DEVELOPMENT OF SURFACE FRICTION ASSESSMENT MODEL AND MEASUREMENT FRAMEWORK FOR AIRPORT RUNWAY

A THESIS BY

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Submitted in Partial fulfillment of requirement for degree of

M.Sc. Engg.(Civil and Transportation)

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DEVELOPMENT OF SURFACE FRICTION ASSESSMENT MODEL AND MEASUREMENT, FRAMEWORK FOR AIRPORT RUNWAY.

:

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(CIVIL AND TRANSPORTATION)

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This thesis is dedicated to my parents Sri Paritosh Karmakar and Nilima Karmakar. Their blissful inspiration has made all my achievements possible.

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ABSTRACT

International Civil Aviation Organization (ICAO) is the controlling authority of air traffic movement all over the world. Contracting states are given the authority to develop detailed schemes to provide acceptable levels of safety, both in respect of the objective and operational determination of surface friction . As a result, the methods of determination and availability of information differ widely between States. Although runway surface friction coefficient prediction models have been studied for more than half a century in the developed world, research on this topic in Bangladesh as well as in other south-east Asian countries has not been done frequently, indeed. This is mainly due to the complexity of data collection and processing.

Even though the current study has tried to focus some effort in this sector and develop a prediction model of runway surface friction coefficient in Bangladesh perspectives. There are many variables that are involved in this phenomenon including speed, ambient temperature, ground temperature, distance and inflation pressure of tire.

This study focuses on measurement framework and model development for runway surface friction coefficient based on data collected from Shah Amanat International Airport Runway. Friction data have been determined by Airport Surface Friction Tester (ASFT) car. The multiple linear regression equation has been developed from runway friction data at different speed, ambient temperature, ground temperature, distance and inflation pressure of wheel. This study outcome can be utilized for determination of friction coefficient of runway surface of other airports of our country, identification of level of safety of air traffic movement, evaluation of the effectiveness of aircraft performance, assessment of runway surface conditions and reporting a dissemination of runway surface conditions. This study has analyzed that cruise speed is more dominant over surface friction coefficient of runway surface. This study has revealed that an increment of 20% of speed value increases the friction coefficient value by 42% considering remaining parameters constant. On the other hand, increment of air temperature value by same amount increases friction coefficient value by 4.4%. Similarly, an increment of ground temperature, tire pressure and distance value by 20% result in a decrement of friction coefficient value by 8.8%, 32.6% and 2.9% respectively. The understanding of each of these variables will help one to realize the magnitude of the problem that one faces and eventually design more reliable friction measuring techniques.

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ACRONYMS AND ABBREVIATIONS

AGA	Aerodromes and Ground Aids
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Services
ARC	Aviation Rulemaking Committee
ASFT	Airport Surface Friction Tester
ASM	Airport Services Manual
ATC	Air Traffic Control
ATS	Air Traffic Services
ATIS	Automatic Terminal Information Service
CAAB	Civil Aviation Authority of Bangladesh
CFME	Continuous Friction Measuring Equipment
CI	Confidence Interval
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
GPS	Global Positioning System
GPRS	General Packet Radio Service
HMA	Hot Mix Asphalt
ICAO	International Civil Aviation Organization
IATA	International Air Transport Association

MFL	Minimum friction level

MPC	Mean Profile Depth
MPD	Measurement personal computer
NOTAM	Notice to Airman
NCHRP	National Cooperative Highway Research Program
PPC	Presentation Personal Computer
PDF	Portable Document Format
PFC	Porous Friction Course
RADAR	Radio Detection and Ranging
RSCSG	Runway Surface Condition Study Group
RPM	Revolutions per minute
SNOWTAM	Snow Notice to Airman
SARPS	Standards and Recommended Practices
SAS	Scandinavian Airlines System
SAIA	Shah Amanat International Airport
TALPA	Takeoff and Landing Performance Assessment
USA	United States of America
USB	Universal Serial Bus
WIFI	Wireless Fidelity

Chapter1

INTRODUCTION

Airtrafficcommunicationdoesnothavesuchalonghistoryasroadtrafficorrailcommunication,yetthediversityofopinionsrelatedtothelawsthatgovernfrictionisenormous.Thepurposeofthisdissertationistoprovidemostup-to-dateguidanceonthesubjectoffrictionissuesinaviationsectorasfarasispossible,giventhepresentstateofknowledge.Itiswidespreadknowledgethatpavementshaveatendencytobecomeslipperytobothpedestriansandvehicleswhentheyarewetorinundatedorarecoveredwithslush,snoworice;however,nooneyethasaholisticunderstandingofthephysicaleffectscausingthisslipperinesswhichinturncancauseaccidents.Thesamephenomenonappliestoaircraftoperationontheaircraftwheelmovementareas.Theinformationwithinthisdissertationshouldbeusedbynationalauthoritieswhenimplementingtheirflightsafetyactivitiesandasnecessaryreferencedforusebyaerodromeoperators,aerodromeairnavigationserviceproviders,aircraftoperatorsandindividualswithintheorganizations.Thisdissertationprovidesanoverarchingconceptualunderstandingofthesurfacefrictioncharacteristicscontributingtocontrollingtheaircraftviathecriticaltiretogroundcontactarea.Sufficientrunwayfrictionhasaconsiderableimpactonaircraftlandingperformance.Thisphenomenonisespeciallyobservedwhenaircraftsarelandingonwetorotherwisecontaminatedrunwaysduetothereducedbrakingaction.Withaviewtopreventingrunwaylandingexcursionaccidentsandincidents,andenhancingairportandflightsafety,availablerunwayfrictionshouldbestudied.Therefore,arunwaysurfacefrictionassessmentshouldbeconductedfollowinganysignificantmaintenanceactivityconductedontherunwayandbeforetherunwayisreturnedtoservice.Runwaysurfacefrictionassessmentsshouldalsobeconductedfollowingpilotreportsofperceivedpoorbrakingaction,iftherearevisiblesignsofabuildupofrubberdeposits,runwaysurfacewear,orforanyotherrelevant reason.

1.2 ObjectiveswithSpecificAimsandPossibleOutcomes

ThisresearchisconcernedwiththedeterminationoffrictioncoefficientofrunwaysurfaceofShahAmanatInternationalAirport,Chittagong.Theobjectivesofthisresearchare:

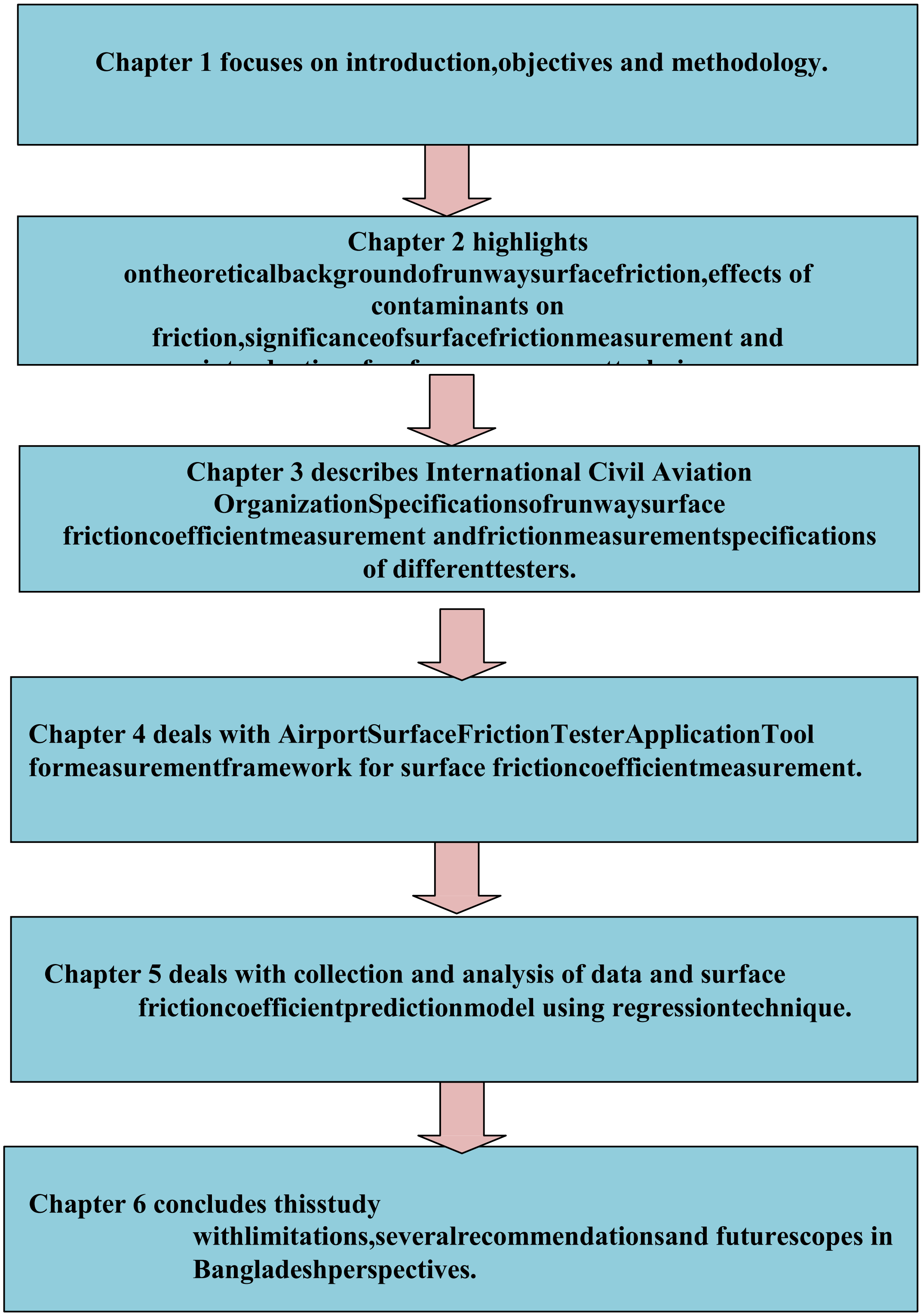
a) Todevelopacomprehensiveconceptualunderstandingofthesurfacefrictioncharacteristicscontributingtocontrollingtheaircraftviathecriticaltiretogroundcontact area.

b) TocalibratetheASFTsystemandinputthedataintoASFTintegratedsoftwareandmeasurecoefficientoffrictionofRunwaysurfacetosuggestanapplicablemeasurementframeworkfollowing ICAO specifications.

c) Todeveloparunwaysurfacefrictioncoefficientmodelincorporatinglocalgeo-environmentalparameters.

Theairportauthoritycouldusethisinformationtoassessthesurfacefrictioncharacteristics,evaluateaircraftperformanceconsideringinterrelationamongindividualcomponentsofthesystemsuchas,pavementsurface(runway),tire(aircraft),contaminants(betweenthetireandthepavement)andatmosphere(temperature).Thesefindingswillleadandsupplementnumerousinitiativesregardingestablishmentsofrulesandregulationsofaviationsafety,developasystemforreportingfrictionissuesofthemovementareaaspartofastandardizedreportingformat.Thisformatmustmeettheneedsofthepilotforsafeoperationoftheaircraft;anddevelopasystemformaintenanceof themovement area.

1.3 ThesisStructure



Chapter 1 focuses on introduction,objectives and methodology.

Chapter 2 highlights ontheoreticalbackgroundofrunwaysurfacefriction,effects of contaminants on friction,significanceofsurfacefrictionmeasurement and

Chapter 3 describes International Civil Aviation OrganizationSpecificationsofrunwaysurface frictioncoefficientmeasurement andfrictionmeasurementspecifications of differenttesters.

Chapter 4 deals with AirportSurfaceFrictionTesterApplicationTool formeasurementframework for surface frictioncoefficientmeasurement.

Chapter 5 deals with collection and analysis of data and surface frictioncoefficientpredictionmodel using regressiontechnique.

Chapter 6 concludes thisstudy withlimitations,severalrecommendationsand futurescopes in Bangladeshperspectives.

Chapter2

THEORETICALBACKGROUNDOFFRICTION

2.1 GeneralFrictionTheory

The simplestdefinitionoffrictionis:TheforceF,requiredtotowanobject,generating acertainnormalreactionN,againstaflathorizontalsurface.Mathematically,thefrictioncoefficient is expressedas below:

$$\mu(mu) = F / N \ldots\ldots\ldots\ldots\ldots(1)$$

When friction is measuredatairports accordingtoICAO procedures inAnnex14 andassociateddocuments, the frictionmeasuredshall be the MAXIMUMFRICTION.Frictionforceisinfluencedbyacombinationofaircrafttires,aircraftbrakingsystems,andairportrunwaypavementsurfaces.Thefollowinglistedfactorsarethemainfactorsaffectingrunwayfriction.

- GroundSpeed
- SlipRatio;
- Tiretexture andinflationpressure
- Pavementtexture
- Water or contaminations.

2.1.1 TheClassicLawsofFriction

Theclassiclaws of frictionevolvedfrom theearlywork ofAmontons andCoulomb.These laws werebased onempirical observations andcanbe summarized as follows:

(1) Friction is independent of the apparent or nominal contactarea.
(2) Frictionforce is proportional to the normal load.
(3) Static coefficient offriction is greaterthat the kinetic coefficient of friction.
(4) Kinetic friction is independent of the slidingspeed.

Thefriction at therubbertire-pavementinterfaceconstitutes acomplexphenomenon dueto the viscoelasticnature ofthe rubber.Empiricalworkconductedbymanyinvestigatorsshowsthattheclassicallawsoffrictionarenotvalidonviscoelasticmaterials.Denny(1953)conducted laboratoryexperiments on rubber-like materials and showed that undercontaminatedconditionsthecoefficientoffrictiondecreaseswithincreasingcontactpressure. Thirion(1946)confirmed theload dependence ofrubberfriction andproposedanempirical relationship between thecoefficientoffrictionandpressure.Schallamach(1952)showed that the load dependence ofrubberfrictioncanbeexplained byassumingsphericalsurfaceasperitiesandelasticbehaviorofrubberincompression.Although themechanismsoftire-pavementfrictioninteractionarenotfullyunderstood,theMolecularAttractionTheory,developedbyTomlinsonandHardyinthe1930s,seemstobethemostaccepted(Moore,1975).Thecurrentinvestigationislimitedtofrictionorskidresistance onwetpavementsurfaces only.

2.1.2 PavementFriction vs TireSlip

This friction is measuredbyconsideringa certain slip as followingequation

[illegible] = [illegible] ………(2)

[illegible]

Slip,S,isgenerallyexpressedinpercent.100%slipstipulatesthatthebrakedwheelisskidding.Maximumµ(mu)ismeasuredbetween10and20%slip.Frictionforcehastwocomponents: the rolling resistanceforceandtheslipresistanceforce.Whenthe tire isrollingfreely,onlyarollingresistanceforceisappliedonthewheel.Asbrakingforceisapplied,aslip occursbetweenthetireandthepavementsurface.AsshowninFigure2.1,thetireproceedsfromfreerollingtoalockedwheel,thecoefficientoffrictionvarieswiththesimultaneouschangesofthetireslip.Thecoefficientoffrictionincreasesrapidlyfromacertainvalue,whichisreferredasrollingresistancecoefficient,toapeakfrictionvalueandthen itdecreases toanothercertainvalue,which is referred as slideresistancecoefficient.

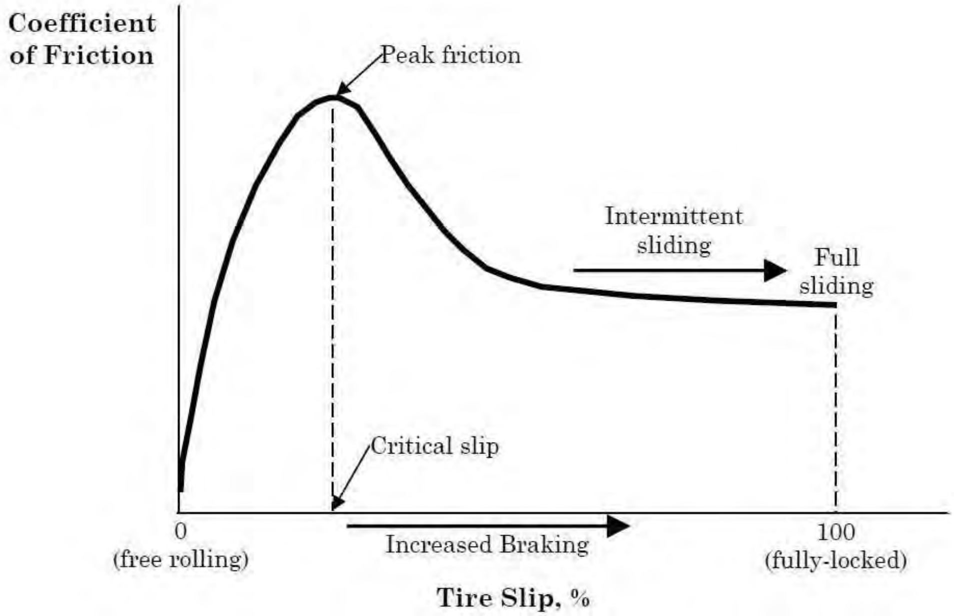


Figure 2.1 : PavementFriction vs TireSlip

Thepeakfrictionusuallyoccurswhenthetireslipexistsbetween10%to20%slip,whichisdesignated asthecriticalslip.Whentheslipproceedsto100%slip,whichreferstothatwheelis completelylocked, thecoefficientdecreasesto a slideresistancefrictioncoefficient.The slipresistancefrictionis lowerthan thepeakfriction.The differencebetweentheslipresistancefrictionandpeakfrictionislargerforwetandcontaminatedpavementsin comparisonwithdry pavements.Frictioncharacteristics of a runwaydependsonthestructureoftherunwaysurface.Agoodmacrostructureshouldhaveameandepthofabout1mm.Themicro-textureisdependsontheaggregateused.Forexample,limestonewillprovideverylowmicro-textureandarunwaywillbe veryslippery,especiallywhenwet.Ontheotherhand, macrotexturereferstotheoveralltexture ofpavement.Figure 2.2showsthemicroscopicviewofmicrotexture andmacrotextureofpavement.Thespeedhasasignificanteffectonthefrictionoftherunwaysurface whenwet.If bothmacro-textureand micro-texturearepoorthe effect on frictionofarunwaywhen wet will beextremelydependent on speed.If both macro-textureand

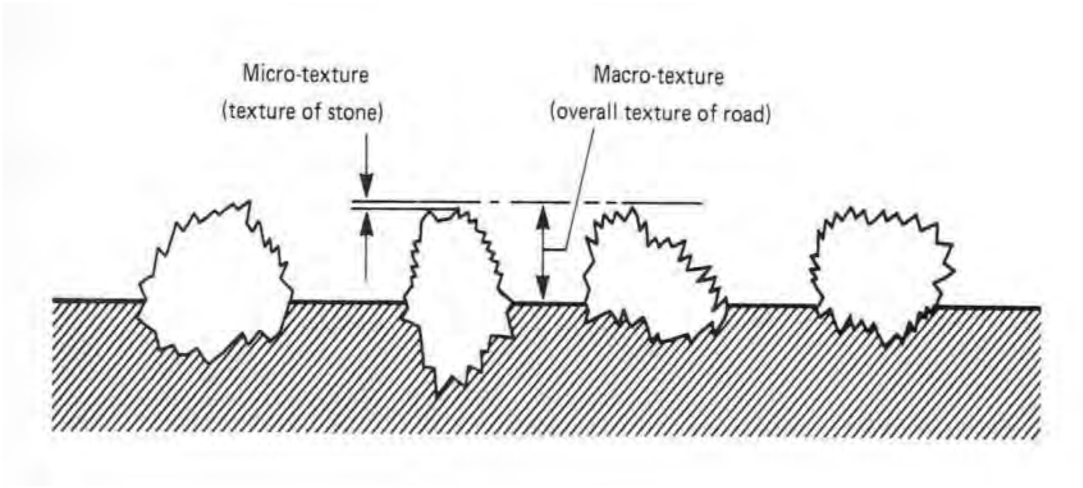


Figure 2.2: Micro-texture andMacro-texture

micro-texturearepoortheeffectonfrictionofarunwaywhenwetwillbeextremelydependentonspeed. Naturally,ifonlyoneofthetexture kinds ispoorthe effectofspeedon friction will be lessconsequently.

2.2 Vehicle OperationalParameters

2.2.1 Slip Ratio

Frictionresearchers usethe slip ratio term to indicate thedifferencebetween tirevelocityandvehicle velocity,asindicated in Equation(3).

$$Slip = \frac{S-wR}{S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where*S*isthevelocityofthevehicle,*w*istheangularvelocityofthetireand*R*isthe nominalradiusofthetire.ItisseenfromEquation(10)thatwhenthetireisrollingfreelytheslipmustbe0(*S*=*wR*).Ontheotherhandwhenthetireislockeduptheslipratiois1(*wR*=0).Lockedwheelssuffersevere localizedwearunderdryconditionssincethereisnorollingandsubsequentuniformwearinthewheelswhenlocked.Thusthematerialatthecontactareabetweenthewheelandthepavementsurfaceissubjectedtoafrictionalforcethatcanleadtopermanentdeformationlocalizedintoonepointonly ofthewheel.Ontheotherhand,arollingwheeldistributestheseeffectsinauniformmannerthroughoutthecircumference;thereforethewearisconsiderablylowerthanthatinthelockedwheelcondition.Experimentalwork(NCHRP,2009)showsthatthemaximumcoefficientoffrictionformostsurfacesisgenerallyreachedinarangebetween0.1and0.2slipratio,dependingonthetypeofsurface,asshownintheFigure2.3.

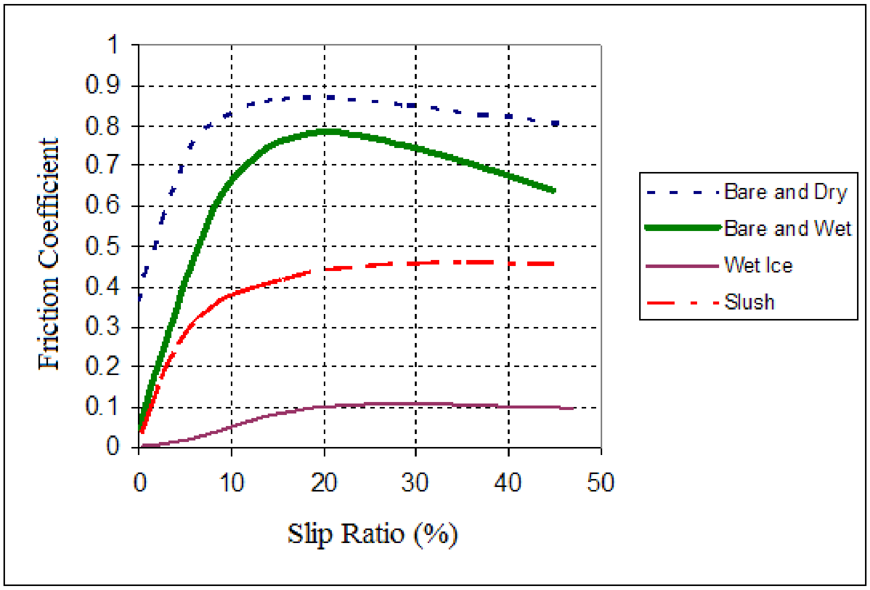


Figure 2.3:Coefficient of frictionvs.Slip ratioon differentsurfaces(Adapted fromNCHRP, 2009)

ThisistheprincipleonwhichAntilockBrakeSystems(ABS)work.AnABSsystemrecognizes that themaximum coefficient offriction is reachedat acertainslip range,andhencecontrols therotation of thetires forthe slip ratio to be around that slip range. ThusABSpreventsthetiresfromlocking,whichprovidesvehiclestability,steerabilityandimprovesstoppingcapabilities.TheABSisanindependentsysteminthatonlythewheelsthatareabouttobelockedwillbepumpedandslip-controlled,whiletheotherswill be subjected to the full brakingpressure. Consequentlythis system would allow oneto stop a vehicle within the shortest possible distance. A computer monitors the speed ofeachwheel, which is fedin to the ABSsystem(Mauer,1995). When the system detects thatoneormoretireshavelockeduporareturningrelativelyslowercomparetotheremainingtires ,thecomputersendsasignaltomomentarilyremoveandre-applythebrakingpressuretotheaffectedtiretoallowittocontinueturning.This"pumping"ofthe brakesoccursattenormoretimesasecond,farfasterthanahumancanpumpthebrakesmanually.

2.2.2 Vehicle Speed

Ingeneral,thefrictioncoefficientdecreaseswithspeedonwetconditions.Thisphenomenonisattributedtothefacilitationofdrainageunderthetire.Thehigherthespeed,thelesstimethewaterunderthepatchhastodrainoff.Pavementmacrotexture(MPD)isusuallyusedtoexplainthefriction-velocitydependency.Highmacrotextureimprovesthedrainagepropertiesofthetirepatcharea,avoidinghydroplaningconditions.Figure3showsboththeeffectsofpavementmacrotextureand vehiclespeedon the coefficient offriction.

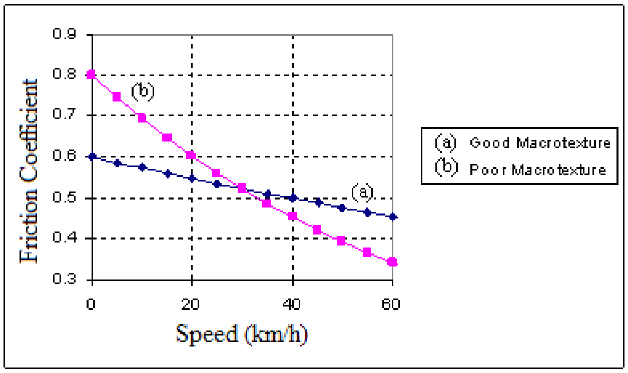


Figure 2.4: Texture Effect onFriction

2.2.3 Tire Characteristics

2.2.3.1 TireTread

Thetiretreadisamajorfactorwhenconsideringfrictiononcontaminatedpavementsurfaces.Tire treadprovidesadrainagesystemtoevacuatecontaminantsatthetireinterface;thushavingthesamefunctionaspavementmacrotexture.Theuseofsmooth tiresisrecommendedwhenperformingfrictiontestsonapavementsurface,becausetheninformationspecifictodrainagecapabilitiesandtextureofthepavementcanbeobtained.

2.2.3.2 TireInflation Pressure

Tireinflationpressureisdirectlyrelatedtothetirestiffness.Hencefrictionalcharacteristicsofatirearerelateddirectlytoitsinflationpressure.Lowtirepressureswillbereflectedinhigherrollingresistance.Figure2.5showstheresultsfromaload-deflectiontestperformedbytheinvestigatorusingthesmoothtireoftheLockedWheelTester.It is seen that thetirestiffnessincreases with increasinginflationpressure.

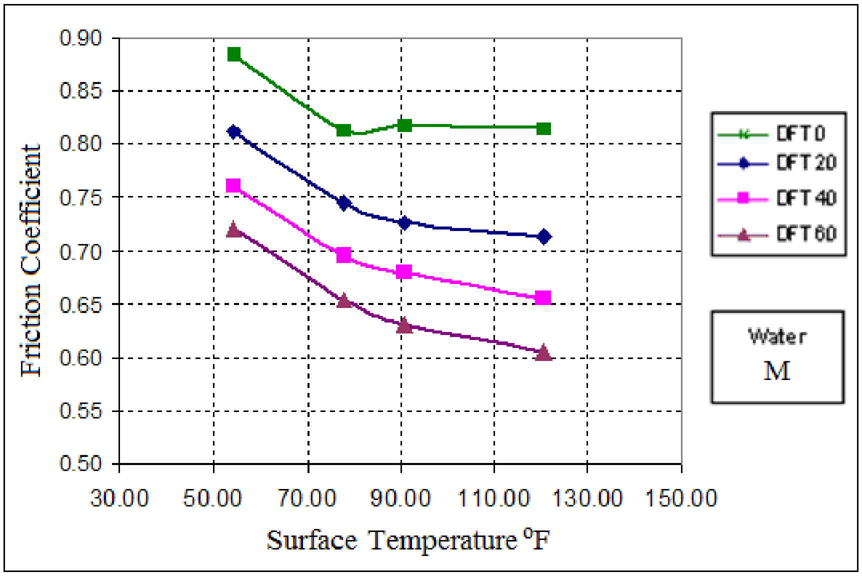


Figure2.5:FrictionCoefficientvs.WaterTemperatureintherangeof65to80^{0}F(Medium)

FromFigure2.6onecaninfertheeffectsthattireinflationpressurewouldhaveontheverticalload at thetirepavement interface. Asan example, a stiffer tireis more sensitiveto a vertical displacement due to a profile thana softertire.

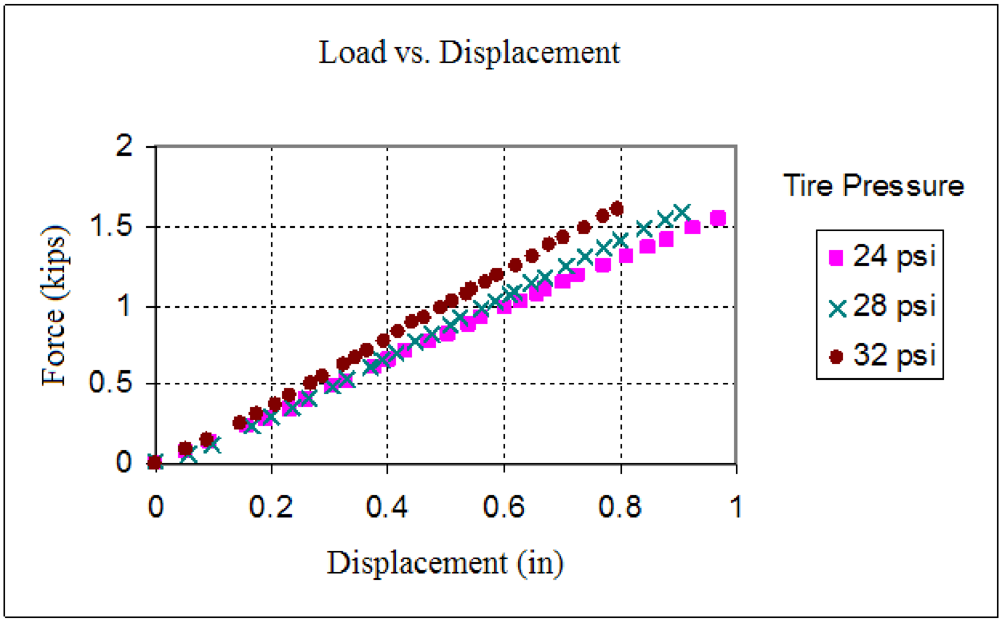


Figure 2.6:Effect of tireinflationpressure on tirestiffness.

2.2.4 EnvironmentalFactors

Asignificantvariationisobservedinfrictionvaluesmeasuredonthesamepavementsurfaces at different times of theyear. Several studies have suggested that this variationcan beattributed to differentenvironmental factors, such asrainfall,drydays precedingthe measurement,temperature,cumulativevehicles passeson test lane;andgreasedeposits, etc(Jayawickramaet.al.,1998).

2.2.4.1 PavementSurface Temperature

Temperaturehasasignificanteffectonthefrictionalbehaviorofthetires,duetotheviscoelasticnatureofrubber.Frictioninrubberlikematerialgenerallydecreaseswithincreasingtemperature.Temperature effect on friction is the mainparameterresponsibleforseasonalvariationsoffrictionmeasurements.Therefore,itisnecessarytoapplyatemperaturecorrectionto frictionmeasurementsin orderto performcomparisonsbetweenthoseatdifferenttemperaturesordifferentseasonsoftheyear(Fuenteset.al.,2009).

2.3 Brakingforces-general effects

Brakingforcesaregeneratedbythefrictionbetweenthetireandtherunwaysurfaceduringapplicationofbraketorquetothewheel.Frictiongenerateswhenthereisarelativespeedbetweenthewheelspeedandthetirespeedatthecontactwiththerunwaysurface.Theslipratioisdefinedastheratiobetweenthebrakedandun-braked(zeroslip)wheelrotationspeedsinrevolutionsperminute(rpm).Themaximumpossiblefrictionforceisdependentmainlyontherunwaysurfacecondition,thewheelload,thespeedandthetirepressure.Themaximumfrictionforceoccursattheoptimumslipratiobeyondwhichthefrictiondecreases.Themaximumbrakingforceisdependentonthefrictionavailableaswellasthebrakingsystemcharacteristicsincludinganti-skidcapabilityandtorquecapability.Themaximumfrictioncoefficientμ_{max}canexceed0.6onagooddrysurface,whichmeansthatthebrakingforcecanrepresentmorethan60percentoftheloadonthebrakedwheel.Onadryrunway,speedhaslittleimpactonμ_{max}.Whentherunwaysurfaceconditionisdegradedbycontaminantssuchaswater,rubber, slush, snow, or ice, μ_{max}canbereduceddrastically,affectingthecapabilityoftheaircrafttodecelerateafterlandingorduringarejectedtakeoff.Generaleffectsofrunwaysurfaceconditionsonthebrakingfrictioncoefficientcanbebrieflysummarizedas follows:

2.3.1 Wetcondition(lessthan 3 mmwater)

FrictionCoefficientinwetconditionsismuchmoreaffectedby speed(decreasingwhenspeedincreases)incomparisonwithdryconditions.Atagroundspeedof100kts,μ_{max}onawetrunwaywithstandardtexturewillbetypicallybetween0.2and0.3,thisisroughlyhalfatalowspeedsuchas20kts.Onawetrunway,μ_{max}isalsodependentonrunwaytexture.Ahighermicrotexture(roughness)willdevelopthefriction.Ahighmacrotexture,porousfrictioncourse(PFC)orsurfacegroovingwillenhancedrainagebenefits;howeveritshouldbedepictedthattheaircraftstopping performancewillnotbethesimilarasonadryrunway.Conversely,runwayspolishedbyaircraftoperationsor contaminatedbyrubberdepositsorwheretextureisaffectedbyrubberdepositsafterrepeatedoperationscanbecomeveryslippery.Therefore,maintenancemustbeperformedperiodically.Thereareseveralmethodsofremovingrubberdepositfromrunwaysurface.Themostcommonproceduresincludeusingchemicalsolvent,applyingultrahighpressurewaterjet,mechanicalgrindingandshotblasting.Figure2.6showsthe ultrahigh pressurejet vehicleand its effectiveness in removing rubberfromrunway.

Figure 2.7(a):Before and after cleaning highpressureby water jet

Figure 2.7(b):Ultra water jetvehicle

Figure 2.7(c):Cleaning without highpressuredamagingsurface

Figure 2.7(d):Ultra water jet

2.3.2 Loose contaminants (standing water,slush, wet ordry snowabove3mm)

Thesecontaminantsdegradeμ_{max}tolevelswhichcouldbeexpectedtobelessthanhalfofthoseexperiencedonawetrunway.Microtexturehaslittleeffectintheseconditions.Snowresultsinafairlyconstantμ_{max}withvelocity,whileslushandstandingwaterexhibitasignificanteffectofvelocityonμ_{max}.Waterandslushcreatedynamicaquaplaningathighspeedsbecausetheyhaveafluidicbehaviour,aphenomenonwherethefluid’sdynamicpressureexceedsthetirepressureandforcesthefluidbetweenthetireandground,effectivelypreventingphysicalcontactbetweenthem.Figure2.7showsthephenomenonofaquaplaningonamovingwheel.Intheseconditions,thebrakingcapabilitydrops drastically,approaching/reaching nil.

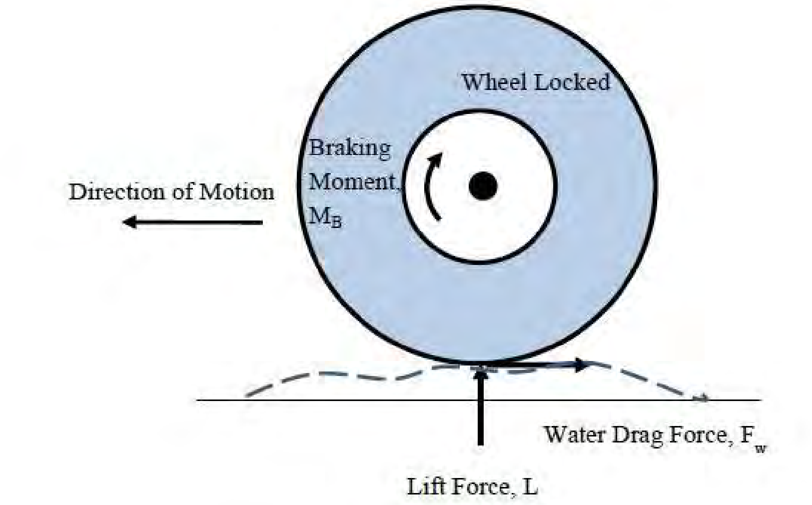


Figure 2.8:An Aquaplaning LandingGear Wheel onWetRunwayPavement.

2.2.3 Solidcontaminants(compacted snow, iceand rubber)

Thesecontaminantsaffectthedecelerationcapabilityofaircraftbyreducingμ_{max}duringlandingandrejectedtakingoff.Thesecontaminantshavenoeffectonacceleration.Compactedsnowmayexhibitquitegoodfrictioncharacteristics,perhapscomparingwithawetrunway.However,whenthesurfacetemperatureapproachesorexceeds0ºC,compactsnowwillbecomemoreslippery,potentiallyreachingaverylowμ_{max}.Thestoppingcapabilityonicecanvarydependingonthetemperatureandroughnessofthe surface.Generally,weticehasshowsvery lowfriction(μ_{max}droppingtoaslowas0.05)andwilltypicallypreventnormalaircraftoperations untilthefrictionlevelisimproved.However,icethatisnotmeltingmaystillallowoperations,albeitwithaperformancepenalty.

2.4 Reasons ofmeasurement of frictionofrunway

FlightSafetyisthemainreasonformeasuringfrictionofrunwaysurface.ithasbecomemoreimportanttocheckfrictioninabetterwaythanmakingskidtests.Scandinavia,particularlySweden,hastakenaconsiderablepartinthedevelopmentoffrictionmeasuringtechnique.Amongreasons forfrictionmeasurementsare:

- Determine frictioncharacteristics of runways underwinterconditions
- Verifyfrictioncharacteristics of new orresurfacedrunways
- Assess periodicallythe slipperiness ofpaved runwayswhen wet
- Assess the effect on frictionwhendrainage characteristicsarepoor
- Assessfriction of runwaysbecomingslipperyunder unusualconditions

2.4.1 Earlyreportingtechnique.

Theearlyreportingtechniquewasdevelopedinjointco-operationoftheAirportAuthorityatBrommaAirportandSAS.Thistookplaceintheearly1950. Thisledtoreportingfrictioncharacteristicsforthreepartsoftherunwayseeninthedirectionoflanding.SoonthethirdswerecalledA,B,andC.Aisalwayscalledthelownumberrunwayend.AnaeroplanelandingfromthehighnumberdirectiongotthereportonfrictionintheorderC,B,andA.SASanddomesticSwedishoperatorsunderstoodwhatthefrictionnumbersmeanttothem.However,operatorscomingintoe.g.Brommaairportdidnotunderstandwhatthereportednumbersmeant. Therefore,theexpressionsGood,Medium,andPoorwereintroduced.SASsentoutaquestionnaireaskingforinformationfrompilotsonhowtheyexperiencedinformationonbrakingaction,i.e.

friction,andalsooncontrollabilityincrosswind.About3000answersonthisquestionnaireswerereceived.Theanswersdemonstratedthatwhenafrictioncoefficientof0.40orabovehadbeenreportedtherewerenopronouncedproblemsonbrakingorcontrollabilityincrosswind. When 0.25 orlowerhad been reported the problems becamesevere.As aresult of this studyin Sweden was introduced the terminology:

Table 2.1 : Reporting of PavementSurface Condition

Good	0.40 andabove
Medium to Good	0.36 to 0.39
Medium	0.30 to 0.35
Medium to Poor	0.26 to 0.29
Poor	0.25 andbelow

Ascanbeseenfromtheaboverangeoffrictioncoefficients,weconsiderthatnomorethantwosignificantfiguresshouldbereported.More thantwofigureswouldgiveafalseimpression ofaccuracyof thefrictionmeasuring equipment.

2.5 Terminology

Micro texture

Microtextureisthe`finescaleroughness'contributedbysmallindividualaggregateparticleswhichisdetectablebytouchratherthanappearance.Itallowsthetiretobreakthroughtheresidualwaterfilmthatremainswhenthebulkofwaterhasrunoffandisespeciallyimportant at low speeds.

Macrotexture

Macrotextureis"visibleroughness"andallowswatertoescapefrombeneathaircrafttires.Itbecomesmoreimportantasthefactorswhichcanleadtoaquaplaningcomeintoplay-increasingspeed, decreasingtiretreaddepthandincreasingwaterdepth.

Aquaplanning

Aquaplaning or hydroplaning by the tires of a road vehicle aircraft occurs when a layer of water builds between the wheels of the vehicle and the road surface, leading to a loss of traction that prevents the vehicle from responding to control inputs.

Contaminant

A deposit (such as snow, slush, ice, standing water, mud, dust, sand, oil, and rubber) on an aerodrome pavement which is detrimental to the friction characteristics of the pavement surface.

Braking action

A term used by pilots to characterize the deceleration associated with the wheel braking effort and directional controllability of the aircraft.

Surface friction characteristics.

The physical, functional and operational features or attributes of friction that relates to the surface properties of the pavement that can be distinguished from each other.

Chapter3

SURFACEFRICTIONOFAIRPORTRUNWAY

3.1 General

InternationalAirTransportAssociation,IATA,arrangedaconferencein1952whereSASwasgiventheprospecttosignifytheScandinavianexperienceaboutknowingthefrictioncharacteristicsofarunwaysurfaceandtheproceduresformeasuringandreportingfrictioncharacteristicsatairports.Discussionsdealtonlywithoperationalmeasurementsastheinevitabilityformeasuringoffrictionalsoonwetrunwayshadnotyetbeendocumented.ThefindingsofthemeetingwasthatIATAformulatedthatthereisanoperationaldemandforconsistentandstandardizedinformationconcerningthefrictioncharacteristicsofice andsnowcoveredrunways.AtICAOfifthAerodromesandGroundAidsDivisionalmeeting,1952,AGA5,IATAforwardeditsconclusion.TheconclusionmadebyIATAwasestablishedandisstillfoundintheexistingvalideditionofICAOAnnex14,Aerodromes,July1995.TheICAOeffortondevelopmentofspecificationsonoperationalfrictionmeasurementsatairportsthatwascommencedattheAGA5thdivisionalmeeting1952hascontinuedovertheyearsandgradually leadtothe specifications now found in Annex14.

3.2 ICAOAnnex 14 regarding operationalsurface frictioncoefficient

TheintentofthesespecificationsistosatisfytheSNOWTAMandNOTAMpromulgationrequirements.Itisrecommendedthatwheneverarunwayisaffectedbysnow,snoworice,andithasnotbeenpossibletocleartheprecipitantcompletely,theconditionoftherunwayshouldbeassessed,andthefrictioncoefficientmeasured.Thereadingsofthefrictionmeasuringdeviceonsnow,slushorice-coveredsurfacesshouldadequatelycorrelatewiththereadingsofoneothersuchdevice.Theprimaryaimistomeasuresurfacefrictioninamannerthatisrelevanttothefrictionexperiencedbyan aircrafttire,therebyprovidingcorrelationbetweenthefrictionmeasuringdeviceandaircraft brakingperformance.

3.3 Accidents andIncidents Leading to NewRules

Anairtrafficaccidentinthe1970,atLosAngelesInternationalAirportconspicuouslydemonstratedthatthisaccidentwouldnothaveoccurred,ifasystemofperiodicalmeasurementsoffrictioncharacteristicsofrunwayswhenwethadbeeninuse.TheaccidentresultedincompletelossofaJumbo-jetDC-10.Theaccidentinvestigationshowedthatthetouchdownzonewasextremelyslipperyunderwet conditions.Theaccidentwouldnothaveoccurred,iftheunsatisfactoryfrictioncharacteristicshadbeenknownandcorrectivemeasurestaken.Ithappenedalsoalotofotheraccidentsandincidents,whereslipperinessofrunwayswhenwethadbeenaconducivefactor.Asimilaraircraftaccidenttookplaceonthe8thOctober,2004atOsmaniInternationalAirport.AF28aircraftofBangladesh Bimanskiddedofftherunwaywhilelandinginheavydownpourshown infigure 3.1.

Figure 3.1: AircraftAccidentat Osmani International Airport,Sylhet.

ICAOcommencedworkonincludingspecificationsrelatedtofrictionmeasurementsonrunwayswhenwetinAnnex14.FortheAGA8thDivisionalmeeting1981aspecial workinggroup,theRunwaySurfaceConditionStudyGroup,RSCSG,preparedproposals for material to be included inAnnex14.

3.4 Frictionmeasuringtechnique onwet runways

When studyingfrictionmeasuringtechniqueon runways whenwet, it wassoonobservedthatthemeasuringequipmenthadtomakeacontinuousmeasurementoffriction.Italsohadtohavecapabilityofselfwateringtherunway.Whendiscussingtheselfwateringcapabilitywithinthe ICAORSCSG,itwasarguedthatthisrequirementwasnotnecessary asinmostcountriesitrainssooftenthatartificialwateringwasnotnecessary.However,ifdependingonnaturalrainonewouldnotknowwhatisthewaterdepthduringthefrictionmeasurement.Thisargumentwasacceptedandself-wateringfeaturesbecameanagreedrequirement.

3.5 ICAOAnnex 14 RegardingSurface FrictionCoefficientMeasurements

- Dealswithfrictiononneworresurfacedrunways.Thefrictiontestshouldbemadeonacleansurface.Especiallyonnewsurfaces,orresurfacedrunways,anaerodromeoperatorshouldcarryoutadditionalfrictiontestingtoestablishfrictionreadingsduringadverseweatherconditionsandtoidentifythoseareasoftherunwaywherecontamination(i.e.water) maybuildupoverashortperiodoftime.Thisisofparticularimportancewherereprofiling oftherunway'slateral,longitudinalorsloping planeshasbeenaccomplishedaspartofanyrehabilitationproject.

- Drawsattentiontothefrictiononrunwaysduringwetconditionandshouldbecheckedperiodicallyinordertoidentifyrunwayshavingunsatisfactoryfrictioncharacteristics when wet.

- DepictsthatStatesshoulddefinewhatminimumfrictionlevelitconsidersacceptable.TheminimumfrictionvalueshouldbepublishedintheAeronautical

InformationPublication,AIP.WhenthefrictionfoundisbelowthisvalueaNOTAMshouldbeissuedandpilotsshouldbeinformedthattherunwaysurfacemaybeslipperywhen wet.Whenfrictionisbelowthislevelcorrectiveactionshouldbeinitiated.However,whenthefrictionlevelfoundisfoundtobebelowminimum levelcorrective action must be taken without delay.

- Providesguidelineson timeintervalofmeasurement.Frictionmeasurementsshouldbetakenatintervalsthatwillensureidentificationofrunwaysinneedofmaintenancebeforetheconditionbecomesserious,orthatthefrictionoftherunwaywhenwethasnotfallenbelowtheminimumfrictionlevelspecifiedbytheState.Thetimeintervalbetweenmeasurementswilldependonfactorssuchas:aircrafttypeandfrequencyofusage,climaticconditions,pavementtype,and pavementservice and maintenance requirements.Table 3.1 showsrecommendedmaximumintervalbetween runwaysurface friction assessments.

Table 3.1 RecommendedMaximumIntervalBetween Runway SurfaceFrictionAssessments.

Average number ofmovements ontheRunway per day	**MaximumInterval betweenAssessment**
Lessthan400	11 months
400 ormore	5 months

- Depictsabouttirecategoryofdifferentfrictionmeasuringvehicles.Differenttypesoffrictionmeasuringdeviceshavebeenshowninfigure3.2.Thetwofrictionmeasuringtiresmountedontheμ(mu)meterweresmoothtreadandhadaspecialrubbercompound,i.e.TypeA.ThesinglefrictionmeasuringtiresmountedontheSkiddometer,SurfaceFrictionTester,RunwayFrictionTesterandTatraweresmoothtreadandusedthesamerubbercompound,i.e.TypeB.

TheGriptesterhadasimilartirebutthesizewassmaller,i.e.TypeC.Table3.2shows the specifications of differentfriction testers.

Table 3.2: Specifications ofDifferent FrictionTesters.

TestEquipment	Tire Type	TirePressure(bar)	Testspeed (Km/h)	Water depth (mm)	Newsurface	Maintenance planning	Minimum frictionlevel
Mu-metertrailer	A	70	65	1.0	0.72	0.52	0.42
	A	70	95	1.0	0.66	0.38	0.36
Skiddometer Trailer	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.60	0.34
Surface Friction Tester	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
Runway Friction TesterVehicle	B	210	65	1.0	0.82	0.54	0.50
	B	210	95	1.0	0.74	0.54	0.41
TATRA Friction Tester Vehicle	B	210	65	1.0	0.76	0.54	0.48
	B	210	95	1.0	0.67	0.57	0.42
GRIPTESTER Trailer	C	140	65	1.0	0.74	0.57	0.48
	C	140	95	1.0	0.64	0.36	0.24

Lockedwheelsmooth/ribbed

Griptester (GT)

SkidWheelTesters

Dynamic FrictionTester

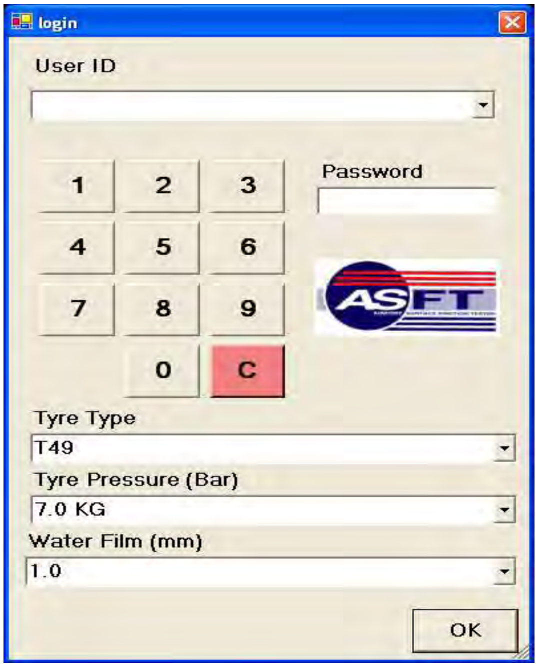
Figure 3.2: Differenttypes ofFrictionMeasuringDevices.

Chapter4

SURFACEFRICTIONMEASUREMENTFRAMEWORKBY ASFTTOOL

4.1 General

Whenthesystemstartsup,thedriverhastologinwithauniqueIDandapasswordasshowedinFigure4.1.Thetypeoftire,tirepressureandwaterfilmlevelshouldalsobeinputhere.Theseloginvaluesareusedasaconfirmationfromtheuserthatmeasuringvehicle hasbeencheckedfor the correct measuringtire andpressure.



Tyre Type: T49
Tyre Pressure (Bar): 7.0 KG
Water Film (mm): 1.0

Figure 4.1:UserID popup menu.

Therearefourlevelsofsecurityfortheusers:Measurer,Calibrator,ConfigurerandSuperuser.

- Measurer (MEAS),canmeasureand test calibration accuracy

- Calibrator(CALIB),has the samerights as measurerandcancalibrate thesystem.

- Configurer (RWY), has the samerights as measurerandcalibratorand can definerunways(measureobjects),deleterunways,andcanerasemeasurementsfromthesystem when doingbackups.

- Superuser (SUPER), service personnellevel with access to somefunctions forsystemdiagnose.

4.2 MainMenu(Measure tab)

Allinteractionwiththemeasuringsystemisdoneviathetouchscreenonthe PPCasshowed in Figure 4.2.

Runway Configuration TEST

Frict Meas conf:TEST date:10-12-07 07:41:27 RWY05

Run No.

Max 0 μ

Min 0 μ

Zone A Avg 0 μ

Zone B Avg 0 μ

Zone C Avg 0 μ

TOT Avg. 0 μ

Speed 0 km/h

Ice 0 %

Surface Temp Air Temp (C)

29.1 24.6

Dist 0

Status

Link Connected MPC Idle Server Connected GPS FIX

Wheel UNDEF

Water OFF

Figure 4.2: Mainmenu.

ThistabistheviewofthePPCthatisusedtooperatetheequipment.Fromthisviewthedriverwill start, stop andsupervise measuring.

Link

WhenthesystemisstartedandthePPChasestablishedaconnectionwiththeMPCthisstatusbox willoutput“Connected”andwillappearingreen,elseitwillread“ReadytoConnect” in red.

MPC

ThisboxdemonstratesthestatusoftheMPC,normallyifthesystemisnotmeasuringthis will demonstrates“Idle”on agreen background.

Server

ThisboxshowsthestatusoftheconnectiontotheASFTMeasureServer,itcouldbeconnected(greencolour)ornotconnected(redcolour).ToconnecttotheASFTserverthis requires anInternetconnection,throughGPRS, WIFIorother.

GPS

ThisboxtellsthedriveriftheGPSantennahaspickedupthepositionofthevehicle.This is then displayed inwhite with thetext “Fix”.

Wheel /Water status

WhenthesystemisstartedtheMPCsendstheactualstatusofthewheel(undefined,up,down orpumping)and the water (on oroff).

MeasureGraph

Friction,airtemperature,surfacetemperatureandspeedwillappearhereasthreeseparategraphs(thetemperatureswillbecombinedintoonegraph)inrealtimeasameasureis performed.

Send Email

Thisbuttonwillsendallmeasurefilesandpdfreportsthathasnotpreviouslybeensent,to two predefinedemailaddresses.

Messagearea

Variousmessagesfromthe system will end up here, it can bee.g. WaterTankEmpty.

Run No

Shows the current run number,useful if the equipment is used for multi runs.

Max, Min

Shows the maximum/minimumfriction value forthe currentmeasure.

Zone A Avg, ZoneB Avg, ZoneC, TOT Avg.

Shows the average frictionforA,B, C zone and the total average of the currentmeasure.

Speed

Shows the current speedofthe vehicle.

Ice

Showstherunwayicepercentageofthecurrentmeasure(whatisregardedasiceisconfigured forthe runwayin the Configuration tab)

Surface Temp/Air Temp(C)

Shows the currenttemperaturefor airandsurfaceif there is a temperature sensorinstalled.

Dist

Shows actualdistance measured.

Friction

Bar showingthe currentfrictionvaluegraphicallyin color codedsquares.

Start

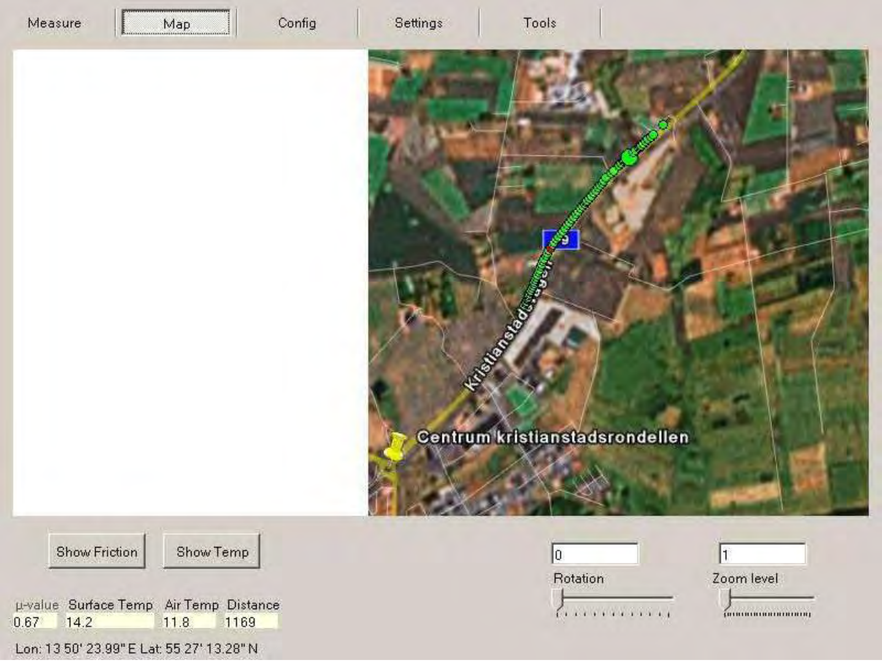
ThisbuttonstartsameasureaccordingtothecurrentsettingsinConfigtab.Whenthesystemisstartedthemeasuringwheelwillbeloweredandaninstructionwindowwilltell theuserwhat to do.

Cancel

This button will cancel an ongoingmeasurewhentheuserfor anyreasonwants tostopit.

4.3 MapMenu(Map tab)

ThismenuwillonlybeavailablewhentheGPSantennaisconnected.WhentheGPSantennaisconnectedandamapfortheareaisloaded,everypointoffrictionisplottedon the mapas the measureis conducted. Themeasuredtemperatureis alsoplotted hereifa temperaturedeviceis connectasshowed inFigure4.3.



µ-value	Surface Temp	Air Temp	Distance
0.67	14.2	11.8	1169

Lon: 13 50' 23.99" E Lat: 55 27' 13.28" N

Rotation: 0

Zoom level: 1

Figure 4.3: MapMenu(Map tab).

Map

Thistabshowsthemapoftheareathatismeasured(configuredbyASFTpersonnel,inThesettings file).AllmeasurevalueswillbepresentedhereasrounddotsiftheGPS antennaisengagedduringthemeasure.Thefrictionwillbeindicatedhereasred,yellowor green dotsaccordingto the levelsthat are configured in the system.

Show friction

Ifthetemperaturevaluesarecurrentlyvisibleinthemapareathisbuttonwillswitchtofrictionvalues.

Show temperature

Ifthefrictionvaluesarecurrentlyvisibletheviewwillchangetoshowthetemperaturevalues.

Single dot data

Whenasinglemeasuredvalueisselected,thedataforthatpositionisdisplayedinthelowerpartofthescreen.Thefriction,surfaceandairandtemperature,speed anddistance fromorigin is displayed here together with the positions latitudeandlongitude.

Rotationandmagnificationof map

Thesliders in the bottom of theview controls therotationangle and zoom level of themap.

4.4 4 Configurationmenu (Config Tab)

Thistabisusedforconfigurationofmeasuringobjectse.g.runwaysorroadfragments.Herearealsoutilitiesfortechnicianstocheckdifferentpartsofthesystemasshowedinfigure4.4.

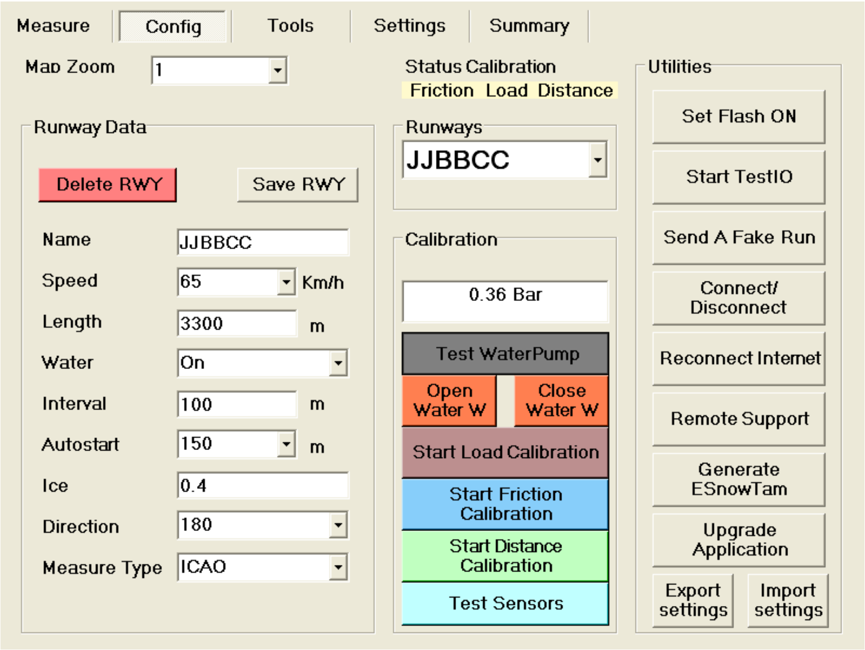
Runway DataGroup

Name

All runwayshaveauser chosen namethat is defined in this text field

Speed

Thisisthecruisespeedfortheconfiguredrunway.Whenthisspeedhasbeenameasure,a signalwill sound so that the driverwill know that thecruisingspeed has beenreached.



Map Zoom: 1

Name: JJBBCC

Speed: 65 Km/h

Length: 3300 m

Water: On

Interval: 100 m

Autostart: 150 m

Ice: 0.4

Direction: 180

Measure Type: ICAO

Runways: JJBBCC

Calibration: 0.36 Bar

Figure 4.4:Configurationmenu (Config Tab).

Length

Thisisthelengthofthedistancetobemeasuredinmeters.Itisnotedthatthisisnotthecompletelength oftherunway/road,onlythepartis to bemeasured.Distanceforaccelerationand breakingshould beallowed.

Water

This configuration tells if watershall beengaged duringthe measuring, On,Off, Auto.

Interval

This configuration tells on whatdistance theaverage of thefrictionvalue iscalculatedin thetools datatableview.

Autostart

This configures the length in meters that thevehicle should move before the actualmeasuringstarts. (0 =Manual start)

Ice level

This tellswhatfrictionlevelthat will be consideredasice, usedin themeasuretab.

Direction

Thistellswhatdirectionthemeasuringstartsin,thisparameterdetermineswheretheAB andCzonesareregardedtobe,TheAzoneisalwaysconsideredtobe inthedirectionwherethe degree valueis below 180 degrees.

Measure Type

This configures what typeof measure to do, normal maintenance measuresareofICAOtype.

Save / Delete RWYbutton

ItisthebuttontosavetheRunwaydatatofile.Whenanewrunwayisconfigured,pressthisbuttonandthedataissavedandreadytouse.Iftheuserwantstodeletearunway,hecanchoosetherunwaytobedeletedfromthedrop-downlistandpress“DeleteRWY”.

Runways

Drop-down list providesan option to chooseandopen a predefinedrunwaydata file.

Default Map Zoom

This configures the startup map zoom level.

Calibrationstatus

These labels indicatethecalibrationstatus. A red label indicatesthat thecalibrationforthat functionhas notbeenperformed.

Water Pressure

This shows current water pressurewhen measuring. This window is usedforsettingthe pressurewhen not usingtheelectrical watering system.

Test Pump button

Theusercanstarttheelectricpumpbypressingthisforafewsecondstotestthatitisworkingproperly.Whenusing thiswateringsystemtheuserdon'tneedtocalibrate.Theusercansetthewaterfilmduringlogging andthenconfigurethewatertoAuto.Thepressurewill beautomaticallyadjusted.

Open / Close WaterValve

During ameasure,the user can usethesebuttons to set the pressure when not usingtheelectricalwateringsystem.

Start Load Calibration

This starts the calibrationof theload cell.

Start FrictionCalibration

This starts the calibrationof thefriction cell.

Start Distance Calibration

This starts the calibrationof thedistance.

Check Calibration

TheCheckCalibrationbuttonistotestiftheloadandfrictioncalibrationwasperformedcorrectlyandalsogives thepossibilityto seeif thepulse transmitter(distance) works.

Special buttons

Theonlybuttonavailableforregularusersisthe“RemoteSupport”button.Thisisusedtomake ASFTservicepersonnelabletohelpwithproblemsviaInternet.ThisispossibleonlyonequipmentwithaconnectiontoInternete.g.aGPRSmodemoralinktoawirelessnetwork(WIFI).

Set FlashOn

This is used to set the flashinglight on ifyou havea trailer(T5 or T10).

Start TestIO

This is used byauthorized servicepersonnel to check the system.

Send A Fake Run

ThissendsmeasurementstotheASFTservertocheckthattheconnectionisworkingproperly.Itis neededtopressthebuttonasecondtimetostopthesendingofmeasurevalues.

Connect/Disconnect

This createsa newloginto the server.

Reconnect Internet

Thisisusedonlyforoldermodemswhereitdisconnectsandthenreconnectswithuserandpassword authentication.

Remote Support

Thisstartsaremotesupportprogram,TeamViewer,inanewwindow.ThisrequiresaccesstoInternet(Option).TheusercangetanIDandpasswordthatASFTneedtoconnect to PPC. From this connectionASFTcan support PPC aswellasMPC.

GenerateSnowtam

This starts a viewwhere the user can createaSNOWTAM report. Measured valueswillbeautomaticallyfilled. This reportcan then besent bye-mail.

UpgradeApplication

Iftheuserchoosestoupgradeapplicationwithe.g.SnowtamorExternalapplications,this is usedto transfer thesoftware to PPC.

Export Settings

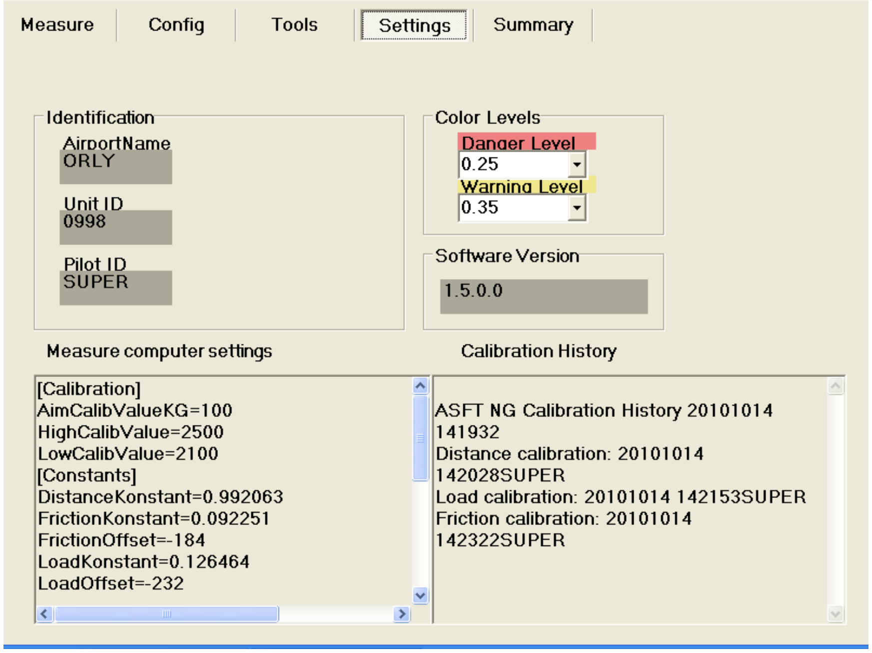
It'srecommendedtousethistomakeasecuritybackupofsystemfiles.Thiswillcopyyourrunways,settings,ports,users,mapsandothersystemfilestobeabletorecreateyour system.Theywill all be saved to a USBmemorystick.

ImportSettings

This is used to import allyour system settings.

4.5 5 Settingsmenu(Settings Tab)

Thistabisusedforthesettingsasshowedinfigure4.5.Theonlyvaluestheusercansetarethewarninganddangerlevels.Otherwisethistabisonlyforshowingthesettingsofthe system.



AirportName
ORLY

Unit ID
0998

Pilot ID
SUPER

Danger Level
0.25

Warning Level
0.35

Software Version
1.5.0.0

```
[Calibration]
AimCalibValueKG=100
HighCalibValue=2500
LowCalibValue=2100
[Constants]
DistanceKonstant=0.992063
FrictionKonstant=0.092251
FrictionOffset=-184
LoadKonstant=0.126464
LoadOffset=-232
```

```
ASFT NG Calibration History 20101014
141932
Distance calibration: 20101014
142028SUPER
Load calibration: 20101014 142153SUPER
Friction calibration: 20101014
142322SUPER
```

Figure 4.5: Settingsmenu(Settings Tab)

Airport Name

Shows the airport nameforthe equipment asdefined in the settings file.

Unit ID

TheUniqueIDforequipment.TheSFTNumberisdefinedinthesettingsfileaswellasimprinted in the vehicle.

Pilot ID

This shows theID ofthepersonlogged in.

Color Levels

Shows the threshold friction valuesforthe warninganddangerlevel in thesystem.

SoftwareVersion

Thesoftware revision ofthe PPC is displayed here.

Measure ComputerSettings

Thisareadisplaysthesettings,calibrationandsoftwarerevisionvaluesforthemeasurecomputer, this can beused fortroubleshootingissues.

Calibration History

Thisareadisplaysthecalibrationhistory.Dateandtime,userIDandtypeofcalibrationdoneis displayedhere.

4.6 6 Tools Menu(ToolsTab)

Thetoolsmenuisatabwhereitispossibletoloadoldmeasurementsforexaminationasshowed in figure 4.6.It is also possible to viewthe data in tabular format and do backupsto memorystick.

Run No

Thisshowswhichrunthatisdisplayedinthedataareaandgivesthepossibilitytochange run to view.

Run Data

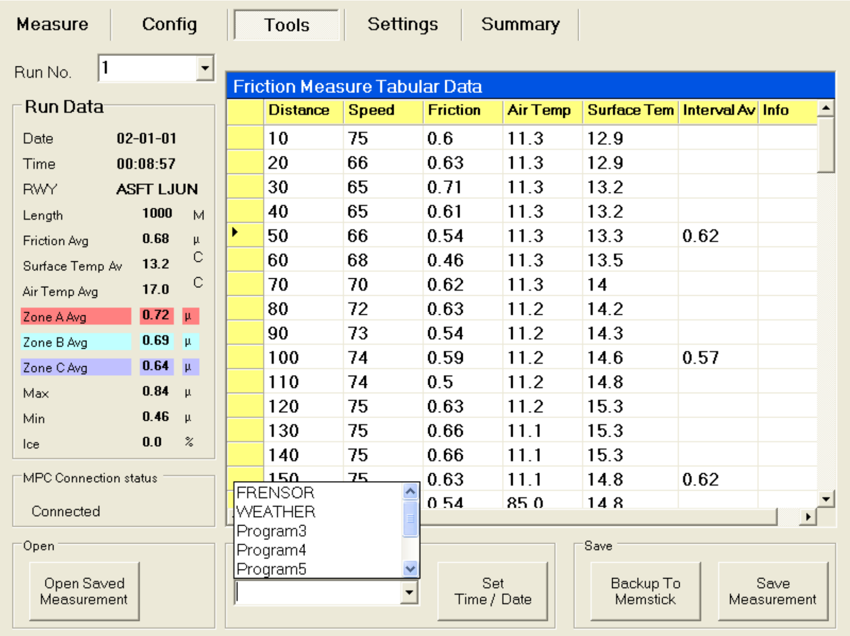
This shows acollectionofdatafrom therunwayand the displayedrun.

Friction Measure Tabular Data

Thisshowsthecurrentmeasurementdataintabularformat.Aclickintheaveragecolumn will recalculate averageswith the distanceof that rowas base

MPC Connectionstatus

This button shows the currentstatus of the MPC.



Run No. 1

Run Data

Date 02-01-01
Time 00:08:57
RWY ASFT LJUN
Length 1000 M
Friction Avg 0.68 µ
Surface Temp Av 13.2 C
Air Temp Avg 17.0 C
Zone A Avg 0.72 µ
Zone B Avg 0.69 µ
Zone C Avg 0.64 µ
Max 0.84 µ
Min 0.46 µ
Ice 0.0 %

MPC Connection status

Connected

Friction Measure Tabular Data

Distance	Speed	Friction	Air Temp	Surface Tem	Interval Av	Info
10	75	0.6	11.3	12.9		
20	66	0.63	11.3	12.9		
30	65	0.71	11.3	13.2		
40	65	0.61	11.3	13.2		
50	66	0.54	11.3	13.3	0.62	
60	68	0.46	11.3	13.5		
70	70	0.62	11.3	14		
80	72	0.63	11.2	14.2		
90	73	0.54	11.2	14.3		
100	74	0.59	11.2	14.6	0.57	
110	74	0.5	11.2	14.8		
120	75	0.63	11.2	15.3		
130	75	0.66	11.1	15.3		
140	75	0.66	11.1	15.3		
150	75	0.63	11.1	14.8	0.62	
		0.54	85.0	14.8		

Figure 4.6:Tools Menu(Tools Tab)

OpenSavedMeasurement

This is the button to openan old, previouslysavedmeasurement with.

External Application

This gives the possibilityto open anotherapplication.

Open / Print PDF Report

This opens aAdobePDF readerwindow where theusercan report in thecar.

Backup To Memstick

Backupofall measuredata to aUSBmemorystick.

Save Measurementbutton

Saves the currentmeasurement.

4.7 Start up the system

Fromthetimethatthesystemisstartedittakesoneminutebeforethesystemisreadytomeasure,soit’sagoodideatostartthesystemassoonasthecarengineisstarted.Thesystem is readyto measure when the status of theLink and MPC shows uplikethis.

Trailer(T5, T10)

OnthetrailertheuserhastostartthePPCandMPCindependently,itdoesn’tmatterwhatunitisstartedfirstaslong asbothsystemsarestarted.The startbuttonfor theMPCisplacedintheTrailer,settheswitchto1.ThePPCisstartedwiththepowerbuttononthe bottom of thescreen.

Car

Thecarhasoneswitchthatstartsthewholesystem.It'splacedinthecar'scenterconsole.

4.8 8 Shut downthe system

Trailer(T5, T10)

Whentheswitchinthetrailerissetto0thesystemwillshutdownin~30seconds.When the systemhas shut downyou need to turnoff thepower to thePPC.

Car

Thesameswitchasisusedtostartthesystemisusedtoturnthesystemoff,nootheractioniscalledfor,thesystemhastobeoffminimumtwominutesbeforeitsisreadytobe startedagain thepower.

4.9 9 Calibrationofthe system

Thesystemhastobecalibratedbeforeitcanbeused.Itisofbigimportancethatthisisdonewithaccuracy,anincorrectlycalibratedsystemwillnevergiveanytrustworthyresults.

ScalesFloor scale

Thefloormountedscalecanbeusedwithapowercord(usablefor100–240V)orthreeLR14batteries.

Top mounted scale

ThisscaleusesthreeAAbatteries.Bothscalesshouldturnoffautomaticallyafterafewmoments.

Calibrationofvertical load cell(red lane)

Itisimportantthatvehiclehasthesameweightthroughouttheentirecalibrationprocess.Thismeansthattheusercannotfillthewater-tankwhilstcalibratingnorcanusersalternate between sitting in thecaror being on theoutside.It'srecommendedto have twousersdoingthecalibration,onereadingthescaleandoneoperatingthePPC,oroneuserbeing on the outsideof thecarat all times, the userhas to lean inand operatethe PPC.

Calibrationof water pressure (orange lane)

Calibrationofwaterpressureisonlyintendedforselfwateringsystems.Theactualpressureispresentedinthepressuredisplay.Thisdisplayisintheconfigmodejustaboveopen/closewatervalvebuttons.Thecalibrationhastobeperformedinthedesiredspeedtousewhenmeasuring.Forsafetyreasonsit'srecommendedtobetwooperators,onetocalibrateandonetodriveandholdthespeed.Itisahazardtokeeptrackofthecar,speed,pressureandoperationsimultaneously.Thepressureshouldbeadjustedaccordingto this table 4.1.

Table 4.1: Pressure Adjustment Table

Filmthickness	Pressure (Bar)	Speed
1 mm	0.20	65 Km/h
1 mm	0.42	96 Km/h
0.5 mm	0.10	65 Km/h
0 .5 mm	0.21	96 Km/h

4.10 0 Datatransfer systeminASFT

AllfrictiondataiscreatedintheMeasureComputer(1)sentviaBluetoothtothePresentation/ControllerComputer(2)whereitispermanentlystoredandrelayed(3)totheMeasureDatabase(4)whereeverysinglemeasurepointisbackedupandforwardedtoany clientthatisauthorizedtoviewitinrealtimeorlater(5,6,7)asshowedinfigure4.7.

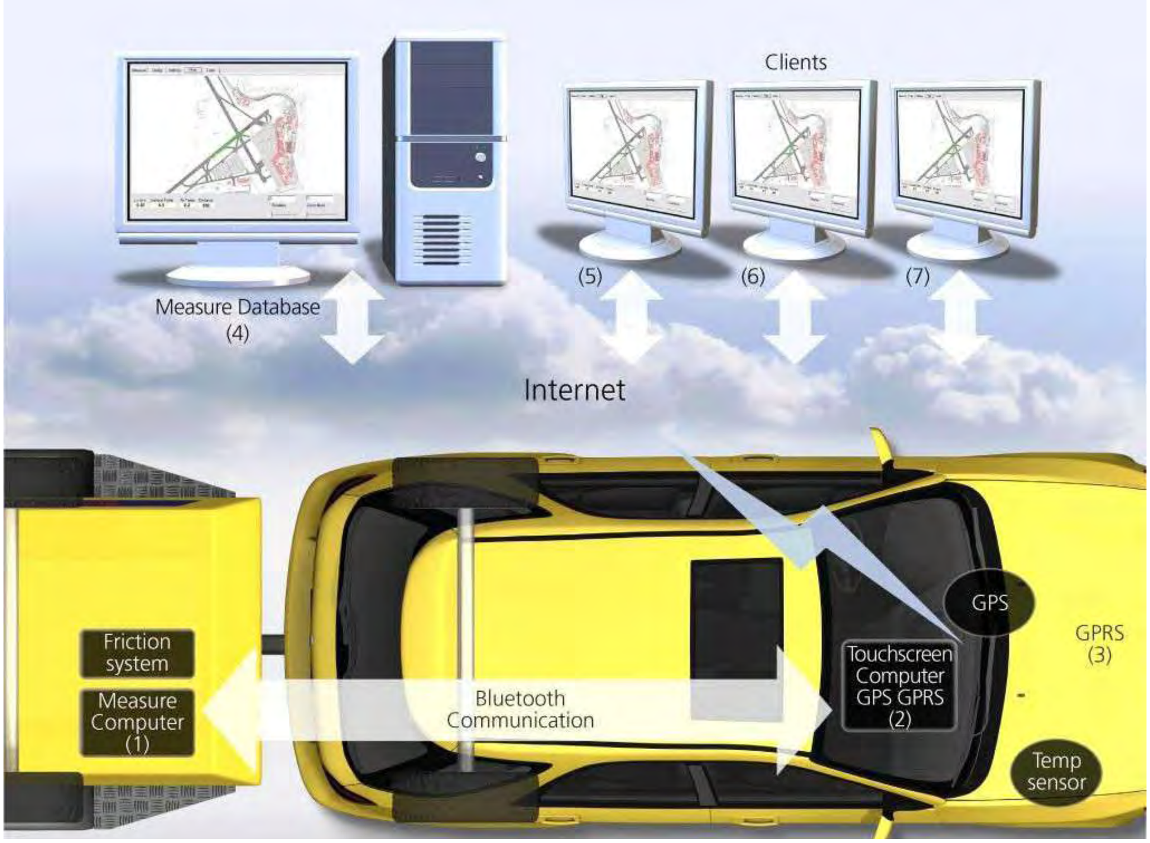


Figure 4.7: Technique of DataTransfer SysteminASFT.

CHAPTER5

RUNWAYSURFACEFRICTIONDATACOLLECTIONAND ANALYSIS

5.1 Background

ShahAmanatInternationalAirportisthesecondlargestinternationalairportofBangladeshsituatedinthesoutheasternportcityofChittagong.AnaerialviewofShahAmanatInternationalAirporthasbeenshowninfigure5.1.TheairportislocatedinthePatengaareaofthecity,20kilometres(13mile11NM)westfromthecity'smaincommercialhub,GECCircleand18.5kmsouthofthecity'srailwaystationonthenorthbank oftheKarnaphuli River.It is thesecondlargestairport inBangladeshoperatedandmaintainedbytheCivilAviationAuthorityofBangladesh.ItisalsousedbytheBangladesh AirForce.

Figure 5.1: Aerial Viewof ShahAmanat International Airport,Chittagong.

ItwasformerlyknownasMAHannanInternationalAirport,namedafterAwamiLeaguepoliticianM.A.Hannan,butwasrenamedon2April2005bythegovernmentofBangladesh,afteran islamicsaint Hazrat Shah Amanat.

5.2 BriefHistory ofShahAmanat International Airport

Theairfieldwasbuiltintheearly1940sduringtheBritishreign.KnownasChittagongAirfieldduringWorldWarII,theairportwasusedasacombatairfield,aswellasasupplypointandphotographicreconnaissancebasebytheUnitedStatesArmyAirForcesTenthAirForceduringtheBurmaCampaign1944-1945.ItofficiallybecameaBangladeshiairportin1972afterBangladesh'sliberationwar.Atfirst, itwasmainlyusedforconnectingDhakaandChittagong,butinthemid-1990sBimanstartedinternationalflightstoDubaiandafewSaudiArabiancitiesandtheairportofficiallybecameaninternationalairport.InMarch1998,amajorrenovationandexpansionbeganat theairport,whichendedinDecember2000.CAABreceivedfinancialassistancefromtheJapanInternationalCooperationAgencyfortheUS$51.57millionupgrade.Theprojectwascarriedout byJapanesefirmsShimizu&Marubeni.Theupgradationprojectmodernizedtheterminalwithnewandbetterseats,morecheck-incounters,betteraviationsecurityequipmentandotherfacilities.TheAirTrafficControltower alsoreceivednewhi-techequipmentsuchas3DRADARs.Therunway,taxiwaysandtheapronwereexpandedandimproved.Aftertheupgrade,aircraftsuchastheBoeing747-400ortheAirbusA340canlandeasilyattheairport.In2010sEmiratesSkyCargolaunchedcargoservicesin2013,makingitthefirstscheduledcargoairlineintheairport.BesidestheseseveralairlinesarehighlyinterestedforoperatingCargoflightfrom this airport.

5.3 General Description ofShahAmanat International Airport

ShahAmanatInternationalAirport,isaninternationalairportservingBangladesh'ssoutheastern portcityofChittagongasshowninfigure5.2.Operatedandmaintainedbythe Civil AviationAuthorityof Bangladesh,it is the secondlargestairportin

Bangladesh.ShahAmanatInternationalAirport,locatedinChittagonghassinglerunway,which is9646feet(2940metres)long.Thegeographiccoordinatesofthisairportare22degrees,14minutes,59secondsnorth(22.249611)and91degrees,48 minutes,48secondseast(91.813286).ShahAmanatInternationalAirportis12feet(4 m)abovesealevel.Theairportiscapableofannuallyhandling1.5millionpassengersand6,000tonsofcargo.TheairportisreferredtobytheInternationalAirTransportAssociation(IATA)usingtheairportcodeCGP.TheInternationalCivilAviationOrganization(ICAO) uses VGEGwhenreferringtoShahAmanatInternationalAirport.

(a) Terminal

Theairport'ssole220,000squarefeet(20,000m^2)Passengerterminalisdividedintotwoparts:InternationalandDomesticwithaboardingbridgeineach.TheInternationalpartoftheterminalislargerthantheDomesticoneduetohighernumberofpassengers.Thebuildingisalsodividedintotwofloors:Thelowerfloorisusedforcheckingin,boardingorgettingoffsmallplanesandreceivingluggagewhiletheupperfloorisusedforboardingorgettingoff large planes only. Theairport also has only29,063squarefeet (2,700 m^2) cargoterminal without CargoAircraftParkingApron.

(b) Control Tower

Theairport'sairtrafficcontroltoweris50meterswestoftheairportterminal.Ithasaclearviewoftheapronandtaxiwaysbutisfarfromtherunway.Heavyrainorfogcanmakeit difficult for controllers to observeplanes takingoff orlanding.

(c) Runway

Theairporthasasinglerunway(05/23),whichis2,940m×45 m(9,646ft×148 ft)asshowninfigure5.2.ThelargestaircraftthatcanlandintheairportisaBoeing777-300ER.

Figure 5.2:Runway ofShah Amanat International Airport,Chittagong.

(d) Taxiways andApron

Theairporthastwotaxiways,AlphaandBravo,thatdirectlyleadstotheapronoraircraftparkingzone,fromtherunway.Theaproncanaccommodateamaximumoffouraircraft;twowide-bodyBoeing747-400s,awide-bodyMcDonnellDouglasDC-10andanarrow-bodyAirbusA320canbeparkedthereatonce.Theairporthastwoboardingbridgesandtwopassengersteps.TheparkingpointsareusuallyemptyasmostoftheplanesthatarrivetheretakeoffsoonafterandtheplanesoflocalairlinesaregenerallyparkedatShahjalalInternationalAirportovernight.Asmallcivilplane hangarbelongingtoBangladeshBimanisavailablebutisrarelyused.TheBangladeshMilitaryhasaparking zone and two plane hangarseastof therunway. TheBangladesh Air Force storesa few planes here whichhave directaccess to therunway.

Figure 5.3:AirsideViewof ShahAmanat InternationalAirport(SAIA).

(e)) Aerodromes

Theairporthastwolongitudinalcanalsparalleltotherunwayoneitherside.Thesidestripatthebothsideoftherunwayis150mx2940masperICAOstandardforaninternationalairport.Thestripsareproperlygradedandmaintainedasperaerodromemaintenancemanual.Theairporthastheprovisionofparalleltaxiwaystoenhancethecapacityin future.

5. 4 DataCollection

ShahAmanatInternationalairport,Chittagonghasasinglerunwaywhichismadeofasphaltconcrete.Thelocationofairporthasbeenshowninfigure5.4.Thenorthernendofthisrunwayisdesignatedas RWY23andthesouthernendisdesignatedasRWY

05.SurfacefrictionoftherunwayhasbeenmeasuredbyASFTcarfollowingtherulesandregulationsratifiedby International Civil Aviation Organization.ThetiretypewasselectedT520whichismadeofnaturalrubberandhasahighairpressure(7baror100psi)asshowninfigure5.5.It'saribbedtirewiththreegroovesandsimilartoaircrafttire.Thesystemshouldbecalibratedbeforeitisbeused.Itisofbigimportancethatthisisdonewithaccuracy,anincorrectlycalibratedsystemwillnevergiveanytrustworthyresults.Calibration offriction,loadanddistancewere

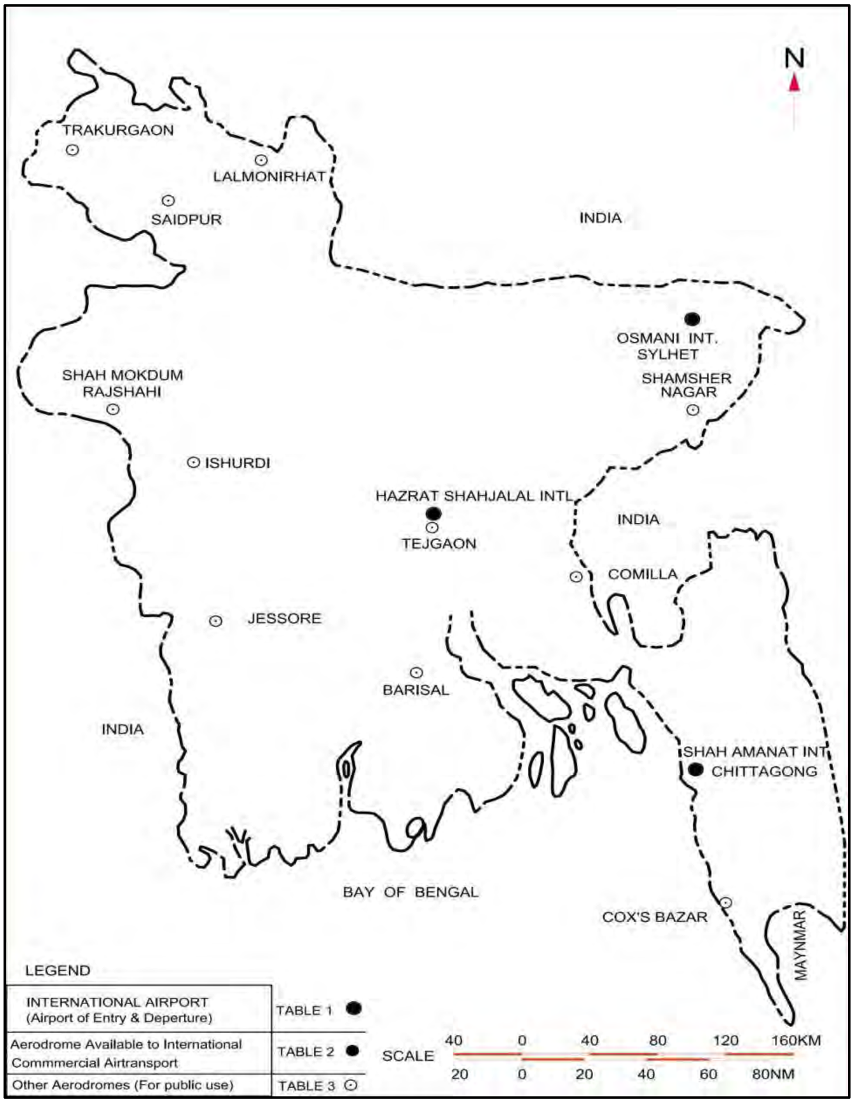


Figure 5.4: LocationMapofShahAmanat International Airport(SAIA).

accomplishedaccordingtoASFTmanuals.Thewaterpressurewasalsocalibratedbecause it is significant forselfwateringfrictionmeasuringdevice.

Figure 5.5: Tiretype T520.

Frictioncoefficientvaluewastakenfromasinglerunofthecarfromoneendtotheanotherendoftherunwaymaintainingtheproceduresof ASFTcompanywhichisalsoapprovedbyICAObyCAABteam as shown in figure 5.6.

Figure 5.6: RunwaySurfaceFrictionMeasurement TeamofCAAB

ThespeedofthefrictionmeasuringcarwasspecifiedbytheASFTandICAO.Themeasureddatahavebeentabulatedinthefollowingtablesandppcgeneratedgraphshave been illustrated in the following figures.

Table 5.1: FrictionMeasure Report 1.

Configuration	RWY05	TireType	T520
Dateand Time	15-03-14 12:21:44	WaterFilm	ON
Type	ICAO	Average Speed	100km/hr
Equipment	SFT0746		
Pilot	Parimal		
IceLevel	0.25		
RunwayLength	2500		
Location	CHITTAGONG		

Table 5.2: ResultSummary offirst measurement.

Runway	Fric. A	Fric.B	Fric. C	Fric.Max	Fric.Min	Fric avg	Ice
RWY05	0.52 µ	0.65 µ	0.68 µ	0.76 µ	0.29µ	0.62µ	0.00%
RWY23	0.54 µ	0.68 µ	0.69 µ	0.80 µ	0.30 µ	0.64 µ	0.00%

Table 5.3: RunwayFrictionCoefficientfromfirstmeasurement.

RW	Fric. A	Fric.B	Fric. C	Fric.Max	Fric.Min	Fric avg	Ice
All	0.53	0.67	0.69	0.80	0.29	0.63	0.00%

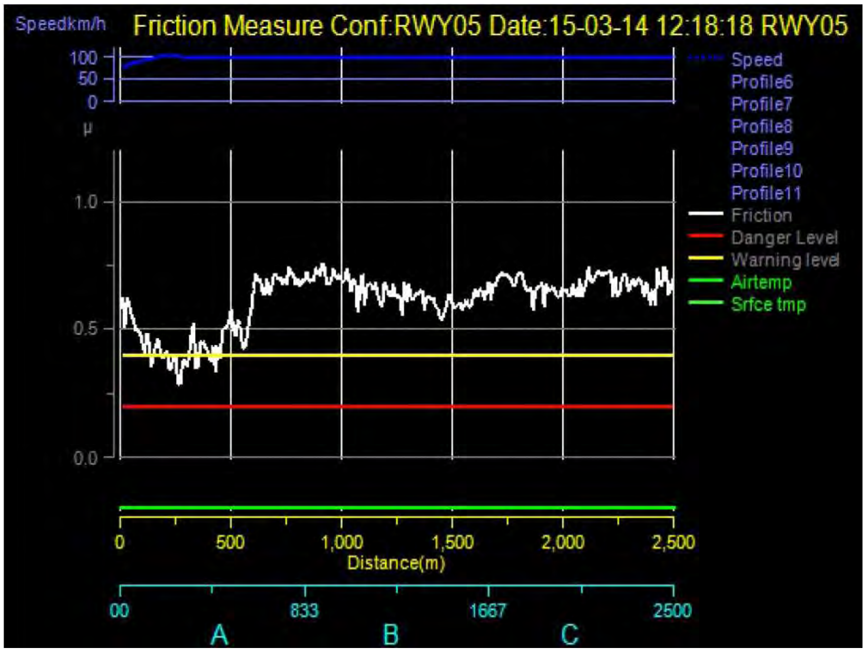


Figure 5.7:FrictionMeasurementGraph from RWY05to RWY23.

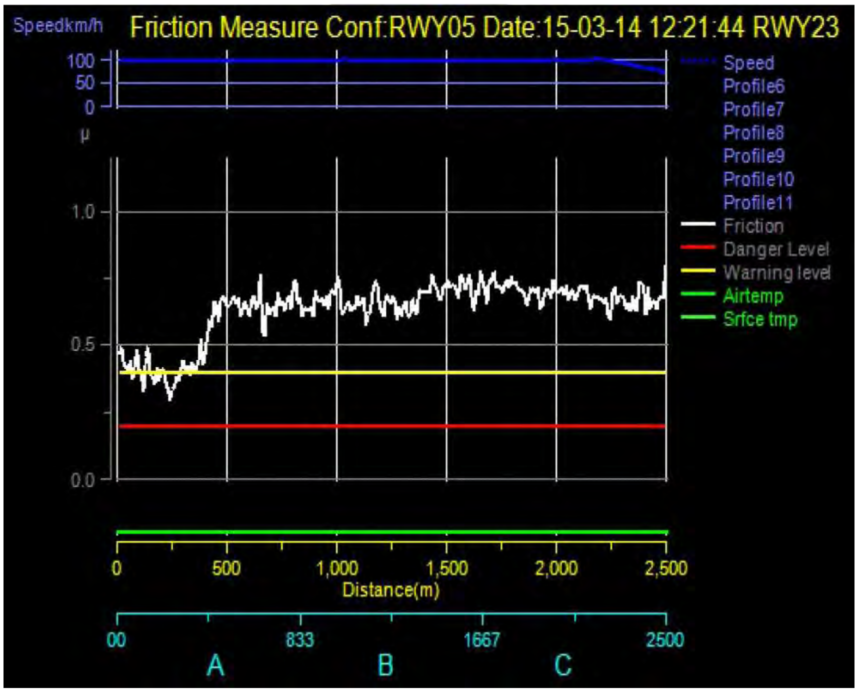


Figure 5.8:FrictionMeasurementGraph from RWY23 toRWY05.

Table 5.4: FrictionMeasure Report 2.

Configuration	RWY05	TireType	T520
Dateand Time	15-03-14 12:41:58	WaterFilm	ON
Type	ICAO	Average Speed	98km/hr
Equipment	SFT0746		
Pilot	Parimal		
IceLevel	0.25		
RunwayLength	2500		
Location	CHITTAGONG		

Table 5.5: ResultSummary ofsecondmeasurement.

Runway	Fric. A	Fric.B	Fric. C	Fric. Max	Fric.Min	Fricavg	Ice
RWY05	0.51 µ	0.63 µ	0.68 µ	0.76 µ	0.28µ	0.61µ	0.00%
RWY23	0.51 µ	0.67 µ	0.69 µ	0.85 µ	0.27 µ	0.62 µ	0.00%

Table 5.6: RunwayFrictionCoefficientfromsecond measurement.

RW	Fric. A	Fric.B	Fric. C	Fric.Max	Fric.Min	Fric avg	Ice
All	0.51	0.65	0.69	0.85	0.27	0.61	0.00%

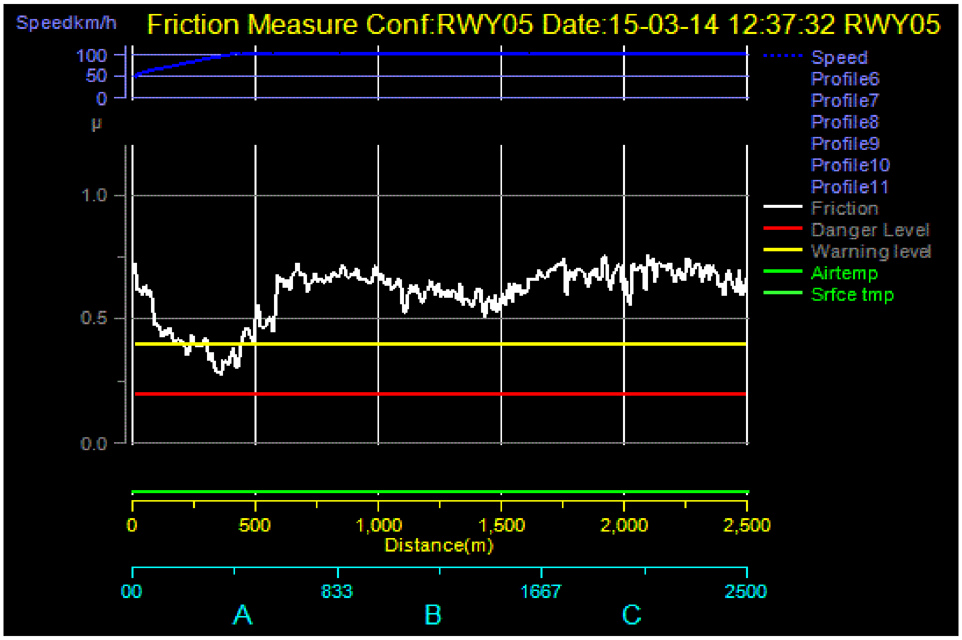


Figure 5.9:FrictionMeasurementGraph from RWY05 toRWY23.

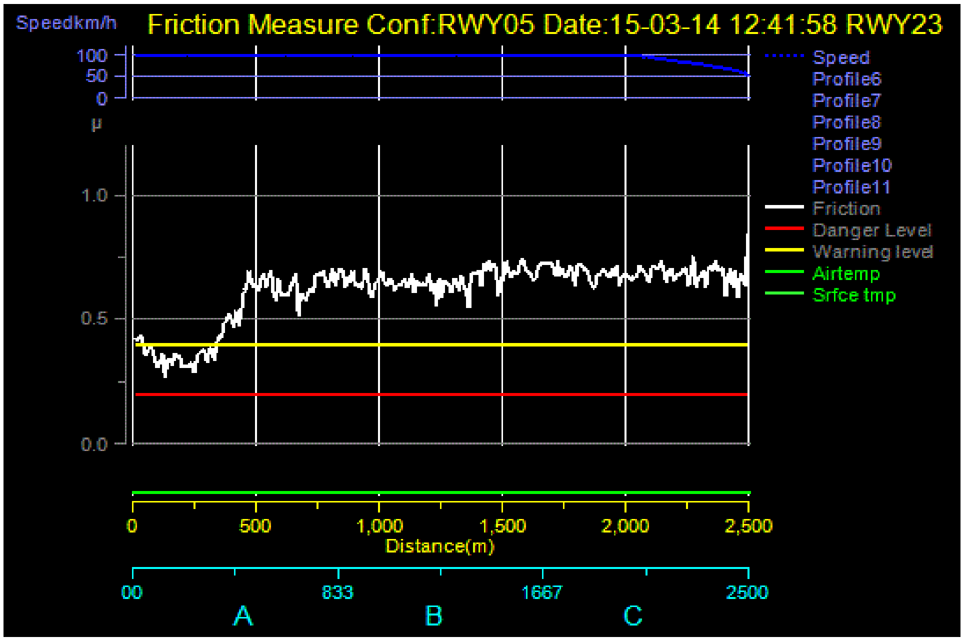


Figure 5.10:FrictionMeasurementGraph from RWY05 toRWY23.

5.5 5 Reporting of aircraftmovement surface condition

Aaircraftmovementsurface condition reportcan be presentedbyafriction coefficientnumberalongwitha surfacedescriptionand otherrelevantinformation.Typicallyduringpreflightplanning,aNOTAMisavailable.Onceairborne,thecrewgetsinformationthroughtheATIS(AutomaticTerminalInformationService)andwithrapidlychangingconditions,verbalupdates are usuallyavailablethrough the tower.

5.6 6 Development of RunwaySurface Friction Coefficient PredictingModel

RunwaysurfacefrictioncoefficientpredictingmodelwillbedevelopedapplyingMultipleLinearRegressionAnalysisTechnique.Multipleregressionisalogicalextensionoftheprinciplesofsimplelinearregressiontosituationsinwhichthereareseveralpredictorvariables.Forinstanceifwehavetwopredictorvariables,X_1andX_2,then the form of the model isgivenby:

$Y = b_0 + b_1X_1 + b_1X_2 + \ . \ \varepsilon$. . . . .(5.1)

whichcomprisesadeterministiccomponentinvolvingthethreeregressioncoefficients(b_0,$b_1$andb_2)andarandomcomponentinvolvingtheresidual(error)term,.Theerrortermeisunknownbecausethetruemodel is unknown.Oncethemodelhasbeenestimated,theregressionresidualsaredefinedasthedifferencebetweentheobservedandpredictedvalues.Theresidualsmeasuretheclosenessoffitofthepredictedvalues.Thealgorithmforestimatingtheregressionequation(solutionofthenormalequations)guaranteesthat theresidualshave a mean of zero. The variance of the residualsmeasures
the “size” of the error, and is small if the model fits thedata well.Inthisrespect,the MultipleLinearRegression equation will be

Frictioncoefficient,$\mu = b0 + b_1 \times \text{Distance} + b_2 \times \text{Speed} + b_3 \times \text{airtemperature} + b_4 \times \text{ground temperature} + b_5 \times \text{tire pressure}$. . . ..(5.2)

AnalyzingdatasetfromfirstmeasurementAppendixA)applyingregressionanalysisbyMaxStatsoftware,weobtainthenumericalvaluesoftheregressioncoefficientsb_0,b_1 , b_2, b_3,$b_4$and$b_5$tabulated in table 5.10.

Table 5.10: Statistical Analysis ofRegressioncoefficients.

Regression coefficients	**Magnitude**	**CI Lower 95%**	**CI Upper 95%**
Intercept, b_0	0.6623		
Distance passed,b_1	-0.0001167	-0.000166	-0.000067
Speed, b_2	+0.01405	0.0038	0.0242
Air temperature, b_3	+0.0044	-0.051	0.0602
Ground temperature,b_4	-0.00933	-0.038	0.0387
Tire pressure,b_5	-0.16	-0.5477	0.2284

Friction coefficient predictionmodel equation = 0.6623 -0.0001167 Distance +0.01405 Speed + 0.0044Airtemperature -0.00933Ground temperature-0.16Tirepressure.

GoodnessoffitofthismodelcanbeassessedbyR^{2}andadjustedR^2.TheexplanatorypoweroftheregressionissummarizedbyitsR^{2}value,alsocalledthecoefficientofdetermination,isoftendescribedastheproportionofvarianceexplainedbyregression.WeneedtokeepinmindthatahighR^{2}doesnotimplycausation.TheR^{2}valueforaregressioncanbe madearbitrarily highsimplyby includingmoreandmorepredictorsinthemodel.TheadjustedR^{2}isoneofseveralstatisticsthatattemptstocompensateforthis artificial increase inaccuracy.The value ofR^{2}and adjusted R^{2}are respectively0.80and0.749.Thenumericalvaluesofestimates,tvalueofttestoftheparametersof the regression modeland p value have been tabulated in table 5.11.

Table 5.11 : Statistics of Surface FrictionPrediction Model.

Parameter	**Estimate**	$t_{critical}$	**t**	**Pvalue**
Intercept	0.6623			< 0.0001
Distance	-0.0001167	2.064	8.829	< 0.0001
Speed	+0.01405	2.064	65.060	< 0.0001
Air temperature	+0.0044	2.069	31278.7	< 0.0001
Ground Temperature	-0.00933	2.069	125.292	< 0.0001
Tire pressure	-0.16	2.069	273.372	< 0.0001

Linearregression of μ predicted (y) vs μ observed(x)

Graphical relationship between predicted μ and observed μ has been shown in figure5.13.

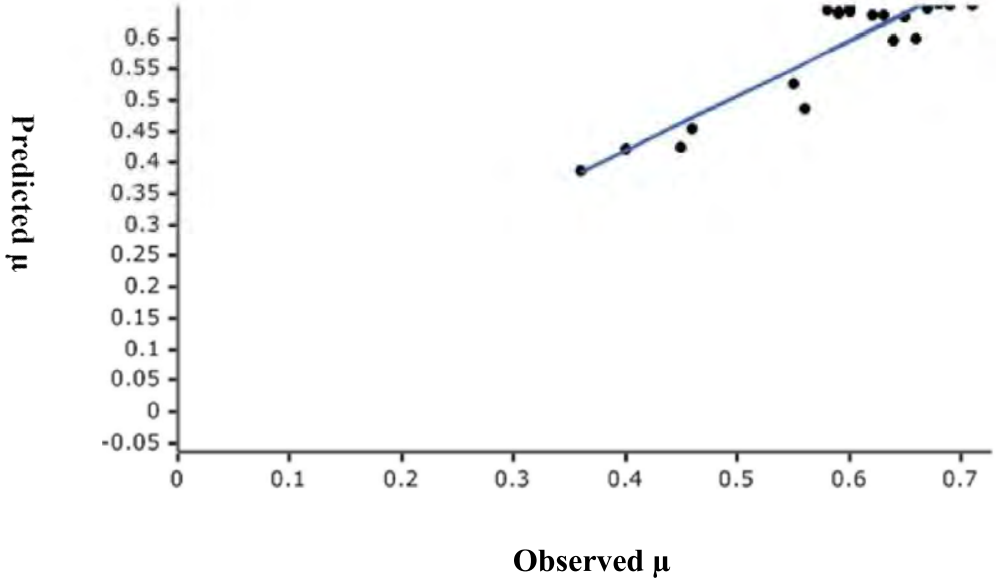


Figure 5.13: Correlation betweenPredicted μ andObserved μ.

Applying regressionanalysisbyMaxStat software, we obtain the numericalvalues of theregression coefficientsb_0, b_1.

b_0=0.11 (C.I. (95%) of b0± 0.099)

b_1=0.801 (C.I. (95%) of b1± 0.172)

ThenumericalvaluesofregressioncoefficientR^{2}andadjustedR^{2}are0.80and0.79respectively.

5.7 Correlationof runway surfacefriction coefficient withparameters

The Pearson correlationcoefficient,r,cantakearange ofvalues from+1 to-1.A valueof 0indicatesthatthere isnoassociation betweenthe two variables.A value greaterthan0indicatesapositiveassociation,thatis,asthevalueofonevariableincreasessodoes thevalueoftheothervariable.Avaluelessthan0indicatesanegativeassociation,thatis,as thevalue ofone variableincreasesthe valueof theother variabledecreases.Valuesforrbetween+1and-1(forexample,r=0.8or-0.4)indicatethatthereisvariationaroundthelineofbestfit.Thecloserthevalueofrto0thegreaterthevariationaroundthelineofbestfit.Theabovestatisticalanalysisstipulatesthatthereisapositiveassociationbetweenrunwaysurfacefrictioncoefficientandspeed.PearsonCorrelationCoefficientrhasbeendeterminedfromRunwaysurfacefrictioncoefficientvsSpeedgraph.Thevalueof Pearson CorrelationCoefficientris 0.76.Confidenceinterval(95%)ofrislowerCI.is0.51andupperCI.is0.89.Withtheconfidenceintervalwecanexpresstheprecisionofthemeanwithadefinedprobability(usually95%).Theconfidenceintervaldependsonthesamplesizeandthevariability(standarddeviation).The95%confidenceintervalliesbetween0.51and0.89,i.e.therealmeanliesinthis rangewithaprobabilityof95%.ThisPearsonCorrelationCoefficient valueofairtemperature,groundtemperature,distanceandtirepressurefromtable5.1withsurfacefrictioncoefficienthasalsobeendeterminedandcorrespondinglowerCI,upperCIand p valuehave been tabulatedinthe following tablesand graphicalrelationshipshave beenillustrated in the following figures.

Table 5.12 : CorrelationStatistics of Friction CoefficientandSpeed.

Correlation coefficient	LowerCI 95%	Upper CI 95%	P value
0.76	0.51	0.89	0.1639

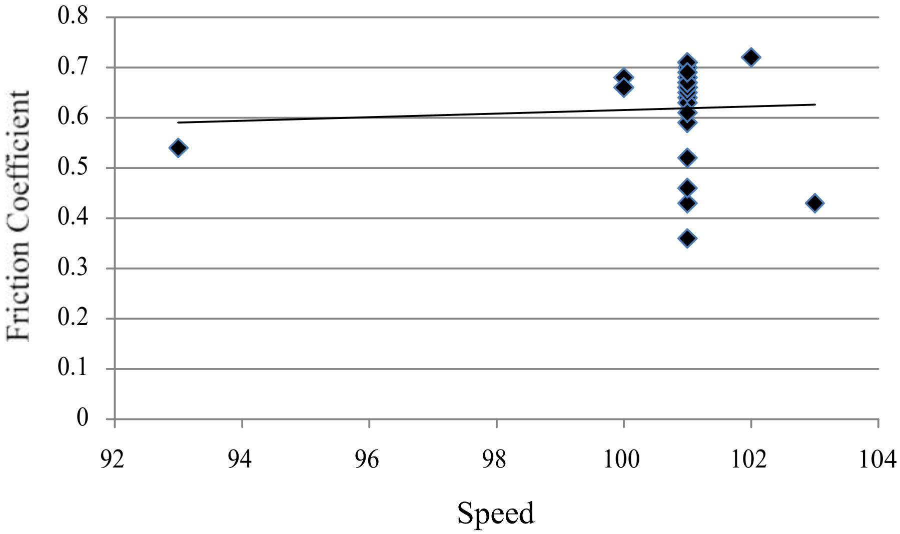


Figure5.14: Correlation betweenFriction Coefficientand Speed.

Correlationof runway surfacefrictioncoefficient with air temperature

Table 5.13 : CorrelationStatistics of FrictionCoefficient and Air Temperature.

Correlation coefficient	LowerCI95%	Upper CI95%	P value
0.337	-0.008	0.610	0.1074

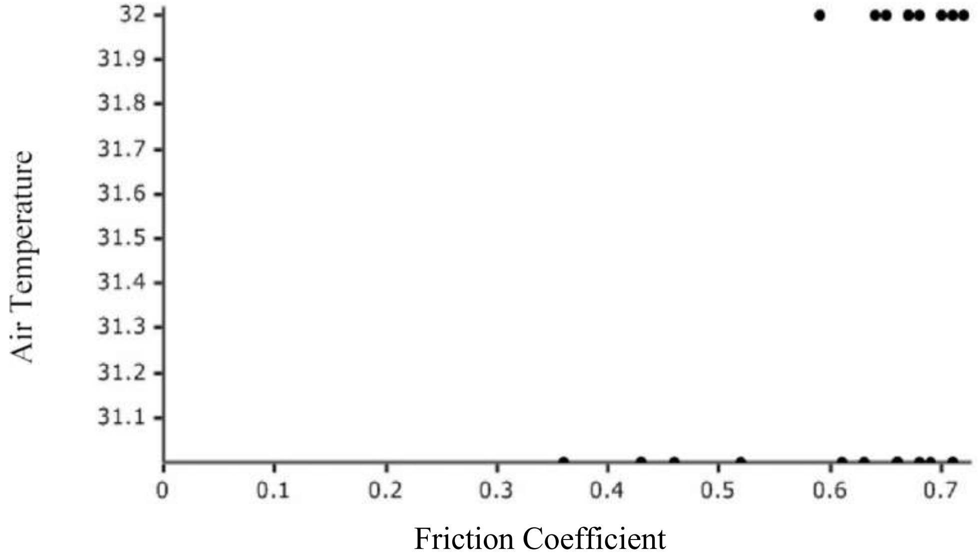


Figure5.15: Correlation betweenFriction Coefficientand Air Temperature.

Correlationof runway surfacefriction coefficient withdistance

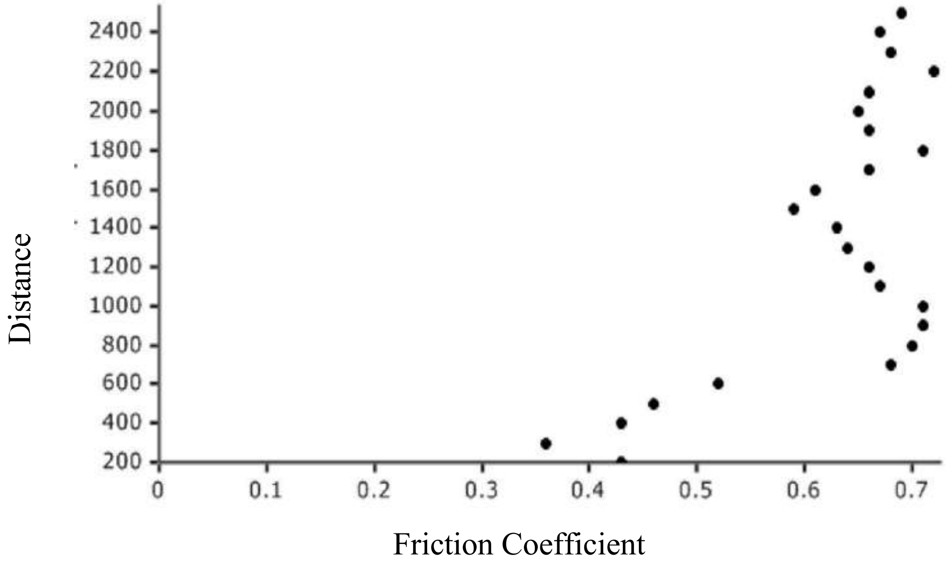


Figure5.16: Correlation betweenFriction CoefficientandDistance.

Table 5.14 : CorrelationStatistics of FrictionCoefficient and Distance.

Correlation coefficient	LowerCI95%	Upper CI 95%	P value
0.661	0.352	0.840	0.0004

Correlationof runway surfacefriction coefficient withtire pressure

Table 5.15 : CorrelationStatistics of FrictionCoefficient and Tire Pressure.

Correlation coefficient	LowerCI 95%	Upper CI 95%	P value
-0.228	-0.578	0.193	0.2834

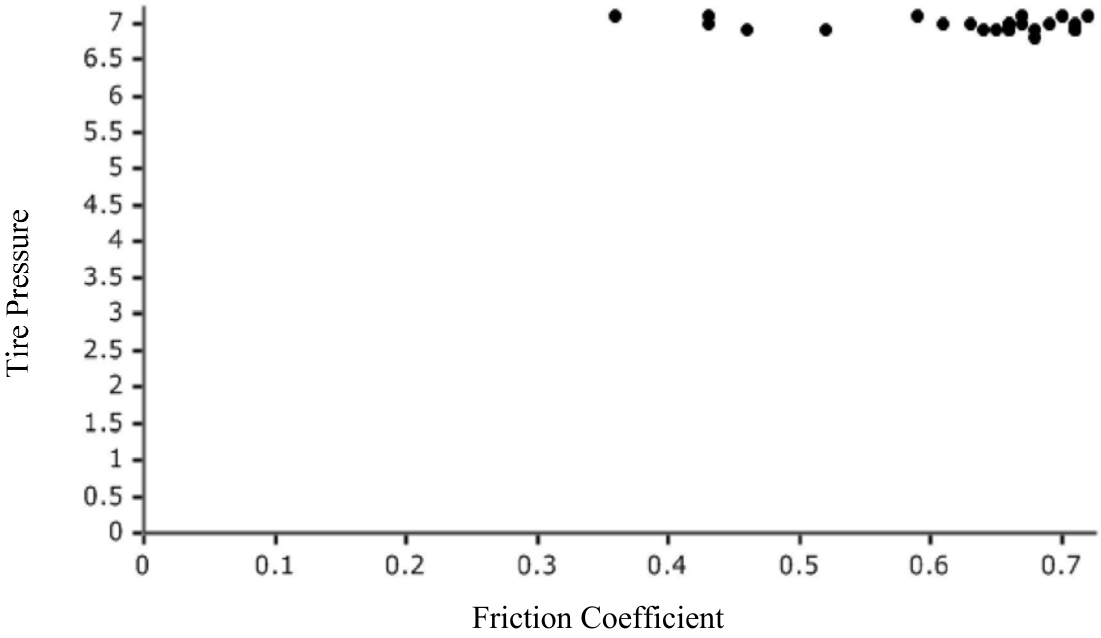


Figure5.17: Correlation betweenFriction Coefficientand Tire Pressure.

Correlationof runway surfacefriction coefficient with ground temperature

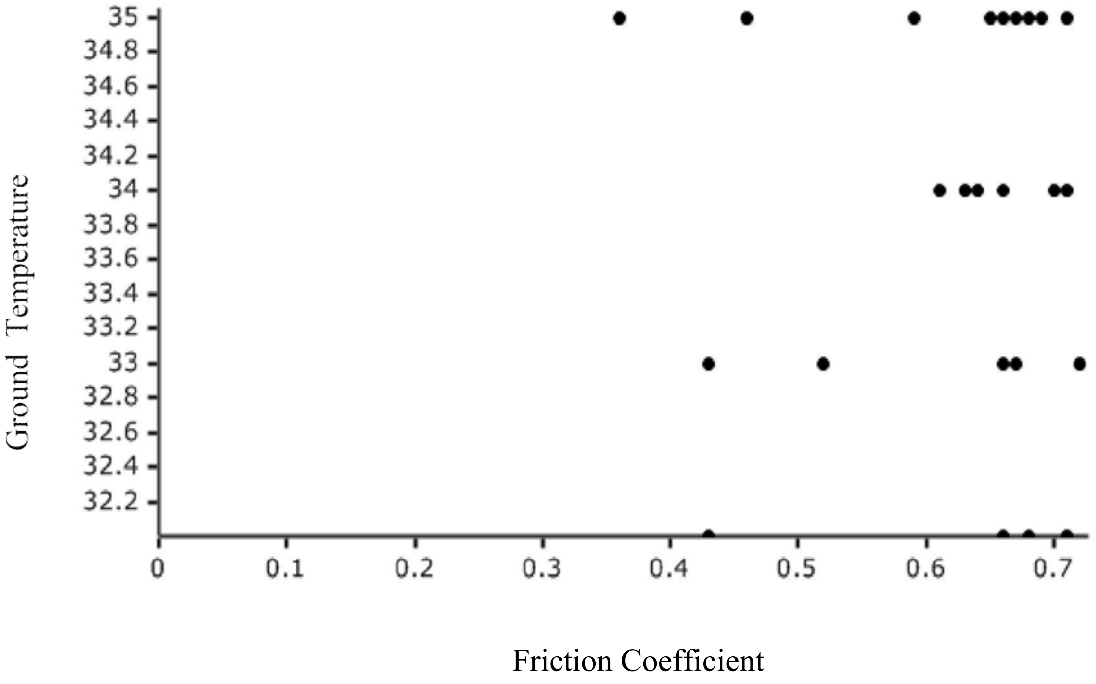


Figure5.18: Correlation betweenFriction Coefficientand Ground

Temperature.Table 5.16 :CorrelationStatistics ofFriction Coefficient and

GroundTemperature.

Correlation coefficient	LowerCI95%	Upper CI 95%	P value
-0.003	-0.405	0.401	0.9907

5.8 Sensitivity Analysis ofdifferentparameters ofsurface frictioncoefficient

Themostsignificantparameterinfluencingsurfacefrictioncoefficienthasbeenidentifiedbyincreasingnumericalvalueofeverysingleparameterby20%andconsideringremainingparametersconstant.Thisanalysishasbeendoneforeachparameter.Thenumericalvalueofeachparameterforthisanalysishasbeentakenfromappendix B. This sensitivityanalysis has been tabulated in the table 5.17.

Table 5.17 : Sensitivity Analysisof surface frictioncoefficient predictionmodel.

Parameter	μ valuefrom modelequation	μ value after 20%increment ofparameter	Remarks
Distance	0.68	0.66	2.9% decrement
Speed	0.68	0.96	42% increment
Ground Temperature	0.68	0.62	8.8% decrement
Air temperature	0.68	0.71	4.4% increment
Tire pressure	0.68	0.46	32.6%decrement

5.9 Terminology

R^2

TheR^2 measures the variation the "dependent" variable that can be accounted for or "explained" by independent variables.

Adjusted R^2

Ifthenumberofvariablesisasignificantfractionofthenumberofobservations,thentheproblem ofover-fittingoccurs.TheadjustedR^{2}isameasureofthenoisearoundtheregression line, correcting for this over-fittingproblem.

t test

Apairedttestisusedtocomparemeansoftwodatagroupsandwhereobservationsinone group can be pairedwith observations in theother group.

Pearson CorrelationCoefficient

Similartolinearregression,correlationdeterminesthelinearrelationshipbetweentwovariables ,butneitherisassumedtobefunctionallydependentoneachother.Itismostimportant that correlation does not mean causation.

p value

Thepvaluecanbeinterpretedintermsofahypotheticalrepetitionofthestudy.Assumingthenull hypothesistrueandanewdatasetisobtainedindependentlyofthefirstdatasetbutusingthesames ampling,thentheprobabilityofthenewvalueconfirmingthe original value is p value.

Chapter6

CONCLUSIONSANDRECOMMENDATIONS

6.1 Conclusion

Inthispaper,wetandcontaminatedconditionofrunwaysurfacehasbeentakenintoconsiderationindevelopingrunwaysurfacefrictioncoefficientpredictionmodel.Thekeyfindingsof this paper are as follows:

- Availablebrakingfrictioncoefficientisgroundspeeddependent.Withthespeedincrease the available braking friction coefficientdecreases.

- Inordertobeabletoexplainthephenomenonoffrictionalvariationduetotemperaturetheoretically,one needs tounderstandthe properties ofthetwotypesofmaterialsthatinteractinproducingpavementfriction.Thestiffnessofbothmaterialsincontact,rubberandasphalt,areexpectedtodecreasewithincreasingtemperature.

- Thedecreaseofcoefficientoffrictionwiththeincreaseinwatertemperaturecouldbeattributedtothesensitivityofthehydrodynamicpropertiesofwatertotemperature.Theviscosityofwaterdecreasesastemperatureincreasestherebydecreasingtheboundarylayershearstress.ThisisbecausetheshearstressinaNewtonianfluidisequaltotheproductoftheviscosityandthetimerateofstrain.

- Thepresenceofcontaminantsontherunway reducesthefrictionbetweenthetireandrunwaysurface.Thereductionisafunctionofseveralfactorsincludingthetire-pavementinteraction,theanti-lockingsystemperformance,typeofrunwaypavement, and the type of contaminantsalso.

- The centred best fit straight line in friction coefficient vs speed graph stipulates that wet runway remains a good runway friction condition which is similar to the dry runway pavement findings.

- The results indicate that when the speed is low, the wet runway have a maximum available braking friction that is nearly the same as the dry runway. With the speed increases, the maximum available braking friction increases for both wet runways and dry runways. However, a bigger drop in maximum available braking friction occurs when the runway is wet. An increment of speed value by 20% deduces 42% increment of coefficient of surface friction value of runway surface.

- The cruise speed of the ASFT car was not in wide range. Therefore, the graph has not demonstrated a distinct relationship between speed and friction coefficient. Pearson correlation coefficient found from statistical analysis is 0.337. From the regression equation, we can conclude that with the increase of speed, friction coefficient value will increase and vice versa.

- The results reveal that distance parameter shows a negative association with friction coefficient of runway surface. An increment of distance value by 20% simultaneously decreases numerical value of friction coefficient by 2.9%.

- The regression equation stipulates that when the ground temperature is high, the friction coefficient will decrease consequently. Friction measurement was accomplished in a day. Therefore, there was no variation in ground temperature data points and pearson correlation coefficient was found very insignificant. It is found that an increment of ground temperature value of 20% is associated with a 8.8% decrement of friction coefficient value of runway surface.

- Theresultsrevealthatairtemperatureparametershowsapositiveassociationwiththefrictioncoefficientofrunwaysurface.Anincrementofairtemperaturevalue by20% increases friction coefficient valueof runwaysurfaceby4.4%.

- The results reveal that whentirepressure increases, frictioncoefficient ofrunwaysurface decreases.Duringthedatacollection period, thetirepressurewasalreadysame.Consequently,variationoffrictioncoefficientwithtirepressuredidnotshowasignificantrelationship.Pearsoncorrelationcoefficienthasshowedanegative association between tirepressureand frictioncoefficient.Itisfoundthatanincrementoftirepressurevalueby20%decreasesfrictioncoefficientvalueof runwaysurface by32.6%.

6.2 Future ScopeoftheStudy

- Inthisresearch,runwayroughnessisnottakenintoconsideration.However,itsinfluenceonrunwaysurface friction coefficientshould be conductedin the futurestudy.

- Fullbrakingormaximumbrakinglandingtestofcommercialaircraftarealsorecommended tovalidatethesurface friction coefficient prediction model.

- ShahAmanatInternationalAirportmaintainsitsrunwayrapidlyinagoodcondition,hydroplaningandinsufficientfrictionbrakingduetocontaminantsdidnotoccurinthecollecteddata.Future aircraftlandingtestonrunwayswithseverewet and contaminated conditionsare recommendedto validate the model.

- Thisresearchcan beusedasasignificanttoolfordevelopingamodelforpredictingaircraftlandingdistanceirrespectiveofaircrafttypeasafunctionofrunwaysurface frictioncoefficient.

- This research will help to identify possibilities of harmonizing runway friction characteristic measurement technologies and provide a basis for improving and harmonizing the implementation of current ICAO Standards and Recommended Practices (SARPS). This could provide the opportunity for a global standardized application, and contribute to the progress of the ICAO action plan.

- The results retrieved from this research are ready for discussion with ICAO working groups, experts and the stakeholder communities but may also be reviewed in the light of the work carried out by the FAA Takeoff and landing performance assessment-Aviation Rulemaking Committee (TALPA/ARC).

- By adopting a systematic approach to the measurement of runway surface friction characteristics, the degradation of runway surface friction can be determined by the comparison and assessment of data over time. By utilising this data, aerodrome operators should be in a position to target maintenance as required in order to help ensure aircraft braking performance does not fall below internationally accepted levels.

6.3 Recommendations

- The friction characteristics of a runway will vary over time as the runway is subject to wear and tear (polishing), accumulation of rubber deposits and to the effects of weather and other environmental conditions. Aerodrome operators should monitor the results of assessments and should alter the interval between assessments depending on the results. If historical data indicate that the surface is deteriorating relatively quickly, more frequent monitoring may be required in order to ensure that maintenance is arranged before the friction characteristics deteriorate to MFL. The aerodrome operator should record the justification for any variation from the recommended periodicity for assessments.

- When there are indications that the friction characteristics of a runway may be reduced because of poor drainage, an additional assessment should be conducted, but this time under natural conditions representative of local rain. This assessment differs in that water depths in the poorly drained areas are normally greater in local rain conditions. The results are thus more appropriate to identify problem areas having low friction values that could induce hydroplaning than the standard assessment method. If circumstances do not permit assessments to be conducted during natural conditions representative of rain, then dousing the runway surface with water may simulate this condition.

- When conducting assessments on wet runways, it is important to note that, unlike compacted snow and ice conditions, in which there is very limited variation of the friction reading with speed, a wet runway produces a drop in friction with an increase in speed. However, as the speed increases, the rate at which the friction is reduced becomes less. Among the factors affecting friction between the tire and the runway surface, texture is particularly important. If the runway has a good macro-texture (roughness) allowing the water to escape beneath the tire, then the friction value will be less affected by speed. Conversely, a low macro-texture (smooth) surface will produce a larger drop in friction as speed increases.

- CFME manufacturers should be consulted concerning any special operating procedures involved in testing at higher speeds. Operational safety assessments relating to specific aerodrome procedures may need to be reviewed to take into account testing at higher speeds.

- The CFME operator should ensure that the equipment is in full working order and calibrated in accordance with the manufacturers' operating instructions. Those with responsibility for the provision of CFME should ensure that the equipment is serviced regularly and that the measuring tire is of the correct specificationandremainswithin manufacturers' tolerance. General guidance on testspeeds,nominaltestwaterfilmthickness,testtiretype,testtirepressureandtest tirecondition should be sought from the CFME manufacturer.

Thesuccessoffrictionmeasurementindeliveringreliablefrictiondatadependsgreatlyontheper sonnelwhoareresponsibleforoperatingtheCFME.Alloperators competentequipment's operationand should be trained and in the maintenanceandbeawareof thecriticalfactorsaffectingtheaccuracy offrictionmeasurements.Trainingmaybeconductedduringnormalassessmentrunsprovidedt hatsuitablemeasuresareinplacetoensurethattheresultsoftherunsarevalid.Ifadditionalrunsare conductedforthepurposeoftrainingormaintenanceofcompetence,theresultsmaybeincludedi ntheassessmentsystem if theyare known to be valid.

AerodromeoperatorsshouldmakeeffectiveuseoftheassessmentdataproducedbyCFME.Reg ularreviewscoupledwithplannedmaintenanceactivitiesdrivenbytrendanalysiswillensuretha tsurfacefrictioncharacteristicsareconsistentlyacceptable.AerodromeLicenseHoldersarerec ommendedtouseeitherCFME manufacturers'softwarebased reporting orto export rawdataintoanappropriatespreadsheetformat.However,detailedexaminationofthedataforea ch10mreadingshouldbecarriedoutaftereachassessmenttoidentify areasoftherunway, which mayrequire maintenance or closer monitoring.

Onheavilytraffickedrunwayswithaprevailingdirectionofuse,CFMEoperatorsmaydetectadif ferenceinresultswhencollectingdataonreciprocalruns.Shouldthisbethecasetheaerodromeo peratormaywishtoseekexpertopinion on theimplications of anydifferences recorded.

Dampness,fogandmistconditionsmightalsoaffecttheoutcomeoftheassessmentandaerodromeoperatorsshould be awarethat crosswindsmightaffectassessmentsutilizingself-wetting.Aerodromeoperatorsshouldseekadvice on these issues from the CFME manufacturer.

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APPENDIXA

LENGTHWISEFRICTION DATA FROM RWY 05(LAP1).

Distance(m)	Friction	Speed(km/h)	T_{air}(°C)	T_{gnd}(°C)	Tire pressure(bar)
100	0.54	93	32	34	7
200	0.43	103	31	33	7.1
300	0.36	101	31	35	7.1
400	0.43	101	31	32	7
500	0.46	101	31	35	6.9
600	0.52	101	31	33	6.9
700	0.68	100	32	32	6.9
800	0.70	101	32	34	7.1
900	0.71	101	32	35	6.9
1000	0.71	101	31	32	7
1100	0.67	101	32	33	7
1200	0.66	101	31	34	7
1300	0.64	101	32	34	6.9
1400	0.63	101	31	34	7
1500	0.59	101	32	35	7.1
1600	0.61	101	31	34	7
1700	0.66	100	31	33	6.9
1800	0.71	101	31	34	6.9
1900	0.66	101	31	35	7
2000	0.65	101	32	35	6.9
2100	0.66	101	31	32	6.9
2200	0.72	102	32	33	7.1
2300	0.68	101	31	35	6.8
2400	0.67	101	32	35	7.1
2500	0.69	101	31	35	7

APPENDIXB

LENGTHWISE FRICTION DATA FROM RWY23(LAP 2).

Distance(m)	Friction	Speed(km/h)	T_{air}(°C)	T_{gnd}(°C)	Tire pressure(bar)
100	0.54	85	32	34	7
200	0.68	94	31	33	7.1
300	0.67	102	31	35	7.1
400	0.69	101	31	32	7
500	0.70	101	31	35	6.9
600	0.70	101	31	33	6.9
700	0.71	101	32	32	6.9
800	0.73	101	32	34	7.1
900	0.71	101	32	35	6.9
1000	0.73	101	31	32	7
1100	0.66	101	32	33	7
1200	0.65	101	31	34	7
1300	0.67	101	32	34	6.9
1400	0.67	101	31	34	7
1500	0.67	101	32	35	7
1600	0.68	101	31	34	7
1700	0.66	101	31	33	6.9
1800	0.65	101	31	34	6.9
1900	0.64	101	31	35	7
2000	0.66	101	32	35	6.9
2100	0.61	101	31	32	6.9
2200	0.43	101	32	33	7.1
2300	0.37	101	31	35	6.8
2400	0.40	101	32	35	7.1
2500	0.45	101	31	35	7

APPENDIXC

LENGTHWISE FRICTION DATA FROM RWY05 (LAP 3).

Distance(m)	Friction	Speed(km/h)	T_{air}(°C)	T_{gnd}(°C)	Tire pressure(bar)
100	0.60	69	32	34	7
200	0.44	80	31	33	7.1
300	0.40	92	31	35	7.1
400	0.32	102	31	32	7
500	0.41	102	31	35	6.9
600	0.53	103	31	33	7
700	0.67	102	32	32	6.89
800	0.66	103	32	34	7.1
900	0.69	103	32	35	6.9
1000	0.67	103	31	32	7
1100	0.64	102	32	33	7
1200	0.61	102	31	34	7
1300	0.62	103	32	34	6.9
1400	0.59	103	31	34	7
1500	0.57	103	32	35	7
1600	0.61	102	31	34	7
1700	0.68	103	31	33	6.9
1800	0.70	103	31	34	6.9
1900	0.68	102	31	35	7
2000	0.69	102	32	35	6.9
2100	0.68	103	31	32	6.9
2200	0.71	103	32	33	7.1
2300	0.71	102	31	35	6.8
2400	0.67	103	32	35	7.1
2500	0.65	103	31	35	7

APPENDIXD

LENGTHWISE FRICTION DATA FROM RWY23(Lap4).

Distance(m)	Friction	Speed(km/h)	T_{air}(°C)	T_{gnd}(°C)	Tire pressure(bar)
100	0.68	70	32	34	7
200	0.70	79	31	33	7.1
300	0.69	87	31	35	7.1
400	0.70	95	31	32	7
500	0.68	101	31	35	6.9
600	0.69	100	31	33	7
700	0.67	100	32	32	6.9
800	0.66	100	32	34	7.1
900	0.69	100	32	35	6.9
1000	0.67	100	31	32	7
1100	0.64	100	32	33	7
1200	0.61	100	31	34	7
1300	0.62	100	32	34	6.9
1400	0.59	100	31	34	7
1500	0.57	100	32	35	7
1600	0.61	99	31	34	7
1700	0.68	100	31	33	6.9
1800	0.70	100	31	34	6.89
1900	0.68	100	31	35	6.9
2000	0.69	100	32	35	7
2100	0.68	100	31	32	6.9
2200	0.71	100	32	33	7.1
2300	0.71	99	31	35	6.9
2400	0.67	99	32	35	7.1
2500	0.65	100	31	35	7

APPENDIXE

LENGTHWISE FRICTION DATA FROM RWY23(LAP 5).

Distance(m)	Friction	Speed(km/h)	T_{air}(°C)	T_{gnd}(°C)	Tire pressure(bar)
100	0.56	97	32	34	7
200	0.46	98	31	33	7.1
300	0.40	99	31	35	7.1
400	0.36	100	31	32	7
500	0.45	99	31	35	6.9
600	0.55	96	31	31	6.9
700	0.64	94	32	32	6.9
800	0.66	94	32	34	7.1
900	0.65	93	32	35	6.9
1000	0.63	93	31	32	7
1100	0.62	93	32	33	7
1200	0.59	93	31	34	7
1300	0.59	93	32	32	7
1400	0.60	93	31	34	7
1500	0.58	93	32	35	7
1600	0.60	93	31	34	7
1700	0.67	93	31	33	6.9
1800	0.60	93	31	34	6.9
1900	0.71	93	31	35	6.9
2000	0.69	93	32	35	6.9
2100	0.68	93	31	32	6.9
2200	0.68	93	32	33	7.1
2300	0.68	93	31	35	6.9
2400	0. 72	93	32	35	7.1
2500	0.72	93	31	35	7

APPENDIXF

LENGTHWISE FRICTION DATA FROM RWY05(LAP 6).

Distance(m)	Friction	Speed(km/h)	T_{air}(°C)	T_{gnd}(°C)	Tire pressure(bar)
100	0.63	87	32	34	7
200	0.66	87	31	33	7.1
300	0.71	87	31	35	7.1
400	0.72	87	31	32	7
500	0.73	87	31	35	6.9
600	0.70	87	31	31	6.9
700	0.70	87	32	32	6.9
800	0.68	87	32	34	7.1
900	0.71	87	32	35	6.9
1000	0.71	87	31	32	7
1100	0.71	87	32	33	7
1200	0.72	87	31	34	6.9
1300	0.71	87	32	32	7
1400	0.69	87	31	34	6.9
1500	0.66	87	32	35	7
1600	0.63	87	31	34	7
1700	0.67	87	31	33	6.9
1800	0.64	87	31	34	7
1900	0.70	87	31	35	7
2000	0.69	87	32	35	7.1
2100	0.58	87	31	32	6.9
2200	0.49	87	32	33	7.1
2300	0.48	87	31	35	6.9
2400	0. 47	87	32	35	7.1
2500	0.72	93	31	35	7

APPENDIXG

HAZARDS RELATED TO FRICTION ISSUES AND PAVEMENT

Hazard	Friction characteristics			Significant change
	Physical	Functional	Operational	
	Microtexture	Slippery	Slippery	Retexture
	Macrotexture	Wet smooth		BC
	Macrotexture	Wet skid resistant		DE
No slope	Standing water	Poor drainageat tire/groundinterface	Longer stopping distance	New drainage
		Hydroplaning	Loss ofdirectional	
Naturalrounded aggregate	Susceptible for polishing	Slippery	Slipperywhen wet	Retexture Repave
Rubber deposit on crushed aggregate	Cover texture	Reduced texture	No performance credit on Wetskid resistant pavement	Remove Rubber deposit
		Slippery	Slippery	
Rubber deposit on natural, smooth aggregate	Cover texture	Reduced texture	Longers topping distance ,Slippery	
		Slippery		
Grooves	Closing due to deformation	Poor drainageat tire/groundinterface	Longers topping distance	Open grooves
			No performance credit on Wetskid resistant pavement	
	Filled with contaminant	Poor drainageat tire/groundinterface	Longers topping distance	Remove contaminant

APPENDIXH

HAZARDS RELATED TO FRICTION ISSUES AND AIRCRAFT

Hazard	**Friction characteristics**			**Significant change**
	Physical	**Functional**	**Operational**	
Tire wear	Tire tread depth	Drainage attire/groundinterface.	Basicassumption for wet skid resistance	Basicassumption based on tire tread depth of 2mm.
Change ininflation pressure	Inflation pressure	Drainagecapabilityattire/groundinterface.	Basicassumption for wet skid resistance	Curves (e.g.equations) inharmonized certificationspecificationsfor

APPENDIXI

HAZARDS RELATED TO FRICTION ISSUES AND REPORTING FORMAT

Hazard	**Friction characteristics**			**Significant change**
	Physical	**Functional**	**Operational**	
Clear anddry	Dry	Certification limited	Clear anddry	Dry
Damp	Wet performance data	Damp	Wet performance data	Damp
Wet smooth	Wet	Reduced braking action	Wet performance data	Less than 3 mm
Wet skid resistant	Wet	Reduced braking action	Wet skid resistant performance data	Less than 3 mm
Standing water	Wet	Hydroplaning susceptible	Above 3 mm	Standing water
Rime or frost	Thin layer			

covered	depth normally less than 1 mm			
Loose snow	20 mm1			20 mm1
Drysnow				
	Coverage	Reduced braking action.	Longer stoppingdistanc	10, 25, 50, 100 per cent
	Depth	Drag force	Longer takeoffdistanc	202,40,60… mm
Wet snow				
	Coverage	Reduced braking action.	Longer stoppingdistanc	10, 25, 50, 100 per cent
	Depth	Drag force	Longer takeoffdistanc	10,20,30… mm
Slush				
	Coverage	Reduced braking action.	Longer stoppingdistanc	10, 25, 50, 100 per cent
	Depth	Drag force	Longer takeoffdistanc	3, 6, 9, 12 mm
Wet ice				
Compacted snow or ice				
Ice				
	Coverage	Reduced braking action	Longer stoppingdistanc	10, 25, 50, 100 per cent
Compacted or rolled snow	Coverage	Reduced braking action.	Longer stoppingdistanc	10, 25, 50, 100 per cent
Frozen ruts or ridges	Coverage	Reduced braking action.	Longer stoppingdistanc	10, 25, 50, 100 per cent
Sand	Present	Reduced braking action.	Longer stoppingdistanc	
Mud	Present	Reduced braking action.	Longer stoppingdistanc	
Oil/fuel spillage	Present	Reduced braking action.	Longer stoppingdistanc	

APPENDIXJ

HAZARDS RELATED TO FRICTION ISSUES AND ATMOSPHERE

Hazard	**Friction characteristics**			**Significant change**
	Physical	**Functional**	**Operational**	
Precipitation	Contaminant	Influence antiskid	Reduced brakingaction	
Wind	Crosswind	Move aircraft	Loss ofdirectional	
Temperature	Freezing precipitation	Influence antiskid	Reduced brakingaction	
Radiation	Freezing moisture on ground	Influence antiskid system	Reduced brakingaction	