NUMERICAL STUDY FOR THE WING LIFT-TO-DRAG INCREASE AT SUPERSONIC SPEEDS

Nikita Ageev
Moscow Institute of Physics and Technology, Department of the Aeromechanics and Flight Engineering
Central Aerohydrodynamic Institute named after prof. N. E. Zhukovsky
Moscow

n.d.ageev@gmail.com

Abstract. This paper presents a series of studies for the increase of the L/D of isolated wing at supersonic speeds. All calculations presented are based on the RANS governing equations system with the turbulence model SST at M = 1.2 - 2.1 and Re = 1000000 - 10000000. A family of airfoils (relative thickness 9%) with different leading edge radius is developed. It is shown that at transonic (low supersonic) Mach number blunt airfoil (R=2.2%c) has a drag of about 5% less than sharp one. This phenomenon is caused by the flow peculiarities in local subsonic area near the leading edge of the airfoil. At M = 2.1 sharp foil has drag smaller in a factor of 2 than blunt one due to the attachment of the bow shock wave. These calculations agree well with the experimental data obtained at TsAGI.

A series of studies to determine the combined effect of leading edge sweep angle and radius for a thin (relative thickness 4.5%), low aspect ratio (AR=2.18) wing is presented. It is shown that with the leading edge radius change from 0 to 0.2%c lift to drag ratio change as follows:

- decreases monotonically with LE sweep angle of 45 degrees by 12 %
- decreases monotonically with LE sweep angle of 56 degrees by 4 %
- changes non-monotonically (convex upward) in the range from 10.4 to 11.3 with the LE sweep angle of 73 degrees

Maximum lift to drag ratio increase by the 13 % is obtained by the LE sweep angle change from 45 to 56 degrees as a result of turning of the wing (AR=2.18) around OZ axis. It is concerned with the combined effect of the wave drag decrease and vortex drag increase. The rough optimization of the wing thickness distribution was carried out by two-level method. Zero AoA drag reduction ~ 3% is obtained. Preliminary investigation on the effect of the wing middle surface form was made. Surface form is specified by the system of the 8 parameters. A set of the 30 random parameters combinations is considered. An increase of the maximum lift to drag ratio is about 2% in the set.

Keywords. supersonic speed, wing, lift-to-drag, sweep angle, midsurface, LE radius, CFD

1 Introduction

The following methods of reducing of the wing drag are investigated:

- Change the radius of curvature of the leading edge for different sweep
- Change of the airfoil of the wing in general
- Change of the wing sweep

Study of these methods can be carried out by both experimental methods, engineering methods and calculations based on the solution of the Navier-Stokes equations. Calculations on the Euler equations that are often used for applications requiring rapid assessment [1] are of little use due to the large influence of viscosity in the flow around the leading edge. For engineering techniques data on the impact of the radius of nose curvature at the drag of the airfoil are required. The data obtainment from the experimental files is difficult due to the simultaneous change the radius of curvature and other airfoil parameters (the relative thickness, the position of maximum thickness, profile type, etc.). One of the goals of this work is obtainment of this data. Another important parameter in determining the drag of a wing at supersonic speeds is leading edge (L.E.) swept. The paper presents the numerical parametric study of the joint effect of the wing leading edge sweep and airfoil nose radius of curvature change on the aerodynamic characteristics of the wing at supersonic speeds.
To explore the use of the changeable wing sweep, the analysis of changes in the aerodynamic characteristics of the wing was performed at its sweep change by rotating around a fixed vertical axis passing through the front critical point of the wing (trim of the wing by symmetry plane of the original wing).
In [2], the optimization of the middle surface of the wing to the regime of supersonic flight was carried out. The wing was described by 8 parameters: local angle of attack, curvature and max curvature position at 3 sections of the wing (9 minus 1-root AoA). Calculations were carried out for 3 AoA. Approximation and calculation of the maximum lift-to-drag ratio was made for every model. It was found that for the models wing, similar to those considered in this paper, this method can provide growth of the lift-to-drag ratio near 2%.
An attempt of the airfoil optimization was made. Total decrease of the zero AoA drag coefficient of 3% was obtained. The result requires more careful research due to simultaneous unpredictable change in subsonic aerodynamic performance.

2 Airfoil nose radius influence

For study the effect of the airfoil nose radius family of leading edge profiles was constructed, based on a modification of the original profile (Fig. 1). In the construction of the family the method of correcting functions [3] was used, slightly changed for the nose modification. As a corrective function the next one is selected

$$x^* = Axy^B \quad (1)$$

where

(x,y)-old coordinates of the point

(x*,y)-new coordinates of the point

A, B-factors gleaned from the condition of smoothness of the surface profile

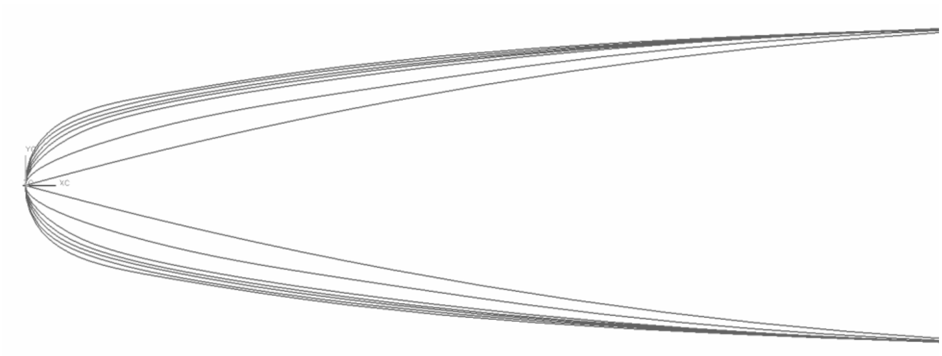

Figure 1: Airfoil family nose parts

The choice of this correction function allows the smoothness of the second order. The calculation is performed in the size 20x20c, where c - the length of the chord . In the construction of a multi-block structured computational grid of combined CH topology (Figure 2) the requirement for detailed modeling of the detached head (in some cases attached) shock wave and trailing shock at the trailing edge of the foil is taken into account. The mesh ensures a sufficiently high quality of the flow field simulation, including the boundary layer. The grid contains 400 thousand cells. The size of the wall cell is about 10^{-6}c. Calculations were performed at M = 1.2-2.1. The parameters correspond to the free stream conditions of international standard atmosphere at H = 11 km. Chord length c = 1m. Re calculated by chord profile Re = 22 million. The calculations use the full system of the Reynolds averaged Navier-Stokes equations with the closure of the turbulence model for SST [4]. The equation of state of the environment is the ideal gas equation. Calculations were carried out by the second-order approximation scheme for all the equations [5]. In the calculation the following boundary conditions were used. The left boundary condition is supersonic input (turbulence intensity 0.4%). The right boundary condition is a supersonic output. The upper and lower boundaries are no flow conditions. On the surface of the airfoil no-slip condition on the adiabatic wall is set. The calculations were carried out to establish the residual mean square for the entire field of flow $3*10^{-6}$. In carrying out the calculations dynamically changeable time step was used. The number of iterations spent in one calculation, is about 1000. Stop criterion of calculation - the establishment of the fourth decimal place in the values of the aerodynamic coefficients. Comparison of the results obtained from the calculation with the experimental data [6] is shown at Fig. 3.

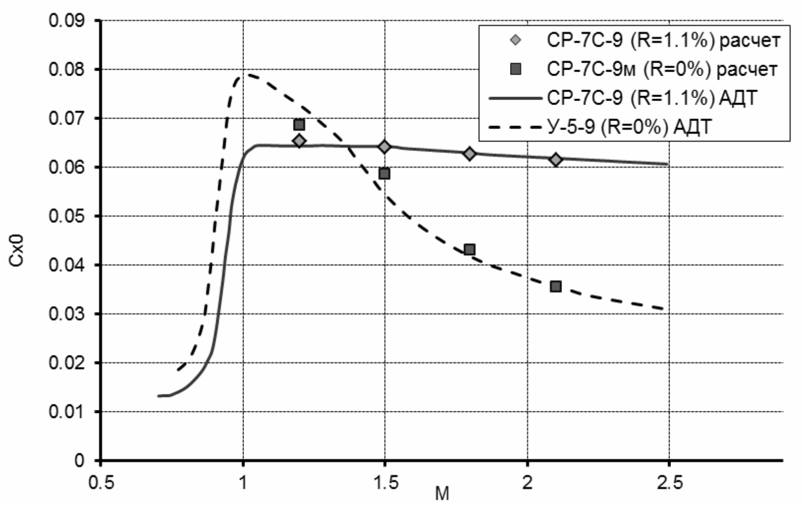

Figure 3: Experimental (curves) and calculated (points) data comparison.

Dependence of the drag of the family based on the SR-7S from the Mach number at the International Standard Atmosphere (ISA) for H = 11 km conditions is shown in Fig. 4.

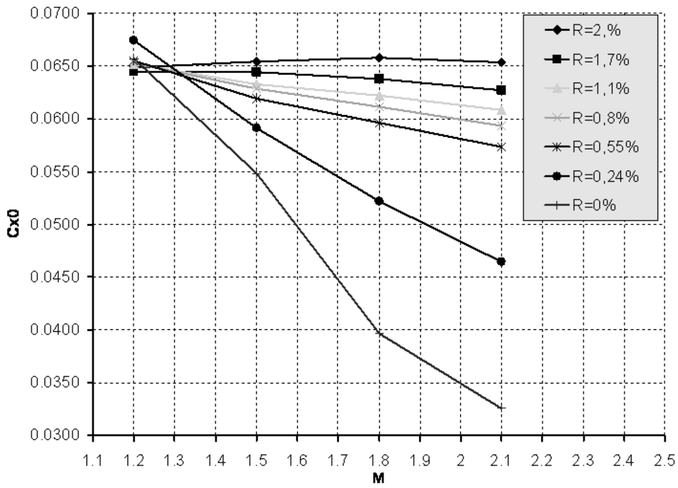

Figure 4: Dependence airfoil drag from the Mach number for airfoils with different L.E. radius

Dependence of the drag of the family based on the SR-7S from the L.E. radius at the International Standard Atmosphere (ISA) for H = 11 km conditions is shown in Fig. 5.

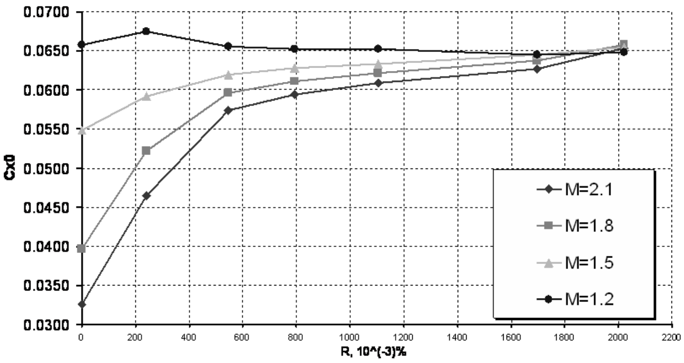

Figure 5: Dependence airfoil drag from the L.E. radius for different M numbers

It is shown that at the M ~ 2 drag significantly increases with the LE radius due to the growing size of the local subsonic zone, as shown in Fig. 6.

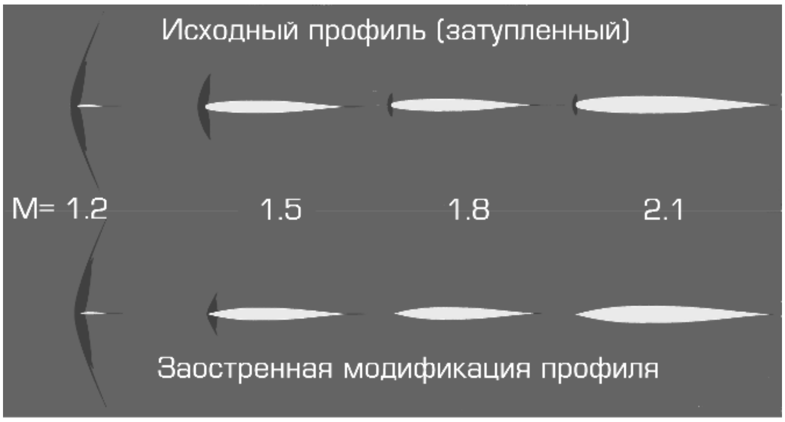

Figure 6: Local subsonic zones for different M numbers for blunt (top) and sharp (bottom) airfoils

At transonic Mach numbers, the drag is almost independent of the LE radius. In this range of Mach numbers drag decreases with increase radius of curvature. This is explained by the presence of zones of negative static pressure in local subsonic zones. The above explanation is supported by the pressure distribution along the axis Y (area under the curve is equal to the drag) (Fig. 7).

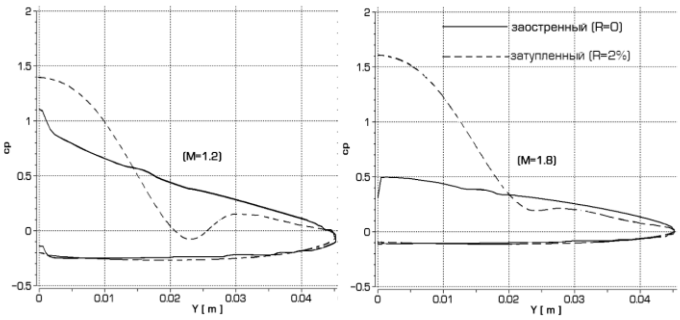

Figure 7: Pressure coefficient distributions

3 The combined influence of the sweep and the LE radius on the aerodynamic characteristics of low aspect ratio wing

The family of wings is constructed on the family of the airfoils. Each foil is compressed by a factor of 0.5 in Y direction (relative to the thickness of 4.5%). Family of trapezoidal wings with a flat middle surface was constructed. The family has the restriction $\eta = 10$, equal distribution of land in scale, elongation $\lambda = 2.18$. The computational domain built around half-model of the wing is a rectangular box with the appropriate size 6x10x6 root chord of the wing. This size provides sufficient accurate calculation of the solution of the problem in the absence of reflection of shock waves from the boundaries of the computational domain on the wing and in the local subsonic zone. Model is located at the side wall at the front of the computational domain. In the calculation of constructed multi-block structured computational grid of the combined C-H topology. The grid consists of 6.5 million cells in 30 blocks (Fig. 8).

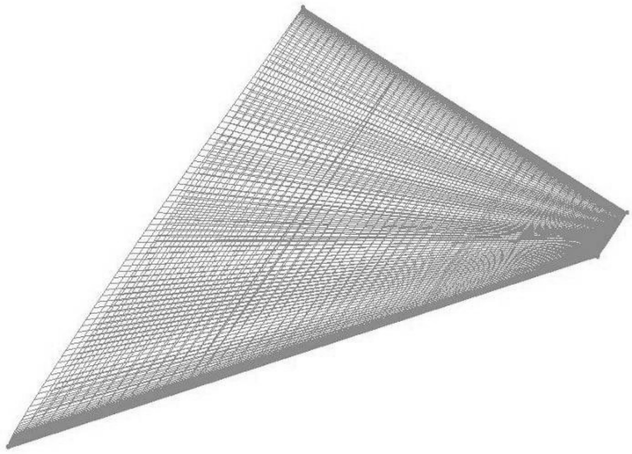

Figure 8: Computational grid.

Calculation procedure is the same as for the airfoil. It is shown that with the leading edge radius change from 0 to 0.2%c lift to drag ratio change as follows (Figure 9):

- decreases monotonically with LE sweep angle of 45 degrees by 12 %
- decreases monotonically with LE sweep angle of 56 degrees by 4 %
- changes non-monotonically (convex upward) in the range from 10.4 to 11.3 with the LE sweep angle of 73 degrees.

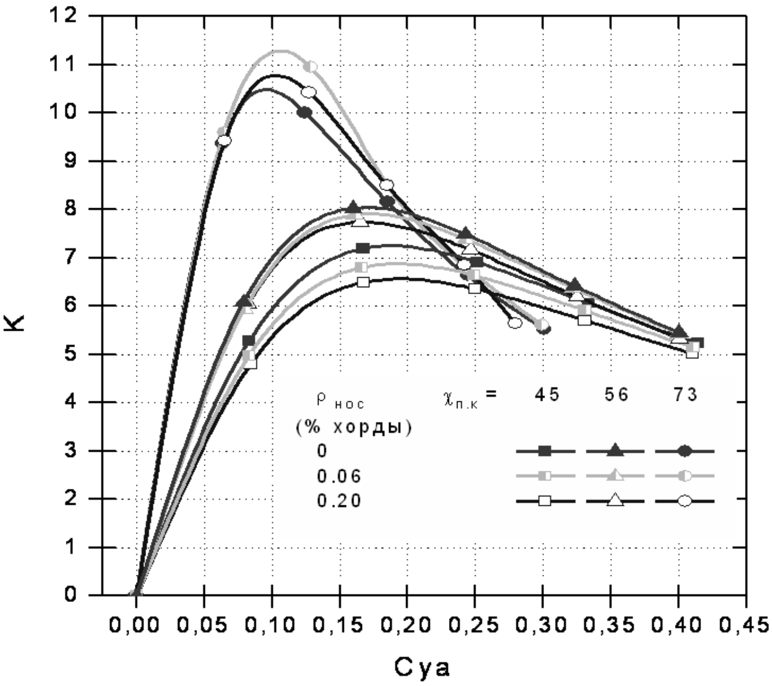

Figure 8: Lift-to-drag dependence from the Lift coefficient for wings with different LE sweep and radius.

Maximum lift to drag ratio increase by the 13 % is obtained by the LE sweep angle change from 45 to 56 degrees as a result of turning of the wing (AR=2.18) around OZ axis (Figure 10). It is concerned with the combined effect of the wave drag decrease and vortex drag increase.

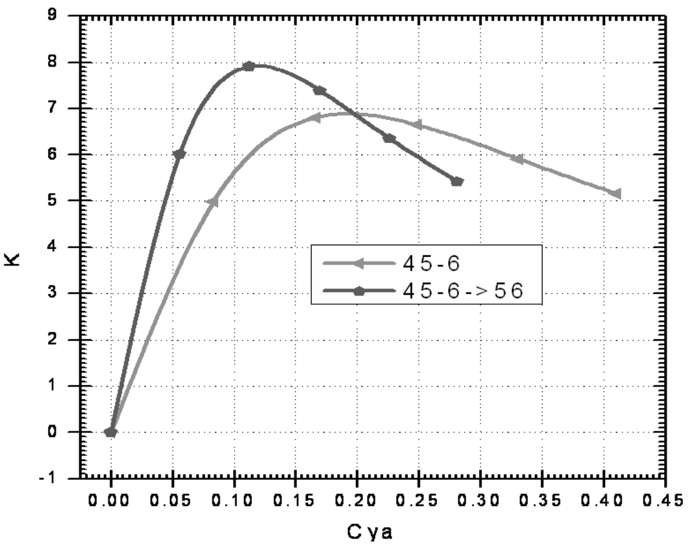

Figure 9: Lift-to-drag dependence from the Lift coefficient for the initial and turned wing.

4 Airfoil and midsurface optimization

The rough optimization of the wing thickness distribution was carried out by two-level method [7]. At first stage pre-optimization of the airfoil by the corrective function method was made. At the second stage optimization of the maximum thickness position by method of the parabolas was performed. Zero AoA drag reduction ~ 3% is obtained.

Preliminary investigation on the effect of the wing middle surface form was made. Surface form is specified by the system of the 8 parameters: local angle of attack, curvature and max curvature position at 3 sections of the wing (9 minus 1-root AoA). Calculations were carried out for 3 AoA. Approximation and calculation of the maximum lift-to-drag ratio was made for every model. A set of the 30 random parameters combinations is considered. An increase of the maximum lift to drag ratio is about 2% in the set (Fig. 10).

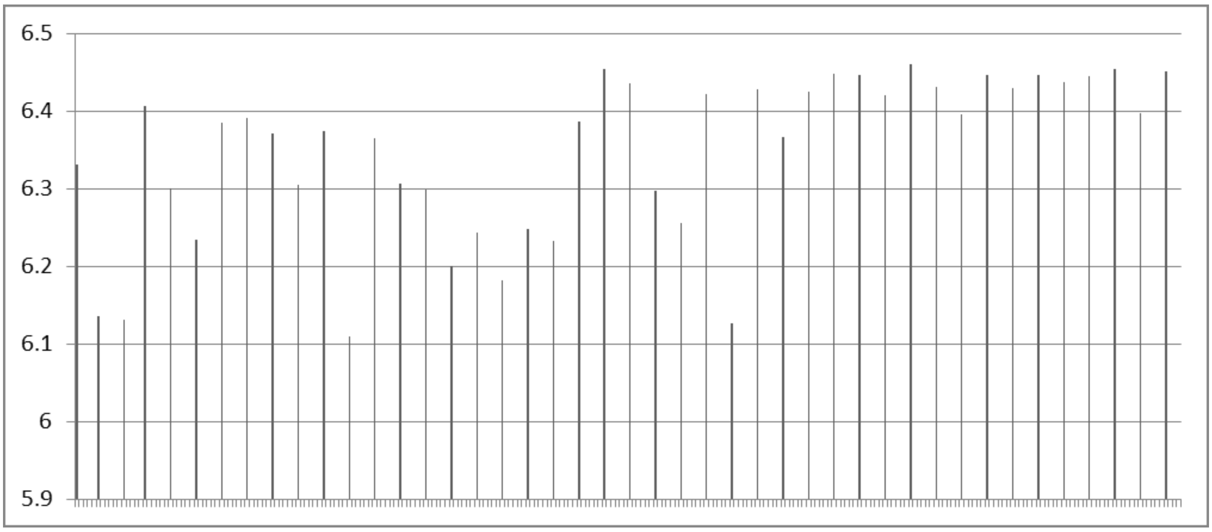

Figure 10: Lift-to-drag ratios for the wings from the set. Initial L/D is 6.33.

5 Conclusion

Calculation procedure for supersonic speed was developed. A series of studies to determine the combined effect of leading edge sweep angle and radius for a thin (relative thickness 4.5%), low aspect ratio (AR=2.18) wing is presented. It is shown that with the leading edge radius change from 0 to 0.2%c lift to drag ratio change as follows:

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