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THE RECONFIGURABLE FLIGHT CONTROL SYSTEM FOR RECOVERING STABILITY AND CONTROLLABILITY OF THE AIRPLANE IN SPECIAL FLIGHT SITUATIONS

In this paper is given comparative analysis of the statistics adverse flight conditions in flight. Possibility of application of system methods parametric and structural reconfiguration in order to prevent the current flight situation in catastrophic is examined. In this paper, reconfigurable (active) flight control system for recovering stability and controllability of the aircraft when an unexpected problem (such as faults or failures to the actuators/sensors or structural damage) occurs during a flight is proposed.

Key words: *aircraft; reconfiguration; flight control system; loss of control in flight; controllability; special flight situation.*

Introduction. Damage to, or loss of, aerodynamic or stability/control surfaces of transport aircraft can pose serious implications for continued flight to a safe landing. While such events are not very common, occurrences involving significant damage often result in large numbers of fatalities. Some recent events include [1]:

– 1979 – DC-10 Engine separation and resulting asymmetric slat condition, 272 Fatalities [2];

– 1985 – B747 Vertical tail loss, 520 Fatalities [3];

– 1992 – B747 Multiple engine separation and resulting wing damage, 51 Fatalities [4];

– 2001 – A300 Vertical tail loss, 265 Fatalities[5];

– 2003 – A300 Wing damage (missile strike), safe landing, no casualties, hull loss [6];

– 2005 – A310 Rudder loss, safe landing, minor casualty [7].

Aircraft performance characteristics undergo significant changes during the long-term operation. More significant aerodynamic changes occur while the sudden damage of external contour of the aircraft due to collision with its surface at high speeds, mechanical, biological, electrical or other foreign objects. The danger of such damages is that they are random in nature and their occurrence cannot be foreseen. The result of these collisions, depending on the speed and mass of the object can be as minor dents, and the catastrophic destruction of the aircraft structure or its systems. Unfortunately, existing methods of monitoring and diagnosis [8], [9] does not allow to register changes of the external contour of the aircraft itself in flight. At the same time, the availability of complete and accurate information about time, place and degree of damage of the aircraft external contour in flight would allow to objectively evaluate the development of an emergency situation and take necessary action to prevent its development by reorganizing the aircraft flight control or change the aircraft flight mode.

Analysis of the results of domestic research and publications shows that in the CIS countries, the topic is not sufficiently developed. Study of foreign sources indicate that problem of changes of aerodynamics aircraft wing in flight involved in such companies, agencies and management as Boeing, Airbus, Insight SRI Ltd, the Federal Aviation Administration United States, the European Aviation Safety Agency, Johns Hopkins University in U.S. and others in studies of all these companies and agencies, one of the central places occupied research of damage in a collision with foreign objects and changes of aerodynamics aircraft wing in flight. But even in these countries have problems, do not close these studies because there are a number of unresolved issues Known Boeing patent GB24355519A “Capacitive sensor for sensing structural damage” [10] also does not solve the problem.

While in some of the cases noted above, the damage caused immediate, unrecoverable loss of control, others resulted in stabilized and controlled (albeit limited) flight capability for at least some duration following the initial event. Enhanced control capability in such situations can increase the possibility of maintaining controlled flight to a safe landing from an otherwise ultimately non-recoverable situation. The Integrated Resilient Aircraft Control (IRAC) Project of the NASA Aviation Safety Program is conducting research towards the development of flight control capability to recover and safely land an aircraft following an adverse, loss-of-control event or condition, including those due to aircraft damage. IRAC research activities are considering many potential aspects of aircraft control, encompassing integration of aerodynamics, structures, propulsion, and flight planning/guidance issues [11].

Purpose of article. The reconfigurable (active) flight control system for recovering controllability and stability of the aircraft when an unexpected problem (such as faults or failures to the actuators/sensors or structural damage) occurs during a flight is considered.

Main part. At first let us clarify the terminological distinction between a fault and a failure [12-17]:

– fault is an undesired change in a system parameter that degrades performance: a fault may not represent a component failure;

– failure is a catastrophic or complete breakdown of a component or function (to be contrasted with a fault which may be a tolerable malfunction.

A reconfigured flight control system is required to perform failure detection, identification, and accommodation following a battle damage and/or failure to a critical control surface. To implement a failure accommodation strategy, a variety of control surfaces (speed brakes, wing flaps, differential dihedral canards, spoilers, etc.) and thrust mechanisms (differential thrust, thrust vectoring) can be used. This means, most control surfaces will have triple redundancy. In terms of the control surface itself, there exist secondary control surfaces that can be used in an emergency or in an unconventional way to achieve the same effect as the primary control surface. In large passenger transport aircraft for example, the spoilers which are typically deployed to reduce speed, can also be used differentially to create roll which normally is achieved by using ailerons; also engines can be used differentially to create yaw, which is typically achieved by using the rudder; and finally the horizontal stabilizer (Fig. 1, 2) which is normally used to set the angle of attack, can also replace elevators for pitch movement [12].

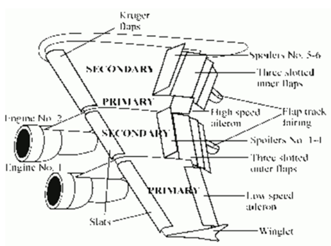

Fig. 1. Large transport aircraft: typical control surfaces

The proposed DS-IAFTCS system is shown in Fig. 3. It consists of the parametric and structural reconfiguration, identification current condition, reserve algorithm control surface actuator, diagnostic system. In the conditions of considerable uncertainty arising from the sudden failures or faults elements of automatic control system, damages the external contour of the aircraft, changes in the external environment, decision of choosing the tactics and strategies of extension the flight is possible with crew or probabilistic models. However, in both cases, traditional approaches are characteristic unacceptably high decision-making time, which may lead to undesirable shift the current flight situation to emergency of flight, and in some cases even a catastrophic situation. Based on the above, scientific task is to restore the aircraft controllability and stability in the unexpected flight conditions based on the reconfiguration methods and intelligent technologies.

Fig. 2. SU-34 flight control surfaces scheme: *1* – two consoles canards; *2* – two sections rotary wing socks; *3* – two sections flaperons; *4* – two sections rudder; 5 – two consoles horizontal tail

The failures/faults elements of automatic control system, assessment of the dangerousness of the refusals and operational decision-making by the method of further flight control are very essential tasks.

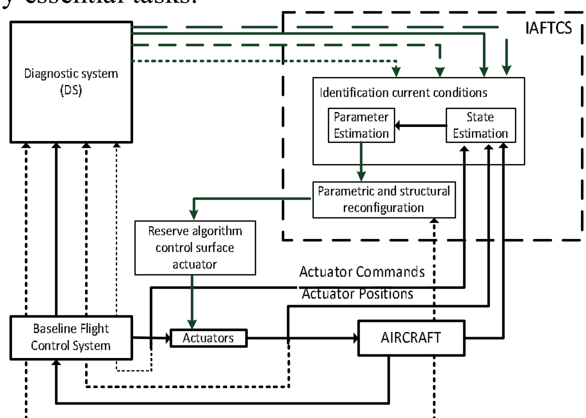

Fig. 3. Structure of the DS- AFTCS (diagnostic system- intelligent active fault tolerant control system)

Depending on the specific situation in flight offered the following algorithms:

– parametric reconfiguration is to change the gains of the regulator;

– structural reconfiguration is to the redistribution of control on a serviceable actuators or control surfaces;

–reconfiguration flight program and its criteria;

– changing purpose of the flight;

– bailout.

On Fig. 4 the simplified structure chart of reconfigured flight control system is provided. Let's suppose that movement of the aircraft is described by a differential equation:

$$\dot{x} = F(x, a, q, u, t) + \xi_x$$

where: x – n-dimensional state vector of object defined in space X, a – r–dimensional vector of parameters accepting values from a A-set and defined by properties of the environment; q – vector of integrity of external contour of the airplane in the flight, considering influence of standard damages on aerodynamic properties of the airplane, and the m-dimensional vector of controlling influences created by reconfigured control system and belonging to the set U; t – the current time belonging to a segment $[t_0, t_f]$ on which unexpected situation in flight is defined; ξ_x – n-dimensional vector of uncontrollable perturbations (noise, measurement noises etc.); F – n- the-dimensional vector function of the specified arguments known, according to the assumption, on the basis of theoretical and pilot studies.

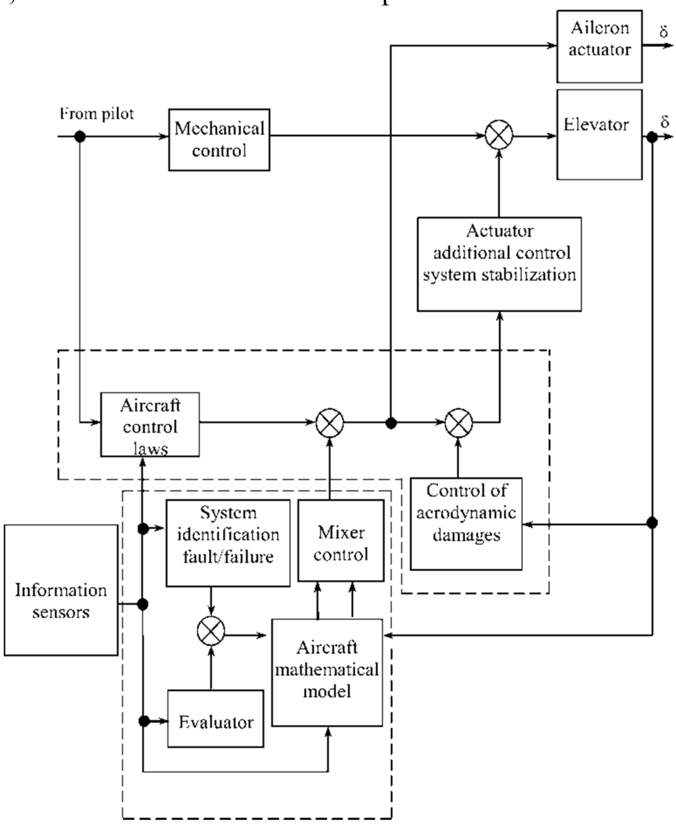

Fig. 4. Reconfigured flight control system

Observation over movement of the airplane is carried out by means of a complex of the sensors measuring components of a status of object and control, and also integrity of its external contour in flight:

$$z = h(x, a, q, u, t) + \xi_z$$

where: z – l-dimensional vector of observations in space Z, ξ_z – l-dimensional vector of the additive noises distorting indications of sensors; h – l-dimensional vector function of the specified arguments known on the basis of theoretical and pilot studies of sensors of information. Results of measurements arrive in reconfigured management system where are used for determination of response characteristics of the airplane and optimum (suboptimal) estimation of its status.

The following stage of functioning of the offered reconfigured management system is process of parametric identification of response characteristics of the airplane in the conditions of unexpected situation origin in flight which in a general view is described by the operator:

$$\hat{a} = H(z, \overline{a}, \overline{q}, t)$$

Thus, in considered structure it is necessary that identification is carried out in some neighborhood of program value of a vector of parameters. In the course of identification the reconfigured management system considers the factors influencing dynamic properties of the airplane (unfavorable external factors and degrading internal processes).

On the basis of signals of sensors and estimates of parameters of object it is carried out optimum (or suboptimal) estimation of a status of the object, allowing substantially to increase accuracy of information on a vector:

$$\hat{x} = N(z, \hat{a}, \hat{q}, t)$$

where: $\hat{x}$ - n-dimensional vector of an assessment of parameters of a vector x.

Total procedure of reconfigured management system is optimization of controlling impacts on airplane executive bodies on a basis, set the purposes of control and criteria of optimization for preventing of development of unexpected situation in flight. The operator describing formation of a vector of optimum controls, looks like:

$$u = \Omega(z, \hat{a}, \hat{q}, t)$$

The optimality criterions created beforehand, define a measure, leaning on which control algorithm selects an optimum way of achievement by object of the given status. The structure of the operator depends on a method of the work of the purpose of the control, minimized criteria and a choice of a method of the optimization, to unexpected situation had time development in flight, and also an aerodynamic status of external contour of the airplane.

Conclusions. The reconfigurable (active) flight control system is a main element of the strategy change the configuration of the control actions. It can take the initial information about the existing laws the aircraft flight control and redistribute the initial commands intact control surfaces in terms of emergency situations. In addition, important elements of reconfiguration flight control system is element of identification fault/failure.

The main element of the strategy change the configuration of the control actions is a mixer control. It can take the initial information about the existing laws the aircraft flight control and redistribute the initial commands intact control surfaces in terms of emergency situations. In addition, important elements of reconfiguration flight control system is element of identification fault/failure. Thus, the proposed concept to recovering the survivability of aircraft in terms of fault/failure control surfaces or flight control system will maintain acceptable flight and technical characteristics and safe implementation flight task.

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СИСТЕМА РЕКОНФІГУРАЦІЇ КЕРУВАННЯ ПОЛЬОТОМ ДЛЯ ВІДНОВЛЕННЯ КЕРОВАНОСТІ ТА СТІЙКОСТІ ПОВІТРЯНОГО КОРАБЛЯ В УМОВАХ ВИНИКНЕННЯ ОСОБЛИВИХ СИТУАЦІЙ У ПОЛЬОТІ

Складність вирішення проблеми забезпечення заданого рівня безпеки польотів безперервно зростає у зв'язку з підвищенням інтенсивності використання авіаційної техніки, що крім відомих впливів, веде до значного збільшення імовірності зіткнення у польоті з механічними, біологічними та електричними формуваннями, а також розширенням кола виконуваних нею функціональних завдань (розвитком стратегії використання авіації у локальних війнах, що змусило провідні держави світу негайно зайнятися дослідженнями, спрямованими на підвищення рівня живучості повітряних кораблів (ПК)). Порівняльний аналіз статистичних даних ICAO показав, що 35% авіаційних подій спричинено пошкодженнями зовнішніх обводів ПК і керувальних органів, відмовами та пошкодженнями елементів пілотажно-навігаційного комплексу, причому головним чином відмовами їх приводів. Варто відзначити надзвичайно високу швидкоплинність розвитку аварійної ситуації, що в свою чергу потребує миттєвого втручання в ситуацію для вжиття необхідних керувальних дій щодо запобігання її розвитку або переростання у катастрофічну. У статті пропонується концепція системи автоматичного керування із функціями реконфігурації, що забезпечує відновлення керованості та стійкості ПК в умовах виникнення особливих ситуацій за рахунок реконфігурації керувальних сигналів, структури системи, конфігурації ПК або цільових завдань, тобто збереження безпечного режиму польоту, а також наведено її функціональну схему. Пропонується інтелектуальна система автоматичного діагностування, яка забезпечує своєчасну реєстрацію ушкоджень зовнішнього ободу ПК з підвищеною достовірністю та точністю фіксації місця, ступеня та моменту раптового пошкодження зовнішнього обводу ПК у польоті. Рішення поставленої задачі досягається тим, що у внутрішню порожнину елементів конструкції ПК за матричною схемою вмонтовано «n» датчиків лінійного прискорення та «m» датчиків кутової швидкості. Сигнал з кожного окремого датчика надходить до класифікатора типових пошкоджень, який розпізнає отримане пошкодження зовнішнього обводу ПК у польоті, якщо воно раптово виникло, згідно з «базою даних» класифікатора.

Ключові слова: повітряний корабель; реконфігурація керування; система керування польотом; керованість; стійкість, особлива ситуація у польоті.