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INVESTIGATION THE EFFECT OF FLAP DESIGN OPTIMIZATION ON WAKE PROPAGATION BEHIND WINGS OF TRANSPORT PLAN

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ABSTRACT

Present paper study aerofoil with NACA2412 with Fowler and Single Slotted flaps that were used for the purpose of numerical investigation the effect of energy adder on the trace of wake behind the proposed wing at a Reynolds number of (2x105) with multi-element flap geometry having different gap, overlap distances, and different flap deflection angle (α). This all were inspected with various angle of attack (AOA) for both types of flaps. Such as [gap = (4.3% c) &(5.3% c)] for single slotted flap, and [(overlap= -5% c with gap =1.25% c) & (overlap= 5% c with gap= 3.75% c)]. Flap deflection is varied in the range of [20^{o}, 35^{o}45^{o}] and the angle of attack in the range of (AOA) is [-5^{o}, 5^{o}, 10^{o}, 15^{o}]. The numerical study involves simulation to the flow behavior by using ANSYS FLUENT 15.0, the governing equation were solved in three dimensions turbulent regime with appropriate turbulent model (k - ω, SST). Using airfoil of NACA2412 for the wing section, to study the formation of wake turbulence downstream of the trailing edge under the effect of varying different variables related to the geometry of flap position relative to the wing since they form together a multi element airfoil. Present study conducted the effect of dynamic pressure, static pressure, and the kinetic energy in addition to the velocity vector and magnitude in both (x) and (y) directions. Results show that for a gap distance equal to (5.3 % c) it is not recommended to work with both higher flap deflection and angle of attack for single slotted flaps which can be used in multi-element airfoil .And the best positions of single slotted flaps are not so well defined. Hence maximum lift coefficients of single slotted flaps are very sensitive to flap position, however, and optimum configurations cannot be predicted with any degree of accuracy. For a Fowler flap it's convenient to use the combination for an angle of attack equal to (15°) with deflection angle equal to (35° and 45°). Also it was concluded for Fowler flap that as the flap deflection angle increase to a value of (45°) with the existence of an angle of attack equal to (5°) it is clearly revealed the improper combination of these two angles due to large wake vortex generated downstream of multi-element airfoil since the boundary layer that pass over main part of the airfoil.

Keywords: flap design, wake propagation, flow patterns.

INTRODUCTION

A component or mechanism on an aircraft's wing that upsurges the amount of lift created by the wing is a high-lift device that is in aircraft design and aerospace engineering. A fixed component or a moveable mechanism is how the device could be which is deployed when necessary. High lift device assume a huge part in the outline of the design of air vehicles. Leading edge slats and trailing-edge flaps are methods that are usually used when the wings on most modern-days air vehicles are equipped. These gadgets have been appeared to improve the aerodynamic performance of air vehicles through expanding the maximum coefficient of lift, lift-to-drag ratio, as well asstall angle.

In addition, High lift device are intended to grow the flight envelope by changing the local geometry (mechanization wing), they commonly camber fluctuations relying upon the phase of flight (landing, take-off).By means of controls, the aircraft they created aeromechanical has impacts with suggestions for the protection structure of the wings, and the most critical impact is the twisting of the wing.

A flap is a part of the wing that can be changed by rotating around several hinges, or to be curved into airflow to produce extra lift. There are several types of flaps such as Plain, Split, Slotted, Fowler, Junkers, Gouge, Fairey-Youngman, Zap and Gurney flap. To cure the premature separation agonized with the plain flap, the slotted flap was presented. The flap also travels rearwards to crop a convergent slot once the flap is rotated downwards. Air from the wing's lower surface is inserted through the slot to the upper; this is caused by the pressure transformation between the upper and lower surfaces. Thus, a slot located in the direction of the trailing edge carries on similarly as one at the main edge, it lessens the pinnacle suction on the flap and permits another limit layer to build up itself on the flap and stay appended for longer. Greater flap deflections and caber is permitted before separation occurs.

Fowler flap stays identified with the slotted flap, the key distinction being that the flap moves significantly facilitate after far set of tracks, subsequently expands the chord and in this manner wing area. It is hence characterized by expansive increased in greatest lift for least changes in drag. To attain a decent slot profile when the flap deflects downwards a lengthy overhanding shroud is required. Due to the great rearward motion obligatory, the Fowler is a comparatively multifaceted and heavy system.

The aim of this work is to examine the consequence of combining a (NACA2412 wing with a fowler flap) and a (NACA2412 wing with a single slotted flap) in different configurations numerically. A numerical study of a NACA2412 rectangular wing is conducted to study the effect of airfoil and flaps airfoil for different positions such as [gap =(4.3% c) & (5.3% c)] for single slotted flap ,and [(overlap= -5% c with gap =1.25% c) & (overlap= 5% c with gap= 3.75% c)]at different flap deflection such as [,20°,35°,45°] and different angle of attack (AOA)[-5°,5°,10°,15°].The numerical analysis of this work is done using computational fluid dynamics (CFD) with ANSYS FLUENT 15.0, by adopting SIMPLE algorithm to solve the continuity and momentum equations of airflow over a 2D airfoil..

LITERATURE SURVEY

M. M. Koochesfahani. 1989 [1] studied the vertical flow patters in the wake of a NACA 0012 airfoil contributing at little amplitudes a low-speed water channel. The airfoil depended on the NACA 0012 wing segment with a chord of C = 8 cm, a span of b = 39 cm, the free-stream velocity $U\infty \approx 15$ cm/sec, bringing about a chord Reynolds number of 12,000. An essential perception in this investigation is the presence of an axial flow in the cores of the wake vortices.

Laser Doppler velocimetry to obtain quantitative measurements of the mean stream wise velocity component used Laser

Doppler velocimetry (LDV). Utilizing the speed profiles, the reliance of the airfoil drag/thrust on the oscillation amplitude and frequency is resolved. The presence of an axial flow in the cores of the wake vortices is brought up. Its source and reliance on the oscillation amplitude and frequently are deliberated.

T. Lee • Y. Y. Su. 2010 [2] Completed a test in a (0.9 m× 1.2 m × 2.7 m) low-speed, suction-type wind tunnel, with a free stream turbulence density of 0.1% at U_∞ = 15.2 m/s and the chord Reynolds number stayed static at 2.45 $\times 10^5$. A solid aluminum rectangular wing of a NACA 0015 airfoil area, with a chord c = 25 cm and a span b = 38 cm, was utilized as a test model. The effect of the airfoil display and the trailing-edge flap (TEF) in addition Gurney folds (GF), of various heights (h = 0.7, 1.5, 2.1, 3, 4.5 and 6%c) and porosities (σ = 0, 23 and 40%c based on open to closed area of the flap surface) on the aerodynamic and wake qualities of a NACA 0015 airfoil. A further increment in the descending turning of the mean flow (increased aft camber) when addition the Gurney flap to the trailing-edge, this process leads en route for a important raise in the lift, drag, and pitching moment compared to that produced through independently deployed (TEF) or (GF). The close wake behind (TEF) or (GF) autonomously conveyed wound up thinner and had a small speed deficit and fluctuations compared to the joint (TEF) and (GF) together

The Gurney flap aperture had just less impact on the wake and aerodynamics features attributes contrasted with (TEF) with a solid (GF). The fast ascent in lift generation of the joint (TEF) and (GF) application, contrasted with exemplary (TEF) deployment, could give an enhanced off-outline high-lift device amid landing and takeoff.

David Demel. 2014 [3] studied the effect of a fowler flap gap and overlap Size on the Flow Field in airfoil and fowler flap both are (Clark Y),where flap chord is 40% from the airfoil chord (Cf =0.4 Cw) and the Fowler flap deflected to 40° (δ = 40°). The experiment's work has been completed in the 16" x 16" wind tunnel, and wind speeds up to 38 m/s and the Reynolds Number within the wind tunnel (Re = 1.0 x 10^6). The dimensions of the airfoil section are chord of 16.5" and a span of 15.5".

At a variable angle of attack in the perfect configuration (flap stowed), landing configuration (flapdeployed and avoided to 40°) a cross Section of the CP-140 Aurora wing was investigated, as well as the effect that occurs in the wing when changing the flap gap and overlap was studied. In the experiments side was used a Particle Image Velocimetry (PIV). The stream over the flap was observed to be wide range isolated for all the arrival design researched. The focal point of the examination was on the limit layer (BL) on the wing trailing edge (TE) promptly upstream of the flap slot. It was discovered that while an expansion in flap gap profited the BL on the wing TE by influencing a more full speed profile.

While increment in flap cover harmfully affected the wing (TE), that is caused by a partition rise toward the end.

Cory S. Jang. 1998[4] studied the effect of a Gurney flap on a NACA 4412 airfoil by using 2D numerical solution at Reynolds number Rec=1.64×106. A Gurney fold arranged opposite to the chord line and situated at the trailing edge of the airfoil which is a flat plate on the request of 1-3% of the airfoil chord in length. By means of INS2D (an incompressible Navier-Stokes solver) the flow field around the airfoil was numerically foretold. The size of Gurney flap 0.5%, 1.0%, 1.25%, 1.5%, 2.0%, and 3.0% of the airfoil chord bedeliberate. The numerical solutions display that some Gurney flaps increase the airfoil lift coefficient with a minor increase in drag coefficient. To builds the airfoil lift coefficient by$\triangle C_L \cong 0.3$ and diminishes the angle of lift attack required to get a given lift coefficient by$\triangle_{\alpha=0} > -3°$ he constraint to use a Gurney flap of a 1.5% chord length and that considered optimum lift coefficient. The particulars of the flow construction by the trailing edge is shown by studying the numerical solutions, also, it provides a conceivable clarification aimed at the augmented aerodynamic performance.

M. S. Kumar and K. N. Kumar. 2013 [5] Studied a NACA0012 airfoil with plain flap by utilized Computational fluid Dynamics (CFD) to forecast precisely the gradual lift because of usage of inert lift - augmentation gadget 'Flap'. In a 2-D wing, lift at an assumed angle of attack approach can be expanded by expanding camber. The directions for the airfoil are created by utilizing the java applet JAVA FOIL, to test different flap deflection (δ =0°, 5°, 10°, 15°) and angle of attack (AOA=0°, 4°, 8°, 12°). By expanding camber, lift at a given approach can be expanded in a 2-D wing. To decide the take-off and landing separations in air ship outline, the estimations of Maximum Lift Coefficient (Clmax) are utilized, on the theories of use of some sort of lift-upgrading gadget. Passive lift upgrade device, for

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example, a trailing edge plain flap, is significant to a large portion of the air ship plans aside from Short Take Off and Landing (STOL). To anticipate its impact on incrementing the lift amid basic periods of flight at low speed a computational study of a plain flap with NACA0012 airfoil is taken up. The flow examination is finished utilizing CFD device FLUENT.

Effect of Plain flaps on basic aerodynamic parameters such as CP, CL, and CD are studied by analyzing the flow over an airfoil with plain flap. To build up the impact and significance of flap as a successful high lift gadget he should look at the outcomes that are gotten from the examination with explanatory arrangements. The results of the computational approach showed that it must increase the Camber of the wing to enhance the lift by flap redirection. The aims of this examination were effectively finished by making that at frequencies well underneath the stall; there is a steady increment in lift coefficient.

MATHEMATICAL MODEL

Simulation methods are available to calculate the behavior of fluid surrounding airfoil and flap. Some methods depend on ordinary boundary layer analysis for low angle of attack. Naiver-Stocks and Continuity equations are used for high angles of attack. FEM is preferred since it could easily handle complex airfoil shapes and boundary layer conditions. Finite element method is used to solve the previous equations. In this method, the area to be solved is divided into several small elements. These elements can be triangular, quadrilateral, tetrahedral, hexahedral, etc. ANSYS is being used to perform Finite Element Method calculations [6]. The domain - which represents air - is being split into a number of sub regions. The number of sub regions is increased near the airfoil to increase the accuracy of calculations. As for parts that are not affected by airfoil, or do not have important results, the number of regions is reduced [7] - i.e. the sub region is larger in size.

Boundary conditions

In Figure-1, the airfoil and flap in the test section is being shown. The height of the test section is 300 mm, while the width is 610 mm. Figure-2, shows the boundary conditions, where (A) is the speed of air that is entering the test section which is 35 m/sec. (B) represents the outlet pressure of the test section where the air exits, pressure gauge =0. (C) Is the wall, where the air speed is zero? (D) is the airfoil and (E) is flap, which the test is being applied to. The speed of the airfoil and flap is zero relative to the airflow because it is fixed. Details for boundary conditions are explained next.

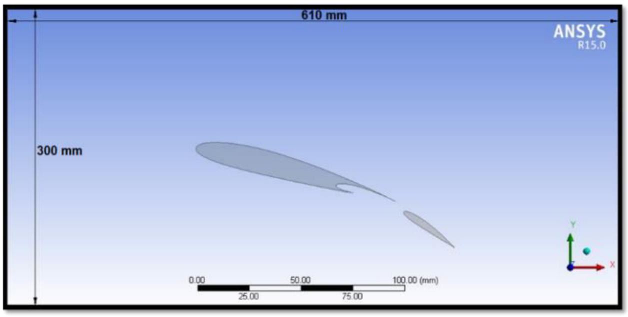

Figure-1. NACA2412 in test section.

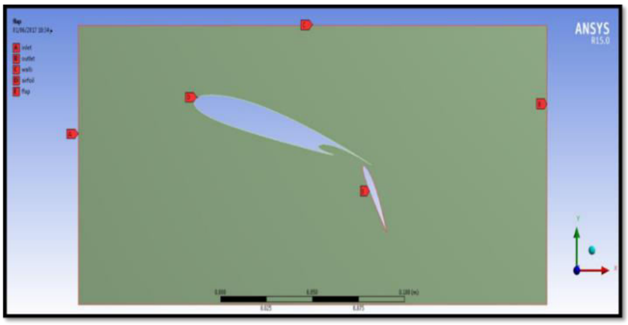

Figure-2. Boundary conditions.

Design and simulation software

The following sections describe the software used to design the airfoil and solving the turbulence model. AutoCAD is used to design the airfoil and flap, while ANSYS is used to calculate wake propagation behind wing.

Designing airfoil using AutoCAD

AutoCAD is commercial software that is used for 2D and 3D designs. This application has been used to design the wings, specify locations of main wing, auxiliary airfoil, their different angles of attack (AOA) and flap deflection (δ).The elliptical shape explains the shape of the guide that is used at wing ends. After finishing the drawing in AutoCAD we will take the data of airfoil and flap and put it in excel sheet to export it to ANSYS fluent.

ANSYS Meshing

ANSYS Meshing is used to generate a mesh for the domain - which represents the airflow around the wing. Regions are created as shown in figure (3) which are small in size near the airfoil and flap, and get larger the more distance from the wing the region is. These regions are then used by ANSYS fluent.

Solution method

This section discusses how ANSYS solves equations and calculate the wake propagation. The solution steps are as follows:

a) First the initial values are being set. These values are passed to the momentum equations.

b) Momentum equations are solved to get the velocity.

c) Next, the continuity equation is used based on results from previous steps, the pressure correction is calculated.

d) The correction for each sub region is calculated.

e) If convergence is not reached, then the current results are passed to momentum equations, and step 2, 3, 4, and 5 are repeated.

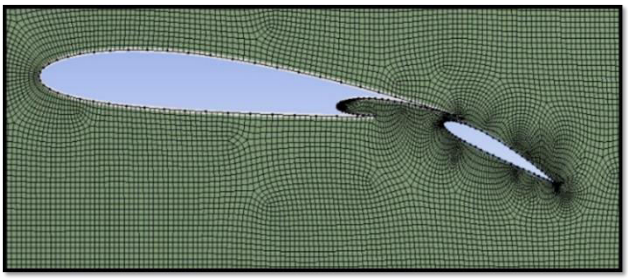

Figure-3. Meshing for airflow over NACA2412 wing.

Convergence criteria

The process of calculating the solutions are repeated until a convergence is reached. The criteria for convergence mainly depend on monitoring the normalized residuals of different variables - continuity, x, y, z momentums, k and ω after each iteration. First the unscaled residuals are calculated. These contain some numerical errors. As the system goes from one iteration to another, the errors become smaller and smaller. The values of these residuals are then divided by the largest residual from the first iteration to give a normalized value. Figure-4 shows how the value converges over time.

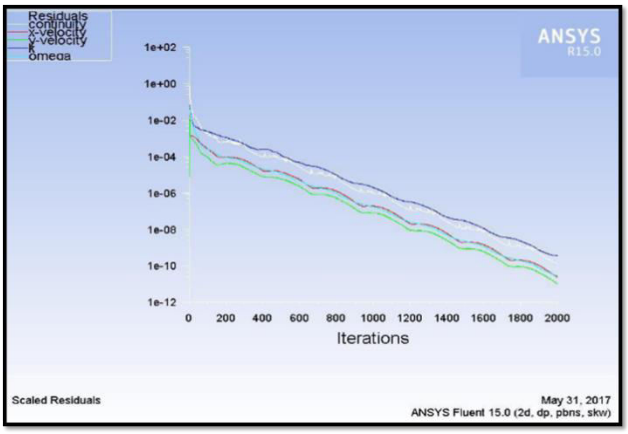

Figure-4. Convergence history for continuity, momentum, turbulence equation.

RESULTS AND DISCUSSIONS

The flaps are the most common high-lift devices used on aircraft, and their contribution to the amount of lift an airfoil can produce will be discussed in more detail in this paper. A few flaps are situated on the trailing edge of the wing, typically inboard nearby to the fuselage, and are alluded to as trailing edge flaps. These surfaces add to the camber of the wing airfoil in most cases, on top of the zone of the wing in different cases. By expanding the angle of attack of the wing, and in some cases the area of the wing, they enable the aircraft to fly at inferior speeds, which might be required for departure and landing or for times of expanded manoeuvrability.

Effect of using fowler flap on the wake shading behind airfoil

The following section will examine how the type of fowler flap will affect the formation of wake turbulence downstream of the trailing edge under the effect of varying different variables related to the geometry of flap position relative to the wing since they form together a multi element aerofoil. A variable that was used consists of the gab distance which is selected as a percentage from the chord length in addition to the overlap distance which is also measured relative to the chord length and finally the flap deflection angle was also conducted here.

Study conducted two values for the gap distance which are equal to (1.25% C and 3.75% C) while the overlap distance was kept unchanged with a value equal to (-5% C). The flap deflection angles was altered in the sequence of (20 ^{o}, 35 ^{o}, and 45 ^{o}) These geometrical variables was also combined with the effect of varying the angle of attack in which four different values were introduced having a magnitudes of (-5^{o}, 5^{o}, 10^{o}, and 15^{o}).

Figure (5a & b) illustrate the mesh generation for the first case used with NACA2412 in addition to the boundary conditions for a gap distance equal to (1.25% c) and overlap equal to (-5% c) while the angle of attack (AOA) equal to (-5°). In this case the flap deflection angle was chosen to be equal to (20°). Figures (6&7) represent the variation of dynamic pressure, static pressure, and the kinetic energy in addition to the velocity vector and magnitude in both (x) and (y) directions respectively. It can be noticed from figure (6 a and b) that the distribution of the dynamic pressure upward the aerofoil and the static pressure downward the aerofoil reflect the actual behavior for the wing to produce the required lift in which there is an excessive decrease in the speed of flow downward the aerofoil which accompanied with obvious increase in the static pressure that is enough to produce the required lift while the flow start to accelerate upward the aerofoil leading to the increase of flow speed affected by the shape of upper surface which work as a nozzle causing of dynamic pressure build up.

Moreover, the effect of utilizing the fowler flap start to be noticed with Figure- 8 (c) which illustrate the colored map for the turbulent kinetic energy. It can be seen that the shading of the wake turbulent downstream of the fowler flap is not have a large effect to the structure of the flow that can be related to the small gap conducted in this case in addition to the effect of relatively small flap deflection which minimize the amount of energy added from the high pressure side. Figures (6 a, b, & c) and (7a, b, & c) that illustrate the velocity in x, y direction and contours of velocity magnitude respectively again persist the previous outcomes mentioned in Figure- (4.2).

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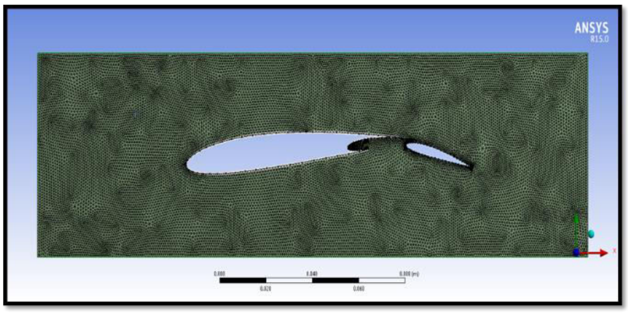
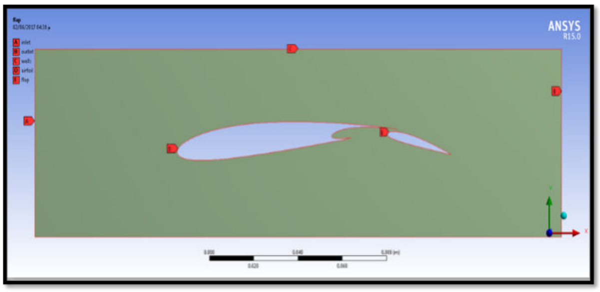
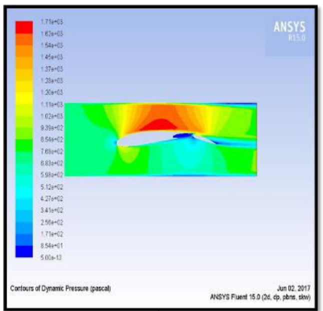


(a)

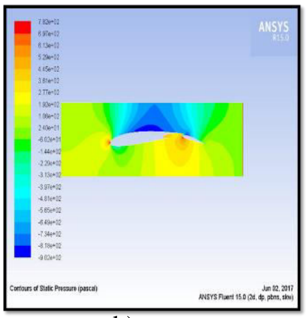


(b)

Figure-5. (a) Mesh for NACA2412 in test section, (b) Boundary conditions (for G=1.25% c , O= -5% c , AOA= -5°, α=20°).



a)



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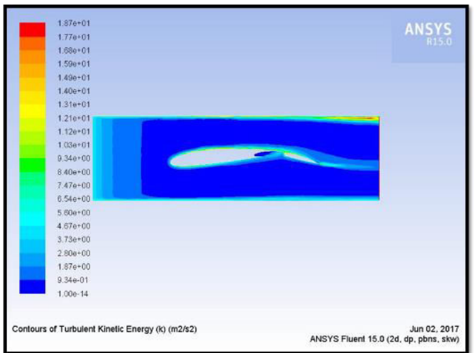
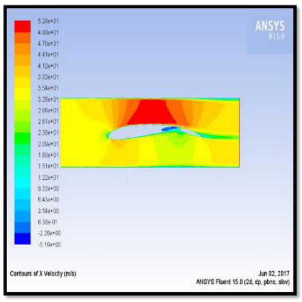


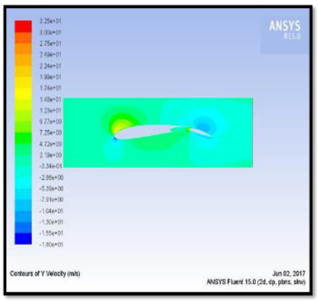
c)

Figure-6. (a) Dynamic pressure , (b) Static pressure, (c) Kinetic energy (for G=1.25% c , O= -5% c , AOA=-5°, α=20°).

Figure (5a &b) manifest the mesh generation for the second case used with NACA2412 in addition to the boundary conditions for a gap distance equal to (1.25% c) and overlap equal to (-5% c) while the angle of attack (AOA) equal to (-5°).



a)



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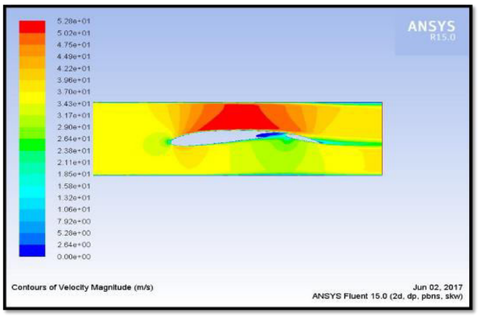

c)

Figure-7. (a) Velocity VX, (b) Velocity VY, (c) Velocity magnitude (for G=1.25% c, O= -5% c, AOA= -5°, α=20°).

In this case the flap deflection angle was chosen to be higher than the first case with a value equal to (35°). It can be seen from Figures (6 a & b) that same trend regarding the behavior of dynamic and static pressure contours downward and upward of the aerofoil is repeated here since three major variables were kept unchanged represented by the gap distance, flap overlap, and the angle of attack although a noticeable effect can be shown in the area above and downstream of fowler flap section that is accompanied with the increase of flap deflection angle to a value of (35°). This effect is shown in Figure-6 c for the turbulent kinetic energy in which the formation of shaded vortex wake revealed to trace the downstream of flap trailing edge as a result of the energy added from the high pressure side since fowler flaps are commonly found on larger transport category aircraft, as they are heavier than the other flap designs and incorporate more complex systems to operate. Fowler flaps slide out and back from the wing, which offers the benefit of not only increasing the camber of the wing but also of the wing region.

Figure (7 a, b, & c) for velocity contours in x and y direction in addition to the contours of the velocity magnitude respectively in addition to the combination of velocity vectors components and magnitude shown in Figure (8 a, b, & c) which illustrate the trace and structure of wake vortex within the velocity flow field with a moderate flow velocity magnitude for both (x and y) components marked by a green contours which consisted with magnitude of the flow that across the slotted passage of fowler flaps leading to assist the enhancement of flow

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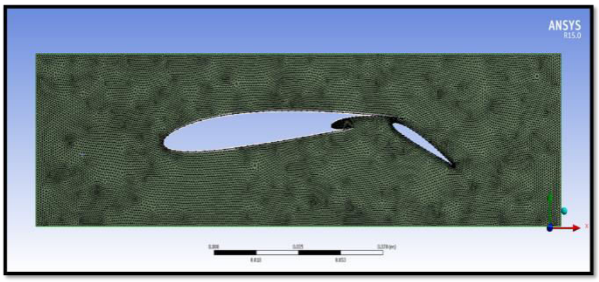
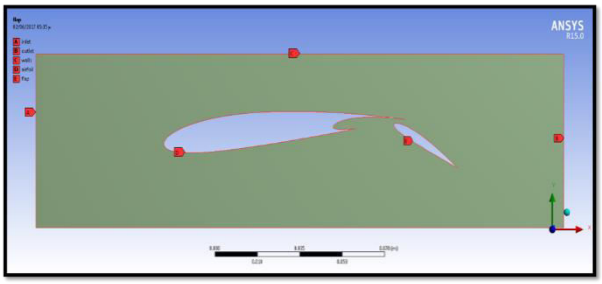
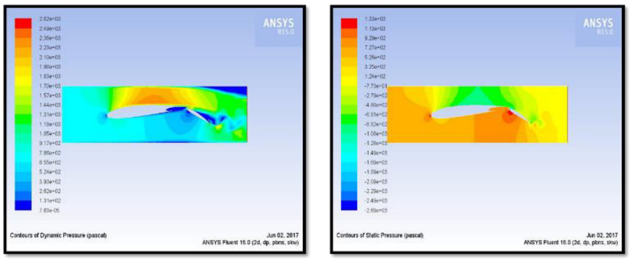
during takeoff therefore its obvious at this stage to mentioned that for an aerofoil consist of a fowler flap possess a constant gap and overlap distance for a given angle of attach higher energy air from beneath the wing to flow over the deployed flap area for an increase in the flap deflection angle of about (15°).



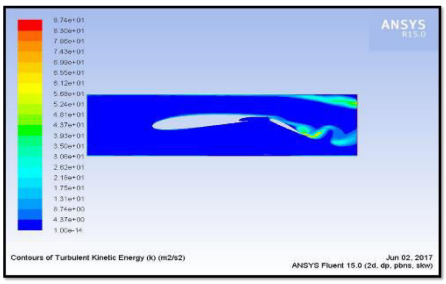


(a) (b)

Figure-8. (a) Mesh for NACA2412 in test section, (b) Boundary conditions (for G=1.25% c, O= -5% c, AOA= -5°, α=35°).



(a) (b)

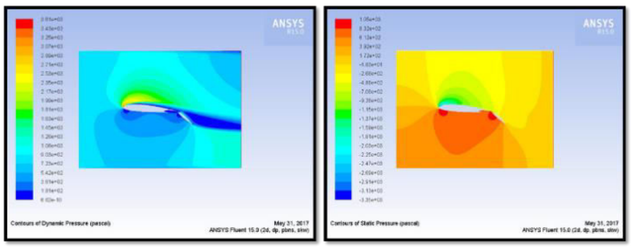


(c)

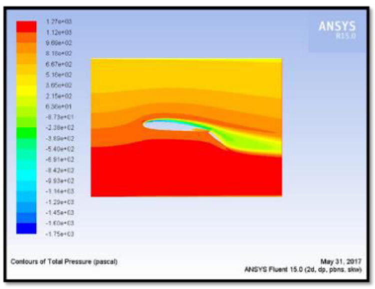
Figure-9. (a) Dynamic pressure , (b) Static pressure , (c) Kinetic energy (for G=1.25% c , O= -5% c , AOA= -5°, α=35°).

In order to investigate the effect of increasing the value of the flap deflection angle another case was selected for the purpose of the present study in which flap deflection angle is increased to have a value of (45°). Mesh generation for this case used with NACA2412 in addition to the boundary conditions for a gap distance equal to (1.25% c) and overlap equal to (-5% c) while the angle of attack (AOA) equal to (-5°) is illustrated in figure (8 a & b). After reviewing the behavior of the dynamic and static pressure contours located downward and upward of the aerofoil in addition turbulent kinetic energy and the contours of the velocity magnitude respectively in addition to the combination of velocity vectors components and magnitude it is shown that no major differences in the trend discussed for these parameter having a flap deflection angle of (35°) which means that this value of flap deflection reflect the major roll for the flow field behind fowler flap having a value greater than (35°).

Now, since the effect of flap deflection on the vortex wake behind a multi-element aerofoil was discussed properly it is convenient to introduce the effect of new parameter on the performance of fowler flaps which at this stage of discussion can be summarized by the increasing of the angle of attack to a value of (5°) while keeping the gap and overlap distance un altered for the purpose of discussion. This case was introduced by varying the flap deflection angle again in the range of (20°, 35°, and 45°) as shown in Figures (10 to 12). It can be seen from the contours of dynamic, static, and total pressure that the effect of increasing the angle of attack by (10°) appear clearly through the formation of wake area that experience a certain decrease in the bulk of total pressure values due to retardation of flow structure inside the wake region. This behavior was also replicated in Figure (11a & c) in which the region of wake marked with a blue region as a reference of the low velocity field.



a) b)



c)

Figure-10. (a) Dynamic pressure, (b) Static pressure, (c) total pressure (for G=1.25% c, O= -5% c, AOA= 5°, α=35°).

As the flap deflection angle increase to a value of (45°) with the existence of an angle of attack equal to (5°) it is clearly revealed the improper combination of these

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two angles due to large wake vortex generated downstream of multi-element aerofoil since the boundary layer that pass over main part of the aerofoil. Wake turbulence is straightforward to understand once you know how a wing makes lift by redirecting the air streaming crosswise over it downwards this is due to the downward movement of air will make a void above it, and the air underneath needs to make place for that descending moving stream tube. Additionally, the pressure field around the wing will influence the air in the region of the stream tube too, and in outcome air from beneath will be pushed sideways as of now by the wing, and the air above will begin to stream towards the low pressure region over the wing.

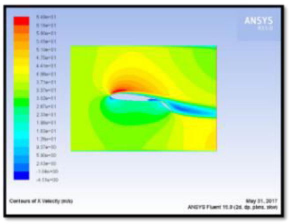
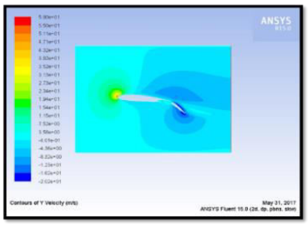
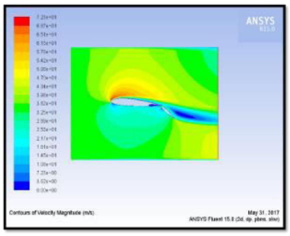

(a)

(b)

(c)

Figure-11. (a) Velocity VX, (b) Velocity VY, (c) Velocity magnitude (for G=1.25% c, O= -5% c, AOA= 5°, α=35°).

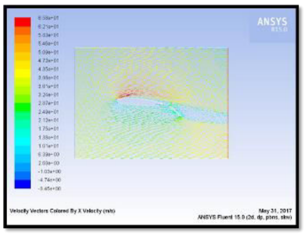
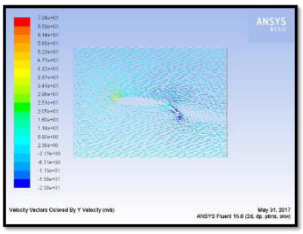
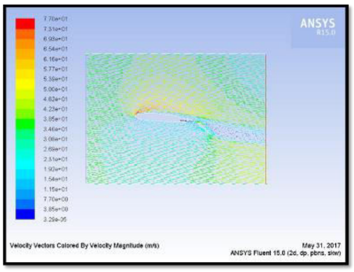



(a) (b) (c)

Figure-12. (a) Velocity vector VX, (b) Velocity vector VY, (c) Velocity vector magnitude (for G=1.25% c, O= -5% c, AOA= 5°, α=35°).

This sideways movement will become more pronounced, to such an extent that air will constantly be squeezed outwards underneath the wing's wake, climb left and right of it and inwards over the wake. The inertia of the down-wash keeps it moving downwards for a few minutes, consistently displacing the air beneath it and sucking more air into the space above. In other word wake generated behind the multi-element aerofoil is innate impact of creating lift over limited wingspan. To create lift or a power on the plane, the aircraft machine applies constrain on the encompassing air (by Newton's third law). As the air is allowed to move, this power quickens it (as per Newton's second law) descending. Because of the way liquids work the power influences air both above and underneath the wing, yet not + the sides.

At this stage of discussion, the results for multi element aerofoil with fowler flap having different gap and overlap distances in addition to different flap deflection angle it is more convenient to discuss the effect of increasing the gap distance on the structure of boundary layer downstream. As the gap distance increases from (1.25 % c) to (3.75 % c) it can be seen that the nature of flow start to possess different trend than that shown in the small value for gap distance. Figures (13 to 4.44) illustrate the case of gap distance equal to (3.75 % c) with an angle of attack (-5°) and flap deflection of (20°) in which the effect of varying the gap distance start to be noticed with dynamic and static pressure contours and especially for the turbulent kinetic energy as the formation of the vortex wake again start to shad the area behind flap due to continues effect of the slotted area that associates the high pressure locale on the lower surface of an aerofoil to the moderately low pressure area on the highest surface it subsequently goes about as a blowing sort of limit layer. This is easily recognized if the region over the flap is observed in which no vortex region is found but only a trace for the wake that is generated from the blowing type of boundary layer.

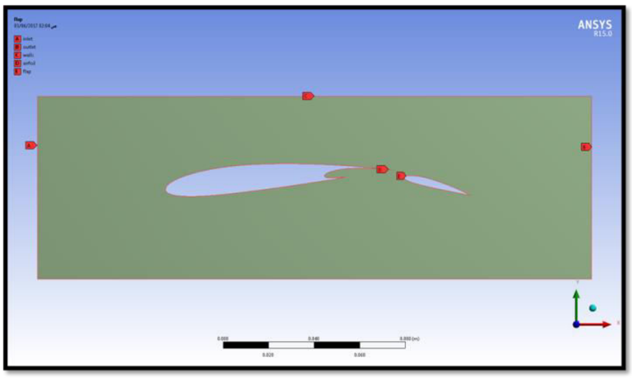


Figure-13. Boundary conditions (for G=3.75% c, O= 5% c, AOA= -5°, α=20°).

Once the flap deflection start to increase from an angle of (35° to 45°) then the vortex wake start to develop aggressively as the flap angle increase with the variation in

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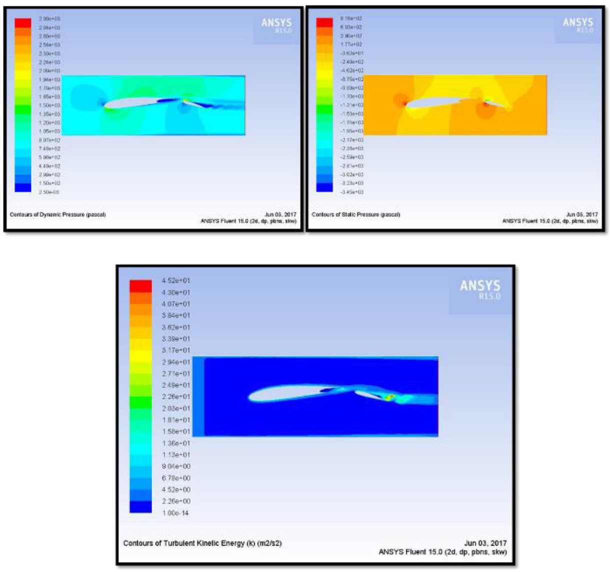
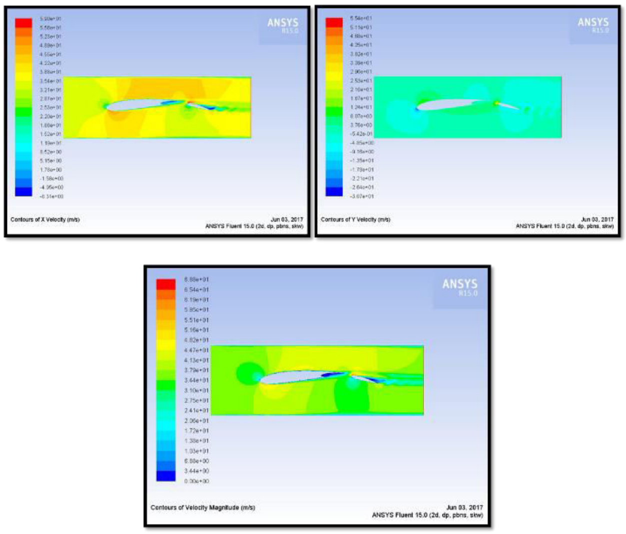
the value of the angle of attack. Hence, for the aerodynamic characteristics of the variable camber Fowler flap that were studied by computational simulation, and cambering was found to be beneficial for improving the flow structure behind the multi-element aerofoil when the gap distance increased and accompanied with an angle of attack larger than (5°) for all values of flap deflection as the energy added from the high pressure side increased with comparison of small gap distance and that leads to extend the boundary layer to increase the camber in order to increase the lift as shown with an angle of attack equal to (10° & 15°) while for the angle of attack equal to (-5° & 5°) the energy added from the high energy side (high pressure) through the slotted area is not enough to energize the retard boundary layer which lead to the formation of a different size of wake propagate over the flap upper surface without the effect of increasing the camber line. This trend is observed for the different parameter used for the purpose of the present study such as dynamic pressure, static pressure, turbulent kinetic energy, velocity vectors and magnitude.



(a) (b) (c)

Figure-14. (a) Dynamic pressure, (b) Static pressure, (c) Kinetic energy(for G=3.75% c, O= 5% c, AOA= -5°, α=20°).



(a) (b) (c)

Figure-15. (a) Velocity VX, (b) Velocity VY, (c) Velocity magnitude (for G=3.75% c, O= 5% c, AOA= -5°, α=20°).

CONCLUSIONS AND RECOMMENDATIONS

It was concluded that for a multi-element aerofoil consist of a fowler flap having a constant gap and overlap distance with a given angle of attack higher energy air cross from beneath the wing to flow over the deployed flap area which accompanied with an increase in the flap deflection angle of about (15°). In addition, it was concluded that for the behavior of the dynamic and static pressure contours located downward and upward of the aerofoil in addition turbulent kinetic energy and the contours of the velocity magnitude respectively there is no major differences in the trend discussed for these parameter having a flap deflection angle of (35°) which means that this value of flap deflection reflect the major roll for the flow field behind fowler flap having a value greater than (35°).

It was concluded that as the flap deflection angle increase to a value of (45°) with the existence of an angle of attack equal to (5°) it is clearly revealed the improper combination of these two angles due to large wake vortex generated downstream of multi-element aerofoil since the boundary layer that pass over main part of the aerofoil.

Finally, it was found that it is in convenient to use the combination for an angle of attack equal to (15°) with a fowler flap deflection angle equal to (35° and 45°)

It is recommended that it is essential to conduct an experimental studies that can deal with the same cases that were conducted in the present study in order to accomplish a fair comparison with data obtained here which can find some answer for the questions raised at some part of this discussion in order to illustrate every aspect of the proposed case study to be introduced and submitted with fulfilment of require aspect.

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