NASA TECHNICAL
MEMORANDUM

NASA TM X- 73913

(NASA-TM-X-73913) PLASTIC (WIRE-COMBED) GROOVING OF A SLIP-FORMED CONCRETE RUNWAY OVERLAY AT PATRICK HENRY AIRPORT: AN INITIAL EVALUATION (NASA) 32 p HC A03/MF A01 CSCL 01E G3/09
N77-27135
Unclas
35502

NASA TM X-

PLASTIC (WIRE-COMBED) GROOVING OF A SLIP-FORMED CONCRETE RUNWAY OVERLAY AT PATRICK HENRY AIRPORT---AN INITIAL EVALUATION

By

Eugene C. Marlin (Peninsula Airport Commission) and
Walter B. Horne

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

PLASTIC (WIRE-COMBED) GROOVING OF A SLIP-FORMED CONCRETE RUNWAY OVERLAY AT PATRICK HENRY AIRPORT--AN INITIAL EVALUATION

By

Eugene C. Marlin, Executive Director, Peninsula Airport Commission

And

Walter B. Horne, NASA Langley Research Center

INTRODUCTION

In the early 1960's, NASA research indicated that aircraft skidding incidents/accidents were principally the result of tire dynamic hydroplaning effects which occurred during high speed landings on wet or flooded runways. Since that time much research has been devoted to develop new runway surface treatments in an effort to improve water drainage and to provide high skid resistance when wet. As a consequence of this research, grooved pavements, using the diamond saw technique on cured hard concrete, and the friction course (porous) asphalt overlay have come to the foreground as standard and reliable surface treatment methods for overcoming the aircraft tire hydroplaning problem. At the same time research has been devoted to finding methods for applying the grooving technique to fresh concrete; that is, grooving the concrete while it is still in an uncured plastic state. Diamond cut concrete grooving can be expensive, especially if the aggregate in the concrete is hard, and the economic advantages of grooving concrete while in a soft or plastic state are obvious.

The purpose of this paper is to describe a low-cost plastic grooving technique using wire combs which was recently used to treat the surface of a 12-inch concrete overlay installed on Runway 6/24 at Patrick Henry Airport. Also described in the paper are the results of an initial evaluation of the traction and drainage characteristics of this new concrete runway surface treatment conducted by the NASA Langley Research Center.

BACKGROUND

Patrick Henry Airport is located 7 miles from the NASA Langley facility where runway hydroplaning research has been conducted for 17 years. Through association with the personnel conducting test work on runway grooving, members of the Peninsula Airport Commission have been conscious of the efficacy of this technique. Therefore, a goal of eventually applying some form of grooving at the municipal airport has been The Commission's policy for some years.

With an 8,000 ft. instrument runway, most of which was built in the early 1950's for DC-3 airline operation, it was inevitable that the impact of three-engine jet planes on the 8-inch concrete would introduce a deteriorating effect. Consequently, when a 12-inch concrete overlay was designed for construction in the spring of 1973 to beef up the distressed portion, a grooved surface was a prime consideration.

In the summer of 1972, the Virginia Highway Department completed a 22-mile section of Interstate 64 between Bottoms Bridge and Diascund Creek using a longitudinal wire-combed surface finish. The work was done by the same contractors who later overlayed Patrick Henry Airport's runways. This highway (Interstate 64) is the major artery between Hampton, Newport News, and Richmond; and the general public has shown a considerable interest in the grooving technique. Because it is grooved longitudinally, some criticism has been unofficially expressed as to its tendency to create directional instability, especially with motorcycles. Mr. Fred Burroughs, Construction Engineer for the Virginia Highway Department, believes the objections have no real significance. In fact, the State of California made tests and were never able to identify a real problem. Highway engineers place more emphasis on vehicle skid resistance than the hydroplaning problem encountered by aircraft on runway surfaces. The rumbling noise generated by automobile tires crossing transverse grooving is thought to be offensive to vehicle occupants. A grooved transverse finish has never been used in Virginia, although some experimenting was attempted with a heavy burlap drag to obtain a very rough texture. This was prior to the decision to use the plastic grooving technique on Interstate 64. Longitudinal grooves are apparently the solution to the dynamics of curve negotiation where the downhill effect is lowered especially in superelevated curves. The rumble is also avoided.

To meet the provisions of design for grooving during the plastic stage of concrete finishing, the contractor bought a $22,000 machine that had been developed by the CMI Corporation. This machine combined two functions and was used as the fourth unit in the paving train. Besides the precision rake device that grooved the plastic floated surface, the machine also held the nozzle used to spray a white curing compound over fresh concrete.

During the period when the airport engineer was designing Patrick Henry Airport's overlay, the paving contractor offered to rebuild the grooving device, rotating the mechanism so that it operated transversely across the surface. Since the wire combing technique meant only an insignificant increase to the total cost over that for obtaining a longitudinal burlap drag finish, and since the estimated costs for diamond sawing the cured concrete ran as high as $60,000, the specifications were written around this simple grooving technique.

Two recent airport construction projects in the FAA Southern Region used the same type wire combing technique that The Commission's contractor used on Patrick Henry Airport. Mr. Harry Johns, Paving Engineer, FAA, Atlanta, reports that an identical CMI machine textured the new 9,000 ft. Runway 9R/27L that was completed and opened in February 1973 at Atlanta's William B. Hartsfield International Airport. Over 500,000 yards of pavement were grooved. Although parallel and crossover taxiways were not required to have the wire combed finish, the contractor elected to perform the operation without additional cost in lieu of the alternative burlap drag finish.

A different and possibly more costly method was performed on the 75-ft. wide keel section of Savannah Airport's 7,000 ft. overlay. This was completed and opened on October 1, 1973. Specifications called for a broom finish and the contractor performed the work by hand, grooving it with a 4 1/4 ft. wire comb. After a float finish was completed, the surface was raked from both sides of each strip by use of a long-handle tool. Although considered to be equivalent to a machine job, the grooves are naturally not as uniform as the precision application of the CMI equipment.

The concrete overlay work including drainage, lighting, etc., performed on Patrick Henry Airport was a 50 percent Federal Aid Project that was contracted at a total cost of $2,039,078, of which $1,586,407 was the concrete portion. The PC concrete varied in depth from 12" in the center to 8" at the outer edges of the 150 ft. runway width. It was placed directly over the existing concrete pavement for a total length of 6,100 ft. on the 8,000 ft. Runway 6/24 and on Runway 2/20 for a length of 1,000 ft. through the intersection of the two runways. Also, a 1,140 ft. portion of the 75 ft. taxiway A was included. Since all of the concrete surfaces were wire combed, the total amounted to 373,166 yds.

PLASTIC GROOVING (WIRE COMB) SURFACE FINISH SPECIFICATIONS

The wire-comb surface finish used at Patrick Henry Airport on the 12-inch concrete overlay was in accordance with the following specification added to reference 1.

> "P-501-3.11 (g)(4) Runway Surface Finish: After surface irregularities have been removed, the concrete shall be given a uniformly roughened surface finish by use of a wire comb or other approved texturing device which produces a texture similar to that produced by a wire comb. The texturing operation shall be executed so that the transverse corrugations will be uniform in appearance. Successive passes of the comb or other approved device shall be overlapped the minimum necessary to obtain a continuously textured surface. The surface texture produced shall have the characteristics of a texture produced using a wire comb as described hereinafter. Texturing shall be completed while the concrete is in such condition that it will not be torn or unduly roughened, and before it has attained its

> initial set. The texturing device shall be cleaned or replaced as often as necessary to obtain the required surface texture. Upon completion of texturing, the pavement surface shall be uniform in appearance and free from surplus water, rough or porous spots, irregularities, depressions, and other objectionable features. Small or irregular areas, or areas not suitable for machine texturing when adjacent surrounding concrete is ready for texturing, shall be textured with a hand operated device producing a textured surface equivalent to that required for machine combing.
>
> The wire comb shall not be less than 10 feet in length with a single line of wires exposed to a length of 4 inches. The wire shall be blue tempered and polished spring steel, with nominal dimensions of 0.028 inches in thickness and approximately .08 inches in width. The wires shall be speced at 1/2 inch centers and securely mounted in a rigid head with the width of each wire parallel to the longitudinal centerline of the head. The wire comb shall be mechanically operated with the length of the comb parallel to the pavement centerline and capable of traversing the full width of pavement in a single pass at a uniform speed and at a uniform depth. Final approval of the wire comb will be based on satisfactory performance during actual construction. Texturing equipment, other than a wire comb, may be approved provided it produces a texture equivalent to that produced by a wire comb and upon satisfactory performance during actual construction."

PLASTIC GROOVING (WIRE COMB) EQUIPMENT

The final process in constructing the concrete overlay by the slipform paving technique at Patrick Henry Airport required the use of the compactor/leveler and translating straight edge equipment shown in figure 1. These devices prepared the concrete surface (in plastic state) to grade line for the final wire comb surface finish performed by the equipment shown in figure 2(a). The wire comb was 10 ft. long with spring steel fingers 0.04-inch wide and spaced on 1/2-inch centers. When dragged across the concrete surface, the wire comb cut grooves in the fresh concrete that approximate a 1/2 x 1/16-1/8 x 1/8-inch groove pattern as shown in figure 2(b) and figure 3. No technique has yet been devised to determine the exact moment to start the wire comb finish treatment to produce a uniform texture on the concrete surface. As a result, the contractor foreman uses his best judgment as to the state of plasticity of the concrete to determine when this finish treatment should start. The variability inherent in such human judgment decisions explains the difference in texture shown for the wire combing examples given in figure 3.

1970 NASA TRACTION AND DRAINAGE STUDY ON PATRICK HENRY AIRPORT RUNWAY 6/24

During 1970, the NASA DBV performed traction tests on the longitudinal burlap drag concrete finish surface of Runway 6/24 during natural rain conditions. The sections of runway studied have since been covered over by the 12-inch concrete overlay (August 1973). In these tests, a portable rain gage was installed at the side of the runway test areas to record rainfall intensity, and a NASA water depth gage was used to record the water depths present on the runway in the DBV wheel tracks (approximately 10 ft. from runway centerline). The results of this study are shown in figure 4 and indicate that appreciable water depth can build up on the runway surfaces at precipitation rates greater than 0.1 in/hour when surface winds are present. The data shown in figure 4 also indicate that DBV stopping distances (from 60 mph brake application speed) and wet/dry stopping distance ratio (SDR) also increase with increasing water depth and rainfall intensity on the runway surface.

The increase in runway slipperiness with increasing water depth on the runway as reflected by the increase in DBV SDR values is attributed to the loss in vehicle tire/pavement braking friction at high speeds due to tire dynamic hydroplaning effects. Table I shows that water depths on the runway greater than 0.05-0.10 inch can cause aircraft tires at time of touch down during high speed landings to develop dynamic hydroplaning with large losses in cornering and braking friction following.

SEPTEMBER 1973 NASA TRACTION AND DRAINAGE STUDY ON PATRICK HENRY AIRPORT RUNWAY 6/24

The study consisted of making comparative NASA Grease (surface texture) tests, NASA DBV (traction) tests, and NASA dye (water drainage) tests on both the old longitudinal burlap drag finish concrete portion of Runway 6/24 and the new plastic grooved (wire combed) concrete overlay portion of Runway 6/24.

NASA Grease Test.- A measurement of the surface texture depth was made for the two concrete surface finish treatments by means of the NASA grease test which entailed spreading a known volume of grease between parallel tape spaced a known distance apart on the runway surface. The length of the surface between the tapes required for the grease to fill all the asperities, multiplied by the distance between the tapes gives the grease area on the runway. This area divided into the known volume of grease yields the average texture depth of the pavement surface. The results of these measurements are shown in Table II and figures 3 and 5. The data indicate that the average texture depth of the grooved pavement from the wire combing treatment was 2 1/2-3 1/2 times greater than that obtained from the conventional longitudinal burlap drag finishing treatment.

Runway Wetting.- A large 3000 gallon water tanker equipped with spray bar furnished by the paving contractor was used to wet a test strip approximately 10 ft. wide and 800 ft. long on each of the three runway test areas evaluated. Two successive passes with the water truck were made before each DBV test to insure adequate wetting of the test surface. It is felt that this wetting procedure simulated the wetness found on runways immediately after the stopping of a moderate/light natural rainfall.

NASA Dye (water drainage) Test.- After the second water truck pass on each test surface, sodium fluorescein dye to improve water drainage flow visualization was injected into the water-covered test section on the side nearest the runway centerline (top of runway crown). In each case, the cross slope of the runway was 1 percent $(\frac{1\text{ ft.}}{100\text{ ft.}})$. At the time of the tests, a 10 knot wind was blowing straight down the runway (wind from 60°). As shown in figure 6, this wind prevented water drainage down the cross slope of the runway having the longitudinal burlap drag surface finish. Instead, the drainage flow path was inclined at a direction nearly parallel with the runway centerline (figure 6(a)). The water drainage was slow and water depths ranging from 0.02-0.04 inch remained in the wetted test section throughout the DBV test period. On the other hand, the NASA dye test indicated water drainage from the plastic grooved (wire-combed) surface of the runway to be much faster than found for the conventional longitudinal burlap drag surface and directed nearly parallel to the transverse runway grooves (nearly straight down the runway cross slope (see figure 6(b)). This rapid water drainage down the pavement grooves resulted in the grooved wetted test section having no measurable water depths (only damp surface) at time of DBV test.

These results suggest that on the conventional concrete surface treatment (longitudinal burlap drag) the draining water is forced to flow on top of the pavement surface where it is exposed to the force of the surface wind. On the other hand, water drainage in the plastic grooved surface is below the top of the surface texture (in the groove channels) and is thus shielded from the force of the surface winds.

It is expected from these drainage trends that the rainfall intensity required to flood the new grooved (wire-combed) surface of Runway 6/24 will be much higher than that shown for the old longitudinal burlap drag surface of Runway 6/24 in figure 4. As a result, the possibility of aircraft hydroplaning on the new surface treatment during most rainstorms is also greatly reduced.

<u>NASA DBV Tests</u>.- As soon as the water truck made the final wetting pass and cleared the test zone on the runway, the NASA diagonally-braked vehicle was accelerated to a speed slightly above or near 60 mph. Just before entering the test zone, the transmission was placed in neutral gear. The DBV then coasted into the wetted test zone whereupon the driver sharply applied brakes, locking the diagonal pair of wheels equipped with smooth tread ASTM test tires. At approximately 50 lb/inch pressure in the wheel brakes, circuits to the digital speed meter and the digital stopping distance counter were energized. These circuits recorded on a meter the DBV speed at the time of brake application and started measuring the stopping

distance from the brake application point. The speed at brake application and the stopping distance from this speed were visually read from these instruments by the driver/observer when the DBV came to a complete stop in the test section. Other instruments on board the DBV measured the angular velocity of each DBV main wheel, the angular velocity of the trailing test (fifth) wheel, and the longitudinal acceleration of the DBV. These parameters were recorded on a direct writing recorder equipped with an accurate timer in the DBV so that a permanent record and time history of the variation of these parameters during a test run could be obtained. A more detailed description of the DBV test technique is given in references 2 and 3. It should be noted that several tests were also made by the DBV on the Runway 6/24 test surfaces immediately following a natural rain. The DBV wet stopping distances and DBV wet/dry stopping distance ratio (SDR) obtained from these tests as well as from the artificial wetting tests are shown in Table II.

DBV SDR Analysis.- At the present time no federal standards for acceptable or unacceptable levels of runway slipperiness exist for civil airports in this country. However, the present Federal Aviation Regulations (FAR) for aircraft landing certification (FAR-25.125) and aircraft landing operation (FAR-125.195) may be used to obtain a reference wet runway slipperiness level. This reference wet runway slipperiness level turns out to be the equivalent of an aircraft wet/dry stopping distance ratio (SDR) = 1.92. In other words, the present FAR make allowance for wet runways to be only approximately twice as slippery as dry runways.

The NASA-developed DBV SDR method for estimating the slipperiness of airport runways is extremely simple in concept and easily obtainable from DBV wet and dry stopping distance measurements. Correlation tests performed with several jet transport type aircraft indicate that the DBV SDR reasonably predicts the aircraft SDR up to DBV SDR values of approximately 2.0 for many wet runway surfaces (see Tables III and IV). The NASA method is based on a DBV brake application speed of 60 mph. Usually, the DBV will not be at exactly 60 mph when brakes are applied, and the test stopping distance is corrected to the 60 mph base by means of the equation

$$S_B = \frac{3600}{V^2_{B\ (test)}} S_{B\ (raw)} \qquad \text{(equation 1)}$$

where S_B - DBV stopping distance (V_B = 60 mph), ft

$S_{B(raw)}$ - DBV stopping distance at V_B (test), ft

$V_{B(test)}$ DBV test brake application speed, mph

This DBV SDR is obtained from the equation

$$SDR = \frac{S_{B\ (wet)}}{S_{B\ (dry)}} \qquad \text{(equation 2)}$$

where $S_{B\ (wet)}$ - DBV wet pavement stopping distance corrected to 60 mph base (equation 1), ft.

$S_{B\ (dry)}$ - DBV dry pavement stopping distance corrected to 60 mph base (equation 1), ft.

Using this procedure, the raw DBV stopping distance data acquired at Patrick Henry Airport were corrected to the 60 mph base and converted to DBV SDR. The values obtained are presented in Table II. It can be seen from the table that the plastic grooved surface treatment is considerably less slippery under the natural rain and artificial wetting conditions investigated than the conventional longitudinal burlap drag surface finish on Runway 6/24. Comparison of the DBV SDR data in Table II with the aircraft and DBV SDR data in Tables III and IV indicate that the plastic grooves (wire comb) surface treatment used at Patrick Henry Airport is less slippery than other conventional concrete runway surface finishes and compares favorably with grooved pavement surfaces using the diamond saw cutting technique.

Pavement Skid Resistance.- Research performed at NASA and elsewhere concur in that pavement wet skid resistance is highly dependent upon the macrotexture and microtexture of a pavement surface. Tire/ground friction losses that occur on wet pavements result from the development of viscous and dynamic water pressures under the rolling or sliding tire footprint as vehicle or aircraft speeds increase. Only very thin unbroken water films need to be present on a smooth pavement surface for viscous hydroplaning to occur at the higher speeds. A good sharp pavement surface microtexture (like gritty sand paper) can puncture and displace the thin water film trapped in the tire footprint and thus prevent or greatly alleviate the buildup of viscous water pressures with speed that create this type of friction loss. Standing water on the pavement must be present for dynamic water pressures to be developed under the tire footprint. This type water pressure develops with the square of the vehicle speed and creates the well known phenomenon called tire dynamic hydroplaning unless alleviated by the pavement macrotexture. A good pavement macrotexture has hills and valleys produced by the protruding aggregate exposed in the pavement surface over which the tire drapes during the rolling or sliding process. Drainage channels are thus formed in the valleys of the pavement macrotexture which allows bulk water trapped in the tire footprint to escape and thus alleviate the development of dynamic water pressures with increasing vehicle speed and reduce this type of friction loss.

<u>Skid Resistance of Runway 6/24 Surface Treatment</u>.- The skid resistance of Runway 6/24 surface treatments was obtained from the DBV test records by use of the following procedure. Figure 7 shows the DBV velocity-time profiles obtained on Runway 6/24 for the different test conditions from the DBV test (fifth) wheel instrumentation. The slopes of the velocity-time curves in figure 7 are the decelerations experienced by the DBV during braking stops. The ASTM smooth tire braking friction coefficient may be obtained from these slope measurements with the aid of the equation

$$\mu_{skid} = 2 \left[\left(\frac{dv}{dt}\right)_{vehicle} - \left(\frac{dv}{dt}\right)_{tare} - \chi \right] \quad \text{(equation 3)}$$

where	$\left(\frac{dv}{dt}\right)_{vehicle}$	DBV braking deceleration, g
	$\left(\frac{dv}{dt}\right)_{tare}$	DBV unbraked deceleration, g
	χ	incremental DBV deceleration due to longitudinal runway gradient, g (+) uphill, (-) downhill
	μ_{skid}	locked-wheel braking friction coefficient

Typical results from this procedure are shown in figure 8. The data in figure 8 indicate that the skid resistance of the longitudinal burlap drag surface treatment is reduced when coated with rubber deposits over clean surface values under wet conditions. This result is attributed to the rubber deposits filling the texture of the surface and reducing both the pavement microtexture and macrotexture. The NASA grease test data in Table II also shows this trend. The curves of this figure also show that the high-speed skid resistance of the plastic grooved (wire-combed) surface treatment is considerably higher than the conventional surface treatment values under wet conditions. This result indicates that the better drainage characteristics of the grooved surface (higher macrotexture) has reduced the water depth present on the surface in wet conditions and thus reduced the hydroplaning potential. Figure 9 shows that the plastic grooving treatment ranks favorably in this regard with the recognized effective diamond saw grooving and friction course (porous) asphalt surface treatments.

CONCLUDING REMARKS

The low cost plastic grooving (wire comb) surface treatment for new concrete runway construction used at Patrick Henry Airport has been described. The initial traction and drainage evaluation performed by the NASA Langley Research Center of this surface treatment shows it to be a considerable improvement over a conventional longitudinal burlap drag concrete surface treatment when tested under runway wetness conditions that simulate moderate to light natural rainfalls. The plastic grooved (wire-combed) surface treatment compared favorably in drainage and skid resistance with pavement grooving from the diamond saw technique and to the friction course (porous) asphalt surface treatment for this wetness condition.

It should be cautioned that the initial evaluation was performed on the new concrete overlay before the runway was opened to aircraft operation. Thus, factors which may affect the economics and safety of both airport and aircraft operations on runways using this surface treatment have not yet been evaluated. These factors include such items as runway maintenance and durability, snow and ice removal and traction, tire wear and rubber deposits, and rainfall rates required to flood the pavement surface.

REFERENCES

1. ANON.- Standard Specifications for Construction of Airports. Department of Transportation Federal Aviation Administration, Washington DC, May 1968.

2. Yager, T. J., A Diagonally Braked Vehicle for the Investigation of Tire Traction. Tire Science and Technology, TSTCA, Vol. 1, No. 2, May 1973, pp 138-151.

3. Yager, T. J., Phillips, W.P., Horne, W.B., and Sparks, H.C. (with Appendix D by R. W. Sugg). A Comparison of Aircraft and Ground Vehicle Stopping Performance on Dry, Wet, Flooded, Slush-, Snow-, and Ice-Covered Runways. NASA TN D-6098, 1970.

TABLE I.- EFFECT OF WATER DEPTH ON TIRE HYDROPLANING PHENOMENA

RUNWAY WATER DEPTH RANGE, IN.	HYDROPLANING PHENOMENA EXPERIENCED
>0.05 - 0.10	(a), (b), (c), and (d)
<0.05 - 0.10 >0.03 - 0.02	(b), (c), and (d)
<0.03 - 0.02 to DAMP	(c) and (d)

(a) DYNAMIC HYDROPLANING: Unbraked wheel spindown, zero tire braking and cornering friction coefficients (aircraft ground speeds 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, lb/in.^{2}

TABLE II.- COMPARISON OF WATER DRAINAGE AND WET TRACTION OF (OLD) LONGITUDINAL BURLAP-DRAG AND (NEW) WIRE-COMBED OR GROOVED CONCRETE SURFACES ON RUNWAY 6/24, PATRICK HENRY AIRPORT.

MEASUREMENT	OLD RUNWAY SURFACE ***		WIRE-COMBED (GROOVED) SURFACE
PAVEMENT AVERAGE *	RUBBER-COATED	0.006	-----
TEXTURE, DEPTH, IN.	CLEAN	0.011	0.038 - 0.026
NATURAL RAIN - SEPTEMBER 14, 1973**			
WATER DRAINAGE DURING CROSSWIND CONDITIONS	SLOW (AT ANGLE)		FAST (DOWN GROOVES)
AVERAGE DBV STOPPING	RUBBER-COATED	---	-----
DISTANCE, FT (FROM 60 MPH)	CLEAN	602	395
DBV WET/DRY STOPPING	RUBBER-COATED	---	-----
DISTANCE RATIO	CLEAN	1.94	1.27
ARTIFICIAL WETTING (WATER TRUCK) SEPTEMBER 17, 1973			
WATER DRAINAGE DURING CROSSWIND CONDITIONS	SLOW (AT ANGLE)		FAST (DOWN GROOVES)
AVERAGE DBV STOPPING	RUBBER-COATED	712	-----
DISTANCE, FT. (FROM 60 MPH)	CLEAN	575	403
DBV WET/DRY STOPPING DISTANCE	RUBBER-COATED	2.30	-----
RATIO	CLEAN	1.85	1.30

* NASA GREASE TEST

** RAIN STOPPED AT START OF TEST

*** LONGITUDINAL BURLAP DRAG FINISH CONCRETE

TABLE III.- TRACTION DATA OBTAINED WITH C-141 AIRCRAFT AND NASA DBV ON SEVERAL GROOVED AND UNGROOVED WET RUNWAY SURFACES (FROM REFERENCE 3).

Runway	Airport	Material	Surface treatment	Test condition	Average wet-dry stopping distance ratio		RCR dry-wet ratio
					Aircraft (*)	DBV	
1	Dyess AFB	Concrete	Conventional	Artificially wet	2.77	2.70	1.28
2	England AFB	Concrete	Conventional	Artificially wet	2.47	2.16	1.45
3	Marham RAFB	Concrete	Conventional	Artificially wet	2.24	1.93	1.00
4	Offutt AFB	Concrete	Conventional	Artificially wet	2.21	2.15	1.24
5	Ellington AFB	Concrete	Conventional	Light rain	2.17	2.16	2.00
6	Edwards AFB	Concrete	Conventional	Artificially wet	2.15	1.91	1.16
7	Wright-Patterson AFB	Concrete	Conventional	Artificially wet	2.12	1.95	1.04
8	Lockbourne AFB	Concrete	Conventional	Artificially wet	2.05	1.84	1.02
9	Langley AFB	Concrete	Conventional	Artificially wet	1.90	1.95	1.41
9	Langley AFB	Concrete	Conventional	Damp after light rain	1.42	---	---
10	Yeovilton RNB	Concrete	Wire combed	Artificially wet	1.78	1.65	.96
11	Yeovilton RNB	Concrete	Scored transversely	Artificially wet	1.65	1.76	1.15
12	John F. Kennedy Airport	Concrete	Grooved, $1\frac{3}{8}$ in. by 3/8 in. by 1/8 in.	Artificially wet (clean)	1.57	1.75	---
12	John F. Kennedy Airport	Concrete	Grooved, $1\frac{3}{8}$ in. by 3/8 in. by 1/8 in.	Artificially wet (rubber deposits)	1.86	2.20	---
13	Seymour Johnson AFB	Concrete	Grooved, 2 in. by 1/4 in. by 1/4 in.	Artificially wet (clean)	1.38	1.35	1.21
13	Seymour Johnson AFB	Concrete	Grooved, 2 in. by 1/4 in. by 1/4 in.	Artificially wet (rubber deposits)	1.47	1.50	1.21
14	Chicago Midway Airport	Concrete	Grooved, $1\frac{1}{4}$ in. by 1/4 in. by 1/4 in.	Artificially wet	1.25	1.35	---
15	Offutt AFB	Concrete	Grooved, $1\frac{1}{4}$ in. by 1/4 in. by 1/4 in.	Artificially wet	1.20	1.32	1.24
16	Beale AFB	Concrete	Grooved, 1 in. by 1/4 in. by 1/4 in.	Artificially wet	1.11	1.20	1.05
17	Mildenhall USAFE**	Asphalt	Slurry seal	Artificially wet	---	3.15	---
18	Spangdahlem USAFE	Asphalt	1/8 in. German antiskid coat	Artificially wet	2.35	2.50	1.41
19	Elmendorf AFB	Asphalt	Plant mix	Artificially wet	2.32	2.48	1.53

*Average value of revolution-counter and acceleration-time measurements.

**Resurfaced with porous friction course, November 1970.

TABLE IV.- EVALUATION OF 2 X 1/4 X 1/4-INCH GROOVE PATTERN AT HOUSTON INTERNATIONAL AIRPORT (FROM JOINT FAA-USAF-NASA RUNWAY RESEARCH PROGRAM).

TESTS BEFORE GROOVING - JUNE 1970
TEST VEHICLE: NASA DBV

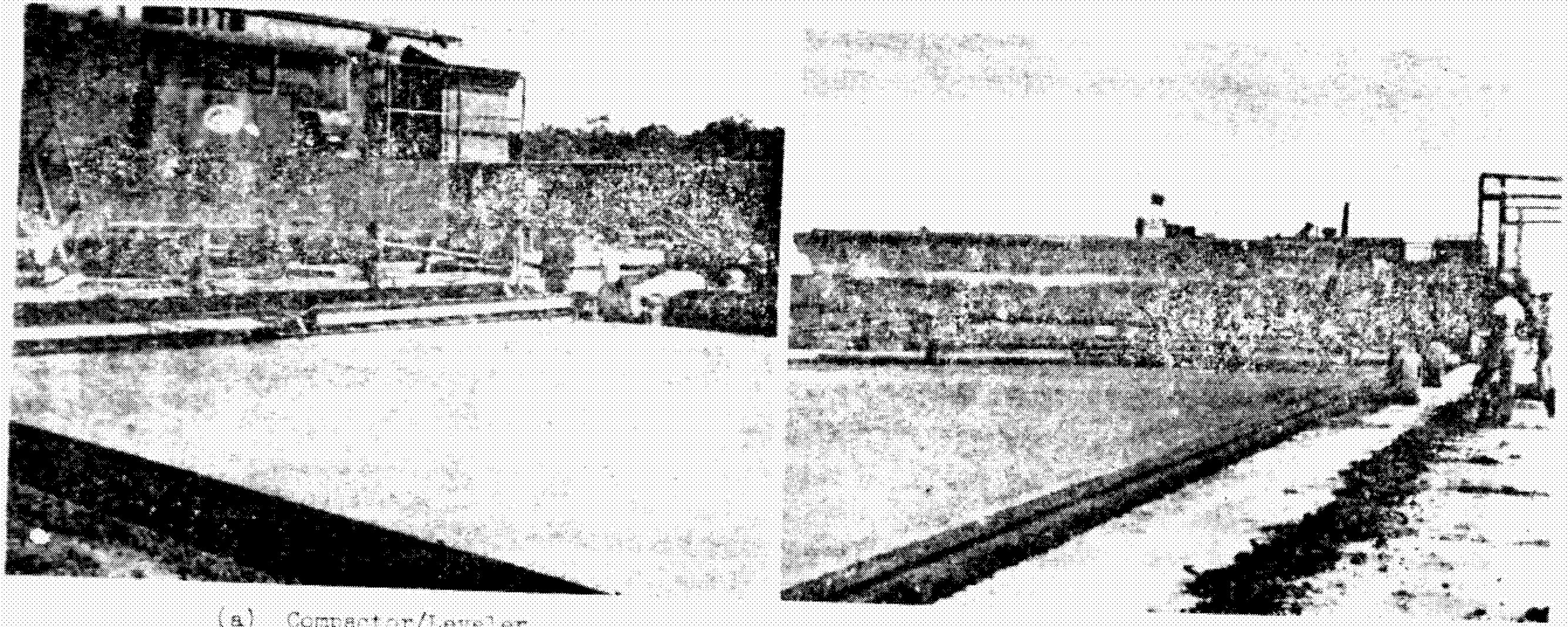
WETNESS CONDITION	WATER DEPTH, IN.	WET/DRY STOPPING DISTANCE RATIO		
		TOUCHDOWN ZONE (RUBBER COATED)	BRAKING ZONE (CLEAN)	ROLLOUT ZONE (RUBBER COATED)
WET	0.02-0.05	3.46	2.42	2.94
DAMP	TRACE-0.01	3.36	1.88	2.25

TESTS BEFORE GROOVING - OCTOBER 1971
TEST VEHICLES: B-727, NASA DBV, AND FAA MU-METER

WETNESS CONDITION	WATER DEPTH, IN.	WET/DRY STOPPING DISTANCE RATIO		MU-METER FRICTION READING
		B-727	NASA DBV	
WET	0.022	2.52	2.37	0.51
WET	0.016	1.91	2.08	0.43
WET	0.019	2.27	2.29	0.42

TESTS AFTER GROOVING - FEBRUARY 1972
TEST VEHICLES: DC-9, NASA DBV, AND USAF MU-METER

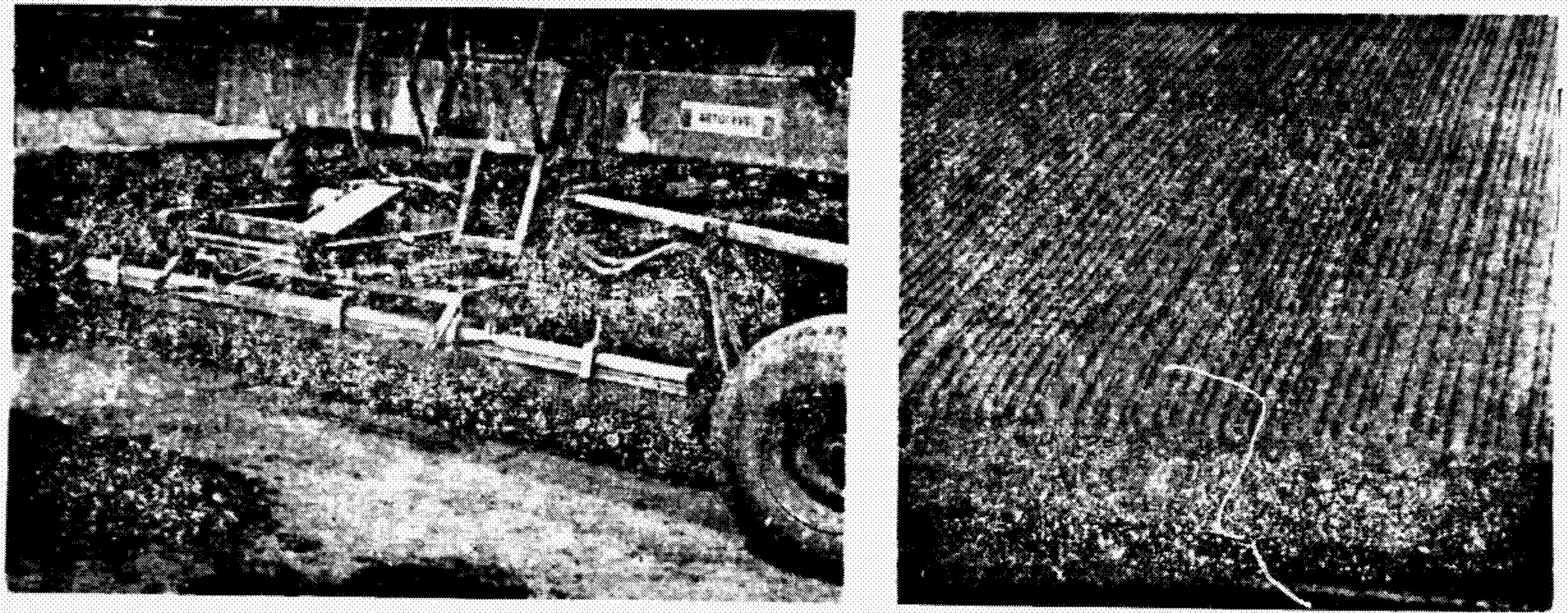
WETNESS CONDITION	WATER DEPTH IN.	WET/DRY STOPPING DISTANCE RATIO		MU-METER FRICTION READING
		DC-9	NASA DBV	
DAMP	<0.01	1.10	1.13	0.72
WET	<0.01	1.34	1.31	0.69
WET	<0.01	1.53	1.40	0.67
WET	<0.01	1.44	1.44	0.66



(a) Compactor/Leveler

(b) Translating straight edge

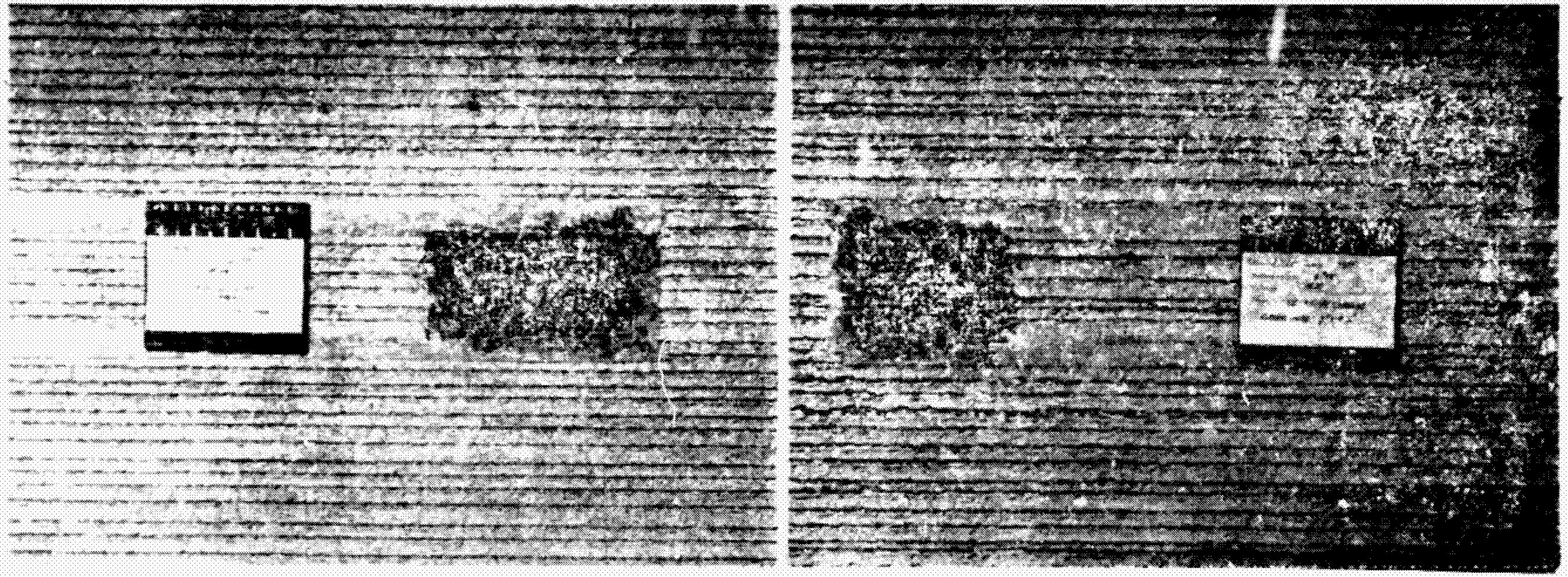
Figure 1.- Slip-form concrete paving equipment used at Patrick Henry Airport.



(a) Translating wire comb

(b) Typical groove pattern after comb pass

Figure 2.- Paving grooving equipment used at Patrick Henry Airport.



(a) Medium wire combing

(b) Heavy wire combing

Figure 3.- Photographs of typical wire combed surfaces showing results of NASA grease test. Runway 6/24, Patrick Henry Airport.

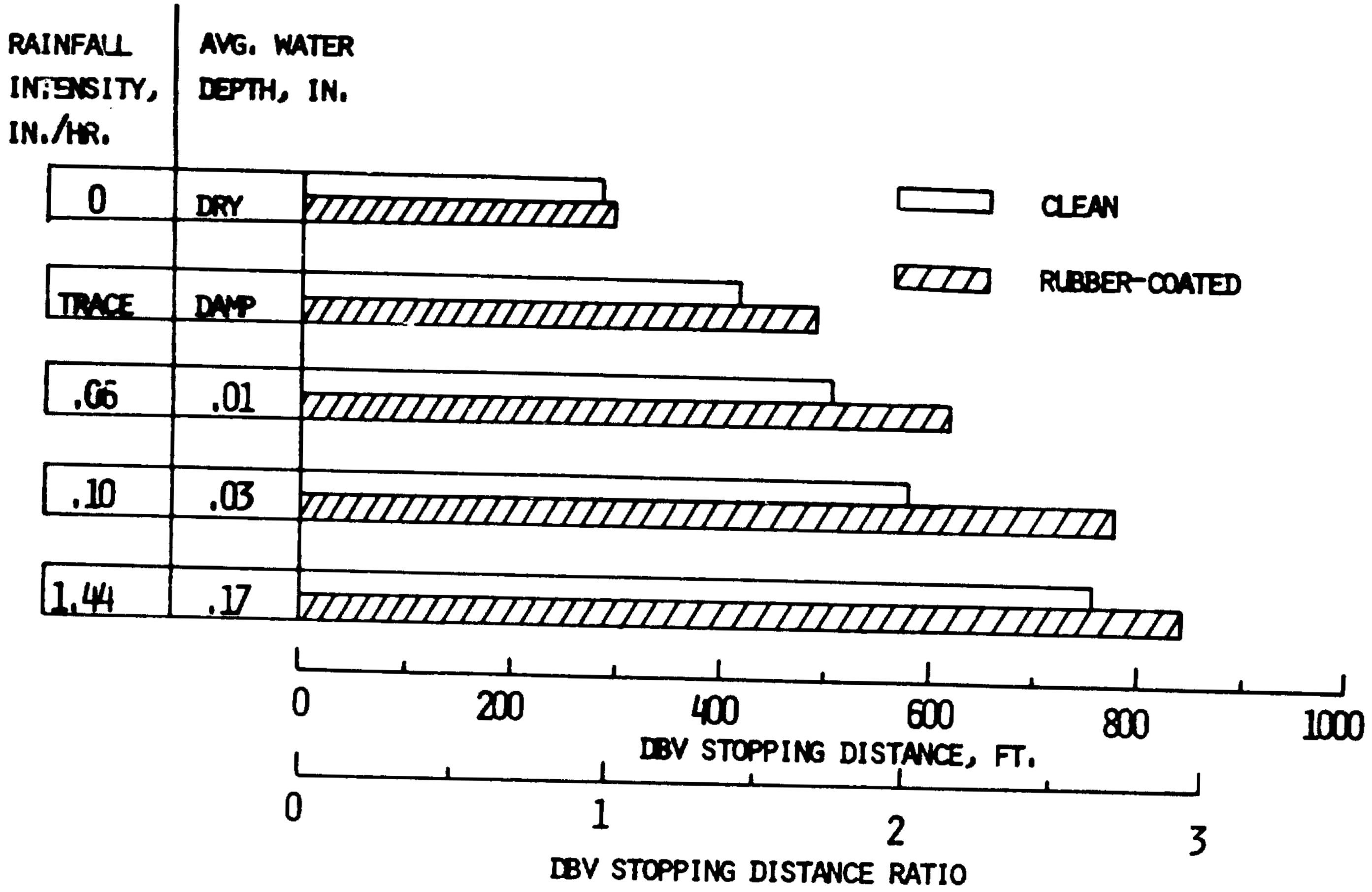
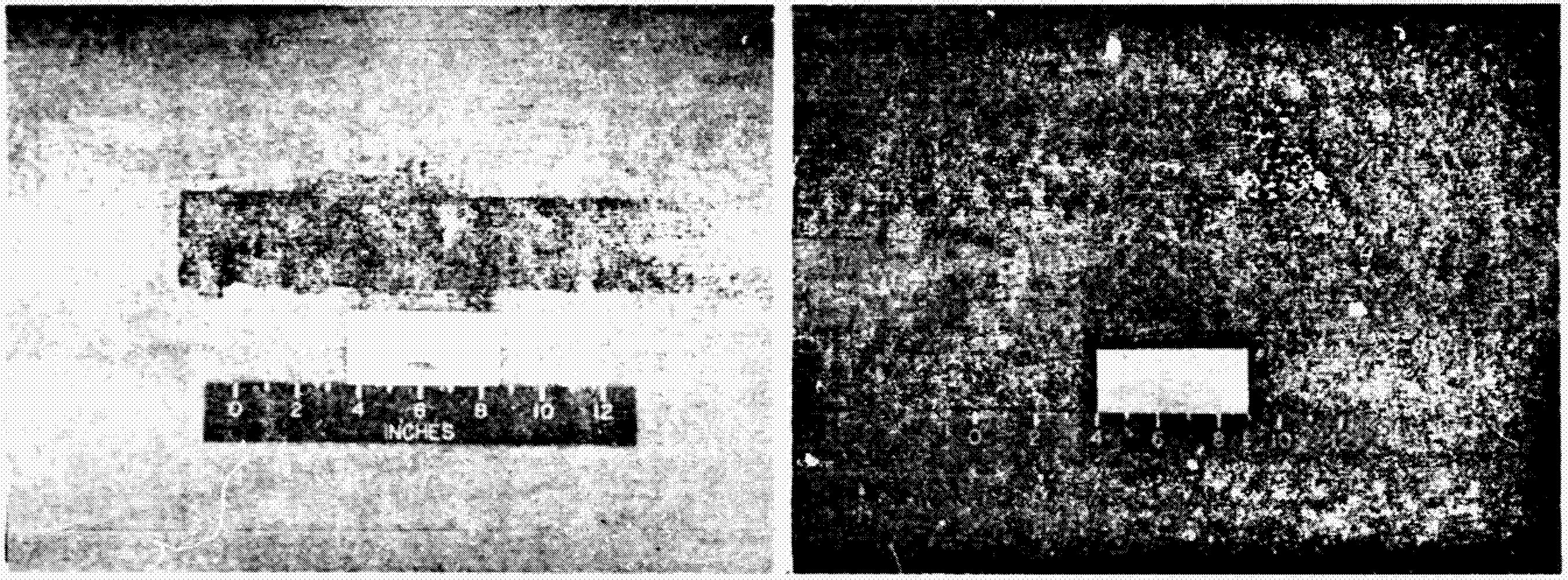


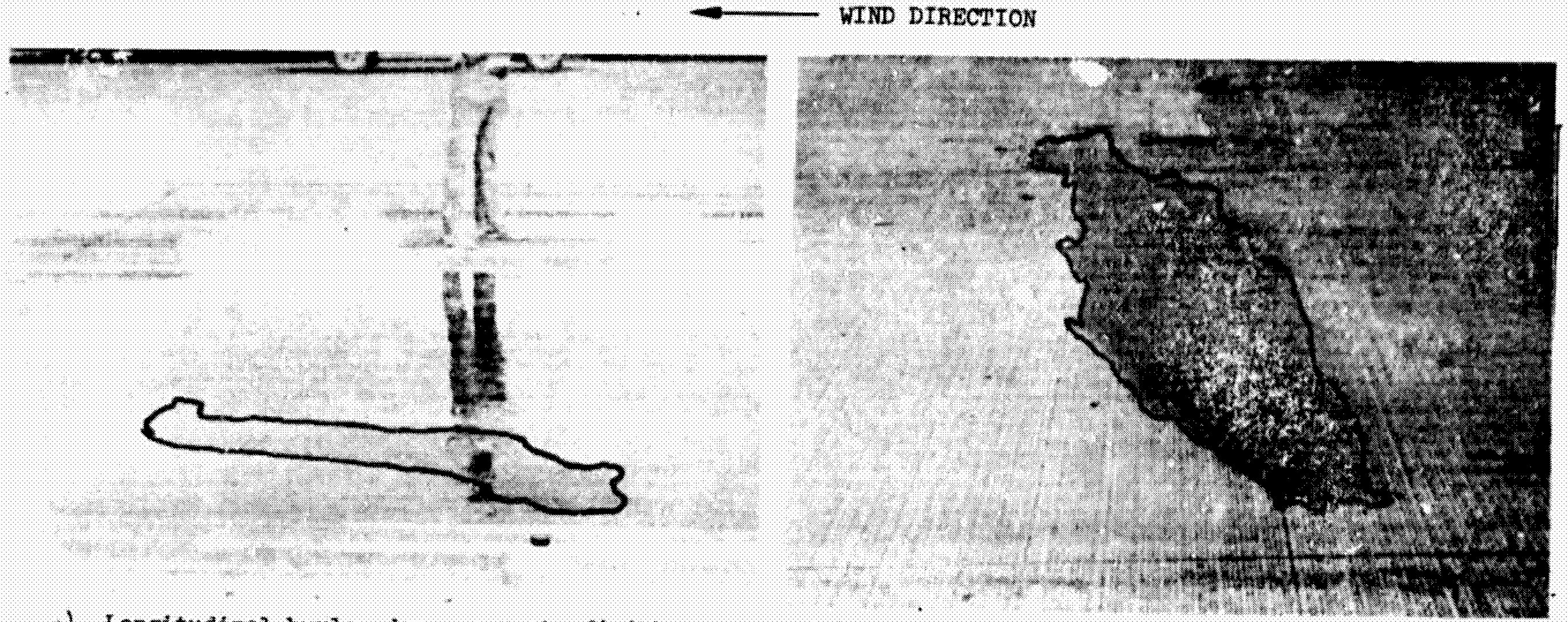
Figure 4.- Results from NASA DBV tests at Patrick Henry Airport in natural rain. Concrete runway with longitudinal burlap drag finish.



(a) Clean surface

(b) Rubber-coated surface

Figure 5.- Photographs of longitudinal burlap drag surface showing results of NASA grease test. Patrick Henry Airport.



(a) Longitudinal burlap drag concrete finish

(b) Wire-combed (plastic grooved) concrete finish

Figure 6.- Photographs illustrating water drainage on Runway 6/24 at Patrick Henry Airport. Wind from 60 degrees at 10 knots.

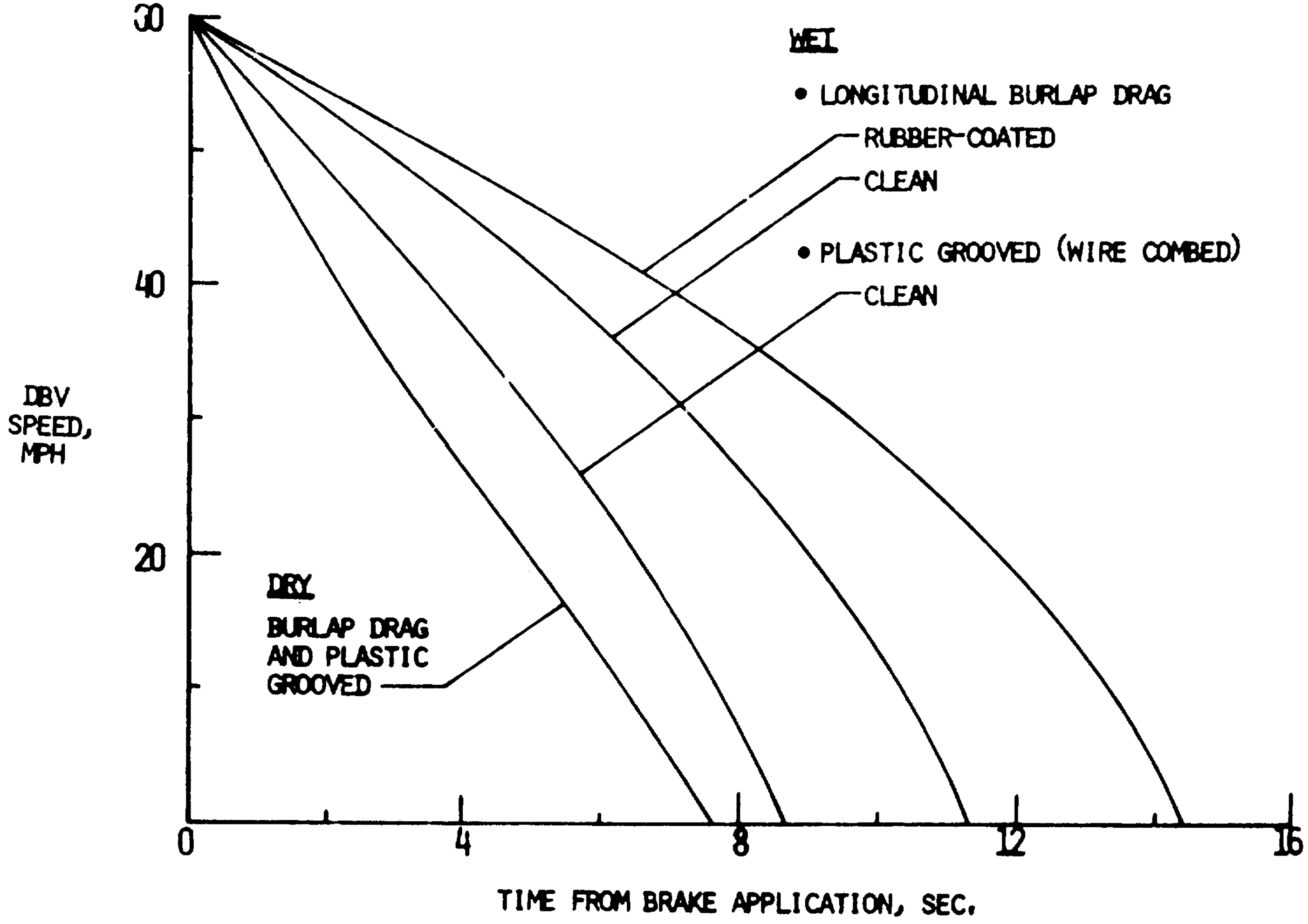


Figure 7.- DBV velocity-time profiles on wet and dry concrete runway surfaces at Patrick Henry Airport.

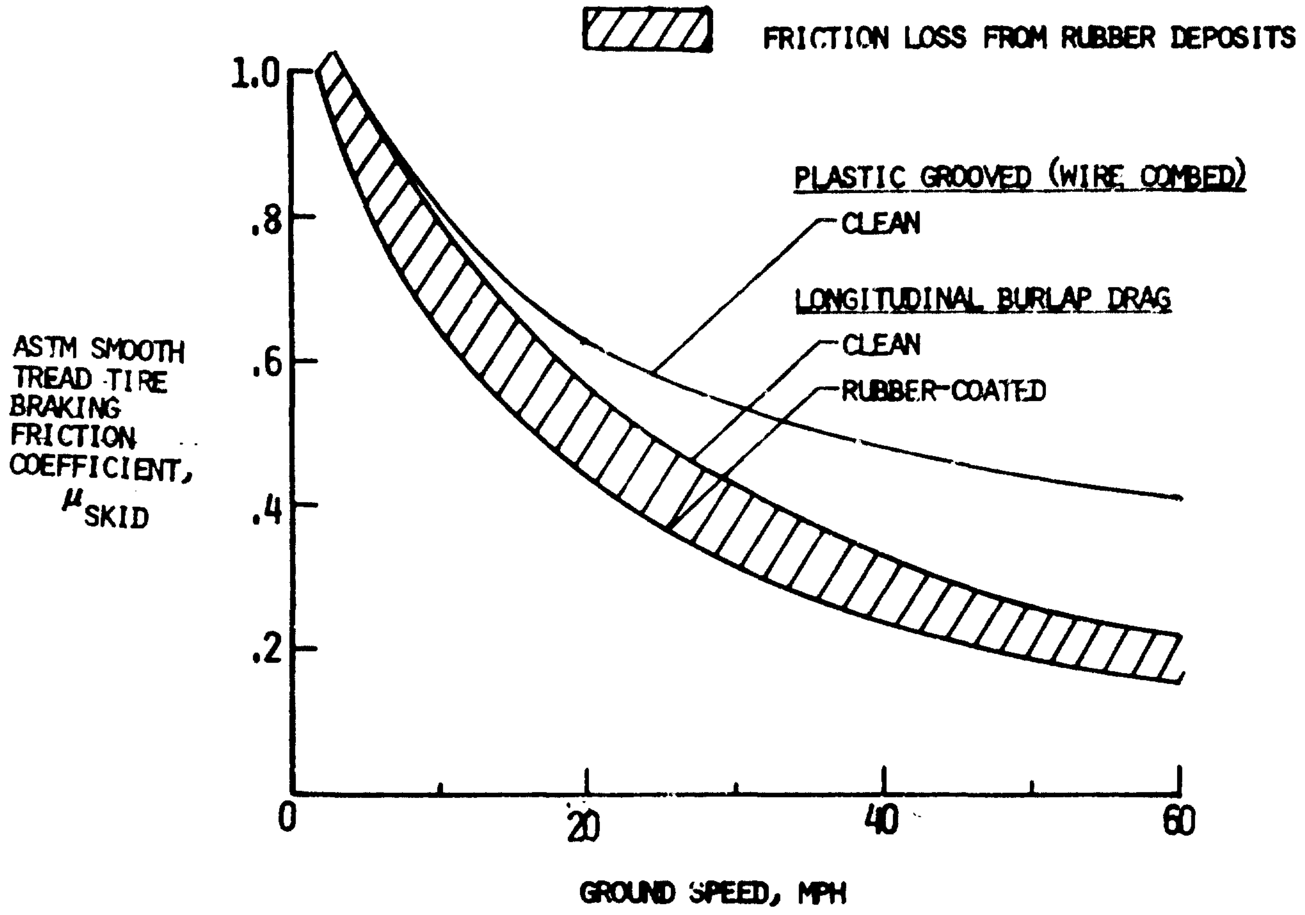


Figure 8.- Wet skid resistance measurements on concrete runway surfaces at Patrick Henry Airport as derived from DBV tests.

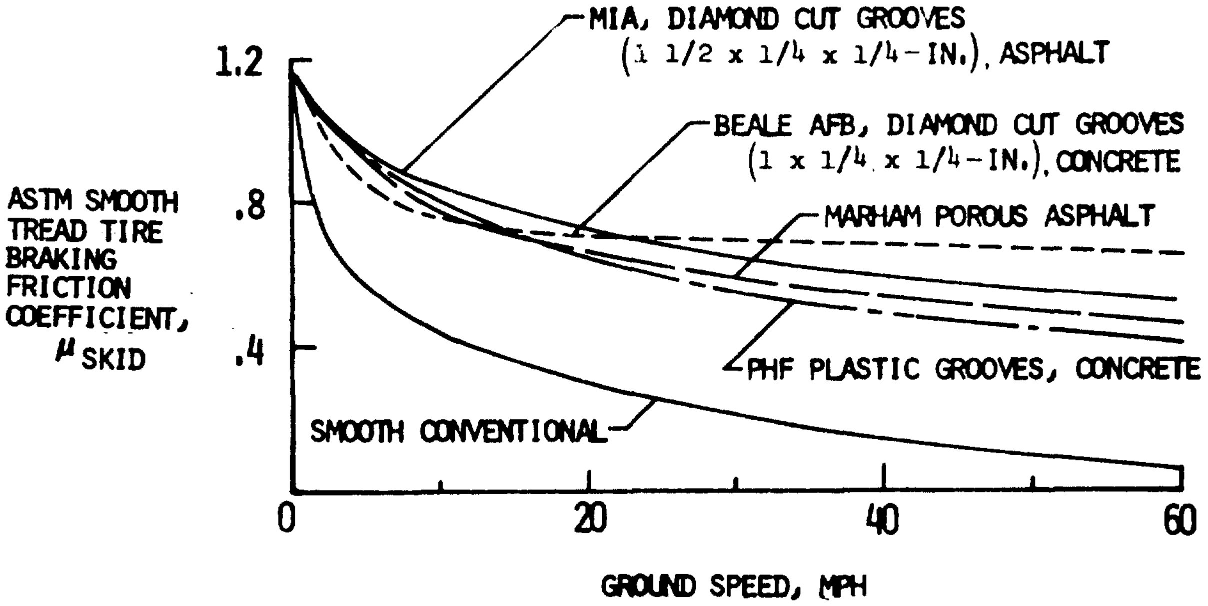


Figure 9.- Wet skid resistance of several runway surface treatments.

1. Report No. NASA TM X-73913	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle PLASTIC (WIRE-COMBED) GROOVING OF A SLIP-FORMED CONCRETE RUNWAY OVERLAY AT PATRICK HENRY AIRPORT---AN INITIAL EVALUATION	5. Report Date May 1977 6. Performing Organization Code
7. Author(s) Eugene C. Marlin (Peninsula Airport Commission) and Walter B. Horne	8. Performing Organization Report No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665	10. Work Unit No. 505-08-31-01 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics & Space Administration Washington, DC 20546	13. Type of Report and Period Covered Technical Memorandum 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This paper describes a wire-comb technique to transversely groove the surface of a freshly laid (plastic state) slip-formed concrete overlay installed at Patrick Henry Airport. The paper also describes the improvement in water drainage and pavement skid resistance obtained with this new type concrete surface texturing over that obtained with a older conventional burlap drag concrete surface treatment installed on an adjacent portion of the runway.

17. Key Words (Suggested by Author(s)) Runway slipperiness Runway surface treatments Aircraft-ground vehicle stopping performance Friction coefficient	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 24	22. Price* $3.50

* For sale by the National Technical Information Service, Springfield, Virginia 22161