Boeing Bump Index Computations for Airport Pavement Roughness

Injun Song, Ph.D., P.E., SRA International, Inc.
Albert Larkin, Federal Aviation Administration
November 4, 2015
Road Profile Users' Group (RPUG) Meeting
Raleigh Marriott City Center Hotel, Raleigh, NC

SRA
Enduring Values. Inspired Performance.™

Acknowledgement

- Jeffrey Gagnon, P.E., FAA Airport Technology R&D Branch
- Albert Larkin, FAA Airport Technology R&D Branch
- Mike Roginski, P.E., Boeing

Outline

- Boeing Bump Index
  - Boeing Bump Index Computations.
  - Background for Development of BBI.
  - Current Standards for BBI.
  - Computer Program for BBI Computations.
  - Application for Rut Depth Measurements.
- Runway Surface Drainage
- Case Studies
  1. BBI for In-Service Airfield Pavement Evaluation.
  2. Aircraft Responses to Wavelength Changes.
  3. FAA Simulator Project.
  4. Runway Intersection Profiling

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.
- BBI*i*=(computed bump height) / (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.
- Boeing Commercial Airplane Group, “Runway Roughness Measurement, Quantification, and Application - Boeing Method,” Document No. D6-81746, Boeing, November 1995.

Document No. D6-81746

- Boeing Commercial Airplane Group, “Runway Roughness Measurement, Quantification, and Application - Boeing Method,” Document No. D6-81746, Boeing, November 1995.

- http://www.airporttech.tc.faa.gov/Pavement/25rough.asp

CAGE CODE 81205

THIS DOCUMENT IS:

CONTROLLED BY BOEING COMMERCIAL AIRPLANE GROUP
AIRPORT TECHNOLOGY ORGANIZATION (B-B210)

ALL REVISIONS TO THIS DOCUMENT SHALL BE APPROVED BY THE ABOVE ORGANIZATION PRIOR TO RELEASE

PREPARED UNDER
☐ CONTRACT NO.
☐ IR&D
☒ OTHER

PREPARED ON IBM PC (WINWORD 6.0) FILED UNDER D6-ROUGH.DOC

DOCUMENT NO. **D6-81746** MODEL ALL

TITLE **RUNWAY ROUGHNESS MEASUREMENT, QUANTIFICATION, AND APPLICATION - THE BOEING METHOD**

ORIGINAL RELEASE DATE

ISSUE NO. TO DATE

☒ THE INFORMATION CONTAINED HEREIN IS NOT PROPRIETARY.

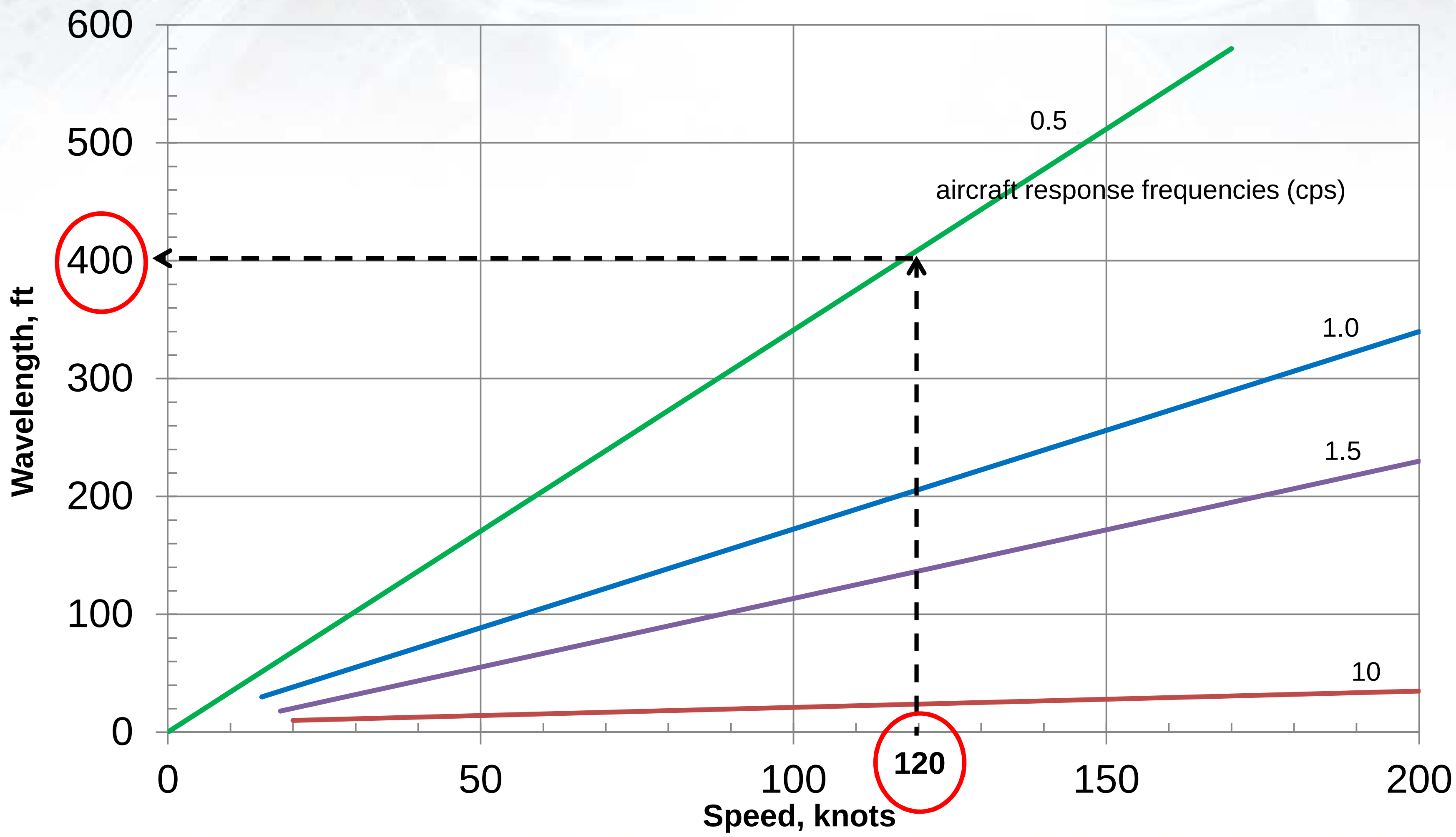
☐ THE INFORMATION CONTAINED HEREIN IS PROPRIETARY TO THE BOEING COMPANY AND SHALL NOT BE REPRODUCED OR DISCLOSED IN WHOLE OR IN PART OR USED FOR ANY DESIGN OR MANUFACTURE EXCEPT WHEN SUCH USER POSSESSES DIRECT, WRITTEN AUTHORIZATION FROM THE BOEING COMPANY.

ANY ADDITIONAL LIMITATIONS IMPOSED ON THIS DOCUMENT WILL BE FOUND ON A SEPARATE LIMITATIONS PAGE.

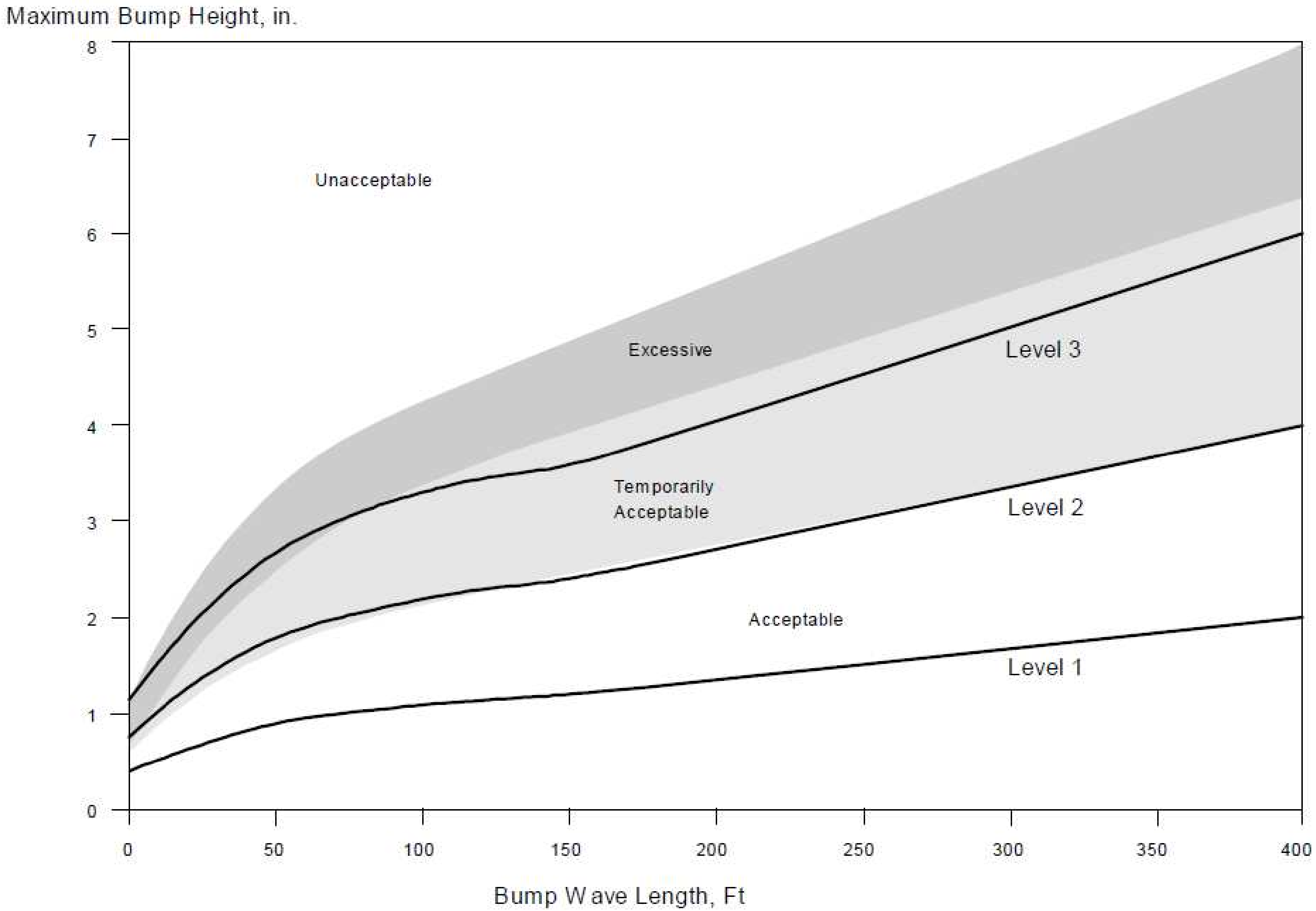
	SIGNATURE	ORGN	DATE
PREPARED BY:	K. J. DeBord, P.E., Airport Technology	B-B210	
CHECKED BY:	E. L. Gervais, P.E., Airport Technology	B-B210	
CHECKED BY:	J. S. Hagelin, Manager, BCAG Ground Loads	B-YB23	
APPROVED BY:	W. W. Jenkinson, Manager, Airport Technology	B-B210	

REV NEW D6-81746 i

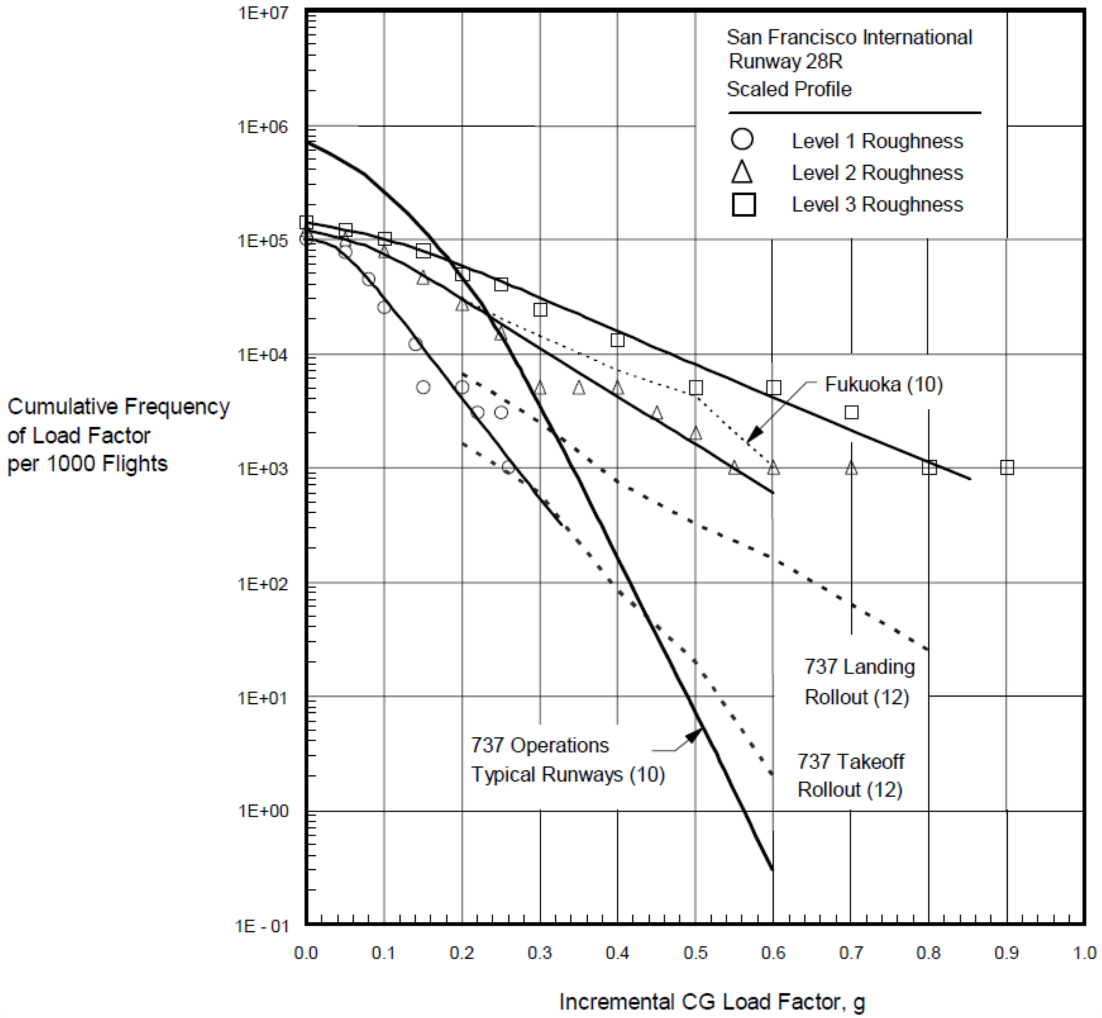
Aircraft Response
– NASA Studies (Lee and Scheffel, 1968)



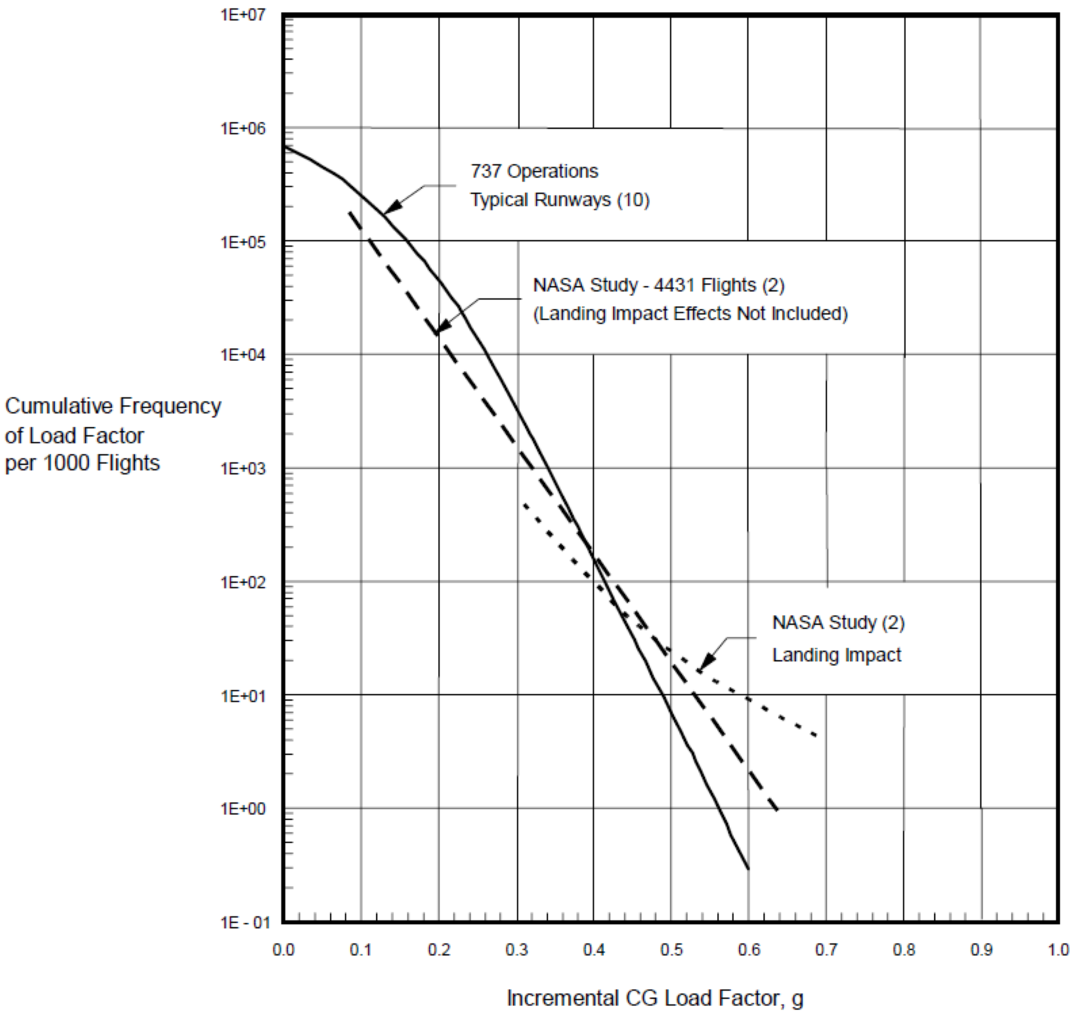
Roughness Criteria 1975 vs 1994



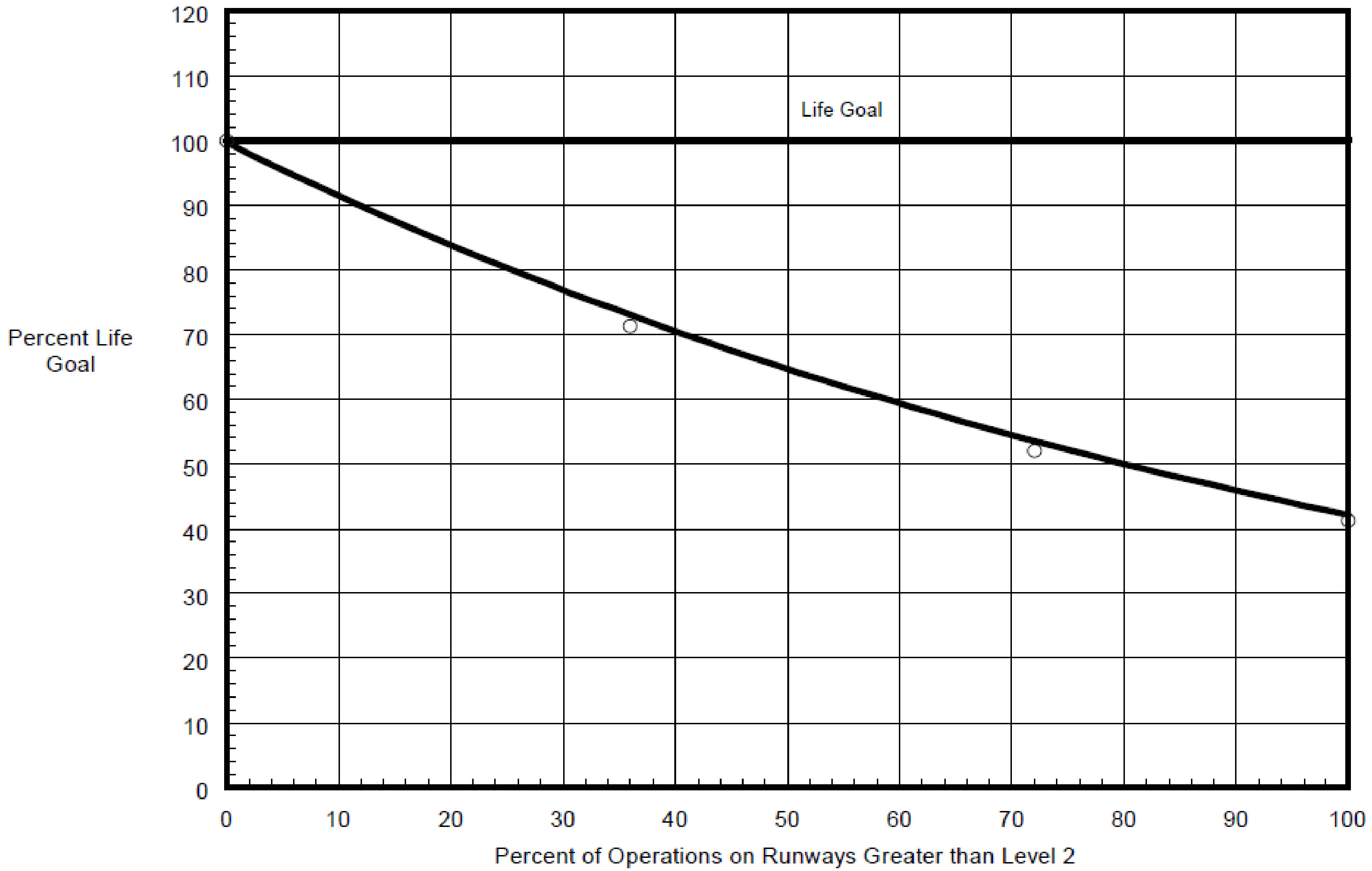
Airplane Load Factor Exceedances for Fatigue Life Study in 1974



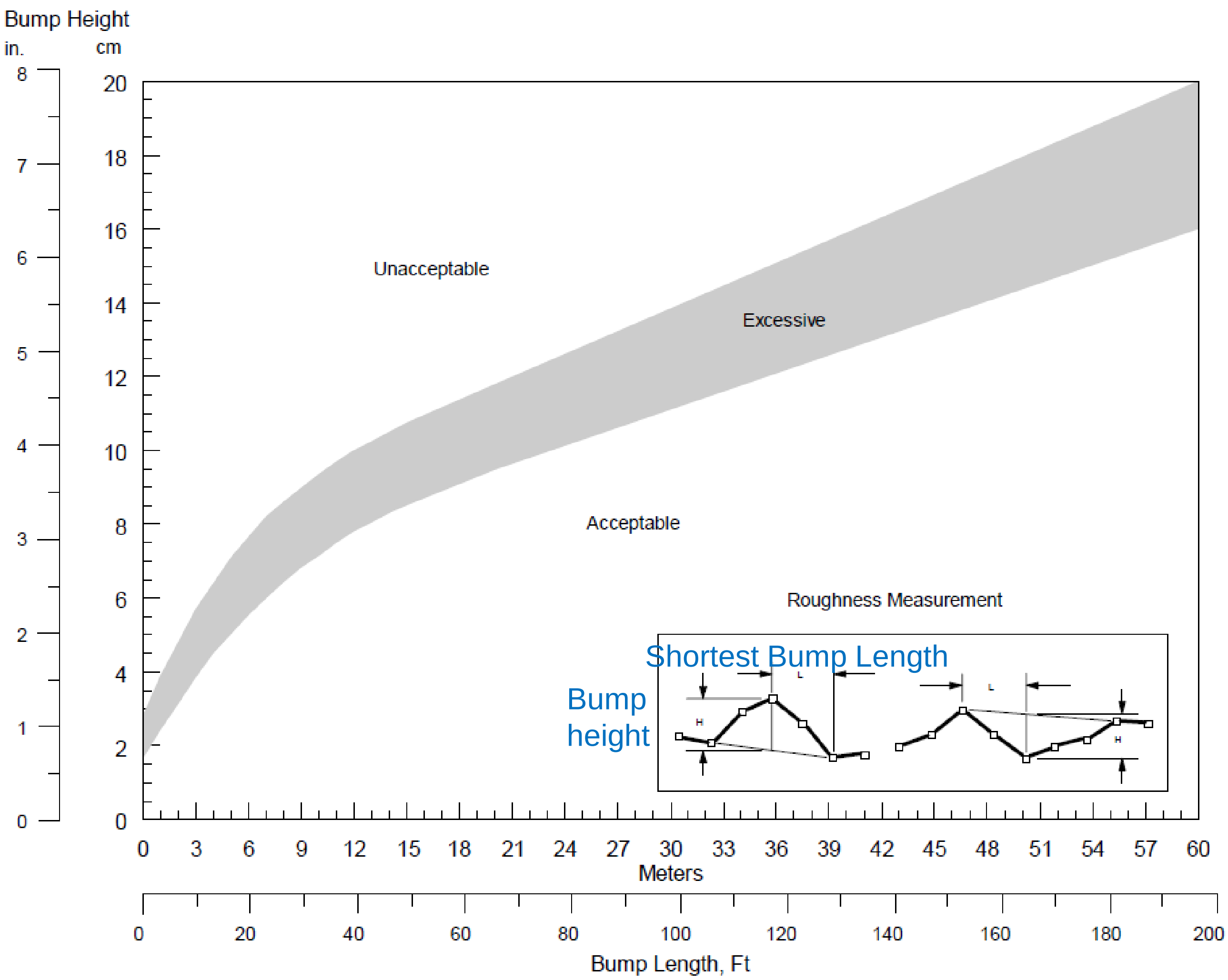
Roughness Occurrence Frequency of Typical Runways



Main Landing Gear Axle Fatigue Life (1975)



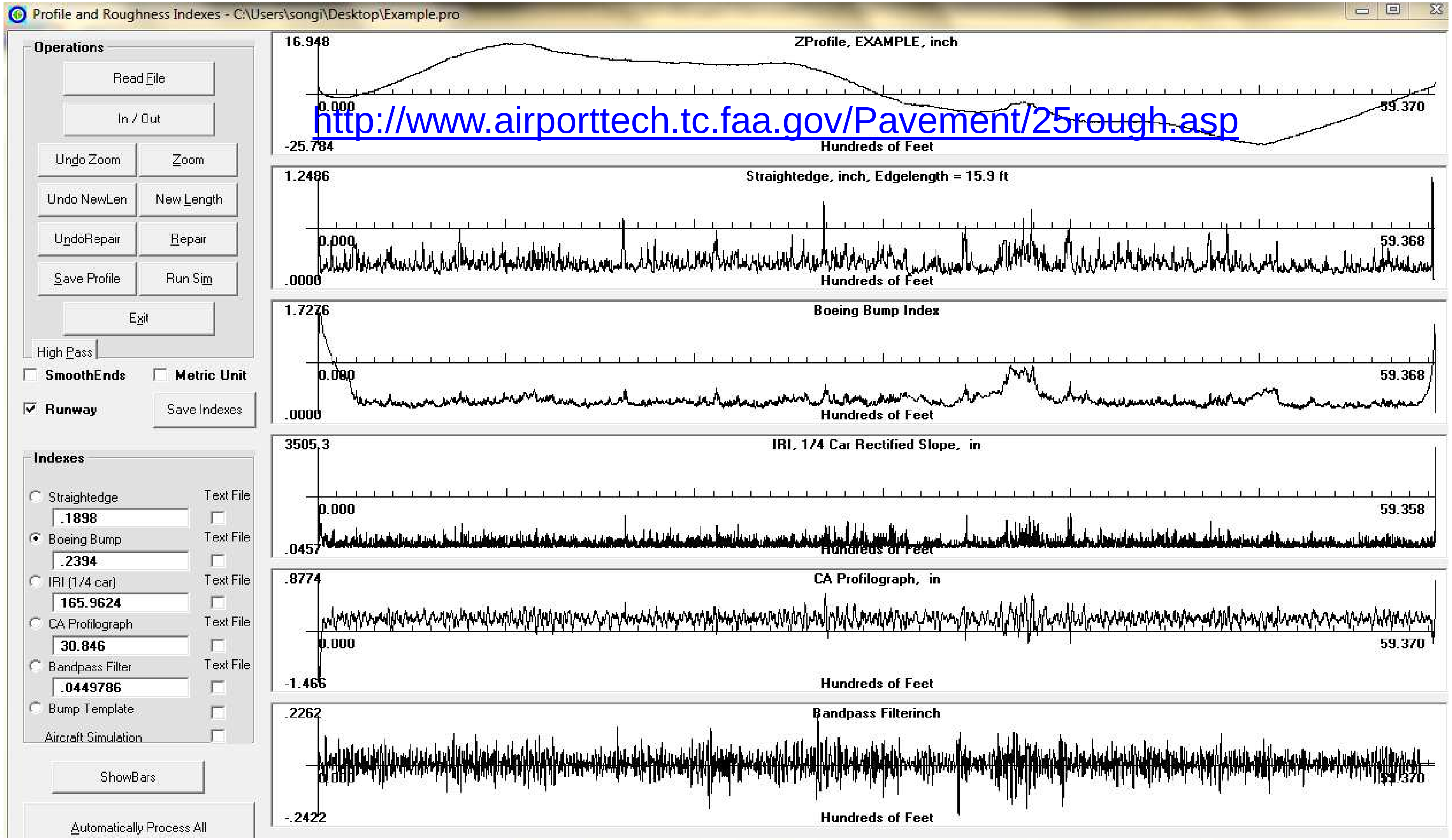
1995 Boeing Roughness Criteria



Current Standards for BBI

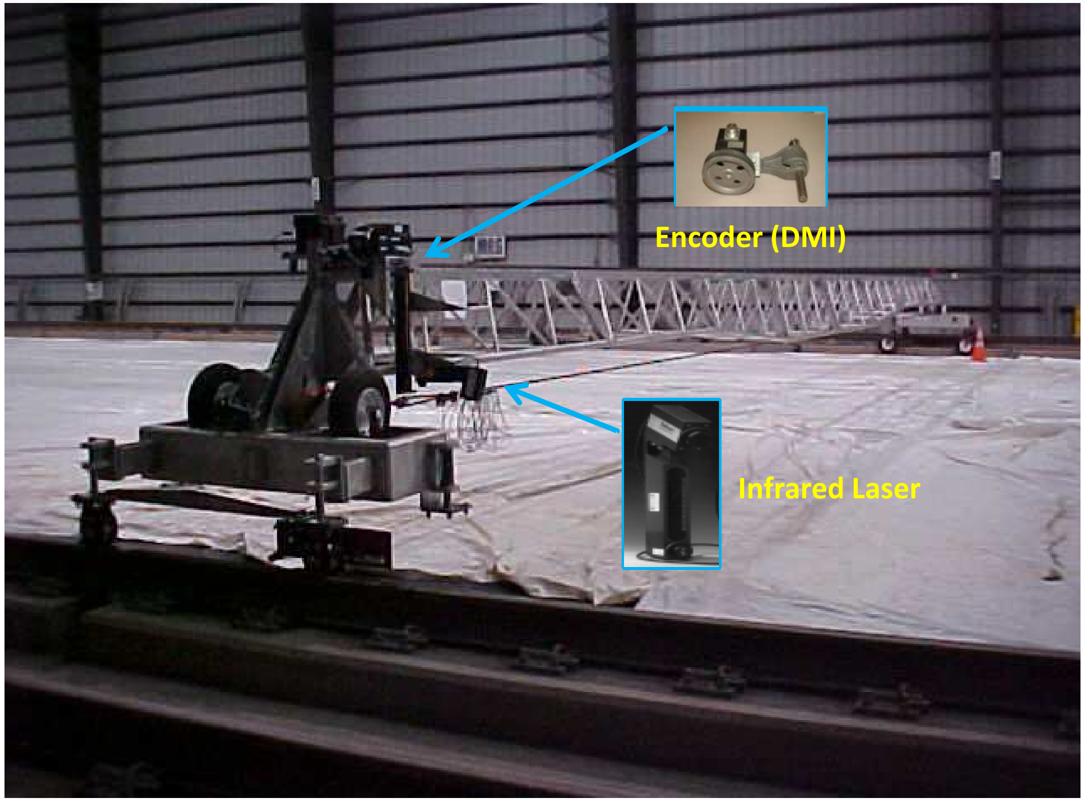
- AC 150/5380-9, Guidelines and Procedures for Measuring Airfield Pavement Roughness.
- ICAO Annex 14, Aerodrome Design and Operations.
- ASTM, WK41777, New Standard Boeing Bump Index Computations Based on Bump Template Simulations (under development).

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 Heated Pavement

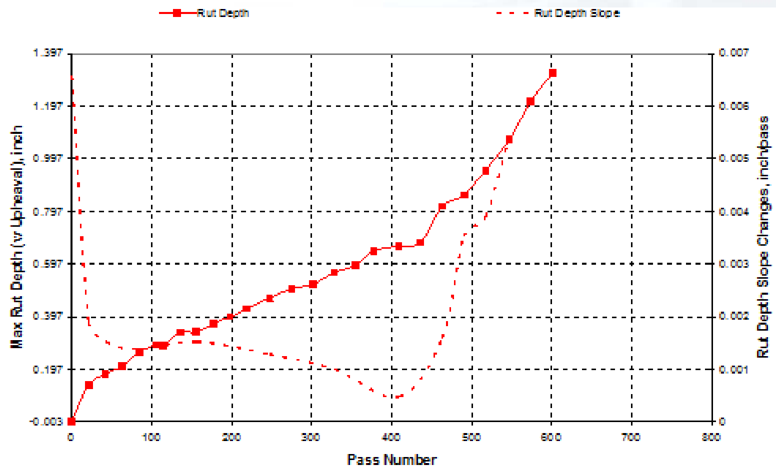
Prepared by

FAA Airport Technology Research and Development Team
AJP-6310
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405
U.S.A.

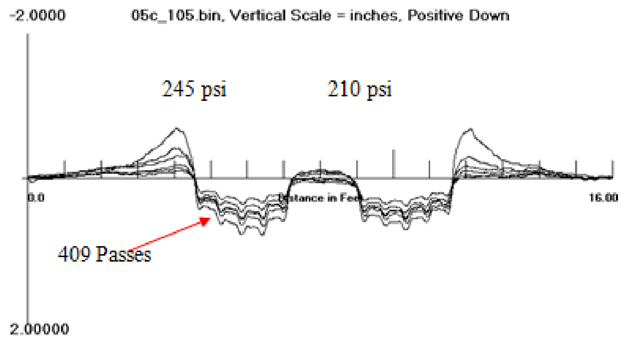
Submitted to

ICAO
Aerodrome Operations and Services Working Group
Aerodromes Panel
Pavement Subgroup

August 31, 2010



(a) Accumulated Rut Depth and Slope Changes.



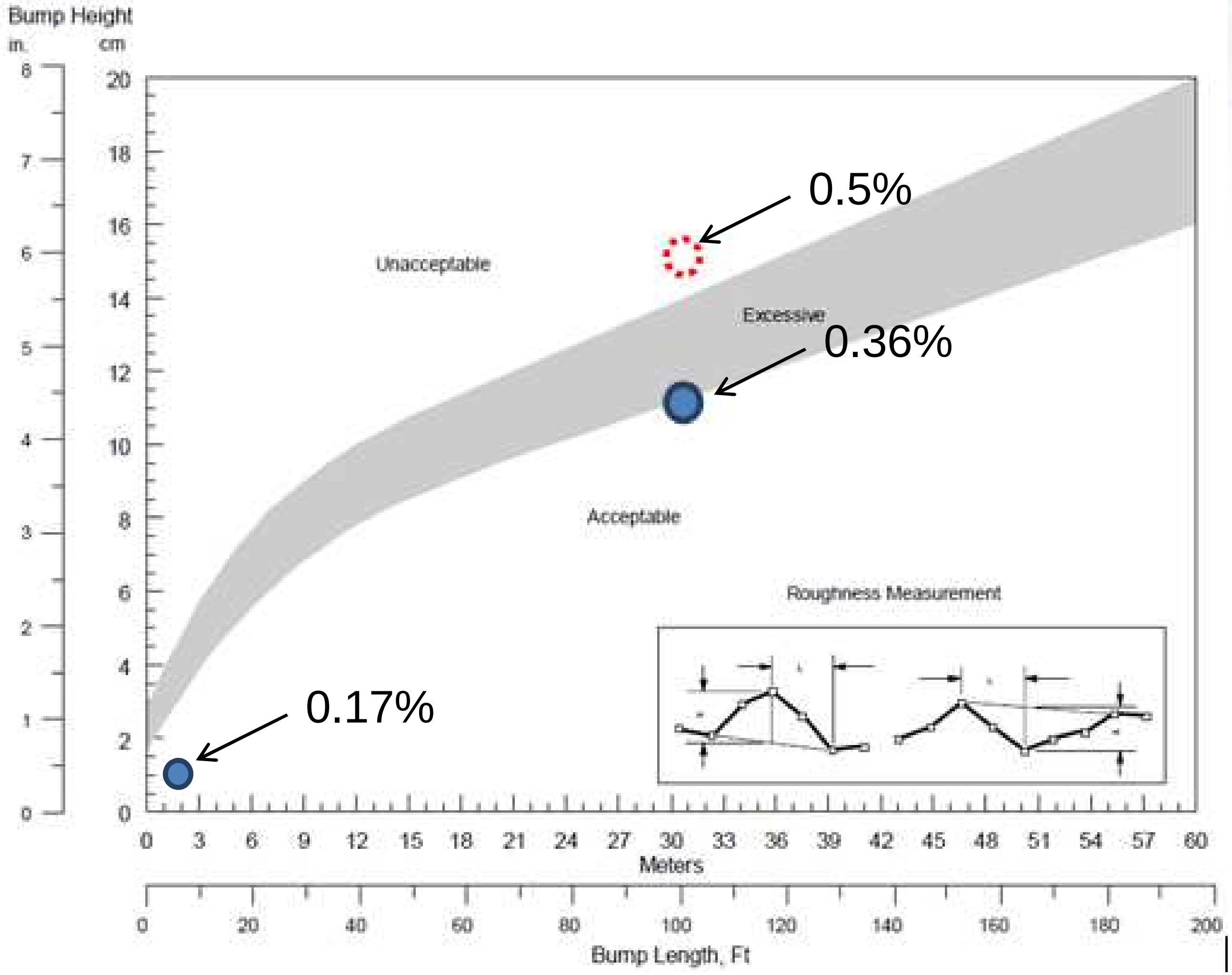
(b) HMA Surface Profile Changes.

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

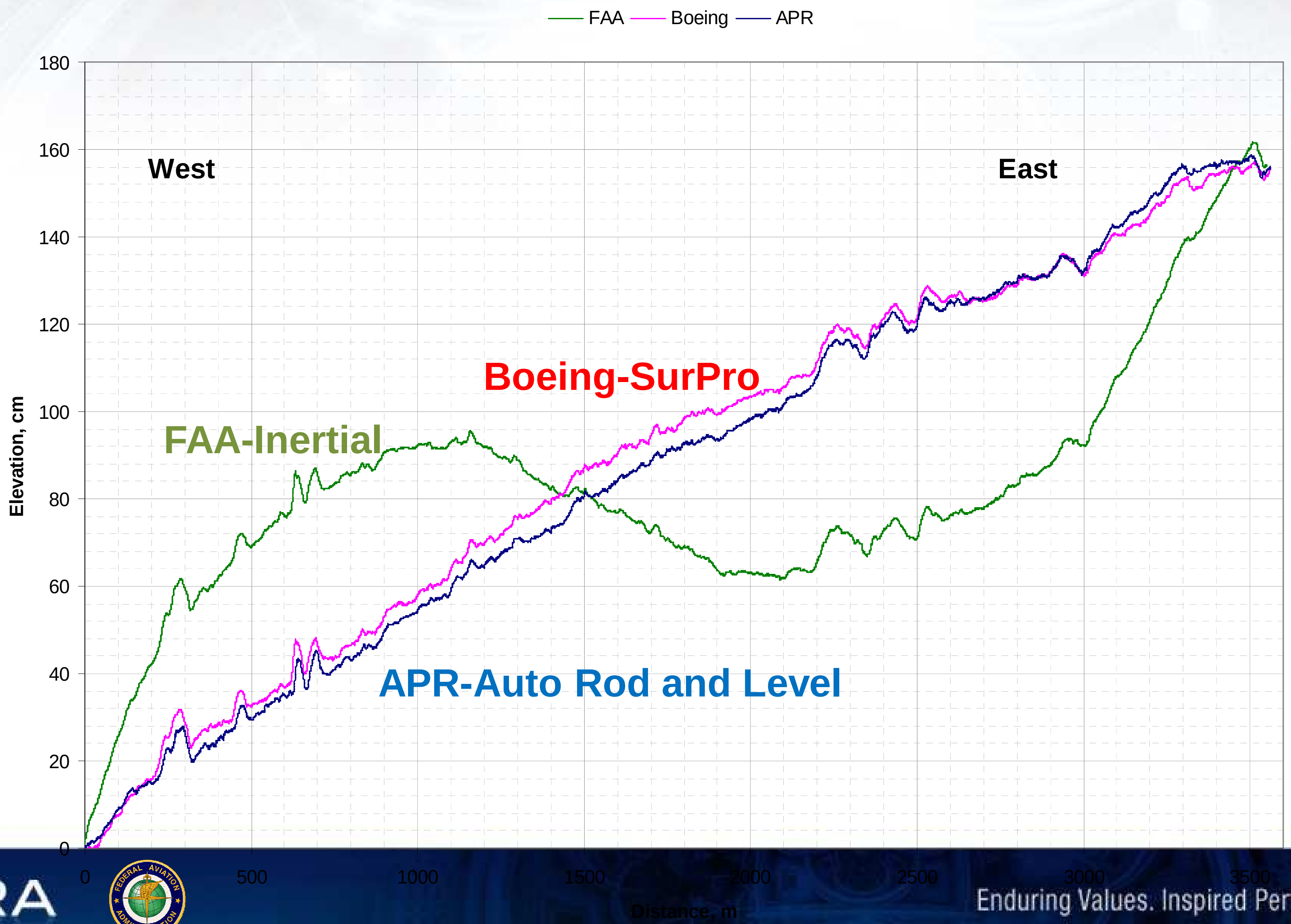
Runway Surface Drainage

- 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)

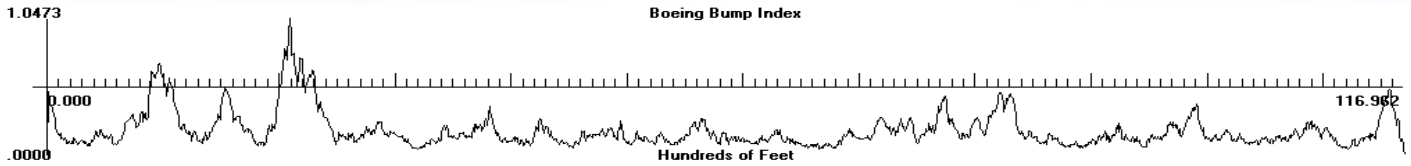


Case Study I: BBI for In-Service Airfield Pavement Evaluation – Runway Profile

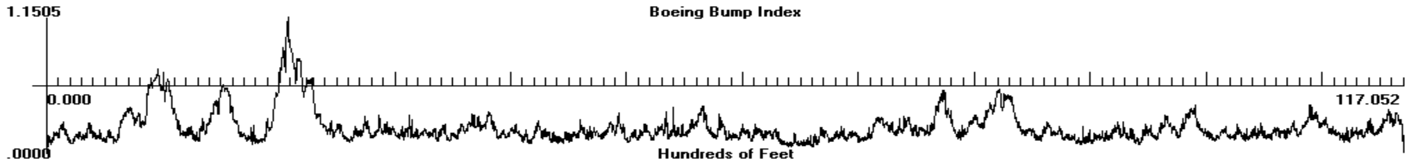


Case Study I: BBI for In-Service Airfield Pavement Evaluation

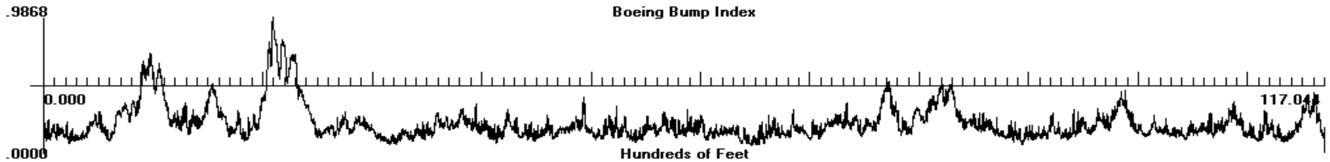
FAA-Inertial



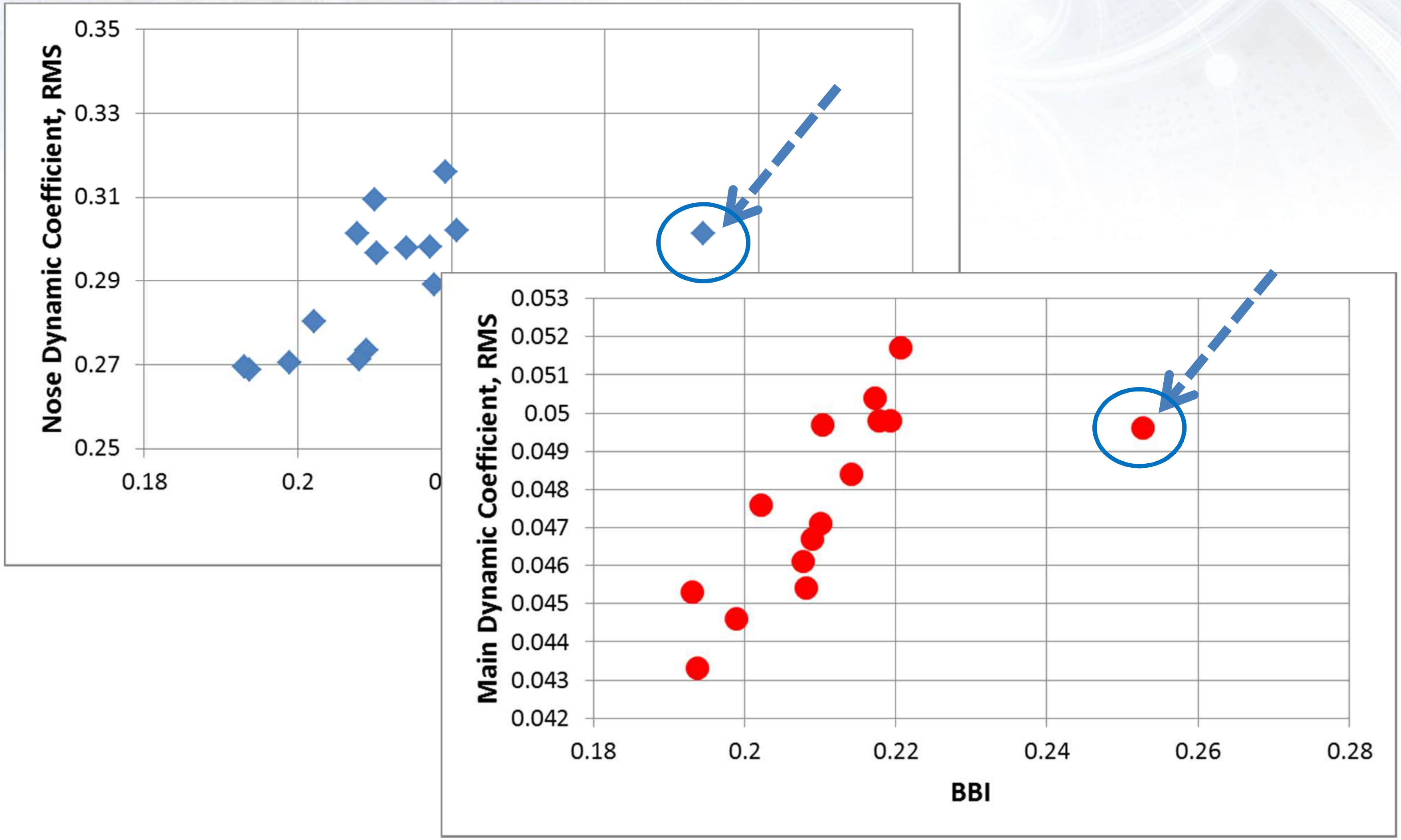
Boeing-SurPro



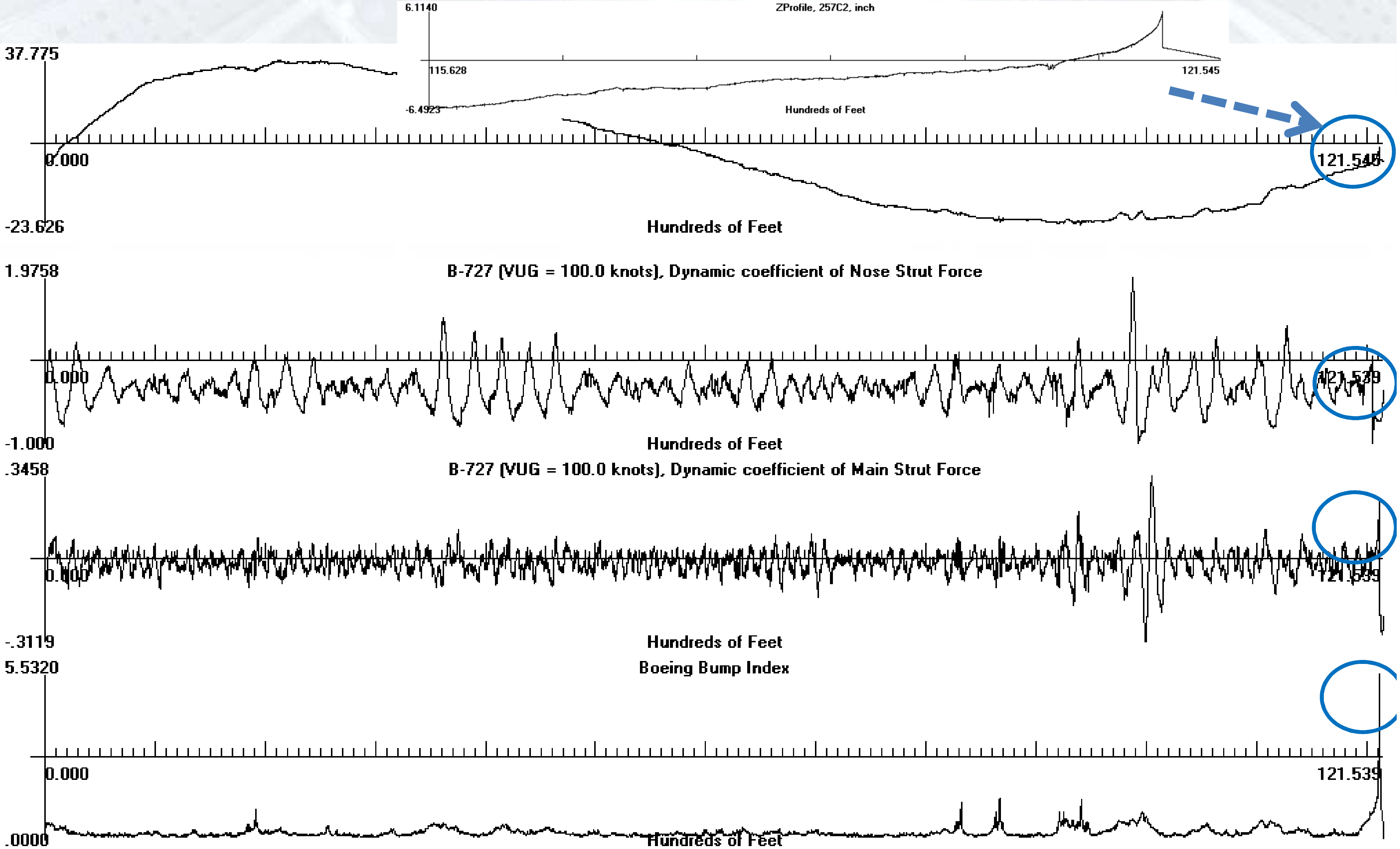
APR-Auto Rod and Level



Case Study I: BBI vs Dynamic Force (B-727)



Case Study I: BBI vs Dynamic Force (B-727)

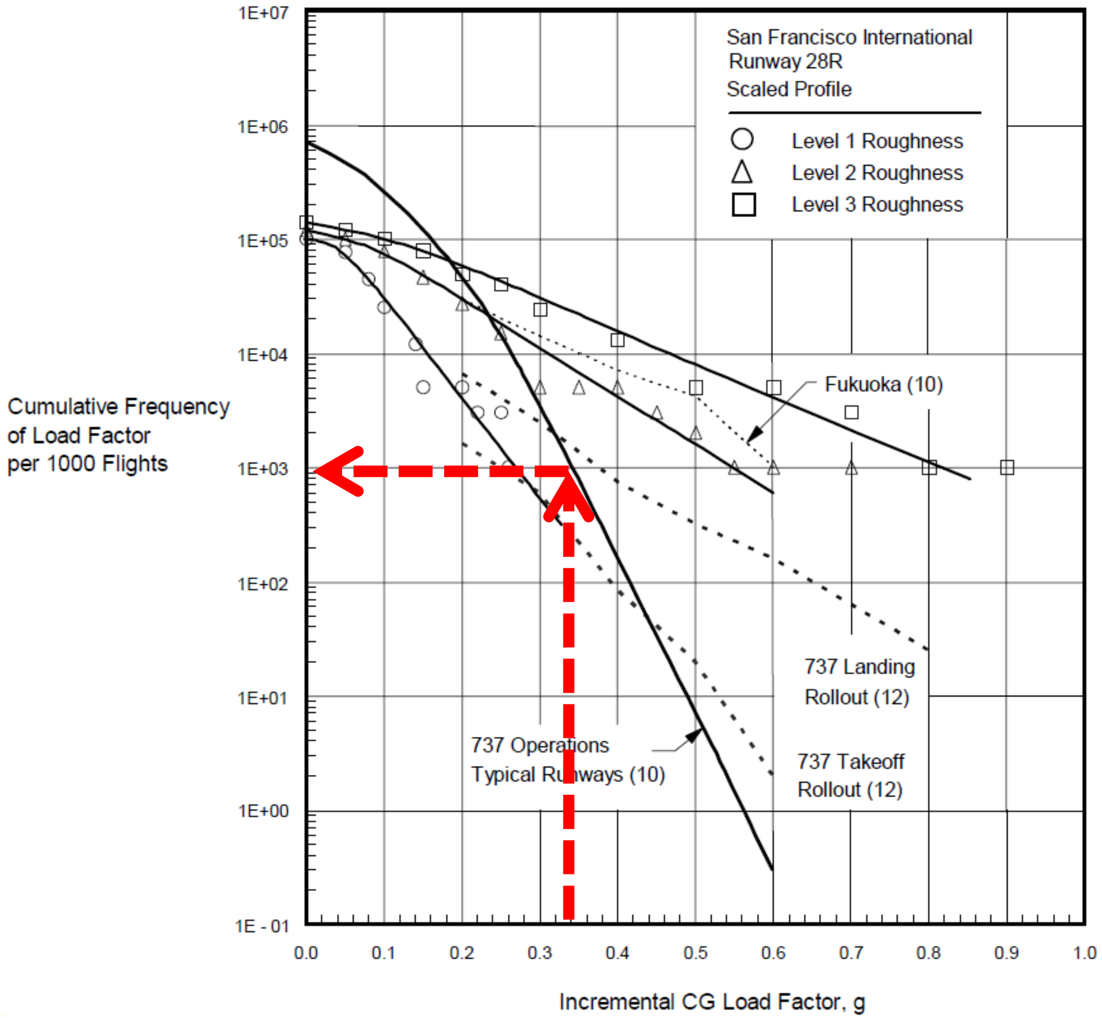


Case Study II: B-737 Simulator Study at the FAA Mike Monroney Aeronautical Center

- 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

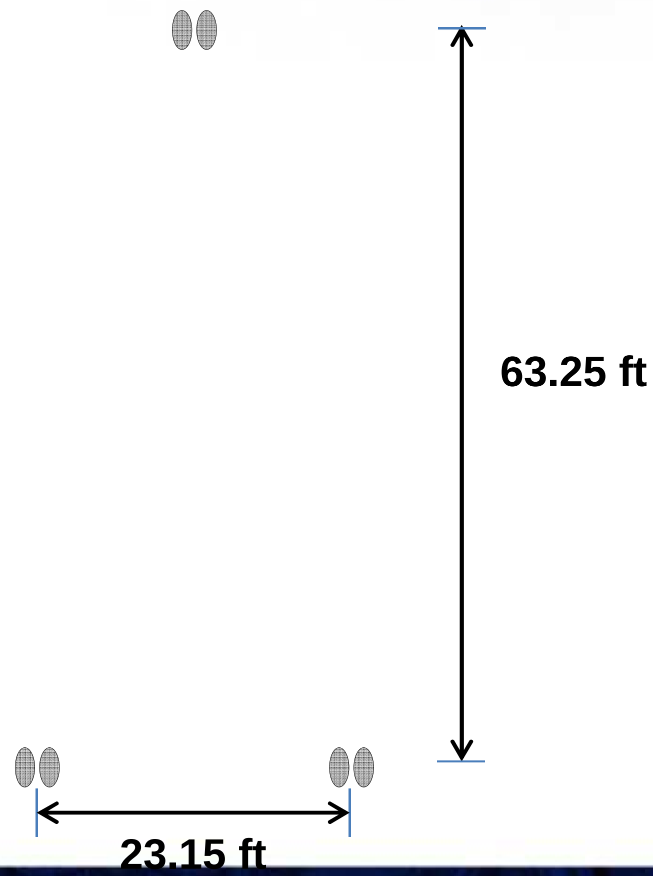
Case Study II: B-737 Simulator Study at the FAA Mike Monroney Aeronautical Center – f vs CGg



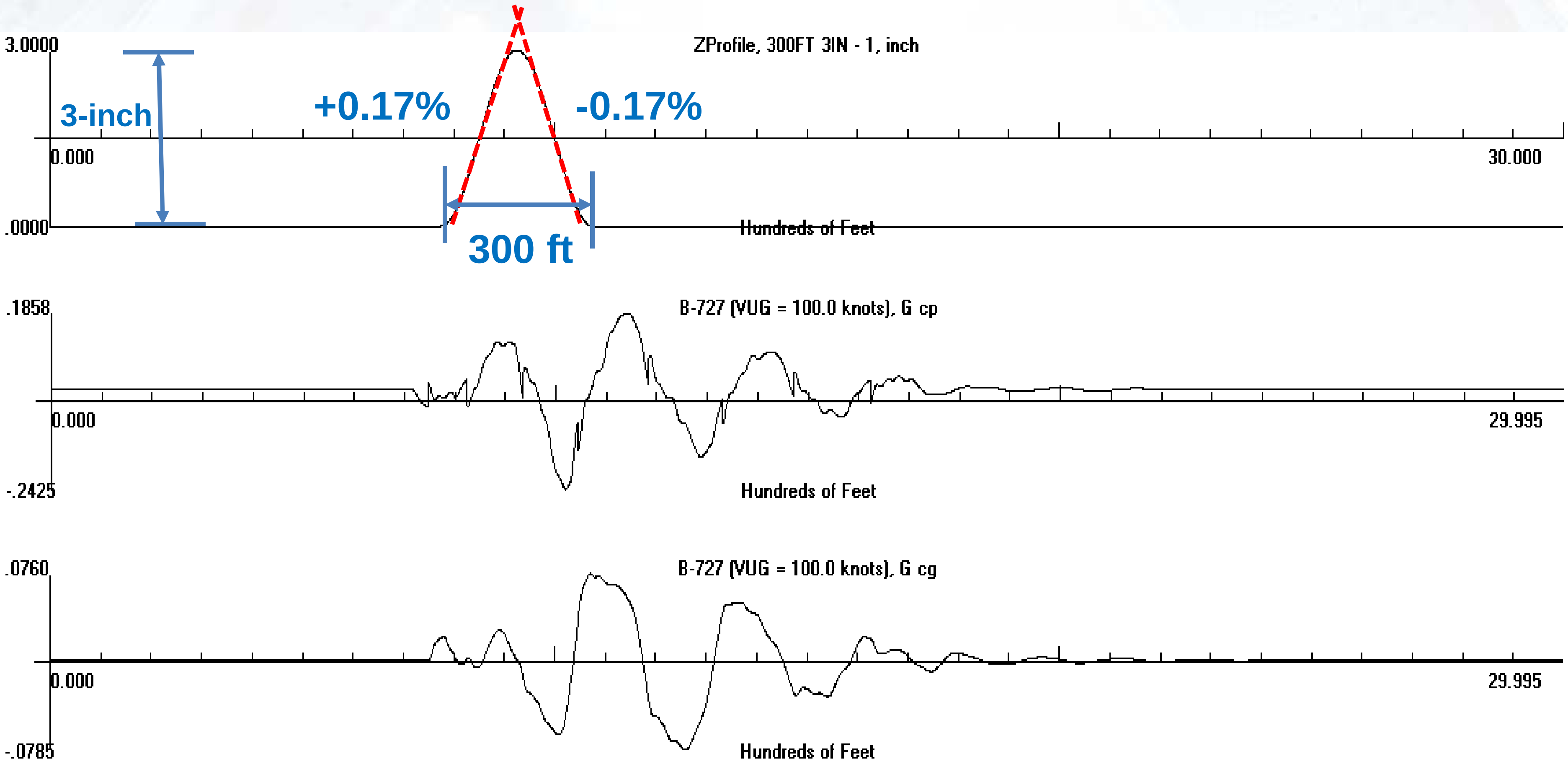
Case Study III: Aircraft Responses to Wavelength Changes – ProFAA

- 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).

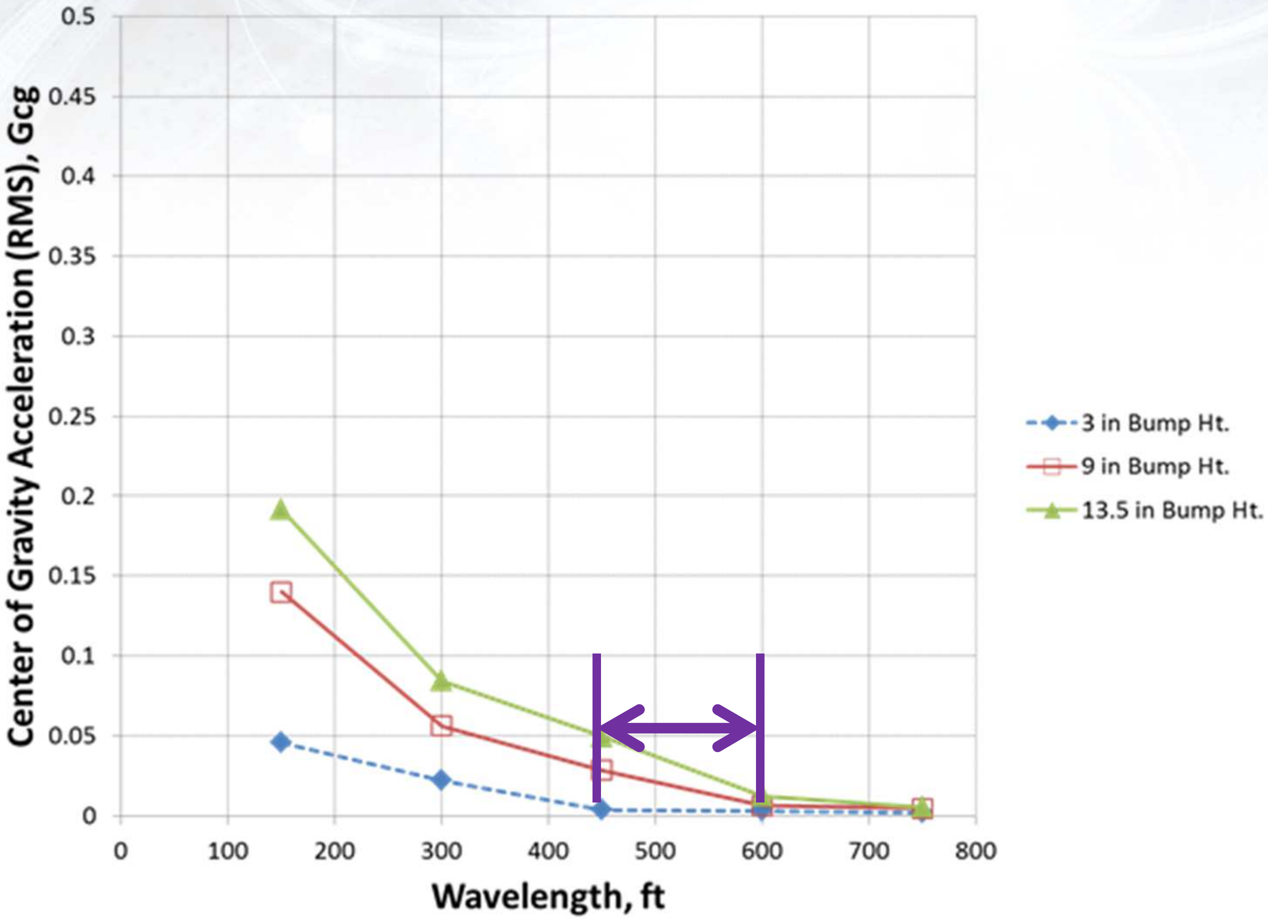
- B727 Gear Config.



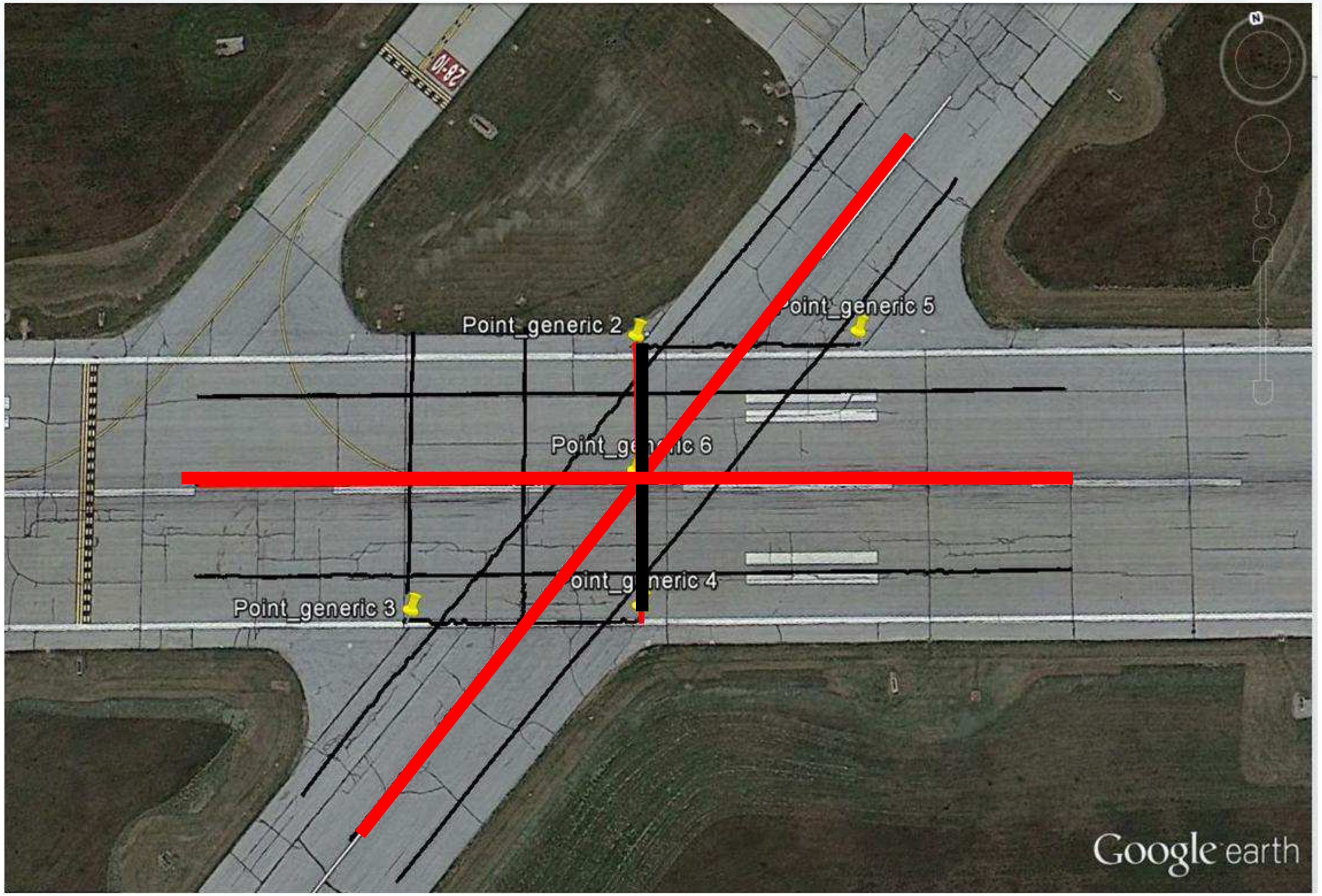
Case Study III: Aircraft Responses to Wavelength Changes – G Responses



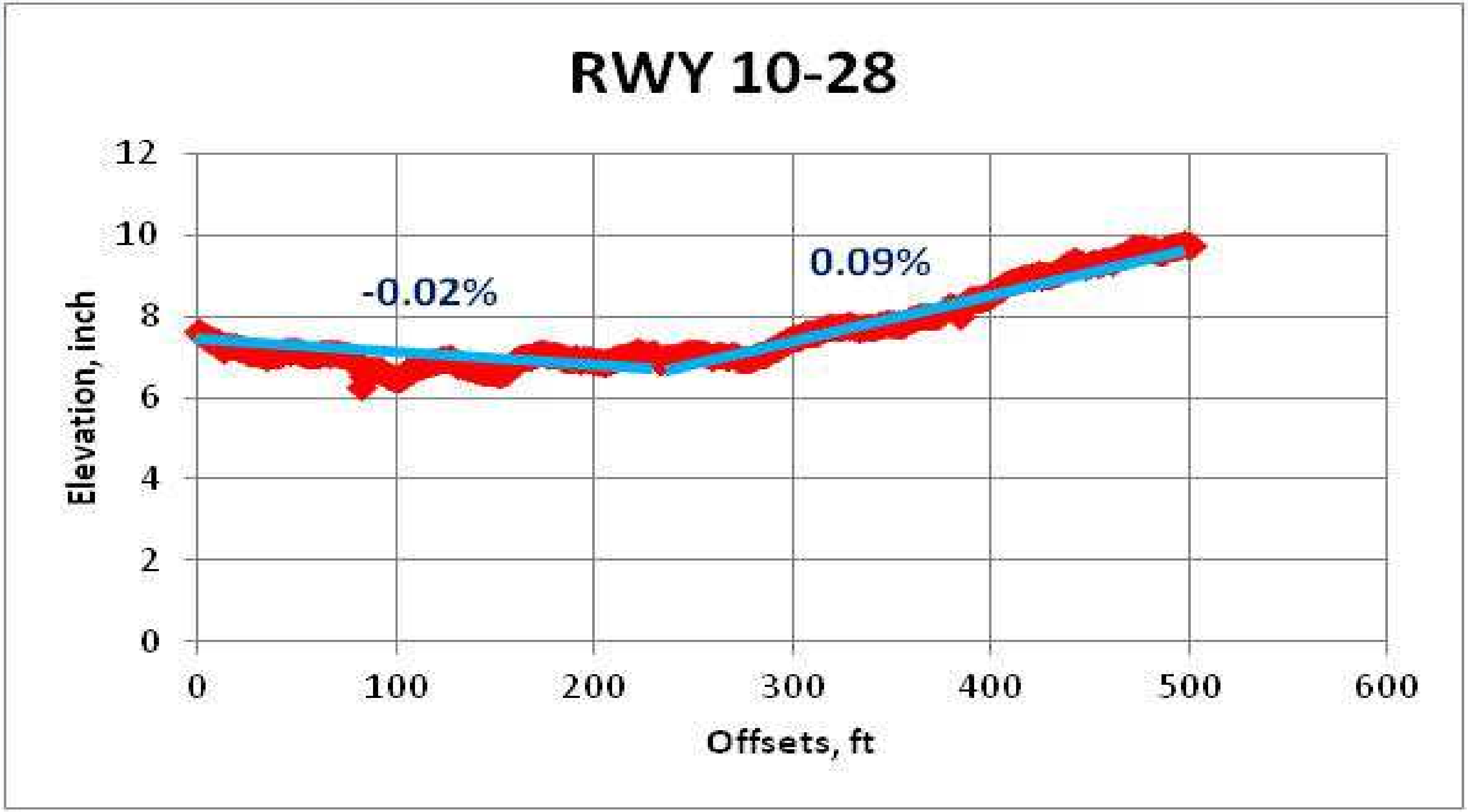
Case Study III: Aircraft Responses to Wavelength Changes



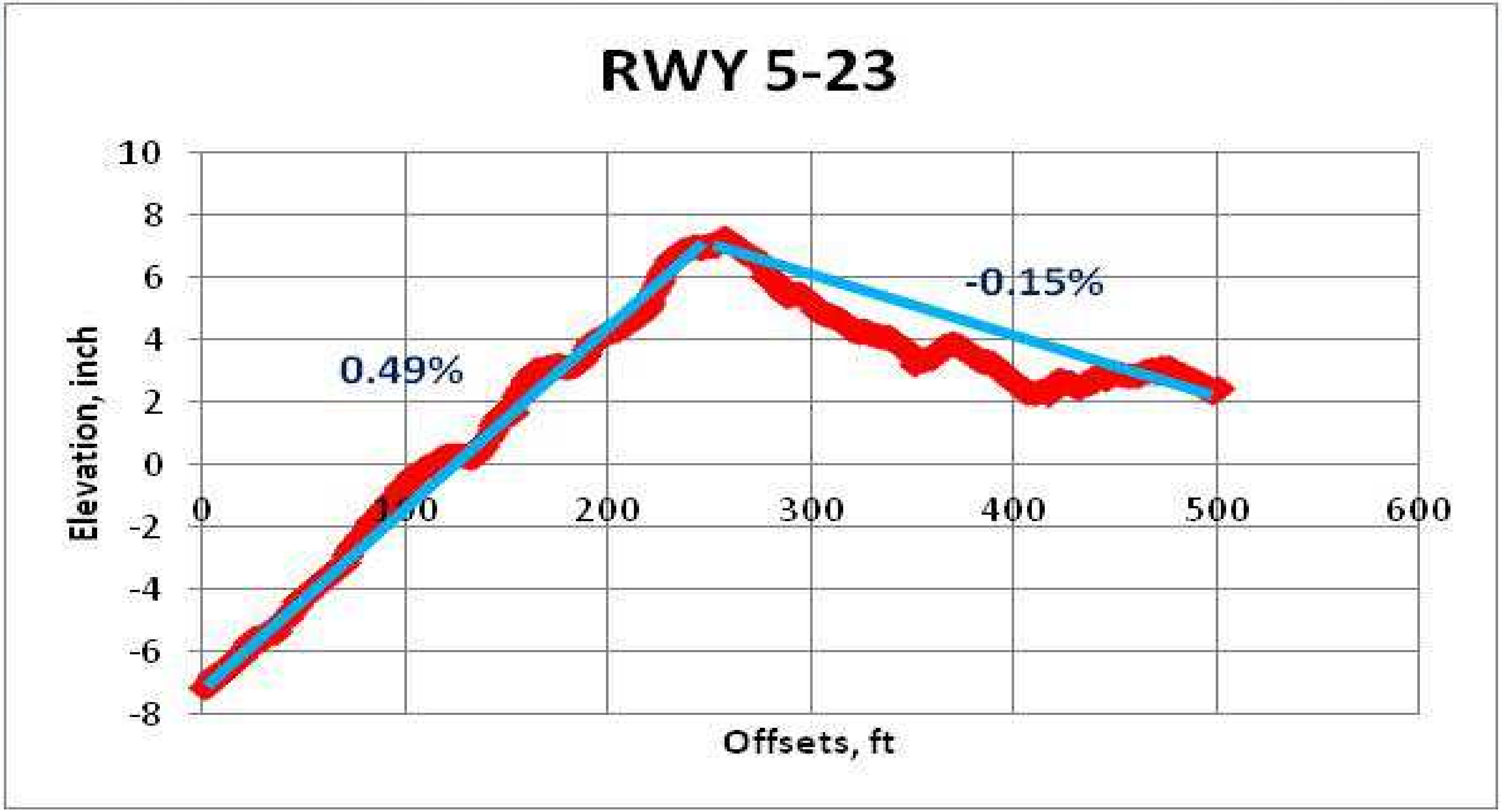
Case Study IV: Runway Intersection Profiling



Longitudinal Slope at Primary Runway



Transverse Slope Secondary Runway



Questions?

Injun Song, Ph.D., P.E.
SRA International, Inc.
Phone: (609) 601 – 6800 ext.173
Email: injun_song@sra.com