Good Pavement Texture = Good Tire Friction
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ABSTRACT

This paper summarizes the factors influencing pavement texture, identifies available techniques to improve texture and discusses how tire friction performance is directly related to pavement texture. Several methods/devices are described to measure both micro- and macro-texture characteristics of pavements and examples of different pavement treatments are shown including grooving, grinding, water blasting and high velocity impact. In addition to water removal to minimize tire hydroplaning, the importance of removing solid pavement contaminants such as rubber deposits and ice is illustrated by the significant variation in aircraft/ground vehicle tire friction performance. A variety of continuous friction measuring equipment (CFME) is also described and the correlation with the International Friction Index is given. The paper concludes with recommendations to improve the operational safety of both ground vehicles and aircraft operations under adverse weather conditions.

Key Words: aircraft tire friction, runway pavement texture, measurement devices

1. INTRODUCTION

Runway water, ice or snow was a factor in more than 50 airplane accidents between 1998 and 2003. Most of those accidents involved fatalities. NASA supports a national safety goal to substantially reduce the fatal aircraft accident rate during ground operations under other than clean and dry conditions. Unfortunately, these aircraft accidents continue to occur such as the A340 aircraft landing overrun at Toronto during a heavy rainstorm and the B737 aircraft landing overrun on a snow covered runway at Chicago Midway airport. Lack of adequate tire friction and pavement texture was shown to contribute to these accidents. The paragraphs below describe how these two factors interact as well as the complexity of the many components that define their characteristics. Test equipment used in measuring tire/runway friction and texture is described and recommendations for future activities are given.

2. TEXTURE MEASURING DEVICES

One suggested texture classification of five (A – E) different runway surfaces is given in Figure 1., which shows surfaces varying in average texture depth from 0.02 to 2.5 mm (0.001 to 0.1 in.). The higher textured surfaces (D and E) are mostly grooved and include both concrete and asphalt pavements.

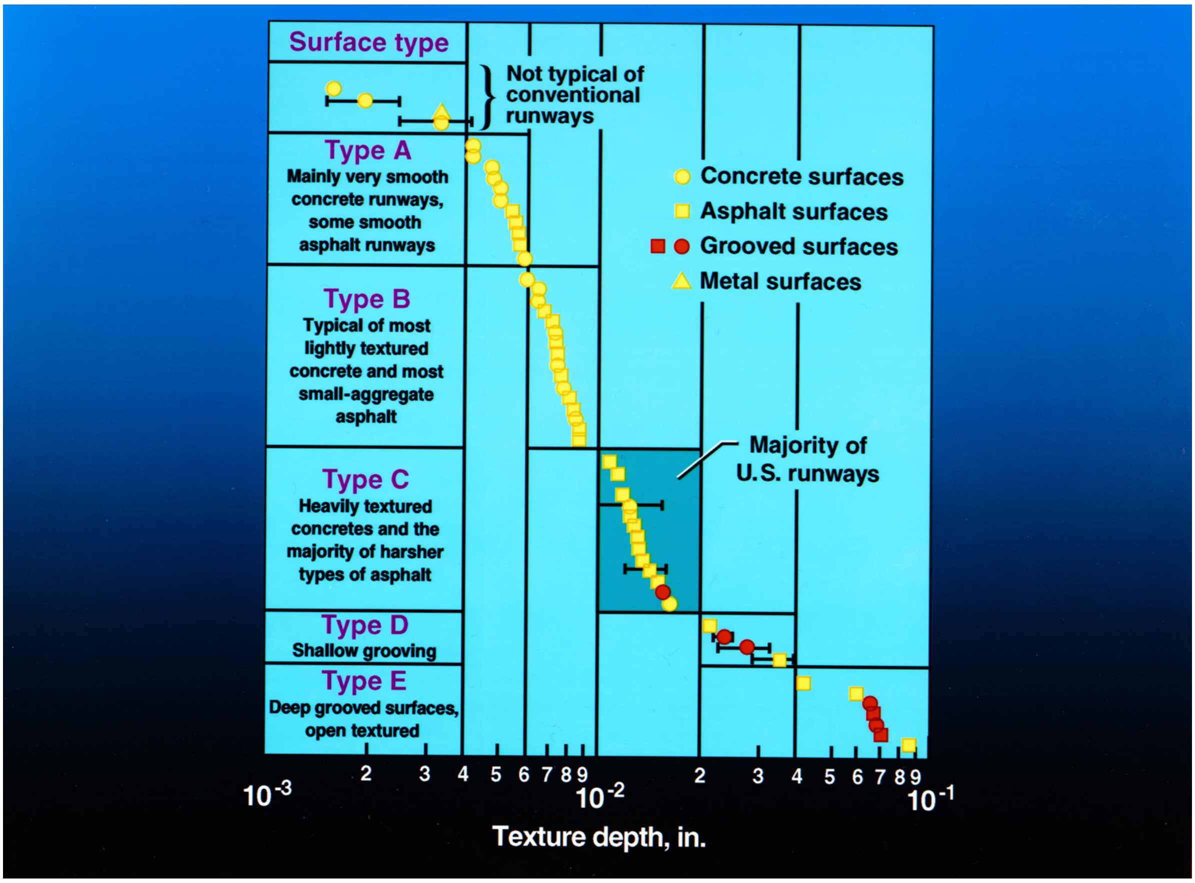

Figure 1: Texture classification of runway surfaces

As a result of several years of friction and pavement texture tests (Boccanfuso, 2004 thru to Yager, 1994), the general trend of these data strongly indicates that the slope of the friction/speed gradient curve is a function of macro-texture and the magnitude is a function of the micro-texture, as shown in the plot of Figure 2. The equipment used to collect this friction/texture database is listed in this figure. Micro-texture is defined as very small scale "sandpaper" finish at microscopic level, whereas macro-texture provides a surface roughness comparable to the scale one would perceive if one rubbed a hand on the surface.

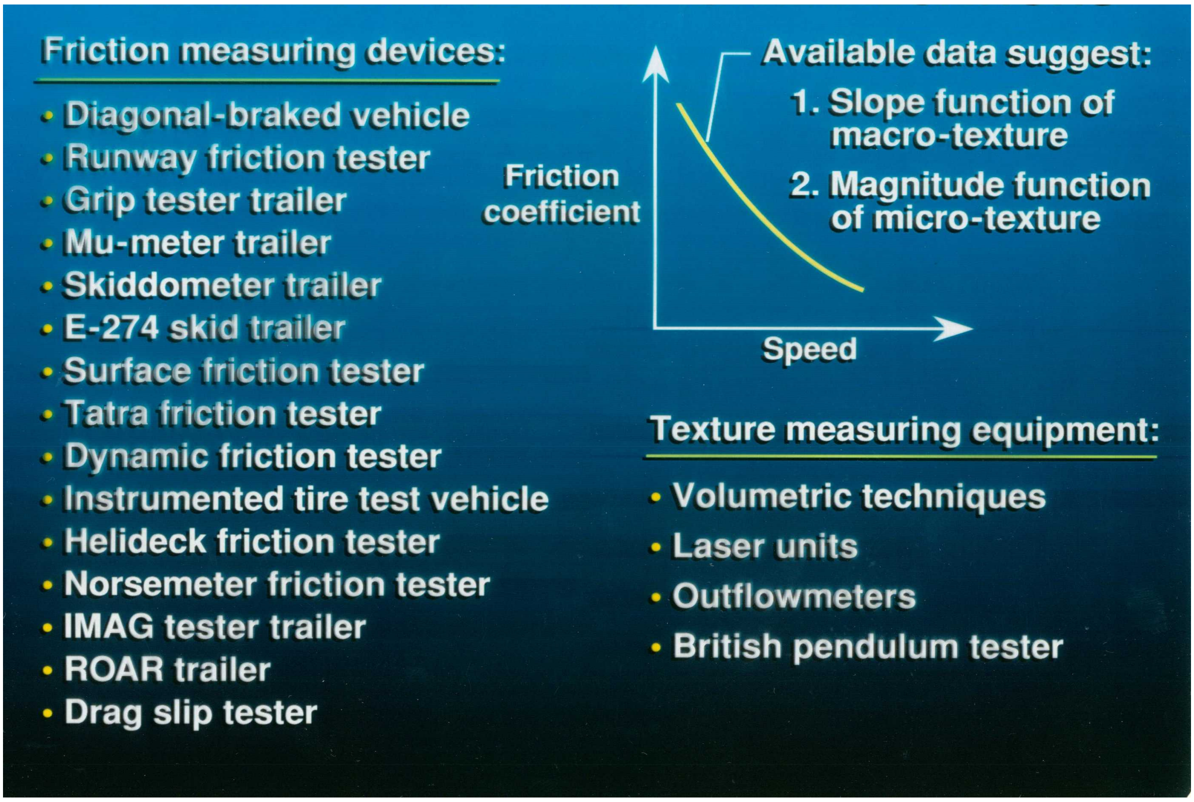

Figure 2: Runway surface friction evaluations

There are several surface treatments available to improve runway texture, including high velocity shot impact, rubber removal, grooving/grinding and open-graded overlays. The Skidabrader high velocity shot impact equipment shown in Figure 3 can be adjusted to not only remove rubber/paint markings but also to provide higher or lower surface macro-texture value.

Figure 3: Skidabrader

Some of the devices used to measure surface texture are shown in Figures 4-6. The outflow meter in Figure 4 consists of a rubber doughnut attached to the bottom of a tube open at its top end. A measured quantity of water is poured into the tube, the operator pulls up the plunger to release the water, and the time for a known quantity of the water to escape is recorded. Thus, the shorter the time for the water to escape, the higher the surface macro-texture.

Figure 4: Outflow meter

Figure 5 shows a volumetric macro-texture measurement using a known volume of sand, spreading it in a circular motion with a hard, flat disc, measuring the average diameter of the sand-covered circle, and computing the area covered. The average macro-texture is computed by dividing the volume of sand spread by the area covered. The wood frame shown in the photograph is very useful if winds are blowing when these sand patch measurements are taken. The British pendulum tester shown in Figure 6 uses a rubber slider pad at the end of the pendulum arm to obtain a measure of surface micro-texture. The pendulum is raised to a predetermined height and then released. When the pendulum traverses the vertical position, the rubber pad scrapes the wetted surface and the pendulum swings upward to a height lower than the release point. The larger the difference is between these two heights means higher, rougher micro-texture value. Since these are each "spot" measuring tests, more than one measurement needs to be taken on a given runway surface. More detailed information on these devices as well as some others can be found in American Society of Testing and Materials (ASTM) E17 Committee standards (Anon., 2008).

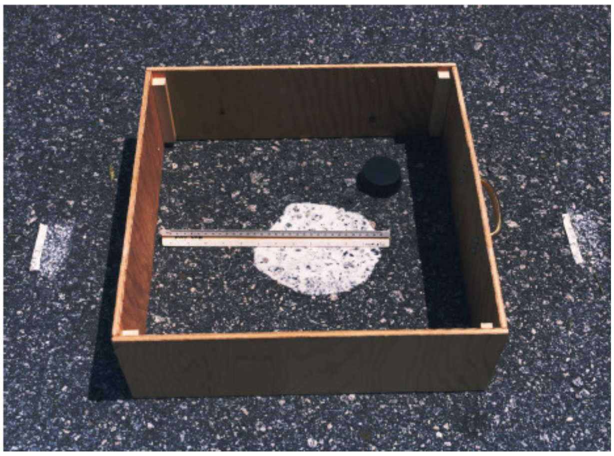

Figure 5: Sand patch

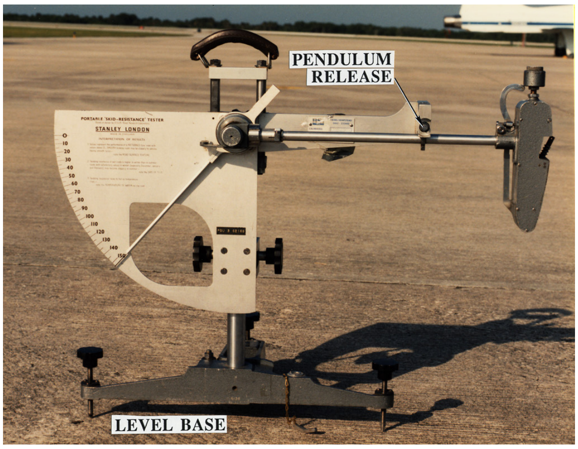

Figure 6: British Pendulum Tester

3. FRICTION MEASURING EQUIPMENT

Figure 7 shows several different ground friction measuring vehicles and Figure 8 shows several trailer devices. Except for the diagonal braked, electronic recording decelerometer and E-274 skid trailer (all locked wheel, 100% slip devices), this equipment is considered by the Federal Aviation Administration (FAA) to be continuous friction measuring equipment (CFME) with the friction measuring tire operating between 10 and 20% slip. The term "slip" can be defined in that free rolling tire operation is considered 0% slip whereas locked wheel operation is 100% slip relative to the speed of the test vehicle. For summer maintenance, wet surface friction measurements, these CFME's normally collect friction data at 65 km/h (40 mph) with a smooth tread tire and a uniform water depth of 1 mm (0.04 in.). More information on these devices as well as others can be found in (Boccanfuso, 2004 and Anon., 2008). All of these devices have participated in most of the 15 Annual NASA Tire/Runway Friction Workshops and the 10 year Joint Winter Runway Friction Measurement Program (Wambold, 2002 and Boccanfuso, 2004).

Figure 7: Ground test vehicles

Figure 8: Ground test trailers

4. RUNWAY FRICTION LEVEL CLASSIFICATION

Table 1 is taken from the FAA Advisory Circular 150/5320 – 12C dated March 18, 1997. Eight different CFME's are listed on the left and friction values for three different categories are given for both 65 and 95 km/h (40 and 60 mph). The runway categories are minimum, maintenance planning and new design/construction. These friction values were obtained over ten years ago with smooth tread friction measuring tires and using 1 mm (0.04 in.) water depth.

		65 km/h (40 mph)				95 km/h (60 mph)		
Device		Min	Mntn	N Con		Min	Mntn	N Con
MuMeter		0.42	0.52	0.72		0.26	0.38	0.66
RFT		0.50	0.60	0.82		0.41	0.54	0.72
BV11		0.50	0.60	0.82		0.34	0.47	0.74
SARSYS		0.50	0.60	0.82		0.34	0.47	0.74
SFT		0.50	0.60	0.82		0.34	0.47	0.74
DND GT		0.43	0.53	0.74		0.24	0.36	0.64
Tatra		0.48	0.57	0.76		0.42	0.52	0.67
RUNAR		0.45	0.52	0.69		0.32	0.42	0.63
Abbreviations: Min = minimum; Mntn = maintenance; N Con = new construction								

Table 1: Copy of Table 3-2 in FAA AC 150/5320 – 12C

Much more data has been collected since 1997 and the ASTM E17 Committee has prepared a preliminary, more accurate, table for FAA review and approval. This new preliminary table is shown in Table 2 for the two test speeds.

			65 km/h (40 mph)					95 km/h (60 mph)			
Device	Notes		Min	Mntn	N Con	N Grv		Min	Mntn	N Con	N Grv
SFT85			0.48	0.63	0.81	0.87		0.29	0.45	0.67	0.76
SARSYS			0.40	0.57	0.78	0.86		0.27	0.44	0.67	0.76
RFT			0.40	0.56	0.75	0.82		0.25	0.4	0.6	0.68
DND GT			0.39	0.51	0.65	0.70		0.22	0.32	0.51	0.58
NASA GT			0.40	0.54	0.71	0.77		0.26	0.38	0.55	0.62
RT3			0.45	0.58	0.76	0.81		0.25	0.4	0.65	0.73
NAC DFT			0.38	0.49	0.63	0.67		0.35	0.43	0.57	0.62
Russia	1		0.47	0.56	0.69	0.72		0.43	0.56	0.7	0.72
MuMeter	2		0.45	0.53	0.65	0.69		0.21	0.54	0.72	0.7
FAA BV11			0.41	0.58	0.78	0.86		0.22	0.38	0.62	0.73
SC BV11	3		0.40	0.54	0.72	0.78		0.15	0.45	0.68	0.73
Notes: Test run anomalies 1) Known to read high, 2) No self-watering, 3) Device broke down. Abbreviations: Min = minimum; Mntn = maintenance; N Con = new construction; N Grv = new grooved											

Table 2: ASTM Revised FAA Table 3-2 PRELIMINARY

These new table values for 11 different devices were determined using the International Friction Index (IFI) (see Anon., 2008) for each device and runway category. An additional runway category of "new grooved" has been added to this new table since more and more runways are being transversely grooved.

5. NEW FRICTION MEASURING EQUIPMENT

Figure 9 shows the new NASA Mobile Tire Test Facility (MTTF), which can test small aircraft tires up to 120 km/h (80 mph) at fixed or variable slip. The tire test fixture mounted on the back of the MTTF can accommodate free rolling, braked rolling, yawed rolling or combined braked/yawed rolling. The MTTF also has an onboard self watering system to distribute 1 mm (0.04 in.) water depth in front of the test tire when required. The large compartment behind the operator cab contains the data acquisition system, which is manned during all test runs.

Figure 9: NASA Mobile Tire Test Facility

Figure 10 shows an NAC friction test trailer device that has a second measuring wheel to monitor free rolling drag during all fixed slip braking runs with the other test tire.

Figure 10: NAC friction test trailer

Figures 11 and 12 show a new Russian AFT-3 trailer and a US Halliday RT3 trailer. These three trailer devices are considered CFMEs which operate at fixed slip.

Figure 11: Russian AFT-3 trailer

Figure 12: Halliday RT3 trailer

6. FUTURE ACTIVITIES AND RECOMMENDATIONS

We cannot overlook the fact that at times a pilot's training, skill and experience can be all that prevent an aborted takeoff or landing from becoming a catastrophic accident (i.e., the miracle landing on the Hudson River, NY, of January 2009). For the most part, however, optimum runway conditions are crucial to giving even the best pilots, aircraft and airports the proper environment for safe, efficient service. Therefore the work of evaluating new equipment, keeping old devices calibrated, and training new operators to use them correctly must continue. Additional government-industry-academia support and funding can establish equipment calibration centers for friction measuring equipment at geographically spaced locations in a given region, such as Canada, the US or the Common Market countries. Friction-texture-roughness measurement workshops should continue in order to improve operation of friction measurement equipment, test techniques and data analysis procedures.

7. REFERENCES

Anon., 2008. Annual Book of American Society for Testing and Materials Standards. Section four – Construction, Volume 04.03, Road and Paving Materials; Vehicle-Pavement Systems. ASTM International; West Conshohocken, PA, USA.

Boccanfuso, A., 2004. Proceedings of the 3rd International Meeting on Aircraft Performance on Contaminated Runways: IMAPCR 2004, Transport Canada, TP13579, Montreal, Canada.

Dougherty, R. H. and Yager, T. J., 1997.Texture Modification of the Shuttle Landing Facility Runway at Kennedy Space Center. NASA TP 3626, USA.

Galloway, B.M., Epps, J.A., and Tomita, H.. 1971. Effects of Pavement Surface Characteristics and Textures on Skid Resistance. Research Report 138-4,Texas Transportation Institute, Texas A & M University, USA.

Horne, W. B., Yager, T. J., and Taylor, G. R., 1968.Review of Causes and Alleviation of Low Tire Traction on Wet Runways. NASA TN D-4406, USA.

Leland, T. J.W., Yager, T. J., and Joyner, U.T.,1968. Effects of Pavement Texture On Wet-Runway Braking Performance. NASA TN D-4323, USA

Wambold, J.C., Antel, C.E., Henry, J.J., and Rado, Z., 1995. International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements". Final Report, World Road Association (PIARC), Paris, France.

Wambold, J.C. and Henry, J.J., 2002. NASA Wallops Tire/Runway Friction Workshops 1993 -2002. Transport Canada report TP 14190E, Montreal, Canada.

Yager, T. J., Vogler, W. A., and Baldasare, P., 1990. Evaluation of Two Transport Aircraft and Several Ground Test Vehicle Friction Measurements Obtained for Various Runway Surface Types and Conditions – A Summary of Test Results from Joint FAA/NASA Runway Friction Program. NASA TP 2917, USA.

Yager, T. J. and Buhlmann, F.,1982. Macro-texture and Drainage Measurements on a Variety of Concrete and Asphalt Surfaces. Pavement Surface Characteristics and Materials, C.M. Hayden, ed., ASTM Spec.Tech. Publ. 763, USA.

Yager, T.J. and Billiard, G.A., 1994. Evaluation of Pavement Texturing Treatment to Improve Tire Friction Performance. Presented at Transportation Research Board Committee A2B07 meeting on Surface Properties-Vehicle Interaction, Washington DC, USA.

Tom Yager's Biography

Worked 45 years at NASA Langley Research Center, Hampton, Virginia USA conducting studies of aircraft ground handling performance and identifying ways to improve safety of operations, i.e. pavement grooving and grinding, facilitating use of continuous friction measuring vehicles (CFME) and evaluating new tire tread and brake system designs. Helped facilitate several joint international programs with the Federal Aviation Administration, Transport Canada, National Transportation Safety Board, Airline Pilots Association, International Civil Aviation Organization, US military branches and many other aviation organizations. Started consulting business in 2010 focused on measuring and improving tire/pavement friction performance. Married to Susan, 3 children, 7 grandchildren. When not working, I enjoy being with the grandkids, playing golf and tennis, fishing, hiking and doing volunteer work for charities.