Experimental Flutter Analysis over Different Selected Wing Planforms by Varying the Wing Cross Section Geometry

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Abstract - *Flutter is a phenomenon that occurs in structures which are subjected to aerodynamic forces. As the wing model flies at increasing speeds and increasing angle of attack the vibrations get increased and the frequency of these modes coincide with each other which leads to resonance, this is called Flutter and this may lead to catastrophic failures in the aircraft flight. An appropriate wing model design includes various parameters that need to be selected according to the wind-tunnel test conditions. The material used for skin is monocot, spars are made of aluminium, ribs are made of balsa wood. We follow an iterative approach in which angle of attack and true airspeed are constant per iteration. In the present note, parameters we are going to use are design lift coefficient and location of maximum camber, the flutter response of the wing models is detected experimentally with the help of accelerometers placed at the leading edge and trailing edge of the aero elastic models. The aero elastic models we use in the present experiment have two degrees of freedom, these wing models with accelerometer setup are placed in the test section of the wind tunnel where Arduino UNO gives the code to encrypt the flutter response to save the values from each iteration; by the observation of this iterative approach we can reach a conclusion. This experimental flutter analysis on aircraft wings ensures that flutter does not occur if we make sure the model strictly operates in its design limitations.*

Keywords: *Aero elasticity, Flutter, Experimental Flutter analysis.*

I INTRODUCTION

Aero elasticity is the phenomenon where we study the interaction between the deformations of elastic structure and the resultant aerodynamic forces. Engineers in today's world want to build flying vehicles that are faster and use less fuel, which puts them under pressure to design lifting surfaces that are thinner, lighter, and more flexible. Aero elasticity is therefore important in the design of aircraft lifting surfaces. The deformation of an elastic body in a cross flow due to aerodynamic loads is the focus of aero elasticity.

Structural dynamics, static aero elasticity, and dynamic aero elasticity are only a few examples of interactions. In aero elasticity, the loads (aerodynamics) are mostly determined by deformation, and the deformation (structural dynamics) is primarily determined by the loads, resulting in a linked problem. The main area of interest in static aero elasticity is static instability, also known as "Divergence," while the most important phenomenon in dynamic aero elasticity is Flutter. At threshold airspeed, known as the flutter speed, the self-sustaining motion is shown by aircraft. Oscillation varies above this speed, producing intense vibrations which can cause structural damage by rising amplitudes or may cause eventual destruction to the aircraft. In the cross flow; flutter is one of the most extreme forms of instability that an aircraft's wing and tail can show. Both input and output vibration properties of a system are studied to help identify the system on the basis of mass, stiffness, and damping.

The measurement of a structure's or machine's natural frequencies is useful in determining the operational speeds of nearby machinery to avoid resonant conditions.

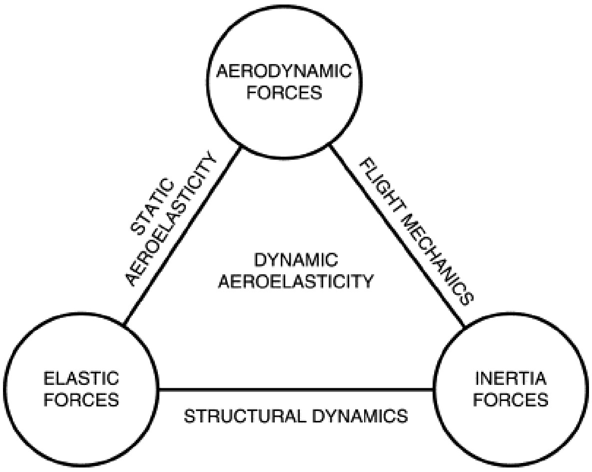

Figure 1: Collars Triangle

Coupling high-level Computational Fluid Dynamic (CFD) methodologies with structural dynamic tools to perform aero elastic analysis is referred to as Computational Aero Elasticity (CAE). CAE has acquired popularity since significant development has been achieved in CFD, Computational Structural Dynamics (CSD), and computer technology. While computational approaches for studying various elements of aero elastic response have been explored for some time, there are still several unresolved research challenges. Many techniques in computational aero elasticity, for example, strive to combine distinct computational methodologies for the aerodynamic and structural dynamic subsystems. Flutter, as we recollect, is one of the physical occurrences that tends to happen when a solid’s elastic nature/behavior interconnects with the gas or fluid which is naturally passing over it. Flutter is an instability which happens due to the elasticity of the body and varies over a particular time characterized by strong solid-structure vibrations of quickly rising amplitude. It frequently results in either major structural damage or total demolition of the structure. When the parameters detailing fluid-structure interaction approach’s critical values, flutter happens. The physical explanation for this phenomena is that, under certain conditions, the energy of the flow is rapidly absorbed by the structure and converted into mechanical vibration energy. Flutter must be prevented in engineering practice by either designing the structure or implementing a control system capable of suppressing unwanted vibrations.

The prior work should have been thoroughly examined in order to obtain a clear understanding of how to set up an experimental setup for inspection of the flutter response to the changes happening in the test section The Structural Dynamics Division at NASA Langley Research Center, known as the Benchmark models Program, organized wind tunnel tests to reach their objective. The wing used in the test has the airfoil of NACA 0012 rectangular in shape when seen from top was fixed on the flexible two DOF mount system. There's no inertial connection in between two modes (Pitch/Plunge) because the system was developed that way [1]. The pitch and plunge motion parameters were determined using servo accelerometers. The research concentrated on conventional flutter, Stall flutter and plunge instability. Static ports arranged chord wise just on the wing were used to calculate pressure distributions. As per the findings, the traditional flutter boundary is distinguished by an unusual pattern of increasing dynamic pressure with increasing Mach number. A plunge instability domain was observed in the transonic regime, indicating that plunge mode caused flutter in that regime [2]. Later, NASA conducted the research using the same benchmark model but with alternative airfoil wings. Where they tested airfoils named NACA 0012, NACA 64A010, and NACA SC (2)-0414. Classical flutter, transonic stall flutter, and plunge instability were all taken into account this time. The supercritical airfoil was the focus of most experiments. For measuring forces, the experimental setup was not up to the mark and unproven. Dynamic movements were monitored using strain gauges and accelerometers installed on the model. For the data collecting system, benchmark active control technology was employed. Pressure transducers were carefully installed on wing models in a chord wise orientation at a certain span point [3]

Chung presented an incremental technique for solving aero elastic issues with free play. Using the NASTRAN software and research has been done regarding data (mode shapes, natural frequencies, and damping) collected from ground vibration measurements, Pankaj developed a system for estimating the flutter characteristics of an aircraft construction. Hasheminejad used the Runge–Kutta technique to compute the open-loop supersonic aero elastic behavior and flutter motion of a rectangular shaped and sandwich plate that has been elastically supported [4]. The experimental model was created to test the flutter response and stall flutter properties of the wing in the wind tunnel at the University of Liege, Belgium. Linear springs were used to describe the pitch and plunge stiffness of the wing in this experimental model. The tests were carried out on NACA 0018 wing's Pitch and plunge motion were measured using accelerometers. Oscillations in the high and low limit cycles were noticed and the real instantaneous velocity on a single plane parallel to the free stream velocity was visualized. Experiments revealed sharp-leading-edge stall flutter behavior caused by vortex shedding and the formation of a laminar separation bubble at the leading edge [5]. Bendiksen and Saber investigate fluid–structure interaction problems that involve both structural and fluid nonlinearities. The exploration of nonlinear aero elastic stability constraints with wings with a high aspect ratio. Large deflections cause either aerodynamic and structural nonlinearities, which their finite element models account for. Svacek proposed a numerical simulation model of two-dimensional incompressible viscous flow coupling with a vibrating air foil [6]. In the pitching direction, Zhen and Yang designed two-dimensional wings with cubic stiffness. The system's flutter velocity was then tested to Hops bifurcation theory. The unpredictable reactions of an aero elastic system were estimated using a numerical integration method. Structural vibration has been determined by a Computational Structural Dynamics (CSDs) solver only with geometric nonlinearity shown in the modelling, and unsteady aerodynamics were simulated using a Computational Fluid Dynamics (CFDs) solver with the Euler equations presented as fluid governing equations [7]. The interaction of CFD and CSD is examined, and the limit cycle oscillation response of a basic transport wing is estimated. By utilizing analytical and semi-analytical techniques, researchers have been attempting to forecast the frequency and amplitude of an airfoil's flutter oscillations for many years. The characterizing function approach, also known as harmonic balancing or linearization, is a common way for producing an analogous linear system that can subsequently be evaluated using classic linear aero elastic techniques. Chung proposed an incremental method and used it to solve free-play aero elastic problems. Haul and Chen investigated flutter using ANSYS software and the full-order and multimode methods [8]. Kargarnovin and Mamandi explored the effects of a sharp edged gust on an airfoil's reaction and flutter. Wang and Qiu11 investigated the sensitivity of wing flutter speed to structural parameter uncertainty. An interval finite element model was developed and utilized to forecast the flutter critical wind speed range prediction. Bendiksen and Seber research fluid–structure interaction involves both structural and fluid nonlinearities. They looked at nonlinear aero elastic stability issues with high aspect ratio wings. Their finite element models account for both aerodynamic and structural nonlinearities caused by significant deflections. Svacek created a numerical simulation model of the interaction of two-dimensional incompressible viscous flow with a vibrating airfoil [9]. Aero elastic investigations of airfoil wings have been a fascinating component of the present study topic. Mazidi and Fazelzadeh recently showed the significance of wing sweep angle on the flutter limits of a wing/engine arrangement. A wing with an external storage has also been the subject of several studies as a common airplane layout. However, there is a scarcity of experimental research on these topics. Dowell and his research group have completed several tests on flutter experiments of a constant thickness cantilever delta wing with external storage. The air speed and flutter velocity are quite modest in the majority of these trials [10].

II METHOD

A comprehensive experimental investigation is done to identify the flutter phenomenon of the aircraft wing. The experimental setup for determining the flutter response was built for this purpose. The mechanical design is a two-degree-of-freedom system. This arrangement will be capable of analyzing the flutter behavior of any sort of two-dimensional wing. Here in this case wing models with rectangular planform with NACA 34015, NACA 31015, NACA 24015 airfoils are being examined for the wing's flutter response. A rectangular planform is considered because our main aim of experiment is to know the effect of design lift coefficient and location of maximum camber on wing flutter.

Figure 2: Wing Model with NACA 31015, NACA 24015 and NACA 34015

2.1. Main Parameters

Design lift coefficient: The camber line of the airfoil is determined by the design lift coefficient. When the design lift coefficient is reached, the flow reaches the airfoil exactly parallel to the start of the camber line. In a simple way we can say the lift coefficient of an airfoil at ‘0’ degree angle of attack is the airfoils design lift coefficient. This equates to a lift coefficient of 0.15 x 2 = 0.3 for a NACA 23015.

Location of maximum camber: Maximum camber is the maximum distance between the mean camber line and the chord line; maximum thickness is the maximum distance between the lower and upper surfaces.

2.2. Fabrication of the Wing Models

To begin the construction process, we must first create a design layout by printing the design on paper and then assembling the parts.The wing’s chord length is 240mm, half wingspan (length of half wing from root chord to tip chord) is 450mm and aspect ratio is 1.875. Laser cutting files were prepared to make 4 ribs for the wing models and then used a laser cutting tool to cut them out. The material used to make these ribs is 8mm thick balsa wood.Wings are the largest portion of an aircraft; so we employ 6mm thick aluminum rods as spars that go into the wings and reinforce the structure.Monocot is used as the skin of these wing models which makes the surface of these models lighter and smoother.

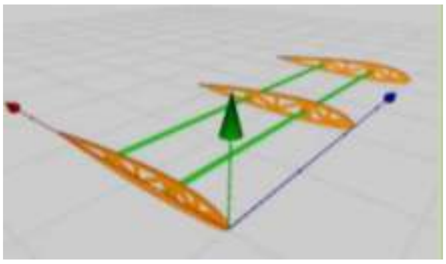

Figure 3: Laser Cutting File

2.3. ARDUINO Setup

2.3.1. Accelerometer

In this experiment we used the ADXL345 accelerometer sensor. It is a package of 3-axis acceleration measurement systems all in a single piece. It has a measurement range of 16g minimum. The ADXL345 uses a single structure for sensing the X, Y and Z axis.

The x-axis of the accelerometer is positive in the opposite direction of flow on the accelerometer and the y-axis is positive in the starboard side of the accelerometer which is attached to the wing model and placed in the wind tunnel test section and the z-axis is positive in the vertically upward direction of the accelerometer.

2.3.2. Arduino UNO

Arduino uno board is the device used to transmit the code to the accelerometer where the device helps the sensor to obtain the acceleration in the x,y and z plane along with timestamp.

III RESULTS AND DISCUSSION (10 PT)

These plots were generated for acceleration magnitude vs frequency and also for acceleration vs time graphs. Graphs were generated for different wings with variations/ change in parameters like air foil, Angle of attack, velocities. For this experimental flutter analysis on the wing we followed the iterative approach in which we placed our model in the test section and tested the behaviour of the model per each inlet velocity per an angle of attack simultaneously. Here in the present report we have given the plots of acceleration amplitude vs time and acceleration amplitude vs frequency of a model which consists of the air foil named NACA 24015. There are a total of almost 90 iterations performed in the wind tunnel test section including all 3 air foils whereas we are presenting only 30 of the 90 iterations executed due to the space constraint. (i.e graphs of only NACA 24015)

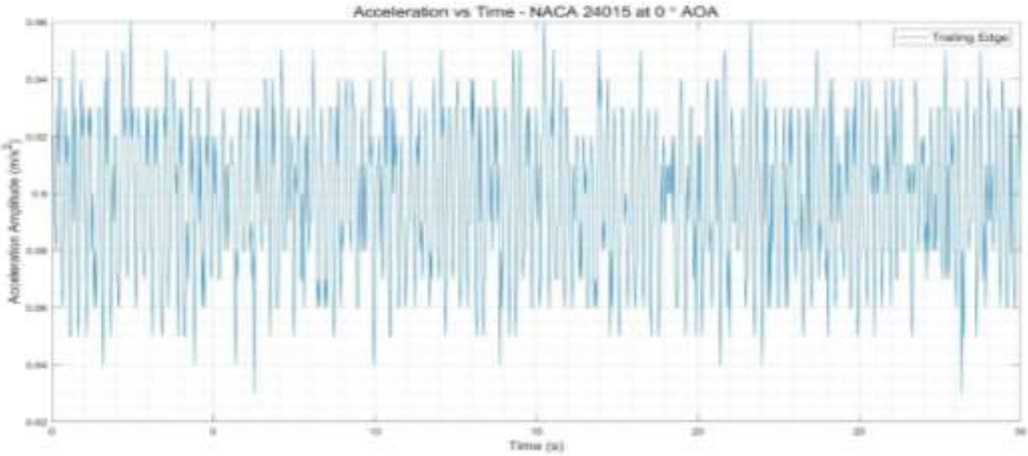

Figure 4: 24015 - 0deg AOA - 6.7 m/s- Accelerometer Reading

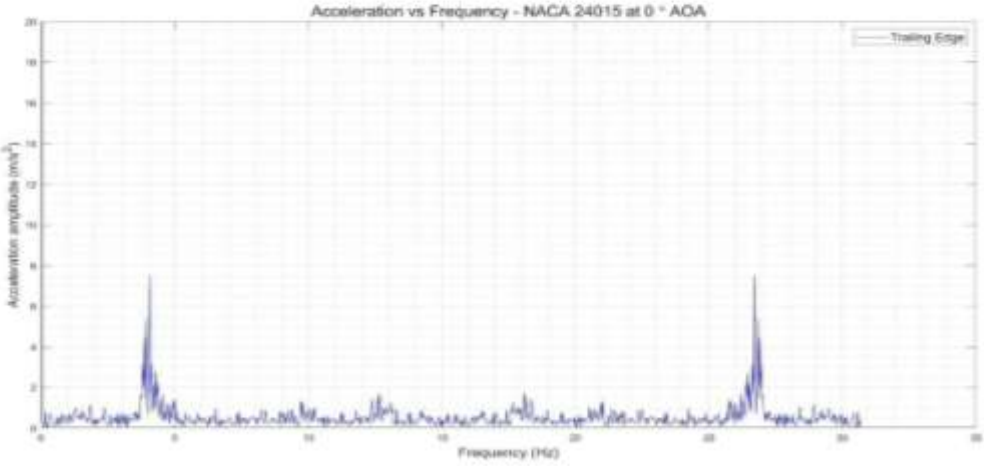

Figure 5: 24015 - 0deg AOA - 6.7 m/s- Frequency Vs Acceleration Values

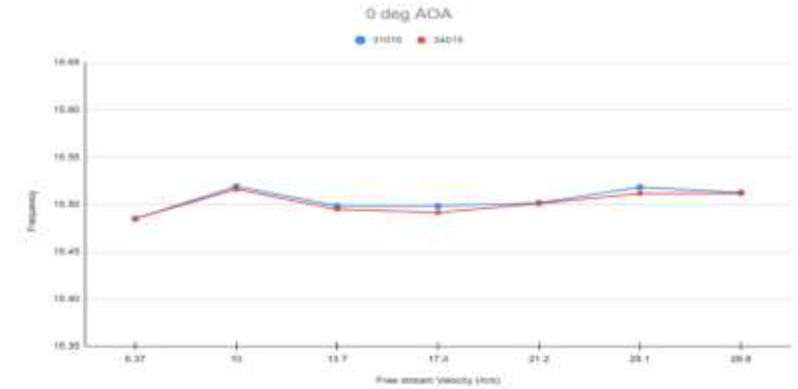

Figure 6: Comparison of v-f Graphs for 34015 and 31015 at 0 deg AOA

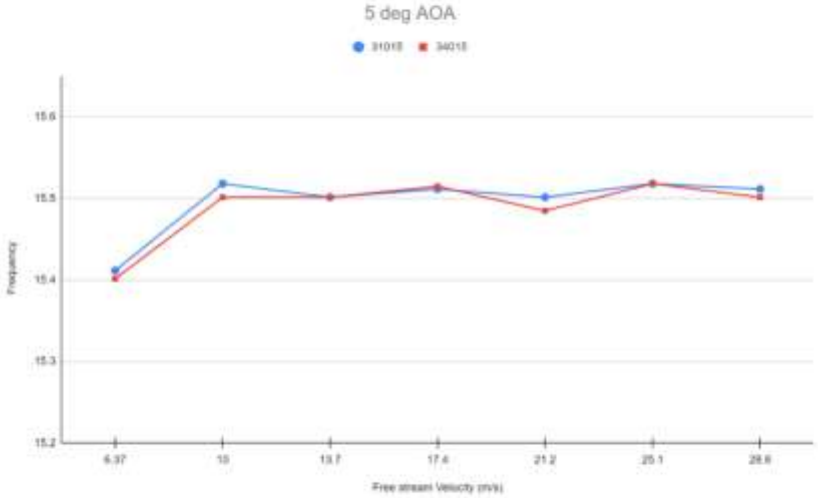

Figure 7: Comparison of v-f Graphs for 34015 and 31015 at 5deg AOA

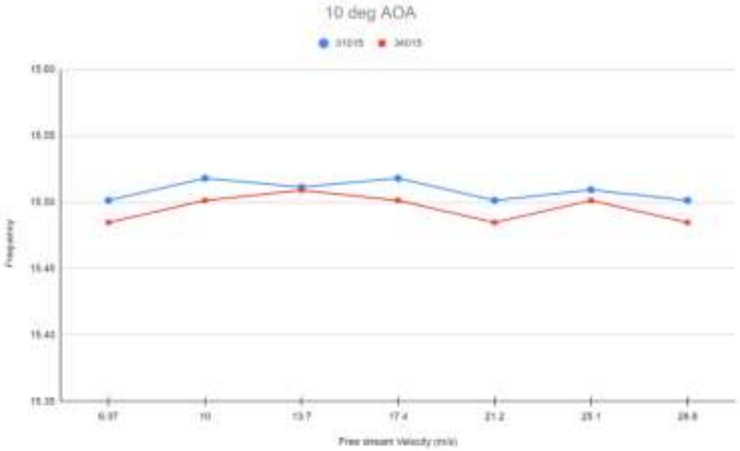

Figure 8: Comparison of v-f Graphs for 34015 and 31015 at 10deg AOA

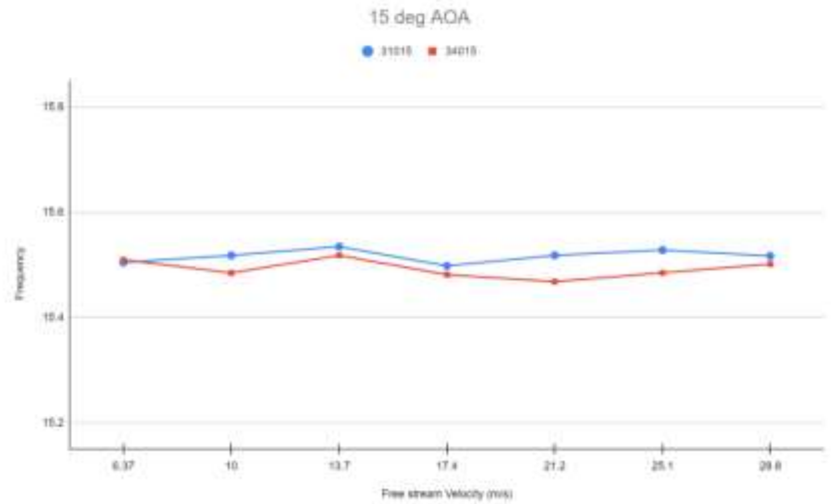

Figure 9: Comparison of v-f Graphs for 34015 and 31015 at 15deg AOA

IV CONCLUSION

When effect of angle of attack and velocity are observed, we can understand that if the angle of attack of the wing is increased, the velocity envelope seems to reduce, and flutter occurs at early airspeeds. Both the wings seem to vibrate at similar frequencies at lower angle of attack and lower air velocities. As the angle of attack was increased, the wing that has the position of maximum camber closer to the location of flexural axis which is 34015 seem to vibrate at lower frequencies than the wing that has its maximum camber positioned far from the flexural axis. From this it can be concluded that the airfoil that has the location of maximum camber closer to the center of gravity has a late onset of flutter.

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