THE INVESTIGATION OF A POSSIBILITY OF INCREASING THE LIFT-TO-DRAG RATIO OF A MANEUVERABLE AIRCRAFT AT SUBSONIC SPEEDS

A.A.Pavlenko
TsAGI – Central Aerohydrodynamic Institute, Russia
alexander.a.pavlenko@gmail.com

Keywords: *maneuverable aircraft, subsonic speed, lift-to-drag ratio, wing mid surface, leading edge flap*

Abstract

Presented are the results of the experimental investigation of the possibility of increasing the subsonic lift-to-drag ratio of a maneuverable aircraft with thin wing by virtue of wing mid surface deformation.

The experiments were carried out in the TsAGI T-112 wind tunnel on the two research models of a maneuverable aircraft at free stream Mach number of 0.6.

Studied on the first model was the effect of the whole wing mid surface deformation. The model was tested with several variants of a thin trapezoidal wing of moderate aspect ratio (AR = 4) with the same plan form and thickness distribution: one had the flat mid surface, the shape of the two others was calculated so that at the design regime (M = 0.6, $C_{L\,des}$ = 0.5 and 0.8) there were no load peaks at the wing leading edge, the shape of the fourth wing was calculated with an additional constraint on the pitching moment value.

It is shown that with respect to the flat mid surface wing the lift-to-drag ratio increment due to wing deformation is $\Delta L/D \approx$ 4.5... 3.0, C_L = 0.6... 1.2, M = 0.6. It is also shown that the additional constraint on the pitching moment could be fulfilled practically without decreasing the lift-to-drag ratio gain.

Studied on the second model was the possibility of increasing the lift-to-drag ratio by means of deflecting the leading edge flap. The model was tested with thin trapezoidal wing of medium aspect ratio (AR = 3.2) and moderate camber and twist, equipped with several variants of a leading edge flap with constant spanwise absolute chord: two smooth flaps deflected at 20 and 40 degrees, and one with sharp bend deflected at 20 degrees. It is shown that deflection of the smooth leading edge flap results in considerable increase in the lift-to-drag ratio: $\Delta L/D \approx 3$, C_L = 0.7... 1.0, M = 0.6. In comparison with the LE flap with sharp bend the smooth LE flap yields appreciably greater increments in the lift-to-drag ratio: $\Delta L/D \approx 1.5$, C_L = 0.5... 0.9.

1 Introduction

The local leading edge flow separation at subsonic speeds and moderate angles of attack is a characteristic feature of modern maneuverable aircraft thin wing aerodynamics. This decreases the wing leading edge suction force and eventually the lift-to-drag ratio of an aircraft – the parameter defining its maneuverability. To prevent this phenomenon the wing mid surface is made cambered and twisted and the wing is equipped with the leading edge flaps. By proper selection of mid surface twist and camber it is possible to provide for smooth unseparated wing leading edge overflow at a particular design regime. A leading edge flap deflection may be used for adjusting wing mid surface shape for other regimes. It is desirable to choose the wing leading edge flap planform so that its deflection should prevent the local leading edge flow separation along the whole leading edge. Moreover a smooth junction of the leading edge flap with the main wing is desirable too for preventing flow separation from the junction region [1]. The importance of smoothing the leading edge junction region was demonstrated in the full scale experiment on the flying laboratory based on F-111 aircraft in the framework of the mission adaptive wing programme in the mid 80-th [2, 3].

2 Models and test conditions

2.1 Variants of the model wing with deformed mid surface

Variants of the thin trapezoidal wing of moderate aspect ratio with mid surface deformed for certain regime were tested on the research fighter aircraft model. All the variants had identical planform (aspect ratio 4, leading edge sweep 38 grad, taper ratio = 0.25) and thickness distribution (airfoil relative thickness 0.05). One of them had flat mid surface, mid surface of two others was calculated so that at the design regime (M = 0.6, $C_{L\,des}$ = 0.5, 0.8) there should be smooth unseparated overflow of the wing leading edge, mid surface of the forth wing was calculated for regime (M = 0.6, $C_{L\,des}$ = 0.5) with an additional constraint on the pitching moment coefficient value.

The wing mid surface shape was calculated using linearized theory in the result of solving the mixed problem of aerodynamics: at a given values of the subsonic inflow Mach number and the total lift coefficient the wing planform load distribution was specified so that to provide for minimum induced drag and absence of additional drag due to incomplete realization of the leading edge suction force (i.e. without leading edge singularity and with elliptical spanwise distribution of velocity circulation), as well as mid surface of the fuselage centreplane. Obtained as a result were the angle of attack of the fuselage centreplane and distribution of angles of lifting surface inclination, based on which the lifting surface form was restored.

The flow downwash induced by continuous distribution of aerodynamic load on the lifting surface was calculated by the relationship:

$$\frac{w(x,y)}{U_\infty}=\frac{1}{8\pi}\int_{y_{root}}^{y_{tip}}\frac{\Phi(x,y,\eta)}{(\eta-y)^2}d\eta,$$

$$\Phi(x,y,\eta)=$$

$$\int_{x_{L.E}(\eta)}^{x_{T.E}(\eta)}\Delta C_p(\xi,\eta)\left[1-\frac{\xi-x}{\sqrt{(\xi-x)^2+(\eta-y)^2}}\right]d\xi \qquad (1)$$

Since pressure difference between lower and upper sides of the lifting surface equals zero at the leading (applied condition) and trailing (Zhoukovsky condition) edges, the function $\Delta C_p(\bar{x},y)$ may be represented as Fourier series:

$$\Delta C_p(\bar{x},y)=\frac{1}{c(y)}\sum A_n(y)\sin n\theta, \qquad (2)$$

where $\cos\theta=1-2\bar{x}$, $x=x_{L.E}(y)+c(y)\bar{x}$, with the first two coefficients being defined by spanwise distribution of section velocity circulation and centre of pressure position:

$$A_1(y)=\frac{8}{\pi}\frac{\Gamma(y)}{U_\infty}, \qquad (3)$$

$$A_2(y)=2\,A_1(y)\,(1-2\bar{x}_{C.P}(y)) \qquad (4)$$

All subsequent members of series (2) do not affect the lift and the pitching moment coefficients of the lifting surface.

In the optimum wing mid surface calculations the aerodynamic load distribution was prescribed as the sum of the first two members of series (2), the section velocity circulation $\frac{\Gamma(y)}{U_\infty}$ was determined by the total lift coefficient and the requirement of elliptical spanwise variation of circulation. The section relative centre of pressure location was prescribed to be spanwise constant and equal to $\bar{x}_{C.P}$ = 0.43. In that case the inflection point of the longitudinal section of the surface is situated near its trailing edge, and the surface may be conditionally treated as mid surface of a wing with smoothly deflected leading edge flap. Also computed was optimum lifting surface with more forward position of the section relative centre of pressure position $\bar{x}_{C.P}$ = 0.29.

The longitudinal sections of the two variants of the wing with optimum mid surface shape for the regime M_{des} = 0.6, $C_{L\,des}$ = 0.5 with different relative centre of pressure positions, $\bar{x}_{C.P}$ = 0.43 и 0.29, are shown in figures 1 and 2, respectively.

Fig. 1. Longitudinal sections of the wing with mid surface optimized for the regime M = 0.6, $C_{L\,des}$ = 0.5; $\bar{x}_{c.p}$ = 0.43 ($\frac{y}{l/2}$ = 0.3, 0.4, 0.7, 0.9, 1.0)

Fig. 2. Longitudinal sections of the wing with mid surface optimized for the regime M = 0.6, $C_{L\,des}$ = 0.5; $\bar{x}_{c.p}$ = 0.29 ($\frac{y}{l/2}$ = 0.3, 0.4, 0.7, 0.9, 1.0).

2.2 Variants of the deflected wing leading edge flaps

An analysis of the wing mid surfaces providing for smooth subsonic overflow of the leading edge has shown that they are characterized by section camber increasing towards wing tips and negative twist, with lines of constant mid surface inclination in the wing plan view being nearly parallel to the leading edge [1]. Therefore for approximating optimum mid surface by virtue of leading edge flap deflection it is worth while to select it with spanwise constant absolute chord.

The effectiveness of deflected leading edge flap with spanwise constant absolute chord was investigated on the second model. The model was tested with the series of wings with identical planform (aspect ratio 3.2, leading edge sweep 40 grad, taper ratio 0.25) and thickness distribution (relative thickness 0.05).

One of the wings had flat mid surface, the other – mid surface with moderate deformation (camber varying from 0.6% at the root section to 1.5% at the tip one and negative twist of –2 grad) for increasing the maximum value of the subsonic lift-to-drag ratio.

Tested were also two other wings with the same moderate deformation equipped with leading edge flaps with spanwise constant absolute chord which were smoothly deflected at angles 20 and 40 degrees and besides that one more wing with deflected at 20 degrees leading edge flap with sharp bend junction region. Longitudinal sections of the two wings with smooth and conventional leading edge flaps deflected at 20 degrees are presented in figures 3 and 4.

Fig. 3. Longitudinal sections of the wing with the leading edge flap smoothly deflected at 20 degrees ($\frac{y}{l/2}$ = 0.3, 0.64, 0.95)

Fig. 4. Longitudinal sections of the wing with the leading edge flap deflected at 20 degrees with sharp bend ($\frac{y}{l/2}$ = 0.3, 0.64, 0.95)

2.3 Test conditions

The test was carried out in the TsAGI T-112 wind tunnel.

Trans- and supersonic wind tunnel T-112 is ejector type wind tunnel with periodical operation having semi-closed contour and closed test section with square cross section of 0.6×0.6 m^2 and 2.55 m length. Horizontal panels of the test section are perforated. Besides, there is perforated part of vertical panels in the vicinity of a model location.

An experiment was carried out at free stream velocity corresponding to the Mach number of 0.6 in the range of an angle-of-attack from –4 to 24 degrees. The angle of attack was measured from the fuselage reference plane.

The both models were attached to the external balance by virtue of sting holder.

Corrections adopted for T-112 wind tunnel were introduced into experimental data for accounting for balance frame and support system blowing, for flow wash, for elastic sting deformation under aerodynamic loads, for base pressure, and for the internal ducts drag. In calculating the base drag correction an equality of the base pressure and the free stream static pressure was assumed. The internal ducts drag was calculated based on static and full pressure measurements in outlet section performed separately from the balance test.

In calculating aerodynamic coefficients of the research models 1 and 2 the following characteristic geometrical parameters were used: the wing trapeze area (S = 0.05 и 0.0423 m^2, respectively), the middle aerodynamic chord length (c_{MAC} = 0.126 и 0.1256 m, respectively). The pitching moment coefficient was calculated with respect to conditional model center of mass position, corresponding to 27% of MAC.

3 Experimental results

3.1 Variants of the wing with all mid surface deformation

Experiment showed that optimum forming of the wing mid surface for specified regime (M_{des}= 0.6, $C_{L\,des}$ = 0.5 и 0.8) results in slight increase in the lift coefficient ($\Delta C_L \le$ 0.1, $\alpha \le$ 15 deg, Fig. 5), in appearance of the pitching moment coefficient increments on diving in the whole angle-of-attack range tested ($\Delta C_m \approx$ –0.05, for the wing variant with $C_{L\,des}$= 0.5, Fig. 6), and in considerable increase in the lift-to-drag ratio both the maximum value and values at high lift coefficients ($\Delta(L/D)_{\max} \approx 2.0$, $\Delta(L/D) \approx$ 4.5... 3.0, based on envelope, C_L = 0.6... 1.2, M = 0.6, Fig. 6).

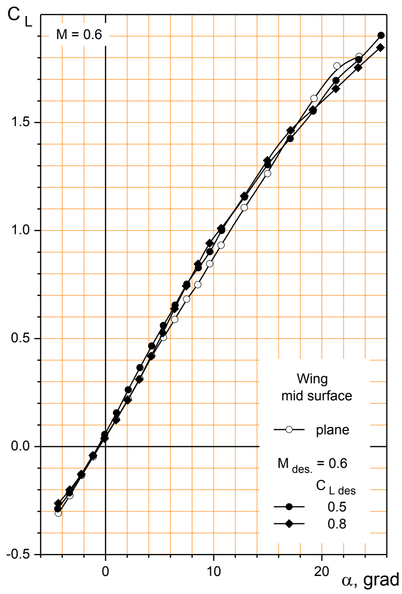

Fig. 5. The effect of all wing mid surface deformation on the model lift coefficient

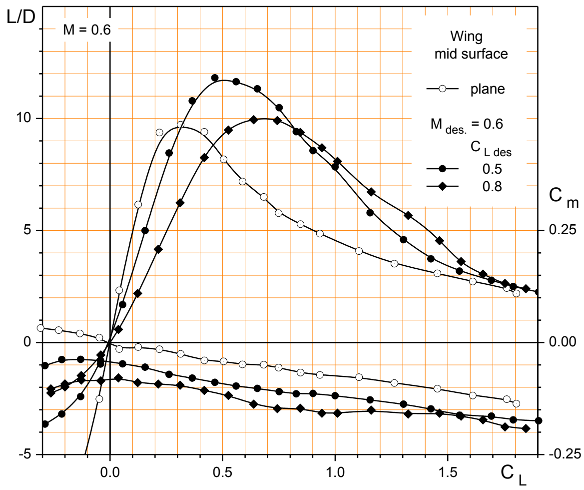

Fig. 6. The effect of all wing mid surface deformation on the model lift-to-drag ratio and the pitching moment coefficient

The optimum wing mid surface obtained in computations with prescribed front centre of pressure line position, which is characterized by larger surface inclination angles near the leading edge and upward deflection of the rear part of the surface, yields practically the same increments in the model lift-to-drag ratio as the surface obtained without the pitching moment constraint, but in that case the model has appreciable nose-up increments in the pitching moment coefficient and nearly the same lifting capabilities ($\Delta C_m \approx$ 0.07, M = 0.6, Fig. 7, 8).

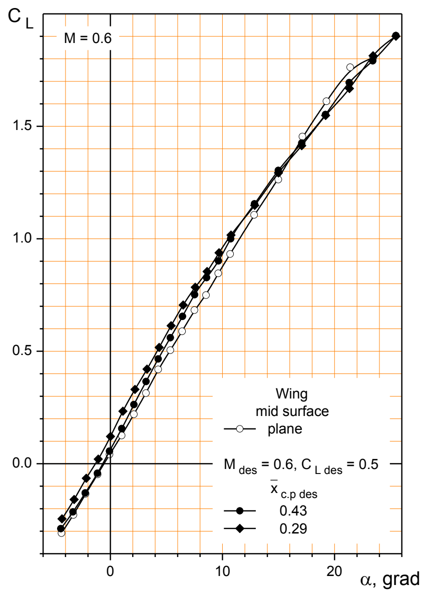

Fig. 7. The effect of design position of the wing section center of pressure line on the model lift coefficient

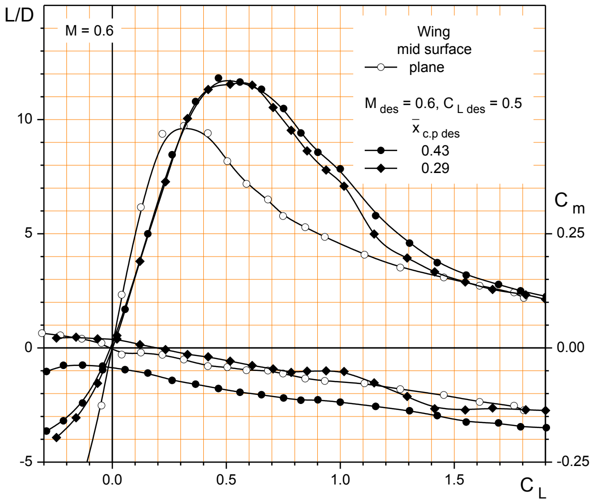

Fig. 8. The effect of design position of the wing section center of pressure line on the model lift-to-drag ratio and the pitching moment coefficient

3.3 The effect of smooth wing leading edge flap deflection on the model aerodynamic characteristics

Smooth deflection of the leading edge flap with spanwise constant absolute chord on the wing with moderate wing mid surface deformation results in substantial increase in the model lift-to-drag ratio at subsonic speed in the lift coefficient range above $C_{L\,(L/D)_{\max}}:\Delta\left(L/D\right)\approx$ 3.0, C_L = 0.7... 1.0, M = 0.6. Some increase in the lift coefficient at angles of attack above 10 degrees ($\Delta C_L \leq$ 0.1) and increments in the pitching moment coefficient on diving ($\left|\Delta C_m\right| \leq$ 0.05) are also obtained, Figs. 9, 10.

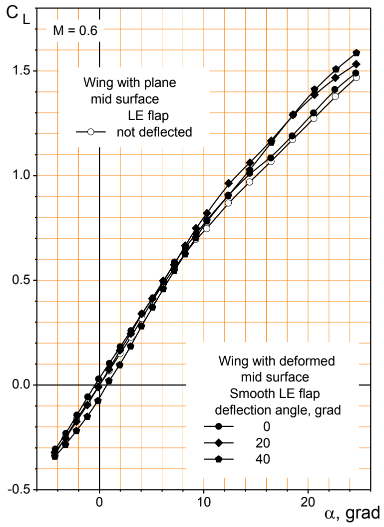

Fig. 9. The effect of wing leading edge flap smooth deflection on the model lift coefficient

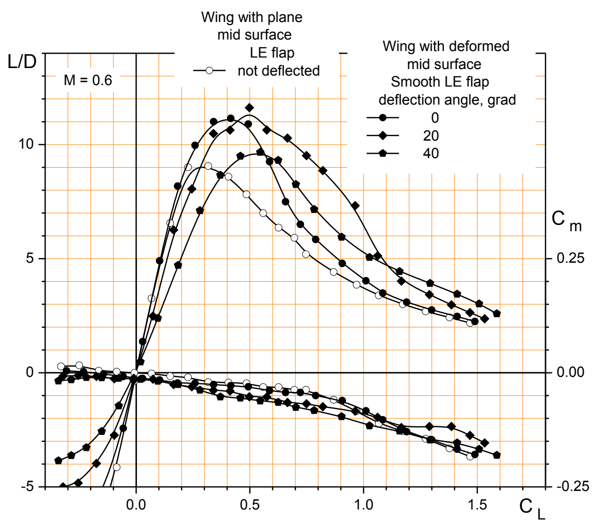

Fig. 10. The effect of the wing leading edge flap smooth deflection on the model lift-to-drag ratio and the pitching moment coefficient

3.4 The effect of smoothness of the leading edge flap junction region on its effectiveness

Presented in figures 11 and 12 are the results of investigation of two variants of a leading edge flap: one with the smooth junction region, the other – with sharp bend.

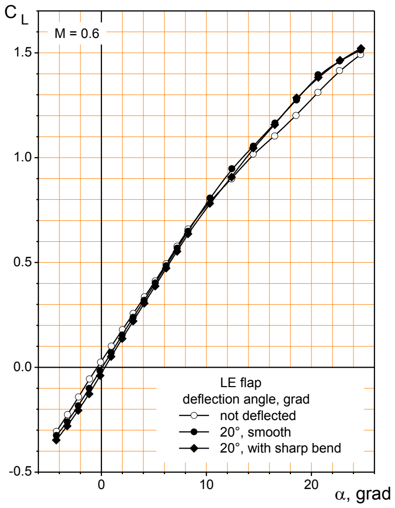

Fig. 11. The effect of wing leading edge flap junction smoothness on the model lift coefficient

The lift-to-drag ratio increments due to deflection of the wing leading edge flaps with smooth junction are considerably larger than for flaps with sharp bend ($\delta_{LEF} = 20\,\deg$, $\Delta(L/D) \approx$ 1.5, in the range 0.6 $\le C_L \le$ 0.9, Fig. 12), whereas the shape of junction region has practically no effect on the lift and the pitching moment coefficients (Figs. 11, 12).

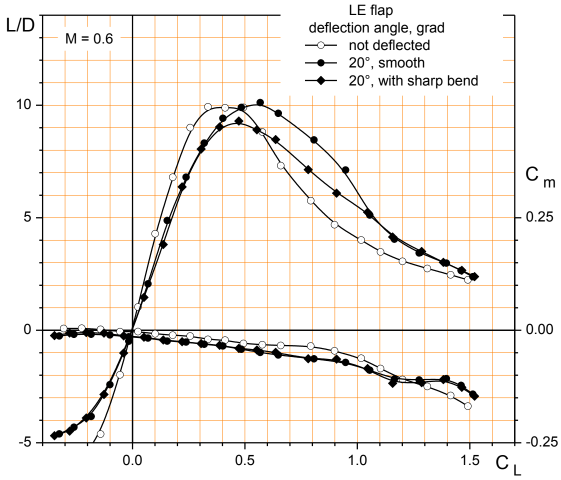

Fig. 12. The effect of wing leading edge flap junction smoothness on the model lift-to-drag ratio and the pitching moment coefficient

4 Conclusions

It is shown that forming wing mid surface for providing for smooth unseparated overflow of the wing leading edge makes it possible to increase the model subsonic ligt-to-drag ratio up to $\Delta(L/D) \approx$ 4.0… 3.0 ($C_L =$ 0.6... 1.2, $M =$ 0.6) in comparison to wing with flat mid surface. Additional constraint on longitudinal model trimming applied in computation of the optimum mid surface shape do not practically diminish the lift-to-drag ratio increments.

Smooth deflection of the leading edge flap with spanwise constant absolute chord on the wing with moderate camber and twist results in substantial increments in the model lift-to-drag ratio at high values of the lift coefficient: $\Delta(L/D) \approx$ 3.0 ($C_L =$ 0.7... 1.0, $M =$ 0.6).

In comparison to the leading edge flap with sharp bend the smooth one yields substantially larger increments in the model lift-to-drag ratio: $\Delta(L/D) \approx$ 1.5 ($C_L =$ 0.5... 0.9, $M =$ 0.6).

References

[1] Bushgens G.S., editor. *Aerodynamics, stability and controllability of supersonic aircraft*. Moscow. Nauka. Fizmatlit. 2001.

[2] Webb L.D, McCain W.E, Rose L.A. Measured and predicted pressure distributions on the AFTI/F-111 mission adaptive wing. *NASA TM* 100443, 1988.

[3] Powers S.G, Webb L.D, Friend E.L, Lokos W.A. Flight test results from a supercritical mission adaptive wing with smooth variable camber. NASA TM 4415, 1992.

Copyright Statement