AERODYNAMIC DESIGN TRANSONIC WING USING CFD AND OPTIMIZATION METHODS

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Abstract

With regard to the aerodynamic design of a transonic wing, frequently a one-sided approach is used. For optimization some use only aerodynamic characteristics and section and wing surface design using inverse methods.

In "Antonov" there was developed and widely used in practice the technology of an aerodynamic design transonic wing based on the CFD and optimization methods, taking into account weight and structure factors.

Optimization process of the transonic wing surface is iterative and divided in three steps:

-optimization of circulation spanwise distribution and maximal relative thickness of the wing;

-optimization of wing central section shape;

-optimization of spanwise distribution wing sections and geometric twist.

The first step for acceptance of the wing planform is provided by taking into account the characteristics of drag and weight, and the lifting characteristic and stability with using semiempirical and theoretical dependencies for components as well as theoretical calculation of spanwise load.

The section shape optimization program for required aerodynamic characteristics, taking into account structural (geometrical) restrictions, is based on the parametric description of the airfoil or modification of its shape by using special table functions. Optimization program uses a standard minimization algorithm with restrictions. The main 2D transonic full potential code (like BGKJ) allows one to obtain aerodynamic characteristics, taking into account a weak trailing edge separation.

In this article some examples of structural (geometrical) and aerodynamic restrictions influence on section characteristics are discussed. The way of using parametric investigation of optimized airfoils for choosing parameters of the wing planform is shown.

While creating the transonic wing of the new passenger airliner An-218 Application of the aerodynamic design technology developed in "Antonov "has allowed us to reduce essentially the volume and cycle of experimental investigations for wing choice in comparison with the traditional methods (4 versions of the wing for An-218 versus 30 versions for An-124).

1.Introduction

During the last decade leading aviation companies made significant efforts to increase the economic efficiency of passenger airplanes. These efforts have resulted in the essential increase of fuel efficiency and passenger-kilometer cost reduction due to constant growth of aerodynamic efficiency, decrease of the specific fuel consumption of modern engines and increase of weight efficiency of an airframe.

A wing is one of the most important units of a plane, determining its performance, efficiency and safety of flight. Analysis of Breguet's equation of range:

$$R = \overset{\downarrow}{M}\left(\overset{\downarrow}{C_L/C_D} \right)(a/C_T)\ln\frac{\overset{\downarrow}{W_{oe}}+W_{pl}+\overset{\downarrow}{W_f}}{W_{oe}+W_{pl}} \quad (1)$$

shows that perfection level of a wing project has considerable influence on many terms of this equation (which are marked by pointers). Selection of the geometric parameters and shaping of a wing is rather contradictory, both in point of the terms of the equation and of their optimum combination.

Let's consider this thesis as applied to such an important characteristic as flight Mach number. The increase of Mach number is advantageous not only because of a range increase, as it follows from a Breguet equation, but also because it is purely an economical factor, which increases turnover of airplanes and saves time for the passengers .

The conventional ways of increase of the critical Mach number, which limits flight speed, are sweep increase and wing thickness reduction. This results in an increase of wing weight and operational empty weight of an airplane W_{oe}, as well as reduction of volumes for required fuel W_f. The lifting characteristics of a wing in cruise and takeoff-landing flight modes are worsened. Nonlinearity of longitudinal moment characteristics (so-called "nose-up") is amplified. This results either in a decrease of a trim range, or an increase of the sizes of a horizontal tail, or else it necessitates a more complicated airplane control system.

On the other hand, increase of a wing sweep and reduction of its thickness causes lowering of critical speed of flutter $V_{cr.fl}$, that limits increase of flight Mach number.

The development and the promotion of supercritical airfoils and wings, the ensuring increase of critical Mach number at greater relative thickness and the smaller sweep of a wing, have allowed to raise economically the expedient flight speed.

However, by developing supercritical airfoils and wings there are also some natural contradictions, making it necessary to take a compromise decision.

The increase of critical Mach number of a supercritical wing is related to a decrease of the top surface curvature and the increase of the bottom surface curvature of a tail part of an airfoil.

A longitudinal moment increases, to such a degree that reduces aerodynamic efficiency (C_L/C_D) due to large plane balancing expenditures, increases a load on its tail part and operating empty weight W_{oe}. Besides, constructive restrictions on thickness of leading edge and the tail part of an airfoil are imposed, that complicates designing of a wing mechanization and increases its weight.

Thus, citing as an example of only one of airplane characteristics, included in Breguet equation, a contradictory character of influence of wing geometrical parameters and airfoil shape both on Mach number and on other terms of this equation can be seen. It follows from this, when choosing the wing configuration, to taking into account only the aerodynamic factors is obviously insufficient. An optimization process considering both aerodynamic, weight and constructive factors is necessary to define more advantageous geometrical parameters and shaping of a wing.

Taking into account limited opportunities of methods, software and computer facilities, the optimization process can be only iterative.

The recent development of the programs for calculation of an airfoil [1,2], wing [3,4] and wing-fuselage combination [4] in Russia, as well as inverse method of an airfoil and wing shape design by given pressure distribution [5] at the transonic flight mode has allowed us to complete theaerodynamic design technology for transonic wings, created in 'Antonov'.

The conventional methods of the wing surface design, used in "Antonov" earlier, consisted in optimization of the mean wing surface form with use of direct and inverse solution of a thin lifting surface problem by discrete vortex method [6,7]. In the process of optimization the sets of airfoils developed earlier in TsAGI were considered. To choice of the best wing shaping analysis of experimental investigations of models with various wing versions in a wind tunnel T-106M was performed. Such design method proved to be effective in experimental investigations of a large number of wing versions. For example, when designing aerodynamic configuration of An-124, thirty versions of wings were investigated.

The development of a new aerodynamic module of the wing surface shape design has allowed us to reduce essentially the volume of experimental research, because the main part of investigations was shifted into a calculation stage. When designing a passenger aircraft An-218 with use of the described technology, a large volume of calculation research was performed and the experimental research of only four wings was needed to choose the best wing version.

In this article structure of the aerodynamic module, used methods and programs, as well as technology and feature of its application are described.

2. Structure of aerodynamic module

Aerodynamic module is intended to design the wing surface shape for the given flight conditions (M, C_L, Re) and accepted at the previous design stages planform.

The design process consists of three steps.

At the first step the optimization of the circulation and maximal spanwise section thicknesses (Γ_{sect}, (t/c) $=f(z)$) distribution is performed. Generally it is possible to optimize spanwise chord distribution ($C_{sect}=f(z)$), i.e. to specify planform . However, taking into account the constructive and the technological restrictions narrows the possibilities of this procedure.

At the second stage the optimization of the central section shape for the given designed conditions (C_{Lsect}, M_{sect}, Re_{sect}) is carried out. It is possible to impose the restrictions both being aerodynamic (for example $C_{m0} \leq C_{m0given}$), and constructive (leading edge radius r_0 , maximal relative thickness (t/c), thicknesses in the spar location zones).

At the third step using the previously obtained optimal dependency Γ_{sect}, (t/c)=f(z) and the central section shape, the optimization of the airfoil shape in the other designed sections and spanwise twist distribution is performed.

In the next sections the aerodynamic module procedures construction at each design step are discussed.

3. The optimization of circulation and thickness spanwise distribution.

The circulation spanwise distribution $\Gamma_{sect}=f(z)$ is one of the most important wing characteristics ,which on the one hand connects the planform parameters $C_{sect}=f(z)$, the mean surface shape $y_c=f(x,z)$, and the spanwise geometrical twist distribution $\varepsilon=f(z)$, and on the other hand:

-defines the quantity of the induced drag, which is about 50 % of the wing drag;

-influences essentially on the wave and profile drag spanwise distribution (through C_l);

-defines the wing bending moment spanwise distribution;

-influences essentially on the stall characteristics.

Taking into account the contradictory character of the influence of $\Gamma_{sect}=f(z)$ on identified above factors, the optimization process for this dependency with account of the aerodynamic and the weight factors is needed.

In "Antonov" the program for optimization of circulation and thicknesses, spanwise distribution is developed. For these purposes the special algorithms were employed: one based on an analytical approach, the other one - on a numerical optimization.

The complex optimization is applied, taking into account the drag, the weight, the lifting properties and the stability with the use of the empirical and theoretical dependencies for the components and the theoretical calculation of the spanwise load distribution.

The final distribution of a load differs from the elliptic in the load increasing in a root part of the wing and the reducing it on the end (fig.1).

In the case of the elliptic distribution of the normalized load $\Gamma=f(z)$ the value of $\Gamma(0)$ makes 1.273. The optimum value changes in limits $\Gamma(0)$=1.33-1.42 depending on the planform and the requirements for stability on large angles of attack. It occurs by virtue of the following

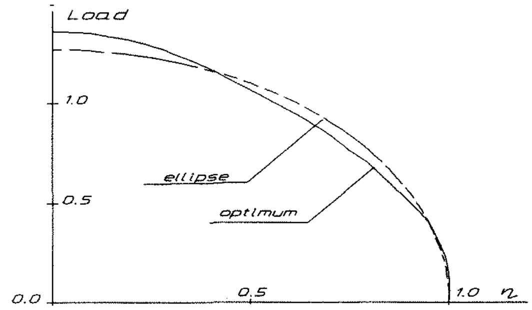

Fig.1. Comparison optimum and elliptic of circulation spanwise distribution.

reasons:

1. The decrease of a load on the end of a wing permits a fixed weight of the wing to increase the aspect ratio and to decrease the induced drag. The small loading of root sections changes the value $A=C_{Di} / C_{Diopt}$ very little, but the bending moment in a root essentially (linearly) changes, in certain limits up to $\Gamma(0)$=1.33 the load increasing of the central sections which is useful.

2. Some additional increase of $\Gamma(0)$ is expedient from the point of view of the reduction C_{mo} and the decrease of the drag losses on balancing.

3. Some additional increase $\Gamma(0)$ appears necessary at the amplification of the requirements to the longitudinal and lateral stability on the large angles of attack.

An increasing $\Gamma(0)$ reduces C_l in the sections of the end wing panel and results in the displacement of the flow separation beginning closer to the root of the wing.

4. The decrease C_{mo} results in the reduction of the airplane weight due to the reduction of the body tail part weight at balancing.

4. The optimization of the wing central section form

The optimization of the central section form makes up for the given mode of the flight (M, C_l) following the accepting criterion. The value of C_l is defined from the received earlier optimum dependencies Γ_{opt} (z) for the design C_L of the wing.

The program of optimization consists of three components:

-the program of creation or modification airfoil form on its parameters;

-the program of optimum search (nonlinear programming) with restrictions;

-a transonic flow analysis code.

The effectiveness of the optimization

process depends on the successful work of all components: the ability of the program to create or to modify airfoils for any contours and also to pass smoothly from one contour to an other; the ability of the program of nonlinear programming to find the optimum decisions and to do it enough quickly; the abilities of the aerodynamic program precisely to obtain the airfoil performances.

The program of an airfoil form optimization which was design in "Antonov" meets these requirements.

4.1. The parametrical description of the airfoil form and the method of its modification

For the optimizing program two different codes of creation and modification of an airfoil are used.

The first code is based on the analytical representation of an airfoil form through its parameters. For this purpose the airfoil is divided into a symmetric part and an average line, which is presented in the following polynomial:

$$t = a_1\sqrt{x} + a_2 x + a_3 x^2 + a_4 x^3 + a_5 x^4$$
$$y_c = b_1 x + b_2 x^2 + b_3 x^3 + b_4 x^5 + b_5 x^6 \qquad (2)$$

With the help of a linear equations system all factors are presented through 10 characteristic parameters of an airfoil (t/c; X_t; $(y_c)_{max}$; $X(y_c)_{max}$; H_{te}; y_t; r_0; Θ; Φ; ε), the determination of which is clear from fig. 2.

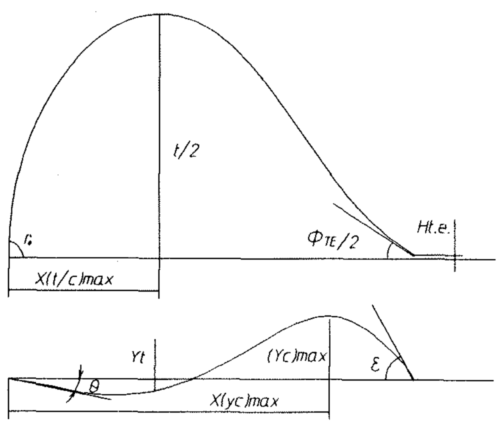

Fig.2. Main airfoil parameters, used for its form description in optimization program

Such a description of an airfoil form is very good for airfoils with an aft loading (for example, supercritical), possessing some inflexions in dependence $y_{low}=(X)$ and a great difference between the significances X_t and $X(y_c)_{max}$. For the description of usual airfoils, for which parameters X_t and $X(y_c)_{max}$ - are close, it is expedient in the equation (2) to omit the member with a maximum degree and from the characteristic parameters to exclude $(y_c)_{max}$. Otherwise a sharp change in the airfoil form at some small changes of the parameters can appear.

The second program is based on the well-known method [8]. The modification of an initial contour is executed with the help of the special base functions. In "Antonov" 8 functions are used, identical as for the upper and the lower airfoil surfaces (whole 16). The kind of functions is received as a difference between an initial contour and the contour of a modified airfoil, received from an inverse method for the inviscid incompressible flow.

Analysis of 15 high-speed airfoils TsAGI has shown that all of them satisfactorily coincided with the initial representation under the first program, and well approximate from one to the other on the second one.

The mean-square deviation of the coordinates approximated airfoil from initial makes ± (0,01-0,015)%, that is half of the tolerance on the accuracy of the manufacturing of the aerodynamic models. The aerodynamic characteristics of the approximated and the approximate airfoil practically coincided. The final error in a geometry was practically identical for both programs and only sometimes slightly less for the second. The speed of the convergence of the geometry on the second method was three times higher than on the first one with such. By aerodynamic optimization, however, the speed of the convergence and the result has appeared identical.

The advantage of the first approach had as the effect that at statement of a real problem of designing the number variable decreases ((t/c) and r_0 become fixed) and the problem is simplified, while with the second method the problem is complicated: there are additional restrictions due to inequalities ($(t/c) \le (t/c)_{giv-one}$, and for $r_0 \ge r_{0giv}$ has to enter two restrictions on the reduction of the thickness in the nose of a airfoil). Besides at the first approach the airfoil is received smooth, and at the second approach - the final result requires smoothing. Historically the first approach was realized before the appearence of work [8] and only it was used at designing of the wing An-218.

4.2. The program of the optimum search

In the program of the optimum search algorithm of the moving tolerance with the restrictions [9] is used. As an algorithm of search in the solution without restrictions a Nelder-Meed's deformed polyhedrons method is used. As a whole the algorithm is very reliable, though is not fast enough .

4.3. The aerodynamic program

In the airfoil optimization program a numerical solution is used based on the potential flow model which gives satisfactory results, close to Euler's method in case of the weak shock. It was developed in Russia by S.Lyapunov and Yu.Michailov [2] by a coupling method like BGKJ and a zonal approach for the calculation boundary layer. Its advantage is in the drag separation correction [2], that is extremely important by thre numerical optimization of transonic airfoil, as far as it hinders the appearance of the larger gradients in the vicinity of the airfoil trailing edge.

4.4. The results of the optimization

By the optimization, the transition to a sliding wing on the known relations is used. And for a coning wing as a sweep it is expedient to use a 0,5 chord sweep as it better reflects the pressure distribution in the real wing.

The criterion of the optimization:

$$\min(C_d)=\min(C_{dp}+C_{dw}+C_{dbal}) \quad (3)$$

The last component is defined as a balancing drag and is calculated proportionally to an airfoil longitudinal moment.

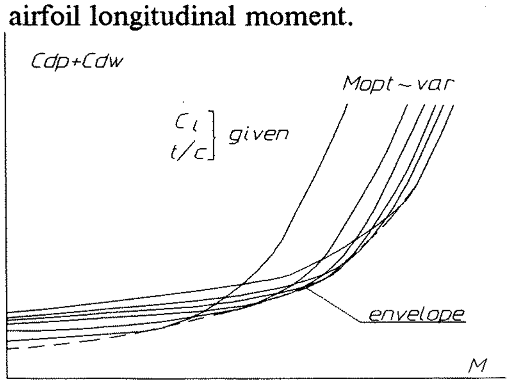

Fig.3. Results of airfoil optimization for given C_l and t/c with a various Mach numbers.

The optimization is carried out for the given significances of C_l and (t/c) at given constructive restrictions. Then the received results are counted for some of Mach numbers (fig.3) and the choice of the necessary airfoil amog the received family is carried out. The

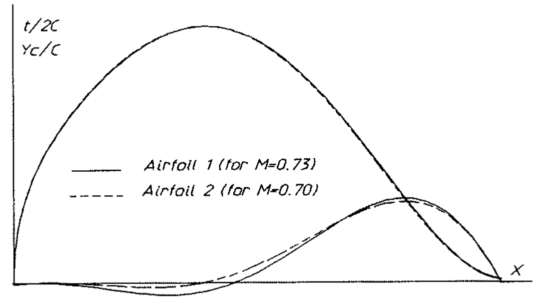

Fig.4. Comparison of an airfoil form, optimized for M_{cr}=0.7 and 0.73.

envelope of the curved lines C_d=f(M) for the given Mach numbers optimum airfoils gives a line of the minimum drag significances, which can be received for the accepted thickness, C_l and M at the given restrictions.

From the received airfoil family that particular airfoil is chosen, the critical Mach number of which is close to M_{cr} for envelope, and the drag level on cruise Mach number is close to minimum.

On fig.4 is the comparison of the airfoil geometry, received for different design Mach numbers, and on fig.5 - the comparison of the pressure distribution is shown at these design Mach numbers. As it is visible from fig.4, at the increasing of design Mach number the maximum camber of the airfoil mean line grows, and the camber of the mean line in position of the maximum thickness decreases. Thus the symmetric part of an airfoil remains practically constant.

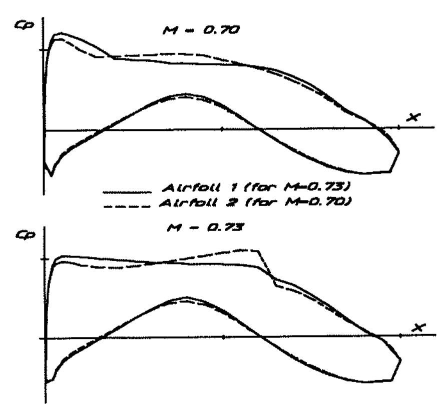

Fig.5. Comparison of pressure distribution of an airfoil, optimized on M_{cr}=0.7 and 0.73.

The program is realized on the computer VAX6000. The minimum necessary steps for the optimization are 40, the direct accounts are 60. The time account is about 10 minutes.

. The influence of the constructive and the aerodynamic restrictions on the results of the airfoil optimization

The program of the optimization permits

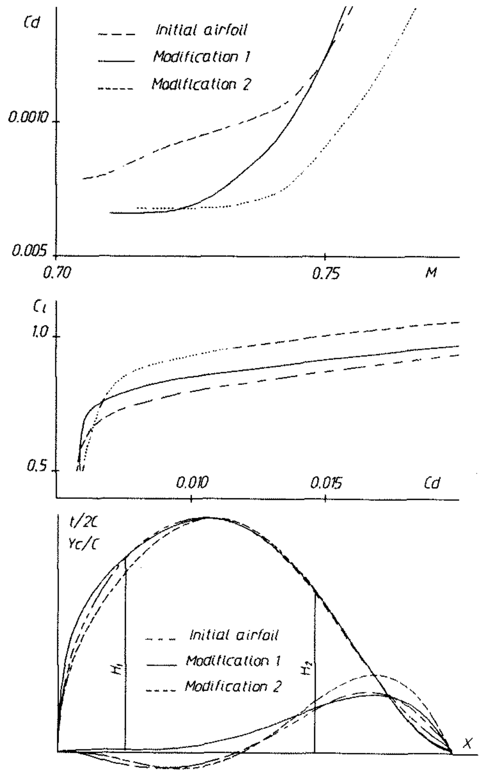

Fig.6. Influence of restrictions to forward spar height on the form and aerodynamic characteristics of an optimized airfoil.

us to analyze the influence of the constructive (geometrical) and aerodynamic restrictions. The typical ones are the restrictions on:

- the maximum relative thickness $(t/c) \geq (t/c)_{giv}$, as well as the height forward and aft spars from a condition of the required strength and volumes;
- the leading-edge radius $r_0 \geq r_{0giv}$ from a condition of the required significance's C_{Lmax} on the cruise and the takeoff-landing modes of the flight;
- the airfoil thickness at 85-90% of the chord to guarantee of the required flap thickness, the increase of the flaps lifting abilities and the reduction of its weight.

From the typical aerodynamic restrictions it should identify restrictions on C_{m0} an airfoil and C_{Lmax}. The analysis of the aerodynamic restrictions influence is difficult (though it is possible and conducted within of designing of An-218), as far as each step of the optimization, reducing the objective function at availability of restrictions, accompanied by numerous (order of 20-30) calculations of penal function - function of infringement upon restrictions, that about in as much time extends a time of the accounting of the program.

Fig.6 illustrate the influence of the restrictions to a geometry and characteristics of an optimized airfoil. On the basis of the initial airfoil, offered by TsAGI for one version of An-218 wings, but possessing the unfavorable drag characteristics at the large design $C_l=0.775$, appropriates $C_{Lsect}=0.625$ and $C_{Lw}=0.55$ optimization is conducted at fixed $(t/c)_{max}$ with the restriction in the beginning on height of the forward and the back spars, and then only on the height of the back spar.

The results of the optimization (fig.6) show that in the first case the leading edge radius was increased up to $r_0=2.1\%$ (instead of $r_{0init}=1.18\%$) , a little form of an airfoil mean line has changed, that has resulted in the essential improvement of the drag characteristics at $M < M_{cr}$ and the increase of C_{Lmax}.

The second modification (fig.6) has resulted in the reduction of the leading-edge radius up to $r_0=1.05\%$ and the height forward spar up to $h_l=9.5\%$ (instead of $h_{linit}=10.2\%$) as well as in the further increase M_{cr} and C_{Lmax}.

4.6. The influence of the optimum airfoil characteristics to make choice of the wing planform parameters

The program of an airfoil optimization permits us to make rather interesting and useful conclusions concerning the choice of the wing planform parameters at the initial stage of the design.

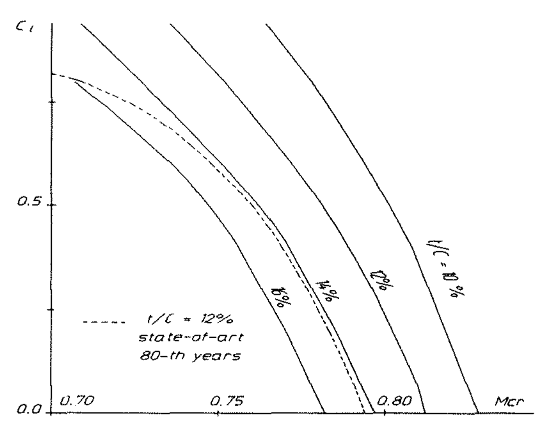

Fig.7. Critical Mach number of various thickness optimum airfoils at restriction of leading edge radius $r_0 \geq$ 0.79%.

On fig.7 the results of the parametrical research of optimum airfoils on different thickness in the range C_L=0 - 1.0 are shown at the unique restriction on the size of the leading-edge radius of r_o>0.79%. This restriction appears significant at C_L>0.5.

For comparison purposes the efficiency of the optimization on fig.7 puts a line, which describes state-of-art of 80-th years.

This diagram (fig.7) accepts the basis for the further analysis. It is necessary to remember, that any curve of this diagram presents an airfoils family, optimized for the combination of conditions M_{cr}, C_L and the restrictions $(t/c)_{max}$, r_0>0.79% and is not limiting on M_{cr} for the given thickness $(t/c)_{max}$ and C_L, but is close to it. Accepting of the spanwise shock distribution on the taper wing, we shall receive the diagram of a sweep influence at various significance's of the central section C_L and the given chordwise relative thickness (fig.8).

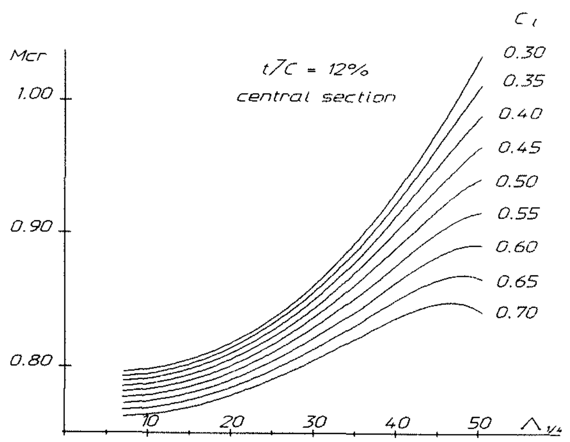

Fig.8. Dependence of critical Mach number of optimum wing central section from wing sweep.

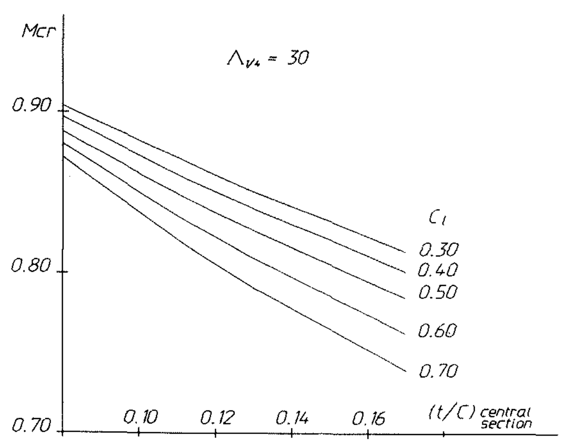

Fig.9.Dependence of critical Mach number of optimum airfoils from their thickness at sweep30°

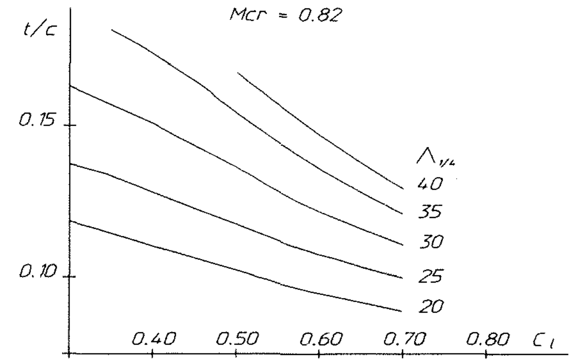

Fig.10. Dependence of relative thickness of optimum airfoils from section lift coefficient and sweep angle.

In such a way the influence of the central section thickness on the significance of M_{cr} is received at a fixed sweep (fig.9) and the influence of C_L to relative thickness section at fixed M_{cr} (fig.10).

These diagrams assist to analyze the change of the geometrical parameters at change of the design aerodynamic conditions, as well as a feedback between the aerodynamic characteristics and the section geometry.

The last dependencies (fig.10) permit, knowing C_l spanwise distribution, to receive the relative spanwise thickness for a chosen sweep from the condition of the spanwise constancy of M_{cr}. It should be noted, that the dependencies on fig.8-10 do not present a simple transition on a sweep or C_L of the given section, but for each combination of Λ and C_L optimum section form for maximum M_{cr} is selected.

It is further possible to show, as from the optimization program a geometry of a high-speed wing in account to the weight characteristics is received. The weight of a wing consists of three components: the weight of a box (the power part of the wing), the weight of non power elements of the structure and weight of lift devices.

Only the first part basically depends on the wing parameters: the aspect and taper ratio, the thickness and the sweep. This dependence can be expressed in the first approximation by a simple ratio:

$$W_w \approx \frac{AR^{1.5} \cdot (1+2\lambda)}{(t/c)_{av} \cdot \cos^2 \Lambda_{ea} \cdot (1+\lambda)} \qquad (3)$$

where $(t/c)_{av}$ - a half-sum of the root and the central section thickness;

Λ_{ea} - sweep angle of the elastic axis.

This dependence is received strictly from the representation of a wing as a simple beam and is well confirmed by accounts of the known wings. Having taken the typical planform of a wing (λ=0.21;λ_{tr}=0.29), the typical spanwise load distribution at which C_{Lroot}=0,78C_{Lw}; C_{Lbreak}=1.19C_{Lw} for the given planform and, assuming, that the position of rigidity axis is on 35 % of the chord, and the shock position at M_{cr} - is on 60%, as well as using the known formulas for the drag definition C_{Di} and C_{Dp}, we shall receive at the fixed weight of the wing for design C_{Lw} significance of total drag for the given numbers M_{cr} and the sweep (fig.11).

The dependence $C_d=f(\Lambda_{1/4})$ has a minimum, the availability of which is explained by the opposite character of change co-factors of a denominator of the weight function (3) $(t/c)_{av}\cdot\cos^2\Lambda_{ae}$ with a change of a wing sweep, and the displacement of a minimum in the party of a smaller sweep at reduction of a critical Mach number is stipulated by an opportunity for an increase of the aspect ratio, that results in the decrease of induced drag.

It should be noted, that the optimum sweep of a real wing should be a little less, than determined by the minimum significance of C_D, that will allow the improved take-off-landing and flutter characteristics, to facilitate the problems of the wing configuration, balancing of a plane, to reduce non linearity of the longitudinal characteristics. Proceeding from it, for the definition of the optimum parameters expediently to accept significance $C_D=C_{Dmin}$-0.00001, that equivalent to quality loss of the order ΔK=-0.01.

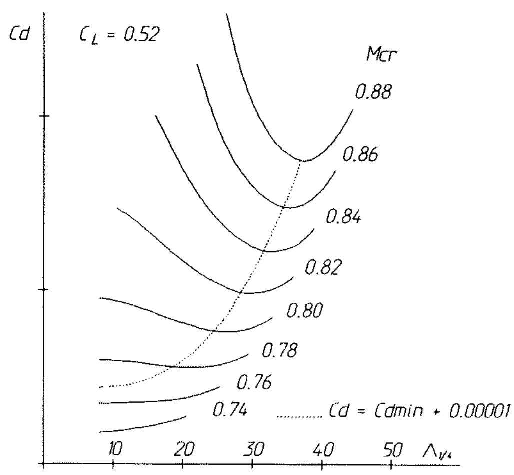

Fig.11. Dependence of the wing total drag from a sweep and required critical Mach number.

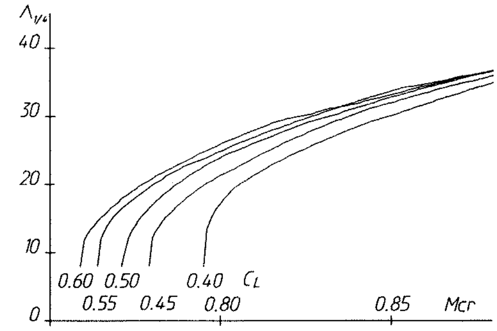

Fig.12. Dependence between a sweep of the wing with optimum airfoils and critical Mach number.

Thus, the indicated analysis permits us to receive for the given significances of M_{cr} and C_L the optimum geometrical parameters of a wing: the sweep (fig.12), the aspect ratio (fig.13), and the thickness spanwise distribution (fig.10).

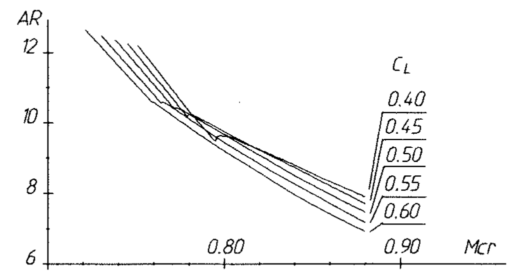

Fig.13. Dependence between aspect ratio of the wing with optimum airfoils and critical Mach number.

The received dependencies are used also in the program of optimization of the circulation and the thickness spanwise distribution on the first step of work of the aerodynamic module.

5. The optimization of the section form and the twist

After the reception of the optimum form of the central section or the optimum distribution of pressure in the central section the form of the section and the twist in other sections for a high-speed wing is received proceeding from the following requirements:

-the keeping of the optimum law Γ_{opt}=f (z);

-the keeping of necessary linearity of isobar down to the line M=1.0, despite of a body influence and inboard part of the wing extension;

-the necessity of reduction in trailing edge gradients in the sections of the wing outer part for decreasing of C_{DP} and improvement of the linearity of the londitudinal characteristics.

The required section shape can be received as by the optimization of the separate sections in a wing (for a combination W+B) similarly to how it was done for an airfoil, as under the inverse program. The analysis of transonic flow combination W+B with taking into account of viscous effects with weak aft separate provides by method from [4].

In "Antonov" are realized and used both approaches by An-218 wing design. The final result that appeared is identical. In essence the program does not differ from the program of airfoil optimization..

The optimization process concerns one section on the wing. Consistently passing on all the sections from the first up to the last one we obtain the optimum wing. For achieve of the result on one section it requires 14-17 steps of the optimization process or 50-60 functions evaluations. It requires about 2-3 hours of a processor time of computer VAX6000. The process of reception of the optimum decision is easier than with the application of inverse methods, where it requires setting the distribution of pressure on all the wing. Alongside with inverse methods this procedure was applied during the design of one of the version of An-218 wing .

On fig.14-16 application of the optimization procedure for An-218 wing design is shown. The initial version of a wing, designed with optimization procedure and tested in a windtunnel T-106M TsAGI was the basis for the optimization of a wing on smaller and greater Mach number. The purpose of the optimization - to define an opportunity of a critical Mach number increase on the one hand ($M=M_{cr}+0.01$) and the reduction of the wing drag on smaller Mach number ($M=M_{cr}-0.015$) on the other hand.

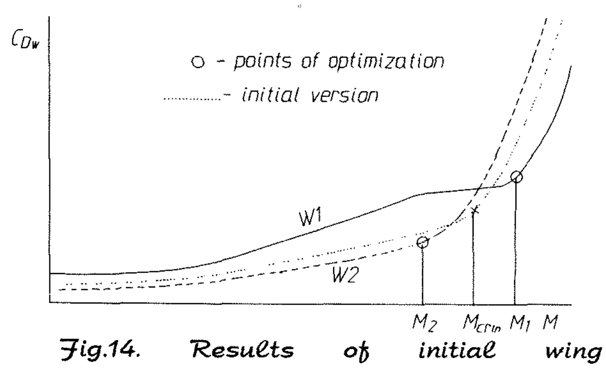

Fig.14. Results of initial wing optimization on higher M_1 and smaller M_2 critical Mach numbers.

The optimization was conducted for conditions of a windtunnel T-106M: Re=2.5 x10^6, the point of transition X_{tr}=20% of chord. The Mach number corresponds to critical Mach number for the given significance of C_L.

On fig.14 dependencies profile and wave drag from the Mach number for three versions of wings is shown: initial and two optimized. On fig.15 comparison of pressure distribution on both optimized wings is submitted at Mach number M_1 and for optimized version on Mach number M_2 for this same Mach number.

The pressure distribution for the first optimized version is not shown in view of larger shocks. On fig.16 are shown appropriate isobars.

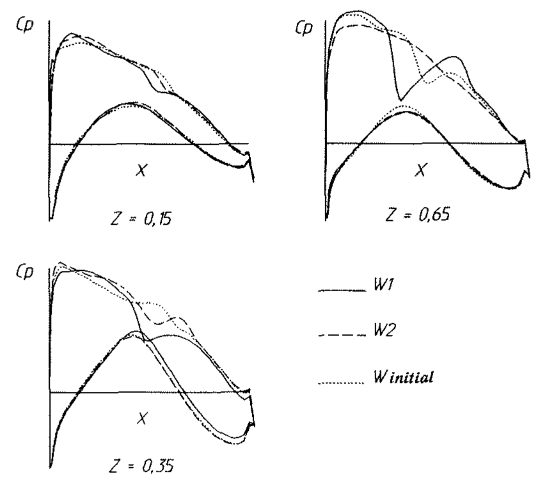

Fig.15. Comparison of section pressure distribution of two optimized wing W1 and W2 and W initial on M_2.

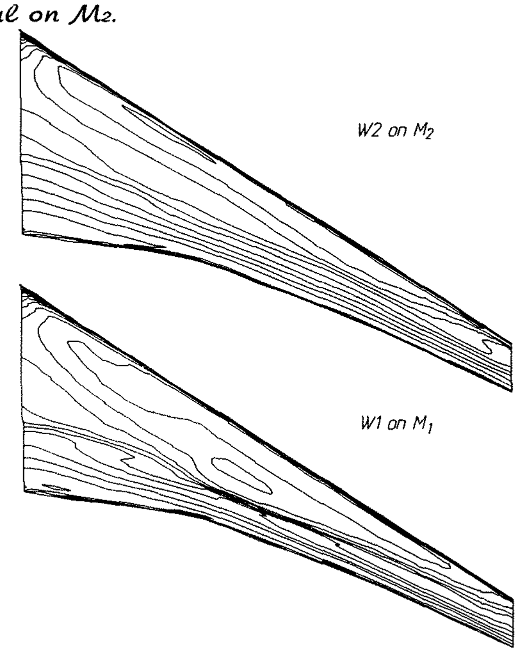

Fig.16. Upper surface isobar lines of two optimized wings.

The optimization program gives a rather real result, aiming to lower not only the wave component, but also some other components of drag, in particular, reducing gradients on the trailing edge in the outboard sections of the wing, which flow at rather small local Re numbers in conditions of a windtunnel.

On the basis of these results a conclusion was made that the transition on higher design Mach number for the An-218 wing is not expedient while of the large drag growth on smaller Mach numbers some facilitation of conditions on critical Mach number gives an insignificant benefit in size of aerodynamic quality $\Delta K=0.02$.

At definition of a surface shape of the wing by inverse methods, the twist of a wing is received automatically, proceeding from the given law of pressure distribution on a wing together with the sections form.

Some difficulties can arise by use of the optimization procedure, connected with the probable strong (order of 1 degree) required changes of a twist in the inboard part of the wing. As a result of different speed of the change of the section shape and the twists in onboard section, if one begins from a "bad" airfoil, the final outcome can be strongly deformed the sections. The problem is decided by choosing a more acceptable initial airfoil or the selection of a factor, which equalize the speed of convergence under definition the form of section and the twist of the wing.

For the efficiency control of a described above technology of a wing aerodynamic designing, the results of an optimization in a kind of dependence $M_{cr}=f(t/c)$ at $C_L=0.5$ and $\Lambda_{1/4}=30^{\circ}$ are compared with the results of wing researches of latter years and being present data for planes, are in operation now.

The wing of an airplane An-218, designed on the present technology, was tested in a transonic aerodynamic windtunnel T-106M TsAGI and has shown a high level of the critical Machnumber characteristics, the aerodynamic efficiency, the lifting and the anti-stall properties.

From fig.17 it is visible, that the An-218 wing at average thickness of 12,3% has the highest significance M_{cr}, and the level $M_{cr}=f(t/c)$, limited by a line, received as a result of the optimization, does not exceed one of the planes being constructed till now.

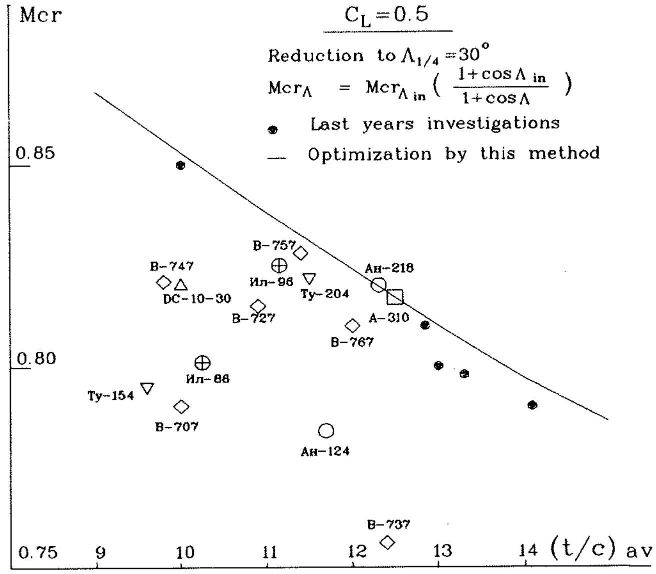

Fig.17. The efficiency level of a modern transonic wings in view of its critical Mach number.

The significance of maximum aerodynamic efficiency of An-218, determined on the basis of the windtunnel researches, corresponds to a level of the best passenger airliners of the world (fig.18).

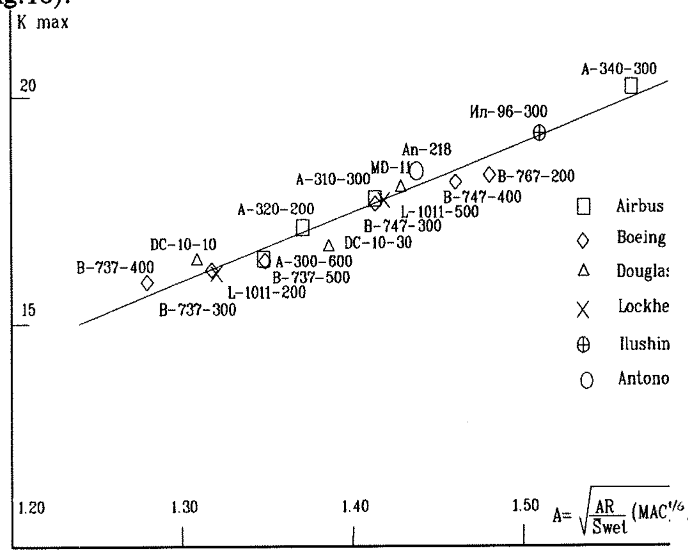

Fig.18. The efficiency level of the passenger airliners in view of its maximum aerodynamic quality.

Both considered factors confirm the high efficiency of the submitted technology of transonic wing design.

Conclusion

1. The expansion of computer possibilities and the numerical methods of aerodynamics has allowed us to create the technology for aerodynamic designing of a transonic wing, based on the methods of numerical optimization in view of complete drag characteristics and possessing the following main advantage before the methods of designing, based only on the inverse problems:

- an opportunity to receive the optimum form of an airfoil and wing for the given conditions in view of the restrictions (geometrical, weight);
- an opportunity to analyze the influence of the restrictions to the aerodynamic characteristics of the optimized airfoils and wings;
- an opportunity to analyze influence of the optimized airfoils characteristics to choice of the planform wing parameters.

2. The process of aerodynamic designing of a wing surface for the accepted planform has iterative character and is constructed in three steps:

- the optimization of an air load and the thickness spanwise distribution taking into account the separation characteristics, the weight and the constructive restrictions;
- the optimization of the wing central section for the given design conditions (C_{Lsect}, M_{sect}, Re_{sect}) and the constructive restrictions;
- the optimization of the design sections shape and the twist of a wing.

3. The application of the aerodynamic designing technology created on "Antonov" at the development of a wing configuration of a passenger airplane An-218 has allowed us essentially to reduce volume of the experimental researches for choice of a wing in comparison with the conventional methods (4 versions of a wing for An-218 versus 30 versions for An-124).

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