The “Use of Elasticity” Concept and Flight Safety in View of Advanced Airplane Designs

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One of the very promising areas in aircraft design today is associated with the ‘**use of aeroelasticity’** concept. Directly or implicitly, this is just the idea we can find behind a new class of so called **‘selectively deformable’ structures** that has been developed in Central Aerohydrodynamics Institute (TsAGI) basing on earlier proposals of new aerodynamic controls, also the product of TsAGI. Efficient integrated analytical and experimental methods of **multi-disciplinary studies** also originated in TsAGI in conjunction with the concept.

The efficiency of appropriate priority Russian developments is proved by the experience of several past decades, but this is as well the matter of future to guarantee safety, weight and aerodynamic perfection, and finally the competitiveness of airplanes of the next generation.

I. The very early 60-th in Russia faced exigency to raise structural stiffness of thin wings of the M-50 and R-020 airplanes to alleviate negative effect of elastic deformations on lateral control efficiency. However the required weight increase of primary structure to solve aileron reversal problem appeared to be far beyond acceptable limits, even if this was done with use of optimization procedures. That was the time when a solution, paradoxical at first glance, was proposed: don’t fight wastefully against elasticity, just use it [1]!

The first off-set (tip aileron shifted forward with respect to elastic line) and extension ailerons were developed and tested in TsAGI T-109 wind tunnel on an elastically scaled model of the M-50, then on the models of R-020, MiG-25, and Yak-28 planes [2], [3], [4]. Another type of “using elasticity” control surface, namely differentially deflected wing leading edge (forward aileron), was under investigation since 1963 [3], [4], [5]. Both wind tunnel testing on elastically scaled models of Su-27 and MiG-29 and analysis confirmed effectiveness of leading edges differential deflections, as well as of the new concept in general. More over, use of elasticity of Yak-28 wing structure with the aid of off-set ailerons, as flight tests showed later, solved the difficult problem of roll control reversal of the airplane when the need for sufficient increase of maximum flight speed for one of the plane version arouse [6]. Traditional approach required unacceptable (by several times) increase of skin thickness in the area of wing root, while off-set ailerons allowed it to be made even thinner. The first open information on TsAGI work on use of elasticity (particularly, results of forward aileron studies) was published in 1980, at Soviet-France Symposium in Paris [5], and more comprehensive information was published in 1991 during a working meeting of TsAGI and Boeing experts in Seattle [7].

A new version of American F/A-18 fighter was another example, for which the prospects of firstly proposed in TsAGI controls and use of elasticity were confirmed in late 90-th [8]. The vital problem of higher efficiency of lateral control was solved just in the same manner as it had been suggested by TsAGI in the mid 60-th for high speed manoeuvrable and other aircraft types.

As one of the Boeing officials said in March 2002, at the presentation of the F/A-18 version built in line with the concept of ‘new’ technology called ‘active aeroelastic wing’: "The active aeroelastic wing presented for your attention is the triumph achieved by creative approach of our experts, as well as by means of the newest technologies we use". NASA and Boeing claimed that development of the active aeroelastic wing technology became “the first step on the way to radical enhancement of operating performance and safety level of the XXI century aircraft". The main task of NASA, US Air Force and Boeing was established as "research of possibilities of using an elastic wing in the newest aircraft designs, and possibilities of roll control by means of wing torsion". The major new elements of the new wing, "the real breakthrough in control system development", as the program was also called, are differentially deflected outboard sections of leading edge, located in front of the ailerons – these are just the same forward ailerons. Inboard leading edge sections, flaperons, and stabilizers are not used for lateral control. Thus, the system has been realized (‘outboard forward and conventional ailerons’) that had been persistently recommended for several years to Mikoyan and Suchoi Design Bureaus by Aeroelasticity Department of TsAGI at the early stages of MiG-29 and Su-27 development. The problem to provide required efficiency of roll control for the Su-27 test prototype appeared to be so complicated and important, that it became the subject of consideration for the complex commission of TsAGI and Design Bureau experts in aerodynamics, flight dynamics, control systems, strength and aeroelasticity. It was found out on the base of testing elastically scaled models in TsAGI T-109 wind tunnel and multidisciplinary analysis that to get the needed control efficiency by means of ailerons required extra weight of approximately 30% of outboard wing weight ($G_{outb.\ wing}$ =1040 кг), or 35% in case of differentially deflected horizontal tail. The commission did not find it possible to use interceptors and made the following general conclusion: the most promising in terms of weight efficiency is the use of forward aileron for roll control, which required extra weight not more than 10% of the wing weight. By that time, in early 70-th, it had been shown however that forward aileron efficiency was rather a complicated function of Mach number, angle of attack and dynamic pressure. Thus, use of forward aileron led to more complicated control system, which was one of the reasons to reject forward aileron on the Su-27 in mass production version.

According to American experts' forecasts, the 'new' (actually, already existing) system must provide increase of roll angle rate from 150°/sec to 225°/sec at M=1,0 and altitude 3 km for the original airplane (with flaperons and differentially deflected horizontal tail), with more than twice the increase at supersonic speed.

As a Boeing representative noted: "However, we are just at the beginning. But we shall create the very new airplanes and spacecrafts on the base of new solutions using the concept of control by means of the aeroelastic wing".

Let us repeat that is already known from the references below [5, 9-11] – publications, International Symposium papers and especially, presentation by TsAGI experts at Boeing in 1991 on the topic of use of structural elasticity [7]. The very idea of using the structural elasticity in the meaning we put today in the term 'use of aeroelasticity', or 'active aeroelastic wing', which main elements are differentially deflected leading edges – forward ailerons, had been born and became established in TsAGI in cooperation with Design Bureaus twenty or thirty years before it appeared in USA. Also, it became clear in 70-th that forward ailerons can be used not only to solve the problems of static aeroelasticity, but of structural dynamics as well, and to effectively reduce airframe weight. Today this is the breakthrough in the practice of designing the newest airplanes in USA and Europe. Nowadays, the intensive work is being done on the project "Theoretical and Analytical Studies of the Active/Passive 'Use of Aeroelasticity' Concept to Enhance Aircraft Flight Performance" within the framework of activities of the International Scientific Technical Center (ISTC). The Project has been initiated by a set of major European aviation organizations, which take part in the "Fifth Framework Program of the European Community Commission". The priority of Russia in development of this advanced concept has been recognized be leading European scientists [10, 11], and TsAGI experts has been invited to participate in the Project. Research in another area, also proposed in TsAGI (in the mid 90-th) has been continued also under this Project, the research being related to the use of divergent properties of wing and empennage on the base of rational selection of their plane-forms. High efficiency and prospects of this approach were demonstrated by TsAGI and Design Bureaus experts in solving the problem of following an assigned law of angular velocity variation in time to stabilize a missile motion along its trajectory [12].

II. The first multi-disciplinary studies based on the method of polynomials [13, 14] were undertaken to develop and substantiate the use of elasticity concept. These are only multi-disciplinary approach and the complex research on the problems of reversal, flutter, aerodynamics and strength that made it possible to prove the validity and prospects of the concept. Later this approach, which also has its independent value, was used in TsAGI to create more powerful tool, ARGON software package, for multidisciplinary studies and structural optimization [15]. Running multidisciplinary analysis in aeromechanics started in USA earlier [16] than in Soviet Union, though this was not related to the development of active aeroelastic wing concept.

III. The first steps in implementation of multidisciplinary approach into experimental research for solving aeromechanical problems were made in TsAGI. A concept of the multi-purpose aeroelastic modular model made of composite materials was developed in 1994 [17, 18]. The model is intended for wind tunnel tests on flutter, reversal, divergence, buffeting, total and distributed aerodynamics loads of a "rigid" and elastic airplane with the possibility to vary dynamic pressure scale of similarity and mass distribution. The advantage of the approach is its fastness, cost effectiveness, and, the main, the high accuracy it brings into experimental studies. The prospects of the idea, in which multidisciplinary analysis methods are interlinked with experimental ones, have been also recognized by international community [19]. Born by the development of the use of elasticity concept, the approach has its own value today and is being actively developed in some countries.

IV. Control of elastic deformations with the aid of using composite materials for solving the problems of divergence was proposed abroad in 80-th [20]. These are so called “purpose-in-mind-deformable” structures [21-24] that are in line with the concept.

This is a new class of structures proposed in TsAGI, which awarded the gold medal at Brussels International Salon of Inventions in 1996. The structures of this kind exhibit higher elasticity in one direction (e.g. tension/compression) while keeping high stiffness in others (bending, torsion, shear), with extremely wide usage. The areas of application are: engineering and civil buildings and constructions; automotive, railway, sea shipping, and pipeline transport; medical equipment; aviation and rocketry. The important part of the concept is so called adaptive controllable and “smart” structures studied in various countries now. Major foreign aviation organizations, particularly those participating in the above "Fifth Framework Program of the European Community Commission", address to TsAGI with proposals on cooperation. It concerns mainly the developments and studies on adaptive wing, and studies on ‘use of empennage divergence’.

Russian developments: the ‘use of elasticity’ concept and related methods of multidisciplinary tests and analysis in aeromechanics have been world-wide recognized as innovative areas in advanced aviation designs of the XXI century. These are the most intensively developing areas of research in aeromechanics today.

Appropriate methods have been developed, and important experimental and analytical results of multidisciplinary studies have been obtained (in flutter, loading, stress/strain state) to substantiate prospects of the concept regarding safety, high weight efficiency and competitiveness of advanced airplanes.

References

1. Г.А.Амирьянц. Способ поперечного управления крылатыми летательными аппаратами. Авторское свидетельство на изобретение № 31962, 1964.
G.A. Amiryants. The Lateral Control Method of Winged Flying Vehicles. “The Author’s Rights Witness” (Certificate of Invention), N 31962, 1964, (in Russian).
2. Г.А. Амирьянц. Об одном способе повышения критического скоростного напора реверса элеронов. ТВФ №4, 1967.
G.A. Amiryants. About one Method of Ailerons Reversal Critical Dynamic Pressure Increasing. Technika Vozdushnogo Flota Journal, TVF №4, 1967 (in Russian).
3. Г.А. Амирьянц.Об эффективности предэлерона на упругом крыле. ТВФ №7, 1970.
G.A. Amiryants. About Effectiveness of Differential Leading Edge (Forward Aileron) on Elastic Wing. TVF № 7, 1970 (in Russian).
4. Г.А. Амирьянц, Н.И.Баранов и др. Устройство для поперечного управления крылатых летательных аппаратов. Авторское свидетельство № 57330, 1970.
G.A. Amiryants, N.I.Baranov and other. The Means for Lateral Control of Winged Flying Vehicles. “The Author’s Rights Witness” (Certificate of Invention), N 57330, 1970, (in Russian).
5. Г.А. Амирьянц, Я.М. Пархомовский. О влиянии упругости конструкции на стационарные аэродинамические характеристики самолетов. Доклад на советско-французском симпозиуме. Париж, 1980.
G.A. Amiryants, Ya.M.Parchomovsky. About Influence of Structural Elastic Deformations on Aerodynamic Characteristics of Aircrafts. Presentation on Soviet-France Workshop. Paris, 1980.
6. К.Б. Бекирбаев, И.В. Криволуцкий, Г.С. Пульхров. Безреверсное поперечное управление. ТВФ №3, 1966.
K.B.Bekirbaev, I.V.Krivolutsky, G.S.Poulchrov. Nonreversal Lateral Control. TVF, №3, 1966.
7. G.A.Amiryants. Use of Aeroelasticity Concept and Multidisciplinary Investigations. Boeing Videotape Recording of TsAGI Presentation. Seattle, 1991.

8. Pendleton Ed, Sanders B., Flick P., Sensburg O. Controllable Aeroelastic Lifting Systems. International Forum on Aeroelasticity and Structural Dynamics, Madrid, 2001.
9. Kuzmina S. I., Amiryants G. A., Ishmuratov F. Z., Mosunov V.A., Chedrik V. V. Some Applications of Active Aeroelasticity Concepts to Aircraft Design. International Forum on Aeroelasticity and Structural Dynamics, Madrid, 2001.
10. Schweiger J., Suleman A. The European Research Project: “Active Aeroelastic Aircraft Structures”. International Forum on Aeroelasticity and Structural Dynamics, Amsterdam, 2003.
11. Kuzmina S., Amiryants G., Schweiger J., Cooper J., Amprikidis M., Sensburg O. Review and Outlook on active and passive Aeroelastic Design Concept for future Aircraft. Proceedings of 23-rd ICAS Congress, Toronto, 2002.
12. Г.А. Амирьянц, А.В. Крапивко, О.С. Мамедов, А.С. Редько. Об использовании дивергентных свойств оперения. ТВФ, в печати.
G.A.Amiryants, A.V.Krapivko, O.S.Mamedov, A.S.Redko. About using of Tail Divergence. TVF, in printing (in Russian).
13. Г.А. Амирьянц, В.Г.Буньков, Э.Н.Набиуллин. Расчет на флаттер и реверс крыла малого удлинения с элеронами. Труды ЦАГИ, 1968.
G.A.Amiryants, V.G.Bounkov, E.N.Nabiullin. Calculations of Flutter and Aileron Reversal Characteristics of Low Aspect Ratio Wing. Trudy TsAGI, 1968 (in Russian).
14. Г.А. Амирьянц. Теоретическое определение влияния упругости и распределения масс конструкции на некоторые аэродинамические характеристики самолета в квазиустановившемся движении. Ученые Записки, том X, №1, 1979.
G.A.Amiryants. Theoretical Estimation Of Influence of Structural Elasticity and Mass Distribution on Aircraft Aerodynamic Characteristics… Uchenye Zapisky TsAGI, vol. X, №1, 1979 (in Russian).
15. Д.Д. Евсеев, Ф.З. Ишмуратов, В.В. Чедрик и др. Комплекс программ аэропрочностного проектирования самолета “АРГОН”. Ученые записки ЦАГИ, том XXII, № 5, 1991.
D.D.Evseev, F.Z.Ishmuratov, V.V.Chedrik and other. Multidisciplinary Software Package "ARGON". Uchenye Zapisky TsAGI, vol. XXII, № 5, 1991 (in Russian).
16. Rodden W. P. My First Half-Century as an Aeroelastician or How I Avoided Getting One Year of Experience Fifty Times. International Forum on Aeroelasticity and Structural Dynamics, Madrid, 2001.
17. Г.А. Амирьянц. Универсальная аэродинамическая модель и способ её изготовления. Патент РФ № 2083967, 1994.
G.A.Amiryants. Multi-Purpose Aerodynamic Model and Method of its Fabrication. Russisn Patent № 2083967, 1994.
18. G.A.Amiryants, F.Z.Ishmuratov. Multi-Purpose Modular Aerodynamic/Aeroelastic Model. International Forum on Aeroelasticity and Structural Dynamics, Madrid, 2001.
19. Carlsson M. Aeroelastic Model Design Optimization with Experimental Verification. International Forum on Aeroelasticity and Structural Dynamics, Amsterdam, 2003.
20. Krone N. Divergence Elimination with Advanced Composites. AIAA Paper №75 - 1009, 1975.
21. Г.А. Амирьянц. Адаптивное крыло. Патент РФ № 1762488, 1990.
G.A.Amiryants. Adaptive Wing. Russian Patent № 1762488, 1990.
22. G.A. Amiryants. Adaptive Selectively-Deformable Structures. Proceedings of Congress ICAS, Melbourne, 1998.
23. Г.А. Амирьянц, С.В. Ефименко, А.В. Крапивко, К.Ф.Лацоев, Ю.М. Муллов, В.В. Назаров. Адаптивные управляемые конструкции. ТВФ № 6, 2000.
G.A. Amiryants, S.V.Efimenko, A.V.Krapivko, K.F.Latsoev, Yu.M.Mullov, V.V.Nazarov. Adaptive Controllable Structures. TVF, № 6, 2000 (in Russian).
24. G.A. Amiryants, V.D.Grigoriev, G. Kawiecki. Selectively Deformable Structures Analysis. International Forum on Aeroelasticity and Structural Dynamics, Amsterdam, 2003.