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ANALYSIS OF THE STANDARD USAF RUNWAY SKID RESISTANCE TESTS

MAY 1975

Final Report For Period July 1973 to December 1974

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AIR FORCE CIVIL ENGINEERING CENTER
(AIR FORCE SYSTEMS COMMAND)
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Data gathered during the Air Force Civil Engineering Center (AFCEC) standard skid resistance surveys conducted on 56 runways during the period November 1973 to September 1974 are analyzed. This report outlines the major milestones leading up to the present AFCEC program to determine runway skid resistance characteristics; refinements made to the program, description of equipment used to determine runway skid resistance characteristics, operating and test procedures and analysis of the skid measurement program.

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FOREWORD

During the period November 1973 through September 1974, the Air Force Civil Engineering Center Pavement Surface Effects Team (PSET) performed skid resistance/hydroplaning potential surveys on 56 runways at 39 Air Force installations/operating locations using the Air Force Weapons Laboratory developed procedures for conducting standard skid resistance tests (Ref 23). This report outlines the major milestones leading up to the present AFCEC program to determine runway skid resistance characteristics; refinements made to the program, equipment description, operating and test procedures, and analysis of the skid measurement program. A tabular summary of data and conclusions are included.

This report has been reviewed and approved.

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TABLE OF CONTENTS

APPENDICES PAGE

ILLUSTRATIONS

Figure		Page

TABLES

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TECHNICAL REPORT
AFCEC TR 75-3

MAY 1975

DIRECTORATE OF LABORATORIES
AIR FORCE CIVIL ENGINEERING
CENTER

ANALYSIS OF STANDARD USAF RUNWAY SKID RESISTANCE TESTS

I. PURPOSE: This study was undertaken to outline the present procedures of conducting the standard runway skid resistance tests, to summarize test results, to evaluate the present procedures for conducting the standard runway skid resistance tests, and to propose new methods for determining runway skid resistance characteristics.

II. BACKGROUND: Since November 1973, the Air Force Civil Engineering Center (AFCEC) has been measuring the skid resistance properties of airfields and this testing effort is an outgrowth of several skid resistance research, testing and operational endeavors. The problems of pavement slipperiness have been with us for years; yet researchers still do not have a complete understanding of the physical effects which result in pavement slipperiness. As a consequence, research and published reports continue to explore this phenomena. Technically, skid resistance (the antonym of slipperiness) is the force developed when a tire, which is prevented from rotating, slides along a pavement surface. Since the term does not have a precise meaning, it is used to generally describe the interface between a pneumatic tire and a pavement surface.

A. Hydroplaning Phenomena: Although research in pavement slipperiness began in the 1920s with studies at Iowa State College, the problem of aircraft skidding did not come to the forefront until the introduction of jet aircraft in the 1950s (Ref 1). The increased number of turbojet aircraft skidding accidents were the result of two major factors:

(1) higher takeoff and landing speeds

(2) greater number of adverse weather operations permitted by advances in all-weather airport and aircraft equipment.

Appendix A is a resume of recent Air Force and civilian aircraft accidents and incidents where wet runway operations were cited as a possible cause factor.

1. Dynamic Hydroplaning: In 1956, it was demonstrated on a tire treadmill apparatus that a tire in an unbraked condition will spin down to a complete stop on a flooded surface at some critical ground speed (Ref 2). The spin-down is the result of dynamic fluid pressures in the tire-ground contact area and if enough water is present, the tire will completely lift off the pavement surface. This condition is very serious and can result in complete loss of tire braking and steering capability. Research performed in the late 1950s and early 1960s indicated that tire dynamic hydroplaning or aquaplaning would occur at an approximate speed (V_p) of:

$$V_p = 9\sqrt{p}\text{, knots} \quad \text{(EQ 1a)}$$

$$V_p = 10.35\sqrt{p}\text{, mph (statute)} \quad \text{(EQ 1b)}$$

where the tire inflation pressure (p) is expressed in pounds per square inch. The above equation is based on three major assumptions: (1) that the average tire contact pressure (vertical wheel load/tire contact area) is approximately the same as the tire inflation pressure; (2) that the fluid density is approximately that of water; and (3) that the hydrodynamic lift coefficient developed by the tires on a fluid covered surface is approximately 0.7. Total tire dynamic hydroplaning speed is defined as the ground speed required for the average hydrodynamic pressure acting in the tire footprint region to equal the average tire ground bearing pressure, which is approximately equal to the tire inflation pressure (Ref 3). Associated with dynamic hydroplaning is wheel spin-down of a free rolling unbraked wheel. Wheel spin-down is the result of two phenomena: (1) the ground friction spin-up moment tending towards a zero value since the tire separates from the pavement surface and (2) the hydrodynamic center of pressure and resultant lift point shifting increasingly forward of the wheel axle as the ground speed increases, thus producing a wheel spin-down moment. At some high forward speed (normally very near the total dynamic hydroplaning speed of the tire) the wheel spin-down moment overcomes the wheel spin-up moment (drag forces) and the wheel begins spin-down to a complete stop (Ref 3). Once an aircraft tire has spun-down to a complete stop due to dynamic hydroplaning or braking, an unbraked wheel will not begin spin-up (ref 4) on a flooded runway until the aircraft ground speed has decreased to an approximate value of:

$$V_{p,s} = 7.7\sqrt{p} \quad \text{(EQ 2)}$$

where $V_{p,s}$ is the ground speed required for initiating a wheel spin-up. Therefore, prolonged locked-wheel skidding will continue until the aircraft has decelerated to this speed which normally can only be accomplished using aerodynamic drag devices such as spoilers, drag chute, reverse thrust, etc., and all brake pressure is released.

2. <u>Viscous Hydroplaning</u>:

a. Besides dynamic hydroplaning, another form of hydroplaning can result from fluid viscous (lubricating film) pressures, namely, viscous hydroplaning. Studies conducted by the National Aeronautical and Space Administration (NASA)(Ref 5) showed that when a surface was thoroughly saturated with water and then had all standing water removed so that the surface was only damp to the touch, loss in traction can result from viscous type hydroplaning down to very low ground speeds (see Figure 1). On relatively smooth textured runways, such as longitudinal burlap drag finish Portland cement concrete (PCC) surfaces, friction values obtained were nearly identical to those of wet ice. The studies indicated that increased pavement texture would drastically reduce the effects of viscous hydroplaning but that changes in tire vertical load and inflation pressures would not significantly affect the potential for viscous hydroplaning (Ref 5). Examination of Figure 1 suggests that friction coefficients on damp asphaltic surfaces are about 75 percent of the dry surface values, while friction losses on smooth finish PCC surfaces are nearly total.

b. In Figure 2, examples of the dynamic and viscous fluid pressures developed between the tire (smooth tire tread) and pavement contact area are shown for a free rolling and unyawing tire. The graph suggests that viscous fluid pressure rises significantly at lower ground speeds, which accounts for the influence of viscous hydroplaning down to very low speeds, whereas, dynamic fluid pressures increase with the square of the ground speed (Ref 6).

3. <u>Reverted Rubber Hydroplaning</u>: In the mid-1960s, NASA studied aircraft skidding accidents (Ref 5). They found that for numerous wet runway skidding accidents, the runway surface had white streaks and that the aircraft tires had reverted rubber patches. The patches were sticky, tacky and soft to the touch and the surface rubber appeared to have reverted to its uncured state. They discovered that when a wheel is prevented from rotating by applying brake pressure and the tire is forced to skid along a wet surface, the tire will develop tread rubber reversion in the tire footprint region and very low friction coefficient will result (even at speeds down to 5-10 knots). At this time, the phenomenon of reverted rubber hydroplaning is still not fully understood; however, for tire rubber to become reverted, temperatures on the order of 400°F-600°F must be generated.

4. <u>Influence of Water Depth</u>: Research by NASA

indicates that the depth of water present on a pavement surface has a significant role in determining the type of hydroplaning phenomena an aircraft tire will experience. Their studies indicate that an aircraft tire can experience various types of hydroplaning depending upon the thickness of water film (see Table 1, Ref 7). A Texas Transportation Institute (TTI) study (Ref 25) revealed that water depth on a pavement surface is primarily influenced by pavement texture, rainfall intensity, pavement cross slope and water drainage path length. For a "no wind" condition, the water depth, and thus the type of hydroplaning encountered, can be predicted using the following TTI equation:

$$d = 3.38 \times 10^{-3}\{(\frac{1}{T})^{-.11}(L)^{.43}(I)^{.59}(\frac{1}{S})^{.42}\}-T \qquad \text{(EQ 3)}$$

where: d = water depth, in
T = average pavement texture depth, in
L = drainage path length, ft
I = rainfall intensity, in/hr
S = pavement cross slope, ft/ft

The important conclusions drawn by TTI are: (1) increasing surface texture resulted in a decrease in water depth for a given rainfall intensity, cross slope, and drainage length, and this effect was more pronounced at the flatter cross slopes and lower rainfall intensities; (2) increasing pavement cross slope resulted in reduced water depths and this effect was very significant at the flatter cross slopes where a slight increase in cross slope resulted in a pronounced reduction in water depth; i.e., for a rainfall intensity of 1.5 in/hr, a surface texture of 0.003 inches, and a drainage length of 24 feet, increasing the cross slope from approximately 0.5 percent to 2 percent decreased water depths by 62 percent; and (3) greater drainage lengths increased water depths; however, the rate of increase in water depth became smaller as drainage lengths increased.

B. Tire Properties: Although most of the recent literature on aircraft skid resistance is concerned with the three types of hydroplaning, several other important properties of tire pavement interaction must be briefly addressed so the reader of this report will have a basic understanding of the operating principals for the three types of measuring devices to be discussed (diagonally braked vehicle [DBV], Mu-Meter and Swedish Skiddometer).

1. Brake-slip: Brake-slip is defined by the equation:

$$S_b = \frac{\omega - \omega_t}{\omega} \qquad \text{(EQ 4)}$$

where: S_b = slip ratio, braked, dimensionless.

ω = angular velocity of a freely rolling or unbraked tire, which corresponds to the velocity of the vehicle.

ω_t = angular velocity of the slipping tire or torqued wheel (braked wheel).

For a free rolling wheel, the slip ratio is zero and for a locked wheel, the slip ratio is one. Figure 3 shows that the maximum braking friction coefficient develops when the brake slip ratio is approximately 0.15-0.20. Therefore, the maximum deceleration (minimum stopping distance) for an aircraft occurs when the slip ratio is held in this range (incipient skid), and not when the wheels are locked, which frequently occurs during emergency situations ("standing" on the brakes). The Swedish Skiddometer and the DBV operate on the principle of brake-slip. The Swedish Skiddometer operates at a constant slip ratio near the incipient skid while the DBV operates at a slip ratio of 1.0.

2. Cornering-Slip: Cornering or side-slip occurs when a slip angle develops between the direction of motion and the plane of the tire (see Figure 4). The cornering slip friction coefficient (μ_S) is defined as:

$$\mu_S = \frac{F_C}{F_V} \quad \text{(EQ 5)}$$

where: F_V = wheel load.
F_C = cornering slip resistance or force.

Two important tire characteristics are associated with cornering slip. First, as the brake slip ratio increases (braking), the cornering capability of the tire is decreased and, if the wheel locks, steering capability or directional control is entirely lost. Secondly, for a yawing unbraked tire, the maximum cornering slip coefficient is produced at some critical yaw angle (see Figure 5). The Mu-Meter (discussed in Section III) operates in the side-slip mode.

3. Finally, in order to complete the description of tire properties, the relationship of contact pressure (tire inflation pressure) and tire temperature on braking friction coefficient must be understood. Figure 6 shows the relationship of tire temperature and contact pressure on a dry surface. Lower tire inflation pressures raise friction coefficients and increased tire temperatures lower friction coefficients (Ref 8).

C. Alleviation of Low Friction:

1. Several methods have been tried to alleviate the problem of low friction, e.g., improved aircraft systems and pavement alterations. One rather novel scheme was tried in 1958 when air

nozzles were placed in front of aircraft tires and high-pressure air was used to displace the surface water. Further testing by NASA in 1964 showed that a beneficial effect was derived by expelling bulk water from the tire footprint area by high pressure air blasts (Ref 9); however, this air jet stream was not feasible due to aircraft weight penalties and bleed air requirements. Also the air jet system could not expell the residual water film; thus, viscous hydroplaning potential was not significantly reduced on relatively smooth finish pavements. Although the air jet system was abandoned, other aircraft systems have been tested and introduced into the Air Force inventory to improve braking performance, e.g., aircraft tire and antiskid systems. Recently the Air Force completed the F-4 Rain Tire Performance Flight Test Project (Ref 24) at Edwards AFB (Jan 73-Apr 74) and this test program proved that modifying the main tire tread can increase the braking friction coefficient by as much as 25 percent and installing an improved antiskid system (Mark III) can decrease aircraft stopping distance as much as 10 percent on the F-4. Generally speaking, braking efficiency is far more dependent on the characteristics of the pavement surface than on the type of tire or its tread design. As a result, considerable research effort has been undertaken to improve the skid resistance properties of pavements. Since pavement texture plays a significant role in determining the relative slipperiness of a pavement, several techniques have been developed to improve surface texture, thereby allowing water to escape from between the tire footprint and the pavement. One such technique is runway grooving. The British developed the grooving techniques and utilized transverse grooves on their military asphaltic concrete runways as early as 1956. In the 1960s, NASA evaluated the performance of various grooved configurations on the Langley Landing-Loads Track (Ref 1). Their data indicated that pavement grooving resulted in: (1) no significant increase in aircraft tire rolling resistance; (2) substantial improvement in aircraft tire cornering force or steering capability; and (3) greatly improved aircraft stopping performance on wet pavements. The 1-inch pitch X 1/4-inch width X 1/4-inch depth groove pattern performed better than any other configuration tested.

2. During 1966-67, at the NASA Wallops Station research runway, tests were conducted to determine the effects of runway surface grooves on an F-4D and a Convair 990. Nine different surface finishes were tested (grooved and ungrooved canvas-belt drag and burlap drag finish concrete, grooved and ungrooved small and large aggregate asphalt, and gripstop transition surface). Test data (Ref 1) substantiated the results obtained previously at the Langley Landing-Loads Track in that grooving caused a significant increase in aircraft braking capability on wet surfaces (see Figure 7). As a

result of these groove tests, several civilian and Air Force runways were grooved. Although these tests confirmed the obvious merits of runway grooving, many unanswered questions remained since the Wallops Station evaluation was conducted on a relatively short test section (3,450 ft test section on an 8,750 ft long runway).

D. Project Combat Traction: In 1969, the Air Force and NASA jointly sponsored Project Combat Traction to further examine the benefits and disadvantages of different pavement surfaces and treatments for a full length runway (Ref 10). The objectives were to: (1) assemble a priority listing of Air Force runways requiring corrective measures to prevent skidding/hydroplaning accidents; (2) determine the optimum runway surface for Air Force use; (3) establish and validate a procedure for predicting aircraft stopping distance for various surfaces by using a ground vehicle as a means of assessing surface condition; and (4) investigate the merits of a water-depth warning system or other measuring system. During the period July 1969 to March 1970, the Combat Traction Team tested approximately 50 military and civilian runways. Since this program required a ground vehicle to assess runway conditions, a ground measuring system had to be selected prior to testing. The diagonal braking system was selected since the 1968 NASA studies at Wallops Station showed that the DBV correlated well with aircraft stopping performance (Ref 1). Three vehicles from Great Britain and 18 vehicles from the United States had participated in the Wallops Station skid correlation study. The US vehicles included six two-wheel braking trailers built according to ASTM (E 274-65T) skid trailer specifications, a single-wheel braking trailer, a constant-slip three-wheel trailer (Swedish Skiddometer), two DBVs and five four-wheel braking vehicles (Tapley Meter and James Brake Decelerometer [JBD]). The three British friction measuring vehicles were a Miles Trailer, a Mu-Meter and a Heavy Load Friction Vehicle (Juggernaut).

1. The Combat Traction effort investigated the responses of the C-141 on wet, snow and ice covered runways of several pavement types and compared them with those of the DBV as well as those of the Air Force Runway Condition Reading (RCR) vehicle from each test base to determine these systems' capability of predicting aircraft stopping distances. Since the RCR system is currently being used to estimate aircraft landing performance on ice and snow covered USAF runways, a discussion of the RCR system is included in Appendix B. Analysis of the Combat Traction data resulted in several important conclusions:

a. The RCR system was not an adequate method for predicting aircraft stopping distance on wet runways, but the system could predict aircraft stopping distance on ice and snow covered runways.

b. A diagonally braked vehicle could predict aircraft distance and crosswind limitations for wet, ice and snow covered runways and could be used to measure runway slipperiness.

c. Grooved pavements and porous asphalt surfaces were the most effective surface treatments investigated for alleviating surface flooding and wet runway slipperiness.

d. Aircraft stopping distance generally increased with increasing water depth on the runway.

Prior to the publication of the final Combat Traction report (Nov 1970) several meetings were held by NASA and several Air Force agencies (Aeronautical Systems Division [ASD], Air Staff Operations, Safety and Civil Engineering) to formulate an Air Force position on the RCR system and follow-on skid resistance programs. As a result of this meeting, the Director of Safety issued ALSAFECOM 16/70 message (see Appendix C) which invalidated the RCR measurement system on wet runways. The message directed that an RCR of 12 for wet asphalt runways, and RCR of 9 for wet concrete runways and an RCR of 6 or 7 for portions of the runway where heavy rubber deposits are present would be used when the runway was reported wet. However, this message was rebutted by operational commanders since it imposed a severe penalty on aircraft operations from wet runways and it was subsequently withdrawn.

2. A meeting was held in September 1970 with Air Staff Civil Engineering, Operations, and Safety and Systems Command personnel to decide on the approach to the Air Force traction program and to determine procedures for predicting stopping distance of aircraft on wet runways. As a result of this meeting, the responsibilities for determining runway skid resistance were divided between AFCEC and the Air Force Weapons Laboratory (AFWL). AFWL was directed to conduct further runway skid resistance measurement research and the AFCEC was tasked to determine the skid resistance characteristics of Air Force runways not tested in the Combat Traction program with the NASA DBV. This working group also prepared a joint Operations-Safety message (ALMAJCOM 1494/70, 132352Z Nov 70, see Appendix D) which directed: (1) Combat Traction data would not be used pending publication of the final report; (2) the requirements of AFR 60-13 that applied to measurement of wet runway RCRs were deleted; (3) RCR values for wet runway operations recommended in applicable aircraft dash-one handbooks would be used when wet runway conditions existed; (4) relieved NASA from further requirement to respond to

requests for Air Force runway traction tests; and (5) delegated the responsibility for the continuation of the Air Force runway skid resistance measurement program to the AFCEC (designated Project Concrete Traction).

E. Project Concrete Traction: Skid resistance measurements were made on 75 runways at 48 Air Force installations between January and September 1971. Measurements were made on the primary and secondary touchdown areas (rubber deposit areas) and on the interior portion of the runway. NOTE: In Combat Traction, only the central interior (nonrubberized area) portion of the runway was tested. The validity of test results of the Concrete Traction program was questionable since adequate control of water application was not achieved. Water was randomly applied to each test section after which the water depth was measured by the NASA developed water surface depth instrument (see Appendix E). However, since a pavement surface is not homogeneous, several different readings can be measured by the NASA water depth gauge in a relatively small sampling area. Thus water depth was not accurately determined and standardization between tests was not achieved.

F. Project Combat Traction II: In 1971 a two phase "Joint Federal Aviation Agency (FAA)-USAF-NASA Runway Research Program" was initiated which is commonly called Combat Traction II (Refs 11 and 12). The objectives of the program were:

(1) Phase I - Determine if a relationship exists between the B-727 and the DC-9 aircraft, and the DBV and/or the Mu-Meter for predicting aircraft stopping distances.

(2) Phase II - Conduct a computer study of several aircraft antiskid braking systems to ascertain which parameters have major influences in aircraft/ground vehicle correlations for determining aircraft stopping distances.

The Phase I testing results serve as the basis (pavement rating parameters) for rating in the present AFCEC skid resistance/hydroplaning survey program. In October 1971, a B-727-100 aircraft was tested on six different runways (NASA Wallops Station, Houston International Airport (IAP), Edwards AFB, Seattle-Tacoma IAP, Lubbock Regional Airport and John F. Kennedy IAP). Analysis of the B-727 tests indicated that the antiskid braking system allowed wheel lockups to occur over a wide range of operating conditions. Wheel lockups occurred during all wet stops on smooth Portland cement concrete (PCC) pavements resulting in excessively long stopping distances due to viscous and reverted rubber hydroplaning. The data showed that for the B-727, wheel lockups were likely when runway conditions corresponded to a DBV stopping distance ratio (wet/dry ratio) equal to 2.05 or greater and a Mu-Meter reading of 0.47 or less (see Figures 25 and 26). Figure 8 graphically illustrates the importance of reverse thrust and runway grooving. Testing of the DC-9 ascertained that no wheel lockups would occur, but excessive long stopping distances (see Figure 9) were encountered which exceeded the wet stopping distance prescribed by Federal Air Regulation (FAR) 121.195 (see Appendix F).

G. AFWL Skid Resistance Measurement System: As previously noted, AFWL was tasked in 1970 to develop a skid resistance system that would accurately evaluate runway skid resistance/hydroplaning characteristics. Their research was aimed toward evaluating available skid resistance measuring equipment and developing a standard procedure for determining runway skid resistance properties. The AFWL skid resistance measurement system (Ref 23) is an outgrowth of the Project Combat Traction program and the ground friction measurement correlation studies held at NASA Wallops Station in 1968. The hydroplaning potential rating system is predicated on Combat Traction II, Phase I data.

III. TEST PROGRAM: The AFCEC standard skid resistance tests are conducted in accordance with the procedures developed by AFWL (Ref 23) except that several procedural refinements have been made.

A. Basic Test Equipment: The standard skid resistance test uses four basic pieces of equipment to evaluate runway skid resistance/hydroplaning characteristics: (1) diagonally-braked vehicle (DBV); (2) British developed Mu-Meter; (3) slope measurement device; and (4) water application equipment. All skid resistance measurement equipment was transferred from AFWL to AFCEC in July 1973. Several modifications have been made to the AFWL equipment and equipment changes will be discussed in this section of the report.

1. Diagonally Braked Vehicle (DBV): The AFCEC DBV is a 1971 Plymouth Satellite station wagon (see Figure 10) which has been modified to permit braking of one front wheel and the diagonally opposite rear wheel, allowing the other diagonally opposite wheels to roll freely (unbraked). The free-rolling wheels provide directional stability and control when the diagonal set of wheels are locked in a skid. In addition to braking modifications, the DBV is specially instrumented to record the stopping performance of the vehicle during a locked wheel skid.

a. Braking System: The modified braking system of the vehicle permits three types of braking - four wheel braking, and two combinations of diagonal braking (see Figure 11). The desired mode of braking is selected by the vehicle operator and is obtained by hydraulic shutoff valves. The station wagon was originally equipped with a double-piston master cylinder; therefore, a T-connection had to be installed between the cylinder and the selector valves to insure equal pressure to all brakes. From the selector valves, lines were installed to the wheel brakes.

b. Vehicle Tires: All skid resistance tests are conducted with ASTM bald-tread tires, 7.50 X 14 (specification E249-66), that are installed on the diagonally braked set of wheels. The ASTM bald or slick tires are inflated to a pressure of 24 psi. These special test tires help insure repeatability of data and eliminate the effects of tire-tread design on braking performance. The unbraked wheels are equipped with conventionally treaded tires to assist in maintaining directional control while accelerating and braking on wet pavement surfaces.

c. Instrumentation: Two primary instrumentation systems are used to collect and record vehicle speed, stopping distance and deceleration. The instrumentation system is graphically depicted in Figure 12.

(1) Fifth Wheel Assembly Instrumentation: The fifth wheel assembly (Track test - Laboratory Equipment Corp [LABCO]) is an instrumentation system used for determining the speed of the vehicle at time of wheel lockup and during the skid, and measuring the distance transversed by the DBV during the skid. The fifth wheel assembly consists of a bicycle type of wheel (Bendix Elipse, type K hub with 120-gauge spokes and heavy-duty rim; pneumatic tire, 26-inches by 2.125-inches, see Figure 13) which is attached to the rear bumper; a direct drive wheel actuator; and electronic digital speed and distance readout units (see Figure 14). The direct drive wheel actuator provides the signal for both the speed and distance readout units. The actuator is a magnetic actuated read switch that gives one pulse per foot traveled by the wheel. A pressure switch actuated by brake pressure and supplied by a 12 volt power source provides an input signal to the speed and distance readout units at the time of brake application. This signal initiates the hold system of the velocity readout unit and initiates the distance readout counter; thus, the DBV speed at the time of brake application (wheel lockup) and distance transversed can be determined from the displays on the digital readout units. The power requirement for each digital readout unit is 9.5-17 volts DC (12 volts normal) and 0.95 amperes (1.2 amperes maximum). The units are sensitive to high level electromagnetic fields such as engine ignition noise due to broken spark plug wires.

(2) Recorder: A Model TR-444 Techni-Rite four channel direct writing analog recorder is installed behind

the two front seats to record speed, distance transversed, and deceleration of the DBV during test runs. The data recorded by the analog recorder upon receipt of the DBV from AFWL included only vehicle deceleration and total brake pressure supplied to the brake selector valve assembly. Brake pressure data monitoring was eliminated when AFCEC acquired the capability of recording speed and distance. The four-channel recorder (see Figure 15) is equipped with a heated stylus for each channel for recording data traces on heat-sensitive paper. The recorder consists of a main-frame and four plug in preamplifiers. Recorder controls provide for power on/off, chart speed (2.5, 10 or 20 mm/sec used for tests), trace width, gain and positioning. A digital to analog (D-A) converter is installed in the DBV so that records of velocity and distance measurements versus time (chart speed) can be registered. Input signals to the D-A converter come directly from LABCO electronic digital speed and distance readout units and output signals from the D-A converter go directly to the input channels on the strip chart recorder. Two linear accelerometers (Setra Model 100 ± 1 g) are mounted in the vehicle for the purpose of determining the point of DBV brake application and roll back (stop point determination) on the recorder chart paper. The excitation power for the accelerometers is furnished by a Power Mate Corporation Model UNI-76 DC power supply (115-VDC input, and 0-34 VDC/0.5 amp regulated output). The two accelerometers provide inputs to two channels of the recorder. 115 VAC power is supplied by a inverter manufactured by Trippe Manufacturing Co., Model PV 500FC, to operate the recorder, D/A converter and accelerometer power supply.

d. Safety Equipment: A roll bar fabricated from two pieces of 1-5/16 inch diameter stainless steel tubing is installed behind the front seats of the vehicle. The DBV operators are secured to their seats by aircraft shoulder harness, inertial reel and lap belt system. A Class BC, five pound fire extinguisher and crash helmets are provided to further protect the operators.

e. Operation: The skid resistance characteristics of a runway are defined by computing the ratio of the wet to dry stopping distance of the DBV. The stopping distance is measured from brake application at 60 mph in a diagonally locked wheel mode. Under the AFWL concept of operation, to insure rating standardization between airfields, the standard dry stopping distance of the vehicle for all pavement conditions is taken as 300 feet for computation of the wet/dry stopping distance ratio (SDR). All DBV tests are conducted in accordance with the DBV Operations Checklist (see Appendix G). During a test run, the driver accelerates the vehicle to a speed slightly in excess of the desired test speed (60 mph) and shifts the transmission to the neutral position just prior to the designated brake-on point. Experience has shown that if the transmission is shifted to neutral at a speed of 63 to 64 mph at a distance of 300 feet from the brake-on point, the DBV will decelerate to a speed of 60 mph at the brake-on point. The test wheels must remain in a locked mode for the duration of the skid to insure validity of the test. Normally, when the wheels are locked, a slight torque on the steering in the direction of the locked wheel is experienced. In evaluating the pavement surface traction, the wet/dry stopping distance ratio (SDR) reflects the degree of pavement slipperiness (see Table 2).

2. Mu-Meter: The following is an excerpt from the M.L. Aviation Co. Ltd. Instruction and Service Manual for the M.L. Mu-Meter.

a. Description: The Mu-Meter (see Figure 16) is a lightweight (540 lbs), three wheel trailer unit that is towed by a standard vehicle (see Figure 17) fitted with a standard towing ball and a remote readout unit, stowed in and operated from the cab (see Figure 18). The trailer unit is comprised of a triangular frame on which are mounted two friction measuring wheels (size 16 X 4 X 6 ply), a rear wheel which drives the recorder and stabilizes the machine, a ballast, a load cell, and a recorder mechanism (see Figure 19).

b. Operation: When the Mu-Meter is towed over the test surface, the toed-out (at approximately 15 degrees included angle), smooth tread, measuring wheels tend to move apart, and this force is sensed by a load cell mounted between the fixed and pivoted side frame members on which the wheels are mounted. The load cell feeds this data to the recorder by hydraulic pressure through a flexible interconnecting tube. The distance traveled is transmitted by the rear wheel to the recorder roll chart drive mechanism (one inch on the roll chart paper equates to 450 feet traveled by the Mu-Meter). The recording apparatus includes an integrator which provides the average friction value of the recording over any distance. The Mu-Meter thus measures a component of side-force friction coefficient generated between the test surface and the smooth tread tires. All test runs are conducted in accordance with the Mu-Meter Operations Checklist (see Appendix H). All measurements are made at a constant speed (normally 40 mph) and the event marker bulb located in the cab of the tow vehicle is utilized to remotely mark the roll chart paper so that the beginning and end of a test section as well as the DBV brake-on and stop locations can be determined. In evaluating the pavement surface skid resistance properties, the average friction coefficient reflects the degree of pavement slipperiness (see Table 2).

c. Calibration Procedures: Functional checks are performed prior to each day of testing, after each change of tires, and when sudden unexpected changes occur, to insure correct friction values are being transmitted from the load cell to the recorder mechanism. AFWL recommended that the tires be "warmed up" prior to any calibration check and the tire pressure reset to the calibration pressure (10 psi) after tire warm up. However, the M.L. Aviation Co. Ltd. recommended that such procedures be discontinued since erroneous readings result. They reported that as the tires become heated, the friction coefficient will decrease (see Figure 6) but the friction loss due to temperature rise is compensated for due to a corresponding rise in tire pressure; thus, the Mu-Meter will record the same friction coefficient over any surface as long as it is not continuously operated on a dry surface in excess of 20 miles. Therefore, all calibration checks must be performed at ambient temperatures (above freezing) and tire pressure not changed after calibration. The procedures for calibrating the Mu-Meter are contained in Appendix H.

3. Slope Measurement Device: A 10 foot X 3 in X 3/4 inch rectangular bar with five machinists levels attached is used to determine the transverse and longitudinal runway slopes to the nearest 0.1 percent (see Figure 20). Since the relative slipperiness of a pavement is related to the depth of water held on a pavement surface, slope measurements are taken along the entire runway to reflect drainage characteristics.

4. Water Application Equipment: Probably the most important and distinctive feature of the AFCEC skid resistance measurement program is the manner in which water is applied. Three equipment items are utilized to apply water to each test section and insure water application standardization:

a. Water Truck: A water tanker truck employed by the base fire department, usually an F-6 or F-7 Runway Foamer unit, is normally used to artificially wet each test section. The base provided water tractor/trailer unit must conform to the following specifications:

(1) A water tank capacity of at least 2,500 gallons is necessary in order to wet a 2,000 foot by 10 foot test section. NOTE: If an F-6 or F-7 Runway Foamer unit is not available, then a 1,500 gallon water distributor is utilized; however, only a 1,200 foot test section can be wetted with this equipment.

(2) The water pump engine should operate as a separate unit, independent of the tractor drive train, and should have either a dependable tachometer or discharge pump pressure gauge to determine constant water flow output.

(3) A shutoff valve located between the water

pump and the AFCEC spray bar is required so that the pump can be stabilized at a constant static pressure before commencing a water lay.

(4) The water truck should have a capability to insure that foaming agent does not contaminate the test water.

(5) The tractor unit should be equipped with an accurate tachometer or fifth wheel assembly for determining precise operating speed. A portable electronic tachometer can be provided by the team in the event the tractor's tachometer is inoperative. A 100 rpm division engine tachometer has been found to be the best system for maintaining constant tractor speed under changing load conditions.

(6) The tractor unit must have a gear/axle ratio which enables the driver to maintain a constant speed (normally 5.5 mph) under changing load conditions.

b. Spray Bar: A special water spray bar has been fabricated by AFCEC to insure standardized water application on all test sections (see Figure 21). The majority of the base fire departments were found not to have spray bars that would uniformly wet each test section; e.g., water would discharge mainly from one side of the spray bar. Therefore, AFCEC fabricated a water spray bar from 2 1/4 inch copper tubing with several 1 1/2 inch by 1/2 inch slots cut in the bottom to permit water discharge at low pressures and high volumes.

c. Flow Meter: A 300 gpm fuel flow meter (see Figure 22) measures the amount of water discharged by the water truck. The flow meter has been an invaluable aid to the team since it shortens the time required to calibrate the water truck and is utilized to insure the correct quantity of water has been applied to each test section. Two and one-half inch fire department hose connections have been welded to the inlet and outlet ports of the flow meter to permit connection of the flow meter to fire department equipment.

B. Testing Sequence: The following outlines the events that must take place prior to and during the testing program:

1. Priority of Base Selection: Prior to each fiscal year, HQ USAF/PREE requests that each MAJCOM submit a priority listing of their bases for skid resistance testing. From the MAJCOM listings 30 bases are selected by HQ USAF/PREE for skid resistance testing. All adjustments to the priority listing and scheduling must be approved by HQ USAF/PREE.

2. Base Testing Sequence: AFCEC determines the base testing schedule. Five to six deployments are scheduled for

each fiscal year and test bases for each deployment are normally geographically grouped.

3. Notification of Base Testing: Prior to each deployment, the AFCEC notifies the MAJCOMs of the proposed deployment schedule and support requirements. MAJCOM and base support requirements are outlined in the operations plan (see Appendix I) attached to the notification letter.

4. Predeparture Preparations: Prior to shipment of the equipment, the Pavement Surface Effects Team (PSET) insures that all equipment is in operational condition and properly packed (see Equipment Requirements Checklist, Appendix J) for overland or air shipment. MAJCOMs are responsible for funding all transportation requirements.

5. Base Testing Sequence: The following outlines the sequence of events when the PSET arrives at a base and during the testing program:

a. Before Testing: Normally during the afternoon prior to the test day, the following actions are accomplished by the PSET chief:

(1) Brief base personnel on project.

(2) Insure vehicle maintenance support arrangements are made (tire changing/mounting facilities for standard tubeless tires, premium gasoline for the DBV and Mogas for pickup truck).

(3) Insure arrangements for a flightline driver (normally the project officer) and vehicle (equipped with a radio for communications with the tower) are accomplished. NOTE: The flightline vehicle is used by the team chief for controlling all testing operations.

(4) Insure a secure, dry, clean, and enclosed area is provided for calibrating the test equipment, preferably near the flightline. Normally a fire department stall is utilized since the team works closely with personnel of the fire department.

(5) Obtain one copy of the runway layout plan detailing the transitions between pavement types, runway historical data, and weather data.

(6) Insure arrangements are made to remove runway barriers as soon as the runway is closed.

(7) Insure a NOTAM is dispatched, closing the test runway during daylight hours (two and one-half hours for

dry testing and four hours for wet testing).

(8) Insure arrangements for two personnel to operate the water application truck are made and that the water application truck is operationally ready for testing.

(9) Brief team personnel and make team assignments.

b. <u>One Hour Before Testing</u>:

(1) The two team members assigned to the DBV complete the DBV operational checklist (see Appendix G) and assist in mounting the AFCEC spray bar onto the rear of the water application truck.

(2) The DBV data recorder briefs the water application crew (driver and pump operator, see Appendix L, Form 1).

(3) The two team members assigned to the pickup truck (Mu-Meter) complete the vehicle operational checklist (see Appendix H), calibrate the Mu-Meter and assist in mounting the AFCEC spray bar onto the water truck.

(4) A final check is made to insure all radios are operational, the barrier crew is prepared to remove barriers and the flightline vehicle is made available at least 20 minutes prior to testing effort. Brief the flightline vehicle driver on his responsibilities (remain with Mu-Meter and monitor applicable tower frequency for runway clearance instructions).

c. <u>Dry Testing (2 1/2 hours)</u>:

(1) The PSET chief, accompanied by the DBV driver, selects and marks all test sections. Distance measurements are provided by the DBV distance digital readout units. Figure 23 shows a typical layout of test strips on a runway. The following procedures should be utilized when laying out test sections:

(a) The PSET chief makes a full length inspection of the runway surface to determine and categorize the extent of the primary and secondary touchdown rubber deposits, and locate the transitions between different pavement materials and intersection of runways and taxiways.

(b) The lateral displacement of the test sections is determined. The lateral displacement will vary according to the base mission (landing gear configuration) and should encompass the heaviest rubber buildup area. Normally the center of each test section is displaced 8 feet from the marked centerline so that the marked centerline does not influence DBV stopping performance.

(c) The primary and secondary rubber deposit test sections should encompass the heaviest rubber buildup areas, and accordingly, the longitudinal location of these test sections depends on location of rubber deposits Normally at TAC and ATC bases (predominately fighter and trainer type aircraft operations), the significant rubber buildup begins approximately 500 feet from the runway threshold, whereas, at MAC and SAC bases (transport and bomber type aircraft operations) the significant rubber deposits begin approximately 1,000 feet from the runway threshold and extend for several thousand feet. At least one test section should be tested at each end of the runway in order to determine the skid resistance characteristics of the primary and secondary touchdown/rubber deposit areas, and the single test section should be located on the upwind side of the marked centerline. For standardization purposes only, the primary touchdown rubber deposit area test sections are designated sections "A" and "B" and the secondary touchdown test sections are designated "E" and "F".

(d) The central interior test sections (designated sections "C" and "D") should be sited to position the first interior test section closest to the primary approach end and on the upwind side of the marked centerline. Normally, only one test section is required for runways less than 8,000 feet long.

(e) The edge test section (designated section "G") should be laterally displaced from the interior test section in order to determine the traction characteristics of a nontraffic area. It is important to insure that the edge test section and central interior test section are constructed of the same pavement material to permit a valid comparison of the skid resistance properties. NOTE: Asphaltic concrete (AC) runways have nontraffic areas that are sometimes constructed of different material types or aggregate gradations than the interior portions of the runway.

(f) The dimensions of each test section are 2,000 feet long by 10 feet wide, when the water capacity of the base furnished water tank is 2,300 gallons or greater. If only a 1,500 gallon capacity tanker is available, the test section length is reduced to 1,200 feet. The DBV brake-on-point should be 300 feet from the beginning of the test section (50 feet when sections are reduced to 1,200 feet). For standardization purposes the beginning of each test section is marked with spray paint using a single line symbol, the DBV brake-on-point is marked with an arrowhead symbol, and the end of the test section is marked with a circular symbol (see Figure 24).

(g) In the event the runway is construed of several surface materials (e.g., PCC touchdown areas and asphaltic concrete interiors), test sections should be laid out in such a manner that data will be obtained on as many surfacing materials as possible. In addition, if drainage conditions differ significantly between different portions of the runway, then test sections should be located to examine all extremes of the runway.

(2) The Mu-Meter operators make transverse and longitudinal slope measurements utilizing the following procedures:

(a) Transverse slope measurements encompass the normal aircraft wheel path area, 20 feet each side of the marked centerline. Measurements are taken abreast of each runway remaining distance marker (1,000 foot intervals) and at each runway threshold. In the event the transverse slope measurements are 0.5 percent or less, supplemental measurements are made at the midpoint between the runway remaining distance markers (500 foot intervals). Measurements are also taken in the edge test section abreast of the applicable runway remaining distance markers.

(b) Longitudinal slope measurements are taken along the marked runway centerline at the same locations as the transverse slope measurements.

(c) Care should be taken to insure protruding portions of the runway surface such as joint seal material do not influence the slope measurements.

(3) DBV dry stops are accomplished after all test sections have been selected. Dry stops are accomplished in as many sections as possible and the tires are checked after each run for excessive wear. Normally two to six dry stops can be accomplished before tire changing is required. Dry stops will be accomplished in accordance with the following priority sequence: primary rubber deposit test section, central interior test section closest to the primary touchdown area, secondary rubber deposit test section, edge test section, and central interior test section closest to the secondary touchdown area. A single traffic cone is used to mark the DBV brake-on-point and it is placed abreast of the brake-on-point (driver's side). All test runs are accomplished in accordance with the DBV operations checklist.

(4) The water application truck is calibrated

to assure that 0.1 inch of water is applied as the truck passes abreast of any given point. Calibration procedures follow:

(a) The DBV data recorder insures that the AFCEC spray bar is properly attached to the rear of the water truck (12 inches above ground level and centered on truck) and he proceeds with the water truck crew to the most suitable flightline water servicing point. The flow meter is connected to the service hydrant and sufficient hose is connected to the outlet side of the flow meter for servicing the water truck.

(b) The pump operator starts the pump engine and discharges water through the spray bar at a rate that will not cause water to spray six inches past each end of the spray bar (eight feet). Note the pump discharge pressure reading and/or engine tachometer reading. The pump engine reading(s) cannot be allowed to fluctuate, in order to maintain constant water flow through the spray bar.

(c) Reservice the water tank to full capacity before the start of each calibration run.

(d) Proceed to the runway. The DBV paces the water truck at 5.5 MPH and the driver notes the tractor's tachometer setting for maintaining a speed of 5.5 mph.

(e) As soon as the desired tachometer setting is determined, the DBV proceeds to the rear of the water truck and the pump engine is throttled at a setting slightly above the pre-established pump engine setting(s). The DBV signals the pump operator by flashing the DBV headlights to begin discharging water through the spray bar. The DBV operators measure the actual width of the water lay as the water truck transverses the calibration area.

(f) Just prior to 2,000 feet of water discharge, the DBV driver signals to the pump operator to shut-off the water by flashing the DBV headlights. The DBV operator determines the distance of discharge and the time required for discharge using the vehicle instrumentation.

(g) The water truck proceeds immediately to the service point and the amount of water discharged is determined by measuring the refill quantity with the flow meter.

(h) Calculate the required tractor

speed in revolutions per minute (rpm) to place the necessary volume of water utilizing the two water discharge computation work sheets (see Appendix L, Forms 2 and 3).

(i) Return to the runway and make another calibration run to verify the revised tractor speed. NOTE: If a substantial decrease in speed is required, the water pump output should be increased.

(5) Mu-Meter personnel measure pavement texture, utilizing the NASA developed grease smear method (Ref 14) in accordance with the following procedures:

(a) Apply 15 cc (0.91 cubic inches) of grease to an area between two strips of masking tape laid four inches apart with one end masked off, forming a "U" shape.

(b) Work the grease into the surface voids with a rubber squeegee that has a hardness approximately equivalent to that of tire tread rubber.

(c) After the grease is evenly spread between the strips of masking tape, measure the area covered (4 inches times the length of spread).

(d) Determine the average texture depth of the surface which is equal to the volume of grease (15 cc) divided by the area covered.

(6) At the completion of DBV dry stop testing and water truck calibration, the DBV is released for tire changing.

d. <u>Wet Testing (4 hours)</u>:

(1) Time hack is made (Mu-Meter, DBV and Team Chief).

(2) The DBV data recorder accompanies the water truck to the runway and rebriefs water truck crew. Additionally, he accompanies the driver during the first water lay to insure all operations are correctly performed.

(3) The PSET chief places traffic cones to denote the location of each test section. Two traffic cones approximately 10 feet abreast of one another are used to designate the beginning and end of each test section and a single traffic cone is used to designate the DBV brake-on-point (placed on the driver's side). NOTE: The testing priority will normally be the primary touchdown test section,

interior test section closest to the primary end of the runway, secondary touchdown area test section, edge test section, and interior test section closest to the secondary touchdown end of the runway.

(4) PSET chief instructs vehicle operators to begin their applicable checklists and start water truck through the test section.

(5) When the water truck completes the first water lay, the truck returns to the beginning of the test section and immediately proceeds through the test section for the second water lay. NOTE: Application of water is always made in two passes, each applying 0.1 inch of water. The total application of 0.2 inch of water within a 15 minute time period simulates a heavy rainfall rate of approximately 0.8 inch per hour.

(6) The PSET chief records, during the second water lay, the times that the water truck passes abreast of the entry, DBV brake-on and exit points. He also starts the DBV on its first test run when the water truck has transversed a safe distance into the test section. Based on the DBV brake-on-point placed 300 feet from the beginning of the test section, the PSET chief can use the following guide for determining when the DBV should start:

TYPE OF TEST SECTION	DISTANCE WATER TRUCK HAS TRANSVERSED
Rubber Deposit	1400 feet
Interior or Edge	1000 feet

The DBV driver applies brakes abreast of the single traffic cone. As soon as the DBV comes to a complete stop, a traffic cone is placed abreast of the DBV on the recorder's side of the vehicle to designate the brake-on-point for the return run. All data are recorded (velocity at wheel lock-up, distance of skid, time of wheel lock-up and time DBV came to a complete stop) and the DBV turns sharply out of test section, accelerates past water truck and positions for return run.

(7) The PSET chief starts the Mu-Meter when the water truck is approximately 200 to 300 feet from the end of the test section. The Mu-Meter conducts all runs at 40 mph and the driver events or "blips" the roll chart paper as he passes abreast the traffic cones. Two event marks indicate the test section ends and one event mark is used to designate the DBV section. The data recorder records the time the Mu-Meter enters and exits the test section, and operates the readout counter.

(8) As soon as the Mu-Meter clears the test section, the DBV makes a return run going in the opposite direction of travel from the first run and locks the brakes at the point the DBV came to a full stop during the first run. Once the DBV is clear of the section, the Mu-Meter begins its second pass. The DBV makes as many runs as possible until the tires squeal or smoke (normally an SDR of 1.3 to 1.5). If it appears the DBV can make runs up to 30 minutes, the runs will be spaced so that a total of 20 runs can be accomplished. The Mu-Meter will make continuous runs until the pavement returns to a friction coefficient of 0.5. Both the DBV and Mu-Meter must make runs at five minute intervals. NOTE: Data sampling must be taken at intervals not greater than every five minutes in order that the computer analysis program properly curve fits input data.)

(9) The PSET chief computes a reference time for determining the 30 minute testing interval. The reference time is the time the water truck passes the mid-point of the test section during the second water lay and is calculated by taking the average time between the times the water truck enters and exits the test section. The reference time is relayed by radio to the DBV and Mu-Meter data recorders.

(10) The PSET chief obtains weather information (ambient temperature, dew point, wind speed/direction) from the control tower.

(11) The PSET chief accompanies the water truck to the service point and monitors reservicing. He records amount of water required to reservice the water truck to insure that correct amount of water was laid.

(12) The PSET chief places traffic cones on the next section and starts the water truck just prior to completing DBV and Mu-Meter testing on the previous test section.

C. Data Collection: Data are recorded on special forms which are designed in such a manner that they require minimum additional effort for preparing the skid resistance computer analysis package.

1. Slope Measurement Data Collection Form: All measured transverse and longitudinal slopes are recorded on this form (see Appendix L, Form 11).

a. Transverse Slope Measurements: Transverse slope measurements encompass the normal aircraft wheel path area, 20 feet each side of the marked centerline and the edge test section. Positive transverse slopes indicate water drainage away from the marked centerline while negative slopes indicate water drainage towards the marked runway centerline. Station number 0+00 starts at the threshold of the primary approach end of the runway.

b. Longitudinal Slope Data: Positive longitudinal slopes indicate water drainage away from the primary approach end of the runway (station number 0+00) while negative slopes indicate water drainage toward the primary approach end of the runway.

2. Water Truck Forms:

a. Briefing Checklist: A checklist for briefing the crew operating the water truck is included in Appendix L, Form 1.

b. Water Discharge Requirements: The "Water Discharge Corresponding to Varying Spray Bar Lengths" form (see Appendix L, Form 3) is used to determine the quantity of water required to wet a 1,000 foot section to a depth of 0.1 inch.

c. Water Truck Speed and Time Computation Form: This worksheet (see Appendix L, Form 2) is used to compute the desired tractor rpm setting for required water discharge based on calibration water lays. This worksheet is also used to calculate the time required to place the required volume of water on a test strip.

3. Mu-Meter Data Collection Forms:

a. Mu-Meter Runs on Dry Pavement: Appendix L, Form 7 shows this data sheet which has provisions for recording the run designator number, the time of run (to the nearest minute), the Mu-Meter integrator reading (counter "C") and the Mu-Meter distance reading (counter "B"). The run designator number is a six digit designator - two alpha digits to designate the section, two numerical digits to designate the run sequence number, one alpha digit to designate the condition of the pavement (wet or dry) and one alpha digit to designate the direction of the vehicle (north, east, south, or west). For example, a run designator number of AA04DE indicates a run in Section "AA", run number four, pavement condition dry and vehicle traveling in an easterly direction. The form has provisions for recording four dry Mu-Meter runs on any given test section.

b. Mu-Meter Runs on Wet Pavement: Appendix L, Form 9 shows this data sheet which has provisions for recording, data for a maximum of 20 runs. It contains entry blanks for run designation number, the times that the Mu-Meter enters and exits the test section (to the nearest second), remote readout unit counter "C" and "B" readings, and the minimum and maximum friction coefficients (Mu).

4. DBV Data Collection Forms:

a. DBV Runs on Dry Pavement: Appendix L, Form 8 shows this data sheet which has provisions for recording the run designator number, the time of run (to the nearest minute), the velocity of the DBV at time of wheel lockup and the distance transversed during the skid. This form has entries for recording four dry DBV runs in a single test section.

b. DBV Runs on Wet Pavement: Appendix L, Form 10 shows this data sheet which has provisions to record data for 20 wet runs. It contains entries for the time the DBV initiates wheel lockup (to the nearest second), the time the DBV comes to a complete stop, DBV speed at time of wheel lockup and the distance that the DBV transversed during the skid.

5. Test Section Layout Form: Appendix L, Form 4 is used to locate the test sections in relation to the runway remaining distance markers, thresholds and marked centerline. The form has provisions for recording the location and extent or rubber deposit areas, and grease smear test results.

6. Computer Analysis Data Recording Forms:

a. Header Card Form: Appendix L, Form 5 is used to provide essential information to the computer analysis package including the base name, the number of sections tested, and runway designator number. It also contains entries that designate which test section data will be combined to give overall ratings for the primary touchdown area, the central interior portion of the runway, the secondary touchdown area, and the runway edge. When designating the test sections to be combined, a space before and after the single test section letter designated is skipped unless the section is designated by a double letter, such as "AA".

b. General Information, Weather & Water Record Form: Appendix L, Form 6 is used to record the test strip designation and description (rubber, interior, or edge section), weather data (ambient temperature, dew point, wind velocity and direction), the time the water truck passes abreast of the test section ends and DBV brake-on point, section length, the number of dry and wet runs by the Mu-Meter and DBV, and the date of testing.

D. Data Collation: As stated earlier, the special data collection forms are arranged so that minimum effort is required in preparing input information for the computer analysis package. The correct order of the data collection forms for inputing data is as follows:

1. Header Card Form 1/3.

2. The following forms must be repeated in the sequence shown for each test section:

a. General information, weather, and water record.

b. Mu-Meter runs on dry pavement.

c. DBV runs on dry pavement.

d. Mu-Meter runs on wet pavement.

e. DBV runs on wet pavement.

3. Pavement slope measurements.

E. Test Results Interpretation:

1. Rating Tables: The pavement skid resistance results are reported in terms of Mu (friction coefficient), as measured by the Mu-Meter, and SDR, the wet to dry (300 feet) stopping distance ratio as measured by the DBV. Test results are compared with the skid resistance/hydroplaning potential tables (see Table 2). These rating tables were developed from data obtained during the joint NASA-Air Force-FAA test (Combat Traction II, Phase I). Figures 25 and 26 show the boundary condition in terms of SDR and Mu when wheel lockups were experienced by the B-727. The computer output provides 3, 15, and 30 minutes Mu and SDR values after the "zero" water time. These skid resistance values are derived from third degree polynomial equations obtained from field data. The "zero" water time for each test section is the time the water truck passes the mid-point of the test section during the second water pass. The mid-point of the test section for the Mu-Meter is halfway between the beginning and end of the test section, whereas the mid-point of the test section for the DBV is the halfway point between the DBV brake-on-point and the end of the test section. The "zero" water time is determined by averaging the time the water truck passes the applicable points. An important feature of the computer analysis package is the calculation of SDRs. All wet stopping distances are normalized to 60 mph brake application speed when the brake-on speed is different than 60 mph by the equation:

$$S_N = \frac{V_{60}^2}{V_B^2} S_B \qquad \text{(EQ 6)}$$

Where: S_N = normalized DBV stopping distance from 60 mph, feet.

S_B = DBV stopping distance during test run, feet.

V_B = DBV brake-on speed, mph.

V_{60} = 60 mph.

2. Friction Variation: Friction coefficient versus distance traces as recorded by the Mu-Meter indicate the relative slipperiness of a pavement surface. Figure 27 shows typical Mu-Meter traces for rubber coated 2,000 foot test sections. Sharp dips in the curve indicate lower friction values which can result from surface contaminants (oil, JP-4, etc.), localized water ponding, and airfield markings (paint).

F. Skid Resistance Survey Report: The Skid Resistance Survey Report summarizes the significant field data (see Appendix K, example report). A computer analysis package processes all field data to eliminate the manual calculation and plotting of data points, as well as increasing accuracy and speed. The computer products consist of pavement rating tables, weather data summary, tables summarizing all test results and recovery graphs. Each summary table contains complete information pertinent to a single test section: section designation, run number, surface condition heading, wetting, average Mu value, maximum and minimum Mu values, and SDRs. The recovery curves graphically depict the pavement recovery characteristics for the climatic and pavement conditions at the time of testing. These curves are derived by a third degree polynomial regression curve-fitting process utilizing field data.

IV. DISCUSSION:

A. Analysis of DBV Test Data:

1. Dry DBV Stopping Distance: Dry stops were accomplished on all runways when weather conditions permitted. Sixty-six (66) DBV dry stops were accomplished on ungrooved PCC pavement and the dry stopping distances ranged between 274 and 378 feet, with an arithmetic mean of 324.1 feet. Fifty-seven (57) DBV dry stops were accomplished on ungrooved AC pavement and the stopping distance ranged from 274 to 348 feet, with an arithmetic mean of 313.2 feet. For grooved PCC pavement, the stopping distances ranged from 285 to 320 feet, with an arithmetic mean of 306.6 feet (five dry stops) and for one grooved AC pavement the stopping distance was 309 feet. The

arithmetic mean for all dry stops was 318.5 feet. Figure 28 is a histogram derived from all DBV dry stopping distance data on PCC and AC pavements. The DBV dry stopping distance is normally increased if rubber deposits accumulate on the pavement surface. Figure 28a is a histogram derived for all DBV dry stops on PCC and AC nonrubberized pavement surfaces (interior and edge test sections). For PCC pavements, the dry stopping distances ranged from 274 feet to 349 feet, with an arithmetic mean of 317.8 feet, and for AC pavements, the dry stopping distance ranged from 284 feet to 350 feet, with an arithmetic mean of 313 feet. The arithmetic mean for all dry stops on nonrubberized pavements was 314.7 feet. Data indicate that on both AC and PCC pavements a 300 foot stopping distance would be considered a very good response and 300 feet appears to be a valid choice for a standardized dry stopping distance. A standardized dry stopping distance is required in order to compare and rank order the skid resistance characteristics of runways utilizing SDR rating tables. [Recently a base (Webb AFB), where an emulsion had been applied to preserve the asphalt surface, was tested; however, this surface treatment resulted in excessively long stopping distances (dry: approximately 600 feet; wet: approximately 1,200 feet). Therefore, if the SDR was computed using the actual dry stopping distance (600 feet), the runway would have been rated as having satisfactory skid resistance characteristics (SDR of 2.0); however, this runway exhibited extremely poor skid resistance properties and if a dry stopping distance of 300 feet is used to compute the SDR, the resulting value of 4.0 would signal unacceptable traction properties for the runway which was the actual case.]

2. <u>Analysis of SDR Data</u>:

a. <u>Primary Touchdown Area</u>: Table 3 lists all test results for primary touchdown or rubber deposit areas and is arranged in a descending order or potential for hydroplaning. All data were obtained from Runway Skid Resistance Survey Reports utilizing the three minute SDR values (Data Summary Pavement Rating Tables). Analysis of the data indicates that the slipperest primary touchdown areas are at Air Force installations where large/heavy aircraft operate, such as B-52, C-5, C-141, and KC-135 aircraft. On PCC pavements, 31 out of 34 touchdown areas exhibited hydroplaning potential (see Figure 29) with an arithmetic SDR mean of 2.86. On AC pavements, the majority of the primary touchdown areas also show some degree of hydroplaning potential with an arithmetic SDR mean of 2.87. Thus, regardless of pavement type, the majority of primary touchdown (rubber deposit) areas exhibit hydroplaning potential, and the arithmetic SDR means for PCC and AC pavements are nearly identical.

b. Central Interior Area: The central interior area of the runway is normally where aircraft perform their primary braking. Normally aircraft deceleration is accomplished initially using aerodynamic braking (drag chute, spoilers, reverse thrust, high angle of attack) followed by wheel braking. Therefore, it is imperative that the central interior portion of a runway exhibit good skid resistance properties. On PCC pavements, 12 out of 19 runway central interior areas showed some degree of hydroplaning potential (see Figure 30) three minutes after water application. However, on AC pavements the reverse is true in that the majority of AC pavements do not exhibit potential for hydroplaning (30 out of 37 pavements do not exhibit potential for hydroplaning three minutes after water application, see Figure 30). The results of these tests were anticipated since AC pavements normally have greater surface asperities or texture than PCC burlap drag pavements. It should be noted, that the shortest wet stopping distance was recorded on a new wire-combed PCC pavement at Shaw AFB, South Carolina (see Table 4).

3. DBV Velocity Versus Time Traces:

a. Background: The surface texture (sometimes referred to as surface asperities or roughness) significantly influences the skid resistance characteristics of a pavement. Texture performs two functions in regard to skid resistance: (1) it facilitates the expulsion of water between the tire-pavement interface and (2) it produces resistance to motion (hysteresis effects in the tread rubber - energy loss [heat] that occurs as the rubber is alternately compressed and expanded). For AC pavements, texture is primarily influenced by the size and type of aggregate, while for PCC pavements, texture is normally controlled by the finishing method such as burlap drag, wire-combed, etc. Texture of a pavement is usually described in terms of the pavement's microtexture and macrotexture. Microtexture refers to the surface coarseness as controlled by the size of individual mineral grains and the matrix in which they are bonded (such as gritty sand paper); whereas, macrotexture refers to the ability of the surface to expel bulk water and it is associated with the angularity of the aggregate particles and the voids in the pavement. Microtexture governs the ability of the pavement surface to break through thin water films after the bulk water has been displaced and reduces the potential for viscous hydroplaning. Figure 2 suggests that viscous fluid pressures (influenced by microtexture) significantly rise to approximately 0.4 times the dynamic hydroplaning speed and then tend to level out. In the case of dynamic hydroplaning, the dynamic fluid pressures developed under the tire footprint significantly rise (square of the speed) as the vehicle approaches the total dynamic hydroplaning speed. The theoretical total dynamic hydroplaning speed of the DBV is approximately 51 mph. Therefore, if the performance of the DBV can be determined through the various speed ranges, the data should reflect the interface of the pavement macro-micro texture. At higher DBV speeds (51-60 mph) the DBV performance should reflect the potential for hydroplaning (influenced by macrotexture ability to expel bulk water), while the performance of the DBV at intermediate speeds should reflect a combination of dynamic and viscous hydroplaning potential, and the performance of the DBV at lower speeds (20 mph and less) should reflect the potential for viscous hydroplaning (microtexture).

b. DBV Velocity Versus Time Records: Figures 31-34 are velocity versus time histories obtained from test records at Travis AFB, McChord AFB, Malmstrom AFB, Mather AFB, and Andrews AFB. Figure 35 is a velocity versus time history of a tare run (unbraked deceleration). The time history data in all figures are normalized to a zero velocity time base for each test run. These curves show very interesting relationships for both wet and dry conditions.

(1) Dry Stops: On dry surfaces the DBV will decelerate in approximately eight seconds from 60 mph to a complete stop. The slope of the line (deceleration) is normally greater at higher speeds than at slower speeds (see Figure 33). When the brakes are applied, all the kinetic energy developed by the DBV is absorbed in a small contact patch on each of the two test tires and energy loss is in the form of heat. Figure 6 suggests that the braking coefficient decreases when the tire tread temperature is increased which explains the reason for some loss of deceleration at the lower speeds (Ref 10).

(2) Wet Stops: On wet pavements, several conclusions can be drawn. First, for those pavements which have both good micro- and macrotexture, the velocity versus time history curves for wet stops should cross the velocity versus time history curves for dry stops (see Figure 34, Section "CC"). This may not seem reasonable because the performance of the DBV should be better when the pavement is dry than when it is wet. However, on wet pavements, the water tends to cool the tire and thus increases the frictional coefficient, resulting in greater deceleration. On pavements where the texture is relatively smooth, such as for rubber deposit areas, the velocity versus time history curves (see Figure 31, Sections "A" and "AA") do not approach or cross over the dry stopping curves. This indicates that the primary touchdown or rubber deposit areas do not have satisfactory micro- or macrotexture (potential for viscous and dynamic hydroplaning). On pavements where there is flooding, but the pavement has good microtexture the curves should look similar to Figure 31, Section "C". This

curve indicates that the pavement does not have the ability to rid itself of bulk water (which was the actual condition due to poor transverse gradient); however, at lower speeds, the curve crosses over the curve for dry stops indicating good pavement microtexture. Thus, the velocity versus time history curves provide a means for assessing the potential of dynamic and viscous types of hydroplaning.

4. DBV Braking Friction Coefficient: The DBV braking friction coefficient (μ_{skid}) is determined by applying Newton's second law of motion:

$$F = MA \qquad \text{(EQ 7)}$$

Where: M = mass of the body, which is equal to W/g.
A = deceleration of the body.
W = weight of body.
g = gravitational deceleration.

The horizontal resisting forces acting on the DBV during a skid are the frictional forces between the tires and pavement, air resistance, transmission drag and incremental deceleration forces due to runway gradient. Therefore, the following relationships are derived:

$$F = \frac{W}{g}A = \mu W \qquad \text{(EQ 7a)}$$

= frictional forces of locked wheels + frictional forces of rolling wheels + drag forces

$$= \mu_s\left(\frac{W}{2}\right) + \mu_r\left(\frac{W}{2}\right) + D \qquad \text{(EQ 7b)}$$

$$\therefore \frac{\mu_s}{2} = \frac{A}{g} - \left[\frac{\mu_r}{2} + \frac{D}{W}\right]$$

$$\mu_s = 2\left[\partial v/\partial t\frac{1}{g} - \text{Tare}\right] \qquad \text{(EQ 8)}$$

Where: $\partial v/\partial t$ = A = deceleration of the DBV, ft/sec^2.
μ_s = braking friction coefficient.
μ_r = rolling resistance of the unbraked wheels.
D = drag forces = air resistance and transmission drag, lbs.
Tare = DBV unbraked deceleration, ft/sec^2.

If a runway has longitudinal slope then the equation becomes:

$$\mu_s = 2\left[\left(\frac{\partial v}{\partial t}\right)_{skid}\Big/g - \left[\frac{\partial v}{\partial t}\right]_{tare}\Big/g - \frac{L}{g}\right] \qquad \text{(EQ 8a)}$$

Where L = is the incremental deceleration or acceleration due to longitudinal runway gradient.

For uphill gradients, the deceleration is approximately 0.01g for each one percent increase in gradient. For downhill gradients the sign of L must be reversed since the DBV is accelerated. The deceleration of the DBV can be determined from the velocity versus time records since deceleration is the slope of the velocity versus time curve. The DBV also provides a means for computing the average braking friction coefficient assuming that the kinetic energy of the DBV is totally dissipated in producing work against the frictional resistance of the pavement tire contact area. The following expressions are presented to derive the braking frictional coefficient:

$$1/2MV^2 = 1/2 \frac{W}{g}V^2 \qquad \text{(EQ 9)}$$

$$F = MA = \mu_b W \qquad \text{(EQ 7a)}$$

$$V = s/t \qquad \text{(EQ 10)}$$

$$A = v/t = s/t^2 \qquad \text{(EQ 11)}$$

Where: M = mass of the DBV , $lb\text{-}sec^2/ft$.
V = initial velocity of the DBV, mph.
W = weight of the DBV, pounds.
g = gravitational constant, $32.2\ ft/sec^2$.
μ_b = average braking frictional coefficient.
F = force opposing the force of friction, pounds.
S = stopping distance of the DBV, feet.
T = time required to stop the DBV, seconds.

The expression for the kinetic energy of a body can be rewritten in terms of:

$$1/2\left(\frac{W}{g}\right) V^2 = 1/2 \left(\frac{\mu_b W}{A}\right) \left(\frac{s}{t}\right)^2 \qquad \text{(EQ 9a)}$$

$$\text{thus:} \quad \mu_b = \frac{V^2}{gS} \qquad \text{(EQ 12)}$$

If the DBV is braked at 60 mph, then the above expression becomes:

$$\mu_b = \frac{240.5}{S} \qquad \text{(EQ 12a)}$$

In the case of a 300 foot dry stop (the standardized dry stopping distance), the average braking friction coefficient is 0.8017. In terms of SDR, where 300 feet is taken as the standard dry stopping distance, the above expression becomes:

$$\mu_b = \frac{0.802}{SDR} \qquad \text{(EQ 12b)}$$

Where: $SDR = \frac{S}{300}$

5. USAF DBV Correlation with Other DBVs: PSET conducted traction surveys at several airfields that were previously tested under Projects Combat and Concrete Traction. Table 6 is a comparison of data from the three programs and Figure 36 shows the relationships between the three programs. Examination of Figure 36 reveals significant data dispersion. However, the data dispersion was anticipated due to several factors. First, the pavement surface had been naturally and mechanically altered since first tested; e.g., Cannon AFB and Shaw AFB had their runways grooved and the rubber deposit areas at Blytheville AFB had changed with time. Secondly, different water application procedures were utilized in all three programs, and the time that DBV measurements were taken after water application differ; i.e., Combat Traction DBV runs were accomplished approximately 7 to 8 minutes after water application. Finally, seasonal changes have had some effects on the skid resistance characteristics of the pavements. Research by the Arizona Highway Department indicates that a pavement will have different frictional characteristics during different times of the year (Ref 15).

6. USAF DBV Correlation with NASA DBV: During Oct 73, the USAF DBV particiapted in the FAA-Concorde special condition landing requirement evaluation tests at Roswell, New Mexico. Figure 37 shows the comparison of the NASA DBV (1969 Ford XL sedan, weight of 5520 lbs) and the USAF DBV (1971 Plymouth Satellite station wagon, weight of 4880 lbs) when the two vehicles were tracking one another on the Roswell Industrial Air Center burlap drag finished PCC runway. Comparative tests were conducted on 24 and 25 Oct 73 when sand bags were added on several runs to the USAF DBV to equalize its operational weight with the NASA DBV. Varying the weight of the USAF DBV appears to have reduced the data scatter slightly. The SDRs plotted on Figure 37 are the actual wet stop distance (normalized to 60 mph) divided by the actual dry stop distance obtained on the Roswell runway. The majority of the data points are below the line of perfect correlation indicating that the NASA DBV normally shows the runway to be slipperier than the USAF DBV. This is an important factor in the USAF program since the AFWL Pavement Rating Table is predicted on the Combat Traction II test data as measured by the NASA DBV.

B. Analysis of Mu-Meter Data:

1. Dry Mu-Meter Runs: During the first year of AFCEC skid testing operations, Mu-Meter dry runs were not conducted due to scarcity and nonavailability of test tires. However, the average dry Mu-Meter readings are obtained for each runway by reviewing the historical data traces for the pavement just prior to entering and after exiting the wet test sections. The Mu-Meter readings normally range between coefficients of 0.78 and 0.90.

2. Primary Touchdown Area: Table 3 lists all test base results for primary touchdown or rubber deposit areas. Figure 29 depicts the data for both PCC and AC pavements in the form of a histogram. On PCC pavements, the majority of the touchdown areas (19 out of 29) exhibit potential for hydroplaning and the arithmetic Mu-Meter reading mean is 0.36, the same as for PCC pavements.

3. Central Interior Area: Table 4 lists all test base results for the central interior portion and Figure 30 is a histogram of Mu-Meter data obtained on the primary aircraft braking area. The data indicate that the majority of the runways tested do not exhibit hydroplaning potential on the central interior portions of the runway. On PCC pavements 11 of 15 central interior areas do not exhibit potential for hydroplaning three minutes after water application and the arithmetic Mu-Meter reading mean for these pavements is 0.55. On AC pavements, 29 of 34 central interior areas do not exhibit potential for hydroplaning three minutes after water application and the arithmetic Mu-Meter reading mean is 0.62.

C. Analysis of Texture Measurements:

1. Correlation Between Texture and SDR: Figure 38 is a plot relating first run SDRs (Table 5) and the pavement texture as measured by the grease smear method. The DBV data are plotted as 1/SDR in order that the origin of the graph has like values (0,0). The data spread for highly textured pavements is considerable; e.g., for textures between 0.018 inch (equates to 12.5 inches grease smear) and 0.032 inch (equates to a 7 inch grease smear), the SDR values range from 1.2 to 3.0. However, when the pavement texture is relatively smooth (0.016 inch or less), the majority of data points lie below the suggested hydroplaning potential 1/SDR value of 0.5. Since the primary purpose of the texture measurement program is to determine if the grease smear method can assist base personnel in arriving at a decision on when to remove rubber deposits, pavement texture versus 1/SDR is shown separately in Figure 39 for rubber deposit areas. In the majority of cases where the pavement texture is less than 0.016 inch (equates to a grease smear of 14 inches), potential for hydroplaning exists, even if the runway transverse slope is greater than one percent. When the texture is greater than 0.016 inch, but less than 0.036 inch, it is not possible to accurately predict the potential for hydroplaning solely on the basis of a grease smear test method (see Figure 38). Therefore, the data indicate that the grease smear procedure can predict potential for hydroplaning only when the surface texture is relatively smooth.

2. Correlation Between Texture and Mu: Pavement texture versus friction coefficient (Mu) as measured by the Mu-Meter is shown in Figure 40. Approximately the same dispersion of data points occurs for the Mu plots as was noted in the 1/SDR plots. Examination of Figure 40 indicates that when the texture is greater than 0.016 inch, it is not possible to predict potential for hydroplaning. However, Figure 41 (pavement texture versus Mu for rubber deposit areas) again indicates that when the texture is less than 0.016 inch, there is possible potential for hydroplaning.

3. Correlation With Other Test Efforts: Figure 42 shows the correlation between the AFCEC, Concrete Traction and Combat Traction grease smear texture measurements. Examination of Figure 42 indicates that significant dispersion exists among all measurements. However, it was not possible to ascertain the exact location where measurements were taken during the Combat and Concrete Traction programs and some runways have subsequently had their surfaces altered. For example, the runway at Myrtle Beach AFB had a sand slurry placed during 1971 and the measurements made by the AFCEC PSET did not correlate with Combat Traction data as expected. However, the Concrete Traction and PSET measurement correlate extremely well on this runway. Out of 16 comparative measurements between the Combat Traction and AFCEC PSET programs, fifty percent of the measurements fall within a three inch grease measurement smear of one another. The FAA traction team reportedly has discontinued the grease smear measurement program since a runway surface is not homogeneous and a multitude of different readings can result on the same runway. (Ref 26). Experience has shown that the selection of test locations does significantly influence the measurement since the surface aggregate gradation on different portions of the runway can vary considerably. On the Travis AFB primary approach runway, the DBV wet stopping distance was very high (first run by DBV was aborted since the vehicle traveled a distance greater than the test section length); however, the measured texture depth was greater than in comparison to other rubber deposit areas since the Travis AFB touchdown area had voids or pits in the rubber coated surface. Also the dispersion of data may be attributed to the fact that since a runway surface does not have homogeneous texture, the measurements are not a true average representation of the pavement texture. However, as the pavement surface texture becomes smoother, the selection of a site for the measurement becomes less important for purposes of predicting hydroplaning potential.

D. Relationship Between Potential for Hydroplaning and Cross Slope: The ability of a pavement surface to rid itself of bulk water is a very important skid resistance consideration since potential for dynamic hydroplaning is directly related to the amount of bulk water present. Figure 43 is a histogram showing the relationship between pavement slope and potential for hydroplaning based on data taken immediately following water application (data obtained from Table 5). Examination of data indicates that pavement slope in itself does not eliminate or substantially reduce potential for hydroplaning immediately following water application and it is not possible to correlate pavement slope and potential for hydroplaning using this analysis. Figures 43a and 43b are histograms showing the relationship between pavement slope and texture for various SDR and Mu ranges immediately following water application. Tests conducted by AFWL (Ref 18) and the Arizona Highway Department (AHD) (Ref 15) have shown that when a minimum quantity of water (0.005 inch for self watering systems and 0.05 inch for water flooding systems) is applied to a pavement, the minimum Mu is developed and an increase of water depth will not cause a substantial decrease in skid resistance properties as sensed by the Mu-Meter. Therefore, pavement slope significantly influences the recovery characteristics of the pavement. Normally, when a surface has relatively good texture and cross slope, measurements made by the DBV are discontinued 10-15 minutes after water application to reduce tire wear when the runway has recovered to nearly a dry condition. However, when the runway does not have sufficient transverse slope to shed the bulk water, even where the surface has extensive asperities, the pavement will not show significant recovery. This situation was found on the Aviano AB, Italy asphaltic runway. Visual assessments indicate that transverse slope is probably the single most important factor for expelling bulk water from pavements with the exception of porous friction course asphalt or grooving treatments. Once the bulk water is removed from the pavement surface, then environmental factors determine to a great extent the remaining recovery characteristics. It should be noted that protruding joint seal material can restrict water run off and act as a dike resulting in localized water ponding.

E. Relationship Between DBV and Mu-Meter: Considerable testing has been performed over the past several years to determine what, if any, correlation exists between different friction measuring devices. In fact, it now has become standard procedure to correlate measuring devices whenever they are involved in skid measurement programs and normally these tests reveal poor correlation between the different devices. However, this is expected since the operational modes of the measurement devices are entirely different; e.g., locked wheel, side slip, constant slip, variable slip, etc. Poor correlation was achieved between the DBV and the Mu-Meter in the AFCEC testing program as shown in Figures 44 through 47. Examination of Figures 44 through 46 reveals that for a particular test section there is an apparent correlation between the DBV and the Mu-Meter, but when data from several test sections are combined and compared for the same runway, considerable dispersion is evident. All data points from Figures 44-46 are plotted on Figure 47 and the spread of data becomes very apparent and significant.

1. The data illustrated in Figures 44-46 were selected because they represented the greatest range of SDR and Mu readings over a 30 minute time interval. The Mu-Meter readings (Mu) were taken directly from the historical record charts for only that portion where the DBV measurements were recorded. The data dispersion shown in Figure 47 is very significant since in the majority of tests the Mu-Meter indicates less hydroplaning potential for a given equivalent SDR value based on the AFWL measurement standard (see Table 2). For example, a SDR value of 2.0 (1/SDR = 0.5, breakpoint for possible hydroplaning potential), the Mu-Meter readings range from Mu values of 0.55 to 0.8 and for a Mu value of 0.5 (breakpoint for possible hydroplaning potential), the SDR readings range from 2.5 (possible hydroplaning) to 4.2 (extremely high hydroplaning potential). Therefore, these two measuring devices assess the hydroplaning potential differently on the same pavement surface. It should be noted that an SDR value of 2.0 (1/SDR = 0.5) does not necessarily equate to a Mu reading of 0.5; however, these values are the hydroplaning potential rating breakpoints based on Combat Traction II, Phase I data.

2. The question then arises as to which measuring device better assesses the skid resistance properties of a runway. Since the present program is based on very limited aircraft and vehicle correlation testing, namely B-727 flight test data, analyses of field test measurements and reported hydroplaning mishaps are the only other means to determine which device can better assess the hydroplaning potential for a runway. To date, the AFCEC PSET has tested only two bases where the touchdown areas did not have significant rubber deposit accumulation to influence overall braking capability, and pilots have reported suspected hydroplaning (England AFB and Soesterberg AB, The Netherlands). The skid resistance values three minutes after water application were: SDR of 2.66/Mu of 0.46 at England AFB and SDR of 2.29/Mu of 0.53 at Soesterberg AB. Therefore, based only on these limited data, the DBV appears to better assess potential for hydroplaning.

F. Correlation Between Mu-Meter and Skiddometer: In conjunction with the standard skid resistance survey tests conducted on Runway 03/21 at Charleston AFB in June 1974, correlation measurements between the Swedish Skiddometer BV-6 and Mu-Meter were conducted. The Skiddometer is a three wheel, 3,300 pound, towed trailer which measures and records the brake slip coefficient of friction at approximately 12.7

percent slip ratio (see Figure 3). The test tire is the same tire as used on the DBV (7.50 X 14, ASTM E-249, smooth tread, inflated to 24 psi). The correlation tests were conducted by running the Skiddometer immediately behind the Mu-Meter at a constant speed of 40 mph. Since these tests were conducted in conjunction with the standard skid resistance survey tests, water application and section layout were identical to those described in Section III. Tests were conducted on the primary touchdown area (Section "BB", Figure 49), central interior area (Section "DD", Figure 50), and secondary touchdown area (Section "FF", Figure 51). Figures 49 through 51 are traces of the recorded side slip and constant slip friction coefficients. The comparative data are presented in this manner so that point-by-point data values and overall trends can by analyzed. Examination of the traces show that both measurement systems see the same relative slipperiness in that the overall or average traces appear to rise and fall together. However, the Mu-Meter traces show significantly greater friction variations which permits an easier assessment of the relative slippery runway areas. No direct correlation between these two devices was expected since the operating principles are entirely different.

G. Runway Recovery Characteristics: As described earlier, test runs are accomplished over a 30 minute time interval in order to determine the recovery characteristics of a pavement. Since the test procedures were developed to simulate a heavy rainfall rate by applying 0.2 inch of water within a 15 minute time interval to each test section, it was assumed that the testing effort would reflect the natural recovery characteristics (inverse of water depth) of the pavement. However, limited field experience has shown that this testing procedure does not assess the natural recovery characteristics after a heavy or moderate rainfall (see Figure 48). On 16 June 1974 at McGuire AFB, testing was accomplished in the morning hours during a heavy rainfall. Test runs were conducted during and immediately following the rainstorm and then during the afternoon after the runway had time to completely recover to a dry condition. The following data table summarizes the results of the initial DBV and Mu-Meter test runs:

CONDITION	SECTION			
	"A"/"AA"	"C"	"D"	"A"/"AA"
	INITIAL SDR VALUES:			INITIAL MU VALUES:
During Rainfall	4.15	2.15	2.39	-
Immediately Following Rainfall	3.61	-	-	0.38
Artificially Wet	3.88	2.03	2.33	0.37

Section "A"/"AA" is the rubber deposit/touchdown area (Runway 24 end), whereas Sections "C" and "D" are central interior test sections. All tests were conducted on asphaltic concrete pavement. The weather conditions during the tests were:

CONDITION	AMBIENT TEMP	DEW POINT	WIND
Immediately Following Rainfall	73°F	73°F	180°/4 knots
Artificially Wet	78°F	68°F	180°/4 knots

Although the ambient temperatures and wind conditions were nearly identical, the recovery characteristics immediately following the rainfall and artificial wetting were different (see Figure 48) primarily due to dew point spread. Therefore, it is not possible to accurately determine skid resistance values of a pavement several minutes after the cessation of a heavy or moderate rainfall utilizing this evaluation system due to changing environmental conditions, but it is possible to determine the worst skid resistance condition. Although the natural pavement recovery characteristics cannot be duplicated using the artificial wetting procedures, the present testing procedures reflect pavement drainage characteristics.

H. Mu-Meter Considerations:

1. Speed Variation (Speed Gradient): All Mu-Meter measurements conducted by AFCEC PSET are run at a constant speed of 40 mph. However, several agencies that utilize a self contained watering device to insure a constant water depth in front of the measuring wheels at various speeds, found that with increasing speed, the friction coefficient, as recorded by the Mu-Meter, is reduced (see Figure 52, Ref 15). This factor is extremely important since a pavement may exhibit satisfactory skid resistance properties (Mu greater than 0.50) at speeds at or less than 40 mph, but at greater speeds the pavement surface may exhibit poor skid resistance properties. The International Civil Aviation Organization (ICAO) recognizes the fact that wet runways usually produce a marked drop in friction coefficient with an increase in speed, which is unlike snow and ice covered runways where friction coefficients remain nearly the same throughout the speed spectrum. The ICAO study group on snow, slush, ice and water for aerodromes (Ref 22) recommended making friction measurements at 40 mph when assessing the skid resistance properties of a runway during and following rainfall. Information on the braking action should be given on the basis of the following table:

MEASURED MU:	BRAKING ACTION DESCRIPTION
0.50 or above	Good
0.49 to 0.40	Medium
0.39 and below	Poor

However, when assessing a runway to determine whether remedial action is required to improve the runway surface, ICAO recommends that the Mu-Meter be operated at 80 mph using controlled wetting conditions (self-wetting system) and the following classification table used:

MEASURED MU	SURFACE FRICTION CHARACTERISTICS
0.65 and above	Above average
0.64 - 0.45	Average
0.44 and below	Below average

2. Standardization/Calibration Procedures:

a. Tire Yaw Angle: The Arizona Highway Department (AHD) is calibrating its Mu-Meter differently than recommended in the M.L. Aviation Mu-Meter Operator's Manual and this approach warrants consideration as a standard procedure (Ref 27). The AHD is setting both measuring wheels at the same yaw angle from centerline (approximately 7 1/2 degrees) and not varying the toed-out angle of the port wheel in order to obtain a desired reading on the calibration board. It should be noted that when the yaw angle of the tire is changed (see Figure 5), resulting in a slightly different operational mode, the resultant side-force developed by one tire will differ from the other. This phenomenon is observable since the test tires do not wear evenly. By precisely setting the measuring wheels at the same yaw angle from centerline will insure that the wheels are measuring identical friction coefficients.

b. Load Cell Calibration: A user calibration procedure has not been formally established to insure the integrity of the recording system, although such a system has been developed by the M.L. Aviation Co. This procedure consists of loading the load sensor with weights and noting the values sensed by the recording system. When fifty pound weights are attached to the load sensor, readings recorded by the Mu-Meter should stay within the parameters shown in Figure 53. This calibration procedure provides a method for determining the integrity of the Mu-Meter system from the load cell (hydraulic system) to the recording mechanism (mechanical system).

3. Operational Deployment of the Mu-Meter: At the present time, considerable interest is being shown in the

operational use of the Mu-Meter since it is a continuous recording device which permits an operator to make measurements of the entire runway without significantly delaying aircraft traffic; measurements are made at a relatively safe speed (40 mph) during inclement weather conditions; and modifications required for the towing vehicle are minor. However, several malfunctions of the load cell mechanism have been experienced and to insure mechanical reliability and repeatability, further refinements are necessary before the Mu-Meter should be procured by base level personnel.

I. Proposals for Assessing and Alleviating Hydroplaning Potential:

1. Assessing Aircraft Performance: Considerable effort over the last several years has been devoted to predicting the stopping performance of aircraft on wet runways. The James Brake Decelerometer (JBD) was used in the 1960s to determine aircraft performance; however, the Combat Traction testing effort revealed that the JBD could not accurately predict aircraft performance on wet runways (see Appendix B). Since the Combat Traction Project, controversy over the correlation between the DBV and aircraft performance has arisen. For example, Figure 55 shows less than desirable relationship between aircraft SDRs and DBV SDRs for a range of different conditions. Although the DBV showed significant improvement over the JBD during Project Combat Traction, the DBV did not consistently correlate with aircraft performance. During the FAA Concorde Landing Requirement Evaluation Tests in 1973, the Mu-Meter was operated by AFCEC PSET to determine the correlation between aircraft performance and Mu-Meter readings. Figure 54 shows the relationship between the L-1011/B-737 and Mu-Meter during these tests (Ref 17). Examination of the data indicates that the Mu-Meter, like the DBV, is not a measuring device that can reliably predict aircraft stopping distance performance. Thus, the present state-of-the-art does not appear to permit accurate prediction of aircraft stopping distance on wet runways.

2. Assessing Hydroplaning Potential: Project Combat Traction II (Refs 11 and 12) and F-4 Rain Tire Performance Flight Tests at Edwards AFB CA (Refs 19 and 20) data are the primary sources for assessing aircraft hydroplaning potential. Flight test data indicates that the B-727 and F-4 will probably hydroplane whenever the SDR is greater than 2.0 (see Figure 25). Although DBV measurements were not conducted during the majority of the F-4 Rain Tire Flight Tests, the DBV data show that the PCC runway at Edwards AFB exhibits potential for hydroplaning (SDR value of approximately 2.2). Thus it appears that for some aircraft, the probability for hydroplaning is high whenever the SDR is greater than 2.0. Therefore,

the AFWL DBV pavement rating table should be superseded by the following table:

3 MINUTE SDR	HYDROPLANING POTENTIAL
1.0 - 2.0	No hydroplaning problems are expected.
2.0 - 2.5	Hydroplaning potential for some aircraft.
Greater than 2.5	High hydroplaning potential.

Since the Mu-Meter apparently was not properly calibrated during the F-4 Rain Tire Tests, Combat Traction II flight test data and ICAO standards are the primary sources for determining aircraft braking assessments. Aircraft braking assessments are currently rated according to the following table:

Mu-Meter Reading:		Aircraft Braking and Steering Response
AFWL	ICAO/United Kingdom	
0.50 and above	0.50 and above	Good
0.42 - 0.49		Fair
	0.40 - 0.49	Medium
	below 0.40	Poor
0.25 - 0.41		Marginal
below 0.25		Unacceptable

Where the braking action assessments are defined by the United Kingdom Aeronautical Circular 142/172 as:

a. Good - pilots should not expect to find conditions as good as when landing on clean, dry runway and the aeroplanes should not experience directional control or braking difficulties because of the runway condition.

b. Medium - braking action may be such that the achievement of satisfactory landing performance, taking into account the prevailing circumstances, depends upon the precise reproduction of recommended flight techniques.

c. Poor - significant deterioration both in braking performance and direction control. If a landing is to be made, it is advisable to ensure that the landing distance required for very slippery/wet conditions specified in the Flight Manual/

Operations Manual does not exceed the landing distance available. Aborted takeoff stop may not be possible from a speed of V_1 and the takeoff may need to be delayed depending on limiting conditions.

Therefore, based on the Combat Traction II data (see Figure 26) and the ICAO/United Kingdom Rating Table, the AFWL Mu-Meter pavement rating table should be superseded by the following table:

Mu-Meter Reading	Hydroplaning Potential
0.50 and above	No hydroplaning problems are expected.
0.40 - 0.49	Hydroplaning potential for some aircraft.
below 0.40	High hydroplaning potential.

Since the present skid resistance survey program cannot predict pavement conditions 15 and 30 minutes after rainfall due to varying environmental conditions, all runway remedial actions should be based on the skid resistance data obtained immediately following water application (3 minute SDR and Mu values) which reflect the worst pavement condition.

3. Alleviating Hydroplaning Potential: Since the present state-of-the-art does not permit accurate prediction of aircraft stopping distance on wet runways, while the AFCEC skid resistance program can determine the relative hydroplaning potential of runway surfaces, every effort should be made to upgrade the skid resistance characteristics of runways identified as being slippery to minimize the possibility of aircraft mishaps. This means that virtually every burlap drag finish PCC runway should be grooved since the majority of smooth finish concrete runways exhibit potential for hydroplaning (SDR greater than 2.0). The fact that smooth finish concrete runways can significantly increase the potential for hydroplaning was recently verified during the F-4 Rain Tire Performance flight tests at Edwards AFB (Refs 19 and 20). During the very first F-4 landing on the smooth finish concrete runway, one wheel spun down to a complete stop within five seconds after brake application on the wet and nonrubberized portion of the runway and the wheel remained in the locked-up condition for the entire braking run (7,800 feet). The F-4 Rain Tire tests demonstrated the necessity for the primary braking area (central interior portion of the runway) to have good skid resistance properties so that good braking response and directional control can be achieved. Since the F-4 tests were not accomplished on any rubber deposit areas, it was not possible to determine the influence rubber deposits might have

on F-4 braking action. However, the AFCEC PSET recently tested a runway that had significant potential for hydroplaning on the touchdown area (initial SDR value of 3.15) due to rubber accumulation and the central interior portion of the runway exhibited very good skid resistance properties (initial SDR value of 1.49). It was reported to PSET that a F-4 blew a tire on this runway allegedly due to hydroplaning because the wheel became locked on the rubber deposit area and the sudden good traction of the central interior area caused tire failure. Although tire failure was experienced, the pilot was able to maintain directional control and the aircraft stopped safely due to the good traction of the central interior area.

4. This and other examples show why rubber removal is a constant concern for both base civil engineering and operational personnel; however, both economical and operational constraints sometimes prevent bases from removing rubber deposits. Normally at bases where continuous heavy/large aircraft operations occur (e.g., Travis AFB, Castle AFB), very substantial rubber deposits accumulate in minimum time periods. Since the determination for rubber removal is normally very subjective without the aid of skid resistance measurement equipment, it is difficult to determine at base level the requirements for rubber removal. A possible rational approach to this problem would be: (1) advise pilots to delay braking until the aircraft has transversed the primary rubber buildup areas when the runway is reported as wet (reduced braking capability is experienced only when rubber deposits are wet); (2) perform rubber removal only when the deposits become significant (all surface asperities filled with deposits; significant deposits on the primary touchdown area cover approximately 15 to 20 percent of the runway; and the NASA grease smear measurement method indicates the texture is less than 0.016 inch); and (3) perform rubber removal prior to the heaviest rainfall season but not more than once every six months. The long range solution to the frequent rubber removal problem is to increase the pavement texture, thereby increasing the time required before the majority of the pavement asperities become filled. Construction techniques currently available to increase pavement texture are grooving and porous friction courses. Testing at Shaw AFB substantiated that runway grooving can increase the skid resistance properties of a rubber deposit area. The rubber coated, burlap drag finsih portion of the Shaw AFB runway exhibited lower traction characteristics than the adjacent rubber coated grooved portion (see Figure 27). However, since landings on dry grooved pavements can result in tire tread damage (tire chevron cutting) and increased landing gear structure stresses, runway touchdown grooving is not recommended at this time. A recent laboratory study was conducted to evaluate tire response for different pavement grooving configurations (Ref 21). The laboratory test results show that tire chevron cutting occurs

at the instant the aircraft tire contacts the pavement and that a 1/4 inch X 1/4 inch X 1 inch PCC groove pattern can cause greater tire damage than a 1/4 inch X 1/4 inch X 2 inch PCC groove pattern. The FAA is presently conducting research to determine the optimum groove pattern for all portions of the runway. Once full scale tests can be performed to substantiate satisfactory reduction in tire chevron cutting (tires replaced primarily due to wear rather than damage resulting from chevron cutting) for a particular groove pattern, then the Air Force should consider adopting this groove pattern for touchdown areas.

V. CONCLUSIONS:

A. The AFCEC Skid Resistance Survey Program can determine runway skid resistance characteristics and runway hydroplaning potential. However, the present state-of-the-art is such that aircraft stopping distance cannot be accurately determined using data obtained from the DBV or Mu-Meter.

B. The present rating table indicates that significant hydroplaning potential is encountered only when the SDR exceeds 2.5 or the Mu value is less than 0.42. However, Combat Traction II and F-4 Rain Tire flight test data shows that hydroplaning potential is very high for some aircraft whenever the SDR exceeds 2.0 and the Mu value decreases below 0.5.

C. The DBV and Mu-Meter are suitable measurement devices for assessing relative skid resistance characteristics. The two measurement devices complement one another since the DBV determines the skid resistance characteristics over a speed range while the Mu-Meter identifies the incrementally slipperier areas.

D. The DBV velocity versus time histories appear to assess the potential for dynamic and viscous types of hydroplaning and these curves reflect the pavement macro-and microtexture.

E. Regardless of pavement material, the majority of touchdown areas exhibit hydroplaning potential due to rubber deposits.

F. The majority of burlap drag finish PCC runways exhibit some degree of hydroplaning potential primarily due to poor pavement texture.

G. The 300 foot DBV dry stopping distance reflects the traction response of a desirable dry pavement and it is a valid choice for a standardized dry stopping distance. The standardized dry stopping distance allows the relative ranking of runways.

H. The NASA DBV and USAF DBV assess the pavement slipperiness slightly differently from one another and correlation between the DBVs is required for interpretation of test data.

I. The NASA grease smear measurement procedure cannot predict hydroplaning potential when the measured texture depth is greater than 0.016 inch. However, this measurement system can normally assess relative hydroplaning potential when the texture depth is less than 0.016 inch and could assist base personnel in objectively determining when rubber removal is required.

J. The natural recovery characteristics of a runway cannot be accurately determined using the artificial wetting system; however, worst runway skid resistance condition can be determined using the present AFCEC skid resistance measurement program.

K. The skid resistance on a wet pavement normally decreases as the speed of a vehicle is increased. Thus, it appears to be important to measure the skid resistance characteristics over a range of speeds.

L. Protuding joint seal material can impede water runoff, thereby significantly delaying the drainage of bulk water from a pavement surface.

M. Improving pavement texture and cross slope appear to be the most effective means for alleviating hydroplaning potential.

VI. RECOMMENDATIONS:

A. The AFCEC skid resistance program to assess runway skid resistance characteristics should be continued. Procedural improvements should be made as new techniques and further information concerning aircraft stopping performance on wet pavements become available.

B. The DBV velocity versus time histories should be incorporated into the evaluation procedure as a valuable tool for assessing pavement characteristics.

C. The present pavement rating tables should be revised to indicate that only the 3-minute skid resistance values are valid for assessing the skid resistance characteristics of a runway. Additionally, the rating tables should be superseded by the following table:

3 - Minute Value:		Hydroplaning Potential:
SDR Value:	Mu Value	
< 2.0	> 0.5	No hydroplaning problems are expected.
2.0 - 2.5	0.4 - 0.5	Hydroplaning potential for some aircraft.
> 2.5	< 0.4	High hydroplaning potential.

D. Program action should be initiated on a long term basis to groove PCC burlap drag finish runways that exhibit hydroplaning potential (SDR greater than 2.0).

E. Runway design specifications should require a minimum of one percent runway transverse gradients and special surface treatments for PCC runways, e.g., grooving or wire-combing. Joint sealing material should be installed in a manner that will not restrict water runoff.

F. The determination for removal of runway rubber deposits should be made in accordance with the procedures outlined in Section IV, paragraph I.

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TABLES

TABLE I

Effect Of Water On Tire Hydroplaning Phenomena (Data From Reference 7)

RUNWAY WATER DEPTH RANGE (INCHES)	HYDROPLANING PHENOMENA EXPERIENCED
Greater than (0.05-0.1)	(a), (b), (c), and (d)
Between (0.02-0.03) and (0.05-0.1)	(b), (c), and (d)
Less than (0.02-0.03)	(c) and (d)

(a) DYNAMIC HYDROPLANING: Unbraked wheel spindown, zero tire braking and cornering friction coefficients (aircraft ground speed must be greater than tire dynamic hydroplaning speed $V_p = 9\sqrt{p}$).*

(b) COMBINED DYNAMIC AND VISCOUS HYDROPLANING: Reduced tire braking and cornering coefficients, slow recovery of wheel synchronous (ground speed) angular velocity from braking skid (from brake application).

(c) VISCOUS HYDROPLANING: Reduced tire braking and cornering coefficients, slow recovery of wheel synchronous (ground speed) angular velocity from braking skid (from brake application).

(d) REVERTED RUBBER HYDROPLANING: Very low tire braking friction coefficients at all ground speeds, tire cornering friction coefficient = 0 (only develops if prolonged locked wheel tire skid occurs due to pilot or antiskid failure to release wheel brake pressure after wheel skid from brake application).

*Where: V_p = tire dynamic hydroplaning speed, knots

p = tire inflation pressure, lb/in^2

TABLE 2

MU-METER AIRCRAFT PAVEMENT RATING (1)

MU	EXPECTED AIRCRAFT BRAKING RESPONSE	RESPONSE
Greater than 0.50	GOOD	No hydroplaning problems are expected.
0.42 - 0.50	FAIR	Transitional
0.25 - 0.41	MARGINAL	Potential for hydroplaning for some A/C exists under certain wet conditions.
Less than 0.25	UNACCEPTABLE	Very high probability for most A/C to hydroplane.

STOPPING DISTANCE RATIO/AIRFIELD PAVEMENT RATING (1)

SDR	HYDROPLANING POTENTIAL
1.0 - 2.0	No hydroplaning potential
2.0 - 2.5	Potential not well defined
2.5 - 3.5	Potential for hydroplaning
Greater than 3.5	Very high hydroplaning potential

(1) Technical Report No. AFWL-TR-73-165 (Source of Ratings)

TABLE 3

BASE LISTING - SDRs/MUs ON RUBBER DEPOSIT AREAS

Base listing of primary touchdown (rubber deposit) area test results. Data were obtained from Runway Skid Resistance Survey Reports, Data Summary Pavement Rating Tables, Three-Minute SDR and Mu values.

DBV MEASUREMENTS

BASE	SDR VALUE	PAVEMENT TYPE
Travis AFB (03R/21L)	5.79	PCC
Fairchild AFB	4.75	PCC
Castle AFB	4.60	AC
Loring AFB	4.58	AC
Travis AFB (03L/21R)	4.01	AC
McGuire AFB (06/24)	3.92	AC
Torrejon AB	3.85	AC
Mather AFB (04R/22L)	3.75	PCC/AC
Blytheville AFB	3.73	PCC
Dover AFB (01/19)	3.62	PCC/AC
Scott AFB	3.61	AC
Robbins AFB	3.59	PCC
Cannon AFB (03/21)	3.59	PCC/PCC Grooved
Rickenbacker AFB (05R/23L)	3.40	PCC
Homestead AFB	3.37	PCC
Grissom AFB	3.23	AC
Charleston AFB	3.21	PCC/AC
Zaragosa AB	2.93	AC
Mather AFB (04L/22R)	2.90	AC
Andrews AFB(01L/19R)	2.89	PCC
Charleston AFB (03/21)	2.79	AC
Shaw AFB (04R/22L)	2.77	PCC/PCC Grooved
McConnell AFB (18R/36L)	2.77	PCC
Hector Fld	2.72	PCC
Dover AFB (13/31)	2.66	AC
Columbus AFB (13L/31R)	2.62	PCC/AC
Glasgow AFB	2.61	PCC
Andrews AFB (01R/19L)	2.60	AC
England AFB (14/32)	2.54	PCC
Aviano AB	2.51	AC
Richard Gebaur AFB	2.50	PCC
Vance AFB (17R/35L)	2.50	PCC/AC
Soesterberg AB	2.42	AC
Columbus AFB (13R/31L)	2.40	PCC
England AFB (18/36)	2.39	PCC/AC
Moody AFB (18R/36L)	2.38	PCC/AC
Zweibrucken AB	2.34	AC
RAF Bentwaters	2.33	AC
Moody AFB (18L/36R)	2.32	PCC/AC
Craig AFB (14R/32L)	2.27	PCC
Rickenbacker AFB (05L/33R)	2.26	AC
Vance AFB (17C/35C)	2.25	PCC
Columbus AFB (13C/31C)	2.22	PCC

BASE	SDR VALUE	PAVEMENT TYPE
RAF Woodbridge	2.22	AC
Niagara Falls IAP	2.12	AC
Vance AFB (17L/35R)	2.10	PCC
McConnell AFB (18L/36R)	2.03	PCC
McGuire AFB (18/36)	2.00	PCC/AC
Myrtle Beach AFB	2.00	PCC/AC
Cannon AFB (12/30)	2.00	PCC/PCC Grooved
Shaw AFB (04L/22R)	1.99	PCC/PCC Wire Comb
Erding AB	1.93	PCC
Hurlburt Fld	1.89	PCC/AC
McChord AFB	1.87	AC

MU-METER MEASUREMENTS

BASE	MU-VALUE	PAVEMENT TYPE
Travis AFB (03R/21L)	0.22	PCC
Torrejon AB	0.24	AC
Homestead AFB	0.25	PCC
Castle AFB	0.26	AC
Fairshild AFB	0.29	PCC
Zaragosa AB	0.30	AC
Loring AFB	0.32	AC
Charleston AFB (15/33)	0.34	PCC/AC
Andrews AFB (01L/19R)	0.34	PCC
Rickenbacker AFB	0.38	PCC
Dover AFB (01/19)	0.38	PCC/AC
McGuire AFB	0.39	PCC/AC
Craig AFB(14R/32L)	0.40	PCC
Mather AFB (04R/22L)	0.40	PCC/AC
Mather AFB (04L/22R)	0.40	AC
Glasgow AFB	0.40	PCC
Blytheville AFB	0.43	PCC
Shaw AFB (04R/22L)	0.43	PCC/PCC Grooved
Robbins AFB	0.44	PCC
England AFB (18/36)	0.44	PCC/AC
Grissom AFB	0.44	AC
Soesterberg AB	0.44	AC
Charleston AFB (03/21)	0.45	AC
Andrews AFB (01R/19L)	0.47	AC
Travis AFB (03L/21R)	0.47	AC
Shaw AFB (04L/22R)	0.48	PCC/PCC Wire Comb
Columbus AFB (13C/31C)	0.49	PCC
Hector Fld	0.50	PCC
Malmstrom AFB	0.50	AC
Hurlburt Fld	0.50	PCC/AC
Rickenbacker AFB (05L/23R)	0.51	AC
Columbus AFB (13R/31L)	0.52	PCC
Scott AFB	0.52	AC
RAF Bentwaters	0.53	AC
Erding AB	0.53	PCC
Niagara Falls IAP	0.53	AC
McGuire AFB (18/36)	0.53	PCC/AC
England AFB	0.53	PCC

BASE	MU-VALUE	PAVEMENT TYPE
Myrtle Beach AFB	0.54	PCC/AC
Moody AFB (18L/36R)	0.56	PCC/AC
RAF Woodbridge	0.57	AC
Craig AFB (14L/32R)	0.58	PCC/AC
Zweibrucken AB	0.59	AC
Richard Gebaur AFB	0.60	PCC
Moody AFB (18R/36L)	0.60	PCC/AC
Aviano AB	0.60	AC
Columbus AFB (13L/31R)	0.63	PCC/AC
Dover AFB (13/31)	0.63	AC
McChord AFB	0.75	AC

TABLE 4

BASE LISTING - SDRs/MUs ON CENTRAL INTERIOR AREAS

Base listing of central interior (primary aircraft braking) area test results. Data were obtained from Runway Skid Resistance Survey Reports, Data Summary Pavement Rating Tables, Three-Minute SDR and Mu values.

DBV MEASUREMENTS

BASE	SDR VALUE	PAVEMENT TYPE
Travis AFB (03L/21R)	2.71	AC
England AFB (14/32)	2.66	PCC
England AFB (18/36)	2.57	PCC
Charleston AFB (15/33)	2.55	PCC
Blytheville AFB	2.45	PCC
Soesterberg AB	2.29	AC
Travis AFB (03R/21L)	2.28	AC
Columbus AFB (13R/31L)	2.28	PCC
McChord AFB	2.23	AC
Richard Gebaur AFB	2.22	AC/PCC
Mather AFB (04L/22R)	2.18	AC
Andrews AFB (01L/19R)	2.14	PCC
Glasgow AFB	2.11	PCC
Vance AFB (17L/35R)	2.09	PCC
Erding AB	2.04	PCC
Rickenbacker AFB (05R/23L)	2.04	PCC
McConnell AFB (18R/36L)	2.03	PCC
Robbins AFB	2.01	PCC
Castle AFB	2.00	AC
Loring AFB	1.99	AC
Fairchild AFB	1.97	PCC
Hector Fld	1.95	PCC
Rickenbacker AFB (05L/23R)	1.94	AC
McGuire AFB (06/24)	1.93	AC
Homestead AFB	1.92	PCC
Hurlburt Fld	1.92	AC
Columbus AFB (13C/31C)	1.90	AC
Dover AFB (13/31)	1.89	AC
Charleston AFB (03/21)	1.88	AC
Mather AFB (04R/21L)	1.86	AC
Torrejon AB	1.85	AC
Scott AFB	1.83	AC
Niagara Falls IAP	1.80	AC
Columbus AFB (13L/31R)	1.80	AC
Shaw AFB (04R/22L)	1.79	AC/PCC Grooved
Cannon AFB (03/21)	1.74	PCC Grooved
Dover AFB (01/19)	1.74	AC
McConnell AFB (18L/36R)	1.73	PCC
Aviano AB	1.73	AC
Andrews AFB (01R/19L)	1.73	PCC
Craig AFB (14L/32R)	1.70	AC
Malmstrom AFB	1.67	AC
McGuire AFB (18/36)	1.66	AC
Grissom AFB	1.66	AC

BASE	SDR VALUE	PAVEMENT TYPE
Moody AFB (18L/36R)	1.66	AC
Cannon AFB (12/30)	1.65	AC
Myrtle Beach AFB	1.57	AC
RAF Woodbridge	1.53	AC
Craig AFB (14R/32L)	1.52	AC
Vance AFB (17R/35L)	1.50	AC/PCC Grooved
Moody AFB (18R/36L)	1.48	AC
Vance AFB (17C/35C)	1.45	AC
RAF Bentwaters	1.44	AC
Zweibrucken AB	1.35	AC
Zaragosa AB	1.31	AC
Shaw AFB	1.13	PCC Wire Comb

MU-METER MEASUREMENTS

Columbus AFB (13L/31R)	0.43	AC
Craig AFB (14L/32R)	0.44	AC
England AFB (18/36)	0.44	PCC
Glasgow AFB	0.44	PCC
Columbus AFB (13R/31L)	0.45	PCC
Torrejon AB	0.46	AC
England AFB (14/32)	0.46	PCC
Mather AFB (04L/22R)	0.47	AC
Hurlburt Fld	0.50	AC
Columbus AFB (13C/31C)	0.52	AC
Robbins AFB	0.52	PCC
Soesterberg AB	0.53	AC
Myrtle Beach AFB	0.53	AC
Erding AB	0.54	PCC
Travis AFB (03L/21R)	0.54	AC
Fairchild AFB	0.54	PCC
Blythville AFB	0.55	PCC
Rickenbacker AFB (05L/23R)	0.55	AC
Castle AFB	0.55	AC
Andrews AFB (01R/19L)	0.55	PCC
Andrews AFB (01L/19R)	0.56	PCC
Charleston AFB (15/33)	0.56	PCC
Homestead AFB	0.56	PCC
Moody AFB (18L/36R)	0.56	AC
Scott AFB	0.57	AC
Rickenbacker AFB (05R/23L)	0.59	PCC
McGuire AFB (18/36)	0.59	AC
Aviano AFB	0.61	AC
Richard Gebaur AFB	0.61	AC/PCC
Loring AFB	0.62	AC
Hector Fld	0.62	PCC
McChord AFB	0.62	AC
Mather AFB (04R/22L)	0.63	AC
Shaw AFB (04R/22L)	0.63	AC/PCC Grooved
RAF Bentwaters	0.66	AC
Malmstrom AFB	0.66	AC

BASE	MU-VALUE	PAVEMENT TYPE
Craig AFB (14R/32L)	0.66	AC
Travis AFB (03R/21L)	0.69	AC
Niagara Falls IAP	0.70	AC
RAF Woodbridge	0.71	AC
Zweibrucken AB	0.71	AC
Dover AFB (13/31)	0.71	AC
Moody AFB (18R/36L)	0.73	AC
Charleston AFB (03/21)	0.74	AC
Dover AFB (01/19)	0.75	AC
McGuire AFB (06/24)	0.75	AC
Zaragosa AFB	0.76	AC
Shaw AFB (04L/22R)	0.80	PCC Wire Comb
Grissom AFB	0.83	AC

TABLE 5

COMPILATION OF TEST DATA

The data compiled and tabulated for each test base are presented in this table. The compilation includes the following data: Name of the airfield tested; date tested; designation of test sections; pavement type; transverse slope; macrotexture depth (as measured by the NASA grease smear method); water depth (Combat and Concrete Traction program, water depth measured by NASA water depth gauge; PSET water applied in accordance with Section III), first run SDRs (NOTE: PSET SDRs are actual wet stopping distance divided by 300 feet); average first run Mu-Meter readings for entire test section and for only that portion of the test section where the DBV braked; and DBV dry stopping distance. Projects Combat Traction and Concrete Traction data are listed for comparative purposes where applicable.

AIRFIELD	DATE (1) PSET (2) PCCT (3) PCBT	TEST LOCATION PRIMARY END INTERIOR SECONDARY END EDGE	PAV. TYPE	SLOPE (1) > 1 % SLOPE (2) 0.5-1% SLOPE (3) < 0.5% SLOPE	TEXTURE, IN PCBT	TEXTURE, IN PCCT	TEXTURE, IN PSET	WATER DEPTH, IN PCBT	WATER DEPTH, IN PCCT	WATER DEPTH, IN PSET	DBV READINGS SDR PCBT	DBV READINGS SDR PCCT	DBV READINGS SDR PSET	DBV READINGS DRY SD, FT	Mu METER READINGS TOTAL SECTION	Mu METER READINGS DBV PORTION
ANDREWS AFB MD (HQ COMD)	4 MAR 74 (1)	01 END	PCC	(2)			.016			0.2			2.95	342	.37	.40
		CPTA	PCC	(2)			.022			0.2			2.56	349	.43	.45
		CSTA	PCC	2			.032			0.2			1.85	332	.73	.72
		19R END	PCC	3			.015			0.2			3.21		.35	.33
		EDGE	PCC	2			.037			0.2			2.33		.51	.58
		01R END	PCC	1			.013			0.2			2.60	332	.46	.44
		CPTA	AC	1			.025			0.2			1.97	297	.43	.35
		CSTA	AC	1			.031			0.2			1.52		.64	.64
		19L END	AC	1			.022			0.2			2.49	312	.63	.60
		EDGE	AC	1			.027			0.2			1.93		.54	.64
AVIANO AV, ITALY (USAFE)	15 SEP 74(1)	05 END	AC	3			.035			0.2			2.29	290	.56	.52
	4 AUG 69 (3)	INTERIOR	AC	2	.014		.046	0.04		0.2	1.60		1.56	293	.50	.58
		23 END	AC	3			.021			0.2			2.62		.42	.35
		EDGE	AC	3			.038			0.2			1.82		.55	.32
RAF BENTWATERS, ENGLAND (USAFE)	29 SEP 74(1)	25 END	PCC/AC	3			.0191			0.2			2.35	274	.48	.48
		CPTA	AC	2			.0458			0.2			1.51	284	.60	.64
		CSTA	AC	3			.0508			0.2			1.58	303	.61	.62
		07 END	PCC	3						0.2			2.36		.48	.48
		EDGE	AC	3			.0241			0.2			1.67		.66	.60
BLYTHEVILLE AFB AR (SAC)	12 DEC 73(1)	17 END	PCC	2		.025			.02	0.2		2.98	MLFNCT	329	.45	.45
	16 APR 71(2)	INTERIOR	PCC	-		.025			.01			2.33				
		CPTA	PCC	2						0.2			2.31	329	.52	.54
		CSTA	PCC	2						0.2			2.79	329	MLFNCT	MLFNCT
		35 END	PCC	2		.025			.01	0.2		3.55	3.42	316	.59	.58
		EDGE	PCC	-						0.2			1.64	337	.70	.75
CANNON AFB NM (TAC)	28 NOV 73(1)	21 END	PCC/GPCC	1		.024			.03	0.2		3.36	3.45	310	MLFNCT	MLFNCT
	26 APR 71(2)	INTERIOR	PCC	-		.024			.03			2.44		297		
		CPTA	GPCC	1						0.2			1.94	320	MLFNCT	MLFNCT
		CSTA	GPCC	1						0.2			1.73	310	MLFNCT	MLFNCT
		03 END	PCC/GPCC	1		.024			.03	0.2		2.44	2.46	310	MLFNCT	MLFNCT
		EDGE	GPCC	-						0.2			1.53	285	MLFNCT	MLFNCT
		30 END	PCC/AC	2		.024				0.2			2.02	310	MLFNCT	MLFNCT
		INTERIOR	AC	-		.033			.03			1.61				
		CPTA	AC	2						0.2			1.63	290	MLFNCT	MLFNCT
		CSTA	AC	2						0.2			1.69	290	MLFNCT	MLFNCT
		12 END	PCC/AC	2		.033				0.2			2.16	310	MLFNCT	MLFNCT
		EDGE	AC	-						0.2			1.75	320	MLFNCT	MLFNCT

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AIRFIELD	DATE (1) PSET (2) PCCT (3) PCBT	TEST LOCATION PRIMARY END INTERIOR SECONDARY END EDGE	PAV TYPE / SLOPE	(1) > 1 % SLOPE (2) 0.5-1% SLOPE (3) < 0.5% SLOPE	TEXTURE, IN PCBT	TEXTURE, IN PCCT	TEXTURE, IN PSET	WATER DEPTH, IN PCBT	WATER DEPTH, IN PCCT	WATER DEPTH, IN PSET	DBV READINGS SDR PCBT	DBV READINGS SDR PCCT	DBV READINGS SDR PSET	DBV READINGS DRY SD, FT	Mu METER READINGS TOTAL SECTION	Mu METER READINGS DBV PORTION
CASTLE AFB CA (SAC)	24 APR 74(1) 10 MAR 71(2)	30 END	AC	1		.023	.00570		.02	0.2		5.3[illegible]	4.95		.24	.22
		INTERIOR	AC	-		.026			.02			2.00				
		CPTA	AC	2						0.2			2.42		.49	.48
		CSTA	AC	1			.0230			0.2			2.04		.54	.55
		12 END	AC	1		.023	.0078		.02	0.2		2.54	3.11		.34	.26
		EDGE	AC	1			.0327			0.2			1.70		.50	.51
CHARLESTON AFB SC (MAC)	20 JUN 74(1) 4 APR 71 (2)	15 END	AC/PCC	2		.042	.0085		.02	0.2		3.38	3.63		.37	.32
		INTERIOR	PCC	-		.042	.0110		.02			2.19				
		CPTA	PCC	1						0.2			2.70	324	MLFNCT	MLFNCT
		CSTA	PCC	2						0.2			2.73		.46	.44
		33 END	PCC/AC	1		.024	.0095		.02	0.2		3.59	3.17		.31	.28
		EDGE	PCC	1			.0130			0.2			2.36		MLFNCT	MLFNCT
		21 END	AC	2		.056	.0131		.02	0.2		2.38	2.48		.50	.38
		INTERIOR	AC	1		.056	.0229		.02			2.02	2.10		.73	.76
		03 END	AC	1		.056	.0127		.02	0.2		2.63	3.00		.49	.38
COLUMBUS AFB MS (ATC)	12 JAN 74(1) 18 APR 71(2)	13R END	PCC	1		.042			.02	0.2		2.23	2.81	343	.48	.48
		INTERIOR	PCC	2		.042			.02	0.2		2.23	2.27	341	.40	.42
		31L END		2									2.61		.22	.20
		13C END	PCC	2		.048			.02	0.2		2.41	2.52	301	.40	.46
		INTERIOR	AC	-		.022			.02			2.10				
		CPTA	AC	2						0.2			2.11		.44	.55
		CSTA	AC	2						0.2			1.96	322	.54	.63
		31C END	PCC	1		.048			.02	0.2		2.16	2.90		.50	.55
		EDGE	AC	-						0.2			2.33	348	.45	.48
		13L END	PCC/AC	2		.020	.0191		.02	0.2		2.32	2.84		.62	.62
		INTERIOR	AC	-		.024			.02			2.14				
		CPTA	AC	2			.0191			0.2			1.93		MLFNCT	MLFNCT
		CSTA	AC	2			.0191			0.2			2.04		.51	.54
		31R END	PCC/AC	2		.030	.0218		.02	0.2		2.29	2.33		.45	.42
		EDGE	AC	-			.0218			0.2			1.91		.54	.58
CRAIG AFB AL (ATC)	5 JAN 74 (1) 27 JAN 74(2)	32R END	PCC/AC	3		.041	.0170		.04	0.2		1.32	MLFNCT	337	MLFNCT	N/A
		INTERIOR	AC	-		.125			.03			1.29				
		CPTA	AC	1			.0131			0.2			1.68	298	.36	.52
		CSTA	AC	1			.0131			0.2			2.00		.37	.40
		14L END	AC	2		.041	.0109		.04	0.2		1.32	1.51	321	.54	.75
		EDGE	AC	-			.0530			0.2			2.22	314	.30	N/A

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AIRFIELD	DATE (1) PSET (2) PCCT (3) PCBT	TEST LOCATION PRIMARY END INTERIOR SECONDARY END EDGE	PAV. TYPE / SLOPE (1) > 1 % SLOPE (2) 0.5-1% SLOPE (3) < 0.5% SLOPE	TEXTURE, IN			WATER DEPTH, IN			DBV READINGS				Mu METER READINGS	
										SDR					
				PCBT	PCCT	PSET	PCBT	PCCT	PSET	PCBT	PCCT	PSET	DRY SD, FT	TOTAL SECTION	DBV PORTION
CRAIG AFB AL (cont'd)		32L END	PCC 2		.047	.0117		.03	0.2		2.16	2.34	340	.38	.33
		INTERIOR	AC -		.072			.02			1.58				
		CPTA	AC 2			.0327			0.2			1.54	326	.69	.60
		CSTA	AC 1			.0458			0.2			1.61		.66	.66
		14R END	PCC/AC 2		.047	.0153		.02	0.2		2.58	2.50		.50	.32
		EDGE	AC -			.0305			0.2			1.57		.70	.74
DOVER AFB DE (MAC)	1 MAR 74 (1) 6 OCT 69 (3)	01 END	PCC/AC 2	.015			.05		0.2	1.58		3.42		.37	.28
		INTERIOR	AC -												
		CPTA	AC 2						0.2			1.65		.73	.72
		CSTA	AC 2						0.2			1.79		.77	.78
		19 END	PCC/AC 2						0.2			2.33		.58	.54
		EDGE	AC 1						0.2			1.54		.77	.76
		31 END	AC 3						0.2			2.93		.53	.55
		CPTA	AC 3						0.2			1.87		.70	.75
		CSTA	AC 2						0.2			1.81		.72	.78
		13 END	AC -						0.2			1.58		.77	.74
		EDGE	AC -						0.2			1.30		.83	.86
ENGLAND AFB LA (TAC)	15 JAN 74(1) 13 OCT 69(3)	14 END	PCC 2	.0064			.06		0.2	2.21		2.76		.58	.60
		INTERIOR	PCC -												
		CPTA	PCC 2						0.2			2.89		.48	.47
		CSTA	PCC 2			.0199			0.2			2.95		.42	.43
		32 END	PCC 3						0.2			2.95		.44	.44
		EDGE	PCC -						0.2						
		18 END	PCC 1			.0254			0.2			2.57		.40	.42
		CPTA	PCC/AC 2			.0251			0.2			2.76		.38	.38
		36 END	PCC/AC 2						0.2			2.58		.48	.48
		EDGE	PCC -						0.2			2.56		.40	.44
ERDING AB, GERMANY (USAFE)	17 SEP 74(1)	26 END	PCC 1			.0086			0.2			2.15		.48	.48
		CPTA	PCC 1			.0191									
		CSTA	PCC 1						0.2			2.36		.48	.48
		08 END	PCC 1			.0114			0.2			2.31		.45	.48
		EDGE	PCC 1			.0176			0.2			1.89		.49	.56
FAIRCHILD AFB WA (SAC)	2 MAY 74 (1)	23 END	PCC 1			.0043			0.2			4.28	308	.32	.28
		CPTA	PCC 3			.0170			0.2			1.92	314	.45	.45
		CSTA	PCC 3						0.2			2.58		.50	.50
		05 END	PCC 3			.0139			0.2			3.12	337	.42	.39
		EDGE	PCC 2			.0109			0.2			1.97	274	.53	.61

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AIRFIELD	DATE	TEST LOCATION	PAV. TYPE / SLOPE		TEXTURE, IN			WATER DEPTH, IN			DBV READINGS				Mu METER READINGS	
	(1) PSET (2) PCCT (3) PCBT	PRIMARY END INTERIOR SECONDARY END EDGE		(1) > 1 % SLOPE (2) 0.5-1% SLOPE (3) < 0.5% SLOPE	PCBT	PCCT	PSET	PCBT	PCCT	PSET	SDR PCBT	SDR PCCT	SDR PSET	DRY SD, FT	TOTAL SECTION	DBV PORTION
GLASGOW AFB MT (SAC)	9 MAY 74 (1)	28 END	PCC	1			.0143			0.2			2.67		.36	.34
		CPTA	PCC	1						0.2			2.66		.38	.35
		CSTA	PCC	1			.0097			0.2			2.05		.45	.41
		10 END	PCC	2			.0085			0.2			2.34		.43	.41
		EDGE	PCC	-			.0068			0.2			2.80		.40	.40
GRISSOM AFB IN (SAC)	7 JUN 74 (1)	22 END	AC	3			.0041			0.2			3.20	340	.41	.33
		CPTA	AC	2			.0199			0.2			1.93	295	.81	.80
		CSTA	AC	2			.0208			0.2			1.90		.75	.73
		04 END	AC/PCC	2			.0095			0.2			3.93	352	.36	.32
		EDGE	AC	2			.0208			0.2			1.63	311	.75	.71
HECTOR FIELD ND (ANG/ADC)	12 MAY 74(1)	35 END	PCC	2						0.2			2.75	324	.48	.42
		CPTA	PCC	2			.0241			0.2			2.06	321	.56	.52
		CSTA	PCC	2						0.2			2.17		.54	.52
		17 END	PCC	2						0.2			2.25	345	.60	.66
		EDGE	PCC	1						0.2			1.96		.53	.44
HOMESTEAD AFB FL (TAC)	20 JUL 74(1) 21 JAN 71(2)	05 END	PCC	3		.030	.0088		.02	0.2		2.34	3.31	305	.25	.28
		INTERIOR	PCC	-		.063			.04			1.80				
		CPTA	PCC	3			.0278			0.2			2.13	311	.47	.48
		CSTA	PCC	2						0.2			2.03	324	.53	.58
		23 END	PCC	3		.030	.0163		.04	0.2		1.82	2.19		.46	.40
		EDGE	PCC	2			.0163			0.2			2.12		N/A	N/A
HURLBURT FIELD FL (TAC)	10 JAN 74(1) 20 JAN 71(2)	35 END	PCC/AC	2		.025	.0199		.035	0.2		1.75	2.03		.52	.48
		INTERIOR	AC	-		.024			.035			1.36				
		CPTA	AC	2			.0269			0.2			1.92		.50	.53
		CSTA	AC	1			.0305			0.2			2.07		.48	.54
		17 END	AC	1		.025	.0208		.02	0.2		2.23	2.55		.34	.36
		EDGE	AC	-			.0327			0.2			1.34		.71	.72
LORING AFB ME (SAC)	14 JUN 74(1)	01 END	AC	1			.00586			0.2			4.73	312	.30	.28
		CPTA	AC	1						0.2			2.01	309	.55	.55
		CSTA	AC	1			.0163			0.2			2.16		.54	.52
		19 END	AC	1			.0208			0.2			2.12	315	.58	.57
MALMSTROM AFB MT (SAC)	7 MAY 74 (1)	20 END	AC	1			.0139			0.2			2.49	307	.49	.50
		CPTA	AC	1						0.2			1.71	322	.65	.67
		CSTA	AC	1			.0131			0.2			1.97		.53	.58
		02 END	AC	1			.0117			0.2			2.01		.53	.54
		EDGE	AC	1			.0117			0.2			1.81	321	.60	.60

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AIRFIELD	DATE (1) PSET (2) PCCT (3) PCBT	TEST LOCATION PRIMARY END INTERIOR SECONDARY END EDGE	PAV TYPE	SLOPE (1) > 1 % SLOPE (2) 0.5-1% SLOPE (3) < 0.5% SLOPE	TEXTURE, IN PCBT	TEXTURE, IN PCCT	TEXTURE, IN PSET	WATER DEPTH, IN PCBT	WATER DEPTH, IN PCCT	WATER DEPTH, IN PSET	DBV READINGS SDR PCBT	DBV READINGS SDR PCCT	DBV READINGS SDR PSET	DBV READINGS DRY SD, FT	Mu METER READINGS TOTAL SECTION	Mu METER READINGS DBV PORTION
MATHER AFB CA (ATC)	21 APR 74(1) 8 MAR 71 (2)	22L END	PCC/AC	2		.022	.0082		.03	0.2		3.97	3.92	342	.41	.32
		INTERIOR	AC	-		.042			.02			1.53	2.12	334	.64	.64
		CPTA	AC	2			.0163			0.2			1.92	312	.61	.60
		CSTA	AC	2			.0229			0.2		2.20	2.88		.52	.54
		04R END	PCC	1		.022			.03	0.2						
		EDGE	AC	-						0.2						
		22R END	AC	2		.037			.03	0.2		1.79	3.63	338	.36	.34
		INTERIOR	AC	2		.037			.03	0.2		1.58	2.31	350	.39	.38
		04L END	AC	3		.037			.03	0.2		N/A	2.36	319	.37	.38
		EDGE	AC	1						0.2			1.75	336	.45	.50
McCHORD AFB WA (MAC)	[illegible] APR 74(1) [illegible]	34 END	AC	1	N/A		.0305			0.2	1.94		2.24	335	.70	.70
		INTERIOR	AC	-			.0305			0.2			2.94	346	.55	.48
		CPTA	AC	1			.0327			0.2			1.72		.68	.72
		CSTA	AC	1			.0286			0.2			1.97		.62	.69
		16 END	AC	1			.0305			0.2			2.40		.54	.56
		EDGE	AC	1												
McCONNELL AFB KS (SAC)	4 DEC 73 (1)	18L END	AC	2						0.2			3.08	325	N/A	N/A
		CPTA	AC	1						0.2			2.61	308		
		CSTA	AC	1						0.2			1.93	292		
		36R END	AC	2						0.2			2.60	315		
		EDGE	AC	-						0.2			2.21			
		18R	AC	1						0.2			2.38		N/A	N/A
		CPTA	AC	1						0.2			1.72	315		
		CSTA	AC	1						0.2			1.68			

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AIRFIELD	DATE (1) PSET (2) PCCT (3) PCBT	TEST LOCATION PRIMARY END / INTERIOR / SECONDARY END / EDGE	PAV. TYPE	SLOPE (1) > 1 % SLOPE (2) 0.5-1% SLOPE (3) < 0.5% SLOPE	TEXTURE, IN			WATER DEPTH, IN			DBV READINGS SDR			DBV READINGS	Mu METER READINGS	
					PCBT	PCCT	PSET	PCBT	PCCT	PSET	PCBT	PCCT	PSET	DRY SD, FT	TOTAL SECTION	DBV PORTION
McGUIRE AFB NJ (MAC)	16 JAN 74(1)	24 END	AC	2			.0062			0.2			3.88		.37	.32
		CPTA	AC	1						0.2			2.03		.77	.74
		CSTA	AC	2			.0121			0.2			2.33		.68	.64
		06 END	AC	2			.00538			0.2			5.11		.29	.22
		EDGE	AC	2						0.2			1.43		.69	.75
		36 END	PCC/AC	1						0.2			2.15		.42	.43
		CPTA	AC	1						0.2			1.81		.60	.55
		18 END	AC	1						0.2			2.06		.39	.30
		EDGE	AC	1						0.2			1.33		.79	.80
MOODY AFB GA (ATC)	23 FEB 74(1) 24 JAN 71(2)	18L END	PCC/AC	2		.018	.0121		.04	0.2		2.54	1.78		.42	.42
		INTERIOR	AC	-		.023			.04			1.79				
		CPTA	AC	-			.0208			0.2			1.71	339	.42	.40
		CSTA	AC	2			.0153			0.2						
		36R END	PCC/AC	2		.018	.0143		.03	0.2		2.02	2.17		.40	.41
		EDGE	AC	2			.0241			0.2			1.44		.49	.50
		18R END	PCC/AC	2		.031	.0191		.03	0.2		1.93	2.39	304	.58	.52
		INTERIOR	AC	-		.050			.03			1.51				
		CPTA	AC	2			.0458		.03	0.2			1.48	306	.73	.73
		CSTA	AC	2			.0199			0.2						
		36L END	PCC/AC	1		.031	.0148		.03	0.2		1.60	2.34		.63	.58
		EDGE	AC	1			.0458			0.2			1.34		.77	.80
MYRTLE BEACH AFB SC (TAC)	14 JUL 74(1) 19 JAN 71(2) 8 OCT 69 (3)	17 END	PCC/AC	2		.020	.0158		.02	0.2		1.88	2.19	314	.50	.42
		INTERIOR	AC	-	.0067	.020		.06	.04		1.67	1.69				
		CPTA	AC	1			.0208			0.2			1.56	313	.44	.56
		CSTA	AC	2			.0286			0.2			1.99		.42	.42
		35 END	PCC/AC	1			.0127		.04	0.2		1.73	2.54		.47	.40
		EDGE	AC	2			.0254			0.2			1.55		.43	.60
NIAGARA FALLS IAP, NY (ANG/ADC)	10 JUN 74(1)	28 END	AC	1			.0065			0.2			2.15	278	.50	.52
		CPTA	AC	1			.0191			0.2			1.58	292	.85	.81
		CSTA	AC/PCC	1			.0095			0.2			2.49		.51	.49
		10 END	PCC	1			.0104			0.2			2.08	309	.53	.53
		EDGE	AC	1			.0241			0.2			1.33	307	.65	.64
RICHARDS-GEBAUR AFB MO (AFCS)	8 DEC 73 (1)	36 END	PCC	1						0.2			3.31	325	.50	.44
		CPTA	AC/PCC	1						0.2			2.69	326/308	.60	.60
		CSTA	AC/PCC	1						0.2			2.28	300	.60	.60
		18 END	PCC	2						0.2			2.91	331	.52	.52
		EDGE	PCC	-						0.2			2.29	324	.64	.62

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SD: STOPPING DISTANCE
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MU: Mu METER READING
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PCCT: PROJECT CONCRETE TRACTION
PSET: PAVEMENT SURFACE EFFECTS TEAM

AIRFIELD	DATE (1) PSET (2) PCCT (3) PCBT	TEST LOCATION PRIMARY END INTERIOR SECONDARY END EDGE	PAV. TYPE	SLOPE (1) > 1 % SLOPE (2) 0.5-1% SLOPE (3) < 0.5% SLOPE	TEXTURE, IN PCBT	TEXTURE, IN PCCT	TEXTURE, IN PSET	WATER DEPTH, IN PCBT	WATER DEPTH, IN PCCT	WATER DEPTH, IN PSET	DBV READINGS SDR PCBT	DBV READINGS SDR PCCT	DBV READINGS SDR PSET	DBV READINGS DRY SD, FT	Mu METER READINGS TOTAL SECTION	Mu METER READINGS DBV PORTION
RICKENBACKER AFB, OH	4 JUN 74 (1)	23L END	PCC	1			.0109			0.2			3.49	302	.39	.38
(SAC)	30 SEP 69(3)	INTERIOR	PCC	-	.0064			.03			1.84					
		CPTA	PCC	1			.0191			0.2			2.38	307	.57	.56
		CSTA	PCC	1			.0191			0.2			1.99		.52	.55
		05R END	PCC	1			.0191			0.2			2.77	342	.37	.33
		EDGE	PCC	1			.0199			0.2			1.87	303	.59	.63
		23R	AC	3						0.2			2.19		.58	.42
		INTERIOR	AC	3						0.2			2.04		.51	.50
ROBBINS AFB GA	26 FEB 74(1)	32 END	PCC	2		.042	.0114		.02	0.2		1.77	3.29		.44	.44
(AFLC)	1 FEB 71 (2)	INTERIOR	PCC	-		.042			.02			2.20				
		CPTA	PCC	3			.0191			0.2			1.93	310	.54	.56
		14 END	PCC	2		.042	.0153		.02	0.2		3.30	2.44	304	.59	.60
SCOTT AFB IL	10 DEC 73(1)	31 END	AC	N/A						0.2			4.02	330	.52	.58
(MAC)	14 OCT 69(3)	INTERIOR	AC		.0067			.06		0.2	1.80		1.94	323	.66	.70
		13 END	PCC/AC							0.2			2.81	314	.50	.44
		EDGE	AC							0.2			1.61	305	.70	.72
SHAW AFB SC	16 JUL 74(1)	04L END	PCC/GPCC	2		.043	.0124		.02	0.2		3.38	2.70	300	.39	.32
(TAC)	3 APR 71 (2)	INTERIOR	PCC/AC	-		.033			.02			2.17				
		CPTA	GPCC/GAC	2			.0163			0.2			1.66	309	.53	.57
		CSTA	GAC	2						0.2			2.01	309	.66	.54
		22R END	PCC/GAC	2		.043	.0143		.02	0.2		3.35	2.27		.41	.58
		EDGE	GAC/GPCC	2						0.2			1.54	309	.59	.68
		04R END	WCPCC	1			.0135			0.2			2.07	348	.57	.40
		INTERIOR	WCPCC	1			.0286			0.2			1.21	338	.81	.81
		22L END	WCPCC	1			.0131			0.2			2.01		.51	.36
		EDGE	WCPCC	1			.0191			0.2			1.54		.68	.72
SOESTERBURG AB, THE NETHERLANDS (USAFE)	25 SEP 74(1)	28 END	AC	3						0.2			2.77		.40	.40
		CPTA	AC	3						0.2			2.32		.57	.58
		CSTA	AC	3						0.2			2.50		.44	.45
		10 END	AC	3						0.2			1.99		.57	.61
		EDGE	AC	3						0.2			1.64		.62	.58
TORREJON AB, SPAIN	10 SEP 74(1)	23 END	AC	1			.0064			0.2			4.00	299	.20	.20
(USAFE)		CPTA	AC	3			.0458			0.2			2.12	308	.40	.40
		CSTA	AC	3			.0305			0.2			1.68		.40	.46
		05 END	AC/PCC	1			.0086			0.2			3.00		.25	.25
		EDGE	AC	1			.0254			0.2			1.61	316	.56	.54

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AIRFIELD	DATE (1) PSET (2) PCCT (3) PCBT	TEST LOCATION PRIMARY END INTERIOR SECONDARY END EDGE	PAV. TYPE / SLOPE	(1) > 1 % SLOPE (2) 0.5 - 1% SLOPE (3) < 0.5% SLOPE	TEXTURE, IN PCBT	TEXTURE, IN PCCT	TEXTURE, IN PSET	WATER DEPTH, IN PCBT	WATER DEPTH, IN PCCT	WATER DEPTH, IN PSET	DBV READINGS SDR PCBT	DBV READINGS SDR PCCT	DBV READINGS SDR PSET	DBV READINGS DRY SD, FT	Mu METER READINGS TOTAL SECTION	Mu METER READINGS DBV PORTION
TRAVIS AFB CA (MAC)	26 APR 74(1) 9 MAR 71 (2)	21L END	PCC	1		.028	.0148		.02	0.2		3.85	5.30	328	.34	.30
		INTERIOR	AC	-		.042			.02			2.15				
		CPTA	AC	2			.0381			0.2			2.40		.78	.80
		CSTA	AC	2			.0191			0.2			2.15		.66	.64
		03R END	AC/PCC	1		.028	.0241		.02	0.2		2.12	2.58		.51	.48
		21R END	AC	2		.042	.0143		.02	0.2		3.52	4.36		.42	.38
		INTERIOR	AC	-		.042			.02			2.28				
		CPTA	AC	3			.0163			0.2			2.93		.52	.56
		CSTA	AC	2			.0158			0.2			2.74		.46	.45
		03L END	PCC/AC	1		.026	.0241		.02	0.2		2.56	2.98		.50	.50
		EDGE	AC	2			.0218			0.2			2.32		.53	.56
VANCE AFB OK (ATC)	1 DEC 73 (1)	17R END	PCC/AC	2						0.2			2.60	283	N/A	N/A
		CPTA	AC/GPCC	3						0.2			1.70			
		CSTAA	AC/GPCC	2						0.2			1.47			
		35L END	PCC/GPCC	3						0.2			2.62	294		
		EDGE	AC/GPCC	-						0.2			1.42			
		17C END	PCC	1			.00565			0.2			2.13	305		
		CPTA	PCC/AC	2			.0352			0.2			1.49	327		
		CSTA	AC	1						0.2			1.54	370		
		35C END	AC/PCC	1			.0327			0.2			1.70	366		
		EDGE	AC	-						0.2			1.55	380		
		17L END	PCC	2						0.2			2.28	290		
		INTERIOR	PCC	2			.0191			0.2			2.00	310		
		35R END	PCC	2						0.2			2.20	305		
RAF WOODBRIDGE, ENGLAND (USAFE)	28 SEP 74(1)	27 END	AC	1						0.2			2.35	328	.51	.45
		CPTA	AC	1						0.2			1.45	308	.71	.69
		CSTA	AC	1						0.2			1.93		.65	.71
		09 END	AC	1						0.2			2.14		.47	.47
		EDGE	AC	1						0.2			2.23		.53	.50
ZARAGOSA AF, SPAIN (USAFE)	13 SEP 74(1)	31R END	AC	1			.0102			0.2			3.15	320	.27	.26
		CPTA	AC	1			.0229			0.2			1.49		.67	.70
		CSTA	AC	1			.0241			0.2			1.34	322	.75	.81
		13L END	AC	1			.0241			0.2			1.58	304	.62	.60
		EDGE	AC	1			.0218			0.2			1.46		.60	.62
ZWEIBRUCKEN AB, GERMANY (USAFE)	21 SEP 74(1)	03 END	AC	1			.0208			0.2			2.35	303	.56	.48
		CPTA	AC	1			.0352			0.2			1.42	296	.68	.70
		CSTA	AC	3			.0508			0.2			1.32	305	.71	.73
		21 END	AC	1			.0286			0.2			1.95	307	.63	.62
		EDGE	AC	1			.0286			0.2			1.20		.71	.77

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TABLE 6

SDR COMPARISONS BETWEEN DIFFERENT TEST EFFORTS

Comparitive stopping distance ratio (SDR) test results for those bases tested during Project Combat Traction, Project Concrete Traction, and the AFCEC Skid Resistance Program.

SDR VALUES

BASE	COMBAT TRACTION	CONCRETE TRACTION	*AFCEC
Aviano AB	1.6		2.09
Blytheville AFB		3.55	3.42
Castle AFB		2.0	2.23
Charleston AFB		2.19	2.71
Cannon AFB		2.44	1.83
		1.61	1.66
Columbus AFB		2.23	2.44
		2.10	2.03
Craig AFB		1.29	1.84
		1.58	1.57
Dover AFB	1.58		1.72
England AFB	2.21		2.92
Homestead AFB		1.80	2.08
Hurlburt Field		1.36	1.99
Mather AFB		1.53	2.02
		1.58	2.31
McChord AFB	1.94		2.33
Myrtle Beach AFB	1.67	1.69	1.77
Moody AFB		1.79	1.71
		1.51	1.48
Rickenbacker AFB	1.84		2.18
Robbins AFB		2.20	1.93
Scott AFB	1.80		1.94
Shaw AFB		2.17	1.83
Travis AFB		2.15	2.27
		2.28	2.83

* SDR is the average of the two central interior test sections (normally designated test sections "C" & "D")

TABLE 7

COMPARISON - AIR FORCE AND NASA DBVs

Comparison of SDR data between the Air Force DBV and the NASA DBV on the Roswell Industrial Center Runway.

RUN NUMBER	SECTION DESIGNATION	AIR FORCE SDR	NASA SDR
		24 October 1973	
16	A-B	1.83	1.90
16	C-D	2.24	2.33
16	E-F	2.26	2.51
17	A-B	2.13	2.32
17	C-D	2.50	2.66
17	E-F	2.45	2.81
18	A-B	1.86	2.15
18	C-D	2.22	2.45
18	E-F	2.33	2.47
		25 October 1973	
1	A-B	2.34	2.32
1	C-D	2.38	2.46
1	E-F	2.40	2.45
2	A-B	2.26	2.27
2	C-D	2.27	2.28
2	E-F	2.30	2.21
3	A-B	2.38	2.53
3	C-D	2.40	2.47
4	A-B	2.40	2.45
4	C-D	2.32	2.34
5	A-B	2.52	2.62
5	C-D	2.58	2.47
5	E-F	2.52	2.54
6	A-B	2.15	2.27
6	C-D	2.27	2.27
6	E-F	2.33	2.30
without sandbags added to increase weight of USAF DBV			
7	A-B	2.02	2.39
7	C-D	2.34	2.39
7	E-F	2.59	2.47
8	A-B	2.08	2.16
8	C-D	2.25	2.24
8	E-F	2.28	2.29
9	A-B	2.28	2.44
9	C-D	2.48	2.44
9	E-F	2.55	2.59
10	A-B	2.21	2.13
10	C-D	2.16	2.24
10	E-F	2.20	2.30

F I G U R E S

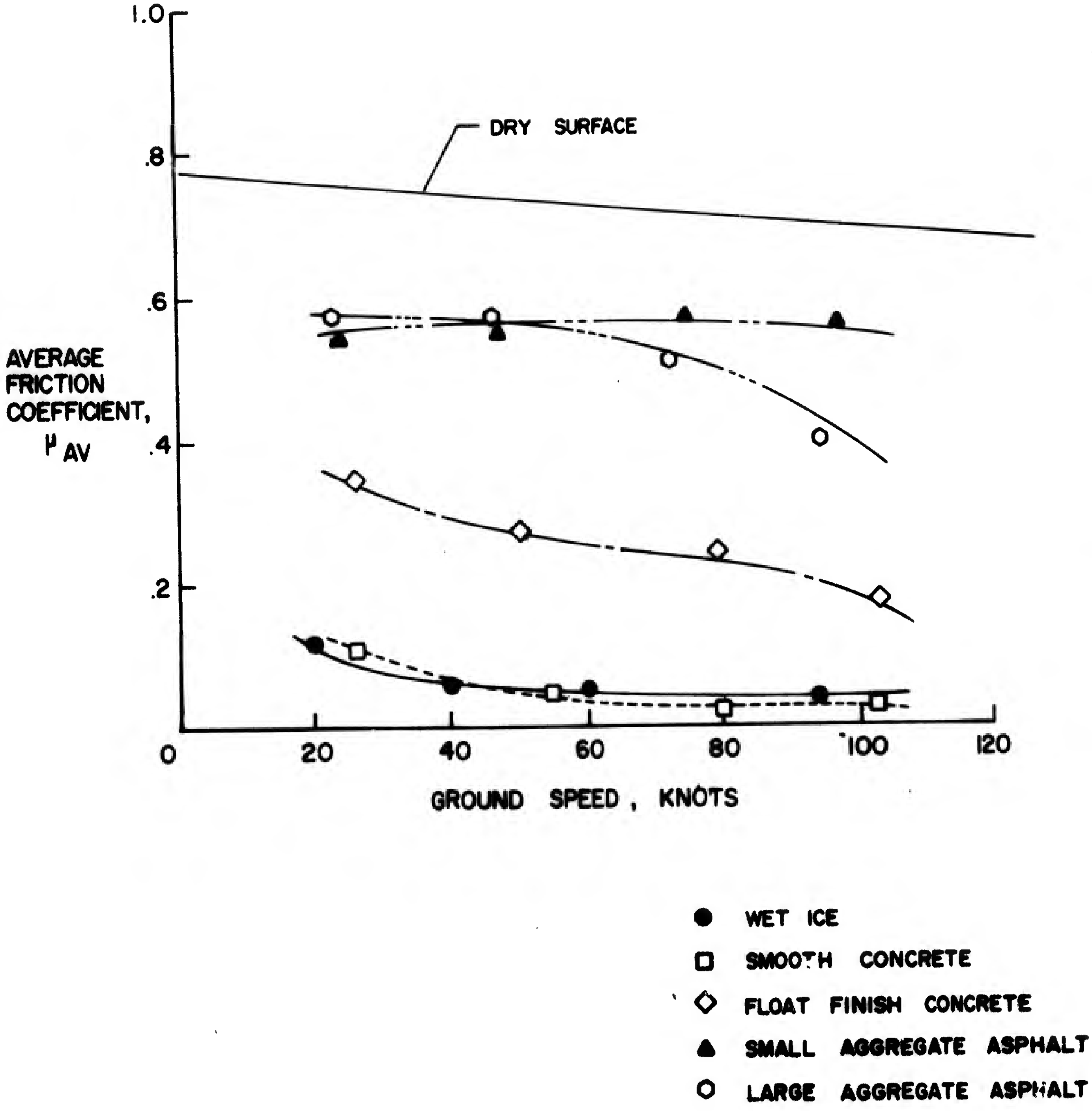


FIGURE 1. DAMP RUNWAY BRAKING EFFECTIVENESS. 32 X 8.8 SMOOTH TREAD; F_Z = 12000 LB (53.4 KN); P = 140 LB/IN² (96.5 N/CM²). (DATA FROM REFERENCE 5)

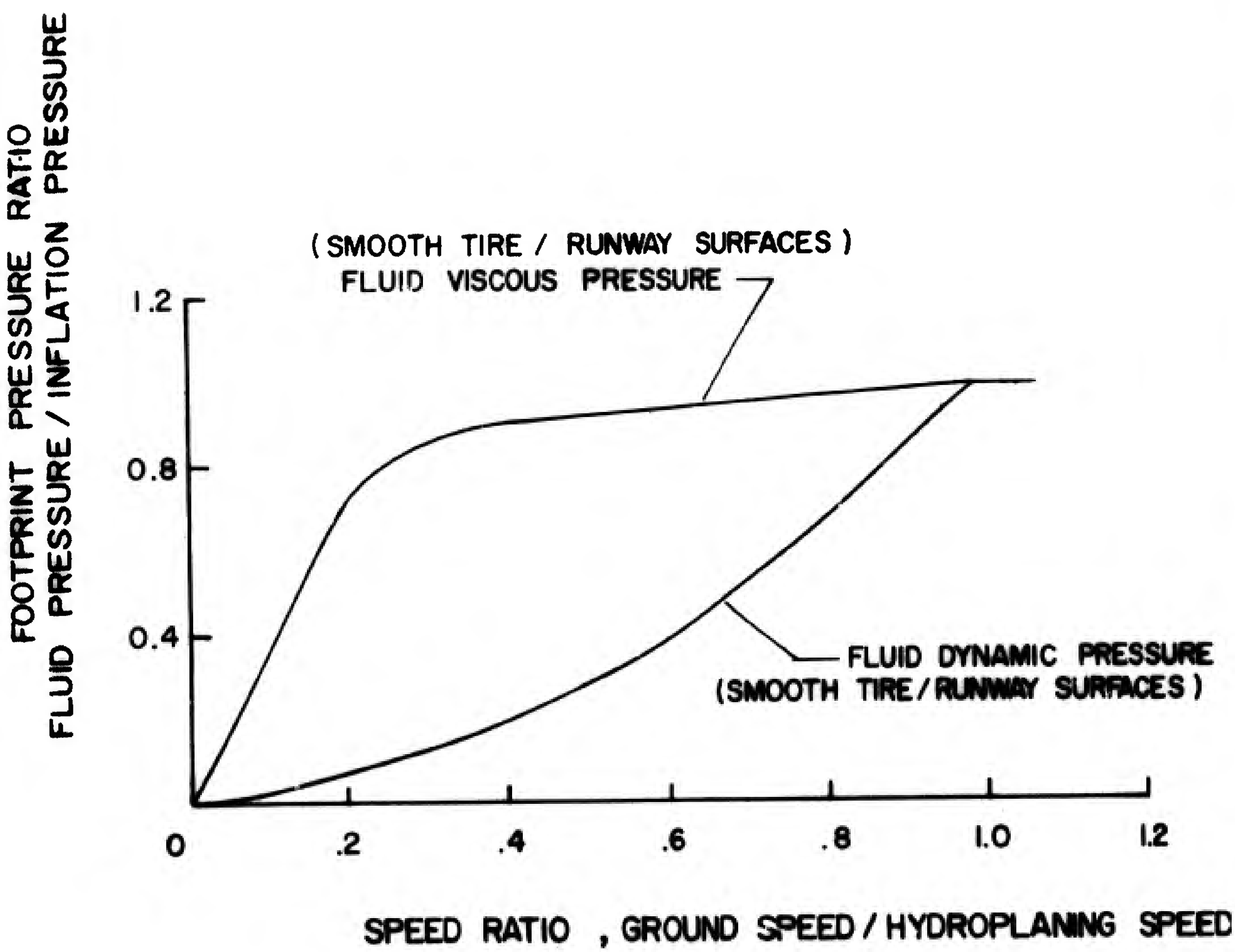


FIGURE 2. FLUID PRESSURE DEVELOPMENT IN TIRE/RUNWAY CONTACT ZONE WITH GROUND SPEED. (DATA FROM REFERENCE 7)

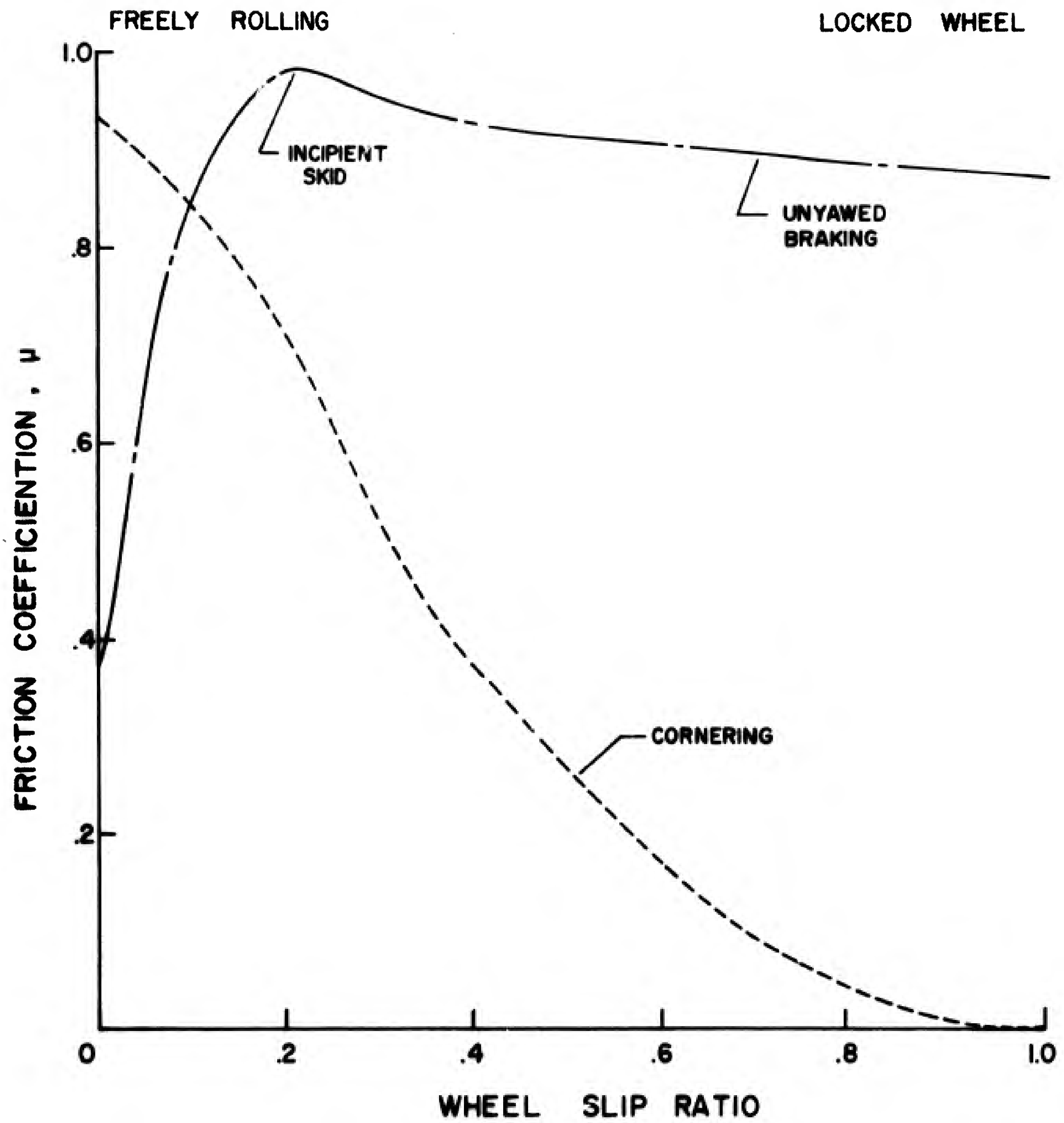


FIGURE 3. TIRE OPERATING MODES, DRY RUNWAYS. (DATA FROM REFERENCE 7)

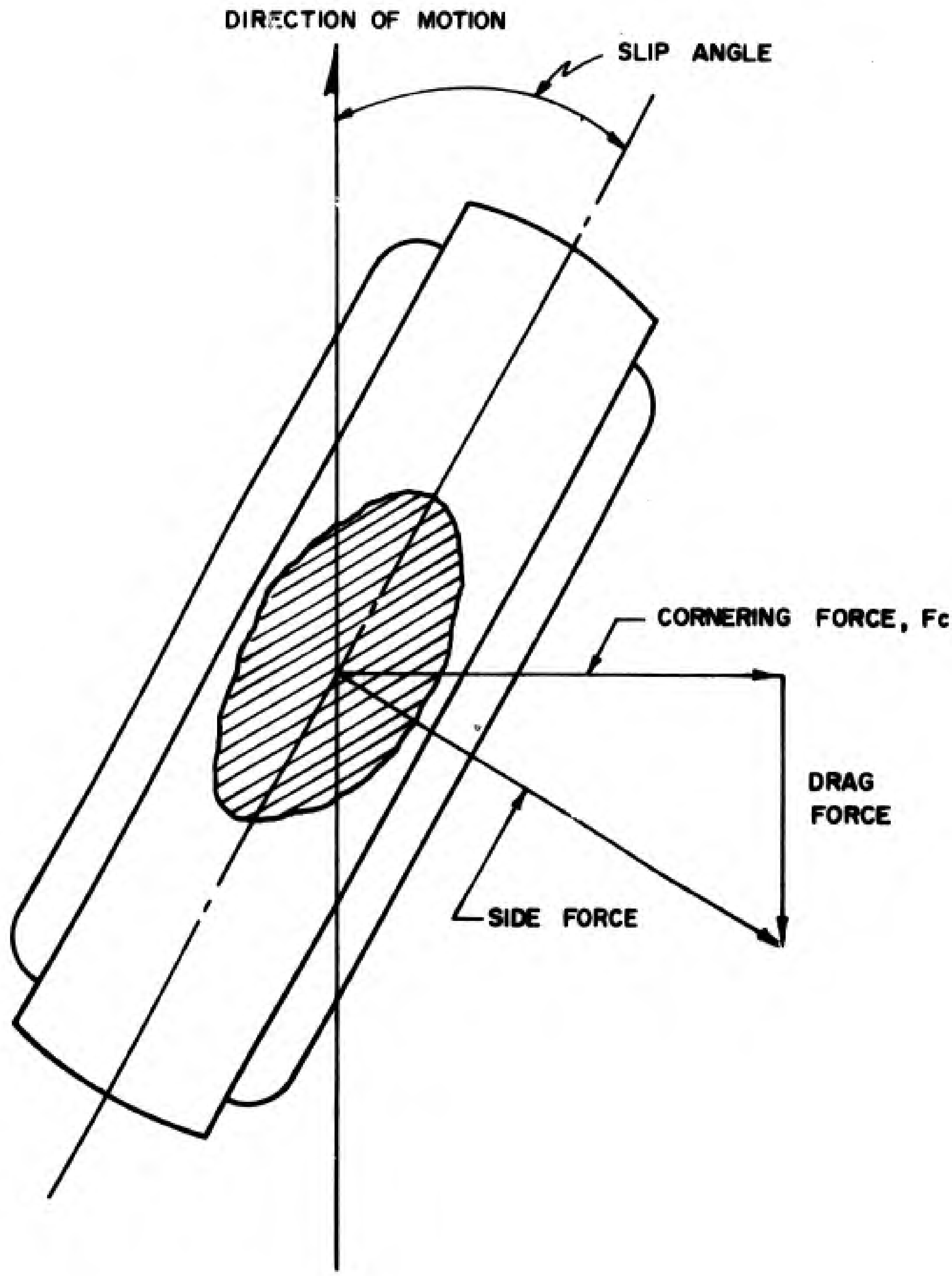


FIGURE 4. TIRE IN CORNERING SLIP MODE.

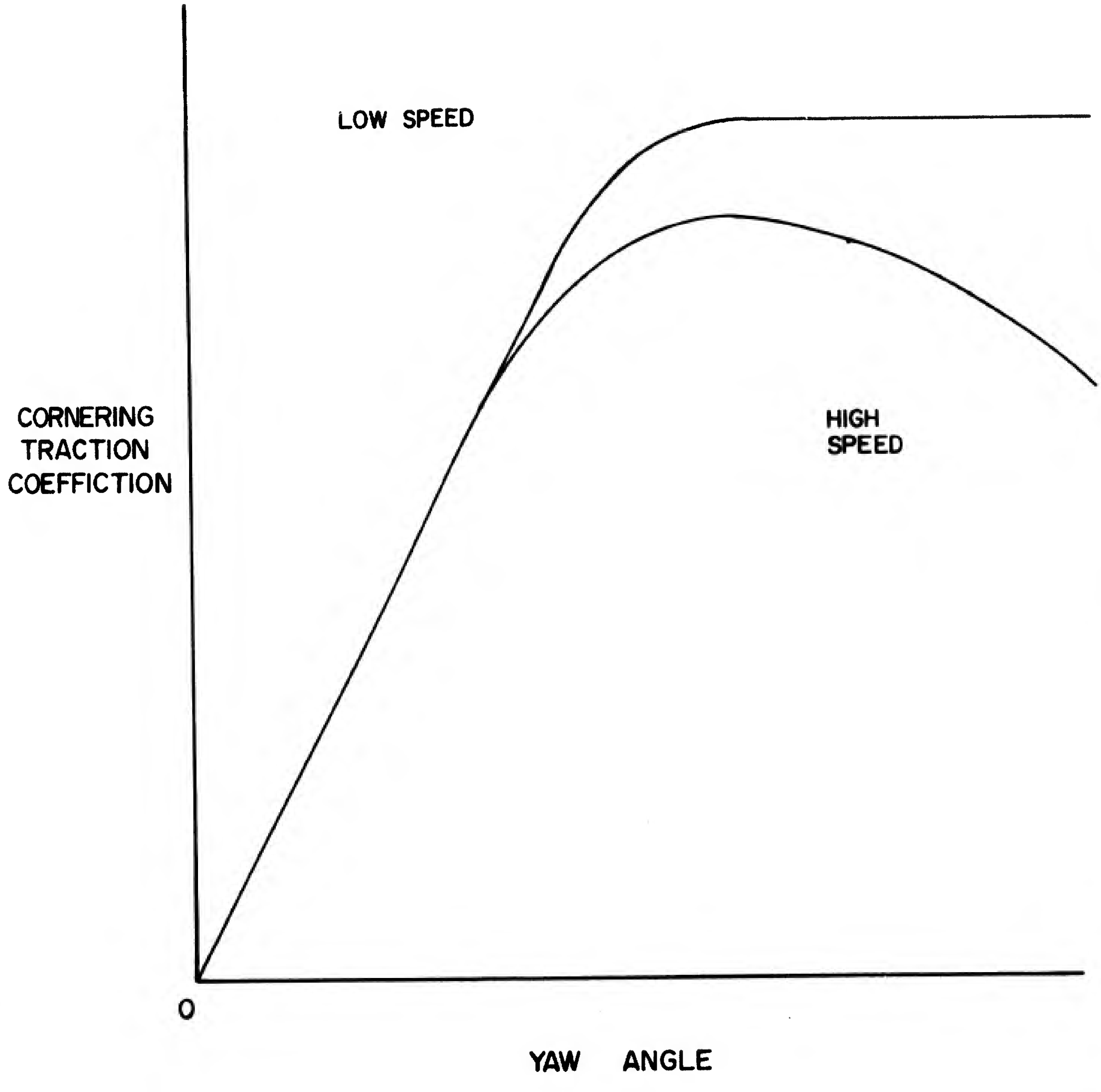


FIGURE 5. UNBRAKED YAWED ROLLING MODE. (FROM DATA REFERENCE 7).

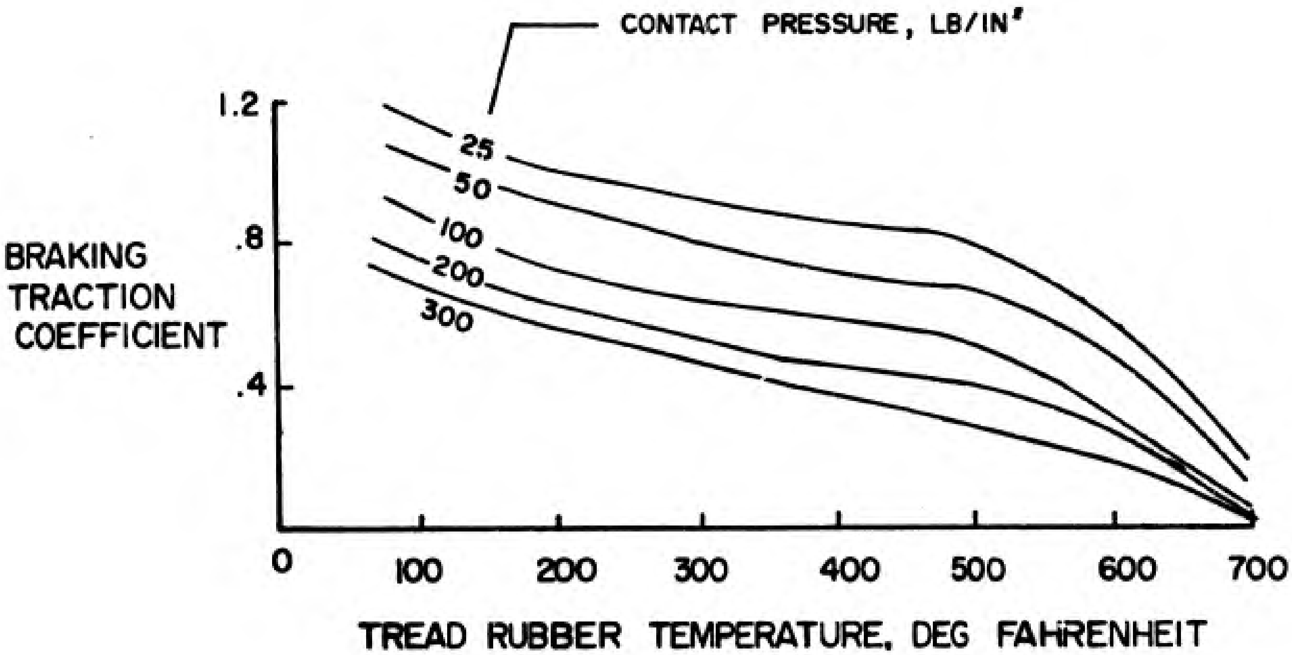


FIGURE 6. TRACTION OF SMALL RUBBER BLOCK SLIDING ON DRY CONCRETE. SPEED < 1 KNOT. (DATA FROM REFERENCE 7)

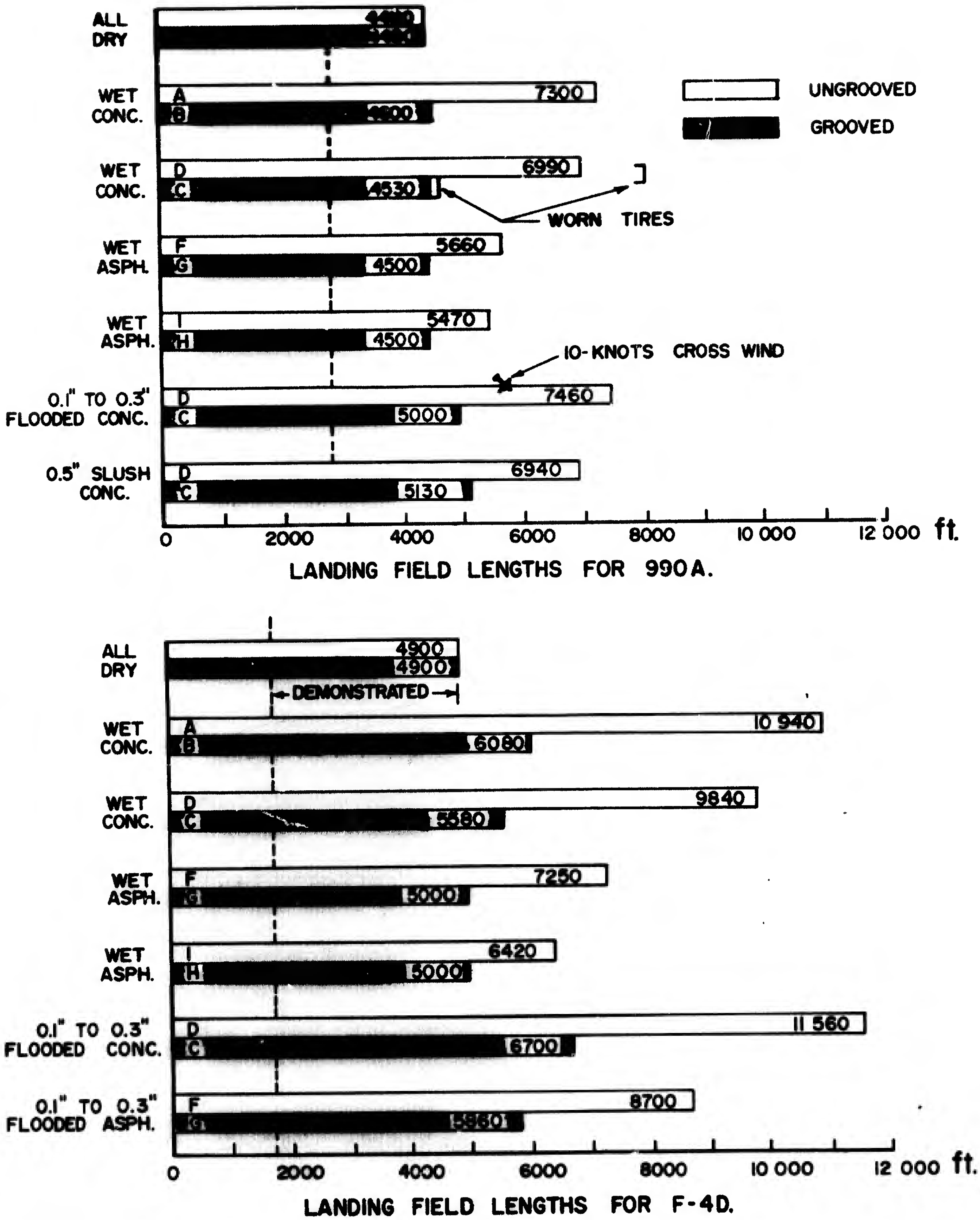


FIGURE 7. LANDING DISTANCES. (DATA FROM REFERENCE 1)

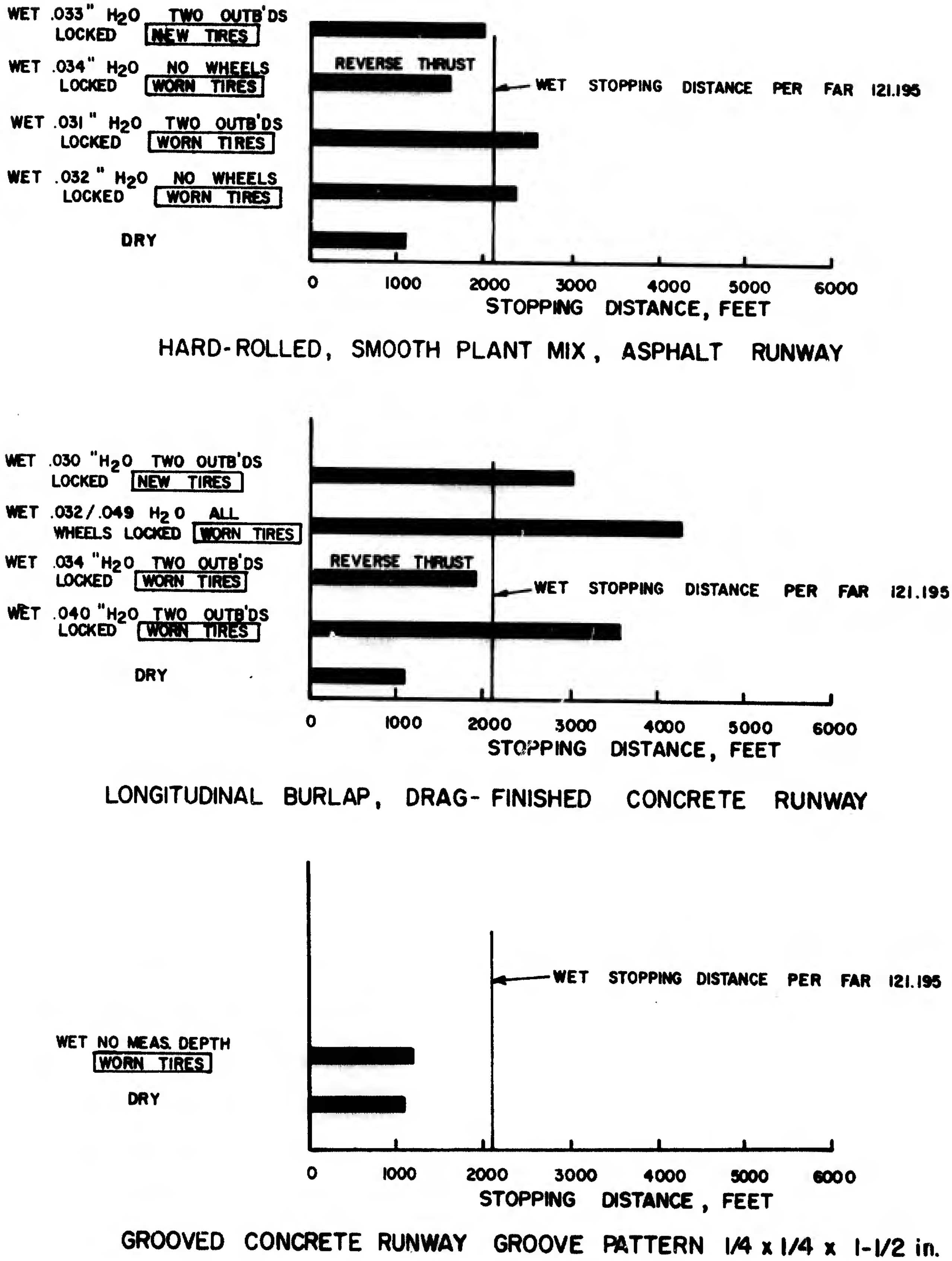


FIGURE 8. WET STOPPING PERFORMANCE FOR B-727. (DATA FROM REFERENCE 13)

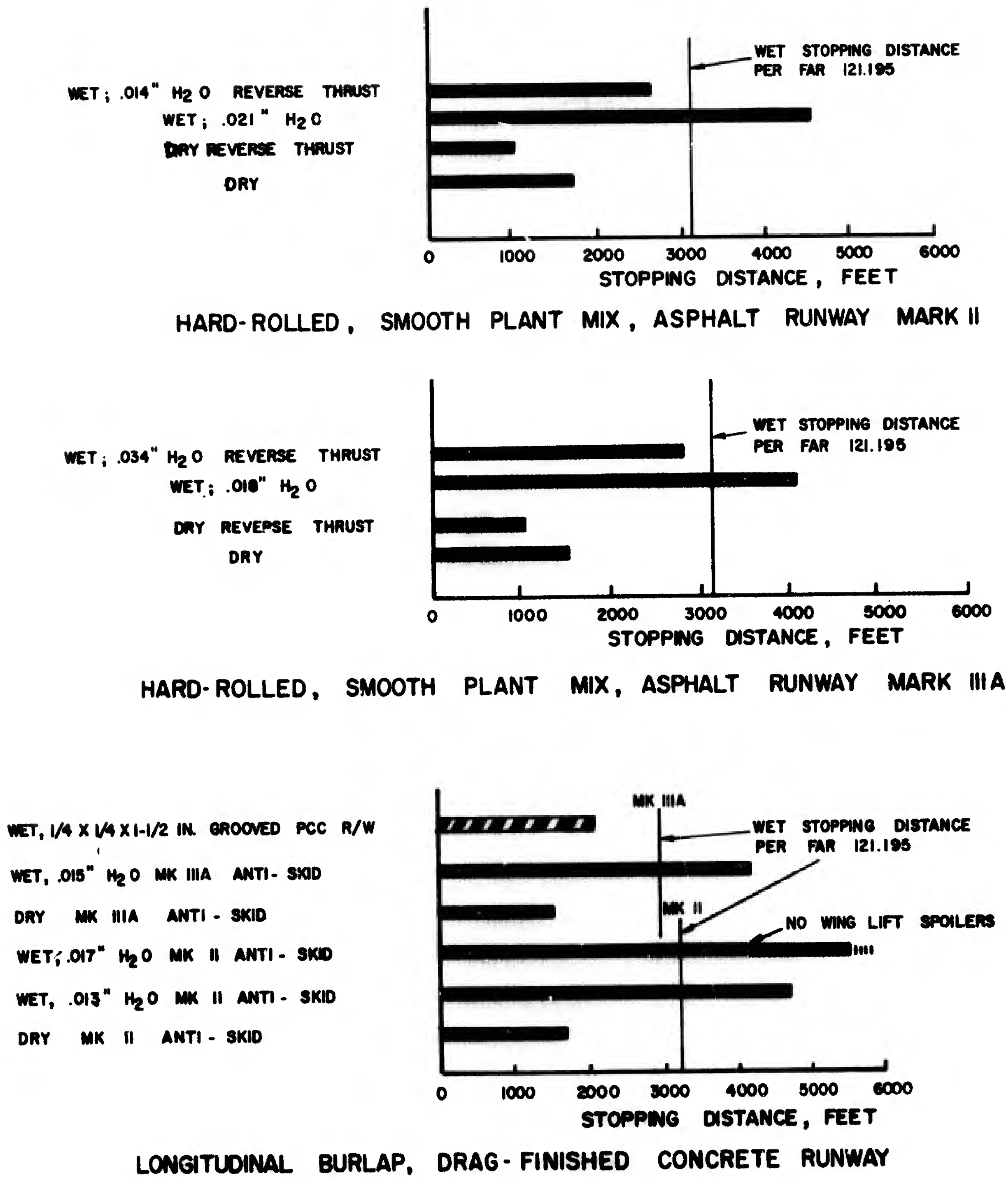


FIGURE 9. WET STOPPING PERFORMANCE FOR DC-9. (DATA FROM REFERENCE 13)

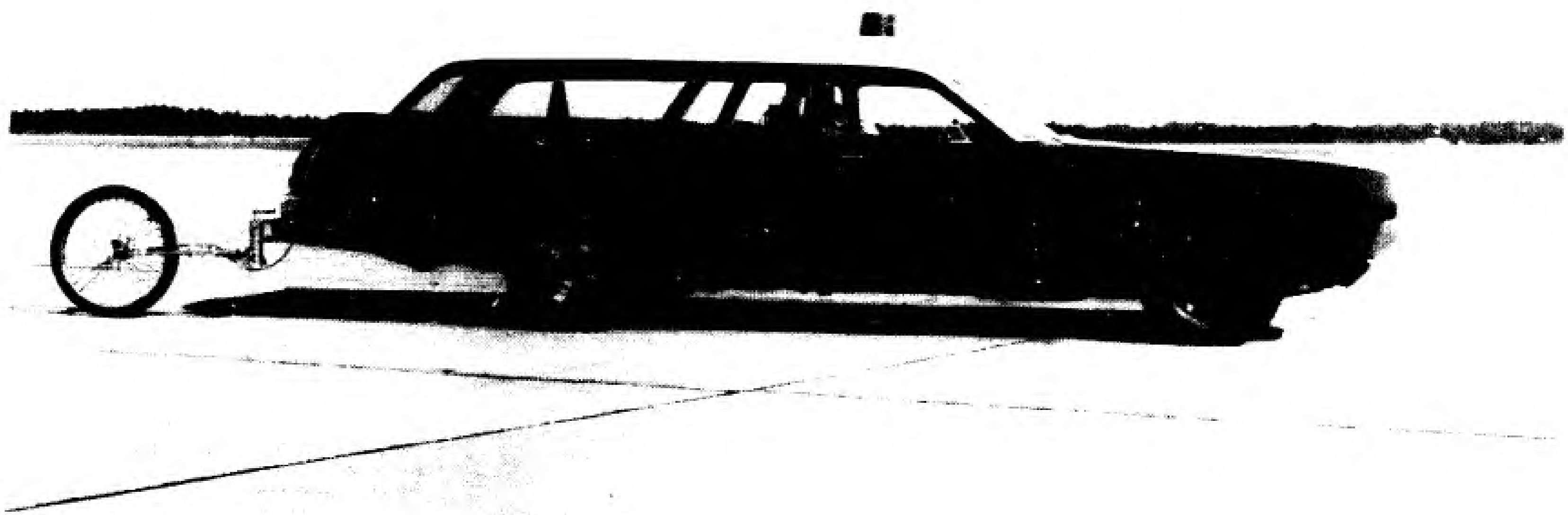


Figure 10. Photograph showing diagonally-braked-vehicle (DBV).

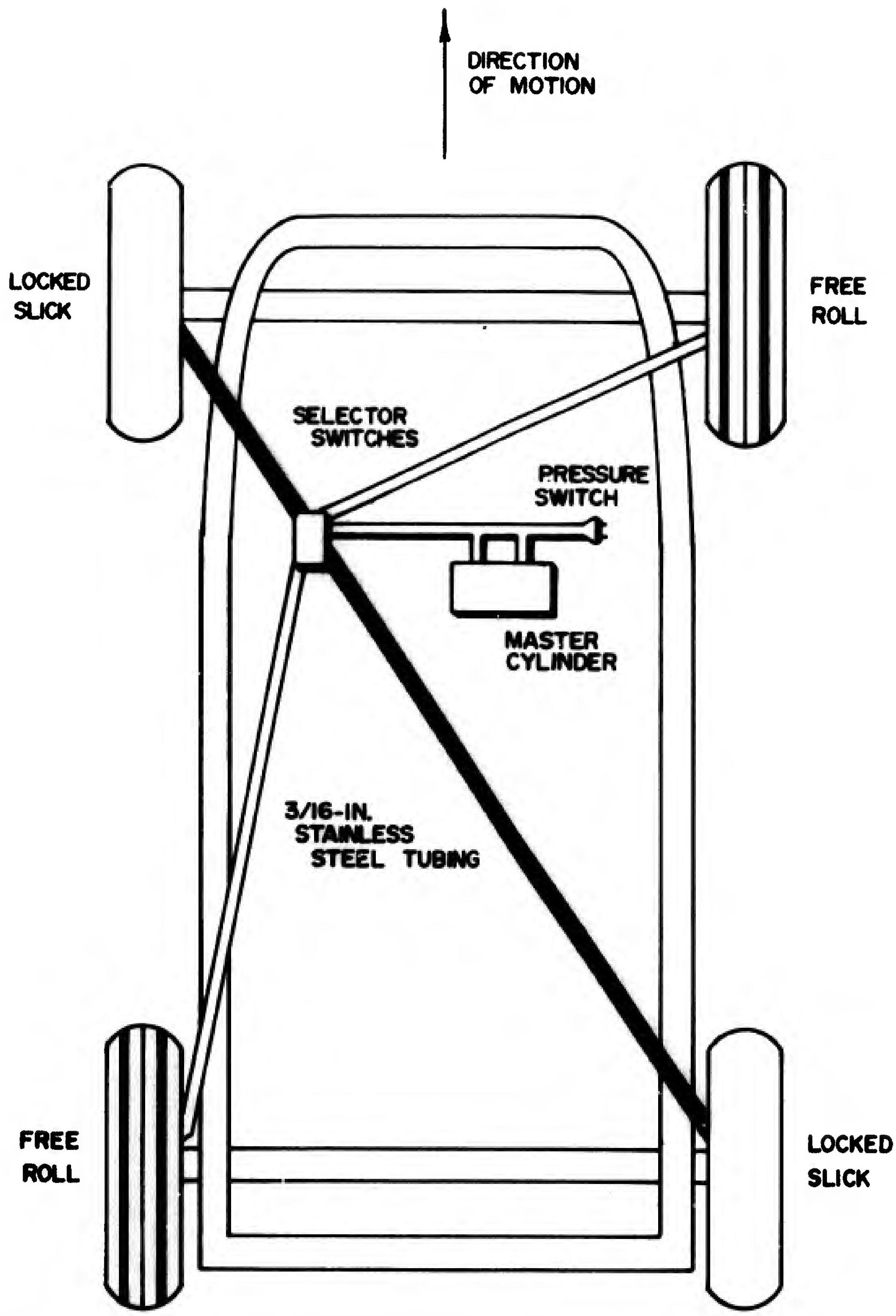


FIGURE 11. MODIFIED BRAKING SYSTEM FOR AFCEC DBV.

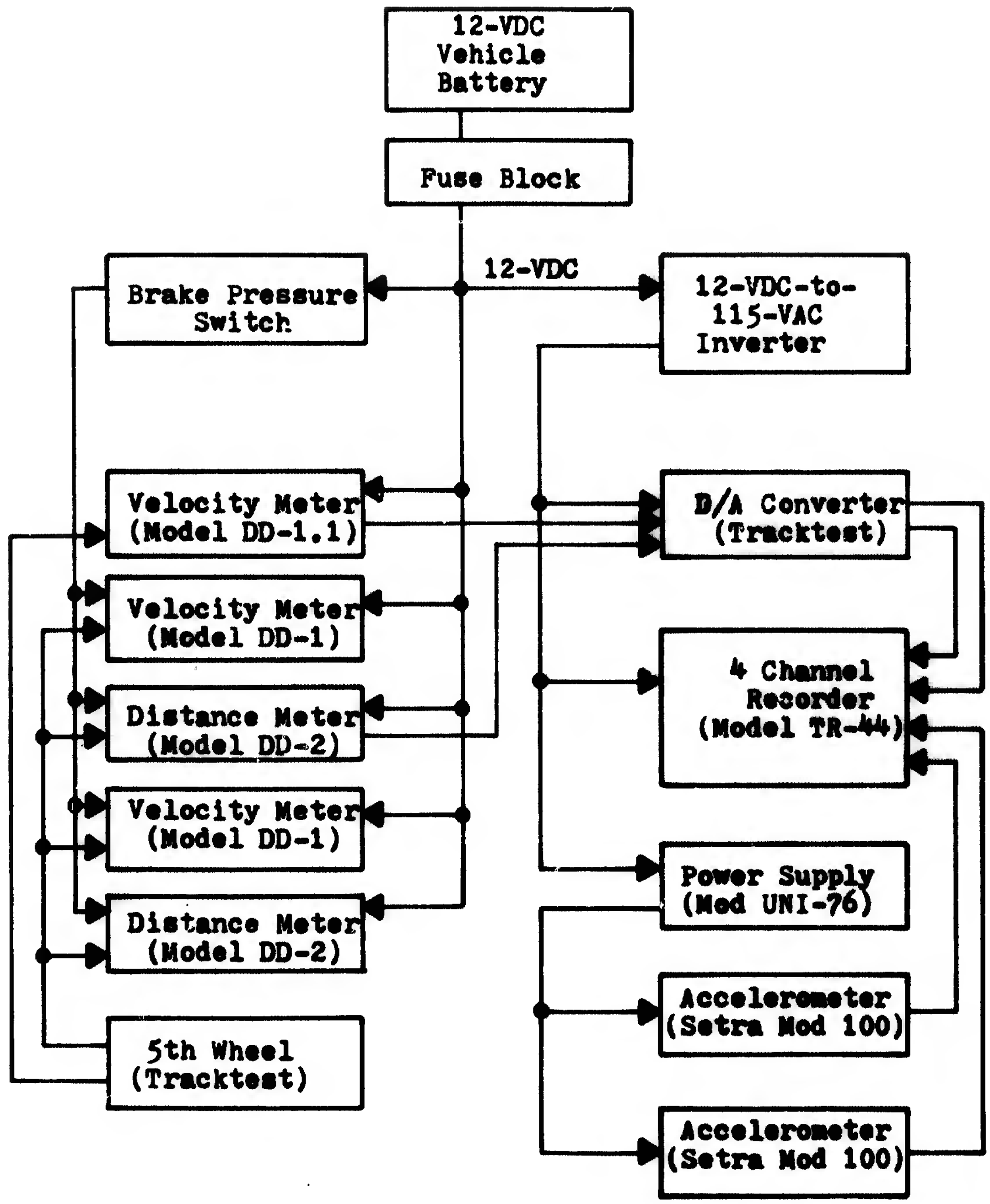


FIGURE 12. DBV INSTRUMENTATION SYSTEM BLOCK DIAGRAM

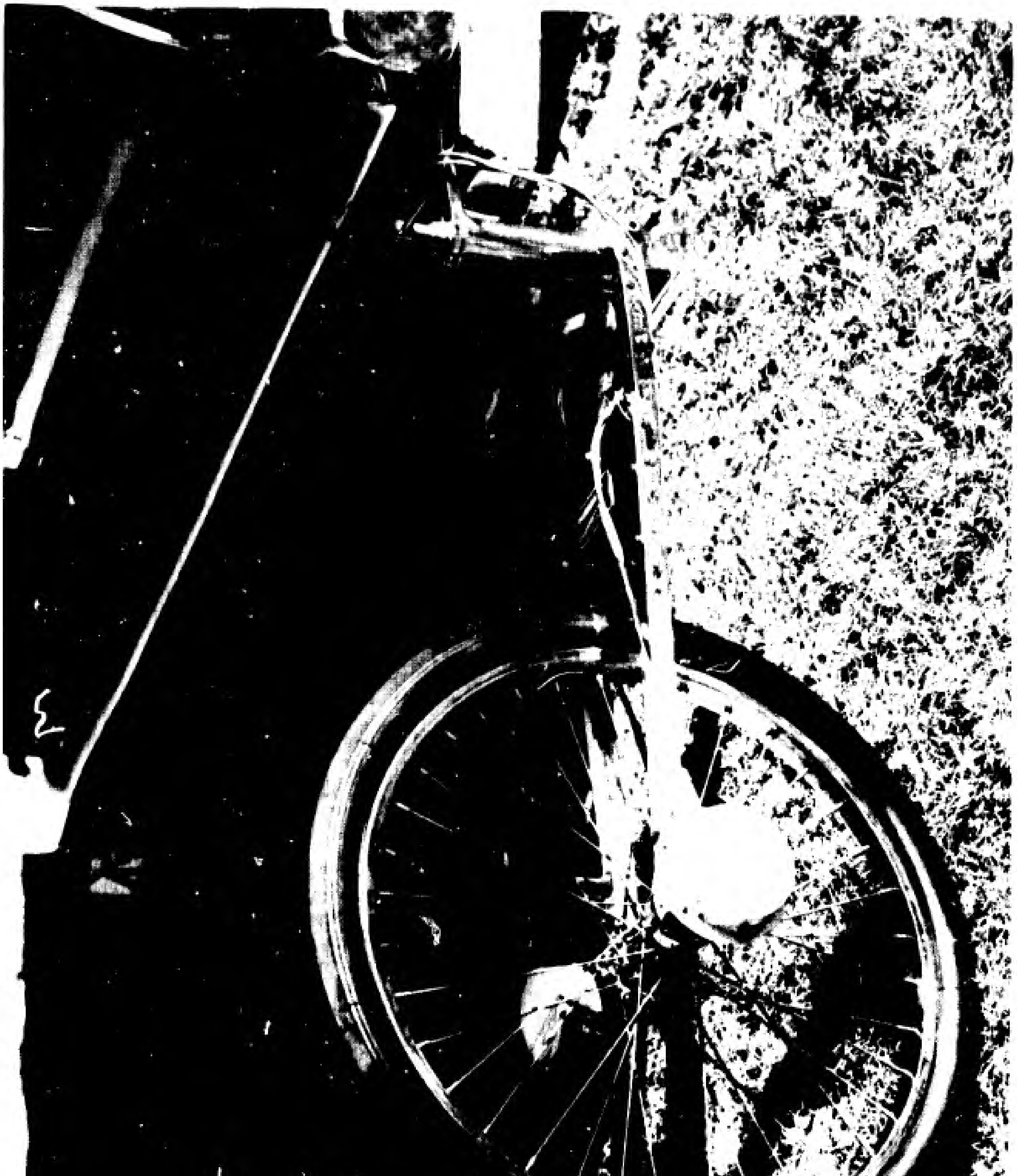


FIGURE 13. PHOTOGRAPH SHOWING FIFTH WHEEL ASSEMBLY ATTACHED TO DBV.

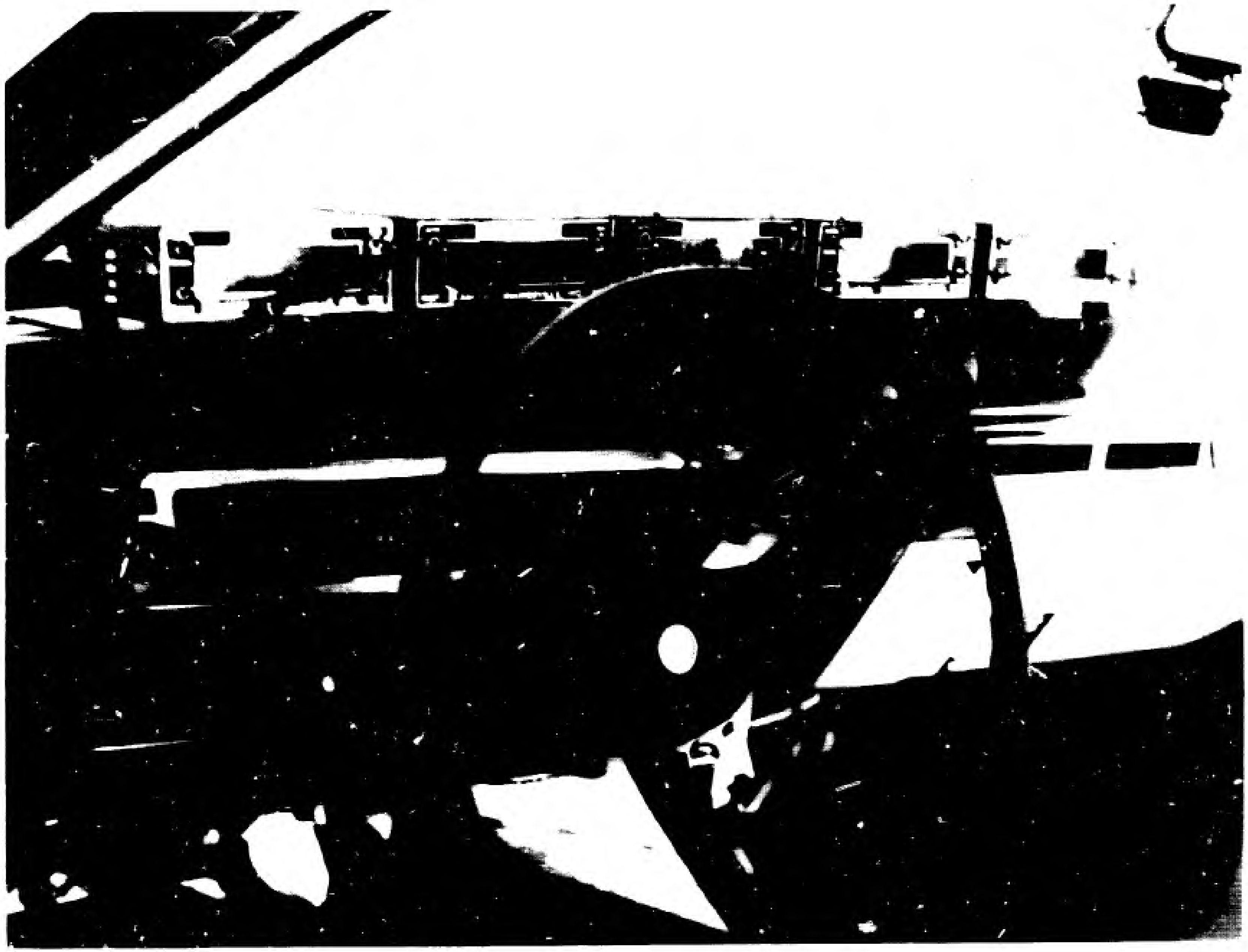


Figure 14. Photograph showing digital speed and distance readouts.

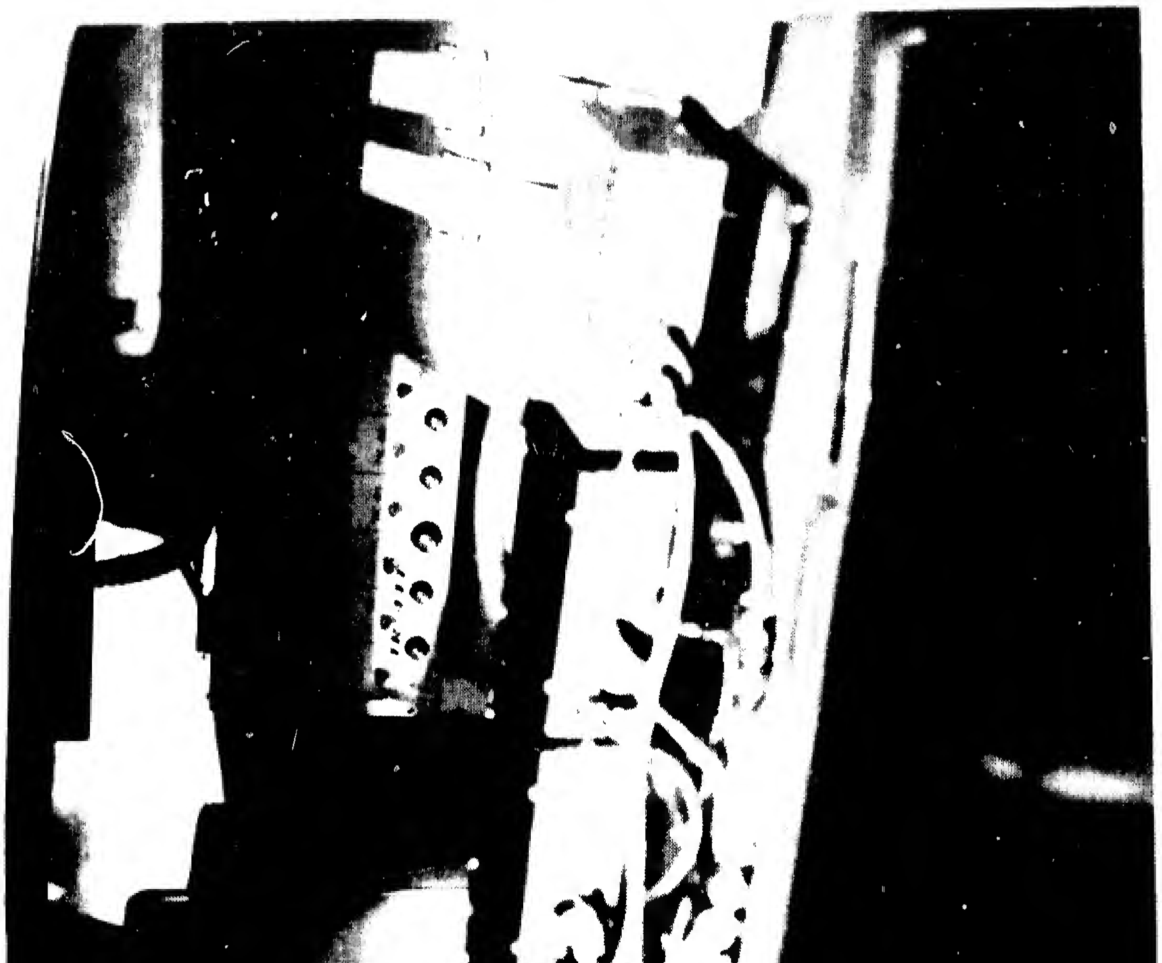


FIGURE 15. PHOTOGRAPH SHOWING DBV RECORDER.

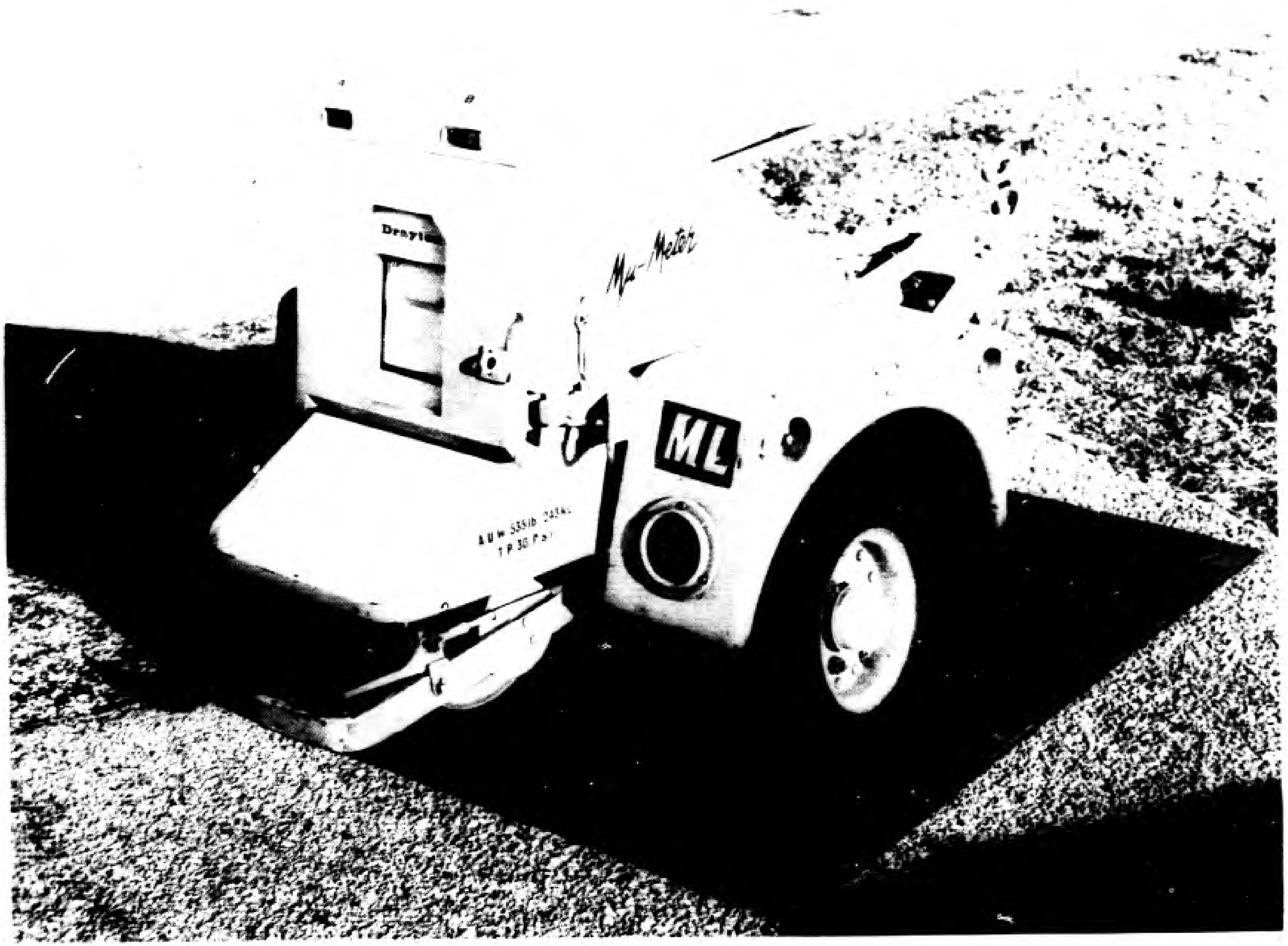


FIGURE 16. PHOTOGRAPH SHOWING MU-METER AND CALIBRATION BOARD.

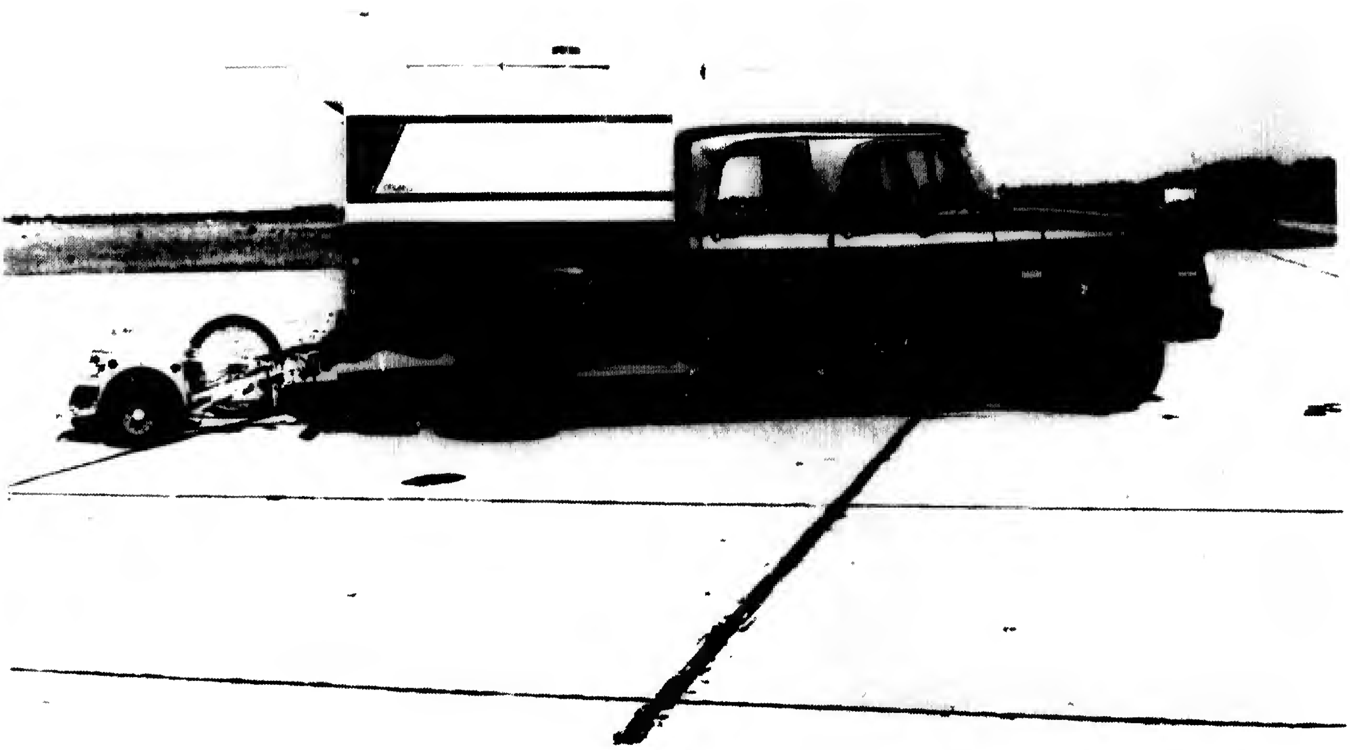


FIGURE 17. PHOTOGRAPH SHOWING MU-METER AND TOWING VEHICLE.

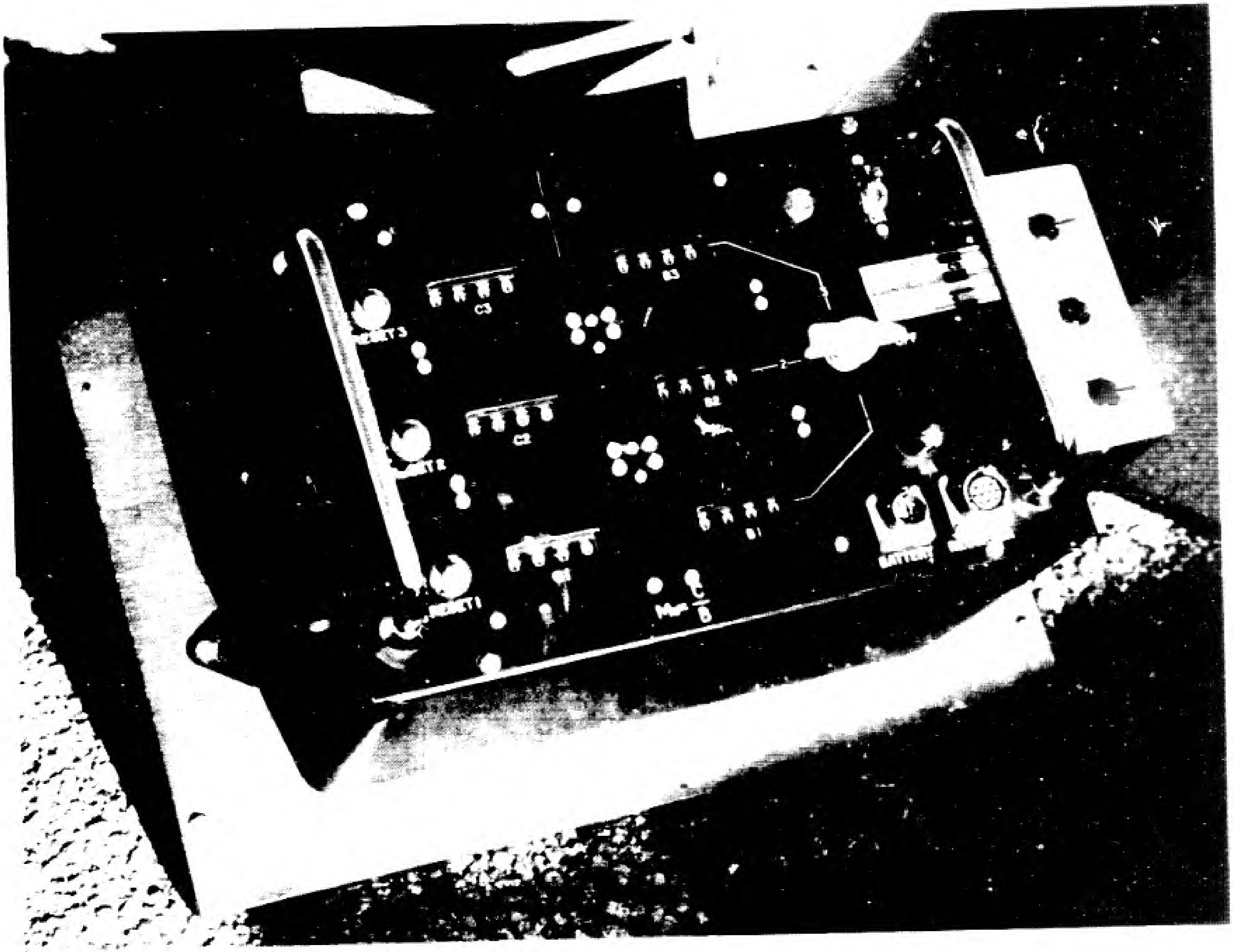


Figure 18. Photograph showing remote readout unit.

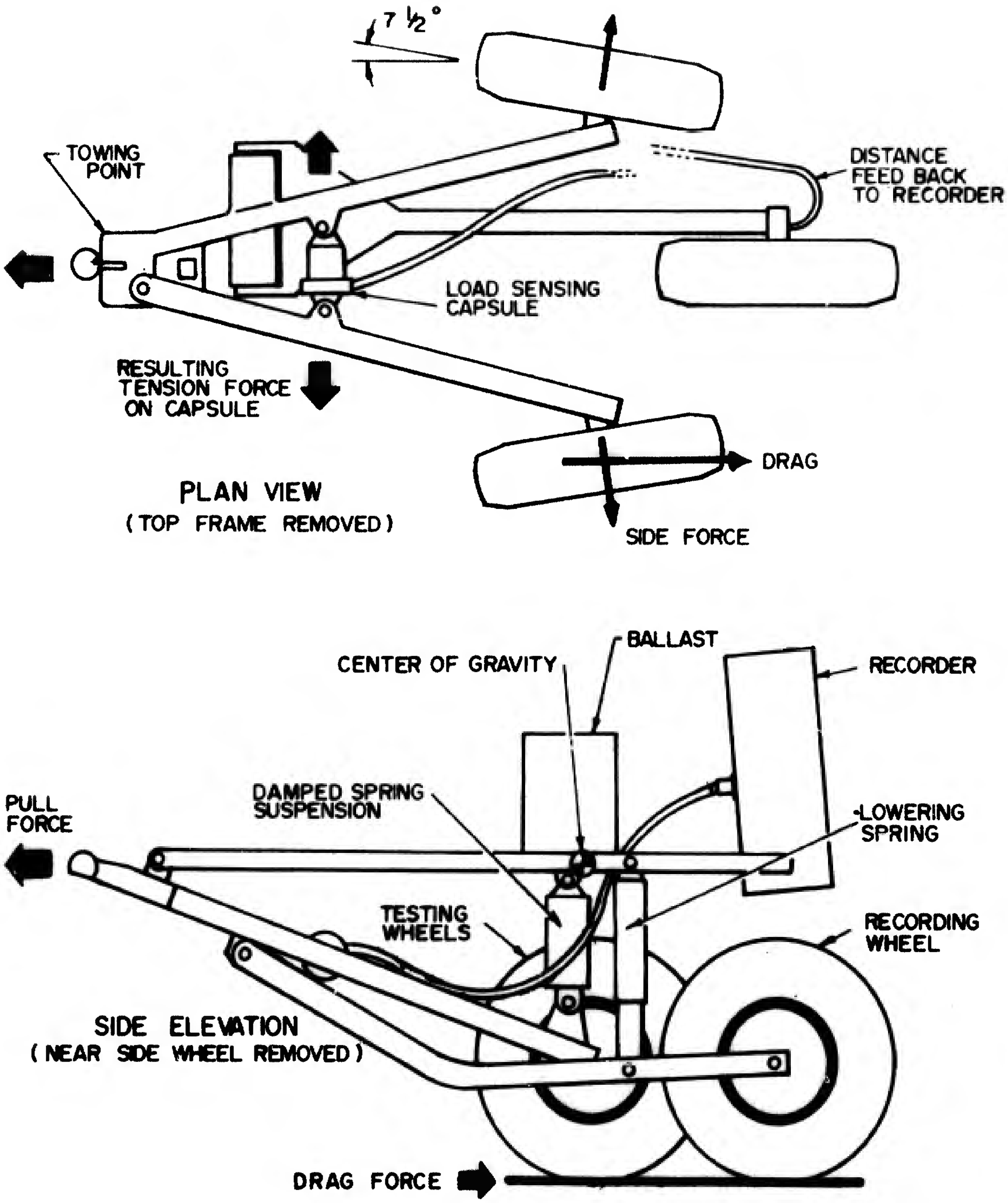


FIGURE 19. D.AGRAMMATIC LAYOUT OF MU-METER.

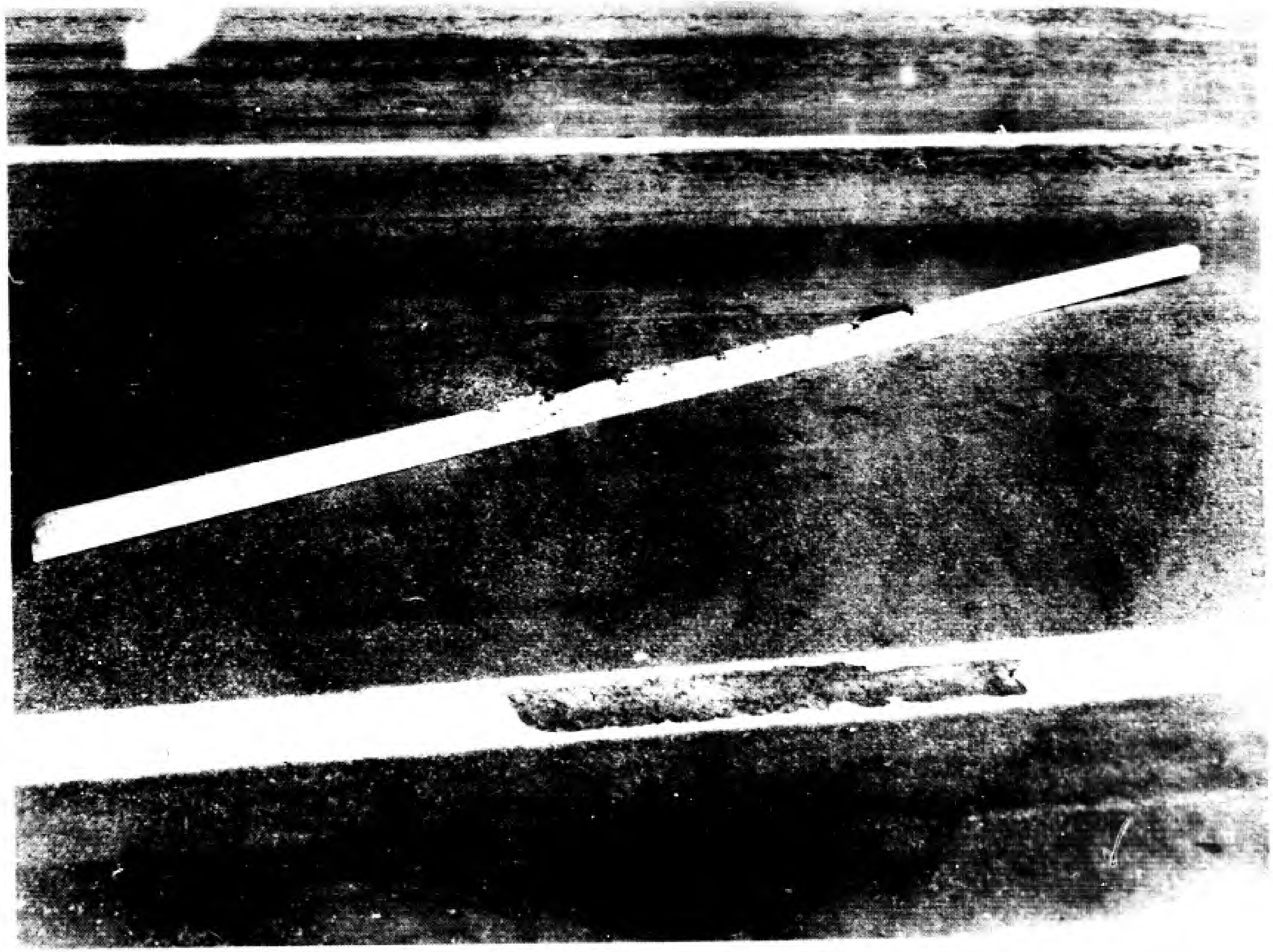


Figure 20. Photograph showing slope measurement device.

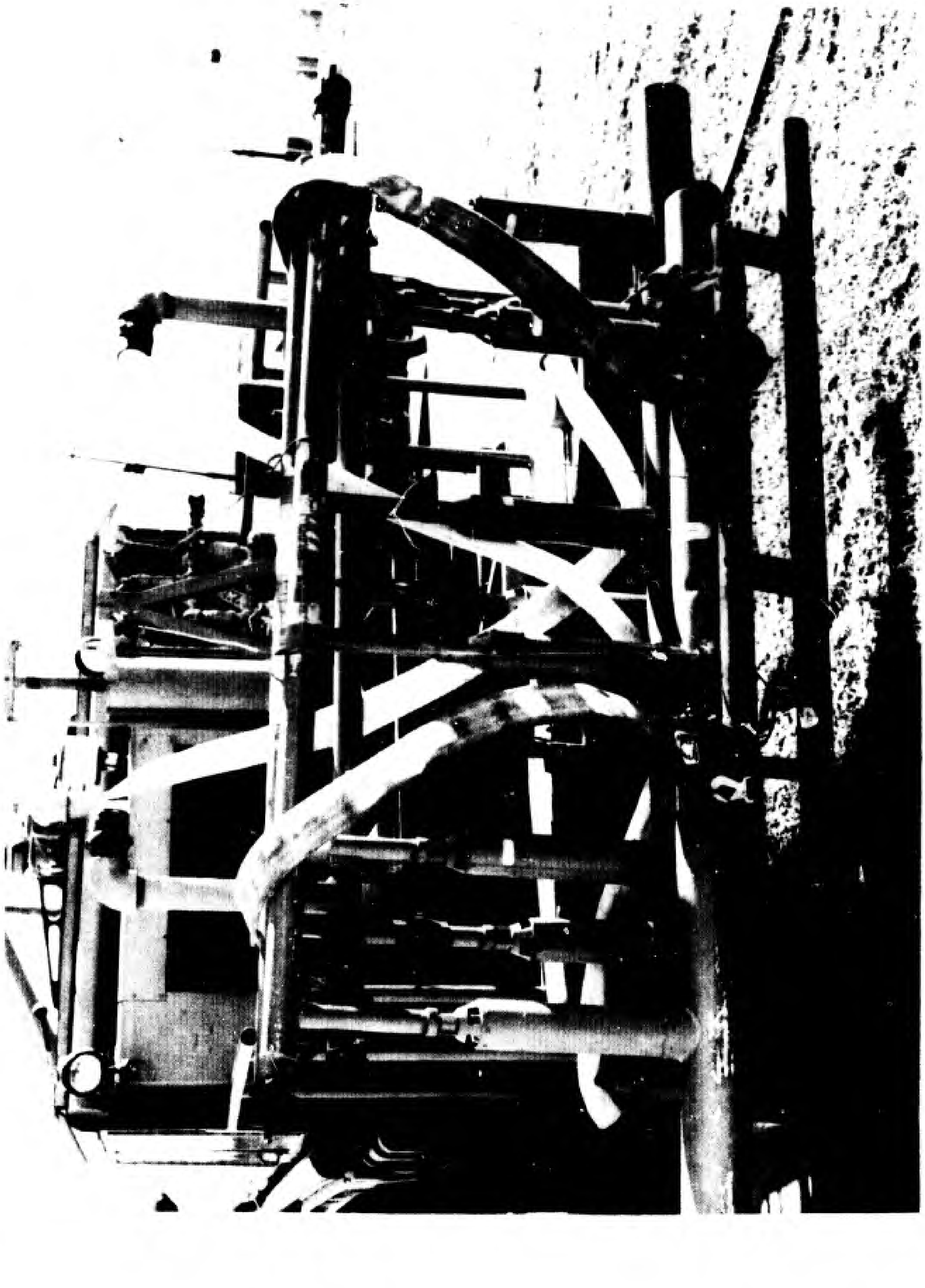


FIGURE 21. PHOTOGRAPH SHOWING AFCEC WATER SPRAY BAR.

FIGURE 22. PHOTOGRAPH SHOWING 300 GPM FLOW METER.

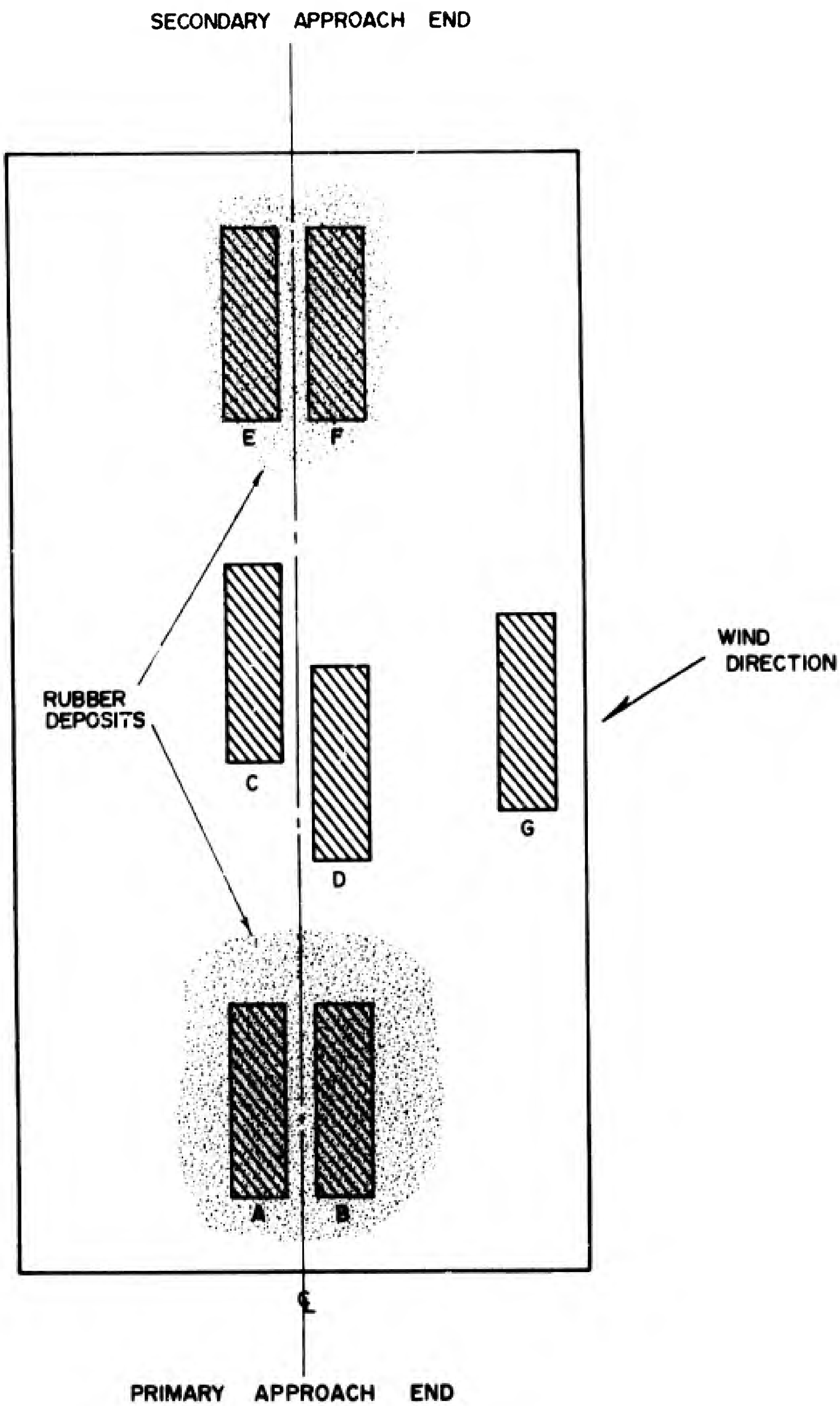


FIGURE 23. TYPICAL LAYOUT OF TEST SECTIONS.

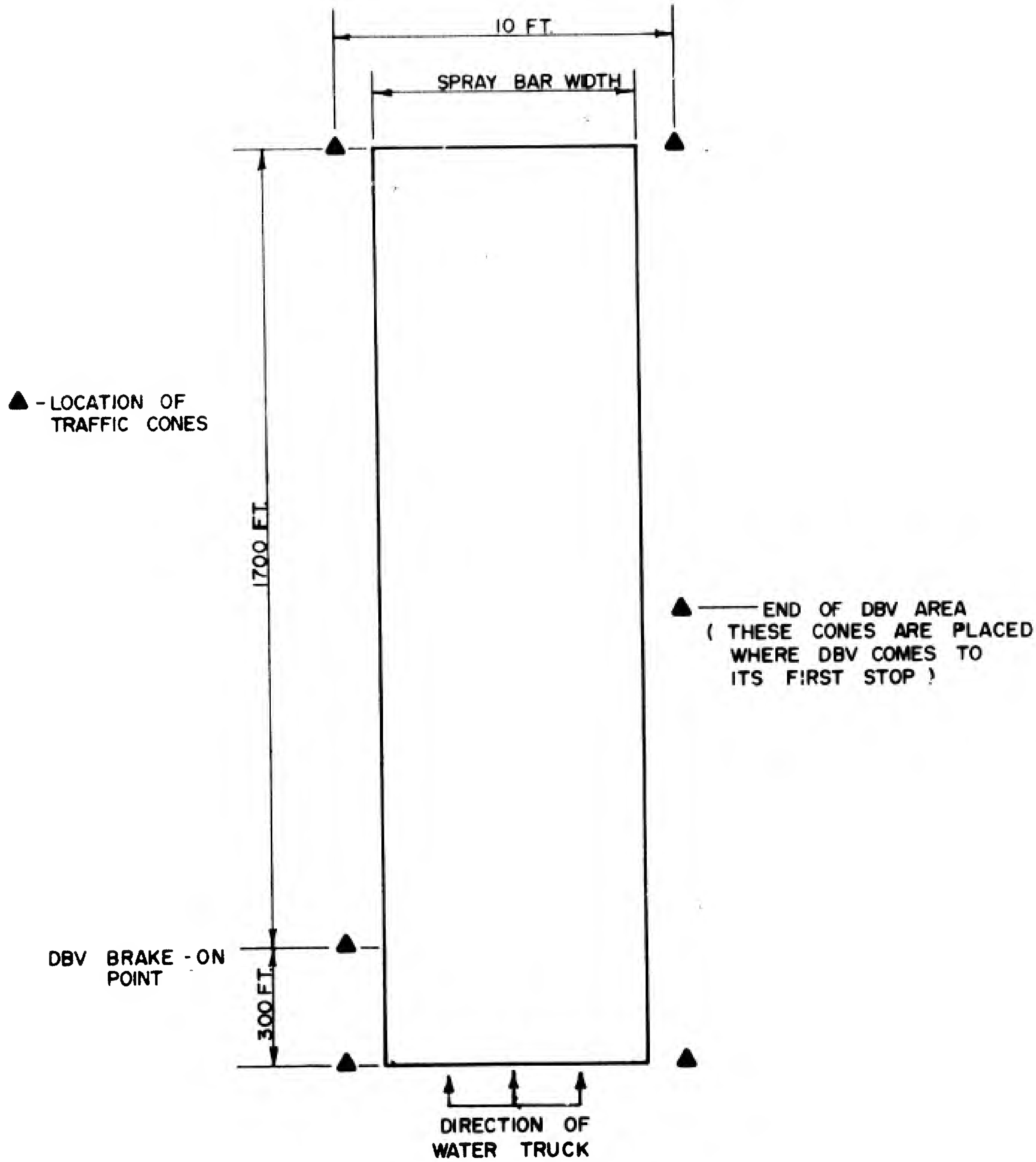


FIGURE 24. TYPICAL SECTION LAYOUT.

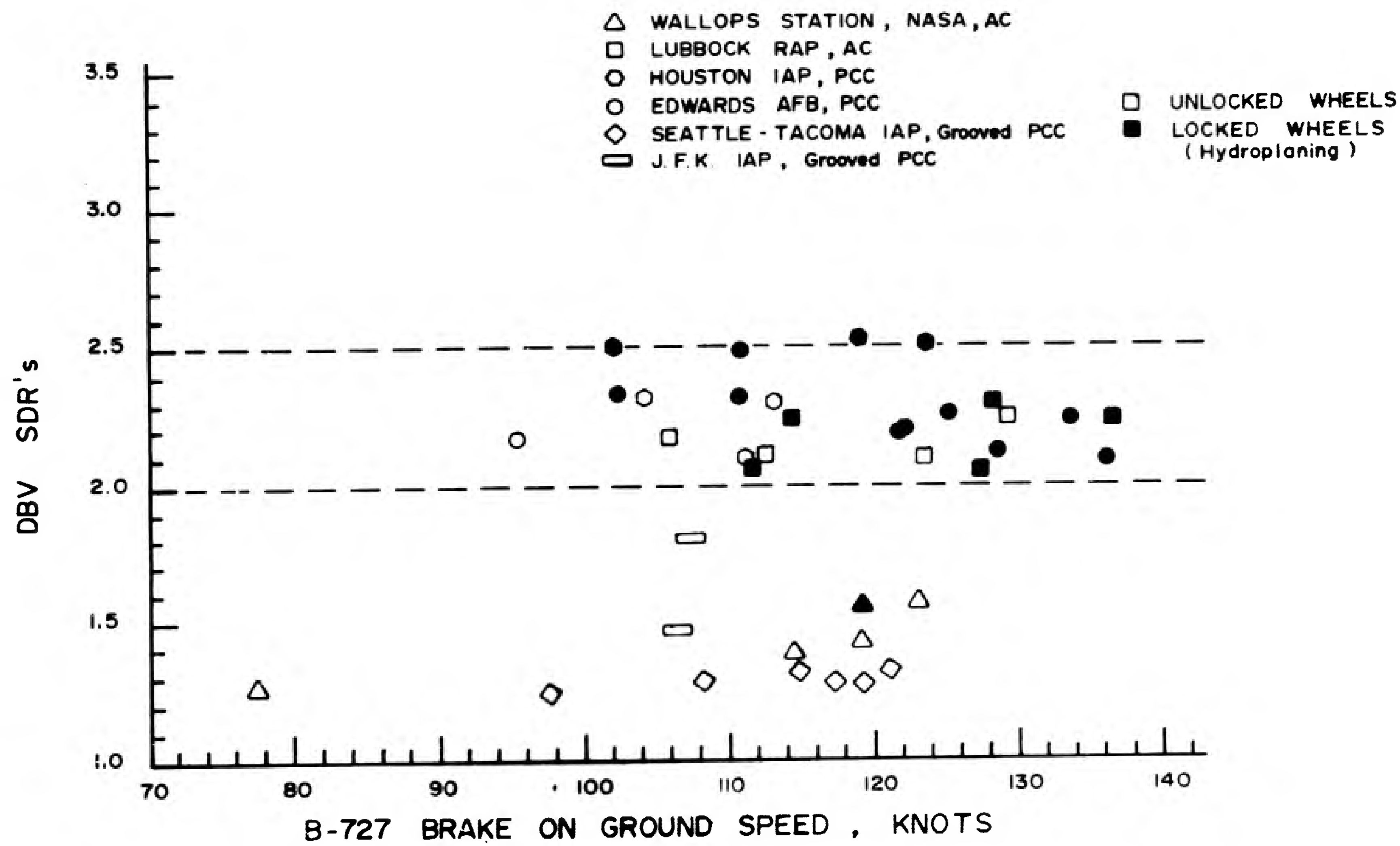


FIGURE 25. COMBAT TRACTION II, PHASE I TEST RESULTS - DBV DATA.

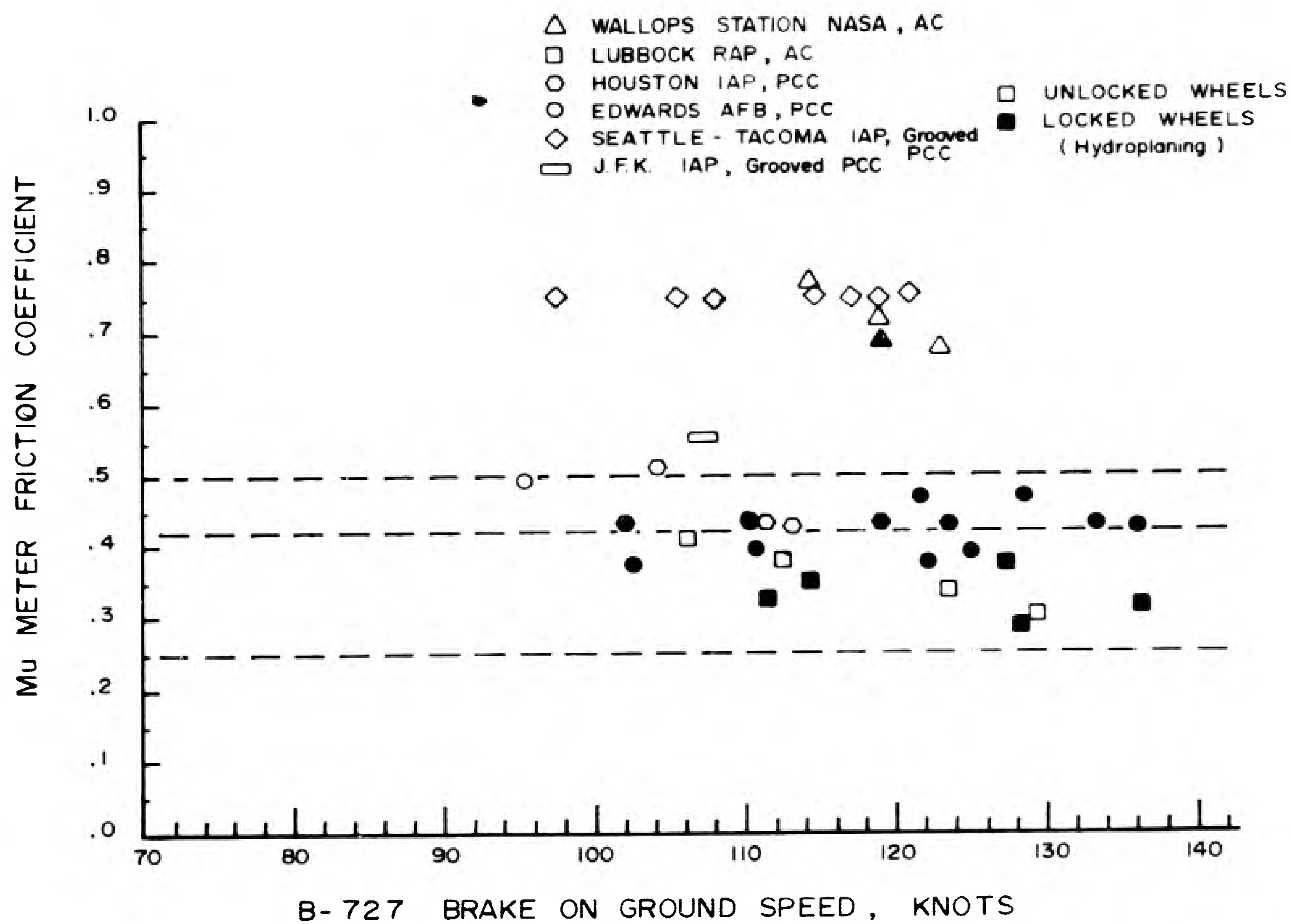
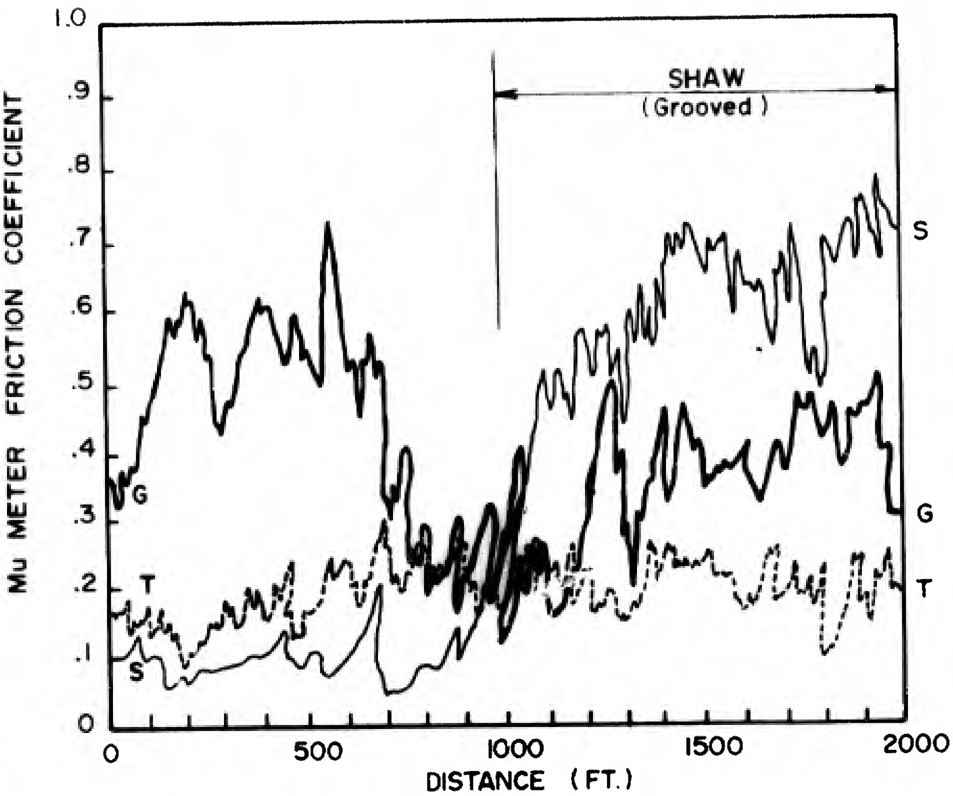


FIGURE 26. COMBAT TRACTION II, PHASE I TEST RESULTS - MU-METER DATA.



S —— SHAW AFB, R/W 04L/22R, SECONDARY TOUCHDOWN END

G —— GRISSOM AFB, R/W 04/22, PRIMARY TOUCHDOWN END

T ---- TRAVIS AFB, R/W 03R/21L, PRIMARY TOUCHDOWN END

FIGURE 27. INITIAL MU-METER TRACES FOR RUBBER DEPOSIT AREAS.

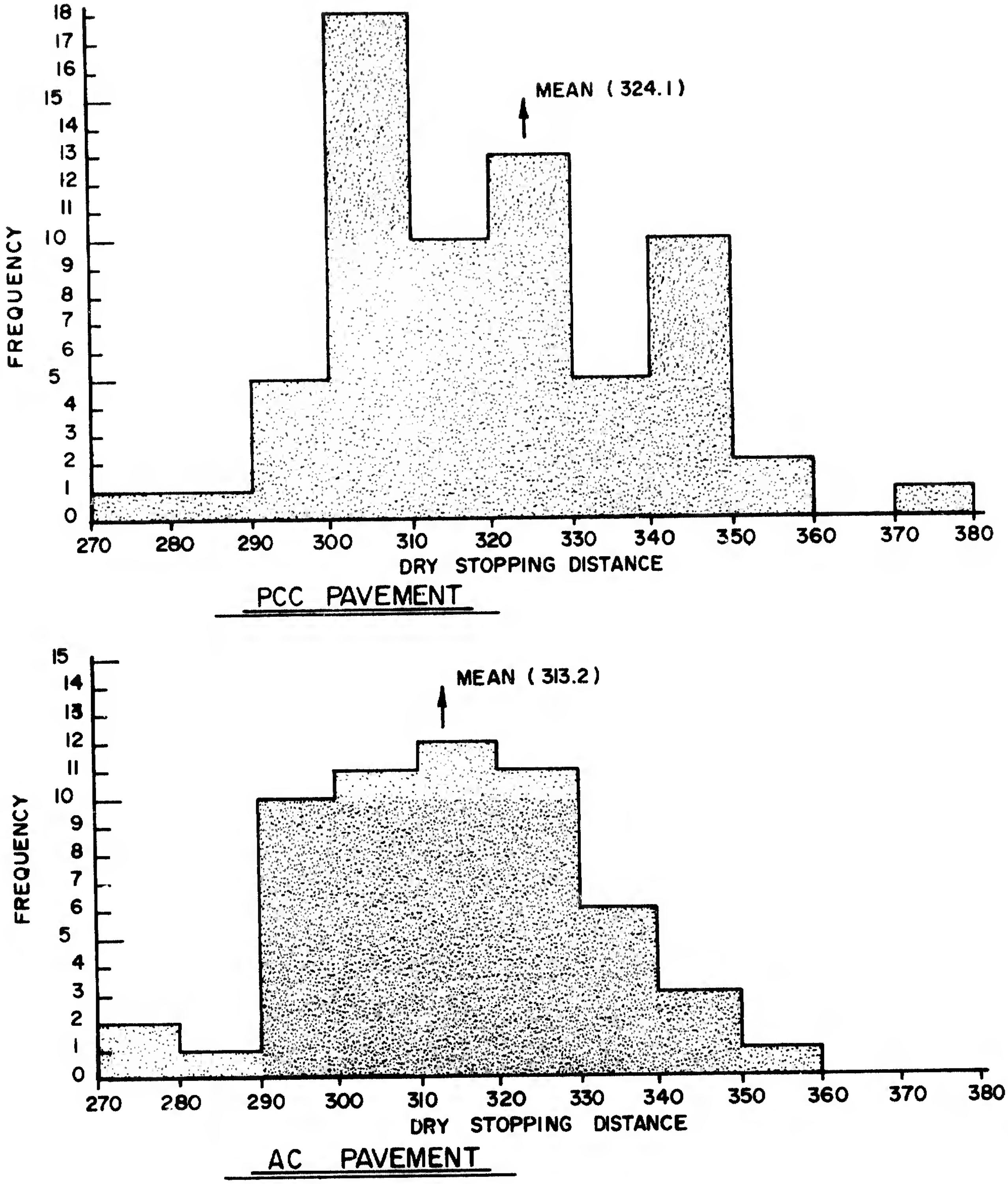


FIGURE 28. HISTOGRAM OF DBV DRY STOPPING DISTANCE.

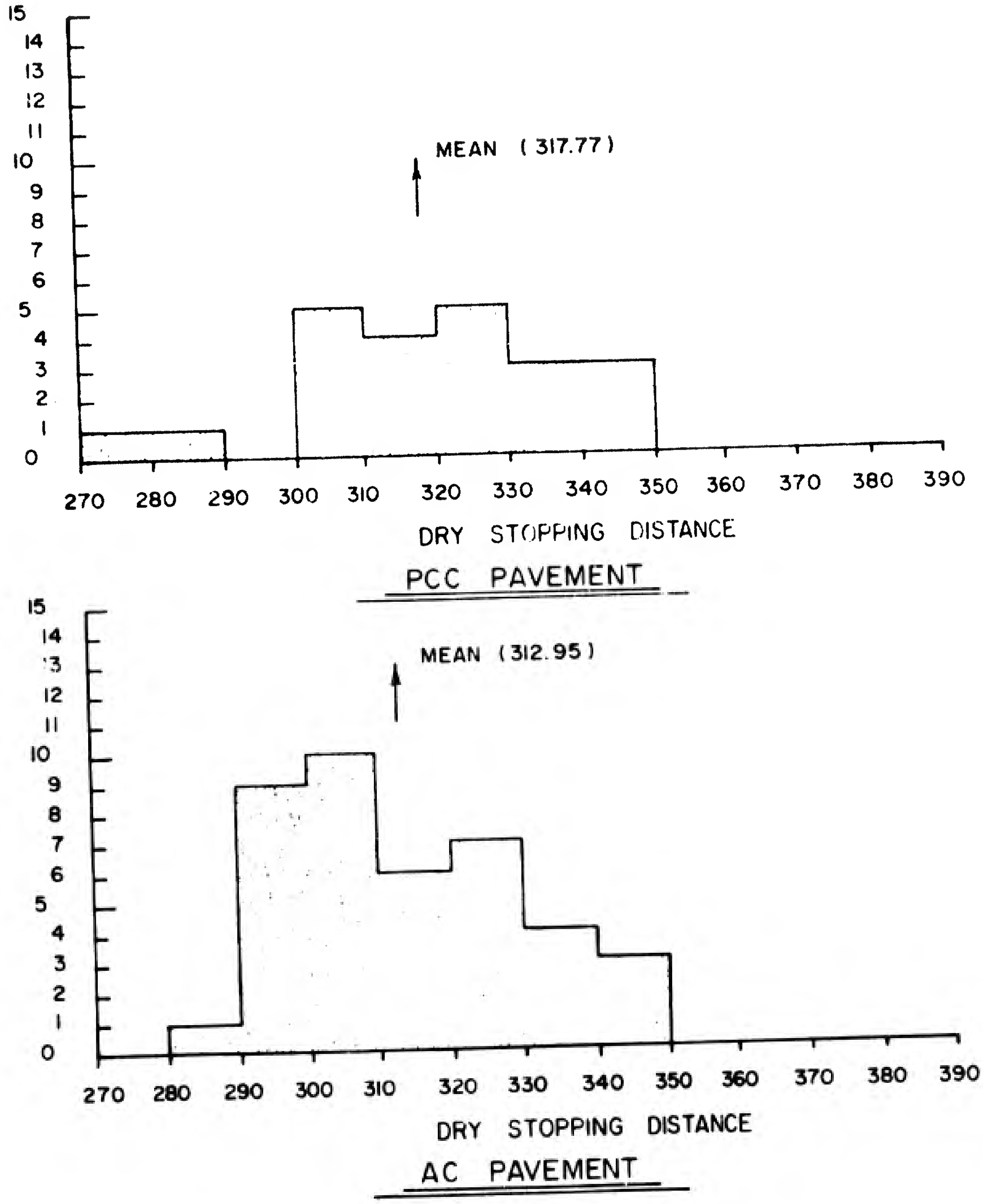


FIGURE 28A. HISTOGRAM OF DBV DRY STOPPING DISTANCE ON CENTRAL INTERIOR AND EDGE TEST SECTIONS.

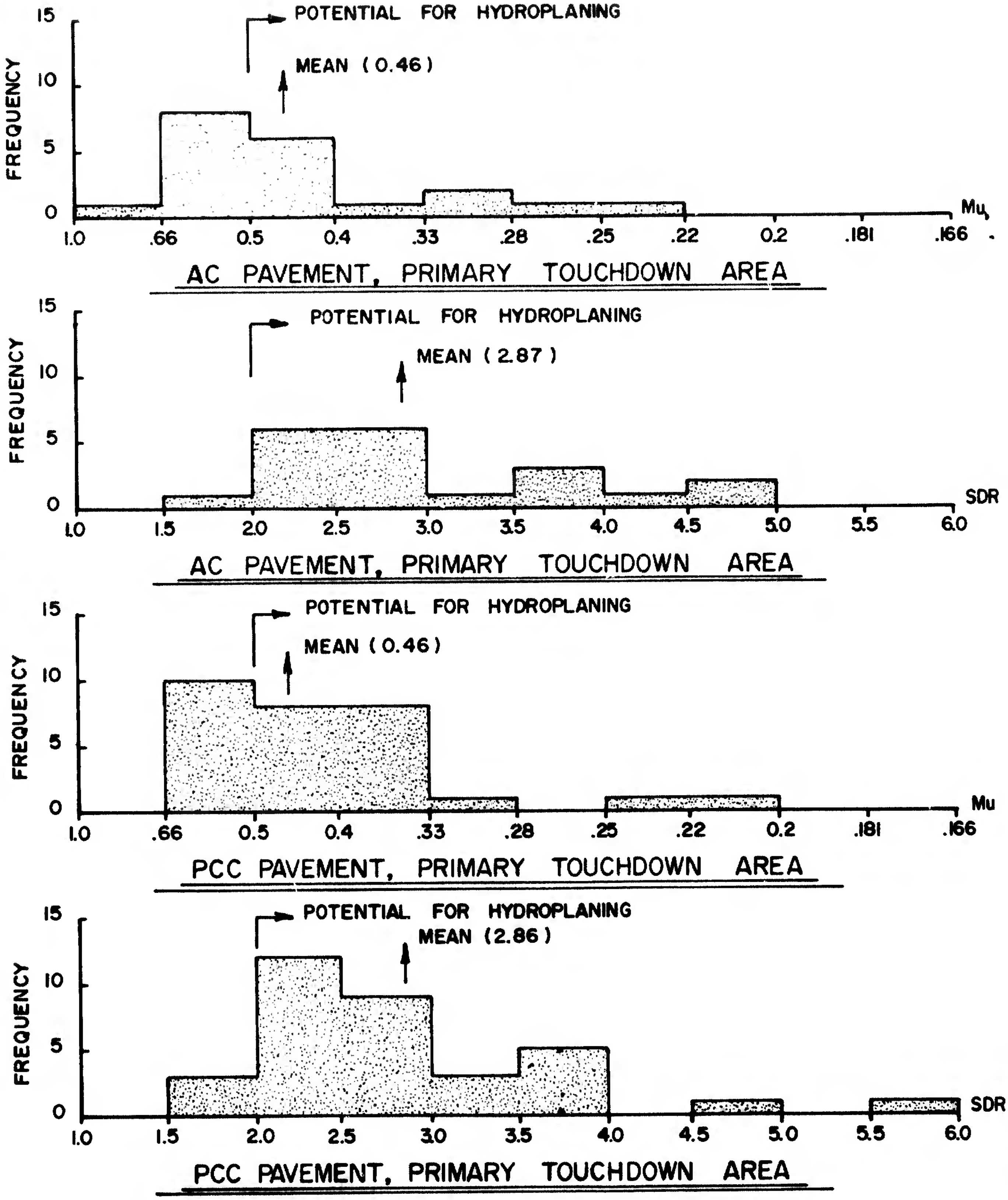


FIGURE 29. HISTOGRAM OF SDR & MU-METER READINGS ON PRIMARY TOUCHDOWN AREAS.

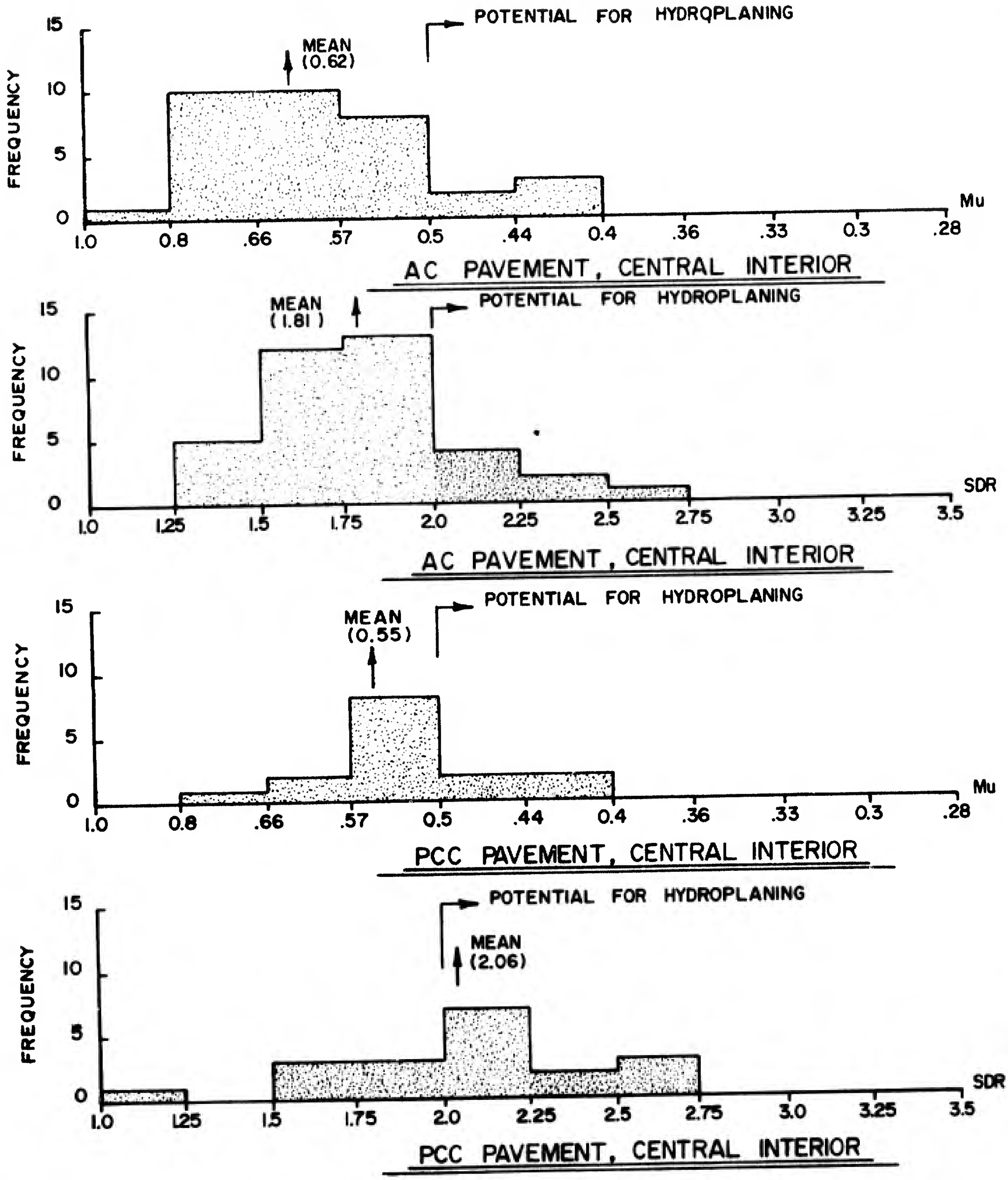


FIGURE 30. HISTOGRAM OF SDR & MU-METER READINGS ON CENTRAL INTERIOR AREAS.

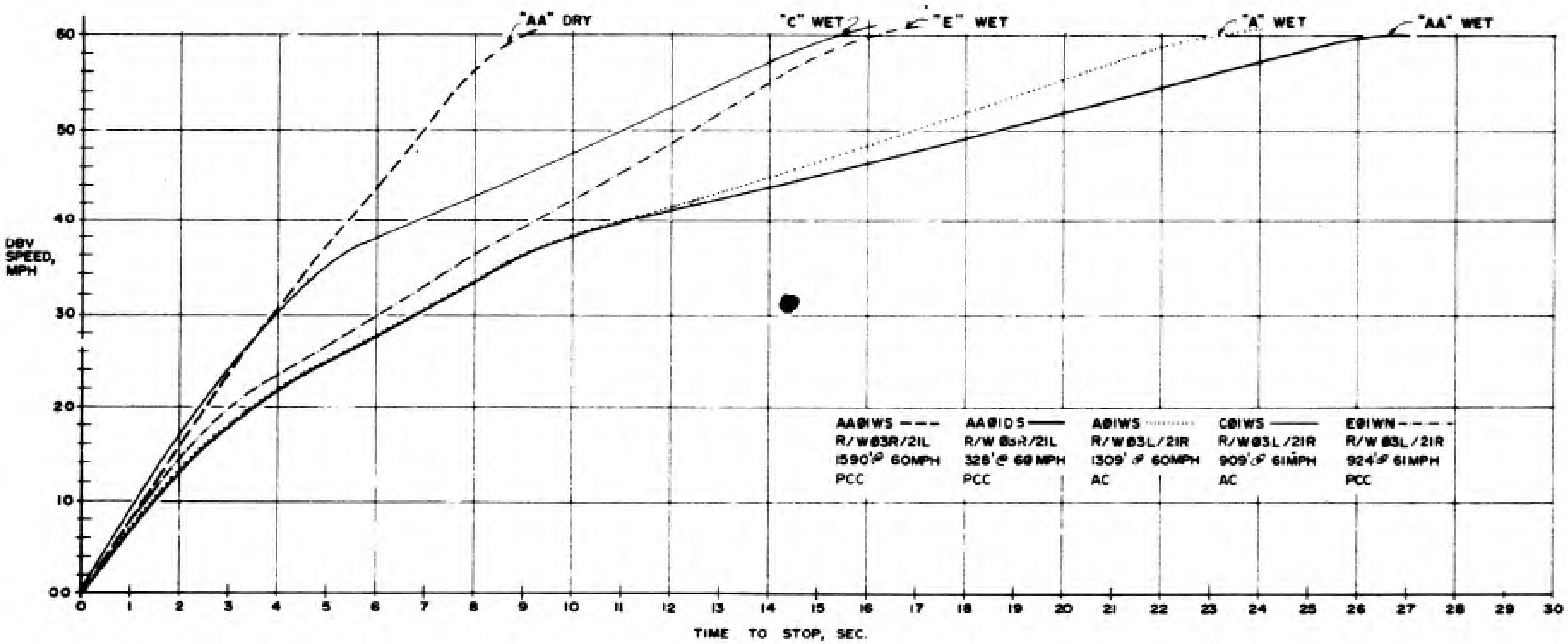


Figure 31. Normalized DBV velocity time histories, Travis AFB (25 APR 74 & 27 APR 74).

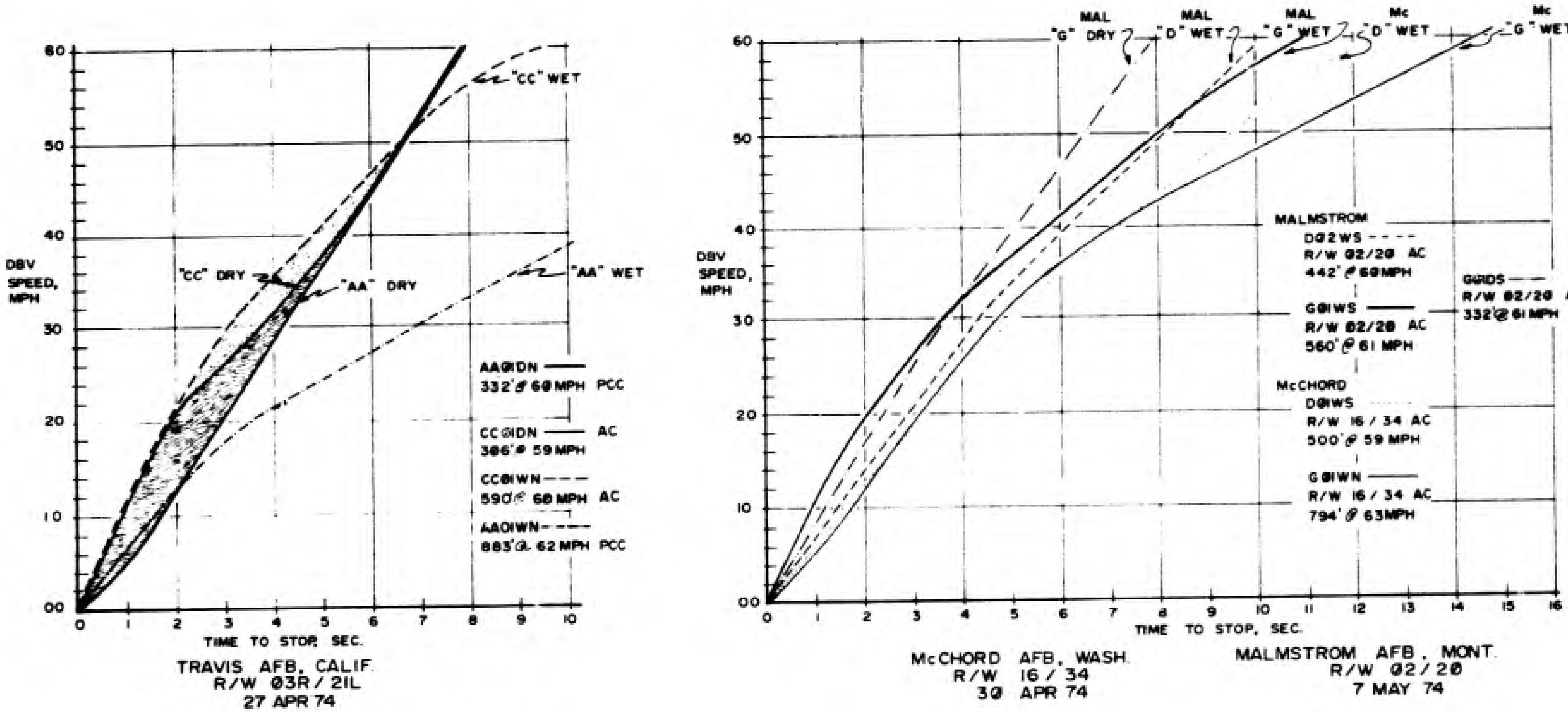


FIGURE 32. NORMALIZED DBV VELOCITY TIME HISTORIES, TRAVIS AFB, McCHORD AFB & MALMSTROM AFB.

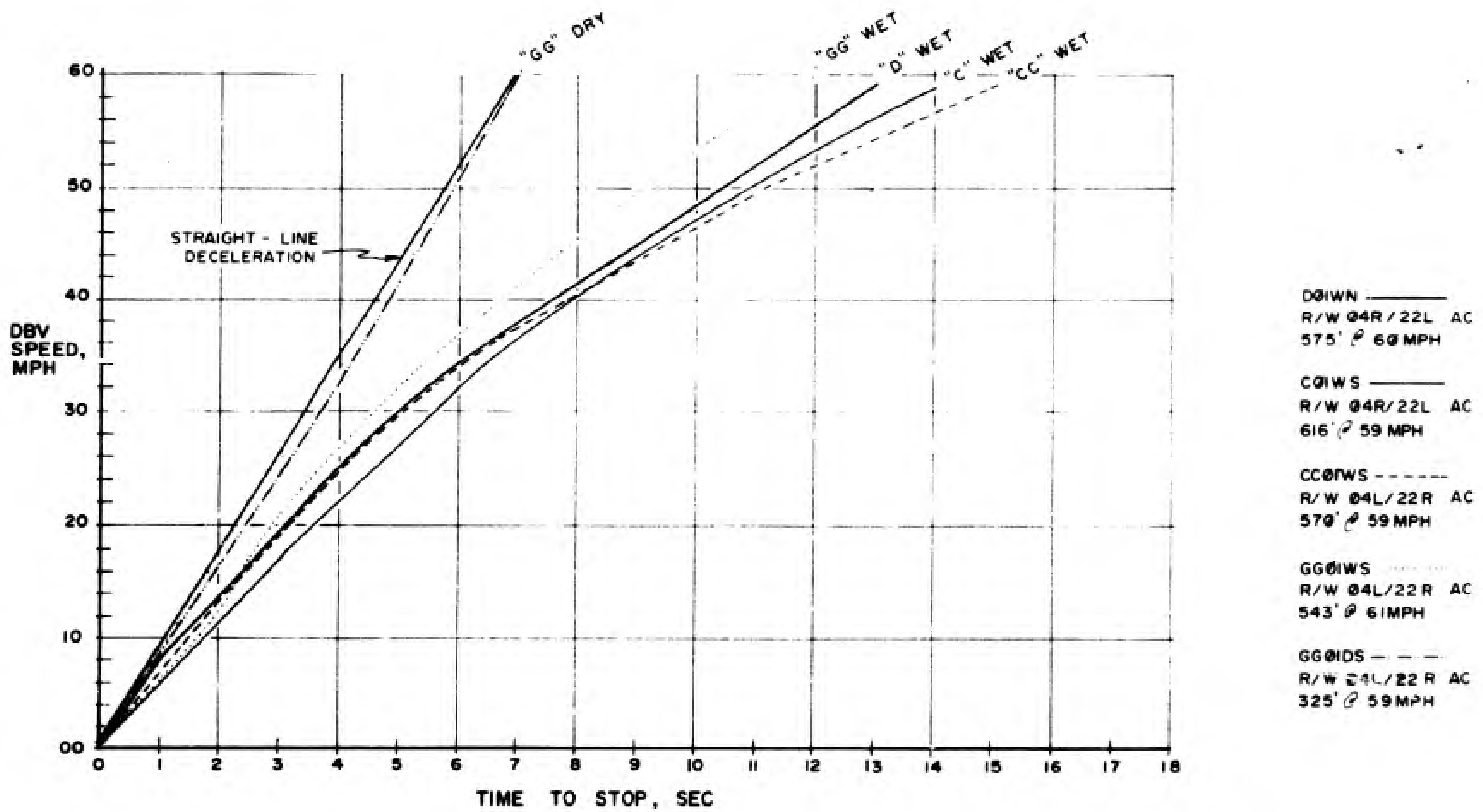


FIGURE 33. NORMALIZED DBV VELOCITY TIME HISTORIES, MATHER AFB.

R/W 01L/19R 22 APR 74
R/W 01R/19L 21 APR 74

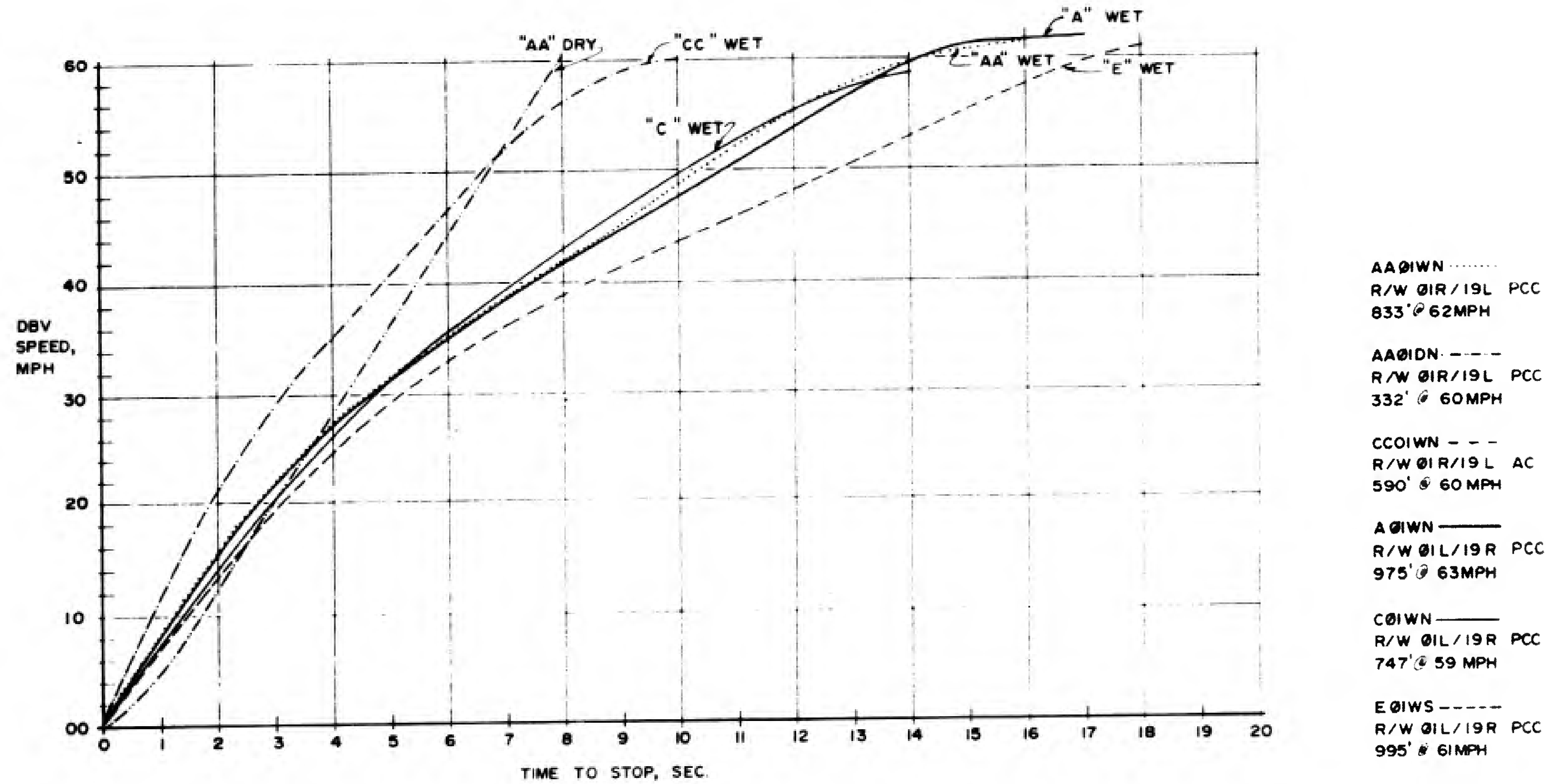


Figure 34. Normalized DBV velocity time histories, Andrews AFB
R/W 01L/19R & R/W 01R/19L
4 March & 5 March
1974

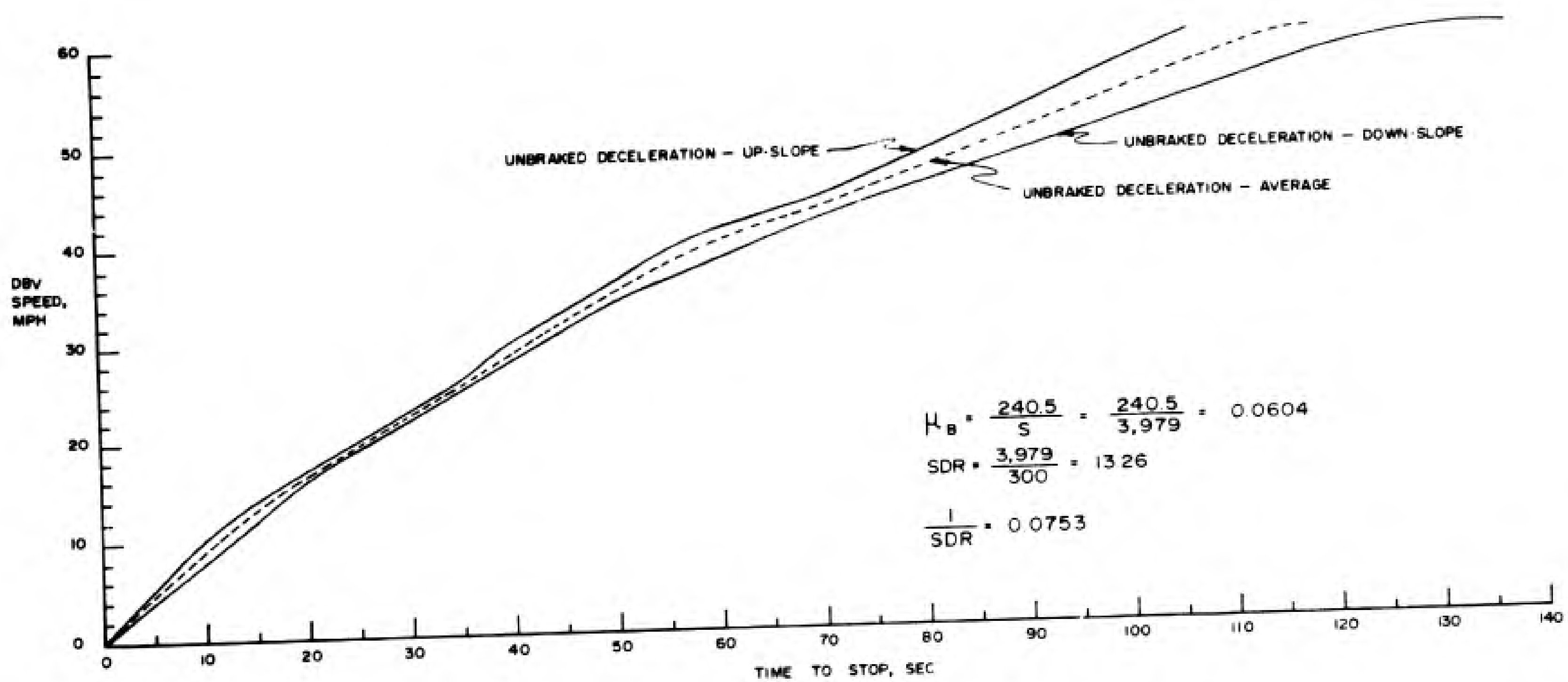


FIGURE 35. NORMALIZED DBV VELOCITY TIME HISTORIES, TARE RUN.

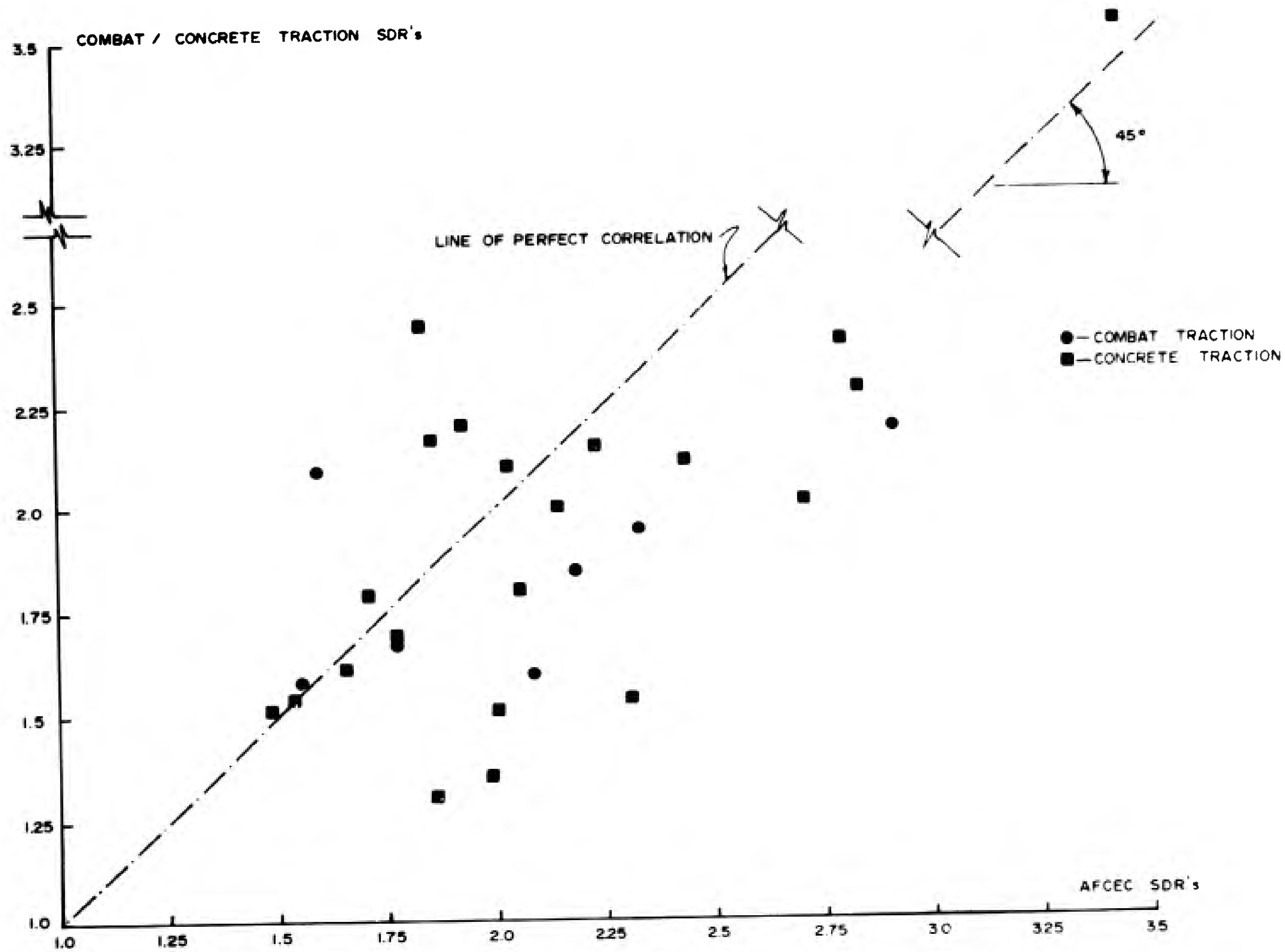


FIGURE 36. COMPARISON OF AFCEC TESTS WITH THAT OBTAINED FROM COMBAT & CONCRETE TRACTION TESTS.

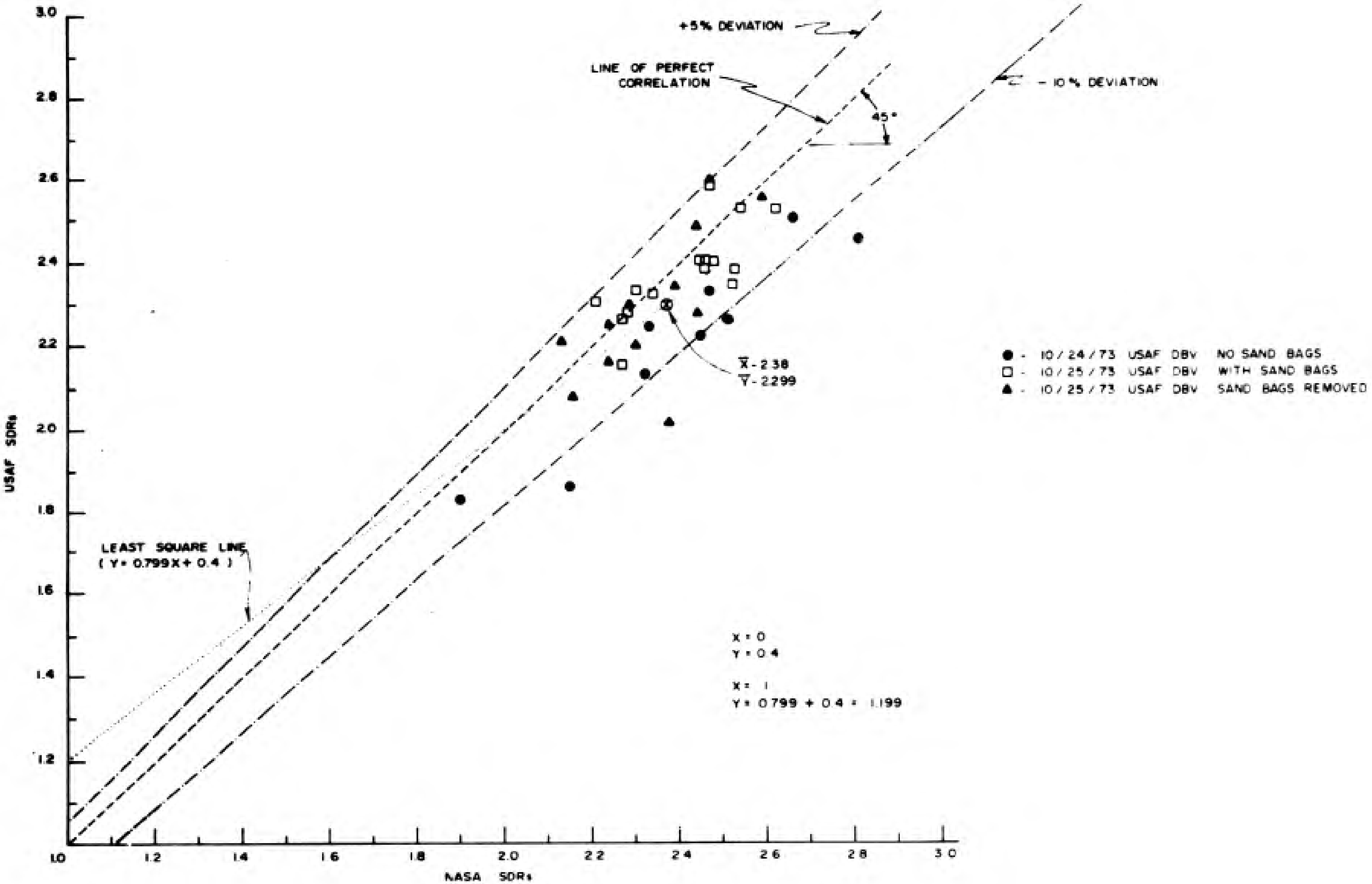


FIGURE 37. USAF & NASA DBV RELATIONSHIP ON R/W 03/21, ROSWELL NM.

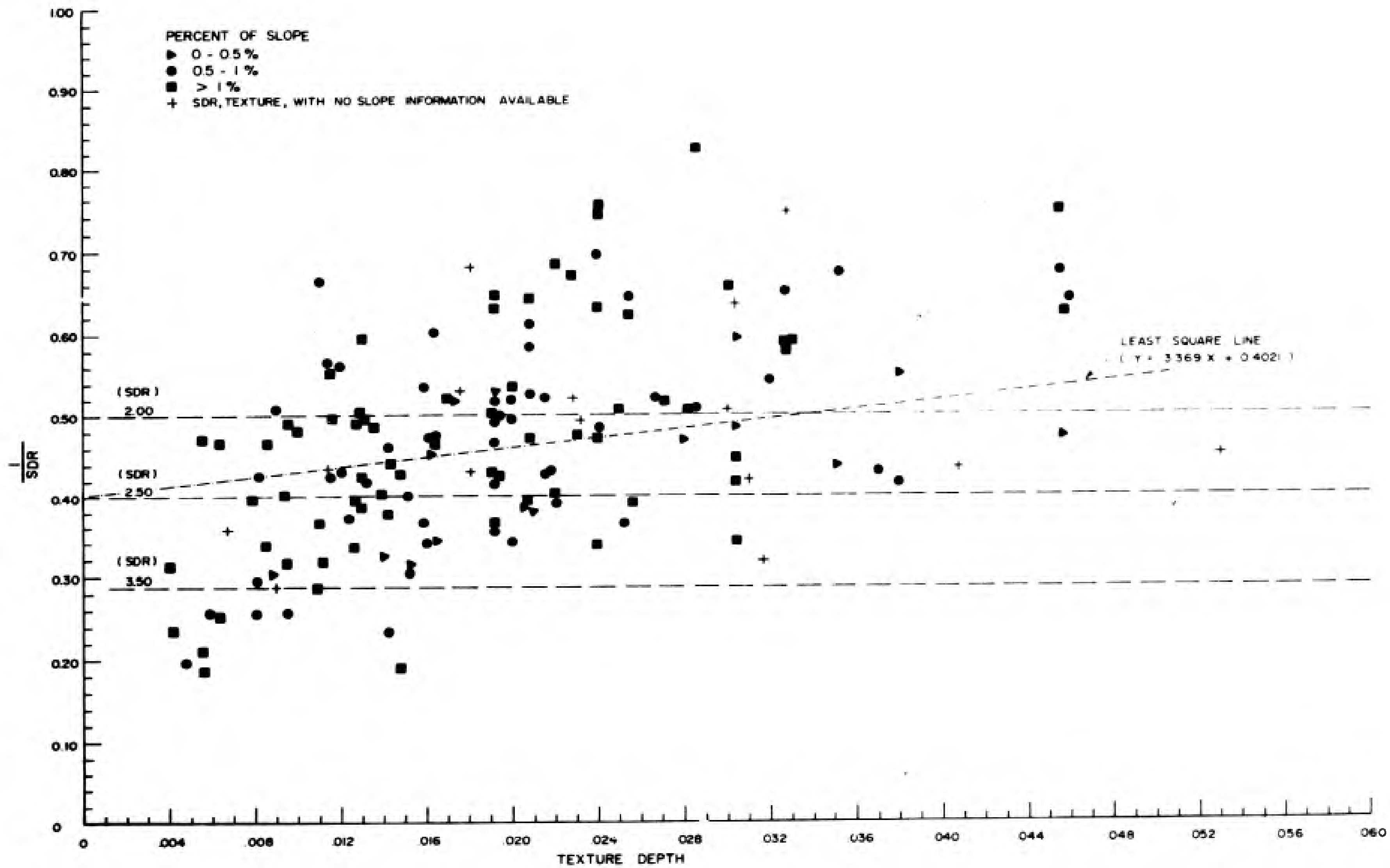


FIGURE 38. RELATIONSHIP OF SDR, PAVEMENT TEXTURE AND CROSS SLOPES.

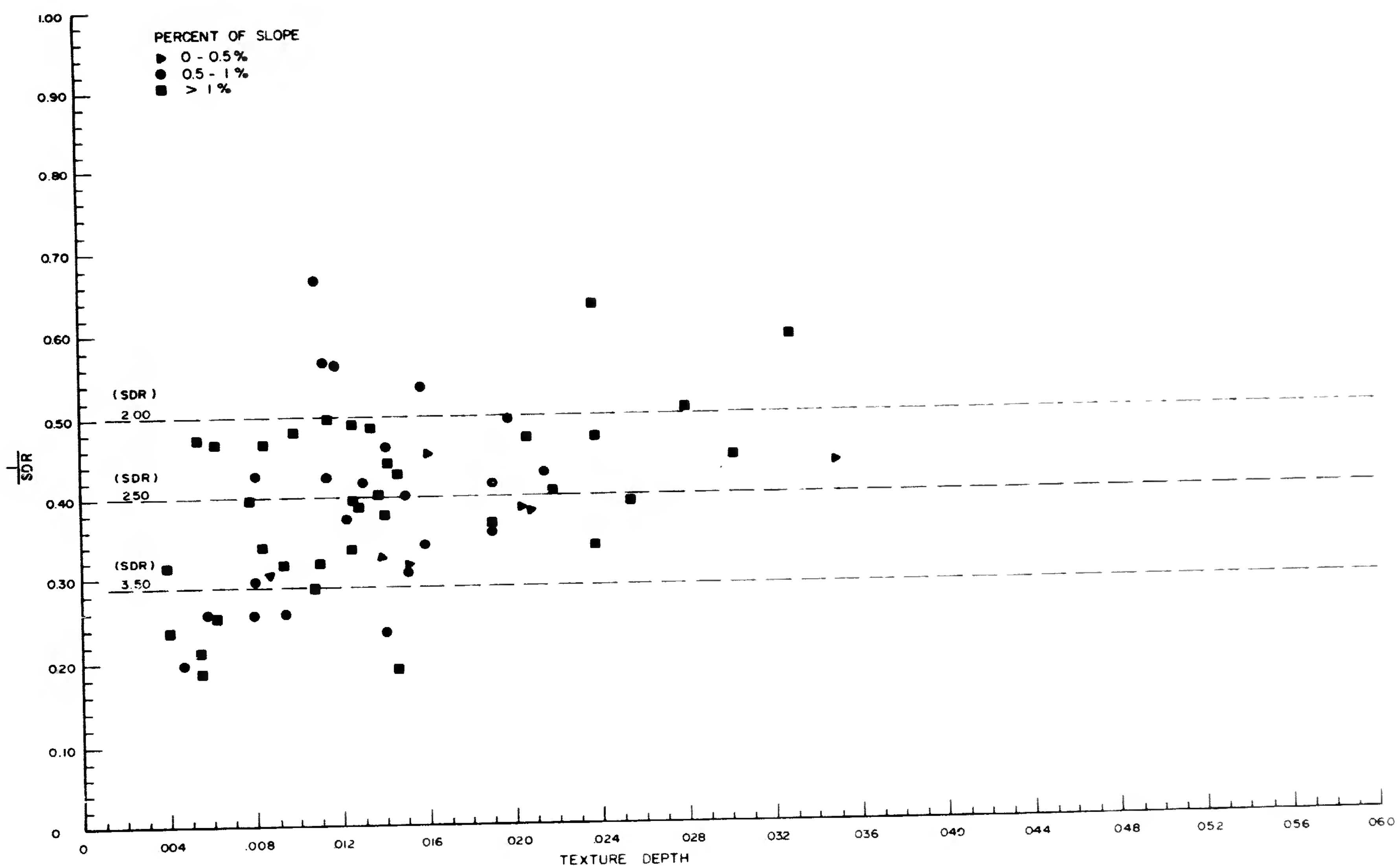


FIGURE 39. RELATIONSHIP OF SDR, PAVEMENT TEXTURE AND CROSS SLOPES ON RUBBER DEPOSIT AREAS.

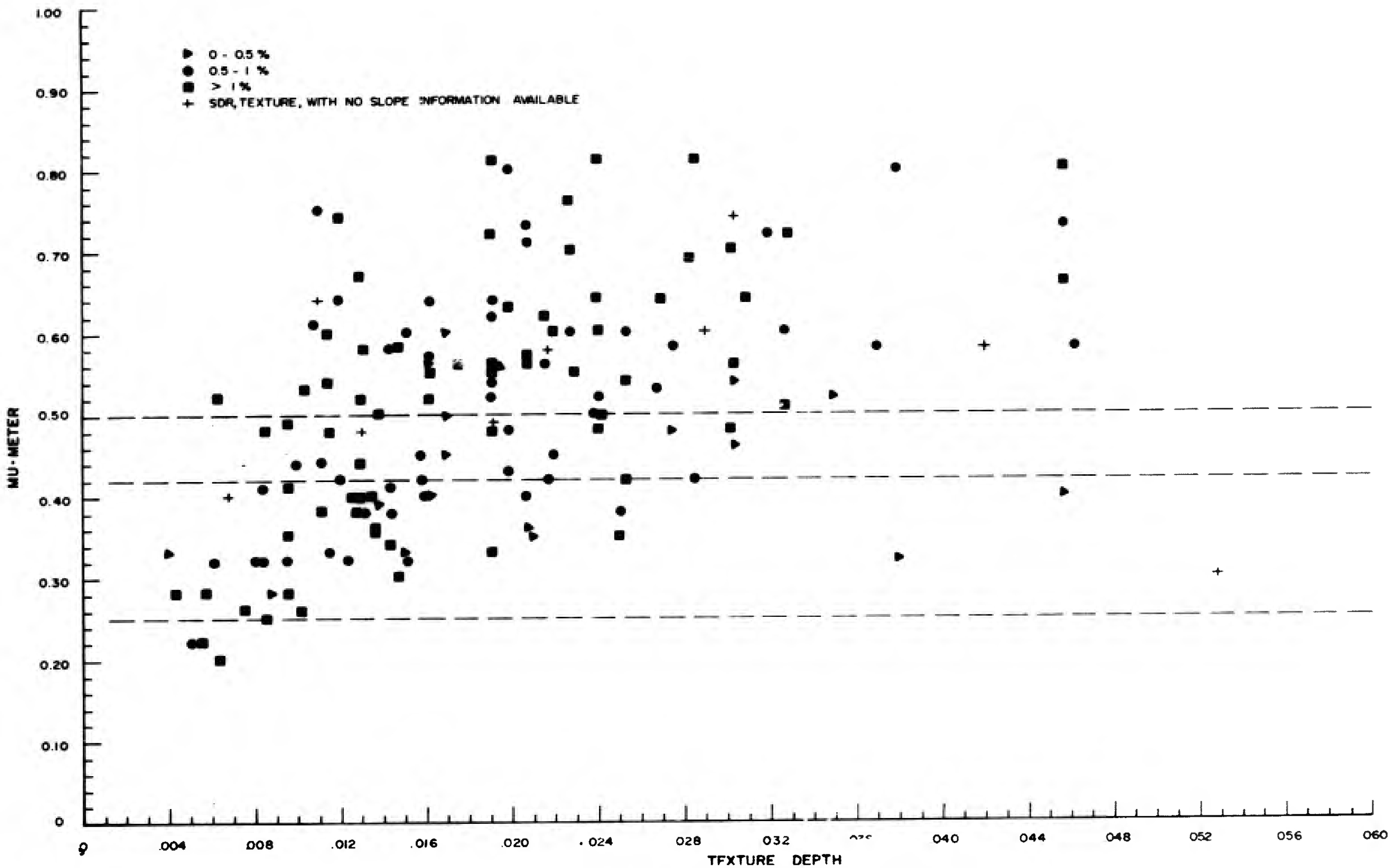


Figure 40. Relationship of Mu-Meter readings, pavement texture and cross slopes.

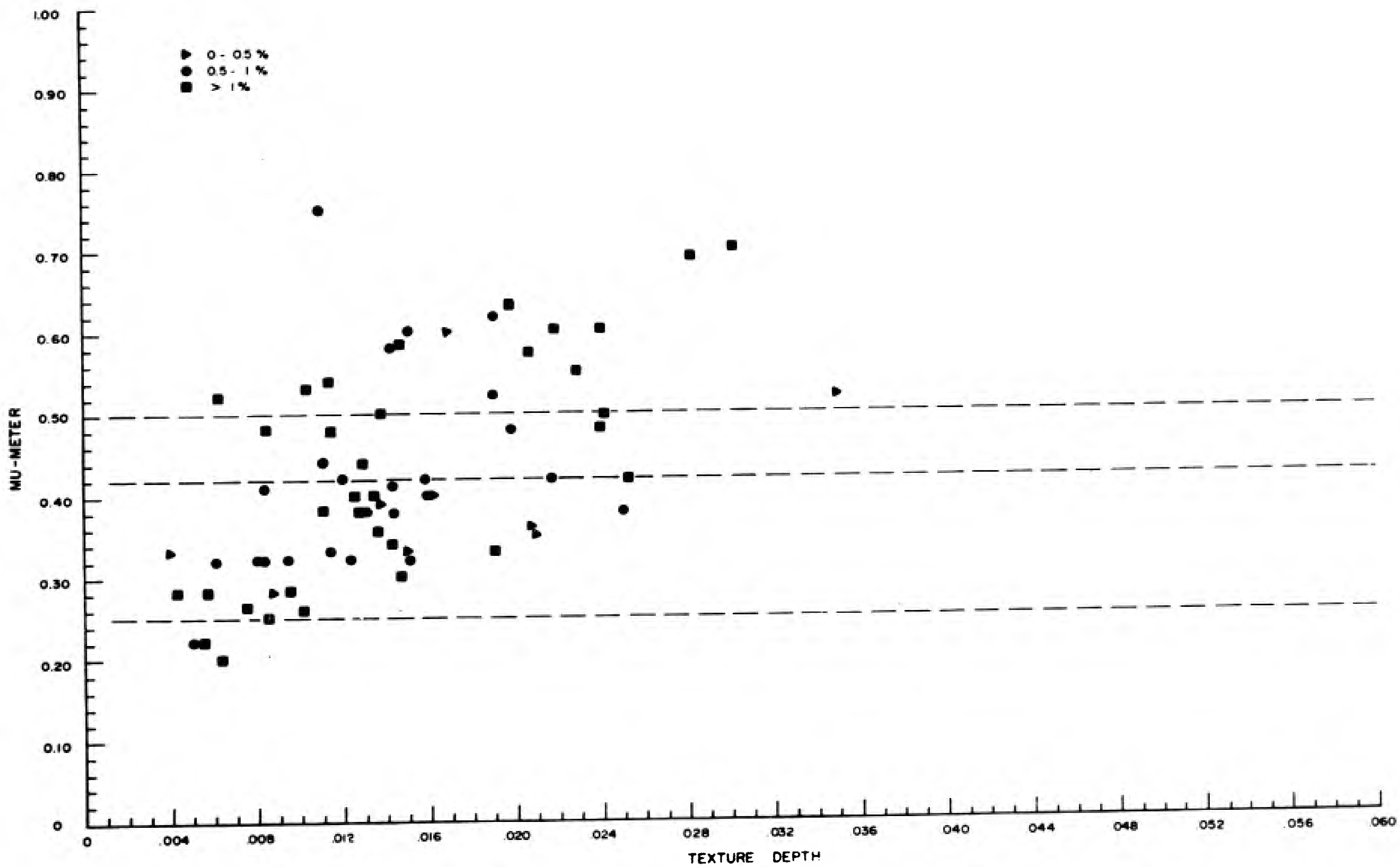


FIGURE 41. RELATIONSHIP OF MU-METER READINGS, PAVEMENT TEXTURE AND CROSS SLOPES ON RUBBER DEPOSIT AREAS.

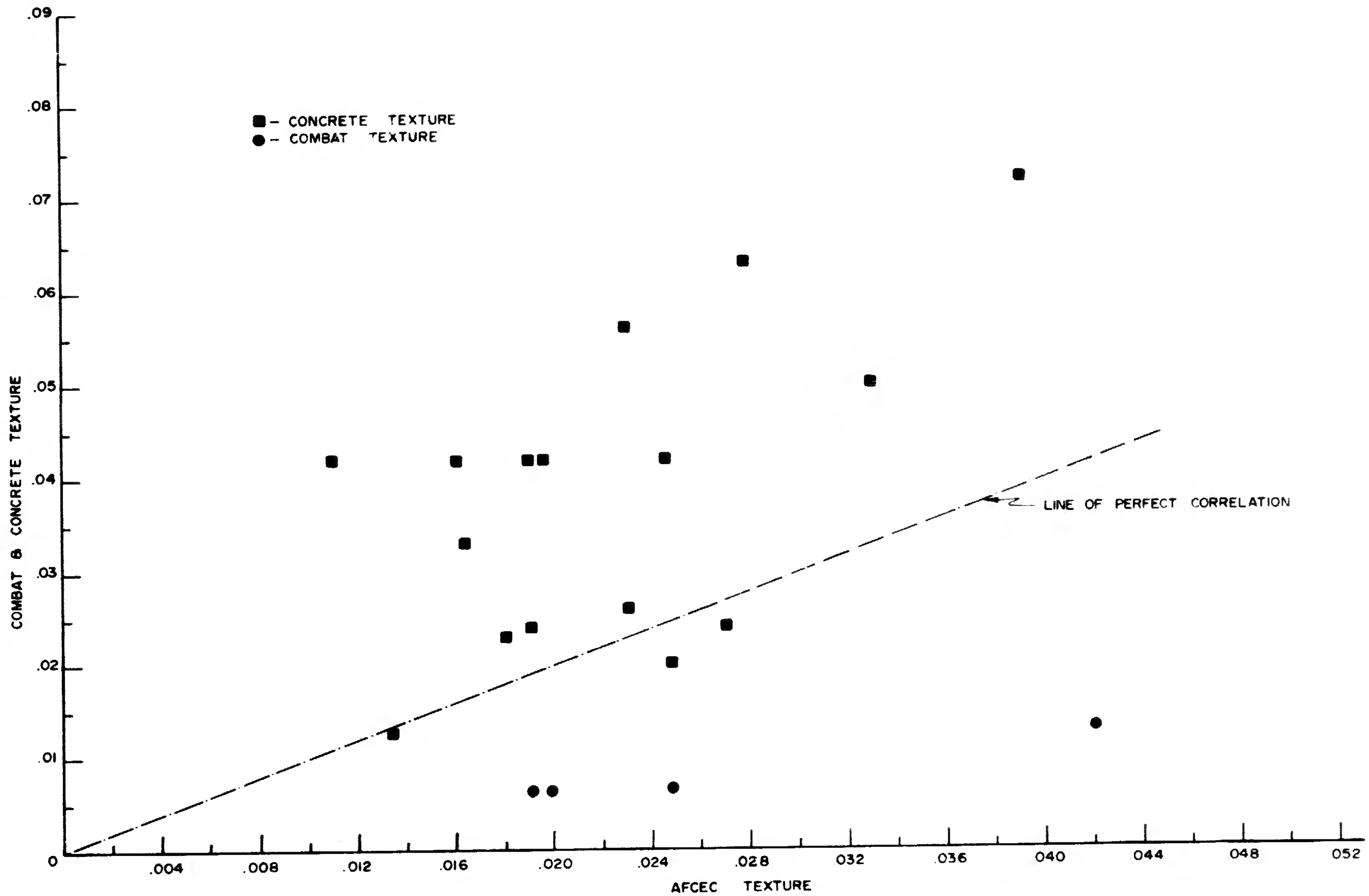


FIGURE 42. COMPARISON OF TEXTURE MEASUREMENTS - AFCEC, COMBAT AND CONCRETE TRACTION PROGRAMS.

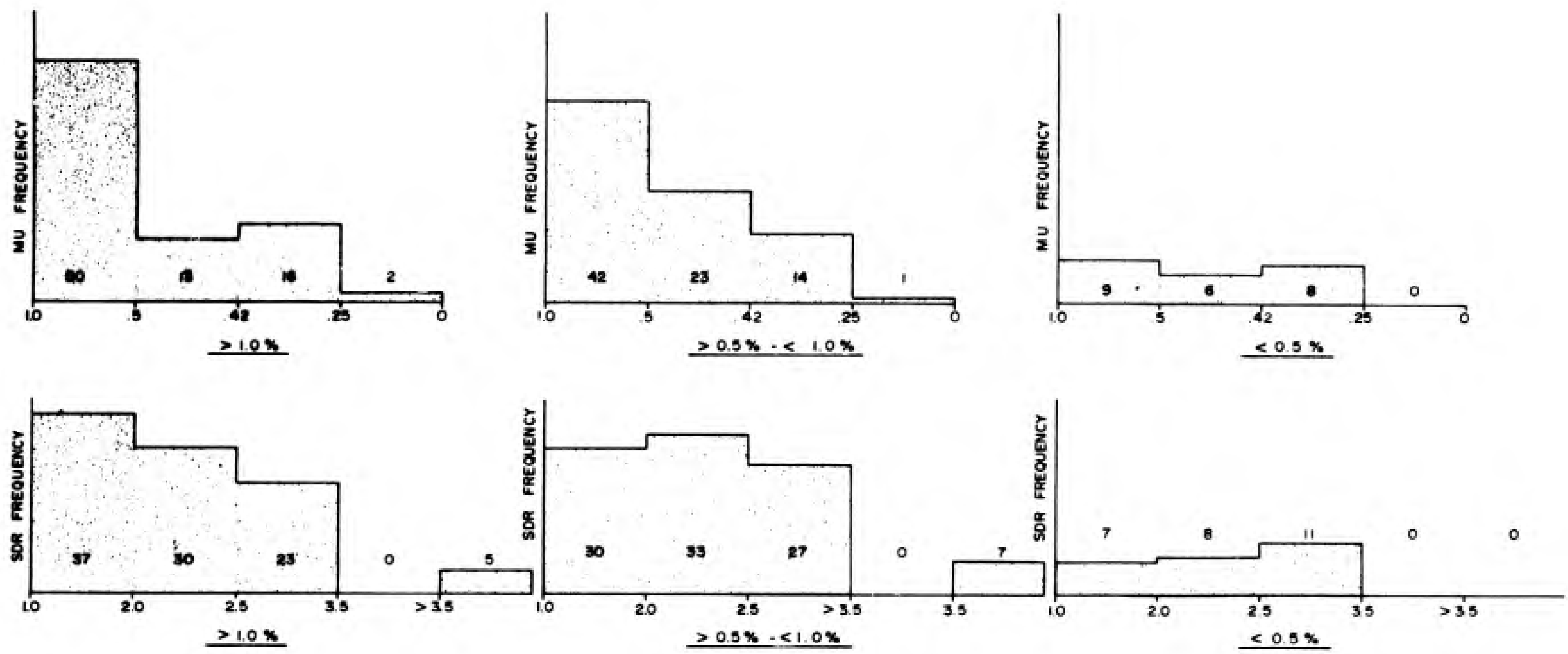


FIGURE 43. HISTOGRAM OF SDR & MU-METER READINGS FOR RUNWAY CROSS SLOPES.

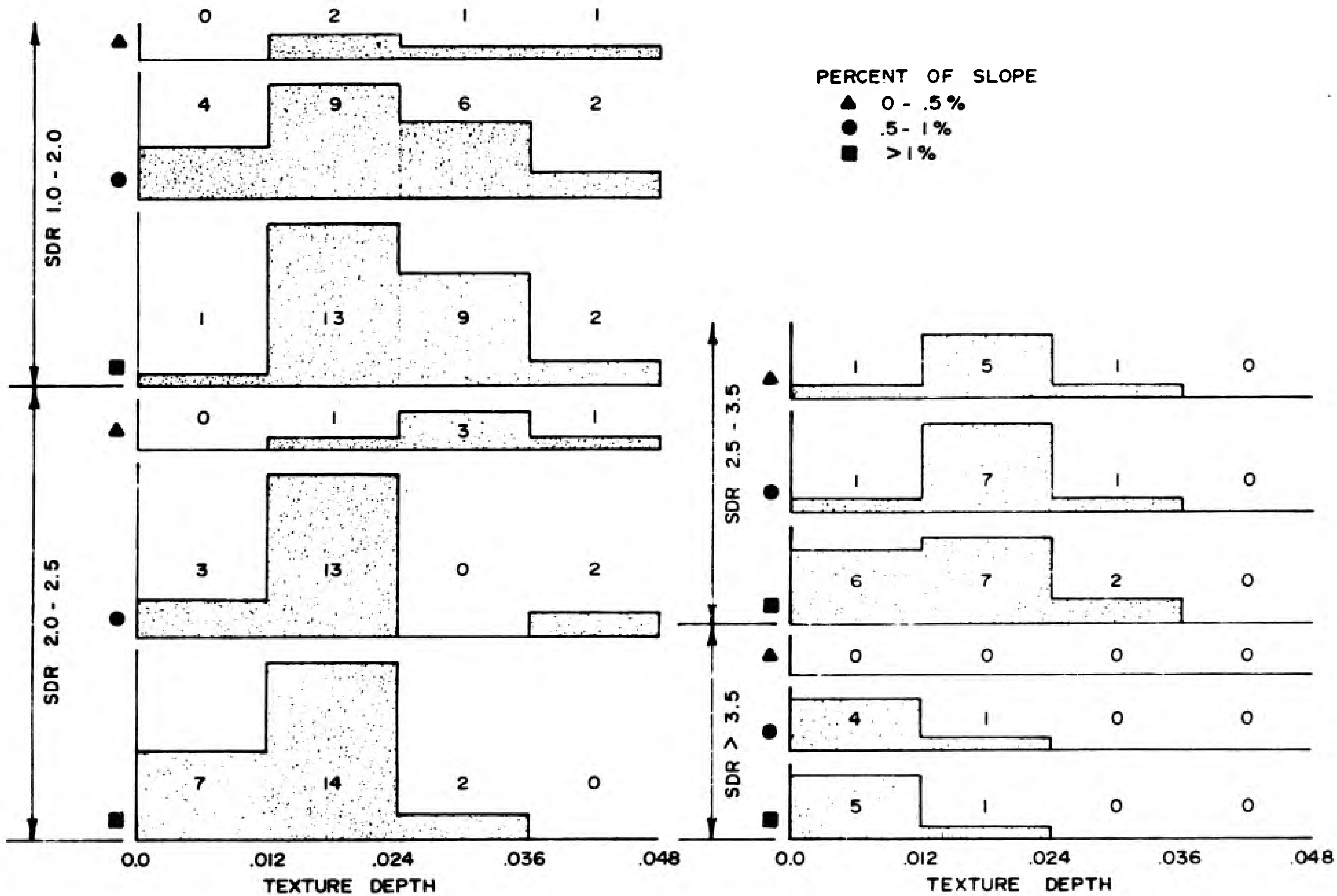


FIGURE 43A. HISTOGRAM OF PAVEMENT TEXTURE FOR DIFFERENT SDRs & CROSS SLOPES.

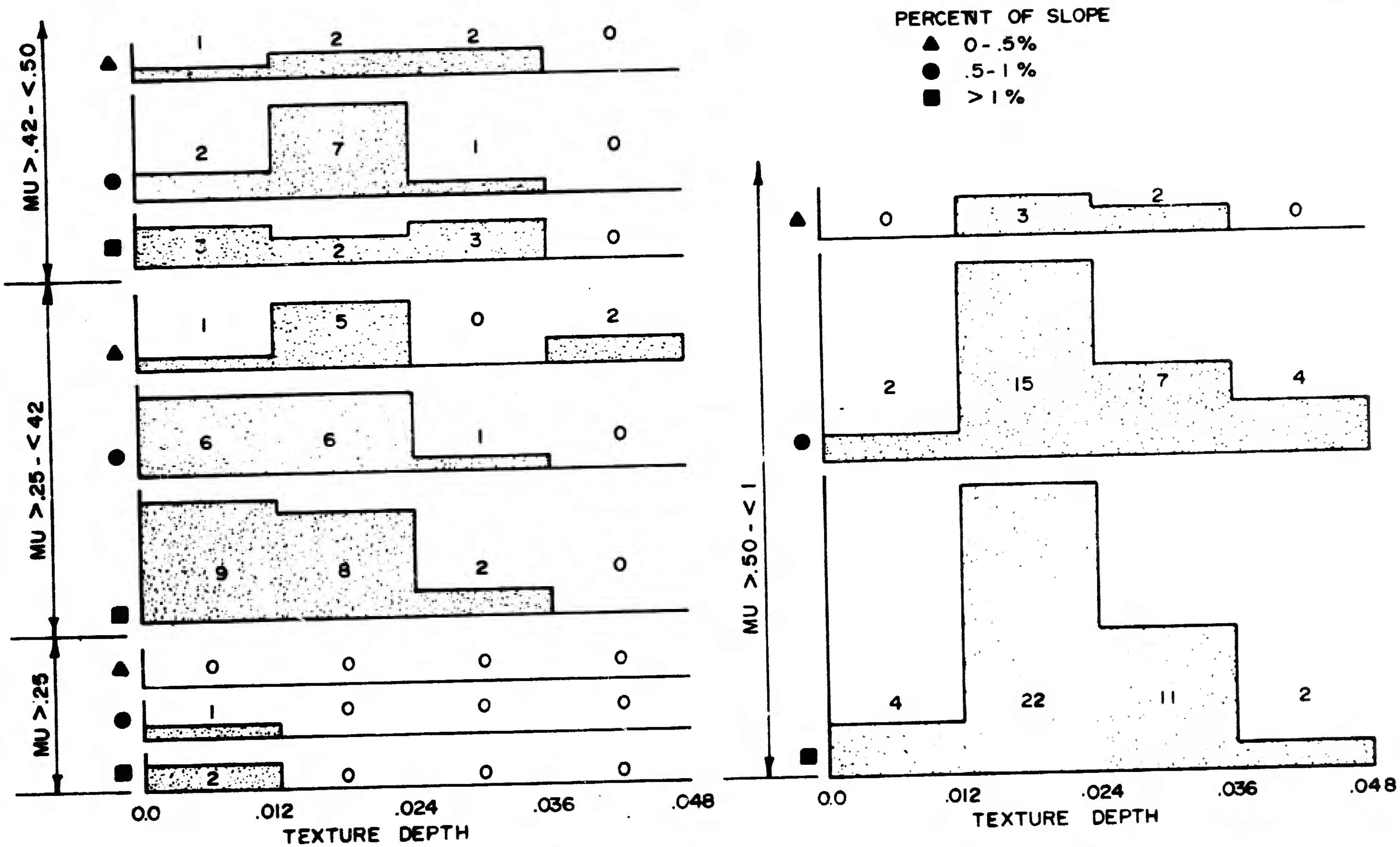


FIGURE 43B. HISTOGRAM OF PAVEMENT TEXTURE FOR DIFFERENT MU-METER READINGS & CROSS SLOPES.

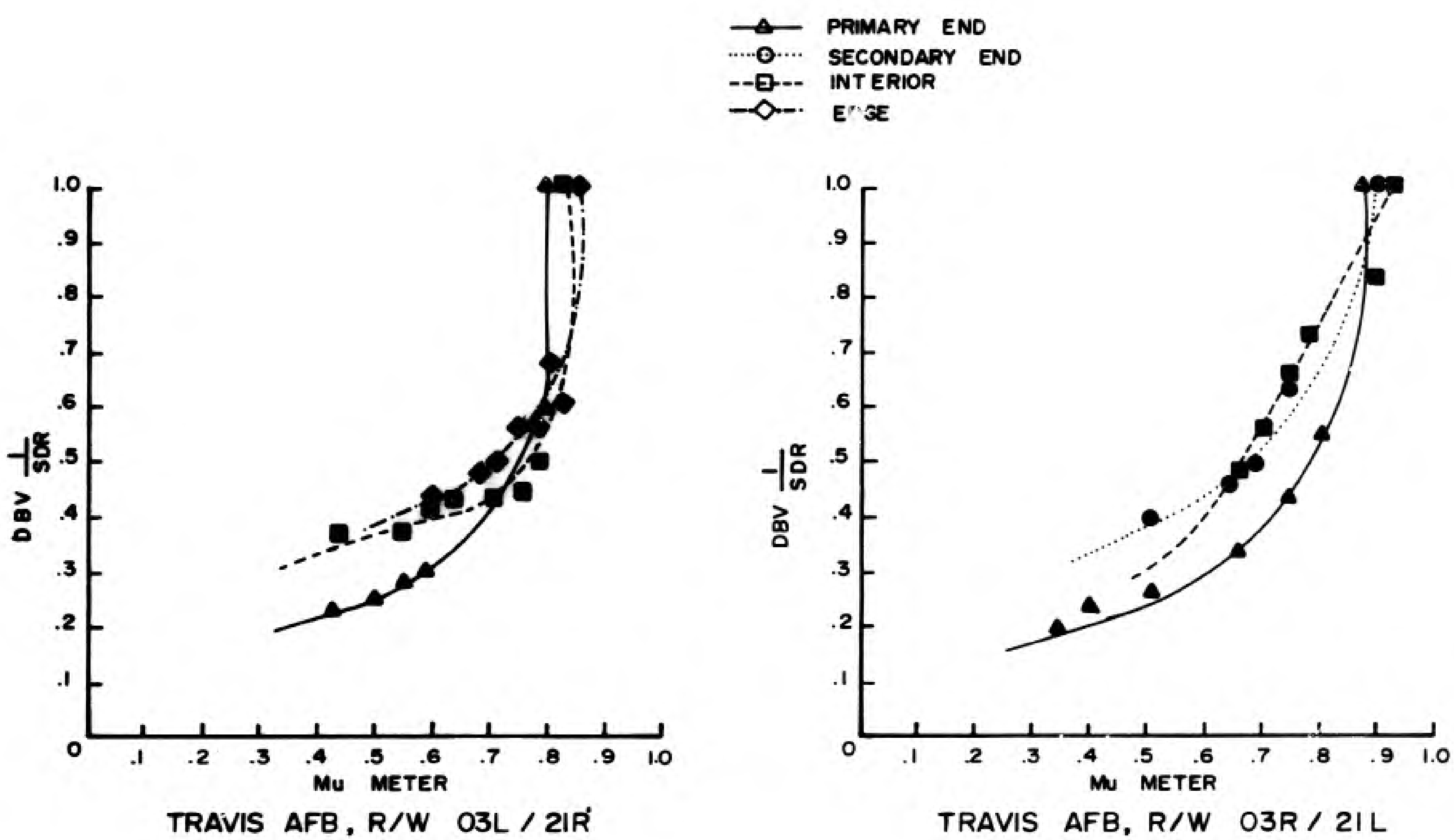


FIGURE 44. DBV & MU-METER RELATIONSHIP, TRAVIS AFB.

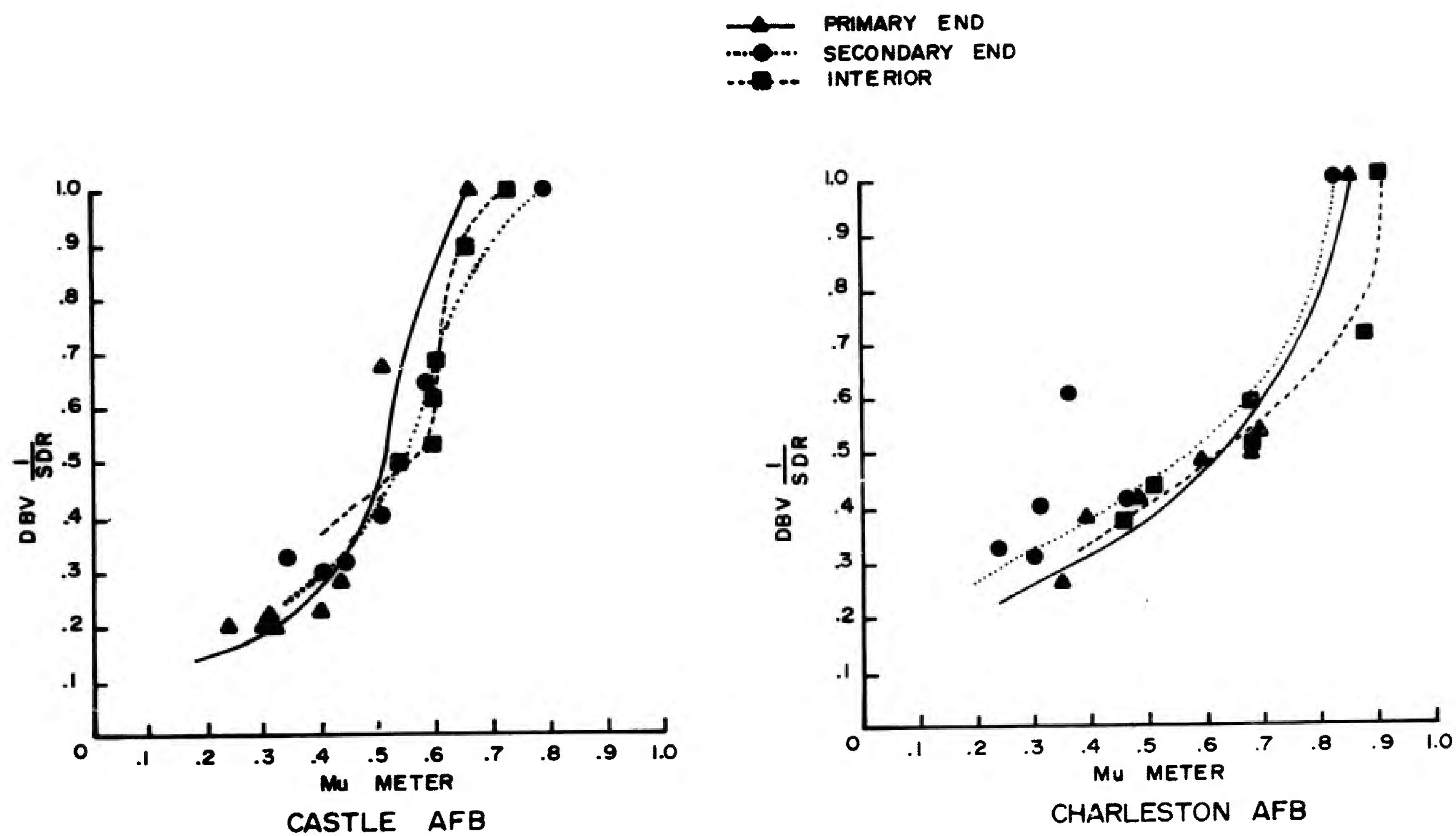


FIGURE 45. DBV & MU-METER RELATIONSHIP, CASTLE AFB AND CHARLESTON AFB.

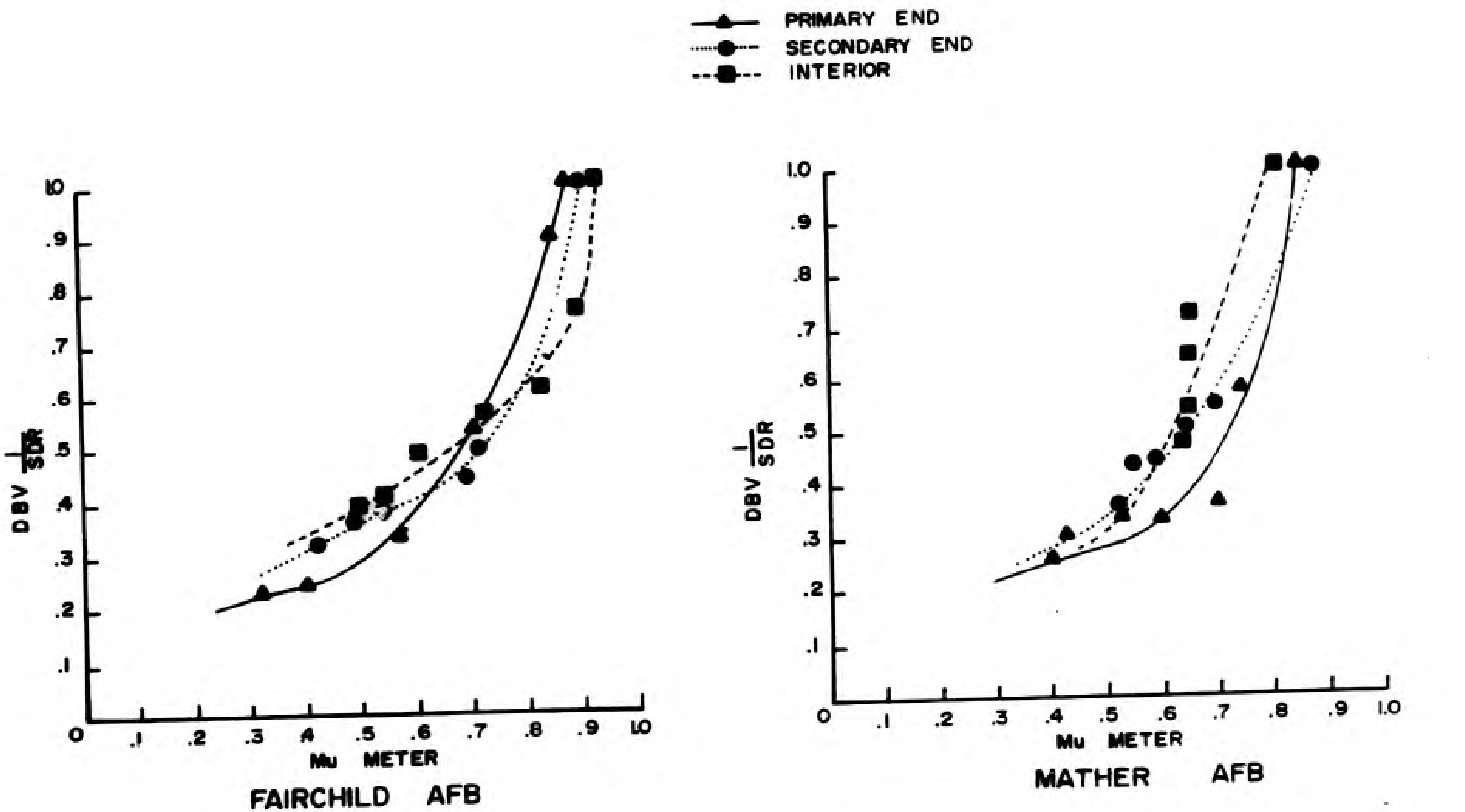


FIGURE 46. DBV & MU-METER RELATIONSHIP, FAIRCHILD AFB AND MATHER AFB.

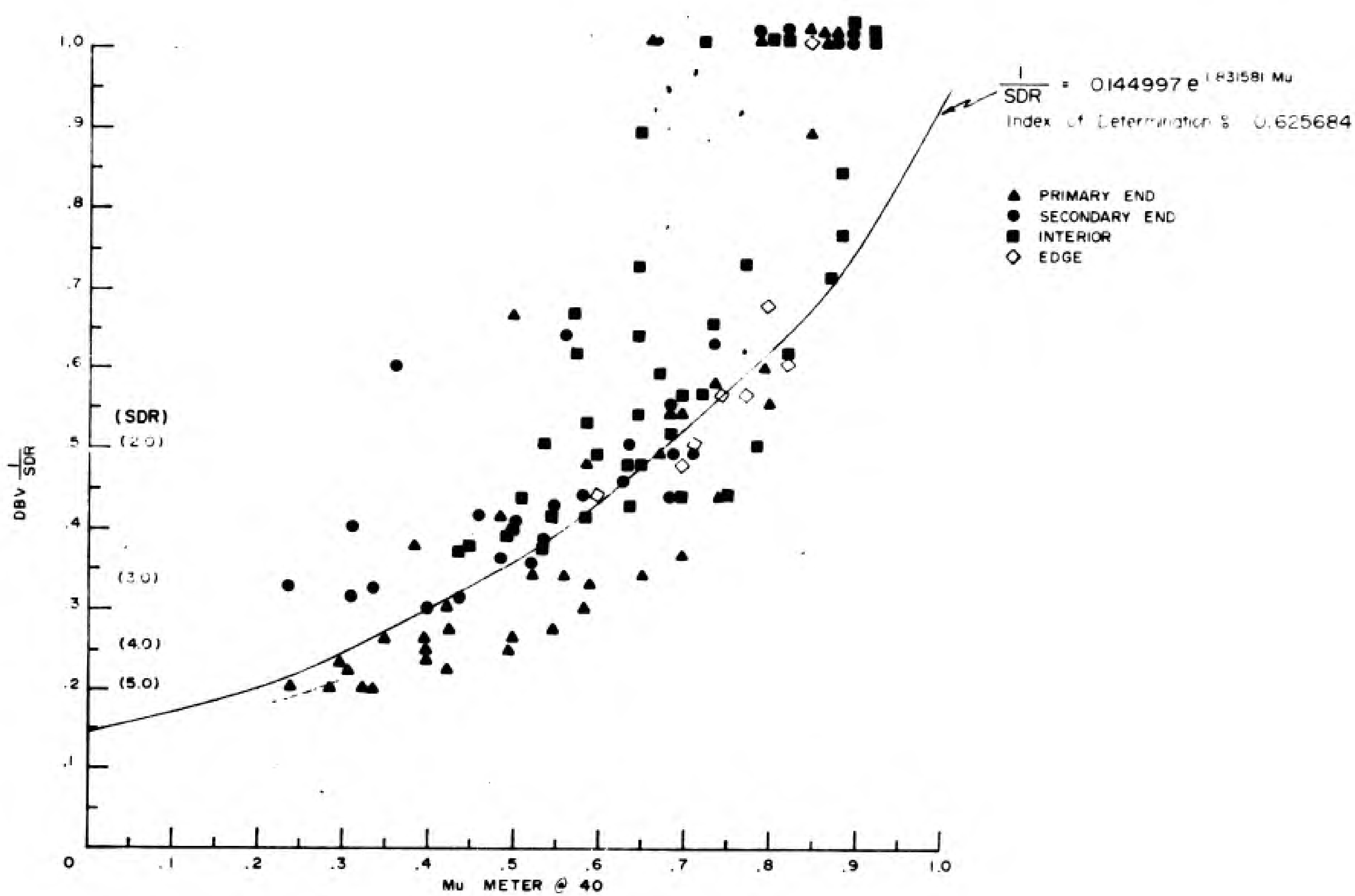
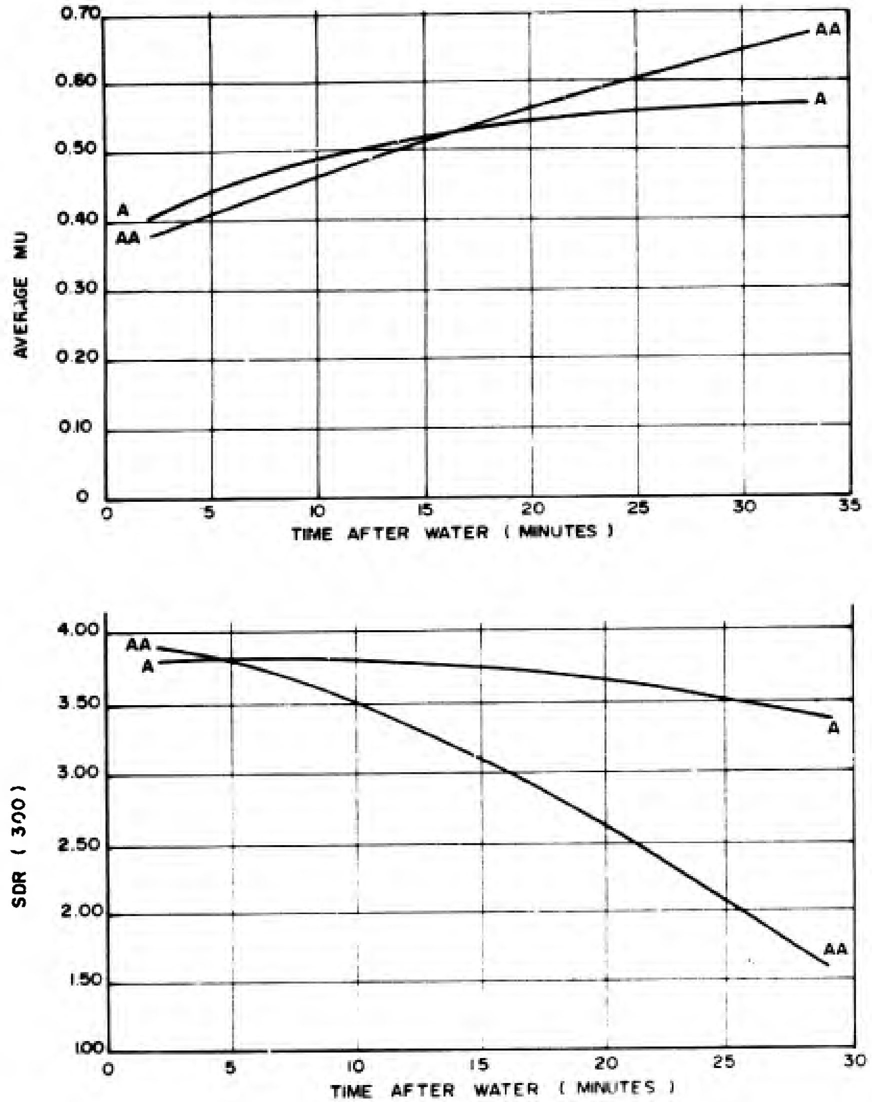


FIGURE 47. DBV & MU-METER RELATIONSHIP, COMBINED DATA.



TEST AREA	RUN NO	MU-METER AVG TIME AFTER WET	MU-METER MU AVG	DBV AVG TIME AFTER WET	DBV SDR 300
A	1	2 16	38	1 82	3 61
A	2	3.34	43	5 12	4 14
A	3	6.37	46	6.57	3 66
A	4	810	48	7.95	4 34
A	5	978	50	9 68	3 63
A	6	13 83	51	11 35	3 88
A	7	18.28	58	12 71	3 65
A	8	21 53	.53	14.10	3 83
A	9	25 06	.53	15 45	3 45
A	10	2999	55	16.92	3 77
A	11			18.32	3.33
A	12			19 92	3 79
A	13			21 38	3 45
A	14	SECTION A		22 96	3.86
A	15	FOLLOWING		24 32	3 33
A	16	HEAVY		26 78	3 62
A	17	RAINFALL		28 11	3 34
A	18			29 47	3 69
A	19			30 77	3 33
AA	1	1 75	37	1 72	3 88
AA	2	3.70	39	3.31	4.41
AA	3	5.47	41	5 18	3 18
AA	4	7 35	47	7 01	3 49
AA	5	9.20	47	8 87	3.47
AA	6	11 23	51	10.70	3 71
AA	7	15.62	.49	12 79	3 17
AA	8	1997	.55	14 43	3 45
AA	9	24.90	59	15 82	3 08
AA	10	29 94	.67	17 12	2 94
AA	11			18 45	2 90
AA	12			19 73	2 62
AA	13			21 59	2 61
AA	14	SECTION AA		22 85	2 54
AA	15	FOLLOWING		24 17	1.89
AA	16	ARTIFICIAL		26 33	2 06
AA	17	WETTING		27 65	1.38
AA	18			28 98	1 58

FIGURE 48. RECOVERY CHARACTERISTIC GRAPHS FOR MCGUIRE AFB, RUNWAY 06/24, IMMEDIATELY FOLLOWING HEAVY RAINFALL AND ARTIFICIAL WETTING.

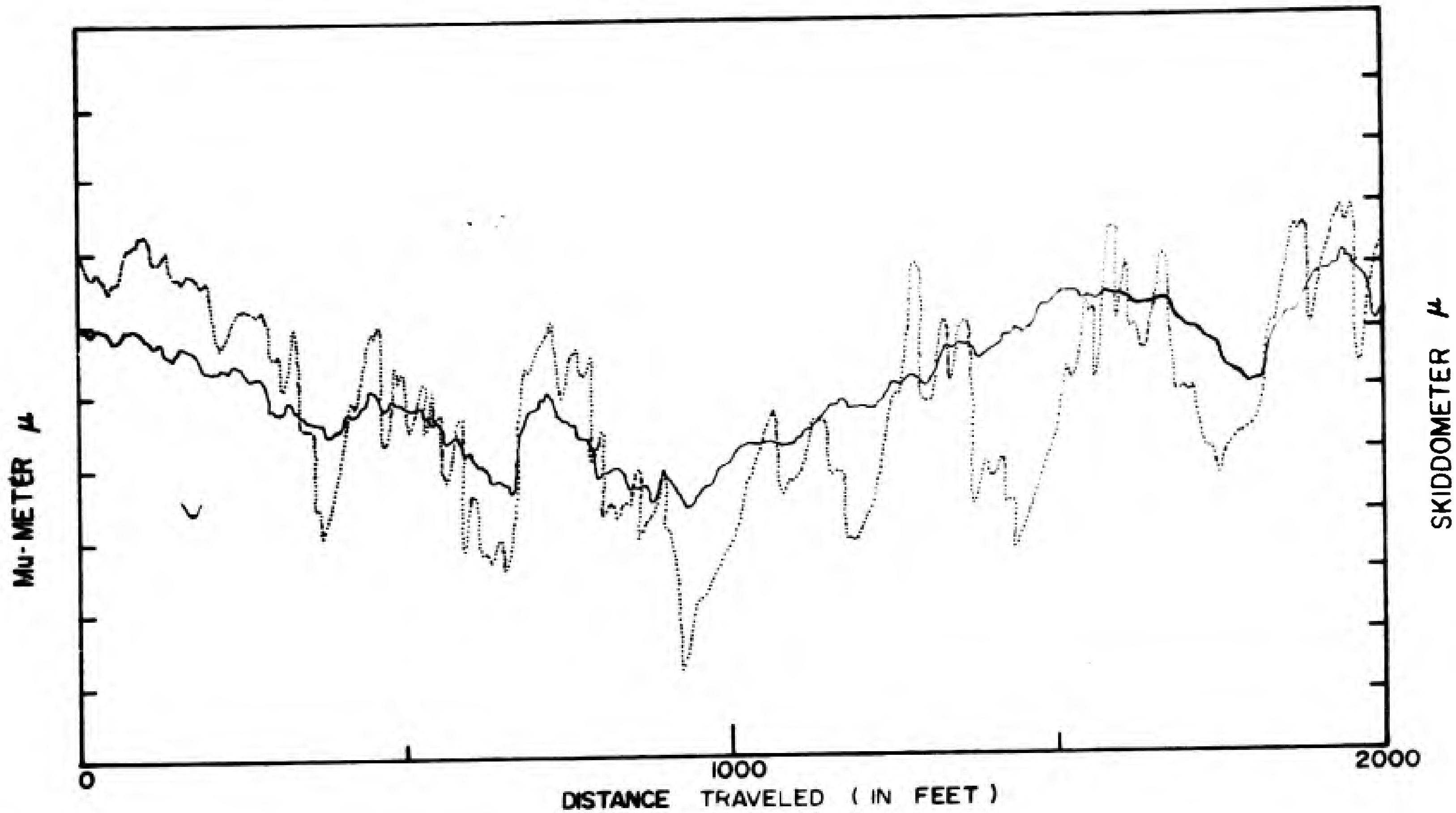


FIGURE 49. COMPARATIVE TESTS OF THE MU-METER AND SKIDDOMETER.
CHARLESTON AFB R/W 03/21
TEST SECTION "BB" RUN #6

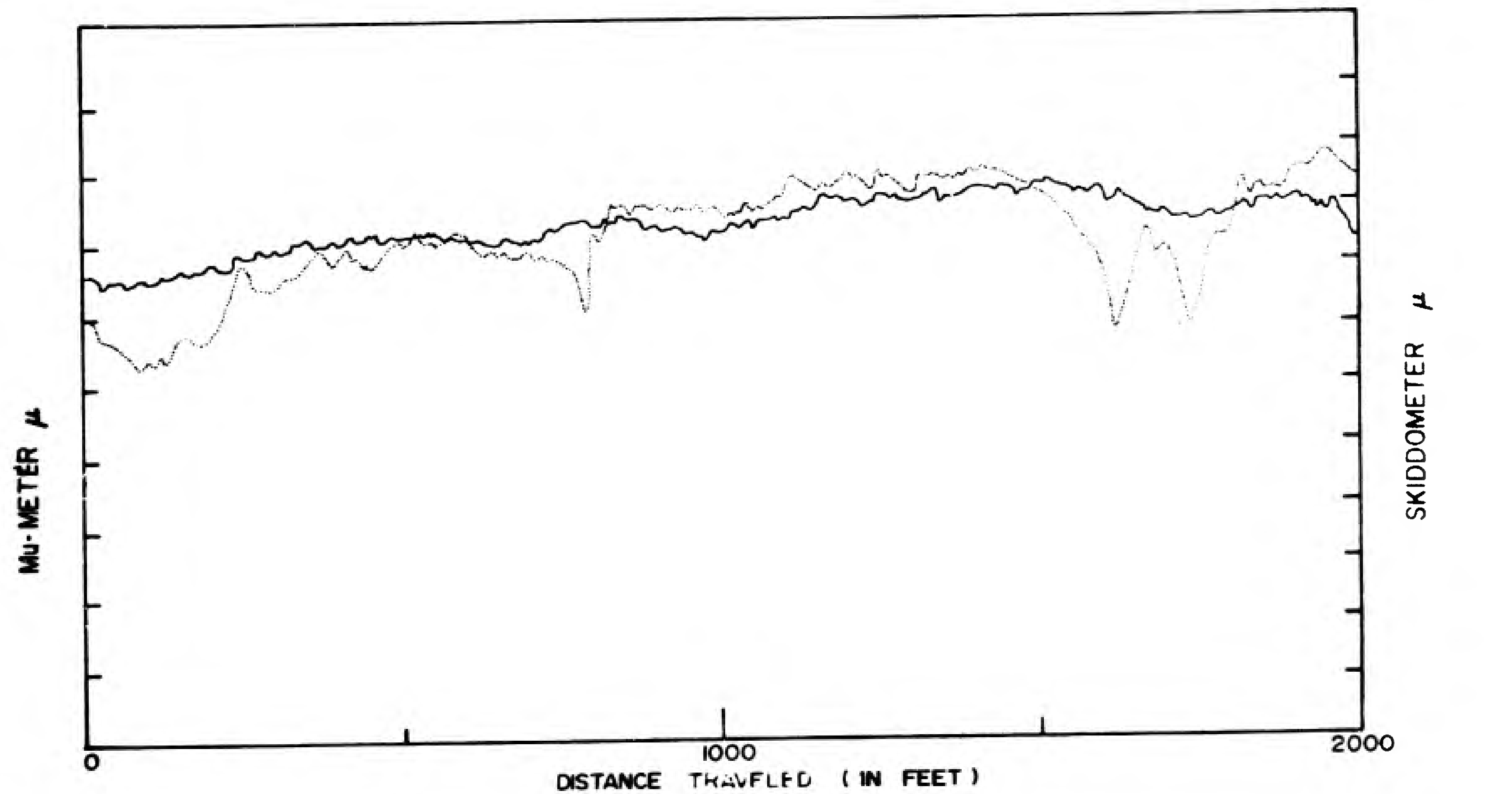


FIGURE 50. COMPARATIVE TESTS OF THE MU-METER AND SKIDDOMETER.
CHARLESTON AFB R/W 03/21
TEST SECTION "DD" RUN #1

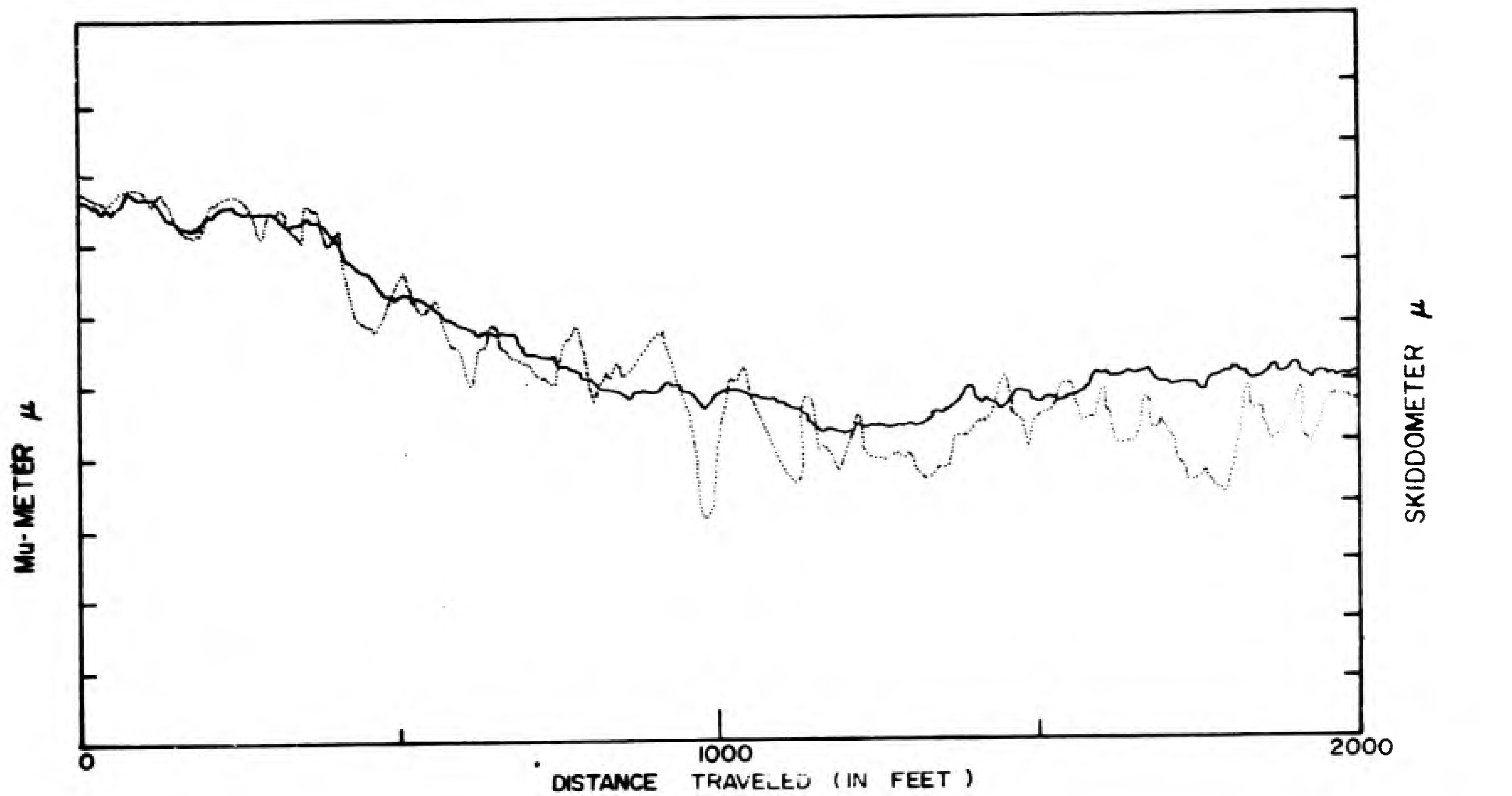


FIGURE 51. COMPARATIVE TESTS OF THE MU-METER AND SKIDDOMETER.
CHARLESTON AFB R/W 03/21
TEST SECTION "FF" RUN #7

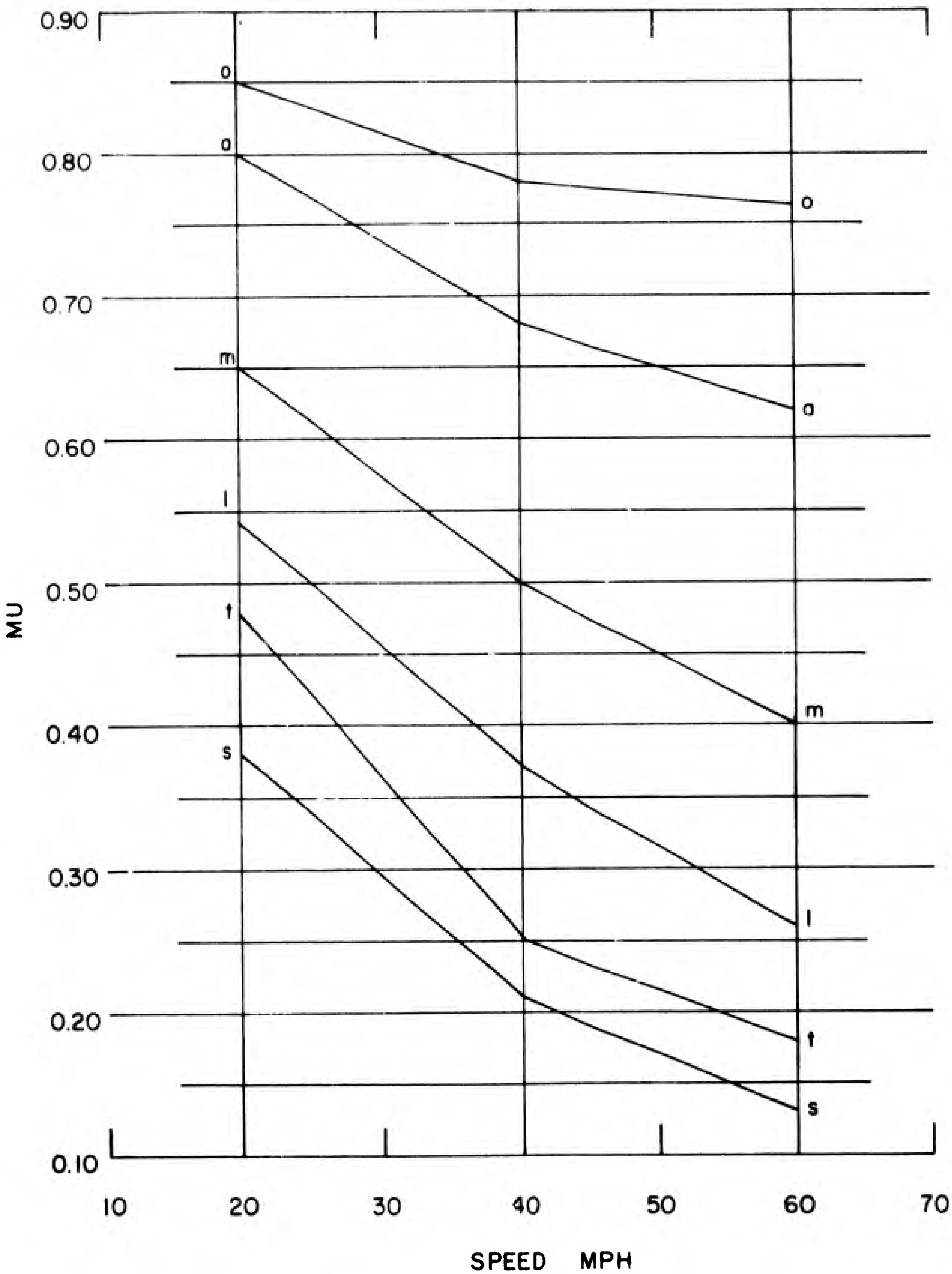
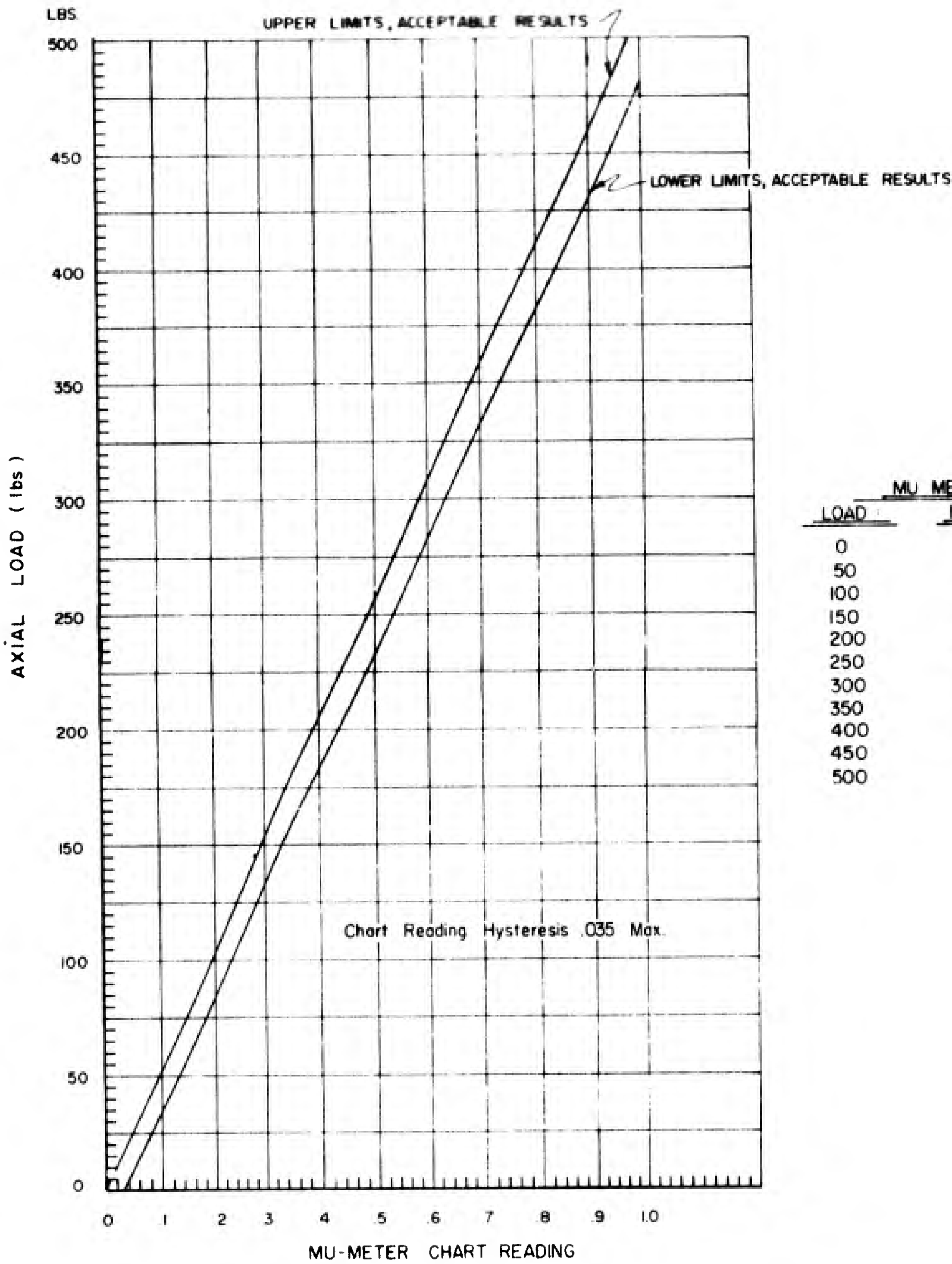


FIGURE 52. MU-METER, SPEED, VS FRICTION GRADIENTS. (DATA FROM REFERENCE 15)



	MU METER READINGS	
LOAD	RECORDER	INTEGRATOR
0	0-3	42 - 48
50	8-12	59-65
100	18-22	76-82
150	28-33	89-93
200	38-43	110 - 116
250	48-53	127-133
300	58-63	144-150
350	68-74	161 - 167
400	78-84	178-184
450	88-94	194-201
500	98-103	211 - 218

FIGURE 53. MU-METER STATIC LOAD TEST PARAMETERS. (REFERENCE: M.L. AVIATION CO. LTD)

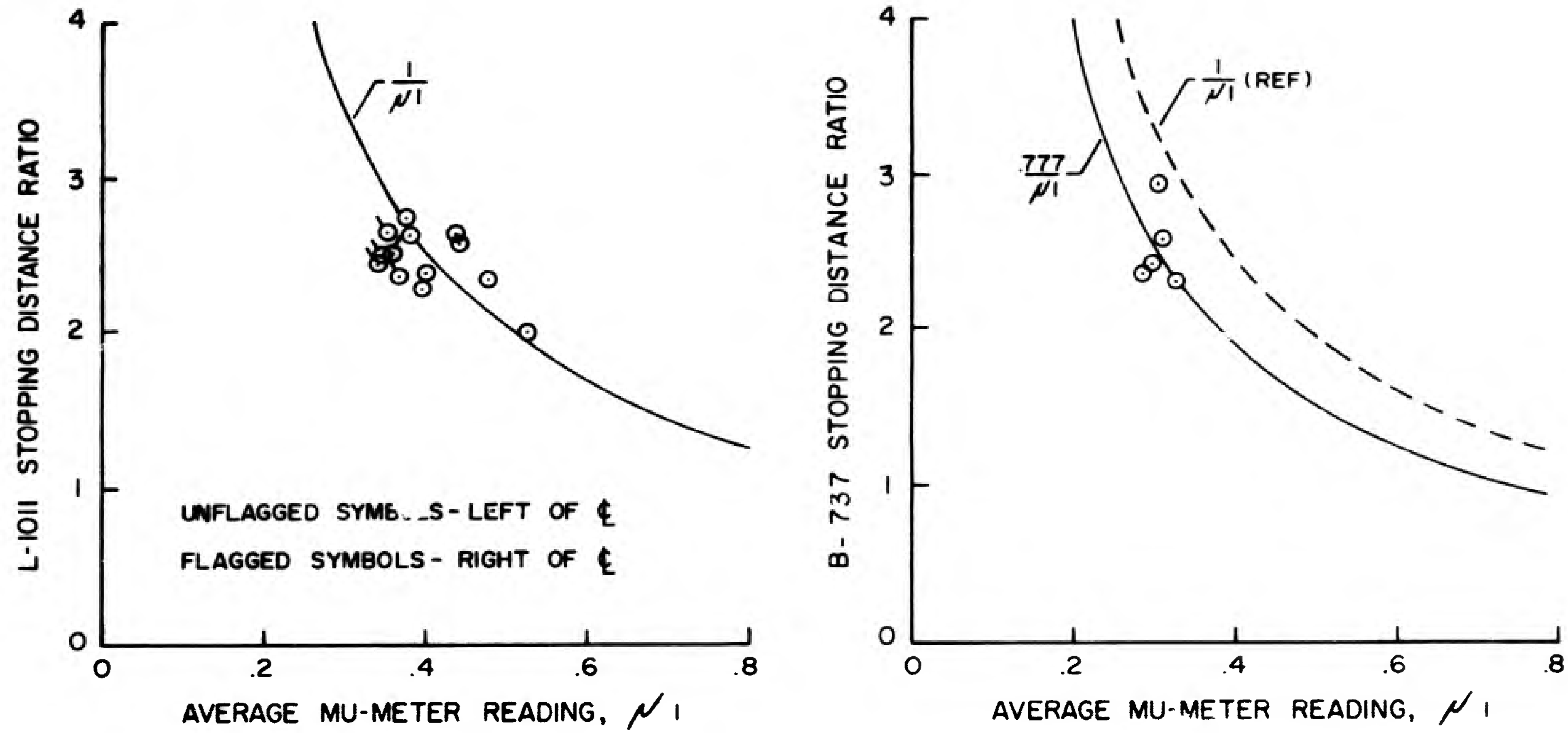


Figure 54. Comparison of the L-1011 & B-737 stopping distance ratios and Mu-Meter readings. (Data from Reference 17)

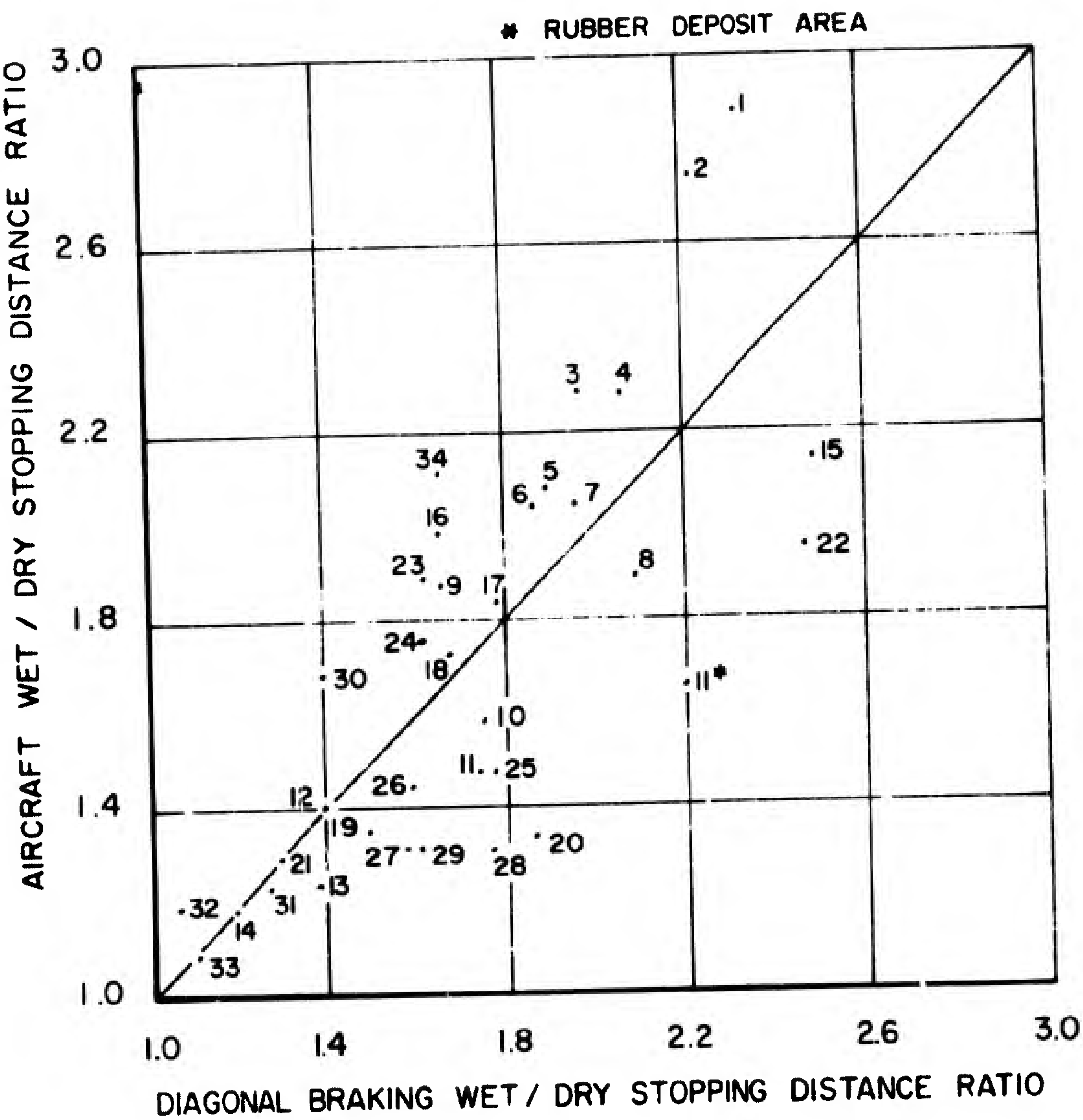


FIGURE 55. COMPARISON OF WET-DRY STOPPING DISTANCE RATIOS FOR DIAGONAL-BRAKED CAR AND C-141 AIRCRAFT. (DATA FROM REFERENCE 16)

A P P E N D I C E S

APPENDIX A

Listing of Aircraft Accidents & Incidents on Wet Runways

1. Listing of Air Force Aircraft Accidents & Incidents
2. Listing of Scheduled Air Carrier Aircraft Accidents
3. Listing of Scheduled Air Carrier Aircraft Incidents

1. Listing of USAF Aircraft Accidents and Incidents from January 1972 to November 1974 Involving Loss of Control on Wet Runways:

Aircraft Type	Number of Accidents/Incidents	Total Dollar Loss
A-37B	2	$ 810
B-52	5	8,944,123
FB-111	1	98
KC-97	1	3,067
C-130A	1	16,790
KC-135	2	2,689
C-141	1	228
F-4	16	4,490,805
F-100	1	44,425
F-101	5	1,586,140
F-102	1	0
F-105	2	2,137,551
F-106	1	50
F-111	2	68,495
T-29	3	1,049
T-33	3	6,259
T-38	2	329
T-39	21	796,935

2. Listing of Scheduled Air Carrier Aircraft Accidents on Wet Runways where Mishaps Resulted in Overrun or Veer-Off. (Reference: 13)

Date	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
3-20-68	Evansville, Ind	CV-340	Aircraft Slid off end of runway; wet runway (water).	0	0	Aircraft Landed Gear up; Small Fire was extinguished.
8-12-69	St. Thomas, V.I.	DC-9	Aircraft went off end of runway and hit auto; wet runway	2	3	Substantial Damage to nose Landing gear, nose Section, wings and Fuselage
2-11-70	Stockton, Calif.	B-707	Aircraft overran end of runway, wet runway (water)	0	1	Unknown
12-15-72	Miami, Fla.	B747	Hydroplaned after landing, wet runway (water)	0	0	Nose gear collapsed, damaged lower fuselage and wheel well, distorted cabin floor; No.3 engine fan blades damaged, holes punched in cowl; tires damaged

Date	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
3-3-73	Wichita, Kan	B-727	Aircraft weather-cocked during reversing, went off wet runway (water)	0	0	Went off left side and ground looped; left MLG was torn away
10-23-73	Greensboro, N.C.	B-737	Aircraft landed long, went off end of runway (heavy rain)	4	0	Substantial damage to the aircraft. All landing gear and right engines separated
11-27-73	Akron/Canton,OH	DC-9	Aircraft overshot on landing went into ravine; rain showers (fog)	16	4	Aircraft demolished (broke into three pieces); overhead racks collapsed

3. Listing of Scheduled Air Carrier Incidents on Wet Runways Where Mishap Resulted in Overrun or Veer-Off. (Reference: 13)

Date 1971	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
Jan 24	Marion, Ill	FH-227	Ran off runway (slightly wet), light rain	0	0	No Structural damage, scuffed spots on MLG tires indicate possible locked-brake condition
April 26	Denver, Colo	B-747	Overshot runway, light rain showers	0	0	No. 2 engine had some nicked fan blades
May 23	Minneapolis, Minn.	B-747	Overshot wet runway	0	0	No damage to aircraft
June 27	Rochester, N.Y.	B-727	Ran off side wet runway	0	0	No damage to aircraft
July 2	New Orleans, La.	DC-8	Overshot end wet runway; raining 2hr	0	0	No damage to aircraft
July 11	Allentown, Pa.	DC-9	Ran off wet runway. Cement plant nearby; rain made cement dust slippery	0	0	No damage to aircraft
July 18	Sydney, Australia	B-747	Ran off wet runway, 3/8 in water in spots	0	0	Nose and one main wheel were replaced as a precautionary measure

Date 1971	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
Sept 4	Moline, Ill	B-727	Overshot wet runway, heavy rain	0	0	Replaced right nose wheel and tire assembly because of rim damage
Sept 11	Baton Rouge, La	CV-600	Overshot end wet runway, thunderstorm	0	0	No damage to aircraft
Oct 13	Louisville, Ky	B-727	Skidded off slick damp taxiway	0	0	No damage to aircraft
Dec 2	Greenville, Miss	DC-9	Ran off side runway; water on runway	0	0	No damage to aircraft
1972 Feb 9	Miami, Fla.	B-747	Hydroplaned off wet runway (raining)	0	0	Nos. 1 and 2 engines overtemped during reversing; no.2 tire and anti-skid transducer replaced, fan blades on no. 3 engine damaged due to ingestion
Feb 23	Washington D.C.	B-727	Hydroplaned off snowcovered runway	0	0	Damage limited to flat spots on all four main tires; white blisters on tires

Date	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
March 15	Paducah, Ky.	FH-227	Undershot runway, rain, hail	0	0	No damage to aircraft; left gear struck three runway lights and a small sign
April 4	Birmingham, Ala.	DC-9	Slid off runway; heavy rain, wind gusts	0	0	Four main tires blown out
April 12	International Falls, Minn.	CV-440	Slid off runway, heavy wet snow falling	0	0	Left engine-strut damage, right engine ingested snow in intake and compressor; both changed
April 12	Grand Forks, N.D.	DC-9	Slid off runway, runway cleared; slush 15 ft	0	0	Minor damage to flap trailing edge and to left tire (hit four runway lights)
April 22	Pittsburg, Pa	B-737	Slid off taxiway (wet)	0	0	Replaced No.1 tire-deep cuts running over taxi lights

Date	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
June 22	Jamaica, N.Y.	B-747	Ran off end of wet, and slick runway	0	0	Six tires replaced due to cuts
July 9	Erie, Pa.	DC-9	Lost control on landing; thunderstorm, raining, runway wet	0	0	No damage to aircraft
Aug. 7	Tokyo, Japan	B-747	Runway wet, ran off highspeed taxiway	0	0	No. 16 Wheel failed; No. 11 tire deflated; several tires received cuts; No. 6 cande broken; replaced
Aug. 20	Tampa, Fla	DC-8	Went off end of wet runway	0	0	No damage to aircraft
Sept. 29	Buffalo, N.Y.	B-707	Hydroplaned off end of wet runway	0	0	Nos. 7 and 8 tires-evidence of hydroplaning; No. 6 tire changed-hydroplaning evident

Date	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
Oct. 12	Rochester, N.Y.	BAC-111	Hydroplaning off runway (heavy rain)	0	0	All four main wheels-hydro-burns, left inboard tire cut and worn-replaced
Nov. 7	Lynchburg, Va.	YS-11	Aquaplaned off side runway (heavy rain)	0	0	No damage to aircraft; hit two runway lights
Nov. 25	Greensboro, N.C.	DC-9	Ran off end runway in medium-intensity rain; runway wet	0	0	No damage to aircraft
Dec. 30	New Orleans, La	B-727	Runway wet; hydro-planed off taxiway into mud	0	0	No damage to Aircraft
1973 March 17	Ft. Wayne, Ind.	DC-9	Hydroplaned off and back on runway with 1/2 in slush and snow	0	0	Small hole in right trailing edge flap; small puncture in APU door caused by mud slush and gravel

Date 1973	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
March 17	Jamaica, N.Y.	B-707	Hydroplaned off end of wet runway	0	0	No damage to aircraft
March 17	Allentown, Pa.	B-727	Went off wet taxiway	0	0	Minor damage to left gear door
April 27	Jamestown, N.Y.	CV-580	Hydroplaned off wet runway	0	0	No damage to aircraft
May 1	Alexandria, La	DC-9	Hydroplaned off end wet runway	0	0	No damage to aircraft
June 21	Jamaica, N.Y.	B-747	Slid off wet runway (raining)	0	0	One tire blown, three others changed
Sept 6	Houston, Tx	DC-10	Hydroplaned off wet runway (light rain)	0	0	No. 2 main tire blown; both left main wheel assemblies and right nose wheel assembly replaced
Sept. 14	Charlotte, N.C.	DC-9	Hydroplaned off wet runway	0	0	Breakage inner radius of left nose wheel in bearing recess area

Date	Location	Aircraft Type	Remarks	Injuries Minor	Injuries Serious	Aircraft Damage
Sept. 23	Aberdeen, S.D.	DC-9	Slid off right side wet runway, thundershowers	0	0	No damage to aircraft
Oct. 28	Charlotte, N.C.	DC-9	Ran off runway for 600 ft. before returning, wet runway, thunderstorm in process	0	0	No damage to aircraft; one runway light damaged

A P P E N D I X   B

Runway Condition Reading (RCR) System

APPENDIX B
RUNWAY CONDITION READING (RCR) SYSTEM

1. JAMES BRAKE DECELEROMETER: The Air Force has utilized the Runway Condition Reading (RCR) System for predicting aircraft stopping performance since 1960. The RCR system is based on the data obtained from a James Brake Decelerometer (JBD) instrument. The decelerometer consists basically of an air damped pendulum plate that is geared to an indicator needle which points to a dial at the maximum deceleration in feet/sec^2 achieved during a stop. The pointer remains locked on the maximum reading until it is manually reset to zero. The JBD is normally placed in a level position on the floor of the base operations vehicle. Procedures for obtaining JBD readings are as follows (Ref T.O. 33-1-23):

a. Drive the vehicle at a speed of 20 mph down the center or within 20 feet right or left of the runway centerline. Avoid placing the wheels on the centerline or any other painted runway areas. NOTE: If taking readings on a surface which gives good braking (readings of 18 or greater), tests should be made from a speed of 30 mph.

b. Apply brakes smoothly and firmly to induce a full skid. Then release the brakes to prevent the vehicle from coming to a full stop.

c. Record the JBD reading, zero the instrument and repeat the above procedure at approximately 1,000 foot intervals for the entire length of the runway.

d. The readings for each 1,000 feet are added and averaged by the total number of readings to give the RCR.

From these procedures it is apparent that any of several factors can drastically influence the average JBD reading, e.g., operator error (speed and technique for locking the wheels), installation error, type vheicle, tire characteristics, calibration, etc. However, if these variables could be controlled, the theoretical principles of the JBD should predict aircraft stopping performance.

2. BRAKING FRICTION COEFFICIENT: When Newton's Law of Motion is applied, the locked wheel friction coefficient (μ_s) can be determined, and it was thought that μs determined by the JBD would correlate with μs experienced by aircraft. The μ_s of the JBD vehicle can be calculated from the equations:

$$F = MA = \frac{W}{g} A \qquad \text{(EQ B-1)}$$

and

$$\mu_s = \frac{F}{W} \quad \text{(EQ B-2a)}$$

$$\mu_s = \frac{A}{g} \quad \text{(EQ B-2b)}$$

Several tests have been conducted to determine the correlation between the RCR system and aircraft stopping distance performance. Correlation studies of the F-4D, C-141 and Convair-990A show that on a wet surface the RCR system does not correlate with stopping distance performance. This is very evident in the plots shown in Figure B-1. During the Combat Traction Program, NASA queried several organizations to determine how the RCR landing distance charts were derived. It was reported that the JBD normally developed a baseline reading of 23 on a dry runway. Then to correlate aircraft stopping distance performance to the RCR system, the dry runway aircraft braking friction coefficient had to be determined during certification tests. A linear relationship of RCR aircraft braking coefficient was assumed as shown in Figure B-2. In Figure B-2, the average braking friction coefficient of 0.3 was obtained during dry aircraft runway braking tests. Accordingly, RCR number 11.5 would correlate to a μ_b of 0.15. However, during the Combat Traction Program it was shown that the JBD underestimated aircraft performance on wet runways (primarily due to the efficient design of the vehicle tires) and that an RCR number of 11.5 did not correlate to an aircraft braking coefficient of 0.15 for the above example.

3. CORRELATION BETWEEN DBV SDRs AND RCRs: Also during the Combat Traction Program, a correlation between DBV stopping distance ratios and RCR numbers listed in the C-141 dash-one handbook was made as shown in Figure B-3. Two important observations arise from analysis of Figure B-3. First, aircraft braking loss rapidly deteriorates (0% to 75%) for a relatively small range (1-3) of DBV stopping distance ratios. Secondly, a DBV stopping distance ratio of 2.0 equates to a 50% aircraft braking loss or an RCR value of 11.5. Most dash-one flight handbooks recommend the use of an RCR number of 12 (approximately 50% aircraft braking loss) when computing landing on wet runways. There has been considerable discussion on extending the use of Figure B-3 for computing stopping distance performance of all aircraft. However, the Combat Traction Report (Ref 10) cautions against using this technique of equating RCR numbers and DBV stopping distance ratios until further validation with other aircraft types can be made. To date, limited validation testing has been accomplished. The RCR system is still being utilized to predict aircraft stopping distance capability on snow and ice covered runways predicted on the results of the Combat Traction Report (Ref 10). Test results showed that the

RCR system would overestimate aircraft performance as indicated by Figure B-4.

4. ICE AND SNOW COVERED RUNWAY CONDITIONS: On glazed ice and snow covered runways (Figure B-4), the aircraft friction coefficient was found to be constant over a wide range of ground speeds and the JBD vehicle followed similar deceleration trends as the aircraft, resulting in some correlation between the C-141 and the JBD vehicle. However, it should be emphasized that the snow and ice covered runway testing was conducted during relatively narrow range of temperatures and had insufficient samples to make meaningful judgments.

5. CONCLUSION: In conclusion, the RCR system now employed by the Air Force is predicated on a system (JBD) which cannot predict relative slipperiness of a wet or flooded runway. Most flight handbooks recommend standard RCR numbers (usually 12 [52% braking loss] or 9 [61% braking loss]) for use in computing aircraft performance on wet runways and the validity of RCRs for other conditions is doubtful.

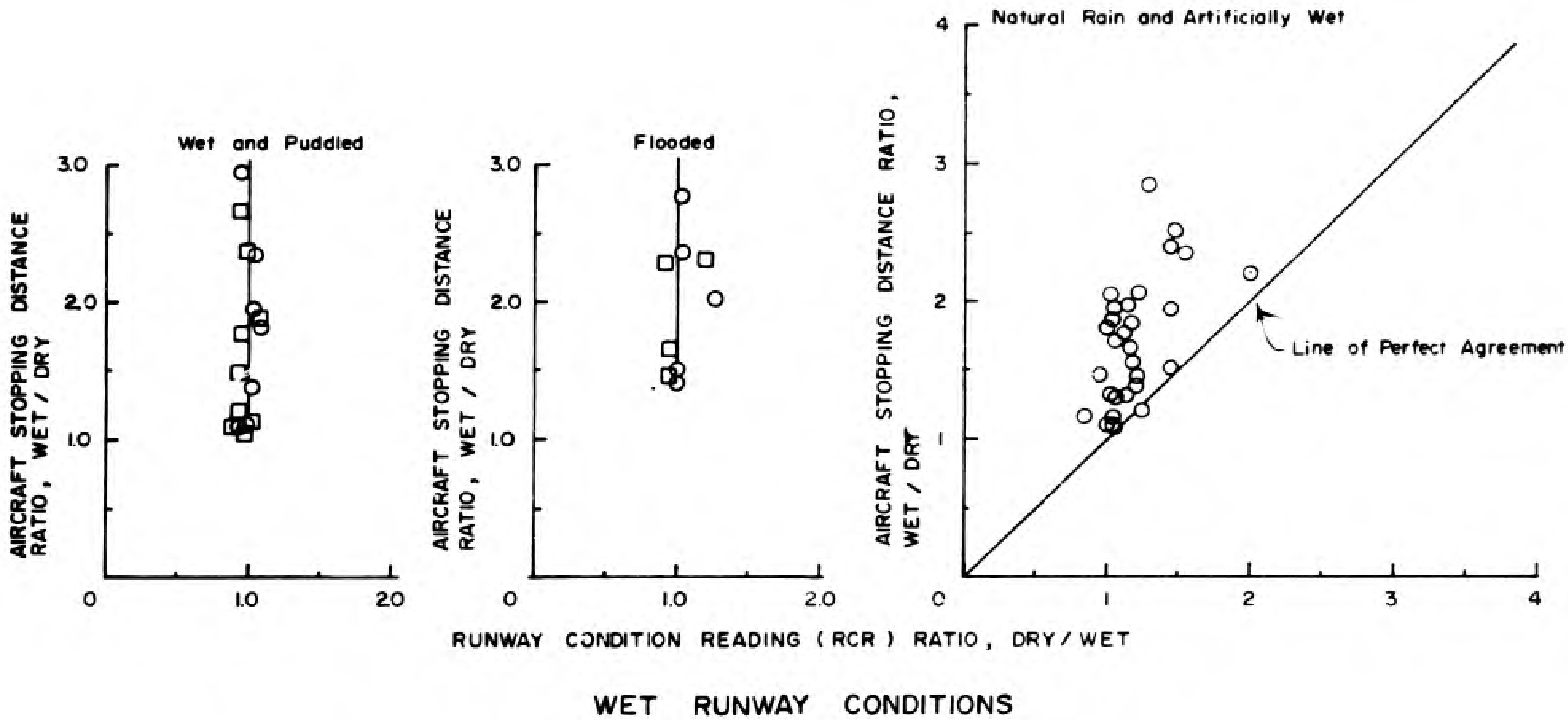


FIGURE B-1. COMPARISON OF AIRCRAFT STOPPING DISTANCE RATIOS WITH RCR RATIOS. (DATA FROM REFERENCE 10)

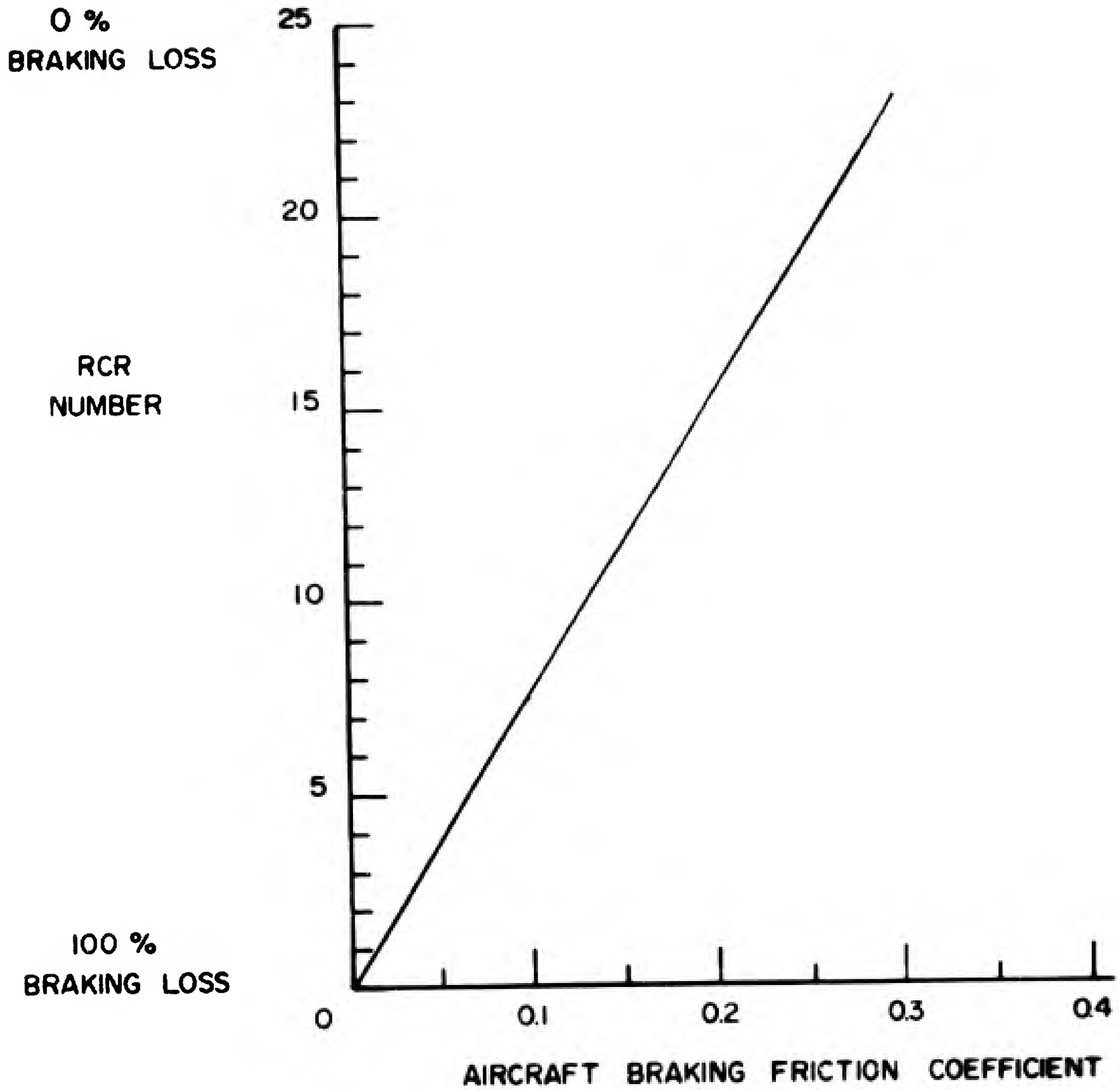


FIGURE B-2. DETERMINATION OF AIRCRAFT BRAKING FRICTION COEFFICIENT. (DATA FROM REFERENCE 10)

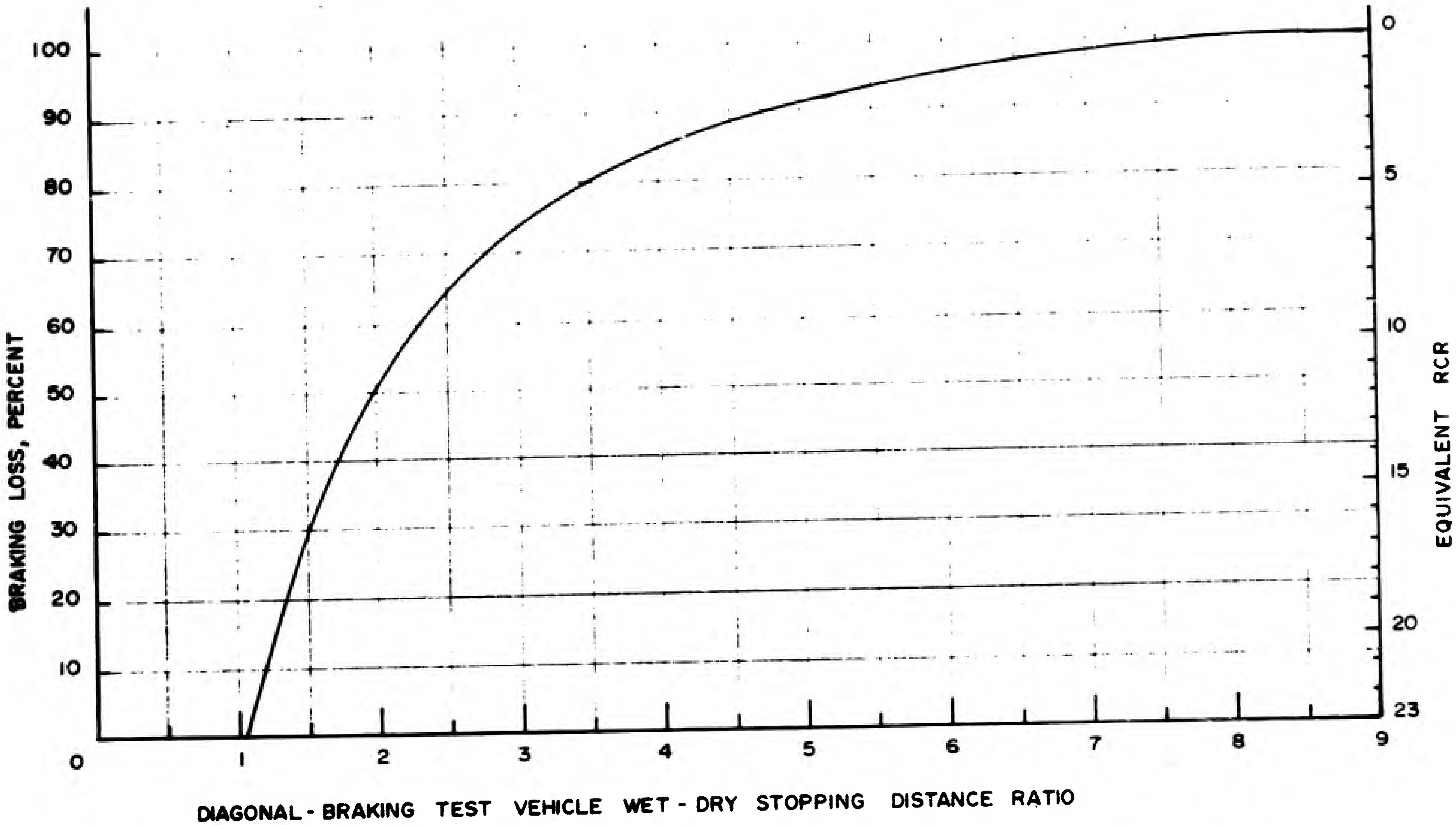
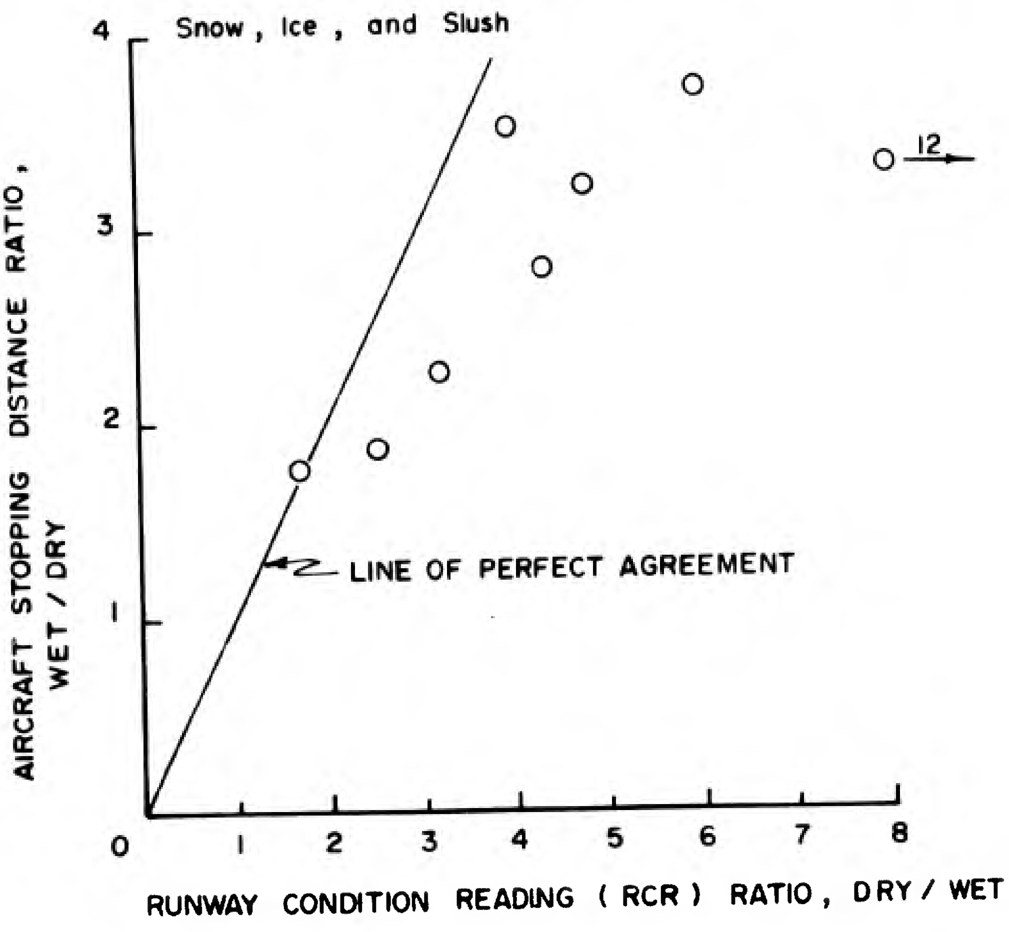


FIGURE B-3. CONVERSION OF DIAGONAL-BRAKED VEHICLE WET-DRY STOPPING DISTANCE RATIO TO THE EQUIVALENT RCR. (DATA FROM REFERENCE 10)



SNOW, ICE, AND SLUSH RUNWAY CONDITIONS

FIGURE B-4. COMPARISON OF AIRCRAFT STOPPING .ISTANCE RATIOS WITH RCR RATIOS. (DATA FROM REFERENCE 10)

A P P E N D I X C

ALSAFECOM 16/70, Wet Runway Accidents

APPENDIX C

ALSAFECOM 16/70, WET RUNWAY ACCIDENTS

In September 1970, the Director of Aerospace Safety dispatched ALSAFECOM 16/70 which is considered a major skid resistance historical milestone. The message is quoted as follows:

FOR COMMANDERS AND SAFETY OFFICERS:

SUBJECT: Wet Runway Accidents. Dir of Aerospace Safety IGDS/ ALSAFECOM 16/70.

1. Two recent landing accidents in one day graphically confirmed the results of Project Combat Traction. Simply stated, the runway condition report (RCR) readings obtained by James Braking Decelerometer on wet and flooded runways provide an extremely optimistic figure for calculating the required stopping distances. In almost every test of wet and flooded runways during Project Combat Traction an (RCR) of from 17 to 22 was obtained from the James Braking Decelerometer. An instrumented C-141 proved that a more realistic RCR would have been in the range of 9 for concrete to 12 for asphalt runways. It should be noted, however, that quite valid stopping distances can be determined from the James Braking Decelerometer RCR values taken on snow and ice covered runways. It is where there is enough water on a runway to allow viscous skidding or hydroplaning that the James Braking Decelerometer readings can trap you.

2. The diagonal braking vehicle technique used by NASA for obtaining stopping distances has been proven accurate within plus or minus five percent. A number of these specially modified vehicles will be available to Commands in the future; however, wet runway mishaps continue to occur. New precautions must be taken in predicting wet runway stopping distances.

3. During the Combat Traction test several runways in CONUS and Europe were evaluated. The data from these tests can be used as a guide at those bases checked until diagonal braked vehicles are available. Commanders at bases that have not been evaluated should use an RCR of 9 for concrete runways when wet, an RCR of 12 for wet asphalt runways, and RCRs of 6 or 7 for portions of the runway where heavy rubber deposits are present.

4. Commanders must ensure that realistic RCR figures be used during wet runway operations. Action is being taken by this headquarters to expedite procurement of a diagonal braking vehicle for evaluating all USAF runways.

APPENDIX D

ALMAJCOM MSG 1494/70 142352Z Nov 70, Wet Runway Operation

APPENDIX D

ALMAJCOM MSG 1949/70 132352Z Nov 70, Wet Runway Operation

Due to the controversy over ALSAFECOM 16/70, an ALMAJCOM message was dispatched. The provisions of Part I still apply for determining aircraft performance and the message is quoted as follows:

JOINT AF/IGDS, AF/XOOTFB MESSAGE

SUBJECT: WET RUNWAY OPERATION

PART I. As a result of a meeting at HQ USAF, the following instructions will apply to operations on wet runway. Effective immediately, those provisions of AFR 60-13 that apply to measurement of RCR on wet runways will not be used. However, those instructions in AFR 60-13 applicable to operation on snow and ice are valid and will be used. RCR values for wet runway operation recommended in the applicable aircraft dash-one flight handbook will be used by all USAF aircraft when wet runway conditions exist. (Wet runways are defined as a runway where water is visibly discernible on the runway surface.) This surface condition will be disseminated in accordance with the provisions of AFR 60-13, except that the sequence will state only that the runway is wet.

PART II. Those bases evaluated by the diagonal braking vehicle technique during the Combat Traction test program will receive RCR values to be used on their runways. These values and the method of dissemination of this information await the final report of Combat Traction, but should be issued in 60 days. No further requests should be forwarded to NASA for evaluation of additional runways. Testing of additional bases will be on an operational priority basis. Request all Major Commands determine the priority of bases requiring evaluation and forward requirements to AF/PREC, Wright-Patterson AFB, Ohio. Information copies will be sent to AF/XOOTFB, AF/IGDSFRO and AF/PREES.

PART III. Additional testing of AF runways and further research of the procedures developed during Combat Traction will be conducted. It is anticipated that this phase will require at least one year.

APPENDIX E

NASA Water Surface Depth Instrument

April 1970

Brief 70-10103

NASA TECH BRIEF

NASA Tech Briefs are issued to summarize specific innovations derived from the U.S. space program, to encourage their commercial application. Copies are available to the public at 15 cents each from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

Water Surface Depth Instrument

Tripod Base of Water Gauge

A measurement gage has been devised to provide instant visual indication of water depth based on capillary action and light diffraction in a group of solid, highly polished polymethyl methacrylate rods. The device consists of a flat polymethyl methacrylate disc mounted on a small tripod. The 1/2-inch diameter polymethyl methacrylate rods are circularly mounted in the disc, parallel to the plane of the tripod base. The base height of each rod above the plane of the tripod feet (corresponding to the surface on which the water depth is to be measured) is numerically indicated on the disc top.

When the countersunk end of the polymethyl methacrylate rods contacts the water surface, a capillary effect is initiated. The effect is instantly visible by light refraction at the polished upper end of the rods which

(continued overleaf)

are immersed. Water depth is indicated by the highest rod immersed. Rod lengths are adjustable to measure various water depths in any desired increments.

These water depth gages will be used at air bases to correlate rainfall precipitation rate with water depth on the runway.

Note:

No additional documentation is available. Specific questions, however, may be directed to:

Technology Utilization Officer
Langley Research Center
Hampton, Virginia 23365
Reference: B70-10103

Patent status:

Inquiries about obtaining rights for the commercial use of this invention may be made to NASA, Code GP, Washington, D.C. 20546.

Source: Quinton C. Davis IV
Langley Research Center
(LAR-10576)

A P P E N D I X   F

Federal Aviation Regulation 121.195, Transport Category Airplanes: Turbine Engine Powered; Landing Limitations: Destination Airports

APPENDIX F

Federal Aviation Regulation 121.195, Transport Category Airplanes: Turbine Engine Powered; Landing Limitations: Destination Airports

Federal Aviation Regulation (FAR) 121.195 is applicable to air carriers engaged in interstate or overseas air transportation and establishes the landing limitations for turbine engine aircraft at destination airports. FAR 121.195 states;

a. No person operating a turbine engine powered transport category airplane may take off that airplane at such a weight that (allowing for normal consumption of fuel and oil in flight to the destination or alternate airport) the weight of the airplane on arrival would exceed the landing weight set forth in the Airplane Flight Manual for the elevation of the destination or alternate airport and the ambient temperature anticipated at the time of landing.

b. Except as provided in paragraphs (c),(d) or(e),of this section, no person operating a turbine engine powered transport category airplane may take off that airplane unless its weight on arrival, allowing normal consumption of fuel and oil in flight (in accordance with the landing distance set forth in the Airplane Flight Manual for the elevation of the destination airport and the wind conditions anticipated there at the time of landing), would allow a full stop landing at the intended destination airport within 60 percent of the effective length of each runway described below from a point 50 feet above the intersection of the obstruction clearance plane and the runway. For the purpose of determining the allowable landing weight at the destination airport the following is assumed:

(1) The airplane is landed on the most favorable runway and in the most favorable direction, in still air.

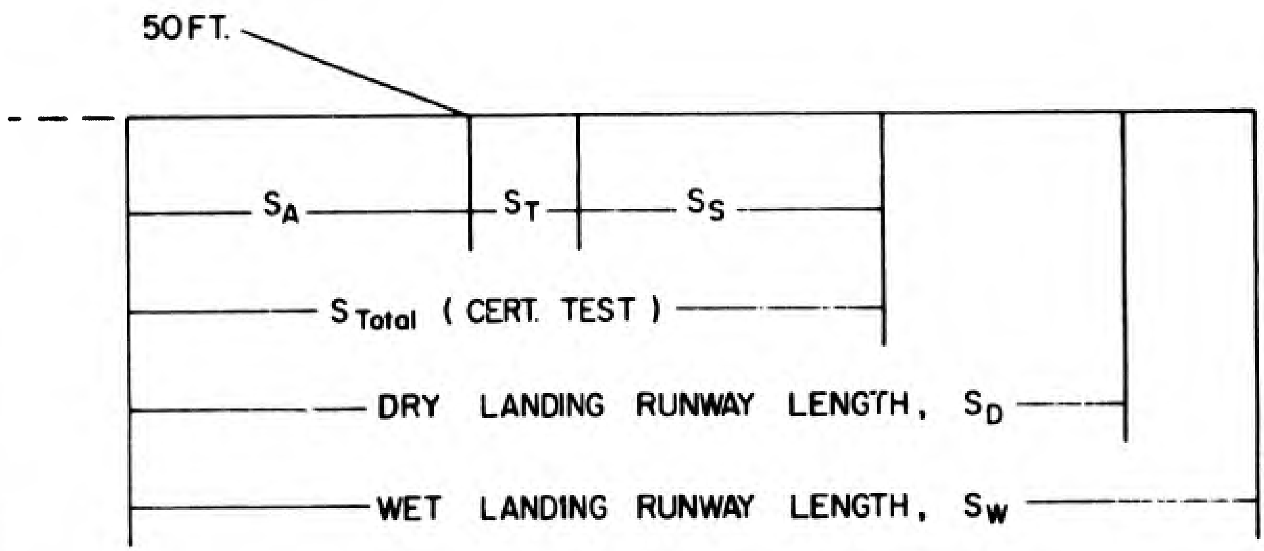
(2) The airplane is landed on the most suitable runway considering the probable wind velocity and direction and the ground handling characteristics of the airplane, and considering other conditons such as landing aids and terrain.

c. A turbopropeller powered airplane that would be prohibited from being taken off because it could not meet the requirements of paragraph (b)(2) of this section, may be taken off if an alternate airport is specified that meets all the requirements of this section except that the airplane can accomplish a full stop landing within 70 percent of the effective length of the runway.

d. Unless, based on a showing of actual operating landing techniques on wet runways, a shorter landing distance (but never less than that required by paragraph (b) of this section) has been approved for a specific type and model airplane and included in the airplane flight manual, no person may takeoff a turbojet powered airplane when the appropriate weather reports and forecasts, or a combination thereof, indicate that the runways at the destination airport may be wet or slippery at the estimated time of arrival unless the effective runway length at the destination airport is at least 115% of the runway length required under paragraph (b) of this section.

e. A turbojet powered airplane that would be prohibited from being taken off because it could not meet the requirements of paragraph (b)(2) of this section may be taken off if an alternate airport is specified that meets all the requirements of paragraph (b) of this section.

The above rule is shown graphically in Figure F1. The dry certification landing distance is frequently referred to a maximum performance landing. The aircraft is landed from a steady glide approach path with a calibrated airspeed of not less than 1.3 of stall speed. To obtain the shortest air distance from 50-feet above the landing surface, the shortest transition distance and the shortest stopping distance, the aircraft is normally flown between a three to four and one-half degree glide path with a touchdown sinkrate of seven to nine feet per second. From the certification trials, the dry and wet landing runway lengths are established utilizing the above rule.



$$S_D = \frac{S_{Total}}{0.6} = \frac{S_A + S_T + S_S}{0.6}$$

$$S_W = 1.15\, S_D = 1.15 \left(\frac{S_A + S_T + S_S}{0.6} \right) = 1.92\, S_A + 1.92\, S_T + 1.92\, S_S$$

Figure F1. Schematic of FAR 121.195 (Data from Reference 14)

A P P E N D I X G

DBV Operational Checklist

APPENDIX G

DBV OPERATIONAL CHECKLIST

BEFORE STARTING ENGINE:

1. Perform Vehicle Check: AFTO 374, Vehicle Inspection Checklist.

2. Stow Equipment:

   a. Spray paint with handle.

   b. Five small traffic cones.

   c. Forms - DBV dry and wet runs; section layout, water truck calibration.

   d. Slide rule.

3. Mount test tires.

4. Mount fifth wheel attachment and check for freedom of movement.

5. Check tires (commercial tires: 32 psi; test tires and fifth wheel tire: 24 ± 1 psi).

6. Turn all instrument switches to OFF.

7. Check and rewind stop watch.

CAUTION

Do not back vehicle with fifth wheel in test position.

AFTER STARTING ENGINE:

1. Check engine instruments.

2. Check brake pedal action.

3. Check brake selector valve for free movement and leaks. Return selector valves to four-wheel braking.

WARNING

When not testing, operate vehicle in four-wheel braking mode only.

4. Turn inverter power switch to ON.

5. Press recorder POWER switch to ON. (Power light should come on and motor should start running.)

6. Turn power switches for digital velocity and distance readouts to ON.

7. Turn digital to analog (D-A) converter to ON.

8. Zero all instruments as follows:

a. Reset velocity and distance readouts to clear displays. (Reset velocity meter first.)

b. Press TEST on velocity readout, should read 888.

c. Press TEST on distance readout, should read 888.

d. Place AUTO-MAN switch on velocity meter to AUTO-MODE EXCEPT for DD-1.1 velocity meter.

e. Place AUTO-MAN switch on distance meters to AUTO-MODE.

9. Set amplifier gain control.

10. Zero styluses with position control on amplifiers.

11. Press calibration switch on D-A converter.

12. Set CHART SPEED (2.5 mm/sec for tare runs; 10 mm/sec for wet stops; 20 mm/sec for dry stops) and set heat control for sharply defined traces.

13. Turn all instruments OFF; turn two-way radio to ON and set radio squelch and volume.

PROCEEDING TO TEST AREA:

1. Lower fifth wheel to test position; gently apply brakes and check wheel lockup circuit of velocity and distance meters.

CAUTION

Do not back vehicle with fifth wheel in test mode.

2. Do not proceed onto runway until directed by team.

3. Turn roof warning light to ON.

PRIOR TO TESTING:

1. Examine and assess test zone entrance and exit for possible emergency recovery action.

2. With brakes fully released, close brake valve to road tires. Apply full brake pressure and check for leakage of brake system. With diagonally braking selected, check for torque to the direction of front test tire.

WARNING

Do not select four-wheel braking during testing to preclude uncontrollable spins on wet pavement.

3. Insure fifth wheel is lowered.

4. Insure safety belts and shoulder harnesses are secure; safety helmet on and confirm that all items are stowed.

5. Turn velocity and distance meters to ON.

6. Turn inverter power to ON.

7. Turn recorder chart speed control to desired speed (2.5 mm/sec for tare runs; 10 mm/sec for wet stops; and 20 mm/sec for dry stops).

8. Turn D-A converter power to ON.

ACCELERATION POINT:

1. Reset distance and velocity meters.

2. Recheck that manifold brake valves are in DBV mode.

3. Advise test conductor that vehicle is ready for test.

TEST RUN:

1. Accelerate test vehicle to approximately 63-65 mph.

2. Turn recorder to ON just prior to entering test section.

3. Note readings of velocity and distance. Distance meters should indicate zero and velocity meters indicate DBV speed.

4. Shift vehicle transmission to neutral position just as all four wheels of vehicle enter test zone.

5. Allow vehicle to coast into test zone. At 60 mph, stamp on brake pedal and hold down hard (abreast of DBV break on point).

NOTE

Test wheels must lock up and remain locked for duration of test to be of any value. At lock up there will be a slight torque on the steering in the direction of the front wheel that is locked, so be prepared for this.

6. Hold pedal down hard until DBV has come to a complete stop.

AFTER STOPPING VEHICLE:

1. Stop recorder.

2. Place traffic cone on right side of the strip to denote return brake-on-point (recorder side of DBV).

3. Read and record velocity and distance meter readings.

4. Release all brake pressure.

5. Clear test section and proceed to acceleration point for next run.

NOTE

DBV will remain in the two wheel braking mode throughout the entire test. Prior to leaving test area place in four-wheel braking mode.

COMPLETION OF TESTING:

1. Return brake selector valve to four wheel braking.

WARNING

Do not operate vehicle in diagonally braked mode when not on runway.

2. Turn recorder power switch to OFF.

3. Turn inverter power to OFF.

4. Turn D-A power to OFF.

5. Turn velocity and distance meters to OFF.

6. Raise fifth wheel.

7. When departing runway, turn rotating beacon OFF.

8. Turn radio to OFF.

A P P E N D I X H

Mu-Meter/Pickup Truck Operational Checklist

APPENDIX H

Mu-Meter/Pickup Truck Operational Checklist

MU-METER CALIBRATION PROCEDURES

The following steps outline the procedures for calibrating the Mu-Meter prior to each day of testing, after each change of tires and when sudden unexpected changes in readings occur. A minimum of two operators are required.

1. Insure the Mu-Meter tires are clean and dry. The wheel tires must be completely smooth and all tire tread removed by operating the tires for approximately 20 minutes over dry pavements.

2. All test board readings must be conducted when the tires are at ambient temperature. Note: Tires that have been cold soaked (temperatures near or below freezing) will harden the tire rubber causing high friction readings on the test board.

3. Tire pressures for the recording wheels must be at 10 ± 1/2 psi and for the third wheel 30 ± 2 psi.

4. Conduct all testing on a clean and dry floor (brush the area of the floor where testing is to be accomplished and wipe the test tires with a clean rag). The calibration board should be thoroughly cleaned with a stiff bristle brush (not metal bristles) from the inside toward the outer edge. Position the Mu-Meter with jockey wheel attached, third wheel down and right wheel locked in recording position just short of the test board. Do not walk on the abrasive surface while conducting the test. Prior to each check insure that data will be properly recorded by:

   a. Lifting styli (recording and event) using lifting arm.

   b. Unlatching chart mechanism catch and moving mechanism clear of gears.

   c. Advancing chart paper about 1/2 inch.

   d. Relatching chart mechanism.

   e. Lowering styli using lifting arm. Note: Insure lifting arm is clear and not touching styli.

   f. Tighten chart paper by rotating gear wheel on right hand side of take-up spool.

5. While one operator pulls the Mu-Meter forward over the

checking board at a slow and constant speed, the second operator follows and without placing any weight on the Mu-Meter oscillates the roll chart as the machine is moving, thus reading the friction between the recorder stylus and the roll chart surface.

6. Repeat steps 4 and 5 above until consistent results are obtained. Normally the first check will be slightly different than subsequent checks.

7. If the friction readings are low, adjust the turnbuckle so that the recording wheel angle is increased (shorten turnbuckle) and if the readings are high, the turnbuckle should be lengthened to decrease the recording wheel angle. The correct amount of adjustment can be arrived at in either case only by trial and error.

8. Once an average reading of 0.77 is obtained, the third or trail wheel should be raised and a calibration test performed. The reading should increase to approximately 0.87. If an increase in friction reading of about 0.1 is not obtained, it indicates the load sensing system has lost fluid and should be refilled in accordance with the procedures outlined in the M.L. Aviation Co. Ltd. instruction and servicing manual.

9. After off loading the Mu-Meter from the pickup truck, the integrator readings should be checked by:

a. Disconnecting the lower end of the bourden vertical link from the bourden arm.

b. Setting stylus and distance counter (Window B) to zero.

c. Disconnecting the flexible drive at the rear of recorder mechanism assembly.

d. Turning the vertical drive shaft connecting the distance counter to the chart drive until a reading of at least 20 digits is obtained in Window B.

e. Assuring the integrator counter will not count with stylus set to zero.

f. Setting the stylus to 0.03 and repeating step D above.

g. Assuring the integrator just starts to count.

h. Setting stylus to 0.5 and distance counter to zero. Repeat step d above, Window A should read 50% of that for window B.

i. Setting stylus to 1.0 and distance counter to zero. The integrator counter Window A should read the same count as on the distance counter (Window B).

j. Checking the integrator window for the following:

INTEGRATOR WINDOW READING:	STYLUS POSITION:
45	0.0
130	0.5
215	1.0

PICKUP TRUCK OPERATIONAL CHECKLIST

BEFORE STARTING ENGINE:

1. Perform vehicle check: AFTO Form 374 Vehicle Inspection Checklist.

2. Mount fifth wheel and check for security and freedom of movement.

3. Turn remote readout and digital readout instrument switches to OFF.

4. Insure proper forms are available (Mu-Meter dry and wet runs; and slope measurement).

5. Check and rewind watch.

6. Insure slide rule is available.

7. Remove jockey wheel and attach Mu-Meter. Connect power/instrumentation cord and pneumatic tube to receptacles.

8. Check Mu-Meter event marker system from cab of vehicle.

CAUTION

Do not back vehicle with fifth wheel in test position or Mu-Meter attached.

AFTER STARTING ENGINE:

1. Check engine instruments.

2. Check brake pedal action.

3. Turn radio to ON and set volume and squelch controls.

4. Turn power switches for digital velocity and distance readouts to ON.

5. Press TEST on velocity meter, should read 888.

6. Press TEST on distance meter, should read 8888.

7. Place velocity meter to AUTO-MODE.

8. Place distance meter to MAN.

AT TEST AREA:

1. Lower fifth wheel.

2. Turn distance and velocity meter to ON.

3. Turn remote readout unit to ON.

4. Turn rotating beacon to ON.

5. Do not proceed onto runway until directed by team chief.

6. Proceed to acceleration point.

AT ACCELERATION POINT:

1. Lower fifth wheel of Mu-Meter.

2. Toe out moveable test wheel to locked position.

3. Check supply of roll chart paper.

4. Annotate chart paper with proper run designation number.

5. Reset remote readout unit counters to zero.

6. Advise test conductor that vehicle is ready for testing.

DURING TEST RUN:

1. Accelerate to 40 ± 3 mph prior to entering test section.

2. Upon passing double cones, driver blips event marker twice and data collector starts remote readout unit while recording time entering test section.

3. Driver blips event marker once abreast of DBV brake-on and stop points.

4. Upon passing double cones at end of test section, driver blips event marker twice, and data collector stops remote readout unit while recording time of exit.

5. Decelerate and stop.

6. Annotate chart paper for next run.

AFTER COMPLETING TEST SECTION:

1. Raise third wheel of Mu-Meter.

2. Toe in moveable test wheel.

3. Remove recorded roll chart paper.

4. Proceed to next test section.

COMPLETION OF TESTING:

1. Complete 1, 2 and 3 above.
2. Raise fifth wheel.
3. When departing runway turn rotating beacon to OFF.
4. Turn velocity and distance meters to OFF.
5. Turn remote readout unit to OFF.
6. Turn radio to OFF.

APPENDIX I

OPERATIONS PLAN
SKID RESISTANCE TESTING OF RUNWAYS

1. Introduction. A requirement to test the skid resistance/hydroplaning potential of runway(s) utilized by the USAF exists. The Air Force Civil Engineering Center (AFCEC) has been tasked to conduct the pavement traction tests using specially designed equipment to determine skidding/hydroplaning potential. Test results will be provided to the major commands including recommendations detailing the location and severity of expected hydroplaning potential. This Operations Plan outlines the test procedures, base support requirements and general discussion of skidding/hydroplaning.

2. Task Organizations. The base will task appropriate organizations that are required to support this testing effort.

3. Test Objectives. The objectives of this testing effort are:

a. Determine if and where there is a skidding/hydroplaning potential.

b. If a problem exists, determine the severity.

4. Responsibilities:

a. The Team Chief of the Pavement Surface Effects Team has overall responsibility for conducting the skid resistance tests.

b. The Base Project Officer is responsible for coordinating all local base support prior to and during the testing effort to include coordination of the runway closure times with the Chief of Airfield Management.

5. Background. The problem of tire hydroplaning and aircraft skidding, which the pilot may not have any control over, did not become acute until the introduction of Jet aircraft, due to their increased landing speeds and increased frequency of adverse weather landings. There are three reasons why an aircraft tire will hydroplane:

a. Dynamic hydroplaning - occurs when an unbraked aircraft tire operating at a high ground speed on a wetted pavement surface spins down to a complete stop. This phenomenon results when a water film from 0.1 in. to 0.4 in. (when water depth exceeds the tire tread depth) is present on a runway surface and the aircraft is traveling at a ground speed equal to or greater than nine times the square root of the tire pressure (knots). The tire stops rotating since the water cannot be ejected by the pressure of the rolling tire; consequently the center of pressure of the lift force moves forward of the wheel axle and creates a spin-down movement. If dynamic hydroplaning occurs during a crosswind landing, the aircraft will drift off towards the downwind side of the runway.

b. Viscous hydroplaning - occurs when contaminants such as dust and rubber particles are present on a smooth damp runway surface. This type of hydroplaning can occur at speeds much lower (35%) than dynamic hydroplaning.

c. Reverted rubber hydroplaning - results from a locked wheel skid of lengthy duration on a wet pavement. The runway friction is insufficient to bring the wheel up to speed, but enough friction is available to heat the water into steam forming a seal which delays water expulsion, thereby preventing tire contact with the pavement surface. Reverted rubber skidding normally leaves telltale white streaks on the pavement surface and forms elliptical shaped, sticky, tacky, slightly raised rubber patches on the aircraft tire.

6. Test Program.

a. Equipment. The standard skid resistance test requires the use of four pieces of equipment to evaluate the runway skid resistance/hydroplaning characteristics:

(1) The Mu-Meter is a small trailer unit, developed by the British, for the specific purpose of recording the coefficient of friction (Mu). The Mu-Meter continuously records the side-slip force between the test surface and the pneumatic tires which are set at a fixed toed-out angle. The coefficient of friction versus distance along the pavement is recorded on a paper graph and instrumentation in the vehicle cab integrates the coefficient of friction between any two selected points. The Mu-Meter must be towed at a constant speed of 40 MPH.

(2) The Diagonal Braked Vehicle (DBV) is a highly instrumented station wagon which evaluates the stopping characteristic of a pavement surface. The DBV concept was developed by NASA and the DBV instrumentation records the stopping distance of the vehicle from 60 MPH in a diagonally locked wheel mode.

(3) The slope measurement device is a 10-ft. long rectangular section with machinists levels attached in order to determine in percent (to the nearest 0.1 percent) the slope of the pavement surface.

(4) The water application truck (normally furnished by the base fire department) is used to apply water to the test section. The tank trailer should hold a minimum of 2500 gallons, and be equipped with a pump-force water system (independent of the vehicle drive train) and operative pump pressure gauge used to maintain a constant water output. The tractor unit must be equipped with an operative engine tachometer in order to maintain a precise forward speed and a gearing/axle ratio which will enable the truck to maintain a constant low forward speed under changing load conditions. Normally the base F-6/7 runway foamer meets these specifications. The team will attach a special water spreader bar to the water application truck.

b. Test Preparation. Prior to the skid resistance testing, the following actions must be accomplished by the base:

(1) NOTAM prepared and dispatched, closing the test runway during the daylight hours. The closure times are:

(a) Two and one-half hours for dry testing.

(b) Four hours for wet testing. NOTE: Additional closure time may be required if the water truck malfunctions. A time interval of at least one hour between the two testing periods is required to reservice and calibrate equipment.

(2) Arrange for two personnel to drive the water application truck and operate the pump engine. Insure the water application vehicle(s) are in operational condition. The water, both in storage and during the spraying application, must not become contaminated with foaming agent. The pump should be operated for a minimum of ten minutes to insure its operational capability before the team arrival. From previous experience, the tractor is operated at 1800 rpm tachometer setting or 500 ft/min on the fifth wheel indicator readout in second gear, low range axle. The water application vehicle will be reserviced utilizing special equipment provided by the team.

(3) Arrange for a flightline driver and vehicle (equipped with a radio for communications with the tower). The vehicle will be used by the skid team chief for controlling all testing operations.

(4) Obtain one copy of the runway layout plan detailing the transition between pavement types (normally Tab C-5, Airfield Pavement Plan (see AFM 86-9, chap 2) of the master plan, contains the required drawings).

(5) Arrange for vehicle maintenance support. Tire changing/mounting facilities for standard tubeless tires, premium gasoline for the DBV and Mogas for the pickup truck.

(6) Arrange for quarters for the military members of the skid resistance team, consisting of one officer and four enlisted personnel. Quarters will be required for the day preceding the test and the day of the test.

(7) Arrange for barrier personnel to remove and reset barriers during each testing period.

(8) Arrange for a clean, dry enclosed and secure area for calibrating test equipment, preferably near the flightline. Normally a fire department stall is utilized since the team works closely with personnel of the fire department.

c. Test Procedures. The standard skid test is conducted on preselected 2000 ft. x 10 ft. sections of the pavement surface. Normally six to eight test sections are selected to examine the pavement traction in the aircraft touchdown area (rubber deposit areas), the runway interior (primary braking area) and the pavement edge (representative of a non-traffic area). Cross-wind conditions will determine the selection of the central interior and edge sections since on a crowned runway the water will pile up on the upwind side causing a greater depth of water than on the downwind side; thus if an aircraft were landing, using the center of the runway, the tire on the upwind side would hydroplane at a lower velocity than the tire on the down-wind side. A typical test section is shown in Figure 1. Once the sections have been determined, actual testing can be accomplished according to the following event schedule:

(1) Dry Testing ($2\frac{1}{2}$ hours): During this phase of the test program the dry skid resistance properties of the runway surface are measured. Transverse slope measurements are made at 1000 ft. intervals (500 ft., if required), test section marked, dry stops performed by the DBV, dry test runs conducted by the Mu-Meter and the water truck calibrated. Note at the conclusion of the DBV dry stops, the vehicle will be immediately released to the motor pool for servicing and changing of tires.

(2) Wet Testing (4 hours): During this phase each test section is artificially wetted using the water application truck to simulate a heavy rainfall rate (0.5 to 0.8 inch per hour). Water is applied to each test section in two passes, each pass places 0.1 inch of water for a total of 0.2 inch of water. Both the DBV and Mu-Meter tests are conducted immediately following water application. Tests are continued for thirty minutes after wetting to determine the pavement recovery/water runoff characteristics. At the completion of the second water pass, the water truck will proceed to the nearest water refill point.

7. Data. The skid resistance team chief has overall responsibility for data acquisition, reduction and evaluation. Data collection will be accomplished in accordance with the standard skid resistance test manual. Meteorological observation weather reports by the Base Weather Detachment are required during the testing periods. This information is normally relayed to the team by the control tower.

8. Test Site Operations. All work or functions performed on the test runway will be controlled and managed by the skid resistance team chief. Due to the inherent dangers in this testing effort (vehicles working on wet pavements and at high speeds) all visitors must be approved and briefed prior to proceeding onto the runway. All pavement/barrier maintenance must be approved by the team chief.

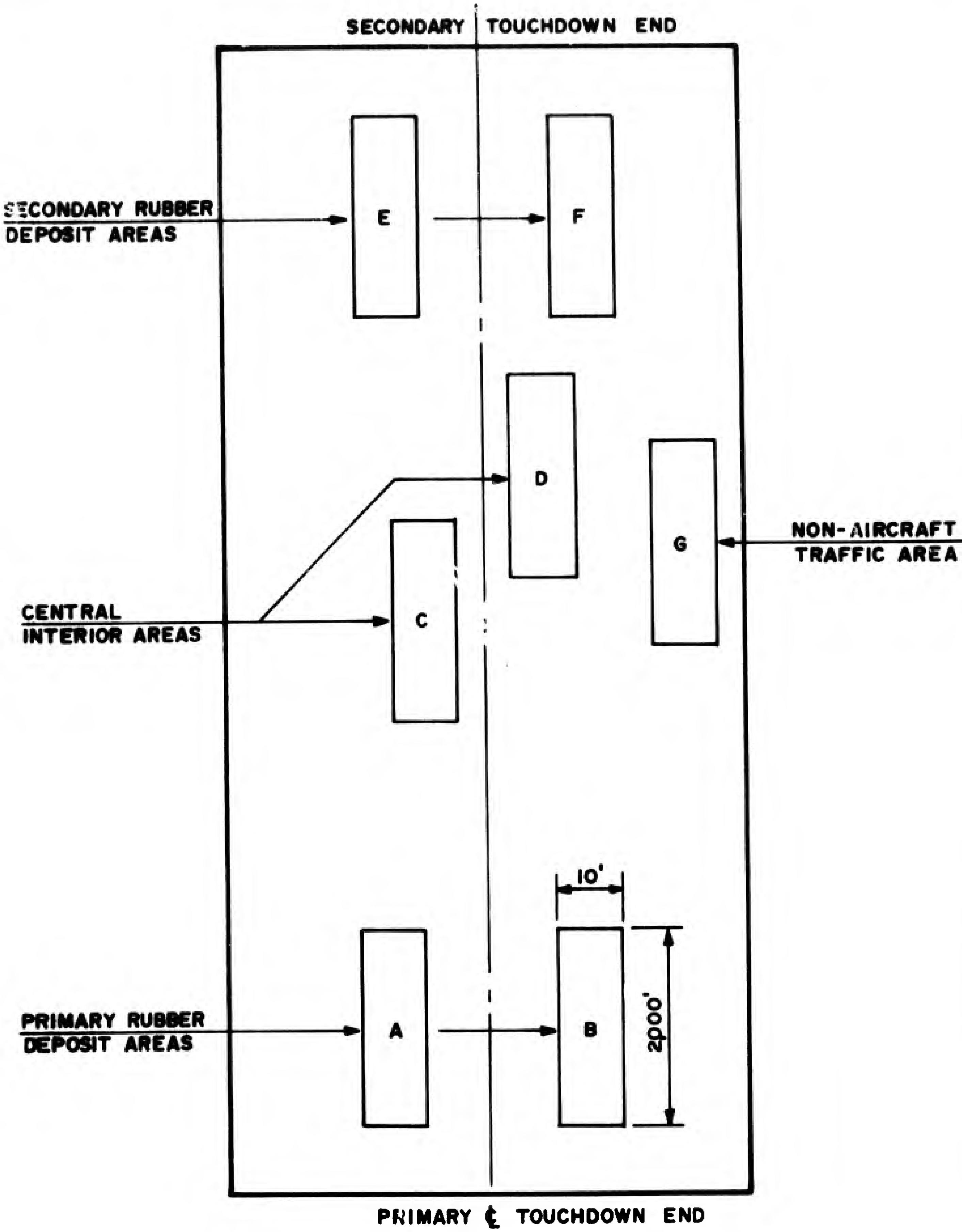
9. Safety. The skid resistance team chief is responsible for the overall safety conduct during the testing effort. All personnel participating in the testing effort will be thoroughly briefed as to their designated duties. In the event of a mishap the following procedures will be followed:

a. The senior supervisor at the scene will direct appropriate first aid.

b. If required, ambulance service will be notified through the tower communications net.

c. The skid resistance team chief will notify the host base safety office and the AFCEC.

10. Communications. Adequate communications will be maintained between the skid resistance team chief and the control tower. In the event of an impending aircraft emergency, tower personnel will inform the skid resistance team chief to clear the runway (note personnel and equipment can clear the runway in less than five minutes). The skid team operates four portable radios on an approved CONUS-wide frequency 149.275MHz. The local base frequency management representative is required to approve use of this frequency. In the event frequency 149.275MHz cannot be utilized, the base will be required to supply four portable radios on an approved frequency.



TYPICAL TEST SECTION LAYOUT

MOBILE EQUIPMENT SPECIFICATIONS

FOR

AIRLIFT SUPPORT

DIAGONALLY BRAKED VEHICLES:

Type: 1971 Plymouth Station Wagon
Weight: 4400 lbs
Cube: 700 cu ft
Length: 216 in
Height: 67 in
Width: 82 in
Hazardous: Fuel in Tank; Battery Acid

MU-METER VEHICLE:

Type: 1971 Truck Cargo Pickup, W/4 Door Cab
Weight: 6700 lbs
Cube: 976 Cu Ft
Length: 227 in
Height: 94 in
Width: 79 in
Hazardous Cargo: Fuel in Tank; Battery Acid

NOTE: When team members accompany test equipment, MAJCOM airlift request should state that the five team members are authorized as couriers to accompany the dangerous cargo.

A P P E N D I X J

Predeployment Checklist

SKID RESISTANCE EQUIPMENT AND SUPPLY LISTING

NOUN	QUANTITY	STATUS
DBV:		
Street Tires w/rims	4 ea	
Crash Helmets	3 ea	
Bumper Jack and Handle	1 ea	
Hydraulic Jack and Handle	1 ea	
Chain	1 ea	
Tire Pressure Gauge	1 ea	
Stop Watch	1 ea	
Chocks	1 ea	
Magnetic Compass	1 ea	
MU-METER TRUCK:		
Mu-Meter Tires	(2 for every 6 R/W tested + 2 spares)	
Mu-Meter Tire Rims	4 ea	
ASTM DBV Tires	2 R/W + 2 spares	
DBV Tire Rims	4 ea	
Mu-Meter Chart Paper	1 1/2 roll/RW	
DBV Chart Paper	1 roll/4 bases	
Calibration Board	1 ea	
Remote Readout-Mu	1 ea	
Transverse Slope Indicator	1 ea	
Space Levels	2 ea	
Water Spray Bar	1 ea	
Compass	1 ea	

NOUN	QUANTITY	STATUS
Tire Pressure Gauges		
0-60 psi	2 ea	
0-100 psi	1 ea	
Stop Watches	2 ea	
Steel Tape - 100 ft	1 ea	
Clip Boards	3 ea	
Computer Forms	7 ea/RW	
Envelopes	1 ea/RW	
Pavement Thermometer	2 ea	
Portable FM Radios	4 ea	
Portable Radio Chargers	2 ea	
Portable Radio Batteries	4 ea	
Grease Syringes	2/RW	
Grease Spreader	2 ea	
12" Ruler	2 ea	
Masking Tape - 3/4" wide	3 rolls	
Operational Manual	1 ea	
Armament Tape	2 rolls	
Slide Rule	2 ea	
Spray Paint/Applicator Handle	3 ea	
Silicon Spray	2 cans	
Double MALE Connector	2 ea	
Double FEMALE Connector	2 ea	
2 1/2 to 1 1/2 Reducing Coupling	2 ea	
Plain "Y" Coupling	1 ea	

NOUN	QUANTITY	STATUS
Hose Cap	2 ea	
Spanner Wrench	2 ea	
Soft Suction Hose (4 1/2, 7, 10-ft)	4 ea	
8" Wrench	1 ea	
10" Wrench	1 ea	
String	1 ea	
NASA Water Depth Gauge	2 ea	
Spare Levels	4 ea	
Slope Indicator Calibration Blocks	2 ea	
Scissors Jack	1 ea	
50' Extension Cord	1 ea	
Jumper Cables	1 ea	
Bungee Cord	1 ea	
Tool Box	1 ea	
Air Tank	1 ea	
Flashlight with Batteries	1 ea	
Motor Oil	2 qt	
Mu-Meter	1 ea	
Tie Down Straps	2 ea	
Traffic Cones	18 L/6 S	
Fifth Wheel Assembly	2 ea	
Flow Meter	1 ea	
Detergent	1 box	
Bucket	1 ea	

NOUN	QUANTITY	STATUS
Sponges	3 ea	
Jug	1 ea	
Assorted Rags	1 bundle	
Brushes, Nylon	2 ea	
Tachometer	1 ea	
Cups	2 dz	
Silicone Fluid and Eye Dropper	1 ea	
OTHER:		
GSA Credit Card	1 ea	
Car Keys	3 sets	
Orders: Courier/Mess Statement, Additional Baggage	1/person	
Trip Itinerary	1/vehicle	
Camera (16mm/35 mm)	as Reg	
Film	as Reg	
Freq Clearance Msg	1 ea	
Pens/Pencils	5 ea	
Sign Out/In		
Impress Fund		
Request Military Air		
Airline (TR) Reservations		
Form 15	1 ea	
Runway Identification Signs for Photos	1 set/base	
Preposition DBV Tires	as Reg	

A P P E N D I X K

Typical Runway Skid Resistance Survey Report

(Torrejon AB, Spain)

United States Air Force

RUNWAY SKID RESISTANCE SURVEY REPORT

Torrejon AB, Spain

AIR FORCE
CIVIL ENGINEERING CENTER
Tyndall AFB, Florida

RUNWAY SKID RESISTANCE SURVEY REPORT

TORREJON AIR BASE

SPAIN

BY

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AIR FORCE CIVIL ENGINEERING CENTER

TYNDALL AFB, FLORIDA

NOVEMBER 1974

ABSTRACT

The Air Force Civil Engineering Center (AFCEC) Pavement Surface Effects Team conducted a skid resistance/hydroplaning analysis at Torrejon AB, Spain on 10 Sep 1974. Test results indicate that Runway 05/23 central interior area has satisfactory skid resistance characteristics; however, water ponding occurred along the wheel path area of the central interior portion of the runway. The skid resistance properties of the primary touchdown area (Runway 23 end) were poor due to accumulation of rubber deposits and the secondary touchdown area had reduced skid resistance properties due to deposits of paraffin compound used to cure the PCC pavement.

TABLE OF CONTENTS

EVALUATION OF RUNWAY SKID RESISTANCE

1. Introduction - This report contains a summary of the significant data resulting from skid resistance testing conducted by the AF Civil Engineering Center. The field tests were conducted to evaluate the runway skid resistance and hydroplaning characteristics in order to determine if any corrective action is necessary to improve the runway traction performance.

2. Test Program - The test program consisted of field measurements of the pavement surface under dry and standardized artificially wet conditions. In addition, transverse slope measurements were obtained for areas (approximately 20 feet) on each side of the runway centerline to evaluate the surface drainage characteristics.

3. Test Locations - Several test sections, each 2000 feet in length, were selected to reflect a representative sampling of the skid resistance/hydroplaning characteristics of the entire surface. The test section layout is shown in Figure 1. The test sections were selected to examine the pavement traction in the aircraft touchdown areas (rubber deposit areas), the runway interior (primary aircraft braking area) and the pavement edge (representative of a non-traffic area).

4. Equipment - The skid resistance/hydroplaning characteristics of the runway surface were evaluated by two types of test equipment, a Mu-Meter and a Diagonally-Braked Vehicle (DBV). Supporting equipment included a water application truck for artificial wetting and a special level device for measuring the slope of the pavement surface.

a. The Mu-Meter is a small trailer unit designed and manufactured by M. L. Aviation (Maidenhead, Birks, England) for determining the coefficient of friction (MU) between the pavement surface and the mu-meter tires. The Mu-Meter physically evaluates the side-slip force between the tires and pavement surface. It is a continuous recording device that graphically records the coefficient of friction (MU) versus distance along the pavement. This system is also equipped with instrumentation which integrates the MU versus distance curve to obtain the average coefficient of friction for selected areas within a test section. The Mu-Meter was operated at a constant speed of 40 mph, which is 1.2 times the theoretical hydroplaning speed of the Mu-Meter.

b. The DBV is a specially instrumented vehicle which was developed to evaluate the stopping characteristics of runway surfaces. The vehicle used is a station wagon configuration.

The DBV concept was developed by NASA in conjunction with the combat traction program (NASA TN D-6098, November, 1970). The DBV records the stopping distance of the vehicle in a diagonally locked wheel mode from a speed of 60 mph. The diagonal braked wheels were equipped with ASTM tires (specification E249) which are essentially bald tires that eliminate the effects of tire-tread design on braking traction. The free rotating diagonal wheels assist the driver in maintaining directional control while the diagonally braked wheels are locked during a skid. The stopping characteristics of the runway were determined by ascertaining the dry stopping distance of the vehicle (approximately 300 feet for both Asphalt Concrete (AC) and Portland Cement Concrete (PCC) surfaces) and comparing it with the wet stopping distance. The ratio of the wet stopping distance divided by 300 feet (average dry stopping distance) defines the runway stopping characteristics.

c. The water distribution truck was a locally furnished vehicle equipped with a spray bar and a means to precisely control the rate of water application. The water was applied in two passes, with the truck carefully calibrated so that each pass placed 0.1 inch of water on the test strip. The first pass was used for an initial wetting, and testing followed immediately after the second pass. The "zero" water time was the time the water truck passed the mid point of the test section during the second water pass.

d. The slope measuring device consisted of a rectangular section of aluminum (10 feet long, 5/8 inches thick, and 2 1/2 inches high) with machinist's levels attached so as to define slopes from 0 to 2.0 percent, to the nearest 0.1 percent. The slope measuring device was used to measure transverse gradients in the wheel path areas, with measurements taken at two places on each side of the runway centerline.

5. <u>Field Test Procedures</u> - The field test procedures used for the evaluation of the skid resistance/hydroplaning characteristics of the runway surface are outlined below.

a. Test areas (each typically 2000 feet long) were determined and marked on the runway (see Figure 1).

b. Transverse slope measurements were obtained on each side of the runway centerline at the intervals shown in Table 2.

c. The water truck was precisely calibrated to discharge 0.1 inch of water each time it passed over a given line.

d. The Mu-Meter made entire runway length dry pavement runs on each side of the runway centerline (wheel path areas) and along the pavement edge. The DBV ascertained the dry stopping pavement performance.

c. Skid resistance tests under a standardized artificially wet condition were conducted as follows.

(1) Water was applied to the test area in two passes. Each pass placed 0.1 inch of water.

(2) DBV and Mu-Meter tests were conducted immediately following the second pass of the water truck. Half the test section runs were conducted in each runway direction.

(3) All water truck, Mu-Meter, and DBV operations were recorded versus local time in order to determine the tractive recovery characteristics versus "zero" water time.

6. Test Results - The pavement skid resistance results are reported in terms of MU, coefficient of friction as measured by the Mu-Meter and stopping-distance-ratio (SDR), the wet to dry stopping distance ratio as measured by the diagonally braked vehicle. A summary of the test data and pavement rating tables is presented in Table 1. The rating tables were developed from data obtained during joint Air Force/NASA/FAA tests. While the current state-of-the-art prevents a more precise delineation of exact aircraft responses, Table 1 provides a good rule of thumb for interpretation of data. Table 1 presents the combined average skid resistance values over different areas of the runway. The significant data are shown for periods of 3, 15, and 30 minutes after water was applied. Table 1 indicates how fast the skid resistance properties recover after the various sections of the runway surface are wetted. By comparing the actual measured values of MU and SDR shown at the top of Table 1 to the expected aircraft response shown at the bottom of the table, it is possible to judge if potential hydroplaning problems exist.

7. Friction Variation - Figure 2 shows the actual friction versus distance trace as recorded by the Mu-Meter during the first test run after wetting for typical areas of the runway surface. It shows the variation of friction within the 2000 feet test sections, and compares these results with the dry pavement condition. Sharp dips in the curve indicate lower friction values at these points, and probably results from one of several causes--ponding of water, local slick spots, etc.

8. Recovery With Time Charts/Graphs - Appendix A contains charts summarizing all test results from the DBV and the Mu-Meter runs. Each chart contains complete information about a single test section. Appendix B contains graphs for each test section showing the effect of time after wetting (inverse of water depth) to changes in surface friction and on the stopping distance ratio of the DBV. These graphs demonstrate the natural drainage characteristics of the runway surface

and the time required for the skid resistance properties of each test section to return to a dry pavement condition. The curves were derived by curve fitting the data obtained in Appendix A.

9. Transverse Surface Slopes - Table 2 is a tabular summary of the measured surface slopes along both sides of the runway centerline. The relative slipperiness of a pavement and, consequently, its tendency to encourage hydroplaning is closely related to depth of water held on its surface. Since the amount and depth of water held are directly related to the surface slope, a complete evaluation of surface slopes is conducted. Transverse slope measurements are normally taken at the thresholds and abreast of each runway distance marker. Slopes are measured with a ten-foot long device perpendicular to and touching the marked runway centerline. A second measurement is taken perpendicular to and at a distance of 10 feet from the marked runway centerline. Thus, the transverse slope measurements encompass the aircraft wheel path areas, 20 feet each side of the runway centerline. In addition to the aircraft wheel path area transverse slopes, transverse slope measurements were taken in the edge test section abreast of the applicable runway distance markers. The center of the slope indicator was aligned perpendicular with the center of the 10 foot wide edge test section. Positive slopes indicate water drains away from the centerline towards the edge while negative slopes indicate water drainage toward the runway centerline. In general, surface slopes in excess of one percent promote good to excellent drainage conditions, if water is able to run-off the surface without ponding (crown and single tilted slab runways). AFM 86-8, Chapter 2, Table 1 specifies the transverse grades for Air Force runways. These standards are applicable to future authorized construction only and existing installations will not be modified nor expanded merely because of nonconformity. For rigid pavements the minimum transverse slope is 0.5% and the maximum transverse slope is 1.0%. For flexible pavements the desired transverse gradient is 1.5%. The transverse runway grade requirements are not mandatory at or adjacent to runway intersections, where the pavement surfaces must be warped. Certain exceptions are also made where runway shoulder and gutter construction is involved. The maximum transverse gradient specified for rigid pavements may be increased to not more than 1.5% when new construction must match existing pavement and when excessive rainfall introduces a requirement for increased runoff.

10. Longitudinal Surface Slope - Table 2 also contains a tabular summary of the runway longitudinal surface slope. Slope measurements were taken along the runway centerline abreast of each runway distance marker. Positive slopes indicate water drainage away from the referenced runway threshold while negative slopes indicate water drainage toward the referenced runway threshold. The referenced runway threshold is designated in Table 2.

11. Weather - Test sections were selected in order that the wind would impede the water runoff. Table 3 is a resume of the weather data for each test section.

12. Pavement Description/History - Appendix C is a brief description of the runway including the construction and maintenance history. This information was obtained from the base and it is the best assessment of the pavement history/condition. If a pavement condition survey was accomplished, this information was incorporated to supplement/verify historical records.

13. Discussions/Conclusions:

a. Examination of field data indicates that the skid resistance properties of Runway 05/23 range from good to satisfactory. The central interior portion of the runway, where aircraft normally accomplish their primary braking has satisfactory skid resistance properties. The primary touchdown zone exhibited poor skid resistance properties due to poor pavement texture resulting from accumulation of rubber deposits (see Figure 3). The secondary touchdown zone (Runway 05 end, PCC portion only) also exhibited poor skid resistance properties, not due primarily to rubber deposit accumulation (spotty) but rather due to deposits of paraffin compound used to cure the PCC pavement (See Figure 4). Visual observation and transverse slope measurements indicated that the central interior portion of the runway has poor water drainage characteristics (see Figures 5 & 6). Both touchdown areas exhibited good drainage.

b. The effects of aircraft traffic and foreign material (oil, JP-4, etc.) accumulation on the skid resistance characteristics can generally be detected by comparing the skid resistance properties of the edge section and the central interior test sections. Differences were noted between the edge section (G) and the two central interior test sections (C and D) due to water ponding which occurred in the interior test sections. It is not valid to make textural comparisons between a section with excessive water ponding and a section with good drainage characteristics (G). Figure 7 shows the pavement texture of Section C.

c. The three minute SDR value (see Table 1) for the central interior area does not exceed the suggested hydroplaning threshold SDR value of 2.0; thus little or no hydroplaning should be enocuntered; however, it should be noted that the mu-meter values and the initial SDR value for Section C suggest a slight chance for hydroplaning due to water ponding. The primary touchdown area (Runway 23 end) did exhibit very high hydroplaning potential due to the accumulation of rubber deposits. It should be noted that all test sections were reduced from 2,000 feet to 1,200 feet in length due to the water capacity limitations of the base water distributor. Therefore, it was not possible to determine the extent of pavement slipperiness using the DBV, since the DBV departed the 1,200 foot section on the initial run. Visual observation of the primary touchdown area did not indicate heavy rubber buildup; however, it is probable that the chemical process for removing rubber deposits sealed the normal AC surface texture resulting in a very smooth AC textured pavement. The secondary touchdown area (Runway 05 end, PCC pavement) exhibited potential for hydroplaning due to deposits of paraffin. The new AC overlay (Runway 05 end) exhibited good traction characterisitcs. In particular, the DBV came to a sudden stop on the new overlay when the vehicle transversed from the slippery secondary touchdown PCC surface to the new AC surface.

d. Two aircraft hydroplaning mishaps were reported to the team. In Aug 73, both main gear tires of an F-111 were blown after suspected hydroplaning and in Jan 74, the left main gear tire of an F-4C was blown during landing roll on a wet runway. The base safety office stated that poor runway drainage characteristics and the crosswind landing limitations imposed by USAFE for F-4 aircraft necessitates an approach end barrier engagement any time hydroplaning is anticipated. Four F-4C approach end barrier engagements were made since 1973 due to anticipated hydroplaning problems.

e. It should be noted that the primary and secondary touchdown area recovery graphs (Appendix B) have very steep slopes which is indicative of a pavement that recovers extremely fast. The good recovery characteristics were primarily due to the high ambient/pavement temperatures and low relative humidity. During natural rainfall conditions the pavement would recover at a much slower rate.

T A B L E S

TABLE 1

DATA SUMMARY

RUNWAY 05/23

COMBINED SECTIONS LOCATION	3 MIN. MU	3 MIN. SDR	15 MIN. MU	15 MIN. SDR	30 MIN. MU	30 MIN. SDR
B TOUCHDOWN, PRIMARY	.24	3.85	.72	1.70	.95	1.00
C D CENTER	.46	1.85	.62	1.57	.77	1.06
E TOUCHDOWN, SECONDARY	.31	2.71	.73	1.33	.84	1.00
G EDGE	.72	1.43	.84	1.15	.84	1.02

MU-METER AIRCRAFT PAVEMENT RATING(1)

MU	EXPECTED AIRCRAFT BRAKING RESPONSE	RESPONSE
GREATER THAN 0.50	GOOD	NO HYDROPLANING PROBLEMS ARE EXPECTED.
0.42 -0 .50	FAIR	TRANSITIONAL.
0.25 - 0.41	MARGINAL	POTENTIAL FOR HYDROPLANING FOR SOME A/C EXISTS UNDER CERTAIN WET CONDITIONS
LESS THAN 0.25	UNACCEPTABLE	VERY HIGH PROBABILITY FOR MOST AIRCRAFT TO HYDROPLANE

STOPPING DISTANCE RATIO/AIRFIELD PAVEMENT RATING(1)

SDR	HYDROPLANING POTENTIAL
1.0 - 2.0	NO HYDROPLANING ANTICIPATED.
2.0 - 2.5	POTENTIAL NOT WELL DEFINED.
2.5 - 3.5	POTENTIAL FOR HYDROPLANING.
GREATER THAN 3.5	VERY HIGH HYDROPLANING POTENTIAL.

(1) TECHNICAL REPORT NO. AFWL-TR-73-165 (SOURCE OF RATINGS)

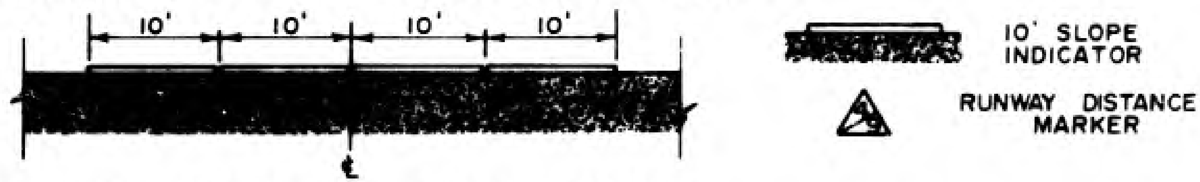
TABLE 2
DATA FROM CROSS-SLOPE MEASUREMENTS
TORREJON AB, R/W 05 / 23

TRANSVERSE SLOPE

					1.2	1.1	1.2						
0.9	1.6	1.5	1.1	1.2	1.1	0.9	0.7	1.0	0.8	1.1	1.6	1.4	1.2
1.0	1.0	1.2	1.3	1.6	0.2	0.4	0.3	0.9	-0.7	1.2	1.2	1.2	1.4
0.8	1.3	1.0	1.2	1.3	0.9	0.8	0.7	-0.4	0.0	1.3	1.1	1.3	1.4
1.4	1.3	1.5	1.4	1.0	1.2	0.7	0.7	-0.7	0.0	1.3	1.3	1.5	1.3

SECTION "A-A", LONGITUDINAL SLOPE

0.4	0.4	0.5	0.2	0.5	0.3	0.4	0.3	0.3	-0.4	0.2	0.7	0.5	0.1



SECTION "B-B" CROSS SLOPE

All Transverse Slope Measurements Were Taken Within 20' Of The Centerline And In The Edge Test Section

Positive Transverse Slope Values Indicate Water Drainage Away From Centerline And Negative Transverse Slope Values Indicate Water Drainage Toward The Centerline

Longitudinal Slope – Positive Values Indicate Water Drainage Away And Negative Values Indicate Water Drainage Toward Runway 23 End

TABLE 3

WEATHER DATA SUMMARY

TORREJON AB

RUNWAY 05/23

11 SEP 74

SECTION	FREE AIR TEMP	DEW POINT	WIND DIRECTION/VELOCITY(1)
B	84 DEG F	48 DEG F	210/ 2
C	84 DEG F	46 DEG F	210/ 8
D	84 DEG F	48 DEG F	220/ 8
E	84 DEG F	46 DEG F	210/ 6
G	84 DEG F	46 DEG F	220/ 2

(1) DATA OBTAINED FROM CONTROL TOWER DURING TESTING EFFORT, WIND GIVEN IN MAGNETIC DIRECTION.

F I G U R E S

1. Layout of Test Sections
2. Friction Variation Traces

3 - 7. Photographs

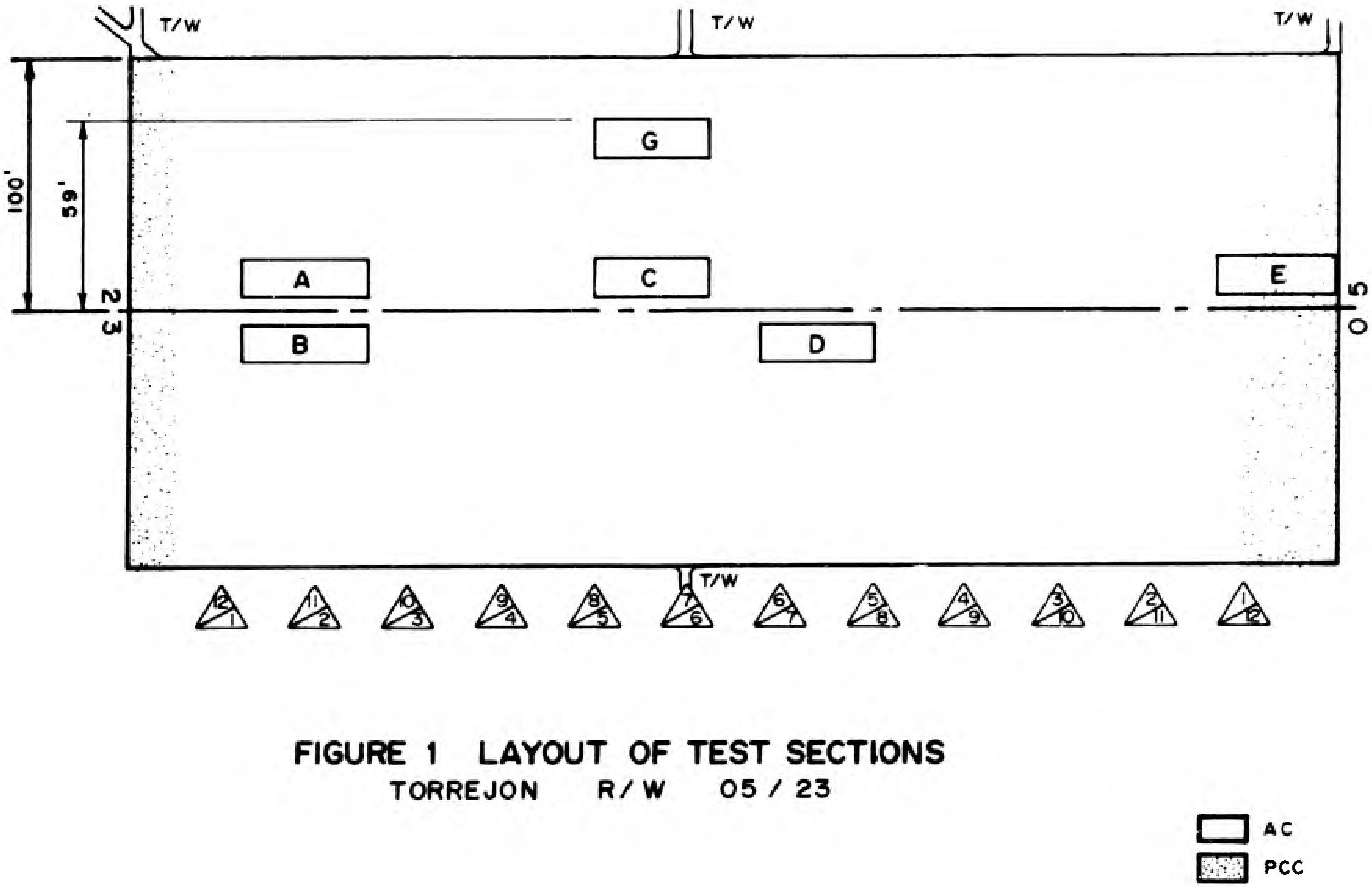
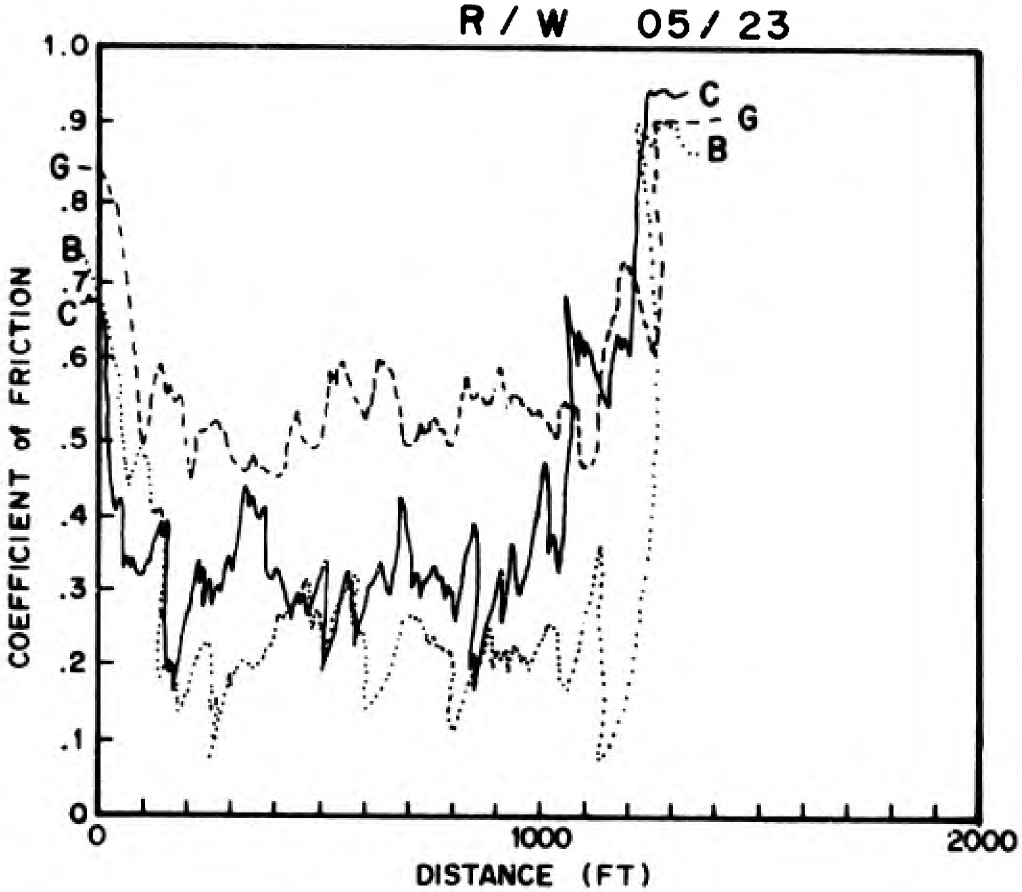


FIGURE 1 LAYOUT OF TEST SECTIONS
TORREJON R/W 05 / 23



PRIMARY TOUCHDOWN SECTION B

CENTER SECTION C

EDGE SECTION G

FIGURE 2. INITIAL Mu METER TRACES FOR TEST SECTIONS
TORREJON AB, SPAIN

FIGURE 3. Photograph showing the rubber deposits of the primary touchdown zone (Section A). Note water distributor applying second pass of water.

FIGURE 4. Photograph showing the pavement texture (Portland Cement Concrete) of Section E.

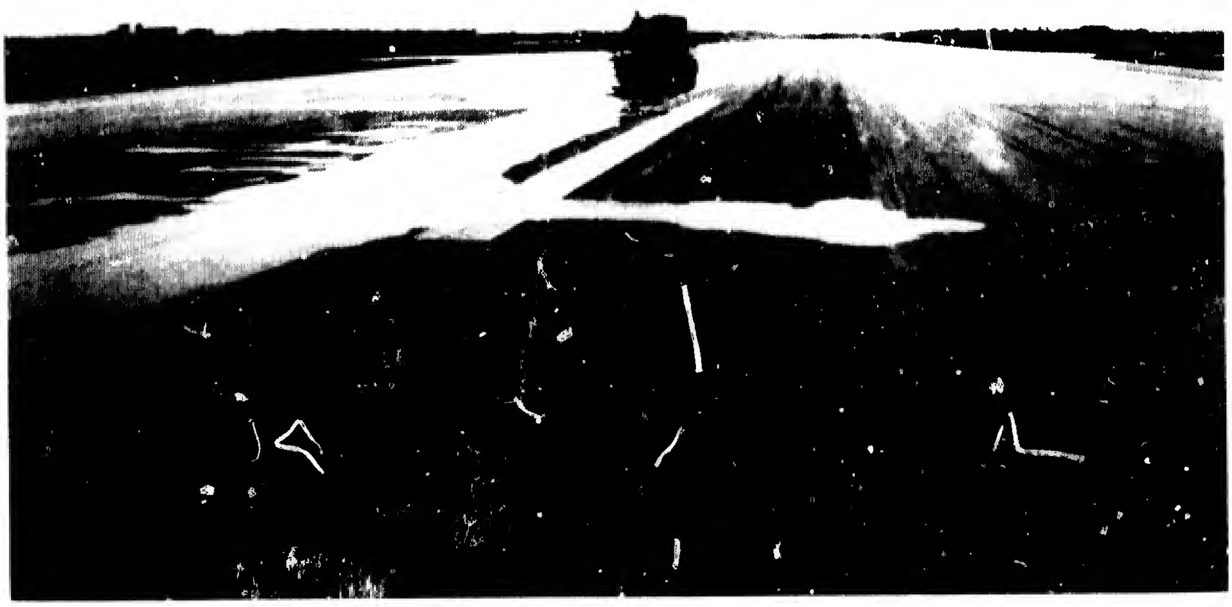


FIGURE 5. Photograph showing the water ponding in Section C (interior test section) due to poor transverse slopes.

FIGURE 6. Photograph showing the water ponding in Section D (interior test section) due to poor transverse slopes.

FIGURE 7. Photograph showing the pavement texture (asphaltic concrete) of Section C.

A P P E N D I X   A

Summary Data Charts

TORREJON AB

RUNWAY 05/23

TEST AREA	RUN NO.	SURFACE CONDITION	HEADING	MU-METER AVG AFTER WET	MU-METER TIME	MU-METER MU MIN	MU-METER MU MAX	MU-METER MU AVG(1)	AVG TIME AFTER WET	D B V WET STOP DIST	D B V DRY STOP DIST	SDR(2) 300	SDR(3) ACT
B	1.	DRY	23.								299.		
B	1.	WET	23.	1.31		.07	.34	.20	1.39	1200.		4.00	4.02
B	2.	WET	5.	3.23		.11	.47	.34	2.73	1110.		3.70	3.72
B	3.	WET	23.	4.55		.09	.44	.24	4.14	1165.		3.96	3.98
B	4.	WET	5.	6.08		.17	.55	.42	5.53	990.		3.30	3.31
B	5.	WET	23.	7.46		.18	.47	.37	7.03	997.		3.32	3.34
B	6.	WET	5.	8.41		.16	.69	.53	8.36	885.		2.35	2.96
B	7.	WET	23.	10.34		.21	.60	.56	9.90	747.		2.49	2.50
B	8.	WET	5.	12.20		.24	.84	.57	11.50	677.		2.26	2.27
B	9.	WET	23.	14.93		.61	.90	.82	13.38	379.		1.26	1.27
B	10.	WET	5.	19.31		.74	.92	.90					
B	11.	WET	23.	24.96		.66	.92	.86					

(1) INTEGRATED COEFFICIENT FOR EACH TEST LANE
(2) COMPUTED USING DRY STOPPING DISTANCE OF 300 FEET
(3) COMPUTED USING ACTUAL DRY STOPPING DISTANCES

TORREJON AB

RUNWAY 05/23

TEST AREA	RUN NO.	SURFACE CONDITION	HEADING	MU-METER AVG TIME AFTER WET	MU-METER MU MIN	MU-METER MU MAX	MU-METER MU AVG(1)	AVG TIME AFTER WET	D WET STOP DIST	R V DRY STOP DIST	SDR(2) 300	SDR(3) ACT
C	1.	DRY	23.							308.		
C	1.	WET	23.	1.96	.16	.67	.40	1.91	635.		2.12	2.07
C	2.	WET	5.	3.53	.17	.76	.50	3.57	609.		2.03	1.98
C	3.	WET	23.	5.08	.30	.66	.50	5.15	545.		1.82	1.77
C	4.	WET	5.	6.69	.20	.71	.55	6.80	561.		1.87	1.82
C	5.	WET	23.	10.26	.36	.69	.55	8.25	542.		1.81	1.76
C	6.	WET	5.	15.08	.30	.80	.52	9.40	564.		1.88	1.83
C	7.	WET	23.	20.64	.40	.80	.67	11.66	506.		1.69	1.64
C	8.	WET	5.	28.09	.38	.88	.77	13.28	529.		1.76	1.72
C	9.	WET	23.	30.06	.52	.89	.81	14.86	504.		1.68	1.64
C	10.	WET	5.					16.31	541.		1.80	1.76

(1) INTEGRATED COEFFICIENT FOR EACH TEST LANE
(2) COMPUTED USING DRY STOPPING DISTANCE OF 300 FEET
(3) COMPUTED USING ACTUAL DRY STOPPING DISTANCES

TORREJON AB

RUNWAY 05/23

TEST AREA	RUN NO.	SURFACE CONDITION	HEADING	MU-METER AVG AFTER TIME WET	MU-METER MU MIN	MU-METER MU MAX	MU-METER MU AVG(1)	AVG AFTER TIME WET	WET STOP DIST	DRY STOP DIST	SDR(2) 300	SDR(3) ACT
D	1.	WET	5.	1.14	.07	.65	.46	1.29	505.		1.68	0.00
D	2.	WET	23.	2.99	.07	.71	.47	3.22	535.		1.78	0.00
D	3.	WET	5.	4.34	.09	.72	.53	4.76	517.		1.72	0.00
D	4.	WET	23.	6.64	.09	.72	.48	7.01	482.		1.61	0.00
D	5.	WET	5.	10.81	.15	.74	.61	8.52	466.		1.55	0.00
D	6.	WET	23.	14.87	.23	.71	.57	9.82	470.		1.57	0.00
D	7.	WET	5.	20.28	.29	.84	.71	12.17	420.		1.40	0.00
D	8.	WET	23.	25.06	.34	.85	.73	14.98	482.		1.61	0.00
D	9.	WET	5.	30.03	.24	.90	.73					

(1) INTEGRATED COEFFICIENT FOR EACH TEST LANE
(2) COMPUTED USING DRY STOPPING DISTANCE OF 300 FEET
(3) COMPUTED USING ACTUAL DRY STOPPING DISTANCES, WHEN AVAILABLE

TORREJON AB

RUNWAY 05/23

TEST AREA	RUN NO.	SURFACE CONDITION	HEADING	MU-METER AVG TIME AFTER WET	MU MIN	MU MAX	MU AVG(1)	AVG TIME AFTER WET	D B V WET STOP DIST	DRY STOP DIST	SDR(2) 300	SDR(3) ACT
E	1.	WET	5.	1.68	.05	.39	.25	1.82	899.		3.00	0.00
E	2.	WET	23.	3.15	.05	.45	.31	3.30	661.		2.87	0.00
E	3.	WET	5.	4.33	.07	.68	.32	4.45	766.		2.55	0.00
E	4.	WET	23.	5.95	.13	.70	.42	6.00	728.		2.43	0.00
E	5.	WET	5.	7.18	.19	.80	.48	7.24	521.		1.74	0.00
E	6.	WET	23.	8.68	.21	.67	.61	8.80	443.		1.48	0.00
E	7.	WET	5.	12.[illegible]	.03	.93	.7[illegible]					
E	8.	WET	23.	16.72	.36	.91	.79					
E	9.	WET	5.	20.78	.44	.83	.7[illegible]					

(1) INTEGRATED COEFFICIENT FOR EACH TEST LANE
~~(2) COMPUTED USING DRY STOPPING DISTANCE OF 300 FEET~~
(3) COMPUTED USING ACTUAL DRY STOPPING DISTANCES, WHEN AVAILABLE

TORREJON AB

RUNWAY 05/23

TEST AREA	RUN NO.	SURFACE CONDITION	HEADING	MU-METER AVG TIME AFTER WET	MU-METER MU MIN	MU-METER MU MAX	MU AVG(1)	AVG TIME AFTER WET	DBV WET STOP DIST	DBV DRY STOP DIST	SDR(2) 300	SDR(3) ACT
G	1.	DRY	23.									
G	1.	WET	23.	1.53	.44	.72	.55			316.		
G	2.	WET	5.	2.95	.42	.85	.75	1.82	484.		1.51	1.53
G	3.	WET	23.	4.32	.61	.84	.75	3.30	468.		1.56	1.48
G	4.	WET	5.	5.57	.57	.85	.86	4.56	390.		1.30	1.24
G	5.	WET	23.	9.07	.70	.97	.84	5.95	412.		1.37	1.31
G	6.	WET	5.	13.14	.66	.75	.80	7.31	393.		1.31	1.25
G	7.	WET	23.	17.20	.75	.87	.94					
G	8.	WET	5.	21.20	.75	.87	.84					

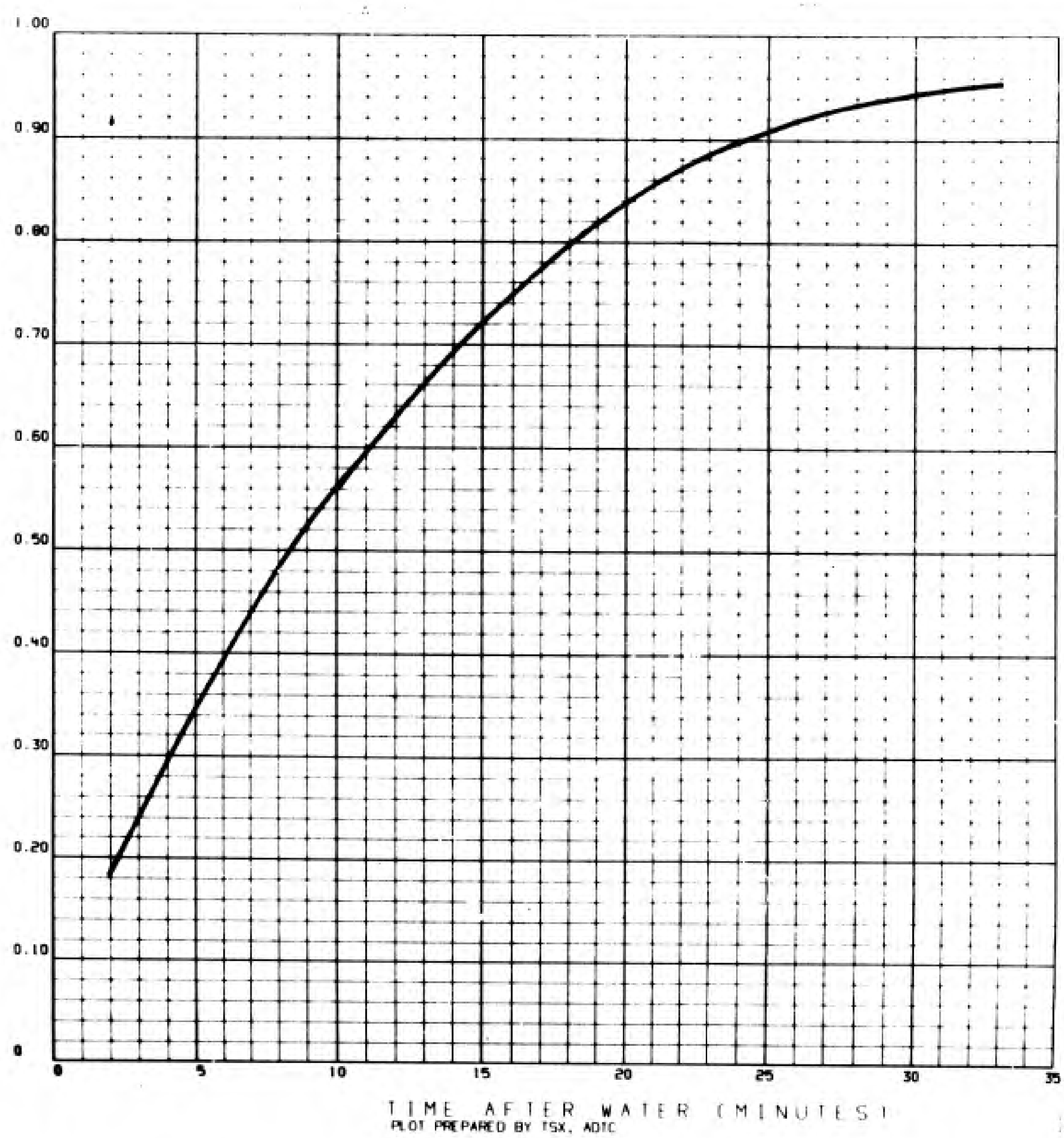
(1) INTEGRATED COEFFICIENT FOR EACH TEST LANE
(2) COMPUTED USING DRY STOPPING DISTANCE OF 300 FEET
(3) COMPUTED USING ACTUAL DRY STOPPING DISTANCES

A P P E N D I X B

Recovery Characteristic Graphs

Average Coefficient of Friction (MU) vs Time

Stopping Distance Ratio vs Time



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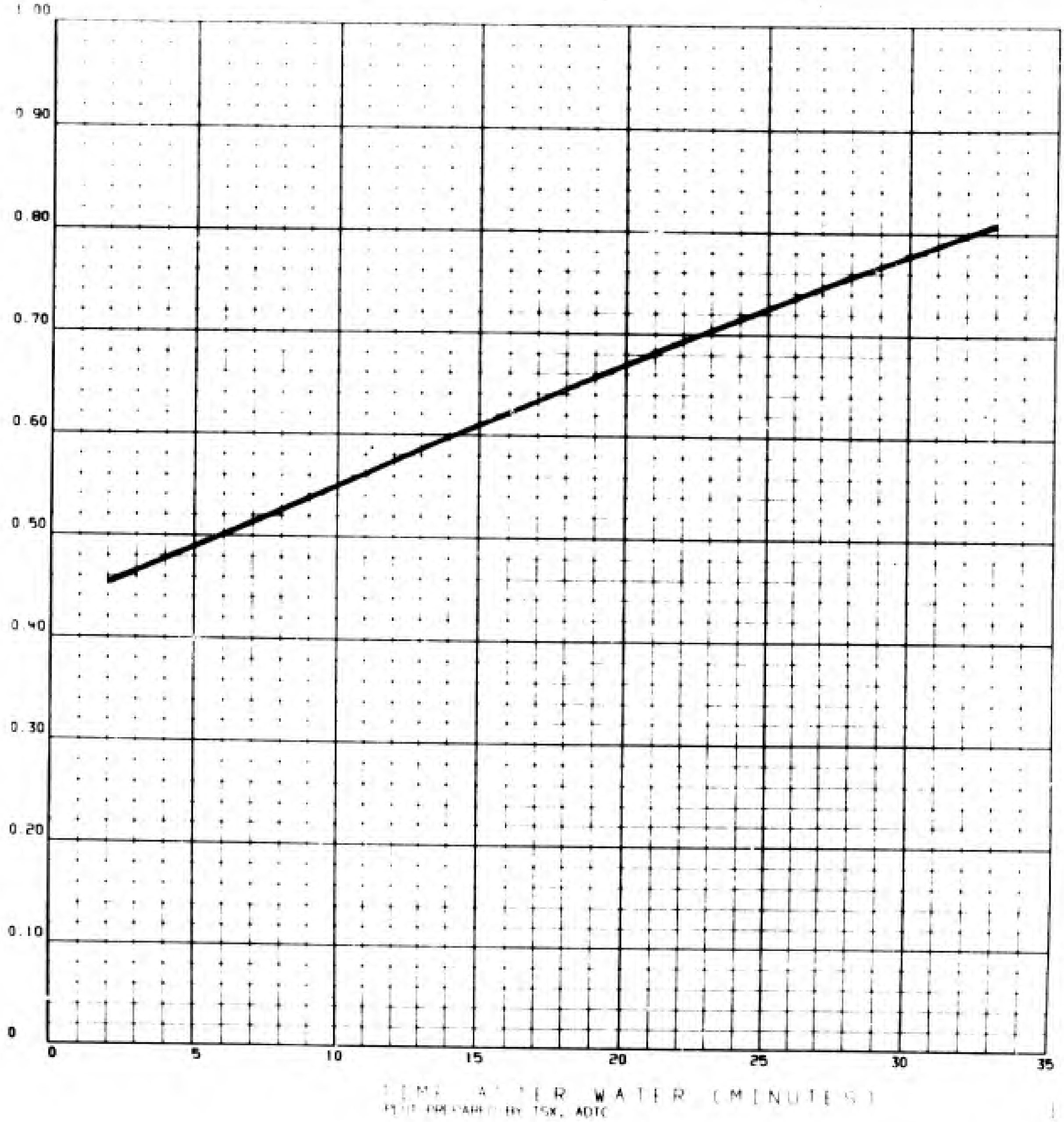
TIME AFTER WATER (MINUTES)
PLOT PREPARED BY TSX, ADTC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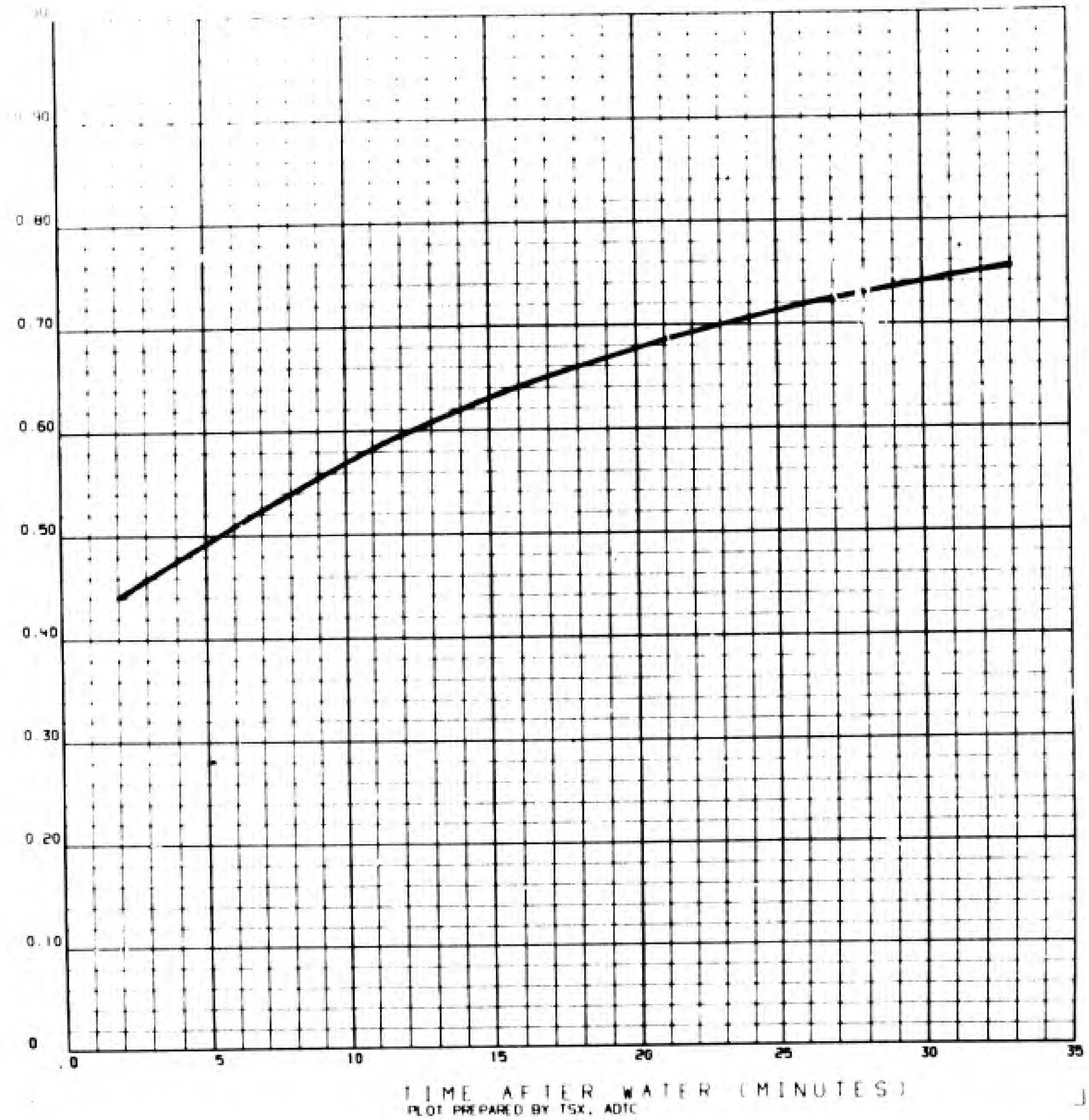
PLOT PREPARED BY TSX, ADTC



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TIME AFTER WATER (MINUTES)
PLOT PREPARED BY TSX, ADTC


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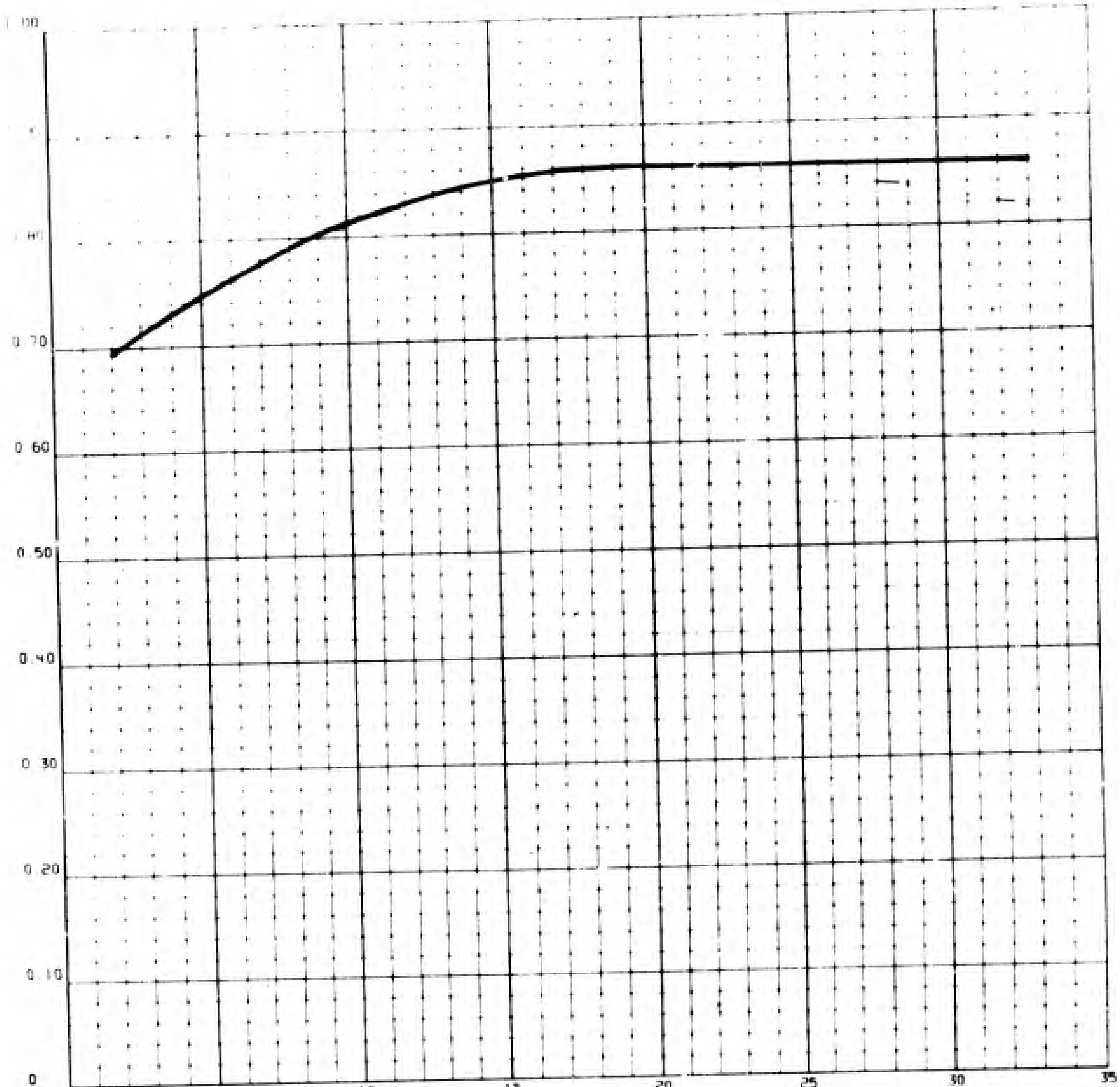
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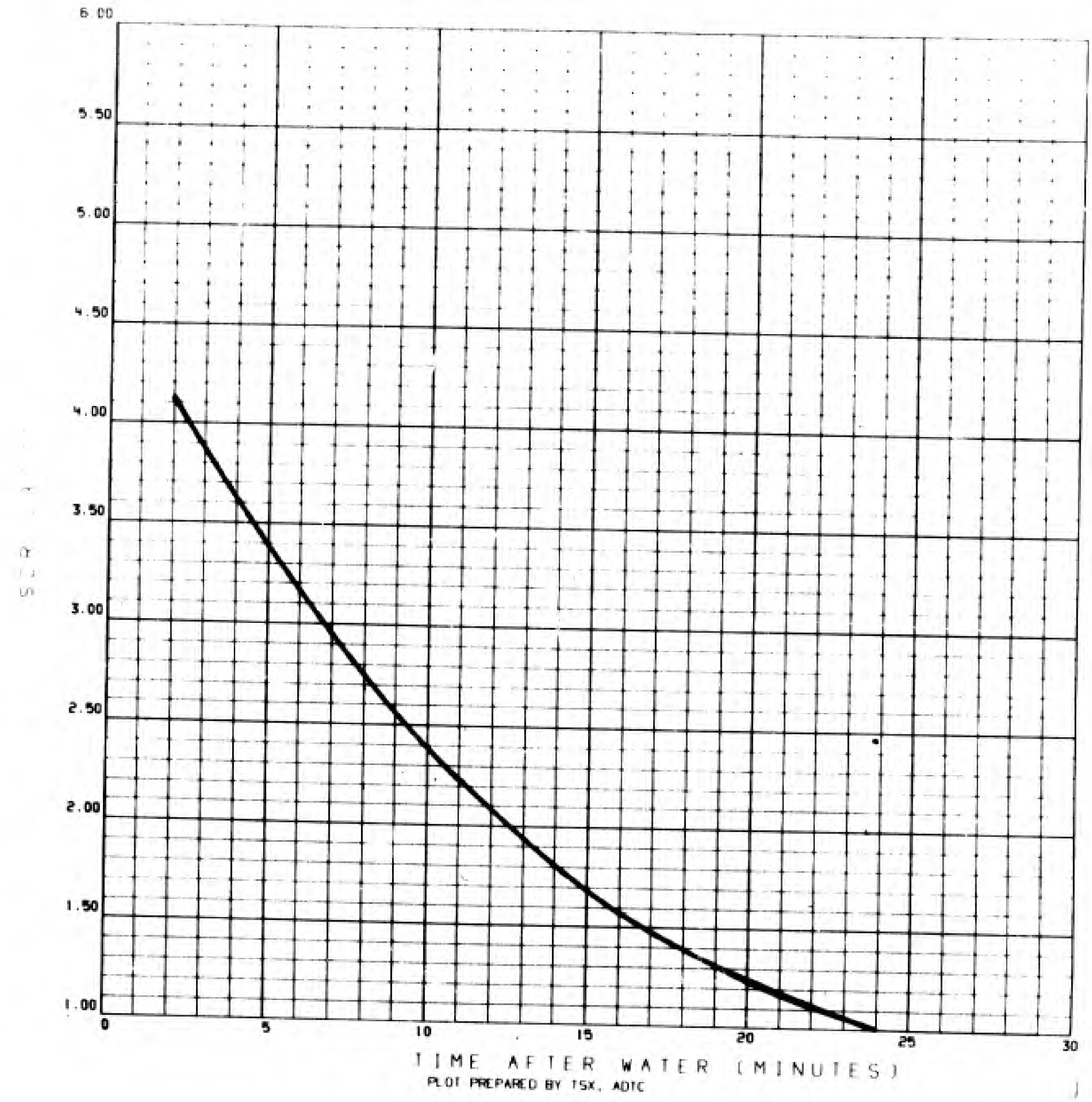
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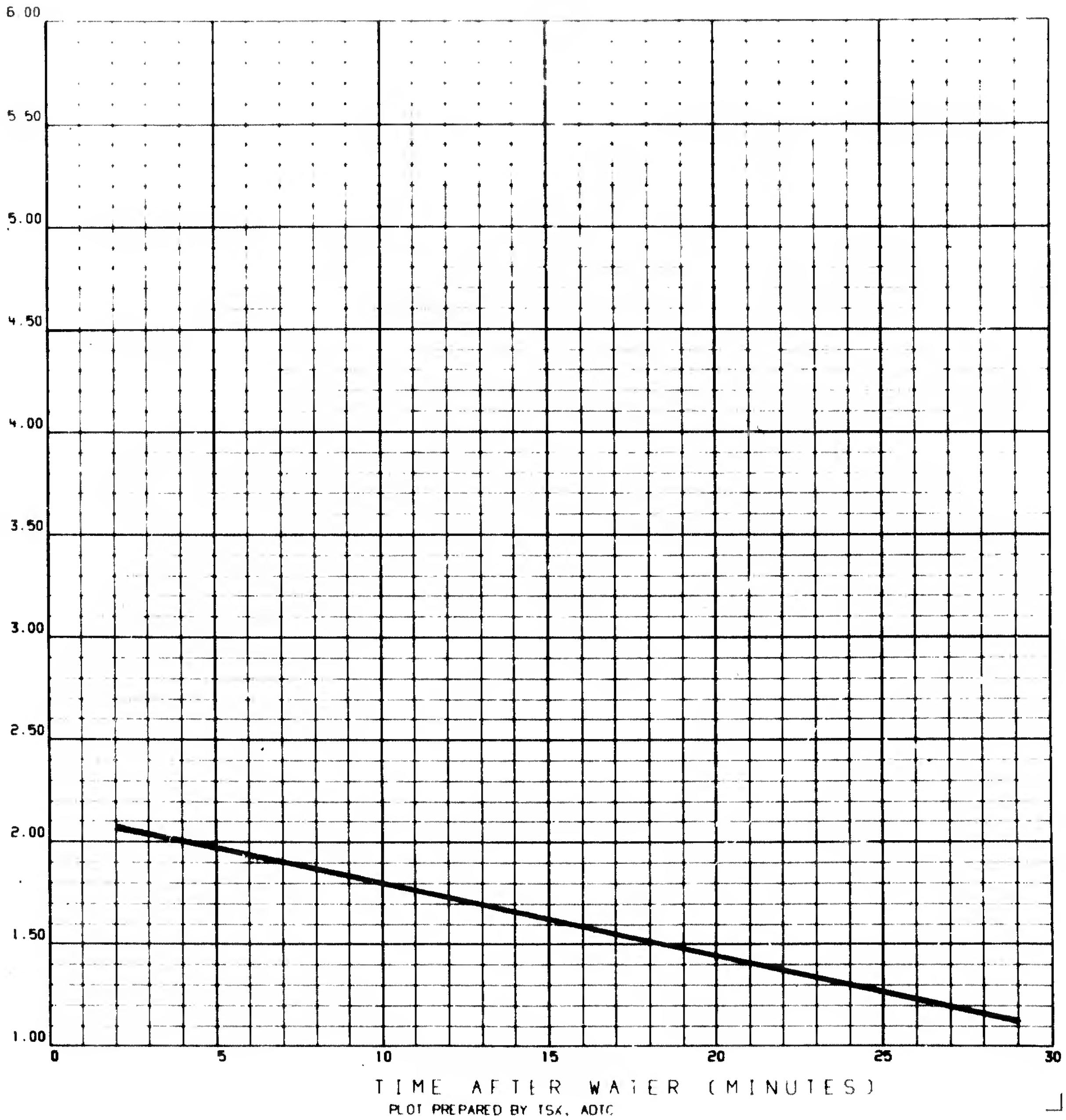
TIME AFTER WATER (MINUTES)
PLOT PREPARED BY TSX, ADTC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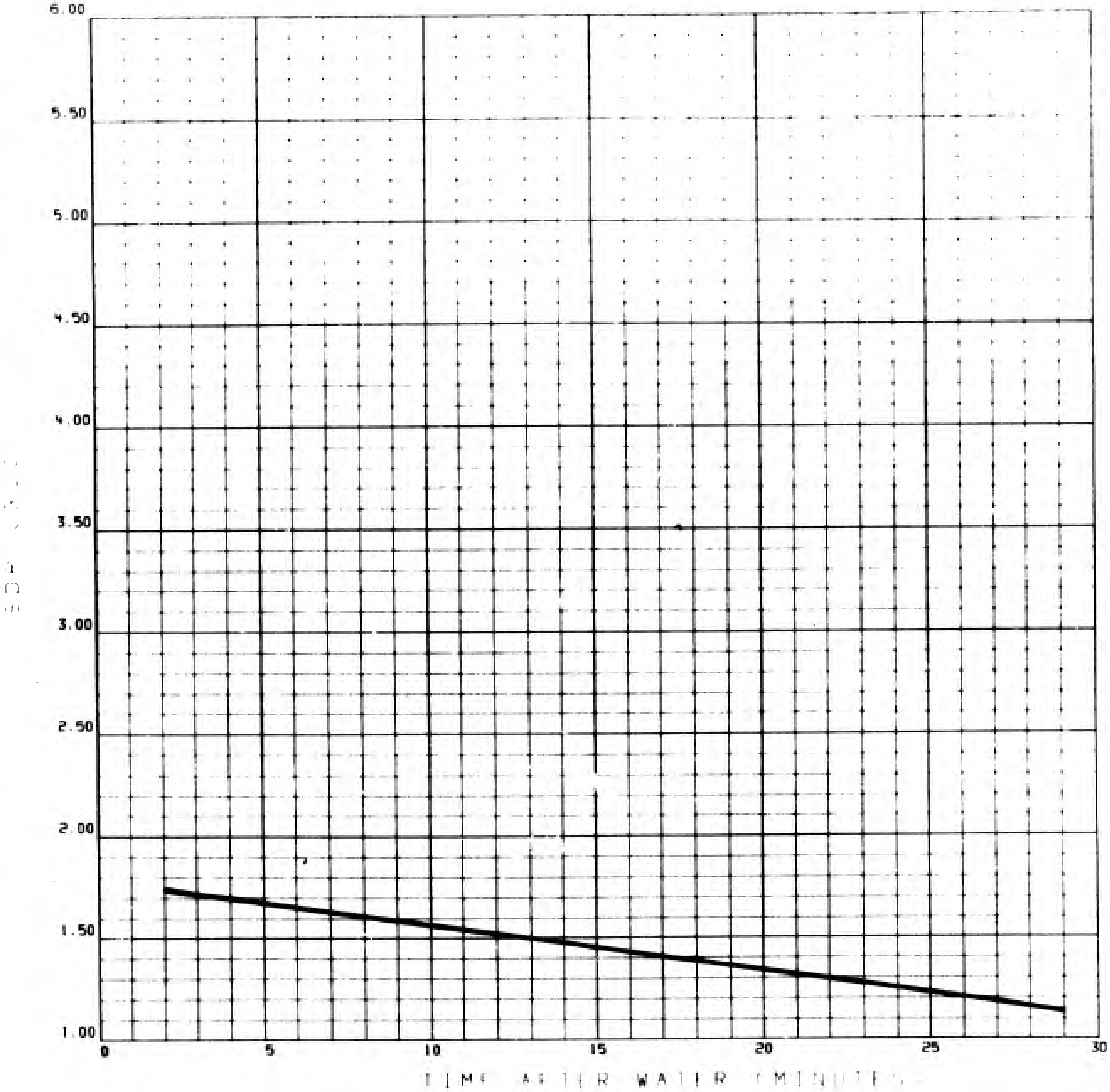
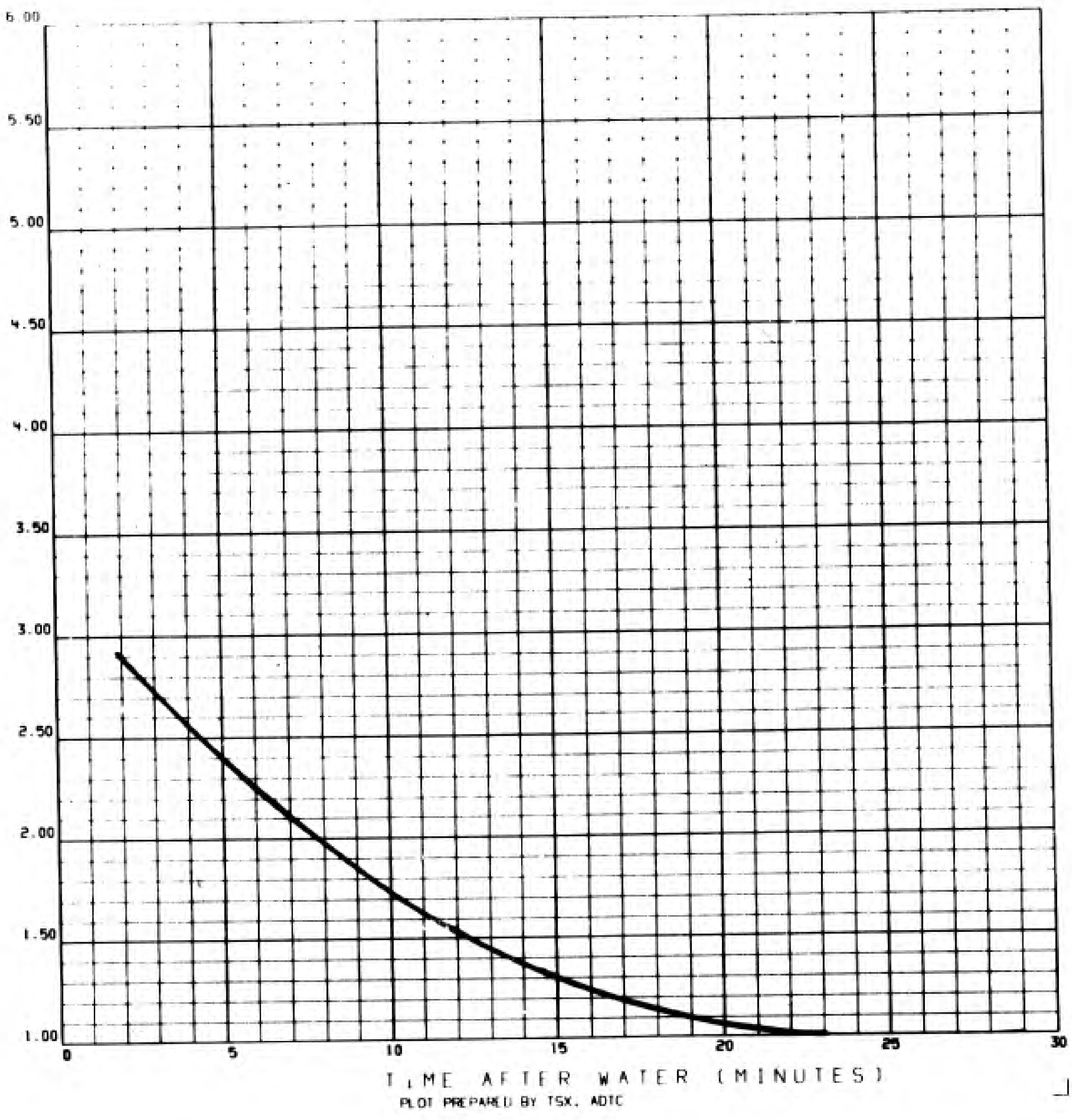
TIME AFTER WATER (MINUTES)
PLOT PREPARED BY TSK, ADTC



PREPARED BY TSX, ADTC



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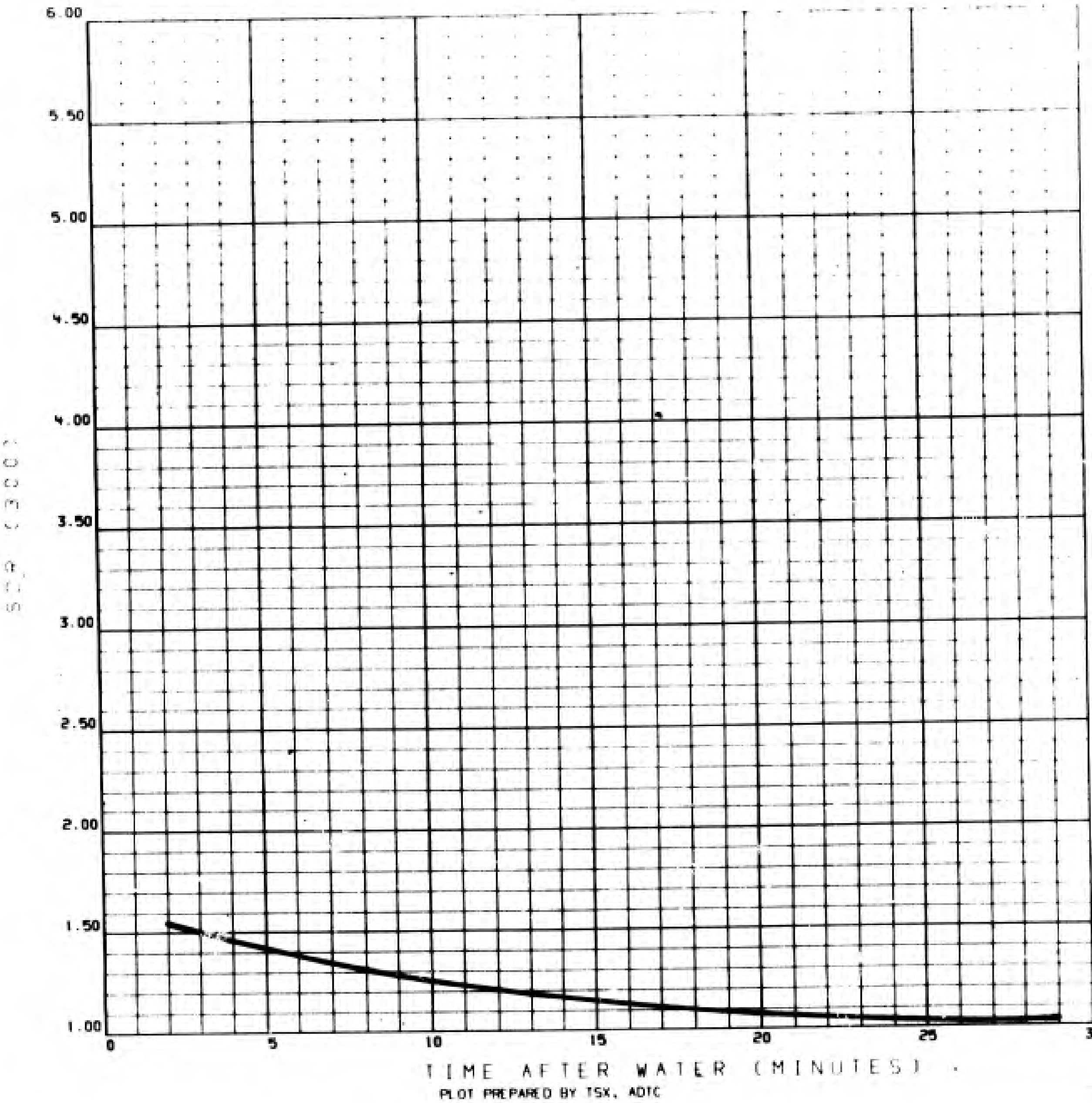
TIME AFTER WATER (MINUTES)
PLOT PREPARED BY TSX, ADTC



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TIME AFTER WATER (MINUTES)
PLOT PREPARED BY TSX, ADTC

APPENDIX C

Pavement Description/History

TORREJON AB, SPAIN - RUNWAY 05/23

Primary Approach End: R/W 23 End

Length: 13,400 Feet

Width: 200 Feet

Construction in 1955-56: The interior portion of the runway was overlayed with AC. Aggregates were a mixture of crushed limestone, crushed river gravel, sand and mineral filler, with 5-6% bitumen in the surface course.

Construction in 1973-74: Runway 23 end: The first 425 feet of PCC was replaced and the next 1,075 feet received an AC overlay (coal tar emulsion with granite chip seal coat). Runway 05 end: Two center PCC slabs replaced for 1,000 feet and the next 500 feet was overlayed with AC.

Last Rubber Removal: Deposits removed by chemical process (dicloro-ethyl benzine) and mechanical abrasion, 1971.

Precipitation:

Annual Rainfall	- 17.54 inches
Annual Snowfall	- Trace
Highest Month	- Nov (2.67 inches)
Lowest Month	- Aug (0.33 inches)

Pavement Condition: Both Ends: GOOD. Interior: FAIR

DISTRIBUTION

	Copies
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NASA Langley Research Center M S 497 (Attn: Mr Horne) Hampton VA 23665	1
Dept of Transportation Federal Aviation Administration Flight Test Branch, (AFS-160) Washington DC 20591	1

A P P E N D I X L

Skid Resistance Forms and Checklists

Water Truck Crew Briefing Check List

______1. Does driver know proper tachometer setting to follow?
Tachometer:________rpm

______2. Does driver know proper gear/axle range to use, and does he understand this cannot be changed during a wetting operation: ________gear (low)(high)______range.

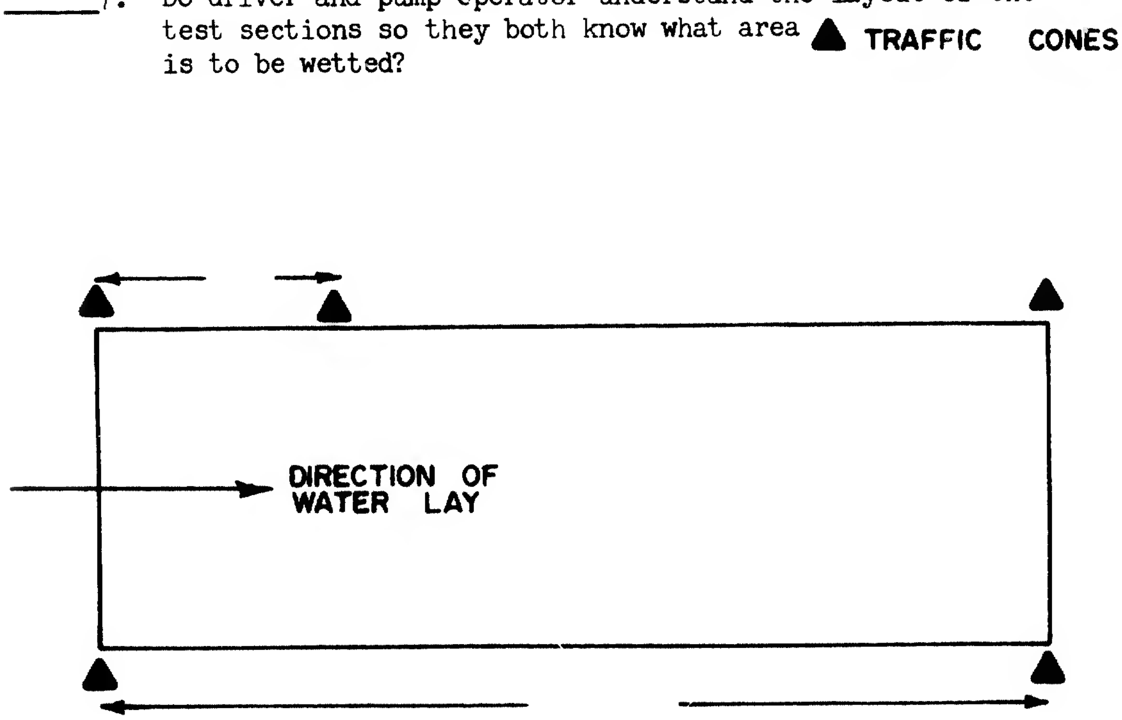
______3. Does driver know to make all wetting passes in the same direction, starting the initial pass from the same end the test vehicles will make their initial runs?

______4. Does driver know that upon completion of the final wetting run in each test strip, he should turn sharply out of the way of the test vehicles traveling at 40-60 mph? Turn towards the refill location.

______5. Does pump operator know to begin water discharge 50 feet prior to entering the test strip, not to vary the discharge rate in any way, and wet **25** feet after exiting the test strip? Pump pressure:____________psi.

______6. Is there sufficient fuel to operate the waterpumping system and truck so that no refueling is required during testing sequence?

______7. Do driver and pump operator understand the layout of the test sections so they both know what area is to be wetted?



Form 1. Water Truck Crew Briefing Checklist.

DATE ________ BASE ________________

TYPE TRUCK (F-6) (F-7) (1500-gal W/D)

GALLONS DISCHARGED (GD): ________________

FEET TRAVELED ________________

TIME ________ (MIN) / ________ (SEC) TOTAL SEC. ________

TRACTOR RPM ________________

PUMP PRESSURE ________________

PUMP RPM_a ________________

$$RPM_d = \frac{W_a\ (RPM_a)}{W_d} = \frac{(\text{NO. GALs WATER DISCHARGED})\ (\text{RPM})}{\frac{(\text{DIST. OF DISCHARGE})}{(1000)}\ (W_d)}$$

$$RPM_d = \frac{[GD]\ [RPM_a]}{\left[\frac{\text{Dist of Discharge}}{1000}\right] W_d}$$

$$TIME_d = \frac{W_a\ (TIME_a)}{W_a} = \frac{(W_d)(\text{TIME}_a \text{ OF DISCHARGE})(2)}{(\text{GALLONS DISCHARGED})}$$

$$= \frac{(\quad)(\quad)(2)}{(\quad)}$$

$$=$$

READJUSTED RPM

$$RPM = \frac{(TIME_a)(RPM_a)}{(TIME_d)}$$

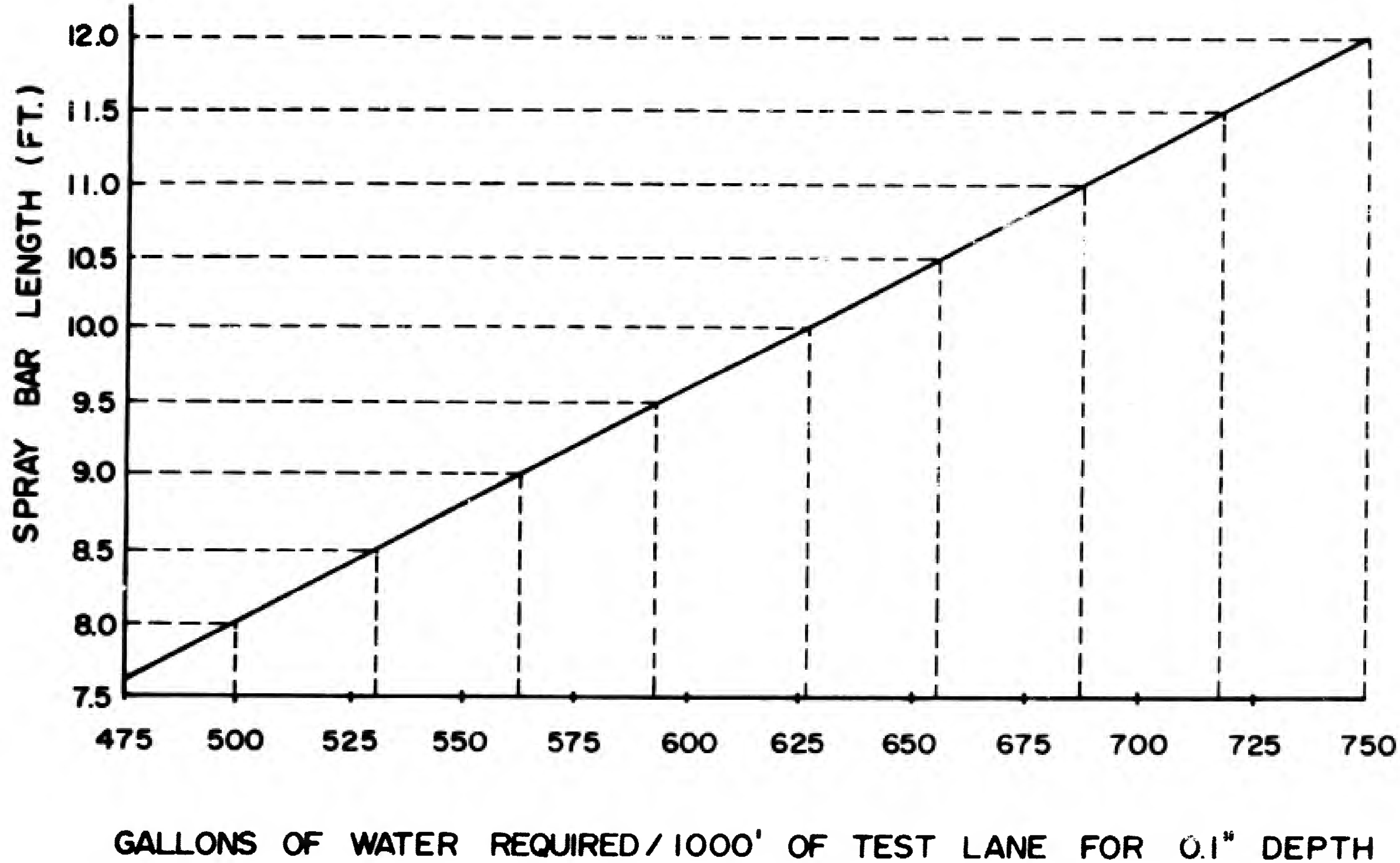
$$= \frac{(\quad)(\quad)}{(\quad)}$$

$$=$$

W_d = No. Gallons of Water Desired / 1,000 ft., for given spray bar width

a - ACTUAL d - DESIRED

Form 2. Water Truck Computation Worksheet.



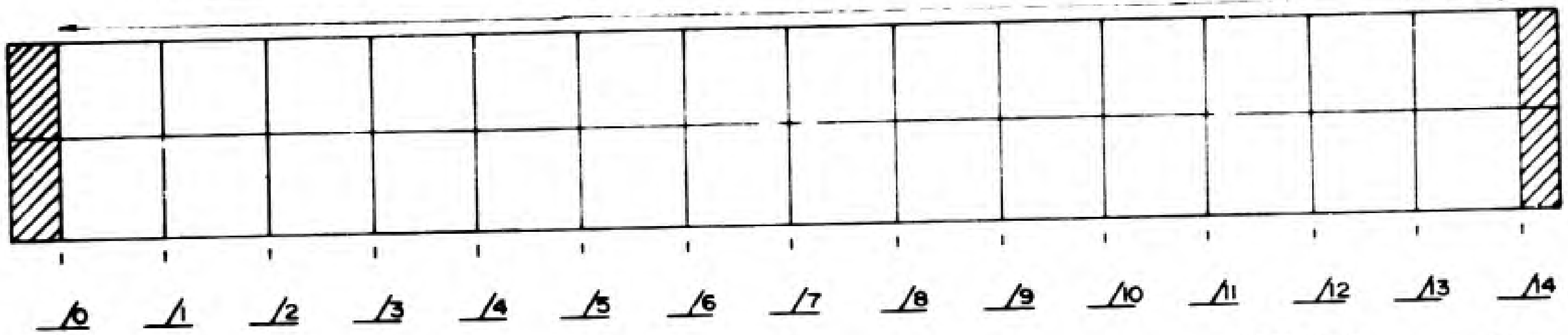
Form 3. Gallons of Water Required/1,000 Feet of Test Lane

TEST SECTION LAYOUT

BASE: ____________________ DATE ____________________ FOR (T/C) (DBV) (MU) (W/T) ____________________

DBV BOP ______ Ft DBV BOP ______ Ft
DFT ______ Ft DFT ______ Ft

RUNWAY



DBV BOP ______ Ft
DFT ______ Ft

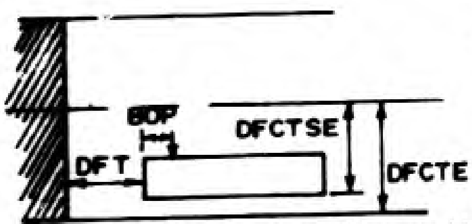
DFCTE ______ Ft
DECTSE ______ Ft

DBV BOP ______ Ft
DFT ______ Ft

DFT TO 1st R/W MARKER ______ Ft
RUBBER DEPOSIT AREA:
DFT (BEGIN) ______ Ft
DFT (END) ______ Ft
HEAVY / MEDIUM / LIGHT / SPOTTY / CLEAN

DESIGNATE:
1. Pavement Material (PCC-AC)
2. Location of T/Ws & R/Ws
3. Photographs

DFT TO 1st R/W MARKER ______ Ft
RUBBER DEPOSIT AREA:
DFT (BEGIN) ______ Ft
DFT (END) ______ Ft
HEAVY / MEDIUM / LIGHT / SPOTTY / CLEAN



DFT - Distance From Threshold
BOP - Brake On Point

SECTION:	AREA:	Avg. Texture
______	4" x ______ = ______	______
______	4" x ______ = ______	______
______	4" x ______ = ______	______
______	4" x ______ = ______	______
______	4" x ______ = ______	______

DFCTE - Distance From ℄ To Edge
DFCTSE - Distance From ℄ To Section Edge

REMARKS ____________________

Form 4. Test Section Layout Worksheet.

HEADER CARD NO.1

BASE NAME																				NO. SECTIONS TESTED					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

(CENTER BASE NAME)

AGENCY PERFORMING TEST																																	
27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
A	I	R		F	O	R	C	E		C	I	V	I	L		E	N	G	I	N	E	E	R	I	N	G		C	E	N	T	E	R

NO. CARDS USED									
61	62	63	64	65	66	67	68	69	70
									Ø

No of Reasons for Testing

RUNWAY DESIG.						
71	72	73	74	75	76	77
			/			

(EX 13R / 31L)

HEADER CARD NO.3

NO. SECTIONS TO BE COMBINED FOR OVERALL RATING OF PRIMARY TOUCHDOWN AREA									
1	2	3	4	5	6	7	8	9	10

DESIGNATION OF PRIMARY TOUCHDOWN SECTIONS									
11	12	13	14	15	16	17	18	19	20

NO. SECTIONS TO BE COMBINED FOR OVERALL RATING OF RUNWAY CENTER (MAX.=4)									
21	22	23	24	25	26	27	28	29	30

DESIGNATION OF CENTER SECTIONS									
31	32	33	34	35	36	37	38	39	40

NO. SECTIONS TO BE COMBINED FOR OVERALL RATING OF SECONDARY TOUCHDOWN AREA (MAX.=4)									
41	42	43	44	45	46	47	48	49	50

DESIGNATION OF SECONDARY TOUCHDOWN SECTIONS									
51	52	53	54	55	56	57	58	59	60

NO. SECTIONS TO BE COMBINED FOR OVERALL RATING OF RUNWAY EDGE (MAX.=4)									
61	62	63	64	65	66	67	68	69	70

DESIGNATION OF EDGE SECTIONS									
71	72	73	74	75	76	77	78	79	80

Form 5. Header Card No. 1 and 3.

GENERAL INFORMATION, WEATHER, AND WATER RECORD

RECORDER ____________________ DATE ____________________

GENERAL INFORMATION

BASE ABBREVIATION								TEST STRIP							RUNWAY IDENT					TEST STRIP DESCRIPTION						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
																	/									

WEATHER INFORMATION

TEMP °F						DEW PT °F			WIND DIR				WIND VEL			GUST WIND VEL	
28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

WATER RECORD

	WATER 'IN', TOT STRIP								WATER 'IN', DBV STRIP								WATER 'OUT', TOT STRIP						
	HR.			MIN.			SEC.		HR.			MIN.			SEC.		HR.			MIN.			SEC.
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72

ZERO WATER TIME							
HR.			MIN.			SEC.	

"GAL'S": ____________

Pavement Temp ____________ °F

TYPE PAVEMENT						LONG. SLOPE					TRANS-VERSE SLOPE					SECTION LENGTH			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
																2	0	0	0

		DIST FROM ℄					DIST TO START OF DBV SECT								WATER DEPTH				
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

			NO DRY MU RUNS			NO DRY DBV RUNS			NO. TARE RUNS			NO. WET MU RUNS			NO. WET DBV RUNS				
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

DATE (S) OF TEST																			
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

Form 6. General Information, Weather and Water Record.

MU-METER RUNS ON DRY PAVEMENT

BASE ____________________ RUNWAY ____________________

RECORDER ____________________ DATE ____________________

TEST SECTION ____________________

FIRST RUN

RUN DESIGNATION						TIME						C DIAL					B DIAL		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Ø	1	D															

SECOND RUN

RUN DESIGNATION						TIME						C DIAL					B DIAL		
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

THIRD RUN

RUN DESIGNATION						TIME						C DIAL					B DIAL		
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

FOURTH RUN

RUN DESIGNATION						TIME						C DIAL					B DIAL		
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

NOTES: O = LETTER O
Ø = ZERO
ALL DATA IS RIGHT JUSTIFIED. THIS MEANS ANY BLANK SPACES ARE AT LEFT OF FIELD.

EXAMPLE

RUN DESIGNATION						TIME						C DIAL					B DIAL		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	A	Ø	1	D	W	1	3	5	6				3	3			1	Ø	2

Form 7. Mu-Meter Runs on Dry Pavement Record.

DBV RUNS ON DRY PAVEMENT

BASE ________________ RUNWAY ________________

RECORDER ________________ DATE ________________

TEST SECTION ________________

FIRST RUN

RUN DESIGNATION						TIME							VEL mph			STOP DIST			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Ø	1	D															

SECOND RUN

RUN DESIGNATION						TIME							VEL mph			STOP DIST			
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

THIRD RUN

RUN DESIGNATION						TIME							VEL mph			STOP DIST			
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

FOURTH RUN

RUN DESIGNATION						TIME							VEL mph			STOP DIST			
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

NOTES: O = LETTER O
Ø = ZERO
ALL DATA IS RIGHT JUSTIFIED. THIS MEANS ANY BLANK SPACES ARE AT LEFT OF FIELD.

EXAMPLE

RUN DESIGNATION						TIME							VEL mph			STOP DIST.			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	A	Ø	1	D	E	1	3	5	8				6	1			3	5	5

Form 8. DBV Runs on Dry Pavement Record.

MU-METER MEASUREMENTS OF PAVEMENT FRICTION ON WET PAVEMENT

AIRFIELD ______________ RUNWAY ______________ ZERO WATER TIME : ______________

\+ 25 : ______________

RECORDER ______________ DATE ______________ + 30 : ______________

RUN DESIGNATION (1–6)	TIME IN h (8–9)	TIME IN m (11–12)	TIME IN s (14–15)	TIME OUT h (18–19)	TIME OUT m (21–22)	TIME OUT s (24–25)	"C" DIAL (28–30)	"B" DIAL (33–35)	MIN. MU, TOTAL SECTION (37–40)	MAX. MU, TOTAL SECTION (42–45)	INTEGRATED COEF (47–50)
Ø1W											
Ø2W											
Ø3W											
Ø4W											
Ø5W											
Ø6W											
Ø7W											
Ø8W											
Ø9W											
1[illegible]W											
11W											
12W											
13W											
14W											
15W											
16W											
17W											
18W											
19W											
2ØW											

EXAMPLES

RUN DESIGNATION	TIME IN h	m	s	TIME OUT h	m	s	"C" DIAL	"B" DIAL	MIN. MU	MAX. MU	INTEGRATED COEF
AAØ1WN	1Ø	13	19	1Ø	13	54	32	1Ø3	3Ø	6Ø	5Ø
OOØ1WS	9	15	23	9	16	Ø3	63	99	31	62	49
B1ØWS	1Ø	54	26	1Ø	54	54	61	96	25	55	45

NOTES: ZERO = Ø, LETTER = O. ALL DATA IS RIGHT-JUSTIFIED. THIS MEANS ANY BLANK SPACES ARE AT LEFT OF FIELD

Form 9. Mu-Meter Measurements of Pavement Friction on Wet Pavement Record.

DBV STOPPING TIME AND DISTANCE ON WET PAVEMENT

AIRFIELD ____________________ RUNWAY ________________

RECORDER ____________________ DATE ________________

ZERO WATER TIME : ______________ +25 : ______________ +30: ______________

RUN DESIGNATION (1–6)	LOCK TIME h (8–9)	LOCK TIME m (11–12)	LOCK TIME s (14–15)	STOP TIME h (18–19)	STOP TIME m (21–22)	STOP TIME s (24–25)	TEST SPEED mph (28–30)	STOP DIST FT (32–35)	STOP DIST ADJ. TO 60 MPH
Ø1W									
Ø2W									
Ø3W									
Ø4W									
Ø5W									
Ø6W									
Ø7W									
Ø8W									
Ø9W									
1ØW									
11W									
12W									
13W									
14W									
15W									
16W									
17W									
18W									
19W									
2ØW									

EXAMPLES

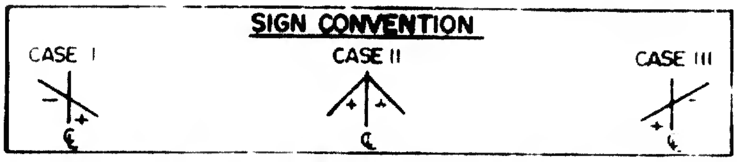
RUN DESIGNATION	LOCK TIME h	LOCK TIME m	LOCK TIME s	STOP TIME h	STOP TIME m	STOP TIME s	TEST SPEED mph	STOP DIST FT	STOP DIST ADJ. TO 60 MPH
AAØ1WS	1Ø	55	21	1Ø	55	42	6Ø	1116	1116
B1ØWN	1Ø	59	Ø6	1Ø	59	28	61	352	34Ø

NOTES: ZERO—Ø, LETTER O—O. ALL DATA IS RIGHT-JUSTIFIED.
THIS MEANS ANY BLANK SPACES ARE AT LEFT OF FIELD

Form 10. DBV Stopping Time and Distance on Wet Pavement Record.

PAVEMENT CROSS-SLOPE MEASUREMENTS

RECORDER ________________ RUNWAY ________________ BASE ________________



1	2	3	4	5	6	
						BASE ABBREV.

7	8	9	10	11	12	13	14	15	
									RUNWAY END (NORTH, ETC)

16	17	18	19	20	
					NO LINES USED BELOW

R/W ________ END

15' — ℄ — 15'
5' — 5'

STATION NO. (R/W DIST. MARKER)	% SLOPE	% SLOPE	% SLOPE	% SLOPE	% SLOPE EDGE	% SLOPE LONG.
0+00	.	.	.	.	.	.
0+50	.	.	.	.	.	.
1+00	.	.	.	.	.	.
1+50	.	.	.	.	.	.
2+00	.	.	.	.	.	.
2+50	.	.	.	.	.	.
3+00	.	.	.	.	.	.
3+50	.	.	.	.	.	.
4+00	.	.	.	.	.	.
4+50	.	.	.	.	.	.
5+00	.	.	.	.	.	.
5+50	.	.	.	.	.	.
6+00	.	.	.	.	.	.
6+50	.	.	.	.	.	.
7+00	.	.	.	.	.	.
7+50	.	.	.	.	.	.
8+00	.	.	.	.	.	.
8+50	.	.	.	.	.	.
9+00	.	.	.	.	.	.
9+50	.	.	.	.	.	.
10+00	.	.	.	.	.	.
10+50	.	.	.	.	.	.
11+00	.	.	.	.	.	.
11+50	.	.	.	.	.	.
12+00	.	.	.	.	.	.
12+50	.	.	.	.	.	.
13+00	.	.	.	.	.	.
13+50	.	.	.	.	.	.
14+00	.	.	.	.	.	.
14+50	.	.	.	.	.	.
15+00	.	.	.	.	.	.
15+50	.	.	.	.	.	.

℄

R/W ________ END

0+000	+1.5	+1.4	+1.3	+1.2	EXAMPLE

Form 11. Pavement Cross-Slope Measurements Record.