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EXPERIMENTAL INVESTIGATION OF THE CORNERING CHARACTERISTICS OF 18 × 5.5, TYPE VII, AIRCRAFT TIRES WITH DIFFERENT TREAD PATTERNS

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In both text and figures, all yaw angles mentioned should be multiplied by 1.36. Thus, the test yaw angles 4°, 8°, and 12° should be 5.4°, 10.9°, and 16.3°, respectively.

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16. Abstract

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The results of this investigation indicated that a tread pattern with pinholes in the ribs reduced the tire cornering capability at high yaw angles on a damp surface but improved cornering on a dry surface. A tread pattern which had transverse grooves across the entire width of the tread was shown to improve the tire cornering performance slightly at high speeds on the flooded runway surface. The cornering capability of all the tires was degraded at high ground speeds by thin film lubrication and/or tire hydroplaning effects. Alterations to the conventional tread pattern provided only marginal improvements in the tire cornering capability; this would suggest that runway surface treatments may be a more effective way of improving aircraft ground performance during wet operations.

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SUMMARY

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INTRODUCTION

A large percentage of wet runway skidding accidents involving high-performance jet aircraft occur because the aircraft slides off the side of the runway under the influence of a crosswind. During the approach and initial roll-out phases of the landing operation, the crosswind is usually manageable because the pilot can maintain directional control by taking advantage of aerodynamic forces. As the ground speed is reduced, however, aerodynamic control forces become less effective and the pilot must rely more upon nose-gear steering to provide the desired aircraft heading on the runway. Past research (refs. 1 to 4, for example) has indicated that aircraft steering capability is decreased during wet runway operations by thin film lubrication and/or dynamic hydroplaning effects. One approach to eliminate or at least delay the deleterious effects attributed to hydroplaning is to modify the design of the tire tread. Tread pattern research (refs. 1 and 5, for example) indicates that the friction level generated by a tire on a wet runway surface may be improved by an increase in the number of circumferential grooves or by the addition of transverse grooves in the tread. It should be noted, however, that tread wear and chunking during high-speed ground operations are limiting factors to any tread alteration.

The purpose of this paper is to present the results of an investigation to evaluate the wet runway cornering characteristics of 18 × 5.5, type VII, aircraft tires with four different tread configurations. These characteristics, which include the cornering-force and drag-force friction coefficients and the self-alining torque, were obtained for the tires on damp and flooded runway surfaces, with limited tests on a dry surface, over a range of yaw angles from 0° to 12° and at ground speeds from 5 to 90 knots (1 knot = 0.5144 m/sec). The tires used in the tests were supplied by the U.S. Air Force (Rain Tire – Project 5549).

SYMBOLS

Measurements and calculations were made in U.S. Customary Units and converted to SI Units. Factors relating the two systems are presented in reference 6.

T_z self-alining torque, N-m (in-lb)

μ_d drag-force friction coefficient, parallel to the direction of motion, $\dfrac{\text{Drag force}}{\text{Vertical force}}$

μ_s cornering-force friction coefficient, perpendicular to the direction of motion, $\dfrac{\text{Cornering force}}{\text{Vertical force}}$

APPARATUS AND TEST PROCEDURE

Tires

The tires of this investigation were 18 × 5.5, type VII, 14-ply-rating aircraft tires employed on the nose gear of several military and civilian jet aircraft. A photograph of the test tires is presented in figure 1. Tire A has the standard three-groove tread configuration currently in use. Tire B has seven circumferential grooves with a large number of "pinholes" in each rib. Tires C and D have a circumferential groove pattern similar to that of tire A, but modified with transverse grooves. These grooves are limited to the shoulder area in tire C and extend across the entire tread in tire D. The dimensions of the various tread grooves and special features are listed in table I.

All tires were tested at an inflation pressure of 1138 kPa (165 psi), and the vertical load was varied with ground speed to simulate the effects of wing lift. This loading was determined from U.S. Air Force aircraft tests and varied from approximately 20.69 kN (4650 lbf) at 5 knots to 11.12 kN (2500 lbf) at 90 knots, as shown in figure 2.

Runway Surface Conditions

For the tests described in this paper, approximately 82 m (270 ft) of a concrete test runway were divided into two sections to provide tire cornering data on flooded and damp surfaces. The first 58-m (190 ft) section was maintained in a damp condition (no visible standing water), and the last 24-m (80 ft) section was surrounded by a dam and flooded with water to a depth of approximately 0.64 cm (0.25 in.). To define the effect of wetness further, a limited number of tests were conducted with each tire on a dry surface. A grease sampling technique, described in reference 7, indicated that the average texture depth was 244 μm (0.0096 in.) for the surface in the damp test section and 99 μm (0.0039 in.) in the flooded test section, whereas typical texture depths for operational runways generally vary between 100 μm (0.0039 in.) and 400 μm (0.0157 in.).

Test Facility

The investigation was performed at the Langley aircraft landing loads and traction facility, which is described in reference 8, and utilized the test carriage pictured in figure 3. Presented in figure 4 is a schematic of the instrumented dynamometer which supports the wheel and measures the various axle loadings. The instrumentation consisted of load beams to measure vertical, drag, and side forces at the axle. Additional instrumentation was provided to measure wheel angular velocity, carriage displacement, and vertical, drag, and side accelerations at the axle for inertial corrections. Continuous time histories of the output of the instrumentation were recorded on an oscillograph mounted on the test carriage.

Test Procedure

The test procedure consisted of either propelling or towing the test carriage across the runway test sections at the desired ground speed, releasing the test fixture to apply the desired vertical load on the tire, and monitoring the output from the onboard instrumentation. The tire yaw angle was held constant for each test run, and in a test series, was varied from 0° to 12° in 4° increments. Ground speeds for these tests ranged from approximately 5 to 90 knots. For a ground speed of 5 knots, the test carriage was towed by a ground vehicle; for higher speeds, the carriage was propelled by the hydraulic water jet, as described in reference 8.

RESULTS AND DISCUSSION

Time histories of forces in the vertical, drag, and side directions and of wheel angular velocity were recorded on an oscillograph throughout each test. These time histories were used to compute steady-state values of the cornering-force friction coefficient μ_s perpendicular to the direction of motion and the drag-force friction coefficient μ_d parallel to the direction of motion. The self-alining torque T_z about the vertical or steering axis of the wheel was computed from the load transfer between the two drag-load beams shown in figure 4. The following sections discuss the variation of these cornering characteristics with yaw angle and ground speed for the different surface wetness conditions.

Effect of Yaw Angle

The effects of yaw angle on the cornering- and drag-force friction coefficients and the self-alining torque developed by the various test tires on damp and flooded surfaces at nominal ground speeds of 5, 50, and 90 knots are presented in figure 5.

Cornering-force friction coefficient.- The cornering-force friction coefficients μ_s for all test tires operating on wetted surfaces are faired by a single curve for each test condition in figure 5. The cornering-force friction coefficient for each tire is shown to vary with yaw angle in an expected manner (refs. 1 to 3). At 5 knots μ_s increases with increasing yaw angle up to and including the maximum yaw angle tested on both the damp and flooded surfaces, whereas at the higher test speeds, μ_s peaks between 4° and 8° and then decreases with a further increase in yaw angle. The figure further shows that at 5 knots, μ_s is essentially independent of the surface wetness condition; but at higher test speeds, particularly at 90 knots, where the tire approaches its predicted hydroplaning speed of 116 knots (ref. 9), μ_s decreases more rapidly on the flooded surface than on the damp surface.

Of the tires examined, one tire develops somewhat higher cornering friction and another tire develops somewhat lower cornering friction than the others. However, the conditions which provided these differences appear to be quite limited. As shown by the data of figures 5(b) and 5(c), tire D provides a slightly higher cornering capability than the other tires at high speeds on the flooded surface. The improved performance of this tire is attributed to the transverse grooves in the tread, which extend from shoulder to shoulder. These grooves apparently provide escape routes for the bulk of the water in the tire footprint under flooded conditions and thereby delay dynamic hydroplaning effects. Tire C also has transverse grooves, but only in the shoulder area; hence, their lateral drainage capability in the center of the footprint is negligible. This trend is in agreement with the results noted in reference 1 for similar tread patterns. Since the data of figure 5 suggest that only marginal improvements in the cornering capability can be gained through modifications to the conventional tread pattern, it appears that runway grooving or other surface treatments would be a more effective means for providing an airplane with directional control on wet runways.

Of the tires evaluated, tire B demonstrated the poorest cornering capability at the highest test yaw angle and on a damp surface. The reduced cornering friction provided by this tire, best illustrated by the data of figure 5(c), is attributed to the numerous pinholes in the tread, which apparently trap water in the tire footprint and thus reduce its wet cornering capability. This trend is similar to that noted for dimple-tread tires in reference 5.

The results from the limited tests to ascertain the level of friction provided by each tire on an unwetted surface are presented in figure 5(c). These tests were conducted only at a nominal ground speed of 90 knots and examined tire A, with the conventional tread design, at all test yaw angles and the remaining tires at an arbitrarily selected yaw angle of 8°. The available data indicate that, except for tire B, all the tires provide essentially the same dry cornering capability. The higher dry cornering friction provided by tire B is believed to be due to the numerous pinholes in the tread of that tire, which would tend to soften the tread rubber sufficiently to increase the size of the footprint and, hence, improve the dry traction.

Drag-force friction coefficient.- Figure 5 shows that the drag-force friction coefficient μ_d developed by all test tires appears to increase linearly with an increase in yaw angle and is essentially faired by a single curve for each test condition; hence, no major differences between the tires in terms of yawed drag are implied. The figure further shows that at 5 knots, μ_d is essentially independent of the surface wetness condition at all yaw angles; but at the higher test speeds, μ_d is higher on the flooded runway than on the damp runway, particularly at small yaw angles. The higher values of μ_d on the flooded surface are attributed to fluid drag and are in agreement with the results from similar tests conducted on other tires presented in references 2 and 3.

Data from tests on a dry surface (fig. 5(c)) show that μ_d increases with yaw angle and, in general, is slightly higher than that developed on the damp surface, particularly at higher yaw angles.

Self-alining torque.- The self-alining torque is significant in that it provides the feedback necessary to ensure a stable (self-centering) steering system. Positive torque values denote a stable steering system and negative values denote an unstable one. Data illustrating the effect of yaw angle on the self-alining torque T_z produced by the four test tires are also presented in figure 5. The data indicate that for all test conditions, T_z reaches maximum positive values at a yaw angle of approximately 4°, except for the high-speed tests on a flooded surface, where the maximum values occur between 4° and 8°. At higher yaw angles, the trend of tha data for all conditions is toward negative torque.

This destabilizing torque is exhibited by all tires on the dry surface at a yaw angle of 8°. The range of yaw angles through which the torque is self-alining is shown to increase with increasing ground speed. Again, similar trends were noted in references 2 and 3. The data provide no trends to suggest that on the basis of self-alining torque, one tire tread design is significantly superior or inferior to the others.

Effect of Ground Speed

The effects of ground speed on the cornering-force and drag-force friction coefficients and on the self-alining torque for all the test tires are presented in figure 6.

Cornering-force friction coefficient.- The data in figure 6 indicate that except for the test condition of a damp runway and a 4° yaw angle, the cornering-force friction coefficient μ_s developed by the different tires decreases with increasing speed. This trend is most prominent on the flooded surface, where dynamic hydroplaning effects of the tire become significant. On the damp runway at a 4° yaw angle, μ_s for all tires increases slightly with speed up to and including the maximum speed tested. Figure 6(c) shows more clearly the relatively poor cornering capability of tire B on the damp runway at a 12° yaw angle. As noted previously, at high speeds on the flooded runway surface, tire D appears to have a slightly higher cornering capability than the other tires tested.

Drag-force friction coefficient.- Figure 6 shows that the drag-force friction coefficient μ_d is essentially insensitive to speed. Because of fluid-drag effects, μ_d values on the flooded surface are slightly higher than those on the damp surface at high ground speeds; no significant differences exist at low speeds.

Self-alining torque.- Figure 6 shows the variation of the self-alining torque T_z with ground speed and further illustrates its dependency upon yaw angle and its insensitivity to surface wetness condition. At a yaw angle of 4°, which generally corresponds to the yaw angle for maximum T_z, the self-alining torque decreases with increasing ground speed. A similar but less prominent reduction occurs with speed at a yaw angle of 8°. At 12° yaw angle the effect of ground speed is to increase T_z from small negative values at 5 knots to small positive values at 90 knots.

SUMMARY OF RESULTS

Tests were conducted at the Langley aircraft landing loads and traction facility to determine the cornering characteristics of 18×5.5, type VII, aircraft tires with four tread patterns. These characteristics, which include the drag-force and cornering-force friction coefficients and self-alining torque, were obtained on dry, damp, and flooded runway surfaces over a range of yaw angles from 0° to 12° and at ground speeds from 5 to 90 knots. The results from these tests are summarized as follows:

1. Of the tires examined, the tire with a large number of pinholes in the tread provided the highest cornering capability on a dry surface but was shown to have the poorest cornering capability on a damp surface. On the flooded runway, the tire with transverse grooves extending across the tread width provided the best cornering capability at high ground speeds.

2. The cornering-force friction coefficient for all test tires was shown to (a) increase with yaw angle, at a ground speed of 5 knots, up to and including the maximum yaw angle tested; (b) reach peak values between yaw angles of 4° and 8° for speeds of 50 to 90 knots, then decrease with a further increase in yaw angle on all surfaces; (c) increase with increasing ground speed on the damp runway at a yaw angle of 4°; and (d) decrease with increasing ground speed on the flooded and damp runway surfaces for all other test conditions.

3. The drag-force friction coefficient for all test tires was shown to (a) increase linearly with increasing yaw angle, (b) be independent of surface wetness condition at 5 knots, and (c) be higher on the flooded runway surface than on the damp runway surface at small yaw angles and high ground speeds because of increased fluid drag.

4. The self-alining torque for all test tires was shown to (a) reach maximum stabilizing values between yaw angles of 4° and 8° and to decrease with a further increase in yaw angle, (b) decrease with increasing ground speed at 4° and 8° yaw angles, and (c) increase from small negative values at 5 knots to small positive values at 90 knots at a 12° yaw angle.

The results of this investigation indicate that since alterations to the conventional tread pattern provide only marginal improvements in the tire cornering capability, runway surface treatments may be a more effective way of improving aircraft ground performance during wet operations.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., November 21, 1974.

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TABLE I.- FEATURES OF TIRE TREAD GROOVES

Tire	Number of circumferential grooves	Groove dimensions, width × depth, cm (in.)	Special features	Feature dimensions, width × depth, cm (in.)
A	3	0.48 × 0.30 (0.19 × 0.12)	None	---------------------
B	7	0.64 × 0.30 (0.25 × 0.12)	Pinholes	0.15 diam × 0.30 deep (0.06 diam × 0.12 deep)
C	3	0.64 × 0.30 (0.25 × 0.12)	Transverse grooves, shoulder only	0.79 × 0.53 (0.31 × 0.21)
D	3	0.64 × 0.30 (0.25 × 0.12)	Transverse grooves across tread	0.79 × 0.53 (0.31 × 0.21)

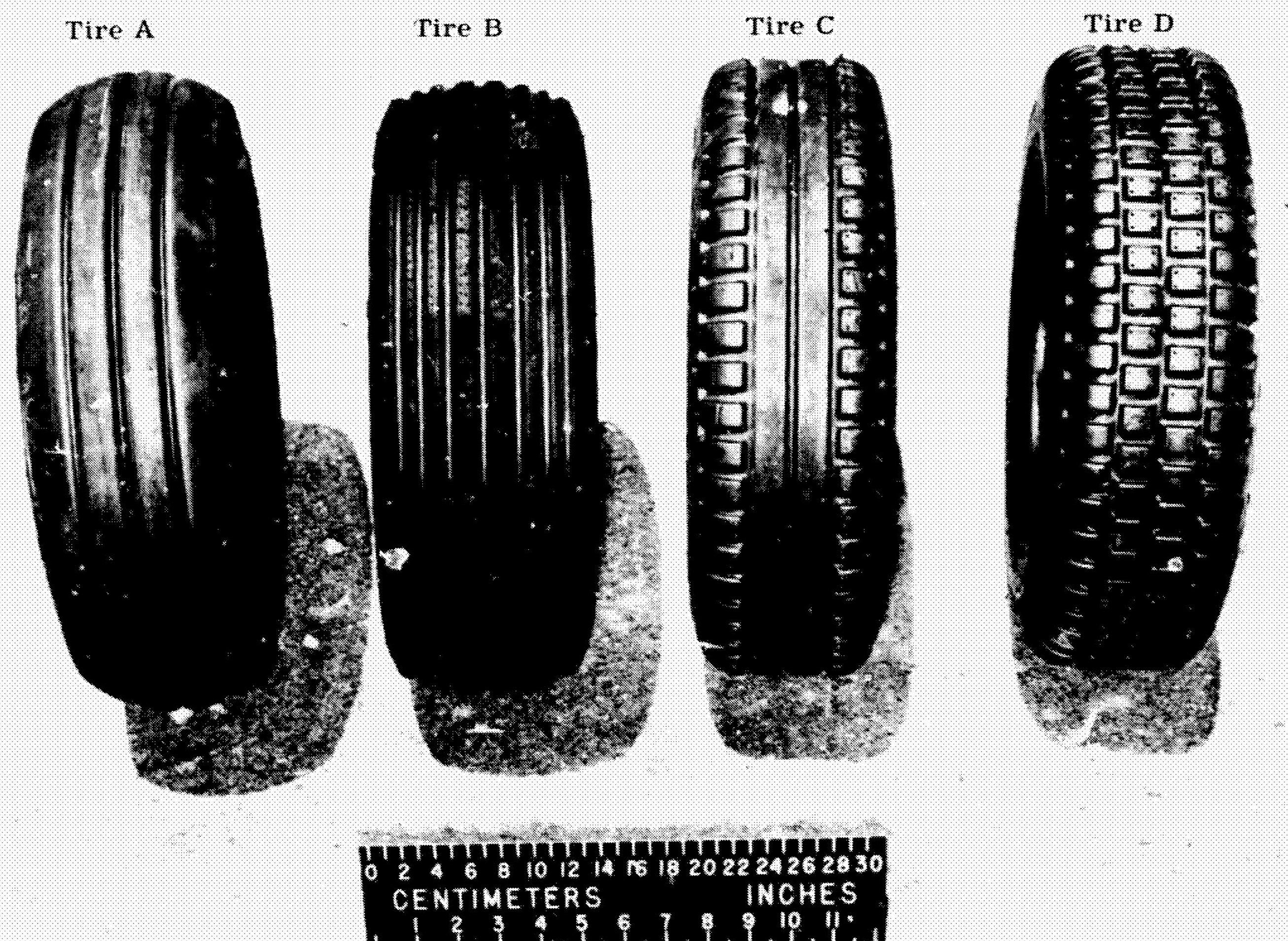

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Figure 1.- Photograph of test tires showing the different tread patterns.

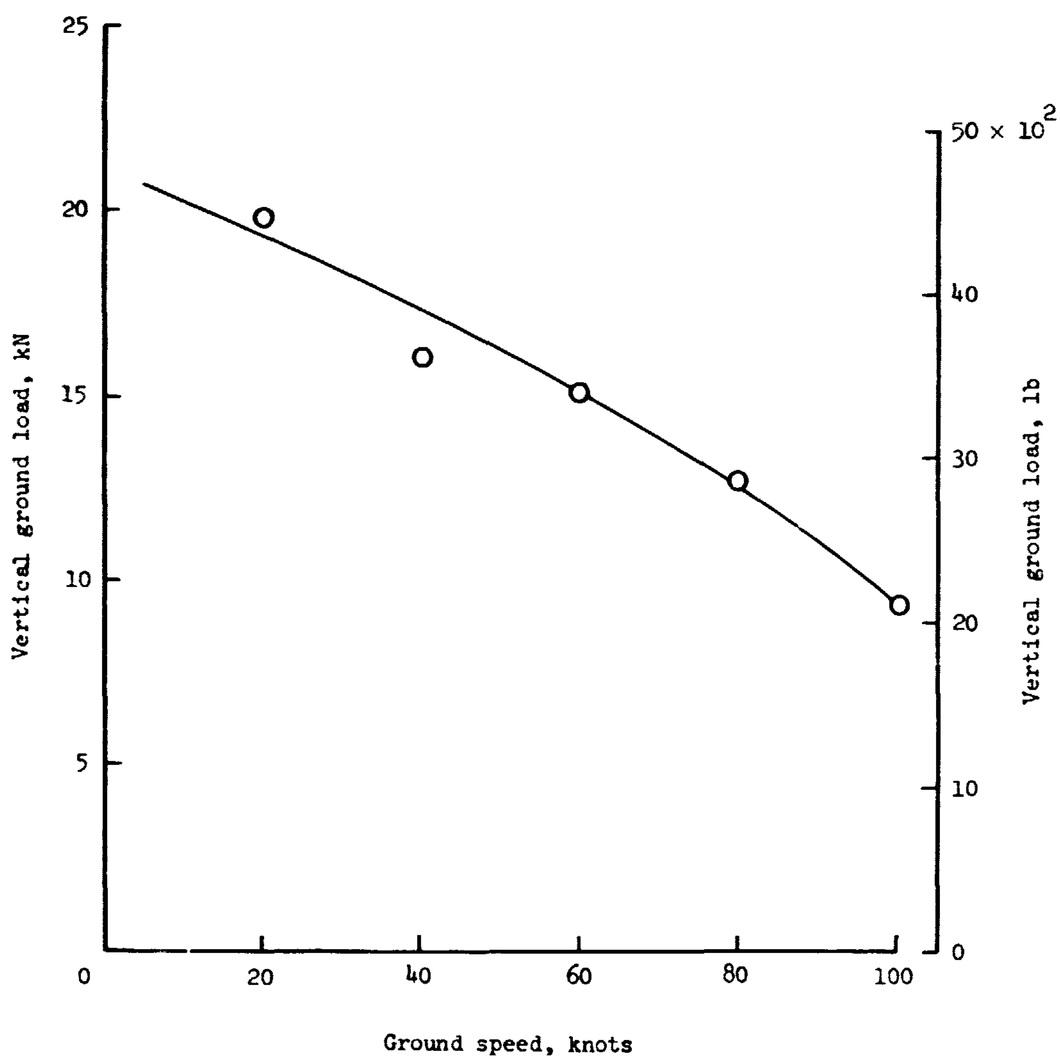

Figure 2.- Variation of tire vertical ground load with ground speed obtained in U.S. Air Force aircraft tests.

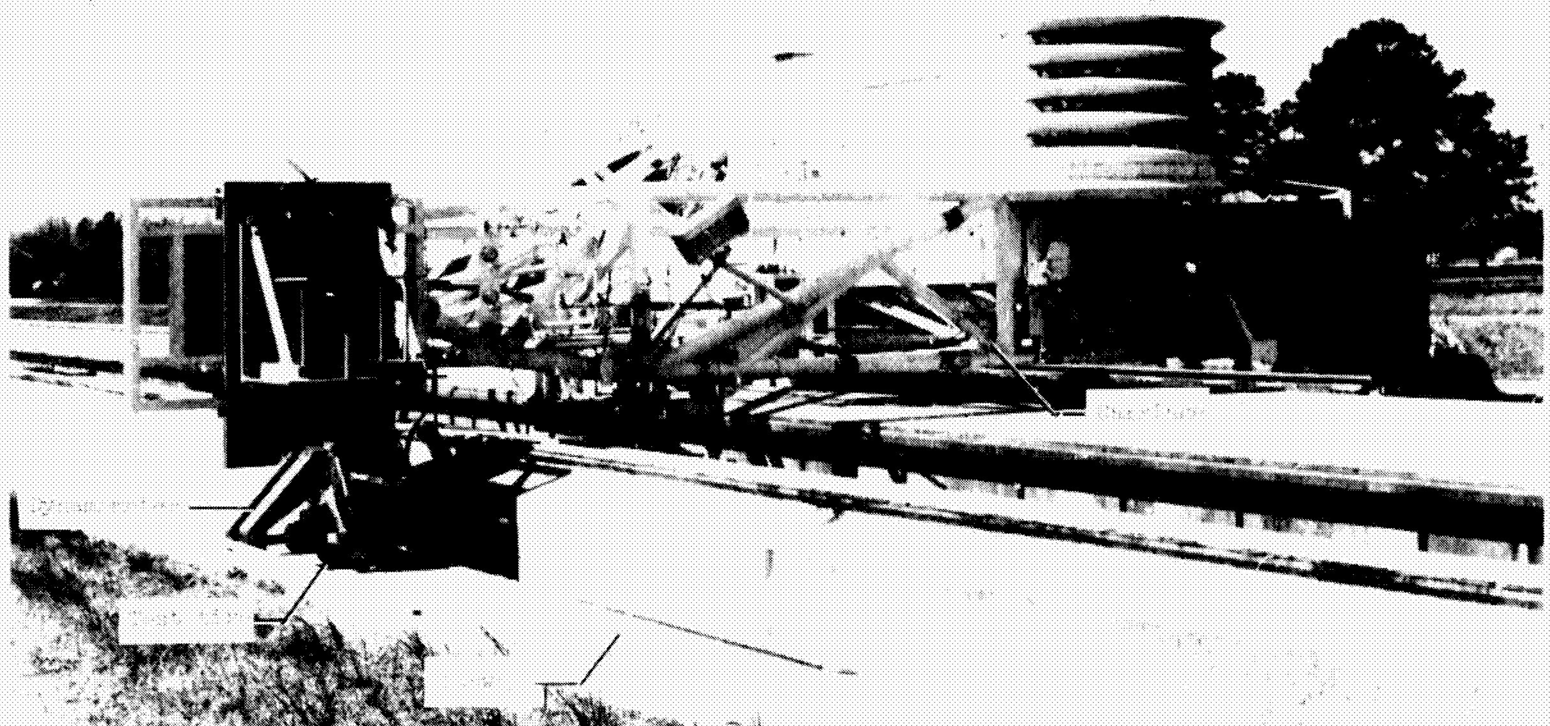

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Figure 3.- Dynamometer mounted on test carriage.

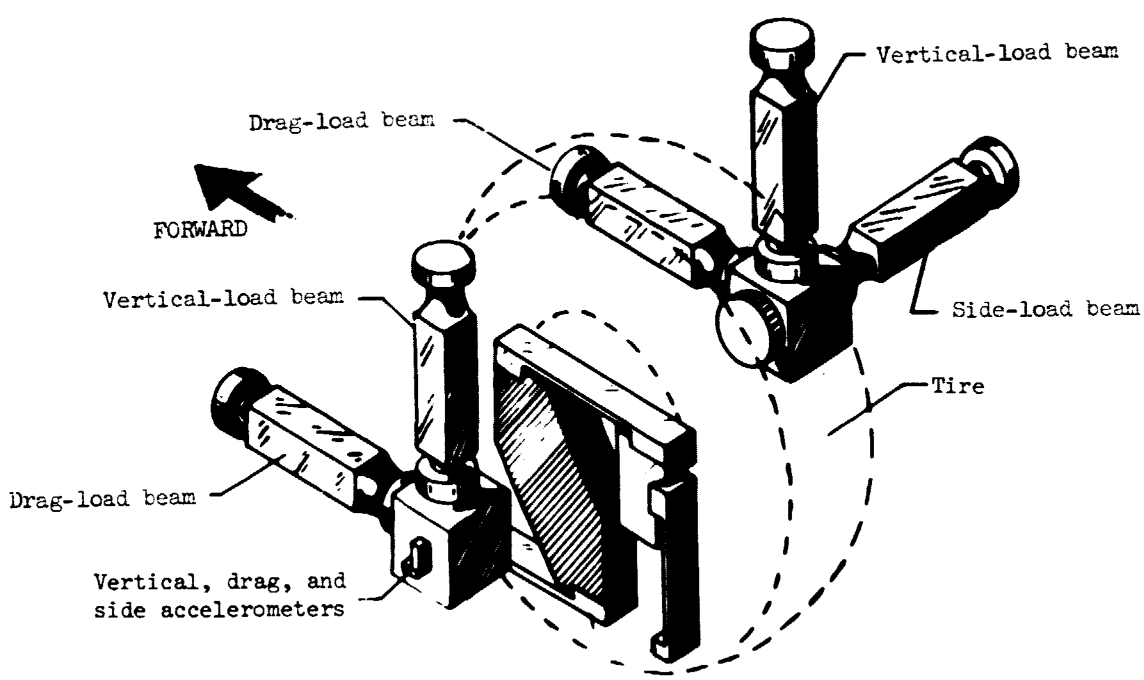
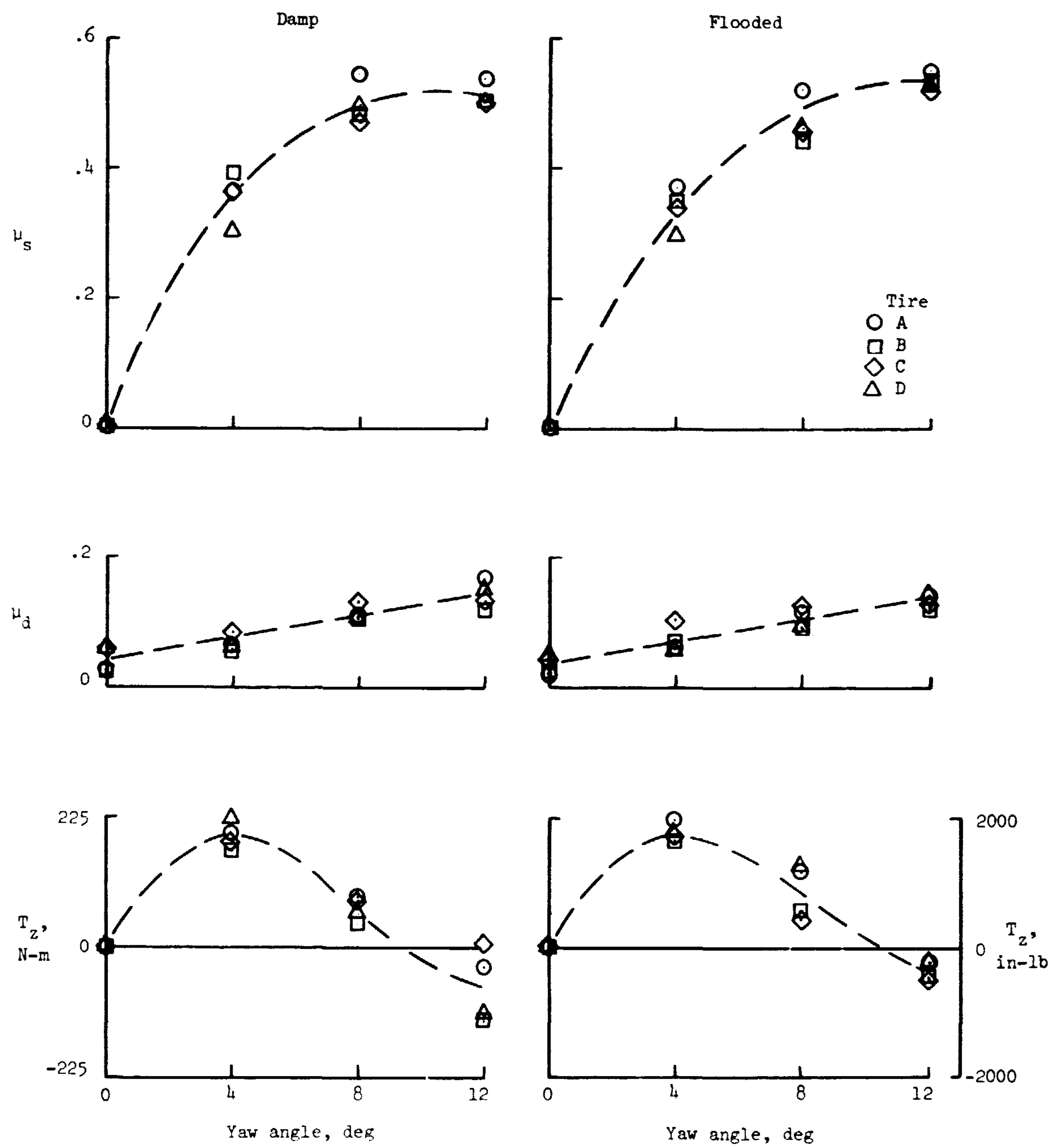
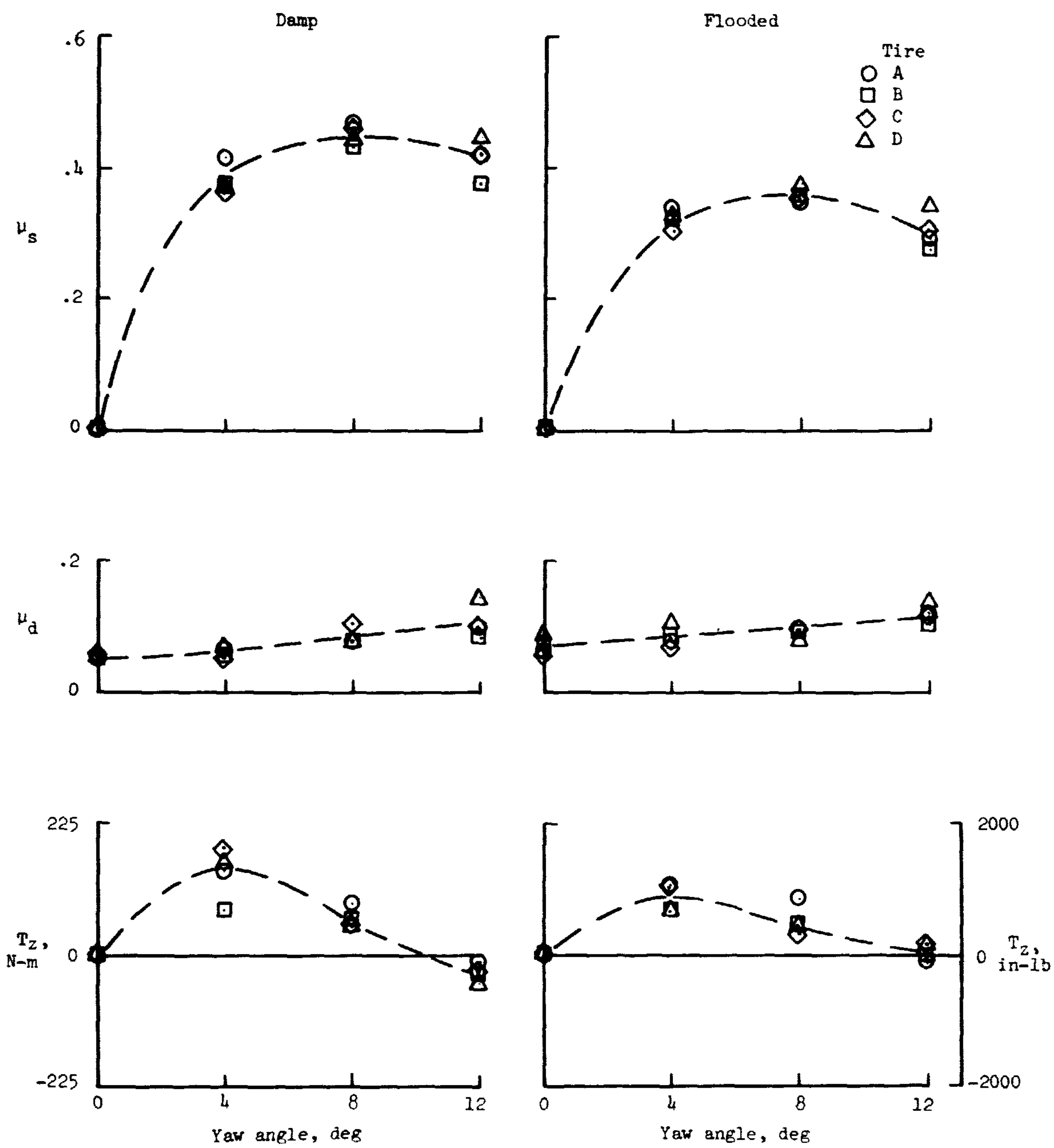


Figure 4.- Schematic of dynamometer used in tests.



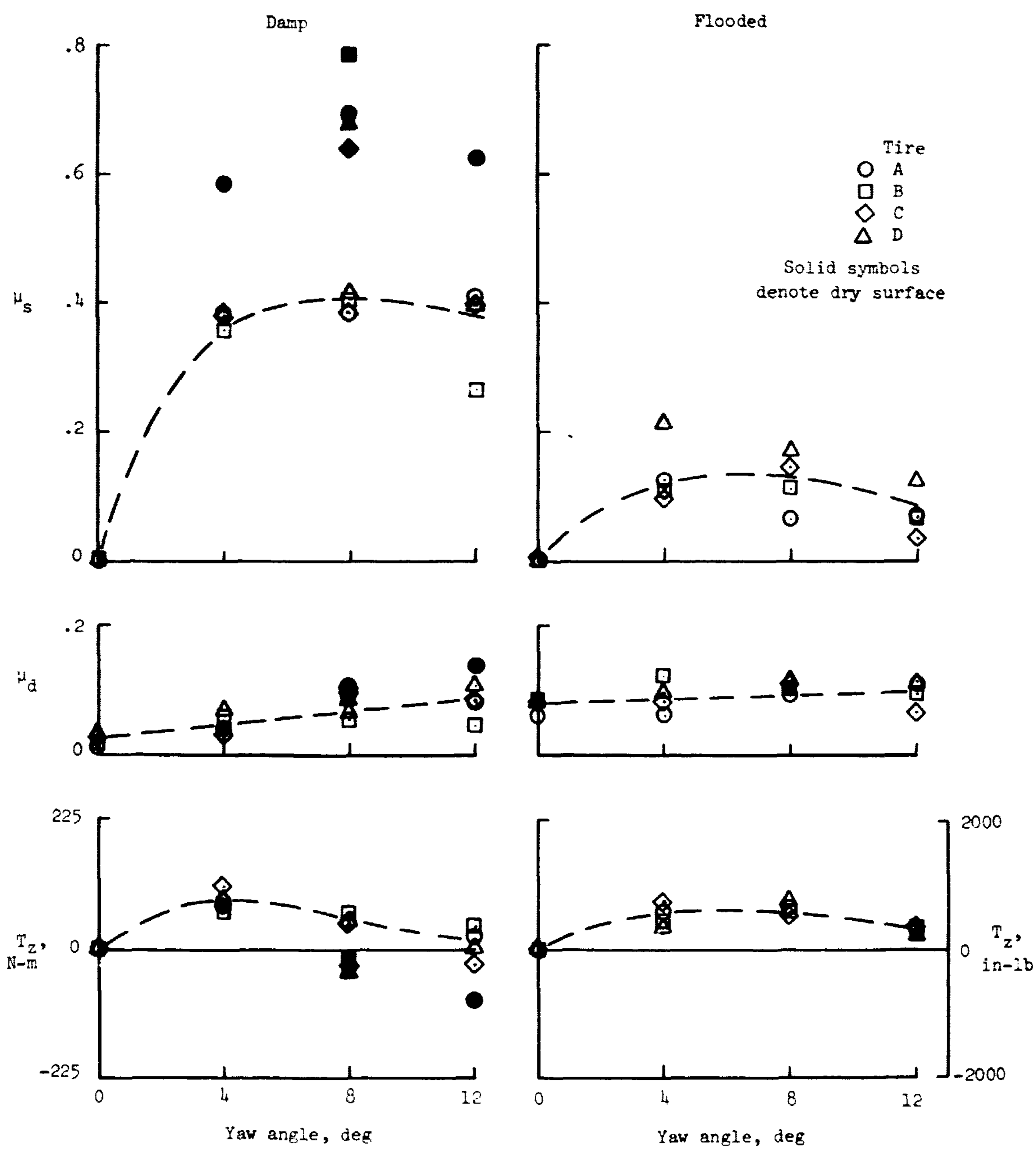
(a) Ground speed ≈ 5 knots.

Figure 5.- Effect of yaw angle on cornering-force friction coefficient μ_s, drag-force friction coefficient μ_d, and self-alining torque T_z at various ground speeds for the four test tires on damp and flooded surfaces.



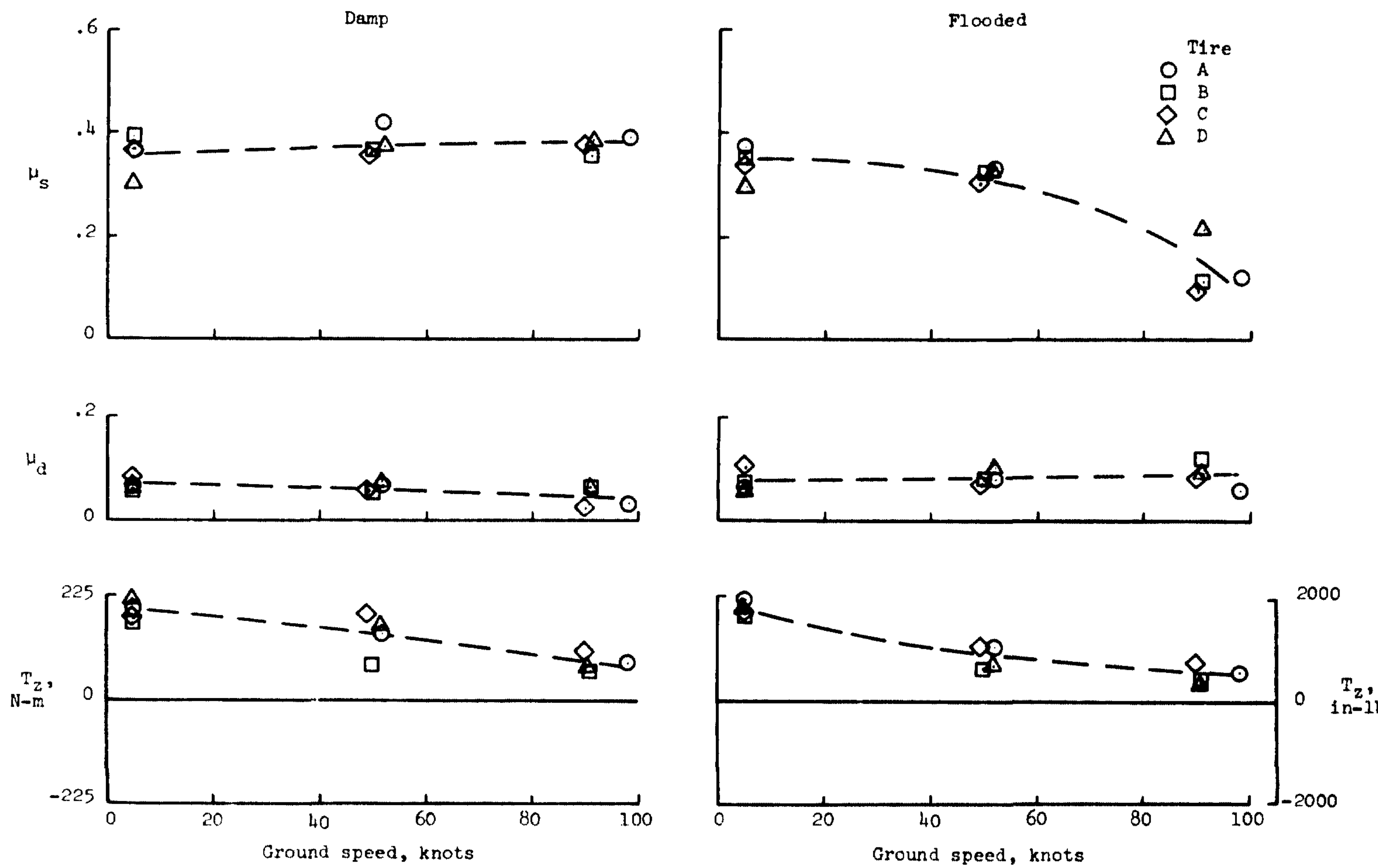
(b) Ground speed ≈ 50 knots.

Figure 5.- Continued.



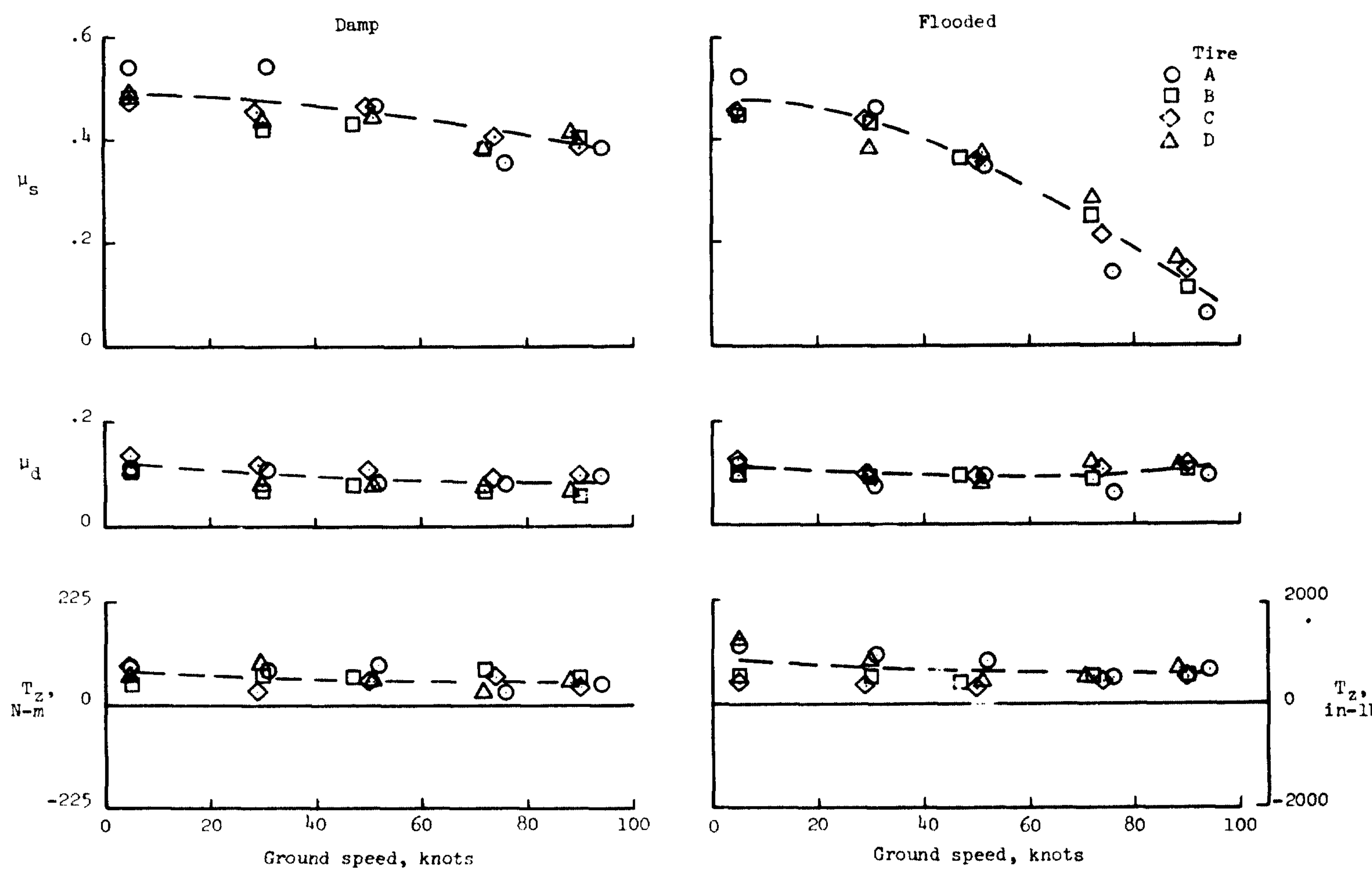
(c) Ground speed ≈ 90 knots.

Figure 5.- Concluded.



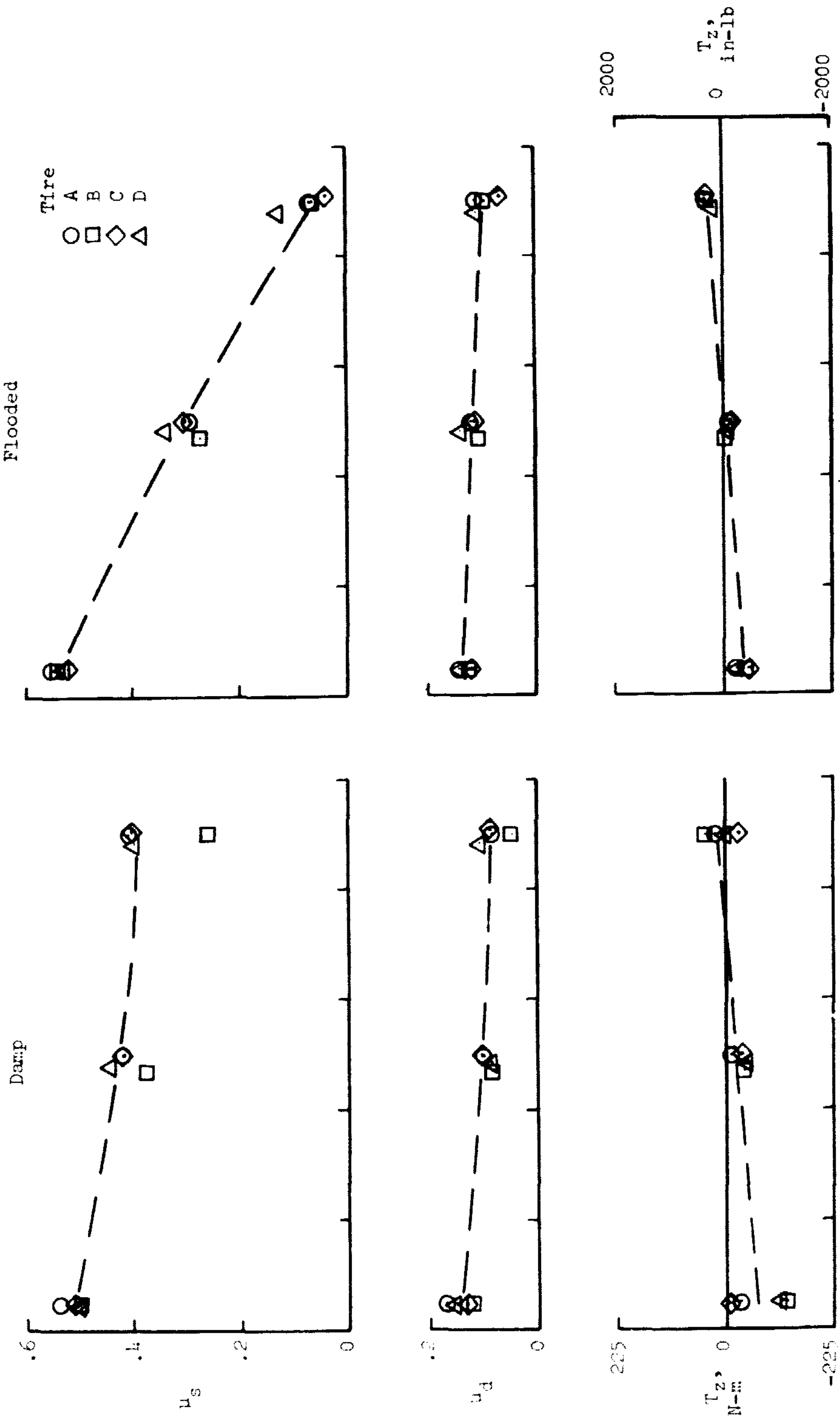
(a) Yaw angle, 4°.

Figure 6.- Effect of ground speed on cornering-force friction coefficient μ_s, drag-force friction coefficient μ_d, and self-alining torque T_z at various yaw angles for the four test tires on damp and flooded surfaces.



(b) Yaw angle, 8°.

Figure 6.- Continued.



(c) Yaw angle, 12°.

Figure 6.- Concluded.