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GURNEY FLAP AND T-STRIP ALTERNATIVES IN APPLICATION TO TYPICAL AIRCRAFT STEER SURFACE

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Abstract

Classic Gurney flap and double Gurney flap (called T-strip) are well-researched trailing edge modifications used in aerospace engineering. However, one of the inevitable effects of their use is the aerodynamic drag increase at low lift conditions, concerned as the major drawback of these solutions. This article presents Gurney flap and T-strip passive alternatives, which guarantee similar advantages in terms of e.g. lift enhancement, but without significant drag increase. Their aerodynamic analysis was performed on the application case of a typical symmetrical aircraft stabilizer with movable steer. Both solutions, consisting of plates nearly parallel to the direction of flow, were modelled as two-dimensional cases and CFD calculations were performed for specified range of angles of attack and steer deflections. Obtained aerodynamic characteristics allowed assessing the influence of selected modifications on the stabilizer effectiveness, as well as on hinge moment characteristics. The flow pattern changes in the presence of analysed devices were also investigated. In this way, performed analysis provided valuable information about the advantages and disadvantages of using of such devices in comparison to classic Gurney Flap and double Gurney flap. The results showed that using proposed solutions gives the possibility of significant reduction of the aerodynamic drag of the whole stabilizer at low lift conditions, while still maintaining favourable lift characteristics.

Keywords: *CFD, steer, stabilizer, Gurney flap, T-strip*

1. Introduction

Gurney flap is one of the most popular airfoil trailing edge modifications used in aerospace engineering. It allows increasing the lifting force of a wing or stabilizer in a simple way. The results in better overall performance and wider usable angle of attack range without necessity of a lifting surface major redesign [1]. Classic Gurney flap is an unsymmetrical device, but there is also a symmetrical version of this flap called T-strip or double Gurney flap, used mainly on vertical stabilizers of many helicopters. These solutions, despite their high popularity, have also some disadvantages. One of the major drawbacks is the increased aerodynamic drag at low lift conditions, connected with vortex shedding behind plates situated perpendicularly to the flow direction [3]. To minimize this effect, sometimes there is another plate placed behind T-strip or Gurney flap, called flow splitter. It is nearly parallel to the flow direction and its purpose is to organize the flow and therefore reduce flow disturbances and aerodynamic drag. However, in fact, profit from such solution is not large [2]. The most obvious method of reducing the aerodynamic drag at low lift conditions is to make these devices retractable and extend them only when necessary. The described active flow control is actually investigated on helicopter rotor blades [4, 5], but it is a quite complicated system, not always possible to use.

This article presents another idea for achieving a similar aerodynamic characteristics improvement to classic Gurney flap or T-strip. The idea relies on passive solutions, which are expected to not increase the aerodynamic drag significantly. They involve replacing original devices (Gurney Flap and T-strip respectively) only with plates nearly parallel to the flow direction, to avoid vortex generation. Such solutions do not disturb flow so heavily, but could guarantee similar lift force or hinge moment increments when placed on a typical movable steer of an aircraft. Their principle of operation is similar to the flaps of conventional airplane wings.

2. Alternative solutions geometry and computational case

In this work, two alternative solutions to classic Gurney flap and double Gurney flap (T-strip) were analysed. The performed calculations concerned only two-dimensional cases (2D). The representative geometry of the analysed stabilizer and steer cross section was modelled on the base of the I-31T airplane horizontal tail geometry (more information about I-31T project could be found in [6]). It is equipped with symmetrical airfoil NACA0012, very often used in general aviation airplanes tails. The gap between the stabilizer and the steer was properly modelled to capture the airflow through it. The stabilizer chord length was $c = 0.7$ m, total steer length $c_s = 0.28$ m and steer length beyond the deflection axis $c_s' = 0.238$ m. The steer deflection axis was placed at (0.0) point. The geometry of representative section was shown in Fig. 1. Moreover, the sign convention of steer deflection angle δ and hinge moment coefficient Cm_H, used during results post-processing, were marked.

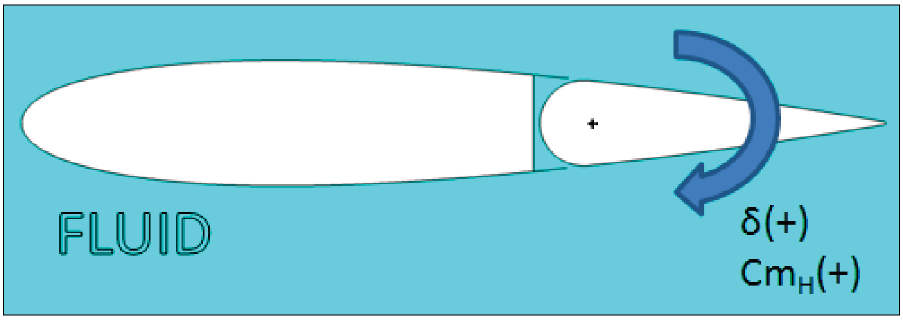

Fig. 1. Analysed representative cross section of an aircraft stabilizer, based on NACA0012 airfoil (with marked sign convention)

The analysed modifications of the baseline airfoil were presented in Fig. 2. In the first case the non-deflected trailing edge flap replaced T-strip, while in the second classic Gurney flap was converted into the -4 degrees deflected flap. The original, perpendicular to the flow direction, flaps have height $H = 5$ mm $= 0.7\%\ c = 1.8\%\ c_s = 2.1\%\ c_s'$ and thickness of 0.5 mm. On the other hand, the proposed solutions were twice as thick (1 mm) and their length equals to $L = 50$ mm $= 7\%\ c = 18\%\ c_s = 21\%\ c_s'$. The value of length L was chosen to guarantee the most similar lift force characteristics of T-strip and non-deflected TE flap (see Fig. 4a). The deflection angle of deflected TE flap was appointed with the assumption of the same length value as previously. Finally, the value of -4 degrees deflection gave relatively small error between classic Gurney flap and deflected TE flap lift force characteristics (see Fig. 4b). Designating of both quantities, length and deflection angle of the flap, was done in the iterative way.

The flight conditions parameters were also determined from I-31T specification. Flight speed was set to 160 km/h (44.4 m/s), which corresponds to Re value of 2.3×10^6. Five different deflections of the steer were taken into account for every case: -15, -10, 0, 10, 15 degrees. The angle of attack varied from -10 to 10 degrees, with 2-degree step.

3. CFD analysis method and meshes

CFD analysis, based on the Finite Volume Method (FVM), is a very useful tool in aircraft design and prototyping. It combines high reliability and accuracy of results with relatively low cost. In the following work, one of the most widely recognized as an industrial standard RANS solvers – ANSYS Fluent – was used.

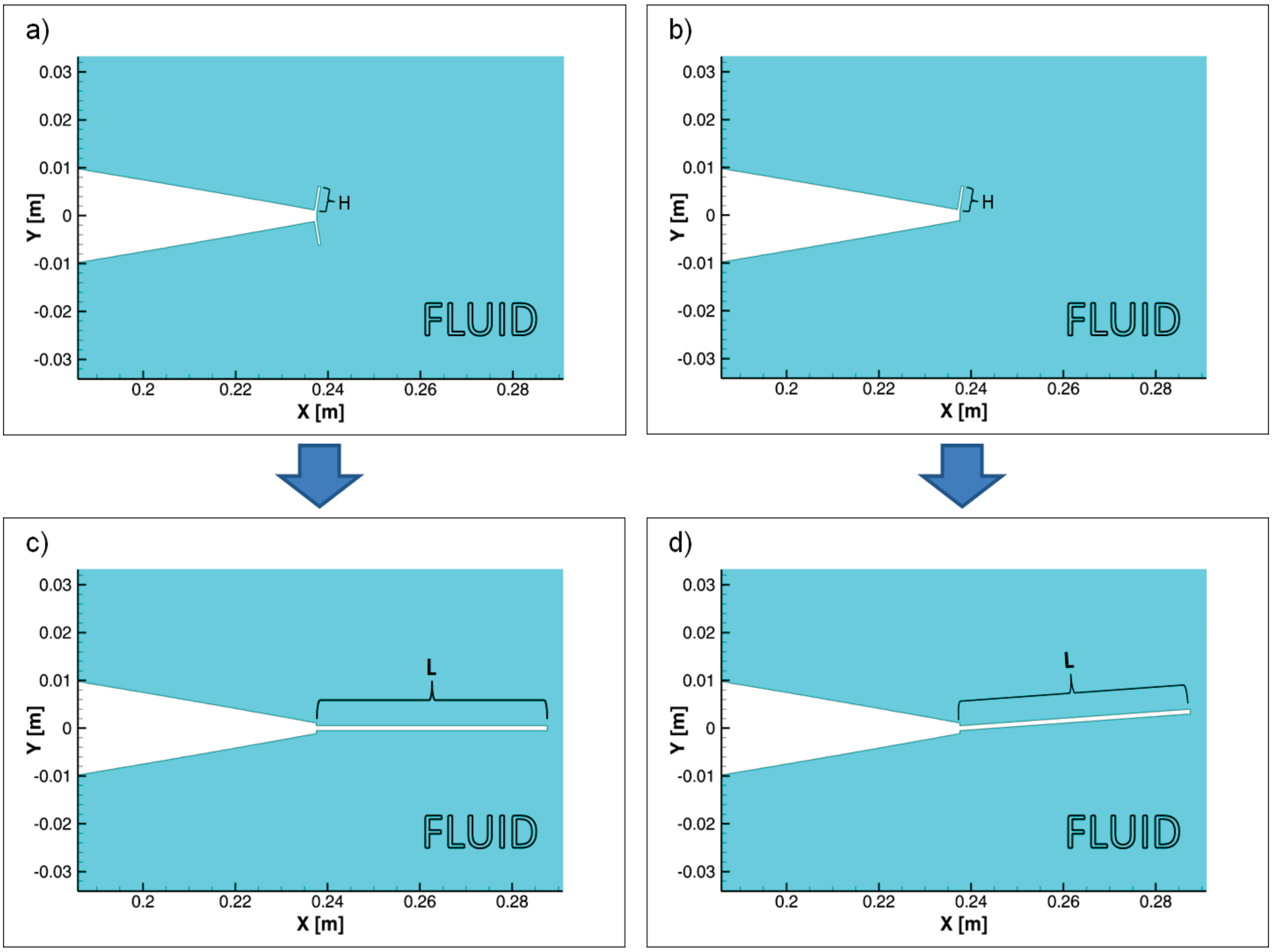

Fig. 2. Technical solutions analysed: a) Gurney Flap (H = 5 mm); b) T-strip (H = 5 mm); c) non-deflected trailing edge flap (L = 50 mm); d) deflected (-4 degrees) trailing edge flap (L = 50 mm)

All cases were analysed with the same solver settings and mesh parameters. Double precision pressure based solver with incompressible flow and *k*-*ω* SST (2 equations) turbulence model was used. This implied the necessity of high resolution meshes generation with *y*+ values around 1 and below. Unstructured QUAD meshes with structured boundary layers were created for all analysed cases (example mesh is shown in Fig. 3). Surface roughness was not modelled, which corresponds to the assumption of perfectly smooth wetted surfaces of all calculation models.

In all prepared models, the following boundary conditions were used:

– Velocity Inlet – for inlet surfaces of the computational domain,
– Pressure Outlet – for outlet surfaces of the computational domain,
– Wall – for all airfoil surfaces.

4. CFD results

In this section of the article, the results of performed calculations are presented with short commentary. Both analysed solutions were always compared with corresponding original configuration (T-strip for the non-deflected flap and Gurney flap for the deflected one). The dimensionless lift and drag coefficients were calculated on the base of stabilizer chord length *c*, while in hinge moment coefficient calculations the steer length beyond the deflection axis c_s' was used as a reference value (typical convention for this type of analysis). The reference values remained constant for all cases.

Firstly, the influence of selected modifications on lift coefficient characteristics of entire stabilizer was investigated. The results were presented in Fig. 4. It turns out that replacing T-strip with the

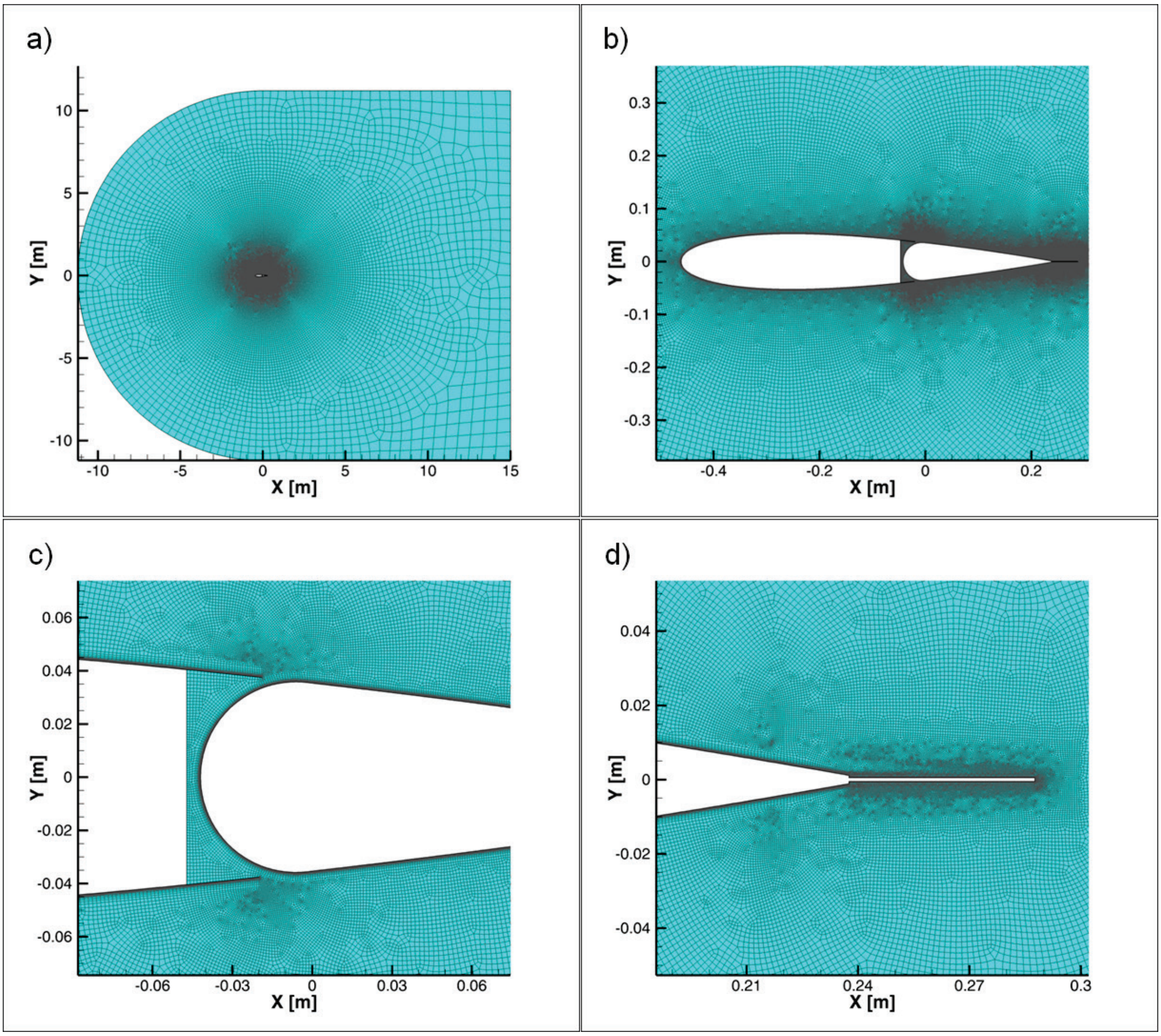

Fig. 3. Example meshes details around: a) the entire domain; b) the airfoil; c) the hinge gap; d) the non-deflected trailing edge flap

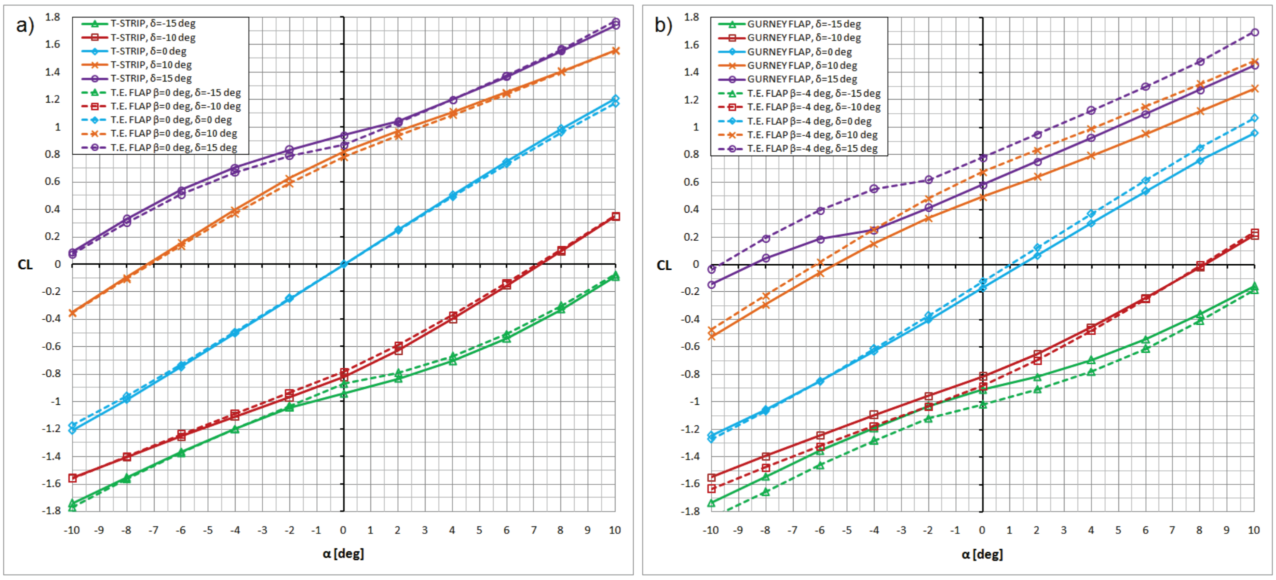

Fig. 4. Lift coefficient characteristics for: a) T-strip and non-deflected TE flap; b) Gurney Flap and deflected TE flap

non-deflected TE flap of adequate length allowed achieving almost identical CL characteristics. In the second case, there are slightly higher differences between the original flap and its proposed alternative, which guarantees higher increments of CL when the steer is deflected at specified angle of attack.

Secondly, the drag characteristics of analysed flaps were taken into account. The analysis was done on the base of CL(CD) charts presented in Fig. 5. As expected, both alternative solutions, nearly parallel to the flow direction, produce lower drag than the original devices. It is especially visible when the non-deflected TE flap is compared with T-strip at low lift conditions. High improvement could be also noted for the deflected TE flap, compared with Gurney flap at medium positive CL.

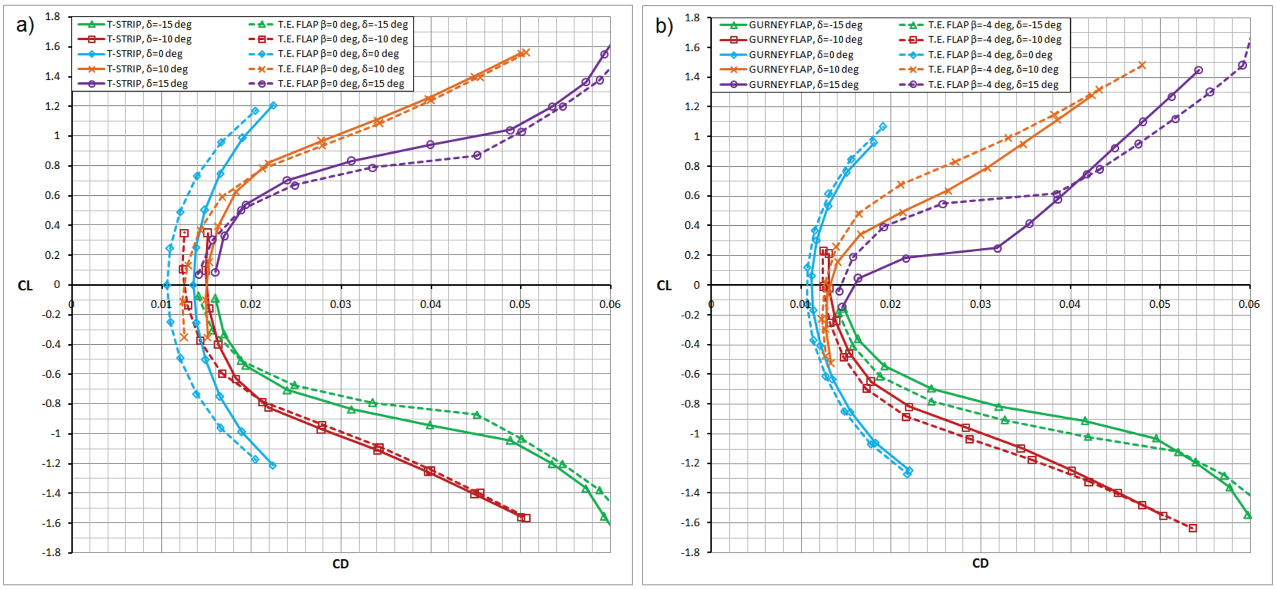

Fig. 5. CL(CD) characteristics for: a) T-strip and non-deflected TE flap; b) Gurney Flap and deflected TE flap

In Fig. 6, hinge moment characteristics were presented. First pair of trailing edge modifications has relatively similar characteristics, with some discrepancies only at high positive angles of attack and steer deflections, as well as for high negative values of these quantities. Similarly as previous, in the second case the differences between presented solutions are higher. Although they guarantee similar CL and Cm_H values at zero deflection angle and zero angle of attack, the absolute values of Cm_H possible to achieve are much higher for the deflected TE flap than for classic Gurney flap.

The rate of change of hinge moment value with respect to steer deflection change, represented by $d(Cm_H)/d\delta$ derivative, was shown in Fig. 7 (T-strip and non-deflected TE flap) and Fig. 8 (Gurney flap and deflected TE flap). In both cases, the values of derivative are presented for negative and positive steer deflections. In Fig. 7, these charts are symmetrical, because both presented technical solutions are symmetrical in relation to the airfoil chord. It could be noticed that the non-deflected TE flap guarantees higher or at least the same hinge moment increments in all conditions, compared to T-strip modification. In the case of non-symmetrical solutions, hinge moment increments for the proposed alternative flap are significantly higher, especially for positive steer deflections (Fig. 8b).

5. Discussion

The presented results show that the TE flap nearly parallel to the flow direction can replace T-strip flap, without changing the CL and Cm_H characteristics significantly and providing, at the same time, even 21% drag reduction of the whole stabilizer in the low lift conditions and steer deflection angles. This improvement is connected with the absence of reversed flow behind the TE flap – the comparison of turbulent kinetic energy levels at CL = 0 was shown in Fig. 9.

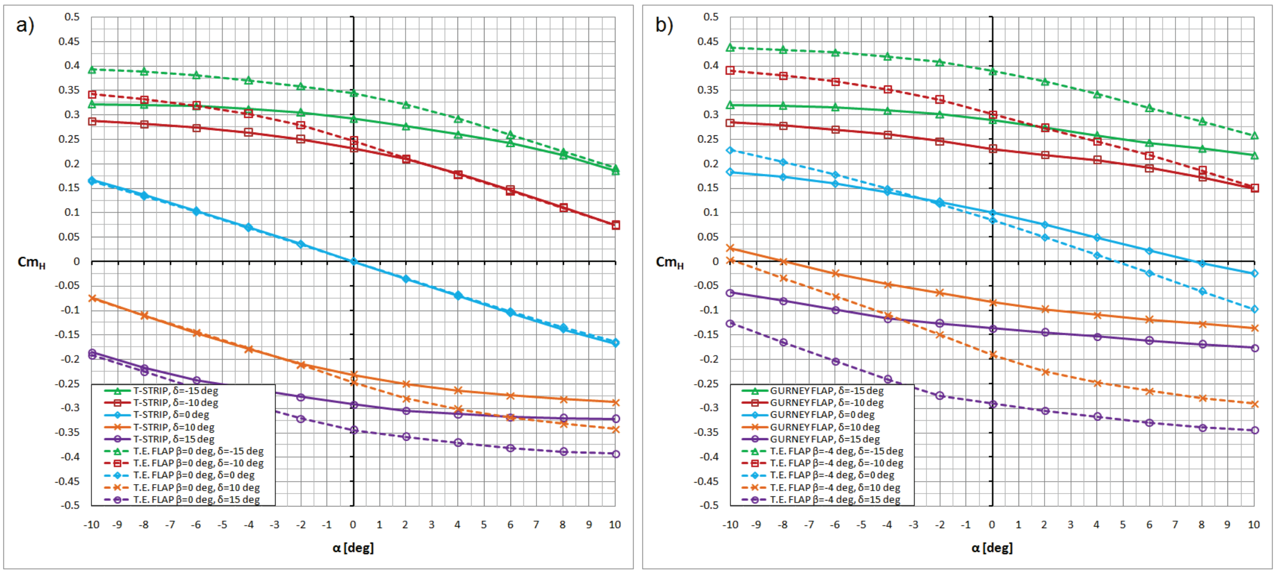

Fig. 6. Hinge moment coefficient characteristics for: a) T-strip and non-deflected TE flap; b) Gurney Flap and deflected TE flap

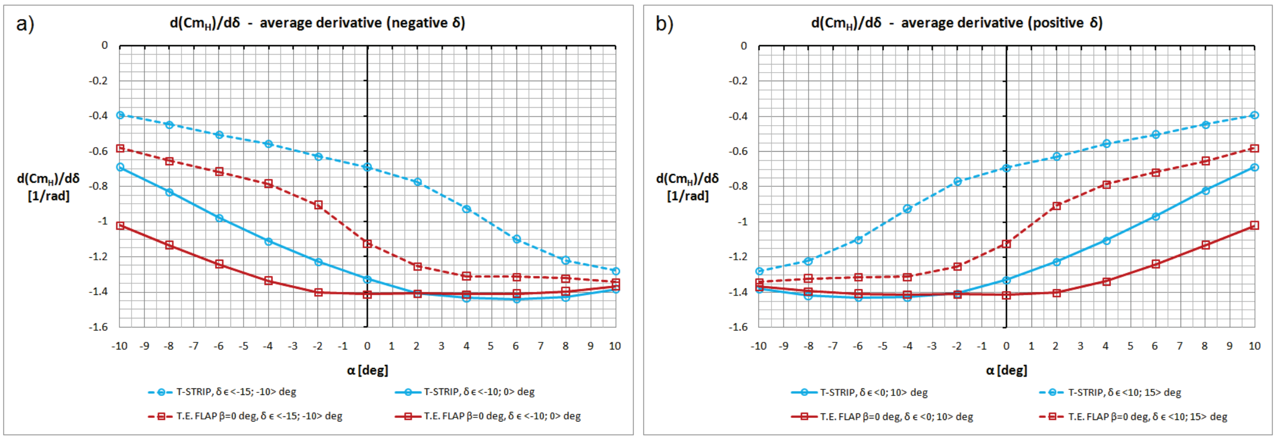

Fig. 7. Average d(Cm$_H$)/dδ derivative characteristics for T-strip and non-deflected TE flap: a) negative steer deflections δ; b) positive steer deflections δ

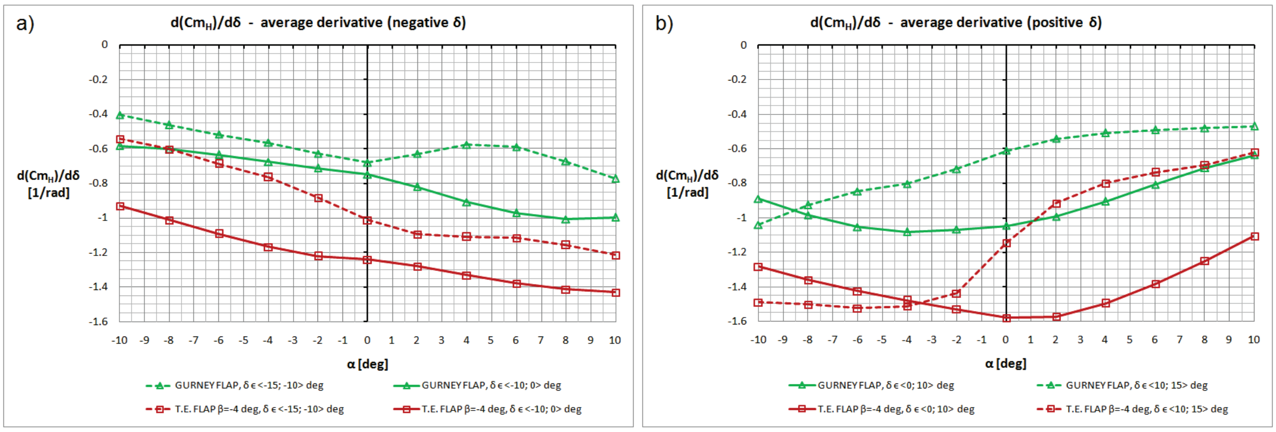

Fig. 8. Average d(Cm$_H$)/dδ derivative characteristics for Gurney Flap and deflected TE flap: a) negative steer deflections δ; b) positive steer deflections δ

At high lift conditions the drag improvement is lower and, for the highest deflection angles (-15°/15°) and CL around -0.9/0.9, can be even negative. However, such a high steer deflection angles occur usually for a very short periods, so the corresponding drag increase is not a substantial problem. The differences in Cm_H values and their derivatives result from the larger effective steer area in the TE flap case. At high positive angles of attack and steer deflection, as well as at high negative, the angle between steer chord and undisturbed flow direction achieves 25 degrees, and for these conditions steer effective area has the highest influence on final CL and Cm_H values.

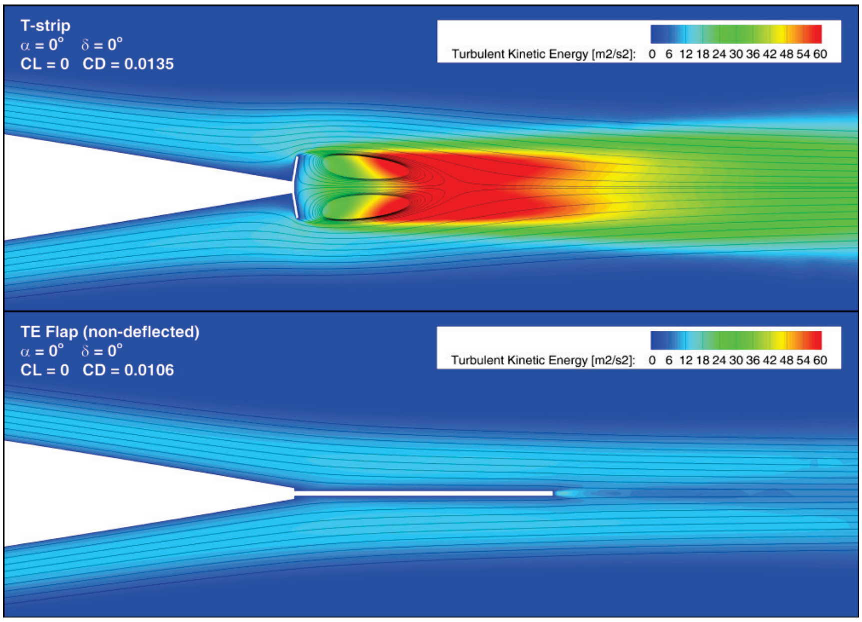

Fig. 9. Contours of turbulent kinetic energy for T-strip and alternative non-deflected TE flap (CL = 0)

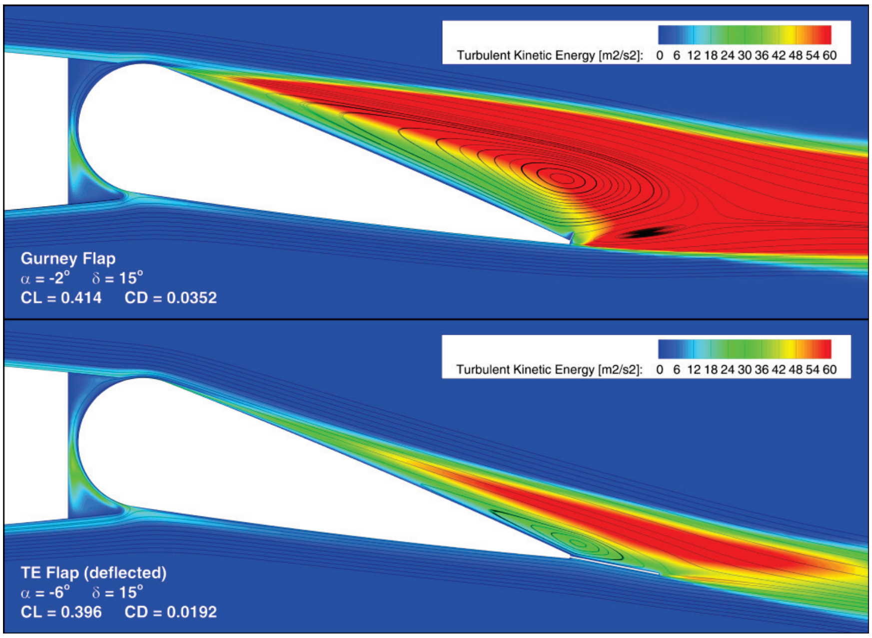

Fig. 10. Contours of turbulent kinetic energy for Gurney Flap and alternative deflected TE Flap (CL ≈ 0.4)

The second pair of presented modifications appeared to not-match in terms of aerodynamic characteristics as well as the previous one. The deflection of the TE flap by -4 degrees, without changing its length, allowed achieving similar CL characteristics, but Cm_H values and their derivatives with respect to steer deflection are significantly higher in absolute values. In addition, the highest drag reduction is visible at high positive steer deflection angles, not zero-lift conditions. It is connected with the fact, that unsymmetrical Gurney flap, placed on the top surface of the steer, is practically completely hidden in the stall region at high positive steer deflection angles and therefore ineffective (Fig. 10). For negative steer deflections (up) there are much smaller differences between the deflected TE flap and Gurney flap. However, the aerodynamic drag reduction is visible here for a wider range of flow conditions than in the case of previously discussed symmetrical flaps.

It should be mentioned that aerodynamic efficiency improvement for the alternative solutions is connected with the hinge moment increment, especially when compared the unsymmetrical devices. This fact should be taken into consideration during design process, because it could cause significant steer force increments. However, this is sometimes a desirable effect and these solutions could allow achieving steer force requirements stated in certification specification rules, without serious redesign of an aircraft. Mentioned requirements could also be met by, for example, a proper control system design, but this approach requires complicated design modifications. Therefore, the changes in hinge moment characteristics should not be clearly recognized as advantage or disadvantage of presented flaps, but as additional design parameter, which has to be taken into account. Depending on the needs, these changes could be favourable or compensated in the other way.

6. Conclusions

In the article, the alternative solutions to classic Gurney flap and double Gurney flap (T-strip) were proposed and tested on the movable steer of the typical symmetrical aircraft stabilizer, using CFD analysis. The analysis concerned the representative cross section of the stabilizer (2D case) and a few different angles of steer deflection and angles of attack. Presented results allowed to assess the aerodynamic performance changes of the entire stabilizer and pointed out advantages and disadvantages of selected trailing edge devices. As expected, the simulations showed the possibility of reducing the aerodynamic drag at low lift conditions by using one of the presented solutions, compared to classic Gurney flap or T-strip. Simultaneously, obtained lift force characteristics for proposed devices are very similar to original trailing edge modifications. The main differences were noticed in the hinge moment values and derivatives. In general, solutions based on nearly parallel to the flow direction plates guarantee higher absolute values and derivatives of hinge moment coefficient. This should not be clearly identified as advantage or disadvantage of presented modifications, because in certain conditions such hinge moment characteristics can be favourable. However, better control system effectiveness without excessive drag increment make these devices very usable and competitive flow control solutions for movable steers.

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