How Best to Determine Runway/Highway Pavement Surface Friction Performance

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Outline

- Friction history
- Aircraft landing dynamics facility
- Friction measuring equipment
- Texture measuring equipment
- Pavement surface treatments
- Future activities and recommendations

Pavement Slipperiness - The Horse Era

Miles traveled by a horse on American pavements before an accident occurs

Captain F.V. Green, 1885

Kind of Pavement	Falls on Knees	Falls on Haunches	Complete Fall	Accidents of any kind
Asphalt/ Artificial Sheet	1534	2180	1647	583
Granite Block	510	5934	3472	413
Wood	408	983	4901	272

Miles traveled by a horse on London pavements before an accident occurs

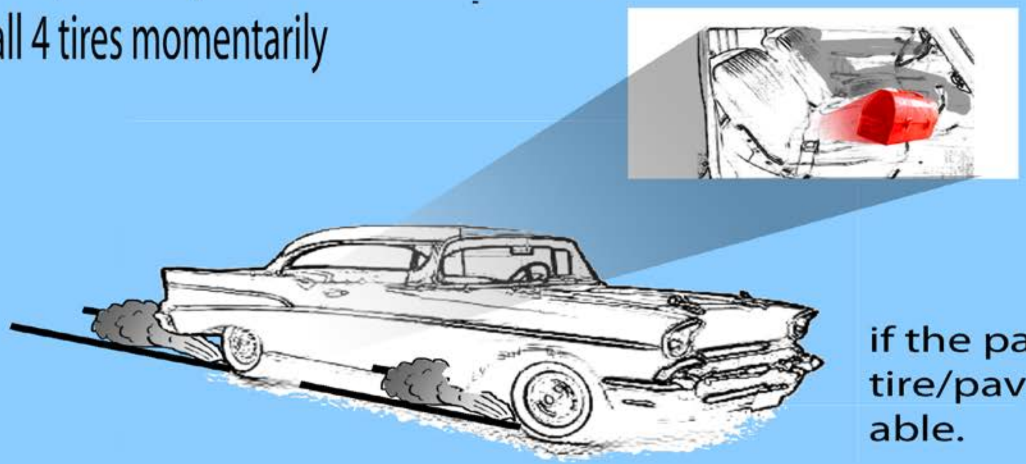
Colonel W. Haywood, 1873

Kind of Pavement	Dry weather	Damp weather	Wet weather	Accidents of any kind
Asphalt/ Limestone	223	125	192	191
Granite Block	78	168	573	132
Rectangular Wood Block	646	193	432	330

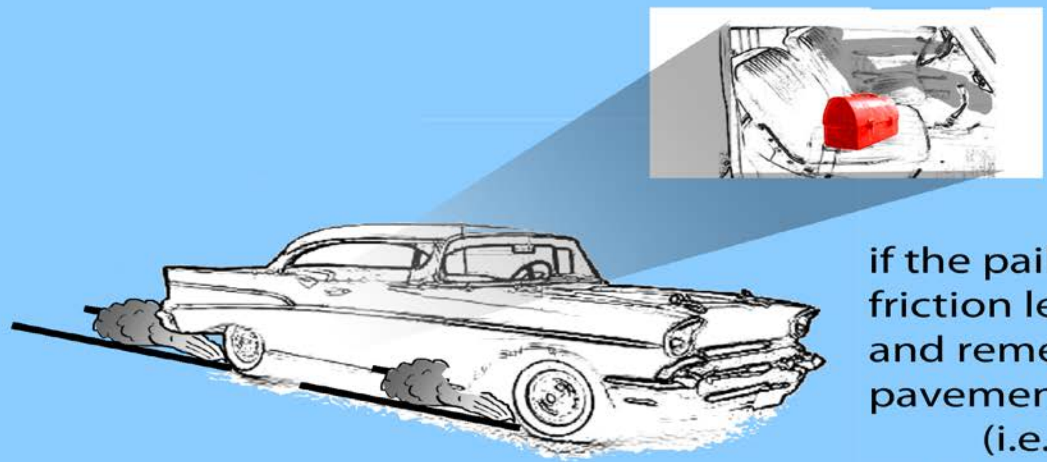
Slipperiness Alleviation: **Asphalt- Sprinkle coarse sand on surface**
Wood- Sprinkle pebbles on surface

THE LUNCH BOX FRICTION TEST

Accelerate up to 30mph then slam on the brakes, locking all 4 tires momentarily



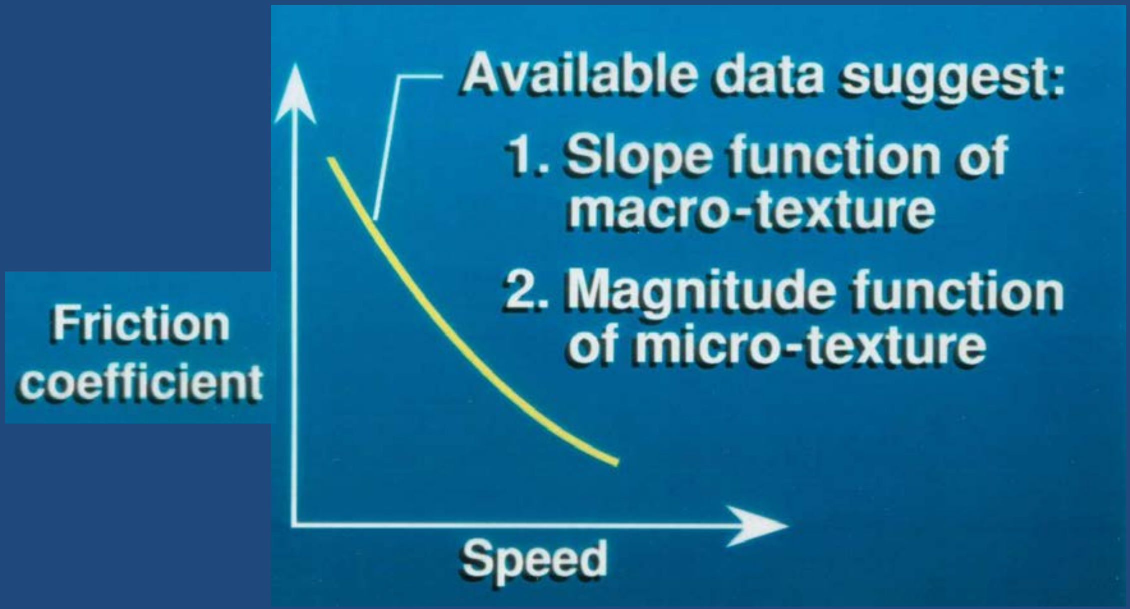
if the pail fell off the seat, the tire/pavement friction was acceptable.



if the pail stayed on the seat, the friction level was not acceptable and remedial treatment of the pavement was needed.

(i.e. removal of water, snow, or ice)

Friction/Speed Relationship



Notes

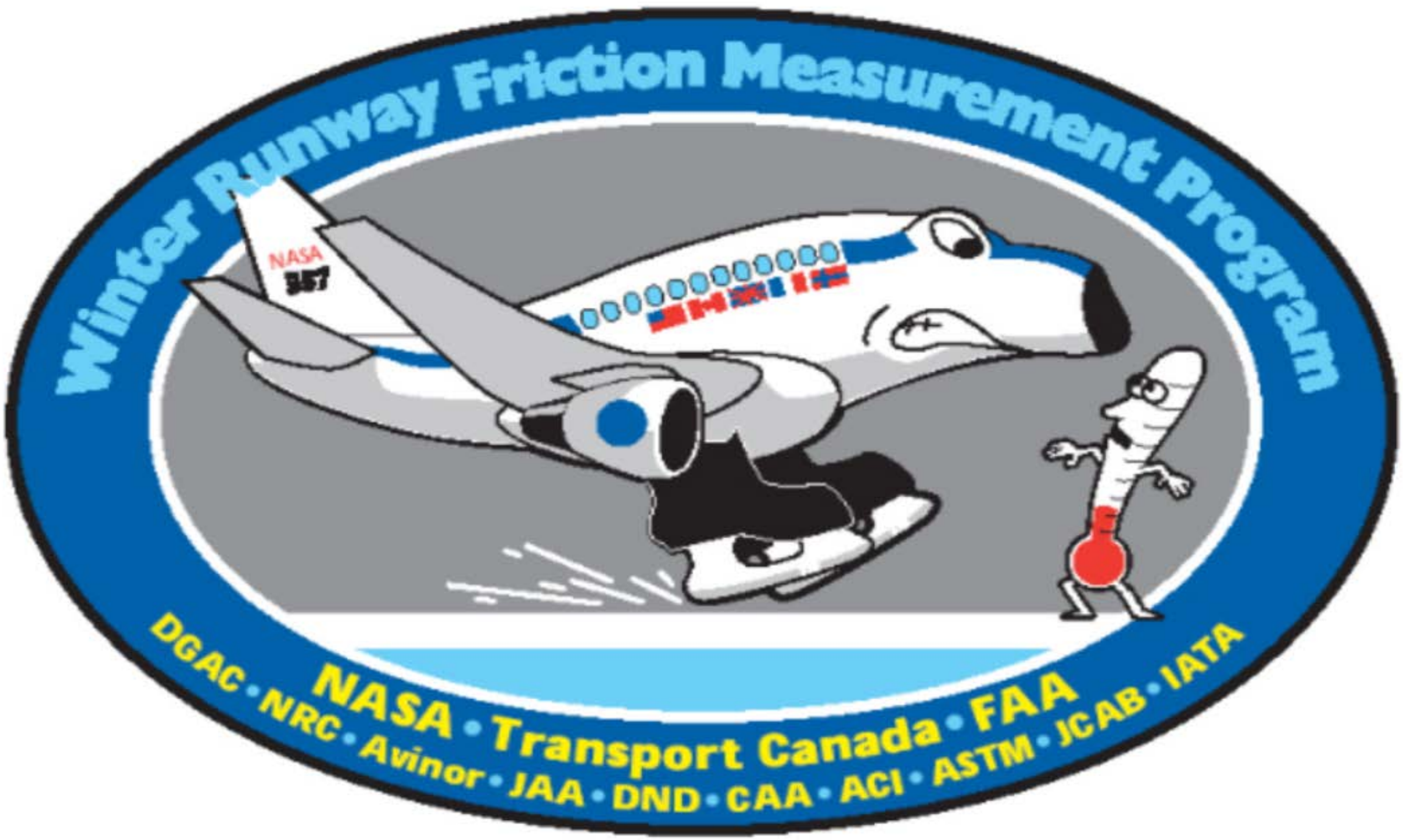
- Relationship based on over 10,000 data sets on nearly 100 wet pavement surfaces
- Texture measurements obtained on the same surfaces under dry conditions

Aircraft Landing Dynamics Facility

Scope

- Free-rolling, cornering and braking friction studies
  - Tire types and tread designs
  - Pavement surface types and conditions
  - Parameter tests, i.e. speed, load & inflation pressure
- Tire wear investigations including Shuttle tires
- Unique landing gear systems evaluations
- Landing gear performance parameter testing
- New brake system performance tests

VIDEO:
NASA Langley’s
Aircraft Landing Dynamics Facility


Winter Runway Friction Measurement Program
NASA
NASA • Transport Canada • FAA
DGAC • NRC • Avinor • JAA • DND • CAA • ACI • ASTM • JCAB • IATA

Friction Measuring Vehicles

Instrumented Tire Test Vehicle

Diagonal Braked Vehicle

Electronic Recording Decelerometer Vehicle

Runway Friction Tester

Airport Surface Friction Tester

Surface Friction Tester

Friction Measuring Trailers

IMAG Variable/Fixed Slip

Runar Variable/Fixed Slip

GripTester Fixed Slip

BV-11 Skiddometer

Mu-meter

E-274 Skid Trailer

Functional Ground Vehicle Friction Levels

Ground Vehicle Readings										
ICAO LEVEL	Speed (km/h)	MuMeter	Skiddometer BV11	Surface Friction Tester (SFT)	Runway Friction Tester (RFT)	TATRA	Locked Wheel[1]	Grip Tester	IMAG[2] µd
Conception level	65 95	0.72 0.66	0.82 0.74	0.82 0.74	0.82 0.74	0.76 0.67	0.51 0.45	0.74 0.64	0.56 0.47
Maintenance level	65 95	0.52 0.38	0.60 0.47	0.60 0.47	0.60 0.54	0.57 0.52	0.40 0.30	0.53 0.36	0.41 0.31
Minimum level	65 95	0.42 0.26	0.50 0.34	0.50 0.34	0.50 0.41	0.48 0.42	0.25 0.10	0.43 0.24	0.34 0.23

- Maintenance friction level: below this level corrective action should be initiated
- Minimum friction level: below this level information should be made available that runway may be slippery.

1. Equipped with E-524 smooth tire inflated to 170 kPa (24 psi)
2. French trailer device operated at fixed 15% slip and using smooth PIARC tire inflated to 150 kPa. Friction coefficient (µd) based on horizontal traction due to the skid resistance of surface measured with the strength gauge.

Friction Rating

GOOD: If each friction value is above Maintenance Level for each 100 m section
FAIR: If each friction value is above Minimum Level for each 100 m section
POOR: If friction values for 3 consecutive 100 m sections are under Minimum Level or if there is no value above Maintenance Level and at least one value under the Minimum Level.

Operational Ground Vehicle Friction Levels

Friction Rating	Ground Vehicle Readings Nominal Test Speed, 65 km/h (40 mph)[10]										
	RCR[1]	Grip-Tester[2]	JBI[3]	Mu-Meter	Surface Friction Tester[4]	Runway Friction Tester[5]	Bv-11 Skiddo-Meter[4]	Decel Meters[6]	Locked Wheel Devices[7]	IMAG [8]	ICAO Index [9]
Good	>17	>.49	>.58	>.50	>.54	>.51	>.59	>.53	>.51	>.53	5
Fair	12-17	.34-.49	.40-.58	.35-.50	.38-.54	.35-.51	.42-.59	.37-.53	.37-.51	.40-.53	3-4
Poor	≤11	≤.33	≤.39	≤.34	≤.37	≤.34	≤.41	≤.36	≤.36	≤.40	1-2

1. RCR = Runway condition reading = Decelerometer reading X 32 obtained at 40 km/h (25 mph)
2. Measurements obtained with smooth ASTM tire inflated to 140 kPa (20psi)
3. JBI = James Brake Index obtained at 40 km/h (25mph)
4. Measurements obtained with grooved aero tire inflated to 690 kPa (100 psi)
5. Measurements obtained with smooth ASTM 4x8.0 tire inflated to 210 kPa (30 psi)
6. Decelerometers include Tapley, Bowmonk, and electronic recording decelerometer at 40 km/h
7. ASTM E-274 skid trailer and E-503 diagonal-brake vehicle equipped with ASTM E-524 smooth test tires inflated to 170 kPa (24 psi)
8. French trailer device operated at 15% slip; grooved PIARC tire inflated to 690 kPa (100 psi)
9. ICAO=International Civil Aviation Organization
10. A wet runway produces a drop in friction with an increase in speed. Friction values also can be reduced by poor drainage because of depressions or inadequate slopes in the runway surface.

Friction Rating

GOOD: If each friction value is above Maintenance Level for each 100 m section
FAIR: If each friction value is above Minimum Level for each 100 m section
POOR: If friction values for 3 consecutive 100 m sections are under Minimum Level or if there are no values above Maintenance Level and at least one value under the Minimum Level.

New Friction Measuring Devices

NAC Friction Tester

Dynamic Friction Tester

Russian AFT-3 Trailer

Halliday RT3 Trailer

TWO Friction Trailer

NASA Mobile Tire Test Facility (MTTF)

FRICTION LEVEL CLASSIFICATION FOR RUNWAY PAVEMENT SURFACES

FAA A.C. 150/5320-12C; March 18, 1997

	40 mph			60 mph		
	Minimum	Maintenance Planning	New Design/ Construction	Minimum	Maintenance Planning	New Design/ Construction
Mu Meter	.42	.52	.72	.26	.38	.66
K. J. Law Runway Friction Tester	.50	.60	.82	.41	.54	.72
Airport Equipment Co. Skiddometer	.50	.60	.82	.34	.47	.74
Airport Surface Friction Tester	.50	.60	.82	.34	.47	.74
Airport Technology USA Safegate Friction Tester	.50	.60	.82	.34	.47	.74
Findlay, Irvine, Ltd. Griptester Friction Meter	.43	.53	.74	.24	.36	.64
Tatra Friction Tester	.48	.57	.76	.42	.52	.67
Norsemeter RUNAR (operated at fixed 16% slip)	.45	.52	.69	.32	.42	.63

ASTM Revised FAA Table 3-2 at 40 mph

PRELIMINARY

Device	Min	Mntn	N Con	N Grv	Note	Fit	Rsq	Std Err	CV	N
SFT85	0.48	0.63	0.81	0.87		F60=0.506*FR60+0.160	0.858	0.021	0.074	14
SARSYS	0.40	0.57	0.78	0.86		F60=0.469*FR60+0.195	0.807	0.807	0.067	13
RFT	0.40	0.56	0.75	0.82		F60=0.496*FR60+0.191	0.869	0.869	0.054	14
DND GT	0.39	0.51	0.65	0.70		F60=0.633*FR60+0.157	0.849	0.849	0.075	14
NASA GT	0.40	0.54	0.71	0.77		F60=-0.559*FR60+0.171	0.866	0.020	0.055	14
RT3	0.45	0.58	0.76	0.81		F60=-0.542*FR60+0.171	0.785	0.032	0.047	14
NAC DFT	0.38	0.49	0.63	0.67		F60=-0.675*FR60 + 0.154	0.822	0.019	0.047	13
Russia	0.47	0.56	0.69	0.72	1	F60=0.696*FR60 + 0.114	0.926	0.008	0.039	11
MuMeter	0.45	0.53	0.65	0.69	2	F60=0.728*FR60 + 0.115	0.708	0.044	0.114	14
FAA BV11	0.41	0.58	0.78	0.86		F60=0.474*FR60 + 0.192	0.811	0.028	0.102	14
SC BV11	0.40	0.54	0.72	0.78	3	F60=0.538*FR60 + 0.181	0.639	0.039	0.139	11

Notes: Refers to various test run anomalies. **Abbreviations:** **Min** = minimum; **Mntn** = maintenance; **N Con** = new construction; **N Grv** = new grooved; **Rsq** = correlation coefficient; **Std Err** = standard error; **CV** = coefficient of variation (standard deviation divided by the mean); **N** = number of data points

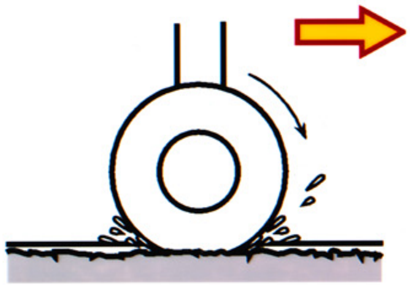
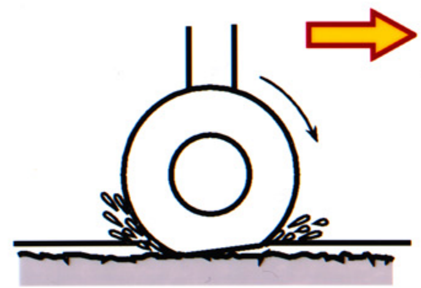
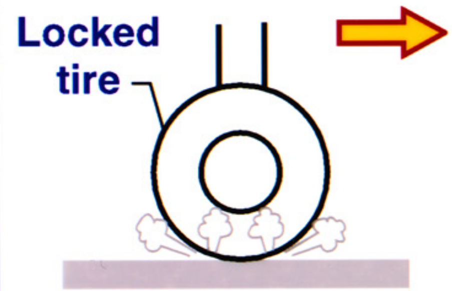
ASTM Revised FAA Table 3-2 at 60 mph

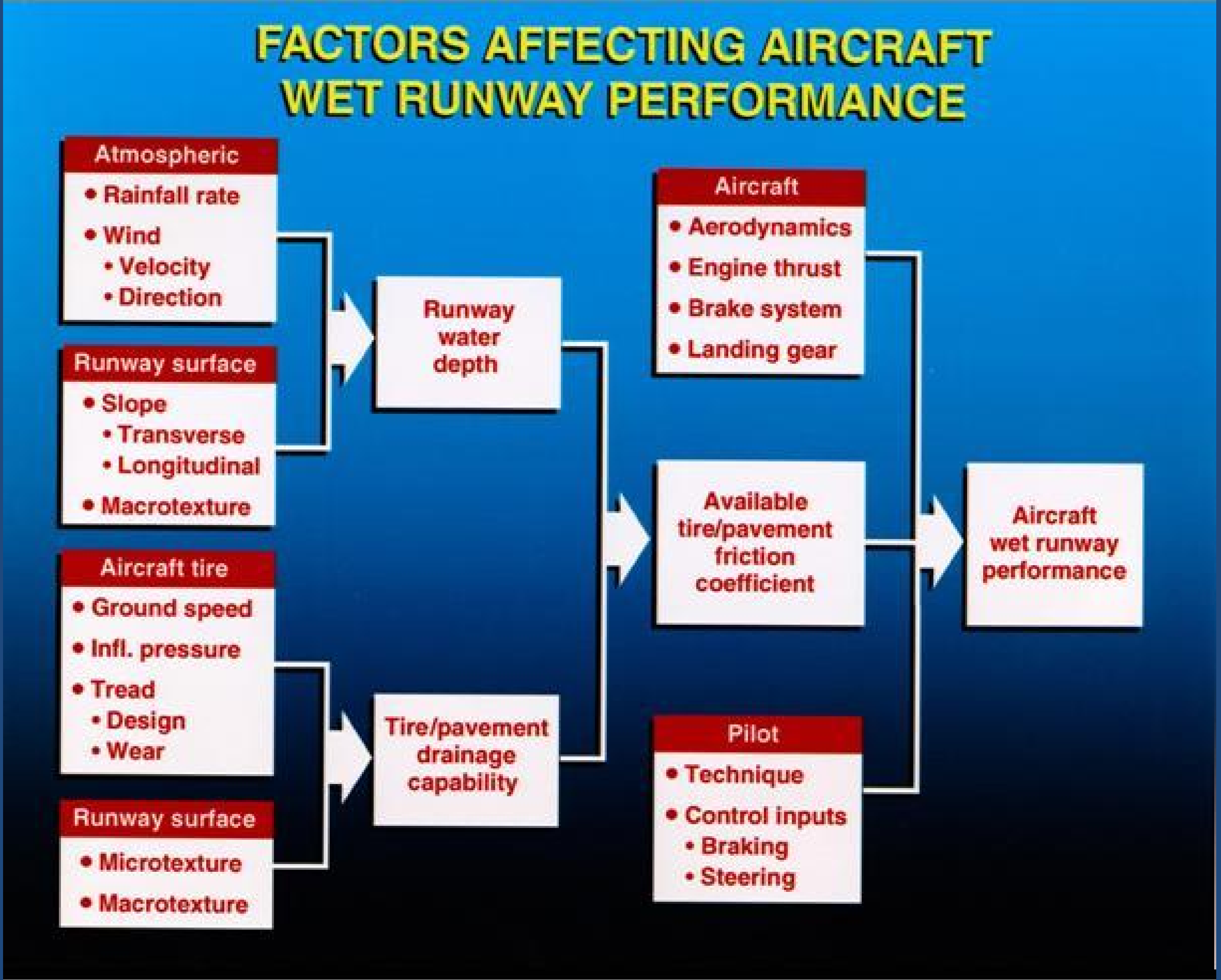
PRELIMINARY

Device	Min	Mntn	N Con	N Grv	Note	Fit	Rsq	CV	N
SFT85	0.29	0.45	0.67	0.76		BS95=0.454*BS642 + 0.575*BS64 -0.0.92	0.956	0.042	14
SARSYS	0.27	0.44	0.67	0.76		BS95=0.239*FS642 + 0.772*FS65-0.077	0.986	0.067	13
RFT	0.25	0.4	0.6	0.68		BS95=0.219*FS642 + 0.738*FS65 -0.078	0.946	0.054	14
DND GT	0.22	0.32	0.51	0.58	4	BS95=1.094*FS642 -0.034*FS65 +0.06	0.881	0.075	14
NASA GT	0.26	0.38	0.55	0.62		BS95=0.367*FS642 + 0.538*FS65 -0.014	0.833	0.055	14
RT3	0.25	0.4	0.65	0.73		BS95=1.127*FS642 -0.094*FS65+0.067	0.937	0.047	14
NAC DFT	0.35	0.43	0.57	0.62		BS95=0.701*FS642 + 0.188*FS65+0.175	0.637	0.047	13
Russia	0.43	0.56	0.7	0.72	1	BS95=-1.881*FS642 + 3.426*FS65 -0.771	0.889	0.039	11
MuMeter	0.21	0.54	0.72	0.7	2	BS95=-12.85*FS642 + 16.67*FS65 -4.69	0.253	0.114	14
FAA BV11	0.22	0.38	0.62	0.73		BS95=0.678*FS642 + 0.257*FS65+0.006	0.956	0.102	14
SC BV11	0.15	0.45	0.68	0.73	3	BS95=-2.307*FS642 + 4.23*FS65 -1.171	0.956	0.139	7

Notes: Refers to various test run anomalies. **Abbreviations:** **Min** = minimum; **Mntn** = maintenance; **N Con** = new construction; **N Grv** = new grooved; **Rsq** = correlation coefficient; **CV** = coefficient of variation (standard deviation divided by the mean); **N** = number of data points

PRINCIPAL CAUSES OF WET PAVEMENT TIRE FRICTION LOSSES

	Hydroplaning		Reverted rubber skidding
	Viscous	Dynamic	
Causes			
Contributing factors	Damp or wet pavement Medium to high speed Poor pavement texture Worn tire tread	Flooded pavement High speed Low tire pressure Worn tire tread	Wet or flooded pavement High speed Poor pavement texture Deficient brake system
Alleviating factors	Pavement microtexture Pavement grooving Good tread design	Pavement macrotexture Pavement grooving Increased tire pressure Good tread design	Good pavement texture Pavement grooving Improved antiskid


FACTORS AFFECTING AIRCRAFT WET RUNWAY PERFORMANCE
Atmospheric
• Rainfall rate
• Wind
• Velocity
• Direction
Runway surface
• Slope
• Transverse
• Longitudinal
• Macrotexture
Aircraft tire
• Ground speed
• Infl. pressure
• Tread
• Design
• Wear
Runway surface
• Microtexture
• Macrotexture
Runway water depth
Tire/pavement drainage capability
Aircraft
• Aerodynamics
• Engine thrust
• Brake system
• Landing gear
Available tire/pavement friction coefficient
Pilot
• Technique
• Control inputs
• Braking
• Steering
Aircraft wet runway performance

Test Aircraft

Falcon 20

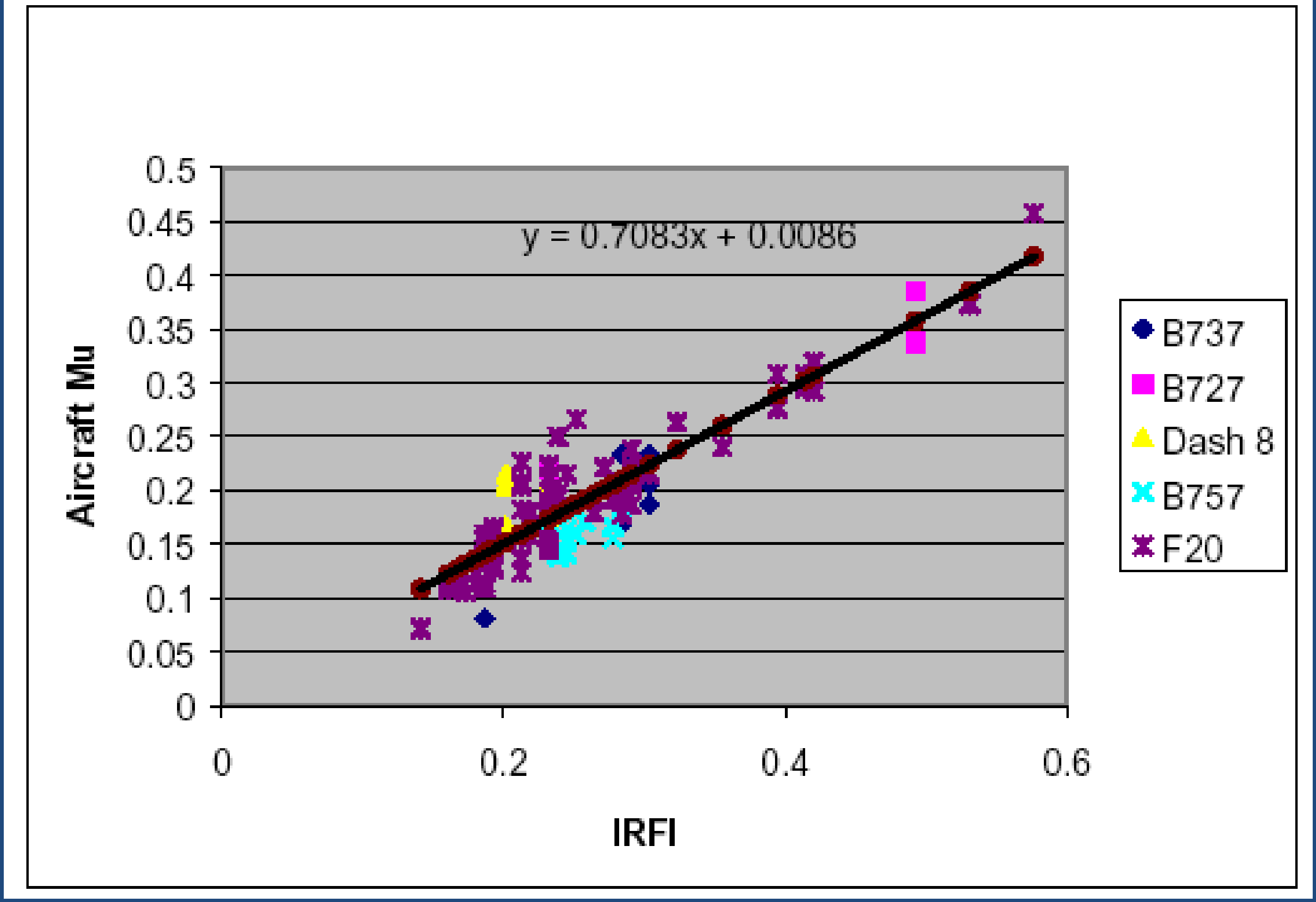
Dash 8

B727-100

B737-100

B757-100

Aircraft vs. IRFI



CRFI Table

Bare and Dry Landing	CRFI											
Distance	**0.60**	**0.55**	**0.50**	**0.45**	**0.40**	**0.35**	**0.30**	**0.27**	**0.25**	**0.22**	**0.20**	**0.18**
1800	3120	3200	3300	3410	3540	3700	3900	4040	4150	4330	4470	4620
2000	3480	3580	3690	3830	3980	4170	4410	4570	4700	4910	5070	5250
2200	3720	3830	3960	4110	4280	4500	4750	4940	5080	5310	5490	5700
2400	4100	4230	4370	4540	4740	4980	5260	5470	6520	5880	6080	6300
2600	4450	4590	4750	4940	5160	5420	5740	5960	6130	6410	6630	6870
2800	4720	4910	5090	5290	5530	5810	6150	6390	6570	6880	7110	7360
3000	5070	5240	5430	5650	5910	6220	6590	6860	7060	7390	7640	7920
3200	5450	5630	5840	6090	6370	6720	7130	7420	7640	8010	8290	8600
3400	5740	5940	6170	6430	6740	7110	7550	7870	8100	8500	8800	9130
3600	6050	6260	6500	6780	7120	7510	7990	8330	8580	9000	9320	9680
3800	6340	6570	6830	7130	7480	7900	8410	8770	9040	9490	9840	10220
4000	6550	6780	7050	7370	7730	8170	8700	9080	9360	9830	10180	10580

IRFI Table

Bare and Dry Landing	IRFI											
Distance	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.27	0.25	0.22	0.20	0.18
1800	3032	3125	3225	3334	3453	3585	3733	3831	3900	4013	4094	4180
2000	3356	3462	3576	3700	3836	3986	4155	4266	4345	4473	4565	4664
2200	3610	3732	3864	4007	4164	4338	4531	4660	4751	4899	5005	5118
2400	3975	4121	4279	4450	4638	4845	5077	5231	5340	5516	5643	5779
2600	4326	4476	4637	4813	5005	5218	5455	5613	5725	5906	6036	6175
2800	4619	4781	4956	5146	5354	5584	5841	6012	6133	6329	6470	6621
3000	4929	5105	5295	5502	5729	5979	6259	6445	6577	6790	6944	7108
3200	5288	5483	5694	5923	6173	6450	6760	6965	7112	7347	7517	7699
3400	5572	5781	6008	6254	6524	6822	7155	7375	7533	7786	7969	8164
3600	5865	6089	6332	6596	6885	7204	7561	7798	7966	8238	8434	8643
3800	6146	6386	6645	6926	7235	7576	7957	8209	8389	8679	8887	9111
4000	6344	6593	6863	7156	7477	7831	8228	8490	8678	8979	9197	9429

Joint Program Summary

- In nearly 10 years of the joint program, tests with 10 aircraft and 49 ground vehicles have been conducted at 10 test sites
- 450 individuals representing over 65 organizations from 16 different countries have participated
- The Canadian and the International Runway Friction Indices have been established

VIDEO:
Joint Winter Runway Safety Test Program

Texture Measuring Techniques/Devices

Grease Sample

Outflow Meter

Sand Patch

British Pendulum

Circular Track Meter

Classification of Pavement Surfaces

CLASS	TYPE OF SURFACE	HYDRO-PLANING POTENTIAL	MACROTEXTURE DEPTH, MM (IN.)		OUTFLOW METER TIME, SEC.
			GREASE SAMPLE METHOD	SAND PATCH METHOD	
I	DEEP GROOVING OPEN TEXTURE POROUS FRICTION COURSE	LOW	> 1 (0.04)	> 1.8 (0.07)	< 2
II	SHALLOW GROOVING SCORING & WIRE COMBING SOME LARGE AGGR ASPHALT	POOR	1 (0.04) TO 0.5 (0.02)	1.8 (0.07) TO 0.9 (0.035)	2 TO 5
III	HEAVILY TEXTURED CONCRETE SOME MIXED-GRADATION AGGR ASPHALT	FAIR	0.5 (0.02) TO 0.3 (0.01)	0.9 (0.035) TO 0.6 (0.024)	5 TO 20
IV	LIGHTLY TEXTURED CONCRETE SOME WORN & TRAFFICKED MOST SMALL AGGR ASPHALT	GOOD	0.3 (0.01) TO 0.01 (0.004)	0.6 (0.024) TO 0.25 (0.01)	20 TO 80
V	VERY LITTLE TEXTURE PAINTED AND RUBBER COATED SOME HEAVILY TRAFFICKED	HIGH	< 0.01 (0.004)	< 0.25 (0.01)	> 80

Pavement Treatments to Improve Friction Performance

- Shot blasting
- Grooving
- Grinding
- Overlays

Overlay Treatments

- Micro-surfacing
- Slurry seals
- Rejuvenators
- Porous friction course

Current Status of FAA Activities

- Takeoff and Landing Performance Assessment
- Status of TALPA data collection
- Notice for Proposed RuleMaking (NPRM) concerning Part 139
- Participation in friction workshops

ASTM E17 Committee Activities

- New standards
- Friction workshops
- Support for FAA rulemaking efforts to amend part 139

ASTM E17 – New Standards

- CFME calibration center requirements
- CFME operator training procedures
- Identifying proper CFME software/hardware maintenance requirements
- Standards supporting FAA recent rulemaking effort to amend part 139

Reference Documents

- FAA Advisory Circular 150/5320-12C: “Measurement, Construction and Maintenance of Skid-Resistant Airport Pavement Surfaces”; March 18, 1997.
- Wambold, James C., and Henry, J.J.: draft report “Correlations of MU Values of Continuous Friction Measurement Devices for Use in Updating Table 3-2 of Advisory Circular 150/5320-12C”; December 2007.
- American Society of Testing and Materials (ASTM) Standard Practice E1960: “Standard Practice for Calculating International Friction Index of a Pavement Surface”; August 2003.

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- ICAO Annex 14, Aerodromes, Fifth Edition, July 2009
- ICAO Friction Task Group airport guidance report
- Transport Canada TP 312E, Aerodrome Standards and Recommended Practices
- Transport Canada TP 13579, Proceedings of the 3rd International Meeting on Aircraft Performance on Contaminated Runways, Nov. 2004, Montreal, Canada
- Civil Aviation Authority, London; "Procedures for Runway Friction Classification and Monitoring", CAP683, July 2000

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- EASA, Research Project EASA 2008/4, RuFAB-Runway friction characteristics measurement and aircraft braking, Volume 1, Summary of Findings and Recommendations, March 2010.
- NASA Technical Paper 2917, Evaluation of Two Transport Aircraft and Several Ground Test Vehicle Friction Measurements Obtained for Various Runway Surface Types and Conditions, February 1990.

Reference Documents – Concluded

- NASA Technical Memorandum 85652, Factors Influencing Aircraft Ground Handling Performance, June 1983.
- ESDU-71025, Frictional and retarding forces on aircraft tires, October 1971.

Future Activities and Recommendations

- Compare additional friction/texture data collected during annual Penn State Friction Workshop to previous data collected
- Encourage more organizations to become involved in ongoing tire/pavement friction performance research investigations
- Establish calibration centers for friction measuring equipment
- Encourage airport operators to continue monitoring runway friction under adverse weather conditions and provide accurate and timely information to pilots
- Improve timely analysis of aircraft flight recorder data for immediate use by subsequent landing aircraft

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