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EXPERIMENTAL INVESTIGATION OF THE CORNERING CHARACTERISTICS OF A C40 × 14-21 CANTILEVER AIRCRAFT TIRE

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16. Abstract

An experimental investigation was conducted at the Langley aircraft landing loads and traction facility to define the cornering characteristics of a size C40 × 14-21 aircraft tire of cantilever design. These characteristics, which include the cornering-force and drag-force friction coefficients and self-alining torque, were obtained for the tire operating on dry, damp, and flooded runway surfaces over a range of yaw angles from 0° to 20° and at ground speeds of 5 to 100 knots, both with and without braking. The results of this investigation show that the cornering-force and drag-force friction coefficients and self-alining torque were influenced by the yaw angle, ground speed, brake torque, surface wetness, and the locked-wheel condition.

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SUMMARY

An experimental investigation was conducted at the Langley aircraft landing loads and traction facility to define the cornering characteristics of a size C40 × 14-21 aircraft tire of cantilever design. These characteristics, which include the cornering-force and drag-force friction coefficients and self-alining torque, were obtained for the tire operating on dry, damp, and flooded runway surfaces over a range of yaw angles from 0° to 20° and at ground speeds of 5 to 100 knots, both with and without braking. The results of this investigation show that the cornering-force and drag-force friction coefficients and self-alining torque were influenced by the yaw angle, ground speed, brake torque, surface wetness, and the locked wheel condition.

INTRODUCTION

As the weight and landing speeds of airplanes increase, more severe demands are placed upon the braking capability of the landing-gear system for safe ground operations. One of the more efficient approaches to obtain greater brake torque for larger aircraft is to increase the brake diameter, but to do so requires a wheel with a larger diameter. This approach implies a tire with a larger diameter, an increased storage space requirement, and added landing-gear weight. Recently, however, the tire industry introduced a new tire design which has the same overall diameter as that of the standard or conventional tire but with a larger inside diameter (rim opening) which permits the use of larger brakes. This design has been referred to as the cantilever tire, so-called because the sidewalls overhang the rim in an unsupported manner. A few of these cantilever tires have become available for airplane use, and in view of the continuing interest of the National Aeronautics and Space Administration to determine the performance characteristics of aircraft tires of various design and construction, a study was undertaken to determine the cornering properties of a tire of cantilever design. The purpose of this paper is to present the results of that study.

An experimental investigation was conducted at the Langley aircraft landing loads and traction facility to define the cornering characteristics of a size 40 × 14-21 aircraft tire of cantilever design. These characteristics, which include the cornering-force and drag-force friction coefficients and self-alining torque, were obtained for the tire operating on dry, damp, and flooded runway surfaces over a range of yaw angles from 0° to 20° and at ground speeds of 5 to 100 knots, both with and without braking. (1 knot = 0.5144 meter/second.)

SYMBOLS

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

$B_{T,D}$	brake torque measured on dry surface
T_z	self-alining torque
V	ground speed
μ_d	drag-force friction coefficient parallel to direction of motion
μ_s	cornering-force friction coefficient normal to direction of motion
ψ	wheel yaw angle

APPARATUS AND TEST PROCEDURE

Test Tire

The cantilever tires used for this test were size 40 × 14-21 bias-ply aircraft tires of 22 ply rating and they had a rated maximum speed of 200 knots. A photograph of one of the tires, taken subsequent to the investigation, is presented in figure 1. Several large commercial and military airplanes are presently using a tire of this diameter on their main landing gears. Throughout this investigation, the tire inflation pressure was maintained at 107 N/cm^2 (155 psi) and the vertical load was fixed at a nominal 111 kN (25 000 lb). The tire was replaced when approximately 50 percent of the original tread was worn off.

The sketch of figure 2 compares the cross section of the cantilever tire with that of the corresponding tire of conventional design. As illustrated, the larger rim opening available with the cantilever tire provides space for a larger brake assembly without increasing the tire outside diameter. An additional advertised feature of the cantilever tire is its "run-flat" capability. In the event of complete loss of inflation pressure, the tire purportedly collapses symmetrically without folding to one side as does a conventional tire.

Runway Surface Conditions

For the tests described in this paper, approximately 174 meters (570 feet) of a concrete test section were divided into three subsections to provide tire cornering data on dry, damp, and flooded surfaces. The first 76 meters (250 feet) of the test section were maintained dry, the next 37 meters (120 feet) were dampened (no standing water visible), and the remaining 61 meters (200 feet) were surrounded by a dam and flooded with water to a depth of approximately 0.8 cm (0.32 in.). Thus, during the course of one test, data were obtained for the three surface-wetness conditions. The dry subsection was necessarily long to provide time for full wheel spin up, and, for those tests which involved braking, time for brake actuation. The concrete surface in the test section had a light broom finish which was somewhat smoother than that of most operational concrete runways.

Test Facility

The investigation was performed at the Langley aircraft landing loads and traction facility which is described in reference 1 and utilized the main test carriage shown in figure 3. A photograph of the dynamometer used in the investigation is shown in figure 4 and a schematic of the instrumentation is presented in figure 5. The dynamometer was instrumented with load beams to measure vertical, drag, and lateral forces, and the brake torque at the wheel axle. Additional instrumentation was provided to measure brake pressure, wheel angular velocity, and carriage horizontal displacement. Continuous time histories of the outputs of the instrumentation were recorded by an oscillograph mounted on the test carriage. For this investigation a landing-gear strut was not employed because the dynamometer was needed to measure the forces accurately.

Test Procedure

The test technique consisted of setting the dynamometer and tire assembly to the preselected yaw angle, propelling or towing the test carriage to the desired ground speed, releasing the drop-test fixture to apply a preselected vertical load to the tire, and monitoring the outputs from the onboard instrumentation. The yaw angle was increased in 5° increments from 0° to 20° and ground speeds ranged from 5 to 100 knots. To obtain a speed of 5 knots, the test carriage was towed by a ground vehicle; for higher speeds, the carriage was propelled by the hydraulic jet as described in reference 1. In tests which incorporated wheel braking, the brake was actuated after the vertical load had been applied and the tire was in a steady-state rolling condition. Time histories of the outputs of the instrumentation were recorded as the tire passed consecutively through the dry, damp, and flooded test surfaces.

RESULTS AND DISCUSSION

Time histories of forces in the vertical, drag, and side directions; brake torque; and 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 5. The following sections discuss the variation of these cornering characteristics with yaw angle, ground speed, brake torque, and surface-wetness conditions and concludes with remarks on tire wear and surface rubber contamination resulting from the high-speed yawed rolling tests.

Effect of Yaw Angle

The effects of yaw angle on the cornering characteristics of the test cantilever tire are presented in figure 6 for various ground speeds, surface-wetness conditions, and braking torques.

Cornering-force friction coefficient.- Data obtained with no brake torque (fig. 6(a)) indicate that as the yaw angle ψ increases from 0°, the cornering-force friction coefficient μ_s generally increases sharply, reaches a peak value, and then gradually decreases with a further increase in ψ. Figure 6 also shows that there is a pronounced effect of ground speed on μ_s, particularly on the damp and flooded surfaces. The lower the ground speed, the higher the cornering-force friction coefficient. The maximum value of μ_s occurred at the lowest test speed, 5 knots, and was about 0.6 on the dry surface and about 0.5 on the damp and flooded surfaces. On the flooded runway at the higher ground speeds μ_s is shown to increase slightly when the yaw angle was increased from 15° to 20°. This increase can be attributed to an increase in the side force produced as the tire displaces surface water rather than to an increase in the tire friction force. The maximum value of μ_s occurs at a 10° yaw angle for all cases except at the 5-knot speed on the dry surface.

Two brake torque conditions are presented in figures 6(b) and 6(c). The brake torque values given in the figures were those measured on the dry surface and the same brake pressures were used in the tests on the damp and flooded surfaces. With the introduction of braking, the variation of cornering-force friction coefficient with yaw angle at a test speed of 5 knots was very similar to that for the unbraked wheel. The figures show that at 5 knots the maximum μ_s on all surfaces was developed at yaw angles between 10° and 15°. At a ground speed of 100 knots, maximum μ_s was developed at a 10° yaw angle on the dry surface and at a 5° yaw angle on the damp surface when brake torque was applied. However, at yaw angles greater than 5° at that speed on the damp surface, even light braking was sufficient to induce a locked wheel skid which reduced μ_s to negligible values. When the runway surface was flooded, any braking effort at 100 knots resulted in a locked wheel skid and a corresponding loss in cornering capability, regardless of the yaw angle.

Drag-force friction coefficient.- The drag-force friction coefficient μ_d for the free rolling tire is shown in figure 6(a) to increase almost linearly with yaw angle on the dry, damp, and flooded surfaces and to decrease slightly with increasing ground speed. Figure 6(b) shows that with a light braking effort, μ_d increases with ψ on all three surfaces at a ground speed of 5 knots. A similar trend is noted at 100 knots on the dry surface; however, at this speed light braking induces locked wheel skids on the damp surface at high yaw angles and on the flooded surface at all yaw angles. With heavy braking (fig. 6(c)), μ_d reaches a peak value of about 0.4 at yaw angles of 10° to 15° under the three surface conditions at a ground speed of 5 knots. The variation in the drag friction coefficient with yaw angle at 100 knots on the dry surface is similar to that at the lower speed although there was a partial wheel spin down at the 15° yaw angle. At yaw angles above 5° on the damp surface and at all yaw angles on the flooded surface, heavy braking at 100 knots caused locked wheel skids. The skidding value of μ_d on these wet surfaces is shown to be about 0.1 for both light and heavy braking.

Self-alining torque.- A positive value of the self-alining torque T_z is a stabilizing torque developed at the ground about the vertical or steering axis of the wheel which would tend to aline an unrestrained tire with the direction of motion. The unbraked yawed-rolling data of figure 6(a) indicate that T_z reaches a maximum positive value at a 5° yaw angle and then decreases with any further increase in yaw angle for all surface conditions. Negative values of T_z are generally noted for the higher yaw angles; thereby an unrestrained tire at those angles would have a tendency to diverge from the direction of motion. The figure further shows that ground speed has little effect on the magnitude of T_z on a dry surface; however, T_z generally decreases with increasing ground speed on the wet surfaces. The data of figure 6(b) show that with light braking at 5 and 100 knots, there is a large reduction in the maximum positive value of T_z which occurred at a yaw angle of 5° on all surfaces. At higher yaw angles the value of T_z becomes negative. At 100 knots on the wet surfaces, negative values of T_z were obtained for all yaw angles. Note that when the tire is in a locked wheel skid, the torque values are very small. As shown in figure 6(c), negative values of T_z are obtained at all yaw angles and speeds on all surfaces when heavy braking is applied.

Effect of Ground Speed

The effect of ground speed on the cornering characteristics of the test cantilever tire is presented in figure 7. These data were obtained from additional tests with the tire free rolling (unbraked) at a fixed 10° yaw angle and covered a speed range from 5 to 100 knots.

Cornering-force friction coefficient.- Figure 7 shows that the ground speed appears to have little effect on the cornering-force friction coefficient on the dry surface. However, on the wet surfaces, μ_s decreases significantly with an increase in ground speed. This loss is attributed to thin-film lubrication and tire hydroplaning. The calculated hydroplaning speed for this tire is 112 knots. (See ref. 2.)

Drag-force friction coefficient.- The drag-force friction coefficient μ_d for the unbraked tire is the result of the tire rolling resistance and the drag-force component generated by the yawed rolling condition. The figure shows that μ_d is essentially unaffected by variations in the ground speed on the dry surface and decreases slightly with increasing ground speed on the damp and flooded surfaces.

Self-alining torque.- The self-alining torque T_z for the unbraked tire was shown in figure 6(a) to reach a maximum positive value at a 5° yaw angle and then to decrease with a further increase in ψ. The data of that figure further show that the torque was essentially independent of the ground speed on a dry surface and, at low yaw angles, decreases with increasing ground speed on the wetted surfaces. The 10° yaw angle data presented in figure 7 reflect this reduction in T_z from its peak value for all surface conditions. The data further show that at a 10° yaw angle, there is only a slight reduction in T_z with increasing ground speed for the two wet surface conditions.

Effect of Brake Torque

Appropriate data of figure 6 are presented in figure 8 to show more clearly the effect of brake torque on the cornering-force and drag-force friction coefficients. The brake torque values given in the figure are those measured on the dry surface and the same brake pressures were used in the damp and flooded runway tests.

Cornering-force friction coefficient.- The data presented in the figure indicate that on the dry surface the maximum value of μ_s occurs at a 10° yaw angle and decreases approximately 20 percent as the brake torque is increased from 0 to 12 205 N-m (9000 ft-lb). Heavy braking at a 15° yaw angle causes the wheel to spin down toward a locked wheel skid. On the damp surface the maximum value of μ_s is reduced by hydroplaning effects. The maximum value of μ_s is obtained at a 10^{o} yaw angle with no braking and at a 5^{o} yaw angle with either light or heavy braking. Light braking on the damp surface causes locked wheel skids for yaw angles above 5^{o} and heavy braking causes locked wheel skids at all test yaw angles. On the flooded surface the maximum value of μ_s is even further reduced by tire hydroplaning effects, and any braking effort causes a locked wheel skid and a complete loss in μ_s regardless of the yaw angle.

Drag-force friction coefficient.- The drag-force friction coefficient μ_d increases with increasing brake torque on the dry surface for all yaw angles tested. Because of thin film lubrication and tire hydroplaning effects, μ_d is generally reduced from its dry values when the surface is dampened. On the flooded surface μ_d was essentially unaffected by variations in the brake torque since any braking effort resulted in a locked wheel skid and hence a low value of μ_d.

Effect of Surface Wetness

To better illustrate the effect of surface wetness on the cornering-force and drag-force friction coefficients, selected data of figure 6 are again presented in figure 9. These data were obtained at a ground speed of 100 knots with no brake torque and covered a range of yaw angles from 0^{o} to 20^{o}.

Cornering-force friction coefficient.- The maximum value of μ_s is shown to reduce appreciably when the surface becomes wet. For the test condition shown in figure 9, the dampened surface results in more than a 50-percent reduction in μ_s from its dry value at all test yaw angles. The percent reduction is even greater on the flooded surface. These reductions can be chiefly attributed to thin-film lubrication and tire hydroplaning effects.

Drag-force friction coefficient.- Figure 9 shows that surface wetness also reduces the value of unbraked μ_d again as a result of lubrication and hydroplaning effects. Increased fluid drag causes the value of μ_d to be slightly higher on the flooded surface than on the damp surface.

TIRE WEAR AND SURFACE CONTAMINATION

Since this study included tests at high yaw angles and/or brake torques, tire wear was appreciable, and a considerable amount of rubber was deposited on both the dry and damp test surfaces. No rubber contamination was observed on the flooded surface. A photograph of the contaminated dry surface subsequent to this investigation is presented in figure 10. Average texture depth measurements for the dry and damp surface test sections obtained from a grease sampling technique (ref. 3) before and after the tests are presented in the following table:

Dry section		Damp section	
Before tests	After tests	Before tests	After tests
0.0787 mm (0.0031 in.)	0.0533 mm (0.0021 in.)	0.0813 mm (0.0032 in.)	0.0762 mm (0.0030 in.)

Results from cornering tests made at a 20° yaw angle with no brake torque indicate that the value of μ_s decreased from 0.46 to 0.42 at 50 knots and from 0.42 to 0.39 at 100 knots because of the rubber contamination on the dry surface. On the damp surface where the rubber contamination was less severe, no decrease in the value of μ_s was noted. Although the absolute magnitude of the data obtained on the dry surface may be affected by the deposited rubber from earlier tests, it is assumed that this contamination had little effect on the reported trends.

CONCLUSIONS

Tests were conducted to determine the cornering characteristics of a C40 × 14-21 cantilever aircraft tire. These characteristics, which include the cornering-force and drag-force friction coefficients and self-alining torque were obtained for the tire operating on dry, damp, and flooded runway surfaces over a range of yaw angles from 0° to 20° and at ground speeds of 5 to 100 knots, both with and without braking. The results of these tests suggest the following major conclusions:

1. The cornering-force friction coefficient was shown (1) to increase with yaw angle, reach a peak value, and then gradually decrease with further increases in yaw angle; (2) to decrease with an increase in ground speed, particularly on the wet surfaces where tire hydroplaning conditions exist; (3) to decrease appreciably with increasing brake torque at higher yaw angles; and (4) to be negligible when locked wheel skids are encountered.

2. The drag-force friction coefficient was shown (1) to increase with yaw angle and to decrease slightly with ground speed and (2) to increase with brake torque and then to decrease to a skidding value when a locked wheel skid is encountered.

3. The self-alining torque was shown (1) to reach a maximum positive value at a 5° yaw angle with no brake torque and to decrease rapidly with a further increase in

yaw angle; (2) to become negative with high yaw angles and/or brake torques; and (3) to reduce to small negative values when locked wheel skids are encountered.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., March 5, 1973.

REFERENCES

1. Joyner, Upshur T.; Horne, Walter B.; and Leland, Trafford J. W.: Investigations on the Ground Performance of Aircraft Relating to Wet Runway Braking and Slush Drag. AGARD Rep. 429, Jan. 1963.

2. Horne, Walter B.; and Dreher, Robert C.: Phenomena of Pneumatic Tire Hydroplaning. NASA TN D-2056, 1963.

3. Leland, Trafford J. W.; Yager, Thomas J.; and Joyner, Upshur T.: Effects of Pavement Texture on Wet-Runway Braking Performance. NASA TN D-4323, 1968.

L-72-4751

Figure 1.- Test tire after tests.

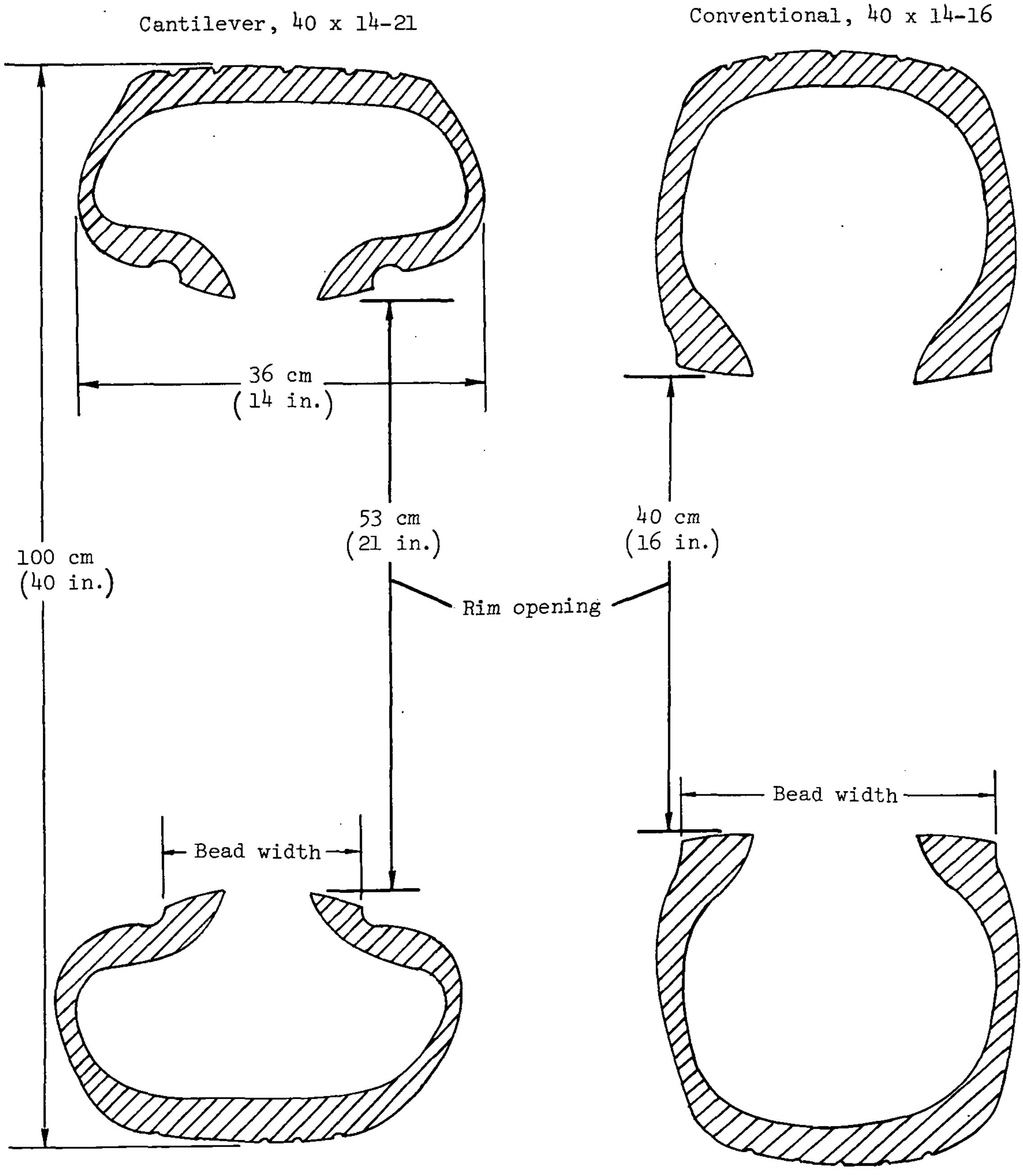

Figure 2.- Comparison of cantilever and conventional tire cross sections.

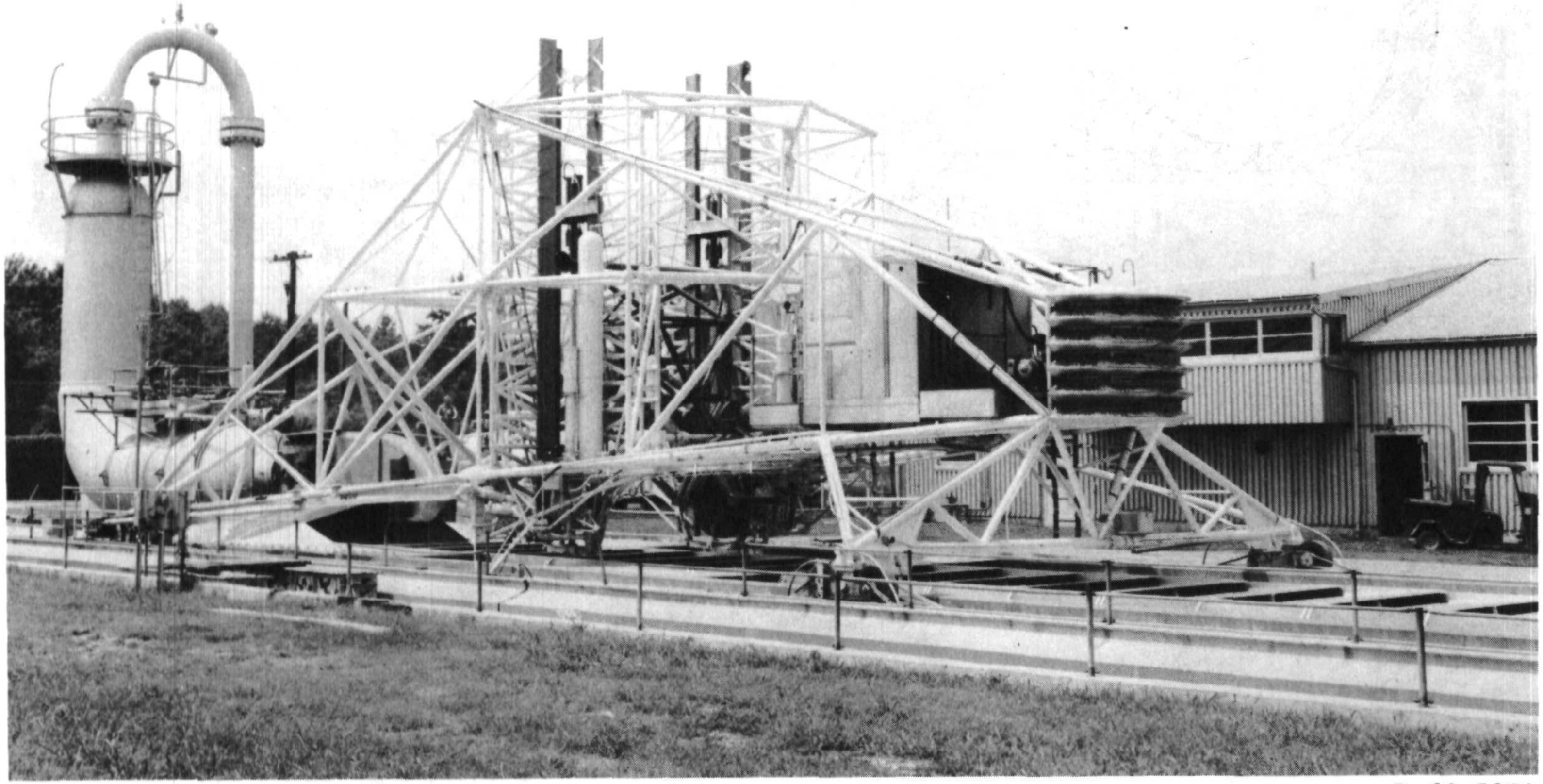

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Figure 3.- Main test carriage at Langley aircraft landing loads and traction facility.

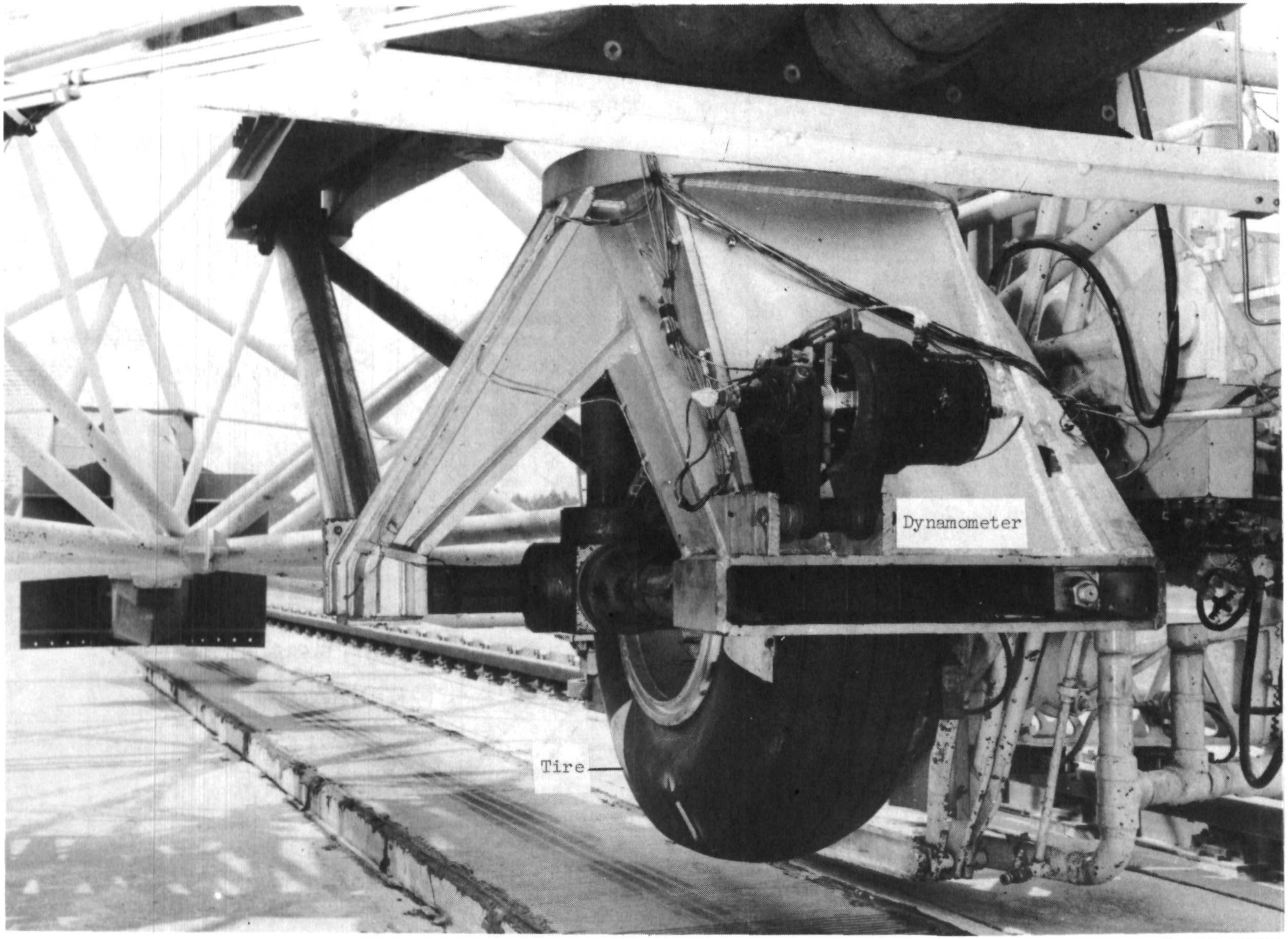

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Figure 4.- Dynamometer used in tests.

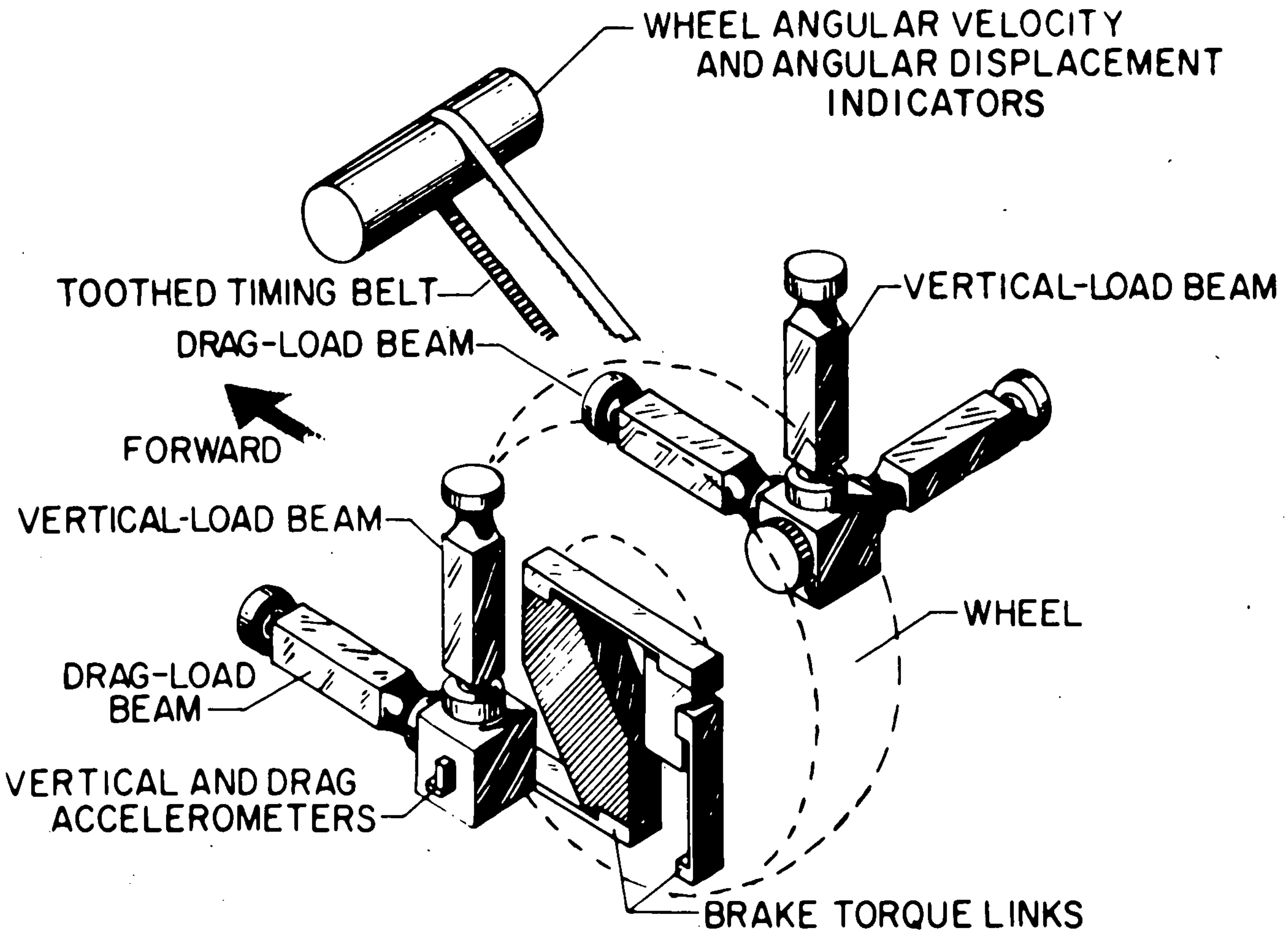
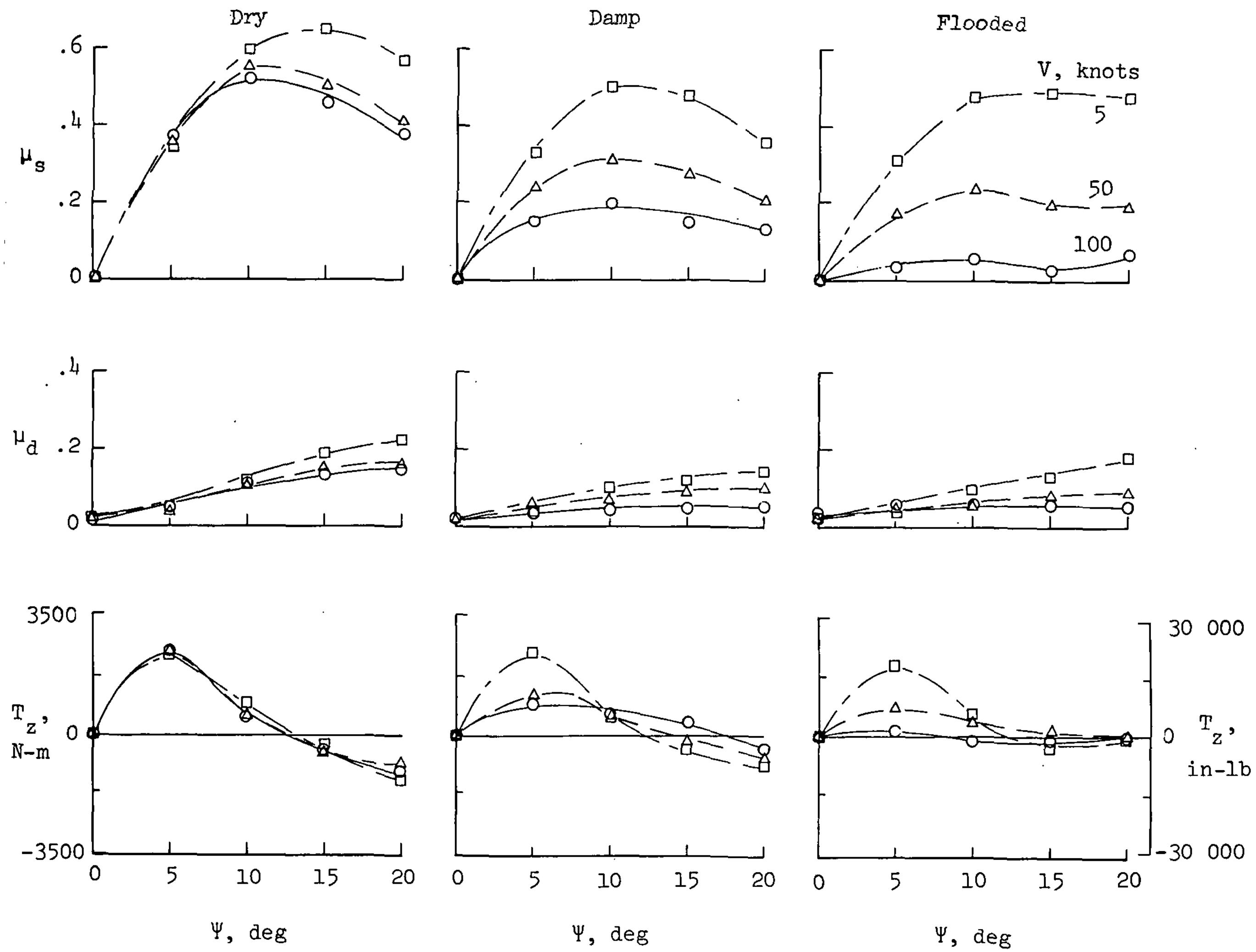
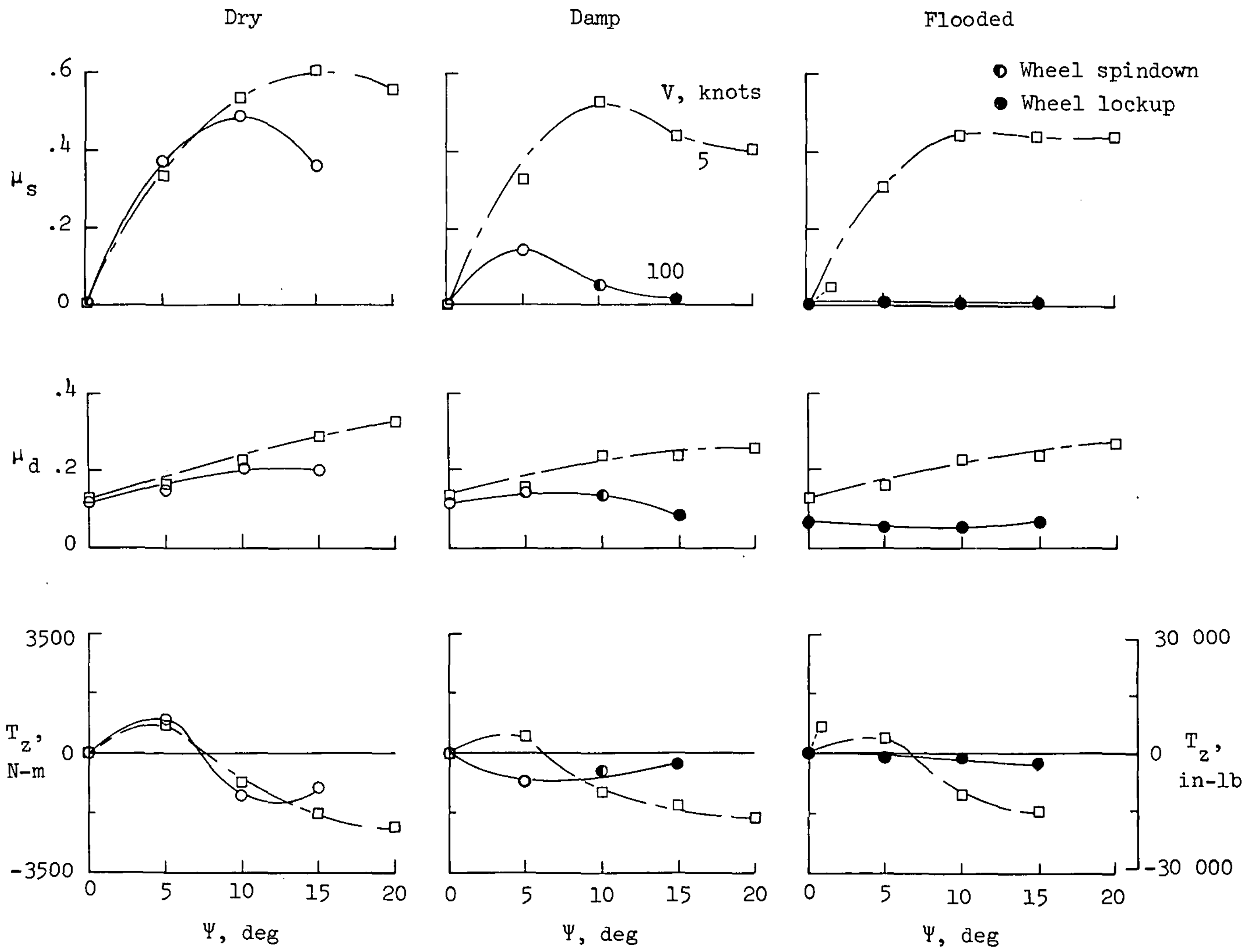


Figure 5.- Schematic of dynamometer showing location of load beams.



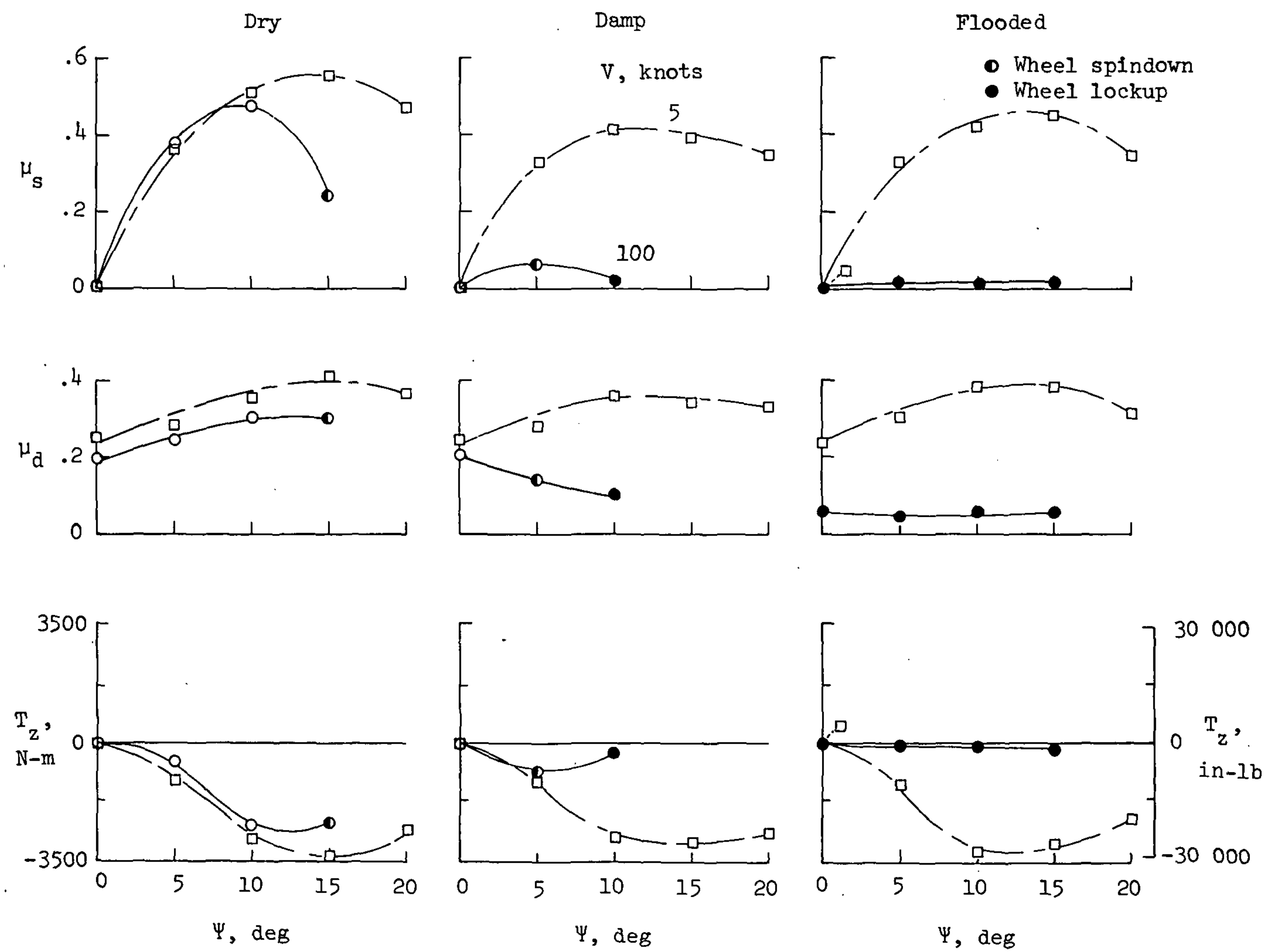
(a) No braking; brake torque, $B_{T,D} = 0$.

Figure 6.- Effect of yaw angle ψ on μ_s, μ_d, and T_z at various ground speeds on dry, damp, and flooded surfaces with and without brake torque.



(b) Light braking; brake torque, $B_{T,D}$ = 5420 N-m (4000 ft-lb).

Figure 6.- Continued.



(c) Heavy braking; brake torque, $B_{T,D}$ = 12 205 N-m (9000 ft-lb).

Figure 6.- Concluded.

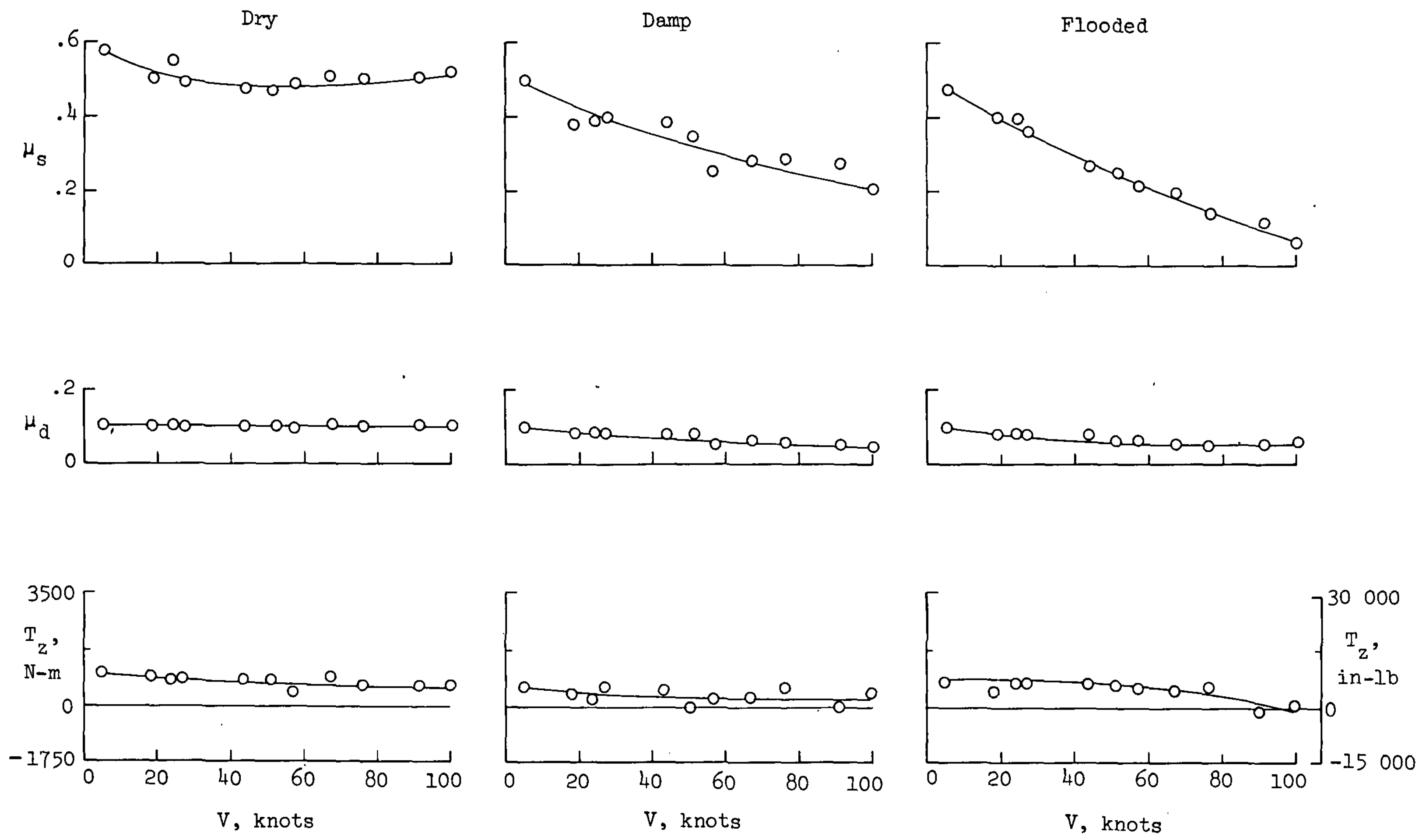


Figure 7.- Effect of ground speed on μ_s, μ_d, and T_z at 10° yaw angle on dry, damp, and flooded surfaces. Brake torque, 0.

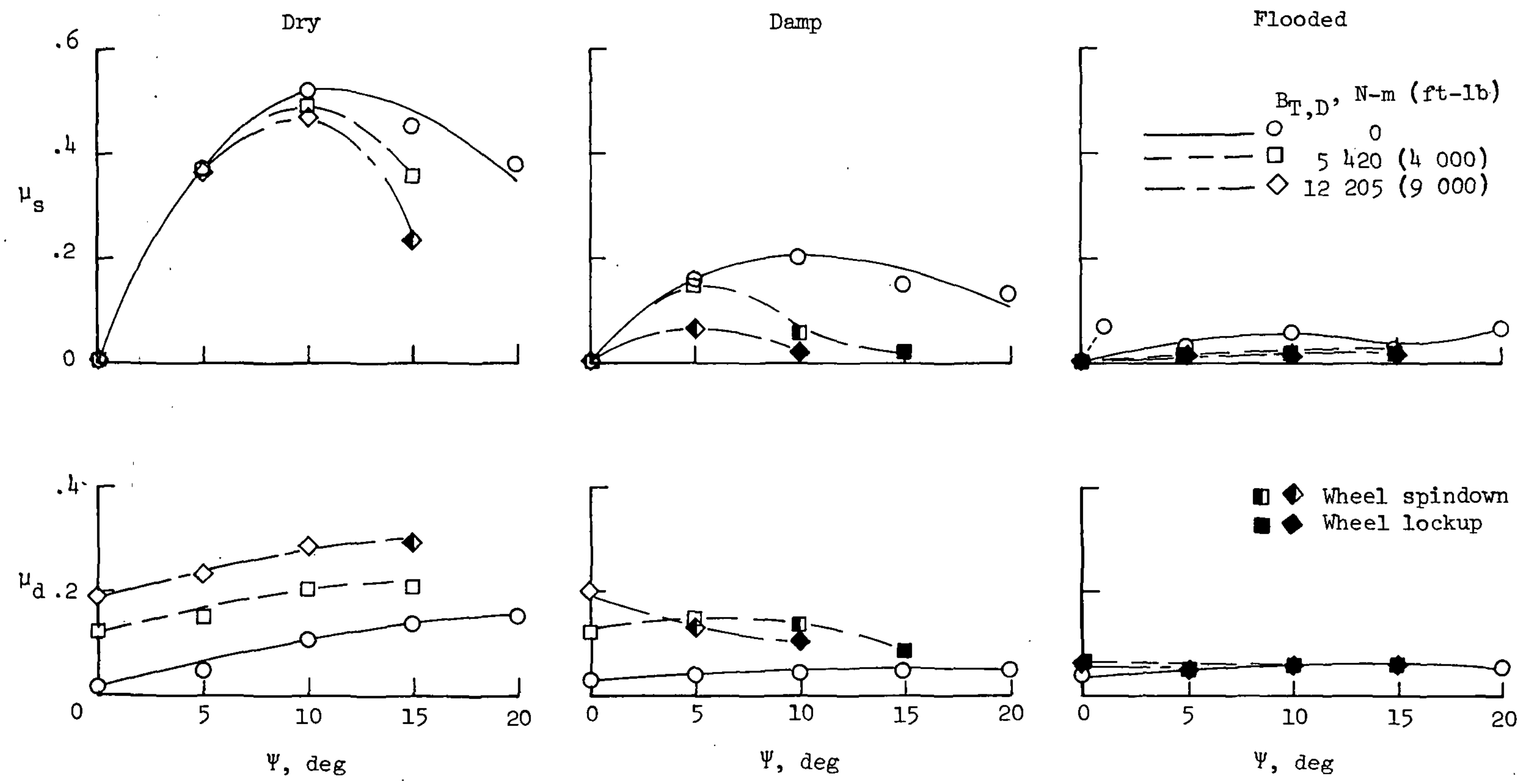


Figure 8.- Variation of μ_s and μ_d with yaw angles at various brake torques on dry, damp, and flooded surfaces at a ground speed of 100 knots.

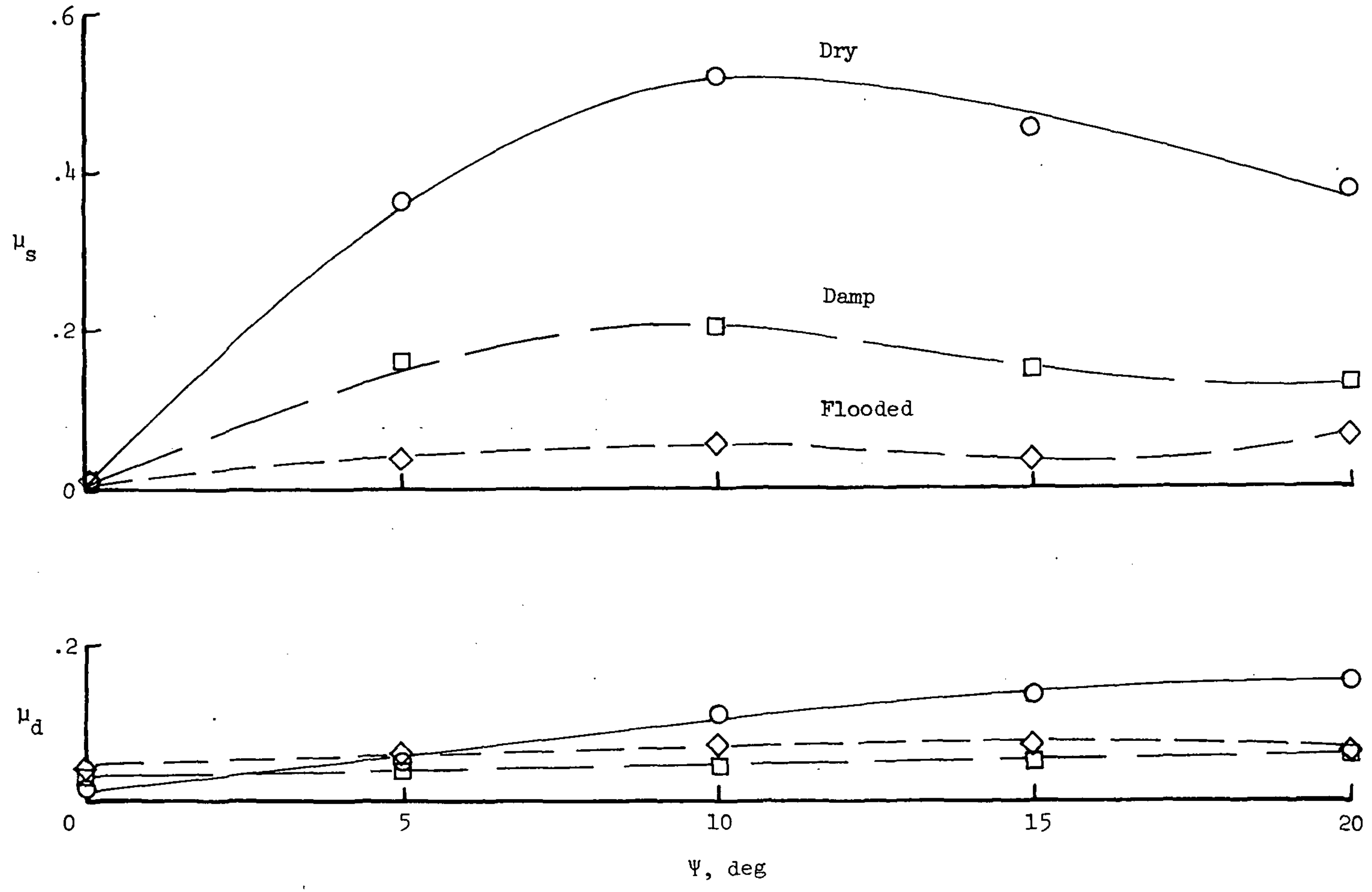


Figure 9.- Effect of surface wetness on μ_s and μ_d at various yaw angles ψ. Brake torque, 0; ground speed, 100 knots.

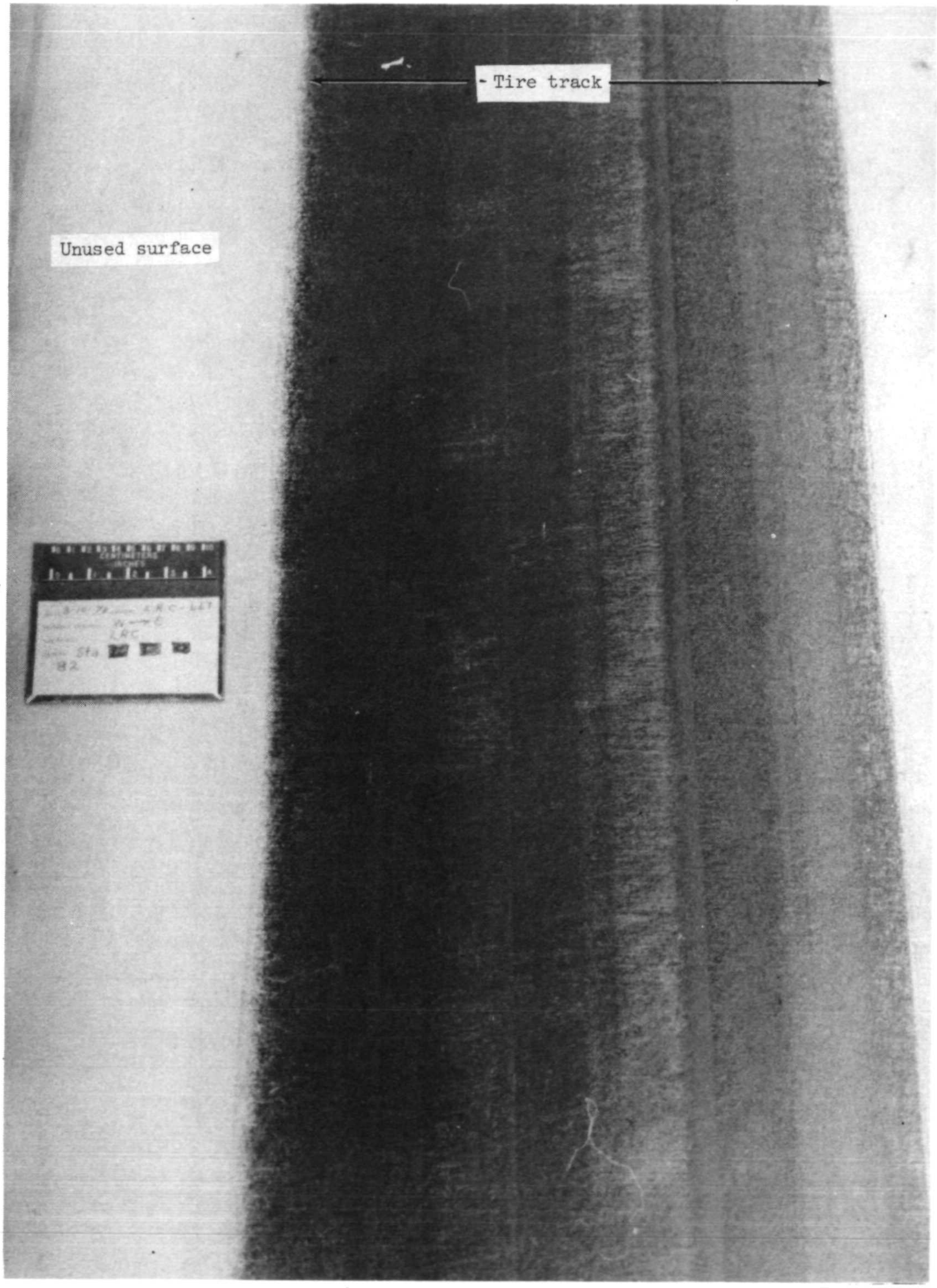


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Figure 10.- Dry surface test area after tests.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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