NASA MEMO 2-23-59L

NASA

MEMORANDUM

NASA MEMO 2-23-59L

TIRE-TO-SURFACE FRICTION ESPECIALLY UNDER WET CONDITIONS

By Richard H. Sawyer, Sidney A. Batterson,
and Eziaslav N. Harrin

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

WASHINGTON

March 1959

G

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MEMORANDUM 2-23-59L

TIRE-TO-SURFACE FRICTION ESPECIALLY UNDER WET CONDITIONS

By Richard H. Sawyer, Sidney A. Batterson,
and Eziaslav N. Harrin

SUMMARY

The results of measurements of the maximum friction available in braking on various runway surfaces under various conditions is shown for a C-123B airplane and comparisons of measurements with a tire-friction cart on the same runways are made. The results of studies of wet-surface friction made with a 12-inch-diameter low-pressure tire on a tire-friction treadmill, with an automobile tire on the tire-friction cart, and with a 44 x 13 extra-high-pressure type VII aircraft tire at the Langley landing-loads track are compared. Preliminary results of tests on the tire-friction treadmill under wet-surface conditions to determine the effect of the wiping action of the front wheel of a tandem-wheel arrangement on the friction available in braking for the rear wheel are given.

INTRODUCTION

The coefficient of friction which can be developed between an airplane's tires and the runway surface is, in many cases, a primary factor in determining whether the airplane can make a safe stop in a landing on a given runway. Since most of the information available on tire-to-surface friction in braking is limited to measurements made at low speeds with automobile tires for the full-skid (that is locked wheel) condition, investigations have been undertaken by the Langley Research Center to provide information on tire-to-surface friction more directly applicable to aircraft braking. In these investigations, because of the increasing use on aircraft of automatic braking devices which attempt to prevent locking of the wheels and at the same time attempt to take advantage of the greater friction-coefficient values obtainable for the wheel in the incipient-skidding condition, particular attention has been paid to measuring the incipient-skidding (that is, maximum) value of the friction coefficient.

MEASUREMENTS ON ACTUAL RUNWAYS UNDER VARIOUS CONDITIONS

The first investigation was made in actual landing runs of a C-123B airplane (fig. 1) on various runways under various conditions. The main gear of this airplane was equipped with 49-inch-diameter (type III, 17.00-20, 16 ply rating) low-pressure tires which were inflated to a pressure of 65 lb/sq in. The airplane was equipped with an antiskid braking system which cycled the brakes on and off at a rate of about 2 cycles per second, producing traverses of the wheel slip ratio through the incipient-skidding condition and thereby allowing measurements of the maximum friction coefficient to be made frequently during the braked portion of the landing run.

Tire-to-surface friction measurements have also been made with the friction cart shown in figure 2. This cart, which is equipped with two 4-ply 6.70-15 automobile tires, was developed as a possible operational device for measuring the available friction on the runway. The two wheels of the cart are geared with a gear ratio less than 1.0 so that one wheel is forced to operate near the incipient-skidding condition. Figure 3 presents mean values of the maximum friction coefficient obtained over a speed range of about 15 to 115 knots for the airplane and up to about 50 knots with the cart on the same surfaces.

The agreement of the airplane and cart results for the surfaces shown is seen to be good. For dry surfaces, values of maximum friction coefficient of about 0.8 were obtained. On snow-covered surfaces, values of maximum friction coefficient ranging from about 0.24 to 0.37 were found, with the value apparently dependent on the subsurface. On ice, values of maximum friction coefficient of 0.18 to 0.20 were obtained, with no effect of temperature noted at the two temperatures of the investigation.

For wet surfaces, an example of comparative results with the airplane and cart is shown in the lower part of figure 4. It can be seen that the apparent decrease in maximum friction coefficient with speed and the large variations in maximum friction coefficient, which are attributed to the effect of differences in depth of water along the runway, made correlation of the results difficult. The apparent decrease in maximum friction coefficient with speed is believed to be associated with a gradual penetration by a film of water under the tire. This gradual penetration occurs because as speed is increased the tire has less time to overcome the inertia and viscous effects of the water in displacing the water from the path of the tire. Therefore, with increasing speed, the water penetrates farther and farther under the tire until the whole footprint is supported on a film of water and the tire is in effect "aquaplaning." The extremely low values of maximum friction coefficient obtained with the airplane, which are especially apparent at the high speeds, in the heavy rain condition shown in the upper part of figure 4 are believed to be associated with a considerable penetration by a film of water under the tire.

An elementary analysis of this wet-surface phenomenon, based only on pressure and inertia-force considerations, indicates that the friction available should decrease with increase in the dynamic pressure exerted by the water on the tire, decrease with decrease in the tire footprint bearing pressure, and decrease with increase in the depth of water. Other factors such as footprint shape and tread design also influence the friction coefficient.

WET-SURFACE MEASUREMENTS BY VARIOUS METHODS

To study this low-friction wet-surface phenomenon under controlled conditions, the apparatus shown in figure 5 was built. In testing, a sheet of water is flowed onto the endless belt from the nozzle at the same speed as the belt while the 12-inch-diameter low-pressure tire is braked.

Some illustrative results of friction-coefficient measurements with the treadmill taken from reference 1 are shown in figure 6. The losses in maximum and full-skid values of friction coefficient with increase in speed are as predicted by the elementary analysis of the effect of the dynamic pressure of the water. For speeds in the equilibrium region indicated in figure 6, the wheel tends to stop with no braking applied, reaching a condition of stable equilibrium in the stopped position. At these speeds it can be seen that the free-roll friction coefficient has increased to a value as great as or greater than the full-skid value. Apparently, in this condition the pressure, inertia, and viscous forces of the water create a torque on the wheel which is equal and opposite to the torque from the frictional force.

Studies of wet-surface friction have also been made by towing the friction cart at various speeds through a water trough. The trough testing method was originated and developed by James P. Trant, Jr., at the Langley Research Center. The trough was constructed by simply erecting two low parallel walls on a concrete road surface. Some of the results of these measurements are given in figures 7 and 8. Figure 7 shows the effect of the depth of water and, as predicted by the elementary theory, the maximum friction decreases with increase in depth. It is interesting to note the large losses at the higher speeds, even for the thinnest depth of water. In figure 8, the predicted favorable effect of increasing the tire footprint bearing pressure is borne out by the increase in the maximum friction coefficient with inflation pressure.

To study wet-surface friction at speeds and tire pressures more representative of aircraft operation, some tests have been made of a 44 × 13 extra-high-pressure, 26 ply rating, type VII tire at the Langley landing-loads track. For this purpose a water trough was constructed on the track roadbed. Preliminary results from these measurements are shown in figures 9 and 10.

Figure 9 shows that the maximum friction coefficient for this aircraft tire decreased rapidly as water depth increased in a similar fashion to the results obtained with the friction cart. The large decrease in friction from the dry-surface value (maximum friction coefficient of the order of 0.7 to 0.8) for the thinnest depth is also similar to the cart results.

Measurements on the local runways indicated that in a moderate rain depths of water up to 0.35 inch existed in puddles several hundred feet long and that 90 percent of the surface was covered with a minimum depth of water of 0.03 inch. A depth of water of 0.1 inch was accordingly selected for the tests at several tire pressures and speeds, and the results of these tests are shown in figure 10.

The μ_{MAX} values are seen to drop rapidly with increase in speed, values equal to about zero occurring at a little over 100 knots. The influence of inflation pressure is somewhat difficult to see, but there is some indication that at speeds below 80 knots the lowest tire pressure gives somewhat higher values of μ_{MAX}, whereas at speeds above 80 knots the highest tire pressure gives somewhat higher friction.

Since the elementary analysis indicated that the friction would be a function of the dynamic pressure of the water and the tire footprint bearing pressure, the results from the treadmill, friction cart, and landing-loads track are compared for one depth in figure 11 on the basis of the ratio of the dynamic pressure q to the gross footprint bearing pressure p_g. The results for the treadmill are for 0.09 inch of water, while the results for the friction cart and landing-loads track are for 0.1 inch of water. The treadmill and friction-cart results are for the recommended tire inflation pressure for the wheel loading used in each case. The recommended inflation pressure for the aircraft tire as loaded is 150 lb/sq in. The measured rolling friction has been subtracted from the treadmill results as the friction-cart and landing-loads-track measurements do not include rolling friction. The agreement of the results from the three methods, compared on the basis of q/p_g, is seen to be fairly good. In general it appears that prediction of the friction for the aircraft tire from either the treadmill or cart results on this basis would lead to somewhat unconservative results, with the predicted friction coefficient being somewhat high. Attempts to strengthen the agreement of these results by involving other parameters such as footprint shape, tread design and wheel size have not yet proved successful.

The problem of low friction on wet surfaces can be alleviated, of course, by providing better drainage, perhaps through more crown on the runways, or creating escape paths for the water by better tread design or through use of a knobby surface. Higher bearing pressures attained through use of higher inflation pressures, tread design, or use of sharp angular-textured aggregates in the surface which give local bearing pressures of 2,000 to 8,000 lb/sq in. can all increase the friction available.

Another possibility, removal of the water by wiping action, has been tried on the treadmill with the tandem-wheel arrangement shown in figure 12. The wheel on the right in the figure wipes a path for the other wheel which is braked. Tests were made with the wheels as shown and also with the wiper wheel lifted out of the way. Results of these measurements are given in figure 13.

The favorable increase in the maximum and full-skid friction coefficients for the tandem arrangement at the higher speeds is quite evident. Considering the maximum friction values for both the tandem- and single-wheel arrangements, for a bogie gear with equal loads carried on the front and rear wheels and both wheels braked the effective maximum friction coefficient would be about 0.3 at the highest speed, an increase of 50 percent over the single-wheel value or the mean of two single-wheel values. Actually, in these tests only about 20 percent of the total weight was carried on the front wheel, and for such a weight distribution a gain of about 80 percent in the effective friction coefficient can apparently be realized. For the tandem arrangement, the full-skid and free-roll curves appear to indicate that the speed at which difficulty would be experienced in having the wheel attain the condition of equilibrium would be extended considerably.

CONCLUDING REMARKS

The effect of runway surface on the maximum friction coefficient has been shown for actual landings of a C-123B airplane on various surfaces under various conditions. Results of measurements made with a friction cart were found to agree with the airplane results for dry, snow-covered, and icy surfaces, but correlation of airplane and cart results for wet surfaces was found to be very difficult. Study of wet-surface friction indicated that the loss of adhesion is related to the dynamic pressure of the water, the tire footprint bearing pressure, and the depth of water. Measurements of friction obtained by three methods for one depth of water agreed fairly well when compared on the basis of the ratio of the dynamic pressure of the water to the gross footprint bearing pressure. The wiping action of the front wheel of a tandem-wheel arrangement was shown to increase considerably the friction available on the rear tire.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 5, 1958.

REFERENCE

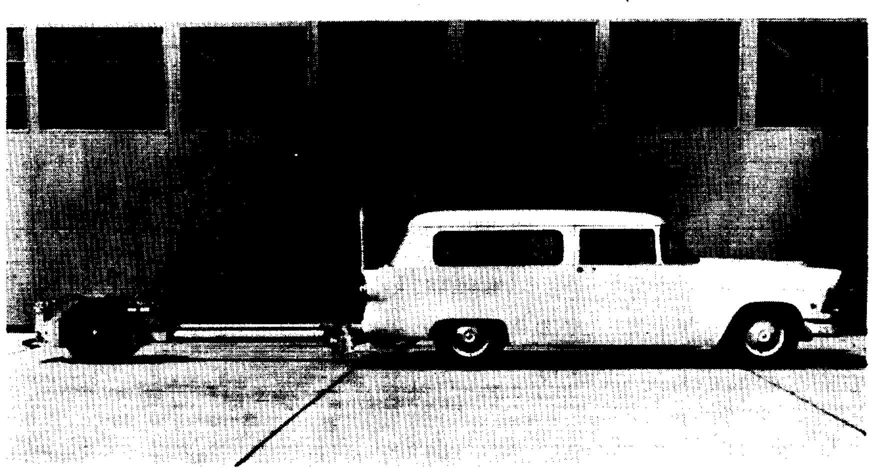
1. Harrin, Eziaslav N.: Low Tire Friction and Cornering Forces on a Wet Surface. NACA TN 4406, 1958.

C-123B AIRPLANE

Figure 1

L-94879

TIRE-FRICTION CART AND TOWING VEHICLE



L-57-1126.1

Figure 2

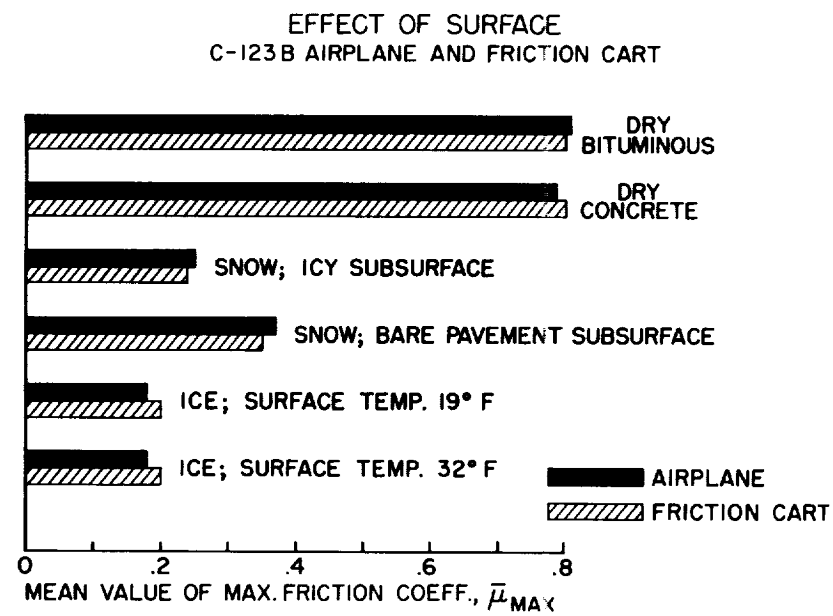


Figure 3

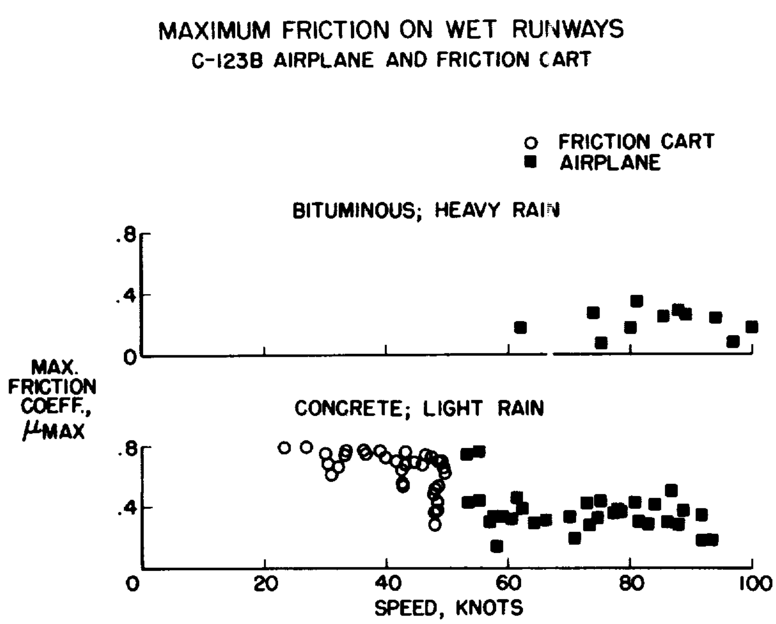
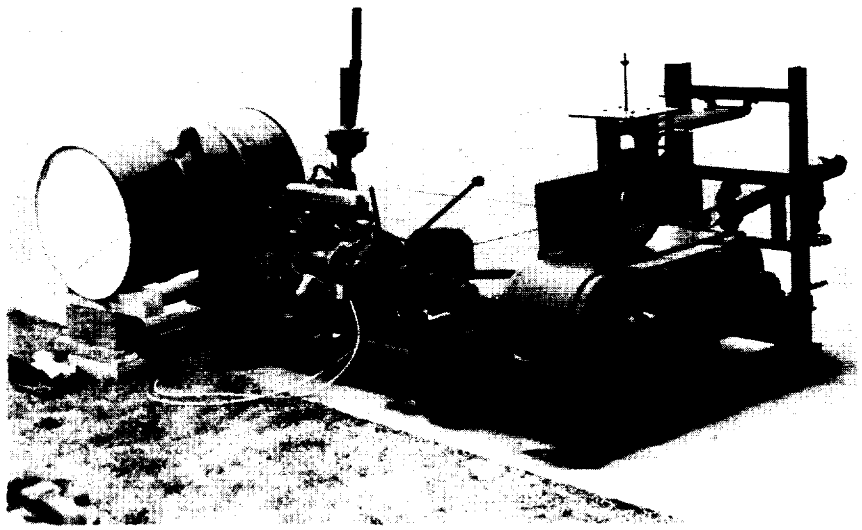


Figure 4

L-439

TIRE-FRICTION TREADMILL



L-93303

Figure 5

EFFECT OF SPEED

TREADMILL; SMOOTH TIRE; 13 LB/SQ IN.; 0.02-IN. WATER

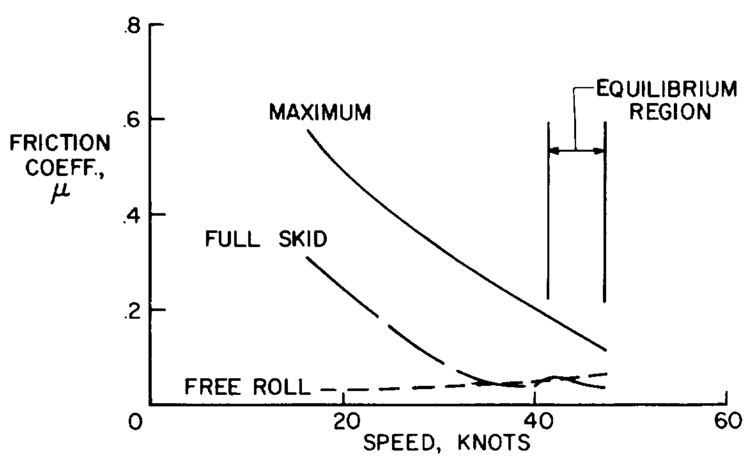


Figure 6

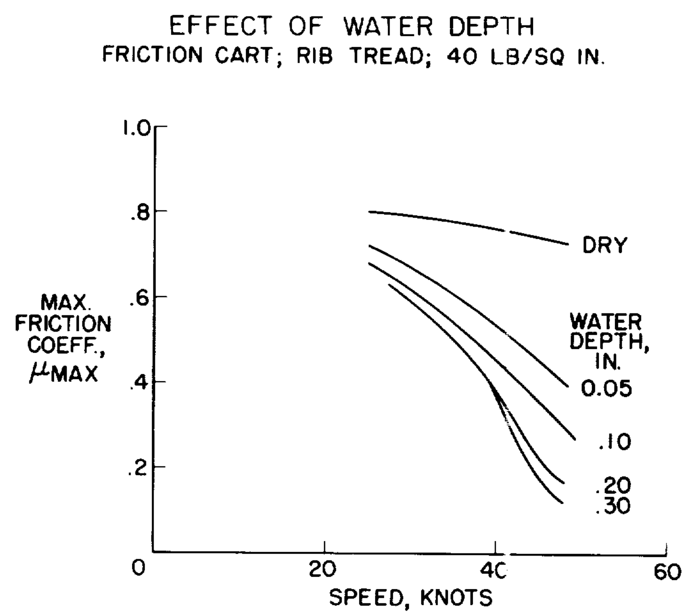


Figure 7

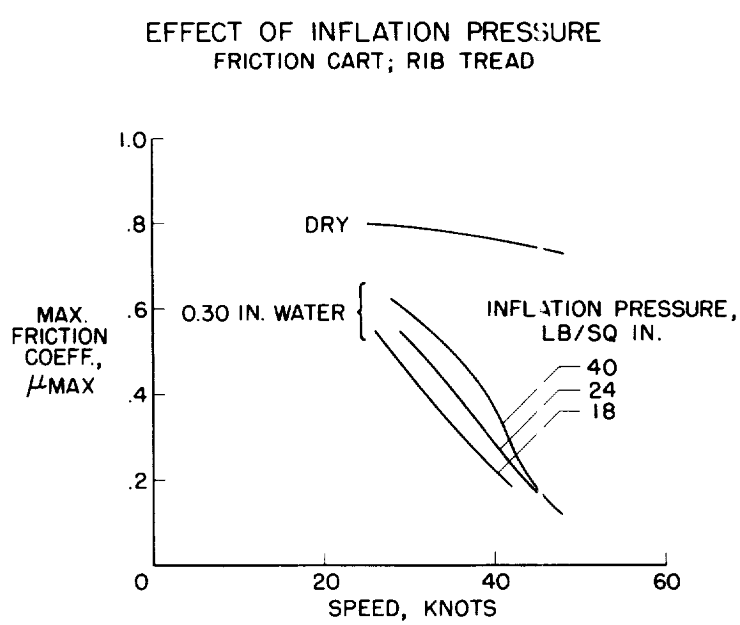


Figure 8

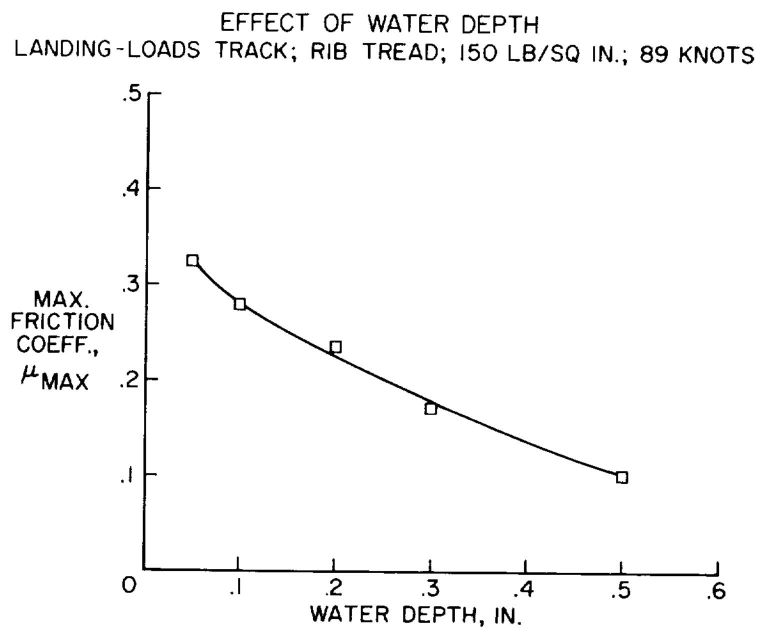


Figure 9

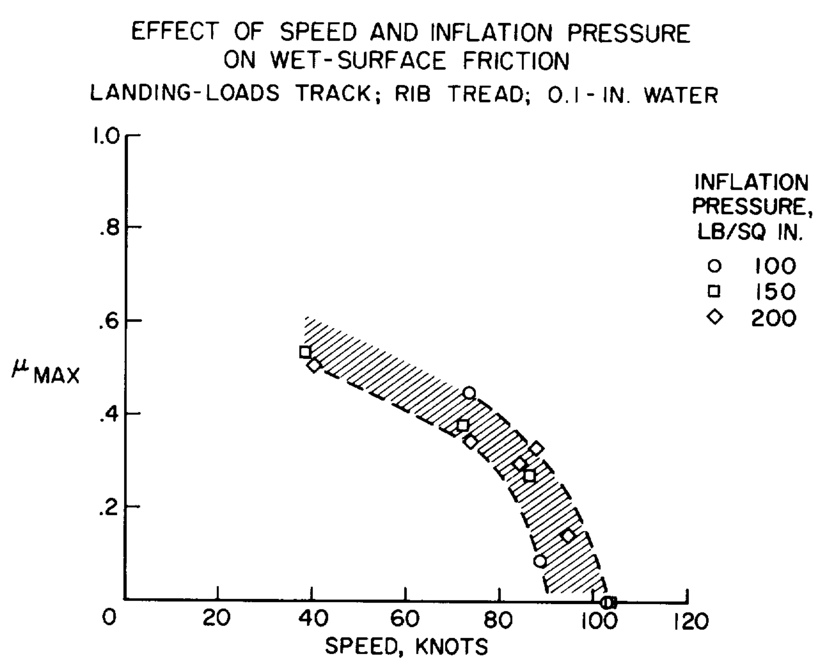


Figure 10

COMPARISON OF WET-SURFACE FRICTION RESULTS FROM TREADMILL, FRICTION CART, AND LANDING-LOADS TRACK

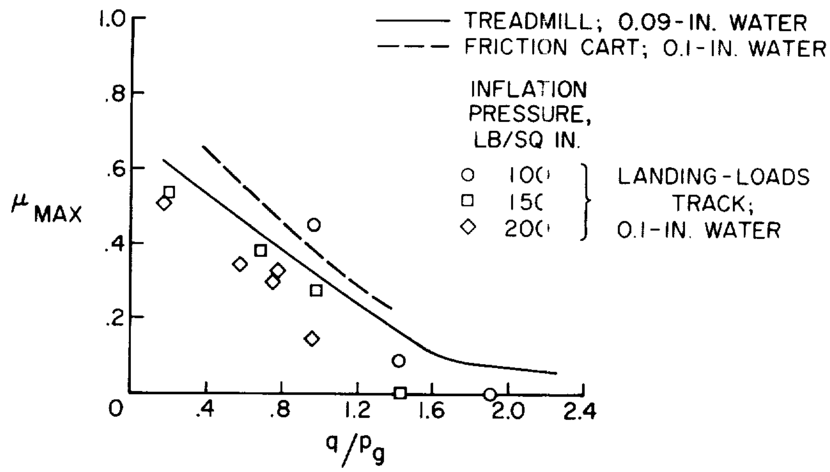


Figure 11

TANDEM WHEEL ARRANGEMENT ON TIRE-FRICTION TREADMILL

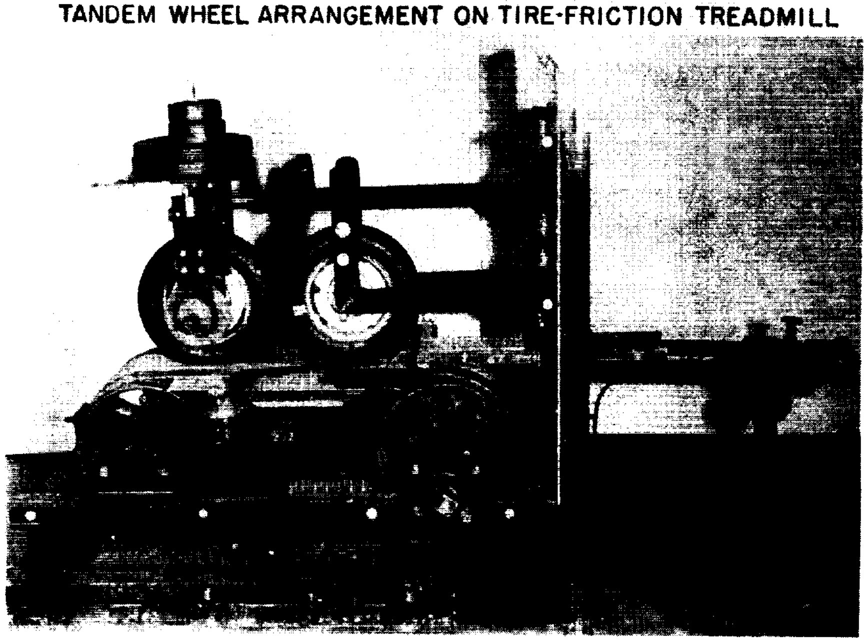


Figure 12 L-58-41

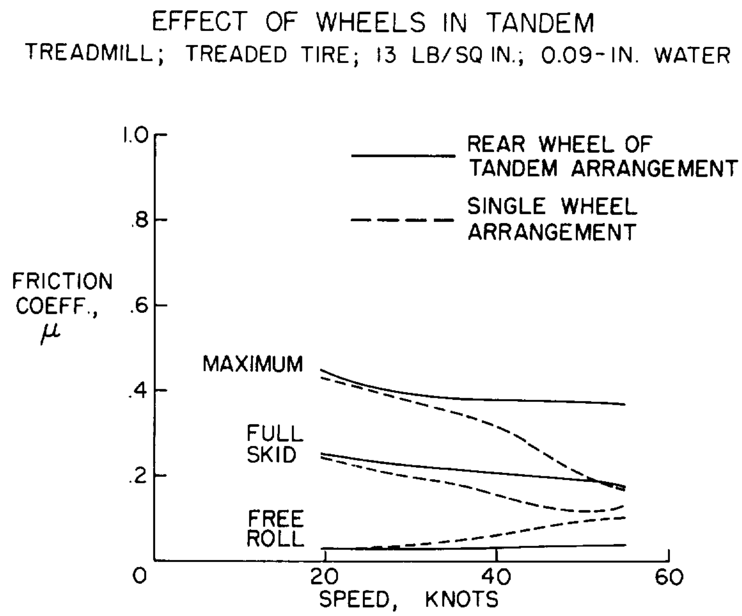

EFFECT OF WHEELS IN TANDEM
TREADMILL; TREADED TIRE; 13 LB/SQ IN.; 0.09-IN. WATER
REAR WHEEL OF TANDEM ARRANGEMENT
SINGLE WHEEL ARRANGEMENT
FRICTION COEFF., μ
1.0
.8
.6
.4
.2
0
MAXIMUM
FULL SKID
FREE ROLL
20
40
60
SPEED, KNOTS

Figure 13