THE COMPARATIVE ANALYSIS OF THE RUSSIAN AND FOREIGN STRENGTH REQUIREMENTS (AR-25, FAR-25, CS-25) TO THE CIVIL TRANSPORT CATEGORY AIRPLANES

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Historically the airplane strength normative requirements were formed in Russia (the USSR) in 1925-1965 substantially independently of the similar foreign requirements. At the same time they held the requirements to the military and civil planes and usually had closed character.

The approximation of native and foreign requirements was started during the preparation of the first Airworthiness Requirements for Civil Planes of the USSR (NLGS-1 of 1967 [1]) and was continued during the issue of the next Requirements (NLGS-2 of 1974 [2], NLGS-3 of 1984 [3]).

The fundamental approximation of Requirements took place early in 90th under the development of the Aviation Rules (AR-25 [4]) which were based on FAR-25 [5] that resulted in cardinal change both structure and wordings. At the same time a number of additional requirements based on the Russian airplane design practice, the experience of their tests and maintenance is retained in the AR-25. The most considerable of them are listed below.

§ 25.307 Proof of structure

According to the AR-25 [6] and CS-25 [7], if the static tests are necessary to prove the compliance with the strength requirements they must be conducted up to the ultimate loads and at the same time the Airworthiness Authority may agree in every specific case to equivalent substantiation of sufficient strength obtained from tests to lower loads. By FAR-25 the Administrator may require ultimate load tests in cases where limit load tests may be inadequate. The grounds of the Russian approach are the following:

- the fracture criteria necessary for the right construction bearing capacity estimation can be obtained only under the loads close to ultimate load;
- in accordance with the native and American statistic data each new airplane has under static tests in average about six premature failures with three of them occur at load lower by 80% than the ultimate load.
- the state when the Airworthiness Authority (the Administrator) has to look for the proofs for the load level increase under the

tests seems unnatural and the way when the Declarant bases the possibility of some lightening of requirements is more understandable;

– having the modern methods of calculations using the final structure method and experimental methods applying the multichannel strain measurement the phased bringing of the tested construction to the loads close to the ultimate load without destruction is possible and allows to carry out in series (with the construction local areas strengthening realization on the increased strain detection if it is necessary) the static strength reliable estimation for many components of the construction.

§ 25.331 Symmetric maneuvering conditions

The paragraph 25.331(c)(2) of AR-25 contains the design conditions for the determination of the loads on the airplane at checked pitch maneuver between V_A and V_D speeds which differ from FAR-25 ones and prescribe to take such regulated limiting values of positive and negative maneuver load factor whose increase in relation to the initial state (level flight) are equal by absolute value. At the same time the positive limit maneuver load factor equals to the maximum limit maneuver load factor and the negative limit maneuver load factor exceeds the minimal limit maneuver load factor or equals to it. The requirements of the paragraph are complemented with the instructions on the control deflection regulated frequency determination method used if the airplane aerodynamic properties have essential nonlinearity and the requirement to consider the influence of the automatic control system on the loads with allowance for operations and failure of the system. Moreover the recommendations on the deflection law modification are given for the case when the limiting values of the load factor may not be attained at the control wheel (stick) deflection allowed by the control system. The recommendations close to these ones by their influence on the airplane

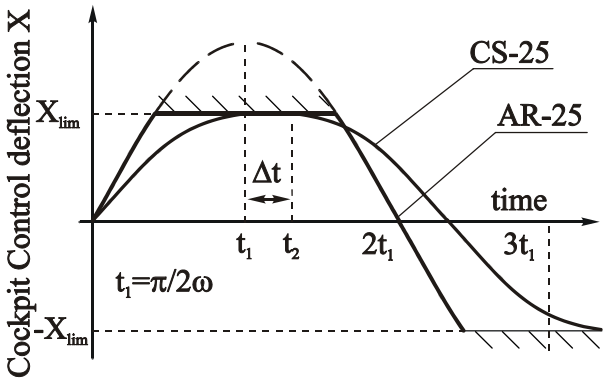

Fig. 1

maneuver pattern are contained in CS-25 (fig. 1) but the limiting negative load factor value mismatching with the value accepted in AR-25 and equal to zero is used there.

It follows from the consideration of the airplane maneuver characteristics according to the AR-25 design conditions that the arising angular accelerations comply with the FAR paragraph 25.331(c)(2) requirements.

§ 25.333 Flight maneuvering envelope

The following fundamental modifications are introduced to the diagram (fig. 2) given in the subparagraph (b) of the given paragraph in comparison with FAR-25 and CS-25:

– the point E corresponding to the zero load factor and to the velocity equal to V_D At

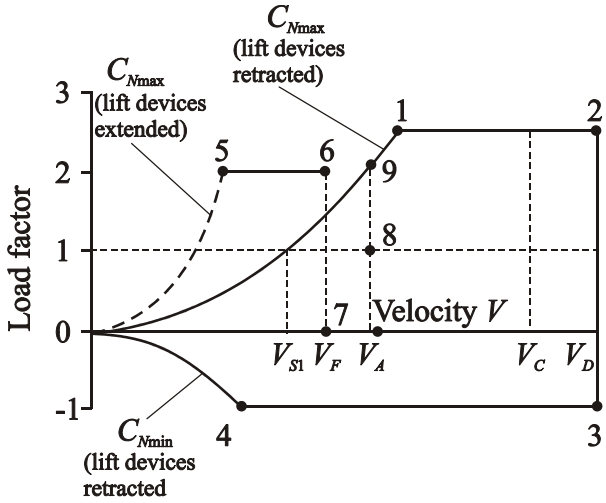

Fig. 2

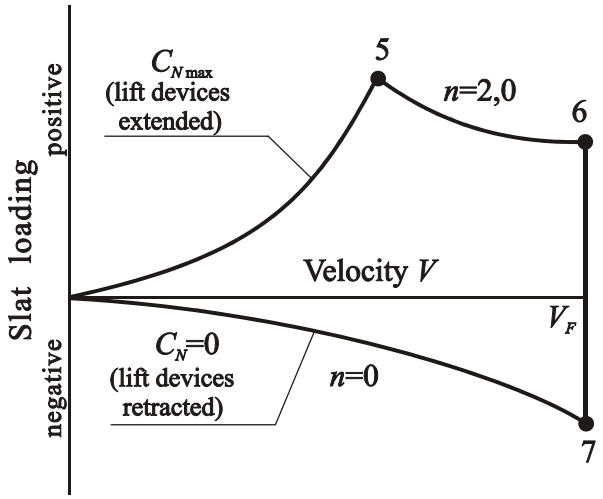

Fig. 3

the FAR-25 diagram is changed for the point 3 in which the load factor $n = -1{,}0$ is accepted at the same velocity V_D;

– the points 5, 6, 7 are marked out in the part of the diagram which is the fight condition envelope at the realization of the maneuvers with the lift devices up, with the maximum positive load on the slat, maximum load on the flap and the load on the slat which is maximum by absolute value being reached at these points. The airplane structure strength must be additionally provided for the load factor and velocity combinations corresponding to these points, namely:

- at the point 5 the load factor value equal to 2.0 and the minimum velocity at which this load factor may be attained (fig. 3), i.e. corresponding to the flight at $C_{N\max}$ with the lift devices up, are taken;
- at the point 6 the load factor value equals to 2.0 and the velocity is equal to V_F;
- at the point 7 the load factor value equals to 0 and the velocity is equal to V_F.

§ 25.351 Yaw maneuver conditions

The main difference of the AR-25 requirements is that the pedal return from deflected state to neutral must be carried out right away after the plane has yawed to the maximum sideslip angle (taking the transient overshoot into account). According to FAR-25 the pedal return to neutral is carried out from the airplane flight regime with the steady sideslip angle that leads to the decrease of the total loading of the keel and the rudder. At the same time in accordance with FAR-25 the pedal effort must be kept constant at first maneuver stage (by AR-25 the initial pedal stroke is maintained constant) and the rudder may deflect additionally as the hinge moment increases that makes for some increase of the maximum sideslip angle and the keel loading respectively. The AR-25 requirements usually result in more severe load conditions for the vertical empennage.

§ 25.367 Unsymmetrical loads due to engine failure

As the paragraph 25.417 of AR-25 subpart B – Flight like FAR-25 requires assure the directional and transverse controllability of the airplanes with four or more engines when the two critical engines are out of work and the loads appearing while the shutdown of two engines on the one side of symmetry occur may turn out to be determinant on the estimation of the strength of a number of airplane aggregates, vertical empennage first of all, the following requirements are included in the § 25.637(a) of AR-25:

«For airplane with four or more engines if it is not shown that a simultaneous or successive stoppage of engines from one side of the airplane symmetry plane is extremely improbably, then it also is necessary to consider such kind of failure. In such a case the design conditions are coordinated with the Airworthiness Authority».

There is also pointed out in the § 25.637(a)(2) of AR-25 that the loads resulting from the disconnection of the engine compressor from the turbine or from loss of the turbine blades are considered to be limit loads but factor of safety, specified in § 25.303, may be reduced to 1.25. Reasoning from the common safety en-

suring conception the FAR-25 requirement to consider these loads as ultimate loads seems to be technically groundless since the possibility to prove the compliance with the requirement of § 25.571(e) on the flight successful completion ensuring in case of uncontained engine failure is not clear in this case.

Moreover, according to the §25.367(b) of AR-25 pilot corrective action is provided to initiate at the time when maximum sideslip angle (not maximum yawing velocity as in FAR-25) is reached. This change inserted in AR-25 is based on the regulation experience and contributes to the safety level increase.

§ 25.427 Unsymmetrical loads

The requirements of this paragraph of AR-25 are complemented with design conditions for combined loading of horizontal and vertical single-finned surfaces contained in NLGS and based on the long-term experience of airplane design and maintenance. It is necessary to consider simultaneous loading of these surfaces in all cases provided for isolated symmetric horizontal surface loading and separate symmetric vertical surface loading. However the loads acting on each surface are determined at the diminished maneuver parameters in the vertical plane; pedal deflection angles and gust loads being equal to 75% of their values at isolated loading. It should be mentioned that the indicated gust loads are practically conform to ones obtained from "circular" gust acting at 45° relatively to the vertical plane ($\sin 45° = \cos 45° = 0{,}707$) in accordance with the 25.331(c)(2). Furthermore it is specially indicated in AR-25 that the vertical surface loading must be distributed asymmetrically accordingly to the sideslip angle determined in the considering combined loading condition. If the horizontal surface is situated on the vertical one it is also required to consider combined load of the vertical surface with the loads effecting it in the isolated loading conditions and the horizontal surface with the level flight balancing load distributed asymmetrically at the limit sideslip angle proper to the corresponding isolated loading case for the vertical surface. The last requirement complements the §25.427(c) instructions since the loads acting on the vertical surface during the vertical maneuver must be considered apart from the gust loads. Simultaneously the paragraph 24.427(d) of FAR-25, according to which the asymmetric empennage loading due to buffeting should be taken into account, is excluded from AR-25 and CS-25 as the additional requirements inserted in AR-25 ensure necessary empennage and airplane tail part strength at the buffeting load conditions given in §25.251.

§ 25.473 Landing load conditions and assumptions

The following changes and supplements are inserted in this paragraph of AR-25:

- the concepts of the limit energy at the design landing and takeoff weights and the maximum energy at the design landing weight are introduced;
- the expression is given for the determination of the limit descent velocity depending on the airplane landing velocity and the designed value slope of airfield in airplane touchdown zone, the low bound of the limit descent velocity equal to 3.05 m/s is established that corresponds to the FAR-25 requirements (10 fps) extending to the all transport airplane classes and ground characteristics;
- the instructions on determination of the airplane descent velocities are given in order to compute the maximum energy at the design landing weight and the limit energy at the design takeoff weight;
- it is explained that the coefficient of friction between the tires and the ground need not be more than 0.5 for maximum energy absorption, the loading with zero coefficient of tire-ground sliding must be also considered;
- for conditions of absorption the maximum energy it is admitted to take the factor of

safety reduced down to 1.0; however if this factor is taken less than 1.3, it must be shown by objective data that under the action of ultimate loads there would not be any failure of airplane and landing gear struts or such a degradation of their strength, which can cause dangerous consequences.

It should be specially mentioned that the requirements to the ensuring of the structure strength under ultimate loads at the maximum energy absorption though at reduced value of the coefficient of safety, which are included in this and a series of following paragraphs of AR-25, are transferred from NLGS, they comply with the airplane design practice and make for the increase of safety at rough landing. §25.723 is the only paragraph in FAR-25 and CS-25 that contains the instruction that the landing gear may not fail in demonstration of the landing gear shock-absorbing system ability to absorb the maximum energy (that is reserve energy in terms of FAR-25) during drop tests.

§ 25.479 Level landing conditions

The instructions to consider a combination of the maximum drag (on and against flight) loads arising at spin-up of a the wheel, and vertical loads appropriate to them on time, and a combination of the maximum vertical load and the drag load appropriate to it on time, contained in §25.479(c) of FAR-25 and AR-25 1994, are included in the end of §25.479.

The §25.479(d) requirements to the conditions of lateral drift landing are changed:

- in addition to the combination of vertical, drag and lateral loads determined from the maximum vertical load arising at limit energy absorption, given in FAR-25, the similar combination of loads corresponding to the maximum load at maximum energy absorption should be considered;
- the requirement to consider lateral loads determined on the wheel slipper characteristics at given vertical loads and wheel slipper angles at the same values of vertical loads and at drag load equal to zero in conditions of limit and ultimate energy absorption.

The last addition sets a connection between the wheel slipper angles, given for the lateral loads to be determined acting on the landing gear, and the lateral wind velocity that is necessary in order to set in the Flight Maintenance Guidance the maximum admissible value of this velocity at the airplane takeoff and landing.

In addition the special instruction concerning the way of determination of loads effecting the nose landing gear, if simultaneous contacting the ground by the nose and main wheels is unattainable at the specified descent and forward velocities, is included in the §25.479(c)(2).

§ 25.481 Tail down landing conditions

The requirements concerning the load conditions for the tail skid are inserted in this paragraph of AR-25 and based on the NLGS instructions. In order to approximate to the real load conditions, the requirement to consider the backward horizontal force applied at the contact point along with the vertical point is additionally included in the new issue of AR-25.

§ 25.499 Nose-wheel yaw and steering

The difference between the requirements of FAR-25 with the amendment 25-91 of 1997 and AR-25 is that the subpart (e) of this paragraph requires to increase in 1.33 times not only the static reaction effecting the nose wheel, as it is prescribed by FAR-25 and JAR-25, but the torque acting on the nose gear from the control system. Such an increase is equivalent to the transfer from the normal safety coefficient equal to 1.5 to the increased one that equals to 2.0 (1,5·1,33=2,0) and it is explained by the greater possibility to amount at the airplane taxi to the combination of static load acting on the landing gear and the torque taken as the initial combination and consequently by the possibility to exceed this combination during maintenance.

§ 25.515A Shimmy

The requirements concerning to the ensuring the landing gear wheels shimmy and the instructions on the works that should be realized to prove shimmy safety are inserted.

§ 25.533 Hull and main float bottom pressures

The expression for the local pressure determination containing in FAR-25 and transferred to AR-25 are complemented with the instructions on the size of minimal area (a cell) to which the pressure are applied and on its increase at the bottom upward the step. In addition the requirement to design the strength of bottom plating from nose to main and second steps for local suction is inserted. The values of this suction and the law of distribution along the float are given.

Unlike FAR-25, where the value of the coefficient C_4 depends on the value of the coefficient C_1 that may be increased according to §25.527, in AR-25 the coefficient C_4 is set to be constant and corresponds to the minimal value of C_1 since practically the necessity to change its value does not arise at real designing.

§ 25.629 Aeroelastic stability requirements

This paragraph is complemented with the instruction to analyse the aeroelastic interaction between the airplane and the control system. The additional subpart (a*) contains the specific requirements on the margins that must be ensured on the module and the phase of the frequency response function of the open loop "Airplane-Control System", which are fully agree with the requirements preset in the American Military Airplane Requirements (MIL-A-8870), where the name "aeroservoelastity" is given to this phenomenon. However, there is an additional instruction in AR-25, which states that the mentioned margin values may be accepted only under the condition that they are verified by flight test results. According to AR-25, if only design and ground frequency response function experimental research results are used to prove the safety from the aeroelastic phenomenon under consideration, the required module margin must be increased from 2 to 3.3 and the phase range being investigated is extended from $\pm 60°$ to $\pm 90°$.

AR-25 has another fundamental difference. The safety from the aeroelastic instability must be ensured at all flight speeds up to V_D/M_D enlarged by 20%. In FAR-25 the velocity margin, early also equal to 20%, is decreased to 15% by the amendment 25-77, 57 FR 28949 of July 29, 1992. In Ar-25, Jar-25 and CS-25 the requirement of 20% velocity margin is saved up to present time because of the absence of the necessary data testifying to the possibility of margin values change without safety level decrease.

In order to allow for the difference between the separate airplane specimens the supplementary instruction stating that the investigations must be fulfilled for initial state of structure, so as to probable changes of parameters, that determines the phenomenon.

Apart from the flutter, the divergence and the control reversal are included in the subpart (e) of this paragraph to the list of aeroelastic phenomena that must be investigated during flight tests. In accordance with the flight tests practice such investigations are fulfilled together with the stability and controllability characteristics researches.

§ 25.631 Bird strike damage

In AR-25 the requirements of this paragraph are extended to the whole airplane, not only to the empennage (as in FAR-25). At the same time the weight of the bird is accepted to be equal 1.8 kg, like in the §25.571(e) "Damage tolerance (discrete source) evaluation". The bird weight increase made only for design conditions of impact with the empennage seems to be groundless. It should be

mentioned that in CS-25, as earlier in JAR-25, the requirements of this paragraph are analogous to the AR-25.

Common remark

In a number of paragraphs of AR-25 of 2004 the text changes in relation to FAR-25 are due to the transfer from system of measurements used in the USA (pounds, foots, etc.) to one used in the Russia (kilogram, meter, etc.). Besides the main changes mentioned above the editorial correcting and the indication change introduced during translation are made in certain paragraphs, they do not influence on the requirements substance. Some misprints are also corrected.

References

[1] *The Airworthiness Requirements for Civil Planes*. TsAGI. 1961.

[2] *The Airworthiness Requirements for Civil Planes of the USSR, second edition, NLGS-2*. MVK USSR, Moscow. 1974.

[3] *The Airworthiness Requirements for Civil Planes of the USSR, third edition, NLGS-3*. MVK USSR, Moscow. 1984.

[4] *Part 25 of the Aviation Regulations. Airworthiness Requirements for Transport Category Planes. AR-25.* LII, Moscow. 1994.

[5] *Federal Aviation Regulations. Airworthiness Standards: Transport Category Airplanes. FAR-25*. 1990.

[6] *Part 25 of the Aviation Regulations. Airworthiness Requirements for Transport Category Planes. AR-25.* IAC, Moscow. 2004.

[7] *Certification Specifications for Large Aeroplanes. CS-25*. 2003.