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SIMULATOR VERIFICATION OF CESSNA 172 RG REPEATED TAKE-OFF RUNS IN EXTREME TEMPERATURE CONDITIONS

Abstract: *The paper presents the results of the research of performance measurement of a selected aircraft type in the take-off phase under extreme temperature conditions. For this purpose, a flight simulator of the Cessna 172 RG aircraft from the ELITE Company was used. For the purpose of verifying the take-off run length, the article provides a measurement methodology that was developed using information obtained during experimental take-offs. The aim was to obtain a procedure that would allow for repeated take-off runs in the same conditions with the possibility of changing individual influencing factors. Considering the whole measurement chain, the article analyses the influencing factors and quantifies their impact on the uncertainty of the measurement result. The data obtained experimentally we compared with the data in the Flight Manual and at the end carried out the assessment of the impact of global warming on the take-off run of the Cessna 172 RG and generally on the safety of the take-off and on air transport..*

Keywords: simulator, aircraft, performance, take-off, take-off run, methodology, uncertainty, safety

1. Introduction

In the context of climate changes, the issue of aircraft performance is a highly topical issue, as air parameters are among the significant factors affecting the performance of aircraft during take-off and their impact on the safety of take-off is essential. The factors affecting the take-off run length of the aircraft are as follows [1-4]:

- aircraft weight
- air temperature
- air pressure
- air humidity
- wind direction and strength
- runway elevation
- runway surface condition
- flap position
- contamination of the aircraft surface

Air parameters, temperature, pressure and humidity affect aircraft performance through air density. The value of the aerodynamic forces is significantly influenced by the value of the air density, while the effect is direct. The greater the air density, the more e.g. the magnitude of the aerodynamic upward force and this has a beneficial effect on aircraft performance. Conversely, the lower the air density, the lower e.g. the aerodynamic upward force and it means an adverse effect on aircraft performance [1-4].

These patterns result from the following relationship for the aerodynamic upward force F_L, which implies that air density affects the aerodynamic upward force directly. Thus, the greater the air density, the greater the aerodynamic upward force and vice versa.

$$F_L = c_L \cdot \frac{1}{2} \cdot \rho \cdot v^2 \cdot S \; [\mathrm{N}] \tag{1}$$

where: c_L – coefficient of lift
ρ – air density [kg.m^{-3}]
v – flight speed [m.s^{-1}]
S – reference surface [m^2]

The air density at the point of take-off of the aircraft depends on the pressure, temperature and humidity of the surrounding air while affecting:

a) Engine thrust and power. Decreasing air density reduces the thrust and power the engine can produce. Therefore, the acceleration decreases during take-off and the take-off distance is extended [1-4, 19, 20].

b) The true TAS airspeed for a given value of the indicated IAS speed. The decreasing air density increases the TAS for a given IAS value the pilot uses for control. Therefore, the aircraft accelerates longer to an increased TAS value; thereby the take-off distance is extending [1-4].

c) Initial climb angle. As the air density decreases, the power and thrust of the engines decrease, and therefore the initial climb angle will be smaller, this increases the take-off distance due to the greater horizontal distance to reach the standard take-off altitude set for its completion [1-4].

For air density ρ, the following relation is applied:

$$\rho = \frac{p}{R \,.\, T} \quad \left[\mathrm{kg.m^{-3}}\right] \tag{2}$$

where: p – average value of an air pressure in the measured sector [Pa]
T – average air temperature in the measured sector [K]
R – universal gas constant; R = 287 $\mathrm{J.kg^{-1}.K^{-1}}$

The relation indicates that the air pressure directly affects the air density, so the higher the air pressure, the greater the air density. Air temperature affects air density indirectly, so the higher the air temperature, the lower the air density.

Air humidity affects air density indirectly, so the higher the air humidity, the lower the air density.

This implies that global warming adversely affects aircraft performance. Higher air temperatures during take-off increase the take-off run length and overall take-off distance. The mentioned theoretical regularity was investigated in this project and the ELITE flight simulator for the Cessna 172 RG aircraft was used for this purpose. This was compared with the data provided in the Cessna 172 RG flight manual. In order to verify the take-off run time, it was necessary to develop a measurement methodology and to analyse the influencing factors and quantify their impact on the uncertainty of the measurement result for the whole measurement chain.

2. Methods

In aviation, simulations are used both in aircraft development, verification of their characteristics and durability, as well as in the simulation of the flight itself, e.g. for the purpose of practicing crew operations, etc. In this project, the flight simulator of the aircraft Cessna 172 RG from the ELITE Company, designed for practicing basic pilot´s skills during pilot training, was used.

The plane's motion and its properties can be expressed using a system of differential equations. The complexity of mathematical relationships depends on the number of variables considered that will be taken into account for the calculation. This complexity generates demands on the computational performance of the simulator. The actual movement of an aircraft in space, manifestations of its properties, the impact of meteorological phenomena, etc. are the tasks of the software. It constantly uses the power of computing and recalculates the differential equations of aircraft position and movement. The results are visualized by the visualization and audio systems, reflected in the driving forces, the movement of the platform and the changes in the data on the instruments in the cockpit.

The more input data processed by the software, the more realistic its output. Of course, there is a strong relationship between software and hardware. These two parts must be perfectly matched in terms of the performance and function. Current simulation technologies provide almost identical flight perception and its control and flying on top simulators is comparable to real flying [5-8, 10-12].

For the research activities in this project, the use of the flight simulator is very efficient and inexpensive. The use of flight simulators for research purposes is an important method applied in the field of aviation [9, 14-16, 21, 22].

For the purpose of measuring the take-off run length of the Cessna 172 RG on the ELITE flight simulator, a measurement methodology has been developed which takes into account the possibilities of flight simulator software tools and the experience gained from experimental flights. The aim was to obtain a procedure that would allow for repeated take-off runs in the same conditions with the possibility of changing individual influencing factors.

Measurement Methodology:

- Kosice airport was chosen for research flights.
- To start the simulator in the standard way.
- Perform all pilot operations up to the pre-take-off phase.
- At this point, it is advisable to save the current aircraft configuration for performance measuring. After the flight, the simulator can be paused and reloaded for a saved aircraft configuration, thus making repeated measurements. This is done as follows: at the bottom of the screen there is the "aircraft state" window, where after clicking on "save", a new window opens in which you can name the set configuration and then save it.
- It is also necessary to turn on the vertical track profile before take-off to determine when the aircraft lift-off the ground takes place. At this point, it is possible to stop the simulator and measure the take-off run length. In the right part of the screen you have to click on "profile", at the bottom of the screen you will see a vertical profile. Next, you need to zoom to the maximum, so set the "1250 % zoom" in the lower right corner of the vertical profile to make the measurement as accurate as possible.
- When measuring the take-off run length, the weight of the aircraft, pressure head and ambient air temperature have been changed. The weight of the aircraft can be changed by clicking on "Menu" and then clicking on "CONTROL", after the window is displayed move to the column "Load / Fuel", where you set the appropriate take-off weight. The resulting take-off weight is shown in the "Total weight" window.
- Temperature and pressure head can be changed similarly to weight. Click on "Menu" and select "METEO". Set the pressure altitude in the line "QNH (hPa)", change QNH so that the altimeter in the cockpit shows the corresponding altitude. The ambient air temperature is set in the "Temperature" line by deviating from the

standard temperature. Finally, check the last column "Actual Weather at current position" to see if we have set the required values. To be sure, it is also advisable to check the altimeter and the ambient air thermometer in the cockpit.

- After take-off weight, ambient air temperature and pressure altitude are set, take-off can be performed. We chose the zero wind, concrete take-off and landing runway of Kosice airport, set as dry, for the research flights, and take-offs were performed in 008o direction. The take-off procedure followed the short-range take-off instructions. This is defined in the Cessna 172 RG flight manual as follows [17]:
    1) Flaps for take-off (10°)
    2) Cooling flap open
    3) Throttle full (2700 rpm)
    4) Brakes released
    5) The lift-off speed depends on the take-off weight
    6) At 50 ft AGL pause the simulator (freeze)
- After take-off (we are interested only in take-off run length, but for better accuracy of reading distance on the ground from vertical track profile, we pause the simulator at take-off height about 50 ft AGL (click "Menu" and then "FREEZE", or use the keyboard shortcut "Alt + F").
- Then take a photo of the current screen using the "Prt Scr" key on the keyboard, then use the "Windows" button to open the "Start" menu and run a suitable drawing program (e.g. Paint), where we save our photo so we can measure the take-off run length and count it to the real value using the scale determined.

The scale was determined so that the runway at Kosice Airport was rolled over three times in the whole section. After each taxiing, the length of the path in the Paint on the vertical track profile was measured using an inserted ruler. The average path length in the vertical profile was calculated from these three values. As the runway length at Kosice Airport is 3100m, the ratio was determined for further research activities: 1mm = 17.213m.

3. The analysis of influencing parameters and quantification of their influence on the indeterminateness of measurement results

The uncertainty of the measurement of the take-off length on the ELITE Cessna 172RG flight simulator using the developed method is determined in accordance with the Technical Standard Metrological TPM 0050-93, Determination of measurement uncertainties [13]. Measurement of the take-off run length on a flight simulator allows observing completely identical outdoor conditions - unlike real measurements in the real atmosphere.

In order to determine the uncertainties of the measurement of the take-off run length, we performed a total of 20 take-off runs / take-offs (n = 20). As conditions during measurements have been identical, we consider the measurements performed to be repeatable.

Measurements were made under the following conditions:

- take-off weight m = 2650 lbs
- ambient air temperature T = 0°C
- pressure head Hp = 0 m
- Kosice take-off airport, dry runway, horizontal
- wind speed V = 0 m.s-1
- take-off run and take-off methodology: short runway procedure
- flap position: take-off (10°)

Since only the distance between the brake release point and lift-off was repeatedly measured at individual take-off runs, the uncertainty analysis is made for the direct measurement of one quantity in accordance with the procedure in TPM 0050-93. For the same reason, no correlations affecting the quantities were analyzed.

The standard uncertainty of *uA* type

Evaluation of standard uncertainty of the A measurement type is a method of uncertainty evaluation based on a statistical analysis of a series of measurements. In this case, the standard uncertainty is the sample standard deviation of the mean value, which is obtained by averaging or by appropriate regression analysis [13]. In this case, averaging was used. To calculate the uncertainty u_A, the measurement results were processed in accordance with the point 4.1, paragraph b) of TPM 0050-93, so-called line-by-line processing.

Standard uncertainty of type A is equal to the sample standard deviation of the sample average in accordance with TPM 0050-93:

$$u_A = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(s-\bar{s})^2} \quad (3)$$

$$u_A = 1{,}44m$$

where: $\bar{s}$ – selective average
i – i-th measurement

$$\bar{s} = \frac{\sum_{i=1}^{n} s}{n} = 274{,}85m \quad (4)$$

Table 1

Processing of the take-off run length measurement results for u_A determination

i	Take-off run length according to an inserted ruler [mm]	scale	Take-off run length s [m]	s-$\bar{s}$ [m]
1	16,0	1 mm = 17,213 m	275	0,15
2	16,0	1 mm = 17,213 m	275	0,15
3	15,5	1 mm = 17,213 m	267	-7,85
4	16,5	1 mm = 17,213 m	284	9,15
5	16,0	1 mm = 17,213 m	275	0,15
6	15,5	1 mm = 17,213 m	267	-7,85
7	16,0	1 mm = 17,213 m	275	0,15
8	16,0	1 mm = 17,213 m	275	0,15
9	15,5	1 mm = 17,213 m	267	-7,85
10	16,5	1 mm = 17,213 m	284	9,15
11	15,5	1 mm = 17,213 m	267	-7,85
12	16,5	1 mm = 17,213 m	284	9,15
13	16,0	1 mm = 17,213 m	275	0,15
14	16,5	1 mm = 17,213 m	284	9,15
15	16,0	1 mm = 17,213 m	275	0,15
16	16,0	1 mm = 17,213 m	275	0,15
17	15,5	1 mm = 17,213 m	267	-7,85
18	16,5	1 mm = 17,213 m	284	9,15
19	16,0	1 mm = 17,213 m	275	0,15
20	15,5	1 mm = 17,213 m	267	-7,85

The standard uncertainty of u_B type

The resulting standard uncertainty of the type B $\boldsymbol{u_B}$ consists of the following partial standard uncertainties of type B u_{Bj}:
u_{B1} - the source of uncertainty Z_1 is a scale factor error
u_{B2} - the source of uncertainty Z_2 is an error in inserting the ruler starting point from the beginning of take-off run
u_{B3}- the source of uncertainty Z_3 is a pixel error
u_{B4} - source of uncertainty Z_4 is subtraction error
The next section provides the calculation of u_{B1} to u_{B4} (for u_{B1} also with complete procedure and commentary).

$\boldsymbol{u_{B1}}$

The scale was determined based on three experimental measurements:

- the declared runway of Kosice airport with a length of 3100m was taxied from the beginning to its end

- taxiing was performed by placing the aircraft at the beginning of the runway and then taxiing to the end of the runway where the aircraft was stopped
- the length of taxiing in millimetres was read from the vertical taxi trajectory profile using the inserted ruler
- we got the scale dividing the declared path length by the length of taxiing obtained from the inserted ruler (the average was calculated from three measurements)

In experimental measurements, the difference in length of taxiing obtained from the inserted ruler was ± 1 mm. Because the smallest scale of the ruler is 1 mm, the length of taxiing determined by the ruler (for scaling purposes) was subtracted to the nearest millimetre. Therefore, the source of uncertainty Z_{1max} = ± 1 mm, and exceeding these values is unlikely. The most appropriate approximation for the probability of these deviations is the normal Gaussian distribution with a coefficient χ = 3, which is associated with an estimate of Z_{max}, which is unlikely to be exceeded (paragraph 3.2.3 and Table 1 of TPM 0050-93).

$$u_{B1} = \frac{Z_{1max}}{\chi} = \frac{1}{3} = 0{,}333mm \qquad (5)$$

The estimated uncertainty u_{B1} is transmitted to the standard uncertainty of the measurement result u_B and forms its component u_{x1} (the so-called contribution to uncertainty), which is calculated from the relationship

$$u_{x1} = A_{x1} \cdot u_{B1} = 17{,}213 \cdot 0{,}333 = 5{,}74m \qquad (6)$$

where the transmission sensitivity coefficient A_{x1} = 17,213 m.mm^{-1} (which is actually a calculated scale).

u_{B2}

The source of uncertainty Z_2 is an error in inserting the ruler starting point at the beginning of the take-off run. As with the uncertainty source Z_1, the uncertainty source Z_2 is estimated to be ± 1 mm.

Z_{2max} = ± 1 mm

Normal Gaussian distribution s χ = 3

$$u_{B2} = \frac{Z_{2max}}{\chi} = \frac{1}{3} = 0{,}333mm$$

$$u_{x2} = A_{x2} \cdot u_{B2} = 17{,}213 \cdot 0{,}333 = 5{,}74m$$

$$A_{x2} = 17{,}213\ m.mm^{-1}$$

u_{B3}

The source of the uncertainty of Z_3 is a pixel error of the screen (at a zoom setting of 1250%), which is estimated to be ± 0.5 mm.

Z_{3max} = ± 0,5 mm

Bimodal (Dirac) distribution s $\chi = \sqrt{2}$

$u_{B3} = \frac{Z_{3max}}{\chi} = \frac{0,5}{\sqrt{2}} = 0,355mm$

$u_{x3} = A_{x3} \cdot u_{B3} = 17,213 \cdot 0,355 = 6,11m$

$A_{x3} = 17,213\ m.mm^{-1}$

u_{B4}

The source of uncertainty Z_4 is the error of subtracting the take-off run length from its vertical profile using an inserted ruler. Because the smallest scale of the ruler is 1 mm, the take-off run length was subtracted to half a millimetre. The reading error is estimated to be ± 0.5 mm.

$Z_{4max} = \pm 0,5$ mm

Normal Gaussian distribution s $\chi = 3$

$u_{B4} = \frac{Z_{4max}}{\chi} = \frac{0,5}{3} = 0,167mm$

$u_{x4} = A_{x4} \cdot u_{B4} = 17,213 \cdot 0,167 = 2,87m$

$A_{x4} = 17,213\ m.mm^{-1}$

Table 2

Audit of standard Type B uncertainty measurement of the take-off run length

Source of uncertainty Z_j	Estimate Z_{jmax}	Selected distribution	χ	uncertainty u_{Bj}	Transition sensitivity coefficient A_{xj}	Contribution to the resulting uncertainty type B u_{xj}
Z_1	± 1 mm	Normal Gaussian	3	0,333 mm	17,213 $m.mm^{-1}$	5,74 m
Z_2	± 1 mm	Normal Gaussian	3	0,333 mm	17,213 $m.mm^{-1}$	5,74 m
Z_3	± 0,5 mm	Bimodal (Dirac)	$2^{1/2}$	0,355 mm	17,213 $m.mm^{-1}$	6,11 m
Z_4	± 0,5 mm	Normal Gaussian	3	0,167 mm	17,213 $m.mm^{-1}$	2,87 m

Resulting standard uncertainty of the type B

The resulting standard B u_B uncertainty is determined by transmitting and merging the estimated uncertainties u_{xj} using the Gaussian uncertainty propagation law in accordance with TPM 0050-93 (in this case, without correlation evaluation)

$$u_B = \sqrt{\sum_{j=1}^{4} u_{xj}^2} = 10,56m \quad (7)$$

Combined standard u_C uncertainty

The combined standard uncertainty of the u_C measurement result is determined by combining the standard uncertainty types A and B using the Gaussian uncertainty propagation law in accordance with TPM 0050-93.

$$u_C = \sqrt{u_{A1}^2 + u_B^2} = \sqrt{1{,}44^2 + 10{,}56^2} = 10{,}66m \tag{8}$$

Extended uncertainty *U*

The expanded uncertainty is used in cases where high reliability (probability) is required that the actual value of the measured quantity will lie within the interval defined by this uncertainty. In terms of statistics, this is the task of determining the confidence interval, or limits of the confidence interval for the chosen confidence probability. Therefore, the expanded uncertainty was also determined for measuring the take-off run length on the ELITE Cessna 172 RG flight simulator using the developed method.
The expanded uncertainty of the measurement result *U* is determined in accordance with the paragraph 6.3.3 of TPM 0050-9, where the coefficient k_U takes into account the number of repeated measurements:

- for $n = 5$ je $k_U = 1{,}4$
- for $n = 7$ je $k_U = 1{,}3$
- for $n = 8$ je $k_U = 1{,}2$
- for $n = 10$ až 20 je $k_U = 1{,}05$ (selected for the calculation)
- for $n > 20$ je $k_U = 1{,}0$

$$U = 2.\sqrt{k_u^2.u_A^2 + u_B^2} = 2.\sqrt{1{,}05^2.1{,}44^2 + 10{,}56^2} = 21{,}34m \tag{9}$$

For this stated extended uncertainty of the measurement result of the take-off run length on the ELITE Cessna 172 RG flight simulator using the developed method, the confidence probability of 95% is assigned at the assumed normal Gaussian distribution.

The expanded uncertainty of the result of measuring the take-off run length on the ELITE Cessna 172 RG flight simulator using the developed method is

$$U = \pm\ 21{,}34\ m$$

where the expanded uncertainty of the measurement result has been determined in accordance with paragraph 6.3.3 of TPM 0050-93 for a number of measurements n = 20, and is assigned a confidence probability of P = 95%.

4. Results

To verify the take-off length of the Cessna 172 RG aircraft on the ELITE flight simulator, 27 take-offs were carried out under selected conditions and were compared with the data in the flight manual and the theoretical laws applicable to the performance of the aircraft in the take-off phase.

For experimental verification of the take-off run length, the procedure was chosen in the short-range take-off flight manual, for three different take-off weights (2650, 2500 and 2300 lbs) within which the ambient air temperature (0°C, 20°C and 40°C) for three different pressure altitudes (SL – sea level, 2000 m and 4000 m above sea level) [17].

Table 3

Take-off run lengths obtained experimentally and take-off run lengths obtained from the flight manual [m]

Measurement results									
	2650 lbs			2500 lbs			2300 lbs		
	Lift-off speed 58 kt			Lift-off speed 56 kt			Lift-off speed 54 kt		
	0°C	20°C	40°C	0°C	20°C	40°C	0°C	20°C	40°C
S.L.	275	310	327	232	275	293	224	241	267
S.L.	291	335	384	255	293	335	210	241	276
difference	-16	-25	-57	-23	-18	-42	14	0	-9
2000	301	318	361	258	310	310	232	267	318
2000	348	401	460	303	349	401	250	287	330
difference	-47	-83	-99	-45	-39	-91	-18	-20	-12
4000	327	370	396	293	327	379	275	310	336
4000	418	483	555	364	419	482	299	345	395
difference	-91	-113	-159	-71	-92	-103	-24	-35	-59

Notes to the Table № 3 and Table № 4

(blue)	Take-off run lengths obtained experimentally on the ELITE Cessna 172 RG flight simulator
(yellow)	Take-off run lengths obtained from the Cessna 172 RG flight manual [17]

Comparison of take-off distances obtained experimentally with take-off distances obtained from the flight manual under the same conditions (take-off weight, ambient air temperature, pressure altitude, windless):

- The average deviation of experimentally obtained take-off run lengths from the take-off run lengths obtained from the AFM is 51 m. With a high probability this deviation is burdened by a systematic error (another take-off procedure on the simulator compared to a take-off procedure on a real aircraft that was used in measuring take-off run lengths in the preparation of the flight manual).
- This implies that take-offs in experimental verification of take-off run lengths have lower values than take-off run lengths given in the flight manual.

Possible causes for this are:

- The description of the short-range take-off methodology in the AFM does not indicate whether stamina is required after the front wheel rotation (and if so, for how long) and subsequently spontaneous aircraft lift-off or whether the aircraft must lift-off the runway immediately after the front wheel rotation.
- The flight manual contains only the lift-off speed, but the rotation speed is not specified. For this reason, during research flights on a flight simulator, the pilot performed a take-off by rotating the front wheel with the immediate aircraft lift-off the runway after reaching the lift-off speed.
- All take-offs within the research activities were carried out by one pilot - all measurements were burdened with a specific piloting technique characteristic for this pilot.

Experimental take-off run lengths obtained under different conditions copy the take-off run lengths obtained from the flight manual (with an average negative deviation of 51 m) and correspond to the theoretical performance patterns of the aircraft at take-off phase.

5. Discussion

Comparisons of measured take-off run lengths with theoretical laws applicable to aircraft performance at take-off phase:

<u>Take - off weight change</u>

As weight increases, acceleration at take-off run decreases and the lift-off speed must be higher. Both of these effects prolong the overall take-off run lengths, which was also confirmed by the measurements.

<u>Pressure altitude change</u>

The air density decreases with height exponentially. As air density decreases, thrust and engine power are reduced and true airspeed increases. The take-off run length is therefore prolonged, which was also proved in measurements.

<u>Ambient air temperature change</u>

The air density decreases as the temperature rises. As the density decreases, thrust and engine power decrease. The temperature increases, the density decreases and the actual flight speed increases at a constant indicated flight speed. The take-off run length is therefore prolonged, which was also proved in measurements.

Variations in the measured take-off run lengths under different conditions (take-off weight, ambient air temperature, pressure altitude) correspond to the theoretical performance patterns of the aircraft during the take-off phase.

To determine the effect of the increased temperature on the take-off run length, the following table shows the variations in the take-off run length when the temperature changes (TEMP changes) from 0°C to 20°C and to 40°C.

Table 4

Effect of temperature changes on take-off length [m]

Measurement results						
	2650 lbs		2500 lbs		2300 lbs	
	Lift-off speed 58 kt		Lift-off speed 56 kt		Lift-off speed 54 kt	
	TEMP change from 0°C to 20°C	TEMP change from 0°C to 40°C	TEMP change from 0°C to 20°C	TEMP change from 0°C to 40°C	TEMP change from 0°C to 20°C	TEMP change from 0°C to 40°C
S.L.	35	52	43	61	17	43
S.L.	44	93	38	80	31	66
2000	17	60	52	52	35	86
2000	53	112	46	98	37	80
4000	43	69	34	86	35	61
4000	65	137	55	118	46	96
Average acceleration take-off run length	43	87	45	83	34	72

The average increase is 81 meters in take-off run length when changing temperature from 0°C to 40°C. This calculation included results from experimental flight simulator measurements as well as results obtained from the flight manual. As a result, a temperature rise of 1°C increases the take-off run length by 2.02 m.

“If greenhouse gas emissions continue to rise, we will certainly be facing severe climate changes across the globe by the end of the 21st century. Depending on how much fossil carbon we release into the atmosphere, the global air temperature may increase by an additional 1.1 to 6.4°C by the end of this century, which means an increase of 2 to 7°C.“[18]

This prediction of the future climate scenario suggests that the rise in temperature on the Earth is unstoppable. For air transport, especially for aircraft performance, this means that it will decrease with increasing temperature. One consequence of higher temperature is e.g. because the lower the temperature difference between the air at the engine inlet and the exhaust gases at the engine outlet, the lower the engine power. Also, lower cruising speeds at higher temperatures will increase flight time and hence fuel consumption. An increase in the average temperature by 1.1 to 6.4°C by the end of the 21st century [18] in terms of aircraft performance is acceptable. Nevertheless, even these small changes in terms of aircraft performance will cause, for example, a significant increase in fuel consumption in the global aviation sector. The power plants of existing aircraft have sufficient power to enable all phases of flight to be carried out within specified safety limits even at these elevated temperatures. In borderline situations, e.g. in the case of a short take-off run or high obstacles after take-off, however, such small temperature changes may already limit air traffic. Another adverse factor in terms of global warming is the increase in the number of days with high temperatures above 30-35°C. In such cases, air transport is already significantly restricted even today and e. g. insufficient take-off performance at high temperatures must be solved by lower load weight.

6. Conclusions

The elaborated methodology of measuring the take-off run length of the Cessna 172 RG on the ELITE flight simulator provides the same outdoor conditions - unlike real measurements in real atmosphere. Measurements are therefore repeatable, and when one of the influencing factors is changed, it is possible to determine its influence on the take-off run length using statistical tools. Thus, a research flight tool is available to detect the effect of temperature changes (and hence global warming) on the take-off run length of the Cessna 172 RG. The analysis of influencing factors and quantification of their effect on measurement uncertainty gives the numerical value of the extended uncertainty of the measurement of the take-off run length measurement on the ELITE Cessna 172 RG flight simulator using a developed method that is $U = \pm$ 21,43 m.

The results obtained from experimental measurements on the flight simulator and at the same time the results obtained from the Flight Manual show that a temperature increase by 1°C prolongs the take-off run length for the Cessna 172 RG by 2.02 m. Such a small change in the take-off run length is acceptable for a sufficiently long take-off run. With global warming, however, the number of days with high temperatures above 30 to 35°C will increase, and in this case the performance of the aircraft is already significantly reduced and the safety of take-off may be adversely affected. As a result of global warming, air transport is also one of the areas where technological changes will have to take place in the next 50 to 100 years in the form of e.g. eliminating these negative effects on aircraft power units.

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