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Carbon fibers released from composites by aircraft fires and crashes can cause electrical shorts and consequent equipment damage. This report investigates less vigorous release mechanisms than that previously simulated by explosive burn/blast tests.

When AS/3501-6 composites are impacted by various head and weight configurations of a pendulum impactor, less than 0.2 percent by weight of the (over)

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20. ABSTRACT (Continued)

original sample is released as single fibers. Other fiber release mechanisms studied were air blasts, constant airflow, torsion, flexural, and vibration of composite samples.

The full significance of the low single fiber release rates found here is to be evaluated by NASA in their aircraft vulnerability studies.

FOREWORD

The work described in this report was performed in the Environmental Test Chamber at the Naval Surface Weapons Center (NSWC). This test program was sponsored by NASA, Langley Research Center, in support of the aircraft structural parts test program (L62936A) to study the effects of thermal degradation and reduced impact energies (i.e., nonexplosive) upon graphite reinforced plastics. The data and conclusions reported herein will be utilized by NASA in their multiphase accidental release risk analysis program.

Other research groups (i.e., Arthur D. Little Corp., The Bionetics Corp., ORI, Inc., et al) in conjunction with NASA, have also provided inputs of data and analyses that, when brought together by NASA (as chief government agency responsible for risk assessment due to carbon fiber release from civil aircraft), will determine the potential hazard from the accidental release of carbon fibers. Therefore, the results of this report, although they may be of major importance, cannot by themselves indicate the magnitude of the risk in using the particular materials tested.

This document has been reviewed by Dr. K. A. Musselman, Program Manager, Materials Science Branch; J. D. Hall, Head, Materials Science Branch; and D. S. Malyevac, Head, Survivability and Applied Science Division.

Released by:

CDR R. P. FUSCALDO
Assistant for Weapons Systems
Weapons Systems Department

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CONTENTS

OBJECTIVE

The objective of the work described in this report was to design test procedures that would measure the release of single fibers from graphite reinforced epoxy resins. These data were collected to provide information for NASA to be used in their government-wide risk assessment analysis of the electrical hazards from the release of carbon fibers by aircraft accidents. Previous work used explosives to provide the graphite composite breakup energy; this work involved investigating less-energetic methods to disturb the burned/burning aircraft structural materials to provide a broad spectrum of possible fiber release mechanisms. Final risk/vulnerability evaluations of the materials tested are dependent on these reported results, along with other factors being considered by NASA in their extensive vulnerability program.

INTRODUCTION

During the previous two years, NSWC has evaluated various composite aircraft structural members and composite materials for fiber release data. This information for NASA, Langley Research Center, provided inputs for risk assessment evaluations performed elsewhere. All tests were conducted using 57 g of C-4 explosive, which provided the blast force to accomplish the particle dissemination. Alternate, less-vigorous methods of supplying the composite breakup force after burning the test materials were evaluated during the past year.

A standard material was selected to be used for most of the tests [AS/3501-6, 24 ply, 0.34 cm (0.132 in.) thick], except for the initial impact tests. These initial tests, though conducted primarily for equipment proof testing, are reported herein, since they provide some interesting contrasts to the standard AS/3501-6 samples.

Other mechanical properties of the burned composite were briefly evaluated and are reported herein: mechanical impact (pendulum), air impulse (air blast), torsion, flexural, vibration, drop, and continuous airflow. Also reported are some miscellaneous burn-only tests completed during this past year. These tests were conducted using spoiler parts and two spools of Thornel 300 and Hercules HMS graphite fibers. Finally, six tests were conducted on the floorboard material currently used in the Boeing 747--two tests using each method: burn-only, air blast, and constant airflow.

TEST CONDITIONS

PENDULUM IMPACT TESTS

The impact tests were conducted with a test fixture designed so that various mechanical forces could be imparted to the sample using the same basic apparatus. For the pendulum impact mode, the swinging impact arm was constructed so that various removable impactor head configurations could be utilized. The sample holder was designed so that the test specimens could be rotated and impacted at any desired angle. There were two impactor head weights used: 11.34 and 5.44 kg (25 and 12 lb), which were designated as large and small, respectively. Figure 1 shows the four impact heads evaluated in these tests with the five available configurations. The large impactor was reversible, so that it provided both a wedge and a rounded impact face. The small impactor configurations were provided by three separate heads: wedge, square, and rounded leading edge weight.

The samples to be tested were placed in the test fixture (Figure 2) holders so that they were impacted at 0°, 45°, 90°, and 135° from the horizontal. All samples were burned for 20 min with the propane burner 15.2 cm (6 in.) beneath the sample (thermocouple temperatures of 1070±100°C were recorded at the edge of the test specimens).

Impact tests 1-23 were used to confirm operation of the test fixture and to give a qualitative assessment of the effects of the various impact heads and specimen orientation. These tests were made with various scrap pieces of unidentified NASA-provided material, usually 11.4 x 24.1 x 0.64 cm (4.5 x 9.5 x 1/4 in.). Only a minimum amount of sticky paper samples (10) were used for these tests, and the results from them were not evaluated.

A standard sample of AS/3501-6 [24 ply, nominal thickness of 0.34 cm (0.132 in.)] was used for all remaining tests (impact tests 24-63). Duplicate runs were made for the five head configurations at each angular position (0°, 45°, 90°, and 135°).

The pendulum arm had a 121.9 cm (4 ft) travel, so the impact forces involved were on the order of 663.5 and 1382 kg-cm (48 and 100 ft-lb) for the small and large impact weights, respectively.

AIR BLAST TESTS

Six tests were made with an air blast device that directed a blast force of from 13,826 to 27,651 kg-cm (1000 to 2000 ft-lb), depending on accumulator tank pressure, at the burned sample. The device shown in Figure 3 is a model MBA3, Monitor Manufacturing Co. blast aerator.

Four tests were made using the standard AS/3501-6 material evaluated by the pendulum impactor. Also, two tests were run with a Boeing 747 floorboard material, which was a 0.95-cm-thick (3/8-in.-thick) nomex honeycomb with top and bottom layers of graphite/epoxy composite skin.

AIRFLOW TESTS

Two constant air velocities were evaluated for their effects on both burning graphite composites and preburned material. The 10-knot velocity was attained using an air compressor directed through an outlet box with a variable slit opening (Figure 4). Since a 30-knot simulated wind was just beyond the system's capabilities, a *red devil* electric air blower was utilized to provide the desired output for the 30-knot air velocity (Figure 5).

Tests AF 1-4 again evaluated the AS/3501-6 0.34-cm (0.132-in.) sample; this time at airflows of 10 and 30 knots for both burning samples with simultaneous airflow and previously burned (20 min) specimens.

Tests AF 5-16 evaluated T-300 crossplied and unidirectional samples of three different thicknesses. Duplicate runs were not made. Each type material was tested by subjecting it to a 30-knot airflow for 10 min after burning for 10 and 20 min (two samples). A third test sample of each material type and thickness was used for burn-only tests, which gave weight loss and particle distribution background information.

The Boeing 747 floorboard material mentioned earlier was tested similarly in tests AF 17-18 at 30 knots after a 20-min burn period only. Duplicate 20-min burns for background information were made with this material.

Sticky paper samples (total of 50) of the entire chamber area were utilized for particle analysis, which was performed at NASA, Langley Research Center.

MISCELLANEOUS STRENGTH TESTS

The pendulum impact apparatus was modified by various attachments to accommodate the performance of torsion, flexural, vibration, and drop tests. These tests were made for qualitative comparisons of the breakup characteristics of the burned graphite composites with a minimum number of samples. Hence, these tests were relatively simple, and no measurements were taken of the applied or breakdown forces encountered. Two tests of each mode were conducted, except with the vibration tests, where three were completed. Again, these tests were conducted using the AS/3501-6 standard 24-ply material.

For the torsion test (Figure 6), the sample was preburned for 20 min with one side of the sample holder twisted by a constant speed motor attached to this end through a wire cable and pulley arrangement. The rotational speed of the two tests was 0.5 cm/sec (0.2 in./sec).

Figure 7 shows the arrangement for the two flexural tests using a different clamping configuration for the free end of the sample. Burn times of 5 and 20 min were used for the two flexural tests. This test was also conducted at a 0.5-cm/sec (0.2-in./sec) arm movement speed.

Vibration tests were run at 30 cycles/sec with a deflection of ±0.64 cm (0.25 in.) using the same attachment arm that was used in the flexural tests. This arm was connected to the vibration motor directly beneath the sample by the rod shown in Figure 8.

Two drop tests of preburned AS/3501 specimens were accomplished by placing the weighed specimens on a flat plate attached to the arm of the pendulum impactor (Figure 9). The sample was dropped by releasing the solenoid that held the arm in a horizontal position with the specimen dropping to the floor from a height of 215-227 cm (84-89 in.).

BURN TESTS

Burn tests conducted to gather weight loss and particle analysis information were run independently of the previously described tests. These tests were run under essentially the same conditions, with the burn times varied as required. The same two propane burners with constant gas pressure have been used throughout the entire HAVE NAME Environmental Test Chamber test programs. Some variations in temperature have been attained as measured by a chromel-alumel thermocouple usually placed 0.63-1.25 cm (0.25-0.50 in.) from the outer edge of the sample. Thermocouple short circuits and infrequent improper thermocouple location are the chief causes of the low-temperature readings that were occasionally recorded.

Included in these separate burn-only tests were three spoiler parts that were burned for 20 min each. These parts corresponded to sections 1, 2, and 9 of spoiler 1 (Figure 10), which was burned earlier.[1]

Two spools of graphite yarn material were burned for 20 min each in BT-247 and BT-267: 453.6 g (1 lb) of Union Carbide Thornel 300, Grade WYP, lot 576.0; and 630.5 g (1.39 lb) of Hercules HMS, batch 3N-1. Both samples were burned as received, with the T-300 on a cardboard spool and the HMS on a plastic spool.

A series of burn tests for weight loss and particle emission information was conducted for the AS/3501-6 standard sample at 1-, 3-, 5-, 10-, and 20-min burn times in BT-249 through BT-258.

TEST RESULTS

PENDULUM IMPACT TESTS

During the initial pendulum impact tests with the NASA scrap samples, 10 sticky papers per test were the maximum number used; these were not analyzed for particle count. Test 19 was the first one where the sample was drilled and bolted to the sample holder. In some of the first 18 tests, the sample may have been torn loose from the holder instead of being shattered by the impactor head.

Figures 11 and 12 show the results of impact 17, where a weave configuration material did not break up into any significant amount of smaller particles. Most of these earlier impacts using scrap samples were thicker than the standard material used in tests 24-63. They seemed to produce more smaller particles on impact than the 24-ply material [0.34 cm (0.132 in.)] thick . Impact 20 (Figures 13 and 14) illustrates the case of the thicker material (except for weave types) giving more relative amounts of finer particles.

Figures 15 and 16 show the appearance of the impacted sample and the residues found on the floor from test 24, which was a horizontal (0°) specimen hit by a large, rounded face impactor. The residue shown is fairly typical of that produced from all the standard samples tested.

Table 1 gives the parameters for all the pendulum impact tests, and Tables 2 and 3 give the results of the tests for both the scrap and AS/3501-6 specimens, respectively. They show the zapper activity observed, residue appearance, weights recovered, and impactor travel. The impactor travel measured the maximum angle from the vertical axis of the sample plane through which the pendulum swung as it penetrated through the specimen. No significant differences in the amounts of residues or percentage of single fibers produced in the various tests of the AS/3501 standard samples could be determined. This was apparent whether considering the position of the specimen before impact (0°, 45°, 90°, or 135°) or the type or size of the impact head.

Table 1. Pendulum Impact Test Parameters

Test	Sample Weight (g)	Burn Time (min)	Impact Head*	Sample Position (deg)	Sample Type
1	298.1	10	S,F	0	Scrap
2	299.4	10	S,F	45	Scrap
3	266.3	10	S,F	90	Scrap
4	340.5	10	S,F	135	Scrap
5A	270.5	20	S,F	0	Scrap
6	254.9	20	S,F	45	Scrap
7	266.6	20	L,W	0	Scrap
8	266.7	20	L,W	45	Scrap
9	328.1	20	L,W	90	Scrap

Table 1. Pendulum Impact Test Parameters (Continued)

Test	Sample Weight (g)	Burn Time (min)	Impact Head*	Sample Position (deg)	Sample Type
10	67.7	N/A	L,W	45	AS/3501/Crossply
11	69.0	N/A	L,W	45	AS/3501/Unidirectional
12	105.7	N/A	L,W	45	AS/3501/Unidirectional
13	154.5	N/A	L,W	45	AS/3501/Crossply
14	264.0	20	L,R	45	Scrap
15	304.9	20	[illegible],W	45	Scrap
16	265.6	20	S,W	90	Scrap
17	389.2	20	S,R	45	Scrap
18	260.0	20	S,R	90	Scrap
19	173.2	20	S,R	0	Scrap
20	251.9	20	S,R	45	T-300/520
21	238.8	20	L,W	0	T-300/520
22	239.5	20	L,W	90	T-300/520
23	237.6	20	L,R	45	T-300/520
24	114.4	20	L,R	0	AS/3501, 24 Ply
25	114.2	20	L,R	45	AS/3501, 24 Ply
26	114.0	20	L,R	90	AS/3501, 24 Ply
27	114.6	20	L,[illegible]	135	AS/3501, 24 Ply
28	114.9	20	L,R	0	AS/3501, 24 Ply
29	115.0	20	L,R	45	AS/3501, 24 Ply
30	115.7	20	L,R	90	AS/3501, 24 Ply
31	115.7	20	L,R	135	AS/3501, 24 Ply
32	113.8	20	S,R	0	AS/3501, 24 Ply
33	116.9	20	S,R	45	AS/3501, 24 Ply
34	115.6	20	S,R	90	AS/3501, 24 Ply
35	107.7	20	S,R	135	AS/3501, 24 Ply
36	105.0	20	S,R	0	AS/3501, 24 Ply
37	114.6	20	S,R	45	AS/3501, 24 Ply
38	113.9	20	S,R	90	AS/3501, 24 Ply
39	114.8	20	S,R	135	AS/3501, 24 Ply
40	115.6	20	L,W	0	AS/3501, 24 Ply
41	113.7	20	L,W	45	AS/3501, 24 Ply
42	114.0	20	L,W	90	AS/3501, 24 Ply
43	112.8	20	L,W	135	AS/3501, 24 Ply
44	112.6	20	L,W	0	AS/3501, 24 Ply
45	101.9	20	L,W	45	AS/3501, 24 Ply
46	106.6	20	L,W	90	AS/3501, 24 Ply
[illegible]	108.1	20	L,W	135	AS/3501, 24 Ply
48	107.5	20	S,W	0	AS/3501, 24 Ply
49	106.0	20	S,W	45	AS/3501, 24 Ply
50	102.5	20	S,W	90	AS/3501, 24 Ply
51	104.7	20	S,W	135	AS/3501, 24 Ply
52	105.7	20	S,W	135	AS/3501, 24 Ply
53	103.1	20	S,W	0	AS/3501, 24 Ply
54	104.6	20	S,W	45	New Panel
55	103.8	20	S,W	90	New Panel
56	103.4	20	S,Sq	0	New Panel
57	103.9	20	S,Sq	45	New Panel
58	102.6	20	S,Sq	90	New Panel
59	102.6	20	S,Sq	135	New Panel
60	103.7	20	S,Sq	0	New Panel
61	102.8	20	S,Sq	45	New Panel
62	103.0	20	S,Sq	90	New Panel
63	103.5	20	S,Sq	135	New Panel

* L = Large
S = Small
F = Flat
R = Round
Sq = Square
W = Wedge

Table 2. Pendulum Impactor Test Results From Miscellaneous Graphite/ Epoxy Samples

Test	Zapper Activity	Residue Appearance	Recovery Breakdown (%) Hand 1	Hand 2	Broom
1	2-3 events	98% remained in holder	--	N/A	--
2	None	98% in one piece thrown out	--	N/A	--
3	1 arc	Broke loose from one side	--	N/A	--
4	--	No data recorded	--	--	--
5	--	No data recorded	--	--	--
6	--	No data recorded	75.6	--	0.7 (vac)
7	Light activity, 1-2 min	Laminar strips	61.5	11.0	2.8
8	1-2 events, 3-4 min after	One piece thrown clear, fibrous, stuck on impactor	--	72.9	(Hand & Broom)
9	2 min after, light, sparadic	One large piece and laminar	65.1	14.1	1.1
10	1-2 arcs	Some smaller particles, heavy, not fibrous	80.2	--	18.3
11	Few arcs, 1-2, 3-4, 5, 8 min	Large piece hit zapper, fibrous, stringy in sample holder	--	98.8	--
12	Minor activity	Fine material produced coated w/resin	60.3	13.6	22.1
13	1-2 arcs, 1-2 min after	Similar to 12, bigger pieces of laminar	33.0	38.2	27.0
14	After 1 min for 3-4 min	Most in one piece, some laminar, fibrous	65.1	4.8	1.7
15	Medium activity, 2-3 min	Weave, most residue in sheets	32.0	37.0	0.7
16	1 min, sample hit zapper	Most in one piece, laminar strips, minor laminar fragments	69.4	5.7	0.3
17	Medium activity, 2 min	Weave, layers laminar strips	63.8	10.7	0.8
18	Medium activity, 1-2 min	Most in one piece laminar, lint, brush clump	70.6	3.7	0.5
19	None	Most remained in holder	77.5	--	--
20	None	Laminar and small fragments	35.1	--	34.0
21	None	Laminar small fragments and fibrous residue in holder	44.6	--	26.0
22	None	Mostly large laminar	28.1	--	44.7
23	Slight activity	Blast type (more), laminar strips (less)	42.3	--	27.6

Table 3. Pendulum Impactor Test Results From AS/3501-6, 24-Ply Samples

Test	Zapper Activity	Residue Appearance	Weight Percent Recovery Fixture	Weight Percent Recovery Floor	Impactor Travel (deg)
24	None	Brush clump, strips	57.3	12.7	73
25	1 (laminar strip)	Laminar strips	58.6	7.1	84
26	None	Thin laminar strips	68.3	5.0	80
27	None	Laminar strips, Short	53.6	11.6	85
28	1 arc at 15 sec	Laminar and brush clump,	53.0	18.8	75
29	None	Thin laminar strips	60.1	5.7	85
30	None	Thin laminar strips	69.1	6.1	81
31	1 at 4 min	Wide and thin laminar	55.1	5.5	85
32	1 at 2 min	Brush clump, laminar	58.4	7.0	53
33	None	Mostly laminar, some brush clump	57.1	8.0	71
34	None	Thin laminar strips	71.0	2.9	67
35	None	Thin laminar strips	52.2	10.9	73
36	2 arcs, 1/2 and 1-1/2 min	Laminar, wide and thin	59.0	5.9	60
37	None	Laminar, wide and thin	54.9	6.9	72
38	None	Laminar, mostly wide	53.5	9.3	54
39	3 arcs	Wide laminar, brush clump	52.8	10.0	75
40	3 at 20, 30, 75 sec	Large clumps, laminar	52.9	10.9	74
41	1 arc at 1-1/2 min	Thin laminar	60.3	5.7	84
42	None	Thin laminar on floor; wide, stuck to impactor face	70.4	4.6	83
43	None	Brush clump, laminar strips	55.7	8.0	85
44	2 arcs 10-20 sec after impact	Brush clump, wide and narrow laminar	52.8	9.3	77
45	1 arc 2-1/2 min after impact	Mostly thin laminar	56.0	5.2	84
46	None	Thin laminar	70.1	5.4	82
47	None	Wide and narrow laminar, brush clump	50.1	7.4	85
48	Arcs at 15-90 sec after impact	Mostly brush clump, wide laminar	51.2	11.0	55
49	2 arcs, 15 sec, 4 min after impact	Mostly thin laminar, minor amount of brush clump	54.2	10.1	79

Table 3. Pendulum Impactor Test Results From AS/3501-6, 24-Ply Samples (Continued)

Test	Zapper Activity	Residue Appearance	Weight Percent Recovery Fixture	Weight Percent Recovery Floor	Impactor Travel (deg)
50	None	Mostly wide laminar	68.5	6.0	78
51	None	Brush clump, wide laminar	51.7	9.8	75
52	4 arcs 30, 40, 80 sec, 4 min after impact	Bulk of residue in 1 clump, some narrow laminar	53.7	10.9	74
53	1 arc 2 min after impact	Brush clump, assorted laminar, some short pieces	55.2	11.0	62
54	5-10 arcs 10-30 sec after impact	Brush clump, laminar, one larger piece in floor residue	47.8	9.6	75
55	1 arc 15 sec after impact	Mostly thin laminar strips	66.5	6.0	76
56	1 arc 30 sec after impact	Brush clump, thin, wide laminar	55.0	12.4	63
57	5 arcs, 15-20 sec after impact	Mixture thick and thin laminar	46.6	15.1	75
58	None	Thin laminar, small amount	68.5	4.8	72
59	1 arc 20 sec after impact	Wide and thin laminar	55.2	11.2	77
60	None	Wide laminar, brush clump	49.4	11.0	63
61	None	Brush clump, wide and narrow laminar	50.5	11.4	74
62	1 arc 1-1/2 min after impact	Small amount, mostly thin laminar	67.5	5.7	73
63	None	Brush clump, thin laminar, minor amounts of wide laminar	51.0	12.7	75

Figure 17, from test 27, shows the test fixture residue where the specimen appears to be more severely disturbed than most other samples, yet, the residue was dispersed about the same as the others.

Table 4 gives the results of the sticky paper analysis of the compartment test residues as reported by NASA, Langley Research Center. Test 56, which gave one of the highest particle counts, exhibited the typical visual amounts of residue (Figures 18 and 19). Note that the greatest amount of residues seen are laminar strips. This run was made with the small, square faced impactor at 0° (horizontal). Figures 20 and 21 show the case where the specimen does not appear to be disturbed significantly, yet, the residues are typical and evenly distributed on the floor in front of the test apparatus. These residues were from run 58, in which a small, square impactor configuration was used and the sample was positioned at a 90° orientation. Figures 22 and 23 (run 63) show a severely broken up test specimen. Particle analysis was not run on this particular specimen because it was a duplicate run of impact 59.

In general, visual observations of either residue or zapper activity did not reveal which samples produced more single fibers; however, post test sticky paper particle analysis did. The weight of material dispersed by the action of the pendulum impacting the samples was not significantly large, and the area over which the particles hit the floor (and sticky papers) was small.

AIR BLAST TESTS

Test parameters and results are presented in Table 5, and single fiber release data are tabulated in Table 6. Although the Boeing floorboard material was thicker than the AS/3501 specimens (1-4), it was lighter due to its honeycomb type structure and, hence, were more easily broken up by the blast forces. Typical results obtained from these two materials are shown in Figures 24 and 25 for the AS/3501 and Figure 26 for the Boeing floorboard material. As with the previous pendulum impact tests, no significant amounts of free fibers could be seen with the other residues on the compartment floor after these tests. Nevertheless, free-floating fibers could be observed immediately after each air blast by looking into the floodlight beam used to illuminate the test fixture. The test residues were scattered over a wide area (Figure 25), but they were not significantly different in appearance than those from the pendulum impact, although there may be less of the wide laminar strips produced by the air blast.

The particle counts of single fibers increased in this series of tests. The AS/3501 differed from the floorboards in that they produced fewer singles and were of standard length. The longer fibers from the floorboard specimens were noted by both visual observation and from the particle analysis data. Neither material produced any great increase in zapper activity commensurate with their increased percentage.

Table 4. Effects of Pendulum Impact on Release of Carbon Fiber From Burned Composite Samples (AS/3501-6, 0.34-cm-Thick)

Sample	Sample Weight (g)	Carbon Fiber Weight (g) (calculated)	Test Parameter*	Number of Carbon Fibers Collected	Number of Carbon Fibers for Test	Weight of Carbon Fibers (g)	Average Length (mm)	Percent Carbon Fiber
IMP-24	114.4	80.1	25-R-0	4.3×10^4	8.2×10^5	0.10	1.3	0.13
IMP-25	114.2	80.0	25-R-45	3.1×10^4	5.9×10^5	0.11	2.0	0.13
IMP-26	114.0	79.7	25-R-90	4.3×10^4	8.2×10^5	0.18	2.4	0.22
IMP-27	114.6	80.1	25-R-135	4.2×10^4	8.0×10^5	0.15	2.1	0.19
IMP-31	115.7	81.0	25-R-135	3.4×10^4	6.4×10^5	0.11	1.9	0.14
IMP-32	113.8	79.6	12-R-0	3.2×10^4	6.1×10^5	0.09	1.6	0.11
IMP-33	116.9	81.8	12-R-45	5.0×10^4	9.6×10^5	0.18	2.0	0.22
IMP-34	115.6	81.0	12-R-90	2.2×10^4	4.2×10^5	0.03	0.8	0.04
IMP-35	107.7	75.4	12-R-135	2.5×10^4	4.8×10^5	0.07	1.5	0.09
IMP-40	115.6	81.0	25-W-0	6.1×10^4	10.7×10^5	0.13	1.4	0.16
IMP-45	101.9	71.3	25-W-45	5.0×10^4	9.6×10^5	0.17	2.0	0.24
IMP-42	114.0	79.8	25-W-90	2.6×10^4	5.0×10^5	0.09	2.1	0.11
IMP-43	112.8	78.9	25-W-135	4.7×10^4	9.0×10^5	0.19	2.4	0.24
IMP-48	107.5	75.3	12-W-0	4.6×10^4	8.8×10^5	0.14	1.8	0.19
IMP-49	106.0	74.2	12-W-45	2.4×10^4	4.6×10^5	0.07	1.6	0.09
IMP-50	102.5	71.8	12-W-90	3.3×10^4	6.3×10^5	0.12	2.2	0.17
IMP-51	104.7	73.2	12-W-135	3.6×10^4	6.9×10^5	0.14	2.2	0.19
IMP-56	103.4	72.5	12-F-0	6.5×10^4	12.4×10^5	0.20	1.8	0.28
IMP-57	103.9	72.6	12-F-45	3.8×10^4	7.3×10^5	0.14	2.1	0.19
IMP-58	102.6	71.8	12-F-90	2.3×10^4	4.4×10^5	0.07	1.8	0.10
IMP-59	102.6	71.8	12-F-135	3.5×10^4	6.6×10^5	0.11	1.8	0.15

* Weight of pendulum head (lb)--shape of head (flat, round, or wedge)--angle of impact (deg)

Table 5. Air Blast of Graphite Composites, Test Parameters and Results

Test	Sample Type	Sample Size (cm)	Sample Weight (g)	Temperature (C)	Recoveries Weight (g)/ % Original Weight Fixture	Broom	Vacuum	Tank Pressure (psi)	Sample (deg)*
AB-1	AS/3501-6	15.2x15.2x0.34	103.6	1150	52.4/50.6	25.1/24.2	13.2/12.7	95**	90
AB-2	AS/3501-6	15.2x15.2x0.34	103.4	1230	42.8/41.4	33.5/32.4	6.3/6.1	75	90
AB-3	AS/3501-6	15.2x15.2x0.34	102.6	1188	10.0/9.7	64.2/62.6	3.4/3.3	98	45
AB-4	AS/3501-6	15.2x15.2x0.34	103.6	1150	37.3/36.0	41.8/40.3	3.4/3.3	50	45
AB-5	Boeing 747 Floorboard; Honeycomb	15.2x15.2x0.96	66.2	1200	2.6/3.9	25.0/37.8	8.5/12.8	99	45
AB-6	Boeing 747 Floorboard; Honeycomb	15.2x15.2x0.96	68.2	1176	3.5/5.1	21.6/31.7	7.2/10.6	98	45
AB-7	Boeing 767 Floorboard; Graphite/Epoxy	15.2x15.2x0.96	64.5	—	1.0/1.6	27.1/42.0	6.4/9.9	99	45
AB-8	Boeing 767 Floorboard; Graphite-Kevlar/Honeycomb	15.2x15.2x0.96	52.1	—	1.5/2.9	12.1/23.2	5.8/11.1	98	45

* Sample angle (deg)--displacement of sample from horizontal (0°)
** May have been less--pressure released prematurely.

Table 6. Effect of Air Blasts on Release of Single Carbon Fibers From Burned* Graphite/Epoxy Composites

Test	Sample Weight (g)	Carbon Fiber Weight (g) (calculated)	Blast Velocity (ft/sec)	Number of Carbon Fibers Collected	Number of Carbon Fibers for Test	Weight of Carbon Fibers (g)	Average Length (mm)	Percent Carbon Fiber
AB-1	103.6	72.5	800	1.39×10^5	8.9×10^6	1.76	2.2	2.4
AB-2	103.4	72.4	310	1.61×10^5	10.3×10^6	1.76	1.9	2.4
AB-3	102.6	71.8	800	1.81×10^5	11.6×10^6	2.61	2.5	3.6
AB-4	103.6	72.5	230	1.49×10^5	9.5×10^6	1.71	2.0	2.4
AB-5	66.2	13.9	800	4.32×10^4	2.22×10^6	1.08	5.4	7.8
AB-6	68.2	14.3	800	4.28×10^4	2.19×10^6	1.18	5.0	8.3
AB-7	64.5	21.2	800	4.20×10^4	2.15×10^6	0.50	2.6	2.4
AB-8	52.1	6.83	800	3.18×10^4	1.63×10^6	0.47	3.2	6.9

* All samples burned for 20 min, propane burner

AIRFLOW TESTS

In the airflow series of tests, essentially three sets of samples were evaluated. The parameters for the tests are summarized in Table 7, and Table 8 gives the test conditions and weight losses for the control samples burned to give basic data for the subsequent airflow series of T-300 and Boeing floorboard specimens.

Table 7. Airflow Test Parameters

Test	Sample Type	Sample Size (cm)	Sample Weight (g)	Burn Time (min)	Airflow (knots)
AF-1	AS/3501-6/24 Ply	15.2x15.2x0.34	102.8	20	10*
AF-2	AS/3501-6/24 Ply	15.2x15.2x0.34	102.2	20	10
AF-3	AS/3501-6/24 Ply	15.2x15.2x0.34	103.7	20	30*
AF-4	AS/3501-6/24 Ply	15.2x15.2x0.34	103.6	20	30
AF-5	T-300/Crossply	14.6x14.6x0.64	191.3	10	30
AF-6	T-300/Crossply	14.6x14.6x0.64	198.4	20	30
AF-7	T-300/Crossply	14.6x14.6x0.32	96.7	10	30
AF-8	T-300/Crossply	14.6x14.6x0.32	96.3	20	30
AF-9	T-300/Crossply	14.6x14.6x0.16	49.9	10	30
AF-10	T-300/Crossply	14.6x14.6x0.16	49.2	20	30
AF-11	T-300/Unidirectional	14.6x14.6x0.64	195.3	10	30
AF-12	T-300/Unidirectional	14.6x14.6x0.64	190.4	20	30
AF-13	T-300/Unidirectional	14.6x14.6x0.32	101.1	10	30
AF-14	T-300/Unidirectional	14.6x14.6x0.32	101.2	20	30
AF-15	T-300/Unidirectional	14.6x14.6x0.16	52.9	10	30
AF-16	T-300/Unidirectional	14.6x14.6x0.16	52.1	20	30
AF-17	Boeing 747 Floorboard	15.2x15.2x0.95	67.0	20	30
AF-18	Boeing 747 Floorboard	15.2x15.2x0.95	68.3	20	30
AF-19	Boeing 767, Graphite/Epoxy	15.2x15.2x0.95	63.8	20	30
AF-20	Boeing 767, Graphite-Kevlar	15.2x15.2x0.95	51.9	20	30

* During burn period, all other tests for 10 min after burn completed.

Table 8. Burn Test Parameters and Weight Loss, Airflow Test Sample Controls

Test	Sample Type	Sample Size (cm)	Weight (g)	Burn Time (min)	Temperature (C)	Weight Loss (%)
BT-259	T-300/Crossply	14.6x14.6x0.64	194.4	20	1070	18.9
BT-260	T-300/Crossply	14.6x14.6x0.32	96.6	20	1044	26.9
BT-261	T-300/Crossply	14.6x14.6x0.16	48.8	20	1076	27.9
BT-262	T-300/Unidirectional	14.6x14.6x0.64	194.3	20	1072	18.1
BT-263	T-300/Unidirectional	14.6x14.6x0.32	102.4	20	1176	22.8
BT-264	T-300/Unidirectional	14.6x14.6x0.16	52.1	20	1044	32.8
BT-265	Boeing 747 Floorboard	15.0x15.0x0.95	64.9	20	1046	51.0
BT-266	Boeing 747 Floorboard	15.0x15.0x0.95	65.6	20	1058	49.4
BT-268	Boeing 767 Floorboard, Graphite/Epoxy	15.2x15.2x0.95	63.3	20	—	43.0
BT-269	Boeing 767 Floorboard, Graphite-Kevlar/Epoxy	15.2x15.2x0.95	62.6	20	1050	57.2

The AS/3501 tests (1-4) showed that simultaneous airflow and burning caused very little disturbance of the sample; although, at 10 knots, the sticky paper analysis indicated the presence of some free fibers.

The control test results shown in Table 9 and the airflow test recoveries in Table 10 indicate that the T-300 unidirectional samples were slightly less subject to single fiber release than the T-300 crossply material. In both cases, the weight percent recovered from the test fixture after the 10-min runs closely approximated that of the respective burn-only test. This was true in all cases except for AF-9, where a 27.9-percent weight loss in the corresponding burn test (BT-261) would have resulted in 72.1 percent retained in the test fixture instead of the actual 53.3 percent. This was the thinnest cross-section piece of the crossply type tested. Less material was dispersed from the 20-min burn with this thickness of crossply also; this was in contrast to all other pairs tested (10-min burn times vs 20 min for each type). It was noted that some of the test specimens were partially delaminated prior to testing, which indicated nonuniform construction and a possible source of run variation.

All samples (T-300) showed an increase in weight loss as sample thickness decreased. The unidirectional samples were placed in the test fixture so that the fiber direction was perpendicular to the airflow direction, which gave them more resistance to this disturbance and a more uniform test condition than for the crossply samples.

Table 9. Effect of Burn on Single Fiber Release From Constant Airflow Test Sample Controls

Test	Sample Weight (g)	Carbon Fiber Weight (g) (calculated)	Number of Carbon Fibers Collected	Total Carbon Fibers for Test	Weight of Carbon Fibers (g)	Average Length (mm)	Percent Carbon Fiber
BT-259	194.4	152.0	378	2.42×10^4	0.0029	1.3	0.0019
BT-260	96.6	69.9	486	3.11×10^4	0.0073	2.6	0.0105
BT-261	48.8	37.4	4050	2.59×10^5	0.0540	2.3	0.1440
BT-262	194.3	155.0	7610	4.87×10^5	0.1000	2.3	0.0650
BT-263	102.4	79.4	1526	9.76×10^4	0.0180	2.0	0.0230
BT-264	52.1	39.2	2817	1.80×10^5	0.0290	1.8	0.0740
BT-265	64.9	13.6	117	7.49×10^3	0.0007	1.0	0.0040
BT-266	65.6	13.8	117	7.49×10^3	0.0030	4.5	0.0170
BT-268	63.3	20.8	2268	1.16×10^5	0.0400	4.0	0.1920
BT-269	52.6	6.89	972	4.99×10^4	0.0150	3.3	0.2130

Table 10. Constant Airflow Tests of Graphite Composites, Test Results

Test	Residue Description	Residue Fixture Weight (g/%)	Recovery Total Weight (g/%)	Zapper Activity
AF-1	Few thin strips on floor	87.7/85.3	87.7/85.3	None
AF-2	Laminar, some clumps	---	53.9/52.7	Slight
AF-3	Sample charred, layer separation	101.1/97.5	101.1/97.5	None
AF-4	Center section of sample blown away	41.6/40.2	50.1/48.4	Sporadic, over entire airflow
AF-5	Sample relatively undisturbed except for burning effects	158.4/82.8	158.4/82.8	None
AF-6	Upper layer sample eroded, one corner	149.5/75.4	150.0/75.6	3 arcs, 8-9 min
AF-7	Sample eroded slightly	70.6/73.0	70.6/73.0	None
AF-8	Large laminar pieces blew off	54.7/56.8	59.5/61.8	Slight, free-floating fibers visible
AF-9	Forward section of sample eroded	26.6/53.3	27.2/54.9	Moderate
AF-10	Top layer eroded through center	27.6/56.1	28.1/57.1	Frequent, 1-1/2-2-1/2 min after air on
AF-11	Sample essentially intact	164.3/84.1	164.3/84.1	Sporadic
AF-12	Some erosion of top sample layer	146.9/77.2	146.9/77.2	Moderate

Table 10. Constant Airflow Tests of Graphite Composites, Test Results (Continued)

Test	Residue Description	Residue Fixture Weight (g/%)	Recovery Total Weight (g/%)	Zapper Activity
AF-13	Top center of sample eroded (2-3 layers)	78.1/77.3	78.1/77.3	Very light
AF-14	Top layer peeled back, intact	75.5/74.6	75.5/74.6	Minimal, 2-3 arc
AF-15	Hole eroded through center of sample	37.2/70.3	37.2/70.3	Very slight
AF-16	Front and rear portions eroded	33.1/63.5	33.1/63.5	1 arc
AF-17	Cloth, laminar, piece of honeycomb on floor	22.0/32.8	29.0/43.3	Moderate, 2 min
AF-18	Laminar, brush clump on floor, much of honeycomb remained with sample, forward half of sample mostly gone	24.2/35.4	28.6/41.9	Moderate, long fibers visible
AF-19	Top layer disintegrated, mostly pieces of weave residue on floor	13.0/20.4	20.5/32.1	Heavy activity
AF-20	Top layer peeled back, honeycomb material blown out of sample residue	12.3/23.7	21.7/41.8	Moderate

The Boeing 747 floorboard sample, which lost approximately 50 percent of its original weight during the 20-min burn period, produced some longer single fibers as observed visually. No 10-min burn period samples were run with this material, because of the limited number of specimens available.

Figure 27 (AF-9 test fixture residue) shows the remains of the 0.16-cm-thick (6.3-in.-thick) crossply material after the 10-min burn. Figure 28 of AF-11 shows the residue for the thickest [0.64 cm (0.25 in.)] specimen after a 10-min burn, while Figure 29 (AF-12) shows the residue for the 30-knot test of the 0.64-cm (0.25-in.) unidirectional material after a 20-min burn. The remains from the floorboard specimen of AF-17, both in the test fixture and on the floor, are shown in Figures 30 and 31. The light-colored material in Figure 31, best observed on the nearest sticky paper, is some of the cloth-like residue (fiber glass). Table 10 gives the zapper activity and briefly describes the residues for each airflow test.

Table 11 summarizes the fiber count data for the airflow tests. The correlation between the weight losses of the burn samples and the percent of free fibers from the weight percent by sticky paper analysis was direct for the T-300 crossply samples. For the crossply samples, increased weight losses were always accompanied by increased fiber counts, which indicates that these data were realistic if not numerically precise. For example, the 0.16-cm-thick (0.063-in.-thick) crossply samples (AF-9 and 10) showed unusually low recovery percentages (54.9 and 57.1) for the 10- and 20-min burn times and fiber percentages of 3.64 and 2.18, respectively. Although

Table 11. Effect of Airflow* on Release of Single Carbon Fibers From Burned Composites

Test	Sample Weight (g)	Carbon Fiber Weight (g) (calculated)	Burn Time (min)	Number of Carbon Fibers Collected	Number of Carbon Fibers for Test	Weight of Carbon Fibers (g)	Average Length (mm)	Percent Carbon Fiber
AP-1	102.8	72.0	20	8,640	$5.52x10^5$	0.210	4.3	0.30
AP-2	102.2	71.6	20	9,460	$6.1x10^5$	0.170	3.2	0.24
AP-3	103.7	72.5	20	2,380	$1.52x10^5$	0.047	3.4	0.07
AP-4	103.6	72.5	20	45,400	$2.9x10^6$	0.600	2.3	0.8
AP-5	191.8	150.0	10	2,561	$1.65x10^5$	0.031	2.1	0.02
AP-6	198.4	155.0	20	36,370	$2.33x10^6$	0.500	2.4	0.32
AP-7	96.7	70.0	10	6,123	$3.92x10^5$	[illegible]	1.7	0.086
AP-8	96.3	69.5	20	181,250	$1.16x10^7$	1.040	1.7	1.44
AP-9	49.9	38.2	10	93,150	$5.95x10^6$	1.390	2.6	3.64
AP-10	49.2	37.7	20	78,410	$5.01x10^6$	0.820	1.8	2.18
AP-11	195.3	156.0	10	42,390	$2.72x10^6$	0.490	2.0	0.31
AP-12	190.4	152.0	20	162,000	$1.04x10^7$	1.500	1.6	1.05
AP-13	101.1	78.3	10	20,250	$1.30x10^6$	0.210	1.8	0.27
AP-14	101.2	78.4	20	5,940	$3.80x10^5$	0.082	2.4	0.10
AP-15	52.9	39.7	10	8,640	$5.53x10^5$	0.100	2.0	0.25
AP-16	52.1	39.2	20	5,400	$3.46x10^5$	0.065	2.1	0.17
AP-17	67.0	14.1	20	5,790	$2.96x10^5$	0.150	9.5	1.1
AP-18	68.3	14.4	20	9,450	$4.84x10^5$	0.310	7.1	2.2
AP-19	63.8	20.9	20	94,700	$4.85x10^6$	0.865	2.0	4.1
AP-20	51.9	6.8	20	4,270	$2.19x10^5$	0.077	3.9	1.1

* AP-1--10-knots airflow during burn period
AP-2--10-knots airflow subsequent to burn period
AP-3--30-knots airflow during burn period
AF-4--18-knots airflow subsequent to burn period

one would expect the 10-min burn to have a greater material recovery and less free fibers produced than the 20-min burn, the test results were consistent (i.e., greater weight loss was accompanied by increased single fibers produced).

The unidirectional samples did not show any relationship between the burn test results and fiber count data, except for the 0.64-cm-thick (0.25-in.-thick) specimens. When considering the sample compositions, the weight recoveries for these samples were not too far off that expected. As stated earlier, the poor quality of the specimens and their cracking when bolted to the test fixture may account for some of the anamolous data. The 0.64-cm (0.25-in.) specimen burned for 20 min (AF-12) was the only unidirectional sample with a relatively high fiber count (1.05 percent).

The long fibers noted visually for the floorboard samples was corroborated in the sticky paper analysis, and the percentages were reproducible in the two tests (AF-17 and -18) at 1.1 and 2.2 percent, respectively.

MISCELLANEOUS STRENGTH TESTS

Since this group of tests was not conducted to determine actual residual strengths of the burned composites but rather comparative analyses between sample targets, the results were evaluated for the entire group as a single entity. The residue produced looked similar for each separate test and consisted mostly of wide laminar pieces. The resultant dispersed residue did not travel far from the test fixture, and no significant zapper activity was observed throughout the entire group of tests. Table 12 gives the test parameters, and Table 13 gives the single fiber counts for the group. As observed in Table 13, the fiber counts were of the same order of magnitude, except with the two torsional tests, in which the test mode was not reproducible (0.18 and 0.09 percent singles).

Table 12. Miscellaneous Strength Tests Parameters

Test	Type Test	Sample Type	Sample Size (cm)	Sample Weight (g)	Test Parameter
TOR-1	Torsion	AS/3501-6	15.2x15.2x0.34	103.3	Speed = 0.5 cm/sec
TOR-2	Torsion	AS/3501-6	15.2x15.2x0.34	104.1	Speed = 0.5 cm/sec
FLX-1	Flexural	AS/3501-6	15.2x15.2x0.34	102.9	Speed = 0.5 cm/sec
FLX-2	Flexural	AS/3501-6	15.2x15.2x0.34	102.6	Speed = 0.5 cm/sec
VIB-1	Vibration	AS/3501-6	15.2x15.2x0.34	103.4	30 Hz, ±0.64 cm
VIB-2	Vibration	AS/3501-6	15.2x15.2x0.34	103.6	30 Hz, ±0.64 cm
VIB-3	Vibration	AS/3501-6	15.2x15.2x0.34	103.[illegible]	30 Hz, ±0.64 cm
DP-1	Drop	AS/3501-6	15.2x15.2x0.34	103.2	Drop height = 215 cm
DP-2	Drop	AS/3501-6	15.2x15.2x0.34	104.3	Drop height = 227 cm

Table 13. Effects of Miscellaneous Strength Tests on Release of Single Carbon Fibers From Burned AS/3501-6 Composites

Test	Sample Weight (g)	Carbon Fiber Weight (g) (calculated)	Number of Carbon Fibers Collected	Number of Carbon Fibers for Test	Weight of Carbon Fibers (g)	Average Length (mm)	Percent Carbon Fiber
TOR-1	103.3	72.3	1.04×10^4	6.6×10^5	0.131	2.2	0.18
TOR-2	104.1	72.8	4.10×10^3	2.6×10^5	0.063	2.7	0.09
FLX-1	102.9	72.0	6.70×10^3	4.3×10^5	0.116	3.0	0.16
FLX-2	102.6	71.8	5.83×10^3	3.7×10^5	0.113	3.4	0.16
VIB-1	103.4	72.4	5.62×10^3	3.6×10^5	0.075	2.3	0.10
VIB-2	103.6	72.5	6.91×10^3	4.4×10^5	0.075	1.9	0.10
VIB-3	103.3	72.3	5.08×10^3	3.3×10^5	0.080	2.7	0.11
DP-1	103.2	72.3	6.27×10^3	4.0×10^5	0.075	2.1	0.10
DP-2	104.1	72.8	4.75×10^3	3.0×10^5	0.049	1.8	0.07

This test group produced an average carbon fiber concentration of singles of 0.12 percent of the original fiber weight. This is only slightly less than the 0.132 percent attained for the pendulum impact series, which is a relatively more severe test. Figures 32 through 35 show the residue produced by this series. Note that even though VIB-2 (Figure 34) produced much less laminar floor residue than DP-1 (Figure 35), the percentages of single fibers were the same.

BURN TESTS

Table 14 gives the parameters and weight losses of the burn tests for this set of miscellaneous samples. Single fiber particle analysis data are shown in Table 15 for this group of specimens. The weight losses of the spoiler samples gave results as expected; the lighter pieces (BT-244 and 245) were similar to the Boeing floorboard specimens mentioned previously. Piece 9 (BT-246) was a heavier piece with a slightly different composition. Figure 36, a photograph of this test residue, shows the relatively heavy bottom portion of this spoiler part.

The weight losses for the AS/3501-6 material [0.34-cm (0.132-in.) thick], which was the standard sample type used in most of the pendulum impact, air blast, and miscellaneous strength tests, had good reproducibility for the duplicate burn times. The single fibers produced were all low, as expected, with each at approximately 0.01 percent; except for BT-251, a 5-min burn, which resulted in 0.03 percent of the fiber content being disseminated.

Table 14. Burn Test Parameters and Weight Loss, Miscellaneous Samples

Test	Sample Type	Sample Size (cm)	Sample Weight (g)	Burn Time (min)	Temperature (°C)	Weight Loss (%)
BT-244	Spoiler, piece 1	15.2x22.9x1.4	154.3	20	1122	48.8
BT-245	Spoiler, piece 2	15.2x22.9x1.4	124.6	20	1124	51.9
BT-246	Spoiler, piece 9	29.2x30.5x1.4	702.3	20	1096	26.4
BT-249	AS/3501-6	15.0x15.0x0.34	113.7	1	1124	10.7
BT-250	AS/3501-6	15.0x15.0x0.34	114.5	3	1150	14.1
BT-251	AS/3501-6	15.0x15.0x0.34	113.3	5	1096	18.2
BT-252	AS/3501-6	15.0x15.0x0.34	113.6	10	1102	20.2
BT-253	AS/3501-6	15.0x15.0x0.34	113.3	20	1150	25.9
BT-254	AS/3501-6	15.0x15.0x0.34	114.3	1	1078	10.5
BT-255	AS/3501-6	15.0x15.0x0.34	111.9	3	1032	14.1
BT-256	AS/3501-6	15.0x15.0x0.34	113.2	5	1070	17.3
BT-257	AS/3501-6	15.0x15.0x0.34	113.2	10	1058	20.1
BT-258	AS/3501-6	15.0x15.0x0.34	110.6	20	1088	25.4
BT-247	T-300 carboard spool	8.9Dx29.2	453.6	20	818*	90.3
BT-267	HMS plastic spool	8.9Dx30.5	630.5	20	1070	(2.0 gain)

* Thermocouple malfunction

Table 15. Effects of Burn-Only Tests on Release of Single Carbon Fibers, Miscellaneous Samples

Test	Sample Weight (g)	Carbon Fiber Weight (g) (calculated)	Number of Carbon Fibers Collected	Number of Carbon Fibers for Test	Weight of Carbon Fibers (g)	Average Length (mm)	Percent Carbon Fiber
BT-244	154.3	64.0	*	1.9×10^4	0.0030	1.8	0.0050
BT-245	124.6	69.0	*	3.4×10^3	0.0006	1.9	0.0008
BT-246	702.3	178.0	*	4.5×10^3	0.0009	2.1	0.0005
BT-249	113.7	79.5	810	5.2×10^4	0.0050	1.4	0.0070
BT-250	114.5	80.1	418	3.7×10^4	0.0080	2.8	0.0100
BT-251	113.3	79.3	1,728	11.1×10^4	0.0200	2.4	0.0250
BT-252	113.6	79.5	756	4.8×10^4	0.0080	2.3	0.0100
BT-253	113.3	79.3	351	2.2×10^4	0.0050	3.3	0.0070

Table 15. Effects of Burn-Only Tests on Release of Single Carbon Fibers, Miscellaneous Samples (Continued)

Test	Sample Weight (g)	Carbon Fiber Weight (g) (calculated)	Number of Carbon Fibers Collected	Number of Carbon Fibers for Test	Weight of Carbon Fibers (g)	Average Length (mm)	Percent Carbon Fiber
BT-254	114.3	80.0	189	1.2×10^4	0.0030	3.4	0.0040
BT-255	111.9	78.2	1,026	6.6×10^4	0.0070	1.5	0.0090
BT-256	113.2	79.2	891	5.7×10^4	0.0080	1.9	0.0100
BT-257	113.2	79.2	432	2.8×10^4	0.0040	2.0	0.0050
BT-258	110.6	77.4	418	2.7×10^4	0.0040	2.0	0.0050
BT-247	453.6	453.6	*	8.7×10^3	0.0020	2.5	0.0004
BT-267	630.5	630.5	12,500	9.7×10^5	0.5100	5.8	0.0800

* Dugway Proving Ground data—not given

The T-300 graphite yarn on a cardboard spool lost 90 percent of its original weight, while the HMS on a plastic spool lost no weight (2 percent gain) after 20 min of the propane burn. The T-300 material continued glowing red for 90 min after the burner was shut off, while the HMS started cooling immediately after the 20-min burn period. The two residues are shown in Figures 37 and 38. The burn through the bottom center of the T-300 material can be seen and, in comparison to the HMS type, much of the interior is depleted, which left a sagging residue.

The results of the AS/3501-6 burn tests at 1- to 20-min burn times are plotted in Figure 39, which shows a maximum release at 300 sec and a subsequent decrease at 600 and 1200 sec. During earlier tests, it was noted that similar material had most of its matrix consumed between 5 and 7 min after burning started.[1] Additional burning beyond matrix consumption may have destroyed fibers that could have been released after the burn period was over in the lesser burn times. In all tests, the percent of fiber released was of a low order of magnitude.

SUMMARY

1. The Boeing 747 floorboard samples briefly evaluated showed slightly higher tendencies to release single fibers and were of longer average length than any of those tested in this series or in previously reported work.

2. Various type head configurations and two different weights [5.5 kg (12 lb) and 11.4 kg (25 lb)] used in a pendulum type impactor on AS/3501-6 burned composites in four sample positions (0°, 45°, 90°, and 135°) produced roughly the same amounts of free fibers (average = 0.16 percent of original fiber content). Impact angle had no effect on the amount of fibers released.

3. Airflow tests of a 30-knot simulating wind on 10- and 20-min burn samples of T-300/5208 crossply specimens showed an increase of single fibers released as sample thickness decreased. Amounts of free fibers produced by burn tests gave a good indication of how these samples were weakened and, thus, were related to amounts released in subsequent airflow tests.

4. The same tests conducted (constant airflow) with unidirectional material of T-300 samples did not give the uniform results that were observed with the crossply material, but did indicate that the latter samples were less vulnerable to single fiber release. This may be due to the uniform orientation of the unidirectional fibers normal to the airflow in the tests.

5. During burn tests of 0.34-cm-thick (0.132-in.-thick) AS/3501-6 samples, weight loss increased with burn times from 1 to 20 min. Fiber release reached a maximum at 5 min and decreased thereafter as burn time increased. The amounts of free fibers released by the burns was in the vicinity of 0.01 percent of the original 30 percent fiber content of each sample.

6. Burn tests of pure fibers on spools showed minor amounts of free fibers to be released. T-300 on cardboard spools when burned for 20 min gave 0.0004 percent of original weight released, while HMS fibers on a plastic spool showed 0.08 percent.

7. From the tests reported herein and those reported earlier from burn/blast with explosives, the descending order of their ability to release single fibers from burned composites are

explosion
air blast
constant airflow
mechanical impact, flexural, torsional, vibration, drop
burn-only

The approximate range of percent single fiber release for the above groupings are, respectively,

10 percent
2-3 percent
0.10-1 percent
0.01-0.10 percent
0-0.02 percent

CONCLUSIONS

When AS/3501-6 composites are impacted by various head and weight configurations of a pendulum impactor, less than 0.2 percent by weight of the original sample is released as single fibers. Also, laboratory flexure, torsional, and vibrational mode stress tests were successfully developed to simulate aircraft in-flight, crash, and post-crash burn scenarios. Fiber release tests conducted under these simulated conditions produced less single fibers than in the impact mode.

The preliminary conclusion drawn from these tests and the resultant data is that single fibers are released from burned/impacted graphite reinforced composites, but not in sufficient quantities or size range to cause electrical shorts and subsequent equipment damage. However, the full significance of the low single-fiber release rates found herein is to be evaluated by NASA in their extensive aircraft vulnerability studies program.

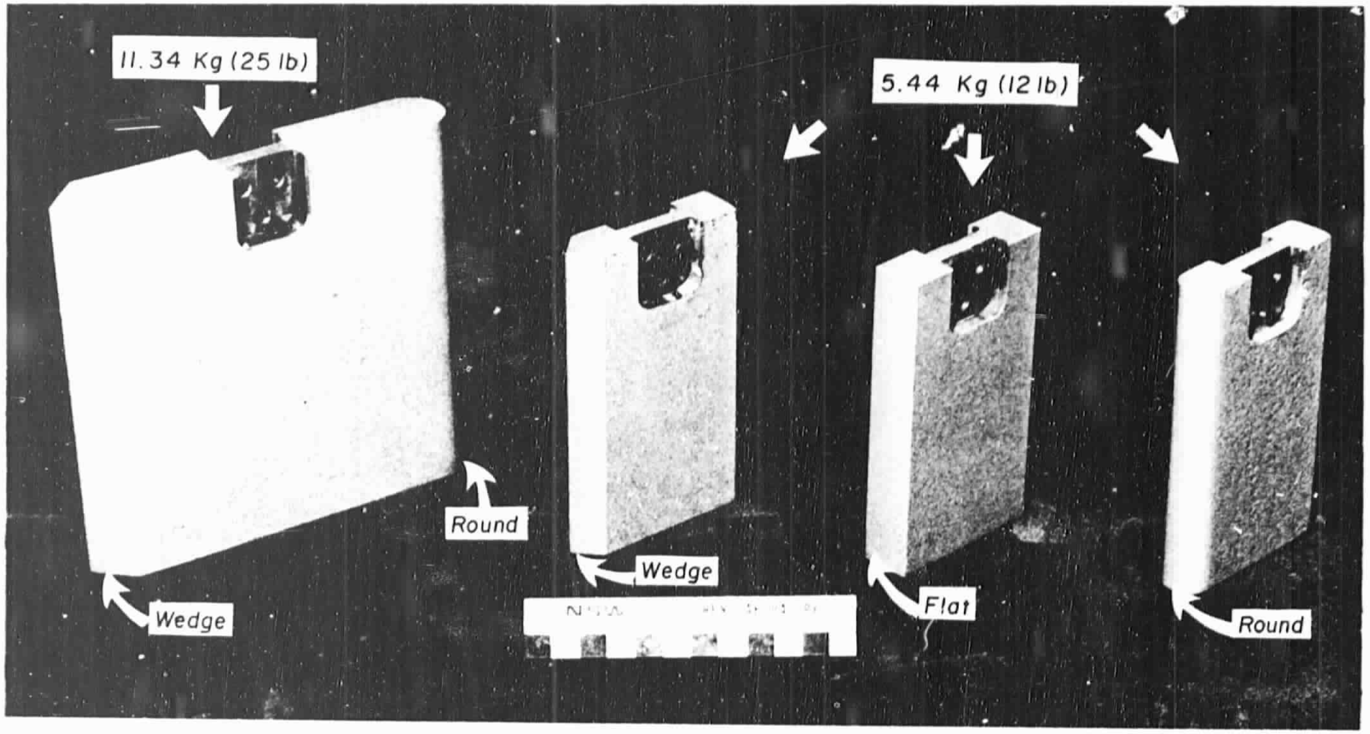

Figure 1. Pendulum Impact Head Configurations

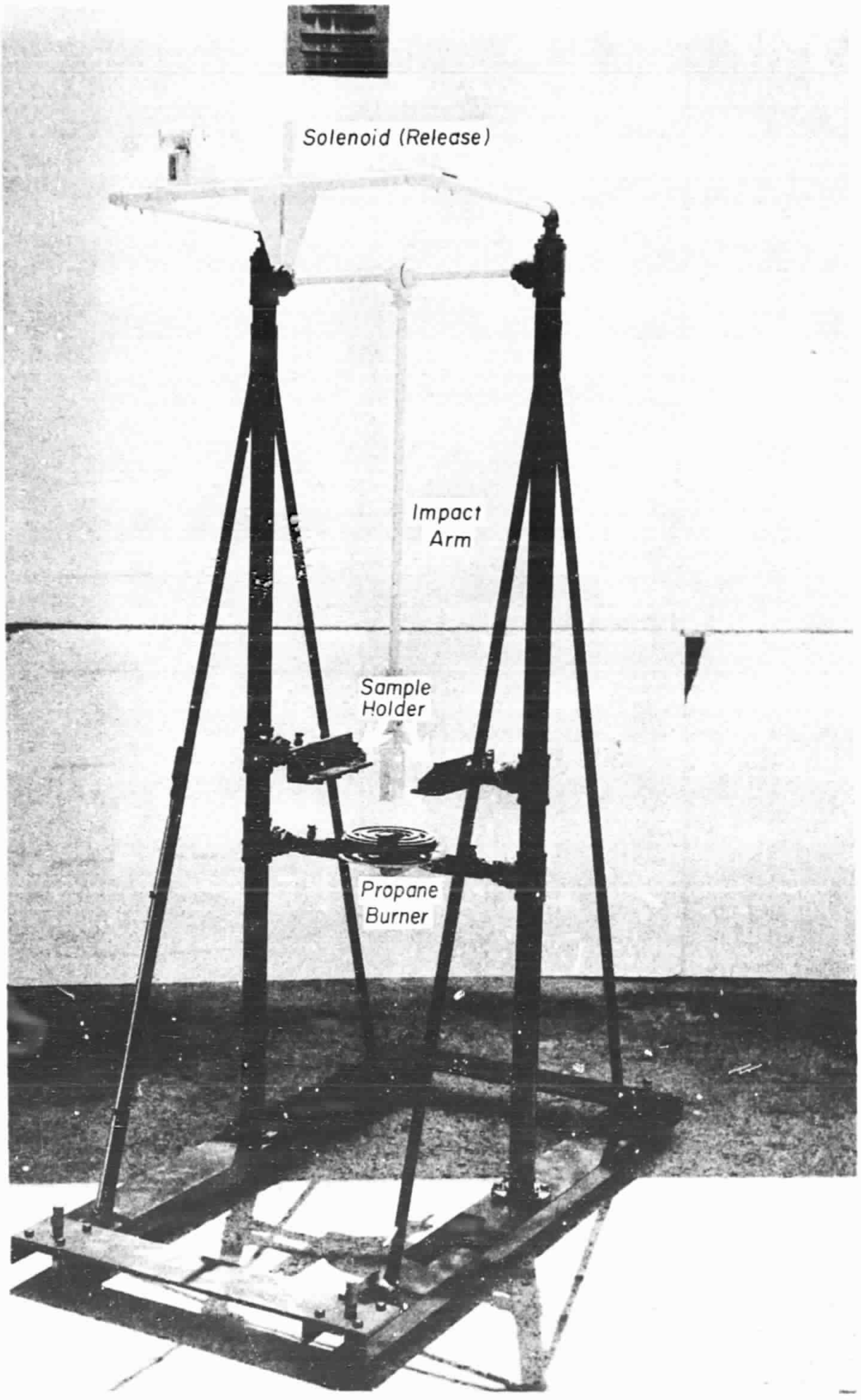

Figure 2. Pendulum Impact Test Fixture

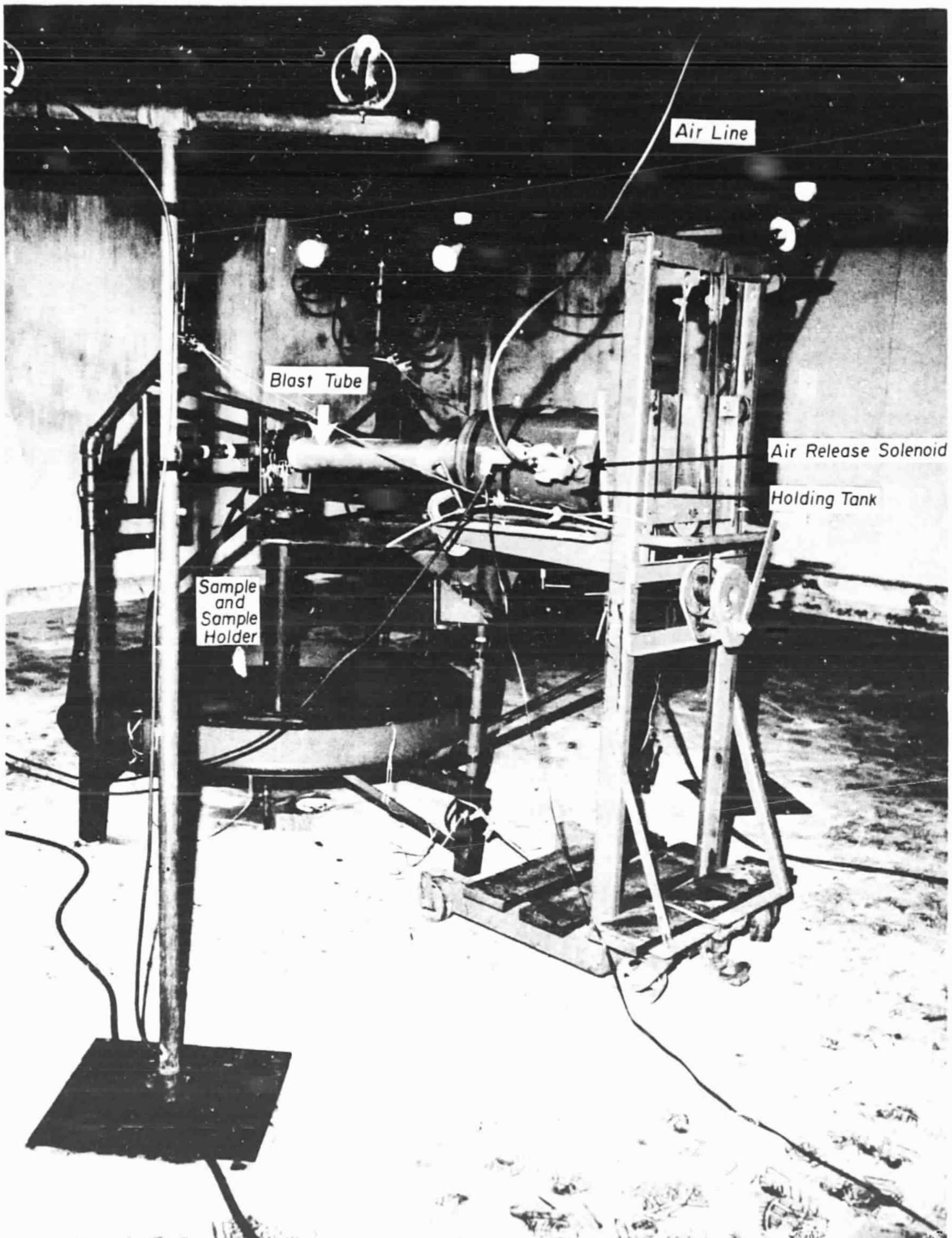

Figure 3. Air Blast Test Apparatus

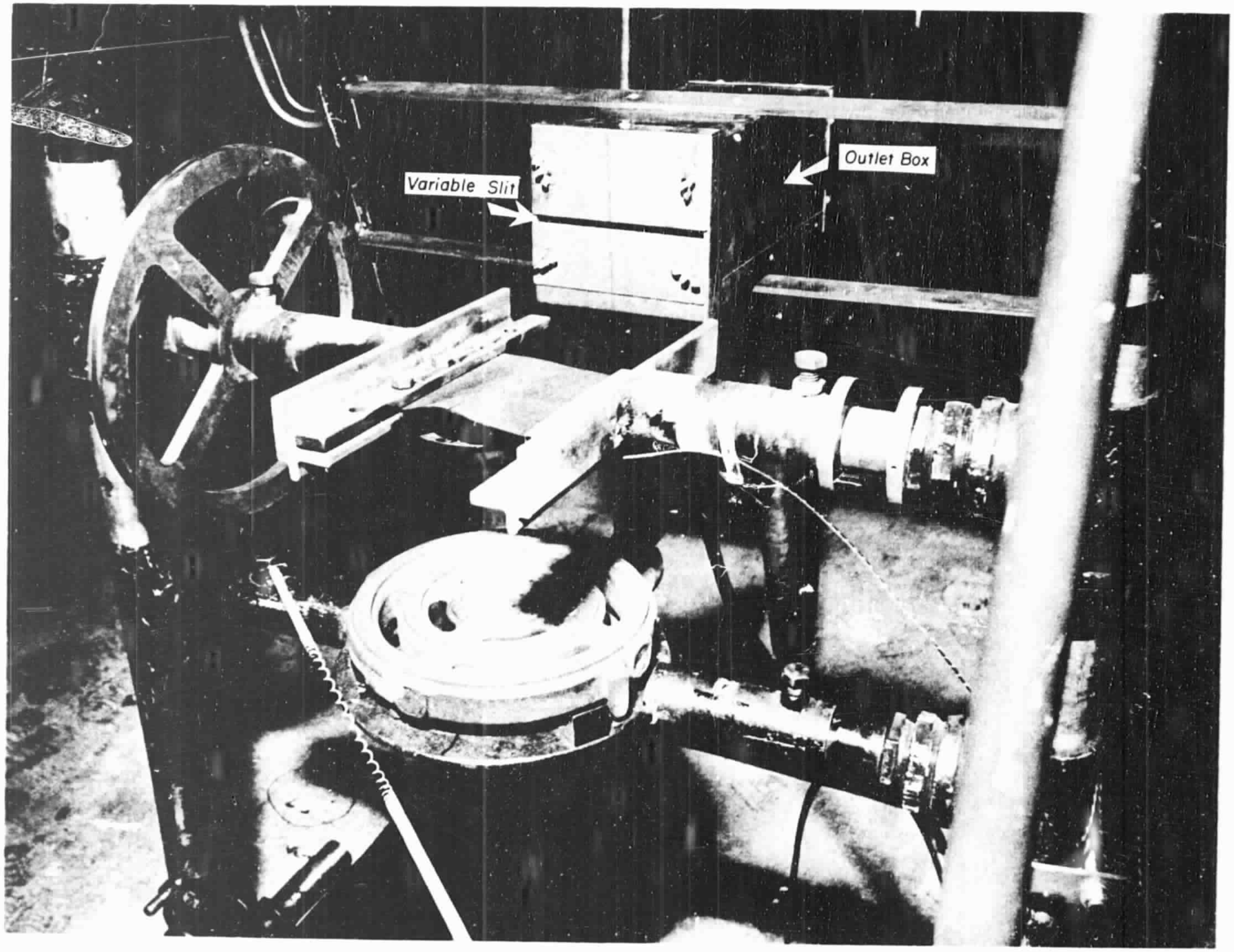

Figure 4. 10-Knot Airflow System

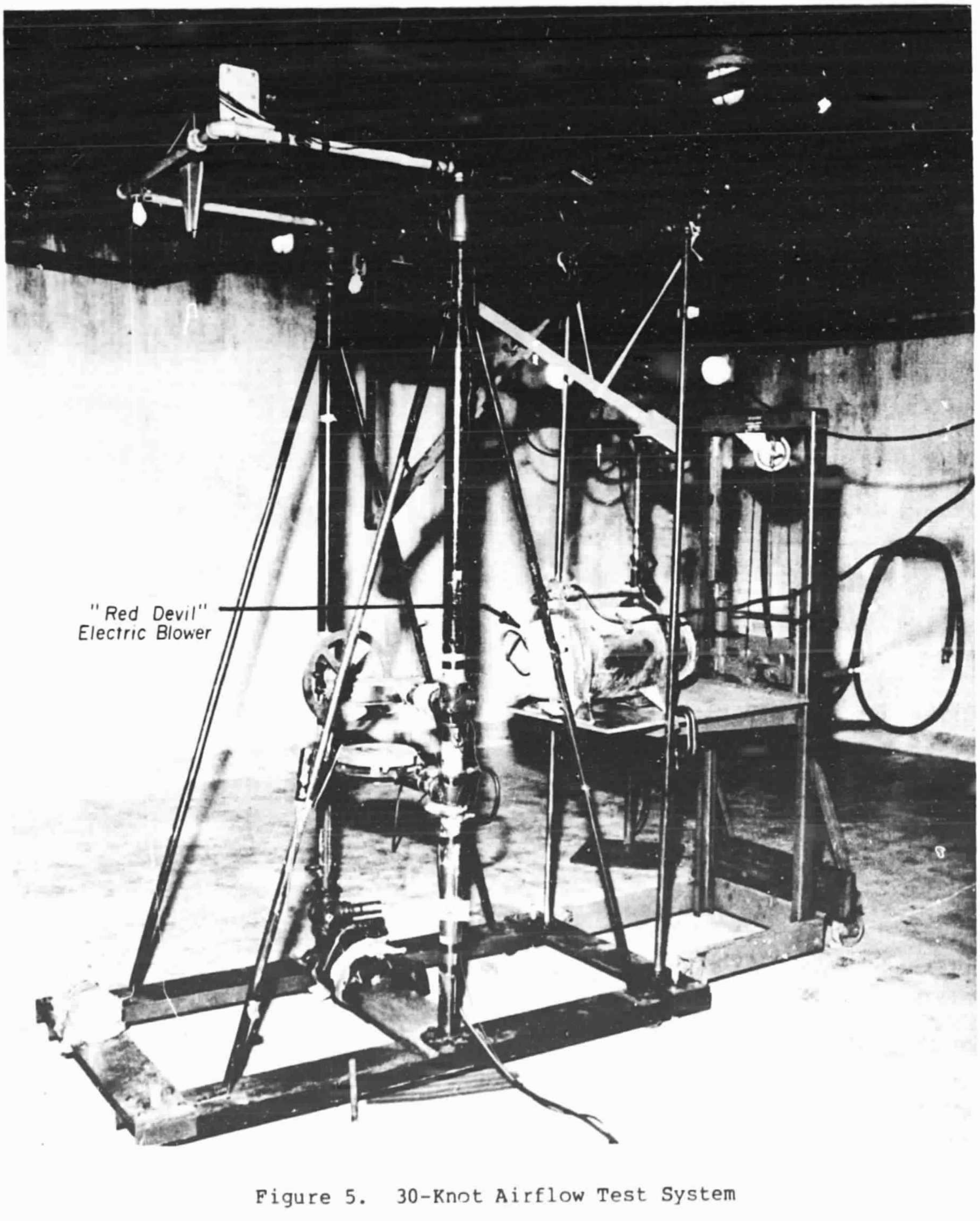

Figure 5. 30-Knot Airflow Test System

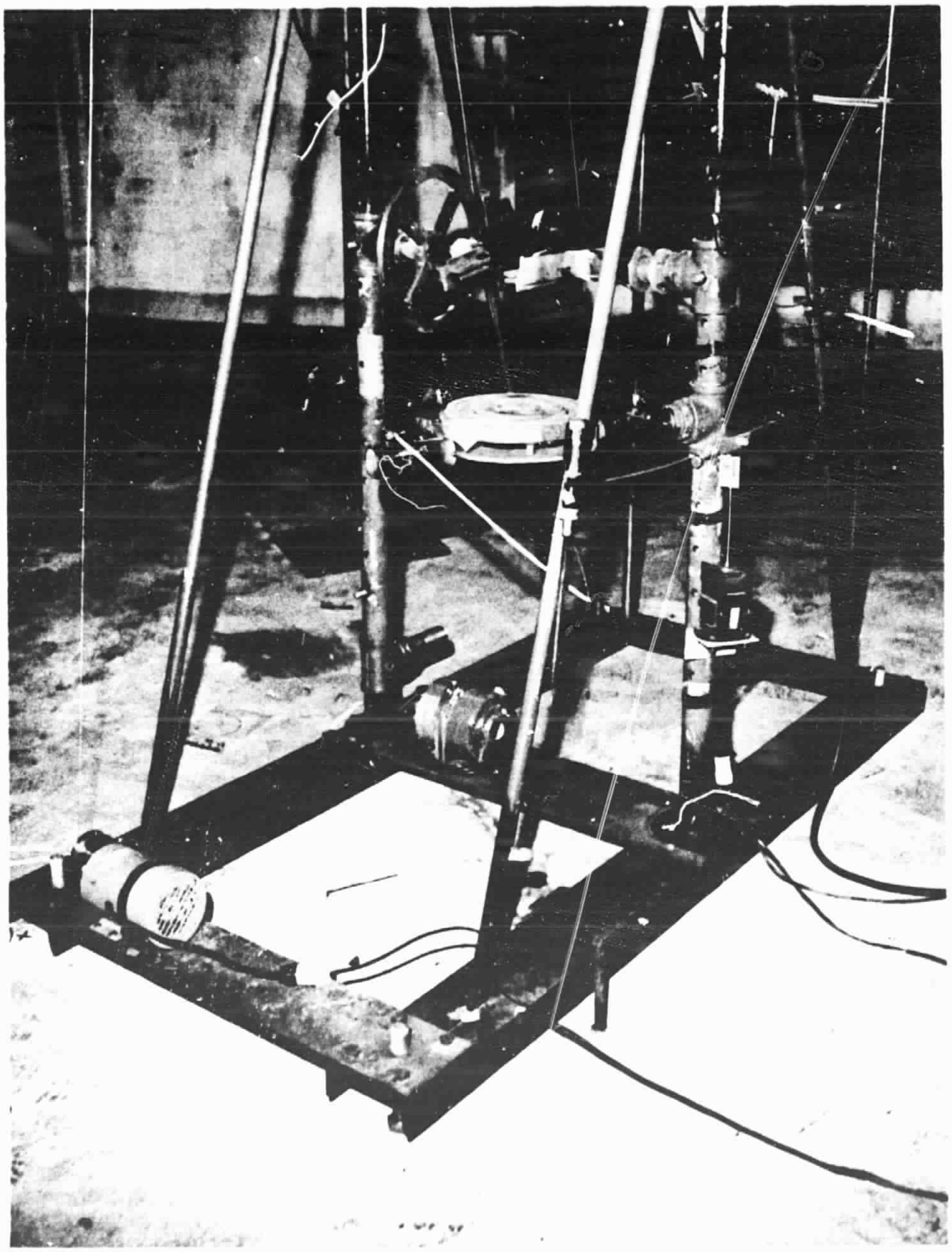

Figure 6. Torsion Test Fixture

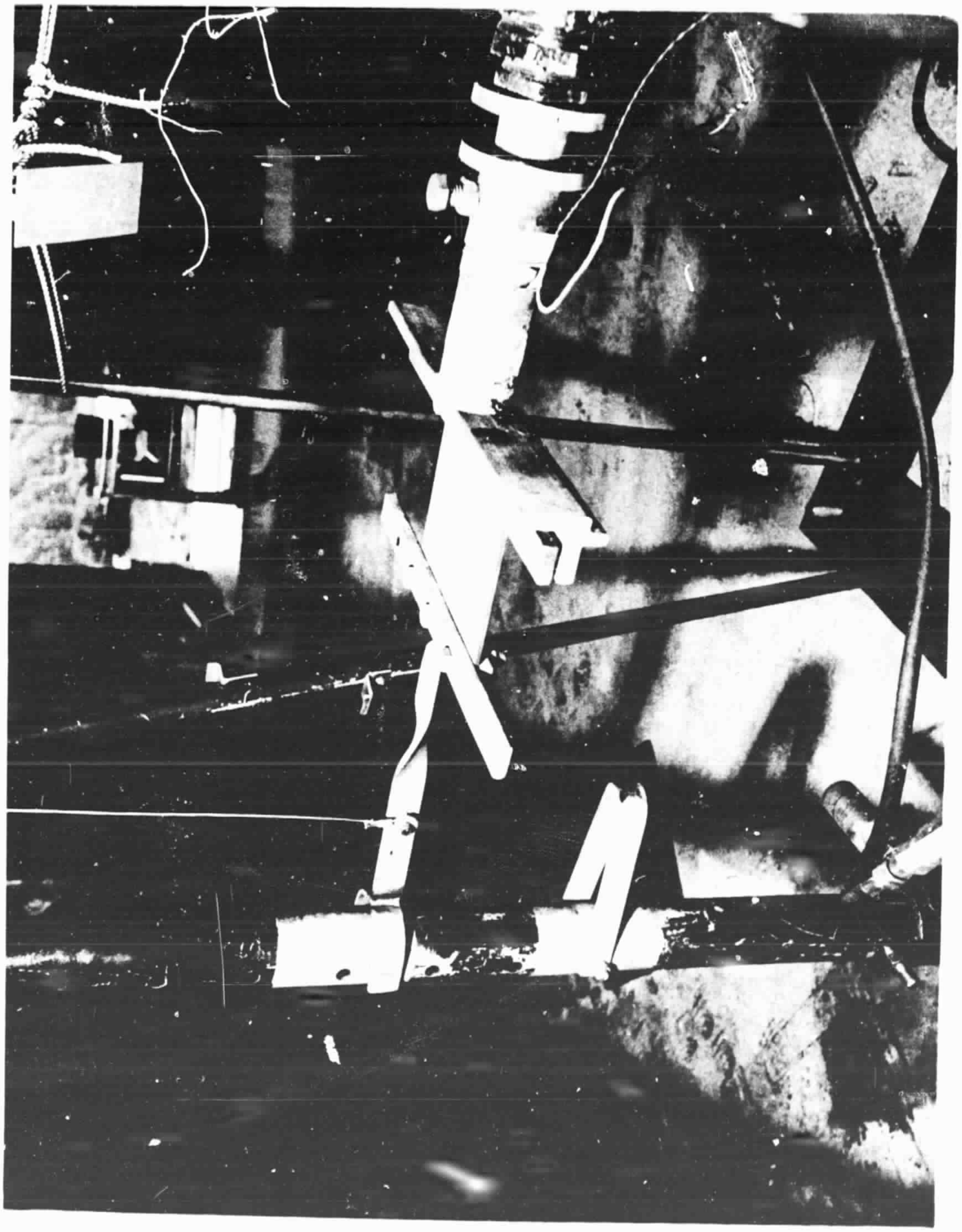

Figure 7. Flexural Test System

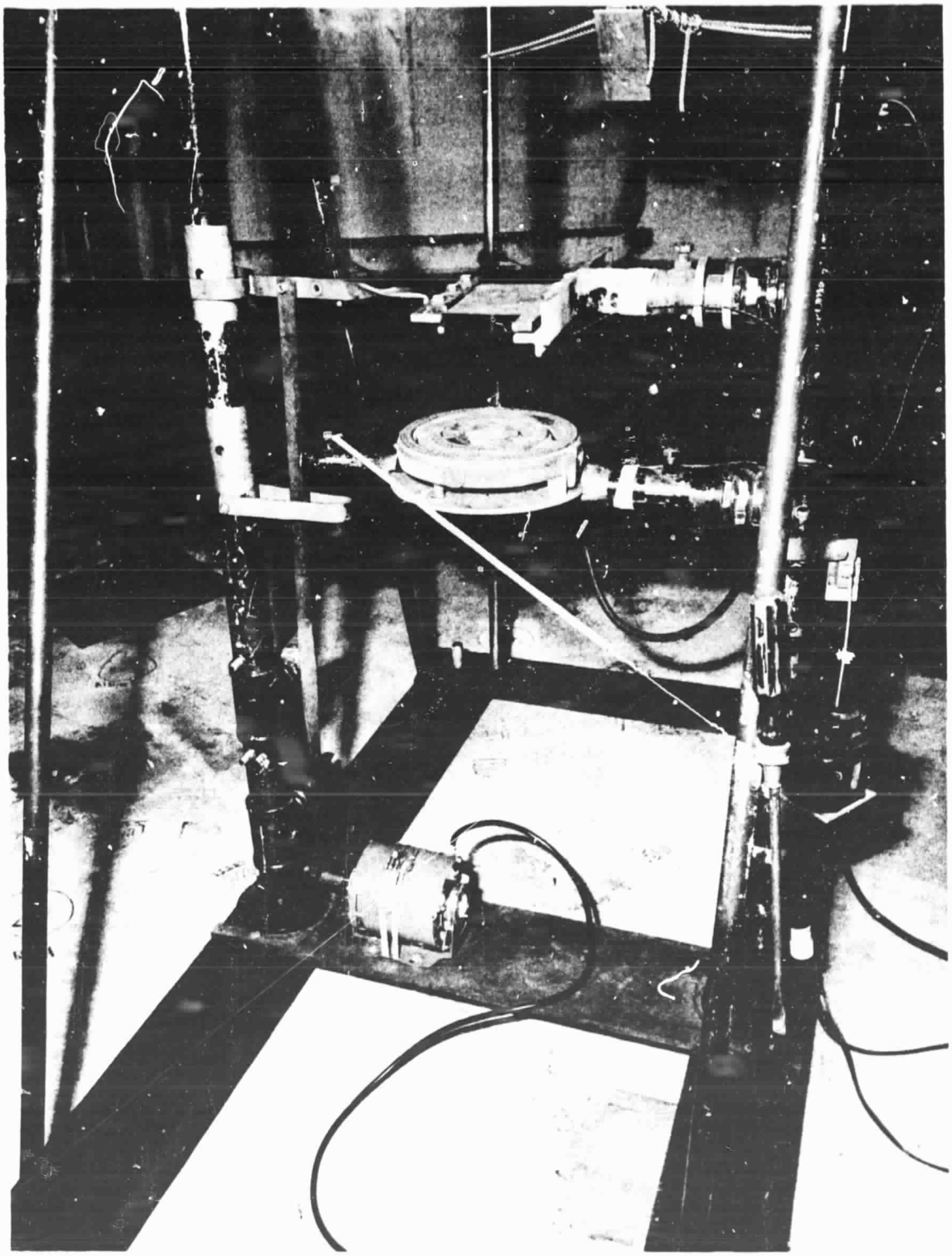

Figure 8. Vibration Test System

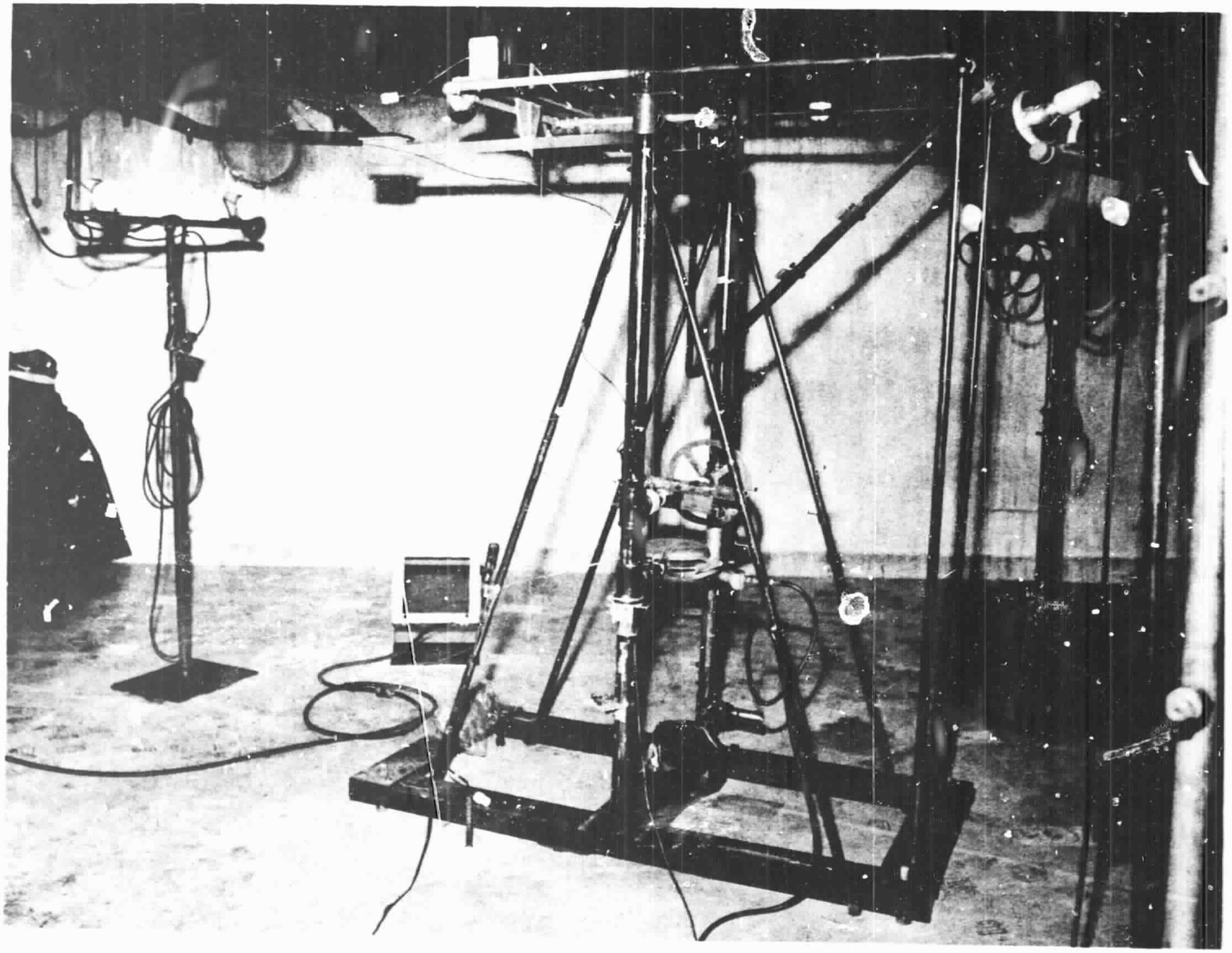

Figure 9. Drop Test Fixture

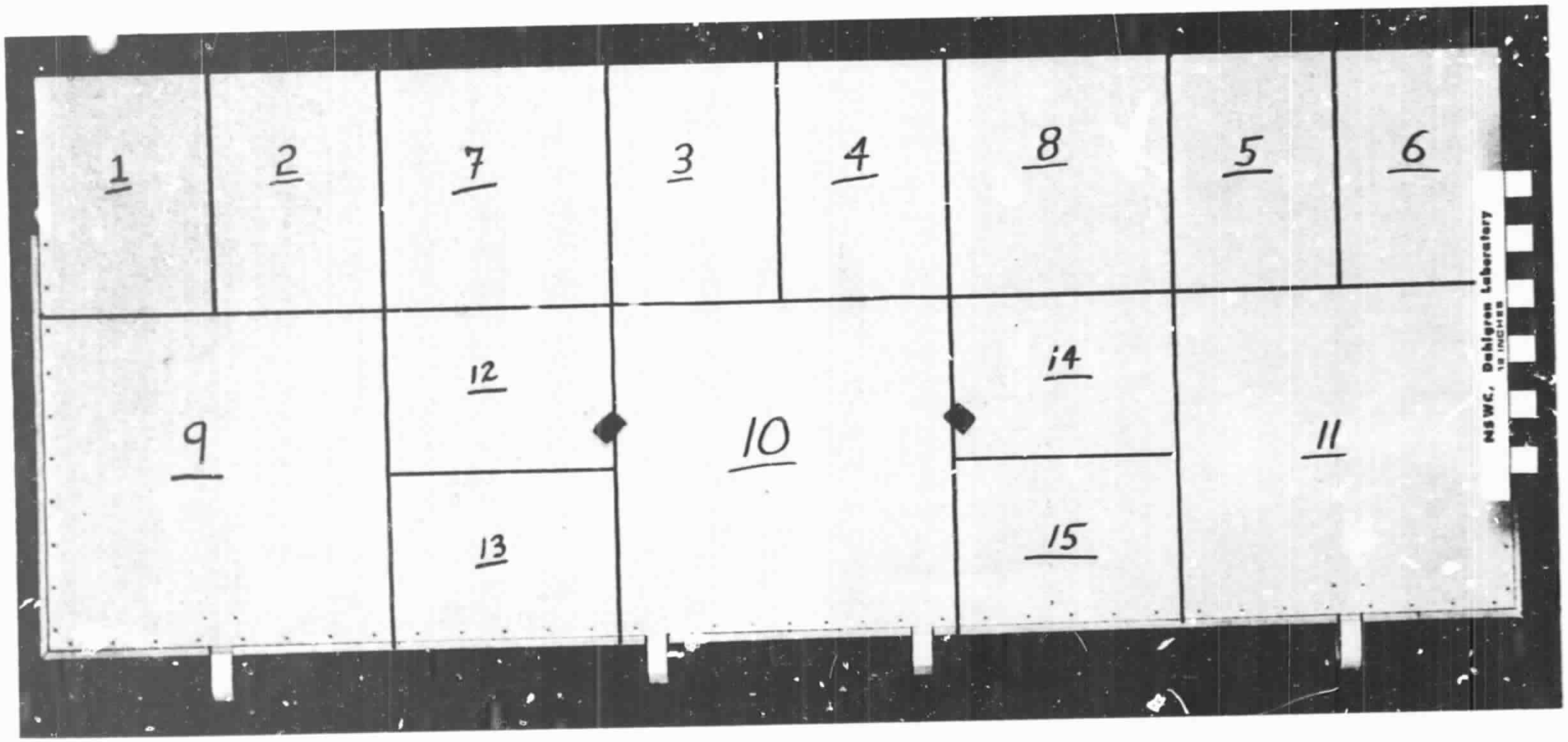

Figure 10. Spoiler 1, Boeing 737

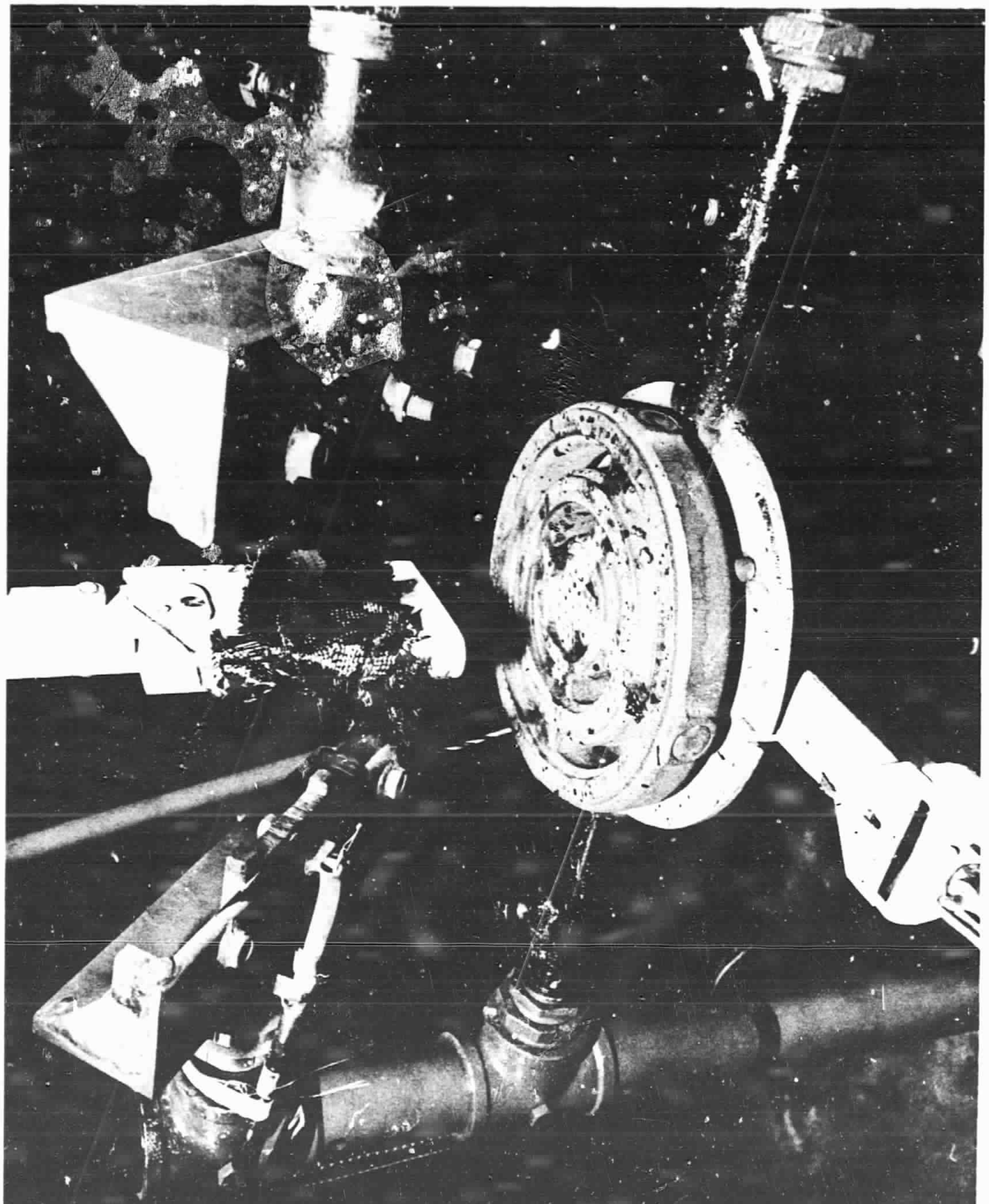

Figure 11. Impact 17, Weave Sample

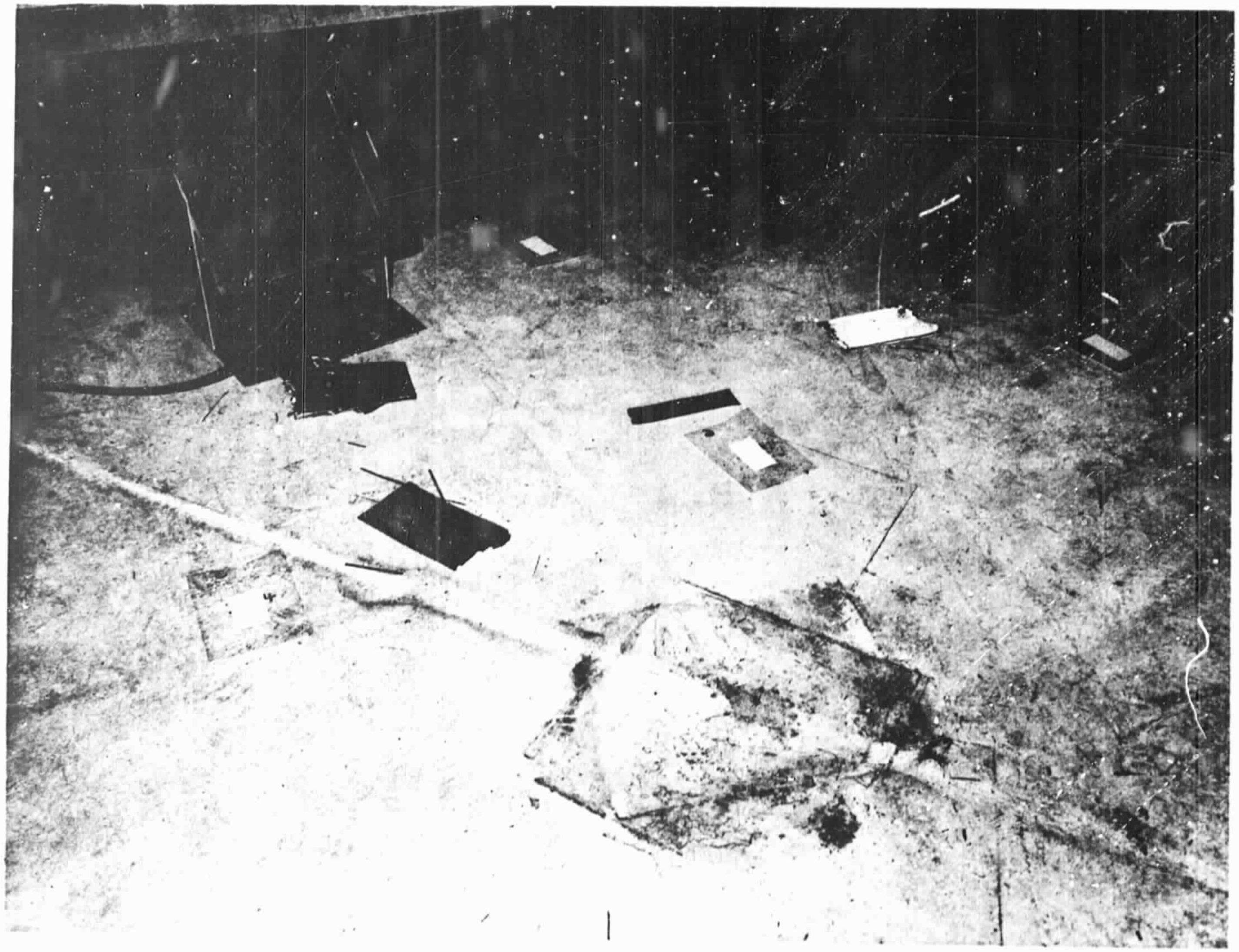

Figure 12. Test 17, Weave Sample Residue

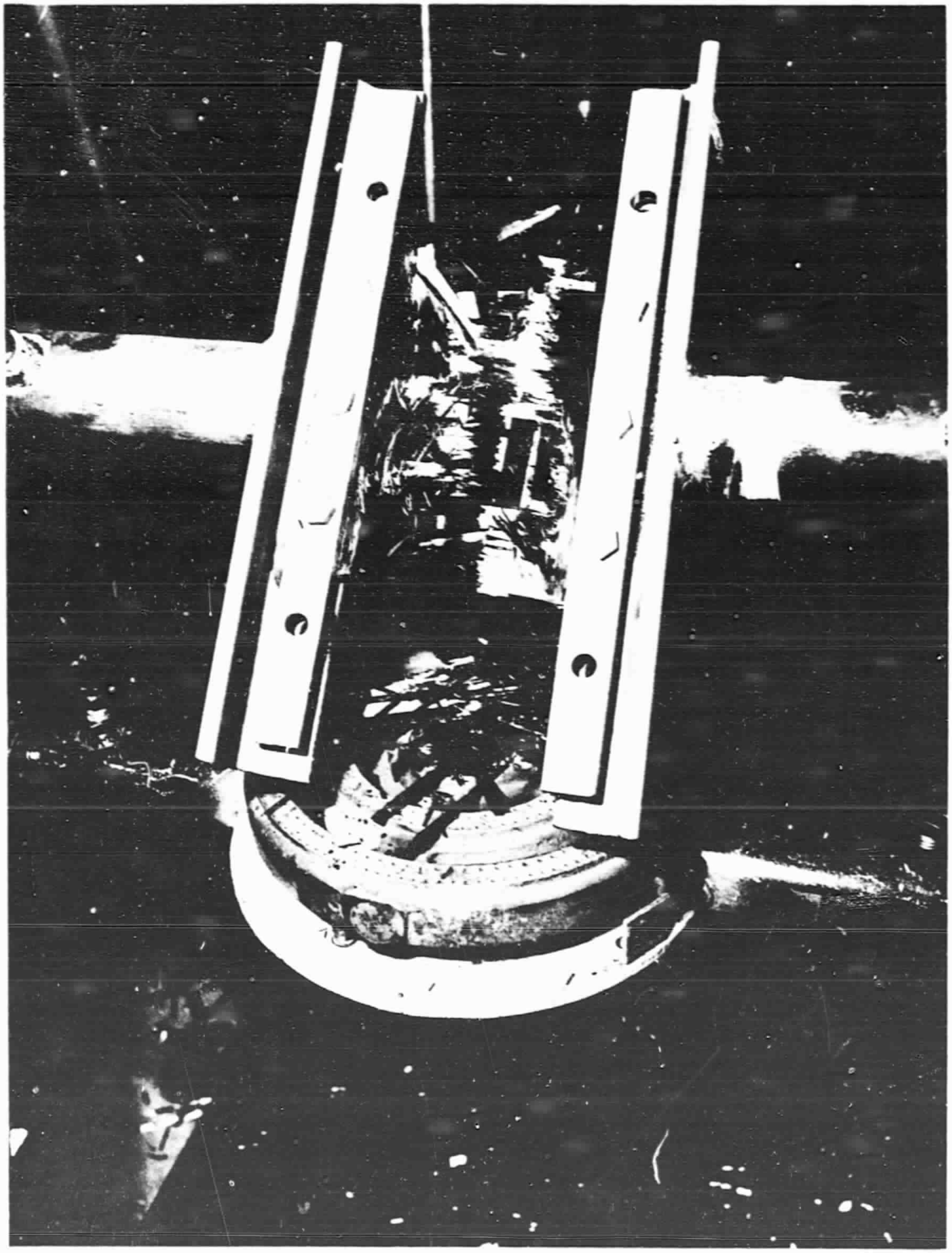

Figure 13. Impact Test 20, Fixture Residue

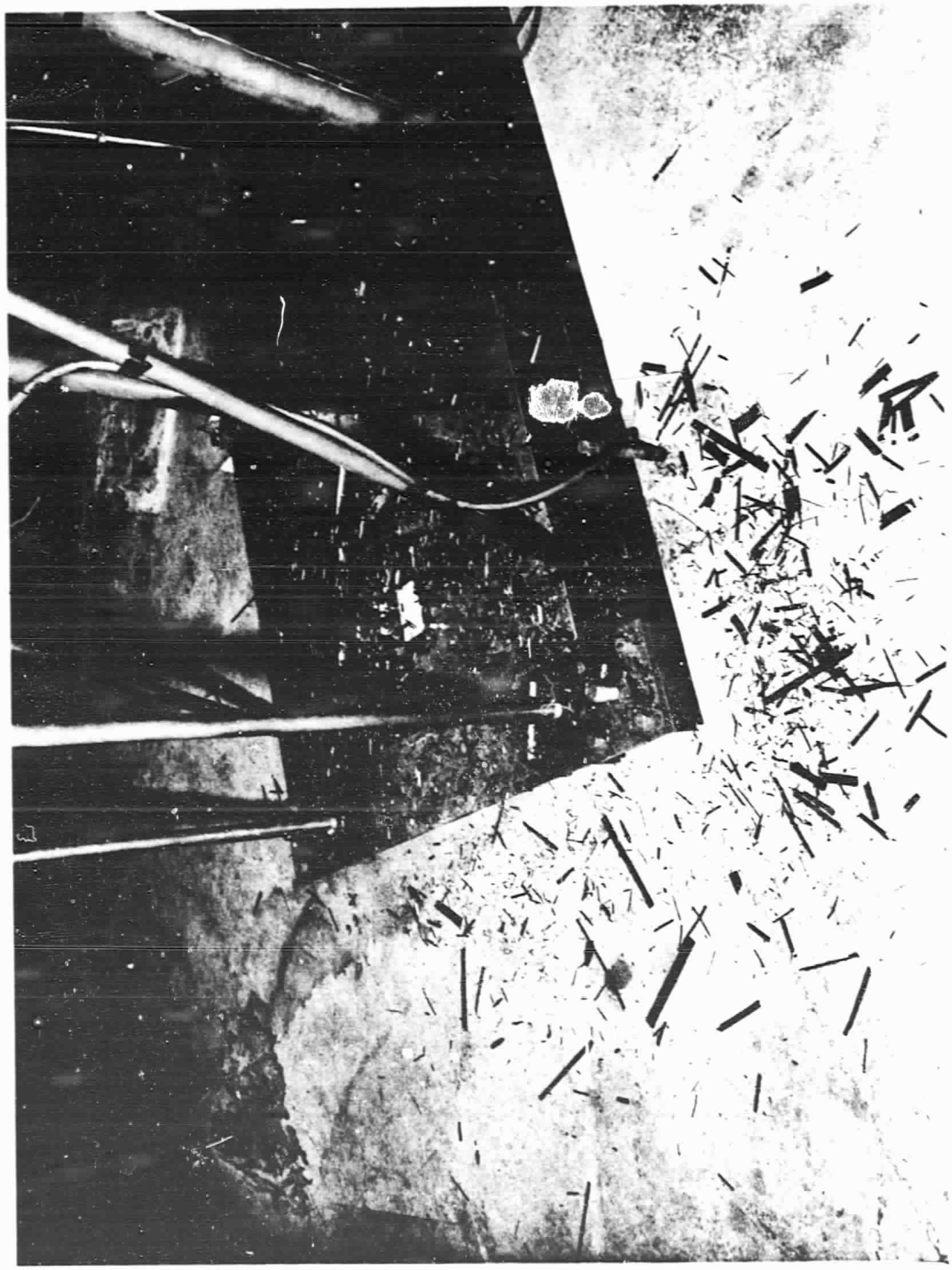

Figure 14. Impact Test 20, Floor Residue

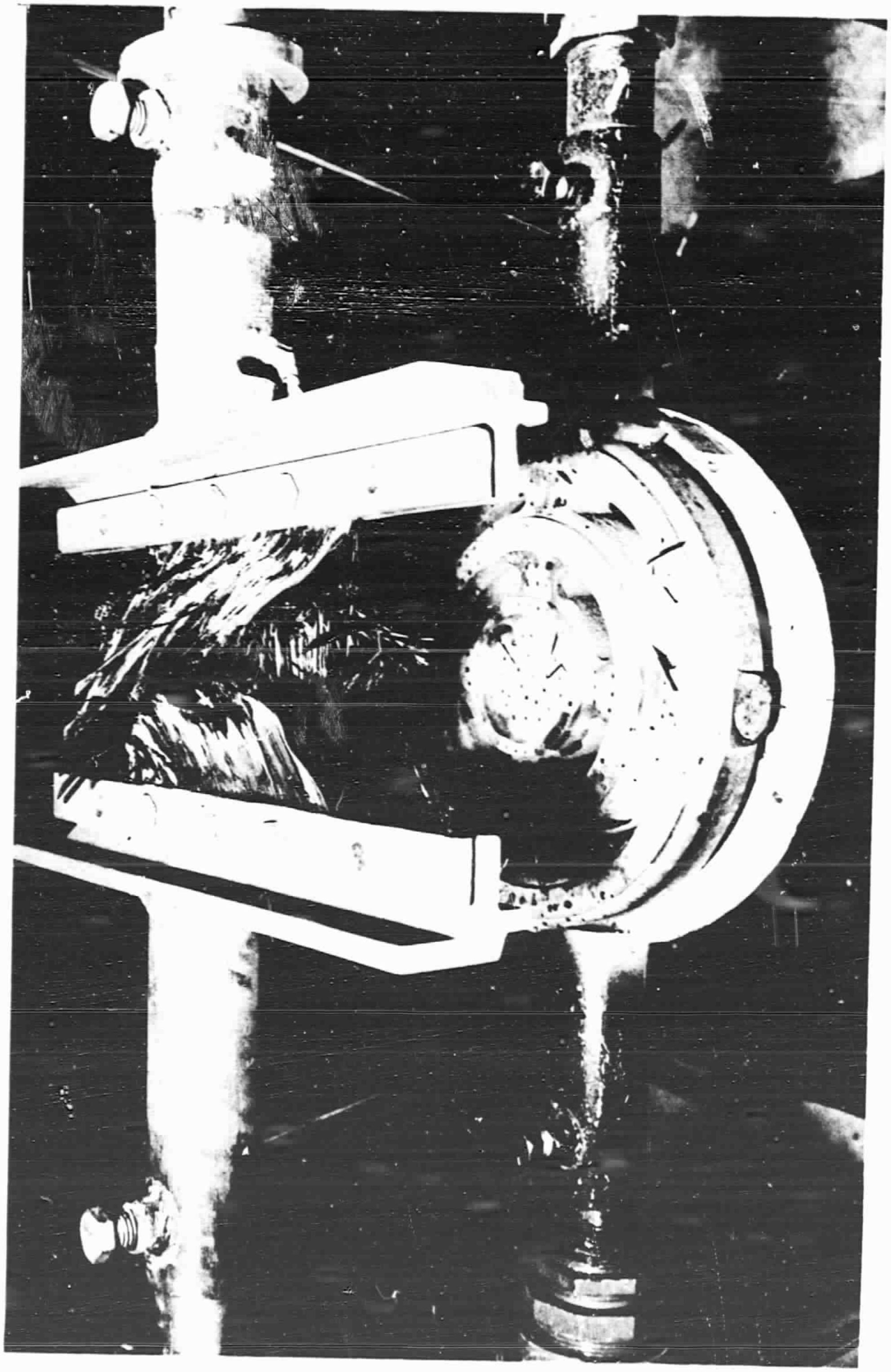

Figure 15. Impact Test 24, Fixture Residue

Figure 16. Impact Test 24, Floor Residue

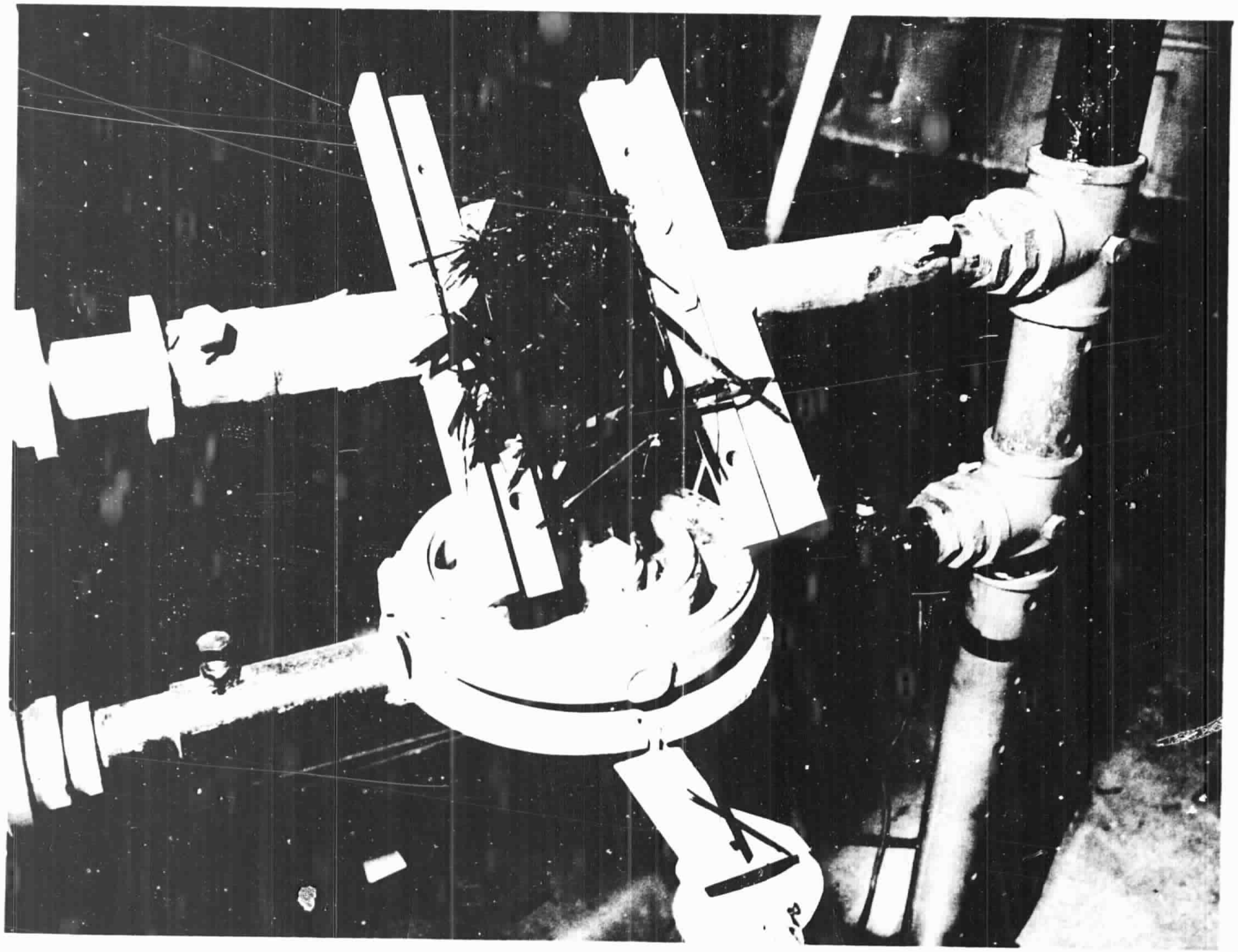

Figure 17. Impact Test 27, Fixture Residue

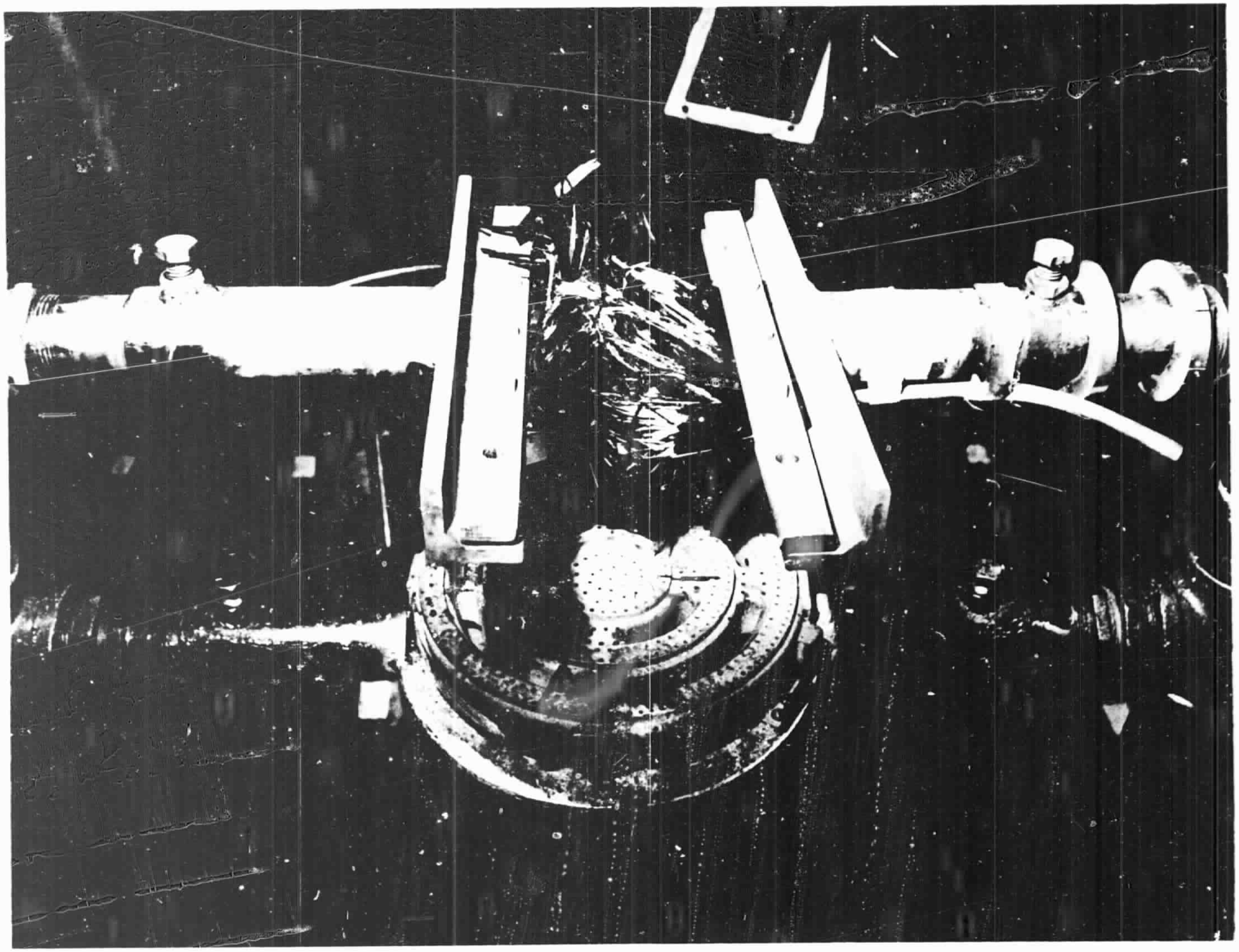

Figure 18. Impact Test 56, Fixture Residue

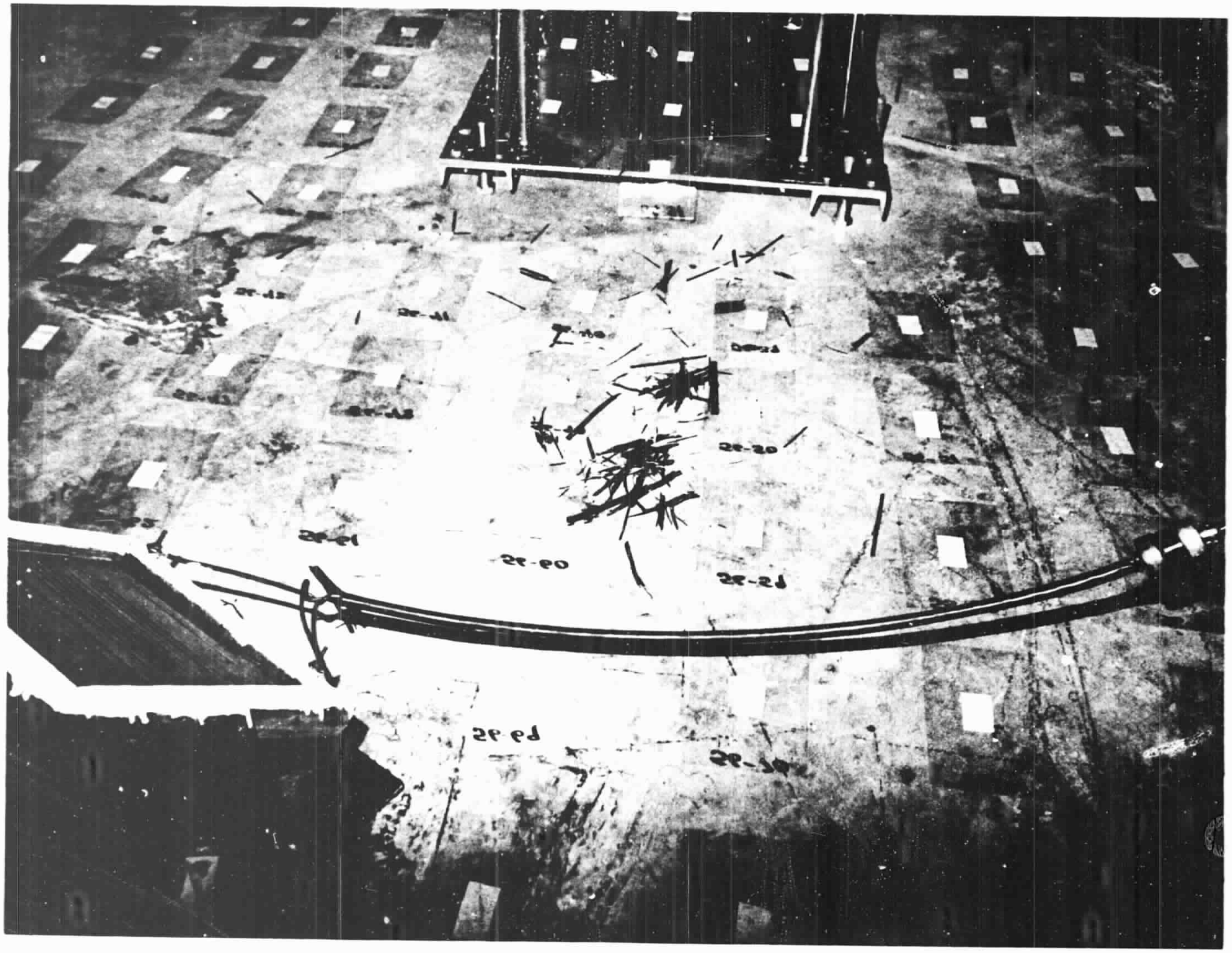

Figure 19. Impact Test 56, Floor Residue

Figure 20. Impact Test 58, Fixture Residue

Figure 21. Impact Test 58, Floor Residue

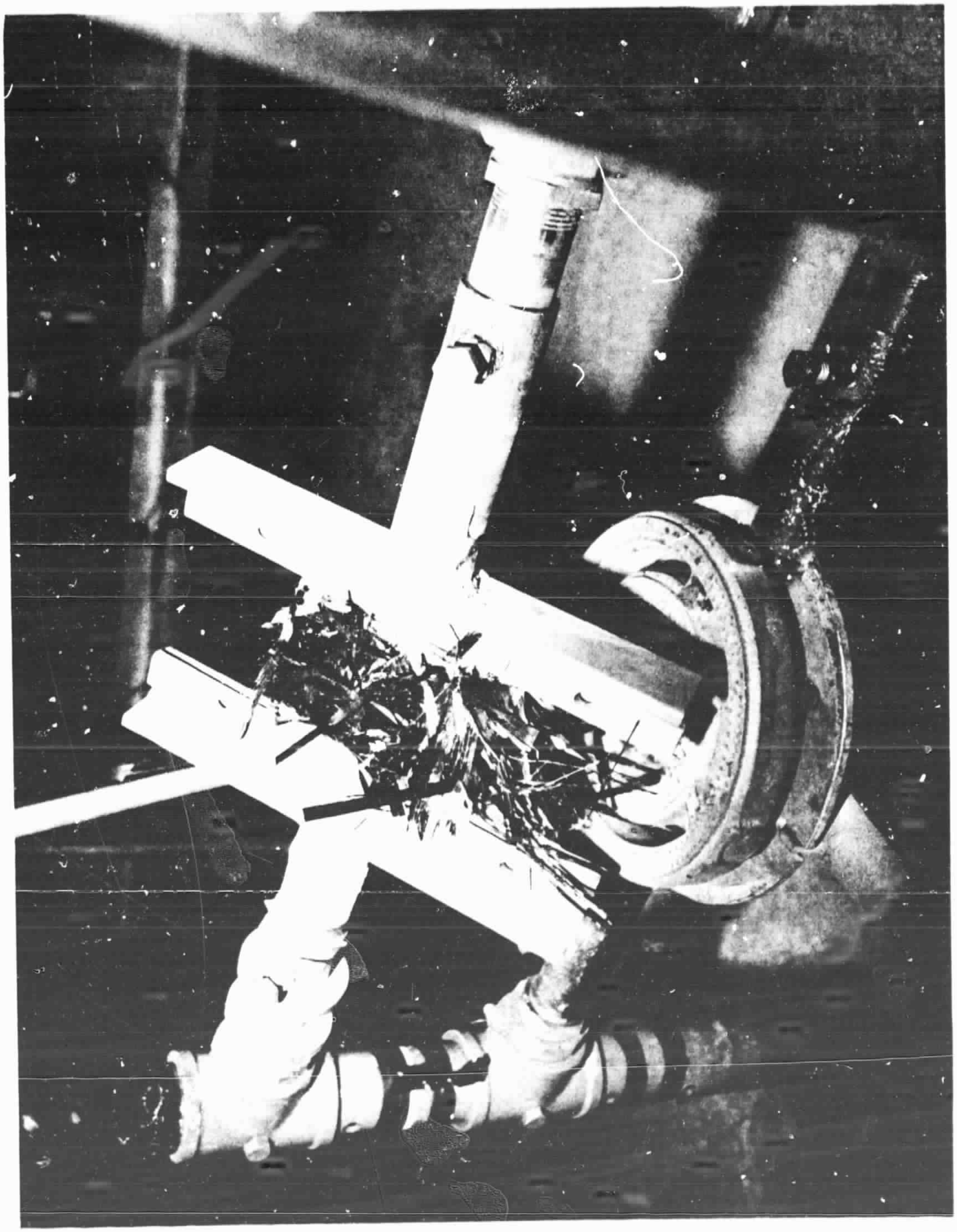

Figure 22. Impact Test 63, Fixture Residue

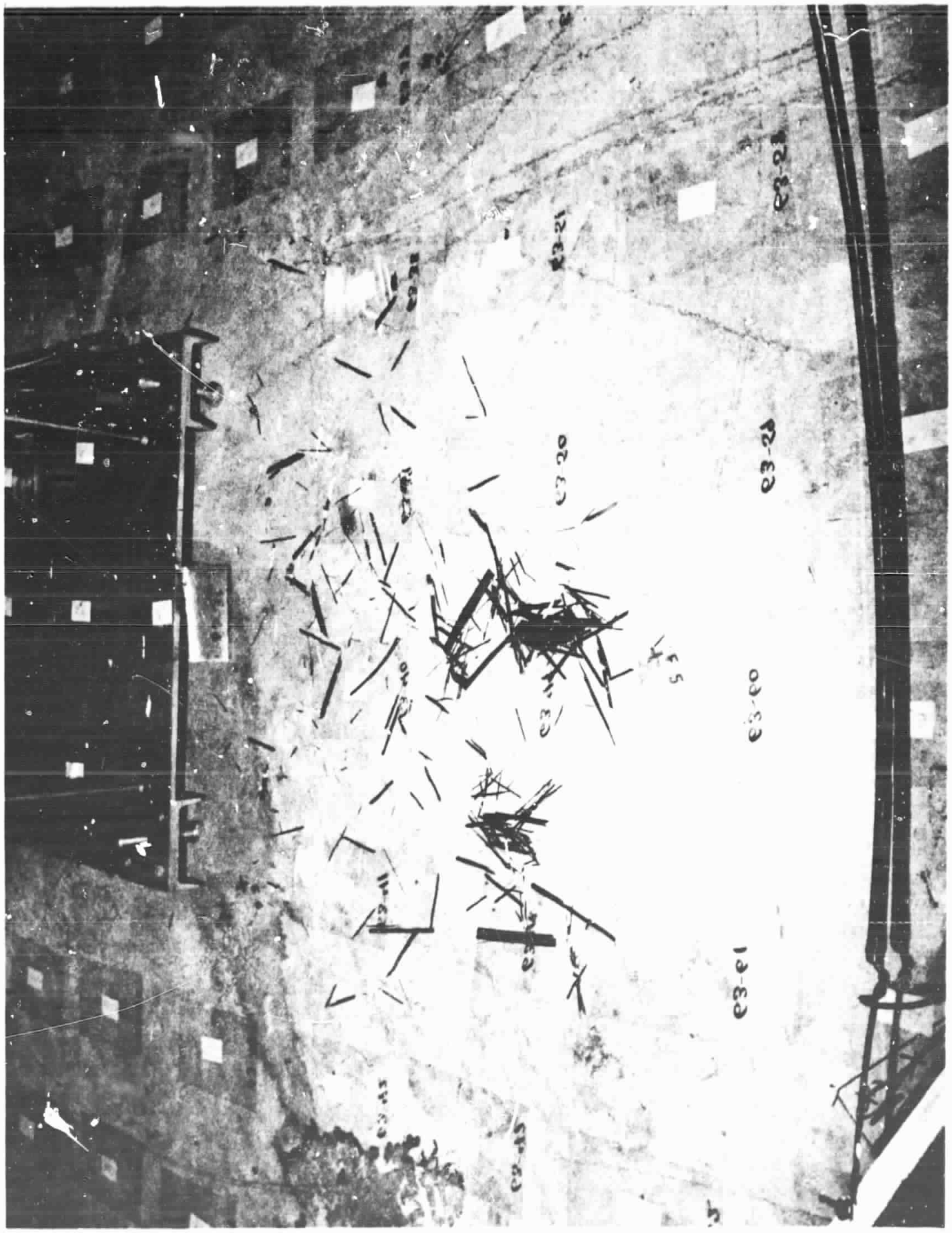

Figure 23. Impact Test 63, Flocr Residue

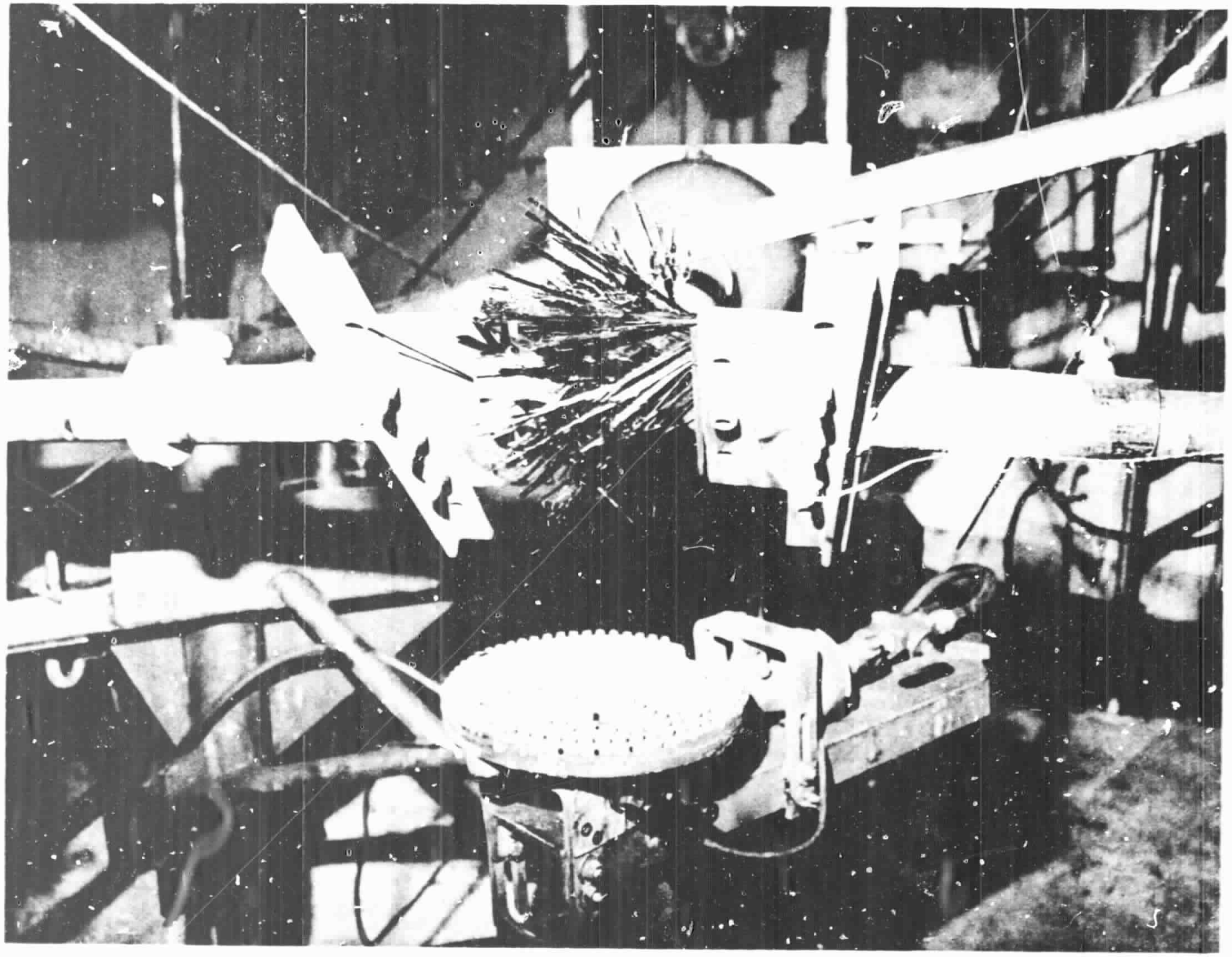

Figure 24. Air Blast Test AB-4, AS/3501-6, Fixture Residue

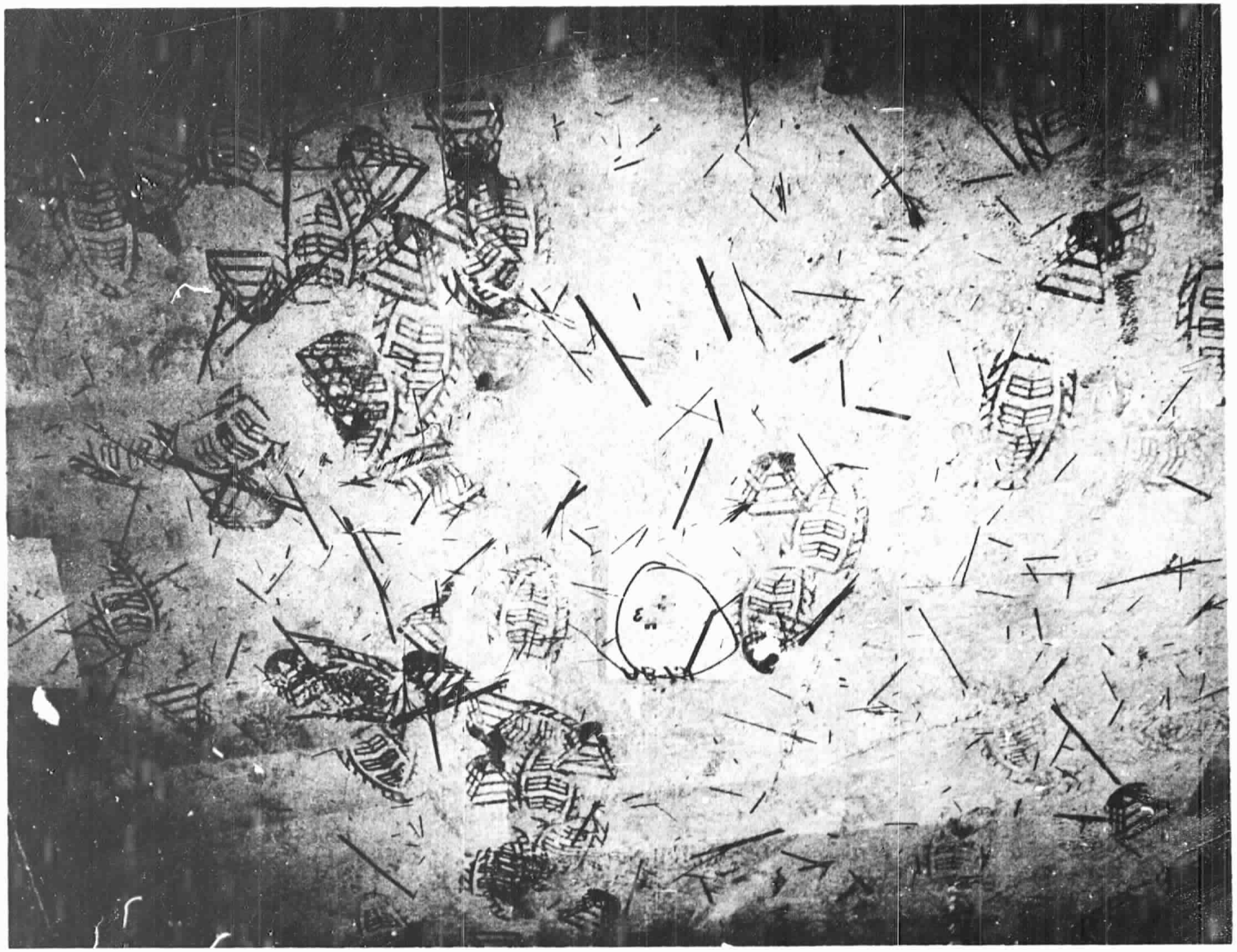

Figure 25. Air Blast Test AB-4, AS/3501-6, Floor Residue

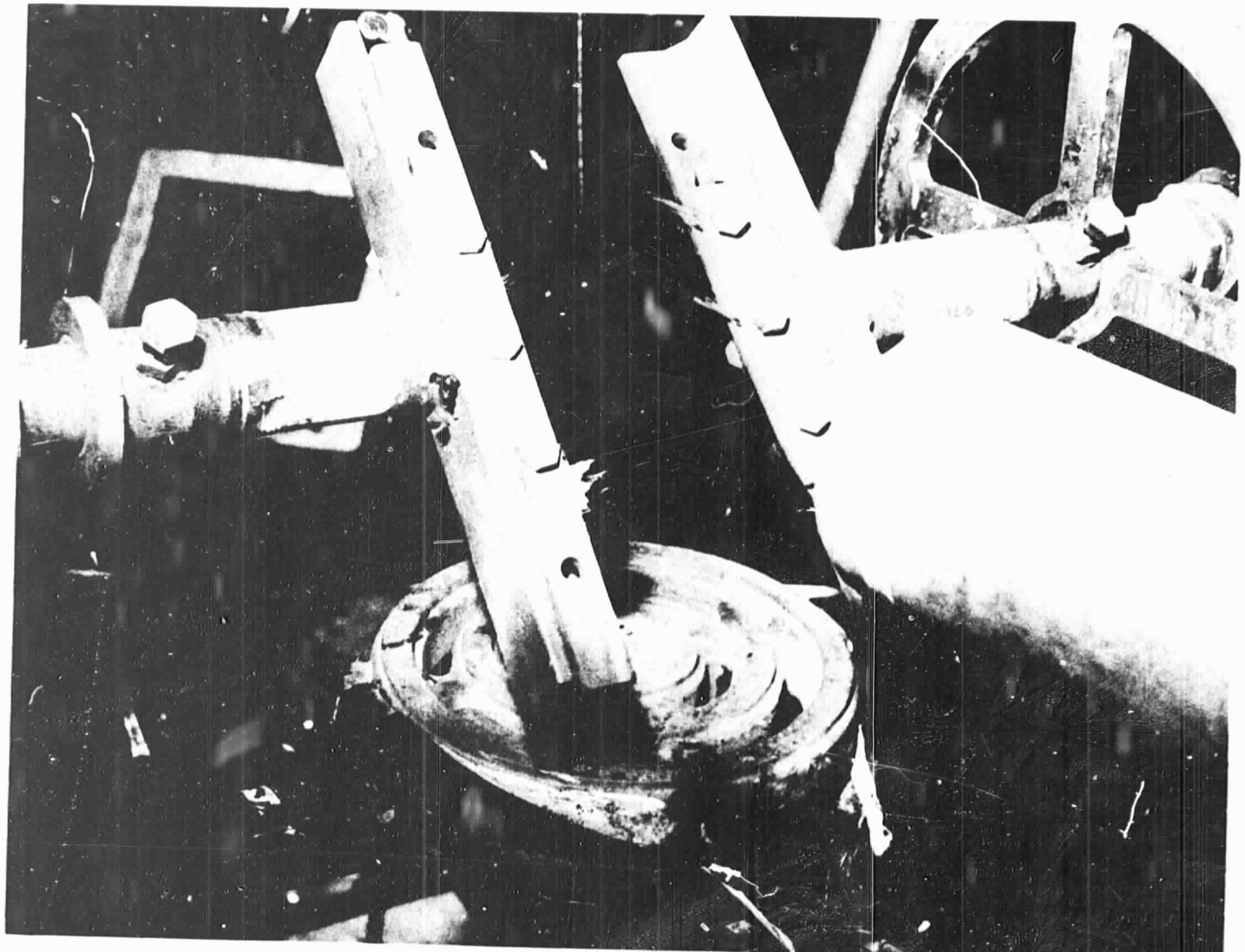

Figure 26. Air Blast Test AB-6, Fixture Residue, Boeing Floorboard Sample

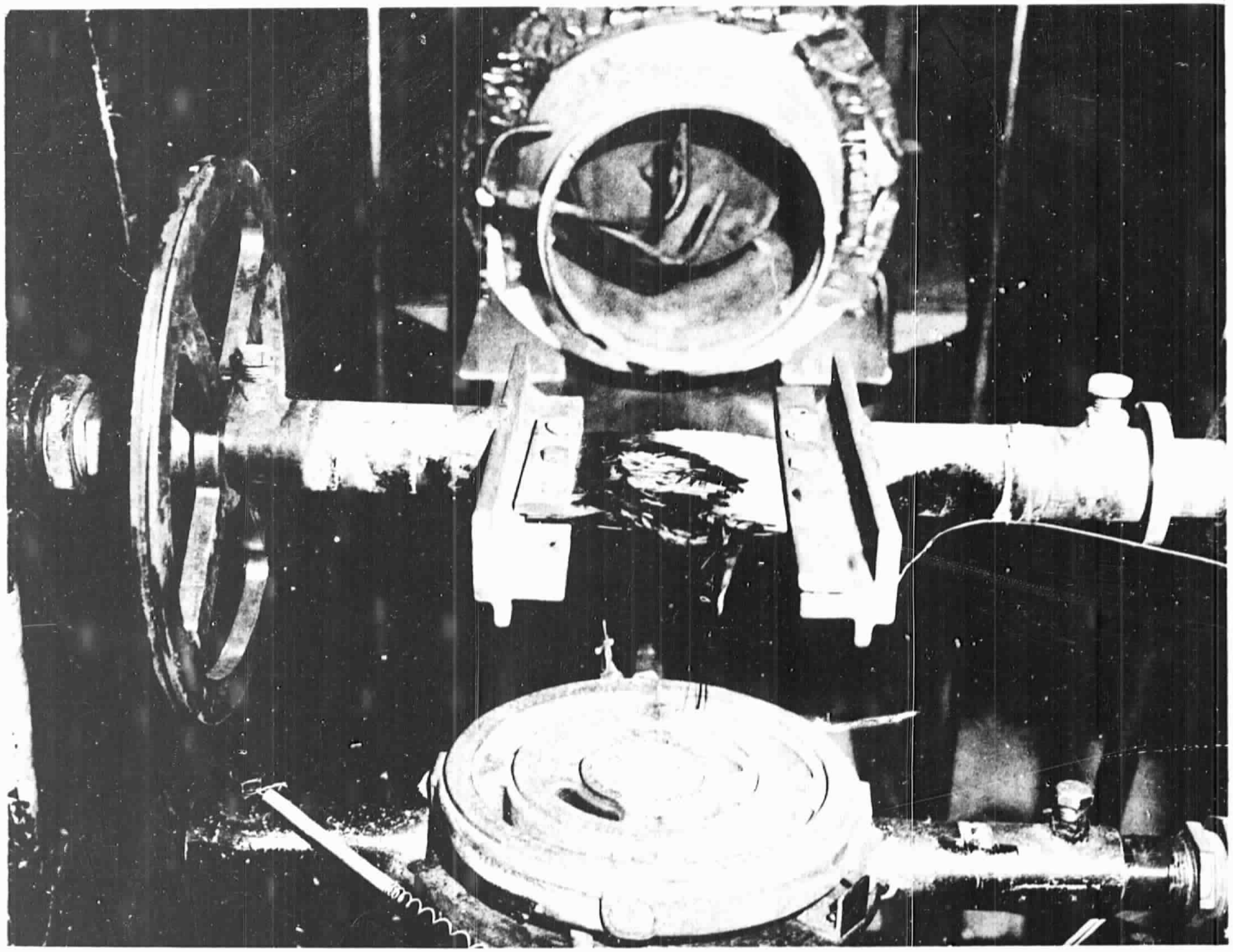

Figure 27. 30-Knot Airflow Test, AF-9, Fixture Residue, 0.16-cm Thick, Crossply Sample

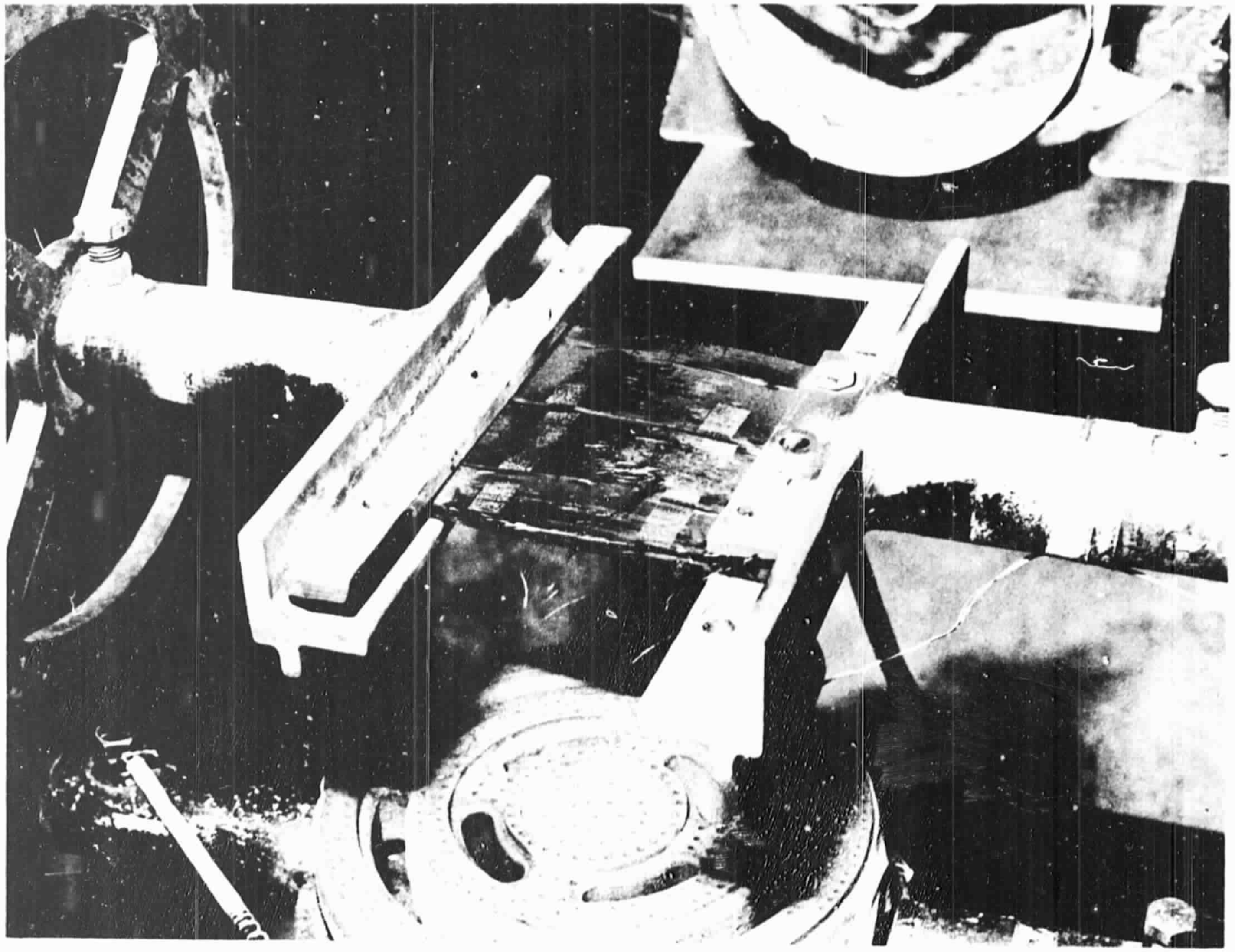

Figure 28. 30-Knot Airflow Test, AF-11, Fixture Residue, 0.64-cm Thick, Unidirectional Sample

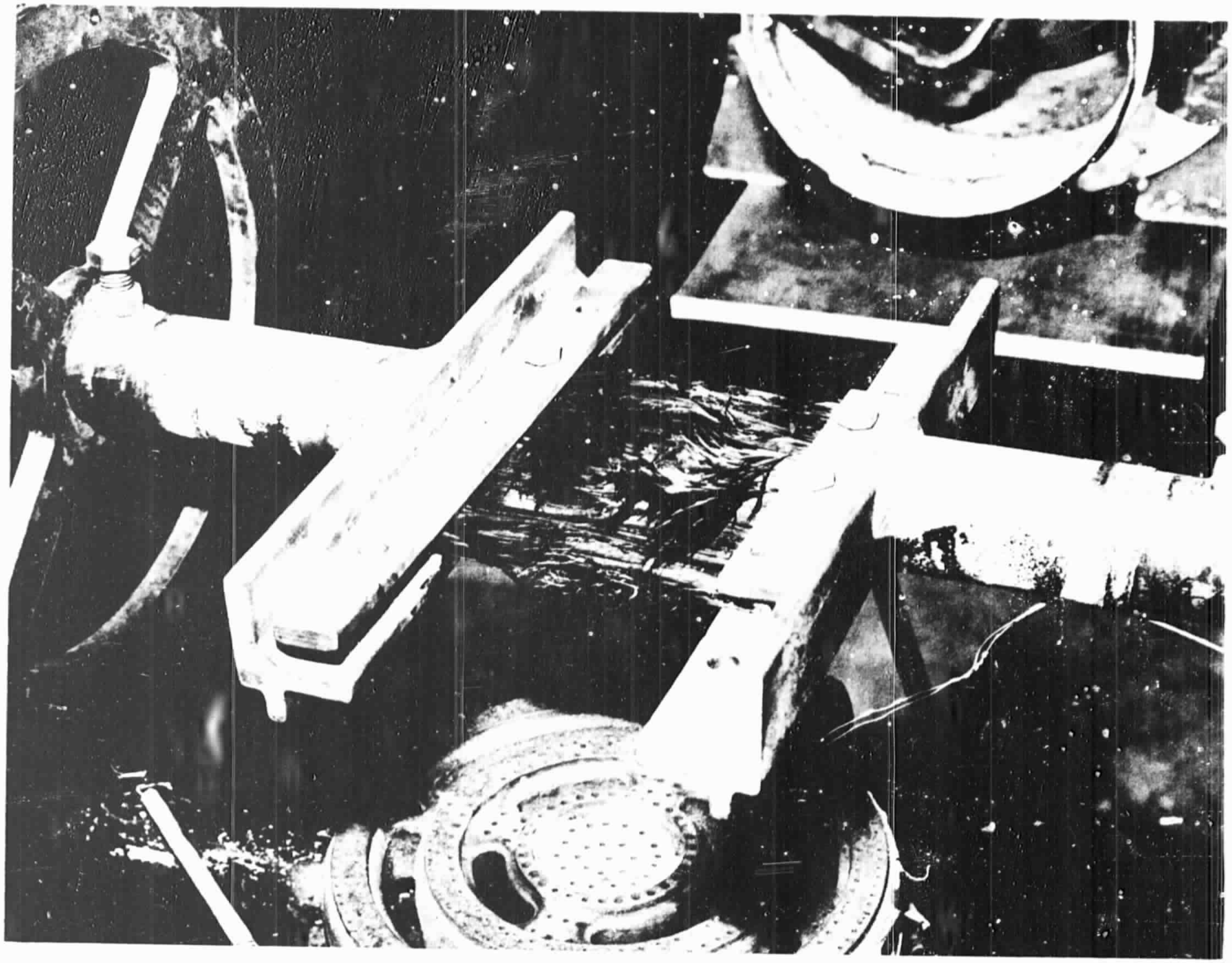

Figure 29. 30-Knot Airflow Test, AF-12, Fixture Residue, 0.64-cm Thick, Unidirectional Sample

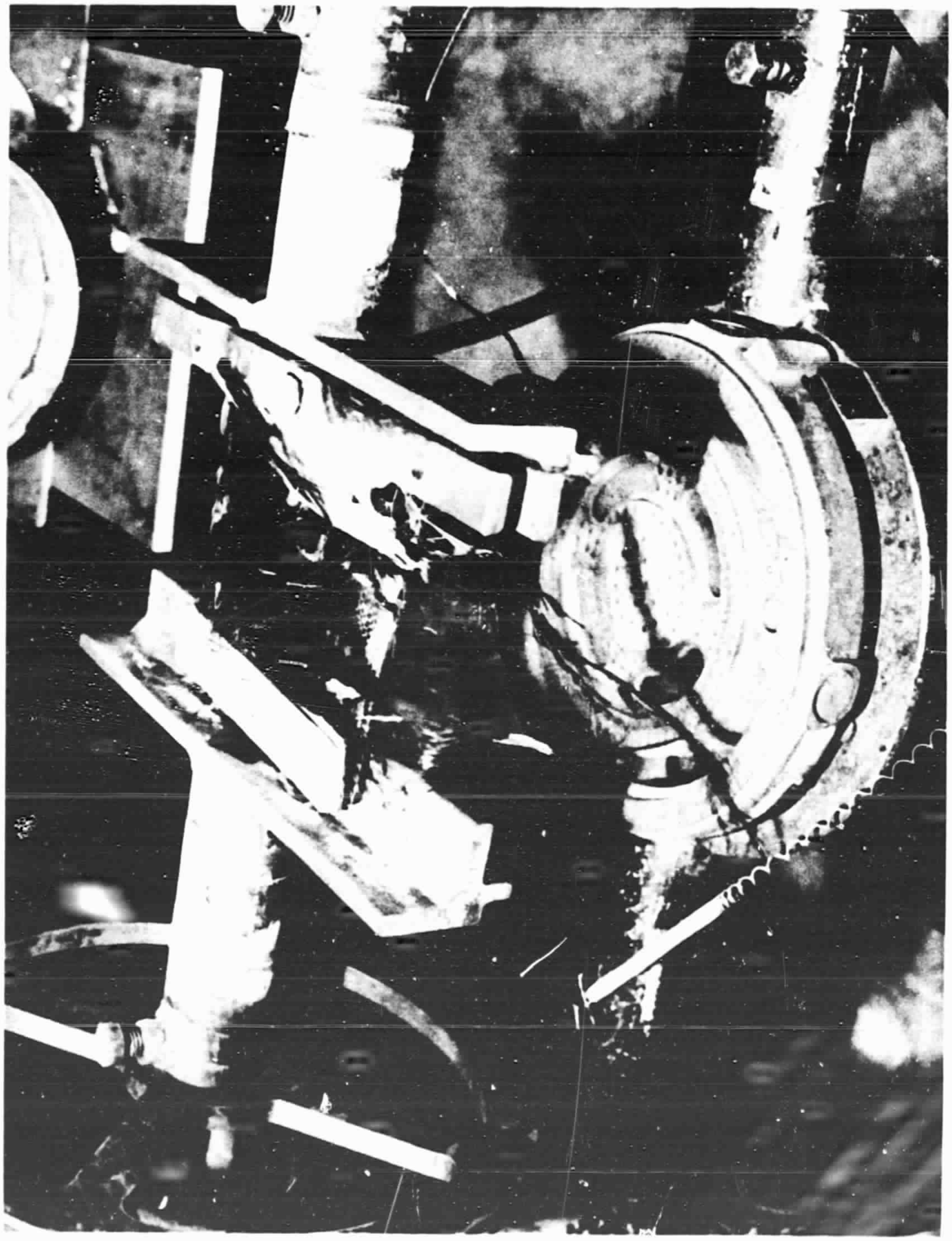

Figure 30. Test Fixture Residue, AF-17, Boeing Floorboard Sample

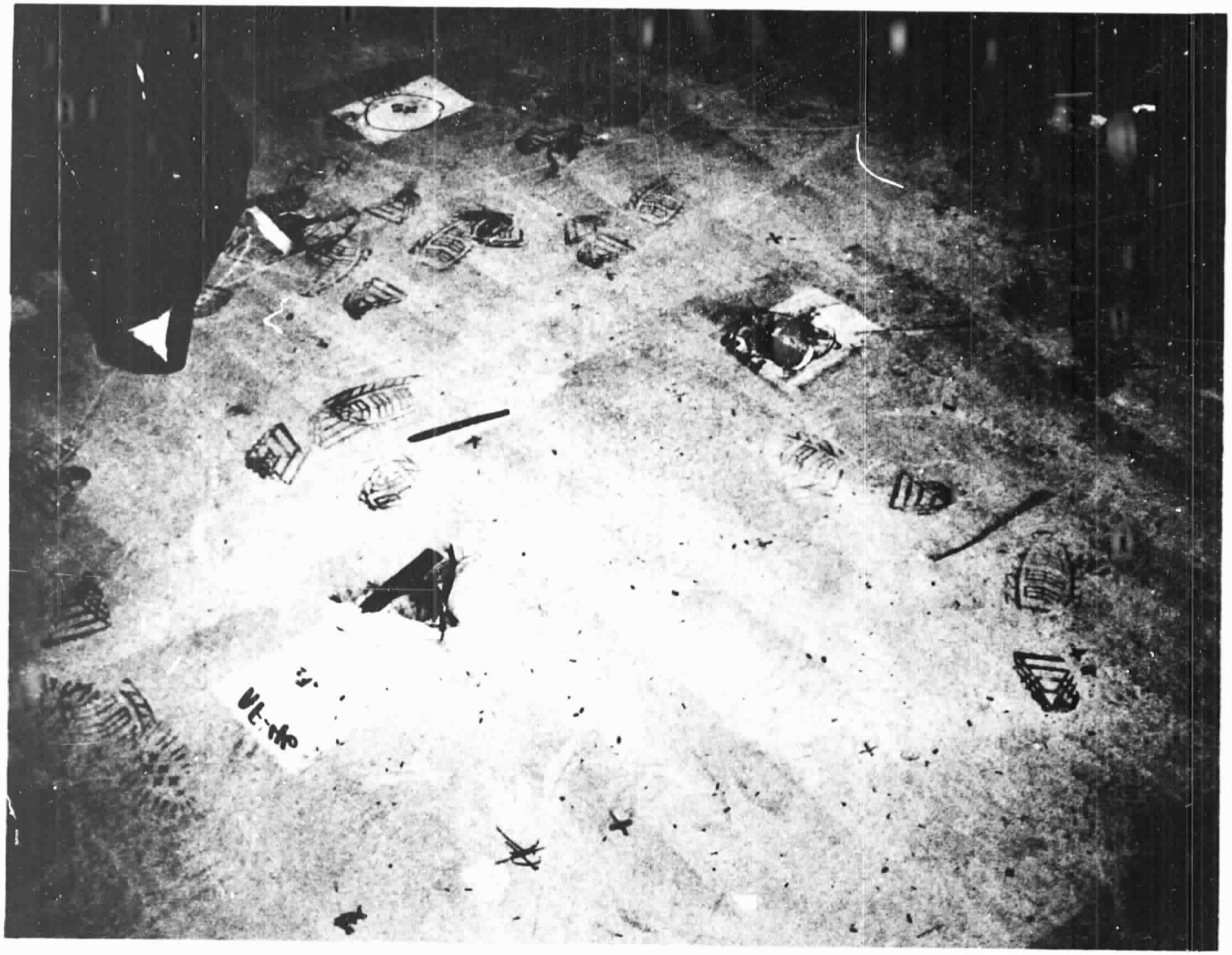

Figure 31. Boeing Floorboard Residue, 30-Knot Airflow Test, AF-17

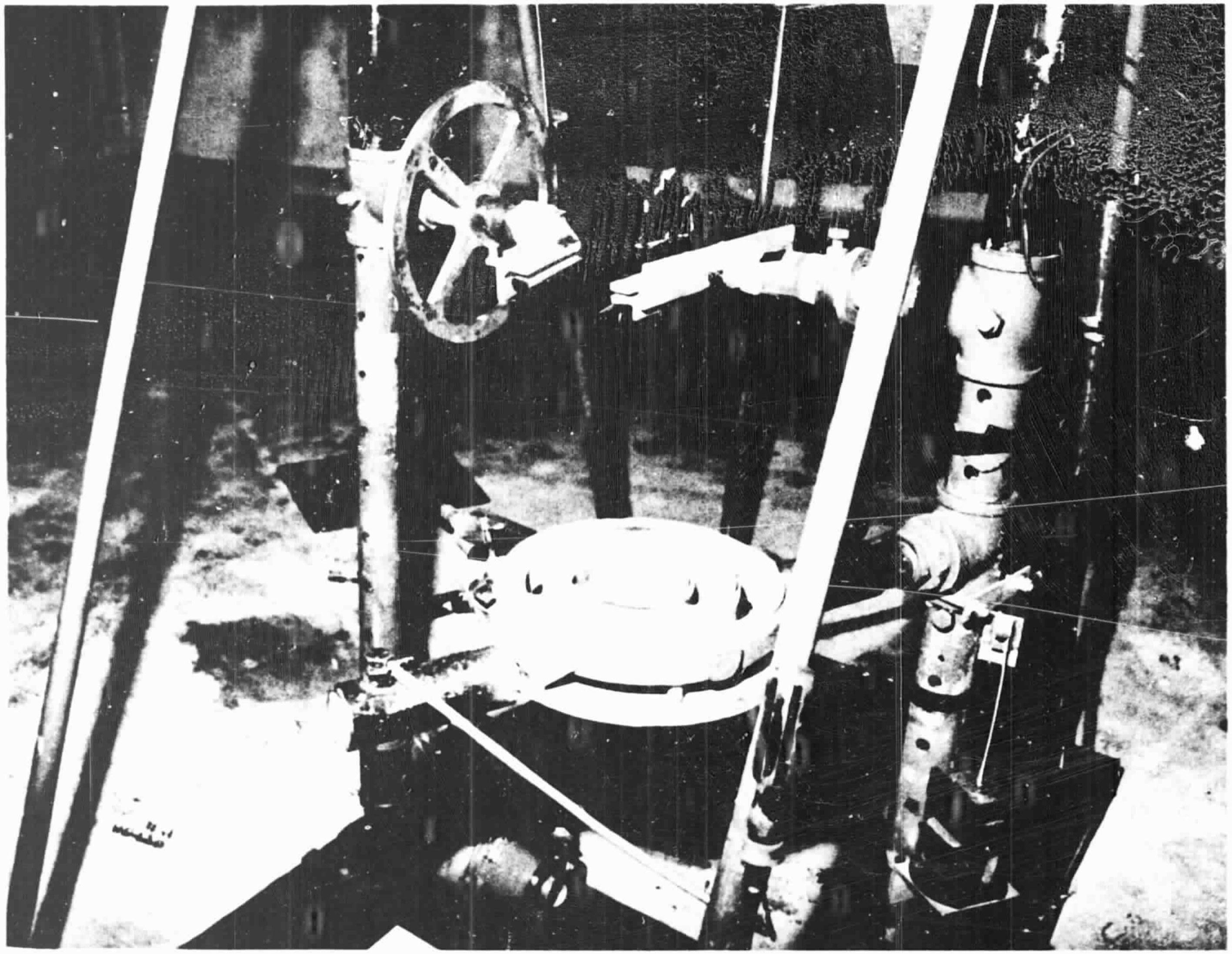

Figure 32. Fixture Residue From Torsional Test, TOR-1

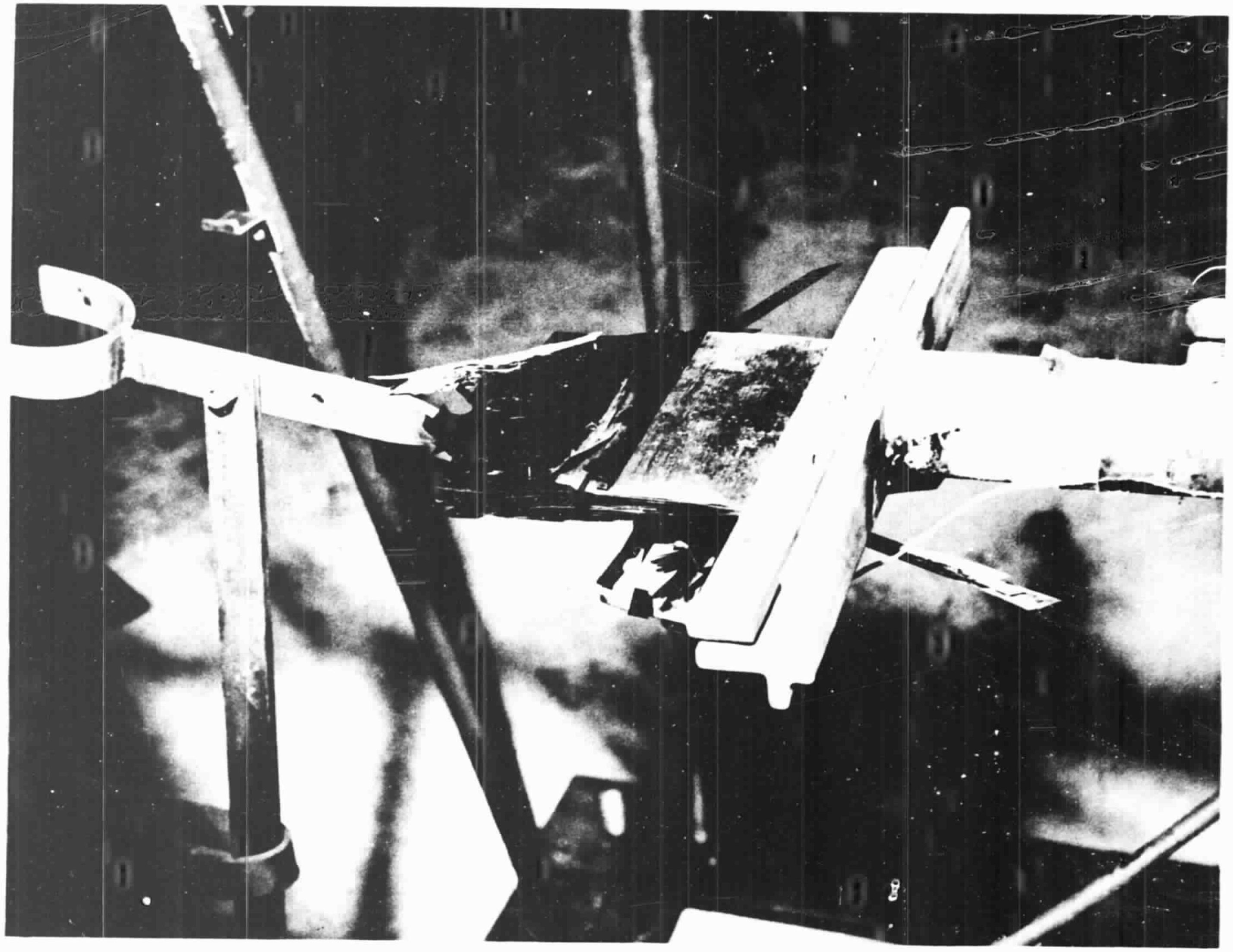

Figure 33. Fixture Residue From Vibration Test, VIB-2

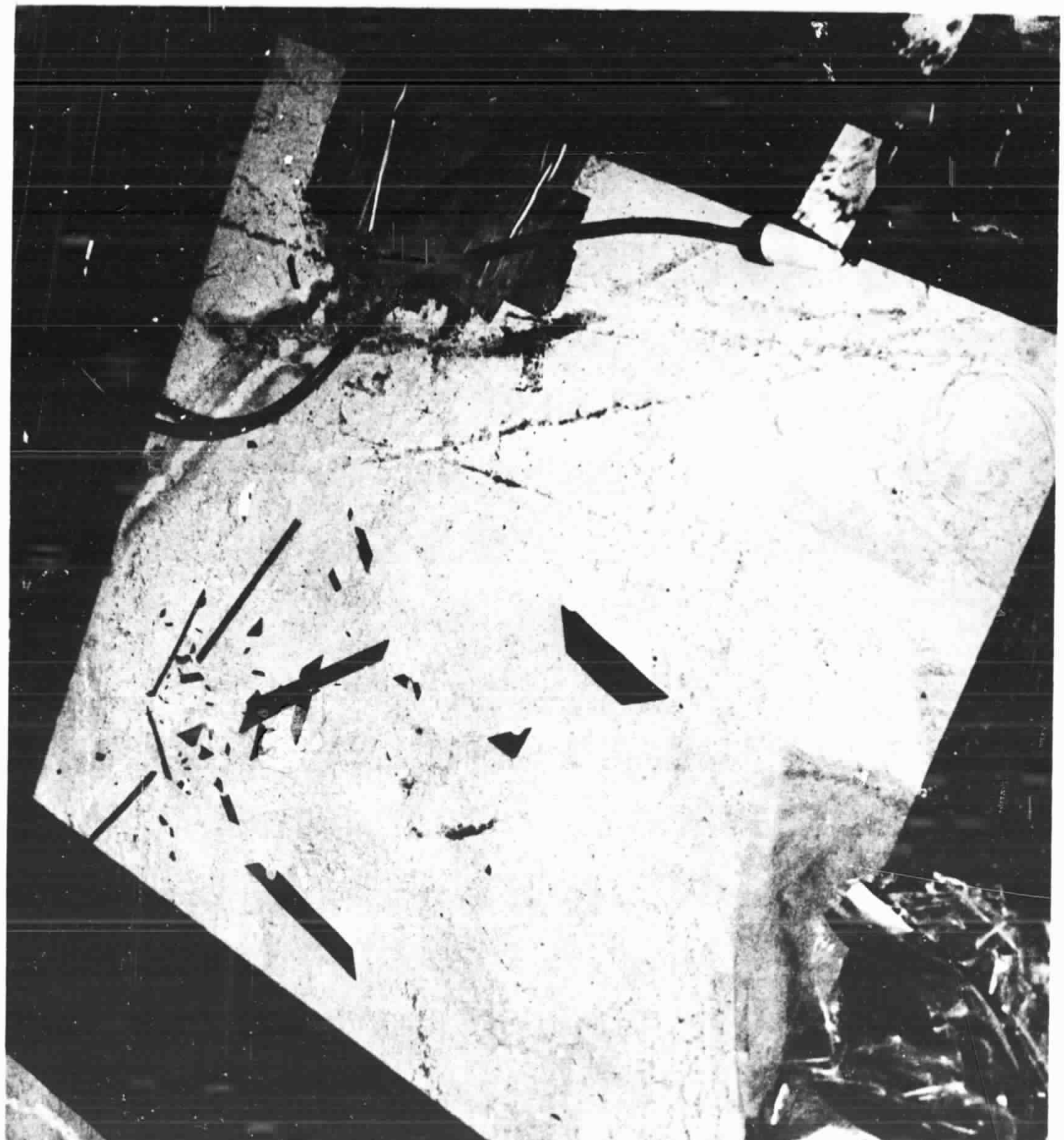

Figure 34. Floor Residue, Vibration Test VIB-2

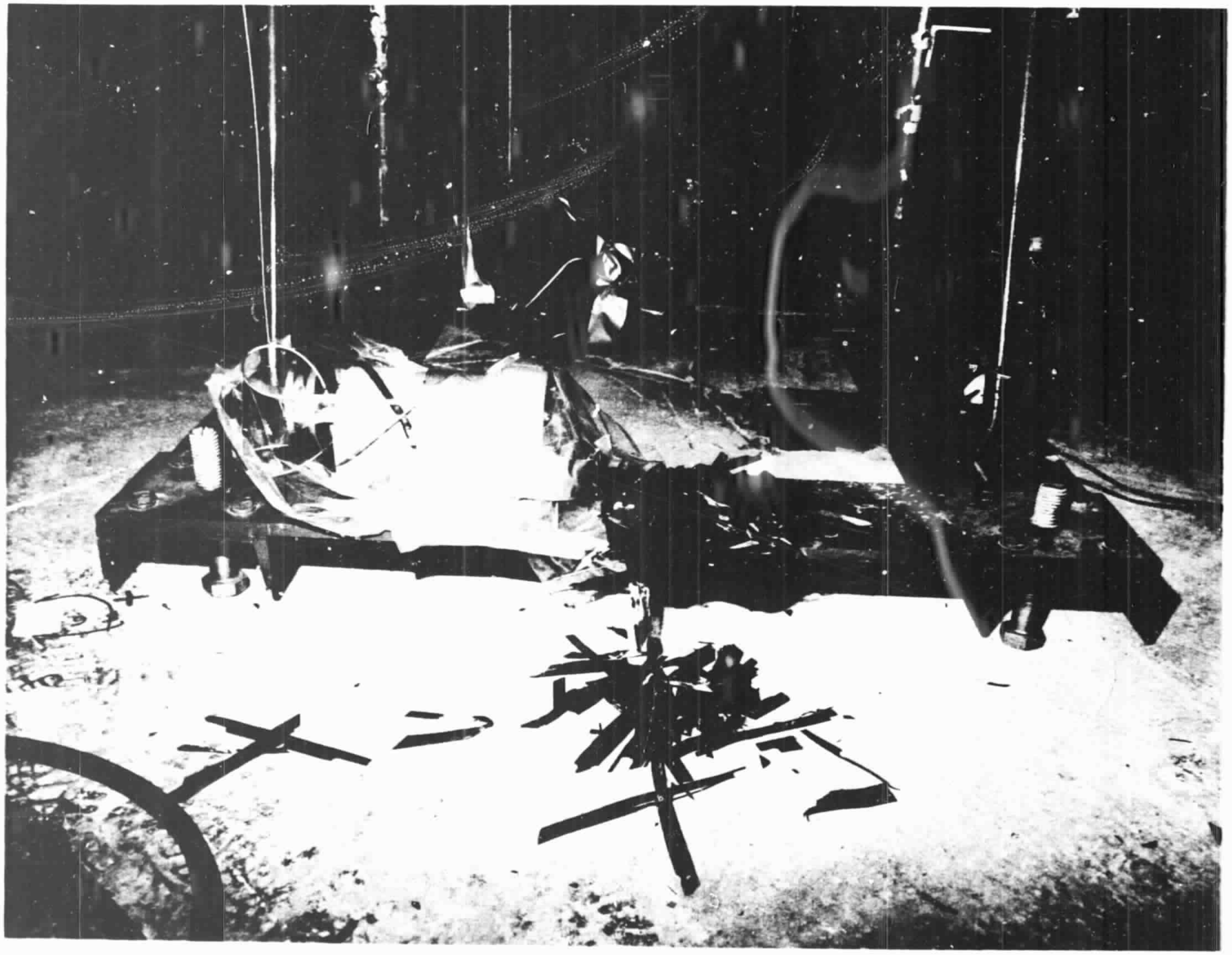

Figure 35. Floor Residue From Drop Test, DP-1

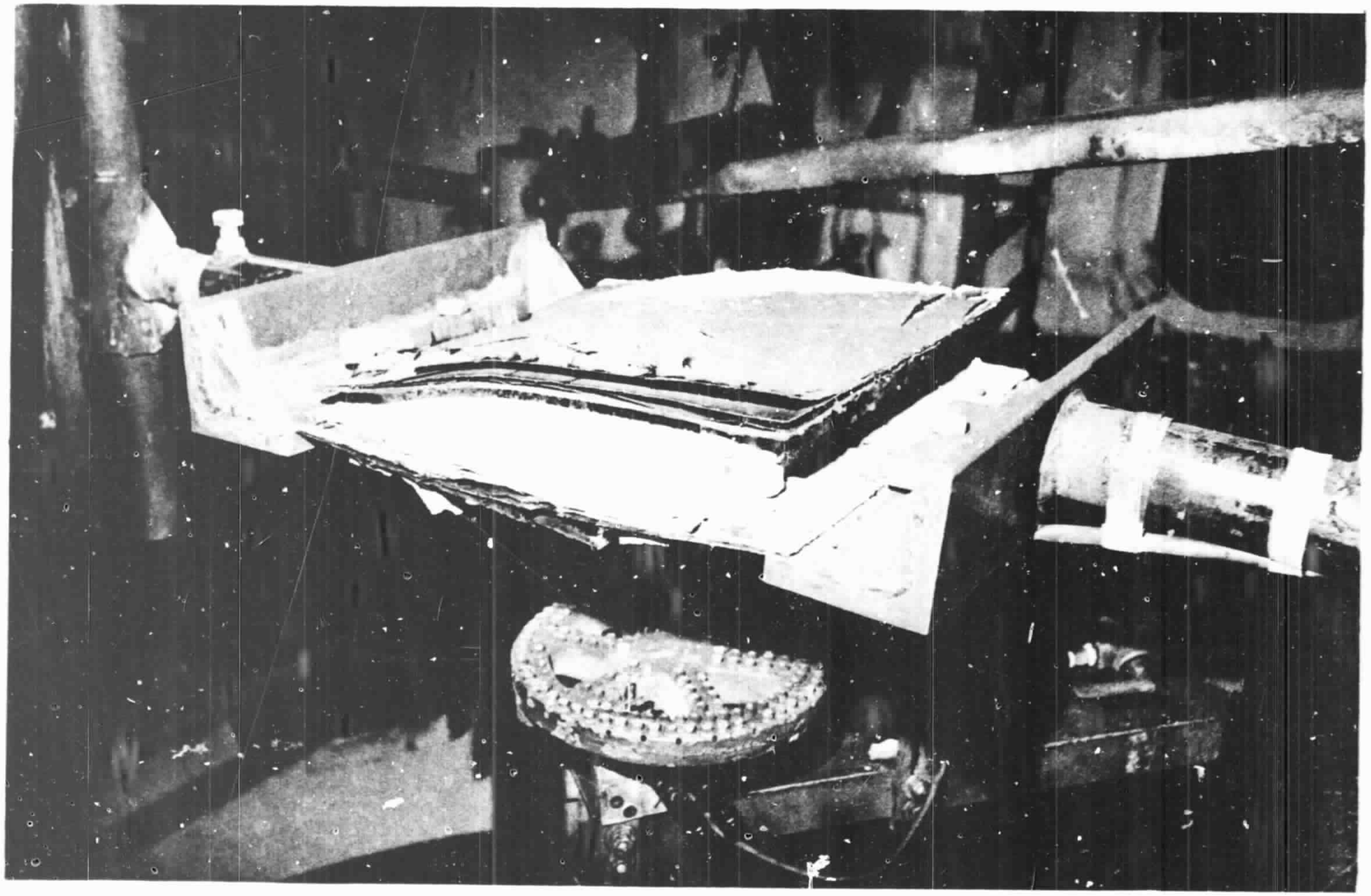

Figure 36. Test Residue From 20-Min Spoiler Burn Test, BT-246

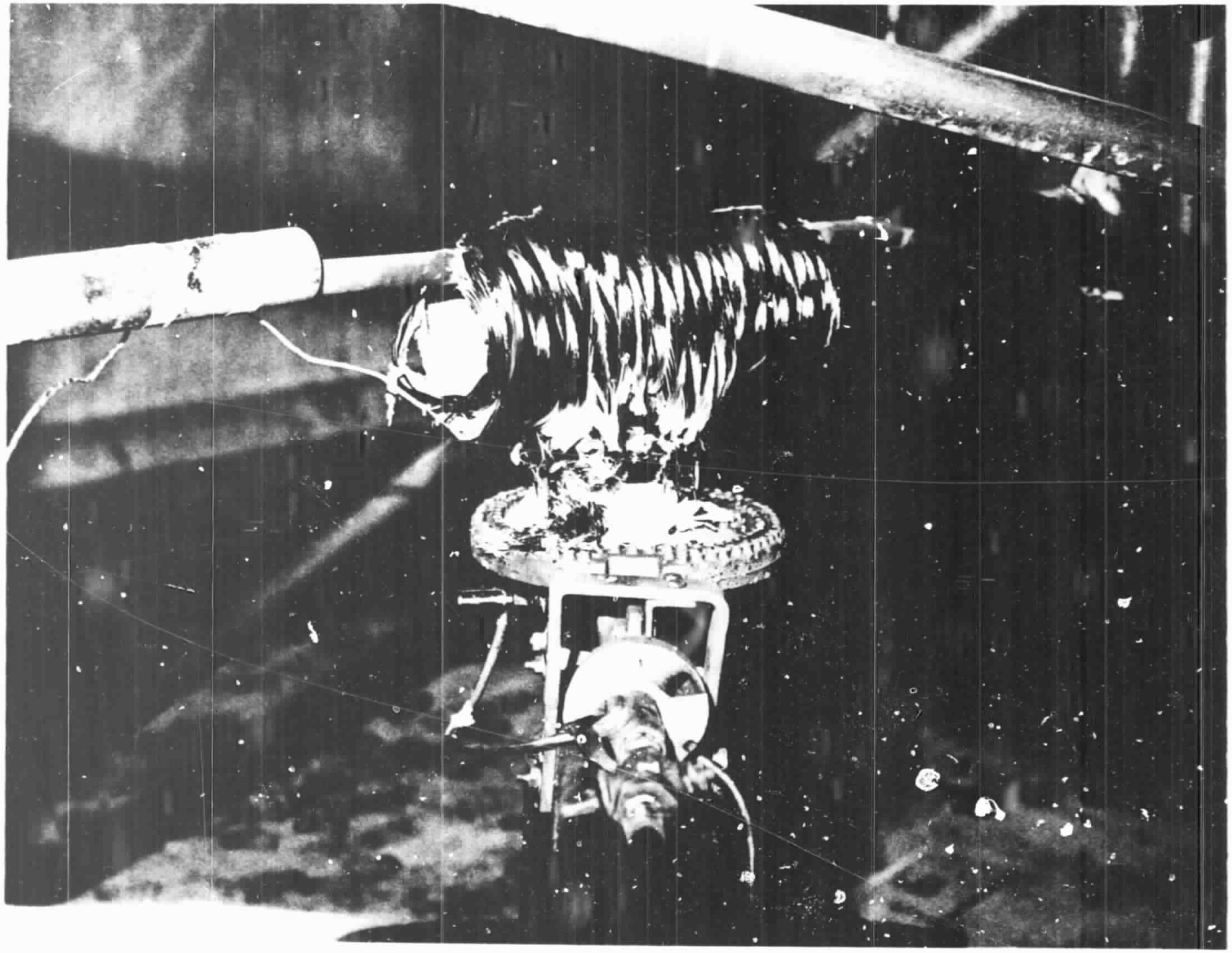

Figure 37. Residue From 20-Min Burn Test of T-300 Graphite Fiber/ Cardboard Spool, BT-247

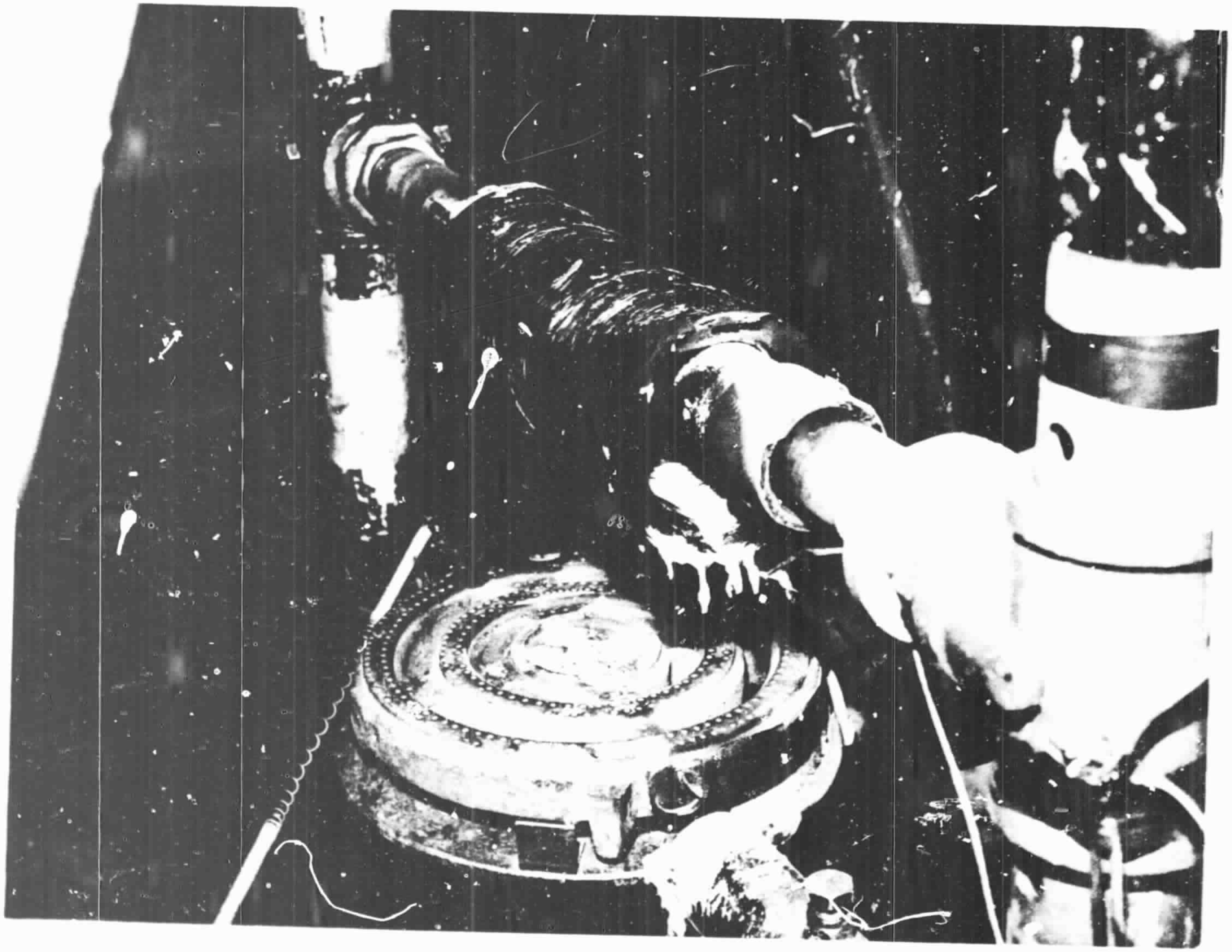

Figure 38. Residue of 20-Min Burn Test of HMS Graphite Fiber/ Plastic Spool, BT-267

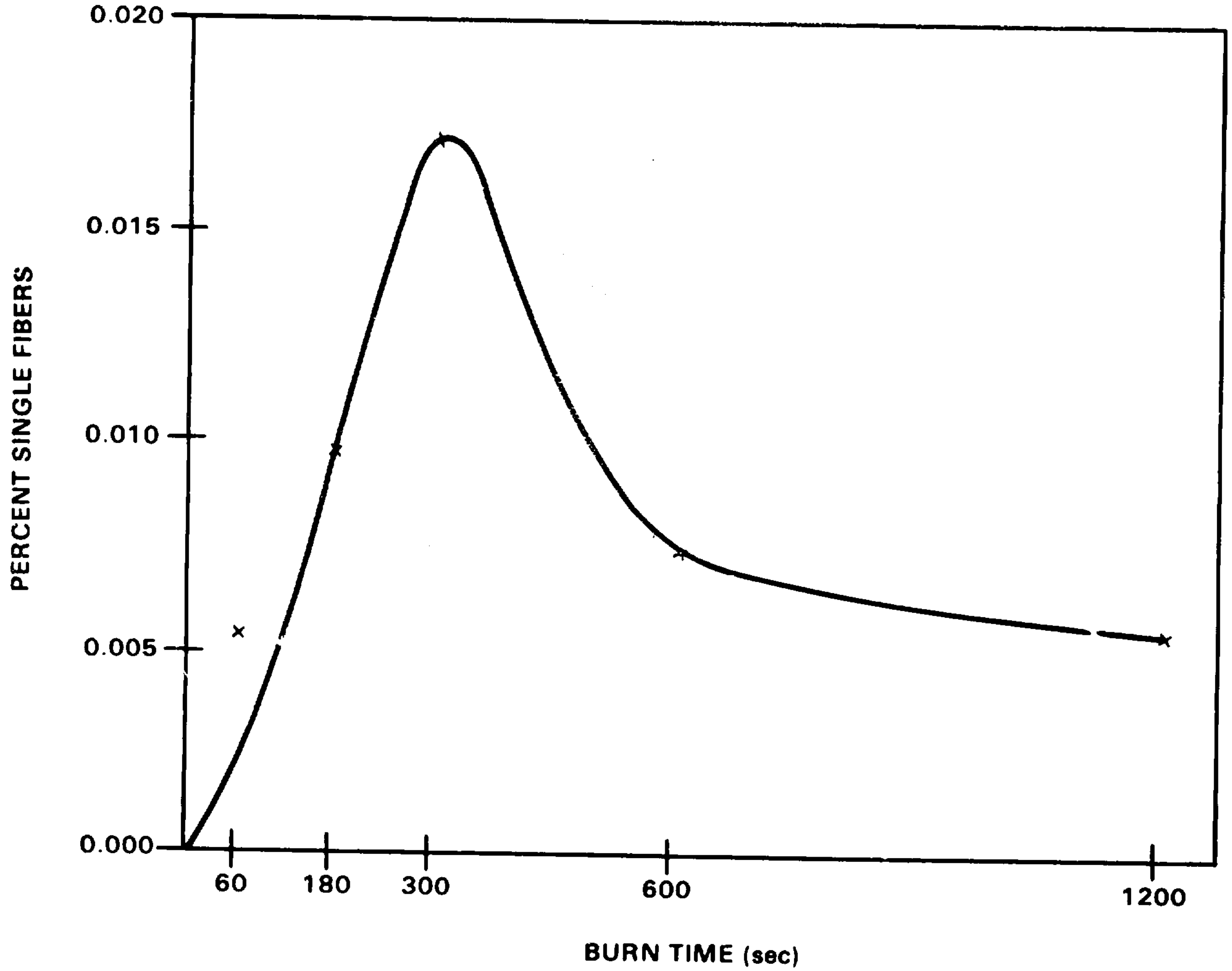

Figure 39. Effect of Burn Time on Single Fiber Release From AS/3501-6 Composites (0.34-cm Thick)

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