Current Tendencies in the Development and Designing Technologies of Aircraft Adaptive Neural Flight Control Systems

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CURRENT TENDENCIES IN THE DEVELOPMENT AND DESIGNING TECHNOLOGIES OF AIRCRAFT ADAPTIVE NEURAL FLIGHT CONTROL SYSTEMS

The design technology for adaptive neural flight control systems (ANFCS) has largely developed by now.

There are three major developments in design technology:

- development of software for modeling the dynamics of controlled movement of aircraft;
- software development (onboard programs);
- development of a bench complex for semi-natural modeling, which completes the development stage before flight tests.

The software allows you to select and justify the structure of the ANFCS, settings, analyze the stability of the system and prove the fulfillment of the requirements of the technical specification for the control system with a given probability.

The development of software ends with the synthesis of control algorithms based on a complete mathematical model of a closed control loop, including, among other things, statistical modeling (Fig.1).

Software development refers to the development of onboard programs that implement synthesized algorithms. After development of the stand complex the development of a closed control loop should be done, which includes real computers, drives, control panel. The developed stand complex is a symbiosis of hardware and software, which has versatility and allows quite simply reconfigure it for any aircraft with its aerodynamics, traction and inertial characteristics, control wiring, steering system and other features. When conducting mathematical modeling blocks of deterministic and statistical modeling are provided.

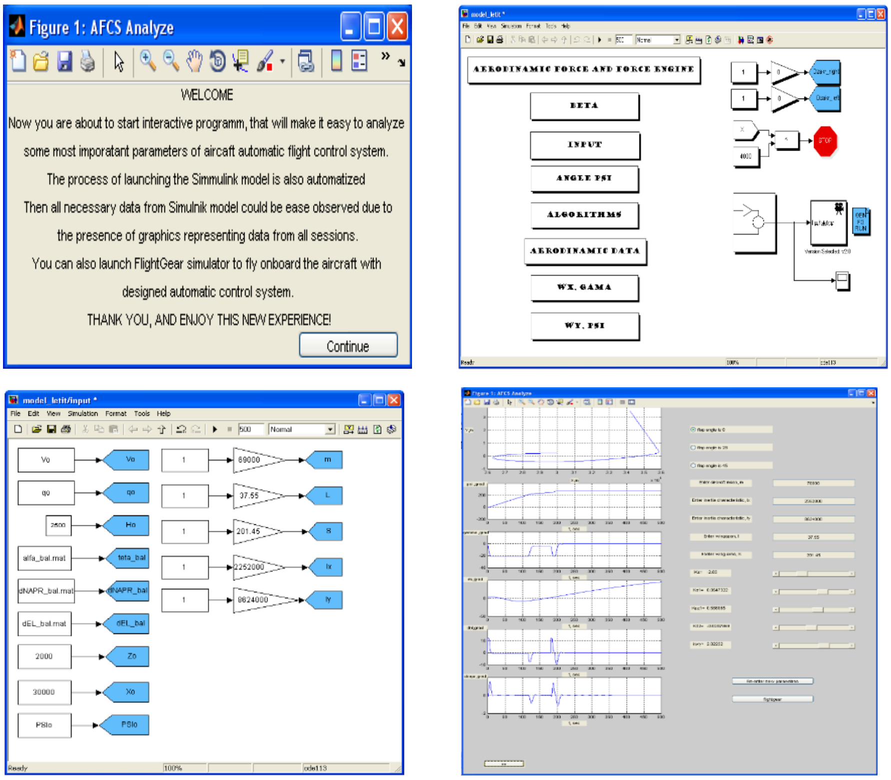

Fig. 1. Development of the program for ANFCS development and analyzing.

The block of aerodynamic characteristics includes numerical data on the components of these characteristics, obtained from the aircraft designer, interpolation program in two, three variables, mass-director and combined trajectory control.

The outputs of the trajectory algorithms are signals that are transmitted to the control elements of the aircraft (elevator, ailerons, rudder, spoilers, stabilizer etc.) or directly to the drives.

The mathematical model includes a block for graphical presentation of results and a block for statistical processing of simulation results (Fig. 2), which makes it possible to estimate thread the system for compliance with the requirements of technical specification.

Mathematical modeling begins after the control object is verified. This procedure consists in comparing the obtained on the mathematical model and the balancing characteristics and transient processes specified by the Aircraft Designer as a reaction to the influence of the controls. Such a comparison makes it possible to identify errors in the assignment or software implementation of aerodynamic and thrust characteristics.

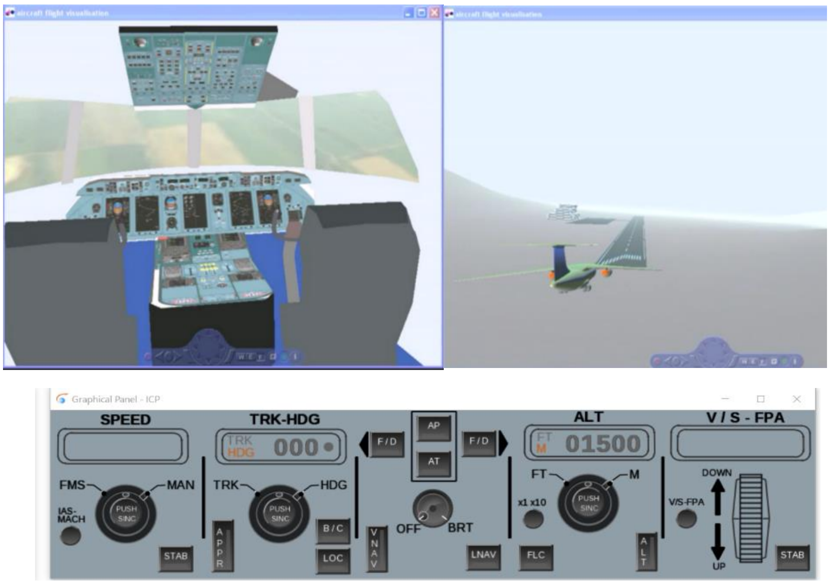

Fig.2 Visualization of simulation results

After verification of the object, a similar analysis is performed on the transient processes of the system. At the same time, analytical calculations are made of the energy capabilities of the facility, allowing to make the necessary adjustments, for example, to the method of climb, go-around or landing specified by the Aircraft Designer. After agreement with the General Designer of the characteristics of the object, mathematical modeling of automatic control modes begins.

The mathematical modeling technique has two stages - deterministic and statistical modeling. In deterministic modeling, the operation of the algorithm is analyzed for a certain set of initial conditions, alignments, weights, and disturbing influences. Since such a set has been worked out several times, it is included in the simulation program with a special block that provides an automatic selection of all conditions.

The proposed ANFCS software application can be hosted in a dual Command/Monitor architecture on four (4) independent ARINC-653 based Communication Processor Modules of the Multi-Function Displays (MFDs). Figure 3 provides ANFCS notional architecture. Each of the 4 ANFCS software application will be embedded in a dedicated partition of the MFD.

The ANFCS supports CAT IIIA ILS precision approaches. This capability can be enabled provided a simulator with a very accurate flight model can be used to demonstrate CAT IIIA performance prior to aircraft flight tests. The simulator must be the equivalent of an FAA Level D Full Flight Simulator. Activation of CAT IIIA is not priced at this time but can be priced upon agreement of roles and responsibilities and schedule.

The ANFCS should interface with the following systems:

Dual Duplex Fly-By Wire Control System: the ANFCS will produce control signals output to the Fly-By Wire Control System when in automatic control mode under the form of surface position (short- and long-term commands).

Multi-Function Displays

Triple Attitude and Heading Reference System

Triple Integrated Air Data System

Dual Radio Altimeter.

Dual Flight Management System

Dual VOR/ILS Receiver

Power Plant Automatic Control System: the ANFCS will produce thrust command output to the Power Plant Automatic Control System when in automatic thrust control mode.

Flight Data Recorder

On-Board Maintenance System (output of maintenance labels only)

It should be noted that the set of initial conditions for deterministic modeling includes extreme situations, for example, maximum weight in combination with centering. This also includes extreme conditions for speed and altitude, wind disturbances, delay of input information sensors etc.

Analysis based on the results of deterministic modeling allows to select the settings for the coefficients and make adjustments to the structure. This adjustment mainly boils down to the introduction of additional filters, additional damping circuits and circuits that guarantee compensation for engine failure.

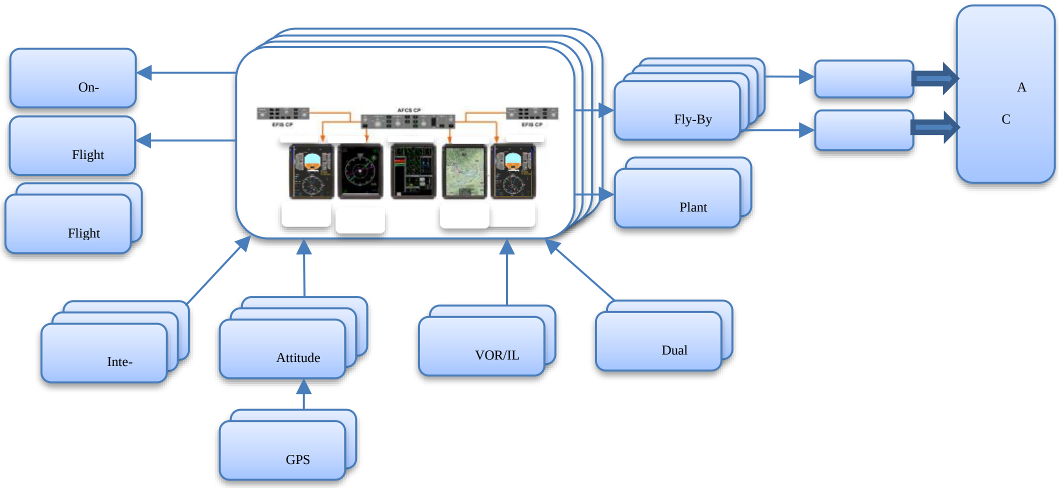

Fig. 3. ANFCS notional architecture

Statistical modeling, carried out at the final stage of the algorithms development, allows confirming the compliance to the technical specification with a given probability.

At the present stage of development of technology for designing products of aerospace technology, including ANFCS of aircraft, there is a tendency to transfer the main volume of works at the stage of ground development, including mathematical and semi-natural bench modeling. This is caused by economic reasons, since the cost of detecting and eliminating a defect at the stages of mathematical modeling, bench testing and flight tests is in a ratio of 1: 10: 100.

Modern aircraft are complex multifunctional objects. Together with the aircraft, starting from the stages of substantiation of requirements to it and design, its mathematical models (MM) should be created. They allow to move from solving individual problems to the study of the aircraft as a complex unified system. During the design and creation of the aircraft, as well as at all stages of its existence - during testing, operation, modernization, there is an increasing need to use MM. Gradually improving, aircraft MM will be used with it, helping to solve new problems [1].

Mathematical modeling ANFCS allows to substantiate tactical and technical requirements perform analysis of ANFCS modes at the stage of preliminary assessment of its operation, statistical assessment of landing approach by ICAO categories, support flight tests of ANFCS and its certification. The basis of mathematical modeling of ANFCS is a mathematical description of its operation. Currently, we can distinguish three groups of methods for mathematical description of the system: the method of transfer functions and closely related frequency characteristics; methods of state variables; structural and topological methods. The first and third methods have been widely used in the development of automatic control systems in engineering practice. To analyze the initial nonlinear system, it is advisable to use the methods of the second method. To develop the structure of the automatic control system, the necessary initial information is information about the properties of the aircraft as an object of control and clearly defined requirements for ANFCS. The initial data are [9]:

- purpose and tactical use of the aircraft;
- geometric data of the aircraft;
- mass-inertial characteristics of the aircraft;
- aerodynamic characteristics of the aircraft;

- kinematic and kinetic characteristics of the aircraft;
- operational characteristics of the aircraft;
- controllability characteristics;
- characteristics of the aircraft control wiring.

In addition, one of the features of the flight experiment is that during its implementation it is not always possible to carry out the necessary volume of experimental studies of the functioning of the object as a whole or of its individual systems and subsystems in real conditions. In these cases, the completeness and reliability of the experimental material obtained can be guaranteed if modeling methods are involved in the research. The widespread involvement of modeling methods in flight experiments allows obtaining results in a limited time from a minimum amount of experimental data.

One of the most important tasks of modeling is the study of their characteristics in the process of improving the tested systems and the identification of hidden properties. These properties include: optimal design and technological characteristics; actual values of the main parameters for any combination of external and internal factors; values of parameters that determine extreme test conditions, distribution reliability characteristics of systems under specified operating conditions, including failures.

Modeling, as a research method, is widely used not only in the preparation of technical proposals and the formation of technical requirements for the created sample, but also at the stages of sketch and technical design, when working out samples in closed systems in which they are supposed to be used, as well as at the stage of various types of full-scale tests that determine the characteristics of objects, their maturity and the possibility of moving from this stage of testing to the next one or serving as the basis for transferring objects to the serial production.

Modeling methods are usually used to solve the following main range of problems:

- substantiation of technical requirements for the created object and its individual parts;
- comparative assessment of the effectiveness of existing samples and their parts, similar to those under development;
- the choice of rational technical solutions for the construction of the created object, its systems and subsystems and verification of the compliance of the obtained characteristics with those specified at the stage both design development and testing;
- development of systems, subsystems, blocks and their elements, specification of technical solutions and requirements for objects in the process of their creation;
- selection and development of algorithms for the functioning of objects in real conditions of use; - preliminary assessment of the expected efficiency of the object being created;
- development of the object as a whole before carrying out field tests;
- substantiation of programs and methods for conducting various types of tests of an object, its systems, subsystems, blocks and elements;

- solving problems related to the ergonomic support of both the functioning of the object and its testing;

- obtaining characteristics that cannot be determined (due to possible economic, technical, organizational and other types of restrictions) in field tests, as well as statistical characteristics necessary to assess the tested object;

- determination of the conformity of the characteristics of the object to the specified requirements and control verification of these characteristics, taking into account field tests;

- evaluation of the efficiency of the object in the entire range of real conditions of its use, etc.

When solving the listed problems, mathematical modeling is used when a sufficiently reliable mathematical description of the modeled process is known. Semi-natural modeling is used to evaluate hardware solutions, ergonomic evaluation and during the development of samples to clarify technical solutions, obtain objective assessments for making decisions on conducting field tests.

In the process of experimental development of the system its "reliability" grows. This dynamic growth is described by some mathematical dependencies, the main of which is exponential [13]:

$$R_i\,(t_i) = a_i - (a_i - R_{oi})exp\{-\theta_i\,,t_i\},$$

where i index denotes the development stage;

t_i - development time at this stage;

R_{oi} - the initial reliability value for this stage;

θ_i - intensity of detection and, consequently, elimination of defects at this stage;

a_i - the limiting value of reliability for this stage, determined by the completeness of the simulation at this stage of the operating conditions of the system.

The justification for the exponential model is the fact that the increase in reliability is proportional to the detected unreliability, i.e [13].

$$\dot{R} = \theta\ (a - R),$$

The study of the growth dynamics of the reliability of a wide variety of aerospace systems in the process of their experimental development makes it possible to reveal the following regularities [13]:

- the intensity of defect detection decreases with the transition to the next stages, i.e.

$$\theta_i\text{-}1 > \theta_i,$$

- the limiting value increases with the transition to the next level, i.e.

$$a_{i-1} < a_i,$$

Analysis of foreign experience in the development of aviation equipment shows that flight tests, which play an important role in domestic practice to establish compliance of the main characteristics of an aircraft with airworthiness standards, abroad have a significantly lower, mainly demonstration value, since up to 80% of all problems arising in the development of appropriate systems are solved on the ground.

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