

# Summary of NASA Friction Performance Data Collected with ASTM E501 and E524 Test Tires

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A summary of friction performance data collected during NASA Langley Aircraft Landing Dynamics Facility track, diagonal-braked vehicle, and instrumented tire test vehicle evaluations using the ASTM E501 (rib tread) and E524 (blank tread) test tires is given. A variety of pavement types, both grooved and ungrooved, and conditions are included. The principal factors influencing tire-pavement friction performance are discussed, and the advantages of using the blank-tread tire for wet pavement evaluations are identified. An indication of some future tire-pavement friction investigations is also given.

Personnel at the National Aeronautics and Space Administration (NASA) Langley Research Center's Landing and Impact Dynamics Branch have been involved in instrumented aircraft, ground vehicle, and controlled track tests since in the mid-1950s. Extensive aircraft tire tests at the Aircraft Landing Dynamics Facility (ALDF) track at Langley have provided a basic understanding of the phenomenon of tire hydroplaning and identified the major factors influencing tire-pavement friction performance (1-7). Concurrent with these ALDF track tests, several joint NASA/FAA/Air Force/aviation industry programs were conducted with different instrumented aircraft and a variety of ground friction measuring vehicles (8-13). During these tests, a diagonal-braked vehicle (DBV) was developed by NASA Langley engineers for measuring runway friction performance under locked-wheel friction conditions (14,15). Because of tire tread wear under locked-wheel conditions, impetus was generated to develop a blank- or smooth-tread test tire, but one with full-tread rubber skid depth. The ASTM E17 Committee on Pavement Management Technologies had a standard for a rib-tread test tire designated E501. In the early 1970s, ASTM Standard E524 was approved for a blank- or smooth-tread test tire of the same bias-ply construction and tread rubber composition as the E501 tire tread. Since then, thousands of test runs have been conducted with the NASA DBV equipped with the E524 blank-tread test tires. In tire friction studies using the NASA Langley instrumented tire test vehicle (ITTV), both the rib-tread and blank-tread ASTM tires have been evaluated under a variety of pavement surface types and conditions. The NASA DBV has conducted tests on more than 150 runways in 42 states in the United States and also in Canada, England, Germany, Italy, and Spain. Other DBVs equipped with the ASTM E524 tires have been used successfully in Sweden, France, Switzerland, Japan, and other countries to evaluate runway friction

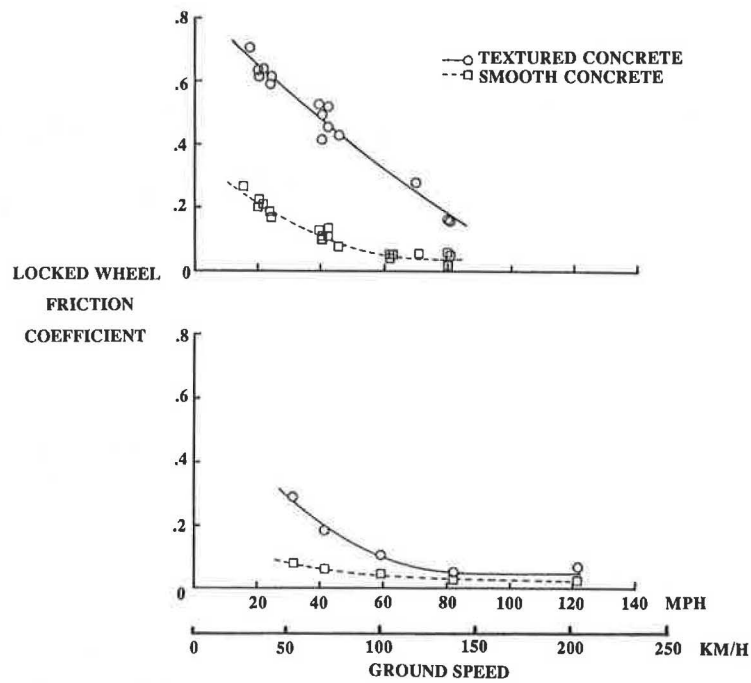
performance and identify problem runways under less-than-ideal surface conditions. The purpose of this paper is to summarize the test results from NASA ALDF track, DBV, and ITTV studies using the ASTM E501 and E524 test tires for pavement friction evaluations. Justification is given to prefer use of the blank-tread E524 tire for meaningful wet pavement friction assessments. Future test plans and requirements aimed at improved techniques for adequately measuring wet pavement friction capability are also described.

## ALDF TRACK RESULTS

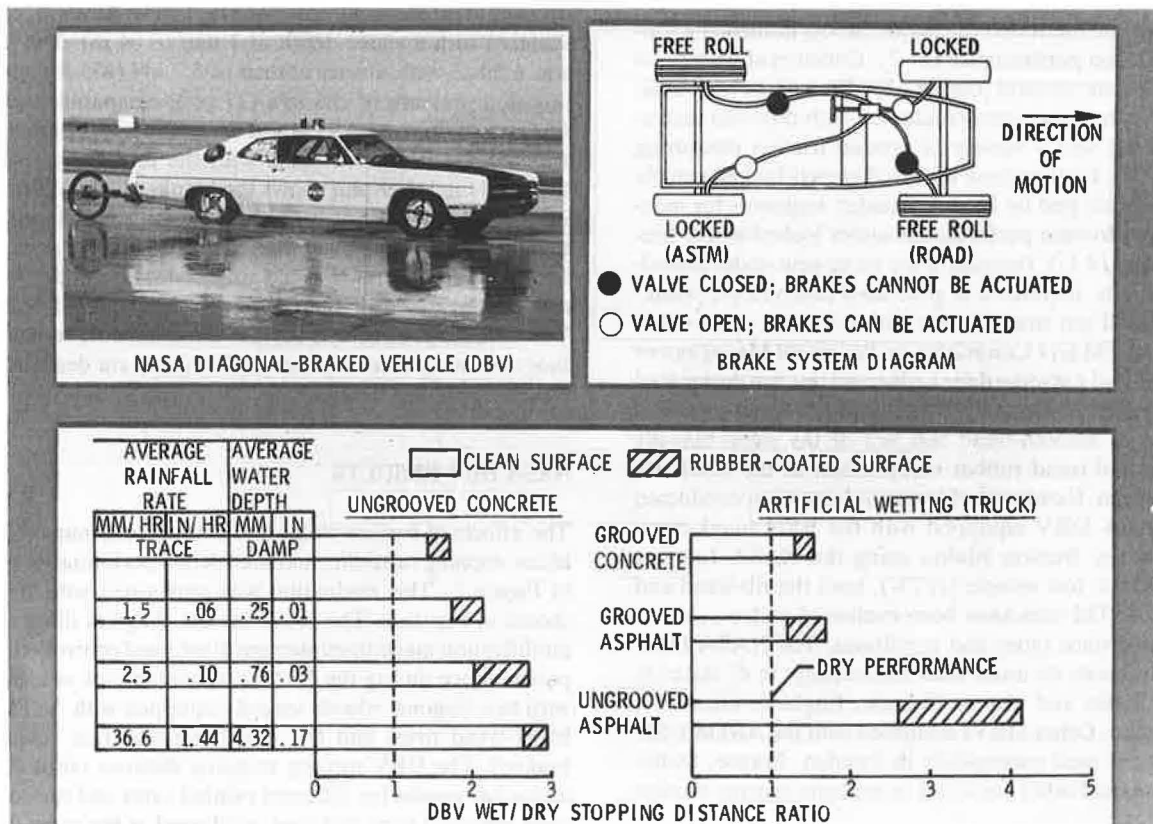
The influence of automobile tire tread design, pavement surface texture, and speed on the locked-wheel friction coefficient developed on wet surface conditions is shown in Figure 1. These results were obtained during ALDF track tests (7) on highly textured and very smooth (trowel-finished) concrete surfaces with a water depth of 1 mm (0.04 in). The tire size was 6.50-13 with a vertical load of 3.7 kN (835 lb) and a tire inflation pressure of 186 kPa (27 psi), comparable specifications for the current ASTM test tires. The upper plot of Figure 1 shows the results obtained with the four-groove rib-tread tire, and the lower plot shows the blank- or smooth-tread tire results. The friction values obtained with the smooth-tread tire are significantly lower than the rib-tread tire, as expected. Increased speed and reduced surface texture under wet conditions also decrease the friction performance of both tires. The additional effects of surface contaminants reducing surface texture and tire friction performance are described from NASA DBV test results.

## NASA DBV RESULTS

The effects of surface water and rubber contaminants on vehicles stopping capability and tire friction performance is shown in Figure 2. This evaluation was performed with the DBV shown in Figure 2. The brake system diagram illustrates the modification made to implement stable and controlled vehicle performance during the friction measurements at high speed with two diagonal wheels locked (equipped with ASTM E524 blank-tread tires) and the remaining pair free rolling (unbraked). The DBV wet/dry stopping distance ratios depicted in the bar graphs for different rainfall rates and surface types were obtained from test runs conducted at the same distance off runway centerline with brakes applied at 98 km/hr (60



**FIGURE 1** Effect of tire tread design, pavement texture, and speed on locked-wheel friction developed on a wet surface: *top*, four-groove rib-tread tire; *bottom*, smooth-tread tire (ALDF track data).



**FIGURE 2** Effect of surface contaminants on DBV stopping performance.

mph) to a complete stop. Measurements of surface water depth and DBV stopping distance during different periods of rainstorm activity on an ungrooved concrete runway with a 1 percent crown reveal a direct relationship between average water depth and stopping distance. As rainfall rates increase, greater water buildup on the runway surface occurs, which decreases tire friction performance as reflected in the increased stopping distance ratios. The runway was even more slippery near the end of it, where it was contaminated by rubber deposited during aircraft tire spin-up following touch-down. The buildup of the rubber coating on runway surfaces tends to reduce pavement texture and hence degrade tire friction, particularly under wet conditions. The cross-hatched DBV stopping distance increment shown in Figure 2 illustrates the effects of rubber contamination on the ungrooved concrete runway slipperiness measurements for different rainfall rates. Also shown in the figure are comparable DBV measurements made on other grooved and ungrooved runways under artificially wetted (truck) conditions where the average water depth was 0.5 mm (0.02 in.). The longer DBV wet/dry stopping distance ratios measured on the ungrooved asphalt runways compared with the concrete surfaces are the result of lower surface macrotexture.

In the late 1960s, Runway 4/22 at the NASA Wallops Flight Facility on the eastern shore of Virginia was modified to provide a level test section 16 m (50 ft) wide and 1128 m (3,700

ft) long in the middle portions of the runway. Both grooved and ungrooved, concrete and asphalt test surfaces were installed as shown in the runway schematic in Figure 3. NASA DBV tests were conducted on these surfaces after truck wetting that left wet and puddled surface conditions. Results from these DBV tests are shown in Figure 4 for the ungrooved and grooved surfaces on Runway 4/22 at NASA Wallops. Tests with ASTM bald- and rib-tread tires were conducted with the DBV. On the grooved surfaces, the variation in locked-wheel friction coefficient with speed shows similar results for these two test tires, but on the ungrooved surfaces, the rib-tread tire developed higher friction—particularly at the higher test speeds. The ASTM bald-tread E524 tire data suggest a greater sensitivity to surface texture variation than the rib-tread E501 tire for the ungrooved surfaces shown in Figure 4.

### ITTV RESULTS

A photograph of the NASA ITTV during a wet surface run at NASA Wallops Flight Facility is shown in Figure 5, and the general specifications for this test vehicle are indicated. The test fixture can be rotated horizontally to accommodate testing at fixed yaw angles. The test-wheel axle can be coupled to a chain-drive gearbox off the left rear truck wheel to obtain data at fixed braking slip conditions. Figure 6 shows five test

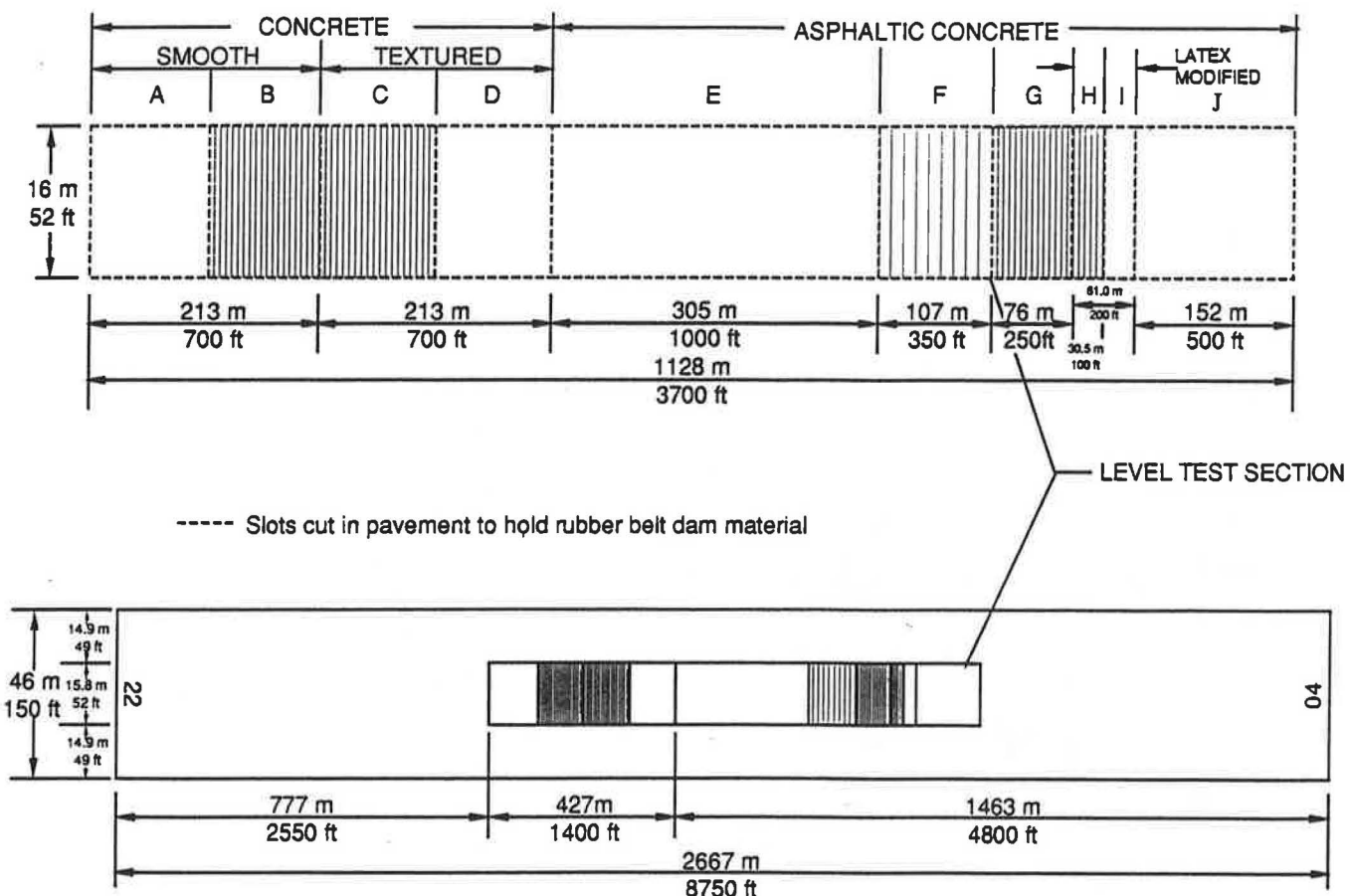
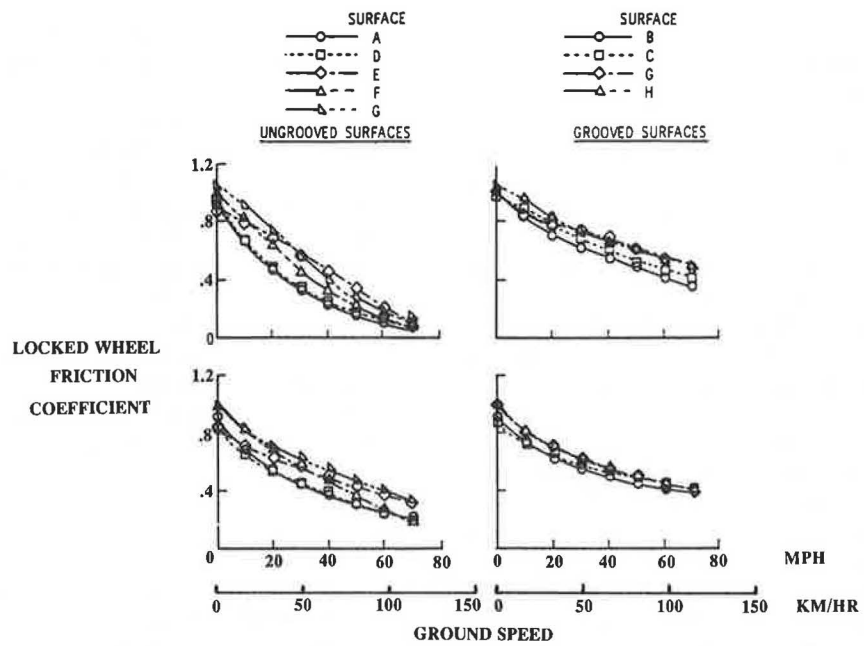


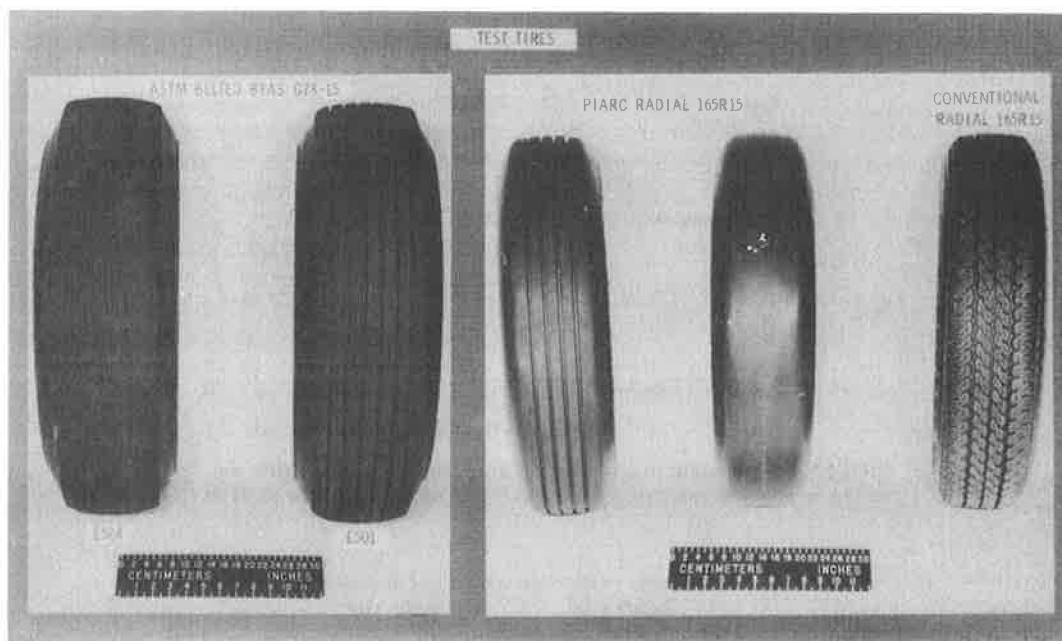
FIGURE 3 Schematic of NASA Wallops Flight Facility Runway 4/22 test surfaces (Surfaces B, C, G, and H transversely grooved  $0.25 \times 0.25 \times 1.0$  in.; Surface F transversely grooved  $0.25 \times 0.25 \times 2.0$  in.).



**FIGURE 4** Variation of DBV locked-wheel friction coefficient with ground speed: *top*, ASTM smooth-tread tire; *bottom*, ASTM rib-tread tire.



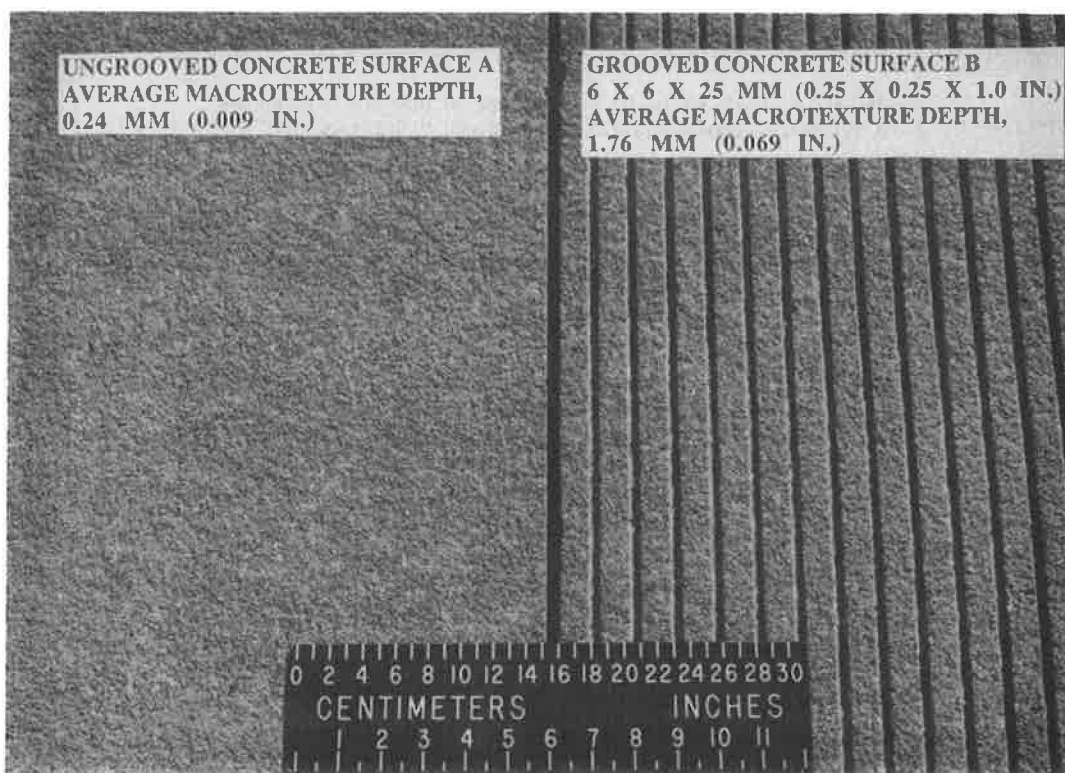
**FIGURE 5** Instrumented tire test vehicle.



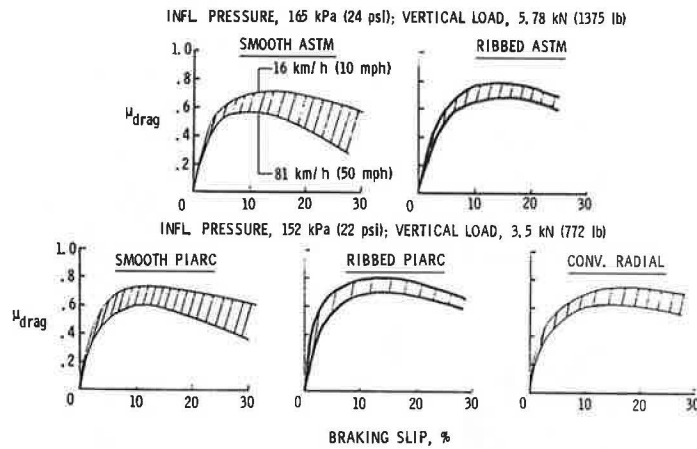
**FIGURE 6** Test tires used in ITTV evaluation at NASA Wallops Flight Facility.

tires, including the ASTM E501 and E524 tires, that were used in a study of tire friction performance. Close-up photographs of the two concrete test surfaces used in this study are shown in Figure 7 with their average macrotexture depth values. The variation of braking drag force friction coefficient with slip ratio for the five test tires under wet conditions is

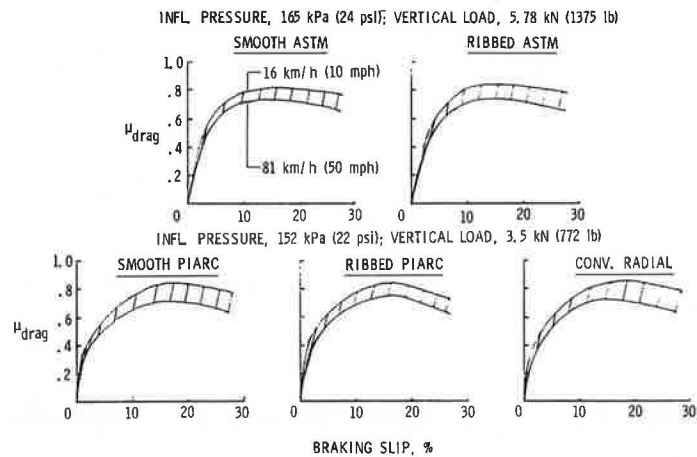
given in Figure 8 for the ungrooved concrete surface and Figure 9 for the grooved concrete surface. The smooth-tread test tires showed the greatest influence of speed on braking friction, as expected, and the grooved concrete gave higher friction values, particularly at the higher slip ratio. In general, the peak braking friction coefficient was developed between



**FIGURE 7** Concrete test surfaces at NASA Wallops Flight Facility.

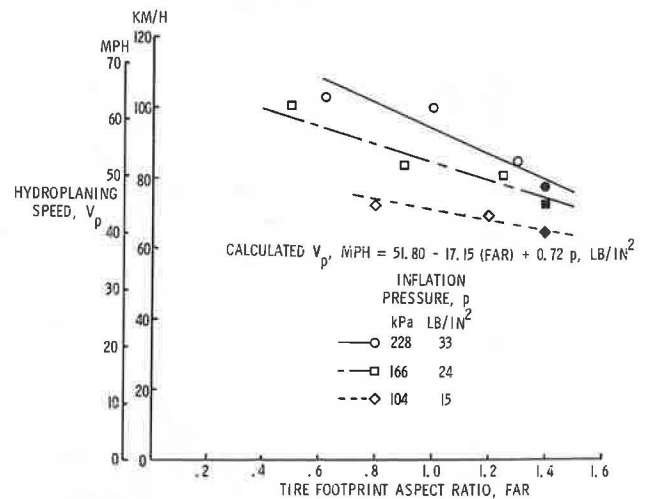


**FIGURE 8** Variation in tire braking drag friction with braking slip on wet ungrooved concrete [average water depth = 0.25 mm (0.01 in.)].



**FIGURE 9** Variation in tire braking drag friction with braking slip on wet grooved concrete [average water depth = 0.25 mm (0.01 in.)].

10 and 20 percent braking slip for these five tires. Results from another study using the ITTV to evaluate the effects of tire footprint aspect ratio (footprint width divided by length) on hydroplaning speed are shown in Figure 10. These data were obtained using the ASTM E524 tire inflated at three different pressures (open symbols) with a larger truck size (solid symbols). As expected, the hydroplaning speed increased with inflation pressure, but with greater tire footprint aspect ratio values, the tire hydroplaning speed value decreased significantly. Additional tests are planned using the ITTV to study a variety of ground vehicle tires to better identify how the footprint aspect ratio influences tire hydroplaning speeds. Other future test programs include a joint program with the Air Force and aviation industry to define the factors effecting tire tread wear and consequently optimize tire tread design.



**FIGURE 10** Variation of dynamic hydroplaning speed with tire footprint aspect ratio (open symbols = automobile tire data, closed symbols = truck tire data).

## CONCLUDING REMARKS

A summary of friction performance data collected during NASA Langley ALDF track, DBV, ITTV evaluations using the ASTM E501 and E524 test tires is given. A variety of pavement types and contaminants were included, and the principal factors influencing tire-pavement friction performance were discussed. These results indicated that under wet pavement conditions, the ASTM E524 smooth-tread tire is more sensitive to variations in speed, surface texture, and contaminants than the ASTM E501 rib-tread tire. Another advantage is that the influence of tire wear on the friction data is eliminated using the blank-tread tire. Some future test plans aimed at improving tire-pavement friction performance have also been described.

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