Shanu Varghese
Shanuaero@gmail.com

Bhuvana Kandhan
bhuvanakandhan@gmail.com

Aero Elastic Flutter Analysis and Rectification of an Aircraft Wing

Abstract - **This paper consist of flutter prediction on zodiac aircraft wing and its redesign method. So here we are trying to create a model with better flutter capability.**

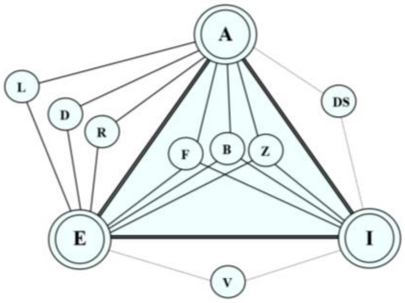
Index terms - **Aero Elasticity, buffering, dynamic response, flutter.**

I. INTRODUCTION

This paper is focused on providing the first view on aero elasticity behavior of wing aircraft ZODIAC CH-601 XL. And exploring the possibility of solution static aero elasticity problems by using FEM software. Used software for solution is MSC Pattran. The studies of the unsteady flows past oscillating airfoils has been mostly motivated by the efforts made to avoid or reduce undesirable unsteady effects in aeronautics such as flutter ,buffeting and dynamic stall. The unsteady aerodynamic forces acting on the oscillating airfoil has three degrees of freedoms. Aero elastic problems would not exist if airplane structures where perfectly rigid. Many important aero elastic phenomena involve inertia forces as well as aerodynamic and elastic forces.

II. COLLAR DIAGRAM

Describes the aero elastic phenomena by means of a triangle of forces



A – Aero elastic force.
B – Elastic force.
I – Inertial force.

A. DYNAMIC AEROELASTICITY

Phenomena involving all three type of forces:

- **F** – Flutter: dynamic instability occurring for aircraft in flight at a speed called flutter speed
- **B** – Buffeting: transient vibrations of aircraft structural components due to aerodynamic impulses produced by wake behind wings, nacelles, fuselage pods, or other components of the airplane
- **Z** – Dynamic response: transient response of aircraft structural components produced by rapidly applied loads due to gusts, landing, gun reactions, abrupt control motions, and moving shock waves

B. STATIC AEROELASTICITY

Science which studies the mutual interaction between aerodynamic forces and elastic forces, and the influence of this interaction on airplane design. Phenomena involving only elastic and aerodynamic forces

- **L** – Load distribution: influence of elastic deformations of the structure on the distri- bution of aerodynamic pressures over the structure
- **D** – Divergence: a static instability of a lifting surface of an aircraft in flight, at a speed called the divergence speed, where elasticity of the lifting surface plays an essential role in the instability.
- **R** – Control system reversal: A condition occurring in flight, at a speed called the control reversal speed, at which the intended effect of displacing a given component of the control system are completely nullified by elastic deformations of the structure.

RELATED FIELDS :

- **V** – Mechanical vibrations
- **DS** – Rigid-body aerodynamic stability

III. FLUTTER

Flutter is a self-feeding and potentially destructive vibration where aerodynamic forces on an object couple with a structure's natural mode of vibration to produce rapid periodic motion. Flutter can occur in any object within a strong fluid flow, under the conditions that a positive feedback occurs between the structure's natural vibration and the aerodynamic forces. That is, the vibration movement of the object increases an aerodynamic load, which in turn drives the object to move further. If the energy input by the aerodynamic excitation in a cycle is larger than that dissipated by the damping in the system, the amplitude of vibration will increase, resulting in self-exciting oscillation. The amplitude can thus build up and is only limited when the energy dissipated by aerodynamic and mechanical damping matches the energy input, which can result in large amplitude vibration and potentially lead to rapid failure. Because of this, structures exposed to aerodynamic forces including wings and airfoils, but also chimneys and bridges are designed carefully within known parameters to avoid flutter. In complex structures where both the aerodynamics and the mechanical properties of the structure are not fully understood, flutter can only be discounted through detailed testing. Even changing the mass distribution of an aircraft or the stiffness of one component can induce flutter in an apparently unrelated aerodynamic component. At its mildest this can appear as a "buzz" in the aircraft structure, but at its most violent it can develop uncontrollably with great speed and cause serious damage to or lead to the destruction of the aircraft, as in Banff.

INPUT	OUTPUT
Oscillatory Aerodynamics	Flutter Analysis
Structural Stiffness	
Inertia Properties	Dynamic Stability Derivative
Control System (optional)	

IV. ZODIAC CH 601XL AIRCRAFT

The ZODIAC is a sleek and docile aircraft, ideal for both local and long cross-country flights. All ZODIAC models offer comfortable two-place side-by-side seating in an ergonomically designed 44-inch wide cabin. The huge tinted bubble canopy, which provides outstanding 360 degree visibility, is hinged on both sides of the cabin, to allow access from either side of the aircraft. Access to the cabin is easy over the 20-inch wide reinforced wing walkway on both sides of the cockpit, and facilitated by a 'step' located below the trailing edge of the wing

SPECIFICATIONS	ZODIAC CH 601 (XL)
WING SPAN	27 FT.
WING AREA	130 SQ.FT.
LENGTH	19 FT.
EMPTY WEIGHT	550 LB.
USEFUL LOAD	508 LB.
GROSS WEIGHT	1,058 LB.
WING LOADING	8.0 psf
POWER LOADING	13.2 LB./HP
DESIGN LOAD FACTOR	+/- 6 "G"
CABIN WIDTH	44 INCHES
FUEL CAPACITY (std)	16 Gallons (US)
with Optional Wing Tanks	30 Gallons (US)

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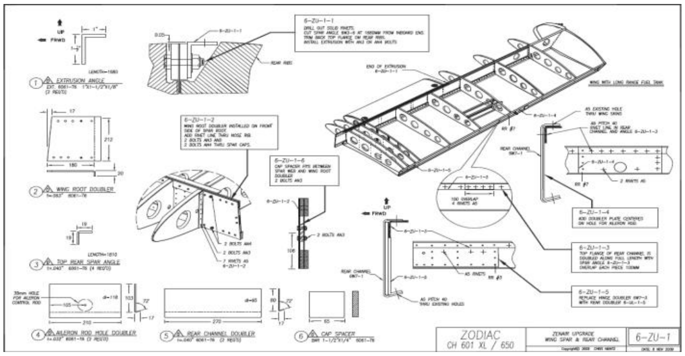
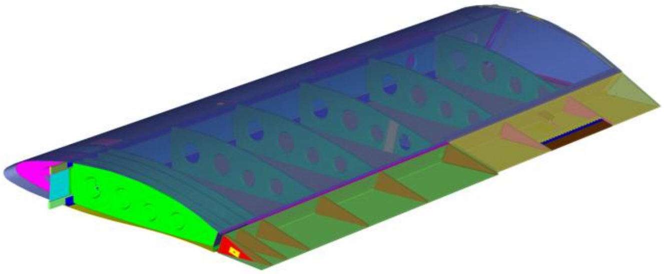
V. AIRCRAFT WING

ZODIAC CH 601 Wings are made up of a single cantilevered spar with near full-span non-hinged ailerons. The CH 601 and CH 601 HD models use a simple constant-chord airfoil, while the CH 601 HDS and the new ZODIAC XL feature tapered 'speed' wings. The high-lift low-drag airfoils provide an efficient cruise speed, as well as desired slow flight and gentle stall characteristics. Flaps are not required with the high-lift wing designs of the ZODIAC. The outboard wing panels can easily be removed in 15 minutes each for tailoring and storage. With the wings removed, the fuselage fits through the door of a standard single-car garage and can be tailored.

VI. WING DESIGN



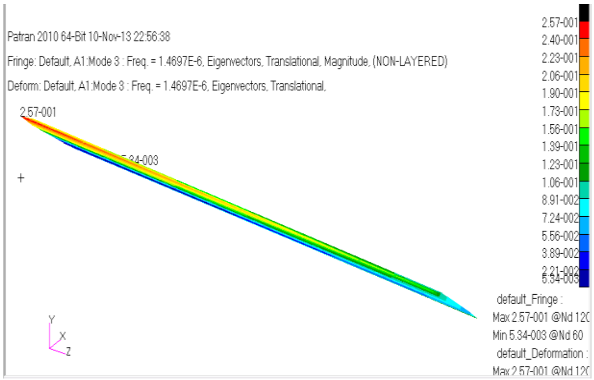
Wing design was carried out in Msc. Patran (2010). Basic design parameters were taken from existing Zodic aircraft model. Main difficulty in design was the generation of airfoil geometry. In order to achieve the basic airfoil geometry we made the airfoil coordinates as GRID point ID card in *.bdf, and imported those grid points to Msc. Patran using import option. From those grid points required curves was generated and followed by top and bottom surface.



VII. NORMAL MODE ANALYSIS

Understanding the basic and fundamentals of vibration analysis are very important in forming solid background to analyze problems on a flexible wing. All systems can be break down into two categories Mass and stiffness. The governing equation behind normal mode analysis is $\mathbf{f_n = 1/2\pi\sqrt{K/m}}$. So stiffness and mass will matter while a dynamic run happens. Wing is considered as cantilever beam. So it has to follow the basic dynamic behavior of cantilever beam.

VIII. NORMAL MODE ANALYSES



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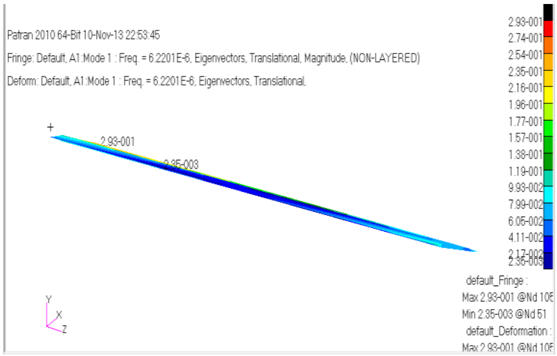
Rotation along Z axis



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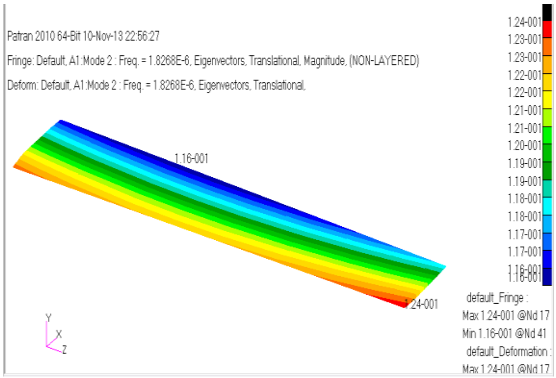
Translation along Z axis



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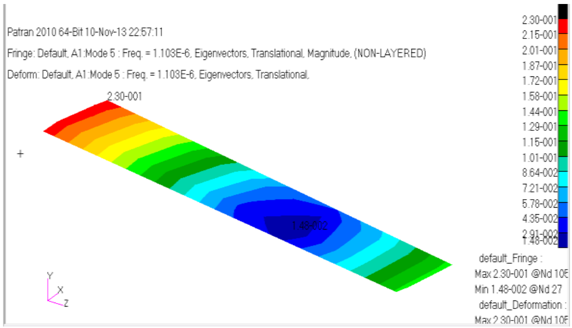
Rotation along X axis



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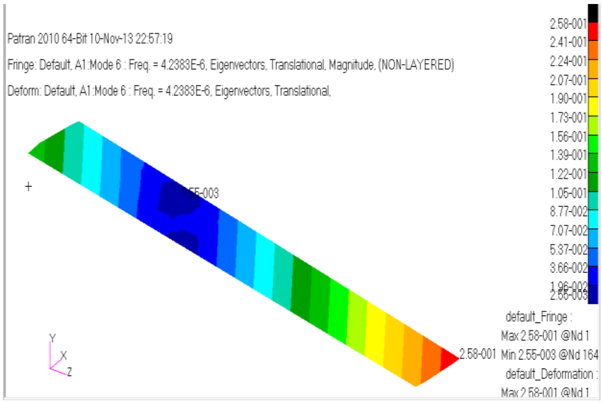

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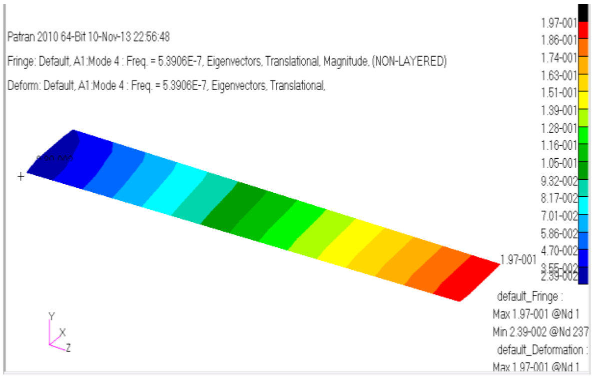
Rotation along Y axis



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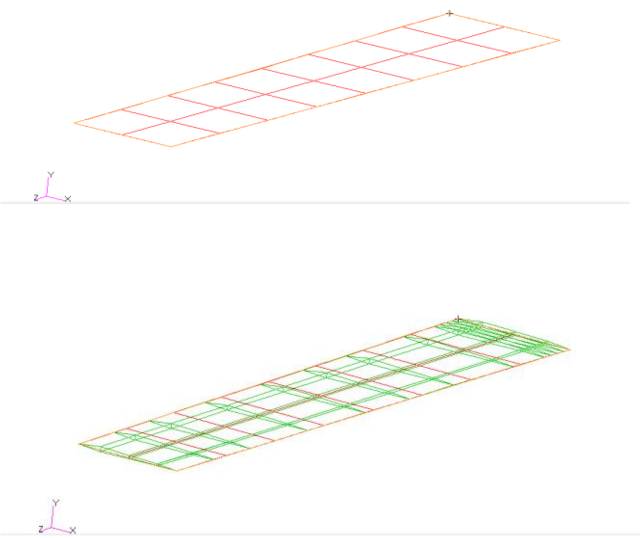
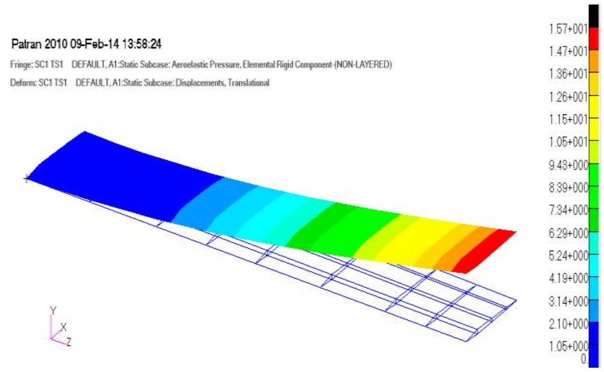
Translation along Y axis

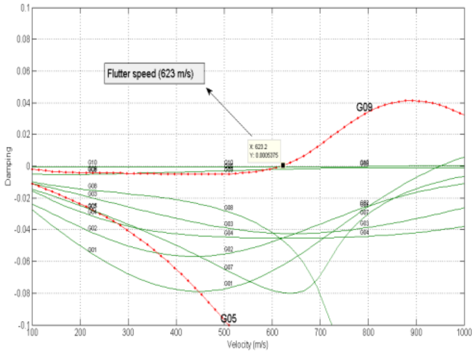
IX. AERODYNAMIC AND STRUCTURAL MESH COUPLING

Flutter analysis model is generated using MSC Flight Loads software. SOL 145 run to get the flutter speed



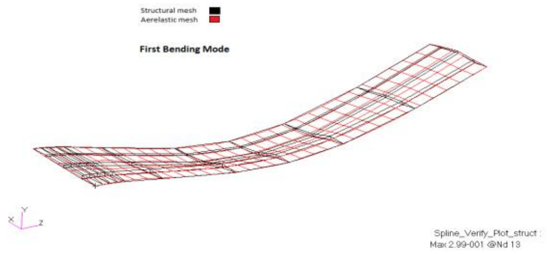
Flat plate aerodynamic mesh



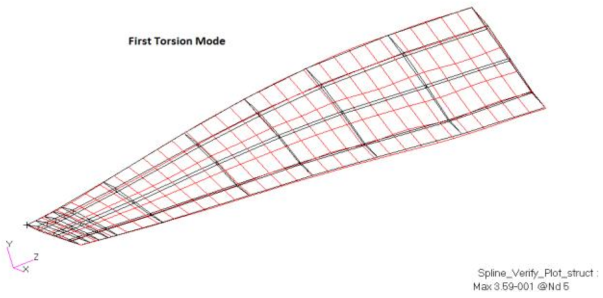


Flat plate coupling method is used to couple structural and aerodynamic mesh.

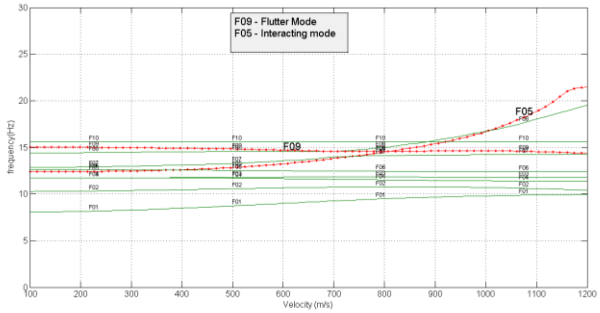
X. FLUTTER ANALYSIS



Above figure shows the coupled aerodynamic and structural effects. From the figure it is clear that the coupling is so fine and the required modes are able to obtain.



XI. MAXIMUM DISPLACEMENT OCCURRED DURING SOL 145



Maximum displacement occurred on wing tip, and is acceptable.

Above figure shows the flutter prediction from the Nastran output post processed in MATLAB. We almost considered 2.5 FOS and able to achieve 1.8 Mach with expected FOS. Major modification done in the mid wing box region by adding two more ribs and rear spar shape changed to I section and in order to achieve the weight expectation composite added to spar and wing skin region.

XII. CONCLUSION

To make sure that the model is proper, we can go ahead with SOL 103 analysis (Normal mode). In our analysis, we got all the 6 rigid modes in proper manner. This showing that our modeling of aircraft wing is matching with the reality [Rigid modes means stress free displacement of a structure without undergoing deformation]. Always wing will give up with 6 rigid body modes and it the 7th mode should follow the cantilever beam mode shape pattern.

If we look on the results all the shapes they are providing is so always matching with the required shapes. But the frequency values are quiet low, because of low stiffness. If we go ahead with this model, flutter prediction is not at all possible to the required limit. From the model analysis we came to know that there is an urgent need of model update to achieve the required flutter speed.

We almost considered 2.5 FOS and able to achieve 1.8 Mach with expected FOS. Major modification done in the mid wing box region by adding two more ribs and rear spar shape changed to I section and in order to achieve the weight expectation composite added to spar and wing skin region.

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