Optimization of the Slotted Gurney-Flap geometry applied to NACA 0012 airfoil for aerodynamic performance improvement

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ABSTRACT

The salient aim of this paper is the shape optimization of an airfoil equipped with Gurney-Flap for aerodynamic performance improvement. The optimization of the slotted Gurney-Flap for improving the aerodynamic efficiency and increasing the lift force of NACA 0012 is the novelty of this research. The Genetic Algorithm, Artificial Neural Network, and Computational Fluid Dynamics are employed for shape optimization. The optimization variables include the height and thickness of the Gurney-Flap; also, the thickness and position of the slot. All analyses have been conducted at Re=0.45×10^6 and AoA=8^o to simulate the take-off phase. After validation, the optimization process was conducted with two different fitness functions of Cl and L/D. According to the results, the geometry representing an optimized lift coefficient compared to the geometry with optimized L/D has a considerably higher height. Furthermore, the thickness of the slot in the first geometry is lower than the second geometry. As a result, the first optimized geometry leads to a 21.64 percent lift coefficient increment; there is a 293 percent increment in aerodynamic efficiency due to the second optimized geometry. As a result, it can be indicated that the help of slotted optimized Gurney-Flap can provide the required lift force for a Short Take-Off Landing distance.

KEYWORDS

NACA 0012, Gurney-Flap, Genetic Algorithm, ANN, CFD.

1. Introduction

Recently, a meaningful effort has been made to develop aircraft concepts for vertical take-off and landing capabilities of the aircraft and shortening their take-off/landing distances [1]. Using different methods for improving the aerodynamic performance of the aircraft, especially at low Reynolds numbers, are one of the mentioned efforts for making STOL[1] an aircraft. Utilizing High-Lift Devices [2], Vortex generators [3], Suction [4], Blowing [4], and Winglets [5, 6] are examples of the flow control methods for improving the aerodynamic performance of the aircraft. Also, Gurney Flap is a useful passive flow control method for enhancing aerodynamic performance. This device, which was introduced by Dan Gurney in 1971, is a small tab projected from the trailing edge of the wing and airfoils [7]. This device generates three different vortices at the trailing edge of the model, makes a virtual camber higher than the geometrical one, and results in a more attached flow to the upper surface of the wing, which leads to a higher value of the lift force. Liebeck and his coworkers [8] inspiredly presented that more than 50% lift coefficient enhancement could be achievable using this small flow control device. Other researchers also studied the effects of different parameters of GF on the flow characteristics meticulously Variation of the GF height [9-11], mounting angles [12, 13], locations and shape of

[1] Short Take Off/ Landing

the Gurney Flap [14] are the previous research parameters.

This study focuses on optimizing an airfoil equipped with a slotted Gurney Flap for aerodynamic performance enhancement, which could shorten the take-off distance of the aircraft. In this research, a NACA 0012 airfoil is selected as a base geometry, and for finding the higher values of Cl and L/D, a GF is attached to it. Furthermore, due to reducing the drag force of the GF, a 2-D slot is generated on it. Generally, the novelty of this study is the optimization of the geometry of the slotted Gurney Flap to lift coefficient and aerodynamic efficiency enhancement. The Genetic Algorithm, Artificial Neural Network, and Computational Fluid Dynamics are employed for shape optimization. The optimization variables include the height and thickness of the GF; also, the thickness and position of the slot. All analyses have been conducted at Re=0.45×10^6 and AoA=8° to simulate the take-off phase. After validation, the optimization process was conducted with two different fitness functions of Cl and L/D.

2. Methodology

2.1. Geometry, Meshing, and Numerical solution set-up

According to the basic novelty of this research, a NACA 0012 airfoil is selected for the base geometry. The airfoil chord is considered 0.2 m, and free stream velocity equal to 30 m/s and AoA=8° are selected for analysis. Reynolds number based on these values was calculated about to 0.45×10^6. A rectangular GF with a maximum height and thickness of 0.015C was attached normally to the T.E of the model. GAMBIT software is utilized for mesh generation in this research. Generally, the hybrid mesh is selected for the analyses, and the domain divided into the near-wall zone and far-field of the model. The Y+ value of the first layer of the mesh lower than one is guaranteed in all case studies for exact turbulence modeling. The C-type shape is selected for the air domain, and after mesh independency study, the number of 635000 cells is determined for the final mesh and domain. RANS equations for incompressible, viscous, and steady flow coupled with $\kappa - \omega\ SST$ turbulence modeling are solved for numerical flow simulation. The finite volume method in FLUENT software and the SIMPLE method for pressure-velocity coupling terms are employed in this research. Velocity inlet, Pressure outlet, and no-slip condition for airfoil walls were selected for the Boundary-Conditions of the flow governing equations. According to the previous experimental results, the numerical method is validated, which are described exhaustively in this paper.

2.2. Optimization procedure and design parameters

The optimization process contains a Genetic Algorithm, Artificial Neural Network, and Computational Fluid Dynamics conducted with two different fitness functions of Cl and L/D by four different optimization variables, including, 1. Height and 2. The thickness of the GF; 3. Thickness and 4. Position of the slot. These variables are made with the help of 8 different prints and 11 different values for each X or Y of the points presented in Figure 1. For the first phase of the project, GA is employed for geometry creation, and then auto meshing in the GAMBIT and auto solving in FLUENT is done until the GA convergence is achieved. After this step, a reasonable database is created for ANN training. When an appropriate network is reached by the training method of Levenberg-Marquardt, the explained process of the optimization is started again. Coupled with the GA, training of the network, ANN and CFD are employed until the relative difference between CFD and ANN lower than 0.01 is attained. This process is employed for two different fitness functions separately.

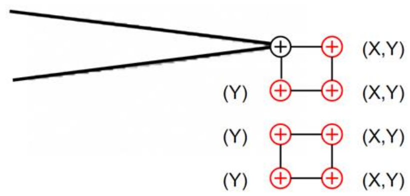

Figure 1 Optimization parameters for generating Gurney Flap geometry

3. Results and Discussion

By neglecting the Validation data and results of the GA created a database for ANN training, the final values of the Geometry, Cl, and L/D for two different fitness functions are presented in Table 1. The values of $L/D = 34.906$ and $Cl = 0.945$ are achieved by the optimization process representing two massive different shapes of the Gurney Flaps. These shapes of the GFs are depicted in Figure 2. As visible in this figure, the height of the GF in shape with maximum Cl is impressively higher than the shape for maximum L/D, in contrast to the thickness of the GF. Also, the thickness of the slot is lower for the optimum Cl shape compared to the optimum L/D shape. For the final optimization parameters, the slot position in the optimum Cl shape is lower than the optimum L/D shape, which is a direct impact of the higher the GF for the first shape. The mentioned effects on the GF shape are affected by flow behavior around the airfoil. As presented in Figure 3, the vortex generated in the forward face of the GF has an impressive impact on the lift force, forcing the optimization process to find a high value of the GF height to produce a stronger vortex. Also, maximizing the virtual chord and camber of the airfoil makes a shape with a maximum value of the L/D.

Table 1 Optimum values of the L/D, Cl, and geometry

	Base	Optimum Cl	Optimum L/D
Cl	0.777	0.945	0.891
L/D	8.861	31.851	34.906
GF Height (mm)	-	2.890	1.395
GF Thickness (mm)	-	1.120	3.000
Slot Thickness (mm)	-	0.280	0.760
Slot Starting Height (mm)	-	2.320	0.470

(a)

(b)

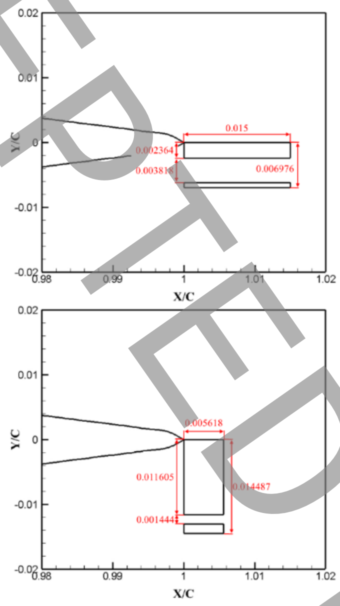

Figure 2 Optimum GF geometry for (a) maximum aerodynamic efficiency and (b) maximum lift coefficient

(a)

(b)

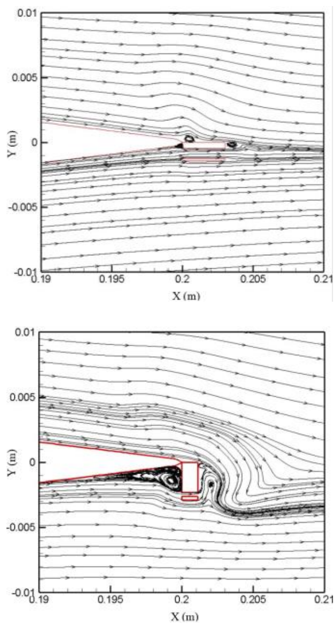

Figure 3 Flow streamlines of (a) maximum aerodynamic efficiency and (b) maximum lift coefficient

4. Conclusions

In this research, a NACA 0012 airfoil is selected as a base geometry, and for finding the higher values of the Cl and L/D, a Slotted Gurney Flap is attached to it. The Genetic Algorithm, Artificial Neural Network, and Computational Fluid Dynamics are employed for shape optimization. The optimization variables include the height and thickness of the GF; also, the thickness and position of the slot. After validation, the optimization process was conducted with two different fitness functions of Cl and L/D. Generally, with the help of this optimization procedure, 21.64% increment in Cl and 293% enlargement in L/D are achieved. The height of the GF in shape with maximum Cl was higher than the shape for maximum L/D. Also, the GF and slot thickness are lower for the optimum Cl shape compared to the optimum L/D shape. Also, the slot position in the optimum Cl shape is lower than the optimum L/D shape.

5. References

[1] S.B. Anderson, Historical overview of V/STOL aircraft technology, NASA Technical Memorandum, 81280 (1981) 9-5.
[2] Y. Nozaki, STOL aircraft, in, Google Patents, 1992.
[3] V.J. Rossow, Lift enhancement by an externally trapped vortex, Journal of Aircraft, 15(9) (1978) 618-625.
[4] R.E. Kosin, Laminar flow control by suction as applied to the x-21a airplane, Journal of Aircraft, 2(5) (1965) 384-390.
[5] M. Daude, Winglets for aircraft wing tips, in, Google Patents, 1984.
[6] J. Weierman, J. Jacob, Winglet design and optimization for UAVs, in: 28th AIAA Applied Aerodynamics Conference, 2010, pp. 4224.
[7] J. Wang, Y. Li, K.-S. Choi, Gurney flap—Lift enhancement, mechanisms and applications, Progress in Aerospace Sciences, 44(1) (2008) 22-47.
[8] R.H. Liebeck, Design of subsonic airfoils for high lift, Journal of aircraft, 15(9) (1978) 547-561.
[9] Y.-C. Li, J.-J. Wang, P.-F. Zhang, Experimental investigation of lift enhancement on a NACA 0012 airfoil using plate/serrated Gurney flaps, Acta Aeronautica et Astronautica Sinica, 24(2) (2003) 119-123.
[10] P. Giguere, G. Dumas, J. Lemay, Gurney flap scaling for optimum lift-to-drag ratio, AIAA journal, 35(12) (1997) 1888-1890.
[11] F. Ajalli, M. Mani, Effects of adding strip flap on a plunging airfoil, Aircraft Engineering and Aerospace Technology: An International Journal, (2014).
[12] Y. Li, J. Wang, P. Zhang, Influences of mounting angles and locations on the effects of Gurney flaps, Journal of Aircraft, 40(3) (2003) 494-498.
[13] L.W. Traub, A.C. Miller, O. Rediniotis, Preliminary parametric study of Gurney flap dependencies, Journal of aircraft, 43(4) (2006) 1242-1244.
[14] D.H. Neuhart, O.C. Pendergraft Jr, A water tunnel study of Gurney flaps, (1988).