RESEARCH MEMORANDUM

RECENT DATA ON TIRE FRICTION DURING LANDING

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

June 7, 1957

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SUMMARY

An investigation was made at the Langley landing-loads track to obtain data on the coefficient of friction during wheel spin-up. A landing gear was tested at horizontal velocities ranging from 0 to 180 feet per second together with vertical velocities of 7.0 and 9.3 feet per second. The results indicate the effect of forward speed and tire inflation pressure on the coefficient of friction.

INTRODUCTION

The National Advisory Committee for Aeronautics has been engaged for some time in an experimental study of the wheel spin-up phenomenon during landing. As a result of these investigations, it has been possible to separate the effects of a number of parameters on the coefficient of friction. Until recently, however, data could not be obtained under controlled conditions for either the large landing gears or the high forward speeds which are required for modern airplanes. In order to obtain such data the NACA has put into operation a new research facility called the landing-loads track. This paper presents the first data obtained at the track and indicates the effect of forward speed and tire inflation pressure on the coefficient of friction. Although the trends are clear it is not yet possible to define the variations accurately because of the limited number of available test results.

TEST CONDITIONS

The total dropping weight was 20,000 pounds. The test covered a horizontal velocity range from 0 to 180 feet per second and vertical velocities of 7 and 9.3 feet per second. The landing gear was equipped with a 44 × 13, type VII, 26-ply-rating tire. The normal inflation pressure for the 20,000-pound weight is 140 pounds per square inch; however, the tire pressure was varied in one series of tests. All tests were made with the strut inclined at an angle of 15°. A lift force of 20,000 pounds was applied to the dropping mass throughout the impact, but the airplane flexibility characteristics were not simulated. Comparisons made of the landing surface at the landing-loads track and an active runway at Langley Field, Va., showed the roughness of both surfaces to be about the same.

RESULTS AND DISCUSSION

Effect of Horizontal Velocity

Figure 1 shows the effect of forward speed on the vertical and drag reactions at the ground and on the coefficient of friction. Time histories are shown of three tests made at horizontal velocities V_h of 110, 130, and 160 feet per second. The sinking speed V_v was 9.3 feet per second for all three tests. In reference 1 it was shown that the coefficient of friction is affected by the vertical load. However, during the three tests shown in figure 1, the maximum coefficient of friction occurred at approximately the same value of vertical load. This is apparent from the upper set of curves where the circles appearing on the curves indicate the value of the vertical load at the instant of maximum coefficient of friction for each test. These data, therefore, isolate the effect of forward speed on the maximum coefficient of friction, and show that increases in forward speed reduce the maximum coefficient of friction. At the present time insufficient data are available at constant vertical load to define this variation accurately.

In figure 1 it can be seen that the maximum drag reaction as well as the maximum coefficient of friction changes over a limited range of forward speed. Figure 2 shows the variation of maximum drag reaction over a much larger range of horizontal velocities. The vertical velocity is 9.3 feet per second. This vertical velocity is the same as for the data in figure 1. Each point represents a separate test, and the maximum drag reaction is plotted against the horizontal velocity of the test. The curve reaches a maximum at a forward speed of about 110 feet per second. It can be seen in figure 1 that this is the forward speed where wheel spin-up occurs just as the vertical load roughly levels off. At forward speeds less than 110 feet per second spin-up occurs sooner and at a lower value of vertical load and results in smaller drag loads. At the higher forward speeds, although the vertical loads remain approximately constant, the decrease in maximum coefficients of friction causes smaller drag loads.

Effect of Tire Pressure

Figure 3 shows the effect of variation in tire pressure on the coefficient of friction. Four tests were made at a horizontal velocity of

160 feet per second and a vertical velocity of 7 feet per second. The tire inflation pressures p covered a range from 35 to 210 pounds per square inch. In figure 3 the coefficient of friction is plotted against the instantaneous skidding velocity. Skidding velocity is defined as the difference in velocity between the peripheral speed of the tire and the runway. Since the skidding velocity is maximum at the instant of touchdown, spin-up occurs from right to left in figure 3. In the region where the skidding velocity is large, the curves form two groups. Although the difference between the two curves which form each group is small, the difference between the two groups is large. Furthermore, the curves obtained at the higher tire pressures exhibit lower coefficients of friction. It is believed that this is caused primarily by differences in temperature in the tire footprint region. Since as the tire inflation pressure is increased the tire footprint areas decrease, the heat generated during skidding is distributed over a small area, and the rubber is hot and primarily molten and exhibits a low coefficient of friction. However, at the low inflation pressures, where the tire footprint areas are larger, the heat is distributed over a greater area; the rubber is cooler and primarily in the solid state and exhibits a higher friction coefficient. Evidently, the transition region from solid to molten rubber occurs somewhere in the region of tire pressures between 70 and 140 pounds per square inch. All the curves reach approximately the same maximum value at the low skidding velocities. This indicates that the tire has turned sufficiently so that cool rubber predominates in the footprint region when spin-up occurs.

Figure 3 shows that the maximum coefficient of friction obtained at a tire inflation pressure of 35 pounds per square inch occurs at an appreciably higher skidding velocity than those obtained at the higher tire pressures. This is attributed primarily to the method used in measuring the skidding velocity. In order to obtain the peripheral speed of the tire, measurements are made of the rotational velocity of the wheel, and the rotational motion of the tire with respect to the wheel is neglected. As the tire pressure is decreased the response of the wheel to the motion of the tire is lowered. This is not too critical in the early stages of the impact where the increase of the drag load is relatively slow. However, appreciable errors are introduced as spin-up is approached since the wheel is unable to follow the rapid changes of the tire motion caused by the rapidly changing drag load.

Effect of Braking and Wet Landing Surface

Figure 4 shows time histories of drag reactions obtained for tests made at a horizontal velocity of 160 feet per second and a vertical velocity of 7 feet per second. Wheel spin-up in all cases occurred subsequent to the leveling off of the vertical-load curve. The curve indicated as "braked" was obtained during a landing made with partial brake pressure applied to the wheel. The curve labeled "free" was obtained during a normal landing with the wheel free to rotate. Braking caused reduced spin-up accelerations and, to a certain degree, simulated the effect of increasing the moment of inertia of the wheel. It can be seen that, even though the braked wheel skidded for a longer time, the maximum drag load in both cases was the same.

The curve labeled "wet" in figure 4 was obtained from a landing made on a wet runway with the wheel free to turn. The other curve was obtained from a landing made with the wheel locked, and the rubber in the footprint area was undoubtedly molten. For both curves the skidding velocities are high, up to 0.10 second after impact, and it can be seen that the drag loads are approximately the same during this time. This indicates that the lubricating effects of water and molten rubber are about the same.

In the case of the landings on wet concrete where the lubricant is spread along the runway, an appreciable reduction is seen in the maximum drag load when compared with the maximum drag loads occurring in either the free or the braked landing. This indicates that runway lubrication, in addition to reducing the coefficient of friction at high skidding velocities, also results in a reduction in the coefficient of friction at the very low skidding velocities where the friction is of the static or interlocking type.

SUMMARY OF RESULTS

The principal results indicated by these tests are as follows:

1. The maximum coefficient of friction developed during wheel spin-up appeared to decrease as the horizontal velocity was increased.

2. Landings made with varying tire inflation pressures indicated that at the high skidding velocities the coefficient of friction was lower for the higher tire inflation pressures. However, at the low skidding velocities, the value of the maximum coefficient of friction appeared to be substantially independent of the tire inflation pressure.

3. The maximum drag load obtained during a landing made with partial brake application was the same as that obtained during a landing with the same initial conditions and with the wheel free to rotate.

4. At high skidding velocities the lubricating effect of water on the runway is approximately the same as that of molten rubber.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 5, 1957.

REFERENCE

1. Milwitzky, Benjamin, Lindquist, Dean C., and Potter, Dexter M.: An Experimental Study of Applied Ground Loads in Landing. NACA Rep. 1248, 1955. (Supersedes NACA TN 3246.)

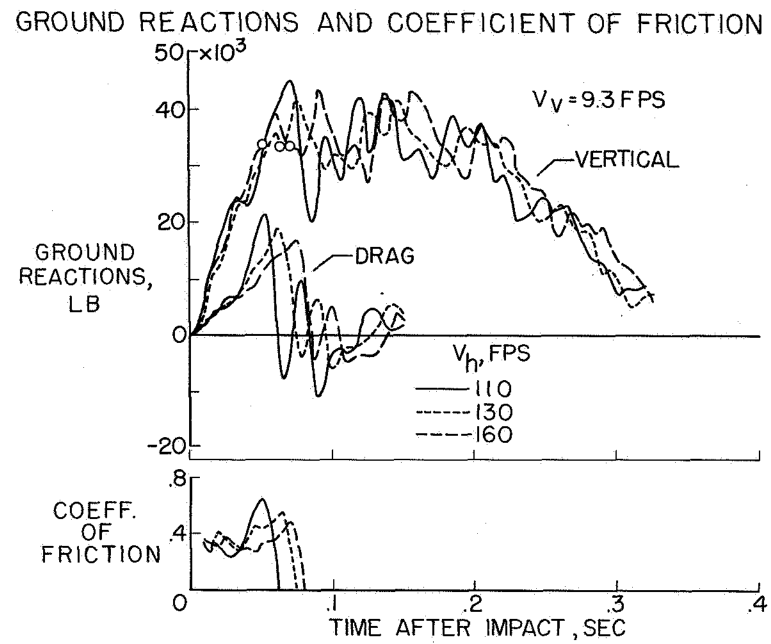

Figure 1

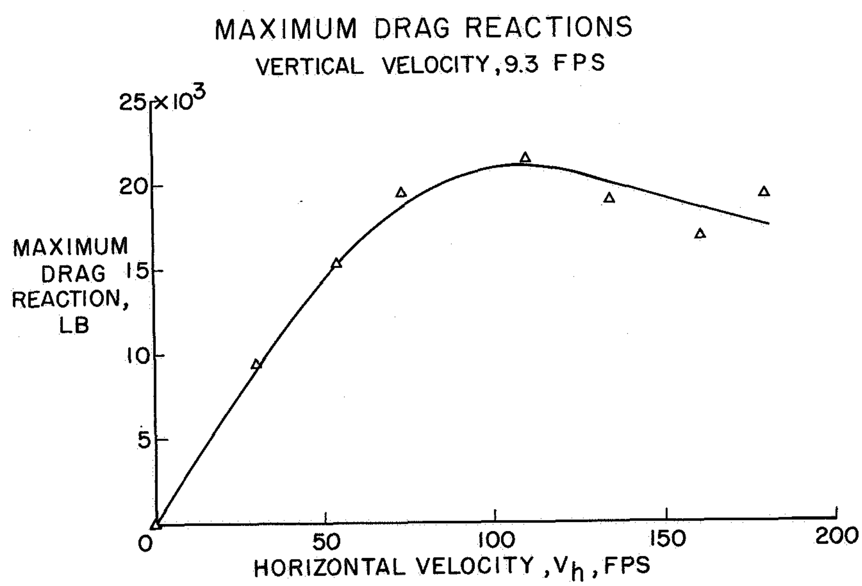

Figure 2

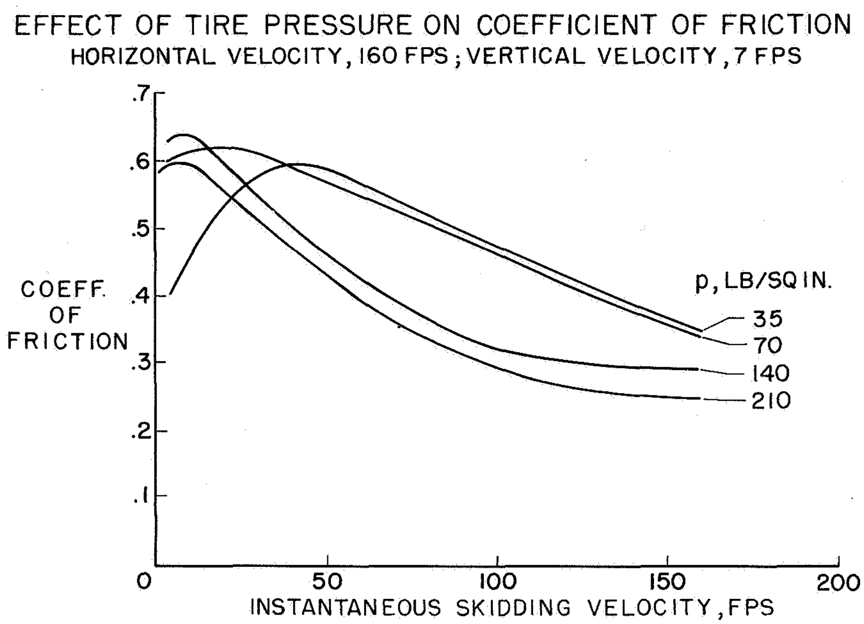

Figure 3

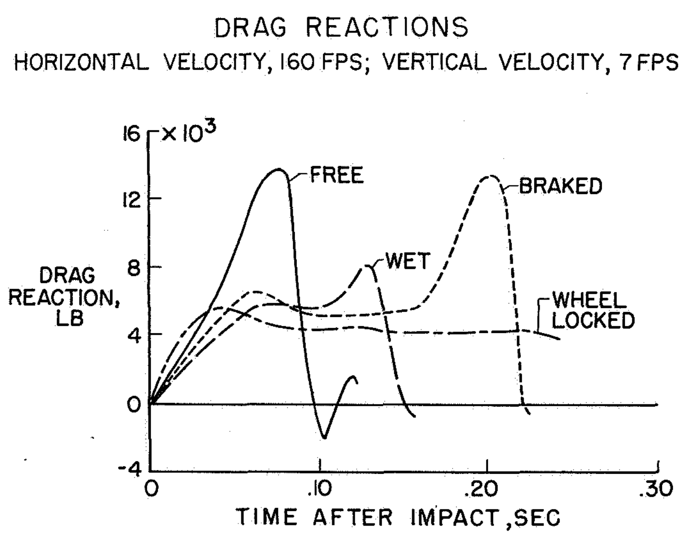

Figure 4