International Journal of Engineering Science Invention **(IJESI)**
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ‖ PP.01-05

Identification of airfoil sections with improved aerodynamic characteristics

Prabhu L[1], Dr. J. Srinivas[1]

[1]*Department of Mechanical Engineering, National Institute of Technology, Rourkela, India.*

ABSTRACT: *Research on advanced aerodynamic technology airfoils has been conducted over the last several years; as a result many airfoil shapes were constructed rationally and systematically. The airfoil profile variation has deterministic effect on the aerodynamic coefficients. The aerodynamic characteristics are depending on factors like profile of upper surface and lower surface, leading edge radius, maximum thickness, location of maximum thickness, camber, and others. To enhance the aerodynamic characteristics of an airfoil, the optimization of its profile is a common procedure. In the past, several researchers have developed optimization methods that directly adjust airfoil shapes. In this work, a multi-factor optimization analysis is presented. Here, first factor is to identify the aerofoil cross-section having a maximum thickness location that gives better aerodynamic parameters; second factor is optimization of nose section of maximum thickness optimized airfoil identified in first step. Nose optimization of an airfoil is done by normal to chord method. The baseline airfoil considered is NACA 0012. Maximum thickness locations used are 20%, 40%, and 50% of chord. Results of optimized and baseline cross-sections are compared.*

Keywords: *Aerodynamic characteristics, Airfoil optimization, Maximum thickness location, Airfoil nose optimization*

I. INTRODUCTION

Airfoil is common cross-section of the wings. The advent of successful powered flight at the end of nineteenth century reveals the importance of aerodynamics comes into play almost overnight. In turn, interest grew in the understanding of the aerodynamic action of such lifting surfaces as fixed wings on airplanes and, later, rotor on helicopters. Ludwig Prandtl and his colleagues showed the aerodynamic consideration of wings could be split into two parts: first the study of the section of a wing-airfoil and second the modification of such airfoil properties to account for the complete, finite wing. First patented airfoil shapes were developed by Horatio F. Phillips in 1884. In early 20th century the Wright brothers conducted their own airfoil tests in a wind tunnel, developing relatively efficient shapes which contributed to their successful first flight. In the early days of powered flight, airfoil design was basically customized and personalized. The National Advisory Committee for Aeronautics (NACA)-embarked on a series of definitive airfoil experiments using airfoil shapes that were constructed rationally and systematically. Many of these NACA airfoils are in common use today. Nowadays the research work concentrates on the best airfoil section. Hicks et al. [1] Airfoil and wing design methodologies have made large steps forward through the availability of rapid computational tools which allow for specification of goals in aerodynamic performance. An airfoil design program has been developed for the automated design on a minicomputer of low speed airfoils. The program utilizes a generalized Joukowski method for aerodynamic analysis coupled with conjugate gradient, penalty function, and numerical optimization algorithm to give an efficient calculation technique for use with minicomputers. Bruscoli [2] In the design of an airfoil for solar powered aircraft, the upper surface was modified to obtain an arc so as it could be covered by solar cells uniformly; here baseline airfoil coordinates are modified in CATIA software and tested for aerodynamic characteristics in Xfoil. Campanile [3] the belt-rib mechanism constitutes a very good option for the successful realization of shape-adaptable airfoil structures. It has advantages over conventional mechanism because: absence of backlash and wear, no need for lubrication, reduced noise, smooth geometry changes, a lighter design, and reduced manufacturing cost. Chiguluri [4] First airfoil is designed by using inverse method-Modified Garabedian McFadden Technique and then it is modified for take-off configuration by new technique. The developed optimization technique requires the translation of the common surface between the slat and the wing element to a polynomial. This could be easily done by importing the points on the common surface into MATLAB and using the built-in “polyfit” function to derive the equation that defines the line for new surface. Topliss et al. [5] presents a strategy for exploring the design space for use in aerodynamic optimization. This is achieved by perturbing the values of the geometric shape variables, angle of attack, and free stream Mach number for a 2D transonic aerofoil. The approach uses the 'quasi-analytical' method, which arises from the direct differentiation of the nonlinear governing equations. Antony [6] says control theory can be used to formulate computationally feasible procedures for aerodynamic design. Allen et al. [7] says optimal airfoil shapes are found through manipulation of the velocity distribution by a genetic algorithm. The airfoil geometries are generated by an inverse method from velocity distribution parameters, and a viscous-flow analysis code is used to determine proper fitness values for candidate airfoils based on preset performance criteria Mukesh et al. [8] described an optimization scheme for airfoil shapes by considering 12 variables in a polynomial fit. Tomas Melin et al. [9] present a parameterization method for two dimensional airfoils, aimed at providing a wide design space, at the same time keeping the number of parameters low. Balu et al. [10] describes the problem of finding a set of given number of control points for an arbitrary two dimensional curve is formulated as an optimization problem and solved using Genetic Algorithm. Manikandan et al [11] presented airfoil optimization by changing maximum thickness location by Genetic algorithm and experiment was carried on optimized airfoils to find the aerodynamic characteristics.

In present work NACA 0012 airfoil is taken as a baseline airfoil and it is modified by changing the position of maximum thickness without changing its nose radius. Then the best modified airfoil is considered for nose optimization using a technique called normal to chord method. Results are presented for 3 different maximum thickness locations. JAVAFOIL tool is used to assess the aerodynamic parameters for each case.

II. PROPOSED METHODOLOGY

Airfoils with optimum geometry are predicted in present task by a two-stage formulation.

2. 1Optimization by changing maximum thickness position

Particular airfoil will have the defined aerodynamic characteristics, when better aerodynamic characteristics are needed the factors influencing it can be modified. In this paper to enhance the aerodynamic characteristics: the modification of maximum thickness location is varied along the chord without changing the maximum thickness and nose radius. NACA 0012 airfoil is selected for the optimization. It is four digit airfoil which shows that the airfoil is symmetric and maximum thickness is of 12 percentage of chord. The maximum thickness locations on chord for modification are 20%, 40%, and 50%. The coordinates for modified airfoil is obtained from DesignFoil software. Analyses for aerodynamic characteristics are done in JavaFoil software. JAVAFOIL is user friendly software, uses a potential flow analysis module which is based on higher order panel method. To find the lift, drag and moment characteristics of airfoils, the local velocity and the local pressure obtained are related to the Bernoulli equation. The distribution of pressure can be integrated over the surface. Values of density, kinematic viscosity, and speed of sound are 1.225 kg/m^3, 0.000014607 m^2/s, 340.29 m/s. coordinates of airfoils are imported and the analysis is carried out. First NACA 0012 airfoil is analyzed and the other airfoils with various maximum thickness locations, without changing nose radius are analyzed. Analysis is done for various aerodynamic characteristics like lift and drag coefficient, pressure coefficient at different Mach numbers (0.2, 0.4 0.6) and angle of attack 1 to 16 degrees

2.2 Optimization of nose by Normal to Chord Method

Airfoil can be optimized by techniques like Genetic algorithm; Simulated annealing. Instead of optimizing entire airfoil, nose section alone can be optimized which also helps us to find the better aerodynamic characteristics of an airfoil. This method consumes very less time comparing to airfoil optimization. Here the technique called Normal to chord method is employed to optimize the airfoil nose. Airfoil is shape is controlled by number of control points (coordinates). In this method first, reference line (R) is drawn from 0, 0 coordinate to coordinate having maximum Y value. Next step is getting control points (C_i) between 0, 0 coordinate to coordinate having maximum Y value. Now the normal line to chord will be drawn from selected control points to reference line, N_i is the notation used for normal line through particular control points (C_i). Then the normal lines will be divided into equal number of parts (n_i). When n_i of all N_i are joined new airfoil nose is obtained. **Fig. 1 (a), (b), (c) given below shows the clear picture of Normal to chord method.**

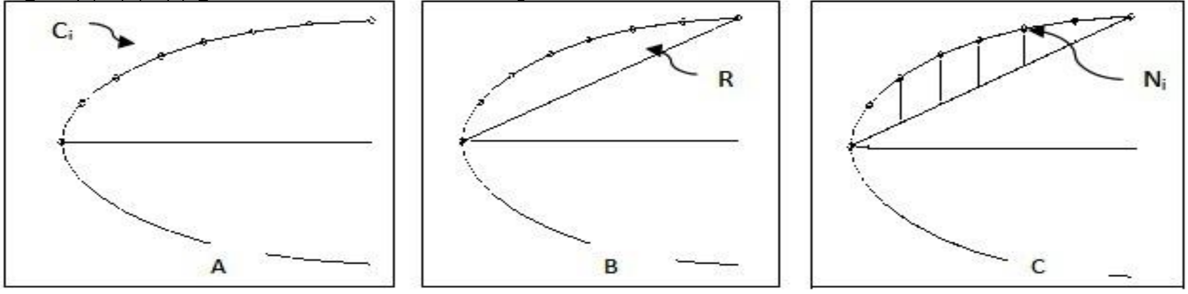

Fig. 1: Normal to chord method

MATLAB coding is written to get the coordinates for new airfoil nose directly by giving control points between (0, 0) coordinates and coordinates having maximum Y value. In this investigation Normal to chord method is applied to the optimized airfoil obtained by varying the maximum thickness location along the chord. In this method n_i number of airfoils are obtained. Each airfoil is analyzed in JAVAFOIL to get the best airfoil. This helps to identify the airfoil with the better aerodynamic property.

III. RESULTS AND DISCUSSION

The NACA 0012 airfoil is first analyzed in JAVAFOIL by changing its maximum thickness location along chord without changing nose radius. The better aerodynamic characteristic airfoil is selected and nose optimization is carried out. Fig. 2 to Fig. 7 shows the plotting of coefficient of lift and drag versus angle of attack (AOA).

In Fig. 2 coefficient of lift for different angle of attack at Mach number 0.2 is plotted. Cl of all airfoil increases till 12 degree of angle of attack, after Cl starts to decline. The maximum Cl value of NACA 0012, NACA 0012-62 (maximum thickness at 20% of chord), NACA 0012-64 (maximum thickness at 40% of chord), NACA 0012-65 (maximum thickness at 50% of chord), are 1.181, 1.227, 1.143, 0.969.

In Fig. 3 coefficient of drag for different angle of attack at Mach number 0.2 is plotted. Cd of all airfoil fluctuates till 8 degree of angle of attack, after Cd starts to increase. The minimum Cd value of NACA 0012, NACA 0012-62 (maximum thickness at 20% of chord), NACA 0012-64 (maximum thickness at 40% of chord), NACA 0012-65 (maximum thickness at 50% of chord), are 0.01182, 0.01221, 0.01035, 0.00714.

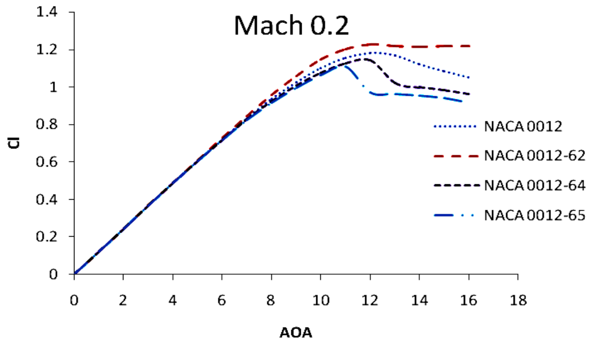

Fig. 2: Cl vs AOA at Mach: 0.2

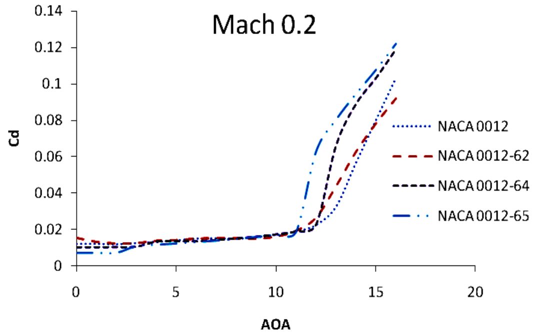

Fig. 3: Cd vs AOA at Mach: 0.2

In fig. 4 coefficient of lift for different angle of attack at Mach number 0.4 is plotted. Cl of all airfoil increases till 13 degree of angle of attack, after Cl starts to decline. The maximum Cl value of NACA 0012, NACA 0012-62 (maximum thickness at 20% of chord), NACA 0012-64 (maximum thickness at 40% of chord), NACA 0012-65 (maximum thickness at 50% of chord), are 1.289, 1.352, 1.239, 1.082.

In fig. 5 coefficient of drag for different angle of attack at Mach number 0.4 is plotted. Cd of all airfoil fluctuates till 9 degree of angle of attack, after Cd starts to increase. The minimum Cd value of NACA 0012, NACA 0012-62 (maximum thickness at 20% of chord), NACA 0012-64 (maximum thickness at 40% of chord), NACA 0012-65 (maximum thickness at 50% of chord), are 0.0117, 0.0115, 0.0106, 0.0072.

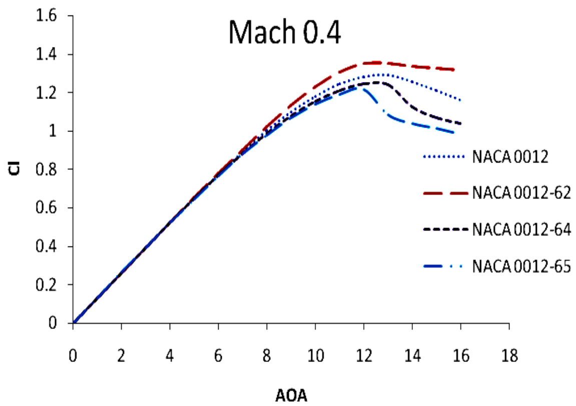

Fig. 4: Cl vs AOA at Mach: 0.4

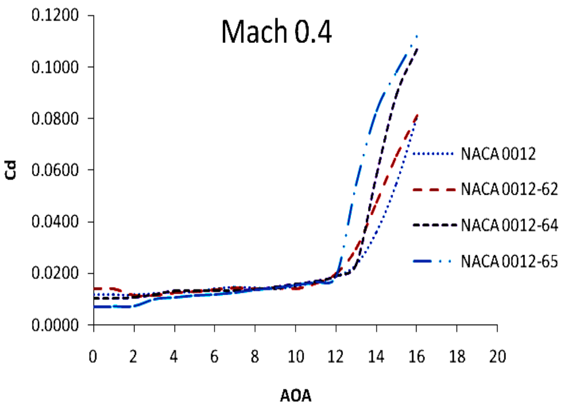

Fig. 5: Cd vs AOA at Mach: 0.4

In fig. 6 coefficient of lift for different angle of attack at Mach number 0.6 is plotted. Cl of all airfoil increases till 13 degree of angle of attack, after Cl starts to decline. The maximum Cl value of NACA 0012, NACA 0012-62 (maximum thickness at 20% of chord), NACA 0012-64 (maximum thickness at 40% of chord), NACA 0012-65 (maximum thickness at 50% of chord), are 1.495, 1.578, 1.439, 1.399.

In fig. 7 coefficient of drag for different angle of attack at Mach number 0.6 is plotted. Cd of airfoil NACA 0012-62 fluctuates till 5 degree of angle of attack, after Cd starts to increase, for other airfoil Cd starts to increase right from 0 degree of angle of attack. The minimum Cd value of NACA 0012, NACA 0012-62 (maximum thickness at 20% of chord), NACA 0012-64 (maximum thickness at 40% of chord), NACA 0012-65 (maximum thickness at 50% of chord), are 0.012, 0.011, 0.011, 0.007.

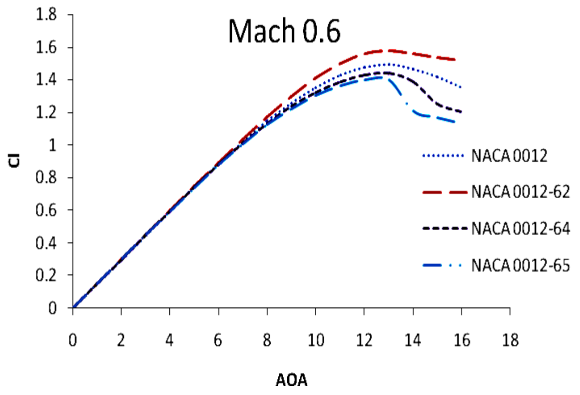

Fig. 6: Cl vs AOA at Mach: 0.6

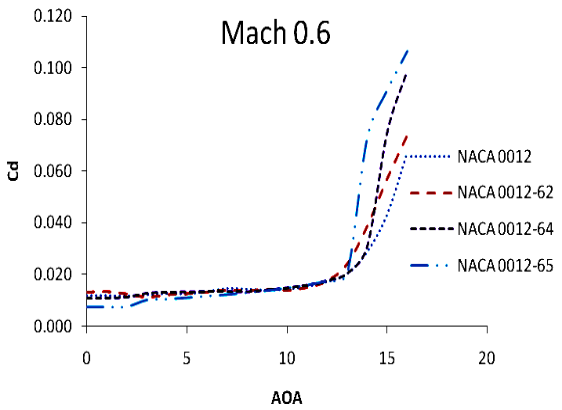

Fig. 7: Cd vs AOA at Mach: 0.6

According to above results NACA 0012-62 is having better aerodynamic characteristics is selected for nose optimization method. The control points used for optimization and optimized control points are given below in table. 1. In normal to chord method: normal lines are divided into 198 equal points, so 198 new nose sections are obtained and analyzed in JAVAFOIL. The coordinates of nose with better aerodynamic characteristics is given in Table. 1

Table. 1: Coordinates of airfoils

NACA 0012-62		MODIFIED	
x	y	x	y
0.154469	0.059375	0.154469	0.059324
0.123464	0.057486	0.123464	0.057395
0.095492	0.053962	0.095492	0.053844
0.070776	0.048751	0.070776	0.048619
0.049516	0.042045	0.049516	0.041913
0.031883	0.034202	0.031883	0.034081
0.018019	0.025666	0.018019	0.025566
0.008035	0.016885	0.008035	0.016813
0.002013	0.008243	0.002013	0.008205
0.000000	0.000000	0.000000	0.000000

The coefficient of lift and drag is tabulated in table. 2. Data from table 2 shows that the coefficient of lift of both NACA 0012-62 and nose optimized airfoils follows the same path up to angle of attack 0 to 8 degrees, after that value of optimized is decrease by average of 0.09%. The maximum coefficient of lift of NACA 0012-62 and optimized airfoil are 1.227 and 1.225. The coefficient of drag of optimized is average of 1.61% less than NACA 0012-62.

Table. 2: Cl, Cd of NACA 0012-62 and modified airfoil at various Mach numbers

Mach 0.2				Mach 0.4				Mach 0.6			
NACA 0012-62		Modified		NACA 0012-62		Modified		NACA 0012-62		Modified	
Cl	Cd	Cl	Cd	Cl	Cd	Cl	Cd	Cl	Cd	Cl	Cd
0	0.01526	0	0.01521	0	0.01388	0	0.01385	0	0.01325	0	0.01323
0.123	0.01304	0.123	0.01302	0.132	0.01393	0.132	0.0139	0.151	0.01348	0.151	0.01345
0.246	0.01221	0.246	0.01199	0.263	0.0115	0.263	0.01129	0.302	0.01254	0.301	0.01212
0.369	0.0124	0.369	0.01223	0.394	0.01157	0.394	0.0114	0.451	0.01132	0.451	0.01114
0.49	0.01368	0.49	0.01352	0.524	0.01265	0.524	0.01249	0.601	0.01226	0.6	0.0121
0.611	0.01409	0.611	0.01395	0.653	0.01311	0.653	0.01297	0.748	0.01266	0.748	0.01252
0.73	0.01484	0.73	0.01471	0.78	0.01377	0.78	0.01365	0.894	0.01329	0.894	0.01317
0.845	0.0152	0.845	0.01409	0.903	0.0144	0.903	0.01283	1.035	0.01403	1.035	0.01235
0.956	0.01499	0.956	0.01493	1.022	0.01403	1.022	0.01374	1.171	0.01371	1.17	0.01324
1.06	0.01475	1.059	0.01469	1.133	0.01455	1.132	0.01447	1.298	0.01442	1.297	0.01435
1.145	0.01599	1.144	0.01589	1.229	0.01414	1.228	0.01402	1.412	0.01395	1.411	0.01379
1.203	0.01914	1.202	0.01913	1.303	0.01625	1.302	0.01622	1.5	0.01507	1.499	0.01506
1.227	0.02643	1.225	0.02636	1.349	0.01977	1.347	0.01974	1.562	0.01761	1.559	0.01756
1.217	0.04358	1.218	0.0429	1.352	0.02957	1.352	0.02921	1.578	0.02414	1.577	0.02392
1.214	0.06257	1.212	0.06269	1.335	0.04759	1.332	0.04759	1.559	0.03873	1.556	0.0389
1.218	0.07813	1.216	0.07788	1.325	0.06553	1.323	0.06511	1.538	0.05713	1.536	0.05665
1.218	0.09183	1.215	0.09168	1.316	0.08124	1.314	0.08068	1.521	0.07389	1.519	0.07327

IV. CONCLUSIONS

Optimization of NACA 0012 airfoil is carried out in two ways: first by changing its maximum thickness location on chord, second by normal to chord method. When maximum thickness location is altered along chord, the better aerodynamic characteristics of airfoil comparing to baseline is NACA 0012-62 because achievement of high maximum coefficient of lift is expected while airfoil is designed. The airfoil with better aerodynamic characteristics is opted for nose optimization by normal to chord method. The nose optimized airfoil shows the coefficient of lift follows and coefficient of drag is lower than the NACA 0012-62 airfoil.

REFERENCES

[1]. Raymond M. Hicks, C. A. Szelaczek, 'Airfoil Design by Numerical optimization using a Microcomputer', *NASA Technical Memorandum 78502.*, 1978.

[2]. Sara Bruscoli, 'Airfoil Optimization for Solar Powered Aircraft', *University of Pisa, Thesis*., 2011.

[3]. L. F. Campanile, 'Modal Synthesis of Flexible Mechanisms for Airfoil Shape Control', *Journal of Intelligent Material Systems and Structures*., 2007.

[4]. Bhanu Chiguluri, 'Multipoint Optimization of Airfoils' *Georgia Institute of Technology, B.Tech Thesis.*, 2011.

[5]. Topliss. M.E., Toomer. C.A., and Hills, D.P., 'Rapid Design Space Approximation for Two-Dimensional Transonic Aerofoil Design', *Journal of Aircraft.*, Vol. 33, No. 6, 1996, pp. 1101–1108.

[6]. Jameson, A., 'Aerodynamic Design via Control Theory', *Journal of Scientific Computing.*, Vol. 3, 1998, pp. 233–260.

[7]. B. Allen Gardner, Michael S. Selig, 'Airfoil Design using a Genetic algorithm and an inverse method', *AIAA*., 2003-43.

[8]. R.Mukesh, K.Lingadurai and U.Selvakumar, 'Application of nontraditional optimization techniques for airfoil shape optimization', *Modeling and Simulation in Engineering*., vol.2012, DOI:10.1155/2012/636135.

[9]. Tomas Melin, Kristian Amadori, and Petter Krus, 'Parametric wing profile description for conceptual design', *CEAS*., 2011, 24-28 October.

[10]. R. Balu, U.Selvakumar, 'Optimum Hierarchical Bezier parameterization of arbitrary curves and surfaces', *11th Annual CFD Symposium.*, 11th – 12th August 2009, Bangalore.

[11]. G. Manikandan and M Anannd Rao 'Effect of Maximum Thickness Location of an Aerofoil on Aerodynamic Characteristics', *International Journal Of Advanced Engineering Sciences And Technologies*., Vol No. 3, Issue No. 2, pp. 122-133.