UDC 629.735.015.7.2:656.7.08 (045)

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# THE ACTIVE FAULT TOLERANT CONTROL SYSTEM FOR PROCEEDING CONTROLLABILITY AND STABILITY AIRPLANE UNDER ADVERSE FLIGHT CONDITIONS

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***Abstract—****The article gives* 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. *The active fault tolerant control system is given in the article.*

**Index Terms**—Airplane; loss-of-control; control system; adverse flight conditions; stability and controllability; reconfiguration; active fault tolerant control system; actuator; sensor; failure.

## I. 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 can not 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.

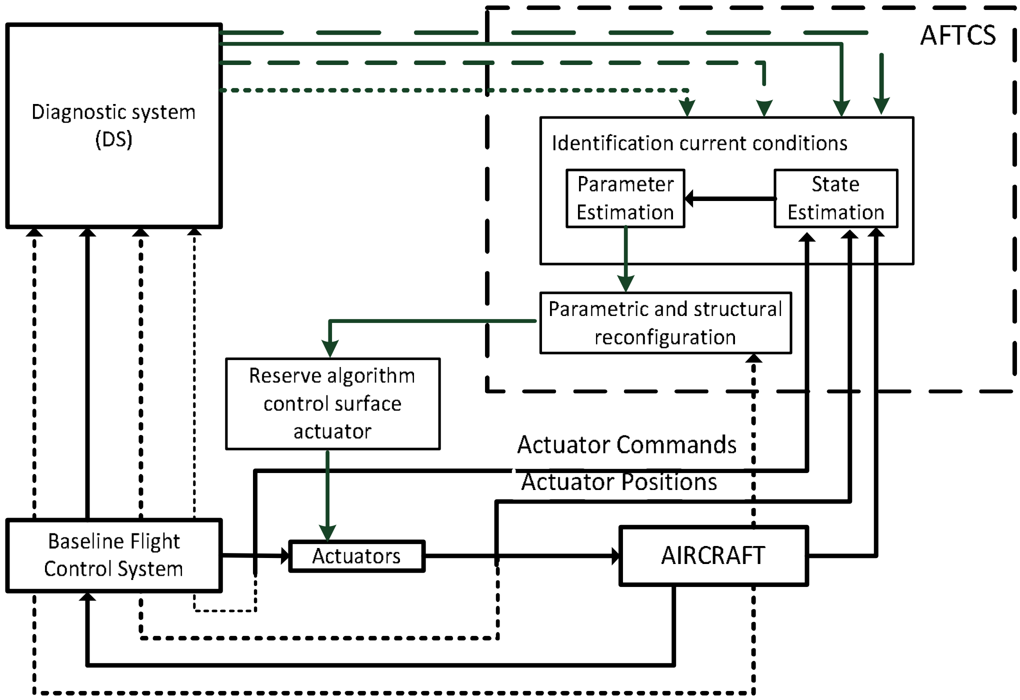
Analysis of the results of domestic research and publications shows that in the CIS countries, the topic is not sufficiently developed. Study of foreign sources indicate that problem of changes of aerodynamics aircraft wing in flight involved in such companies, agencies and management as Boeing, Airbus, 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.

In the literature, most of the motivation and research work in fault tolerant control involves solving problems encountered in safety critical systems such as aircraft. To design active fault tolerant control systems (AFTCS), one of the important issues to consider is whether to recover controllability of aircraft under adverse flight conditions. AFTCS is a complex combination of three major research fields, fault detection and isolation (FDI), robust control, and reconfigurable control [11]. Patton [12] also discussed the relationship between these fields of research. For a typical AFTCS scheme, when a fault/failure occurs either in an actuator or sensor, the FDI scheme will detect and locate the source of the fault. The reconfigurable controller will try to adapt to the fault, therefore providing controllability and stability. Both the FDI and reconfigurable controller need to be robust against uncertainty and disturbance [11]. In article [13] is given a good bibliographical review of reconfigurable fault tolerant control systems. The paper also proposes a classification of reconfiguration methods which is based on a few categories (the mathematical tools used, the design approach used, the way of achieving reconfiguration, reconfiguration mechanisms, control structures e.t.c). It also provides a bibliographical classification based on the design approaches and the different applications, discussing open problems and current research topics in AFTCS.

Development of methods and models of reconfiguration of controlling influences aboard the airplane in the conditions of origin special situations in flight operation [14] is devoted. For reconfiguration of controlling influences in case of failures of drives and governing bodies two approaches [14] are used: parametric and structural. Parametric change of feedback factors of the executive mechanisms taking into account a technical status of the airplane, for improving of efficiency of their functioning. Structural – control redistribution between operational governing bodies for recovery of acceptable characteristics of controllability and stability in the conditions of unexpected situations in flight. Patton [11], [12], classify FTC into 2 major groups: passive fault tolerant control systems (PFTCS) and active fault tolerant control systems (AFTCS). In passive fault tolerant control systems, the controller is designed to be robust against faults and uncertainty. Therefore when a faults occurs, the controller should be able to maintain stability of the system with an acceptable degradation in performance. PFTCS does not require FDI and does not require controller reconfiguration or adaptation.

## II. Main part

The proposed DS-AFTCS system is shown in Figure. It consists of the parametric and structural reconfiguration, identification current condition, reserve algorithm control surface actuator, diagnostic system.




Structure of the DS-AFTCS (diagnostic system-active fault tolerant control system

Let the control object is represented in space of states control in the form:

$$\dot{x} = \mathbf{A}x + \mathbf{B}u,\ x(t_0) = x_0,\ x \in R^n,\ u \in R^s,$$

where $x - n$ is dimensional state vector; $u - s$ is dimensional control vector.

Constant matrices (**A**, **B**) determine its dynamic properties.

In the case of the introduction of the state feedback control law is given by:

$$u = \mathbf{G}\sigma - \mathbf{K}x,\ x \in R^r,$$

where **G** is matrix by which independent (external) vector of input signals $v$ are pre-transformation; **K** is state matrix regulator in the feedback loop.

Write the equations of the system in the form of the Laplace transform, omitting for brevity, Laplace operator $p$:

$$(pI_n - \mathbf{A})x = \mathbf{B}u + x_0,$$

$$u = \mathbf{G}\sigma - \mathbf{K}x.$$

The change of the state vector $x$ of a closed linear system is the sum of a reaction to the nonzero initial conditions $x_0$ and input signals $\sigma$ [15]:

$$x = \mathbf{W}_x^0(p)x_0 + \mathbf{W}_x^\sigma(p)\sigma,$$

where $\mathbf{W}_x^0, \mathbf{W}_x^\sigma$ are transfer matrices of the initial conditions $x_0$ and input signals $\sigma$ to the vector of the system state. The connection of these transfer matrices with the structure of the system is determined by known operator equations:

$$\mathbf{W}_x^0(p) = (pI_n - \mathbf{A} + \mathbf{BK})^{-1}, \quad (1)$$

$$\mathbf{W}_x^\sigma(p) = (pI_n - \mathbf{A} + \mathbf{BK})^{-1}\mathbf{BG}. \quad (2)$$

Transfer matrices (1), (2) determine the reaction of plane to nonzero initial conditions and input signal.

Introduce the diagonal matrix $\mathbf{Z}$, characterizing the state of the elements of the automatic control system (ACS) (sensors, controllers, actuators, control surfaces). When all the elements of ACS are intact, the matrix $\mathbf{Z}$ is identity $\mathbf{Z} = I_s$. The failure of element of ACS is characterized by zeroing of $i$th component of matrix $\mathbf{Z} = \mathrm{diag}(1 \ldots 0_i \ldots 1)$.

Introduction of matrix $\mathbf{Z}$ is equivalent to zeroing $i$th component of the control vector, that is $\mathbf{u}_f = [\mathbf{u}_i \ldots 0_i \ldots \mathbf{u}_s]^{\mathrm{T}}$.

Object model with failure can be written as:

$$\dot{x}_f = \mathbf{A}x_f + \mathbf{B}\Delta u. \quad (3)$$

where $x - n$ is dimensional state vector with failure; $u - s$ is dimensional vector control with failure.

Due to (3) transfer matrices (1), (2) take the form:

$$\mathbf{W}_{xf}^0(p) = (pI_n - \mathbf{A} + \mathbf{BZK})^{-1},$$

$$\mathbf{W}_{xf}^\sigma(p) = (pI_n - \mathbf{A} + \mathbf{BK})^{-1}\mathbf{BZG}.$$

where $\mathbf{W}_{xf}^0$, $\mathbf{W}_{xf}^\sigma$ are transfer matrices of the initial conditions $x_0$ and input signals $\sigma$ to the vector of the system state in case of actuator failure.

To save the desired dynamic properties of an object, the following equalities must be met:

$$\mathbf{W}_{xf}^0(p) = \mathbf{W}_x^0(p), \quad (4)$$

$$\mathbf{W}_{xf}^\sigma(p) = \mathbf{W}_x^\sigma(p), \quad (5)$$

Conditions (4), (5) are the criteria of the reconfiguration, structural and parametric reconfiguration.

Conditions (4), (5) may be realized in one of two ways [15]:

1. The calculation of the new values of the matrices **G** and **K**, satisfying (4), (5).

2. Introduction of additional elements in the control system allows to provide the equality of (4), (5).

The first way involves a complete change of the gain control system, which is unacceptable for modern ACS. The second way is more simple to implement. It does not change the regular control system settings, and the task of maintaining the dynamic properties is achieved by introducing additional elements to the control system.

## III. CONCLUSIONS

The time interval over which the AFTCS has wrong information about the faults/failures need not be known. If the AFTCS eventually generates an accurate estimate of the failure parameters, the proposed approach will result in provided increased controllability and stability of airplane under adverse flight conditions. The proposed AFTCS can be readily extended to the case of nonlinear aircraft dynamics.

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Received 27 February 2014.

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**Д. О. Шевчук. Активна відмовостійка система для збереження керованості та стійкості літака в несприятливих умовах польоту**

Наведено порівняльний аналіз статистичних даних виникнення особливих ситуацій у польоті. Обґрунтовано можливість застосування системних методів параметричної та структурної реконфігурації керуючих поверхонь для запобігання переходу поточної польотної ситуації у катастрофічну. Представлено структурну схему активної відмовостійкої системи керування.

**Ключові слова:** літак; втрата керованості; система управління; несприятливі умови польоту; стійкість і керованість; активна відмовостійка система; привід; датчик; відмова.

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Освіта: Національний авіаційний університет, Київ, Україна (2003).
Напрям наукової діяльності: методи відновлення керованості літака в умовах виникнення особливих ситуацій у польоті.
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**Д. О. Шевчук. Активная отказоустойчивая система для сохранения управляемости и устойчивости самолета в неблагоприятных условиях полета**

Приведен сравнительный анализ статистических данных возникновения особых ситуаций в полете. Обоснована возможность применения системных методов параметрической и структурной реконфигурации управляющих поверхностей для предотвращения перехода сложившейся полетной ситуации в катастрофическую. Представлена структурная схема активной отказоустойчивой системы управления.

**Ключевые слова:** самолет; потеря управляемости; система управления; неблагоприятные условия полета; устойчивость и управляемость; активная отказоустойчивая система; привод; датчик; отказ.

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Образование: Национальный авиационный университет, Киев, Украина (2003).
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