Design and structural analysis off lutter predictionin zodiac CH-601XL aircraft wing to reduce drag

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Abstract---The wings of the aircraft reflect an aircraft's primary lift unit. The aerodynamic strain, weather, wind and vibration are the liability of the aircraft's wing throughout the ride. Aeronautical and structural stresses may often be handled by aircraft wings. Therefore, aircraft wings must be constructed to have good overall efficiency throughout each period of operation, both structurally and aerodynamically. Spar, ribs, thongs and skin are the main structural elements of a wing construction. It is a fluttering experiment regarding the wing and re-designing of zodiac aircraft. The method was identified in the literature survey to decide the current wing design parameters. Here we are exploring the possibility of static aero elastic problems by using PATRAN of FEA software Main objective of this project is to makes a stable aircraft wing which can overcome all flutter related problems in the design limit region. We always tried to keep the weight margin in same limit.

Keywords---PATRAN, software, CH-601XL.

Introduction

The aircraft wings must be designed structurally and aerodynamically well for providing good overall performance in all phases of flight. The Zodiac is a family of Canadian all-metal, two-seat; fixed landing gear airplanes that first flew in 1984. The aircraft have been produced as kits and completed aircraft by Zenair in Canada and Zenith Aircraft Company in the USA. A Lightened version of the ZODIAC CH 601 HD, the basic CH 601 model was developed specifically for the Advanced Ultra-light (AULA) category in Canada and other European countries, where the CH 601 can be used as a trainer and personal aircraft. An Advanced Ultra-light category is really more than an ultra-light; it would be better described as a primary aircraft category. **A.K. Slone & K. Pericleous, [1]**. - Computational modelling of dynamic fluid–structure interaction (DFSI) is a considerable challenge. There approach to this class of problems involves the use of a single software framework for all the phenomena Involved, employing finite volume methods on unstructured meshes in three dimensions. This method enables time and space accurate calculations in a consistent manner.**Charbel Farhat[3]:-** "Flutter can be catastrophic and must be avoided at all cost," says Charbel Farhat, who directs the University of Colorado's Center for Aerospace Structures.Through a collaborative program with Edwards Air Force Base, he's been trying out his methods on the F-16 fighter. "We do blind tests," explains Farhat. "We develop the simulation technology and try it on the aircraft. Then they fly it to get actual flight data, and we see how we'redoing." In the spring of 2001, "friendly user" time on the prototype Terascale Computing System allowed him to improve the resolution of the F-16 model and achieve his best results to date.**P.A. Chamara & B.D. Coller[2]:-** The study of nonlinear flutters phenomena in a system of two airfoils in close proximity in an ideal fluid. In particular, we are interested in cases for which two aero elastic instabilities are nearly critical simultaneously. Such Hopf–Hopf interactions, in general, are capable of generating a rich variety of dynamic phenomena, behaviours that possibly can be exploited to develop flow actuators.**TaehyounKim[8]:-** A new, improved frequency-domain system identification technique to convert frequency-valued aerodynamic forces into time-domain is presented. Unlike conventional methods such as Roger's Rational Function Approximation (RFA) where aerodynamic poles are predetermined and constrained to be real, the new methods real and complex poles by solving a set of optimization equations. These poles are then used to approximate the aerodynamic data and the corresponding zero locations are found by minimizing the error between the data and the assumed rational form.**Xinyun Guo &ChuhMei[10] :-** This paper shows that the use of aero elastic modes, instead of the traditional in vacuum natural modes, can reduce drastically the number of coupled nonlinear modal equations for the large amplitude nonlinear panel flutter analysis at an arbitrary yawed supersonic flow angle and elevated temperatures.A finite element time domain formulation using AEM is presented for the analysis of nonlinear flutter of isotropic and composite panels.

A new and efficient method is presented using the AEM to reduce the system equations in physical structural node DOF to a reduced set of equations in aero elastic modal coordinates.**W.A. Silva & R.E. Bartels[9]:-** Flutter results for the AGARD 445.6 Wing computed using CFL3D v6.0 are presented, including discussion of associated computational costs. Modal impulse responses of the

unsteady aerodynamic system are then computed using the CFL3Dv6 code and transformed into state-space form. Important numerical issues associated with the computation of the impulse responses are presented.The reduced-order model (ROM) shows excellent agreement with the aero elastic analyses computed using the CFL3Dv6.0 code directly.This latest version of the flow solver includes a deforming mesh capability, a modal structural definition for nonlinear aero elastic analyses.**Seung-KilPaek& In Lee[6]:-** The root locus and iterative *V-g* method have been applied to analyze the flutter for a control surface of a launch vehicle with control actuators. The actuator is considered as a spring with dynamic stiffness.The effect of the sweep angle on the flutter characteristics of the wing with dynamic stiffness is investigated and is compared with that of the wings with several values of static stiffness.The dynamic characteristics of actuators must be properly considered for an accurate flutter prediction.**Herbert J. Cunningham&Robert N. Desmarais[4]:- A** generalized subsonic unsteady aerodynamic kernel function, valid for both growing and decaying oscillatory motions, is developed.Rates of change of damping ratios with respect to dynamic pressures near flutter are substantially lower from the generalized-kernel-function calculations than from the conventional velocity-damping (V-g) calculation.**Jinsoo Cho &YounhyuckChang[5]:-** The flutter analysis is done using the normal mode approach and a U-g method in frequency-domain. The U-g procedure requires the generalized aerodynamic forces for a range of reduced frequencies calculated from the aerodynamic module.The methods for flutter analysis are classified according to the characteristics of unsteady aerodynamics, and the governing equations used to calculate the unsteady aerodynamic forces.**SeYong, Sang yong and changmin cho.[7]**:-Aeroelastic analysis of an aircraft with a high aspectratio wing for medium altitude and long endurance capability was attempted in his paper. In order to achieve such objective, various structural models were adopted. The traditional approach has been based on one dimentional Euler-Bernoulli beam method.

Aero Elasticity

Aero elasticity is the branch of physics and engineering that studies the interactions between the inertial, elastic, and aerodynamic forces that occur when an elastic body is exposed to a fluid flow. An elastic force is the kind of force that arises from the deformation of a solid body, which depends on the body's instantaneous deformation and not on its obvious history. This type of force is also conservative.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. The study of aero elasticity may be broadly classified into two fields: static aero elasticity, which deals with the static or steady response of an elastic body to a fluid flow; and dynamic aero elasticity, which deals with the body's dynamic (typically vibration) response.

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

A –
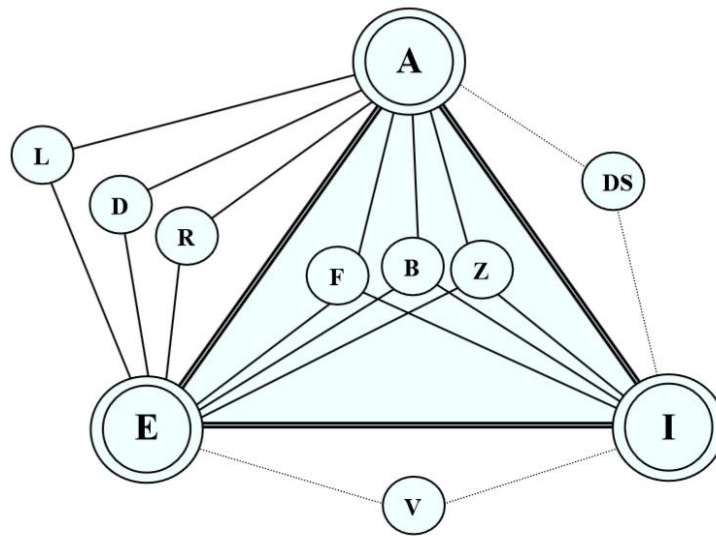
Aeroelastic force.
E – Elastic force.
I – Inertial force.

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.

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 distribution 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.

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.

Buffeting

Buffeting is high-frequency instability, caused by airflow separation or shock wave oscillations from one object striking another. It is caused by a sudden impulse of load increasing. It is a random forced vibration. Generally it affects the tail unit of the aircraft structure due to air flow downstream of the wing.

Model

Aircraft specification and performance

The specification of Zodiac CH 601 is given Table 3.1. 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.

Table 3.1 Specification of Zodiac Aircraft

SPECIFICATIONS	ZODIAC CH 601 (UL)
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)

The ZODIAC has been configured to take full advantage of its increased useful load. The fuel is located in dual welded-aluminum wing tanks. The standard dual wing tanks offer a fuel capacity of 24 US gallons. Long Range fuel tanks are optionally available, which increase the total capacity to 30 US gallons (2 x 15 gallons) to provide superior range and endurance which is given in Table 3.2.

Table 3.2 Performance of zodiac aircraft

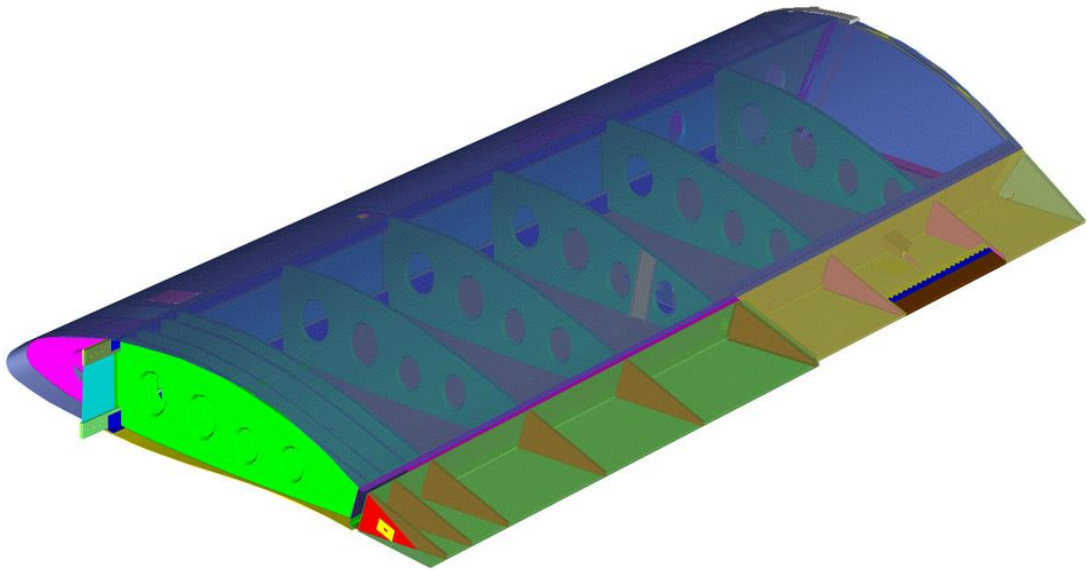| PERFORMANCE	SINGLE 800 LB.	DUAL 1,050 LB.
TOP SPEED (mph)	135	135
CRUISE (mph)	120	120
VNE (mph)	150	150
STALL SPEED (mph)	39	44
RATE OF CLIMB (FPM)	1,400	1,200
TAKE-OFF ROLL (ft.)	360	430
LANDING DISTANCE (ft.)	450	550
SERVICE CEILING (ft.)	12,000+	12,000+
RANGE (std., SM)	480	480
RANGE (with wing tanks, SM)	820	820
LOAD FACTOR (G)	+/- 7.9	+/- 6.0

Fig 3.2 Schematic diagram of zodiac wing

The ZODIAC CH 650 (and the earlier ZODIAC XL model) features an efficient wing design for increased capability. The wing design features a newairfoil and a larger wing area than the ZODIAC CH 601 HDS model, which allows the new Zodiac design to achieve higher speeds with a higher payload.With the addition of wing flaps, the stall speed has been kept low for recreational sport pilots.While the wing design is new, the simple construction techniques that have made the ZODIAC famous have remained the same. The wings bolt to the ZODIAC fuselage section, and can be readily removed for trailing or storing the aircraft. Six bolts in the wing spar bolt to the fuselage center section, and in fig 3.3 which shows the exploded view of the wing structure. With the wings removed the aircraft is less than 8 feet wide for easy tailoring or storage of the aircraft.

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. It is made up of all light metal. The configuration is shown in table 3.3.

Table 3.3 Wing Details

Component	Material	Element Property	No: of element
Lower Skin	Aluminum	Membrane	36
Upper Skin	Aluminum	Membrane	36
Rib	Aluminum	Shear Panel	39
Spar Flange	Aluminum	Shear Panel	48
Spar Web	Aluminum	Shear Panel	24
Total			183

Methodology

According to the light of literature review and data collection, we designed the Zodiac CH-601 XL aircraft wing in MSC PATRAN software. For validating those structures we then tried in FEM. Then we needed to confirm our model, so we went on through the model analysis process in software. If all the above analysis were supporting, we will move to flutter analysis. If the testing showing that the model still having the flutter problem we wereplanning for the redesign process.

MSC Patran

The finite element method is a proven technique for using computers to model and solve a wide variety of engineering problems. Its application in the real world was hindered, however, by the amount of time spent both in producing the raw data to feed a Finite Element Analysis (FEA), and in interpreting the usually large volumes of results from the analysis, new wide range of software were developed. MSC PATRAN is softwarewhich is developed to provide a systematic approach towards making FEA modelling fast and accurate. It uses a simple step-by-step approach that helps to create, analyze and interpret a mathematically realistic model of the structure. This approach is built around geometric modelling, interactive computer graphics, and current finite element theory.

4.1.1 The capabilities of MSC/PATRAN:

- A full set of tools for the creation of parameterized model geometry. In addition, MSC/PATRAN has Single Geometric Model (SGM) capability. SGM accesses geometry data, topology, and evaluators from the CAD (Computer Aided Design/Drafting) system without transformation and establishes and maintains associatively with the corresponding MSC/PATRAN finite element entities throughout the entire design and analysis process.
- Finite modelling tools for analysis, model creation, and verification, including mapped meshing, automatic surface meshing, and automatic tetrahedral solid modelling is an advantage for this software.
- A complete set of functional (loads, boundary conditions, and material/element properties) assignment capabilities, including the capability to assign these directlyto the geometry or the finite element model. In application, this means that the finite element mesh can be deleted and the geometry can be re-meshed without reapplying the functional assignments. All functional assignments can be collected into load cases and named, modified or deleted at the user's discretion.
- PATRAN Command Language (PCL) for the customization of MSC/PATRAN, the performance of variance and design sensitivity studies, and automation of routine.
- Table 4.1 identifies the four MSC/NASTRAN solution sequences used in aeroelastic analysis. SOL 144 addresses static aeroelasticity and, as such, is useful for making a preliminary assessment of the aircraft design loads and provides estimates for rigid and elastic stability and control derivatives.

Table 4.1 Solution Sequences Related to Aeroelasticity

SOLUTION	DESCRIPTION
144	Static Aeroelasticity
145	Aerodynamic Flutter
146	Dynamic Aeroelastic Response
200	Design Sensitivity and Optimization

The aerodynamic flutter of SOL 145 represents the most mature of the four solution sequences which is used in this project. The Dynamic Aeroelastic Response capability of SOL 146 provides the capability to analyze the transient or frequency structural response in the presence of either an aerodynamic (gust) or other dynamic (e.g., landing) loading.

In this analysis PK method is used. With the PK method, all combinations of these parameters are used so that the input of two densities, two Mach numbers and eight velocities results in 32 flutter analyses. The new method requires input of the complete specification of density, Mach number and velocity for each point that is to be analyzed and is designed to address the requirement of performing only match point flutter analyses. It is suggested that this method be applied by moving through the atmosphere at a constant Mach number in order to avoid the expensive generation of aerodynamic matrices at a large number of Mach numbers.

Computational Analysis
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

$$f_n = 1/2\pi\sqrt{K/m}.$$

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. Normal model analysis will give proper mode shape as similar as cantilever beam in 7th mode onward in a free run condition. Up to 7th mode it will give the rigid modes of wing.
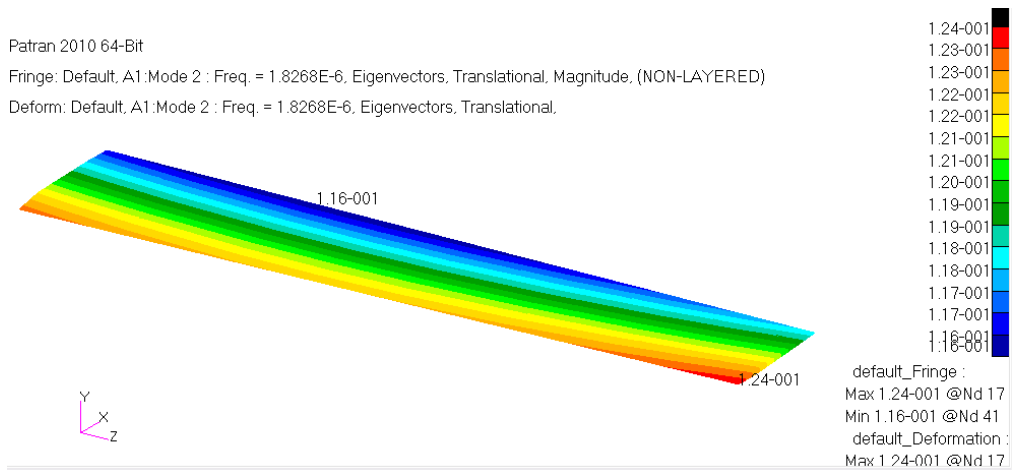
Patran 2010 64-Bit

Fringe: Default, A1:Mode 1 : Freq. = 6.2201E-6, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

Deform: Default, A1:Mode 1 : Freq. = 6.2201E-6, Eigenvectors, Translational,

2.93-001
2.74-001
2.54-001
2.35-001
2.16-001
1.96-001
1.77-001
1.57-001
1.38-001
1.19-001
9.93-002
7.99-002
6.05-002
4.11-002
2.17-002
2.35-003

2.93-001
2.35-003

default_Fringe :
Max 2.93-001 @Nd 108
Min 2.35-003 @Nd 51
default_Deformation :
Max 2.93-001 @Nd 108

Fig 5.19 Rotation along Z axis

Patran 2010 64-Bit

Fringe: Default, A1:Mode 2 : Freq. = 1.8268E-6, Eigenvectors, Translational, Magnitude, (NON-LAYERED)

Deform: Default, A1:Mode 2 : Freq. = 1.8268E-6, Eigenvectors, Translational,

1.24-001
1.23-001
1.23-001
1.22-001
1.22-001
1.21-001
1.21-001
1.20-001
1.19-001
1.19-001
1.18-001
1.18-001
1.17-001
1.17-001
1.16-001
1.16-001

1.16-001

1.24-001

default_Fringe :
Max 1.24-001 @Nd 17
Min 1.16-001 @Nd 41
default_Deformation :
Max 1.24-001 @Nd 17

Fig 5.20 Translation along Z axis
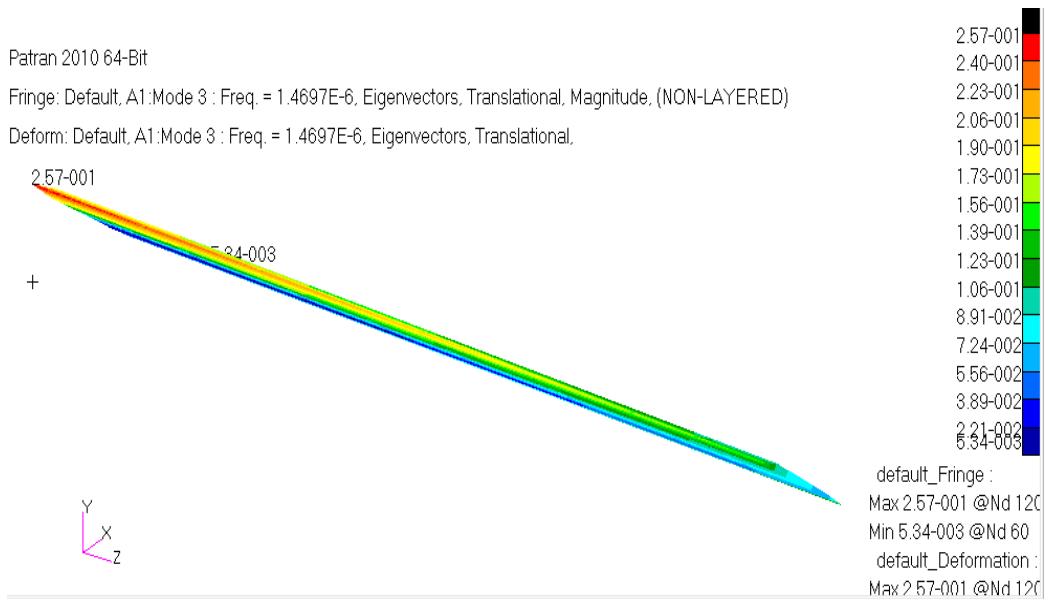
Fig 5.21 Rotation along X axis
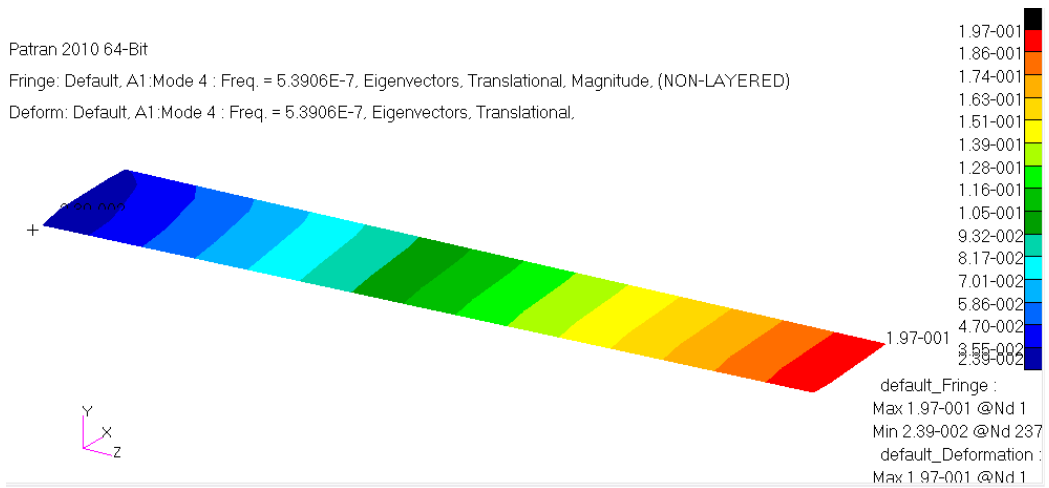
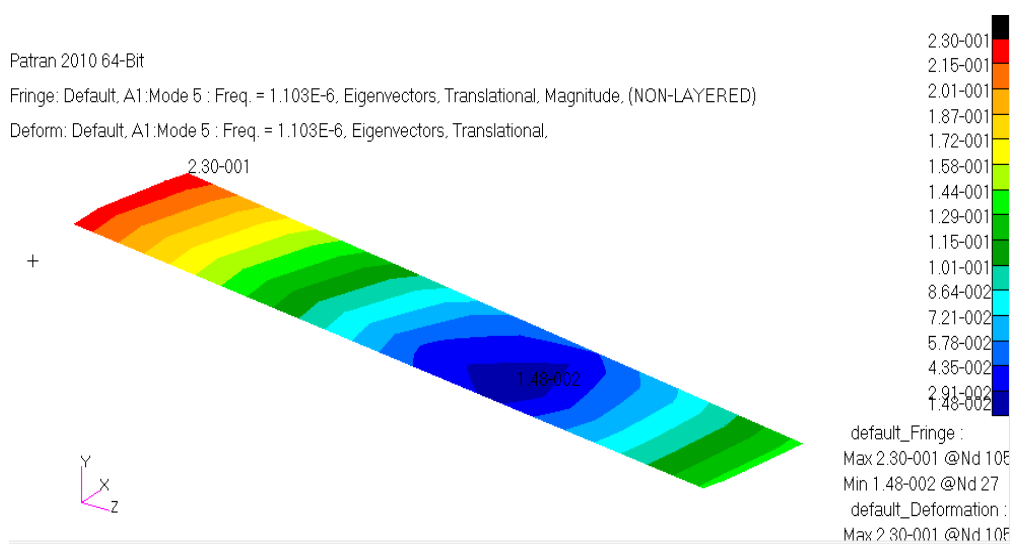Fig 5.22 Translation along X axis

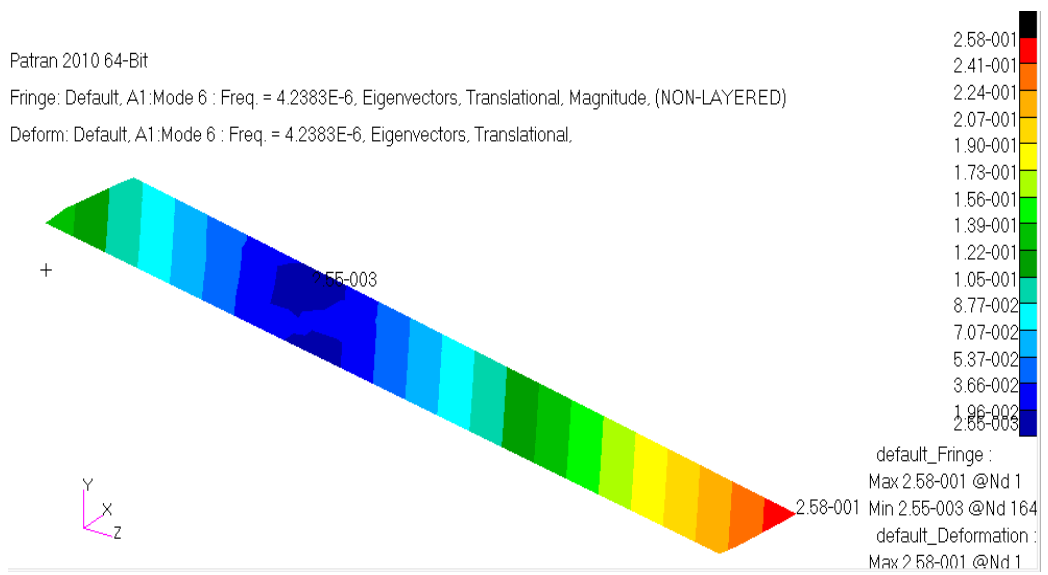Fig 5.23 Rotation along Y axis

Fig 5.24 Translation along Y axis
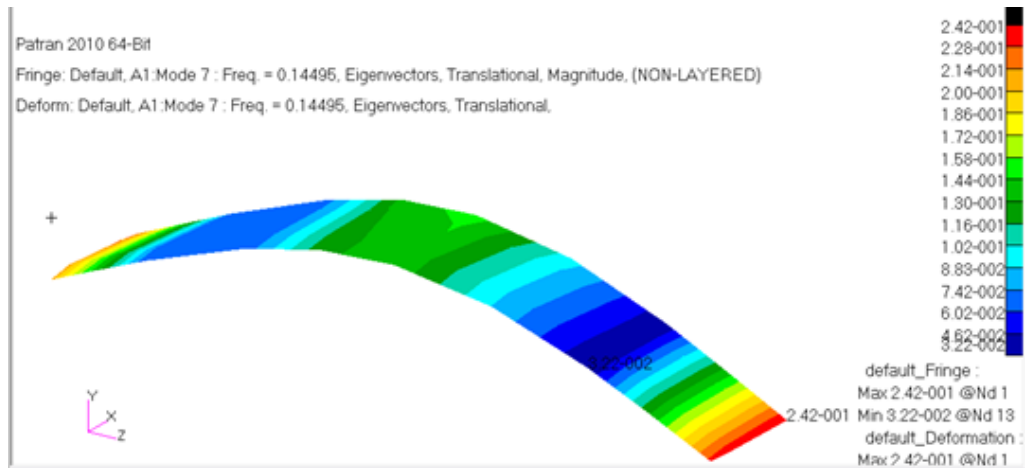
Natural Frequency Analysis
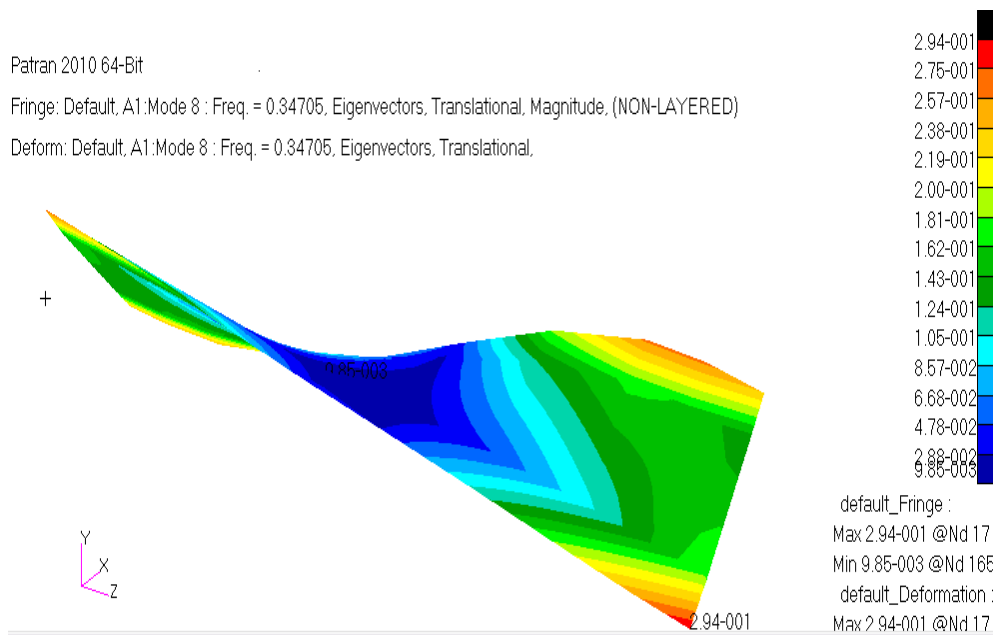

Fig 5.25 1st lateral bending mode
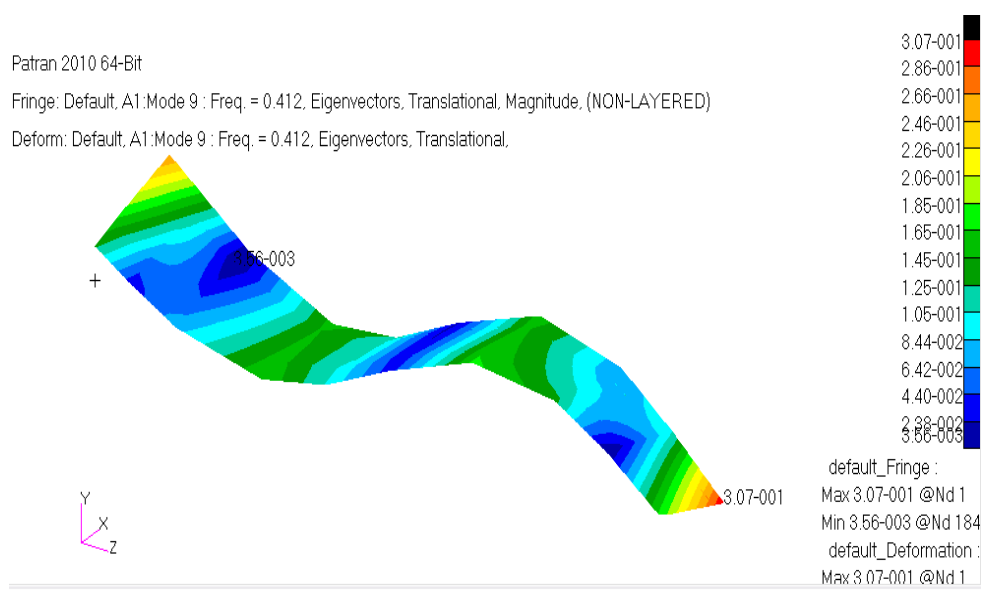

Fig 5.26 2nd lateral torsion
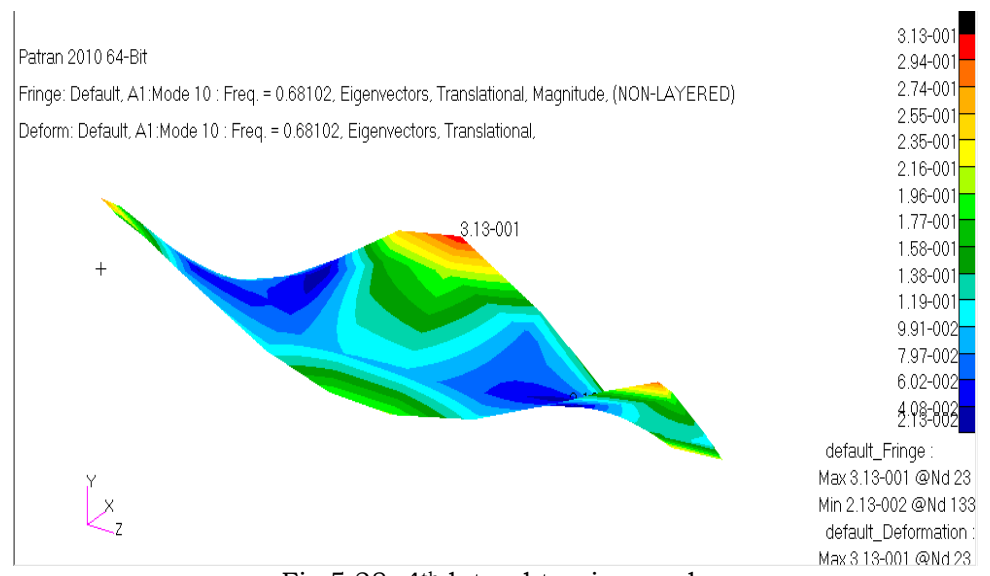
Fig 5.27, 3rd lateral bending
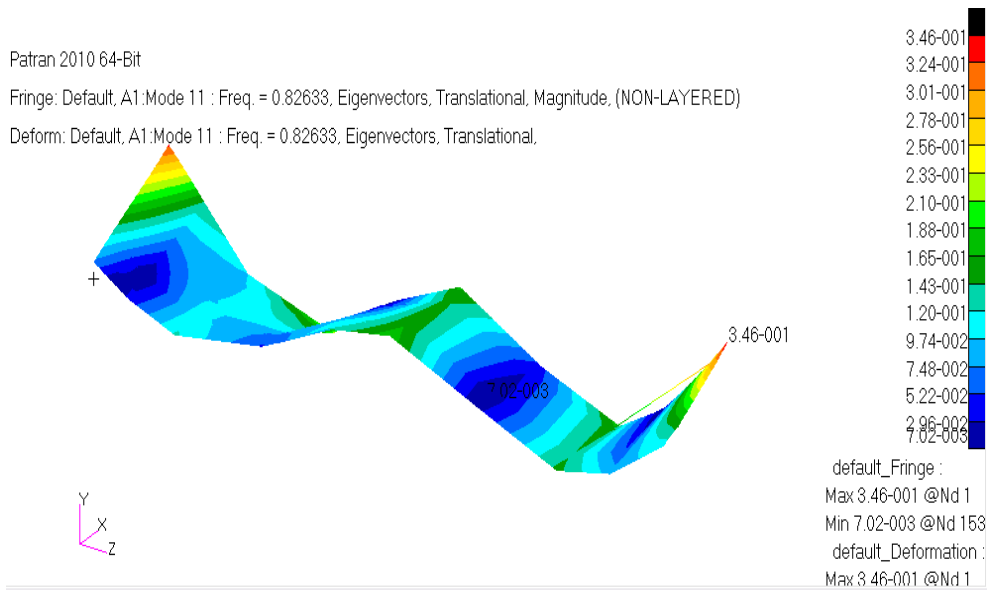

Fig 5.28, 4th lateral torsion mode

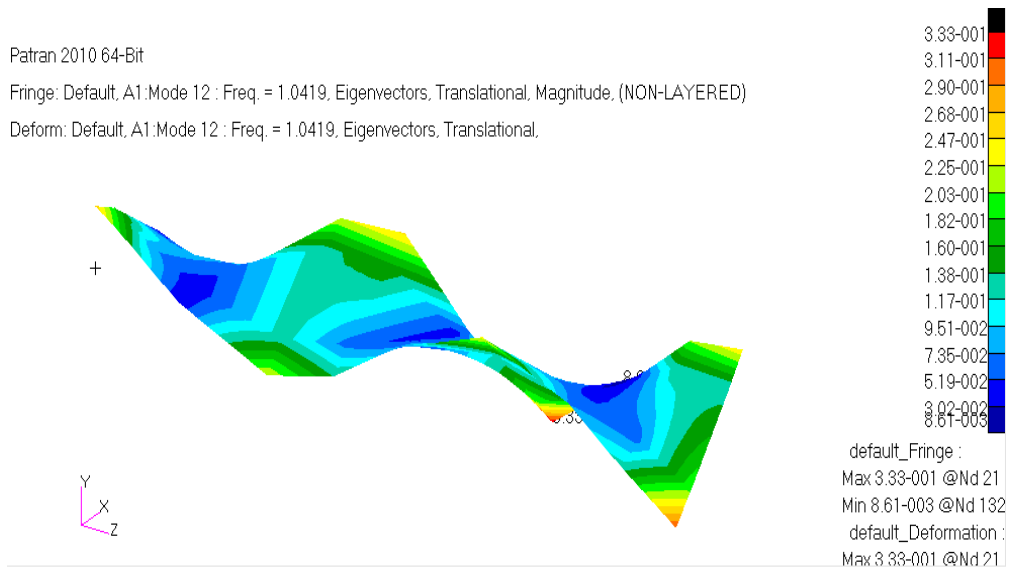Fig 5.29, 5th lateral bending mode
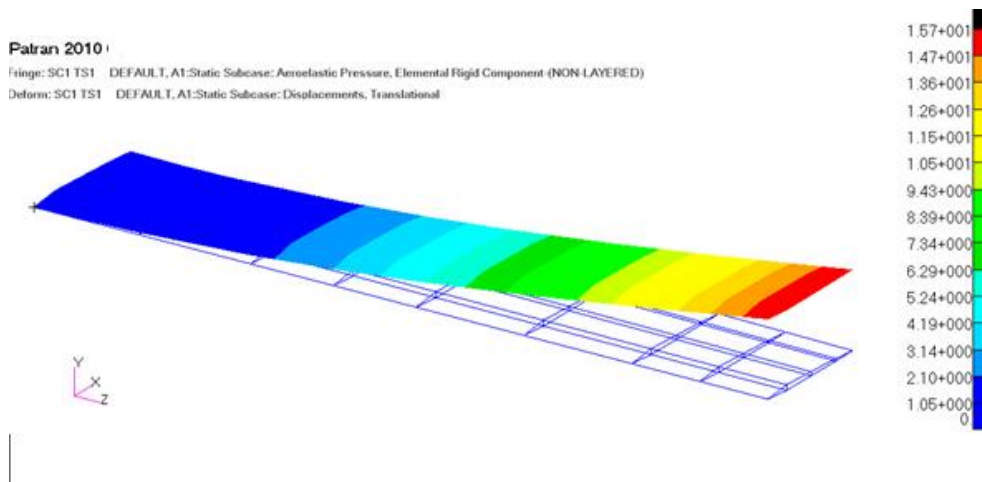

Fig 5.30, 6th lateral torsion mode

Fig 5.31 Test result after the design change

Change of sign in damping values from positive to negative. Corresponding speed value for change in sign from positive to negative is the flutter. Maximum displacement occurred on wing tip, and is acceptable.

Flutter Analysis

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

```
SOL 145
TIME 600
geomcheck none
CEND
$ Direct Text Input for Global Case Control Data
TITLE = MSC.Nastran Aeroelastic job created
ECHO = NONE
MAXLINES = 999999
AECONFIG = AeroSG2D
SUBCASE 1
$ Subcase name : 145__
   SUBTITLE=Untitled.SC1
   METHOD = 1
   SPC = 2
   VECTOR(SORT1,REAL)=ALL
   SPCFORCES(SORT1,REAL)=ALL
FMETHOD = 1
AESYMXZ = Symmetric
AESYMXY = Asymmetric
$ Direct Text Input for this Subcase
BEGIN BULK
$ Direct Text Input for Bulk Data
PARAM    POST    0
PARAM    WTMASS 1.
PARAM    SNORM  20.
PARAM    PRTMAXIM YES
EIGRL    1                    30    0
```

```
$ MKAERO2 card
$
$  Mach-Frequency Pair  .MRG_MK_3
MKAERO2 .7      7.500-00.7      .114056 .7      .228037 .7      .342019
MKAERO2 .7      .456
$
$ Aeroelastic Model Parameters
PARAM   AUNITS  1.
$
$ Global Data for Steady Aerodynamics
$
$ A half-span model is defined
$
AERO    0       1.      1600.   .002378
AEROS   0       0       1600.   8200.   6560000.
$
$ Flat Aero Surface: aeromsh
$
PAERO1  100001
CAERO1  100001  100001  0       5       5                       1
        1.626-051.322-058200.   1400.   1.858-051.510-050.      1600.
$
$ Surface Spline: wingspline_11
$
SPLINE4 11      100001  1               1               FPS     BOTH
        10      10
AELIST  1       100001  100002  100003  100004  100005  100006  100007
        100008  100009  100010  100011  100012  100013  100014  100015
        100016  100017  100018  100019  100020  100021  100022  100023
        100024  100025
```

<div align="center">Fig 6.1 Result</div>

Results & Discussion

From the analysis it is 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. Always wing will give up with 6 rigid body modes and it the 7th mode should follow the cantilever beam mode shape pattern.

Above figure shows the flutter prediction from the Patran output. 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.

Conclusion

Based on the evidence and the review of the project we can infer that the rigidity of ZODIAC CH 601XL aircraft wing is very weak. These tests revealed that the wing structure could not sustain the manufacturer's original design loads. This may be one of the primary root causes for the wing's structural deformations and subsequent failures, and may be a potential link to the flutter or vibrations experienced by CH 601 XL operators in flight. Because of the problems with the wing construction, structural rigidity may have affected the wing's fluttering characteristics. It is clear that owners and operators may not fully understand the necessary process.

From our analysis we came to know that our aircraft wing is not at all stiffening enough to take the loads. So first we need to make our wing stiffen enough without increase in weight by changing the cross section of internal structures. . 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. Then it will be followed by static flutter analysis and end up with the prediction of flutter speed that which our aircraft can reach in a safe manner.

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