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FINAL REPORT

Project No. 510-003-07X

FRICTION EFFECTS OF RUNWAY GROOVES, RUNWAY 18-36 WASHINGTON NATIONAL AIRPORT

DECEMBER 1968

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

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AIRCRAFT DEVELOPMENT SERVICE

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ABSTRACT

Wet and dry runway friction tests were conducted on bituminous concrete Runway 18-36 at Washington National Airport using a Fixed Slip Runway Friction Tester. These tests were conducted to determine if significant friction changes were generated as a result of grooving the runway surface with 1/8- by 1/8-inch-transverse grooves spaced on 1-inch centers. Data analysis indicates that at test speeds of 10 to 60 mph, no appreciable increase or decrease in overall runway friction values was obtained for this series of tests. The treatment of the runway surface, however, by the cutting of uniformly spaced grooves markedly smoothed the resultant wet runway friction values. It is hypothesized that these smoother wet runway friction values result in a surface that affords more efficient operation of aircraft antiskid braking devices and more effective manual braking.

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INTRODUCTION

Purpose

The primary purpose of this phase of the project was to measure the brake slip friction value of Runway 18-36 at Washington National Airport, before and after runway grooving, using the Federal Aviation Administration (FAA) Fixed Slip Runway Friction Tester (FSRFT) Measuring System. The secondary purpose was to investigate hydroplaning effects within the limitations of the test equipment and test conditions.

Background

Commercial jet transport aircraft have generally experienced more difficulty in stopping on wet runways than propeller-driven aircraft. This is due mainly to the higher landing speeds and low aerodynamic drag inherent in the sleek jet transports.

In April 1966, jet transports began operating at Washington National Airport which is owned and operated by the FAA. The longest runway (18-36) is 6870 feet long, 200 feet wide, and accommodates most of the jet traffic.

To enhance safety operations on this runway, the FAA awarded a contract to groove the entire runway length and 150 feet of the runway width, omitting touchdown lights, and subsurface wiring areas. The primary purpose of grooving is to forestall hydroplaning by improving surface water drainage properties (Reference 1). The contract effort to cut transverse grooves 1/8-inch wide, 1/8-inch deep, on 1 inch spacing was begun in March 1967, and completed in April 1967.

Description of Equipment:

Friction Tester - The equipment used to measure runway friction was the FAA's FSRFT, Figure 1, which is a modified Swedish Skiddometer, Model BV-6. The Skiddometer operates in a fixed slip mode and was originally conceived by the Swedish Road Institute for the purpose of measuring the friction values of snow and ice-covered runways. This friction tester utilizes the standard automotive test tire and loading, specified by the American Society of Testing Material (ASTM) for friction testing.

This tester was used in a different manner than that prescribed by the Swedish Road Institute; namely, to measure friction of wet and dry runway surfaces. To accomplish this, the project engineering personnel designed and installed a special water dispensing system, Figure 2. This design incorporated a belt-driven constant displacement water pump coupled to the axle of the FSRFT. The output of the pump varies directly with speed, thereby providing a constant water thickness independent of vehicle speed. A water thickness of approximately .020 inch was obtained, meeting the ASTM Specification E-274

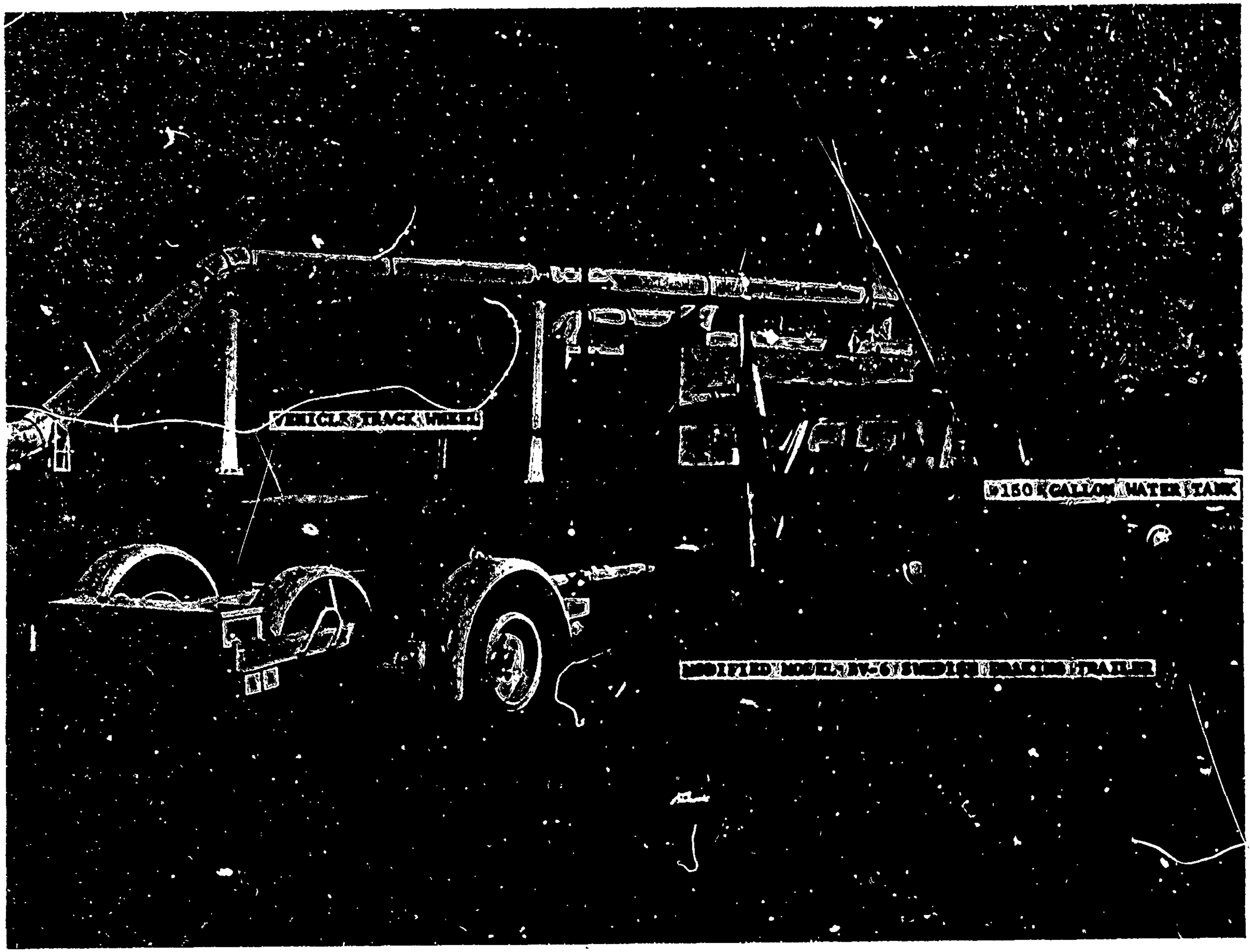


FIG. 1 FAA'S FIXED SLIP RUNWAY FRICTION TESTER AND TOWING VEHICLE

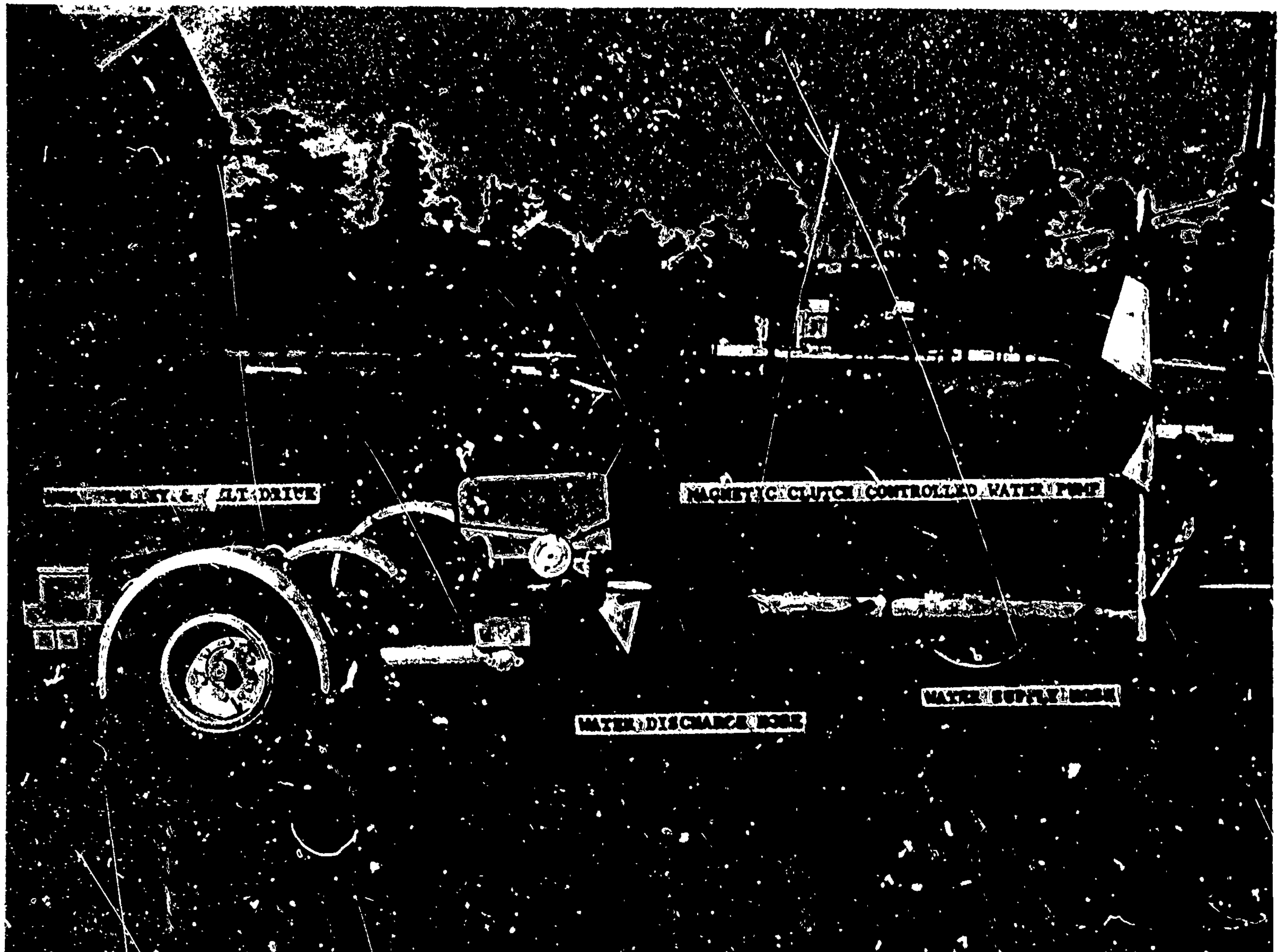


FIG. 2 WATER DISPENSING SYSTEM

which states that a water depth of .020 ± .005 inch be used when measuring wet pavement friction. The pump is operated by means of a magnetic clutch, powered and controlled from the tow vehicle. During friction measuring operations, the magnetic clutches of the three-wheel axle are engaged (locked) thus forcing the test wheel to rotate with the same angular speed as the two outer wheels. Since the diameter of the test tire is smaller than the diameter of the outer tires, the peripheral speed of the test tire becomes less than that of the outer tires. Thus, the design causes the test tire to be retarded, generating a tire/pavement slipping action. This action produces a constant slip ratio of approximately 13 percent. The torque of the test wheel, generated by friction forces between the test tire and pavement, is measured by a strain gage force transducer.

The water dispensing system and friction recording system are separately and remotely controlled by the operator in the tow vehicle enabling, first, dry testing, followed by wet testing over the same path. When the water dispensing system is activated, a water film approximately .020-inch thick is deposited on the pavement surface 18 inches ahead of the test tire, thus providing conditions for wet testing.

Instrumentation - The friction forces exerted on the test wheel are registered by a pen recorder, Figure 3. The recorder and associated electrical equipments are located in an instrument cabinet mounted on the frame of the trailer. The readout on the chart paper is traced in analog format and the displacement of the pen provides a numerical value known as "Brake Friction Number" (BFN_{13}). This value is the measured coefficient of friction times 100, obtained by testing in the brake slip mode at 13 percent slip. The recorder has a combination electric chart paper drive which is used during calibration, and a mechanical external chart paper drive for recording friction.

The mechanical drive consists of a flexible cable connected to the left outer trailer wheel. This arrangement produces chart paper lengths proportional to the distance tested - independent of test speed. Each distance subdivision of chart paper length is equal to approximately 77 2/3 feet of runway distance and each friction subdivision represents an uncorrected BFN_{13} value of 1, full scale representing a BFN_{13} value of 120. The recorder is also equipped with an electric timer which provides a pip at 1-second intervals. This pip is recorded by a pen on the margin of the chart paper. The distance between pips facilitates verifying the speed of the tester.

Test Tire - The friction measuring tire used in these tests was developed by the ASTM to provide a standard test tire which is manufactured to closely held specifications. The tire, designated by ASTM as E-249, was specifically designed for pavement friction measuring. This four-ply tire is a standard automotive size (7.50/14) which is inflated to a specified pressure of 24 psi and vertically loaded to

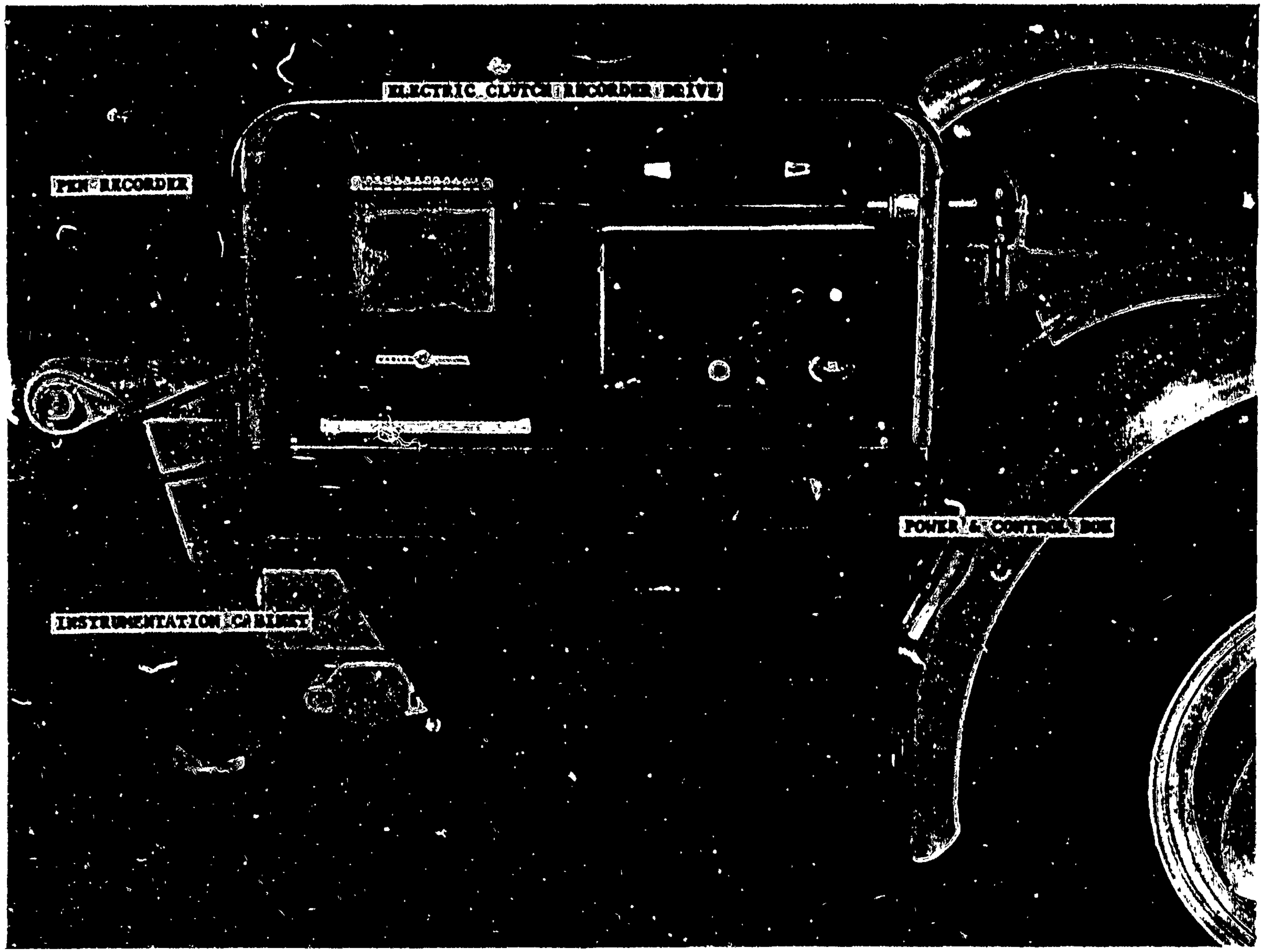


FIG. 3 INSTRUMENTATION CABINET AND RECORDER

1085 pounds. A smooth tread configuration (no circumferential grooves) was used to eliminate variances in friction due to wearing tire tread and groove depths.

Towing Vehicle - The vehicle provided for towing the Skiddometer was a late model station wagon. This automobile is equipped with a two-way radio (for airport communications) and a specially built 150-gallon capacity water tank. This amount of water is sufficient to wet 20,000 linear feet of pavement. The gross weight of the vehicle, with two operators and a full tank of water, totaled approximately 4500 pounds. When towing the 3400-pound FSRFT with the test wheel in the braking mode, the top speed of the system was limited to slightly over 60 mph. Acceleration was also affected, and 50 mph was the maximum speed within 1000 feet.

Test Methods and Procedures:

Calibration - Prior to each series of test runs, the FSRFT was calibrated, Figure 4. This calibration was accomplished by applying known horizontal loads to the platform of the calibration stand. The horizontal forces are transmitted to the contact area of the tire resting on the platform. The dynamometer reading was related to the displacement of the recorder pen which recorded the uncorrected coefficient of friction (BFN). Repeated calibrations provided information from which system accuracy and/or deterioration would be observed.

Runway Pattern and Nomenclature - The test pattern used on the 6870-foot runway consisted of four test tracks or paths shown in Figure 5. One thousand feet at each end of the runway were reserved for accelerating and stopping; the remaining 4870 feet were friction-tested. Track No. 1 is located 3 feet east of the runway centerline, to clear centerline paint marks, and all runs on Track No. 1 were made in the 36 or north direction. Track No. 2 is located 35 feet from the east edge of the runway, and tests on this track were conducted in the 18 or southerly direction. Test runs on Track No. 3 were conducted in the 36 direction, 75 feet from the west edge of the runway (25 feet west of the centerline), while tests on Track No. 4 were made in the 18 direction and 75 feet from the east edge of the runway (25 feet east of centerline). Tracks Nos. 1, 3, and 4 provided data of the most contaminated portion of the runway, while Track No. 2 (runway edge) provided data on the least contaminated portion of the runway. This test design allows a comparison to be made between the rubber-contaminated (touchdown and rollout area) portions of the runway and the relatively uncontaminated portion along the runway edge.

Test Runs - Twenty-four "standard" test runs were made on each of the four tracks. Of these runs, 12 were made in a dry condition (without use of the water dispensing system) at 10, 30, and 50 mph, followed by 12 wet runs at the same speeds. At the completion of the

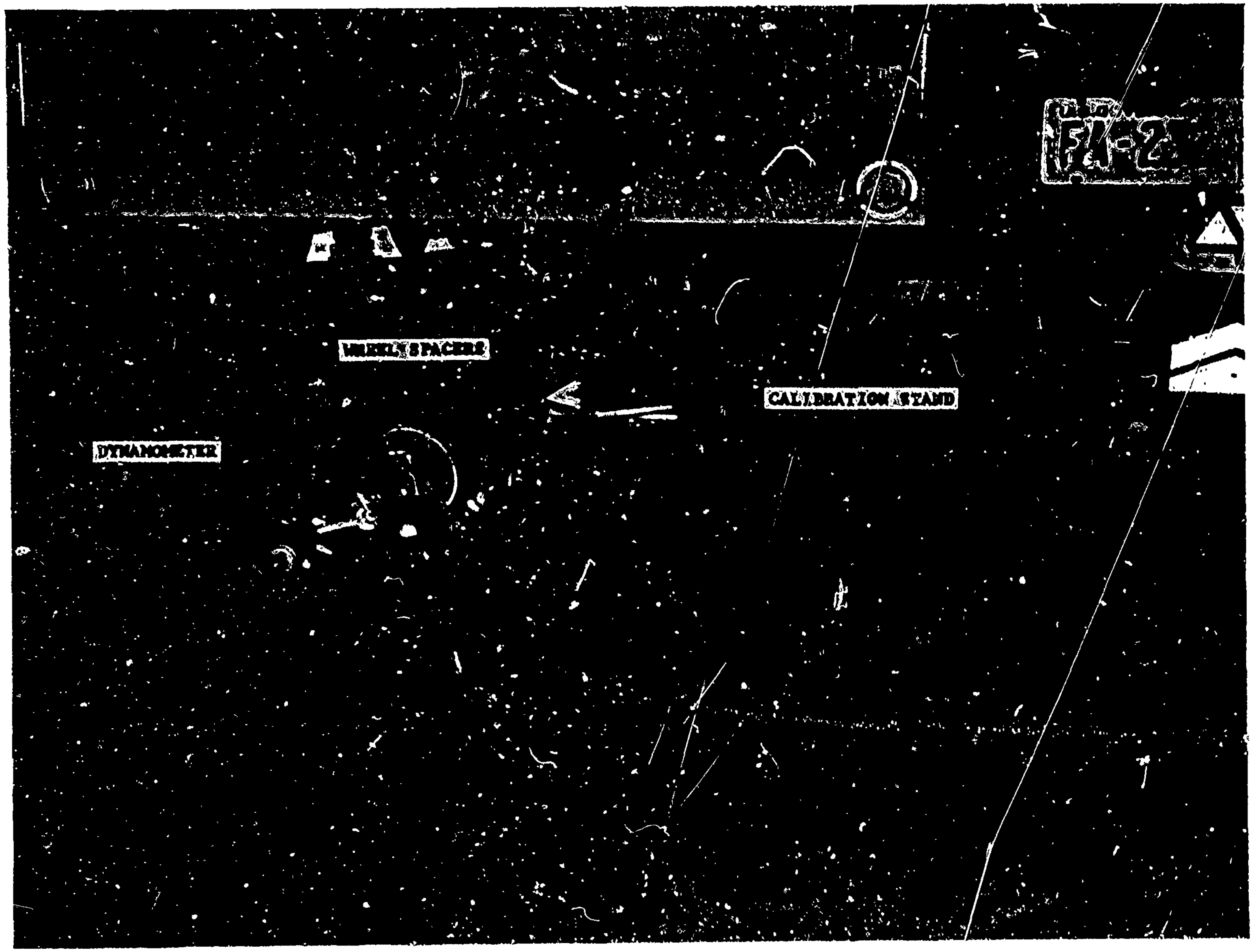


FIG. 4 CALIBRATION EQUIPMENT

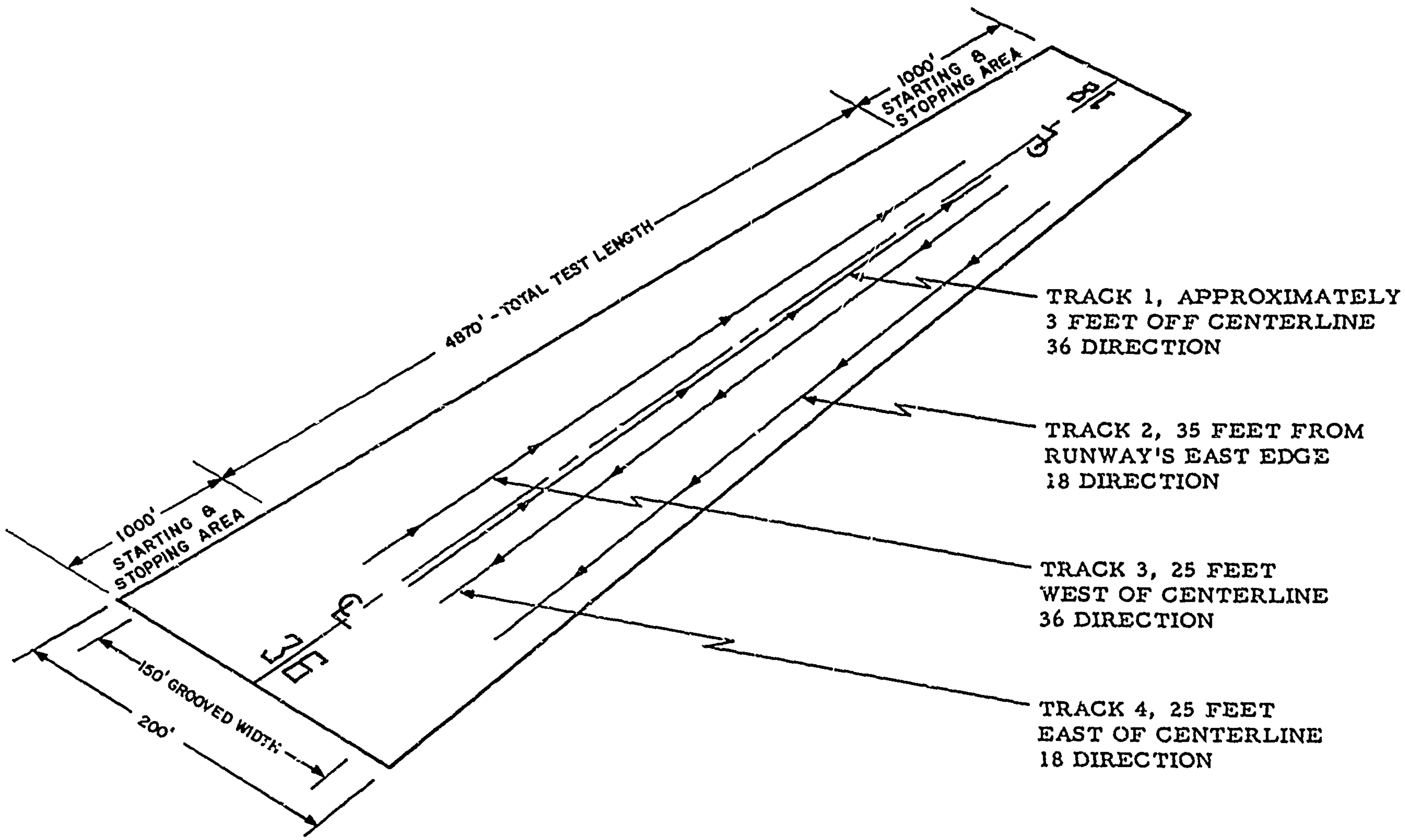


FIG. 5 RUNWAY 18-36 TEST TRACK CONFIGURATION

24th run, 4 additional higher speed wet runs were made, 1 on each track, at approximately 60 mph. These runs, however, required an additional 500 feet for acceleration, thereby reducing the test portion of the runway by an equal amount. The higher speed runs were conducted in an attempt to approach speeds at which dynamic hydroplaning could occur. Dynamic hydroplaning has been calculated to occur at approximately 65 mph in accordance with the four-ply automotive tire formula of 13.2 times the square root of the tire pressure (Reference 2).

Test speeds over 60 mph were unobtainable due to horsepower limitations; consequently, other efforts to induce hydroplaning or the onset of hydroplaning were attempted by lowering the test tire pressure. The pressure was lowered from an initial 24 psi to 17.4 psi, then to 14.3 psi, and finally to 11.6 psi, at which, if the proper conditions are present, dynamic hydroplaning should occur at 55, 50, and 45 mph, respectively.

DISCUSSION

Friction Tests

Friction measurement tests were made on 12 occasions, of which 6 were conducted before the runway was grooved and 6 after, (Table I). Similar tests, matched for environmental conditions, were compared; i.e., before-grooving tests were compared with after-grooving tests conducted in similar environmental conditions. Visual inspection of the four test tracks disclosed deposits of tire rubber predominately at the 1000-foot ends of Tracks 1, 3, and 4. Track 2 was found to be relatively uncontaminated by rubber deposits.

Dry Runway Surface Conditions - December 10, 1966, and May 4, 1967 Tests: In comparing the pre-grooved tests conducted December 10, 1966, with the post-grooved tests conducted May 4, 1967, the following results are noted from the test data shown in Appendix I:

Track 1 (centerline) - There is no significant change either in BFN_{13} or curve shape for the dry tests, pages 1-1, and 1-2. In the wet test configuration, however, pages 1-3 and 1-4, there is noticeable and measurable differences in the BFN_{13} values, favoring the after-grooving condition. The BFN_{13} values are generally increased and the overall analog traces are markedly smoother.

Track 2 (runway edge) - Since this track is near the edge of the runway and relatively free of rubber deposits and the polishing action of traffic, it would be expected that any friction value changes would be caused mainly by the grooves. The rough trace of the 10 mph after-grooving dry test is unexplainable; otherwise, the dry tests are almost identical before and after grooving, pages 1-5 and 1-6. In the wet tests, pages 1-7 and 1-8, the before- and after-grooving traces of the 10- and 60-mph tests are very similar, whereas a definite

TABLE I

FRICTION MEASURING TESTS
WASHINGTON NATIONAL AIRPORT RUNWAY 18-36
TEST RUN LOG

PRE-GROOVING TESTS

Test No.	Test Date	No. of Test Runs	Ambient Temp. °F	Test Water Temp. °F	Runway Surface Conditions	Remarks
1	12/10/66	28	54 - 55	50 - 50.9	Dry	Standard test runs at standard tire pressure.
2	12/22/66	7	32 - 33	Not used	Dry	Test curtailed by airport authorities due to freezing temperatures.
3	2/2/67	28	41 - 46	44.6	Damp	Very light rains at start of test runs. Standard test runs at standard tire pressure.
4	2/3/67	36	35 - 40	42.6 - 52.6	Damp	Rain ended 4 hours prior to tests at variable tire pressures. First 20 runs standard water flow. Last 16 runs high water flow rate.
5	2/21/67	42	39 - 40	41 - 50.9	Wet	Light rains first 26 runs at standard 24 psi tire pressure, all tests high water flow rate.
6	3/16/67	40	34 - 38	42.8	Damp	Rain ended 3 hours prior to tests. First 28 runs standard tire pressure, last 12 tests conducted at variable tire pressures.

POST-GROOVING TESTS

Test No.	Test Date	No. of Test Runs	Ambient Temp. °F	Test Water Temp. °F	Runway Surface Conditions	Remarks
7	4/6/67	24	55	54.5	Damp	Tested partially-grooved section 2000 feet south end of runway. Standard tests at standard tire pressure.
8	4/20/67	24	45 - 47	56.8	Damp	Tested partially-grooved section 4000 feet south end of runway. Standard tests at standard tire pressure.
9	5/4/67	40	45 - 48	59.9 - 64.4	Dry	First 28 runs standard test at standard tire pressure, last 12 tests conducted at variable tire pressures.
10	5/10/67	28	49	59	Dry	Standard test runs at standard pressure.
11	5/23/67	28	52 - 53	59 - 59.9	Damp	Rain and fog prior to tests. Standard test runs at standard tire pressure.
12	9/14/67	28	56 - 57	74 - 75	Dry	Standard test runs at standard tire pressure.

smoothing of the traces is noted in the 30- and 50-mph post-grooving tests. The BFN_{13} values at 30 and 50 mph wet are also slightly higher after grooving, while the 60-mph values are slightly lower.

Track 3 (25 feet west of centerline)- This track, like Track 1, is also in a highly rubber-contaminated area. The post-grooving tests, pages 1-9 through 1-12, show an unexplainable decrease in BFN_{13} values for the 30- and 50-mph dry test runs and also for the 30-mph wet test run. The remainder of the wet and dry test runs, however, indicates no significant decrease or increase in friction value, but, again, a definite smoothing of the analog traces is evident in the post-groove friction data.

Track 4 (25 feet east of centerline) - Track 4 is the counterpart of Track 3 and, consequently, produces similar friction data as those from Track 3. This is borne out by an analysis of the data, pages 1-13 through 1-16.

Damp Runway Surface Conditions - March 16, 1967, and May 23, 1967 Tests: Comparing the pre-grooved tests conducted on March 16, 1967, with the post-grooved tests conducted on May 23, 1967, both for similar damp runway environmental conditions, the following results are noted from the test data shown in Appendix II:

Track 1 (centerline) - The BFN_{13} values for the post-grooving dry tests for the 10- and 30-mph runs are higher than the pre-grooving values and all the traces are smoother, pages 2-1 and 2-2. The values for the wet tests, pages 2-3 and 2-4, indicated that, although the curve shapes are similar, there was no major change in BFN_{13} values except that a post-grooving decrease is noted in the 60-mph tests. Again, the post-grooving traces are smoother.

Track 2 (runway edge) - These test data, pages 2-5 through 2-8, indicate that the BFN_{13} values and curve shapes are almost identical for the pre- and post-grooving wet and dry tests and, again, a definite smoothing of the analog friction traces is noted, especially for the wet tests. A slight post-grooving decrease in friction values is noted for the 60-mph wet tests and the 50-mph dry tests.

Track 3 (25 feet west of centerline) - The test data for this track, pages 2-9 through 2-12, show that the after-grooving BFN_{13} values for the wet and dry tests were generally lower than the pre-grooved values except for the 10-mph dry tests. Again, the curve shapes are similar and the post-grooving traces smoother.

Track 4 (25 feet east of centerline) - Track 4 is the counterpart of Track 3 and, consequently, has produced data similar to those found in analyzing Track 3, with the exception that the 10-mph dry tests produced no significant change of friction values. Again, the analog traces are similar and the post-groove traces exhibit more smoothness.

Runway Contamination Comparative Tests - Dry Surface Conditions - May 10, 1967, and September 14, 1967 Tests: It was noted while conducting the immediate post-grooving tests that a dust-like residue was present. These dust deposits, resulting from the grooving operation, were found primarily along the edges of the runway. To determine if the post-grooving friction values were influenced by this contaminant, another series of friction tests was conducted on September 14, 1967, approximately 4 months after grooving. These test results were compared to the post-grooving friction values obtained on May 10, 1967, which were conducted under similar runway environmental conditions, shown in Appendix III. No significant changes of friction values or trace shape were observed, thus indicating that groove dust did not influence test results to any appreciable degree. These September traces were also compared to the post-grooving analog traces obtained May 4, 1967, contained in Appendix I, pages 1-2, 1-4, 1-6, 1-8, 1-10, 1-12, 1-14, and 1-16, with similar results.

Low Tire Pressure Tests

Tests were run with low tire pressures in an attempt to assess the effects of grooves with respect to the phenomenon of hydroplaning. The results indicated that lowering the tire pressure had little or no effect on the wet runway friction values obtained. This agrees with the results obtained at NASA Langley that slip frictional forces are only slightly affected by inflation pressures (Reference 3).

It will be noted from the oscillograph records in Appendix IV that the friction force traces did not indicate low friction values associated with hydroplaning either before or after grooving. The analog curves are very similar both in shape and magnitude for the various tire pressures, and if hydroplaning or partial hydroplaning had occurred, lower BFN_{13} values would have been recorded. Decreasing tire pressure or increasing speed are the only two factors governing hydroplaning that could be readily controlled during the tests. There are other important factors, however, which govern hydroplaning and which have to be taken into consideration; such as, ample water depth and surface drainage. After the first attempt to achieve hydroplaning by lowering tire pressure failed (February 3, 1967), it was indicated by the data that sufficient water depth was not present. The output of the water dispensing system was then approximately doubled by changing pump drive pulleys. This small increase in water depth, however, still did not provide any evidence of hydroplaning.

During the rain environment tests conducted February 21, 1967, hydroplaning tests with low tire pressures in conjunction with the high capacity water dispensing system provided the deepest water test condition of this series. These tests also proved futile in producing evidence of hydroplaning. It must be noted that in the above tests, the standard 24-psi tire was used, and at the lower inflation pressures (for which it was not designed) an elongated footprint resulted which could have reduced the onset of hydroplaning.

The lowering of tire pressure affected both the fixed slip ratio of the braked test tire as well as the unit-bearing pressure, the net result being to increase slip ratio and, correspondingly, decrease the average unit-bearing pressure. The slip ratio and average bearing pressure for the 24-psi tire was 12.8 percent and 39 psi; for the 17.4-psi tire, 13.5 percent and 33 psi; for the 14.3-psi tire, 14.1 percent and 31 psi; and for the 11.6-psi tire, 15.0 percent and 28 psi, respectively.

Calibration

The analysis of the calibration records made prior to each series of tests and past records indicate that this tester produces calibration results of less than ± 3 percent deviation.

SUMMARY OF RESULTS

In summary, these friction tests indicate that at test speeds from 10 to 60 mph and with the test tire loading and pressure inherent in this friction measuring system, no major increase in wet runway friction values, due to these grooves, were observed. Markedly smoother wet runway friction traces were obtained, however, in the post-grooved data as compared to the pre-grooved data. These post-grooved data resembled the pre-grooved data of the unused runway edge, Track 2, thus indicating that grooving may tend to restore the runway surface to friction values approaching its original clean and homogenized state. It is evident from the data that uniform spacing of grooves has created a homogenizing effect which, in turn, produced a more uniform friction surface. By grooving a runway and reducing the magnitude and the amount of the fluctuations in friction coefficient, it is hypothesized that a more effective braking surface is produced. The smaller changes in friction should generate smaller fluctuations in braking forces, ultimately resulting in shorter stopping distances. Most aircraft antiskid systems operate on the principle of modulating brake pressure upon sensing incipient skid conditions. Constant application of brake pressure as opposed to intermittent brake application will stop an aircraft in shorter distances.

For comparative purposes, the test portion of the runway was divided into three lengthwise sections. These three sections were the 1000-foot sections at the 36 and the 18 ends, and the 2870-foot center section. The 1000-foot end sections were located primarily in the heaviest rubber-contaminated portion of the tested runway where definite changes of friction usually occur. The approximate percentage increase and decrease in measured friction values have been calculated, and the results are contained in Tables II, III, and IV. The random increases, decreases, and zero changes present no set pattern from test to test and also indicate no overall significant change of friction values due to grooving.

TABLE II

APPROXIMATE PERCENT CHANGES IN MEASURED FRICTION VALUES DUE TO GROOVING DECEMBER 10, 1966, AND MAY 4, 1967 TESTS, DRY RUNWAY SURFACE CONDITIONS

	DRY TEST			WET TEST		
Test Speed (mph)	1000' Test Sec.36 End (percent)	2870' Test Center Sec. (percent)	1000' Test Sec.18 End (percent)	1000' Test Sec.36 End (percent)	2870' Test Center Sec. (percent)	1000' Test Sec.18 End (percent)
TRACK 1 - CENTERLINE						
10	+7	+5	+6	+5	+3	+11
30	-3	+3	+3	+14	+11	+42
50	0	+2	0	+88	+35	+76
60				-28	+3	+50
TRACK 2 - EAST RUNWAY EDGE						
10	+7	+6	+5	+4	0	+3
30	-7	-8	-8	+8	+3	0
50	+9	+13	0	+23	+14	+15
60				-7	-6	-8
TRACK 3 - 25 FEET WEST OF CENTERLINE						
10	+7	+5	0	-6	-6	-6
30	-7	-26	-32	-13	-26	-36
50	-21	-14	-18	0	-8	+5
60				0	+3	-9
TRACK 4 - 25 FEET EAST OF CENTERLINE						
10	+3	+3	-9	0	-5	-8
30	-21	-20	-22	-49	-37	-47
50	-10	-12	-8	0	-10	-11
60				0	0	-7

Note: (+) Denotes an after-grooving increase
(-) Denotes an after-grooving decrease
(0) Denotes no significant increase or decrease

TABLE III

APPROXIMATE PERCENT CHANGES IN MEASURED FRICTION VALUES DUE TO GROOVING
MARCH 16, 1967, AND MAY 23, 1967 TESTS, DAMP RUNWAY SURFACE CONDITIONS

Test Speed (mph)	DRY TEST 1000' Test Sec.36 End (percent)	DRY TEST 2870' Test Center Sec. (percent)	DRY TEST 1000' Test Sec.18 End (percent)	WET TEST 1000' Test Sec.36 End (percent)	WET TEST 2870' Test Center Sec. (percent)	WET TEST 1000' Test Sec.18 End (percent)
			TRACK 1 - CENTERLINE			
10	+33	+24	+26	+9	-7	0
30	-9	+14	-5	-5	-8	+15
50	+8	0	0	+5	-4	+29
60				+4	-14	+17
			TRACK 2 - EAST RUNWAY EDGE			
10	+5	+5	+5	-6	-7	-10
30	0	0	0	0	0	-12
50	-9	-12	-9	+9	+4	0
60				-18	-11	-17
			TRACK 3 - 25 FEET WEST OF CENTERLINE			
10	0	+17	+15	+10	-22	-17
30	-10	0	-6	-11	-21	-9
50	-13	-12	-10	+11	-19	0
60				-23	-20	0
			TRACK 4 - 25 FEET EAST OF CENTERLINE			
10	-5	0	0	-15	-13	-10
30	-26	-22	-29	-18	-18	-20
50	-6	-8	-9	+7	-12	-15
60				+24	0	-15

Note: (+) Denotes an after-grooving increase
(-) Denotes an after-grooving decrease
(0) Denotes no significant increase or decrease

TABLE IV

APPROXIMATE PERCENT CHANGES IN MEASURED FRICTION VALUES BETWEEN POST-GROOVING TESTS MAY 10, 1967, AND SEPTEMBER 14, 1967 TESTS DRY RUNWAY SURFACE CONDITIONS

Test Speed (mph)	DRY TEST 1000' Test Sec.36 End (percent)	DRY TEST 2870' Test Center Sec. (percent)	DRY TEST 1000' Test Sec.18 End (percent)	WET TEST 1000' Test Sec.36 End (percent)	WET TEST 2870' Test Center Sec. (percent)	WET TEST 100C' Test Sec.18 End (percent)
TRACK 1 - CENTERLINE						
10	-13	-10	-13	-5	-7	-7
30	-5	+3	+3	0	0	0
50	-8	+8	+15	-60	-13	0
60				-70	-3	0
TRACK 2 - EAST RUNWAY EDGE						
10	+3	0	-2	+2	-3	-9
30	+4	+5	+2	+5	+3	-8
50	+27	+20	0	+54	+24	+7
60				+15	+17	+33
TRACK 3 - 25 FEET WEST OF CENTERLINE						
10	0	0	+3	+4	+3	+2
30	0	+6	+9	-20	+3	-6
50	-25	+10	+16	-56	0	0
60				-50	0	0
TRACK 4 - 25 FEET EAST OF CENTERLINE						
10	-6	-6	+6	+9	+7	+4
30	+9	0	-27	+10	+5	-26
50	+21	+8	-21	+11	0	-48
60				0	+9	0

Note: (+) Denotes a September 14 increase
(-) Denotes a September 14 decrease
(0) Denotes no significant increase or decrease

The friction values of Runway 18-36, prior to grooving, were in the high range; i.e., above 50 BFN_{13}. The cutting of grooves did not materially improve this already high friction condition. Moreover, grooving is accomplished primarily to substantially aid in the prevention of hydroplaning, Reference 1, and not necessarily as a means to improve friction.

A study of the comparison of the data for the same track for wet and dry, and for before and after grooving contained in Appendices I, II, and III, revealed a striking similarity in the analog trace shape and, to a lesser degree, magnitude. Variance in magnitude can be attributed to deviation of test path, tire and pavement temperatures, environmental effects, and other variables. Since these tests encompassed a period of 9 months, the results attest to the reliability, dependability, and repeatability of the data obtained with this friction measuring system.

CONCLUSIONS

Based upon analysis of the results of these tests, it is concluded that:

1. There is no appreciable increase or decrease in the overall friction values of Runway 18-36 at Washington National Airport before and after runway grooving (1/8-inch wide by 1/8-inch deep at 1 inch spacing) based on the wet and dry friction data obtained at test speeds of 10 to 60 mph; the test conditions and the limitations of the equipment used in these tests did not produce any evidences of hydroplaning effects.

2. A more homogeneous friction surface due to grooving is indicated by the wet post-grooved analog friction traces being smoother than the pre-grooved values; i.e., fewer oscillations and of lesser amplitude.

3. The braking effectiveness on wet runway surfaces is likely to be improved by the homogeneous friction surfaces created by runway grooving.

4. The FAA's Fixed Slip Runway Friction Tester is a reliable friction-measuring system which has the capability of producing repeatable friction data under similar test conditions.

RECOMMENDATIONS

It is recommended that:

1. Friction tests be conducted at speeds up to 80 mph and higher, if obtainable.

2. Aircraft braking tests be conducted to determine the effectiveness of transverse grooves in reducing stopping distances.

REFERENCES

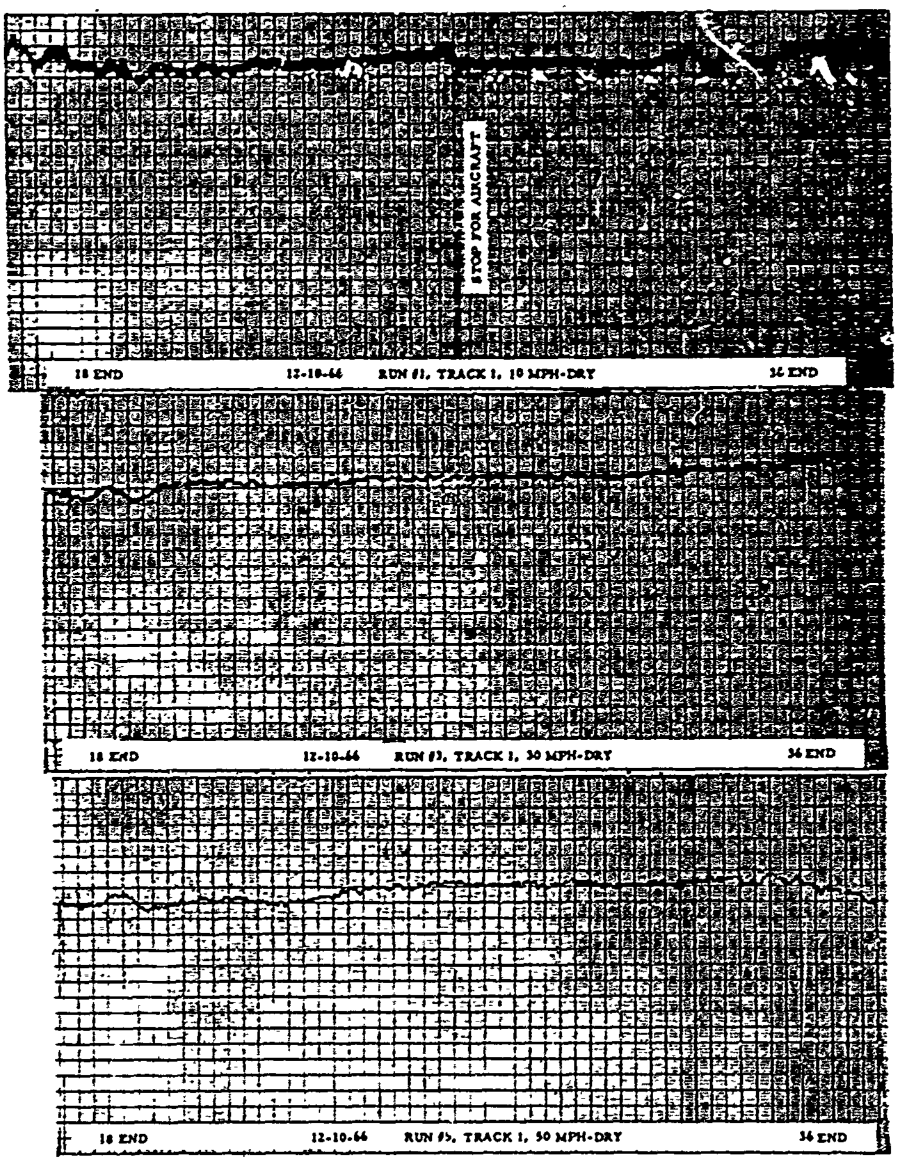
1. Horne, W. B. and Lelend, T. J. W., "Influence of Tire Tread Pattern and Runway Surface Condition on Braking Friction and Rolling Resistance of a Modern Aircraft Tire," Langley Research Center, NASA, September 1962, Technical Note D-1376, Page 29.

2. Horne, W. B., Yager, T. J., and Taylor, G. R., "Recent Research on Ways to Improve Tire Traction on Water, Slush or Ice," AIAA Meeting, Los Angeles, November 1965, Page 28.

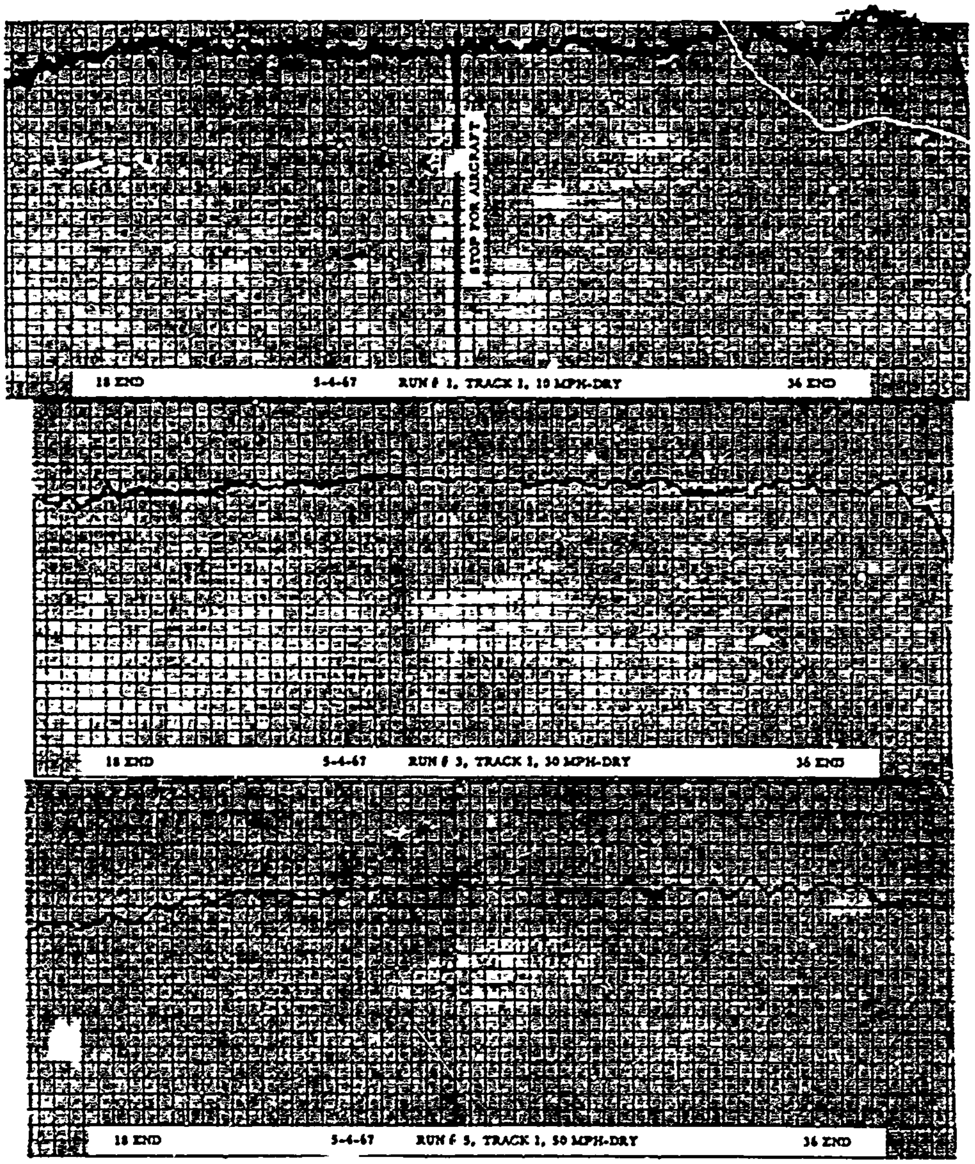
3. Kummer, H. W., "Unified Theory of Rubber and Tire Friction," Pennsylvania State University, College of Engineering, Engineering Research Bulletin, B-94, July 1966, Page 119.

APPENDIX I

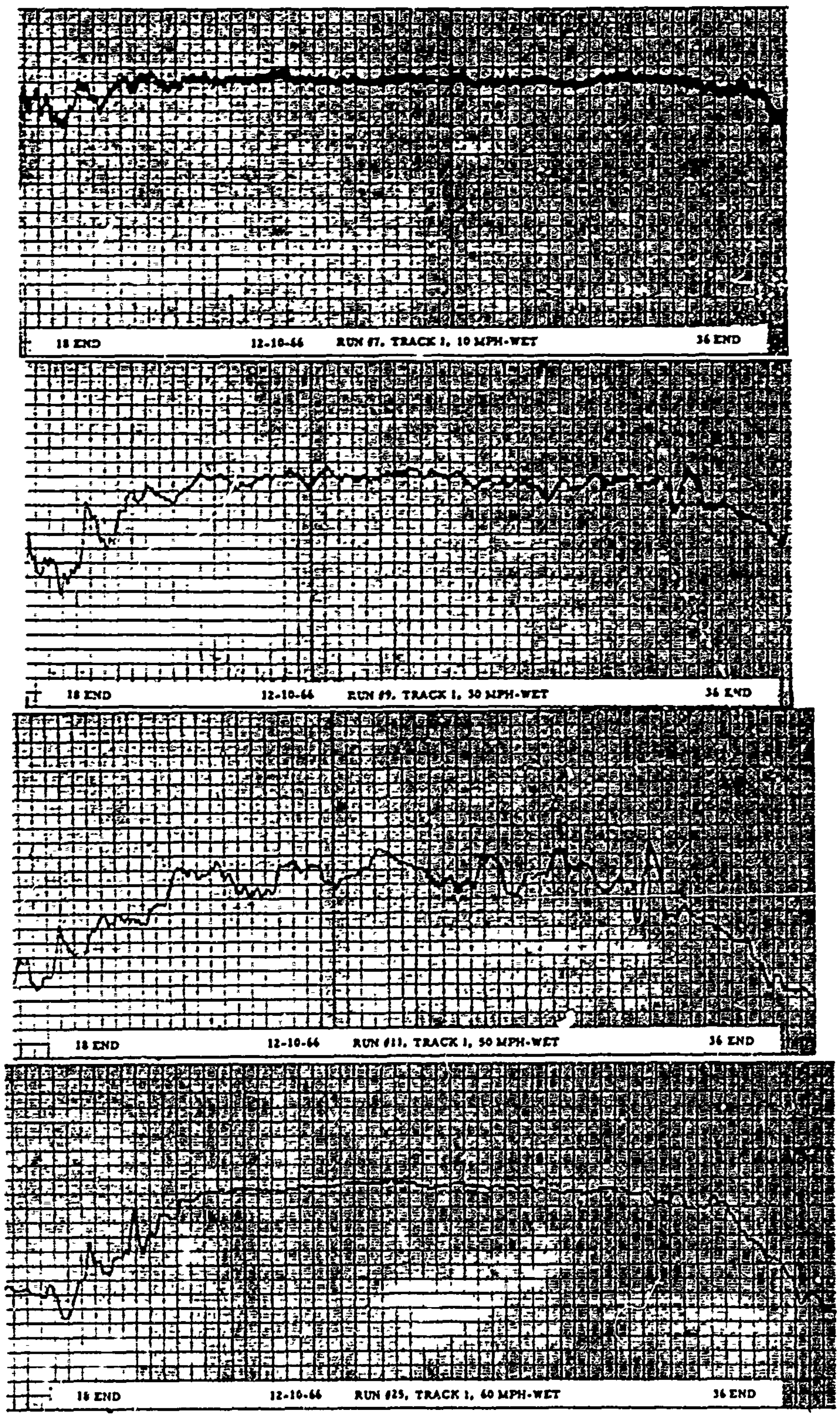
FRICTION DATA - DRY RUNWAY SURFACE CONDITIONS - DECEMBER 10, 1966, AND MAY 4, 1967 TESTS



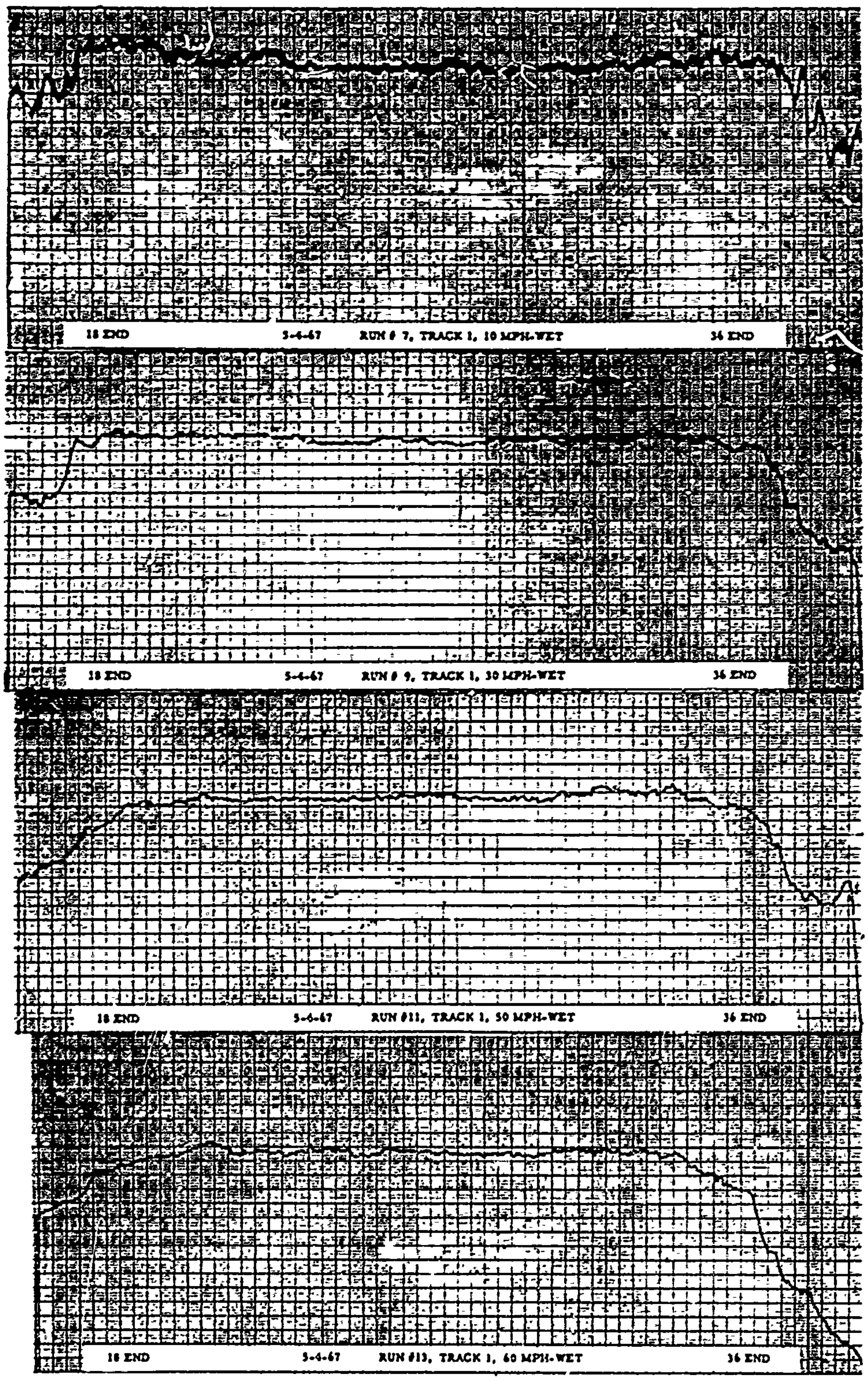
BEFORE GROOVING - TRACK 1, CENTERLINE
DRY TESTS



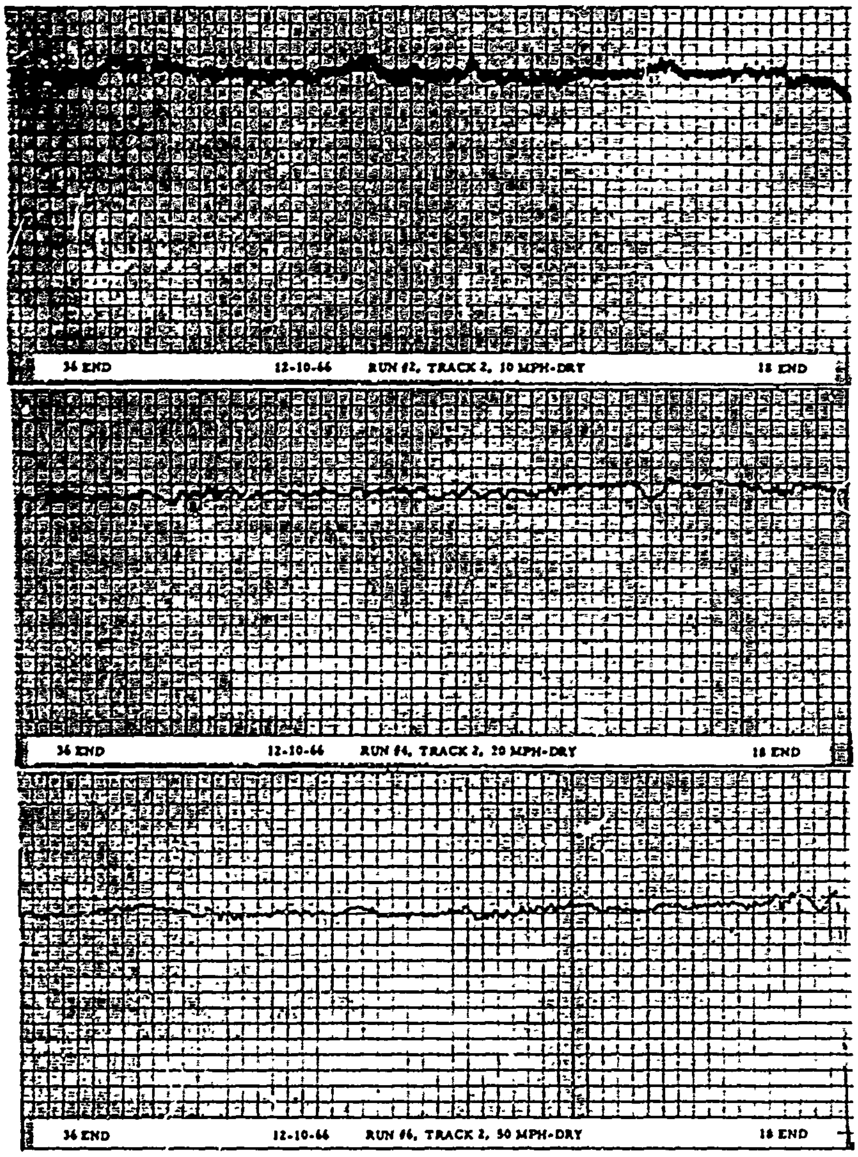
AFTER GROOVING - TRACK 1, CENTERLINE
DRY TESTS



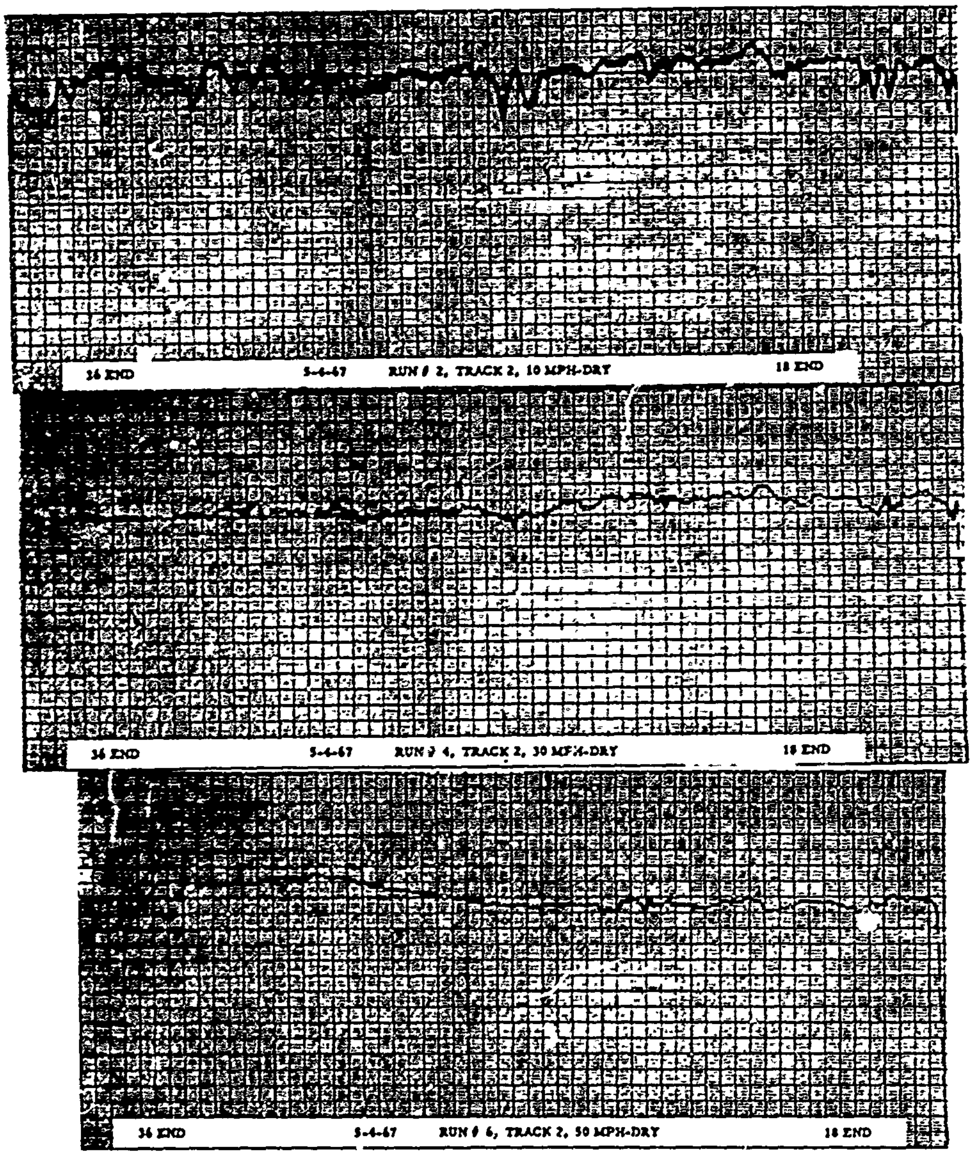
BEFORE GROOVING - TRACK 1, CENTERLINE
WET TESTS



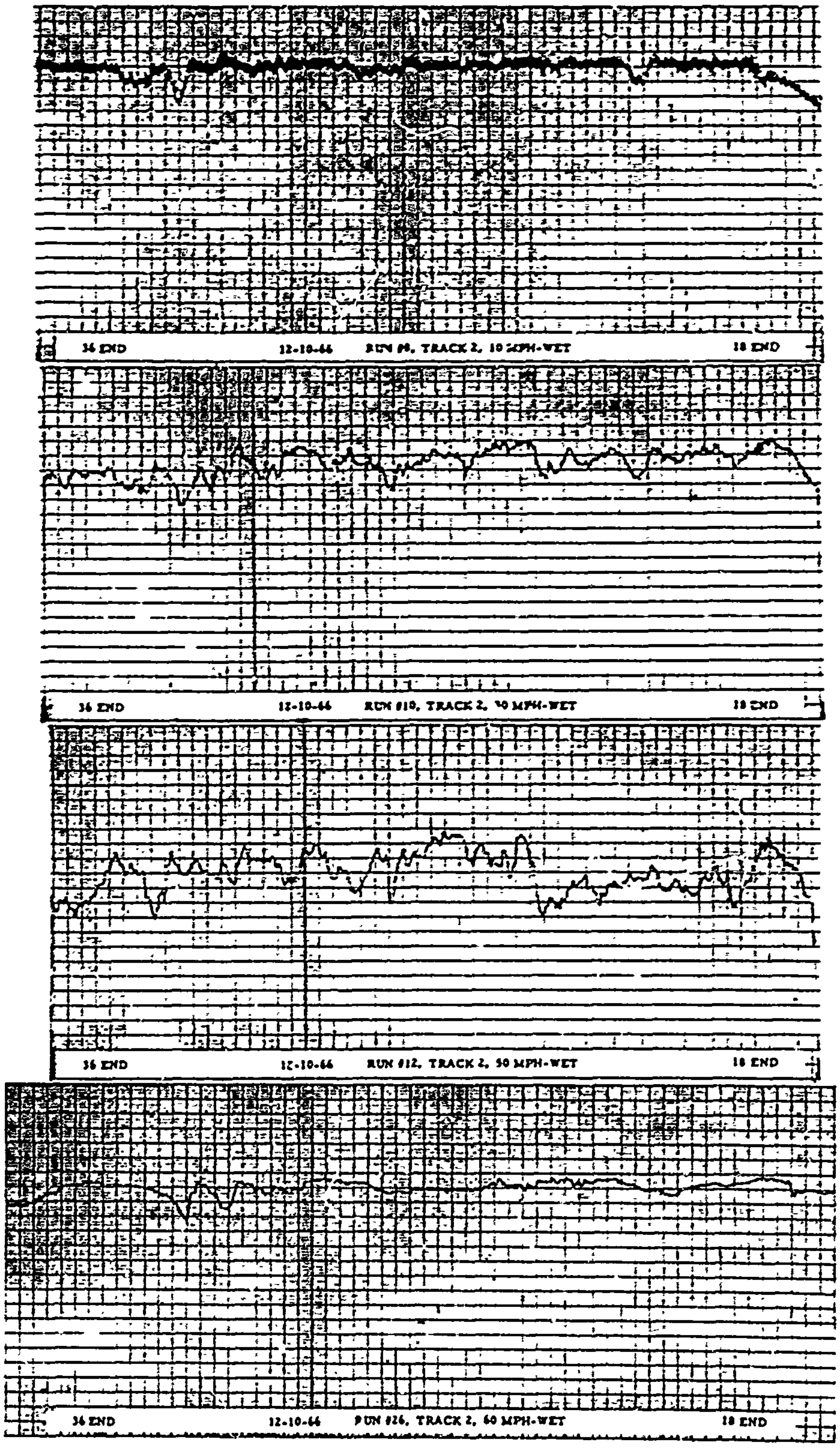
AFTER GROOVING - TRACK 1, CENTERLINE
WET TESTS



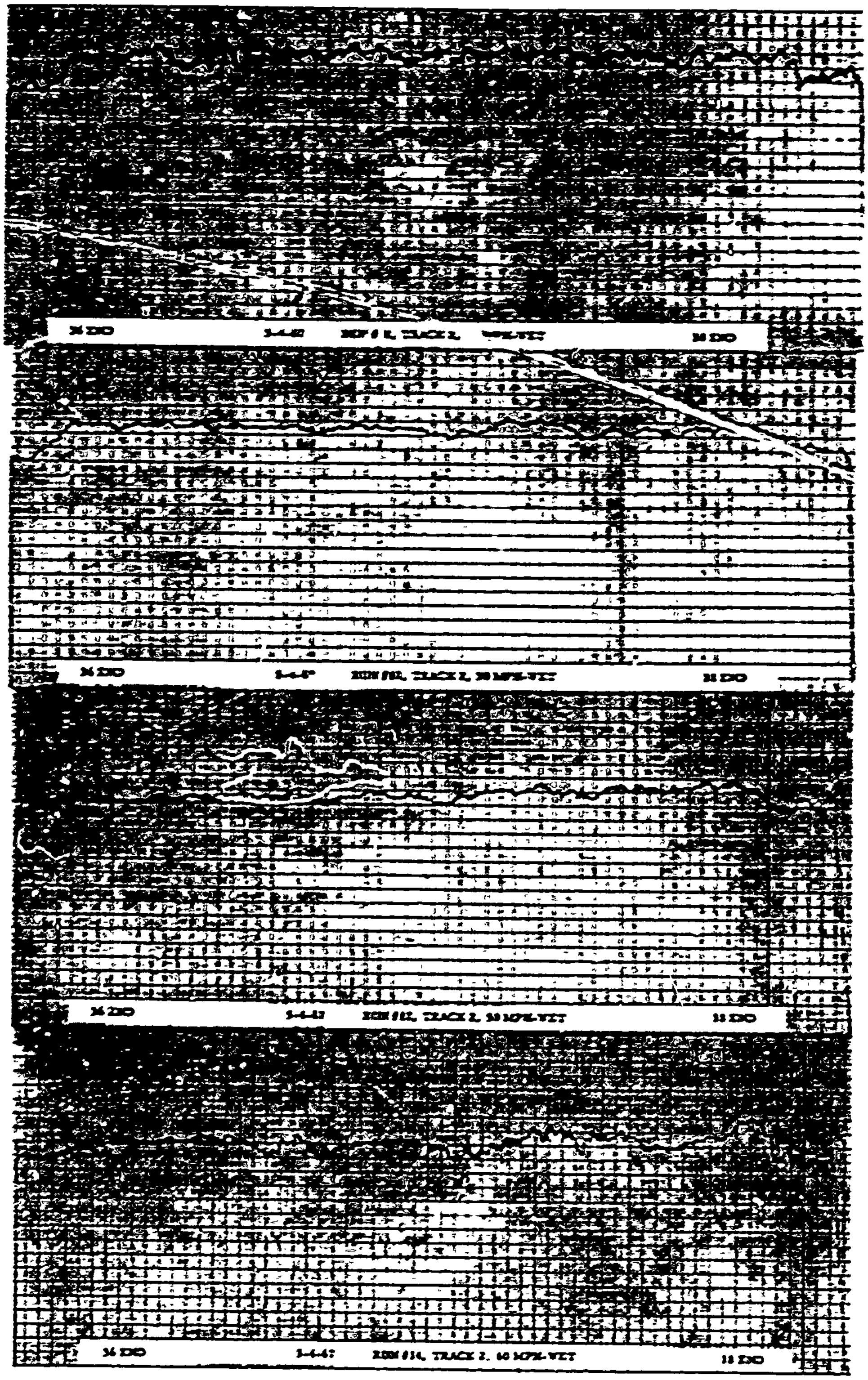
BEFORE GROOVING - TRACK 2, EAST RUNWAY EDGE
DRY TESTS



AFTER GROOVING - TRACK 2, EAST RUNWAY EDGE
DRY TESTS

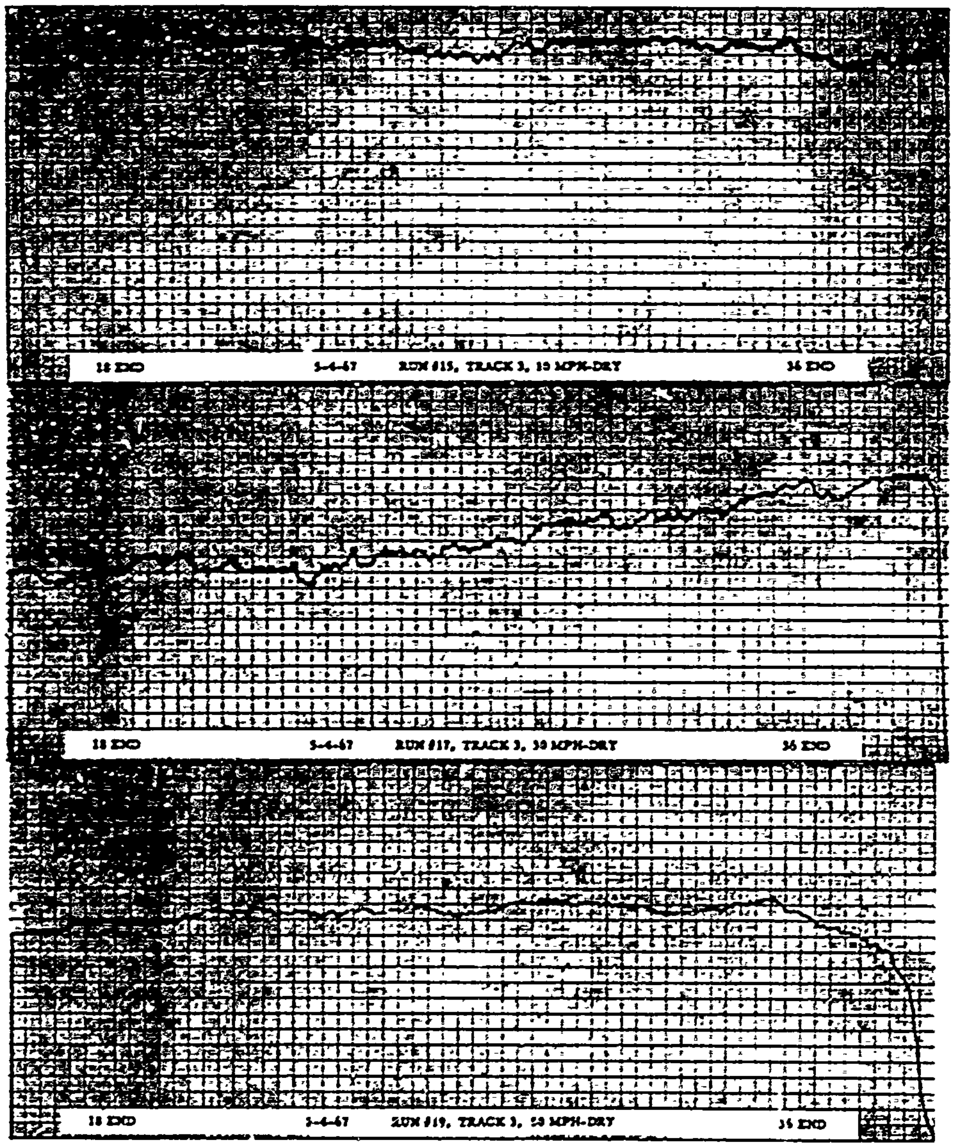


BEFORE GROOVING - TRACK 2, EAST RUNWAY EDGE
WET TESTS



AFTER GROOVING - TRACK 2, EAST RUNWAY EDGE
WET TESTS

BEFORE GROOVING - TRACK 3, 25 FT. WEST OF CENTERLINE
DRY TESTS



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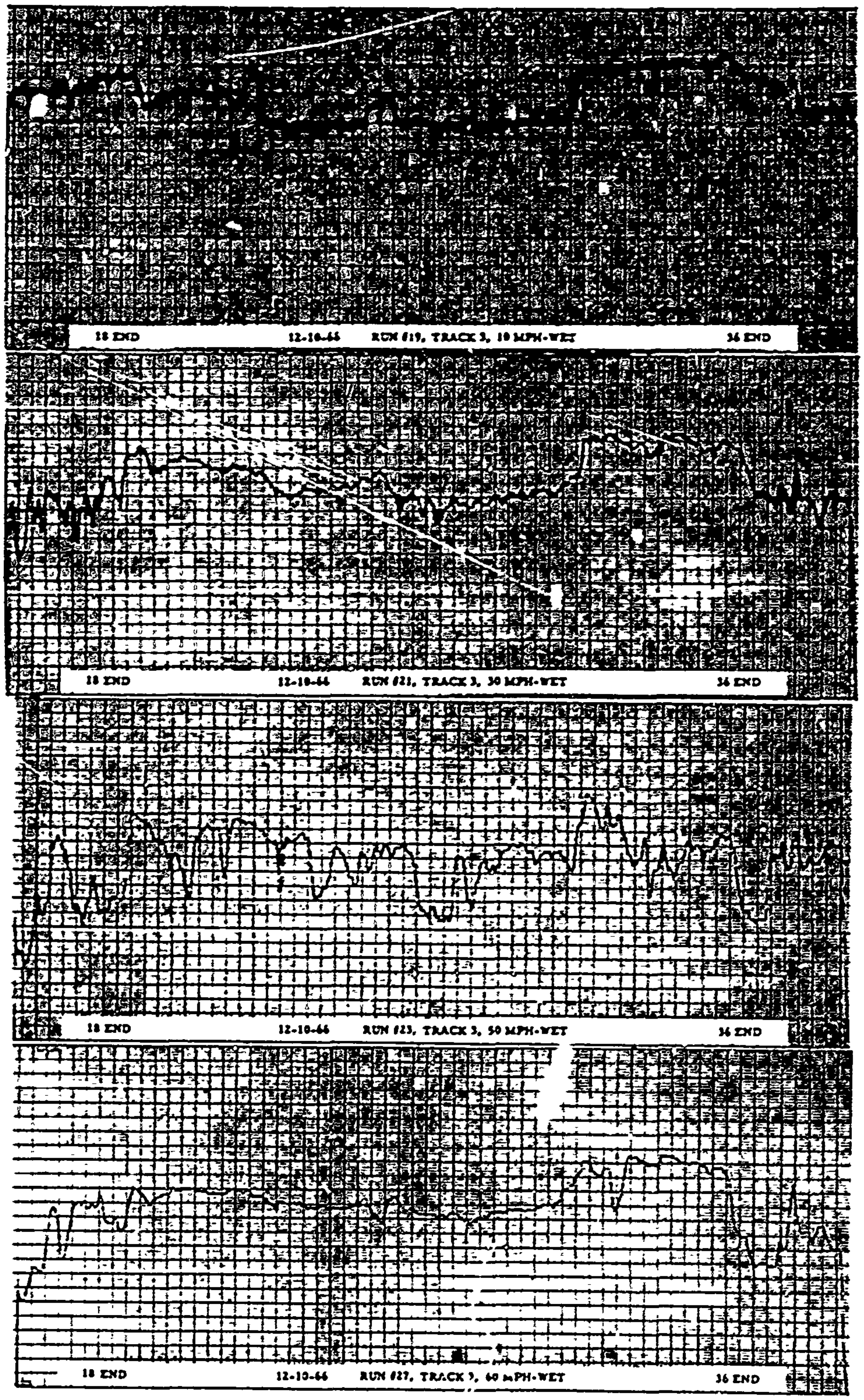
DRY TESTS



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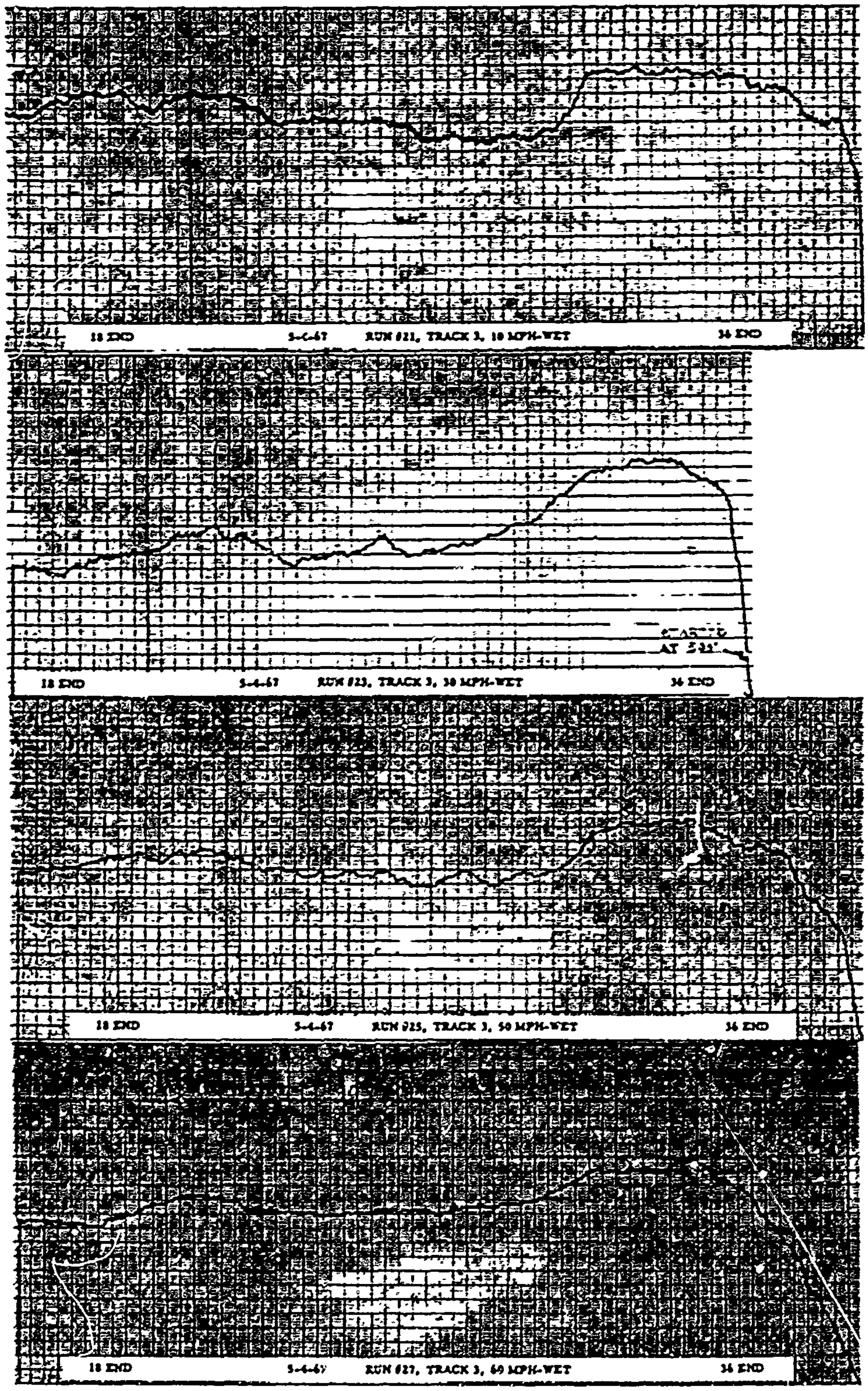
WET TESTS



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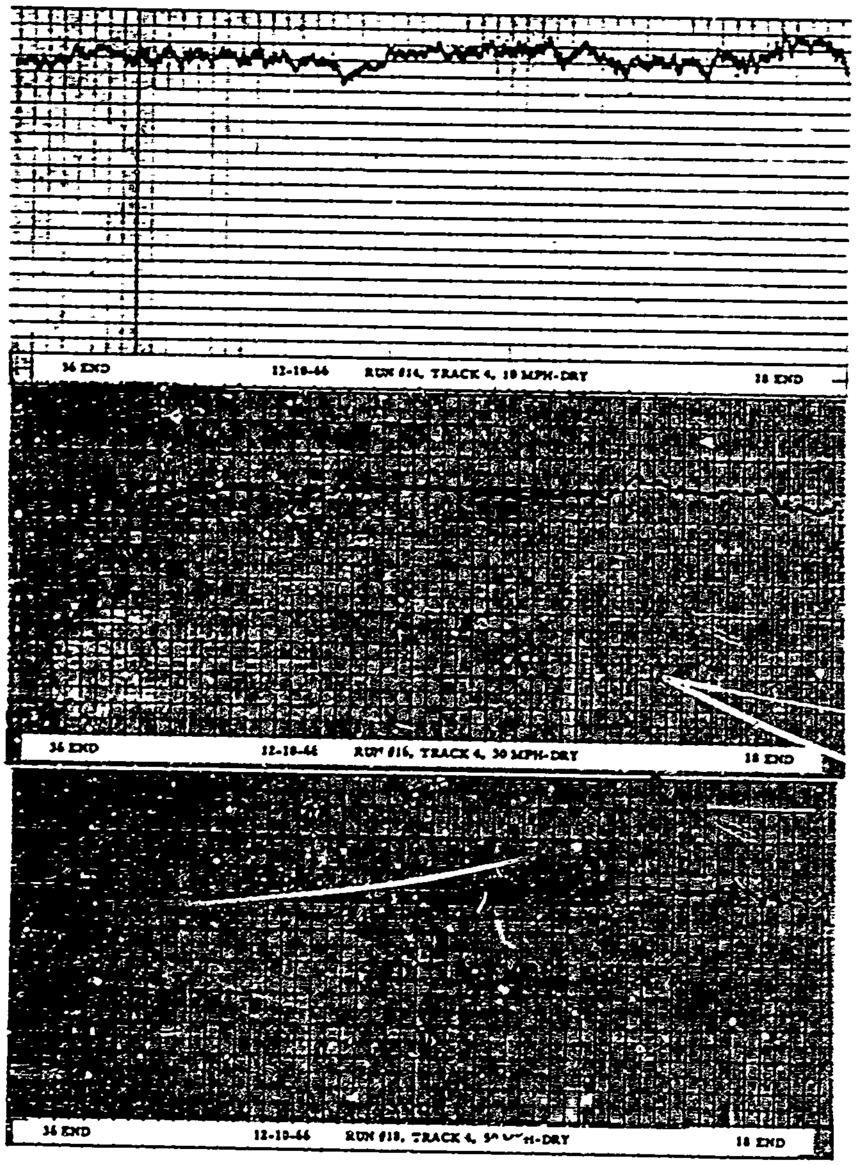
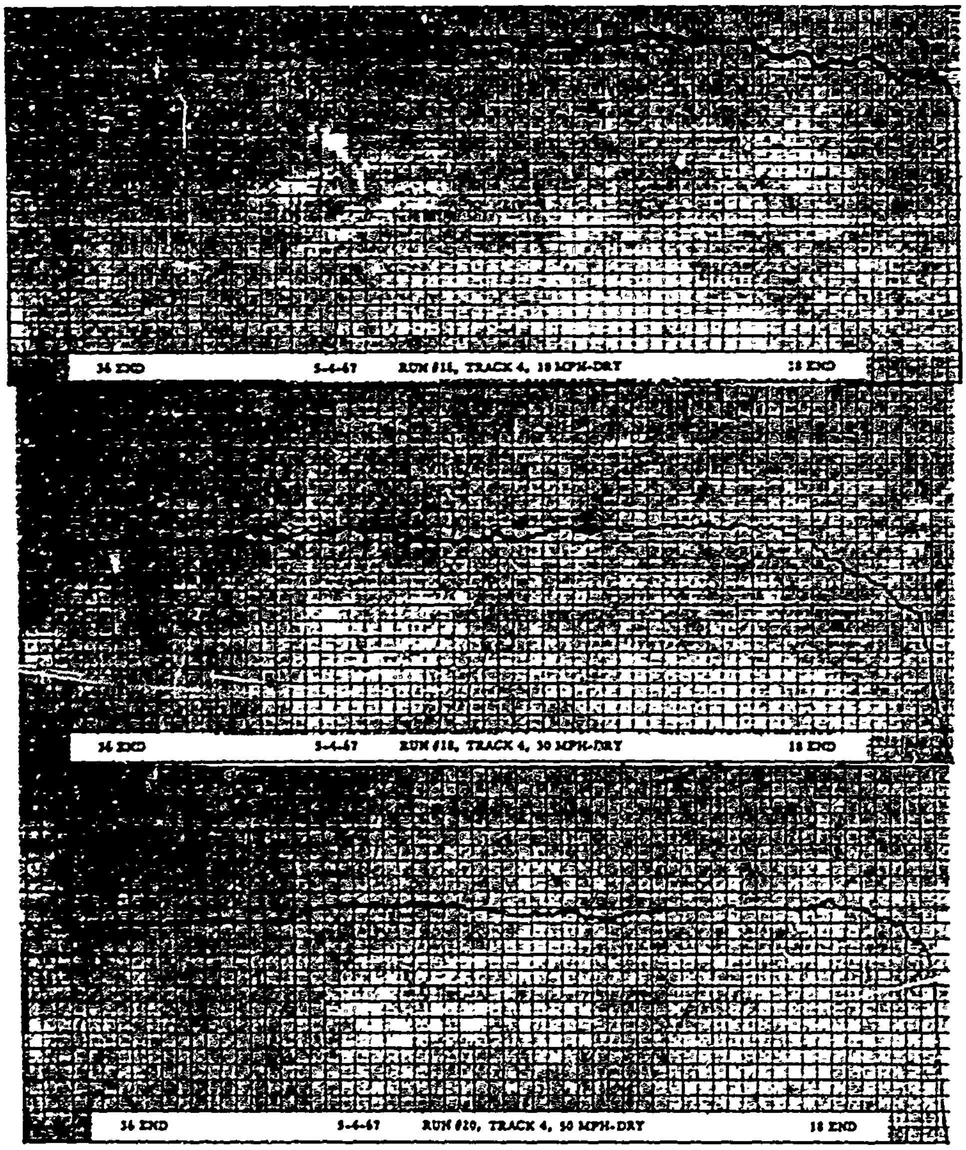
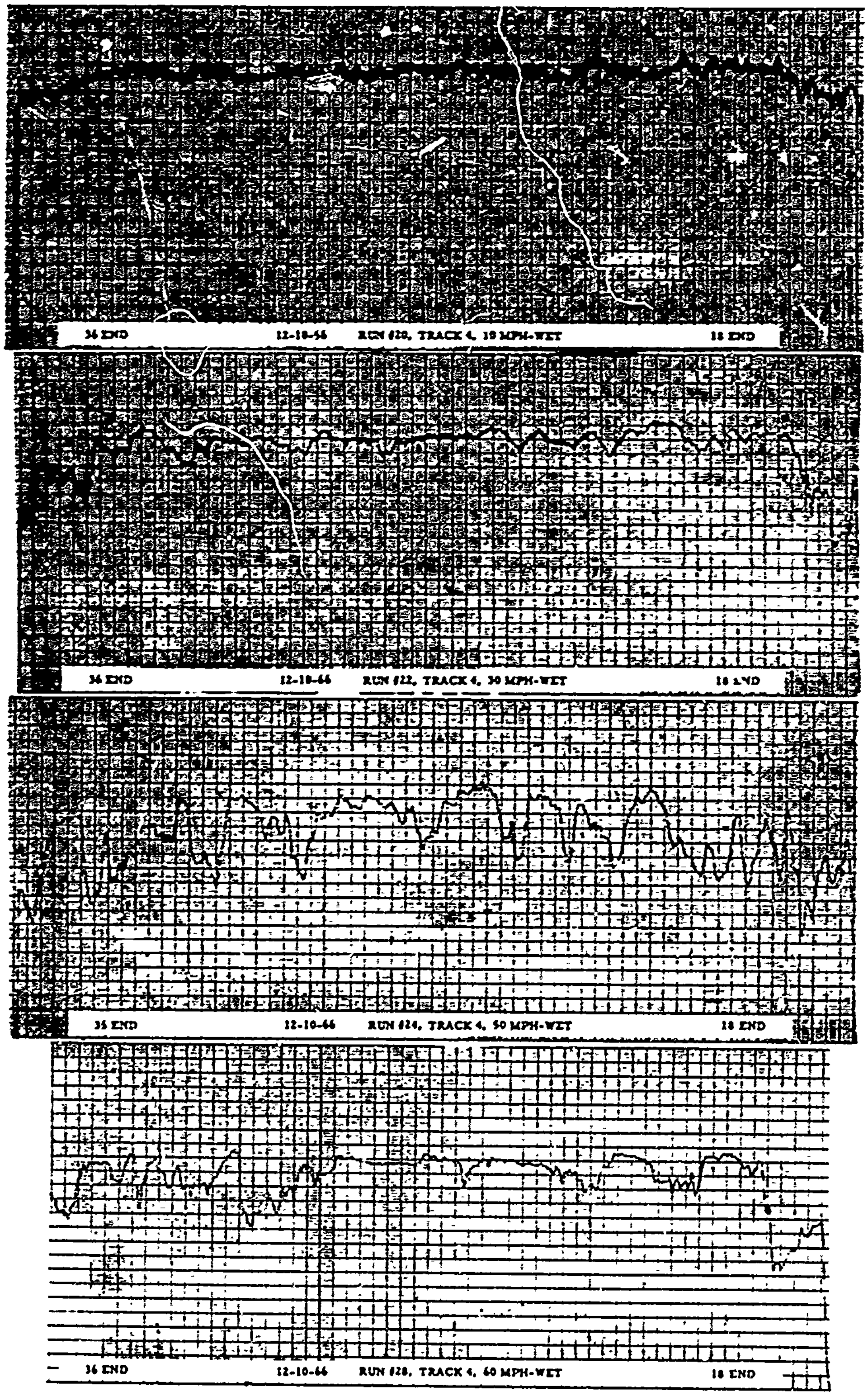
WET TESTS



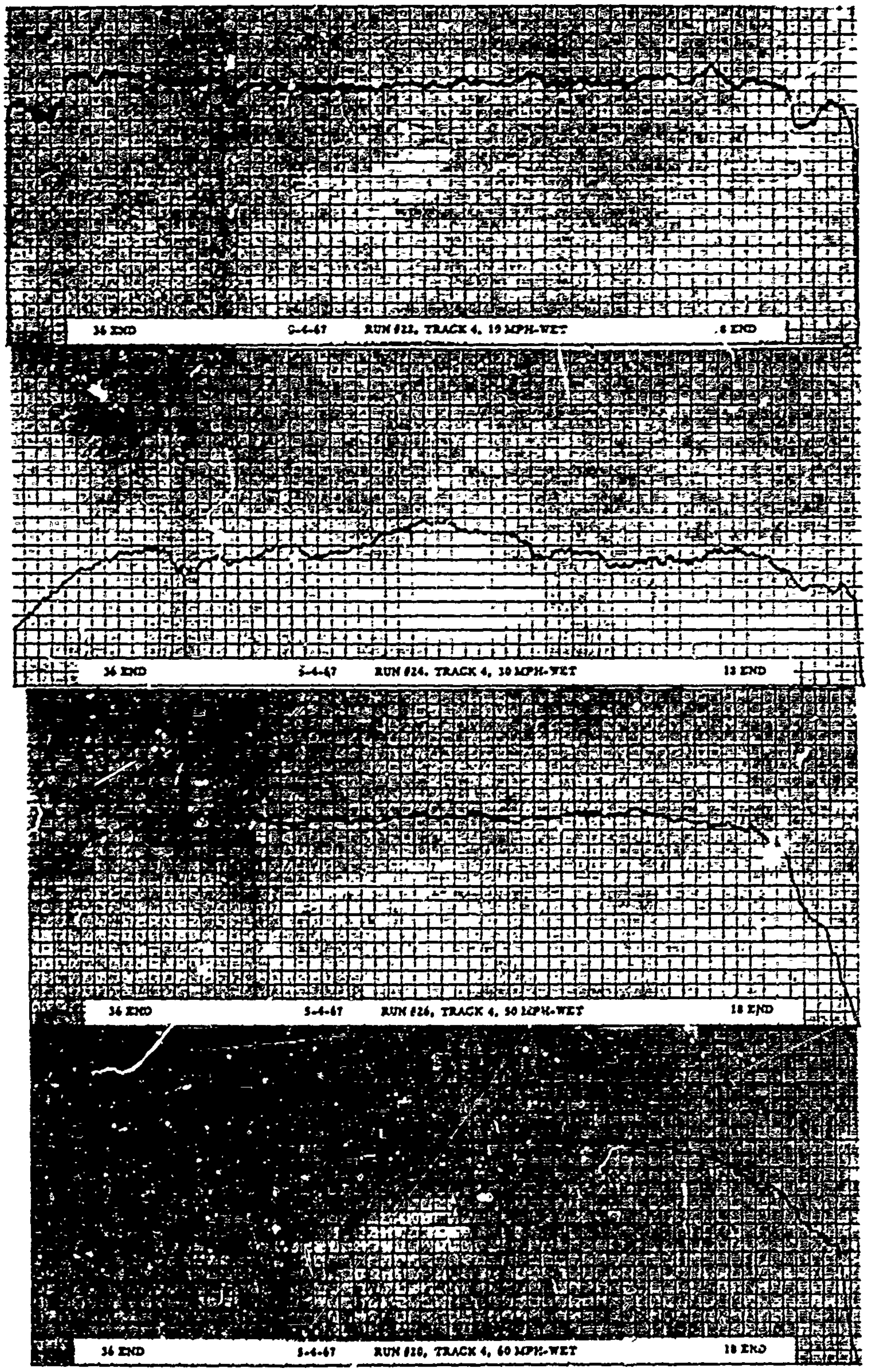
BEFORE GROOVING - TRACK 4, 25 FT. EAST OF CENTERLINE
DRY TESTS



AFTER GROOVING - TRACK 4, 25 FT. EAST OF CENTERLINE
DRY TESTS



BEFORE GROOVING - TRACK 4, 25 FT. EAST OF CENTERLINE
WET TESTS



AFTER GROOVING - TRACK 4, 25 FT. EAST OF CENTERLINE
WET TESTS

APPENDIX II

FRICTION DATA - DAMP RUNWAY SURFACE CONDITIONS - MARCH 16, 1967, AND MAY 23, 1967 TESTS

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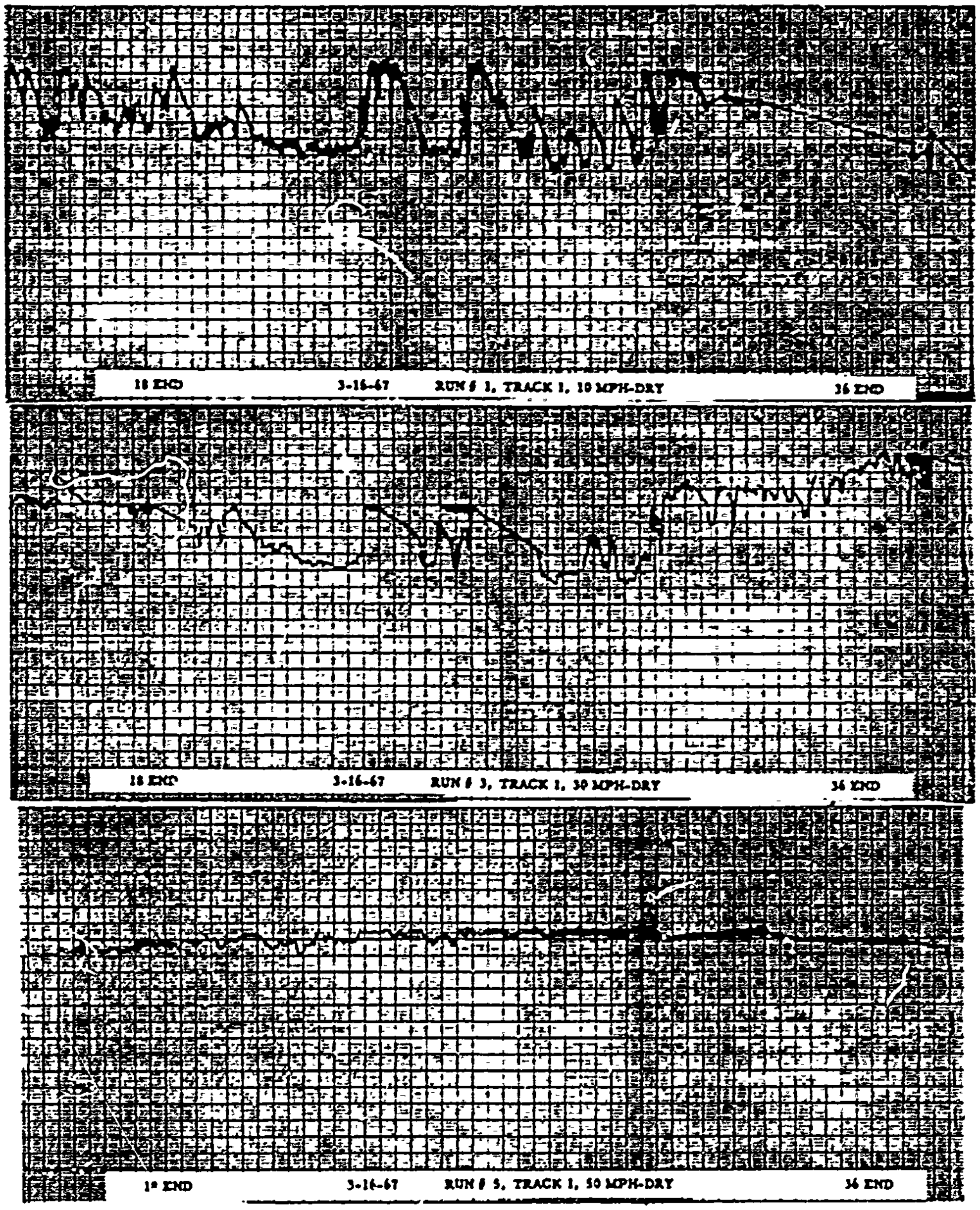
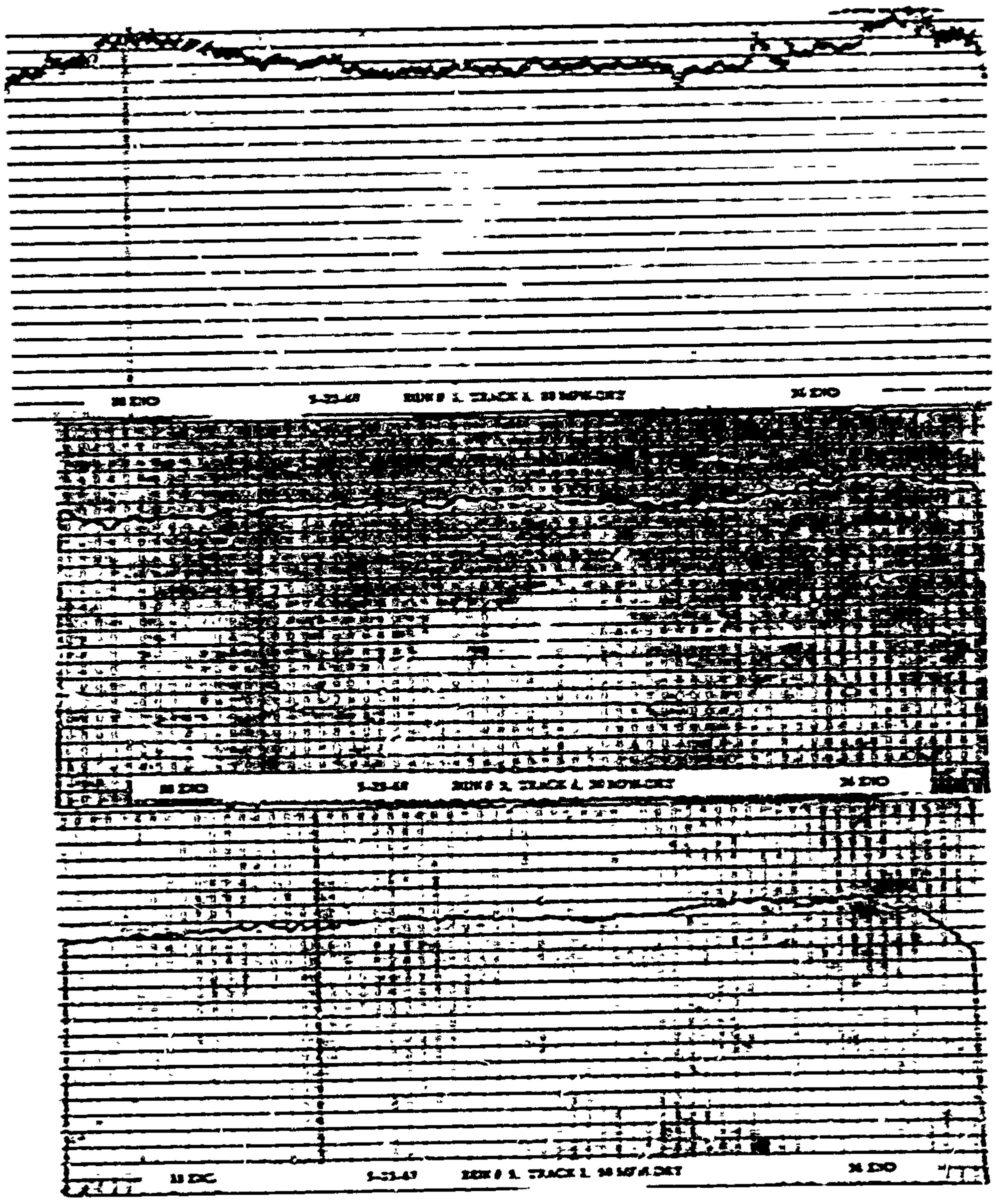
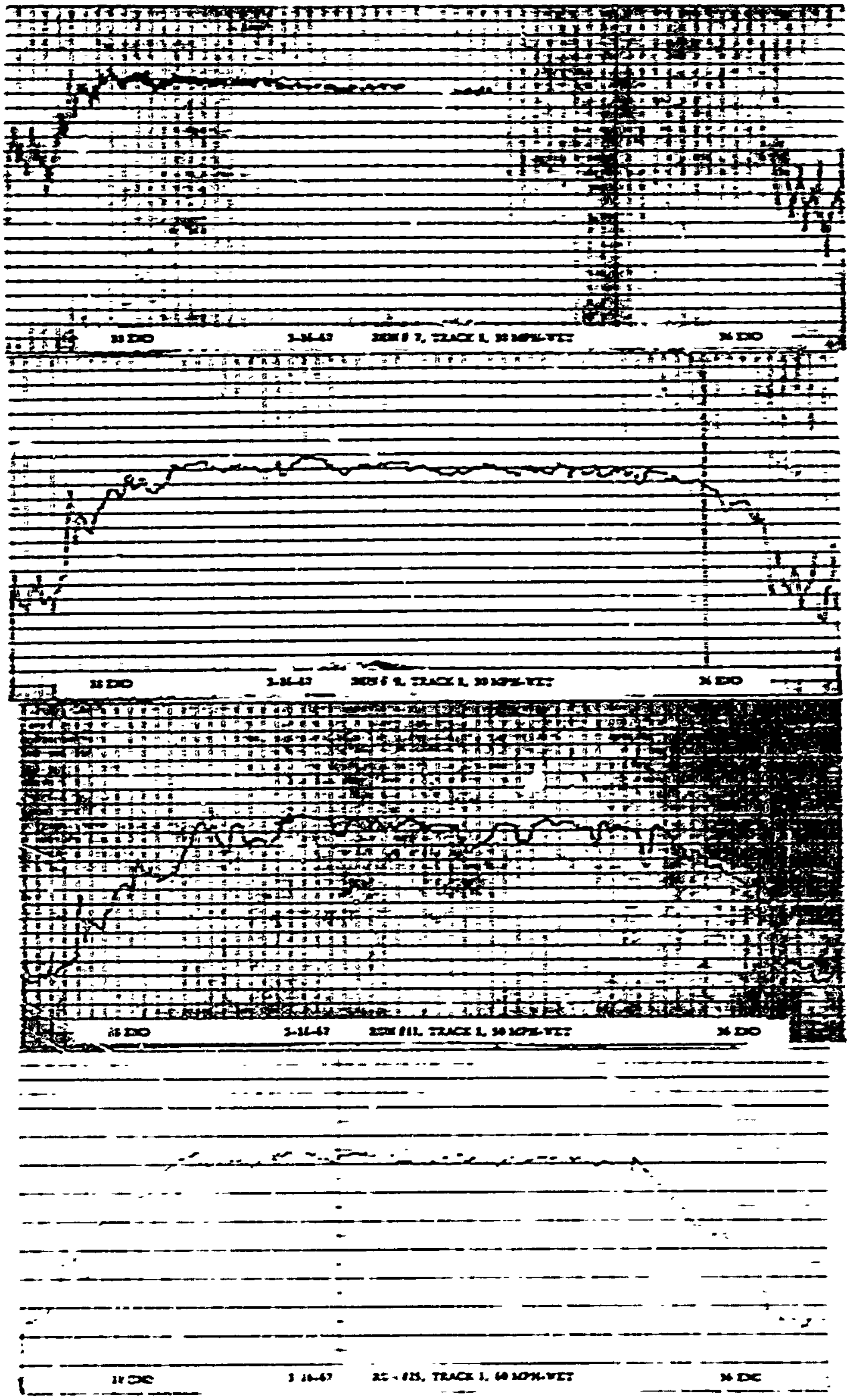


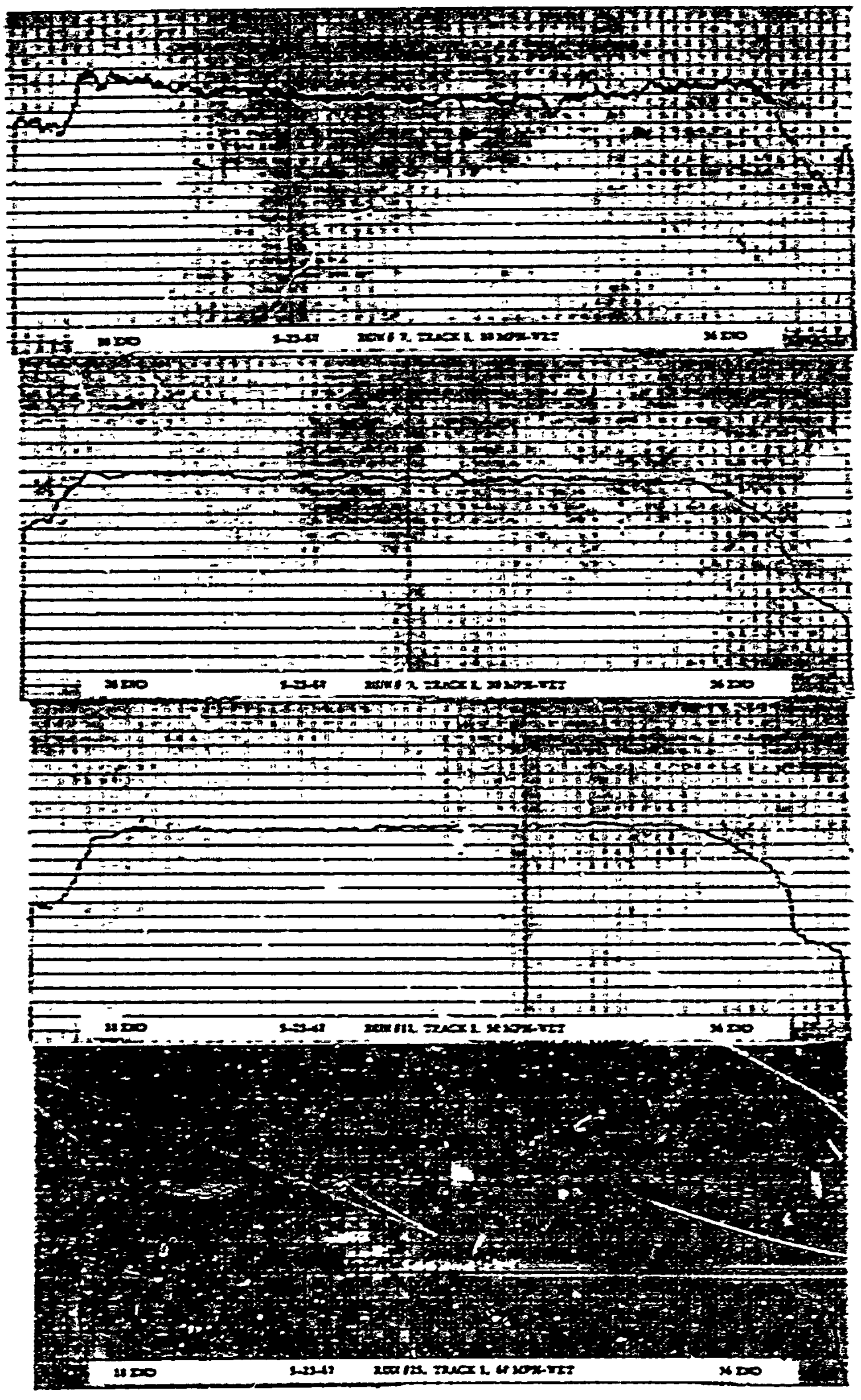
BEFORE GROOVING - TRACK 1, CENTERLINE
DRY TESTS



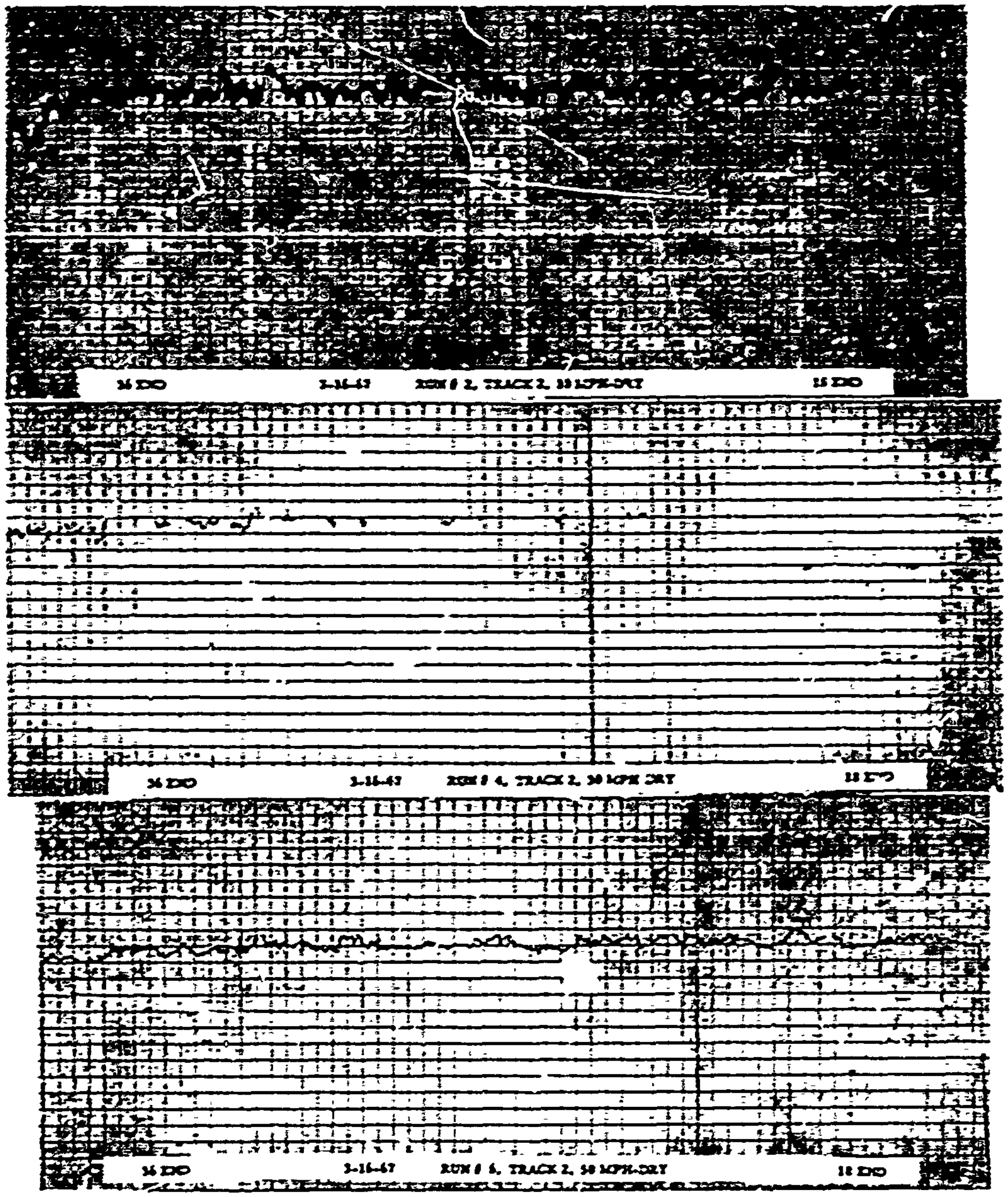
AFTER GROOVING - TRACK 1, CENTERLINE
DRY TESTS



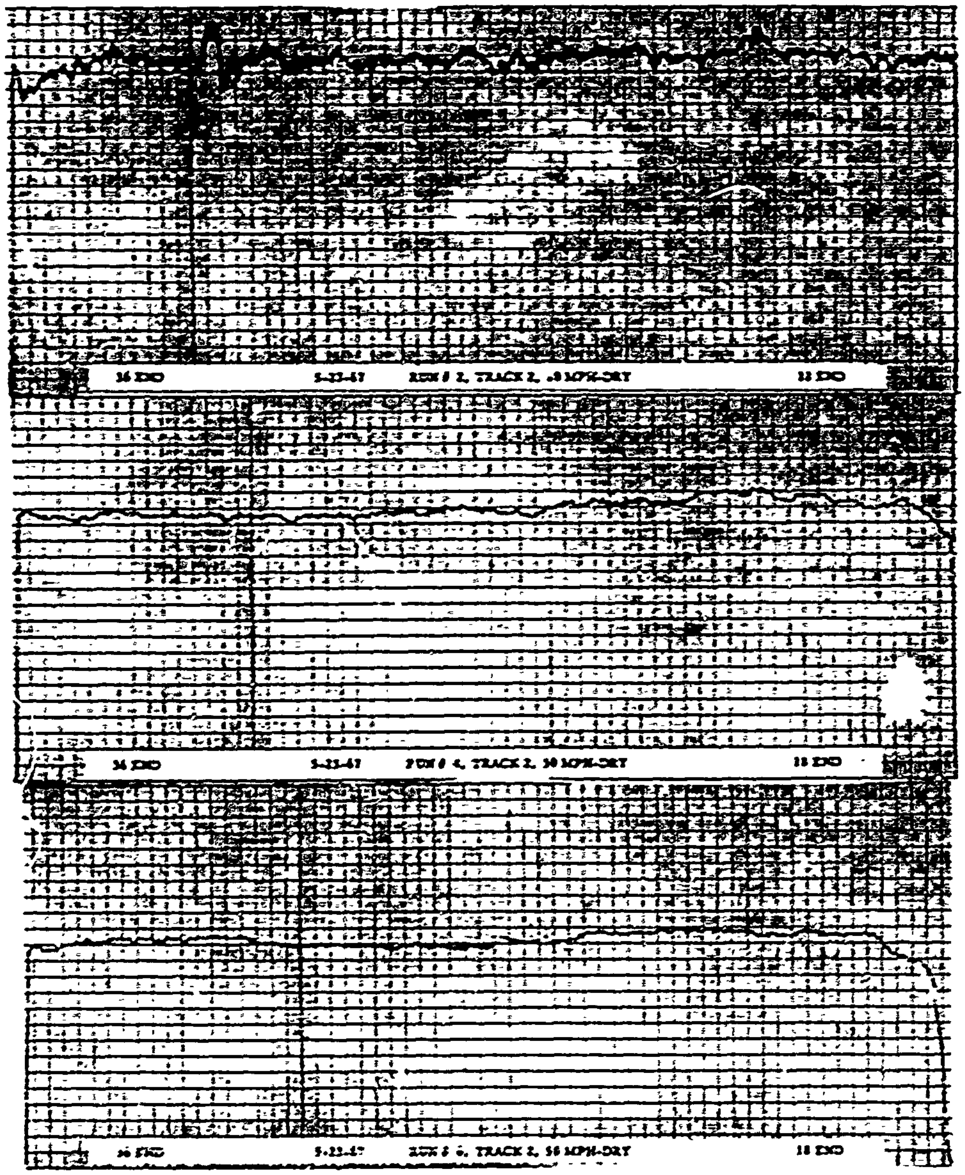
BEFORE GROOVING - TRACK 1, CENTERLINE
WET TESTS



AFTER GROOVING - TRACK 1, CENTERLINE
WET TESTS

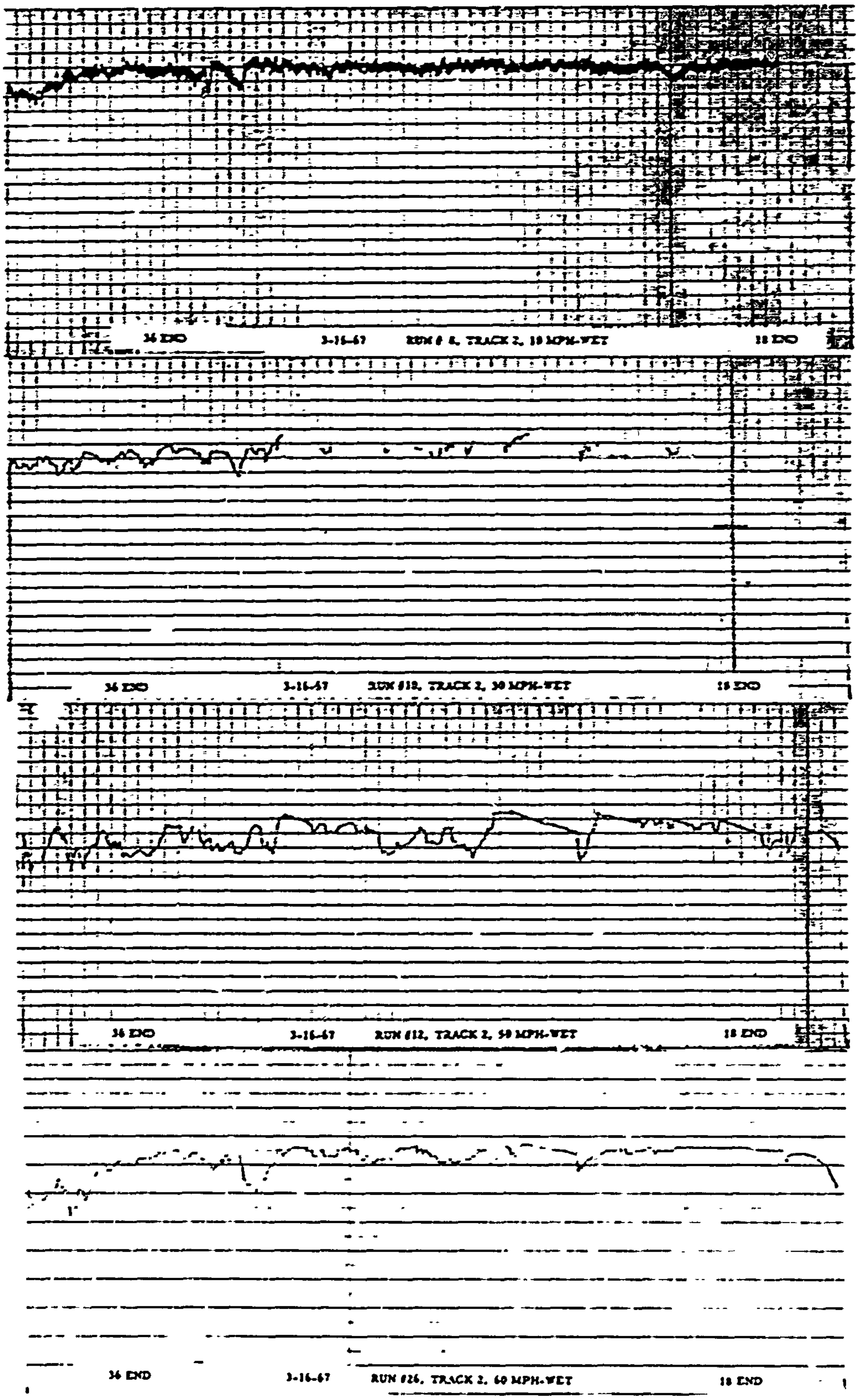


BEFORE GROOVING - TRACK 2, EAST RUNWAY EDGE
DRY TESTS

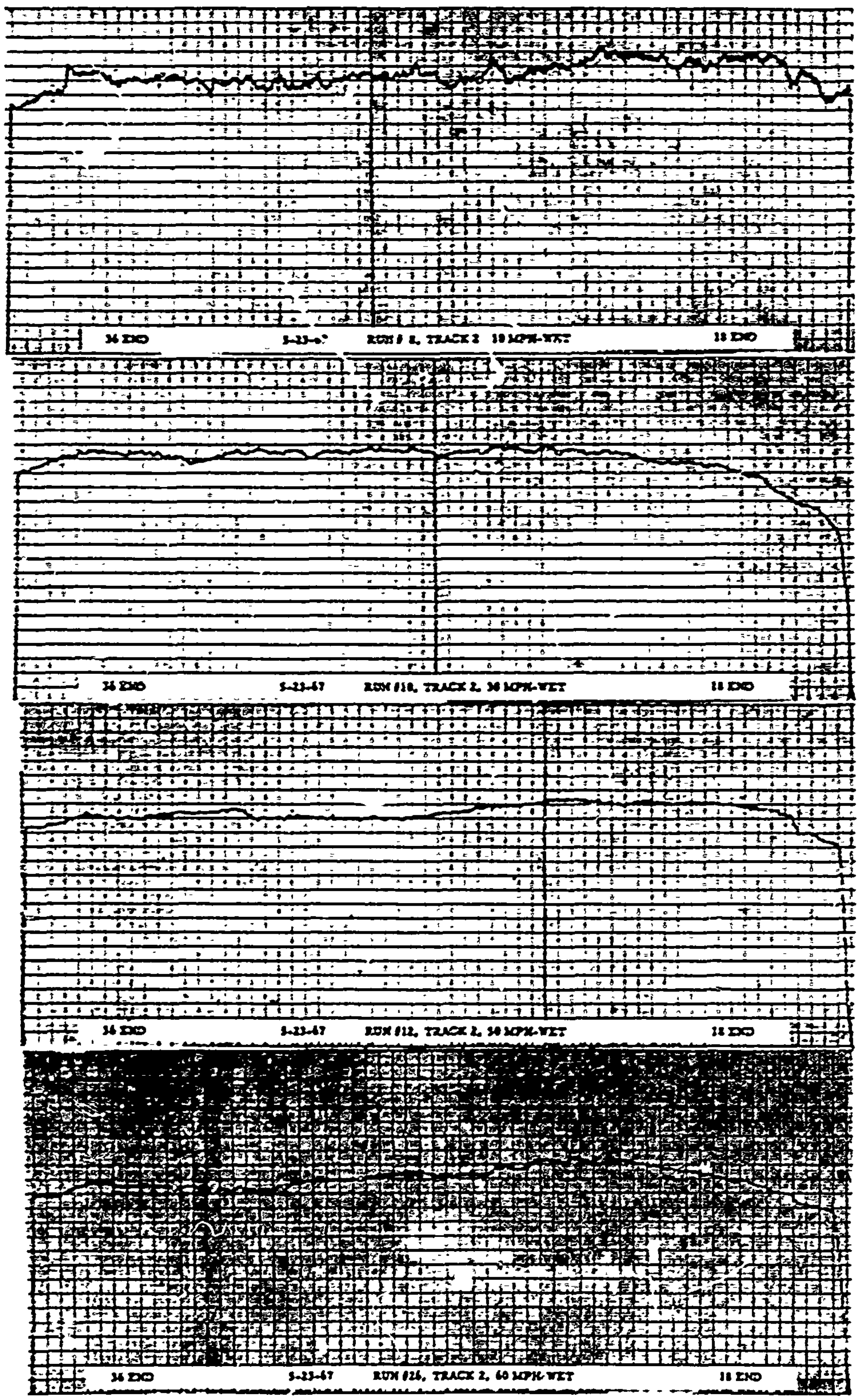


AFTER GROOVING - TRACK 2, EAST RUNWAY EDGE
DRY TESTS

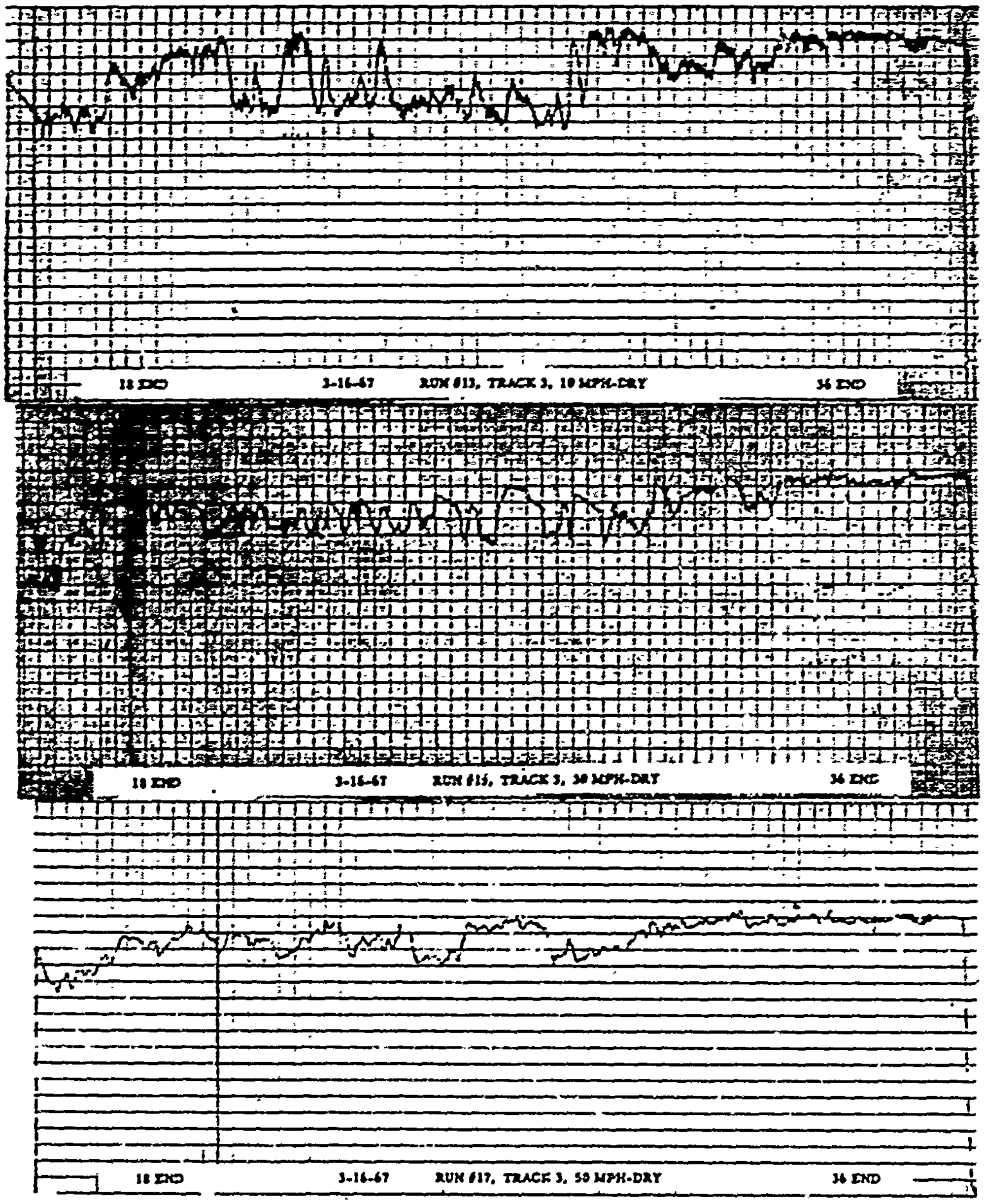
NOT REPRODUCIBLE



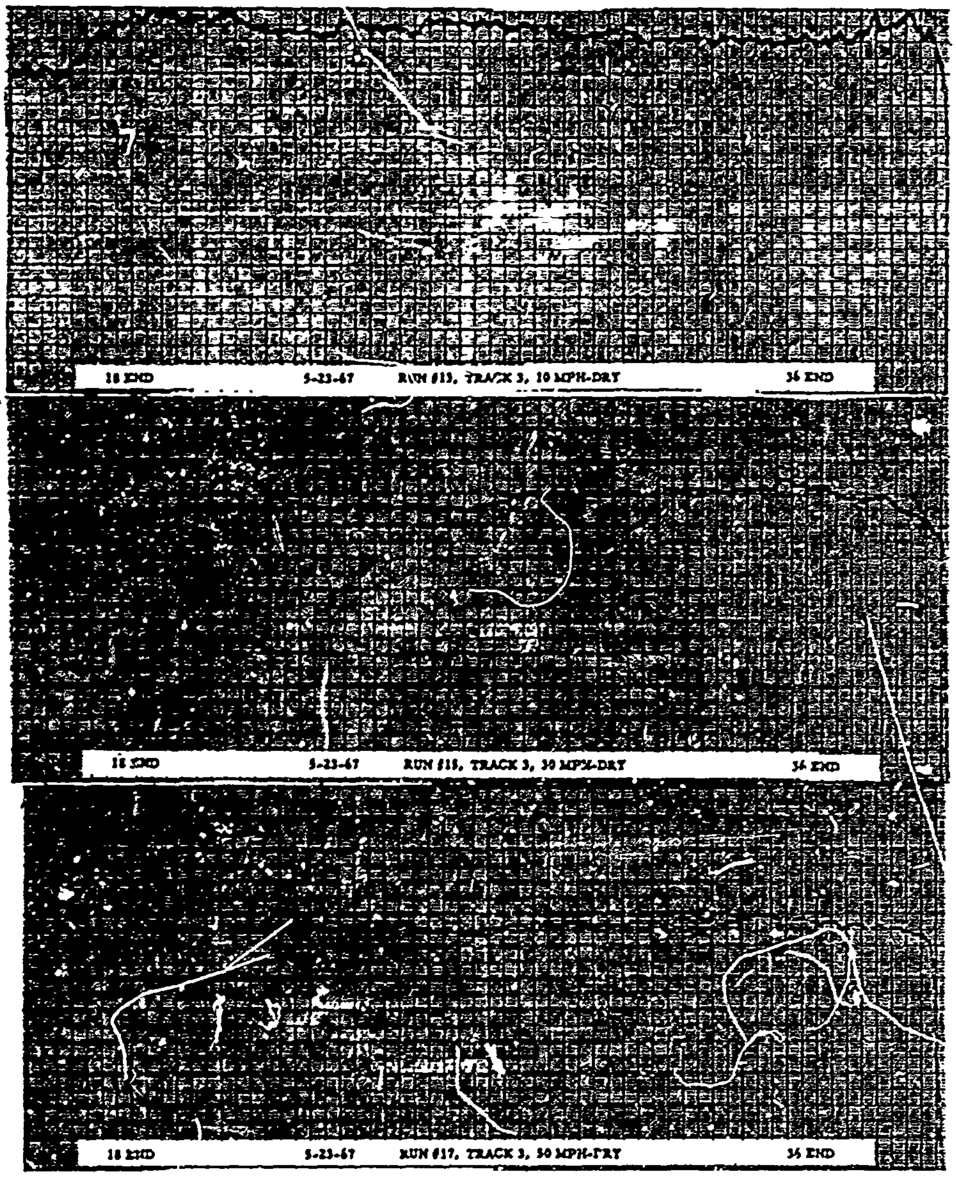
BEFORE GROOVING - TRACK 2, EAST RUNWAY EDGE
WET TESTS



AFTER GROOVING - TRACK 2, EAST RUNWAY EDGE
WET TESTS



BEFORE GROOVING - TRACK 3, 25 FT. WEST OF CENTERLINE
DRY TESTS



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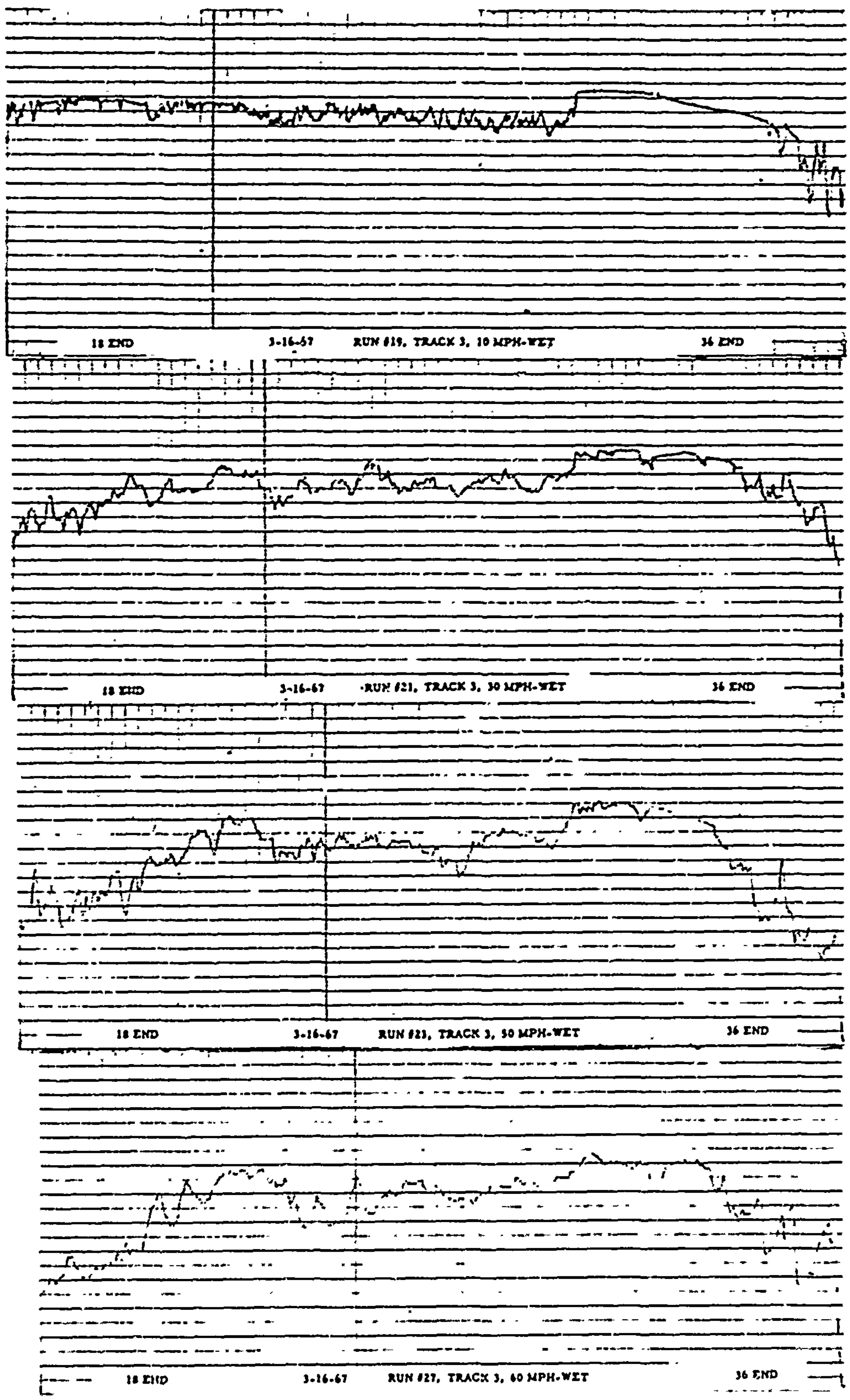

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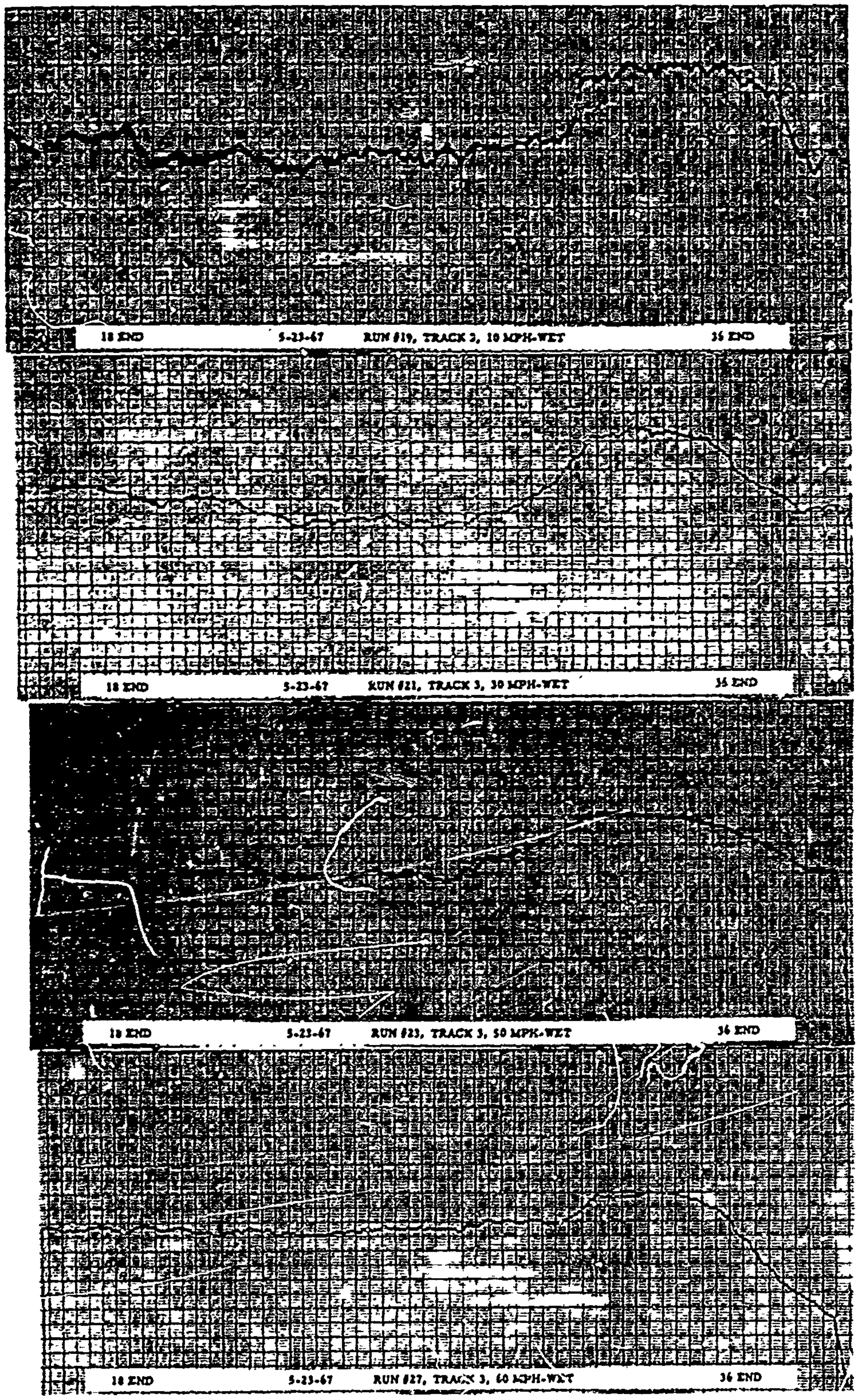

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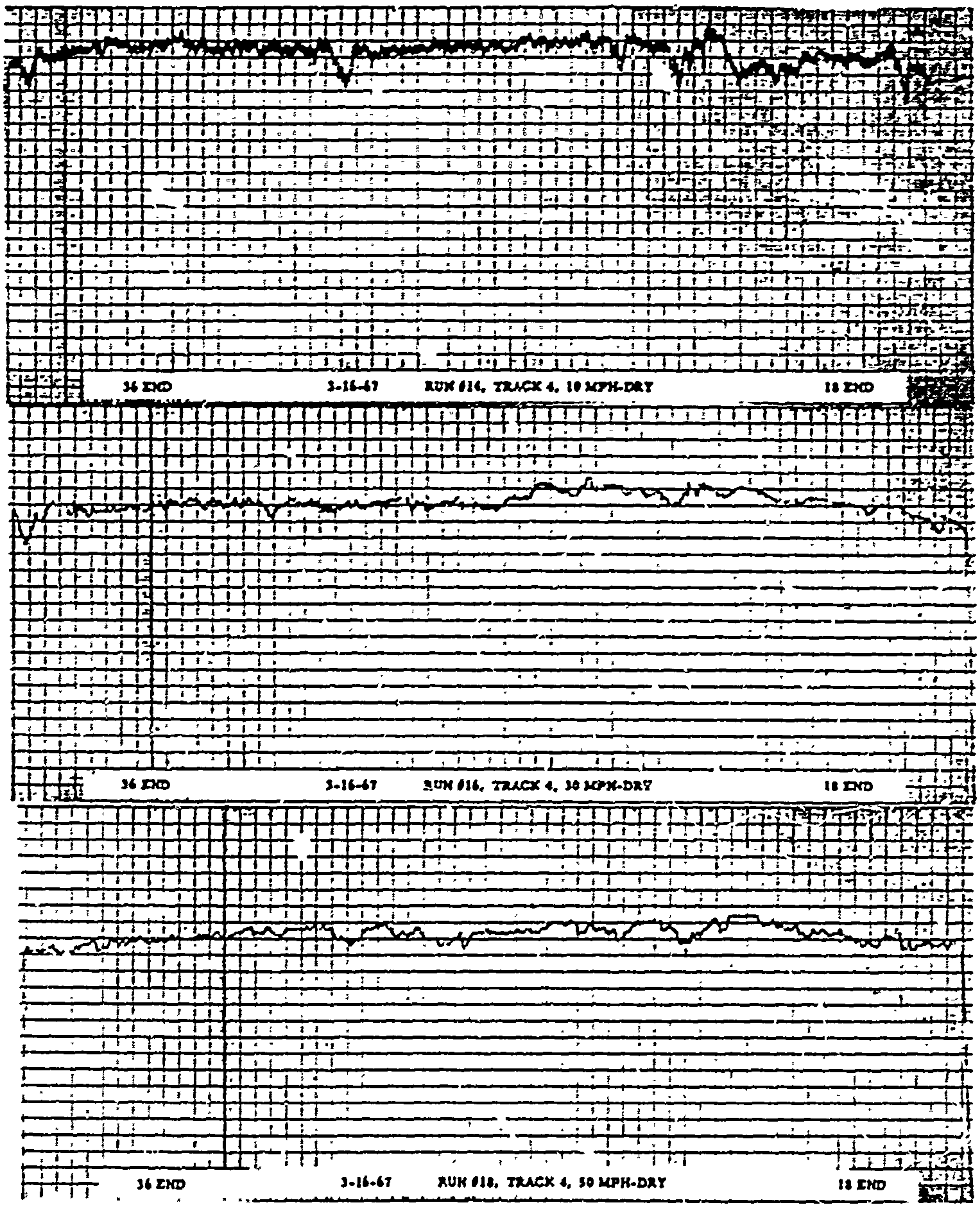

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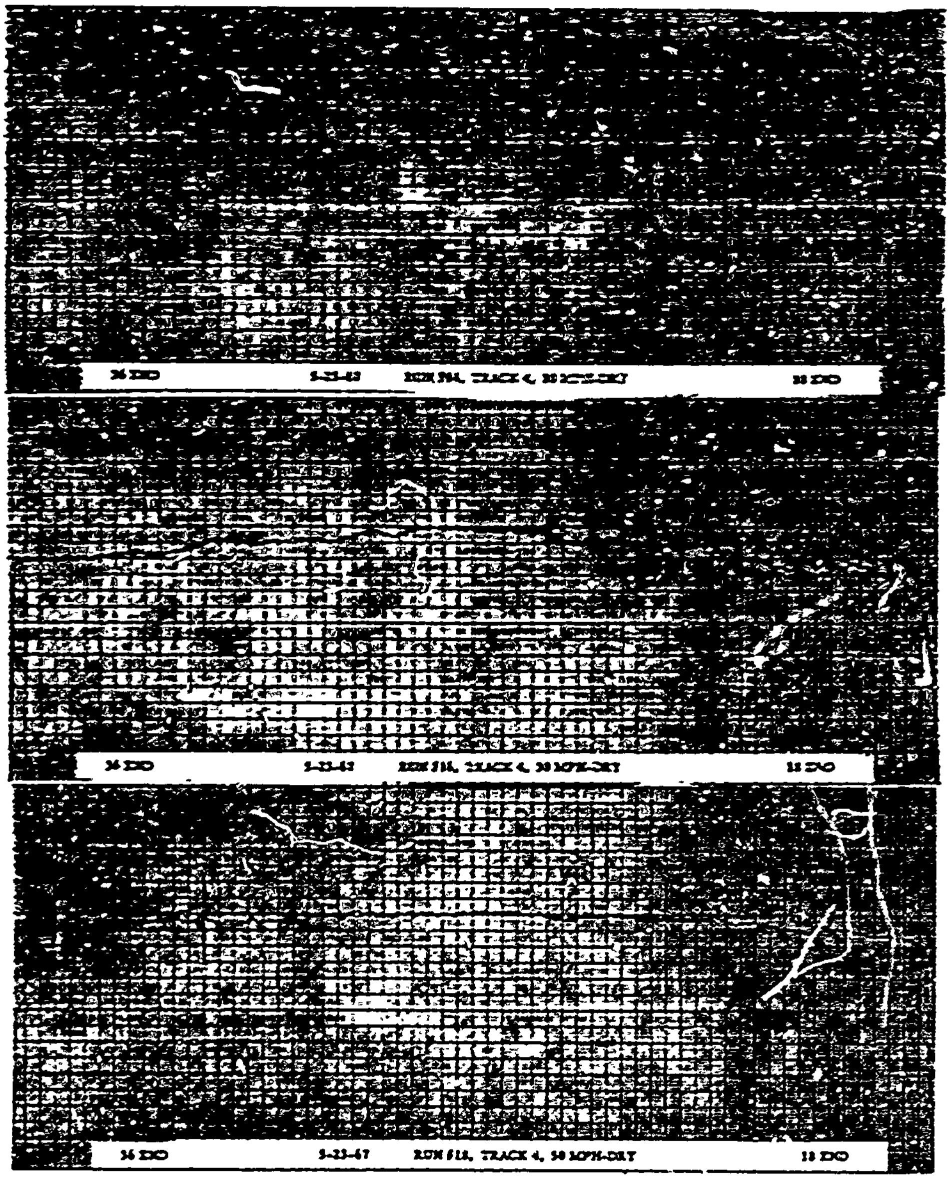

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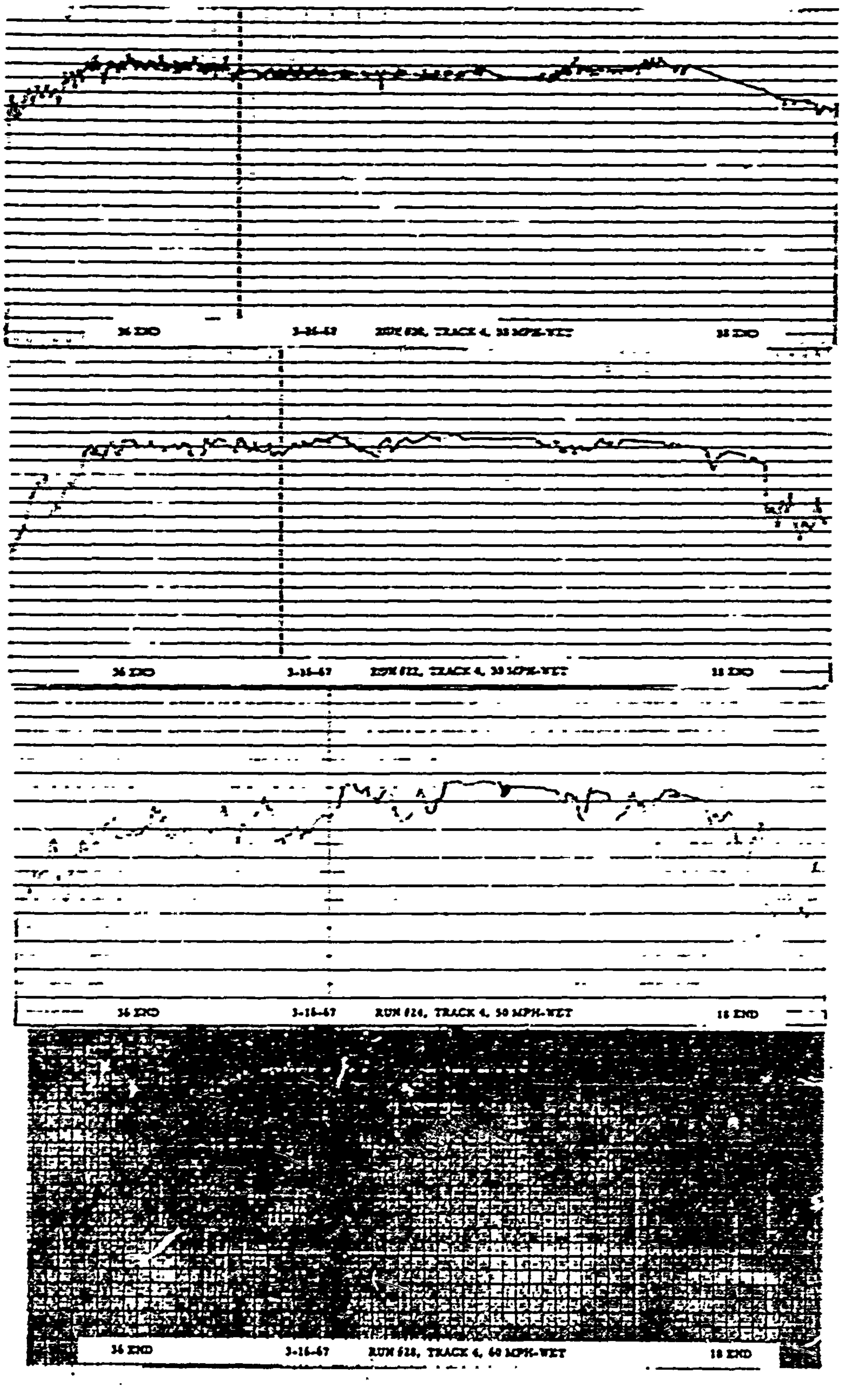

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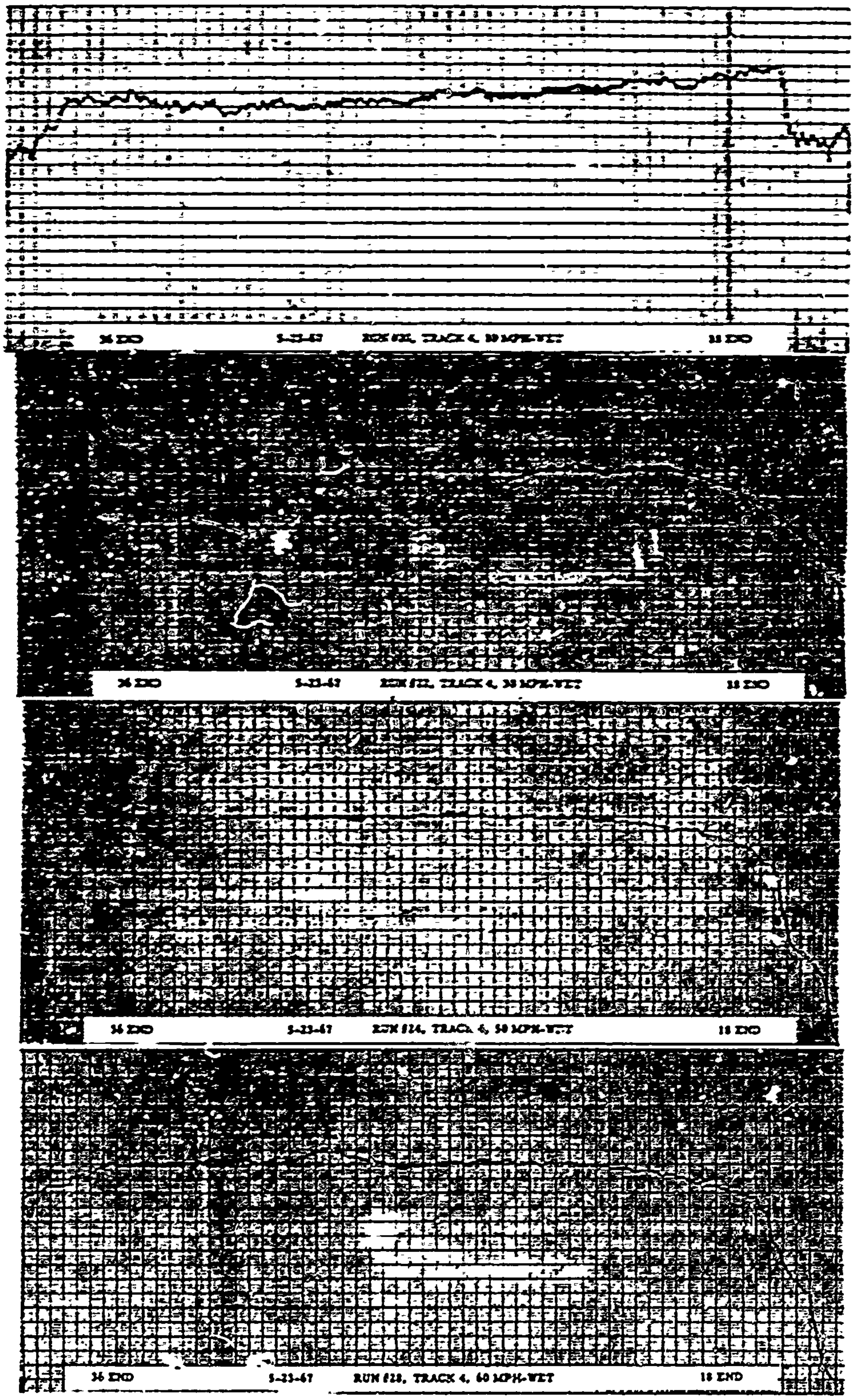
WET TESTS



AFTER GROOVING - TRACK 4, 25 FT. EAST OF CENTERLINE
WET TESTS

APPENDIX III

FRICTION DATA - RUNWAY CONTAMINATION COMPARATIVE TESTS -
DRY SURFACE CONDITIONS - MAY 10, 1967, AND SEPTEMBER 14, 1967 TESTS

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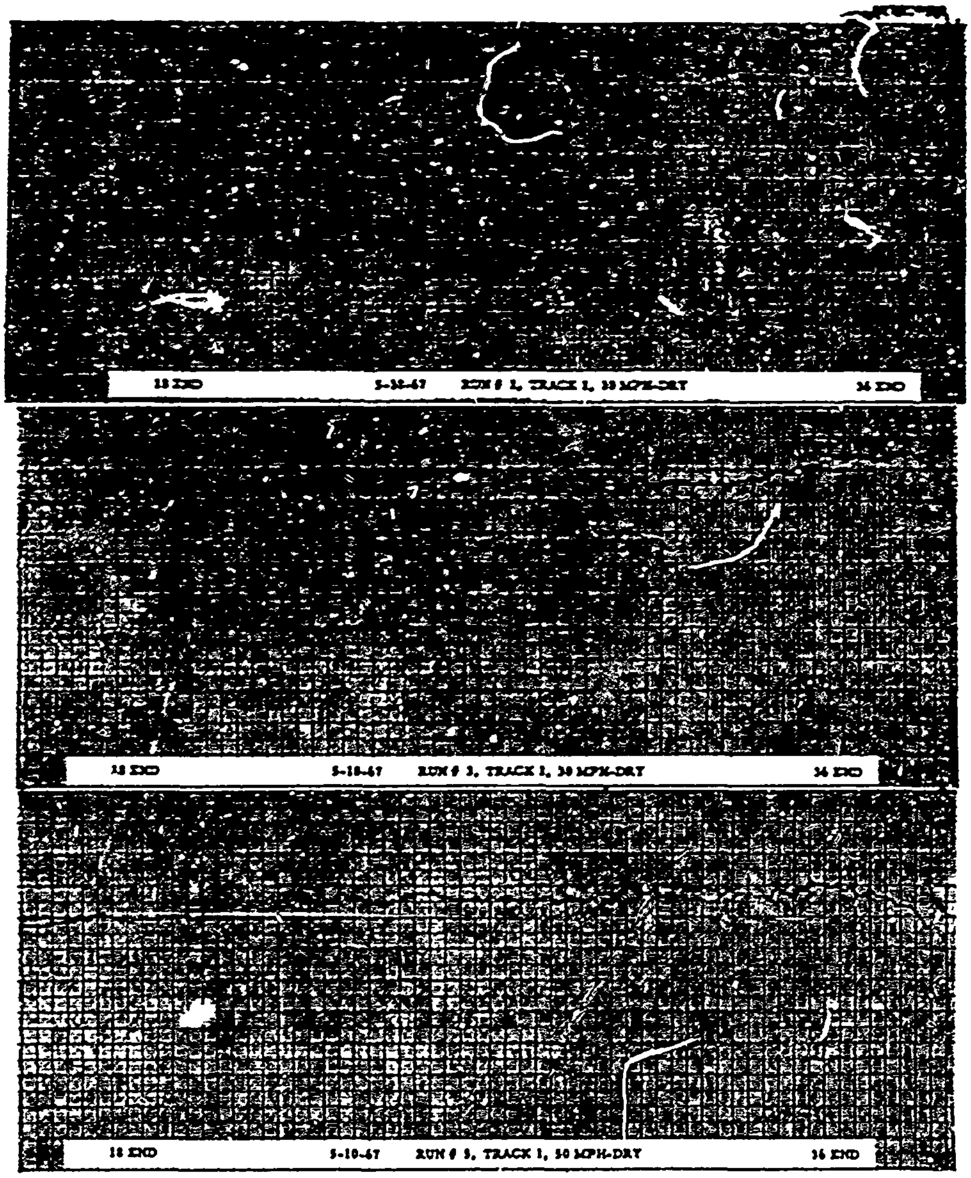
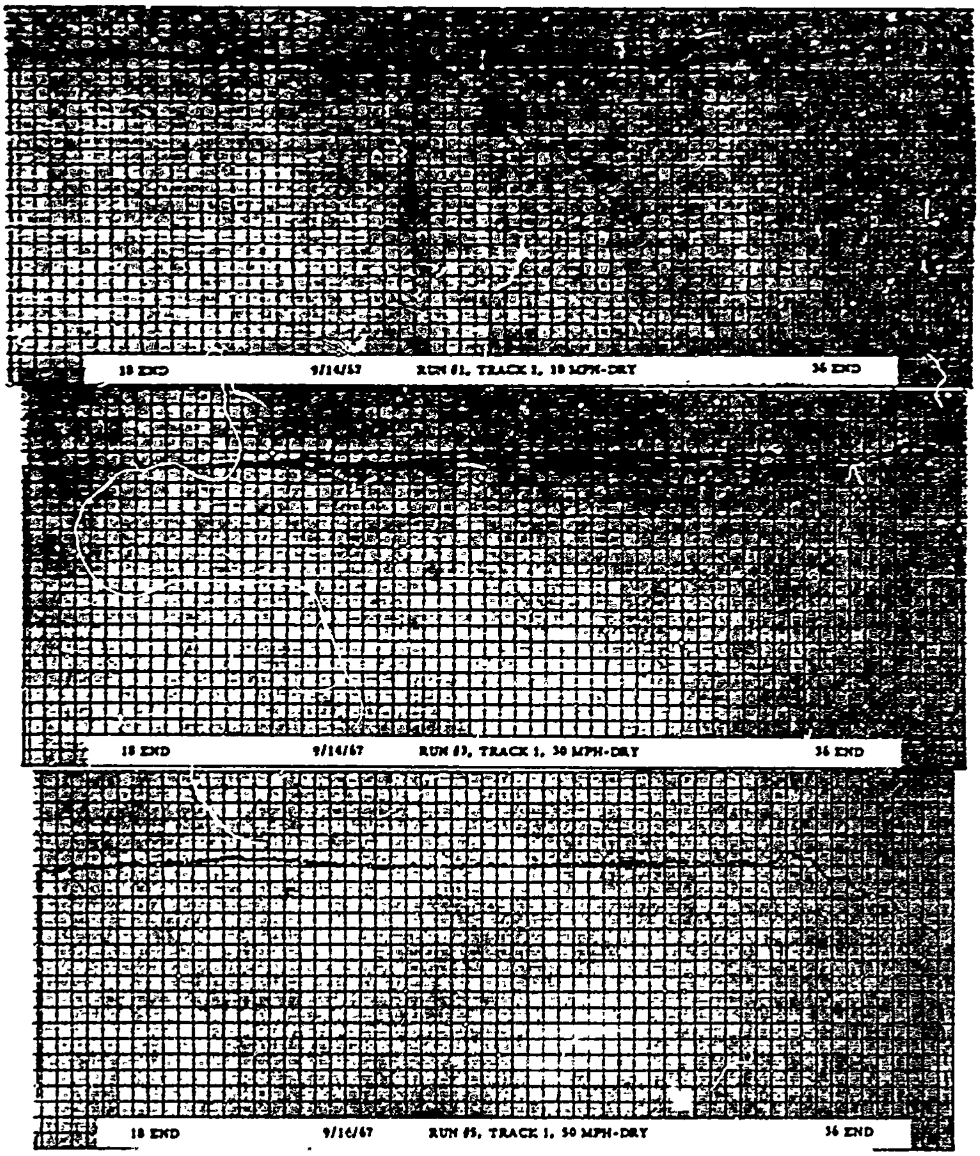


AFTER GROOVING - TRACK 1, CENTERLINE
DRY TESTS



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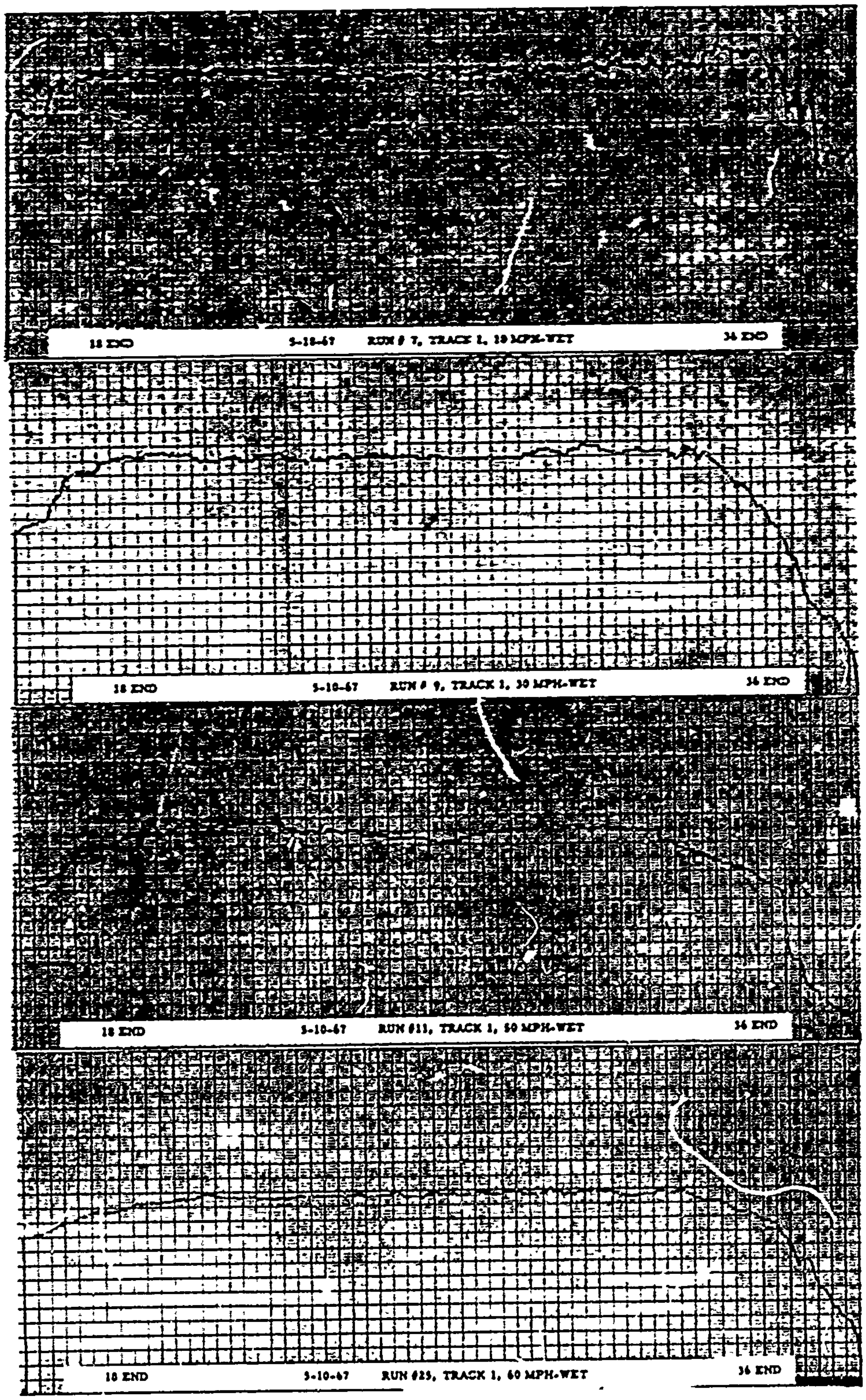

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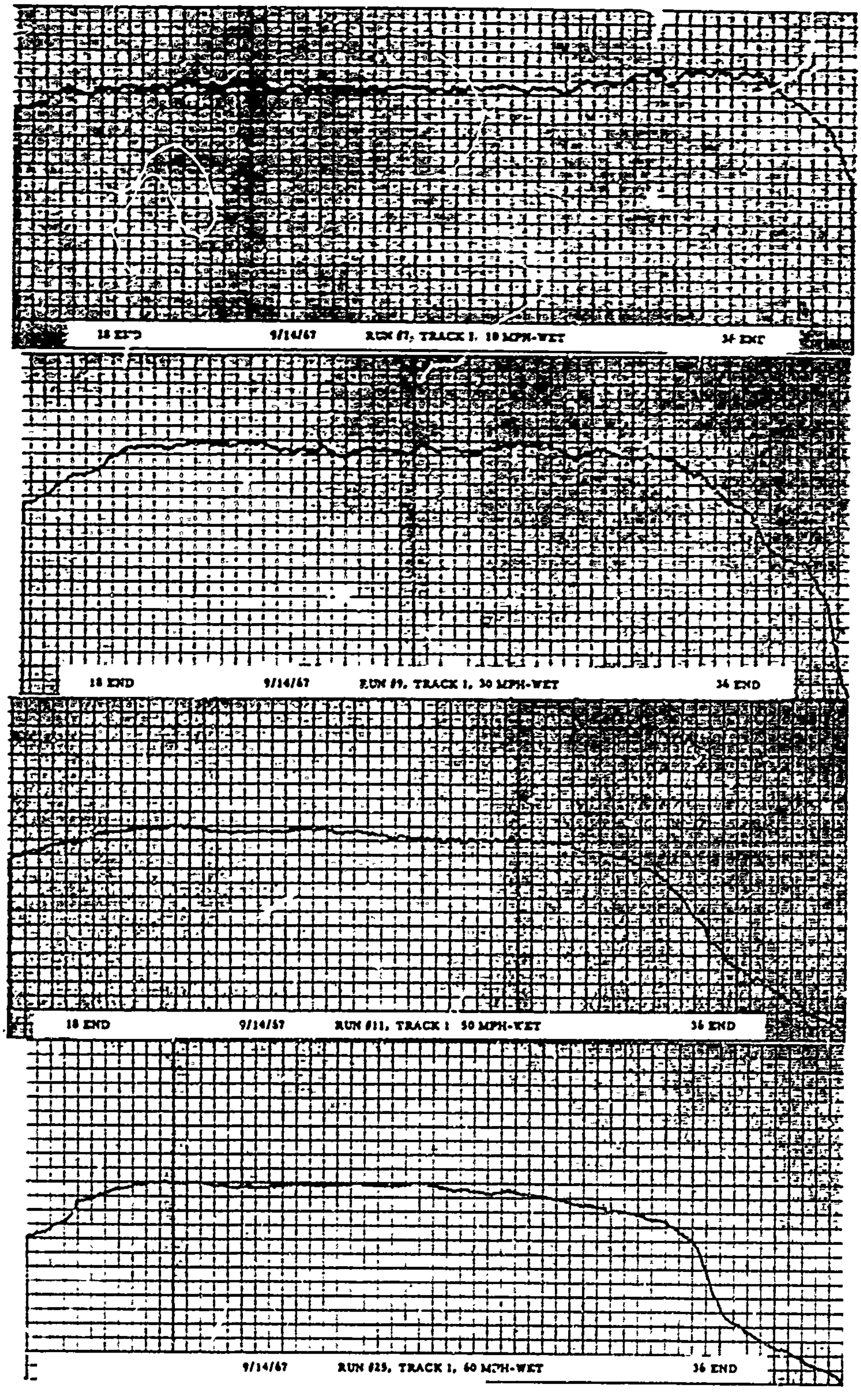

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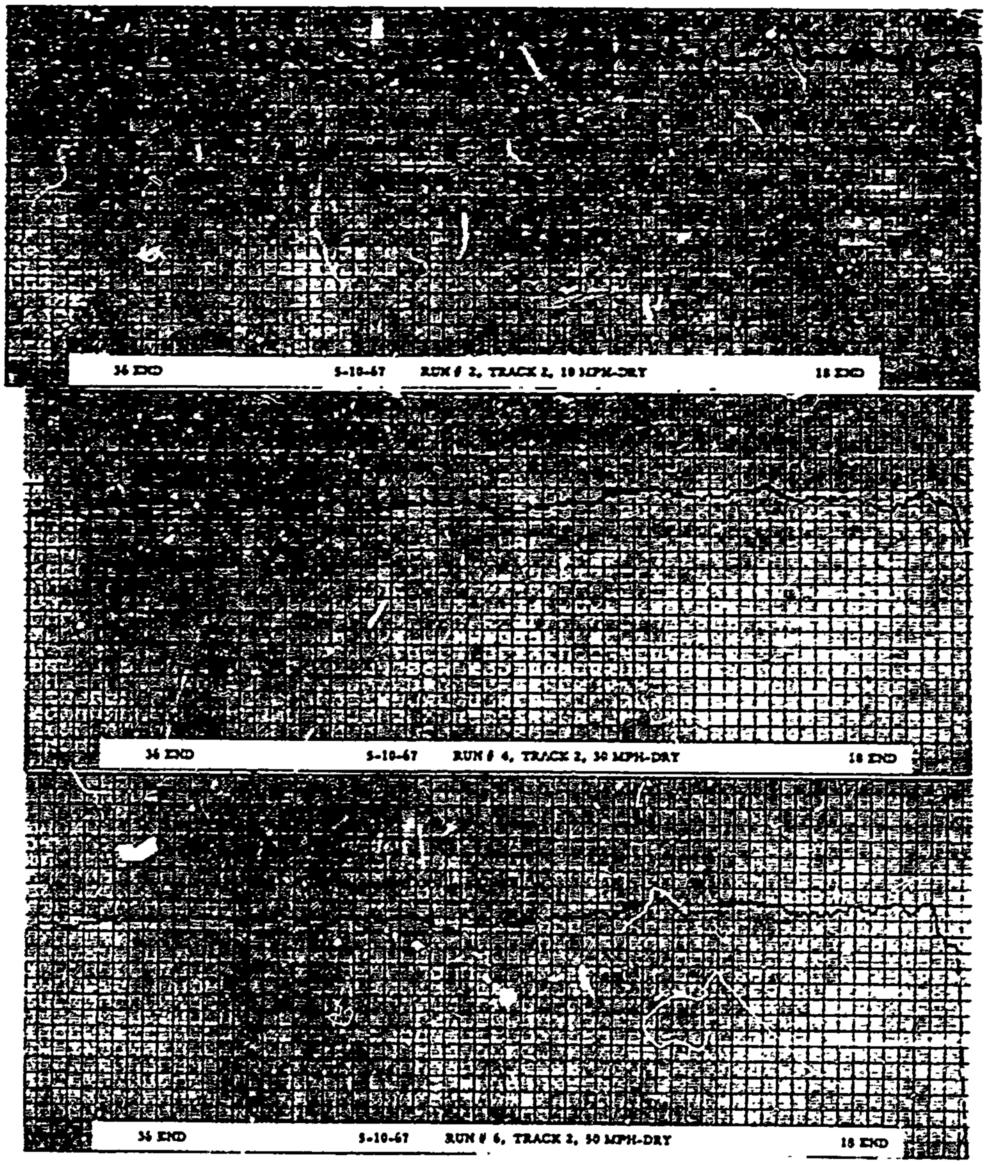

AFTER GROOVING - TRACK 2, EAST RUNWAY EDGE
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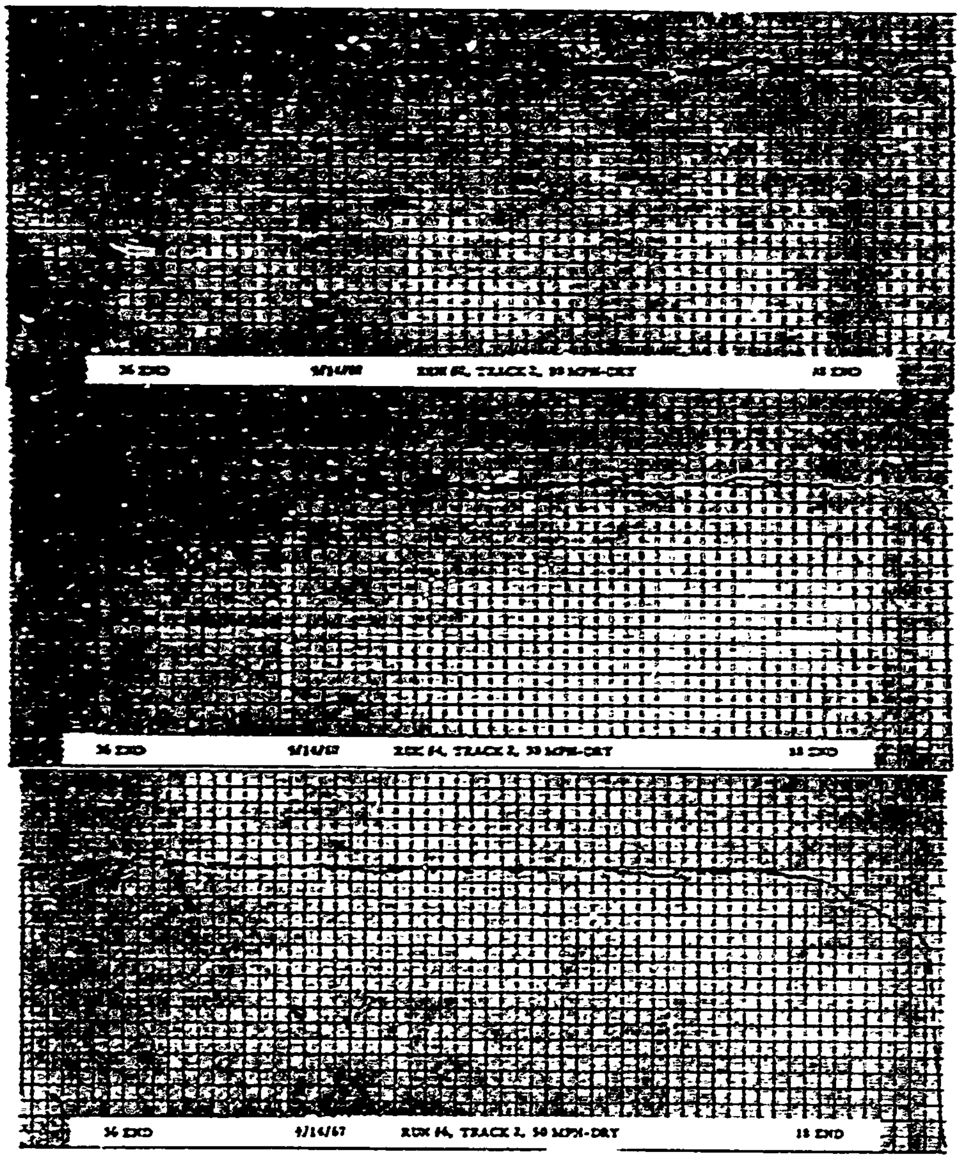

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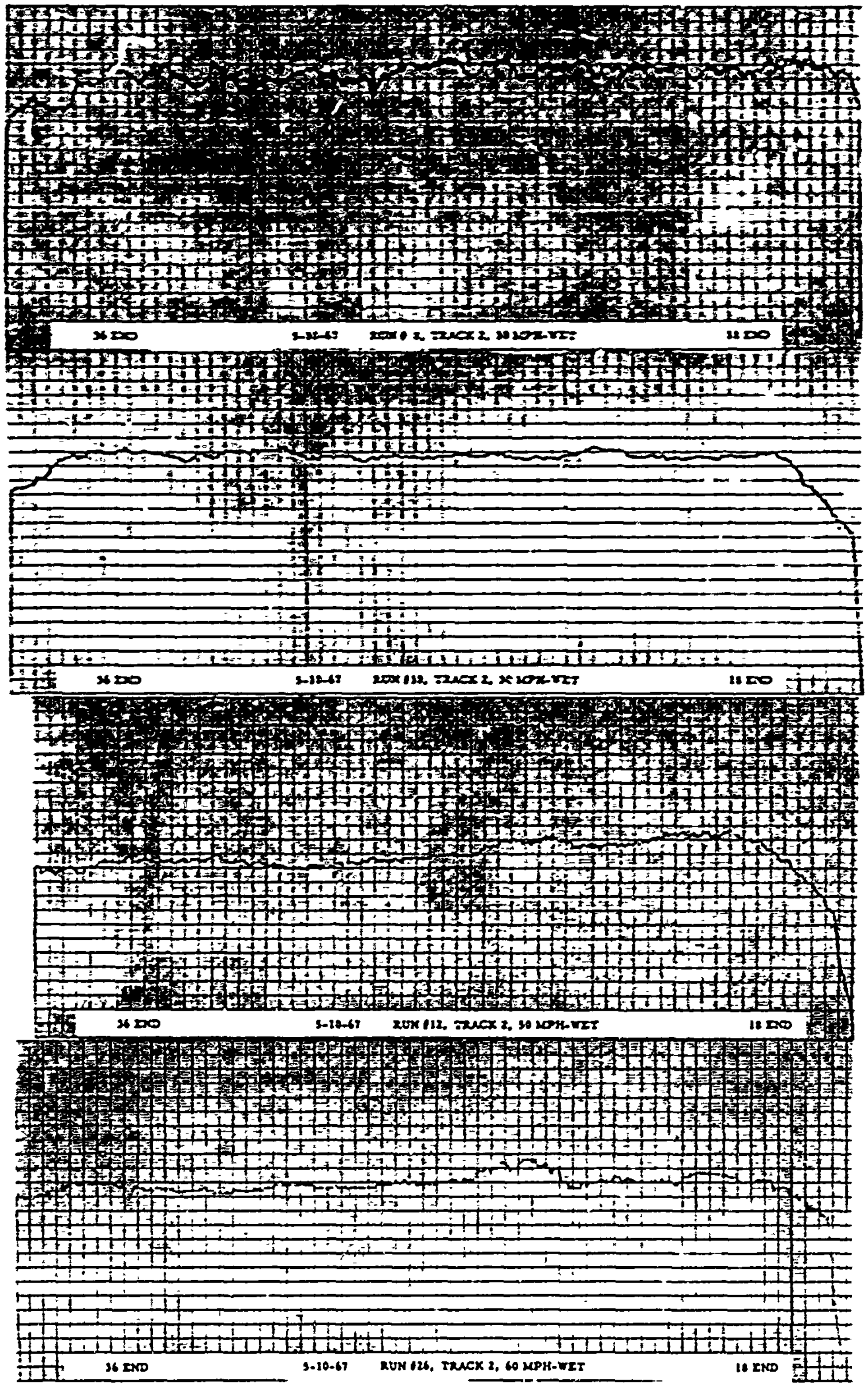

AFTER GROOVING - TRACK 2, EAST RUNWAY EDGE
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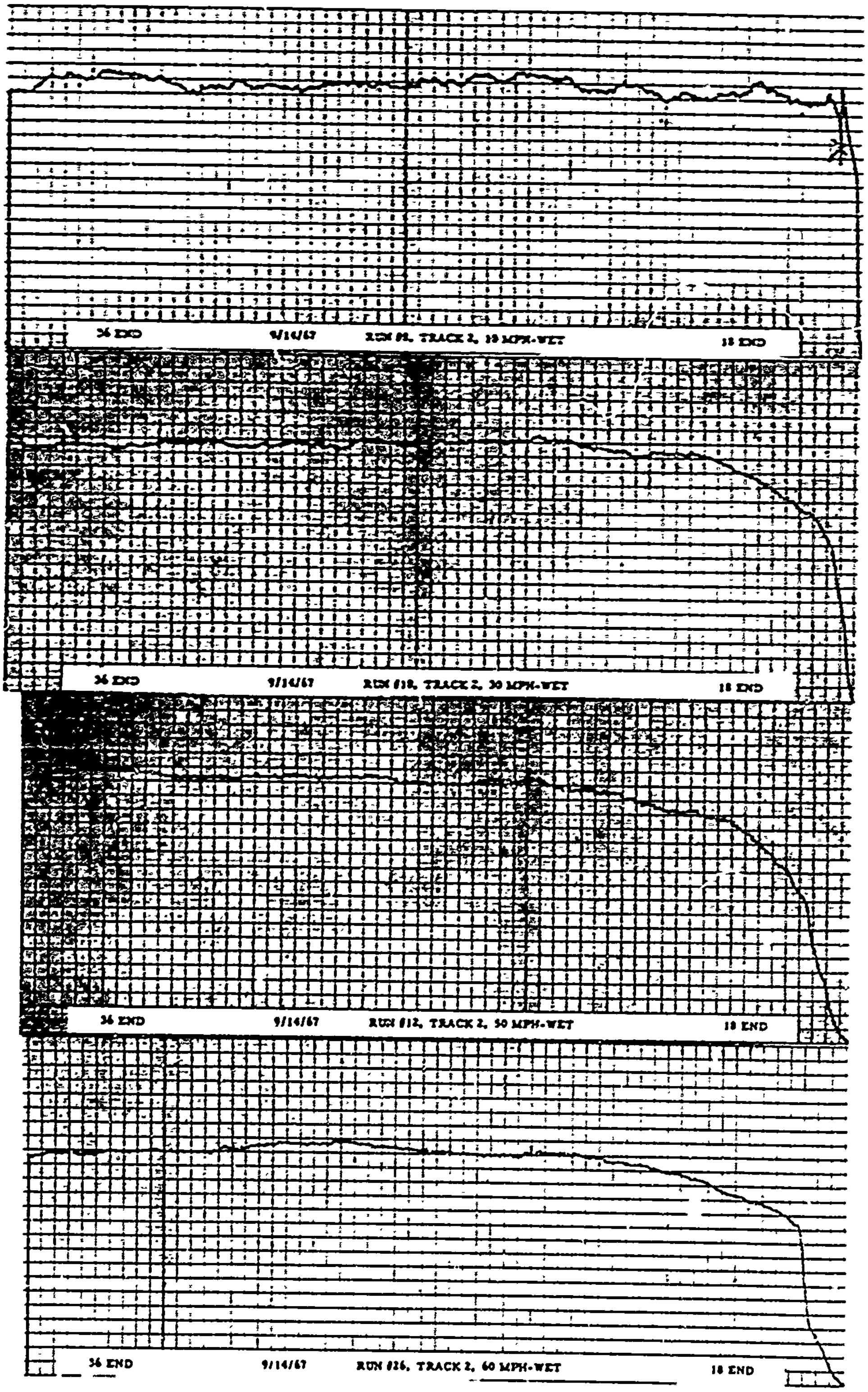

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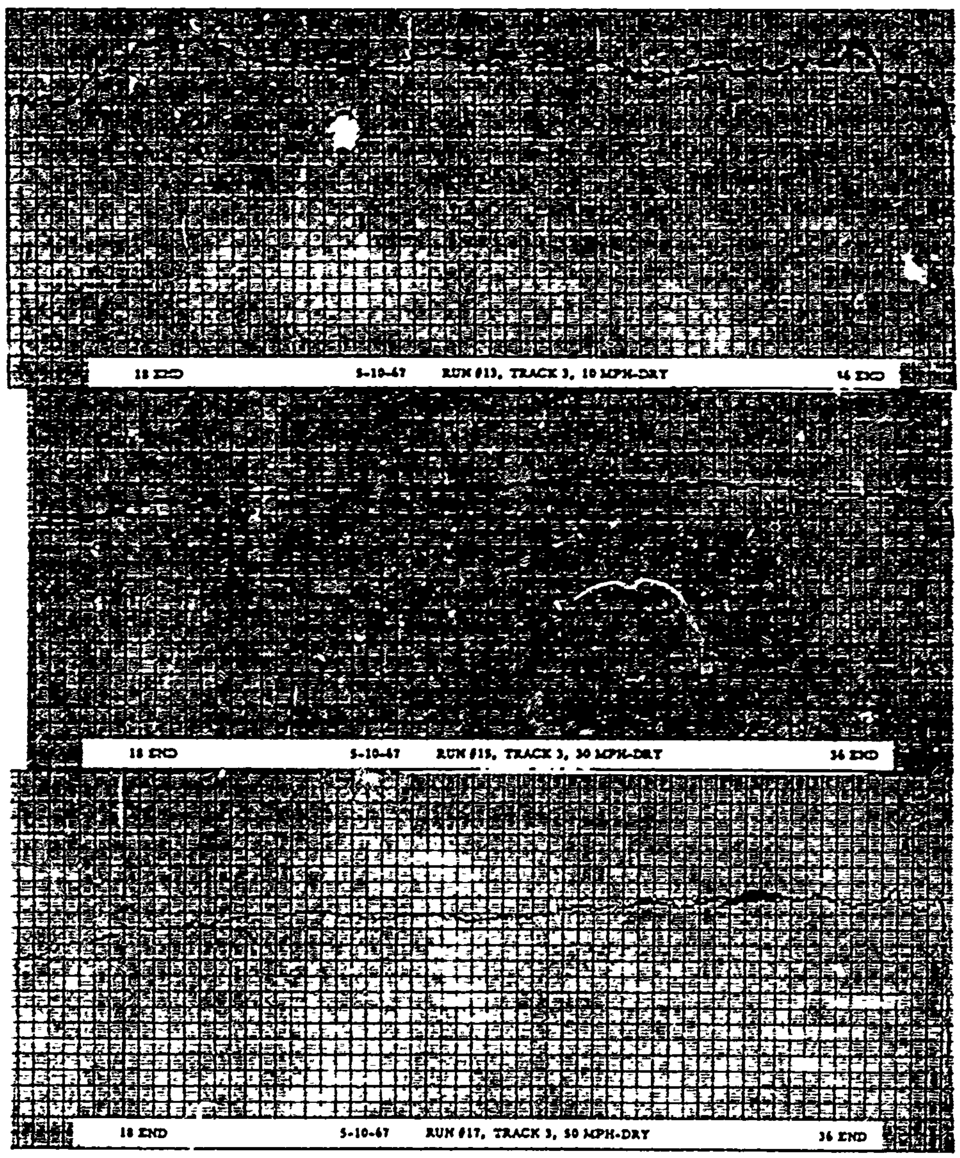
WET TESTS



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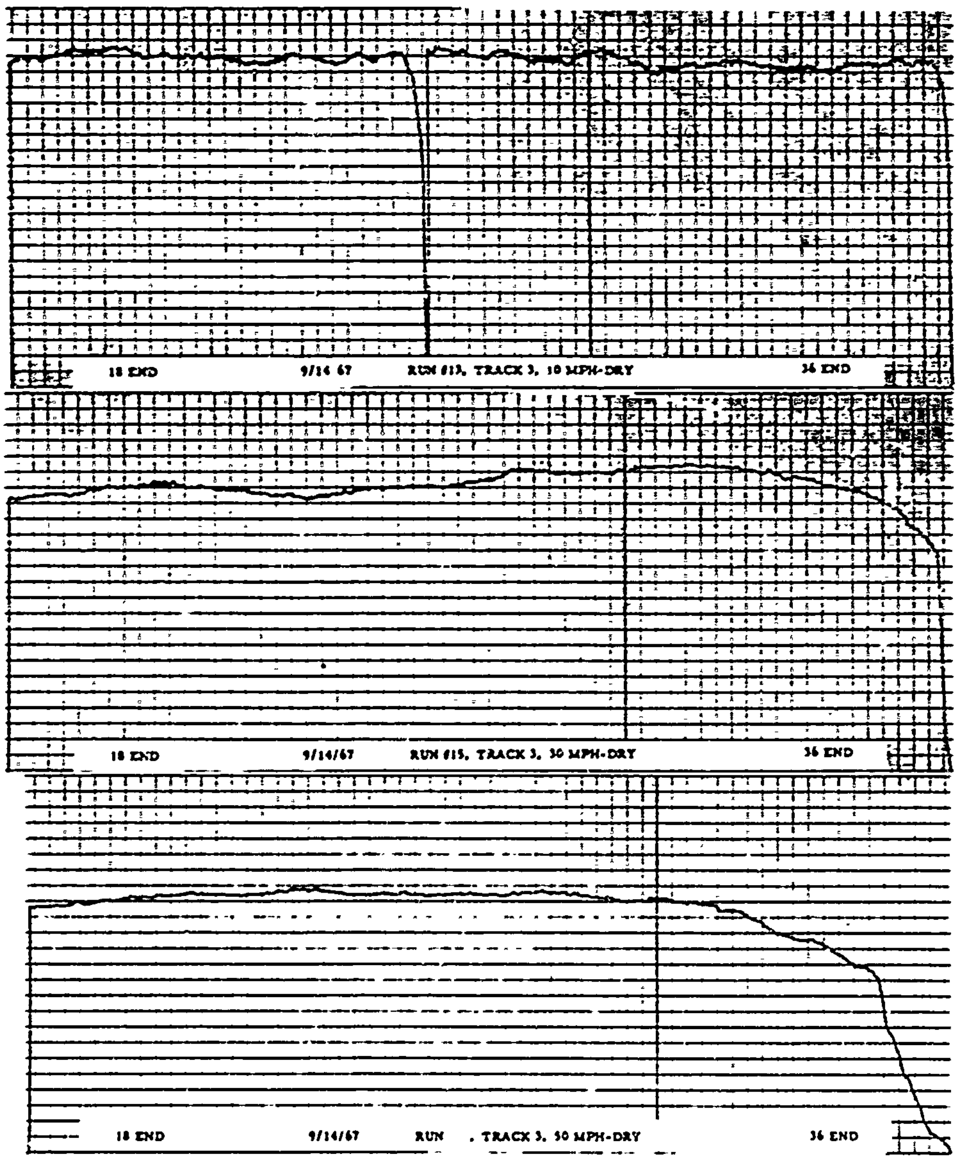

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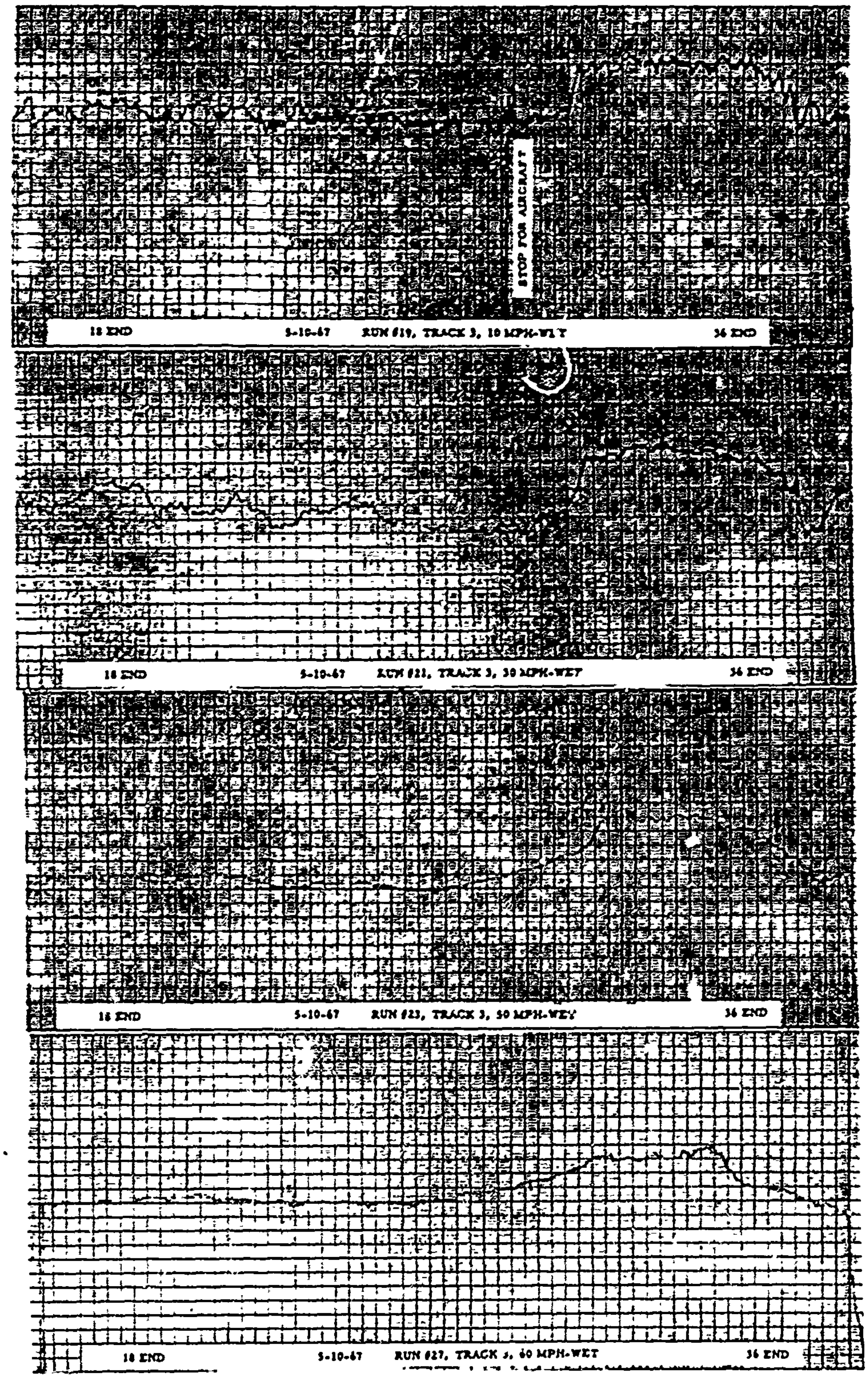

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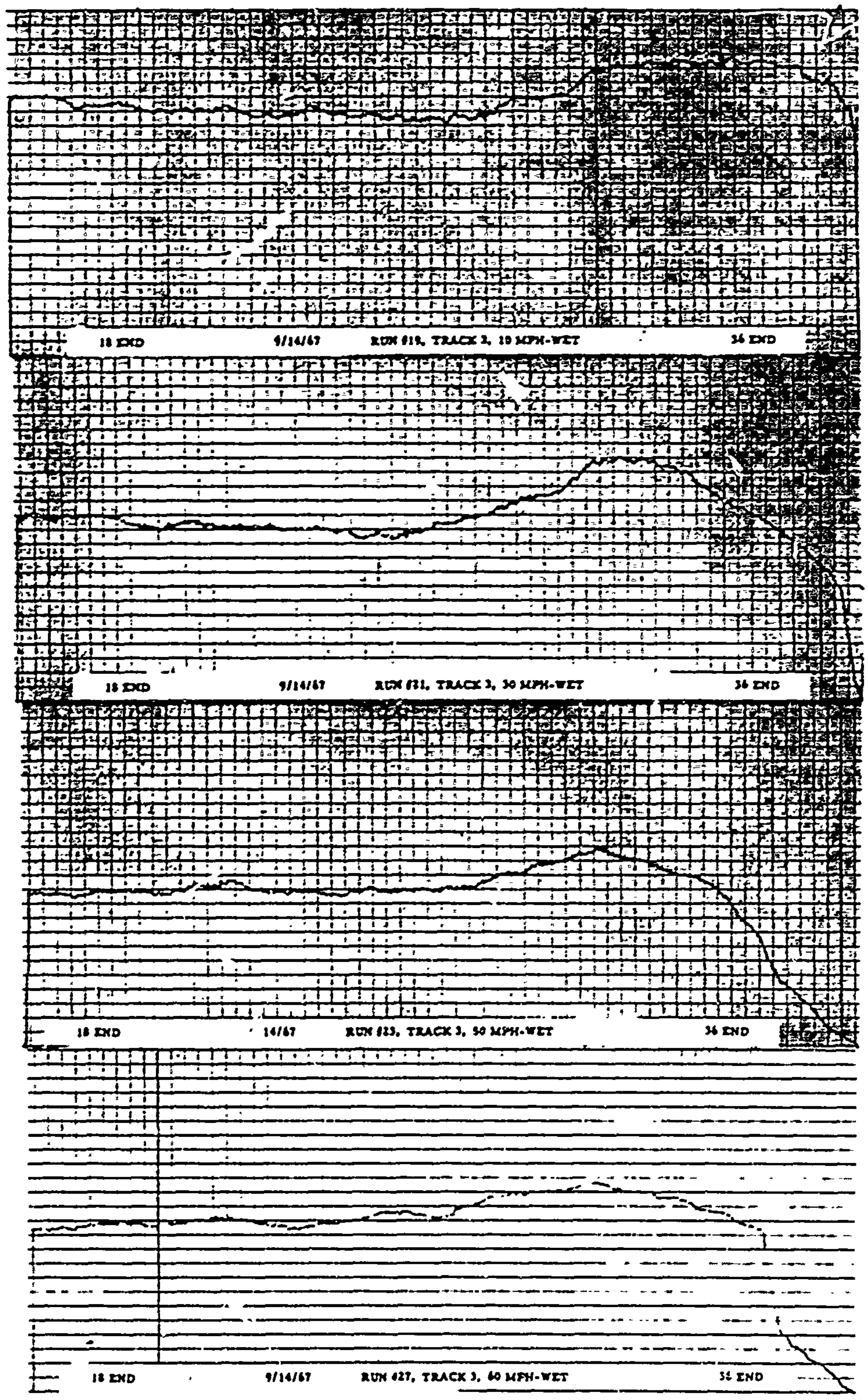

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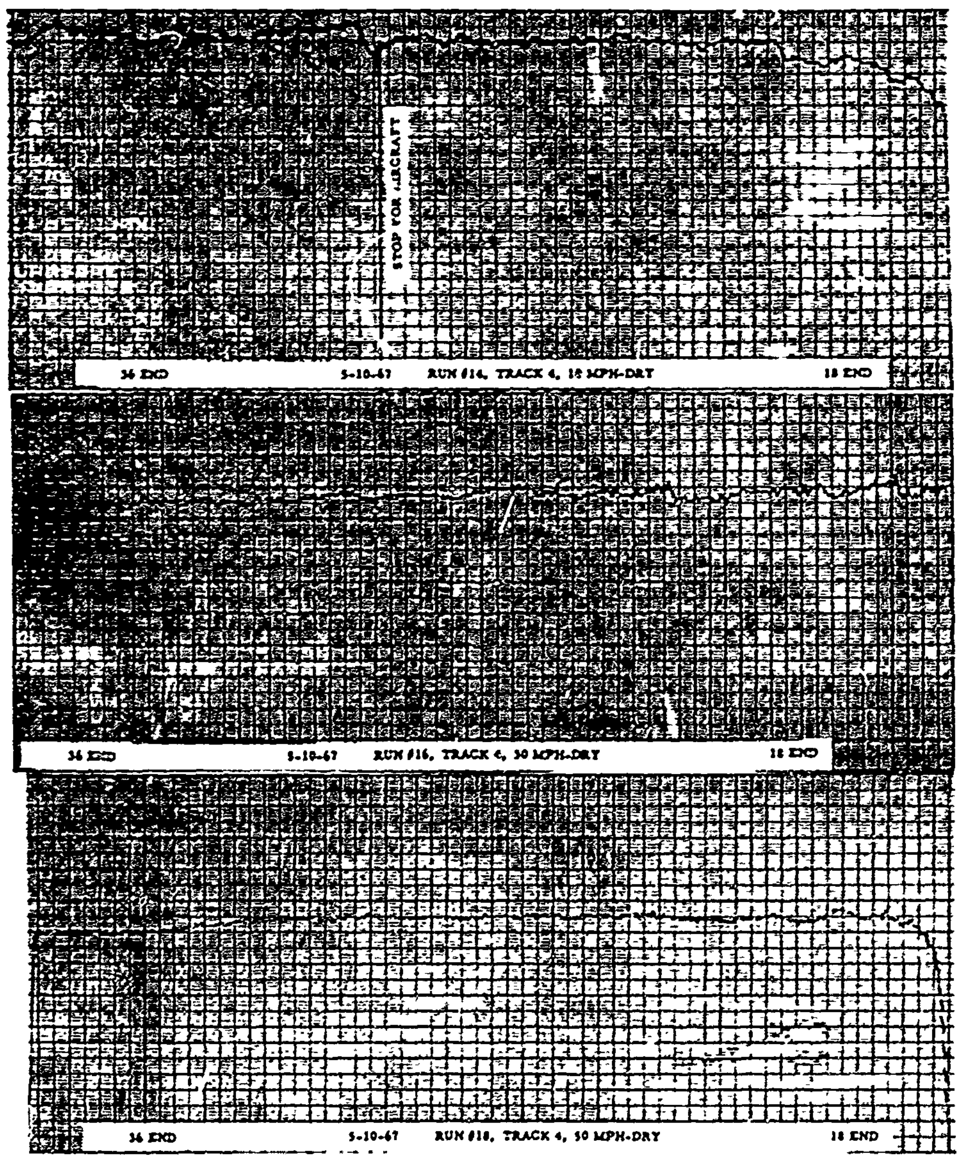

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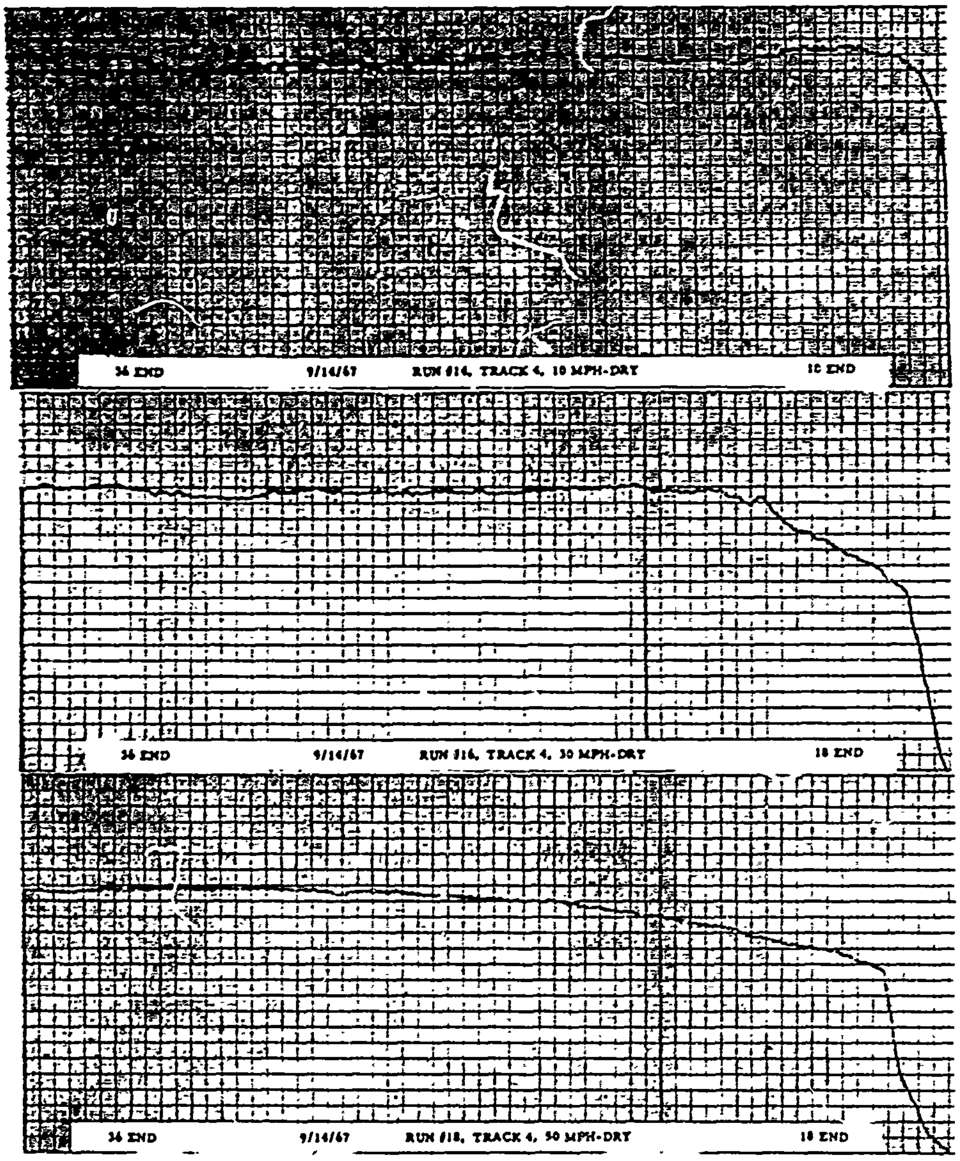

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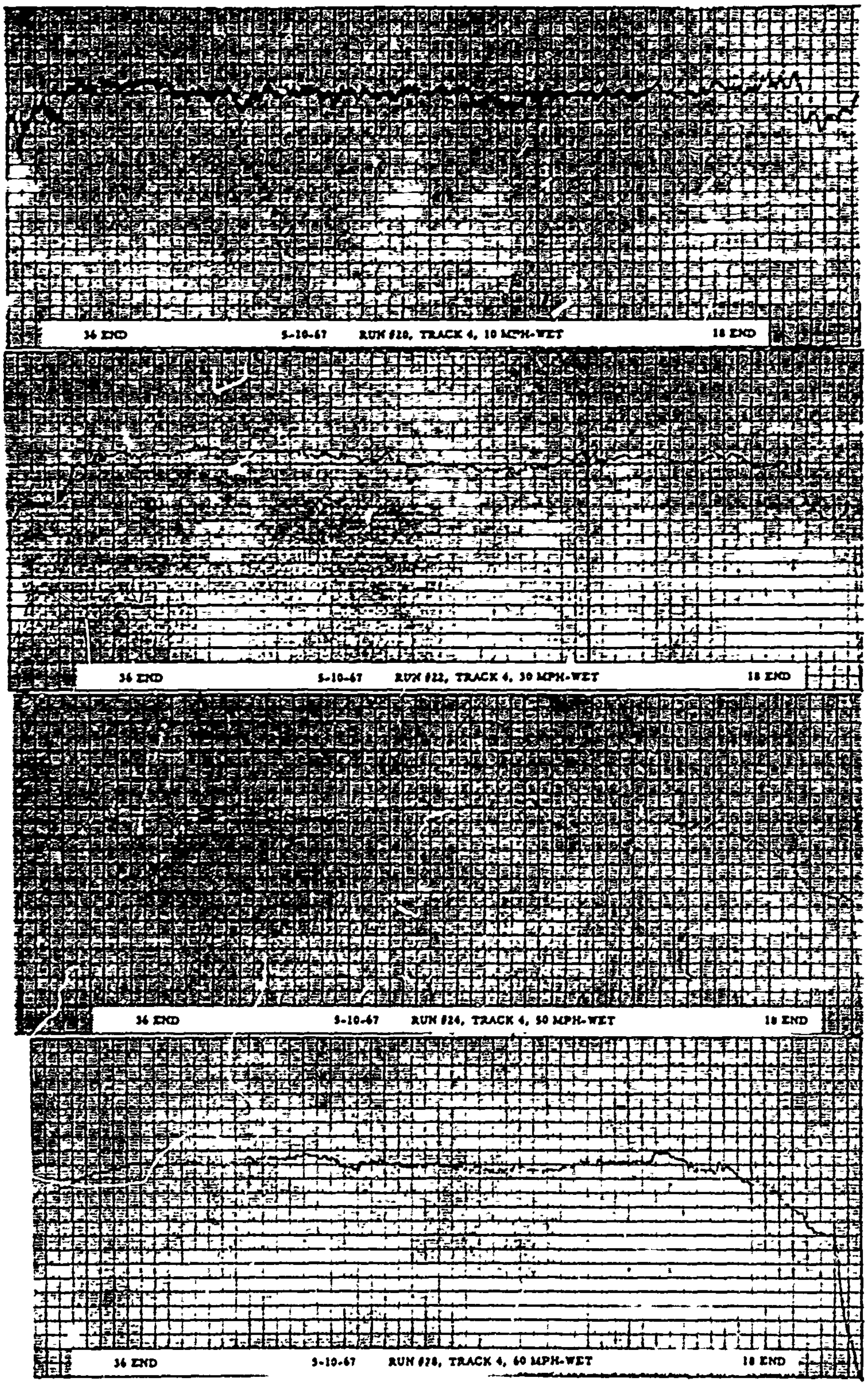

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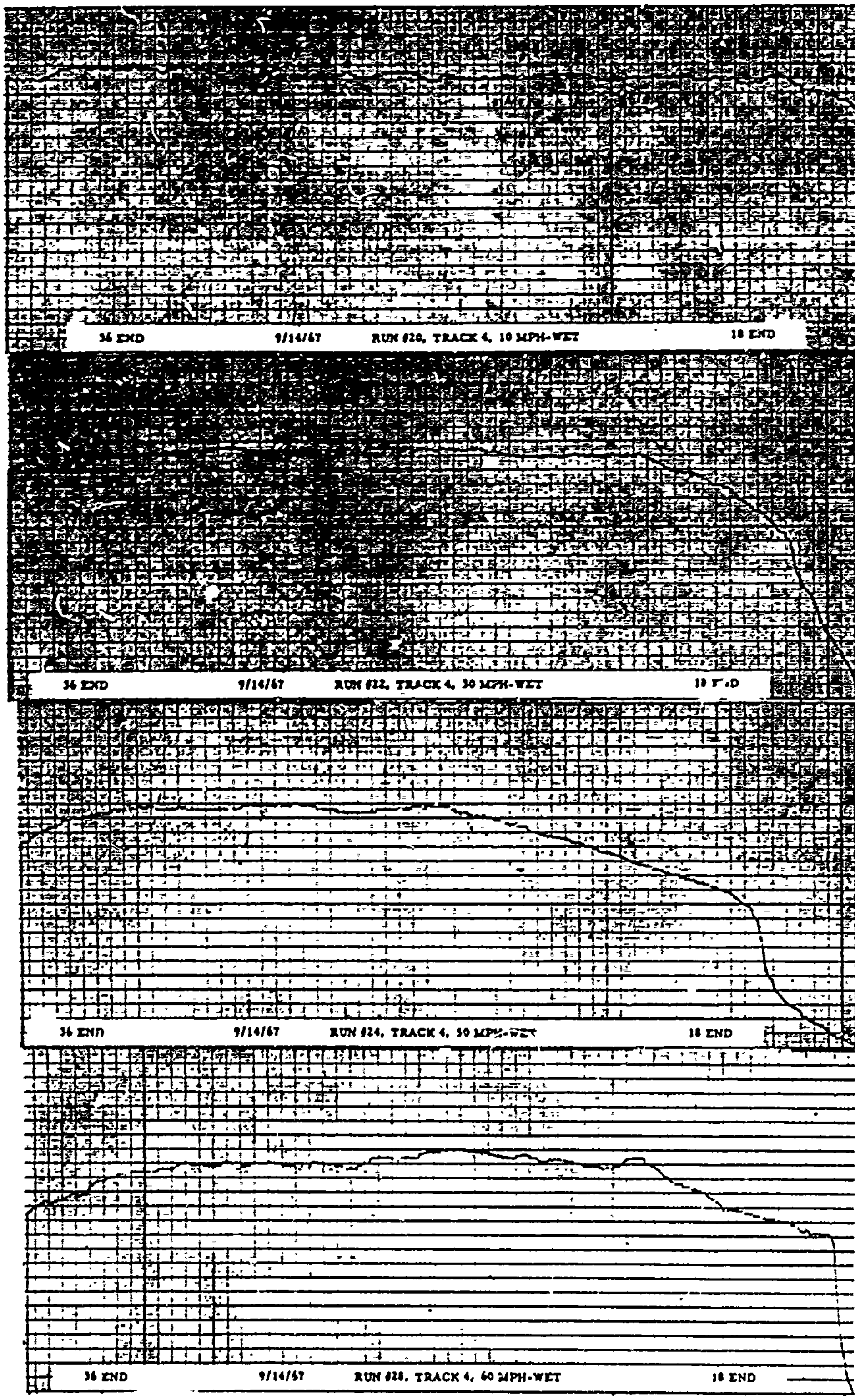

AFTER GROOVING - TRACK 4, 25 FT. EAST OF CENTERLINE
WET TESTS

APPENDIX IV

LOW TIRE PRESSURE FRICTION DATA

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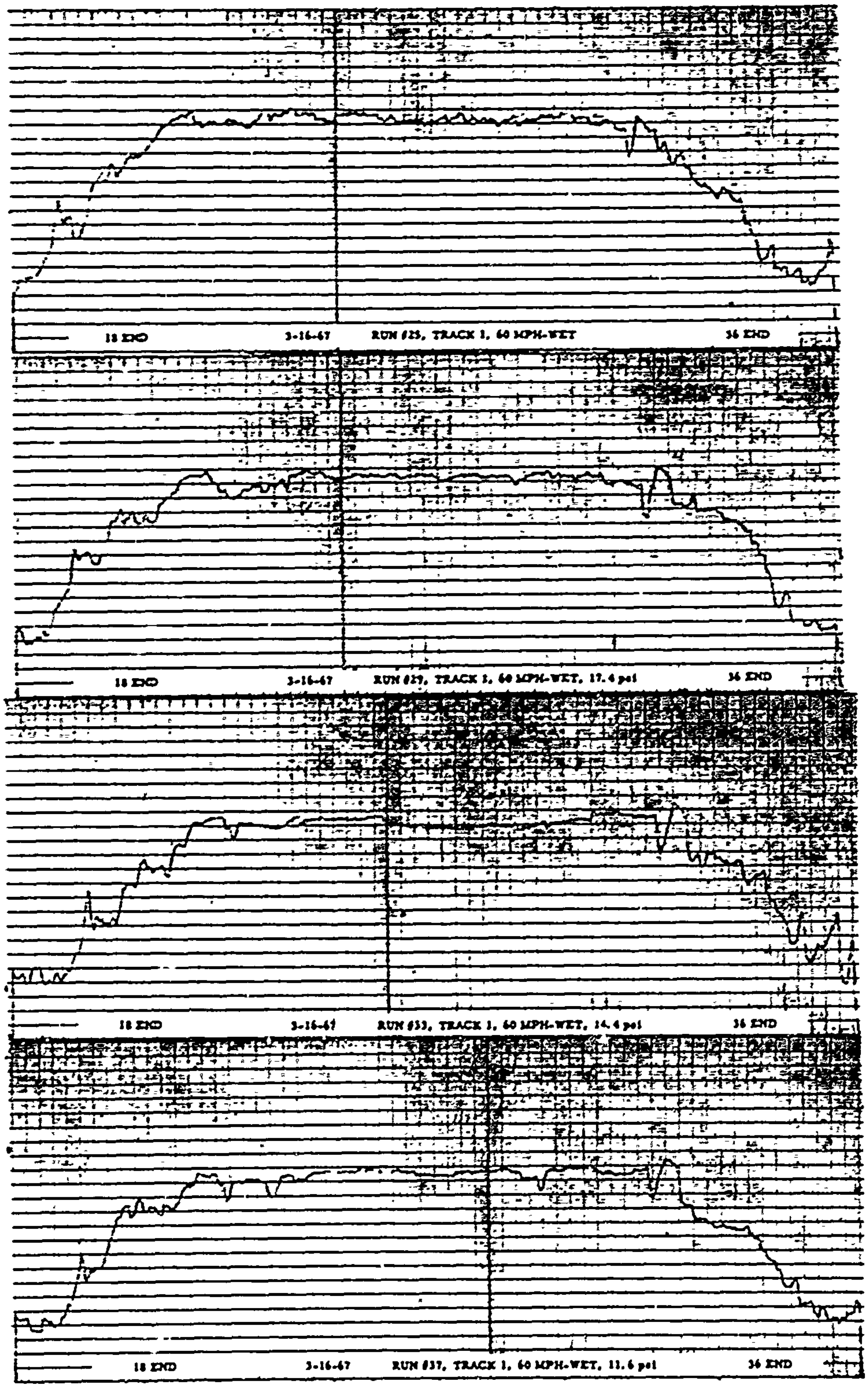
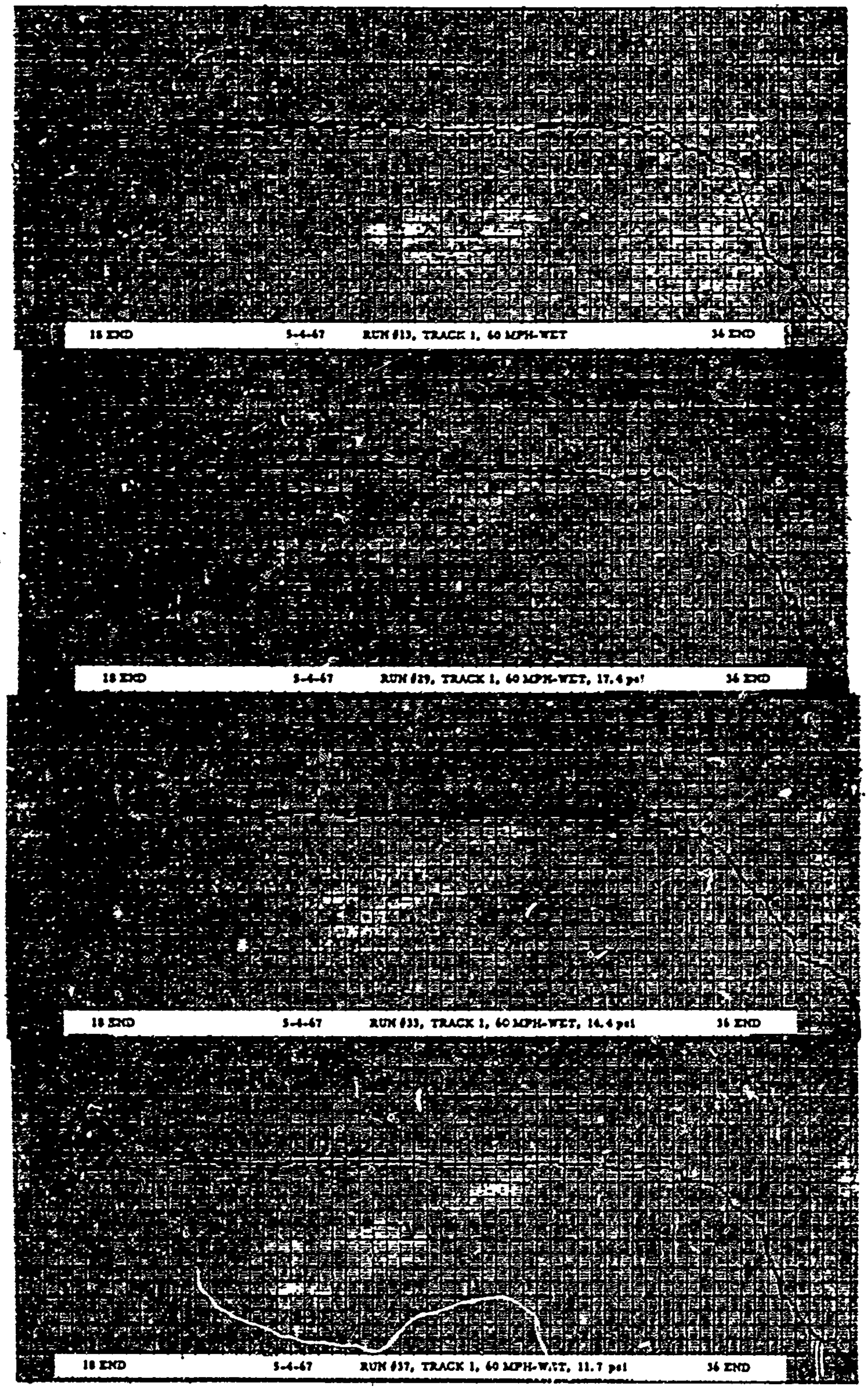
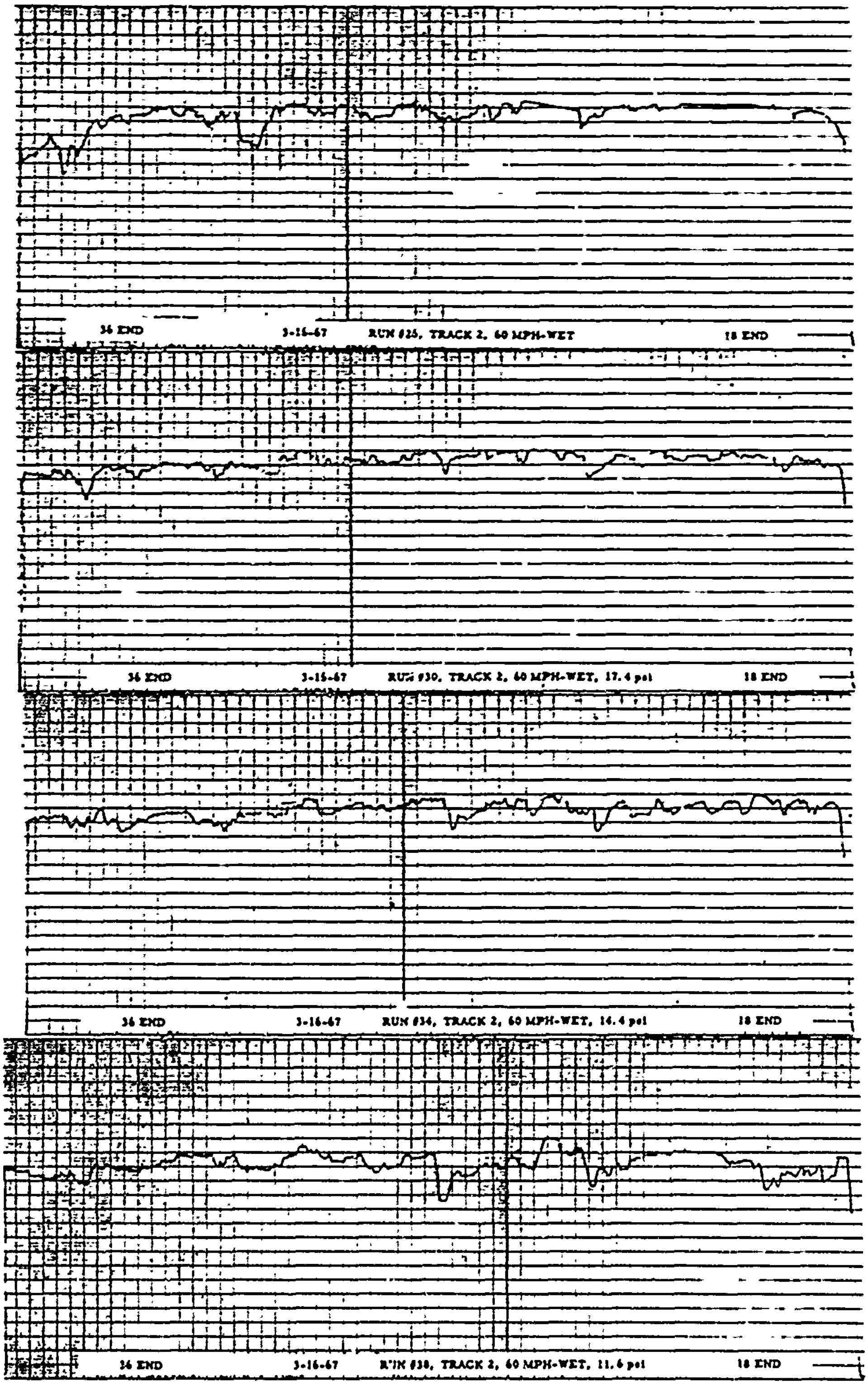


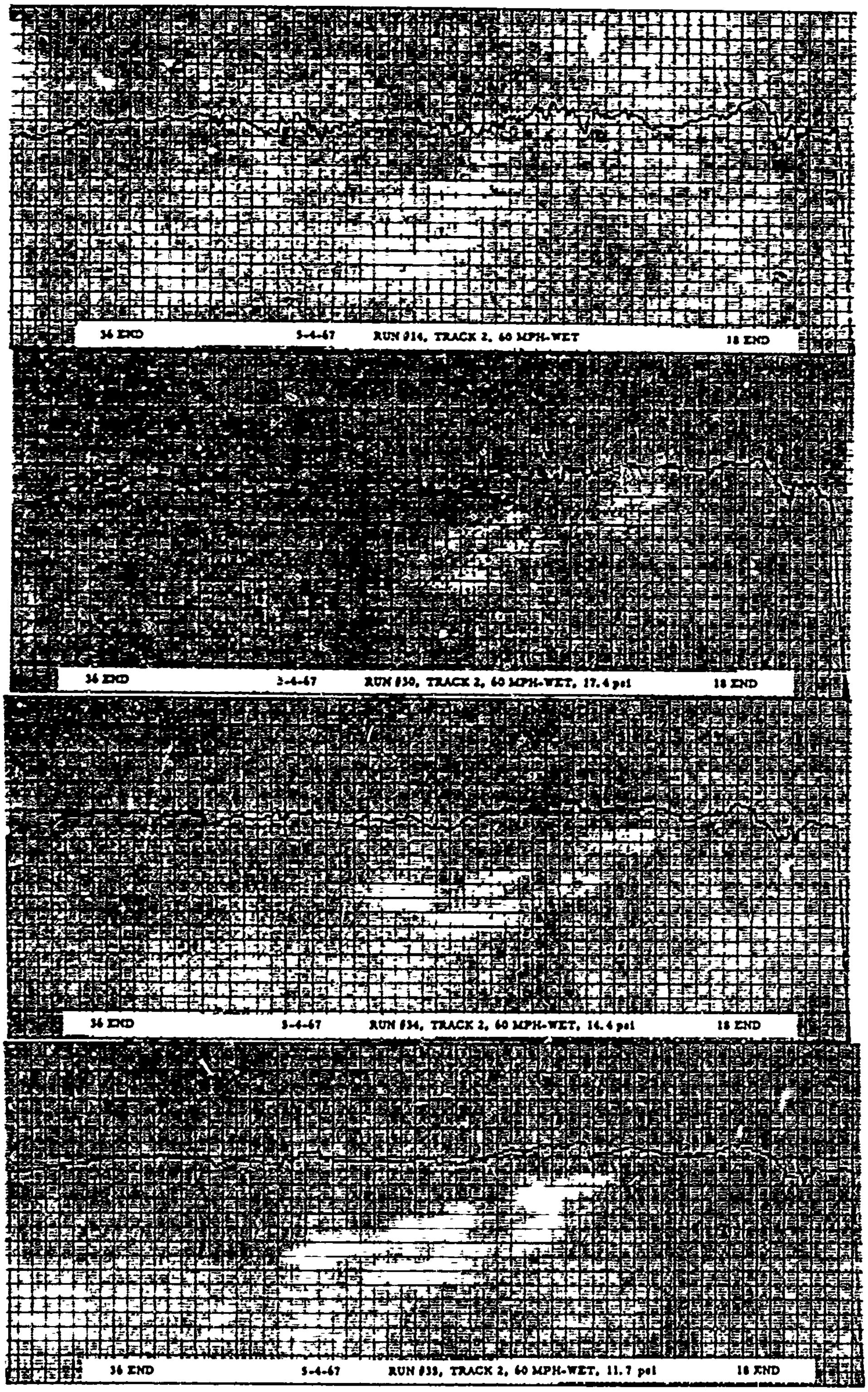
BEFORE GROOVING - TRACK 1, CENTERLINE
WET TESTS



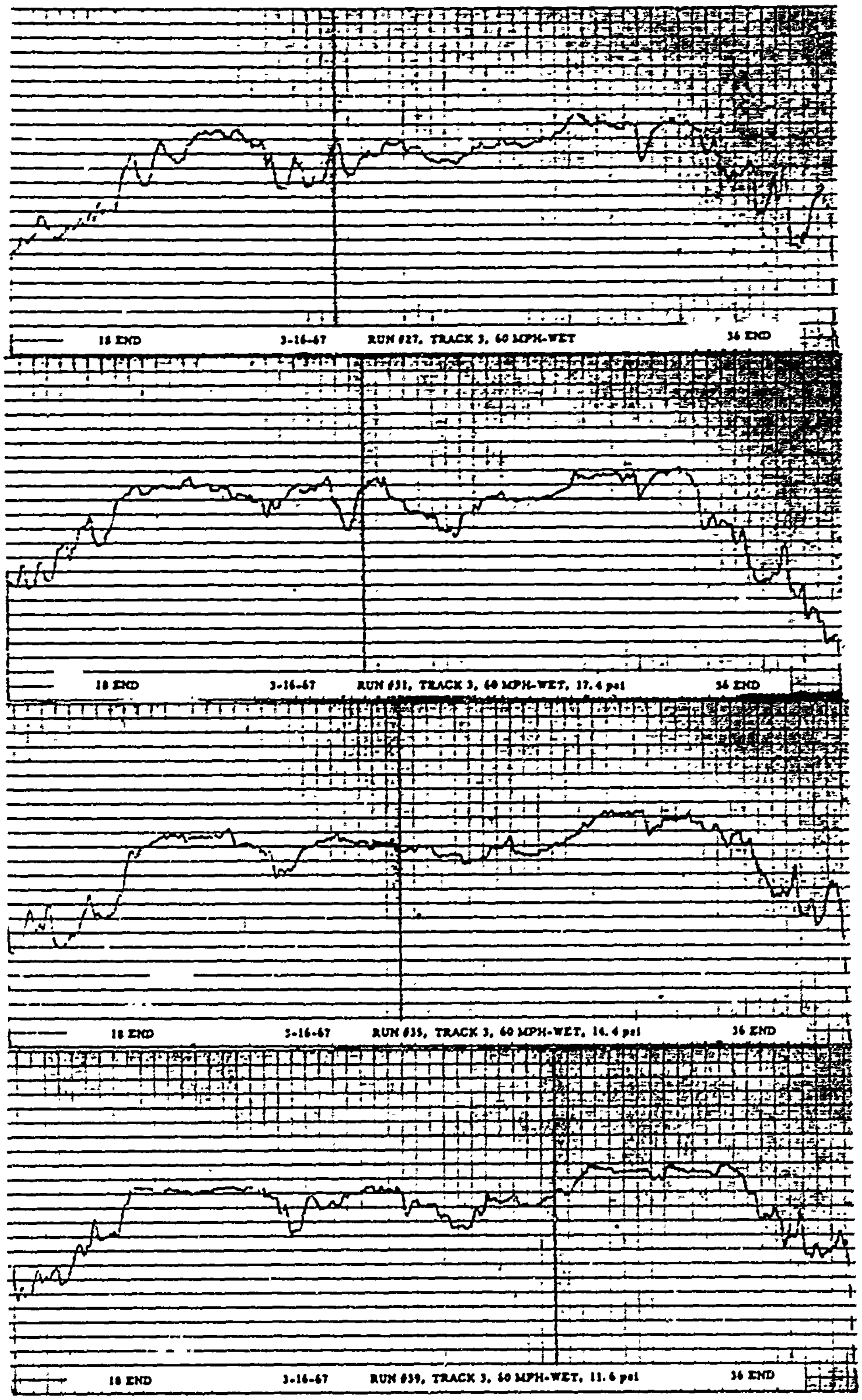
AFTER GROOVING - TRACK 1, CENTERLINE
WET TESTS



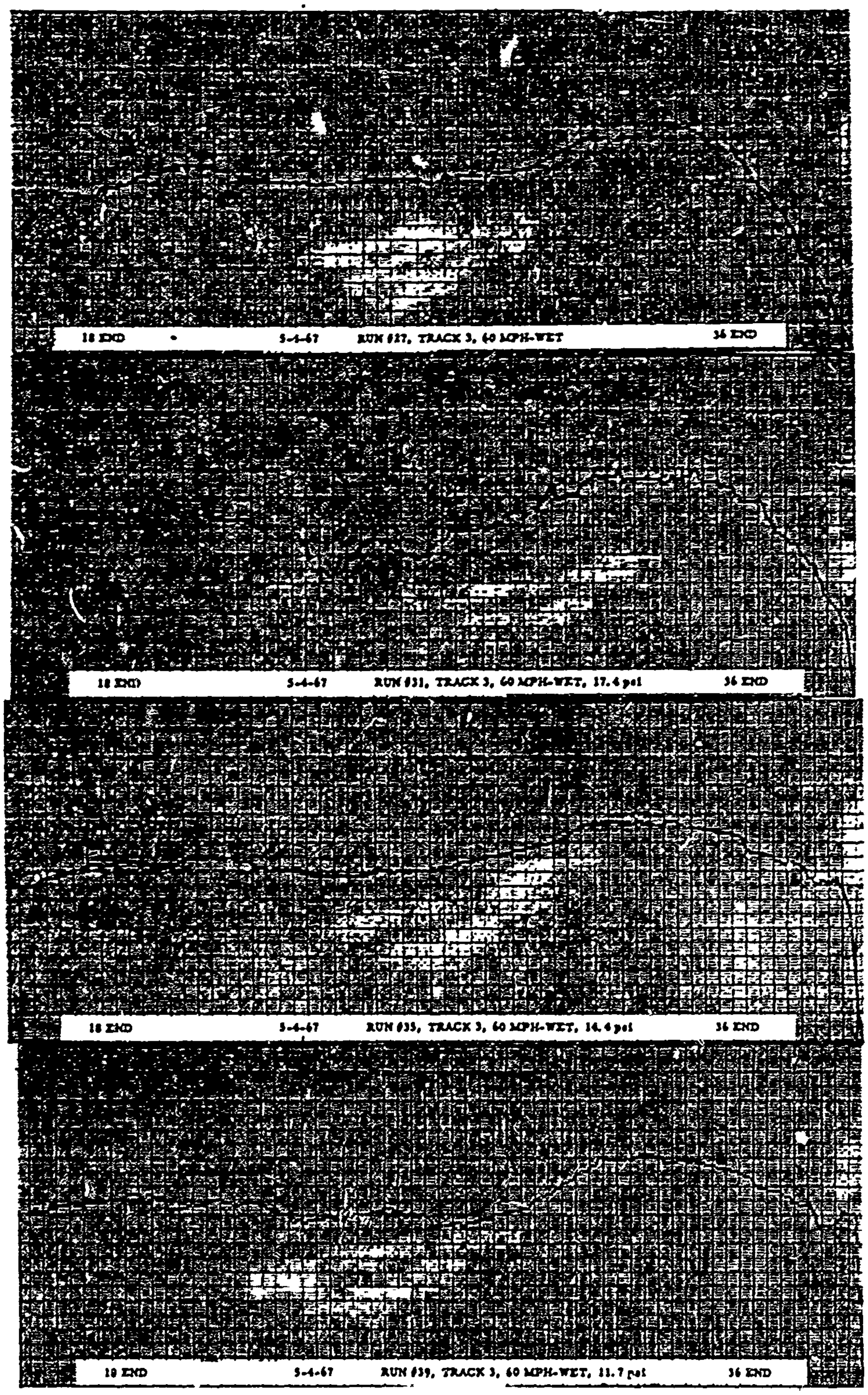
BEFORE GROOVING - TRACK 2, EAST RUNWAY EDGE
WET TESTS



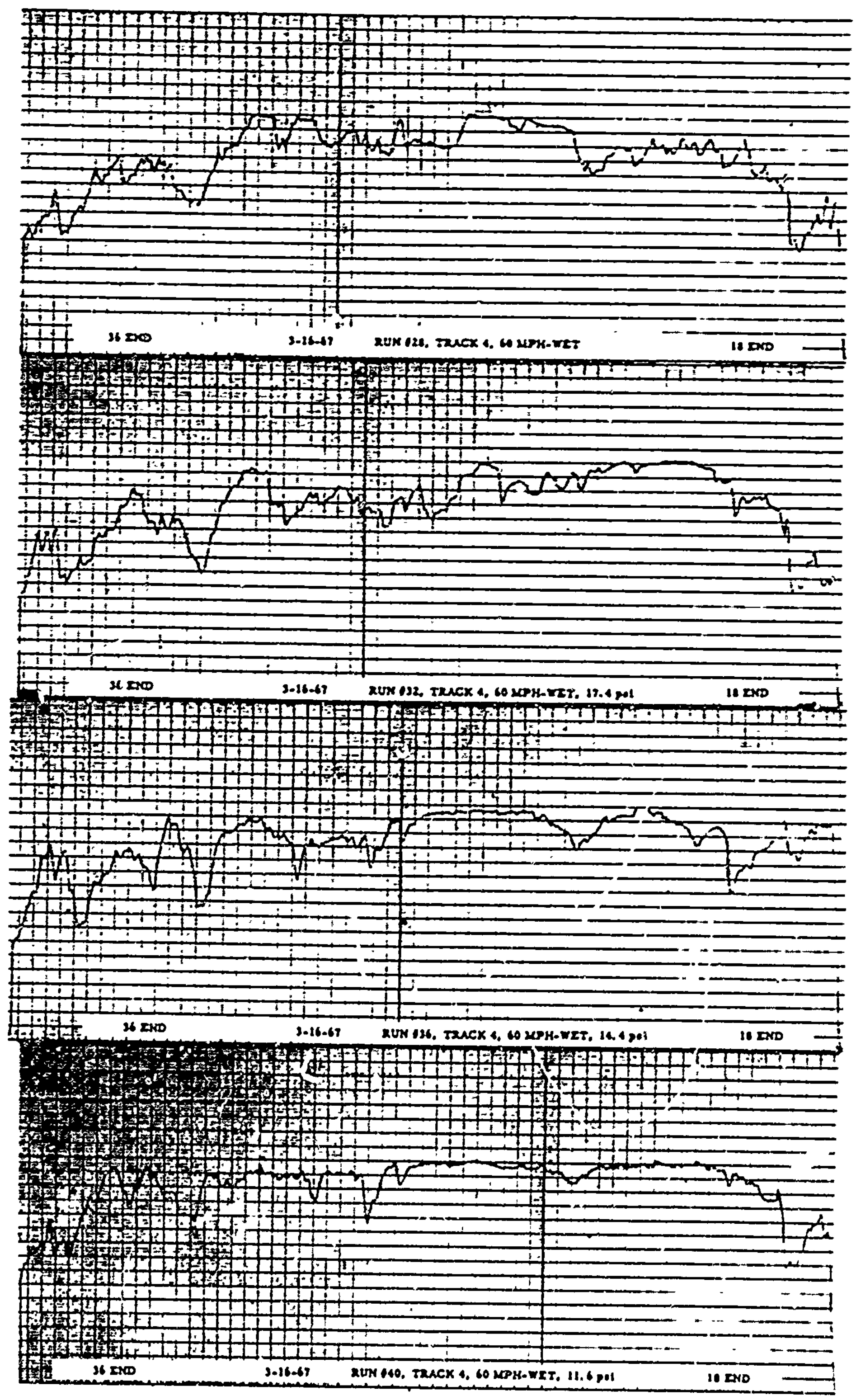
AFTER GROOVING - TRACK 2, EAST RUNWAY EDGE
WET TESTS



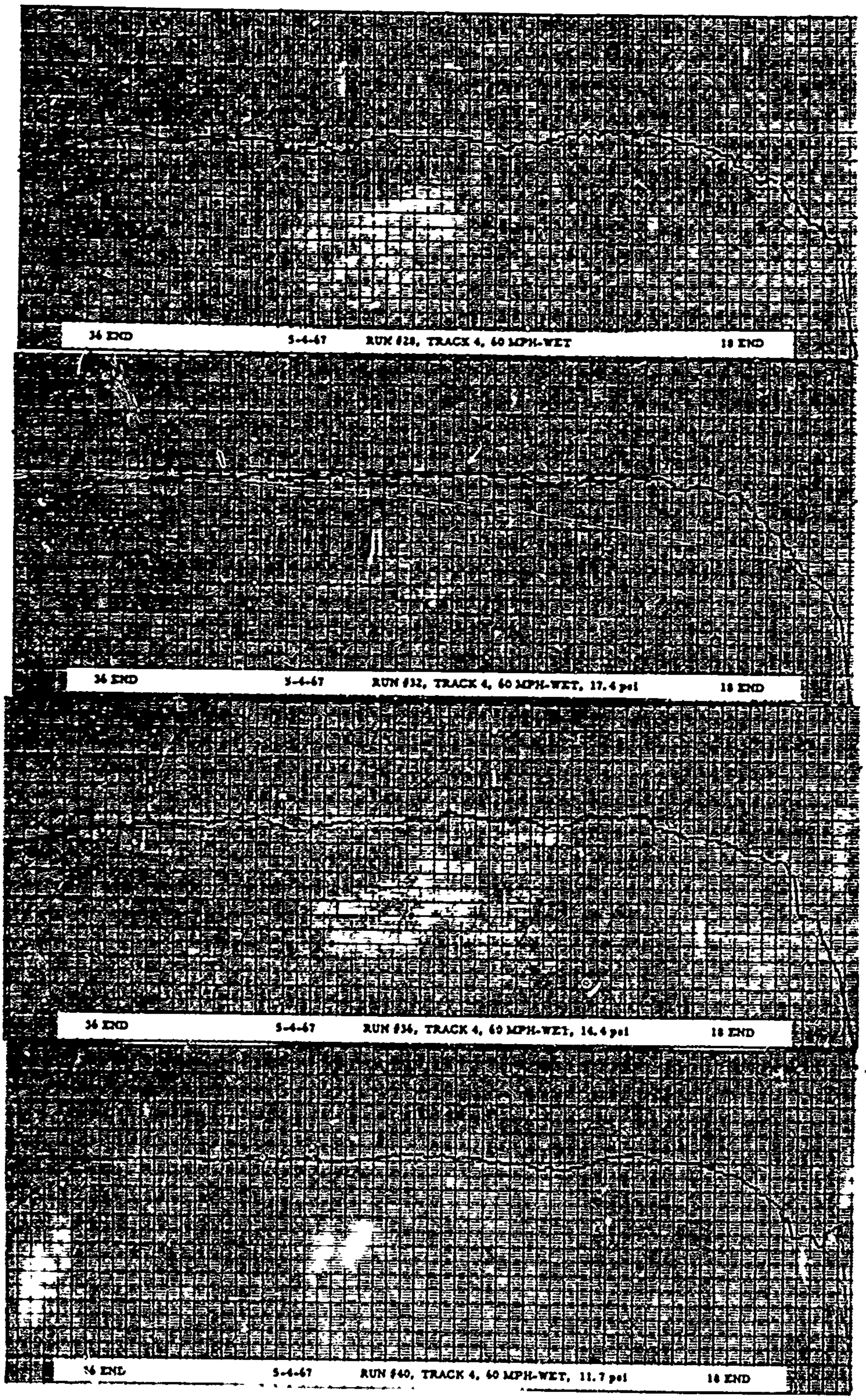
BEFORE GROOVING - TRACK 3, 25 FT. WEST OF CENTERLINE
WET TESTS



AFTER GROOVING - TRACK 3, 25 FT. WEST OF CENTERLINE
WET TESTS



BEFORE GROOVING - TRACK 4, 25 FT. EAST OF CENTERLINE
WET TESTS



AFTER GROOVING - TRACK 4, 25 FT. EAST OF CENTERLINE
WET TESTS