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RUNWAY GROOVING FOR INCREASING TIRE TRACTION - THE CURRENT PROGRAM AND AN ASSESSMENT OF AVAILABLE RESULTS

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INTRODUCTION

It has become increasingly evident in recent years that the safe operation of high-speed aircraft requires substantial improvements in tire traction. The rapid shift from smaller propeller-driven air transports to larger high-performance jet transports has substantially increased the problem of keeping the aircraft within the confines of the runway when landing under adverse weather conditions. It is highly significant too that the cost and passenger loading of the new aircraft are high and the relative burden of an accident or incident is rapidly increasing.

Current aircraft operational experience indicates that aircraft braking systems, tire-tread designs, and runway surface materials now in use are unable to cope individually or collectively with runway wetness or flooding conditions frequently encountered. Analysis of the incidents of tire hydroplaning and skidding indicates that increasing runway lengths would be beneficial; however, it is noted that more departures occur off the side of the runway than off the end. Hence, increasing the lengths of runways or the erection of arresting barriers will not solve the problem.

Considerable research has been conducted during the past several years in the United States and in Great Britian to find useful and efficient ways to alleviate the problem and a good summary of the results obtained is presented in references 1 and 2. Methods explored include new tire designs, changes in tire-tread patterns, a variety of pavement textures, air jets to remove water ahead of the tire tread, and pavement grooving. Although there are beneficial aspects of all of these approaches, early quantitative and qualitative results from pavement grooving studies in Great Britain (ref. 3) and at the Landing Loads Track at NASA Langley Research Center (refs. 1 and 2) show that grooving is perhaps the most effective means for alleviating all known phenomena which result in low tire-ground friction and associated traction losses.

Because of the critical nature of the problem and the encouraging results from early pavement grooving studies, substantial programs are now underway to fully assess the merits and limitations of grooving. These programs include: research at the NASA Langley Research Center and at the Landing Research Runway at the NASA Wallops Station; and runway grooving programs supported and coordinated by the Federal Aviation Administration, the Air Transport Association, and the U.S. Air Force.

The reader will observe that the results presented are initial findings and subject to revision as additional data become available from the programs now in progress. He will also recognize that the pavement grooving programs and results presented represent the cooperative efforts of both governmental and industrial agencies to achieve solutions to a pressing problem. The authors are indebted to numerous individuals who have contributed to the information presented in this paper, and it is hoped that their objective of achieving improved safety of aircraft will be enhanced by this early release of available results.

NASA PAVEMENT GROOVING PROGRAMS

Landing Loads Track

Optimum groove arrangement for tire traction study.- One of the first objectives of the research program at the NASA Langley Landing Loads Track was to determine the relative merits of various groove configurations before their installation on operable runways. Eighteen different transverse groove patterns were installed in the 2-foot-wide by 10-foot-long runway sections of the Landing Loads Track and tested under damp and flooded conditions over a speed range of 4 to 100 knots. The runway sections are shown in figure 1. Three groove spacings were used: 1 inch, $1\frac{1}{2}$ inches, and 2 inches. Groove widths were 1/8 inch, 1/4 inch, and 3/8 inch. Two grooved depths were studied: 1/8 inch and 1/4 inch. The nine 1/8-inch-deep groove patterns studied were cut by the flailing method, while the nine 1/4-inch-deep groove patterns were cut using the diamond-saw technique. Three different size aircraft tires were used in the evaluation which consisted of making both yawed rolling (4°) and braking runs over the test grooves. The groove arrangement that provided the greatest increase in traction in this study was the 1/4-inch-wide by 1/4-inch-deep groove on 1-inch pitch. However, all groove arrangements studied improved the cornering and braking performance of the test tires relative to the ungrooved test slabs. Preliminary results obtained from this study indicate:

(a) No increase in tire rolling resistance on a grooved runway over an ungrooved runway.

(b) No increase in tire damage under yawed rolling conditions on a grooved runway as compared with an ungrooved runway.

(c) No tire damage occurs to tires during braking on grooved runways up to and well beyond peak braking.

On wet or flooded runways, if the tire is allowed to skid in the 0.7 to 1.0 (wheel locked) slip ratio range, tire cutting (chevron-type cuts) can occur. (See fig. 2.) This type of tire cutting is not likely on properly operating antiskid-equipped aircraft braking systems, since the friction coefficients obtained on the grooved runways are so high and locked wheel skids should not occur. As shown in figure 3, the 49×17 size smooth-tread aircraft tire used in this study developed skidding coefficients of about 0.5 on the damp and 0.4 on the flooded 1-inch pitch, 1/4-inch-wide, 1/4-inch-deep runway grooves at a ground speed of 100 knots. This tire developed a skidding coefficient of only 0.04 on an ungrooved concrete runway under similar wetness and speed conditions. Thus, since the friction coefficients are so high, one would expect that tire damage similar to that which occurs on dry runways would occur if the antiskid systems permit the wheels to lock up during heavy braking on wet grooved runways. However, experience to date shows that when wheels lock up on wet grooved pavements, the tire damage is substantially less than is encountered when the wheels are locked up on dry pavements, even though the friction coefficients developed are approximately the same. This result may be observed by comparing figures 2 and 4. However, the information available is not adequate to fully assess the effects of runway grooving on tire wear, and additional studies are now being planned to resolve this question.

Freeze-thaw cycle tests on selected concrete groove patterns.- A second objective of the early studies at the Landing Loads Track was to determine the effect of freeze-thaw cycles on the wear and braking performance of selected groove patterns in concrete test slabs. Rectangular grooves 1/8 inch wide by 1/8 inch deep, and 1/4 inch wide by 1/8 inch deep on 1-inch pitch were cut transversely (by flailing method) on concrete test slabs 10 feet long and 2 feet wide. The test slabs were installed in the track ice runway section. (See fig. 1.) The test procedure was to flood the test sections in the afternoon, freeze overnight, and run braking tests in the morning under ice-covered and water-flooded conditions at a speed of 4 knots, using an aircraft tire. After 22 freeze-thaw cycles, no decrease in friction from initial values was observed, nor was any deterioration of the grooved slabs detectable. Minimum brine temperatures measured during the tests were approximately 15° Fahrenheit.

Landing Research Runway at Wallops Station

Study of aircraft take-off and landing performance on grooved runways.- Runway 4/22 at Wallops Station is presently being modified to the configuration shown in figure 5 to provide level test areas consistent with research requirements. An enlarged view of the test areas is shown in figure 6. The grooves installed in this runway were cut using the diamond-saw technique and are 1/4 inch wide by 1/4 inch deep on 1-inch pitch. This groove arrangement was selected because the results of the groove study conducted at the Landing Loads Track showed that it provided the best traction of the various configurations studied. Construction of the runway is complete and the first airplane is now being instrumented for flight tests.

(a) The basic objectives of the program at the Landing Research Runway are as follows:

1. To determine the effectiveness of pavement grooving in increasing aircraft take-off and landing performance on dry, wet, water-flooded, and slush-covered runways having different surface textures.

2. To determine whether undesirable vibrations are introduced into aircraft by pavement grooving, and if so, to determine their frequency, amplitude, and effect on the aircraft.

3. To obtain additional data on the effects of aircraft loading and climatic conditions on grooved runway life on both asphalt and concrete surfaces.

(b) Airborne and ground instrumentation will be installed on the aircraft and runway to insure quantitative measurements of aircraft performance. This instrumentation includes: high-frequency vibration pickups; low-frequency vertical, longitudinal, and lateral accelerations of the aircraft c.g.; aircraft pitch and yaw attitude; air pressure in oleo strut (vertical load); wheel brake pressure; wheel angular velocity; nosewheel steering angle; rudder position; aircraft ground speed, engine speed, and airspeed; air temperature; direction and velocity of wind; and measurements of runway wetness conditions. Extensive photographic coverage using movie and still cameras is planned to record aircraft and landing-gear wheel behavior during tests.

(c) Plans are now being implemented to test various types of military, commercial, and private aircraft to assure realistic coverage of significant variables in the evaluation of the effects of runway grooving on aircraft performance.

Correlation of aircraft and ground vehicle friction data.- A comprehensive program has been organized to obtain friction data on the four grooved and five ungrooved pavement surfaces at the Landing Research Runway under dry, damp, water-flooded, and slush-covered conditions with the use of various ground vehicles. This is a cooperative program between NASA and the British Ministry of Aviation. The British plan to test various friction-measuring devices currently used in England. These include a high-speed skid trailer (over 100 mph), the Juggernaut (a heavy vehicle equipped with a test aircraft tire, antiskid braking system, and capable of speeds up to 60 mph), a side-force-measuring machine, and devices to measure pavement texture. NASA plans to use its tire research truck, capable of measuring both side-force and braking friction coefficients, and an antiskid-equipped car. The FAA has been invited to participate in the study using its Swedish braking trailer and JITCO braking vehicle. Other agencies employing skid trailers or other friction-measuring means, such as the Air Force decelerometer based runway condition rating (RCR) technique, will also be invited to participate. The purpose of this correlation study is to determine whether runway friction levels, as measured by ground vehicles, can be used to adequately predict aircraft braking performance under the various pavement wetness conditions of the study.

FAA PAVEMENT GROOVING PROGRAMS

Washington National Airport

Except for touchdown zone lights and surfaces over wiring, the instrument runway (18/36) at Washington National Airport, which is 6800 feet long, 150 feet wide, and of asphalt construction, was completely grooved in April 1967. It took 35 days, working between 11 p.m. and 7 a.m., 7 days a week, using seven power-driven diamond-saw machines. Each machine cut 13 grooves at a speed of 10 to 20 feet per minute. Approximately 200 feet of runway length was grooved per day. The cost of grooving was approximately $0.09 per square foot. The transverse groove pattern used was 1/8 inch wide and 1/8 inch deep on 1-inch pitch. These and similar data for other civil airports grooved and discussed in subsequent sections are summarized in figure 7.

This runway was grooved to enhance aircraft stopping performance on wet runways. Up to December 1, 1967, about 80,000 take-offs and landings were performed on this runway and no deterioration of the grooves was experienced. Pilot reports on the effectiveness of grooving, while meager at this time, indicate an improvement in aircraft performance during landings under wet runway conditions since the runway was grooved.

Environmental Effects on Pavement Grooving

Eighteen different rectangular groove patterns have been installed on concrete and asphalt taxiways at Cleveland, Salt Lake City, Las Vegas, Miami, and New York City (JFK) airports. These groove patterns are similar to the groove patterns selected for study at the NASA Landing Loads Track during its pavement groove traction study. The groove patterns used were as follows:

2" spacing: 3/8" wide, 1/4" wide, 1/8" wide; 1/8" deep, 1/4" deep

1-1/2" spacing: 3/8" wide, 1/4" wide, 1/8" wide; 1/8" deep, 1/4" deep

1" spacing: 3/8" wide, 1/4" wide, 1/8" wide; 1/8" deep, 1/4" deep

The purpose of this study is to determine the effects of water, snow, ice, snow-removal equipment, chemical deicing agents, high ambient temperatures, and aircraft traffic loads on pavement groove life. Although the test grooves have been installed for only about 6 months, some results have been obtained. Except for the 1-inch- by 1/8-inch- by 1/8-inch-groove configuration, the main wheel track portions of the groove patterns installed in the asphalt taxiways at Las Vegas, Salt Lake City, and Miami Airports were distorted by tire loads and the effects of summer high daily temperatures which ranged from 90° Fahrenheit to 120° Fahrenheit for extensive periods. This trend has also been observed on the test groove patterns installed on Miami and Salt Lake City asphalt taxiways. Such failures have not been detected on the grooved asphalt runways at Washington National Airport. In general, the test groove patterns installed on taxiways of the airports under study appear to be holding up well. Some observations made also indicate that the wider grooves (1/4 to 3/8 inch) 1/4 inch deep can trap stones on the runway, which may indicate a housekeeping problem for airports without grass borders.

AIR TRANSPORT ASSOCIATION PAVEMENT GROOVING PROGRAMS

The Air Transport Association, in an attempt to further aircraft safety and to obtain operational experience with transport-type aircraft on grooved runways, has sponsored grooving selected runways at two commercial airports in the United States. The major costs of grooving have been provided to the airport authorities by the Air Transport Association member airlines using these airports.

Kansas City Municipal Airport

The instrument runway, 18/36, at Kansas City was grooved over 130 feet of its 150-foot width and over 4500 feet of its 7000-foot length in May 1967. The transverse groove pattern selected, 1/8-inch-wide by 1/4-inch-deep rectangular grooves on 1-inch centers, was cut in the runway by means of powered gang-type diamond saws. Both asphalt and concrete sections of the runway were grooved. The cost of grooving was approximately $0.14 per square foot. As of December 1, 1967, more than 80,000 take-offs and landings occurred since the runway was grooved and pavement deterioration attributable to grooving had not been significant. The airport management is quite pleased with the performance of the grooved runway at this point in time. Apparently, grooving this runway has considerably increased water drainage from the runway during times of precipitation, an effect which is noticeable when approaching the runway from the air. The ungrooved portions are reflective due to water retention, whereas the grooved portions are dull in appearance because of the lack of water ponding. From the ground, the difference between grooved and ungrooved portions is equally striking. Considerable water spray can be seen coming from the aircraft wheels on the ungrooved runway sections as contrasted to practically no spray on the grooved portion of the runway. The implications of this result to the aircraft engine spray ingestion problem and to the occurrence of dynamic hydroplaning are obvious; the severity of both these problems on the grooved runway is evidently reduced because of the decreased amount of water present. Another significant result of pavement grooving has been noted at Kansas City. Before grooving, a considerable number of aircraft diverted from landing at Kansas City during times of precipitation as pilots sought alternate airports with longer runways or better landing conditions. Since grooving, the tendency of aircraft to divert from landing at Kansas City in times of precipitation has been greatly reduced which indicates that grooving has improved aircraft landing performance on this runway.

John F. Kennedy International Airport

The main instrument runway at John F. Kennedy International Airport, runway 4R/22L (concrete), was grooved from end to end and side to side in early August 1967. The transverse groove pattern selected was 3/8-inch-wide by 1/8-inch-deep grooves on $1\frac{3}{8}$-inch pitch. The grooves were not rectangular in cross section, but had 45° sloping sides with the width of the grooves 3/8 inch at the top. The bottom of the grooves was 5/32 inch and rounded. The cost of grooving was approximately $0.13 per square foot. Approximately 15,000 landings were made on this grooved runway prior to December 1, 1967, and airport authorities have indicated that grooving has improved water drainage from the runway during times of precipitation. They also report a decrease in water spray levels during aircraft passage on the wet runway, as was noted at Kansas City. Tower observations indicate that before the runway was grooved most jet aircraft used to exit the runway after landing from the end taxiway during times of precipitation. After grooving, most jet aircraft now use the high-speed taxiways located further up the runway. This qualitative result appears to indicate that aircraft wet-landing performance has been improved by the grooving process.

In September 1966, test grooves were installed in the touchdown area of runway 13L at John F. Kennedy International Airport. Observations in October 1967, 13 months later, showed that the grooves appeared to be holding up well. While the lands between the grooves have been coated with molten rubber from dry touchdown skids from the aircraft tires, the grooves themselves have been left free and clear of rubber deposits. It should also be noted that these test grooves had withstood the climatic effects of one winter season at John F. Kennedy International Airport without any detrimental effect.

Pilot Questionnaire

The Air Transport Association, in the months of August and September of 1967, initiated a pilot-operational evaluation program to determine the effects of runway grooving on aircraft landing performance during wet conditions. Questionnaires were filled out by pilots immediately following a wet runway landing on any of the three presently grooved runways. Pilots were asked to indicate degree of precipitation, the amount of standing water on runway, crosswind component, aircraft touchdown speed, and the number of times the pilot had landed on this runway, both before and after grooving. The pilot was then asked to comment on the degree of improved lateral controllability and the number of feet of decreased stopping distance associated with grooving the runway. While returns from this questionnaire are not complete, early reports indicate that in all cases lateral controllability was significantly improved and that stopping distance was decreased by at least 1000 feet on these wet runways after being grooved. Pilots also indicated a strong desire to have all instrument runways grooved at the earliest possible date.

AIR FORCE PAVEMENT GROOVING PROGRAMS

In August 1966, two highly used Air Force concrete runways were grooved in an attempt to improve the landing performance of aircraft using these bases during wet operations. The transverse groove pattern selected was 1/4-inch-wide by 1/4-inch-deep rectangular grooves on 2-inch centers. Only the center 37-foot width of the runways was grooved and the grooving was not continuous, i.e., along the runway length, 26 inches of the runway was grooved, then a distance of 26 inches was ungrooved, etc. Results obtained thus far indicated that water drainage from the runways during times of precipitation has been greatly improved, and that aircraft skidding incidents during wet operations have been significantly reduced. The only wet skidding accident to occur on either of these runways since grooving occurred recently in a rainstorm. The aircraft touched down to the right of runway center line, and thus missed the grooved portion of the runway, which was only 37 feet wide. The pilot reported no braking action and no nosewheel steering action and the airplane departed the runway off the right side 2000 feet after touchdown. This result indicates the need to groove the entire width of the runway, and in fact, this was one of the major recommendations made by the accident board held to investigate the accident. Another Air Force concrete runway is currently being grooved. The groove pattern selected is 1/4-inch-wide by 1/4-inch-deep rectangular grooves on 1-inch centers.

GENERAL OBSERVATIONS

The operators of airports having grooved runways have been questioned regarding receipt of complaints from aircraft operators concerning either excessive tire-tread wear or new aircraft maintenance problems since their runways were grooved. The reply in every case has been - no complaints. One airline has commented that an increase in chevron-type cuts on the tires of its aircraft fleet has been noted coincident with the start of operations on grooved runways. Since approximately 90 percent of the airline tire dollar goes for recapped tires, a major aircraft tire recapping company was contacted regarding the frequency of occurrence of chevron-type cuts on tires received for recapping. The results reported are that approximately 1 percent of the tires received for recapping have this type of cut. None of the tires received were removed because of the chevron cuts, but were removed because of other considerations such as tread wear or foreign object damage. Tire recapping experts say that chevron-type cuts have occurred on tires for years (long before the time of grooved runways) and was attributed to brake chatter.

On runways grooved by the diamond-saw technique, complaints have been received from pilots regarding the dust clouds thrown up by aircraft tire passage over the grooved runway while the runway was being grooved. This was especially noted at runway intersections. This appears to be a finishing problem and should not occur if the fine slurry formed by the grooving process is water flushed from the runway at the time of grooving. Removing the slurry has been found to be quite difficult especially if low water pressures are used and time delays occur between the grooving operation and the flushing or cleaning operation.

In summary, the results obtained from limited operational use of grooved runways, though subject to reevaluation and change as more data becomes available, are very encouraging. These results show that tire braking and cornering performances are substantially improved under wet conditions. Test results from the NASA Landing Research Runway program at Wallops Station are needed to properly assess the quantitative improvements in aircraft performance during operations on grooved runways. Results obtained during the current winter season are expected to provide a further evaluation of possible deterioration of grooved surfaces as a result of weathering and should also furnish information on grooved runway performance under snow and ice conditions.

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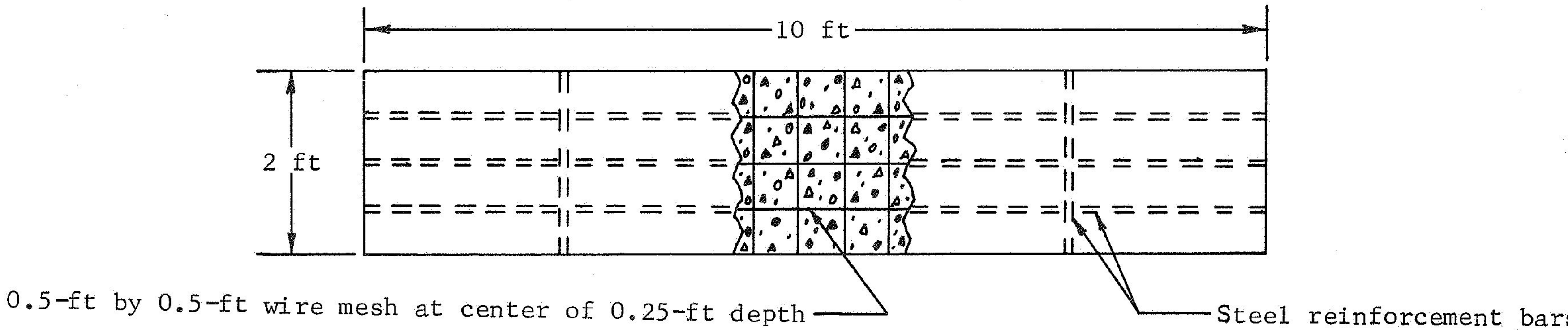
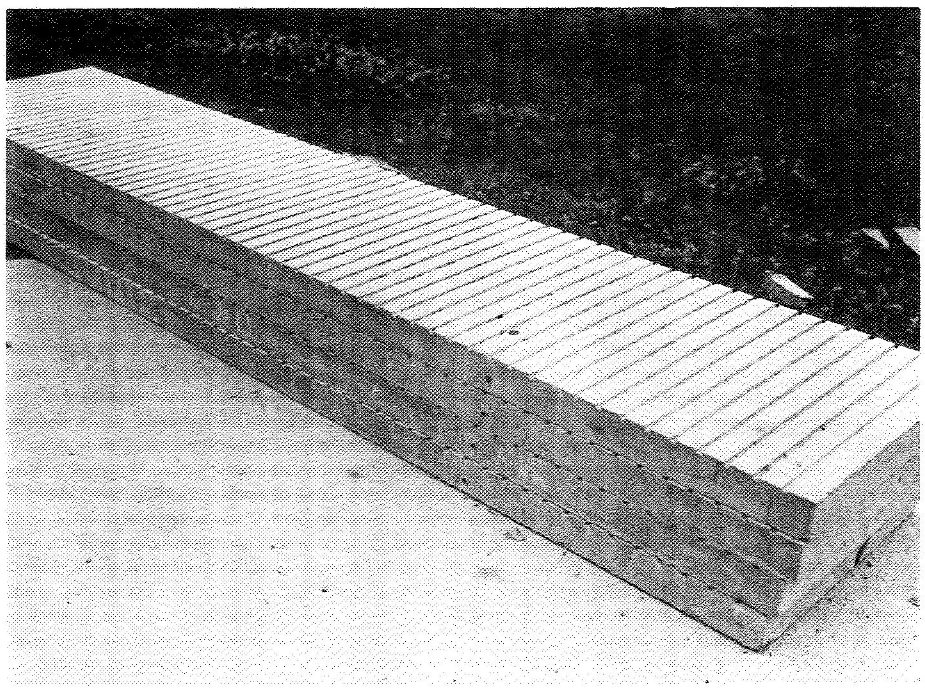
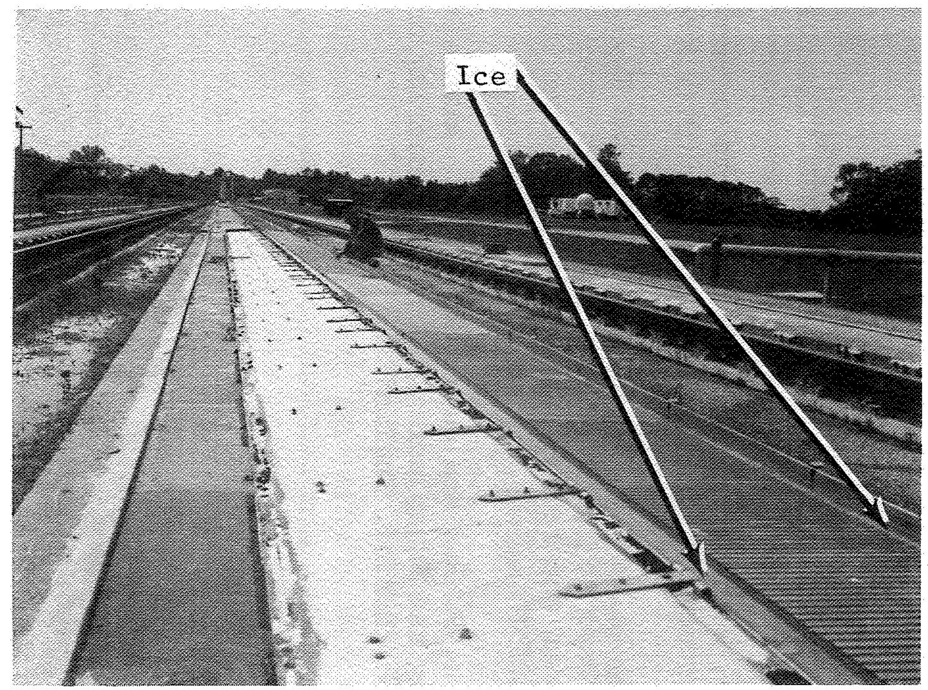
3. Martin, F. R.; and Judge, R. F. A.: Airfield Pavements - Problems of Skidding and Aquaplaning. Civil Engineering and Public Works Review, December 1966, London, England.



(a) Topside plan drawing of precast concrete test strips.



(b) Grooved concrete strips before testing.



(c) Concrete strips installed in runway.

Figure 1.- Grooved runway sections at the Landing Loads Track.

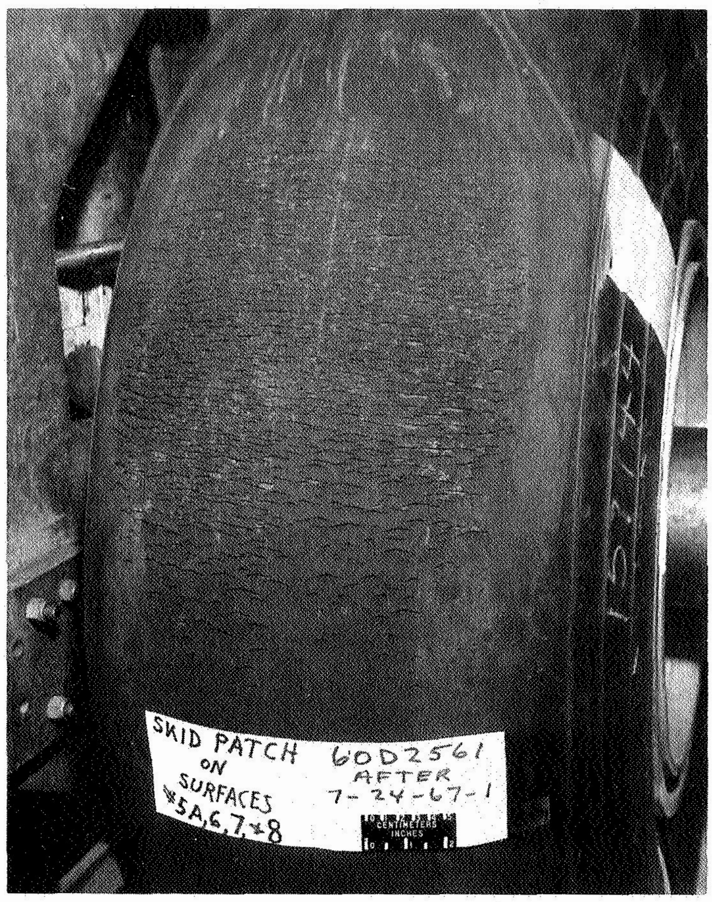


Figure 2.- Chevron type tire cuts encountered during skidding on a flooded runway. (Tire pressure = 170 psi; vertical load = 30,000 lb; skid length ≈ 120 ft.)

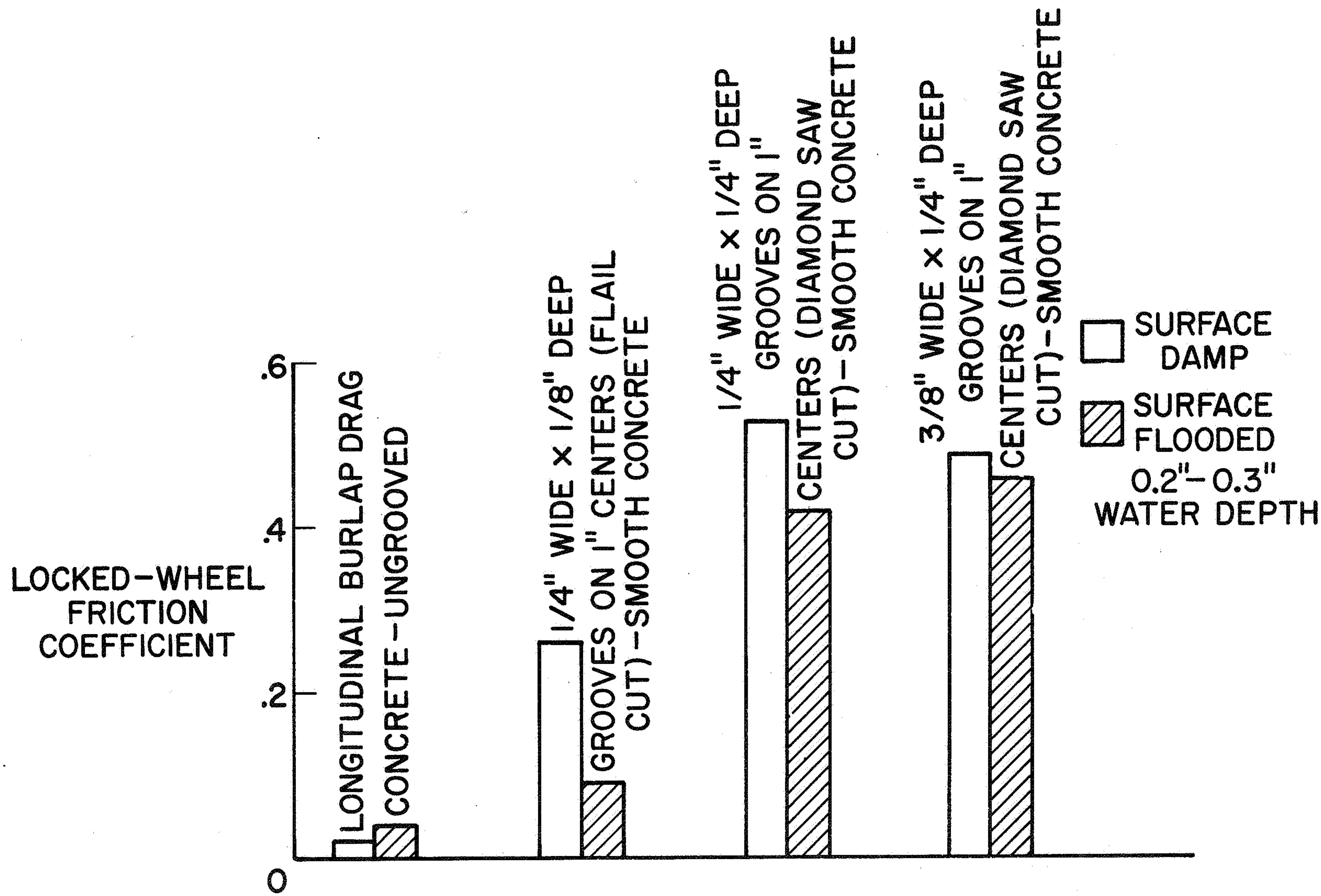


Figure 3.- Effect of pavement grooving on braking performance of smooth tread jet transport aircraft tire. (Tire pressure = 170 psi; vertical load = 30,000 lb; ground speed = 100 knots.)

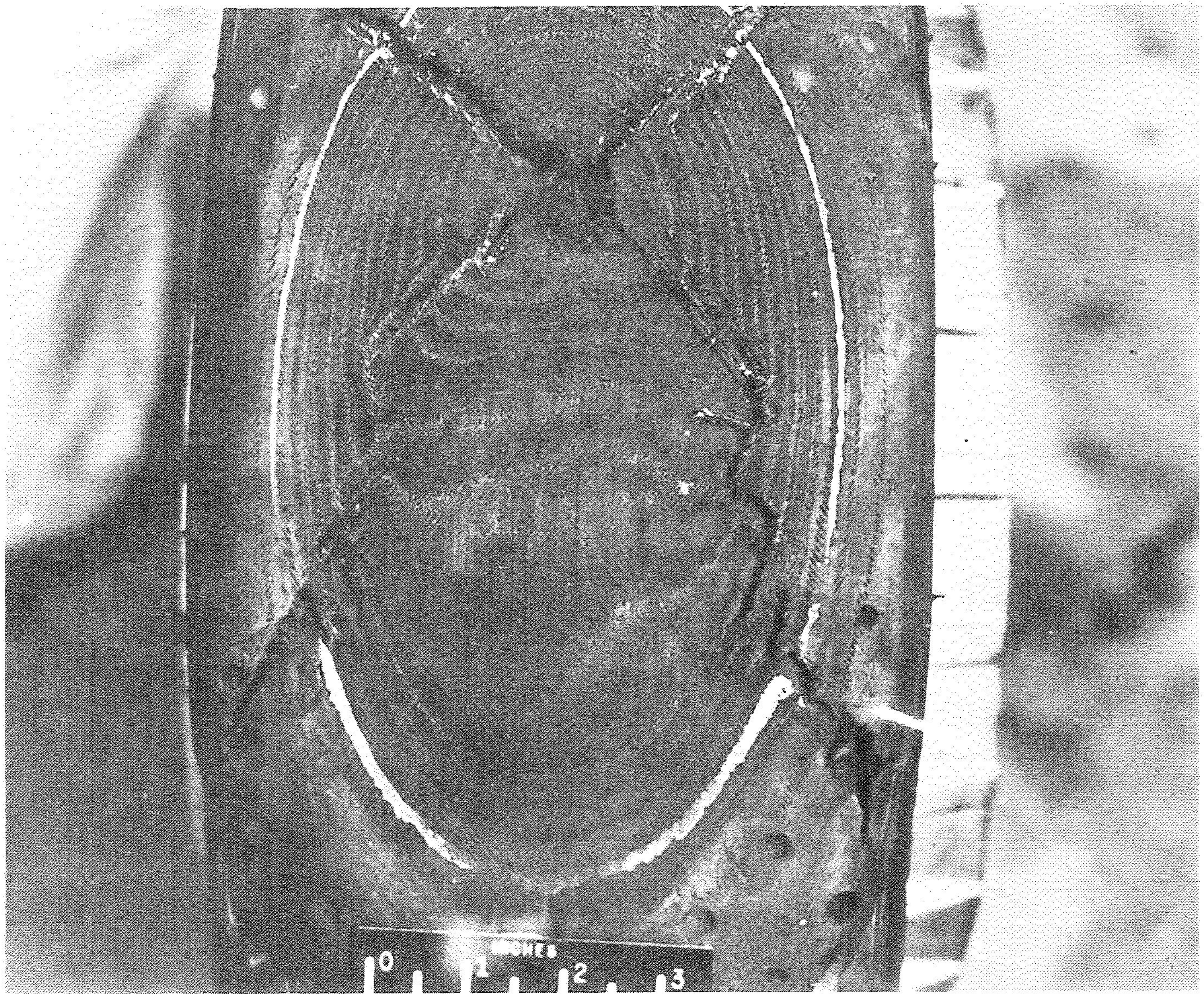


Figure 4.- 32 × 8.8 aircraft tire blowout after skidding 60 ft on dry concrete from a touch down speed of 100 knots.

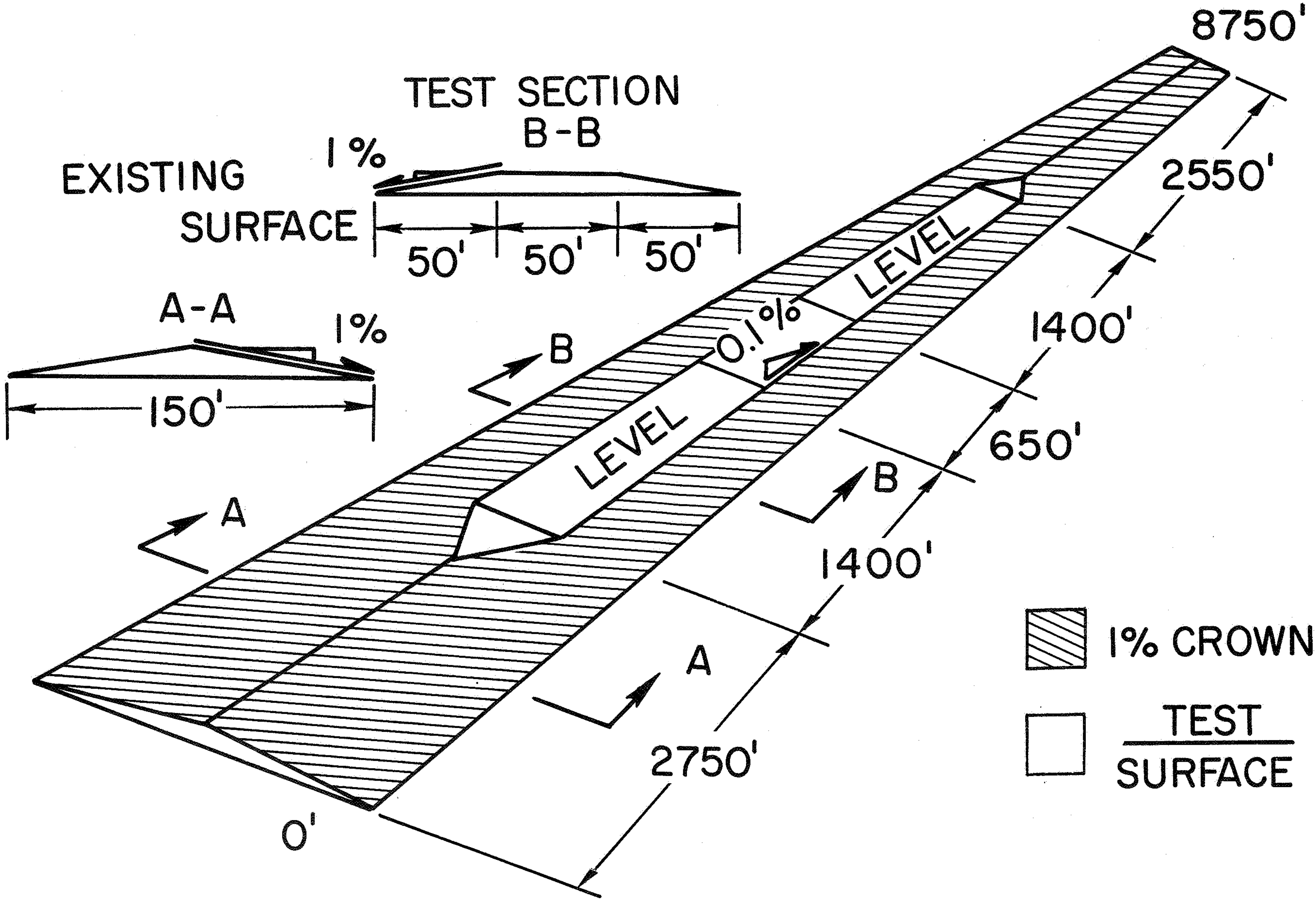


Figure 5.- Landing Research Runway at NASA Wallops Station (Runway 4-22).

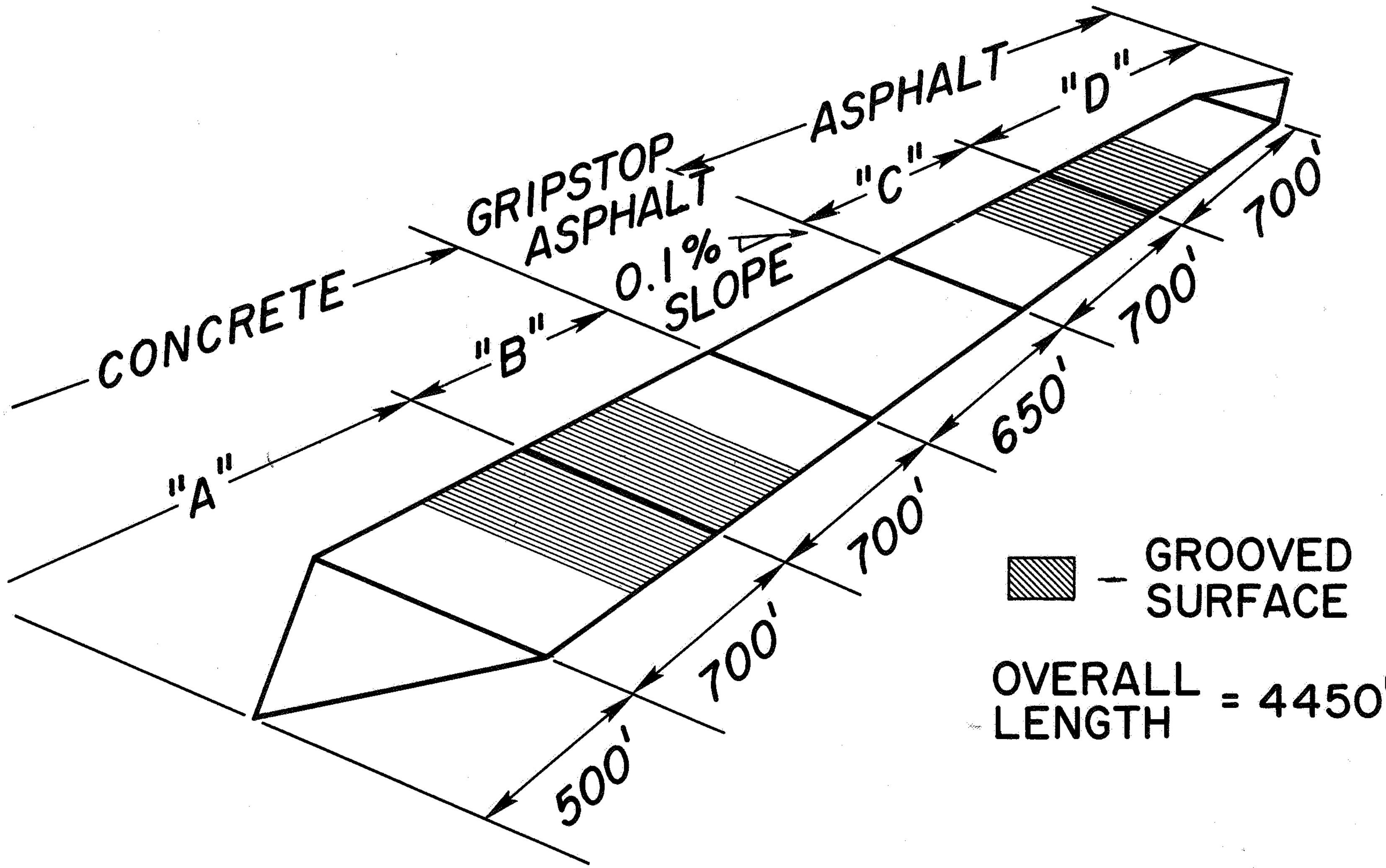


Figure 6.- Features of test section of Landing Research Runway at NASA Wallops Station.

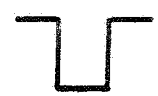
AIRPORT	JFK	KC	WNA
COST/ft^2	0.13	0.14	0.09
MATERIAL	CONCRETE	CONCRETE AND ASPHALT	ASPHALT
DAILY GROOVING TIME	6 a.m. - 3 p.m.	12 p.m. - 7 a.m.	12 p.m. - 7 a.m.
RUNWAY USE DURING GROOVING OPERATIONS	CLOSED	15 min. OPEN 15 min. CLOSED	CLOSED
GROOVE PATTERN			
WIDTH	3/8 inch	1/8 inch	1/8 inch
DEPTH	1/8 inch	1/4 inch	1/8 inch
PITCH	1-3/8 in.	1 inch	1 inch
SHAPE			
COMPLETION DATE	AUG 1967	MAY 1967	APRIL 1967

Figure 7.- Transverse-grooved runways in the U.S.A.