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THERMAL FIELDS DIAGNOSTIC METHOD OF CHANGING AIRCRAFT AERODYNAMIC STATE IN FLIGHT

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Abstract—*A result of the research was the method of aerodynamic condition of the aircraft on the thermal fields. Based on the mathematical and natural experiments, regularities of formation of temperature gradients in the boundary layer of air that occurs when damage to the contours detected parameters that affect the behavior of the temperature gradient arising from damage, namely the speed and angle of attack of the aircraft, the shape of the profile wings, nature of damage, place of occurrence of damage relative to the outer contours.*

Index Terms—Aircraft; structural damage; reconfiguration; external contour, temperature gradient; thermal method; boundary layer; diagnostics.

I. INTRODUCTION

In the past ten years, 59% of the fatal airliner aircraft accidents were caused by loss-of-control in flight and another 33% by controlled flight into terrain [1]. The accident reports published by NTSB (National Transportation Safety Board) have revealed that most in-flight loss-of-control accidents were triggered by faults including subsystem/component failures, external hazards, and human errors [2]. With hindsight, it is easy to say that most of these accidents could have been prevented if the maintenance were performed better to avoid component failures, or if the aircraft had not entered the hazardous region, or if the flight crews had not made mistakes, but it is impossible to eliminate all the faults that may threaten flight safety.

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 [3]. Patton [4] 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 [3]. In article [5] 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 etc.). It also provides a bibliographical classification based on the design approaches and the different applications, discussing open problems and current research topics in AFTCS.

II. PROBLEM STATEMENT

Analysis of the factors causing damage to the external contour of the aircraft, as well as an analysis of accidents allows to distinguish three main groups of damages by reason of occurrence:

– collision with mechanical (radiosondes, balloons, transzondy and other means necessary to control the meteorological state of the atmosphere) or biological objects;

– electrostatic discharges and lightning;

– chemical processes occurring in the metal construction of aircraft as in contact with the surface of reactive substances and longer connected to the operating conditions of the aircraft (corrosion, aging and degradation of the metal, etc.).

By the time damage can be distinguished as a gradual or sudden. Gradual damage characterized by the presence of trends or patterns of change given the aerodynamic characteristics of the external contour of the aircraft at the time preceding the time of the fault. The cause of such damage is the effect of physical and chemical processes. Studying the laws of their development by means of predictive methods of diagnosis, we can predict their occurrence in the process of preparing the aircraft for operation, as well as for the technical inspection of the aircraft ground services at the airport or repair airlines.

Sudden damage characterized by an abrupt change in the value of one or more specified parameters. The change is caused by the action of physical or mechanical processes, the course of which is not controlled, to provide the appearance of such lesions is not possible. As the analysis of publication [6], a significant number of accidents was caused precisely by sudden structural damage to the aircraft. Therefore there is a need to develop methods of diagnosing the external contour of the aircraft in order to identify the date, place and degree of damage, as well as methods of preserving stability and control to prevent the development of an emergency in flight.

III. MAIN PART

During the flight, the aircraft interaction with the airflow occurs heating the outer casing, which can be described by the following expressions [6, 7]:

$$\operatorname{div} \rho_{\mathrm{T}} (k \cdot \operatorname{grad} T) = Q - \frac{\partial T}{\partial t}, \qquad (1)$$

$$\rho_{\mathrm{T}} = -k \cdot \operatorname{grad} T, \qquad (2)$$

$$\frac{\partial U}{\partial t} = \frac{\partial(\rho C T)}{\partial t} = \rho C \frac{\partial T}{\partial t}, \qquad (3)$$

where ρ_T is the density of thermal power; Q is the volumetric power density of outside sources of heat; U is the bulk density of the internal heat of the substance; k is the thermal conductivity of the material; T the temperature; C is the specific heat of the substance.

Expression (1) is fundamental equation of the thermal field; (2) is equation describing heat-conducting properties of matter; (3) an equation that describes the dynamic thermal properties of matter.

Substituting (2) and (3) in (1), we obtain the heat equation with respect to the temperature field:

$$\rho C \frac{\partial T}{\partial t} - \operatorname{div}(k \cdot \operatorname{grad} T) = Q. \qquad (4)$$

In case of damage to the outer covering of a typical aircraft, its aerodynamic characteristics change, that is accompanied by a temperature gradient plating:

$$\operatorname{grad} t = \lim |\Delta t / \Delta n|_{\Delta n \to 0} = \frac{dt}{dn},$$

where $\operatorname{grad} t$ is the vector directed along the normal (Δn) to isotherm surface towards the growth of the temperature and the many levels simultaneously derivative of the temperature in this area.

For the computer simulation program complex SolidWorks Flow Simulation is selected in the following profiles:

- airfoil An-148 at the root of the wing;
- airfoil P-III (15.5 %).

An-148 aircraft wing profile is supercritical (supercritical), with a sharp nose. For this wing flattened profile characterized by the use of properly folded back part, which gives a more even distribution of pressure along the chord profile and thus leads to a shift of the center of pressure back, and increases the critical Mach number by 10–15%.

Rectangular wing model with the following characteristics:

- the size of the model: 300 mm × 300 mm;
- extension: 1;
- material – D16T (2024-T3), inside – solid billet;
- parameters of a single injury: an elongated square with a side length of 50 mm, forming a hole in the front edge of the fragment profile perpendicular to the chord.

Turbulence options:

- turbulence intensity of 1%;
- the turbulent length 4.64×10^{-4} m.

For modeling parameters used International standard atmosphere for different heights according to GOST 4401–81.

In the simulation takes into account the following recommendations Support SolidWorks, are based knowledge engineering analysis SolidWorks Simulation Knowledge Base.

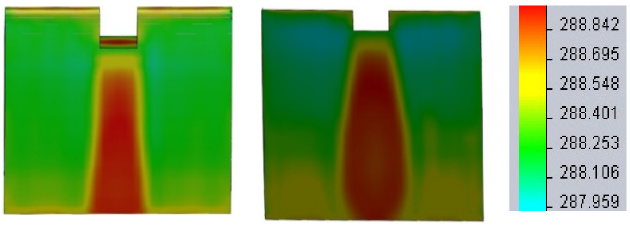
The impact velocity of the oncoming flow on the temperature gradient that occurs when damage rectangular shape.

Research of the oncoming flow velocity on temperature gradient was carried out under the following parameter values:

- speed: 40 m/s and 80 m/s, 120 m/s, 160 m/s, 200 m/s, 240 m/s;
- international standard atmosphere (ISA): ambient temperature: 288.2 K (15° C), atmospheric pressure 101 325 Pa (760 mm Hg. Art.) At an altitude of 0 meters above sea level;
- angle of attack $\alpha = 0°$.

The flow around a rectangular wing profile model An-148 and temperature distribution under these conditions are shown in Figs 1 – 4 [6, 7].

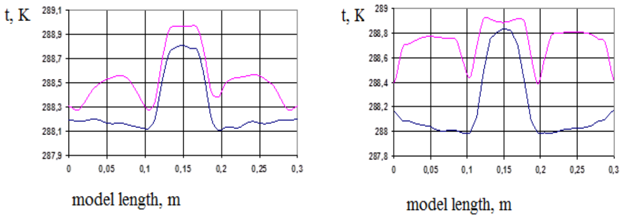
As can be seen from the analysis of Fig. 1, the flow around the damaged part of the local temperature profile in the boundary layer directly damage increases, i.e., there is a temperature gradient, which tends to spreading closer to the trailing edge of the model.



a b c

Fig. 1. The temperature gradient that occurs in the boundary layer for damage at the oncoming flow velocity of 40 m/s: (a) is the upper surface of the rectangular model wing profile-148; (b) is the lower plane of the rectangular model wing profile-148; (c) is the temperature scale in Kelvin

Let us analyze the temperature distribution along the upper and lower wing surfaces to distant 1/3 and 2/3 of the front edge of the model (Fig. 2).



a b

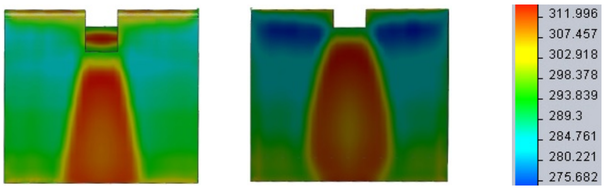
Fig. 2. The temperature distribution along: (a) is the upper boundary layer and (b) is the lower surfaces external contour model for oncoming flow velocity of 40 m/s at a distance from the front edge of the 1/3 chord (blue line) and the 2/3 chord (red line)

Data analysis graphs, shown in Fig. 2, leads to the conclusion that the maximum temperature difference observed in the distance from the leading edge to 1/3 chord and reaches 0.65 K on the upper surface of the model and 0.82 K on the lower plane. The local temperature difference approaches the damage will increase. At the distance from the leading edge 2/3 chord is also observed fever, but it is uneven distribution, especially on the lower plane of the model, and their difference is less than 0.5 K.

By increasing the speed of the oncoming flow, an increase in not only the local temperature difference between damaged and undamaged areas of the model, but also the area of the spreading of the temperature gradient (Figs 3 and 4). Thus, at a speed of 240 m/s maximum temperature difference on the distance from the leading edge to 1/3 chord is 35 K.

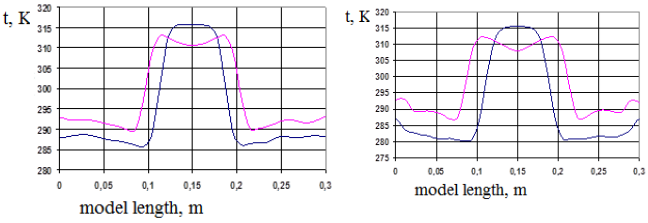
Hence, at a speed of 40 m/s local temperature difference on the distance from the front edge of the 1/3 chord higher than the distance from the leading edge 2/3 chord at 0.3 K along the upper surface and at 0.4 K along the bottom plane model. And at a speed of 240 m/s, these figures are 6.5 K and 10 K, respectively.

So, if you have the means to measure the temperature can detect temperature differences of damaged and undamaged areas of the outer contour, placing meters far from the leading edge of the lower 1/3 of the chord plane model or close to the site of injury at a speed of 40 m/s.



a b c

Fig. 3. The temperature gradient that occurs in the boundary layer for damage to the oncoming flow velocity at 240 m/s: (a) is the upper surface of the rectangular model wing profile-148; (b) is the lower plane of the rectangular model wing profile-148; (c) is the temperature scale in Kelvin



a b

Fig. 4. The temperature distribution along the (a) is the upper boundary layer and (b) is the lower surfaces external contour model for oncoming flow velocity of 240 m/s at a distance from the front edge of the 1/3 chord (blue line) and the 2/3 chord (red line)

Impact damage location on the temperature gradient, arising from damage.

Study of fault location on the temperature gradient was carried out under the following parameter values:

– oncoming flow velocity: 100 m/s;

– international standard atmosphere (ISA): ambient temperature: 288.2 K (15° C), atmospheric pressure 101 325 Pa (760 mm Hg. Art.) At an altitude of 0 meters above sea level;

– angle of attack;

– the distance from the leading edge to the front edge damage: 25 mm, 125 mm and 225 mm.

IV. CONCLUSION

From the analysis of the results shows that the difference in temperature between the damaged and undamaged portions of the external contour is influenced by the speed and angle of attack. With increasing speed of 40 m/s to 240 m/s the temperature difference increases, along the line remote from the leading edge chord 1/3 and 2/3 of the chord on the upper plane of the external contour from 30 K and 0.7 K to 0, 7 K to 23 K, respectively. At the bottom of the external contours of the difference in temperature also tends to increase along the line remote from the leading edge chord 1/3 and 2/3 of the chord from 0.85 K to 36 K and from 0.53 K to 25.2 K respectively.

Changing the geometrical shape of the wing at the entry of foreign forces in most cases leads to a violation of the nature of flow, further turbulence and flow separation due to damage. When turbulence flow significantly increases the intensity of heat transfer processes in the boundary layer, as well as the inhibition of the flow at the site of damage, all of which leads to a temperature gradient of the damage. The intensity of the temperature gradient and the temperature difference increases with increasing flying speed, area of spreading gradient remains practically unchanged.

The results obtained can be used when creating a system of diagnosing the state of the external contour of the aircraft in flight based on their thermal fields.

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В. М. Казак, Д. О. Шевчук, М. П. Кравчук, Л. В. Панчук. Метод діагностування аеродінамічного стану літака у польоті на основі зміни термічних полів

Проведено дослідження в результаті яких розроблено метод аеродинамічного стану літака за тепловими полями. На основі математичного та натурного експериментів, встановлено закономірності формування температурного градієнту у примежовому шарі повітря, що виникає у разі пошкодження зовнішніх обводів. Виявлено параметри, які впливають на поведінку температурного градієнту, а саме: швидкість та кут атаки літака, форма профіля крила, характер пошкодження, місце появи пошкодження відносно контурів зовнішніх обводів.

Ключові слова: зовнішні обводи; пошкодження; повітрянний корабель; температурний градієнт; тепловий метод; примежовий шар; діагностування.

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В. Н. Казак, Д. О. Шевчук, Н. П. Кравчук, Л. В. Панчук. Метод диагностирования аэродинамического состояния самолета в полете на основе изменения термических полей

Проведены исследования, в результате которых был разработан метод аэродинамического состояния самолета по тепловым полям. На основе математического и натурного экспериментов, установлены закономерности формирования температурного градиента в пограничном слое воздуха, который возникает при повреждении внешних обводов. Установлены параметры, которые влияют на поведение температурного градиента, а именно: скорость и угол атаки самолета, форма профиля крылья, характер повреждения, место появления повреждения относительно контуров внешних обводов.

Ключевые слова: внешние обводы; повреждения; воздушный корабль; температурный градиент; тепловой метод; пограничный слой; диагностирование.

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