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SOME EFFECTS OF GROOVED RUNWAY
CONFIGURATIONS ON AIRCRAFT TIRE
BRAKING TRACTION UNDER
FLOODED RUNWAY CONDITIONS

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SUMMARY

An experimental investigation was conducted to study the effect of grooved runway configurations on aircraft tire braking traction on flooded runway surfaces. The investigation was performed at the Langley aircraft landing loads and traction facility, utilizing size 49×17 , type VII, aircraft tires with an inflation pressure of 117 N/cm^2 (170 lb/in^2) at ground speeds up to approximately 120 knots.

The results of this investigation indicate that when the runway is flooded, grooved surfaces provide better braking traction than an ungrooved surface and, in general, the level of braking traction was found to improve as the tire bearing pressure was increased because of an increase in the groove area of either the surface or the tire tread. Rounding the groove edges tended to degrade the tire braking capability from that developed on the same groove configuration with sharp edges. Results also indicate that braking friction coefficients for the test tires and runway surfaces decreased as ground speed was increased because of the hydroplaning effects.

INTRODUCTION

In recent years, the braking capability of aircraft tires on wet runways has been significantly improved by the introduction of advanced antiskid braking systems and by modifying the tire tread design and runway surface finish to provide greater water drainage between the tire and ground. (See refs. 1 to 6.) Perhaps the most significant improvement has occurred with the use of transverse grooves cut into the runway surface. In addition to substantially reducing the amount of water acting at the tire-surface interface for a given rainfall condition, the grooved surface channels promote a mechanical interlock with the tire tread. Recent studies have indicated that tire braking capability on some grooved surfaces under wet conditions is comparable to that developed under dry surface conditions. (See ref. 3.) As a result of runway grooving, aircraft stopping distances under adverse weather conditions have been reduced and the safety

of aircraft ground operations, particularly during landings and rejected take-offs, has been improved significantly.

In view of the wide variety of grooving configurations (pitch, width, and depth) currently in use (see ref. 6), a need exists to identify the configuration or configurations which provide the best braking traction under wet conditions. In addition, a need exists to establish the effect that tire tread design differences have on the traction provided by various grooved pavement configurations under flooded runway conditions. The purpose of this paper is to present the results of a limited experimental investigation to study the effect of grooved runway configurations on the braking performance of two tires of the same size under flooded runway conditions. The investigation was conducted at the Langley aircraft landing loads and traction facility in conjunction with a program to evaluate tire tread damage associated with the landing of some aircraft on grooved runways. Both the damage data, presented in reference 7, and the braking data of this paper were obtained with 49×17 , type VII, aircraft tires operating at ground speeds up to approximately 120 knots on grooved test surfaces generally considered for airport use.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units and converted to SI units.

V_p	computed dynamic hydroplaning speed, knots
μ_{\max}	maximum instantaneous drag-force friction coefficient for a braked rolling tire
μ_{skid}	drag-force friction coefficient for a sliding tire

APPARATUS AND TEST PROCEDURE

Test Facility

The investigation was performed at the Langley aircraft landing loads and traction facility and utilized the main test carriage shown in figure 1. A description of this facility and its operation is given in reference 8. The tire, wheel, and brake assembly (shown in fig. 2) were mounted on a dynamometer similar to that described in reference 8, which was instrumented to measure the various axle loadings. The dynamometer, in turn, was attached to a drop test fixture which, during a test, was positioned to allow the tire to roll on the test surfaces under a predetermined vertical load simulating an airplane rollout

condition. The simulation was not entirely complete, however, since there was no wing lift and no strut system linking the wheel to the drop test fixture.

Vertical and drag loads and brake torque applied to the test wheel were measured by the dynamometer load beams, and a dc generator indicated the instantaneous wheel angular velocity. The outputs from the load cells and the generator, together with signals which described the carriage ground speed, were transmitted to an oscillograph on board the carriage.

Test Tires

The tires of the investigation were size 49×17 , 26-ply rating, type VII, aircraft tires currently used on several different commercial and military jet transports. Photographs of the test tires are presented in figure 3 together with corresponding footprints obtained under a vertical load of 66.7 kN (15 000 lb) and an inflation pressure of 117 N/cm^2 (170 lb/in^2). The relatively low vertical loading was selected for these tests to assure wheel lockups under all test conditions with the torque-limited brake used in this investigation. Both test tires were five-groove retread tires; however, as shown in figure 3, only the three middle tread grooves of tire B were in contact with the runway surface under the test loading conditions. The tread groove depths of both tires were nearly identical, but the tread grooves of tire A were much wider than those of tire B. The tread groove area represented approximately 33 percent and 13 percent of the total tire footprint area for tires A and B, respectively. In a companion study with four different tires of this size (see ref. 7), tire A exhibited the greatest susceptibility to chevron cutting tread damage and tire B the least damage during touchdown on grooved surfaces.

Test Surfaces

Tire braking data were obtained from the eight concrete test sections described in table I. Each of these sections was installed along the runway of the facility for distances which extended from approximately 6 meters to 15 meters (20 ft to 50 ft). As noted in the table, surface 1 was ungrooved whereas the remaining surfaces were grooved transversely to the direction of tire motion. The configurations of the grooves are defined by the groove pitch or center-to-center distance, width, depth, and cross-sectional shape. Surfaces 5 and 6 were modified V-groove cross sections whereas the other groove cross sections were rectangular. Two methods, combing and sawing, were used to form the grooves in the surfaces. The combing technique involved raking or combing the groove shape into the surface while the concrete was in a plastic state, whereas in the saw technique the groove shape was cut into the cured concrete surface with a diamond-tipped circular blade. Except for surface 8 which had a float finish, the surface of all test sections had a transverse brush finish wherein the striations left by the broom paralleled

the grooves. It should be pointed out that during the course of the sawed grooving operation, the lands of large areas of surface 6 were inadvertently ground by the grooving apparatus which essentially removed the striations, and left a polished surface between grooves. The photographs of figure 4 illustrate the texture and groove configuration of each test section but do not depict an area of surface 6 with polished lands. The figure shows that the grooves obtained from the combing technique, surfaces 2 and 3, are less uniform in width and depth than those obtained from the sawing technique, because, unlike the powered saw blade, the hand-operated rake tends to ride over the random aggregate in the concrete mix.

In order to simulate an extremely wet runway condition, the surfaces were flooded for all tests. The flooded condition was obtained by surrounding the test area with a dam and applying water to a depth of approximately 0.63 cm (1/4 in.) above the lands of the grooved surface. It is recognized that for operational grooved runways, this flooded condition is not likely to occur under normal rainfall conditions.

Test Procedure

The testing technique involved propelling the carriage to the desired test velocity with the test wheel rolling on the runway under a steady-state vertical load. Full pressure to the test wheel brake system was applied for a sufficient time period to produce a momentary wheel lockup on a preselected test surface. Pertinent data, obtained at ground speeds between approximately 40 and 120 knots, were recorded with an onboard carriage oscillograph. (1 knot = 0.514 m/sec.) The data monitored by the oscillograph consisted of the vertical and drag loads, wheel angular displacement and velocity, and the horizontal displacement of the carriage.

After each test run, the tire tread was examined to locate and identify the skid patch and to determine the maximum amount of tread wear. When the tread was worn to approximately 75 to 80 percent of its original depth, the tire was changed to another equivalent tire to minimize the effect of tread wear on the data.

RESULTS AND DISCUSSION

The instantaneous maximum drag-force friction coefficient μ_{\max} and the steady-state, locked-wheel, drag-force friction coefficient μ_{skid} were computed from histories of the vertical loading and drag loading measured at the wheel axle during braking runs. The values of μ_{skid} represented the average of those measured over the approximate 3.05 meters (10 ft) skidding distance. The variation of μ_{\max} and μ_{skid} with ground speed is used as a basis of comparison in evaluating the braking performance of different test tire and surface combinations. Figure 5 summarizes the results obtained with the two tires on each of the test surfaces (surfaces 1 to 8). The curves faired through these

data are repeated in figure 6 to provide a ready comparison of the braking traction afforded by the different groove configurations.

The data of figure 5 generally show a significant reduction in traction with an increase in ground speed for both tires on all test surfaces. The computed dynamic hydroplaning speed for these tires, based upon an inflation pressure of 117 N/cm^2 (170 lb/in^2), is 117 knots. (See ref. 9.) On the ungrooved surface (surface 1), both the maximum and skidding friction coefficients decrease to negligible values as the hydroplaning speed is approached. However, on the grooved surfaces, the ground speed at which the friction levels approach zero appears, in general, to be somewhat greater than the hydroplaning speed. This delay in dynamic hydroplaning may be attributed to the higher bearing pressures in the tire footprint which result from the reduced contact area provided by the grooving configurations combined with improved water drainage and possible mechanical interlock between the tire tread and the grooved surface. (See refs. 3, 10, and 11.)

Effect of Groove Configuration

The effect of runway groove configuration on the friction coefficients developed by both tires are summarized in figure 6 for all test surfaces. The figure shows that the friction coefficients developed on the grooved surfaces were higher than those developed on the ungrooved surface at corresponding ground speeds except for values of μ_{max} developed on surface 6 at the lower speeds. The low friction measured on surface 6, a modified V-groove configuration, is attributed to the polished lands and the rounded groove edges of this particular surface. The data of figure 6 show that with tire A, surfaces 4, 5, and 8 provided comparable flooded traction at a level slightly greater than that provided by the other grooved surfaces and, with tire B, surface 8 is shown to provide the best traction. The data suggest that tire braking capability under wet conditions increases as the total cross-sectional area of the pavement grooves in the tire footprint increases (or as the tire-to-surface contact area decreases). Of the groove configurations investigated, that of surface 8 (2.5 cm by 0.6 cm by 0.6 cm or 1 in. by 1/4 in. 1/4 in.) provided the greatest groove cross-sectional area and, in general, offered the best traction under flooded conditions. The groove configuration of surface 8 is the same configuration which was determined to be the best of 18 configurations evaluated during an earlier tire braking study conducted in 1967. The data of that study, reported in reference 10, were obtained from a smooth tread, size 27.5×7.5 , type VIII, aircraft tire inflated to 275 N/cm^2 (400 lb/in^2) undergoing locked-wheel skids at ground speeds up to 100 knots.

An effect of pavement groove shape is indicated in figure 7 by the braking traction levels developed with both test tires on three grooved configurations (surfaces 4, 5, and 6) with similar groove dimensions. Surface 4 has a rectangular groove shape with sharp

edges, surface 5 has rounded groove edges on the bottom with sharp edges on the top, and surface 6 has rounded groove edges at both top and bottom. No significant difference in the traction levels is noted between surface 4 and surface 5; however, there is a significant reduction in traction on surface 6 that is attributed to the rounded groove edges and to the inadvertently polished lands between the grooves. It should also be pointed out that rounding the groove edges tends to reduce the susceptibility of the tire tread to chevron cutting damage at touchdown. (See ref. 7.)

Effect of Tire Tread Design

Some effects of tire tread design on traction can be established from the data of figure 5. Data are presented for both test tires on each surface except for surface 3 where no data were obtained with tire A. Tires A and B were observed in reference 7 to be, respectively, the most and least susceptible to chevron cutting tread damage of the four tires tested and, as a result, were selected as the test tires in this program. The figure shows that tire A generally developed the higher value of μ_{\max} and μ_{skid} , the difference in friction levels between the two tires being greater on some surfaces than on others. This difference is attributed to the higher net bearing pressure associated with tire A (145 N/cm^2 (210 lb/in^2)) as compared with tire B (107 N/cm^2 (155 lb/in^2)). The tread groove area in the static footprint of tire A is nearly three times that of tire B (see fig. 3) which would alleviate dynamic hydroplaning effects and improve traction by increasing water drainage from the tire-ground contact zone.

CONCLUDING REMARKS

An experimental investigation was made to evaluate the effect of grooved runway patterns on the braking performance under flooded conditions of two aircraft tires having the same size and ply rating but of different tread design. The results indicate that the grooved surfaces provided greater tire braking traction than that obtained on the ungrooved surface for both tires. On all surfaces, tire braking traction varied inversely with speed due to hydroplaning effects. The level of braking traction under wet conditions was found to improve as the bearing pressure in the tire footprint was increased because of an increase in the groove area of the surface or the tire tread. The tire equipped with the greater tread groove area in the static footprint provided higher traction on essentially all test surfaces. The groove configuration which appeared to provide the best braking traction was a sawed rectangular groove 2.5 cm by 0.6 cm by 0.6 cm (1 in. by 1/4 in. by 1/4 in.) and the results obtained with this configuration substantiated test data obtained with a different tire in an earlier investigation. The groove configuration with rounded edges afforded the least braking traction of all those tested. Of the two tech-


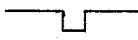
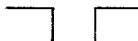

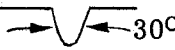
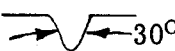

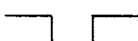
niques used to install the grooves in the test surface, the sawing technique provided more uniform and consistent groove patterns than those obtained with the combing technique.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., March 17, 1973.

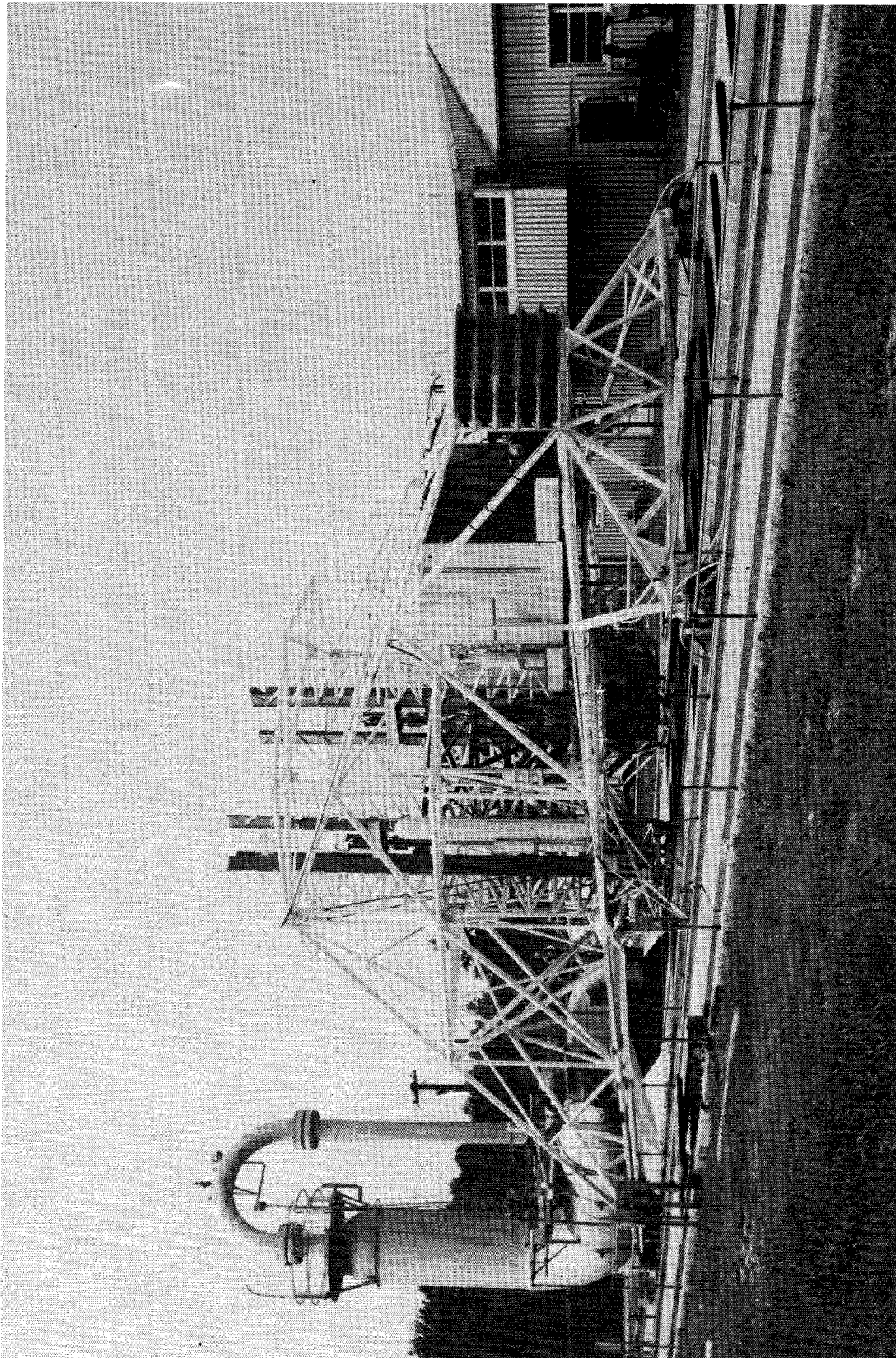
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TABLE I.- TEST SURFACES

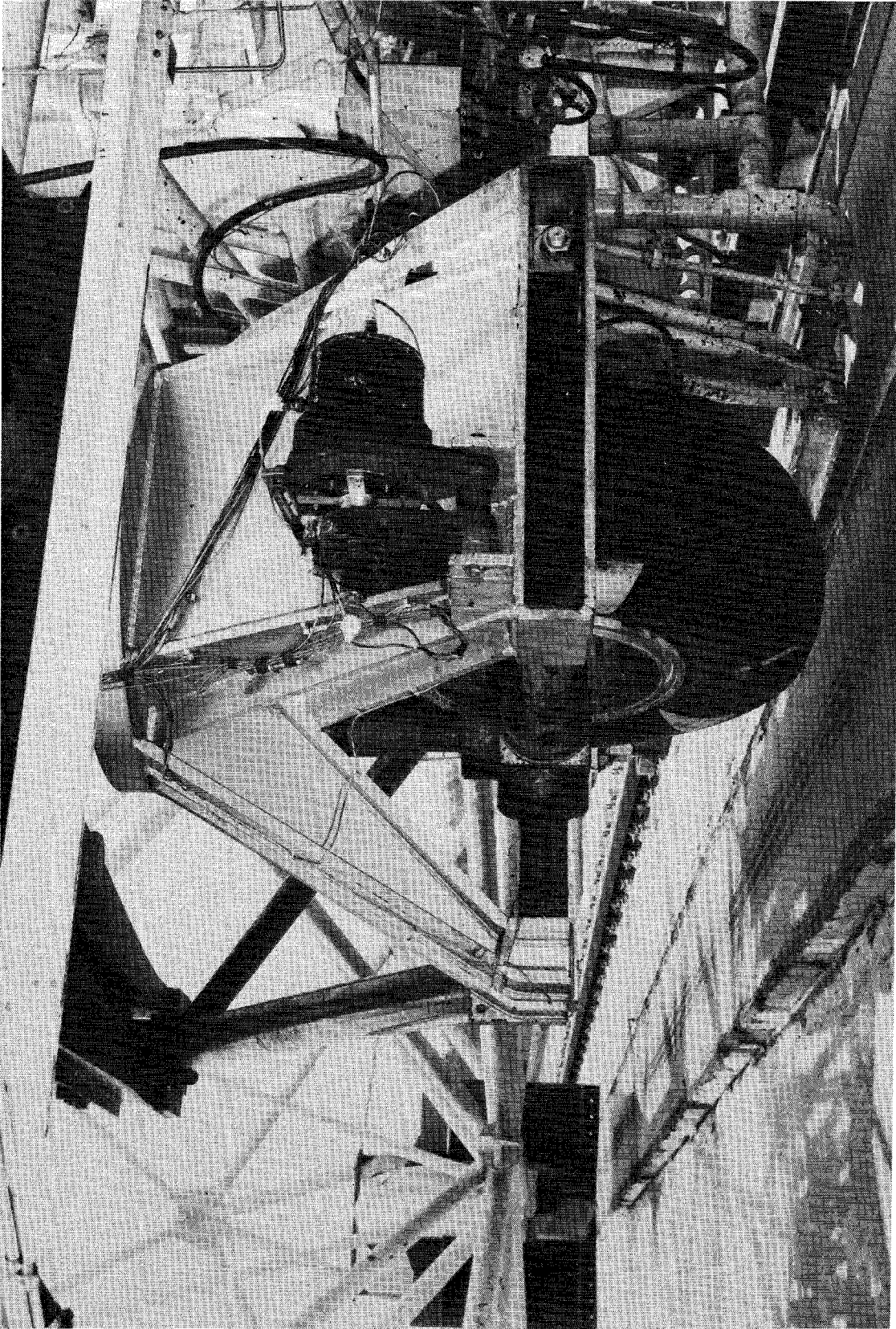
Surface	Groove configuration		Grooving technique	Surface and finish	
	Cross section	Dimensions			
		cm			in.
1		0	0	Ungrooved	Concrete, brush
2		$1.9 \times 0.3 \times 0.3$	$\frac{3}{4} \times \frac{1}{8} \times \frac{1}{8}$	Combed	↓
3		$3.2 \times 0.6 \times 0.6$	$1\frac{1}{4} \times \frac{1}{4} \times \frac{1}{4}$		
4		↓	↓	Sawed	↓
5					
*6					
7		$3.2 \times 0.5 \times 0.5$	$1\frac{1}{4} \times \frac{3}{16} \times \frac{3}{16}$	↓	Concrete, float
8		$2.5 \times 0.6 \times 0.6$	$1 \times \frac{1}{4} \times \frac{1}{4}$		

*Areas of the surface finish inadvertently polished during grooving operations.



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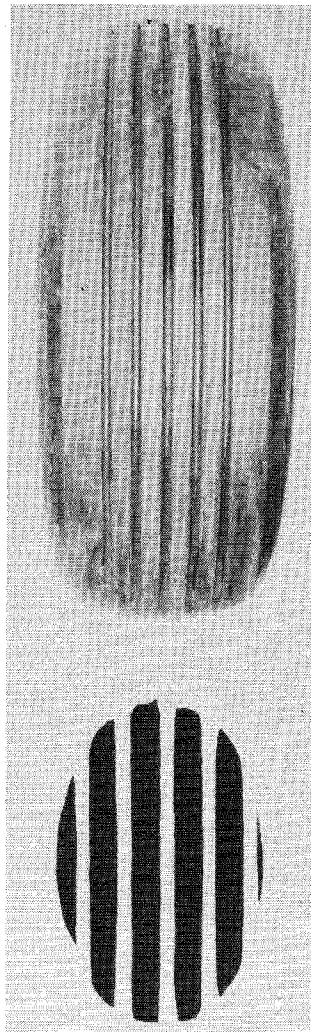
Figure 1. - Main test carriage at the Langley aircraft landing loads and traction facility.



L-69-5862

Figure 2.- Main test carriage dynamometer with tire, wheel, and brake assembly.

Tire A

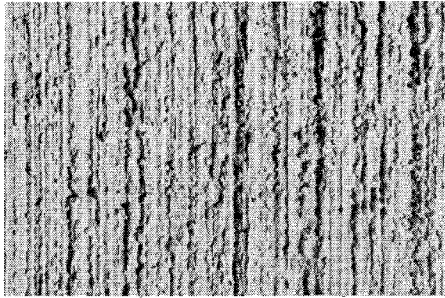


Tire B

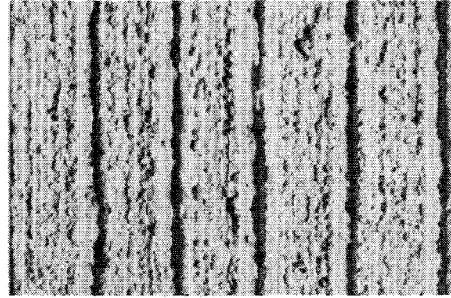


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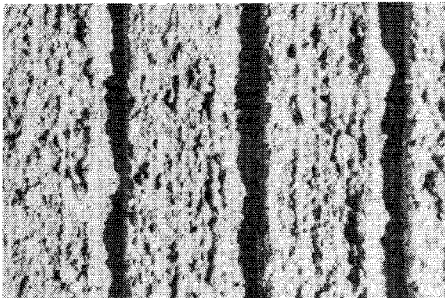
Figure 3.- Photographs of test tires and footprint under a vertical loading of 66.7 kN (15 000 lb) and inflation pressure of 117 N/cm² (170 lb/in²).



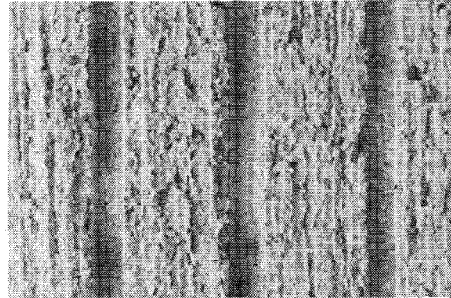
Surface 1



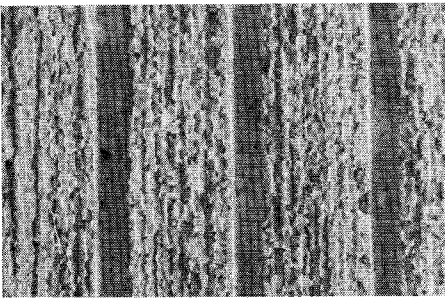
Surface 2



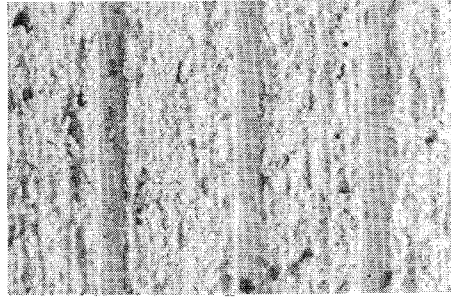
Surface 3



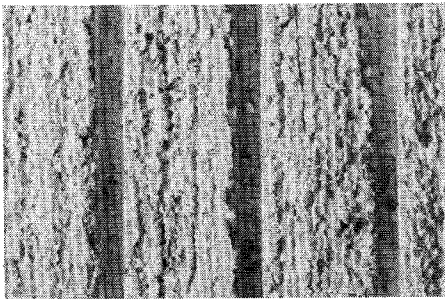
Surface 4



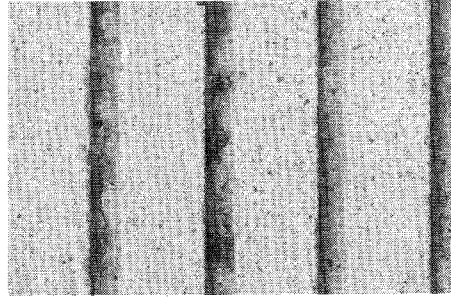
Surface 5



Surface 6



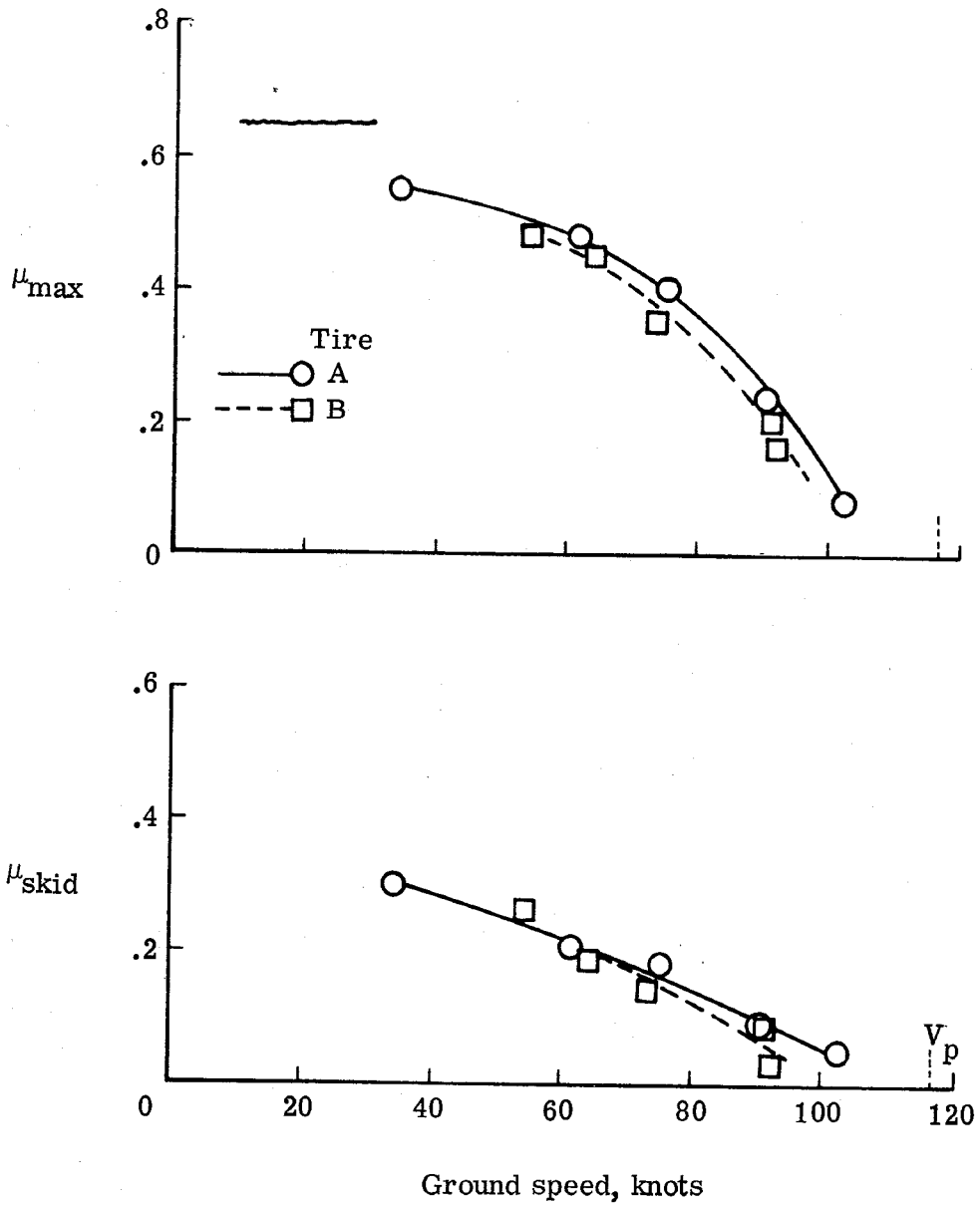
Surface 7



Surface 8

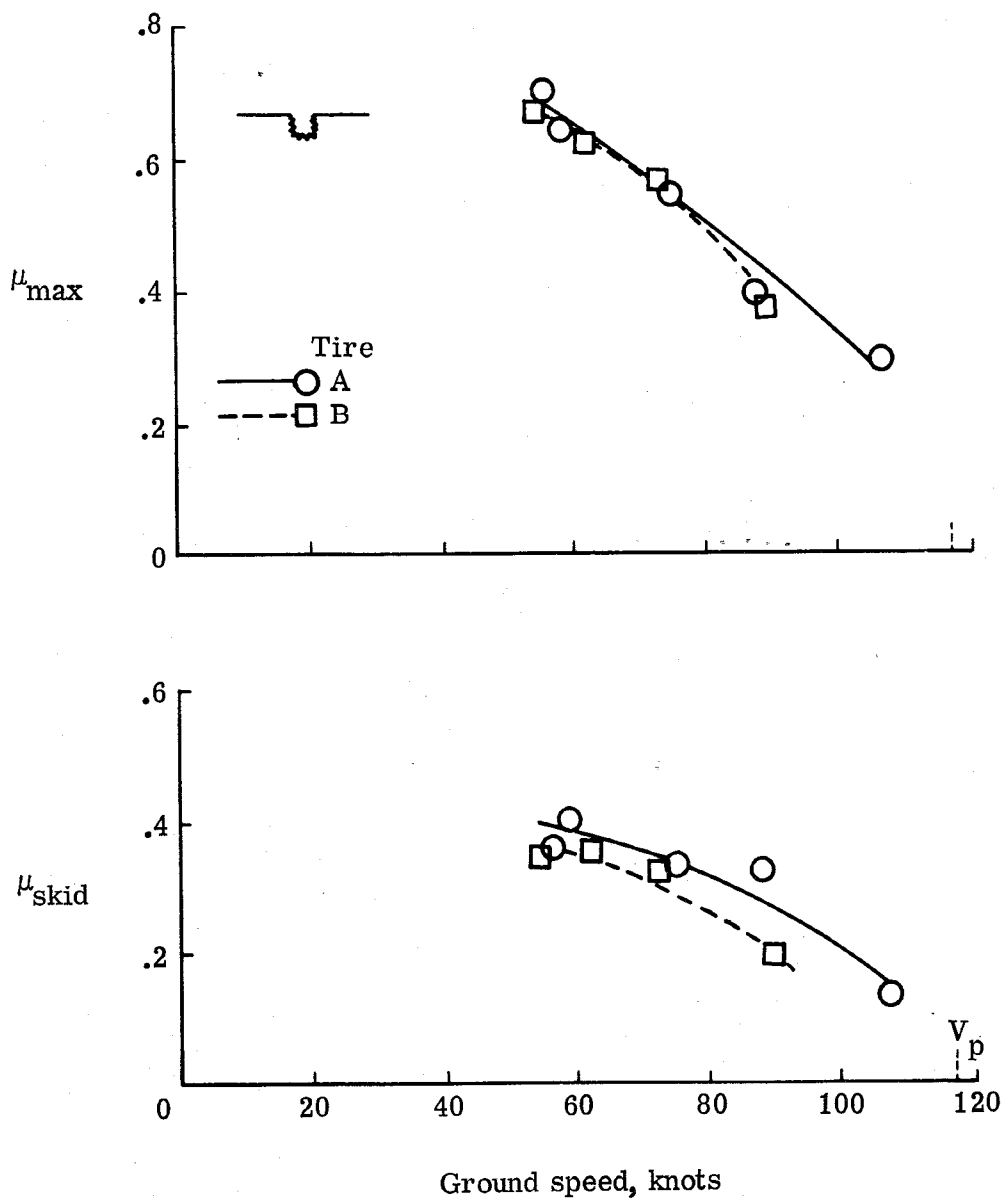
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Figure 4.- Photographs of test runway surfaces.



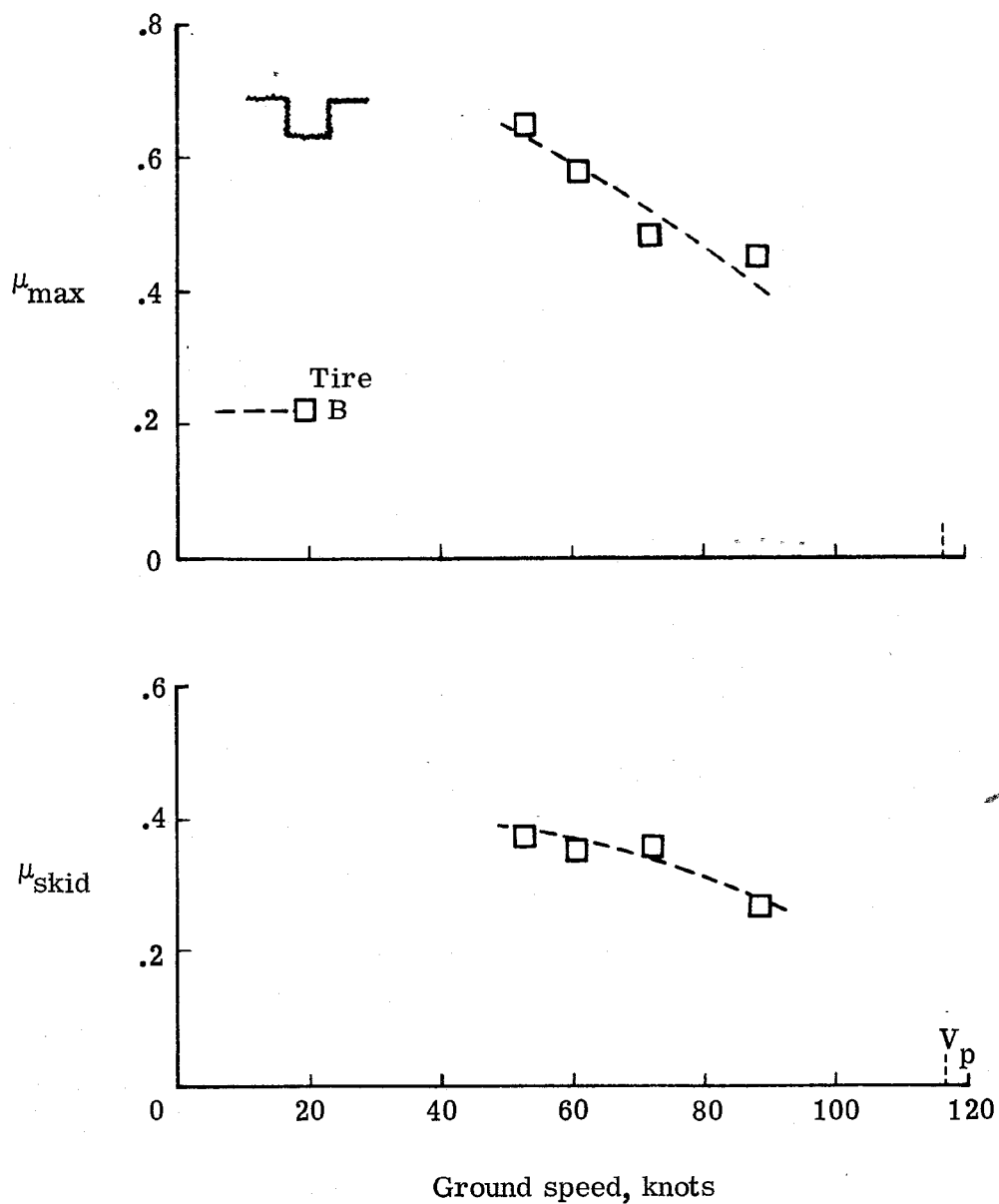
(a) Surface 1 (ungrooved).

Figure 5.- Summary of braking traction results on different test surfaces under flooded conditions.



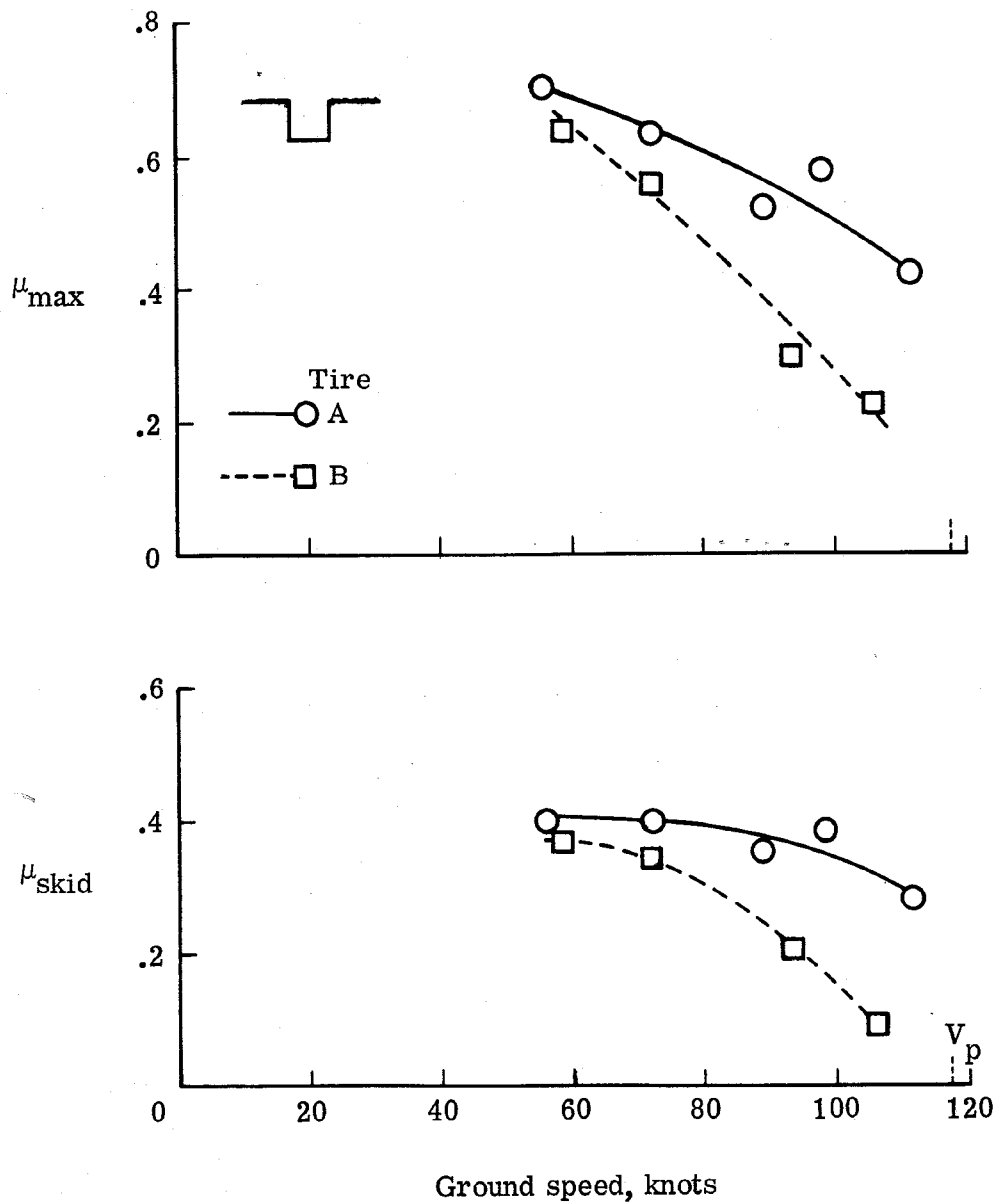
(b) Surface 2 (combed); 1.9 cm by 0.3 cm by 0.3 cm
 (3/4 in. by 1/8 in. by 1/8 in.); rectangular.

Figure 5.- Continued.



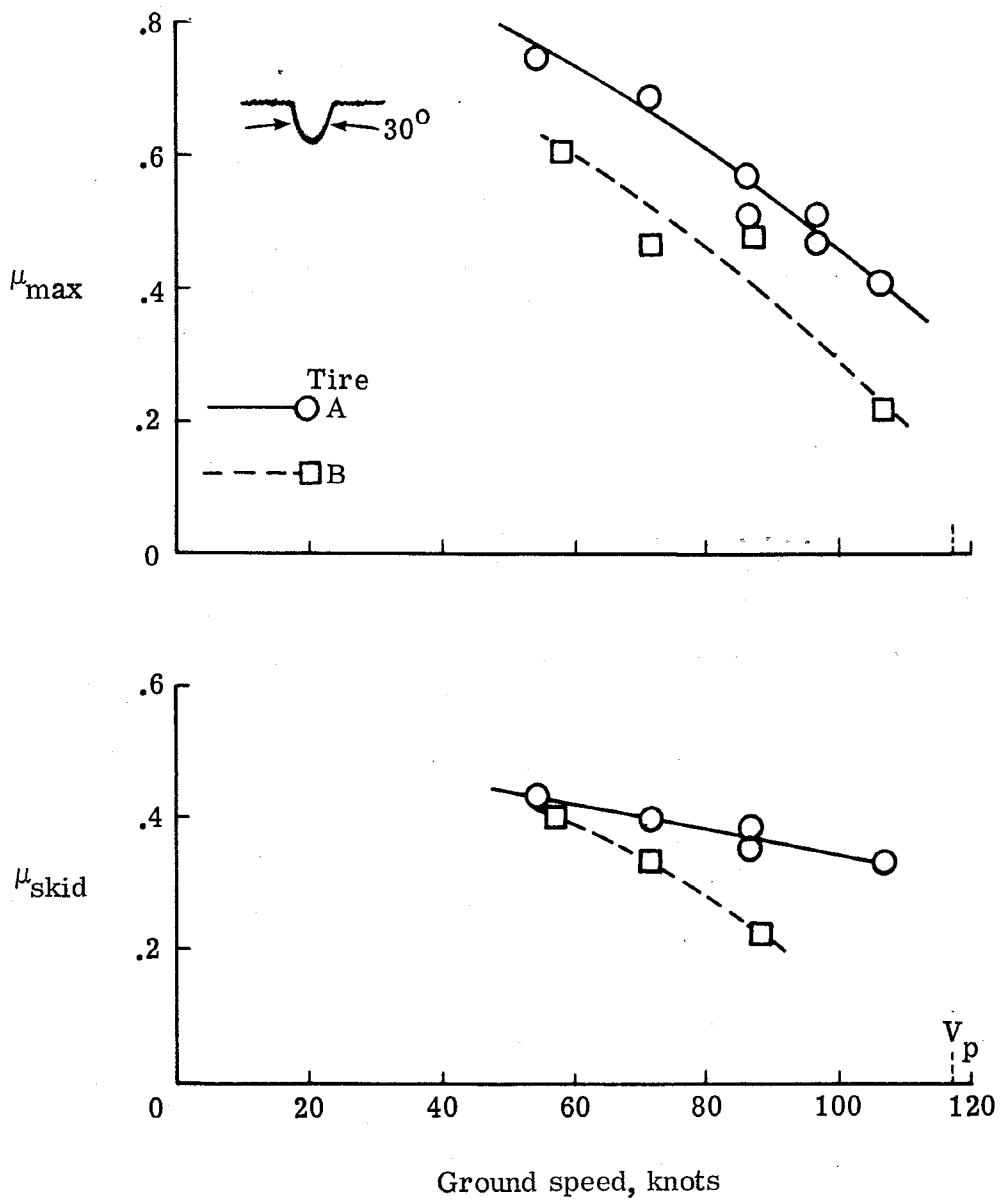
(c) Surface 3 (combed); 3.2 cm by 0.6 cm by 0.6 cm ($\frac{1}{4}$ in. by $\frac{1}{4}$ in. by $\frac{1}{4}$ in.); rectangular. Data not obtained for tire A.

Figure 5. - Continued.



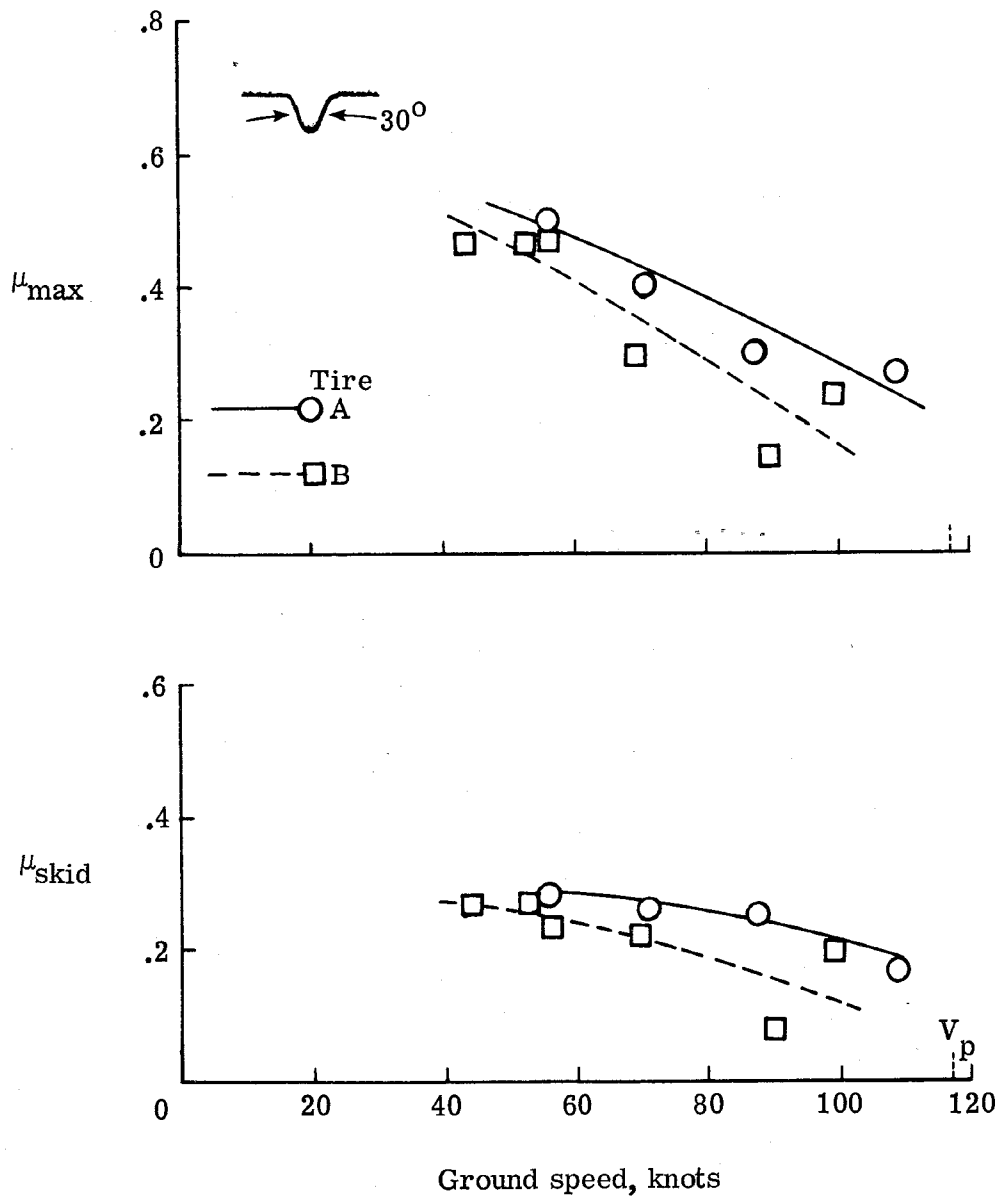
(d) Surface 4 (sawed); 3.2 cm by 0.6 cm by 0.6 cm
 ($1\frac{1}{4}$ in. by $\frac{1}{4}$ in. by $\frac{1}{4}$ in.); rectangular.

Figure 5. - Continued.



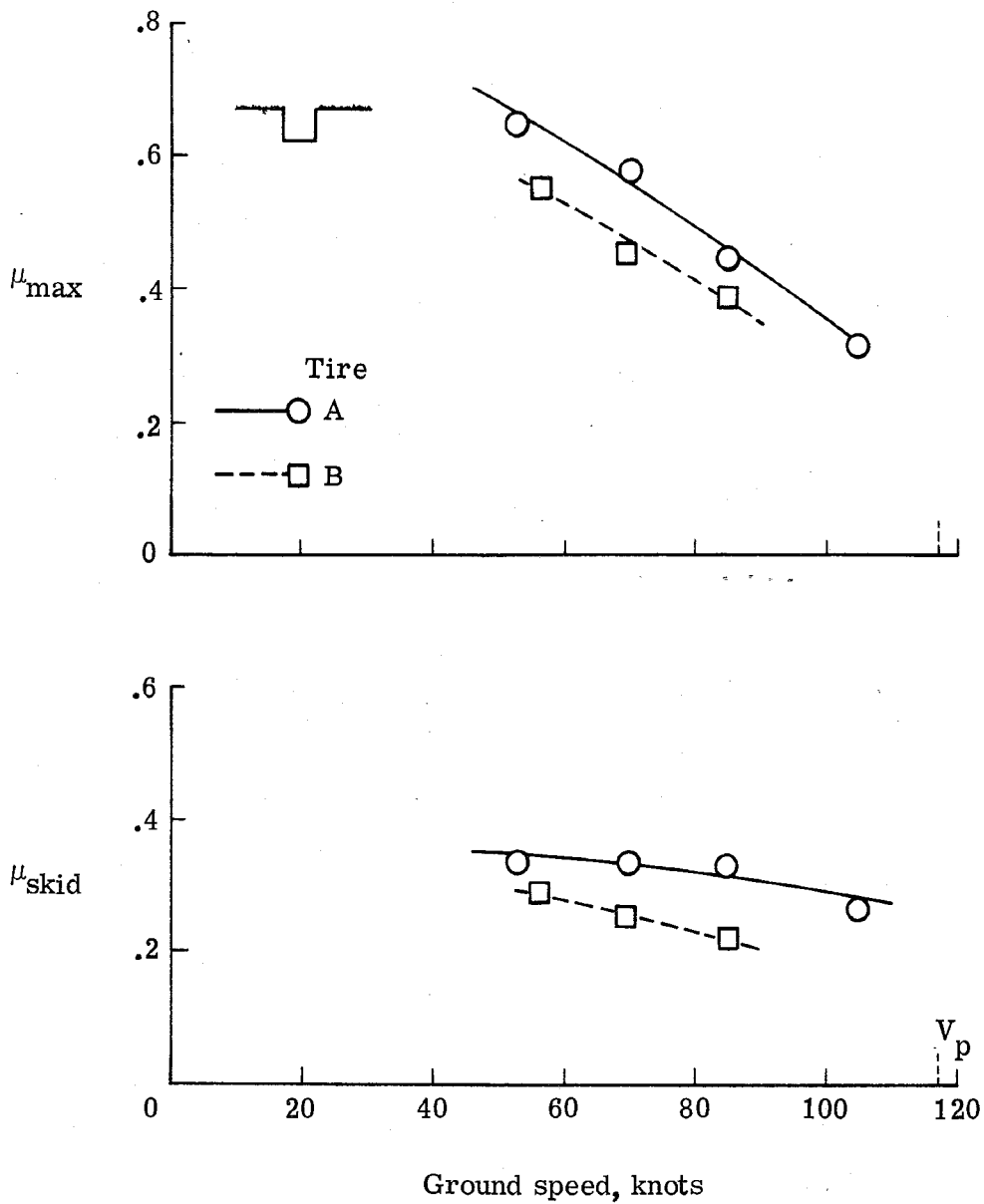
(e) Surface 5 (sawed); 3.2 cm by 0.6 cm by 0.6 cm
 ($1\frac{1}{4}$ in. by $\frac{1}{4}$ in. by $\frac{1}{4}$ in.); V-rounded bottom.

Figure 5. - Continued.



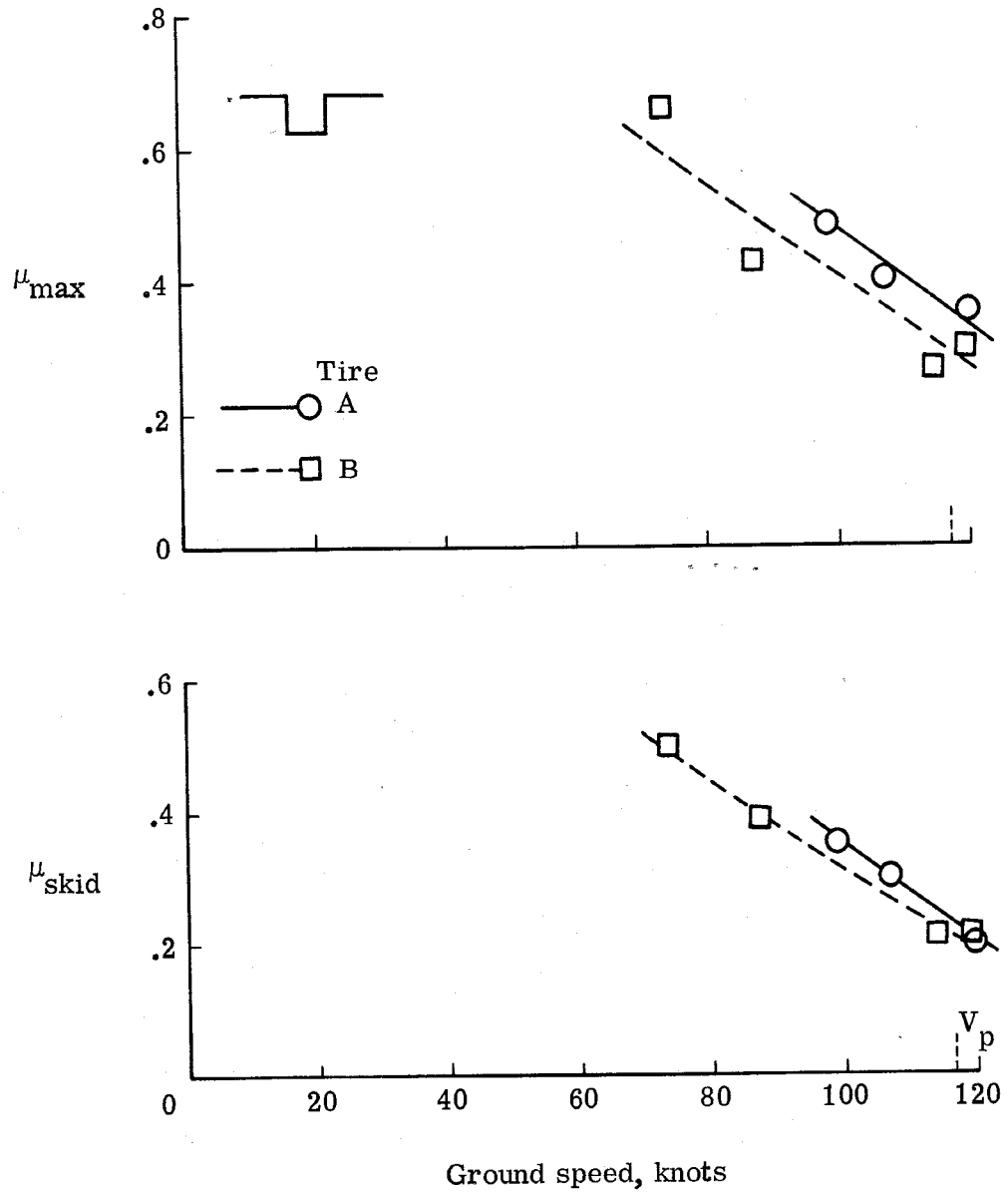
(f) Surface 6 (sawed); 3.2 cm by 0.6 cm by 0.6 cm ($1\frac{1}{4}$ in. by $\frac{1}{4}$ in. by $\frac{1}{4}$ in.); V-rounded edge and bottom.

Figure 5. - Continued.



(g) Surface 7 (sawed); 3.2 cm by 0.5 cm by 0.5 cm
 ($1\frac{1}{4}$ in. by $\frac{3}{16}$ in. by $\frac{3}{16}$ in.); rectangular.

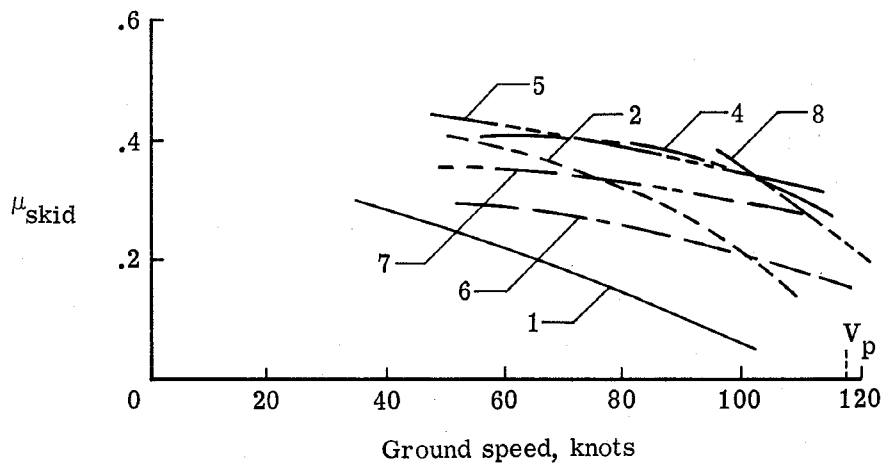
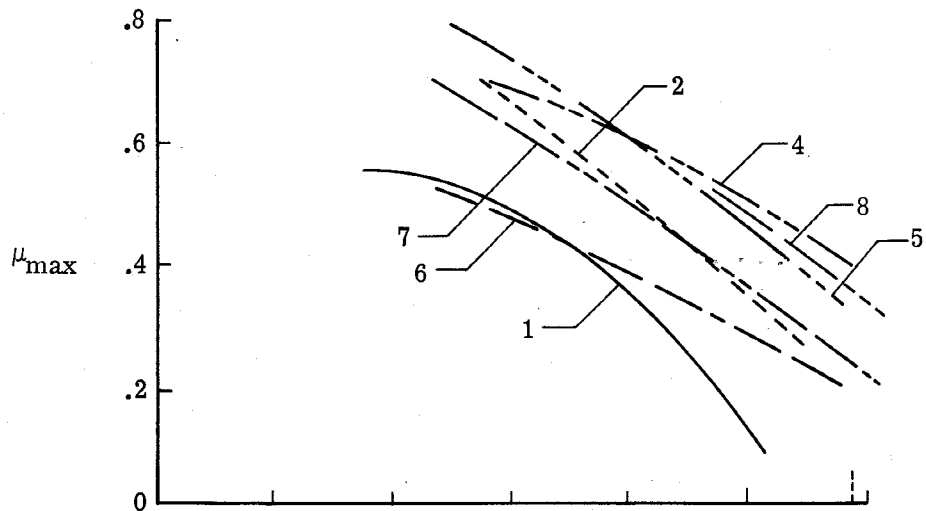
Figure 5. - Continued.



(h) Surface 8 (sawed); 2.5 cm by 0.6 cm by 0.6 cm
 (1 in. by 1/4 in. by 1/4 in.); rectangular.









Figure 5.- Concluded.

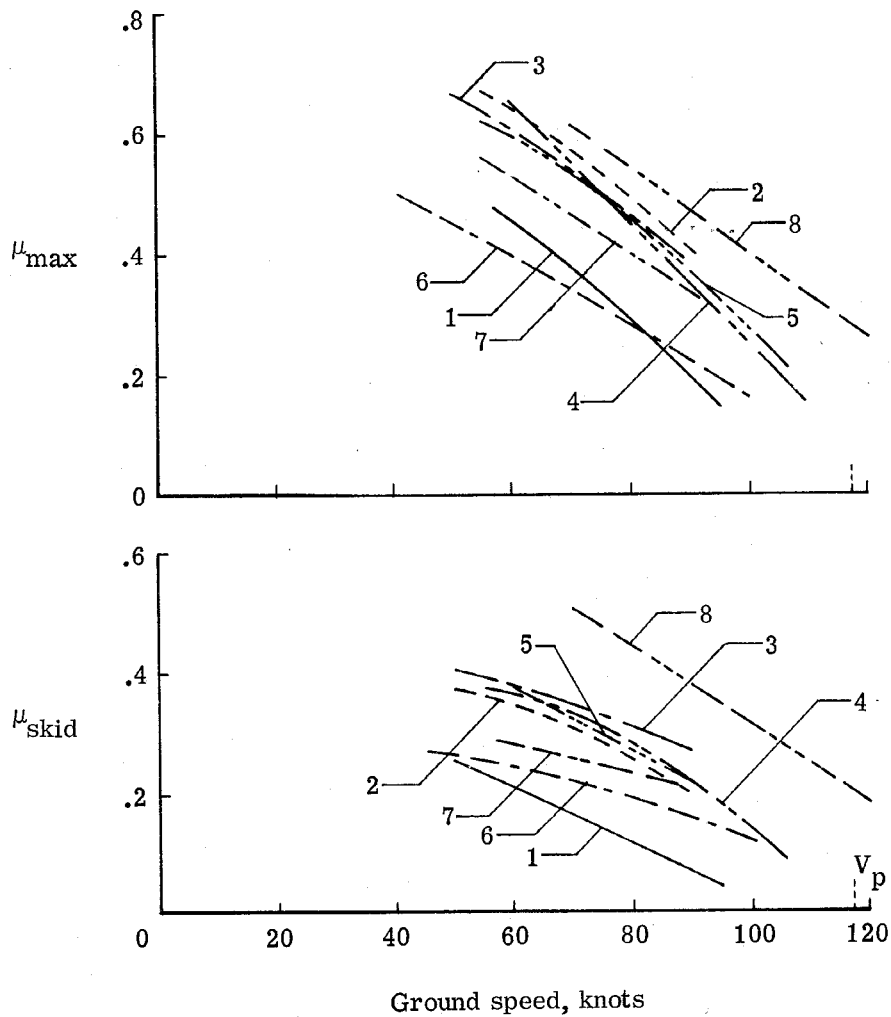
Surface	Line code	Grooving technique	Grove pattern dimensions		Surface shape
			cm	in.	
1	————	None	————	————	————
2	- - - -	Combed	1.9 × 0.3 × 0.3	3/4 × 1/8 × 1/8	
3	- - - -	Combed	3.2 × 0.6 × 0.6	1-1/4 × 1/4 × 1/4	
4	- - - -	Sawed			
5	- - - -				
6	- - - -				
7	- - - -		3.2 × 0.5 × 0.5	1-1/4 × 3/16 × 3/16	
8	- - - -		2.5 × 0.6 × 0.6	1 × 1/4 × 1/4	



(a) Tire A.

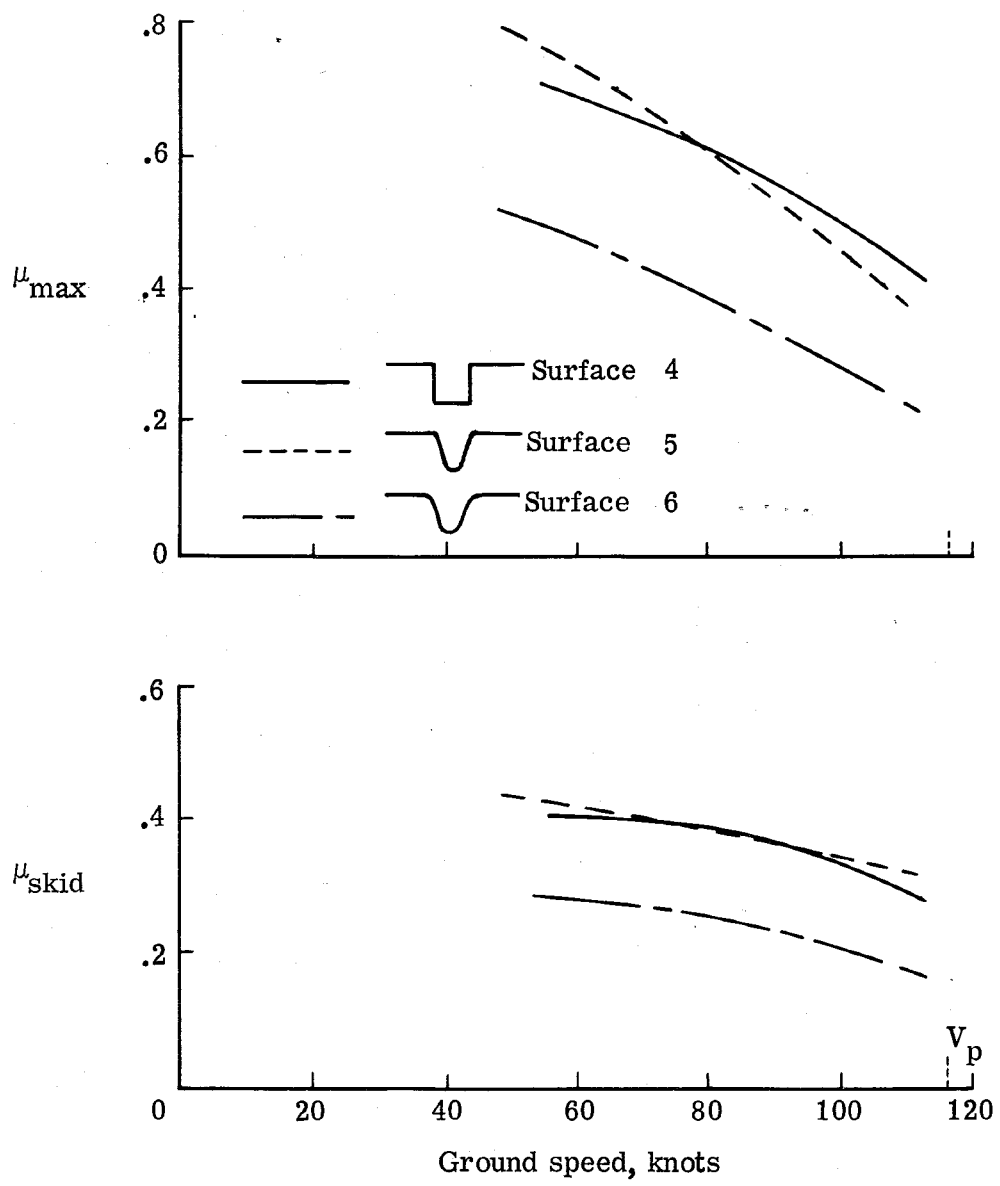
Figure 6.- Effect of runway groove patterns on flooded braking traction.

Surface	Line code	Grooving technique	Groove pattern dimensions		Surface shape
			cm	in.	
1	————	None	————	————	
2	- - - -	Combed	1.9 × 0.3 × 0.3	3/4 × 1/8 × 1/8	
3	- - - -	Combed	3.2 × 0.6 × 0.6	1-1/4 × 1/4 × 1/4	
4	- - - -	Sawed	↓	↓	
5	- - - -	↓	↓	↓	
6	- - - -	↓	↓	↓	
7	- - - -	↓	3.2 × 0.5 × 0.5	1-1/4 × 3/16 × 3/16	
8	- - - -	↓	2.5 × 0.6 × 0.6	1 × 1/4 × 1/4	



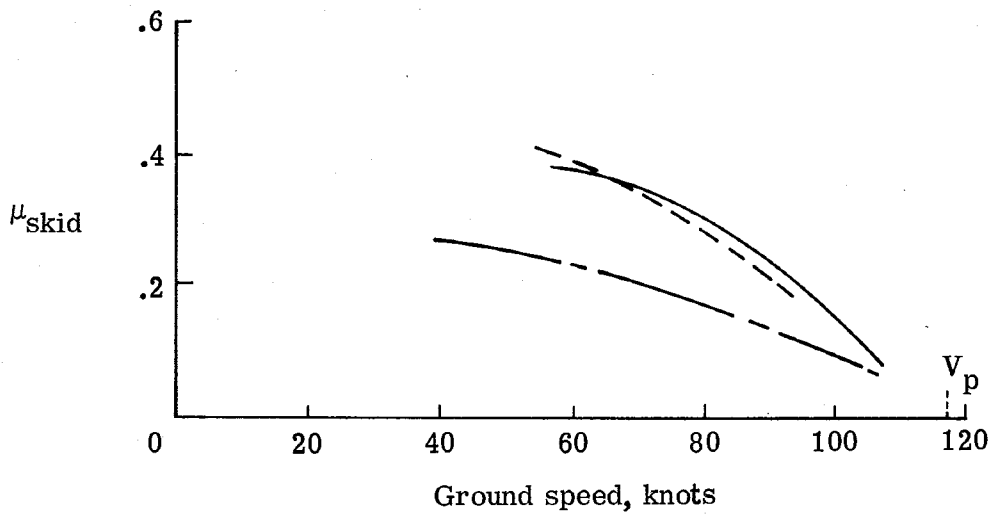
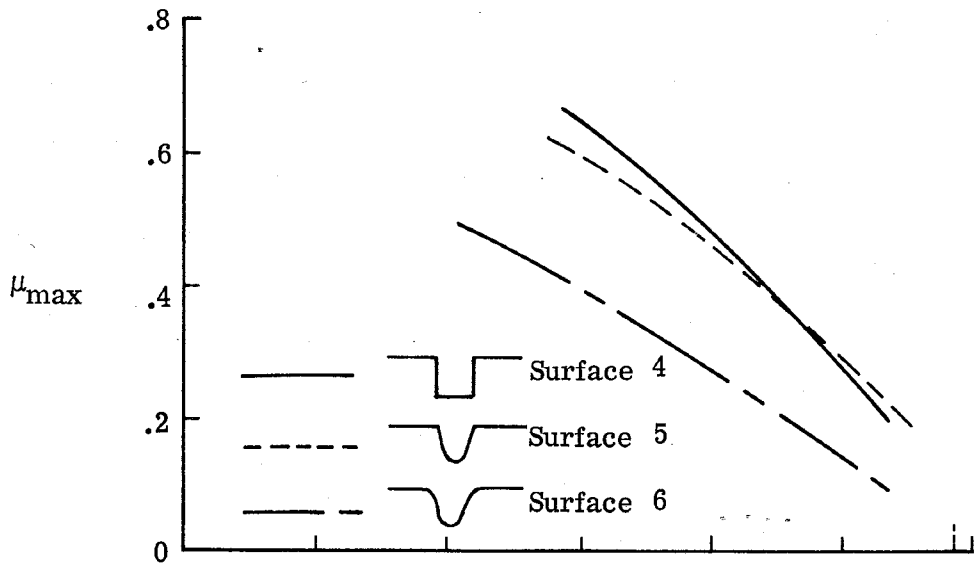
(b) Tire B.

Figure 6. - Concluded.



(a) Tire A.

Figure 7.- Effect of groove shape on braking traction.



(b) Tire B.

Figure 7.- Concluded.



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