Runway Grooving and Surface Friction

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ALACPA X
Mexico City
September 30 to October 4, 2013
Problem: The Water Covered Runway

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Problem: The Water Covered Runway
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Runway Grooving

- **Misconceptions** Have Developed Relative to Its Purpose During Its More Than 40 Years of Application.
Runway Grooving

- Prudent to Stress Reasons for Which It Is Not Used
Runway Grooving

- Not Used to Provide Drainage of Water from the Pavement Surface
Drainage

- Provided by the **Transverse Slope** of the Pavement Surface
- **Grooves** Are Cut in the Runway Surface Transversely to the Pavement Centerline and Make a **Secondary** Contribution to Drainage.
- **Grooves** Do **Reduce** the Level of **Standing Water** as the Pavement Floods or Drains.
Runway Grooving

- **Not Used to Provide an Increase in the Friction Capability of the Pavement Surface**
Friction

- Friction Capability of the Pavement Surface Provided by the Quality of the Microtexture - Macrotexture Combination

Friction Provides the Skid Resistance
Skid Resistance by Other Names

- Friction
- Friction Coefficient
- Braking Coefficient
Mechanism of Friction

Courtesy of Dr. Satish K. Agrawal of the FAA Technical Center
Runway Grooving

- Provides Forced Water Escape from the Pavement Surface under Aircraft Tires Traveling at High Speed
Runway Grooving

- Does Not Eliminate Hydroplaning
- Reduces Hydroplaning to a Manageable Level
- A Higher Degree of Contact is Maintained Between Aircraft Tires and the Pavement Surface under the Condition of Standing Water.
Runway Grooving

- Enables Pavement Surface Microtexture - Macrotexture Combination to Provide Sufficient Braking and Directional Control to Aircraft
- Effectiveness Increases from Slight to Significant as Speed of Aircraft or Water Depth on Pavement is Reduced
Runway Grooving
Runway Grooving

- Reduces Dynamic Hydroplaning (Standing Water)

- Reduces Viscous Hydroplaning (Wet Pavement with Little to No Standing Water)
Functions of Runway Surface Characteristics in the Presence of Water

- Transverse Slope Provides Drainage.
- Texture of Pavement Provides Friction.
- Grooving Enables Aircraft Tires to Contact the Pavement.
Runway Grooving

- In the Presence of Water, Totally Worn Aircraft Tires Experience Better Braking on a Grooved Pavement than Newly Treaded Tires on a Nongrooved Pavement.
Porous Friction Course
Substitutes for Runway Grooving

- Provides **Drainage** of Water from the Pavement Surface (Primary)
- Provides **Forced Water Escape** from the Pavement Surface under Aircraft Tires Traveling at High Speed Similar to Grooving (Secondary)
- Application Limited Relative to Density of Aircraft Operations
Not Substitutes for Runway Grooving

- Tire Tread
  (Demonstrated in Full Scale Tests)

- Coarse Pavement Surface Macrotexture
  (Demonstrated to a Limited Degree in Full Scale Tests)
Grooving vs. Macrotexture

- **Grooving** Lies Below the Pavement Surface. Flexibility of Tire Cannot Seal the Path of Water Escape.

- **Macrotexture** Is the Pavement Surface. Flexibility of Tire Can Seal the Path of Water Escape.
Grooving vs. Macrotexture

- Macrotexture is a component of the pavement surface friction.

- Inferences drawn from limited available data indicate that the effectiveness of macrotexture in providing rapid water evacuation from beneath aircraft tires is questionable.
Grooving vs. Macrotexture

- Term “Surface Cavity” is Introduced in Order to Make the Comparison.
- Surface Cavity is Produced by Grooving or Macrotexture.
- Inferences Drawn from Limited Available Data Indicate that, for Comparable Surface Cavity, Grooving Is More Effective than Macrotexture in Reducing Hydroplaning.
Grooving vs. Macrotexture
FAA Full Scale Test Program
Braking/Hydroplaning

- 1975 to 1983
- 600 Full Scale Tests
- Dynamic Test Track
- Asphalt and Portland Cement Concrete
- Variety of Pavement Surface Treatments
- Wet to Flooded Conditions
- Speeds of 30 to 150 Knots
FAA Full Scale Test Program
Braking/Hydroplaning

- Aircraft Tire, 49 by 17, 26 ply, type VII (Boeing 727 and 747)
- Tire Pressure, 140 psi
- Wheel Load, 35,000 lbs
- Maximum Braking Data Base
- Test Facility, NAEC (Navy), Lakehurst, New Jersey
FAA Full Scale Test Program
Braking/Hydroplaning
Water Depth Conditions on Pavement

- Wet 0.00 in. Standing Water
- Puddled 0.10 in. Standing Water
  2.54 mm
- Flooded 0.25 in. Standing Water
  6.35 mm
Launch End of Test Track
Launch End of Test Track
Dynamometer with Tire-Wheel Assembly
New and Worn Tire Tread
Saw Cutting Grooves in the Test Pavement
Test Pavement at the Recovery End of the Test Track
1/4 x 1/4 in. Grooves Spaced at 1 1/4, 2, and 3 ins.
1/8 x 1/8 in. Grooves Spaced at 1/2 in. and Porous Friction Course
Experimental Percussive Grooves at 3 in. Spacing
Grooved Pavement

- FAA Standard 1/4 x 1/4 Saw-Cut Grooves Spaced at 1½ inches
- Represented by Curve Fits between Data Points for 1¼ inch and 2 inch Spacing
- FAA Standard in Metric: 6mm x 6 mm Grooves Spaced at 38 mm
Braking on a Wet Asphalt Pavement

- Worn Tire, Grooved Pavement
- New Tire, Non-Grooved Pavement
- Worn Tire, Non-Grooved Pavement
- Hydroplaning
Braking on a Puddled Asphalt Pavement

![Graph showing braking coefficient vs. speed for different tire and pavement conditions.](image-url)
Braking on Flooded Asphalt Pavement

![Graph showing braking coefficient vs. speed for different tire and pavement conditions.](image)
Braking on a Wet Asphalt Pavement

- Worn Tire, Grooved Pavement
- Worn Tire, Porous Friction Course
- Hydroplaning

Braking Coefficient vs. Speed (knots)
Braking on an Asphalt Pavement Under a Heavy Downpour

![Graph showing braking coefficient vs speed for different conditions.]

- Worn Tire, Grooved Pavement, Puddled
- Worn Tire, Porous Friction Course, Wet
- Hydroplaning

Braking Coefficient

Speed (knots)
Braking on an Asphalt Pavement Under a Heavy Downpour (Flooded)
Essentials of an Aircraft Braking/Hydroplaning Test System

- Full Scale
- High Speed
- Standing Water
- Uniformity of Water Depths
- Close Control of Variables
Aircraft Braking/Hydroplaning Test System Scenarios

- Full Scale Tire-Wheel Assembly on a Dynamic Test Track (Best Control of Variables)
- Aircraft on a Runway
FAA Standard and Proposed Saw-Cut Groove Patterns

Standard

Proposed
Grooving vs. Macrotexture
Worn Tire on a Wet PCC Pavement

- 0.023 in. Surface Cavity
- Macrotexture 0.007 in.
- Groove Spacing at 4 ins.

- 0.007 in. Surface Cavity
- Macrotexture 0.007 in.
- (Broomed Finish)

- 0.021 in. Surface Cavity
- Macrotexture 0.021 in.
- (Broomed 0.007 in., Percussive Treatment 0.014 in.)

Hydroplaning

Braking Coefficient vs. Speed (knots)
Grooving vs. Macrotexture
Worn Tire on a Wet PCC Pavement

- 0.57 mm Surface Cavity, Macrotexture 0.18 mm, Groove Spacing at 102 mm
- 0.18 mm Surface Cavity, Macrotexture 0.18 mm (Broomed Finish)
- 0.53 mm Surface Cavity, Macrotexture 0.53 mm (Broomed 0.18 mm, Percussive Treatment 0.35mm)

Braking Coefficient vs. Speed (knots)
Grooving vs. Macrotexture
New Tire on a Puddled PCC Pavement

- 0.57 mm Surface Cavity
- Macrotexture 0.18 mm
- Groove Spacing at 102 mm

- 0.53 mm Surface Cavity
- Macrotexture 0.53 mm (Broomed 0.18 mm, Percussive Treatment 0.35 mm)

Hydroplaning

Braking Coefficient vs. Speed (knots)
Grooving vs. Macrotexture
New Tire on a Puddled PCC Pavement

<table>
<thead>
<tr>
<th>Speed (knots)</th>
<th>Braking Coefficient</th>
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<tbody>
<tr>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>110</td>
<td>20</td>
</tr>
<tr>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>170</td>
<td>0</td>
</tr>
</tbody>
</table>

- 0.97 mm Surface Cavity  Macrotexture 0.18 mm  Groove Spacing at 51 mm
- 0.53 mm Surface Cavity  Macrotexture 0.53 mm (Broomed 0.18 mm, Percussive Treatment 0.35 mm)
- Hydroplaning
FAA Standard Groove Pattern vs. High Macrotexture
New Tire on a Puddled PCC Pavement

- Low Macrotexture Grooved Pavement: 0.007 in. plus Standard Grooves (Surface Cavity 0.049 in., 1.24 mm)
- High Macrotexture Non-Grooved Pavement: 0.021 in. (Surface Cavity 0.021 in., 0.53 mm)

Braking Coefficient vs. Speed (knots)
Landing of a Jet Transport Aircraft on a Stone Matrix Asphalt (SMA) Runway under Rainfall Conditions
Takeoff of a Jet Transport Aircraft on a Stone Matrix Asphalt (SMA) Runway under Rainfall Conditions
Relationship between Results on the Test Track and Performance of the Aircraft on a Runway
Braking on a Wet Asphalt Pavement

- Worn Tire, Grooved Pavement (Track)
- In-Service Tires, Grooved Pavement (B727 ACY)
- Worn Tire, Non-Grooved pavement (Track)
- In-Service Tires, Non-Grooved Pavement (B727 ACY)
Braking on a Wet Asphalt Pavement

- Worn Tire, Grooved Pavement 1 1/2 in. Spacing (Track)
- In-Service Tires, Grooved Pavement 1 1/2 in. Spacing (B727 ACY)
- Worn Tire, Grooved Pavement 3 in. Spacing (Track)
- In-Service Tires, Grooved Pavement 3 in. Spacing (B727 ACY)
Braking on Wet Porous Friction Course

![Graph showing braking coefficient versus ground speed for worn tires, in-service tires, and hydroplaning.](image)

- **Effective Braking Coefficient (B727)**
- **Ground Speed (knots)**
- **Braking Coefficient (Track)**

- **Worn Tire (Track)**
- **In-Service Tires (B727 - Pease AFB)**
- **Hydroplaning**

The graph illustrates the braking coefficient as a function of ground speed for different tire conditions.
Grooving vs. Macrotexture
Braking on Wet Asphalt Pavements

Braking Coefficient (Track) vs. Effective Braking Coefficient (B727)

- Worn Tire, Grooved Pavement, 3 in. Spacing, (Track), (Surface Cavity 0.035 inches, 0.88 mm)
- In-Service Tires, Grooved Pavement, 3 in. Spacing, ACY, (B727), (Surface Cavity 0.029 inches, 0.73 mm)
- In-Service Tires, Porous Friction Course (Age 11 Years), Portland Airport, Maine (B727), (High Surface Cavity from Macrotexture)
Grooving vs. Macrotexture Wet PCC Pavements

- New Tire, Grooved Pavement, 4 in. Spacing (Track), (Surface Cavity 0.023 inches, 0.57 mm)
- In-Service Tires, B737, Langley Airforce Base, (Surface Cavity 0.027 inches 0.69 mm)
- Hydroplaning
Dynamic Test Track Data Can Be Used to Simulate Tire-Pavement Interaction During the Landing and Takeoff of a Jet Transport Aircraft with Worn Tires on a Runway under Rainfall Conditions.
Inference Drawn from Simulation on Asphalt Pavement

- Runway Grooving Offers the Potential to Double The Magnitude of Tire-Pavement Interaction for Jet Transport Aircraft Operating on Water Covered Runways.
Landing
Fast Touchdown at 150 Knots

![Graph showing braking coefficient vs. water depth for grooved pavement, non-grooved pavement, and hydroplaning conditions.](image-url)
Touchdown at 130 Knots

![Graph showing braking coefficient vs. water depth for grooved and non-grooved pavement, and hydroplaning.](image)
Braking at 110 Knots

![Graph showing braking coefficient vs. water depth for grooved and non-grooved pavement, and hydroplaning.](image-url)

**Axes:**
- **Y-axis:** Braking Coefficient
- **X-axis:** Water Depth (Inches)

**Legend:**
- Grooved Pavement
- Non-Grooved Pavement
- Hydroplaning

- At various water depths, the braking coefficient decreases for both grooved and non-grooved pavement.
- Hydroplaning is indicated by a dashed line at the lowest braking coefficient values.
Braking at 90 Knots

- Grooved Pavement
- Non-Grooved Pavement
- Hydroplaning

Braking Coefficient vs Water Depth (Inches)
Braking at 70 Knots, Approaching High Speed Turnoff

[Graph showing braking coefficient vs. water depth for grooved and non-grooved pavement, with a line indicating hydroplaning.]
Takeoff
Takeoff Roll at 70 Knots

- Grooved Pavement
- Non-Grooved Pavement
- Hydroplaning

Braking Coefficient vs. Water Depth (Inches)
Takeoff Roll at 90 Knots

- Grooved Pavement
- Non-Grooved Pavement
- Hydroplaning

Water Depth (Inches) vs. Braking Coefficient
Takeoff Roll at 110 Knots

- Grooved Pavement
- Non-Grooved Pavement
- Hydroplaning

Braking Coefficient vs Water Depth (Inches)
Decision Point at 130 Knots
Takeoff or Abort

<table>
<thead>
<tr>
<th>Water Depth (Inches)</th>
<th>Braking Coefficient</th>
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<tbody>
<tr>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>0.05</td>
<td>50</td>
</tr>
<tr>
<td>0.1</td>
<td>40</td>
</tr>
<tr>
<td>0.15</td>
<td>30</td>
</tr>
<tr>
<td>0.2</td>
<td>20</td>
</tr>
<tr>
<td>0.25</td>
<td>10</td>
</tr>
<tr>
<td>0.3</td>
<td>0</td>
</tr>
</tbody>
</table>

- Grooved Pavement
- Non-Grooved Pavement
- Hydroplaning
Summary
FAA Full Scale Test Program
Braking/Hydroplaning
Technical Advances Achieved

- Maximum Braking Data Base
- Asphalt as well as Portland Cement
- Porous Friction Course as well as Grooving
- Benefit of Grooving versus Tire Tread
- Uniformly Puddled Condition
- Groove Spacing up to 4 inches
- Speeds up to 150 Knots
FAA Full Scale Test Program
Braking/Hydroplaning
Products of the Effort

- Supports Current FAA Grooving Standards.
- Spacing of $\frac{1}{4} \times \frac{1}{4}$ in. Saw-Cut Grooves Extended from $1\frac{1}{4}$ ins. to $1\frac{1}{2}$ ins.
- Grooving Costs Reduced by an Estimated 7%.
- More Significant Cost Savings Possible with Slightly Greater Increases in Spacing.
Data Base Can Be Useful to Foreign Aviation Authorities in Supporting the Grooving of Runways in their Respective Countries.

Data Base Can Support the Establishment of International Guidelines for the Grooving of Runways.
FAA Full Scale Test Program
Braking/Hydroplaning

- Briefing and DOT/FAA Technical Reports Available for Download from NAPTF Website
- Google, Bing, or Yahoo
- faa naptf
- About the NAPTF
- Menu on left
- Located under “Downloads”, “Safety”
Dynamic Test Track

- Naval Air Engineering Center (NAEC)
- Lakehurst, New Jersey
- High Speed Films of Tests Follow:

Double Click Here

Runway Grooving 2.wmv
FAA Governing Documents Covering Relevant Runway Surface Characteristics

- Transverse Slope Provides Drainage.
- Texture of Pavement Provides Friction.
- Grooving Enables Aircraft Tires to Contact the Pavement.

The Following Data Are Listed in this Presentation for Purposes of Continuity.
Reference Should Be Made Directly to the FAA Advisory Circulars When Actually Performing Work at an Airport.
FAA Governing Documents for Establishing Transverse Slope

- **AC 150/5300 -13A**  
  Airport Design  
  Transverse Slope  1% to 1.5%

- **AC 150/537O -10F**  
  Standards for Specifying Construction of Airports  
  Departure from Surface Design Plane  
  P-401 Asphalt  ± 1/2 inch (13 mm)  
  P-501 Portland Cement  ± 1/4 inch (6 mm)
FAA Governing Document for Surface Texture

- AC 150/5320-12C
  Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces
Surface Texture

- **Asphalt**
  
  Hard, Angular Aggregates
  Resistant to Rounding and Polishing

- **Portland Cement**
  
  Surface Finish as Entrained with Fine Aggregate
Surface Texture Effectiveness

- **Continuous Friction Measurement Equipment (CFME)**
  - 8 Different Ones Are Listed
  - Either Self-Contained or Trailer
  - Operated at 40 and 60 Miles per Hour
  - Self-Watering to Effective Depth of 0.04 Inches (1 mm)
  - Friction Values are Recommended for New Construction and Maintenance
Example of a CFME
# Friction Survey Frequency

<table>
<thead>
<tr>
<th>Number of Daily Minimum Turbojet Aircraft Landings Per Runway End</th>
<th>Minimum Friction Survey Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 15</td>
<td>1 Year</td>
</tr>
<tr>
<td>16 to 30</td>
<td>6 Months</td>
</tr>
<tr>
<td>31 to 90</td>
<td>3 Months</td>
</tr>
<tr>
<td>91 to 150</td>
<td>1 Month</td>
</tr>
<tr>
<td>151 to 210</td>
<td>2 Weeks</td>
</tr>
<tr>
<td>Greater than 210</td>
<td>1 Week</td>
</tr>
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# Friction Level Classification

## Table 3-2. Friction Level Classification for Runway Pavement Surfaces

<table>
<thead>
<tr>
<th></th>
<th>40 mph</th>
<th>60 mph</th>
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<tbody>
<tr>
<td>Mu Meter</td>
<td>.42</td>
<td>.52</td>
</tr>
<tr>
<td>Dynatest Consulting, Inc. Runway Friction Tester</td>
<td>.50</td>
<td>.60</td>
</tr>
<tr>
<td>Airport Equipment Co. Skiddometer</td>
<td>.50</td>
<td>.60</td>
</tr>
<tr>
<td>Airport Surface Friction Tester</td>
<td>.50</td>
<td>.60</td>
</tr>
<tr>
<td>Airport Technology USA Safeguard Friction Tester</td>
<td>.50</td>
<td>.60</td>
</tr>
<tr>
<td>Findlay, Irvine, Ltd. Griptester Friction Meter</td>
<td>.43</td>
<td>.53</td>
</tr>
<tr>
<td>Tatra Friction Tester</td>
<td>.48</td>
<td>.57</td>
</tr>
<tr>
<td>Norsemeter RUNAR (operated at fixed 16% slip)</td>
<td>.45</td>
<td>.52</td>
</tr>
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</table>
Surface Texture Degradation

- Rubber Deposits
- Wear and Polish
- Weather Erosion

Corrective Measures Are Discussed.

Grease Smear Test Can Be Taken at Any Time to Determine the Surface Macrotexture.
## Rubber Deposit Removal Frequency

<table>
<thead>
<tr>
<th>NUMBER OR DAILY TURBOJET AIRCRAFT LANDING PER RUNWAY END</th>
<th>SUGGESTED RUBBER DEPOSIT REMOVAL FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>LESS THAN 15</td>
<td>2 YEARS</td>
</tr>
<tr>
<td>16 TO 30</td>
<td>1 YEAR</td>
</tr>
<tr>
<td>31 TO 90</td>
<td>6 MONTHS</td>
</tr>
<tr>
<td>91 TO 150</td>
<td>4 MONTHS</td>
</tr>
<tr>
<td>151 TO 210</td>
<td>3 MONTHS</td>
</tr>
<tr>
<td>GREATER THAN 210</td>
<td>2 MONTHS</td>
</tr>
</tbody>
</table>

Note: Each runway end should be evaluated separately, e.g. Runway 18 and Runway 36.
CFME Workshops

- NASA
  Annual Runway Friction Workshop
  Wallops Island, Virginia

- Penn State
  Annual Runway Friction Workshop

- International Friction Pavement Association (IFPA)

- Transport Canada
  Correlation of CFME at LCPC, Nantes, France
FAA Governing Document for Groove Placement

- AC 150/5370 -10F
  Standards for Specifying Construction of Airports

P-621
Saw-Cut Grooves
Time Frames Associated with Grooving

- **Curing of Pavements Prior to Grooving**
  - Asphalt: 30 Days
  - Portland Cement Concrete: 28 Days
  - Can be Decreased at the Discretion of the Engineer.

- **Grooving Operation**
  - 1 to 2 Weeks
Grooving Machine
Cutting Blades Mounted on Arbor
Tolerances for Each Day’s Production by a Machine

- **Alignment**
  ± 1 1/2 in. in 75 ft.  (± 38 mm in 23 meters)

- **Groove Dimensions**
  Depth: 90% or more at least 3/16 in. (4.75 mm)
  60% or more at least 1/4 in.  (6 mm)
  Not more than 10% to exceed 5/16 in.  (8 mm)

Width: Same Tolerances
Tolerances for Each Day’s Production by a Machine (Cont’d)

- Center-to-Center Spacing
  
  Standard  1 1/2 in.  (38 mm)
  Minimum  1 3/8 in.  (35 mm)
  Maximum  1 1/2 in.  (38 mm)

- Grooves Can Be Terminated Within 10 ft. (3 Meters) of the Pavement Edge.
Daily Acceptance Testing

- Depth, Width, and Spacing
- Each of 5 Zones Across Pavement Width
- 5 Consecutive Grooves
- Each Arbor on Each Machine
- 3 Times per Day
- Adjustments When More Than 1 Groove On an Arbor Fails to Meet Depth, Width, or Spacing in More Than 1 Zone
FAA Governing Document for Grooving Maintenance

- AC 150/532O -12C
  Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces
Grooving Degradation Limits

- Groove Dimensions
  Depth: 40% of Grooves are 1/8 inch (3.18 mm) or Less for a Longitudinal Runway Distance of 1,500 ft. (457 Meters)

Width: Same Limits
A Grooved Runway is a Safer Runway