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Modelling of aircraft braking coefficient from IMAG friction measurements

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Abstract

Aircraft braking performance depends strongly on runway surfaceconditions which can be severely degraded under adverse weather. Runway surface conditions are commonly characterized byfriction measuring devices. To provide aircraft pilots with relevant information assisting them in landing or take-off operations, friction measurements must be reliably related to aircraft braking coefficient. However, friction results are highly scale-dependant (in terms of speed, mass, tire dimension and pressure, etc.) and differ between friction measuring devices and aircraft. This paper presents a method aiming at solving the scale effect, and making more reliable the prediction of aircraft braking coefficient from ground friction measurements. Works are based on the so-called ESDU model which is now used as a reference. The aim is to adjust friction coefficient – using the model – to aircraft characteristics such as speed, mass and tire pressure. The approach is applied to the IMAG friction measuring device and tested on results from the Joint Winter Runway Friction Measurements Program.

*Keywords:*Friction ; Joint Winter Runway Friction Measurement Program ; ESDU ; aircraft braking ; drag force ; IMAG ; contaminated runway

Résumé

Les performances de freinage des avions sont fortement dépendantes de l'état de surface des pistes, qui peut être sévèrement dégradé lorsque les conditions météorologiques sont mauvaises. Les appareils de mesure du frottement sont un outil largement utilisé pour caractériser cet état de surface. Afin de pouvoir fournir aux équipages des informations pertinentes pour calculer leurs performances opérationnelles, les résultats de mesure des appareils de mesure du frottement doivent être représentatifs des coefficients de frottement des avions. Cependant, les résultats des mesures de frottement sont dépendants de la vitesse, la masse, la charge, les dimensions des pneumatiques et leur pression de gonflage… L'effet d'échelle existant entre les appareils de mesure du frottement et les avions explique que le coefficient de frottement mesuré soit différent de celui ressenti par les avions. Cet article présente une méthode qui a pour objectif de résoudre ce problème d'échelle, afin de rendre plus fiable la prévision des coefficients de frottement des avions à partir des mesures des appareils au sol. Les travaux s'appuient sur le modèle ESDU, qui est une référence reconnue. L'objectif est d'ajuster – à l'aide du modèle – les coefficients de frottement mesurésaux caractéristiques des avions telles que la vitesse, la masse et la pression des pneumatiques. Cette approche s'appuie sur l'utilisation de l'appareil de mesure IMAG et est testée sur les résultats du JWRFMP.

*Mots-clé:*Adhérence, Joint Winter Runway Friction Measurement Program ; ESDU ; freinage avion ; force de trainée ; IMAG ; piste contaminée

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Nomenclature

CRFI	Canadian Runway Friction Index
IRFI	International Runway Friction Index
C_D	Drag coefficient
d	Contaminant depth (m)
D, w	Tire diameter (m) and width (m)
F_m, F_v	Measured horizontal and vertical force (N)
F_B, F_R	Braking and rolling force (N)
$F_{Cont.Drag}$, $F_{Displacement}$, $F_{Compression}$	Contaminant, displacement and compression drag force (N)
g	Gravity (m/s^2)
MuR	Recommended friction coefficient
p, p_a	Tire inflation pressure (absolute) and atmospheric pressure (N/m^2)
R	Wheel radius (m)
T	Torque (N.m)
V, v	Ground and slip speed (m/s)
Z	Vertical load (N)
σ, ρ	Contaminant specific gravity (dimensionless) and density (kg/m^3)
ξ_0, ξ_1, η_0, η_1, η_2, γ_0	Empirical constants ($N^{-1/3}$, $m^{-1}.N^{-1/3}$, $N^{1/3}$, $N^{1/3}.m^{-1}$, dimensionless, m^{-2})
μ_{Total}, μ_{Slip}, μ_{Roll}, $\mu_{Cont.Drag}$, μ_{Ref}	Total deceleration coefficient, braking coefficient, rolling resistance, contaminant drag coefficient, reference friction coefficient
$\mu_{Displacement}$, $\mu_{Compression}$	Displacement and compression drag coefficient
μ_{Force}, μ_{Torque}	Friction coefficient measured from force and torque sensors

1. Introduction

Aircraft operational performances, at landing or take-off, are strongly dependant on runway surface conditions. Bad weather conditions may severely degrade runway surface condition. For obvious safety reasons, when such events appear, methods and means must be implemented to characterize runway surface condition and to provide pilots with relevant information about how well the surface will perform.

Norheim (2004) provides a complete history of studies about relation between aircraft braking capability and ground friction measuring devices on snow- and ice-contaminated runways. Several relations have been proposed through more than 50 years of research. First approved method, known has the “full stop” method consisted in measuring the stopping distance of a 10 wheeled GMC truck with skidding wheels. The following rule was established: “The effective aircraft friction coefficient is half the measured friction coefficient”.

As friction measuring devices was developing in several countries, the need for harmonization of reporting arose. Different tables have been developed, to relate aircraft braking capability to different friction measuring devices. The most popular table is the International Civil Aviation Organisation (ICAO) table, which can be found in ICAO documents (ICAO, 2009). ICAO table has been developed using a decelerometer type device, known as the Tapleymeter. Its use is strictly limited on runways covered with ice or compacted snow. The authorities and industry have not been convinced by these correlations, as United States National Transportation Safety Board (NTSB) (quotes by Norheim, 2004) stated in 2002: “Technology currently does not exist to convert the friction index to an operational tool that can be used daily”.

As research effort was going on, the effect of drag forces on slush- or dry snow-contaminated runways was emphasized. Drag forces effects on aircraft have been extensively studied by National Aeronautics and Space Administration (NASA) (Horne et al., 1960) and National Aerospace Laboratory (NLR) (Van Es, 1998, Giesbert, 2001). It is acknowledged that on contaminated runways, the presence of a non-solid contaminant have a double effect on the aircraft: it reduces the friction and generates drag forces, contributing to the deceleration. The European project CONTAMRUNWAY (Van Es, 1998) studied precipitations drag calculations and proposed a model which is now implemented in European Certification Specifications CS 25 – Large Airplanes. However, few works have been carried out on the drag force effect on ground friction measuring devices. Drag force is now seen as disrupting friction readings, resulting in following recommendation from United Kingdom Air Traffic Services Information Notice (ATSIN) (quoted by Norheim, 2004): “In conditions of slush or deposits of wet snow, friction measuring devices can produce inaccurate readings. If queried, aircraft crews should be informed that measurements of coefficients of friction are unreliable in conditions of slush and wet snow, consequently, braking action assessments are not available". It results the question of relating a friction index to aircraft braking performances on contaminated runways is still wide open.

An extensive work has been carried out during the Joint Winter Runway Friction Measurement Program (JWRFMP) (Wambold & Henry, 2003). It aimed at developing an international friction index, called International Runway Friction Index (IRFI), to relate friction measurements to aircraft braking coefficients. This index was experimentally determined from friction trials and consisted in linear correlation. However, both friction and drag forces are scale dependent (in terms of speed, mass, tire dimension and pressure, etc.) and differ between friction measuring devices and aircraft.

It can be learned from the JWFMP that: 1/ linear modelling do not allow a correct account of the scale-effect, and 2/ drag should be differentiated from the friction when performing and analysing friction measurements.
This paper presents a method aiming at making more reliable the prediction of aircraft braking coefficient from ground friction measurements. It is based: 1/ on the use of the so-called ESDU model to relate ground friction measurement to aircraft friction coefficient, and 2/ on the use of the IMAG device. ESDU model allow prediction of rolling resistance, drag force and braking on dry, wet and snow- or ice-contaminated runways. The aim is to adjust friction coefficient – using the model – to aircraft characteristics such as speed, mass and tire pressure, to solve the identified scale effect problem. IMAG device is used because it is equipped with several sensors and is able to distinguish between friction and drag force. Moreover, an extensive database exists for the machine because of more than 20 years of use and its participation as a reference to JWRFMP.

First part of the paper presents current practices about measurements and reporting of runway friction. Then, the proposed method is presented. Finally, current methods are tested and compared to the proposed method, using the JWRFMP results.

2. Current practices

The European Aviation Safety Agency (2009) provides a clear state of the art about the measurements and reporting of runway friction.

2.1. Measuring runway friction

Two methods are commonly used to measure runway friction. The first is based on the measurements of a deceleration. It consists in a piezo-electric force sensor rigidly fixed in a vehicle. The vehicle must not be equipped with an ABS. Full braking is then applied to block the four wheel of a vehicle, measuring the maximal deceleration reached until a complete stop of the vehicle. The deceleration is then converted into a friction coefficient. This method is a spot measuring method, and requires several spot measurements to get an average runway friction coefficient. The device is calibrated to provide deceleration in g unit, expressed as a friction index (friction index = deceleration / g).

The second is based on the measurements of the friction force generated between a braked wheel at a constant speed and slip ratio, and the surface. These devices are known as continuous friction measuring devices, because they allow measuring the whole runway length. The force can be measured either by measuring the braking torque applied on the wheel, or by measuring the force required to tow the wheel. Several devicesare currently in use, including the Instrument de Mesure Automatique de Glissance (IMAG) device. IMAG has the ability to measure friction coefficient from both braking torque and traction force. Machet (2010) demonstrated that drag force can be deduced from these measurements, as torque measures only the friction, when force measures both friction and drag.

As aircraft braking coefficient measurements performed during JWRFMP was based on deceleration (Croll et al, 2002), decelerometers have an advantage on CFME. Nevertheless, decelerometers do not use ABS vehicle, when aircraft does. The decelerometer itself may be simple to use, but complexity of this system rose from the choice, maintenance and standardisation of the test vehicle, and from the brake pressure test operator applied, or the choice of the spot measurements in case of non-uniform contamination. It is a spot measuring device and thus requires a longer runway occupancy time. It does not have the ability to distinguish between effort due to the friction and the drag. On the contrary, IMAG is able to distinguish between friction and drag, and requires a shorter runway occupancy time. The operator influence on the friction results is of lesser importance, but greater difficulties arose from the complexity of the device, and especially from the calibration.

2.2. Reporting runway friction

Several way of reporting runway friction exists (European Aviation Safety Agency, 2009)). Runway friction can be reported in terms of braking action (Good/Medium/Poor), or as a friction index. In the first case, the friction value has to be converted in braking action. The most popular tool to convert a friction value in braking action is the ICAO table. ICAO table has been established in 1959, using a Tapleymeter, a decelerometer-type device, on surfaces contaminated with ice or compacted snow. Its use should therefore be limited to these situations (device and surface conditions).

Table 1: ICAO table

Measured Coefficient µ	Estimated surface friction	Code
0,40 and above	Good	5
0,39 to 0,36	Medium to good	4
0,35 to 0,30	Medium	3
0,29 to 0,26	Medium to poor	2
0,25 and below	Poor	1

Some States provide the measured friction values to pilots. Following JWRFMP, Transport Canada developed another friction index called Canadian Runway Friction Index (CRFI). As IRFI, CRFI is a harmonized index using the Electronic Recorder Decelerometer as reference device. Croll et al. (2002) presents series of experimental data comparing aircraft braking with CRFI, based on three aircraft types (business jet, medium transport and turboprop). It concludes good correlation can be found between aircraft braking coefficient and CRFI. Moreover, a similar relationship has been found for the three types of aircraft.

Then, Croll et al. (2002) determined a conservative equation from the experimental correlation to get high level of confidence.The relation between Aircraft Braking coefficient and CRFI developed by Transport Canada is:

$$MuR = 0{,}40\,CRFI + 0{,}02 \qquad (1)$$

Where MuR is the recommended aircraft braking coefficient. MuR has a conservative value of 0,34 (CRFI=0,80) and a minimal value (rolling resistance) of 0,02 on a surface with nil braking (CRFI=0,00). Croll et al.(2002) then developed a model to calculate aircraft landing distance from CRFI. It results that landing distances can be read from CRFI value using Transport Canada tables.

Finally, the working group known as Take-off And Landing Performance Assessment (TALPA) (Subbotin & Gardner, 2013) provided a new method to provide information about runway condition. A matrix has been developed relating runway contaminant type, depth, runway temperature, friction value and pilot braking estimation to a single number called runway condition code (RCC). RCC ranges from a value of 6 (Dry) to a value of 0 (Nil). TALPA chose to de-emphasize the role of friction measuring devices and prefer to consider information about the runway surface condition, such as type, depth of contaminant, and runway temperature.

2.3. Evaluation of predicted aircraft braking coefficient

Results of the JWRFMP have been analysed using the three methods used for reporting runway friction presented in part 2.2. Aircraft braking coefficient have been plotted against the braking action code determined from IMAG measurements (figure 1) and from decelerometer measurements (figure 2) using ICAO table, and from runway surface condition using TALPA matrix.

Figure 1 presents the comparison of Aircraft braking coefficient and predicted braking action code, using the boxplot technic. Figure 1 summarizes the Aircraft Braking coefficient distribution for each braking action code and shows five statistics: the minimum, first quartile, median, third quartile and maximum. Figure 1 also shows the outliers.

It clearly shows that this method does not allow differentiating aircraft braking coefficients, except for the good case. It is therefore not relevant to use it to get information about aircraft braking performances.

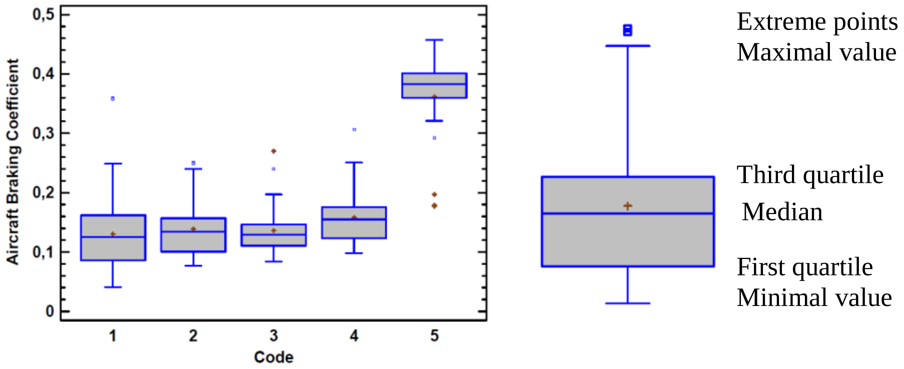

Figure 1: Aircraft braking coefficient versus estimated braking action from IMAG data

This conclusion was expected as this method has been developed from decelerometer measurements on compacted snow- and ice-covered runways, and should not be used differently. That is why the method has also been used using the CRFI instead of IMAG data (figure 2). Results show a slight increase of aircraft braking coefficient with the code. Nevertheless, the distinction between codes 1 to 4 is not clear enough to be confident in the predicted aircraft braking performance.

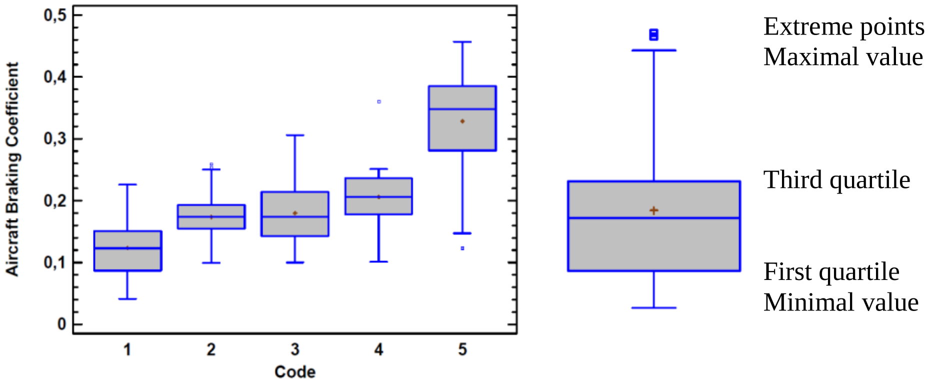

Figure 2: Aircraft braking coefficient versus estimated braking action from CRFI data

Finally, the TALPA method has been used, using runway descriptor only. Figure 3 shows there a clear relation between aircraft braking coefficient and RCC, except for code 3. The dispersion of data is still important, but may be explained by experimental difficulties.

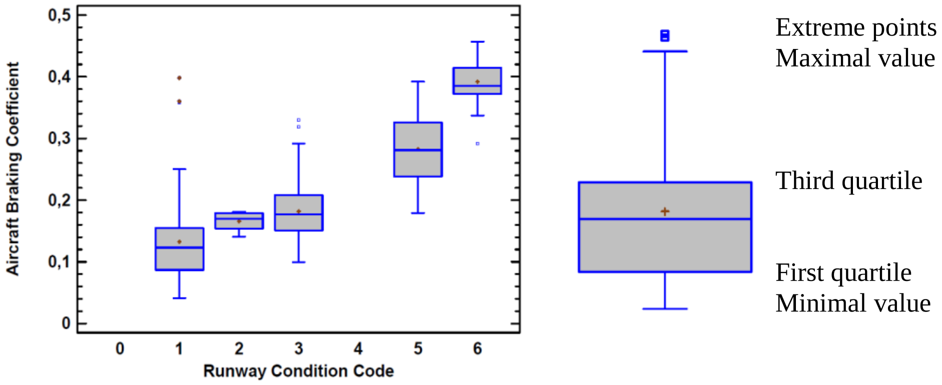

Figure 3: Comparison between aircraft braking coefficient and Runway Condition Code from JWRFMP data

Figure 3 does not show any data for code 4 because temperature was often missing in the database, and it was decided to consider compacted snow as being code 3 when there was no data for temperature.

TALPA matrix provides the best relation between braking action code and aircraft braking coefficient from the three tested method. However, TALPA is mainly based on runway condition description (type, depth of contaminant, runway temperature, contamination coverage…). This information is subjective and difficult to obtain, from an operational point of view. Using friction measuring devices to predict aircraft braking coefficient would be easier, faster, more objective and probably more physically significant.

3. Research methodology

Chapter 2 demonstrates that currently no method exits to predict aircraft braking coefficient from friction measurements. This work aims at developing a new method to relate friction measurements toaircraft braking coefficients.It is based: 1/ on the use of the so-called ESDU model to relate ground friction measurement to aircraft friction coefficient, and 2/ on the use of the IMAG device.

ESDU model allow prediction of rolling resistance, drag force and braking on dry, wet and snow- or ice-contaminated runways. The aim is to adjust measured friction coefficient – using the model – to aircraft characteristics such as speed, mass and tire pressure, to solve the identified scale effect problem.

IMAG device is used because it is able to distinguish between friction and drag force, and because an extensive database exists for the machine, due toits participation as a reference device to JWRFMP.

The proposed method is tested on JWRFMP data.

4. Use of ESDU model

4.1. Model of aircraft braking coefficient and drag forces

The developed approach is based on a model, the so-called ESDU model. This model is chosen because it is a recognized reference (for example for the Certification Specifications for Large Aeroplanes of the European Aviation Safety Agency – EASA) for the calculation of aircraft performances. It allows modelling rolling, braking and drag efforts.

Assuming the different effort can be summed, it results the total deceleration (μ_{Total}) coefficient is:

$$\mu_{Total} = \mu_{Slip} + \mu_{Roll} + \mu_{Cont.Drag} \qquad (2)$$

Where μ_{Slip}, μ_{Roll} and $\mu_{Cont.Drag}$ are respectively the braking coefficient, the rolling coefficient and the contaminant drag coefficient.

According to ESDU (2003), the braking coefficient on snow- or ice-covered runways can be modelled as a function of vehicle parameters (speed, slip ratio, tire pressure and mass) according to the following equation:

$$\mu^{AC}_{Slip} = \frac{\left(1-e^{\eta_2 s}\right)}{\left(1+\left(\eta_0+\eta_1\frac{v^2}{2g}\right)\frac{p/p_a}{Z^{1/3}}\right)}\mu^{AC}_{Ref} \qquad (3)$$

η_0, η_1, η_2 are empirical constants, s, v, p, p_a, Z, g and μ^{AC}_{Ref} are respectively slip ratio, slip speed, tire pressure, atmospheric pressure, vertical load, gravity and the aircraft reference friction coefficient.

In ESDU, μ^{AC}_{Ref}depends on the surface-tire couple. It can be seen as characterizing the tyre-surface interaction, and includes the runway conditions dependency. Rolling coefficient is only vehicle dependant, and can be calculated from the following equation:

$$\mu_{Roll} = \left(\xi_0 + \xi_1 \frac{V^2}{2g}\right)\left(\frac{Z^{1/3}}{p/p_a}\right) \tag{4}$$

Where ξ_0 and ξ_1 are empirical constants and V is the ground speed.

Depending on the type of contaminant, the contaminant drag includes:

- Spray impingement: it is the drag caused by precipitation striking the airframe.
- Displacement drag: it is the drag caused by the displacement of the contaminant by the nose and landing gear.
- Compression drag: it represents the drag due to the compression of the contaminant.

Giesbert (2001) demonstrated that there is little projection on low density contaminant, such as dry snow, and compression drag can be neglected on high density contaminant, such as slush or wet snow. It finally proposed equation for each of these phenomena. These results have been implemented in the ESDU model:

$$\mu_{Cont.Drag} = \mu_{Displacement} + \mu_{Spray} \quad (slush) \tag{5}$$

$$\mu_{Cont.Drag} = \mu_{Displacement} + \mu_{Compression} \quad (dry\ snow) \tag{6}$$

ESDU proposes modelling for these efforts:

$$\mu_{Displacement} = \frac{1}{2}\frac{\sigma \rho d V^2 C_D}{\sqrt{pZ}} \tag{7}$$

$$\mu_{Compression} = \gamma_0 w D \sigma \sqrt{\frac{p}{Z}}\, d \ln\left(\frac{1}{\sigma}\right) \tag{8}$$

μ_{Spray} depends on the aircraft geometry. Therefore, no analytical formula is proposed. σ, ρ, d, C_D, w and D are respectively the specific gravity, density, depth of contaminant, drag coefficient, tire width and diameter. γ_0 is an empirical constant.

Croll et al. (1999) explains that aircraft braking coefficient during JWRFMP have been obtained from aircraft deceleration, using a deceleration model. Drag and rolling efforts have been removed, so the aircraft braking coefficient is represented in ESDU model by the μ^{AC}_{Slip} coefficient.

4.2. Analysis of IMAG measurements

Andresen & Wambold (1999) provide a clear explanation and analysis of reaction forces for a tribometer on different runway conditions. Figure 4 presents the situation for the system IMAG.

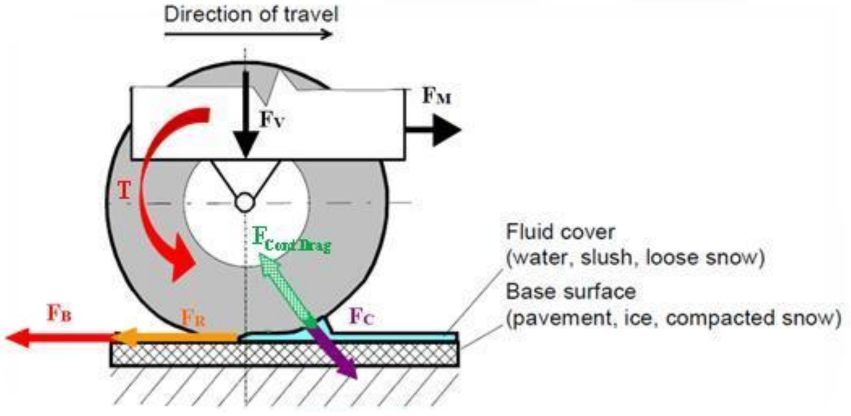

Figure 4: Reaction force system for a tribometer in a non-solid contaminant, adapted from Andresen & Wambold (1999)

Andresen & Wambold (1999) demonstrated that the measurement results of the system IMAG comprises: 1/ Rolling resistance, 2/ Drag, and 3/ Friction. Rolling resistance arises from the tire deformation on the surface, drag from the displacement and compression of the non-solid contaminant, and friction from the surface skid resistance. F_M and F_V on figure 4 are the measured horizontal force and vertical load, T is the braking torque and R the wheel radius. Assuming these efforts are cumulative, IMAG friction results can therefore be expressed as:

$$\mu^{IMAG}_{Force} = \frac{F_M}{F_V} = \mu^{IMAG}_{Roll} + \mu^{IMAG}_{Drag} + \mu^{IMAG}_{Slip} \tag{9}$$

$$\mu^{IMAG}_{Torque} = \frac{T/R}{F_V} = \mu^{IMAG}_{Slip} \tag{10}$$

It results from part 4.1 that μ^{IMAG}_{Slip} is the relevant parameter to connect to aircraft braking coefficient. That is why only torque measurements are used in this paper. Applying ESDU model to IMAG measurements, the following equation can be written:

$$\mu^{IMAG}_{Slip} = \frac{\left(1 - e^{\eta_2 s}\right)}{\left(1 + \left(\eta_0 + \eta_1 \frac{v^2}{2g}\right) \frac{p/p_a}{Z^{1/3}}\right)} \mu^{IMAG}_{\mathrm{Re}\,f} \tag{11}$$

It results from equation 3 and 11 that the aircraft braking coefficient can be calculated from IMAG measurements, providing the following assumption:

$$\mu^{IMAG}_{\mathrm{Re}\,f} = \mu^{AC}_{\mathrm{Re}\,f} \tag{12}$$

5. Results

The main output of the JWRFMP was the International Runway Friction Index (IRFI). IRFI is based on experimental correlations to a reference device, called International Reference Vehicle (IRV). After harmonising friction results, the aim of JWRFMP was to predict Aircraft Braking coefficient from friction measurements. Again, the model used to predict aircraft braking coefficient is based on experimental linear correlations. IRFI has been measured on different contaminated or non-contaminated surfaces, in a closely time from aircraft measurements. Aircraft braking coefficient have been calculated from deceleration tests using a deceleration model described by Croll et al. (2002). Aircraft drag forces have been calculated from rolling tests using the same deceleration model.A new interpretation of JWRFMP data has been realised based on the method described above.

5.1. International Runway Friction Index

Figure 5 shows JWRFMP results, as presented by Wambold & Henry (2003). Aircraft braking coefficient is plotted against IRV friction measurements or IMAG friction measuring device converted into reference IRV (using experimental harmonisation constant). It results that several ground friction coefficient may be compared with one Aircraft Braking coefficient. Figure 5 shows that there is a lot of scatter, resulting in a low coefficient of determination R^2.

The correlation is largely dependent on the dry runways (IRFI above 0,5) test points. If data on contaminated runways are considered alone, the coefficient of determination drops to a value below 0,05, meaning zero correlation.

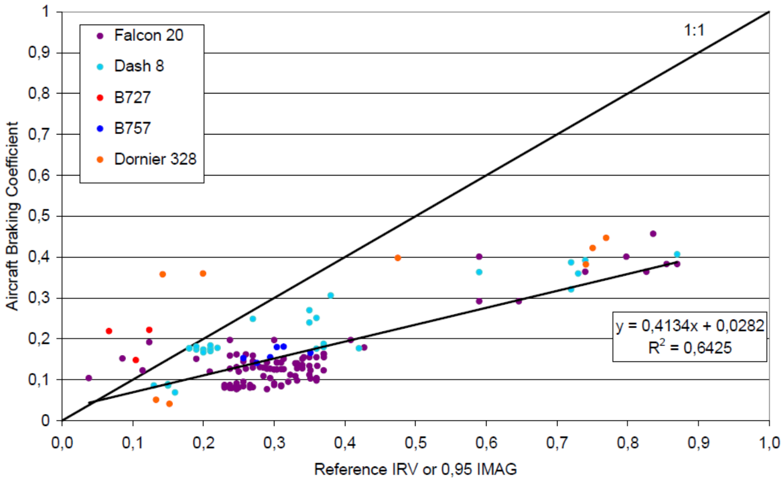

Figure 5: Aircraft braking coefficient versus reference IRV or 0,95 IMAG measurements (JWRFMP results from Wambold & Henry, 2003)

The correlation provided by Wambold & Henry (2003) is then improved by removing data based on torque measurement only and outliers. Friction data based on torque measurement are removed because they do not take drag effects into account. Outliers are removed when they differ from the mean of more than two standard deviations. Removal of these data results in an improved R² but a significantly lower number of aircraft data. Indeed, only two aircrafts data remains after this process, and most of them come from the Falcon 20.The number of year data has also been reduced as 93 % of remaining data are from year 2000. This reduction in test year raises the issue of stability of the harmonisation constants.

5.2. Proposed method

The process described in chapter 4 has been implemented on data from the JWRFMP. As explained in part 4, data from torque sensors have been preferentially used. When not available, data from force sensors have been used, and corrected of rolling resistance and drag effects. Only one ground friction data have been used, preferentially IRV data. Figure 6 presents the results. It can be seen in figure 6 that results are close to the line of perfect agreement, especially for the Falcon 20. Dash 8 is parallel to the line of perfect agreement, but the proposed method under-estimate the Aircraft Braking coefficient. Only two runway conditions are available for the NASA B757 and the Dornier, respectively slush and compacted snow, and smooth ice untreated and treated with chemicals. No clear conclusion can be drawn from these two aircrafts.

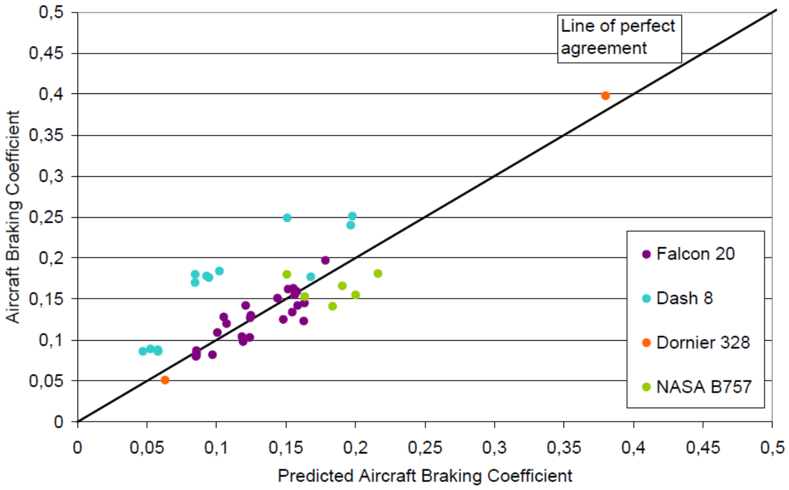

Figure 6: Comparison of Aircraft Braking Coefficient to Predicted Aircraft Braking Coefficient using the process described above

The proposed method required assumptions for the aircraft slip ratio. Results from JWRFMP showed that slip ratio is surface dependant. That is why different values have been used depending on surface conditions. Some values were adopted from real aircraft tests and some have been assumed from literature. These assumptions will require confirmation.

Figure 6 contains data from three years (1999 to 2001) and four different aircrafts, giving a relative universality to the proposed method.

Such an approach has several advantages compared to experimental correlation, as it can be adapted to any aircraft or ground friction measuring devices, does not depend on experimental conditions and does not require periodic comparisons tests.

6. Conclusions and perspectives

This paper presented a new method to relate aircraft braking performance to friction index. The proposed method is based on the use of a model, the so-called ESDU model. It takes into account drag forces and allows correcting scale-effects. First results sound promising even if further developments are still required.

For a complete description of aircraft performances, contaminant drag efforts have to be determined. The aim will be to determine drag force effort from IMAG measurements as well. Drag forces can be measured using the IMAG device, as demonstrated by Machet (2010), and can be modelled as described in part 4.

It can be noted in equation 5 and 6 that drag forces modelling are composed of two parts: the first is purely vehicle dependant, and the second is related to surface conditions through density, specific gravity and the depth of contaminant. Density and specific gravity can be seen as means to assess the type of contaminant. Nevertheless, further developments are required as, with current instrumentation, the displacement and compression drag cannot be distinguished from IMAG measurements. The case of spray impingement drag for the IMAG should also be investigated.

This method would be an improvement of the classical way of characterising runway conditions as it can provide direct comparison with aircraft performances instead of indirect indicators.

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