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MODERN TRENDS OF AIRCRAFT FLY-BY-WIRE SYSTEMS

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Specifics of civil aviation modern transport aircraft fly-by-wire control systems are described. A comparison of the systems-level hardware and software, expressed through modes of guidance, provision of aircraft Airbus A-320, Boeing B-777, Tupolev Tu-214, Sukhoi Superjet SSJ-100 are carried out. The possibility of transition from mechanical control wiring to control through fly-by-wire system in the backup channel is shown.

Keywords: *fly-by-wire control system; the control law; the control mode*

Introduction

The first serial transport aircraft which is used fly-by-wire, within the modern understanding of the term, with digital technology control surfaces steering was aircraft of Airbus Company A-320 (first flight in February 22, 1987)

Another significant event in fly-by-wire system evolution of transport aircraft was the building by Boeing, the main rival Airbus, longrange B-777 aircraft, which was different from the proposed A-320 fly-by-wire control system architecture.

On the territory of the Soviet Union and the CIS work in this area led to the creation of passenger aircraft of Tupolev bureau: Tu-204, Tu-214, Tu-334, Antonov bureau An-148, An-158 and Sukhoi Superjet 100 .

Thus, at this stage of fly-by-wire in civil transport aircraft observed several ideologies to build a control system:

- Airbus company ideology, for the first time there is provided an airplane A-320 and later developed into A-330/340 and A-380;
- Boeing company ideology, implemented on aircraft B-777 and B-787;
- Ideology implemented on aircraft Tupolev and Antonov Companies;
- Sukhoi company ideology applied in Superjet 100 aircraft, which distinguish separately.

The implementation of each approach has advantages and disadvantages.

Analysis of studies and publications

The aviation community attends on Airbus and Boeing [5, 6, 7] fly-by-wire ideologies comparing. At the same time very little attention is paid to this issue in the domestic bureaus aircraft and, especially, with Western aircraft comparison. It's connected with small park of national aircraft, although recently there has been increasing interest in the aircraft Superjet 100 and An-148 as the closest competitors in segments of regional passenger in the CIS.

The aim of work is to examine in particular aircraft Airbus A-320, Boeing B-777, Tupolev Tu-214 and Sukhoi Superjet 100 fly-by-wire system architecture.

The focus is on comparison of features of these aircraft fly-by-wire work in normal and backup modes.

Modern fly-by-wire concept

For modern fly-by-wire, except main-task of the aircraft control, is characteristic of additional requirements relating to the provision of [9]:

- The necessary stability and control characteristics of the airplane;
- Maximum efficiency controllability of the aircraft at all flight conditions in its operating range;

- Preventing the release of the aircraft beyond the range of flight envelope.

Airbus manufacturer uses for aircraft protection regimes which does not allow pilots to leave flight envelop (only in alternative law) [9].

Another algorithm was chosen by Boeing: a plane B-777 pilots are able to overcome limitations that creates fly-by-wire system on control leavers [8].

Summary of aircraft fly-by-wire systems that are discussed in this paper are given in the table.

Airbus A-320 fly-by-wire system

Airbus A-320fly-by-wire system is double-redundant digital-to-analog system with additional, backup and mechanical control channels [8].

The main components of system are next digital computers and control surfaces:

1. Digital computers:

- Two Elevator and Aileron Computers (ELAC);
- Three Spoiler and Elevator Computers (SEC);
- Two Flight Augmentation Computers (FAC);
- Two Flight Control Data Concentrator (SFCC).

2. Controls in the cockpit:

- Side stick;
- Flaps control;
- Spoilers control;
- thrust lever;
- Pedals;
- Pitch trim wheel.

Computers ELAC, SEC and SFCC together constitute Flight Control Computer (FCC).

In addition, the system has two computers to analyze information on the flight and all onboard systems, as well as to display this information on Flight Management and Guidance System (FMGS).

Formation of the command signal in fly-by-wire system is shown in Fig. 1. The solid line is electrical digital signal, dash-dotted line is electric analog signal and dashed line is the mechanical signal. Command signal (Fig. 1) is formed by the position of the control levers 1 in the cockpit estimation [5, 8].

Command signal on two mutually independent channels «Command channel» and «Monitor channel» via digital ARINC 615 bus is transmitted to the FCC *2* where they are compared, and subject to analysis under the flight envelope.

“Command channel” has priority in control signals transmitting in Normal mode [8].

After the FCC digital signal transmitted over a digital bus to the ARINC 615 digital-to-analog converter where it is converted into an analog signal and in a modified form goes to the Power Control Unit (PCU) *3*, which in turn moves the control surface *4*.

Backup control circuit consists of a ruder, which has a mechanical connection with the pedals and adjustable stabilizer, which is also mechanically connected to controls in the cockpit.

Scheme of the two channels is used, be to identify faults through comparing baseline data with each other.

To control the airplane use one of the following control law [9]:

- Normal Law. When in this mode, control plane full compliance with the operational flight envelope range and automatically controlled in three axes by FCC commands.
- Alternate Law. Replicate Normal Law, except for automatic control of the position of the aircraft.
- Direct Law. Control mode, in which the transfer is done directly from control levers to appropriate hydraulic actuator. This signal passes FCC.

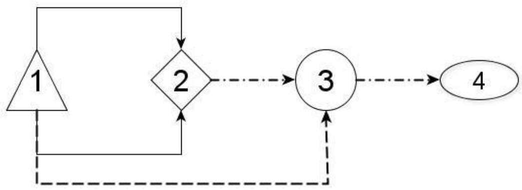

Fig.1. A-320 system schematic diagram
1 - control levers; 2 - FCC; 3 - PCU;
4 - control surfaces.

Aircraft fly-by-wire features

Parameters	Airbus A-320	Boeing B-777	Tupolev Tu-214	Sukhoi SSJ-100
Number of computers	7	7	6	7
Type of computer	All digital	3 digital, 4 analogue	3 digital, 3 analogue	All digital
System redundancy	Rudder and stabilizer mechanical backup	Spoilers and stabilizer mechanical backup	Total mechanical backup	There is no mechanical backup. Only AFDX
Cockpit control levers	Standard levers and side stick	Standard levers and column wheel	Standard levers and mini column wheel	Standard levers and side stick
Type of data acquisition and processing system	ARINC 615	ARINC 629	PU-56 MN	AFDX
Channel capacity	Up to 1Mbit/sec	Up to 10 Mbit/sec	Up to 128 Kbit/sec	Up to 100 Mbit/sec

Boeing B-777 fly-by-wire system

Boeing B-777 fly-by-wire system has three times redundant on a digital-to-analog computer system with an additional backup mechanical control channel (Fig. 2).

The plane fly-by-wire system contains the following components:

1) Position Transducers (PT) is position sensors that determine the position of control levers and create analog electrical signal proportional to the levers deflection;

2) Actuating Computer Electronic (ACE) that controls actuators. The aircraft B-777 has four ACE;

3) Primary Flight Computer (PFC) is responsible for processing and analyzing flight data create command signals for controlling the movement of surfaces and transfer the data to the ACE through the ARINC data bus 629. The aircraft has three PFC, each of that consists of three mutually independent channels of the signal: «command lane», «standby lane» and «monitor lane» [4].

4) Power control unit (PCU) is a mechanism that converts the analog electrical signal into mechanical movement of control surface. Controls levers in the cockpit are control column, pedals and spoilers controls and pitch trim wheel.

Controls *1* in cockpit mechanically connected to sensors position *2*, which form an analog electrical signal proportional to the control levers deflection. Then the command signal is sent to ACE *3* and through a digital bus exchange ARINC 629 falls into three PFC *4*, where it is processed and analyzed. The signals of the three PFC compared with each other for detecting differences that could indicate a fault in order to form the final command signal returns to the ARINC 629 bus and then goes to ACE. The ACE transform digital signal into analog and then it will be sent to PCU *5* [8, 9] and controls the movement of control surfaces *6*.

The PFC use similar to Airbus structure, but it is used not two, but three of independent channels of signals transmission, "command lane», «standby lane», «monitor lane». This structure is used to improve the reliability of the system and to control its operation by comparing data from all channels together.

A characteristic feature of the aircraft fly-by-wire is the presence of back drive actuator *8* that while the autopilot moves the controls, allowing pilots to visually evaluate the automated systems work [8]. This system is active by Autopilot Flight Director Computer (AFDC) *7*.

Backup a mechanical circuit consists of spoiler panels number 4 and number 11, which mechanically connected to a control wheel, and adjustable stabilizer, which is also mechanically connected to controls in the cockpit.

The aircraft can be operated in one of three modes:

- Normal control. The aircraft will be controlled within flight envelope and only in this mode it is possible to use an autopilot;
- Secondary control. By means of direct transferring of the analog control signal from the position sensor to a control surface;
- Direct control. It's coincides with the preceding mode except of yaw damper [8].

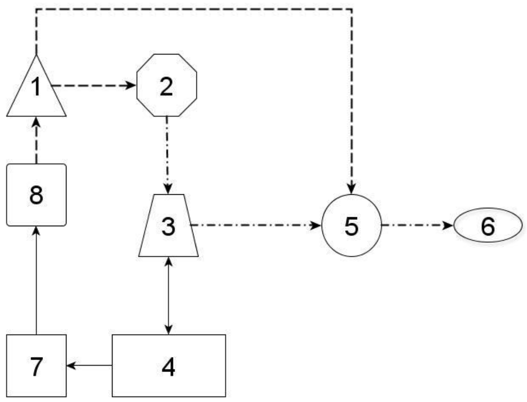

Fig.2. B-777 system schematic diagram:
1 - control levers; 2 - PT; 3 - ACE;
4 – PFC; 5 - PCU; 6 - control surfaces;
7 – AFDC; 8 - back drive actuator

Tupolev Tu-214 fly-by-wire system

Tu-214 has three times redundant digital-to-analog system in which information and backup sensors circuit is analog and computer main circuit that is digital [1].

Fly-by-wire system or automatic control column system (ACCS) [1] consists of a main and backup units (Fig. 3). Main circuit forms a longitudinal and lateral channel.

Backup circuit is designed as three analog blocks.

Computers in the longitudinal and lateral channels via bus data transfer PU-56 MN get digital and analog signals from various aircraft systems and sensors.

Longitudinal and lateral computers of the primary and backup channels form analog control signal, which is formed by the controls *1* movement, information about the state of the system ACCS *2* and information systems for magnetic registration of flight parameters, which is transmitted via the bus data transmission PU-56 MN.

Steering and automatic control of the aircraft via roll, pitch under normal operation of the rudders control system (RCS) is carried out through the main fly-by-wire control circuit of RCS.

When the main electric circuit of RCS the control surface deviating through command signals from the main digital circuit ACCS, which then enter to the control units. These units, in turn, convert the digital signal into analog and then directing them to the executive mechanisms *3* that move control surface *4*.

In case of ACCS totally failure it is automatically transferring control to the mechanical channel of RCS.

Ruder and elevator are controlled through mechanical channel. It's impossible to use elevator control in case of fly-by-wire system failure so instead it will be spoilers used.

Mechanical linkage is cables and pulleys [1].

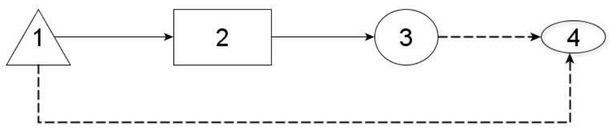

Fig.3. Tu-214 system schematic diagram:
1 - control levers; 2 - ACCS; 3 - hydraulic actuator; 4 - control surfaces.

Sukhoi SSJ-100 fly-by-wire system

The control system of the aircraft SSJ-100 (Fig. 4) has no mechanical backup *1*. Power management and control actuators (ACE) *2* and Motor and Actuator Control (MACE) *3* used to transmit a command signal between the primary flight computer PFCU *6* and hydraulic *4* [2, 3].

The control system has multiple redundant and cross-fade all of its components.

The use Avionics Full-Duplex Switched Ethernet (AFDX) [4] standard is a new step in the transfer of data and monitoring on board. The principle of this system is that it uses a server that is responsible for receiving, processing and transmitting data. It uses no ordinary copper wiring and fiber optic cable multi-channel bandwidth, which allows for communication of twenty four sensors only one cable and one server. This server is using bus can be connected to other servers.

As a result of the use of such technology has greatly increased the speed of data transmission as receiving, and data transfer. Rate of 100 Mbit/s.

During the flight, the aircraft may be operated by one of the three control laws [2]:

- Normal Law: while operating the aircraft is within the flight envelope, and can be automatically adjusted on three axes according to PFCU commands;
- Alternate Law: identical to the Normal Law with the exception of the automatic adjustment of the position of the aircraft;
- Direct Law: in this mode, there is a direct transmission of a control signal from the control dial to the appropriate hydraulic drive without using the FCC.

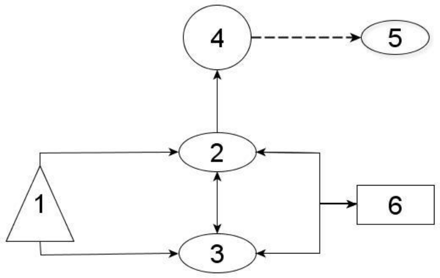

Fig.3. SSJ-100 system schematic diagram:
1 - control levers; 2 - ACE; 3 - MACE;
4 - PCU; 5 - control surfaces; 6 – PFCU.

Conclusions

Current trends of fly-by-wire systems for civil transport aircraft development eliminate the mechanical backup control wiring channel, and this, in turn, reduces the weight of the structure.

Also use multiredundant in an emergency can extend the range of aircraft flight and reduce the loads on the flight crew.

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Keywords: Fly-by-wire control system; the control law; the control mode

С.С. Юцкевич[1], Н.М. Юдин[2] СОВРЕМЕННЫЕ ТЕНДЕНЦИИ РАЗВИТИЯ ЭЛЕКТРОДИСТАНЦИОНЫХ СИСТЕМ УПРАВЛЕНИЕ САМОЛЕТАМИ

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Описаны особенности работы электродистанционной систем управления современных транспортных самолетов гражданской авиации. Проведено сравнение функционирования систем на уровне аппаратного и программного, выраженного через режимы управления, обеспечений самолетов Airbus A-320, Boeing B-777, Туполев Ту-214, Sukhoi Superjet SSJ-100. Показана возможность перехода от механической проводки управления к управлению через электродистанционную систему управления в резервном канале.

Ключевые слова: закон управления; режим управления; электродистанционная система управления

[1]С.С. Юцкевич, [2]М.М. Юдін.СУЧАСНІ ТЕНДЕНЦІЇ РОЗВИТКУ ЕЛКТРОДИСТАНЦІЙНИХ СИСТЕМ УПРАВЛІННЯ ЛІТАКІВ

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Описано особливості роботи електродистанційних систем управління сучасних транспортних літаків цивільної авіації. Проведено порівняння функціонування систем на рівні апаратного та програмного, вираженого через режими управління, забезпечень літаків Airbus A-320, Boeing B-777, Туполев Ту-214, Sukhoi Superjet SSJ-100. Показана можливість переходу від механічної проводки управління до управління через електродистанційну систему керування у резервному каналі.

Ключевые слова: закон керування, електродистанційна система керування, режим керування