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Mini Review

A Mini-Review on High Lift Devices used in Aerodynamics

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Introduction

Research on high lift devices has been done for many decades as a high lift is quite advantageous for more stability and lesser fuel consumption in aerodynamics. Apart from aerospace vehicles, high lift devices have been used in automobile vehicles. A small flap or slat could give a higher lift for the aircraft wings and could help in choosing not a wing of very larger area and thus also decreases fuel consumption. If the boundary layer is controlled, the occurrence of boundary layer separation takes time. The high lift device could be either fixed or a movable device. They are used at liftoff and landing of the aircraft thus reducing the distance and speed needed to safely land the aircraft. Gurney flap is a type of high lift device used in aircrafts as well as in automobile which increases the pressure on the lower side and decreasing the pressure on the suction side of the airfoil which helps in keeping the boundary layer attached to the airfoil up to the trailing edge. CFD simulations and experiments have been done by many researchers for achieving a desired performance of the aerodynamic component. High lift devices include, slats, slots, different types of flaps, boundary layer control, leading edge root extensions, co-flow jet, circulation control wing. Although high lift devices have been a topic of research from the time of first and Second World War not much of the research has been published.

Gurney flaps was first invented for automobiles by Dan gurney [1,2] but later it was also used in aerospace vehicles. Many researchers have done numerical and experimental analysis to calculate the optimum dimension of the Gurney flap for particular applications. Cory et. al. [3] has numerically investigated the effect of Gurney flap of varying lengths on NACA 4412 airfoil. INS2D is an incompressible Navier-Stokes solver used for the simulation and Baldwin-Barth one equation turbulence model has been used. The length of the Gurney flap considered for the simulation is 0.5, 1.0, 1.25, 1.5, 2 and 3 % of the length of the airfoil's chord length. The authors have compared the results with the experimental data by Wadcock [4]. The results show that as the separation points are farther to the leading edge. For airfoil without Gurney flap, the separation point at 12° angle of attack is at length of about 0.75 and it increases with decreasing angle of attack. At angle of attack 4°, the Gurney flap of length 0.5%C, shows an onset of the separation point aft by about 4% compared to the clean airfoil case. When the length is further increased over 1%C, the recirculation region on the upper surface is almost negligible as the separation point now has shifted to a length 99%C. The pressure difference between the upper and lower airfoil surface is high when the Gurney flaps are used mainly in the trailing edge region. The increased pressure difference in trailing edge region increases the nose down pitching moment. The lift force however after a flap size of 1.25% of the chord of the airfoil increase at the expense of drag. The analysis has also showed a huge increase in trailing edge loading when the Gurney flap is used. Bruce and Cory [5] have also used NACA 4412 airfoil for studying the vortex generators and Gurney flap effect on the lift force experimentally. The span-wise pressure difference show that the flow over the airfoil was 2D at lower angles of attack but it transitioned to 3D near the angles of attack of maximum lift force at 12°. After this angle of attack, the three-dimensional effect becomes more apparent and when compared to three chord wise pressure distribution, a good correlation is found at highest lift condition where 3D flow is observed at the stall condition. NACA 4412 airfoil with Gurney flap of various lengths have been investigated through ANSYS Fluent by Kumar et. al. [6] at 30m/s to determine the most optimum flap length. The results showed that the most optimum flap length is 1.5%C when the aerodynamic performance has been compared with other flap lengths. When the Gurney flap is used in a tilt rotor aircraft by Chen and Chen [7], the lift coefficient of the system increases significantly. By 10.67 %, 15.33%, and 20.67% for 1%, 2%, and 4% flap lengths. Drag penalty has also been observed, as at angle of attack 2 degree, and 4%C of flap length, a significant 31.47% decrease in lift to drag ratio is reported. The increments in the lift force are proportional to the square root of the flap height. With the increase in flap length the lift increment is reported but at the same time the drag increment is also reported at lower angles of attack. Depending on the thickness of the airfoil and the boundary layer, an optimum Gurney flap would be highly beneficial.

Leading edge flaps popularly known as slats have also been used for increasing the aerodynamic efficiency of the lifting surface. A small airfoil having a higher camber is places at the leading edge keeping a small gap between the flap and the airfoil which increases the camber and reduces the chord length thus affecting the pressure distribution on the pressure and suction surface of the airfoil. S8036 profiled wing has been experimentally investigated by Lance and Kaula [8] at Reynolds number 250,000 in low speed wind tunnel with various gaps and rotation angles. The results have shown a systematic and higher decrease in lift with the rotation of the slat which reflects the modulating downwash effect from wing tip region in wing. The wing upon the application of the slat shows a remarkable improvement in the behavior of the flow which has been observed as the flow separation is withheld extending over the outer third of the wing. The Maxwell slot by William et. al. [9,10] is in between slot and slat which only rotates about the leading edge which simplifies the design when seen from prospective of the slat, but the hinged doors adds complexity. The results from William [9] has shown an increase maximum coefficient of lift of a Maxwell slot which is found to similar to that achievable with a Handley Page slat, whereas Clarence and McKee [10] determined the most optimum gap width of 0.0175C. The investigation also showed that drag of the slat increased with gap size. Finite span wings with three various planforms having sinusoidal leading edge perturbances have been investigated experimentally by Custodio and Henoch [11] up to 30° angle of attack and $4.5*10^5$ Reynolds number. The results have shown an increase in drag for all the modified wings at all the angles of attack except the, modified flipper model which showed a lower drag compared to the baseline flipper. These technologies are mainly used to delay the stall and produce a higher lift force after the stall angle. The wings with smart flap have shown an improves lift to drag ratio because of their higher efficiency in generating lift force. The research on these should be done more in detail as they can be of a great help for the vehicles which required a high maneuverability.

Multi-Element Airfoils have also been used as they provide an improves aerodynamic performance which can be used in airplane wings, wind turbines etc. Slats and flap have been used in various airfoils by Bhargava et. al. [12] for investigating lift and drag phenomena using numerical panel method. The flow field shows a delayed stall because of the slat at the leading edge which helped in generating a higher lift. The results have shown that at higher angles of attack, the coefficient of lift on the flap reduces but increases on the slat, whereas the coefficient of drag remains steady up to 10° angle of attack and then decreases at higher angles of attack. When both the flap and slat elements have been used, the highest lift and drag coefficient reported is 3.67 and 0.36. The authors had used 30P30N, GA (W)-1, RAF16, NLR 7301 airfoils for the analysis and MATLAB to investigation. Three element airfoils have been investigated by Murayama [13], to investigate slat noise in a subsonic wind tunnel. 30P30N airfoil's noise radiation from the slat at leading edge has been studied for various angles of attack. The results show that up to 10° angle of attack, the coefficient of pressure distribution results agree with the computational predictions, with a slight exception regarding the flow separation at the slat. The source map has been plotted and analyzed for the study. Surface pressure spectra and the acoustic spectra associated with cove dynamics shows a mixture of narrow band peaks and broadband components, both of which become weaker with increase in the angle of the attack. Trip dots are present between the slat cusp and the stagnation point which have resulted in enhanced levels of the narrow-band peaks in acoustic spectra. Tenasi solver is a flow solver that can used in various flow regimes namely, Incompressible [14], Compressible and Arbitrary Mach Number [15], Incompressible Surface Capturing [16], and Compressible Multi-Species [17]. Adhikari [18] has used the Tenasi incompressible solver to investigate two JSM high lift wing and has discussed that the compressible equation is not compulsory for accurately calculating the high lift aerodynamics and have also raised a concern that how effective are the incompressible solvers before the compressibility effects come into play. HiLiftPw3 meshing has been followed for the current study, but the viscous spacing were too restrictive for this as SAS turbulence model has been used in the current study. The turbulent flow has been assumed for the boundary layer in this research. Transition modelling has not been investigated here which is extremely crucial phenomena and needs further research. Gurney flap has been used in a supersonic airfoil SC-0414 to test the performance by Nguyen [19] computationally and experimentally. Smoke wind tunnel has been used for the experiment and ASNYS Fluent has been used for the numerical simulation. Steady smoke lines have been observed between angles of attack 5° and 8°. The authors have reported that the pressure on the suction and pressure side of the airfoil changes when the height of the Gurney flap is increased. Modified Yamana method has been used to calculate the experimental results and the results agree with the numerical results. With increasing the height of the flap, the coefficient of lift is increasing. High lift characteristics of the oscillating faps have been investigated by Ruhland [20]. NASA-SC2 airfoil has been used, and a two-dimensional advanced dropped hinge flap high-lift system has been examined. For the high lift device, a spoiler, a droop nose, and a trailing-edge fap were integrated. The analysis was done for two Reynolds number $20*10^6$ and $0.5*10^6$. For both the flap movements, an increased coefficient of lift and drag has been observed with the averaged lift increasing by 2.1%. The flow separation could be suppressed even after the maximum deflection angle of static flap. Through the oscillating flap around dropped hinge point, the reattachment of the separated flow seems possible.

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For designing the aircrafts, the high lift systems have always been given importance mostly the aircrafts with short takeoff and landing capabilities. Computational effort and experiments have been used to examine various aspects of the aircraft's performance. CFD analysis for 3D models are still researched on but transition regime should be more focused. Turbulence flow phenomena should also be studied for various high lift systems. Prediction of aerodynamic performance using other high lift systems like blowing and suction should also be investigated in detail both experimentally and numerically to understand the flow field near the high lift devices and the transition regime. Although lot of research work is going on to understand the flow phenomena of high lift devices, there is still difficulty in accurately predicting the flow field near the maximum lift devices which could be done if advances are made in recent CFD methodologies like adaptive grid technique. Turbulent shear-stress predictions have to be improved by analyzing the turbulence model employed as this directly impacts the transition effects. Grid refinement is also required to a large degree near the high lift devices to further understand the flow and boundary layer which could assist in developing and determining more accurate high lift devices. More research on determining an optimum flap and slat dimensions and its rotation has to be determined to fully utilize these devices. Different types of slats have also been investigated but there has not been a significant research at hybrid slats which could be developed for a certain type of aircraft. LES and DNS solvers have to be used to understand the flow field near the high lift devices to get a detailed flow field which can be used to further modify the devices in order to decrease the drag augmentation.

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Conflict of Interest

The authors declare no conflict of interest.

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