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Challenges for Correlating Airport Pavement Roughness Simulator Results

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B737-800 Flight Simulator

• **FAA Mike Monroney Aeronautical Center in Oklahoma City**

•**Level D Certified**

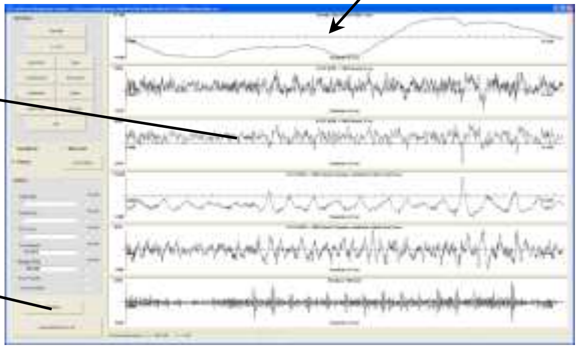
• **Full Flight Simulator**

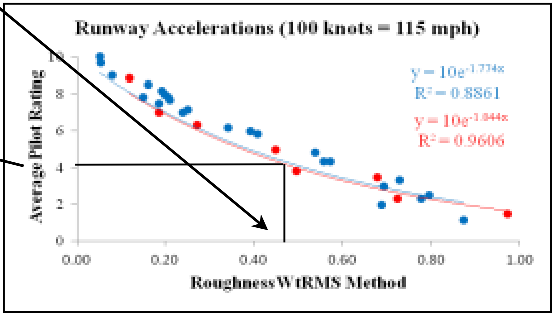
• **Six-degree-of-freedom motion system**

• **High resolution visual display and sound system**

Final Objective Outline

- 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





Data Collection and Analysis

- FAA Inertial Profiler

- Boeing 737-800 Simulator

Pilot Rating Scale and ISO

Rate the Level of Pavement Roughness or Smoothness for this Scenario

Run Number ______

Seat Position ______

Pilot Number ______

Perfect	10
Very Good	9
	8
Good	7
	6
Fair	5
	4
Poor	3
	2
Very Poor	1
Impassable	0

NEED FOR IMPROVEMENT (Check Only One Box)

☐ Acceptable: Ride Quality Does Not Need Improvement

☐ Unacceptable: Ride Quality Needs Improvement

INTERNATIONAL STANDARD

ISO 2631-1

Second edition 1997-06-01

Corrected and reprinted 1997-07-15

Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration —

Part 1:
General requirements

Vibrations et chocs mécaniques — Évaluation de l'exposition des individus à des vibrations globales du corps —

Partie 1: Exigences générales

ISO

Reference number ISO 2631-1:1997(E)

Final Study Test Scenarios

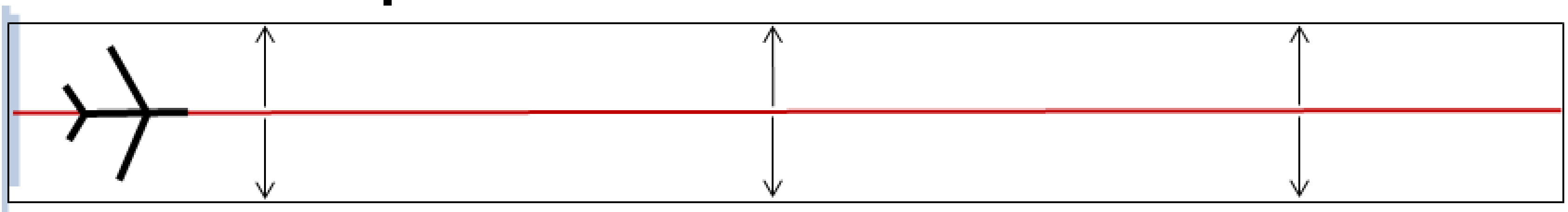
- **Taxiway and runway profiles selected from U.S. and foreign airports to provide a wide range of surface roughness.**
- **Each scenario provides a 30 second profile section**
- **40 constant speed taxiway scenarios – 37 km/hr.**
- **40 constant speed runway scenarios – 185.2 km/hr.**
- **Scenarios provide automated movement along the profile sections with no pilot input required.**

Enhancements to the Flight Simulator Software

- Integration of real world profiles into the simulator ground model.
- Alignment of taxiway and runway visuals.
- Compare cockpit acceleration to real world profiles.
- Develop aircraft fuselage flexible modes.
- Integrate rigid body and flexible mode accelerations into the simulator model.
- Tune flexible and mode and motion models.
- Test and validate simulator enhancements.

Real-World Surface Profile Integration

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



- Changed standard 1 inch (2.54 cm) profile sample spacing to 2 feet (24 in/61 cm) for runways and 0.4 feet (4.8 in/12.2 cm) for taxiways.
- Converted elevation units from inches to feet.
- Filtered profiles to remove low frequency variations in elevation.

Real-World Surface Profile Integration

- The real world profiles consist of airport surface elevation changes along the longitudinal axis of the airport runway or taxiway. The elevation profiles are two-dimensional; height varies only with respect to x-distance along the runway.
- The simulator flight model transfers only the CG (not cockpit) accelerations to the motion system the motion software transforms the CG accelerations into cockpit accelerations.
- The flexible mode model provided uses strut force as input to excite the bending mode accelerations.

Simulator Data Collection

- B737 - 800 Simulator flight model collects data at 60Hz.
- Runway scenarios at 185.2 km/hr. provided height sampling every 0.85 meters.
- As the simulated aircraft moves along the profile, the tire and landing gear react to changes in surface height and generate strut forces.
- Strut forces are then input to flight model equations and accelerations at aircraft CG.

Data Analysis Challenges

- **Correlate subjective pilot ratings and objective ISO index values.**
- **ISO values were generated from an accelerometer mounted under the cockpit floor.**
- **Consideration of crest factor as an indicator of large shocks or jolts.**
- **Determination of curve fits as a function of each ISO index.**

ISO Runway and Taxiway Results

Table 3 Correlation Coefficients Relating Subjective Pilot Avg. Ratings to Objective ISO Roughness Indices

	Weighted RMS (m/s²)	Weighted MTVV (m/s²)	Weighted VDV ($m/s^{1.75}$)	DKup (m/s^2)
Taxiway Avg. Rating (0-10)	-.960	-.942	-.972	-.951
Runway Avg. Rating (0-10)	-.973	-.962	-.983	-.972

- **High negative or inverse correlation between pilot ratings and ISO indices – rising ISO index values correspond to falling pilot ratings.**
- **Curve fits of average pilot ratings were made as a function of each ISO index and showed that taxiways and runways had distinct trends as a function of any index.**

Calculated ISO Airport Pavement Limits

Table 8 - ISO Index Values for Which Taxiways and Runways Are Unacceptable to 5% of Pilots

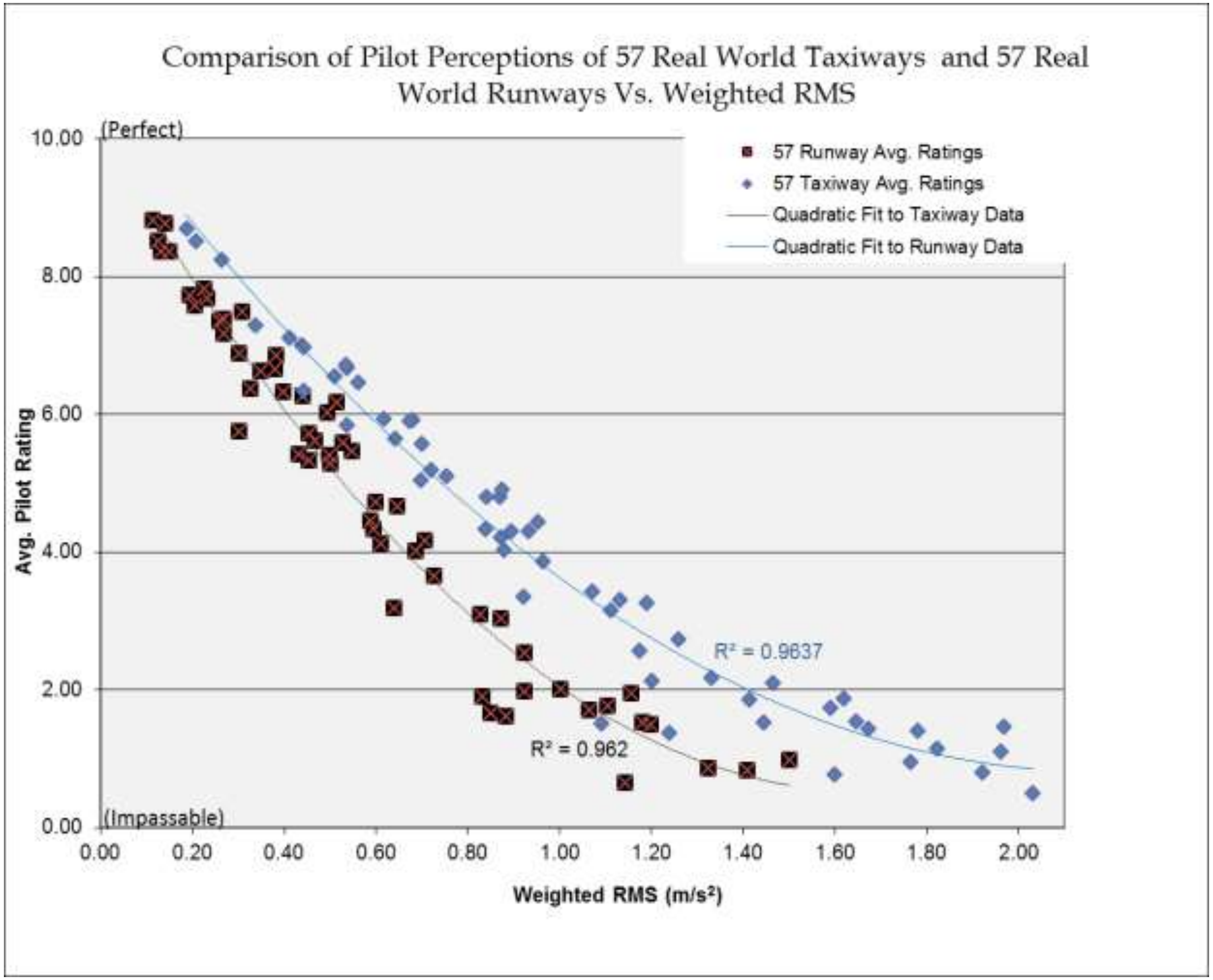
ISO Roughness Index[8]	Unacceptable Taxiway Limits	Unacceptable Runway Limits
Weighted RMS (m/s^2)	*≥0.31*	*≥0.35*
Weighted MTVV (m/s^2)	*≥0.71*	*≥0.68*
Weighted VDV ($m/s^{1.75}$)	*≥4.11*	*≥4.16*
DKup (m/s^2)	*≥1.82*	*≥1.69*

- These numbers suggest that the "a little uncomfortable" level of the Standard is closely related to the point at which 5% of pilots rate taxiways and runways as unacceptable and the "fairly uncomfortable" level is closely related to the point at which 50% of pilots rate taxiways and runways as unacceptable.

Table 7 - ISO Standards for Discomfort

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

Comparison of Pilot Ratings to Weighted RMS



- This Figure illustrates that combining runway average ratings from final and preliminary testing yields a single trend line for taxiways and for runways, indicating consistency in the two test sessions.

Conclusions

- **The least scatter occurred in fitting the pilot ratings as a function of weighted RMS or weighted VDV by a quadratic fit or a shifted logarithmic The ISO crest factor was computed for each taxiway and runway profile because a large crest factor indicates large individual jolts in the ride.**
- **For the four taxiway rides with high crest factor it was found that the best fit of pilot average numerical rating was achieved using weighted VDV as the roughness indicator.**
- **It is therefore recommended to use the weighted VDV for surfaces with single events. Runway profiles did not contain examples of crest factors significant enough to warrant analysis.**
- **One strategy for maintaining in-service pavement would be to service the pavement when any one of the four indices (Weighted RMS, Weighted MTVV, Weighted VDV or DKup) exceeded some threshold value, such as the 5% level.**
- **Another strategy would be to service pavement only when a threshold value for weighted RMS or weighted VDV was exceeded, because these two indices have the best fit statistics, appear more frequently in literature, and estimate discomfort from overall vibration and from occasional shocks, respectively.**

Future Work

- Simulator roughness testing for other aircraft types.
- Incorporation of pilot seat accelerometer for future testing.
- Correlations of pilot ratings with standard roughness indices (Boeing Bump, IRI, etc.).
- Evaluation of new pavement construction limits for roughness.
- Analysis of rideability ratings for asphalt vs. concrete surfaces.
- Analysis of recommended ISO Indices.

Questions?

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Real-World Surface Profile Integration

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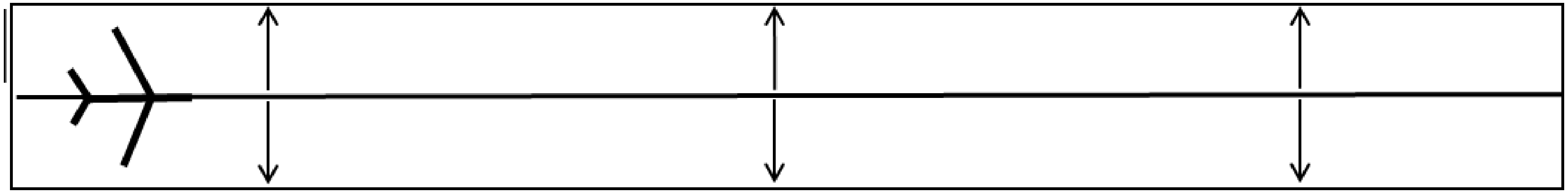

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