

2D Analysis Flow over NACA 6 Series High Lift Devices

Ms. Alka

Associate Professor

MLRITM

Dundigal, Hyderabad.

Santosh Kumari. K

M.Tech Student,

MLRITM

Dundigal, Hyderabad.

ABSTRACT

An analytical study of performance enhancing devices for an aerofoil is performed using ANSYSFLUENT. The purpose of this project is to analyze flow over a NACA 64(1) -212 aerofoil with multi-element high-lift systems, designed using GAMBIT and analyzed using FLUENT software.

Two simple passive devices (a slat and a flap) are examined to explore alternate methods for stall control and lift to drag improvement. An evaluation scheme is presented to compute lift, drag at stall angles-of-attack of aerofoil with passive elements like leading-edge slat, trailing-edge flap. The motivation behind this report is to study effective techniques to improve performance.

NACA 64(1) -212 single- element, slatted and slotted flap Aerofoil fluid dynamic results of lift, drag, pressure coefficients are compared at various angles of attacks [-4, 0, 4, 8,12,14]. Slat deflected to 5 and 10degrees, along with slotted flap with 0, 15, 30, 60 deflections and a modified aerofoil with both slat and flap deflected to 10 and 15 respectively has been analyzed

Key Words: ANSYSFLUENT, NACA 64(1) -212, GAMBIT etc.

INTRODUCTION

An airfoil is the shape of a wing as seen in cross-section. An airfoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. The lift on an airfoil is primarily the result of its angle of attack and shape. Most foil

shapes require a positive angle of attack to generate lift, but cambered airfoils can generate lift at zero angle of attack. Camber causes the air that flows over the top of the airfoil to move faster with less air pressure than the air that flows beneath it. This difference in pressure will cause the wing to move and generate a force lift.

By virtue of its shape alone, an airfoil will generate lift as air flows over it. However, even more lift can be generated by the airfoil if it is tilted with respect to the airflow. This tilt is called an airfoil's angle of attack. As the wing is tilted, the air flowing over the top of the wing flows even faster than the air flowing underneath. As the difference in the speed of the two airflows increases, the difference in pressure also increases. So, as its angle of attack increases, the wing generates more lift, which is limited by boundary layer.

The boundary layer is a very thin layer of air lying over the surface of the wing and, for that matter, all other surfaces of the airplane. Because air has viscosity, this layer of air tends to adhere to the wing. As the wing moves forward through the air the boundary layer at first flows smoothly over the streamlined shape of the airfoil. Here the flow is called the laminar layer. As the boundary layer approaches the centre of the wing, it begins to lose speed due to skin friction and it becomes thicker and turbulent. Here it is called the turbulent layer.

The point at which the boundary layer changes from laminar to turbulent is called the transition point. Where the boundary layer becomes turbulent, drag due to skin friction is relatively high. As speed increases, the transition point tends to move forward. As the angle of attack increases, the transition point also tends

to move forward. With higher angles of attack and further thickening of the boundary layer, the turbulence becomes so great the air breaks away from the surface of the wing and lift will not be generated. We say the wing "loses its lift" or "stalls". A stall is a condition in aerodynamics and aviation wherein the angle of attack increases beyond a certain point flow separates and the lift begins to decrease. The angle at which this occurs is called the critical angle of attack, at which separated flow is so dominant that further increases in angle of attack produce less lift and vastly more drag. Below figure shows at normal angle of attack and the airflow staying in contact with the wing, at an extreme angle of attack and the airflow separating and becoming turbulent on the top of the wing, which is stall.

The Lift Coefficient and the Drag Coefficient represent the changes in lift and drag as the angle of attack changes. C_L and C_D are not expressed by any physical unit, they are rather absolute numbers obtained from either wind tunnel tests or derived mathematically. Initially both C_L and C_D increase as the angle of attack increases. At the Critical Angle of Attack, the lift begins to drop while the drag increases sharply. After critical angle of attack all lift will be lost while the drag continues to increase.

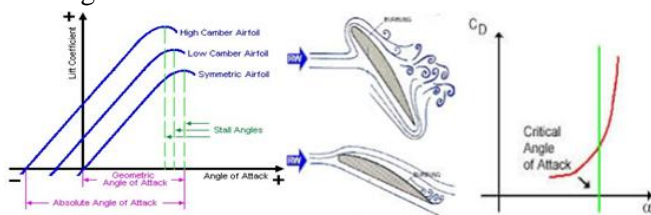


Figure- C_L and C_D graphs of airfoil at stall

High Lift Device

When an airplane lands it is desirable to fly as slowly as possible. Ideally for landing, an airplane would have a large wing with a much cambered airfoil. However, airfoils designed to perform well at slow speeds are not good for flying at faster speeds, and vice versa. Airplane designers have developed high lift devices that allow the pilot to increase the wing area and change the airfoil shape to compensate for this.

The wings on most modern-day air vehicles are equipped with high-lift systems, generally in the form of leading-edge slats and trailing-edge flaps. These devices have been shown to enhance the aerodynamic performance of air vehicles through increasing the maximum coefficient of lift, lift-to-drag ratio, and stall angle.

Advantages of such performance-enhancing devices include improvements in manoeuvrability, turn rates, glide range and payload, and reductions in take-off/landing distance and field length requirements. Flaps and slats are used during take-off and landing. They enable the airplane to get off the ground more quickly and to land more slowly.

TRAILING EDGE FLAPS

Flaps are the most common high-lift devices used on aircraft. These surfaces, which are attached to the trailing edge of the wing, increase both lift and induced drag for any given AOA. Flaps allow a compromise between high cruising speed and low landing speed, because they may be extended when needed, and retracted into the wing's structure when not needed.

There are four common types of flaps:

1. Plain,
2. Split,
3. Slotted, and
4. Fowler flaps.

CONSEQUENCE OF MULTI-ELEMENT AIRFOIL

Many studies have been developed on the high-lift devices; Nevertheless, the actual effect of the gaps between the different elements was not understood entirely in the past. As it is suggested by, there are five main consequences due to the presence of the gaps between the elements of an airfoil:

- Slat effect.
- Circulation effect.
- Dumping effect.

- Off-the-surface pressure recovery
- Fresh-boundary-layer effect

METHODOLOGY

Open the Gambit GUI by typing gambit at the Linux prompt or clicking on the Gambit icon in Windows machine.

Step 1: Importing:

- Change the default tolerance by going to Edit/Defaults/GEOMETRY/TOLERANCE. Change the EDGE_FACET value from 0.001 to 1.0e-08. This helps to build more precise geometry.
- First of all, the geometry must be imported from the vertices.dat file ,this file contains 3 columns of x, y, z coordinates that define the elements of the airfoil (which are tabulated in references). Once the set of point is imported in GAMBIT the curves that represent the airfoil are created. Figure 1 shows the imported NACA 641-212 with high lift device coordinates.



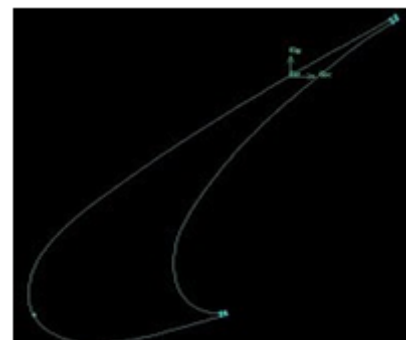
Figure- NACA 641212 profile

Step 2: Creating the geometric domain:

- Join the vertices by box picking or individually picking each vertices by using the NURB option. To do so, go to Geometry/EDGE COMMAND BUTTON/NURBS. It is advised to split each element into multiple parts as shown in figures for slat, main and flap respectively. Segmentation of each element helps in better control during edge meshing.
- Create faces for slat, main and flap using the curves. Go to FACE/Create Face From Wireframe.
- Create a circular surface with a radius of 3 chord by going to FACE COMMAND BUTTON/CREATE FACE, right click and

choose Create Real Circular Face. In the Radius tab put 300 and press Apply. You will need to translate the newly created face in the x-direction to make sure that the multi element profile is sitting in the center. Next create a bigger circular Face of 100 chord radius by inputting a radius of 10000. So you have totally 4 to 5 Faces, 2 circular Faces and 2 to 3 belonging to the multi element airfoil as mesh generation is done separately for different airfoil configurations with only flaps, only slats or both which are shown above.

- Use boolean operation to get our final geometric domain. Go to BOOLEAN OPERATIONS, right click and choose Subtract. In the first Face tab pick the big circular Face and in the second Subtract Faces tab pick the inner smaller circular Face. Press Apply. A Face extending from the inner circle to outer circle is created and the inner circular Face is deleted out. Next recreate the inner circular Face by going to FACE/Create Face From Wireframe and picking up the edge forming the inner circle. Once this is done use once again the BOOLEAN OPERATIONS to subtract each of the elements (slat, main, flap) Faces from the newly created inner circular Face. With this you have totally 2 Faces namely one inner circular Face with the 2 or 3 elements profile curved out and one outer circular Face extending from the inner circle to outer circular farfield. The geometry for generating the grid is ready.



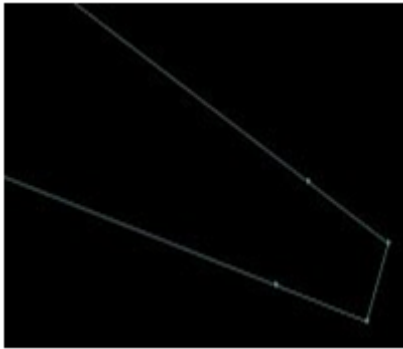


Figure- Leading edge slat and trailing edge flap segmentation

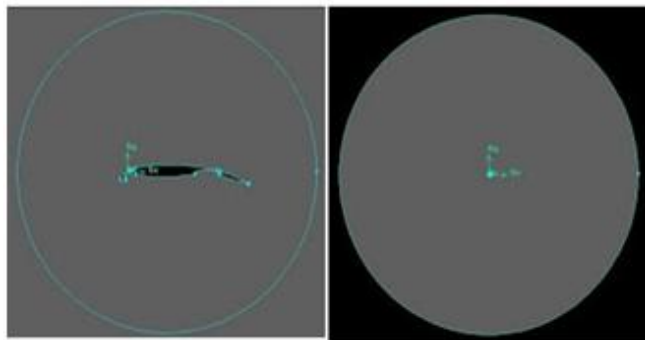


Figure- Inner and complete domain

Step 3: Meshing the multi element airfoil Edges:

1. Edge meshing will be done using the sizing function tool. Firstly change the default setting of sizing function by going to Edit/Defaults/TOOLS/SFUNCTION. Change the default value of BGRID_MAX_TREE_DEPTH from 16 to 25 and that of BGRID_NONLINEAR_ERR_PERCENT from 25 to 15.
2. The leading edge of slat and the trailing edge of the slat, main and flap elements will be meshed with 30 elements. Go to MESH COMMAND BUTTON/Mesh Edges, pick the leading and trailing edges of slat and the trailing edges of main and flap elements and enter a Mesh count of 30. Press Apply. Mesh as shown in figure is created.

Two sizing functions will be used to mesh the airfoil. One to capture the curvature of the airfoil and the other to put small cells at the trailing edge. Go to TOOL COMMAND BUTTON/Create Size Function.

Sizing function 1:

Choose Curvature in Type, for Sources and Attachment pick all the edges of the airfoil except the leading edge of the slat and the trailing edges of the slat, main and flap. Input the following parameters. Angle = 3, Growth rate = 1.125, Max. size = 13, Min. size = 0.01. Press Apply.

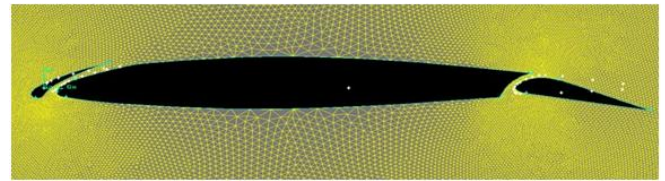


Figure- Mesh around the NACA 64(1)-212 airfoil

Sizing function 2:

Choose Fixed in Type. For Source pick the leading edge vertices of slat and trailing edge vertices of slat, main and flap. For Attachment pick all the edges of the 3 elements excluding the leading edge of slat and trailing edge of slat, main and flap. Input the following parameters. Start size = 0.5, Growth rate = 1.125, Max. size = 13. Press Apply. This sizing function is applied to get a gradual mesh from the trailing edges. 3. Now to mesh the airfoil go to MESH COMMAND BUTTON/Mesh Edges. Pick all the edges except the leading edge of slat and trailing edge of slat, main and flap. Press Apply.

Step 4: Creating the unstructured grid :

Finally to generate the unstructured grid we will make use of two more sizing functions.

1. Go to TOOLS COMMAND BUTTON / SIZING-FUNCTION COMMAND BUTTON/Create Sizing Function.c: Sizing function 3: Pick Meshed under Type, pick all the 3 edges of the airfoil as Source and domain surface as Attachment. Let the Growth rate = 1.125 and Max.size = 20000.d: Sizing function 4: Let Type be Fixed. Pick the trailing edge vertex as Source and the domain surface as Attachment. Input the following parameters, Start size = 0.01, Growth rate = 1.125, Max. size = 20000.
2. Now to mesh the domain go to MESH COMMAND BUTTON/FACE COMMAND BUTTON/Mesh Faces.

Pick the domain surface, let Elements be Tri and Type be Pave. Press Apply.

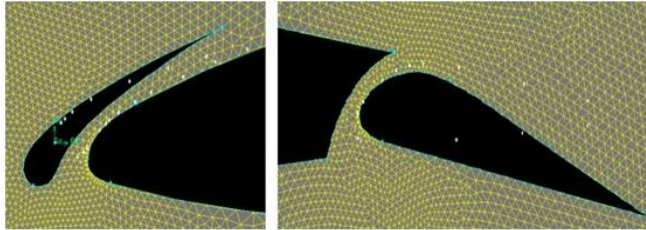


Figure- Mesh around leading edge slat and trailing edge flap

Step 5: Applying boundary conditions and exporting the mesh:

1. As a last step before exporting the mesh we will apply boundary conditions. Go to ZONE COMMAND BUTTON/Specify Boundary Types.
2. Pick the edges forming the slat and Name it as slat. Apply Type as WALL. Similarly pick all the edges of main and flap and give the Name as main and flap respectively with Type as WALL.
3. Pick the outer edge and Name it as farfield and apply PRESSURE_FAR_FIELD under Type. Press Apply.
4. Now go to CONTINUUM TYPE COMMAND BUTTON in ZONE. Here pick the two Faces representing the computational domain and Name it as fluid with FLUID as Type.
5. This completes applying boundary conditions. To export go to File/Export/Mesh/ and type out the name as nhlp2d.msh. Make sure to activate the button of Export 2-D(X-Y) Mesh. If all the steps are done properly one will get the message "Mesh was successfully written to nhlp2d.msh" under Transcript.

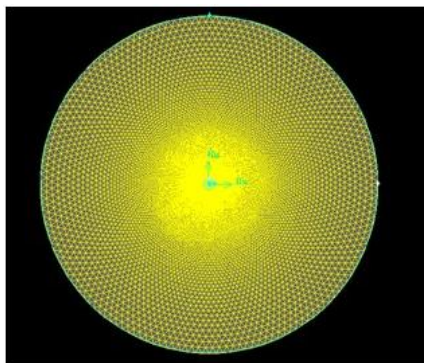


Figure- Complete mesh with Fairfield

Results and Discussions

NACA 641-212 airfoil having different flap angles (δ) and slat angles was subjected to flow of Reynolds number 6.0×10^6 . Flow having Mach number less than 0.3 is considered incompressible, so pressure based solver is utilized. The resultant forces are typically resolved into two forces and moments. The component of the net force acting normal of the airfoil is lift force (L) and acting horizontal to the airfoil is drag force (D). The curves showing variation of lift coefficient (Cl) and drag coefficient (Cd) with different flap and slat angles (δ) are analysed to realize the aerodynamic behaviour of slotted flap and slatted NACA 641-212 airfoil. Curves of Cl/AOA (α) and Cd/AOA (α) are analysed further, as these are crucial factors affecting range and endurance of aircrafts. However, flow at high flap angles (δ) (i.e. 0, 15, 30, 60 degrees) are very unstable and it remains unconverged even after 10000 iteration in Ansys Fluent flow solver. Hence, flow for flap angle (δ) 0, 15, 30, 60 degrees are slightly erratic.

Variation of Cl and Cd with α and flap angle (δ)

The following plot shows the variation of coefficient of lift (Cl) with varying AOA and flap angle (δ) 0, 15, 30, 60 airfoil and it is clearly suggest that, the increment of lift can be achieved through increasing AOA and flap angles. The increment of lift value for different angles has been presented in tables 1-5 and it clearly shows that, up to the AOA of 12 degree, the lift increases for increasing flap deflection angle but beyond AOA of 12 degree, it will leads to stall so it is undesirable for any aircraft. Similarly the variation of Drag Coefficient (Cd) with α and δ is presented in tables 1-5 and it is showing that, we cannot get the lift for free of cost, the drag coefficient is the price for lift.

For 0° flap angle maximum Cl is 1.1693 which occurs at AOA of 12° , similarly for 15° flap angle maximum Cl is 1.6185 which occurs at AOA of 8° , for 30° flap angle maximum Cl is 1.5689 which occurs at AOA of 12° , for 60° flap angle maximum Cl is 1.6296 which occurs at AOA of 8° . The increment in lift due to flap deflection is presented above and it clearly

shows that the lift increases as flap deflection angle increases. From the plot it's clear that as the flap gets deflected the pressure distribution over the airfoil increases thus the lift force generated by the airfoil also increases.

LIFT VARIATION WITH AOA FOR DIFFERENT FLAP ANGLES

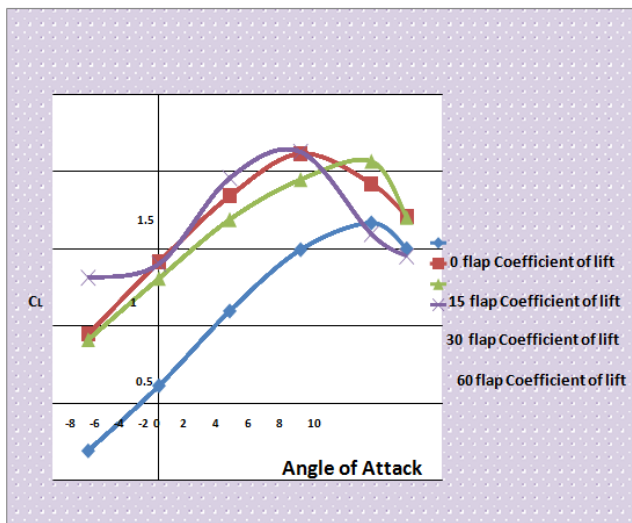


Chart.1: Cl with AOA of various flap angles

DRAW VARIATION WITH AOA FOR DIFFERENT FLAP ANGLES

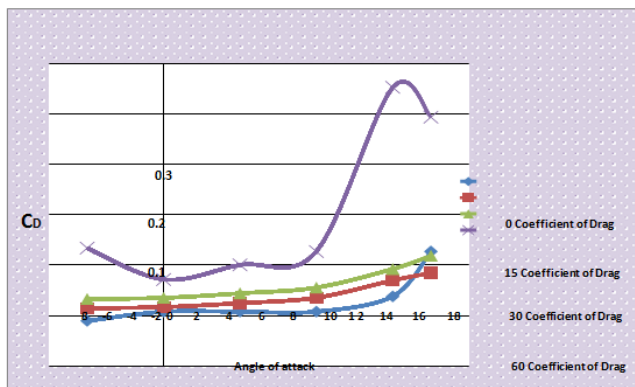


Chart.2: Cd with AOA of various flap angles

Conclusion

From the analysis of above results the following statements are inferred.

- Above c_p variation along chord shows that the pressure distribution over the airfoil increases when the flap is deflected. From the plot it's

clear that as the flap gets deflected the pressure distribution over the airfoil increases thus the lift force generated by the airfoil also increases.

- The main effect produced by flap deflection is an increase in the effective camber of the wing; this reduces the zero lift incidences, without affecting the lift curve slope. Thus at incidences well below the stall, there is a constant increase in lift coefficient. The effect may be slightly enhanced because flap deflection additionally produces a slight increase ineffective incidence. A further effect is however is to hasten the onset of the stall, because separations tend to occur early over the rear of the flap, where the airfoil is in effect so highly cambered.
- From the plot it's clear that as the slat gets deflected the pressure distribution over the airfoil increases thus the lift force generated by the airfoil also increases at higher angle of attacks which delays stall.
- Hence multi-element airfoil has the both benefits of flap and slat.

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