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Aircraft and Ground Vehicle Winter Runway Friction Assessment

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ABSTRACT

Some background information is given together with the scope and objectives of a 5-year, Joint Winter Runway Friction Measurement Program between the National Aeronautics & Space Administration (NASA), Transport Canada (TC), and the Federal Aviation Administration (FAA). Participants recently completed the fourth winter season of testing. The primary objective of this effort is to perform instrumented aircraft and ground vehicle tests aimed at identifying a common number that all the different ground vehicle devices would report. This number, denoted the International Runway Friction Index (IRFI) will be related to all types of aircraft stopping performance. The range of test equipment, the test sites, test results and accomplishments, the extent of the substantial friction database compiled, and future test plans will be described.

Several related studies have also been implemented including the effects of contaminant type on aircraft impingement drag and the effectiveness of various runway and aircraft de-icing chemical types and application rates. New equipment and techniques to measure surface frictional properties are also described. The status of an international friction index calibration device for use in ensuring accuracy of ground vehicle friction measurements will also be discussed. NASA considers the success of this joint program critical in terms of ensuring adequate ground handling capability in adverse weather conditions for future aircraft being designed and developed as well as improving the safety of current aircraft ground operations.

INTRODUCTION

Improving aviation safety has long been one of the principal goals of NASA, Transport Canada and the Federal Aviation Administration. With global aviation safety as one of NASA's three pillars or thrusts for research activities, the announced metrics of "five fold reduction in commercial transport fatal accident rates within 10 years and a ten fold reduction within 20 years" were deemed achievable. In today's economic climate, aviation industries are committed to affordable, cost-effective technology for improved safety and profitability. Hand in hand with this outlook, government agencies such as the FAA, NASA and Transport Canada, are partnering to share cost, expertise and facilities to achieve program objectives in a timely and acceptable manner with industry's guidance. The Joint Winter Runway Friction Measurement Program will contribute significantly towards meeting these one and two decade metrics by providing better tools for airport operators to use and more accurate and reliable runway friction data for pilots in making their "go/no go" decisions during operations in adverse weather conditions.

Inconsistent, inaccurate reporting of winter runway conditions to pilots has contributed to a disproportionate number of ground handling accidents as shown in **Figure 1**. This recent Boeing survey of commercial jet transport landing/taxi accidents indicates that over a 35 year period (1958-93), many accident events occurred on wet/icy runways with aircraft going off the end or side of the runway. An obvious step in the solution of these ground handling accidents is to standardize and harmonize ground friction measuring vehicle values to provide the pilot with uniform and reliable runway condition information that is independent of the type of measuring device.

One objective of this program includes harmonizing friction measurements obtained with a variety of ground test vehicles (13 thus far) on a wide range of winter runway conditions. Accurately relating these harmonized vehicle friction measurements to aircraft braking performance is also a goal of this program. To ensure the accuracy of these different devices including a new RUNAR trailer and an Airfield Surface Friction Tester (ASFT), the American Society for Testing and Materials E17 Committee has formed a task group to design an international friction index calibration tester with completion of prototype next year. A variety of instrumented test aircraft have been involved since testing in this 5-year program started in January 1996. During the course of conducting the aircraft test runs, a determination has been made on the magnitude of runway contaminant-produced drag on aircraft takeoff performance. The general test schedule for the joint program is given in **Figure 2** and it is hoped that a sixth instrumented aircraft, preferably a wide-body type, will participate in the fifth winter season of testing. The United States Air Force as well as two civil transport aircraft manufacturers have been approached to provide or support such wide-body aircraft testing.

BACKGROUND AND SCOPE

This study is being led by NASA and Transport Canada with support from the Canadian National Research Council (NRC) and the FAA. Also participating are organizations and equipment manufacturers, both aircraft and ground vehicle, from North America, Europe and several Scandinavian countries. A variety of instrumented test aircraft and ground friction measuring vehicles have been used at different test sites in the U.S., Canada and elsewhere. The NASA Langley 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 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 and to establish a Canadian Runway Friction Index (CRFI) to be used by pilots to determine their aircraft stopping distance under compacted snow and ice conditions from Electronic Recording Deceleration (ERD) readings. In March 1998, several different ground friction measuring devices participated 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, Falcon-20 aircraft and ground vehicle data was collected at North Bay, NASA B-757 aircraft and ground vehicle data was collected at a new test site, Sawyer Airbase, Gwinn, MI and additional ground vehicle (9 different devices) 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. 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 IRFI methodology was further substantiated. The joint program friction database collected during testing in 1996-99 includes nearly 400 instrumented aircraft test runs and more than 8000 ground vehicle runs under bare and dry, rain and artificially wet, artificially flooded, loose and compacted snow, smooth and rough ice, sanded and chemically-treated ice, and slush. Five weeks of NASA Aircraft Tire/Runway Friction Workshop data (1994-98) have been combined with data from thirteen weeks of winter testing at North Bay, ON (1996-99), one week at Sawyer Airbase, Gwinn, MI (1999) and two weeks at Oslo, Norway (1998-99). References 1 to 10 provide documentation of the 1996-98 test results obtained with instrumented aircraft and ground friction measuring vehicles.

Future testing with other aircraft types such as the B-777 or A320 aircraft and with new or improved ground test vehicles will further validate the IRFI methodology and help identify an Aircraft Friction Index (AFI) to harmonize different aircraft braking friction 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, the International Civil Aviation Authority (ICAO), the American Society for Testing and Materials (ASTM), the Joint Aviation Authority (JAA), the International Federation of Air Line Pilots (IFALPA), the U.S. 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 and may also be applicable to vehicular safety where winter conditions are severe.

PRELIMINARY TEST RESULTS

Figure 3 shows four friction data comparisons between ground vehicles on six different runway conditions which varied from bare and dry (high values) to ice-covered (low values). The devices each operatedwith a fixed-slip value which varied from 12 to 100 percent with zero percent equal to a free rolling and 100 percent equal to a locked-wheel skid. The NASA Instrumented Tire Test Vehicle (ITTV) is used in comparisons with the ERD, the Surface Friction Tester (SFT), the IMAG trailer and the GripTester trailer. These comparisons of actual measured friction values obtained with different test vehicle and tire combinations are considered quite good. The relative agreement, expressed by the "r squared" values with 1 being perfect agreement, in each of the four comparisons is nearly 0.92 on an average.

Figure 4 shows range of friction values obtained with a Norwegian variable slip trailer device (RUNAR) on several similar runway surface conditions. It should be noted that not only do the overall values of friction change with the different surface conditions, but the percent slip at the peak friction and the slope after the peak are also functions of the surface conditions. One can also conclude from this data that as the peak friction magnitude decreases, the difference between individual ground test vehicle measurements would also decrease. This has been observed in comparing data under different runway conditions obtained at all three test sites.

Figure 5 shows a comparison between the friction values measured in 1996 by the instrumented Falcon-20 aircraft and the ERD ground vehicle during testing on several different snow- and ice-covered runway conditions. The comparison in actual aircraft and ERD measurements is not as close as between the ERD and ITTV (r squared of 0.841 vs. 0.924) but that is to be expected because of differences in test tire slip ranges (100 percent for ERD, 15 to 20 percent for aircraft) and tire contact areas.

Figure 6 shows the effect of speed on the instrumented B-737 aircraft braking friction data. For the variety of runway conditions listed, the friction range varies from 0.5 under dry conditions down to 0.07 for patchy thin ice. A decrease in friction with speed is noted for the wet conditions whereas an increase is shown for dry loose snow (2 – 3 in. in depth), which may be attributed to a change in temperature during the test run series. The lower depth loose snow conditions and the patchy thin ice showed little effect of speed on the measured friction values. This trend was still evident after removing the contaminant drag values from the snow covered runway data. As expected, the patchy thin ice produced the lowest aircraft braking friction measurements which were obtained at a constant below-freezing temperature. Along with tire temperature, tire load or contact area has been found to be a significant factor in the level of friction developed by a given vehicle and/or aircraft on snow- and ice-covered runway conditions. Ground speed, on the other hand, does not have the influence on friction values developed on these winter runway conditions that it has under wet pavement conditions.

Figure 7 shows the effect of contaminant drag on the B-737 aircraft deceleration values with speed for three different snow-covered runway conditions. The contaminant drag values were a combination of the displaced contaminant drag by the aircraft tires together with that developed from impingement onto the aircraft. For these nonbraking tests, the aircraft was operated in the takeoff configuration. In general, the deceleration values increase with increased speed and contaminant depth as expected. The specific gravity of the base snow contaminant varied between 0.5 and 0.6. Similar data trends were found during nonbraking test run series with the Falcon-20, the Dash-8 and the B-727 aircraft.

FUTURE PLANS

More testing with the Falcon-20 and Dash-8 aircraft are planned for the 1999-00 winter seasons in North Bay, ON and additional testing with NASA Langley's instrumented B-757 aircraft will be conducted at Sawyer Airbase, Gwinn, Michigan. At least six of the ground friction measuring devices will participate in these tests at North Bay and Gwinn, MI and also in tests planned for the Gardermoen Airport test track facility near Oslo, Norway. Further participation of the FAA's

B-727 aircraft is expected. Efforts are also ongoing to get a wide-body aircraft, i.e. B-777 or Airbus 320 to participate in the 2000 winter season at Sawyer Airbase, MI. The United States Air Force has also been approached relative to use of an instrumented C-17 or C-130J transport aircraft in the testing. More ground vehicle tests evaluating friction, texture and pavement roughness are planned during the Sixth Annual NASA Tire/Runway Friction Workshop at Wallops Flight Facility, VA, May 10-14, 1999. In the fall, a 2-3 day international conference is planned with site and dates yet to be determined, to review all the joint program data and findings with the aviation community and get their guidance and recommendations for next year's program activities. The year 2000 marks the fifth and final year of the program.

CONCLUDING REMARKS

In the four years of testing aircraft and ground vehicles in the joint program, a substantial friction database has been established. Both an International Runway Friction Index (IRFI) and a Canadian Runway Friction Index (CRFI) have been identified from ground vehicle and aircraft friction data measurements. Data analysis is underway to improve the harmonization of ground vehicle friction measurements and determine a suitable Aircraft Friction Index (AFI), based on calculated aircraft stopping distances using IRFI, that pilots could use in making their "go/no go" decisions. Although next year marks the end of this ambitious 5-year program, discussions have taken place between the various participating government organizations and the International Civil Aviation Organization (ICAO) on extending this 5-year period to include different aircraft types and conditions. More aircraft and ground vehicle data are needed for the slush covered runway conditions and manufacturers and airlines are interested in reverse thrust performance data. Aircraft braking performance and contaminant drag measurements at speeds from 120 to 170 knots have also been identified as part of future aircraft test run matrices together with monitoring aircraft wheel brake torque variations during braking efforts.

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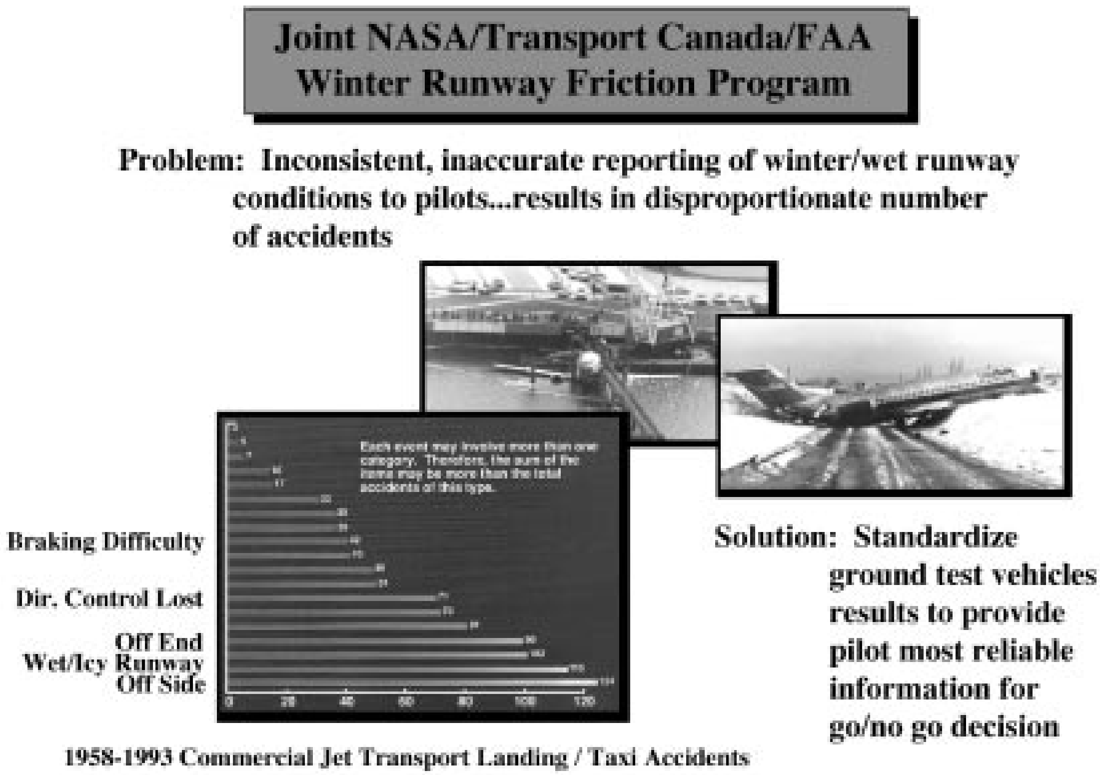
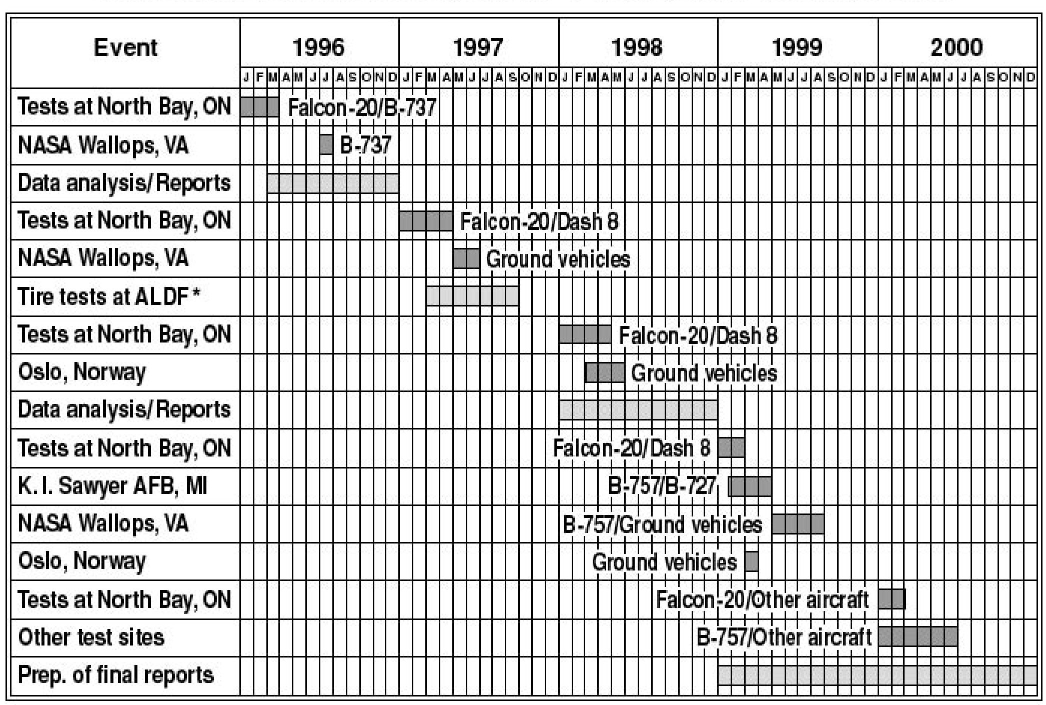


Figure 1

OVERALL JOINT NASA/TC/FAA WINTER RUNWAY FRICTION PROGRAM SCHEDULE

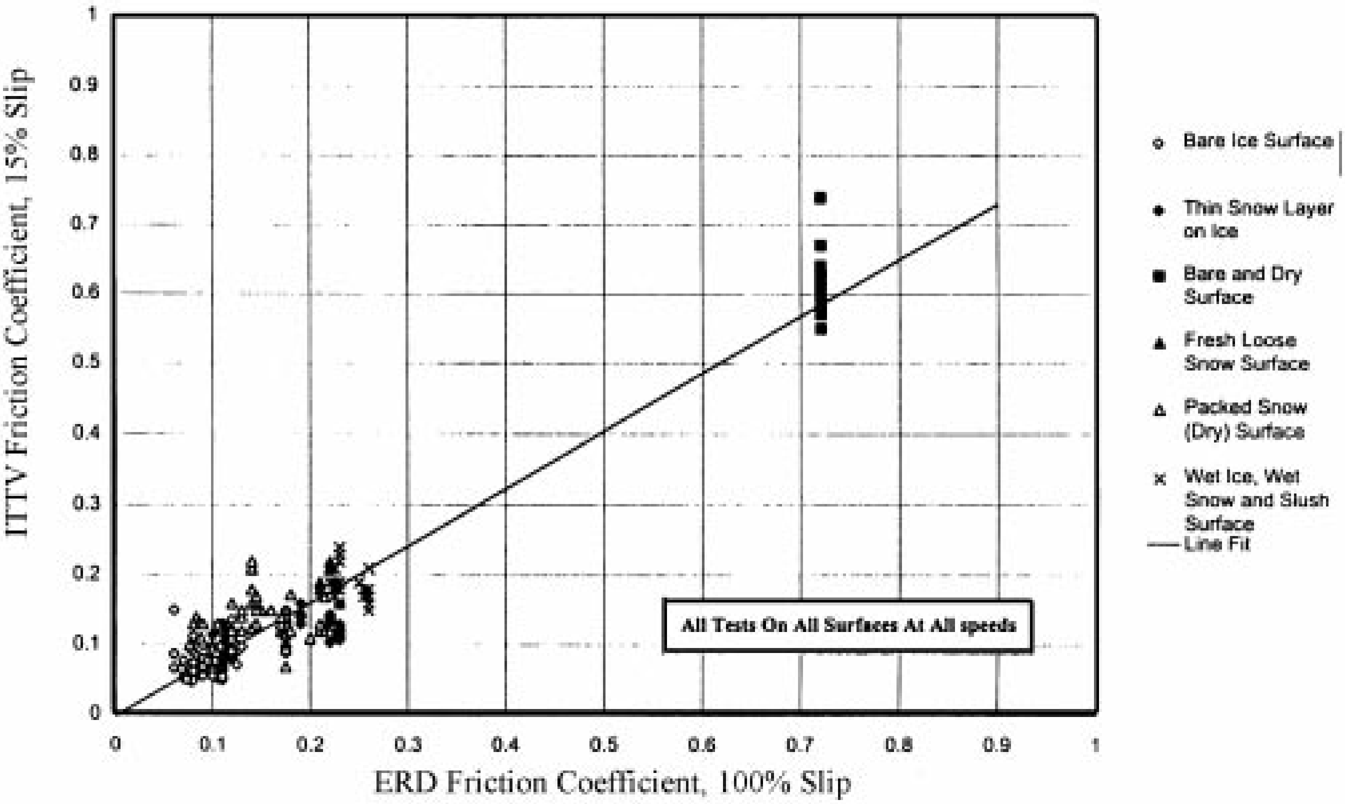


*ALDF – Aircraft Landing Dynamics Facility

Figure 2

A) **Correlation ITTV - ERD**

$y = 0.8148x - .0024$; $R^2 = 0.9243$



B) **Correlation SFT TC'79 - ITTV**

$y = 1.4482x + .0030$; $R^2 = 0.9226$

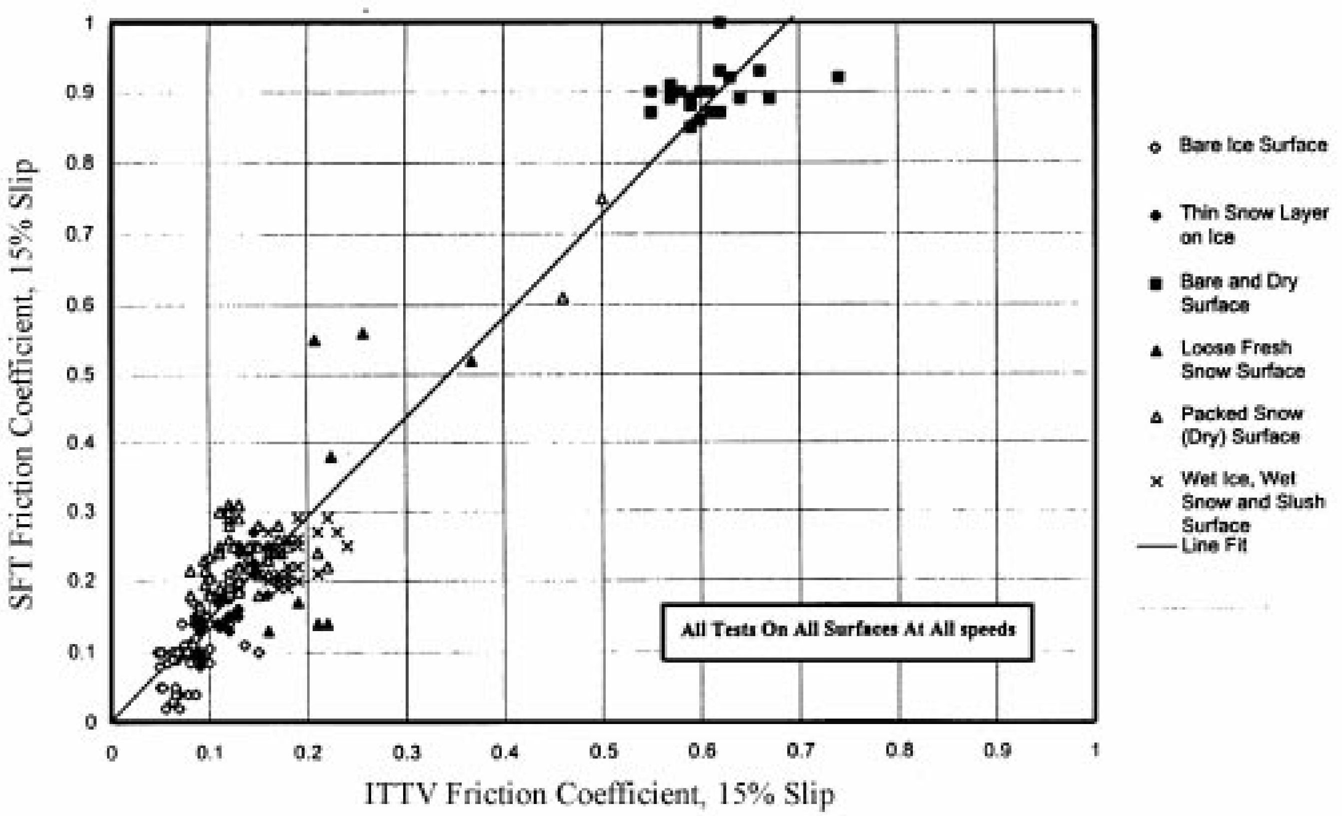
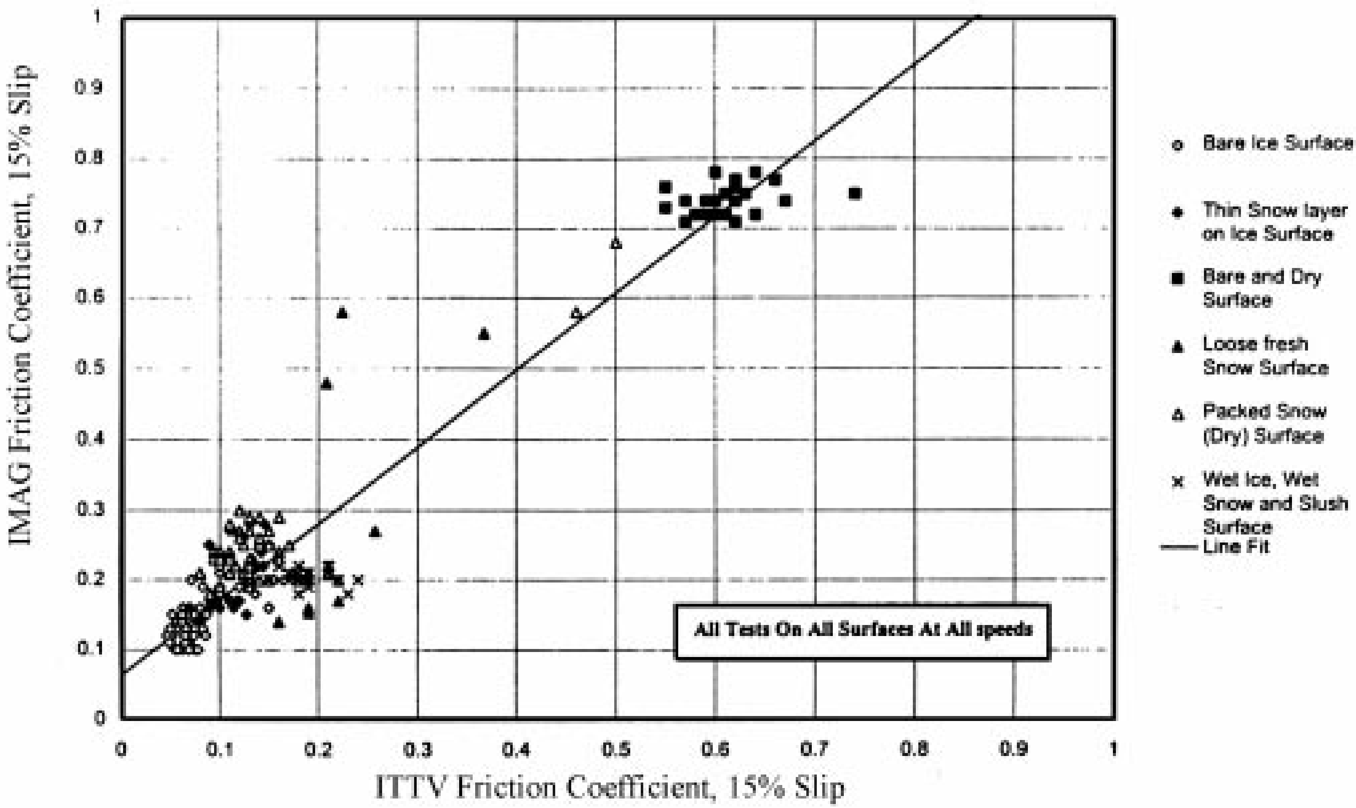


Figure 3

C) **CORRELATION OF IMAG AND ITTV**

$y = 1.0902x + 0.0625$; $R^2 = 0.9189$



D) **CORRELATION OF GRIPTESTER AND ITTV**

$y = 1.2171x + 0.0592$; $R^2 = 0.9182$

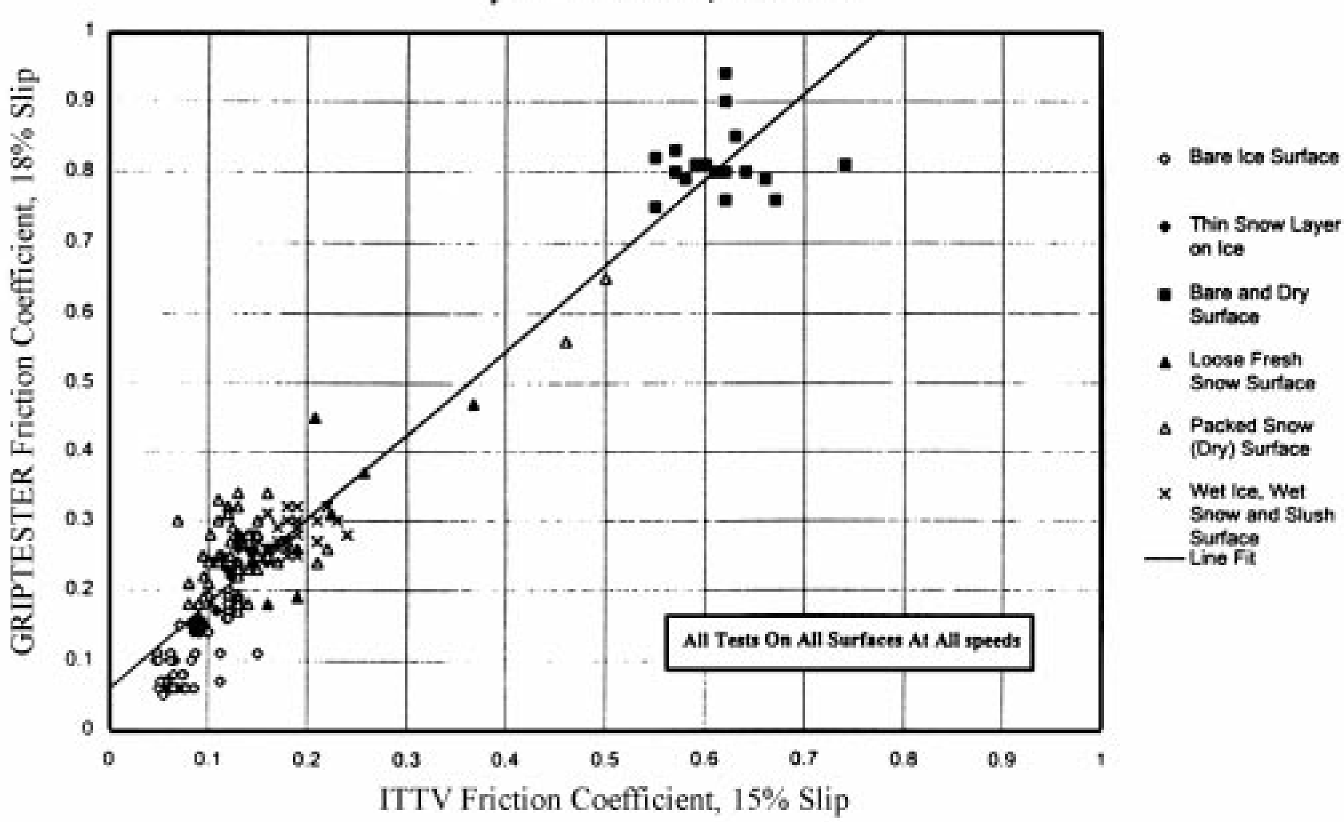


Figure 3 - Concluded.

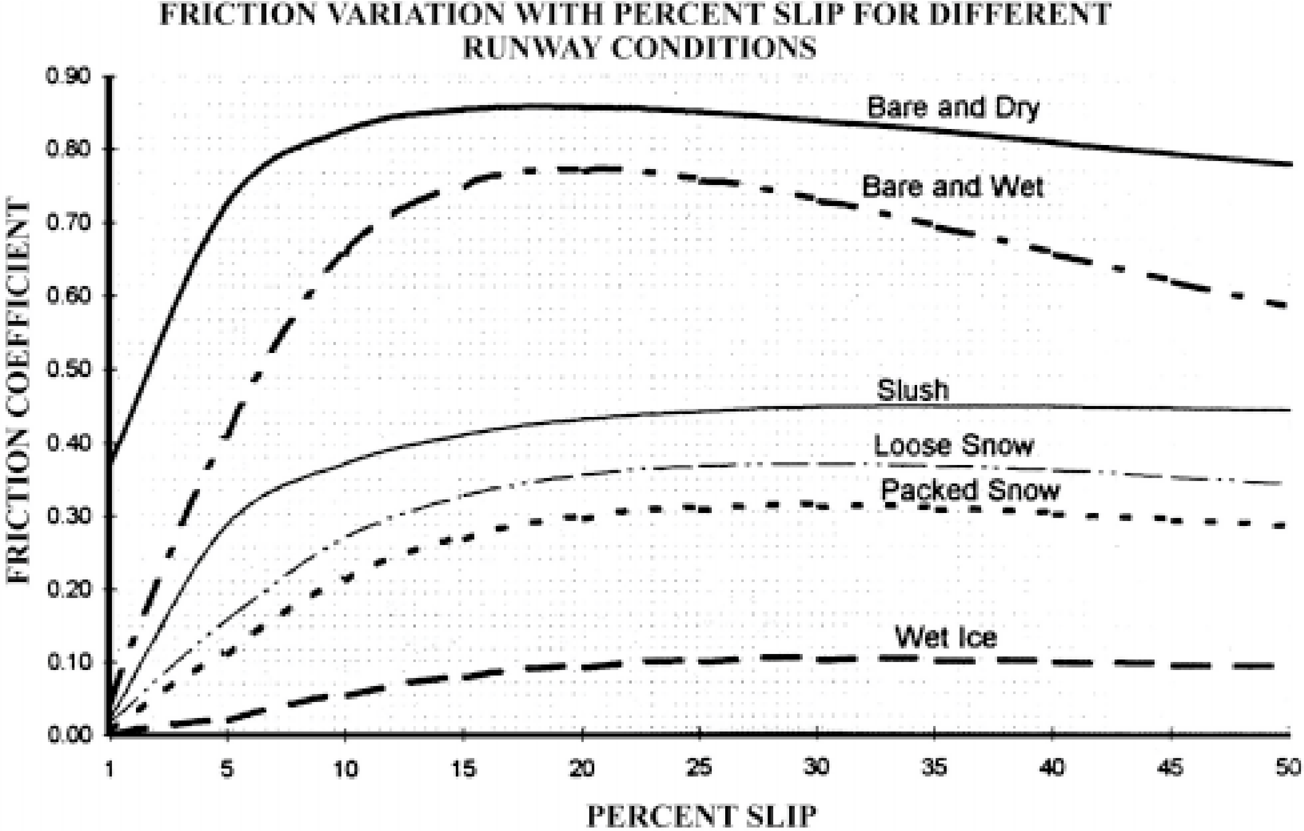


Figure 4

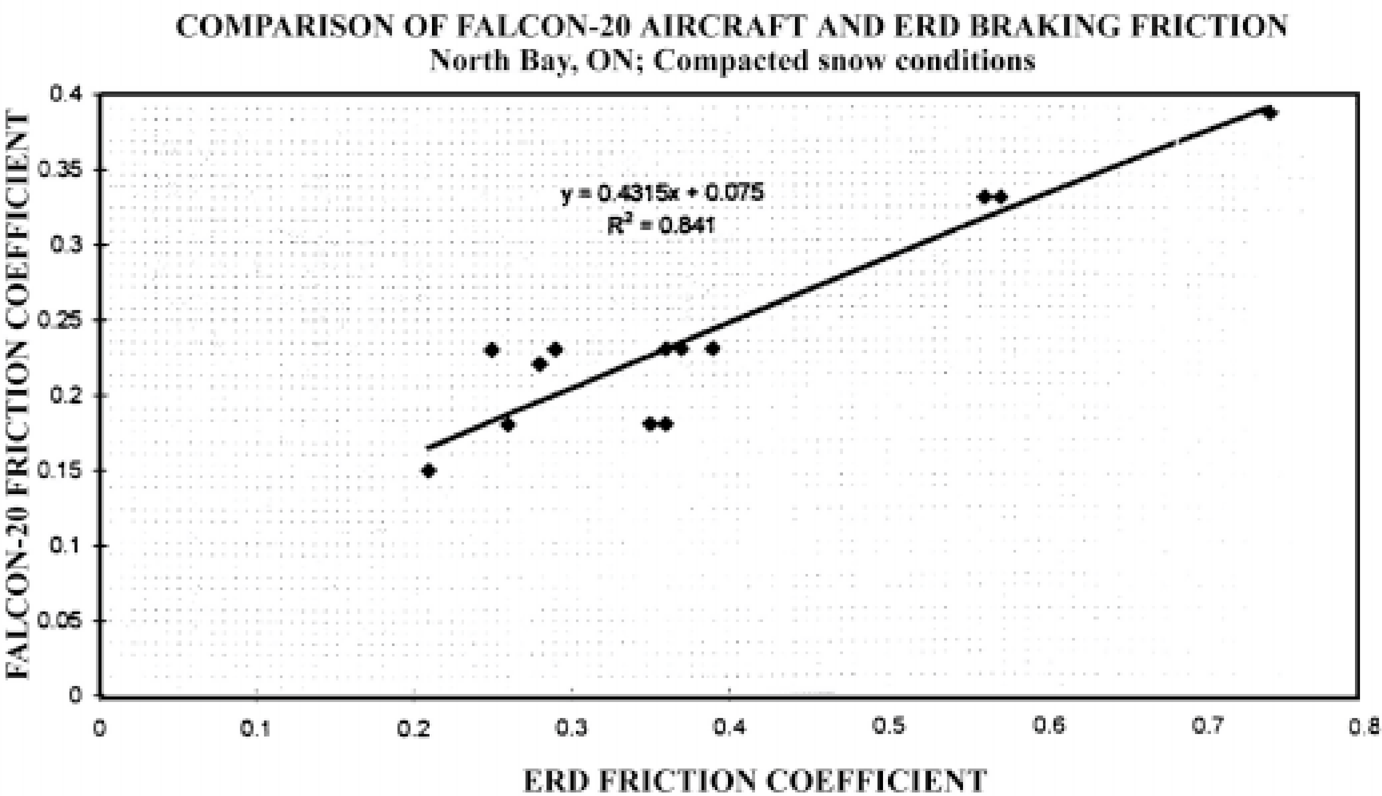


Figure 5

NASA B-737 AIRCRAFT BRAKING PERFORMANCE
Landing Configuration; North Bay, Ontario; R/W 8/26; March 1996
NASA Wallops Flight Facility; R/W 4/22; August 1996

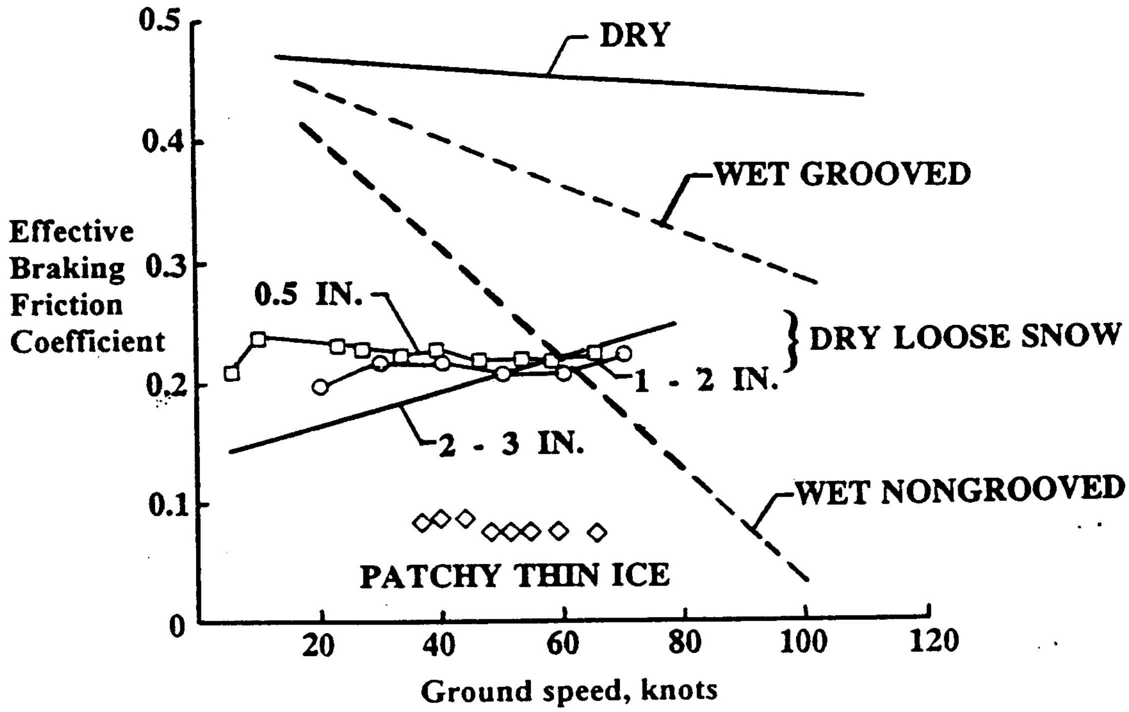


Figure 6

NASA B-737 Contaminant Drag Measurements
North Bay, ON; March 1996; takeoff configuration; loose dry snow

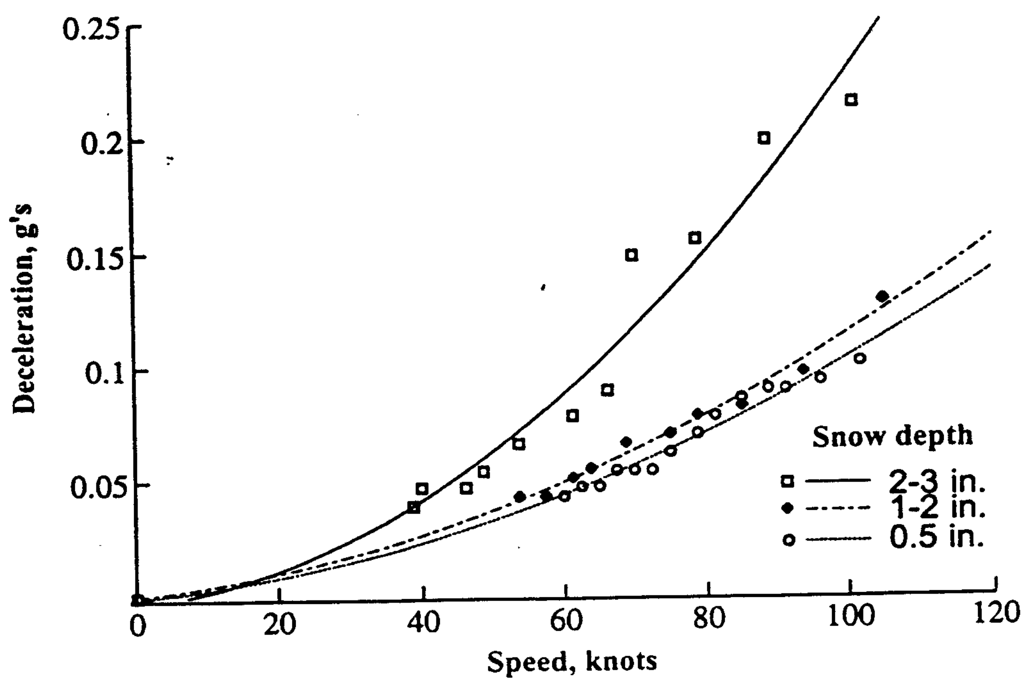


Figure 7

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