

**EXPERIMENTAL RESEARCH INTO SHALLOW FLOWS OF RAIN-WATER
ON THE AIRPORT RUNWAYS****Andrey Beljatynskij¹, Irina Klimenko², Olegas Prentkovskis³, Julij Krivenko⁴**^{1,4} *Dept of Airport Reconstruction and Automobile Roads, Institute of Airports, National Aviation University, Kosmonavta Komarova ave 1, 03680 Kiev, Ukraine*² *Dept of Economics, National University of Transport, Suvorova str. 1, 01010 Kiev, Ukraine*³ *Dept of Transport Technological Equipment, Vilnius Gediminas Technical University, Plytinės g. 27, LT-10105 Vilnius, Lithuania*E-mails: ¹beljatynskij@mail.ru, ²kirak76@mail.ru, ³olegas.prentkovskis@vgtu.lt, ⁴krivenko.yul@yandex.ru

Abstract. Hydroplaning is associated with the complete loss of the grip of a tyre because of the presence of a rain-water film between the tyres of a moving vehicle (an automobile, an aircraft, etc.) and the road surface. In this case, a vehicle becomes uncontrollable. As a result, a rain-water film of several millimeters is formed under the wheel, and a vehicle actually floats up. When a runway is covered with a rain-water film, its operational conditions become rather complicated and flight safety may be not properly secured. The surface rain-water decreases the holding capacity of pneumatic tyres. When the take-off or landing speed of an aircraft is relatively high (reaching 100–350 km/h), while the pressure in the pneumatics is relatively low, hydroplaning and wheeling out of the plane beyond the rear or side safety belt may take place. As mentioned in ICAO documents, hydroplaning may occur, when a pneumatic runs into a pool with the depth of about 3 mm, and this process continues even when the rain-water film becomes much thinner. In some airports, hydroplaning was observed on the flat smooth runway surface covered by a rain-water film of the depth of only 0.6 mm. A large amount of rain-water causes spraying as well as increasing the resistance of the aircraft wheels to rolling and extending the take-off distance. Getting of rain-water into the engine may be also very dangerous. The holding capacity of tyre is considerably reduced when the rain-water turns into ice, causing an ice-slick. To carry out the research, two laboratory-scale plants, one for working in the laboratory and another intended for work in the outdoor conditions, were created. In addition, the research was carried out on the take-off/landing runways. The paper presents the results obtained in the experimental research of the flows of rain-water, whose depth is comparable with that of depressions and cambers of rough roadway pavement. It is stated that the relationships used for calculating surface flows should be corrected for shallow flows, taking into account the actual roughness of road covering.

Keywords: shallow rain-water flow, depth of a rain-water film, mode of flow, slope, surface roughness traffic safety, road-holding capacity of a tyre, hydroplaning

1. Introduction

Hydroplaning is associated with the complete loss of the grip of a tyre because of the presence of a rain-water film between the tyres of a moving vehicle (an automobile, an airplane, etc.) and the road surface. In this case, a vehicle becomes uncontrollable. Hydroplaning (aquaplaning) occurs when the speed of a vehicle reaches the critical value, when the wheel does not have time enough for rain-water compulsion, which leads to the formation of a permanent rain-water film between it and the road surface. The higher the depth of the rain-water on the road surface under the tyre, the higher the risk of hydroplaning.

In other words, hydroplaning is the floating of the wheel on the rain-water wedge. In physical terms, it is the loss of the ability of a tyre of the effective rain-water compulsion from the contact area with the road. As a result, a rain-water film of several millimetres is formed under the wheel, and a vehicle actually floats up.

The term hydroplaning originated in aviation, but since the 60-ies of the 20-th century, it has become used (as aquaplaning) in transport, when the number of high-speed automobiles and the quality of road surface had increased considerably. An aircraft taking off from the runway reaches the speed of up to 350 km/h. Such speed was hardly possible for ordinary (not racing) automobiles even in the middle of the 20-th century. Therefore, it is natural that aviators were first to come across the effect of hydroplaning. When runways became almost ideally smooth and high-speed aircraft were developed, hydroplaning became a big problem for aviators. After several crashes of the aircraft which were caused by hydroplaning during the take-off, drastic measures, including the heating of the runway, were taken. At the same time, motor vehicle manufacturers also began to pay attention to this problem.

The problem of hydroplaning, shallow flows of liquid and scientific-practical related problems has been

investigated by researchers of various countries for many years now, for example Benedetto (2002); Beljatynskij *et al.* (2010); Gopalakrishnan (2006, 2008); Joubert *et al.* (2004); Ong, Fwa (2007); Thenoux *et al.* (1996); Wang *et al.* (2008, 2010); Reznik, Beljatynskij (Резник, Белятынский 2009); Vansauskas, Bogdevičius (2009); Jirka (2001); Aziz, Scott (1989); Daoyi, Jirka (1998), etc.

2. Negative influence of rain-water on runway

When a runway is covered with a rain-water film, its operational conditions become rather complicated and flight safety may be not properly secured. The surface rain-water decreases the holding capacity of pneumatic tyres. When the take-off or landing speed of an aircraft is relatively high (reaching 100÷350 km/h), while the pressure in the pneumatics is relatively low, hydroplaning and wheeling out of the plane beyond the rear or side safety belt may take place. As mentioned in ICAO documents (Airport Services Manual 2002), hydroplaning may occur, when a pneumatic runs into a pool with the depth of about 3 mm, and this process continues even when the rain-water film becomes much thinner. In some airports, hydroplaning was observed on the flat smooth runway surface covered by a rain-water film of the depth of only 0.6 mm.

A large amount of rain-water causes spraying as well as increasing the resistance of the airplane wheels to rolling and extending the take-off distance. Getting of rain-water into the engine may be also very dangerous. The holding capacity of tyre is considerably reduced when the water turns into ice, causing an ice-slick.

3. Experimental Research

The National Aviation University (Kiev, Ukraine), in cooperation with the Vilnius Gediminas Technical University (Lithuania), has been carrying out the research aimed at developing the automatic system of distant control and prediction of the runway state (Кривенко 2002). In the framework of this research, a sensor of the rain-water film depth on the take-off/landing runway has been suggested. To assess the state of the whole surface based on the readings of the sensors, fixed at certain points of the pavement, and for determining these points, the experimental study of the rain-water flows with the depth of 0.2÷20.00 mm was performed. To carry out the experiments, two laboratory-scale plants, one for working in the laboratory and another intended for work in the outdoor conditions, were created. In addition, the research was carried out on the take-off/landing runways (Beljatynskij *et al.* 2010).

The laboratory plant (Fig. 1) is 3.7 m-long double tee steel on which 40 mm-thick layer of concrete is placed and compacted by a vibrator. The surface was smoothed and floated with Cement 400. Floating with cement is a method of protecting the surface of concrete structures from water penetration, allowing for smoothing their surface as well as increasing strength and durability. The slope of the shoot can be changed from 0° to 0.02°

and the readings are shown by indicator 4. The water is supplied to the shoot by a water pipe-line or by a pump if the consumption is over 150÷200 cm³/sec. The depth of the flow was measured by measuring needles on three section-lines shown in Fig. 1. The section-lines were chosen so that the influence of the inlet and outlet sections could be eliminated. The stability of the flow depth and consumption was controlled by the flow depth sensor 11 and register 12.

To check the effect of the rain drops on a transit flow, a sprinkler system, consisting of a pipe-line of 20 mm in diameter and having the opening with the fixed nibs for forming drops and ensuring their uniform distribution over the flow surface was used.

The plant aimed at working in the outdoor conditions differs from the laboratory plant only in size (the width of the flow is 370 mm, while its length is 8 m) and it does not have a sprinkler system and a pump. The surface of the shoot of this plant is much rougher due to the exposure of concrete to rain, snow and low temperatures (for more than three years).

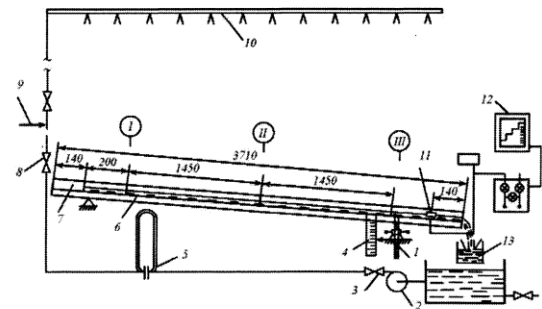


Fig. 1. A schematic view of the laboratory plant with a shoot of 280 mm width:

- 1 – a hoist; 2 – a pump for the follows deeper than 5–6 mm;
- 3, 8 – a gate valve and valves for regulating water consumption;
- 4 – shoot slope indicator; 5 – water meter; 6 – a double tee;
- 7 – a damper; 9 – water supply by a water pipe-line;
- 10 – a sprinkler system; 11 – the water flow depth sensor;
- 12 – a register; 13 – a vessel for measuring water consumption

The roughness of the surface was measured following the ICAO recommendations (Airport Services Manual 2002), i.e. by covering it with sand and lubricating material. Then the measured sand or lubricant was smoothed and the mark (print) was measured. The roughness of the concrete surface of the shoot in the laboratory was about 0.1 mm, while, under the outdoor conditions, it reached about 0.4 mm.

At the considered stage of research, a transit flow was investigated, implying that the effect of the rain drops was not taken into account. It should be noted that such flows are most often observed on the runway. The runway was 40÷50 m wide, while a transit flow was formed at the start of the slope. The effect of the rain drops is likely to be strong at the first slope section, which will be an important factor for short slopes, which

are most common for automobile roads. The authors hope to study the considered effect in the future.

The results of the laboratory experiments are presented in Fig. 2 as the relationships between the flow depth h and the consumption Q , and in Fig. 3 as the relationships between the resistance λ and Reynolds number Re .

The roughness of the runway section surface, where the experiments were made (Kiev City International Airport, Ukraine – Zhuliany till 2011), reached 0.44 mm. The experiments (Fig. 4) were performed before the reconstruction of the runway was made in 2009, therefore, the influence of the expansion joints of the slabs could be observed. It should be noted that the slabs (3 × 4 m) were placed after the Second World War and the expansion joints were not always filled appropriately, i.e. flush with the concrete surface. A shoot on the runway was 1 m wide and 12±20 m long, while the surface roughness of the shoot was about 0.44 mm.

4. Conclusions

1. The experiment study of shallow flows of liquid allowed the authors to reveal and quantitatively evaluate a considerable effect of the surface roughness on the design

relationships (which, as far as they know, has not been done before) and to suggest a new coefficient to be introduced into a well-known formula for calculating flat laminar flows of rain-water. This coefficient turned out to be $167/96 = 1.73$ times (see Fig. 3) higher than that, which is commonly used for relatively flat and smooth surfaces.

2. A hypothesis is made that the increase of the coefficient is caused by considerable bending of the streams of liquid and the variation of their speed under the influence of rough surface and power loss due to the interaction of the streams.

3. It has been found that strong effect of surface roughness still does not lead to flow tubulisation. The critical Reynolds numbers are considerably larger for shallow flows than those obtained for common and enforced flows of liquid.

4. The rain drops did not cause flow tubulisation in the experiments performed.

5. It has also been found that, in turbulent shallow flows, the resistance does not increase, which may be accounted for by a considerable increase of the kinetic energy of the streams and the sufficient increase of the depth of turbulent flows under the experimental conditions.

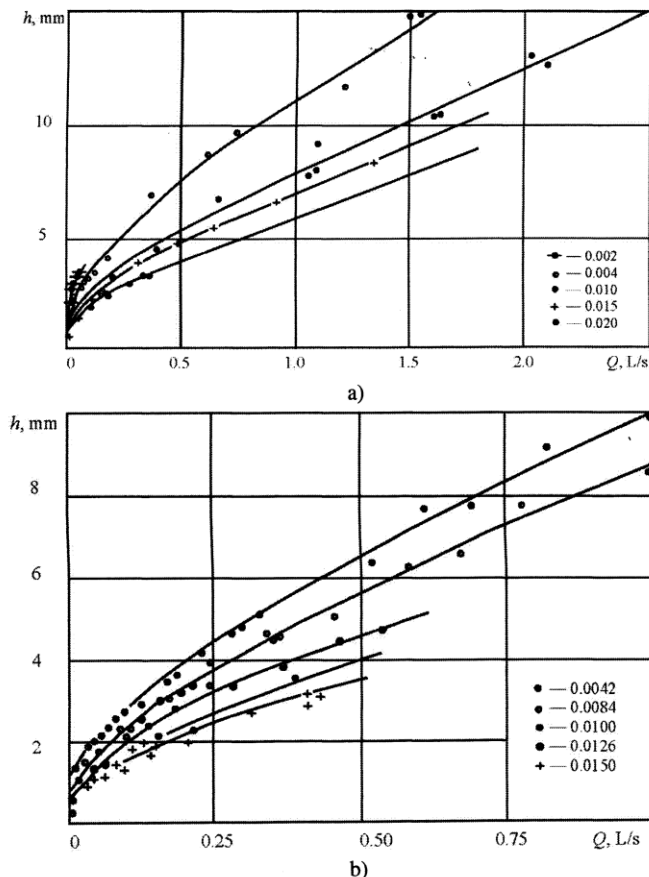
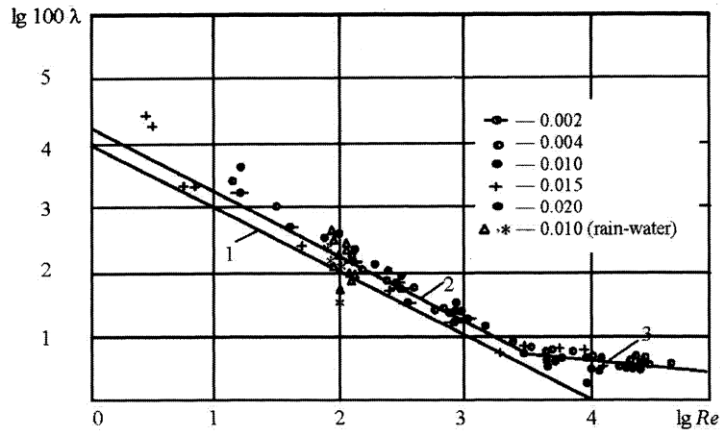
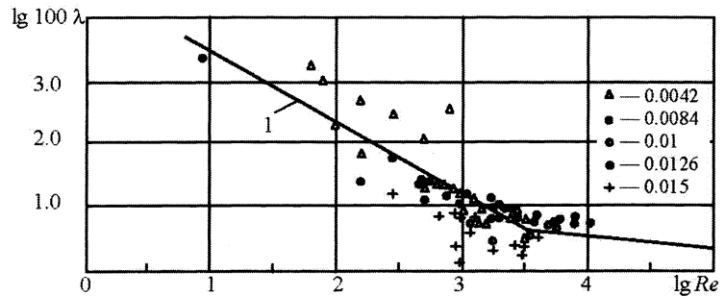


Fig. 2. The dependences of the flow depth h on the consumption Q on the concrete surface: a – roughness $\Delta = 0.1$ mm; b – roughness $\Delta = 0.4$ mm of the surface exposed to atmospheric action for a long time (the bed slope of the flow is points)



a)



b)

Fig. 3. The dependences of the resistance coefficients λ on the flow mode (Reynolds numbers) for shallow flows on concrete surface:

a – surface roughness $\Delta = 0.1$ mm; 1 – a line corresponding to ordinary smooth flows ($\lambda = 96/Re$); 2 – a line corresponding to laminar flow ($\lambda = 167/Re$); 3 – a line corresponding to turbulent flow ($\lambda = 0.11 \cdot (\Delta/4 \cdot h)^{0.25}$); b – surface roughness $\Delta = 0.4$ mm (the surface was exposed to atmospheric action for a long time), 1 is the line corresponding to the surface with $\Delta = 0.1$ mm given in Fig. 3a

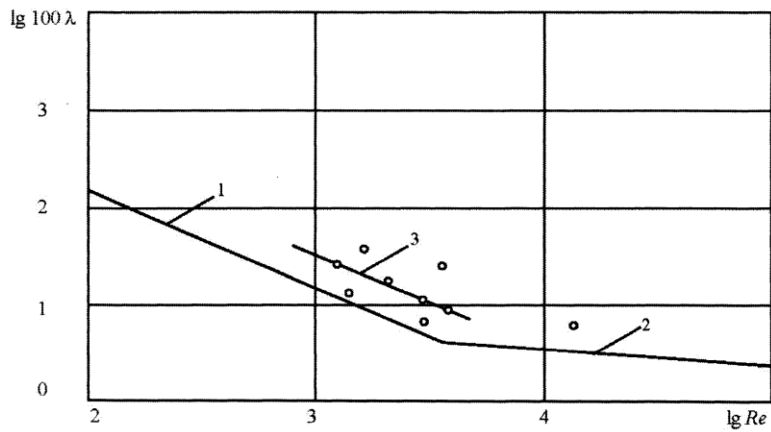


Fig. 4. The dependences of the resistance coefficients λ for shallow flows on concrete surface on the flow mode (Reynolds numbers) – for the Kiev City International Airport (Ukraine) ($\Delta = 0.44$ mm and there are densely spaced joints between slabs): 1 – the line corresponding to the line 2 in Fig 3a which refers to the laminar flow on a relatively smooth surface; 2 – the line, corresponding to a turbulent flow on a relatively smooth surface; 3 – a laminar flow for the surface of an old runway in the Kiev City International Airport (Ukraine) with the slabs (3×4 m), having low quality joints ($\lambda = 344/Re$)

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