The Ministry of Education and Science of the Russian Federation
Samara State Aerospace University
(National Reserch University)

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FUNCTIONAL FAILURE EFFECTS AIRPLANE SYSTEMS

Electronic Manual

SAMARA
2011

УДК 629.7.015(075)
ББК 68.53
М 889

The development programme for 2009-2018 of Samara State Aerospace University named after Academician S. P. Korolyov (National Research University)

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Mrykin, S. V. FUNCTIONAL FAILURE EFFECTS AIRPLANE SYSTEMS = Последствия функциональных отказов самолётных систем [Electronic resource]: Electronic Manual/ S. V. Mrykin; The Ministry of Education and Science of the Russian Federation, Samara State Aerospace University. — Electronic text (369KB). — Samara, 2011. — 1 CD-ROM.

Attributes classification of aircraft systems by failure effect, list and attributes special situations, arising owing to failures system according to AR-25 [1] are presented in the manual. List typical failures and examples of classification for special situations are presented also.

This manual is a part of the Masters educational programmes which were developed based on using new educational technologies, resources and distance-learning systems for the Masters programme "Designing, construction and CALS-technologies in Aeronautical Engineering" for education direction 160100.68 "Aeronautical Engineering". It is also useful for students of the speciality 160100 "Airplane construction", 160900 "Technical maintenance of aircrafts and engines", 160201 "Airplane and helicopter construction" for discipline "Reliability and operation of airplanes".

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Content

Introduction

Purpose this textbook — to acquaint students with problems by estimation failures effects airsystems and view such ways solve this problems by example.

Concepts special situations, operating and extreme limitations is theoretical based for methods of the analisys failures effects airsystems. List and attributes special situations is contained in normative document AR-25 [1]. As rule, functional failures lead to additional limitations modes of flight. Classification special situation is executed by comparison additional limitations with operating and extreme limitations.

Failures effects analisys include:

- influence failures elements on system's good state and up state;

- determination additional limitations modes of flight caused full or partial failure system;

- classification special situation.

Functions and design systems and their elements are studied in "Airplane equipment systems".

Theoretical methods for estimate extreme limitations are studied in aerodynamics (polars, flight, maneuverable, take-off and landing characteristics), flight dynamics (trajectory, range and time in flight, takeoff paths and landings, characteristics of stability and controllability, admissible center mass positions), calculation of airplane on durability (limitations on a high-speed pressure).

Theoretical and experimental methods for analysis failures effects systems are based on experience tests and operation systems and airplanes-leaders. Extreme limitations are updated and operating limitations are established by results flight tests. Limitations are fixed in technical and operational documents for airplane.

1 Structure of functional systems airplane

Specified reliability measures are appointed proceeding from requirements normative document AR-25 [1] by designe. For convenience designe and analysis airplane is divided on functional groups (system):

1. Airframe with skin.
2. Power plant.
3. Hydro- and airsystem .
4. Take-off and landing devices.
5. Control system.
6. Flight and navigation equipment.
7. System of electrosupply.
8. Radio-electronic equipment.
9. Central air and life-support.
10. Cargo handling, passenger and special equipment.

This division, however, as well as any another, is not strict, but standard [2, 9].

Usually, division by groups are executed thus, that groups not depend from each other. It essentially facilitates designing and the analysis. However, in modern airplane layout, systems or/and elements systems are part of several groups.

For example: fuel system, air intakes and exhaust nozzles in equal measure belong to groups 1 and 2; ice protection system is included in groups 1 (canopy transparency, leading edges for wing and tail), 2 (inlet guide vanes, rotors), 4 (slats) and 6 (receivers of air pressure); power-boosters and electric motors are included in groups 3, 4, 5, 7, 9 and 10; hydro- and airsystem get energy from groups 2, 7 and put energy for some elements in groups 2, 4, 5, 7, 9 and 10; system of electrosupply get energy from groups 2, 3 and put energy for groups 2–10; some elements from groups 9 (panel heating systems), 8 (antennas) and 10 (baggage compartment doors, ramps) are included in group 1.

Full list links is possible to make for concrete airplane only. Initial data for analysis are:

- purpose and shape of airplane, possible configurations, typical structure of flight, key parameters, characteristics and list functional systems;
- basic schemes and descriptions work functional systems;
- purpose systems, that is functions lists are executed each system;
- list failure on each system;
- analysis failure causes (phisical nature failure);
- statistics of failures for elements functional systems.

Accessory system or element several groups means, that between this groups are link. Link may be unilateral (from source to result only), bilateral (result directly influence by source) and mediated (result influence by source through another system).

At the analysis of interrelation of various functional systems it is necessary:

1. To determine kinds of consumed energy of everyone functional system and communication of consumers of energy with sources of this energy.
2. To determine information communications between separate systems, that is to reveal all signals which are developed in one functional systems also are used in others.
3. To determine adverse conditions which will arise at failure one functional systems and as they will affect work of other systems (output of temperature or pressure for admissible limits, occurrence of vibrations, icing, absence submission of neutral gas in tanks-caissons at to gear-up landing, failure fuel fire shut-off valve in engine, outflow of fuel, oil or liquid from hydrosystem and so on).

Links considerably complicates the analysis of work systems and demands good knowledge of disciplines “Airplanes” and “Airplane equipment systems”.

2 Failures and faulty state classification

In the theory of reliability [2, section 2.3] is applied set attributes for classification failures and faulty state: through character of display, at the moment of fixing (detection), by effects, by causes, on way of elimination.

Plurality of attributes for classification is caused by a number of the reasons, most important of which are:

- increase reliability products aeronautical engineering;
- establishment legal responsibility parties,

participating in life cycle airplane.

Life cycle airplane can be presented in the form of the following stages: designing and manufacturing copies for tests, tests, certification, batch production, operation and recycling. A number of attributes for classification corresponds with stages of life cycle of an airplane.

Through character of display failures as random events may be: dependent and independent, joint and not joint, gradual and sudden [1].

Events are independent if their probabilities of occurrence do not depend from each other. For example, if failure one element system is caused failure other element, such failures will be dependent events (failure drive of constant turns leads to stop electric generator).

Events are joint if may to be or not to be during work system simultaneously. For example, events “jamming” in two (or more) connections control rods in airplane flight controls is joint events. If events cannot occur simultaneously, they are considered not joint. For example, event “work pump” and event “failure pump” not joint if it is a question about the same pump.

At the moment of fixing (detection) distinguish following failures and faults: on the Earth at service of airplane; on take-off (till speed of acceptance decisions, up to rise nose landing gear, up to rise airplane from earth, up to rise airplane by safe flight level, till move landing gear in retracted position, till begin move wing high-lift devices in retracted position, up to flight configuration, up to rise airplane by cruiser flight level); in flight at performance of the flying mission (commercial or noncommercial flight, training or fighting flight); by landing (during decrease at altitude circle in route configuration, at altitude circle with let out landing gear, at altitude circle in landing configuration, on glidepath, on air site above runway, on run after landing); at production tests of airplane (running in failures and faults).

By effects distinguish following failures and faults: without effects; un-

[1] Gradual and sudden failures see in the Glossary.

availability of airplane to flight; caused special situation. In the literature [2, 8] there are also others effects. For example, the interrupted take-off and emergency landing, precondition to flight incident and flight incident, dangerous rapproachement.

By causes distinguish following failures and faults: constructive and industrial lacks (defects); mistakes; external effects.

On way of elimination distinguish following failures and faults: eliminated at operative maintenance service; eliminated at periodic maintenance service; eliminated at repair.

In following section of the textbook special situations are considered and some reasons of their occurrence.

3 Failures effects

Functional systems failures lead to special situations. List and attributes special situations are defined in [1, section A-0]. Special situations are defined by expected conditions of operation, that is:

1. Parameters of condition and factors of effect on airplane external environments.

2. Operational factors.

3. Modes of flight.

Parameters of condition and factors of effect on airplane external environments: barometric pressure, density, temperature and humidity of air, direction and speed of wind, horizontal both vertical impulses of air and their gradients, effect of atmospheric electricity, icing, hailstones, snow, rain, birds.

Operational factors: structure of crew; class and category of aerodrome; parameters and condition of runway; purpose of airplane and feature of its application; possible configurations of airplane depending on stages and modes of flight; weight and balance data for all stipulated configurations of airplane; operating mode of engines and operation time on the determined modes; characteristics airways, lines and routes; structure and characteristics of ground radio engineering means of flight support and landing; a minimum of weather during takeoff and landing; applied fuel, oil, additive and other spent technical liquids and gases; periodicity and categories of maintenance and repair; the appointed life and lifetime of functional systems and all airplane as a whole.

Modes of flight: flight levels; horizontal and vertical speeds; accelerations; angles of attack, sliding, yaw, roll and pitch; extreme and operating limitations of these parameters depending on configuration of airplane.

Let's note, that special situations arise not only because of failures, but also owing to mistakes and external effects. External effects are understood as combination as parameters and factors of environment, and number of operational factors.

3.1 Special situations

Complication of flight's conditions is expressed in insignificant deteriration flight characteristics, characteristics of stability and controllability, durabilities and works of systems, or insignificant increase in the worker loadings on crew (for example, change plan of flight).

Complex situation is characterized by appreciable deterioration of characteristics, output of one or several parameters for operating limitations, but without achievement of extreme limitations, or reduction ability of crew to cope with adverse conditions both because of increase in working loading, and because of conditions lowering efficiency actions of crew.

Emergency situation is characterized by significant deterioration characteristics, achievement or excess of extreme limitations, or such loading of crew at which it is impossible to rely, that crew will carry out duties precisely and completely.

Disaster situation is such special situation, at which to prevent death of people practically impossible.

In literature [2, 9] there are references to situation which is determined as *default of flying mission*. This situation define result of flight for state aircraft[2]. In state aircrafts enters big number of different types of flight vehicles which number formally does not fall under action AR-25. For example: fighters, helicopters, prospecting and fighting pilotless flight vehicles (UAV) and others. In this textbook it is supposed, that definitions of special situations on AR-25 use for any flight vehicles, without dependence from their purpose.

To establish conformity between special situations on AR-25 and *default of flying mission*, we shall consider that:

- at performance of training mission default of flight is equal loading on crew of complication of flight's conditions or complex situation, depending on the order, concrete conditions of flight and counteraction from conditional opponent;

- at performance of fighting mission default of flight is equal loading on crew complex, emergency or even disaster situation, depending on the order, concrete conditions of flight and counteraction from the real opponent.

3.2 Categories of random events

Functional failures so also their effects, at the determined assumptions are random events [2]. In AR-25 [1] classification of random events on the basis of frequency occurrence is entered.

Probable random events can occur one or some times during lifetime each airplane of the given type. Probable random events are subdivided on frequent and moderately probable.

Improbable random events hardly will occur on each airplane during its lifetime, but can arise some times if to consider a plenty of airplanes of the given type.

[2]According to [5] state aircraft is military aircraft, aircraft of EMERCOM, etc.

Rare random events (incredible) are subdivided on two categories: extremely improbable and practically incredible.

Extremely improbable random events hardly will arise for total lifetime all airplanes of the given type, but should be considered as possible.

Practically incredible random events, that is, there is no necessity to consider possible their occurrence.

3.3 Numerical values of probabilities

By requirements AR-25 [1] it is established, that airplane should be designed and constructed so that in expected conditions of operation at actions of crew according to Flight Manual:

1. Any functional failure one system leading to complication flight's conditions, it was estimated as event moderately probable:

$$10^{-5} < Q < 10^{-3},$$

where Q — probability of functional failure. Extremely undesirable, but admissible, to estimate the functional failure one system leading to complication of flight's conditions, as event frequent: $Q \leq 10{-}3$. In this textbook is recommended take $Q \approx 10{-}5$.

2. Any functional failure one system leading to complex situation, was estimated as event improbable:

$$10^{-7} < Q \leq 10^{-5}.$$

In this textbook is recommended take $Q \approx 10^{-6}$ for default flight's mission and $Q \approx 10^{-7}$ for complex situation.

3. Any functional failure one system leading to emergency situation, was estimated as event extremely improbable:

$$10^{-9} < Q \leq 10^{-7}.$$

In this textbook is recommended take $Q \approx 10^{-8}$.

4. Any functional failure one system leading to disaster situation, was estimated as event practically incredible: $Q \leq 10^{-9}$.

4 Classification of functional systems by failures effects

Failure effect is change state of functional system (good or faulty state, up or down state). As rule, in application to functional systems, is a question about partial failure, that is either number of functions is decreased or functions performance is burdened additional limitations by modes of flight.

Additional limitations which appear owing to failures of functional system, should be correlated with recommended modes of flight, operational and extreme limitations, and also with change of loading on crew. This comparison is basis for estimate danger of failures and conclusion about occurrence special situation.

In [9, tab. 7.1] was written examples classification consumers aviation hydrosystems by failures effects for airplane as whole. According to this classification functional systems (subsystem) and elements of systems are broken into three groups.

Systems and elements systems concern to the first group if their failures leads to occurrence catastrophic situation. In this group enter:

- Hydraulic boosters in flight control system (actuators) for channels pitch, roll and yaw.
- Servo units in automatic control system, working on take-off and landing.
- Auxiliary hydraulic boosters in flight control system.
- Ice protection system.
- Fire protection system.

Systems and elements systems concern to the second group if their failures leads to occurrence emergency situation. In this group enter:

- Landing gear and subsystem providing down position.
- Wheels with brake and subsystem providing work for brake.
- Variable geometry wing and subsystem providing set minimal sweepback angle.
- Wing high-lift devices (slats, flaps) and subsystem providing landing position.
- Air intake devices and subsystem providing move central body in initial position.
- Arms compartment doors and subsystem for their opening.
- Main and emergency doors, baggage compartment doors and subsystem for their opening.
- System for latching control surfaces (ailerons, rudder, elevator) on parking.
- Monitoring system feed and working capacity of artificial horizons.

Systems and elements systems concern to third group if their failures leads to occurrence default flight mission (complication of flight's conditions or complex situation). In this group enter:

- Spoilers and subsystem providing work by landing.
- Steering nose landing gear and susysem providing work.
- Aerial radar.
- Camera compartment door.
- Drive for electric generator.
- System for thrust reverser or release of brake parachute.
- Drive for fuel pump.
- Moving out fuel receiving device.
- Injection of water in engines on take-off.
- Feel mechanism for control column and pedals.
- Braking of wheels at cleaning.

For concrete airplane there can be deviations from aforesaid classification which should be proved proceeding from features of its purpose, conditions of application and design. Results of classification functional systems by failures effects are fixed in minimal list state up equipment in manual on flight operation.

5 Typical functional failures

Results of the analysis functional failures depends on purposes analysis which in compressed form reveal as “rule of reliability” [8, section 6.1]: reliability is pawned at designing, proved at certification, provided in manufacture and realized in operation.

In operating documents would be described those failures which did not translated in category practically incredible at designing and manufacture.

Operational manual is written by developer main product (airplane) and developers systems and elements of systems. This document includes description, procedures of search failures and faults, technological cards for maintenance and recovery.

Now sequence of statement material in operational manual is changed [8, section 39.4]. Earlier statement of material was formed on services air-technical base: mechanics, hydraulics, pneumatic, electrician, electronics and so on. Now statement of material is formed by principle of functional (time) sequence operate system, that is material is stated in that sequence, in which systems or elements systems are put into operation.

Flight operation manual is written by developer of aircraft and affirms special authorized bodies [5]. This document includes basic flight performances of airplane, imitations, instruction by actions of crew in normal flight, in special situations, etc.

Forecast functional failures is problem. This problem possible simplify if consider, that systems and their functions are identical (or similar) on different airplanes. Then possible write *typical* list functional failures [8, section 4.3]. This list allows to reduce influence subjective values developers and analysts.

Typical list will be transformed to list functional failures systems for concrete airplane by addition or exception functions reflecting specificity this airplane that allows to reduce time for analysis functional failures considerably.

5.1 Airframe with skin

Purpose **ice protection system** is prevent or removal ice from some parts of airplane.

Functional failures:

- neither switch on nor switch off system;
- inefficient work owing to reduction disposed capacities.

5.2 Power plants

Fuel system execute following functions:

1. Fuel supply in engine(s).

Functional failure: not supply fuel in engine(s).

2. Storage of fuel.

Functional failure: nontightness fuel tanks.

3. Fuel transfer from tanks to consumed tank, fuel swapping between tanks.

Functional failure: infringement order fuel supply from tanks.

4. Fuel jettisoning in flight and on the Earth.

Functional failure:

- absence jettisoning;
- self-jettisoning.

5. Refuelling of the set fuel content.

Functional failure: discrepancy fuel load demanded.

Purpose **reversing system for engine(s)** is reductions distance of run after landing.

Functional failures:

- not reversing engines;
- asymmetrical reversing.

Control system for supersonic air intake execute following functions:

- steady engine run on all modes of flight;
- compression airstream and transformation his kinetic energy in pressure;
- engine protection against hit in it extraneous subjects.

Functonal failures:

- non-uniform field of pressure in compressor;
- insufficient quantity of air for steady burning torch in combustion chamber;
- excessive increase C_D for airplane.

5.3 Hydraulic and pneumatic system

Hydrosystem (pneumatic system) is intended for submission necessary quantities liquid (gas) under the set pressure to consumers hydraulic (pneumatic) energy.

Functional failures:

- nontightness system;
- reduction of disposed capacity owing to reduction submission of pumps Or pressure of forcing.

5.4 Wing high-lift devices

Purpose **flaps control system** is increase C_L on take-off and landing.

Functional failures:

- neither move flaps in landing (take-off) position nor move flaps in flight position;
- self-move flaps in landing (take-off) position or in flight position;
- asymmetrical move flaps in landing (take-off) position or in flight position.

Purpose **slats control system** is increase C_L and critical angle of attack on take-off and landing.

Functional failures:

- neither move slats in take-off position nor move slats in flight position;
- self-move slats in take-off or flight position;
- asymmetrical move slats in take-off or flight position.

Landing gear execute following functions:

1. Movement airplane on aerodrome (concrete, ground, snow, water).

Functional failure: destruction of basic elements (tires, skis, floats).

2. Amortization of shock loadings on landing, run, start and movement to start or parking point.

Functional failure: absence or deterioration of amortization.

System for move landing gear in flight or landing position execute following functions:

1. Landing gear up or down.

Functional failures:

- neither up nor down one or a few landing gear;
- self-up landing gear on the Earth;
- self-down landing gear in flight.

2. Open and close landing gear doors.

Functional failures:

- not close landing gear doors;
- self-open landing gear doors.

System for braking wheels execute following functions:

- brake wheels on run and movement to start or parking point;
- separate braking wheels at turns on the Earth;
- braking rotating wheels before up landing gear.

Functional failures:

- nonsynchronism braking wheels;
- reduction disposed brake torque;
- self-braking wheels;
- down state skid detector;
- overheat braking wheels.

Steering cylinder and shimmy damper execute following functions:
1. Control of airplane at motion by the ground.
Functional failures:
- steering cylinder jamming;
- self-turn nose landing gear from neutral position;
- jamming nose landing gear in turned position.
2. Shimmy damper.
Functional failure: shimmy damper failure.

5.5 Control system

Aileron control is intended for necessary efficiency of lateral controllability.
Functional failures:
- increase efficiency control on a roll;
- reduction efficiency control on a roll;
- self-rotation one or both ailerons;
- change of operating efforts;
- fluctuations one or both ailerons.

Elevator control is intended for necessary efficiency of longitudinal controllability.
Functional failures:
- increase efficiency control on a pitch;
- reduction efficiency control on a pitch;
- self-rotation one or both part of elevator;
- change of operating efforts;
- fluctuations one or both part of elevator.

Horizontal stabilizer control is intended for longitudinal balancing.
Functional failures:
- reduction speed moving horizontal stabilizer;
- jamming horizonal stabilizer;
- self-turning horizontal stabilizer.

Rudder control is intended for necessary efficiency of lateral controllability.
Functional failures:
- reduction efficiency control in yaw channel;
- increase efficiency control in yaw channel;
- self-moving rudder or his part;
- change of operating efforts;
- fluctuations rudder or his part.

Lateral control spoilers is intended for increase efficiency lateral control.
Functional failure: reduction efficiency lateral control.

Control spoilers is intended for reduction C_L at run or at sharp decrease level.

Functional failures:
- neither extended nor retracted spoilers;
- self-extended or self-retracted spoilers;
- nonsynchronous extended or retracted spoilers.
Automatic control system execute following functions:
1. Stabilization airplane by roll, pitch and yaw.
Functional failures:
- not stabilization;
- false operating signals.
2. Damping oscillations by roll, pitch and yaw.
Functional failures:
- not damping;
- increase amplitude fluctuations (“swing”).
3. Airplane control on level and direction.
Functional failures:
- not operating signals for change level and direction;
- false operating signals.
4. Flight speed control.
Functionals failures:
- not operating signals for flight speed control;
- discrepancy actual and set speeds owing to false signals.
5. Thrust control.
Functional failures: absence automatic thrust control engines.
6. Balancing airplane.
Functional failure: not balancing.

5.6 Electrosupply system

Electric power sources execute following functions:
1. Active current (AC) source with set frequency and voltage.
Functional failures:
- reduction available capacity;
- absence frequency stabilization;
- absence voltage variation;
- self-oscillations in system frequency and voltage variation;
- fire in AC source.
2. Direct current (DC) source with set valtage.
Functional failures:
- reduction available capacity;
- absence voltage variation;
- fire in DC source.

5.7 Radio-electronic equipment

Radio communication equipment execute followinf functions:
1. Communication inside airplane.
Functional failure: disrupt radio communication.
2. Radio communication with radio stations on Earth and other airplanes.
Functional failure: disrupt radio communication.
3. Entertainment of passengers.
Functional failure system entertainment of passengers.
4. Confidential radio communication.
Functional failures:
- absence encryption;
- disrupt radio communication.
5. Registration talks of crew, parameters of flight and work of systems.
Functional failures:
- absence registration or registration false signals;
- absence synchronization with world time or false signals synchronization.

5.8 Central air and life-support

Central air and life-support system execute following functions:
1. Change air pressure in admissible limits in pressure cabin.
Functional failure: change air pressure out admissible limits.
2. Change air temperature in admissible limits in crew cabin and passenger compartments.
Functional failure: change air temperature out admissible limits.
3. Ventilation pressure cabin.
Functional failures:
- reduction air quantity submitted in pressure cabin;
- occurrence of harmful impurity.
4. Humidity variation.
Functional failure: change humidity out admissible limits.
5. Cooling special equipment and change air pressure in admissible limits in special equipment compartment.
Functional failures: absence cooling and reduction submission of air.
Fire protection system execute following functions:
1. Signal system about fire or smoke.
Functional failures:
- absence signal about fire or smoke;
- false signal.
2. Fire extinguishing.
Functional failures:

- fire is not extinguished (full or partial);
- spontaneous operation without fire.

3. Prevention of explosion in fuel tanks.

Functional failures:
- absence submission neutral gas in fuel tanks;
- spontaneous operation.

The resulted typical list of functional failures shows logic approach, that is formulations of functional failures for concrete systems turn out from formulations of corresponding functions without dependence from the physical nature of failures.

Advantage logic approach consists that the set of functional failures though is great, but is finite. Physical nature of failures forms continuum set which studying requires basic researches. Results of researches, field experience and find out physical nature concrete failures very much valuable as allow or translate part of failures in category practically incredible, or to develop methods of diagnostics transition state from up to down.

Primary and secondary failures should be cosidered at drawing up the list of functional failures. Considering, that from point of view logical approach power and information dependences between systems are estimated in hundreds, is admissible to consider functional failures practically incredible if one of following conditions is executed:

1. Functional failures results from two and more consecutive failures of various elements considered system or systems cooperating with it with probability less 10−9 at one o'clock of typical flight.

2. Functional failure is consequence of concrete mechanical failure (destruction, jamming, disconnect etc.) one element system and the developer will prove practical incredibility such failure, using for proof:

- analysis schematic diagrams and real construction;
- statistical estimation of failure-free operation similar constructions for long period of time operation (at presence of necessary data);
- tests results to find out useful life elements system;
- tests results to find out admissible range of change working (controllable) parameters system or element system, written in specifications;
- tests results to find out limits of transition state from up to down (determination tests) and written in specifications;
- analysis principles of quality assurance manufacturing and applied constructional materials in batch production, and also stability technological processes;
- analysis methods and periodicity maintenance are stipulated in operational documentation.

6 Physical nature of failures

Studying physical nature of failures begins with studying damages part of construction and elements systems of airplane.

6.1 Typical damages

Fuselage: cracks in spoilers, heat shields, cowls, sockets, landing gear compartments doors etc.; easing and breakage of rivets in channels of air intakes; leakage fuel tanks placed in fuselage.

Wing: cracks in tail part of wing, landing gear compartments doors, in wing fences; leakage fuel tanks placed in wing.

Tail unit, control surfaces and wing high-lift devices: cracks in skin; tearing frictionless or slider bearing in hinges fitting; turning bearing cup in hinges fitting.

Landing gear: cracks in welded seams and pin hinges landing gear; cracks in shock strut piston; deterioration and teases in shock strut bearings; leakage shock struts; cracks and overheat brake wheels; puncture, cut, tread-wear.

Hydrosystem: external leakage pipelines, armatures, case hydrounits; internal leakage hydrounits (pumps, hydroaccumulators, boosters, monitoring drives etc.)

Pneumatic system: internal and external leakage units, pipelines and armatures.

Fuel system: internal and external leakage cocks, valves, pipelines, units (fuel accumulator) and armatures; cracks in sockets and fairings intakes pressurization system.

Electrosupply system: circuit opening and short circuit in current sources; solid and intermittent faults; attrition brushes in generators etc.

Central air and life-support system: leakage valves; cracks in pipelines; corrosion and asphaltization in valves, pipelines and units are supplied hot air from compressor.

Control system: contact loss in electrical elements; free play; increase friction and jamming bearings in control rods, bell cranks and brackets.

Mount and cooling engines: hogging exhaust nozzle; leakage accessory box; cracks in sockets and fairing intakes cooling system; cracks in sockets turbostarter.

Oil system: external leakage oil tank; internal leakage fuel-oil cooler.

6.2 Causes and effects typical damages

Experience shows [2], that most part of failures arises owing to pressure pulsations airflow at external and internal flow airplane surface (fatigue cracks in skin and airframe elements, easing and breakage of rivets); pressure pulsations in systems with carrier of energy and information in form of liquid or gas (leakage); vibrations in systems with carrier of energy and information in form of electric current (contact loss).

Fatigue cracks, leakage and contact loss, in turn, are consequence of defects. Defects can appear as at stage of designing, owing to incorrect estimation of dynamic (vibrating) durability and ways vibroisolation, and by manufacture, owing to choice inadequate technology, or non-observance technology.

Cracks in skin and airframe come to light set of ways — from simple visual survey to application methods not destroying control. Danger of the given kind of damages depends on sizes of cracks and places of their occurrence. Some cracks is eliminated drilling out apex of crack or patching. Cracks in power units (cap strip, attachment fittings, landing gear pivot pin etc.) which destruction conducts to destruction airplane are eliminated at repair on manufacturer. Such order of maintenance and repair airplane is realized in event that construction is fail-safe.

External leakage is found out at surveys airplane and depends from leakage class [9, tab. 6.3] . For example: for liquid in form of sweating, leaking without tip leakage, drip leak and so on; for hot air pipelines in form spots of soot, traces overheat etc.

Vibration from pressure pulsation and/or from next units lead to damage seals and microcracks occurrence through which there is leaking. Danger of this failure is determined proceeding from analysis airplane. For example: hit of liquid on hot surfaces can lead to a fire; spots of oil or liquid from hydrosystem will lead to the accelerated corrosion and so on.

Internal leakage is found out on output working parameters for limits of admissible range (boosters and monitoring drives, shock strut, steering cylinder and shimmy damper, fuel cocks etc.) Internal leakage is consequence damage of seal or deterioration in pairs friction.

Deterioration in pairs friction is found out on structure, concentration and speed of accumulation products of deterioration in oil or liquid of hydrosystem. The physical nature of deterioration is complex and demands finding-out of operating conditions airplane, knowledge about materials properties and manufacturing technologies. Also, danger of this damages consists that they can lead to failures other elements system sensitive to liquid cleanliness. For example: jamming operating slide-valve in boosters, obliteration jets, filter loading and so on.

Feature of systems with carrier energy and information in form of electric current consists that time of transition from fault to failure is strictly limited. Fault leads to infringement normal operating mode and transition system in new state — abnormal operating mode. As shown experience [4, chapter 11] following kinds of abnormal modes are possible: short circuits; excessive increase or downturn voltage; excessive increase or downturn frequency; self-oscillations voltage or frequency; excessive distortion form of voltage curve; overheat.

In abnormal operating mode channels system of electrosupply save working capacity quickly (some minutes or even seconds), long work conducts to failure. Therefore protection disconnects faulty channel, develops signal "channel failure" and switches consumers to reserve or emergency channels and/or energy sources.

If failure channel does not lead to additional limitations, then special situation either does not arise, or is classified as complication of flight conditions, owing to increase in psychological loading at crew.

If channel failure leads to appearence additional limitations, because of part of consumers are switched-off, then special situation is classified proceeding from comparison of additional limitations to operational and extreme limitations.

If protection against failure is not stipulated or has not worked, then special situation is heaviest. Considering a level of electrification airplanes, special situation is classified as emergency or even disaster. More exact classification is possible only by consideration concrete failure.

In systems there are plenty of elements with transfer of energy by liquid and information an electric current. For example: electromagnetic cocks and valves in fuel and hydrosystem, electrohydraulic steering units in control system [9, section 8.3]. Analysis failure effects such elements is included failures by energy carrier and by data carrier, depending on structure and principle of action concrete element.

7 Classification examples

Functional failures description is resulted by example of airplane Tupolev 154 which reliability is realized during operation practice of long standing.

The greatest influence on safety of airplane Tupolev 154 is rendered by following systems [3, p. 253]: control system; power plant; landing gear and high-lift devices; central air and life-support system; fire protection system.

7.1 Power plant failures

Engine failure on take-off is defined to following attributes:

- reduction speed engine at constant position handle of engine control;
- pressure drop of fuel and oil;
- increase or downturn temperature of gases in front of turbine;
- engine vibration;
- alarm lamp “Swarf in oil”;
- reduction acceleration by start;
- turn and roll aside failed engine.

If $V \leq V_1$, then take-off should be interrupted, else take-off can be continued under condition of:

$$m_0 \leq [m_0], \tag{1}$$

where V — speed; V_1 — take-off decision speed; m_0 — take-off weights; $[m_0]$ — maximum take-off weights.

Condition (1) is operational limitation. Take-off technique with one failed engine is fulfilled during flight tests and recommendations are written in Flight Manual.

If condition (1) is executed, then special situation is classified as complication of flight conditions.

If condition (1) is not executed, there is complex situation.

Failures two engines from three in flight. Operating experience airplane Tupolev 154 has shown, that this extremely improbable event, therefore special situation can be classified as emergency on the basis of frequency occurrence.

7.2 Emergency descent

Emergency descent is executed by decompression cabin, by failures three generators and by fire. All these cases lead to infringement one or several extreme limitations, hence special situation is classified as emergency.

7.3 Failures in control system

Structure control system. Airplane Tupolev 154 has [7, p. 77]:
- longitudinal control system;
- rudder control system;
- lateral control system;
- automatic control system (ACS 154);
- spoilers control system;
- flaps control system;
- slats control system.

Main control surfaces Tupolev 154 are elevator for pitch, rudder for yaw, ailerons and lateral control spoilers for roll. Additional control surfaces: spoilers are used by landing, emergency descent and interrupted take-off; flaps, slats and horizontal stabilizer [3].

Airplane Tupolev 154 is controlled by means irreversible hydraulic drives (boosters), that is hinge moments control surfaces do not create efforts to wheel, column and pedals. Efforts for moving operating slide-valve in hydraulic drives are insignificant. Main (take-off and landing) load feel springs mechanisms are used for imitation efforts on wheel, column and pedals. In flight are switched additional load feel spring mechanisms for column and pedals. DC motors are used for switch and switch-off additional feel mechanisms.

If balancing position elevator, rudder or ailerons are changed then efforts for moving column, wheel or pedals are removed DC motors (trim tab effect).

Control system Tupolev 154 has three autopilot servo units for boosters controlling by signals from ACS 154. Servo unit is indirect action unit with rigid negative feedback. Servo unit consists from actuators, feedback gauges, demodulation and strengthening blocks.

Actuator is executive mechanism servo unit. Actuators are attached to control system through summarizing bell crank [7, fig. 5.3].

Feedback gauge has mechanial link with operating rod actuator and together with demodulation and strengthening blocks are realized rigid negative feedback.

Failure horizontal stabilizer control system.

Greatest danger is self-turning stabilizer by take-off, landing and flight. This functional failure is excluded structurally, that is confirmed by flight tests and operating experience.

[3] Tupolev 154 has extreme limitation [3, p. 14] flight speed for which admissible turning horizontal stabilizer $V \leq 425$ km/h, therefore turn is executed after take-off and before landing.

Stabilizer turning implements from two electric drives. At failure one electric drive turning time increases twice and any additional limitations is not entered. Special situation can be classified as complication of flight conditions.

Jamming stabilizer is found out under position index stabilizer. This failure is consequence two failures electric drives in control system stabilizer that is event practically incredible.

Failures in elevator control system:

- jamming one half of elevator;
- moving operating rod DC motor trim tab effect in extreme position;
- not switch-off flight load feel spring mechanism by extending flaps;
- not switch flight load feel spring mechanism by retracting flaps.

Jamming one half elevator is reduction efficiency longitudinal control. For exception secondary failure (jamming) second half elevator, in control system are spring links. Special situation can be classified as complex.

Effect move operating rod DC motor trim tab effect in extreme position is depended from stage typical flight, center mass position, airplane configuration, operating mode ACS 154, pilot competence, weather conditions. Effect this functional failure is change effort on column for keeping airplane in horizontal flight.

Criterion to classify special situation is:

$$P_c \leq [P_c], \tag{2}$$

where P_c — pilot effort to column for turn elevator; $[P_c]$ — maximal pilot effort to column.

In accordance with [1, item 25.143] $[P_c] = 4.5$ daN for long time effort and $[P_c] = 35$ daN for short time effort[4]. Thus criterion (2) is extreme limitation for pilot effort to column.

Let's consider some sets of initial data.

1. Moving operating rod DC motor trim tab effect in extreme position corresponding column motion from pilot; horizntal flight by level landing circle ($H = 450$ m, $V = 400$ km/h); forward position center mass; flight configuration; ACS 154 in mode manual control with improve stability and controlability.

As shown flight tests, failure is accompanied by growth pulling efforts on column. Efforts increase up to 90 daN during 10–12 s at actuated flight load feel spring mechanism. Manual switching-off flight load feel spring mechanism allows to reduce efforts up to 40 daN. Criterion (2) is not executed, extreme limitation hence is upset and there is emergency situation.

[4]Effort is short time if period of time less or equal 3–5 s.

2. Moving operating rod DC motor trim tab effect in extreme position corresponding column motion to pilot; horizontal flight by level landing circle ($H = 450$ m, $V = 400$ km/h); aft position center mass; flight configuration; ACS 154 in mode manual control with improve stability and controlability.

As shown flight tests, failure is accompanied by growth pressing efforts on column. Efforts increase up to 15 daN during 10–12 s. Airplane control is loss in atmosphere turbulence ("bumpiness"). Criterion (2) is not executed, extreme limitation hence is upset and there is emergency situation.

3. Moving operating rod DC motor trim tab effect in extreme position correponding column motion from or to pilot at intermediate position center mass. Additional effort on column less than earlier considered cases. At some position center mass criterion (2) is executed. Up to this center mass position special situation is classified as emergency, after — as complex, because Flight Manual recommends to approach with increased speed.

4. Moving operating rod DC motor trim tab effect in extreme position corresponding column motion to pilot at forward center mass position and from pilot at aft center mass position. Additional effort is not on column in any flight mode. Criterion (2) is executed. This is complex situation because Flight Manual recommends to approach with increased speed.

Not switch-off flight load feel spring mechanism by extending flaps. If airplane has forward center mass position on landing then effort on column up to 17 daN. Criterion (2) is not executed, hence there is emergency situation.

Not switch flight load feel spring mechanism by retracting flaps. Flight can be continued, because in normal flight column motion less than need for flight load feel mechanism began to work. However, enhanced attention from pilot is required, that there was no big column shift at flight with greater speed. Special situation can be classified as complication of flight conditions.

Failures in ailerons control system. In aileron control system airplane Tupolev 154 has spring links, feel spring mechanism and DC motor trim tab effect, therefore are possible following functional failures.

Jamming of one aileron leads to reduction efficiency lateral control. With the purpose of exception secondary failure (jamming) second aileron, spring links are actuated. Special situation can be classified as complex.

Moving operating rod DC motor trim tab effect in extreme position corresponding column motion from or to pilot is determined by turn wheel and roll airplane, or increase effort on wheel by keeping airplane in horizontal flight.

Criterion to classify special situation is:

$$P_w \leq [P_w], \tag{3}$$

where P_w — pilot effort to wheel for turn ailerons; $[P_w]$ — maximal pilot effort to wheel.

In accordance with [1, item 25.143] $[P_w] = 2{,}5$ daN for long time effort and $[P_w] = 27{,}0$ daN for short time effort. Thus criterion (3) is extreme limitation for pilot effort to wheel.

As shown flight tests, failure electrical mechanism ailerons trim effect and released wheel, roll angle increases slowly, about five degrees for five seconds. After elimination roll, effort to wheel is 10–12 daN. Maximal effort to wheel no more 25 daN also arises on turns with roll angle 25 degrees aside, opposite to moving operating rod DC motor.

Effort to wheel are removed at balancing aeroplane due to sliding. Sliding forms at turn rudder, and pedal effort is removed by means of rudder trim effect. Thus criterion (3) is executed due to increase load at crew. Special situation can be classified as complication of flight conditions, if will be no failure side engine and on landing will be no lateral wind.

Rudder control system failures:

- moving operating rod DC motor in extreme position;
- not switch-off flight load feel spring mechanism by extending flaps;
- not switch flight load feel spring mechanism by retracting flaps.

Moving operating rod DC motor rudder trim effect mechanism in extreme positions with released pedals is determined by roll. Roll angle increases in the same rate, that for ailerons, that is one degree per second.

Criterion to classify special situation is:

$$P_p \leq [P_p], \tag{4}$$

where P_p — pilot effort to pedal for turn rudder; $[P_p]$ — maximal pilot effort.

In accordance with [1, item 25.143] $[P_p] = 9{,}0$ daN for long time effort and $[P_p] = 70{,}0$ daN for short time effort. Thus criterion (4) is extreme limitation for pilot effort to pedals.

In horizontal flight the effort to pedals makes 25 daN and can be completely removed by sliding. For this ailerons turns in the opposite party, and efforts to wheel are removed by the aileron trim effect mechanism. Thus criterion (4) is executed due to increase in loading at crew. Special situation can be classified as complication of flight conditions, if will be no failure side engine and on landing will be no lateral wind.

Not switch-off flight load feel spring mechanism by extending flaps lead to additional extreme limitation: landing is authorized on dry strip with lateral wind up to 7 m/s (with take-off and landing load feel mechanism up to 12 m/s).

Considering, additional actions of crew at detection of failure, and also increased requirement to pilot competence, special situation is classified as complication of flight conditions.

Not switch flight load feel spring mechanism by retracting flaps. Flight can be continued, because in normal flight pedal motion less than need for flight load feel mechanism began to work. However, enhanced attention from pilot is required, that there was no big pedals shift at flight with greater speeds. Special situation is classified as complication of flight conditions.

Landing with retracting flaps. Aerodynamic characteristics airplane with retracting flaps or extended flaps are essentially various [3, ch. 4]:

$$c_L(\delta_f = 45°) = 1{,}27 > c_L(\delta_f = 0°) = 0{,}82,$$

where δ_f — extended flaps angle; c_L — lift coefficient.

$$K(\delta_f = 45°) = 5{,}2 < K(\delta_f = 0°) = 11{,}2,$$

where K — lift-to-drag ratio for Tupolev 154 with extended landing gear.

As consequence, landing speed airplane with retracting flaps ($\delta_f = 0°$) approximately on 50–80 km/h is more, than in normal landing configuration ($\delta_f = 45°$). Piloting technique at landing becomes complicated, and also, approximately in 1,5 times the landing distance increases. Brake wheels after landing are desirable cooling water in order to prevent their overheat. Special situation can be classified as complex.

7.4 Failures in hydraulic system

The hydraulic system of airplane Tupolev 154 consists of three independent hydrosystems. Sources of pressure are four pumps mounted on engines, by one on each side engines and two on center engine, and two electrically driven pump. Electrically driven pump capasity (20 litres per minute) is less than pump capasity mounted on engines (55 litres per minute).

Pressure in first hydrosystem forms from two pumps mounted on left side and center engines. Pressure in second hydrosystem forms from second pump mounted on center engine and/or from electrically driven pump. Pressure in third hydrosystem forms from pump mounted on right side engine and/or from second electrically driven pump.

First hydrosystem provides with energy[5]: actuators and units in three channels of control; spoilers actuators; flaps actuators; landing gear actuating cylinder (main); braking of wheels (main and emergency).

[5] Those consumers which failure renders the greatest influence on safety are resulted only.

Second hydrosystem provides with energy: actuators and units in three channels of control; flaps actuators; landing gear actuating cylinder (emergency).

Third hydrosystem provides with energy: actuators and units in three channels of control; landing gear actuating cylinder (emergency duplicating).

From aforesaid follows, that engine failures directly influence to up state pumps, this is *dependent* events. Failure critically power plant for airplane as whole is: engines failure effect (change of aircraft performance), hydrosystem failure effect (reduction of hydraulic power), failures effects systems and units feeding from hydrosystem (airplane control, landing gear control and so on). Therefore, for analysis simplification we shall assume, that hydraulic system capasity reduction is caused only by pumps failures.

If there will be pump failure on left side engine, then three hydrosystems will work all, but capasity in the first hydrosystem will decrease twice.

If there will be pumps failure on center engine, then two hydrosystems will work: first (with half capasity) and third. It is possible to provide work second hydrosystem with reduced (approximately on a quarter) capasity, if to actuate electrically driven pump.

If there will be pump failure on right side engine, then two hydrosystems will work: first and second. It is possible to provide work third hydrosystem with reduced capasity, if to actuate electrically driven pump.

If there will be pumps failure on two engines[6], then effect will be depend from remained pump(s). The crew is recommended to be climbed to altitude 3 km, to start auxiliary power plant and to connect its AC source to system of electrosupply and to actuate both electrically driven pumps.

If working there was pump on left side engine, all hydrosystems will save up state, but with reduced capasity.

If working there were pumps on center engine, all hydrosystems will save up state: second with full capasity, first and third with reduced capasity.

If working there was pump on right side engine, two hydrosystems will save up state: second with reduced capasity, third with full capasity.

Estimating failures effects pumps for airplane as whole, it is possible to draw following conclusions:

At failures pumps and electrically driven pump from second or third hydrosystem, all crucial systems save up state. Special situation can be classified as complication of flight conditions.

At failures pumps from first hydrosystem there are down state for landing gear retracting, spoilers extanding and is at a loss wheels braking after landing. From braking means there are engines reversers and emergency

[6]It's probably in flight to repair factory, when units are in transition state from up to down.

wheels braking from hydroaccumulators. Special situation can be classified as emergency.

At good state only first hydrosystem all crucial systems save partial up state. Servo units are switched-off, actuators efforts decrease. Special situation can be classified as complex.

At good state only second hydrosystem all crucial systems save partial up state. Servo units are switched-off, actuators efforts decrease. There are flaps extending and emergency retracting landing gear. From braking means there are engines reversers and emergency wheels braking from hydroaccumulators. Special situation can be classified as emergency.

At good state only third hydrosystem all crucial systems save partial up state. Servo units are switched-off, actuators efforts decrease (with additional limitation by flight speed), flaps are not extended. There is duplicating emergency retracting landing gear. From braking means there are engines reversers and emergency wheels braking from hydroaccumulators. Special situation can be classified as emergency.

7.5 Servo unit failures

Failures of servo unit can be full, that is with switch-off servo unit and partial, that is with reduction efforts.

Full failure all servo units lead to switch-off ACS 154 and change airplane performance:

- not damping longitudinal and lateral fluctuations;
- airplane control efficiency on greater speeds increases;
- airplane control efficiency on small speeds decreases.

Owing to switch-off all servo units (and ACS 154) there are additional limitations flight modes[7]:

- by Mach number $M \leq 0{,}8$;
- by indicated air speed $IAS \leq 500$ km/h;
- by center mass limits 20 % $\leq \bar{x}_m \leq$ 28 %.

Operating rod servo unit is stopped by switch-off. To exclude influence position operating rod on movings control surfaces, aligning spring link are attached to differential bell crank. Aligning spring link is intended for moving operating rod servo unit to neutral position, after switching-off servo unit from hydrofeed.

In view of additional limitations flight modes and structure mechanical part of control system, special situation can be classified as complex.

Full failure one or two servo units leads to partial failure ACS 154 depending on in what control channel the given up unit is mounted: pitch,

[7] Extreme limitations for normal flight: 0,88; 575 km/h; 18 % and 40 % accordingly.

roll or yaw.

Partial failure effects are determined by features of servo unit structure. Servo unit is the electrohydromechanical device receiving energy from hydrosystem and information in the form of electric operating signals from ACS 154.

On airplane three-channel[8] servo units are mounted. Each subchannel is unified and consist from: electrohydraulic valve, two-cascade electrohydraulic amplifier [9, fig. 8.26], hydraulic cylinder of bilateral action with linear moving operating rod and feedback gauges.

Electrohydraulic valve is intended for switch (or switch-off) hydrofeed to subchannel.

Two-cascade electrohydraulic amplifier is intended for control charging and discharging liquid to hydraulic power cylinders. Operating rod speed moving is proportional electrical signal. This control signal is formed in ACS 154 and input to amplifier.

Feedback gauge give electric signal proportional to position of operating rod. Feedback signal is subtracted from input control signal to amplifier. It leads to delay and stop motion operating rod at approach to extreme position.

At such structure servo unit following failures are possible: hydrofeed loss, circuit opening of control and circuit opening of feedback.

Hydrofeed loss or circuit opening of control or circuit opening of feedback. Failed subchannel is switched-off. Servo unit is up state with decrease efforts. ACS 154 is up state. Special situation is classified as complication of flight conditions.

Hydrofeed loss or circuit opening of control or circuit opening of feedback in two subchannels. Failed subchannels are switched-off. Servo unit is down state and ACS 154 is switch-off this servo unit.

Aircraft performance is worsen by channel in which failed servo unit is mounted. Additional limitations of flight modes are entered. Special situation can be classified as complex.

[8] Here: channel for transfer energy and information. Unlike the previous item where it was a question of airplane control channels by roll, yaw and pitch.

Glossary

Flight safety. Air comlex (crew, airplane, ground maintenance[9]) property to execute flight without special situation.

Airplane safety. Airplane property to execute flight without special situation.

Failure-free operation (reliability). Product property is up state at set period of time (for example during flight) in set conditions.

Sudden failure. It is characterized by short period of time, commensurable with time for one operating cycle. Working parameters change jump out of admissible range.

External effect. Random event not connected with airplane structure, for example: atmospheric conditions (shear wind, temperature inversion, icing, impact of lightning and so on); runway condition; fire in cabin or luggage compartment. Diversions, that is *deliberate* damage or destruction airplane, do not concern to external effects.

Defect. Faulty state is realized during manufacture. Defects can appear both designing and manufacturing. At designing defects owing to incorrect estimation dynamic (vibrating) durability and ways vibroisolation. At manufacturing defects owing to choice inadequate technology or not observe their.

Durability (longevity). Product property to save up state before limiting state with established system of maintenance, recovery and repair.

Fail-safe. Airplane property to save up state under action striking means, unprescribed loads and with collected damages.

Product. Airplane, functional system or element system.

Good state. Product corresponds to all requirements of the normative, technical and design documentation.

Reliability (dependability). Product property to save in time in set limits value all parameters describing ability to execute demanded functions in set modes and conditions of application, maintenance, repairs, storages and transportations. Reliability is generalized property which, depending from purpose product and conditions of its application consists of a combination properties: failure-free operation, durability, maintainability and retentivity.

[9]Incliding air traffic control.

Faulty state. Product mismatches even to one requirement normative, technical and the design documentation.

Down state. Product mismatches even to one requirement normative, technical and design documentation which characterizes ability to execute flying mission.

Expected operating conditions. Are known from practice, their occurrence is possible with sufficient basis to anticipate during lifetime airplane in view of its purpose. These conditions include parameters of condition and factors of effect aboard the plane an environment, and also the operational factors influencing on flight safety. Expected operating conditions do not actuate extreme conditions.

Failure (failed state). Down state airplane, functional system or element system, irrespective of the reasons.

Mistake. Wrong actions crew or maintenance personnel. In [1] is not present, but, apparently, mistakes services air traffic control here should concern.

Parametrical failure. Comes at achievement in working parameter border specified range. System or element system should be injected from operation as inappropriate to specifications.

Damage (fault). Faulty state arising owing to inadmissible operational effects.

Gradual failure. It is characterized by the long period of time, commensurable with lifetime product. Working parameters product come nearer to border admissible specified range, before occurrence parametrical or sudden failure. Any products are subject to gradual failure.

Limiting state. Further using product is to destination inadmissible or inexpedient, and restoration to up state or good state is impossible or is inexpedient.

Extreme limitations. Flight modes limitations, output for which is not admissible under no circumstances.

Up state. Product corresponds to those requirements normative, technical and design documentation which characterize ability to execute the flying mission.

Recommended flight modes. Modes inside area determined by operational limitations, written in Flight manual.

Maintainability. Product property consisting fitness to prevention and to detection failure cause, maintenance and restoration up state at maintenance and repair.

Storability. Product property to save measures reliability, durability and maintainability during and after storage and/or transportation.

Functional system. Set of the interconnected elements and units, intended for performance set general functions.

Operating limitations. Conditions, modes and parameters values, deliberate output for which limits is not admissible while airplane is in operation.

Extreme conditions. Conditions, with which it is possible to avoid a meeting by introduction operational limitations and rules, and also such conditions which arise so seldom, that requirement to execute airworthiness standards in these conditions would lead to higher level airworthiness, than it is necessary and is practically proved.

Bibliography

[1] Aviation rules. Part 25. Airworthiness standards airplanes transport category/ By edited *L. M. Berestov, A. N. Stepanenko.* — Zhukovskiy: M.M.Gromov Flight Reserch Institute, 1994. — 322 p. (in Russian).

[2] *Anceliovich L. L.* Reliability, safety and fail-safe airplane. — M.: Mashinostroenie, 1985. — 296 p. (in Russian).

[3] Aerodynamics airplane Tupolev 154/ *T. I. Ligum, S. U. Skripnichenko, L. A. Chulskiy, A. V. Shishmarev, S. I. Urovskiy.* — M.: Transport, 1977 — 304 p. (in Russian).

[4] *Bruskin D. E., Sindeev I. M.* Electrosupply of flight vehicles. — M.: Vysshay shkola, 1988. — 264 p. (in Russian).

[5] The air code of the Russian Federation. — M.: Norma, 2001. — 56 p. (in Russian).

[6] *Komarov V. A.* Design bearing surfaces flight vehicles: Manual. Samara state airspace univ. Samara, 2002. 96 p. (in Russian).

[7] *Koptev A. N.* Systems of air navigation. — M.: Mashinostroenie, 1984. — 128 p. (in Russian).

[8] Designing of civil airplanes: Theories and methods/ Edited by *G. V. Novozhilov.* — M.: Mashinostroenie, 1991. — 672 p. (in Russian).

[9] Systems of the equipment of flight vehicles/ M. G. Akopov, V. I. Bekasov, V. G. Dolgushev and others; Edited by *A. M. Matveenko, V. I. Bekasov.* — M.: Mashinostroenie, 2005. — 558 p. (in Russian).