Investigation of high lift system for a short range aircraft with a Natural Laminar Flow wing

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Abstract
Laminarization is an advanced aerodynamic technology for future aircraft. Currently this is the only technology in aerodynamics which promises two-digit percentage improvement in fuel burn. The NLF (Natural Laminar Flow) technology is suitable for small regional and short range aircraft with low sweep wing, when LFC (Laminar Flow Control) in some form is necessary for large aircraft.
TsAGI for many years investigates various aspects of a laminarization, and in recent decade these studies received a new impulse. The NLF airplanes considered in TsAGI possess wings with small sweep of about 15 degrees, however they reach high Mach numbers of about M=0.78 due to utilization of advanced supercritical profiles along span. At designing of such wings it is necessary to consider a compromise between laminar and turbulent mode of a flow, and also between NLF and high lift characteristics.
Several aerodynamic models were designed and tested in transonic wind tunnels including configurations with over-wing-trailing-edge engine arrangement (Figure 1) which can reduce community noise considerably and open the road to fuel-efficient ultra-high-bypass-ratio turbofans with large fan diameter on short range planes.
This paper describes the investigation of several suitable types of wing high-lift devices, compatible with NLF, with the aid of modern CFD Navier-Stokes (RANS) methods. Several alternate concepts for inboard and outer laminar wing were studied numerically, including Droop Nose Device, Krueger slat et al. Performed numerical investigations compose a basis for high-lift aerodynamic model to be created soon.

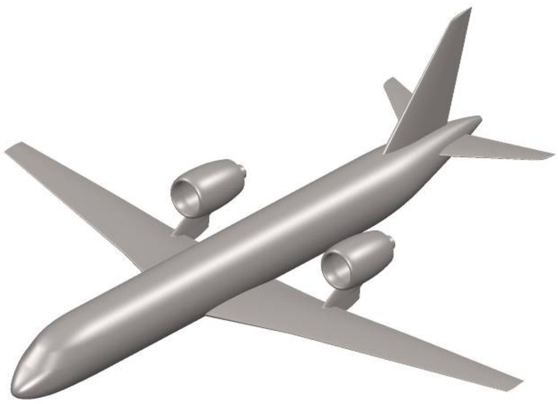

Figure 1: The aerodynamic model of the short-range laminar aircraft with over-wing engines

1. Introduction

One of the most important problems in aircraft design is development of high-lift system. It influences wing area and thus all aircraft layout. If high-lift system effectiveness is not satisfactory, wing area has to be increased with appropriate growth in structure weight and friction drag. High Cl_{max} enables to create more capacious versions in a

future and to improve economy attraction of aircraft in operation - increase takeoff weight and payload and enlarge the number of used runways.
Earlier high-lift system effectiveness was traditionally improved by increasing number of elements [1]. Now there is a tendency to reduction of a number of high-lift system elements with retaining the same efficiency [2,3] (Figure 2). It is possible owing to application of CFD methods in design procedure [4-6].

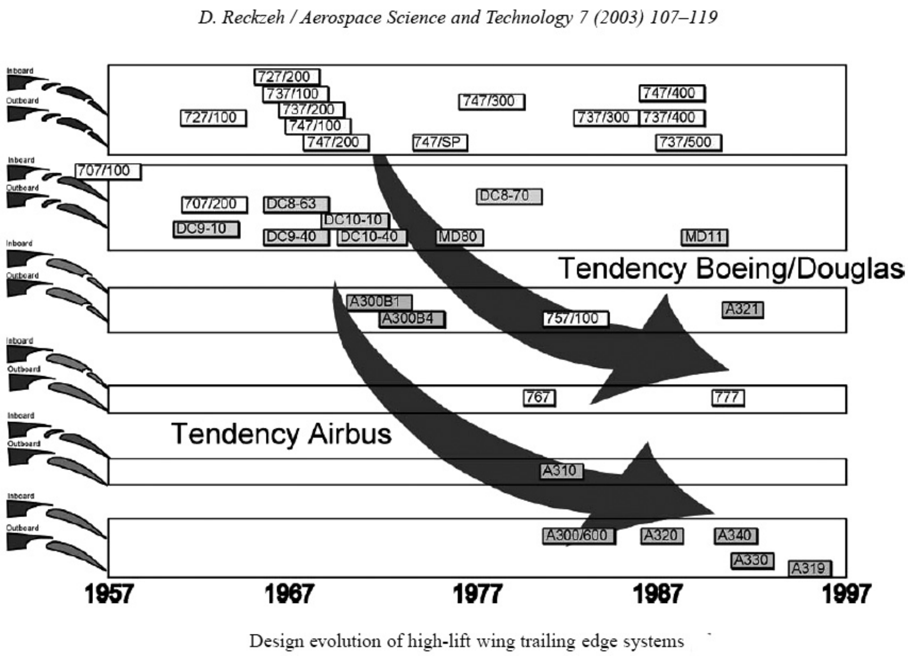

Figure 2: Tendency in high-lift design

Simplified high-lift devices are used on modern long range aircrafts B-787 and A-350. The A-350 wing leading edge is equipped with a Droop Nose Device (DND) inboard and Sealed Slat outboard (Figures 3-4). At the trailing edge two Adaptive Drooped Hinge Flaps (ADHF) are installed, covered by a droop panel and spoilers [7].

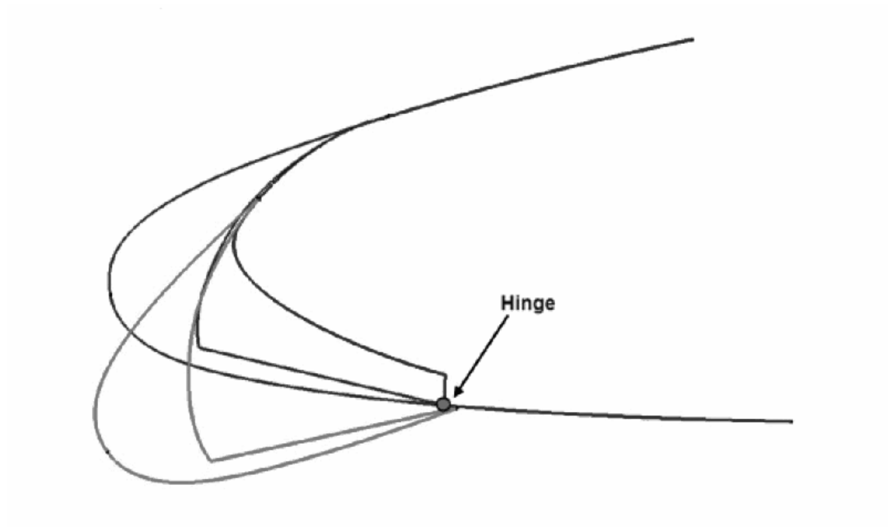

Figure 3: Droop Nose Device (DND) on inboard wing of A-350

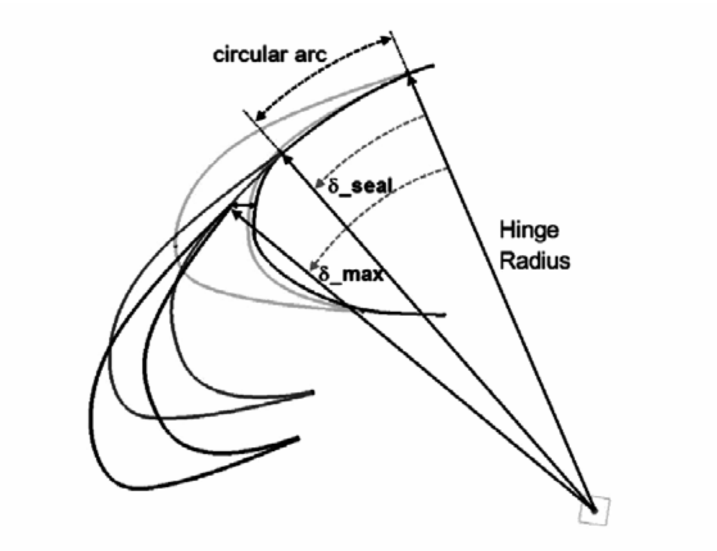

Figure 4: Sealed Slat on outboard wing of A-350

Simplified high-lift devices have lower weight and cost. Using of high-lift system without gap on a leading edge is desirable for increasing lift-to-drag ratio at take-off and reduction of noise.
High-lift system for a Natural Laminar Flow (NLF) wing is a special question [8, 9]. At present Krueger slat is considered to be the only choice for leading edge. It not only increases lift, but also shields upper laminar surface from dirt accumulation (Figures 5-6). However, it leads to turbulization of the lower surface, which reduces overall effect.

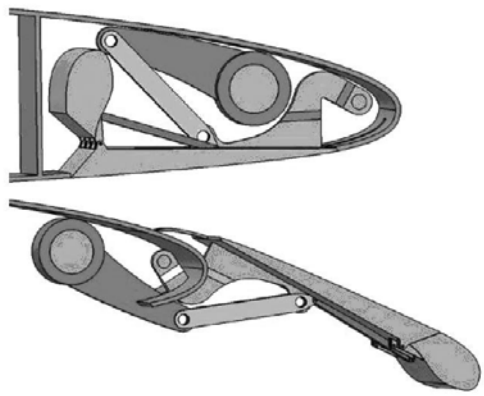

Figure 5 [9]: Slotted and folding Krueger kinematics

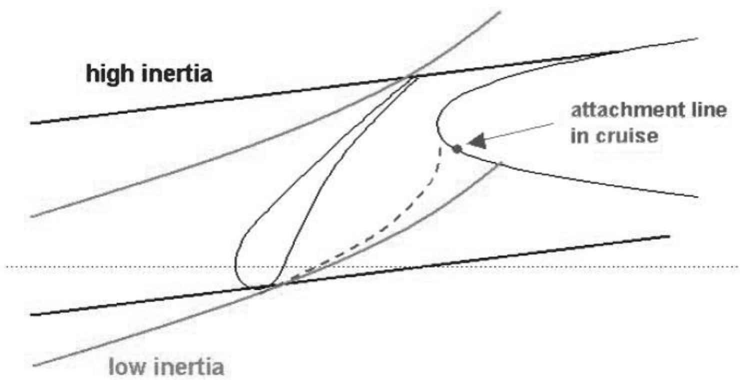

Figure 6 [9]: Krueger slat in insect shielding position

An analysis of a full airplane configuration, including high-lift system, nacelles and low-sized elements, like strakes etc, still remains complex problem and requires a lot of time for meshing and calculations. So design process is based usually on computation of 2-D and simple 3-D configurations and full layout analysis is used for final performance estimation.
The present paper contains results of computational investigations in high-lift devices design for a short range aircraft with a Natural Laminar Flow wing. Research was fulfilled with regard to low-noise configuration with low-sweep wing and over-wing-trailing-edge engine arrangement (Figure 1). Recently model of such aircraft has been tested in large transonic wind tunnel in TsAGI (Figure 7). High-speed performance proved to be satisfactory (M_{cruise}=0.78), but low speed maximum lift is not high enough in comparison with turbulent designs.

Figure 7: Model of low-noise configuration in transonic wind tunnel

Thus the present work was initialized with the purpose to investigate possibilities of Cl_{max} increasing. The aim is to ensure high lift using simplified leading edge high-lift system. A number of alternate concepts for inboard and outboard laminar wing were studied numerically.

2. Investigation of inboard high-lift system

Inboard leading edge high-lift system is usually made less powerful to obtain satisfactory stall behavior at low speed. For example, on A-380, A-350 and An-148 aircraft Droop Nose Device is installed on inboard wing and slat is used outboard. In addition A-380, A-350, CRJ-700/900 have considerable unprotected leading edge part near the root. It is used to improve pitch moment behavior at high angles of attack.
Krueger slat is the only acceptable solution for outboard wing with NLF, as suited for insect shielding. For inboard wing three choices were considered and compared - nose without high-lift devices, DND and opening shaped slot. In particular, such slot was used on the XB-35 flying wing aircraft. Described three configurations for base airfoil P-02 (20% of semispan) with calculated streamlines for flap in take-off position are shown in Figures 8-10. Flap chord is equal to 25%.

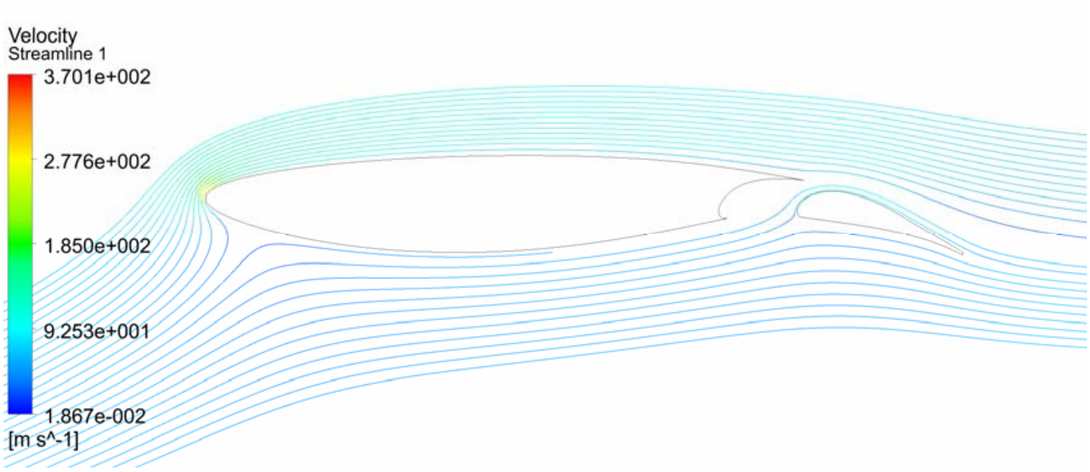

Figure 8: Flow pattern of base airfoil P-02 with flap, AoA=10°

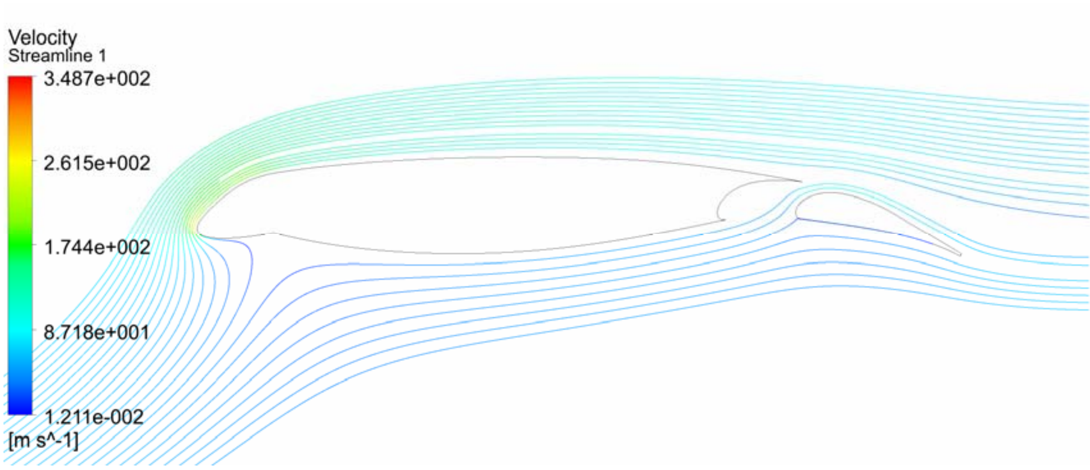

Figure 9: Flow pattern of base airfoil P-02 with DND and flap, AoA=16°

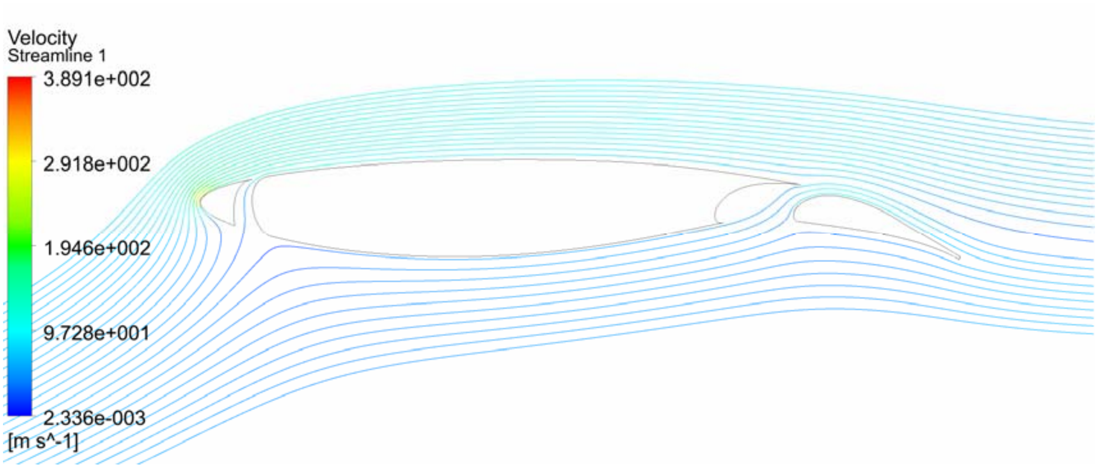

Figure 10: Flow pattern of base airfoil P-02 with opening slot and flap, AoA=11°

Aerodynamic characteristics are calculated by ANSYS CFX with full turbulent flow and Reynolds number Re = 20 mln. Lift coefficient with flap in take-off position and without flap is plotted in Figure 11.

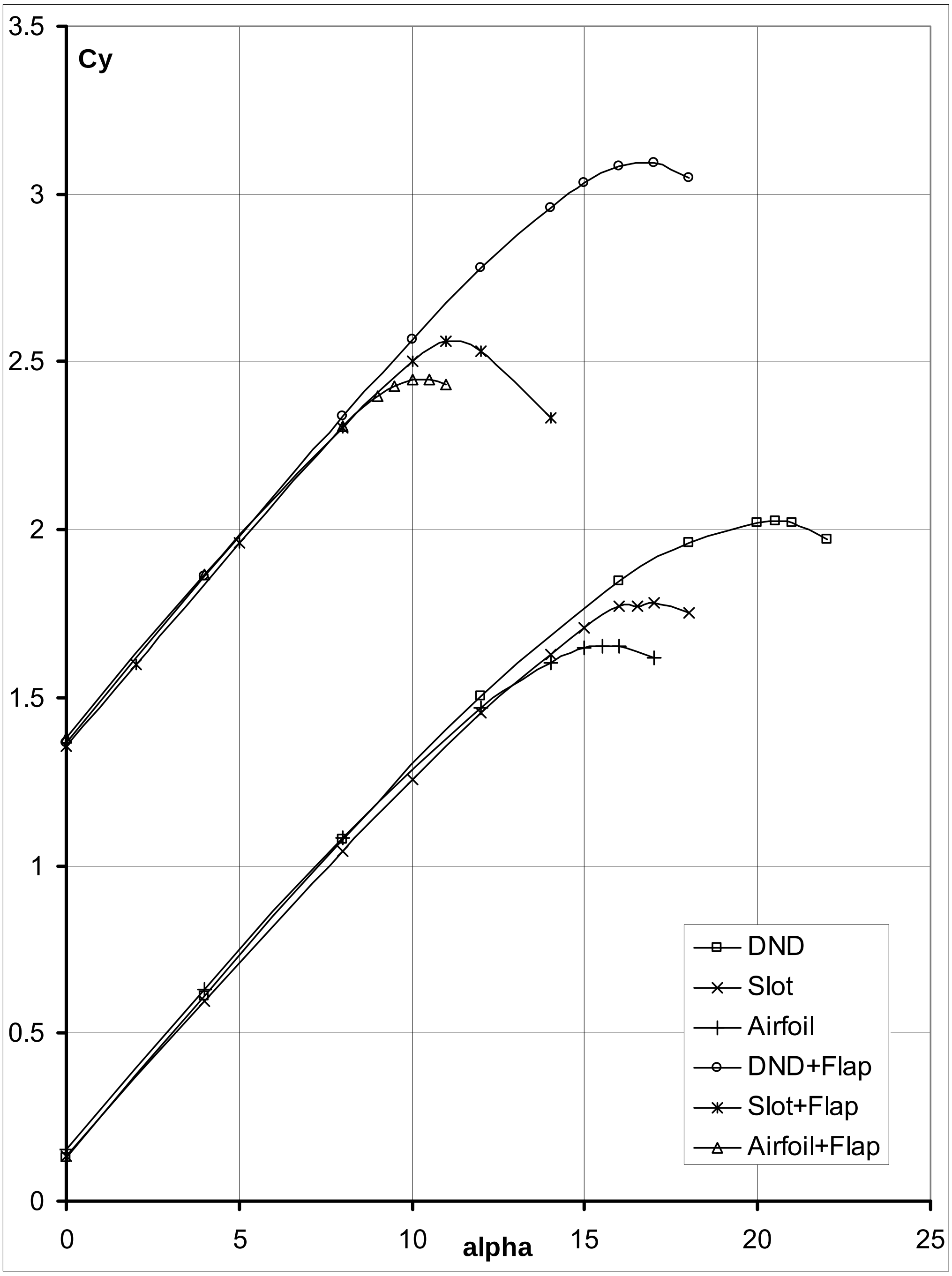

Figure 11: Calculated lift coefficient of base airfoil P-02 with DND, opening slot and without high-lift device of leading edge

As follows from the figure base airfoil has moderate lift characteristics because of small nose radius. DND allows to increase lift considerably. Slot appears to be not very effective, though its parameters were not optimized. Flow separation on the nose part of base airfoil possibly takes place before the slot.

Not so satisfying lift characteristics of base airfoil led to consideration of alternate geometry - high-lift airfoil P-02M (modified) with increased nose radius and small leading edge droop (Figure 12).

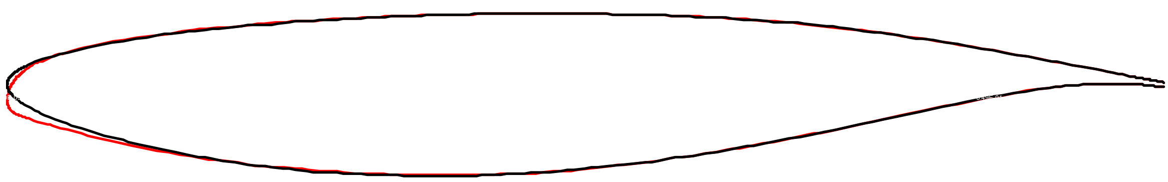

Figure 12: Geometry of base P-02 and modified P-02M airfoils

Trailing part of the airfoil was kept fixed. New high-lift airfoil P-02M is designed by OPTFOIL program [10]. Increased nose radius may lead to turbulization of the leading edge, but increased sweep of leading edge extension seems to result in forward transition any way.

High-lift devices for modified airfoil was examined in the same way. Comparison of base and modified airfoils is shown in Figures 13-14.

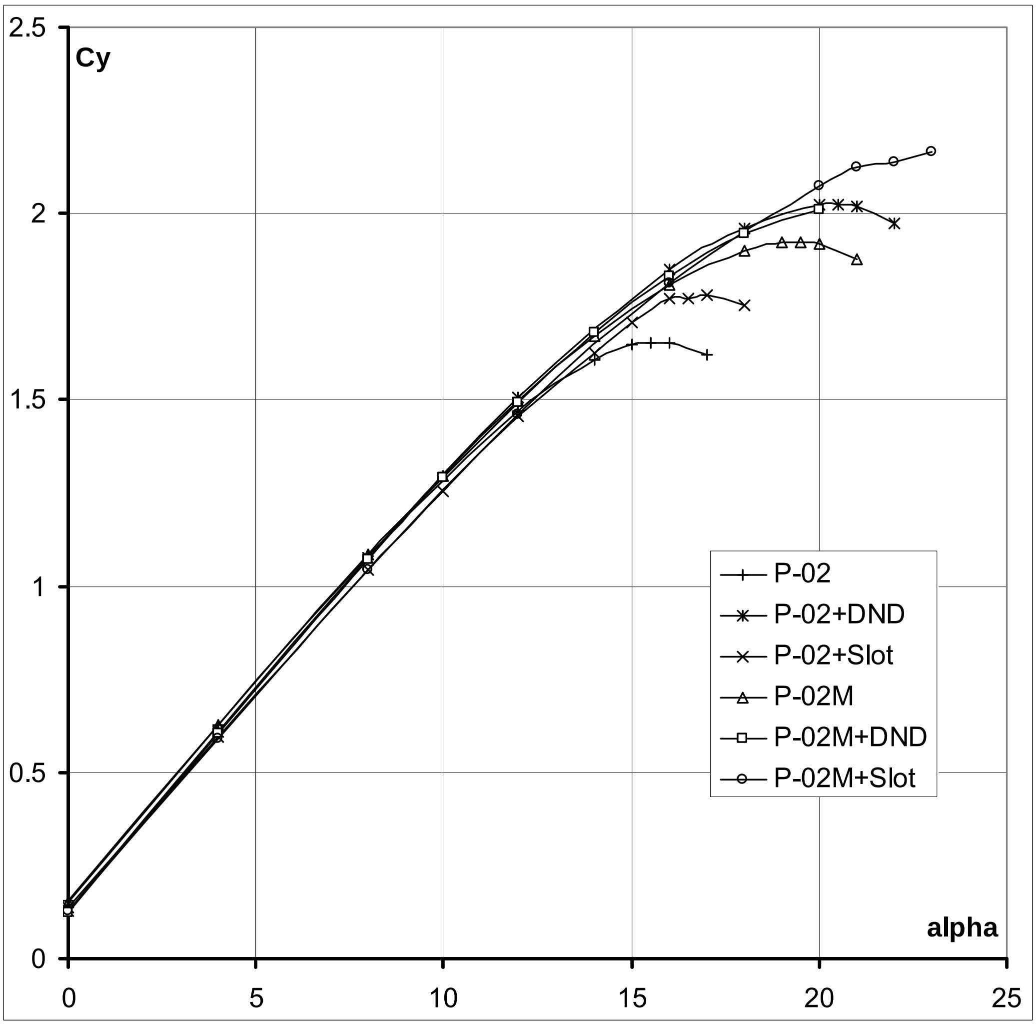

Figure 13: Lift coefficient of base airfoil P-02 and modified airfoil P-02M with different high-lift devices of leading edge

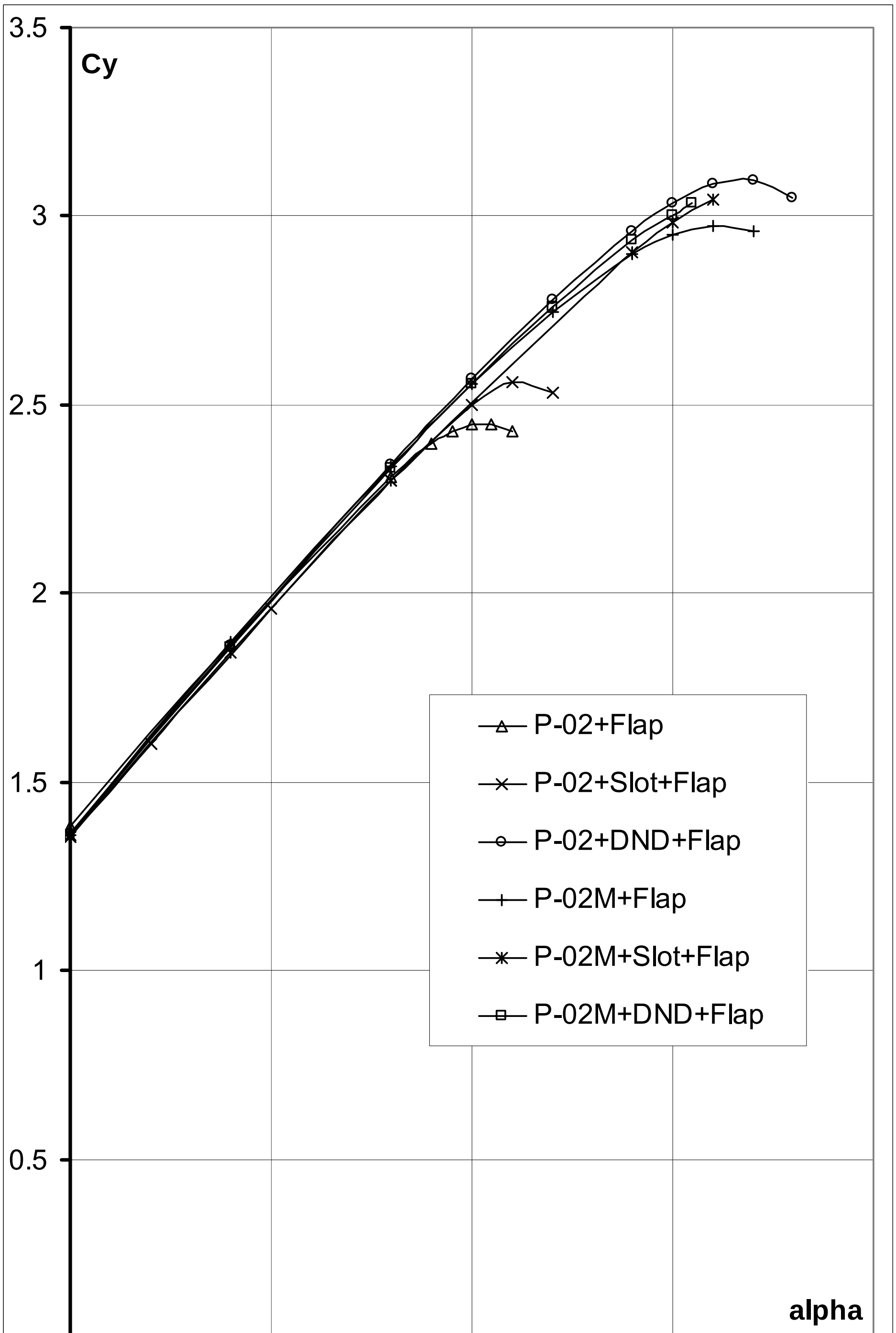

Figure 14: Lift coefficient of base airfoil P-02 and modified airfoil P-02M with different high-lift devices of leading edge and flap in take-off position

As follows from the pictures, modified airfoil itself gives almost the same lift as base airfoil with DND. Lift of the base airfoil with DND and lift of the modified airfoil with DND are similar. Abandonment of using DND evidently simplifies the construction. Using of fixed nose gives an opportunity to consider hybrid laminarization of inboard wing in prospect. However speed characteristics will go slightly down if base airfoil is replaced by the modified one. Modified airfoil with optimized slot looks the most efficient compromise solution for first design phase, despite possible drag and noise increase due to slot.

3. Investigation of outboard high-lift system

Three types of nose part are considered for outboard wing - nose without high-lift devices, Krueger slat and classic slat for comparison. Chord of slat equals 15%. Krueger slat is examined in position of "insect shield" (see Figure 6). Flap chord is equal to 30% and flap angle in take-off position is 20°. New high-lift airfoil P-06M (modified) was designed by means of OPTFOIL code in the same way as for inboard wing described above (Figure 15). It differs from the base airfoil by the nose part. Increase of lift for modified airfoil is slightly lower than in the case above, because greater priority was given to high-speed characteristics (Figure 16).

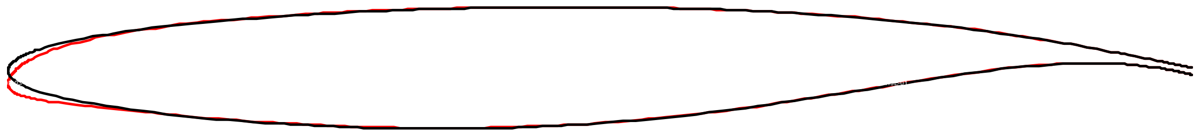

Figure 15: Geometry of base P-06 (60% of semispan) and modified P-06M airfoils

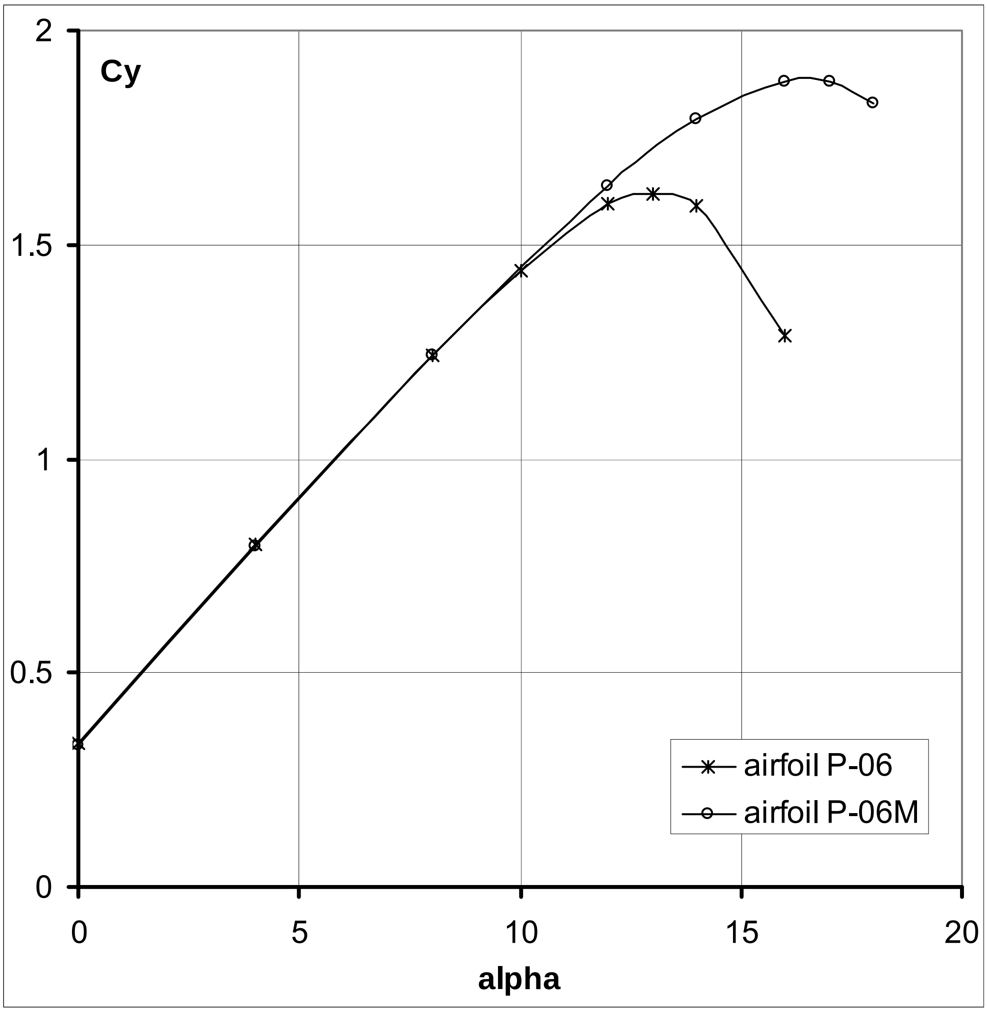

Figure 16: Lift coefficient of base P-06 and modified P-06M airfoils (calculated by ANSYS CFX)

Calculated lift for both airfoils with different types of high-lift devices is shown in Figure 17. Reynolds number Re = 15 mln. Geometries and flow patterns are represented in Figures 18-20.

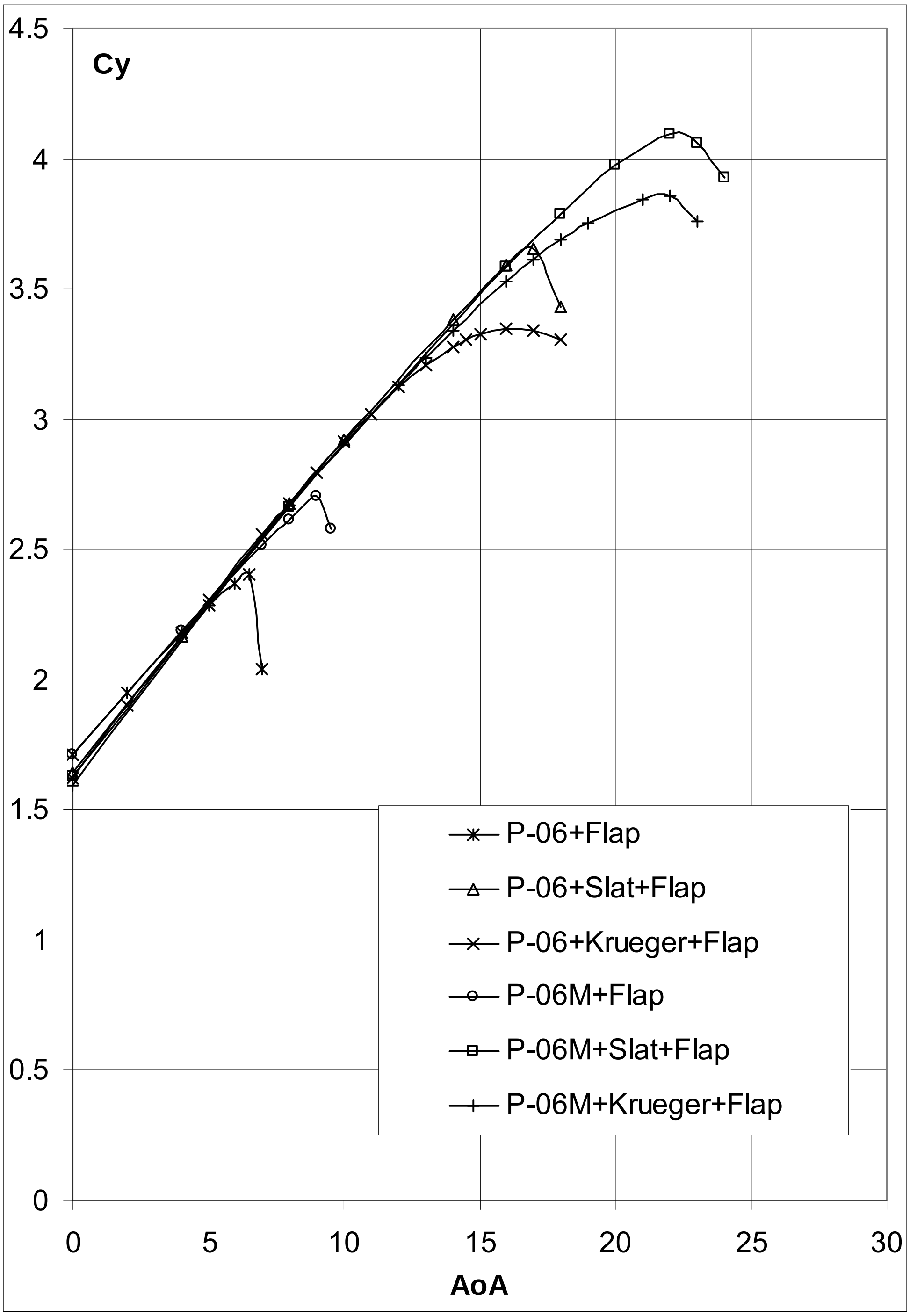

Figure 17: Lift coefficient of base airfoil P-06 and modified airfoil P-06M with different high-lift devices of leading edge and flap in take-off position

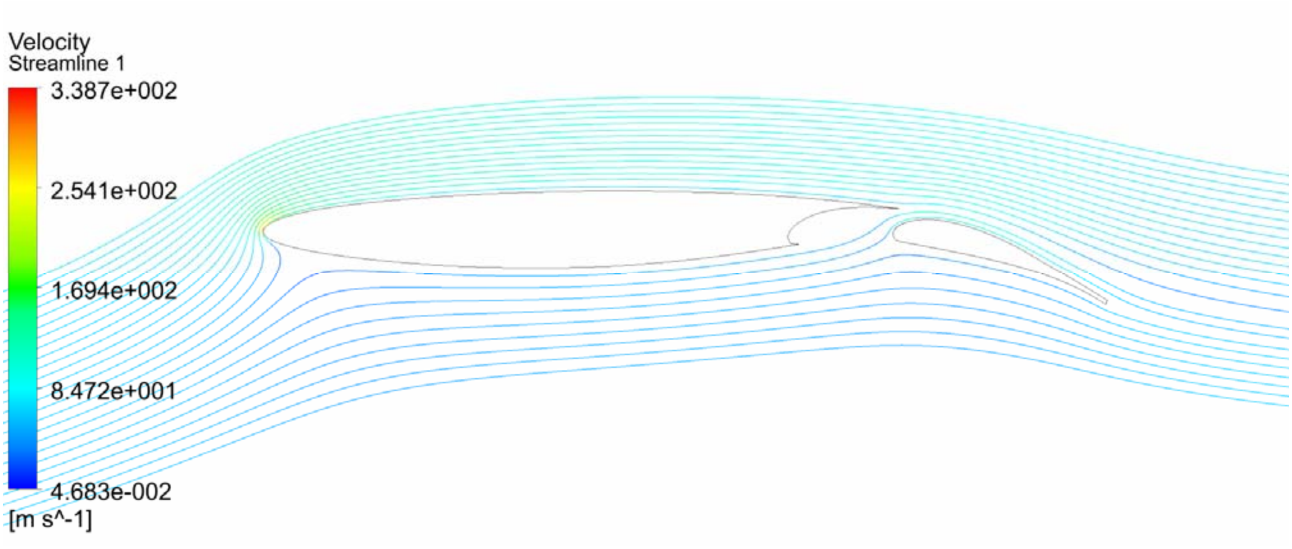

Figure 18: Flow pattern of base airfoil P-06 with flap, AoA=6°

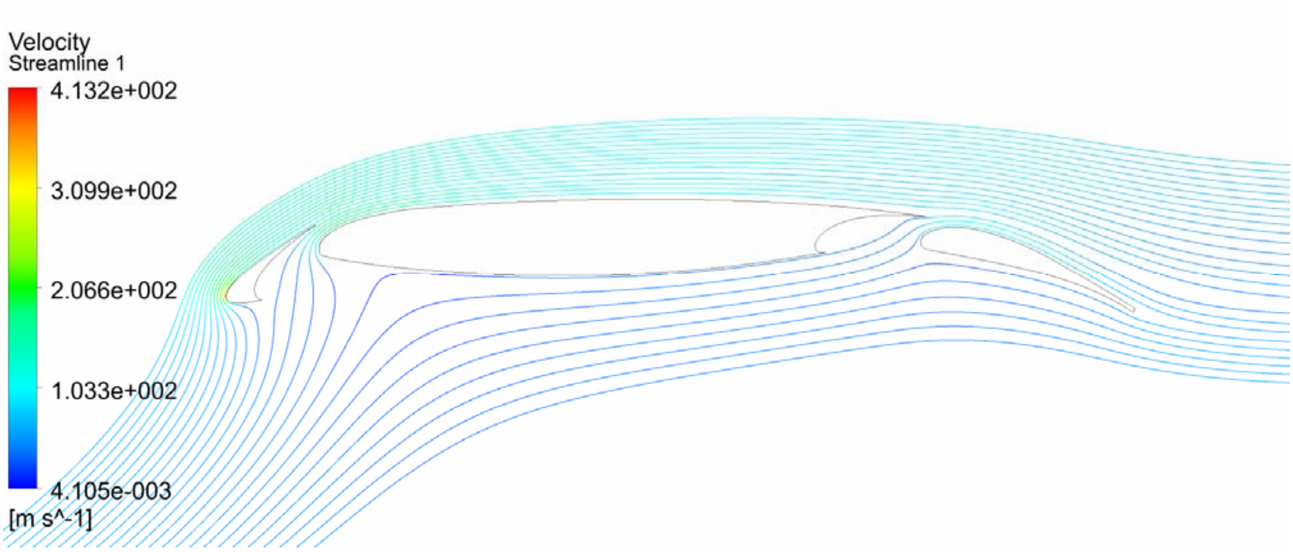

Figure 19: Flow pattern of base airfoil P-06 with classic slat and flap, AoA=17°

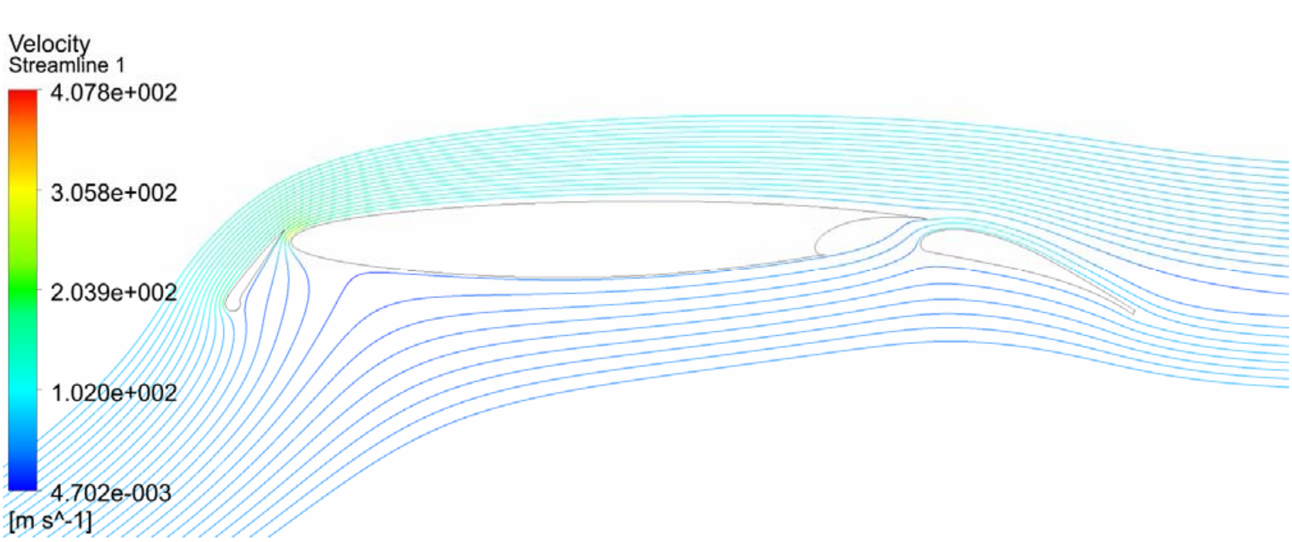

Figure 20: Flow pattern of base airfoil P-06 with Krueger slat and flap, AoA=15°

Apparently that advantage of modified airfoil in lift remains in the presence of high-lift devices - flap, slat and Krueger slat. Slat, as expected, is the best high-lift device for lift increase. Lift efficiency of Krueger slat is about 75% of slat efficiency. It should be emphasized that modified airfoil with Krueger slat gives better lift characteristics than base airfoil with a classic slat.

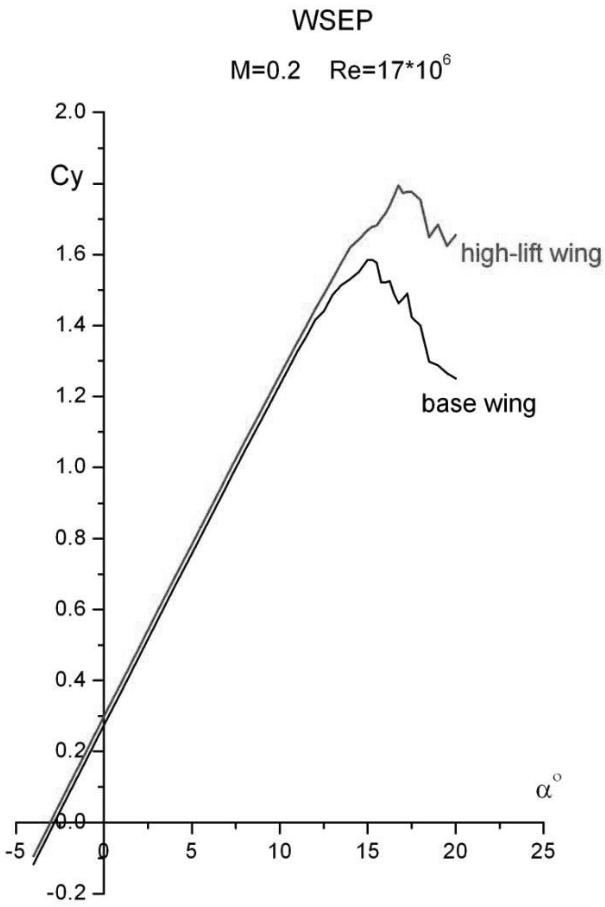

Figure 21: Comparison of lift performance of the wings, M=0.2

4. Conclusions

Different high-lift devices of leading edge with simplified construction for perspective short range aircraft with Natural Laminar Flow have been considered. An analysis of different types of high-lift devices is carried out by means of ANSYS CFX code. It is shown that an increase in lift for airfoil with modified nose part ΔCl_{max}~0.25 remains while using slat or Krueger slat. Droop Nose Device (DND) is not effective for modified airfoil.
Thus we consider fixed nose to be rational compromise for inboard wing, despite some loss in high speed characteristics. It is worth to continue examination and optimization of opening slot, as a simple tool to delay flow separation on landing regime, when drag increase is not so essential.
For outboard wing computation shows that high-lift modification of the airfoil allows reaching considerable lift increase without and with high-lift devices - classic and Krueger slats. In particular, Krueger slat on modified airfoil gives better lift characteristics than classic slat on base airfoil.
Performed numerical investigations compose a basis for a new 3-d wing with increased lift performance (Figure 21). Cruise and high-lift aerodynamic models of the new wing are to be manufactured in the short run.

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