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Fluid Structure Interaction on AGARD 445.6 wing at Transonic Speeds

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ABSTRACT

Aircraft is a complex structure, but a very efficient man made flying machine. An aircraft is a machine that is able to fly by gaining support from the air, or, in general, the atmosphere of a planet. It counters the force of gravity by using either static lift or by using the dynamic lift of an airfoil, or in a few cases the downward thrust from jet. In this project the fluid–structure interaction problem will be illustrated using the AGARD 445.6 wing by predicting its initial boundary condition. AGARD 445.6 wing is used because the experimental results are available. This configuration was chosen because extensive research has been done in the field of aero-elasticity using this model. The main objective of this project is to study the Fluid Structure Interaction over the wing of Aircraft and determine the aero elastic properties through modelling as well as analyzing the AGARD 445.6 wing structure using CATIA V5 to generate solid model and the stress analysis is done using ANSYS –FLUENT. As Fluid Structure Interaction oscillation are strong enough to deform the structure of an aircraft the so the study is quite complex as the method involves a series of iterations.

Keywords:- FSI, CATIA, NACA

I. INTRODUCTION

In Fluid-structure interaction (FSI) problems, solid structures interact with an internal fluid flow as well as 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, this exerts pressure on it which may cause deformation in the structure. As a return, the deformed structure alters the flow field. The altered flowing fluid exerts another form of pressure on the structure and this goes cyclic.

This interaction is called Fluid-Structure Interaction (FSI). Most of these interactions may be stable or oscillatory and are a crucial consideration in the design of many engineering systems, especially aircraft. Failing to consider the effects of FSI can be catastrophic, especially in large scale structures. Fluid-Structure Interaction problems in general are often too complex to solve analytically and so they have to be analyzed by the means of experiments or numerical simulation. Many approaches in computational aero-elasticity seek to synthesize independent computational approaches for the aerodynamic and structural dynamic systems. This strategy is known to be fraught with complications associated with the interaction between the two simulation modules.

In this project the fluid–structure interaction problem will be illustrated using the AGARD 445.6 wing by predicting its initial boundary condition. AGARD 445.6 wing is used because the experimental results are available. This configuration was chosen because extensive research has been done in the field of aero-elasticity using this model.

A computational methodology for performing fluid-structure interaction computations for three-dimensional elastic wing geometry is presented. The computations are performed for AGARD 445.6 by considering the transient flow at subsonic Mach numbers.

II. CLASSIFICATION OF FLUID-STRUCTURE INTERACTION

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 deforms slightly or vibrates with small amplitude, it will affect negligibly the flow field because of the relatively low pressure. These fluid-structure interaction systems are called weakly coupled systems. For these FSI systems, it is assumed that the force acting on the fluid due to the structural motion can be linearly super-imposed onto the original force function in the fluid.

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. In such strongly coupled fluid-structure systems in which large structural deformation or displacement results in a significant alteration of original flow field, both altered and original flow fields cannot be linearly super-imposed upon each other.

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.

History of Fluid-Structure Interaction: In 1828, the concept of hydrodynamic mass was proposed first by Friedrich Bessel who investigated the motion of a pendulum in fluid. He found out that a pendulum moving in a fluid had longer period than in a vacuum even though the buoyancy effects were taken into account. This finding meant that the surrounding fluid increased the effective mass of the system. In 1843 Stokes performed a study on the uniform acceleration of an infinite cylinder moving in an infinite fluid medium and concluded that the effective mass of the cylinder moving in the fluid increased due to the effect of surrounding fluid by the amount of hydrodynamic mass equal to the mass of the fluid displaced. It was known that this finding proposed the concept of fluid-structure interaction.In 1960's some designers of nuclear reactor systems found that the hydrodynamic mass of a structure in a confined fluid medium resulting from the fluid-structure interaction was much larger than that for the structure in an infinite fluid medium which was equal to the mass of fluid displaced by the structure.

III. ADVANTAGES OF FLUID – STRUCTURE INTERACTION

Practical uses fluid film interaction

1. FSI is responsible for countless useful effects in engineering.
2. It allows fans and propellers to function.
3. Sails on marine vehicles to provide thrust.
4. Airfoil's on racecars to produce down force.

IV. AGARD WING

AGARD stands for Advisory group for Aeronautics Research and development and was an agency of NATO that existed from 1952 to 1996. 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.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.

An airfoil (in American English) or aerofoil (in British English) is the shape of a wing or blade (of a propeller, rotor, or turbine) or sail as seen in cross-section. The lift on an airfoil is primarily the result of its angle of attack and shape. When oriented at a suitable angle, the airfoil deflects the oncoming air, resulting in a force on the airfoil in the direction opposite to the deflection. This force is known as aerodynamic force and can be resolved into two components: Lift and drag. Most foil shapes require a positive angle of attack to generate lift, but cambered airfoils can generate lift at zero angle of attack. This "turning" of the air in the vicinity of the airfoil creates curved streamlines which results in lower pressure on one side and higher pressure on the other. This pressure difference is accompanied by a velocity difference, via Bernoulli's principle, so the resulting flow field about the airfoil has a higher average velocity on the upper surface than on the lower surface. The lift force can be related directly to the average top/bottom velocity difference without computing the pressure by using the concept of circulation and the Kutta-Joukowski theorem.

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.

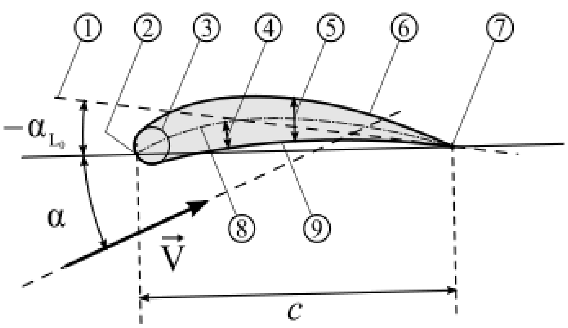


Fig1: Airfoil Geometry

V. NACA SIX-DIGIT 65a004 AIRFOIL

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:

1. The number "6" indicating the series.
2. One digit describing the distance of the minimum pressure area in tens of percent of chord.
3. 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
4. A hyphen.
5. One digit describing the design lift coefficient in tenths.
6. Two digits describing the maximum thickness as percent of chord.

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

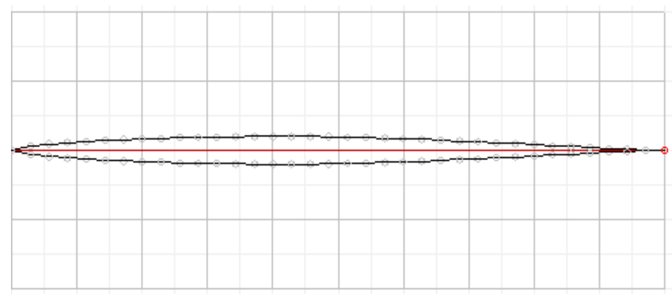
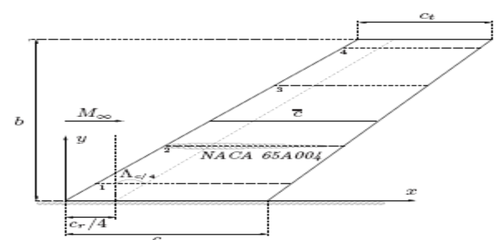


Fig 2: Airfoil generated using Foilsim software

IV. MODEL DESCRIPTION

AGARD 445.6 wing is widely used for many aero-elastic analysis.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 AGARD445.6 wing used in the Experiment Material properties of the wing are shown below.The material use here is laminated mahogany as considered in previously results.



VII. WING SPECIFICATIONS

1. Root chord **Cr** = 0.558m
2. Half-wing span **b** = 0.762m
3. Quarter chord sweepback angle **λ** = 45˚
4. Aspect ratio **AR** = 1.65
5. Taper ratio **T** = 0.66

MATERIAL

6. Laminated mahogany.
7. Density **ρ** = 381.98 kg/m^3.
8. Parallel young's modulus **Ep** = 3.151e9 pa.
9. Orthogonal young's modulus **Eo** = 4.162e8 pa.
10. Tangential modulus **G** = 4.392e8 pa.
11. Poisson's coefficient **η** = 0.31.

VIII. MODELING

The AGARD 445.6 wing is generated in CATIA by importing the point data in to the software using MACROS; AGARD 445.6 wing is a swept back wing with root chord as 558mm and wing tip as 368.2mm. Geometry wing in CATIA is shown in figure below.

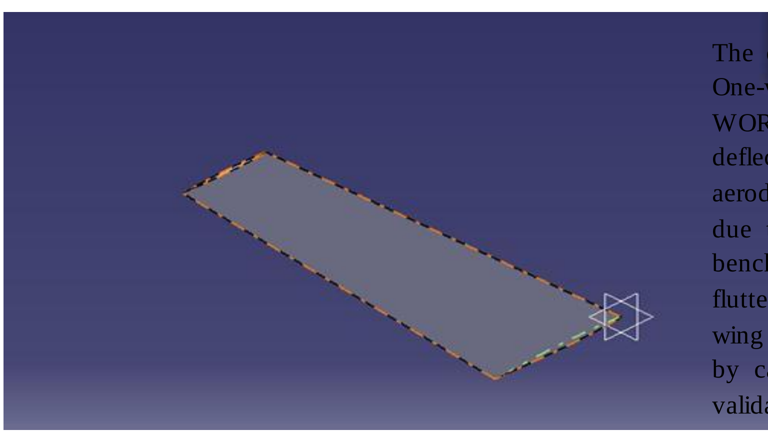


Fig3: Design of AGARD 445.6 wing in CATIA

This designed wing should be save in .igs format in order to import the file in ANSYS workbench. This generated wing is imported to the custom systems in ANSYS WORKBENCH i.e. FSI: fluid flow (FLUENT) □static structural. The link shown below between solutions of fluent and setup of static structure is used to import the pressure load on the wing from fluent to the static structural.

IX. MESHING

CFX-mesh method is used for meshing; Mesh is generated on the domain with the wing as wall-solid.

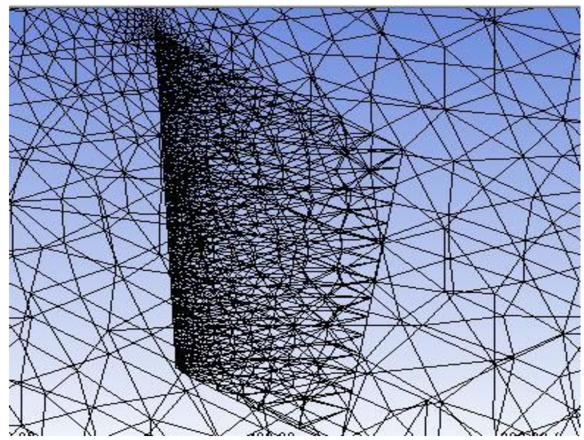


Fig4: Showing mesh over the wing using wireframe view

X. RESULTS

The objective of the project is successfully achieved. One-way FSI has been demonstrated in ANSYS-WORKBENCH. 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 results are available in open literature. 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

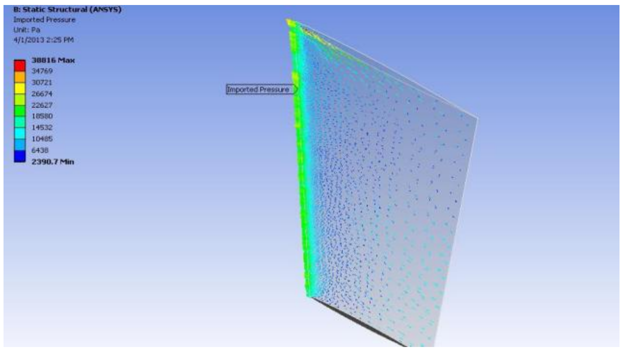


Fig 5 (a) represents the imported pressure on wing at mach 0.8

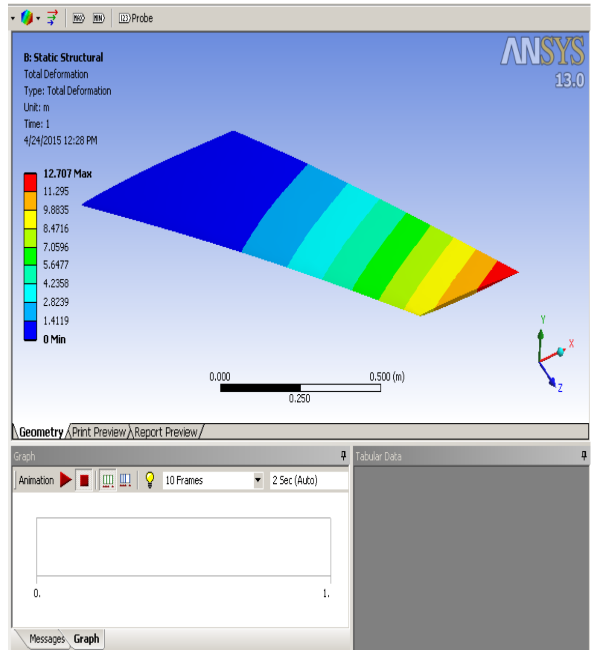
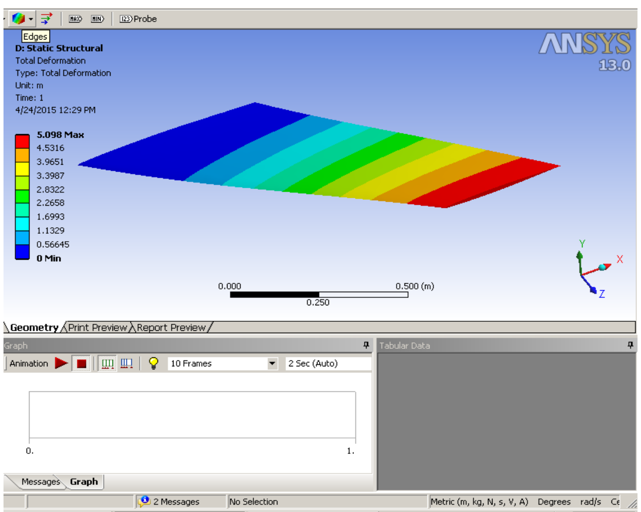


Fig 5 (b) Contour of total deformation on wing at 0.8M



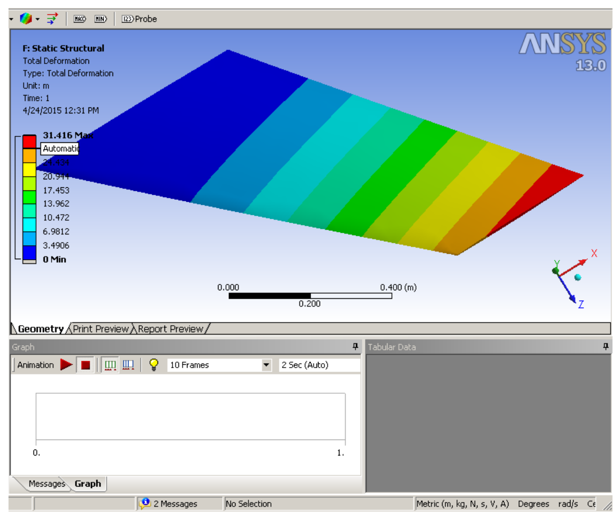
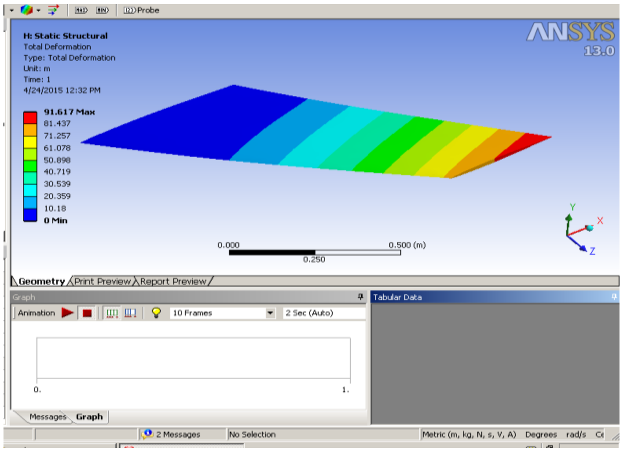


Fig 6 (a) Contour of total deformation on wing at 0.9M Fig (b) Contour of total deformation on wing at 1.0 M



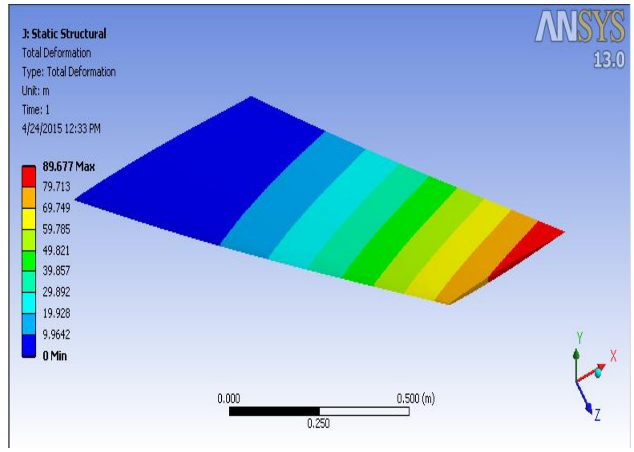


Fig 7(a) Contour of total deformation on wing at 1.1M Fig (b) Contour of total deformation on wing at 1.2 M

.No.	Iach number	.eading edge Pressure contours	gures of the eformation	Iaximum eformation
	8	950e +009	39 (a)	2.707
	9	033e +009	39 (b)	098
		5.141e +009	39 (c)	1.416
	1	657e +010	39 (d)	1.617
	2	2.439e +010	39 (e)	9.677

X1. CONCLUSION

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.

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