Analysis of directions for improvement of flight simulators

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Abstract. The modern development of science and technology makes it possible to modernize imitators for an aviation simulator and increase the number of training situations. This allows you to improve the professional skills of pilots. The development of most imitators is the development of programs for a specialized computer. Modern integrated aviation simulators are designed to teach pilots how to fly an aircraft in special flight situations, or training situations. The increase in training situations is the main task facing the developers of aviation simulators. Improvement of imitators allows to increase the number of training situations. This is possible if the imitators are upgraded to take into account the new capabilities of available software and new hardware. The existing integrated aviation simulators are designed to train pilots in the process of controlling an aircraft. It is impossible to create a complete model of any aircraft unit. Therefore, imitators for flight simulators were developed for training pilots only in special flight conditions. Therefore, the task of developing a imitator is the use of available software and available hardware to develop information processes that inform the pilot as much as possible when solving problems of controlling the aircraft model. Studies have shown that it is expedient to develop imitators taking into account the formation of individual components of the pilot's cognitive model, in which his experience in solving problems of aircraft control and experience in solving navigation problems is deposited. The article considers the main directions for improving imitators for flight simulators, taking into account their impact on the given components of the pilot's cognitive model.

1 Introduction

The modern development of science and technology makes it possible to develop new and modernize imitators for flight simulators [1]. New imitators better synthesize information processes about the behavior of models of individual units of an aviation simulator [2]. This allows you to expand the list of training situations and improve the conditions for the professional training of pilots [3]. Simulators of aircraft controls in the cockpit of an aircraft

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are a copy of real analogs. The rest of the imitators are special software and hardware systems [4]. One imitator synthesizing visual 3*D*-models - "Visual Environment Simulator" - is an ergatic optical-software-technical system [5]. Each imitator at a time t_i synthesizes the pilot information about the operation of the model of one device [6], or about the model of the external environment [7], or the model of the interaction of the airframe of the aircraft with the model of the atmosphere [8] in real time (with a cycle of 80 ms).

Currently, flights on an aviation simulator are part of the pilot training program and allow them to acquire professional skills in controlling an aircraft [9] and partially solve navigation problems [10]. Since it is not possible to create a complete model, the flight simulator is developed with the aim of training the pilot in normal and pre-accident training situations. An increase in the list of training situations increases the level of professional training of pilots. Thus, it is relevant to conduct research to increase the list of learning situations.

2 Materials and methods

Previously, each imitator of an aviation simulator was developed in accordance with the capabilities of the available software and hardware systems. At the first stage, the hardware part was selected. At the second stage, programs for synthesizing information about the behavior of the model of specific units of the aviation simulator were developed. At the third stage, a system of information exchange between individual imitators was developed. The goal of developing all imitators is real-time synchronization of information synthesized by individual imitators. As a result, the pilot receives information sufficient to create the feeling of flying on a real aircraft while flying on an aviation simulator. The quality of information synthesis from the *j*-th imitator at time $I_j^{(T)}\left(t_k\right)$ was evaluated in comparison with the information received in real flight from the *j*-th instrument of the aircraft at the same time $I_j^{(Л)}\left(t_k\right)$. Then the quality of the information synthesized by the *j*-th imitator of the flight simulator is usually estimated as the difference

$$\Delta I_j\left(t_k\right)=\left|I_j^{(T)}\left(t_k\right)-I_j^{(Л)}\left(t_k\right)\right|\to \min . \quad (1)$$

When developing an aviation simulator and analyzing imitators during commissioning, the ability of the *j*-th imitator to effectively simulate a real aircraft unit or part of the external environment was always evaluated. (1) is used, taking into account the capabilities of the software and hardware systems used to implement the *j*-th imitator. During the analysis, areas for improvement directions were considered $I_j^{(T)}\left(t_k\right)$. In most cases, the direction of improvement (1) was defined as taking into account the features of real-time information synthesis. In particular, due to time constraints, the mathematical model of the considered node of the aviation simulator was simplified or the calculation accuracy was reduced $I_j^{(T)}\left(t_k\right)$. The result has always been to limit the number of training situations. For example, it was not possible to train a pilot to fly low-altitude over a 3*D*-model of uneven terrain. However, the Customer was satisfied with such simulators, since their use significantly reduced the number of accidents and prerequisites for flight accidents due to the fault of the pilots. Further improvement of aviation simulators was constrained by the characteristics of the computer technology used. At present, more productive computing systems have appeared, compared to those used at the end of the last century:

- CPU clock speed was 80 MHz, now hundreds of times faster;
- used 24-bit registers, now 64-bit;
- no limit on RAM capacity.

The capabilities of modern software and hardware systems provide an opportunity to use new methods of synthesis $I_j^{(T)}\left(t_k\right)$. In this case, the general task of developing imitators for flight simulators is divided into two tasks. The first is the choice of hardware. The second, taking into account the new capabilities of the hardware, to develop a synthesis algorithm $I_j^{(T)}\left(t_k\right)$, fulfilling (1) and providing the best solution to the tasks set by the Customer for training a pilot in professional skills in controlling an aircraft and solving navigation problems.

Since it is impossible to create a complete model $I_j^{(T)}\left(t_k\right)$ will always be different from $I_j^{(Л)}\left(t_k\right)$. Currently, when solving the minimization problem (1), mathematical synthesis models are developed taking into account the minimum deviation $I_j^{(T)}\left(t_k\right)$ and $I_j^{(Л)}\left(t_k\right)$ in t_k. This does not take into account the redundancy of information for the pilot $I_j^{(T)}\left(t_k\right)$ (for example, a slight backlash of the magnetic compass needle, which does not affect the educational process in any way).

Studies have shown that at present it is advisable to develop the *j*-th simulator, taking into account (1) and taking into account how the individual components of the cognitive model are formed in the *k*-th pilot when he performs flights on an aviation simulator in the *b*-th training situation $C_k\left(b\left(\Delta t_m\right)\right)$.

To this end, at the first stage it is necessary to determine what the pilot uses $I_j^{(T)}\left(t_k\right)$ – for solving problems of aircraft control or for solving navigation problems.

At the second stage, it is necessary to determine the influence $I_j^{(T)}\left(t_k\right)$ on the formation of specific components of the pilot's cognitive model when he solves a specific task and, in accordance with this, determine the requirements for the software and hardware part of the *j*-th imitator.

Let's divide all imitators for flight simulators into three groups.

The first group of imitators for the real-time interval $\Delta^{(1)}t$ synthesize information $I_j^{(T)}\left(t_k\right)$ simulating the behavior of a real *l*-device of the aircraft $l \in 1...\left(L\right)$. During the synthesis, the features of physical processes in the considered units of the aircraft are taken into account, the same group of simulators includes simulators of atmospheric phenomena. The synthesized information $I_j^{(T)}\left(t_k\right)$ from the imitators of this group is reflected on the instrument panels of the cabin equipment imitators. Studies have shown that the formation of the components of the cognitive model of the *k*-th pilot from the *j*-th imitator of this group

$$C_{k(b)}^{(1)}\left(j\right) = F_{j(b)}^{(1)}\left(T_k, I_{j(b)}^{(T)}\right). \tag{2}$$

During the flight on an aviation simulator, the *k*-th pilot, processing information from the imitators from the first group, makes decisions on the control of the aircraft model, just as during a real flight he makes decisions on the control of a real aircraft. Studies have shown that the pilot from each *j*-imitator of this group can receive limited information. This is a consequence of the features of modeling the j-device of the aircraft. The maximum value of this information depends on the ability of the pilot to work with the information panel, which displays $I_j^{(T)}\left(t_k\right)$. Then there is a limit to obtaining the information necessary to control the aircraft model

$$\lim_{T_k \to T_k^{(1)}} C_{k(b_j)}^{(1)}\left(T_k\right) \to const_j^{(1)}, \tag{3}$$

the value of this limit depends on the formed component of the pilot's cognitive model (2), which depends on the time spent $T_k^{(1)}$ by the *k*-th pilot:

- during pilot training;;
- when flying on a real aircraft;
- when flying on an aviation simulator.

(3) determines the professional training of the pilot or his ability, receiving information from the j-device, to make decisions on the control of the aircraft..

The second group is simulators that in real time $\Delta^{(2)}t$ synthesize information $I_j^{(T)}\left(t_k\right)$ about the physical processes of interaction of models of radio beacons with models of *j*-devices that belong to the class of radio engineering devices for solving navigation problems. They allow you to solve navigation problems when flying in fog. The synthesized information from the imitators of this group $I_j^{(T)}\left(t_k\right)$ is reflected on the instrument panels of the cabin equipment flight simulators. Studies have shown that the formation of the components of the cognitive model of the *k*-th pilot from the *j*-th imitator of this group

$$C_{k(b)}^{(2)}\left(j\right) = F_{j(b)}^{(2)}\left(T_k, I_{j(b)}^{(T)} = F_{R_j}\left(M_{S\left(R_j\right)}\right)\right). \tag{4}$$

Simulators of the second group, during the flight on an aviation simulator, synthesize information for the k-th pilot $I_{j(b)}^{(T)} = F_{R_j}\left(M_{S\left(R_j\right)}\right)$. After processing this information, the pilot determines the position of the aircraft model above the flight area mode. $M_{S\left(R_j\right)}$. $M_{S\left(R_j\right)}$ is a map of the flight area developed according to its mathematical model. The map shows the location of the radio beacons for each device R_j modeling $I_j^{(T)}\left(t_k\right)$. This is necessary for solving navigation problems. Studies have shown that the pilot from each *j*-simulator of this group can receive limited information. This is a consequence of the features of modeling the *j*-device of the aircraft. Studies have shown that the maximum value of this information depends on the ability of the pilot to work with the information panel that displays $I_j^{(T)}\left(t_k\right)$ and with a map $M_{S\left(R_j\right)}$ where the locations of models of ground-based radio navigation devices are indicated. There is a limit to obtaining the information necessary to determine the position of the aircraft model above the flight area model

$$\lim_{T_k \to \infty} C_{k(b_j)}^{(2)}\left(T_k\right) \to const_j^{(2)}. \tag{5}$$

Величина этого предела зависит от сформированной составляющей когнитивной модели лётчика (2), которая зависит от времени, проведённого лётчиком:

The value of this limit depends on the formed component of the pilot's cognitive model (2), which depends on the time $T_k^{(2)}$, spent by the pilot:

- during pilot training;;
- when flying on a real aircraft;
- when flying on an aviation simulator.

(4) determines the professional training of the pilot or his ability, using information from the j-device, to determine the place of the aircraft model above the flight area model. In this case, the flight area model is a mathematical plane with the coordinates of the beacon models.

The simulators of the third group synthesize for the pilot a visual 3*D*-model of the space around the flight simulator cockpit. The simulators of the third group are divided into two groups.

The first subgroup of simulators of the third group is the ergatic optical-software-technical system "Visual Environment Simulator" (VES). VES acting on the given components of the human visual apparatus makes him see 3*D*-objects. The technological process of synthesizing a 3*D*-model is as follows. On a 2*D*-screen (or 2*D*-screens), video sequences are synthesized such as 2*D*-projections of 3*D*-models. Thus, $I_j^{(T)}\left(t_k\right)$ this is a constantly changing image on a 2*D*-screen (or 2*D*-screens) of a part of the 3*D*-space model that has fallen into the surveillance camera (or cameras) at a given time.

VES includes an optical system that activates the specified components of the human visual apparatus when viewing video sequences from *2D*-projections of 3*D*-models in real time through the optical component. As a result, a person sees a 3D-object. VES allows you to professionally train the observer's eye, too. Aviation simulators use single-channel optical systems without glasses and two-channel optical systems with disparate glasses. Since it is impossible to create a complete model of a visually observed 3*D*-space, each of the optical systems used has its own advantages and disadvantages. The choice of a optical system depends on the tasks to be solved when training a pilot on an aviation simulator. If the nearest 3*D*-model can be more than 15 meters away, glassesless optical systems are chosen. If the nearest 3*D*-model can be closer than 15 meters, two-channel optical systems with disparate glasses are chosen. VES allows solving navigation problems by viewing images of reference objects through the cockpit glass and finding them on a map of a 3*D*-model of the flight area common to all simulators of the third group M_{S_V}.

The second subgroup of simulators of the third group are software and hardware systems, such as "thermal imager simulator" (TIS). In TIS, it is displayed on a 2*D*-screen as video sequences $I_j^{(T)}\left(t_k\right)$ from appropriately colored 2*D*-projections of 3*D*-models. TIS allows a trained person to solve navigation problems by finding and viewing images of reference objects on a 2*D*-screen and finding them on a map of a 3*D*-model of the flight area common to all simulators of the third group M_{S_V}.

A common feature for simulators of the third group is the use of special software and hardware systems for machine synthesis on a 2*D*-screen of differently colored 2*D*-projections of 3*D*-models and a general map of a 3*D*-model of the flight area M_{S_V}.

2*D*-projections of 3*D*-models are synthesized using computer graphics algorithms. Control primitives and visual primitives from which 3*D*-models are assembled are used as initial information. All primitives are stored in the database of a special software and hardware system for machine synthesis. At the beginning of each real-time cycle, information about the 3*D*-models that have entered the surveillance camera is selected from the database.

Each *j*-simulator has a special *j*-software-hardware machine synthesis system and a *j*-database, which contains information about 3*D*-models of reference objects placed in the 3*D*-model of the flight area $M_{S_V}(j)$.

$$M_{S_V}(j) = F_{S_V}^{(j)}\left(M_{S_V}\right). \tag{6}$$

3*D*-models of reference objects for each *j*-th simulator have their own design and their own color of 3*D*-polygons. Studies have shown that, unlike the simulators of the first and second groups, the components of the pilot's cognitive model $I_j^{(T)}(t_k)$ when flying on real aircraft and when flying on an aviation simulator are constantly being improved and do not have their limit, which could limit the degree of professional training of the pilot.

$$\lim_{T_k \to \infty} C_{k(b_j)}^{(3)}\left(T_k\right) \to \infty_j^{(3)}. \tag{7}$$

This is due to a significant change in the conditions for observing reference objects in each flight. The value of this limit, which is constantly changing during each flight, depends on the previously formed component of the pilot's cognitive model (7), which depends on the time T_k spent by the pilot: during pilot training;;

- when flying on a real aircraft;
- when flying on an aviation simulator.

Thus, when developing new flight simulator simulators, it is necessary to take into account how the formation $I_j^{(T)}(t_k)$ of the corresponding components of the pilot's cognitive model (3), (5) and (7) will be affected.

3 Conclusion

1. When developing simulators of an aviation simulator, it is currently advisable to set the task of forming the given components of a pilot's cognitive model, in which his professional skills in controlling an aircraft and professional skills in solving navigation problems are deposited.

2. When teaching a pilot how to control an aircraft, it is enough to simulate the flight of an aircraft model in the "clouds".

3. It is advisable to divide all flight simulators into three groups, taking into account for what purposes the pilot uses the information received from the simulators.

4. There is a limit to the values of the components of the human cognitive model, which are formed by the information received by the pilot during the flight on an aviation simulator, taking into account flights on a real aircraft. The value of these components depends on the flight time of the pilot on an aviation simulator and on a real aircraft and tends to the limit determined by the purpose of each device.

5. When developing simulators of the first and second groups, it must be taken into account that there is a limit to the information that a pilot receives when flying an aircraft. This limit depends on the experience of the pilot acquired during the training, when flying on a real aircraft and when flying on an aviation simulator.

6. There is no limit to the values of the components of the human cognitive model that are formed during flights with visual observation of the 3*D*-model of the flight area.

7. For each simulator of the third group, its own 3*D*-model of the flight area is developed, taking into account the 3D models of reference objects located in the 3*D*-flight area developed for the visual environment simulator.

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