Evaluation of Trapezoidal-Shaped Runway Grooves

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Ryan King and Hector Daiutolo provided technical expertise throughout the early stages of this research effort.

16. Abstract

The Federal Aviation Administration (FAA) Airport Technology Research and Development Branch initiated research to evaluate a new trapezoidal-shaped pavement groove configuration. The purpose of this evaluation was to determine if the new trapezoidal-shaped pavement groove configuration offered any benefits over the current FAA standard groove configuration, specifically in the areas of water evacuation, rubber contamination, integrity, longevity, and friction values.

The new trapezoidal-shaped groove is 1/4 in. deep, 1/2 in. wide at the top, 1/4 in. wide at the bottom, and spaced 2 1/4 in. apart. The current FAA standard groove is 1/4 in. deep, 1/4 in. wide, and spaced 1 1/2 in. apart.

Test sections of the new trapezoidal-shaped pavement grooves, along with sections of FAA standard grooves, were installed at the FAA National Airport Pavement Test Facility, the Atlantic City International Airport, Marine Corps Air Facility Quantico, and Chicago O'Hare International Airport. Researchers conducted water evacuation measurements, analysis of rubber contamination, width measurements, and surface friction tests on the trapezoidal-shaped pavement groove test sections under a variety of conditions and compared the results directly to those of the current FAA standard grooves.

The results showed that the trapezoidal-shaped pavement groove configuration offered several benefits over the current FAA standard grooves, including improved water evacuation capability, greater resistance to rubber contamination, better integrity, and improved longevity. The friction values for the trapezoidal grooves were comparable to the FAA standard grooves. Analysis of the data collected during this evaluation indicates that the new trapezoidal-shaped pavement groove should be considered an acceptable alternative for pavement grooving on airports.

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LIST OF ACRONYMS

AC	Advisory Circular
ACY	Atlantic City International Airport
FAA	Federal Aviation Administration
MCAF	Marine Corps Air Facility
NAPTF	National Airport Pavement Test Facility
NASA	National Aeronautics and Space Administration
ORD	Chicago O’Hare International Airport
R&D	Research and development
RFT	Runway friction tester
SFME	Surface friction-measuring equipment
SFT	Surface friction tester

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) Airport Technology Research and Development Team initiated research to evaluate a new trapezoidal-shaped pavement groove configuration. The purpose of this evaluation was to determine if a new trapezoidal-shaped pavement groove configuration offered any benefits over the current FAA standard, square-shaped groove configuration, specifically in the areas of water evacuation, rubber contamination, integrity, longevity, and friction values. The new trapezoidal-shaped groove configuration is 1/4 in. deep, 1/2 in. wide at the top, and 1/4 in. wide at the bottom, spaced 2 1/4 in. apart. The current FAA standard groove configuration is 1/4 in. deep, 1/4 in. wide, spaced 1 1/2 in. apart.

The FAA standard groove configuration for saw-cut grooves on runway surfaces is based on comprehensive research conducted in the past that evaluated several groove configurations based on square-cut grooves. The FAA standard groove configuration has performed successfully for both rigid (Portland cement concrete) and flexible (hot mix asphalt) pavements.

Saw-cut grooves deteriorate over time from repeated rubber deposit removal, brooming, and snowplowing operations. Past research considered these sources of deterioration but did not consider trapezoidal-shaped groove configurations partly due to practical limitations in saw blade manufacturing and design technology. A proposal from a recognized industry grooving and grinding enterprise suggested that different geometries for saw blades are feasible. The sloped sides of the proposed groove geometry may have a positive influence on the groove integrity and longevity.

Test sections of the new trapezoidal-shaped pavement grooves, along with sections of the FAA standard grooves, were installed at the FAA National Airport Pavement Test Facility, the Atlantic City International Airport, Marine Corps Air Facility Quantico, and Chicago O'Hare International Airport. Researchers conducted water evacuation measurements, analysis of rubber contamination, width measurements, and surface friction tests on the trapezoidal-shaped pavement groove test sections under a variety of different conditions and compared the results directly to those of the current FAA standard grooves.

The results showed that the trapezoidal-shaped pavement groove configuration offered several benefits over the current FAA standard groove configuration, including improved water evacuation capability, greater resistance to rubber contamination, better integrity, and improved longevity. The friction values for the trapezoidal grooves were comparable to the FAA standard grooves. Analysis of the data collected during this evaluation indicates that the new trapezoidal-shaped pavement groove should be considered an acceptable alternative for pavement grooving on airports.

INTRODUCTION

In response to an unsolicited proposal submitted to the Federal Aviation Administration (FAA) in July 2004, the Airport Safety Technology Research and Development (R&D) Branch at the FAA William J. Hughes Technical Center in Atlantic City, New Jersey, recommended an evaluation of a new trapezoidal pavement groove configuration. The FAA Office of Airport Safety and Standards, AAS-100, FAA Headquarters, Washington, DC, supported the Airport Safety Technology R&D Branch conducting an in-depth evaluation of the merits of the proposed new trapezoidal-shaped groove configuration. This report covers a multiphase assessment of the performance of the proposed trapezoidal-shaped groove configuration as viewed from the standpoint of past test and evaluation history and present work.

The proposed configuration consists of a trapezoidal-shaped groove shape, 1/2 in. at the top, 1/4 in. at the bottom, and spaced 2 1/4 in. center to center. The FAA standard groove configuration, which is described in the FAA Advisory Circular (AC) 150/5320-12C [1], is a 1/4-in.- by 1/4-in.-square groove, spaced at 1 1/2 in. center to center (figure 1). Grooves are installed across the runway surface; transversely to the runway length and perpendicular to the runway centerline.

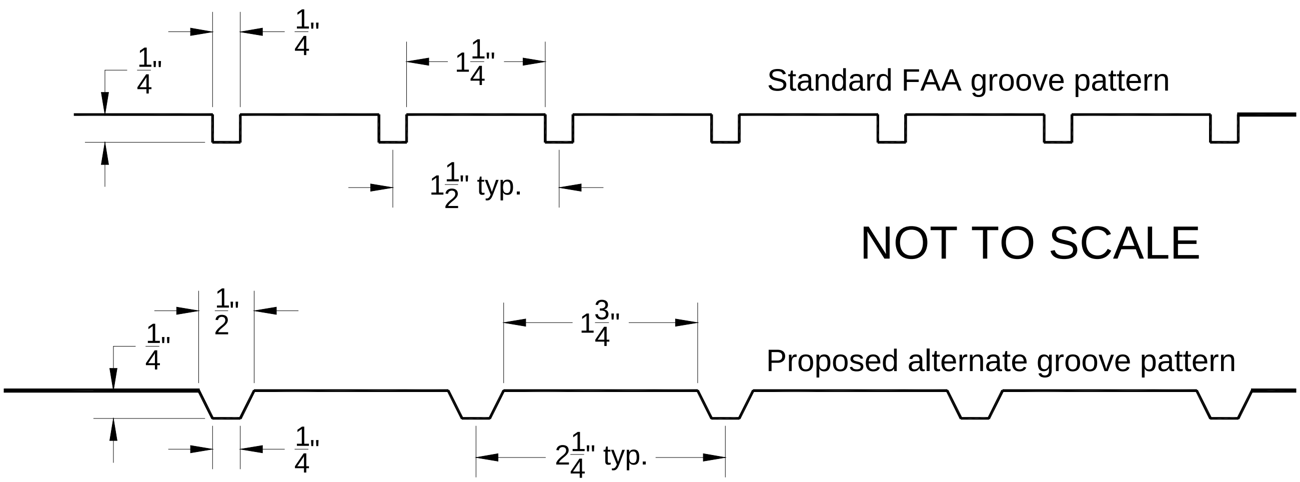


Figure 1. Standard and Trapezoidal-Shaped Groove Configurations

Pavement grooves have been scientifically proven to minimize aircraft hydroplaning during both takeoff and landing operations under rainfall conditions and have performed well when installed in both rigid (Portland cement concrete) and flexible (hot mix asphalt) pavements. Saw-cut grooves deteriorate over time from repeated interaction with aircraft traffic, as well as from additional interaction with pavement maintenance activities such as rubber removal, sweeping, and snowplowing operations. Trapezoidal-shaped grooves were not included in any of these pre-2004 studies due partly to practical limitations in saw blade manufacturing and design technology.

In the unsolicited proposal, it was suggested that different geometries for saw blades were now feasible and could be manufactured through a new manufacturing process. The contractor developed a diamond-surfaced rotary blade that had a trapezoidal-shaped design and had demonstrated that the grooving configuration can be cut repeatedly without the blade integrity deteriorating. In earlier attempts to develop a trapezoidal-shaped blade, it was found that the blade would quickly wear and lose its ability to maintain a trapezoidal-shaped groove after just a few passes across a runway. At the time, blade manufacturing technology and the lack of a properly designed cutting segment did not allow for a blade tip that could resist wear and maintain its trapezoidal shape after repeated cuts. The contractor cited that these issues had been resolved and that they had a blade that would wear much slower and more proportionally than earlier blade designs. Figure 2 shows the blades for cutting standard grooves, and figure 3 shows the blades for cutting trapezoidal-shaped grooves.

As a note, the contractor proposing the new trapezoidal-shaped groove holds a patent on the way the special blade segment that they developed is shaped, not on the pattern that is cut. There are several other blade segments available in the public domain that are capable of producing the same trapezoidal-shaped groove.

Figure 2. Blades for Standard Grooves

Figure 3. Blades for Trapezoidal-Shaped Grooves (Spacers at Left)

In their proposal to the FAA, the contractor cited several advantages of the trapezoidal-shaped grooves, including improved water dissipation, improved integrity, and longevity. Questions remained, however, on whether those claims were true and whether the trapezoidal-shaped groove configuration would provide the same (or better) level of performance as the standard groove configuration. The FAA conducted a multiphase evaluation of the trapezoidal-shaped groove configuration to validate the contractor's claims and to further identify any advantages or disadvantages that the trapezoidal-shaped groove may have over the standard groove in the areas of water dissipation, integrity, longevity, and skid resistance.

OBJECTIVES.

The objectives of this research were to conduct a multiphase evaluation of the trapezoidal-shaped groove configuration to

- compare the construction methods, resources, and requirements between the trapezoidal-shaped groove configuration and the standard groove configuration.

- determine how the trapezoidal-shaped groove configuration performs under heavy loading.

- compare the performance characteristics of the trapezoidal-shaped groove configuration to those of the standard groove configuration in the areas of water dissipation, integrity, longevity, and skid resistance.

- determine whether application of the trapezoidal-shaped groove configuration could provide any advantages over the use of the standard groove configuration.

- determine if the trapezoidal-shaped groove configuration holds the potential to be acceptable to the FAA as an alternative method for runway grooving.

BACKGROUND.

The basic purpose of grooving runway pavements is to provide a path for water to escape from under the tire of an aircraft as rapidly as possible to eliminate the potential for hydroplaning. While the standard groove configuration has proved satisfactory to date, there are several issues associated with grooves that allow room for improvement.

Runway grooving using rotary saw equipment was first accomplished in the United Kingdom in the early 1960s. The National Aeronautics and Space Administration (NASA) conducted an extensive test program in the mid-1960s to determine the most effective runway groove configuration for minimizing aircraft tire hydroplaning. Cornering tests were performed with aircraft tires up to speeds of 100 knots. A 1/4 in.- by 1/4-in.-square groove spaced at 1 in. center to center was identified as providing the best performance [2]. Based on NASA's findings, the FAA adopted a 1/4 in.- by 1/4-in.-square groove spaced at 1 1/4 in. center to center as its standard. Personnel from the Airport Safety Technology R&D Team directed an extensive test effort at the Naval Air Engineering Center in Lakehurst, New Jersey, in the late 1970s and early 1980s. A variety of runway surface treatments were tested. Braking tests were performed with aircraft tires up to speeds of 150 knots, beyond the takeoff and landing speeds of many jet aircraft. These tests showed that hydroplaning could still be minimized with grooves spaced greater than 1 1/4 in. Based on the results of this effort, the FAA Office of Engineering and Standards added 1/4 in. to the standard 1 1/4-in. groove spacing. The revision subsequently called for a standard groove configuration of 1/4-in.- by 1/4-in.-square grooves spaced at 1 1/2 in. center to center. This remains the FAA standard to date.

The recommendations in the unsolicited proposal were presented at the same time the revisions to the standard were being considered. The recommendation, however, was made not as an alternative to the standard, but rather a new standard to be adopted. As a result, the recommendation was rejected by the FAA Office of Engineering and Standards. Action may have been taken at that time had the contractor proposed a test and evaluation effort instead. The trapezoidal-shaped groove proposal that this evaluation effort is based on was introduced by a different contractor.

The most recent proposal that was presented to the FAA provided sufficient background information and data to warrant further consideration, and as a result, it was decided that the FAA would conduct an in depth evaluation of the new trapezoidal-shaped groove configuration.

EVALUATION APPROACH

The Airport Safety Technology R&D Team elected to conduct a multiphase evaluation of the trapezoidal runway groove configuration. Due to the complexity of issues involved with runway grooving, it was determined that it would be best to separate the study into specific phases that would cover all aspects of the research. Each phase was designed to build on the findings of the previous phase and would result in a fully comprehensive analysis of how the trapezoidal-shaped groove configuration performed.

The first phase focused on analysis of literature and theoretical analysis of how the trapezoidal-shaped groove configuration should perform. This included mathematical calculations on the spacing and size of the grooves, the amount of surface area available between the grooves, and drainage capability.

The second phase involved the installation of a series of test grooves within a pavement test section in the National Airport Pavement Test Facility (NAPTF), which allowed researchers to test the trapezoidal-shaped grooves for durability and integrity under heavy aircraft loads.

Phase three involved the installation of small test areas with the trapezoidal-shaped groove configuration on a taxiway at the Atlantic City International Airport (ACY) in Atlantic City, New Jersey. Within this area, small-scale tests were conducted to evaluate installation issues in an actual airport environment. This allowed researchers to determine if there were any differences in the installation process for the trapezoidal-shaped grooves compared to the process used to install standard grooves.

The fourth and final phase involved the installation of large-scale sections of trapezoidal-shaped grooves on runways at large airports. In this phase, almost two-thirds of a concrete runway was grooved with the trapezoidal-shaped grooves at the Marine Corps Air Facility (MCAF) Quantico in Quantico, Virginia, and three large test sections were installed on an asphalt runway at the Chicago O’Hare International Airport (ORD) in Chicago, Illinois. These installations allowed researchers to monitor the trapezoidal-shaped grooves under actual operational conditions, conduct full section friction measurements, and collect data on the durability, longevity, and performance of the grooves, as well as the airport operator’s perception of how the grooves performed.

In combination, each of the four phases provided researchers with sufficient data to arrive at the conclusions presented in this report. The following sections cover each phase of the project in more detail.

PHASE ONE—LITERATURE REVIEW AND THEORETICAL ANALYSIS.

ADVANTAGES. The advantages of using the trapezoidal-shaped groove configuration on runways were reviewed very closely by FAA researchers. Based on the material provided in the proposal, there were some major advantages that the contractor focused on. It was expected that the trapezoidal-shaped grooves would resist rubber accumulation, closure, and collapse better than the standard grooves, especially in heavily trafficked areas. The most critical runway areas for rubber contamination are the aircraft touchdown zone and the braking zone. In these areas, aircraft tires first come in contact with the pavement when landing or when the aircraft brakes heavily. In both cases, the repeated tire skidding in these areas leads to heavy deposits of rubber that can build up on the inner walls of the groove and decrease the width of the opening in the grooves. Although surface cleaning can alleviate this condition, rubber deposits accumulate again within just a few weeks. Portland cement and asphaltic concrete runways are equally susceptible to the rubber deposits. Physical movement or "shoving" of the runway surface can also cause damage to runway grooves, as heavy loading can cause the grooves to close from a condition of collapse. Extreme heat can also soften asphaltic concrete and, when combined with heavy loading, can make this problem even more pronounced.

The proposed trapezoidal-shaped grooves, by design, can better resist closure from rubber contamination or by collapse because they have a 1/2-in. opening at the top, as opposed to the 1/4-in. opening provided by the standard grooves. The trapezoidal-shaped groove also has an included angle of 117° at the edges as opposed to 90° for the standard groove. This design may help resist collapse from the shoving phenomenon, as the wall of the grooves becomes more structurally sound versus the vertical wall of a standard groove.

Trapezoidal-shaped grooves, then, offer the potential for better performance in that they should be more durable under heavy traffic particularly on asphaltic concrete runways. They also offer the potential for deferring the need for either runway reconstruction or overlay if degraded groove condition is one of the major factors considered in making the decision for runway rehabilitation. In this regard, the major economic advantage of the use of trapezoidal-shaped grooves may be realized.

RESISTANCE TO HYDROPLANING. If it is to be seriously considered as an alternative to the standard grooves, the trapezoidal-shaped grooves should offer the cited advantages without compromising the safety of aircraft operations. Aircraft tires have been known to hydroplane on nongrooved runway surfaces during rainfall conditions. Runway grooving was introduced in the early 1960s to alleviate this condition. The specific purpose of runway grooving is to provide a path for forced water to escape from under an aircraft tire traveling at high speed. In doing so, the aircraft tires maintain some degree of contact with the runway surface during wet conditions. As a result, the aircraft can then maintain a sufficient level of braking and directional control to operate safely during takeoff or landing. A high level of wet friction is dependent on the installation and maintenance of good microtexture and macrotexture in the pavement surface itself [1]. Grooves enable the aircraft tires to maintain enough contact with the runway surface to take advantage of the wet friction offered by the pavement.

Relative to hydroplaning, the trapezoidal-shaped groove configuration offers the same cross-sectional area for forced water to escape under aircraft tires as the standard groove configuration. More specifically, the trapezoidal-shaped groove configuration offers the same cross-sectional area for forced water escape over a given length along the runway. It also provides 28% less orifice perimeter, offering a reduction in the amount of resistance there is for the water to escape. It would be expected, then, that the trapezoidal-shaped groove configuration would provide about the same reduction in hydroplaning as the standard groove configuration. The wider trapezoidal-shaped groove spacing of 2 1/4 in. was not expected to affect hydroplaning. The

FAA tests showed that, even with the standard grooves, resistance to hydroplaning could be obtained with spacings up to 3 in. [3] and beyond [4]. The NASA tests, moreover, showed that the standard grooves spaced at 2 in. performed about the same as those spaced at 1 1/2 in. [2]. The FAA permitted the standard grooves to be spaced up to 2 in. prior to the last revision to AC 150/5320-12C [1]. Although many runways were grooved using 2-in. spacing, runways at Boston Logan International Airport were grooved at 2 1/4-in. spacing, and as part of an FAA demonstration, runways at Hector International Airport in Fargo, North Dakota, Jacksonville International Airport in Jacksonville, Florida, and at ACY had standard grooves placed at a 3-in. spacing.

Figures 4 through 7 show the variation of braking coefficient with groove spacing for 1/4- by 1/4-in. standard grooves. The data were taken from full scale dynamic track tests on asphaltic concrete [3]. The grooves were spaced at 1 1/4, 2, and 3 in. and were tested in wet, puddle, and flooded conditions at speeds of 70 to 150 knots. The 1 1/2-in. spacing for the standard grooves and the 2 1/4-in. spacing, consonant with the trapezoidal-shaped grooves, are noted on the figures. It can be concluded that the degradation in braking coefficient with increased groove spacing, in the range covered by the figures, was not noticeable. Moreover, the figures show that the degradation in braking by increasing the spacing from 1 1/2 in. to 2 1/4 in. was minimal. Similar results were obtained on Portland cement concrete [4]. This indicates that the standard grooves at 2 1/4-in. spacing provide braking close to the standard grooves at 1 1/2-in. spacing. The trapezoidal-shaped groove configuration calls for grooves at 2 1/4-in. spacing with grooves 50% larger in cross-sectional area. It would be expected, then, that with the increased capability for forced water escape, the trapezoidal-shaped grooves would provide braking comparable to the standard grooves.

The shape and size of the trapezoidal-shaped grooves posed no problems relative to providing forced water escape. Forced water escape, which is a turbulent flow phenomenon, was found to be adequately provided by surface treatments offering escape paths that were far more constricted. Grooves 1/8 by 1/8 in. spaced at 1/2 in. on a porous friction course were tested [3] and found to provide adequate forced water escape. Adequate forced water escape was sufficient in braking performance within the same range as provided by the standard groove configuration. The 1/8- by 1/8-in. groove configuration offered the same cross-sectional area for forced water escape, per linear foot of pavement, as that offered by the standard grooves spaced at 2 in. The orifice perimeter, however, was double that of the standard. Nonetheless, the braking performance recorded was comparable to the standard grooves spaced at 3 in. Similar performance was noted on the porous friction course, and, in this case, the water escaped through constricted and indirect paths provided by the voids between aggregates.

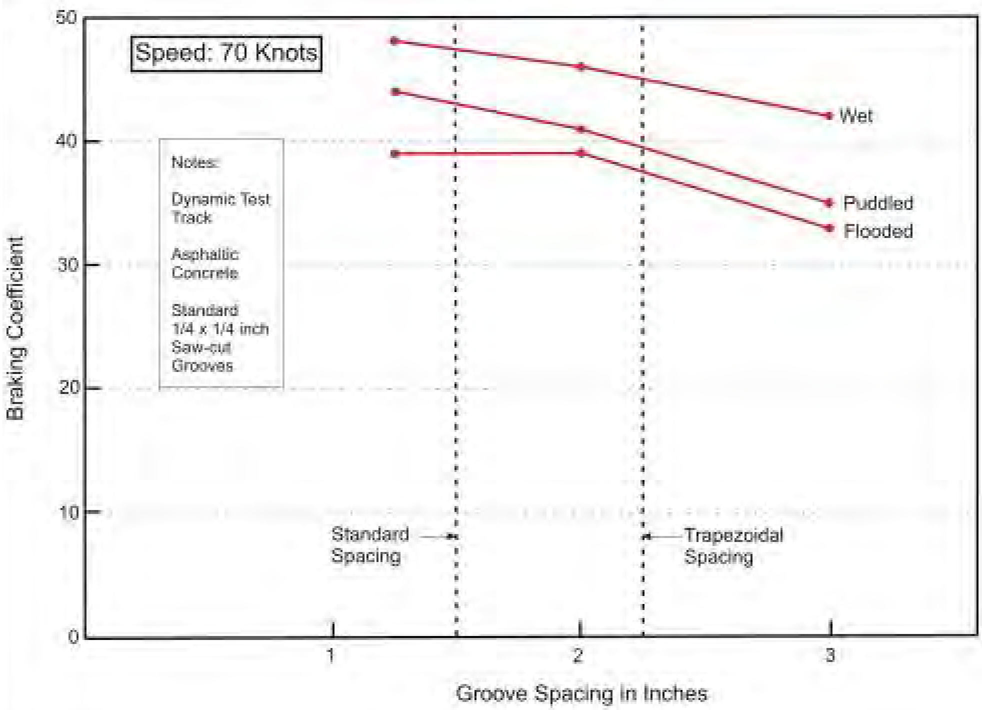


Figure 4. Braking Coefficient Versus Groove Spacing at 70 Knots

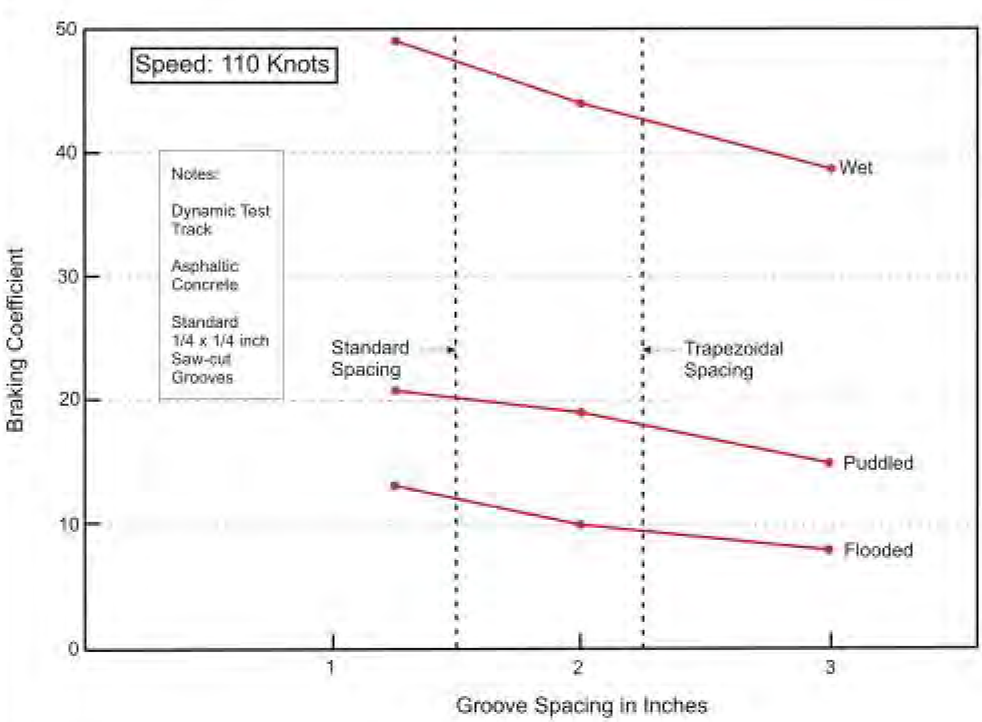


Figure 5. Braking Coefficient Versus Groove Spacing at 110 Knots

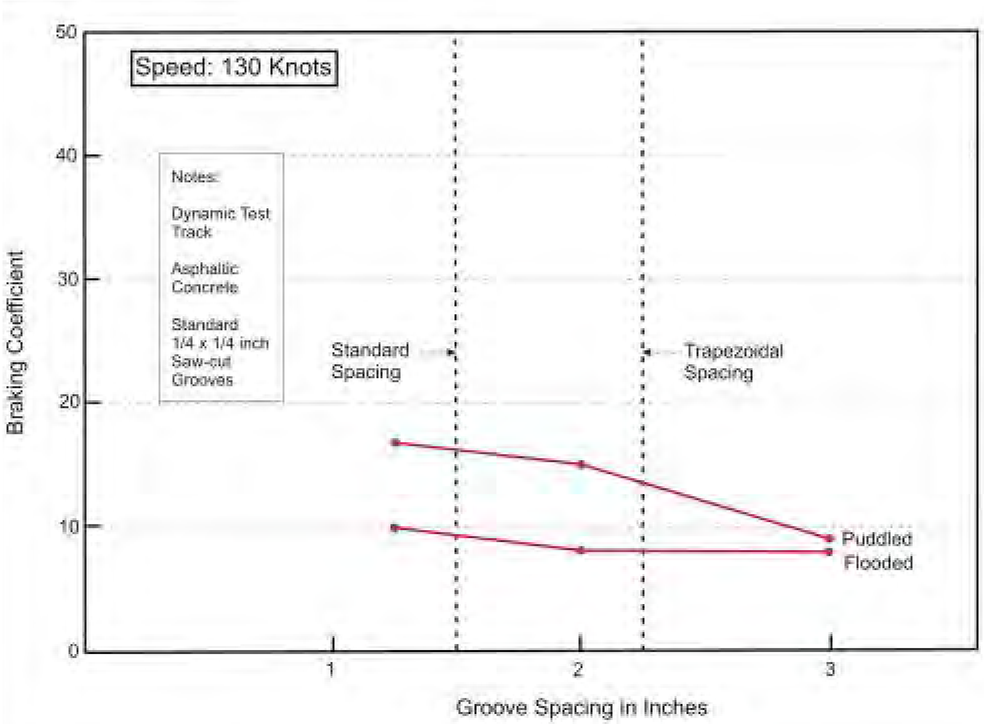


Figure 6. Braking Coefficient Versus Groove Spacing at 130 Knots

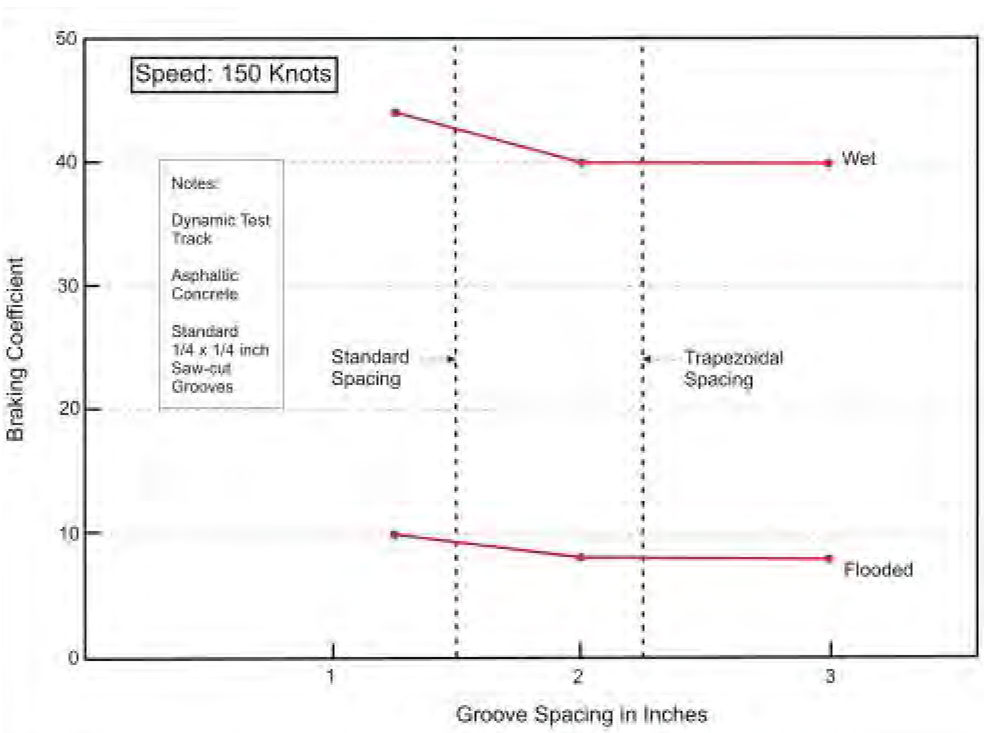


Figure 7. Braking Coefficient Versus Groove Spacing at 150 Knots

It can be concluded from the examination of existing evidence that the placement of the trapezoidal-shaped groove configuration in runways in lieu of the standard would not result in degradation of performance relative to the mitigation of hydroplaning.

DRAINAGE. The primary factor in providing water drainage from a runway surface during rainfall conditions is the transverse slope (or crown) of the runway. The slope generally runs between 1% to 1 1/2% down from the crown of the runway at the centerline. Grooves make a secondary contribution to drainage by being able to accommodate some water that would otherwise be standing on the surface as a measurable water depth. In other words, what would be standing water at a given location on a nongrooved runway would simply be a wet surface on a runway grooved with either of the two groove configuration. Standing water on a grooved runway would likely occur only during a period of heavy rainfall or when the grooves were closed or otherwise blocked by debris, rubber, or sand.

TIRE DAMAGE. In the unsolicited proposal, reference was made to the advantage of physical engagement of the tire to the pavement surface with trapezoidal-shaped grooves because it is wider compared to the standard, and there were fewer grooves per linear square foot of runway. Likewise, the greater angle at the top edge of the trapezoidal-shaped groove, 117° versus 90°, could also be a mitigating factor in reducing tire damage. In early research, damage was noted in aircraft tires when grooves were first introduced on runways [5]. Tire damage usually occurred at the touchdown zone of the runways where aircraft tires were impacting the runway the hardest. Small cuts were noted in some aircrafts tires; however, these cuts did not appear to progress nor were they reported to shorten the life of the tires [5]. Manufacturers subsequently reformulated the materials that they incorporated into their tire construction, and the damage was no longer noted. Other factors also lessened the concern. Continued touchdown operations were found to wear the sharpness of the upper edges of the grooves. Additionally, rubber deposits lessened the possibility of tire damage.

GROOVING COSTS. In the 1970s, the FAA employed a construction cost consultant to assess the cost of grooving runways. The consultant developed a formula to determine costs based on an analysis of grooving data collected from three geographical areas in the United States. The data specifically applied to standard groove-cutting machines containing diamond-tipped rotary blades (the only known practical method at the time) that cut 1/4- by 1/4-in. standard grooves. The primary finding was that the cost of grooving a runway broke down into a 60% fixed cost and a 40% variable cost. The fixed cost covered mobilization, use of the equipment, and labor. The variable cost included blade replacement, with groove spacing being a significant factor. At that time, the FAA grooving standard called for 1 1/4-in. spacing but allowed spacing up to 2 in. Although the relative cost balance of 60% versus 40% was accurate, it was noted that variable costs could increase depending on the hardness of the aggregate in the pavement mix. Cherts, flints, and gravels, for example, significantly increase the variable costs as they tend to wear the cutting blades more quickly, while also reducing the speed of cut, which raises fuel and labor costs on a square-yard basis. The FAA enabled an 8% cost saving to be realized in the grooving of runways when it changed the standard spacing from 1 1/4 in. to 1 1/2 in.

It is difficult to assess the effect of the trapezoidal-shaped groove configuration on grooving costs since not enough is known about the cost and wear characteristics of the blades. The contractor that developed the blades for cutting the trapezoidal-shaped groove suggests that grooving costs could initially be 15-25% higher than standard grooves until economies of scale are reached in trapezoidal-shaped blade manufacturing. As an estimate, the contractor explained that for asphalt pavement, prices typically vary from about $0.55 to $1.50 per square yard and about $0.80 to $2.50 per square yard for concrete pavement. Several other factors can affect the pricing, including the material (concrete or asphalt), type of aggregate, available work hours, wage rates, and other site-specific factors. The higher prices within the ranges provided reflect cutting in the most unfavorable conditions possible, including hard aggregate, shorter than normal work periods, and higher prevailing wages.

The absolute value of the fixed cost would be expected to be approximately the same for both groove types because the same amount of pavement material is removed per linear foot of runway for both configurations. The variable cost associated with the trapezoidal-shaped grooves is not possible to determine because the cost, wear characteristics, and replacement frequency of the blades are not known.

CUTTING SPEED. The speed of grooving operations can vary greatly depending on the conditions of the pavement that is being cut and the conditions at the installation site. Primarily, the cutting speed is dependent on two factors: the type of material being cut (asphalt or concrete) and the hardness of the aggregate (limestone, granite, basalt, gravel, etc.). It also, to a lesser extent, depends on the sharpness of the sand within the material, the size of the aggregate, the age of the pavement, and the level of the pavement. According to an experienced grooving contractor, asphalt can be grooved in a range of 15 ft per minute in very unfavorable conditions, to over 40 ft per minute in very favorable conditions. On average, asphalt can be grooved at 22.5 to 30 ft per minute. For concrete pavement, the range decreases to about 8 to10 ft per minute to a top rate of about 25 ft per minute. Since the same amount of material is being removed in cutting both types of grooves, it can be assumed that the cutting speeds will be the same for the trapezoidal and the standard square grooves in a given pavement material.

RECTANGULAR GROOVE AS AN ALTERNATE. The trapezoidal-shaped groove proposal allows consideration for the acceptance of a rectangular groove that is 3/8 in. wide, 1/4 in. deep, and spaced at 2 1/4 in. center to center. This groove configuration offers some of the advantages of the trapezoidal-shaped groove configuration without introducing anything new in the placement technique. It provides the same cross-sectional area under the aircraft tire for forced water escape as is provided by the trapezoidal-shaped groove configuration. It offers 22% reduction in orifice perimeter over the standard groove configuration, as opposed to a 28% reduction offered by the trapezoidal-shaped groove configuration. NASA performed hydroplaning tests on a groove 3/8 in. wide, 1/4 in. deep and spaced 2 in. center to center [2]. A smooth aircraft tire was subjected to cornering friction under wet to flooded conditions. The rectangular groove configuration performed about the same as the groove configuration that became the FAA standard, 1/4 in. by 1/4 in. spaced at 1 1/2 in. center to center. The FAA initially established 1 1/4 in. as the spacing and later extended it to 1 1/2 in. The FAA was no longer considering any other size groove at the time of the spacing extension.

PHASE ONE SUMMARY. The results of Phase One, which included a thorough review of literature and historical information, as well as a theoretical analysis of the concept of using the trapezoidal-shaped groove configuration, indicated that the proposed groove shape should perform equally to the standard groove in the areas of resistance to hydroplaning and prevention of tire damage. The review also indicated that the trapezoidal-shaped groove may offer improved performance over the standard grooves with regard to groove closure due to rubber contamination and buildup, and may also have better resistance to collapse and failure due to heavy aircraft loading. The costs associated with the trapezoidal-shaped grooves are expected to be about 15-25% more than standard grooves but should become more comparable once large quantities of trapezoidal cutting blades are being manufactured.

Based on the positive findings of Phase One, FAA researchers determined that it would be feasible to pursue further testing of the trapezoidal-shaped groove configuration.

PHASE TWO—LABORATORY TEST AREA EVALUATION.

Phase Two involved the installation of a small series of trapezoidal-shaped grooves within a pavement test section in the National Airport Pavement Test Facility (NAPTF). The objective of this laboratory test area evaluation was to observe and compare the construction process and deformation response over time of the two subject groove geometries under the following conditions:

- Grooves saw-cut transversely into new asphalt pavement in the NAPTF
- Grooved sections subject to repetitive very heavy wheel loads
- Grooved sections protected from exposure to outdoor weather conditions
- Grooved sections exposed to limited, infrequent other vehicular traffic

During the laboratory test area evaluation, the following considerations were evaluated.

- How do the construction methods between the two groove types compare/contrast?

- Is additional manpower or equipment required for the installation of trapezoidal-shaped grooves as compared to the standard grooves?

- How do the trapezoidal-shaped grooved sections deform under heavy loading?

DISCUSSION. Phase Two was conducted inside the NAPTF at the FAA William J. Hughes Technical Center in Atlantic City International Airport, NJ. The primary purpose of the NAPTF is to generate full-scale pavement response and performance data for development and verification of airport pavement design criteria. The test facility consists of a 900-ft (274.3-m)-long by 60-ft (18.3-m)-wide test pavement area, embedded pavement instrumentation with a dynamic data acquisition system (20 samples per second), environmental instrumentation with a static data acquisition system (4 samples per hour), and a test vehicle for loading the test pavement with up to twelve aircraft tires at wheel loads of up to 75,000 lb (34 tonnes). Researchers identified the NAPTF as a possible resource for conducting preliminary observations of the trapezoidal-shaped grooves.

Pavements are regularly tested at the NAPTF. The construction of asphalt test pavements within the NAPTF coincided with the beginning of the trapezoidal-shaped groove evaluation project. A cooperative, coordinated effort between researchers and NAPTF facility personnel enabled two separate, but simultaneous, studies of the same pavement to be conducted.

The layout of the NAPTF test sections provided transition zones between test pavements where grooves could be installed without affecting the nature of the data collection in their other tests. Two transition zones were chosen for grooving, namely "T5" and "T6," shown in figure 8. Each transition zone measured about 25 ft wide and provided sufficient pavement for 20 ft of transverse grooves to be cut within. The NAPTF testing of adjacent test articles "MRC," "MRG," and "MRS" dictated the wander path, frequency, and loading of the test machine. Therefore, the grooves would be subjected to the repetitive machine traffic and loading that was prescribed for the main test articles. No loading or trafficking was conducted specifically for the grooved sections. Based on the wander pattern planned for the test machine, it was decided that within each 20-ft-wide transition, one 10-ft lane would be grooved with trapezoidal-shaped grooves and the other adjacent 10 ft lane would be grooved with standard grooves.

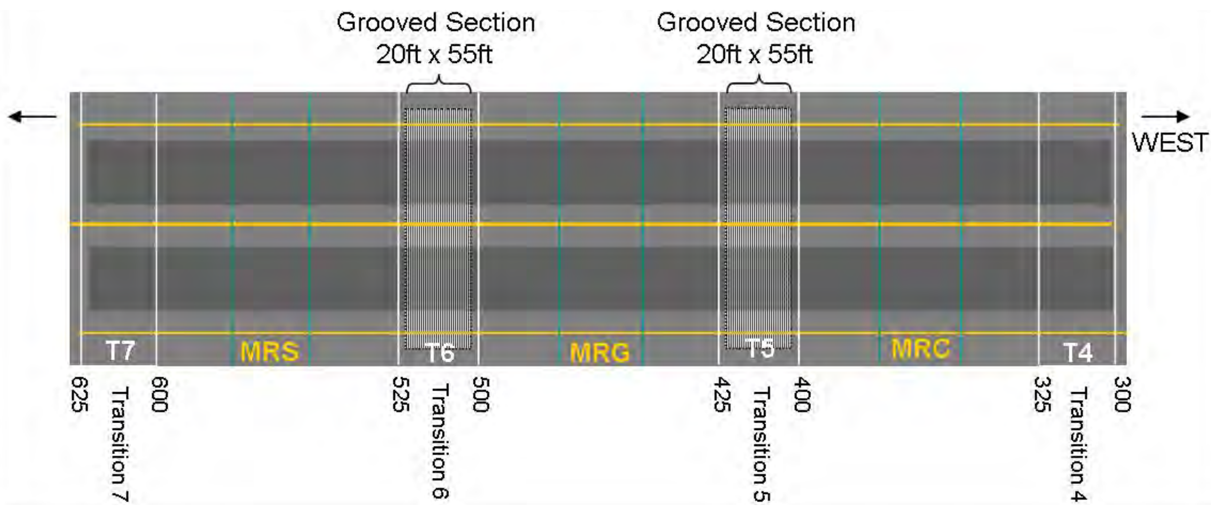


Figure 8. Overview of Pavement Test Articles in NAPTF

Therefore, each 20-ft-wide transition included 10 ft of standard grooves and 10 ft of trapezoidal-shaped grooves. Figure 9 is a photograph of the center portion of T5, which shows the two groove types side by side. In the photograph, the grooves on the right are the trapezoidal-shaped grooves, and the grooves on the left are the standard grooves.

Figure 9. Standard (Left) and Trapezoidal (Right) Grooves Side by Side

CONSTRUCTION PROCESS. One of the objectives of the project was to compare the construction methods, resources, and requirements between the trapezoidal-shaped and the standard grooves. With the grooving operation at the NAPTF, project personnel were unable to identify any differences in the construction process. In fact, both sets of grooves were installed with the same machine and labor effort. The blade mechanism was the only difference between the process of cutting standard grooves and trapezoidal-shaped grooves. A bridge-deck groove-cutting machine was used for this operation, as shown in figure 10. This was because for this particular project, there was limited space at the end of each groove lane for use of a larger runway-scale groove-cutting machine. The bridge-deck groove-cutting machine is typically used for bridge-decks and locations that offer limited maneuverability. On a typical runway groove installation, a much larger machine would be used.

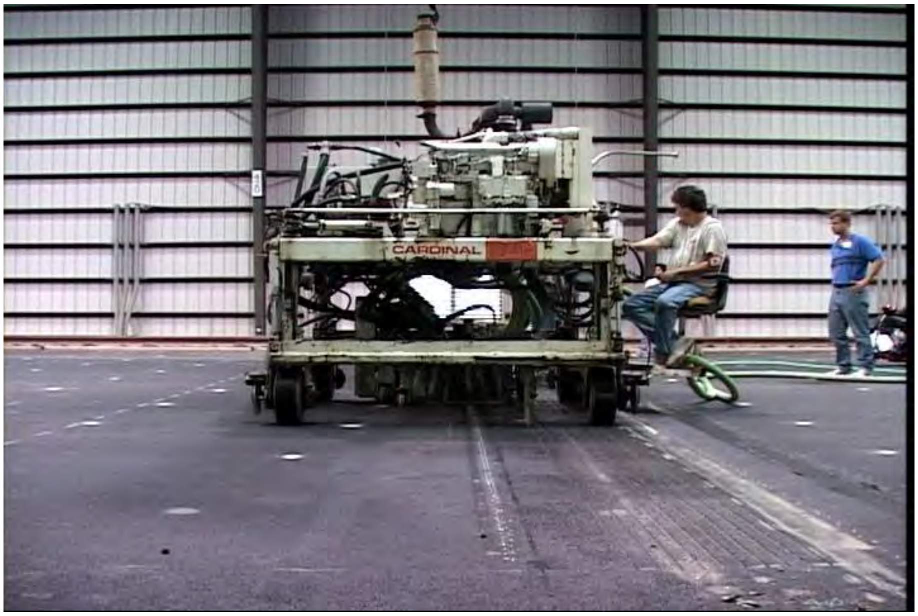


Figure 10. Bridge-Deck Groove-Cutting Machine

The groove-cutting machine uses a series of circular saw blades arranged side by side on a rotating drum. The blade arrangement for standard grooves, shown in figure 11, consisted of 20 blades spaced 1 1/2 in. on center for a total cut width of about 30 in. Figure 12 shows the blade arrangement for the trapezoidal-shaped grooves in which the drum was fitted with ten circular blades spaced 2 1/4 in. on center, for a total cut width of about 22 in. Because this was a demonstration of the proposed trapezoidal-shaped groove shape, the manufacturer had not yet fabricated enough trapezoidal blades for a full drum arrangement.

Figure 11. Rotary Drum With Standard Groove Blades

Figure 12. Rotary Drum With Trapezoidal-Shaped Groove Blades

The grooving process uses a stream of water to cool the blades as they cut through the pavement. As the blades rotate, the machine moves forward slowly in the direction of the groove. A driver steers the machine to keep the groove lane straight. A vacuum system sucks most of the excess water and waste material into a collection tank located on the back of a support truck. Figure 13 shows the cutting of a new groove lane with the trapezoidal setup (machine is moving away in this picture). Some of the water used in the cutting process is visible in the right foreground.

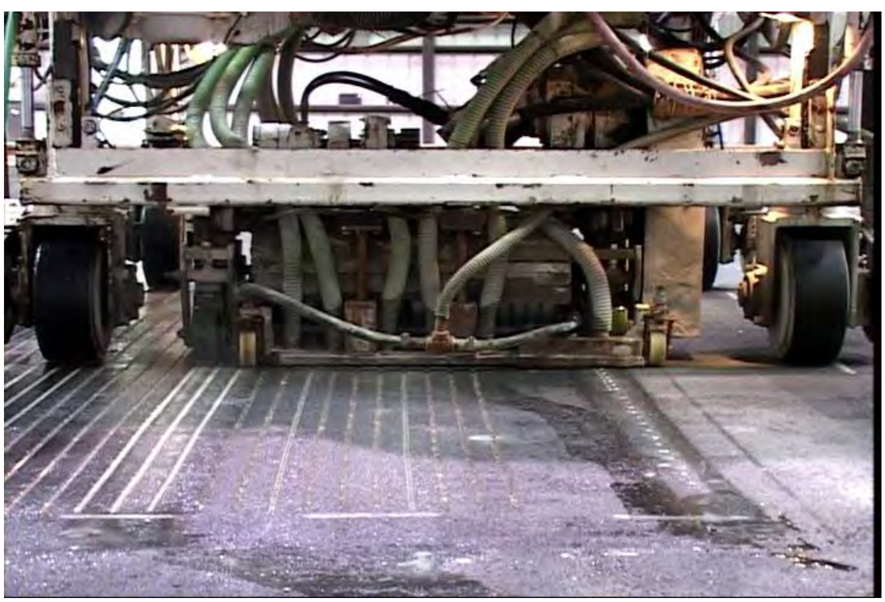


Figure 13. Trapezoidal-Shaped Grooving Using Bridge-Deck Machine

In figure 14, the water source hose and waste collection hose are visible as the machine begins a new groove lane.

Figure 14. Groove-Cutting Machine With Water Supply Hose

Cutting the grooves was performed in a south-to-north direction only. In figure 15, south is to the right and north to the left for reference. Each lane measured 55 ft in length. At the end of each run, the machine lifted the blade mechanism and stopped the flow of water. The vehicle then reversed direction and traveled back to the south side of the pavement. The driver aligned the machine for the next lane cut making sure to space the blades appropriately from the last groove in the previous lane. Cutting each groove lane, i.e., 55 ft in length, took about 4 1/2 minutes including return travel to the south side. The average cutting time was the same for both the trapezoidal-shaped grooves and the standard grooves at a rate of about 32 ft per minute. The contractor explained that the speed was faster than expected when cutting older pavement, as the pavement in the NAPTF was softer and much easier to cut.

Figure 15. Trapezoidal-Shaped and Standard Grooves in Asphalt Pavement at NAPTF

All construction operations were completed within one workday. After the cutting operation was complete, molds were taken of the untrafficked trapezoidal-shaped grooves. A forensic evidence collection kit typically used by law enforcement for capturing accurate positive molds of tire tracks and footprints was used. The plaster is specially formulated to cure rapidly without expansion or shrinkage. Figure 16 is a photograph of one of the molds.

Figure 16. Plaster Mold of Trapezoidal-Shaped Groove

The contractor cutting the trapezoidal-shaped grooves stated that he was able to maintain similar inspection and acceptance tolerances to those that are in place for standard grooves. The tolerances were as follows: depth of the groove was 1/4 in., ±1/16 in., the width of the top of the groove was 1/2 in., ±1/16 in., the width of the bottom of the groove 1/4 in., ±1/16 in., and the spacing between groove centers 2 1/4 in., +0/-1/8 in.

<u>THE NAPTF TEST DESCRIPTION</u>. The pavement in which the test grooves were installed was trafficked with a four-wheel dual-tandem configuration on both north and south traffic lanes. The geometry was the same on both traffic lanes, with dual spacing of 54 in. (137.2 cm) and tandem spacing of 57 in. (144.8 cm). Wheel load was set at 55,000 lb (25 tonnes).

Trafficking started on July 7, 2005, and continued until October 6, 2005, following the schedule in table 1. (The loading was increased after 5082 repetitions, because none of the pavements showed any significant deterioration at that traffic level.) The standard NAPTF 66-repetition-per-cycle wander pattern was used on both traffic lanes. The temperature of the asphalt varied between 66° and 85°F (19° and 29°C) during the test period. The average temperature of the asphalt was about 78ºF (26°C).

Table 1. Trafficking Schedule for Test Items

Dates (from-to)	Repetitions (from-to)	Test Items Trafficked**	Load on North Lane* (lb)	Load on South Lane* (lb)
07/07/05-07/25/05	1-5,082	MRG-N, MRC-N, MRS-N MRG-S, MRC-S, MRS-S	4-wheel, 55,000	4-wheel, 55,000
07/26/05-08/12/05	5,083-11,814	MRG-N, MRC-N, MRS-N MRG-S, MRC-S, MRS-S	6-wheel, 65,000	4-wheel, 65,000
08/15/05-08/18/05	11,814-14,256	MRG-N, MRC-NW, MRS-N MRG-S, MRC-S, MRS-S	6-wheel, 65,000	4-wheel, 65,000
08/19/05-08/24/05-	14,257-16,302	MRG-N, MRS-N MRG-S, MRC-S, MRS-S	6-wheel, 65,000	4-wheel, 65,000
09/13/05-10/06/05	16,303-25,608	MRG-N, MRS-N MRG-S, MRS-S	6-wheel, 65,000	4-wheel, 65,000

*Cold, unloaded tire pressures: 220 psi at 55,000 lb and 260 psi at 65,000 lb.
**Test item identification specific to pavement test, not to this study.
N = North
S = South
NW = Northwest

DATA COLLECTION AND RESULTS. Data collection consisted of visual observation, photographs, and longitudinal profiles. The test machine was stopped for a relatively short time each day in order for researchers to take key measurements and perform any necessary maintenance. This provided researchers the opportunity to capture profile data.

Figure 17 depicts one portion of the grooved pavement in the NAPTF. The image is not to scale but represents the north side of the centerline grooved section in transition T5. The grooves were cut transversely, i.e., perpendicular to the yellow centerline stripe at the top of the image. The loaded wheel assembly of the test machine traveled east and west across the grooves. The wheel paths are shown in the picture as lanes, which are shaded according to how many passes of the gear that section of pavement experienced. Profiles were taken within the region highlighted by green and orange boxes.

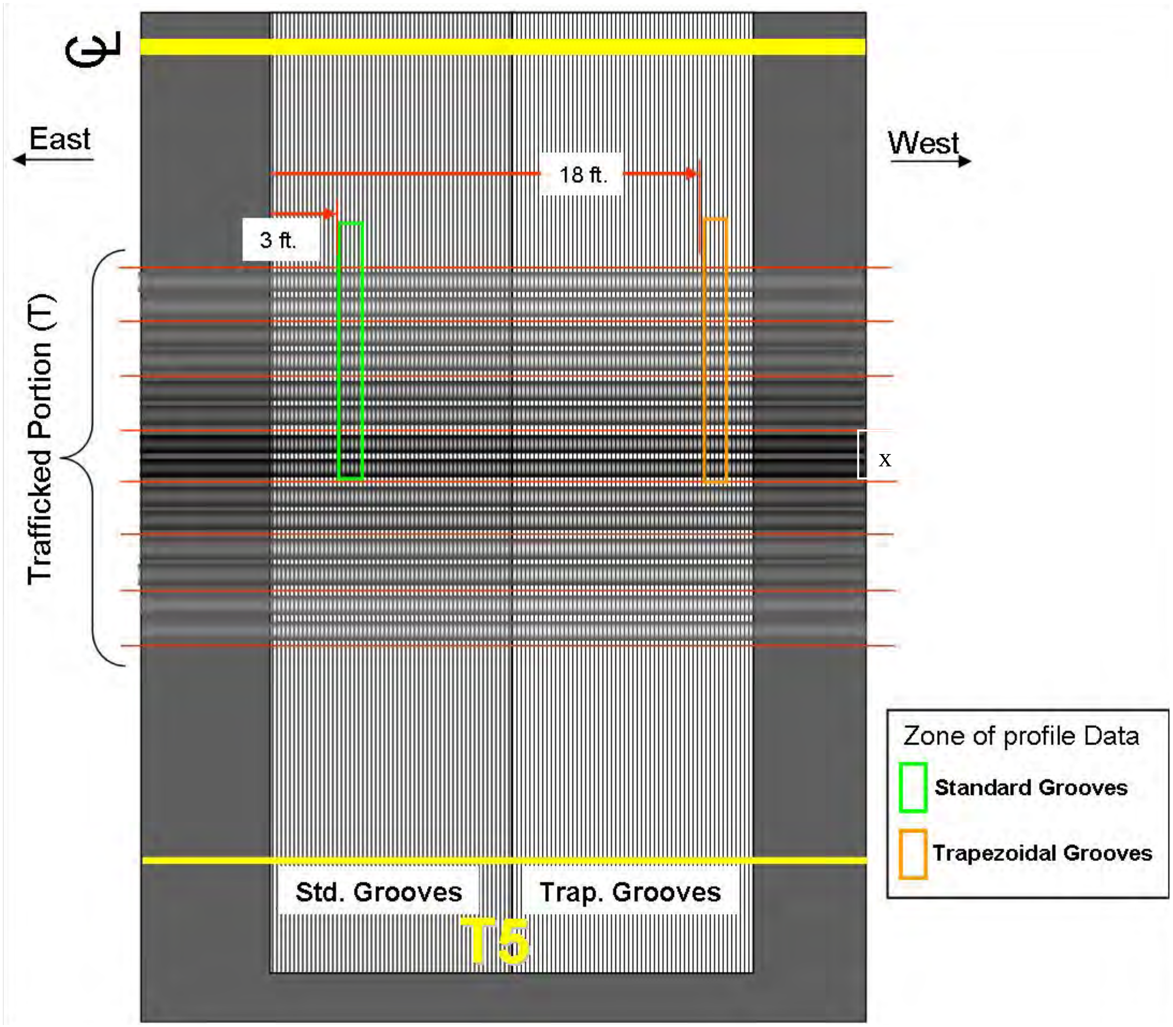


Figure 17. Wheel Tracks and Profile Data Zones

Figure 17 also includes a section labeled "Trafficked Portion," illustrating the wheel paths of the test machine wheel assembly, running left to right across the grooved sections. As discussed in the NAPTF test description section, the wheel assembly is programmed to distribute loadings in a manner that closely represents the concentration of wheel loadings that an actual runway pavement would experience based on pilot deviation from the centerline. Therefore, the largest concentration of passes is designated by the x in figure 17. Wheel paths on either side of the middle one represent progressively fewer passes according to the appropriate distribution. The data in table 2 shows the dates and number of wheel assembly passes at the time of the profile measurement. In total, 10,362 runs were made across the groove installations. Figure 18 defines the terminology used in table 2.

An analysis of the data in table 2 showed that after the standard and trapezoidal-shaped grooves were exposed to 10,362 operations, both grooves experienced some degree of distortion from the heavy wheel loading. The trapezoidal-shaped grooves, however, maintained their shape and height better than the standard grooves. As shown in the data in table 2, the standard groove was measured to have an average height of 0.261667 in. After 10,362 runs, the standard groove had a height of 0.110105 in., while the trapezoidal-shaped grooves had an average height of 0.148 in. The standard grooves decreased in height by 54%, while the trapezoidal-shaped grooves only decreased in height by 43%. The surface, or portion touched by the aircraft tire, and the overall groove unit dimension for both grooves remained the same for both groove types. It is very likely that the structural integrity of the walls of the trapezoidal-shaped groove were key in allowing the grooves to resist crushing better than the standard groove. Figures 19 and 20 show profile measurements that were taken of both the trapezoidal-shaped and standard grooves just after installation and then again after 1,584, 5,082, 8,712, and 10,362 passes. Progressive distortion of both grooves is evident in these figures, although the trapezoidal-shaped grooves appear to maintain their shape better than the standard grooves.

Table 2. Profile Data Table

Date	Pass Number	Trapezoidal Type (18 to 19 ft, E to W)					Standard Type (3 to 4 ft, E to W)				
		Groove	Land Area	Height	Area	Peak #	Groove	Land Area	Height	Area	Peak #
Baseline	0	1.86	1.556	0.261667	0.44656	3.333333	1.304	1.072	0.247333	0.322568	2.833333
7/15/2005	1584	2.139	1.704	0.21975	0.422852	4.5	1.432	1.008	0.159667	0.229064	2.833333
7/25/2005	5082	2.235	1.707	0.1935	0.381744	4	1.47	1.074	0.138667	0.20347	2.166667
8/1/2005	8712	2.259	1.74	0.1535	0.305714	3.25	1.46	0.97	0.138	0.201504	2.666667
8/9/2005	10362	2.262	1.668	0.148	0.29127	2.25	1.466	1.192	0.110105	0.160479	1.166667

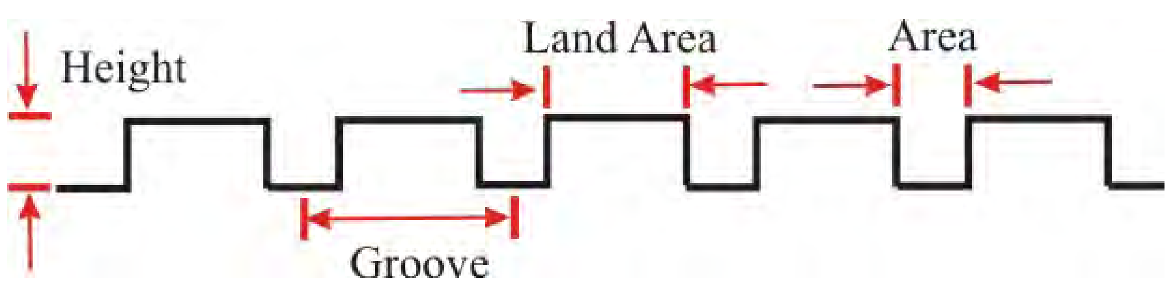


Figure 18. Clarification of Table 1 Terms

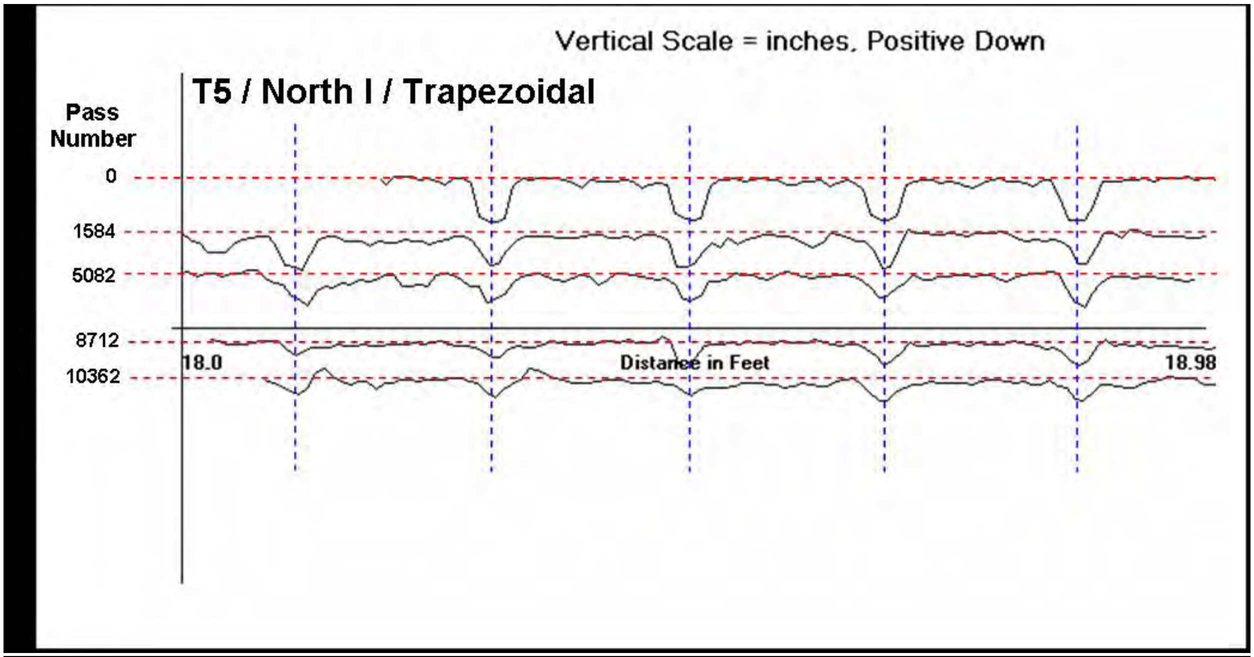


Figure 19. Trapezoidal-Shaped Groove Profiles for T5, North I

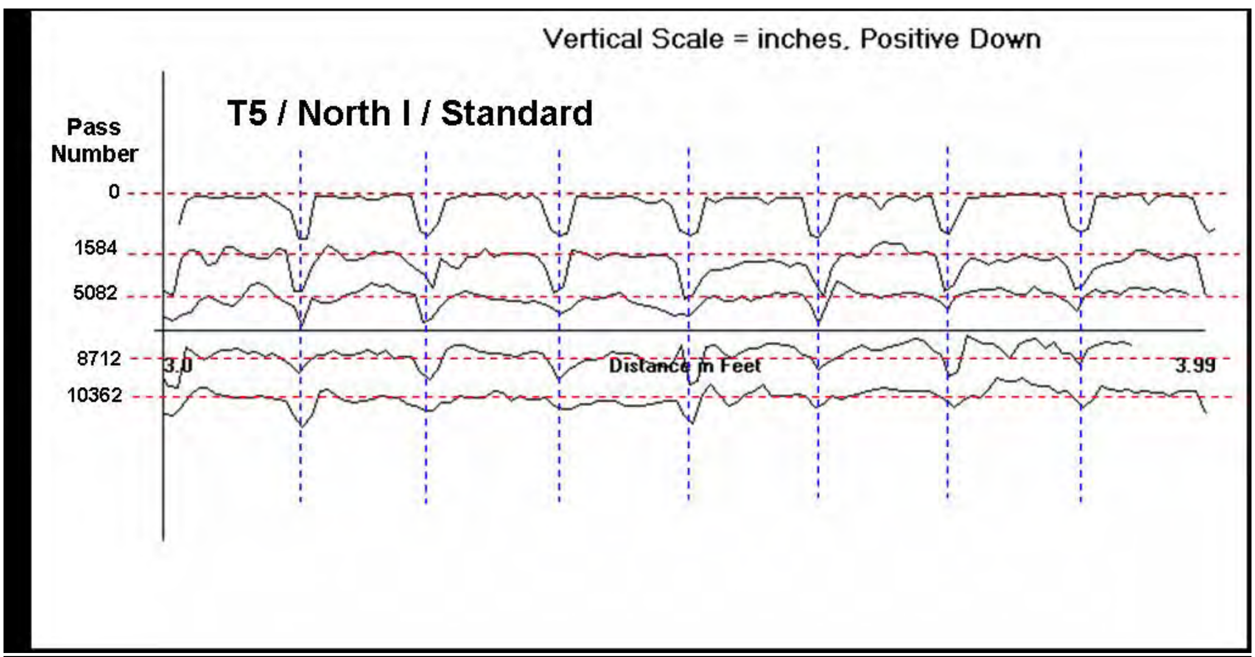


Figure 20. Standard Groove Profiles for T5, North I

PHASE TWO SUMMARY. In Phase Two of this research, a small series of trapezoidal-shaped grooves were cut in a pavement test section in the NAPTF. The objective of this laboratory test area evaluation was to observe and compare the construction process and deformation response over time of the two subject groove geometries when trafficked under heavy aircraft loads.

During the cutting process, researchers were unable to identify any major differences in the amount of manpower, equipment, or process that were required to install the trapezoidal-shaped grooves compared to the standard grooves. The contractor performing the construction of the trapezoidal-shaped groove used exactly the same number of people, the same cutting equipment, and the same construction process that they used for the standard grooves. The contractor used the same water supply, as well as the same vacuuming and sweeping equipment for the installation process. With the exception of taking time to switch between the two different sets of blades, the installation took the same amount of time.

The heavy-load tests that were conducted on the trapezoidal-shaped and standard groove test sections provided researchers with information on how the different groove designs performed after 10,362 passes by the pavement test machine. Profile data collected at various stages of the trafficking provided an indication that the trapezoidal-shaped grooves, at a spacing of 2 1/4 in., lost 43% of its groove height, versus the standard grooves at a spacing of 1 1/4 in., which lost 55% of its groove height. Visual analysis of the profile data collected from both groove types showed that the trapezoidal-shaped grooves maintained a more recognizable shape, versus the standard grooves, which became more distorted. The amount of surface contact area for both grooves, as well as the spacing of the grooves, remained constant throughout the trafficking activity.

Based on the positive findings of Phase Two, FAA researchers determined that it would be feasible to pursue further testing of the trapezoidal-shaped groove configuration on a slightly larger scale in an actual airport environment.

PHASE THREE—SMALL TEST AREA EVALUATION.

In Phase Three, a series of trapezoidal-shaped grooves were installed on a larger scale in an actual airport environment. Researchers directed an effort in which a test area with both trapezoidal-shaped and standard grooves was constructed on Taxiway Bravo at ACY. The objective of this small test area airport environment evaluation was to further observe in a comparative manner, the construction process and deformation response over time of the two subject groove geometries. In addition, this installation would allow researchers to monitor general maintenance activities (e.g., snow plowing) and conduct surface friction testing of the groove sections to identify any difference in the friction characteristics of the two grooves.

DISCUSSION. This portion of the research effort represents a larger test site phase of the evaluation. This was conducted at ACY, on Taxiway Bravo between the intersections of Juliet and Kilo; closer to Taxiway Kilo and the threshold of Runway 31. A diagram of the airport illustrating the location of the test section is shown in figure 21. Taxiway Bravo is a 75-ft-wide taxiway, constructed of asphaltic concrete pavement. ACY is a medium-sized airport that services light commercial aircraft. The groove test area, starting from the intersection of Taxiways Bravo and Kilo, consisted of a 148-ft-long by 75-ft-wide test pavement area that was grooved with standard grooves, followed by a 52-ft-long by 75-ft-wide section of nongrooved pavement, and then a 365-ft-long by 75-ft-wide section of trapezoidal-shaped grooves, as shown in figure 22.

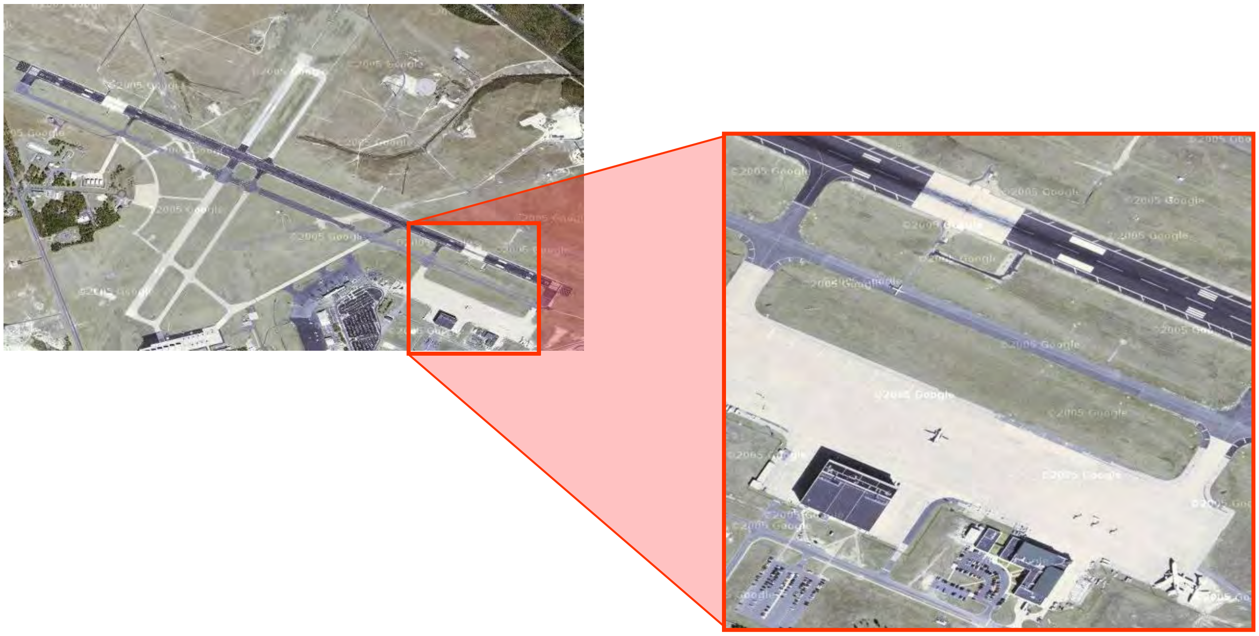


Figure 21. Location of Trapezoidal-Shaped Groove Test Area

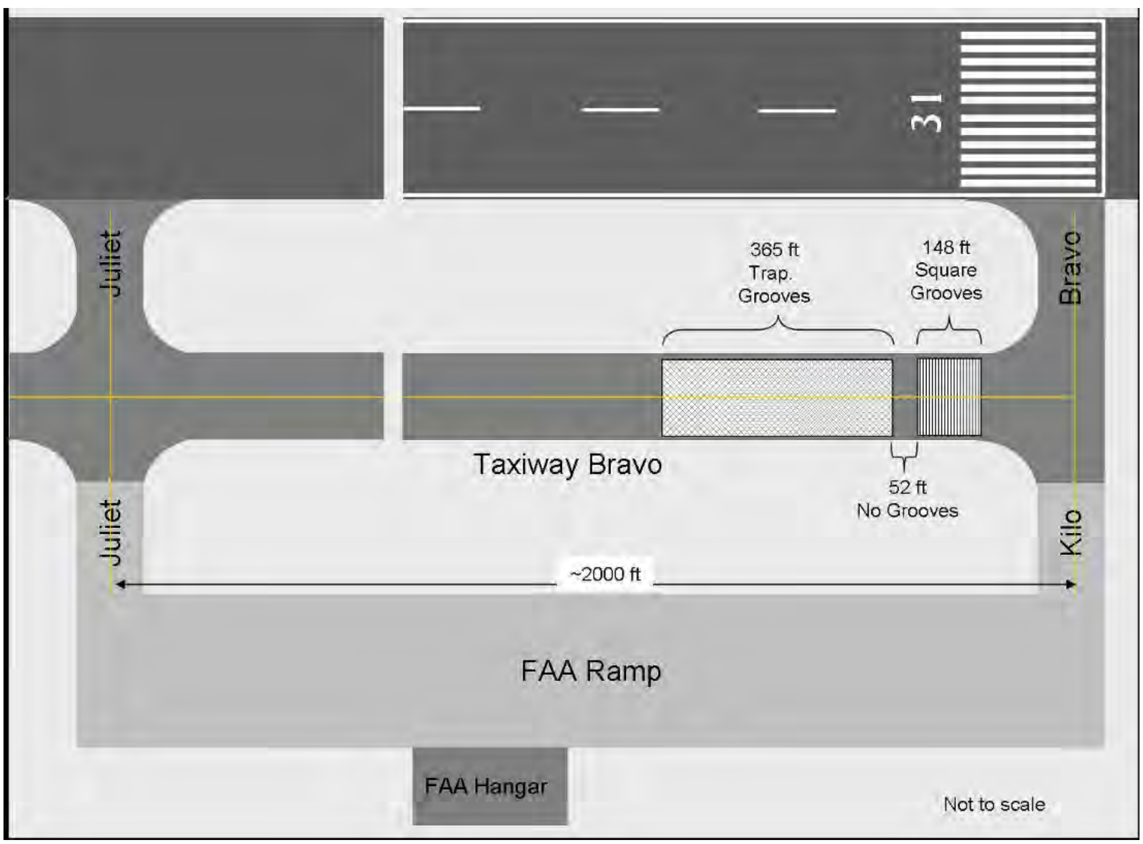


Figure 22. Details of ACY Trapezoidal-Shaped Groove Test Area

The location of the test areas on Taxiway Bravo were optimal for researchers to observe the construction process in an actual airport environment. In addition, this location experiences a moderate amount of taxiing aircraft traffic as Runway 31 is one of the more popular departure runways at ACY.

CONSTRUCTION PROCESS. One objective of Phase Three was to compare the construction methods, resources, and requirements between the trapezoidal-shaped and the standard grooves. In the construction evaluation that occurred under Phase Two, the contractor installed the grooves in a laboratory setting, with many resources immediately available to them. In addition, there was no pressure for time deadlines or impact on air traffic operations. The intent of monitoring the construction process on the airport was to identify any differences in the construction aspect of the operation when performing the installation of trapezoidal-shaped grooves in a realistic airport environment.

On October 4, 2005, researchers installed grooves on Taxiway Bravo. The contractor was able to mobilize and stage all the grooving equipment necessary to perform the installation at the airport. The same manpower, supplies, water trucks, sweepers, and vacuum equipment were used for the installation in the NAPTF. As with the NAPTF installation, the only noticeable issue was the time it took to change the cutting blades on the groove-cutting machine. This step would normally not occur in the real installation. The cutting times for both the standard and the trapezoidal-shaped grooves were identical. Figure 23 shows the bridge-deck groove-cutting machine in position on Taxiway Bravo.

For this particular project, there was no shoulder on the taxiway so the groove-cutting machine had limited space at the end of each groove lane for repositioning. The machine used for this installation was a bridge-deck unit typically used for highways and locations that lack adequate shoulders for larger equipment, so it was able to groove the taxiway surface without the need to depart from the pavement. In a runway environment, there would typically be a paved shoulder that would support the load of a larger groove-cutting machine and allow it to cut the full width of the pavement surface. The groove-cutting machine used the same series of circular saw blades arranged side by side on a rotating drum that was used in the NAPTF installation. Grooves were cut in a south to north direction, starting with the standard grooved section. Figure 24 shows the standard groove installation, and figure 25 shows a portion of the trapezoidal-shaped groove installation.

Figure 23. Bridge-Deck Groove-Cutting Machine in Position on Taxiway Bravo

Figure 24. Standard Groove Installation on Taxiway Bravo

Figure 25. Trapezoidal-Shaped Groove Installation on Taxiway Bravo

DATA COLLECTION AND RESULTS. The average cutting time, per cutting pass, was the same for both the trapezoidal-shaped grooves and the standard grooves. The entire grooving operation was completed over a 3-day period, due to the limited time that the taxiway could be closed. As with the installation inside the NAPTF, all the equipment, manpower, and supplies used for the airport installation were the same. The speed of installation was identical for both the standard and trapezoidal-shaped grooves at a rate of about 29 ft per minute.

Continued analysis of the grooves over the next one year period showed no noticeable disfiguring, collapse, or closure of either of the two groove designs. Researchers attribute this to the fact that the grooves were only trafficked by light commercial aircraft, unlike the heavy loading that was simulated in the NAPTF testing.

PHASE THREE SUMMARY. Phase Three results indicate that installation of the trapezoidal-shaped grooves is very similar to the standard groove installation, as it does not require any unique equipment or manpower. Installation of the trapezoidal-shaped grooves was accomplished in the same amount of time, at the same cutting rate as the standard grooves. These findings indicate that the trapezoidal-shaped groove could be installed at an in-service airport without causing any special accommodations or delays.

Based on the positive findings of Phase Three, FAA researchers determined that it would be feasible to pursue further testing of the trapezoidal-shaped groove configuration at in-service airports.

PHASE FOUR—LARGE-SCALE IN SERVICE EVALUATION.

In Phase Four, a series of trapezoidal-shaped groove test sections were installed on both asphalt and concrete in-service runways at large airports. The objective of this large-scale test area evaluation was to further observe and compare the differences between the two subject groove geometries in the construction process, deformation response over time after exposure to aircraft loading, rubber contamination, cost for installation, wear and durability, performance during heavy-rainfall events, and their friction characteristics.

DISCUSSION. The intent of Phase Four was to install several large test areas of the trapezoidal-shaped grooves at large airports to allow researchers to monitor how the trapezoidal-shaped grooves perform over time in a real-world application. With data collected from Phase Four, researchers can determine if the trapezoidal-shaped groove is suitable as an approved grooving technique. Researchers were able to reach agreements with two major airports that agreed to participate in this effort: MCAF Quantico and Chicago O'Hare International Airport (ORD) in Chicago, Illinois. Both airports had just completed new construction or overlay of their runways, so the timing of the groove installation was ideal. As part of this evaluation, MCAF Quantico allowed researchers to install large sections of the trapezoidal-shaped groove on their concrete runway, and ORD allowed researchers to install small sections of the trapezoidal-shaped grooves on one of their asphalt runways. Both airports agreed to allow researchers to return to the airport periodically after the installation to collect data on any deformation, rubber contamination, and friction characteristics.

TEST SITE 1—MARINE CORPS AIR FACILITY MCAF QUANTICO. MCAF Quantico is a United States Marine Corps airfield that is located in Quantico, Virginia. Runway 02-20 at MCAF Quantico is mostly made of concrete and is 4237 ft long and 200 ft wide. As part of Phase Four, researchers were able to coordinate the installation of the standard and trapezoidal-shaped groove test sections with the airport manager immediately after the runway was resurfaced. This provided researchers with a brand new concrete surface to serve as the first large-scale test area. Runway 02-20 is divided into three sections: the first third of the runway (section 1) is concrete; the second third (section 2) is asphalt, and the last third (section 3) is also concrete. Section one (from Runway 2 threshold), which is 1300 ft long by 130 ft wide, and section three, which is 1540 by 130 ft wide, were grooved with a total of six, equally spaced, 15-ft-long by 130-ft-wide sections of standard 1/4- by 1/4-in.-square grooves, as shown in figure 26. The remaining area within section one was grooved with trapezoidal-shaped grooves. Details of the standard and trapezoidal-shaped groove areas are shown in figure 27. The total grooved area, including both the trapezoidal-shaped and the standard grooved sections, was estimated to be 41,167 square yards. This arrangement allowed researchers to conduct a large-scale evaluation of the trapezoidal-shaped groove sections and provide a side-by-side comparison against the smaller standard groove sections. The center asphalt section of the runway was not grooved but did contain surfaces with various textures. This center section was not evaluated as part of this research effort.

The location of the test areas on Runway 02-20 at MCAF Quantico were optimal for allowing researchers to observe the construction process in an actual airport environment, specifically on a concrete surface. In addition, this location was optimal because it was in close proximity to the

FAA Technical Center, and it supports a moderate amount of aircraft traffic. Runway 02-20 is the only runway available for landing a fixed-wing aircraft at MCAF Quantico.

Figure 26. The MCAF Quantico Test Area

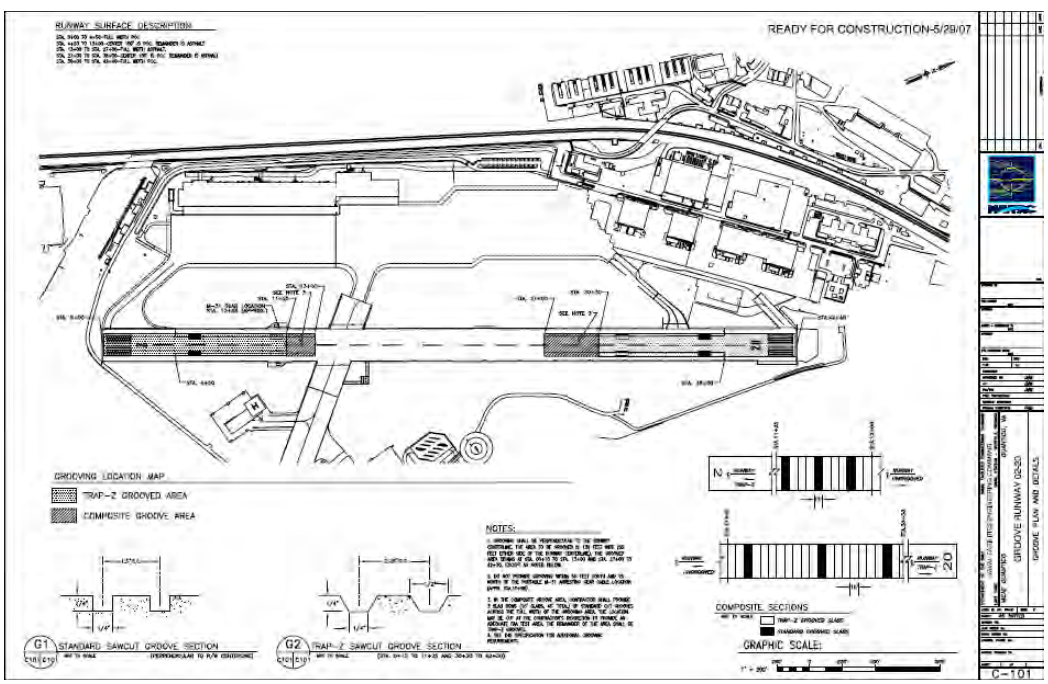


Figure 27. Details of MCAF Quantico Grooving Effort

Construction Process. One objective of Phase Four was to compare differences in the construction methods, resources, and requirements between the standard and trapezoidal-shaped grooves in a real airport environment on an in-service runway. The intent of monitoring the construction process on the airport was to identify any differences in the construction aspect of the operation when performing the installation of trapezoidal-shaped grooves in a realistic airport environment.

In July 2007, researchers initiated the installation of the grooves on Runway 02-20 at MCAF Quantico. The contractor was able to mobilize all of the grooving equipment necessary to perform the installation from their facility in Pennsylvania. The manpower, cutting equipment, supplies, water trucks, sweepers, and vacuum equipment used for the installation were the same equipment that would be used for a typical grooving job at any airport; the only exception was that the groove-cutting machine was fitted with the uniquely shaped blades that create the trapezoidal-shaped groove. For this installation, the contractor used a full-sized groove-cutting machine that was equipped with three cutting drums, as shown in figure 28.

Figure 28. Full-Size Groove-Cutting Machine at MCAF Quantico

Similar to the groove installations at the NAPTF and ACY, the only noticeable issue was the time it took for the contractor to change the cutting blades on the groove-cutting machine when it was time to switch to a different groove pattern. As mentioned earlier in this report, this step would normally not occur in the real installation as the contractor would not be switching between the standard and trapezoidal blades. Figure 29 shows a different view of the groove-cutting machine that was used for this installation.

Figure 29. Large Groove-Cutting Machine Finishing a Pass on Runway 02-20 at MCAF Quantico

The airport manager at MCAF Quantico reported no noticeable differences in the installation process involving the trapezoidal-shaped grooves. Due to the complexity of the test layout requested by the researchers, the contractor spent considerable time measuring the runway to ensure that the sequence and size of the grooved test sections were correct. This, of course, would not be a factor in a real-world installation. The operation resumed without any unexpected issues. It was estimated that the contractor was able to groove the concrete pavement at a rate of approximately 20 linear ft (by 7 1/2 ft wide) per minute, which is comparable to the rate for cutting standard grooves. Figure 30 shows the two types of grooves next to each other at one of the transition areas. The trapezoidal-shaped grooves are on the left side of the photograph.

Figure 30. Trapezoidal-Shaped (Left) and Standard (Right) Grooves Installed on Runway 02-20 at MCAF Quantico

Cost. Another objective of Phase Four was to compare the cost differences associated with trapezoidal-shaped grooves versus standard grooves. For the installation at MCAF Quantico in 2007, the costs for cutting the trapezoidal-shaped grooves averaged $1.75 per square yard, not including transportation and material costs. Comparably, the cost for cutting standard grooves would have been approximately $1.25 per square yard. It has been noted that the cost for cutting the trapezoidal-shaped grooves would be about 15% to 25% higher than the standard grooves until the cost of the blades decreases with large-scale production. Local labor rates, work hours, and other site specific factors can also affect pricing. The typical price range for grooving in concrete pavement ranges from $0.80 to $2.50 per square yard, depending on the conditions and material to be cut.

Wear and Durability. Researchers monitored the trapezoidal-shaped and standard groove areas for differences in wear and durability. Specifically, they observed how the grooves endured over a long term, maintained their specified shape, and resisted rubber contamination.

Approximately 5 months after the groove installation was completed at MCAF Quantico, researchers returned to the airport to conduct their first evaluation. It was noted that there was a difference in the amount of rubber contamination on the two types of grooves. There was less rubber buildup on the top edges of the trapezoidal-shaped grooves, whereas the standard grooves collected more rubber on the top edges. Figure 31 shows the rubber contamination on a standard groove area, and figure 32 shows the rubber contamination on a trapezoidal-shaped groove area. Note the increased buildup of rubber on the leading edge of the standard groove sections in figure 31, as compared to the lesser buildup on the trapezoidal-shaped groove shown in figure 32.

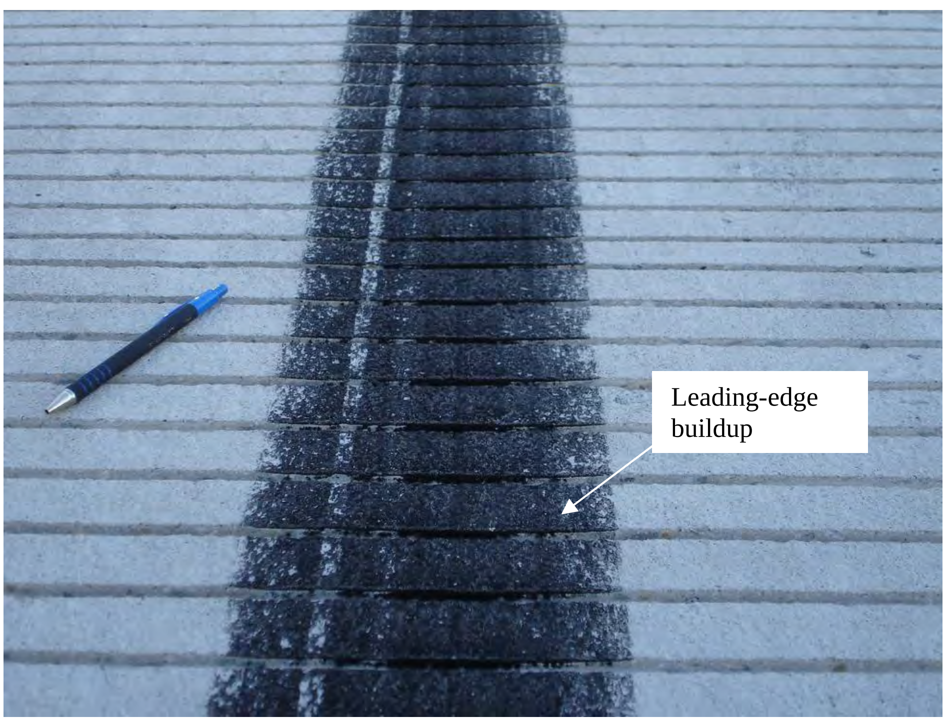


Figure 31. Rubber Contamination at MCAF Quantico—Standard Groove

Figure 32. Rubber Contamination at MCAF Quantico—Trapezoidal-Shaped Groove

Researchers concluded that the difference in the rubber buildup on the leading edge of the grooves was due to the angular differences in the groove design. The standard groove has edges that are 90°, which would be more likely to shave or cut into the aircrafts rubber tire as it passes over it, while the trapezoidal-shaped groove has a slightly flatter angle of 117°. The difference in the sharpness of these edges very likely determines how much rubber is caught on those edges. Researchers observed evidence of this phenomenon at several locations on the runway at MCAF Quantico but decided to wait several more months before making a final determination.

In June of 2009, researchers returned to MCAF Quantico to conduct further evaluation of the grooves resistance to wear and durability. Upon arrival at MCAF Quantico, researchers were disappointed to learn that the airport had recently conducted rubber removal operations on the entire runway. As a result, the rubber buildup that had occurred since the grooves were first installed had been removed. The airport manager explained that they were very pleased with the performance of the trapezoidal-shaped grooves in regards to their resistance to rubber contamination, as they were able to delay the rubber removal process for almost 9 months longer than they have historically been able to do with the standard grooves. This information was valuable to researchers, as it showed that the airport made its own assessment of the trapezoidal-shaped grooves improved wear and durability and was able to appreciate a noticeable difference in their performance. Over the life of the pavement, the airport manager explained that the airport would save a lot of money due to the lesser frequency of rubber removal expenses.

During their visit, researchers conducted their inspection of the grooved surfaces with the understanding that they had been exposed to a recent rubber removal operation. Upon inspection, researchers were still able to see evidence that the standard grooves had collected more rubber than the trapezoidal-shaped grooves, as shown side by side in figure 33. The trapezoidal-shaped grooves, shown in the lower half of the figure, maintained a sharp leading edge with minor rubber buildup, while the standard grooves shown in the upper half of the figure still showed evidence of rubber buildup, even after a recent rubber removal operation. It is important to note that rubber buildup on the leading edge of the groove does not necessarily affect the friction of the pavement surface, but over time, it can greatly reduce the amount of water that the groove can displace in a heavy-rain event. Additionally, the wider opening at the top of the trapezoidal-shaped grooves and their slanted walls most likely allow for a more thorough cleaning during the rubber removal process as compared to the straight walls of the narrower square grooves. The differences in rubber buildup also indicate that the two different groove types have very different impacts on the tires that come in contact with them. The trapezoidal-shaped grooves appear to cause less damage to the tires of passing aircraft, which may prolong the life of the tire over time. Airlines and aircraft operators may benefit financially from a longer tire life should they continuously operate on trapezoidal-shaped grooved runways.

Figure 33. Rubber Contamination After Rubber Removal Operation at MCAF Quantico

During inspection, researchers also noticed that the trapezoidal-shaped grooves were less susceptible to damage from aircraft and maintenance operations. Close inspection of the runway surfaces showed that in several instances, the edges of the standard grooves experienced chipping and breaking. The trapezoidal-shaped groove, however, appeared to resist this type of damage. Figure 34 shows a picture of a transition area where the type of groove switches from standard (on left) to trapezoidal (on right). Note the numerous areas where the edges of the standard groove have broken or chipped. Researchers were only able to find a few isolated locations on the entire runway where the edges of the trapezoidal-shaped groove showed any damage.

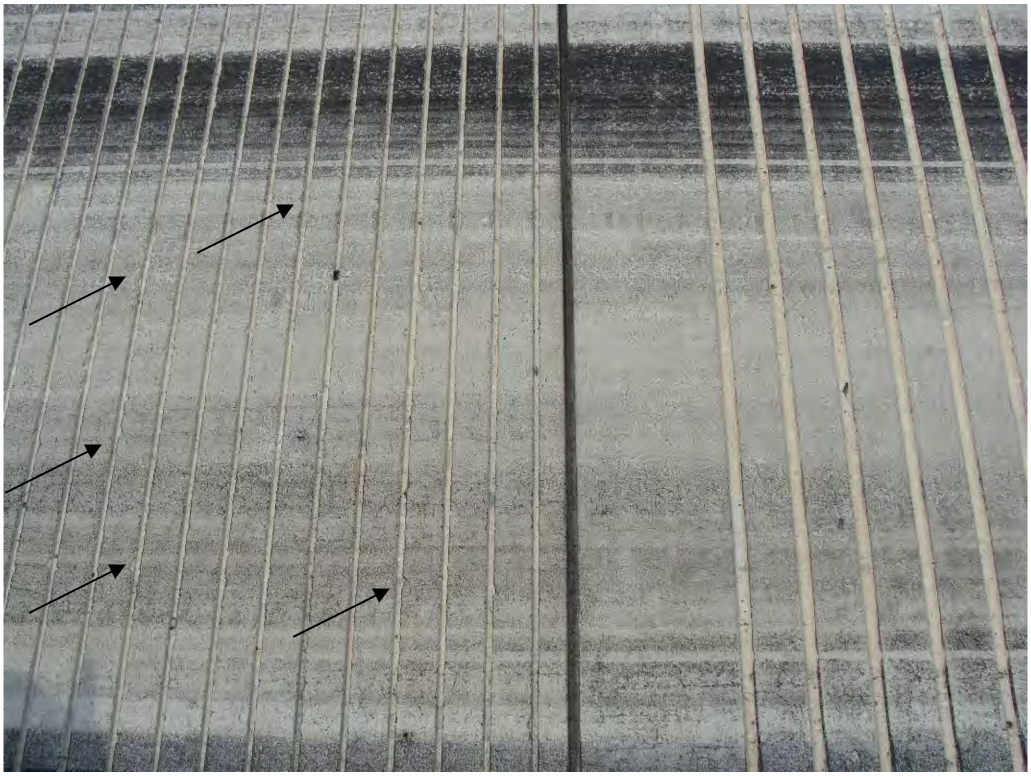


Figure 34. Evidence of Damage to Edges of Standard (Left) and Trapezoidal-Shaped (Right) Grooves

Performance. As part of this evaluation, researchers also determined if there was a difference in the ability of the trapezoidal-shaped grooves to evacuate water from the surface of the runway. To investigate this further, researchers coordinated a special evaluation with the airport manager at MCAF Quantico in which an airport fire truck would dump a significant amount of water on the runway over both the trapezoidal-shaped and standard groove test areas. This evaluation was conducted on July 19, 2007.

Researchers outlined one standard groove test section with orange traffic cones, as shown in figure 35. An airport fire truck slowly traveled through the test area, along the runway centerline, and dumped a large amount of water on the pavement (figure 36). Within a few seconds after the water was dumped on the pavement, researchers noticed that the pavement areas with the trapezoidal-shaped grooves evacuated the water significantly faster than the areas with the standard grooves. In figure 37, note the area just before the orange cone. The water in this area is higher on the runway than in the areas before and after the cone, which are the trapezoidal-shaped grooved areas. The flood line for the standard grooves, which is the point at which the grooves are completely filled with water, can be observed to lag behind the flood line for the trapezoidal-shaped grooves.

Figure 35. Test Area for Water Dispersal Test

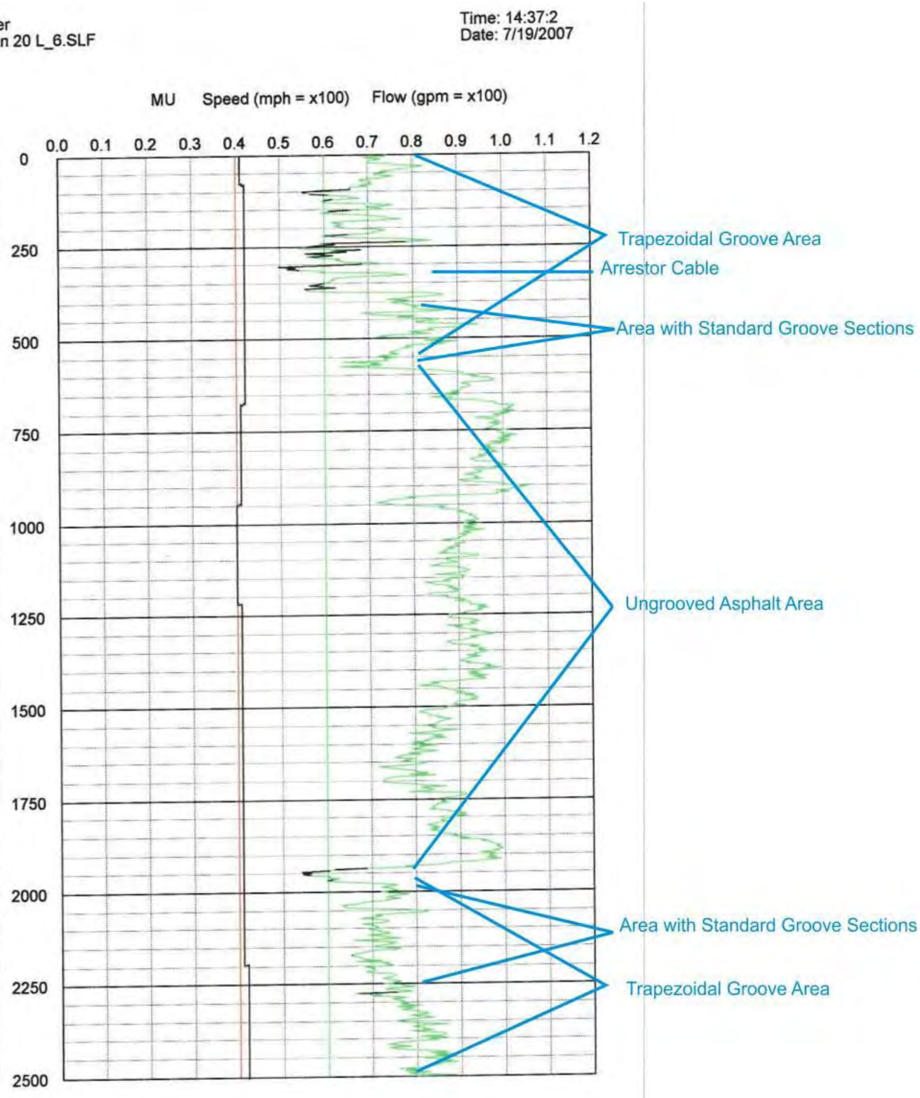
Figure 36. Airport Fire Truck Dispersing Water on Test Area

Figure 37. Illustration of Water Dispersal Difference

This portion of the evaluation, combined with the results of the earlier braking coefficient research, shows that the trapezoidal-shaped grooves were able to displace water faster than the standard grooves which, in heavy downpours, could significantly enhance an aircraft's ability to resist hydroplaning and lead to better stopping capability and reduced runway closures.

Friction Characteristics. During periodic visits to MCAF Quantico, researchers were able to conduct friction-measurements of the entire runway surface using an FAA-owned and -operated surface friction measuring equipment (SFME). The SFME that was used for this evaluation was a Dynatest® 6850 Slip Friction Tester, commonly called the Runway Friction Tester (RFT). This model SFME is approved for use by the FAA and is listed in the FAA AC 5320-12C [1]. Data collection runs for this project were conducted at 40 mph with data collection starting about 700 ft from the threshold of Runway 02. Tests were performed with the vehicle aligned about 10 ft from the center of the runway.

On July 19, 2007, researchers were allowed to collect friction data over the full length of the runway. The runway contains several different surfaces including grooved concrete, ungrooved asphalt, and ungrooved concrete areas where an arresting cable is installed in the runway. Figure 38 shows a sample of the data collected from the RFT during one of the first runs, titled run 1R, with a dry runway surface, and the vehicle using its own self-contained wetting system. With the self-watering system, a calibrated amount of water is applied to the pavement at a 1.0-mm thickness in front of an ASTM E1551 test tire, as installed on the SFME. The locations for all the differing sections of pavement type and surface treatment, including the areas with the standard and trapezoidal-shaped groove areas, are shown in figure 38.



Flow	Speed	MU	Event
0.0	41.7	0.690	
0.0	42.0	0.712	
0.0	41.7	0.889	
0.0	40.8	0.940	
0.0	40.1	0.898	
0.0	41.0	0.919	
0.0	41.0	0.820	
0.0	41.0	0.834	
0.0	41.2	0.718	
0.0	42.0	0.800	

Figure 38. The MCAF Quantico Friction Run 1R—Dry Pavement

Excluding the data collected from the ungrooved pavement area in the middle section of the runway, the average friction value for the grooved areas for the first run, run 1R, was 0.72 mu. Shortly after this first run, light rain began to fall at the airport. The RFT continued collecting data on the wet pavement surface, and the self-contained wetting system still activated. The results of this run, titled run 4R, are shown in figure 39. The average measurement for the grooved areas of the runway was 0.70 mu. Approximately 25 minutes after this run, a significant thunderstorm occurred with heavy rain that reduced visibility at the airport down to near 0 ft. The Operations personnel suspended data collection temporarily until visibility improved. Approximately 5 minutes after the downpour subsided, data collection runs resumed. Figures 40 and 41 show data collected 5 (run 3L) and 10 minutes (run 4L), respectively, after the downpour tapered off. In figure 40, for run 3L, the average reading for the grooved areas was 0.60 mu; and in figure 41 (run 4L), the average was 0.63 mu. All data collected during the site visit was considered acceptable and in accordance with FAA AC 5320-12C. In total, 13 data collection runs were completed.

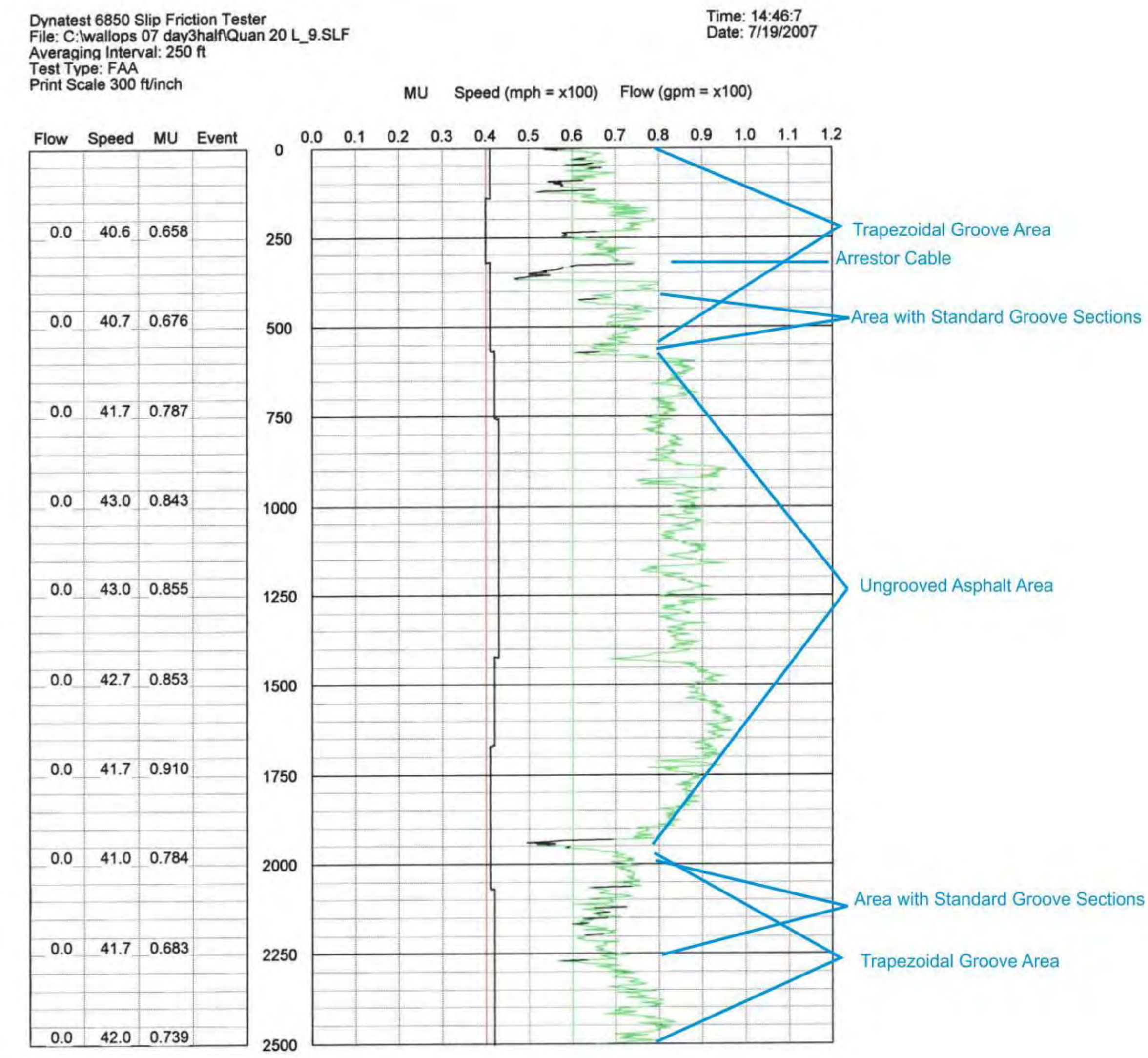


Figure 39. The MCAF Quantico Friction Run 4R—Light Rain, Wet Pavement

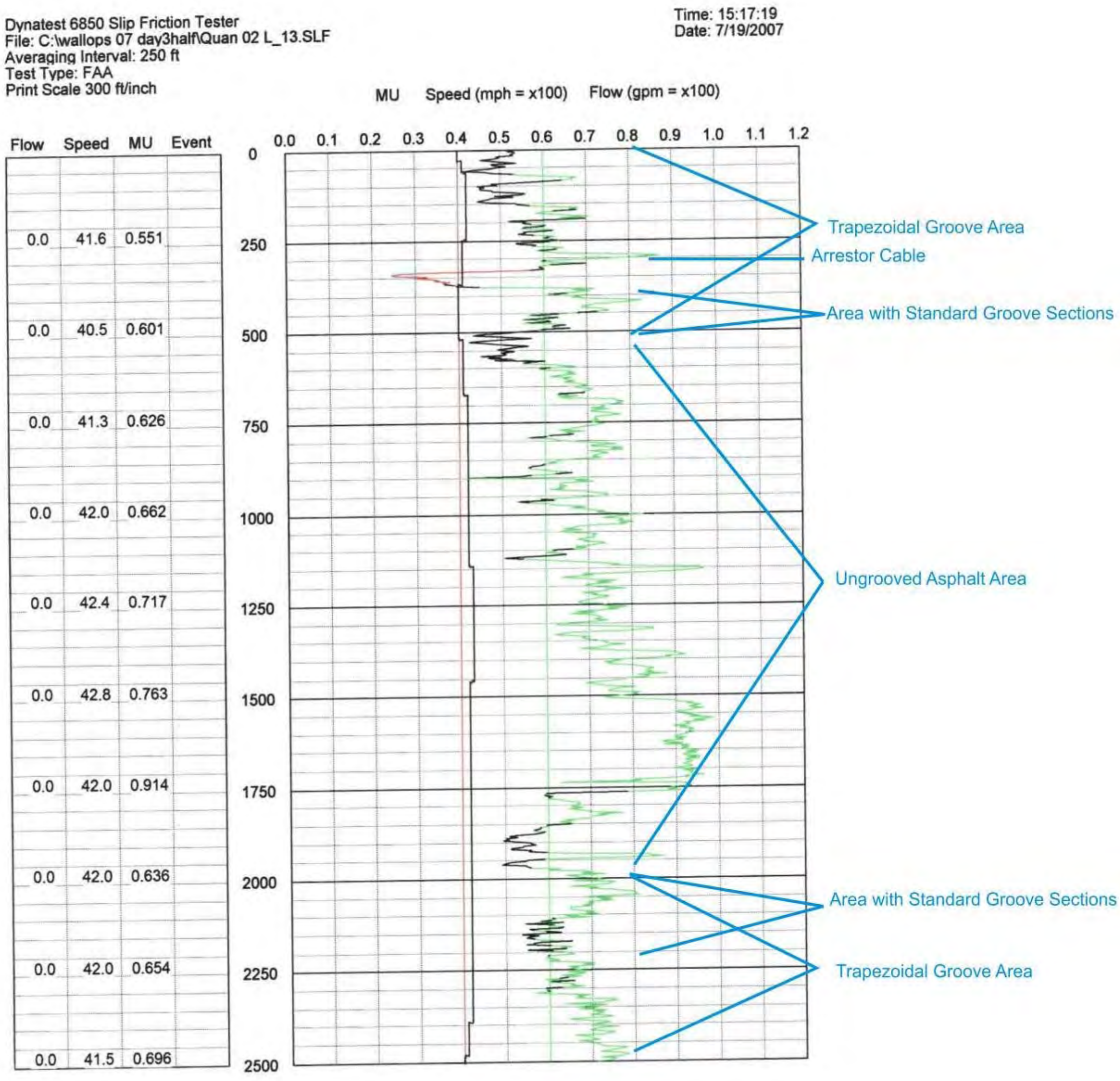


Figure 40. The MCAF Quantico Friction Run 3L—5 Minutes After Heavy Rain

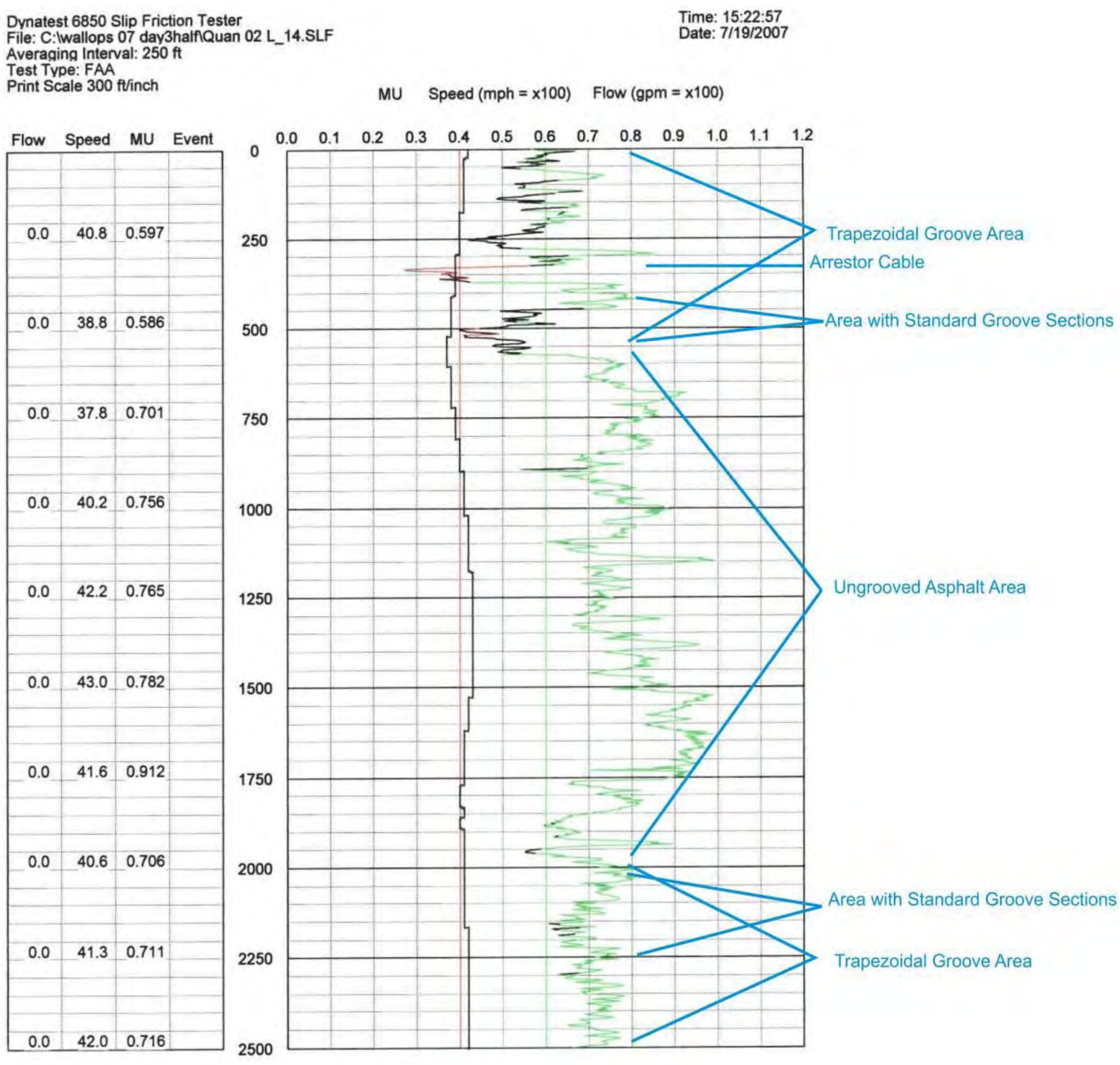


Figure 41. The MCAF Quantico Friction Run 4L—10 Minutes After Heavy Rain

Analysis of figures 38 through 41 indicated that the trapezoidal-shaped grooves provide comparable friction values to the standard grooves, making it nearly impossible to separate the two purely on their friction data. Rubber contamination, oil deposits, and other uncontrollable factors can cause abnormities in the data, which are likely reflected by random spikes in the data graphs, as well as the reduced numbers closest to the touchdown areas (due to rubber contamination). Researchers were not trying to identify specific numerical differences in the friction values but were trying to determine if the trapezoidal-shaped grooves provided comparable friction than the standard groove on the runway as a whole.

It was interesting to note how the friction values collected within the ungrooved asphalt area deteriorated significantly with the increase in water exposure, while the trapezoidal-shaped and standard grooved areas maintained fairly consistent numbers throughout the rain event.

Data Collection and Results—MCAF Quantico. Average cutting time per cutting pass was the same for both the trapezoidal-shaped grooves and the standard grooves, with no identifiable differences in the cutting process. As with the NAPTF and ACY installations, the equipment, manpower, and supplies used for the airport installation were the same. The speed of installation was identical for both the standard and trapezoidal-shaped grooves.

The costs for the trapezoidal-shaped grooves were calculated to be between 15% and 25% higher than the cost of the standard grooves but is expected to decrease as the blade costs come down with the introduction and demand of large-scale production.

Continued analysis over the next year at MCAF Quantico showed no noticeable disfiguring, collapse, or closure of either of the two groove designs, although the standard grooves experienced some chipping and breaking that was not evident on the trapezoidal-shaped grooves.

The airport manager at MCAF Quantico reported that they were able to delay rubber removal operations a few months due to the improved performance of the trapezoidal-shaped grooves in their ability to resist rubber contamination. While they did collect some rubber, it was minimal compared to the amount found on the standard grooves.

Friction measurements taken on the runway at MCAF Quantico indicate that the friction characteristics of the trapezoidal-shaped grooves were comparable to the standard grooves in dry, wet, and soaked conditions.

Phase Four—Test Site 1 Summary. The trapezoidal-shaped grooves performed satisfactorily at MCAF Quantico. While the installation cost for the trapezoidal-shaped grooves was slightly higher than the cost of standard grooves, there may be additional benefits that offset the difference. At MCAF Quantico, it was apparent that the trapezoidal-shaped grooves evacuated water quicker, resisted rubber contamination, and also resisted damage from aircraft and maintenance activity compared to the standard grooves. Friction values for the trapezoidal-shaped grooves were found to be comparable to the values associated with the standard grooves.

TEST SITE 2—ORD. ORD is a large, FAA Part 139-certificated airfield. Runway 10-28 at ORD is paved with asphalt, and at the time of the installation of the grooving, was 10,144 ft long and 150 ft wide. (As part of the O'Hare Modernization Program, Runway 10-28 has since been lengthened to 13,001 ft.) Through cooperation with the airport administration, researchers were able to coordinate the installation of a series of trapezoidal-shaped groove test sections immediately after the runway was resurfaced. This provided researchers with a brand new asphalt surface to serve as a second large-scale test area. Three test sections were installed on Runway 10-28, one near the threshold, one in the touchdown area, and one in the rollout area. Each test section was 750 ft long, consisting of the first 250 ft with the trapezoidal-shaped grooves, followed by 250 ft of standard grooves, and ending with 250 ft of trapezoidal-shaped grooves (500 total ft of alternative grooves). Positioning a section of standard grooves within the two trapezoidal-shaped grooved areas provided researchers with a direct baseline comparison between the two groove patterns. Details on each proposed location are as follows:

- Runway 10 Threshold Area. The first test area began at the threshold of Runway 10, shown as block A in figure 42. From that point, the 750-foot-long test section began with 250 ft of trapezoidal-shaped grooves, 250 ft of standard grooves, and finally 250 ft of trapezoidal-shaped grooves. This test section ended approximately 750 ft from the threshold of Runway 10. This area was selected to capture landing traffic on runway 10. Details of the area are shown in figure 43.

- Runway 10 Touchdown Area. The second test area began 1000 ft from the threshold of Runway 10, shown as block B in figure 42. From that point, the 750-foot-long test section began with 250 ft of trapezoidal-shaped grooves, 250 ft of standard grooves, and 250 ft of alternative grooves. This test section ended approximately 1750 ft from the threshold of Runway 10. This area was selected to capture the touchdown area where the heaviest rubber contamination may be experienced as the aircraft touchdown on the pavement. Details of the area are shown in figure 43.

- Runway 10 Rollout Area. The third test area began 7711 ft from the threshold of Runway 10, shown as block C in figure 42. From that point, the 750-foot-long test section began with 250 ft of trapezoidal-shaped grooves, 250 ft of standard grooves, and 250 ft of alternative grooves. This test section ended approximately 8461 ft from the threshold of Runway 10. This area was selected to capture heavy braking and sharp turning from aircraft attempting to exit Runway 10 on Taxiways M6. Details of the area are shown in figure 44.

Figure 42. The ORD Test Area

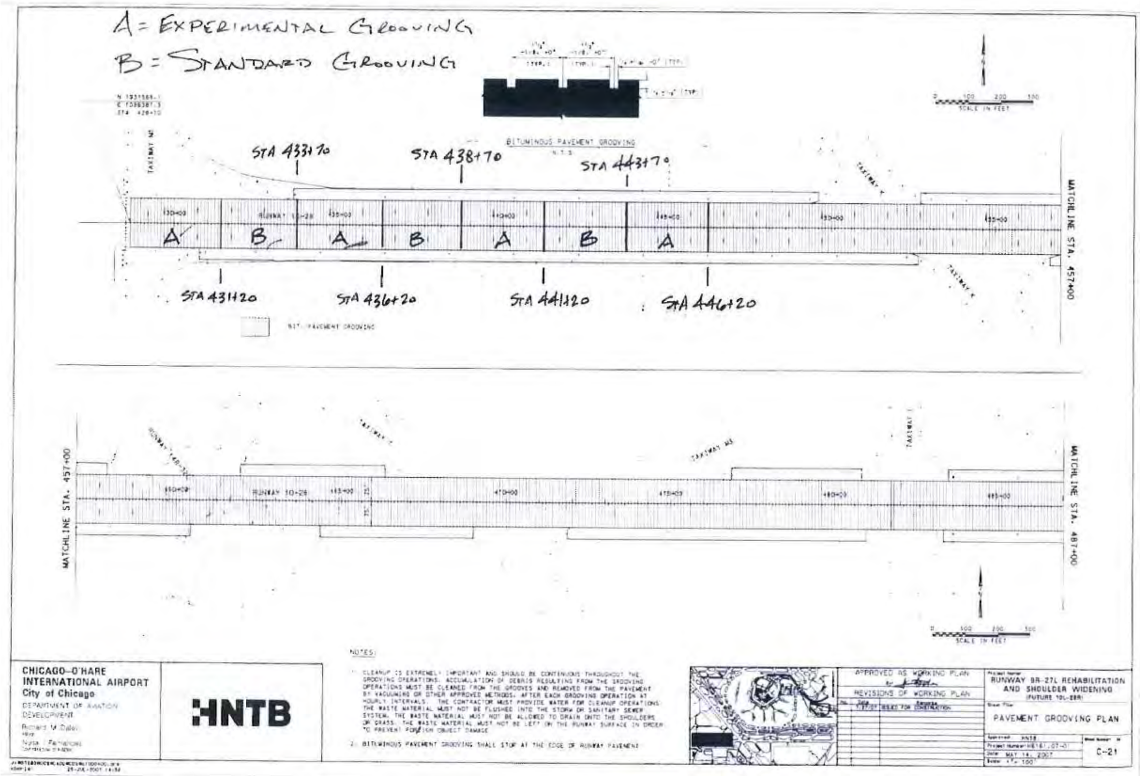


Figure 43. Details of ORD Grooving Effort (West)

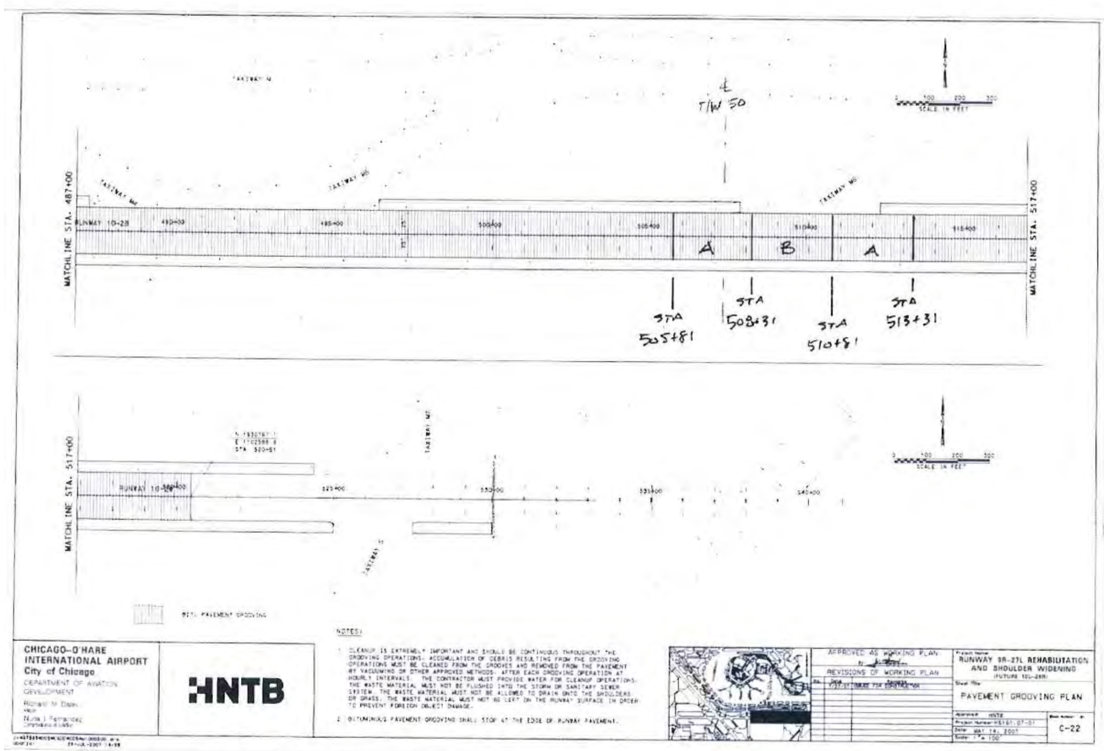


Figure 44. Details of ORD Grooving Effort (East)

The total grooved area, including both the trapezoidal and the standard grooved sections, was estimated to be 37,500 square yards. The first two test sections were separated by a 250-ft section of standard grooves, as shown in figure 43. This was because of the proximity to the intersection of Runway 14R-32L.

The location of the test areas on Runway 10-28 at ORD were optimal for allowing researchers to observe the performance and durability in an actual airport environment on a new asphalt surface. In addition, this location was optimal because it experiences a significant amount of aircraft traffic.

Construction Process. One objective of this evaluation was to compare differences in the construction methods, resources, and requirements between the trapezoidal-shaped and the standard grooves in a real airport environment on an in-service runway. The intent of monitoring the construction process on the airport was to identify any differences in the construction aspect of the operation when performing the installation of trapezoidal-shaped grooves in a realistic airport environment.

In February 2008, researchers initiated the installation of the grooves on Runway 10-28 at ORD. As with the MCAF Quantico installation, the contractor was able to mobilize all of the grooving equipment necessary to perform the installation from their facility on the east coast. The manpower, cutting equipment, supplies, water trucks, sweepers, and vacuum equipment used for the installation was the same equipment that would be used for a typical grooving job at any other airport; the only exception was that the groove-cutting machine was fitted with the uniquely shaped blades that create the trapezoidal-shaped groove. The same full-sized, groove-cutting machine that was used at MCAF Quantico was used at ORD, as shown in figures 28 and 29. Figure 45 shows a side-by-side comparison of the two grooved sections, as installed at ORD.

Figure 45. Trapezoidal-Shaped (Left) and Standard (Right) Grooves Installed on Runway 10-28 at ORD

As with the NAPTF, ACY, and MCAF Quantico groove installations, the only noticeable difference with the installation activity was the time it took for the contractor to change the cutting blades on the groove-cutting machine when it was time to switch to a different groove pattern. As mentioned, this step would normally not occur in the real installation as the contractor would not be switching between the standard and trapezoidal blades.

The airport operations staff at ORD reported no noticeable differences in the installation process involving the trapezoidal-shaped grooves. As with the MCAF Quantico installation, the complexity of the test layout required the contractor to spend some time measuring the runway to ensure that the sequence and size of the test sections were correct. This, of course, would not be a factor in a real-world installation. The operation resumed without any unexpected issues. It was estimated that the contractor was able to groove the asphalt pavement at a rate of approximately 28 linear ft (by 9 3/8 ft wide) per minute, which is comparable to the rate for cutting standard grooves in asphalt.

Cost. Another objective of Phase Four was to compare the cost differences associated in cutting trapezoidal-shaped grooves versus standard groove cutting in asphalt pavement. For the installation at ORD in early 2008, the costs for cutting the trapezoidal-shaped grooves averaged $1.50 per square yard, not including transportation and material costs. Comparably, the cost for cutting standard grooves would have cost approximately $1.10 per square yard. As noted, the cost for cutting the trapezoidal-shaped grooves would be about 15% to 25% higher than the standard grooves until the cost of the blades decreases with the growth of large-scale production. Local labor rates, work hours, and other site-specific factors can also affect pricing.

Wear And Durability. Researchers monitored the trapezoidal-shaped and standard groove areas to observe differences in wear and durability. Specifically, they were watching to see how the grooves endured over a long term, maintained their specified shape, and resisted rubber contamination.

Approximately 10 months after the groove installation was completed at ORD, researchers returned to the airport to conduct their first evaluation. It was noted that there was a difference in the amount of rubber contamination on the trapezoidal-shaped grooves, just as was observed at MCAF Quantico. Researchers noticed that there was less rubber buildup on the top edges of the trapezoidal-shaped grooves than there was on the top edges of the standard groove. Figure 46 shows a portion of the runway at ORD where the grooves transition from standard to trapezoidal. Note the additional rubber contamination on the standard grooves on the left, versus the trapezoidal-shaped grooves on the right.

Figure 46. Rubber Contamination at ORD

Researchers concluded that the difference in the rubber buildup on the leading edge of the grooves was due to the angular differences in the groove design, which was the same conclusion drawn at MCAF Quantico. The difference in the sharpness of the groove edges very likely determines how much rubber is caught on those edges. Researchers observed evidence of this phenomenon at several locations on the runway at ORD.

In June 2009, researchers returned to ORD to conduct further evaluation of the grooves resistance to wear and durability. Researchers were able to inspect the rubber buildup that had occurred since the grooves were first installed. The airport manager explained that they were eager to groove an entire runway with the trapezoidal-shaped grooves, as they were impressed with how the trapezoidal-shaped grooves resisted rubber contamination and did not fill up with rubber deposits, as did the standard grooves. As with the feedback from MCAF Quantico, this information was valuable to researchers, as it showed that the airport made its own assessment of the trapezoidal-shaped grooves improved wear and durability and was able to appreciate a noticeable difference in their performance.

During their inspection, researchers also noticed that the trapezoidal-shaped grooves were less susceptible to damage from aircraft and maintenance operations. Closer inspection of the runway surfaces showed that the edges of the standard grooves began to fail and were essentially closing in on the groove. The edges or walls of the trapezoidal-shaped grooves also experienced some disfiguring but still maintained its basic shape. Figure 47 shows a picture of the standard groove with a 1/4-in. measurement ruler placed over the groove, and figure 48 shows a picture of a trapezoidal-shaped groove with the same ruler. Note how the standard groove has closed to less than a 1/4 in., while the trapezoidal-shaped groove has closed slightly but is still fairly close to its original 1/2 in. width. Figure 49 shows a comparison in the amount of damage in a transition area in which the type of groove switches from trapezoidal (on left) to standard (on right). These results validated the data collected earlier during the profiling activity conducted at the NAPTF that showed the trapezoidal-shaped grooves suffered some failure under extreme weight conditions but were still able to maintain a recognizable shape. The standard grooves, however, did not.

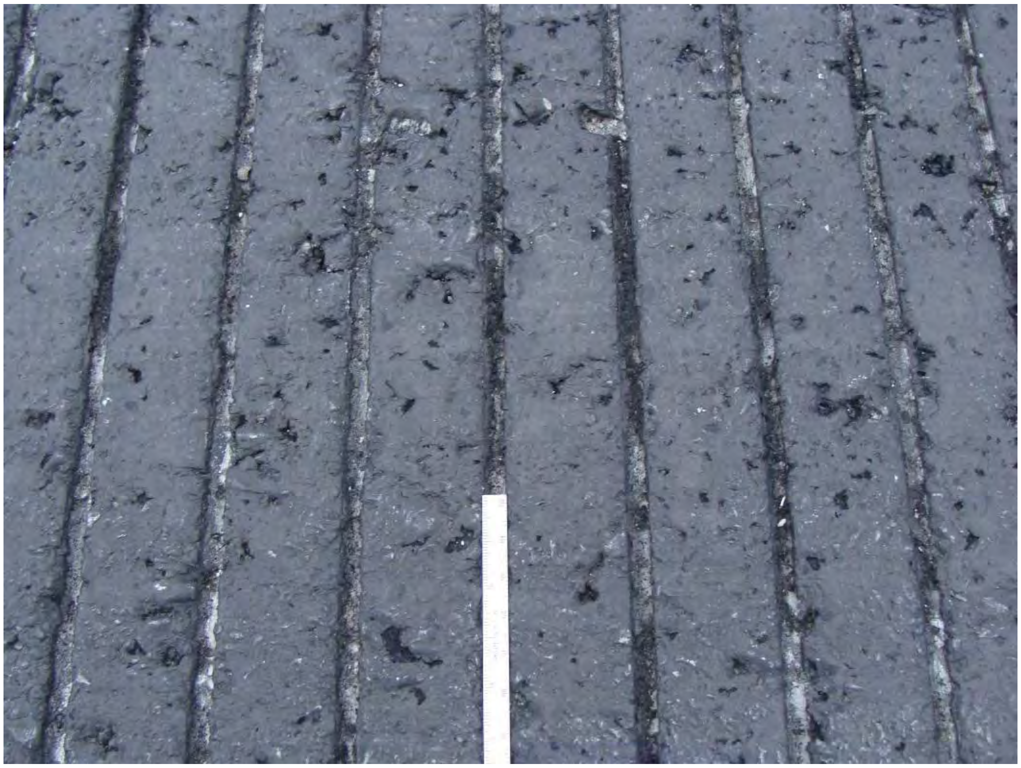


Figure 47. Standard Groove Damage

Figure 48. Trapezoidal-Shaped Groove Damage

Figure 49. Comparative Damage to Grooves

Performance. Researchers also determined the ability of the trapezoidal-shaped grooves to evacuate water from the surface of the runway. Researchers elected not to repeat the performance test that was conducted at MCAF Quantico, as it was assumed that both types of grooves would evacuate water in the same fashion regardless of the pavement type. Rubber contamination and groove closure would obviously have a negative affect on the ability of the grooves to disperse water, so it is assumed the trapezoidal-shaped grooves would continue to dissipate water quicker than the standard grooves since they maintained a wider opening.

The airport manager of ORD reported that he noticed a significant difference in the amount of water vapor created by a jet blast from a departing or landing aircraft as it passes over the different groove sections. He reported that when the aircraft passed over the trapezoidal-shaped grooves, the amount of mist or water in the air decreased. Researchers concluded that this was a result of less water being held in the trapezoidal-shaped grooves, so as the jet engines of the aircraft passed over the trapezoidal-shaped grooves, there was less water for the jet engines to pull from the pavement and throw into the air. The standard grooves, however, must have contained more water and, thus, provided a large source of water that could be vaporized.

Researchers took note of this observation but did not consider it as part of this evaluation effort.

Friction Characteristics. During one visit to ORD, researchers were able to conduct friction measurements of the runway area where the trapezoidal-shaped grooves were installed using an FAA-owned and -operated SFME. The SFME that was used for this evaluation was a Sarsys Saab 9-5 Wagon Surface Friction Tester (SFT). This model SFME, like the RFT used at MCAF Quantico, is approved for use by the FAA and is listed in FAA AC 5320-12C [1]. Data collection runs for this project were conducted at 40 mph. Data collection for the longer test sections toward the threshold of Runway 10 started 100 ft from the beginning of the test section closest to the threshold of Runway 10, and ended 100 ft beyond the end of the last test section, for a total of 1850 ft. Testing was done with the vehicle aligned 10, 15, and 20 ft from the center of the runway. This allowed data collection from different parts of the runway that experience different amount of exposure to traffic and rubber. Data collection for the shorter test section towards the threshold of Runway 28 also started and ended 100 ft from the end of the test section, for a total of 950 ft. Testing was also done with the vehicle aligned at 10, 15, and 20 ft from the center of the runway.

Figures 50 through 55 show the data collected from the SFT during the test runs at ORD. Figures 50 through 52 show data collected for the test runs on the longer test section, closest to the threshold of Runway 10, at 10, 15, and 20 ft from the runway centerline. Figures 53 through 55 show data collected for the test runs on the shorter test section, closest to the threshold of runway 28, also at 10, 15, and 20 ft from the runway centerline. For all runs, the runway surface was dry and the SFT used its own self-contained wetting system. The locations of the standard and trapezoidal-shaped grooved areas are shown in the figures by the letters “T” for trapezoidal and “S” for standard.

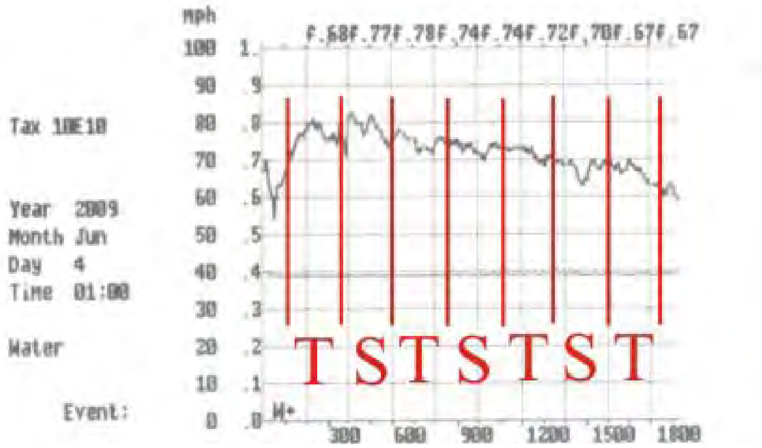


Figure 50. The ORD Friction Run 10E10 (Longer test section, 10 ft from centerline)

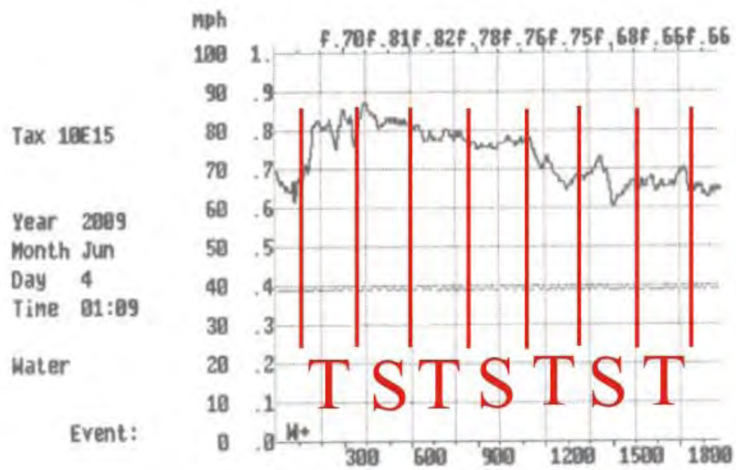


Figure 51. The ORD Friction Run 10E15 (Longer test section, 15 ft from centerline)

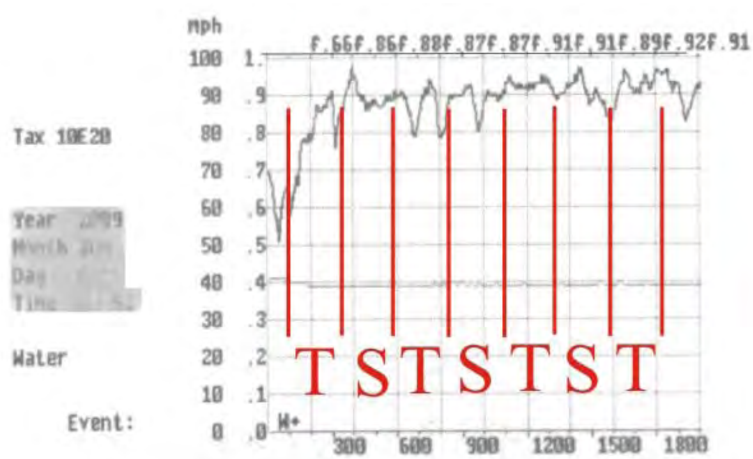


Figure 52. The ORD Friction Run 10E20 (Longer test section, 20 ft from centerline)

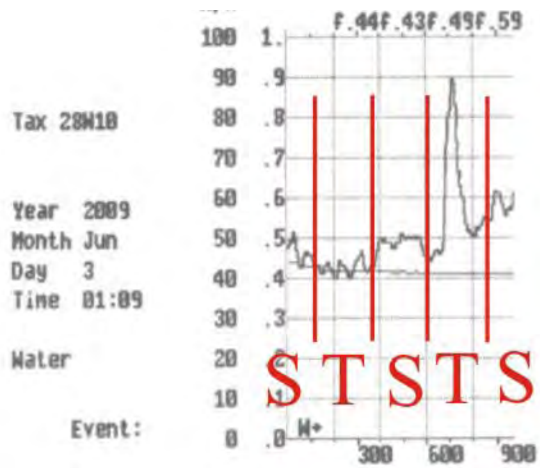


Figure 53. The ORD Friction Run 28W10 (Shorter test section, 10 ft from centerline)

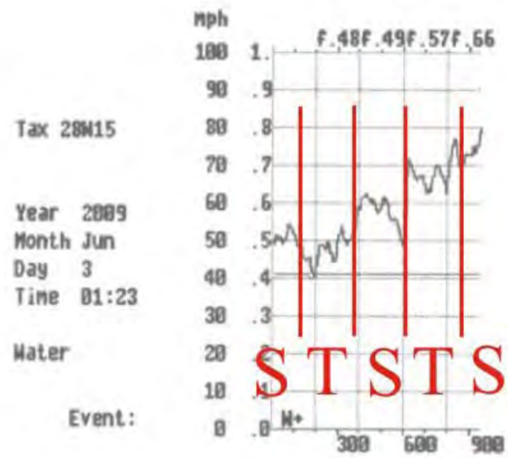


Figure 54. The ORD Friction Run 28W15 (Shorter test section, 15 ft from centerline)

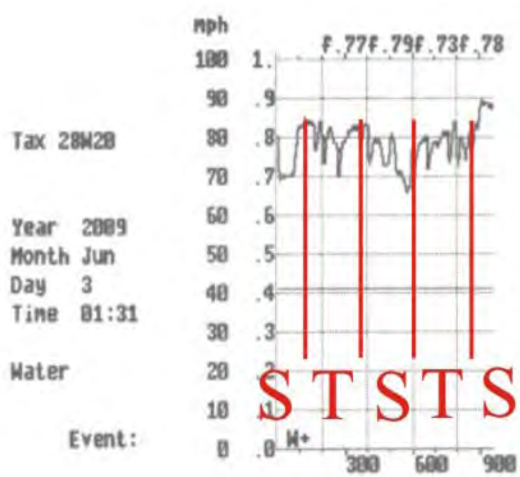


Figure 55. The ORD Friction Run 28W20 (Shorter test section, 20 ft from centerline)

Analysis of the friction data collected at ORD indicated that the trapezoidal runway grooves provide comparable friction values to the standard grooves, making it nearly impossible to separate the two purely on their friction data. Extensive amounts of rubber contamination were present at ORD, due to the high levels of aircraft operations, which likely caused the friction numbers to be lower. This was illustrated in the data readings, as the friction values closest to the runway centerline are lower than those that are 20 ft away, due to the closer proximity to where an air carrier aircraft's main gear would be first touching down on the runway. Likewise, the friction numbers collected from the longer test section closest to the threshold of Runway 10 were generally higher than those collected from the shorter test section where the pavement was exposed to both aircraft landing on Runway 28 and aircraft that landed on Runway 10, which brake heavily before exiting the runway to taxi to the terminal. In all six figures, the standard grooves and trapezoidal-shaped grooves appear to offer comparable results, with a few small sections of trapezoidal-shaped grooves showing slightly higher values than the standard grooves. Researchers were not trying to identify specific numerical differences in the friction values but were trying to determine if the trapezoidal-shaped grooves provided comparable friction than the standard groove on the runway as a whole.

<u>Data Collection and Results—ORD</u>. The average cutting time per cutting pass was the same for both the trapezoidal-shaped and standard grooves, with no identifiable differences in the cutting process. As with the NAPTF, ACY, and MCAF Quantico installations, the equipment, manpower, and supplies used for the airport installation were the same. The speed of installation was identical for both the standard and trapezoidal-shaped grooves.

The costs for the trapezoidal-shaped grooves are calculated to be between 15% and 25% higher than the cost of the standard grooves but are expected to decrease as the blades cost come down with large-scale production.

Continued analysis of the grooves at ORD showed some noticeable disfiguring, collapse, and closure of both groove designs, although the standard grooves experienced more significantly disfiguring and closure than the trapezoidal-shaped grooves.

Within the first six months after installation, the trapezoidal-shaped grooves appeared to show a significant benefit in their ability to resist rubber contamination. After a prolonged period, the trapezoidal-shaped grooves showed evidence of rubber contamination, but were not filled in as much as the standard grooves. The trapezoidal-shaped grooves remained open enough for water to flow through them, providing the escape path needed for water to be displaced under an aircraft tire.

Friction measurements taken on the asphalt runway at ORD indicate that the friction characteristics of the trapezoidal-shaped grooves are comparable, if not slightly higher, than the standard grooves.

<u>Phase Four—Test Site 2 Summary</u>. In conclusion, the trapezoidal-shaped grooves performed satisfactorily at ORD. As with the previous effort at MCAF Quantico, the installation cost for the trapezoidal-shaped grooves was slightly higher than the cost of standard grooves. The trapezoidal-shaped grooves, however, appear to offer additional benefits that may offset the

price difference. At ORD, on asphalt pavement, it was apparent that the trapezoidal-shaped grooves resisted rubber contamination, resisted damage from aircraft and maintenance activity, and resisted the disfiguration, collapse, and closure experience by the standard grooves. Friction values for the trapezoidal-shaped grooves were found to be comparable to the values associated with the standard grooves.

CONCLUSIONS

Based on the data collected during this long-term research effort, the following conclusions were made:

- The construction methods, resources, and requirements to properly install the trapezoidal-shaped groove configuration were found to be very comparable to those of the Federal Aviation Administration (FAA) standard groove. The same equipment, amount of manpower, water, and resources were needed for both installations. The price of installation for the trapezoidal-shaped groove was found to be 15% to 25% higher than the price for the standard groove, although it is expected that the price will come down with large-scale production of the new blades.

- The trapezoidal-shaped grooves were found to perform satisfactorily under heavy loading. Extensive testing at the FAA National Airport Pavement Test Facility showed that after 10,362 passes under a wheel load of 75,000 pounds, the trapezoidal-shaped grooves still maintained a recognizable shape, unlike the standard grooves, which showed serious disfiguring and closure.

- The trapezoidal-shaped grooves were found to offer improved water dispersion capability, integrity, and longevity compared to the standard grooves. The friction values collected on the trapezoidal-shaped grooves was comparable to those collected on the standard grooves. Braking coefficient data collected on a dynamic test track at speeds of 70, 110, 130, and 150 knots indicate that the increased spacing used in the trapezoidal-shaped groove configuration showed a slight decrease in the braking coefficient. Researchers believe that the 50% increase in the cross-sectional width of the trapezoidal-shaped groove may, however, allow for more rapid water displacement and result in braking coefficient values more comparable to that of the standard grooves. Additional data may be necessary to validate.

- The trapezoidal-shaped grooves offered advantages over the standard grooves in the areas of resistance to rubber contamination, integrity under heavy loads, resistance to chipping and closing, and water dissipation.

- The trapezoidal-shaped grooves dimensions should be held to similar inspection and acceptance tolerances that are in place for standard grooves. The depth of the groove should be 1/4 in., ±1/16 in., the width of the top of the groove should be 1/2 in., ±1/16 in.,

- the width of the bottom of the groove should be 1/4 in., ±1/16 in., and the spacing between groove centers should be 2 1/4 in., +0/-1/8 in.

- Analysis of all data collected in this research effort indicates that the trapezoidal-shaped grooves should be considered an acceptable option for pavement grooving on airports.

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