Runway Roughness Evaluation - Boeing Bump Methodology

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Outline

- Types of Roughness and Boeing Bump Criteria
- Profiling Equipment Comparison
- Case Studies
- Standardization of Roughness Criteria
- Conclusions
What Types of Roughness are We Concerned About at Boeing?

- **Three Types of Structural Concerns Affecting Aircraft:**
  1. Limit Loads – Single Discrete Bumps which could lead to structural failure. Currently addressed by Boeing Bump Criteria
  2. Fatigue Loads – Continuous Large Wavelength Bumps exceeding once per flight fatigue criteria based on change in vertical acceleration
  3. Landing Gear Truck Pivot Joint – Continuous Short Wavelength Bumps. Only a real concern in Russia and CIS countries

- Each type imposes a different runway roughness criteria. Types 2 and 3 require dynamic analysis.
- Current standards address mainly first two types.
- Third type is relatively unknown, and not directly addressed in current standards.
Pavement Maintenance Priorities

Runway pavements should fill the following functions

1.) Provide adequate bearing strength- addresses structure of pavement

2.) Provide good ride quality- addresses surface geometrics

3.) Provide good surface friction characteristics- addresses texture and slope of pavement

All of these functions are tied to proper pavement maintenance and the availability of the pavement for safe aircraft operations
Boeing Runway Roughness Criteria-Single Event Limit Load

- **Acceptable**
  - Bump length, m
  - Bump height, cm

- **Excessive**
  - Unacceptable: Closure of runway
  - Repairs needed
  - Pilot complaints

![Diagram showing the relationship between bump length and bump height for runway roughness criteria. The graph indicates zones for acceptable, excessive, and unacceptable conditions based on bump length and height values.](image-url)
Long Wave Depression

Bump Definition

<table>
<thead>
<tr>
<th>Elevation, m</th>
<th>6+220</th>
<th>6+250</th>
<th>6+280</th>
<th>6+304</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centerline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>5.10</td>
<td>5.00</td>
<td>5.00</td>
<td>5.10</td>
</tr>
<tr>
<td>South</td>
<td>4.90</td>
<td></td>
<td></td>
<td>4.82</td>
</tr>
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</table>

Rod Length (10m-120m rods tested)

Bump Height

Bump Length

3C

3N

3S
Details of the Boeing Method-Long Wave Depression

10 cm bump worse due to shorter bump length- all rod lengths must be checked

8 cm bump worse than 10 cm bump- all points along profile for a given rod length must be checked
Boeing Bump Analysis - Plot of Worst Bumps
Boeing Bump Analysis - Detail of Excessive Bumps

Region with Highest Roughness

Profile Height (cm)

Runway Position (m)

Significant Bump
Boeing Bump Analysis - Detail of Excessive Bumps

Region with Highest Roughness

Profile Height (cm) vs. Runway Position (m)

Significant depression
Fatigue Life – Exceedance of Airplane Load Factors

The graph illustrates the relationship between incremental vertical acceleration at the center of gravity (CG) in g units and the number of exceedances per flight. The graph shows three different scenarios:

- **Takeoff Roll (Smooth runway)**
- **Landing Rollout (Smooth runway)**
- **Takeoff Roll- (Rough runway)**

Aircraft fatigue life is affected by the exceedances, with higher exceedances leading to a shorter fatigue life.
Landing Gear Truck Beam Failure- Short wave Roughness Issue
Short Wavelength Runway Profile Analysis
Power Spectral Density (Overall Runway)

- Shows frequency of occurrence of short wave bumps - 2 to 7 meter range

<table>
<thead>
<tr>
<th>Airport</th>
<th>Runway</th>
<th>RMS [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.87</td>
</tr>
</tbody>
</table>

Rough runway - Above threshold
Acceptable threshold RMS = 1.45
Smooth runway - Below threshold
Runways in CIS countries identified having short wave roughness exceeding the PSD threshold must be serviced periodically (i.e. inspect and lube) by airline.
Airports Surveyed by Boeing for Roughness
Comparison Between Boeing Criteria and other Criteria

- **Bump length, m**
- **Bump height, cm**

**Acceptable**
- USAF airplane design criteria MIL-A-008862A paved airfields
- Runway vertical curve (ICAO annex 14) ICAO tolerable limits (3cm over 45m)
- FAA straightedge criteria (6mm over 5m)
- ICAO straightedge criteria (3mm over 3m)

**Excessive**
- Unacceptable

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Runway Profiling Equipment Comparison

High Speed Inertial Laser profiler

Manual rolling inclinometer profiler

Manual rod and level device
Pavement Assessment Process

- Compare profiles from 3 profiling devices

- Verify that the regions of roughness along the profile were similar in magnitude for all profilers

- Compare 2 Lines of Survey (CL and 15 Feet Left of CL)

- Roughness determined using Boeing Bump Criteria was compared for all 3 devices

- Initial consultant request to review runway 07/25 came to Boeing in 2007. Main concern was fatigue, primarily region 1 dual bump exceeding the once per flight fatigue limit.
Areas of Roughness from APR survey - 2006

Painted Threshold on 07 end

Roughest Areas

- 950’ - 2500
Region 1

- 7450’ - 8750’
Region 2
Areas of Roughness from APR survey - 2006

Region 1

Region 2

Image: Courtesy Google Maps
APR Profiles-Regions 1 and 2 as noted
Bump Index Definition

Bump Index = Actual Bump Height / Height from curve

Unacceptable - Bump Index > 0
Excessive - Bump Index > 0
Acceptable - Bump Index < 0

Bump Index = Actual Bump Height / Height from curve
Runway 07/25 Centerline Profile-Bump Index Comparison

APR

Boeing

FAA
Conclusions

- Profiles from all three devices seem to match well—areas of roughness on runway correlate between all three.

- Boeing bump analysis consistent – bump index values, although differing in magnitude, are maximum at the same locations along the runway.

- Locations of overall worst bumps in same areas for all three profiling devices.

- All three profilers are useful in determining general areas of roughness needing repair.
Boeing Runway Roughness Assessment - Unacceptable Condition - Plot of worst bumps

- Unacceptable
- Excessive
- Acceptable

- 2004 profile
- 2005 profile

Bump height (in) vs Bump Length (ft)
Boeing Runway Roughness Assessment - Unacceptable Condition
2004 vs. 2005 Survey

2004

0 500 1000 1500 2000

Primary takeoff direction

Region of pilot complaints

2005

0 500 1000 1500 2000

Excessive
Unacceptable
Boeing Roughness Criteria Applied to Temporary Construction Ramps

- Bump length, m
- Bump height, in
- Bump height, cm

1/100 slope
1/200 slope
Acceptable limit
Runway Ramping Recommendations

A. Ramping prior to aircraft traffic
   Predominant direction of traffic
   Overlay thickness x
   Old surface
   Milled area

B. Surface preparation prior to resumption of paving
   Cut area to depth y

Notes
1. When overlay thickness $x \leq 5$ cm, then ramp slope = 1.0%
2. When overlay thickness $x > 5$ cm, then ramp slope = 0.5%
3. Depth $y$ should be at least 2 times the maximum aggregate size
Working Toward an Industry Standard
Pavement Roughness- Current Situation

- There is no industry standard which clearly defines when a airfield pavement has become “too rough”

- Problems can be aircraft specific

- New construction smoothness criteria is no longer applicable as pavement deteriorates

- Action by the airport is typically initiated by pilot complaints- FAA currently doing aircraft simulator research to assess pilot feedback on runways of varying roughness.
US Guidance on Roughness

FAA Advisory Circular
150/5380-9 (released 9/30/09)

FAA Software PROFAA
Includes Boeing Bump
NEW CONSTRUCTION

AC 150/5300-13, Airport Design

- Surface Gradient
- Maximum grade allowance
- Change in grade provisions

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

- Construction tolerances must be met
- Acceptance criteria for smoothness- straightedge or profilograph

Experience has shown that the current FAA grade and straightedge criteria provide pavements that are safe for aircraft operations.
### Surface Unevenness

If the maximum limits are exceeded, corrective action should be undertaken as soon as reasonably practicable to improve the ride quality. If the temporarily acceptable limits are exceeded, the portions of the runway that exhibit such roughness should have corrective measures taken immediately if aircraft operations are to be continued. If the unacceptable limits are exceeded and the roughness resides in the area of aircraft operations, then the runway should be closed until repairs are made to restore the condition to the acceptable region.

The maximum permissible step type bump, such as that which could exist between adjacent slabs, is simply the bump height corresponding to zero bump length at the upper end of the acceptable region of the roughness curve. The bump height at this location is 1.75 cm.

<table>
<thead>
<tr>
<th>Surface Irregularity</th>
<th>Minimum acceptable length of irregularity (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Maximum surface irregularity height (cm)</td>
<td>2.9</td>
</tr>
<tr>
<td>Temporary acceptable surface irregularity</td>
<td>3.9</td>
</tr>
<tr>
<td>height (cm)</td>
<td>5.8</td>
</tr>
</tbody>
</table>

The table above illustrates the minimum acceptable lengths of irregularity for different surface irregularity heights.
Conclusions

- Runways may become intolerably rough due to:
  - The onset of pavement structural failure (age)
  - Adverse environmental conditions
  - Improper repairs or non-standard temporary construction ramps

- Airport operators are not usually aware of the impact of roughness on aircraft, pilot complaints typically initiate action.

- The Boeing criteria will enable airports to:
  - Determine the extent of roughness
  - Locate the source of roughness
  - Make rational decisions for the best course of action

- Standardizing the roughness criteria for both US and international airports through FAA advisory circulars and ICAO documentation provides proper guidance for developing an airport’s pavement management system.
“Why be worried about tomorrow if it will be finished the day after tomorrow”