Self-Actuated Flaps for Passive Flow Separation Control

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Abstract:- The following study focuses on the simulation of self-actuated flaps used on the upper surface of the wing for flow separation control. Previous studied have shown the effectiveness of such flaps for flow separation control. The simulation was performed on a rectangular section of standard NACA 4412 Airfoil with flaps(self-actuated) attached on the upper surface of the airfoil. The different configurations of the flaps were simulated. The effect of such self-actuated flaps on the aerodynamics of the wing section such as lift and drag was studied. The simulations were conducted on ANSYS-Workbench 16.

Keywords:- *Self-Actuated, Flaps, Bird Feathers, Simulation, Compound Flap.*

I. INTRODUCTION

Birds are the masters of flying, for millenniums they have inspired humans to take to the skies. Over the course of evolution of thousands of years, birds have evolved various ways to overcome different issues while flying; one such issue is the flow separation of air over the wings of birds. The feathers on the wings of the birds act as micro-flaps that control the flow separation on the wings. When the air flow separates on the wing of birds these feathers rise up to provide a new surface for the air to flow upon, thereby reducing the adverse effect of flow separation on the wings.

When air flow separation occurs on the wing of an aircraft the air flow over the wing changes the direction of flow, and starts to flow in the opposite direction. Air flow separation occurs when the pressure gradient becomes positive; that is when the air reverses the flow direction.

Air flow separation has adverse effects on the wing of an aircraft, it causes loss in lift, and increase in the drag experienced by the wing. Air flow separation also causes the wing to experience vibrations. This increase in drag of the wing increases the fuel consumption of the aircraft, thereby making flying more expensive.

Previous studies and experiments have proved the validity of self-actuated flaps as a feasible option for passive flow separation control. Study done by (D.W. Bechert, 2006) has shown notable increase in lift of the wing, when self-actuating flaps were placed on near the trailing edge of the wing. The study also showed increase in drag, which is atributed to the decrease in curvature of the airfoil over which the air flows near the trailing edge of the wing.

The study by (D.W. Bechert, 2006) was conducted at Reynolds number of 1×10^6 to 2×10^6.

Study done by (Wang & Schlüter, 2011) has found that the optimum position for the flap to be placed on the wing is at 70% from the leading edge.

Such flaps can be used on small fixed wing drones and UAVs and MAVs.

II. SIMULATION

- In the study only the wing of the aircraft is taken into consideration.
- The simulations are conducted at low Reynolds number of 1×10^6.
- Effect of flap is studied only on the wing and not on the entire aircraft.
- Tapper and sweep of the wing are not taken into consideration.
- Only the lift and drag forces experienced by the wing are studied.
- The stresses on the wings and flaps are not considered.
- The airfoil cross section is selected as NACA 4412.

Simulations were performed on ANSYS-Workbench 16 in Fluent for fluid interaction. ANSYS-Fluent is capable of solving many fluid-flow cases such as compressible fluid flow, incompressible fluid flow, etc. As previous studies have shown, after the air flow separates this causes a region of turbulent air flow in the separation region to better capture the turbulent flow and boundary flow phenomenon, a solver that is capable of simulating turbulent flow was needed. As in this case the Reynolds number is low the flow was considered as incompressible.

The solver used in the simulations of the flaps is the k-ω SST. Study conducted by (Douvi C. Eleni, 2012) found that the k-ω SST model is the gives the most accurate results and the ability to capture the flow separation phenomenon.

Hence, the k-ω SST model was used to conduct all the simulations.

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III. NACA 4412 MODEL

National Advisory Committee for Aeronautics (NACA) 4412 is a standard airfoil that shows trailing edge flow separation at high angles of attack from the air. It is found that the airfoil shows trailing edge flow separation at angle of attack of 8⁰ and above.

As per (D.W. Bechert, 2006) the most ideal place to attach the flaps is at the point where flow separation occurs. The flap was placed at 70% from the leading edge of the wing, with a span of 80% that of the wing and flap length of 30% the chord of the wing.

When the air flow separates there is a pressure drop in the separation region, this causes the flap to rise up and provide a new surface for the air to flow on thus reducing the effect of air flow separation. As the air flow separation progresses the flap is prone to over turning to avoid this angle limiter is used.

The angle limiter is so used that the flap when self-actuated is horizontal and is parallel to the ground.

IV. SINGLE FLAP NO NOTCH NO SPLIT CONFIGURATION

The single flap configuration used in the simulation is shown in the *Fig1*, it shows the single flap positioned at 70% the chord of airfoil from the leading edge, covering 80% the span of the wing and with length of flap 30% the chord of wing (0.3c/0.7C/0.8S). The flap is shown as fully actuated and is horizontal, parallel to the ground.

The simulation was conducted at Reynolds number of 1×10^6. As the NACA 4412 airfoil shows separation above 8⁰ angle of attack, the simulations were focused on angle of attack of more than 8⁰.

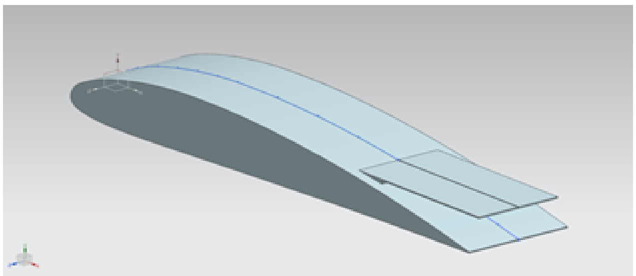

Fig1. Single Flap No Notch No Split Configuration

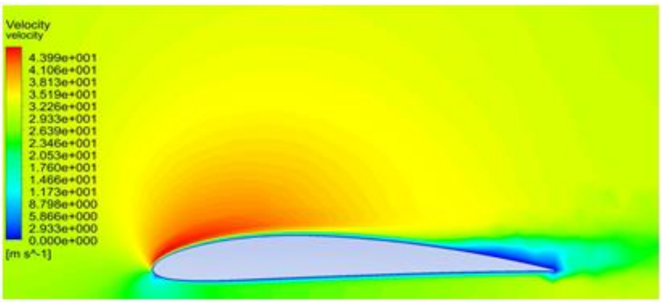

Fig2. NACA 4412 Airfoil Angle of Attack of 8⁰ Velocity Contour

At angle of attack of 8⁰ the wing section with single flap no notch no split configuration shows stagnation of air under the flap. This causes the drag experienced by the wing to increase. This is seen as increase in drag coefficient at lower angles of attack.

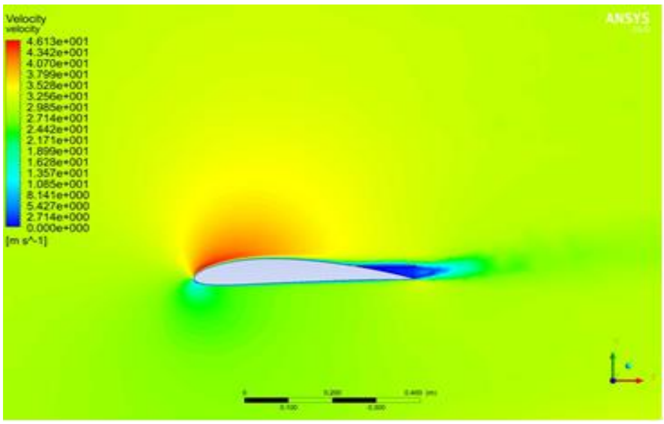

Fig3. Single Flap No Notch No Split Configuration Angle of Attack 8⁰ Velocity Contour

The simulations were conducted till an angle of attack of 15⁰. Above 15⁰, the behavior of flap becomes unpredictable and the turbulent flow dominates and air flow separation covers the majority of wing and the wing stalls.

At angle of attack of 10⁰ the air flow separation progresses beyond the flap onto the plain wing. This is also seen in the drag coefficient value that shows rise in value after the angle of attack of 10⁰.

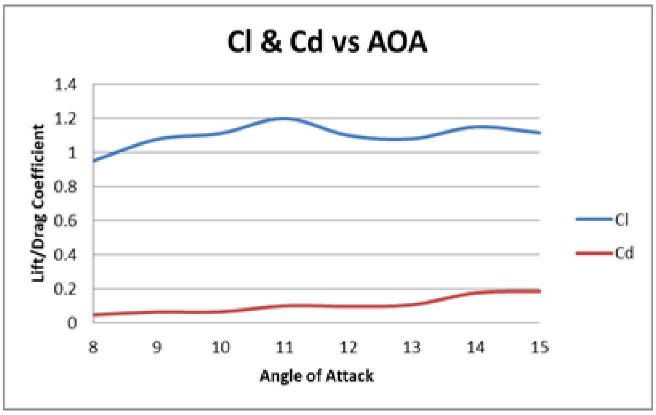

Fig4. Lift Coefficient and Drag Coefficient vs Angle of attack No Split No Notch Configuration

The drag coefficient value shows steady rise after the angle of attack of 10⁰, this is due to the progression of flow separation beyond the flap.

The lift coefficient shows maximum value at angle of attack of 11⁰, after which the lift coefficient decreases.

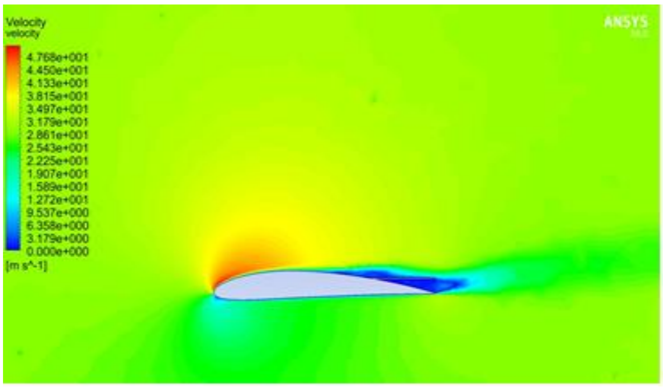

Fig5.Single Flap No Notch No Split Configuration Angle of Attack 10º Velocity Contour

V. SINGLE FLAP SPLIT NOTCHED CONFIGURATION

In Single Flap Split notched configuration the flap is split lengthwise, with notch provided on both sides of the split. The length, position and span of the flap is kept the same as No Notch No Split configuration i.e 0.3c/0.7C/0.8S.

The split in the flap allows the air flow over the flap to interact with the stagnant air under the flap. This causes the causes the air under the flap which was stagnant in No Notch No Split configuration to have a small flow velocity and follow the curve of the airfoil.

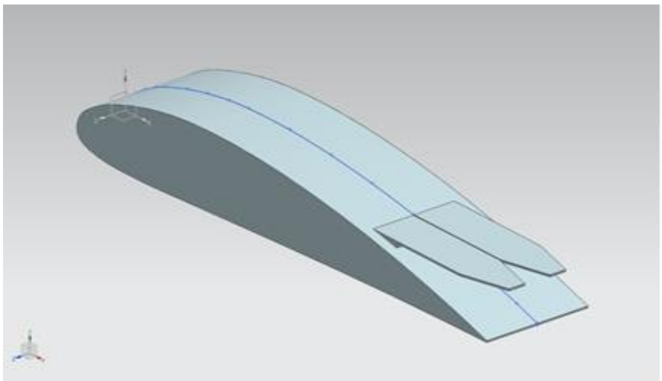

Fig6. Single Flap Split Notched Configuration

As seen in *Fig6* the Single Flap is split in middle lengthwise with the split gap of 0.4% of chord length of the wing. The notch is provided on both sides of the flap as well as on the sides facing the split. The notch has dimensions of; notch width of 2.4% chord of wing and notch length of 9% chord length of the wing.

At angle of attack of 8º the air flow separation is contained under the flap. The split in the flap allows the air flow to interact with the stagnant air under the flap, this is seen as slight reduction in the drag experienced by the wing. This is also due to the fact that the air flow now follows the entire contour of the airfoil from the split gap in the flap.

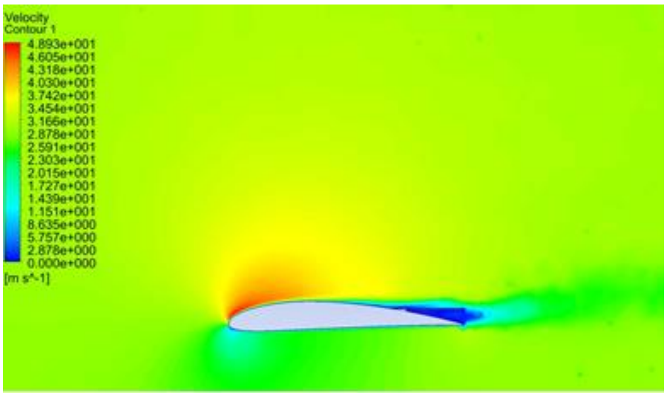

Fig7. Single Flap Split Notched Configuration Angle of Attack 8º Velocity Contour

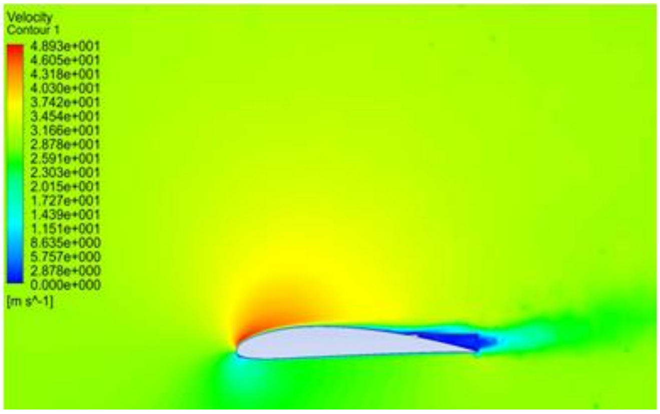

Fig8. Single Flap Split Notched Configuration Angle of Attack 10º Velocity Contour

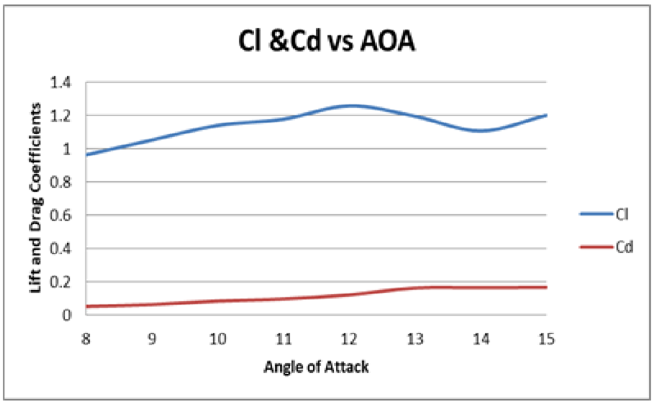

Fig9. Lift Coefficient and Drag Coefficient vs Angle of Attack Split Notched Configuration

The lift coefficient shows maximum value at angle of attack of 12º, which is greater than No Split No notch Configuration.

The drag coefficient shows steady rise till angle of attack of 13º, after which the drag coefficient becomes almost constant. The overall drag for the Split Notched configuration is less than that for No Split No Notch configuration.

VI. COMPOUND FLAP

In case of Single Flap configurations it is seen that at high angles of attack the air flow separation progresses beyond the flap onto the plain wing. This increases the drag experienced by the wing and loss in lift.

The secondary flap placed in tandem with the primary flap serves the purpose of providing a new surface for the air to flow upon when the separation progresses beyond the primary flap.

As for the single flap configuration the Split Notched configuration shows better characteristics, it is used for the secondary flaps as well.

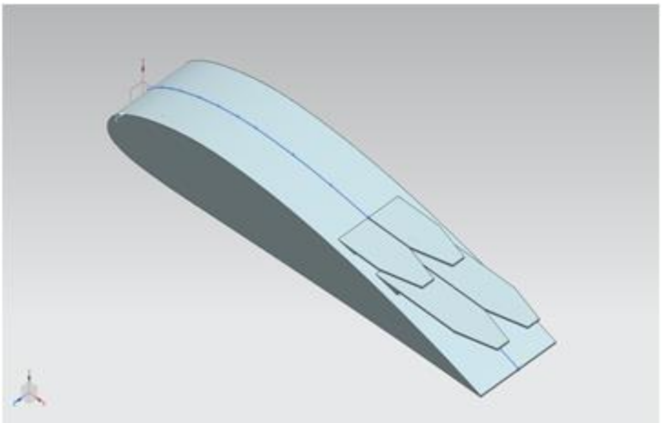

Fig10. Compound Flap

The secondary flap position and dimensions are; length of flap is 20% chord length of wing, flap is positioned at 60% the chord of wing from the leading edge and the flap has a span of 80% the span of the wing. The split in the secondary flap is 0.4% the chord of the wing.

The notch is provided on both sides of the flap and on sides facing the split. The notch width is 2.4% of chord and notch length is 9% of chord of wing.

It is seen that the flow separation progresses beyond the primary flap at an angle of attack of 12º. This progressed flow separation is further controlled by the actuation of the secondary flaps.

The presence of secondary reduces the overall lift coefficient, prior to actuation. This is caused as the air flow doesn't follow the original contour of the airfoil.

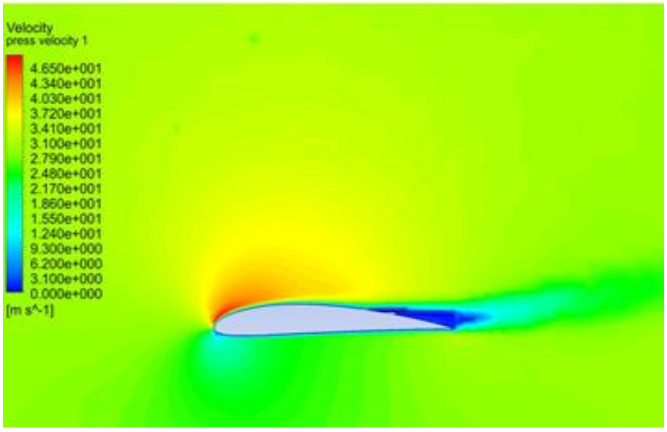

Fig11. Compound Flap Angle of Attack 10º Velocity Contour

For single flap no split no notch configuration the air flow separation progresses beyond the flap onto the plain wing; but in case of compound flap the separation is controlled by the secondary set of flaps.

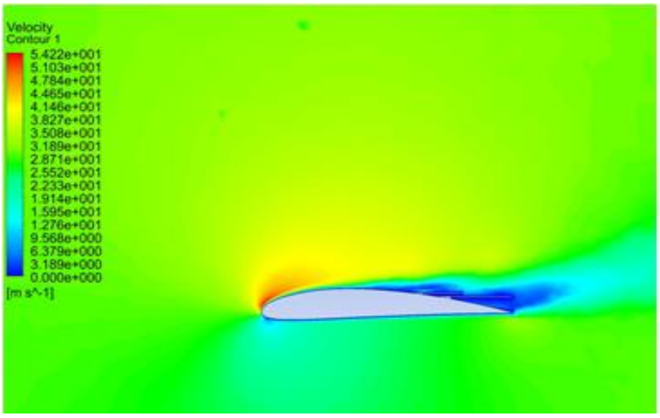

Fig12. Compound Flap Angle of Attack 13º Velocity Contour

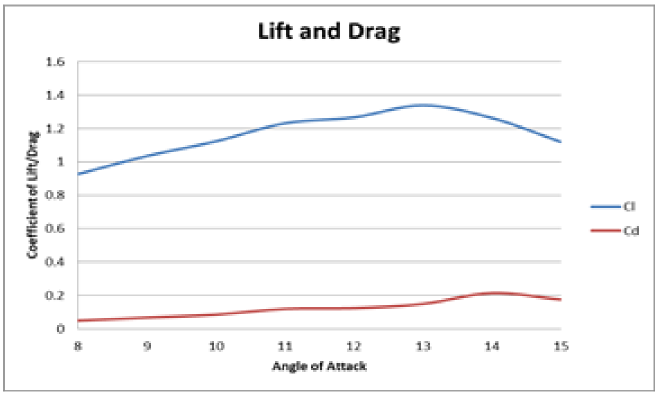

Fig13. Lift Coefficient and drag Coefficient vs Angle of Attack Compound Flap Configuration

The flow separation progresses beyond the secondary flap at an angle of attack of 13º, this results in gradual decrease in the lift coefficient and an increase in drag coefficient after 13º.

Further increment in the number of sets of flaps in compound flap would alter the original contour of the airfoil.

VII. CONCLUSION

The Split Notched configuration gives the best results in single flap configurations. The position of flap at 80% of the chord of wing from the leading edge is the best suited for airfoils that show trailing edge separation. For other airfoils the flap should be placed at point where the air flow separation takes place.

The compound flap configuration shows maximum value of lift coefficient at an angle of attack of 13º, which is greatest among all the configurations. The overall lift coefficient value above angle of attack of 8º is also greater for compound flap configuration.

The compound flap concept can be further extended for multiple sets of flaps, but care should be taken that the flaps should not be placed too close to the leading edge; this would alter the original contour of the airfoil and change the path followed by the air flowing on the top surface of the wing.

Such flaps can be used for flow separation control as an inexpensive device on fixed winged aircrafts such as UAVs and MAVs.

Further study of the flaps can be extended to wings with sweep and tapered wings.

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