

Joint Winter Runway Friction Program Accomplishments

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Presented at
The Virginia Department of Transportation and Virginia Tech
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ABSTRACT

This paper describes the scope and objectives of the Joint National Aeronautics and Space Administration (NASA)/Transport Canada (TC)/Federal Aviation Administration (FAA) Winter Runway Friction Measurement Program which has just completed its seventh winter season of testing. The range of equipment tested, test sites, the friction database and the test accomplishments are described. The primary objective of this effort, which also involved several European aviation organizations, is to perform instrumented aircraft and ground vehicle tests aimed at identifying a “common number” that ground vehicle devices would report. This number, denoted as the International Runway Friction Index (IRFI), will be keyed to all types of aircraft stopping performance. Current correlations between measured aircraft stopping performance and ground vehicle IRFI values are presented for a variety of aircraft and winter runway conditions. Future test program plans are outlined and a summary of test results is given.

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INTRODUCTION

In spite of advances in aviation technology, operational procedures and weather forecasting, safe winter runway operations remain a challenge for airport operators, air traffic controllers, airlines and pilots who must coordinate their efforts under rapidly-changing weather conditions. Complicating the winter weather picture is the fact that criteria for safe operations on a given runway snow/wetness condition differ between airports and countries. Figure 1 shows a photograph of an aircraft accident attributed to inconsistent reporting of winter runway conditions to pilots. This accident occurred at a Mexican airport during a heavy thunderstorm and 4 passengers on the DC-9 were killed when the aircraft departed off the side of the runway. An obvious step in the solution of ground handling accidents such as this is to harmonize and standardize ground friction measuring vehicle values to provide the pilot with uniform and reliable runway condition information that is independent of the airport, country or type of measuring device.

The National Aeronautics and Space Administration (NASA), Transport Canada (TC) and the Federal Aviation Administration (FAA) support the goal of reducing the fatal aircraft accident rate by 80 percent in 10 years and by 90 percent in 25 years. To help accomplish this, NASA entered into a partnership with TC and the FAA in 1996 in a 5-year winter runway friction measurement program. Hand in hand with this effort, other government agencies such as the Canadian National Research Council (NRC), the Canadian Department of National Defense (DND), the French Société Technique des Base Aérienne (STBA), the Norwegian Civil Aviation Administration (NCAA), Prague and Munich Airports and Erding Air Force Base near Munich shared cost, expertise and facilities to achieve program objectives in a timely and acceptable manner with industry's guidance and support. The Joint Winter Runway Friction Measurement Program (JWRFMP) was thus formed to provide better tools for airport operators to use and more accurate and reliable runway friction data for pilots to make "go/no go" decisions for takeoff and landing during operations in adverse weather conditions.

One objective of the JWRFMP includes harmonizing friction measurements obtained with a variety of ground test vehicles on a wide range of winter runway conditions. This approach is similar to the World Road Association (PIARC) experiment to harmonize wet friction and texture measurements that produced the International Friction Index (IFI); which is defined in the American Society for Testing and Materials (ASTM) Standard E1960. Thus far, 18 different makes of ground test devices (44 vehicles in total) have participated. To ensure the harmonization of these different friction-measuring devices, the ASTM E17 Committee has developed a standard; E2100, titled the International Runway Friction Index (IRFI), and a committee task group will specify an acceptable reference calibration tester to ensure consistent and accurate reporting of the IRFI..

Accurately relating these harmonized vehicle friction measurements to aircraft braking performance is also a goal of this program. To achieve this objective, a variety of instrumented

test aircraft have been involved since the start of this program in January 1996. During the course of conducting the aircraft test runs, a determination has been made that the IRFI does relate directly to aircraft stopping performance and that contaminant drag is a significant factor in aircraft takeoff performance.

ABBREVIATIONS/ACRONYMS AND DEFINITIONS

Abbreviations/Acronyms:

| | |
|--------|--|
| ACI | Airports Council International |
| ALPA | Air Line Pilots Association |
| ASFT | Airport Surface Friction Tester, Sweden. |
| ASTM | American Society for Testing and Materials |
| ATA | Air Transport Association |
| DGAC | Direction Générale De L'Aviation Civile Français |
| FAA | Federal Aviation Administration, USA |
| RFT | Runway Friction Tester - manufactured by KJ Law, USA |
| GT | GripTester - manufactured by Findlay Irvine, Scotland |
| IB | Bare Ice |
| ICAO | International Civil Aviation Organization |
| IFALPA | International Federation of Air Line Pilots |
| IFI | International Friction Index |
| IMAG | Instrument de Mesure Automatique de Glissance - France |
| JWRFMP | Joint Winter Runway Friction Measurement Program |
| IRFI | International Runway Friction Index |
| ITTV | Integrated Tire Test Vehicle |
| JAA | Joint Aviation Authority |
| JB | James Brake Index |
| MPD | Mean Profile Depth |
| MTD | Mean Texture Depth |
| NASA | National Aeronautics and Space Administration, USA |
| NRC | National Research Council, Canada |
| PIARC | World Road Association (formerly Permanent International Association of Road Congresses) |
| RFT | Runway Friction Tester manufactured by K.J. Law Engineers, Inc., Michigan, USA |
| RFV | Reference Friction Vehicle |
| ROAR | Road Analyzer and Recorder manufactured by Norsemeter a.s., Norway |
| RUNAR | Runway Analyzer and Recorder manufactured by Norsemeter a.s., Norway |

| | |
|------|--|
| SB | Bare Compacted Snow |
| SD | Compacted Snow with a layer of loose snow |
| STBA | Service Technique des Bases Aériennes, Paris, France |
| SFT | Surface Friction Tester manufactured by Saab, Sweden |
| TC | Transport Canada |

Definitions:

device configuration, n. – a term used to designate the entire test system as used for any friction measurement; it includes, but not limited to, type of device (force or torque measurements), tire type, size and inflation pressure, slip ratio, normal load and braking system control mode.

base surface, n. - the type of surface evaluated; there are four classes (1) bare pavement dry, (2) bare pavement wet, (3) bare compacted snow and (4) bare ice.

surface, n. - a generic term used in the act of reporting frictional characteristics; it includes the base surface class and the base surface condition.

compacted snow, n. - a compressed solid mass of snow, which is sufficiently strong to prevent a normally loaded tire operating in a rolling mode from penetrating to the pavement or breaking up the surface.

ice, n. - water with or without contaminants frozen into a continuous solid body with or without cracks.

local friction device, n. - a particular friction testing device used at a given location to measure friction; the friction values evaluated with this device may be calibrated to IRFI values to provide harmonization.

master friction device, n. - a particular friction testing device used at a given location to calibrate local friction devices; the friction values of this device must have be calibrated to IRFI values

movement area, n. - that part of the airport (aerodrome) used for take-off, landing and taxiing of aircraft, consisting of the maneuvering area and the apron(s).

IRFI reference device, n. - a particular friction measuring device selected as a benchmark or reference; it is used to calibrate any local or master friction device to permit local friction device values to be converted to IRFI values for selected base surfaces.

harmonization, n. - the transformation of the outputs of different devices used for measurement of a specific phenomenon so that all devices report similar values.

OBJECTIVES

The major program objectives are twofold: 1) harmonize ground vehicle friction measurements to report consistent friction value or index for similar contaminated runway conditions, e.g., compacted snow, and 2) establish reliable correlation between ground vehicle friction measurements and aircraft braking performance. Accomplishing these objectives would give airport operators better procedures for evaluating runway friction and maintaining acceptable operating conditions, providing pilots information to base go/no go decisions, and would contribute to reducing traction-related aircraft accidents.

SCOPE AND ACCOMPLISHMENTS

NASA and TC are leading this study with support from the NRC, FAA, NCAA, and STBA. Also participating by providing aircraft and ground vehicles are organizations and equipment manufacturers from North America, France, Norway, Sweden, Scotland, Germany and the United Kingdom. A variety of instrumented test aircraft and ground friction measuring vehicles have been used at different test sites in the U.S., Canada, Norway, Germany and the Czech Republic. The NASA B-737 transport and an NRC Dassault Falcon-20 aircraft were used during January and March 1996 at the Jack Garland Airport in North Bay, Ontario. Seven ground friction measuring devices from six different countries collected comparable friction data for several winter runway conditions including dry, wet, solid ice, dry loose snow and compacted snow. In the January-March 1997 winter season, similar tests were performed at North Bay with an FAA B-727 transport, the NRC Falcon-20 and a De Havilland Dash-8 aircraft together with 13 ground friction measuring devices. Data obtained during these investigations helped define the methodology for an International Runway Friction Index (IRFI) to harmonize the friction measurements obtained with the different ground test vehicles. In the January-February 1998 winter season, additional data were collected at North Bay, ON with the Falcon-20 and Dash-8 aircraft, together with 11 different ground test vehicles, to further refine the IRFI methodology. Based on the Electronic Recording Deceleration (ERD) a Canadian Runway Friction Index (CRFI), was established for use by pilots to determine their aircraft stopping distance under compacted snow and ice conditions. In March 1998, several different ground friction measuring devices were used in conducting nearly 800 test runs under compacted snow- and ice-covered surface conditions at a new test track facility located at Gardermoen Airport near Oslo, Norway.

During the January-March 1999 winter season the Falcon-20 aircraft and ground vehicle data were collected at North Bay. Also, in 1999, NASA B-757 aircraft and ground vehicle data were collected at a new test site, Sawyer Airbase, Gwinn, MI. These tests were followed with additional ground vehicles (9 different devices) that obtained friction data at the Gardermoen test

track site in Oslo, Norway. Data from these tests were used to further refine and improve the IRFI methodology and define the present correlation constants in the IRFI standard. It is interesting to note that under similar runway conditions at these three different test sites, friction data from ground vehicles tested at all three sites were in close agreement and the IRFI methodology was further substantiated.

During the January – March 2000 winter season, one week of testing at North Bay, ON involved the Falcon-20 aircraft and 10 ground friction measuring vehicles. Tests with an Aero Lloyd A320, Sabena Airlines A320, Deutsche British Airways B-737-300 and a Fairchild/Dornier 328 aircraft were conducted at Munich Airport, Germany, February 21-25, 2000. Thirteen ground test vehicles participated in the Munich testing. In 2000, 60 test runs were conducted with five aircraft and over 1000 runs were completed with the ground vehicles.

During the January – March 2001 winter season, 3 weeks of testing at North Bay, ON involved a NAVCAN Dash-8 aircraft and 6 ground vehicles. More tests with the Fairchild/Dornier 328 aircraft were conducted at Erding Airbase, Germany, just outside of Munich, from February 26 to March 2, 2001. Ten different ground friction measuring devices participated in the tests at Erding Airbase. In 2001, nearly 80 test runs were completed with the two aircraft and over 2000 test runs were made with the ground vehicles.

During the January-March 2002 winter season, seven ground vehicle devices participated in over 2200 test runs at North Bay, ON. These tests were aimed at improving the fidelity and accuracy of the IRFI methodology. Over 1200 ground vehicle tests were conducted during the first week in March at the Prague Airport, Czech Republic, to determine the repeatability of friction data measured by similar devices operated under self-wet conditions.

Overall Summary

Eight weeks of NASA Aircraft Tire/Runway Friction Workshop data (1994-2001) have been combined with data from nineteen weeks of winter testing at North Bay, ON (1996-2001), one week at Sawyer Airbase, Gwinn, MI (1999), and two weeks at Oslo, Norway (1998-99), one week at Munich Airport, Germany (2000), one week at the Airbase at Erding, Germany (2001) and one week at the Prague Airport.

Since the beginning of the Joint Winter Runway Friction Measurement Program in January 1996, ten (10) aircraft and forty-four (44) different ground devices collected friction data at North Bay, Ontario, Sawyer Airbase, Gwinn, MI, NASA Wallops Flight Facility, VA, Oslo, Norway, Munich, and Erding Germany and Prague, Czech Republic. A total of 442 aircraft runs and close to 15,000 ground vehicle runs were conducted on nearly 50 different runway conditions. Over 400 individuals from nearly 60 organizations in 15 different countries have participated with personnel, equipment, facilities and data reduction/analysis techniques. The Canadian Runway Friction Index (CRFI) and the International Runway Friction Index (IRFI) are

the major outcomes from these efforts to harmonize ground vehicle friction measurements to aircraft stopping performance. Two international aviation conferences have been held in Montreal (Oct. 1996 and Nov. 1999) to disseminate the test results and obtain recommendations for future testing. Data from the eight annual NASA Tire/Runway Friction Workshops have been successfully completed to add dry and wet surface ground vehicle friction data to the database. Efforts are continuing to not only get funding support from the European Union but also to get expanded support from the aircraft manufacturers and the airlines. Dialogue to obtain assistance from the International Civil Aviation Organization (ICAO), Airline Pilots Association (ALPA) and the Airports Council International (ACI) will continue.

Figure 2 shows the present correlation between aircraft effective braking friction and the IRFI for five different aircraft. Some of this aircraft data is preliminary, but a single correlation of IRFI is possible with the different aircraft tested. The aircraft effective braking friction coefficient values were obtained from test runs with the NASA B737 and B757, the FAA B727, the NRC Falcon 20 and the manufacturer's Dash 8 aircraft under a variety of snow- and ice-covered runway surface conditions. The IRFI values were derived from both the IMAG trailer (15% slip) and the Electronic Recording Decelerometer data measured before and after each aircraft test series. The ambient temperature variation was within 10 degrees Celsius. Table 1 gives the IRFI correlations for each device, the tire type, the "a" and "b" harmonization constants, the linear correlation coefficients and the standard errors using the ground vehicle data through 1999. Additional analysis of the data collected since 1999 is underway and preliminary results indicate a closer correlation, i.e. higher correlation coefficients and lower standard errors.

FRICION DATABASE

A substantial friction database has been established, with both ground vehicle and aircraft friction measurements. For each friction value, the database provides the name/type of device, test location, speed, tire specifications, surface conditions and ambient weather conditions. Figure 3 shows three of the ground friction measuring devices and Table 2 is a list of all of the ground friction devices that have participated in the JWRFMP. Figure 4 is a photo of the Falcon 20 performing a test run and Table 3 is a list of all of the aircraft that have run tests in the JWRFMP.

At all test sites, NRC provided an ice and snow tribology researcher who classified the winter contaminate. Typically, the water content, density, temperature of air, contaminant and pavement, and the depth of the contaminate was measured and observations were recorded on the tire tracks produced during aircraft and ground vehicle test runs. These data along with the hourly flight weather is included in the database. Figure 5 shows researchers collecting snow samples for specific gravity testing.

FUTURE PLANS

Future testing with other aircraft types such as wide bodies, i.e. B777 and A330 aircraft, and new, improved friction testers is planned to further validate the IRFI methodology and help identify an Aircraft Friction Index (AFI) to harmonize different aircraft braking performance to the IRFI.

Dissemination, acceptance and implementation of these test results by the aviation community is expected through the guidance and assistance of several organizations including the FAA, NASA, the International Civil Aviation Organization (ICAO), Airport Council International (ACI), the American Society for Testing and Materials (ASTM), the Joint Aviation Authority (JAA), the International Federation of Air Line Pilots (IFALPA), the US and Canadian Air Line Pilots Association (ALPA and CALPA) and the Air Transport Association (ATA). The overall results from this program are expected to increase aircraft ground operational safety as well as the capacity of airports. Also envisioned is the application to vehicular safety where winter conditions are severe.

CONCLUDING REMARKS

In the seven years of testing aircraft and ground vehicles in the joint program, a substantial friction database has been established. Both an international and a Canadian runway friction indices have been identified from ground vehicle and aircraft friction measurements. Data analysis is continuing to improve the harmonization of ground vehicle friction measurements and determine a suitable Aircraft Friction Index based on calculated aircraft stopping distances using IRFI, that pilots could use in making their “go/no go” decisions. More aircraft and ground vehicle friction data are needed for this analysis and in the remaining 3 years of the current program, every effort will be made to achieve this goal.

Table 1. - Harmonization of Ground Vehicle Friction Measurements

| Device Description | Tire Type | Harmonization Constant a | Harmonization Constant b | Correlation Coefficient R ² | Standard Error of Estimate |
|--|----------------------------------|-----------------------------|-----------------------------|---|----------------------------|
| Airport Surface Friction tester SAAB 95* | Treleborg AERO 890 kPa (100 psi) | 0.0565 | 0.4264 | 0.78 | 0.023 |
| FAA Traler BV-11 | Treleborg T520 690 kPa (100 psi) | 0.0445 | 0.7635 | 0.83 | 0.052 |
| TC ERD in Chevrolet 1500 Truck | | 0.0879 | 0.8814 | 0.73 | 0.045 |
| DND Grip Tester | ASTM E-1844 | 0.0001 | 1.1109 | 0.82 | 0.042 |
| NASA Instrumented Tire Test Vehicle | Aircraft Tire 26 by 6 inches | 0.0907 | 1.0231 | 0.92 | 0.048 |
| FAA Runway Friction Tester** | ASTM E-1551 69D kPa (100 psi) | 0.0226 | 0.7262 | 0.98 | 0.034 |
| Norsemeter RUNAR | ASTM E-1551 207 kPa (30 psi) | 0.0504 | 0.3923 | 0.77 | 0.030 |
| TC Surface Friction Tester SAAB 1979 | ASTM E-1551 69D kPa (100 psi) | 0.0598 | 0.7589 | 0.92 | 0.034 |
| Munich Airport Surface Friction Tester | Treleborg AERO 69D kPa (100 psi) | 0.1261 | 0.6727 | 0.67 | 0.044 |

*1998 data only

**Small number of data points

NOTES:

ERD - Electronic Recording Decelerometer
Defense (Canada)

FAA - Federal Aviation Administration
Space Administration

NCAA - Norwegian Civil Aviation Administration

TC - Transport Canada

DND - Department of National

NASA - National Aeronautics and

Table 2. – List of Ground Test Devices

| Owner | Device Name | Notes | Manufacturer |
|--|---|--------------|--|
| Airport Surface Friction Tester AB, Sweden | Airport Surface friction Tester Ford Taurus | | Airport Surface Friction Tester AB, Sweden |
| Airport Surface Friction Tester AB, Sweden | Airport Surface Friction Tester Generic | | Airport Surface Friction Tester AB, Sweden |
| Oslo Airport, Norway | Airport Surface Friction Tester SAAB 9-5 | | Airport Surface Friction Tester AB, Sweden |
| Airport Surface Friction Tester AB, Sweden | Airport Surface Friction Tester SAAB 9-5C | | Airport Surface Friction Tester AB, Sweden |
| NASA Langley Research Center | BOWMONK mounted in Blazer | | Bowmonk, United Kingdom |
| FAA Technical Center | BV-11 Trailer | | Airport Equipment Company, Sweden |
| Oslo Airport, Norway | BV-11 Trailer | | Airport Equipment Company, Sweden |
| Vienna Airport, Austria | BV-11 Trailer Vienna Airport | | Airport Equipment Company, Sweden |
| Zurich Airport, Switzerland | BV-11 Trailer Zurich Airport | | Airport Equipment Company, Sweden |
| NASA Langley Research Center | Diagonal Braking Vehicle | | NASA Langley Research Center, USA |
| Transport Canada | ERD mounted in Chevrolet Blazer | | Transport Canada, Canada |
| Transport Canada | ERD mounted in NISSAN Van | | Transport Canada, Canada |
| Transport Canada | ERD mounted in truck Staff23, North Bay | | Transport Canada, Canada |
| Transport Canada | ERD-179 mounted in Chevrolet Blazer | | Transport Canada, Canada |
| Transport Canada | ERD-234 mounted in Chevrolet Blazer | | Transport Canada, Canada |
| Irvine Findley Inc., Scotland | Griptester Trailer | | Irvine Findley Inc., Scotland |
| Dept. of National Defense, Canada | Griptester Trailer | | Irvine Findley Inc., Scotland |
| Norwegian Air Traffic and Airport Mgment. | Griptester Trailer | | Irvine Findley Inc., Scotland |
| French Civil Aviation Administration | IMAG Trailer | | S. T. B. A. Airports, France |
| NASA Langley Research Center | Instrumented Tire Test Vehicle | | NASA Langley Research Center, USA |
| French Civil Aviation Administration | IRFI Reference Vehicle Trailer | | S. T. B. A. Airports, France |
| Ministry of Transportation, Ontario | Norsemeter ROAR Trailer | | Norsemeter AS, Norway |
| Department of Transportation, Iowa | Norsemeter SALTAR | | Norsemeter AS, Norway |
| Norwegian Road Research Laboratory, Oslo | Optimum Surface Chart Analyzer Recorder | | Norsemeter AS, Norway |
| Norwegian Air Traffic and Airport Mgment. | RUNAR Prototype Trailer | | Norsemeter AS, Norway |
| FAA Technical Center | Runway Friction Tester | | K. J. Law Engineers, Inc., USA |
| Frankfurt Airport, Germany | Safegate SAAB 9-5 Mrk APT5, Ser #527 | | Safegate, Sweden |
| Munich Airport, Germany | SARSYS SAAB 9000 Mrk V3 | | SARSYS, Sweden |
| Dusseldorf Airport, Germany | SARSYS SAAB 9-5C, Ser #813 | | SARSYS, Sweden |
| Strata Contractor, Germany | SARSYS SAAB 9-5C, Ser #814 | | SARSYS, Sweden |
| FAA Technical Center | Surface Friction Tester | | SAAB GM, Sweden |
| Transport Canada | Surface Friction Tester SAAB 1979 | | SAAB GM, Sweden |
| Transport Canada | Surface Friction Tester SAAB 1985 | | SAAB GM, Sweden |
| Transport Canada | Surface Friction Tester SAAB 1985, Turbo | | SAAB GM, Sweden |

| | | | |
|--|-------------------------------|--------------|---------------------------------------|
| Hannover Airport, Germany | Surface Friction Tester | | SARSYS, Sweden |
| NASA Langley Research Center | Tapley meter mounted n Blazer | | Tapley, Canada |
| Pennsylvania State University | ASTM E-274 2 Wheel Trailer | Wallops Only | Pennsylvania State University, USA |
| Pennsylvania State University | ASTM E-274 trailer Mk III | Wallops Only | Pennsylvania State University, USA |
| Department of Transportation, Virginia | ASTM E-274 Trailer | Wallops Only | International Cybernetics, USA |
| Department of Transportation, Virginia | British Pendulum Tester | Wallops Only | W. F. Stanley, United Kingdom |
| Federal Highway Administration | British Pendulum Tester | Wallops Only | W. F. Stanley, United Kingdom |
| Pennsylvania State University | British Pendulum Tester | Wallops Only | W. F. Stanley, United Kingdom |
| Nippo Sangyo Co., Ltd. | British Pendulum Tester | Wallops Only | Nippo Sangyo Co., Ltd., Japan |
| Generic device | Mu-Meter Trailer | Wallops Only | Douglas Equipment Co., United Kingdom |

Table 3. - List of instrumented test aircraft

| AIRCRAFT TYPE | OWNER/OPERATOR | MANUFACTURER |
|---------------|-------------------------------------|----------------------------------|
| Falcon-20 | National Research Council of Canada | Dassault Aircraft Company |
| B-737-100 | NASA Langley Research Center | Boeing Commercial Airplane Group |
| B-727-100 | FAA Technical Center | Boeing Commercial Airplane Group |
| Dash-8 | DeHavilland Aircraft Company | DeHavilland Aircraft Company |
| Dash-8 | NAV CAN | DeHavilland Aircraft Company |
| B757-200 | NASA Langley Research Center | Boeing Commercial Airplane Group |
| A320 | Aero Lloyd | Airbus Industrie |
| A320 | Sabena Airline | Airbus Industrie |
| DO 328-100 | Fairchild/Dornier GmbH | Fairchild/Dornier GmbH |
| B-737-300 | Deutsche British Airways | Boeing Commercial Airplane Group |



Figure 1

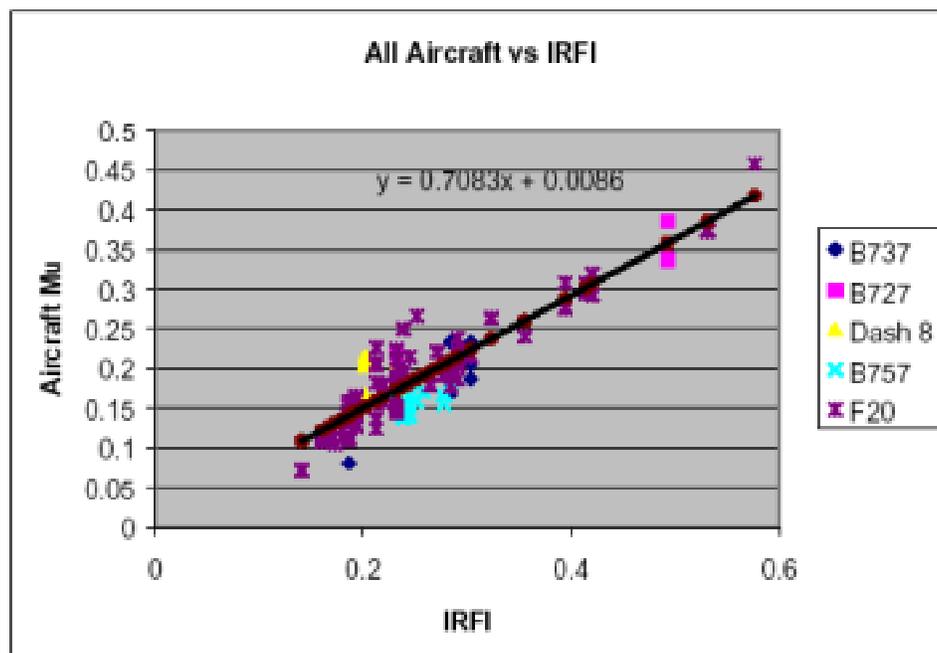


Figure 2. - Correlation between test aircraft effective braking friction and IRFI



Grip Tester (Scotland)



Saab Friction Tester (Sweden)



International Reference Vehicle (France)

Figure 3. - Photographs of three ground friction measurement devices.



Figure 4. - Photograph of Falcon-20 aircraft during test run on snow-covered runway.



Figure 5. – NRC researchers collecting contaminant sample for analysis