NEW TECHNOLOGY OF FLOW PATTERN CONTROL IN CASE OF AN AIRFOIL

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Abstract

The classic slat is a common way of flow control over a wing at high angles of attack. It reduces a high level of negative pressure at main wing section and protects against a boundary layer separation resulting in a significant lift and critical angle of attack increase. A choice of retractable slat leads to a complicated design and heavy weight while for a fixed slat a visible drag increment occurs at cruise speed.

The paper presents a new method of flow control for an aircraft airfoil. The point is that a special element, called a slat-deflector, is located ahead of airfoil leading edge, above a chord line, with a possibility of revolving around a fixed hinge. That slat-deflector allows to obtain a similar maximum lift coefficient and critical angles of attack as classic one, at higher performance ratio. The computational and experimental results bring an exceptionally interesting data. The drag increments, at low lift, are lower than expected. Even comparing to an isolated airfoil, the aerodynamic characteristics of a profile equipped with slat-deflector turned out to be better at cruise conditions.

Nomenclature

b - model span
c - airfoil chord
c_s - airfoil chord of slat-deflector
C_D - drag coefficient
C_L - lift coefficient
C_{Lmax} - maximum lift coefficient
ΔC_{Lmax} – increment in C_{Lmax}
C_M - pitching moment coefficient
D - drag
L - lift
L/D - performance ratio
Re - Reynolds number
S - model reference area
α - angle of attack
α - critical angle of attack
$\Delta\alpha_{cr}$ – increment in α_{cr}
φ - angle of slat-deflector in relation to the chord of airfoil
λ_{ef} - effective aspect ratio

Subscripts:
A, B, C - denotation of version of slat-deflector
1, 2 - location of slat-deflector
15, 20, 25, 30 - angle of slat-deflector

1. Introduction

In case of an airplane a relatively low drag at cruise conditions as well as high lift in case of take-off and landing are required. The common way to improve low speed characteristics is an application of flaps and slat systems. A choice of high lift device influences an aircraft construction, costs and safety. This is especially important for light weight planes, where cost and weight play an important role. Because of many various reasons a development of high lift systems is still an important element in aircraft design process. A slat is rather common way to increase the maximum lift and critical angle of attack [1]. But an application of retractable or fixed slats brings some disadvantages too:

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complicated design, increasing weight, high drag at cruise conditions.

The paper presents a new slat idea which, comparing with classic ones, improves the aerodynamic characteristics of a wing.

Instead of normal slat, a special element, called slat-deflector, can be used as a device responsible for a flow control over a wing. A slat-deflector is located in the proper position, ahead of airfoil leading edge and above a chord line. A proper position should be selected in such a way that in case of high incidence the mentioned device works as a normal slat (reducing pressure gradient along a main airfoil) while at low angle of attack (cruise conditions) is located in low velocity region preserving low friction and total drag.

A slat-deflector can revolve around its fixed hinge point and a final position results from an actual angle of attack. A positioning takes into account an optimisation of actual aerodynamic characteristics: minimum drag at cruise, high lift and high critical angle of attack during a take-off and landing.

From a view point of construction and technology a slat-deflector is much simpler and lighter compared to a normal retractable slat. An adjustment of slat-deflector position can be performed manual or automatic.

It seems that a mentioned device should be very useful in case of general aviation purpose. Moreover, an automatic positioning of slat-deflector improves a safety of plane, preventing an undesirable stall.

2. Models and test conditions

The presented experimental investigations have been carried out in a low speed wind tunnel (open test section of 1.1m. diameter) belonging to Institute of Aeronautics and Applied Mechanics at Warsaw University of Technology.

A sectional model of wing (wing segment), based on NACA 2415 airfoil, was chosen to experimental tests of a new high lift device. The airfoil chord was 0.3m and the wing span 0.6m. Two end-plates were mounted to the tips of tested wing, giving an effective aspect ratio about 3.55. A thin slat-deflector was placed ahead of an airfoil leading edge in different locations. Three versions of slat-deflector –A, B, C (Fig.1) were tested. Versions A and C had a concave-convex shapes. Version B had a symmetrical profile. In case of versions A and B the chords of slat-deflector were the same (0.1c). The chord of slat-deflector in version C had a smaller size (0.067c).

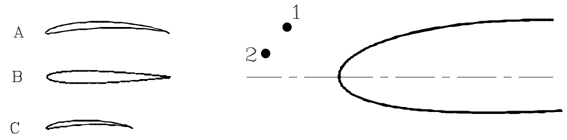


Fig.1. The geometry of slat-deflector and their location ahead of the airfoil

The experimental measurements and computations were performed for Reynolds number 840 000.

The aerodynamic characteristics were measured by means of a triple component strain gauge balance while the pressure distribution measurements were carried out by use of multi channel manometer system.

Parallel to the aerodynamic forces measurements a structure of boundary layer was analysed, basing upon the hot-wire measurements on a simplified model.

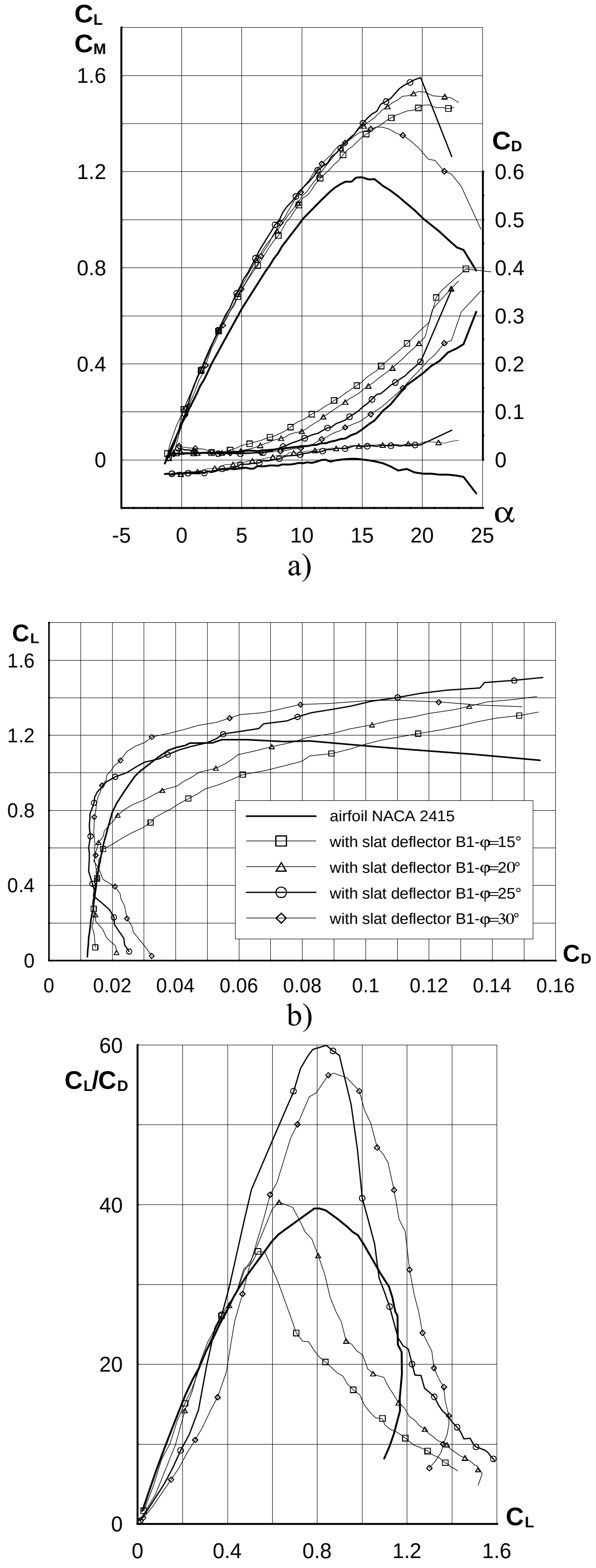
For numerical computations the MSES [2] program was used.

3. Experimental results

The results shown in presented paper represent only a small part of the performed investigations.

The most important is that the obtained results fully confirm the mentioned expectations and the tendencies in aerodynamic characteristics changes.

Fig.2a presents aerodynamic characteristics for the airfoil with B1 version of slat-deflector taken for various angles of attack and slat



a)

b)

c)

Fig.2. Characteristics of the lift coefficient, polar curve and performance ratio at various angle of the slat-deflector

deflections. From a viewpoint of maximum performance ratio that version is the best. The plot shows how a slat-deflector forces considerable increase of maximum lift coefficient and critical angle of attack. The maximum lift coefficient (1.59) is smaller than for a classic fixed slat (1.69) while the critical angle of attack is similar. Moreover a considerable increase of $dC_L/d\alpha$ derivative was obtained. These characteristics seem to be quite surprising - because the classic slat does not produce changes of mentioned derivative.

The polar curves for different angles of slat-deflector are presented in Fig.2b. It becomes obvious how an angle of slat deflector influences a drag. One of possible conclusions is that a rotation of slat-deflector brings the effects similar to those observed in case of speed flaps or manoeuvre flaps (shifts a low drag saddle).

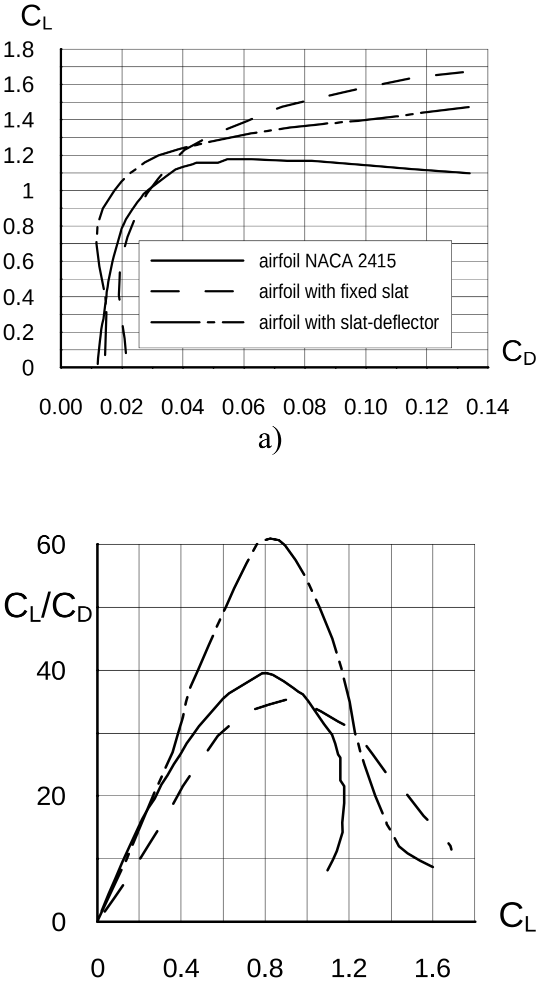
It turned out that introduction of a slat-deflector into flow can bring a meaningful drag decrease comparing with an isolated airfoil, in the range of useful incidences. It means that between a slat-deflector and an airfoil a favourable interference occurs what finally leads to performance ratio increase (Fig.2c).

A comparison of polar and performance ratio for isolated airfoil, an airfoil with slat-deflector and a classic fixed slat is shown in Fig.3a, b. Presented plots show that the slat-deflector is more favourable solution. It leads to smaller drag at cruise conditions and higher performance ratio during take-off.

It seems worthy to notice that a discussed solution could be taken into account as an alternative version of airfoil with a fixed slat-deflector.

This version is realised for slat-deflector position angle $\varphi = 25^{o}$. For such a case a polar curve and performance ratio are only little worse, at small and high lift coefficients.

In the Fig.4 the aerodynamic characteristics for the best tested configuration (considering C_{Lmax}) are presented. The slat-deflector in version A, placed more ahead and closer to a chord line (A2) creates the best configuration. Such a solution allows to obtain the maximum value



a)

b)

Fig.3. Comparison of the polar curves and performance ratio for different versions

C_{Lmax}=1.71 (classic fixed slat C_{Lmax}=1.69). Nevertheless the performance ratio is somewhat smaller than for the solution B1.

The plots shown in fig.5 illustrate that the highest lift (version A2) occurs for a slat-deflector position angle φ = 30^{o} . For a version C2 (same airfoil, 30% smaller chord) C_{Lmax} is smaller about 10%.

From a view point of performance ratio, version B2 is attractive – this is a consequence of a drag drop.

Concluding, it is obvious that the slat-deflectors of concave-convex shape bring the highest lift coefficients while the symmetrical profile shape allow to reach the smallest drag and the highest performance ratio.

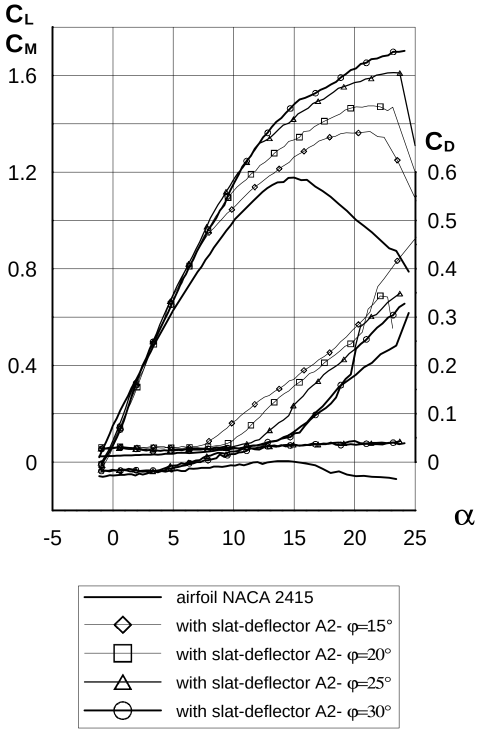
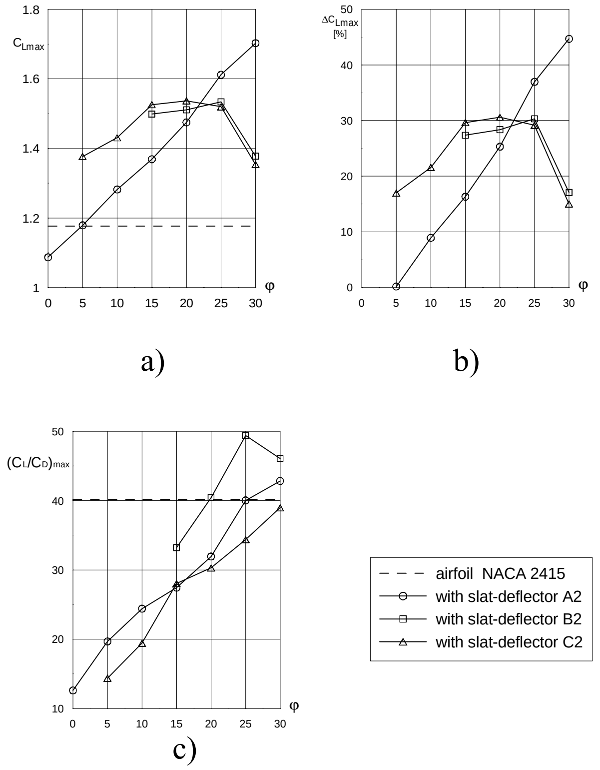


Fig.4. Influence of the angle of slat-deflector A2 on the aerodynamic characteristics



a)

b)

c)

Fig.5. Comparison results for different versions of slat-deflector in location 2.

4.Computational results

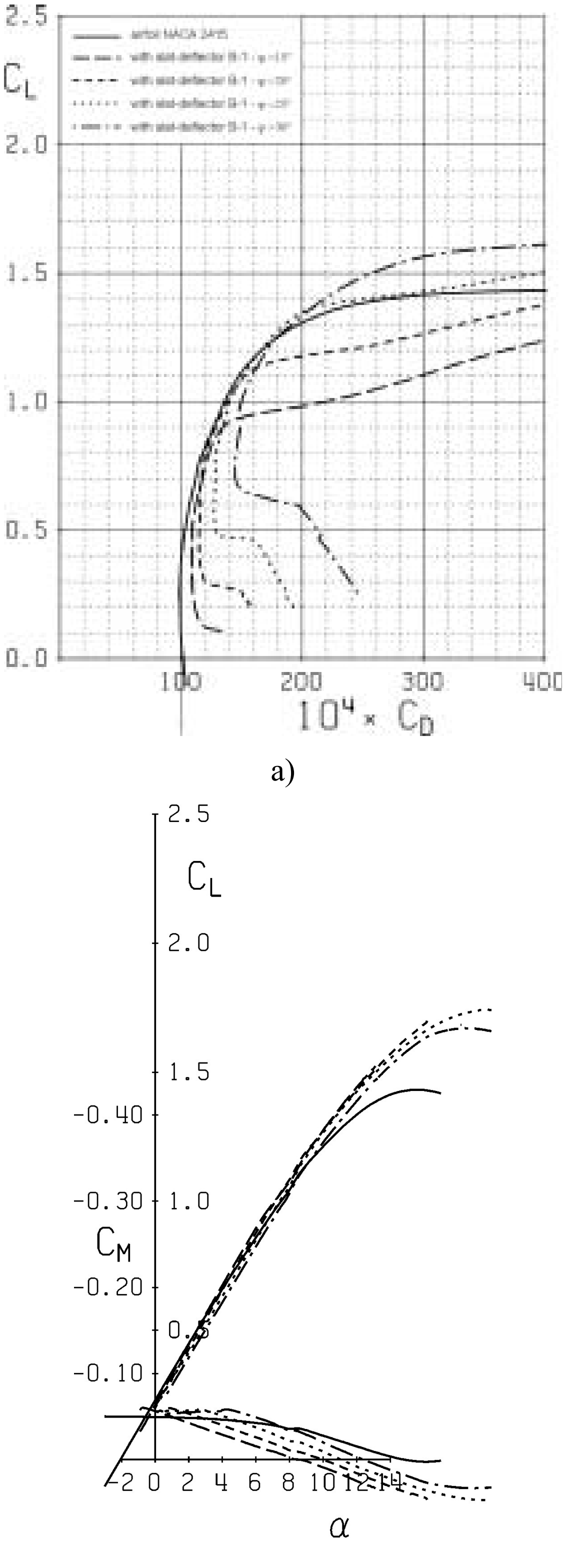
The flow computations were performed by means of MSES program. It solves the Euler equations for inviscid flow and boundary layer equations, in integral form, for viscous region. A strong viscous-inviscid interaction allows to solve cases with flow separation, laminar separation bubbles and confluent boundary layer. The method allows also for inverse design and multipoint optimisation.

The Fig.6 presents the resulting aerodynamic characteristics of the isolated airfoil and airfoil-slat combination at various slat angles. The results are in a good qualitative accordance with the experimental ones. A low value of the *n* amplification ratio for boundary layer transition prediction was specified in order to take into account a high turbulence level in the test section.

The Fig.7 presents the same characteristics, but instead of isolated airfoil drag, a sum of isolated profile drag and minimum of a slat drag (at zero angle of attack) is calculated. The drag of airfoil-slat combination, in the most of lift coefficient range, is lower than it could be expected from friction drag of a slat. An evident favourable interference occurs between slat and main profile.

Similar results were obtained for full scale flow (high Reynolds number and *n*=9 amplification ratio) but with higher lift and lower drag levels. (Fig.8)

The obtained results of optimisation are very interesting too. Performing the optimisation computations a quite unexpected (and may be slightly artificial) solution was obtained. An optimum section of slat is nearly symmetrical (even slightly similar to inverse letter S for mean line shape) with maximum thickness at about 20% of chord. A position of slat is close to a leading edge of main profile. At low lift coefficient such geometry leads to flow separation on lower side of slat – but a drag (computationally) is very low (lower than isolated basic airfoil drag + minimum drag of slat) what indicates a strong favourable interference.



a)

b)

Fig.6. Aerodynamic characteristics of the airfoil– slat-deflector combinations at Re = 840 000

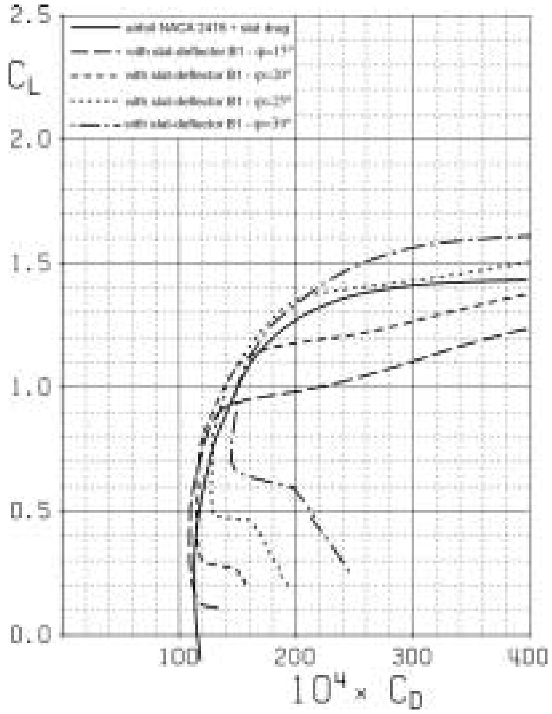


Fig.7. The drag polar for different versions of airfoil with slat-deflector at Re = 840 000

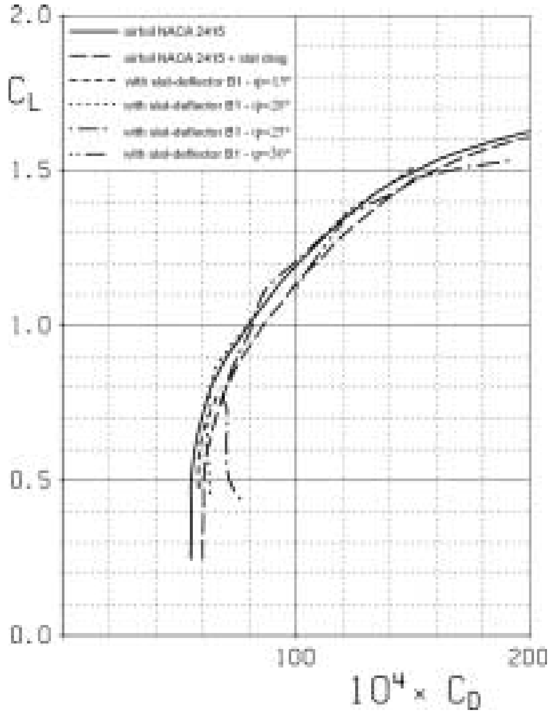


Fig.8. The drag polar of the airfoil with slat-deflector at Re = 4 000 000 / $\sqrt{C_L}$

Fig.9 shows such a flow condition. A strong separation is seen on a lower surface of slat. Unlike in a case of single airfoil, where separation leads to high negative pressure in the separation zone and high pressure drag, a pressure on lower slat surface is still very high due to a close position to main profile stagnation point. The wind tunnel tests for such a position confirm the above computations. The parametric studies for various slat positions and setting angle shows however, that such a location is not optimum for entire flight conditions.

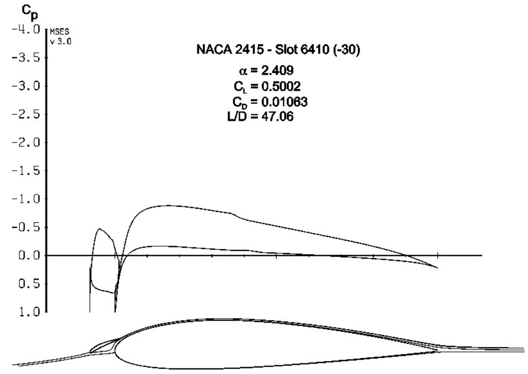


Fig.9. Calculated minimum drag slat position with flow separation

5. Conclusions

The experimental tests and numerical computations confirmed possibilities of flow control by means of a slat-deflector, which is situated ahead of airfoil leading edge and above a chord line.

The presented method improves all aerodynamic characteristics in comparison with the classic fixed slat.

A possibility of adjustment of slat-deflector to actual flight conditions increases an aircraft safety level, because a separation of boundary layer can be avoided.

A construction of wing with slat-deflector can be much simpler and a total weight smaller than in case of classic slat.

The above mentioned slat-deflector brings an advantage during a take-off and landing as well as in cruise conditions.

References

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