TP 14190E

NASA WALLOPS TIRE/RUNWAY FRICTION WORKSHOPS 1993-2002

Prepared for
National Aeronautics and Space Administration (NASA)
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by

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September 2002

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Un sommaire français se trouve avant la table des matières.

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16. Abstract

In the fall of 1992, data was collected in Belgium and Spain for the PIARC International Experiment to compare and Harmonize Friction and Texture Measurements. The following May, some of the devices used in the tests in Belgium and Spain were assembled at the NASA Wallops facility. Measurements were also made at Wallops with other devices that were not used in Europe. Each May for the next consecutive nine years (1994-2002) data was collected with ground vehicles on the test surfaces at the NASA Wallops Flight Facility during the annual Tire/Runway Friction Workshops. This extensive database has been compiled into spreadsheets summarizing the average values of repeat runs made on each site by each device.

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16. Résumé

À l'automne 1992, des données ont été recueillies en Belgique et en Espagne dans le cadre de l'expérience internationale menée par l'AIPCR (Association mondiale de la Route) dans le but de comparer et harmoniser les mesures du frottement et de la texture des chaussées. En mai 1993, d'autres essais ont eu lieu à l'installation de la NASA sur les îles Wallops. Quelques-uns des appareils utilisés l'automne précédent en Belgique et en Europe y étaient réunis, de même que d'autres appareils qui n'avaient pas servi en Europe. Puis, en mai de chacune des neuf années suivantes (de 1994 à 2002), se sont tenues, au Centre de vols spatiaux des îles Wallops, des campagnes d'essais mettant en jeu des véhicules de mesure du frottement au sol. Ces campagnes coïncidaient avec les ateliers annuels sur l'adhérence pneu-chaussée. La base de données considérable ainsi constituée a mené à des tableaux de moyennes représentant les résultats obtenus sur chaque site par chaque appareil, lors d'essais répétés.

17. Mots clés	18. Diffusion
Frottement, texture, rugosité, Indice international de la glissance, IFI, Indice international de la glissance des pistes, IRFI	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

In the fall of 1992, data was collected in Belgium and Spain for the PIARC International Experiment to compare and Harmonize Friction and Texture Measurements. The following May, some of the devices used in the tests in Belgium and Spain were assembled at the NASA Wallops facility. Measurements were also made at Wallops with other devices that were not used in Europe. Each May for the next consecutive nine years (1994-2002) data was collected with ground vehicles on the test surfaces at the NASA Wallops Flight Facility during the annual Tire/Runway Friction Workshops. These differed from the 1993 program in that one day was set aside for presentations by vendors and other interested parties. The actual test programs for these workshops were similar to the 1993 program. This extensive database has been compiled into spreadsheets summarizing the average values of repeat runs made on each site by each device and has been added to the JWRFMP database. In most cases the high-speed testers performed measurements at several speeds ranging form 32 to 96 km/h. The following information is given in the appendices:

Site descriptions and surface photographs
Friction versus speed by site for 1999
Friction versus speed by year
Friction history
Texture history
Comparison of devices (reproducibility)
Group pictures for each year
Photographs of the texture devices
Photographs of the fiction devices
Photographs of the various profiling devices
Profiling site photographs
Other device photographs

Below is a summary of the equipment was used over the years. In the report, the devices are listed for each year along with tables of their measurements.

Texture Devices used to take measurements included:

Circular Track Meter (CT Meter) - Japan
FHWA British Pendulum Tester (BPN) - USA
FHWA Outflow Meter, ROSAN (MPD, ETD), Texture Van, and Outflow Meter - USA
NASA Volumetric Texture Depth, Glass beads and Grease - USA
PTI Volumetric Texture Depth, Glass beads and British Pendulum Tester (BPN) - USA
Skiddabrader Outflow Meter - USA
Virginia DOT British Pendulum Tester (BPN) and Circular Track Meter (CT Meter) - USA
VTI Laser Texture System (MPD, ETD, RMS) - Sweden

Friction Devices used to take measurements included:

Dynamic Friction Tester (DF Tester) - Japan
FAA BV-11, MuMeter, and Surface Friction Tester (SFT) - USA
GripTester - NASA and USAF - USA
GripTester - Scotland
GripTester - USAF (Push mode only)
IMAG and IRV (International Reference Vehicle) - France
International Cybernetics E-274 Locked Wheel Tester (SNB and SNR) - USA
JBI Decelerometer - USA
K. J. Law E-274 Locked Wheel Tester (SNR) and Runway Friction Tester - USA
Maryland DOT E-274 Locked Wheel Tester (SNR) - USA
NASA Diagonal Braked Vehicle - USA
Norsemeter OSCAR, ROAR, RUNAR, and SALTAR (variable slip testers) - Norway
Penn State E-274 Locked Wheel Tester (SNB and SNR) - USA
Pennsylvania DOT E-274 Locked Wheel Tester - USA
Surface Friction Tester (SFT) - Sweden
Transport Canada ERD Blazer and Surface Friction Testers (TC79 and TC85) - Canada
U.S. Navy Slip Meter - USA

US Surface Friction Tester (USFT) - USA
Virginia DOT E-274 Locked Wheel Tester (SNB and SNR) - USA
VTI BV-14 - Sweden

Roughness measuring systems used to take measurements included:

ARP Auto Rod & Level - USA
Dynatest Profiler - USA
DYNVIA - Czech Republic
Greenwood High Speed Profiler - DK
MD DOT High Speed Profiler and Light Weight Profiler - USA
PA DOT ARRB Walker and ICC Light Weight Profiler - USA
Rod and Level
VA DOT FACE Dipstick, ICC High Speed Profile, and profilometer - USA
YSI Roadpro - USA

Site Descriptions

Site	Surface	Description
A	CC	CANVAS BELT-FINISH
B	CC	GROOVED 1X1/4X1/4 IN.
C	CC	GROOVED 1X1/4X1/4 IN. (Different aggregate)
D	CC	BURLAP DRAG-FINISH
E	AC	SMALL AGGREGATE
F	AC	GROOVE 2X1/4X1/4 IN.
G	AC	SMALL AGGREGATE
K	ST	JENNITE SEAL
K0	AC	UNTREATED AREA ADJACENT TO SITE K
L	AC	MEDIUM AGGREGATE
MS0	AC	SURFACE ADJACENT TO MICROSURFACE SITES
MS1	ST	MICROSURFACE
MS2	ST	MICROSURFACE
MS3	ST	MICROSURFACE
MS4	ST	ANTI-SKID OVERLAY
P	P	ALUMINUM PLATE
S0	CC	UNTREATED AREA ADJACENT TO SKIDABRADER SITES
S1	CC	SKIDABRADER LOW TEXTURE
S2	CC	SKIDABRADER MEDIUM TEXTURE
S3	CC	SKIDABRADER HIGH TEXTURE
S4	CC	SKIDABRADER VERY HIGH TEXTURE
S5	CC	SKIDABRADER MEDIUM TEXTURE
S6	CC	SKIDABRADER MEDIUM TEXTURE
WHITE	P	WHITE PANEL WITH FINE ABRASIVE
RED	P	RED PANEL WITH MEDIUM ABRASIVE
BLUE	P	BLUE PANEL WITH COARSE ABRASIVE
SMTH WH	P	SMOOTH WHITE PANEL

KEY:
AC ASPHALT CONCRETE
CC PORTLAND CEMENT CONCRETE
ST SURFACE TREATMENT
P METAL PANEL
X A

Some of the systems that were used in the PIARC Experiment were also used at the NASA Wallops tests starting in 1993. Those systems were calibrated to the IFI using the European data. Unfortunately some of the devices were altered after the PIARC Experiment or used different measuring tires.

The most data for the calculation of the IFI for the Wallops Flight Facility sites through the six-year period from 1993 to 1998 was the combination of MTD (Volumetric Texture Depth using glass beads) and the

BPN (British Pendulum Number). The history of the IFI of the Wallops surfaces, where data is available, is given in the report.

Profiling is a relatively new addition to the workshop. In 1999 the first real data was recorded and a comparison of the dipstick, ARP, RoadPro and a rod and level measurement was shown. The data was in good agreement. The data from 2000 was not recorded, the equipment was only demonstrated. In 2002 there were a number of devices and the data as submitted was put onto a CD; however, much of the data was in the devices' own codes and still needs to be converted into common files so that accuracy and repeatability can be calculated. It is recommended that rod and level data be taken in May 2003 and more profiling activity be attempted, including a fourth site similar to site three.

The Annual NASA Wallops Runway Friction Workshop is considered to be an excellent workshop and are well liked by the friction measuring industries, both aviation and highway. Attendance continues to be well representative of the industry and the workshop always includes an audience from all over the world. One can see by the equipment that is brought to the workshop year after year the effort and importance that many organizations place on these workshops, and all at their own expense. NASA is to be commended for conducting these workshops, which have proven to contribute to the safety of the aviation and highway industry. It is hoped that these workshops continue for many years.

SOMMAIRE

À l'automne 1992, des données ont été recueillies en Belgique et en Espagne dans le cadre de l'expérience internationale menée par l'AIPCR (Association mondiale de la Route) dans le but de comparer et harmoniser les mesures du frottement et de la texture des chaussées. En mai 1993, d'autres essais ont eu lieu à l'installation de la NASA sur les îles Wallops. Quelques-uns des appareils utilisés l'automne précédent en Belgique et en Espagne y étaient réunis, de même que d'autres appareils qui n'avaient pas servi en Europe. Puis, en mai de chacune des neuf années suivantes (de 1994 à 2002), se sont tenues, au Centre de vols spatiaux des îles Wallops, des campagnes d'essais mettant en jeu des véhicules de mesure du frottement au sol. Ces campagnes, qui coïncidaient avec les ateliers annuels sur l'adhérence pneu-chaussée, étaient essentiellement les mêmes qu'en 1993, à ceci près qu'une journée était consacrée à des présentations par des fournisseurs et d'autres organismes concernés. La base de données considérable ainsi constituée a mené à des tableaux de moyennes représentant les résultats obtenus sur chaque site par chaque appareil, lors d'essais répétés, et a été ajoutée à celle du PCRGCAH. Dans la plupart des cas, les appareils prenaient des mesures à plusieurs vitesses variant de 32 à 96 km/h. On trouvera en annexe au rapport les rubriques suivantes :

Description des sites et photographies des surfaces
Glissance en fonction de la vitesse, par site, pour 1999
Glissance en fonction de la vitesse, par année
Données historiques sur la glissance
Données historiques sur la texture
Comparaisons des appareils (reproductibilité)
Photographies de l'ensemble des appareils utilisés chaque année
Photographies des appareils de mesure de la texture
Photographies des appareils de mesure du frottement
Photographies de divers appareils de profilométrie
Photographies de l'opération de profilométrie
Photographies d'autres dispositifs

Voici une liste des appareils qui ont servi aux essais (toutes années confondues). On trouvera dans le rapport la liste des appareils utilisés chaque année, ainsi que les tableaux des résultats obtenus avec chacun.

Appareils utilisés pour la mesure de la texture :

CT Meter (*Circular Track Meter*) – Japon
Pendule SRT (*Skid Resistance Tester*) de la FHWA – É.-U.
Drainomètre, ROSAN (MPD, ETD), véhicule de mesure de la texture de la FHWA – É.-U.
Épaisseur de texture volumétrique - billes de verre et graisse, NASA – É.-U.
Épaisseur de texture volumétrique - billes de verre et pendule SRT (*Skid Resistance Tester*), PTI – É.-U.
Drainomètre Skidabrader – É.-U.
Pendule SRT (*Skid Resistance Tester*) et CT Meter (*Circular Track Meter*) du DOT de Virginie – É.-U.
Système laser VTI d'analyse de la texture (MPD, ETD, RMS) – Suède

Appareils utilisés pour la mesure du frottement :

Appareil de mesure du frottement dynamique (DF Tester) – Japon
FAA BV-11, MuMeter et glissancemètre (SFT) – É.-U.
GripTester – NASA et USAF – É.-U.
GripTester – Écosse
GripTester – USAF (en mode «pousser» seulement)
IMAG et IRV (Véhicule international de référence) – France
Appareil d'essai de la roue bloquée E-274 de International Cybernetics (SNB et SNR) – É.-U.
Décéléromètre JBI – É.-U.
Appareil d'essai de la roue bloquée E-274 de K. J. Law (SNR) et glissancemètre – É.-U.
Appareil d'essai de la roue bloquée E-274 du DOT du Maryland (SNR) – É.-U.
Véhicule à freinage diagonal de la NASA – É.-U.
OSCAR, ROAR, RUNAR et SALTAR de Norsemeter (glissancemètres à taux variable) –Norvège

Appareil d'essai de la roue bloquée E-274 de la Pennsylvanie (SNB et SNR) – É.-U.
Appareil d'essai de la roue bloquée E-274 du DOT de la Pennsylvanie – É.-U.
Glissancemètre (SFT) – Suède
Glissancemètres (TC79 et TC85) et décéléromètre à enregistrement électronique (ERD) et Blazer de Transports Canada – Canada
Glissancemètre de la U.S. Navy – É.-U.
Glissancemètre USFT – É.-U.
Appareil d'essai de la roue bloquée E-274 (SNB et SNR) du DOT de Virginie – É.-U.
VTI BV-14 – Suède

Systèmes utilisés pour la mesure de la rugosité :

Baguette et niveau ARP – É.-U.
Profilomètre Dynatest – É.-U.
DYNVIA – République tchèque
Profilomètre rapide Greenwood – Danemark
Profilomètre rapide et profilomètre léger du DOT du Maryland – É.-U.
Profilomètre léger ICC et ARRB Walker du DOT de Pennsylvanie – É.-U.
Baguette et niveau
Jauge graduée FACE, profilomètre rapide ICC et APL (analyseur de profil en long) du DOT de Virginie – É.-U.
YSI Roadpro – É.-U.

Description des sites

Site	Surface	Description
A	CC	FINITION À LA COURROIE DE CANEVAS
B	CC	RAINURES DE ¼ po x ¼ po ESPACÉES DE 1 po
C	CC	RAINURES DE ¼ po x ¼ po ESPACÉES DE 1 po (granulats différents)
D	CC	FINITION PAR PASSAGE D'UNE TOILE DE JUTE
E	AC	PETITS GRANULATS
F	AC	RAINURES DE ¼ po x ¼ po ESPACÉES DE 2 po
G	AC	PETITS GRANULATS
K	ST	COUCHE DE SCELLEMENT JENNITE
K0	AC	ZONE NON TRAITÉE ADJACENTE AU SITE K
L	AC	GRANULATS MOYENS
MS0	AC	SURFACE ADJACENTE AUX SITES DE MICROSURFAÇAGE
MS1	ST	MICROSURFAÇAGE
MS2	ST	MICROSURFAÇAGE
MS3	ST	MICROSURFAÇAGE
MS4	ST	REVÊTEMENT ANTIDÉRAPANT
P	P	TÔLE D'ALUMINIUM
S0	CC	ZONE NON TRAITÉE ADJACENTE AUX SITES TRAITÉS AU SKIDABRADER
S1	CC	SKIDABRADER – TEXTURE FAIBLE
S2	CC	SKIDABRADER – TEXTURE MOYENNE
S3	CC	SKIDABRADER – TEXTURE FORTE
S4	CC	SKIDABRADER – TEXTURE TRÈS FORTE
S5	CC	SKIDABRADER – TEXTURE MOYENNE
S6	CC	SKIDABRADER – TEXTURE MOYENNE
P BLANC		PANNEAU BLANC REVÊTU D'UN ABRASIF FIN
P ROUGE		PANNEAU ROUGE REVÊTU D'UN ABRASIF MOYEN
P BLEU		PANNEAU BLEU REVÊTU D'UN ABRASIF GROSSIER
P BL LISSE		PANNEAU BLANC LISSE

LÉGENDE :
AC BÉTON D'ASPHALTE
CC BÉTON DE CIMENT PORTLAND
ST REVÊTEMENT SUPERFICIEL
P PANNEAU MÉTALLIQUE

Certains des systèmes utilisés pour l'expérience de l'AIPCR ont aussi servi aux essais réalisés aux installations de la NASA sur les îles Wallops, à partir de 1993. Ces systèmes avaient été étalonnés à l'aide des données européennes. Malheureusement, après l'expérience de l'AIPCR, certains des appareils ont été modifiés ou équipés de pneumatiques différents.

Pendant les six années d'essais (de 1993 à 1998) réalisés aux sites des îles Wallops, la plupart des données recueillies aux fins du calcul de l'IFI avaient trait à la valeur MTD (épaisseur de texture volumétrique mesurée à l'aide de billes de verre) et à l'indice de glissance BPN (pour *British Pendulum Number*). Les tableaux 1 et 2 donnent l'historique des indices IFI qui ont pu être établis pour les surfaces des îles Wallops.

La profilométrie est un ajout assez récent aux essais. En 1999, les premières données ont été enregistrées en conditions réelles, et le rapport a donné les résultats obtenus à l'aide de divers instruments de mesure (jauge graduée, ARP, RoadPro, baguette et niveau). On note une bonne concordance entre les données. En 2000, aucune donnée n'a été enregistrée : le matériel n'a servi qu'à des fins de démonstration. En 2002, quelques appareils ont été mis en oeuvre et les données brutes ont été enregistrées sur CD; mais beaucoup des données étaient exprimées dans le code particulier de l'appareil et il reste à les convertir pour pouvoir les intégrer dans des fichiers communs et établir leur précision et leur répétabilité. Pour mai 2003, il est recommandé de prendre des mesures à l'aide de la baguette et du niveau, et d'intensifier la profilométrie, notamment en ajoutant un quatrième site semblable au site trois.

Les ateliers annuels d'étude de l'adhérence pneu-chaussée tenus par la NASA aux îles Wallops jouissent d'une renommée enviable auprès de l'industrie de la mesure du frottement des chaussées, autant aéronautiques que routières. Ils réussissent encore à attirer, aux quatre coins du monde, un auditoire bien représentatif de l'industrie. D'ailleurs, tout le matériel qu'y apportent, année après année, les nombreuses organisations participantes (à leurs frais, faut-il le souligner) témoigne bien de l'engagement de celles-ci et de l'importance qu'elles accordent à ces ateliers.
Il y a lieu de féliciter la NASA pour la tenue de ces ateliers, qui ont un apport inestimable à la sûreté du transport aérien et du transport routier. Il faut espérer que ces ateliers existeront encore longtemps.

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NOMENCLATURE

ACI	Airports Council International
ALPA	Air Line Pilots Association
ASFT	Airport Surface Friction Tester
ASTM	ASTN International
ATA	Air Transport Association
BPN	British Pendulum Number
BPT	PTI British Pendulum Tester (BPN) - USA
CT-Meter	Circular Track Meter - Japan
DBV	NASA Diagonal Braked Vehicle - USA
DF Tester	Dynamic Friction Tester- Japan
DOT	Department of Transportation
ETD	Estimated Texture Depth
FAA	Federal Aviation Administration, USA
FAA-MU	FAA MuMeter - USA
FAA-RFT	FAA Runway Friction Tester - USA
FAA-SFT	FAA Surface Friction Tester (SFT) - USA
FHWA	Federal Highway Administration, USA
FHWA TV	FHWA Texture Van (MPD)- USA
FHWA-BPT	FHWA British Pendulum Tester (BPN) - USA
FHWA-OM	FHWA Outflow Meter - USA
FHWA-ROSAN	FHWA ROSAN (MPD, ETD) - USA
GT	GripTester - Scotland
IB	Bare Ice
ICAO	International Civil Aviation Organization
ICC-E274	International Cybernetics E-274 Locked Wheel Tester (SNB and SNR) - USA
IFALPH	the International Federation of Air Line Pilots
IFI	International Friction Index
IMAG	IMAG - France
IRFI	Joint Winter Runway Friction Measurement Program
ITTV	Integrated Tire Test Vehicle
JAA	Joint Aviation Authority
JBI	James Brake Index
JWRFMP	Joint Winter Runway Friction Measurement Program
MPD	Mean Profile Depth
MTD	Mean Texture Depth
NASA	National Aeronautics and Space Administration
NASA-GMTD	NASA Volumetric Texture Depth, Grease - USA
NASA-MTD	NASA Volumetric Texture Depth, Glass beads - USA
NRC	National Research Council Canada
PIARC	World Roads Association
PTI-BPT	Penn State PTI British Pendulum Tester (BPN) - USA
PTI-E275	Penn State PTI E-274 Locked Wheel Tester (SNB and SNR) - USA
PTI-MTD	Penn State PTI Volumetric Texture Depth, Glass beads - USA
RFT	K. J. Law Runway Friction Tester - USA
IRV	International Reference Vehicle
ROAR	The Norsemeter ROAR (Norway) variable slip tester - Norway
RUNAR	The Norsemeter RUNAR – Norway
SALTAR	The Norsemeter SALTAR - Norway
SB	Bare Compacted Snow
SD	Compacted Snow with a layer of loose snow
SFT	Surface Friction Tester (SFT) - Sweden
TC	Transport Canada
VA-BPT	Virginia DOT British Pendulum Tester (BPN) - USA
VA-BPT	Virginia DOT British Pendulum Tester (BPN) - USA
VA-E274	Virginia DOT E-274 Locked Wheel Tester (SNB and SNR) - USA
VTI Laser	VTI Laser Texture System (MPD) – Sweden

1.0 INTRODUCTION

In fall 1992, data was collected in Belgium and Spain for the PIARC International Experiment to compare and Harmonize Friction and Texture Measurements [1]. The following May, some of the devices used in the tests in Belgium and Spain were assembled at the NASA facility. Measurements were made with other devices that were not used in Europe. Each May for the next consecutive nine years (1994 – 2002) data was collected with ground vehicles on the test surfaces at the NASA Wallops Flight Facility during the annual Tire/Runway Friction Workshops. These differed from the 1993 program in that one day was set aside for presentations by vendors and other interested parties. The actual test programs for these workshops were similar to the 1993 program. This extensive database has been compiled into spreadsheets summarizing the average values of repeat runs made on each site by each device. In most cases the high-speed testers performed measurements at several speeds ranging from 32 to 96 km/h. Appendies A through F supply the following information:

Appendix A: site descriptions and surface photographs
Appendix B: friction versus speed by site for 1999
Appendix C: friction versus speed by year
Appendix D: friction history
Appendix E: texture history
Appendix F: comparison of devices (reproducibility)

Below is a summary of the equipment used over the years. Appendix G holds group pictures for each year. Appendix H holds photographs of texture devices. Appendix I holds photographs of friction devices. Appendix J holds photographs of various profiling devices. Appendix K holds photographs of profiling sites. Appendix L holds photographs of other devices. In the report, the devices are listed for each year, along with tables displaying the corresponding measurements.

Texture Devices that took part in the measurements are:

Circular Track Meter (CT Meter) - Japan
FHWA British Pendulum Tester (BPN) - USA
FHWA Outflow Meter – USA
FHWA ROSAN (MPD, ETD) – USA
FHWA Texture Van - USA
NASA Outflow Meter - USA
NASA Volumetric Texture Depth, Glass beads - USA
NASA Volumetric Texture Depth, Grease – USA
PSU Volumetric Texture Depth, Glass beads – USA
PTI British Pendulum Tester (BPN) – USA
Skiddabrader Outflow Meter – USA
Virginia DOT British Pendulum Tester (BPN) – USA
Circular Track Meter (CT Meter) – Virginia
VTI Laser Texture System (MPD, ETD, RMS) - Sweden

All of the texture devices were operated according to the manufacturer's procedures. In addition the Volumetric tests with glass beads, the Skidabrader outflow meter, the British Pendulum Tester, and the Circular Track Meter were operated as specified in their ASTM standards.

Friction Devices used to collect measurements included:

Dynamic Friction Tester (DF Tester) – Japan
FAA BV-11 – USA
FAA MuMeter – USA
FAA Surface Friction Tester (SFT) – USA
GripTester – NASA
GripTester – Scotland
GripTester – USAF
GripTester – USAF (Push mode only
IMAG – France
International Cybernetics E-274 Locked Wheel Tester (SNB and SNR) – USA
IRV – International Reference Vehicle - France
JBI Decelerometer – USA
K. J. Law E-274 Locked Wheel Tester (SNR) – USA
K. J. Law Runway Friction Tester – USA
Maryland DOT E-274 Locked Wheel Tester (SNR) – USA
NASA Diagonal Braked Vehicle – USA
Norsemeter OSCAR (variable slip tester) – Norway
Norsemeter ROAR (variable slip tester) – Norway
Norsemeter RUNAR (variable slip tester) – Norway
Norsemeter SALTAR – Norway
Penn State E-274 Locked Wheel Tester (SNB and SNR) – USA
Pennsylvania DOT E-274 Locked Wheel Tester – USA
Surface Friction Tester (SFT) – Sweden
Transport Canada ERD Blazer – Canada
Transport Canada Surface Friction Tester (TC79) – Canada
Transport Canada Surface Friction Tester (TC85) – Canada
U.S. Navy Slip Meter – USA
US Surface Friction Tester (USFT) – USA
Virginia DOT E-274 Locked Wheel Tester (SNB and SNR) – USA
VTI BV-14 – Sweden

All friction devices were operated in their normal mode with their standard tires, unless otherwise noted in the data tabulations. Other modes included non-standard conditions for devices: slip speeds, water film thickness, tire types, inflation pressure, and normal load. For the self-wetting devices, runs were made in the same track and operated consecutively. To minimize the effects of water film thickness variations, one set of runs was generally made by all devices to pre-wet the surfaces. The diagonally braked vehicle and decelerometers were operated on pre-wetted surfaces with water supplied by a tank truck. Table 1 is a list of the normally used tires, pressure and water thickness.

Table 1. Tires with Corresponding Pressure and Water Thickness

Device	Owner	Tire	Tire Pressure kPa	Water Film MM
BV-11	FAA	ASTM E-501	689	1
BV-14	VTI	Trelleborg	689	unknown
DVB	NASA	ASTM E-501	165	external
DFTester	Japan	Slider	Solid Rubber	n/a
E-274 Trailer	ICC	ASTM E-524	165	0.5
E-274 Trailer	Dynatest	ASTM E-524	165	0.5
E-274 Trailer	MD DOT	ASTM E-524	165	0.5
E-274 Trailer	PSU	ASTM E-524	165	0.5
E-274 Trailer	VA DOT	ASTM E-524	165	0.5
ERD	TC	Automotive	unknown	external
GripTester	NASA	ASTM E-1844	138	1
GripTester	Scotland	ASTM E-1844	138	1
GripTester	UFAF	ASTM E-1844	138	1

Table 1. Tires with Corresponding Pressure and Water Thickness (Continued)

IMAG	STBA	PIARC Smooth		1
IRV	STBA	PIARC Smooth		1
JBI	NASA	Automotive	unknown	external
Decelerometer		Automotive		external
MuMeter	FAA	ASTM E670	69	1
OSCAR	Norway	ASTM E-524	165	0.5
RFT	FAA	ASTM E-1551	207	1
RUNAR	Norway	ASTM E-1551	207	0.5
SALTAR	Norway	ASTM E-1551	207	external
SFT	FAA	ASTM E-1551	207	1
SFT	Sweden	Trelleborg	689	0.5
SFT TC79	TC	ASTM E-1551	689	0.5
SFT TC85	TC	ASTM E-1551	689	0.5
Slip Meter	US Navy	Skider	Rubber	External
USFT	ASFT	ASTM E-1551	207	0.5

Roughness measuring systems that took part in the measurements are:

ARP Auto Rod & Level-USA
Dynatest Profiler-USA
DYNVIA -Czech Republic
Greenwood High Speed Profiler-DK
MD DOT High Speed Profiler-USA
MD DOT Light Weight Profiler-USA
PA DOT ARRB Walker
PA DOT ICC Light Weight Profiler-USA
Rod and Level
VA DOT FACE Dipstick -USA
VA DOT ICC High Speed Profiler-USA
Virginia DOT profilometer-USA
YSI Roadpro-USA

Appendix A gives the surface characteristics of each site followed by photographs of each surface.

1.1 Test Surface Description and History

SITE DESCRIPTIONS

SITE	SURFACE	DESCRIPTION
A	CC	CANVAS BELT-FINISH
B	CC	GROOVED 1X1/4X1/4 in.
C	CC	GROOVED 1X1/4X1/4 in. (Different aggregate)
D	CC	BURLAP DRAG-FINISH
E	AC	SMALL AGGREGATE
F	AC	GROOVE 2X1/4X1/4 in.
G	AC	SMALL AGGREGATE
K	ST	JENNITE SEAL
K0	AC	UNTREATED AREA ADJACENT TO SITE K
L	AC	MEDIUM AGGREGATE
MS0	AC	SURFACE ADJACENT TO MICROSURFACE SITES
MS1	ST	MICROSURFACE
MS2	ST	MICROSURFACE
MS3	ST	MICROSURFACE
MS4	ST	ANTI-SKID OVERLAY
P	P	ALUMINUM PLATE
S0	CC	UNTREATED AREA ADJACENT TO SKIDABRADER SITES
S1	CC	SKIDABRADER LOW TEXTURE
S2	CC	SKIDABRADER MEDIUM TEXTURE
S3	CC	SKIDABRADER HIGH TEXTURE
S4	CC	SKIDABRADER VERY HIGH TEXTURE
S5	CC	SKIDABRADER MEDIUM TEXTURE
S6	CC	SKIDABRADER MEDIUM TEXTURE
WHITE	P	WHITE PANEL WITH FINE ABRASIVE
RED	P	RED PANEL WITH MEDIUM ABRASIVE
BLUE	P	BLUE PANEL WITH COARSE ABRASIVE
SMTH WH	P	SMOOTH WHITE PANEL

KEY:
- AC ASPHALT CONCRETE
- CC PORTLAND CEMENT CONCRETE
- ST SURFACE TREATMENT
- P METAL PANEL

1.2 Site Locations

Figure 1 is an overall photograph of the NASA Wallops Flight Facility. Figures 2, 3, and 4 are diagrams of the three test locations showing the location of each test surface.

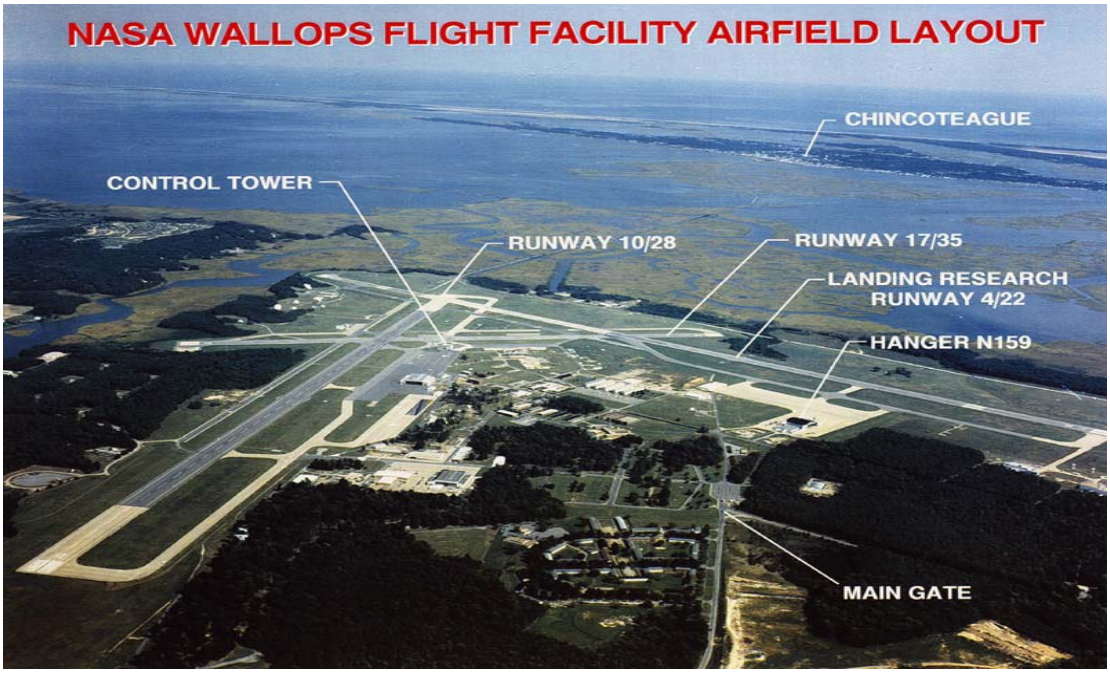

Figure 1. Overview Photograph of the NASA Wallops Flight Facility.

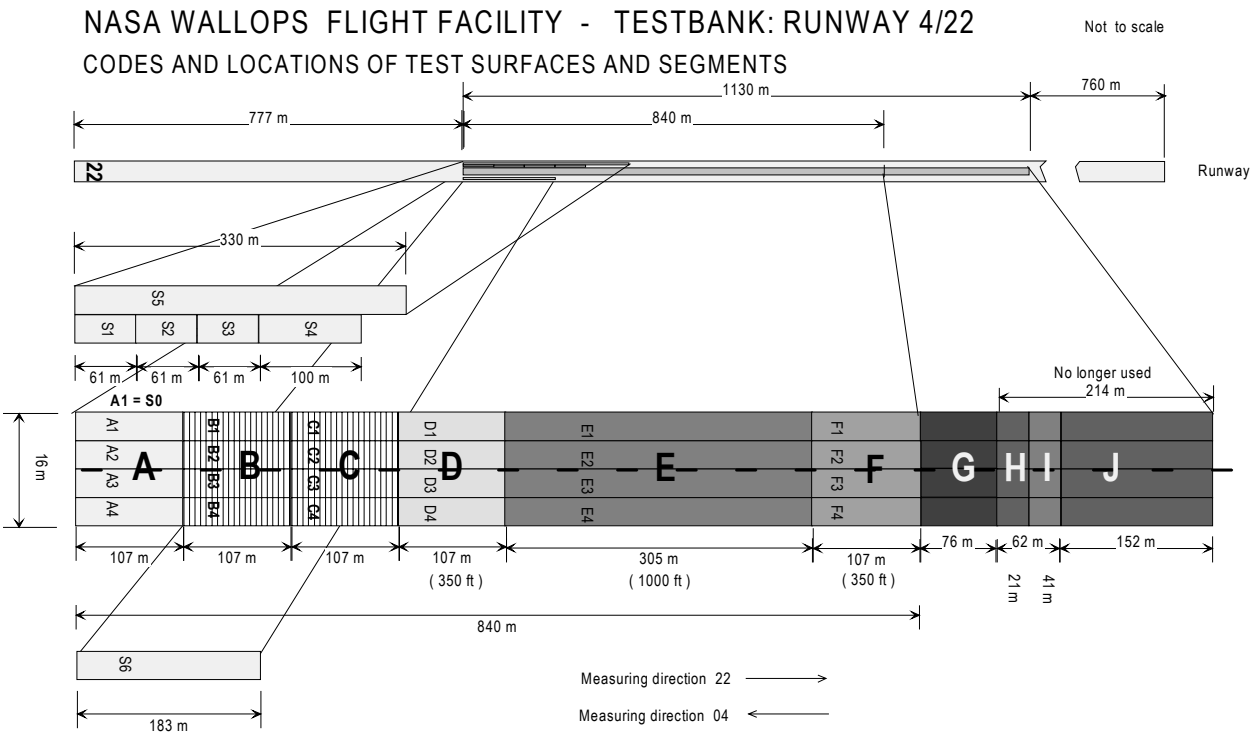

Figure 2. Test Sites on Runway 4/22

Test Site 2
Taxiway 4/22 "ECHO"

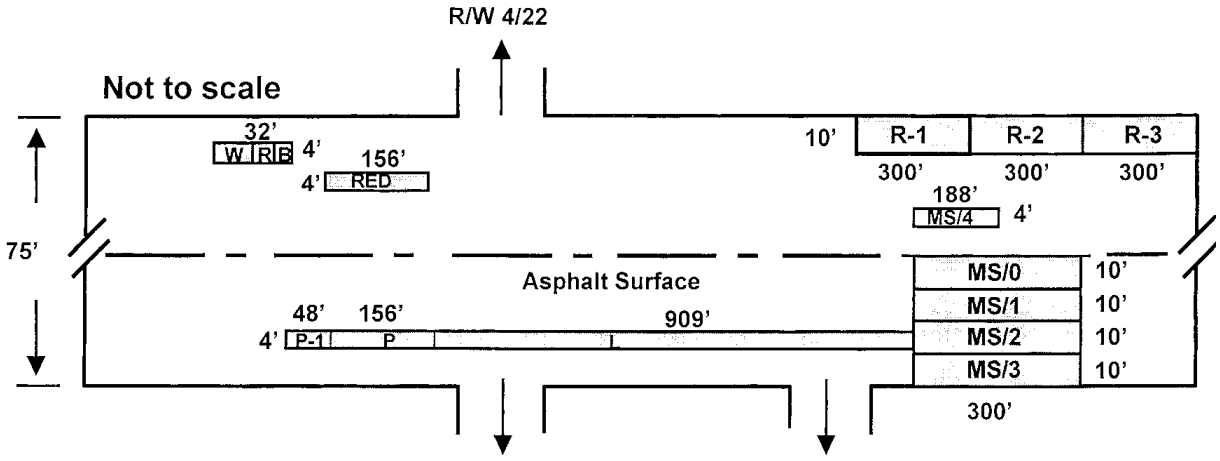

Figure 3. Test Site 2 on Taxiway ECHO

Test Site 3
Taxiway 10/28 "ALPHA"

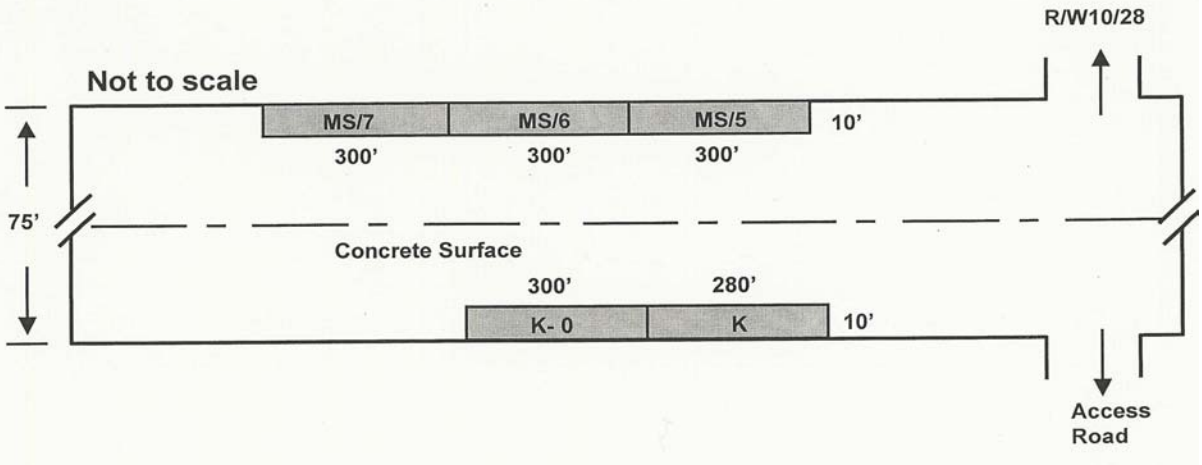

Figure 4. Test Sites on Taxiway ALPHA

1.3 IFI Analysis and History

Some of the systems that took part in the PIARC Experiment also took part at the NASA Wallops tests starting in 1993. Those systems were calibrated to the IFI using the European data. Unfortunately some of the devices were altered after the PIARC Experiment or used different measuring tires.

Most of the data used in the calculation of the IFI for the Wallops Flight Facility sites through the six year period from 1993 to 1998 is the combination of MTD (Volumetric Texture Depth using glass beads) and the BPN (British Pendulum Number). Tables 2 and 3 give the history of the IFI of the Wallops surfaces where data is available.

The relationships for predicting the IFI from MTD and BPN are as found in the PIARC Experiment:

$$S_p = 113.6\ MTD - 11.59$$
$$F60 = 0.0079\ BPN + .0778$$

The other devices took part in the measurements in Europe and Wallops were the DF Tester and the GripTester. In addition an ASTM Locked Wheel Trailer took part in the PIARC Experiment and several different ASTM trailers have been involved in the NASA workshops.

The best correlations for DF Tester in the PIARC Experiment were the values at 20 km/h. The relationship for predicting F60 from that experiment was:

$$F60 = 0.081 + 0.732\ DFT20\ \exp(-40/S_p)$$

where S_p is calculated from MTD as above. The history of the F60 for the Wallops surfaces using the DF Tester data is given in Table 2.

Table 2. History of F60

DFT SITE	F60	F60 1994	F60 1996	F60 1997	F60 1998	F60 1999	F60 2001	F60 2002
A	0.271	0.271	0.227		0.236	0.232	0.259	0.312
B	0.460	0.468	0.290		0.411	0.411	0.530	0.465
C			0.341		0.437	0.403	0.513	0.472
D	0.369	0.354	0.272		0.263	0.291	0.262	0.320
E	0.457	0.451	0.351		0.374	0.420	0.479	0.492
F	0.509				0.440	0.474	0.550	0.550
K	0.257				0.186	0.210	0.172	0.177
K0					0.348	0.347	0.361	0.320
P	0.081						0.081	
S0	0.276				0.249			
S1	0.405	0.396	0.335	0.325	0.347	0.365		0.352
S2	0.480	0.405	0.361	0.330	0.344	0.374		0.377
S3	0.562	0.472	0.433	0.409	0.459	0.463		0.433
S4		0.607	0.461	0.497	0.540	0.533		0.502
S5			0.500	0.435	0.521	0.488		0.422
S6				0.475	0.506		0.464	0.496

NOTE F60=0.0811+.732[DFT20/exp(40/Sp)]
1995 - no data
2000 - no DFTester data

Table 3. History of Sp

	Sp	Sp 1994	Sp 1996	Sp 1997	Sp 1998	Sp 1999	Sp 2000	Sp 2001	Sp 2002
A	47.6	52.3	46.3		41.8	41.8	53.2	42.2	58.2
B	206.0	206.1	95.2		172.4	195.2	238.0	280.2	187.2
C			117.9		209.9	213.3	256.7	243.7	213.2
D	81.2	68.3	56.6		52.0	56.6	67.9	48.8	62.1
E	131.1	109.4	98.6		103.1	129.3	165.9	138.5	175.0
F	198.1				188.3	191.8	225.0	200.5	207.1
K	45.8				42.9	40.7	58.2	44.4	39.9
K0					70.2	63.4	67.3	69.8	55.4
P	6.6					2.4		1.2	
S0	49.4				45.2				
S1	70.8	68.2	62.3	53.2	71.3	63.4	70.2		62.6
S2	98.3	66.7	71.3	60.0	67.9	67.9	88.7		72.6
S3	169.4	106.3	115.6	107.7	105.4	108.8	120.7		98.1
S4		260.1	132.7	234.9	262.2	248.6	240.8		197.2
S5			162.2	95.2	137.2	123.1	118.1		80.4
S6				124.7	106.6		155.4	94.2	114.1

NOTE 1993-1999 Sp derived from MTD where Sp=113.6MTD-11.69
2000-2002 Sp derived from CTMeter where Sp=110.72MPD-1.02

2.0 NASA TIRE/RUNWAY FRICTION WORKSHOPS

Every May for ten years (1993 – 2002) data has been collected with ground vehicles on the test surfaces at the NASA Wallops Flight Facility. This extensive database has been compiled into spreadsheets summarizing the average values of repeat runs made on each site by each device. In most cases the high-speed testers performed measurements at several speeds ranging form 32 to 96 km/h.[1]

2.1 1993: Continuation of the PIARC International Experiment

In the fall of 1992 data was collected in Belgium and Spain for the PIARC International Experiment to compare and Harmonize Friction and Texture Measurements [1]. The following May some of the devices that took part in the tests in Belgium and Spain assembled at the NASA facility and made measurements with other devices that did not take part in Europe. Measurements were made on 14 sites with a wide range of texture and friction characteristics. The devices that took part in May 1993 were as follows:

Devices that also took part in the measurements in Europe:

Dynamic Friction Tester (DF Tester) - Japan
VTI Laser Texture System (MPD, ETD, RMS) - Sweden
FHWA Texture Van - USA
PTI British Pendulum Tester (BPN) - USA
GripTester - Scotland

Devices that took part at Wallops but did not take part in Europe

K. J. Law Runway Friction Tester - USA
Virginia DOT E-274 Locked Wheel Tester (SNB and SNR) - USA*
NASA Volumetric Texture Depth, Glass beads - USA*
NASA Volumetric Texture Depth, Grease - USA
FHWA Outflow Meter - USA*
FAA MuMeter - USA
NASA Diagonal Braked Vehicle - USA

* A similar device took part in Europe, but the equipment and operator were not the same.

[1] In all of the tables of data that follow the friction is expressed as 0.XXX. It is customary to express Skid Numbers (SNR, SNB) and British Pendulum Numbers (BPN) as XX.X, but for consistency and for comparison of data the former form is used for these data as well.

Table 4. 1993 Data

	DFTester					Runway Friction Tester		
	20	30	40	68	80	32	64	96
SITE	Km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.602	0.602	0.602	0.611	0.637	0.730	0.560	0.363
B	0.628	0.644	0.682	0.637	0.677	0.770	0.748	0.695
D	0.643	0.639	0.636	0.642	0.660	0.745	0.583	0.383
E	0.697	0.693	0.665	0.647	0.660	0.800	0.753	0.590
F	0.716	0.707	0.692	0.671	0.709	0.818	0.783	0.718
K	0.577	0.533	0.505	0.480	0.472	0.833	0.568	0.353
L	0.722	0.711	0.696	0.691	0.713	0.898	0.823	0.693
P	0.114	0.103	0.103	0.103	0.062	0.123	0.050	0.038
SO	0.600	0.603	0.606	0.620	0.640	0.763	0.585	0.378
S1	0.780	0.760	0.740	0.713	0.705	0.925	0.680	0.485
S2	0.818	0.796	0.765	0.728	0.713	0.940	0.770	0.535
S3	0.833	0.813	0.766	0.723	0.725	0.915	0.825	0.638

	GripTester				Mean Texture Depth		Profile depth	
	64	96	64	96	MTD	GREASE	MPD	ETD
	Km/h	km/h	km/h	km/h	NASA	NASA	VTI	VTI
	F4-11	F4-11	A2-01	A2-01				
SITE	Tire	Tire	Tire	Tire	mm	mm	mm	mm
A	0.478	0.258	0.520	0.308	0.521	0.20	0.32	0.23
B	0.652	0.538	0.688	0.575	1.915	1.75	1.62	1.58
D	0.533	0.330	0.560	0.365	0.817	0.23	0.42	0.27
E	0.652	0.521	0.707	0.563	1.256	0.34	1.01	0.87
F	0.683	0.595	0.750	0.657	1.846	1.09	1.71	1.69
K	0.493	0.363	0.503	0.317	0.505	0.10	0.62	0.45
L	0.718	0.695	0.797	0.620	1.175	0.38	0.92	0.76
P	0.063	0.088	0.047	0.040	0.160	0.00	0.12	0.20
SO					0.537	0.40		
S1					0.725	0.58		
S2					0.967	0.78		
S3					1.593	1.13		

Table 4. 1993 Data (Continued)

	VA DOT E274 Trailer								Outflow Meter	
	E-524 Tire					E-501 Tire				
	32	48	64	80	96	32	64	96	FHWA	PSU
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h	sec	sec
A	0.434	0.346	0.261	0.190	0.175	0.557	0.490	0.408	11.30	10.14
B	0.522	0.532	0.502	0.501	0.480	0.593	0.527	0.527	1.16	1.26
D	0.494	0.366	0.314	0.236	0.220	0.609	0.513	0.412	7.72	5.43
E	0.598	0.521	0.505	0.417	0.417	0.673	0.591	0.507	3.86	2.34
F	0.610	0.540	0.542	0.478	0.453	0.677	0.599	0.516	1.67	1.24
K	0.481		0.277		0.195	0.584	0.457	0.325	14.61	11.29
L	0.632	0.558	0.521	0.420	0.407	0.729	0.607	0.531	3.01	3.12
P	0.093	0.062	0.033	0.044	0.032	0.200	0.112	0.065	Infinite	Infinite
SO	0.446		0.233		0.177	0.586	0.527	0.465	12.14	10.81
S1	0.581		0.355		0.249	0.755	0.571	0.433	6.59	6.39
S2	0.617					0.749	0.577	0.435	4.20	4.19
S3	0.650		0.460		0.334	0.731	0.590	0.456	3.08	2.26
S4	0.723		0.602		0.504					

	RMS		BPN	Diagonal Braked Vehicle			MuMeter		
	VTI	FHwA Van	PSU	32	64	96	32	64	96
SITE	mm	mm		km/h	km/h	km/h	km/h	km/h	km/h
A	0.24	0.157	0.658	0.45	0.25	0.11		0.44	0.35
B	1.92	2.010	0.893	0.69	0.55	0.42		0.68	0.64
D	0.30	0.208	0.681	0.44	0.30	0.19		0.47	0.41
E	0.67	0.640	0.752	0.67	0.42	0.21		0.63	0.63
F	1.57	1.702	0.875					0.71	0.70
K	0.37	0.345	0.750	0.43	0.26	0.14	0.69	0.58	
L	0.49	0.498	0.793				0.79	0.78	
P	0.06	0.236	0.364	0.21	0.12	0.06	0.17	0.11	
SO		0.183	0.689	0.53	0.28	0.13		0.46	0.34
S1		0.323	0.802	0.61	0.34	0.19		0.70	0.56
S2		0.411	0.791					0.63	0.46
S3		0.477	0.839					0.59	0.40
S4				0.71	0.52	0.32			

2.2 1994: The First NASA Tire/Runway Friction Workshop

In May 1994 NASA began sponsorship of the Tire/Runway Friction Workshops. These differ from the 1993 program in that one day was set aside for presentations by vendors and other interested parties. The actual test programs for these workshops are similar to the 1993 program. In 1994, the following devices made measurements on 12 surfaces:

Dynamic Friction Tester (DF Tester) - Japan
Virginia DOT E-274 Locked Wheel Tester (SNB and SNR) - USA
PTI British Pendulum Tester (BPN) - USA
Virginia DOT British Pendulum Tester (BPN) - USA
GripTester - Scotland
FAA MuMeter - USA
FHWA Texture Van – USA
FHWA Outflow Meter - USA
PSU Volumetric Texture Depth, Glass beads - USA

Table 5. 1994 Data

	DFTester				VADOT E-274 Trailer		
					E-524 Tire		E-501 Tire
	20	30	40	60	64	96	64
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.559	0.600	0.602	0.612	0.306	0.297	0.501
B	0.642	0.656	0.691	0.674	0.509	0.515	0.505
D	0.670	0.672	0.674	0.691	0.386	0.288	0.523
E	0.729	0.720	0.694	0.679	0.475	0.490	0.466
P	0.035	0.035	0.035	0.040	0.030	0.022	0.071
S1	0.775	0.748	0.731	0.714	0.420	0.349	0.559
S2	0.807	0.771	0.739	0.706			
S3	0.779	0.741	0.710	0.680			
S4	0.838	0.804	0.778	0.758	0.493	0.460	0.507

	BPN		MuMeter	GripTester	MTD	Outflow	RMS
	PSU	VADOT	64	64	PSU	FHwA	FHwA Van
SITE			km/h	km/h	mm	sec	mm
A	0.621	0.660	0.408	0.512	0.562	12.38	0.302
B	0.857	1.042	0.646	0.684	1.916	1.08	1.885
D	0.645	0.722	0.454	0.552	0.703	7.22	
E	0.668	0.758	0.644	0.700	1.065	5.02	
F			0.706	0.744			
K			0.427	0.503			
L			0.737	0.797			
P	0.273	0.388	0.100	0.047			0.157
S1	0.713	0.810			0.702		
S2	0.706	0.815			0.689		
S3	0.760	0.869			1.038		
S4	0.799	0.881			2.392		

2.3 1995: The Second NASA Tire/Runway Friction Workshop

The second workshop took place in May 1995. Some metal reference panels were added to the test surfaces. Although these surfaces were not sufficiently long for some of the high-speed equipment, they extended the range of texture and friction levels. Also an additional Skidabrader surface was added to the four that were prepared in 1993. Altogether 17 surfaces were subjected to measurement during the second workshop by the following devices:

Dynamic Friction Tester (DF Tester) - Japan
Penn State E-274 Locked Wheel Tester (SNB and SNR) - USA
FHWA Texture Van - USA
FHWA Outflow Meter - USA
NASA Volumetric Texture Depth, Grease - USA
Surface Friction Tester (SFT) - Sweden
IMAG - France
U.S. Navy Slip Meter - USA
JBI Decelerometer - USA

The GripTester (Scotland) also took part at Wallops, but the data is unavailable.

Table 6. 1995 Data

.	RMS	Texture Depth	James Brake Index (JBI)			Navy Slip Meter			
	FHwA Van	GREASE	Dry	20% Wet	60% Wet	Dry	Wet	Dry	Wet
SITE	mm	mm				Navy Rubber		ASTM Rubber	
A	0.221	0.200	0.590		0.580		0.80		0.96
B	2.159		0.555		0.548				
C	3.114		0.575		0.540				
D	0.206	0.280	0.670		0.560				
E	0.719	0.490							
F	1.016						0.82		0.99
S0	0.292								
S1	0.196	0.200		0.633			0.88		1.08
S2	0.236	0.260		0.615			0.86		1.07
S3	0.345	0.290		0.601			0.85		1.06
S4	0.861	0.850		0.590			0.92		1.08
S5	0.462	0.380							
WHITE	0.069				0.628	0.84	0.73	1.06	0.98
RED	0.241						0.83		1.00
BLUE	0.411					1.04	0.95	1.02	1.11

.	DFTester				PSU E-274 Trailer		IMAG	
					E-524 Tire	E-501 Tire	PIARC Tire	
	20	40	60	80	64	64	64	96
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A					0.238	0.554	0.483	0.317
B					0.533	0.543	0.564	0.494
C					0.525	0.531	0.509	0.357
D					0.258	0.526	0.547	0.450
E					0.398	0.566		
F					0.513	0.512		
S1	0.815	0.758	0.708	0.694			0.550	0.414
S2	0.789	0.719	0.669	0.65			0.585	0.471
S3	0.808	0.716	0.666	0.651			0.608	0.516
S4	0.825	0.736	0.698	0.701			0.653	0.569
S5	0.821	0.719	0.662	0.632				
WHITE	0.252	0.204	0.184	0.179				
RED	0.416	0.342	0.311	0.316				
BLUE	0.786	0.649	0.606	0.639				

Table 6. 1995 Data (Continued)

.	FAA SFT					
	ASTM Tire		AERO Tire		T520 Tire	
	64	96	64	96	64	96
SITE	km/h	km/h	km/h	km/h	km/h	km/h
A	0.527	0.323	0.683	0.534	0.690	0.612
B	0.847	0.732	0.713	0.652	0.727	0.700
C	0.841	0.722	0.697	0.626	0.710	0.688
D	0.501	0.347	0.660	0.512	0.675	0.583
E	0.739	0.663	0.692	0.626	0.725	0.690
F	0.822	0.753	0.702	0.608	0.728	0.710
P	0.010		0.038			
S1	0.613	0.440	0.590	0.495	0.673	
S2	0.648	0.480	0.607	0.513	0.687	
S3	0.750	0.631	0.633	0.558	0.703	
S4	0.855	0.790	0.635	0.582	0.697	
S5	0.832	0.699	0.683	0.642	0.780	

2.4 1996: The Third NASA Tire/Runway Friction Workshop

Three new micro surface treatments were added to the surfaces available for testing for the third workshop. The following devices took part in the third workshop:

Dynamic Friction Tester (DF Tester) - Japan [Two systems]
Penn State E-274 Locked Wheel Tester (SNB and SNR) - USA
International Cybernetics E-274 Locked Wheel Tester (SNB and SNR) - USA
Virginia DOT E-274 Locked Wheel Tester (SNB and SNR) - USA
PSU Volumetric Texture Depth, Glass beads - USA
PTI British Pendulum Tester (BPN) - USA

The GripTester (Scotland) also took part, but the data is unavailable.

Table 7. 1996 Data

	Penn State DFTester				Japan DFTester				PSU	
									MTD	BPN
	20	40	60	80	20	40	60	80		
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h	mm	
A	0.495	0.494	0.495	0.548	0.473	0.482	0.490	0.530	0.510	0.582
B	0.490	0.562	0.541	0.583	0.435	0.511	0.481	0.511	0.940	0.653
C	0.506	0.561	0.521	0.574	0.498	0.575	0.539	0.565	1.140	0.609
D	0.527	0.526	0.531	0.584	0.530	0.525	0.523	0.533	0.600	0.578
E	0.586	0.581	0.551	0.609	0.553	0.554	0.532	0.556	0.970	0.647
R2					0.689	0.639	0.594	0.566		
S1	0.673	0.644	0.614	0.610	0.660	0.629	0.609	0.583	0.650	0.716
S2	0.692	0.642	0.602	0.604	0.670	0.627	0.596	0.578	0.730	0.705
S3	0.717	0.657	0.621	0.616	0.680	0.620	0.598	0.583	1.120	0.717
S4	0.695	0.654	0.643	0.724	0.702	0.669	0.673	0.665	1.270	0.715
S5	0.757	0.662	0.619	0.622	0.732	0.640	0.594	0.566	1.530	0.745
MS1					0.758	0.732	0.724	0.688	1.130	0.806
MS2					0.757	0.741	0.735	0.704	1.460	0.812
MS3					0.806	0.791	0.706	0.778	1.350	0.826
SMOOTH	0.127	0.101	0.107	0.135	0.065	0.049	0.041	0.040		
WHITE	0.246	0.216	0.216	0.229	0.190	0.175	0.168	0.169		0.288
RED	0.346	0.290	0.282	0.301	0.254	0.212	0.203	0.225		0.479
BLUE	0.646	0.529	0.496	0.525	0.617	0.508	0.484	0.490		0.684

	VA DOT E-274 Trailer						ICC E-274 Trailer (No Water)					
	E-524 Tire			E-501 Tire			E-524 Tire			E-501 Tire		
	64	80	96	64	80	96	64	80	96	64	80	96
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.257	0.236	0.162	0.559	0.526	0.457	0.579	0.597	0.564	0.574	0.668	0.605
B	0.594	0.561	0.533	0.590	0.601	0.581	0.599	0.587	0.585	0.608	0.610	0.622
C	0.320	0.405	0.542	0.548	0.558	0.591	0.600	0.601	0.590	0.610	0.605	0.583
D	0.328	0.247	0.263	0.570	0.517	0.465	0.564	0.567	0.494	0.565	0.534	0.487
E	0.578	0.535	0.468	0.614	0.557	0.551	0.593	0.574	0.576	0.609	0.583	0.627
P	0.074	0.031	0.065	0.130	0.118	0.064				0.143	0.107	0.095
S1	0.477	0.447	0.315									
S2	0.393	0.511	0.399									
S3	0.441	0.490	0.306									
S4	0.541	0.505	0.531									
S5	0.515	0.481	0.440	0.631	0.608	0.546						
MS1	0.806	0.681	0.681	0.807	0.703	0.685	0.789	0.727	0.671			
MS2	0.749	0.617	0.608	0.822	0.775	0.744	0.842	0.769	0.707			
MS3	0.696	0.593	0.560	0.836	0.718	0.663	0.851	0.726	0.752			

Table 7. 1996 Data (Continued)

	PSU MARK III E-274 Trailer (E-501 Tire)					
	0.5 mm waterfilm			1.0 mm waterfilm		
	64	80	96	64	80	96
SITE	km/h	km/h	Km/h	km/h	km/h	km/h
A	0.660	0.580	0.490	0.620	0.500	0.420
B	0.790	0.810	0.770	0.780	0.730	0.710
C	0.800	0.780	0.740	0.770	0.730	0.690
D	0.660	0.580	0.490	0.660	0.530	0.460
E	0.840	0.790	0.750	0.760	0.700	0.630
P				0.050		0.030
S5				0.840	0.760	0.700
MS1				0.980	0.990	0.970
MS2				0.970	0.900	0.900
MS3				0.990	0.980	0.960

2.5 1997: The Fourth NASA Tire/Runway Friction Workshop

An additional longer metal panel, sufficiently long for the high-speed devices to obtain data, was added to the surfaces available for testing in 1997. Also an additional Skidabrader surface was added bring the number of those surfaces to six. The following devices took part in the fourth workshop:

Dynamic Friction Tester (DF Tester) - Japan
Virginia DOT E-274 Locked Wheel Tester (SNB and SNR) - USA
PSU Volumetric Texture Depth, Glass beads - USA
PTI British Pendulum Tester (BPN) - USA
FHWA British Pendulum Tester (BPN) - USA
Virginia DOT British Pendulum Tester (BPN) - USA
K. J. Law Runway Friction Tester - USA
FHWA ROSAN (MPD, ETD) – USA

The GripTester (Scotland) also took part, but the data is unavailable.

A new system from Sweden, the BV-14 also took part, however it was unable to distinguish the difference between sites A through F. It showed greater differences between the left and right measuring wheel than between surfaces and the friction levels reported for the sites A – F, although they varied slightly, were inconsistent with all other devices.

The Norsemeter ROAR (Norway) variable slip tester also took part and the vendor provided some partial data noted as preliminary.

A limited number of tests were performed on flooded and dry surfaces.

Several roughness measuring systems also took part in the fourth workshop. These included the DYNVIA (Czech Republic) and the Virginia DOT profilometer.

Table 8. 1997 Data

SITE	MTD PSU mm	DFTester 20 km/h	BPN PSU	BPN FHWA	BPN VA DOT	ROSAN MPD mm	ROSAN ETD mm
A						0.24	0.19
B						1.52	1.88
C						1.52	1.88
D						0.30	0.31
E						0.46	0.64
F						0.88	1.09
S1	0.57	0.71				0.28	0.25
S2	0.63	0.66				0.34	0.39
S3	1.05	0.65	0.703	0.801	0.823	0.52	0.76
S4	2.17	0.67				1.10	1.98
S5	0.94	0.74	0.744	0.834	0.794	0.51	0.75
S6	1.20	0.74	0.875	0.848	0.932	0.55	0.84
MS0			0.741				
MS1	1.25	0.81	0.782	0.865	0.866	0.41	0.54
MS2	1.23	0.77	0.834			0.41	0.54
MS3	1.55	0.74	0.844	0.849	0.873	0.47	0.66
SMOOTH		0.43	0.584	0.814	0.710		
WHITE		0.25					
RED		0.35					
BLUE		0.60					

SITE	VADOT E-274 Trailer E-524 Tire 32 km/h	64 km/h	96 km/h	Runway Friction Tester AERO Tire 100 psi 30 km/h	65 km/h	95 km/h
A	0.455	0.242	0.217	0.85	0.75	0.71
B	0.579	0.512	0.518			
C	0.559	0.485	0.501			
D	0.485	0.259	0.259			
E	0.590	0.480	0.449			
F	0.588	0.521	0.500			
P	0.122	0.042	0.038	0.18	0.08	
S1	0.489	0.721	0.674			
S2	0.758	0.680	0.597			
S3	0.760	0.681	0.601			
LONG RED	0.324	0.205	0.222			
A-SELF WATER	0.544	0.354	0.225	0.84	0.79	0.84
A-FLOODED	0.503	0.586	0.437	0.84	0.70	0.58
A-DRY				0.89	0.81	0.88

2.6 1998: The Fifth NASA Tire/Runway Friction Workshop

Two new surfaces were prepared for the fifth workshop: a micro surface treatment from Germany and a Jennite surface. The following devices took part at Wallops in the May 1998 tests:

Dynamic Friction Tester (DF Tester) - Japan
Circular Track Meter (CT Meter) - Japan
Virginia DOT E-274 Locked Wheel Tester (SNB) - USA
International Cybernetics E-274 Locked Wheel Tester (SNR) - USA
K. J. Law E-274 Locked Wheel Tester (SNR) - USA
GripTester - Scotland
NASA Volumetric Texture Depth, Grease - USA
NASA Volumetric Texture Depth, Glass beads - USA
PSU Volumetric Texture Depth, Glass beads - USA
PTI British Pendulum Tester (BPN) - USA
FAA Runway Friction Tester - USA
FAA Surface Friction Tester (SFT) - USA
IMAG - France

The GripTester, Surface Friction Tester and the Runway Friction Tester performed measurements with both low pressure (30 psi) and high pressure (100 psi) tires.

The Norsemeter RUNAR (Norway) also took part but the data is unavailable.

A new device for measuring profile depth was introduced in 1998. This was the CT Meter from Japan that produced data which is highly correlated to the volumetric method using glass beads (Mean Texture Depth).

Table 9. 1998 Data

	DFTester				MPD	MTD		Texture	BPN
					CTMeter	PSU	NASA	GREASE	PSU
	20	40	60	80					
SITE	km/h	km/h	km/h	km/h	mm	mm	mm	(mm)	
A	0.55	0.56	0.57	0.63	0.50	0.47	0.62	0.59	0.53
B	0.57	0.65	0.60	0.67	1.82	1.62	2.13	2.35	0.65
C	0.59	0.65	0.60	0.65	2.11	1.95	3.34	3.99	0.66
D	0.54	0.54	0.55	0.59	0.68	0.56	0.97	1.64	0.51
E	0.59	0.56	0.56	0.58	1.11	1.01	1.45	1.63	0.54
F	0.61	0.62	0.62	0.65	2.01	1.76	2.18	2.84	0.65
G	0.63	0.67	0.68	0.67	2.70	2.21	2.71	3.57	0.66
K	0.36	0.28	0.25	0.24	0.65	0.48	0.48	0.30	0.43
K0	0.65	0.64	0.65	0.71	0.89	0.72			0.56
S0	0.56	0.57	0.57	0.63	0.48	0.50	0.54	0.51	0.54
S1	0.64	0.62	0.61	0.64	0.65	0.73	0.68	0.60	0.65
S2	0.65	0.63	0.63	0.66	0.82	0.70	0.39	0.70	0.64
S3	0.76	0.71	0.68	0.68	1.19	1.03	1.04	0.83	0.63
S4	0.73	0.70	0.69	0.74	2.43	2.29	1.24	1.30	0.66
S5	0.81	0.74	0.71	0.72	1.29	1.31	1.31	0.98	0.67
S6	0.85	0.74	0.69	0.69	1.15	1.04	1.24	1.00	0.70
MS1	0.62	0.58	0.54	0.55	0.57	0.47	0.48	0.71	0.62
MS2	0.71	0.69	0.66	0.67	0.69	0.52	0.56	0.81	0.63
MS3	0.55	0.47	0.44	0.44	0.62	0.50	0.65	0.56	0.50
MS4	0.92	0.84	0.80	0.86	1.44	1.55	1.62	1.82	0.74
WHITE	0.21	0.18	0.18	0.18	0.31	0.27			0.32
RED	0.32	0.28	0.28	0.30	0.50	0.44			0.45
BLUE	0.66	0.59	0.59	0.63	0.58	0.64			0.67

	ICC E-274 Trailer E-501 Tire		VADOT E-274 Trailer E-524 Tire					
	64	96	48	56	64	72	80	96
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.475	0.500	0.529	0.330	0.332	0.251	0.233	
B	0.485	0.545	0.571	0.509	0.515	0.492	0.489	
C	0.475	0.542	0.499	0.445	0.505	0.484	0.483	
D	0.454	0.480	0.367	0.297	0.275	0.244	0.199	
E	0.440	0.483	0.531	0.478	0.463	0.401	0.406	
F	0.441	0.509	0.560	0.528	0.515	0.499	0.473	
S5	0.512	0.502			0.404			0.309
S6	0.507	0.517			0.512			0.373

Table 9. 1998 Data (Continued)

	K. J. Law E-274 Trailer E-501 Tire					
	48	56	64	72	80	96
SITE	km/h	km/h	km/h	km/h	km/h	km/h
A	0.618	0.59	0.528	0.504	0.444	0.508
B	0.588	0.561	0.547	0.562	0.537	0.474
C	0.594	0.561	0.53	0.538	0.518	0.441
D	0.578	0.545	0.505	0.494	0.466	0.444
E	0.59	0.57	0.506	0.534	0.52	0.474
F	0.608	0.598	0.515	0.55	0.499	0.447

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	FAA Runway Friction Tester (RFT)				GripTester			
	30 psi tire pressure		100 psi tire pressure		A-Series Tire		S-Series Tire	
	64	96	64	96	65	95	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.64	0.45	0.57	0.35	0.48	0.27	0.52	0.42
B	0.74	0.69	0.80	0.75	0.66	0.55	0.64	0.57
C	0.72	0.69	0.79	0.73	0.63	0.54	0.63	0.57
D	0.64	0.47	0.55	0.38	0.51	0.34	0.52	0.42
E	0.71	0.63	0.70	0.62	0.58	0.51	0.56	0.54
F	0.74	0.68	0.76	0.70	0.60	0.56	0.58	0.57
S5	0.80	0.64	0.71	0.50	0.63	0.48	0.63	0.53
S6	0.83	0.65	0.72	0.56	0.66	0.56	0.65	0.57

	IMAG					
	FORCE			TORQUE		
	48	64	96	48	64	96
SITE	km/h	km/h	km/h	km/h	km/h	km/h
A		0.537	0.355		0.456	0.266
B		0.608	0.584		0.547	0.526
C		0.622	0.584		0.544	0.516
D		0.535	0.394		0.455	0.309
E		0.575	0.526		0.506	0.455
F		0.584	0.569		0.518	0.500
S5		0.647			0.593	
S6			0.576			0.504
MS1	0.667	0.508	0.299	0.587	0.439	0.226
MS2	0.653	0.560	0.349	0.570	0.489	0.284
MS3	0.637	0.533	0.307	0.553	0.448	0.236
MS4		0.696	0.610		0.622	0.538
RED		0.696	0.610		0.622	0.538

Table 9 1998 Data (Continued)

	FAA SFT			
	29 psi tire pressure		100 psi tire pressure	
SITE	64 km/h	96 km/h	64 km/h	96 km/h
A	0.627	0.393	0.583	0.367
B	0.810	0.717	0.827	0.700
C	0.787	0.700	0.827	0.687
D	0.600	0.413	0.540	0.320
E	0.747	0.633	0.678	0.527
F	0.787	0.710	0.750	0.650
S5	0.763	0.607	0.673	0.513
S6	0.783	0.660	0.690	0.547

2.7 1999: The Sixth NASA Tire/Runway Friction Workshop

The sixth annual workshop took place on May 10 - 14, 1999. A second series of testing was performed with the CT Meter, MTD and three Outflow Meters on August 9 - 12, 1999.

Dynamic Friction Tester (DF Tester) - Japan
Circular Track Meter (CT Meter) - Japan
Virginia DOT E-274 Locked Wheel Tester (SNB) - USA
Transport Canada Surface Friction Tester (TC79) - Canada
US Surface Friction Tester (USFT) - USA
MuMeter - USA
SALTAR - Norway
GripTester - Scotland
NASA Diagonal Braked Vehicle (DBV) - USA
PSU Volumetric Texture Depth, Glass beads (MTD) - USA
PTI British Pendulum Tester (BPN) - USA
FHWA British Pendulum Tester (BPN) - USA
VA DOT British Pendulum Tester (BPN) - USA
FAA BV-11 - USA
FAA Runway Friction Tester - USA
FAA Surface Friction Tester (SFT) - USA
IMAG - France
FHWA Outflow Meter - USA
Skiddabrader Outflow Meter – USA
NASA Outflow Meter - USA

In this workshop, an additional track was laid out for evaluating longitudinal profiling devices. This track was in front of the N159 Hangar and extended out over the apron covering 58 slabs or 785 feet. The following devices took part:

VA DOT Dipstick -USA
YSI Roadpro-USA
ARP Auto Rod & Level-USA
VA DOT ICC High Speed Profiler-USA
Rod and Level

Table 10. 1999 Data

	BPN			BV-11			DFTester		MTD	MPD
	PSU	FHwA	VDOT	BV11 30 30 km/h	BV11 50 50 km/h	BV11 65 65 km/h	Japan 20 km/h	PSU 20 km/h	PSU mm	CTMeter mm
SITE										
A	0.598		0.66	0.700	0.603	0.590	0.536	0.495	0.50	0.47
B	0.763		1.04	0.800	0.767	0.753	0.553	0.490	2.07	2.15
C	0.635			0.827	0.803	0.750	0.531	0.506	1.88	2.04
D	0.603		0.72	0.700	0.647	0.607	0.581	0.527	0.57	0.53
E	0.653		0.76	0.743	0.730	0.723	0.631	0.586	1.48	1.75
F	0.765			0.770	0.760	0.730	0.662		1.79	1.88
G	0.660						0.630			
K	0.590						0.470		0.46	0.49
K0	0.675						0.684		0.64	0.64
MS1	0.795	0.87	0.87	0.940	0.930	0.900	0.691		1.18	1.16
MS2	0.820			0.970	0.910	0.930	0.748		1.33	1.26
MS3	0.835	0.85	0.87	0.980	0.960	0.970	0.699		1.27	1.12
MS4							0.920		1.58	1.40
S0	0.615						0.643		0.70	0.57
S1	0.720		0.81				0.730	0.673	0.60	0.64
S2	0.710		0.81				0.722	0.692	0.74	0.88
S3	0.730	0.80	0.85				0.754	0.717	1.19	1.29
S4	0.710		0.88				0.725	0.695	1.97	2.36
S5	0.717	0.83	0.79				0.770	0.757	1.06	1.02
S6	0.790	0.85	0.93				0.794		1.04	1.05

	FAA SFT							
	1551 tire 30 psi		1551 tire 100 psi		AERO tire 30 psi		T520 Tire 30 psi	
	65	95	65	95	65	95	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.602	0.376	0.583	0.367	0.683	0.530	0.690	0.610
B	0.804	0.721	0.827	0.700	0.710	0.650	0.730	0.700
C	0.776	0.714	0.827	0.687	0.700	0.630	0.710	0.690
D	0.575	0.397	0.540	0.320	0.660	0.510	0.680	0.580
E	0.745	0.641	0.677	0.527	0.690	0.630	0.730	0.690
F	0.796	0.721	0.750	0.650	0.700	0.610	0.730	0.710
S1	0.610	0.440			0.590	0.500	0.670	
S2	0.650	0.480			0.610	0.510	0.690	
S3	0.750	0.630			0.630	0.560	0.700	
S4	0.860	0.790			0.640	0.580	0.700	
S5	0.735	0.580			0.680	0.640	0.780	

Table 10. 1999 Data (Continued)

	Griptester						
	ASTM Tire		STD Tire	A211 Tire		F11 Tire	
	65	95	65	65	95	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.480	0.270	0.51	0.51	0.31	0.48	0.26
B	0.663	0.547	0.68	0.69	0.58	0.65	0.54
C	0.630	0.537					
D	0.523	0.336	0.55	0.56	0.37	0.53	0.33
E	0.577	0.507	0.70	0.71	0.56	0.65	0.52
F	0.597	0.560	0.74	0.75	0.66	0.68	0.60
K			0.50	0.50	0.32	0.49	0.36
K0			0.80	0.80	0.62	0.72	0.70
S6	0.655	0.563					

	FAA Runway Friction Tester (RFT)								
	1551 tire 100 psi		1551 tire 30 psi				Aero Tire 30 psi		
	65	95	32	48	65	95	32	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.570	0.353	0.783	0.677	0.607	0.428	0.730	0.560	0.360
B	0.800	0.743	0.890	0.883	0.776	0.694			
C	0.793	0.733	0.880	0.867	0.777	0.687			
D	0.547	0.377	0.773	0.667	0.620	0.446			
E	0.700	0.623	0.830	0.790	0.732	0.620			
F	0.763	0.700	0.845	0.820	0.770	0.690			
K			0.830		0.570	0.350			
K0			0.900	0.820	0.690				
MS1			0.980	0.940	0.920				
MS2			0.980	0.950	0.910				
MS3			1.030	1.030	0.940				
S0			0.760		0.590	0.380			
S1			0.930		0.680	0.490			
S2			0.940		0.770	0.540			
S3			0.920		0.830	0.640			
S5					0.757	0.568			

Table 10. 1999 Data (Continued)

	IMAG		Diagonal Braked Vehicle			MuMeter		
SITE	Force 65 km/h	Force 95 km/h	DBV 32 km/h	DBV 64 km/h	DBV 96 km/h	MUM 32 km/h	MUM 65 km/h	MUM 95 km/h
A	0.510	0.336	0.45	0.25	0.11		0.424	0.35
B	0.586	0.539	0.69	0.55	0.42		0.618	0.64
C	0.566	0.471						
D	0.522	0.376	0.44	0.30	0.19		0.462	0.41
E	0.561	0.488	0.67	0.42	0.21		0.637	0.63
F	0.584	0.569					0.710	0.70
K			0.43	0.26	0.14	0.69	0.504	
K0						0.79	0.759	
MS1	0.510	0.300						
MS2	0.560	0.350						
MS3	0.530	0.310						
MS4	0.700	0.610						
S0			0.53	0.28	0.13		0.460	0.34
S1	0.550	0.410	0.61	0.34	0.19		0.700	0.56
S2	0.590	0.470					0.630	0.46
S3	0.610	0.520					0.590	0.40
S4	0.650	0.570	0.71	0.52	0.32			
S5	0.650	0.580						

	SALTAR			TC SFT79 – DRY		
SITE	32 km/h	48 km/h	64 km/h	32 km/h	50 km/h	65 km/h
A	0.565	0.784	0.859	0.957	0.823	0.753
B	0.699	0.933	0.866	0.970	0.937	0.923
C	0.586	0.841	0.853	0.960	0.940	0.923
D	0.612	0.689	0.862	0.907	0.820	0.773
E	0.536	0.747	0.774	0.917	0.867	0.860
F	0.591	0.643	0.833	0.933	0.877	0.840
K0	0.555	0.707	0.901			
MS1	0.720	0.670	0.960			
MS2	0.510	0.660	0.780	0.990	0.990	0.980
MS3	0.900	0.680	0.780	0.990	0.990	0.990
MS4				1.000	1.000	0.990

Table 10. 1999 Data (Continued)

	VADOT E-274 Trailer E-501 tire			
	32	65	80	95
SITE	km/h	km/h	km/h	km/h
A	0.56	0.518	0.597	0.500
B	0.50	0.534	0.606	0.532
C		0.522	0.582	0.516
D	0.61	0.507	0.526	0.459
E	0.67	0.516	0.570	0.506
F	0.68	0.499		0.483
K	0.58	0.460		0.330
K0	0.73	0.610		0.530
MS1		0.798	0.715	0.678
MS2		0.832	0.772	0.726
MS3		0.844	0.722	0.708
S1	0.75	0.565		0.430
S2	0.75	0.580		0.430
S3	0.73	0.590		0.460
S4		0.510		
S5		0.542	0.610	0.513
S6		0.507		0.517

	VADOT E-274 Trailer E-524 tire						
	32	48	56	65	72	80	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.458	0.409	0.33	0.292	0.25	0.220	0.168
B	0.540	0.544	0.51	0.528	0.40	0.534	0.528
C	0.535	0.494	0.41	0.475	0.48	0.496	0.566
D	0.477	0.370	0.30	0.304	0.24	0.227	0.257
E	0.570	0.521	0.48	0.489	0.40	0.483	0.488
F	0.581	0.537	0.53	0.506	0.50	0.476	0.450
K	0.480			0.280			0.190
K0	0.630	0.560		0.520		0.420	0.410
MS1	0.710	0.650		0.690		0.680	0.680
MS2	0.720	0.670		0.685		0.620	0.610
MS3	0.760			0.665		0.590	0.560
S1	0.534			0.493		0.450	0.304
S2	0.689			0.537		0.510	0.400
S3	0.705			0.527		0.490	0.320
S4	0.720			0.545		0.510	0.498
S5				0.460		0.480	0.375
S6				0.512			0.373

Table 10. 1999 Data (Continued)

	USFT					
	1551 Tire			Aero Tire		
SITE	50 km/h	65 km/h	80 km/h	32 km/h	50 km/h	65 km/h
A	0.690	0.628	0.530	0.660	0.613	0.586
B	0.750	0.732	0.735	0.690	0.657	0.640
C	0.755	0.746	0.725	0.677	0.643	0.643
D	0.685	0.655	0.590	0.653	0.620	0.597
E	0.745	0.722	0.670	0.633	0.613	0.607
F	0.785	0.762	0.725	0.657	0.603	0.597
K0	0.520	0.477				
MS1	0.780	0.734	0.685	0.690	0.680	0.660
MS2				0.710	0.690	0.680
MS3				0.730	0.740	0.720
MS4	0.810	0.763	0.705			

	ADDITIONAL TEXTURE - AUGUST					ADDITIONAL TEXTURE - MAY	
	MTD	MPD	Outflow Meter			MTD	MPD
	PSU	CTMeter	FHwA	Skidabrader	NASA	PSU	CTMeter
SITE	mm	mm	sec	sec	sec	mm	mm
A	0.47	0.395	9.2	21.7	16.0		
B	1.82	1.839	1.09	2.0	2.3		
C	1.98	2.019	0.94	2.0	1.7		
D	0.60	0.601	4.96	9.3	9.3		
E	1.24	1.405	1.93	3.7	2.7		
F	1.79	1.976	1.2	2.0	2.3		
K	0.46	0.541	7.35	12.3	13.0		
K0	0.66	0.674	4.74	7.7	7.0		
MS0						0.51	0.44
P						0.08	0.02
R0						0.54	0.46
R1						0.54	0.48
R2						0.51	0.52
S1	0.66	0.614	4.61	8.7	9.3		
S2	0.70	0.780	4.03	9.0	8.3		
S3	1.06	1.070	1.82	3.3	3.0		
S4	2.29	2.172	0.56	0.7	1.0		
S5	1.19	1.186	1.86	3.3	3.0		
SMOOTH						0.15	0.04
WHITE						0.22	0.14
RED						0.44	0.34
BLUE						0.61	0.50
Long White						0.24	0.18
Long Red						0.54	0.42

Figure 5 shows the walkers profiles versus the rod and level and Figure 6 shows the high speed profiler.

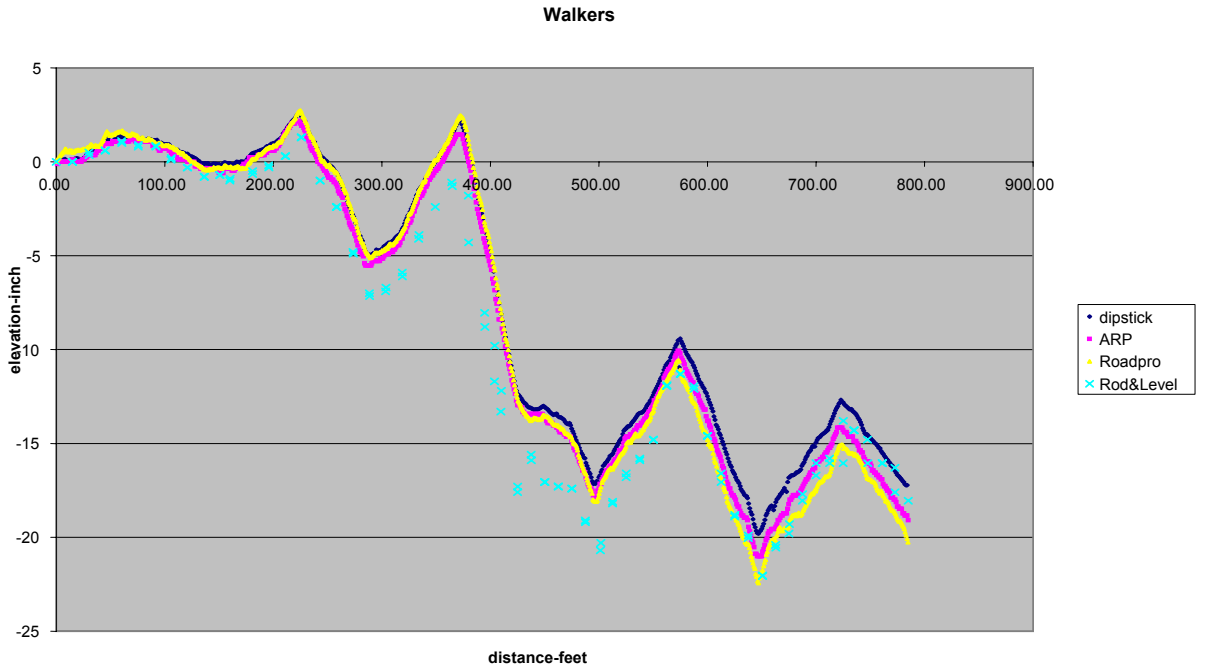

Figure 5. Profiles of the Walkers versus Rod and Level

Figure 6. Three Repeats of a High Speed Profiler

2.8 2000: The Seventh NASA Tire/Runway Friction Workshop

The seventh annual workshop took place on May 15 – 18, 2000. The following friction and texture measuring devices took part:

Circular Track Meter (CT Meter) - Japan
Transport Canada Surface Friction Tester (TC79) - Canada
GripTester – FAA (Push mode only)
FAA BV-11 - USA
FAA Runway Friction Tester - USA
FAA Surface Friction Tester (SFT) - USA
IRV – International Reference Vehicle - France
Skiddabrader Outflow Meter - USA

In addition in this workshop a track was laid out for evaluating longitudinal profiling devices. This track was in front of the N159 Hangar and extended out over the apron covering 58 slabs or 785 feet. A second track was laid out perpendicular to the other track along the end of the apron. The following devices took part:

VA DOT FACE Dipstick -USA
YSI Roadpro-USA
ARP Auto Rod & Level-USA
VA DOT ICC High Speed Profiler-USA
PA DOT ICC Light Weight Profiler-USA

Because of the amount of data, profiles are available on a CD from NASA.

Table 11. 2000 Data

	SFT79 1551 Smooth Tire				IRV PIARC Smooth Tire			
	Force		Torque		Force		Torque	
SITE	65 km/h	95 km/h	65 km/h	95 km/h	65 km/h	95 km/h	65 km/h	95 km/h
A	0.60	0.47	0.48	0.37	0.35	0.32	0.20	0.15
B	0.90	0.85	0.78	0.73	0.61	0.60	0.58	0.56
C	0.87	0.81	0.74	0.68	0.60	0.58	0.56	0.53
D	0.58	0.47	0.47	0.37	0.35	0.31	0.23	0.18
E	0.84	0.81	0.72	0.69	0.53	0.52	0.46	0.44
F	0.87	0.84	0.75	0.72	0.59	0.58	0.55	0.55
K	0.46	0.25	0.35	0.15	0.26	0.24	0.18	0.16
MS0	0.95	0.93	0.83	0.79	0.63	0.51	0.61	0.48
MS2	0.75	0.55	0.61	0.43	0.40	0.19	0.36	0.15
MS4	0.97	0.97	0.87	0.84	0.68	0.66	0.62	0.60
P	0.08	0.05	0.01	0.01	0.07	0.07	0.05	0.05
R1	0.71	0.52	0.58	0.40	0.45	0.44	0.23	0.21
R2	0.61	0.40	0.49	0.30	0.42	0.41	0.29	0.28
R3	0.79	0.57	0.65	0.46	0.39	0.38	0.21	0.19
S2	0.99	0.85	0.89	0.73	0.67	0.65	0.42	0.39
S5	0.85		0.72		0.56	0.54		
Red Panel	0.51	0.41	0.38	0.30	0.38	0.37	0.26	0.24

Table 11. 2000 Data (Continued)

SITE	FAA BV11 1551 SMOOTH 65 km/h	FAA BV11 1551 SMOOTH 95 km/h	CTMeter MPD mm	FAA RFT 1551 SMOOTH 65 km/h	FAA RFT 1551 SMOOTH 90 km/h	Outflow Meter sec	GripTester Push mode
A	0.55	0.44	0.489	0.57	0.37	18.077	0.75
B	0.71	0.69	2.158	0.80	0.73	2.353	0.70
C	0.70	0.67	2.328	0.76	0.67	1.931	0.74
D	0.53	0.42	0.623	0.55	0.39	11.180	0.74
E	0.67	0.65	1.508	0.72	0.61	4.309	0.66
F	0.70	0.72	2.042	0.76	0.69	2.911	0.63
K	0.28	0.17	0.535	0.31	0.23		
K0	0.49	0.35	0.617	0.59	0.38		
MS1			1.248				
MS2			1.421				
MS3			1.161				
P	0.03	0.03	0.031	0.03	0.03		
R1	0.46	0.22	0.629	0.56	0.42		
R2	0.63	0.42	0.743	0.73	0.53		
R3	0.53	0.22	0.509	0.61	0.40		
R4	0.85	0.81	1.434	0.86	0.71		
S1			0.644			10.301	0.81
S2	0.81	0.71	0.810	0.84	0.75	9.887	0.80
S3			1.099			9.524	0.76
S4			2.184			1.786	0.68
S5			1.076			5.320	0.78
S6			1.413			3.140	0.86
WHITE			0.193				
RED			0.379				
BLUE			0.479				
Red Pnl	0.36	0.42	0.450	0.49	0.36		
SMOOTH			0.185				

Table 11. 2000 Data (Continued)

IRV TIRE TESTS AT 15% SLIP ON SITES A - F

	PIARC Smooth tire				PIARC Ribbed tire			
	Force		Torque		Force		Torque	
	65	95	65	95	65	95	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.35	0.32	0.20	0.15	0.65	0.65	0.62	0.60
B	0.61	0.60	0.58	0.56	0.65	0.65	0.65	0.63
C	0.60	0.58	0.56	0.53	0.63	0.62	0.61	0.60
D	0.35	0.31	0.23	0.18	0.62	0.62	0.61	0.59
E	0.53	0.52	0.46	0.44	0.63	0.62	0.62	0.61
F	0.59	0.58	0.55	0.55	0.63	0.62	0.62	0.61

	PIARC Smooth tire - 1990				Aircraft Tire			
	Force		Torque		Force		Torque	
	65	95	65	95	65	95	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.52	0.51	0.43	0.40	0.52	0.50	0.45	0.42
B	0.61	0.61	0.58	0.57	0.56	0.55	0.55	0.53
C	0.59	0.58	0.56	0.55	0.55	0.53	0.54	0.52
D	0.52	0.51	0.42	0.39	0.48	0.46	0.41	0.39
E	0.55	0.55	0.52	0.51	0.49	0.48	0.46	0.44
F	0.56	0.56	0.53	0.53	0.50	0.50	0.49	0.47

IRV SLIP TESTS WITH THE PIARC SMOOTH TIRE ON SITE S2

	Force		Torque	
	65	95	65	95
SLIP	km/h	km/h	km/h	km/h
15%	0.67	0.65	0.42	0.39
30%	0.57	0.55	0.60	0.57
60%	0.55	0.52	0.58	0.55

2.9 2001: The Eighth NASA Tire/Runway Friction Workshop

The Eighth Annual Workshop took place on May 14 – 17, 2001. The following friction and texture measuring devices took part:

Dynamic Friction Tester (DF Tester) - Japan
Circular Track Meter (CT Meter) - Japan
Circular Track Meter (CT Meter) - Virginia
Virginia DOT E-274 Locked Wheel Tester - USA
Pennsylvania DOT E-274 Locked Wheel Tester - USA
Transport Canada Surface Friction Tester (TC85) - Canada
GripTester - NASA
GripTester – USAF
FAA BV-11 - USA
FAA Runway Friction Tester - USA
FAA Surface Friction Tester (SFT) - USA
IMAG - France
Skiddabrader Outflow Meter – USA

In addition in this workshop a track was laid out for evaluating longitudinal profiling devices. This track was laid out on taxiway Alpha to be 1024 feet long with a 300 foot lead-in. The following devices took part:

VA DOT FACE Dipstick -USA
YSI Roadpro-USA
ARP Auto Rod & Level-USA
PA DOT ARRB Walker
MD DOT Light Weight Profiler-USA
PA DOT ICC Light Weight Profiler-USA
VA DOT ICC High Speed Profiler-USA
MD DOT High Speed Profiler-USA
Dynatest Profiler-USA
Greenwood High Speed Profiler-DK

All Light Weights and High Speed Profilers made ten repeat runs on the taxiway alpha site in the same direction. In addition many made a single run on the runway 4-22. Walking profilers made from one to ten runs, some making left and right wheel tracks. All data was collected by Dynatest and is available on CD from NASA or CDRM

Table 12. 2001 Data

	DFTester				CTMeter - Japan		CTMeter-Virginia		OFT
	20	40	60	80	MPD	RMS	MPD	RMS	
SITE	km/h	km/h	km/h	km/h	mm	mm	mm	mm	sec
A	0.629	0.616	0.638	0.656	0.39	0.28			14.299
B	0.708	0.767	0.730	0.695	2.54	3.06			2.585
C	0.696	0.767	0.698	0.672	2.21	2.43			2.260
D	0.560	0.572	0.607	0.638	0.45	0.33			9.757
E	0.725	0.697	0.690	0.661	1.26	0.94			
F	0.782	0.765	0.806	0.747	1.82	1.65			
K	0.306	0.235	0.219	0.232	0.41	0.43	0.37	0.44	10.357
K0	0.678	0.660	0.676	0.649	0.59	0.60			11.635
L									15.171
MS0	0.751	0.690	0.661	0.624	0.47	0.44	0.42	0.35	25.252
MS1	0.781	0.775	0.784	0.746	1.21	1.04	1.11	0.95	3.157
MS2	0.791	0.797	0.818	0.771	1.18	0.70	1.12	0.81	2.750
MS3	0.876	0.872	0.899	0.782	1.01	0.81	0.93	0.78	4.288
MS4	0.920	0.887	0.883	0.785	1.10	0.83	1.12	0.72	3.592
P	0.101	0.075	0.072	0.076	0.02	0.23	0.02	0.12	
R1	0.656	0.581	0.545	0.541	0.45	0.40	0.41	0.36	32.037
R2							0.47	0.42	32.295
R3	0.635	0.567	0.531	0.540	0.50	0.54			
S6	0.800	0.733	0.710	0.662	0.86	0.45			
Long Red	0.478	0.420	0.417	0.467	0.35	0.23	0.29	0.36	16.523
Long White	0.019	0.019	0.021	0.026	0.03	0.23			
White	0.166	0.152	0.153	0.158	0.14	0.21	0.10	0.14	
Red	0.311	0.273	0.270	0.296	0.30	0.22	0.28	0.21	20.326
Blue	0.692	0.647	0.656	0.652	0.39	0.18			13.374

	TC SFT85		USAF GT		NASA GT		FAA SFT		
	65	90	65	95	65	95	40	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.721	0.576	0.496	0.301	0.50	0.33	0.777	0.586	0.465
B	0.883		0.633	0.552	0.71	0.59	0.793	0.744	
C	0.735		0.624	0.544	0.69	0.56	0.770	0.723	
D	0.744		0.518	0.386	0.56	0.46	0.753	0.603	
E	0.760		0.571	0.539	0.65	0.63	0.760	0.679	
F	0.807		0.581	0.560	0.68	0.63	0.777	0.718	
K	0.360		0.331		0.33			0.382	
K0	0.476		0.472		0.52			0.660	
L			0.516		0.60			0.750	
MS2			0.693		0.84			0.846	
P			0.050		0.04			0.037	
S2	0.734	0.643	0.624	0.540			0.797	0.732	0.618

Table 12. 2001 Data (Continued)

	IRV				FAA RFT		
	Force		Torque				
	65	95	65	95	40	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.420	0.286	0.388	0.255	0.71	0.49	0.365
B	0.656	0.626	0.626	0.596	0.84	0.78	
C	0.640	0.598	0.610	0.568	0.84	0.74	
D	0.436	0.346	0.405	0.315	0.73	0.48	
E	0.590	0.565	0.560	0.535	0.79	0.69	
F	0.631	0.612	0.601	0.582	0.83	0.74	
K	0.282		0.248			0.29	
K0	0.422		0.394			0.45	
L	0.396		0.373			0.59	
MS2	0.676		0.656			0.79	
P	0.048		0.02			0.11	
S2	0.600	0.546	0.578	0.524	0.75	0.65	0.522

	FAA BV-11		E-274 VADOT			E-274 PADOT		
	65	95	40	65	95	40	65	95
SITE	km/h	km/h	km/h	km/h	km/h	km/h	km/h	km/h
A	0.578	0.465	0.362	0.253	0.177	0.370	0.274	0.191
B	0.856		0.574					
C	0.837		0.587					
D	0.570		0.395	0.300	0.230		0.304	
E	0.715		0.562	0.495	0.421		0.475	
F	0.776		0.569				0.496	
K				0.151			0.160	
K0				0.252			0.276	
L	0.576			0.343			0.393	
MS2	0.813			0.602			0.589	
P	0.044			0.016			0.056	
S2	0.635	0.611	0.556	0.446	0.313	0.550	0.441	0.345

2.10 2002: The Ninth NASA Tire/Runway Friction Workshop

The ninth annual workshop took place on May 13 – 16, 2002. The following friction and texture measuring devices took part:

Dynamic Friction Tester (DF Tester) - Japan
Circular Track Meter (CT Meter) - Japan
Circular Track Meter (CT Meter) - Virginia
Virginia DOT E-274 Locked Wheel Tester - USA
*Transport Canada Surface Friction Tester (TC85) - Canada
*GripTester - NASA
FAA BV-11 - USA
FAA Runway Friction Tester - USA
*FAA Surface Friction Tester (SFT) - USA
IMAG - France
Skiddabrader Outflow Meter - USA

* The data for these devices has not been received in reduced form.

Table 13. 2002 Data

	CTMeter - Japan			CTMeter - Virginia			DFTester			
	MPD	RMS	MTD	MPD	RMS	MTD	20	40	60	80
SITE	mm	mm	mm	mm	mm	mm	km/h	km/h	km/h	km/h
A	0.54	0.34	0.61	0.53	0.41	0.60	0.628	0.625	0.641	0.637
B	1.69	2.02	1.70	1.71	2.01	1.72	0.650	0.710	0.673	0.627
C	1.75	2.01	1.76	2.12	2.41	2.11	0.644	0.692	0.634	0.605
D	0.57	0.54	0.63	0.57	0.54	0.63	0.622	0.615	0.617	0.598
E	1.55	1.18	1.57	1.63	1.47	1.64	0.705	0.711	0.715	0.658
F	1.88	1.58	1.88	1.88	1.58	1.88	0.777	0.772	0.807	0.680
K0	0.53	0.57	0.60	0.49	0.51	0.56	0.671	0.664	0.673	0.641
K	0.37	0.49	0.44	0.37	0.50	0.44	0.358	0.275	0.252	0.268
MS0	0.52	0.50	0.59	0.42	0.44	0.49	0.756	0.714	0.670	0.624
MS1	1.04	0.76	1.08	1.04	0.72	1.08	0.892	0.887	0.911	0.772
MS2	1.22	0.78	1.25	1.16	0.79	1.20	0.849	0.840	0.862	0.739
MS3	1.20	0.77	1.23	1.19	0.75	1.22	0.842	0.831	0.853	0.748
MS4	1.11	0.77	1.15	1.18	0.76	1.21	0.935	0.891	0.870	0.763
MS6							0.823	0.821	0.833	0.720
R1	0.42	0.47	0.49	0.41	0.40	0.48	0.683	0.904	0.554	0.535
R2	0.61	0.48	0.67	0.58	0.42	0.64	0.781	0.729	0.701	0.653
R3	0.52	0.49	0.59	0.59	0.58	0.65	0.701	0.627	0.578	0.548
S1	0.57	0.36	0.63	0.58	0.72	0.64	0.701	0.686	0.685	0.660
S2	0.66	0.38	0.72	0.67	0.72	0.73	0.701	0.678	0.668	0.629
S3	0.90	0.66	0.95	0.89	0.71	0.94	0.723	0.695	0.678	0.639
S4	1.77	1.53	1.78	1.81	1.42	1.81	0.705	0.670	0.643	0.626
S5	0.76	0.60	0.81	0.71	0.73	0.77	0.767	0.724	0.711	0.650
S6	1.03	0.85	1.07	1.05	1.09	1.09	0.804	0.749	0.734	0.691

	OutFlow Meter
SITE	sec
A	9.576
B	2.625
C	1.841
D	10.926
E	2.737
F	1.788
S1	7.843
S2	6.771
S3	3.510
S4	1.123
S6	2.723

Table 13. 2002 Data (Continued)

REPEATABILITY TESTS AT 65 km/h

SITE	BV-11 - FAA			RFT - FAA		
		n	STD DEV		n	ST DEV
A	0.700	5	0.054	0.522	19	0.081
B	0.876	5	0.037	0.790	19	0.026
C	0.804	5	0.052	0.758	19	0.032
D	0.746	5	0.045	0.507	19	0.067
E	0.838	5	0.048	0.677	19	0.034
F	0.822	5	0.021	0.747	19	0.041

	IRV					
	Force			Torque		
SITE		n	ST DEV		n	ST DEV
A	0.423	25	0.039	0.396	25	0.050
B	0.602	25	0.054	0.583	25	0.099
C	0.588	25	0.046	0.561	25	0.087
D	0.411	25	0.040	0.387	25	0.061
E	0.571	25	0.036	0.545	25	0.056
F	0.588	25	0.026	0.563	25	0.048
K0	0.41	14	0.041	0.39	14	0.049
K	0.31	14	0.031	0.29	14	0.036

	VADOT E-274 Trailer					
	E-524 Tire			E-501 Tire		
SITE		n	STD DEV		n	STD DEV
A	0.235	10	0.012	0.291	9	0.030
B	0.530	10	0.020	0.561	9	0.022
C	0.511	10	0.016	0.550	9	0.029
D	0.278	10	0.010	0.342	9	0.067
E	0.439	10	0.012	0.482	9	0.014
F	0.479	10	0.010	0.538	9	0.013

3.0 DATA ANALYSIS

Presentation of selected data is given in Appendices B through F. Friction and Texture data on sites A through F are given for those cases where sufficient data is available for presentation. For example, when data is available for three or more speeds the friction vs. speed can be plotted (see Appendices B and C). If data is available for three or more years with the same device the friction or texture histories can be plotted (see Appendices D and E). Where data is available for two similar devices the reproducibility can be demonstrated (see Appendix F). All plots of the friction data are scaled from zero to one so comparisons of sensitivity can be readily made.

3.1 Friction vs. Speed for Sites A - F in 1999

Nine friction tests run in 1999 were performed at three or more speeds. These data are plotted for Sites A – F in Appendix B. Note that the measurements with smooth tires and high slips produce the steepest gradients. Tests with ribbed or patterned tires (Figures B.3 and B.9) distinguish the differences between the sites much less than tests with smooth tires.

There are some anomalies. The SALTAR data show an increase of friction with speed (Figure B.6). This may be due to a decrease in the water depth with increasing speed. The Runway Friction Tester (Figure B.1) and the Diagonal Braked Vehicle (Figure B.4) show similar gradients for all sites including the grooved sites.

3.2 Friction vs. Speed for Years 1993 - 1999

Figures C.1 to C.6 show the history of Friction vs. Speed for Sites A – F as measured with the Virginia ASTM E-274 Trailer with a smooth ASTM E-524 Tire. The same device was used for tests in 1993, 1996, 1997, 1998, and 1999. There are relatively small differences over time. This can also be seen in Figures C.4 to C.10 where the first year (1993) and the last year (1999) are compared for sites A, B, D, E and F (Site C was not run in 1993).

One anomaly appears in the data: Site C in 1996 (Figure C.2). The friction increases with speed. This must be regarded as an outlier in the data.

3.3 Friction History of Sites A - F

Four devices have reported friction at 65 km/h at the NASA Friction Workshops for three years or more. Two of these devices reported two sets of data: The E-274 Trailer measured with both the smooth E-524 tire and the ribbed E-501 tire. The IMAG (which was replaced in 2001 with IRV, a similar device) reports friction based on both force and torque. The friction histories at each site for a total of six data sets are presented in bar charts in Figures D.1 to D.6.

3.4 Texture History of Sites A - F

Five texture measurements have been performed at the NASA Friction Workshops for three or more years. Two of these are actually friction devices, but are often used as surrogates for microtexture: The British Pendulum Tester and the 20 km/h data from the DFTester. The histories of these five data sets are shown in bar charts in Figures E.1 to E.5. The texture is relatively consistent, but since these measurements are all spot measurements, there is some difference in the data due to the measurements being made at different locations over the years. This is particularly true for the sites with grooved surfaces.

3.5 Device Reproducibility

At some of the workshops there were two devices of the same type that collected data at approximately the same time and under the same conditions. These tests provided the opportunity to evaluate the reproducibility of those devices. Reproducibility requires a least squares fit of the data from two devices in which the intercept is near zero and the coefficient is close to 1.0 as well as a high correlation coefficient. The results are summarized in Table 14.

Table 14 Device Reproducibility

Device 1	Device 2	Coefficient	Intercept	R-Squared
BPN VADOT	BPN PSU	0.982	0.114	0.837
BPN VADOT	BPN FHwA	1.496	-0.407	0.308
DFTESTER JAPAN	DFTESTER PSU	1.005	0	0.946
CTMETER JAPAN	CTMETER VADOT	1.005	0	0.991
MTD NASA	MTD PSU	1.465	-0.016	0.901
OFT NASA	OFT SKIDABRADER	0.800	0.796	0.942
VADOT SN65B	PSU SN65B	0.985	0	0.978
VADOT SN65R	PSU SN65R	0.254	0.396	0.927

Although the VADOT BPN and the BPN PSU are fairly highly correlated the intercept is very large (in reported BPN units the intercept is 11.4) . The BPN VADOT showed little relationship with the BPN FHwA .

The DFTester and the CTMeter have very high reproducibility with a coefficient nearly 1.0. The intercept was forced to zero for these two correlations at little effect on the correlation coefficient. Forcing the intercept reduced the R^2 value to 0.955 for the DFTester and to 0.992 for the CTMeter.

The MTD data shows that the operator has a significant influence on the result. The two outflow meters may have had a different geometry which affected the reproducibility, although the correlation was good.

The ASTM E-274 Trailers with the smooth E-524 Tire showed good reproducibility. In this case also the intercept was forced to zero reducing the R^2 value from 0.989 to 0.978. There was very little data for the case of the E-274 Trailers with the ribbed E-501 Tire which probably is the reason for the poor result.

3.6 Profiling

Profiling is a relatively new addition to the workshop. In 1999 the first real data was recorded and section 2.7 shows a comparison of the dipstick, ARP, RoadPro and a rod and level measurement. The data was in good agreement. The data from 200 was not recorded, the equipment was only demonstrated. In 2002 there were a number of devices and the data as submitted was put onto a CD; however, much of the data was in the device's own code and still needs to be converted into common files so that accuracy and repeatability can be calculated. Rod and level data never was taken to provide a reference. In 2002 no profiling activity took place. It is recommended that rod and level data be taken in May 2003 and more profiling activity be attempted, including a fourth site similar to site three. Also, the 2001 data should be processed if it can be converted to a common file type.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The Annual NASA Wallops Runway Friction Workshops are considered to be an excellent workshop and well liked by the friction measuring industry, both aviation and highway. Attendance continues to be well representative of the industry and always enjoys a worldwide audience. One can see by the equipment that is brought to the workshop year after year the effort and importance that many organizations have placed on these workshops, all at their own expense. NASA is to be commended for hosting and conducting these workshops, which have proven to be a contributor to the safety of the aviation and highway industry. It is hoped that these workshops continue for many years.

Rod and level never was taken to provide a reference. In 2002, no profiling activity took place. It is recommended that rod and level data be taken in May 2003 and more profiling activity be attempted, including a fourth site similar to site three. Also, the 2001 data should be processed if it can be converted to a common file type

REFERENCES

1. ASTM E 1960-98, “Standard Practice for Calculating International Friction Index of a Pavement Surface”.

2. ASTM E 965-01, “Standard Test Method for Measuring Pavement Macrotexture Depth Using the British Pendulum Tester”.

3. ASTM E 303-98, “Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester”.

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

5. ASTM E 1911-02, “Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester”.

6. ASTM E 274-97, “Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire”.

7. ASTM E 303-98, “Standard Test Method for Measuring Pavement Macrotexture Properties Using the Circular Track Meter”.

8. ASTM E 1845-96, “Standard Test Practice for Calculating Pavment Macrotexture Mean Profile Depth”.

Appendix A: SITE DESCRIPTIONS AND SURFACE PHOTOGRAPHS

TABLE A.1 SITE DESCRIPTIONS

SITE	LOCATION	WIDTH ft	LENGTH Ft	SURFACE DESCRIPTION
A	R/W 4/22	50	350	Ungrooved canvas belt-finished concrete
B	R/W 4/22	50	350	Grooved 1x1/4x1/4 inch canvas belt concrete
C	R/W 4/22	50	350	Grooved 1x1/4x1/4 inch burlap drag-finished
D	R/W 4/22	50	350	Ungrooved burlap drag-finished concrete
E	R/W 4/22	50	1000	Ungrooved small aggregate asphalt
F	R/W 4/22	50	350	Grooved 2x1/4x1/4 inch small aggregate asphalt
G	R/W 4/22	50	250	Grooved 1x1/4x1/4 inch small aggregate asphalt
H	R/W 4/22	50	100	Grooved 1x1/4x1/4 inch latex modified asphalt
I	R/W 4/22	50	200	Ungrooved latex modified asphalt
K	T/W 10/28	10	280	Driveway sealer (w/o sand) on concrete
K0	T/W 10/28	10	280	Ungrooved float finished concrete
L	T/W 4/22	10	300	Ungrooved medium aggregate asphalt
MS0	T/W 4/22	10	300	Small aggregate asphalt without slurry seal overlay
MS1	T/W 4/22	10	300	Slurry seal overlay on sm. aggr. asph. SAA (1995)
MS2	T/W 4/22	10	300	Micro-surfacing, single overlay on SAA (1995)
MS3	T/W 4/22	10	300	Micro-surfacing, double overlay on SAA (1995)
MS4	T/W 4/22	4	188	Anti-skid overlay surface on SAA (1999)
MS5	T/W 10/28	10	300	Slurry seal overlay on float finished concrete
MS6	T/W 10/28	10	300	M-2 micro-surfacing single overlay on concrete
MS7	T/W 10/28	10	300	M-3 micro-surfacing double overlay on concrete
P	T/W 4/22	4	216	Aluminum panels
R1	T/W 4/22	10	300	Rejuvenated asphalt without sand
R2	T/W 4/22	10	300	Small aggregate asphalt
R3	T/W 4/22	10	300	Rejuvenated asphalt with sand
S0	R/W 4/22	12	900	Ungrooved concrete near runway east shoulder
S1	R/W 4/22	12	200	Skidabrader light textured S0 (1994 installed)
S2	R/W 4/22	12	200	Skidabrader medium textured S0 (1994 installed)
S3	R/W 4/22	12	200	Skidabrader high textured S0 (1994 installed)
S4	R/W 4/22	12	300	Skidabrader very high textured S0 (1994 installed)
S5	R/W 4/22	12	900	Skidabrader medium textured S0 (1995 installed)
S6	R/W 4/22	12	600	Skidabrader medium textured S0 (1997 installed)
WHITE	T/W 4/22	4	8	Reference panel, low texture
RED	T/W 4/22	4	8	Reference panel, medium texture
BLUE	T/W 4/22	4	8	Reference panel high texture
LONG RED	T/W 4/22	4	156	Medium Texture Panel
LONG WHITE	T/W 4/22	4	156	Smooth Painted Aluminum Panel

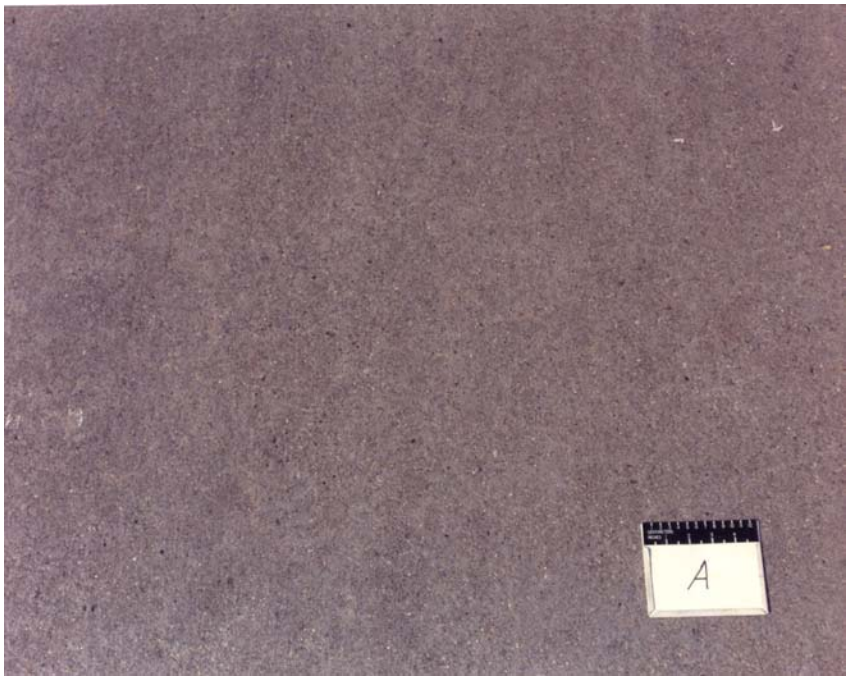

Figure A.1 Site A

Figure A. 2 Site B

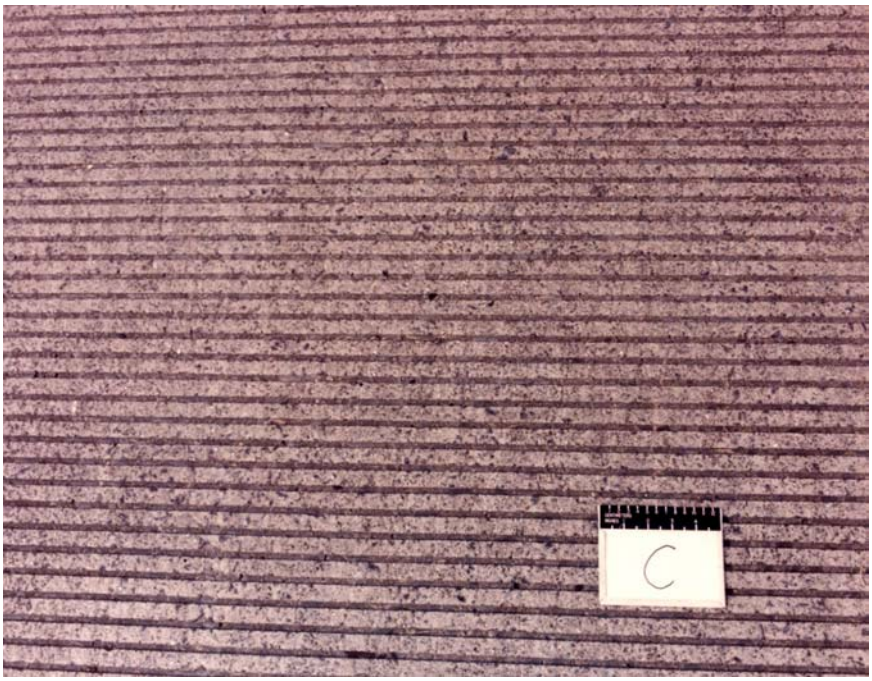

Figure A.3 Site C

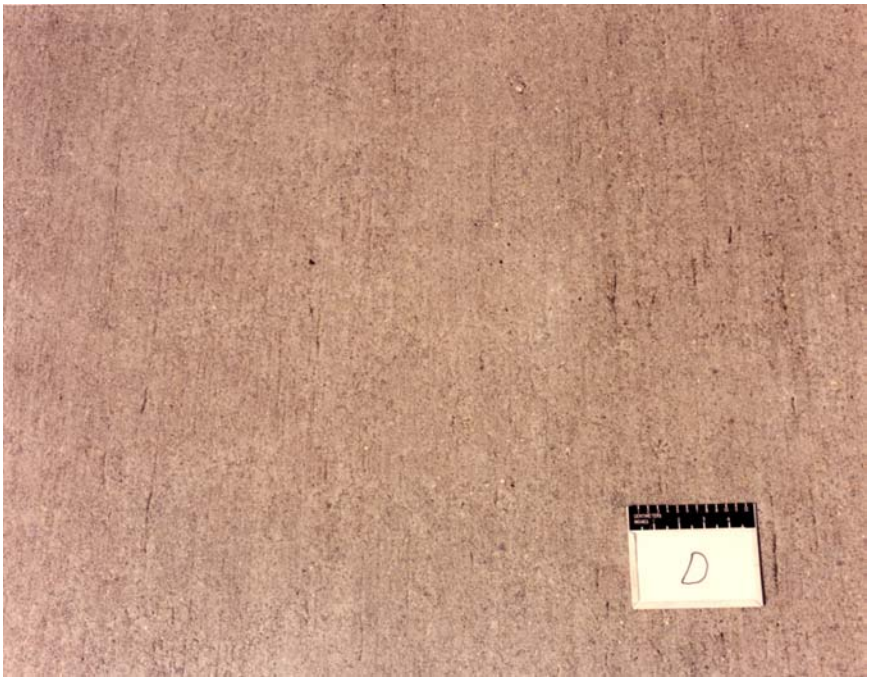

Figure A.4 Site D

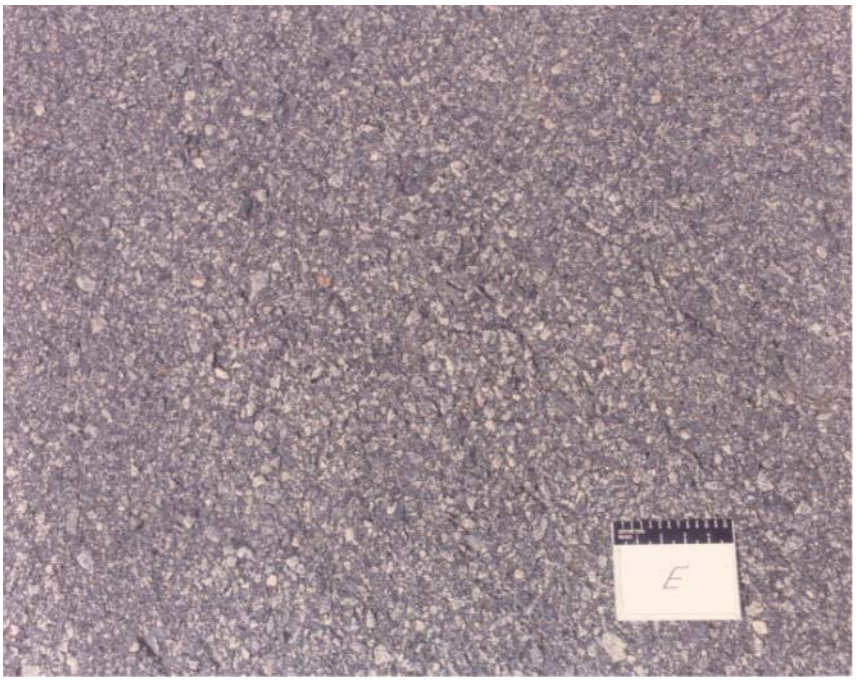

Figure A.5 Site E

Figure A.6 Site F

Figure A.7 Site K

Figure A.8 Site K0

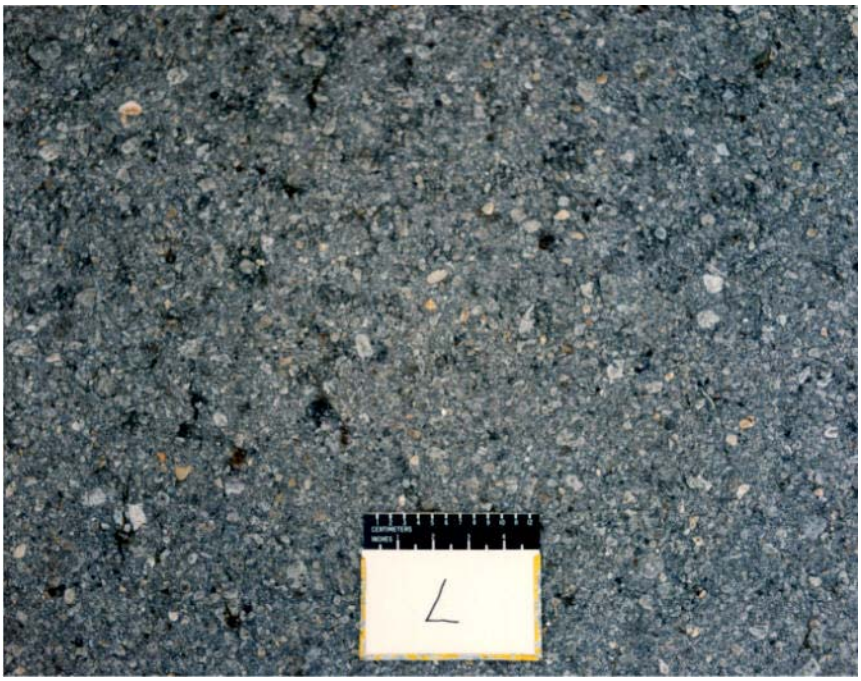

Figure A.9 Site L

Figure A.10 Site MS0

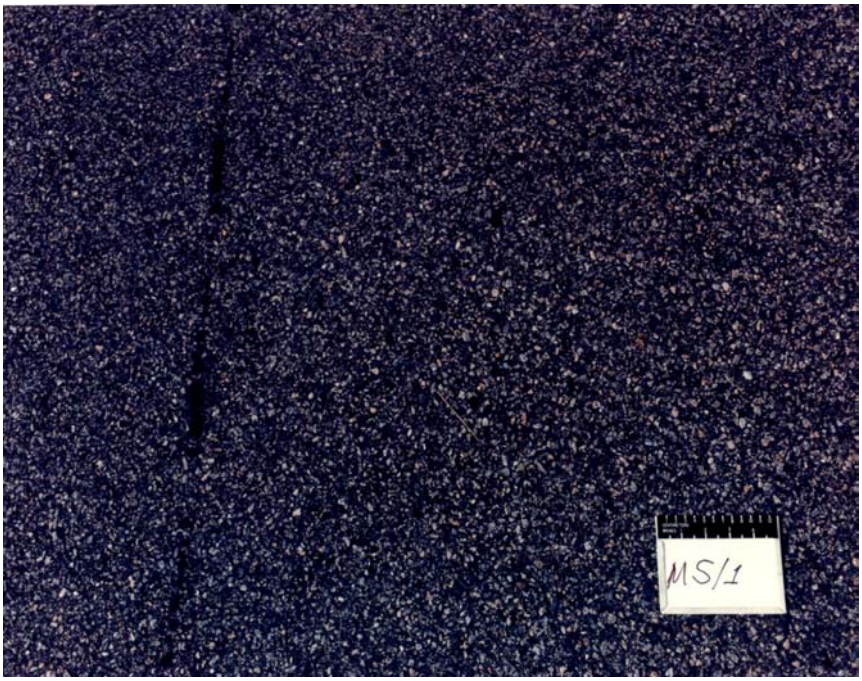

Figure A.11 Site MS1

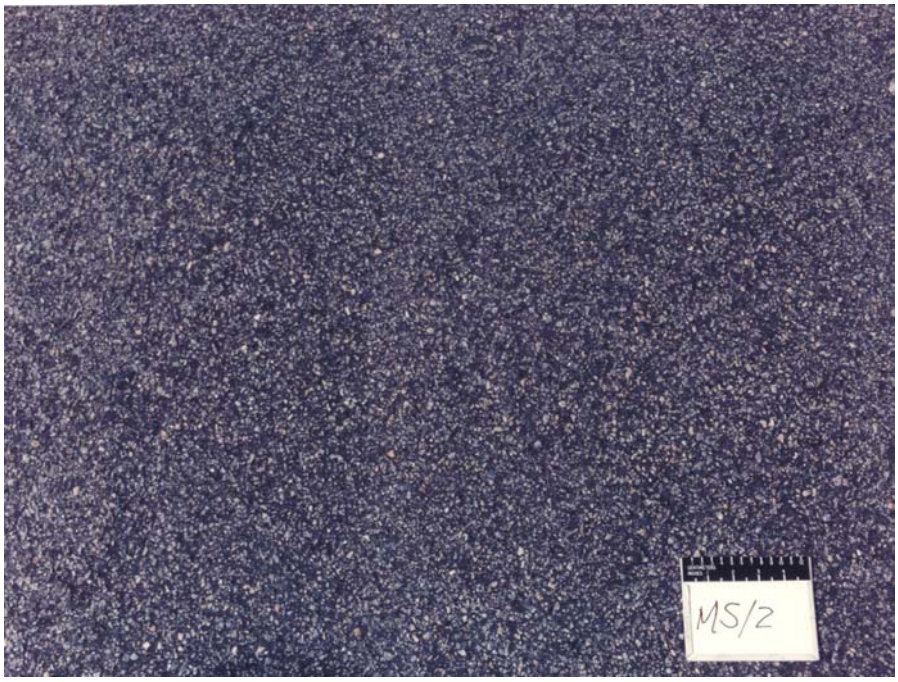

Figure A.12 Site MS2

Figure A.13 Site MS3

Figure A.14 Site MS4

Figure A.15 Site P

Figure A.16 Site R1

Figure A.17 Site R2

Figure A.18 Site R3

Figure A.19 Site S0

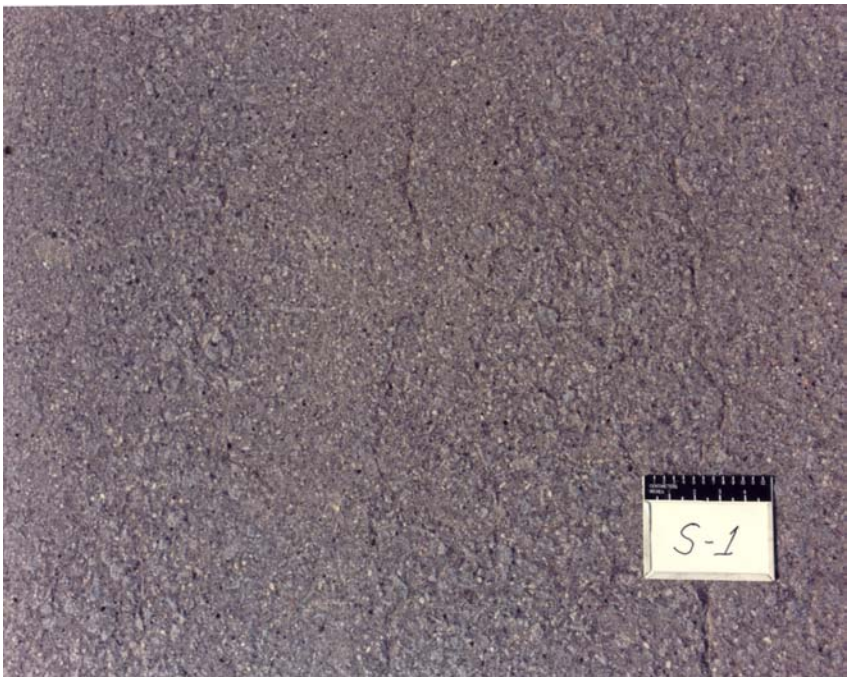

Figure A.20 Site S1

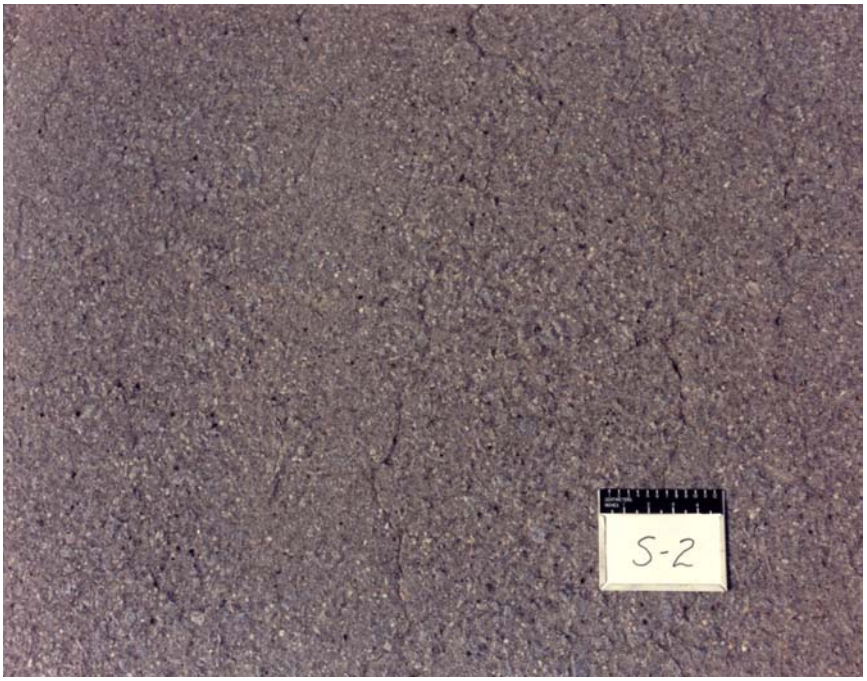

Figure A.21 Site S2

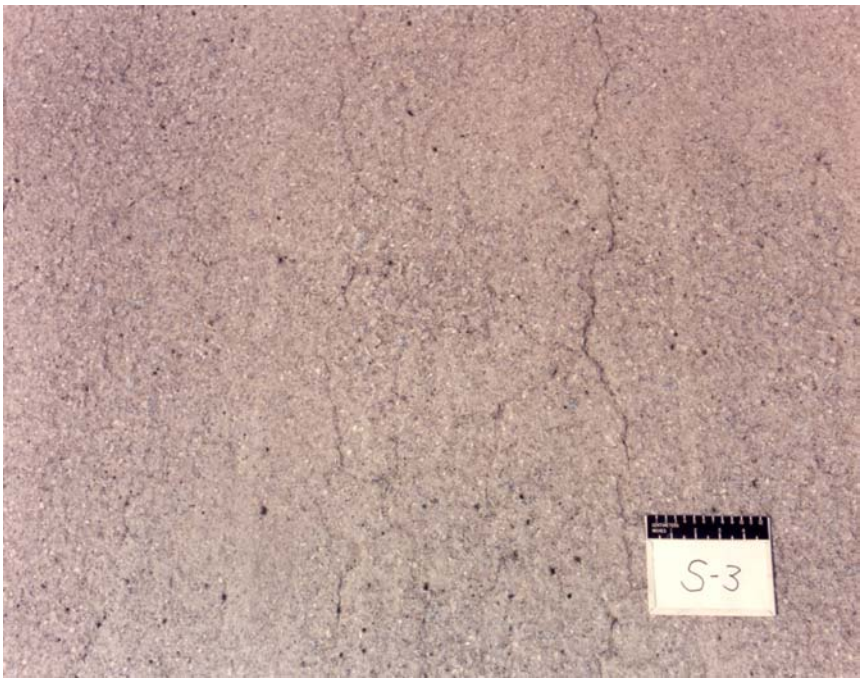

Figure A.22 Site S3

Figure A.23 Site S4

Figure A.24 Site S5

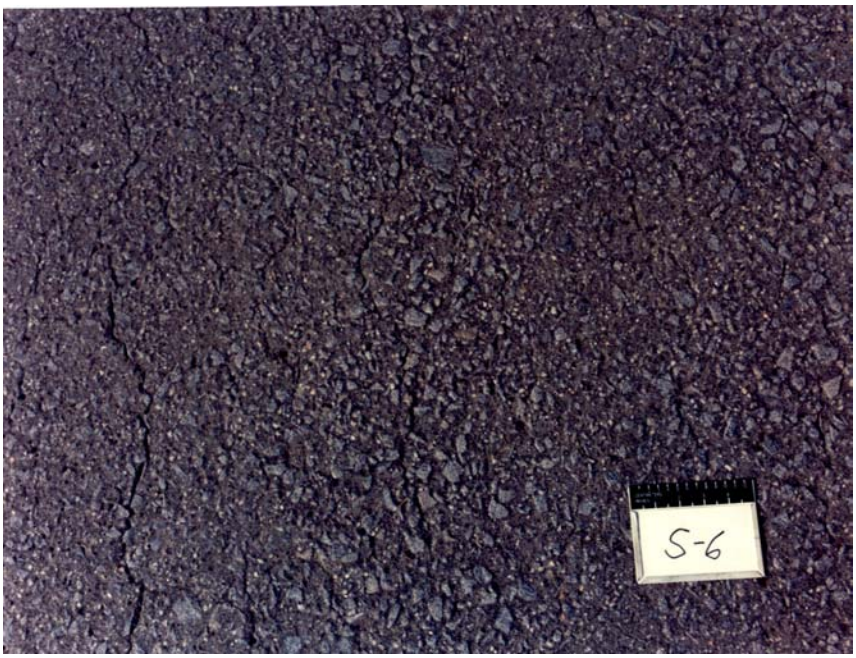

Figure A.25 Site S6

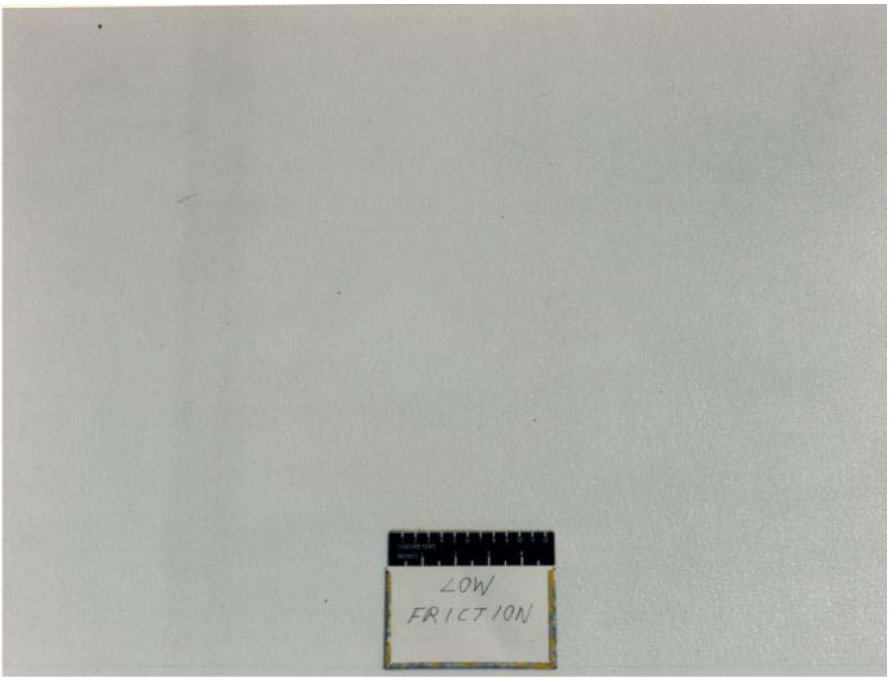

Figure A.26 White Panel

Figure A.27 Red Panel

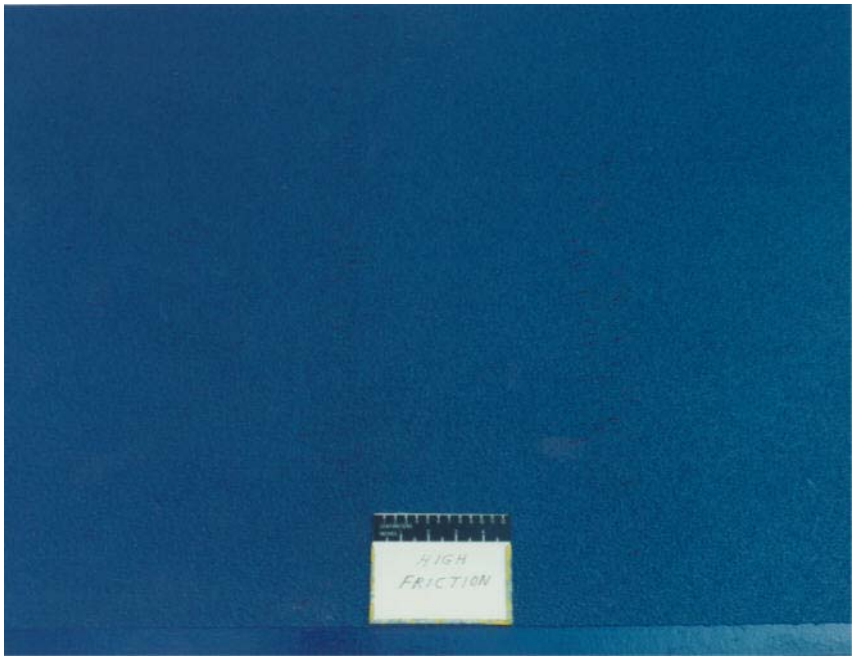

Figure A.28 Blue Panel

Figure A.29 Long Red Panel

APPENDIX B: FRICTION VERSUS SPEED BY SITE FOR 1999

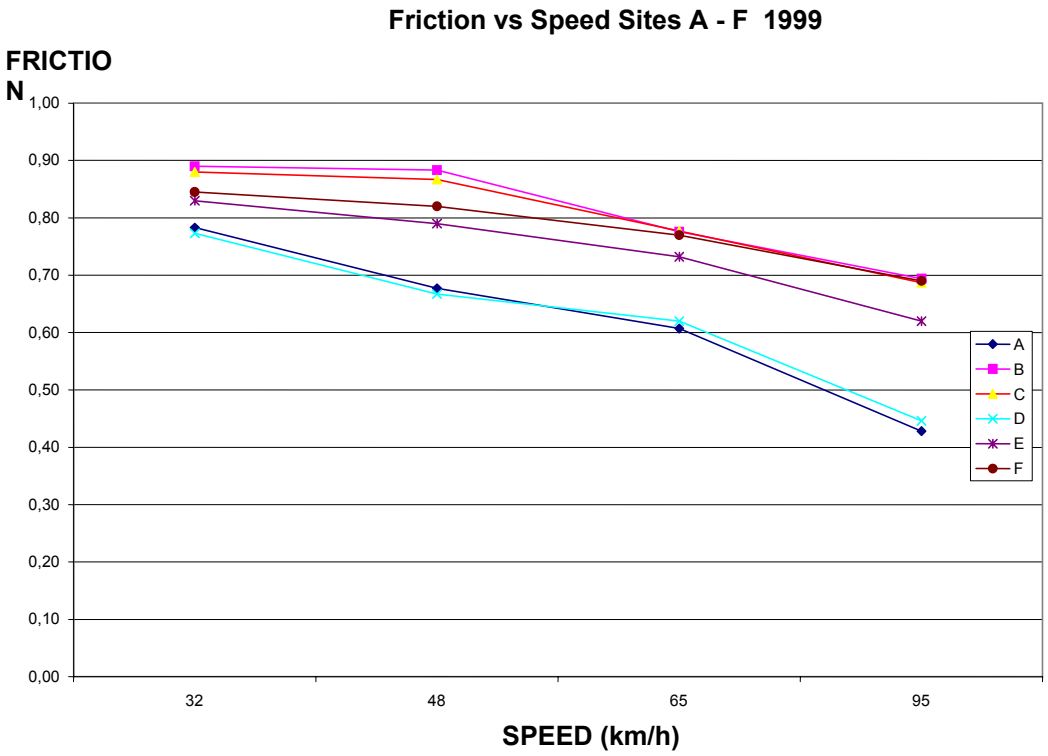

Figure B.1 FAA Runway Friction Tester E-1551 Tire

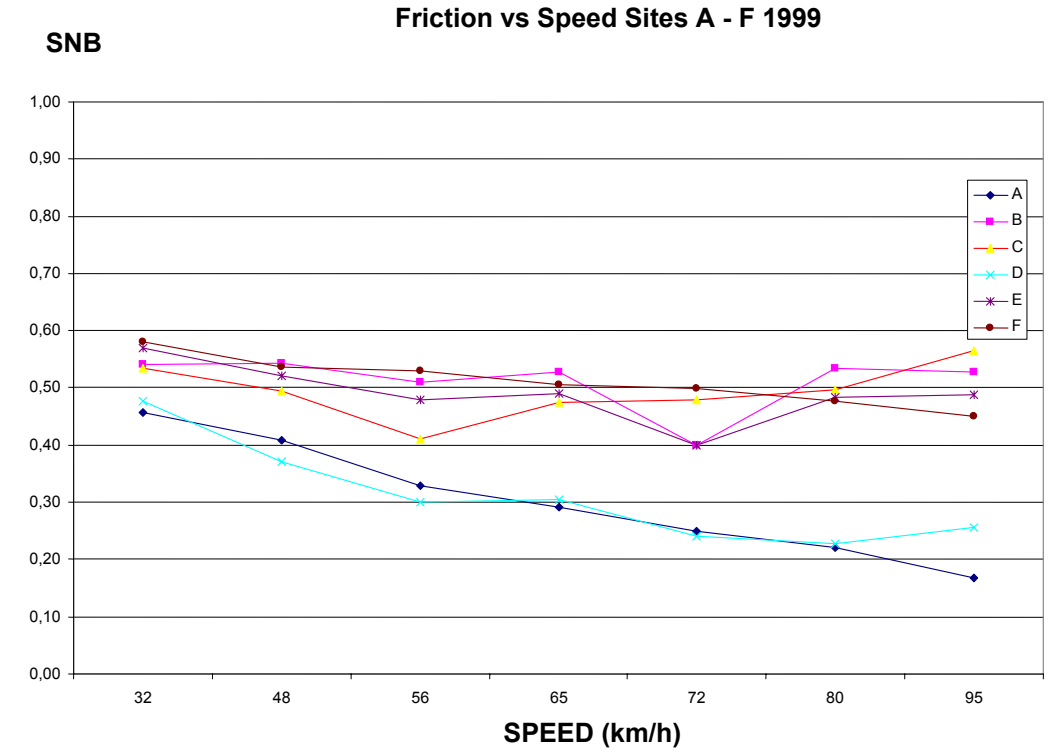

Figure B.2 VADOT E-274 Trailer E-524 Tire

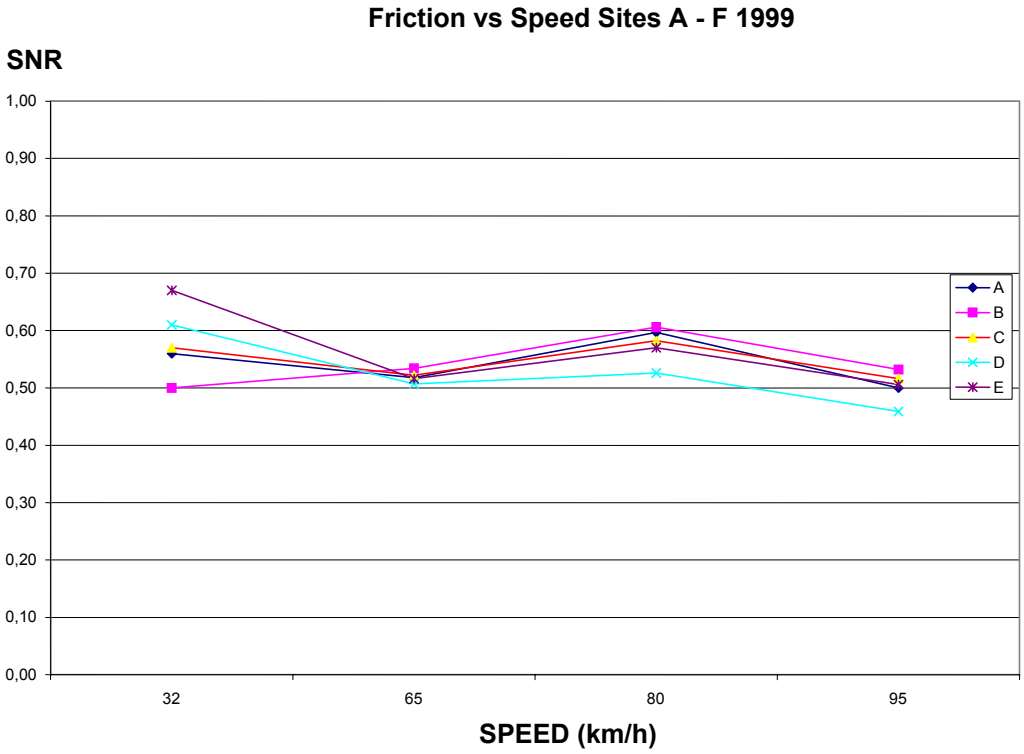

Figure B.3 VADOT E-274 Trailer E-501 Tire

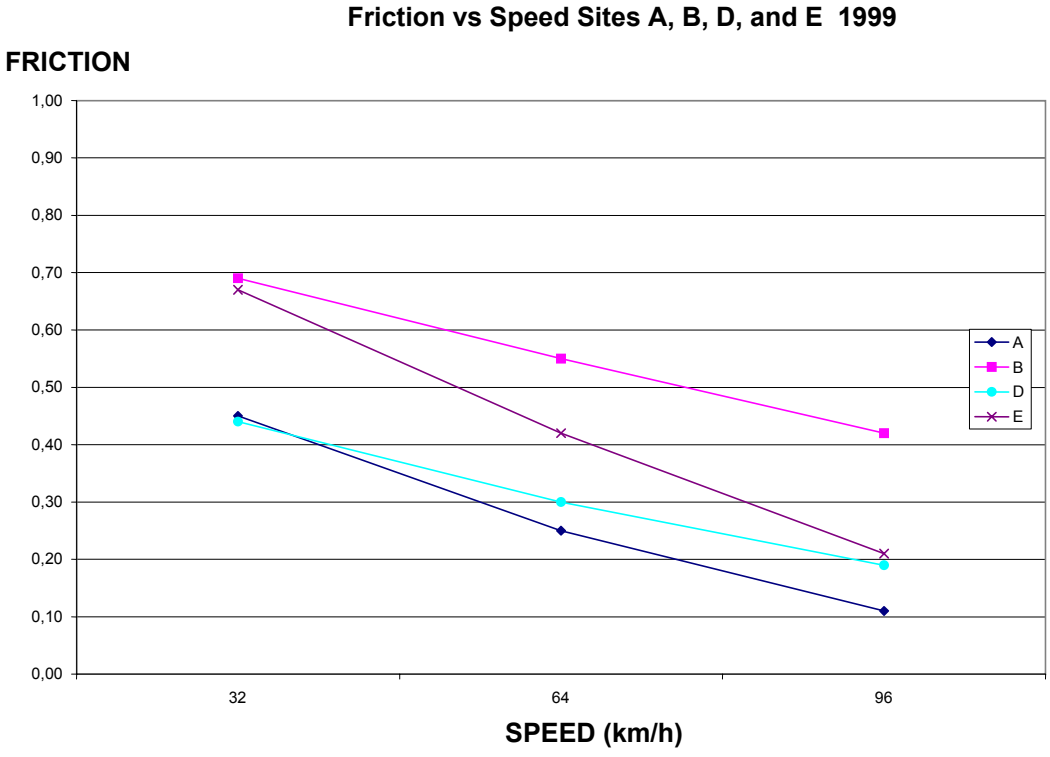

Figure B.4 NASA Diagonal Braked Vehicle

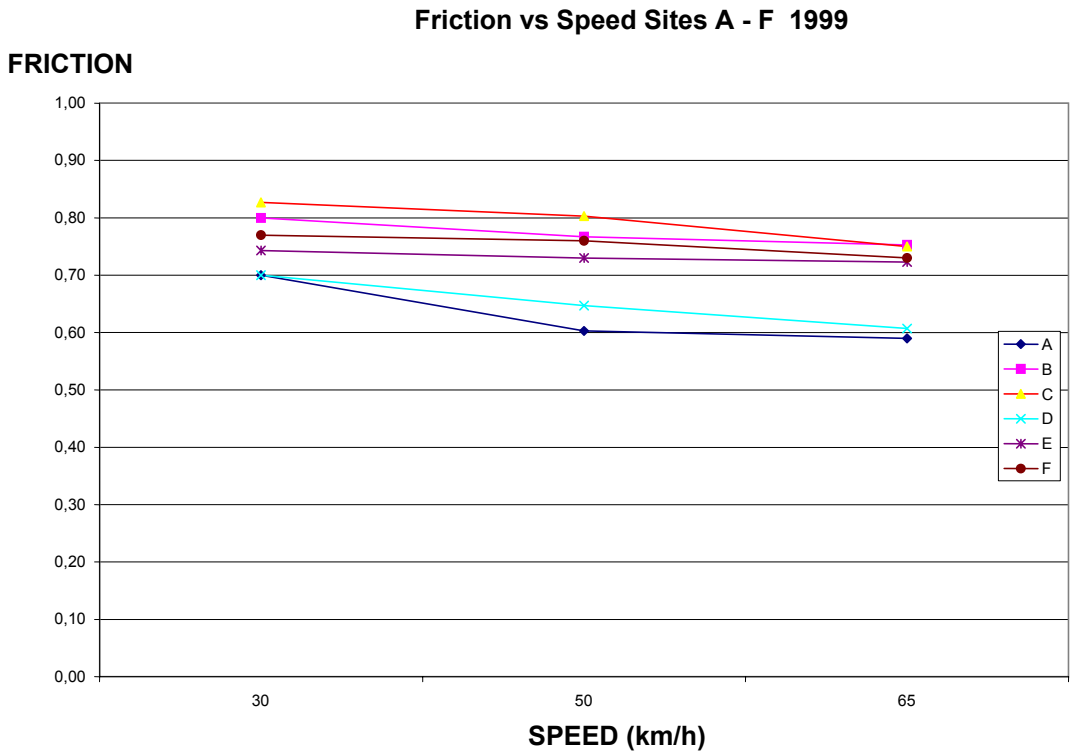

Figure B.5 FAA BV-11

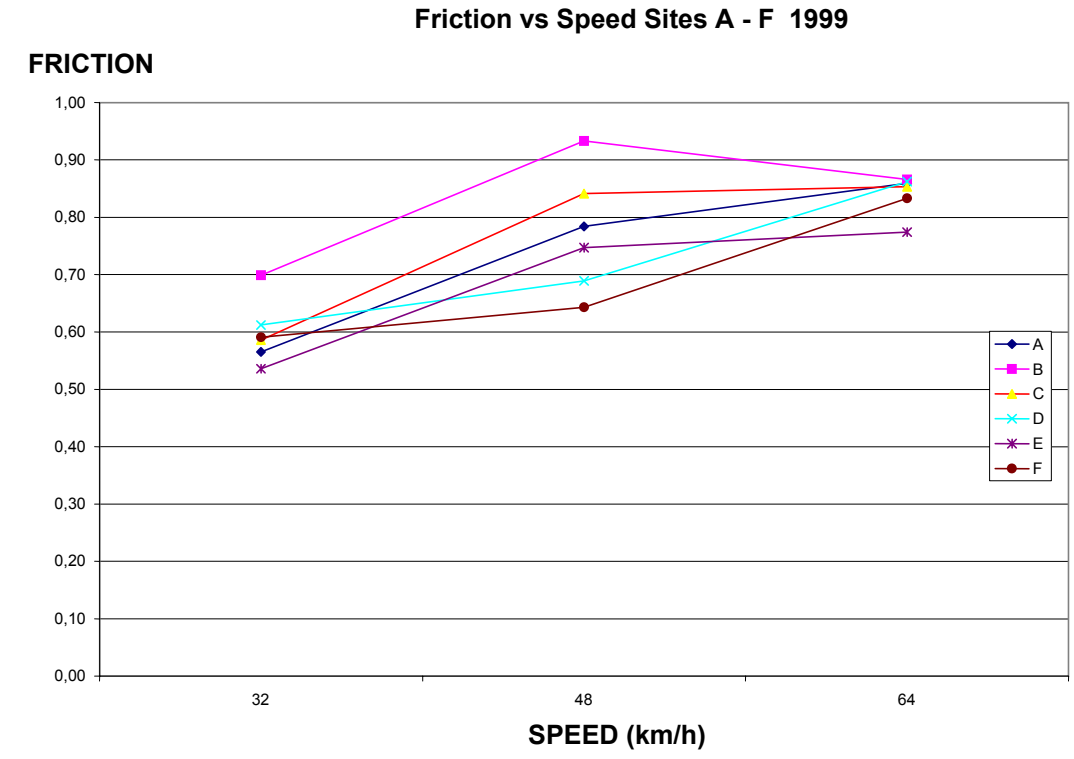

Figure B.6 SALTAR

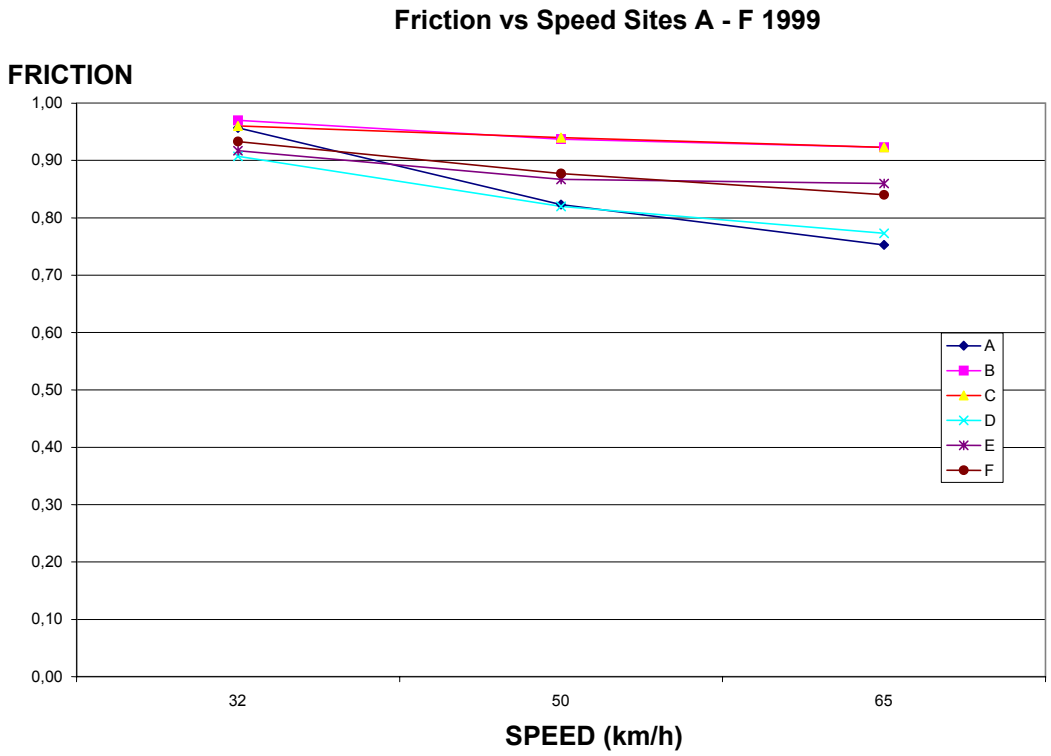

Figure B.7 TC SFT 79 on Dry Pavement

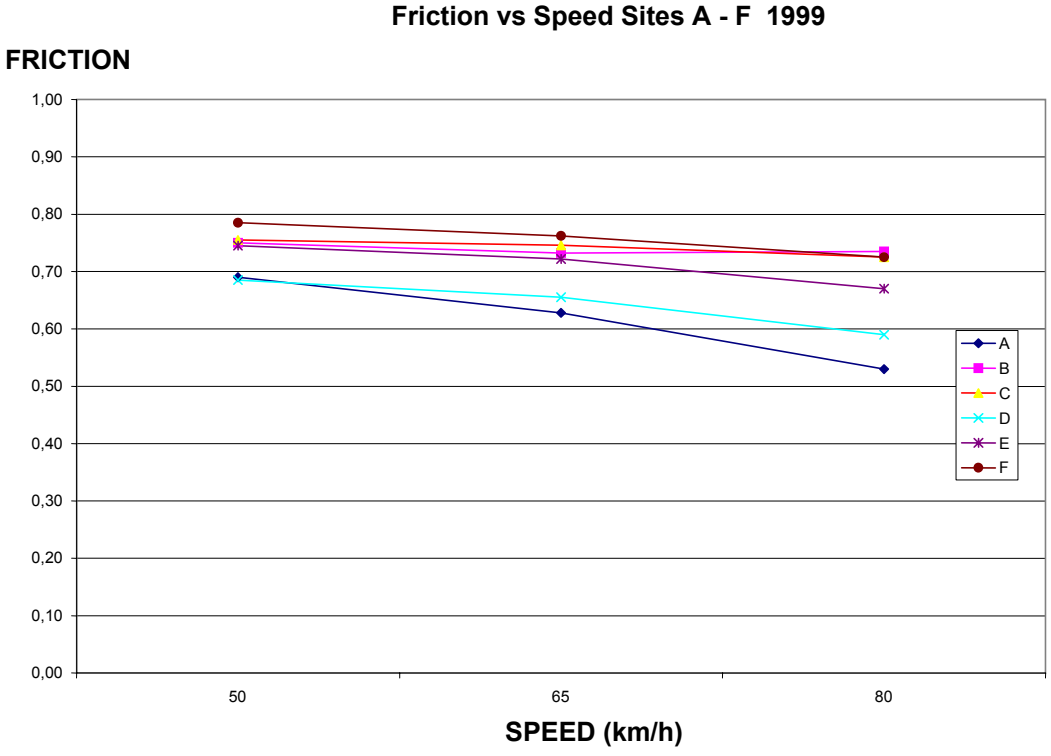

Figure B.8 USFT E-1551 Tire

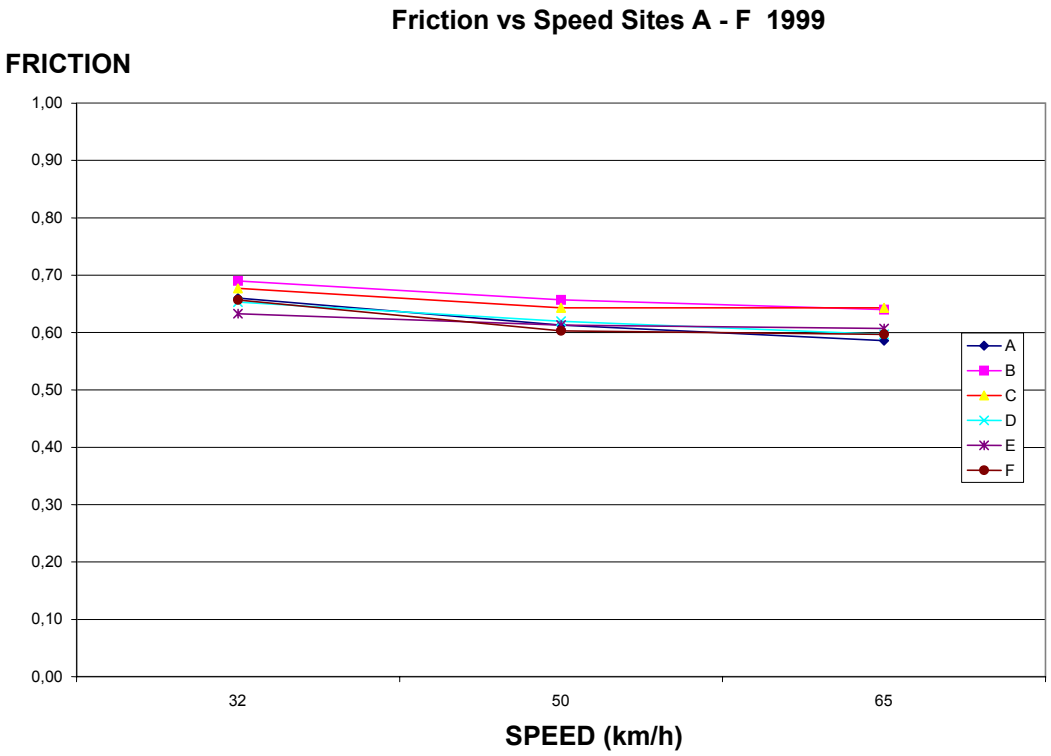

Figure B.9 USFT Aero Tire

APPENDIX C: FRICTION VERSUS SPEED BY YEAR FOR THE VADOT E-274 TRAILER WITH THE E-524 TIRE

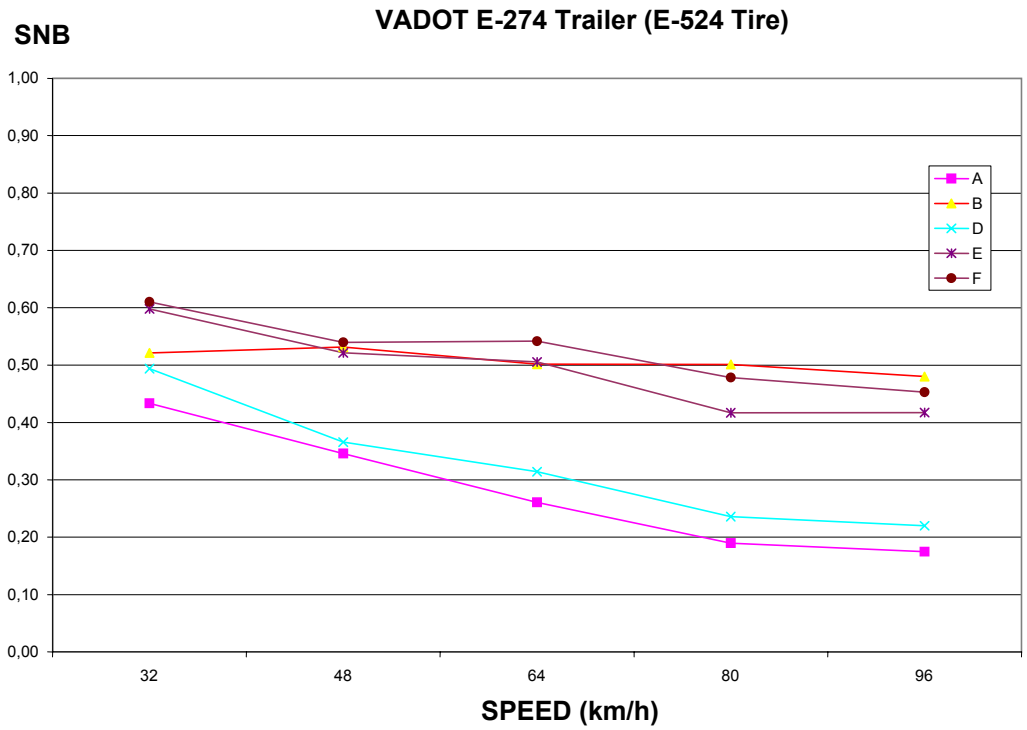

Figure C.1 Sites A – F for 1993

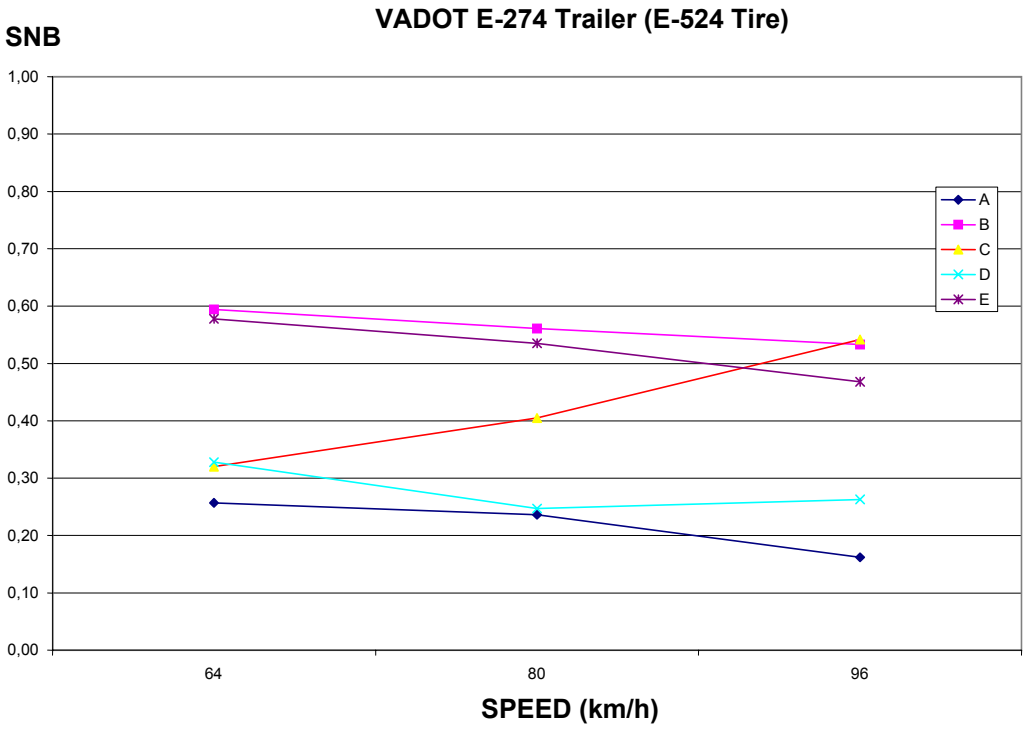

Figure C.2 Sites A – F for 1996

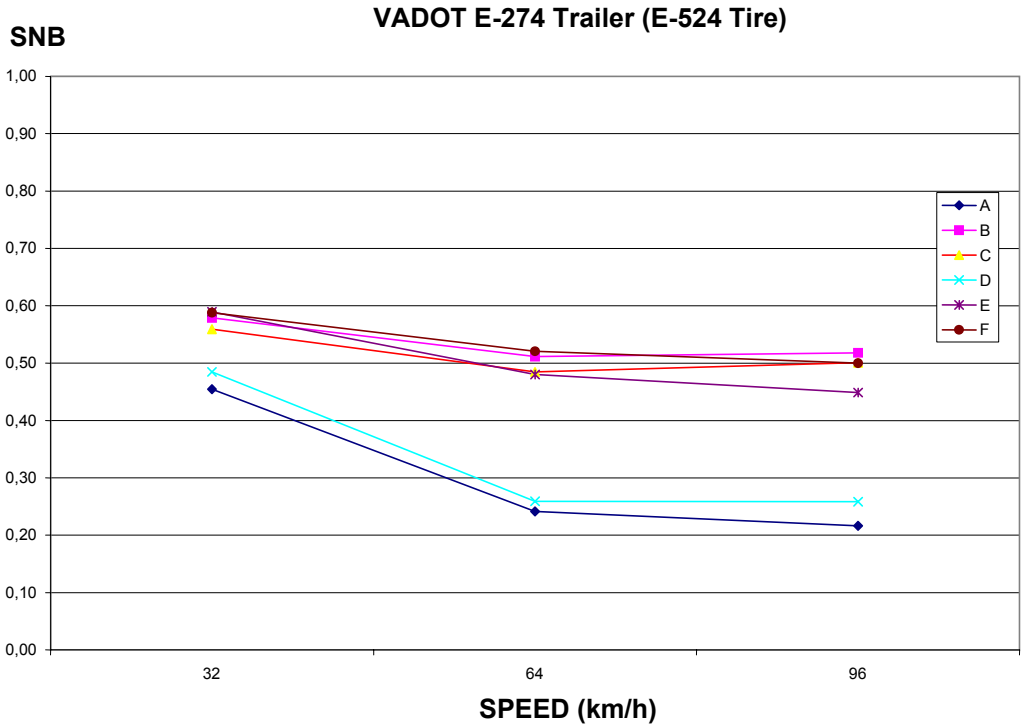

Figure C.3 Sites A – F for 1997

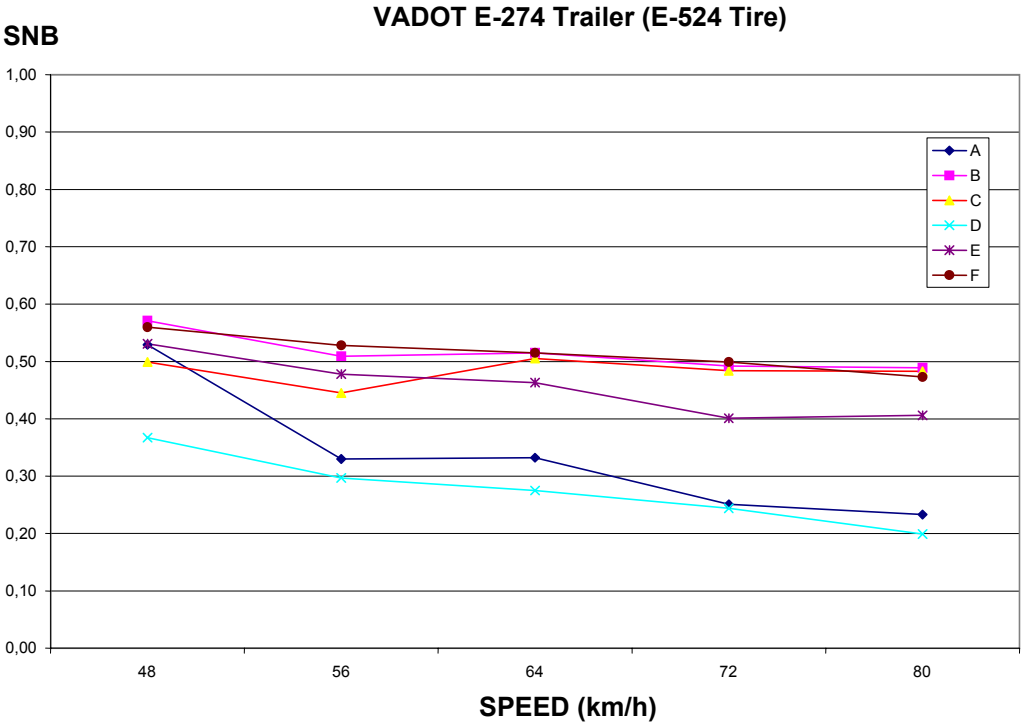

Figure C.4 Sites A – F for 1998

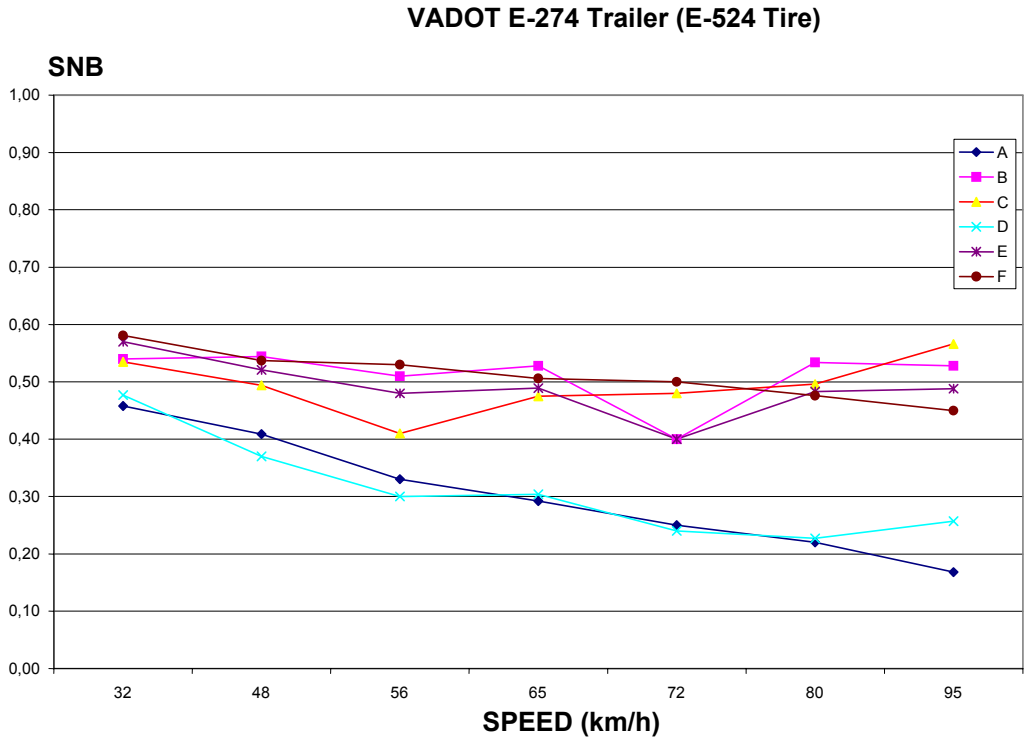

Figure C.5 Sites A – F for 1999

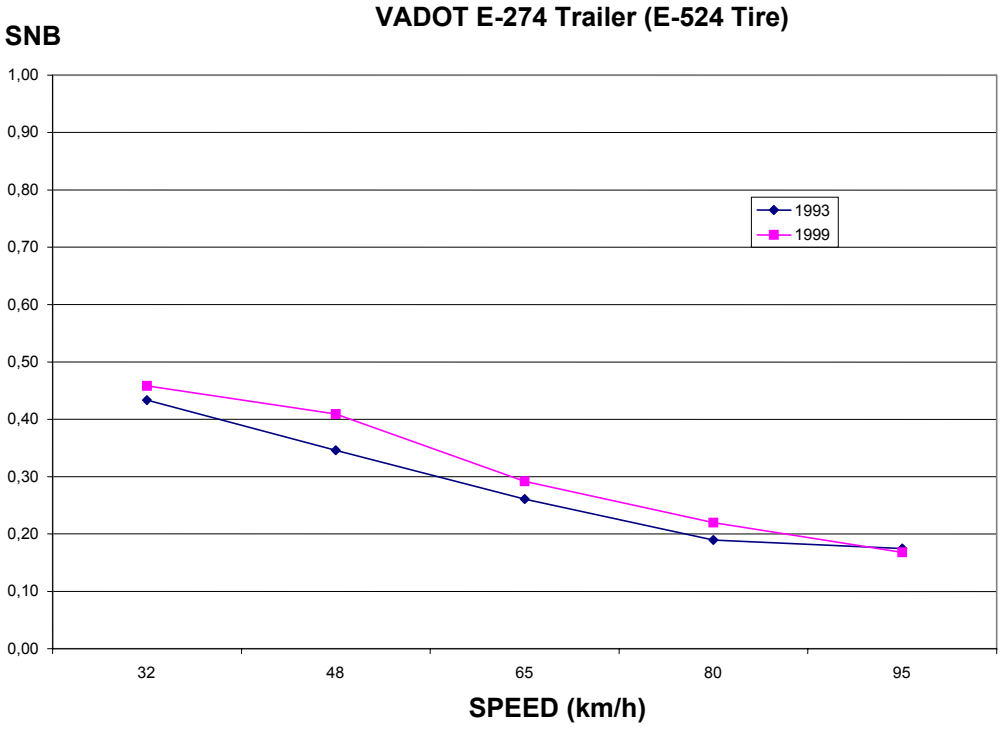

Figure C.6 Site A for 1993 and 1999

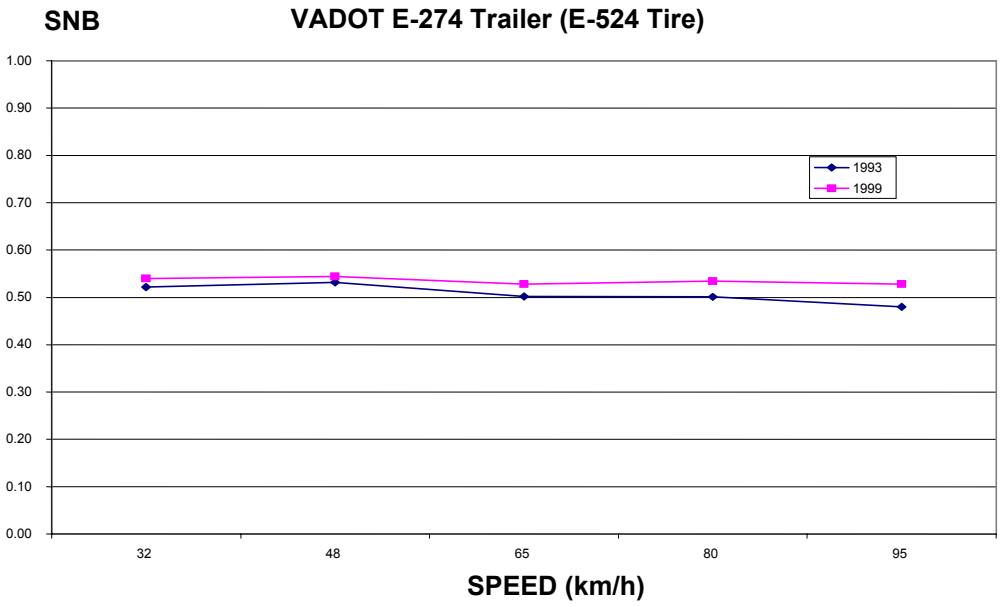

Figure C.7 Site B for 1993 and 1999

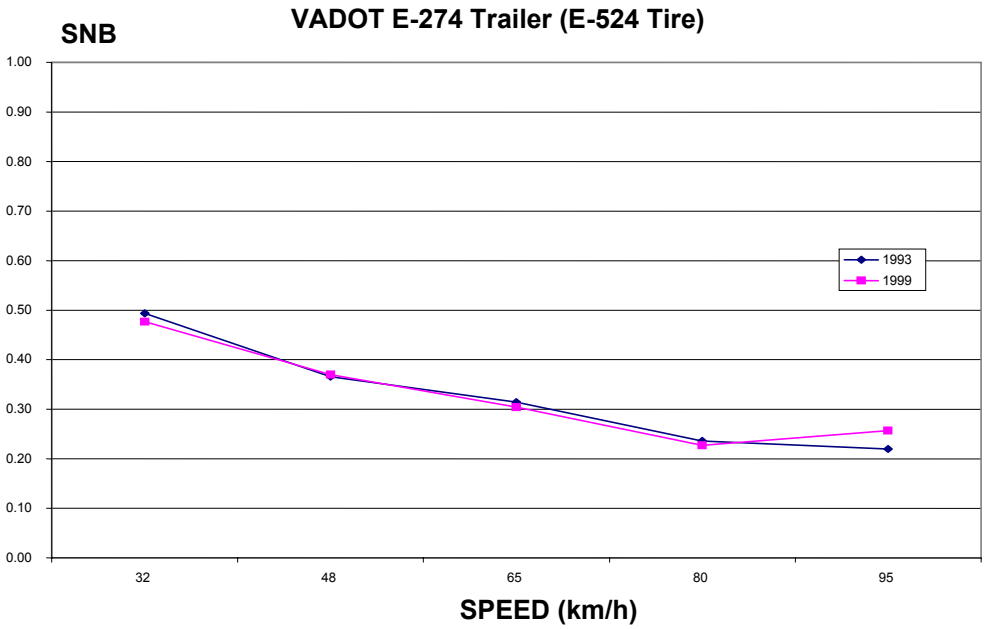

Figure C.8 Site D for 1993 and 1999

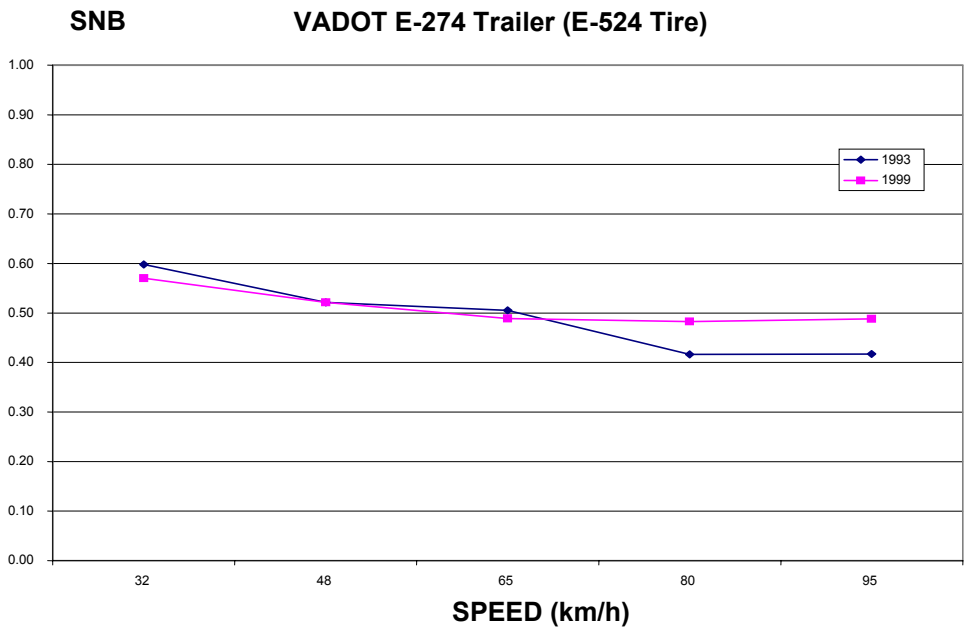

Figure C.9 Site E for 1993 and 1999

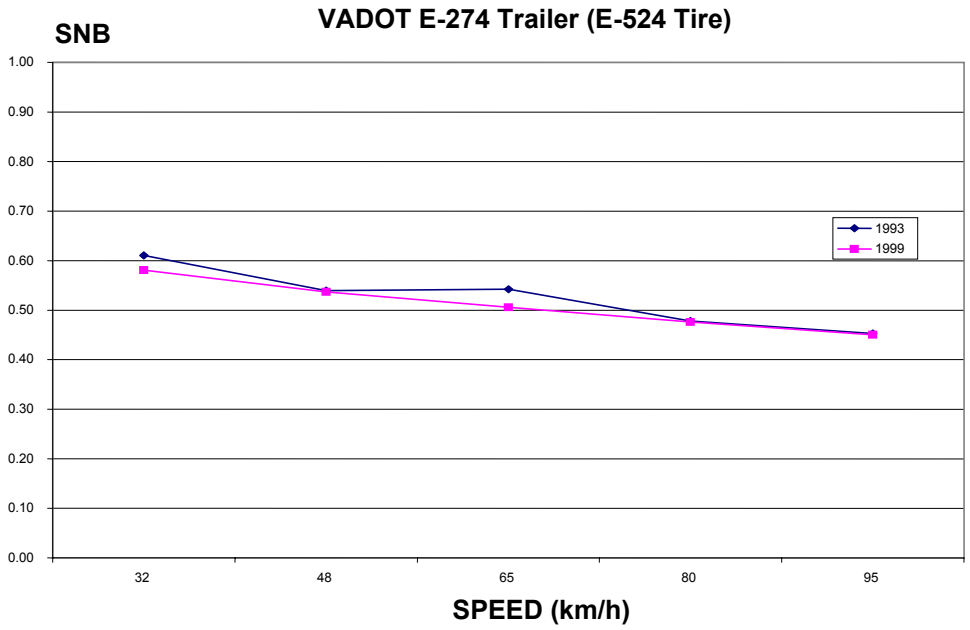

Figure C.10 Site F for 1993 and 1999

APPENDIX D: FRICTION HISTORY

Friction at 65 km/h vs Year Sites A - F

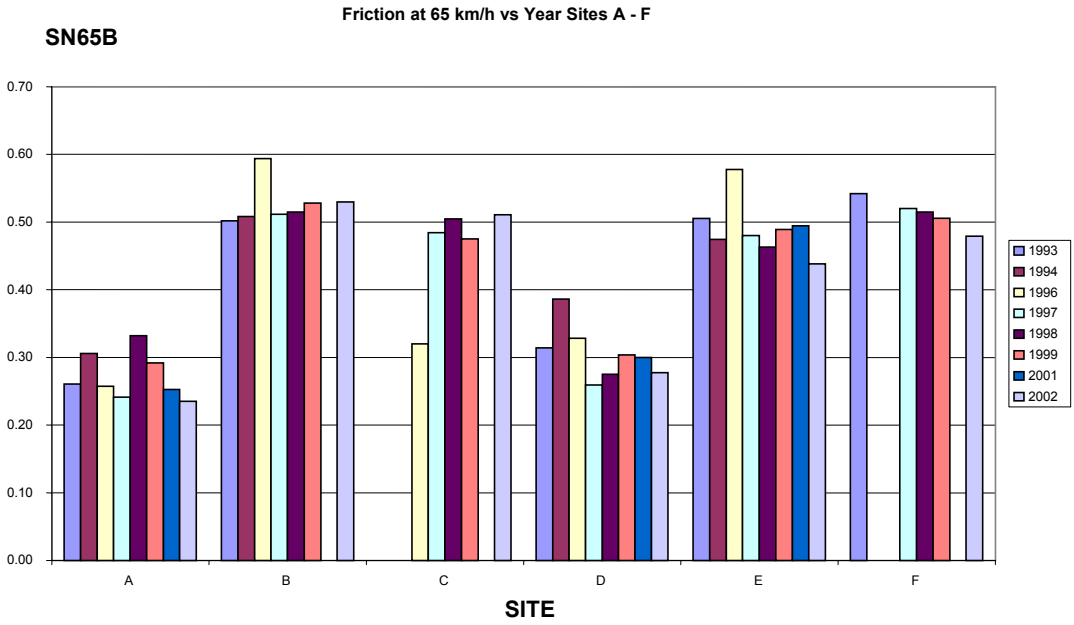

Figure D.1 VADOT E-274 Trailer (E-524 Tire)

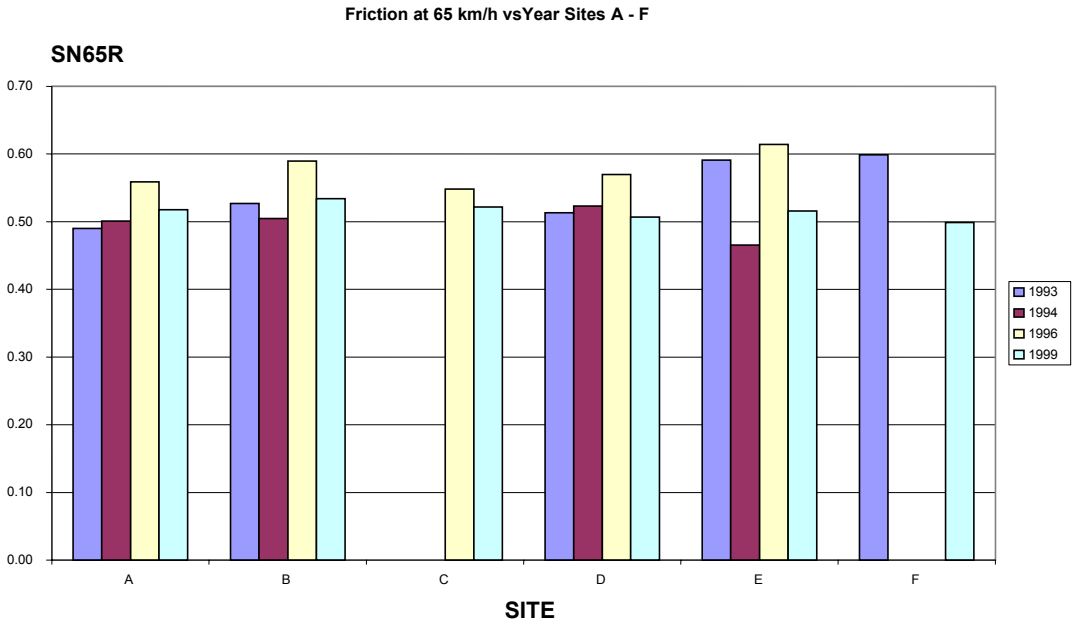

Figure D.2 VADOT E-274 Trailer (E-501 Tire)

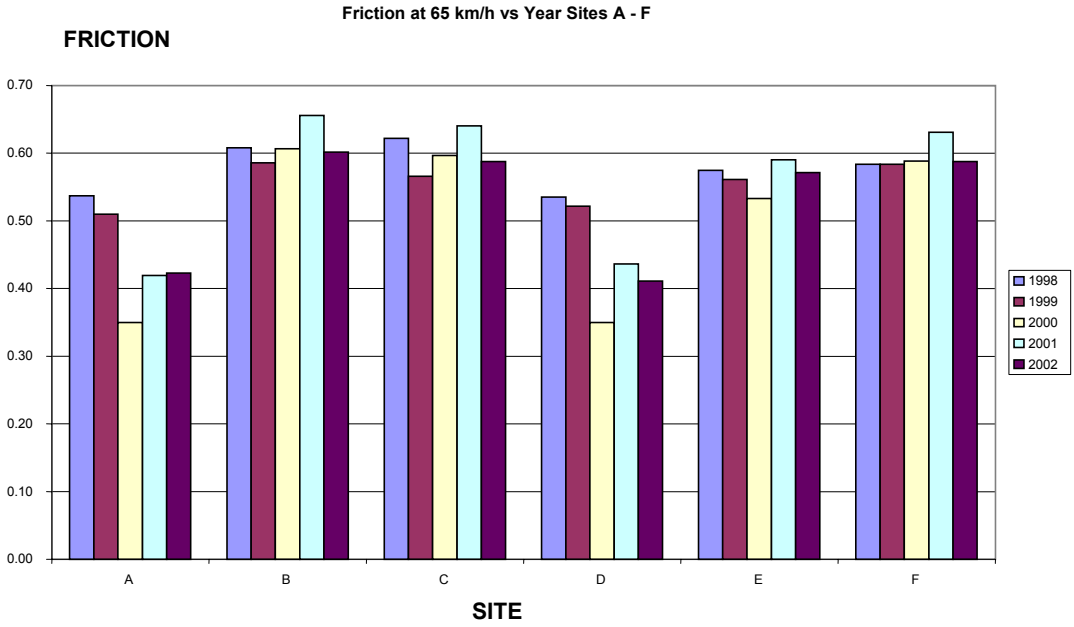

Figure D.3 IMAG/IRV Force

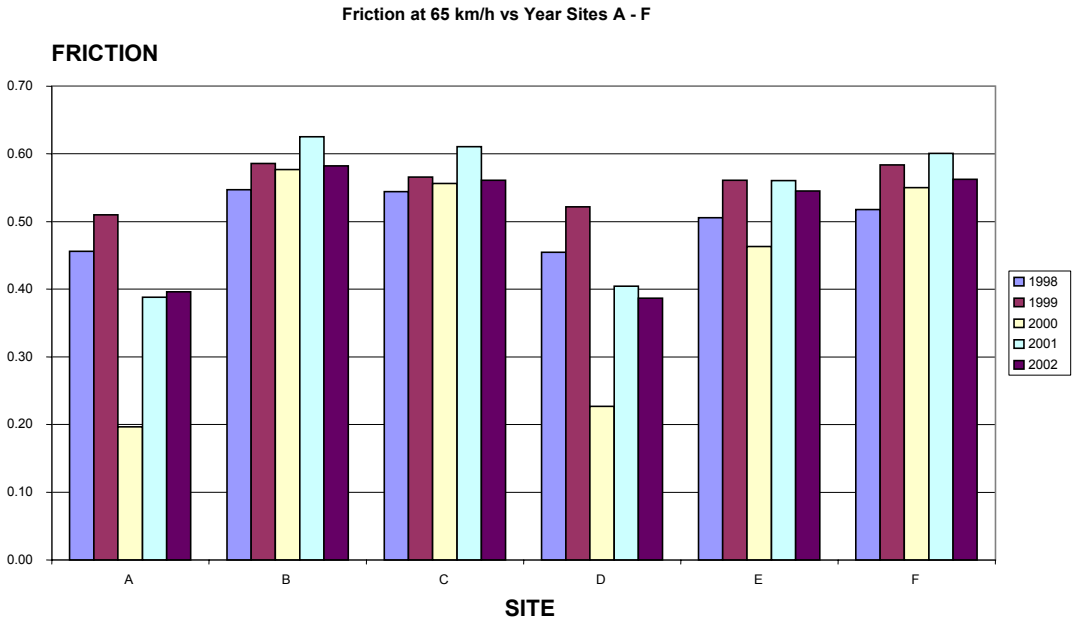

Figure D.4 IMAG/IRV Torque

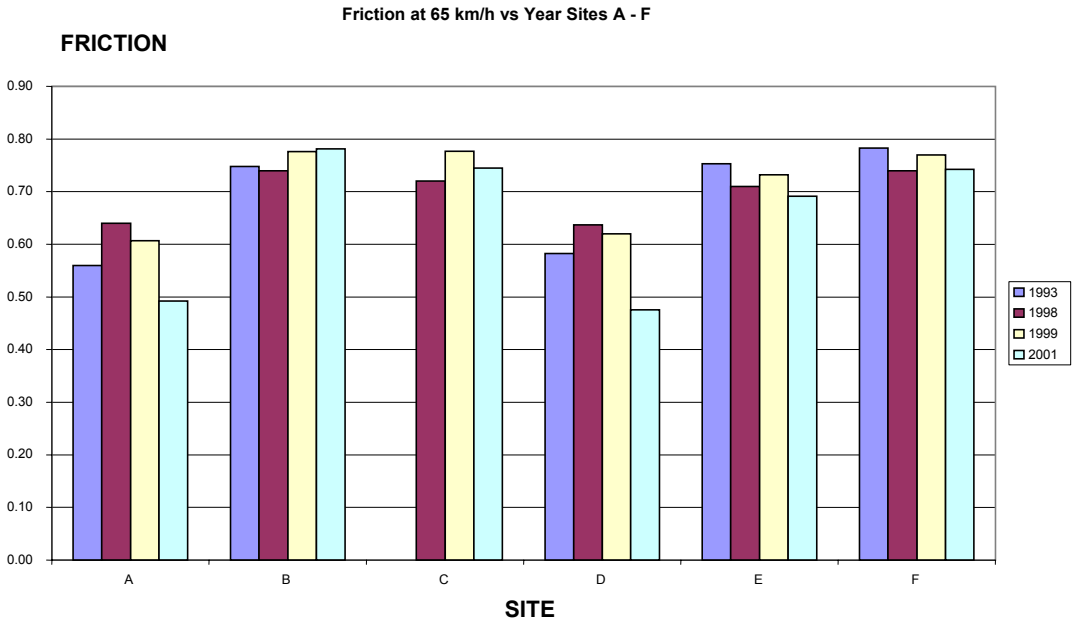

Figure D.5 FAA Runway Friction Tester

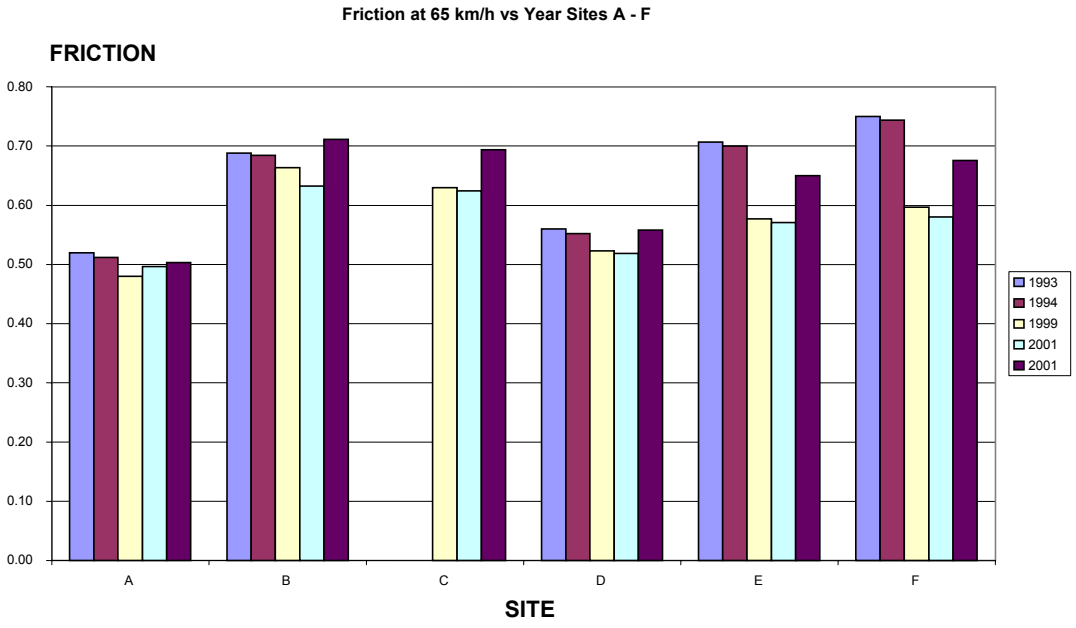

Figure D.6 GripTester

Appendix E: TEXTURE HISTORY

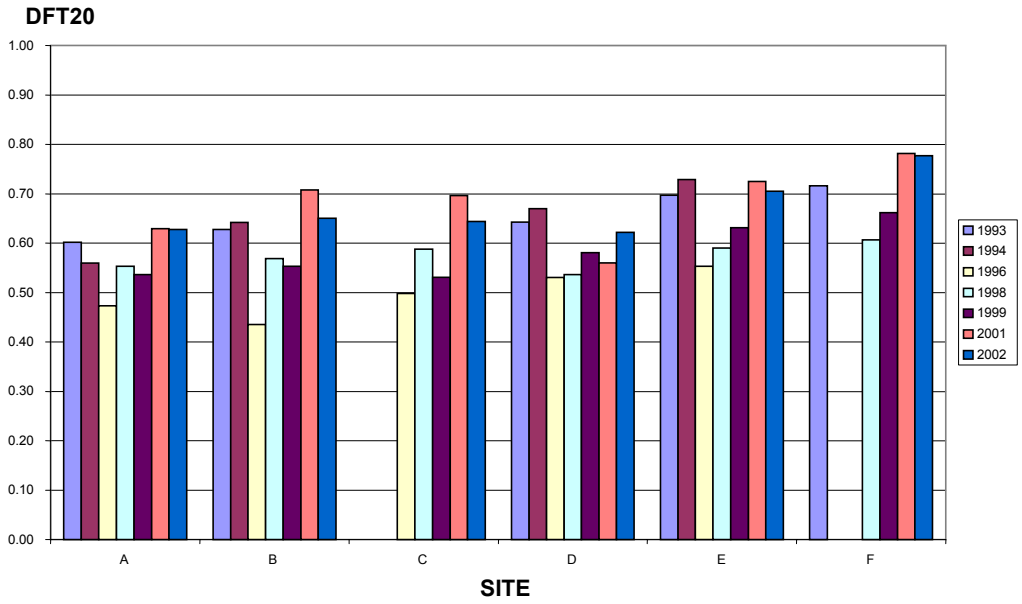

Figure E.1 DFTester at 20 km/h vs Year Sites A - F

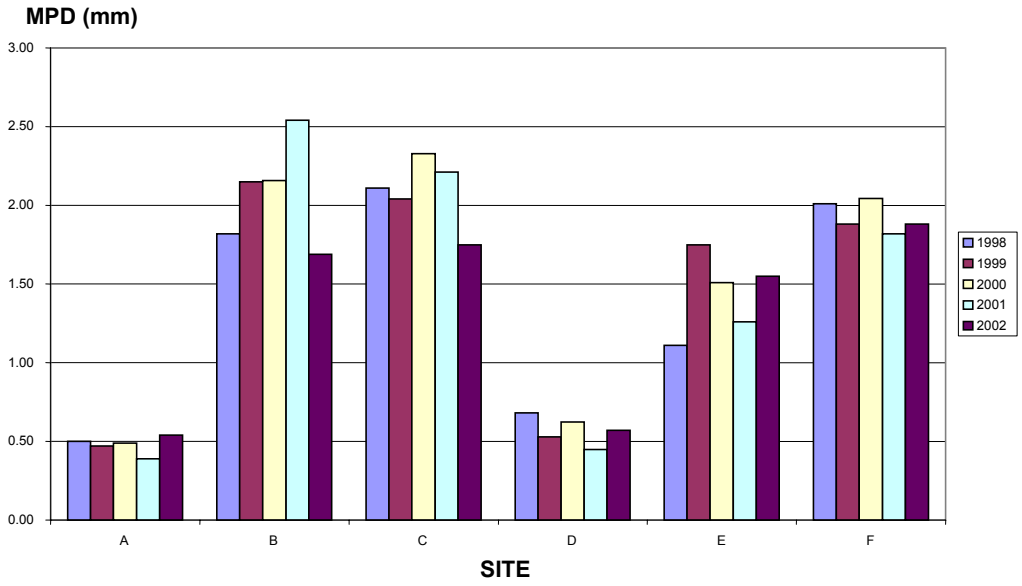

Figure E.2 CTMeter MPD vs Year Sites A – F

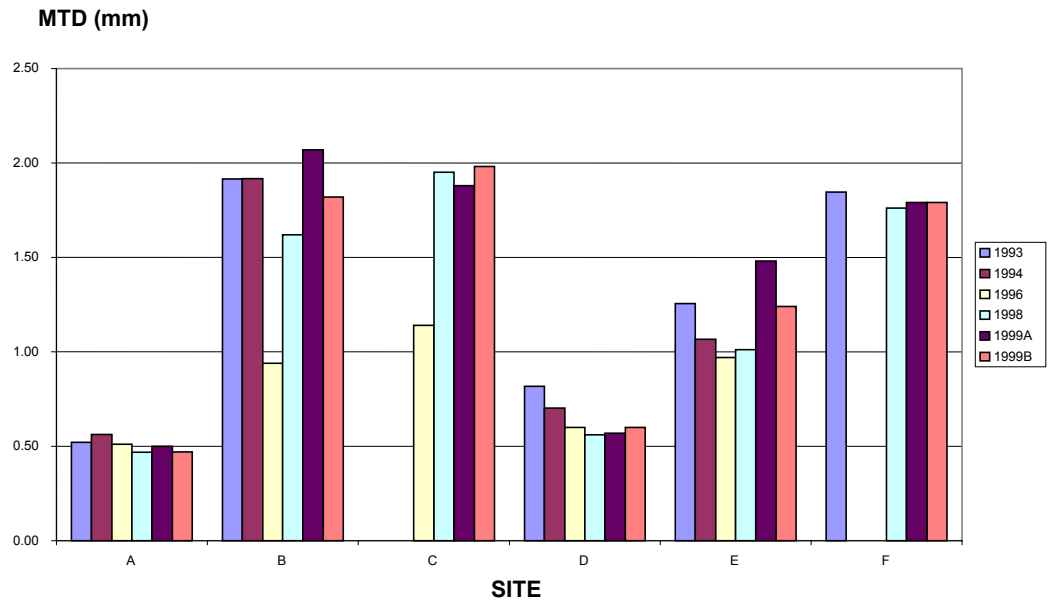

Figure E.3 MTD (Sandpatch) vs Year Sits A – F

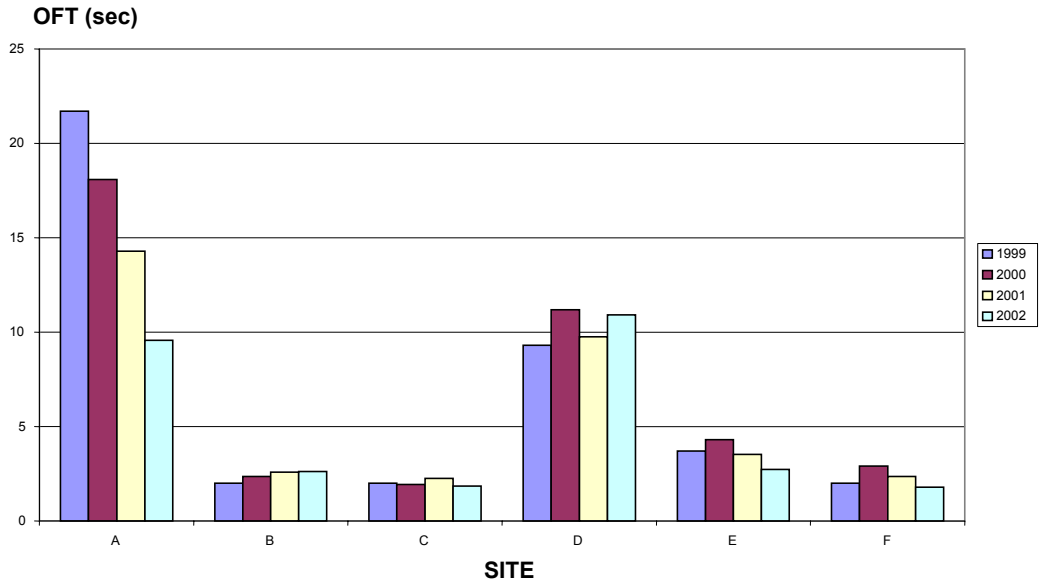

Figure E.4 Skidabrader Outflow Meter vs Year Sites A - F

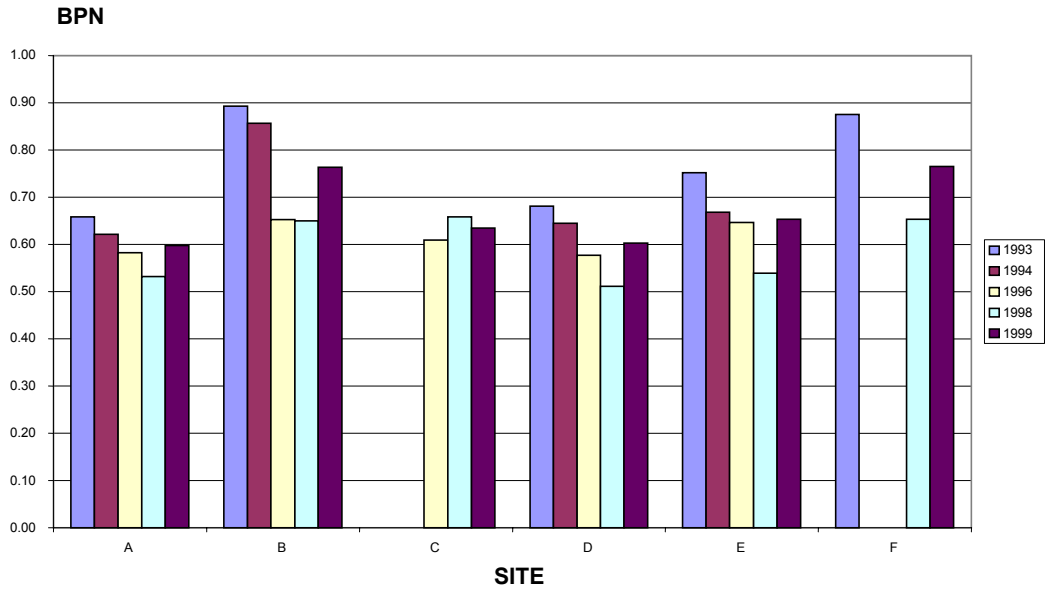

Figure E.5 PSU BPN vs Year Sites A – F

APPENDIX F: COMPARISON OF DEVICES (REPRODUCIBILITY)

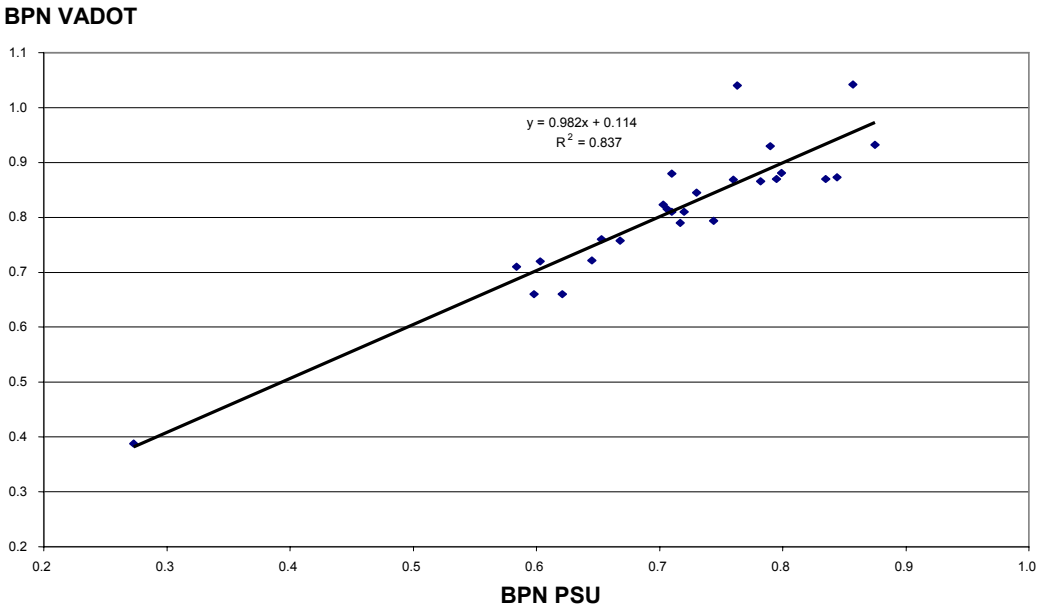

Figure F.1 BPN VADOT vs. BPN PSU for 1994, 1997, and 1999

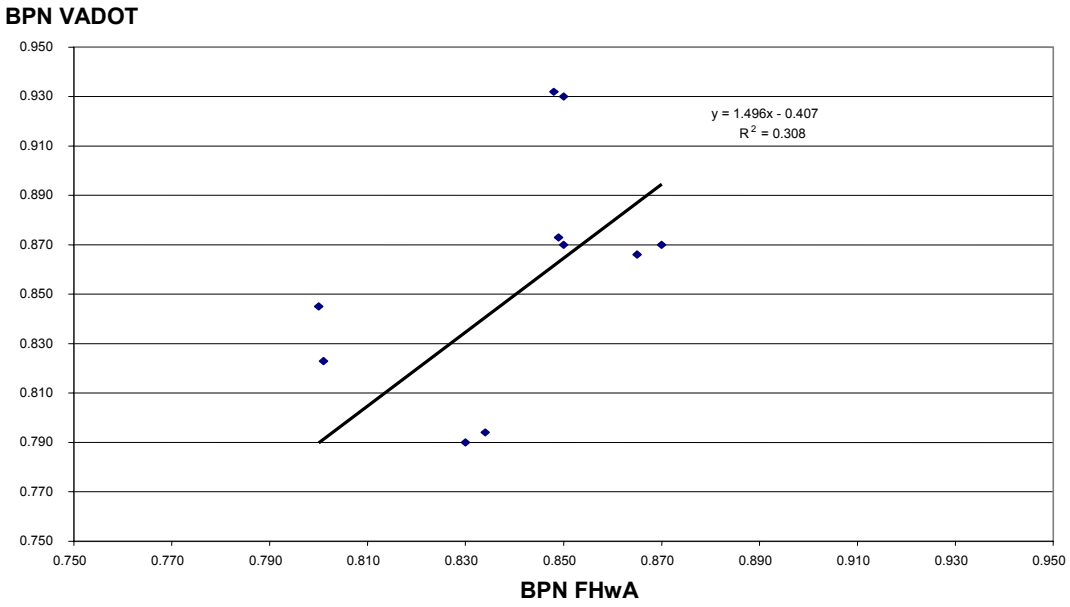

Figure F.2 BPN VADOT vs BPN FHwA for 1997 & 1999

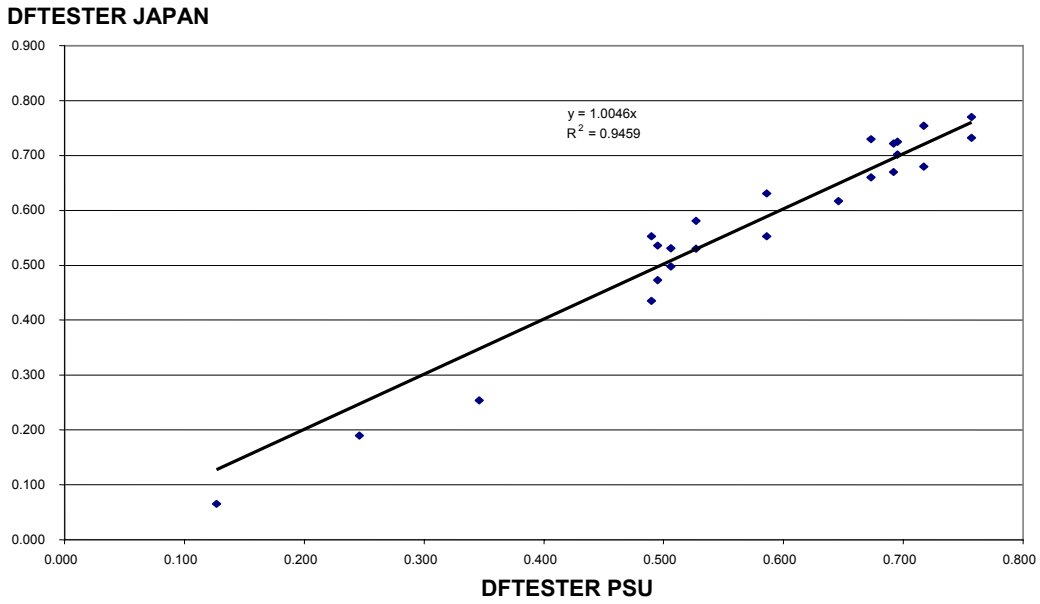

Figure F.3 DFT 20 1996 & 1999 for two DFTesters

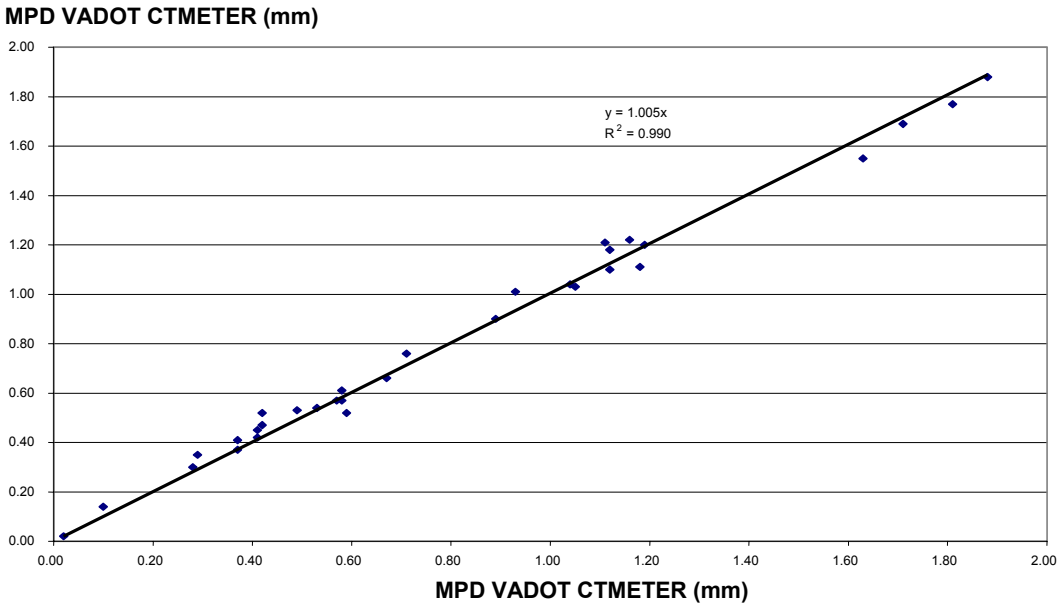

Figure F.4 MPD 2001 & 2002 Data for two CTMeters

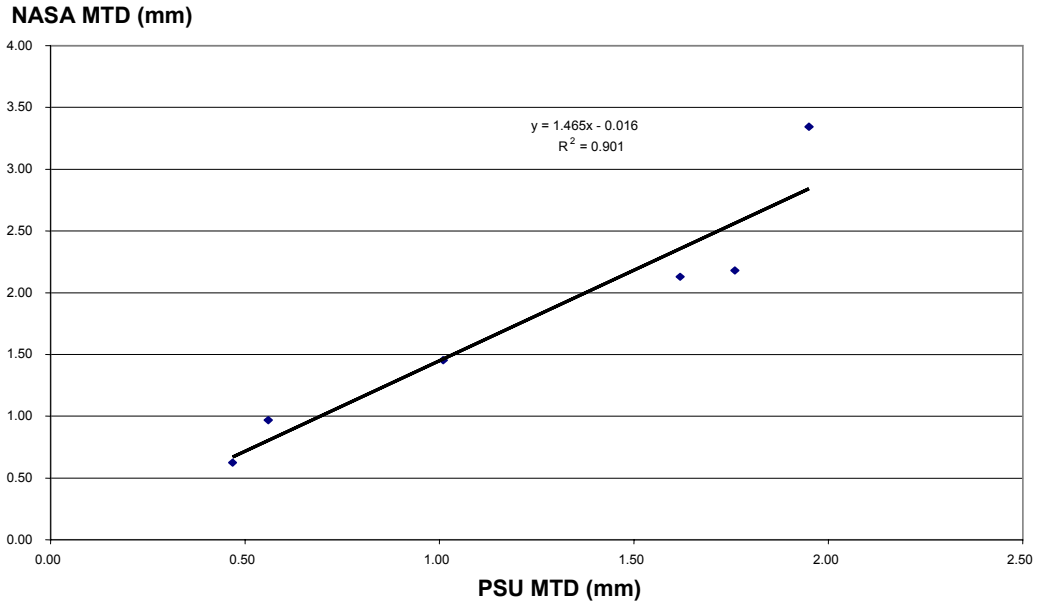

Figure F.5 MTD 1998 Data for two Sandpatch Operators

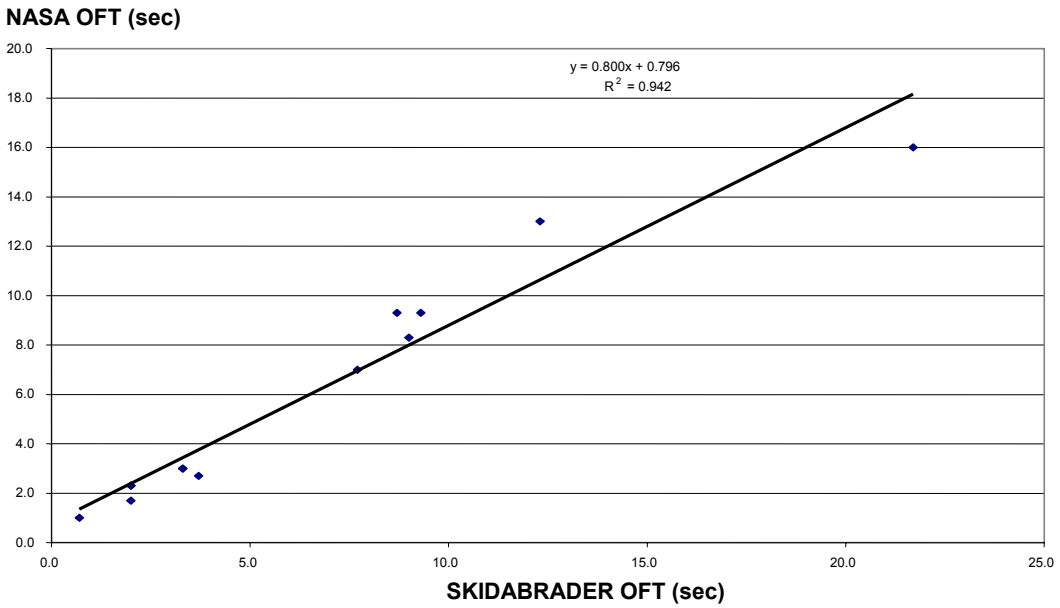

Figure F.6 OFT 1999 Data for two Outflow Meters

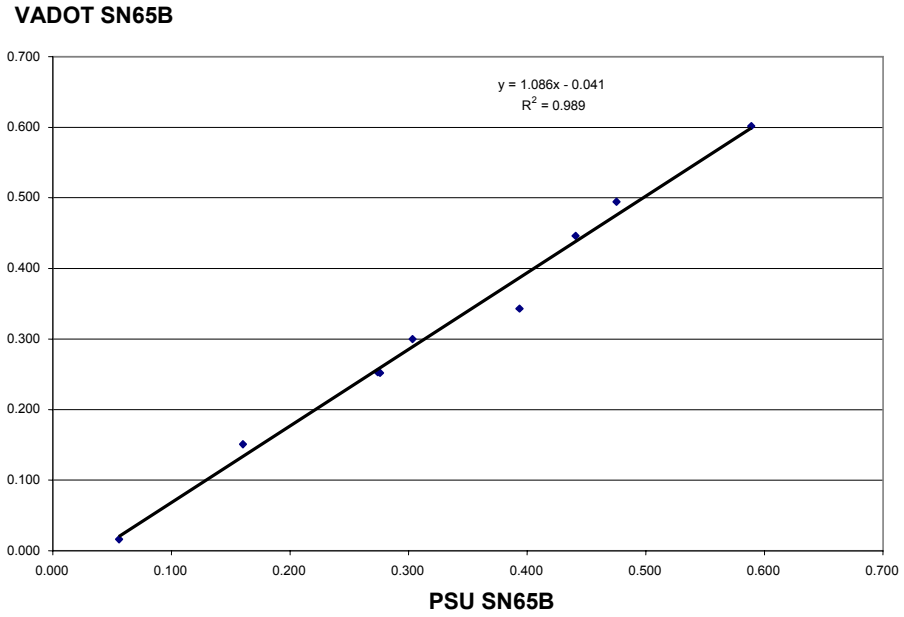

Figure F.7 SNR65 1996 Data for two E-274 Trailers with E-501 Tires

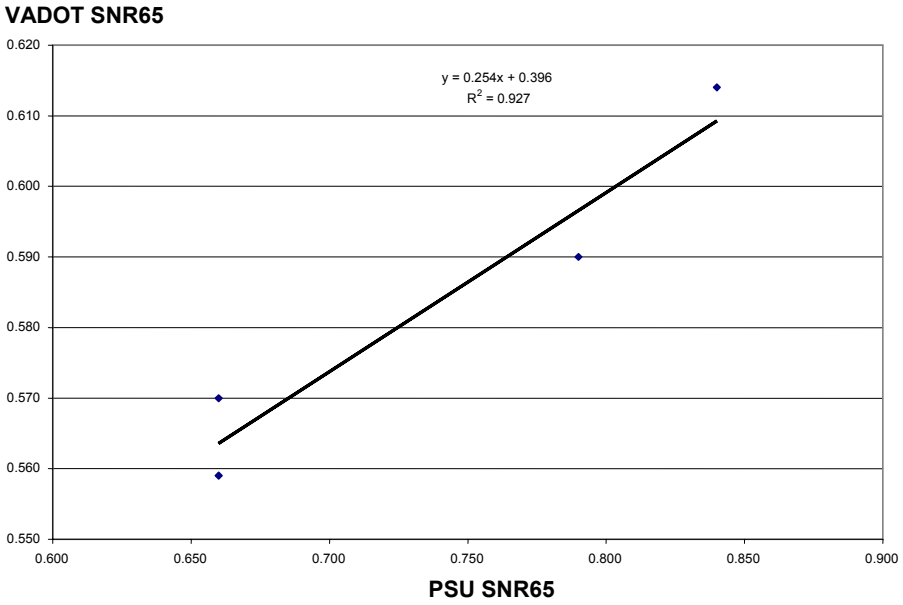

Figure F.8 SNB65 2001 Data for two E-274 Trailers with E-524 Tires

APPENDIX G: GROUP PHOTOGRAPHS

Friction Workshop, NASA Wallops Flight Facility
Date: 5/15/02
Time: 9:10
Briefing

Figure G.1 Photograph of NASA Wallops Friction Workshop Briefing Meeting before Testing

Friction Workshop, NASA Wallops Flight Facility
Date: 5/15/02
Time: 9:10
Briefing

Figure G.2 Second Photograph of NASA Wallops Friction Workshop Briefing Meeting before Testing

Figure G.3 Group Photograph for 1993 NASA PIARC EXTENSION

Figure G.4 Group Photograph for 1994 NASA Wallops Friction Workshop

Figure G.5 Group Photograph for 1995 NASA Wallops Friction Workshop

Figure G.6 Group Photograph for 1996 NASA Wallops Friction Workshop

Group Photographs for 1997 and 1999 NASA Wallops Friction Workshops were not taken.

Figure G.7 Group Photograph for 1999 NASA Wallops Friction Workshop

Figure G.8 Group Photograph for 2000 NASA Wallops Friction Workshop

Group photographs for 2001 and 2002 NASA Wallops Friction Workshops were not taken.

APPENDIX H: TEXTURE DEVICES USED IN THE NASA WALLOPS FRICTION WORKSHOPS

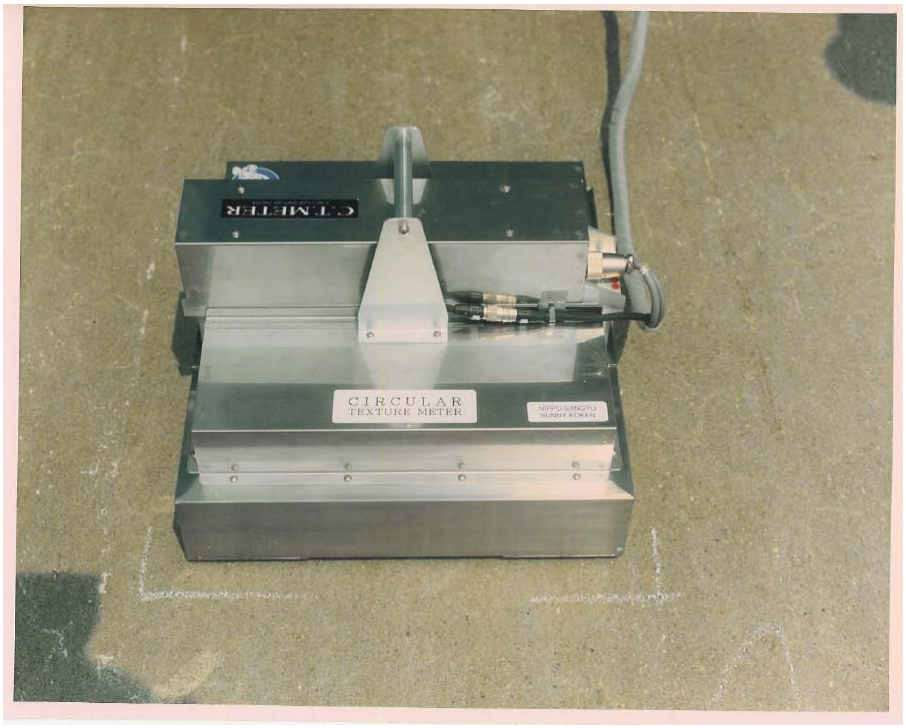

Figure H.1 Circular Track Meter (CT Meter) – Japan

Figure H.2 PTI and FHWA British Pendulum Tester (BPN) – USA

Figure H.3 FHWA AND PTI Outflow Meter – USA

Figure H.4 FHWA ROSAN (MPD, ETD) – USA

Figure H.5 FHWA Texture Van – USA

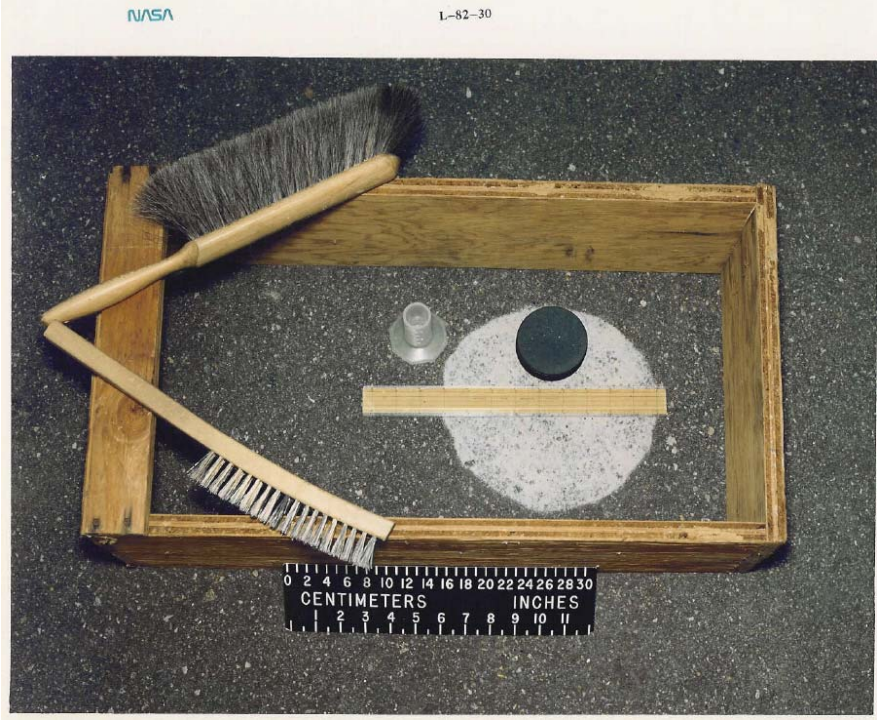

Figure H.6 NASA Volumetric Texture Depth, Glass beads - USA

Figure H.7 NASA Volumetric Texture Depth, Grease – USA

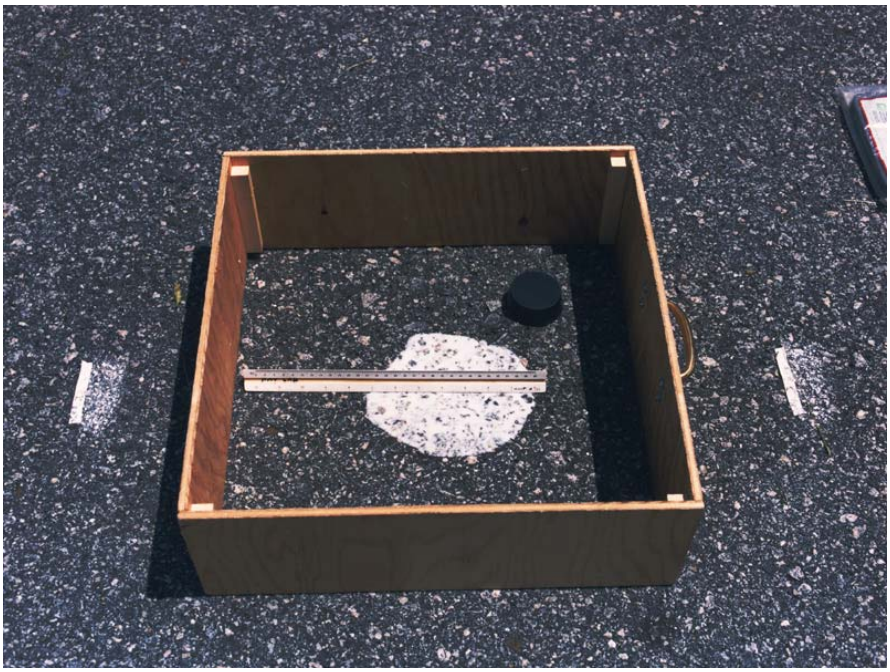

Figure H.8 PSU Volumetric Texture Depth, Glass beads – USA

Figure H.9 NASA British Pendulum Tester (BPN) – USA

Figure H.10 Skiddabrader Outflow Meter – USA

Figure H.11 Virginia DOT British Pendulum Tester (BPN) – USA

Figure H.12 Virginia DOT Laser Texture Meter-USA

Friction Workshop, NASA Wallops Flight Facility
Date: 5/15/02
Time: 11:05:45
VDOT Texture Meter

Figure H.13 Virginia DOT Circular Track Meter (CT Meter)-USA

Figure H.14 VTI Laser Texture System (MPD, ETD, RMS) – Sweden

Figure H.15 Mini Texture Meter-UK

APPENDIX I: FRICTION DEVICES USED IN THE NASA WALLOPS FRICTION WORKSHOPS

Friction Workshop, NASA Wallops Flight Facility
Date: 5/14/02
Time: 14:03:38
Circular Texture Meter and Outflow Meter

Figure I.1 Dynamic Friction Tester (DF Tester) – Japan

Figure I.2 FAA BV-11 – USA

Figure I.3 FAA MuMeter - USA

Friction Workshop, NASA Wallops Flight Facility
Date: 5/15/02
Time: 15:36:46
FAA SAAB Friction Tester

Figure I.4 FAA Surface Friction Tester (SFT) – USA

Figure I.5 GripTester – NASA

Figure I.6 GripTester – Scotland

Friction Workshop, NASA Wallops Flight Facility
Date: 5/15/02
Time: 12:05
USAF Grip Tester

Figure I.7 GripTester – USAF

Figure I.8 GripTester –(Push mode)

Figure I.9 IMAG – France

Figure I.10 International Cybernetics E-274 Locked Wheel Tester (SNB and SNR) – USA

Friction Workshop, NASA Wallops Flight Facility
Date: 5/16/02
Time: 11:47:00
IRV

Figure I.11 IRV – International Reference Vehicle – France

Figure I.12 JBI Decelerometer – USA

Figure I.13 PTI K. J. Law E-274 Locked Wheel Tester (SNR) – USA

Friction Workshop, NASA Wallops Flight Facility
Date: 5/15/02
Time: 12:05:30
FAA Runway Friction Tester

Figure I.14 FAA K. J. Law Runway Friction Tester – USA

Figure I.15 MD DOT E274 Locked Wheel Tester (SNR) – USA

Figure I.16 NASA Diagonal Braked Vehicle – USA

Figure I.17 Norsemeter ROAR (variable slip tester)-Norway

Figure I.18 Norsemeter RUNAR (variable slip tester)-Norway

Figure I.19 Norsemeter OSCAR (variable slip tester)-Norway

Figure I.20 Norsemeter SALTAR – Norway

Figure I.21 Penn State E-274 Locked Wheel Tester (SNB and SNR) – USA

Figure I.22 Pennsylvania DOT E-274 Locked Wheel Tester – USA

Figure I.23 Surface Friction Tester (USFT) – Sweden

Figure I.24 Transport Canada Surface Friction Tester (TC79) – Canada

Friction Workshop, NASA Wallops Flight Facility
Date: 5/15/02
Time: 12:06:00
TC SAAB Friction Tester

Figure I.25 Transport Canada Surface Friction Tester (TC85) – Canada

Figure I.26 Transport Canada ERD Blazer – Canada

Figure I.27 U.S. Navy Slip Meter – USA

Figure I.28 US Surface Friction Tester (USFT) - USA

Friction Workshop, NASA Wallops Flight Facility
Date: 5/15/02
Time: 15:36
E274 Skid Trailer

Figure I.29 Virginia DOT E-274 Locked Wheel Tester (SNB and SNR) - USA

Figure I.30 VTI BV-14-Sweden

APPENDIX J: ROUGHNESS MEASURING SYSTEMS USED IN THE NASA WALLOPS FRICTION WORKSHOPS

Figure J.1 ARP Auto Rod & Level-USA

Figure J.2 Digital Profilite 300-Canada

Figure J.3 Dynatest Profiler-USA

Figure J.4 DYNVIA -Czech Republic

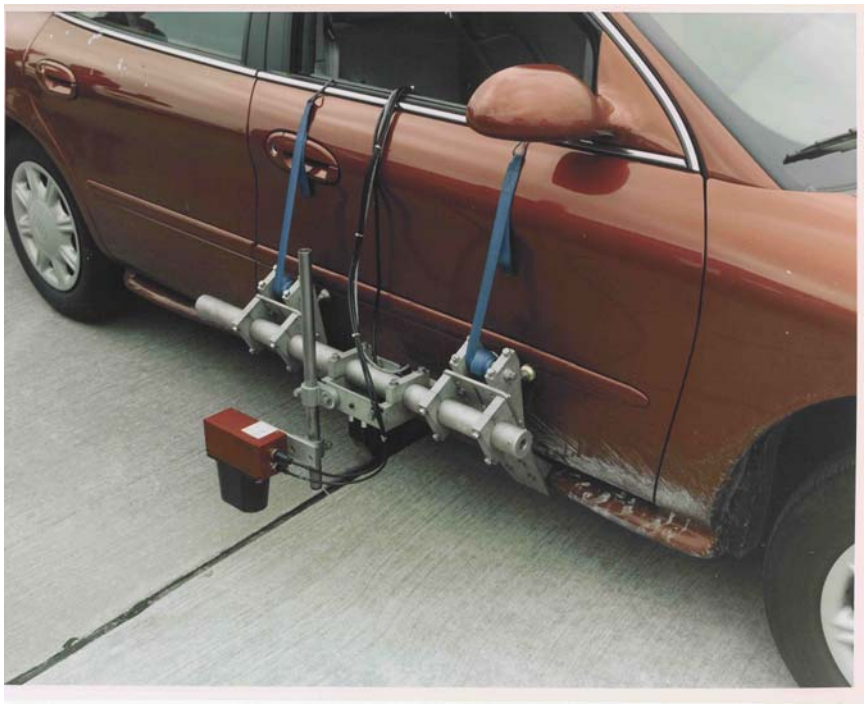

Figure J.5 Greenwood High Speed Profiler-DK

Figure J.6 MD DOT High Speed Profiler-USA

Figure J.7 MD DOT Light Weight Profiler-USA

Figure J.8 PA DOT ARRB Walker

Figure J.9 PA DOT ICC Light Weight Profiler-USA

Figure J.10 VA DOT FACE Dipstick –USA

Figure J.11 VA DOT ICC High Speed Profiler-USA

Figure J.12 YSI Roadpro-USA

APPENDIX K: PROFILING SITES

Figure K.1 Profiling site 1 on South side of Hanger N159

Figure K.2 Profiling site 2 in front of Hanger N159 on Runway 4/22 Side – East Side

APPENDIX L: OTHER PHOTOGRAPHS

Figure L-1 Skidabrader

Figure L-2 Wallops Water Truck 26 and Test Crews

Friction Workshop, NASA Wallops Flight Facility
Date: 5/16/02
Time: 11:57:24
IRV Filling Up

Figure L-3 Wallops Water Truck 2

Figure L-4 T. Yager Demonstrating the Grease Patch