14. NASA STUDIES ON EFFECT OF GROOVED RUNWAY OPERATIONS ON AIRCRAFT VIBRATIONS AND TIRE WEAR

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SUMMARY

Some tire tread wear data obtained from tests conducted at the Langley landing-loads track for a variety of aircraft tire sizes and types on various transversely grooved surfaces are presented and discussed. Comparative tire tread wear data and main strut vibration data obtained during the McDonnell Douglas F-4D and Convair 990 aircraft tests on grooved and ungrooved surfaces at the landing research runway at NASA Wallops Station are also discussed. Within the test limitations of these studies the results indicate that transversely grooved runway surfaces do not significantly increase aircraft vibrations or tire tread wear.

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INTRODUCTION

The purpose of this paper is to discuss the effects of transverse runway grooves on aircraft tire tread wear and aircraft vibrations. Tire tread wear data obtained with various aircraft tires tested at the Langley landing-loads track and the landing research runway at NASA Wallops Station are presented. Vibration data obtained from vertical accelerometers mounted on the right main strut of the F-4D and 990 aircraft during the full-scale tests at NASA Wallops Station are also presented.

AIRCRAFT TIRE TREAD WEAR

During normal aircraft operations on a relatively high friction level surface, some tread wear, cutting, and/or damage occurs. The extent or magnitude of this tire tread degradation is dependent on several different factors, some of which are as follows:

(1) Pavement texture or roughness

(2) Pavement contaminants

(3) Tread type and construction

(4) Amount of skidding

(5) Loading

Pavement texture or roughness and the amount and type of pavement contaminants, such as water, slush, ice, dirt, oil, or rubber deposits, directly affect the level of friction developed between the tire and pavement that causes tire tread wear. Tire tread type and construction (that is, whether the tire has all rubber tread or fabric-reinforced rubber tread) also affect the susceptibility of the tread to shear or cut. The wear associated with skidding depends on the amount of time a tire is subjected to finite slip ratios, the slip-ratio value, and the drag load. (See ref. 1.) Tire loading includes the amount and the variation of tire loading such as occurs at touchdown or during abrupt changes in the friction level developed between the tire and the pavement.

In an attempt to determine the effect of transverse pavement grooves on aircraft tire tread wear and cutting, tests with various types of aircraft tires were made at the landing-loads track. Figure 1 shows the results obtained with a 3-groove fabric-reinforced 30 × 11.5-14.5, type VIII, aircraft tire during a low-speed (4 knots) braking test run on the 1- × 1/4- × 1/8-inch transversely grooved test surface for a dry surface condition. The test tire was inflated to 210 lb/in^2 and the test was conducted at 0° yaw. As shown in the photographs of figure 1, tread rubber was deposited on the test surface but the tire tread did not receive any cuts or damage during this run from a free-rolling condition to a locked-wheel condition. Some tread wear, however, did occur at relatively high slip-ratio values. In contrast to the normal trend observed on smooth surface runways where the rubber deposits adhered to the surface, the tread rubber deposited in the dry surface grooves during locked-wheel braking was powdery or granular in form and could be easily brushed away.

Comparative braking test runs at a ground speed of 4 knots were also made on grooved and ungrooved surfaces for damp conditions. The grooved concrete surface had a groove configuration of 1 × 1/4 × 1/8 inch. The ungrooved surface was a bituminous asphalt overlay containing abrasive aggregate material. The aircraft tire used in these tests had a fabric-reinforced rubber tread and was constrained to run at 4° yaw. Results obtained from these tests are shown in figures 2 and 3.

As indicated by the photographs of the tire skid area, some tire wear occurred for locked-wheel conditions on the 1- × 1/4- × 1/8-inch grooved surface, but on the ungrooved abrasive asphalt surface for the same test conditions, substantial damage to the tire tread occurred. Some of the tread cuts resulting from the braking run on the ungrooved surface were as deep as the tire cord. Considerable side force was developed by this test tire at 4° yaw during the run prior to the locked-wheel condition but no other tread wear or cutting occurred except for that shown in figures 2 and 3.

After the braking runs with this tire, the tread deposit on the grooved test surface was also composed of powdery or granular rubber particles which could be easily brushed off. On the ungrooved surface the tire tread deposit consisted of rubber and fabric in an abraded form which could also be brushed off.

By using a new 30 × 11.5-14.5, type VIII, aircraft tire, a braking test run at 102 knots was made at the landing-loads track to evaluate further the effect of pavement grooves on tire tread wear. The test tire had a 3-groove fabric-reinforced rubber tread, and the variation in friction developed between the tire and the grooved pavement during braking is shown as a function of slip ratio in figure 4. The damp test surface was grooved 1 × 3/8 × 1/4 inch. Figure 5 shows the 5-foot-long rubber deposit from the tread on this grooved surface and the tire tread damage area resulting from the braking run. By measuring the length of the tread damage area and by calculating the rolling circumference and angular velocity of the tire, it was determined that the surface rubber deposit was initiated at a slip ratio of about 0.8. Prior to this point in the braking cycle, no significant tread wear occurred. The tire tread wear and the chevron-type cuts shown in figure 5 occurred between slip ratios of 0.8 and 1.0. Therefore, the results of this test indicate that to minimize tire tread wear and cutting, high slip-ratio values should be avoided during aircraft ground operations.

In order to evaluate further the type and extent of the tire tread damage, locked-wheel tests were conducted at the track with a smooth 49 × 17, type VII, all rubber tread tire. The data obtained from these tests are shown in figure 6.

The time histories of the variation of slip ratio and drag friction coefficient μ_{drag} shown in figure 6 were obtained at a speed of 100 knots on 10 different grooved and ungrooved surfaces for damp and flooded conditions. The high friction that developed between the tire and the 1- × 1/4- × 1/4-inch grooved surface (fig. 6) exceeded the torque limitations of the brake system used on the test carriage and resulted in partial wheel spin-up as indicated by the variation in slip ratio. The other ungrooved and grooved test surfaces, which were flailed-type grooves of 1/8-inch depth, did not develop sufficient friction to overcome the brake torque limitation. The slip-ratio value of 1.0 indicates that the wheel remained locked on the other test surfaces for damp and flooded conditions.

The condition of the tire tread as a result of the locked-wheel runs is shown in figure 7. The numerous, small chevron-type cuts in the all rubber tread of the smooth 49 × 17, type VII, test tire did not exceed 0.06 inch in depth. In subsequent test runs with this tire, the results indicated that these chevron-type cuts did not significantly impair the tire tread life.

These chevron-type cuts in the tire tread were also observed during the tests of the 990 aircraft on the landing research runway. Figure 8 shows the condition of the tire and surface after a firm touchdown of the 990 aircraft on dry grooved concrete. The aircraft was equipped with new 5-groove all rubber tread main tires. Although only the right main gear touchdown area is shown here, the left main gear touchdown area showed similar rubber deposits and all eight main gear tires had similar tread cut areas. In analyzing these results, the width of the rubber deposit on the runway at the point of initial touchdown equaled the width of the tread cut area on the main tires. Since the tires did not have any other cutting around the tread and the rubber deposit on the runway is shown to increase in width, it would indicate that the chevron-type cuts shown in figure 8 occurred only at initial touchdown when the tire was stationary. As soon as wheel spin-up started, the tire tread had no further cutting.

During the maximum antiskid braking tests of the F-4D aircraft, some tire tread wear was experienced but no chevron-type cutting was observed. However, no prolonged wheel lockups occurred during the braking tests of the F-4D, and the main tires of the F-4D had a 3-groove fabric-reinforced rubber tread. During the maximum braking tests of the 990 aircraft on wet and flooded surfaces, prolonged wheel lockups occurred on the ungrooved surfaces particularly with the smooth all rubber tread main tires. Because of the normal test run procedure of applying maximum antiskid braking through adjacent ungrooved and grooved tests surfaces, chevron-type cuts developed on the tire tread when the tire encountered the grooved surface at locked-wheel conditions. Some of the smooth tire tread cuts are shown in figure 9. No further cutting occurred during maximum braking test runs from a grooved to an adjacent ungrooved surface. Approximately 50 maximum antiskid braking test runs were made with the chevron cuts in the tire tread. Again the maximum measured depth of these cuts did not exceed 0.06 inch. As a result of further braking tests, these cuts increased in number but did not increase in depth.

In summary, the tests at the landing-loads track and the aircraft tests on the landing research runway have shown that tire tread wear and/or cuts occur on grooved and ungrooved pavements. The extent or magnitude of tire tread wear or cutting appears to be greatest at or near the locked-wheel condition. The small chevron-type cuts in the aircraft tire tread occurred only at touchdown, when the tire was stationary, or under a locked-wheel condition on a high friction level surface. It can be theorized that at very high slip-ratio values, particularly at the locked-wheel condition, local tension failures of the tread rubber result in the chevron-type cuts. These test results indicate, however, that tire tread life is not significantly impaired because of the chevron-type cutting.

AIRCRAFT VIBRATION

Two vertical accelerometers were mounted on the right main landing gear strut of the F-4D and 990 aircraft during the tests made on the landing research runway to determine the effect of transverse runway grooves on aircraft vibration. An accelerometer was mounted on the upper section of the main strut close to the wing; another accelerometer was mounted on the lower section of the main strut close to the wheel or wheels. The upper strut accelerometer had a natural frequency of 1000 cycles per second, and the lower strut accelerometer had a natural frequency of 3000 cycles per second. Some typical vibrations obtained from these strut accelerometers during the tests of the F-4D aircraft on grooved and ungrooved surfaces are shown in figures 10 and 11.

The upper and lower strut accelerometer traces shown in figure 10 were obtained for free-rolling conditions on dry ungrooved and grooved concrete. These data show that the magnitude of the lower strut vibration is greater than that measured at the upper strut on both test surfaces. As the aircraft ground speed increased from 61.5 to 96.0 knots (fig. 11), the amplitude of the strut vibrations also increased. No change in amplitude could be observed when results obtained on grooved and ungrooved surfaces at the same speed were compared. When the time scales of figures 10 and 11 were expanded, no significant difference was measured in the frequency of the lower strut vibration on the dry grooved surface as compared with the dry ungrooved surface at both test speeds.

Strut accelerometer data similar to the data for the F-4D aircraft were obtained at speeds of 83 knots and 123 knots during the tests of the 990 aircraft on grooved and ungrooved surfaces as shown by the examples in figures 12 and 13. The magnitude of the strut vibrations for the 990 aircraft on dry grooved and ungrooved asphalt at both test speeds is less than that shown for the F-4D aircraft in figures 10 and 11. As in the case of the vibration data of the F-4D aircraft, no significant difference was measured in the frequency or amplitude of the lower strut vibration of the 990 aircraft on the dry grooved surface as compared with the dry ungrooved surface at both test speeds. On the basis of these test results, it is believed that grooved runways do not significantly alter aircraft vibration.

CONCLUDING REMARKS

Braking tests using several types of aircraft tires were conducted at the Langley landing-loads track on various grooved and ungrooved surfaces. The results indicated that the grooves caused no significant increase in tire wear or tire damage. Tire tread degradation, however, was found to increase at the higher slip ratios and was greatest during the locked-wheel skid condition. Full-scale aircraft tests conducted on the landing research runway at NASA Wallops Station substantiated these test results and furthermore indicated that the chevron-type cuts that were developed in the tire tread at the higher slip ratios on the grooved surfaces did not reduce tire tread life. Aircraft strut vibrations measured during operations on 1- × 1/4- × 1/4-inch transversely grooved surfaces were found to be the same as those measured on ungrooved surfaces. Full-scale tests at the landing research runway for a variety of additional aircraft types and tire loadings are planned to obtain further evaluations of the effect of grooved runway operations on aircraft vibrations and tire tread wear.

REFERENCE

1. Batterson, Sidney A.: A Study of the Dynamics of Airplane Braking Systems as Affected by Tire Elasticity and Brake Response. NASA TN D-3081, 1965.

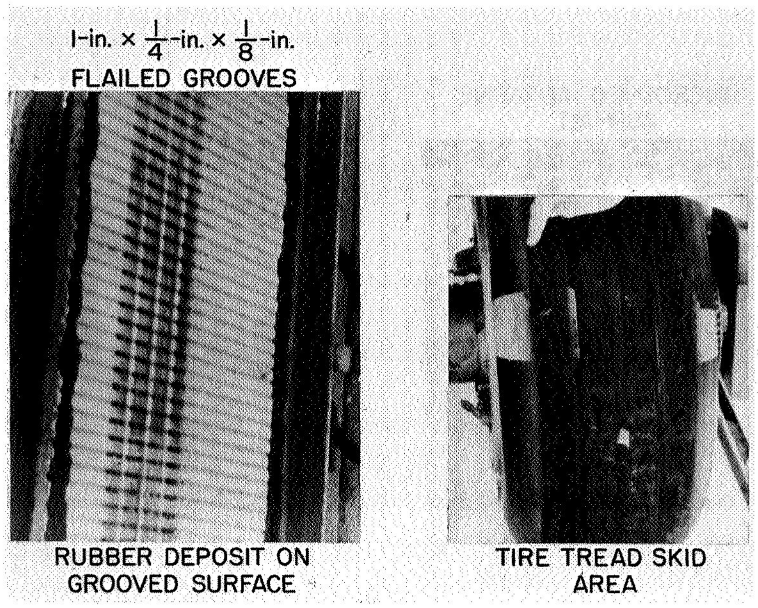

Figure 1.- Condition of grooved surface and tire after braking test. 3-groove fabric-reinforced 30 × 11.5-14.5, type VIII, tire; inflation pressure, 210 lb/in^2; dry surface; ground speed, 4 knots; 0° yaw.

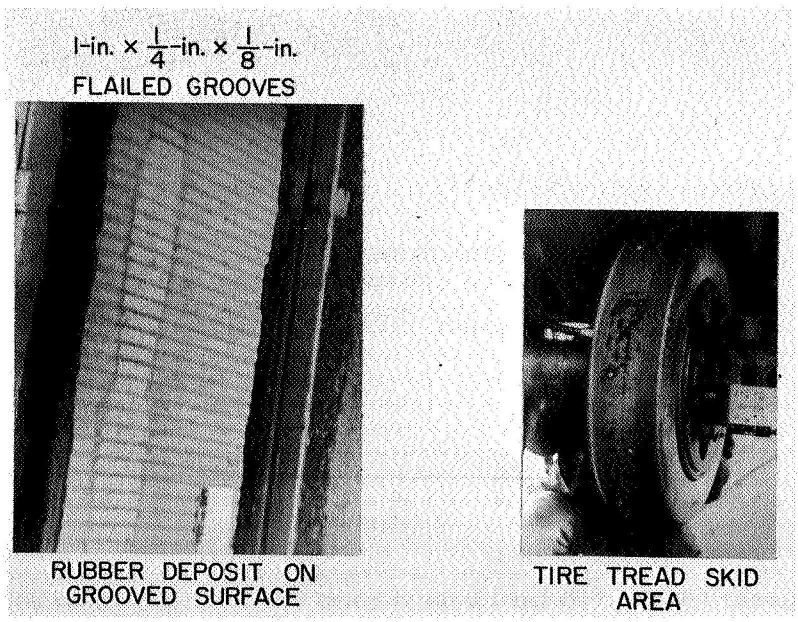

Figure 2.- Condition of grooved surface and tire after braking test. Fabric-reinforced rubber tread tire; inflation pressure, 400 lb/in^2; damp surface; ground speed, 4 knots; 4° yaw.

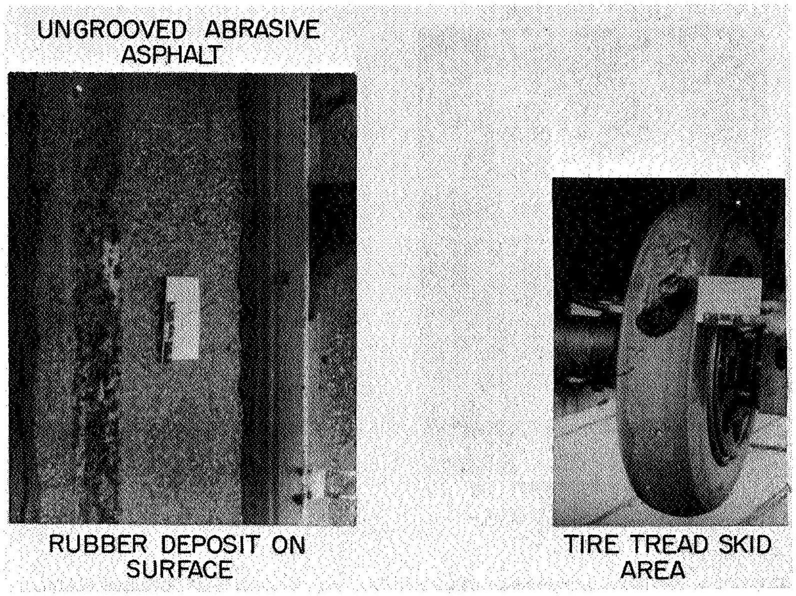

Figure 3.- Condition of ungrooved surface and tire after braking test. Fabric-reinforced rubber tread tire; inflation pressure, 400 lb/in^2; damp surface; ground speed, 4 knots; 4^o yaw.

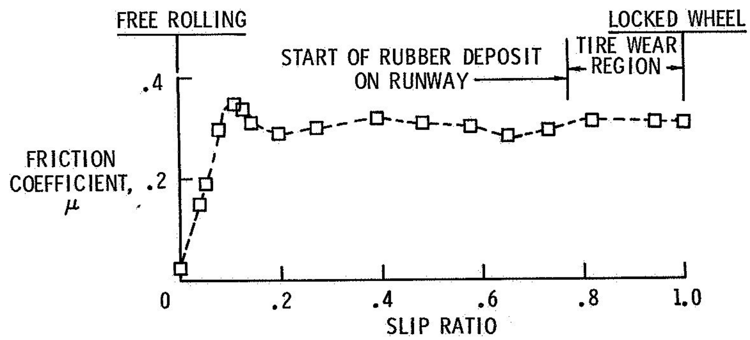

Figure 4.- F-4D aircraft tire during braking on grooved surface. 30 × 11.5-14.5, type VIII, tire; damp concrete; ground speed, 102 knots.

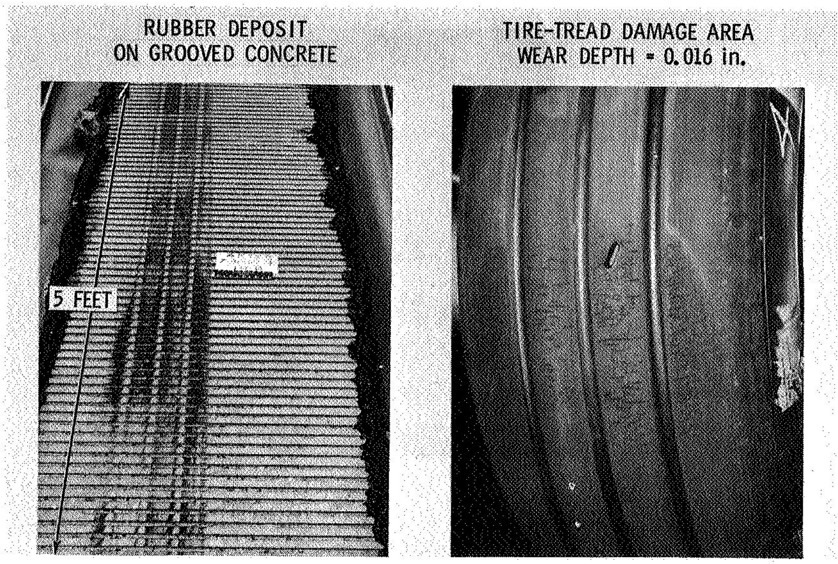

Figure 5.- Condition of test surface and tire after braking.

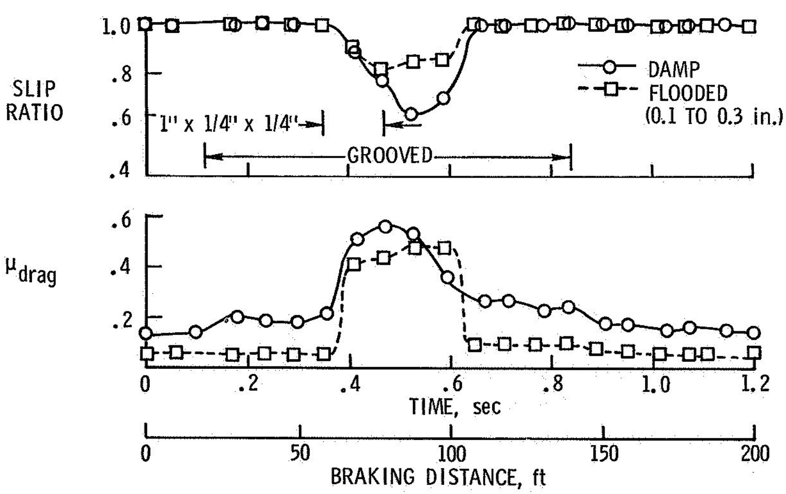

Figure 6.- Comparison of locked-wheel braking on various test surfaces. Smooth 49 × 17, type VII, tire; inflation pressure, 170 lb/in^2; ground speed, 100 knots; yaw angle, 4°.

Figure 7.- Condition of tire tread after locked-wheel runs.

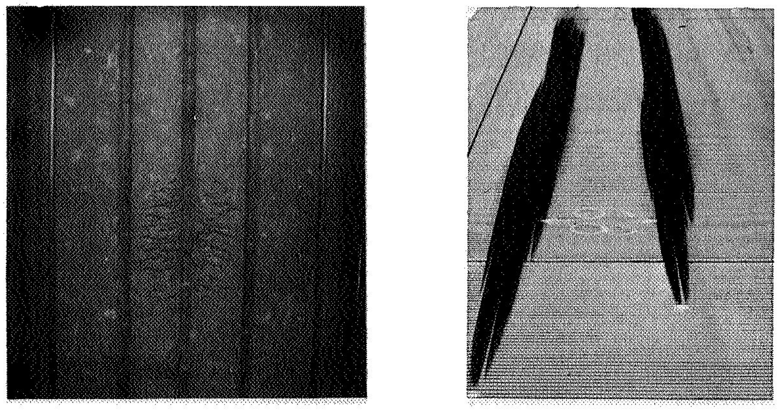

Figure 8.- Condition of grooved surface and tire tread after firm touchdown of 990 aircraft. Dry concrete; inflation pressure, 160 lb/in^2.

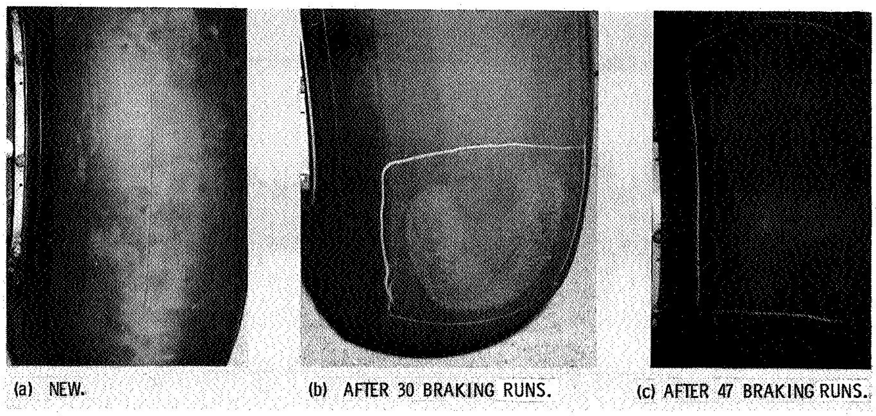

Figure 9.- Effect of braking tests on smooth main tire tread of 990 aircraft. 41 × 15.0-18, type VIII, main tires; inflation pressure, 160 lb/in^2.

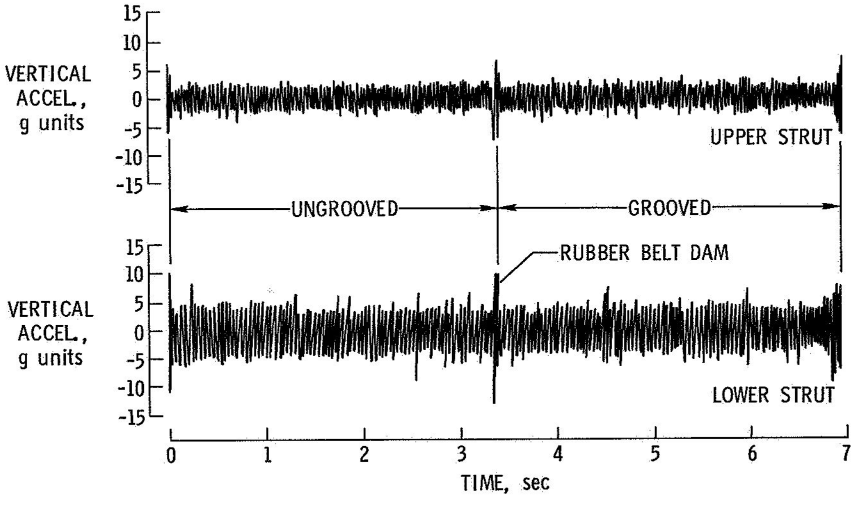

Figure 10.- Free-rolling vibrations from main strut of F-4D aircraft. Dry concrete; ground speed, 61.5 knots.

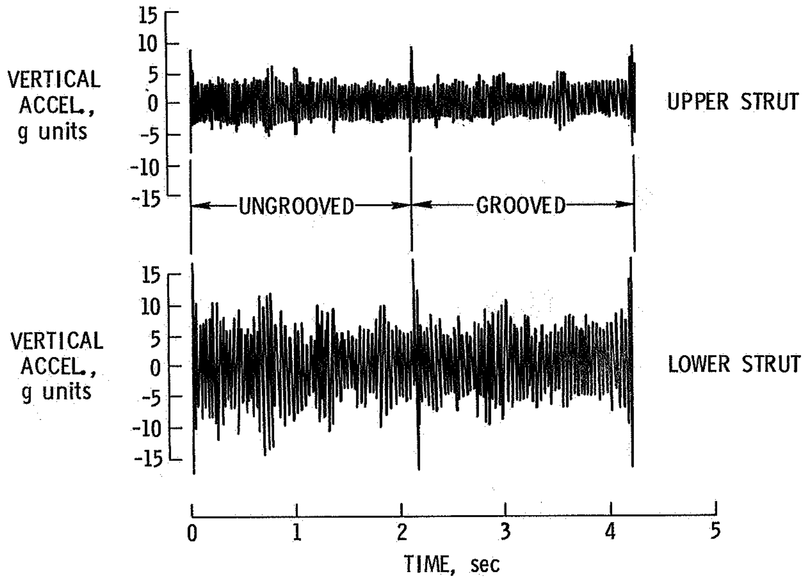

Figure 11.- Free-rolling vibrations from main strut of F-4D aircraft. Dry concrete; ground speed, 96.0 knots.

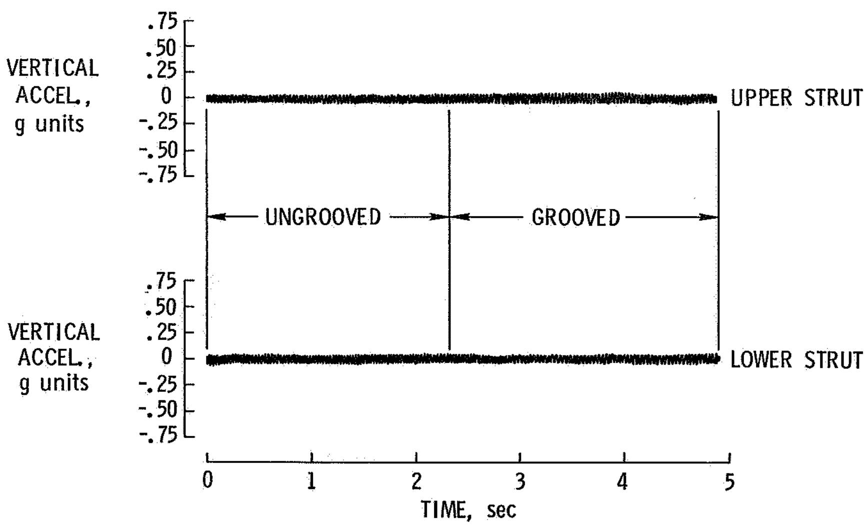

Figure 12.- Free-rolling vibrations from main strut of 990 aircraft. Dry asphalt; ground speed, 83 knots.

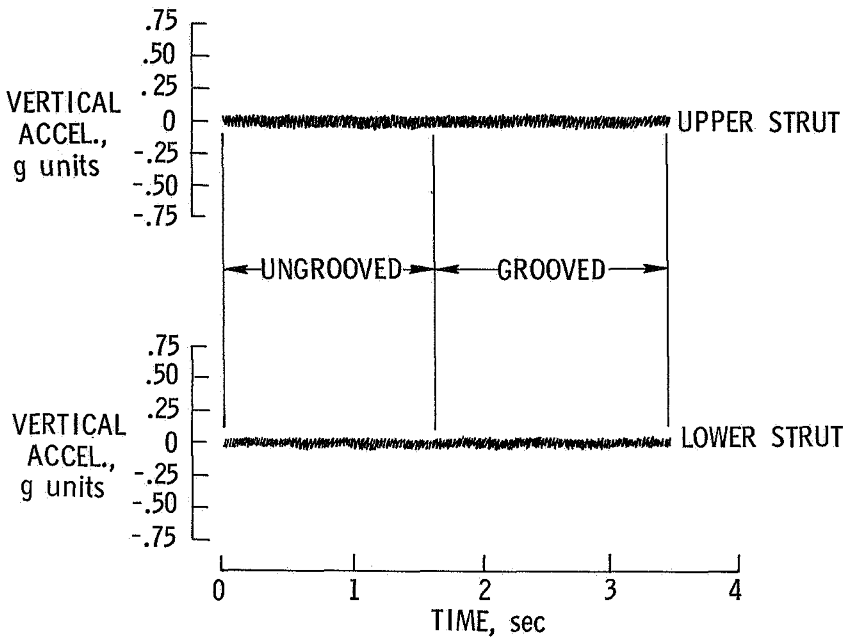

Figure 13.- Free-rolling vibrations from main strut of 990 aircraft. Dry asphalt; ground speed, 123 knots.