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FACTS & FRICTION

HISTORY OF FRICTION MEASUREMENTS AT AIRPORTS
BY
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History of friction measurements at airports

By

Gunnar Antvik

1 Introduction.

Historical review

Early it was realised that flight safety required some control of the slipperiness on the take-off or landing surface. Many of the surfaces were in the old days grass surfaces. Only a few airports had hard surface runways. Once upon a time (in the 1920:ies) one could read a sign at *Le Bourget* airport in Paris: "The largest airport in the world." Paris was a major city in the beginning of development of an air transportation system and *Le Bourget* was one of the first airports to have a hard surface runway. The need for friction measurements was not pronounced in those days.

The airport manager in many cases checked the friction conditions by making a skid test. If he was skidding too long he issued a ban on use of the airport. Due to accidents and incidents it was gradually found that better methods had to be developed for measuring friction of runway surfaces.

Why measure friction?

Flight Safety is the main reason for measuring friction. As the transport aeroplanes became larger it became also more important to check friction in a better way than making skid tests as mentioned above. *Scandinavia*, particularly Sweden, has taken a considerable part in the development of friction measuring technique.

Among reasons for friction measurements are:

- Determine friction characteristics of runways under Winter conditions
- Verify friction characteristics of new or resurfaced runways
- Assess periodically the slipperiness of paved runways when wet
- Assess the effect on friction when drainage characteristics are poor
- Assess friction of runways becoming slippery under unusual conditions

2 Friction Theory.

The simplest definition of friction is: The force **F,** needed to tow an object, creating a certain pressure **N**, against a flat horizontal surface.

Mathematically the friction coefficient: **μ** (mu) = **F / N**

When friction is measured at airports according to *ICAO* procedures in *Annex 14* and associated documents the friction measured shall be the MAXIMUM FRICTION. This friction is measured by having a certain slip.

Slip is defined: Slip = **V** ”free rolling wheel” - **V** ”test wheel” / **V** ”free rolling wheel”
Slip, **S**, is normally expressed in percent. 100 % slip thus means that the braked wheel is skidding. Maximum **μ** (mu) is measured between *10* and *20* % slip. More about slip is found in Section 3.1.3 below. Friction characteristics of a runway is very dependent on the *Structure* of the runway surface. One differentiate between *Macro-texture* and *Micro-texture*. A good macrostructure should have a mean depth of about 1 mm. The micro-texture is dependent on the aggregate used when the surface is being built. E.g. limestone will give very low micro-structure and a runway having such aggregate may become very slippery, especially when wet.

The *speed* has great effect on the friction of the runway when wet. If both macro-texture and micro-texture are poor the effect on friction of a runway when wet will be extremely dependent on speed. Naturally, if only one of the texture kinds is poor the effect of speed on friction will be less.

3 Operational friction measurements under Winter conditions.

Development of the ”Kollerud method” for friction measurements.

Measurements of friction on runways started from a pronounced need for doing so for flight safety reasons. Scandinavian Airlines System, *SAS*, started 1946 to operate **Douglas DC-4** aeroplanes on the then opened route from *Scandinavia* to *New York*. When in traffic the aeroplanes landed at the large military airport *Gardemoen.*

For maintenance reasons *SAS* had occasionally to operate the large **DC-4** aeroplanes also at the Oslo *Fornebu* airport. The main runway at this airport was then only 1200 m long with steep slopes at both ends. In order to avoid accidents at his airport the Airport Manager, Ottar Kollerud, started measurements of friction on the runway surface under Winter conditions before **DC-4** operation should take place.

Mr. Kollerud developed a method for friction measurements. According to this method a *big truck* was loaded with sand, accelerated to 30 km/h and then full brakes were applied resulting in *locked wheels*. Time and/or distance to a full stop were recorded.

From the recorded time, **T**, and distance, **S**, retardation, **r**, can be calculated:

$r = V/T \qquad r = V2/2S \quad (r:\ m/s^2 ,\ V: m/s\ \text{at brake application},\ T:\ s,\ S: m)$

Kollerud reported the retardation in **m/s²**. By test flights made by *SAS* it was found that the reported *retardation* determined according to the formulas above corresponded to approximately half the value for the retardation of the aeroplane. The test flights were made with aeroplanes of the type DC-4. Later tests and calculations have shown that this is valid also for a lot of other aeroplane types.

The Kollerud method for retardation measurements is included in the ICAO Airport Services Manual, ICAO Doc 9137-AN/898, Appendix 5. The method is somewhat modified. In the ICAO document one instead of retardation calculates the friction coefficient, **μ** (mu) . This is made by dividing retardation with $g = 9.81\ m/s^2$. Simplified corrections are given to convert the measured friction values from **μ** (mu) skid to **μ** (mu) max.

Naturally, units can be in the **ft** system. Retardation will have a different value and **g** has to be in **ft/s²**. US Air Force has used for friction measurements the *James Brake Decelerometer*, **JBD**, and that uses the ft-system. The JBD is corresponding to the Tapley- meter mentioned in Section 3.1.3 below.

It should be noted that according to the Kollerud method **skidding friction** is recorded. When *ICAO* discussed friction coefficient measurements it was concluded that the **maximum friction** shall be reported. This friction is recorded at a **certain slip**. Comments on this will be given later.

Need for friction measurements at other airports.

The airport manager, Bertil Florman, at *Bromma* airport soon realised that he had need for friction measurements also at his airport under Winter conditions. At *Bromma* there are roads with intense traffic at both ends of the main runway. *SAS* and other Swedish operators found a need for friction measurements also at additional Swedish airports. *SAS* wanted friction measurements also at Danish and Norwegian airports used by *SAS*. At this early time, late 1940:ies and the very first 1950:ies, friction measurements had not been recognised as a problem internationally.

Early development of friction measurement technique.

Mr. Florman, mentioned above, started at *Bromma* airport operational friction measurements using the Kollerud-method. Soon it was found that that this method could be used because of the low frequency of **DC-4** operation at *Fornebu*, but that frequent use of the Kollerud-method was too time consuming and was ruining the brakes and the tires of the trucks.

Therefore, Mr Florman introduced the Tapley-meter for operational friction measurements. The Tapley-meter is a **decelerometer** that easily can be installed in a car. The car is accelerated and at a selected speed the brakes are applied. When the wheels had become locked and skidding the recording of the Tapley-meter was read.

As the car did not need to be braked to a full stop the car brake and tire wear was less than with the Kollerud method. The Tapley-meter method was also far less time consuming and its introduction was a great step forward in friction measuring technique. Friction characteristics were normally recorded at nine points along three lines, namely along the centerline and five meters on each side of this line.

Although the introduction of the Tapley-meter method was a great step forward in friction measuring technique Mr. Florman asked his friend the Chief Engineer, Mr. Kullberg, at the *Swedish Road Research Institute*, if he could develop a unit that would provide a continuous record of the friction along the runway.

Mr. Kullberg proposed to Mr. Florman to introduce his **Skiddometer** method to record runway friction at *Bromma* airport. The skiddometer method would mean that the maximum-friction was being recorded instead of the skidding friction as up to that time had been the case with the Kollerud and Tapley-meter methods.

With a research Skiddometer, **BV-1**, Mr. Kullberg had shown as early as 1939 that on good summer roads the maximum friction for automobile tires is recorded at about 17 % slip, i.e. the peripheral speed of the braked wheel is 17 % lower than the peripheral speed of the free rolling wheels.

An advantage of the Skiddometer method is that 80 to 85 % of the braked energy can be fed back to other wheels as a propelling force. During normal braking heat generation is a problem, especially when using the Kollerud method for friction measuring but also when using the Tapley-meter method.

Mr. Florman decided in the early 1950:ies to introduce the Skiddometer for operational friction measurements at Bromma airport. A special Skiddometer, **BV-2**, was built. It was a trailer. *SAS* expressed the view that the skiddometer had to be a heavy vehicle in order to reasonably represent normal transport aeroplanes of that time. As a reasonable compromise was decided to load the measuring wheel with *1000 kg* and the total weight of the Skiddometer **BV-2** *was 3000 kg*.

The **BV-2** had three wheels on the same axle. All three wheels had their own bearings and the shaft was equipped with two universal joints allowing the middle wheel, the measuring wheel, to have a smaller diameter than the two outer wheels. The diameters of the tires were chosen to result in a 17 % slip.

As the braking force under good friction conditions can be *500 to 600* kg or even more, if the load on the measuring wheel is *1000* kg, it was very important that 80 to 85 % of this force was fed back to the outer wheels and used to assist in towing the trailer.

The **BV-2** was used at Bromma for many years for operational friction measurements.

Through the introduction of the Skiddometer method Swedish procedures were changed to measuring the **maximum friction** instead of the skidding friction that had been used up to the introduction of the Skiddometer method. Measuring and reporting the maximum friction is in line with ICAO procedures.

However, the Tapley-meter can be set to register the maximum deceleration. This deceleration occurs when the wheels during their spinning down are passing the optimum slip. As the brakes often are adjusted a little bit differently one does not normally record the mathematical maximum friction but the recorded friction is for practical purposes to be considered as the maximum friction. Since the introduction of the Skiddometer method when using the Tapley-meter method for friction measurements the Tapley-meter is set to register maximum friction. This has been welcomed by the airport authorities as it has further reduced the time needed for a test and also reduced the brake and tire wear.

Further development of the Skiddometer has taken place. As experience showed that friction could also be measured with lower measuring wheel load than used on the BV-2, 1 metric ton. The measuring wheel load is *105* kg on the present BV-11.

As the administrations of busy airports found that trailers had certain disadvantages SAAB started in the late 1960:ies to develop a friction measuring unit, the **SAAB Friction Tester, SFT**. A fifth wheel, the friction measuring wheel, was installed in the rear of a SAAB car model 99.

The measuring wheel was connected to the rear wheels of the car via chains and sprocket wheels. This means that the skiddometer principle is used and some 80 to 85 per cent of the braking force is used as propelling force. By selecting the teeth on the sprocket wheels and the diameter of the measuring wheel suitably the desired slip could be obtained. The slip of the **SFT** is *12* %. This slip is selected for operational measurements in order to reduce tire wear.

The wheel load on the **SFT** is *140* kg. As in the case of the Skiddometer trailer further development of the **SFT** has taken place. The **SFT** is since long introduced in the *ICAO* documents and *ICAO* changed the name **SAAB Friction Tester** to **Surface Friction Tester**, which also can be abbreviated **SFT.**

Both the **BV-11** and the **SFT** *use grooved tires with a tire pressure of 700 kPa*. These tires were developed for use in operational friction measurements and is called the AERO tire.

It was shown by tests made by the *Aeronautical Research Institute*, Stockholm, Sweden, that reliable calibration friction measurements results also were obtained, when the runway surface was contaminated by some loose snow or slush. Provided the friction measurements is made with a **SFT** or **BV-11** with a *grooved tire, with tire pressure 700 kPa* and a test speed of 95 km/h is used. Now in Sweden, we have more than 15 years of experience, using this method.

Early reporting technique.

The early reporting technique was developed in co-operation between the *Airport Authority* at *Bromma Airport* and *SAS*. This took place in the early 1950:ies. During a landing the friction characteristics of the middle portion and the far end of the runway are of primary importance. This led to reporting friction characteristics for three parts of the runway seen in the direction of landing. Soon the thirds were called A, B, and C. A is always called the low number runway end. An aeroplane landing from the high number direction got the report on friction in the order C, B, and A.

SAS and domestic Swedish operators understood what the friction numbers meant to them. However, operators coming in to e.g. *Bromma* airport did not understand what the reported numbers meant. Therefore, the expressions **Good, Medium,** and **Poor** were introduced.

SAS sent out a questionnaire asking for information from pilots on how they experienced information on braking action, i.e. friction, and also on controllability in crosswind.

About 3000 answers on this questionnaires were received. The answers showed that when a friction coefficient of 0.40 or above had been reported there were no pronounced problems on braking or controllability in crosswind. When 0.25 or lower had been reported the problems became severe.
As a result of this study in Sweden was introduced the terminology:

Good	0.40 and above
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 and below

As can be seen from the table we consider that no more than two significant figures should be reported. More than two figures would give a false impression of accuracy of the friction measuring equipment.

International presentation of Scandinavian procedures.

International Air Transport Association, *IATA*, arranged **1952** a meeting where *SAS* was given the opportunity to present the Scandinavian experience about knowing the friction characteristics of a runway and the procedures for measuring and reporting friction characteristics at airports. Discussions dealt only with operational measurements as the need for measuring of friction also on wet runways had not yet been recognised.

SAS reported at the meeting of the new findings. The result of the meeting was that *IATA* formulated that there is an operational need for reliable and uniform information concerning the friction characteristics of ice- and snow-covered runways.

Participating in the meeting was also a representative of *NASA*, Mr. Walter B. Horne. Co-operation between NASA and Sweden was started on research in the field of friction measurements at airports. This co-operation still exists.

At ICAO fifth Aerodromes and Ground Aids Divisional meeting, 1952, AGA 5, *IATA* forwarded its conclusion as presented above. The conclusion made by IATA was accepted and is still found in the now valid edition of ICAO Annex 14, Aerodromes, July 1995, as paragraph 6.1 of Attachment A to the Annex 14.

The *ICAO* work on development of specifications on operational friction measurements at airports that was started at the AGA 5:th Divisional meeting 1952 has continued over the years and gradually lead to the specifications now found in Annex 14. As an example of how hard it was in the beginning to get international understanding of the need for a pilot to get information on friction characteristics of a runway, that he intended to use, may be illustrated by the following happening at an ICAO meeting.

When discussing friction on runways the Swedish representative asked the meeting how the other countries represented found out friction of their runways. The answer was: ”We ask the pilot!” The counterquestion was: *”What about the first pilot in the morning?”* The answer was*: ”He has to find out!”* In the continued discussion it was agreed that this was not a satisfactory state of affairs to let him find that the runway surface was too slippery. After this *ICAO* started the work leading to what is now found in the *ICAO* documents on operational friction measurements at airports.

International recognition of Scandinavian procedures.

An international recognition of the *Scandinavian* procedures of measuring of friction characteristics at airports was when the *Flight Safety Foundation* awarded the *Admiral Louis de Florez Flight Safety Award* to the spokesman of *SAS* and the *Swedish Civil Aviation Administration* at numerous *IATA* and *ICAO* meetings since the early 1950:ies.

ICAO Annex 14 specs. related to Operational friction measurements.

Snow, slush or ice on a runway

Note 1 - The intent of these specifications is to satisfy the **SNOWTAM** and **NOTAM** promulgation requirements contained in *Annex 15*.

Note 2 - This Note deals about sensors on runways. Not of interest in this context.

2.9.9 Recommendation. Whenever a runway is affected by snow, snow or ice, and it has not been possible to clear the precipitant fully, the condition of the runway should be assessed, and the friction coefficient measured.

Note 3 - Guidance on determining and expressing the friction characteristics of snow and ice-covered paved surfaces is provided in Attachment A, Section 6. (Ref. 3.3 below.)

2.9.10 Recommendation. The readings of the friction measuring device on snow-, slush-. or ice-covered surfaces should adequately correlate with the readings of one other such device.

Note 4 - The principal aim is to measure surface friction in a manner that is relevant to the friction experienced by an aircraft tire, thereby providing correlation between the friction measuring device and aircraft braking performance.

2.9.11 Recommendation. This recommendation deals with measurement of depth of contamination on an runway. Not of interest in this context. As said in the Note to paragraph 2.9.9 above ICAO Annex 14 contains in Attachment A, Section 6, also material on determining and expressing the friction characteristics of snow- and ice-covered paved surfaces. The material in the Attachment A is of an advisory nature.

Paragraph 6.1 Draws attention to the fact that the best way to get accurate and reliable indications of friction is to use special friction measuring devices.

In **paragraph 6.2** attention is drawn to that friction coefficient should be measured when conditions change.

The friction value recorded should be the maximum value according to **paragraph 6.3.** This value is recorded when a wheel is slipping but still rolling.

Paragraph 6.4 draws attention to material in *Airport Services Manual, Part 2,* on correlation between friction measuring devices.

In paragraph 6.5 attention is drawn to the fact that the results of friction measurements are necessarily related to the design and construction of each friction measuring device as well as to the surface being measured and the test speed used.

Paragraph 6.6 contains the table presented in 3.1.4 above. Code numbers *5, 4,3, 2,* and *1* for friction's Good, Medium to Good, Medium, Medium to Poor, and Poor have been added for use in **Notams** and **Snowtams** according to Annex 15.

Good means that the pilot should not experience any difficulties when manoeuvring his aeroplane. In most cases friction is better than "Good", i.e. 0.40, under summer conditions.

Paragraph 6.7 says that friction necessarily has to be presented for each third of a runway. This is in line with the Swedish procedure mentioned in Section 3.1.4 above. In fact, Sweden proposed this procedure to ICAO and it was included in the ICAO Annex 14. Attention is also drawn to that information on friction should on request be made available also for stopways, where applicable.

In **paragraph 6.8** is said that continuous friction measuring devices, e.g. **Skiddometer, Surface Friction Tester, Mu-meter, Runway Friction Tester, or Grip Tester,** can be used for measuring the friction values for compacted snow- and ice-covered runways. The **paragraph 6.8** also informs that Tapley-meter or equivalent may be used under certain conditions. It is also specified how a type of friction measuring equipment not listed in the ICAO documents can be accepted for use.

In addition, **paragraph 6.8** also says that many types of friction measuring equipment may under certain conditions give misleading friction values. This occurs when there is some loose contamination on the runway surface. This fact is why the Swedish procedures were developed. They have been found fully satisfactory during more than 15 years of operation on Swedish airports and thereby avoiding passenger inconvenience and saving money to Airport Administrations and Operators by reducing number of diversions to alternate airports or cancelled flights.

ICAO A. S. M. Part 2, ref. to Operational friction measurements.

ICAO Airport Services Manual, Part 2, ICAO Doc. 9137-AN/898, provides a lot of very useful information.

Chapter 1 presents guidance material of a general nature. The runway surface characteristics and aeroplane braking performance is commented and the need for assessment of runway surface conditions is stressed. Slip and locked wheel friction is commented.

The three zone concept as developed by *NASA* and *FAA* is presented in Figure 1-3. According to this concept **Zone 1** is where water is being squeezed out, dynamic pressure carries the load, and friction is zero, in **Zone 2** there is a very thin layer of water still left and viscous pressure carries the load, and the friction is practically zero, in **Zone 3**, finally, all water has been squeezed out and friction is as on a dry surface. This means that the recorded friction is the same proportion of the **μ** (mu) max. as is **Zone 3** to the total contact area.

This 3-zone concept has contributed very much to understanding what takes place when a runway surface is wet, which is the subject of Section 4 below.

Chapter 2 presents an assessment of basic factors affecting friction and **Chapter 3** deals with determining and expressing friction characteristics of wet paved surfaces.

Chapter 4, provides guidance on the uniform use of test equipment to get compatible test results. Guidance on reporting friction is also provided.

Chapter 5 presents criteria for new friction measuring devices as well as correlation between friction measuring devices.

In **Chapter 5** of the Manual you can find presentations of various types of friction measuring devices. Among other the two types of *Swedish* friction measuring devices, the **BV-11** and the **Surface Friction Tester**.

Chapter 6 deals with collection and dissemination of pavement surface state information. A so-called *Snowtam proforma* is presented, which is a very effective way for dissemination of conditions at a certain airport to other airports needing the information. This is a very big task and the snowtam proforma presents a very rational way to provide the information.

Snow removal and ice control is the subject of **Chapter 7** and **Chapter 8** deals with Rubber removal. **Chapters 9 and 10** are dealing with clearance of Oil and/or Grease and Debris. In Appendices 1 to 7 you can find useful information on various subjects.

The material in the Manual is quite comprehensive and, therefore, reference is made to the Manual itself.

4 Calibration friction measurements on runways when wet.

Accidents and incidents leading to new rules.

An accident in the **1970:ies** at *Los Angeles International Airport* clearly showed that this accident would not have occurred, if a system of periodical measurements of friction characteristics of runways when wet had been in use.

The accident resulted in complete loss of a **Jumbo-jet DC-10.**

The accident investigation showed that the **touch down zone** was extremely slippery under wet conditions. The accident would not have occurred, if the unsatisfactory friction characteristics had been known and corrective action taken.

It occurred also a lot of other accidents and incidents, where slipperiness of runways when wet had been a contributing factor. *ICAO* started work on including specifications related to friction measurements on runways when wet in *Annex 14*. For the AGA 8:th Divisional meeting 1981 a special working group, the *Runway Surface Condition Study Group, RSCSG,* prepared proposals for material to be included in *Annex 14*.

4.2 Friction measuring technique on runways when wet.

When studying friction measuring technique on runways when wet, it was soon found that the measuring equipment had to make a continuous measurement of friction. It also had to have capability of self wetting the runway.

When discussing the self wetting capability within the ICAO RSCSG, it was argued that this requirement was not necessary as in most countries it rains so often that artificial wetting was not necessary. However, if depending on natural rain one would not know what is the water depth during the friction measurement. This argument was accepted and self-wetting features became an agreed requirement.

4.3 ICAO Annex 14 specs. related to Calibration friction measurements.

2.9.5 Information that a runway or portion (100 m or more) thereof may be slippery when wet shall be made available. (Remark: as a ”portion” is considered 100 m or more.)

2.9.6 A runway or portion thereof shall be determined as being slippery when wet when the measurements specified in 9.4.4 show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State.

Note: Guidance on determining and expressing the minimum friction level is provided in Attachment A, Section 7.

Information on the minimum friction level specified by the State for reporting slippery runway conditions and the type of friction measuring device used shall be made available.

Note: Guidance on friction characteristics of new runway surfaces is given in Attachment A, Section 7. Additional guidance is included in *the Airport Services Manual, Part 2.*

ICAO Annex 14 has, as said in Notes quoted above, in Attachment A material on determination of friction characteristics of wet paved runways. What is said in the Attachment A is Guidance material.

Paragraph 7.1 says that friction should be measured to:

a) Verify the friction of new or resurfaced paved runways when wet;
b) Assess periodically the slipperiness of paved runways when wet;
c) Determine the effect on friction when drainage characteristics are poor; and
d) Determine the friction of paved runways that become slippery under unusual conditions.

Paragraph 7.2 deals with friction on new or resurfaced runways. The friction test should be made on a clean surface.

Paragraph 7.3 draws attention to that friction on runways when wet should be checked periodically in order to identify runways having unsatisfactory friction characteristics when wet. States should define what minimum friction level it considers acceptable

The minimum friction value should be published in the *Aeronautical Information Publication, AIP*. When the friction found is below this value a *NOTAM* should be issued and pilots should be informed that the runway surface may be slippery when wet.

The State should also establish a level for maintenance planning. When friction is below this level corrective action should be initiated. However, when the friction level found is found to be below minimum level corrective action must be taken without delay.

Friction measurements should be taken at intervals that will ensure identification of runways in need of maintenance before the condition becomes serious, or that the friction of the runway when wet has not fallen below the minimum friction level specified by the State.

The time interval between measurements will depend on factors such as: aircraft type and frequency of usage, climatic conditions, pavement type, and pavement service and maintenance requirements.

Paragraph 7.4 says that for uniformity and to permit comparison with other runways friction tests of existing, new or resurfaced runways should be made with a continuous friction measuring device provided with a smooth tread tire. The device should have a capability of using self-wetting features to enable measurements of the friction characteristics of the surface when wet to be made at a water depth of at least 1 mm.

Sweden and the Netherlands *have decided to use the grooved tire with pressure 700 kPa, used for operational friction measurements, also for calibration friction measurements. Sweden will use the friction values for 65/95 km/h test speed 0.70/0.60 for new surfaces, 0.50/0.40 for maintenance planning and 0.40/0.32 as minimum friction level.*

Paragraph 7.5 deals with runways having depressions where water pools may be formed during natural rain. Friction should be measured to identify problem areas that could induce aquaplaning. If tests can not be made in natural rain conditions this condition may be simulated.

Paragraph 7.6 calls for friction measurements under unusual conditions, e.g. after a long dry period, when a runway, which under normal conditions is acceptable, may be slippery when the surface is becoming wet.

Paragraph 7.7 draws attention to that corrective action is important also when only part of a wet runway has become slippery. Information has to be promulgated as necessary.

In paragraph 7.8 attention is drawn to the fact that friction of a wet runway is very speed dependent. However, as speed increases the drop in friction is less. The reduction of friction is dependent upon the runway texture. If the runway has good macro-texture the friction will be less sensitive to speed. On the other hand, a low macro-texture will make friction more sensitive to speed. Tests should be made at speeds revealing the friction/speed variations.

Paragraph 7.9 presents values to be used as guidance to States when specifying friction values for runways when wet for new or resurfaced runways, maintenance planning, and minimum friction level.

The two friction measuring tires mounted on the μ (mu) -meter were smooth tread and had a special rubber compound, i.e. **Type A**. The single friction measuring tires mounted on the **Skiddometer, Surface Friction Tester, Runway Friction Tester** and **Tatra** were smooth tread and used the same rubber compound, i.e. **Type B**. The **Griptester** had a similar tire but the size was smaller, i.e. **Type C**. Specification of the tires are given in *Airport Services Manual, Part 2*. It is desirable to test friction of a runway when wet at more than one speed. (According to Swedish tests friction has to be tested at least at two speeds, preferably at three speeds.)

Table from *paragraph 7.9, Attachment A, Annex 14,* showing friction values to be used by States when specifying friction values for use in the State.

Test Equipment	Tire Type	Tire Pressure kPa	Test speed Km/h	Water depth mm	New surface	Maintenance planning	Minimum friction level
Mu-meter trailer	A	70	65	1,0	0,72	0,52	0,42
	A	70	95	1,0	0,66	0,38	0,36
Skiddometer	B	210	65	1,0	0,82	0,60	0,50
Trailer	B	210	95	1,0	0,74	0,47	0,34
Surface Friction	B	210	65	1,0	0,82	0,60	0,50
Tester Vehicle	B	210	95	1,0	0,74	0,60	0,34
Runway Friction	B	210	65	1,0	0,82	0,60	0,50
Tester Vehicle	B	210	95	1,0	0,74	0,54	0,41
TATRA Friction	B	210	65	1,0	0,76	0,57	0,48

Tester Vehicle	B	210	95	1,0	0,67	0,52	0,42
GRIPTESTER	C	140	65	1,0	0,74	0,53	0,43
Trailer	C	140	95	1,0	0,64	0,36	0,24

Paragraph 7.10 states that friction values in the table are absolute values and are intended to be applied without any tolerance.

Paragraph 7.11 deals with types of friction measuring equipment not listed in the table. Such equipment has to be correlated to at least one of the listed types of equipment.

A. S. M. Part 2, material on Calibration friction measurements.

The *Airport Services Manual, Part 2,* provides further guidance material related to calibration friction measurements.

Chapter 3 of the Manual, Part 2, exclusively deals with Determining and Expressing Friction Characteristics of Wet Paved Surfaces.

There are several reasons to measure the friction characteristics of a wet paved runway. These are:

a) Verify the friction characteristics of new or resurfaced paved runways.
b) Assess the slipperiness of paved runways
c) Determine the effect on friction when drainage characteristics are poor; and
d) Determine the friction of paved runways that become slippery under unusual conditions.

Descriptions of various types of equipment for friction measurements is given in *Chapter 5 of the Manual, Part 2,* as mentioned in Section 3.3 above. It should be noted that equipment to be used for Calibration friction measurements must be able to provide continuous record of friction and be equipped with selfwetting features.

5 Concluding remarks.

In the **1940:ies** development started in Scandinavia of systematic control of friction characteristics of runways. At first the Scandinavian work was concentrated on friction measurements in Winter time, i.e. what is now called Operational friction measurements.

IATA and *ICAO* accepted the Scandinavian findings of the need to provide information on friction characteristics of runways to operators and pilots.

Development of specifications on operational friction measurements was started by *ICAO* in close co-operation with *IATA*. As Sweden and SAS had initiated the *ICAO* work we naturally have participated in the *ICAO* work and presented Scandinavian experience, test results, and procedures to *ICAO*.

A reason for participation in the flight safety work related to operational measurement of friction was that major States expressed a desire that smaller States should contribute to the flight safety work by selecting a certain part of the development of *ICAO* material related to flight safety. To select the snow and ice problem at airports was quite natural as we have long Winters. As a parallel to this reason for flight safety work may be mentioned the outstanding work Canada has made on the bird problem.

The result of the work on friction measurements we now find in Annex 14 and associated documents is commented in Sections 3 and 4 above.

Further work on development of friction measuring technique goes on with the aim of finding better correlation between friction measuring equipment readings and airline performance. So far the work has been limited to calibration measurements.

To promote the work *NASA* arrange yearly workshops at *Wallops Research Centre in Virginia, USA*, with participants from a lot of countries around the world. As mentioned earlier Sweden has contributed to the *ICAO* work and two of the six types of friction measuring devices listed by *ICAO* in the table in 4.3 above are of Swedish design and manufactured in Sweden and, for this among other reasons, Sweden has participated in the three workshops *NASA* has held so far.

I hope that the work for safer airtransports will continue with undiminished effort in the years to come.

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G.A.