Flow Simulation on New Airfoils Design

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Abstract— Airfoil is the cross section of the wing, which produces the lift force due to pressure difference between upper and lower surface of the airfoil, also the airfoil produces some amount of drag force, which resist the forward motion of the aircraft. The main aim of this paper is to formulate a design to reduce the drag force as well as to increase the aerodynamic efficiency of the airfoil. Flow simulation on NACA 2412 airfoil was considered as reference model for comparing with new airfoil designs from various fish shapes by the value of CL, CD and aerodynamic efficiency .i.e. CL/CD ratio. For increasing aerodynamic efficiency, new airfoil shapes were created from world's fastest top fishes and analyzed by using CATIA and ANSYS software respectively. The CL, CD, CL/CD ratio and power required calculation were calculated for both NACA 2412 and new airfoil shapes.

Key words: Flow simulation of different shape airfoils derived from world's fastest fish, CL (coefficient of lift), CD (coefficient of drag), CL/CD (aerodynamic efficiency) and Power required calculation

I. INTRODUCTION

Even though today many techniques are available to reduce the drag like roughness parameter, vortex generator, winglets, etc., there is very high need to increase the aerodynamic efficiency furthermore due to one important reason of the energy depletion. In this paper geometrical base modification was followed in NACA 2412 airfoil to increase the aerodynamic efficiency by introducing world's fastest fish shapes. The reason for implementing fish shapes is density of the fluid medium. Because normal water density is approximately thousand times greater than the air density and sea water density is little bit more than the normal water density. In such condition, fishes are easily achieving them average speed greater than about 15 m/s by overcoming the viscous nature of the sea water. In this design sail fish, Wahoo fish, Sword fish and Tarpon fish shapes were taken from the world's top fast fishes list, because of the unsymmetrical shape. The NACA 2412 airfoil and different fish shapes models were analyzed to improve the aerodynamic efficiency.

II. ANALYSIS OF NACA 2412 AIRFOIL

The National Advisory Committee for Aeronautics 2412 airfoil was generated by NACA application software. Using ANSYS software pre-processing, meshing and pre-posting process were done. The airfoil profile was analyzed under viscous-laminar model; the boundary condition of inlet velocity was 140 m/s at 1 atmospheric pressure, zero outlet pressure and zero angle of attack. Forces were determined and C_L, C_D, C_L/C_D ratio were calculated. Free stream velocity is 140 m/s and wing area is 1.01×1.01 m^2.

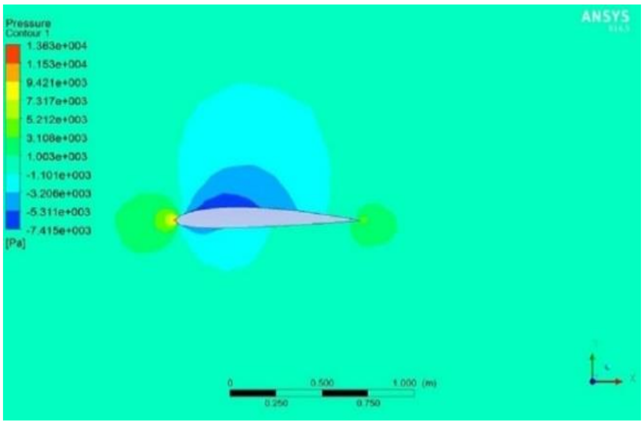

Fig. 1: NACA 2412 airfoil pressure contour

Figure 1 shows the pressure difference around the airfoil. The stagnation pressure, $1.153 \times 10^{\wedge}4$ to $1.363 \times 10^{\wedge}4$ Pa, present at leading edge of the airfoil is represented by the red color. Similarly the thick blue color indicates the pressure level of $-5.31 \times 10^{\wedge}3$ to $-7.415 \times 10^{\wedge}3$ Pa and light blue color value is $-1.1 \times 10^{\wedge}3$ to $-3.2 \times 10^{\wedge}3$ Pa. The medium blue color value is $-3.2 \times 10^{\wedge}3$ to $-5.31 \times 10^{\wedge}3$ Pa. From the above detail values the NACA 2412 airfoil is conformed as an unsymmetrical airfoil. Leading edge and trailing edge point pressure difference is low. The aerodynamic efficiency (C_L/C_D) of the NACA 2412 airfoil is calculated and found to be (0.172/0.0061) 28.16.

III. ANALYSIS OF MODIFIED FISH AIRFOIL MODELS

The NACA 2412 airfoil belongs to many Cessna series aircraft. The Cessna 140 wing is taken for analysis. In this analysis only maximum thickness, positions of camber and chord length were considered. Similarly the modified airfoils from the fish shapes were analyzed under same condition and C_L, C_D, C_L/C_D ratio were calculated. Modified sail fish model airfoil is failure because of no improvement in aerodynamic efficiency, but coefficient of drag value is reduced.

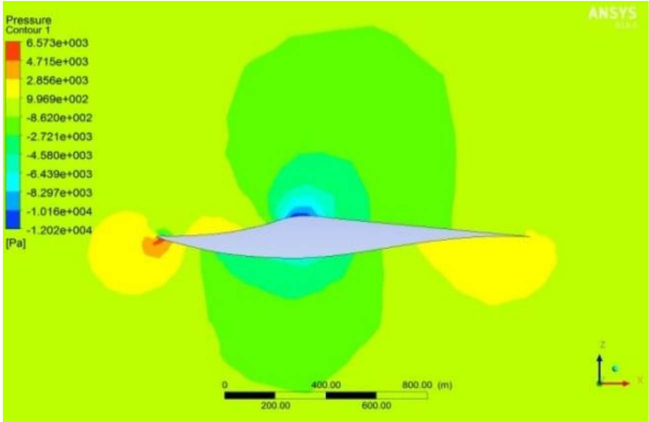

Fig. 2: Modified sail fish model pressure contour

Figure 2 shows pressure variation with respect to the length of the model. The red color represents stagnation pressure $4.7 \times 10\hat{}3$ to $6.57 \times 10\hat{}3$ Pa. The thick blue color represents the low pressure region about $-1.016 \times 10\hat{}4$ to $-1.2 \times 10\hat{}4$ Pa and light blue color represents the value of pressure about $-6.4 \times 10\hat{}3$ to $-8.29 \times 10\hat{}3$ Pa. From the leading edge point and trailing edge point the absorbed pressure difference in longitudinal axis is low compare to the NACA 2412 airfoil. The coefficient of lift, coefficient of drag values were calculated about 0.093 and 0.0059 respectively. The coefficient of drag value was reduced successfully but in the same time the aerodynamic efficiency was also reduced due to by reduction in coefficient of lift value. Other three models were achieved good aerodynamic efficiency than NACA 2412 airfoil.

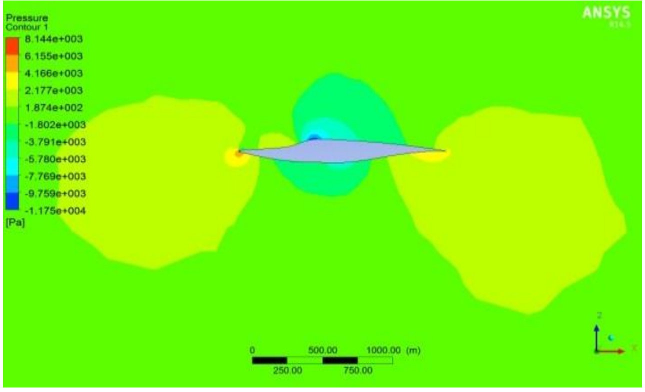

Fig. 3: modified sword fish pressure contour

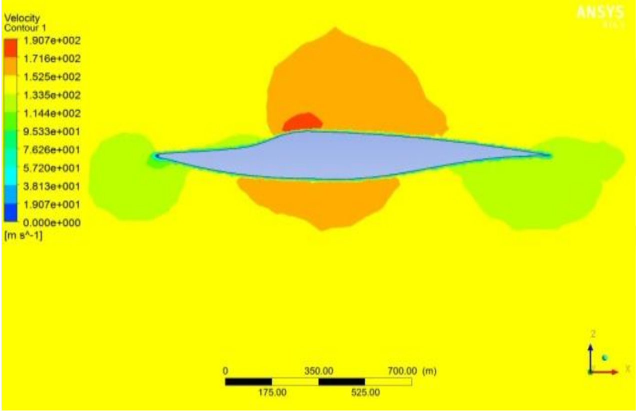

Fig. 4: modified sword fish velocity contour

Figure 3 show lengthwise pressure variation of the model. Very high pressure, very low pressure and medium level of pressure were mentioned by thick red color, thick blue color and combination of light blue and green color respectively. The value of very high pressure region is $6.15 \times 10\hat{}3$ to $8.14 \times 10\hat{}3$ Pa, very low pressure region is $-9.75 \times 10\hat{}3$ to $-1.17 \times 10\hat{}4$ Pa and medium pressure level is $-3.79 \times 10\hat{}3$ to $-5.78 \times 10\hat{}3$ Pa. Here in longitudinal axis the pressure difference between leading edge point and the trailing edge point is low. The aerodynamic efficiency is calculated and is equal to (0.13/0.0032) 40.625.

Figure 4 shows the velocity variation on the upper and lower surface of the model with respect to length. By Bernoulli's equation velocity is inversely proportional to the pressure. From the figures 3 and 4 Bernoulli's statement was proved. Because on the upper surface the flow is accelerated, this is denoted by thick red color in the figure 4. A very low pressure is mentioned at the same place in figure 3. From the figure 3 and 4, wherever the flow has low velocity, there will be high pressure. In figure 4 high velocity region mentioned by thick red color $1.7 \times 10\hat{}2$ to $1.9 \times 10\hat{}2\ m/s$. Medium level of velocity represent by light red color is $1.5 \times 10\hat{}2$ to $1.7 \times 10\hat{}2\ m/s$ and very low velocity is represent by thick blue color is 0 to $1.9 \times 10\hat{}1\ m/s$.

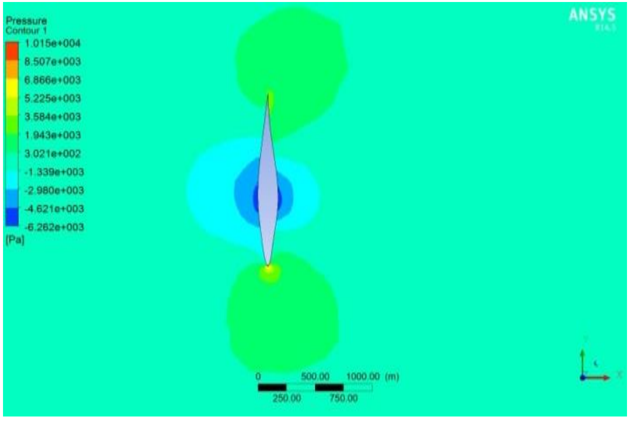

Fig. 5: Modified wahoo fish pressure contour

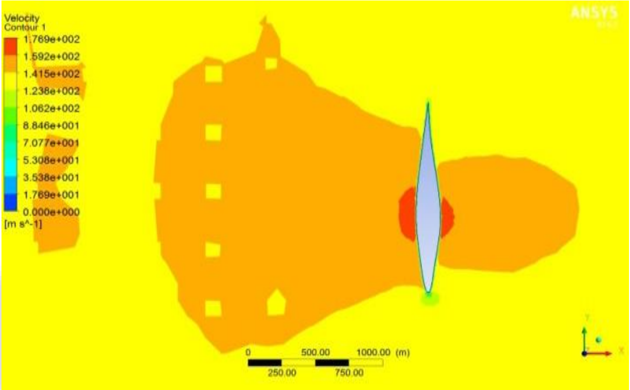

Fig. 6: modified wahoo fish velocity contour

The figure 5 shows the pressure variation on upper and lower surface with respect to the model length. Very low pressure region, $-4.621 \times 10\hat{}3$ to $-6.262 \times 10\hat{}3$ Pa, represented by thick blue and very high pressure $8.5 \times 10\hat{}3$ to $1.015 \times 10\hat{}4$ Pa is represent by thick red. The medium level of pressure, $-1.34 \times 10\hat{}3$ to $-2.98 \times 10\hat{}3$ Pa, is represented by light blue. From the above picture the leading edge point and the trailing edge point pressure difference in longitudinal axis is low compared to first three models. The aerodynamic efficiency of modified wahoo fish model was calculated and found to be (0.114/0.0026) 43.85.

Figure 6 shows the velocity variation on upper and lower surface of the modified wahoo fish model with respect to the length. From this picture the Bernoulli's relation will be clear that wherever the pressure is low, there will be high velocity. From figure 5 and 6 the above statement is proved. Thick red color represent high velocity level of $1.592 \times 10\hat{}2$ to $1.769 \times 10\hat{}2\ m/s$ and the light red color shows that the medium level of velocity, which value is about $1.4 \times 10\hat{}2$ to $1.59 \times 10\hat{}2\ m/s$.

The figure 7 shows the pressure variation on the upper and lower surface of modified tarpon fish model with respect to the model length. Modified Tarpon fish model has excellent pressure variation on upper and lower surface compare to other modified fish models. Because very low pressure (thick blue color), 〖-8.09×10〗^^ 3 to 〖-1.02×10〗^^ 4 Pa, compare to free stream pressure occurred on upper surface and mostly free stream pressure (thick green color), 〖2.3×10〗^^ 2to 〖-1.8×10〗^^ 3Pa, approximately covered by lower surface. The pressure difference between the leading edge point and the trailing edge point in longitudinal axis is very low compare to the NACA 2412 airfoil. So the aerodynamic efficiency of this model is highly differing from other modified fish models about (0.2058/0.0031) 66.39.

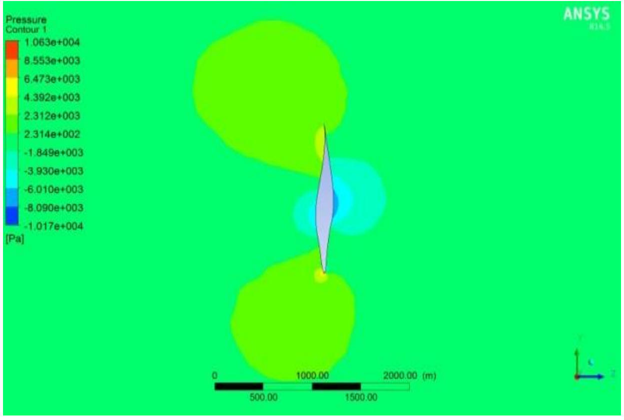

Fig. 7: modified tarpon fish pressure contour

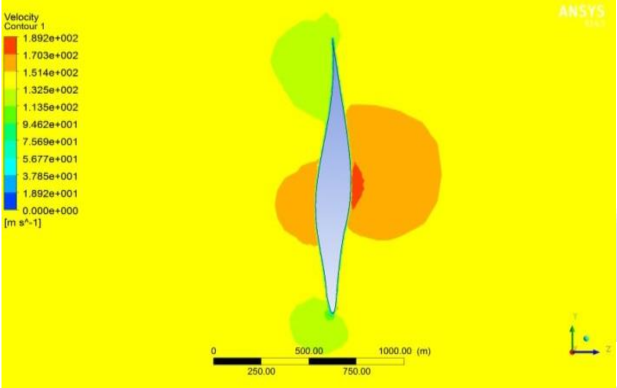

Fig. 8: modified tarpon fish velocity contour

The figure 8 shows the velocity variation on the upper and lower surface of the modified tarpon fish model with respect to the model length. Since there is low pressure, the free stream is accelerated (thick red color of $1.7 \times 10\hat{}2$ to$1.89 \times 10\hat{}2\, m/s$) on the upper surface. On lower surface the free stream is little bit accelerated (light red color of $1.5 \times 10\hat{}2$ to $1.7 \times 10\hat{}2\, m/s$) compare to the upper surface, so high pressure occurs.

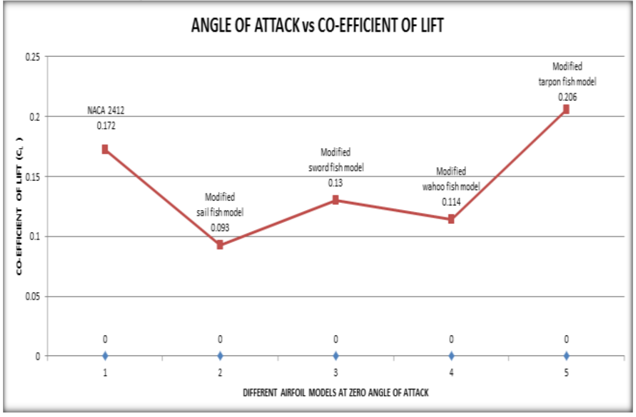

Fig. 9: Coefficient of lift value for NACA 2412 airfoil and different modified fish airfoil models

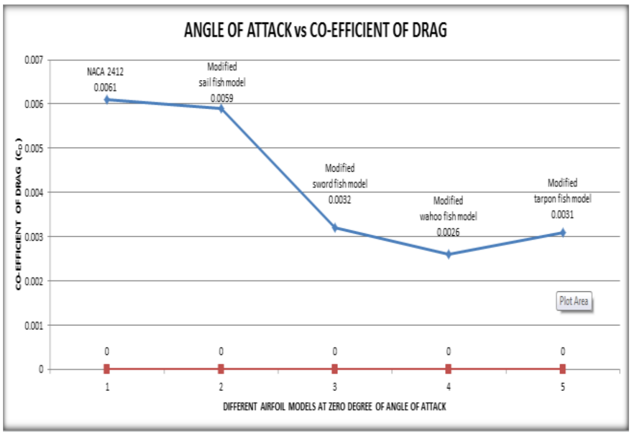

Fig. 10: Coefficient of drag value for NACA 2412 airfoil and different modified fish models

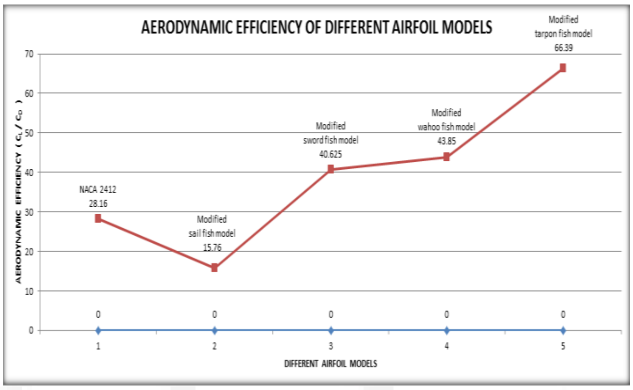

Fig. 11: Aerodynamic efficiency of NACA 2412 airfoil and different modified fish models

The above results are obtained under same boundary conditions and viscous-laminar model. The Cessna 140's maximum speed is $62m/s$. But here the models were analyzed with the free stream velocity of $140m/s$, by which the lift and drag forces values will change. But coefficient of lift and coefficient of drag values will never change. The above charts are shows that the Coefficient of lift, Coefficient of drag and the aerodynamic efficiency of different modified fish airfoil models. Finally the aerodynamic efficiency of the NACA 2412 airfoil is approximately increased double times by the modified tarpon fish model on negligible error condition.

IV. POWER REQUIRED FOR NACA 2412 AIRFOIL AND MODIFIED FISH AIRFOIL MODELS

The empty weight of the Cessna 140 is 408 kg and maximum takeoff weight is 680 kg. There is one crew and passenger, the average weight of the crew and the passenger is 200 kg. Remaining 72 kg belongs to fuel weight in the maximum takeoff weight. Only level, unaccelerated flight condition is achieved by completing takeoff and climbing conditions. So that in level, unaccelerated flight conditions the fuel weight is approximately 50 kg. Therefore the total weight of the Cessna 140 in level, unaccelerated flight conditions is 658 kg. In level, unaccelerated flight condition the power required data for Cessna 140 with NACA 2412 airfoil and different modified fish airfoil models at same velocity is represented by the following chart.

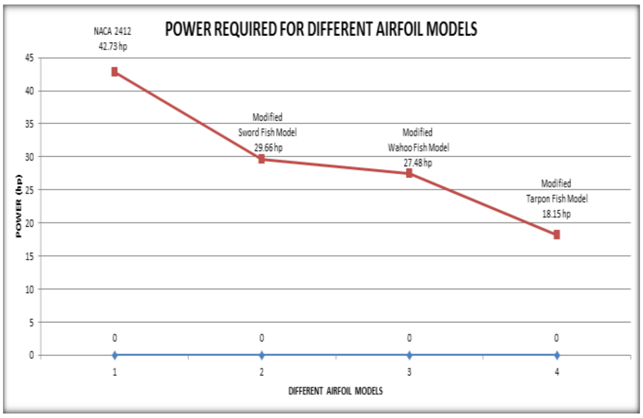

Fig. 12: Power required data for different airfoil models

From the chart 4, it is clear that by implementing modified tarpon fish airfoil model instead of NACA 2412 airfoil, 57.53 % power is reduced.

V. COMPARISON OF NACA 2412 AND MODIFIED TARPON FISH AIRFOIL MODELS AT ONE DEGREEOF ANGLE OF ATTACK

The angle of attack is defined as the angle between chord line of the airfoil and relative wind direction.

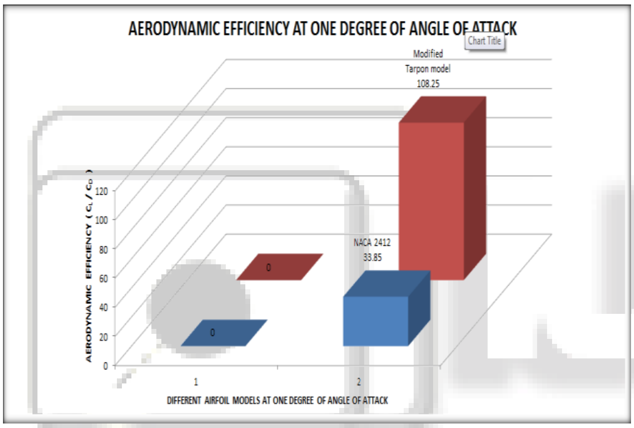

Fig. 13: Aerodynamic efficiency of NACA 2412 airfoil and modified tarpon fish model at One degree angle of attack

The above chart shows that the Aerodynamic efficiency of the NACA 2412 airfoil and modified tarpon fish model at one degree angle of attack. It found that the aerodynamic efficiency is increased triple times more than the NACA 2412 airfoil at one degree angle of attack from chart 4.

VI. CONCLUSION

The NACA 2412 airfoil and the modified fish models from sail fish, sword fish, wahoo fish and tarpon fish were analyzed successfully. The C_L, C_D, C_L/C_D ratio and power required calculation was performed as per the aim. Finally it is found that the aerodynamic efficiency is increased excellently by modified tarpon fish models compare to NACA 2412 airfoil. From this paper, the author would like to conclude that the solution of any problem is hidden in the nature.

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