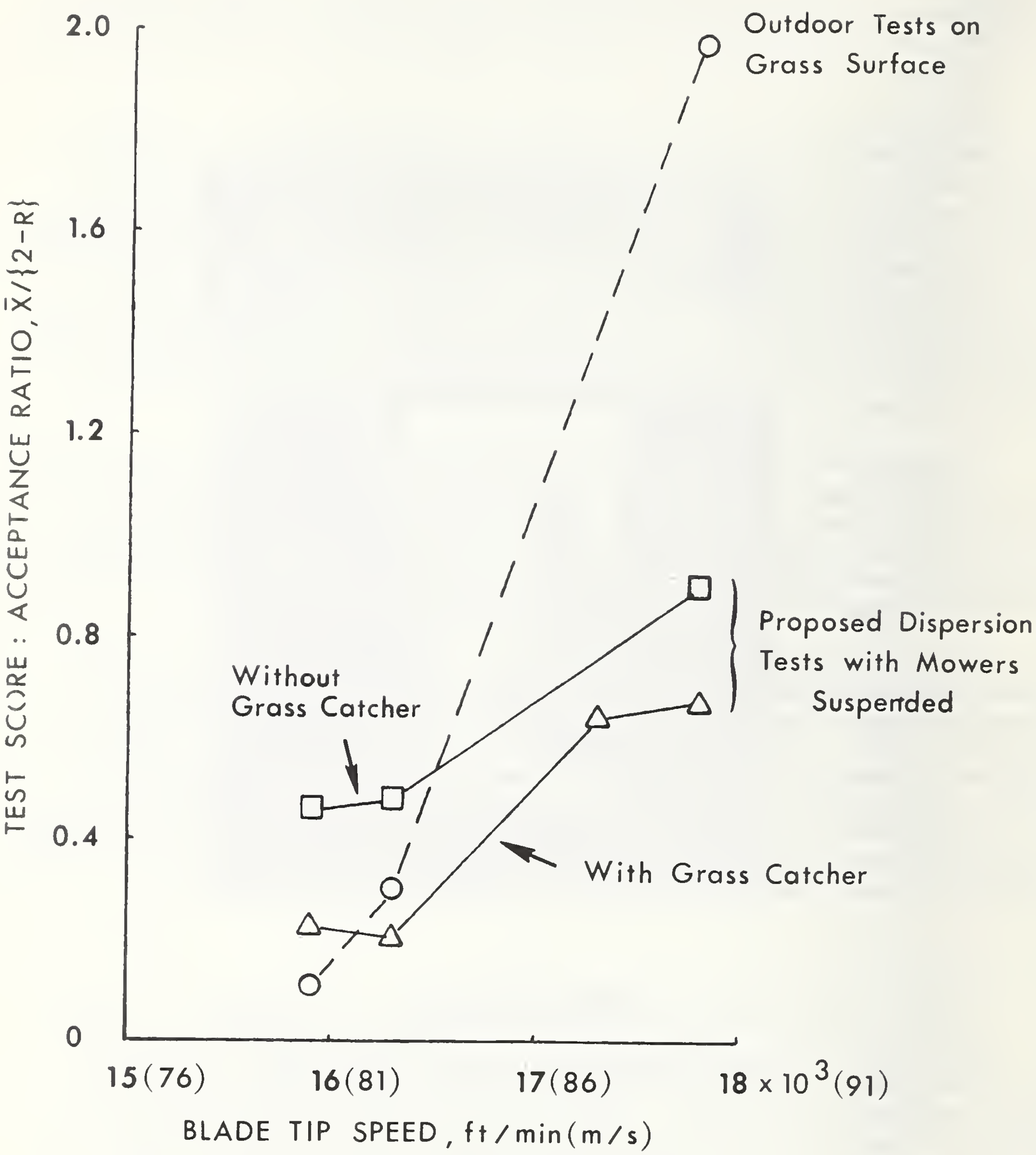

Figure 3 – TEST SCORE : ACCEPTANCE RATIO VS. BLADE TIP SPEED FOR VARIOUS GASOLINE POWER MOWERS

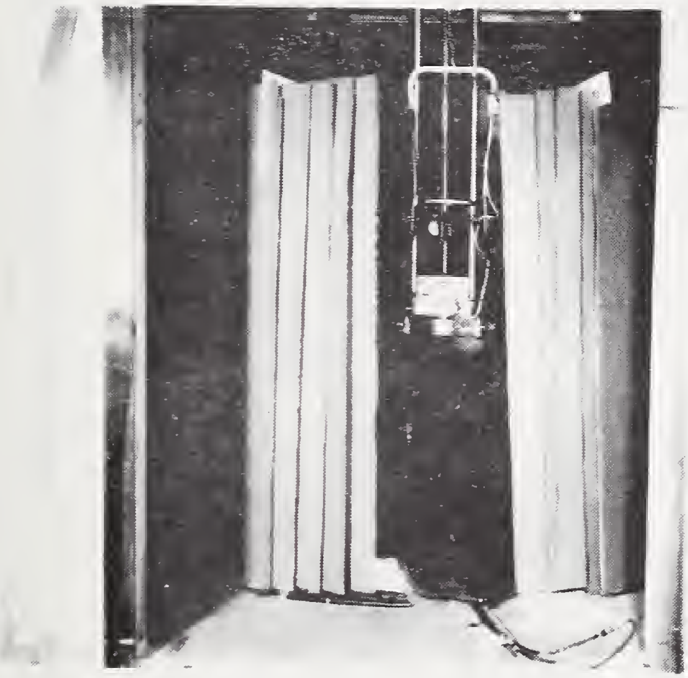

Figure 4 - LAWN MOWER AND TARGET ARRANGEMENT FOR PENETRATION TEST

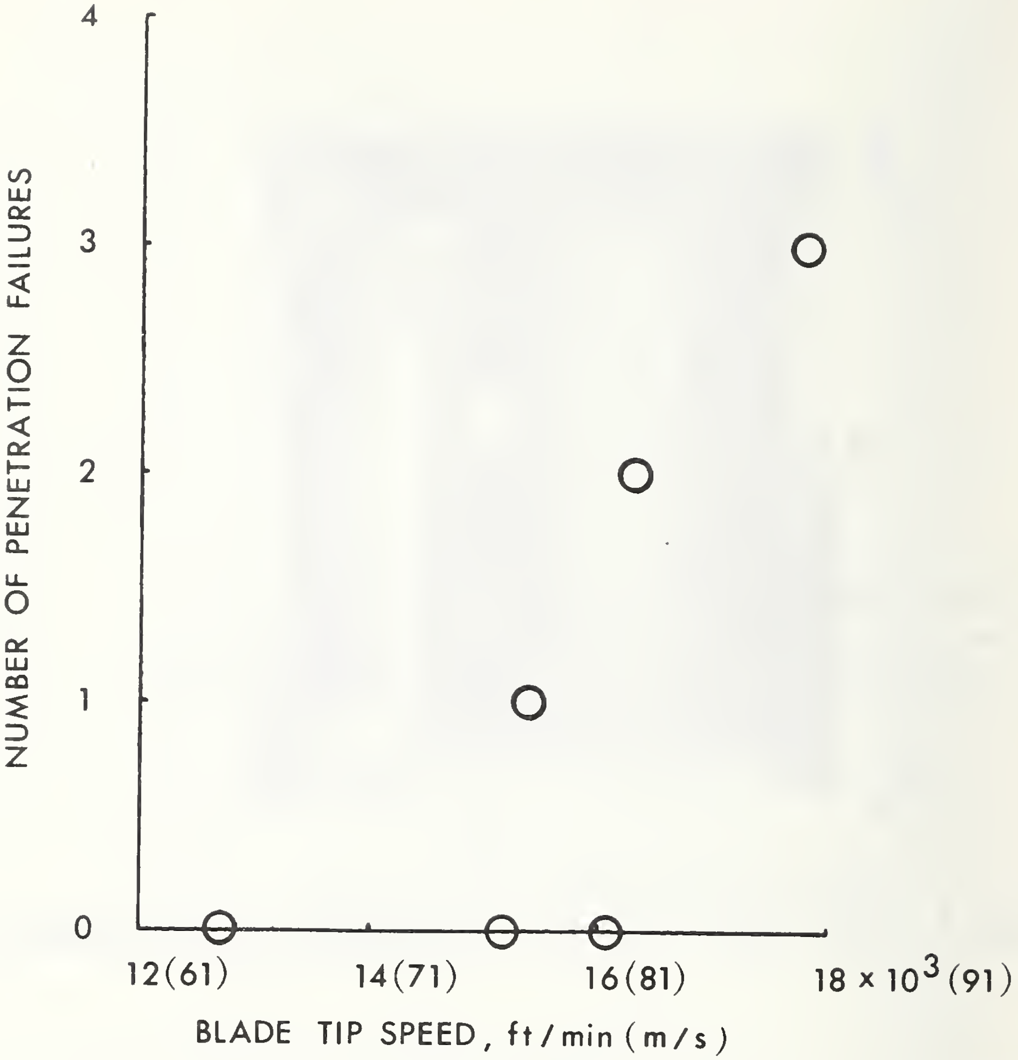

Figure 5 - NUMBER OF PENETRATION FAILURES VS BLADE TIP SPEED FOR SIX LAWN MOWERS

Table 3 - Results of Penetration Tests*

Lawn Mower	Projectile Injection Point Location	Compliance with Proposed Acceptance Criteria
M7B reduced throttle	Left	Passed
	Center	Passed
	Right	Passed
W2B	Left	Passed
	Center	Passed
	Right	Passed
W2A	Left	Failed - fifth target layer penetrated, zone 4
	Center	Passed
	Right	Passed
W4A	Left	Passed
	Center	Passed
	Right	Passed
W5A	Left	Failed - fourth target layer penetrated, zone 3
	Center	Passed
	Right	Failed - fifth target layer penetrated, zone 5
W7A full throttle	Left	Failed - fifth target layer penetrated, zone 4
	Center	Failed - fourth target layer penetrated, zone 3 and fifth target layer penetrated, zone 4
	Right	Passed

*Relative humidity during the tests was 35 - 40 percent.

5. ANALYSIS OF PENETRATION

5.1 Introduction

In this section, we develop a theory of penetration which provides a simplified treatment of the major factors affecting depth of penetration. This theory is compared with available experimental results and the agreement is good. The proposed penetration test is designed to measure the depth of a thrown object for an evaluation of its hazard to people. Penetration depends not only on the kinetic energy of the object, but also on its shape and its orientation with respect to the target surface. That is a nail is less likely to penetrate the target if it strikes the target sideways instead of head-on. This shape variable is eliminated in the proposed test by using spherical thrown objects, i.e., 0.250 in (0.64 cm) diameter steel balls. This tends to give, for a number of randomly spinning objects, an average projected area and thus an average penetration. Undoubtedly, the nail having equal mass and velocity as the sphere (i.e., having the same kinetic energy) will penetrate further than the sphere if the nail strikes point first.

5.2 Theory

Understandably, there is little data available on the penetrability of human flesh as compared to other materials. In general, there is agreement that depth of penetration is a function of particle velocity. By assuming that human tissue acts as a viscous medium, Sperrazza and Kokinakis [4] solved a second-order differential equation, the result of which predicted that depth of penetration should be proportional to impact velocity. In fact, their experimental data indicated that the relationship was linear, but not strictly proportional. If d is the depth of penetration, m is the mass of the thrown object, A is its (cross-sectional) area, V_1 is the impact velocity, and C_1 and V_o are constants, Sperrazza and Kokinakis [4] give, for tissue, the empirical result

$$d \cong C_1(V_1 - V_o)mA^{-1} \tag{1}$$

A similar result was obtained by Whiteford and Regan [5]. The tests were performed using steel cubes fired into wallboard. Other tests, performed by the Army, using spherical and cylindrical objects fired into wallboard and similar media [6,7] gave results which can be expressed as

$$d = C_2V_1^u m^v A^{-w} \tag{2}$$

where u = 1.358, v = 0.925 and w = 0.867 for one brand of wallboard [6] and u = 1.236, v = 1.160 and w = 1.121 for a second brand [7]. Tests performed by Nestelroad and Sevart [8] on 350 pound cardboard using 0.176 in (0.45 cm) diameter, 350 mg balls, showed that

$$d = C_3V_1^{1.72} \tag{3}$$

We may derive a generalized form for these results by allowing for a nonlinear viscoelastic target material behavior. Upon striking the target, the object exerts a dynamic force $m\dot{V}$. This is resisted by a force of nonlinear viscosity, $-C_4A\dot{V}^n$, where C_4 and N are constants. Then,

$$m\dot{V} = -C_4A\dot{V}^n \tag{4}$$

where n = 1 is the linear viscous case [4]. By integration it can be shown that this gives a maximum depth of penetration in the nonlinear case of

$$d = C_5V_1^ymA^{-1}, \; n \neq 1 \tag{5}$$

where y = 2(1 - n). This result neglects oscillatory damped rebound effects prior to stopping. The result agrees directly with the empirical result (equation 2). Similarly, the linear viscous case (n = 1) gives

$$d = \frac{1}{C_4} V_1mA^{-1}, \; n = 1 \tag{6}$$

This is the rational basis for Sperrazza and Kokinakis' [4] empirical equation (1).

This nonlinear viscosity model thus appears to be in quite good agreement with all of the preceding results. Equations 5 and 6 give the general form of the empirically determined equations (1-3). In particular, the theory predicts the exponent for mass to be plus one, whereas values of +1 [4,5], 0.925 [6], and 1.16 [7] were measured. The exponent of area, w, is here predicted to be -1, and empirical values of -1 [4,5], and -0.867 [6], and -1.121 [7] were measured. The flexibility of the model (etc.) fit the exponent of velocity as accurately as we wish.

5.3 Shape Effects

Tests have been conducted [9] which demonstrated the penetrability of 350 lb cardboard by a 0.50 in (1.27 cm) diameter by a 0.50 in (1.27 cm) long steel cylinder. We have tabulated these and the Nestelroad and Sevart [8] results in Table 4. There is some disagreement on the critical values for impact velocities. The data reported in [9] shows that a 0.50 x 0.50 in (1.27 x 1.27 cm) steel cylinder will fully penetrate one layer of 350 lb cardboard at about 4620 ft/min (23.5 m/s). The data in [8] indicates, that for a 0.176 in (0.45 cm) diameter ball, the velocity to penetrate one layer is about 8760 ft/min (44.5 m/s). This can be explained

Table 4 - Thrown Object Penetrability Tests

Thrown Object†	Target	Impact Velocity ft/min	Depth of Penetration	Source Reference
A	350 lb cardboard	2640	outer skin punctured	[9]
A	350 lb cardboard	3960	up to rear layer	[9]
A	350 lb cardboard	4620	full penetration - 1 layer	[9]
A	chicken thigh - loose skin	5400	penetrates skin	[9]
A	chicken thigh - skin taut	4620-4980	penetrates skin	[9]
B	"Dux-Seal"	6000	bounces off skin	[10]
B	"Dux-Seal"	12000	stings, possible skin breakage	[10]
B	"Dux-Seal"	18000	breaks skin	[10]
B	"Dux-Seal"	24000	buries in flesh	[10]
B	350 lb cardboard	17520	penetrates 2 layers	[8]
B	350 lb cardboard	25980	penetrates 6 layers	[8]

†A = 1/2 in x 1/2 in steel cylinder.

†B = 350 mg steel ball commonly used in air rifles.

by the above model from equation (5), for the case of the equal diameter for the cylinder and sphere. From equation (5), for the case of sphere and the cylinder of equal diameters striking the target "end on", the theoretical velocity ratio $(V_1/V_2) = 0.470$ where V_1 is the velocity of the cylinder and V_2 is the velocity of the sphere. The measured velocity ratio is $(V_1/V_2) = (4620/8760) = 0.527$. This suggests the potential usefulness of the model in explaining and predicting relative penetration behavior for various shapes.

5.4 Size Effects

Another application of the theory that is quite pertinent to the development of the proposed standard is the effect of ball size on the depth of penetration. Recall that the proposed standard which uses 0.250 in (0.64 cm) diameter balls was partly based on the 0.176 in (0.45 cm) diameter ball tests [8].

We would like to know if direct comparison can be made between depth of penetration in the 0.176 and 0.250 in (0.45 to 0.64 cm) diameter ball tests at the same velocities. The empirical equation (3) obtained by Nestelroad and Sevart [8] can be rewritten as

$$d = C_5 m V_1^{1.72} A^{-1} \tag{7}$$

by combining equations (3) and (5). For a given spherical material, the ratio of $(m/A) = \rho V/A = \rho(4R/3)$, where R is the ball radius and ρ is the material density. Thus $d = C_6 R V_1^{1.72}$, or the depth of penetration at a given velocity should be directly proportional to the ball radius. Increasing the ball diameter from 0.176 to 0.250 in (0.45 to 0.64 cm) at a given engine speed should increase the depth of penetration by about 42 percent. This is certainly a significant change representing a penetration of over four sheets of cardboard for a 0.250 in (0.64 cm) ball versus about three sheets for a 0.176 in (0.45 cm) ball.

5.5 Velocity Effects

It should be pointed out that a small change in the velocity exponent would correspond to a great variation in depth of penetration according to equation (7). We can also ask the specific question, "What effect should doubling the engine speed have on depth of penetration?". From equation (7) we have $(d_2/d_1) = (2)^{1.72}$. That is, doubling the engine speed should increase depth of penetration by a factor of 3.3.

5.6 Humidity Effects

It could be that the failure of some of the mowers tested was due to the fact that the penetration tests were performed in dry midwinter.

On the other hand, the previous tests were performed elsewhere, in the spring, when humidity was presumably higher.

Even without resorting to the model, we can intuitively rationalize that the dry cardboard tends to fracture rather than yield viscously so that it acts as a relatively brittle material to high speed missiles. Using the model, on the other hand, we see that in a higher humidity environment the cardboard is less brittle and more viscous (large n, hence small y, hence small penetration according to equation (5)). Thus, the dry winter tests would be expected to have greater penetration and the presumably more humid tests performed in the spring would be expected to give lesser penetration. In short, mowers might well pass the penetration tests in spring or summer when the humidity is high and fail the test in winter.

The predicted maximum depth of flesh would be slightly over an inch for a 0.25 in (0.64 cm) diameter steel ball missile. This corresponds to penetration of five layers of cardboard, assuming an equal penetrability for 350 lb cardboard and human tissue. This is of the same order of magnitude as maximum wound depths found in hospital accident reports of about 4 to 5 in (10 to 12 cm) due to wire objects, which are more sharply pointed. At these speeds, either the wire objects or steel balls could kill a bystander if struck in a critical area, such as in the heart or in the head. Indeed, this has happened, as is well known, and has been a primary motivation to developing the standard. The scoring distribution of the proposed test is designed to permit deeper penetration at low elevations, presumably where vulnerability to vital organs is less. However, for a bystander at 22 ft (6.7 cm) from the mower, a penetration of about an inch with a steel ball (or about 4 in (10.2 cm) with a properly oriented wire) is permissible to a height of 6 ft (1.8 m). This is sufficient to cause death. Therefore, it would appear that this whole situation requires further investigation.

6. CONCLUSIONS AND RECOMMENDATIONS

It should be emphasized that the need to answer questions about how realistically the suspended mower test position simulated actual grass mowing was the principal reason for conducting the outdoor tests in which grass cutting conditions were simulated. The single most useful result from the outdoor tests was the observation that there exists a "worst" blade height setting for which the target hits are most frequent, which may depend on some variables not tested. The proposed suspended mower dispersion tests cannot account for this least favorable mode of operation.

Based on the results obtained during the outdoor tests and the proposed dispersion tests, we concluded that the test acceptance criteria may not be rigorous for many walk-behind mowers currently being manufactured.

If the influence of a test surface is to be considered, then we recommend that it be included as an integral part of the retesting. To implement this evaluation, a controlled substrate surface would be preferred to the actual grass surfaces used in this study. Any such refinements to the proposed dispersion test would require further test development.

With regard to the proposed projectiles for the dispersion tests, it is necessary to specify the dimensions of the nails since there is no generally accepted, unique, sixpenny steel box nail configuration. During these tests, three different types of "sixpenny box nails" were purchased at one time or another varying in both head and shank dimensions. We also recommend that either a single layer of double wall cardboard be used for the dispersion test target or that the kraft paper be supported by cardboard, rather than the proposed 50 pound kraft paper alone. A single bent nail can tear a large hole in the kraft paper, and nails which then hit nearby will not be detected.

The limited penetration tests conducted suggest that this is a discriminating test for currently manufactured lawn mowers. To guard the safety of test personnel, it is necessary to provide some additional barrier beyond the fifth target layer in the region where the steel balls are ejected. The test chamber developed for these tests was provided with sliding doors which offer complete protection from thrown projectiles except for a narrow space where the projectile injection tube can protrude. An additional barrier to cover this narrow area is recommended for complete protection of test personnel.

7. ACKNOWLEDGMENTS

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6. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

An evaluation was made of thrown objects dispersion and penetration tests which have been developed for a proposed safety standard for power lawn mowers. To evaluate the proposed laboratory dispersion tests, supplementary outdoor dispersion tests were conducted on walk-behind lawn mowers in which actual grass cutting conditions were simulated. A description of these outdoor tests, a comparison of the outdoor and laboratory dispersion tests for a sample of walk-behind lawn mowers, and an evaluation of the proposed dispersion and penetration tests is given. The evaluation includes a theoretical discussion of the penetration of thrown objects which is related to experimental results in terms of the shape, size and velocity of the thrown projectiles.

7. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Dispersion tests; lawn mowers; penetration tests; power lawn mowers; safety standard; thrown objects tests.

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