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FEATURES OF LANDING APPROACH FOR AIRCRAFT IN AUTOMATIC AND YOKE CONTROL MODES IN CONDITIONS OF HORIZONTAL LATERAL WIND SHEAR

Introduction

The 38th Session of the International Civil Aviation Organization (ICAO) Assembly identified five strategic goals for ICAO, the main of which is Flight Safety. The ICAO Global Aviation Safety Plan states that «The continuous improvement of global flight safety is essential to ensure that air transport continues to play an important role as one of the drivers of sustainable economic and social development around the world. In the industry, which directly or indirectly employes 56,6 million people, generates 2 trillion dollars in the global gross domestic product and annually carries more than 2,5 billion passengers and cargo with a total value of 5,3 trillion dollars. The Flight Safety assurance should be the most important task» [2; 7].

By the ICAO definition, flight safety is a condition in which the risks associated with aviation activities relating to the operation of aircraft or the aircraft maintenance are reduced to an acceptable level and controlled.

Among the many factors that adversely affect the Flight Safety, a wide range of atmospheric phenomena takes place: fogs, thunderstorms, precipitation, clouds, wind, in particular, wind shear at low altitudes, etc. [8].

Definition of the issue

World statistics show that about 36 % of all accidents in aviation transport take place at the landing approach and landing stages. If you take into account that their average duration does not exceed 3–4 the average flight time, the flight safety level at these stages is tens of times lower than the safety level throughout the flight [9].

After all, the landing approach and landing stages are the most complicated, as during their implementation, there is a significant change in the airplane configuration and most of flight parameters under the psychological pressure that crew is expose to such as ground proximity and small speed reserve in time-shortage for the analysis of the situation and taking correct decisions regarding airplane operation.

In [1] and others, the results are given of aircraft flight dynamics study at the landing approach stage on the glide slope signals under conditions of vertical wind shear in the longitudinal plane.

But no less dangerous, from the point of view of safety of flights at low altitudes, there is a lateral wind shear.

Therefore, the study of its impact on the dynamics and flight safety at the landing approach stage is an important and urgent problem.

Analysis of scientific published devoted to the issue

Ukrainian and foreign researchers have devoted their research to various aspects of the problem of wind shear at low altitudes: T. Buran, J. Dobrolensky, A. Fudjito, P. Lazniuk, V. Lomovsky, V. Maximov, M. Obidin, A. Obrubov, O. Trunov, A. Vasiliev, O. Zdanov, A. Zuravlev and others.

In their writings, researchers consider both theoretical and practical aspects of meteorological basics of wind shear and flight safety in the conditions of its operation; the development and implementation of on-board and ground-based equipment for the wind shear areas detection, as well as methods and manuals for aircraft crews training for taking correct actions in this dangerous atmospheric phenomenon zone, etc.

However, the grieving statistics of aviation accidents in recent years have shown that the problems associated with the impact of wind shear on flight safety require further research.

Purpose of the article

The purpose of the work is to study the impact of the horizontal wind shear of the side wind of different intensity on the dynamics and flight safety of the medium-range aircraft at the landing approach stage on the localizer signals (LOC) in the modes of automatic and yoke control, as well as the time delay of the pilot's intervention in aircraft control after the wind shear start.

Presentation of the main material

As follows from the ICAO documents, the wind shear, as an atmospheric phenomenon, is a vector difference in wind velocities at two points in the air space, related to the distance between them. Depending on the spatial orientation of the two points, between which the wind shear is determined, it is divided into vertical and horizontal. The vertical component of the wind shear is called a change in the horizontal component of the speed and/or direction of the wind when changing the flight altitude. Horizontal component is the change of the horizontal speed and/or direction of the wind when changing the distance along the flight direction in the horizontal plane [8].

According to the ICAO recommendation, the following classification of the intensity of the wind shear (vertical — at 30 m altitude, horizontal — at 600 m distance) is adopted: weak wind shear — 0–2 m/s, moderate — 2–4 m/s, strong — 4–6 m/s, very strong — more than 6 m/s [4].

The negative effect of the wind shear in the longitudinal plane on airplane flight safety is that the aircraft, due to its large mass, has a large inertia that does not allow it to instantaneously increase or decrease the ground speed when the wind speed is changing, while the true airspeed changes according to its change.

In this connection, the aerodynamic forces and moments of the aircraft change, and it deviates from the given flight path by altitude, which may cause either its premature collision with the earth's surface, or the later touching of the runway (RW), with subsequent overrun out of its boundary.

In the article [1], it is noted that when solving navigation problems during a flight of an airplane on-route under wind conditions, for simplification, it is considered that the true airspeed and ground speed change simultaneously and instantaneously. This assumption does not cause significant errors in navigational calculations, since the time of aircraft attenuation in the longitudinal and lateral planes is much smaller compared to the time of its flight on-route.

In approaching for landing and landing in the modes of both automatic and manual control, its time of entering the landing course plane and the glideslope plane is comparable to the time of fluctuations damping in the lateral and longitudinal planes.

Therefore, in our opinion, the study of wind shear effect on the flight safety in landing approaches and landing should be considered in dynamics, while taking into account the airplane's geometric, massive-inertial, aerodynamic and piloting characteristics, as well as the nature, intensity and duration of wind shear and the timeliness and correctness of the crew's action when the aircraft hits the wind shear action zone.

For the study of the lateral wind shear effect on the dynamics and flight safety of the medium-range aircraft at the landing approach stage and for the achievement of the above-mentioned goal of research, a digital mathematical model of the airplane's flight dynamics was developed that allows us to investigate the processes of the aircraft's entry into the landing course and stabilizing on it by LOC signals in automatic control mode with the subsequent transition to the manual control mode, both in conditions of calm atmosphere and lateral wind shear. The developed model also provides for the possibility of conducting research at different initial values of the course and lateral deviation of the aircraft from the landing course plane in the Base Leg and Final Leg zones, as well as at different values of the navigational wind direction and the steepness of the signal path of the LOC-LOCR (Localizer Receiver) in the range from minimum to maximum.

Taking into account that when an airplane is approaching for landing by LOC signals, at constant airspeed, the angular parameters of its flight vary in small ranges relative to their initial values in the balanced mode, the authors of the article consider it appropriate to use the mathematical model of the flight dynamics of the plane in the lateral plane in the form of such a system linearized differential equations [5]:

$$\ddot{\psi} = -a_1\dot{\psi} - b_6\dot{\gamma} - a_2\beta_{\text{в}} - a_3\delta_{\text{н}} - b_5\delta_{\text{e}};$$

$$\ddot{\gamma} = -a_6\dot{\psi} - b_1\dot{\gamma} - b_2\beta_{\text{в}} - a_5\delta_{\text{н}} - b_3\delta_{\text{e}};$$

$$\dot{\beta} = \dot{\psi} + b_7\dot{\gamma} + b_4\gamma - a_4\beta_{\text{в}} - a_7\delta_{\text{н}};$$

$$\beta_{\text{в}} = \beta + \beta_w;$$

$$\beta_w = -\text{arc tg}\left(\frac{W_z}{V}\right);$$

$$\psi_{\text{г}} = -\psi;$$

$$\dot{X} = -V\cos(\psi_{\text{г}} + \beta);$$

$$\dot{Z} = V\sin(\psi_{\text{г}} + \beta).$$

In the above system of linearized differential equations, the designation of flight parameters is used in accordance with the requirements of the current standard in Ukraine [3].

During the research of the approach of the medium-range aircraft, the following initial values of its flight parameters were adopted for the LOC signals: the aircraft weight was 73 tons; Holding Area altitude — 500 m; the given true airspeed — 280 km/h; initial distance from the front runway threshold along the landing course — 13 km; initial lateral deviation from the landing course — 2,5 km; angle of the glide path — 2,67°; the LOC-LOCR (Localizer Receiver) signal steepness is 167 μA/deg; landing course — 0°.

The simulation of the landing approach of the aircraft was carried out in accordance with the following technological sequence of processes: in the Base Leg zone, the aircraft gains the landing course and stabilizes in the automatic control mode with the simultaneous stabilization of the given holding area altitude and indicated airspeed; After entering the landing course plane and intercepting glideslope at a distance of 10430,3 m from the front threshold of the runway its «capture» occurs with the transition of the aircraft from the mode of automatic stabilization of the given holding area altitude to the automatic stabilization mode on the glide path; starting from the distance to the front threshold of the runway 3000 m, the horizontal wind shear of the side wind with given intensity is simulated with a linear dependence of its speed from the horizontal distance to the end of the runway; simultaneously with the beginning of the wind shear effect, there is a transition from the mode of automatic control of the position of the aircraft in the landing course plane to the yoke control mode with different delayed pilot intervention into the control after the beginning of the wind shear action.

It is believed that the effect of the lateral wind shear on the motion of the aircraft on the glide path in the longitudinal plane (the change in the true airspeed and aerodynamic forces and moments) is compensated by the corresponding aircraft's controls deviations and the aircraft precisely moves along the glide path.

Below are the results of research for different conditions of approaching the aircraft on the LOC signals.

Fig. 1 shows the line of the airplane's path in the mode of automatic approach on the LOC signals in calm atmosphere conditions until the crossing the front threshold of the runway.

The process of aircraft's landing approach on the LOC signals meets the standard requirements for its entrance the landing course plane and the accuracy of the stabilization in this plane [5].

In particular, the process of entrance into the landing course plane is close to the aperiodic with the current overflow of the Localizer Receiver (LOCR) +22,2 μA (less than the permissible ± 42 μA) and ends with the moment of «capturing» the glide path. When moving in the landing course plane, the airplane is in the «tube» of the LOCR current within the limits, significantly less than the permissible ± 35 μA.

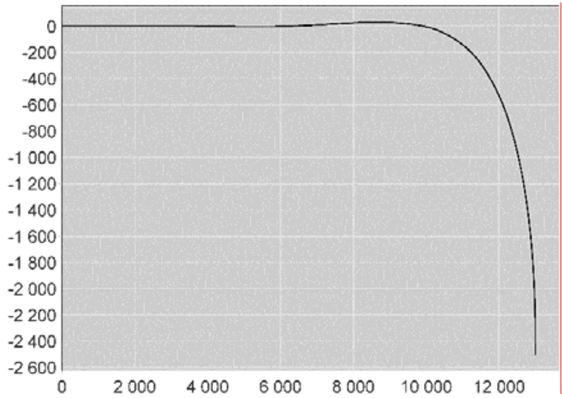

Fig. 1. Landing approach in calm atmosphere conditions

Fig. 2 shows a fragment of the aircraft's trajectories in the Final Leg of the approach stage with the transition from the automatic control in the landing course plane to the yoke control mode at a distance of 3000 m to the front threshold of the runway without pilot interference in the airplane control in the conditions of the horizontal wind shear of the side wind on the right to the airplane movement course with a navigation direction of 270° of different intensities (at 600 m distance): there is no wind shear (1), weak wind shear with intensity of 1 m/s (2), moderate — 3 m/s (3), strong — 5 m/s (4).

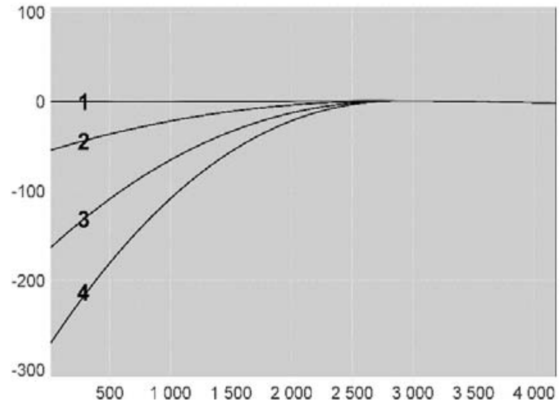

Fig. 2. Landing approach with lateral wind shear of varying intensity

The research results shown in Fig. 2, confirm the main trends of the airplane without pilot intervention in the control when it hits the lateral wind shear zone. After all, if in the wind shear absence, the lateral displacement of the aircraft relative to the landing course plane (the runway axis) at the passage of the front threshold of the runway is equal to +0,2 m (+0,4 μA by the LOCR current) (1), then this displacement under the lateral wind shear action, is already –54,4 m (–127,6 μA) with a weak wind shear (2), -162,2 m (–250 μA — the current reached the limit) — at moderate wind shear (3), –266,1 m (–250 μA) — with strong wind shear (4).

From the mentioned above, it follows that the lateral wind shear during uncontrolled movement of the aircraft causes its significant displacement relative to the landing course plane (RW axis), which makes it impossible to land on the runway and leads to the need of Go-around Execution to prevent landing aside of the runway.

Fig. 3 shows a fragment of the aircraft's trajectories in the final leg of the approach stage with the transition from the automatic control in the landing course plane to the yoke control mode at a distance of 3000 m to the front threshold of the runway at the effect of a moderate lateral wind shear on the right to the airplane flight at an intensity of 3 m/s on 600 m distance, which begins at a distance of 3000 m to the front threshold of the runway, with different delayed pilot interference in the control after the beginning of the wind shear.

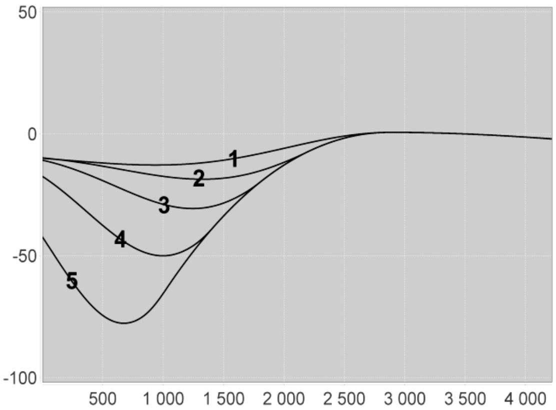

Fig. 3. Landing approach with delayed pilot intervention in control after the beginning of the lateral wind shear

As indicated in [1], the coincidence in time of the beginning of the wind shear action with the moment of transition from the automatic control of the aircraft movement to the yoke control mode was chosen during the research because, in the real flight conditions, this coincidence significantly complicates the landing approach, because during the transition to the yoke control mode is changing the sensory-minded activity of the pilot on the sensormotor, which requires a certain amount of time in time shortage conditions.

According to the results of the study, it was found that when the pilot intervenes in the control of the aircraft attitude in the landing course plane at the same time as the the lateral wind shear occures, the aircraft is in the «tube» of the LOCR current in the range of less than permissible ±35 μA, with a maximum lateral displacement relative the landing course plane –12,9 m (–25,7 μA by the LOCR current) at a distance of 602,4 m from the front threshold of the runway and –10,1 m (–24,2 μA) — during its intersection (1).

In case of time delay, pilot intervention in the control of 10 s duration (2) the aircraft during the movement is in the «tube» at the LOCR current in the limits, less than the permissible ±35 μA, although close to them, with the maximum lateral displacement relative to the landing course plane –18,7 m (–34,1 μA by the LOCR current) at a distance of 1308,5 m from the front threshold of the runway and –10,2 m (–24,3 μA) — during its intersection.

In case of time delay of pilot interference with the duration of 15 seconds (3), the maximum displacement of the airplane relative to the landing course plane is –30,7 m (–56,6 μA by the LOCR current) at a distance of 1215,3 m from the front threshold of the runway and –10,4 m (–24,3 μA) — during its intersection. That is, the aircraft went beyond the «tube» ±35 μA of LOCR current, although it crossed the front end of the runway with a slight displacement relative to the landing course plane.

In case of delayed pilot interference in the control of the duration of 20 s (4) and 25 s (5), the maximum displacement of the airplane relative to the landing course plane is –50,1 m (–96,7 μA) and –77,8 m (–160,4 μA) at a distance of 915,3 m and 565,2 m from the front threshold of the runways, that is, the aircraft went beyond the «tube» ±35 μA of LOCR current. At the same time, at a delay of 20 seconds the aircraft crossed the front threshold of the runway with a displacement of –18,1 m (–44,3 μA) relative to the landing course plane, at a delay of 25 s — with a displacement of –43,9 m (–106,8 μA), which is inadmissible.

Thus, at the aircraft landing approach at the LOC signals, the delayed pilot intervention in the landing course plane after the onset of the horizontal wind shear of the side wind, even of moderate intensity, significantly reduces the flight safety level. If the delay is more than 15 seconds, the accuracy of the aircraft stabilization in the landing course plane does not meet the established requirements, which makes the flight of the aircraft on the final leg and its landing problematic. The aircraft in these cases should go-around for flight safety [5; 6].

Conclusions

A digital mathematical model of the flight dynamics of a medium-range aircraft is developed, which allows to simulate its landing approach in automatic and yoke control modes according to LOC signals in conditions of calm atmosphere and horizontal wind shear of lateral wind.

The influence of the horizontal wind shear of the side wind of different intensity on the flight dynamics on the approach stage, as well as the time delay of the pilot's intervention in the control after the wind shear onset of the moderate intensity, has been studied.

The results of the research suggest that the timely intervention of the pilot in the control of the airplane in the lateral wind shear zone, in the conditions of time deficit, to detect this dangerous atmospheric phenomenon, analysis of its features and making the right decision for further operation of the aircraft, plays a significant role in ensuring flight safety.

The obtained qualitative and quantitative results of the flight dynamics research of the medium-range aircraft at the landing approach stage by the LOC signals in the conditions of horizontal wind shear of the lateral wind are well correlated with the flight safety level with the results of research on the flight dynamics of the aircraft at the approach stage by the glide slope beacon signals under conditions of vertical wind shear in the longitudinal plane, given in [1].

REFERENCES

1. **Бабич Я. О.,** Бочелюк А. О., Полухін А. В. Особливості заходу на посадку літака в режимах автоматичного та штурвального управління в умовах вертикального зсуву вітру. *Проблеми інформатизації та управління*: Зб. наук. праць. Київ: НАУ, 2017. Вип. 4 (60). С. 5–11.

2. Глобальный план обеспечения безопасности полетов, 2017-2019. Издание второе. Doc 10004. Монреаль: ИКАО, 2016. 115 с. URL: http://www.icao.int/Meetings/a38/Documents/GASP_ru.pdf (дата звернення: 19.08.2018).

3. ГОСТ 20058-80. Динамика полета лета-тельных аппаратов в атмосфере. Москва Издательство Стандартов, 1980. 51 с.

4. Метеорологическое обеспечение международной аэронавигации. Приложение 3 к Конвенции о международной гражданской авиации. Издание восемнадцатое (с поправками). Часть 1. Основные SARPS. Часть 2. Добавления и дополнения. Монреаль: ИКАО, 2013. 222 с.

5. **Михалев И. А.,** Окоемов Б. Н., Чикулаев М. С. Системы автоматической посадки. Москва: Машиностроение, 1975. 216 с.

6. **Производство** полетов воздушных судов. Издание пятое (с поправками). Doc 8168 OPS/ 611/ Том 1. Правила производства полетов. Монреаль: ИКАО, 2006. 386 с.

7. Резолюции Ассамблеи ИКАО. Ассамблея — 38 сессия. Монреаль: ИКАО, 2013. 140 с. URL: http://www.icao.int/Meetings/a38/Documents/Resolutions/a38_res_ru.pdf (дата звернення: 19.08.2018).

8. Руководство по сдвигу ветра на малых высотах. Издание первое (с поправками). Doc 9817 AN/449. Монреаль: ИКАО, 2005. 264 с.

9. Statistics. Causesof Fatal Accidents. Fatalities by Phase of Flight. URL: http://www.planecrashinfo/com/cause.htm (дата звернення: 19.08.2018).

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FEATURES OF LANDING APPROACH FOR AIRCRAFT IN AUTOMATIC AND YOKE CONTROL MODES IN CONDITIONS OF HORIZONTAL LATERAL WIND SHEAR

World statistics show that about 36 % of all accidents in aviation transport take place at the landing approach and landing stages. If you take into account that their average duration does not exceed 3-4 % of the average flight time, the flight safety level at these stages is tens of times lower than the safety level throughout the flight It’s been shown that flight safety provision for aircraft in landing approach and landing stages under wind shear conditions is important and crucial issue and requires deep research.

Flight dynamics research has been conducted for mid-range aircraft at landing approach stage under horizontal lateral wind shear conditions.

Keywords: aircraft; wind shear; landing approach; safety of flights.

Полухін А. В., Остапенко О. С.

ОСОБЛИВОСТІ ЗАХОДУ НА ПОСАДКУ ЛІТАКА В РЕЖИМАХ АВТОМАТИЧНОГО ТА ШТУРВАЛЬНОГО УПРАВЛІННЯ В УМОВАХ ГОРИЗОНТАЛЬНОГО ЗСУВУ БІЧНОГО ВІТРУ

Світова статистика свідчить, що близько 36% усіх катастроф на авіаційному транспорті відбувається на етапах заходу на посадку і посадки. Якщо ж врахувати, що їх тривалість у середньому не перевищує 3–4 % часу польоту середньомагістрального літака, то фактичний рівень безпеки польоту на цих етапах у десятки разів менший, ніж рівень безпеки протягом усього польоту. Серед багатьох чинників, які негативно впливають на рівень безпеки польотів, значне місце займають різноманітні атмосферні явища: тумани, грози, опади, хмари, вітер, зокрема, його зсув на малих висотах тощо.

Сумна статистика авіаційних катастроф останніх років свідчить про те, що проблеми, пов’язані з впливом зсуву вітру на безпеку польотів, потребують подальших досліджень.

Для проведення дослідження впливу горизонтального зсуву бічного вітру на динаміку та безпеку польоту середньомагістрального літака на етапі заходу на посадку авторами статті була розроблена цифрова математична модель його динаміки польоту, яка дозволяє дослідити процеси виходу літака в площину посадкового курсу та стабілізації на ній за сигналами курсового радіомаяка в режимах автоматичного та штурвального управління як в умовах спокійної атмосфери, так і зсуву бічного вітру. У розробленій моделі також передбачена можливість проведення досліджень при різних початкових значеннях курсу та бічного відхилення літака від площини посадкового курсу в зоні четвертого розвороту, а також при різних значеннях навігаційного напрямку вітру та крутизни сигналу тракту КРМ-КРП у діапазоні від мінімальної до максимальної.

Показано, що забезпечення безпеки польотів літаків на етапах заходу на посадку і посадки в умовах зсуву вітру є важливою та актуальною проблемою і потребує глибоких досліджень.

Проведено дослідження динаміки польоту середньомагістрального літака на етапі заходу на посадку в умовах горизонтального зсуву бічного вітру.

Ключові слова: літак; зсув вітру; захід на посадку; безпека польотів.

Полухин А. В., Остапенко А. С.

ОСОБЕННОСТИ ЗАХОДА НА ПОСАДКУ САМОЛЕТА В РЕЖИМАХ АВТОМАТИЧЕСКОГО И ШТУРВАЛЬНОГО УПРАВЛЕНИЯ В УСЛОВИЯХ ГОРИЗОНТАЛЬНОГО СДВИГА БОКОВОГО ВЕТРА

Мировая статистика свидетельствует, что около 36 % всех катастроф на авиационном транспорте происходит на этапах захода на посадку и посадки. Если же учесть, что их продолжительность в среднем не превышает 3–4 % времени полета среднемагистрального самолета, то фактический уровень безопасности полета на этих этапах в десятки раз менший, чем уровень безопасности на протяжении всего полета.

Показано, что обеспечение безопасности полетов самолетов на этапах захода на посадку и посадки в условиях сдвига ветра является важной и актуальной проблемой и требует глубоких исследований.

Проведено исследование динамики полета среднемагистрального самолета на этапе захода на посадку в условиях горизонтального сдвига бокового ветра.

Ключевые слова: самолет; сдвиг ветра; заход на посадку; безопасность полетов.

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