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**ANALYSIS OF OPERATING INSTRUMENT LANDING SYSTEM
ACCURACY UNDER SIMULATED CONDITIONS**

Summary. The instrument landing system (ILS) is the most popular landing aid in the world. It is a distance-angled support system for landing in reduced visibility, while its task is the safe conduct of the aircraft from the prescribed course landing on the approach path. The aim of this study is to analyse the correctness of the ILS in simulated conditions. The study was conducted using a CKAS MotionSim5 flight simulator in the Simulation Research Laboratory of the Institute of Combustion Engines and Transport at Poznan University of Technology. With the advancement of technical equipment, it was possible to check the operation of the system in various weather conditions. Studies have shown that the impact of fog, rain and snow on the correct operation of the system is marginal. Significant influence has been observed, however, during landing in strong winds.

Keywords: instrument landing system, flight simulator, CKAS MS5

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1. INTRODUCTION

From the moment when people began to be transported, a major problem has been location. In the beginning, the position and the way forward were determined by the stars. Later, with the development of means of transport, many methods to determine the position in which the object is located were invented. The field of science, in this area of navigation, is defined as the science of the ways, methods and technical means of conducting moving objects according to the route, route selection, determination of the position of movable or immovable objects, and determination of errors of positions measurement [7].

Air navigation as a field of study covers issues, both theoretical and practical, concerning the safe and economical operation of the aircraft after embarking on the set route. Navigating the aircraft is a set of activities performed by the pilot and/or navigator to determine the geographical position of the aircraft, as well as determine and maintain the navigational flight parameters, such as rate, altitude and speed, which are necessary to operate an aircraft on the required route in the appointed time to the destination [10].

Many factors affect the proper operation of the ILS [9]. All of them, however, were examined and described in Annex 10 to the Convention on International Civil Aviation. Thanks to the recommendations issued by the ICAO, the risk of malfunction of the system is minimized to an acceptable level, which significantly improves the safety of the aircraft for the approach and landing. In this work, however, we decided to validate the system under simulated conditions.

The aim of this study is to investigate the correctness of the ILS. The study was conducted in the Simulation Research Laboratory of the Institute of Combustion Engines and Transport at Poznan University of Technology. The CKAS MotionSim5 simulator used in the research was produced by CKAS Mechatronic Pty. Ltd.

2. INSTRUMENT LANDING SYSTEM

ILS tests began in 1929 in the USA [6]. The Civil Aeronautics Administration (CAA) authorized the installation of the system in 1941 at six locations. The first landing of a scheduled US passenger airliner using an ILS was on 26 January 1938, when a Pennsylvania Central Airlines Boeing 247D flew from Washington, DC, to Pittsburgh, PA, where it landed in a snowstorm using only an ILS [8]. The first fully automatic landing using an ILS occurred in March 1964 at Bedford Airport in the UK.

An ILS operates as ground-based instrument approach system, which provides precision lateral and vertical guidance to an aircraft approaching and landing on a runway, using a combination of radio signals and, in many cases, high-intensity lighting arrays to enable safe landing during instrument meteorological conditions, such as low ceilings or reduced visibility due to fog, rain or blowing snow [3, 11].

An ILS comprises two segments: a ground segment and airborne segment. The ground segment includes a localizer (LOC or LLZ), an ILS glide slope, marking markers and DME radio beacons, while the airborne segment consists of three receivers: VOR/LOC, ILS-GP receiver and the markers' receiver.

According to Annex 10 of the ICAO, there are three categories of ILS, with the last category being the most accurate and comprising another three subclasses. The division of ILS categories is shown in Table 1.

Tab. 1

ILS categories for precision instrument approach and landing [4]

Approach category	Decision height	Runway visual range (RVR)
I	200 ft (61 m) or more	550 m (1,800 ft)
II	Less than 200 ft but more than 100 ft (30 m)	1,000 feet (300 m)
III a	Less than 100 ft but more than 50 ft (15 m)	600 feet (180 m)
III b	Less than 50 ft (15 m)	150 feet (46 m)
III c	No limitations	None

Smaller aircraft are generally equipped to only fly with a CAT I ILS. On larger aircraft, these approaches are typically controlled by the flight control system with the flight crew providing supervision. The CAT I relies only on altimeter indications for decision height, whereas CAT II and CAT III approaches use a radio altimeter to determine decision height. Furthermore, as the Category III c ILS is able to perform a precision instrument approach and landing, with no decision height and unlimited RVR, it can be claimed that this offers a fully automatic approach for landing.

3. RESEARCH METODOLOGY

3.1. CKAS MotionSim5 simulator

The CKAS MotionSim5 flight simulation training device (FSTD) is a software- and hardware-based system that couples the reliability of modern desktop computer equipment, on a custom-built motion platform, with a cockpit that provides control devices that are identical or similar to those found on real aircraft. The CKAS MotionSim5 trainer (Fig. 1) is designed to simulate four generic types of light aircraft: a piston single-engine aircraft, such as the Cessna C172, a piston twin-engine aircraft, such as the Piper PA44 Seminole; a light twin-engine turboprop aircraft, such as the Beechcraft KingAir; and a light jet, such as the Cessna CitationJet. It is not intended to simulate a particular aircraft model, but rather to represent a typical aircraft of each class in its handling qualities and features.

The aircraft used for the test is a twin-engine jet designed for use by up to nine people. It is very light business jet.

All simulated aircraft are equipped with a common Garmin G1000-like avionics package. Some equipment, such as throttle quadrants or starter panels, are aircraft-specific and should be installed by the user for each particular model.

The MS5 Visual System provides a wide $200^{\circ} \times 40^{\circ}$ field of view with high resolution [1]. It consists of three full-HD projectors, three high-end PCs for image generation and a screen. An additional PC is used to drive flight instruments and for general flight simulation.

The movement simulator cab is made possible by the electrical motion system with six degrees of freedom. This makes it possible to obtain a high level of accuracy in performing movement. The system tilts the hull in every possible direction at an angle of 18° and moves it by 150 mm [1].

The instructor station provides control over the flight simulator environment in respect of weather, positioning, malfunctions, and real-time tracking and flight recording, for example. Additionally, it is possible to take operations from and to almost every airport in the world.



Fig. 1. CKAS MotionSim5 simulator [5]

3.2. The course of study

The aim of the study was to determine the effect of weather conditions on the correct operation of an ILS system. Poznań-Ławica Airport was selected as the destination airport for the tests. It is equipped with a CAT I ILS installed on RWY28.

Each of the flights started from the same place at the same altitude, i.e., 7 NM from RWY28 and located exactly in the axis of the runway, while the initial height was 2,200 ft.

After setting the frequency of the ILS in Poznan, i.e., 110,300 MHz, the correct interception of the localizer's beam (course and direction), the aircraft should have begun the approach automatically. The operator was responsible only for the disposition of a thrust of engines, as the other parameters were controlled by the on-board computer cooperating with the ILS.

Graphs were generated after each of the flights:

- altitude above ground level
- indicated aircraft speed
- aircraft vertical speed
- pitch

In addition, logs of various approaches were recorded in order to create spatial graphs using Google Earth and charts showing the trajectory deviation from the ideal approach path (azimuth and elevation).

4. RESULTS

4.1. Base flight

The first flight was conducted under CAVOK conditions. CAVOK is an abbreviation of Ceiling And Visibility OKay, indicating no cloud below 5,000 ft (1,500 m) or the highest minimum sector altitude and no cumulonimbus or towering cumulus at any level, a visibility of 10 km or more and no significant weather change [2]. In addition, it established a lack of wind. This flight was supposed to be the base, while its landing approach could be regarded as exemplary.

Figure 2 shows a three-dimensional (3D) glide path made with the Google Earth. To better illustrate this trajectory, we should also compare it with the curve generated by the FS Instructor software. The program, in addition to the glide path in the flight, applied an ideal path.

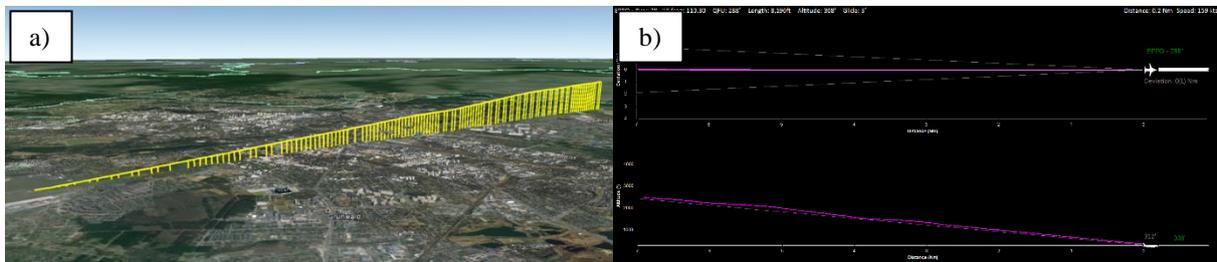


Fig. 2. Glide path in the first flight: a) 3D (Google Earth) and b) generated by FS Instructor

As shown, the deviation from the path defining the axis of the runway is similar to the ideal for the entire approach and landing (Fig. 2a). In the case of the glide path, slight deviations from the ideal can be seen (Fig. 2b). This may be caused by manual thrust control and problems with keeping constant speed while approaching. This scenario is illustrated by the indicated aircraft speed graph (Fig. 3a).

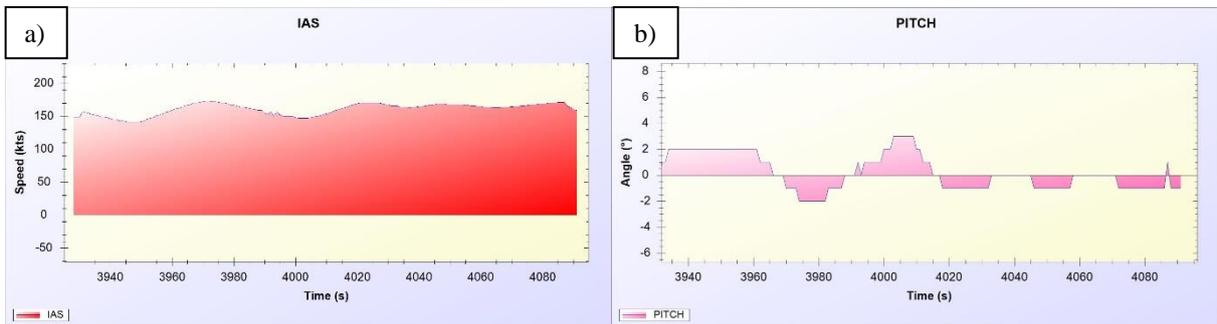


Fig. 3. Parameters in the first flight: a) indicated airspeed (IAS) and b) pitch angle

The IAS was not equal throughout the landing (Fig. 3a), possible due to the manual thrust control and delays between the change in the throttle position and the engine response to this change. Speed fluctuations affect the climbing angle, which is determined automatically by the on-board system in collaboration with the ILS (Fig 3b).

From Figure 3, it can be deduced that, when the speed drops, the aircraft, in order to maintain an adequate rate of glide, changes the climb angle from a negative value (about 2°) to a positive value (such as 3°). The more stable the IAS was, the smaller the fluctuations that occurred in the changed climb angle.

4.2. Flight in fog

The second approach to land was made in order to check the proper operation of the CAT I ILS minima, provided by the ICAO. In addition, as in the case of landing performed by real aircraft, a slight turbulence were generated. Similar to the first flight, wind speed was set to 0 kt. Visualization of a 3D glide path made with Google Earth showed no significant deviation (Fig. 4a).

Figure 4, as in the case of the first (base) flight, shows that, with regard to the deviation from the axis of the runway, the altitude coincides with an ideal path for almost its entire length. Minimum deviation can result from turbulence caused by fog and, identical to the first flight, manual thrust control.

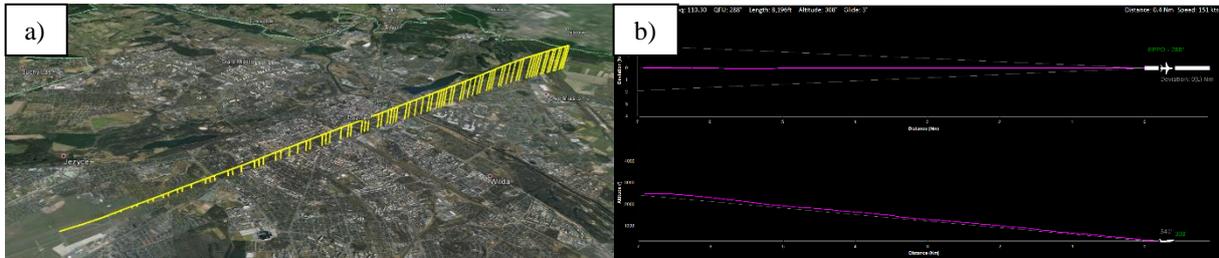


Fig. 4. Glide path in the second flight: a) 3D (Google Earth) and b) generated by FS Instructor

Any change in the IAS was reflected in the change of the climbing angle (Fig. 5b). Compared to a standard flight, it should be noted that, although more frequent changes in speed occur (Fig. 5a), the angle of climb does not change as rapidly as the first flight. The reason for this may be that the speed of the second flight was more stable. The last part of the graph shows a sharp increase in the climbing angle, which is due to the exclusion of the autopilot and acquisition of control by the pilot.

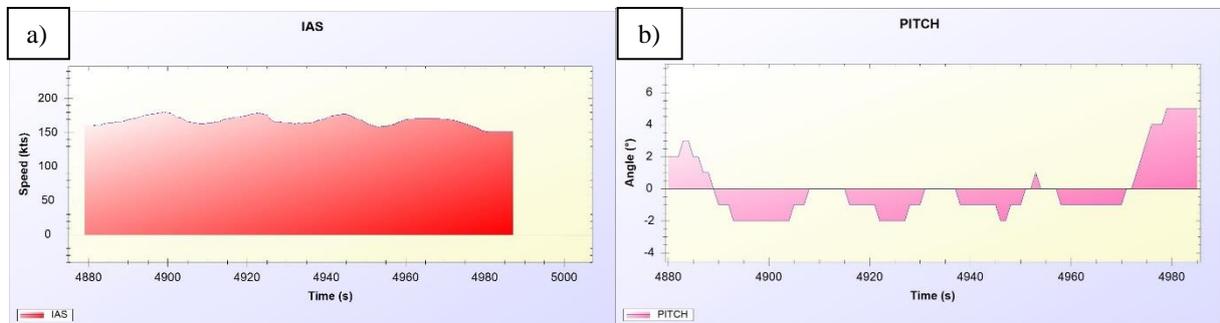


Fig. 5. Parameters in the second flight: a) IAS and b) pitch angle

4.3. Flight in snow

The third simulated approach was landing under snowfall conditions. The purpose of this simulation was to test the effect of snowfall on the proper operation of the ILS. In this case, it also included the force and direction of the wind. In the CKAS MotionSim Driver Remote Control program, two types of wind should be defined: aloft (base: 1,000 ft, speed: 15 kt, direction: 0°) and ground (base: 0 ft, speed: 8 kt, direction: 0°). Figure 6 shows a) a 3D path landing approach made in Google Earth, and b) a graph showing the glide path, along with the applied ideal GP line, created with FS Instructor.

For this approach, the difference with the previous approach is that the aircraft initially deviated from the ideal path and was on the right side of the runway. After about 1.5 NM, the aircraft was on the left side of the runway's centre line. The ideal glide path was not covered until a distance of 4 NM from the runway.

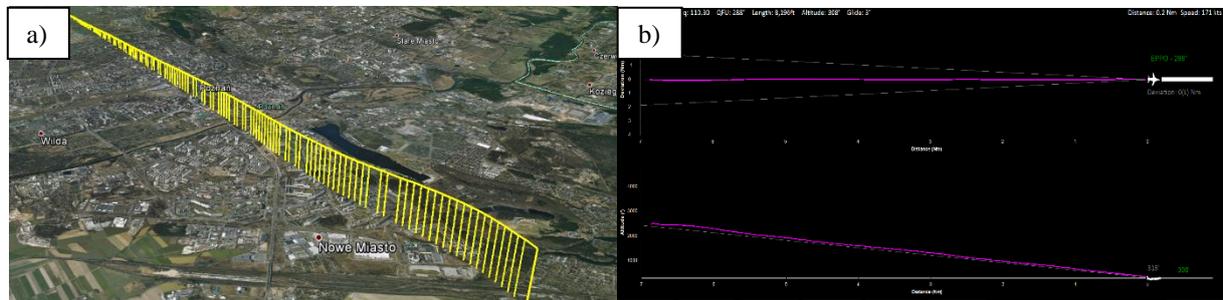


Fig. 6. Glide path in the third flight: a) 3D (Google Earth) and b) generated by FS Instructor

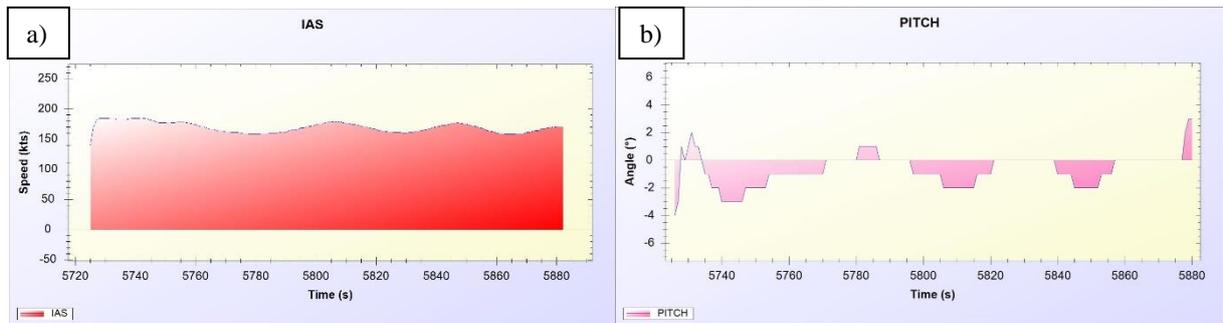


Fig. 7. Parameters in the third flight: a) IAS and b) pitch angle

The IAS (Fig. 7a) is similar to that in the charts created for the previous flights. The difference is in value of the speed. For the previous approaches, it was about 150 kts, while, in the case of landing during a snowfall, the speed was higher by about 30 kts. It can be seen that, despite the higher speed, the glide path still does not deviate significantly from the standard.

In the pitch angle graph (Fig. 7b), a significant moment occurs during the start of the approach with the rapid change in the angle. This is probably due to the fact that the on-board computer sought to direct the aircraft to the ideal path relative to the axis of the runway.

4.4. Flight in strong wind

The fourth simulation was carried out under conditions of strong wind. The meteorological conditions were created specifically for this study. Wind speed was set to 80 kt (150 km/h), which corresponds to the wind speed during a storm strength of 17° on the Beaufort Scale. Winds of similar speed can also be found during a hurricane. Apart from the wind force changes, an additional difficulty for the ILS was that wind direction changed when crossing 1,500 ft. The strength of the turbulence caused by the wind is set to the highest possible level. Figure 8 shows a) a 3D path landing approach made in Google Earth, and b) a graph showing the glide path along with the applied ideal GP line, created with FS Instructor. It can be seen that the ILS failed to guide the aircraft to the runway. Deviation from the ideal glide path took place at the start of approach. The aircraft guided by the ILS touched down about 15 m from the outer edge of the runway. In the case of landing in such conditions, it would be the pilot's responsibility to disrupt the approach. If that were to occur while reaching the decision height, the aircraft would not be in the axis of the runway.

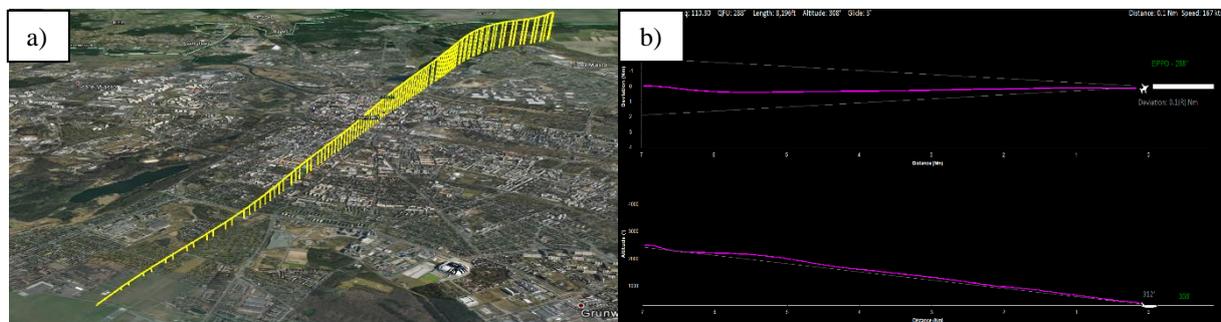


Fig. 8. Glide path in the fourth flight: a) 3D (Google Earth) and b) generated by FS Instructor

The descent of the ideal glide path took place at the beginning of the approach. The aircraft continued until the end of the right path glide. Touchdown occurred at the beginning of the runway. The visualized IAS (Fig. 9a) did not differ from that which could be observed for the standard approach, as the waveform is close to it. Therefore, the impact of speed on the accuracy operation of the ILS can be ruled out. It should be noted that this was the only parameter in the studies that influenced the human factor. The course changes in the pitch angle (Fig. 9b) shows that the descent of the ideal path took place at the moment of the most significant change to that angle.

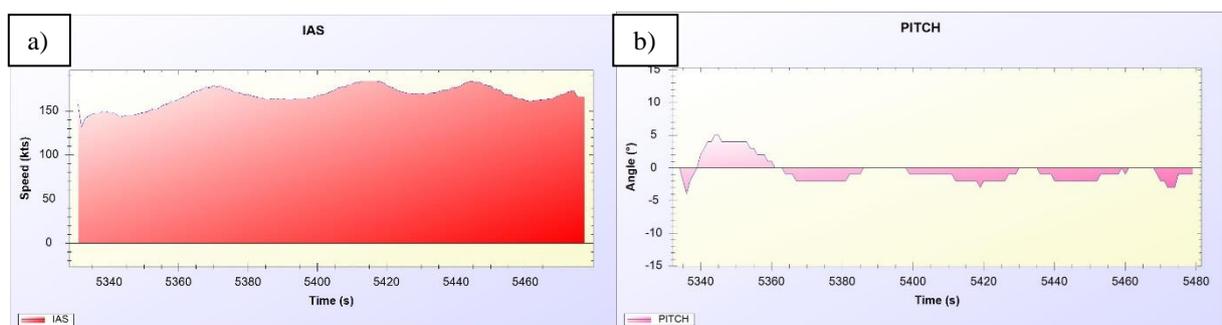


Fig. 9. Parameters in the fourth flight: a) IAS and b) pitch angle

4.5. Flight using the boundary conditions of the wind that can be used in the simulation

The final simulated approach was performed in conditions of maximum obtainable wind. The CKAS MotionSim5 simulator limited wind speed to 150 kt (about 280 km/h). This is equal to the speed at which most powerful hurricanes blow. It should be noted that, on account of the hurricane’s direction and return, the wind undergoes dynamic changes. It is therefore impossible to perform flights under real conditions in this weather. In the simulation, wind direction changed only once after crossing 1,500 ft, while its speed was constant.

The glide path differs significantly from those of previous approaches (Fig. 10), lacking a steady reduction altitude and rectilinear flight in the direction of the axis of the runway. The study was interrupted when the aircraft was at an altitude of about 2,200 ft because it was away from the runway by 2.3 NM (about 4.26 km) in a straight line.

The path marked with a perfect landing path (Fig. 10) shows how dynamically the altitude was changing. Contrary to what can be seen on the previous graphs, the descent to the destination airport did not proceed evenly. In addition, it should be noted that the ILS approach finished within 4 NM of the runway threshold. At this point, the aircraft left the operating range of the system. As can be seen in the chart, control was lost during the glide slope descent at a distance of approximately 1.8 NM from the airport.

The IAS course (Fig. 11a) and the change in pitch angle (Fig. 11b) differ from those of previous approaches. The aircraft’s IAS was substantially higher than in previous landings, which is explained by the lack of control over its speed using the throttle. Despite setting the throttle in the “idle” position, as a result of wind gusts, the aircraft accelerates.

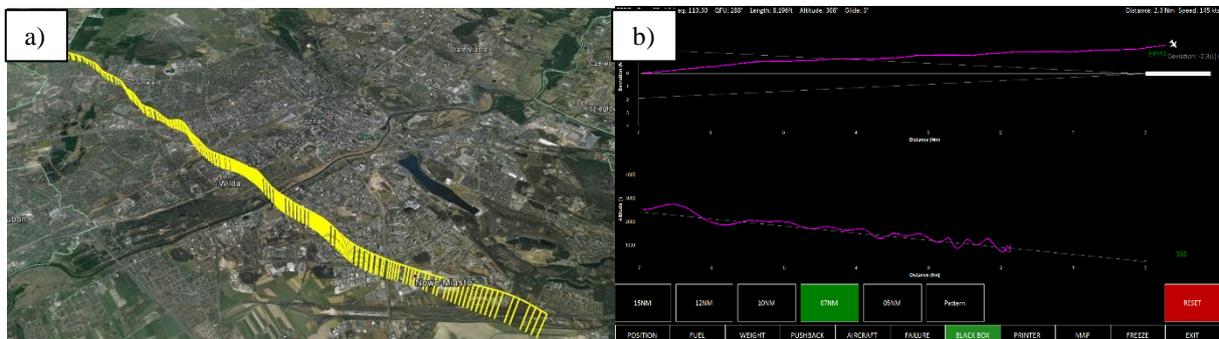


Fig. 10. Glide path in the fifth flight: a) 3D (Google Earth) and b) generated by FS Instructor

It is noteworthy that the pitch angle graph changes the scale of the vertical axis (Fig. 11b). This is due to the fact that the change of angle was larger than that in previous approaches. In previous approaches, we did not observe the angle of ascent reaching a value greater than $\pm 3^\circ$; for this test, the landing angle reached a value as high as $\pm 10^\circ$.

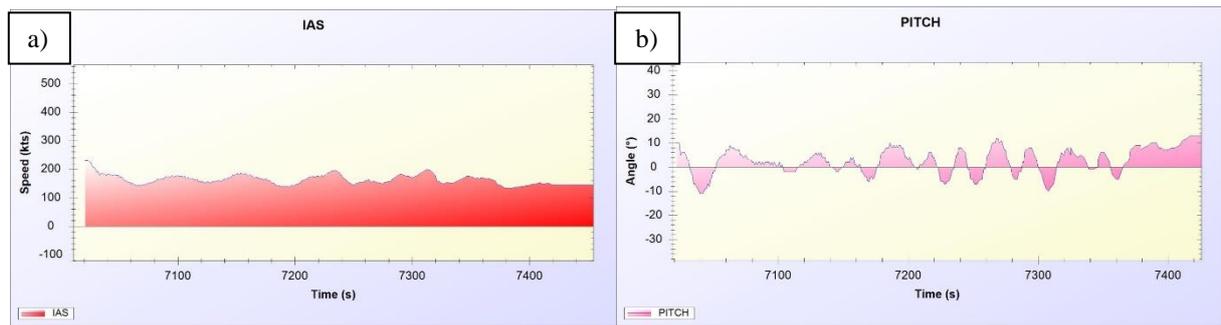


Fig. 11. Parameters in the fifth flight: a) IAS and b) pitch angle

5. CONCLUSIONS

The aim of this study was to examine the accuracy of an ILS in simulated conditions. The study was conducted using the CKAS MotionSim5 flight simulator based in the Simulation Research Laboratory of the Institute of Combustion Engines and Transport at Poznan University of Technology. With the advancement of technical equipment, it was possible to carry out a full set of simulations. The study focused on the impact of weather conditions on the correct operation of the ILS, such as:

- fog
- rain
- snow
- wind

Research began with the base flight under CAVOK conditions, after which four flights were made in adverse weather conditions. During the last simulation, boundary settings for wind conditions, which are possible to use in the simulator, were set.

The research led to the following conclusions about the operation of the ILS system:

- The impact of fog, rain and snow on correct ILS functioning is marginal, as the aircraft in cooperation with the ILS made correct approaches and landings in these weather conditions.
- In the case of landing with the wind blowing at a speed of 50 kt (about 93 km/h), increased operation of the on-board system (autopilot) was observed.
- When landing in strong wind, with a speed of 80 kt (150 km/h), the ILS system in collaboration with the on-board system failed to guide the aircraft on the runway axis.
- When landing in extreme weather conditions, i.e., with gusts of wind of up to 150 kt (about 280km/h), it was impossible to make an approach by only using automatic landing systems.

The conditions in which the ILS system failed to perform the correct approaches are comparable to hurricanes. It should be noted that the most intense tropical cyclone ever recorded in the Atlantic Basin (Hurricane Wilma) has been qualified as a Category 5 hurricane with winds of 185 mph (295 km/h).

Analysis of the IAS and pitch angle charts allowed us to observe the relationship between the flight parameters. In the case of the approach with a CAT I ILS, human intervention was only required for the disposition of engine thrust, which, in part, affected the IAS;

the remaining parameters were set by the system automatically. It has been noted that, with regard to the close relationship between parameters, changing one affects the other.

The work carried out in this study was dictated by the fact that the ILS is the most widely used system in aviation; indeed, every airport is currently equipped with this system. The correct operation of the system affects safety when flying or landing aircraft. As this study is far from exhaustive, however, we recommend that a complete analysis should be carried out on the impact of other factors on the operation of the ILS.

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