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Profiler Correlation for New Airport Pavement Smoothness

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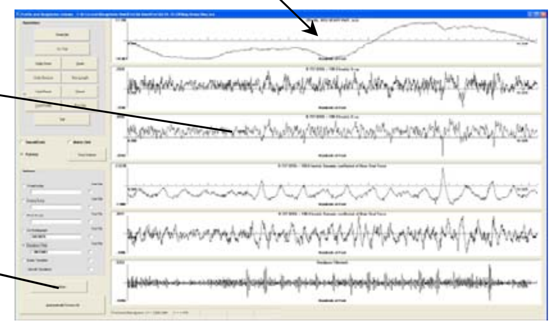
Roughness Study Objectives

- Evaluate the fidelity between pavement profiles and simulator model.
- Develop a rating scale for pilots to evaluate simulator roughness scenarios.
- Use the rating scale to collect pilot ratings of simulator roughness scenarios.
- Use statistical correlation to relate subjective pilot simulator roughness scenarios evaluations to objective measures of airport pavement longitudinal profiles.
- Identify on a rating scale limits for cockpit acceleration resulting in unacceptable or unsafe pavement roughness thresholds.

Roughness Study Objectives

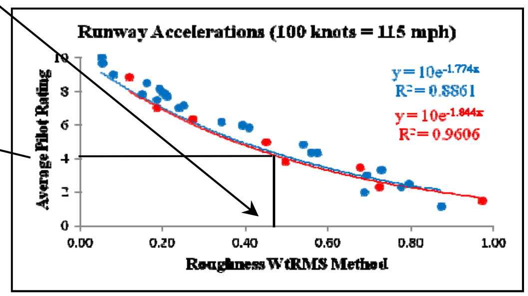
Measure profile and import into ProFAA

Compute vertical cockpit acceleration for a selected aircraft simulation in ProFAA



Filter the cockpit acceleration signal and compute an objective roughness index from the filtered acceleration

Compute a pilot ride quality rating from an established correlation between subjective pilot rating and objective roughness index



Input the ride quality rating into a pavement management database

Field Data Collection

- The FAA collected total of 69 pavement surface profile data from in-service airport runways were used for the statistical analysis including Z-test assuming population mean and standard deviation.
- Sixteen domestic and foreign, Large Hub / Medium Hub / Feeder, Flexible and rigid pavement types, and Runways / Taxiways.

B737 FAA Simulator Study

- 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.
- Simulations included landing gear interaction and fuselage flex and used taxiways and runways having a wide range of roughness.
- Four ISO measures of the vibration experienced in the cockpit were computed for each simulation: weighted Root Mean Square (WtRMS), weighted VDV, weighted MTVV and DKup. Only WtRMS was used for this presentation.
- Pilots gave a 0-10 rating and an acceptable/unacceptable rating to each simulation.
- A model is underway to determine average pilot rating (0-10), uncertainty in pilot rating, and percentage of pilots rating a taxiway or runway as unacceptable as a function of ISO parameter.

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Correlation to Aircraft Simulator Results

- Generally acknowledged that the FAA has accepted standards for pavement roughness construction acceptance as defined by AC 150/5370-10G, Standards for Specifying Construction of Airports.
- There are no models for allowable roughness for in-service airport pavement.
- Develop a rating scale for pilot's subjective response to flight simulator vertical cockpit vibrations excited by longitudinal pavement surface elevation disturbances.
- Incorporate the rating scale in the ProFAA computer program as criteria for establishing limits of allowable roughness for in-service pavement.

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Development of a New Airport Pavement Roughness Index

- Evaluate collected profile data using the FAA inertial profiler from domestic and international airports.
- Additional data using different profiler types such as walking profiling device will be included – PA40 data will be used as well.
- The data includes both flexible and rigid pavement at runways and taxiways.

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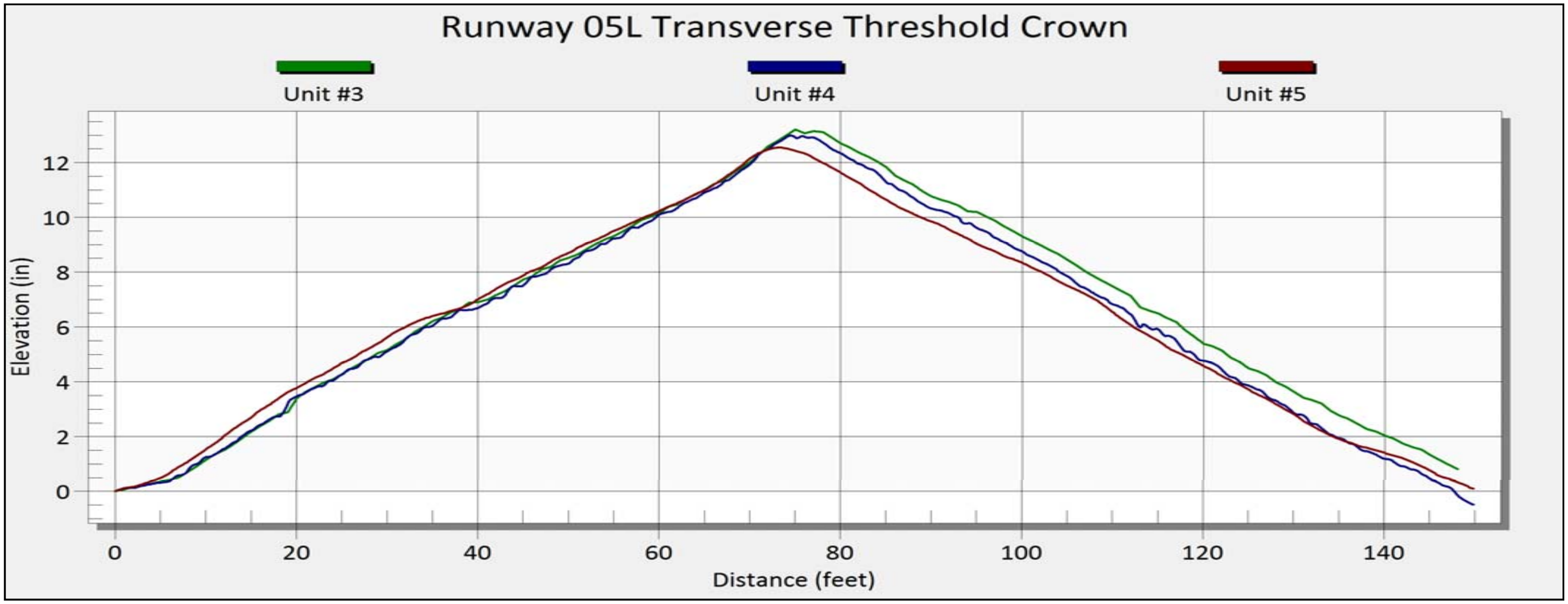
In-Service Airport at a Midwest Location

Site 1 – Non-Grooved PCC Paved in 2012
Site 2 – Grooved PVC Paved in 2010
Site 3 – Grooved HMA Paved in 2012
Site 4 – Non-Grooved HMA (Older)
Site 5 – Rough Grooved HMA (Older)

Profiling Objectives

- Determine if the off-the-shelf profiling devices can produce profile index values that agree with the profilograph profile index values.
- Determine if the off-the-shelf profiling devices can simulate a 12 foot straightedge.
- Determine if the off-the-shelf profiling devices can enhance the process of new pavement acceptance, and reduce unnecessary disputes in the field.

Profile Results



Unit 3 – FAA SurPro • Unit 4 – APR SurPro • Unit 5 - APR Auto Rod & Level

			CP	CP	CP	CP
Start Distance (ft)	Stop Distance (ft)		Run 1	Run 2	Run 3	Average
16.25	528		17.54	14.45	14.96	15.65
528	1,056.00		20	17.00	17.5	18.17
1,056.00	1,516.75		28.08	30.95	30.94	29.99

Pavement Description

Site Number	Length (Feet)	Pavement Type	Notes
Test Site 1	1,600	Non-Grooved PCC paved in 2012	This site will have confined acceleration and deceleration room.
Test Site 2	2,600	Grooved PCC Paved in 2010	Partially confined acceleration room; overrun area can be used.
Test Site 2	150	Grooved PCC Paved in 2010	The transverse crown of this runway will be used to evaluate the 12-foot straightedge
Test Site 3	3,000	Grooved HMA Paved in 2012	The PCC to HMA transition will be the starting point.
Test Site 4	4,000	Older Non-Grooved HMA	Year of pavement placement is unknown at this time
Test Site 5	7,000	Older Grooved HMA	This site offers a relatively rough surface for evaluating profilers on an older in-use pavement. This runway may be closed to air operations for an extended length of time due to other planned construction at WPAFB.

Profiling Devices

List of devices to be evaluated

Profiler Type	Number of Units	Manufacturer	Unit Owner/Operator
Inertial Profiler	1	FAA Inertial Profiler	FAA
	1	AMES 8200	APR
Inclinometer	1	SurPRO	FAA
	1	Dipstick	FAA
	1	SurPRO 4000	APR
External Reference	1	Auto Rod and Level	APR
California Profilograph	1	--	FAA
12-Foot Straightedge	1	--	FAA

Data Analysis Procedure

- Compute Profile Index and Compare to California Profilograph (CP) in 1/10 Mile Sections.
- CP Simulations Will be Compared Using ProFAA and ProVAL.
- Determine the Ability of Each Device to Compute Deviation from a Straightedge and identify areas out of tolerance.

Profiling Equipment

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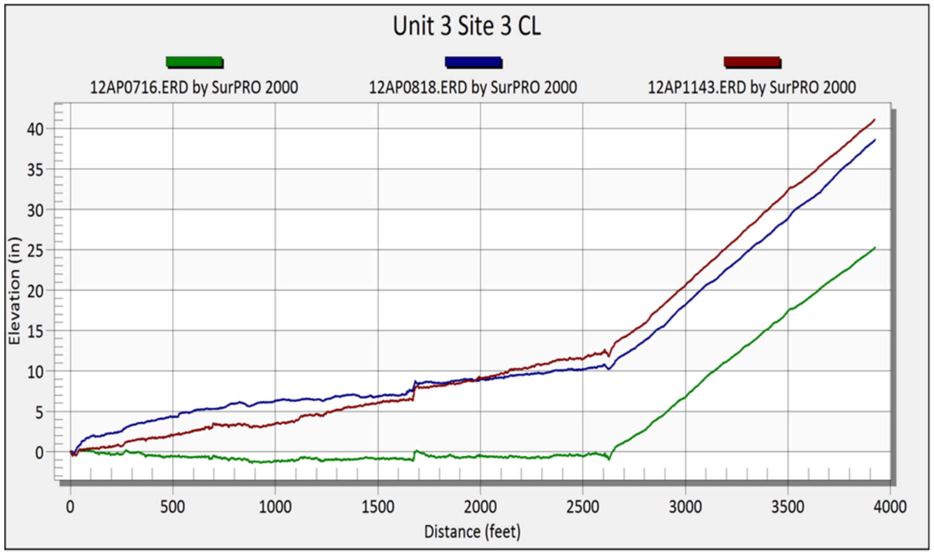
Data Analysis Procedure

- Evaluate Repeatability Between the Profile Index and Straightedge and Expand to other Roughness Indices.
- Evaluate the Capability of Each Device to Measure Grade.
- Using the Aircraft Simulation Capabilities in ProFAA and APRas, Evaluate the Capability of the Profiling Devices to Predict Pavement Response.



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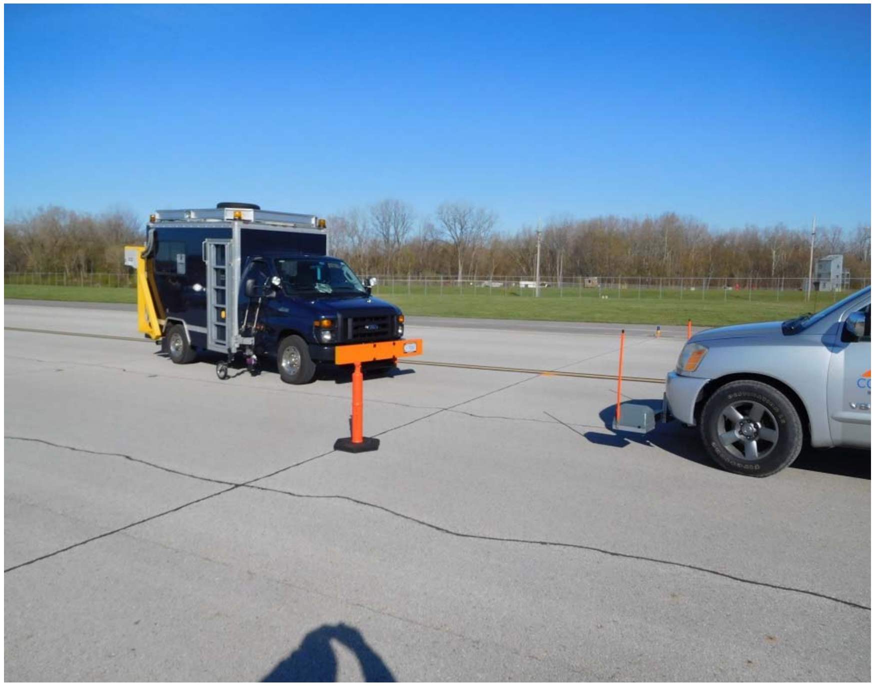
Preliminary Conclusions (A Midwest Location)

- Profile data from several devices was collected in April 2016.
- The walking profilers can produce the same results as a physical 12 foot straightedge.
- ProVAL was compared to the manufacturer’s (SSI) software and to ProFAA used to produce profile index values. The results were comparable. Consequently it is assumed that use the same algorithms and can be used interchangeably.
- Generally, the off-the-shelf profilers tested, show good repeatability when viewing plotted profiles. However some of the tests do show variable results between runs.



B737-800 Flight Simulator

- FAA Mike Monroney Aeronautical Center in Oklahoma City
- Level D Certified Full Flight Simulator
- Six-degree-of-freedom motion system
- High resolution visual display and sound system

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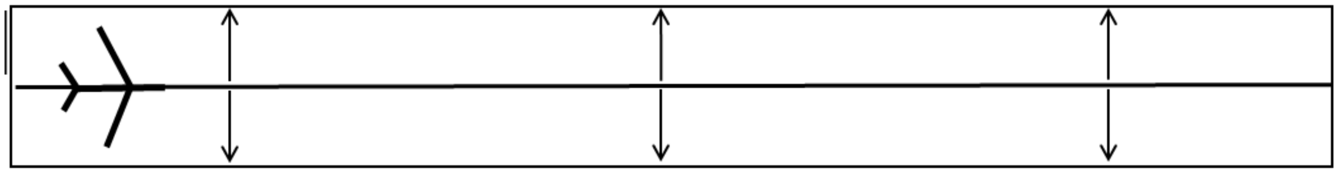
Real-world Surface Profile Integration

- Assumed uniform surface elevation across width of the surface profile.



- Changed standard 1 inch profile sample spacing to 2 feet for runways and 0.4 feet for taxiways.
- Converted elevation units from inches to feet.
- Filtered profiles to remove low frequency variations in elevation

B737 Final Study Test Scenarios

- Taxiway and runway profiles selected from U.S. and foreign airports to provide a wide range of surface roughness.
- Each scenario provides a 30 second profile section:
- 37 constant speed taxiway scenarios – 20 knots (37.0 km/h)
- 37 constant speed runway scenarios – 100 knots (185 km/h)
- Scenarios provide automated movement along the profile sections with no pilot input required

Correlations between Acceleration Thresholds and ProFAA Indexes

- The Correlate ISO simulator thresholds with roughness indexes calculated by ProFAA.
- Statistical analysis for each index using the results from the simulator project.
- Statistical Analysis: Population standard deviation not to exceed 15 percent of the population mean and the 95 percent confidence level.
- Validate the proposed thresholds using the FAA collected profile data of various pavement ages.

ISO Index Definitions

- Acceleration Dose (DkUp): the maximum absolute value of the response acceleration…For the z-direction only positive peaks shall be counted…
- Weighted Maximum Transient Vibration Value (MTVV): the highest maximum vibration level during a measurement period recorded in 1 second intervals to account for transient motion and short acceleration peaks.
- Weighted Vibration Dose Value (VDV): a cumulative measurement of the vibration level received over an 8-hour or 16-hour period
- Weighted Root Mean Square (WtRMS): of a time-varying quantity is obtained by squaring the amplitude at each instant, obtaining the average of the squared values over the interval of interest, and then taking the square root of this average.
- Reference: International standard ISO 2631-1:1997(E), 2631-4:2001(E), & Gracey & Associates Acoustic Glossary

Correlation Coefficients Between Different Seats

- **Correlation coefficients between the ride ratings by pilots in different seats shows that rides in the three seats were similar.**

Taxiway Correlation Coefficients	Captain	1st Officer	Observer
Captain	1.000	0.989	0.991
1st Officer	0.989	1.000	0.990
Observer	0.991	0.990	1.000

Runway Correlation Coefficients	Captain	1st Officer	Observer
Captain	1.000	0.985	0.990
1st Officer	0.985	1.000	0.987
Observer	0.990	0.987	1.000

B737 FAA Simulator Study Results

ISO Roughness Index	Index Value When 5% of Pilots Rate the Taxiway as Unacceptable	Index Value When 10% of Pilots Rate the Taxiway as Unacceptable	Index Value When 50% of Pilots Rate the Taxiway as Unacceptable	Index Value When 5% of Pilots Rate the Runway as Unacceptable	Index Value When 10% of Pilots Rate the Runway as Unacceptable	Index Value When 50% of Pilots Rate the Runway as Unacceptable
Weighted RMS (m/s^2)	***0.31***	***0.39***	***0.67***	***0.35***	***0.47***	***0.91***
Weighted MTVV (m/s^2)	***0.71***	***0.94***	***1.72***	***0.68***	***0.99***	***1.91***
Weighted VDV ($m/s^{1.75}$)	***4.11***	***5.32***	***9.29***	***4.16***	***5.66***	***10.88***
DKup (m/s^2)	***1.82***	***2.40***	***4.45***	***1.69***	***2.40***	***4.81***

ISO Standard for RMS:

Weighted RMS m/s^2	Discomfort Level
0-0.315	not uncomfortable
0.315-0.63	a little uncomfortable
0.5-1.0	fairly uncomfortable
0.8-1.6	uncomfortable
1.25-2.5	very uncomfortable
> 2.0	extremely uncomfortable

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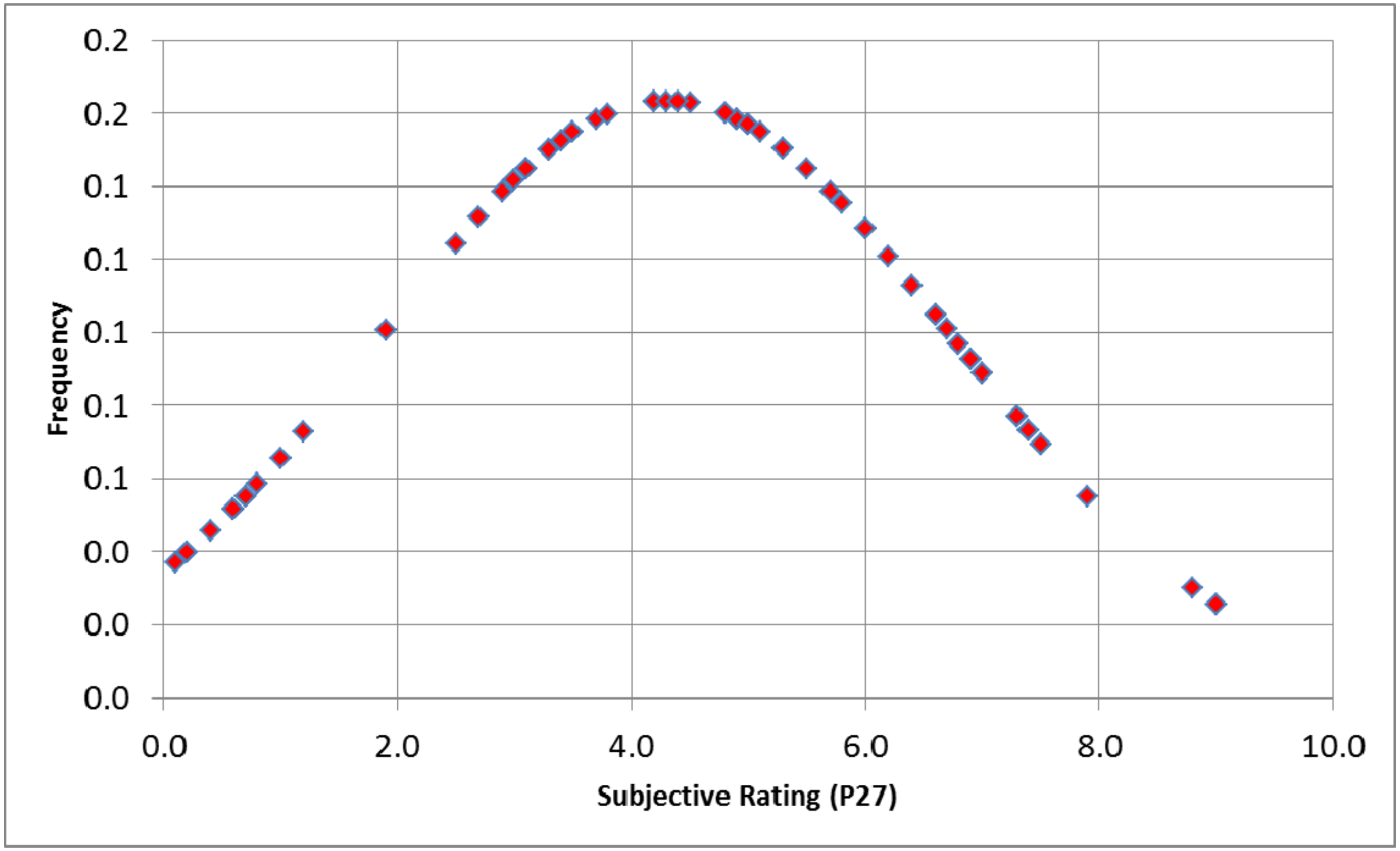
Normal Distribution in Pilot Rating (example)



Roughness Index Correlations with Pilot's Subjective Rating

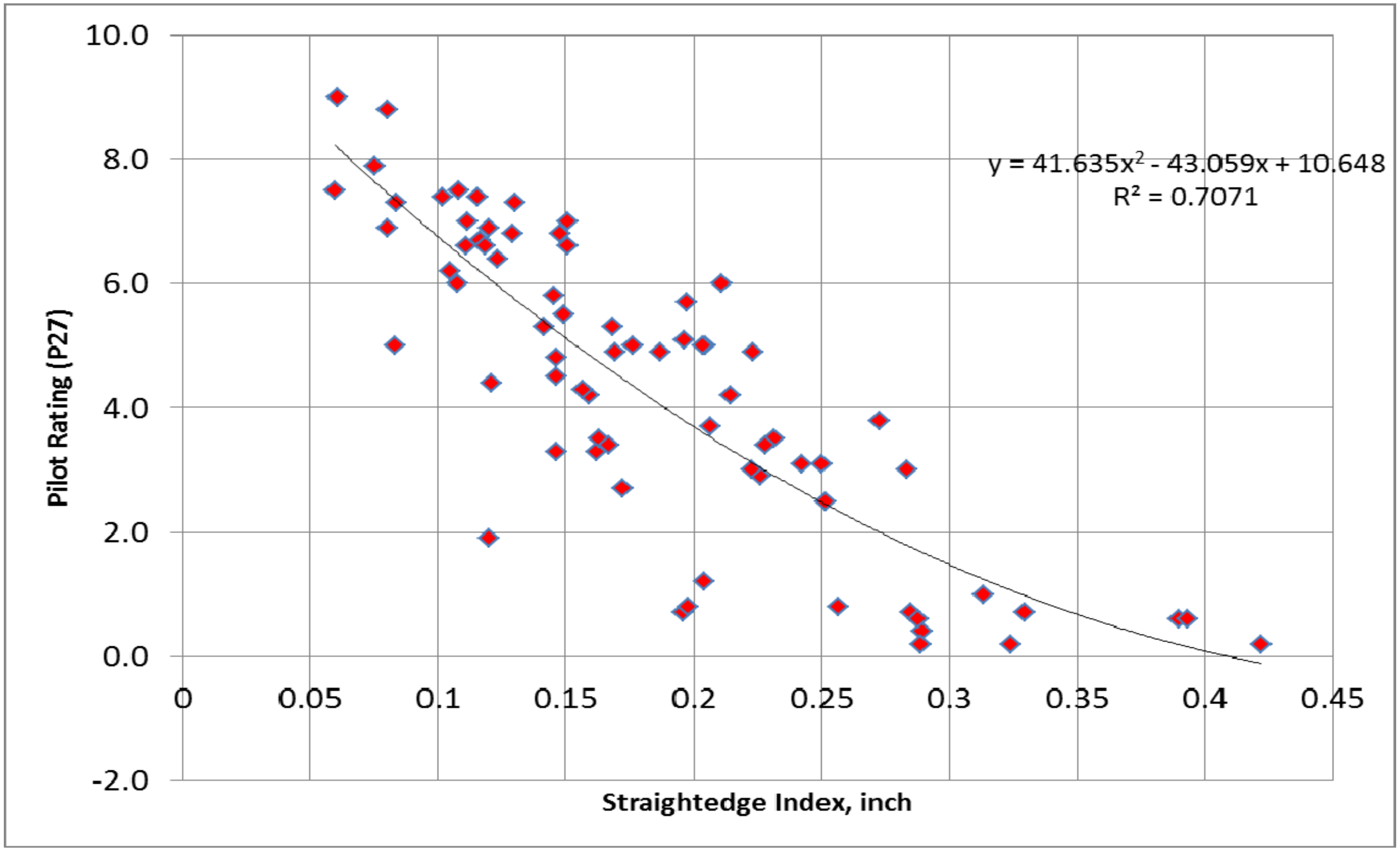
- **Three roughness indexes, WtRMS, IRI, and Straightedge, are correlated better to the pilot's subjective rating.**

Roughness Index\Pilot	P8	P14	P15	P16	P17	P18	P21	P22	P25	P26	P27	P31	P33	P34	Average
Straightedge, inch	0.63	0.58	0.65	0.65	0.68	0.61	0.68	0.62	0.71	0.63	0.71	0.61	0.50	0.56	**0.63**
Boeing Bump Index	0.22	0.21	0.36	0.33	0.38	0.27	0.29	0.21	0.36	0.23	0.36	0.28	0.09	0.21	0.27
IRI, inch/mile	0.64	0.56	0.66	0.68	0.72	0.65	0.65	0.60	0.71	0.64	0.73	0.63	0.45	0.57	**0.64**
Profile Index, inch/mile	0.59	0.52	0.63	0.65	0.69	0.62	0.62	0.56	0.67	0.60	0.71	0.62	0.40	0.53	0.60
BandPass Filter	0.51	0.47	0.54	0.59	0.55	0.56	0.55	0.48	0.62	0.55	0.61	0.51	0.34	0.47	0.52
WtRMS, m/sec^2	0.81	0.77	0.72	0.64	0.73	0.75	0.80	0.85	0.65	0.83	0.80	0.78	0.75	0.72	**0.76**
Average	0.57	0.52	0.59	0.59	0.63	0.58	0.60	0.55	0.62	0.58	0.65	0.57	0.42	0.51	**0.57**

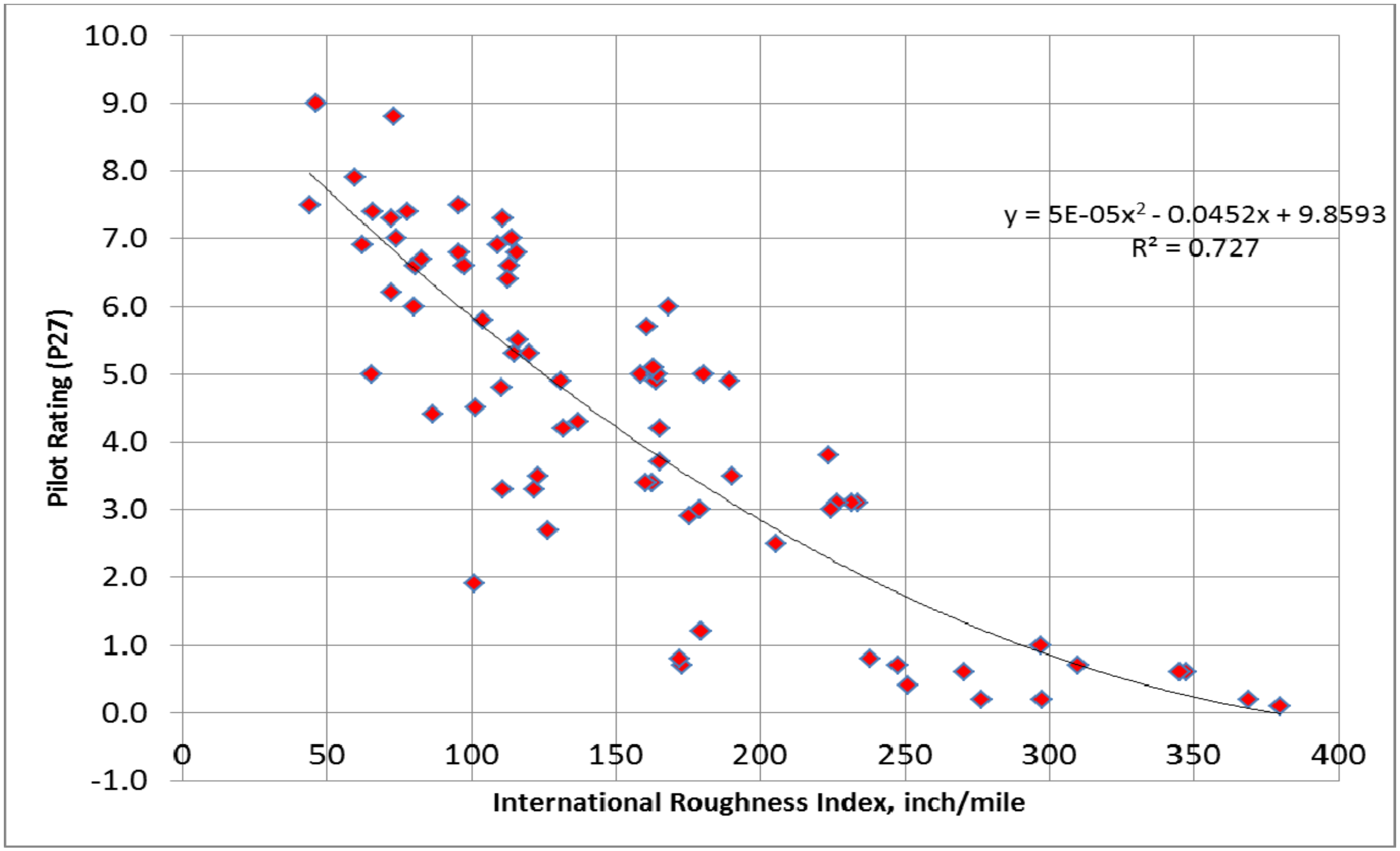
Z-test Results

- For the Boeing Bump Index, with 95.9 percent confidence level we reject the null hypothesis that the 37 pilots data are comparable to a simple random sample from the population of the roughness data.
- The BandPass also satisfy the 95.9 percent confidence level to reject the null hypothesis.
- However, Straightedge, IRI, PI, and WtRMS satisfy 74.3 percent, 76.3 percent, 79.0 percent, and 87.8 percent confident level to reject the null hypothesis, respectively.

Pilot rating vs. Straightedge Index



Pilot rating vs. IRI



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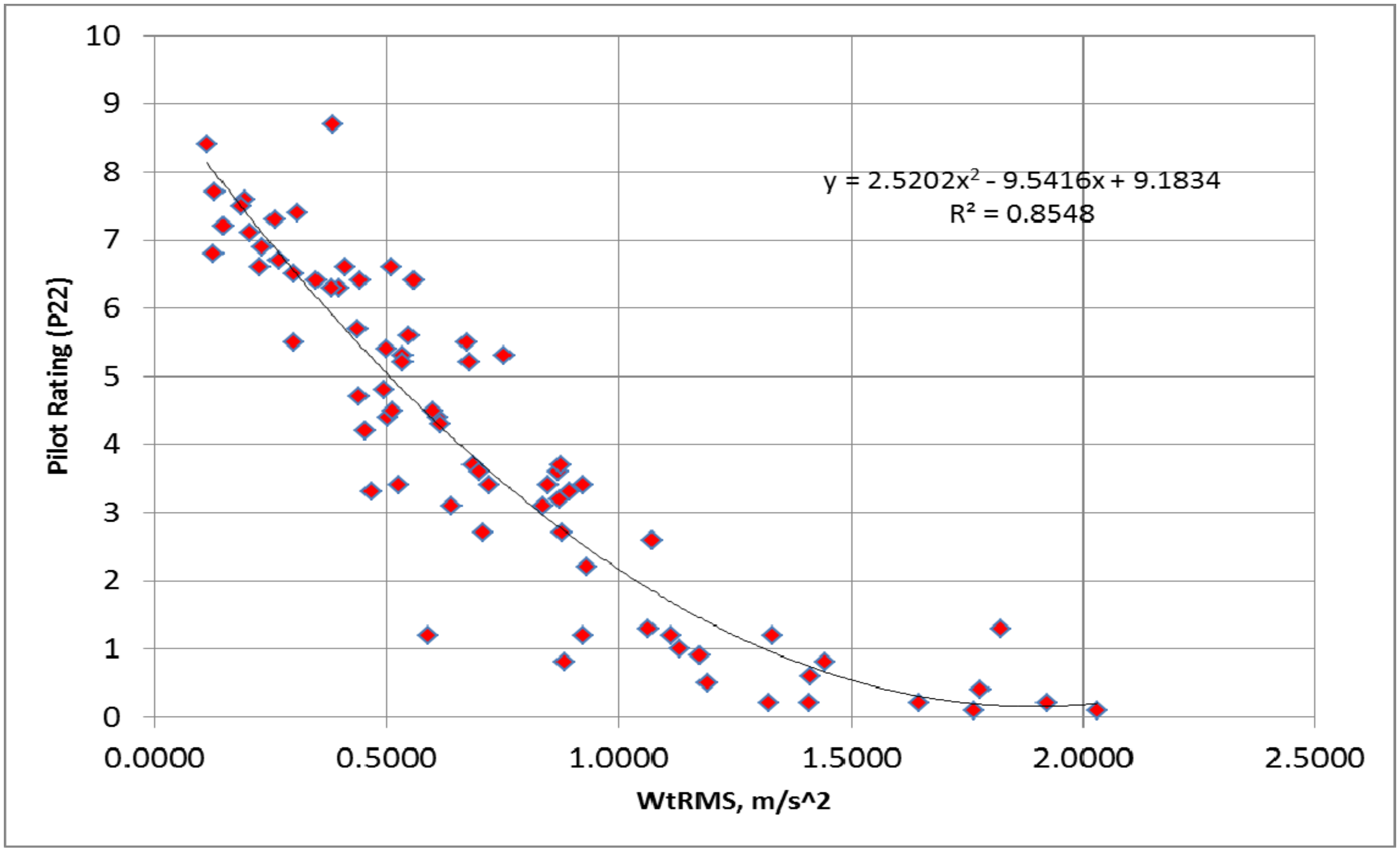
Pilot rating vs. WtRMS



Proposed Steps for New Index Development

1. Consider both User's rideability and Pavement Surface Conditions for In-Service Airport Pavements.
2. Correlate Cockpit Accelerations (g) with Pilot's Subjective Rating with Current Pavement Roughness Indexes.
3. Correlate to Cockpit Simulation (g) in ProFAA.
4. Compare Wavelength Sensitivity Reflecting Constructability (+drainage) with Aircraft Simulation Studies.
5. Select Appropriate Independent Parameters.
6. Develop Protocols to Evaluate In-Service Airfield Pavements including Regression Model(s).

Sample Roughness Modeling

- Rated Cockpit Accelerations (g): Rideability Reflecting Pilot's Subjective Rating.
- Pavement Roughness Index (RI): Pavement Conditions.
- Wavelength Criteria (W): Constructability and Drainage.
- Pavement Type (P): Asphalt or Concrete
- An Example of Preliminary Equation.
- $f(x)=\{x1, x2, x3, x4,\ldots., xn\} = \{g, RI, W, P\ldots\}$

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Conclusions and Recommendations

- Z-test was performed for the data approximately normally distributed under the null hypothesis.
- The 37 pilots' data are comparable to a simple random sample from the population of the roughness data collected from 69 in-service airports.
- For the Boeing Bump Index and BandPass Filter, with 95.9 percent confidence level we reject the null hypothesis that the 37 pilots data are comparable to a simple random sample from the population of the roughness data.
- Correlation Coefficient (R^2) of 0.70, 0.72, and 0.85 are computed between pilot's subjective rating and Straightedge Index, IRI, and WtRMS, respectively.
- The population data will include the FAA collected from in-service airfield pavements after the data used in this presentation.
- The additional data from on-going A330 aircraft simulator project at Mike Monroney Aeronautical Center will be analyzed when they are available.

Airbus A330/340 FAA Simulator

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FAA Airport Pavement Roughness Research Website

http://www.airporttech.tc.faa.gov/Airport-Pavement/Nondestructive-Pavement-Testing/AirportPavementRoughnessResearch

Thanks

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