Evaluation and Selection of Aerofoil based on Flow Induced Vibration and Damping Ratio

Maheswaran M[1], Uthish Shankar S[2], Nithin Kumar P[3], Vijey V S[4]

[1]Assistant Professor, [2,3,4]UG students
Mechanical Engineering Department,
Sri Venkateswara College of Engineering,Chennai,India

***Abstract*— This paper deals with the evaluation and selection of aerofoils based on its performance characteristics. Two different type of aerofoils are used for testing such as ordinary aerofoil and supercritical aerofoil namely NACA0012 and NACA SCA0714 respectively are being considered for analysis. The tests are being conducted using ANSYS CFX Simulation software. The two aerofoils subjected to Flow induced vibration(FIV) for vibrational analysis using fluid structure interface(FSI). They are finally tested on their damping characteristics. These test results of both aerofoils are compared and results are concluded.**

***IndexTerms*—Aerofoils,Performance characteristics,Supercritical Aerofoil, NACA0012, NACA SCA0714, ANSYS CFX, Flow induced vibration(FIV), Vibrational analysis, Fluid structure interface(FSI), Damping characteristics.**

I. INTRODUCTION

Aerofoil

An aircraft in straight-and-level unaccelerated flight has four forces acting on it. (In turning, diving, or climbing flight, additional forces come into play.) These forces are lift, an upward-acting force; drag, a retarding force of the resistance to lift and to the friction of the aircraft moving through the air; weight, the downward effect that gravity has on the aircraft; and thrust, the forward-acting force provided by the propulsion system (or, in the case of unpowered aircraft, by using gravity to translate altitude into speed). Drag and weight are elements inherent in any object, including an aircraft. Lift and thrust are artificially created elements devised to enable an aircraft to fly.

Airfoil is a structure designed to obtain reaction upon its surface from the air through which it moves. Early airfoils typically had little more than a slightly curved upper surface and a flat undersurface. Over the years, airfoils have been adapted to meet changing needs. By the 1920s, airfoils typically had a rounded upper surface, with the greatest height being reached in the first third of the chord (width). In time, both upper and lower surfaces were curved to a greater or lesser degree, and the thickest part of the airfoil gradually moved backward. As airspeeds grew, there was a requirement for a very smooth passage of air over the surface, which was achieved in the laminar-flow airfoil, where the camber was farther back than contemporary practice dictated. Supersonic aircraft required even more drastic changes in airfoil shapes, some losing the roundness formerly associated with a wing and having a double-wedge shape.

By moving forward in the air, the wing’s airfoil obtains a reaction useful for flight from the air passing over its surface. (In flight the airfoil of the wing normally produces the greatest amount of lift, but propellers, tail surfaces, and the fuselage also function as airfoils and generate varying amounts of lift.) In the 18th century the Swiss mathematician Daniel Bernoulli discovered that, if the velocity of air is increased over a certain point of an airfoil, the pressure of the air is decreased. Air flowing over the curved top surface of the wing’s airfoil moves faster than the air flowing on the bottom surface, decreasing the pressure on top. The higher pressure from below pushes (lifts) the wing up to the lower pressure area. Simultaneously the air flowing along the underside of the wing is deflected downward, providing a Newtonian equal and opposite reaction and contributing to the total lift.

The lift an airfoil generates is also affected by its “angle of attack”—i.e., its angle relative to the wind. Both lift and angle of attack can be immediately, if crudely, demonstrated, by holding one’s hand out the window of a moving automobile. When the hand is turned flat to the wind, much resistance is felt and little “lift” is generated, for there is a turbulent region behind the hand. The ratio of lift to drag is low. When the hand is held parallel to the wind, there is far less drag and a moderate amount of lift is generated, the turbulence smooths out, and there is a better ratio of lift to drag. However, if the hand is turned slightly so that its forward edge is raised to a higher angle of attack, the generation of lift will increase. This favorable increase in the lift-to-drag ratio will create a tendency for the hand to “fly” up and over. The greater the speed, the greater the lift and drag will be. Thus, total lift is related to the shape of the airfoil, the angle of attack, and the speed with which the wing passes through the air.

Super Critical Aerofoil

Dr. Richard Whitcomb, a renowned aeronautical engineer at Langley, developed the concept of a supercritical wing. He was one of many engineers in the 1950s and 60s fascinated by the transonic speed regime.An airfoil considered unconventional when tested in the early 1970s by NASA at the Dryden Flight Research Center is now universally recognized by the aviation industry as a wing design that increases flying efficiency and helps lower fuel costs is the supercritical airfoil, the design has led to development of the supercritical wings (SCW) now used worldwide on business jets, airliners and transports, and numerous military aircraft.Conventional wings are rounded on top and flat on the bottom. The SCW is flatter on the top, rounded on the bottom, and the upper trailing edge is accented with a downward curve to restore lift lost by flattening the upper surface.At speeds in the transonic range just below and just above the speed of sound the SCW delays the formation of the supersonic shock wave on the upper wing surface and reduces its strength, allowing the aircraft to fly faster with less effort. Few test results on these aircraft increased transonic efficiency by as much as 15%.

When an aircraft with a conventional wing nears a speed of sound (Mach 1), air flowing across the top of the wing moves faster and becomes supersonic. This creates a shock wave on the wing's upper surface even though the aircraft, as a whole, has not exceeded Mach 1. The aircraft, at this point, is flying at speed is called the critical speed. The shockwave causes the smooth flow of air hugging the wing's upper surface (the boundary layer) to separate from the wing and create turbulence.
Separated boundary layers are like wakes behind a boat the air is unsteady and churning, and drag increases. This increases fuel consumption and it can also lead to a decrease in speed and cause vibrations. In rare cases, aircraft have also become uncontrollable due to boundary layer separation.

Supercritical wings have a flat-on-top "upside down" look. As air moves across the top of a SCW it does not speed up nearly as much as over a curved upper surface. This delays the onset of the shock wave and also reduces aerodynamic drag associated with boundary layer separation. Lift that is lost with less curvature on the upper surface of the wing is regained by adding more curvature to the upper trailing edge. Now the aircraft can cruise at a higher subsonic speed and easily fly up into the supercritical range. And with less drag, the aircraft is using less fuel than it would otherwise consume. Higher subsonic cruise speeds and less drag translates into airliners and business jets getting to their destinations faster on less fuel, and they can fly farther factors that help keep the cost of passenger tickets and air freight down

Flow Induced Vibration(FIV)

Whenever a structure is exposed to a flowing fluid, the fluid forces may cause the structure to vibrate. Fluid flow is a source of energy that can induce structural and mechanical oscillations. Flow-induced vibrations describe the interaction that occurs between the fluid's dynamic forces and a structure's inertial, damping, and elastic forces. The study of flow-induced vibrations has rapidly developed in aeronautical and non-aeronautical engineering. In aeronautics, flow-induced vibration is often referred to as flutter, a topic of aero elasticity concerning the mutual interactions of aerodynamic, elastic, and inertial forces in a flying object, its components, or its propulsion systems.

Fluid-Structure Interaction (FSI)

Fluid-structure interaction (FSI) simulations are coupled CFD (fluids) and FEM (mechanics) cases. FSI is a part of multiphysics simulations and an actual main focus in CFD development. Fluid-structure interaction (FSI) is a coupling between the laws that describe fluid dynamics and structural mechanics. This phenomenon is characterized by interactions which can be stable or oscillatory between a deformable or moving structure and a surrounding or internal fluid flow.

When a fluid flow encounters a structure, stresses and strains are exerted on the solid object forces that can lead to deformations. These deformations can be quite large or very small, depending on the pressure and velocity of the flow and the material properties of the actual structure. If the deformations of the structure are quite small and the variations in time are also relatively slow, the fluid's behavior will not be greatly affected by the deformation. If the variations in time are fast, greater than a few cycles per second, then even small structural deformations will lead to pressure waves in the fluid. These pressure waves lead to the radiation of sound from vibrating structures. Such problems can be treated as an acoustic-structure interaction. If the deformations of the structure are large, the velocity and pressure fields of the fluid will change as a result, and problems are to be treated as a bidirectionally coupled multiphysics analysis. The fluid flow and pressure fields affect the structural deformations, and the structural deformations affect the flow and pressure.

As these solvers use different methods and codes, the transfer of the boundary conditions at the interface is an important feature of an FSI solution.

1-way FSI

1-way FSI typically describes the pure mapping of physical properties resulting from the analysis of a CFD-/FE-model to another FE-model. The two models typically do not rely on matching meshes (e.g. mapping aerodynamic pressure distribution onto a structural Finite Element model). However, in the case of 1-way FSI the mapping of the physical properties does not include the modification of any of the meshes.

2-way FSI

In the case of 2-way FSI the mapping is done in an iterative loop i.e. the results of the first model are mapped to the second model and these results are mapped back to the first model and so on until convergence is found or the process is stopped manually. Very often in the case of 2-way FSI one of the mapping steps involves the modification/morphing of the mesh of one or both of the models (e.g. mapping deformations coming from aerodynamic loads back to the CFD-model and re-evaluating the CFD-model in the deformed configuration).

Mesh morphing

In most cases FSI is quite simple to realize even employing meshes not matching. However as soon as mesh-morphing is needed the whole process gets much more difficult and only few software solutions are around that can handle this. They key-problems with mesh-morphing are:

- Performance: Typical CFD-models as employed today in Formula 1 or Aerospace require very efficient morphing algorithms. A lot of the straight-forward approaches are not able to handle CFD-models consisting of several millions of cells.
- Surface Quality: For calculating pressure distributions in aerodynamics the surface quality in terms of continuity has to be quite high. Otherwise one starts to observe oscillations in the pressure fields. This is namely a challenge in the case where the mesh providing the deformation (typically the structural FE-mesh) is significantly coarser then the surface mesh of the CFD-model (which is quite common).

II. DESIGN OF AEROFOILS

NACA design:

The NACA aerofoils are standard aerofoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA aerofoils 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 aerofoil and calculate its properties.
The formula for the shape of a NACA 00xx foil, with "xx" being replaced by the percentage of thickness to chord, is:

$$y_t = 5t\left[0.2969\sqrt{\frac{x}{c}} - 0.1260\left(\frac{x}{c}\right) - 0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 - 0.1015\left(\frac{x}{c}\right)^4\right]$$

Where:

- c is the chord length,
- x is the position along the chord from 0 to c,
- y_t is the half thickness at a given value of x (centreline to surface), and
- t is the maximum thickness as a fraction of the chord (so t gives the last two digits in the NACA 4-digit denomination divided by 10).

This equation gives the thickness as percentage of the chord length, to get the thickness the above equation should be multiplied with *c*.

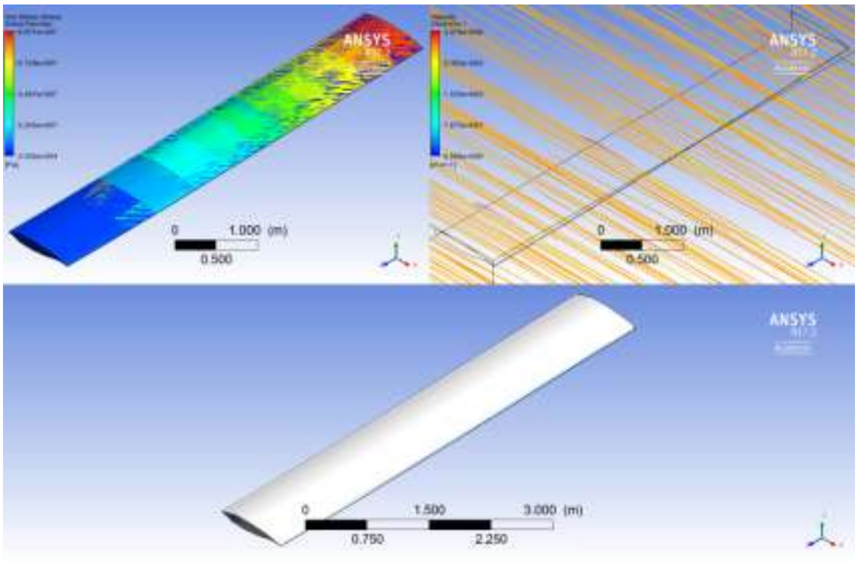
Inputs and Boundary condition:

The problem considers flow around the Aerospatiale aerofoil at different angles of attack. For that we take some initial inputs and boundary condition for our problem which are shown in the table.

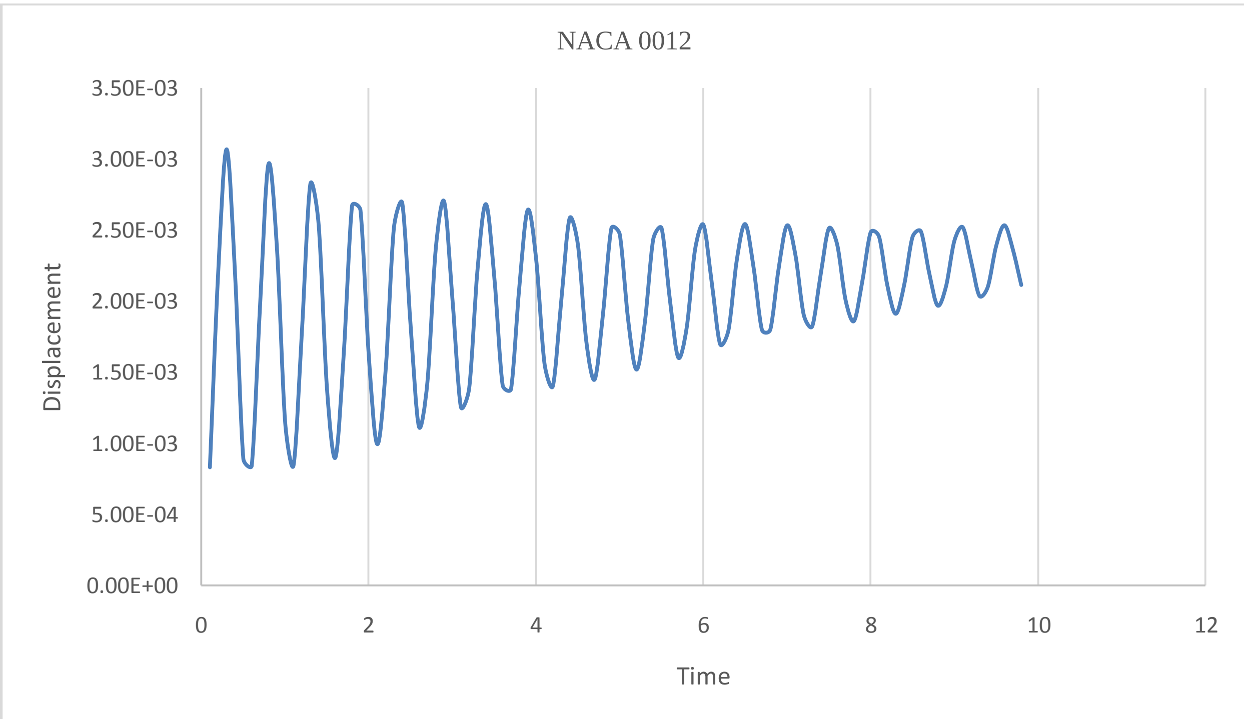
S.No	Input	Value
1	Velocity of flow	945km/hr(subsonic)
2	Operating temperature	300 K
3	Operating pressure	50Pa(assumption)
4	Model	Transition
5	Density of fluid	1.225 Kg/m^3
6	Kinematic viscosity	$1.4607*10^{-5}$
7	Length	1 m
8	AOA	0º,5º,10º,-5º, -10º
9	Fluid	Air as an ideal

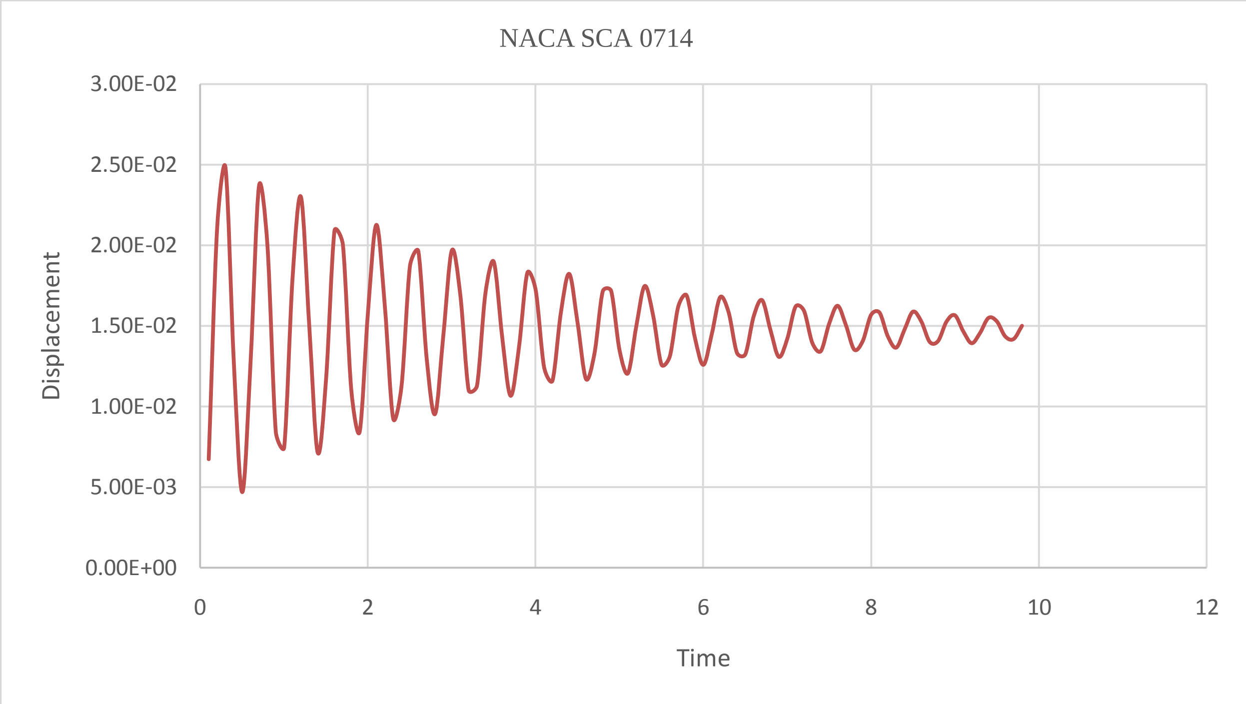
- The problem is considered by inducing the flow only at 0.1^{th} second and flow becomes 0 there onwards.

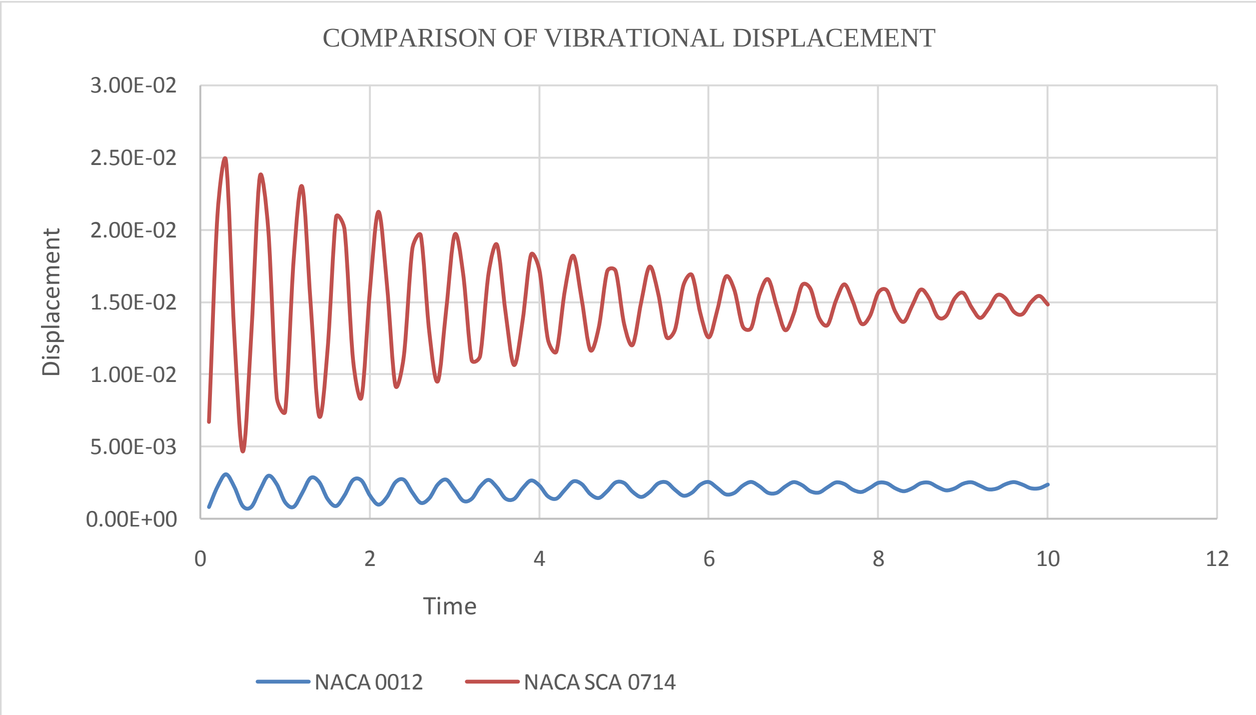
III. ANALYSIS OF FLUID STRUCTURE INTERACTION(FSI)



IV. RESULTS FOR FLUID STRUCTURE INTERACTION(FSI)







V. Calculation on Damping Ratio

Using logarithmic decrement:

1. $\delta = \ln(X_n/X_{n+1})$

2. $\delta = 2\pi\zeta/\sqrt{(1-\zeta^2)}$

Table 1: Damping ratio of both Aerofoils

AEROFOIL	X_n	X_{n+1}	δ	ζ
NACA 0012	0.0030659	0.0029612	0.00354	0.005807
NACA SCA 0714	0.024799	0.023676	0.00474	0.00722

VI. Results and Conclusion

- If aerofoil to be selected under vibrational study,symmetriacal aerofoil provides the best option.
- In an symmetrical aerofoil when initial force is given,is starts to vibrate,causing the centre of gravity to change and when placed under the fluid flow.As the flow in symmetrical body is divided uniform they tend to damp the caused vibration.
- But in case of non symmetrical aerofoil,the flow is not uniform in both the direction of the body,which makes the centre of gravity of the aerofoil to keeps on changing.
- So the vibration is more when compaered to the vibration of symmetrical aerofoil.
- So,in terms of ***vibrational analysisNACA 0012*** is the best aerofoil.
- Though the Vibration occurs, its important to analyze the damping ratio.The Damping Ratio must be higher so that aerofoil reaches the equilibrium position at faster rate.
- So,by analyzing the Damping ratio ***NACA SCA 0714*** provides ***higher damping ratio***.
- Hence, ***NACA SCA 0714*** is selected as ***the best aerofoil*** when compared with NACA 0012.

References

[1] Analysis, design, and testing of aerofoils for use at ultra-low reynolds numbers by peter j. Kunz ,ilan m. Kroo.
[2] Application of direct computing of one-way coupling technique in seismic analysis of concrete gravity dam by Quoc Cong TRINH, Liao-jun ZHANG.
[3] Britannica Encyclopaedia –URL address -https://www.britannica.com/technology/airplane.
[4] Cfd analysis of rae 2822 supercritical aerofoil at transonic mach speeds k.harish kumar, ch.kiran kumar, t.naveen kumar.
[5] Coupled bending-bending-torsion vibration of a rotating pre-twisted beam with aerofoil cross-section and flexible root by finite element method by Bulent Yardimoglua, and Daniel J. Inmanb.
[6] Determination of Natural Frequency of Aerofoil Section Blades Using Finite Element Approach, Study of Effect of Aspect Ratio and Thickness on Natural Frequency by KamleshPurohit and Manish Bhandari.
[7] Flow and Heat Transfer Characteristics Over a NACA0018 Aerofoil and a Test Aerofoil – A Comparative Study by M.Sri Rama Murthy, Dr. K.Rambabu and Dr. A.V.S.S.K.S.Gupta.
[8] Modal Analysis of Aircraft Wing using AnsysWorkbench Software Packageby Nikhil A. Khadse.
[9] Modeling and structural analysis on a300 flight wing by using ansys by kakumani sureka1 and r satyameher.
[10] Transient analysis of plate coupled with fluid by nandu RS and jayaraj kochupillai.
[11] Vibration Analysis of Dragonfly wing section in Gliding Mode at Low Reynolds Numbers by Husain Mehdi, Sayed Fahad Anwer, Akhlaque Ahmad.
[12] Vibrational analysis of circular arc areofoil shaped plates by H.B.Kurashia and S.Rowthani.