

A Model of Interconnection Between Aircraft Equipment Failures and Aircraft “States” in Flight

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Abstract – The article presents a semiotic model of “aircraft conditions” in flight and multi-level structures of an aircraft. The hierarchical structure of abstract models is divided into blocks and levels that make them more compact by applying a mathematical apparatus corresponding to the goals stated. The above models were tested on the basis of statistical data on TU-154 aircraft failures for 10 years. Various aircraft functional system failures in flight were examined. The state of the aircraft is identified by normative indicators recorded in the “Aircraft Technical Operation Manual”.

Keywords – Aircraft, failure, faulty condition, flight delay, flight safety, management.

I. INTRODUCTION

To solve the problem the approach based on the theory of semiotic systems is used. It is known that in recent years there has been a rapid development of research in this area, which represents the mathematical basis for building intelligent systems on a qualitatively new level allowing to adequately describe the current problem objects characterized by complex organizational and constructive structure. As one of the approaches of knowledge representation in the semiotic system a model based on multi-layer logic (Multi-Layer Logic or shortly MLL) [1], [2] is used. MLL is an integration of the logical approach and the approach based on semantic theory and is a convenient way for the formalization of the problem. The hierarchical abstract structure is divided into blocks and levels makes it more compact, applying to which the corresponding mathematical apparatus, the required task is solved.

II. A SEMIOTIC MODEL OF “AIRCRAFT STATE” IN FLIGHT

“The aircraft conditions during the flight” characterize the aggregate of properties of the aircraft and psychophysical performance of pilots under the influence of changes due to malfunctions, which determine their variation from the normative. Therefore, the flight will change from the “state”, i.e. to these conditions, which are described in the Regulations of Airworthiness and are classified as “special situations” [3]–[5].

Regarding this definition during the flight, five possible conditions of the aircraft are distinguished. They are defined as S_i , where $i = 0, 1, 2, 3, 4$: normal (“state”) flight without any faults – S_0 ; complication of flight conditions – S_1 ; dangerous situation – S_2 ; accident situation – S_3 ; catastrophic situation – S_4 . Each of these states arising in flight can go into any other state under the influence of new unfavourable factors or control actions of the pilot.

Thus, the semiotic model, which characterizes the “aircraft condition during the flight”, takes the form of Fig. 1 [6], [7], [12].

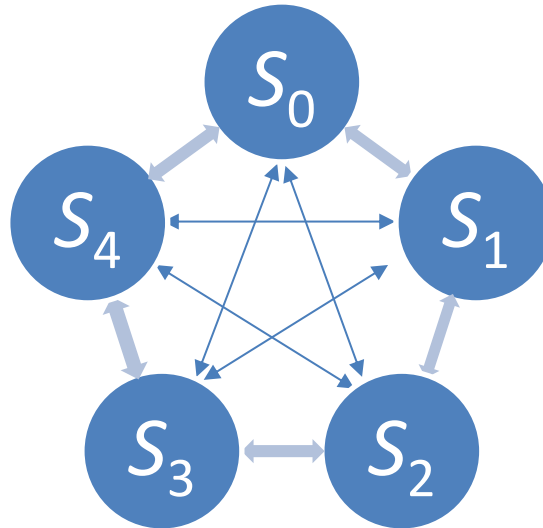


Fig. 1. A semiotic model of aircraft conditions during the flight. The semiotic aircraft model as a complex technical system.

It is necessary to set conditions for the transition of the aircraft from the “state situation” to other conditions in case of failure during the flight. For this purpose, it should be considered the aircraft as a complex multi-level technical system. As with any such system, it is composed of a plurality of subsystems and has a hierarchical structure. This means that each of the subsystems in its turn includes a subsystem of a lower level. The subsystem of the lowest level consists of a set of technical elements. Exactly at this level, flight failures and malfunctions take place causing the transition of the aircraft from the normal (full-time) state to a particular situation in adverse events: incidents or aviation accidents. For the highest level of structural diagram the aircraft itself is accepted. In turn, the aircraft consists of a number of vital subsystems for the safety of flight, which will be named Consumers.

Consumers – are vital structural elements of aircraft characteristics, which directly define the condition of the aircraft during the flight, i.e. its basic parameters. It is said that the resulting characteristics of a special situation normalized in severity depending on the size of their deviation from the permissible values defined by the normative-technical documentation.

In accordance with the Standards and airworthiness of special situations, the threat to safety appears to change the characteristics of stability and controllability of the aircraft, crew and psychophysiological state of the need to change the flight path, regardless of the nature and content of the failure [8], [9], [12]. Therefore, it confidently is assumed that the onset of symptoms in the full volume depends on the output characteristics of Consumers, which are functional systems or their combination that cause a change in offensive stability and control characteristics, change of psychophysiological state of the crew or the need to change the flight path.

A certain composition of consumers on a certain type of aircraft can be set based on operating experience, accident investigation, etc. For major reliability, this is done with the help of expert evaluations by aviation specialists. Based on operating experience to the Consumers, it is referred: aircraft control system, braking system, high-lift devices, life support systems, ensuring the tightness of cabin enclosure, etc.

Then, in the structure diagram, aircraft Consumers will make up the second level. Next, the third level in the structure diagram will present the functional systems of the aircraft, servicing the Consumers. For example, the control system can handle the hydraulic and electrical functional systems, analogically – the brake system, etc. The fourth level of the structure diagram will represent the individual units and other elements of functional systems: units, valves, pipes, etc. Exactly at this level, a failure occurs affecting the output parameters of functional systems, and they, in turn, affect

the output parameters of Consumers, etc. by the chain. The semiotic model of the aircraft, as a multi-level technical system will look like see Fig. 2.

As it is shown below, each Consumer is characterized by a set of characteristics determining the “condition” of the aircraft during the flight. Each functional system “output” is characterized by a variety of characteristics (defining “conditions”,) served by its Consumer. Each element of the system is characterized by a variety of functional features that define its “condition” during the flight [10]–[12]. Individual elements failures of functional systems are recorded quantitatively and qualitatively. This allows to detect the mathematical relationship of failures of aviation equipment and the “conditions” of the aircraft during flight. But it is necessary to define the conditions for transition of the aircraft in different states.

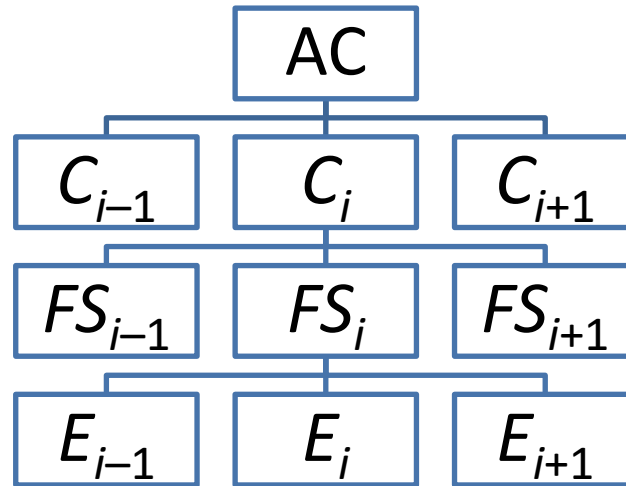


Fig. 2. The semiotic model of the aircraft as a multilevel technical system.
 C_i – consumers: mechanization of the wing devices, landing gear, pressurized cabin, etc.
 FS_i – functional systems: hydraulic, pneumatic, anti-icing, etc.
 E_i – FS elements: pumps, valves, pipes, etc.

III. APPROBATION OF THE PROPOSED MODELS BASED ON THE ANALYSIS OF STATISTICAL DATA ON AIRCRAFT FAILURES IN FLIGHT

The above models have been tested on the basis of the statistical data on TU-154 aircraft failures for 10 years. Examined various functional aircraft systems failures in flight. The state of the aircraft is identified by the normative indicators recorded in the “Aircraft Technical Operation Manual” [13]–[16].

1. Consumer – life support system. Functional system – pressure regulation system in a pressurized cabin (P_c). Regulative demands:

1.1. $P_c > P_{c, norm}$. Overpressure. According to the flight manual, in this case it is required to turn-off the overpressure of the pressurized cabin, emergency landing, and if the aircraft is not provided with pressurized cabin ventilation on low heights from the airflow, landing at the nearest airport. According to the normalized signs, this will be an emergency or situation – S_3 in accordance to proposed classification.

1.2. $P_c < P_{c, norm}$. Depressurization. This pressure regulation system status does not require to turn on the pressurization, that is why the crew, if the echelon is taken according to the safe point of view of the allowed pressure, rain at a safe altitude safe from the point of view of allowed pressure, may continue to fly for as long as it is necessary. Therefore, according to the normalized signs it will be a dangerous situation, or S_2 – according to classification proposed.

1.3. $(dP_c/dt) > (dP_c/dt)_{\text{norm}}$. This condition, as a rule, also leads to depressurization, i.e. S_2 – according to proposed classification.

According to the statistics data for the last 10 years only 10 emergency cases happened to aircraft due to the pressure regulation system, and they all were related to depressurization. In 7 cases, there was a failure of exhaust valve (suspension of the plate in one position). Also, during all of the mentioned failures of elements, the pressure regulation system showed an unexpected opening of the exhaust valve, which has been enough for depressurization of the germocabine, i.e. the aircraft condition S_2 according to proposed classification. A similar condition in the pressure regulation system arises in case of the failure of the command unit (2 cases), but in this case there is a possibility of moving to the backup command unit with the possibility of restoring the operability of the system. However, if the turning valve has also failed, the work of the system cannot be restored, and this will match aircraft condition S_2 .

2. Consumer – life support system. Functional system – environmental control system (ECS).

As statistics shows of 15 emergency cases due to the pressure regulation system of the aircraft: in 9 cases there was observed a temperature rise in the pressure cabin (or its part) and impossibility of back to normal operation. Parameters of the pressurized cabin are going beyond limits due to the failure of distribution damper in the open position. As a result, the aircraft is forced to perform an emergency landing, which according to the classification proposed of aircraft condition – is equal to S_3 . In other five cases, the reason of operation of high temperature sensors was: destruction of air-to-air cooler; destruction of hot air turbo wire. In four mentioned flight emergencies, the crew was forced to turn-off the air offtake from the engines and to perform an emergency landing, which is equal to the aircraft condition – S_3 .

3. Functional system – hydraulic system (HS).

Hydraulic systems of the aircraft serve many consumers, including a failure that may lead to a catastrophic situation, because the number of its consumers includes the units of steering surface control. That is why an analysis of the flight emergencies caused by the hydraulic system failures will be made with the subsystems.

3.1. A subsystem of flight control bodies.

A failure of this subsystem on the aircraft is usually a catastrophic situation – S_4 , according to classification proposed. During the period under review, there were no failures of these subsystems during the flight.

3.2. Subsystem of landing gear retraction and extension.

In these subsystems, the most important function is landing gear extension. However, according to regulations, if the failure or malfunction appears in the retraction line, the crew should make the decision to return to the airport of departure, which is the aircraft – condition S_3 according to the classification proposed.

As statistics shows in 40 cases of landing gear retraction the reason was failure of the electro-hydraulic tap KE-47; malfunction of the lock of the retracted position; improper operation of looping ball valve of spool valves; failure of the cylinder-lift. In half the cases, it was impossible to establish a true ‘culprit’ of the failure in the conditions of the airfield and the aggregates were sent for investigation. Most often, the failures were caused by foreign objects on the seat check valves included in the structure of aggregates.

A. Faults of the landing gear line retraction.

According to statistics they were observed less frequently. Thus, landings were accomplished safely, because when switching to backup systems, landing gear was retracted normally. Therefore, failures in this subsystem lead to the aircraft condition – S_2 .

B. Braking subsystem.

The main type of failure considered in the design is a lack of inhibition. There were no such types of failures during the period under aircraft review. At the same time, as a rule, these subsystems are

not designed for unexpected braking of the wheels, although the consequences of failure is very serious. Landing with locked wheels will lead to their destruction. While studying the statistics three cases of this type were revealed.

C. External impermeability of the hydraulic system.

The consequences of the existence of faults of this type depend on the location of the leak. The leaks in the power supply units, especially in pumps installed on engines (hydraulic hoses, high and low pressure), can lead to an ingress of hydraulic oil into the heated parts and cause a fire, the aircraft condition – S_4 . Leaks of the wheel brake cylinder hydraulic fluid at a lockup in during taxiing and run on friction pairs having a temperature of ignition and sufficient hydraulic fluid, the aircraft – condition S_4 . On aircrafts during the considered period, there were two fires in the area of the main landing gear, which were caused by the failure of the specified type, the aircraft condition S_4 . In other cases, the loss of hydraulic tightness, if a leak is small and does not lead to the emptying of the tanks, generally cannot be seen by the crew and is found only on the ground during the inspection of the aircraft support personnel. Thus, the state of the aircraft with such failures in flight can vary over a wide range from S_1 to S_4 .

D. Power units in the hydraulic system.

Failures of power supply units are manifested in the absence of pressure or flow of hydraulic fluid, in some cases, a harmful pressure pulsation, if hydraulic pressure exceeds the allowable level, the fluid and safety valve is heated until the appearance of smoke in the compartment where they are installed. It results in emergency landing, i.e. the aircraft – condition S_4 according to classification.

In this case, based on this analysis and according to the practical activities, it is consider that the appearance of one of the adverse factors cause the condition of the aircraft not higher than S_1 – complication of flight conditions.

The appearance of the second adverse factor causes a transition to the next condition, i.e. S_{i+1} . Aircraft can get into more dangerous condition when influenced of two or more adverse factors, and the more of these factors appear simultaneously, the more dangerous is the condition of the aircraft. This is seen from the analysis of regulative maintenance documentation. Thus, when failure of the air, which flows to the passenger cabin, heating line of the aircraft occurs at valve open position, the temperature of air may rise up to 80 and more degrees.

In this case, the crew should turn-off the heating line. In this case, the situation may be identified as not more than complication of the flight, which is equal to S_1 condition of the aircraft according to classification proposed.

If the failure of the shut-valve in the heating line occurs in the open position, it requires a total turn-off of the conditioning system, which will demand from its side to decrease the flight height up to a safe height and turn-on the ventilation, i.e. to change the flight plan.

According to the signs of special situation, this will be a dangerous situation – the aircraft condition S_2 . Under the following factors, it is also the errors and the adverse influence of the environment is understood.

For example, in favourable weather conditions the fault of the anti-icing system by itself does not lead to any special situation. However, if there appears adverse environmental influence, this situation should be classified as dangerous, because the aircraft is in disadvantageous weather conditions with anti-icing system not working. Based on these assumptions, let us review a possible mathematical model of interconnection between adverse factors and aircraft conditions (special situations). It is more correct to review only the adverse factors related to the faults of aviation equipment, considering that all other subsystems of the aviation transportation system are working without a hitch. The errors of the crew are also eliminated when parrying the consequences of failures and the crew is strictly guided by the instructions of the flight operations manual. These discourses are fair, because airworthiness regulations in relation to some basic functional systems accept the possibility of one or more faults. So, in the air conditioning and air pressure regulation system it is allowed to stop the air

supply from half of the sources if they fail or malfunction of individual elements of the subsystems, when the minimum allowable physiological-hygienic conditions in the cabin are maintained. This condition of the aircraft may be evaluated as S_2 , i.e. as a dangerous situation. A fault of one or two separate elements in the control system is accepted, but it is required to provide the possibility of safe landing. In the brake system, there are accepted both single and simultaneous faults related to the destruction of the lines if breaking distance restrictions in the first case and brake operability safety in the second case are applied, etc.

IV. CONCLUSION

The article presents a semiotic model of “aircraft conditions” in flight and multi-level structures of the aircraft. The hierarchical structure of abstract models is divided into blocks and the levels making them more compact. The applied mathematical apparatus solves the objectives stated:

- Identification of conditions for the transition from a less dangerous state to a more dangerous state of the aircraft.
- The mathematical model for controlling the technical condition of the aircraft in the course of technical operation.
- The mathematical model of relationship of failures of aviation equipment and aircraft conditions during flight.
- The approbation of the developed method based on information about technical failures of aircraft for the period 1995–2005.

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