Boeing Bump Index Computations for Airport Pavement Roughness

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Outline

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Boeing Bump Index Computations

- A virtual rod between two points of an imaginary longitudinal runway profile line.
- Variable rod length from three times of sample spacing to 400 feet (=120 meters).
- Bump height and shortest bump length for each individual disturbance.
- $\text{BBI}_i = \frac{\text{computed bump height}}{\text{limit of acceptable bump height}}$. 

Background for Developments of BBI – Rational

• “Single discrete, large wavelength bumps on a runway, which if severe enough, could lead to structural failure by exceeding the limit design loads of an aircraft. Currently, the Boeing Bump Criteria addresses this issue, such that bumps reaching the unacceptable level are repaired.”
  – Mike Roginski, “Runway Roughness Evaluation- Boeing Bump Methodology”, ASTM E17 Committee Meeting, Dec 9, 2014

• Structural failure of an axle or bottoming of the main gear oleo strut are typical concerns when the bump falls within the criteria limit.
Background for Developments of BBI – Research

- NASA studies on aircraft response for wavelength variation with speed increases.
- Boeing 737 simulation studies for relationship of roughness level and aircraft vertical acceleration.

http://www.airporttech.tc.faa.gov/Pavement/25rough.asp
Aircraft Response – NASA Studies (Lee and Scheffel, 1968)
Roughness Criteria 1975 vs 1994

The graph shows the relationship between Maximum Bump Height (in.) and Bump Wave Length (Ft) for different roughness criteria levels:

- Level 1: Acceptable
- Level 2: Temporarily Acceptable
- Level 3: Excessive
- Unacceptable

The graph indicates that as the bump wave length increases, the maximum bump height increases, and the criteria levels transition from acceptable to unacceptable.
Airplane Load Factor Exceedances for Fatigue Life Study in 1974
Roughness Occurrence Frequency of Typical Runways
Main Landing Gear Axle Fatigue Life (1975)
1995 Boeing Roughness Criteria
Current Standards for BBI

- AC 150/5380-9, Guidelines and Procedures for Measuring Airfield Pavement Roughness.
- ICAO Annex 14, Aerodrome Design and Operations.
- ASTM, WK41777, New Standard Boeing Bump Index Computations Based on Bump Template Simulations (under development).
Computer Program for BBI Computations – ProFAA

http://www.airporttech.tc.faa.gov/Pavement/25rough.asp
Application for Rut Depth Measurements – FAA NAPTF Transverse Profiler
FAA NAPTF Transverse Profiler for High Tire Pressure Project for ICAO

Full-Scale High Tire Pressure Tests on Hotted Pavement

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Aerodrome Pavement Subgroup

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(a) Accumulated Rut Depth and Slope Changes.

(b) HMA Surface Profile Changes.

Figure 13. Rut Depth and Slope Changes for PG 64-22 / 61,300 lbs / 245 psi Test Item.
Runway Surface Drainage

• AC 150/5320-5D Airport Drainage Design
  – Longitudinal Slope: “…in sag vertical curve….,a minimum slope of 0.3 percent should occur within 50 feet of the low point of curve.”, AASHTO Green Book *A Policy On Geometric Design of Highways and Streets*
  – Transverse Slope: *For roadways*, Use of a cross slope steeper than 2 percent on pavements with a central cross line is not desirable. In areas of intense rainfall, a somewhat steeper cross slope (2.5 percent) may be used to facilitate drainage.”, UFC-3-250-01FA (Pavement Design for Roads, Streets, Walks, and Open Storage Areas)

• For drainage purpose only, minimum 0.50 percent of pavement surface slope in any direction at runway intersection.

• In general, however, pavement roughness would be an issue at runway intersections with increasing slopes like 0.50 percent to improve drainage at pavement surfaces.
Runway Surface Drainage (Cont’d)

- 0.5%
- 0.36%
- 0.17%
Case Study I: BBI for In-Service Airfield Pavement Evaluation – Runway Profile

The diagram shows the elevation profile along the runway with distance in meters on the x-axis and elevation in centimeters on the y-axis. The data is plotted for three different methods:

- **FAA-Inertial**
- **Boeing-SurPro**
- **APR-Auto Rod and Level**

The graph is divided into two sections, labeled **West** and **East**, indicating the direction along the runway. The FAA-Inertial method is represented by a green line, Boeing-SurPro by a pink line, and APR-Auto Rod and Level by a blue line. The elevation profile shows variations along the runway, with higher elevations towards the end of the runway in both sections.
Case Study I: BBI for In-Service Airfield Pavement Evaluation

FAA-Inertial

Boeing-SurPro

APR-Auto Rod and Level
Case Study I: BBI vs Dynamic Force (B-727)
Case Study I: BBI vs Dynamic Force (B-727)

B-727 (VUG = 100.0 knots), Dynamic coefficient of Nose Strut Force

B-727 (VUG = 100.0 knots), Dynamic coefficient of Main Strut Force

Boeing Bump Index
Case Study II: B-737 Simulator Study at the FAA Mike Monroney Aeronautical Center

• The Oklahoma City B-737 flight simulator provided simulations to 33 highly experienced pilots of various backgrounds using 37 vertical profiles of real world taxiways & 37 vertical profiles of real world runways.
• Four ISO measures of the vibration experienced in the cockpit were computed for each simulation: weighted RMS, weighted VDV, weighted MTVV and DKup.
• 5% of pilots rated unacceptable roughness when they experienced 0.31g and 0.35g taxiway and runway profiles based on Weighted RMS.
• A-330 project is on going.
Case Study II: B-737 Simulator Study at the FAA Mike Monroney Aeronautical Center
Case Study II: B-737 Simulator Study at the FAA Mike Monroney Aeronautical Center – f vs CGg

![Graph showing cumulative frequency of load factor per 1000 flights versus incremental CG load factor, g. The graph includes data for different levels of roughness and various locations such as San Francisco International Runway 28R, Fukuoka, and 737 Operations.]

San Francisco International Runway 28R
Scaled Profile

- Level 1 Roughness
- Level 2 Roughness
- Level 3 Roughness

Cumulative Frequency of Load Factor per 1000 Flights

Incremental CG Load Factor, g
Case Study III: Aircraft Responses to Wavelength Changes – ProFAA

- Used FAA’s ProFAA.
- Selected Boeing 727-200.
- Used simulation speed at 100 knots.
- Used 0.025 damping factor.
- Computed accelerations at cockpit (Gcp) and center of gravity (Gcg).

B727 Gear Config.

- 63.25 ft
- 23.15 ft
Case Study III: Aircraft Responses to Wavelength Changes – G Responses

-0.17%  300 ft  +0.17%  3-inch

B-727 (VCG = 100.0 knots), 6 cp

B-727 (VCG = 100.0 knots), 6 cg
Case Study III: Aircraft Responses to Wavelength Changes

![Graph showing the relationship between wavelength and center of gravity acceleration (RMS), GCG. The graph includes data for different bump heights (3 in, 9 in, and 13.5 in).]
Case Study IV: Runway Intersection Profiling
Longitudinal Slope at Primary Runway
Transverse Slope Secondary Runway

RWY 5-23

Elevation, inch

Offsets, ft

0.49%

-0.15%
Questions?

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