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Overview of the

Joint winter runway friction measurement program

July 1999

by

Transportation Development Centre

for

Civil Aviation Directorate

and

other participants in the

Joint winter runway friction measurement program

The information in this report has been obtained through the efforts of numerous participating organizations.

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16. Abstract

This report outlines the activities of the Joint Winter Runway Friction Measurement Program from its inception to the beginning of the 1999 tests. It covers program management, tests, meetings, development of the International Runway Friction Index, achievements, and future goals.

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16. Résumé

Ce rapport fait la synthèse des activités menées dans le cadre du Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver, depuis le lancement du programme jusqu'aux essais de la saison hivernale 1999. Il traite tour à tour des sujets suivants : gestion du programme, essais, réunions, élaboration de l'indice international de la glissance des pistes, réalisations, objectifs futurs.

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SUMMARY

For centuries researchers have tried to understand and quantify the effects of friction. With the advent of aviation, many new questions arose. In winter conditions particularly, an understanding of friction factors is needed for safe operations, and the aviation community has studied the problem from the outset. Wet and icy runways have been shown to be the foremost cause of landing accidents.

A fatal aircraft crash in Dryden, Ontario, in 1989, brought the subject into sharp focus. Among its many recommendations, the Dryden Commission of Inquiry that investigated the disaster stressed the need “to expedite the search for a technically accurate means of defining runway surface conditions and their effects on aircraft performance”.

While most countries have guidelines, no universal measures or practices have been established. Canada used the James Brake Index (JBI) until 1998, when it was revised and renamed the Canadian Runway Friction Index (CRFI). One of the basic technical problems lies in relating aircraft braking performance to the friction measurements taken by ground vehicles.

In response to these concerns, Transport Canada (TC) and the U.S. National Aeronautics and Space Administration (NASA) signed a Memorandum of Understanding in December 1995. The memorandum agreed on a five-year initiative to study winter runway friction measurements. With the added support of other North American and European organizations (the Noverwegian Civil Aviation Administration, for example, also signed a joint agreement) a concerted international effort – the Joint Winter Runway Friction Measurement Program (JWRFMP) – began in January 1996.

Supporting Organizations

The National Research Council Canada (NRC) and the U.S. Federal Aviation Administration (FAA) immediately backed the TC/NASA program. The Norwegian Civil Aviation Administration and France’s Service technique des bases aériennes and Direction générale d’aviation civile also offered support. Over time other agencies, such as the International Civil Aviation Organization, the Joint Aviation Authority (the European counterpart of the FAA), and the Canadian Department of National Defence, as well as Canadian, U.S., U.K., French, and Norwegian aviation operators and manufacturers, have become involved. Participants provide varied assistance: financial backing, data acquired in their own programs, technical expertise, equipment, materials, personnel, and facilities.

The American Society for Testing and Materials (ASTM) offered to work with industry and the aviation community to develop standards for a common reporting index for

ground friction measuring devices, based on the program findings and input from program participants. An ASTM task group with international representation was established to develop concepts for this index, which became known as the International Runway Friction Index (IRFI).

The Transportation Development Centre, TC's research organization, coordinates the overall management of the program, with the guidance of the JWRFMP steering committee.

The Program

To achieve the program objectives, the TC/NASA team planned a five-phase approach: acquisition of data through ground vehicle tests; acquisition of data through tests with instrumented aircraft; data analysis, correlation, and interpretation; application of the knowledge gained to the development of an IRFI; and validation of the IRFI development. Meetings to disseminate information and to discuss the development of the IRFI are also part of the program plan.

Series of tests have been conducted each year (1996, 1997, 1998, 1999) since the program began. The 1999 series is not yet complete. Aircraft tests cover three critical manoeuvres – takeoff, landing, and rejected takeoff (accelerate-stop) – on a variety of surfaces. Measured parameters include the braking coefficient, the increment in drag, and aircraft speed. Ground vehicle friction measurements are taken before and after aircraft runs, to compare the readings from aircraft and ground vehicles. Aircraft-based measurements are used to establish a theoretical model relating the coefficient of friction to operating distances and to develop precise computational tables. Over 13 ground vehicles and five specially instrumented aircraft types – a Falcon 20, a Dash 8, a B 757, a B 737, and a B 727 – have taken part in the program.

The major test site is the Jack Garland Airport in North Bay, Ontario, where the first tests were held in January 1996. NASA's Wallops Flight Facility in Virginia, the Gwinn-Sawyer Air Base in Michigan, and the Ottar K. Kollerud test track at Oslo Airport in Norway are also used for tests.

The data acquired in each series of tests is analysed, interpreted, and used for correlation and validation purposes.

IRFI Development

The ASTM task group first developed and agreed upon a concept for calculating an IRFI and determined the requirements for such an index. As work progressed, the testing program was adapted to address problems and to validate requirements.

After a substantial amount of data had been collected and analysed, a prototype computing tool was developed, based on the principle of correlating maximum friction values of a measurement device with those of a reference device. In January 1998 work towards a reference device began. A virtual vehicle, representing a combination of several devices now in use, was proposed.

An IRFI proposal was then submitted to the ASTM for preliminary review. The reviewers voiced a number of concerns. The 1999 test program is designed to address the questions raised. The results will be incorporated into a revised proposal, and the procedures leading to acceptance will continue.

Achievements

JWRFMP achievements to date include:

- Development of the first extensive set of runway friction data for temperatures at and below 0°C
- Revision of the James Brake Index. The Canadian Runway Friction Index, the revised version developed under the program, provides pilots with more accurate guidelines for calculating landing distances on contaminated runways
- Increased understanding of the many factors affecting friction coefficients, e.g., slush drag and impingement drag
- International cooperation on the development of an approved IRFI, based on the most accurate and comprehensive data possible

Future goals

The overall immediate goals are to develop and validate the IRFI and to achieve its official acceptance by the international aviation community. All other goals are aimed at adding to the accuracy and scope of the index and thus hastening the approval process.

Following official acceptance of the IRFI, it will be important to ensure that it is accepted and implemented by regulatory bodies, airport authorities, airline operators, and pilots.

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1. INTRODUCTION

> *… among all those who have written on the subject of moving forces, there is probably not a single one who has given sufficient attention to friction …*
>
> *Guillaume Amontons 1699 (1)*

1.1 Background

For centuries researchers have tried to understand and quantify the effects of friction. With the advent of aviation, many new questions arose. In winter conditions particularly, an understanding of friction factors is needed for safe operations, and the aviation community has studied the problem from the outset. Wet and icy runways have been shown to be the foremost cause of landing accidents (Figure 1).

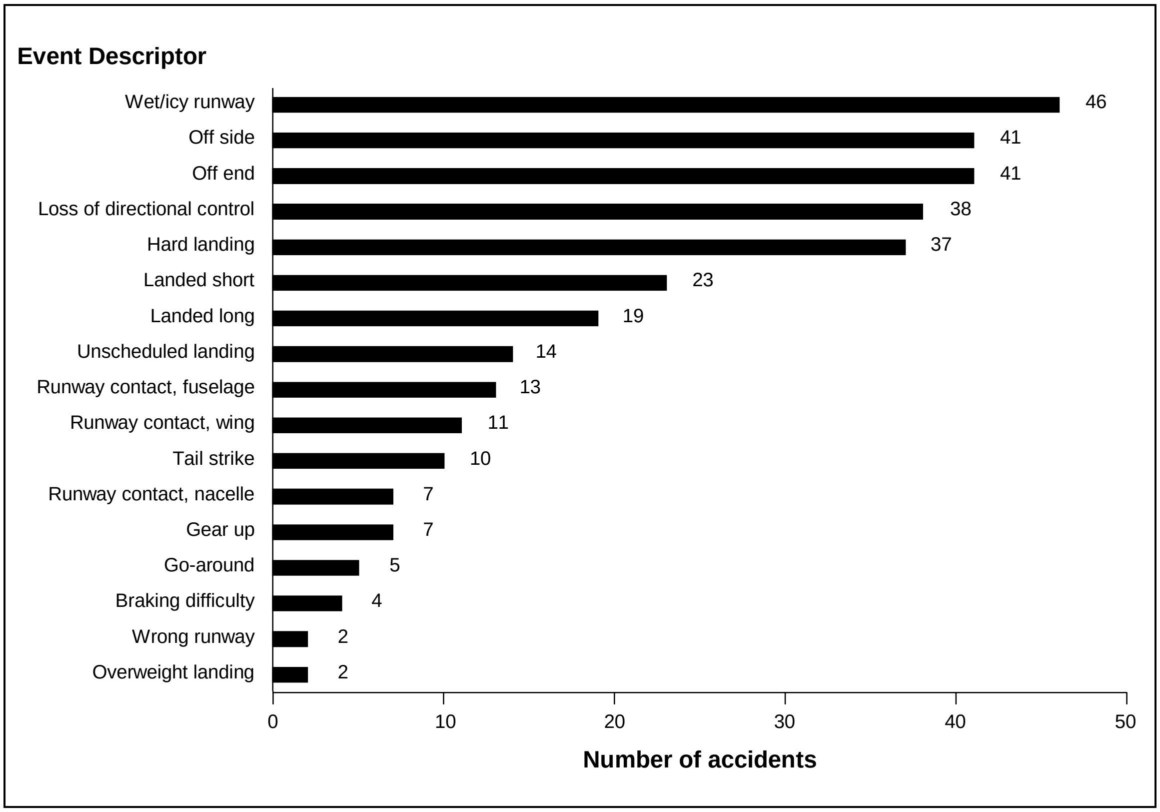

Figure 1 Landing Accidents by Event Descriptor
(Worldwide Commercial Jet Operations – 1988 through 1997)
Source: The Boeing Company

A fatal aircraft crash in Dryden, Ontario, in 1989, brought the subject into sharp focus. Among its many recommendations, the Dryden Commission of Inquiry that investigated the disaster stressed the need “to expedite the search for a technically accurate means of defining runway surface conditions and their effects on aircraft performance” (2). Early work funded by the Dryden Commission indicated the impossibility of reaching conclusions or developing measurements with the data available at that time (3). The introduction of new anti-icing chemicals and new technologies, as well as the streamlining of operational procedures, meant that acquiring adequate data would be a major undertaking.

Safe operation of aircraft on runways contaminated with ice, snow, slush, anti-icing fluids, and the like, depends on the following:

- establishment of accurate performance data for a wide range of conditions
- interpretation of this information
- communication of the results to dispatchers and air crew
- incorporation of the results into regulations and procedures

While most countries have guidelines, no uniform measures or practices have been established. Canada used the James Brake Index (JBI) until 1998, when it was changed to the Canadian Runway Friction Index (CRFI). One of the basic technical problems lies in relating aircraft braking performance to the friction measurements taken by ground vehicles.

In December 1995, following publication and discussion of a joint Canadian government/industry white paper (4), Transport Canada (TC) and the National Aeronautics and Space Administration (NASA) signed a Memorandum of Understanding on a five-year initiative to study winter runway friction measurements. With the added support of other North American organizations, as well as Norwegian and French authorities (the Norwegian Civil Aviation Administration also signed a joint agreement) a concerted international effort – the Joint Winter Runway Friction Measurement Program (JWRFMP) – began in January 1996.

1.2 Objectives

The following program objectives were developed on the basis of the initial TC/NASA agreement:

- To enhance and expand the data base on aircraft/ground vehicle friction on contaminated runways
- To use this data to validate tables for landing distances (and possibly to expand these tables to include accelerate-stop distances for takeoff)

- To improve the definition of slush drag and impingement drag during aircraft operations on runways covered with snow, slush, or standing water
- To determine, over a range of ambient temperatures and winter contamination conditions, how the chemicals used on aircraft and runways affect tire friction performance
- To study the interfacial media, e.g., snow, ice, and chemicals, to allow more accurate prediction of aircraft performance
- To determine the effects of various parameters on aircraft crosswind handling on contaminated runways
- To help harmonize and ultimately standardize the worldwide implementation of program findings through the development of an IRFI
- To gain international acceptance of the improved standards by pilots and airport operators

1.3 Supporting Organizations

The National Research Council Canada (NRC) and the U.S. Federal Aviation Administration (FAA) immediately backed the TC/NASA program. The Norwegian Civil Aviation Administration (NCAA) and France’s Service technique des bases aériennes and Direction générale d’aviation civile (DGAC) also offered support. Over time other agencies, such as the International Civil Aviation Organization (ICAO), the Joint Aviation Authority (the European counterpart of the FAA), and the Canadian Department of National Defence, as well as Canadian, U.S., U.K., French, and Norwegian aviation operators and manufacturers, have become involved. Participants provide varied assistance: financial backing, data acquired in their own programs, technical expertise, equipment, materials, personnel, and facilities.

The American Society for Testing and Materials (ASTM) offered to work with industry and the aviation community to develop standards for a common reporting index for ground friction measuring devices, based on the program findings and input from program participants. An ASTM task group with international representation was established to develop concepts for this index, which became known as the International Runway Friction Index (IRFI).

1.4 Program Management

The program is managed by the JWRFMP Steering Committee, made up of representatives from TC, NASA, FAA, NRC, NCAA, and DGAC. The Committee is chaired by TC, NASA, and the FAA, on a rotating basis. Input from the USAF, the Canadian Department of National Defence, the American Association of Aeronautical Engineers, the Airports Council International, the ASTM, and contractors helps the committee in planning and decision-making.

Transport Canada’s role in the program is overseen by the Aerodrome Safety Branch, and coordinated by TDC. The Aircraft Certification and Commercial Aviation branches take an active role, and the National Research Council is also an integral part of the team.

The specific contributions of participants are outlined below.

The Transportation Development Centre (TDC), TC’s research and development arm, coordinates the program, with the support and guidance of the JWRFMP steering committee. This overall direction promotes continuity and keeps participants’ efforts focussed. TDC ensures that the program meets TC requirements and coordinates all funding, in-kind contributions, materials, facilities, and subcontracts.

TC’s Aerodrome Safety Branch provides financial support and technical management of the program. It is also responsible for developing regulations and standards on the IRFI and on methods of reporting runway surface conditions.

The TC Aircraft Certification Branch supplies flight test engineering expertise to the NRC Falcon 20 test team and performance engineering expertise to the test data analysts. In addition, it provides input on CRFI development and on technical aspects of the program.

Commercial Aviation, the other TC Branch involved in the program, undertakes material reviews, evaluates the commercial viability of program developments, ensures that results are published, and disseminates the information acquired to commercial regulatory bodies.

The National Research Council Canada, through its Institute for Aerospace Research, acts as a source of scientific and technical information and advice and provides the specially instrumented Falcon 20 for the program. It also reports on the Falcon 20 tests and test findings.

NASA provides overall expertise, guidance, and assistance in technical matters, as well as engineering and technical support for the test program. It supplies ground test vehicles, photographic and video coverage of testing, test sites, test aircraft, crew, and associated equipment and maintenance. In addition, the agency processes and analyses test data, and disseminates program information to the aviation community.

The FAA offers another source of technical expertise and acquired knowledge, and participates in all aspects of the program including the technical steering committees. It also provides test aircraft, ground test vehicles, flight crew, and related equipment.

The NCAA provides a particular knowledge of winter runway problems and tests are conducted at its new Oslo site. It contributes significantly to guiding the program towards amending ICAO documents for the overall improvement of aviation operations, and is an active member of the technical steering committee.

The DGAC adds its European point of view and experience to the program's knowledge base, provides test equipment, and takes part in analysis and interpretation of test data. It is a member of the technical steering committee on the development of an International Runway Friction Index.

Figure 2 shows the overall organizational framework that has evolved over the course of the program and Figure 3 outlines the Canadian JWRFMP management structure.

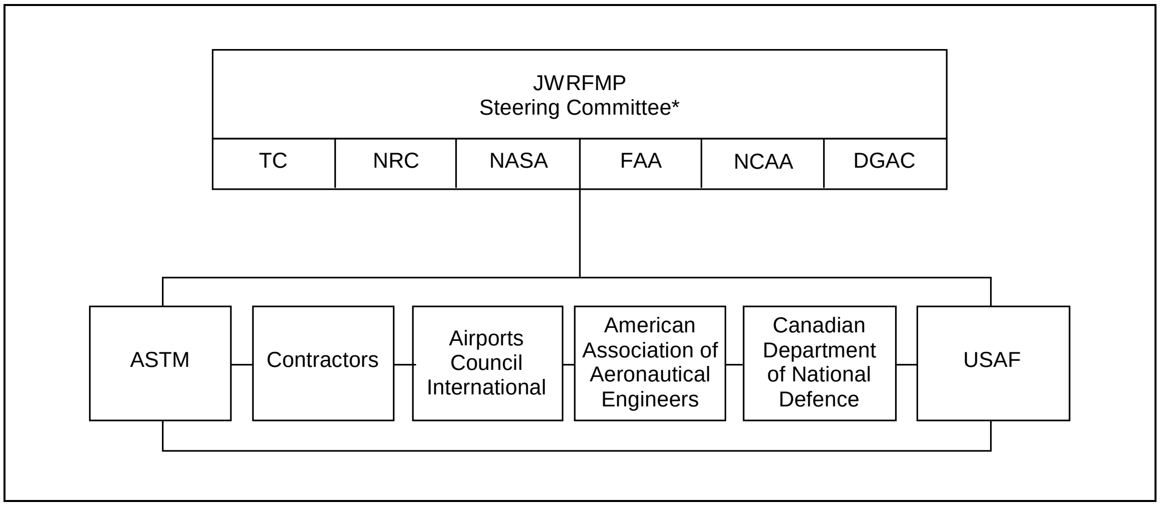

Figure 2 Overall Organizational Framework

** TC, FAA, and NASA chair the committee on a rotating basis.*

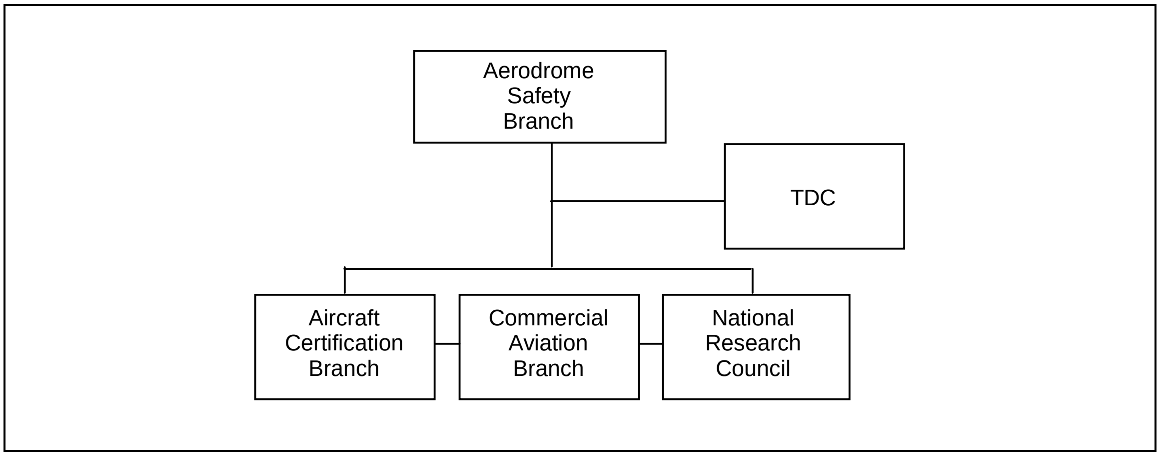

Figure 3 Canadian JWRFMP Management

2. THE PROGRAM

> *The prediction of aircraft performance parameters … needs to be engineered and tested for each type of aircraft on the surface types and conditions it may encounter in operation.*
>
> *Norsemeter Runway Friction Primer (5)*

To achieve the program objectives, the TC/NASA team planned a five-phase approach:

- acquisition of data through ground vehicle tests
- acquisition of data through tests with instrumented aircraft
- data analysis, correlation, and interpretation
- application of the knowledge gained to the development of an IRFI
- validation of the IRFI development

Meetings to disseminate information and to discuss the development of the IRFI are also part of the program plan.

The team decided on the Jack Garland Airport in North Bay, Ontario, as the ideal site for the winter tests. It has three runways, one 3000 m (10 000 ft) long, as well as suitable winter weather, without the cloud cover and lake-effect snow conditions that can hamper testing. In addition, it is not too busy to accommodate test procedures, the equipment and facilities are excellent, and security and maintenance services are available. Figure 4 shows the runway layout.

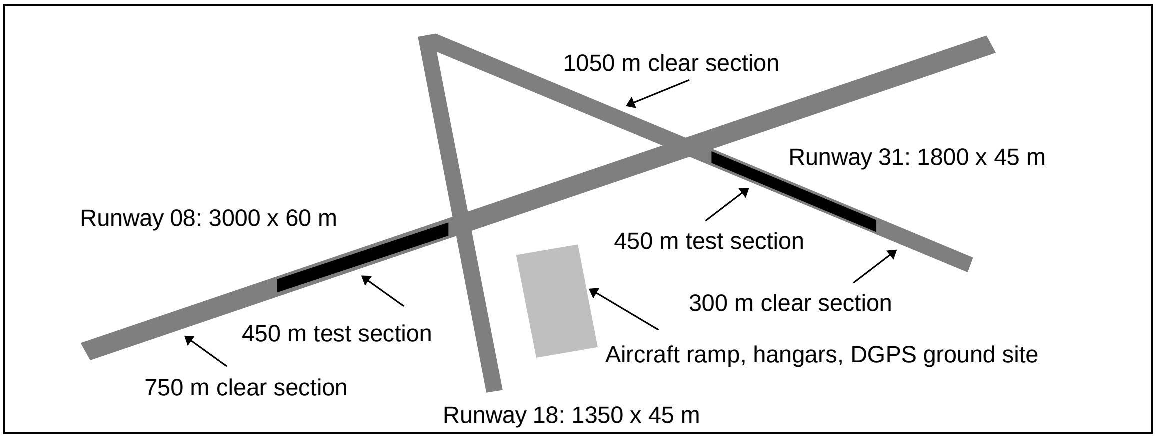

Figure 4 North Bay Airport Runway Layout
Source: NRC (10)

Aircraft tests cover three critical manoeuvres – takeoff, landing, and rejected takeoff (accelerate-stop) – on a variety of surfaces. Measured parameters include the braking coefficient, increment in drag, and speed for the test aircraft under different circumstances (e.g., flaps up, flaps down, braking, non-braking). Ground vehicle friction measurements are taken before and after aircraft runs, to compare the readings from aircraft and ground vehicles. Aircraft-based measurements are used to establish a theoretical model relating the coefficient of friction to operating distances and to develop precise computational tables. Figure 5 gives an overview of the program schedule.

2.1 1996 Tests

The first tests were held at the Jack Garland Airport in January 1996. The test aircraft was an NRC Dassault Falcon 20, instrumented with the following:

- transducers for measuring weight on wheels and brake pressure
- accelerometers and rate gyros in all three axes
- pitch roll and heading sensors
- radar altimeter

Differential GPS was used to directly measure the various segments of the actual landing distance and to provide the real-time aircraft positioning required for consistent precision approaches.

Four different ground friction measuring devices were used to measure the friction for each contaminated runway condition tested:

- a TC electronic recording decelerometer
- a Scottish GripTester fixed slip trailer
- a Norwegian RUNAR variable slip trailer
- a Swedish Saab friction tester

Runway conditions were artificially varied to allow the data collected to cover the greatest range possible. Data was collected for 12 flights on four different surface conditions.

Further tests began in March, with a B 737 from NASA joining the Falcon 20. Three more friction measuring ground vehicles also participated:

- a French IMAG friction measuring vehicle
- a NASA diagonal-braked vehicle
- an FAA K.J. Law runway friction tester

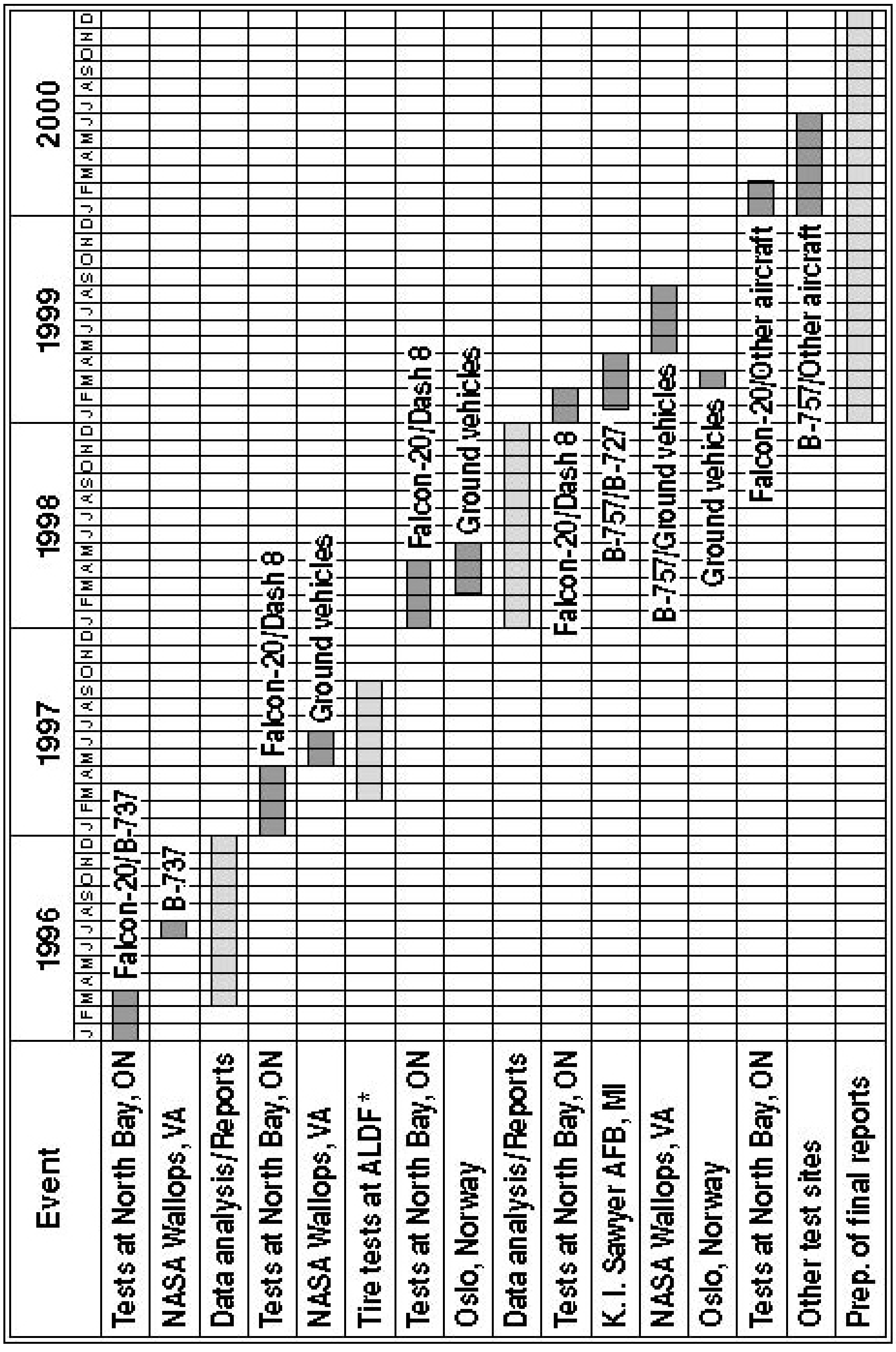

Figure 5 Winter Runway Friction Program Schedule
Source: NASA

The B 737 was instrumented to monitor the position of flight control surfaces, brake-system performance, engine speed and throttle settings, and aircraft acceleration, heading, and forward speed.

In August researchers collected more data from the B 737 and the NASA diagonal-braked ground vehicle in another set of tests on wet and flooded runways at the NASA Wallops Flight Facility on Wallops Island, Virginia.

The data collected was reduced and analysed. For the Falcon 20, the aircraft braking performance for each surface condition was then compared with the corresponding JBI and the friction readings of the ground vehicle devices. An equation to calculate braking distance as a function of approach ground speed and average deceleration was developed and used to calculate total landing distances from a 15.4 m (50 ft) height to a full stop for JBIs between 0.1 and 0.8 (6).

For the B 737, NASA investigated the harmonization of aircraft braking performance with ground vehicle friction measurements, aircraft parameter time history records, induced aircraft contaminant drag, and the effects of other factors on aircraft/ground vehicle friction performance. For a given runway condition, longitudinal acceleration data from non-braking tare runs were analysed to identify incremental components attributable to aerodynamic drag, tire-rolling resistance, engine idle thrust, and a change in the accelerometer’s zero value resulting from runway contaminant displacement/ impingement drag. Aircraft braking coefficients were derived using an average percentage of aircraft gross weight on the main-gear braking wheel (7).

An evaluation of the initial four ground friction measuring devices found that while correlation between the vehicles varies depending on surface conditions, the average slip ratio at peak friction on ice and snow is about double that for wet surfaces (8).

2.2 International Meeting 1996

In October 1996, TC and NASA sponsored IMAPCR ’96, an International Meeting on Aircraft Performance on Contaminated Runways. The objectives of the meeting were:

- to disseminate the results of the first year of the JWRFMP
- to exchange ideas and information with other stakeholders
- to provide a forum for developing the most effective test plans for the next winter season
- to establish the concept of an international runway friction index

The meeting was a great success, attracting 138 delegates from eight countries. They represented aircraft operators, regulators, pilots, ground friction measuring equipment manufacturers, and other related industries.

All agreed on the value of the program and on the concept of an international runway friction index. The workshop recommendations stressed the value of making the program results known at each step, of developing standardized definitions for contaminants and other pertinent factors, and of ensuring continuing input from stakeholders (7).

2.3 1997 Tests

The interest created by the first year of JWRFMP activities and the collaborative planning of the groups involved led to several key recommendations for 1997. The FAA provided an instrumented B 727 with flight test crew and de Havilland offered a Dash 8, the only turbo-prop in the tests. The Falcon 20 remained in the program. Additional friction measuring ground equipment was also used, expanding the possibilities for correlation:

- a Tapley and Bowmonk decelerometer
- NASA's instrumented tire test vehicle
- E-274 Skid
- Mu-meter
- BV-11 Skiddometer

The first 1997 tests began at the Jack Garland Airport on January 20 and continued until January 31. A second round ran from February 23 to March 7. Based on recommendations following the 1996 work, definition of the characteristics of winter contaminants was added to the program objectives (9).

Surface conditions included bare and dry, solid ice, slush, dry loose snow, wet snow compacted snow, and compacted snow with sand. Tests included 130 runs with aircraft and over 1000 with ground test vehicles, and a great deal of data was collected.

The Falcon 20 tests were ended early because of engine snow ingestion. However, 27 runs were completed. Analysis focussed on the anti-skid braking slip ratio, the aircraft braking coefficient with and without contamination drag, and verification of the JBI tables. Results showed inconsistencies compared to 1996, particularly in relation to contamination drag, underlining the importance of defining the physical characteristics of contaminants and of further extending the data base (10).

Analysis of the B 727 data included calculation of the contaminant drag and braking coefficient from the on-board accelerometer readings and from landing gear strain gauge readings. Theoretically, the difference between the two should give the fuselage impingement drag. Contamination drag was found to be nominally constant with ground speed on the surfaces tested. Scatter in the data led to recommendations for further investigations (11).

Analysis of the Dash 8 data included calculation of contaminant drag, as well as total displacement and impingement drag. An empirical model of contaminant drag as a function of velocity was developed and used to determine braking coefficients. A significant difference was found between measured and predicted drag. Since these tests were done on mechanically groomed surfaces, the data analysts raised the question of whether tests on natural snow may produce quite different results (12).

2.4 NASA Workshop 1997

In May 1997, NASA welcomed over 100 participants from 10 countries to a Tire/Runway Friction Workshop at the Wallops Flight Facility. As well as presentations and a task group meeting on development of the international runway friction index, the workshop featured 1000 friction test runs on 21 different surfaces. Close to 500 surface texture/roughness measurements were made, using 11 different measuring devices (13).

2.5 Steering Committee Meeting 1997

A meeting of the Technical Advisory Group Steering Committee was held in October 1997. The objectives of the meeting were:

- to review the JWRFMP results to date
- to coordinate the research activities of the various agencies involved
- to discuss technical input for the next winter season
- to discuss regulatory aspects of operations on winter contaminated runways
- to discuss the progress of the international runway friction index

The thirty-eight members attending the meeting included government and industry representatives from the U.S., Canada, Norway, Sweden, France, and the U.K.

After review and discussion of the 1997 test program, presentations covered:

- tentative plans for the 1998 tests and suggestions for research areas
- an update on the activities of the JAA Sub-Group on Contaminated Runways (CAA/JAA)
- an outline of methods for correlating aircraft and ground vehicle data (ESDU, U.K.)
- a methodology for establishing international definitions of contaminants (NRC)
- proposed Canadian requirements for operating on contaminated runways (Aerospace Industries Association of Canada)
- economic considerations related to operating on contaminated runways (Boeing, Airbus, and Canadair)
- a report on the progress of the IRFI (MFT, Norway)

The discussions following the presentations led to consolidation of plans for the 1998 tests and to a clearer picture of the problems to be addressed (13).

2.6 1998 Tests

A Falcon 20 and a Dash 8 were used in the 1998 tests at the Jack Garland Airport, along with 13 ground friction measuring vehicles. A series of tests were held from Jan. 25 to Feb. 13. The Falcon 20 remained available till March and further tests were conducted on natural wet snow and slush, on every occasion when snow accumulation at North Bay allowed. The surface conditions for the Dash 8 tests were rough ice, moderately smooth ice, and sand on moderately smooth ice.

The 10 separate test sessions with the Falcon 20 yielded important information on contamination drag, and showed that the aircraft’s anti-skid system is well designed for variable tire-surface friction conditions. Overall, braking performance correlated well with CRFI values (14).

For the Dash 8, a contaminant drag study was not possible, because no appreciable impingement or displacement drag occurs on the surfaces tested. Analysis concentrated on braking friction coefficients and wheel slip (15).

Friction factors measured by the ground vehicles were correlated. Results indicated that vertical load is an important parameter affecting friction measurements (16).

2.7 Tests in Norway 1998

A new facility – the Ottar K. Kollerud friction calibration test track – at Oslo Airport was the site for tests of a number of ground friction measuring vehicles in March 1998. This test track was constructed to facilitate calibration of the friction measuring devices used at Norwegian airports. These devices are taken to the facility at the end of the operating season for precision control and adjustments.

The test track has a wide variety of surface textures, an acceleration zone at each end, and is divided into 40 easily identified segments (17). Figure 6 shows the layout of the track.

Measurements taken on a variety of surfaces were compared and correlated. The results were used to provide input to the development of the IRFI (18).

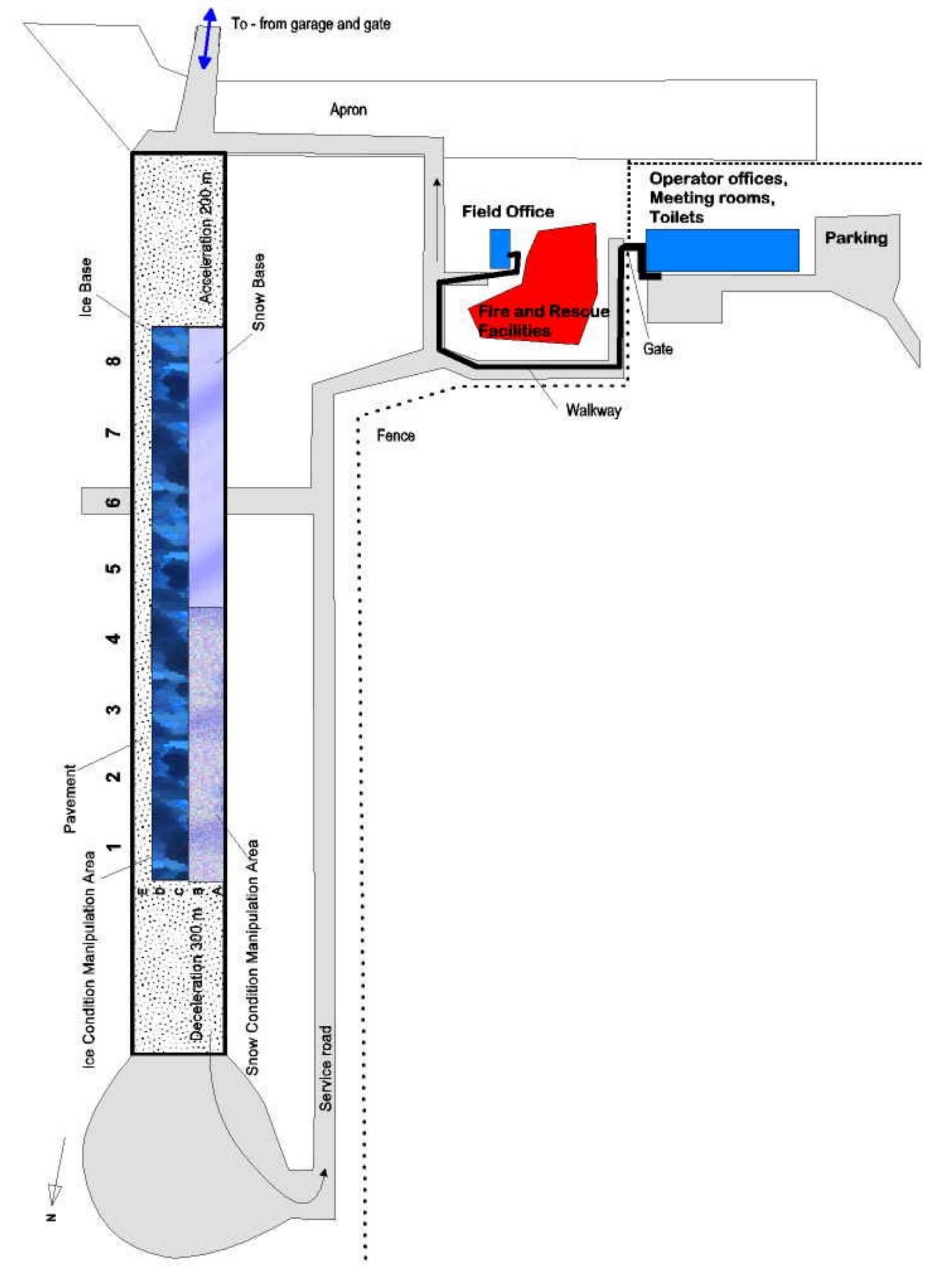

Figure 6 The Ottar K. Kollerud Friction Calibration Test Track Layout (17)

Not to scale

2.8 NASA Workshop 1998

The 1998 Tire/Runway Friction Workshop at the Wallops Flight Facility, held May 11-14, followed the same pattern as the 1997 event. Thirteen ground vehicles were tested on a variety of wet surfaces, and the friction values compared. The data collected was analysed to determine the minimum hydroplaning speed for each vehicle (19).

2.9 1999 Tests

Plans for the 1999 tests call for:

January 17-29	Tests with a Falcon 20 at the Jack Garland Airport
January 31 – February 5	Tests with a B 757 at the Gwinn-Sawyer Air Base, Michigan
February 28 – March 5	Tests with ground vehicles at the Oslo test track
May-August	Tests with a B 757 and ground vehicles at the Wallops Flight Facility

In support of the IRFI development, the two devices chosen to form a reference (see Section 3) will be available at all test sites, for further validation and for extension of validation to other surface measurement vehicles. The ITTV will also be included in the 1999 tests.

Further recommendations by the ASTM task group to be implemented in this year's tests include:

- first priority to tests on operational runway surfaces with bare ice or ice patches, and bare compacted snow or snow patches
- tests on a range of surfaces, temperatures, and wetness (dry, moist, wet)
- careful monitoring and measurement over full length of test surfaces
- pretesting to ensure homogeneity of test surfaces
- photographic documentation of surfaces before and after test runs, and after any change in surface conditions
- tests to validate the IRFI model

At the time of writing, only the first two sets of tests were complete.

At the Jack Garland Airport, from January 18-29, approximately 60 members of the JWRFMP research team were on hand for ground vehicle tests with a number of devices and an instrumented NRC Falcon 20. The ground test vehicles included:

- an instrumented tire test vehicle (ITTV)
- an IMAG trailer
- a GripTester trailer

- a road analyser & recorder (ROAR)
- a runway friction tester (RFT)
- a BV-11 skiddometer trailer
- a Saab friction tester
- an electronic recording decelerometer (ERD)
- a RUNAR trailer

These vehicles completed nearly 500 runs under 12 different snow and ice runway conditions to further validate the IRFI. The Falcon 20 performed 18 braking and contaminant drag (non-braking) test runs on four different winter runway surfaces. The team collected ground vehicle friction measurements before and after each Falcon 20 test series.

At the Sawyer Air Base, close to 70 team members were present when testing commenced on February 1. Because of weather restrictions early in the week, tests were extended to February 7.

The team conducted approximately 300 ground vehicle test runs on ten different snow and ice conditions with five ground vehicles:

- an ITTV
- an IMAG
- GripTester
- a Saab friction tester
- an ERD

NASA’s B-757 aircraft made 29 braking and contaminant drag test runs under seven different winter runway conditions.

The substantial database collected during this three-week test period should provide ample validation of the IRFI methodology and help to establish a reasonable relationship between IRFI values and aircraft braking performance.

3. IRFI DEVELOPMENT

> *The concept may seem overwhelmingly complex, but inexpensive digital computing tools will alleviate that complexity and hide it from users.*
>
> *Arild Andresen (20)*

In 1996, an ASTM task group with international representation from members of the JWRFMP team was established. The group first developed and agreed upon a concept for calculating an IRFI and determined the requirements for such an index. As work progressed, the testing program was adapted to address problems and to validate requirements.

After a substantial amount of data had been collected and analysed, a prototype computing tool was developed, based on the principle of correlating maximum friction values of a measurement device with those of a reference device. To be effective, such a tool would require both a reliable reference device and a standard contaminant classification.

In December 1997 a three-stage approach was proposed:

- harmonization of ground friction measuring devices to the proposed IRFI
- correlation of the IRFI to an aircraft braking coefficient applicable to individual aircraft types
- development of a Stopping Distance Ratio

In January 1998 work towards a reference device began. The consensus was that more data on slush and drag should be available before going ahead and that, in any case, development would be a lengthy process that would delay the progress of the IRFI. A virtual vehicle, representing a combination of several devices now in use, was proposed. In October 1998, the ASTM task group decided to use the average performance of the Saab friction tester 79 and the IMAG for the virtual reference vehicle.

An IRFI proposal was then submitted to the ASTM for preliminary review. The reviewers voiced a number of concerns. The 1999 test program is designed to address the questions raised (see Section 2.9). The results will be incorporated into a revised proposal, and the procedures leading to acceptance will continue.

4. ACHIEVEMENTS

New tools and understanding have created impetus for significant advances.

Norsemeter Runway Friction Primer (5)

In the years since its inception, the JWRFMP has made major steps towards its goals. It has developed the first extensive set of runway friction data for temperatures at and below 0^0 C and this data base is available to and recognized by the international aviation community.

The data acquired and the results of the program team's data analysis have led to the revision of the JBI. The CRFI, the revised version developed under the program, provides pilots with more accurate guidelines for calculating landing distances on contaminated runways.

Understanding of the many factors affecting friction coefficients, e.g., slush drag and impingement drag, has greatly increased and work towards defining contaminants and harmonizing ground vehicle friction measurements is well under way. The program work has established certain points, such as the primary importance of vertical load to friction measurements, and the negligible effect of ground speed on braking coefficients.

The program has gained increasing international support and recognition, and stakeholders are working cooperatively towards an approved IRFI, based on the most accurate and comprehensive data possible. The FAA Airports Group has already expressed its support.

5. FUTURE GOALS

> *We are looking for a model end product and a bridge between current and future technology and practices.*
>
> *Arild Andresen (21)*

The overall immediate goals are to develop and validate the IRFI and to achieve its official acceptance. All other goals are aimed at adding to the accuracy and scope of the index and thus hastening the approval process.

These include:

- to further expand the data base to encompass even more surface conditions and aircraft types
- to complete the harmonization of ground vehicle friction measurements
- to develop a reference vehicle
- to complete the characterization of contaminants, including the study of interfacial media, e.g., snow, ice, and chemicals, and their effects on aircraft performance

Following official acceptance of the IRFI by the International aviation community, it will be important to ensure that it is accepted and implemented by regulatory bodies, airport authorities, airline operators, and pilots.

A long-term goal is the development of an aircraft braking coefficient applicable to individual aircraft types and its correlation with the IRFI. With such tools in hand, the aviation community will be able to operate with much greater safety and productivity in winter conditions.

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