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The Influence of Variable Geometrical Modifications of the Trailing Edge of Supercritical Airfoil on the Characteristics of Aerodynamics

P. Lauk, K. E. Seegel, T. Tähemaa

Abstract**—**The fuel consumption of modern, high wing loading, commercial aircraft in the first stage of flight is high because the usable flight level is lower and the weather conditions (jet stream) have great impact on aircraft performance. To reduce the fuel consumption, it is necessary to raise during first stage of flight the L/D ratio value within Cl 0.55-0.65. Different variable geometrical wing trailing edge modifications of SC(2)-410 airfoil were compared at M 0.78 using the CFD software STAR-CCM+ simulation based Reynolds-averaged Navier-Stokes (RANS) equations. The numerical results obtained show that by increasing the width of the airfoil by 4% and by modifying the trailing edge airfoil, it is possible to decrease airfoil drag at Cl 0.70 for up to 26.6% and at the same time to increase commercial aircraft L/D ratio for up to 5.0%. Fuel consumption can be reduced in proportion to the increase in L/D ratio.

Keywords**—**L/D ratio, miniflaps, mini-TED, supercritical airfoil.

I. INTRODUCTION

FLOW control in transonic regime is complicated. Beginning from Mach 0.74 the Cl optimal value of supercritical airfoils becomes quite narrow. For example, at M-0.78 the Cl of low drag region of airfoil SC(2)-0410 is within the range of 0.4 – 0.5. The Cl of the airfoil SC(2)-0710 with a higher chamber at the same Mach is between 0.55 – 0.70. At the same time, at lower CL values, the last mentioned has a higher drag than the airfoil mentioned first. Due to the meteorological conditions and air traffic, there is often the necessity for commercial aircraft to use the Cl range between 0.45 – 0.7 during the flight. It is possible to design a fixed airfoil for the optimal range of Cl 0.5 – 0.55, but at higher or lower values of that, the drag and fuel consumption will increase. The main reason for drag increase is the shock wave appearing on the wing upper or lower surface (by the negative angle of attack).

Fig. 1 presents the Mach field of the supercritical airfoil SC(2)-0410 mod., and the pressure distribution at the angle of attack of $+0.5^0$. [2] Although the air flow exceeds the supersonic speed on the upper side of the airfoil, the changes in the pressure and speed are relatively smooth.

The situation is significantly different when increasing the angle of attack of the same airfoil up to $+1.5^0$. As it can be seen in Fig. 2, there is a strong shock wave on 65% of the chord on the upper side of the airfoil that causes a sharp decrease of air speed and increase in drag. In field, the increase of the boundary layer behind the shock wave can be seen.

II. RESULTS

To find the solution to the problem discussed above, the authors of the article make use of CFD software STAR-CCM+ designed the cruise miniflap (CMF) to the above-mentioned airfoil with the width of 4% of the chord. Similar to the Fowler flap, it can be retracted at lower Cl values and extended at higher Cl values. During the extension of the flap, it also deflects downward about 3.5 degrees [5].

To get comparable data, the standard atmospheric conditions were used. The Re number taken was 7.7×10^6. Various profiles were tested at the trailing edge of the CMF. Computational calculations based on RANS Solution (equations) were made. Resulting from these modifications, the lift increased, and wave drag reduced. Fig. 3 presents different CMF profiles that were used for modelling. At the angle of attack of 0 degrees, the CMF-D increased the lift coefficient from 0.365 to 0.857, i.e. by 0.492 (Fig. 4). At the same lift coefficient, the angle of attack reduces 2.41^0 when CMF-D is used.

The CMF-C with a cavity trailing edge increased the Cl up to 0.825 at the same angle of attack, i.e. by 0.46. Both of the results obtained are higher when compared to the standard sharp trailing edge of 0.2% thickness, i.e. 0.41. Due to high efficiency, the CMFs are suitable for optimizing the lift distribution along the wing which enables to reduce the induced drag [1].

When comparing the pressure distribution (Fig. 5) of different trailing edge profiles, it can clearly be seen that the CMF significantly reduces the airfoil upper side Cp level from 1.1 to 0.8 as an average and expands the range of negative pressure from 64% to 81%.

This process causes the reduction of air flow speed and wave drag on airfoil upper side. Comparing the Mach fields, it appears that the use of CMF changes the pattern of shock wave. The normal strong shock wave is characteristic of the basic airfoil. When using the CMF, the shock wave moves towards the trailing edge and is wider and of lambda-shaped pattern (Fig. 6).

P. Lauk is with the Estonian Aviation Academy, Lennu 40, Reola küla, Ülenurme vald, 61707 Tartumaa, Estonia (corresponding author, phone: +372 55 697 450; e-mail: peep.lauk@eava.ee).

K.-E.Seegel is with the Estonian Aviation Academy (e-mail: karl-erik.seegel@ eava.ee).

T. Tähemaa is with the Mechanical Engineering Department, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn (e-mail: toivo.tahemaa@ttu.ee).

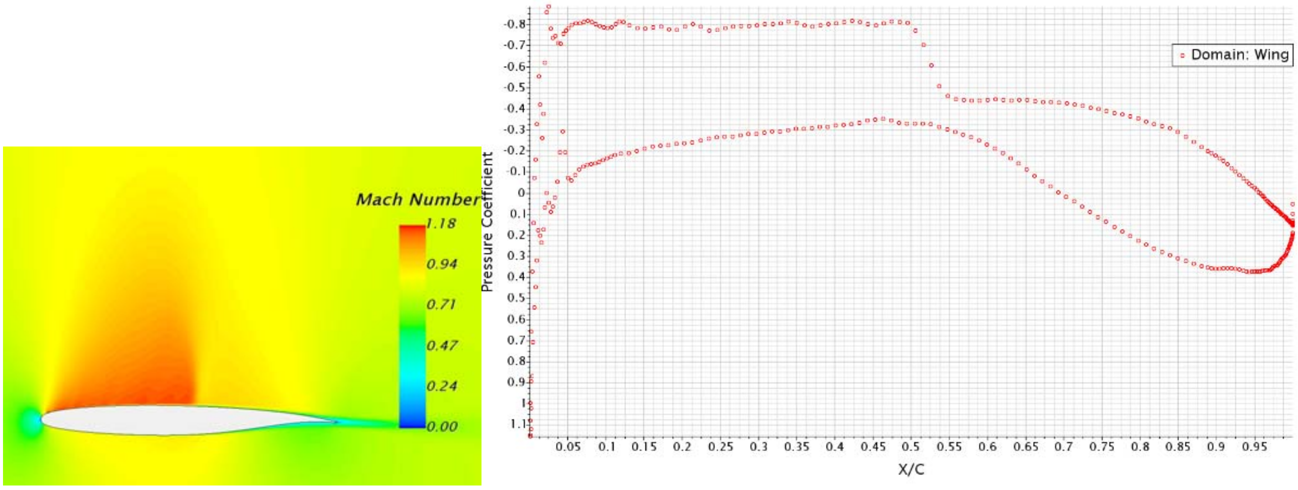

Fig. 1 Supercritical airfoil SC(2)-0410 mod., Mach field and pressure distribution at M=0.78, α =0.5°, Cl=0.476

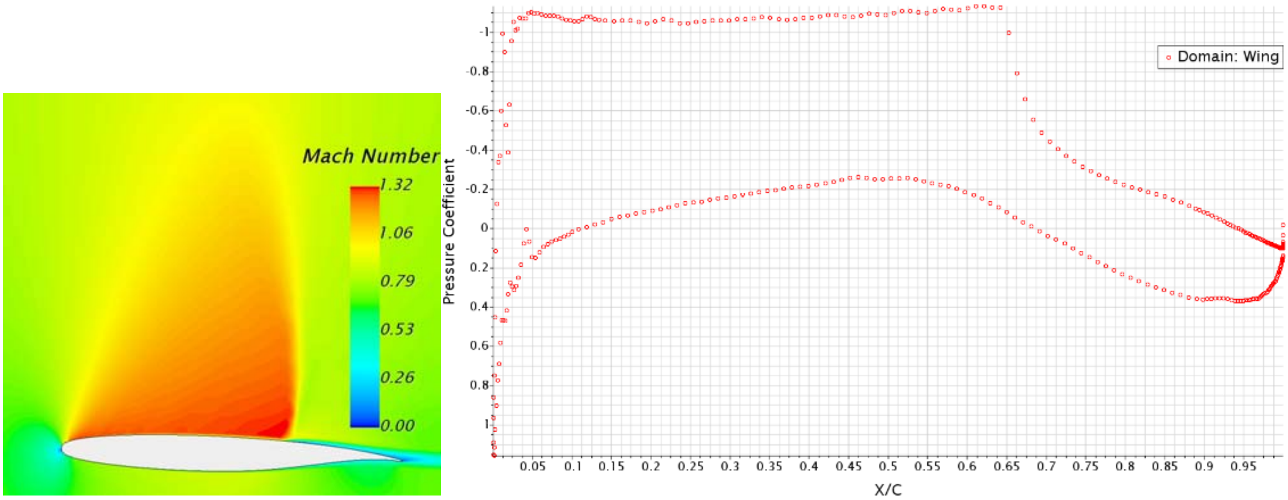

Fig. 2 Supercritical airfoil SC(2)-0410 mod., field and pressure distribution at M=0.78, α =1.5°, Cl=0.7037

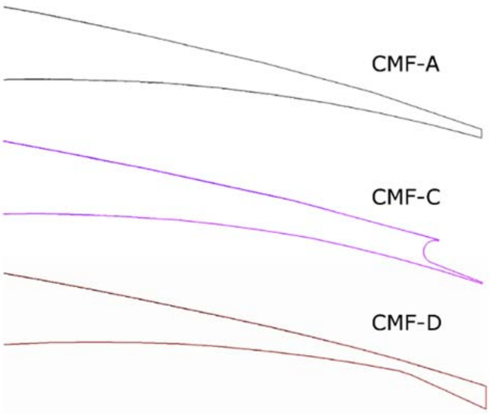

Fig. 3 Different CMF profiles that were used for modelling

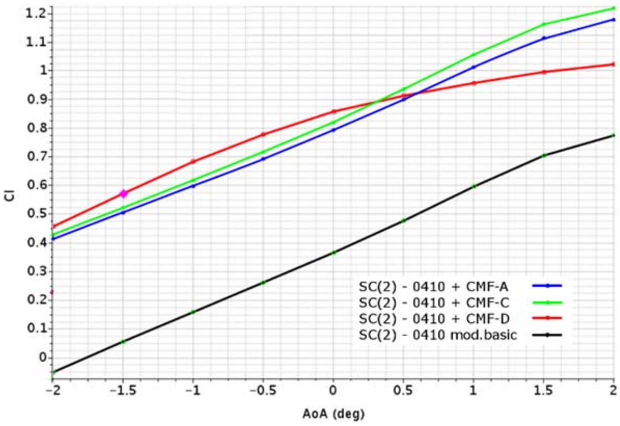

Fig. 4 Effect of different CMF types on airfoil SC(2)-0410 Lift coefficient

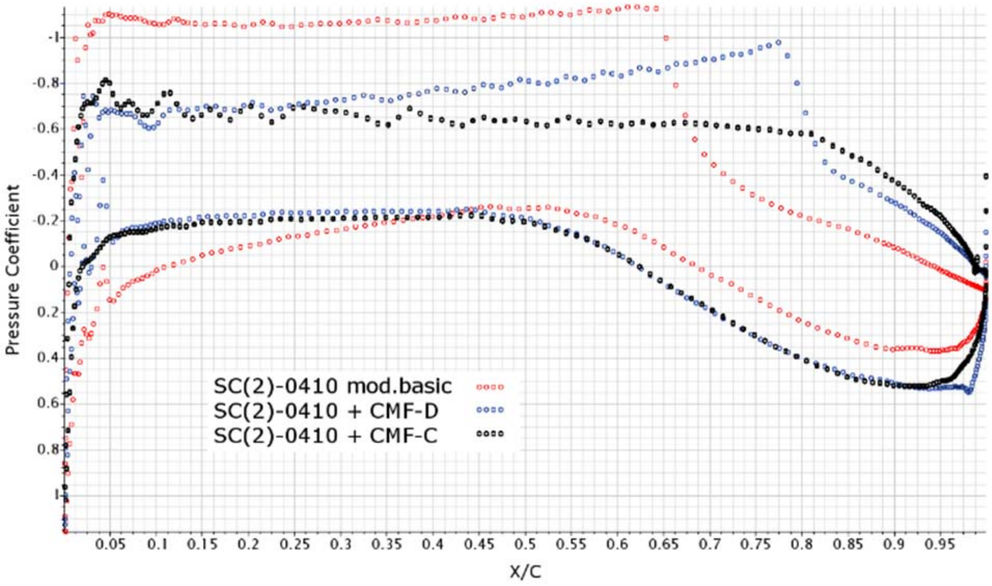

Fig. 5 Impact of different CMF types on pressure distribution at M=0.78, Cl=0.70

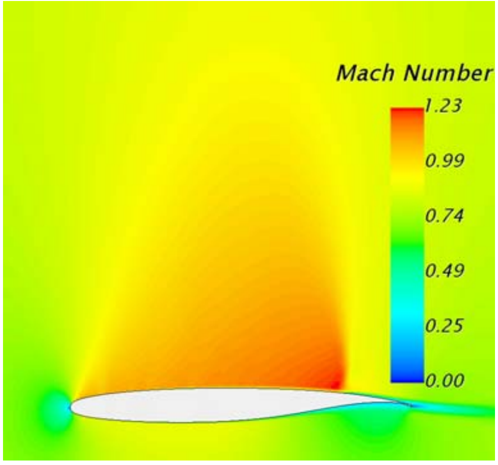

Fig. 6 Supercritical airfoil SC(2)-0410 with CMF-D Mach field M=0.78, Cl=0.682

An especially weak shock wave appears when using the CMF-C the cavity of which is 0.7 % of airfoil chord. The shock wave decreases significantly and the change of air pressure on the upper side of the wing is smoother when compared to other CMF types (Fig. 7). Together with the use of the CMF, the lifting centre moves towards the trailing edge while increasing the nose down coefficient. The comparison of calculated aerodynamic polars revealed (Fig. 8) that the CMFs decrease the drag beginning from Cl>0.50–0.52. CMF-D is more efficient when compared to the other types of CMFs. The use of CMF-D reduces the drag at Cl 0.65 by 20.34% and at Cl 0.70 by 26.57%.

Despite the positive impact of the CMF-C on pressure distribution, its drag is a bit higher than that of the CMF-D. The optimal thickness of the cavity trailing edge remains within the range of 0.5–0.7%, and depends on the relative thickness of the airfoil, Mach number and the Cl value.

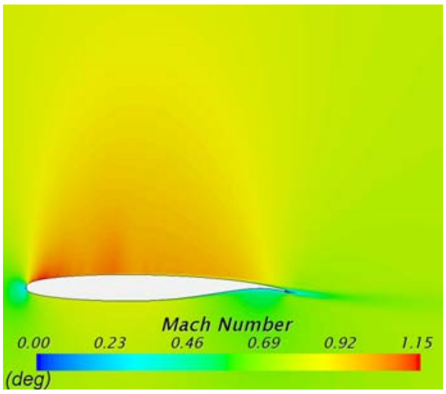

Fig. 7 Airfoil SC(2)-0410 with CMF-C Mach field at M=0.78, Cl=0.70

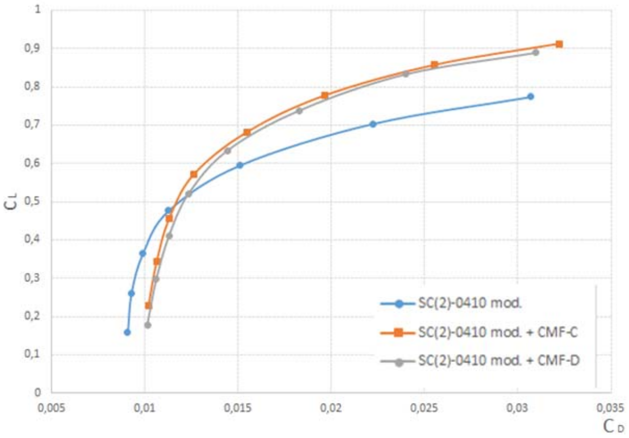

Fig. 8 Calculated aerodynamic polars of SC(2)-0410 airfoil with different CMF types

The higher the Cl is the higher the height of optimal cavity is. The same principle holds true in regard to the CMF-D, the optimal thickness of the trailing edge of which remains 0.5%

of the width of the wing. By modelling wing body L/D characteristics (Fig. 9), the use of CMF-D may increase the value of the L/D ratio of a medium-range commercial aircraft by 5 %.

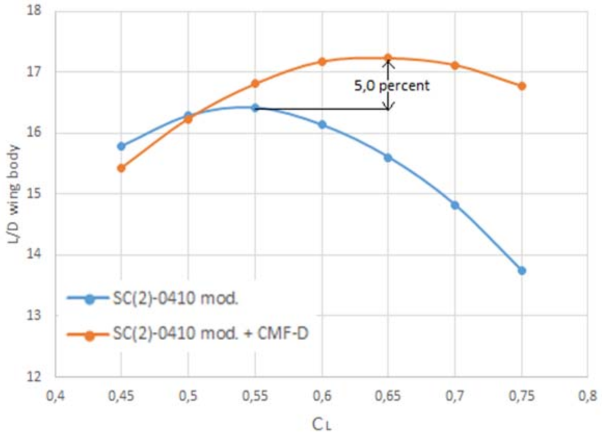

Fig. 9 Comparison of calculated wing body L/D characteristics for a mid-size, two engine airliner

It can also be seen that the use of CMF-D increases the max L/D value at Cl 0.65 on condition that the wing effective aspect ratio (AR) remains within the range of 10.7–12.0. If the wing AR is lower than 10, the efficiency of CMF decreases significantly because the increase in Cl causes the increase in induced drag.

Another important impact is that the use of CMF causes the centre of lift to move towards the trailing edge of the wing. If the centre of gravity is fixed, the use of CMF increases the balanced drag because the stabilizer has to generate higher negative lift. The increase in the value of balanced drag can be up to 2% of the total aircraft drag. The same result was reached to by Henne [3]

The increase in the drag can be avoided by using the trim tank in the tail of the aircraft. Usually it is designed to be inside the stabilizer. When using the CMF during flight, the centre of gravity is moved backward along the chord by pumping the fuel from the central tank to the tail trim tank. Before landing, fuel is pumped back into the central tank in order to increase the longitudinal stability. With the use of CMF, it is possible to increase the specific air range (SAR) (Fig. 10).

The same figure depicts the impact of optimal altitude and the CMF on SAR of a typical two-engine medium range aircraft with the in-flight weight of 77 000 kg. In that case, the optimal altitude will rise for about 3000 ft, and the altitude range will also increase.

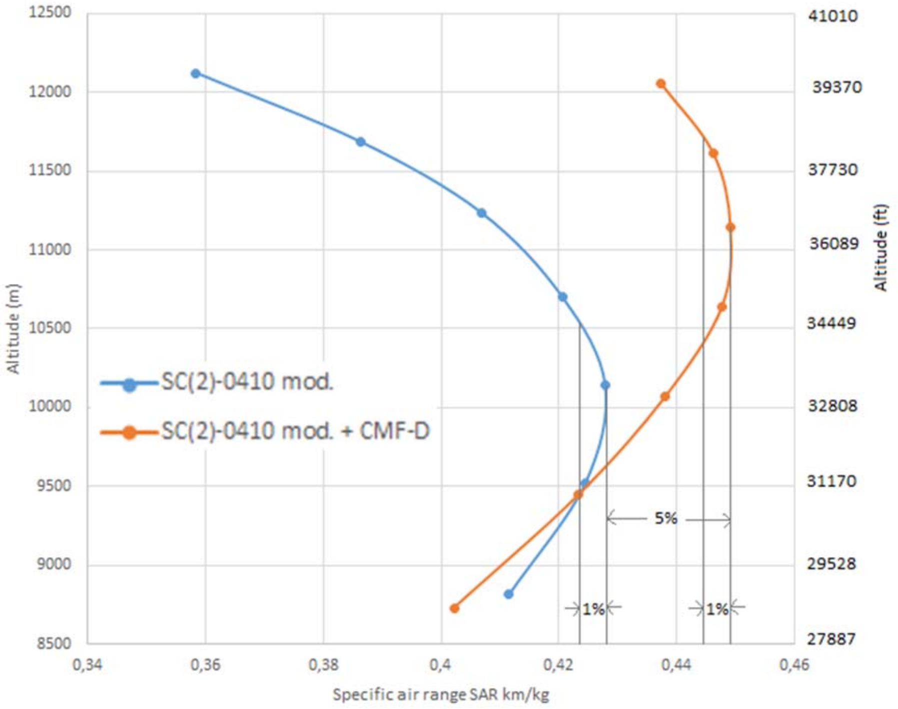

Fig. 10 CMF-D influence on Specific Air Range (SAR) example for a mid-size, twin engine airliner

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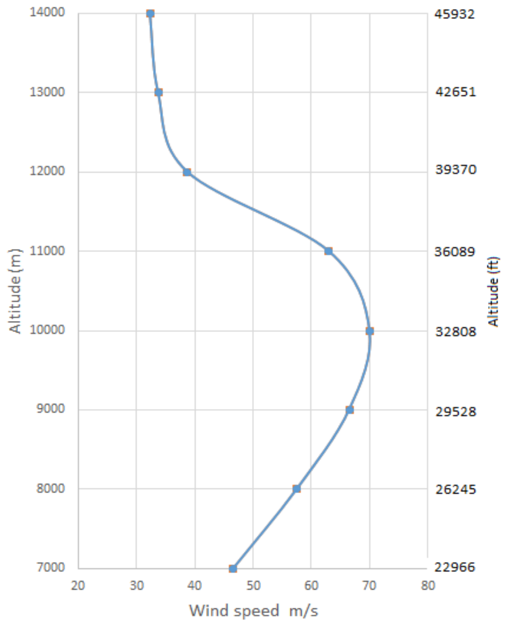

Fig. 11 Wind speed of a typical jet stream at different altitudes

Strong winds or the jet streams, occurring in various regions of the world, have a significant influence on air traffic. The polar jet stream with the dominant direction of the wind from the west to the east has a major impact on European airspace.

The typical jet stream wind speeds in regard to altitudes can be seen in Fig. 11. As it can be seen the maximum wind speed remains within the range of FL 300–340 on an average. The influence of the wind on an aircraft SAR decreases considerably with the rise of altitude from FL 340–400. Therefore, under the condition of headwind it is advisable to fly within the FL 380–400, and under the condition of tail wind within the FL 310–330. In cross-Atlantic east-to-west flights the use of CMF enables to rise altitude from FL 340 to FL 380 which, in its turn, enables to decrease fuel consumption for about 5.7% on condition there is intensive jet stream for about 25% of flight route. On return flight, it is advisable to use FL 330. By the model under discussion, the optimization of flight levels would help to save 3.1% of fuel.

In aviation, the complicated technical solutions have often been the reason why a lot of genuine ideas have not been implemented. The main reason is the ever reducing operating reliability and the increasing maintenance costs of actuating systems. The technical solution patented by the author is simple, reliable and needs little maintenance (Figs. 12 and 13).

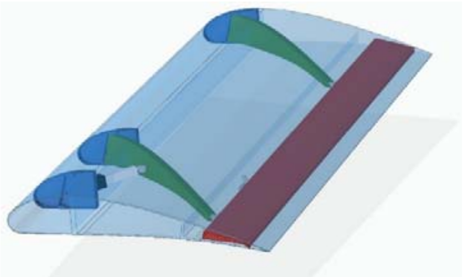

Fig. 12 CMF actuating mechanism in retracted position

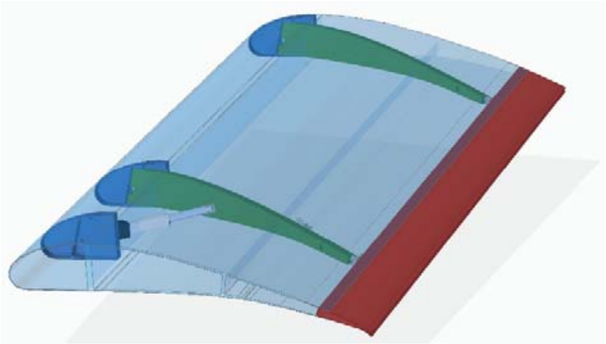

Fig. 13 CMF actuating mechanism in extended position

The main units of the equipment are swivel links that enable to retract and extend the CMF flap and simultaneously move the deflecting angle. The movement of the CMF causes the split flap positioned under it to deflect and reduce the friction drag. The centre of gravity of the unit is positioned in the front side of the flaps. Due to it, the unit can be used inside ailerons because mass balancing to prevent flatter is not complicated.

III. CONCLUSION

The present research is focused on fully-turbulent flow conditions at Mach 0.78 and the Reynolds number 7.7x10^6. State-of-the-art computational fluid dynamic methods were used. The following results were arrived at during the research:

1. Only the CMF with the 4% width of the chord with the deflecting angle of 3.5 degrees increases the Cl by 0.492., therefore being much more efficient than the mini split flaps and other modifications tested previously [4].
2. The use of CMF caused the decrease of airfoil drag at Cl 0.65 by 20.34% and 26.57% at Cl 0.70. It enables to increase the aircraft L/D maximum ratio 5% and significantly reduce aircraft fuel consumption. Reduction of wave drag was the main effect.
3. Using the different CMF deflection angles it is possible to optimize lift distribution along the wing and reduce the induced drag for 3-5%.
4. By using the CMF, the centre of lift will significantly move backward. It is advisable to change the position of CG backward during the flight by pumping the fuel into the trim tank.
5. By using the CMF, it is possible to reduce the influence of meteorological conditions, first and foremost the influence of jet stream. By using the most optimal flight level it is possible to additionally reduce the fuel consumption 3.1–5.7% and reduce the flight time.
6. A simpler CMF technical solution is more reliable and has lower production and maintenance costs. If necessary, the unit can be installed inside the aileron because the centre of gravity of the unit is in the front of the aileron.

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