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16. Abstract

This paper has conducted an evaluation of a high pressure water blast with rotating spray bar treatment for removing paint and rubber deposits from airport runways by means of diagonal-braked vehicle (DBV) traction tests and visual observations. Also included in the evaluation is a comparison of the test rubber removal treatment with reported results obtained by use of other different rubber removal treatments. The results of the evaluation suggest that the high pressure water blast with rotating spray bar treatment is very effective in removing above surface paint and rubber deposits to the point that pavement skid resistance is restored to trafficked but uncontaminated runway surface skid resistance levels.

Aircraft operating problems created by runway slipperiness have been reviewed along with an assessment of the contributions that pavement surface treatments, surface weathering, traffic polishing, and rubber deposits make in creating or alleviating runway slipperiness. The results of this review suggest that conventional surface treatments for both portland cement and asphaltic concrete runways are extremely vulnerable to rubber deposit accretions which can produce runway slipperiness conditions for aircraft operations as or more slippery than many snow and ice-covered runway conditions. Pavement grooving surface treatments are shown to be the least vulnerable to rubber deposits accretion and traffic polishing of the surface treatments examined, especially if close-spaced transverse groove patterns are employed.

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SUMMARY AND ABSTRACT

This paper has conducted an evaluation of a high pressure water blast with rotating spray bar treatment for removing paint and rubber deposits from airport runways by means of diagonal-braked vehicle (DBV) traction tests and visual observations. Also included in the evaluation is a comparison of the test rubber removal treatment with reported results obtained by use of other different rubber removal treatments. The results of the evaluation suggest that the high pressure water blast with rotating spray bar treatment is very effective in removing above surface paint and rubber deposits to the point that pavement skid resistance is restored to trafficked but uncontaminated runway surface skid resistance levels.

Aircraft operating problems created by runway slipperiness have been reviewed along with an assessment of the contributions that pavement surface treatments, surface weathering, traffic polishing, and rubber deposits make in creating or alleviating runway slipperness. The results of this review suggest that conventional surface treatments for both portland cement and asphaltic concrete runways are extremely vulnerable to rubber deposit accretions which can produce runway slipperiness conditions for aircraft operations as or more slippery than many snow and ice-covered runway conditions. Pavement grooving surface treatments are shown to be the least vulnerable to rubber deposits accretion and traffic polishing of the surface treatments examined, especially if close-spaced transverse groove patterns are employed.

INTRODUCTION

Aircraft and ground vehicle traction studies (such as ref 1) conducted in the late 1960's indicate that some airport runways can become slippery when wet in the aircraft landing touchdown areas where the pavement surface is contaminated and covered with rubber deposits resulting from wheel spinup at touchdown. This is especially true to some heavily trafficked runways at airports accommodating large jet aircraft with multi-wheel landing gears. Since 1970, the USAF and FAA have encouraged the development and use of rubber removal techniques to alleviate and remedy this runway contamination problem which can compromise aircraft take-off and landing safety, especially under adverse weather conditions.

Another runway maintenance problem somewhat related to the rubber removal problem is the complete removal of painted runway markings when marking locations on the runway are changed, and the complete or partial removal of runway marking paint which has deteriorated to the point it becomes a foreign object damage hazard to aircraft take-off, landing, and taxying operations. In this latter situation, the flaking old paint must be removed to the point where a satisfactory bond will be provided between new paint and the pavement surface when the runway marking is re-painted.

Over the years a number of different methods have been utilized for rubber and paint removal that range from sand blasting, mechanical grinding, and shot-peening to chemical treatments and high pressure water blast. In the early 1970's chemical rubber removal treatments were used with success especially on portland cement concrete runway surfaces. Chemical rubber and paint removal treatments are little used at the present time because of ecologically harmful side effects to water sheds surrounding airports. Sand blasting and mechanical grinding of paint and rubber-coated pavements have proven to be effective, but contaminant removal rates tend to be low requiring long runway closure times. In addition, these treatments tend to remove some of the underlying pavement surface as well as the contaminating rubber or paint accretions. The shot-peening contaminant removal technique directs high velocity-small diameter steel shot at the pavement surface which tends to pulverize and loosen the rubber or paint coating the runway surface into small particles. A vacuum-magnetic system encorporated in the equipment continuously picks up the steel shot and loose contaminant debris developed during the cleaning process thus eliminating the need to sweep the runway after the rubber/paint removal operation. It is understood that this type equipment cannot be used during rain conditions on the runway. Starting in 1973, high pressure water blast techniques employing stationary, oscillating, and rotating spray bars have been developed for runway paint and rubber removal. At the present time, most paint and rubber removal projects at airport runways in the United States employ the water blast technique in some form since this method has proved to be a relatively inexpensive and rapid means of paint and rubber removal that is ecologically unharmful to the airport environment and does not damage the pavement surface.

In May 1975, the Tactical Air Command Langley Air Force Base conducted a paint and rubber removal evaluation program on water blast equipment that utilize a rotating spray bar. The NASA Langley Research Center assisted in this evaluation by conducting traction tests on the runway surfaces before and after rubber and paint removal with its diagonal-braked vehicle (DBV). It is the purpose of this report to describe the results of the evaluation and to compare these results with published results obtained during other rubber removal projects.

An additional purpose of this paper is to develop a better understanding of the role rubber contamination plays in increasing runway slipperiness and decreasing aircraft landing safety so that more effective criteria can be established for scheduling rubber removal programs, determining the effectiveness of rubber removal programs, and identifying pavement surface treatments that are the least vulnerable to the rubber contamination problem. For this purpose, published data obtained on rubber contaminated and non-rubber contaminated runway surfaces of 182 runways by means of DBV and full scale aircraft braking tests are reviewed and analyzed.

Drawing from this review, and the evaluation of the different rubber removal treatments suggestions are made for improving the "state of the art" regarding alleviation of the runway rubber contamination problem.

EVALUATION OF HIGH PRESSURE WATER BLAST WITH ROTATING SPRAY BAR FOR REMOVING PAINT AND RUBBER DEPOSITS FROM AIRPORT RUNWAYS

Construction History of Langley AFB Runway 7/25

The present portland cement concrete surface of runway 7/25 is the result of the following constructions. In 1944, an 8-inch thick concrete overlay was added to the existing 7000-foot-long,150-foot-wide portland cement concrete runway. A westward 1000-foot-long portland cement concrete extension to the runway was constructed in 1951. In 1958, a further westward 2000-foot extension of the runway was constructed of portland cement concrete, giving the runway its present dimensions of 10,000-foot length and 150-foot width. During the years of 1960, 61, 63 and 1966 - the 8-inch-thick portland cement concrete overlay encompassing the full width (150 feet) of the runway, starting at the east threshold and extending 1200 feet, was removed and replaced with new 8-inch portland cement concrete. Also during the 1960-1961 period, the entire 8-inch portland cement concrete overlay at the intersection of runways 17/35 and 7/25 was removed and replaced. During this period at the west endof runway 17/25, the center 50-foot wide 10-inch portland cement concrete was removed and replaced with 16-inch portland cement concrete. Some random slab replacements were performed in the center 50-foot width of the runway at locations 2000-3000 feet from the west end during 1965, 1968, and 1970. The 14-inch portland cement concrete in the center 50-foot width of the runway at a distance betwen 2000 and 3000 feet from the west threshold was removed and replaced in 1968. As a result of these modifications, the age of the present runway surface varies from 31 to 7 years.

It is understood that neither runways 7/25 nor 17/35 have been cleaned of runway marking paint prior to the present removal program. As a consequence, paint build-up prior to removal approached 1/4 inch thickness on runway edge and threshold bar markings at some of the older runway surface locations. It is also understood that standard Air Force runway marking paint, federal specification TT-P-85 (paint, traffic reflectorized for runway marking-drop in type), has been used to paint the LAFB runway markings for many years.

Paint and Rubber Removal Equipment

The equipment evaluated consisted of a tractor-trailer rig, modified for rubber removal, as shown in figure 1(a). The tractor has special low range gears, transmission, and differential so that the equipment can be run at the low ground speeds (0.5-1.0 mph) required for paint and rubber removal from the runway surface.

The trailer carries two large water tanks (8000-gallon total capacity) which allows 1.5-2.0 hours of operation before refilling is required. The trailer also carries two high pressure water pumps (diesel engine driven) with connecting piping and controls. Two side by side horizontal rotary spray bars (hydraulically driven) are attached to hydraulic pistons extending downward from the floor of the trailer. This arrangement permits vertical height adjustment of the spray bars from surface contact to 27 inches above the pavement surface. The rotational speed of the spray bars is adjustable from 85-100 rpm, with 90 rpm used as a standard setting for both paint and rubber removal. Normally, one diesel driven water pump is used to supply high pressure water to a rotating spray bar. When necessary, both water pumps can be connected to a single rotating spray bar (doubles flow-rate) as is sometimes required during runway paint removal. A side view of a rotating spray bar of the test equipment is shown in figure 1(b).

For paint removal, a 27-inch long spray (10 nozzle) bar is used. The nozzle diameters used are varied from 0.045-0.085-inch depending upon the condition and thickness of the paint. A 40-inch long (12 nozzle) spray bar is used for rubber removal. The nozzle diameters used for rubber removal vary from 0.057 to 0.085-inch. For both paint and rubber removal, fan type spray nozzles are used.

Paint and Rubber Removal Specifications and Procedure

Specifications.- The specifications required that water pressure not exceed 6,000 lb/in.^{2}, that the spray bar rotate, that the nozzles be fan type and that the pump dispense water at 70 gallons/minute. The scope of the work entailed removing rubber deposits from centerline areas of the approach ends of runway 7/25 (strips 50 feet wide and 3000 feet long starting at threshold of each runway end) for a total rubber removed area of 300,000 ft.^{2}. Also included in the work was removal of paint markings on runways 7/25 and 17/35. This latter specification required removal of approximately 200,000 ft.^{2} of paint from the two runways. The specifications required removal of 95% of the rubber and 95% of the paint markings except where obsolete markings were not going to be replaced. In these areas, 100% of the paint had to be removed.

Procedure.- Two test areas were cleaned to establish the height the spray bar nozzles were to be set above the pavement. To obtain 95% rubber removal by visual inspection, the height required was 3 inches, and the height for cleaning 95% of the paint was 1-1/2 inches. Because of the thick paint accretions on some runway markings, only one of the 27-inch spray bars utilizing both water pumps to achieve maximum high pressure water flow was used. It should be noted that two passes were required with this spray bar arrangement to achieve 95% paint removal in runway marking areas that had the heaviest buildup. Some circular lines were left after the first pass, so a second pass was made at a higher rate of ground speed to remove the remaining paint. The tractor-trailer ground speed was 3/4 mph on the first pass. All paint on the runway 07/25 was removed using the 27-inch bar. This bar was also used initially for removing rubber. At the halfway point on removing rubber, the 27-inch bar was replaced with a 40-inch long spray bar. The cleaning remained the same with an increase in production. The 40-inch bar was used during paint removal on runway 17/35 at a 1-1/2 inch height setting. Two passes were still required because of the paint buildup; however, the production rates were much higher. The paint on the threshold markings was removed with one pass made forward and the second backward with the tractor-trailer rig.

Runway Traction Measurements

The Langley Research Center (LaRC) diagonal-braked vehicle (DBV) was used to measure the slipperiness of the runway 7/25 before and after paint and rubber removal. The DBV was developed by LaRC in 1967 to measure the slipperiness of airport runways and is described in reference 1. Since then, flight tests on CV-990, F-4D, C-141, B-727, DC-9, L-1011, B-737, and Caravelle jet aircraft indicate that this device and braking technique can be used to estimate stopping performance for these aircraft on wet runways within ± 15% accuracy using the method shown in figure 2 which was developed in reference 2.

It should be noted that such accuracy of prediction is obtained when the aircraft antiskid braking system is operating normally (no prolonged wheel skids). The flight tests also demonstrated that the DBV, as well as any other ground vehicle friction measuring device, cannot predict aircraft stopping performance when anomalous antiskid braking performance, such as prolonged wheel skids, occurs to an aircraft during braking on slippery runways. Anomalous antiskid braking performance occurrences are infrequent, not predictable, and are dependent upon antiskid system design, runway slipperiness level, and pilot braking imputs as described in reference 3. All aircraft antiskid braking systems employed on aircraft made in the United States at the present time are susceptable to anomalous antiskid performance, especially if the initial pilot brake application is hard and occurs before the wheels are fully spun-up at touchdown under slippery runway conditions.

For the above reason, it is doubtful whether the DBV or any other ground vehicle friction measuring system, can be used to reliably predict aircraft stopping performance at time of landing on slippery runways until the "state of the art" of antiskid braking system design advances to eliminate such anomalous antiskid braking performances. However, it should be understood that this aircraft operational problem with antiskid braking system performance in no way detracts from the ability of the DBV to rate the slipperiness of runways.

DBV runway test zones.- Figure 3 shows the location of areas on LAFB runway 7/25 chosen for DBV tests. As shown in the figure, test zones 1 and 4 were rubber coated. Test zone 2 was located near the middle of the runway beside the runway centerline and is subjected to aircraft wheel traffic, but did not contain any rubber deposits. Test zone 3 was located beside the runway edge abreast of test zone 2. This test zone is subjected to neither rubber deposits nor aircraft wheel traffic, and thus should reflect the original traction characteristics of the runway surface as modified only by surface weathering and contamination blown on to the surface such as from dust or jet fuel. Test zone 5 was a 30- x 150-foot painted runway marker. This test zone was also untrafficked and contained no rubber deposits.

DBV test procedure.- The DBV test technique requires locking a diagonal pair of wheels on a ground vehicle (see figure 2) and measuring the stopping distance required to bring the vehicle to rest from a brake application speed of 60 mph. The test is performed for both wet and dry conditions of the pavement under investigation, and the wet/dry stopping distance ratio (SDR) obtained depicts the slipperiness of the pavement relative to dry conditions. Instrumentation on board the ground vehicle records ground speed, wheel speed, stopping distance, and deceleration. The ground velocity time histories obtained during DBV braking tests can be differentiated with time and, after corrections for air and rolling resistance, be used to estimate the friction coefficients developed between the sliding (locked wheel) tires and the pavement. Both the SDR method and this latter method were used to evaluate the slipperiness of the pavement surfaces under study in this investigation. For the present investigation, the DBV was equipped with ASTM E249 smooth tread test tires (inflated to 24 psi), and the vehicle weighed approximately 5440 pounds.

Runway wetting.- A LAFB fire department foam truck, filled with water and equipped with a pressurized spray bar made two passes (opposite directions) over each DBV test zone just prior to the start of the DBV wet runway braking tests. This wetting technique deposited water uniformly over the width (approximately 15 feet) and length (150-1200 feet) of each test zone to an initial water depth of 0.05-0.04-inch as measured by a NASA water depth gage. When the water truck cleared the test zone, the DBV made its test runs. As many of 6 DBV test runs could be made on a test surface before the runway dried out. The elapsed time from wetting was recorded for each DBV run. Most of the runs were conducted in the early evening and morning hours from 7:00 pm to 7:00 am when the runway was closed to aircraft traffic during the runway paint and rubber removal program.

Results and Discussion

This section of the paper presents and discusses the results obtained from the present investigation in removing paint and rubber deposits and restoring tire-pavement traction by means of high pressure water blast using a rotating spray bar.

Paint and rubber removal production rates.- The high pressure water blast with rotating spray bar equipment removed paint at an average rate of 3,188 square feet/hour, and removed rubber at an average rate of 13,612 square feet/hour. The removal rates on paint varied from a high of 4,800 sq ft/hour to a low of 2,057 sq ft/hour. This large rate difference occurred primarily because of the different type and configurations of runway markings. For example, straight-ahead driving could be employed on runway edge markings while threshold bar markings required frequent repositioning of the equipment with a forward-backward type cleaning operation. Rubber removal rates also varied greatly with this equipment, and ranged from a high of 17,666 sq ft/hour to a low of 8,000 sq ft/hour. This variation occurred primarily because of the different width spray bars used, different thicknesses of rubber buildup, and some experimenting with the rubber removal technique.

Paint removal.- Visual observations and photographs taken during and after paint removal on runways 7/25 and 17/35 (see figure 1, 4, and 5), indicated that the high pressure water blast with rotating spray bar did an excellent job of removing bulk paint from the runway marking areas. The bulk paint was broken up into small particle sizes (see figure 4) which were easily removed from the runway by runway vacuum sweepers, especially when the pavement surface dried out.

In most runway marking areas, a faint residual paint stain remained after two passes of the cleaning equipment. Close visual inspection of the stains showed that the stains appeared to be below the top of the pavement surface texture, and impregnated vertical or nearly vertical slopes of pavement surface granules. These surfaces were probably not exposed to direct impingement by the high velocity water jets of the rotating spray bar. Figure 5 shows a photograph taken of the approach end of runway 17 during re-painting of the threshold bar markings after paint removal. This photograph shows some slight discoloration of the pavement surface in the paint removed areas produced by the residual paint stains. Base civil engineering judged the stain problem to be insignificant and felt that paint removal achieved on the runways satisfied its paint removal specifications. No pavement surface damage attributable to the paint removal equipment could be found on either runway 7/25 or runway 17/35 after the paint removal program was completed.

Rubber removal.- Visual observations and photographs made before and after rubber removal on runway 7/25 (see figures 6 and 7) suggest that the high pressure water blast with rotating spray bar did an excellent job in removing bulk rubber deposits from the runway aircraft touchdown areas. Visual inspection and photographs 6 and 7 also indicate that faint residual rubber stains are frequently left in the cleaned rubber-contaminated pavement surface after a single pass of the rubber removal equipment. As previously mentioned, these stains are felt to be the result of the high velocity water jets of the rotating spray bar not being able to directly impinge on vertical or nearly vertical faces of the pavement surface granules. Base civil engineering judged that the just described rubber removal achieved by the high pressure water blast with rotating spray bar met its 95% rubber removal specification requirement. Comparison of photographs in figures 6, 7, and 8 suggest that the rubber removal achieved at the approach end of runway 7 by the high pressure water blast with rotating spray bar was approximately equivalent to the rubber removal obtained by chemical treatment given this runway in 1970 (discussed later in the paper). It can be seen from these photographs that a uniform rubber removal was obtained by both chemical and the test rubber removal treatments. There was no evidence with these treatments of non-uniform rubber removal such as streaking or grooving that was reported for mechanical grinding (reference 4) and high pressure water blast with stationary spray bar (reference 5 and 6) treatments. No pavement surface damage attributable to high pressure water blast with rotary spray bar was evident on runway 7/25 after the rubber removal program was completed. The high velocity water jets from the spray bar did, however, loosen some small pieces of concrete contained in previously cracked areas of the concrete pavement. These particular areas of the concrete pavement would have been corrected by routine runway maintenance. The water blast rubber removal just accelerated the loosening or unraveling process in the broken concrete pavement area.

Restoration of pavement skid resistance.- The approach ends of runway 7/25 were covered with medium to heavy rubber deposits that has accumulated since the last rubber removal program conducted on this runway in 1973 (see figures 6 and 7). The rubber accretions in these runway areas tended to fill the pavement surface voids and thus reduce the magnitude of the average pavement surface texture depth as measured by the NASA grease test. In addition, the rubber-coated surfaces were very smooth and lacked microtexture. These effects are shown by comparing the surface photographs and NASA grease test average texture depth (A.T.D.) measurements given in figure 9 and 10 for the contaminated and uncontaminated runway test zones.

DBV wet/dry stopping distance ratios (SDR) obtained before and after rubber removal by the high pressure water blast with rotating spray bar in these test zones are shown in figure 3 and given in Table I. These data show two different slipperiness effects. First, an obvious increase in runway slipperiness (increase in SDR values) is noted for test zone 2 over test zone 3 which compares trafficked and untrafficked runway surfaces having no rubber deposits. The increase in slipperiness of test zone 2 over test zone 3 is attributed to aircraft tire polishing the pavement surface in the wheel tracks during landing, taxying, and take-off operations that have occured during the past 31 years (present age of these pavement surfaces). The NASA grease test measurements (see figure 10) indicate that the polishing action must be more associated with decreasing the microtexture rather than the macrotexture of the pavement, since the A.T.D. values for the untrafficked and trafficked surfaces have approximately the same texture depth range. Secondly, the rubber deposits covered areas of the runway show a large increase in SDR magnitudes over a similarly trafficked area (compare zones 1 and 4 with zone 2 in Table I) without rubber deposits. This increase in runway slipperiness most probably stems from the reduced pavement microtexture and macrotexture obtained on the rubber-coated surfaces.

The data in table I indicate that the test rubber removal equipment removed sufficient rubber in the rubber covered areas of the runway to restore traction levels to the trafficked no rubber condition, but not to the untrafficked no rubber condition. This result indicates that the high velocity water jets from the rotating spray bar cleaned the surface of bulk rubber, but did not disturb the underlying pavement surface. Restoring the runway traction to untrafficked surface levels obviously requires retexturing the pavement surface to renovate the existing tire polished surface. To summarize, the high pressure water blast with rotating spray bar removed bulk rubber from the runway sufficient to restore pavement skid resistance to trafficked but uncontaminated runway surface levels. The residual rubber stain left on the pavement after cleaning did not appear to affect pavement skid resistance, and this rubber removal method did not damage or change the underlying bare pavement surface texture.

EVALUATION OF OTHER TECHNIQUES FOR REMOVING RUBBER DEPOSITS FROM AIRPORT RUNWAYS

Chemical Treatment

Traction measurements have been conducted on runway 7/25 since 1969. In July 1969, the slipperiness of the middle portion of this runway (no rubber deposits) was evaluated during Project Combat Traction (reference 1) with a DBV and a C-141 aircraft which gave the following results

TEST VEHICLE	WET/DRY STOPPING DISTANCE RATIO (SDR)
DBV	1.95
C-141	1.90

Runway 7/25 was first cleaned of rubber deposits by chemical treatment August 30-31, 1970. NASA DBV tests at Langley AFB request were made 5 months prior, 4 days after, and 4-1/2 months after this rubber removal treatment with the results listed in the following table.

		DBV SDR *	
DATE OF TEST	SURFACE WETNESS	APPROACH END OF RUNWAY 7 (RUBBER DEPOSITS)	MIDDLE OF RUNWAY (NO RUBBER)
3/70	NATURAL RAIN	2.45	1.6
8/31/70	RUNWAY CLEANED OF RUBBER BY CHEMICAL TREATMENT		
9/3/70	ARTIFICIAL (WATER TRUCK)	1.97	1.92
1/15/71	ARTIFICIAL (WATER TRUCK)	2.57	1.89

* SOURCE: UNPUBLISHED NASA DBV TEST PERFORMED FOR LANGLEY AFB

The data in the above table suggest that the chemical rubber removal treatment effectively removed sufficient bulk rubber from the touchdown area of runway 7 to restore pavement skid resistance to trafficked-uncontaminated pavement skid resistance levels. These data also suggest that 4 1/2 months after rubber removal, rubber deposits from subsequent aircraft landings had degraded pavement skid resistance in the runway 7 touchdown area to pre-rubber removal values. Some indication of the extent of these new rubber deposits may be obtained from comparing the photographs of the approach end of runway 7 taken 4 days and 4 1/2 months after the chemical rubber removal program shown in figure 8. In July 1973, Langley AFB requested further DBV tests on runway 7/25 prior to its planned high pressure water blast rubber removal treatment scheduled later that year. These DBV tests were conducted July 24, 1973 and the data obtained are presented in Table II. DBV tests were not performed after the rubber was removed. The data shown in Table II for the approach end of runway 25 suggest a pronounced grain effect in pavement skid resistance. DBV SDR values are higher when the vehicle is tested in the aircraft landing direction (250°) than for the opposite direction. This result suggests that the sliding tires at touchdown may not contact the back side of some exposed pavement surface granules as much as the front side which are in direct contact with the sliding tire. This type of rubber accretion on the pavement surface results in a surface microtexture which varies with vehicle heading, and thus changes the pavement skid resistance and DBV SDR under wet conditions. In summary, this discussion indicates that the slipperiness of the trafficked-uncontaminated middle portion of runway 7/25 has not changed significantly during the past six years and has a DBV SDR of approximately 2.0. The rubber-coated approach ends of this runway become more slippery when wet, having an SDR range from this value (2.0) to 3.82, depending upon the amount of rubber deposits present at the time of testing. This discussion also indicates that rubber deposits accumulate rapidly on runway 7/25 after rubber removal with a corresonding increase in runway slipperiness. The chemical rubber removal treatment used on runway 7/25 was as effective as the present test high pressure water blast (rotating spray bar) treatment in removing bulk rubber and restoring pavement skid resistance.

High Pressure Water Blast (Oscillating Spray Bar) and Mechanical Grinding Treatments

During September-November 1972, the Canadian Ministry of Transport evaluated two different rubber removal treatments on portland cement concrete runways at Toronto International Airport (reference 4). Table III presents DBV test data obtained when rubber was removed using a high pressure water blast with an oscillating spray bar and Table IV presents DBV test data obtained using a mechanical grinder. These data are somewhat inconclusive since DBV tests on a trafficked-uncontaminated (wheel paths) portion of the runway are not presented for comparison with values obtained on an untrafficked-uncontaminated (runway edge) portion of these runways. As a result, the effect of tire polishing of the pavement surface in the no rubber deposit region of the runway is unknown. This fact prevents making a determination whether the residual slipperiness remaining after rubber cleaning is the result of incomplete rubber removal, or from tire traffic polishing the pavement surface texture. In addition, the DBV brake application speeds used in these tests ranged from 20-36 mph which is much less than the recommended DBV 60 mph brake application speed used in the United States. As a consequence, the DBV SDR values obtained in the Canadian tests may be considerably lower than the values obtained on similar runway surfaces when the tests are conducted at 60 mph. The data shown in Table III indicate that the high pressure water blast did improve pavement skid resistance in the cleaned areas. Insufficient data are available to indicate the degree of improvement for reasons just discussed. Inspection of photographs presented in reference 4 suggest that the high velocity water jets from the oscillating spray bar removed rubber deposits uniformly from the runway surface with no evidence of streaking or grooving the surface. Some residual rubber stains after cleaning are apparent in these photographs. Table IV data indicate that mechanically grinding the rubber deposits from the runway surface improved the pavement skid resistance more than that achieved by the high pressure water blast when the mechanical grinder was operated in a corrugating configuration mode. This grinding mode actually grooved the base pavement surface to a depth of 1/16 inch and reference 4 reports a significant improvement in water drainage from this pavement during water truck wetting or natural rain conditions. Inspection of photographs shown in reference 4 suggest that rubber removal was not complete with this equipment, since some rubber remained on the lands between the grooves on the cleaned surfaces. This result may explain why the skid resistance of the grooved pavement was not completely restored to untrafficked-runway edge values. Reference 4 reported that the mechanical grinder removed rubber at the rate of 1250 to 1400 sq. ft/hour when cleaning a 14-foot-wide test strip on the runway, and estimated that this production would double if a wider strip (80 feet) on the runway was cleaned. The rubber removal rate observed for the high pressure water blast with oscillating spray bar during this evaluation was 3,000 sq. ft/hour.

High Pressure Water Blast (Stationary Spray Bar) Treatment

During the period 20-23 June 1974, a high pressure water blast with stationary spray bar technique was used to remove rubber at Charleston AFB, South Carolina. The effectiveness of this rubber removal treatment in restoring pavement skid resistance in rubber contaminated runway touchdown areas was evaluated by the Air Force Civil Engineering Center (reference 5) and by the FAA National Aviation Facilities Experimental Center (reference 6). The following description of the test equipment was obtained from the just mentioned references. The high pressure water-jet system consists essentially of an 8000-gallon water-tanker truck equipped with pumps and a three-foot-long stationary spray bar which could be adjusted both horizontally and vertically. The spray bar is fitted with 16 hardened stainless-steel nozzles spaced approximately 2 inches apart. The small opening in each nozzle is machined to produce a fan-shaped spray pattern. In operation, four pumps feed a manifold of 4 nozzles each. Water is pumped at the rate of 60 gallons per minute through the nozzles at pressures up to 12000 psi and ejected either straight downward or inclined slightly forward (in same direction as vehicle movement). The water pressure used in removing the rubber at Charleston runway 15/33 varied from 5,500 to 6,500 psi. The speed of the vehicle was varied from 2 mph for heavy rubber deposits to 5 mph for light rubber deposits on the runway. DBV braking tests were made in the locations shown in figure 11 which cover rubber-contaminated and trafficked and untrafficked and uncontaminated surfaces of the runway. DBV SDR values from these tests are presented in Table V. It should be noted that for all test zones, the DBV test runs were made using alternating runway headings and the SDR values obtained were averaged for use in Table V. The data in Table V indicate that some traffic polishing has occurred in the wheel tracks of the runway (compare test zone EA and G with zones C and D). Thus to determine the effectiveness of the rubber removal treatment, SDR values obtained from test zones C and D should be compared with the SDR values shown in table V for zones A, B, E, and F after 1, 2 or 3 rubber removal passes. This comparison suggests that rubber removal was not complete using this treatment, and some residual rubber was left in the cleaned areas of the runway. Examination of pavement surface photographs taken before and after rubber removal in references 5 and 6, suggest that the high velocity water jets from the nozzles on the stationary spray bar of this equipment, tended to remove the rubber in well defined longitudinal furrows which left rubber streaks on the pavement. Production rate data obtained from references 5 and 6 indicate that the high pressure water blast (stationary spray bar) removed rubber from runway 15/33 at an average rate of 8,800 sq. ft./hour.

High Pressure water blast (stationary spray bar) equipment was used to clean runway 9/27 of the Transition and Training Airport (Miami International Airport) during the period Oct 4-9, 1973. The M. I. A. DBV was used to measure pavement skid resistance before and after rubber removal. The data from this study were presented in reference 7 and are shown in Table VI. The data in Table VI exhibit the same trends found at Charleston, that is, the DBV SDR values after rubber removal were found to be somewhat higher than the values for the trafficked portion of the runway with no rubber deposits indicating incomplete rubber removal. Comparison of trafficked and untrafficked (no rubber) SDR values in this table suggest some traffic polishing has occured in the wheel paths of the runway surface.

REVIEW OF RUNWAY SLIPPERINESS PROBLEMS

Since 1969, the skid resistance of approximately 250 civil and military runways has been measured worldwide by diagonal-braked vehicles of the NASA, USAF, FAA, Miami International Airport, Canadian MOT, British CAA, and French STAé. This is a relatively small sample of the number of runways serving jet aircraft when, for example, the FAA alone has 500 airports with approximately 1,000 runways serving air carrier jet transports. However, the published data obtained from these measurements are extremely valuable in that trends can be observed which make possible an assessment of the relative contributions that pavement materials, surface treatments, contaminants such as rubber deposits, and surface weathering or traffic polishing (from aircraft operations) make with regard to preventing, alleviating, or creating runway slipperiness problems for aircraft operation. A large sample of the DBV wet/dry stopping distance ratio (SDR) measurements obtained on airport runways from published USAF, FAA, and NASA test programs are listed in tables VII, VIII, IX, and X. The following discussion is based on the data trends shown in these tables and from a review of other published data related to this field.

Pavement Surface Treatment and Materials

The initial skid resistance of a pavement under wet conditions is determined by the surface micro-macro textures which results from the interplay of two factors during the paving process. The first factor is the asphaltic or portland cement mix which is determined from specifications used at the batching plane when the mix is prepared. A good skid resistant pavement requires use of sharp silicious sands and sharp, angular aggregates with good microtexture. Neither portland cement nor bitumen, which are the primary binding materials used in pavement mixes, possessmicrotexture by themselves, so the resulting pavement matrix depends upon the sand and aggregate constituents for texture. The second factor is the mechanical paving process used. For asphaltic concrete, the use of mechanical rollers to compact the pavement is required after asphalt is laid to meet pavement density specifications. This rolling process, especially when vibrating rollers are used, tends to depress the sand and aggregate into the binder so that the resulting pavement macrotexture can become too small to provide adequate bulk water drainage and pavement skid resistance in the tire-ground contact zone during natural rain conditions. It should also be noted that liquid bitumen coats the surface sand and aggregate of most asphaltic pavements when the pavement is initially installed on a runway. Thus, many asphaltic concrete surfaces can be more slippery when newly installed than some time later when erosion from aircraft traffic and surface weathering has worn away this coating and exposed the surface sand and aggregate to provide better pavement micro/macro textures. On the other hand, for portland cement concrete pavements, mechanical vibrators are required to consolidate the concrete mix as it was placed onto the runway by the paving machine. This technique tends to drive the large aggregate below, and float the fine portland cement grout and sand mixture to the top of the pavement surface. As a result, after leveling the surface to grade with the leveling machine or equipment, the concrete surface tends to be very smooth in texture and requires application of a mechanical surface texturing treatment. For years, the preferred texturing treatments have been by means of longitudinal burlap cloth or canvas belts which are dragged on top of the fresh concrete surface to produce striations that expose the surface sand and form a surface macrotexture when the concrete hardens. Slip-form paving is practically universally employed at the present time for construction of concrete runways or overlays. This type of concrete paving requires the use of a low slump concrete mix. With this stiffer concrete mix, providing an adequate surface micro-macro texture with conventional burlap and canvas belt drag treatments becomes almost impossible. As a result, some slip-formed concrete surfaces are presently being mechanically textured with a longitudinal broom or transverse wire comb treatments which score the fresh concrete surface more deeply than either the burlap drag or canvas belt.

In general, the range of DBV SDR values shown in tables VII to X for trafficked but uncontaminated pavement surfaces (SDR = 2.95-1.13) reflect the type of pavement surface treatment employed during construction. For ungrooved portland cement concrete runways, the most slippery treatments were longitudinal burlap drag and canvas belt. SDR values for these type surfaces nearly always exceeded 2.0 in magnitude. The least slippery treatment was provided by a wire comb (SDR = 1.13) which generally produced much deeper striations in the concrete than that obtained with either burlap drag or canvas belt treatments. For asphaltic concrete surfaces, SDR values ranged from 2.71 to 1.16. The most slippery asphalt surfaces were usually lacking in macrotexture due to the use of rollers, especially vibrating rollers, during pavement compaction when the surfaces were installed. The least slippery asphaltic concrete surfaces were generally those where aggregate and sand were exposed above the level of the bitumen binder at the surface producing a good surface micro/macro texture. It should be noted that the most slippery asphaltic concrete surface not covered with rubber deposits evaluated in table VIII was runway 17L/35R at Webb AFB. This surface was treated with several applications of an asphalt emulsion diluted with water. After this treatment was applied, the SDR was found to be 4.51. It is felt that this smooth emulsion must have covered the existing surface microtexture and reduced the surface microtexture to produce so large an increase in pavement slipperiness.

Surface Weathering and Traffic Polishing

The data shown in figure 12 and table 1, which were obtained from the present investigation, show an interesting trend for the untrafficked pavement surface at the side of the runway to have higher skid resistance (lower SDR) than the trafficked uncontaminated pavement surface subjected to aircraft wheel passages during landing, taxying and take-off. A similar trend is noted for many pavements listed in tables VII and VIII. The age of the LABF concrete surfaces at the points measured at the middle of the runway by the DBV is approximately 31 years. Visual inspection suggests that during this time period, weathering occured on the untrafficked surface which removed cement grout from the surface and exposed the underlying sand and larger aggregates. At the same time, the trafficked surface in the wheel paths on the runway was polished from 31 years of tire passages. The net result appears to be a decrease in skid resistance (higher SDR) for the runway surface that is traffic polished due to a reduction in surface microtexture. The large variance in SDR values between runway edge and trafficked but uncontaminated runway surfaces shown in tables VII and VIII possibly reflect pavement age, surface treatment, and sand/aggregate polish resistance effects.

Rubber Deposits

The most slippery wet runway surfaces shown in tables VII to X were found for smooth portland cement and asphaltic concrete runways that were covered with heavy rubber deposits. For such surfaces, DBV SDR values ranged from approximately

3.0-6.0 for runways subjected to heavy traffic from multi-wheeled jet aircraft. This degree of runway slipperiness exceeded that found for snow-and ice-covered runways in reference 1 where SDR values for the DBV and a C-141 jet transport ranged from 1.62 to 4.16. Comparison of surface photographs of rubber contaminated and uncontaminated pavement such as shown in figures 9 and 10, suggest that rubber deposits tend to fill and smooth the pavement macrotexture while eradicating the pavement microtexture. The former effect is also shown to some extent by the lower NASA grease test A.T.D. values found for rubber-coated areas of runways when compared with non-contaminated areas. The latter microtexture effect is more difficult to deduce from visual inspection, but can be inferred from DBV velocity time history data such as shown in figures 12 and 13 for LAFB runway 7/25. In each of these figures, the DBV velocity-time histories are plotted in the left graphs while the right graphs present tire μ_{skid} (locked-wheel) friction coefficients derived from the DBV time histories as a function of DBV speed. The data shown in these figures suggest that rubber deposits cause a large decrease in tire μ_{skid} to occur at all DBV speeds when compared with tire μ_{skid} values obtained on trafficked but uncontaminated (with rubber) runway surface values. This result causes a large increase in DBV stop times from 60 mph with a significant increase in DBV SDR as shown in table I. As pointed out in references 3 and 11, such degradation of tire μ_{skid} at low speed is the consequence of a reduction in surface microtexture. The reduced microtexture in rubber-coated pavement areas fail to drain the pavement of the residual water film during tire passage as readily as the higher microtexture-uncontaminated pavement surface, and a higher degree of viscous hydroplaning ensues. Also shown in figures 12 and 13 is the restoration of pavement skid resistance brought about by the removal of bulk rubber deposits from the pavement surface by means of a high pressure water blast with rotating spray bar. The closely paralleling curves for the trafficked-no rubber and trafficked-cleaned of rubber surfaces shown in these figures suggest a practically complete restoration of the pavement microtexture by this rubber removal technique.

Runway Marking Paint

Runway marking paints are used to make runways more visible and recognizable to pilots during approach and landing. However, runway paints are viscous fluids that have reflective glass beads added during application to enhance the paint's reflectivity. This paint and glass bead combination when applied to a runway pavement hardens into a smooth surface that usually has a reduced microtexture over the surface that it coats. The result is painted surfaces are usually more slippery when wet than unpainted adjacent runway surfaces. Such a result obtained during the present investigation as shown in figure 14 which compares DBV and tire μ_{skid} braking performance on painted and unpainted surfaces of runway 7.

Pavement Grooving

The first grooved runway in the United States was installed at Washington National Airport in 1967. At the end of 1975 it is expected that approximately 80 civil runways will be grooved along with an additional 11 USAF runways at home and 7 more at overseas bases. Pavement grooving originated in England, but much research and the deep grooving concept for this pavement surface treatment took place in the United States (see reference 12). Pavement grooving has proven to be much superior to conventional pavement surface treatments in draining water from pavements during artificial wetting (water trucks) or during rainstorms as is shown in figures 15 and 16 respectively. As a consequence, the possibility of a flooded runway condition and dynamic hydroplaning occuring to an aircraft landing on a grooved runway is considered extremely remote unless very high rainfall rates are encountered. The safe, caution, and danger zones indicated in figure 16 refer to the critical water depths required for tire dynamic hydroplaning spindown phenomena to occur or not occur. For example, water depths between 0.05 to 0.10 inch, depending upon whether the tire tread is worn or new, or greater are required for an unbraked tire not to spinup at touchdown on a flooded runway. If the water depth on the runway is less than 0.05 inch, this phenomenon is unlikely to occur (see reference 11).

The data in figure 17 (obtained from reference 3) illustrate the powerful effect a close groove spacing (1 x 1/4 x 1/4 inch) has on recovering tire traction lost by a conventional concrete surface treatment (Burlap drag) due to poor ability to drain water from the tire-pavement contact zone. These data also indicate that aircraft stopping capability is further increased by grooving because the high traction levels developed on a grooved runway allow the aircraft antiskid braking system to operate at a higher efficiency. The low DBV SDR values obtained on non-rubber contaminated grooved pavements and shown in tables VII, and VII, and IX, and X further substantiate the effectiveness of grooving treatments in restoring or maintaining good pavement skid resistance during wet runway conditions. These data also confirm the expected trend for grooving effectiveness to decrease as the groove spacing is increased.

The data shown in tables IX and X suggest that close-spaced pavement groove configurations (1-2 x 1/4 x 1/4 inch) when applied to runway pavements can considerably alleviate the runway slipperiness problem caused by rubber deposits. Two effects produced by grooving the pavement are believed responsible for this improved performance over conventional pavements. First, if the grooves are cut at least 1/4 inch deep into the pavement, no molten rubber from the sliding tire at touchdown can be deposited in the bottom of the grooves. As a consequence, the groove channels which funnel bulk water out of the tire-ground contact area remain unchanged with regard to cross-section or openness as rubber deposits accumulated on the pavement surface. This effect is seen in figure 18 where the surface lands between the grooves are completely covered with rubber deposits. Note that the bottoms of the grooves between the lands are free of rubber.

Secondly, tire tread rubber can extrude as much as 1/32 to 1/8 inch into the grooves in the tire/ground contact area during tire passage on the pavement. This effect provides a gear action between tire and pavement which produces a drag force that partially compensates for the friction loss due to viscous hydroplaning occurring on the lands of the grooves (see reference 15). It should be noted that this "gear effect" is rapidly lost as groove spacing is increased, and the number of grooves in the tire/ground contact area is decreased.

DBV braking tests were made at Miami International Airport (M.I.A.) while runways 9R/27L and 9L/27R were being grooved to a 1 1/2 x 1/4 x 1/4 inch pattern (LWP-1114). These tests were conducted in grooved and ungrooved areas of the runway where rubber deposits ranged from heavy to light. Also included were tests areas free of rubber contamination. These data are presented in figure 19 and show a large reduction in DBV SDR due to improved pavement skid resistance as a result of grooving.

Chevron cuts.- The only known detrimental aspect of pavement grooving with regard to aircraft operations is the development of chevron cuts on some aircraft tire treads when aircraft touchdown on grooved runways and the landing gear wheels spin up from a standstill to aircraft ground speed. A typical example of the tire chevron cutting phenomenon is shown in figure 20. From this figure, it can be determined from the width of the chevron cuts on the tire, the rubber streaks on the runway, and the runway groove spacing, that the chevron cuts develop only during the first 1-2 feet of the touchdown skid when the tire is sliding and not fully rolling on the runway surface. Research conducted at NASA Landing Loads Facility (reference 16) indicates that wheel prerotation before touchdown in amounts greater than 10% the aircraft touchdown ground speed can eliminate chevron cutting of tire treads completely.

Visual observation of the tires of aircraft parked at airports having grooved runways suggest that only the larger diameter aircraft tires, and of these, only those employing high inflation pressures, develop chevron cuts on grooved runways. Reference 16 points out that the degree of chevron cutting of tire treads is also affected by the magnitude of the aircraft touchdown speed. Reference 16 states that for each combination of tire and grooved pavement surface, there is a ground speed below which no chevron cutting occurs, and above which the extent of the chevron cut damage increases with increased speed.

The civil airlines in the United States at the present time do not consider chevron cutting to be a serious operational problem to their jet transport fleet. A 10-15% reduction in tire life (number of landings per tire) has been noted for some jet transport aircraft operating on grooved runways. The airlines are closely monitoring tire chevron cutting, however, since more and more jet transport operations are being conducted on grooved runways as the number of grooved runways at airports increases.

On the otherhand, the USAF feels that chevron cutting is a problem to some of its aircraft that utilize tires with large diameters and/or high inflation pressures, and require high landing touchdown speeds. As a consequence, current USAF practice, when grooving runways is to not groove the first 1500 feet at each end of the runway where most aircraft landing touchdowns occur.

It should be noted that the aircraft tire industry has been working in close co-operation with aircraft operators on the chevron cutting problem. In the past 5 years, the aircraft tire industry has developed new tread rubber compounds and tire tread designs that significantly reduce the degree of chevron cutting aircraft tires experience on grooved runways.

Porous Friction Course Overlays

In 1959, the British developed a porous friction course overlay treatment for application to asphaltic concrete runways for improving pavement skid resistance(reference 12). Two of these surfaces were evaluated in reference 1 under artificially wet conditions by a C-141 aircraft and DBV and Mu-Meter ground vehicles. The skid resistance of this pavement treatment was found to be as good as close-spaced runway groove configurations. Since 1971, 21 civil and 3 military asphaltic concrete runways in the United States have been partially or completely overlaid with this treatment (see references 16 and 17). Unfortunately, no full scale aircraft braking tests or ground vehicle tests have been conducted as yet on these porous asphalt surfaces to determine their susceptability to rubber deposits. In fact, it is yet unknown whether the rubber removal treatments presently employed on runways can be used on porous overlays without damaging the pavement surface.

Aircraft Stopping and Directional Control Performance

It is most difficult to correlate aircraft stopping and directional control performance with runway slipperiness during routine operational landings made in adverse weather conditions. The reason is that both civil and military pilots make effective use of available auxilliary deceleration devices such as engine reverse thrust and parabrakes first, and then use the main deceleration device, wheel brakes, last to bring aircraft to a stop under this and dry runway conditions. It should be noted that of these aircraft deceleration devices, only the wheel brakes are affected by the state of runway slipperiness at time of landing. As a result of this delayed wheel braking technique, the ground speed at which brakes are applied is usually considerably below the touchdown speed, and reasonable braking forces are achieved to decelerate the aircraft on most wet runway surfaces. As a consequence, many slippery runways or slippery runway conditions go unnoticed and unreported until very infrequent non-routine aircraft landing situations arise such as from high crosswinds, high approach speed/extended touchdown point, inoperative or assymetrical engine reverse thrust, and failure of the parabrake to deploy which can occur individually or in combination. In such situations, the pilot may be forced to apply wheel brakes and/or nose wheel steering at high speeds. If the runway is slippery, the resulting lack of effective wheel braking/nose wheel steering is immediately noticed by the pilot and is usually emphatically reported to the airport tower when the landing is completed. Otherwise, a similar determination is normally found by an accident investigation board.

Aircraft are usually found most vunerable to slippery runway conditions at two points in the landing sequence. The first occurs at touchdown when the aircraft ceases 3-dimensional flying and becomes a 2-dimensional ground vehicle. Normally, wheel spinup at touchdown occurs within 0.1-0.3 second on dry runways for jet aircraft. Under slippery runway or flooded runway conditions, wheel spin up can be delayed as much as 2-10 seconds from touchdown, depending upon the ratio of the aircraft touchdown speed to tire hydroplaning speed, and the level of runway slipperiness. As an example, reference 2 reported that up to 2 seconds were required for L-1011 and B-737 jet transport main landing gear tires to achieve full spinup after touchdown on the artificially wet smooth concrete runway at Roswell N. M.. During this flight test program, water depths on the runway ranged from .01 to .03 inch and DBV SDR measurements ranged from 2.17 to 2.75 for this wetness condition. If the pilot applies brakes during the period when the wheels are not fully spun up, inefficient antiskid wheel control can result, along with locked-wheel skids as was also demonstrated in the flight test programs described in reference 2. During crosswind landings pilots use aerodynamic controls to steer the aircraft and at touchdown depend upon wheel cornering forces to control lateral drift. Under high speed-slippery runway touchdown conditions, these cornering forces can become small or neglible and the aircraft then behaves like a sailboat without a keel. Pilots in these circumstances have great difficulty controlling aircraft lateral drift after touchdown and during the subsequent roll out.

The second point in the landing sequence when jet aircraft become more vulnerable to slippery runway conditions occurs with or without cross winds at ground speeds between 100-80 knots and below depending upon aircraft configuration. At these ground speeds, aerodynamic controls become ineffective, engine reverse thrust is reduced, parabrakes and aerodynamic braking becomes ineffective, and the pilot must depend upon nose wheel steering and wheel braking to steer and stop the aircraft. Unfortunately for the pilot, both of these critical points in the landing sequence can sometimes occur on the most slippery parts of the runway where extensive rubber deposits are present. As previously mentioned, rubber deposits tend to reduce the pavement microtexture making the aircraft tires vulnerable to viscous hydroplaning, where low tire-ground friction coefficients persists down to very low ground speeds. In this situation, the pilot does not get the anticipated recovery of tire-ground friction during wheel braking that normally develops at lower speeds on wet runways, and an aircraft overrun or off the side type landing incident may occur.

CONCLUDING REMARKS

This paper has conducted an evaluation of a high pressure water blast with rotating spray bar treatment for removing paint and rubber deposits from airport runways by means of DBV traction tests and visual observations. Also included in the evaluation is a comparison of the test rubber removal treatment results with reported results obtained by use of other different rubber removal treatments.

Aircraft operating problems created by runway slipperiness have been reviewed along with an assessment of the contributions that pavement surface treatments, rubber deposits, surface weathering, and traffic polishing make in creating or alleviating runway slipperiness. The results of this evaluation and review yield the following observations.

1. The high pressure water blast with rotating spray bar technique performed well in removing paint and rubber deposits from the concrete runway surfaces at Langley AFB. The results obtained suggest that this treatment completely removed above surface rubber and paint deposits to the point that full restoration of pavement skid resistance in the trafficked runway areas was obtained. It should be noted that some faint below surface paint and rubber stains remained after the removal treatment, but were not considered detrimental when evaluated by base civil engineers.

2. Comparison with results obtained by other different rubbber removal techniques suggests that the high pressure water blast with rotating spray bar technique is superior or equal to other treatments in restoration of pavement skid resistance, is superior or equal in production rates achieved for removing paint and rubber, is nondamaging to the pavement surface, achieves a more uniform rubber removal (no streaking), and is ecologically unharmful to the surrounding runway environment.

3. Rubber removal treatments are employed to improve pavement skid resistance in rubber-contaminated runway touchdown areas. For this reason, the effectiveness of the rubber removal treatment should be judged on the basis of traction measurements made just before and after treatment in these runway areas, as well as on trafficked but non-rubber contaminated areas of the runway. Traction measurements made in untrafficked areas at the side of the runway to judge rubber removal may give an unrealistically low assessment or rubber removal

because of surface weathering effects on skid resistance that are not modified by traffic polishing. Visual determination of the degree of paint removal is quick and effective, but this method should not be used to determine the degree of rubber removal, when the goal is to improve pavement skid resistance for obvious reasons.

4. Unfortunately, the most slippery runway surfaces found for aircraft operation are many of the surfaces produced by conventional paving treatments, such as provided by longitudinal burlap drag and convas belt (portland cement concrete), and asphaltic concrete runways that are heavily rolled by standard or vibrating rollers. These conventional pavement surface treatments also rapidly accumulate rubber deposits at airports subjected to heavy traffic from jet aircraft having multi-wheeled landing gear. The result is wet runway conditions that can be more slippery for aircraft operation than many snow and ice-covered runway conditions. Extensive heavy rubber deposits on runways having conventional smooth pavement surface treatments thus pose a distinct threat to aircraft operational safety during adverse weather conditions. For such airport runway surface conditions, frequent rubber removal programs should be undertaken to prevent rubber deposits accretion from building up to dangerously high slipperiness levels.

5. In recent years, several new surface treatments have been developed for both portland cement and asphaltic concrete pavements that offer large improvements in wet pavement skid resistance. These treatments essentially provide the pavement surface much deeper texture such that both bulk water and water film drainage is improved and pavement skid resistance is increased over that provided by the conventional old style low texture surface treatments. The best of these new treatments appear to be pavement grooving which provides the best water drainage during heavy rainstorms, and the minimum skid resistance loss from rubber deposits and traffic polishing of the pavement surface treatments reviewed. Close-spaced (1-2 inch groove spacing) grooved patterns may not require rubber removal treatments for years if airport traffic is low, and may require only occasional rubber removal treatments if traffic is heavy. Thus, some of the costs of grooving may be recovered thru a reduction in runway maintenance costs after grooving. At the same time, a high level pavement skid resistance is maintained for aircraft operation under adverse weather conditions.

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TABLE I.- DBV STOPPING DISTANCE DATA (VISUAL INSTRUMENTATION) OBTAINED ON LAFB RUNWAY 7/25 BEFORE AND AFTER RUBBER REMOVAL, MAY 1975

TEST ZONE	HEADING, DEG.	BRAKING SPEED, MPH	STOPPING DISTANCE, FT.	CORRECTED STOPPING DISTANCE, FT(60MPH)	WET/DRY STOPPING DISTANCE RATIO(SDR)	ELAPSED TIME AFTER WETTING, MIN.	COMMENTS
#1	250	59.7	905	914	2.95	1	BEFORE RUBBER REMOVAL
		60.4	889	877	2.83	6	
		60.6	847	830	2.68	12	
		60.6	868	851	2.75	16	
#2	70	60.8	627	611	1.97	1	CLEAN-TRAFFICKED
		60.2	580	576	1.86	5	
		60.3	555	549	1.77	8	
		62.4	674	623	2.01	1	
		59.9	551	553	1.78	5	
		60.2	548	544	1.75	7	
#3	70	60.4	437	431	1.39	1	CLEAN- UN-TRAFFICKED
		60.1	401	400	1.29	4	
		60.6	406	398	1.29	8	
		59.4	392	400	1.29	10	
#4	70	61.3	1039	995	3.21	3	BEFORE RUBBER REMOVAL
		61.2	1006	983	3.17	9	
		61.2	1053	1012	3.26	1	
		60.5	950	934	3.01	6	
		61.0	973	941	3.04	11	
		60.8	1043	1016	3.28	1	
		61.0	1008	975	3.15	5	
		59.6	897	906	2.92	9	
		62.0	1064	996	3.21	1	
		59.3	976	999	3.22	5	
		59.7	944	954	3.08	9	
#1	250	60.2	610	606	1.95	1	AFTER RUBBER REMOMAL
		59.6	570	578	1.86	5	
		60.5	576	567	1.83	8	
		60.0	558	558	1.80	10	
		59.8	541	545	1.76	13	
		60.8	540	526	1.70	15	
#4	70	61.8	620	584	1.88	1	AFTER RUBBER REMOVAL
		60.0	580	580	1.87	4	
		61.0	573	554	1.79	6	
		60.0	557	557	1.80	8	
#1	250	60.0	298	298	1.0	-	DRY
#2	70	60.3	324	321	(310ft)	-	

ORIGINAL PAGE IS OF POOR QUALITY

TABLE II.- DBV SDR DATA OBTAINED ON LAFB RUNWAY 7/25 JULY 24, 1973. (RUNWAY WETTED BY LAFB WATER TRUCK)

RUNWAY TEST ZONE	RUNWAY WATER DEPTH, IN.	DBV WET/DRY STOPPING DISTANCE RATIO (SDR)	
		70 DEG. HEADING	250 DEG. HEADING
APPROACH END OF RUNWAY 07, RUBBER DEPOSITS	DAMP W/PUDDLES 0.03	2.58 2.77	2.53 2.75
APPROACH END OF RUNWAY 25, RUBBER DEPOSITS	DAMP W/PUDDLES 0.03	2.07 2.68	3.27 3.82
MIDDLE OF RUNWAY NO RUBBER DEPOSITS	DAMP W/PUDDLES 0.03	1.77 2.16	1.77 2.16

TABLE III. - DBV WET/DRY STOPPING DISTANCE RATIOS (SDR) OBTAINED BEFORE AND AFTER RUBBER REMOVAL USING HIGH PRESSURE WATER BLAST (OSCILLATING NOZZLE BAR). CANADIAN MINISTRY OF TRANSPORT STUDY (REFERENCE 4)

RUNWAY	NUMBER OF PASSES	AVERAGE DBV SDR* (60 MPH)		
		TRAFFICKED BEFORE RUBBER REMOVAL	TRAFFICKED AFTER RUBBER REMOVAL	UNTRAFFICKED NO RUBBER
14/32 LOCATION A**	0	2.47	-	1.15
	1	-	1.80	-
	2	-	1.71	-
05R/23L LOCATION B***	0	1.93	-	1.09
	1	-	1.42	-
	2	-	1.41	-

* DBV TEST SPEEDS RANGED FROM 20-35 MPH

** ARTIFICIAL WATER TRUCK WETTING

*** NATURAL RAIN (0.12 IN./HOUR)

TABLE IV. - DBV WET/DRY STOPPING DISTANCE RATIOS (SDR) OBTAINED BEFORE AND AFTER RUBBER REMOVAL USING MECHANICAL GRINDER OPERATED TRANSVERSE TO RUNWAY DIRECTION. CANADIAN MINISTRY OF TRANSPORT STUDY (REFERENCE 4)

RUNWAY	NUMBER OF MACHINE PASSES	AVERAGE DBV SDR* (60 MPH)		
		TRAFFICKED BEFORE RUBBER REMOVAL	TRAFFICKED AFTER RUBBER REMOVAL	UNTRAFFICKED NO RUBBER
14/32 LOCATION 1 (A)	0	2.66	-	1.23
	1	-	2.12	-
	2	-	2.35	-
	3	-	1.93	-
14/32 LOCATION 2 (A)	0	2.52	-	1.13
	1	-	1.90	-
	2	-	1.82	-
14/32 LOCATION 2 (B)	0	2.74	-	1.32
	1	-	1.52	-
14/32 LOCATION 3 (C)	0	2.45	-	1.05
	1	-	1.55	-
14/32** LOCATION 3 (C)	0	2.52	-	1.06
	1	-	1.42	-

* DBV TEST SPEEDS RANGED FROM 20-36 MPH

** NATURAL RAIN (0.12 IN./HOUR); OTHER TESTS ARTIFICIALLY WET

a) MECHANICAL GRINDER IN PLANING CONFIGURATION

TABLE V.- DBV WET/DRY STOPPING DISTANCE RATIOS (SDR) OBTAINED ON CHARLESTON AFB RUNWAY 15/33 BEFORE AND AFTER RUBBER REMOVAL USING A HIGH PRESSURE WATER BLAST WITH A STATIONARY SPRAY BAR TREATMENT (DATA FROM REFERENCE 5)

DBV TEST ZONE	PAVEMENT SURFACE CONDITION	RUBBER REMOVAL PASSES	AVERAGE DBV SDR*
A	MEDIUM RUBBER DEPOSITS COVERING 17 YEAR OLD AC AND 9-7 YEAR OLD PCC IN LEFT WHEEL TRACKS OF APPROACH END RUNWAY 15	0 1 3	3.94 4.37 2.98
EA	UNTRAFFICKED 17 YEAR OLD AC (NO RUBBER) AT RUNWAY SIDE, APPROACH END RUNWAY 15	0	2.29
B	MEDIUM RUBBER DEPOSITS COVERING 17 YEAR OLD AC AND 9-7 YEAR OLD PCC IN RIGHT WHEEL TRACKS OF APPROACH END RUNWAY 15	0 2 3	4.93 4.07 3.42
C&D	TRAFFICKED (WHEEL PATH) 9-7 YEAR OLD PORTLAND CEMENT CONCRETE (NO RUBBER)	0	2.71-2.39
E	LIGHT RUBBER DEPOSITS COVERING 9-7 YEAR OLD PCC AND 7 YEAR OLD AC IN RIGHT WHEEL TRACKS OF APPROACH END RUNWAY 33	0 2 3	3.36 2.25 2.80
F	LIGHT RUBBER DEPOSITS COVERING 9-7 YEAR OLD PCC AND 7 YEAR OLD AC IN LEFT WHEEL TRACKS OF APPROACH END RUNWAY 33	0 1	3.70 3.10
G	UNTRAFFICKED 9-7 YEAR OLD PCC (NO RUBBER) AT RUNWAY SIDE (ABREAST TEST ZONE C)	0 1	2.20 1.73

PCC: PORTLAND CEMENT CONCRETE
AC: ASPHALTIC CONCRETE

*3 MINUTES AFTER WETTING

TABLE VI .- MIAMI INTERNATIONAL AIRPORT DBV WET/DRY STOPPING DISTANCE RATIOS (SDR) OBTAINED ON TRANSITION AND TRAINING AIRPORT RUNWAY 9/27 BEFORE AND AFTER RUBBER REMOVAL USING HIGH PRESSURE WATER BLAST (STATIONARY NOZZLE BAR). OCT. 4-9, 1973 (DATA OBTAINED FROM REFERENCE 7)

RUNWAY TEST ZONE	PAVEMENT** SURFACE CONDITION	DBV SDR*	
		BEFORE RUBBER REMOVAL	AFTER RUBBER REMOVAL
A RUNWAY 9 TOUCHDOWN AREA	TRAFFICKED RUBBER DEPOSITS	2.97	2.03
E RUNWAY 27 TOUCHDOWN AREA	TRAFFICKED HEAVY RUBBER DEPOSITS	2.54	2.34
C MIDDLE OF RUNWAY	TRAFFICKED NO RUBBER	1.92	——
	UNTRAFFICKED NO RUBBER	1.72	——

* BASED ON DRY STOPPING DISTANCE 305 FT. (60MPH)

** ASPHALTIC CONCRETE WITH LIMEROCK AGGREGATE

TABLE VII. - DBV WET/DRY STOPPING DISTANCE RATIOS (SDR) AND NASA GREASE TEST AVERAGE PAVEMENT SURFACE TEXTURE DEPTHS (ATD) OBTAINED ON RUNWAYS EVALUATED BY THE AIRFORCE CIVIL ENGINEERING CENTER JULY 1973 - DEC. 1974 (REF. 8)

AIRFIELD	RUN-WAY	SURFACE	DBV SDR* AND NASA GREASE TEST ATD. IN.					
			TOUCHDOWN AREA RUBBER DEPOSITS		TRAFFICKED NO RUBBER		UNTRAFFICKED NO RUBBER	
			SDR	ATD	SDR	ATD	SDR	ATD
TRAVIS	21L	PCC	5.79	.0148	2.28	.0381	-	-
FAIRCHILD	23	PCC	4.75	.0043	1.97	.0170	1.97	.0109
CASTLE	30	AC	4.60	.0057	2.00	-	1.59	.0327
LORING	01	AC	4.58	.0059	1.99	.0143	-	-
TRAVIS	21R	AC	4.01	.0143	2.71	.0163	2.18	.0218
McGUIRE	24	AC	3.92	.0062	1.93	.0121	1.33	-
TORREJON	23	AC	3.85	.0064	1.85	.0458	1.50	.0254
MATHER	22L	PCC/AC	3.75	.0082	1.86	.0163	-	-
BLYTHEVILLE	17	PCC	3.73	-	2.45	-	1.57	-
DOVER	01	PCC/AC	3.62	-	1.74	-	1.47	-
SCOTT	31	AC	3.61	-	1.83	-	1.47	-
ROBBINS	32	PCC	3.59	.0114	2.01	.0194	-	-
CANNON	21	PCC/GPCC	3.59	-	1.74	-	1.43	-
RICKENBACKER	23L	PCC	3.40	.0109	2.04	.0191	1.86	.0199
HOMESTEAD	05	PCC	3.37	.0088	1.92	.0278	2.17	.0163
GRISSOM	22	AC	3.23	.0041	1.66	.0199	1.60	.0208
CHARLESTON	15	AC/PCC	3.21	.0085	2.55	-	2.21	.0130
ZARAGOSA	31R	AC	2.93	.0102	1.31	.0229	1.32	.0218
MATHER	22R	AC	2.90	.0082	2.18	.0163	1.67	-
ANDREWS	01L	PCC	2.89	.0160	2.14	.0220	2.28	.0370
CHARLESTON	21	AC	2.79	.0131	1.88	.0229	-	-
SHAW	4L	PCC/GPCC/AC	2.77	.0135	1.79	.0286	1.52	.0191

PCC: PORTLAND CEMENT CONCRETE

AC: ASPHALTIC CONCRETE

G: GROOVED

WC: WIRE-COMBED

* 3 MINUTES AFTER WETTING

TABLE VII. - CONTINUED

AIRFIELD	RUN-WAY	SURFACE	DBV SDR* AND NASA GREASE TEST ATD. IN.					
			TOUCHDOWN AREA RUBBER DEPOSITS		TRAFFICKED NO RUBBER		UNTRAFFICKED NO RUBBER	
			SDR	ATD	SDR	ATD	SDR	ATD
McCONNEL	18R	AC	2.77	-	2.03	-	-	-
HECTOR	35	PCC	2.72	-	1.95	.0241	1.89	-
DOVER	31	AC	2.66	-	1.89	-	1.28	-
COLUMBUS	13L	PCC/AC	2.62	.0191	1.80	.0191	1.71	.0218
GLASGOW	28	PCC	2.61	.0143	2.11	.0097	2.37	.0068
ANDREWS	01R	PCC/AC	2.60	.0130	1.73	.025	1.82	.027
ENGLAND	14	PCC	2.54	-	2.66	.0199	-	-
AVIANO	05	AC	2.51	.035	1.73	.046	1.84	.038
R. GEBAUR	36	PCC/AC	2.50	-	2.22	-	2.29	-
VANCE	17R	PCC/AC/GPCC	2.50	-	1.50	-	1.53	-
SOESTERBERG	28	AC	2.42	-	2.29	-	1.57	-
COLUMBUS	13R	PCC	2.40	-	2.28	-	-	-
ENGLAND	18	PCC/AC	2.39	.0254	2.57	.0251	2.40	-
MOODY	18R	PCC/AC	2.38	.0191	1.48	.0458	1.32	.0458
ZWEIBRUCKEN	03	AC	2.34	.0208	1.35	.0352	1.16	.0286
BENTWATERS	25	PCC/AC	2.33	.0191	1.44	.0458	1.57	.0241
MOODY	18L	PCC/AL	2.32	.0121	1.66	.0208	1.45	.0241
CRAIG	32L	PCC/AL	2.27	.0170	1.70	.0131	1.42	.0530
RICKENBACKER	23R	AC	2.26	-	1.94	-	-	-
VANCE	17C	PCC/AC	2.25	.0057	1.45	.0352	1.52	-
COLUMBUS	13C	PCC/AC	2.22	-	1.90	-	2.13	-
WOODBRIDGE	27	AC	2.22	-	1.53	-	2.01	-

PCC: PORTLAND CEMENT CONCRETE   G: GROOBED   * 3 MINUTES AFTER WETTING

AC: ASPHALTIC CONCRETE   WC: WIRE-COMBED

TABLE VII. - CONCLUDED

AIRFIELD	RUN-WAY	SURFACE	DBV SDR* AND NASA GREASE TEST ATD. IN.					
			TOUCHDOWN AREA RUBBER DEPOSITS		TRAFFICKED NO RUBBER		UNTRAFFICKED NO RUBBER	
			SDR	ATD	SDR	ATD	SDR	ATD
NIAGARA FALLS	28	AC	2.12	.0065	1.80	.0191	1.28	.0241
VANCE	17L	PCC	2.10	-	2.09	.0191	-	-
McCONNEL	18L	AC	2.03	-	1.73	-	1.89	-
McGUIRE	36	PCC/AC	2.00	.0062	1.66	.0121	1.36	-
MYRTLE BEACH	17	PCC/AC	2.00	.0158	1.57	.0208	1.52	.0254
CANNON	30	PCC/AC	2.00	-	1.65	-	1.81	-
SHAW	04R	PCC/WC/PCC	1.99	.0124	1.13	.0613	1.38	-
ERDING	26	PCC	1.93	.0086	2.04	.0191	1.73	.0176
HURLBURT	35	PCC/AC	1.89	.0199	1.92	.0269	1.34	.0327
McCHORD	34	AC	1.87	.0305	2.23	.0327	2.13	.0305

PCC: PORTLAND CEMENT CONCRETE

AC: ASPHALTIC CONCRETE

G: GROOVED

WC: WIRE-COMBED

* 3 MINUTES AFTER WETTING

TABLE VIII - DBV WET/DRY STOPPING DISTANCE RATIOS (SDR) OBTAINED ON RUNWAYS EVALUATED JANUARY-JUNE 1975 BY THE AIRFORCE CIVIL ENGINEERING CENTER (REFERENCE 9)

AIRFIELD	RUNWAY	AVERAGE DBV SDR (3 MINUTES AFTER WETTING)							
		RUBBER-COATED TOUCHDOWN AREAS				TRAFFICKED-NO RUBBER (WHEEL PATHS)		UNTRAFFICKED-NO RUBBER (RUNWAY EDGE)	
		PRIMARY		SECONDARY					
		SDR	SURFACE	SDR	SURFACE	SDR	SURFACE	SDR	SURFACE
PALMDALE	07/25	6.12	PCC	2.55	PCC	2.31	PCC	-	PCC/AC
MARCH	13/31	5.19	PCC	2.46	PCC	2.21	PCC	-	AC
BARKSDALE	14/32	4.73	AC	3.70	AC	1.84	AC	1.40	AC
NORTON	05/23	4.58	PCC	2.75	PCC	2.19	PCC	2.40	PCC
WEBB***	17L/35R	2.95	PCC/AC	1.51	PCC/AC	4.51	AC	-	AC
DYESS	16/34	3.52	PCC	4.46	PCC	2.61	PCC	-	AC
CARSWELL	17/35	3.78	AC/PCC	4.11	PCC	2.36	AC/PCC	1.32	AC
ELMENDORF	05/23	3.53	AC	1.92	AC	2.95	AC	1.52	AC
REESE	17R/35L	3.03	PCC	1.85	PCC/AC	1.80	PCC/AC	1.72	AC
DAVIS MONTHAN	12/30	2.98	AC	2.50	PCC	1.54	AC	1.39	AC
PALMDALE	04/22	2.88	AC	2.43	AC	1.82	AC	2.05	AC
WEBB***	17R/35L	2.82	PCC/AC	2.65	PCC/AC	2.69	AC	-	AC
LAUGHLIN	13C/31C	2.70	PCC/AC	1.88	PCC/AC	1.69	AC	1.75	AC
RANDOLPH	14L/32R	2.65	PCC	2.16	PCC	2.05	PCC	2.27	PCC
YOKOTA	18/36	2.61	PCC	1.95	PCC	1.91	PCC	1.94	PCC
REESE	17C/35C	2.37	AC	2.59	AC	2.15	AC	2.06	AC
WILLIAMS	12L/30R	2.52	PCC/AC	1.57	AC	1.68	AC	1.65	AC
WILLIAMS**	12C/30C	2.39	PCC	-		-		-	
WILLIAMS	12R/30L	2.36	PCC	2.16	PCC	2.22	PCC	2.03	PCC
LAUGHLIN	13L/31L	2.15	PCC/AC	2.31	PCC/AC	1.35	AC	-	AC
ELMENDORF	15/33	2.21	AC	1.86	AC	2.05	AC/PCC	-	AC
LAUGHLIN	13R/31L	1.87	AC	2.20	AC	1.56	AC	-	AC

PCC: PORTLAND CEMENT CONCRETE

AC: ASPHALTIC CONCRETE

*NEW RUNWAY SURFACE

**RUNWAY UNDER CONSTRUCTION

*** ASPHALT EMULSION DILUTED WITH WATER APPLIED TO ASPHALTIC CONCRETE

TABLE VIII - CONCLUDED

AIRFIELD	RUNWAY	AVERAGE DBV SDR (3 MINUTES AFTER WETTING)							
		RUBBER-COATED TOUCHDOWN AREAS				TRAFFICKED NO RUBBER (WHEEL PATHS)		UNTRAFFICKED-NO RUBBER (RUNWAY EDGE)	
		PRIMARY		SECONDARY					
		SDR	SURFACE	SDR	SURFACE	SDR	SURFACE	SDR	SURFACE
RANDOLPH	14R/32L	2.13	PCC/AC	1.90	PCC	1.48	PCC/AC	1.39	PCC/AC
VANDENBERG*	12/30	1.59	AC	1.54	AC	1.60	AC	1.32	AC
REESE	17L/35R	-	PCC/AC	-	PCC/AC	1.39	AC	-	AC

PCC: PORTLAND CEMENT CONCRETE

AC: ASPHALTIC CONCRETE

* NEW RUNWAY SURFACE

** RUNWAY UNDER CONSTRUCTION

*** ASPHALT EMULSION DILUTED WITH WATER APPLIED TO ASPHALTIC CONCRETE

TABLE IX. - DBV WET/DRY STOPPING DISTANCE RATIOS OBTAINED ON 10 CIVIL AIRPORTS EVALUATED BY THE FEDERAL AVIATION ADMINISTRATION NOV. 1971 - APRIL 1972 (REFERENCE 10)

AIRPORT	RUNWAY	AVERAGE DBV SDR					
		TOUCHDOWN AREA RUBBER DEPOSITS				TRAFFICKED NO RUBBER (WHEEL PATH)	
		SDR	SURFACE	SDR	SURFACE	SDR	SURFACE
ST. LOUIS INTERNATIONAL	12R/30L	4.79	12R-AC	3.51	30L-AC	2.90	AC
	6.24	2.48	24-PCC	2.13	6-PCC	1.85	PCC
	12L/30R	1.93	30R-PCC	1.35	12L-WCPCC	1.81	PCC
	17/35	1.77	17-PCC	1.63	35-PCC	1.79	PCC
MIAMI INTERNATIONAL	9R/27L	4.44	9R-AC	2.88	27L-AC	1.81	AC
	9L/27R	2.88	9L-AC	1.98	27R-AC	1.72	AC
	12/30	2.01	12-AC	1.75	30-AC	1.56	AC
	17/35	1.35	17-AC	1.32	35-AC	1.33	AC
MEMPHIS INTERNATIONAL	17L/35R	3.82	17L-PCC	3.51	35R-PCC	2.44	PCC
	9/27	1.83	27-AC	1.58	9-AC	1.32	AC
	17R/35L*	-	-	-	-	1.47	PCC
	3/21	1.18	3-AC	1.16	21-AC	1.17	AC
NEW ORLEANS INTERNATIONAL	10/28	3.76	10-PCC	2.22	28-AC	2.26	PCC
	1/19	3.22	19-PCC	3.03	1-AC	2.17	PCC
	5/23	1.22	23-AC	-	5-AC	1.32	AC
ATLANTA W. B. HARTSFIELD	9L/27R	2.88	9L-WCPCC	2.26	27R-WCPCC	1.38	WCPCC
	15/33	2.21	33-AC	1.72	15-AC	1.50	AC
	9R/27L	2.09	27L-GPCC	1.24	9R-GPCC	1.12	GPCC
	3/21	1.69	21-AC	1.52	3-AC	1.36	AC

PCC: PORTLAND CEMENT CONCRETE

AC: ASPHALTIC CONCRETE

* NEW SURFACE; UNDER CONSTRUCTION

G: GROOVED

WC: WIRE COMBED

TABLE IX. - CONCLUDED

AIRPORT	RUNWAY	AVERAGE DBV SDR					
		TOUCHDOWN AREA RUBBER DEPOSITS				TRAFFICKED NO RUBBER (WHEEL PATH)	
		SDR	SURFACE	SDR	SURFACE	SDR	SURFACE
JACKSONVILLE INTERNATIONAL	7/25	2.77	7-PCC	2.53	25-PCC	2.12	PCC
	13/31	2.65	31-PCC	2.33	13-PCC	1.97	PCC
GREATER CINCINNATI	18/36	2.45	36-AC	1.93	18-AC	1.73	AC
	9R/27L	2.38	27L-AC	2.09	9R-AC	1.77	AC
	9L/27R	1.30	9L-PCC	1.15	27R-PCC	1.25	PCC
CHARLOTTE DOUGLAS	18/36	2.32	36-AC	1.39	18-AC	1.46	AC
	5/23	1.81	5-AC	1.38	23-AC	1.22	AC
NASHVILLE INTERNATIONAL	13/31	2.12	31-AC	1.71	13-AC	1.69	AC
	2L/20R	2.08	20R-GAC	1.82	2L-GAC	2.04	GAC
	2R/20L	1.30	20L-AC	-	2R-AC	1.24	AC
CHARLESTON KANAWHA	5/23	1.33	23-GPCC	1.10	5-GPCC	1.09	GPCC
	14/32	1.20	32-AC	1.09	14-AC	1.16	AC

TABLE X. - DBV AND AIRCRAFT WET/DRY STOPPING DISTANCE RATIOS (SDR) OBTAINED ON TRANSVERSE GROOVED RUNWAY SURFACES WITH AND WITHOUT RUBBER CONTAMINATION.

AIRPORT	DATE TESTED	RUNWAY	RUBBER DEPOSITS	SDR		SURFACE; DATE INSTALLED	GROOVE PATTERN; DATE INSTALLED	SOURCE
				DBV	AIRCRAFT			
CANNON AFB	11/73	3/21	HEAVY NONE	3.59-2.46*** 1.74	-	1000 FT PCC; 8000 FT GPCC, 1000 FT PCC; DATE UNKNOWN	2 x 1/4 x 1/4; GROOVE 2 FT-SKIP 2 FT; 1973	REF. 8
SHAW AFB	7/74	4L/27R	MED-LT NONE	2.77-1.97 1.79	- -	1000 FT PCC, 3500 FT GPCC, 4500' GAC; 1000 FT PCC; DATE UNKNOWN	2 x 1/4 x 1/4 GROOVE 2FT SKIP 2 FT; 1971	REF. 8
VANCE AFB	12/73	17R/35L	LT-MED NONE	2.50*** 1.50***	-	1500 FT PCC, 2800 FT GPCC, 3400 FT AC; DATE UNKNOWN	2 x 1/4 x 1/4; 1973	REF. 8
HOUSTON INTERNATIONAL	6/70* 10/71	8L/26R	HVY-MED LT-NONE	3.46-2.94 2.08-2.52	- 1.91-2.52 (2)	PCC; DATE UNKNOWN	UNGROOVED	LWP-943 LWP-1016
	2/25/71		NONE HEAVY	1.13-1.44 2.27-2.43	1.10-1.53 (3) -		2 x 1/4 x 1/4; 2/24/71	LWP-1051
MIAMI INTERNATIONAL	3/73	9R/27L 9L/27R	HEAVY NONE HVY-MED	4.62-3.51 2.43 3.16-2.38	- - -	AC OVERLAY; 11/72	UNGROOVED	LWP-1107
	5/73	9R/27L 9R/27L 9L/27R	HVY-LT NONE NONE	2.42-1.51 1.51 1.22	- - -		1 1/2 x 1/4 x 1/4; 1973**	LWP-1114
JOHN F. KENNEDY	7/69 7/69 10/71	4R/22L	NONE HEAVY LT-NONE	1.75 2.20 1.47-1.80	1.57 (1) 1.86 1.50-1.67 (2)	PCC; 1959	1 3/8 x 3/8 - $\frac{3}{16}$ x 1/8; 1967	REF. 1 LWP- 1016
ATLANTA INTERNATIONAL	11/71	9R/27L	HVY-MED NONE	2.09-1.24 1.12	-	PCC; DATE UNKNOWN	1 1/4 x $\frac{3/8}{1/8}$ x 1/4; 1969	REF. 10
NASHVILLE INTERNATIONAL	4/72	2L/20R	LT NONE	2.08-1.82 2.04	- -	AC; DATE UNKNOWN	1 1/4 x 1/4 x 1/4; 1970	REF.10

(1) C-141	LT:	LIGHT
(2) B-727	MED:	MEDIUM
(3) DC-9	HVY:	HEAVY

*RUBBER REMOVED AFTER TEST

**9L/27R BEING GROOVED AT TIME OF TEST

***DBV TEST AREA CONTAINED BOTH GROOVED AND UNGROOVED PAVEMENTS

ORIGINAL PAGE IS
OF POOR QUALITY

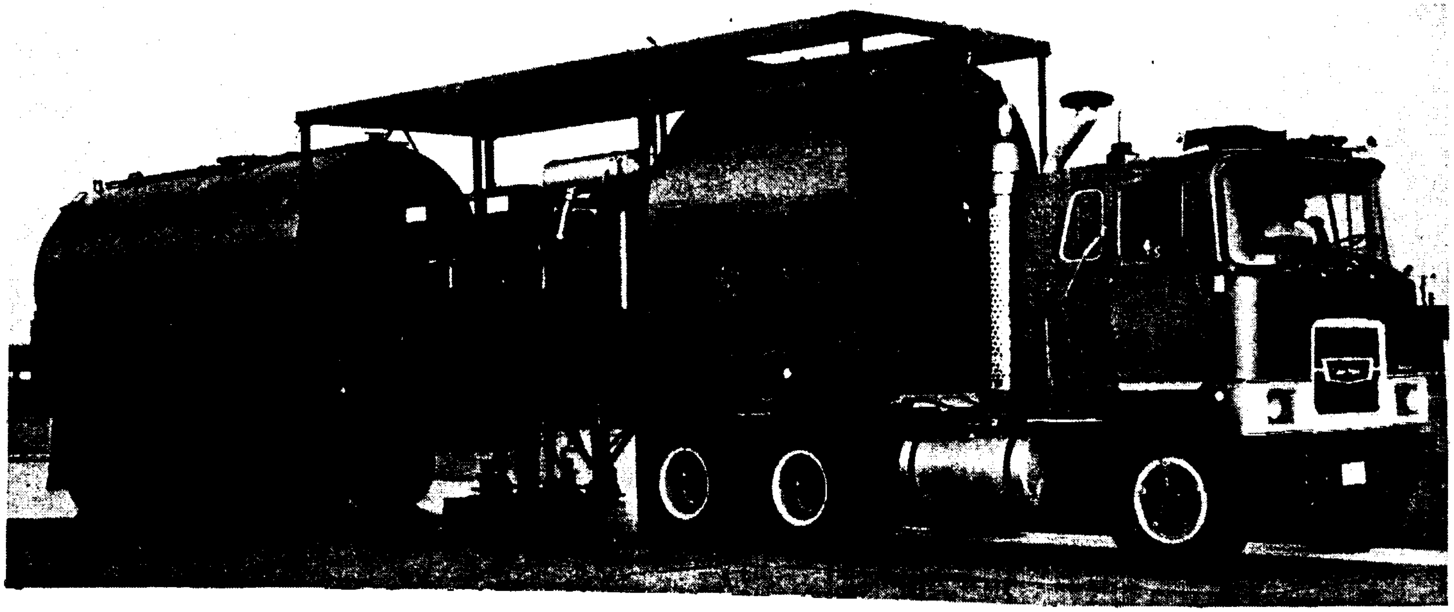
TABLE X.- CONCLUDED

AIRPORT	DATE TESTED	RUNWAY	RUBBER DEPOSITS	SDR		SURFACE; DATE INSTALLED	GROOVE PATTERN; DATE INSTALLED	SOURCE
				DBV	AIRCRAFT			
HARRY S. TRUMAN	6/1970	9/27	HEAVY NONE	2.28 1.40	- -	AC; DATE UNKNOWN	UNGROOVED	LWP-957
			HEAVY NONE	1.69 1.18			1 1/2 x 1/4 x 1/4; 4/70	
SEYMOUR-JOHNSON AFB	7/69	8/26	NONE HVY-LT	1.35 1.50	1.38 (1) 1.47	PCC; 1960	2 1/4 x 1/4 x 1/4 (GROOVE 2 FT-SKIP 2 FT; 1968	REF. 1

(1) C-141
(2) B-727
(3) DC-9

LT: LIGHT
MED: MEDIUM
HVY: HEAVY

*RUBBER REMOVED AFTER TEST
**9L/27R BEING GROOVED AT TIME OF TEST
***DBV TEST AREA CONTAINED BOTH GROOVED AND UNGROOVED PAVEMENTS



a) Overall View of Equipment

b) Close-up View of High Pressure Water Rotating Spray Bar

FIGURE I. - HIGH PRESSURE WATER PAINT AND RUBBER REMOVAL EQUIPMENT REMOVING PAINT STRIPE ON LAFB RUNWAY 25.

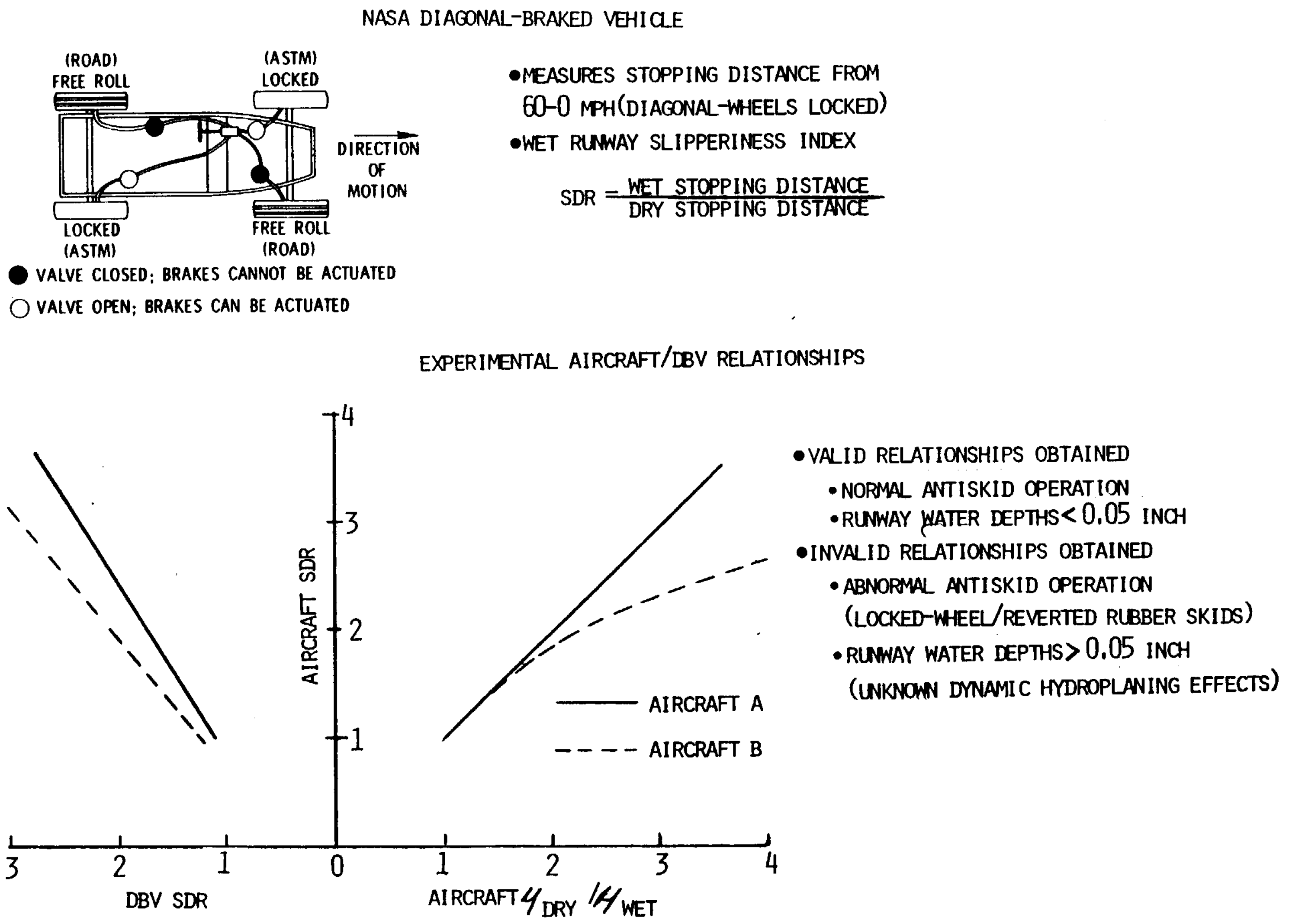
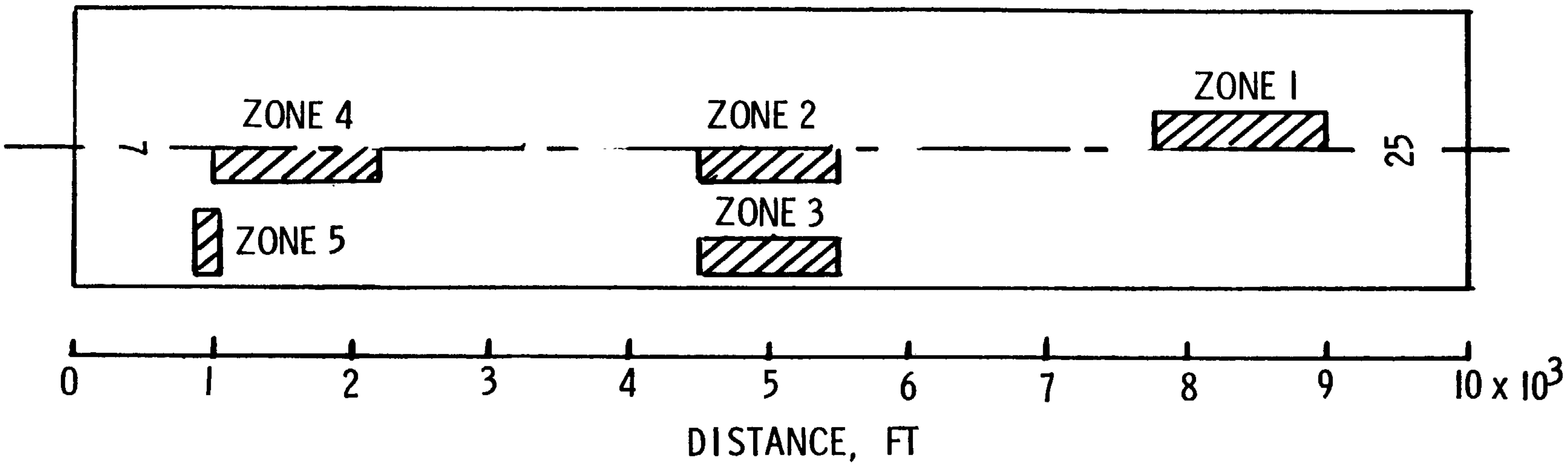
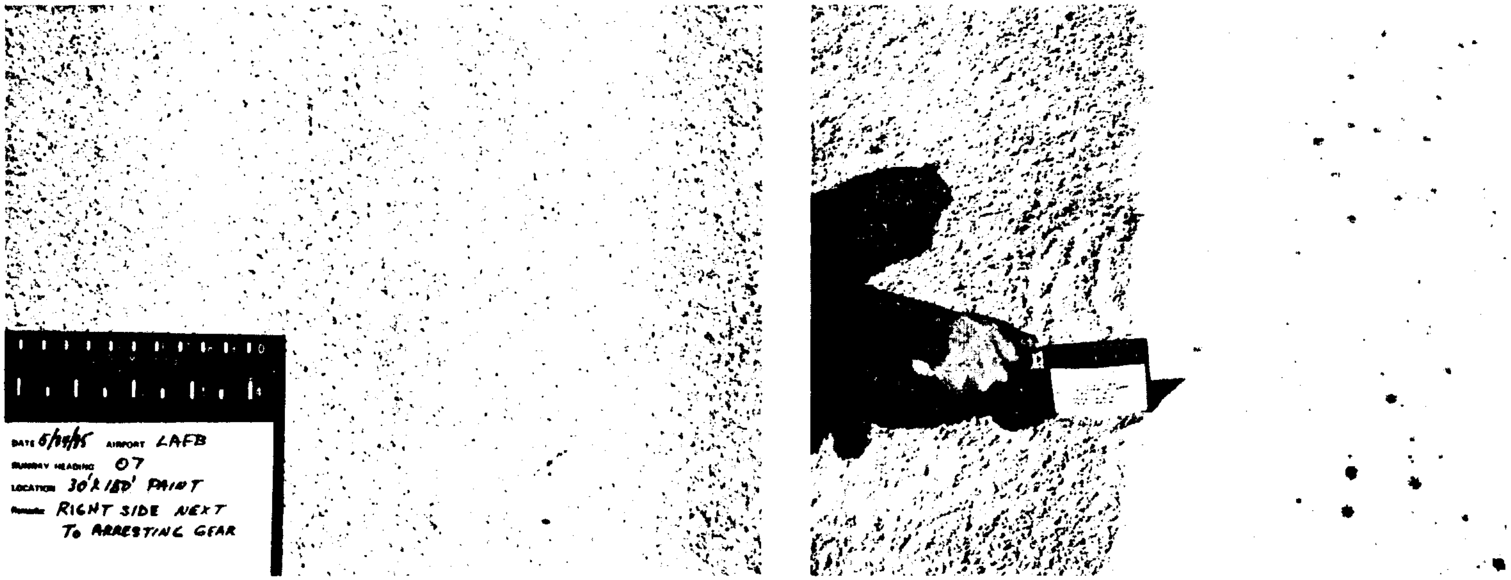


FIGURE 2. - AIRCRAFT/GROUND VEHICLE RATING OF RUNWAY SLIPPERINESS



TEST ZONE	DESCRIPTION
1	HEAVY RUBBER DEPOSITS APPROACH END RUNWAY 25
2	TRAFFICKED CLEAN CONCRETE (NO RUBBER DEPOSITS)
3	UNTRAFFICKED CLEAN CONCRETE
4	HEAVY RUBBER DEPOSITS APPROACHED END RUNWAY 7
5	30 x 150 FOOT PAINT STRIPE (AT ARRESTING GEAR)

FIGURE 3. - LOCATION OF DBV TEST ZONES ON LAFB RUNWAY 7/25



a) TYPICAL RUNWAY PAINT STRIPE SURFACE BEFORE PAINT REMOVAL. A. T. D. = 0.01 IN.

b) LOOSE PAINT PARTICLES ON RUNWAY SURFACE AFTER PASS BY HIGH PRESSURE WATER BLAST

FIGURE 4. - PHOTOGRAPHS OF PAINT STRIPE SURFACE ON LAFB RUNWAY 7/25 BEFORE AND AFTER PASS BY HIGH PRESSURE WATER BLAST USING A ROTATING SPRAY BAR

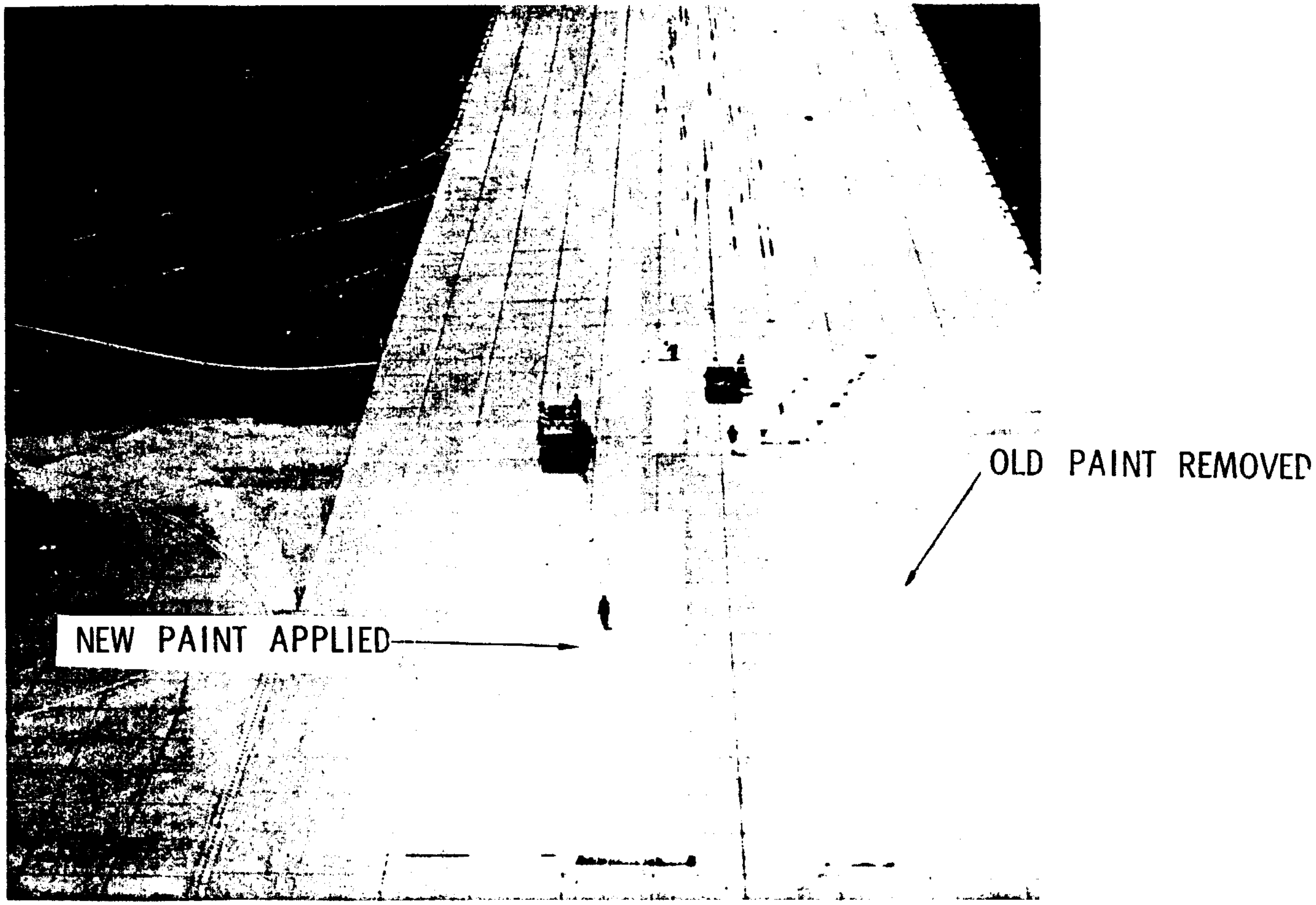
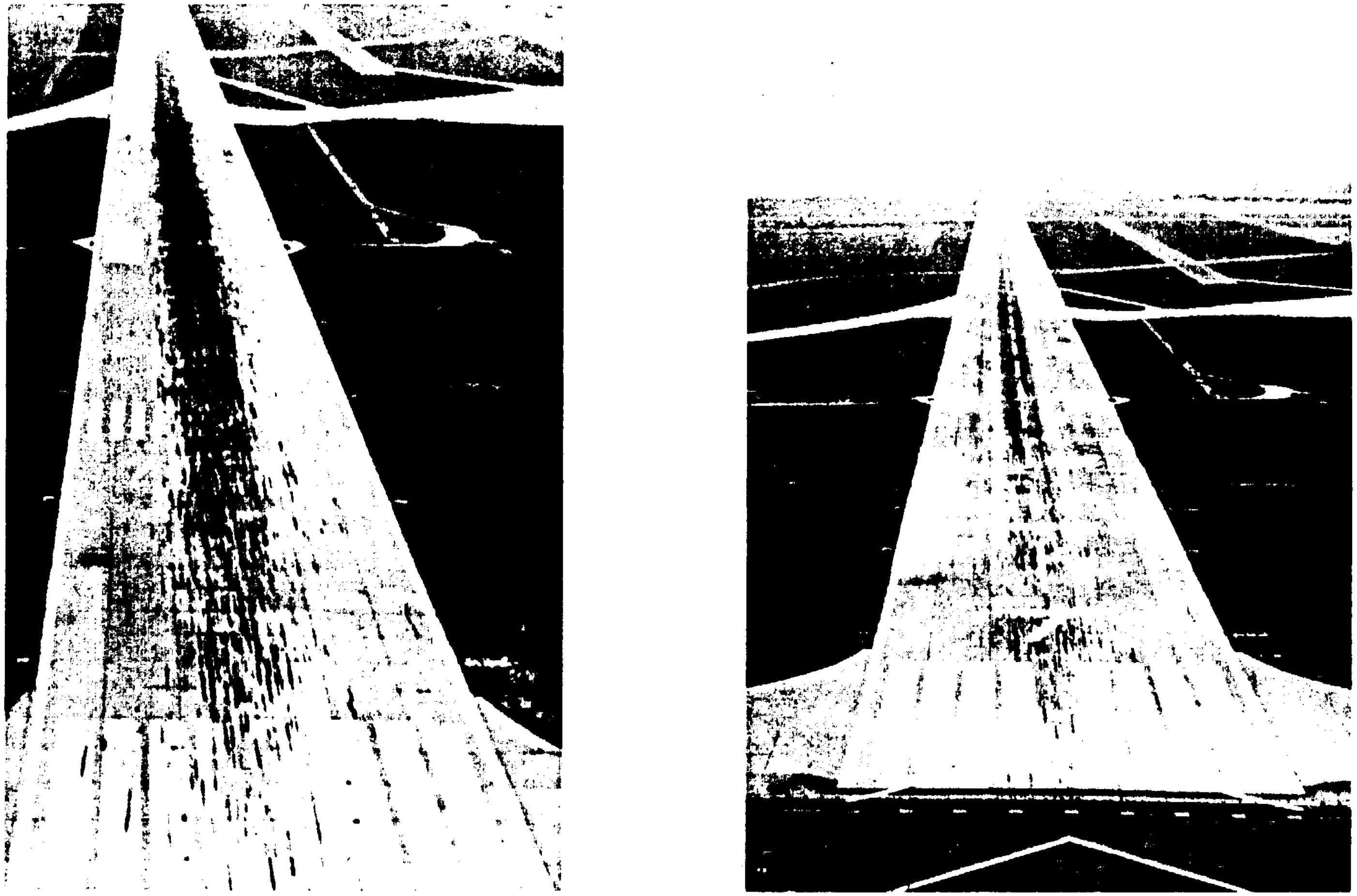


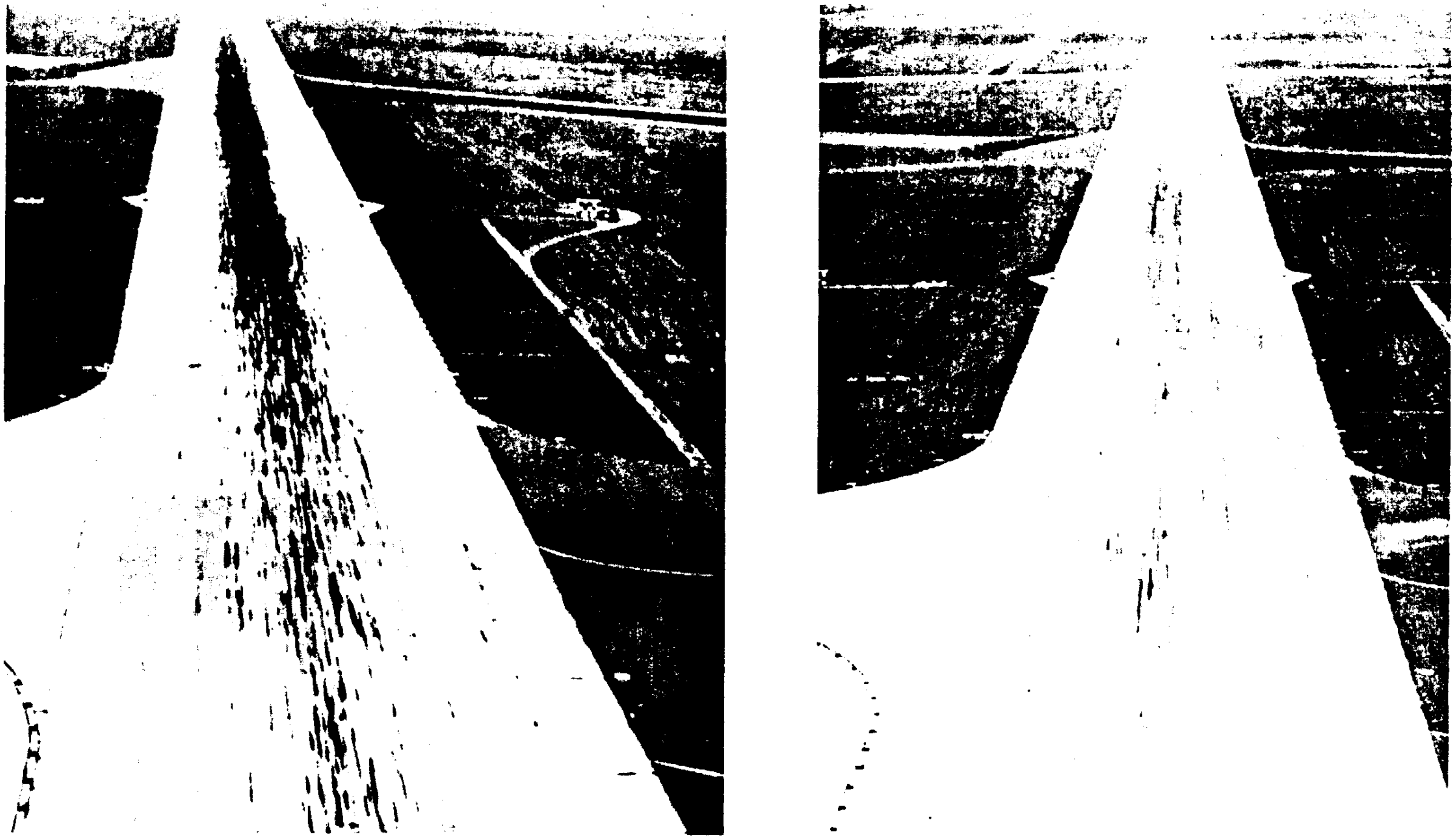
FIGURE 5. - PHOTOGRAPH OF APPROACH END LAFB RUNWAY 17 DURING RE-PAINTING OF RUNWAY MARKINGS AFTER PAINT REMOVAL PROGRAM, MAY 30, 1975. OLD PAINT REMOVED BY HIGH PRESSURE WATER BLAST USING ROTATING SPRAY BAR



a) BEFORE RUBBER REMOVAL; MAY 15, 1975

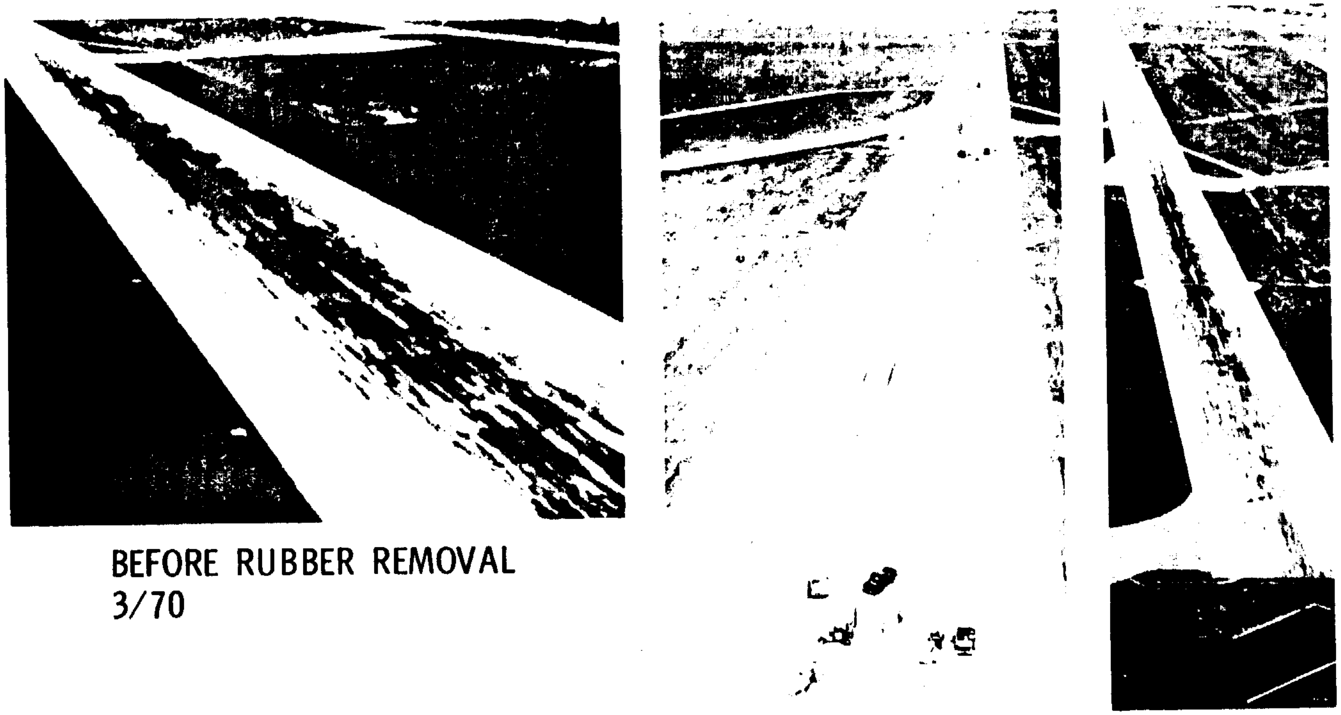
b) AFTER RUBBER REMOVAL; MAY 30, 1975

FIGURE 6. - PHOTOGRAPHS OF APPROACH END LAFB RUNWAY 7 BEFORE AND AFTER PAINT AND RUBBER REMOVAL PROGRAM MAY, 1975. PAINT AND RUBBER DEPOSITS REMOVED BY HIGH PRESSURE WATER BLAST USING A ROTATING SPRAY BAR



a) BEFORE RUBBER REMOVAL; MAY 15, 1975 b) AFTER RUBBER REMOVAL; MAY 30, 1975

FIGURE 7. - PHOTOGRAPHS OF APPROACH END LAFB RUNWAY 25 BEFORE AND AFTER PAINT AND RUBBER REMOVAL PROGRAM MAY 1975. PAINT AND RUBBER DEPOSITS REMOVED BY HIGH PRESSURE WATER BLAST USING A ROTATING SPRAY BAR

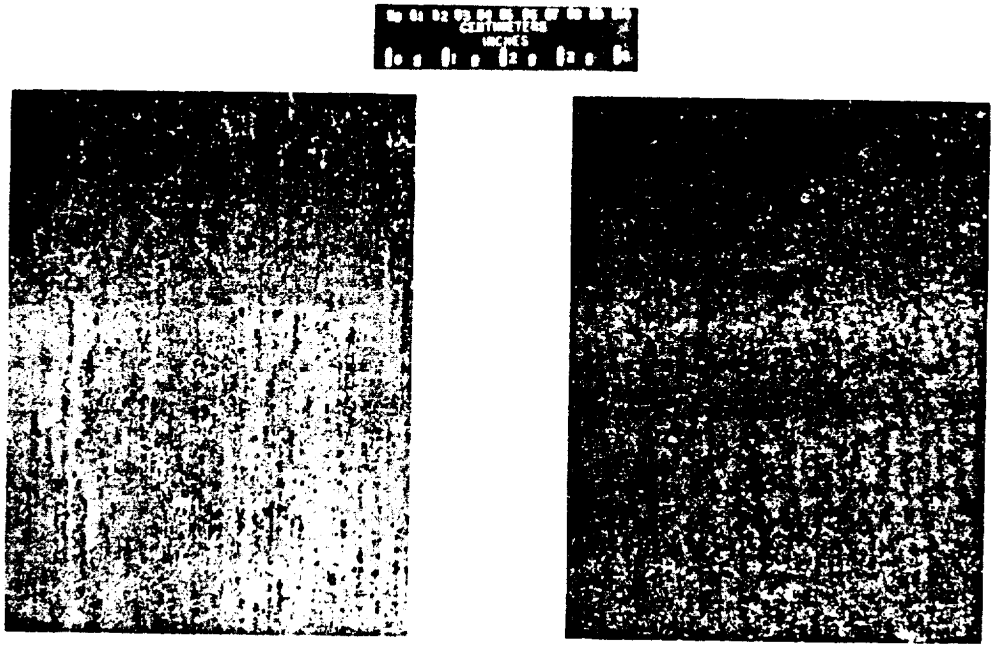


BEFORE RUBBER REMOVAL
3/70

4 DAYS AFTER
RUBBER REMOVAL
9/3/70

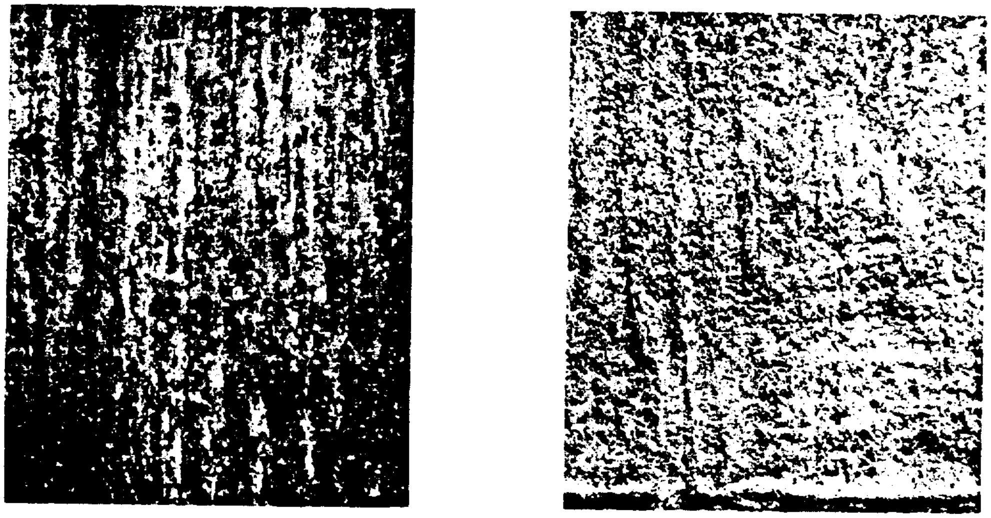
≈ 4 MONTHS AFTER
RUBBER REMOVAL
1/15/71

FIGURE 8. - PHOTOGRAPHS OF APPROACH END RUNWAY 7 AT LANGLEY AFB BEFORE AND AFTER RUBBER REMOVAL BY CHEMICAL TREATMENT.



a) Runway 7: Heavy Rubber Deposits; A.T.D. = 0.004 in.; Test Zone 4.

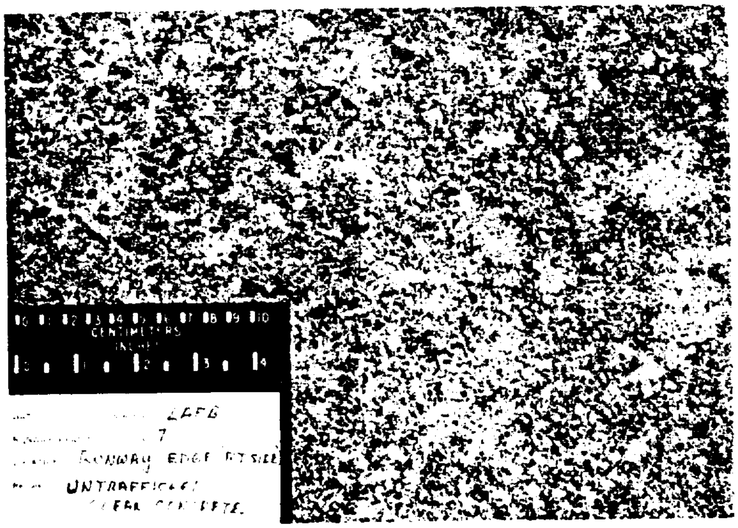
b) Runway 7: Medium Rubber Deposits; A.T.D. = 0.006 in.; Test Zone 4



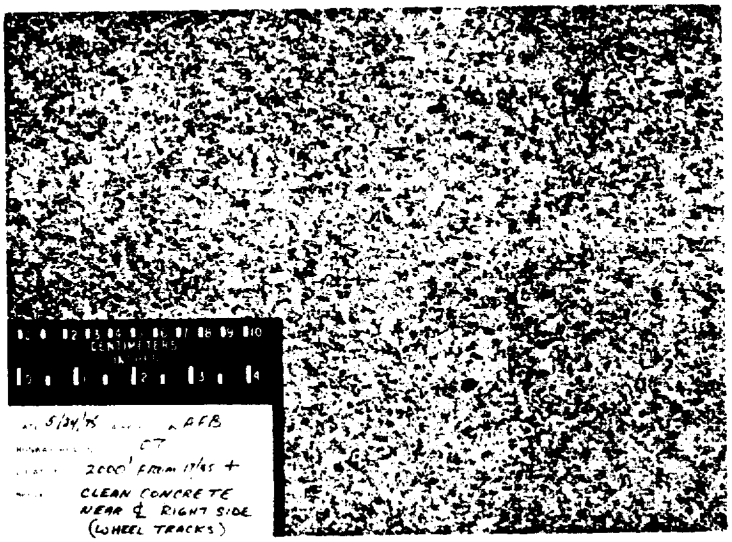
c) Runway 7: Medium Rubber Deposits; A.T.D. = 0.007 in.; Test Zone 4

d) Runway 25: Medium Rubber Deposits; A.T.D. = 0.006 in. Test Zone 1

FIGURE 9. - TYPICAL SURFACE RUBBER DEPOSITS ON APPROACH ENDS OF LAFB RUNWAY 7/25 BEFORE RUBBER REMOVAL PROGRAM. PHOTOGRAPHS TAKEN MAY 24, 1975.

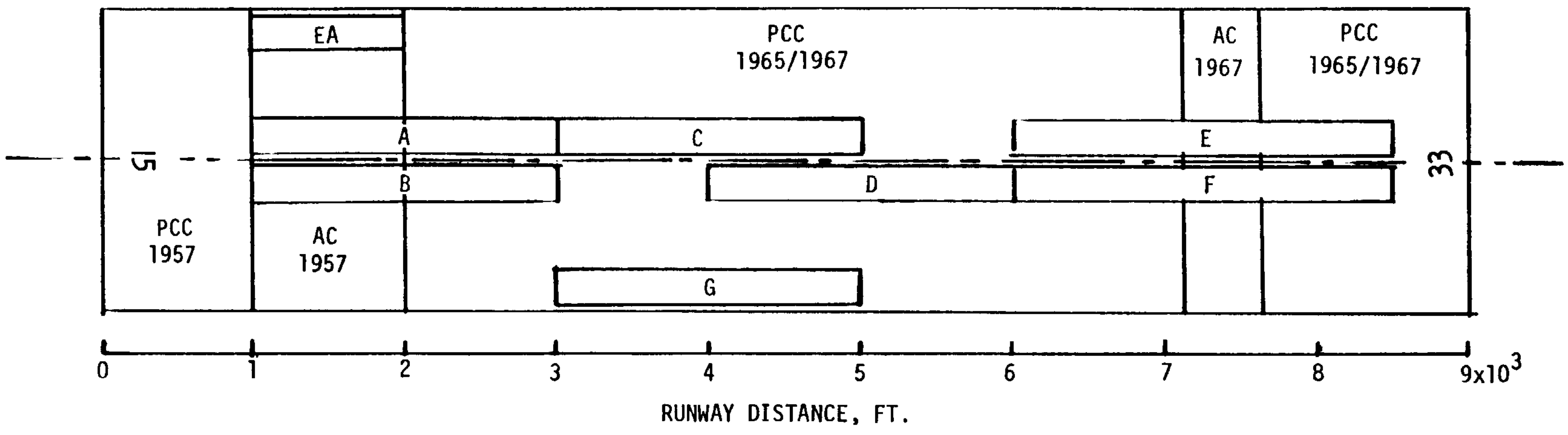


a) Surface Not Subjected To Aircraft Traffic
Test Zone 3; A.T.D. = 0.010 - 0.014 in.



b) Surface Subjected to Aircraft Traffic
Test Zone 2; A.T.D. = 0.010 - 0.014 in.

FIGURE 10. - Typical Surface Textures of LAFB Runway 7/25 (Portland Cement Concrete) In Uncontaminated (No Rubber Deposit) Areas.



DBV TEST ZONE	PAVEMENT DESCRIPTION
A	17-7 YEAR OLD ASPHALTIC AND PORTLAND CEMENT CONCRETE (MEDIUM RUBBER DEPOSITS)
EA	17 YEAR OLD ASPHALTIC CONCRETE, UNTRAFFICKED
B	17-7 YEAR OLD ASPHALTIC AND PORTLAND CEMENT CONCRETE (HEAVY RUBBER DEPOSITS)
C	9-7 YEAR OLD PORTLAND CEMENT CONCRETE, TRAFFICKED (NO RUBBER)
D	9-7 YEAR OLD PORTLAND CEMENT CONCRETE, TRAFFICKED (NO RUBBER)
E	9-7 YEAR OLD PORTLAND CEMENT AND ASPHALTIC CONCRETE (LIGHT RUBBER DEPOSITS)
F	9-7 YEAR OLD PORTLAND CEMENT AND ASPHALTIC CONCRETE (LIGHT RUBBER DEPOSITS)
G	9-7 YEAR OLD PORTLAND CEMENT CONCRETE, UNTRAFFICKED (NO RUBBER)

FIGURE 11 .- DBV TEST ZONE LOCATIONS ON CHARLESTON AFB RUNWAY 15/33 FOR EVALUATION OF HIGH PRESSURE WATER BLAST WITH STATIONARY SPRAY BAR RUBBER REMOVAL TREATMENT. (FROM REFERENCE 5).

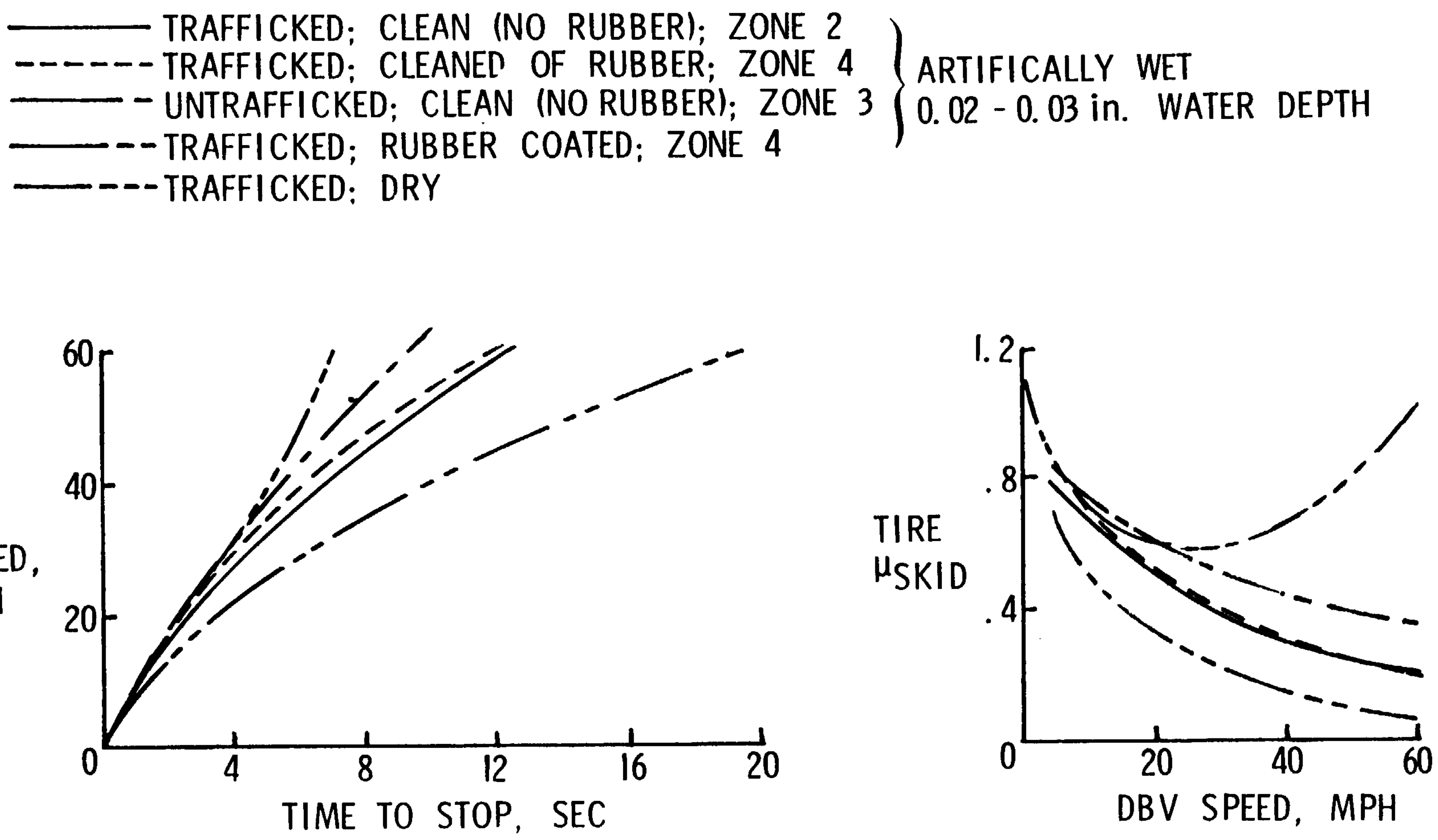


FIGURE 12. - COMPARATIVE DBV STOPPING AND TIRE FRICTION PERFORMANCE ON LAFB RUNWAY 7 UNDER WET AND DRY CONDITIONS

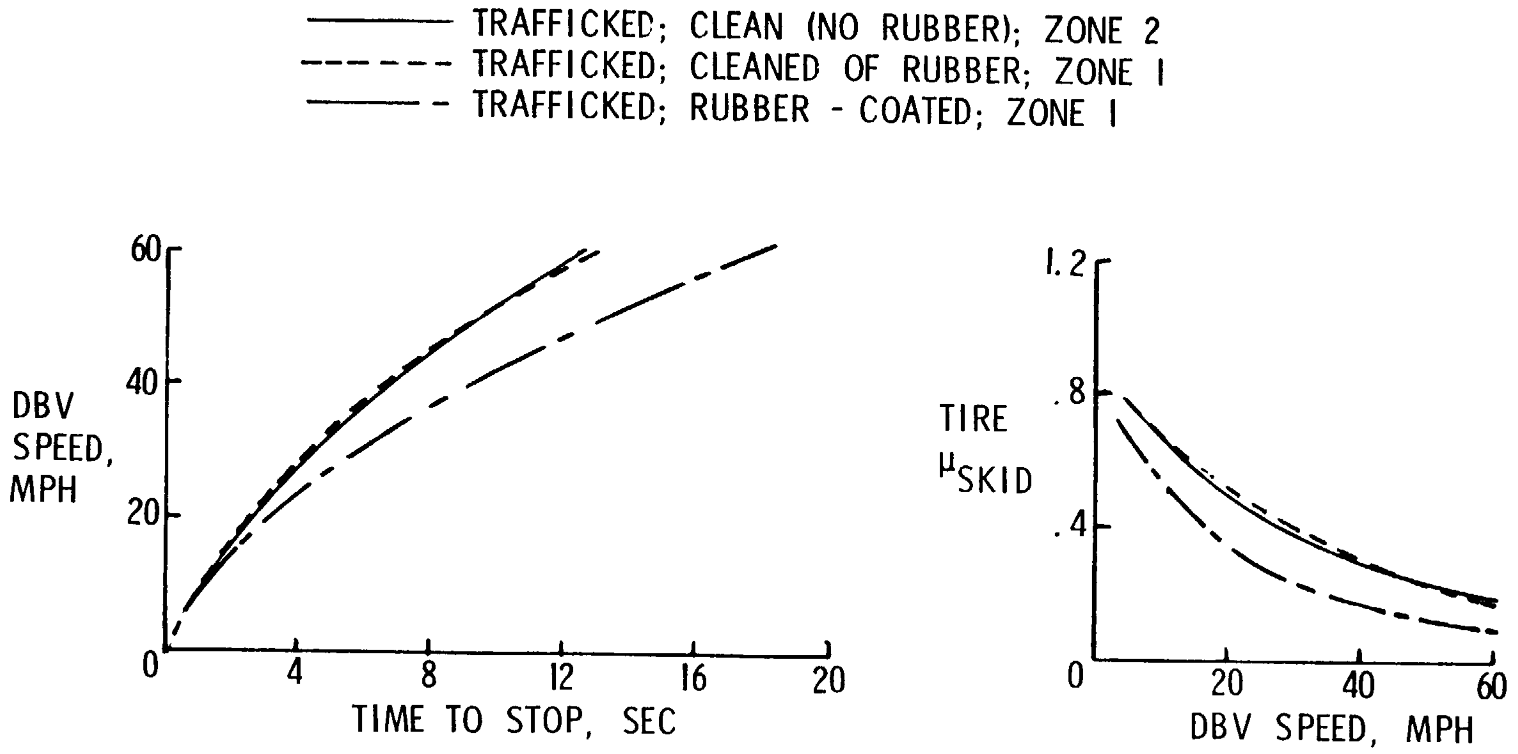


FIGURE 13. - COMPARATIVE DBV STOPPING AND TIRE FRICTION PERFORMANCE ON LAFB RUNWAY 25 UNDER ARTIFICIALLY WET CONDITIONS; 0.02 - 0.03 in. WATER DEPTH

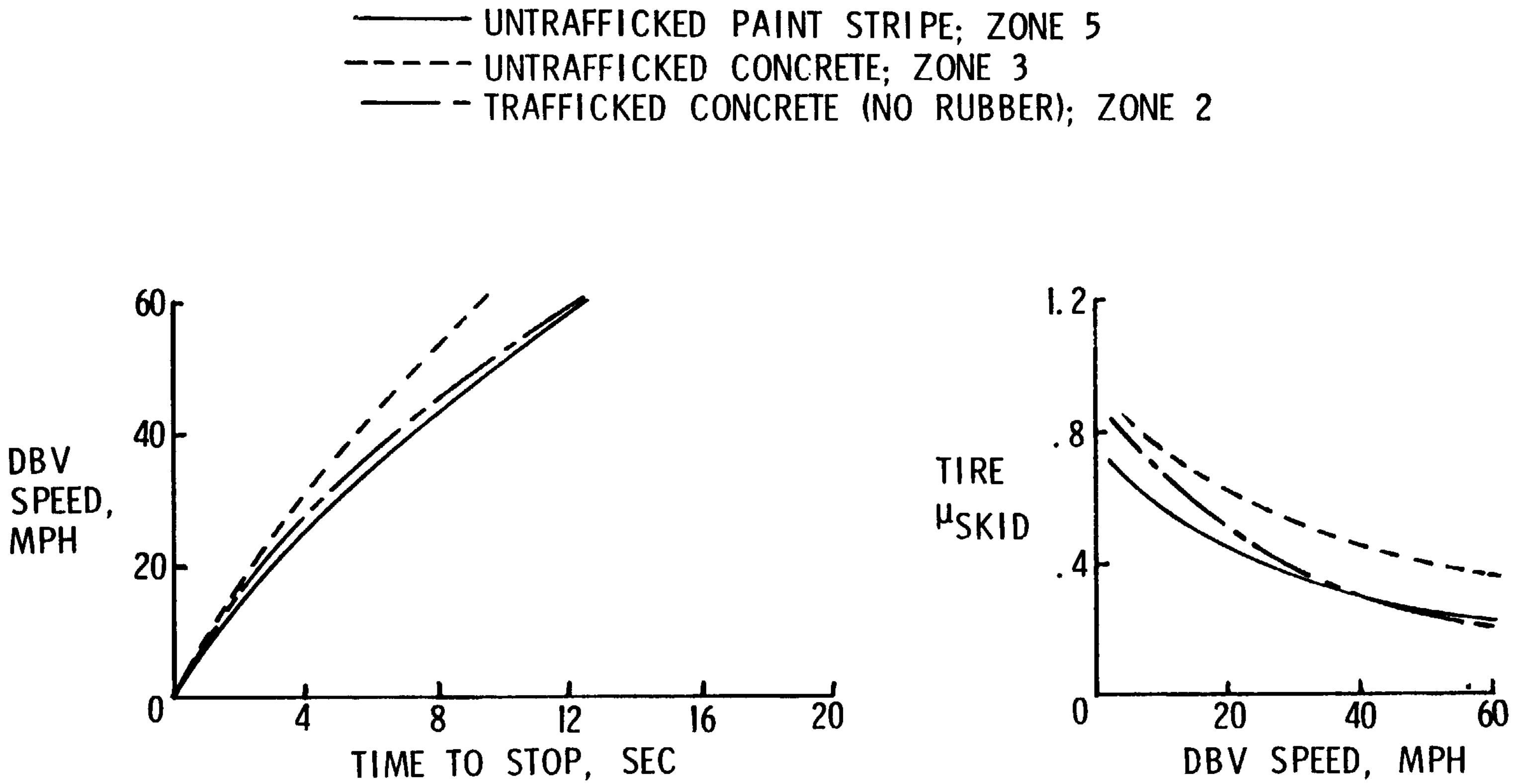


FIGURE 14. - COMPARATIVE DBV STOPPING AND TIRE FRICTION PERFORMANCE ON PAINTED AND CLEAN (NO RUBBER) SURFACES OF LAFB RUNWAY 7 UNDER ARTIFICIALLY WET CONDITIONS; 0.02 - 0.03 IN. WATER DEPTH

RUNWAY 9L/27R, M.I.A.; 1½ × ¼ × ¼ in. GROOVE PATTERN; WATER TRUCK WETTING; WIND FROM 165 deg AT 10 knots

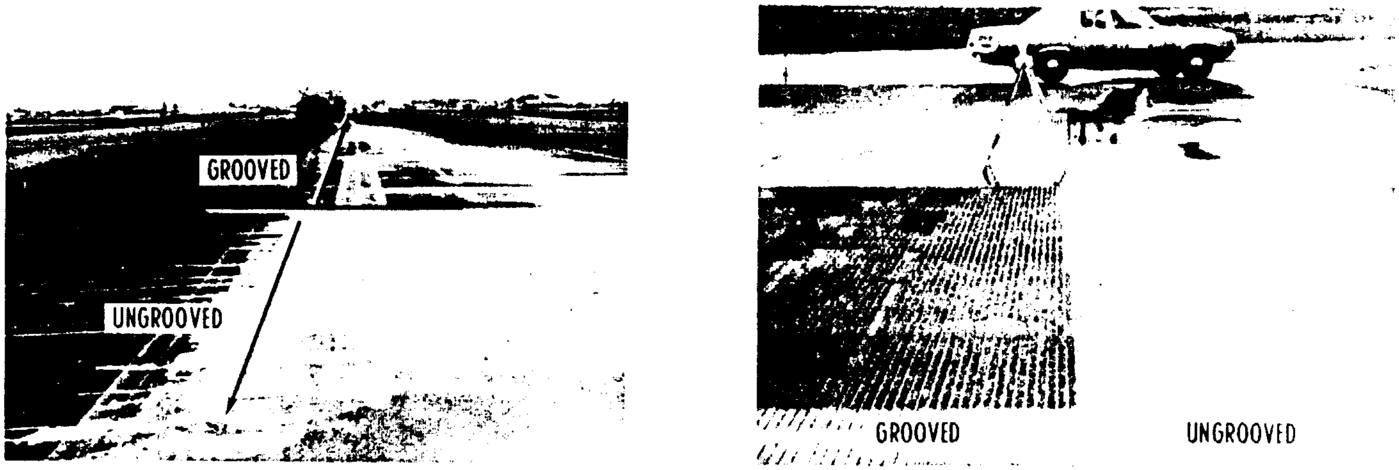
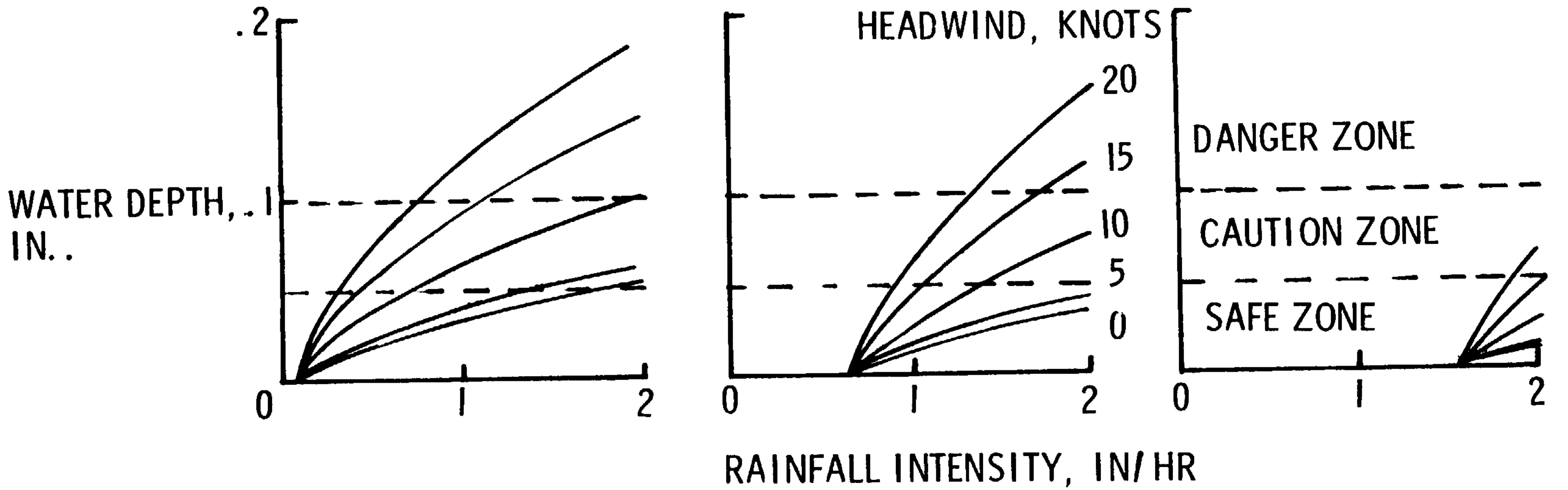


FIGURE 15. - WATER DRAINAGE FOLLOWING WATER TRUCK WETTING FROM GROOVED AND UNGROOVED SURFACES OF A SMOOTH ASPHALTIC CONCRETE RUNWAY.

NOTE: CALCULATIONS BASED ON UNPUBLISHED NASA DRAINAGE ANALYSIS AND REF. 13

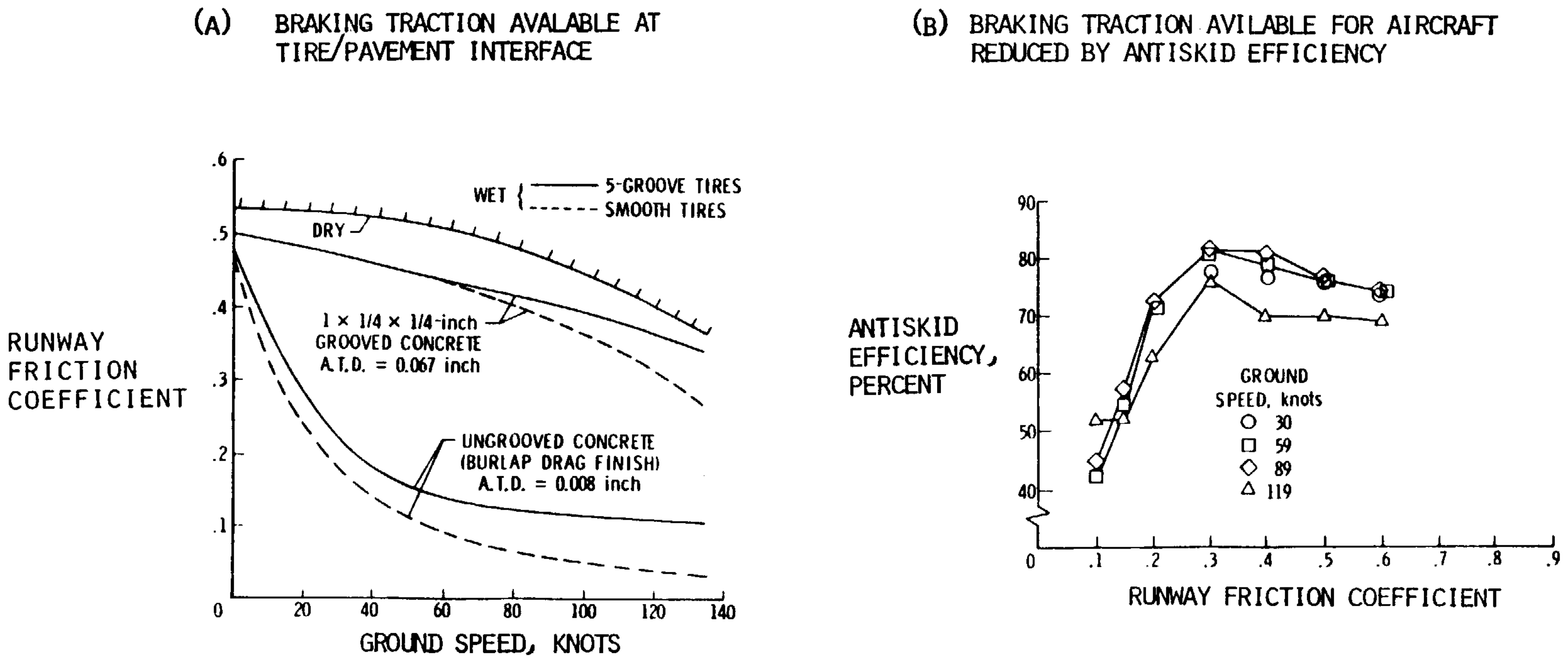


a) UNGROOVED:
A. T. D. = 0.008 IN.

b) TRANSVERSE GROOVES:
2 x 1/4 x 1/4 IN.
A. T. D. = 0.037 IN.

c) TRANSVERSE GROOVES:
1 x 1/4 x 1/4 IN.
A. T. D. = 0.067 IN.

FIGURE 16. - CALCULATED RUNWAY WATER DEPTHS DURING NATURAL RAIN. DRAINAGE PATH LENGTH(DISTANCE FROM TOP OF RUNWAY CROWN TO WHEEL PATH), IN.; RUNWAY TRANSVERSE SLOPE = 1 %; UNGROOVED SURFACE TEXTURE DEPTH(A. T. D.) = 0.008 IN.

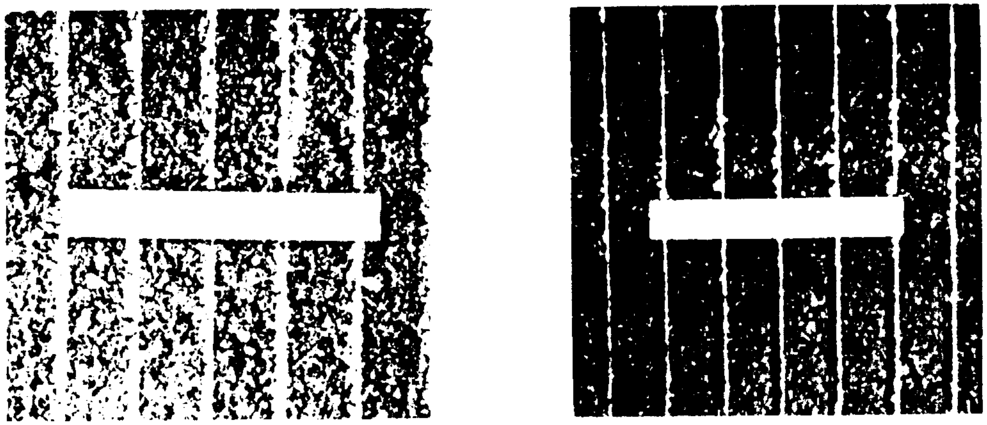


(FROM REF. 12)

(FROM REF. 14)

FIGURE 17. - WET RUNWAY SURFACE TEXTURE EFFECTS ON TIRE/ AIRCRAFT BRAKING TRACTION.

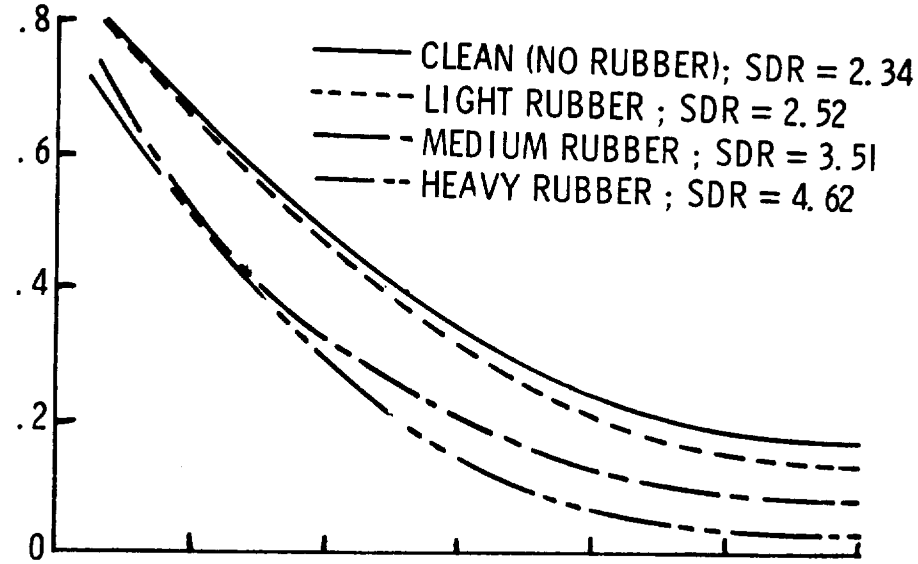
RUNWAY 9R/27L, M.I.A.



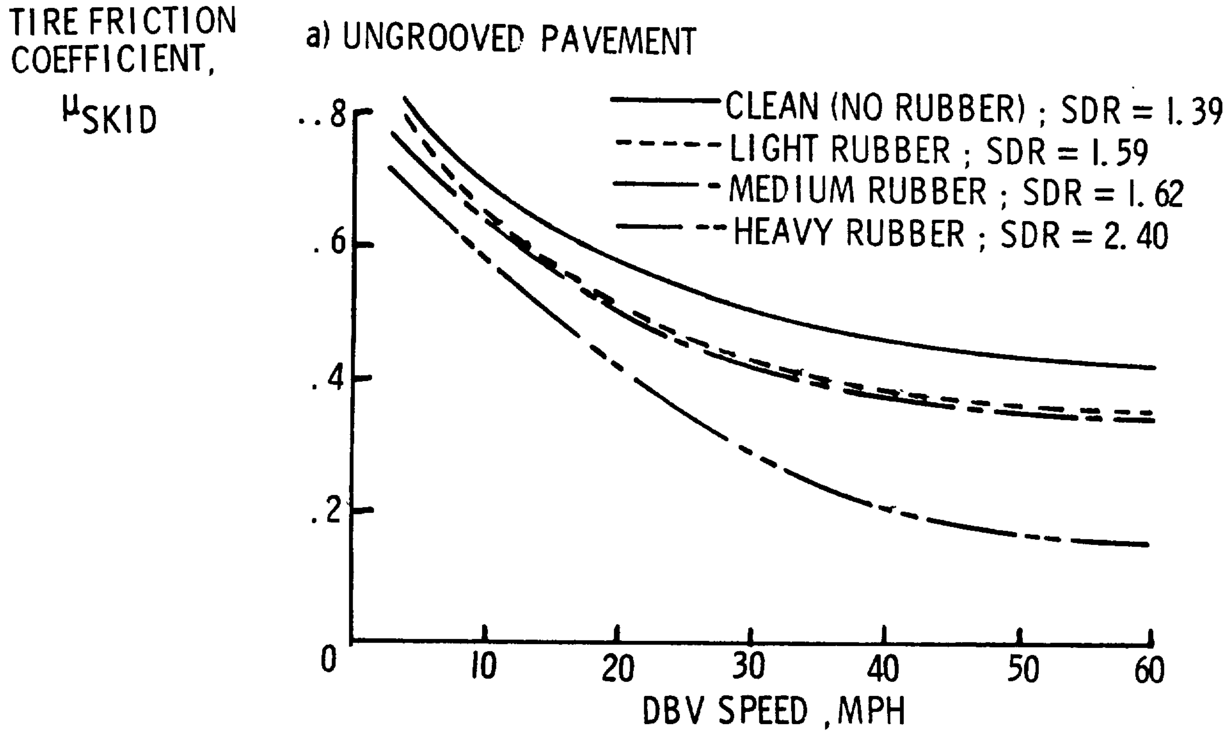
CLEAN (MIDDLE OF RUNWAY)

RUBBER-COATED (TOUCH DOWN AREA)

FIGURE 18. - EFFECTS OF HEAVY RUBBER DEPOSITS ON GROOVED ASPHALTIC CONCRETE RUNWAY (RUBBER COATS LANDS BETWEEN GROOVES BUT DOES NOT FILL GROOVE CHANNELS)



a) UNGROOVED PAVEMENT

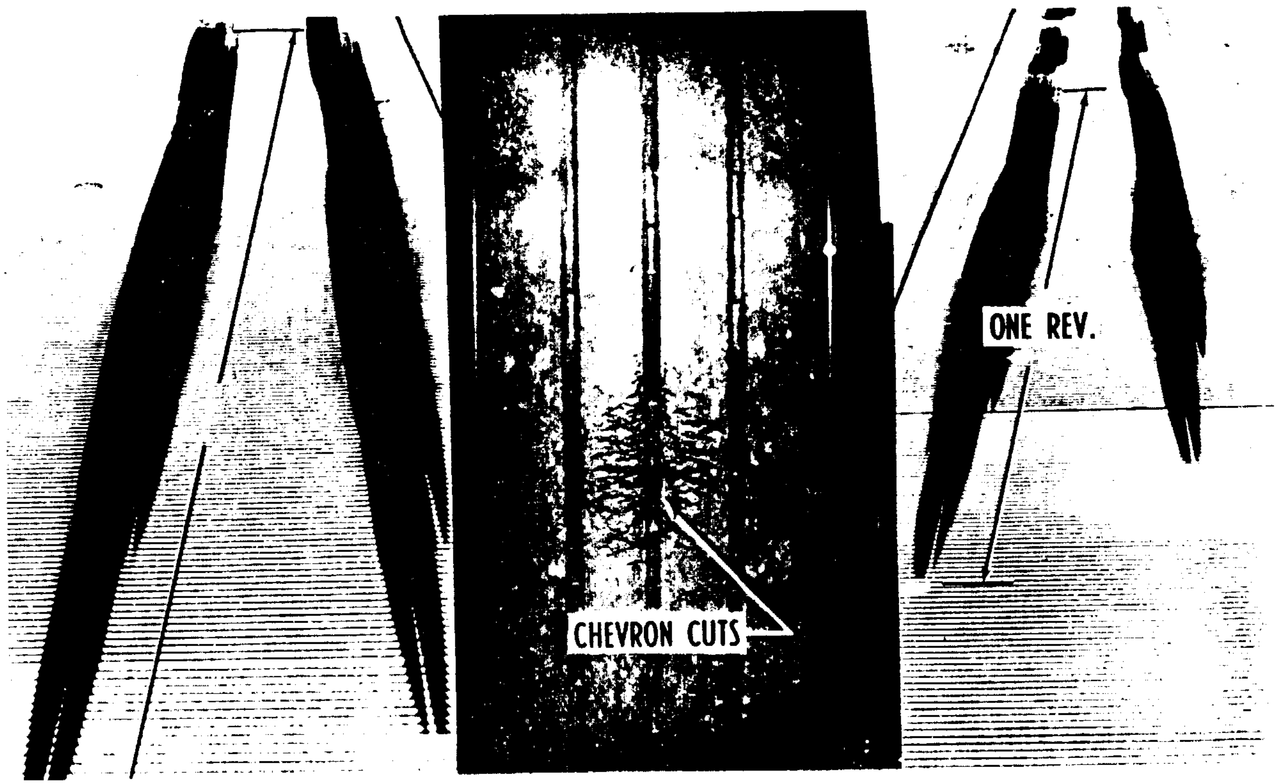


b) GROOVED PAVEMENT (TRANSVERSE 1 1/2 x 1/4 x 1/4 PATTERN)

FIGURE 19. - EFFECT OF RUBBER DEPOSIT ACCRETION ON DBV SDR AND TIRE μ_{SKID} OBTAINED ON WET GROOVED AND UNGROOVED SMOOTH ASPHALTIC CONCRETE SURFACES AT MIAMI INTERNATIONAL AIRPORT

FIGURE 20. - **TIRE DAMAGE FROM WHEEL SPINUP AT TOUCH DOWN ON DRY GROOVED RUNWAY**

WALLOPS GROOVED CONCRETE, 1 × ¼ × ¼ in. GROOVE PATTERN;
CV-990 JET TRANSPORT MLG TIRE; SIZE 41 X 15.0 - 18; $p = 160$ lb/in.^{2};
$V_G = 125$ knots; $V_v = 4 - 5$ ft/sec



NASA-Langley, 1975