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Analysis of Stalling Over FLAPED Wing of an Aeroplane by CFD Code

Mukesh Didwania*[1], Dr. Kamal Kishore Khatri[2]
[1]*Mukesh Didwania is currently pursuing PhD degree program in Mechanical Engineering in Career Point University, Kota, India*
[2]*Dr. Kamal Kishore Khatri is working as Associate professor & HOD at LNMIIT,Jaipur, India, Mob-*
Corresponding Author: Mukesh Didwania

Abstract: *A wing is a type of fin with a surface that produces aerodynamic forces facilitating movement through air and other gases, or water and other liquids. As such, wings have an airfoil shape, a streamlined cross-sectional shape producing lift. Flaps are a type of high-lift device used to increase the lift of an aircraft wing at a given airspeed. Flaps are high lift devices attached to the leading or trailing edge of a wing. They help to increase the value of Lift coefficient and the Stall Angle during the take-off phase of an aircraft. In this paper application of flaps during take-off/landing phase at different angle of attack has been highlighted. By literature review it found that lot of work has been finished on flap wings and lot of research completed on stalling but there is no any work on analysis of effect of combination of Mach no, angle of attack and flap deflection over a 5 digit NACA aerofoil. NACA 23012 aerofoil was selected for this work. This analysis completed for take-off/landing and cruising speed.Mesh was generated with Nodes 75879 and Elements 75000 by Quadrilaterals Method. Mesh quality checked by Minimum Orthogonal Quality and maximum Aspect Ratio. Steady-state density based implicit solver and K-ω SST turbulent model was selected because of compressible aerodynamic flow. NACA aerofoil Scaled Model was manufactured by using NACA profile for experimental work and Wind tunnel setup was developed for 18 measurement points and CFD results were validated by pressure coefficient calculated by wind tunnel setup. Finally concluded that the best condition is AOA = 15 at M=0.3 (Take off & landing speed) with flap to generate High lift or drag and the best condition is AOA= 3 at M = 0.8 (cruising speed) without flap to get high drag and also concluded that after AOA = 15 there is stalling at cruising speed.*
Keywords: *Angle of attack, Mach No., Deflection Angle, CFD, NACA, Aerofoil, Lift, Drag, Stalling*

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I. Introduction

A wing is a type of fin with a surface that produces aerodynamic forces facilitating movement through air and other gases, or water and other liquids. As such, wings have an airfoil shape, a streamlined cross-sectional shape producing lift. The design and analysis of the wings of aircraft is one of the principal applications of the science of aerodynamics, which is a branch of fluid mechanics. The properties of the airflow around any moving object can in principle be found by solving the Navier-Stokes equations of fluid dynamics. For a wing to produce "lift", it must be oriented at a suitable angle of attack relative to the flow of air past the wing. When this occurs the wing deflects the airflow downwards, "turning" the air as it passes the wing. Since the wing exerts a force on the air to change its direction, the air must exert a force on the wing, equal in size but opposite in direction. This force manifests itself as differing air pressures at different points on the surface of the wing. The different velocities of the air passing by the wing, the air pressure differences, the change in direction of the airflow, and the lift on the wing are intrinsically one phenomenon. It is, therefore, possible to calculate lift from any of the other three. For example, the lift can be calculated from the pressure differences, or from different velocities of the air above and below the wing, or from the total momentum change of the deflected air. [5]

Usually, aircraft wings have various devices, such as flaps or slats that the pilot uses to modify the shape and surface area of the wing to change its operating characteristics in flight. Flaps are a type of high-lift device used to increase the lift of an aircraft wing at a given air speed. Flaps are usually mounted on the wing trailing edges of a fixed-wing aircraft. Flaps are used to lower the minimum speed at which the aircraft can be safely flown, and to increase the angle of descent for landing. Flaps also cause an increase in drag, so they are retracted when not needed.

The purpose of the flaps is to generate more lift at slower air speed, which enables the airplane to fly at a greatly reduced speed with a lower risk of stalling. This is especially useful during takeoff and landing. When extended further, flaps also generate more drag which slows the airplane down much faster than just reducing throttle.

Extending the wing flaps increases the camber or curvature of the wing, raising the maximum lift coefficient or the upper limit to the lift a wing can generate. This allows the aircraft to generate the required lift at a lower speed, reducing the stalling speed of the aircraft, and therefore also the minimum speed at which the aircraft will safely maintain flight. The increase in camber also increases the wing drag, which can be beneficial during approach and landing, because it slows the aircraft.

They help to increase the value of lift coefficient and the Stall Angle during the take-off phase of an aircraft. Stall Angle is the angle between the chord line of an airfoil and the undisturbed relative airflow at which stalling occurs where stalling refers to the condition when there is a sudden reduction in the lift generated by the wing. If the stalling angle is higher compared to plain airfoils it allows the aircraft to take off at lower speeds and hence it can even take off from shorter runways. Flaps when fully extended during the landing phase of an aircraft tend to increase the drag so that the aircraft can land on the runway with a safe speed depending upon the shape, size and weight of the aircraft. [3]

1.1 NACA Aerofoil: The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics(NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties.Aerodynamicists control the flow field through geometry definition, and are always interested in possible geometric shapes that would be useful in design.

1.2 The NACA 5-Digit Series Airfoil: The NACA Five-Digit Series uses the same thickness forms as the Four-Digit Series but the mean camber line is defined differently which allowed for camber to be concentrated near the leading edge and the naming convention is a bit more complex. A reflexed camber line was designed to produce zero pitching moment, but has generally not been used.[14]

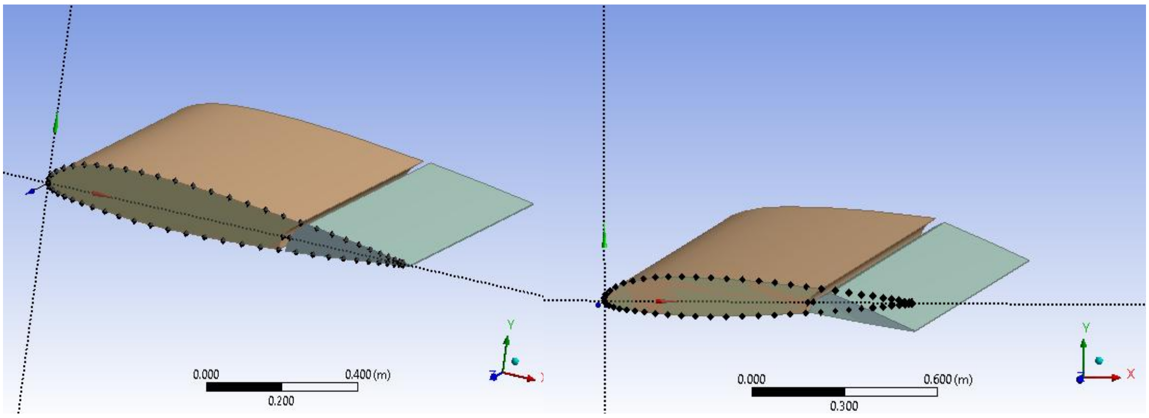
1.3 Statement of Problem: An airplane stall is an aerodynamic condition in which an aircraft exceeds its given critical angle of attack and is no longer able to produce the required lift for normal flight. This type of stall should not be confused with an engine stall, familiar to anyone who has driven an automobile. When flying an airplane, a stall has nothing to do with the engine or another mechanical part. In piloting, a stall is only defined as the aerodynamic loss of lift that occurs when an airfoil (i.e., the wing of the airplane) exceeds its critical angle of attack.Stalling is caused by flow separation which, in turn, is caused by the air flowing against a rising pressure.For the trailing-edge stall, separation begins at small angles of attack near the trailing edge of the wing while the rest of the flow over the wing remains attached. As angle of attack increases, the separated regions on the top of the wing increase in size as the flow separation moves forwards and this hinders the ability of the wing to create lift.So its need to analysis and study of stalling at different angle of attack, Mach no and flap angles.

1.4 Objective

1. Study of effect of different Mach no on NACA 23012 aerofoil.
2. Analysis of Flap deflection angle (δ) on Lift at the time of landing and take-off of aero-plane
3. Analysis of effect of Angle of attack for stalling at Average cruising speed

II. Geometry, Meshing& Solution:

2.1 Geometry: Because of its best design NACA 23012 has selected. It has lift coefficient of $0.15 \times 2 = 0.3$. Its maximum camber point is at $3 \times 0.05 = 0.15$ of the chord. That is, the max camber occurs at the point that is 15% of the chord behind the leading edge. The digit 0 in the middle tells you this airfoil has a simple camber line. The trailing edge does not curve up (reflex camber). The thickest point of the airfoil is 12% of the chord.Geometry & Computational domain was prepared in Ansys Work bench



(a) (b)

Figure 1: Geometry of NACA aerofoil (a) Deflection anlgle =0 (b) Deflection anlgle =20

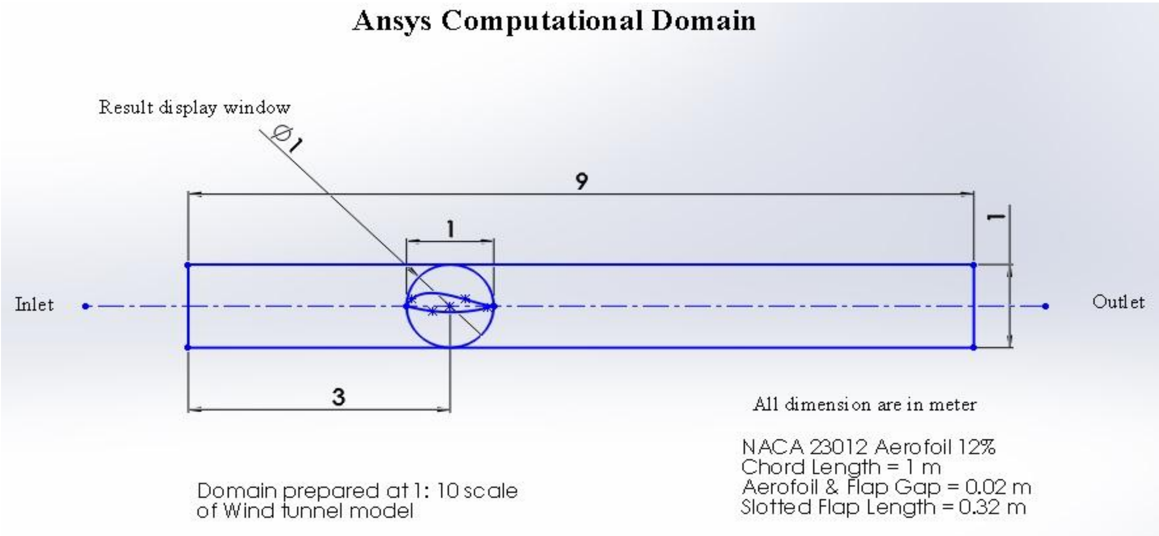


Figure 2: Computational domain of setup

2.2 Meshing: Mesh was generated with Nodes 75879 and Elements 75000 by Quadrilaterals Method and Mesh quality checked by Minimum Orthogonal Quality = 4.64981e-01 which is very good because Poor quality is 0 and best quality is 1 and by Maximum Aspect Ratio = 54.4975 which is not high.

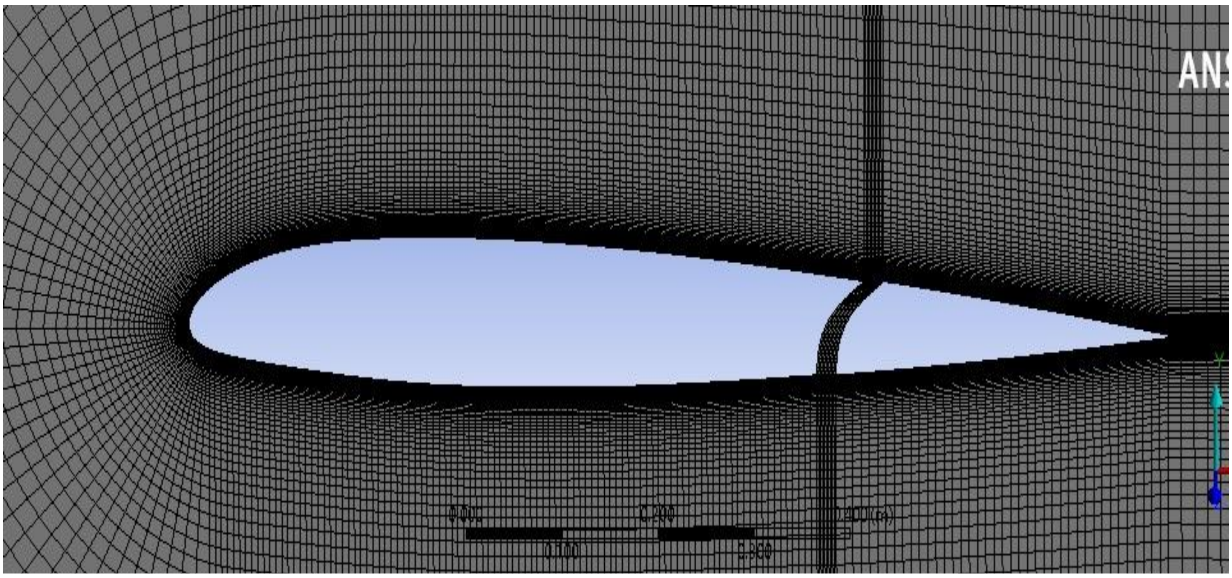


Figure 3: Meshing of Computational Domain

2.3 Solver: Ansys Fluent was used for the analysis of stalling.Study-state density based implicit solver and transition SST turbulent model was selected because of compressible aerodynamic flow.

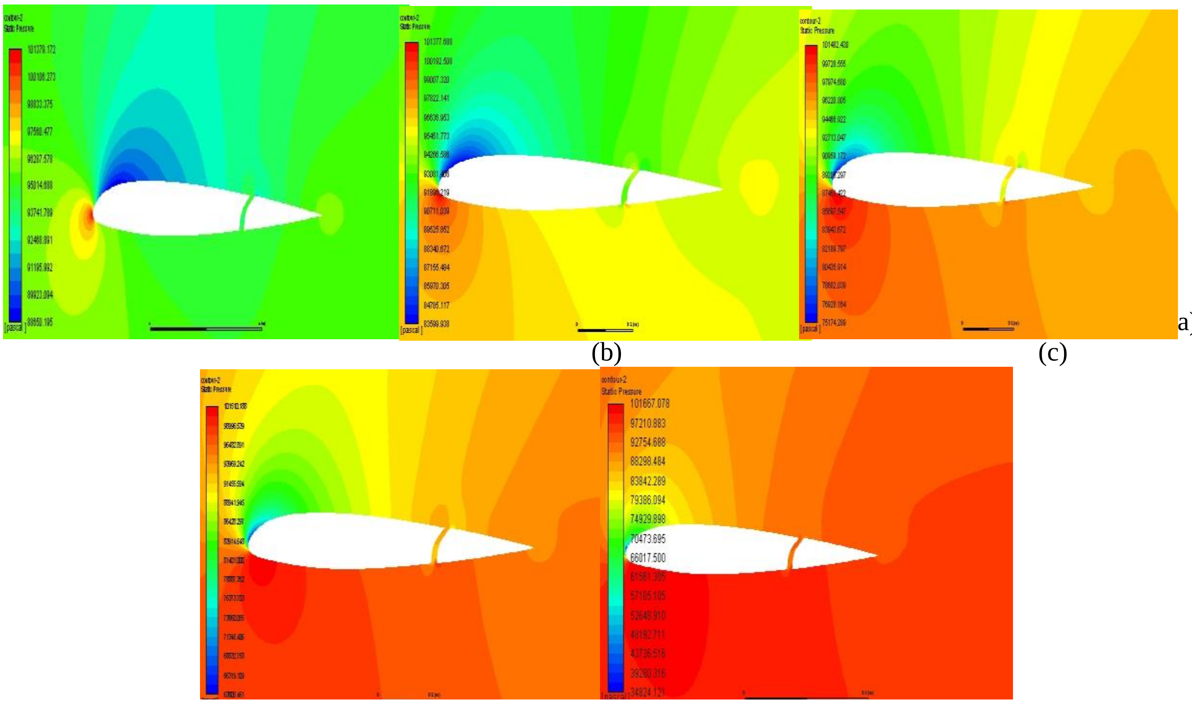
2.4 Boundary Condition: Pressure far field and Pressure outletboundary conditions was selected for inlet, aerofoil surface and outletof computational domain.

2.5 Cases to be investigated: Total 20 Cases were simulated in Ansys fluent CFD code

Table 1: Cases to be investigated by CFD code

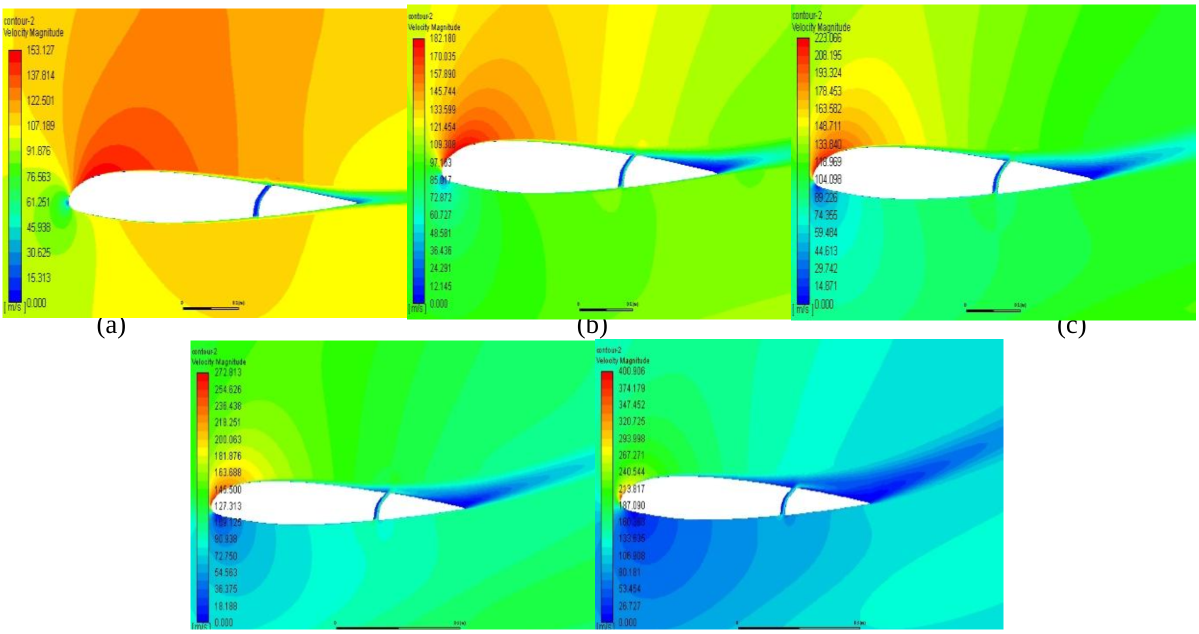
Flap Deflection Angle (δ)	Mach No (M)	AOA (α)	Flap Deflection Angle (δ)	Mach No (M)	AOA (α)
0	0.3 (Landing & take –off speed)	3	20	0.3 (Landing & take –off speed)	3
		8			8
		12			12
		15			15
		20			20
	0.8 (Average Cruising speed)	3		0.8 (Average Cruising speed)	3
		8			8
		12			12
		15			15
		20			20

III. Result and Discussion



(a) (b) (c) (d) (e)

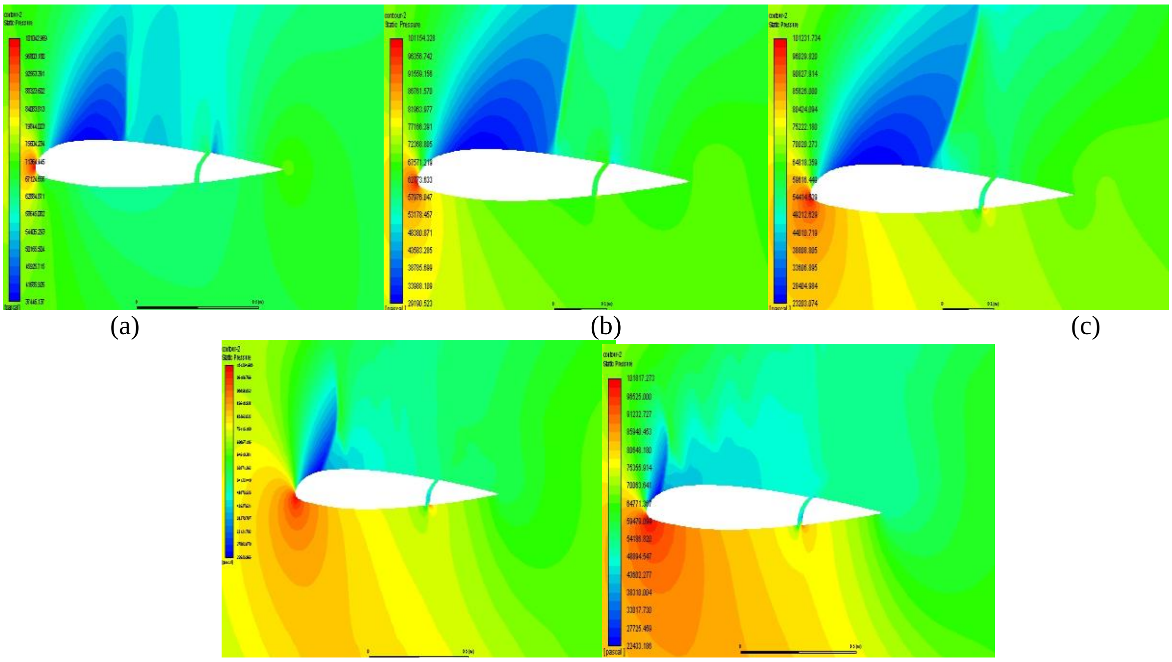
Figure 4: Pressure contour at DA=0 & M = 0.3 for (a) AOA=3 (b) AOA = 8 (c) AOA=12 (d) AOA=15 (e) AOA=20



(a) (b) (c)

(d) (e)

Figure 5: Velocity contour at DA=0 & M = 0.3 for (a) AOA=3 (b) AOA = 8 (c) AOA=12 (d) AOA=15 (e) AOA=20



(a) (b) (c)

(d) (e)

Figure 6: Pressure contour at DA=0 & M = 0.8 for (a) AOA=3 (b) AOA = 8 (c) AOA=12 (d) AOA=15 (e) AOA=20

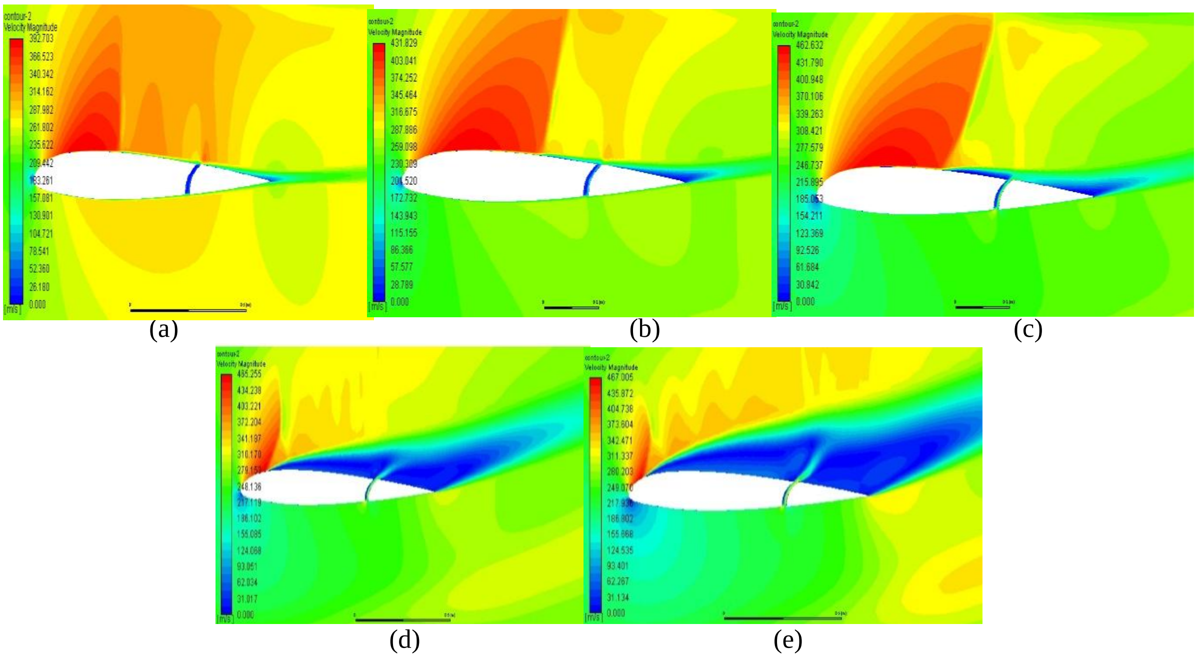


Figure 7: Velocity contour at DA=0 & M = 0.8 for (a) AOA=3 (b) AOA = 8 (c) AOA=12 (d) AOA=15 (e) AOA=20

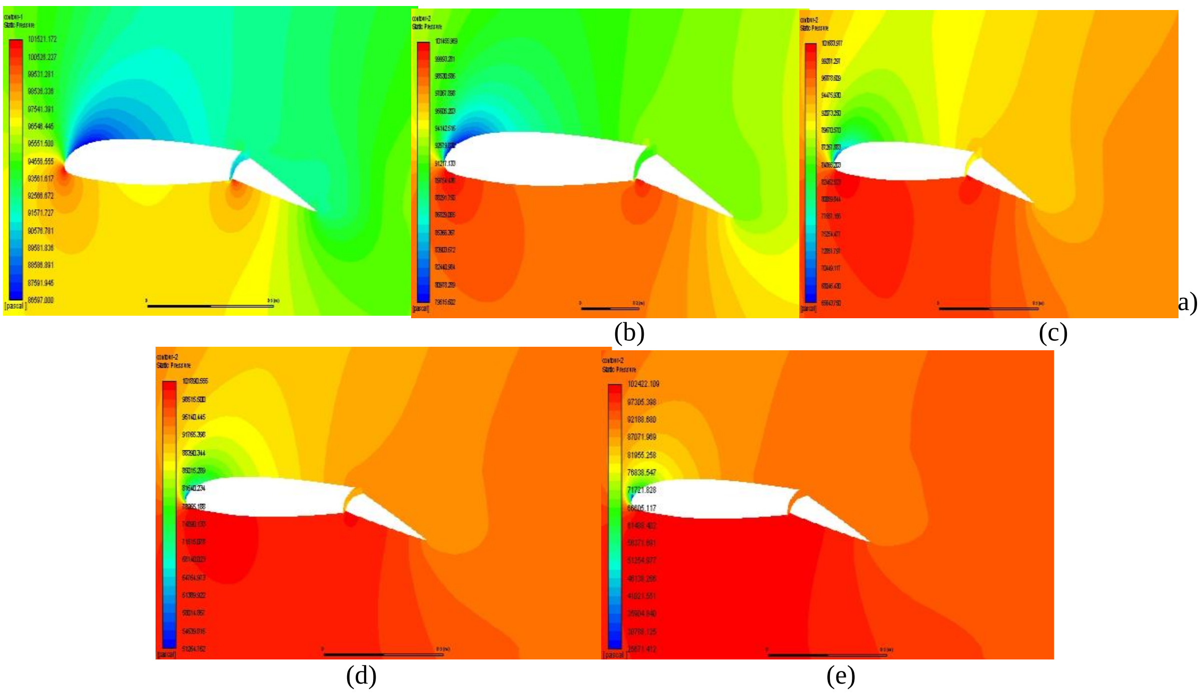
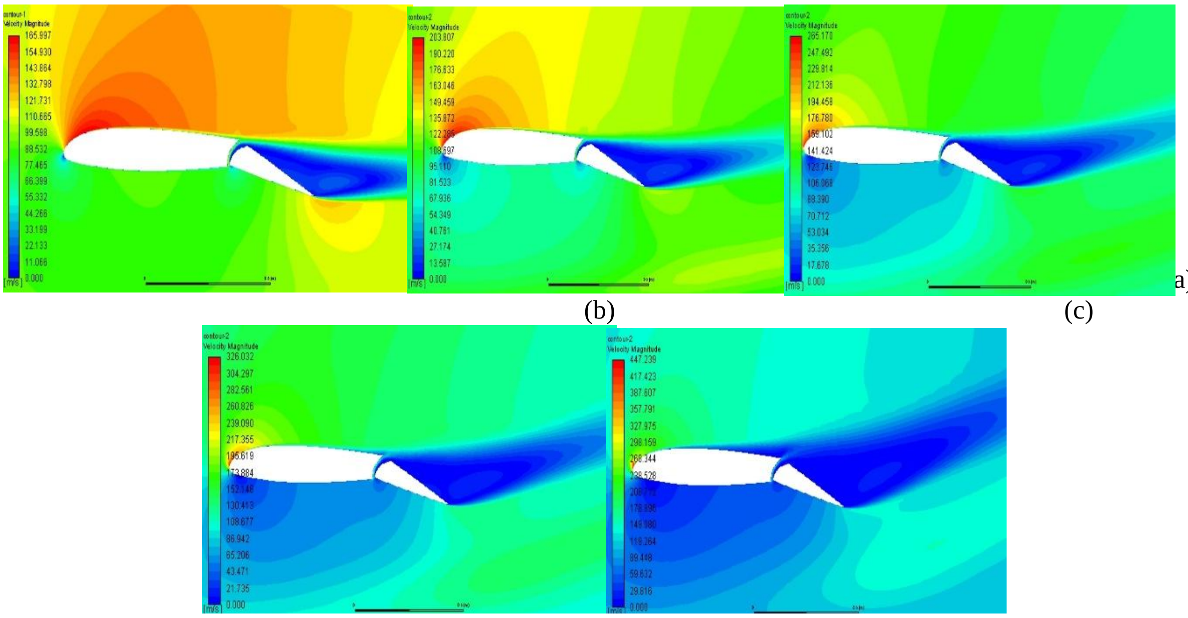
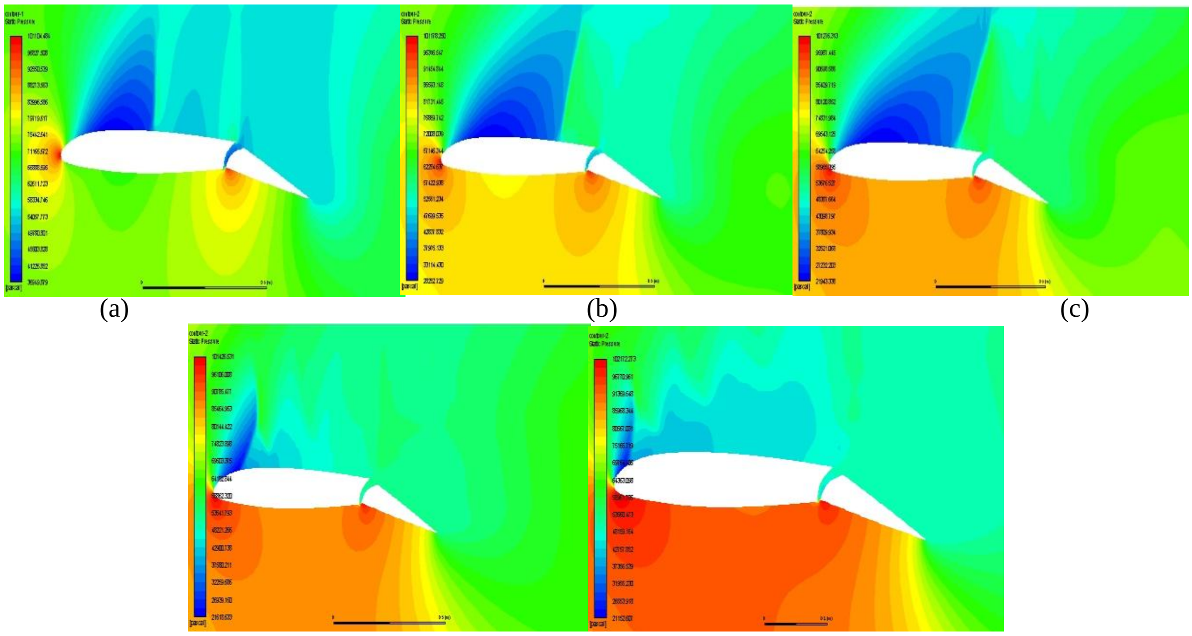


Figure 8: Pressure contour at DA=20 & M = 0.3 for (a) AOA=3 (b) AOA = 8 (c) AOA=12 (d) AOA=15 (e) AOA=20



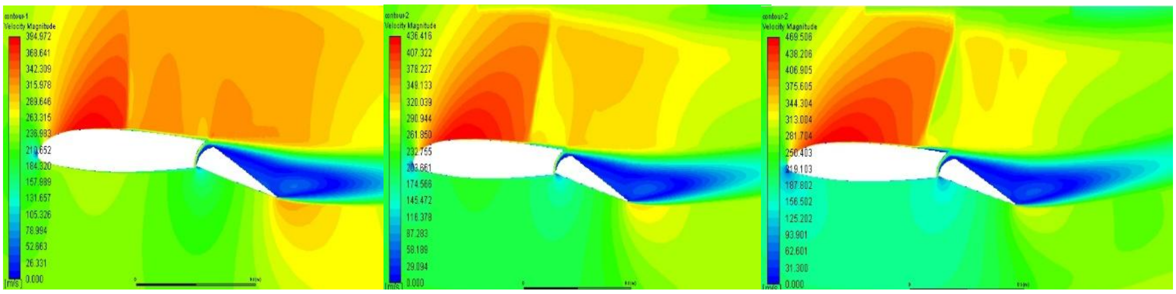
a)
(b) (c)
(d) (e)

Figure 9: Velocity contour at DA=20 & M = 0.3 for (a) AOA=3 (b) AOA = 8 (c) AOA=12 (d) AOA=15 (e) AOA=20

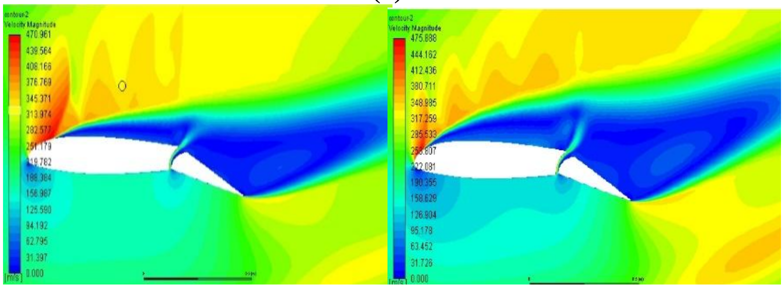


(a) (b) (c)
(d) (e)

Figure10: Pressure contour at DA=20 & M = 0.8 for (a) AOA=3 (b) AOA = 8 (c) AOA=12 (d) AOA=15 (e) AOA=20



(a) (b) (c)



(d) (e)

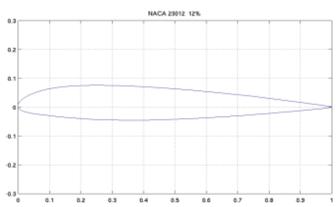
Figure 11: Velocity contour at DA=20 & M = 0.8 for (a) AOA=3 (b) AOA = 8 (c) AOA=12 (d) AOA=15 (e) AOA=20

Discussion

Figure 4-5 show that without using flap at take-off & landing speed if angle of attack increases then pressure increases at bottom side of aerofoil &drag decreases but wake will reduce.Figure 8-9 show that if flap uses at take-off & landing speed there is more increment in presure at bottom side of aerofoil.It means flap increases high lift with AOA increment but after AOA = 12, drag drastically decreases and after AOA=15, there is high wake generation around Aerofoil.Figure 6-7 show that without using flap at cruising speed, if AOA increases then there is no more increment in pressure at bottom of aerofoil but wake increases up to AOA =12 and there is detaching of air at upper surface of aerofoil after AOA =12 and high wake generation and vortex flow will start at this condition.Figure 10-11 show that if AOA increases with Flap at cruising speed, there will be small increment in pressure at bottom of aerofoil but large detech of air will be produce at upper surface of aerofoil after AOA =12 and Wake converts into vortex flow around upper surface of Aerofoil after AOA =12 and it produces Stalling after AOA= 15. It can see in figure 11 clearly.

IV. Experimental Work

NACA aerofoil'sScaled Model was manufactured by using this NACA profile for experimental work.



(a) (b) (c)

Figure 12: (a) NACA aerofoil Profile (b) NACA aerofoil Model (c) NACA aerofoil Model with flap

4.1Wind tunnel setup and validation: Wind tunnel setup was developed for 18 measurement points and CFD code results were validated by pressure coefficient calculated by wind tunnel setup at different Angle of Attack 3, 8, 12, 15& 20 at Mach No. = 0.3 an 0.8 for flap Angle 0 & 20.

(a) (b) (c)

Figure 13: (a)Wind tunnel model (b) Wind tunnel setup (c) Mach no generator

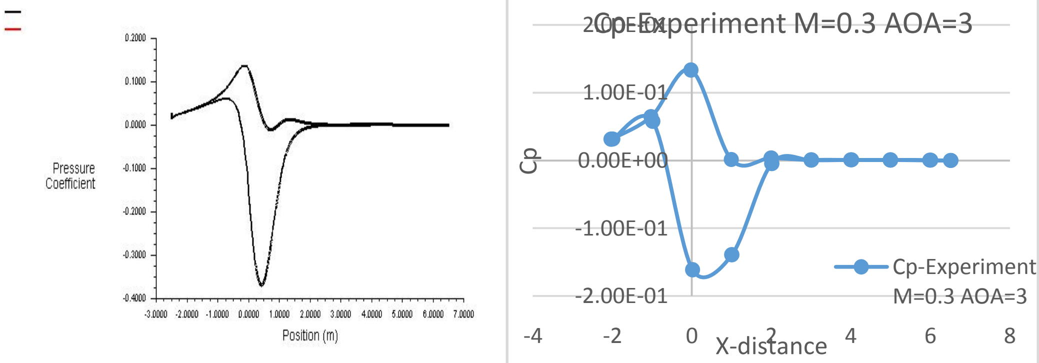


Figure 14: Comparision of Pressure coefficient of CFD and Wind tunnel result for AOA=3, Mach No = 0.3 at DA = 0

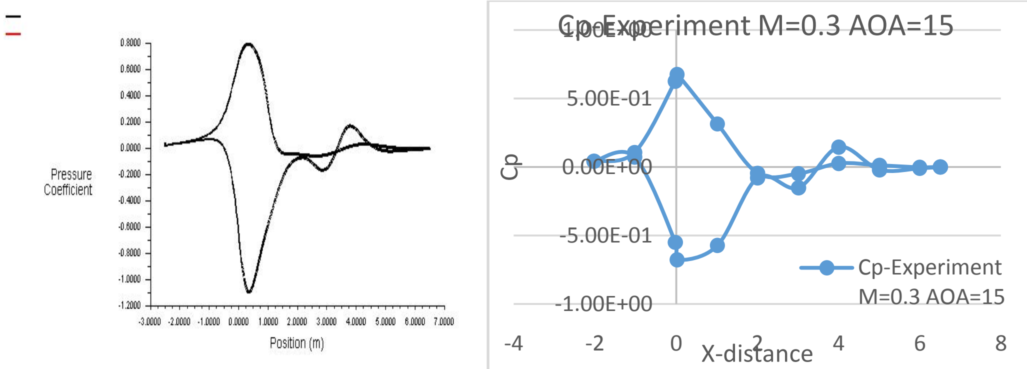


Figure 15: Comparision of Pressure coefficient of CFD and Wind tunnel result for AOA = 15, Mach No. = 0.3 at DA = 20

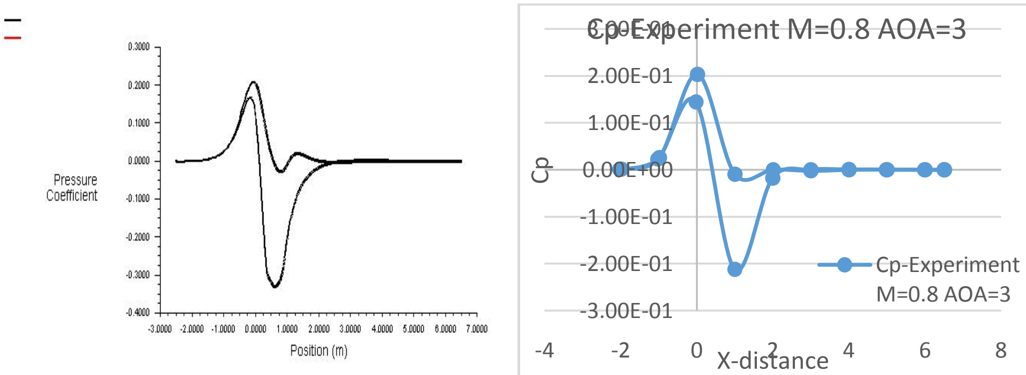


Figure 16: Comparison of Pressure coefficient of CFD and Wind tunnel result for AOA= 3, Mach No. = 0.8 at DA = 0

V. Conclusion

By result & discussion it found that if flap deflection uses at take–off and Landing speed, there is high increment in pressure up to AOA=15. it means flap increases high lift so it can conclude that at landing and take-off speed of aero-plane it needs to use flap deflection and when it reaches at cruising speed there is no use of flap deflection so once the high lift generates, flap should be closed. Other thing if AOA increases at high speed (cruising speed), pressure also increases but it is up to AOA =15 after that if AOA increases, velocity will decrease drastically above the upper surface of aerofoil (wings). So at cruising speed M =0.8 & angle of attack 20 “stalling” is available and it require to nose down to eliminate the stalling because at this condition lift will almost lost by wings. it found that highest lift will generate at AOA= 15 by using flap at M = 0.3 only and there is no loss of drag and also there is no any stalling at M = 0.3. According to Wind tunnel data, coefficient of pressure are almost same with CFD fluent x-y chart so results of CFD fluent for Mach no = 0.3 and Mach no = 0.8 with defferent AOA were validated.

So finally it concluded that at M = 0.3 (Take off & landing speed) the best condition is AOA = 15 with Deflection angle 20 to generate High lift and drag and at M = 0.8 (Cruising speed) the best condition is AOA = 3 with out flap to get high drag and also it can conclude that after AOA = 15 there is stalling at cruising speed.

Future Scope:
In future for same aerofoil model and wind tunnel setup, the research will completed on analysis of shock wave and Vortex flow at combination of high Mach no, Different angle of attack and Deflection Angles.

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