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[1]D. A. Prosvirin,
[2]V. P. Kharchenko

IMPROVEMENT OF "AIRCRAFT-AUTOMATIC FLIGHT CONTROL SYSTEM" CONTROL LOOP QUALITY

Air Navigation Systems Department, National Aviation University, Kyiv, Ukraine
E-mails: [1]dimitry.prosvirin@gmail.com, [2]kharch@nau.edu.ua

***Abstract*—*This article deals with model based approach to mathematical modeling process of an aircraft flight control system. Analysis of emergency situations depend on phases of flight is done. Application of modern model based technologies for automatic flight control systems development is considered. The program for aircraft-automatic flight control system control loop simulation and visualization is developed. Improvement of the automatic flight control system characteristics is showed. Availability of practical application of developed program in aerospace scope is considered. Use of the mentioned approach allows to facilitate automatic flight control system development, analyze and certification process.*

Index Terms—Automatic flight control system, mathematical modeling, simulation, visualization, control law, approach phase.

I. INTRODUCTION

Actually execution of flight task includes a few operation phases which are characterized with intensive maneuvering and limitation for achieving specified terminal states. Particularly the most critical of them are take-off and landing executes with pilot participation. Analysis of emergency situations at home and abroad shows that, more than 50% of general accidents happen at take-off and landing phases of flight. And duration of these phases is only 2% from the average flight duration. So, search for new solutions and methods of improvement automatic flight control characteristics is relevant task and thereby increasing of aircraft flight. In some cases it is not possible to assess the performance of the aircraft flight control systems quality by the direct method – flight tests - because of the limitations of the existing objective conditions for its implementation. This, and the relative duration, spending resource of real assets and substantial economic costs of flight tests enforce to search for a more rational methods of work organization that to assess flight control systems performance [1].

II. PROBLEM STATEMENT

Today aviation companies gradually come to model-based embedded software development process for onboard systems. So, search for a new applications witch support a model-based development paradigm is a relevant task. This article deals with the approach description through a software model, including the graphics and the associated logic, in the sense of DO-178C.

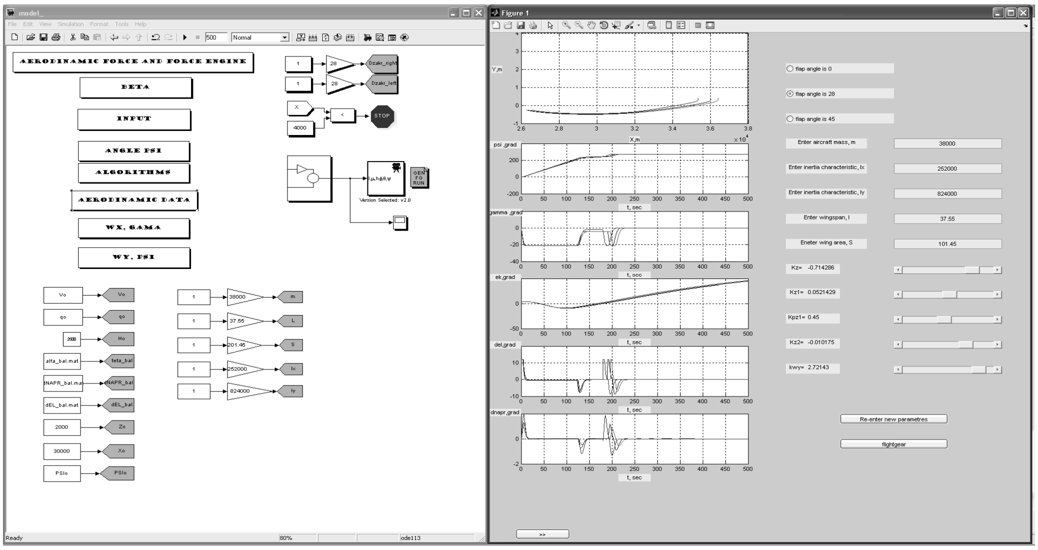
In addition, the U.S. Federal Aviation Administration (FAA), European Aviation Safety Agency (EASA) and other international authorities of aviation security insist on the use of functional safety standards, that to ensure the proper functioning of a complicated electronic equipment of aviation systems in any foreseeable conditions, to exclude defects and the possibility of the aircraft crashes.

III. ANALYSIS OF LAST RESEARCH AND PUBLICATIONS

Many academic papers and researches are dedicated to aircraft control quality improvement at the critical flight phases [3] – [7]. All they are based on knowledge of the nominal aerodynamic characteristics or using normalized diagrams for the correction of the main maneuvers on the take-off and landing according to the a priori known factors: temperature, airport height, runway slope , wind velocity vector , etc. As noted in several studies [3], [4], [8], the existing technique of decision at the take-off and landing based only on the time of reaching the aircraft so-called the decision speed V1, can not prevent accidents are caused by too low acceleration characteristics of the aircraft, the loss of traction, the excess of the permissible mass, brakes failure or deviation of weather conditions from the expected.

IV. SOLUTION PROCEDURE

Formal Model-Based Development consists of a rigorous unambiguous graphical semantic which combines data and control flow as well as a formal action language used to represent the architectural and behavioural aspects of a software-centric system. Mathematical models formalize a significant part of the software architecture and design. The model is written and maintained once in the project and shared among all team members: from the specification team to the review and testing teams. Expensive and error-prone rewriting is thus avoided, interpretation errors are minimized. This formal definition can even be used as a contractual requirement document. Basing the activities on an identical formal definition of the software may save a lot of rework, and acceptance testing is faster using simulation scenarios. In the software requirements process, partial modelling is a good support for the identification of system functions, its interfaces, and data flows.



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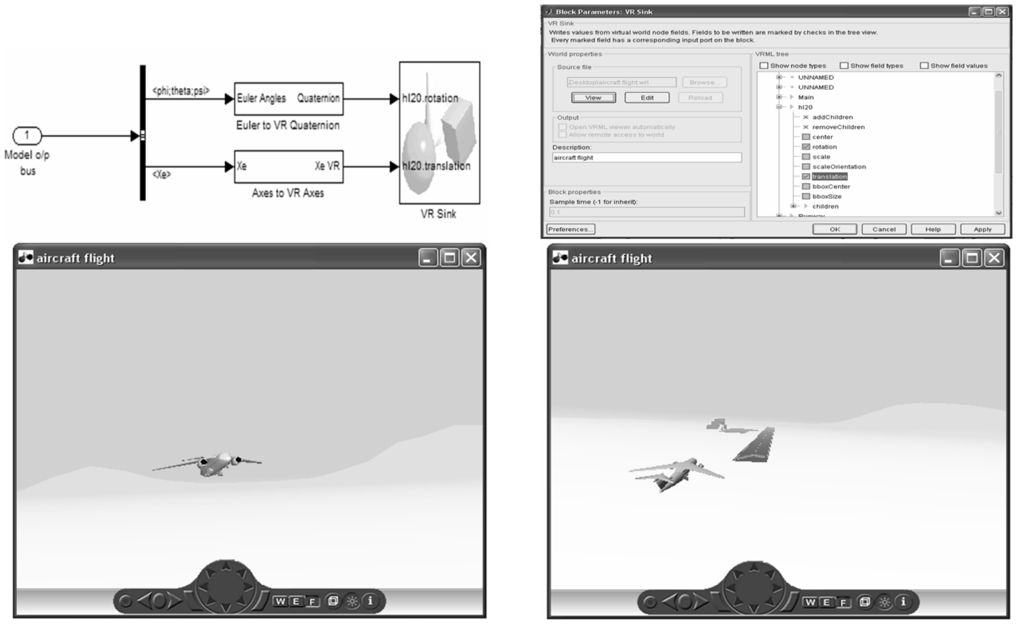

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Fig. 1. Standalone virtual test bench for flight simulation:
(a) the main operator's setting window; (b) 3D Visualization of aircraft flight at approach phase

V. Simulation Results

Automatic control of the lateral movement is implementing through the channel of the rudder and ailerons. Rudder channel provides damping of oscillations around the normal axis, and the eliminating of slip angle. Roll and heading purposive control is provided by ailerons in coordinated turn mode. Testing of the specified roll angle and heading is provided by the simultaneous operation of the rudder and ailerons [4].

Research of the automatic control laws of lateral movement is based on a decomposition principle (division) of rudder and ailerons channels. For this purpose, the original object of the control lateral movement is divides into two sub-objects which are implementing flat turn and coordinated turn modes.

Approbation of flight parameters prediction method at the landing phase was implemented on computer bench. Operator's panel allows set the inertial-mass, geometric characteristics of aircraft and creates landing scenarios in accordance with Flight manual.

For visual observation of received result 3D-models of aircraft and earth surface were developed. Visualization unit contains a module VR Sink, from Virtual Reality Toolbox library and provides GUI Simulink output signals configuration in a virtual space. Control of 3D-model is carried out by its rotation and movement controlled by parameters (quaternions, altitude, range) that can be selected in the menu of Visualization VR Sink block module. Figures 4–7 provides a brief analysis of the lateral movement stability. It shows that the aircraft has a track and cross-resistant with low damping factor.

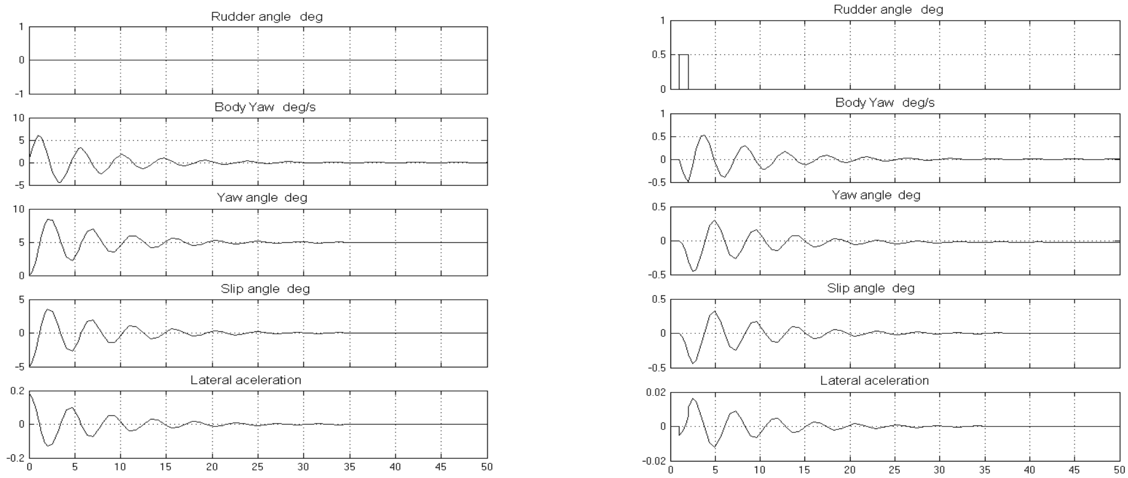

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Fig. 2. Lateral movement stability: (a) gust step response; (b) the response to the impulse of the rudder

Analysis of the control law in the "Approach" mode. In the issue of analysis below, is recommended to reduce the gear ratio for the lateral coordinate to value $K_z = 0.06$ (calculated $K_{z\ \text{calc}} = 0.1$). Inclusion to the control law of the mentioned correction improves the control quality in the wind disturbance, i.e, the presence of this correction is required. Analysis of the $K_{\tilde{\gamma}}$ impact on the control quality at the worst set of disturbances indicates expediency to increase the value $K_{\tilde{\gamma}}$ to 0.2 (previous value was 0.043). In addition, limitation function is added to the integral component of the control law. The results of the of the control law in the "Approach" mode research (Figs 3, 4) are the new (improved) control laws in the rudder and aileron channels. The above approach will: carry out the synthesis of automatic control law in the rudder channel; execute the development of aircraft autopilot lateral movement control schemes, implement the following modes of AFCS: roll stabilization mode , heading stabilization mode and to develop the functional circuits that implement automatic control of the heading and roll angles.

The control law in the rudder channel is:

$$\delta_r = F_{\lim}^{\delta r}\left\{K_{\omega_y}\frac{T_{\omega_y}p}{T_{\omega_y}p+1}\omega_y(p) - K_{\tilde{n}_z}\frac{1}{p}\cdot\frac{1}{T_{n_z}p+1}n_z(p)\right\}, \quad (1)$$

where $F_{\lim}^{\delta r}$ is the limiting function deflection of the rudder is $\pm 7°$; ratios K_{ω_y} = 1.5; T_{ω_y} = 3 s; $K_{\tilde{n}_z}$ = 11,5; T_{n_z} = 20 s.

The control law in the aileron channel is:

$$\delta_a = F_{\lim}^{\delta a}\left\{K_{\dot{\gamma}}p\gamma(p) + K_{\gamma}F_{\lim}^{\Delta\gamma}\left(\gamma(p) - F_{\lim}^{\gamma_s}\gamma_з(p)\right) + F_{\lim}^{\tilde{\gamma}}\left[K_{\tilde{\gamma}}\frac{1}{p}F_{\lim}^{\Delta\gamma}\left(\gamma(p) - F_{\lim}^{\gamma_s}\gamma_s(p)\right)\right]\right\}, \quad (2)$$

where $K_{\dot{\gamma}}$= 1.055; K_{γ}= 1.295; $K_{\tilde{\gamma}}$= 0.043; $F_{\lim}^{\delta a} = \pm 15°$; $F_{\lim}^{\delta a}$ is the limiting function deflection of the ailerons is 15°; $F_{\lim}^{\Delta\dot{\gamma}}$ is the limiting function of the body roll rate (control signal) is $\pm 6°$; $F_{\lim}^{\gamma_s}$ is the limiting function of the specified roll angle similar to above with range ± 30°; $F_{\lim}^{\Delta\tilde{\gamma}}$ is the limiting function of the integral specified deviations in roll (control signal), ±10°.

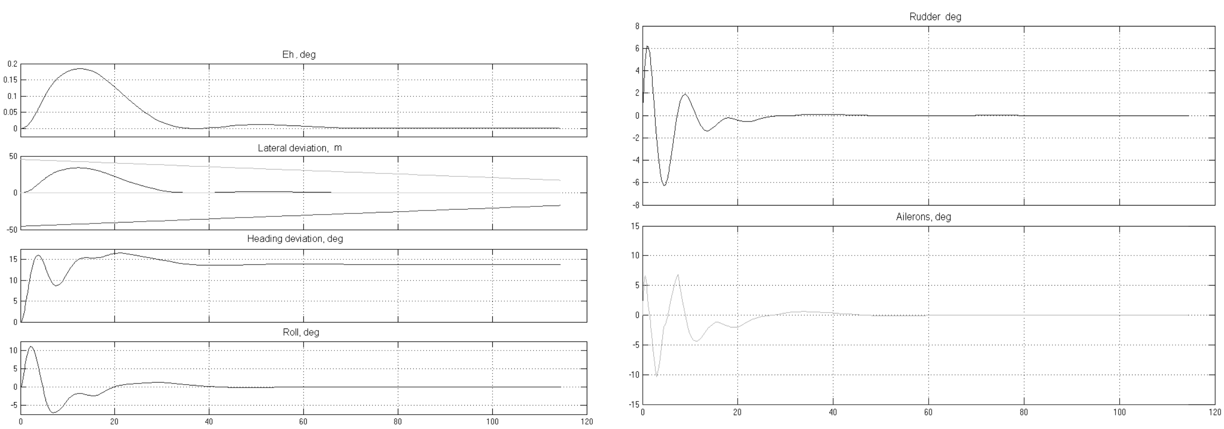

Fig. 3. Investigation of the influence of wind disturbance $U_Z = -15$ m / s with estimated ratios

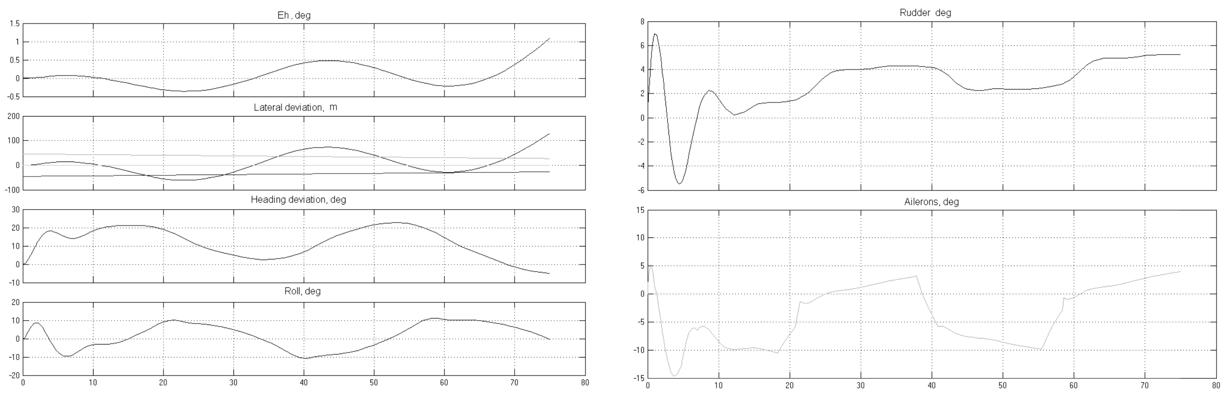

Fig. 4. Research of wind disturbance $U_Z = 15$ m / s with roll disturbance $F_{mx} = \pm 1.5$, yaw disturbance $F_{my} = \pm 1$

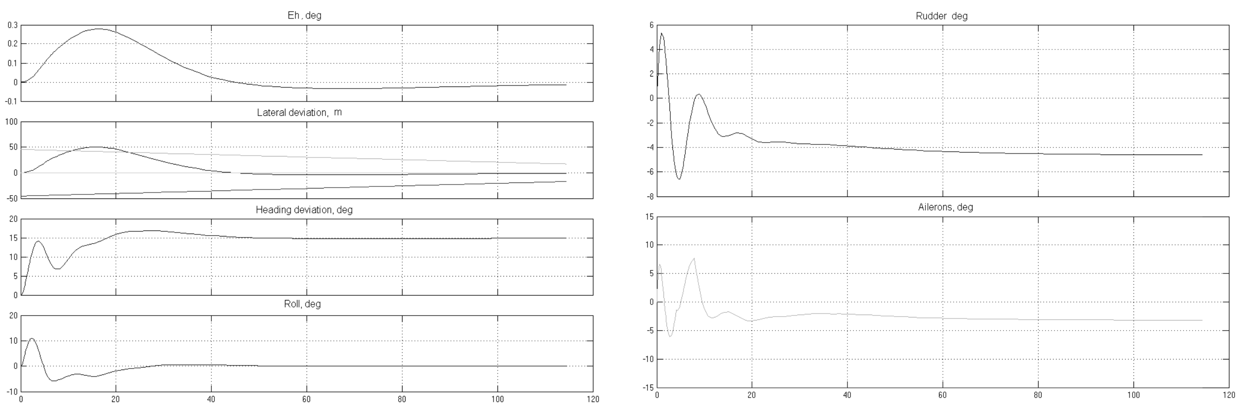

Fig. 5. $U_Z = -15$m / s; $F_{mx} = -1.5$ ($\delta_a^f = 3\,\text{deg}$); $F_{my} = -1$ ($\delta_\gamma^f = 3\,\text{deg}$) and $K_Z = 0.06$

Instability of the control loop is showed at earlier calculated the gear ratios settings. It is recommended to reduce the K_Z from 0.1 to 0.06 (Fig. 5).

The stability of the control loop is provided for calculated gear ratios setting and reduced value of K_Z from 0.1 to 0.06.

The procedure of landing maneuver with approach to the final leg, which coincides with the runway center line is operated by using the navigation system FMS in accordance with the schemes, established for the given aerodrome. In case of failure of two FMS or interruption of the landing maneuver according the above schemes of ATC, landing is performed independently in accordance with the directions of ATC. In this case for the flight in a given by ATC airspace corridor is necessary to maintain the desired track angle relative to the course of the runway. This angle is in the range $\Delta\varphi = 65°...28°$, which is necessary to maintain at the initial stage of approaching to the heading area before enter to linear area of the signal change ε_h (deviation in the heading).

Allowable value of overshoot signal ε_h should not exceed $49\,\mu A$. If a selected magnetic track angle is exceed 65° and automatic approach is activated with large lateral deviation from the axis of the runway then aircraft executes the turn under the influence of automatic flight control system (AFCS) and go on the course 65°, and then at the entrance to the linear zone of change of signal ε_h it performs additional turn on the runway center line. If a selected magnetic track angle is less than 28°, the aircraft under the influence of AFCS go on the course of 28°. Next, it performs additional turn on the runway center line. Before switching on the automatic mode or the guiding approach should ensure that the aircraft is in range of the localizer airport landing. Mentioned methodology can be modified and refined by the results of flight tests.

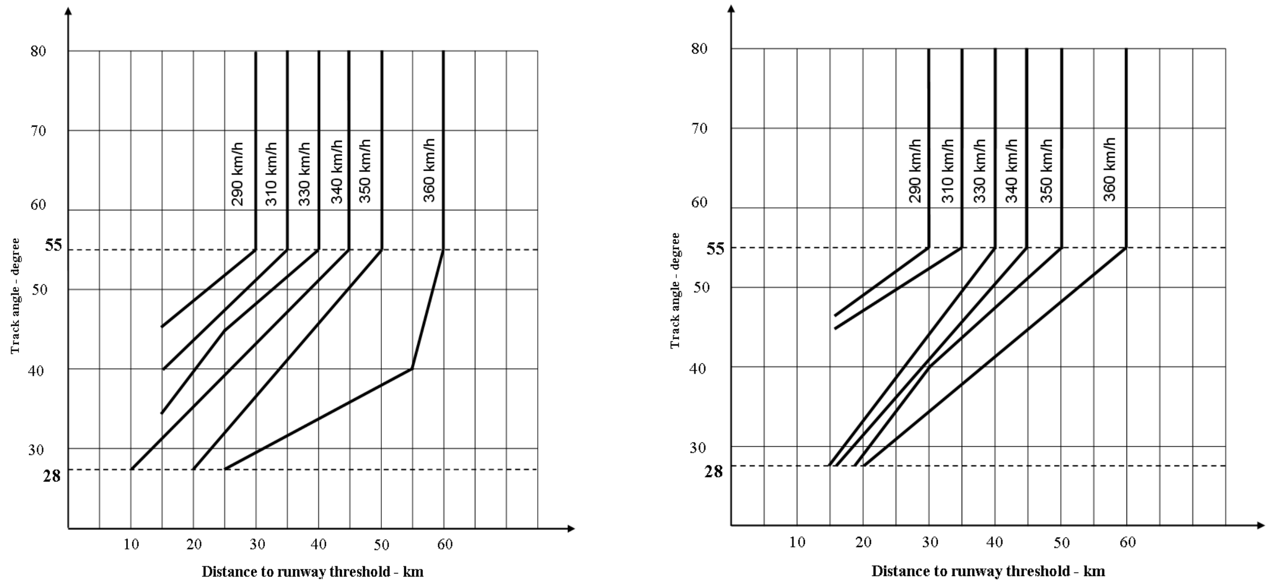

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Fig. 6. Dependence of track angle on distance to runway threshold (ε_k =0.60, U_Z = 0 m / s):
(a) H_0 = 600 m gust step response; (b) H_0 = 1000 m the response to the impulse of the rudder

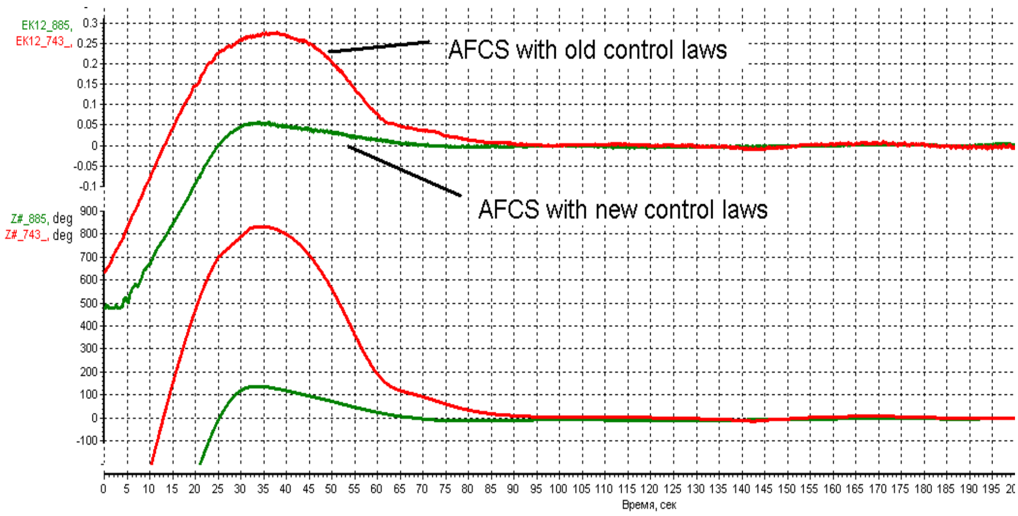

Fig. 7. Analyze fragment of AFCS's comparison with old control laws and new control laws

VI. CONCLUSIONS

Today's systems and software engineers face mounting pressure to develop automatic flight control systems in a timely and cost effective manner. By utilizing model-based systems engineering, embedded software development processes with proposed in this paper approach and developed program of mathematical modeling for automatic flight control system control loop, developers can meet these challenges.

As it can be seen from above results the mathematical modeling was conducted within the permissible range (aileron deflection not greater than ± 15º deflection of the rudder is not more than ± 8º) and did not exceed the requirements of the specified type aircraft. Therefore, the use of the above algorithm is reasonable. In conclusion, we note that the presented approach to the improvement of "aircraft-automatic flight control system" control loop quality will:

Perform a preliminary analysis of the emerging modes of AFCS at the stage of co-design the aircraft and AFCS;

To carry out maintenance of AFCS semi-natural test;

Perform statistical analysis of approach mode with significant savings in material costs during the flight test;

Make recommendations of automatic control loops setting at the flight test of AFCS, which will reduce the time and cost of field research and certification of AFCS

Meet the requirements of safety functional standards, simplify the development process and reduces costs.

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Prosvirin Dmitry. Post-graduate student.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine
Education: National Aviation University, Kyiv, Ukraine (2010).
Research interests: navigation and flight control.
Publications: 10.
E-mail: dimitry.prosvirin@gmail.com

Kharchenko Volodymyr. Doctor of Engineering. Professor.
Holder of a State Award in Science and Engineering of Ukraine.
Acting Rector of the National Aviation University, Kyiv, Ukraine.
Head of the Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Professor of Traffic College of Ningbo University of Technology, Ningbo, China.
Education: Kyiv Civil Aviation Engineers Institute with a Degree in Radio Engineering, Kyiv, Ukraine (1967).
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design, air navigation services in Ukraine provided by CNS/ATM systems.
Publications: 474.
E-mail: knarch@nau.edu.ua

Д. А. Просвірін, В. П. Харченко. Підвищення якості контуру «літак–система автоматичного керування»

Представлено модельно-орієнтований підхід до процесу математичного моделювання законів системи автоматичного керування. Виконано аналіз аварійних ситуацій в залежності від етапу польоту. Розглянуто використання сучасної модельно-орієнтованої технології розробки законів системи автоматичного керування. Розроблено програму моделювання і візуалізації контуру літак-система автоматичного управління. Показано поліп-

шення точності витримування параметрів системи автоматичного керування. Розглянуто можливість практичного застосування розробленої програми в авіаційній галузі. Використання вказаного підходу дозволить скоротити час на розробку, аналіз і сертифікацію системи автоматичного керування.
Ключові слова: система автоматичного керування; математичне моделювання; візуалізація; закони керування; захід на посадку.

Просвірін Дмитро Андрійович. Аспірант.
Кафедра аеронавігаційних систем, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна (2010).
Напрямок наукової діяльності: навігація та управління рухом.
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E-mail: dimitry.prosvirin@gmail.com

Харченко Володимир Петрович. Доктор технічних наук. Професор.
Лауреат Державної премії України в галузі науки і техніки
Виконуючий обов'язки ректора Національного авіаційного університету, Київ, Україна.
Завідувач кафедри аеронавігаційних систем, Національний авіаційний університет, Київ, Україна.
Професор Traffic College of Ningbo, University of Technology, Ningbo, Китай.
Освіта: Київський інститут інженерів цивільної авіації, Київ, Україна (1967).
Напрямок наукової діяльності: управління складними соціально-технічними системами, аеронавігаційними системами та автоматичними системами прийняття рішень, спрямованих на запобігання конфліктних ситуацій, створення інформаційних технологій аерокосмічних систем, аеронавігаційне обслуговування польотів в Україні на основі супутникових систем CNS/ATM.
Кількість публікацій: 474.
E-mail: knarch@nau.edu.ua

Д. А. Просвирин, В. П. Харченко. Повышение качества контура «самолет-система автоматического управления»

Представлен модельно-ориентированный подход к процессу математического моделирования законов системы автоматического управления. Выполнен анализ аварийных ситуаций в зависимости от этапа полета. Рассмотрено применение современной модельно ориентированной технологии разработки законов системы автоматического управления. Разработана программа моделирования и визуализации контура самолет-система автоматического управления. Показано улучшение точности выдерживания параметров системы автоматического управления. Рассмотрена возможность практического применения разработанной программы в авиационной отрасли. Использование указанного подхода позволит сократить время на разработку, анализ и сертификацию системы автоматического управления.
Ключевые слова: система автоматического управления; математическое моделирование; визуализация; законы управления; заход на посадку.

Просвирин Дмитрий Андреевич. Аспирант.
Кафедра аэронавигационных систем, Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина (2010).
Направление научной деятельности: навигация и управление движением
Количество публикаций: 10.
E-mail: dimitry.prosvirin@gmail.com

Харченко Владимир Петрович. Доктор технических наук. Профессор.
Лауреат Государственной премии Украины в области науки и техники
Исполняющий обязанности ректора Национального авиационного университета, Киев, Украина.
Заведующий кафедрой аэронавигационных систем, Национальный авиационный университет, Киев, Украина.
Профессор Traffic College of Ningbo, University of Technology, Ningbo, Китай.
Образование: Киевский институт инженеров гражданской авиации, Киев, Украина (1967).
Направление научной деятельности: управление сложными социально-техническими системами, аэронавигационными системами и автоматическими системами принятия решений, направленных на предотвращение конфликтных ситуаций, создание информационных технологий аэрокосмических систем, аэронавигационное обслуживание полетов в Украине на основе спутниковых систем CNS/ATM.
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E-mail: knarch@nau.edu.ua