Introducing an Alternative Method of Assessing Airport Pavement Roughness

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Presentation Outline

- Part 1 – Brief history and background of the simulator roughness project
- Part 2 – Simulator programming
- Part 3 – Statistical analysis
- Part 4 – Introduction of the new airport pavement roughness index for in-service pavement

Acknowledgements

- The NAPTF gratefully recognizes the following:
- Cooperation and simulator access provided by the Mike Monroney Aeronautical Center AFS-440 Flight Operations Simulation Branch.
- Contributions of Dr. G. Hayhoe, particularly with the implementation of the ISO standards in the data analysis.

Project History

- **Phase 1 – simulator roughness feasibility delivered August 2009.**
- **Phase 2 – Preliminary study four - three man crews total of 12 pilots providing subjective profile evaluations – delivered July 2012**
- **Phase 3 – Final study 12 three man crews for a total of 36 pilots anticipated delivery – August 2014**
- **Phase 4 – replicate phases 1 and 3 (MMAC Boeing simulator) in the MMAC Airbus simulator, anticipated delivery - September 2014.**

Study Application

- Generally acknowledged that the FAA has accepted standards for pavement roughness construction acceptance.
- 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.

Final Objectives

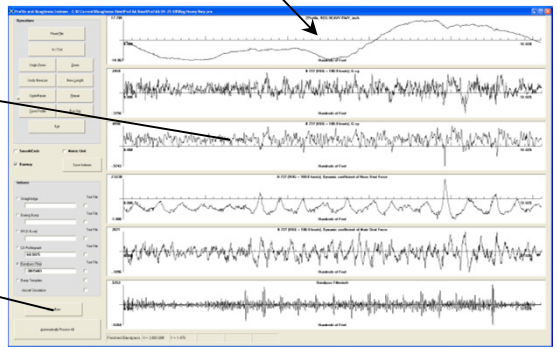
Measure profile and import into ProFAA

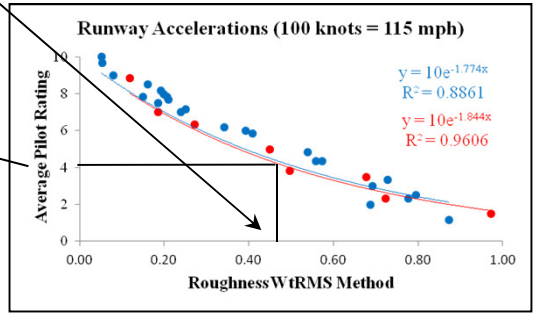
Compute vertical cockpit acceleration for a selected aircraft simulation in ProFAA

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





B737-800 Flight Simulator

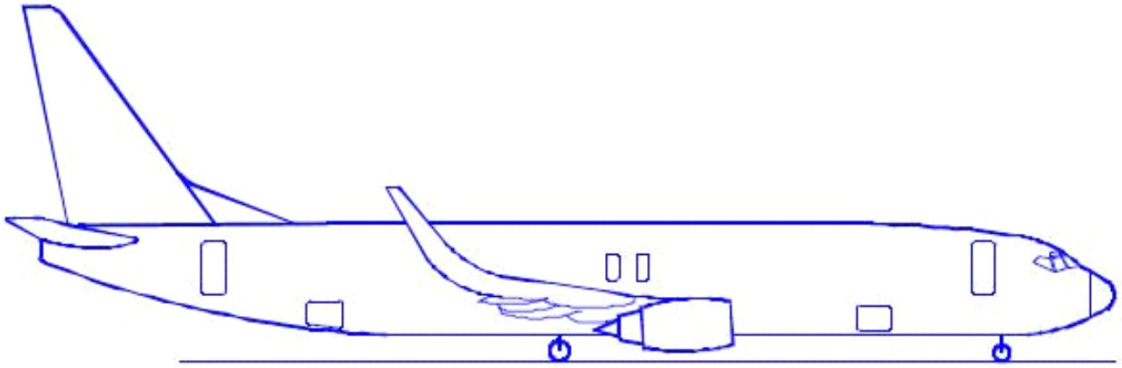
- FAA Mike Monroney Aeronautical Center in Oklahoma City
- Level D Certified Full Flight Simulator
- Six-degree-of-freedom motion system
- High resolution visual display and sound system

B737 Flight Simulator Enhancements

- **Modified the simulator ground model to allow selection and input of real world airport surface elevation profiles.**
- **Updated the simulator software to provide realistic cockpit accelerations in response to the real world profiles.**
- **Developed simulator test scenarios for obtaining pilot subjective ratings of surface roughness and to record objective measures of cockpit acceleration.**

Simulator Flight Model Update

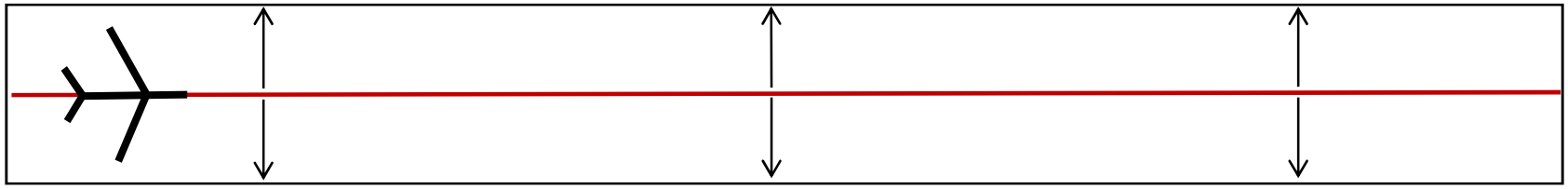
- **The standard simulator flight model assumes a rigid aircraft body.**



- **In order to provide a realistic cockpit response to surface roughness, an airframe flexible mode model was added to the simulator flight model.**

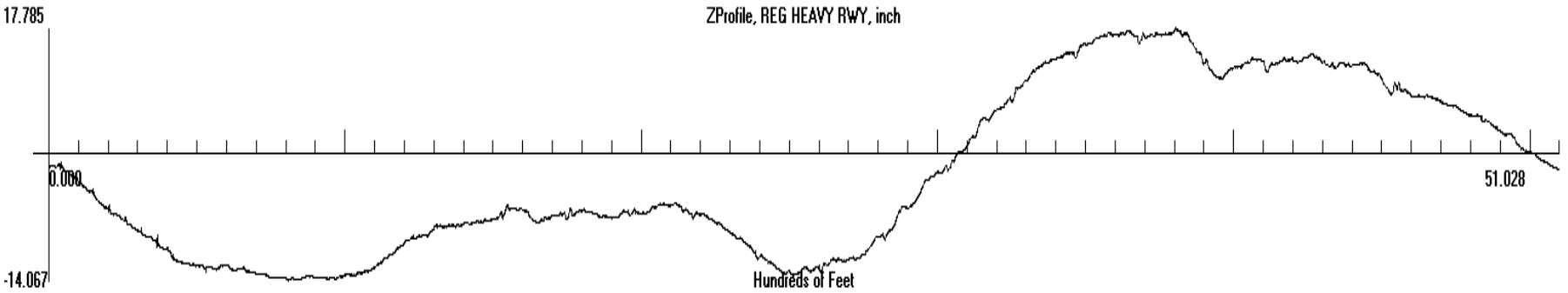
Real-World Surface Profile Integration

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

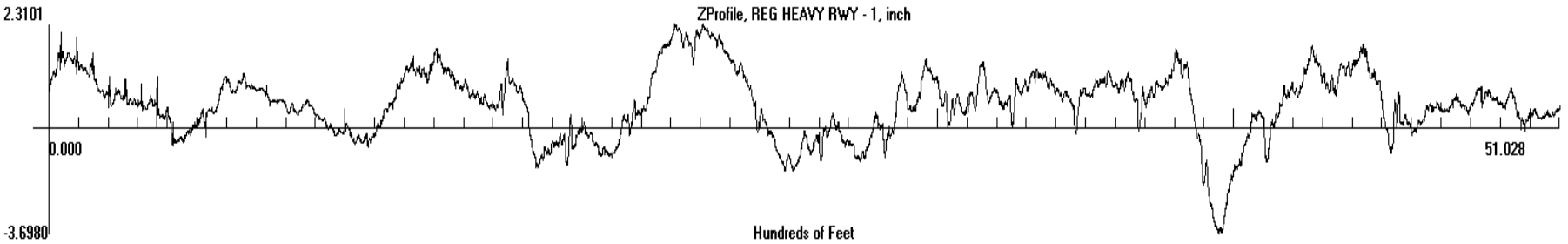


- **Changed original profile sample spacing to 2 feet for runways and 0.4 feet for taxiways**
- **Converted elevation units from inches to feet.**
- **Filtered profiles to remove low frequency variations in elevation**

Profile Filtering Example



Runway elevation profile before 1000 foot high-pass filtering



Runway elevation profile after 1000 foot high-pass filtering

Roughness Study Test Design

1. Pre-briefing to explain study and provide rating instructions
2. Presented a series of taxiway and runway roughness scenarios to three pilots per session (Captain, F/O, Observer seats)
3. Obtained pilot subjective roughness ratings for each scenario
4. Collected objective cockpit acceleration data for each scenario
5. Post-brief session to obtain pilot feedback on realism of simulated roughness and general comments
6. Analyzed data to correlate subjective ratings with cockpit acceleration indices

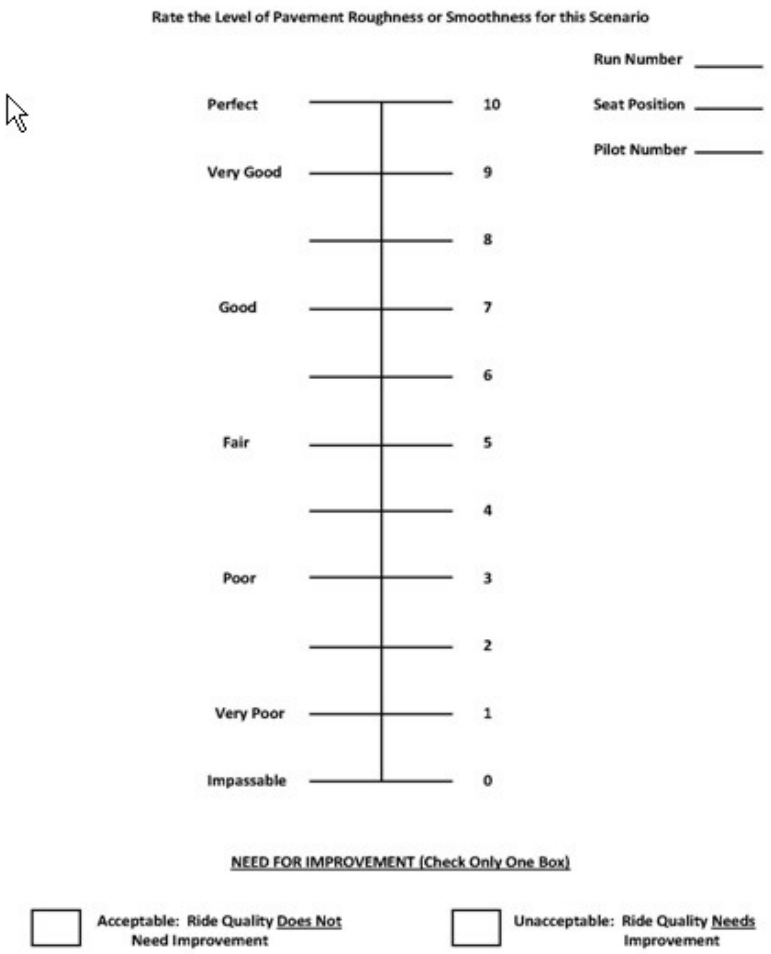
Final Study Test Scenarios

- 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
- 40 constant speed taxiway scenarios – 20 knots
- 40 constant speed runway scenarios – 100 knots
- Scenarios provide automated movement along the profile sections with no pilot input required

Pilot Evaluation Form

Pilots evaluated each profile on a 0-10 scale and provided an acceptable/unacceptable rating after each run.

Rating form developed using ASTM1927 and NCHRP 308.



Currently Updating Airbus A330 Flight Simulator for Phase IV Study

Statistical Analysis

- **Sample averages** for the 37 taxiway and 37 runway real world scenarios (as presented to 33 final study pilots)

- **Individual samples** from a total of 1572 individual pilot responses for taxiways and for runways (37 real world scenarios presented to 36 final study pilots and 20 real world scenarios presented to 12 preliminary study pilots)

Find a quantitative measure to predict when pilots will find a taxiway or runway too rough

Model Data Inputs:

Quantitative measures of runway roughness were computed in terms of four ISO* roughness indices that were evaluated by formulas based on cockpit accelerations:

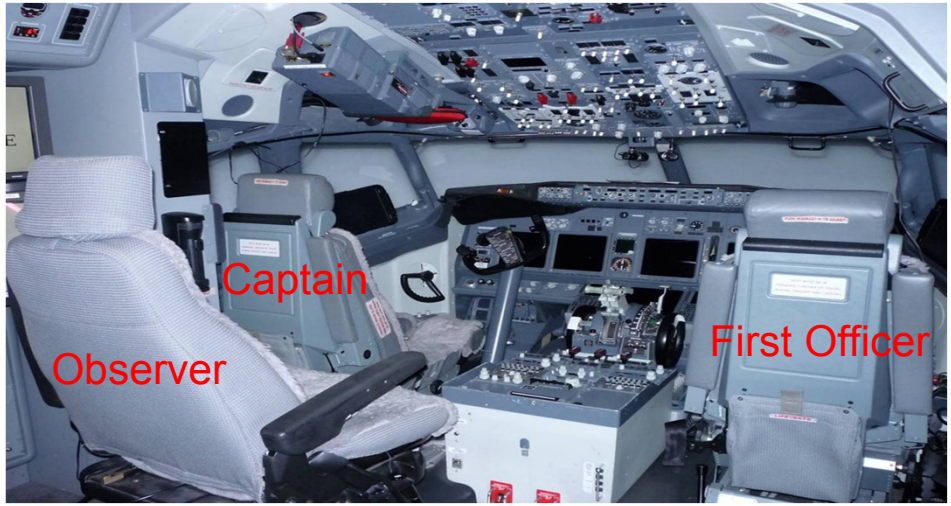
- Weighted root mean square acceleration, RMS
- Maximum transient vibration value from a running RMS computation, MTVV
- Fourth power vibration dose value, VDV
- Spinal response acceleration (sixth power) dose value, DKup

The ISO ratings were compared with pilot subjective responses for the same rides:

- From each pilot on each taxiway or runway, a ride rating of 0-10
- From each pilot on each taxiway or runway, an acceptable or unacceptable rating

* ISO 2631-1, "Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration," Part 1: "General Requirements"

Correlation Coefficients Between the Ride Ratings By Pilots in Different Seats Shows That Rides in the Three Seats Were Similar



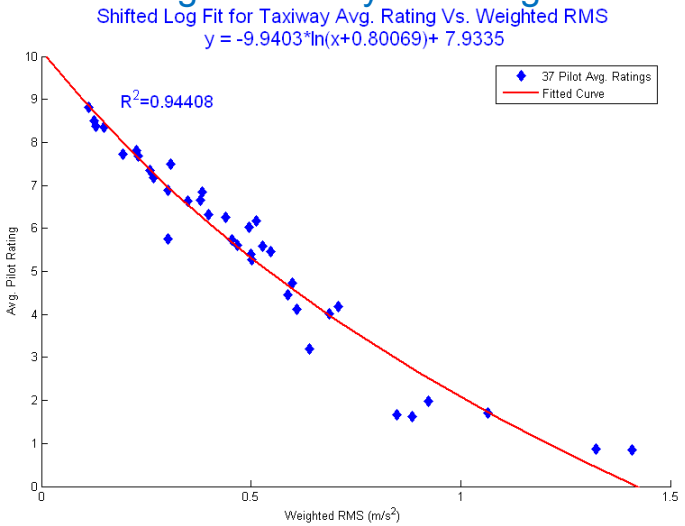
Taxiway Correlation Coef's	Captain	1st Officer	Observer
Captain	1.000	0.989	0.991
1st Officer	0.989	1.000	0.990
Observer	0.991	0.990	1.000

Runway Correlation Coef's	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

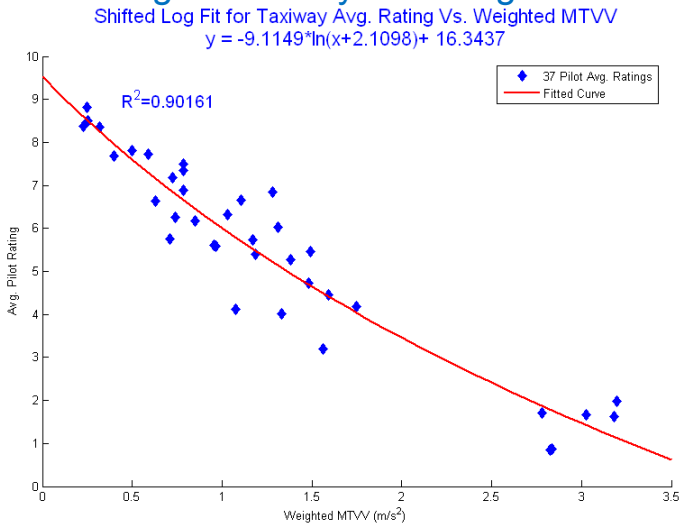
* An average correlation coefficient of 0.99 (99%) was observed between pilot ride ratings (0-10) from different seats, in which a coefficient of 1.0 indicates perfect correlation and 0.0 indicates no correlation

Clear Trends Appear For Pilot Average Ride Rating (0-10) Vs. ISO Indices

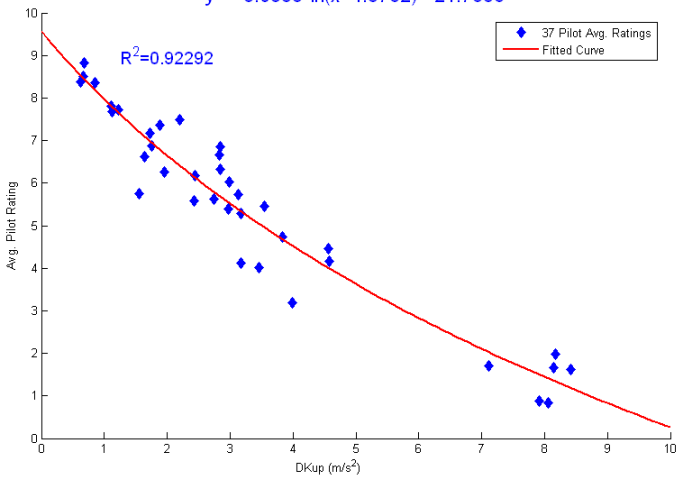
Pilot Rating of Taxiway Vs. Weighted RMS



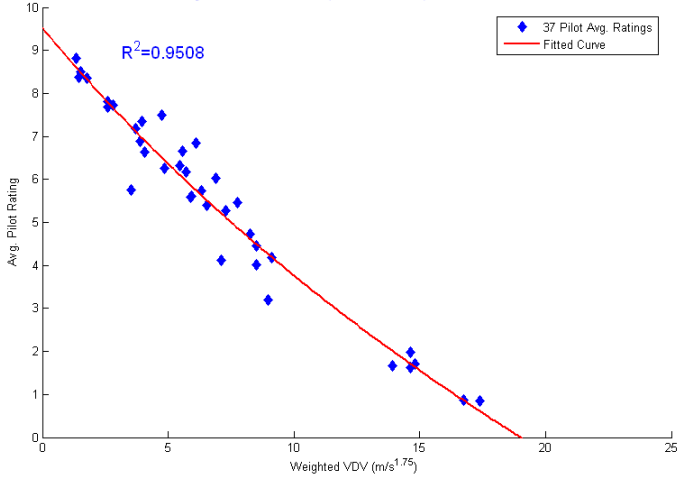
Pilot Rating of Taxiway Vs. Weighted MTVV



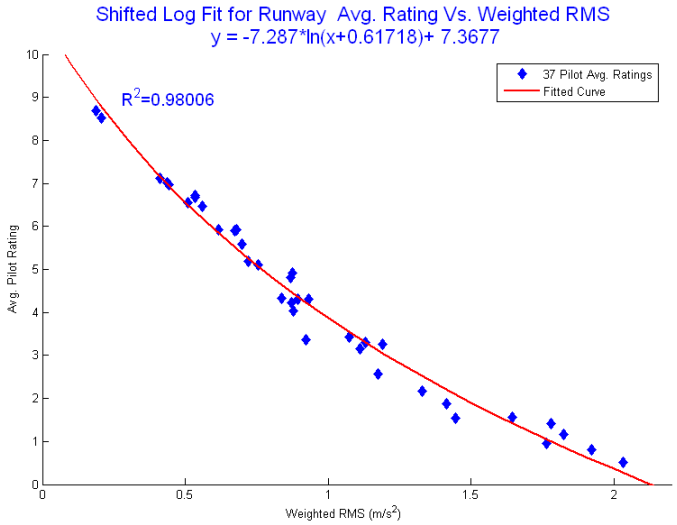
Pilot Rating of Taxiway Vs. DKup



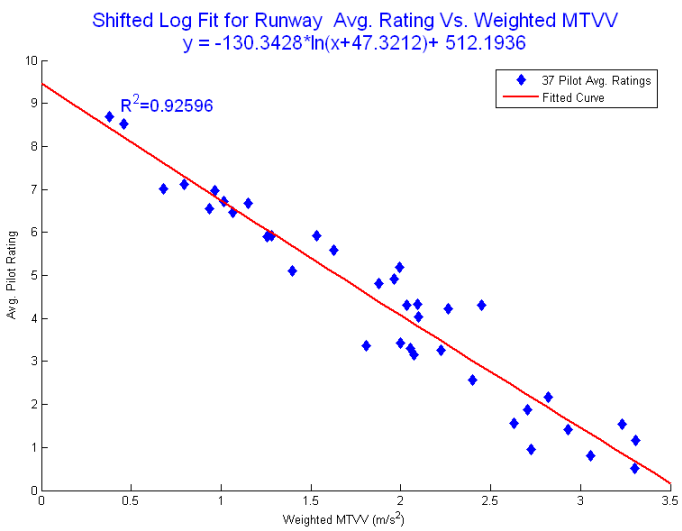
Pilot Rating of Taxiway Vs. Weighted VDV



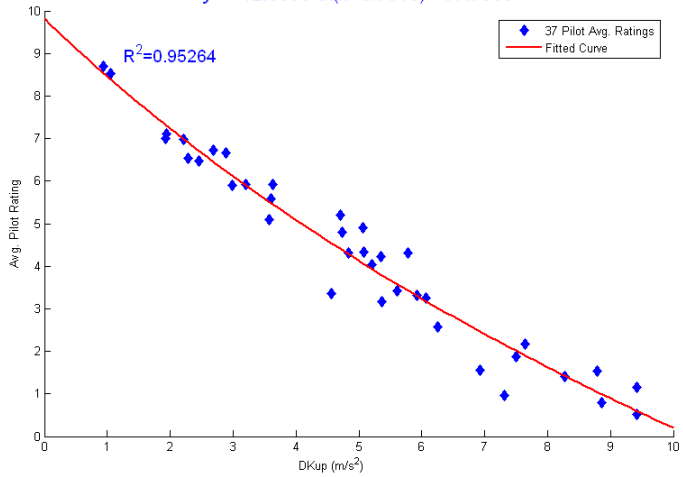
Pilot Rating of Runway Vs. Weighted RMS



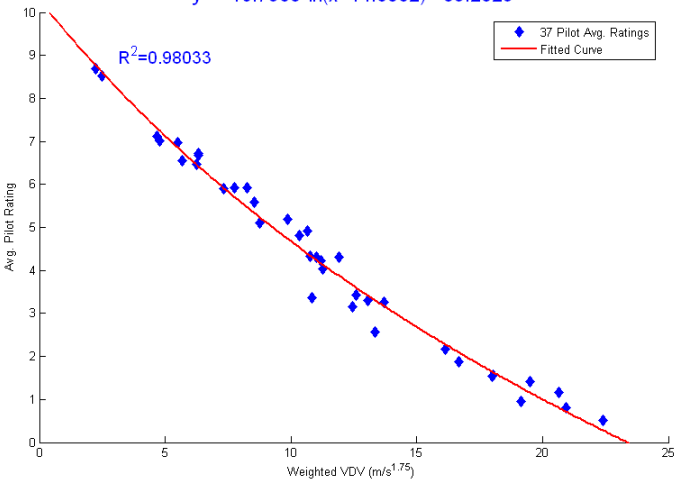
Pilot Rating of Runway Vs. Weighted MTVV



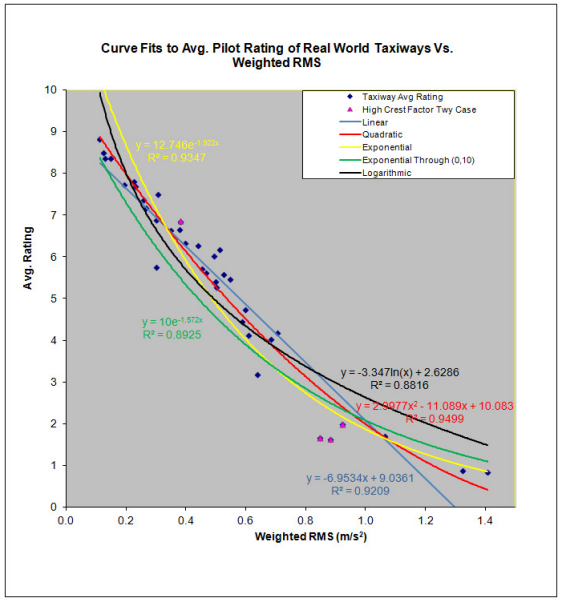
Pilot Rating of Runway Vs. DKup

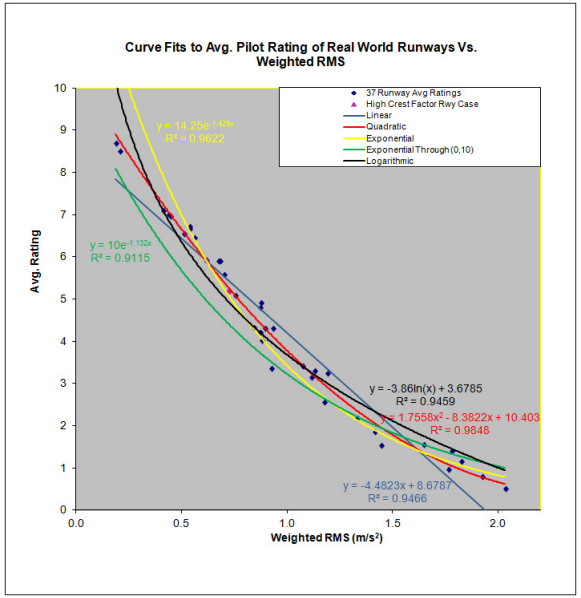


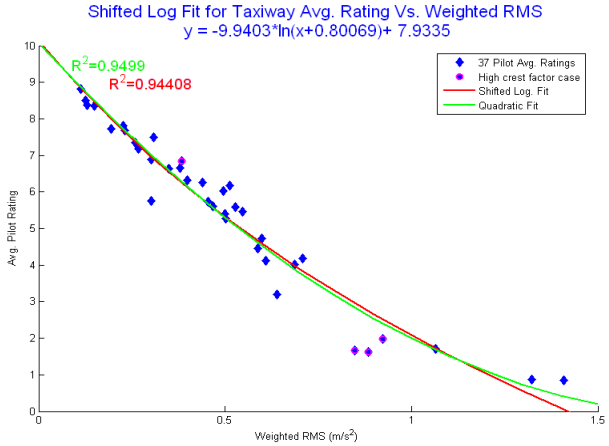
Pilot Rating of Runway Vs. Weighted VDV

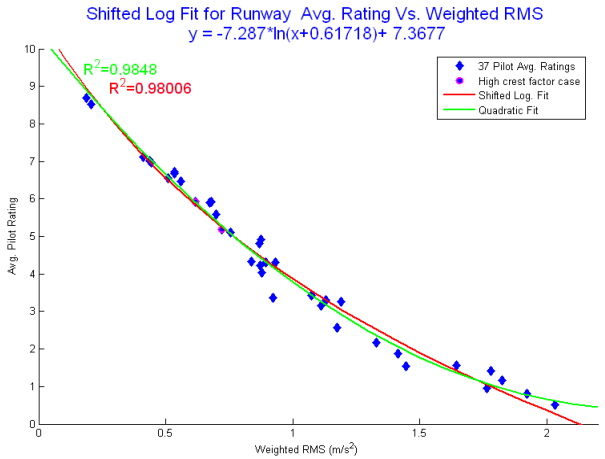


Various Fits Were Attempted









Fits of ISO Index Vs. Percentage of Pilots Rating Surface Unacceptable Were Compared With ISO Standards

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 VDV:

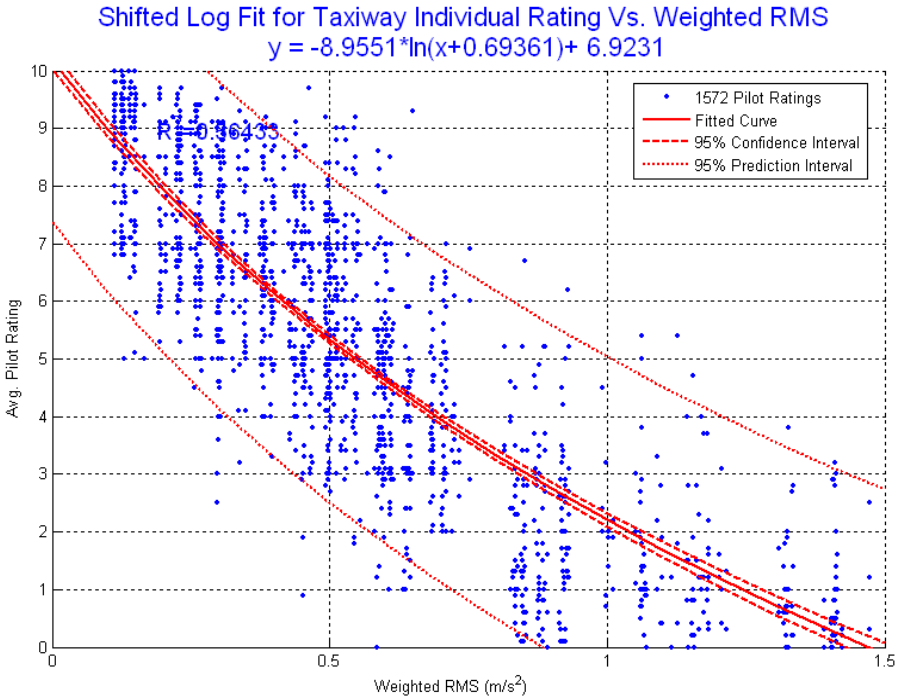
"caution with respect to health risks is indicated" for VDV exposures from 8.5 to 17 $m/s^{1.75}$.

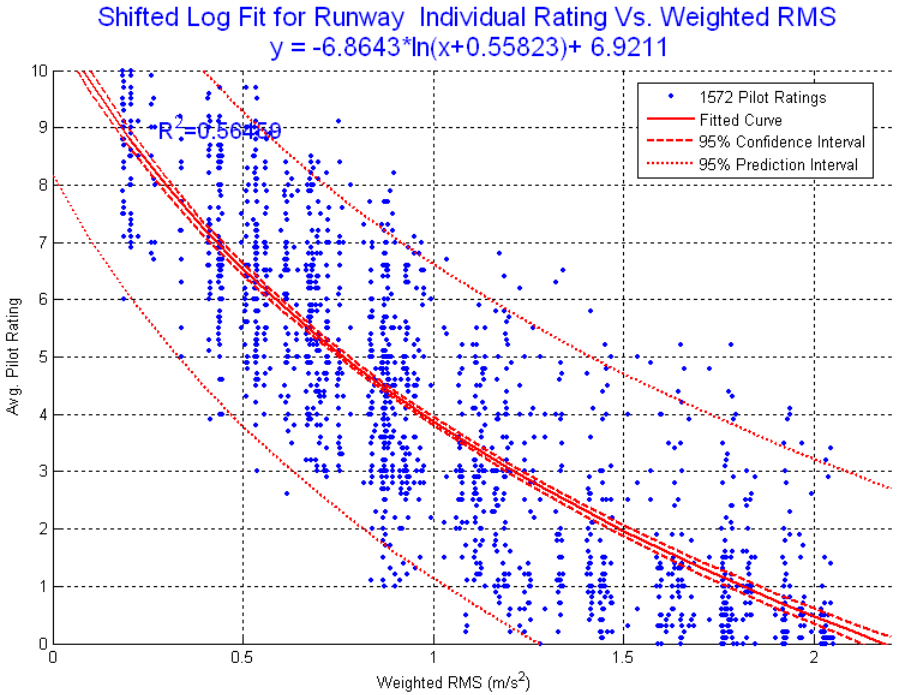
ISO Standard for RMS:

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

Confidence Intervals for the Best Fit Curves Were Small

Prediction Intervals for Individual Pilot Ratings Were Much Larger





Model Using Pilot Rating To Indicate When an In-Service Surface is Too Rough:

1. Measure the taxiway's or runway's vertical profile
2. Run the profile through ProFAA* to calculate ride ISO indices**
3. Use curve fits of simulator test pilot data (such as appear here) to predict what percentage of pilots would find the ride unacceptable and the uncertainty in pilot response
4. Apply criteria (TBD) based on step 3 or similarly fitted quantities to decide if the ride is acceptable

Illustration (not an actual criterion): If surfaces were deemed unacceptable when 5% of pilots rejected them then this table could be applied →

ISO Roughness Index	Unacceptable Taxiway Range	Unacceptable Runway Range
Weighted RMS (m/s^2)	*≥0.31*	*≥0.35*
Weighted MTVV (m/s^2)	*≥0.71*	*≥0.68*
Weighted VDV ($m/s^{1.75}$)	*≥4.11*	*≥4.16*
DKup (m/s^2)	*≥1.82*	*≥1.69*

Index Values at Which Taxiways/Runways Are Estimated Unacceptable to 5% of Pilots

* FAA criteria is expected to require evaluation using multiple aircraft types - not just the B737 data presented here

**No ISO index is recommended since the choice of index may depend upon the application; however, weighted RMS has been applied in some past studies for vibrations near the threshold of human comfort unacceptability

Studies on Existing Roughness Indices

Pavement Surface

- Straightedge Index
- Boeing Bump Index
- Profilograph Index
- International Roughness Index
- Bandpass Filter

Cockpit Acceleration

- RMS (Root Mean Square)
- MTVV (Maximum Transient Vibration Value)
- VDV (Vibration Dose Value)
- DK (Spinal Response Acceleration Dose)

Proposed Steps for New Index Development

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

  $f(x)=\{x1, x2, x3, x4,\ldots., xn\} = \{g, RI, W, P\ldots\}$

Correlations Between Acceleration Thresholds and ProFAA Indexes

- 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.

Questions

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