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Analysis of Fluid-Structure Interaction on an Aircraft Wing

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Abstract- Fluid–structure interaction problems in general are often too complex to solve analytically and so they have to be analyzed by means of experiments or numerical simulation. Studying these phenomena requires modeling of both fluid and structure. Many approaches in computational aero elasticity seek to synthesize independent computational approaches for the aerodynamic and the structural dynamic subsystems. This strategy is known to be fraught with complications associated with the interaction between the two simulation modules. AGARD 445.6 wings will be generated along with the fluid domain. The transonic flow in subsonic flow regime (M= 0.9) over the wing will be simulated and the results will be validated by comparing the computational results with the previously published results. The stresses induced corresponding to the flow will be computed using the ANSYS Workbench. This project provides basic knowledge of FSI in aerodynamics.

Key Words: **FSI, Aero-Elasticity, Wing, Fixed Wing.**

Nomenclature

Cr = Root chord

b = Half-wing span

λ = Quarter chord sweepback angle

AR = Aspect ratio

T = Taper ratio

C_d= Sectional drag coefficient (2D-Airfoil)

C_l=Sectional lift coefficient (2D- Airfoil)

C_D= Drag coefficient (3D-Wing)

C_L= Lift coefficient (3D- wing)

C_{dmin}= Minimum drag Coefficient

C_{Lmax}= Maximum lift coefficient

C_{Lmin}= Minimum lift Coefficient

C_m= Pitching moment coefficient

$C_{mo/4}$= Zero Angle Pitching moment coefficient

C_{mC}= pitching moment about the quarter-chord

$C_{L\alpha}$= Lift-Curve slope

L/D= Lift-to-Drag Ratio

CG= Center of Gravity

t/c = Thickness to Chord Ratio

E = Young's modulus

G= sectional modulus

α= Angle Of Attack

PR= Poison's Ratio

I. INTRODUCTION

In Fluid-structure interaction (FSI) problems, solid structures interact with an internal or surrounding fluid flow. FSI problems play prominent roles in many scientific and engineering fields, yet a comprehensive study of such problems remains a challenge due to their strong nonlinearity and multidisciplinary nature. Fluid-structure interaction (FSI) occurs when a fluid interacts with a solid structure, exerting pressure on it which may cause deformation in the structure. As a return, the deformed structure alters the flow field. The altered flowing fluid, in turn exerts another form of pressure on the structure with repeat of the process. This kind of interaction is called Fluid-Structure Interaction (FSI).

A. CLASSIFICATION of FSI

In general, a fluid-structure interaction system is classified as either strongly or weakly coupled. Weakly coupled fluid-structure system: If a structure in the flow field or containing flowing fluid deforms slightly or vibrates with small amplitude. Strongly coupled fluid-structure system: Fluid-structure systems are called strongly coupled systems if alteration of the flow field due to large deformation or high amplitude- vibration of the structure cannot be neglected.

B. TYPES of FSI

There are three types of fluid-structure interactions

Zero strain interactions: Such as the transport of suspended solids in a liquid matrix.

Constant strain steady flow interactions: The constant force exerted on an oil-pipeline due to viscous friction between the pipeline walls and the fluid.

Oscillatory interactions: Where the strain induced in the solid structure causes it to move such that the source of strain is reduced, and the structure returns to its former state only for the process to repeat.

C.ADVANTAGES

Practical uses fluid film interaction

- FSI is responsible for countless useful effects in engineering.
  - It allows fans and propellers to function.
  - Sails on marine vehicles to provide thrust.
  - Aerofoil's on race cars to produce down force.

II. PROBLEM DEFINITION

AGARD stands for Advisory group for Aeronautics Research and development and was an agency of NATO

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that existed from 1952 to 1996. AGARD 445.6 is widely used benchmark in computational Aero-elasticity. FSI arises in transient flow experiments are highly expensive and can be destructive. AGARD 445.6 wing is selected as it is regarded as benchmark in dynamic aero-elastic analysis. The transient flow in subsonic regime (M= 0.9) over the AGARD 445.6 wing will be simulated and the results will be validated by comparing the computational results with the previously published results. The stresses induced corresponding to the flow will be computed using the ANSYS Workbench

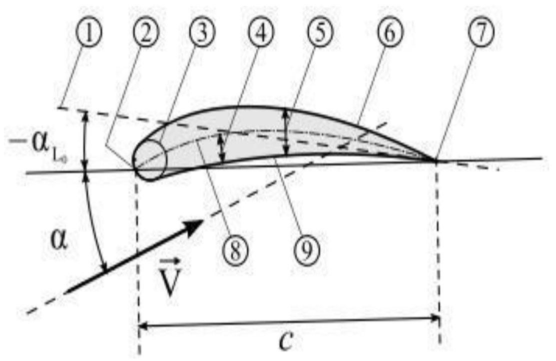
III. WORKING METHODOLOGY

Working methodology involves modeling of the desired wing in the CATIA V5R21. The wing has the similar dimension s of that of AGARD 445.6 since the results are readily available. Later, the wing is analyzed for the aerodynamic performance under the given flight conditions. The pressure distribution resulted from the flow analysis is then applied as a structural load over the wing. The results are then compared with the existing

IV. MODEL DESCRIPTION

The first configuration to be tentatively accepted as an AGARD standard is designated "Wing 445.611. Wing 445.6 identifies the shape of a set of sweptback, tapered research models which were flutter tested in both air and Freon-12 gas in the 16 foot x 16 foot NASA Langley Transonic Dynamics Tunnel(ref.5) . The first digit of this numerical designation is the aspect ratio; the second and third digits indicate the quarter-chord sweep angle; and the last digit is the taper ratio. These wing had 65a004 airfoil sections with no twist and nor camber and were tested at zero angle of attack (fully symmetrical conditions). They were of solid homogeneous construction.

A. AIRFOIL



1: Zero lift line; 2: Leading edge; 3: Nose circle; 4: Camber;

5: Max. Thickness; 6: Upper surface; 7: Trailing edge;

8: Camber mean-line; 9: Lower surface

Fig. 1. Block Diagram of Design Procedure

Selection of an airfoil is the critical aspect of the design for an aircraft, as the co-efficient of lift for an airfoil is an index of total lift generated by the wing. The NACA airfoils are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils 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 airfoil and calculate its properties. AGARD uses NACA 6 digit series for the model so we will be considering the NACA 6 digit series airfoil

B. NACA 6 DIGIT AIRFOILS

Six digit series is an improvement over 1-series airfoils with emphasis on maximizing laminar flow. The airfoil is described using six digits in the following sequence:

The number "6" indicating the series.

One digit describing the distance of the minimum pressure area in tens of percent of chord.

The subscript digit gives the range of lift coefficient in tenths above and below the design lift coefficient in which favorable pressure gradients exist on both surfaces.

A hyphen. One digit describing the design lift coefficient in tenths. Two digits describing the maximum thickness in tens of percent of chord.

The shape 65a004 airfoil using Foil-sim software with a=1 is shown below where subscript represents the range of lift coefficient in tenths above and below the design lift coefficient in which favorable pressure gradients exist on both surfaces.

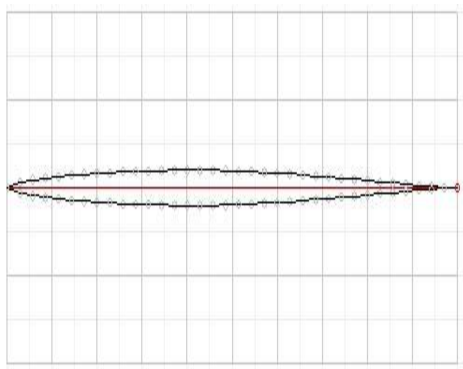


Fig. 2. Airfoil generated using Foilsim software

C.WING

AGARD 445.6 wing is widely used for much aero-elastic analysis, as its experimental results are available in open literature. It is an experimental wing that has 65a004 airfoil and an aspect ratio of 4, sweep of 45˚ and taper 0.6. This model is homogeneous and orthotropic in nature. Figure below shows the plan form of the AGARD 445.6 wing used in the experiment. Material properties of the wing are shown below. The material use here is laminated mahogany as considered in previously available results.

1. WING SPECIFICATIONS

➢ Root chord C_r = 0.558m

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- Half-wing span b = 0.762m
- Quarter chord sweepback angle λ = 45˚
- Aspect ratio AR = 1.65
- Taper ratio T = 0.66

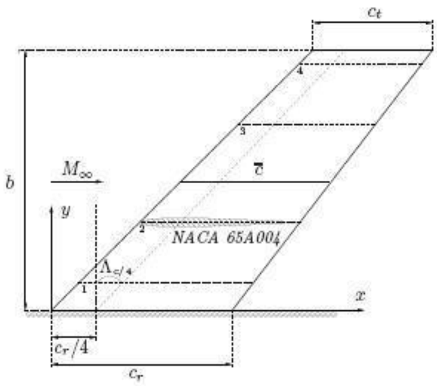

Fig. 3. AGARD 445.6 wing model (with reference to Ramjikamakoti thesis)

V. MODELING

In the process of analysis the first step is to model the problem. For this, we have used some of the available software's.

A. MACROS

To generate the wing the basic requirement is the airfoil section for both the ends of the wing. To generate the coordinates for the airfoils at the tip and root of the wing, MACROS is used. MACROS are a full featured automation software package that provides many ways to interact with applications. A tester can use the Script Editor or Recorder to set up complex test scenarios in minutes with no-programing required.

B. CATIA

CATIA (**Computer Aided Three-dimensional Interactive Application**) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite. The key points generated by using MACROS are then imported into the CATIA. Using these key points the required airfoils and wing are generated. The generated wing must be saved in **.iges format** for its further use in ANSYS workbench

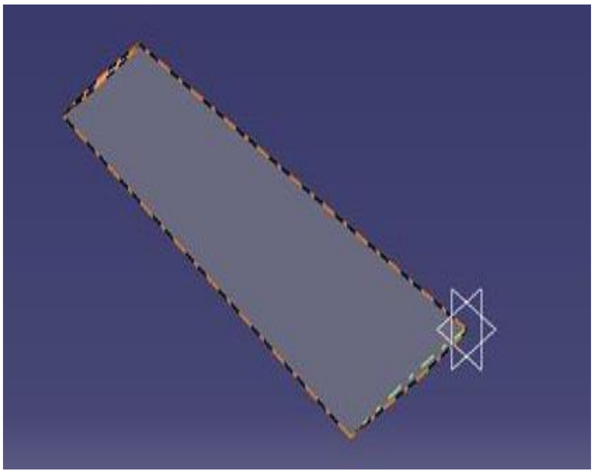

Fig. 4. AGARD 445.6 wing modeled in CATIA

VI. ANALYSIS

The model is then imported to the ANSYS Design modeler for further analysis.

A. ANSYS V12.0

ANSYS is an engineering simulation software which offers engineering simulation solution sets in engineering simulation that a design process requires. Companies in a wide variety of industries use ANSYS software. The tools put a virtual product through a rigorous testing procedure before it becomes a physical object.

B. ANSYS WORKBENCH

The ANSYS Workbench platform is the framework upon which the industry's broadest and deepest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user through even complex multi-physics analyses with drag-and-drop simplicity. With bidirectional CAD connectivity, powerful highly-automated meshing, a project-level update mechanism, pervasive parameter management and integrated optimization tools, the ANSYS Workbench platform delivers unprecedented productivity, enabling Simulation-Driven Product Development.

There are three stages in ANSYS workbench

- ANSYS Design Modeler
- ANSYS Meshing
- ANSYS DesignXplorer

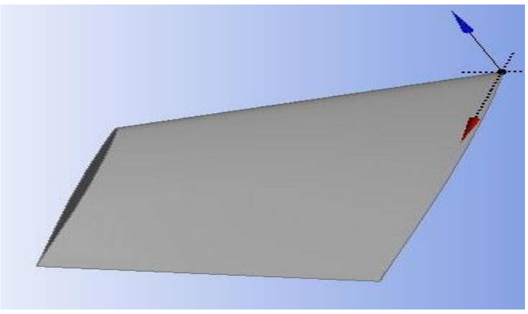

Fig. 5. Generated wing in Design modeler

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VII. CFD ANALYSIS

The flow analysis is carried out in the FLUENT. For this, the model (wing) is placed in the domain

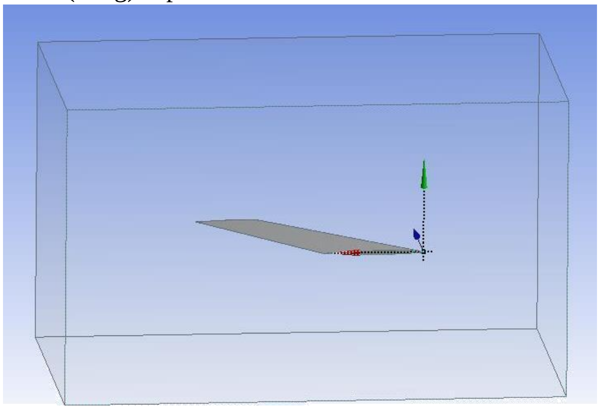

Fig. 6. Wing with Domain

The meshing of the fluid domain is cone in the meshing section of the workbench

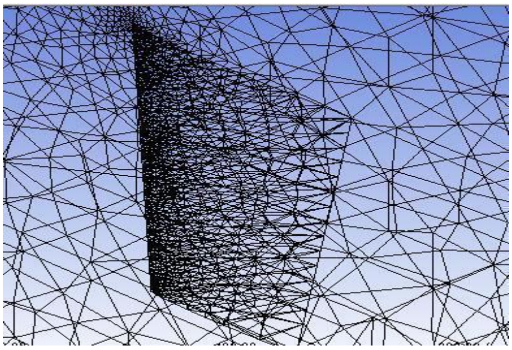

Fig. 7. Showing mesh over the wing for the CFD Analysis using wireframe view

Later, the model is exported to the FLUENT for the flow analysis. The iterations are continued till the solution is converged.

The flow condition are given below

- Velocity - 312 ms^{-1}
- Temperature - 300K
- Pressure - 1 bar
- Density - 1.225 kgm^{-3}

VIII. STRUCTURAL ANALYSIS

The structural analysis for the wing is carried for the pressure and shear distributions of the flow around the wing which are resulted from flow analysis. The mechanical properties of the wing are given below

PROPERTY	VALU
Ex	3.1511E
Ey	4.162E
Ez	4.162E
Poison's Ratio XY	0.31
Poison's ratio YZ	0.31
Poison's Ratio XZ	0.31
GXY	4.392E
GYZ	4.392E
GXZ	4.392E

Table i. Mechanical properties of wing

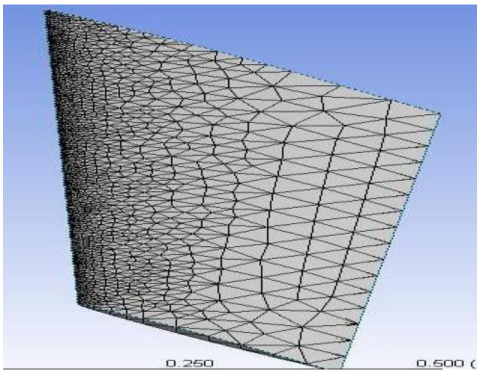

Fig. 8. Meshed geometry in static structural

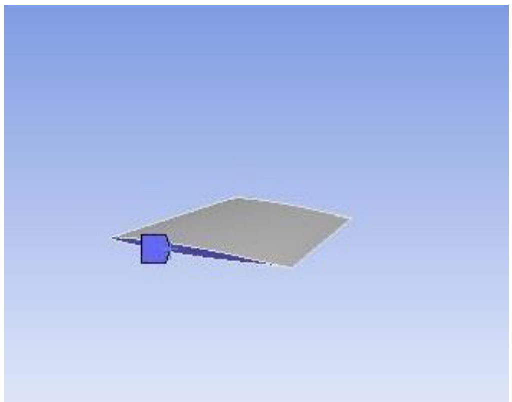

Fig. 9. Fixed support applied at root chord of the wing

IX. RESULTS AND DISCUSSION

The objective of the project is successfully achieved. The object of this test is to show deflection of the wing due to pressure due to aerodynamic loads and resulting change in frequency due to deflection of wing. AGARD 445.6 wing is a benchmark for Aero-elastic analysis as its experimental flutter. This wing is to be checked for dynamic structural stability by carrying out dynamic Aero-elastic study and then validate the results with experimental results. The wing is tested for flutter at Mach=0.9 and dynamic pressure is varied and resulting tip motion is noted. At each Mach number there is a dynamic pressure at which the tip displacement maintains its amplitude, i.e. it is neither increasing nor decreasing, is called Flutter Boundary for that Mach. The region above flutter boundary is unstable i.e. amplitude of deformation increases; while the region below flutter boundary is stable region i.e. deformation decreases. Material properties of the wing are not fully specified in the NASA's paper so these properties are picked because using these properties we get the modal frequencies very close to those that were found experimentally.

A. CFD RESULTS

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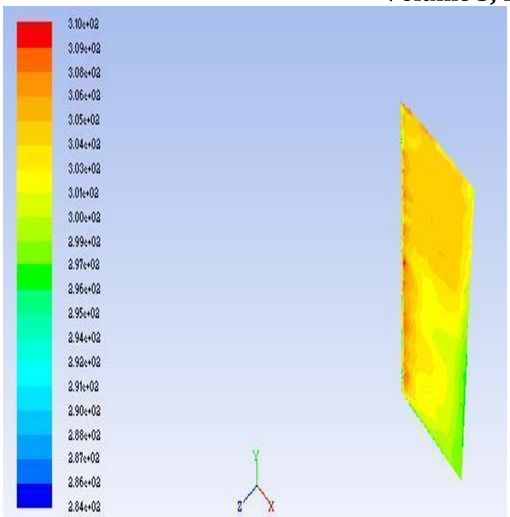

Fig. 10. Pressure contour on wall solid (wing)

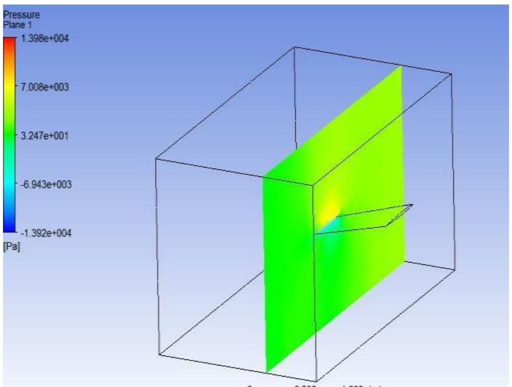

Fig. 11. Plane located on wall-solid showing pressure distribution

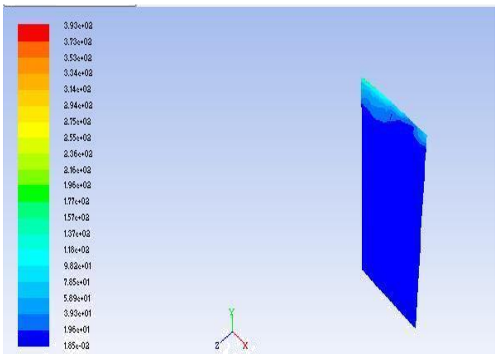

Fig. 12. Contour of Turbulent Kinetic Energy

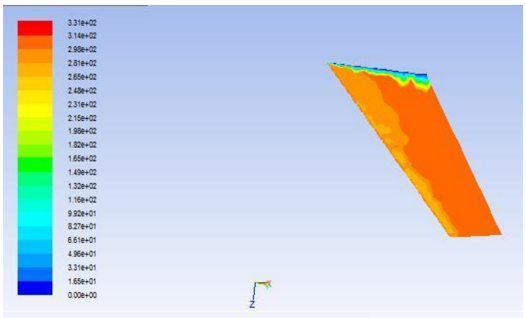

Fig. 13. Contour of Velocity Magnitude

B. *STRUCTURAL ANALYSIS RESULTS*

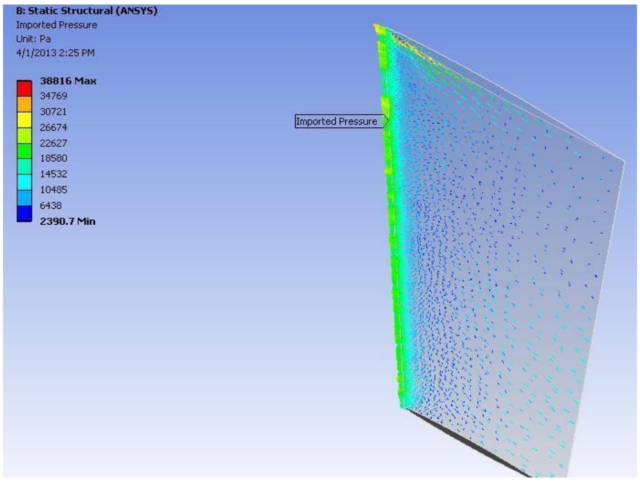

Fig. 14. Showing imported pressure acting on a wing.

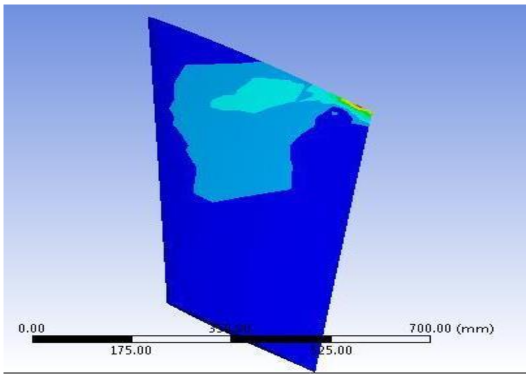

Fig. 15. Contour of total deformation on wing

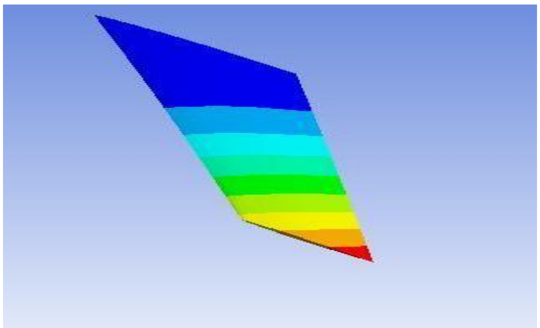

Fig. 16. Contour of Von Moises stress

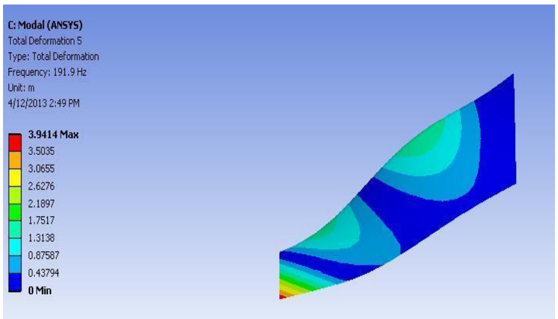

Fig. 17 .mode shape of 5th frequency

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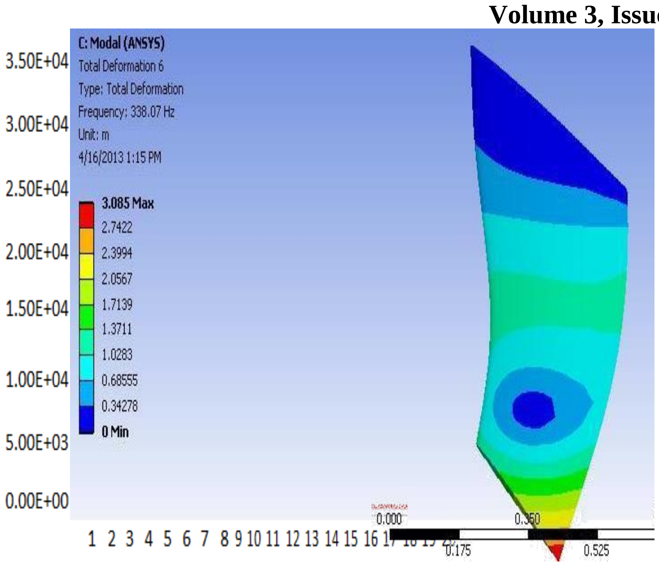

Fig. 18. Mode shape of 6th frequency

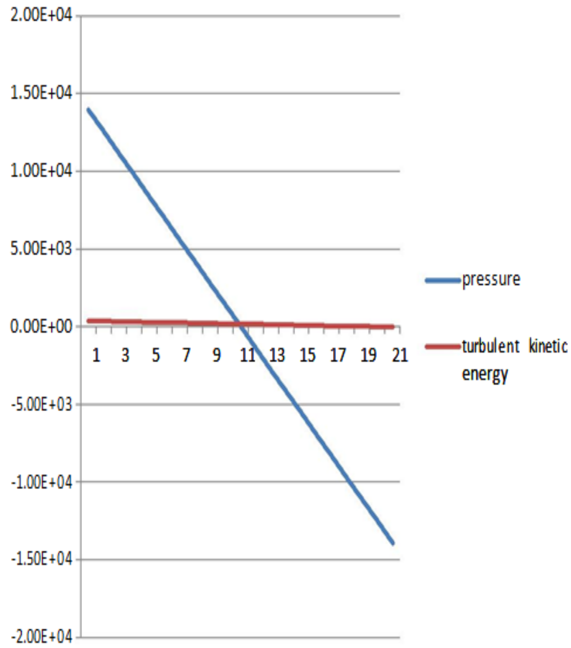

Fig. 21. Pressure vs. turbulent kinetic energy graph

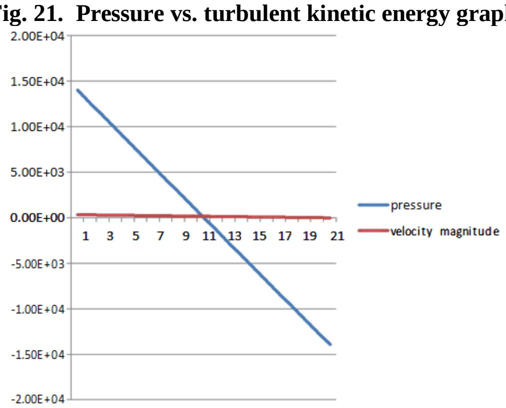

Fig. 22. Pressure vs. Velocity magnitude graph

Fig. 19. Temperature vs. Turbulent kinetic energy graph

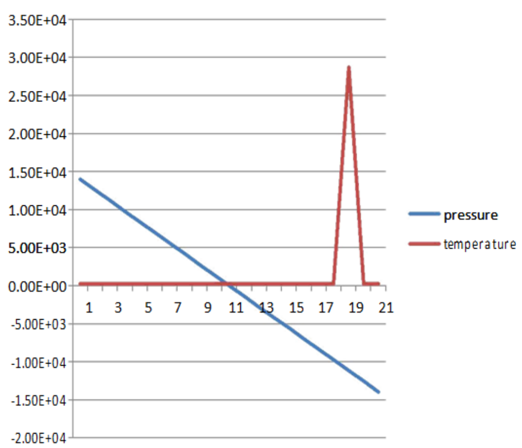

Fig. 20. Pressure vs. Temperature graph

X. CONCLUSIONS

This project was largely aimed at gaining a basic understanding and better overview of the fundamental structural behavior of the AGARD 445.6 wing under practical load conditions, As from the previously discussed chapter we can say that Fluid-structure interaction plays prominent roles in many ways in the engineering fields. These problems are often too complex. In this project the FSI problem was successfully solved using the AGARD445.6 wing. The computations were performed for AGARD 445.6 wing by considering the transonic flow at subsonic mach numbers. The stresses induced corresponding to the flow has been successfully computed using the ANSYS Workbench. Validation of flutter frequency also accomplished by comparing it with the previously published thesis. This project provides the complete exposure to the FSI problem and gives the complete study of fluid on structure and vice-versa. A larger quantum of work has been done to make the study more meaningful.

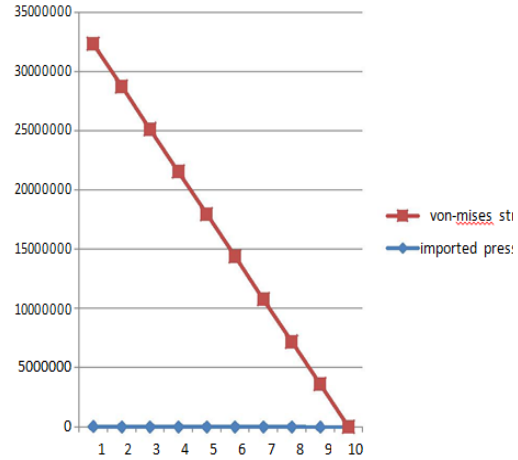

Fig. 23. Imported pressure vs vonmises stress

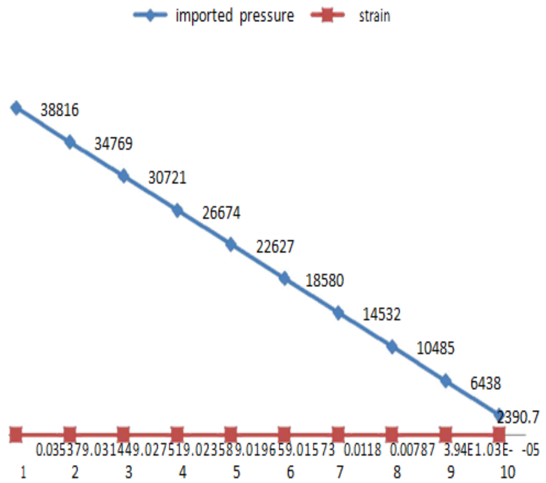

Fig. 24. Pressure vs Von Mises strain

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