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A NEW METHOD FOR TESTING AND EVALUATING GRASSY AIRFIELDS AND ITS EFFECTS UPON FLYING SAFETY

Summary. The paper contains a review of methods and technologies developed during a research project entitled "Methods of testing and evaluation of grassy airfields", conducted at the Lublin University of Technology between 2011 and 2014. Based on the terramechanical studies of wheel-soil interactions, the authors have developed a method for the determination of wheel-grass friction and rolling resistance coefficients, which are of critical importance for the ground performance of an airplane. Moreover, a mobile application has been created for use by pilots, controllers or airfield administration crew. The application connects online with a weather service to gather atmospheric data as inputs for a mathematical model that produces a real-time cone index (CI) value for a given airfield. The paper also discusses the applicability of the method within the air transportation system, as well as possible effects of the described technology upon the safety of flight operations on grassy airfields.

Keywords: grassy runway; general aviation; light airplanes; test method.

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1. INTRODUCTION

Flying from a smooth grassy airfield has obvious advantages for both aircraft and pilots/passengers, with aircraft structure less stressed at touchdown and ground roll, tyres wearing less intensively, and the overall comfort of flying being better for the people on board. There are certainly drawbacks of grass flying, however, especially when the surface is rough or the grass is wet. Low values of surface friction and higher rolling drag can cause dangerous situations during take-off or landing. Incidents such as the failure to get airborne, colliding with obstacles after take-off or overrunning on landing are frequently experienced with light airplanes. Many have occurred on short unpaved runways, as well as strips, often when operating out of the wind or where there was a slope. Poor surfaces, such as long or wet grass, mud or snow, were often contributory factors. Landing on these kinds of field require extra care because they constantly change depending upon the season and the amount of recent rainfall in the area. The problems can also occur during take-off because it will take much longer to get off the ground on a wet grass runway than on a dry runway.

According to Federal Aviation Administration (FAA) and the National Transportation Safety Board (NTSB) information, runway overruns during the landing phase of a flight account for approximately 10 incidents or accidents every year with varying degrees of severity, including fatalities. The NTSB concludes that the main cause of these accidents was the dynamics of a tailwind approach and landing, particularly on wet or contaminated runways [4]. Particular examples of accidents and causes are given below [5]:

- Fatal crash involving a PA-46 Piper Malibu on take-off: high rolling resistance of the airfield’s turf surface plus high altitude.
- Rollover involving a PZL 101 Gawron on landing: wet surface and high surface deformation.
- Crash involving a PZL 104 Wilga 2000 on landing in deep snow.
- Fatal crash involving a PZL 104 Wilga 35 on take-off: too short an airfield plus high rolling resistance.

These accidents illustrate two factors affecting aircraft taking off or landing on unsurfaced airfields:

- High rolling resistance on take-off, causing too long a ground roll.
- High deformability of the airfield surface at touchdown, causing nose-down moments.

The next section includes a discussion of the factors that have significant effects on the performance of light airplanes on a grassy runway.

2. PERFORMANCE OF LIGHT AIRPLANES ON A GRASSY RUNWAY

The following section will discuss the factors that have significant effect on the performance of light airplanes on a grassy runway. We distinguished three major groups of factors: airplane-related factors, grassy runway conditions and human factors, such as pilot training and piloting skills.

2.1. Effects of airplane design

Light airplanes are naturally suitable for grassy runway operations. Some designs have features that make them especially capable of off-field flying, for example, short take-off and landing (STOL) capabilities. Some important factors are discussed below.

Wing design

Wing design elements, such as a high-lift wing section, low-wing loading, wing mechanization (Fowler flaps, flaperons, slats), vortex generators and leading edge cuffs, have a positive influence on the short- and soft-field performance of the entire airplane. These features decrease the occurrence of a stall or minimal speed, while improving stability and manoeuvrability at a high angle of attack. One drawback of wing mechanization is its complexity, while the use of high-lift profiles results in lower cruise speed (see Fig. 1).

Fig. 1. Wing mechanization on a high-performance Just Aircraft Super STOL airplane (note the low-pressure tundra tyres with a big diameter)

Power

Another typical STOL feature is the high power-to-weight ratio, which can be achieved by using powerful engines or lightening the entire design. The latter is especially popular for small, light sport or homebuilt airplanes. The use of reduction gear between an engine shaft and a propeller allows for using low rpm propellers with a greater diameter. This in turn increases thrust, maximizes the propeller’s efficiency and decreases noise.

Landing gear

Wheels with a big diameter, comprising so-called tundra tyres, ensure improvements in field performance, as they offer better accommodation of surface roughness and additional damping by tyres. Moreover, the A-frame landing gear, together with shock absorbers or telescopic springs (as in the Fieseler Storch), helps a lot during landing with a high descent rate. One noteworthy solution is the use of a rocker arm-type suspension with air absorbers, as found on the Wilga airplane (see Fig. 2). This is highly effective on rough terrain without the use of big “tundra” wheels, which adds to the aerodynamic drag.

Fig. 2. The PZL 104 Wilga 35A, a typical STOL airplane
(note the rocker arm-type wheel suspension on the main landing gear)

2.2. Effects of grass runway conditions

Effect of grass

Grass vegetation on a runway surface affects the ground performance of an airplane. An additional drag force acts on the landing gear wheels at rolling, due to grass blades bending (or fracturing) and the compaction of grass under a rolling tyre. Another effect is the lower friction between a tyre and grass, which results in less-intensive braking action. Finally, a positive result of grass on a runway is lower dynamic loads at touchdown on landing gear wheels, as well as on the entire airplane structure, and less wear on the tyre tread. Simple design models regard grass as a homogenous contaminant on the runway surface and refer to it by means of a rolling resistance coefficient or braking friction coefficient. Other important factors are the length and moisture of the grass. Stinton provides a classification of grass and distinguishes short dry and short wet grass, and long dry and long wet grass, giving respective values of rolling resistance coefficients [11]. The same reference introduces the following grass length scale: fresh-cut, short, typical summer airfield, long, but useable, lush, too long with respective lengths of blades in inches (0-2, 2-4, 4-6, 6-10 and 10-12), and with the caution that the length of grass blades is not the same as standing height. However, there is a lack of any correlation to wheel performance. According to agricultural handbooks, grass exhibits measurable physical properties, such as bending, compaction strength and friction. For a given grass species, there is a strong relation between the physical properties of grass blades and their moisture. These properties are important for agricultural equipment design and can probably be of help in predicting the ground performance of an airplane. As an example, according to Kanafojski, the bending strength of a single grass blade can be determined by the following equation [6]:

$$EJ = \frac{FL^3}{3f} \quad (1)$$

where E=Young modulus, J=mass inertia factor, F=force applied to a grass blade, L=distance between the ground and a point where the bending force is applied, and f=bade deflection.

Values of the term *EJ* in Ncm^2 vary between 1.5×10^2 and 10^3 for grass leaves, and between 10^4 and 10^5 for grass blades. Kanafojski also gives sample values of friction coefficients for grass blades and different materials (steel, rubber, wood), as well as for internal friction among grass species. Moreover, the same reference states the effect of speed on grass-steel friction. Within the speed range of 10 to 300 mm/s, μ changes from 0.15 to 0.30, while the relationship is exponential.

Other than grass, wheel performance can be affected by underground parts of grass plants, whose roots form a complex and strong structure, which, together with green parts, builds a lawn (or a sod). The effect of roots on soil shear strength has been researched by Yoshida. By means of a direct shear test, it was shown that soil samples with roots (rice plant roots) exhibited a much higher shear strength than those without roots. A similar effect was noticed for samples taken from three different depths [16].

Effects of moisture (water content)

As mentioned earlier, the effect of moisture on grass is significant. This is probably the most important factor affecting the ground performance of an airplane on grassy airfields. Not only does the braking force coefficient μ become low due to slippery, wet grass blades, but the bearing capacity of the soil underneath also alters. Consequently, in moist soil conditions, wheel sinkage and rolling resistance increase. Different soil types behave differently when becoming moist. A typical soil of a grassy airfield is a mixture of loess, sand and loam, which exhibits mixed mechanical behaviours. The effect of moisture content on the trafficability of a soil can be expressed by the following empirical equation (after Collins [2]):

$$\ln(RCI) = 4.605 + \frac{2.123 + 0.008C - 0.693\ln(MC)}{0.0149 + 0.002C} \qquad (2)$$

where *RCI*=rating cone index, *C*=percentage of clay in the soil tested, and *MC*=soil moisture content (%).

The moisture content in a grassy airfield subsurface changes due to weather conditions. While precipitations irrigate airfields, sun operation, wind and soil water fluxes dry them. Anderson used a soil water finite difference model to refine the potential resolution of a soil trafficability model, based on the *RCI* algorithm. The major advantage was the time resolution of the simulation (1 s step) and the ability to incorporate real-time meteorological data to update forecasts [1]. Pytka et al. measured soil moisture content on a grassy airfield, using a handheld time domain reflectometry (TDR) meter; see Fig. 3 [10]. Sample results are shown in Fig. 4. Measurements were performed approximately twice a week. The highest dynamics were observed in the spring and summer months. Other data show the dynamics of *MC* values obtained for a shorter time. The start of the measurements was 17 May in the evening and the *MC* data were collected at various time intervals for the five days that followed. It was noticed that the highest *MC* value was as high as 37%, while the tendency to decrease was rather low. After five days of mild weather (cloud cover was about 0 to 3/8), with winds of 3-5 m/s, the *MC* decreased to approximately 28% A significant sudden drop in *MC* was observed on a day when the grass was mown, with percentage moisture content decreasing to 25%. Generally, the *RCI* value for the moistest runway surface conditions is barely acceptable. On the other hand, the decrease in *MC*, which implied an *RCI* increase, was rather slow. This is the effect of water uptake by vegetation, plants and roots. A simple corollary: moisture content is not the most important factor but, of course, it affects the ground performance of an airplane.

Fig. 3. A handheld TDR moisture meter used for grass runway monitoring

Surface roughness effects

A grass runway is a vegetating habitat that grows and changes throughout the entire flying season. Some factors, such as heavy rainfall, intensive solar operation or wind, may lead to clumping, which makes the surface rough. Another mechanism involves the activity of small animals (rodents) living in grasslands, which damage the surface by digging burrows and holes. Thus, the effects of surface roughness upon the ground performance of an airplane can be significant and is usually expressed by:

- worse comfort for the people on board
- weakened take-off performance (longer take-off distance available)
- less directional stability
- a nose-down effect on an airplane

The effect of a rough surface is yet more evident for small wheels. Consequently, big diameter tundra tyres are a good solution. However, tundra tyres are not suitable for all types of airplane, especially those with retractable landing gears. Therefore, surface roughness has to be monitored and maintained. A typical routine to address roughness is rolling the surface with a mid-weight road roller.

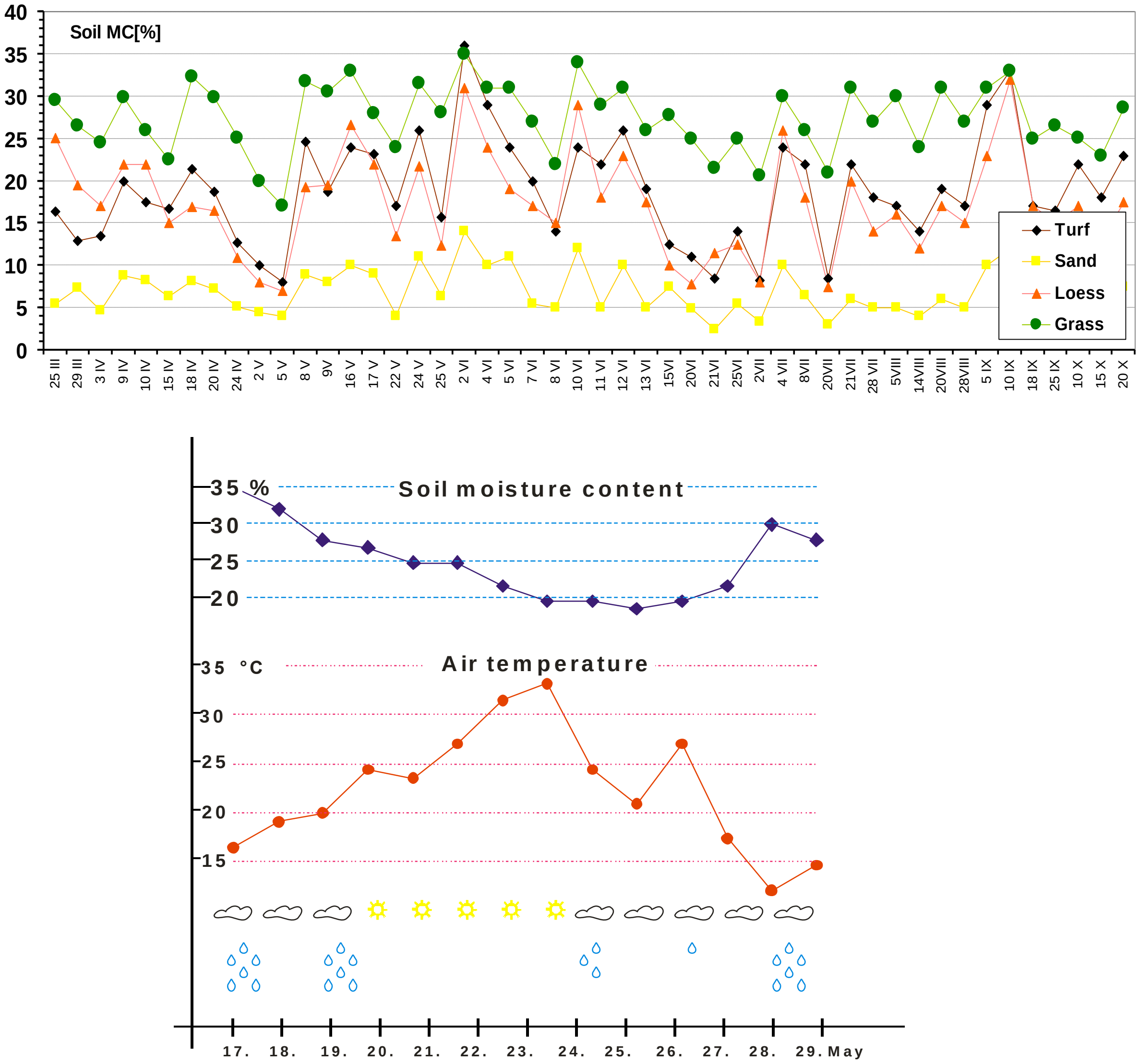

Fig. 4. Dynamics of runway moisture.
The upper graph shows data from the entire flying season for four different surfaces (turf, loess, sand and grass).
The lower picture explains how *MC* changes within a few days as a result of rain, sun operation, clouds and air temperature

2.3. Piloting technique and training

Although short- and soft-field landings are all part of a private pilot's license course, there is a need for continuous training in order to maintain piloting skills, not only for those who operate from airfields. One useful practical exercise involves precision landing, which prepares a pilot for an emergency landing on an opportune, short or sloped field, or one that is surrounded by obstacles. Piloting magazines, handbooks and Internet websites deal with short- and soft-field techniques on a frequent basis. For a pilot who wants to land or take-off from a grassy or gravel airfield, a standard pilot operating handbook gives recommendations about how to calculate ground roll and total distances with respect to aircraft loading and density altitude. These recommendations are based on a dry grass runway and therefore useless for calculating distances in other situations. Meanwhile, civil aviation authorities (CAAs) also suggest increasing landing distances on wet grass by 60%. These are rather basic, approximate methods which do not ensure adequate safety margins when flying under critical surface conditions (long, wet grass, very soft soil etc.). In most cases, a pilot is alone in his or her decision-making and does not have access to any operational help. Thousands of hours of experience may not be enough preparation for take-off from an undefined surface, especially for typical general aviation (GA) aircraft, which are not especially designed and equipped for off-field flying. Therefore, it is suggested that, for safe grass field flying, a practical, yet precise, method for testing and classifying grass airfields, in the sense of surface trafficability, would be valuable.

3. AN OVERVIEW OF EXISTING METHODS FOR GRASS RUNWAY EVALUATION

Since grass airfields are still very popular all over the world, the aviation community tends to avoid aerodromes with this type or runway. The following section summarizes actions towards evaluating and assessing grassy runways in selected countries.

In the UK, the Light Aviation Airports Study Group (LAASG) was formed as a direct initiative arising from the CAA-Industry Joint Review Team in early 2005. Its creation was influenced by GA sector requests for a review of light aviation aerodrome arrangements over a number of years. The main goal of the LAASG was that the UK's CAA would develop detailed proposals to remove the requirement for flight training to be conducted at a licensed aerodrome and accept alternative arrangements, e.g., a code of practice or an enhancement of FTO approval, in order to maintain safety levels for flight training to supplement the requirements in the JAR-FCL. According to the LAASG, the runway surface condition is very important and should be kept as smooth and fully drained as possible. Hard surfaces should be regularly checked for debris, while natural surfaces should be mown, rolled and kept free of debris. It is recommended that grass be kept to a maximum of 10 cm (4 in) high. When laying a grass runway, the use of seed mixtures, which grow more slowly and reduce rolling resistance, should be considered, while it is essential to mark any obstacles, potholes and poor surfaces.

The General Aviation Small Aerodrome Research (GASAR) study analysed 687 aerodromes in England, which come under the scope of GA, and classified 374 into six types. These range in size from regional airports to the smallest farm strip, although 84% of GA flights operate from 134 of the larger aerodromes in the first four categories. The factors used in determining how an individual aerodrome is categorized by the GASAR study are based broadly on size and facilities. The six types of aerodrome are described, in size order, as: regional airports, major GA airports, developed GA airfields, basic GA airfields, developed airstrips and basic airstrips.

Grass airfields are located in Western Europe in significant numbers. In France, Germany, Switzerland and Austria, the prevalent use of grass fields is related to the huge popularity of sailplane flying and air tourism. In sailplane cross-country flying, landings due to lack of thermals occur quite frequently. Evacuation tow flights from opportune landing sites require the take-off distance to be calculated by taking into account the drag of both the towing airplane and the sailplane. In Alpine regions, at high-altitude airfields, density altitude is a significant factor affecting the performance of unpressurized engines and, in turn, the ground performance of the airplane. The advent of electric-powered airplanes is another important issue, since such airplanes, powered by low kW engines, require yet more runway length to get airborne.

In the US, there are about 11,000 grass fields, which add to the potential of the air transport system and improve safety, since these fields can also operate as emergency landing sites. For some years, a research project called “Opportune Landing Sites” (OLS) has conducted in order to collect surface data at a number of places to assess their suitability for military aviation operations. In the process, mapping software has been developed using commercially available Landsat imagery to remotely locate unimproved landing sites, which are sufficiently flat and free of heavy vegetation, obstacles and surface water to allow airlift operations, soil and weather conditions permitting. A second module is capable of determining the soil type based on pixilated satellite imagery and digital terrain elevation data, while a third module can predict the soil moisture content and infer the California bearing ratio (CBR). The OLS has eliminated or minimized the need for on-ground reconnaissance to locate potential landing sites before the start of aircraft operations.

Another initiative, the Recreational Aviation Foundation (RAF), from the US, was founded in order to preserve, maintain and create recreational and backcountry airstrips for public use. This is a volunteer-driven organization, which works to develop partnerships in protecting the common interest of the recreational flying community. The RAF cooperates with public and private landowners and managers, as well as aviation advocacy organizations at state and national levels. The organization aims to improve safety at backcountry airstrips through pilot education.

In Poland, only 56 out of a total of 335 airports have paved runways, with the remainder being grassy airfields or airstrips. A significant number of those airfields is highly maintained, with grass surfaces rolled in order to increase bearing capacity and reduce surface roughness. They are operated by aeroclubs and provide seasonal tower control, aviation fuel and meteorological services. Typical maintenance routines include mowing, rolling and chemical treatments. Other types of grassy airfields are private airstrips with various conditions. A similar situation can be found in most East European countries. Another initiative undertaken by private owners/operators of small grass fields, called “Our Lawns”, has attempted to collect and update information about all possible landing sites, especially those that are privately owned.

Given the low number of airports with paved runways, an initiative was undertaken to incorporate grass airfields into the air transport system. A government-funded research project called “Airfieldtester” was conducted at the Lublin University of Technology from 2010 to 2014 in order to create a method for testing and classifying grass airfields [15]. The main result of this project, a new method for the evaluation of grass runways, is described in the next section of this paper.

4. METHOD FOR EVALUATING GRASSY AIRFIELDS

4.1. The basics of the method

The idea behind the new method is to take into account the coefficients that are related strictly to wheel performance. This approach is expected to perform better than CBR-related methods, since parameters describing wheel performance of true physical meaning are used. Wheel performance data are gathered by means of special equipment, namely, a wheel tester, which enables measurement of both rolling resistance k_{RR} and braking friction μ_B coefficients of a wheel running on a grassy surface. Knowing the actual values of those coefficients facilitates the prediction of an airplane’s airfield performance.

Two strategies are planned regarding the application of the completed method. In the first approach, the surface could be tested with the use of the tester at any time, with the results being the most accurate. Based on the tester data, take-off or landing distances can be determined; a simple mobile application has been developed for this purpose. For this approach, the tester has to be purchased by the aerodrome's administrator.

In the second approach, if the tester is not available, the runway surface could be evaluated by means of an online application, which calculates surface conditions based on online weather data, while a simulation model can evaluate virtually each field around the world. This approach uses detailed meteorological data, such as precipitation, wind, cloud octants and ambient temperature, as well as basic soil physical properties, to predict the wheel coefficients, taking into account in-soil water transport processes and surface transpiration.

4.2. Technical support

The base device employed in this method is a portable surface tester (see Fig. 5), operated by a single technician. This tool is needed for the field application of the method. An operator pushes the arm to move the tester forward at a low speed (the speed of walking adult). The push arm is mounted on the base wheels, while the test wheel is mounted by means of joints to avoid non-horizontal forces. During rolling resistance readings, the test wheel rolls freely; for braking friction measurements, a hand-operated brake is activated to block or fix the wheel.

The measuring system of the tester has been built with a scale wheel (a model airplane landing gear wheel) supported on two load cells, which gives readings of both horizontal and vertical forces acting on the wheel. Based on the results, rolling and braking friction can be determined.

The IT part of the method consists of two elements:

- *An online system for predicting the actual CI value on a given airfield*. Using meteorological data, which are obtained at one-hourly intervals, this system is supported by a customized database of grassy airfields (for the present moment, the database contains only Polish airfields).
- *A mobile application that runs on handheld devices with the Android system*. This application helps the end user (pilot) to predict the take-off or landing performance of his or her airplane on a given airfield, with the software taking density altitude into account.

An important part of the entire project and the method was to calibrate and validate results, since the accuracy of the method may have pronounced effects upon flying safety. For details of these aspects of the method, please refer to [3, 7, 10, 11, 13, 14, 15].

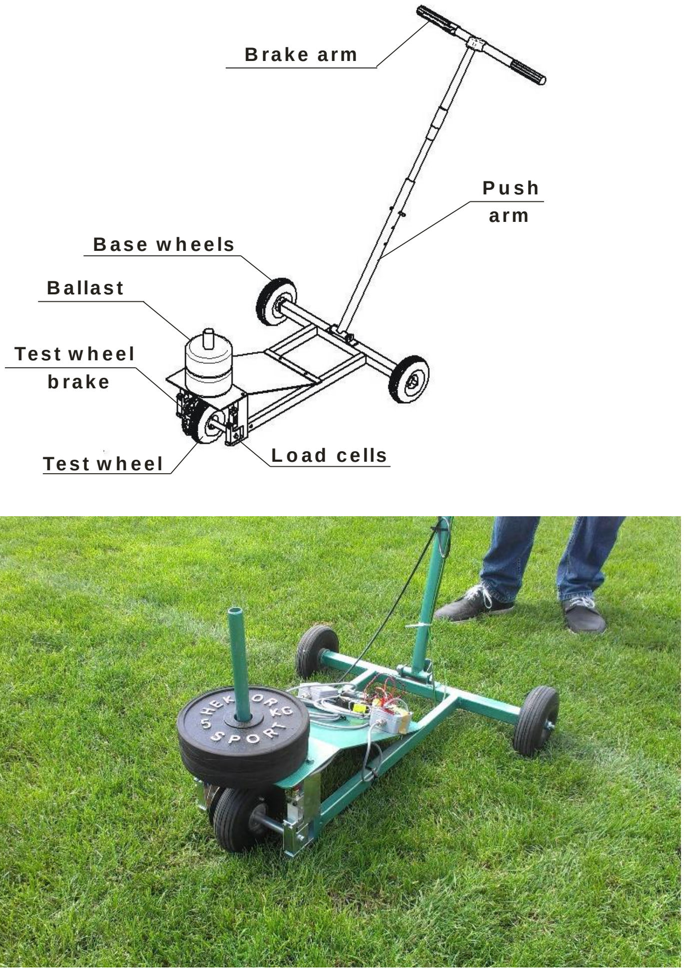

Fig. 5 The surface tester applicable to the presented method.

4.3. Dissemination

Generally, the aim has been to present the method in the European countries, although there we see no barriers for it to be presented outside the EU. Regarding the initial use of this method, however, unified aviation law in Europe would be of help. The application of the method can be expected to:

- Improve safety of operations
- Reduce operational costs in moderate or bad conditions
- Increase the network of grassy airfields and facilitate of access to them
- Enable access to remote locations with no road system
- Extend the flying season.

From our point of view, the most important benefits of the model are improvements in the safety of grass flying and the increasing use of grassy airfields, mainly in those regions where paved airfields are lacking. This would generally expand the air transport system in the respective countries.

The introduction of the method will also result in greater knowledge of an airplane's airfield performance and its limitations, while pilots could learn more about wheel-grass and wheel-soil interactions. Operators would also have a useful tool for better management of their airfields.

To continue to advance the method, we also plan to identify the expectations and needs of potential end users. The completed method (test equipment, methodology, procedures, instructions, handbook, software, conversion tables etc.) will be presented to flying clubs, airfield administrators, private users of airplanes etc in the form of workshops and presentations, which we intend to organize. We also plan to share the prototype tester and its procedures with an airfield operator for practical testing. Some training activities will probably be needed, as end users should benefit from a short course and on-site training. Comments and feedback from users will also help to improve the method.

Regardless of the practical use of the overall method, the wheel tester will be employed in future research in the field of wheel-soil or wheel-grass interaction analysis.

4.4. Expected effects upon flying safety

When properly used, the presented method should have a positive impact on flying safety. The presence of such a tool on its own should inspire pilots to pay more attention about the problems of grass runway performance. As today’s mobile communication and Internet technologies allow for the widespread dissemination of the method, it could be used by every single pilot or aerodrome owner/administrator. We are of the opinion that the introduction of something along the lines of a “grass NOTAMS”, for the busiest grassy airfields and aerodromes with grass runways, would help even more.

The all-important question, however, concerns when. information about grass runway conditions can be introduced into global air traffic management systems.

5. CONCLUSION

A new method for testing and evaluating grassy airfields has been developed. The method can produce rolling and braking friction coefficients for a wheel-grass combination in order to determine the airfield performance of an airplane. The method consists of measuring equipment, a portable tester, software, a mobile application, which can determine the airfield performance of a given airplane, and an online application, which can predict the physical properties of the surface with respect to weather impacts. The most significant and important effect of the application of this method is expected to be greater safety in the area of grass airfield flying, as well as better, more intensive, use of such airfields.

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