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Research Article

TIME-DOMAIN AEROELASTIC ANALYSIS OF AGARD 445.6 WING

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ABSTRACT

A coupled computational fluid dynamic (CFD) and computational structural dynamics (CSD) method is developed for the simulation and prediction of flutter of an aircraft wing. The CFD solver is based on an unsteady transient flow finite volume algorithm for the Navier–Stokes's equations. The CSD solver is based on the time integration of modal dynamic equations extracted from full finite element analysis. A general remeshing and spring analogy mesh deformation methods are used to generate dynamically moving grids for the unsteady flow solver. The solutions of the flow- field and the structural dynamics are coupled strongly in time domain by a fully implicit method. The coupled CFD–CSD method simulates the aeroelastic system directly on the time domain to determine the stability of the aeroelastic system. Based on the commercial solvers with available capability we have setup loosely coupled an aeroelastic analysis method for complete fluid structure interaction and also a closely coupled method to compute and compare the results with each other and also with the experimental data. Computations are performed for the three-dimensional AGARD 445.6 wing. Flutter boundary and transonic dip curve predictions by both the coupled CFD–CSD methods is presented and compared with experimental data for the wing.

Key Words: Time domain analysis; AGARD; CFD; CSD; flutter index; ANSYS

INTRODUCTION

The understanding of aerodynamic flows and their interactions with structures is becoming increasingly important for aerospace vehicles. Since airplane structures are not completely rigid because the limit on the weight of the structure, the aeroelastic phenomena arise due to structural deformations induced by aerodynamic forces. The simulation of the aeroelastic phenomena requires an integrated analysis of fluids and structures. Closed form solutions are available for aeroelastic computations when flows are either in the linear subsonic or supersonic range. Aeroelasticity is the science that concerns the interaction of aerodynamic, elastic and inertial forcesand the resulting phenomena. Static aeroelasticity effects result from the interaction of aerodynamic and inertial forces, however, all three forces are required to interact in order for dynamic aeroelastic effects to occur [1-5].

As the most important aeroelastic phenomena, e.g. flutter and divergence, can potentially lead to structural failure, aircraft structural designs have had to be made heavier (the so-called aeroelastic penalty) in order to ensure that structural integrity has been maintained via changes in the structural stiffness or position of the mass and flexural axes. This new field of analysis is the loosely coupled solution of fluid flows with structural interactions, commonly referred to as fluid-structure interaction (FSI). It is the natural next step to take in the simulation of mechanical systems. In aeroelastic response problems, one looks for the deformation and stress states in the structure as a response to turbulence or any unsteadiness in the flow. When the response of the structure is finite, the structure is stable. The structure flutters when its response to any finite disturbance is highly amplified [6-10].

This paper presents a procedure for solving fluid-structure interaction problems of AGARD 445.6 wing in three-dimensional transonic flow conditions the solution of fluid flow problems are based on the Navier-Stokes equations. The standard turbulent model is employed for the solution of three-dimensional viscous flow problems on unstructured meshes [11].

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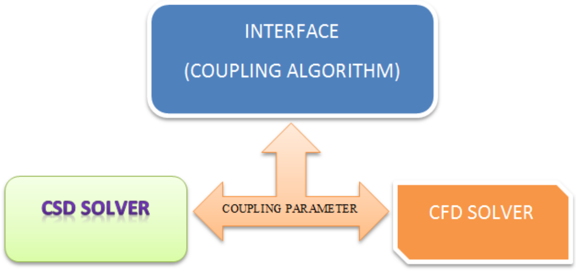

Figure1: Fluid-Structure Interaction Process

Structural modal dynamic equations are solved simultaneously in a strongly coupled fashion with the flow equations by a fully implicit time-marching method. A dual-time-stepping algorithm is used to achieve time accuracy and allow simultaneous integration of the flow and structural equations without any time delay. Based on this data exchange, the methods for solving fluid-structure interaction problems consist on solving both parts of fluid and structure in the same system of equations. The choice of time step is only limited by the required precision [12].

METHODOLOGY

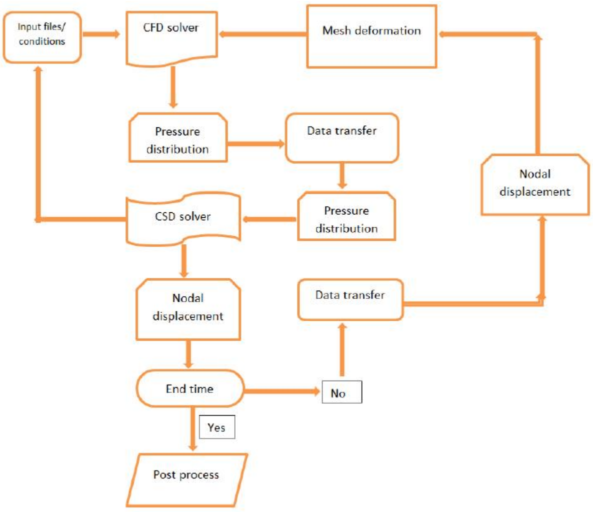

Figure 2: Fluid-Structure Interaction and Data Transfer flow process

The procedure for a full transient dynamic analysis (Available in the ANSYS Multiphysics, ANSYS Mechanical, and ANSYS Structural products) consists of these steps:

- Build the Model
- Establish Initial Conditions
- Set Solution Controls
- Set Additional Solution Options
- Apply the Loads
- Save the Load Configuration for the Current Load Step
- Repeat Steps 3-6 for Each Load Step
- Save a Backup Copy of the Database
- Start the Transient Solution
- Exit the Solution Processor

DESIGN AND INPUT PARAMETERS

MODELLING

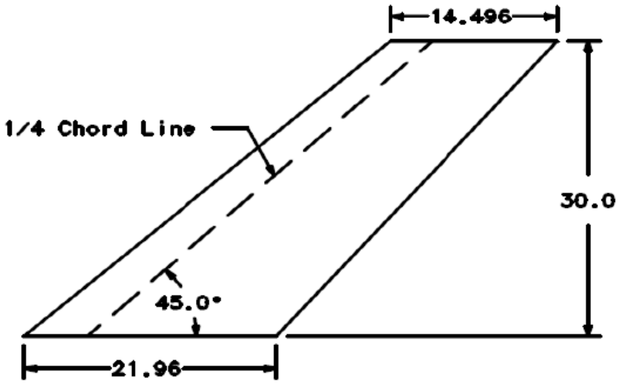

Figure3: Geometry of AGARD 445.6 wing and all dimensions are in inches

Figure 4: NACA 65A004 aerofoil

An unstructured mesh is generated with mesh size of 0.01mm with effective grid independent studies.

DOMAIN

- AGARD 445.6 weakened experimental model n°3
- NACA 65A004 aerofoil parallel to X axis
- Root chord Cr = 0.558 m
- Half-wing span b = 0.762 m
- Quarter chord sweepback angle Lambda = 45 degree
- Aspect ratio AR = 1.65
- Taper ratio lambda = 0.66

MATERIAL

- Laminated mahogany
- Density rho = 381.98 kg/m^3
- Parallel Young's modulus Ep = 3.151e9 Pa
- Orthogonal Young's modulus Eo = 4.162e8 Pa
- Tangential modulus G = 4.392e8 Pa
- Poisson's coefficient nu = 0.31

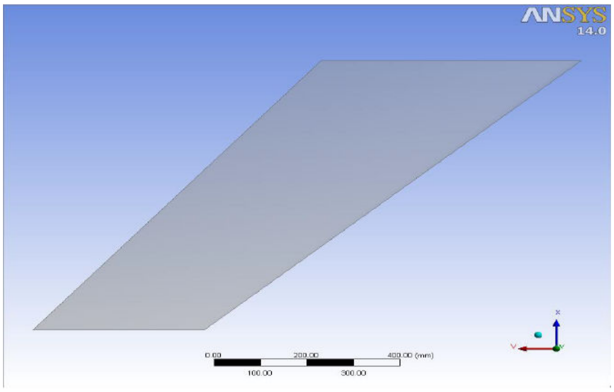

Figure 5: ANSYS model created for analysis of the AGARD 445.6 wing

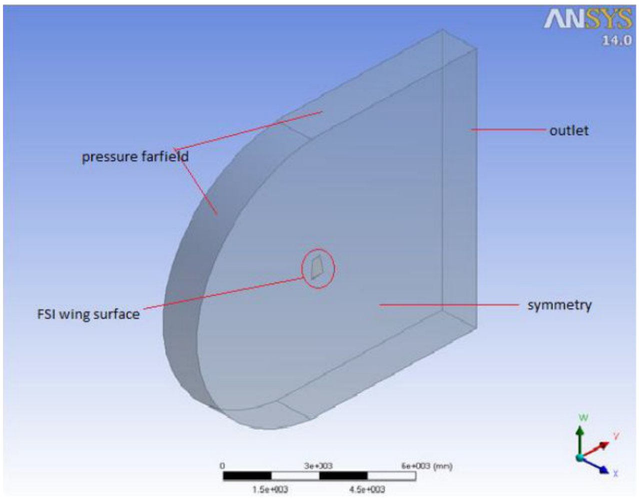

Figure 6: Boundaries specified for the CFD model

MESH GENERATION

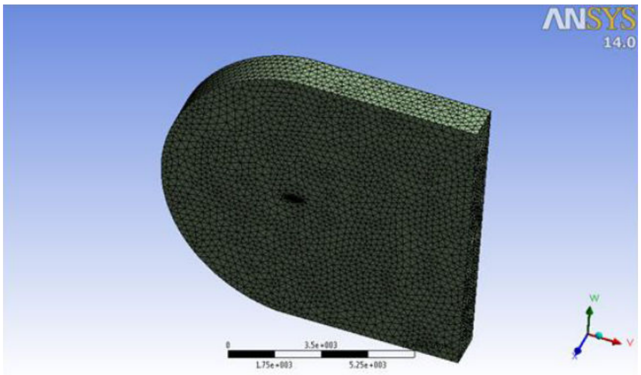

Figure 7: Unstructured mesh generated for CFD analysis

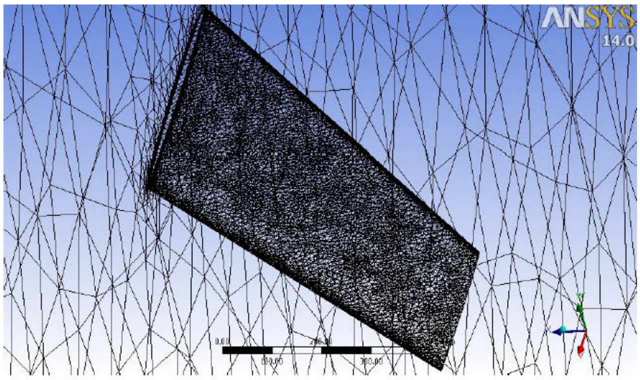

Figure 8: Tetrahedral mesh generated on wing surface

RESULTS

Table1: Comparison of modal frequencies for AGARD 445.6 wing

	Mode 1	Mode 2	Mode 3	Mode 4
Present work	9.5332	39.905	49.98	96.109
Experimental	9.6	38.10	50.70	98.50
Erkut [6]	9.41	39.46	48.96	94.35

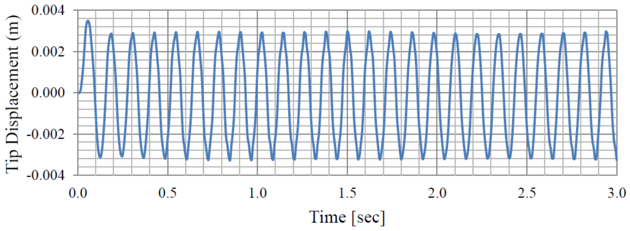

Figure9: Leading edge tip displacement of AGARD 445.6 wing at Mach=0.5 and 2.0 million Reynolds number for Flutter index= 0.4170

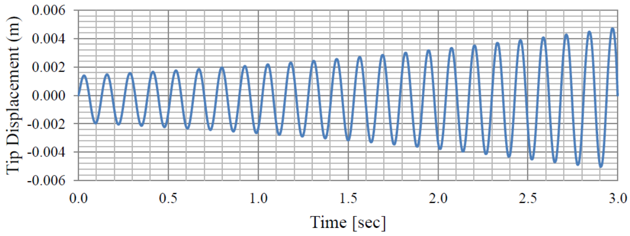

Figure10: Leading edge tip displacement of AGARD 445.6 wing at Mach=0.5 and 2.0 million Reynolds number for Flutter index= 0.4598

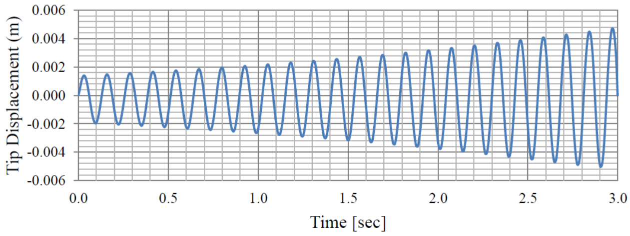

Figure11: Leading edge tip displacement of AGARD 445.6 wing at Mach=0.5 and 2.0 million Reynolds number for Flutter index= 0.5000

Figure 9 shows the damped response of the wing where the provided pressure energy is absorbed by the body in order make the system damp. The flutter index of 0.4170 was calculated by the velocity obtained by variation method at which the damped oscillations trend was good is 170.62 m/s and the density calculated using flutter index formula is 0.383 kg/m3. The density kept constant by varying the freestream velocity and corresponding temperature and reference pressures the dynamic inputs were given to solver along with initial conditions [13].

Figure 10 represents required flutter point for the Mach number 0.5. At which the oscillations of the structure become neutral. The deformation of the structural leading edge tip displacement has been plotted. This ensures that the wing tip deforming normal to the span in both positive and negative direction at a constant magnitude. The velocity at this point is called flutter velocity has been noted as 187.730 m/s and corresponding flutter index value is 0.4589 for the constant density of 0.383 kg/m3. Considering at this point the structural damping value becomes zero and no energy is observed by the structural member (AGARD 445.6 wing) [14].

Figure 11 shows the diverged oscillations for the Mach number 0.5. At this point the structural member starts to oscillate in order it gain the energy from each previous amplitudes and rises continuously in magnitude compared to previous. Thus, the structural member leads to fail and crack propagates. The divergence velocity noted from the analysis is 204.5415 m/s and corresponding flutter index is 0.5 at the constant density of 0.383 kg/m3.

Table 2: Comparison of Mach no Vs. Flutter index values with present works

MACH NO.	EXPT	FLUENT	IMPRANS
0.5	0.4459	0.4589	0.4338
0.678	0.4174	0.4233	0.41794
0.9	0.37	0.37035	0.371
0.96	0.3076	0.34477	0.34173
1.074	0.3201	0.4156	0.4055

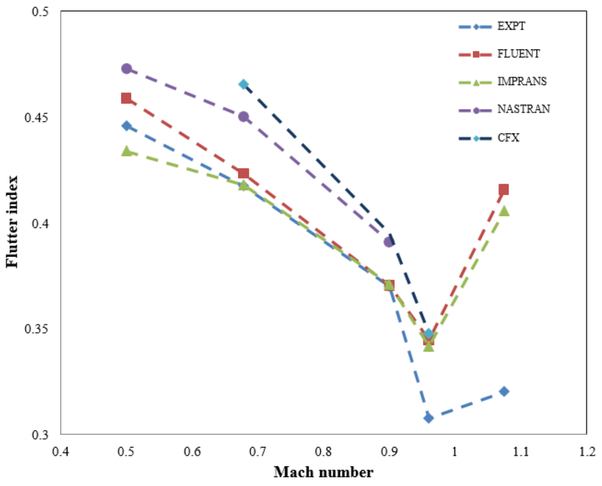

Figure12: Comparison of the flutter boundary of AGARD 445.6 wing with different solvers and experimental results with present work (ANSYS Fluent)

A comparison of flutter boundary produced by the present works using both loosely coupled (ANSYS Fluent) and closely coupled (ANSYS CFX) is shown in figure 12 above. The loosely coupled method predicted the flutter boundary in good range when compared to the closely coupled aeroelastic analysis values. Table 2 shows the values obtained by the present work and also compared with other solver results and experimental data [15-20].

CONCLUSION

This method consists of the application of a three-dimensional, parallel, unsteady Navier–Stokes solver, parallel dynamic grid deformation method, and a CSD solver strongly coupled with the flow solver using dual-time stepping. Based on solvers with available capability we have setup loosely coupled an aeroelastic analysis method for complete fluid structure interaction and also a closely coupled method to compute and compare the results. Loosely coupled method provides the best matching results under supersonic Mach numbers to predict the flutter and is in good comparison with experimental data. The closely coupled method has much difference using ANSYS CFX hence time consuming with smaller time step, so the loosely coupled procedure can be adopted for future works based on complex geometry and analysis.

REFERENCES

1. Lanchester F W.Torsional Vibrations of the Tail of an Airplane. Selected reprint Series,Aerodynamic Flutter Vol. V New York AIAA.1969; 12–5.
2. Liu F, CAI J And Zhu Y, Calculation Of Wing Flutter By A Coupled Fluid-Structure Method,Journal of Aircraft.2001; 38 (2).
3. Stefan Hartmann, Andreas Meister and Michael Schafer, International Workshop on Fluid Structure Interaction Applications, Kassel University, March. 2009.
4. Chansup Byun and Guru P Guruswamy, Aeroelastic Computations on Wing-Body-Control Configurations on Parallel Computers, Journal of Aircraft.1998; 35 (2): 288-294.
5. Ryan J Beaubien, Fred Nitzsche, and Daniel Feszty, Time and Frequency Domain Flutter Solutions for the AGARD 445.6 Wing, Department of Mechanical and Aerospace Engineering, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario, Canada.
6. Erkut Başkut and Ali Akgül, Development ofClosely Coupled Procedure for Dynamic Aeroelastic Analyses, Scientific Technical Review. 2012;62:30-39.
7. Germaine Stanislasse Lauregoura, Time Marching Analysis of Flutter Using Computational Fluid Dynamics, Ph. D Thesis, University of Glassgow .2001.
8. Jack J McNamar, and Peretz P Friedmann, Flutter-Boundary Identification for Time-Domain Computational Aeroelasticity, AIAA Journal.2007;45 (7).
9. Hambergure J, Kumar A and Krishnamurthy,A General Partitioned Fluid Structure Interaction Model For Non-Matching Unstructured Mesh, 20thCongress Mechanica Francisco, September . 2011.
10. Goodwin, S. A., Weed, R. A., Sankar, L. N., and Raj, P., Toward Cost-Effective Aeroelastic Analysis on Advanced Parallel Computing Systems," Journal of Aircraft.1999; 36(4):710–715.
11. Ramji Kamakoti, Computational Aeroelasticity Using A Pressure-Based Solver, University of Florida, Melike Nikbay, LeventÖncü, and Ahmet Aysan, Multidisciplinary Code Coupling for Analysis and Optimization of Aeroelastic Systems, Journal of Aircraft.2009;46(6).
12. Timothy J. Cowan and Andrew S. Arena, Accelerating Computational Fluid Dynamics Based Aeroelastic Prediction Using System Identification., Journal of Aircraft.2001;38 (1).
13. Jadic I, R M So, and Mignolet M P, Mechanical and Aerospace Engineering, Arizona State University, Analysis of Fluid Structure Interactions Using A Time-Marching Technique, Journal of Fluids and Structures.1998;12.

14. Fornasier L, Rieger H, Tremel U and Van Der Weide E, Time-Dependent Aeroelastic Simulation of Rapid Manoeuvring Aircraft, AIAA-0949-.2002.
15. Gregory Hershel Parker Major, USAF, Dynamic Aeroelastic Analysis of Wing/Store Configurations December.2005.
16. Sharanappa V Sajjan, Hemalatha E, Dutta P K, Transonic Flutter Analysis of the AGARD 445.6 Wing Using an Implicit RANS Solver IMPRANS, Project Document CF 1217 NAL CTFD Bangalore.2012.
17. Patrick Guillaume, Department of Mechanical Engineering, Vrije universiteit brussel, Pleinlaan2, B-1050 Brussel, Belgium.
18. Yates, E C, Jr. Norman, S L and Jr. Jerome, T F, Measured and Calculated Subsonic and Transonic Flutter Characteristics of a 45° Sweptback Wing Planform in Air and in Freon-12 in the Langley Transonic Dynamics Tunnel, NASA-TN- D-1616, March.1963.
19. Ansys Structural Chapter 3 Modal Analysis.
20. Arunkumar A, Amit Kumar Onkar, and Manjuprasad M, Transonic flutter prediction of AGARD wing in time domain using unsteady CFD based FSI solver, SAROD. 2013;2: 21-23.