In modern Russian and foreign regulations, the damage tolerance (survivability) is considered to be the main principle of providing safety for operational aircraft structures. Damage tolerance is the property of a structure that enables it to sustain fatigue, corrosion, and accidental defects safely. This principle includes fail-safe and damage tolerance. Soviet and US methods were developed simultaneously. These two methods were analyzed and compared in the work [1]. The Russian method was developed in the TsAGI, in cooperation with the design departments of O. K. Antonov, V. S. Il’yushin, A. N. Tupolev, and A. S. Yakovlev; such research institutes as the All-Russian Scientific Research Institute of Aviation Materials, the State Research Institute of Civil Aviation, and Siberian Aeronautical Research Institute named after S. A. Chaplygin. Publications in the following areas were analyzed: structure survivability of such airplanes as Boeing (W. Goranson), Douglas and FFA USA (T. Swift), and Airbus (J. Schmidt); linear fracture mechanics by such authors as D. Broek (Delft University of Technology, the Netherlands), J. Skyve (Delft University of Technology, the Netherlands), S. I. Kishkina (All-Russian Scientific Research Institute of Aviation Materials), N. A. Makhutov (Institute of Machine Science of the RAS), E. M. Morozov (National Research Nuclear University “MEPhI”), V. V. Panasyuk (Karpenko Physico-Mechanical Institute of the NAS of Ukraine), etc. This work reviews the strategy for aircraft structure survivability developed in the TsAGI, the lead institution of the aviation industry in the USSR and Russia.

In the TsAGI, a system of providing the operational survivability of structures was developed for both passenger and cargo airplanes at the design and operational stages. This system was supposed to increase the safety level of the airframe based on the strength condition by inspecting it and by increasing 1.5–2.0 times the durability compared to the safe-life.

A detailed review of solving the problems of this system for the periods of 1963–1993 and 1993–2003 with the list of main authors is represented in [2, 3]. This article reviews the analysis of results of the main scientific researches in the TsAGI concerning the area of tolerance for these periods and the subsequent years.

In the mid—60s, the TsAGI had started new research on aircraft material fatigue, studying the regularities of fatigue crack growth. The experiments were conducted on rather narrow (up to 100 mm wide) flat samples with the crack passing through the center. In [4] a wide scope of research on samples of different aluminum alloys at regular (sinusoidal) stresses is presented. To obtain a quantitative characteristic of fatigue crack growth, the criterion of linear fracture mechanics or the stress intensity was introduced [5]. This period of research showed that the actual growth of cracks in the airplane structures operating with irregular loads can exceed by 1.5–5 times the growth calculated by means of linear addition. To consider the slowdown of crack growth, a model was introduced in early 70s, in which the braking coefficient was determined by experiment [6].

At the same time, A. F. Selikhov managed the development of statistical methods used to determine the characteristics of fatigue crack development in the components of aircraft structures from operation data [7]. Thus, the developed dependences of crack growth on the aircraft life increase the influence of different operation factors, including irregular loading.

In 1990s, the models of crack resistance were developed for aluminum alloys with smaller cracks (corner cracks near holes) [8].
In fact, TsAGI and Research Institute-18 began studying operational tolerance of real airplane structures after An-10A passenger airplane crash in 1972 after multiple fatigue cracks on the mid-wing lower panels.

An-10A plane crash made it necessary to introduce the requirements of aircraft tolerance into the air flight worthiness during designing and operation stages. These tasks were started to be fulfilled under the supervision of A.F. Selikhov, the corresponding member of Russian Academy of Sciences and TsAGI deputy director. The main author of the operation aircraft structure tolerance methods is G.I. Nesterenko.

Using the materials of this work, he defended his doctoral thesis in the TsAGI (1988), received the USSR National Award (1989), won the first prize and the N.E. Zhukovskii Gold Medal (1995), and won the prize of the Government of the Russian Federation in Science and Technology for the “Studies and introduction of the effective concept of supporting the flight worthiness of An-124-100 in terms of lifetime and operational endurance up to 10000 flights, 50000 flying hours, and 45 years, which provided long-term world leadership in superheavy cargo transport” (2012).

The main scientific results for this method are the following [9]:

— Comprehensive analysis of the results of foreign studies in the area of aircraft structure tolerance [10].

— The crack growth resistance of the Russian aluminum alloys produced in the 70s is lower than that of the alloys produced abroad. The main factor influencing the crack growth resistance of the materials is the percentage of the silicon and iron impurities. In the Russian alloys this percentage is 0.3–0.4%, while in the foreign ones 0.05–0.09% [9]. The crack growth resistance in the Russian alloys can be increased up to the required level, if their percentage is decreased. This problem was solved as a result of developing and introducing the System of Managing the Quality of Aircraft Materials into Russian metallurgy in the 80s [11].

— Based on the analysis of unfavorable fatigue damage of full-size machines and on the limits of airplane maintenance, the main criteria of tolerance were determined, along with the maximal scales of damage and the required time of crack growth from the initial to the maximal size [12, 13]. High reliability of wing structure is provided if two kinds of requirements are simultaneously satisfied—a tolerance limit on the conditions of multicentric damage of the separate characteristics and the requirements for the multicentric damage of a section of the structure (with one center of cracks in a few elements). To satisfy this requirement, the wing structure should remain solid at the operation load \( P' \) if one of the panels is completely demolished, while there are no cracks in other panels, or if there is a double crack in the covering with a demolished stringer in any of the panels, while the other panels have no cracks. In the same way, as in the case of the wing for pressure fuselages, acceptable damage is considered to be any double crack in the cover with a demolished frame or stringer in the middle. These criteria were provided for the wing and fuselage structures of the following planes, the II–96–300, An–124–100, and Tu–204.

To provide economically efficient operation of the projected airplanes, inspections for cracks in the cover under the demolished stringer should be conducted every 3000–5000 flights [12, 13]. The junctions with poor defectoscopy should be designed using the safe-life principle [12]. Criteria for structure tolerance in case of multicentric fatigue cracks should be stated in the regulatory documents [14, 15].

— New methods of calculating the remaining airframe integrity allow estimating the remaining wing and fuselage integrity with some damage. Among the main ones is calculating the remaining integrity of...