MELLON INSTITUTE

Quarterly Report No. 12

From October 1, 1962 through December 31, 1962

on

BALLISTIC PROTECTIVE BUOYANT MATERIALS

U. S. NAVAL SUPPLY RESEARCH AND DEVELOPMENT FACILITY
BUREAU OF SUPPLIES AND ACCOUNTS, DEPARTMENT OF THE NAVY

Contract No. N140(138)72793B

Mellon Institute Research Project No. 388-3

MELLON INSTITUTE

April 4, 1963
Date received

Approved Date

Quarterly Report

From October 1, 1962 through December 31, 1962

U. S. Naval Supply Research and Development Facility
Bureau of Supplies and Accounts, Department of the Navy

No. 4388-3

TABLE OF CONTENTS

Page

SUMMARY

An increase of approximately 50% in the buoyancies of hydrophobed needled felts has been made possible by the use of the "compartmentation" technique.

It was determined that the buoyancy of a submerged hydrophobed batting increased as its angle to the water surface approached zero.

A comparison of carded battings prepared from crimped and straight hydrophobed fine fibers has shown that those containing the crimped staples have superior buoyant and ballistic properties.

In the preparation of needled batts, an increase in the amount of needling is generally accompanied by a decrease in buoyant and ballistic effectiveness. Carded batts are definitely superior to needled batts in body armors.

Although 1.0 dpf Acrilan and 1.25 dpf Dacron fibers have approximately equal diameters, the Acrilan staple is more effective as a buoyant and ballistic filler.

A. BUOYANCY EVALUATIONS

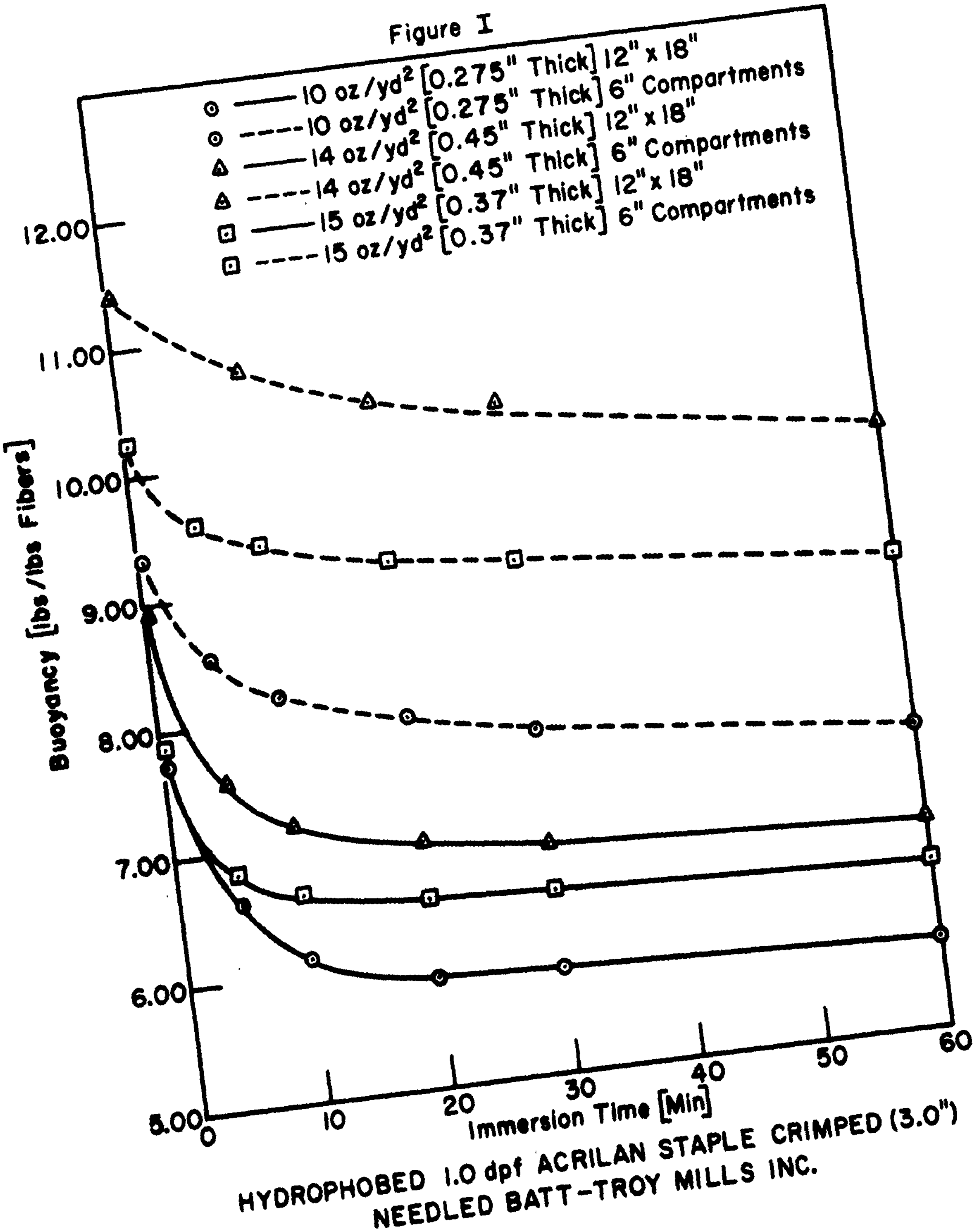
I. 1.0 dpf Acrilan Staple

a. Commercially Prepared Needled Felts - Troy Mills, Inc.

1. Effect of Areal Density Upon Buoyancy

In December 1961, preparation of experimental needled batts composed of 1.0 dpf Acrilan staple coated with 4% Decetex-104 silicone solids was made at Troy Mills, Inc., Troy, New Hampshire. The three needled samples, prepared without any reinforcing fabric ("scrim"), are identified as follows: 10 oz/yd^2 at a thickness of 0.275", 14 oz/yd^2 at a thickness of 0.450", and 15 oz/yd^2 at a thickness of 0.370". The results of the buoyancy tests performed upon 12" x 18" samples of these materials are presented in Figure I. It may be seen that the 14 oz. sample was superior to the 15 oz., which in turn, exhibited greater buoyancy than the 10 oz. sample. The superiority of the 14 oz. sample over the 15 can be attributed to its greater bulk. The 14 oz. sample had been needled to a thickness of .450" while the 15 oz. sample had been excessively needled to a thinner dimension. Undoubtedly, if the 15 oz. sample had been prepared at the same thickness, it would have shown greater buoyancy than the 14 oz/yd^2 sample.

Figure I



HYDROPHOBED 1.0 dpf ACRILAN STAPLE CRIMPED (3.0")
NEEDLED BATT-TROY MILLS INC.

2. Effect of "Compartmentation"

The three distinct samples of needled batts described above were also compartmented. Each "compartmented" batt (over-all areal dimension = 12" x 18") was composed of three 6" x 12" strips separated by thin plastic films. The technique of preparing "compartmented" samples has been previously reported. The curves obtained from the buoyancy evaluation of these "compartmented" samples are also listed in Figure I. The relative buoyancy-performances of the "compartmented" samples were found to be in the same order as the uncompartmented samples, namely 14 $oz/yd^2 > 15$ $oz/yd^2 > 10$ oz/yd^2. However, the most startling results may be found in comparing the "compartmented batts" with the uncompartmented. For example, with reference to the 14 oz/yd^2 material, the uncompartmented sample at the end of 1 hour of immersion showed a buoyancy slightly less than 7 lbs./lb. of fibers; while the similar material, "compartmented", showed a buoyancy at the end of 1 hour of immersion slightly greater than 10 lbs./lb. of fiber. This increase is representative of the three different samples and is a remarkable achievement in upgrading the commercially-prepared felts.

Assuming that 1-1/2 lbs. of the 14 oz/yd^2 needled batt were placed in a jacket as a liner, buoyancy in excess of 15 lbs. would be obtained. This is more than sufficient to afford suitable flotation protection for most individuals.

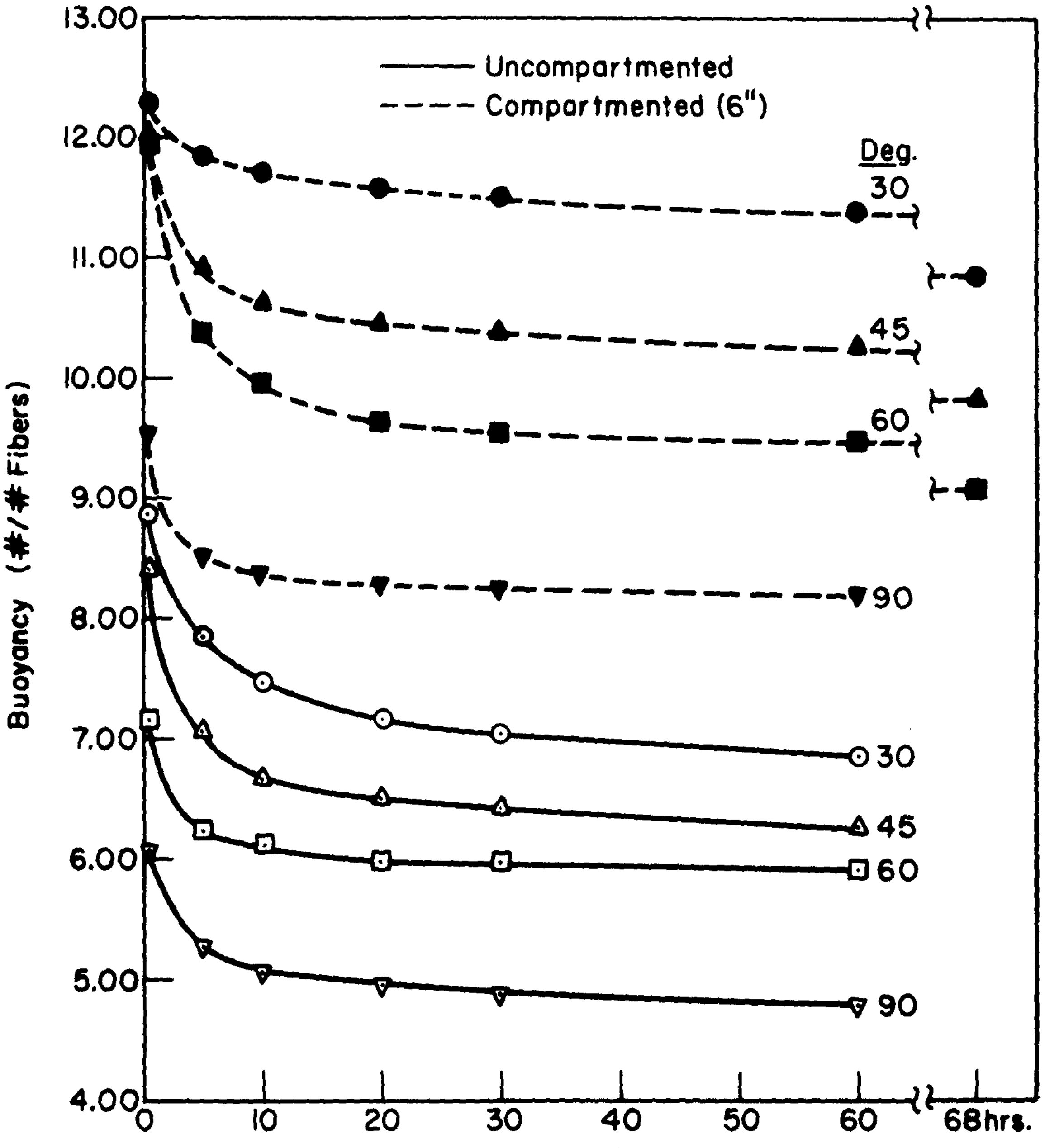
3. Effect of Immersion Angle Upon Buoyancy

To date, all buoyancy tests have been performed with the samples immersed perpendicular to the surface of the water. From past experience with bulk-type life preservers, it is known that such positioning of the sample represents the most rigorous test condition. It has also been known that as the angle of the sample is reduced (as the angle goes from 90° to the surface of the water, to 0°), the buoyancy increases. To project these previous observations to the liner batts, tests were performed where the batts were submerged at various angles to the surface of the water.

(a) Uncompartmented Felts vs. Compartmented Felts

Using the 15 oz/yd^2 needled felt containing hydrophobed 1.0 dpf Acrilan staple (see section A-I-a of this report), both compartmented and uncompartmented samples were subjected to the static buoyancy test. The felts were positioned at the following angles to the water surface, 30°, 45°, 60° and 90° (perpendicular to the surface). By referring to Figure II, one readily finds that the buoyancy of each felt group increases significantly as the angle to the surface approaches 0°.

Figure II



Effect of Immersion Angle Upon Buoyancy of 15 oz/yd^2 Needled Batt (Hydrophobed 1.0 dpf Acrilan-3.0" Cut)

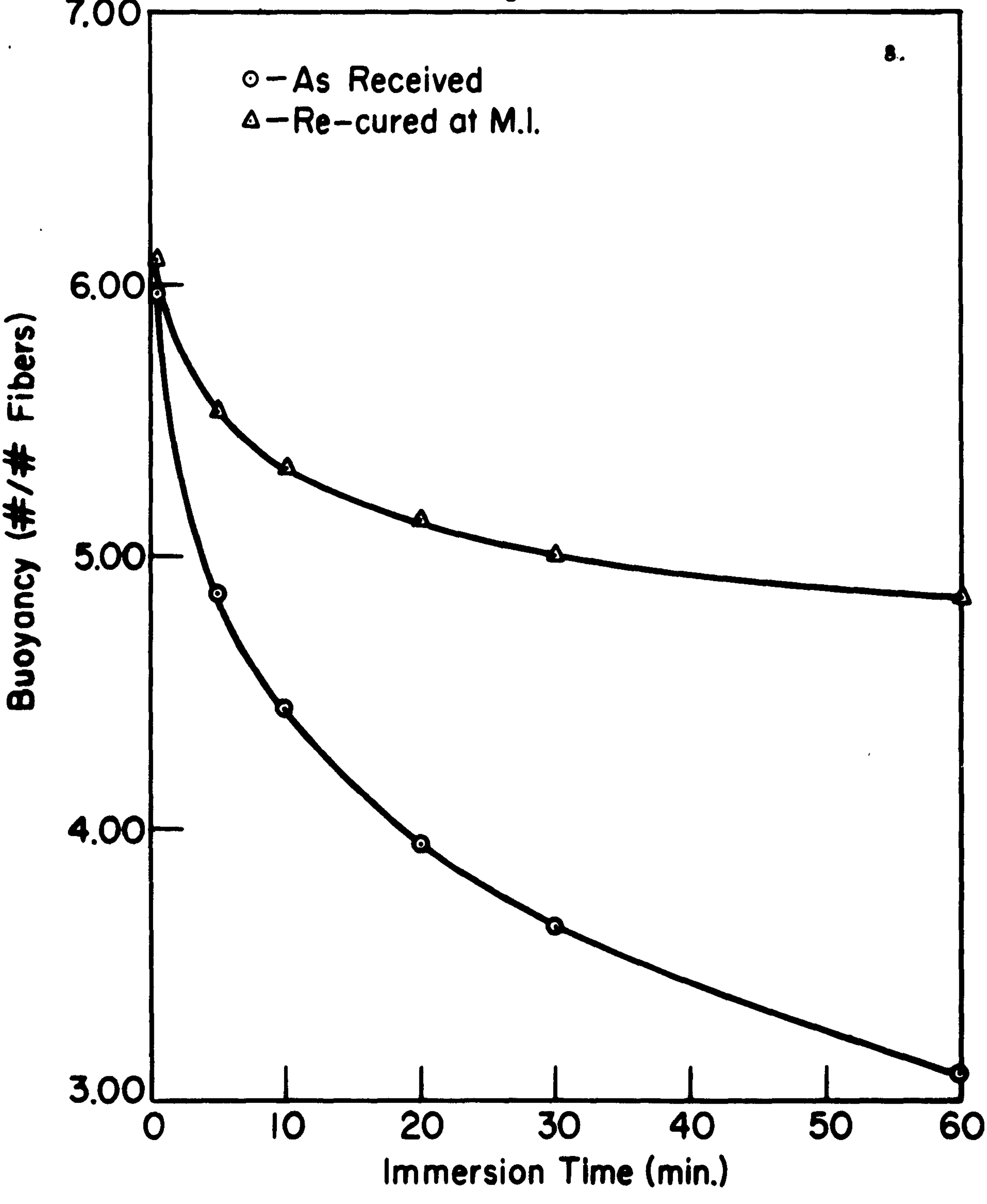
b. Commercially Prepared Needled Felt - Albany Felt Co.

One of the felts independently processed, hydrophobed and needled at the Albany Felt Company was tested for its buoyancy. The sample, 15 oz/yd^2, was prepared from 1.0 dpf Acrilan staple fibers (3.0" cut) and was presumably hydrophobed with Decetex-104. The material, as received, was buoyantly ineffective. However, upon additional curing, the buoyancy increased substantially. The curves representative of these tests are shown in Figure III. The incomplete curing of the water-repellent was undoubtedly a major contributing factor to the poor buoyancy performance of the original felt. Excessive needling verified by the presence of a large amount of broken fibers was also responsible for the failure of the material.

c. Experimental Needled Felts Prepared at Western Felt Works

A large percentage of the research program for the preparation of a buoyant-ballistic liner for jackets had been directed previously towards the use of staple fibers carded into batts. This of course necessitates the use of quilting in order to position the batts firmly. It has been decided that needled batts or felts would offer greater advantages over those of the quilted carded batts. Our observations of several commercial processors of needled felts indicate that no one has, to date, investigated

Figure III



EXPERIMENTAL NEEDLED BATT-ALBANY FELT #40/904, CUT #420 HYDROPHOBED 1.0 dpf ACRILAN (3.0" CUT) 15 oz/yd^2

the various needling techniques and their effects upon the ultimate felt with regard to buoyancy, ballistics and thermal insulation. For this reason a program has been initiated to study needling practices.

The Western Felt Works of Chicago, Illinois, has been gracious enough to place at our disposal a laboratory needle loom upon which our experimental samples could be made. The initial samples that were prepared at the Western Felt Works, their physical data and technique of fabrication are presented in Table I. Because the fibers involved were extremely fine in diameter, 1.0 dpf Acrilan, the finest practical needle (#32) was used. It was found that excessive needle breakage was encountered whenever needles thinner than the #32 were employed. All the samples prepared in this series of tests were processed under identical conditions such as the use of the same needles, the same advance of the sample and the same bed plate penetration. As is evident from the data in Table I, there was some difficulty encountered in obtaining the lighter felts at the same weight. This was partly due to the uncontrollable lateral movement or expansion of the batts as they were exposed to increasing amounts of needling. Referring to the first four samples, A, B, C, and D, it can be seen that the thickness of each batt was decreased during an increase in the amount of needling. Of this group, Sample A offered the most interesting physical appearance. The batt appeared to be a combination of an ordinary carded batt and a needled

Table 1

Equipment Employed: James Hunter Laboratory Needle Loom: Needles 15 x 18 x 32 x 3-1/2 RB, Type A, No Kick-Up Barb

Bed Plate Penetration: 0.25 inches

Advance: 5 strokes/inch

Staple Fiber: 1.0 dpf Acrilan, Type 16, + 4% Decetex-104

Sample	Fiber Length (inches)	Batt Thickness at 0.10 #/in^2 Pressure (inches)	Batt Weight (oz/yd^2)	Fabrication
A	3.0	0.54	16.3	Needled Once on One Side
B	3.0	0.37	15.1	Needled Once on Each Side
C	3.0	0.27	12.3	Needled Twice on Each Side
D	3.0	0.23	13.5	Needled Three Times on Each Side
E	3.0	0.32	14.0	Needled Twice on One Side
F	3.0	0.66	45.0	Three batts of equal weight; each needled once on each side; two needled together (once on each side); the third needled to the previous two (once on each side)
G	3.0	0.48	29.0	Two batts of equal weight; each needled once on each side; then needled together (once on each side)
H	2.0	0.65	31.6	Prepared identically to Sample G

felt. The side that was needled maintained the physical characteristics of a needled felt, the undisturbed side had the appearance of a carded batt. The amount of dimensional stability that this sample exhibited was also extremely surprising. Since preliminary studies indicate that a carded fiber batt may be superior ballistically to needled batt, a batting such as Sample A may be the ideal compromise in forming a liner which is dimensionally stable and retains the superior ballistic qualities of a carded batt.

An interesting phenomenon occurred during the processing of the heavier weight batts. Sample G prepared from the Acrilan staple fiber of length 3.0" was processed into a needled batt without difficulty. However, Sample H proved more difficult in its preparation. It can be noted that the Sample H differs primarily from Sample G in that its fiber length is less (2.0"). Before Sample H was completely processed, it was found that approximately 40-50% of the needles were broken. As a result Sample H was needled less than Sample G, resulting in the greater thickness of its batt. An unsuccessful attempt was made to process a third batt approximately equal in weight to Samples G and H and differing only in that its Acrilan fibers were 1-9/16" in length. In this latter case, breakage of needles occurred to a very great extent (approximately 75%).

1. Effect of the Amount of Needling Upon Buoyancy

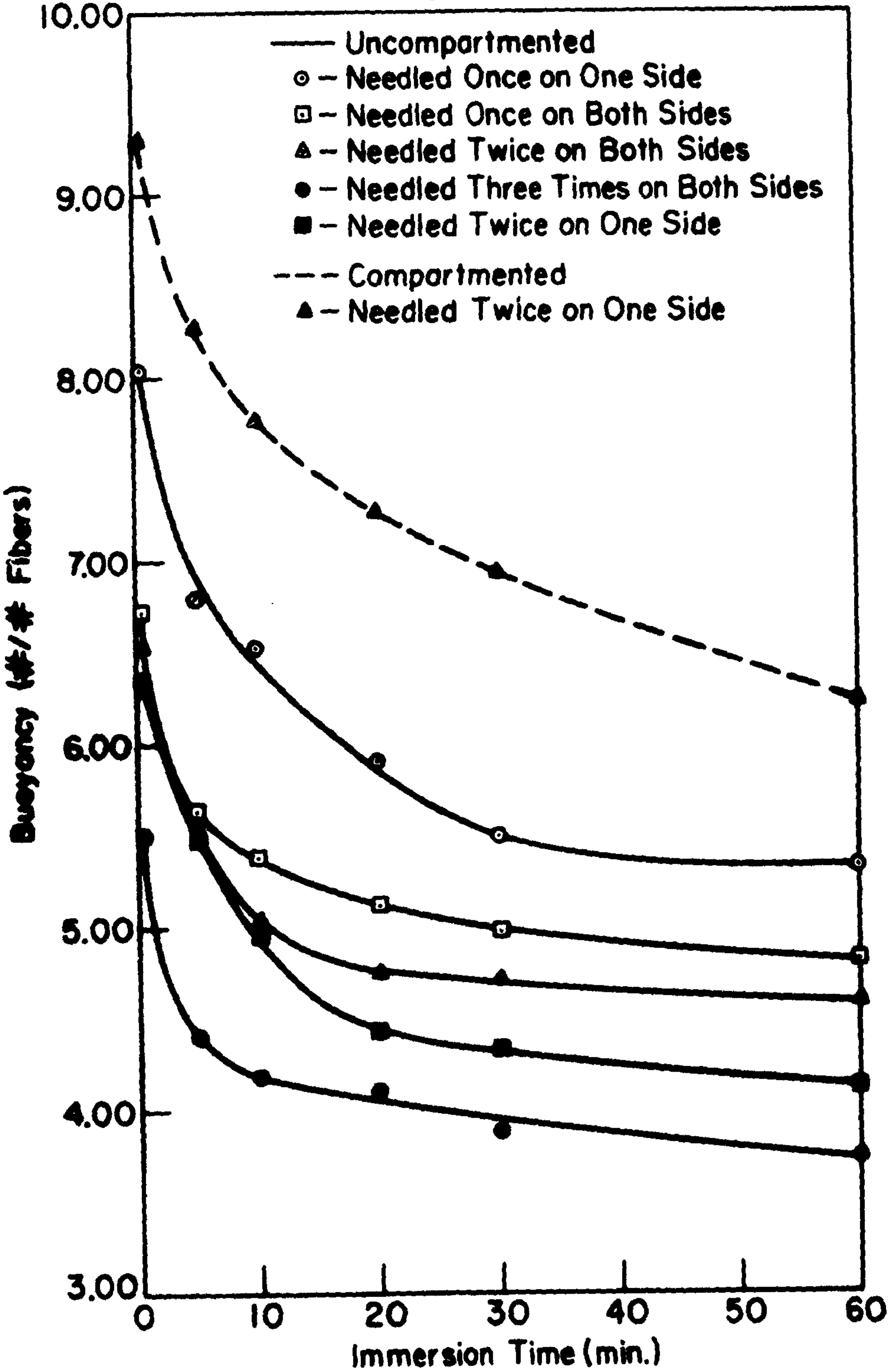
The buoyancies of Sample A, B, C, D, and E whose areal densities are within the desired limits for jacket liners, were obtained. The curves are presented in Figure IV. Sample A which was needled only on one side (once) possessed the greatest degree of buoyancy. In the order of decreasing buoyancy, the samples are rated as A, B, C, E, and D.

Since a larger amount of Sample E was available, it was also tested in the compartmented state. A vast improvement in buoyancy was found again due to the compartmentation.

II. Hollow Cellulose Ester Staple

A small quantity of hollow cellulose ester staple fibers, 5.5 dpf-2.0" cut, was obtained from the Star Woolen Company. The staple fibers were coated with 4% Decetex-104 silicone water repellent and carded into batts. Even though the diameter of each hollow staple was relatively large (5.5 dpf), the possibility existed that the air entraped in each individual fiber would be sufficient to make the fibers buoyant. The test method employed was the bulk-type microstatic buoyancy utilizing 60 grams of the carded fibers. The comparison between the hollow fibers and the relatively buoyant 1.0 dpf Acrilan

Figure IV



EXPERIMENTAL NEEDLED BATTS PREPARED AT WESTERN FELT WORKS 1.0 dpf ACRILAN (3.0") + 4 % DECETEX-104 staple are presented in Figure V. It is to be remembered that this test method is for comparison only, and the results do not reflect the actual values of the battings from which liners are prepared. A comparison of the curves in Figure V shows that the hollow cellulose was vastly inferior buoyantly, indicating that the effect of the large diameter could not be overcome by the amount of trapped air in the individual fibers.

III. 1.25 dpf Dacron Staple

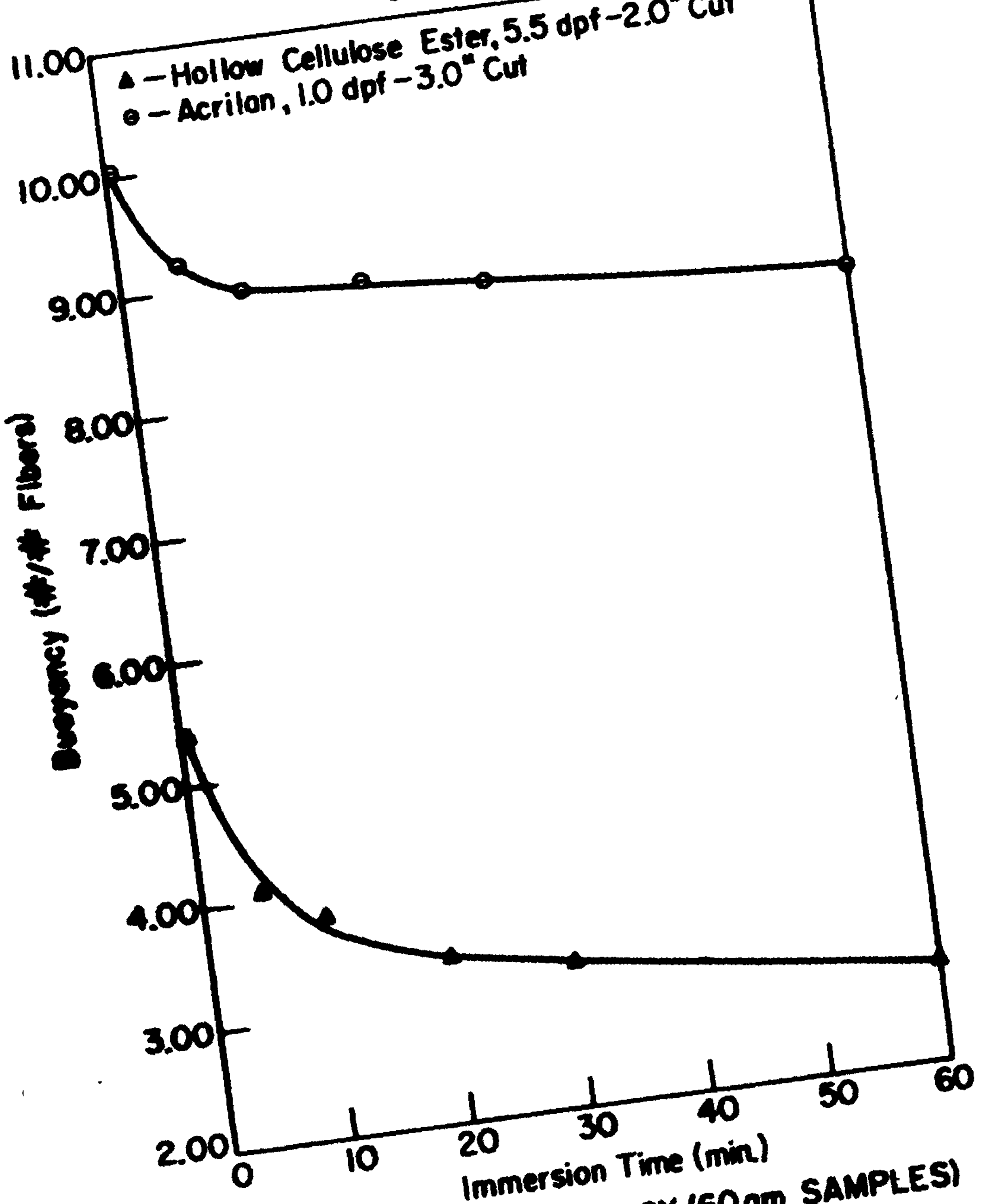
a. Comparison with 1.0 dpf Acrilan

A comparison of the buoyancies of 1.25 denier Dacron and 1.0 denier Acrilan, these diameters being approximately equal, was made using the microstatic buoyancy technique. Again it is important to remember that this method is used for comparison only, and may not represent the actual values of these materials in needled or carded felts. The curves obtained over an immersion time of 60 minutes are shown in Figure VI. The one denier Acrilan again shows its superiority. The lack of compression resistance which is needed to withstand the pressure of water, is undoubtedly a major factor in the low buoyancy values obtained for the Dacron.

b. Experimental Needled Felts Prepared at Western Felt Works

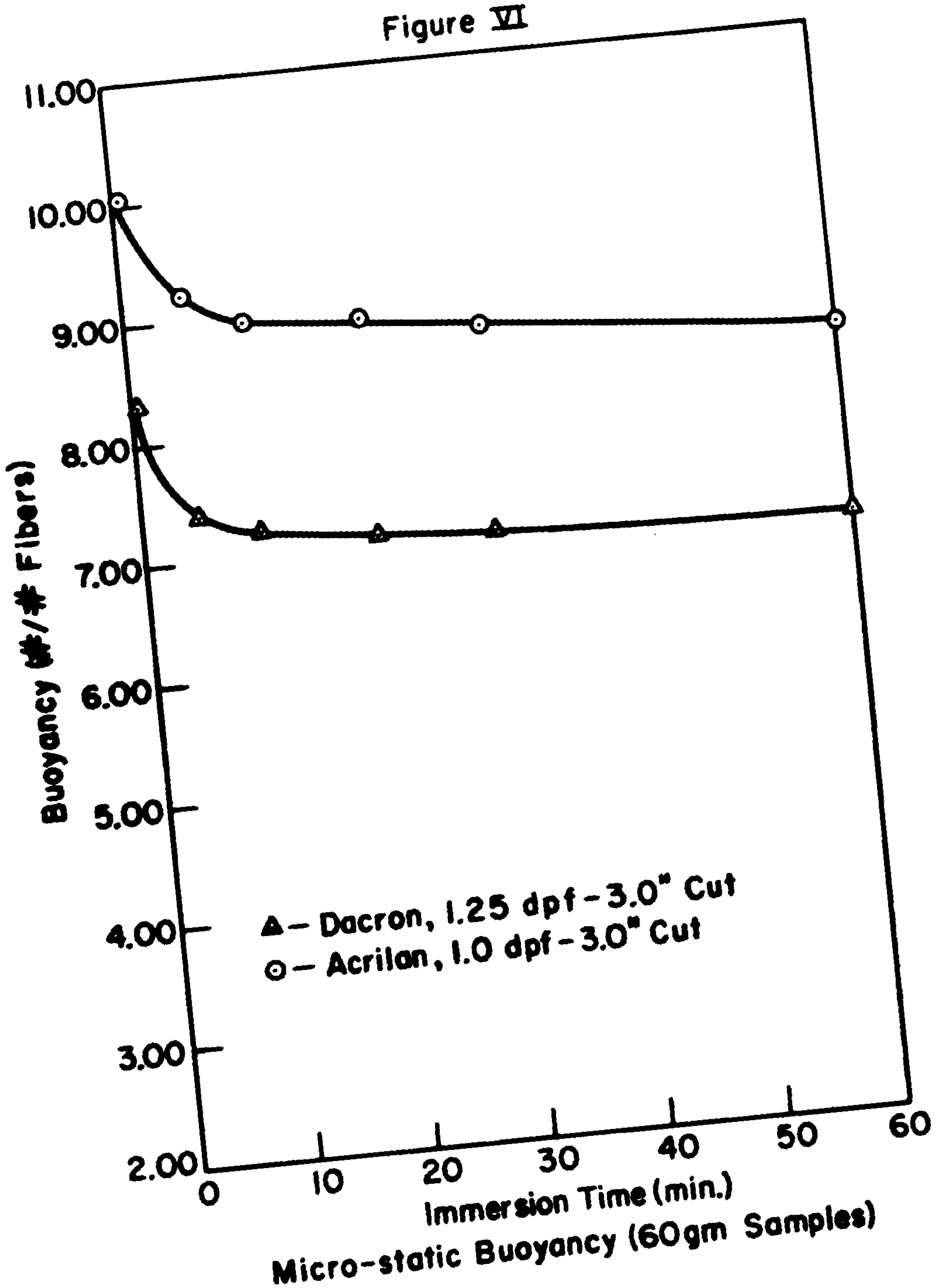
Battings containing 1.25 dpf Dacron staple, hydrophobed with 4% Decetex-104 silicone solids, were prepared by carding and subsequent felting (needling) at the Western Felt Works. Samples were made utilizing 3.0" and 2.0" cuts of

Figure V



MICRO-STATIC BUOYANCY (60 gm SAMPLES)

Figure VI



Micro-static Buoyancy (60gm Samples)

the polyester staple. The data concerning the felts and methods of preparation are tabulated in Table II.

1. Effect of Fiber Length Upon Buoyancy

Samples D, E and F, described above, were compartmented (6" sections) and tested for their buoyant effectiveness. The resultant curves are presented in Figure VII. A comparison between the buoyancies of felts D and F which were prepared identically but contained 3.0" and 2.0" lengths of fibers respectively, shows a slight over-all superiority of the former. Although sample D which had been needled once on one side only had an initial thickness (0.42") greater than E (0.30") which had been needled once on both sides, its initial bulk in water as represented by the initial buoyancy value, was lower. As reported previously (section A-1-c of this report), a batting which has been needled once on one side retains its carded appearance and form on that side which was not needle-punched. Consequently, the compression resistance of sample D was influenced deleteriously by its carded portion when exposed to the pressure of the water after immersion.

2. Effect of the Amount of Needling Upon Buoyancy

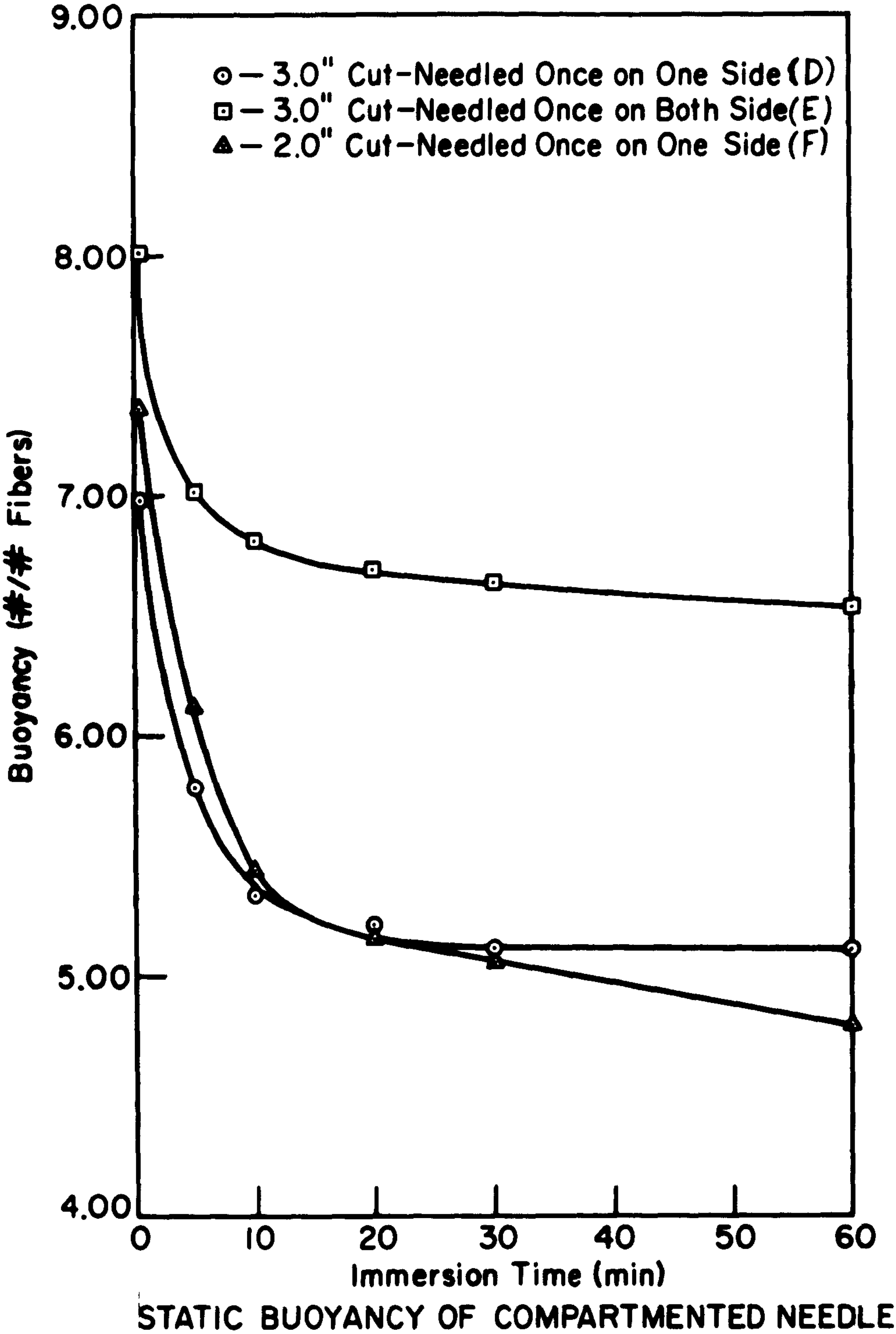
Referring to Figure VII, the effect of the amount of needling upon the buoyancy of the felts containing the hydrophobed 1.25 dpf Dacron fibers is evident. Samples D and E, prepared from the same fibers, differ only because the latter was needled once on both sides while the

Table II

Equipment Employed:	James Hunter Laboratory Needle Loom: Needles: 15 x 18 x 32 x 3-1/2 RB, Type A, No Kick-Up Barb
Bed Plate Penetration:	0.25 inches
Advance:	5 strokes/inch
Staple Fiber:	1.25 dpf Dacron, Type 5400, + 4% Decetex-104

Sample	Fiber Length (inches)	Batt Thickness at 0.10 #/in^2 Pressure (inches)	Batt Weight (oz/yd^2)	Fabrication
A	3.0	0.68	56.2	Three batts of equal weight; each needled once on each side; two needled together (once on each side); the third needled to the previous two (once on each side
B	3.0	0.54	45.6	Same as Sample A
C	3.0	0.40	30.6	Same as Sample A
D	3.0	0.42	17.8	Needled Once on One Side
E	3.0	0.30	15.6	Needled Once on Each Side
F	2.0	0.39	15.7	Needled Once on One Side
G	2.0	0.31	14.9	Needled Once on Each Side

Figure VII



STATIC BUOYANCY OF COMPARTMENTED NEEDLED FELTS CONTAINING HYDROPHOBED 1.25 dpf DACRON STAPLE former was needled once on one side. The low compression resistance of the soft Dacron necessitates sufficient needling to form a firm felt.

IV. Experimental Hydrophobed Acrilan, 1.0 dpf, Prepared by the Chemstrand Company - AT X 966

The Chemstrand Company has made available hand samples of 1.0 dpf Acrilan staple which had been hydrophobed during its preparation. Visual examination of the water-repellency of a batting containing these fibers was extremely encouraging. The bulk and compression resistance of this batting was of a high order.

A larger quantity of this material, designated AT X 966 by the Chemstrand Company, has been received and is being processed for testing.

B. BALLISTIC EVALUATIONS

I. Carded Batts

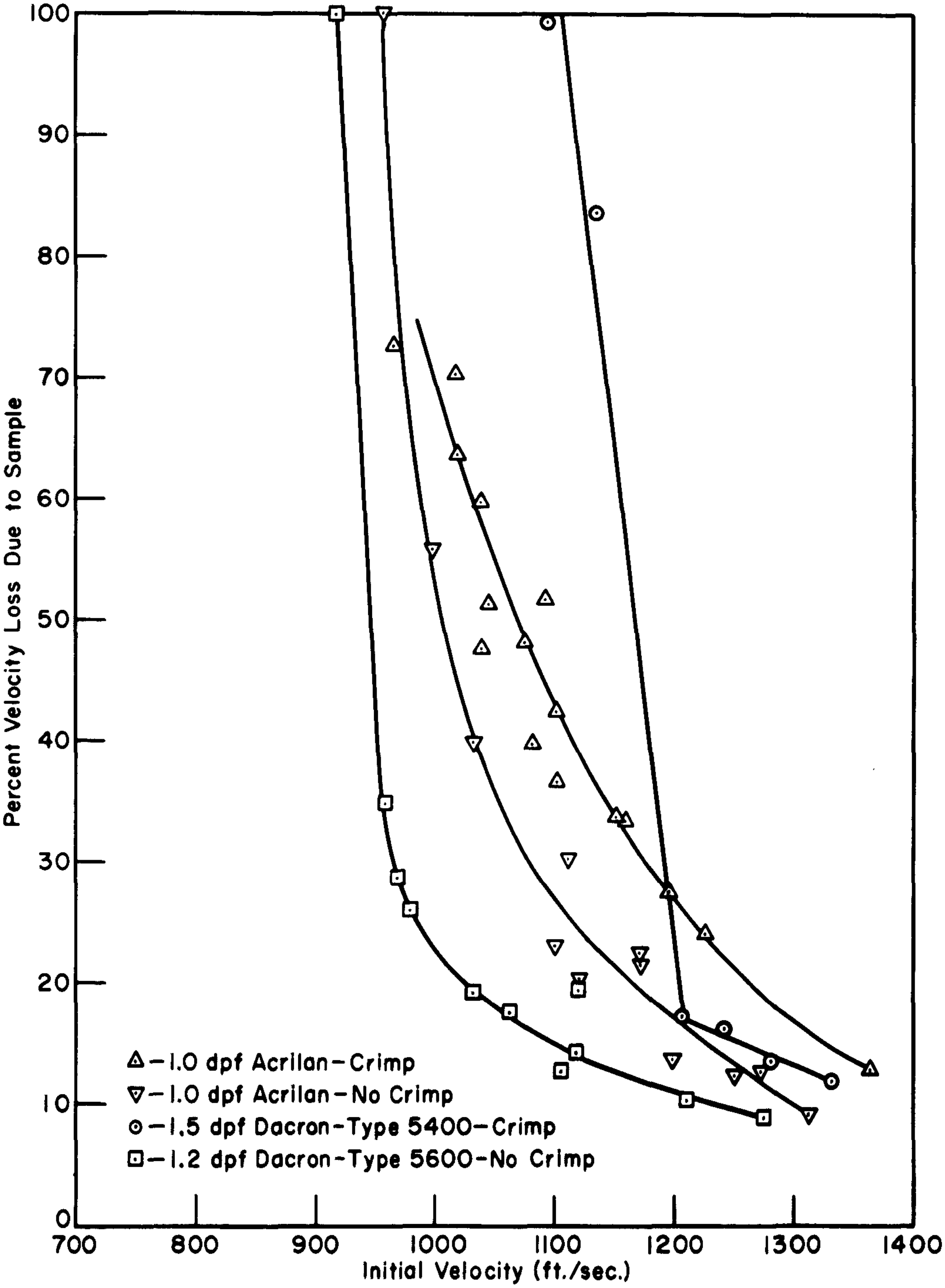
a. Effect of Crimp Upon Ballistics

1. Dacron and Acrilan Staples

Ballistic efficiency curves were obtained for 2 samples of Dacron fibers, one type crimped and the other uncrimped. The Dacron fibers were first hydrophobed with the Decetex-104 water-repellent and carded into 0. 5" thick batts at an areal density of 42 oz/yd^2. The crimped fibers were 1. 5 dpf Dacron staple, type 5400, while the uncrimped fibers were 1. 2 dpf Dacron continuous filament, type 5600. The 1. 5 denier Dacron was obtained at a length of 3", while the 1. 2 denier Dacron was cut in the laboratory to the same size. The resultant ballistic curves are presented in Figure VIII. In spite of the finer diameter of the type 5600 uncrimped fiber, which from previous data should prove superior to similar fibers of larger diameter, the 1. 5 denier Dacron batt exhibited a vastly greater limiting velocity. Since it is reported that the Dacron fibers, type 5400 and type 5600 are quite similar chemically and physically, the difference in ballistic performance can be attributed mainly to the presence of the crimp. This is logical to assume since the mechanism involved in the stoppage of a fragment by the fibers is due largely to the fiber-to-fiber friction, crimped fibers having more resistance to internal movement in a batt.

A further investigation of the effect of crimp upon ballistics was performed upon carded batts composed of 1. 0 dpf Acrilan (3. 0" cut) crimped and uncrimped. In both cases, the Acrilan was obtained from the same original batch or stock. Both types of fibers were hydrophobed with the Decetex-104 and carded into 0. 5" thick batts at areal densities of 42 oz/yd^2. The ballistic data obtained for the crimped and uncrimped Acrilan staple fibers are also presented in Figure VIII. Again, it may

Figure VIII



BALLISTIC PERFORMANCES OF 0.5" THICK CARDED BATTS (42oz/yd²) CONTAINING 3.0" HYDROPHOBED STAPLE FIBERS be seen that the crimped fibers have a greater ability to prevent fragment penetration than the uncrimped. However, in contrast to the Dacron fibers, the difference in ballistic performance between the crimped and uncrimped Acrilan is not as exaggerated. Generally speaking, however, it may be stated that crimped fibers when processed into carded batts offer greater ballistic protection than batts prepared from the uncrimped.

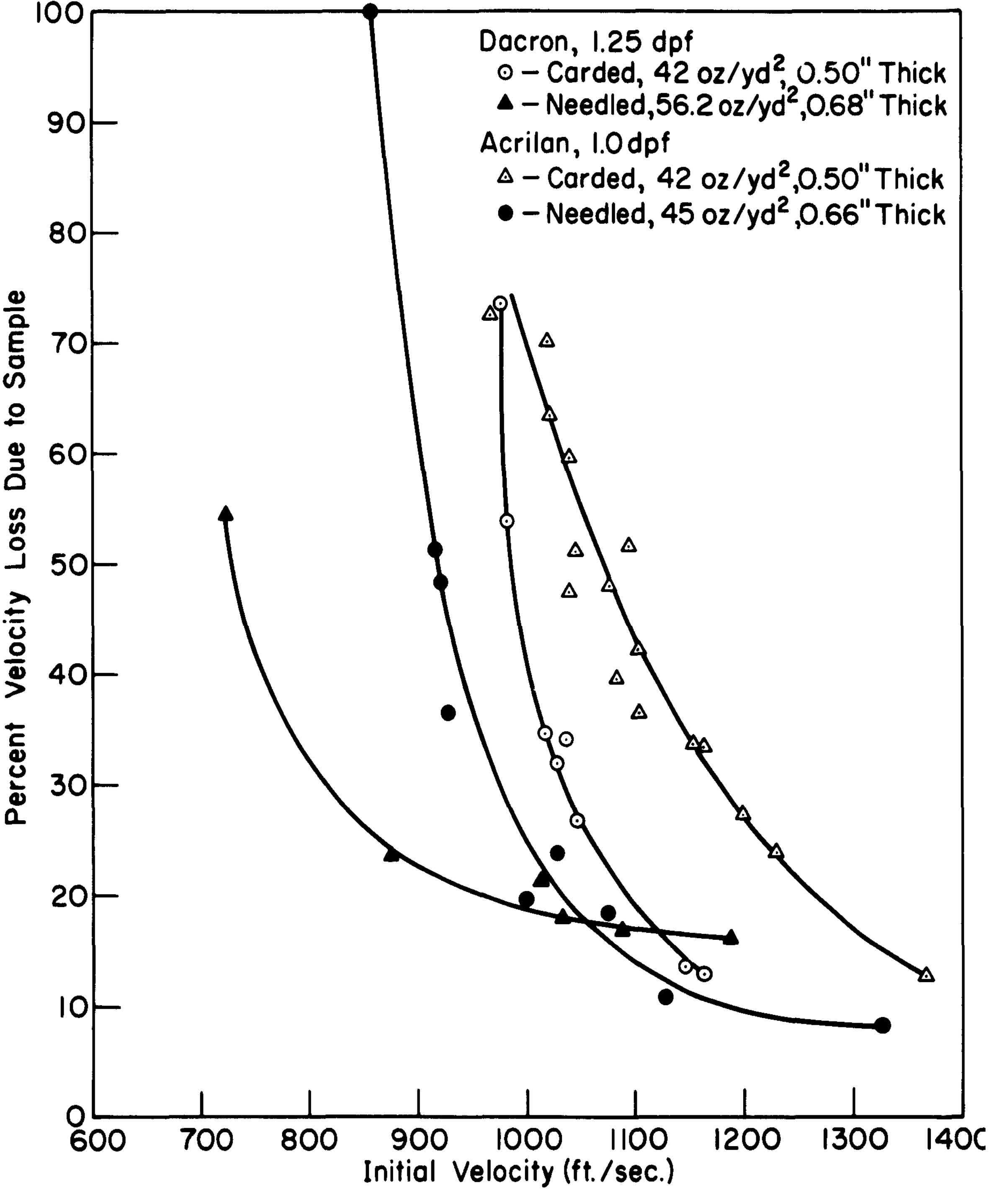
b. Comparison Between Carded and Needled Batts

1. Dacron, 1.25 dpf, and Acrilan, 1.0 dpf, Staples

A considerable portion of our ballistic tests have been performed on carded batts. From this investigation the effect of fiber length, fiber diameter and other factors have been determined. Among the most critical factors has been that of fiber mobility (fiber to fiber friction). It had been seen that excessive fiber to fiber friction was undesirable. As the mobility of the fibers decreased (as a solid body was approached) the ballistic resistance to fragrant penetration also decreased. Since the needling technique immobilizes the fibers by its formation of a dimensionally stable batt, it was conjectured that the needled batts would be inferior ballistically to the carded batts. A preliminary investigation of the ballistic effectiveness of carded and needled batts appears to justify this. Using hydrophobed 1.0 dpf Acrilan (3.0" cut), two separate batts were prepared. One was a 42 oz/yd^2 carded batt (0.50" thick) while the other was a 45 oz/yd^2 needled batt (0.66" thick). The results of the ballistic tests performed on these two items are presented in Figure IX. It can be seen from these curves that in spite of the greater weight and thickness of the needled batt, its ballistic efficiency is less than that of the carded. The fact that the low tenacity staple fibers in the needled batts were prevented from moving appears to be the reason for their lower ballistic efficiency.

A more dramatic proof of the superiority of carded batts over that of the needled type as presented in Figure IX is the comparison between a carded and needled batt containing hydrophobed 1.25 dpf Dacron (3.0" cut). The carded batt was 0.50" thick with an areal density of 42 oz/yd^2, while the needled one was 0.68" thick and definitely heavier with an areal density of 56.2 oz/yd^2. Despite the greater weight, the ballistic performance of the needled batt was very much lower than that of the carded. Here, again, the lack of mobility of the fibers in the needled state is detrimental. The needled batt had been processed in the following manner: Three batts of equal weights were independently needled, once on each side, two were then needled together (needling performed on each side) and then the third was needled to the previous two (again with needling being performed once on each side). This excessive needling undoubtedly lowered the ballistic resistance of the original carded batts.

Figure IX



COMPARISON OF THE BALLISTIC PERFORMANCES OF CARDED AND NEEDLED BATTS CONTAINING 3.0" HYDROPHOBED STAPLE FIBERS

II. Needled Felts

a. Nylon, 6.0 dpf, High Tenacity vs. Acrilan, 1.0 dpf

A quantity of high-tenacity nylon tire cord, 6.0 dpf, was hydrophobed, carded, and then needled into a batt 49.8 oz/yd^2 at a thickness of 0.56". The felt was prepared by needling the carded batt once on each side. The staple length of the fiber was 3.0". A ballistic efficiency curve was obtained and is shown in Figure X. The poor ballistic performance of this Nylon batt is magnified by comparing its ballistic curve with that representing a 16.3 oz/yd^2 batt composed of 1 denier Acrilan. The hydrophobed Acrilan felt has equal ability in opposing fragrant penetration. Thus, a low tenacity acrylic fiber felt of areal density 16.3 oz/yd^2 is approximately equal in ballistic performance to that of the high-tenacity Nylon, 49.8 oz/yd^2. Of course, this particular Acrilan batt had been needled once on one side which again shows that fiber mobility is of great importance.

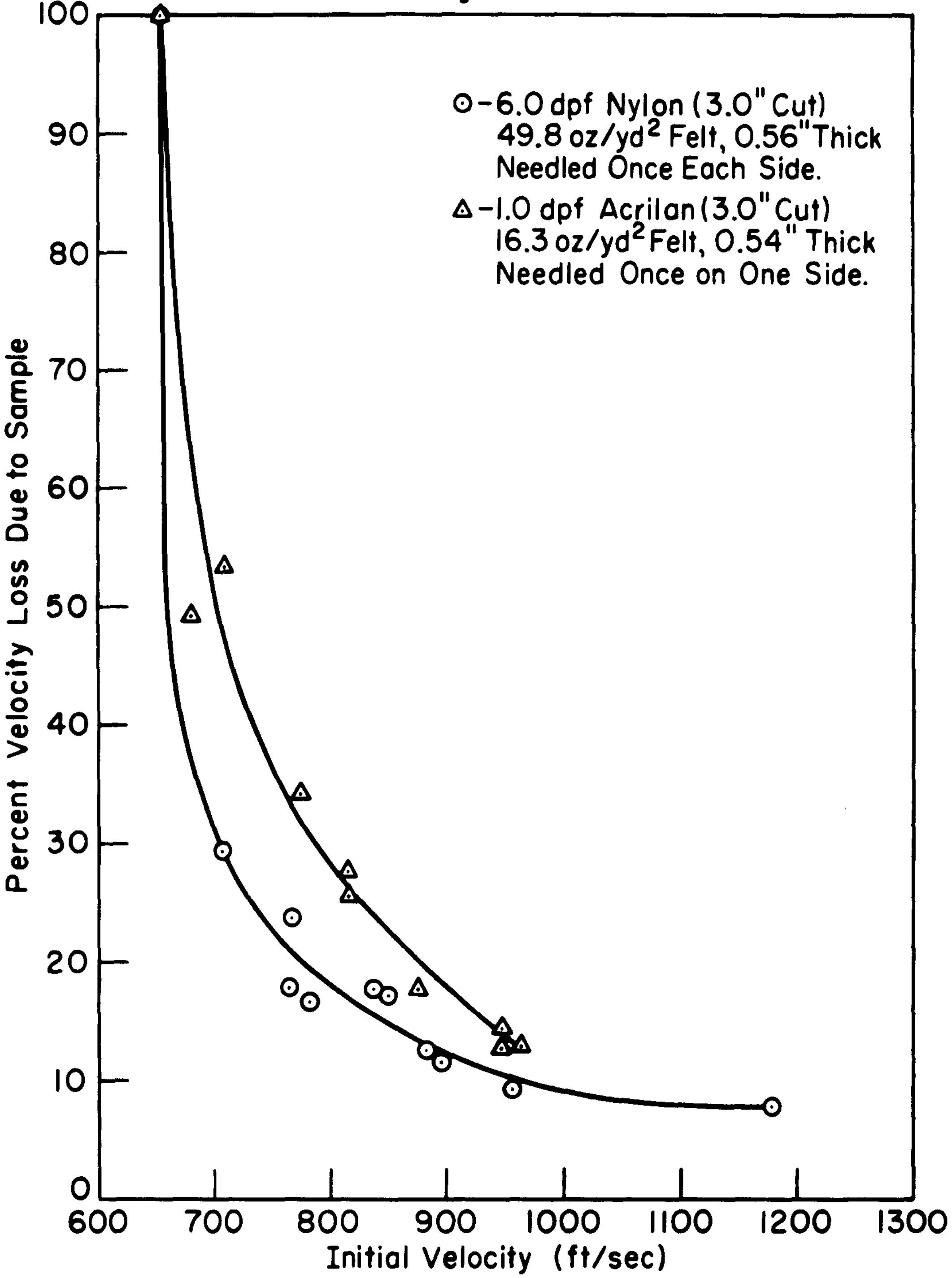
b. Acrilan, 1.0 dpf, Staple

1. Commercial Preparation - Troy Mills, Inc.

(a) Effect of Areal Density Upon Ballistics

The commercially prepared needled felts composed of hydrophobed 1.0 dpf Acrilan fibers (3.0" cut), described previously in this

Figure X



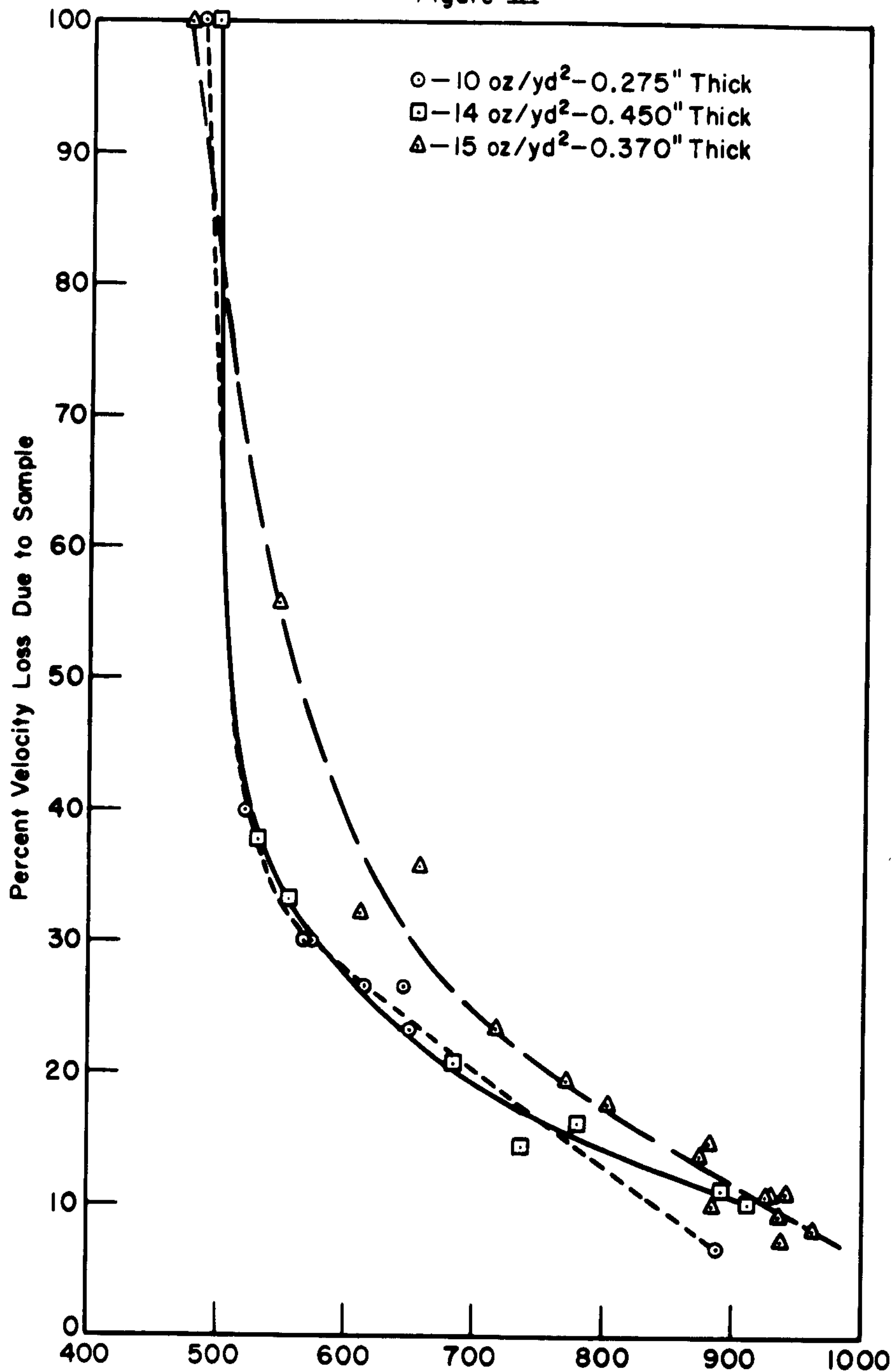
BALLISTIC COMPARISON BETWEEN A DENSE FELT CONTAINING HIGH-TENACITY FIBERS AND A LIGHT WEIGHT FELT CONTAINING LOW-TENACITY FIBERS report under section A-I-a, were tested for their ballistic efficiencies. The curves for the three felts, 10 oz/yd^2, 14 oz/yd^2 and 15 oz/yd^2 are compared in Figure XI. Essentially the limiting velocities of the three different batts are identical. However, at initial velocities above 600 ft./sec. the 15 oz/yd^2 batt appears to offer slightly more protection by reducing the residual velocity. The 10 and 14 oz. samples appear to be completely identical over the range from the limiting velocity to 900 ft./sec. Of course, the variation in thickness of the three samples may have influenced the results of the test. This factor is currently being investigated.

2. Experimental Preparation - Western Felt Works

(a) Effect of the Amount of Needling Upon Ballistics

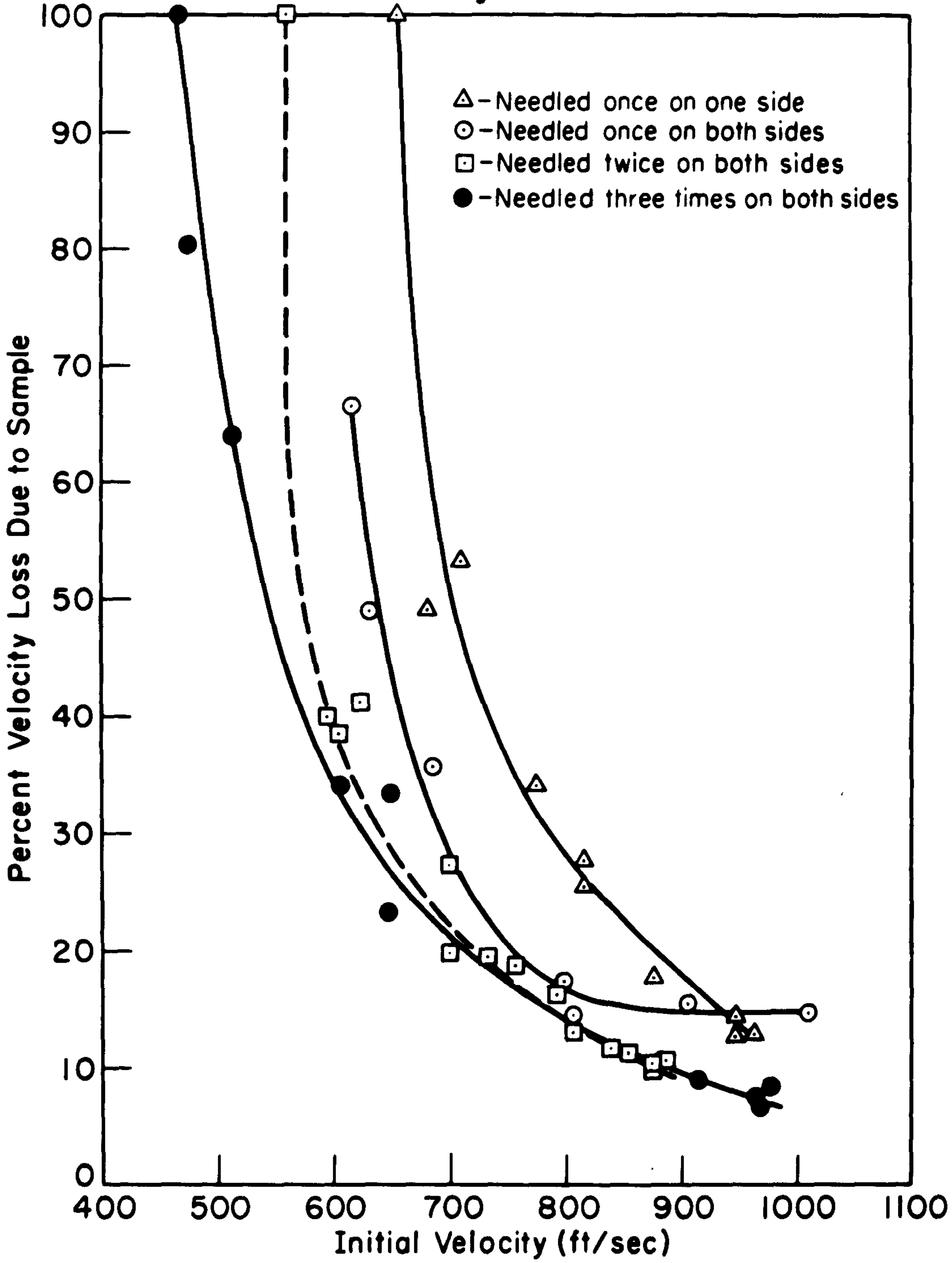
From past observations, it has been our contention that the ballistic performance of fibrous batts decreases as the mobility of the fibers becomes more and more restricted. In other words, the more needling performed upon the battings, the lower the ballistic effectiveness. Figure XII contains the ballistic efficiency curves for the four needled samples that had been prepared at Western Felt. The data describing these felts has been presented under section A-I-c. It is readily seen that the ballistics decreased as the amount of needling

Figure XI



HYDROPHOBED NEEDLED BATTS OF 1.0 dpf ACRILAN (3.0" cut)

Figure XII



Experimental Needled Batts Prepared at Western Felt
1.0 dpf Acrilan (3.0") + 4% Decetex-104

increased. The sample with the best performance was that which had been needled once on one side only. The side that was needled had the appearance of a normal needle felt, the other side had the appearance of a carded batt. During the ballistic test on this material, the side that appeared to be a carded batt faced the projectile and was encountered first. Although the four samples represented in Figure XII had slightly different areal densities, these differences cannot account for the positions of the four curves or their relatively large differences.

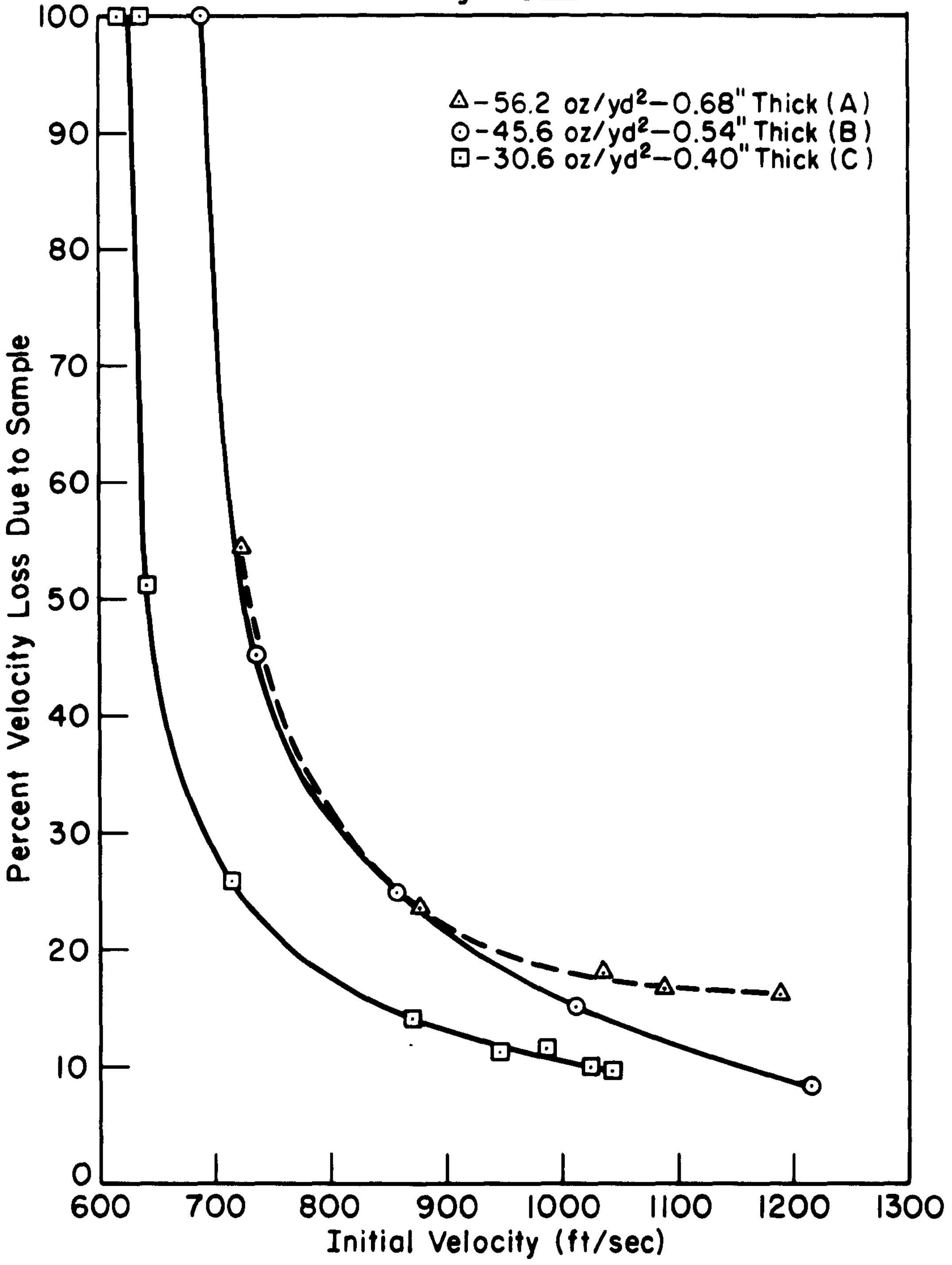
c. Dacron, 1.25 dpf, Staple

1. Experimental Preparation - Western Felt Works

(a) Effect of Areal Density Upon Ballistics

Under section A-III-b of this report, the details are collected concerning the preparation of some experimental felts containing hydrophobed 1.25 dpf Dacron fibers. Three of these samples, A, B and C with areal densities of 56.2 oz/yd^2, 45.6 oz/yd^2 and 30.6 oz/yd^2 respectively, were selected to determine the effect of areal density upon ballistic performance. The resultant ballistic efficiency curves are presented in Figure XIII. The curves for the two heavier felt battings are apparently identical below the striking or initial velocity of 900 ft./sec. However, above that value, the 56.2 oz/yd^2 felt has

Figure XIII



Ballistic Performances of Identically Prepared Needled Batts of Different Areal Densities: Hydrophobed 1.25 dpf Dacron (3.0 Cut) greater ability to reduce the speed of the projectile as it passes through. It appears from this limited investigation that the ballistic effectiveness of needled felts increases with an increase in areal density up to a certain value, above which added weight does not produce any significant improvements.

(b) Ballistic Performances of Felts Containing 2" and 3" Staples

The low density felts containing hydrophobed 1.25 dpf Dacron and described in Table II (section A-III-b), were prepared to detect differences in the buoyant-ballistic behaviors of 2" and 3" staple fibers. Samples D and E were processed with 3" fibers while 2" lengths were used in samples F and G. Felts D and F were needled once on one side, while E and G were needled once on both sides. Although some differentiation appears between the ballistic efficiency curves shown in Figure XIV for these items, no definite conclusions may be derived as to the effect of fiber lengths because of the possible influence of the varying areal densities and felt thicknesses.

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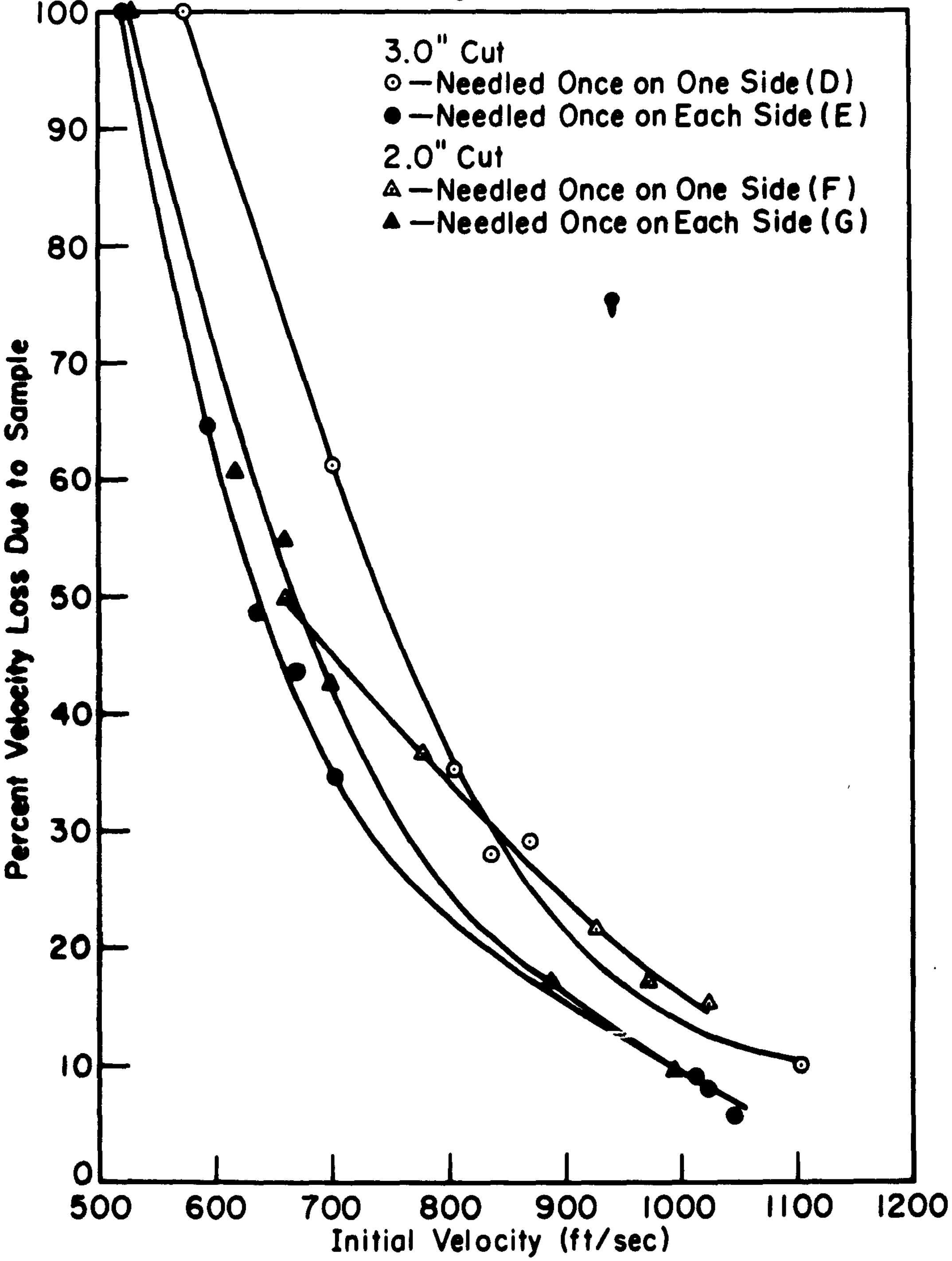
R: 4-4-63
T: 4-5-63

Figure XIV



BALLISTIC PERFORMANCE OF NEEDLED FELTS CONTAINING HYDROPHOBED 1.25 dpf DACRON STAPLE