Effect of camber on the flutter characteristics of different selected airfoils

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Abstract: *Flutter is the phenomenon where the body will experience uncontrolled motions after reaching a certain velocity known as the critical velocity. The focus of this work is on studying the influence of position of camber of an airfoil on its flutter behaviour. Four different NACA five digit airfoils were selected based on the variation in position of camber and were analyzed at different air speeds. These airfoils were studied for their pitch and plunge behaviour which are the base for understanding the flutter characteristics of any body and the flutter characteristics are derived from those results.*

Key Words: *flutter behaviour, airfoil, pitch and plunge, and location of camber*

1. INTRODUCTION

Understanding the aerodynamic behavior and using those results to study the structural response of the body has gained its priority in recent times. The aeroelastic behavior of bodies has to be studied and observed in order to nullify the chances of a catastrophic disaster to happen.

Fluid structure interaction study is conducted to observe the behaviour of a solid body when the fluid forces play their role in structural responses.

This fluid structure interaction is a very complex process as we need to solve the fluid and structural equations simultaneously to obtain accurate results, this might not always be possible as the computational requirements are very high for this method.

In an aeroelastic phenomenon called flutter, the body tends to start oscillating with increasing amplitudes till the structure fails completely and these oscillations of increased amplitudes are caused once the body starts to travel at a velocity known as critical velocity. In this work, airfoil is studied for its flutter behavior based on its oscillatory motion.

Flutter of an airfoil can be analyzed by observing two kinds of motion, one is pitch motion, which can simply be described as pitch up and pitch down of the airfoil and the other kind of motion is heave or plunge motion, which is upward and downward motion of the airfoil, flutter is a phenomenon where the wing experiences both pitching and plunging at the same time.

The wing tends to move uncontrollably in both pitching and plunging directions due to which the structural integrity of the body is eventually compromised. To study the flutter

behaviour of a body, it is critical to understand the pitching and plunging motions of the body over a period of time.

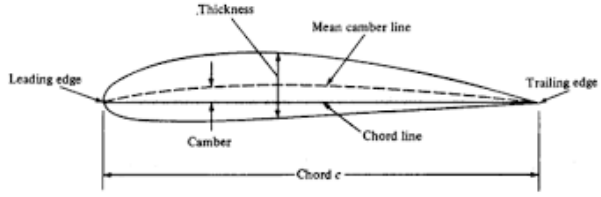


Fig. 1: Nomenclature of the airfoil

In a five arrangement NACA airfoil, every one of the digits address the subtleties of the plan lift coefficient, area point of greatest camber, reflex camber and the most extreme thickness in level of harmony length. In the event that an illustration of NACA 25012 airfoil, the primary digit 2 when increased by 0.15 is the plan lift coefficient of 0.3, the subsequent digit duplicated by 5 gives the mark of area of greatest camber of the airfoil profile in rates of harmony which is 25% for this situation, similarly 0 in the third digit clarifies about the reflex of the camber and the last two digits of the airfoil arrangement addresses about the situation of the most extreme thickness of the airfoil in rates of the harmony measurement of the airfoil, which is 12% on account of NACA 25012. With the end goal of this examination NACA 5 digit aerofoils– 21012, 22012, 23012 and 24012 were chosen as there is variety in the situation of camber steadily.

2. LITERATURE REVIEW

This paper deals with the study of assumptions of stream actuated aeroelastic pitching of an airfoil. Incompressible, thick viscous stream over a changed NACA0015 airfoil is combined with a two DOF model of a flexibly upheld airfoil. The paper proposes the idea of Force-Partitioning technique which uses the submerged limit strategy code ViCar3D created. Three key boundaries are investigated: the decreased speed, the balance approach, and the area of the pivot point. Mathematical investigation is performed utilizing the Force-Partitioning strategy. The results incorporate computational reproductions of the stream actuated pitching motions of NACA0015 airfoils that have been calculated at Re=1000. A parametric investigation of pitching reaction capacity of stable angle of attack, reduced speed and area of flexible pivot is performed. It is seen that expanding the harmony approach decreases the basic amplitude at which the system gets disturbed because of precise disturbances. Further, the framework loses memory of the balance approach for huge sufficiency motions. An investigation of the framework affectability to the area of the flexible pivot showed results that were to a great extent in accordance with the static airfoil steadiness forecasts. Further, a power apportioning device was applied to an example instance of a pitching airfoil and it demonstrates the capacity to take apart the commitment of different vortices to the streamlined powers on the airfoil [1]. The exploration was absolutely founded on the examination of results got between computational investigation done in ANSYS CFX and exploratory methodology. The Aeroelastic Prediction Workshop (AePW) gives a chance to evaluate cutting edge computational strategies and apparatuses for anticipating aeroelastic effect. Two cases were concentrated to legitimize the outcomes. The primary case incorporates consistent and constrained swaying tried in the NASA Langley Transonic Dynamic Tunnel utilizing the Oscillation Turntable (OTT) office, and the second situation where wing shudder was tried in the TDT on an adaptable mount pitch and plunge

mechanical assembly which gives two level of-opportunity dynamic movement. A definite clarification is given in regards to the trial approach towards the wing shudder investigation. An itemized portrayal in regards to the lattices utilized for CFD calculations is provided. An extremely point by point correlation between the test result and calculations are expounded utilizing graphical plots which utilize various models like SST, SST k-w, SA, and so forth. These models also differ in terms of time steps per period. RANS and URANS power coefficient forecast strategies are utilized in the Ansys calculation for producing the particular pressing factor diagrams for correlation with the test ones. Spatial combination with fixed better time-step-size of 128tt and shifting framework size show affectability to compel coefficients. Lift coefficient varieties despite the fact that exceptionally little are seen concerning matrix refinement. Drag and second coefficient shows more prominent affectability with matrix refinement, and the varieties are monotonic. The exploratory FRFs of pressing factor greatness and stage are contrasted and the computationally got FRFs at 60% wing-length area. The size FRFs show affectability to lattice refinement at the basic attractions top district, with medium and fine matrices foresee nearer results. Lower surface pressing factor extent FRF at 60% wingspan shows fantastic match with tests, with no lattice affectability [2]. The primary point of the paper is to investigate the idea of the airplane during the oscillation of subsonic traveler airplane at its journey speed utilizing improvement devices like CFD and FEA tools. A new examination called Fluid design cooperation called FSI. The investigation is done of how the airplane wing structure will disfigure at regard condition. The wing is planned utilizing displaying programming and broke down utilizing Ansys workbench. The results are looked at between singular investigation and consolidated FSI analysis. The paper shows two methodologies for direct underlying technique where the lift power acting at the focal point of pressing factor and the examination is finished. The technique proposed i.e. FSI shows more precise outcomes than the singular examination. Likewise from the outcomes we can know the diverse deflections for different mode shapes. It is finished up saying that the FSI is a high level technique for dissecting the wing [3]. The primary idea of this paper is to look at the frequencies, coefficients of pressing factor and speed of liquid/air acquired both tentatively and computationally. By using the idea of testing and plunging, thus differentiating the pitch and height of the model kept in the air flow, thus changing the air speed to make the appearance of the flutter, the exploratory results are obtained. Ansys multi physics (MFX) module was principally produced for liquid construction association contemplates. On one side, the primary part is addressed utilizing ANSYS Multiphysics and on the opposite side, the liquid part is tackled utilizing ANSYS CFX.A brief clarification is given in regards to the change of cross sections between the underlying and liquid lattices. The ANSYS code works like an expert code and traverses all multi-zone orders. It recovers the interface lattices of the CFX code, makes the planning and conveys the boundaries that control the timescale and coupling circles to the CFX code. A NACA 0012 airfoil was utilized and the construction was just permitted a solitary DoF,i.e., in twist. A harmony length of 8 inches and a sharp edge length of 21 inches were utilized. The wing was made out of an aluminum shell of 1/32 crawls in thickness. A spring steady of 5.826 N•m/rad was utilized. The recurrence existing apart from everything else in a particular speed range is talked about as additional increment in that reach brought about mathematical calculation constraints. For this situation, it will be harder to decide the vacillate speed as the airfoil accomplishes harmony in the slow down zone with the stream speed actually expanding. This article contemplated on the dissimilarity and zero-recurrence ripple marvels. The ANSYS-CFX coupling to demonstrate liquid design communication has been extremely helpful and we have had the option to agreeably display these wonders inside

limits limited by computational limit. It appears to be that the limit among disparity and ripple is extremely restricted. The demonstrating of such unknown phenomena is extremely mind boggling and we see that it is, still, hard to deliver intently reproducible outcomes. The issue lies in computational limits and, additionally, a few refinements to be added into scientific displaying [4]. A NACA 64A006 regular and a MBB A-3 supercritical airfoil were studied. Both the consistent and insecure streamlined coefficients were processed by utilizing LTRAN2-NLR code. Flutter and time-reaction investigations are performed for a NACA 64A006 customary and a MBB A-3 supercritical airfoil, both wavering with plunge, pitch, and aileron pitch levels of-opportunity (DOF's) in little aggravation transonic stream. The streamlined coefficients are determined utilizing the transonic code LTRAN2-NLR. The impacts of different sorts of aeroelastic boundaries on vacillate speeds for the bowing twist, bowing aileron, and twist aileron branches are examined. The ripple speeds related with the twisting twist branch are plotted against Mach numbers for various boundary esteems and the transonic plunge wonder is illustrated. To consider the shudder modes, the ripple speed, sufficiency proportion, and stage distinction at various Mach numbers are plotted against the mass proportion for both a 2DOF and a 3DOF case. Time-reaction results are acquired for the NACA 64A006 and the MBB A-3 airfoils at M=Q.85 and 0.765, individually. For the NACA 64A006 airfoil at Af=0.7, impartially stable reactions were acquired dependent on a bunch of boundary esteems comparing to a shudder condition in a different vacillate analysis. The positive headway of the aileron mass focus cannot just dispense with the ripple limits of aileron related branches yet in addition speed up the twisting twist branch. The impartially stable reactions were gotten when the flight speed was decreased by 3.5% [5]. The values of 'c' which is the congruity length of the airfoil, 'h' and 'α' being the heave (positive vertical) and pitch (positive nose up) movements, Xcp, Xcm and Xo which are the location of center point of pressure, point of center of mass and focal point of flexural axis, respectively are considered in this article. The mesh at the border of the airfoil is kept enhanced because of the presence of higher slope of stream properties (p, ρ, T, V) and turbulence impacts near the airfoil surface when measured against the outside furthest reaches of flow domain. The free stream limits applied at the upstream of the space are u_∞ v_∞ ρ_∞ and p_∞, however zero pressure factor limit condition is applied at the downstream of the space. The behaviour of NACA 0012 airfoil with structural damping is concentrated under different free stream conditions. The results are acquired by coupling ANSYS FLOTRAN with the in-house essential code in time region using the Newmark's computation. At the angle of attack specified, FLOTRAN calculates the pressure gradient over the airfoil which is used to register the lift and moment for structural analysis. These lift and moment values are then passed as input for simulating structural analysis for assessing the response of the airfoil. The structural damping values are assumed as $V_h = 0.01$ and $V_a = 0.0$. The time history of flinging and pitching response of the airfoil at the fixed point and the related lift coefficients for various free stream wind current paces were inspected. Pitch and flinging developments and the relating lift coefficient influence fluctuate and join to zero mean circumstance of the airfoil with time at stream speed of 190 m/sec. At the stream speed of 192.45 m/sec, both the heave and pitch developments of the airfoil are fundamental consonants in nature and their amplitudes stay consistent with time and this speed is identified as critical speed of the airfoil system. It tends to be seen that at a stream speed of 193 m/sec, the airfoil fluctuates unboundedly whose amplitudes increase significantly with time. The results in this manner show that the movements of the airfoil at under-current velocities underneath 192.45 m/sec is consistent, and those previous this fundamental speed are unpredictable [6].

3. METHODOLOGY

As the priority of this study is to understand the flutter behavior of an airfoil, computational fluid dynamics application is used for analysis. NACA five digit series airfoils were selected in such a way that the position of camber moves from leading edge to trailing edge in terms of the percentage of the chord in each airfoil.

The airfoil is very finely meshed using triangles. Once the meshing is satisfactory, the mesh is imported for flow analysis where the pitch and plunge are studied separately at velocities from 60, 80, 100, 120, 140, 160, 180, 190, 195 and 200 meters per second. Six degree of freedom analysis is used to give the input parameters such as mass of the airfoil (m), spring stiffness in plunge motion (K_h), spring stiffness in pitch motion (K_α), mass moment of inertia about support point (I_α), position of center of pressure of airfoil (Xcp), position of center of mass (Xcm).

These values were inspired from the work of Davinder Rana et al [6]. Dynamic mesh is used for this analysis as the body needs to react and displace based on the reactions obtained from the air flow, where the dynamic mesh settings like spring factor constant, diffusion factor and scaling factor were specified.

The wing is treated as rigid body as it should not deform and its surroundings were also treated as rigid but as passive.

The entire external part of the surrounds will be set as a deforming mesh as this part of the mesh has to accommodate the deformation of the mesh caused by the movement of the wing. The airfoil is analyzed for the variation in aerodynamic lift which is based on the movement of the airfoil obliging to free stream velocity and other parameters of spring stiffness constants and position of the center of pressure of the airfoil and the position of the center of mass, etc.

Based on the variation of the aerodynamic lift along the time period, if the fluctuations of the aerodynamic lift damps along the time it can be understood that the wing is getting stabilized; if the fluctuations are constant over the time, it can be understood that the body is oscillating but is not fluttering, in the same way if the variations of the aerodynamic lift is seen to increase with time, it can be understood that the body is fluttering.

The airfoils were constrained to move only between positive angle of attack of 10 deg. to negative angle of attack of 10 deg. and in the same way the airfoils were restricted to a positive upward motion of 0.5 meters and to a downward motion of 0.5 meters.

The mass center of the airfoil was fixed at c/4 and the center of flexural axis was fixed frontward of the center of mass at a distance of 0.15 m from the leading edge of the airfoil. Dynamic mesh was implemented and smoothing, layering and remeshing options were used to create the mesh that will serve the purpose.

For the sake of pitching, one degree of freedom rotation was used where as for the purpose of plunge or heave motion, one degree of translation was selected with the constraints as stated in the above paragraph.

Table 1: Stiffness and inertia properties assumed

Inertia Properties	m = 51.5 Kg, I_α = 2.275 Kg m^2, X_0 = 0.4 m, X_{cm} = 0.4429 m, X_A = 0.0429 m
Stiffness properties	K_h = 50828.463 N/m, K_α = 35923.241 Nm/rad

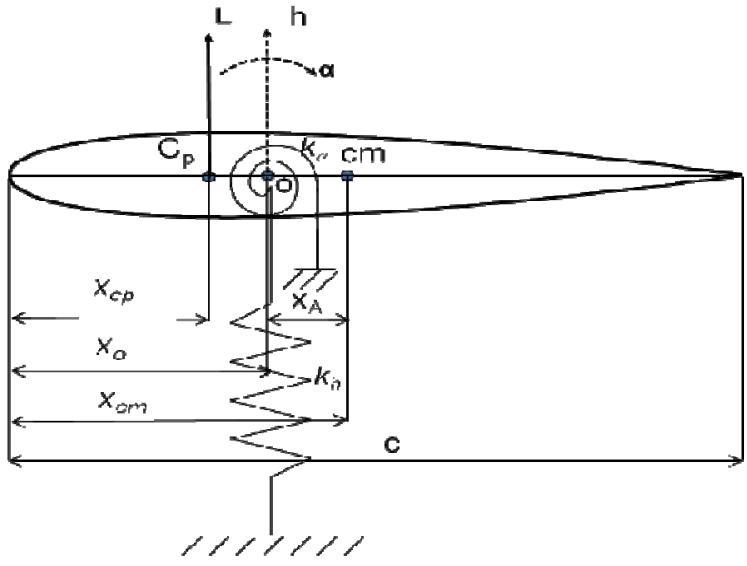


Fig. 2: Airfoil model

4. RESULTS AND DISCUSSIONS

Four different airfoils were analyzed under the same properties and conditions to observe the behaviour of pitch and plunge and to describe the effect of the camber over these motions. From the figures attached below we can see that the motion of the airfoil at lower inlet speeds of 60 m/s is getting stabilized over time with small initial disturbances; when the inlet speed is varied to 160 m/s it is observed that the airfoil has constant movement along the time and it is seen to have constant as well as controlled motion both in pitch and in plunge and at velocities of 195 m/s the airfoil seem to unstable oscillations in pitching movement where as in plunge motion, these airfoils seem to oscillate with more frequency than at lower inlet velocities.

We suppose that the camber moves from the leading edge towards the trailing edge for the airfoils 21012, 22012, 23012, 24012 as the chord length was maintained constant for all the airfoils. By observing the Cl plot of 21012 under pitching motion at low velocities of 60 m/s, the airfoil seems to oscillate in the beginning and was stabilized soon, and at the velocities greater than 160 m/s. The airfoil seems to oscillate uncontrollably for few seconds and then was stabilized over the time and at velocities reaching 200 m/s, the wing was oscillating constantly over a period of time and then started to oscillate in uncontrolled motion.

Coming to the plunging motion, airfoil stabilizes within a short period of time at lower velocities of 60 m/s and motions with lesser frequencies of higher deflections at speed of 160 m/s and finally motions that have a clear smaller phase angles at higher air inlet velocities of 195 m/s. And a similar kind of behaviour can be observed from studying the results of NACA 22012, NACA 23012 and NACA 24012 airfoil sections.

5. CONCLUSIONS

From various results that were obtained after numerous computations, only the results that portrayed a remarkable change in the behaviour of the coefficient of lift were analyzed and from the graphs displayed, it is obvious that the instability in pitching motion of the airfoil was more as the position of maximum camber moves closer to the center of flexural axis on the airfoil. When the plunging motion was observed for the variation of the lift coefficient, there was an unsteady and irregular variation observed in the values of the lift coefficient; this could be seen in the Cl vs time plot of the 21012 airfoil, for this airfoil the location of maximum camber is far than compared to that of the other airfoils which are 22012, 23012 and 24012 as there can be no much fluctuations to be seen in the graph of 21012 compared to the rest. In the case of pitching movement, when both the pitching and plunging motion of the airfoil are combined and observed, it is clearly understood that the airfoil is under flutter motion at the velocity of 195 m/s as there was a constant fluctuations in the plunge motion of the airfoil, where as an unsteady and unpredictable movement was observed in the pitching motion of the airfoil. Focusing on the effect of the position of camber on the flutter phenomenon, as the location of camber is moving closer to the center of flexural axis, it was clearly observed that the flutter was inevitable at the early time itself, this was clearly by observing the pitching motion of 21012, 22012, 23012, 24012 airfoils.

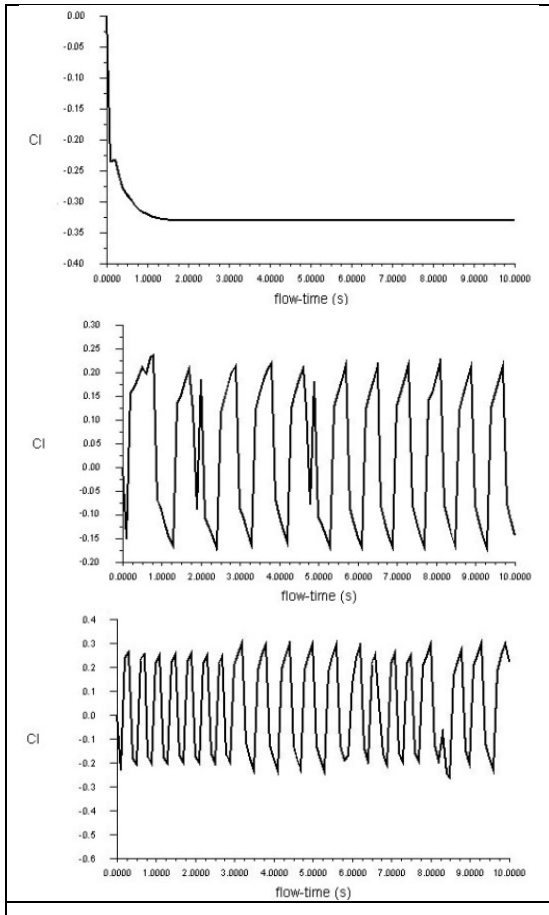


Fig. 3: Coefficient of lift of 21012 in pitching motion

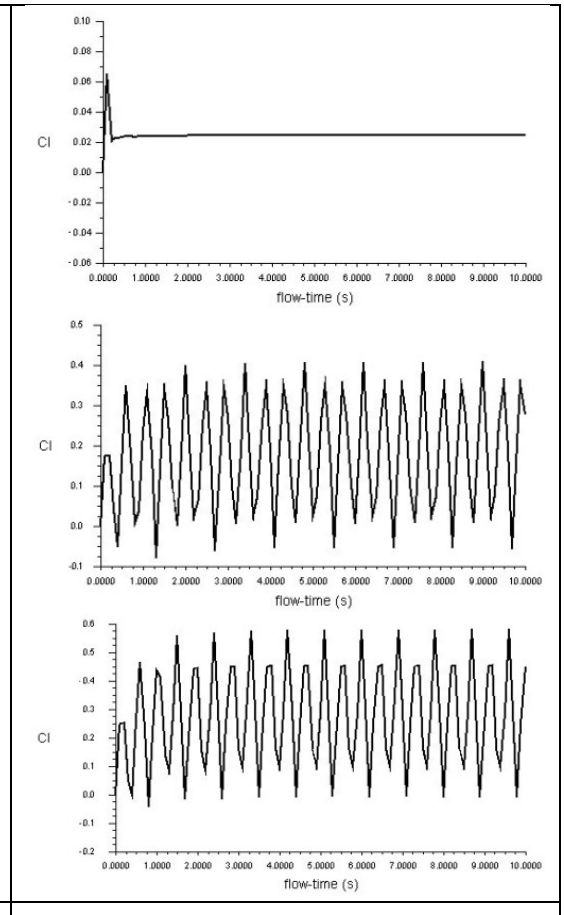


Fig. 4: Coefficient of lift of 21012 in plunging motion

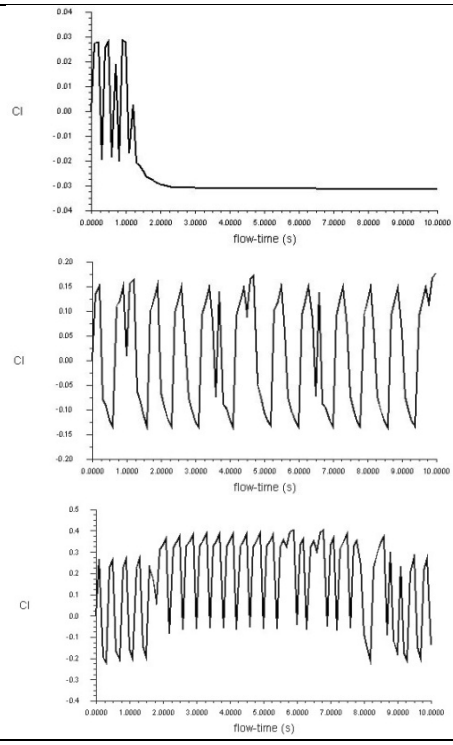


Fig. 5: Coefficient of lift of 22012 in pitching motion

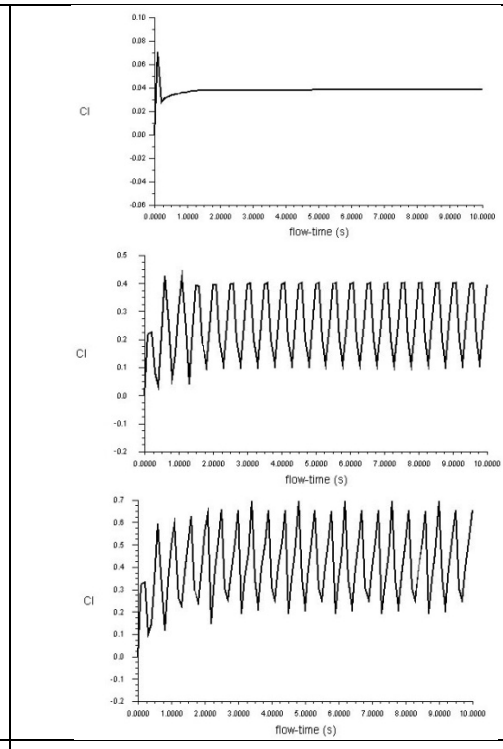


Fig. 6: Coefficient of lift of 22012 in plunging motion

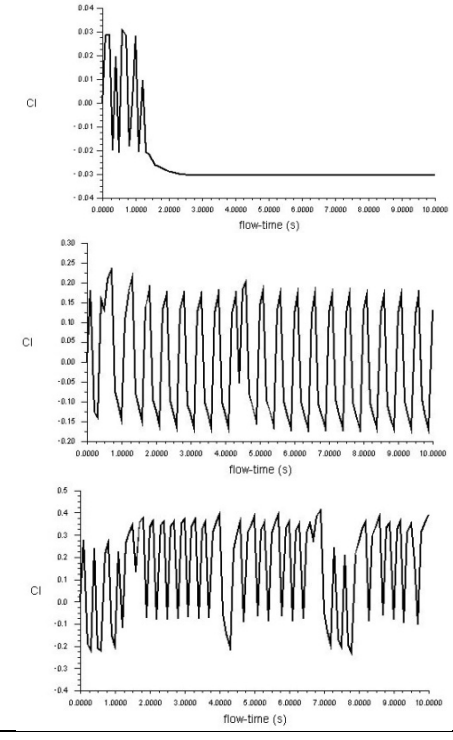


Fig. 7: Coefficient of lift of 23012 in pitching motion

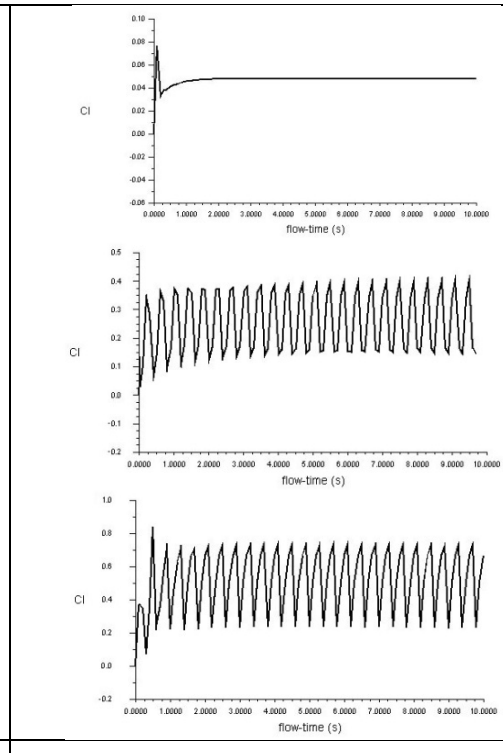


Fig. 8: Coefficient of lift of 23012 in plunging motion

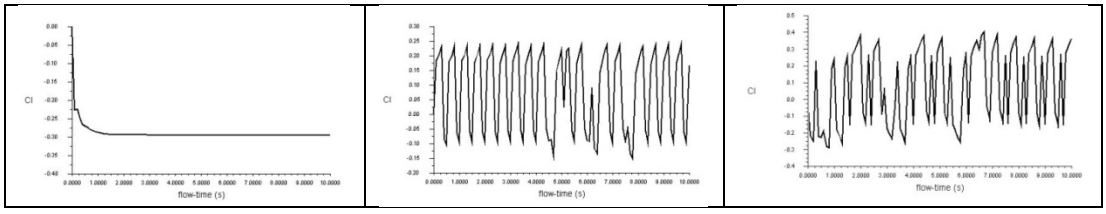


Fig. 9: Coefficient of lift of 24012 in pitching motion

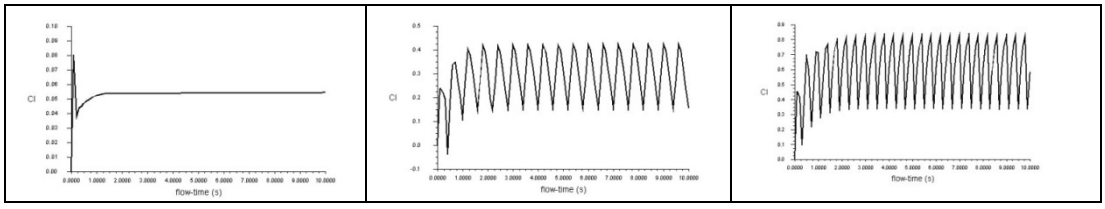


Fig. 10: Coefficient of lift of 24012 in plunging motion

FUTURE SCOPE

Further studies can be made to understand the effect of maximum camber, as well as the study, which can also be conducted by selecting airfoils that have the camber position more aft of the leading edge such as those selected in this study.

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