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REVIEW ARTICLE

PSYCHOLOGICAL ASPECTS OF THE PROBLEM OF INDICATION ON THE ARTIFICIAL HORIZON

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Abstract: The article contains an analysis on 16 criteria of the principles to display the parameters "roll" and "pitch" on the artificial horizon. The result of the analysis leads to a conclusion that the reverse (outside-in) indication has undoubtedly many advantages to the direct (inside-out) indication, with regards to flight safety.

Keywords: artificial horizon indicator, "outside-in", "inside-out" indication, flight safety

The beginnings of the problem of choosing an indication principle for the parameters "roll" and "pitch", as displayed on the attitude indicators, can be traced to the beginning of the 20th century.

At that time, American airplanes began to use the "Sperry" artificial horizon, "which immediately shows to the pilot the attitude of the aircraft, as regards the natural horizon. The device displays roll and pitch the way the pilot is accustomed to perceive them, with regard to the natural point of reference – the real horizon" [21]. The device was designed, in accordance to present-day terminology, based on "a combined principle" i.e., roll indication is "outside-in" (static depiction of the sky and earth, moving aircraft silhouette), and the indication for pitch is "direct" - "inside-out" (moving depiction of the horizon, represented by a white band).

Soon after that, mixed indication was replaced by direct indication, which displays roll and pitch as a virtual movement in space. This development took place after 1936, when a US Navy doctor, John Poppen, reached the logical conclusion, that the correct indication should be precisely analogous to what is usually seen through the windshield during visual flight. Essentially, he views

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the system for indication, as a kind of embrasure, through which the pilot sees a symbolic analogue of the natural horizon [12].

The principle introduced by John Poppen, is characterized by the moving of the gyroscope needle to the left during a right roll, in order to "hold" the index of the system in the appropriate position, with regards to the outside world. Poppen's concept of a moving horizon was applied widely and in practice became the only one used in US and Western aircraft.

The artificial horizons (AI) of Russian aircraft have their own unique history. In the 1950s they used "outside-in" indication for roll and pitch. An example for such an AI is the AGK-47, on which the silhouette of the airplane moves to indicate roll and pitch, while the depictions of the earth and sky, as well as the line that separates them, are fixed with reference to the center of the device. An important disadvantage of this device is its inability to indicate the rolls which exceed 85°; thus it was replaced by an AI utilizing a combined indication principle – a moving airplane silhouette representing roll and a moving line of the horizon, representing pitch.

In the 1960s and 1970s, as a result of the ambition to sell Soviet aircraft in the West, they began using AIs with direct indication for roll and pitch (such as the PKP-77).

Nowadays, Russian-built aircraft use two types of artificial horizon indication – military aircraft use AIs with combined indication (such as IKP-87), and civilian aircraft utilize ones with direct indication. This double standard is a significant potential reason for aircraft incidents.

The PKP-77 artificial horizon symbolically depicts a static airplane and a moving sky/earth and a horizon line for roll and pitch (direct indication); the IKP-81 artificial horizon depicts symbolically a moving airplane and static sky/earth and horizon line, representing roll, (reverse indication) and moving sky/earth and horizon line, representing pitch (direct indication).

The review of the various positions on the issue, conducted by Pavel Kovalenko, based on different sources shows the surprising shift in the attitudes of the same authors throughout the years, as regards the comparative advantages of the types of indication (Tab. 1.).

As seen from the table, the opinions of the authors conducting the comparative studies change with the passing of time. It is difficult to determine the reasons for this, but it must be noted, that the above mentioned studies are based on a behavioral approach, which focuses on registering objective data, such as mistakes, erroneous actions, latency, action time, psycho-physiological indicators (pulse, breathing, skin reaction, eye movement, etc.), which in turn serve for a basis for the choice of indication type; the expert opinions of the pilots are also taken into account.

Behavioral approach, however, does not take into account such an important factor as information processing by the pilots, which includes the choice of spatial orientation method. The choice of spatial orientation method allows determining if the pilots experience the illusion of a moving space and control over the earth (the natural horizon), or they are able to overcome the illusory movements of the space, and perceive the earth as static and themselves as controlling the aircraft. Kovalenko proves in the above mentioned source, that the pilots, who are subject to the illusion of control of the earth, are more inclined to prefer direct indication.

The analysis of the problem of the choice of AI indication method is based on the requirements (criteria) that artificial horizons must meet.

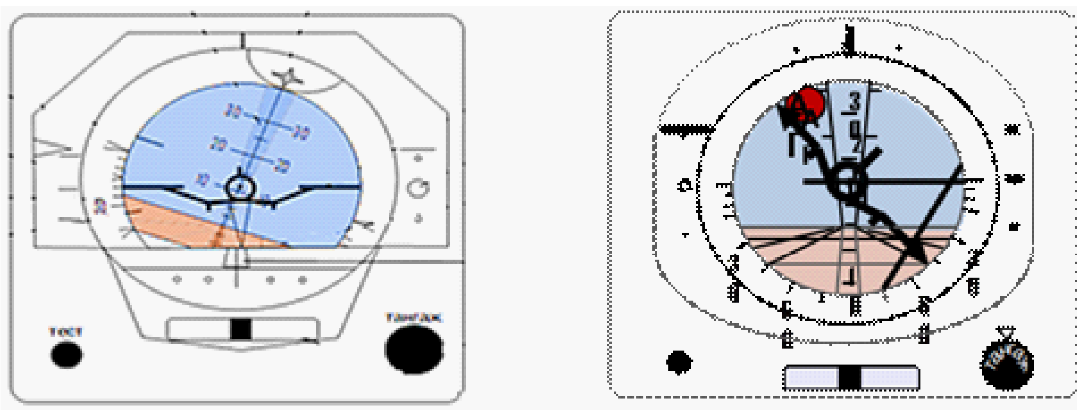

Fig.1. Different types of artificial horizons - PKP-77 (left), and IKP-81 (right).

A total of 16 requirements are identified, which are assessed on a scale from 1 to 5, where 5 is the highest score, and 1 is the lowest.

1. Flight safety. This basic requirement is defined as: "The information model must contribute to the better flight control and ensure flight safety" [26].

To put it in another way, the equipment must not become a source of possible systemic errors on the part of the operators, thus affecting negatively flight safety.

The analysis demonstrates that for the last 70 years there have been no registered flight incidents, resulting from spatial disorientation of pilots using artificial horizons with reverse indication.

At the same time, as Vsevolod Ovcharov points out, for the 1989-2008 period there were 10 air disasters due to spatial disorientation; as a result more than 1000 people were killed, 3 transport helicopters and 7 airplanes of the Russian civil aviation, worth over USD 1.5 billion, were destroyed [22]. Bill Erkoline reported in 2010 that in the last 30 years, the US Air Force lost 82 pilots and aircraft worth USD 1.9 billion [6]. All of the lost aircraft were using direct indication artificial horizons.

The above mentioned data clearly suggests that while reverse indication poses no risk for spatial disorientation, direct indication of roll is the source of repeated errors.

The expert assessment on the "flight safety" requirement is: reverse indication – 5 points, direct indication – 1 point.

2. Erroneous actions. According to the data provided by the German researcher Siegfried Geratewol, erroneous contrary actions with the control stick, performed in an attempt to bring the aircraft out of an unknown spatial position, are 3.6 times more common when using direct indication, as compared to reverse indication [9].

Pavel Kovalenko cites data from his own research, according to which there were no registered erroneous actions when performing rolls during instrument flight using reverse indication, while errors when using direct indication amount to 8.6% [17].

Vladimir Ponomarenko, Vitali lapa and Aleksander Chuntul note that the average values of the deviations when trying to maintain roll of helicopters are 4.2° with reverse indication, and 9.4° with direct indication. With regards to pitch, the values were 5.8° and 10.2°, respectively. The stabilization of the helicopter in roll and pitch, when transitioning from a turn to horizontal flight and using of the IKP-81 artificial horizon result in an mean roll error of 1.2°±1.8°, while when using PKP-77, the error amounts to 3.2°±2.9°; as regards pitch the values of the mean error amounts to 1.7°±1.5° (IKP-81) and 3,7°±1.5° (PKP-77), respectively.

During flights using IKP-81 there were no registered cases of exceeding the roll limits; when using PKP-77, the limits were exceeded in 10% of the cases. The total number of erroneous actions, related to erroneous assessments of the attitude of the helicopter, with a reverse indication attitude indicator amount to 0.8%, while they amount to 18.2% when using direct indication [24].

The data unequivocally confirm that using a reverse indication artificial horizon leads to a significant reduction in the number of erroneous actions,

Tab. 1. Analysis of the conclusions reached by some authors, in chronological order [17].

	Preferred principle of indication		
	reverse	direct	both
Brown 1945	x		
Brown, 1952			x
Brown, 1954	x		
Brown, 1954		x	x
Roscoe et al.. 1948, 1951	x		
Roscoe 1953	x		
Roscoe 1954	x		x
Roscoe 1955	x		
Roscoe 1960		x	
Roscoe 1966			x
Roscoe 1968	x		
Gardner, 1950	x		
Gardner, 1954	x		
Gardner, Lacy, 1954		x	x

as compared to using an AI with direct indication. The expert assessment on the requirements of "erroneous actions" is: reverse indication – 5 points, direct indication – 1 point.

3. Test movements. Indication must be simple and easy to understand. This allows the pilots to determine the attitude of the aircraft without additional mental, or other activities, especially the so called "test movements" of the control stick. In essence, when the pilot cannot determine the attitude of the aircraft along its lateral or longitudinal axes at a particular moment, he will try to reestablish his attitude awareness by deliberately changing the pitch and roll. These test movements, when they are close to the limits for pitch and roll, can be a serious precondition for an incident.

Ponomarenko, Lana, and Chuntul point out that "an indicator for the difficulties in establishing spatial awareness is the presence of such test movements (in 29% to 60% of the cases)"; such test movements are performed using the control stick in order to eliminate the deviations from the established roll, when using PKP-77 [24].

The Committee for the investigation of flight incidents to the International aviation committee of the Russian Federation points out in its final report on the crash of a Boeing 737 near Perm, that there had been "abrupt, uncoordinated movements of the control stick, left and right, in combination with a complete lack of pitch control, which suggests that the first pilot had experienced a total loss of attitude awareness, due to the incorrect understanding of the indications of the artificial horizon" [20].

When using a reverse indication AI such test movements are not observed in practice.

The expert assessment on the criterion "test movements" is: reverse indication 5 points, direct indication – 1 point.

4. Time characteristics of steering actions. "The quality of the provided information must be high, and it must ensure prompt and correct perception, without causing fatigue after prolonged use" [26].

The time needed to percieve the indications of the instruments is an indicativer for the difficulties, which the operators might experience in the process of using the systems.

W. Kopanev sums up the results from the research on the spatial awareness of glider pilots thus: when using a reverse indication AI, the time necessary to transition from visual flight, to instrument flight is on average 6.6 seconds; when using a direct indication AI it is on average 11.8 seconds. The total time needed to bring the glider into level flight, using reverse indication, is 12.5 seconds, and 26.3 seconds when using direct indication. Of the 37 glider pilots who were subjects of the research, 27 expressed a clear preference for reverse indication, 6 – for direct indication, 4 of them did not find a significant difference [14].

Based on the data provided by Ponomarenko, Lapa and Chuntul "(…)in the process of steering the helicopter from one position in space, to another, the pilots do a better job using the IKP-81 AI. The maximum time needed to bring the helicopter into horizontal flight from a downward, or upward tonneau, using the IKP-81 is 4.8 sec. shorter than when using PKP-77. It was also established that the rate of change of the position of the helicopter along the lateral axis when using IKP-81 is consistently higher (1.4 times higher), than the rate when using PKP-77" [24].

The expert assessment on the criterion of "time characteristics of steering actions" is: reverse indication 4.8 points, direct indication – 1.2 points.

5. Latency of the first steering action. "An accurate, easy, quick-glance interpretation of attitude should be possible for all unusual attitude situations and other "non-normal" maneuvers sufficient to permit the pilot to recognize the unusual attitude and initiate an appropriate recovery within one second" [7].

The need for a correct first steering action within one second is determined by the fact that, given the speed and weight of modern aircraft, an incorrect first steering action can prove fatal.

In the above mentioned research on helicopter pilots, Ponomarenko, Lapa and Chuntul point out that the increased latency of first reaction in reestablishing attitude awareness, when using a direct indication AI, suggests that pilots experience difficulties in perceiving and processing the information from the AI. Only 37% of the pilots managed to react correctly within the first second when using a direct indication AI, while 90% of the pilots using reverse indication AI managed to react within the first second. This result was confirmed by I. I. Grigoriev [11].

The expert assessment on the criterion "latency of the first steering action" is: reverse indication – 5 points, direct indication – 1 point.

6. Compatibility between the indications of the instruments and the motor reactions of the pilots.

"When designing the systems (devices) for displaying information and the controls of aircraft, the principle of compatibility between the indications of the instruments and the motor reactions of the pilot must be observed; the indications of the instruments must cause “natural”, expected, predictable movements, which do not contradict the previous experience of the person, acquired throughout his life and specialized professional training” [26].

As seen on Fig. 2., reverse indication of roll corresponds completely to the principle of compatibility of indication and the motor reactions of the pilot. The same conclusioun cannot be made about direct indication.

As regards pitch, both artificial horizons employ direct indication, which shows not the climb, or descent of the aircraft, but the change in the position of the sky and earth and the line of the horizon that divides them. The pilot must determine the attitude of the aircraft, as regards its pitch usin these indications. This type of indication is a prerequisite for the emergence of an illusion of control over the line of the artificial horizon and for a loss of attitude awareness (the illusion of controlk over the surrounding space, instead of the aircraft). It can be concluded that there is an urgent need of research and the development of an AI providing reverse indication of pitch, as well as roll.

The expert assessment on the criterion of “compatibility between the indications of the instruments and the motor reactions of the pilots” is: reverse indication – 5, direct indication 1.

7. Artificial horizons and the characteristics of flying. Ponomarenko, Lapa, and Chuntul point out that by using an AI with reverse indication, pilots are able to divide their attention in a more rational way, while performing manouevres using a direct indication AI requires the pilot to focus on the face of the AI, which leads to a reduction of the time the pilot has to control other parameters, which are also important for flight safety. The needed for controlling the indications of the AI (in per cent) when performing aerobatics manouevres is: reverse indication AI – 61%, direct indication AI 79%. The mean time of the fixed gaze on the display of a reverse indication AI is 1.2±0.8 sec. and 2.4±2.2 sec. for direct indication AI.

At the same time, it has been noted that pilots experience difficulties in acquiring and processing information, making them spend more time looking at the AI when transitioning from visual flight to instrument flight. For example, in 96% of the cases, the duration of the first fixed gaze on a reverse indication AI does not exceed 1 seconds, while in the case of direct indication AI, it usually exceeds the required 1 second and lasts up to 5.2 seconds.

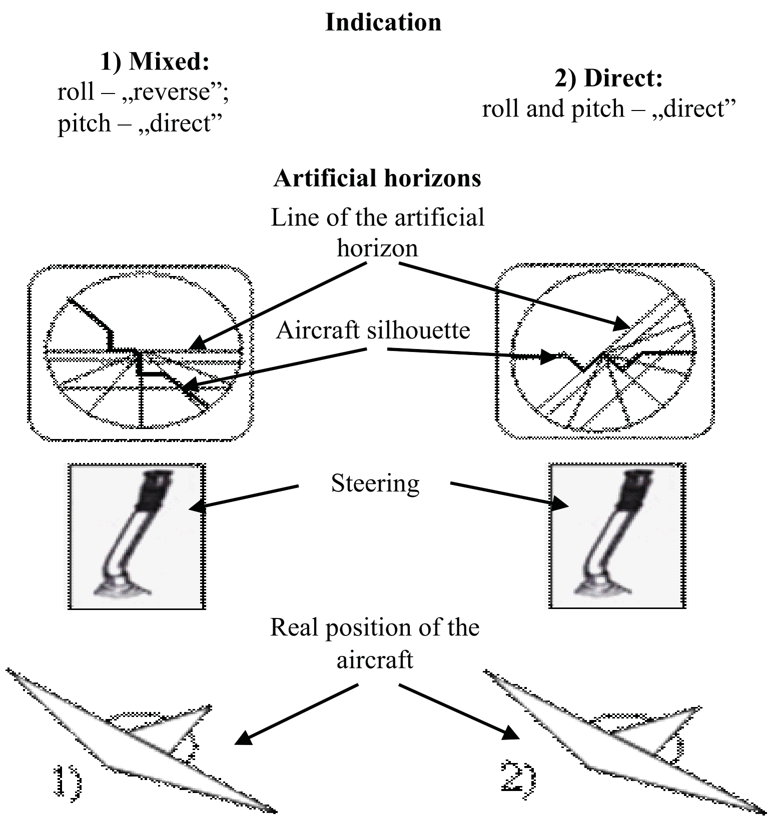

Fig. 2. Indication of the attitude of the aircraft on the artificial horizon during instrument flight, right roll [10].

It should be added also, that when performing a complex manouevre, using a direct indication instrument, the pilot cannot control important flight safety parameters, which leads to a ststistically important ($p<0.05$) loss of altitude [24].

The expert assessment on the criterion of "artificial horizons and the characteristics of flying" is: reverse indication – 5 points., direct indication – 1 point.

8. Compatibility between indication and the real position (attitude) of the aircraft. In their publications, N. W. Adamovich [1] and V. K. Alexandrov [2] claim that at the moment of transition from visual flight to instrument flight, when using a reverse indication AI, the moving silhouette of the aircraft is tilted at an angle which is twice the real roll angle. Supporters of direct indication represent this "double" angle (Fig. 3., position 2), and also, how they understand direct indication (Fig. 3., position 1).

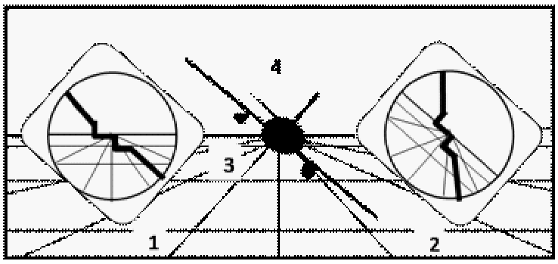

Fig. 3. Indications of a direct indication AI (1), and a reverse indication AI (2), compared to the natural horizon (3) and the real position of the aircraft (4) according to authors, supporting direct indication.

It is notable, that both artificial horizons, regardless of whether indication is reverse, or direct, are depicted at an angle to the line of the real horizon and therefore, to the horizontal line of the instrument panel. Such positioning is unrealistic, because, in order to look at the display of an indicator, which is at an angle, pilots must tilt their heads. In reality, they sit without moving in the cockpit and perceive the information displayed by the fixed instruments on the instrument panel.

Tilting the head, in order to take in the readings of the instruments is extremely dangerous during a maneuver because it is often the cause of vestibular illusions. Besides, there are a number of requirements, which regulate the positioning of the instruments on the instrument panel [26]. There is no regulation requiring the instruments to be mounted at an angle, since this would make the reading of the displayed information inconvenient.

The expert assessment on the criterion "compatibility between the indication and the real position of the aircraft" is: reverse indication - 5 points., direct indication – 1 point.

9. Conducting additional logical operations and other actions when working with the indication. "Information must be presented to the crew in a processed and summarized way, so that the crew is free of the need to perform calculations and logical operations, summarizing diverse data and memorization of maximum acceptable values, etc." [26].

In his publication Pavel Kovalenko points out that when pilots use reverse indication, no perceptible recoding of the indications of the artificial horizon takes place, since if the aircraft is rolling right, then its AI silhouette also tilts to the right. No additional logical operations are needed to acquire correct spatial awareness, because the information displayed by the instrument is realistic – the aircraft is depicted as a moving axis, and the surrounding world is static, which serves as a basis for the system for the recognition of the pilot's own movement.

Direct indication on the AI depicts an unrealistic picture: if the aircraft is rolling right, then the moving picture of the sky/earth tilts to the left, i.e. the pilot needs to perform logical operations in order to be able to stabilize the outside world and to perceive the aircraft as moving. If this does not occur, this is a case of spatial disorientation.

Such logical operations can be useful when the angle of roll and bank is small. With angles greater than 20 -30°, and especially after reaching critical and above critical vales of the angles, logical operations cannot help and this often forces the pilot to perform testing movements with the control stick [16,17,18].

An example of an additional and unnecessary mental effort is the mental "moving" of the silhouette of the aircraft on the display of a direct indication AI, suggested by Adamovich and Alexandrov. In his research Kovalenko proves that the mental "moving" of the aircraft silhouette and the mental "stopping"of the moving sky-earth on display of the direct indication AI is difficult with values of roll and pitch around zero, and practically impossible with values of the angles at, or beyond the critical.

The expert assessment on the criterion of "conducting additional logical operations and other actions when working with the indication" is: reverse indication – 5 points., direct indication – 1 point.

10. Efficiency of the spatial orientation methods. "The structure and composition of the information model must provide confidence during a transition between visual flight and instrument flight, and vice versa…The coding system adopted by the information model must not cause the pilot to experience contradictory perceptions, neither during simultaneous use of the non-instrumental information, nor during the transition from instrument flight to a visual one" [26].

Pavel Kovalenko proves experimentally, that the emerging effect of moving space (the sky, the earth and the line of the horizon, dividing them) can cause the pilot to employ three ways (methods) of spatial orientation.

– The first spatial orientation method (I SOM) – perceiving the sky-earth and the horizon line, which divides them, as static (unmoving), and the aircraft, with the cockpit (the contour of the windshield) as a moving, steerable object during visual flight; during instrument flight, the moving object is the silhouette of the aircraft.
– The second spatial orientation method (II SOM) - both the earth (the line of the horizon), and the cockpit (the contour of the windshield) during visual flight, and the silhouette of the aircraft during instrument flight are perceived as moving.
– The third spatial orientation method (III SOM) – the cockpit is perceived as static during visual flight, as well as the silhouette of the aircraft during instrument flight; the earth (the horizon line) becomes the moving, steerable object.

The results of the research demonstrate in a statistically significant way, that with the I SOM, which corresponds to the principle of reverse indication (outside-in), there are no errors and decision time is short.

When III SOM is used, based on the principle of direct indication (inside-out) - a static aircraft silhouette and moving, steerable sky-earth and horizon line, there are more erroneous actions in taking toe aircraft out of the roll and the decision time is longer, when compared to a pilot using I SOM, It has also been proven, that with III SOM and a direct indication AI, during a transition from visual to instrument flight, pilots tend to use an inefficient image, in which the actually static sky-earth and horizon are depicted as moving; this leads to errors and represents a threat to the safety of the flight.

If the pilots see the earth as static during visual flight, then when they transition to instrument flight with a direct indication AI, they have to readjust their perceptions which are extremely complex and often accompanied by mistakes [16,17,18].

The expert assessment on the criterion "efficiency of the spatial orientation methods" is: reverse indication – 5 points., direct indication – 1 point.

11. Indication and illusions. The information model (indication) must not be the cause illusions, errors in perception, thinking, memory, etc. D. V Gander points out that traditionally, flying instructors teach the pilots to fly in a static airspace and to suppress the perception that is "moving" [8].

In the above mentioned sources, Kovalenko develops the concept of flying in a stabilized airspace. If during visual, or instrument flight the sky-earth and the horizon line dividing them are perceived as moving this means that the pilot is under the effects of an illusion since in reality the aircraft is the moving object. Therefore, it is important that the pilots develop the ability to overcome the illusion of a moving airspace and to learn to perceive the aircraft (and themselves) as a moving steerable object in a stable surrounding space.

Johnson and Roscoe also emphasize that regardless of the circumstances, and the different ways of processing information, "it is important for the pilot to think that the aircraft is the moving object. If he begins to think that the surrounding airspace is moving, then he is disoriented and experiences a vertigo effect" [12].

The results of a study conducted by Kovalenko in 1989 show that 63% of the pilots utilizing a reverse indication AI employ I SOM, therefore 37% of the pilots experience the illusion of a moving space [17].

Another study, conducted by the same author in 2011 shows that 65.2% of the pilots use III SOM, i.e. perceive the earth as moving, which suggests the reverse ratio: present day pilots who mostly fly using direct indication are very often disoriented and experience the effects of illusions; this also means that they are not capable to suppress the perception of a moving space on their own [17,18].

The expert assessment on the criterion "indication and illusions" is: reverse indication - 5 points., direct indication – 1 point.

12. Co-ordinate systems and artificial horizons. The indication of roll and pitch on an AI should provide the ability to determine their direction by means of a static system (basis) of reference – the earth, and a moving, steerable element – the silhouette of the aircraft.

Alan Benson introduced the definition of spatial disorientation during flight while stressing the factor of a fixed co-ordinate system to account for movement. According to him, spatial disorientation during flight is responsible for various phenomena, as a result of which the pilot may lose the correct perception of his own position or that of the aircraft, movement and altitude in the fixed co-ordinate system with reference to the surface of the earth, as well as the gravitational vertical. In a wider sense, the term includes the loss of the correct perception of position, movement and altitude of the aircraft, as regards the movement, position and altitude of other aircraft [3].

When using a reverse indication AI, pilots have at their disposal a co-ordinate system which is fixed to the earth's surface; the moving, steerable object in this system is the aircraft.

Direct indication, especially at the roll limits (an angle of ≥30° for civilian and transport aircraft), the pilots are unable to use the fixed coordinate system of the earth, and are forced to perceive themselves and the aircraft as the basis of such a system, and to try to determine the direction of the roll using the position of the moving earth and the line of the artificial horizon. This can make determining the direction of the roll so difficult, as to become practically impossible, since this requires a whole series of mental recoding operations, in order for the pilot to transition from an egocentric, to a geocentric system. This leads to mistakes and incidents. We must point out that, unfortunately, this conclusion holds true in aviation worldwide.

The expert assessment on the criterion of "co-ordinate systems and artificial horizons" is: reverse indication – 5 points., direct indication – 1 point.

13. Steering the aircraft, and not the indicators. A number of studies point out that pilots must form a clear picture of the flight during all its stages. The adequate picture (image) of the attitude of the aircraft in space presupposes that the pilot must steer the aircraft, and not the needles and indexes of the indicators [5,23,28].

Pavel Kovalenko provides data from research conducted using the method of graphical reconstruction, which shows that when using a reverse indication AI, the silhouette of the aircraft is present in all depictions of the indicator. The analysis of the pilots using direct indication AI suggest that in 68% of the cases the pilots depicted the line of the artificial horizon as if it were a steerable object, and the silhouette of the aircraft, to the extent that it was present at all, was usually depicted as a straight line.

The expert assessment on the criterion "steering the aircraft, and not the indicators" is: reverse indication – 5 points., direct indication - 1 point.

14. Information model and artificial horizons. "The possibility of confusion, of mixing up information from different scales must be eliminated, especially in the case of complex, multifunctional indicators." In order to prevent confusion, and subsequent disorientation, it is not expedient the indications of a particular device to be displayed by parameter clusters, which represent information using different principles [26]. It is not advisable to separate qualitative and quantitative information provided by a particular parameter cluster (needle – scale). The information model (indication) must be built in such a way so that the establishment of the direction of the parameter (qualitative reading) should not be separate from the establishment of the value of the change of the parameter (quantitative reading) [4,16,17,18].

Ronald Small, Alia Fisher, John Keller and Christopher Wickens note that "The moving element of the picture must correspond to the moving element in the mind of the pilot, and this element must move in the same direction as it does in the mental picture. Since the mental model of the pilot represents a moving aircraft in a static world <…>, this principle requires that the aircraft is shown as a moving element, so when the aircraft climbs, or pulls up, the element should move up. The moving horizon violates this principle since here the moving element – the horizon, moves up when the aircraft descends, and rotates to the left (or right), signaling that the aircraft is turning right (or left). In order to stay true to the principle, the aircraft silhouette must move about a static horizon" [27].

On AIs with reverse indication, the scale indicating roll is usually placed in such a way that the tip of the wing of the symbol of the aircraft allows to determine simultaneously both the direction of the roll, and its angle.

On artificial horizons with direct indication, the scale is placed either a) at the bottom, b) to one side, or c) on top of the display.

a) If the scale is located at the bottom of the display (as in the case of PKP-1), it was established that it actually uses the principle of reverse indication for roll, since the index of the scale for roll shows the direction of the roll. The surveyed pilots claim that they perceive the information as if they see the wing of a moving aircraft silhouette, which makes it easy to determine the direction of the roll. This allows them to ignore the direct indication – the static aircraft silhouette in the center of the AI display, as well as the moving depiction of the earth [16,18]. However, in cases when the pilot is subject to extreme stress, the index indicating roll, painted white and small in size, proves difficult to find.
b) If the scale is located laterally as regards the display of the indicator (as in PKP-77), it is moving and appears when the pilot is performing a turn, which requires the information to be "read", which in turn leads to unnecessary waste of time and requires part of the attention of the pilot. In practice, moving scales switch off such an important cognitive function as the forecasting of the particular flying parameter in time. With this

design, there are two scales two indexes for the same scale – the wing of the static silhouette of the aircraft, and the moving line of the horizon, which can lead to mistakes, especially in a complex situation.

c) If the scale is located above, and is static, it is actually marked on the outside of the instrument, or on the display-glass of the electronic indicator. Such scales are only divided in increments up to 50-60°, the rest of the roll values are unmarked. Here, the index is represented by the so called zenith index, which disappears from sight, if the roll exceeds 60°, which makes the quantitative reading of the indications and leads to mistakes.

The expert assessment on the criterion "information model and artificial horizon" is: reverse indication – 5 points., direct indication – 1 point.

15. Genetic factor and the indication on artificial horizons. Some authors have expressed the opinion that the problem with indication on artificial horizons results from the natural, genetically inherited methods for orientation in humans. According to this view, humans fall into two groups – egocentrics, and geocentrics. This view has been researched by Pavel Kovalenko, by studying two groups of people: Russian civilian aviation pilots and test pilots, and non-specialists [15].

The results show that if only "natural" geocentrics are selected for pilots, aviation should become completely unmanned. 98.2% of the surveyed are capable of changing their method of spatial orientation, which suggests that the crews need specialized training, in order for them to be able to develop their skills in stabilizing the surrounding space in flight. On the other hand, the indication, and the symbols used on the indicators, should be technologically well-thought out, clear and consistent with the way pilots process incoming information [19].

The expert assessment on the criterion of "genetic factor and the indication on artificial horizons" is: reverse indication – 5 points., direct indication – 1 point.

16. Reverse and direct indication – the experts' assessment of artificial horizons. Ponomarenko, Lapa, Chuntul note in their research that "Pilots consistently give a higher score to the IKP-81 artificial horizon, as regards its convenience and efficiency (8 on a scale of 1 to 10 for IKP-81, 2.7 for PKP-77)" [24].

Based on the analysis of 54 publications directly related to the issue of the artificial horizon indication, a total of 48 authors have expressed a preference for reverse indication (88.9%), while 4 authors (7.4%) prefer direct indication; 2 authors (3.7%) have expressed support for combining the two types of indication.

The expert assessment on the criterion of "reverse and direct indication – the experts' assessment" is: reverse indication – 4.5 points., direct indication – 1.5 point.

The total score on the 16 criteria is 79.3 points in favor of reverse indication, and 16.7 points In favor of direct indication. In other words, the average score for reverse indication is 4.96, and for direct indication – 1.04.

Based on the analysis of the data, reverse indication has a clear advantage, especially when taking into account the inherent problems associated with the use of direct indication artificial horizons.

Direct indication artificial horizons lead to:

- Sharply decreased flight safety;
- The emergence and perpetuation of the illusions of a moving space and steering of the earth (the natural horizon);
- Lack of understanding and mistakes in the perception of the indications of an essential device, such as an AI;
- Unnecessary difficulties, which pilots experience during instrument flight and which take away from their time to work with the rest of the indicators, these difficulties also diminish their attention and their operational memory.

The research conducted by many experts indicates that onboard aircraft there are basic instruments, which are difficult to read [7,13,25,27].

A lot remains to be done globally in order to solve this problem and this is the reason for the writing of this article. It should be an easy step to change the computer programs, so that the pilots receive pertinent, easy to understand information about aircraft roll by a moving silhouette, instead of offering them the illusory rotating space of direct indication artificial horizons. This is also a much cheaper than burying the remains of the victims of perfectly avoidable disasters and scrapping expensive aircraft.

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