Modified Reflex-Percussive Grooves for Runways

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ABSTRACT

Runway surface treatments, such as grooving, can minimize the danger of aircraft hydroplaning by reducing the water buildup on the runway and by facilitating forced water escape from the tire-runway interface. Square saw-cut 1/4- in. grooves spaced between 1 and 2 1/2 in. have been widely used; the former provides a higher resistance to hydroplaning. Other surface treatments that have been reported as being effective in minimizing aircraft hydroplaning include porous friction overlay and reflex-percussive grooves; the latter are offered as a cost-effective alternative to square saw-cut grooves. As the title of this paper suggests, the modified reflex-percussive grooves are a derivative of reflex-percussive grooves in that the cutting heads for the latter were modified to produce smoother groove edges, which tend to improve water flow through the groove channels. Comparative dynamic tests showed that the braking action of an aircraft tire on modified reflex-percussive grooves is equivalent to that on square saw-cut grooves spaced between 1 1/4 and 2 in. Results also showed that hydroplaning was not initiated at speeds of up to 150 knots. The lower cost of the modified grooves makes them a viable cost-competitive method; however, realistic cost estimates and full savings potential can only be affirmed after application of these grooves in an operational environment.

A rain-soaked runway poses a problem unique to a landing aircraft: if sufficient water is accumulated on the runway as a result of rainfall, the aircraft may hydroplane. In hydroplaning, a thin layer of water separates the aircraft tire from the runway surface. The net result is a severe degradation of the braking action of the aircraft and of the ability to bring the aircraft to a stop. Adequate slope and proper runway surface treatments help reduce the accumulation of large amounts of water. Commonly used surface treatments include grooving and porous friction overlays. Although grooves can be installed on both portland cement concrete (PCC) and asphaltic concrete surfaces, the porous friction overlays are limited to the latter.

In its efforts to determine low-cost surface treatments that provide adequate braking action to aircraft, the Federal Aviation Administration (FAA) has identified (1) a reflex-percussive grooving process as a viable cost-effective alternative to square saw-cut grooves. The process, which is based on the principle of controlled removal of concrete, was first developed in Great Britain to provide a rough finish on the pavement. The great advantage of the cutting process in its ability to not loosen the aggregate particles within the matrix and not create microfractures in the surrounding concrete. When the cutting head strikes the surface of the concrete it causes the material directly under the area of impact to deflect downward, thus creating momentary and localized compression. The compressive strain is mainly elastic and is almost immediately given up in generating a rebound that causes the concrete to attempt to pass through its relaxed state into one of tension nearly equal to the initial compression. However, because it is very weak in tension, the concrete fractures, and elastic energy is given up as kinetic energy of the flying fragments.

Klarcrete Limited of Canada demonstrated that the reflex-percussive process can be readily adapted for grooving in PCC surfaces. However, the cutting heads that performed successfully in PCC (2) were unsatisfactory in cutting smooth grooves in asphaltic concrete surfaces (2); the primary reason is the decrease in the reflex action of the percussive process in viscoelastic asphaltic concrete. The developer of the cutting heads, therefore, designed new heads that produced significantly improved grooves in asphaltic concrete surfaces. Consequently, the research described herein was undertaken to determine if the grooves produced by these modified cutting heads will provide "acceptable braking action" to an aircraft tire and be cost competitive with the square saw-cut grooves.

MODIFIED REFLEX-PERCUSIVE GROOVES AND SQUARE SAW-CUT GROOVES

The cutting heads for the original and modified reflex-percussive grooves are shown in Figure 1. When installed on the machine shown in Figure 2, the cutting head rotates about its axis in a random manner as it strikes the concrete surface. The speeds of forward motion and cutting stroke are pneumatically controlled. It is believed that the continuous cutting edge of the modified head provides overlapping strokes that tend to produce a smooth groove channel. The square saw-cut grooves are installed by a rotary saw equipped with diamond-tipped blades. The rotary saw, shown in Figure 3, is also pneumatically powered.

Figures 4 and 5 show the asphaltic concrete test sections and groove dimensions. The program included square saw-cut grooves at spacings of 1 1/4 and 2 in.; the former spacing provides higher resistance to hydroplaning (1, 2).

HYDROPLANING

When an aircraft lands on a water-covered runway, the tires first contact the top of the water layer and then descend through this layer. The descent is relatively simple until the aircraft weight is transferred to the tires. During this transfer, a
complex water flow exists in the space bounded by the tire at the upper end and the runway at the lower end. Water enclosed in the bounded space undergoes rapid change of momentum and generates large forces. These forces act on the tire surface and deform it radially; if the forces exceed aircraft weight, the tire surface will be lifted and supported entirely by the water layer. This condition is called hydroplaning. Friction forces in the tire-runway contact area approach zero during hydroplaning and aircraft braking and directional control are essentially nil. It is important to note that the time elapsed between the initial contact of the tire with the top of the water layer and eventual hydroplaning (should the conditions be sufficient to induce hydroplaning) is on the order of a fraction of a second (4).

Hydroplaning is not always imminent; operational and environmental conditions determine the nature of water flow under the tire. Water depth on the runway and aircraft speed are the two important parameters that share the most responsibility for inducing hydroplaning. However, because aircraft landing speeds are limited by aerodynamic considerations and cannot be varied much beyond those limits, water accumulation alone becomes the critical parameter for inducing hydroplaning. Efforts are therefore expended in reducing water accumulation on the runway.

Near elimination of aircraft hydroplaning on a
The braking action of an aircraft tire is a function of the frictional forces developed in the tire-runway contact area. These forces are developed as a result of relative motion between the tire surface and the runway. The braking action can be represented by a coefficient of friction that is the ratio of the friction forces developed in the contact area to the vertical load on the tire. As the coefficient of friction decreases, so does the braking action.

In theory, the coefficient of friction approaches zero at the onset of hydroplaning; however, small viscous and mechanical drags are always present. For a direct measure of hydroplaning speed, various drag forces must be separated. This is generally difficult if only because of the need for highly sensitive instrumentation for measuring small quantities. Various indirect methods have been used in the past (5) to identify the onset of hydroplaning. In the present study, incipient hydroplaning is indicated when the computed coefficient of friction is 0.05 or lower. In comparison, the average coefficient of friction between an aircraft tire and a dry runway is approximately 0.70.

There are two methods by which a meaningful comparison of the braking action of an aircraft tire on various surface treatments can be accomplished: (a) measurement of coefficient of friction when the tire is locked and slides over the test surfaces or (b) measurement of maximum value of the available coefficient of friction on each test surface. This study employs the second method.

The maximum value of the available friction coefficient can be obtained by conducting a series of tests in which applied braking effort is gradually increased, other operational conditions of the tire and runway being identical during the series. Because precise duplication of operational conditions is difficult, care should be taken in controlling and monitoring the test conditions. Under ideal conditions, the friction coefficient will initially increase, then reach a maximum value, and finally drop as the braking effort is gradually increased.

Clearly, this method of comparing braking action of an aircraft tire on various surfaces involves a large number of tests. However, it represents a realistic reproduction of the aircraft braking process. The disadvantage of the first method is accelerated treadwear of the tire, which may require frequent tire changes; danger of tire blowout is also present in the first method.
FIGURE 7 Dynamometer and wheel assembly showing vertical and horizontal load links.

FIGURE 8 Test bed at the end of the test track.

representative of light to moderate rain. A summary of the test parameters follows.

Operational Parameters

| Tire                     | Vertical load: 35,000 lb |
|                         | Inflation pressure: 140 lb per square inch |
|                         | Tread design: Worn |
| Pavement                | Size/type: 49 x 17, 26-ply, Type VII |
|                         | Type: Asphaltic concrete |
|                         | Texture: 0.015 (nongrooved) |
|                         | Surface treatments: Reflex-percussive grooves with 20-degree groove angle and 3-in. spacing Square saw-cut grooves, 1/4-in. size at 1 1/4- and 2-in. spacings |

| Aircraft Speed          | 70 to 150 knots |
| Wheel operation         | Rolling to locked wheel |
| Brake pressure (braking effort) | 200 to 2,200 lb per square inch |

Environmental Parameters

|            | Light rain: Wet: water depth less than 0.01 in. |
|            | Moderate rain: Puddled: water depth of 0.10 in. or more |

This investigation included the rainfall conditions that will represent "wet" and "puddled" water conditions on the runway. Wet conditions are normally encountered during or after a light rain. The surfaces may be saturated with water but do not have measurable water depth present on them. The puddled surfaces are representative of conditions that can be expected immediately after heavy rains of short duration.

Test Procedure

The dynamometer assembly, with mounted tire, was positioned at the launch end of the track for the test. A complete braking test consisted of the following steps:

1. Water depth was set on the test sections at the recovery end.
2. Jet engines were started at the launch end and set at a performance level to provide the preselected speed in the test section.
3. The jet car was released to propel the test equipment (dead-load carriage and dynamometer assembly). The test tire remained in free-rolling mode.
4. The jet car was braked and separated from the test equipment several hundred feet ahead of the test bed. This allowed the dead-load carriage and dynamometer assembly to enter the first test section at the preselected speed. The speed decayed by 1 to 2 knots in the remaining sections.
5. Before the dynamometer assembly entered the first section, the hydraulic systems were activated to apply the vertical load and brake pressure on the tire.
6. The wheel entered the test sections under preselected test conditions. The instrumentation was activated and the data were recorded.
7. As the wheel left the test bed, unloading and brake release were initiated and the test equipment was recovered by the use of arresting cables.

The automatic data handling system is a multi-channel analog recording system. It uses standard FM/FM telemetry for transmission of data from the mobile dead load. Both low- and high-level signals are frequency multiplexed for recording on a single magnetic tape. Recovery of these data in analog form permits early validation and review of the data for further testing purposes.

Tables 1 and 2 give the results on the asphaltic concrete sections. The coefficients of friction in these tables are the maximum developed under each set of operating conditions; many more tests were conducted to obtain the maximums. A least squares fit was obtained between speed and coefficient of friction.

DISCUSSION

The relevant figures show the results of the braking tests. The curves show the variation of the maximum friction coefficient with speed under wet or puddled water conditions. The data show the well-established trend that friction coefficient decreases with increasing speed.

Under wet water conditions, the friction coeffi-
coefficients are "relatively high" throughout the speed range (Figure 9). A single curve can adequately represent the braking action of an aircraft tire on both the square saw-cut grooves and the modified reflex-percussive grooves.

When the wetness on the surface is representative of puddled conditions, the spacing of the saw-cut grooves starts to influence the maximum friction coefficient (Figure 10) available in the tire-runway contact area. The separation of the two solid lines in Figure 10 is not large; however, the grooves spaced at 1 1/4 in. provide higher friction coefficients than do the grooves spaced at 2 in. The performance of modified reflex-percussive grooves falls between the curves for saw-cut grooves spaced at 1 1/4 and 2 in. for speeds above 90 knots.

The improvement provided by the modified cutting heads (Figure 1) over the standard cutting heads (Figure 1) can be best evaluated by comparing the results obtained with both heads. Figure 11 shows the data [from Agrawal (2)] using the standard cutting heads for reflex-percussive grooves; the data for square saw-cut grooves are also included. The most distinct feature in Figures 10 and 11 is the shift in the coefficient-of-friction curve for the reflex-percussive grooves; the coefficient curve resulting from the use of modified cutting head lies above the curve for saw-cut grooves spaced at 2 in.; the coefficient curve resulting from the use of standard cutting heads lies below the curve for saw-cut grooves spaced at 2 in.

Although the data on the puddled surface are repre-
FIGURE 9  Braking performance of a worn tire on wet surfaces.

FIGURE 10  Braking performance of a worn tire on puddled surfaces.

FIGURE 11  Braking performance of a worn tire on puddled surfaces (2).


