iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** V **Month of publication:** May 2023

DOI: https://doi.org/10.22214/ijraset.2023.51513

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue V May 2023- Available at www.ijraset.com

Advancement of Aerodynamics in Flutter Characteristics of AGARD 445.6 Wing

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Abstract: The aerospace sector has seen a significant prominence in the field of aerodynamics. Aerodynamic behaviour differs from one structure to the next depending on the specifics of each one. Due to flexible aeroplane structures, aeroelastic phenomena occur, when structural deformations alter aerodynamic forces. A feedback mechanism between the increased structural deformations and the added aerodynamic forces increases further aerodynamic loads. These interactions may diminish until they achieve an equilibrium state or, if resonance takes place, they may diverge drastically. The most challenging to forecast instability aeroelasticity- aeroelastic phenomenon is flutter. An accurate finite element aerodynamic wing model is required for flutter study. A review of various approaches for conducting flutter analysis of AGARD 445.6 wing is presented in this paper. AGARD 445.6 wing has been used as standard configuration for the analogy of all aeroelastic behaviours. Under different flow regimes, the paper examines the platforms for finite element software that are used for flutter analysis.
Keywords: Aerodynamics, Flutter Characteristics, Finite Element, AGARD 445.6 Wing, Flow Regimes

I. INTRODUCTION

Aerodynamics is the study of moving air and how it interacts with objects that are placed in its path as obstacles. Hence the term "fluid-structure interaction" (FSI) refers to the interaction of a mobile or deformable structure with a fluid flow, either internal or external. An aeroelastic effects wouldn't be there, if aircrafts are made perfectly rigid Therefore, it is not possible to design an aircraft as a perfect rigid structure. So aircrafts are designed as lightweight and flexible. Hence flexibility, light weight and aerodynamic stresses are primarily responsible for aeroelastic issues.

The interdisciplinary field of study known as aeroelasticity examines how inertial, elastic, and aerodynamic forces interact when an elastic body is subjected to fluid flow. An aeroelastic phenomenon not only significant to aeroplanes but also has several applications in civil engineering, structural engineering, such as the design of bridges, thin structures, towers, smokestacks, electric lines, and pipelines. (Like cars, ships, submarines) [1]. Aeroelastic phenomena has two classifications: static and dynamic problems. Static aeroelastic phenomena, which omit inertial forces, are marked by the unidirectional deformation of the structure whereas dynamic aeroelastic phenomena, which include inertial forces, are typical in their rhythmic property of structural deformation. Divergence is a static phenomenon whereas flutter is dynamic phenomenon [1]. The different dynamic phenomenons are: Flutter, Buffeting, Aeroelastic response to dynamic load, Dynamic stability and manoeuvrability of deformable aircraft, Aero-servoelasticity. Among them flutter is critical.

The dynamic instability of aeroelasticity is referred to as flutter. One of the most hazardous effects of aeroelasticity is flutter, which has the potential to destroy a structure. The flutter can be defined as the most unstable self-exited vibrations in which the object/structure gains energy from the fluid stream around it and then leads to ultimate failure.

The cause is the unstable aerodynamic forces produced by the structure's elastic deformations, which are typically associated with complex processes including the interaction of the shock wave and boundary layer, flow separation, nonlinear limited cycle oscillation, and more. Flutter has been identified as a key factor in determining the dependability of aeroplane wings or turbo machinery blades. Therefore, flutter issues should be calculated and forecasted during the early stages of the structural design of the air vehicles.

The AGARD Structures and Materials Panel is designating a small number of aerodynamic configurations and experimental dynamic-response data sets as benchmarks for comparison in order to encourage the evaluation of existing and developing unsteady aerodynamic codes and methods for applying them to problems related to aeroelasticity, particularly in the transonic regime. This set is a follow-up to one that was established for comparing estimated and measured aerodynamic pressures and forces several years ago. The information required to perform flutter calculations for the first standard configuration for dynamic response alone is presented in this paper along with the relevant experimental flutter data [2].

It is desirable to compare the flutter data produced in the laboratory with the results of tested theoretical approaches in order to determine the validity of subsonic and transonic flutter data obtained in the Langley transonic dynamics tunnel. These comparisons are presented in this study for a moderately swept, somewhat tapered wing planform that has previously been the focus of in-depth experimental and theoretical flutter investigations. Since Freon-12 or air can be used as a testing medium in the Langley transonic dynamics tunnel, findings for flutter were obtained in both media. Freon-12 is nearly four times as dense as air at a given temperature and pressure, and its sound speed is 55 percent slower than air's [3].

A numerical method for approximating partial differential equation solutions is the finite element method (FEM). It was developed to address complicated elasticity and structural analysis issues that arose in the fields of civil, mechanical, and aerospace engineering. In order to solve almost all aircraft configurations, computational techniques using finite-difference approaches for fluids and finite-element approaches for structures have both made significant progress. In finite element method, every continuum can be broken up into a number of very small bits. 'Finite Elements' are these tiny finite-dimensional units. Each element's field quantity is permitted to exhibit a straightforward spatial variation that may be expressed in terms of polynomials. As a result, the original continuum is viewed as an amalgamation of various such minor components. These components are linked together by a number of joints known as Nodes. It is assumed that the elements are only connected to one another at the nodal points while discretizing the structural system with finite degrees of freedom. The geometrical and material qualities are contained in each element. It is expected that an elements internal material properties remain constant. The response parameter of solid structure is the displacement provided with load in action and stiffness as property. There are three main steps in a general finite element analysis: input file (pre-processor), solver (analysis) and output (post-processor). Under pre-processor, developing geometric model, finite element model (by meshing) and aerodynamic model, defining material properties, establishing boundary conditions and loads. In the solver stage, these singular elements are assembled to run the analysis which is then solved for various unknown variables. All the results are evaluated and displayed at pre-processor stage. Flutter problems are modelled and analysed using a variety of finite element systems. This document also includes a thorough overview of the MSC/NASTRAN software which is integrated with aeroelasticity.

II. COUPLING AERODYNAMICS INTO MSC/NASTRAN

When designing an aeroplane, it's critical to have an exact simulation of both the vehicle's structural and aerodynamic properties. The purpose of the work documented in this paper is to create a system for aeroelastic analysis that provides for higher fidelity aeroelastic loads.

This is achieved by coupling the aerodynamics and aerodynamic geometry from the A502 panel code to MSC/PATRAN V6 and MSC/NASTRAN V69.1 for Solutions 144 and 200.It is preferable to add aerodynamic and aeroelastic data into the MSC/NASTRAN solution sequence that better depicts the actual geometry of the vehicle. The paper gives the sufficient data that replaces or augments the unsteady data. Several important issues have been addressed in this development. First is the removal of the geometric restrictions/assumptions from the aerodynamic geometry. This leads to the most critical area that has been investigated: the means to apply the existing splining (aero/structural coupling) methods to the enhanced aerodynamic geometry. Finally, the problem of data visualization has been addressed to allow the analyst to better understand the behaviour of the aeroelastic system and, hopefully, find and correct modeling problems more quickly. In this paper, several significant concerns have been resolved.

The preliminary step is the partial elimination of the aerodynamic geometric limitations and assumptions. This brings us to the most important topic that has been researched: how to use the current splining (aero/structural coupling) approaches to apply to the improved aerodynamic shape. [8].

III. VARIOUS APPROACHES IN FLUTTER ANALYSIS FOR AGARD WING

An important issue in the research field of aeroelasticity is wing flutter. The paper focuses on the difficulties that can occur when the fluid module interacts with the wing module. The paper covers the challenges associated with solving fluid structure interaction queries analytically and works with ANSYS Workbench to calculate the vibrational analysis of the wing and the wing is modelled in solid modelling software for transonic regimes [3]. In order to investigate the fluid-structure interaction over an aircraft wing and to ascertain the aero elastic properties through modelling. In addition, the AGARD 445.6 wing structure is examined using CATIA V5 to generate solid models, and ANSYS Fluent is used to conduct a stress analysis. The study is highly complicated due to the fact that the method uses a number of iterations as well as the fluid structure interaction vibrations are powerful enough to deform an aircraft's structure [4].

In order to look into a previously noticed contradiction between Euler flutter characteristics and the experimental data, the flutter characteristics of the first AGARD standard configuration for dynamic response, Wing 445.6, are examined using an unsteady Navier-Stokes algorithm. The algorithm was changed for the time-marching, aeroelastic analysis of wings utilising the unstable Euler equations. It is a three-dimensional, implicit, upwind Euler Navier-Stokes code. The isolated 45° swept-back wing's flutter characteristics are ascertained using a linear stability analysis and a time- marching aeroelastic analysis. The paper investigates the effects of fluid viscosity, structural damping, and number of modes in the structural model. To determine flutter characteristics, the conventional v-g analysis is used. The study concluded that the fluid viscosity significantly affects the supersonic flutter border [5].

The Euler/boundary layer equations yield the transonic nonlinear flow field that coincides with boundary layer interaction and system identification techniques are used to translate the aerodynamic forces from the time domain to the frequency domain. The structural dynamic equations in generalised coordinates are used to address structure-related issues. An AGARD 445.6 wing mode flutter boundary forecast serves as a proof-of-concept for the method. In the study, for Mach numbers less than 1, simulation results match those of the experiment result of AGARD wing. Hence, method based on Euler equation is found efficient when compared with time domain analysis [6].

The simulation and forecasting of aircraft wing flutter is accomplished using a linked computational fluid dynamics (CFD) and computational structural dynamics (CSD) technique. The Navier-Stokes equations are solved using a finite volume method that involves erratic transient flow. The time computation of modal dynamic equations taken from complete finite element analysis is the backbone of the CSD solver. Based on solvers, the setup consists of loosely and closely coupled methods for fluid structure interactions. The loosely coupled method compares favourably to experimental data and offers the best matching outcomes for predicting the flutter at supersonic Mach values. Using ANSYS CFX, there are significant differences in the closely coupled technique [7].

The generalised air forces on vibrating supersonic wings with both supersonic and subsonic edges have been calculated using a box technique. This general approach's application to a few simplified situations reveals some surprisingly good consistency with other, more constrained theoretical approaches. The box process seems to provide a straightforward, routine method of analysing flexible wings for supersonic flutter investigations that is well suited to digital computing machinery programming. More boxes can be used within the linearized theory framework to improve accuracy. To extend below the M = 1.414 range, some modification to the current box technique employing square boxes is required [8]. By using CATIA V5 R20, trainer aircraft wing is modelled. The stress parameters were found out using MSC/NASTRAN and hence estimating the safety factors of the wing. The loads along wing orientation, across wing direction, and vertical direction have a significant impact on the wing model. Additionally, the actual case is the combined loading [12].

A true output feedback method for the adaptive management of a nonlinear plunging-pitching wing section operating at an incompressible flight speed has been developed in this study. Analysis of the adaptive controller's performance both with and without actuation dynamics has been performed. It is obvious the controller is capable of controlling the Limit Cycle Oscillations (LCO). A system is often linearized about a set of operating conditions before being used to construct a controller. A state estimator is then created using the separation concept. When the system is linearized, the aeroelastic system, however, loses the LCO above the flutter speed. [9]. CFD based solvers are used for transonic regions.

IV. FLUTTER ANALYSIS USING CFD

Computational fluid dynamics (CFD) is the numerical study of steady and unsteady fluid motion. The aerodynamic performance of flight vehicles is of critical concern to airframe manufacturers, just as is the propulsive performance of aircraft power plants, including those that are propeller, gas turbine, rocket, and electric driven. CFD is used throughout the design process, from conceptual-to-detailed; to inform initial concepts and refine advanced concepts. CFD is also used to lessen the amount of physical testing that must be done to validate a design and measure its performance. CFD is used to predict the drag, lift, noise, structural loads, thermal loads and combustion in aircraft systems and subsystems.

CFD is also a means by which the fundamental mechanics of fluids can be studied. By using massively parallel supercomputers, CFD is frequently used to study how fluids behave in complex scenarios, such a boundary layer transition, turbulence and sound generation, with applications throughout and beyond aerospace engineering.

This paper deals with a numerical approach for predicting 3D transonic wing flutter which couples the Navier-Stokes equations and structural modal equations. The flow solver uses a dual-time phase implicit un-factored Gauss-Seidel iteration with the Roe scheme. The structural response is implemented using a modal technique.

The structural and flow solutions are completely interconnected with respect to subsequent iterations within each physical time step. With ANSYS's finite element solver, the accuracy of the modal approach structure solver is verified. The findings show that for the current investigation, the first five modes are adequate to adequately simulate the reaction of the wing structure. With free stream Mach numbers spanning 0.499 to 1.141, the estimated flutter limit of AGARD wing 445.6 is in good agreement with the experiment [10]. The aeroelastic study of 2-D lifting surfaces for the different flight speed regimes is provided in this paper. Utilising the linear/nonlinear aerodynamic integral functions produced by a combined CFD and analytical technique forms the basis of the aerodynamic modelling. The unstable Euler codes provide the basis of the CFD formulation. 2-D lifting surfaces exposed to time-dependent external excitation are studied for flutter and aeroelastic response; the results are compared and the aeroelastic model is validated [11]. To confirm the static and dynamic instability of a high AR wing, a CFD-CSD coupled analysis is carried out. Here CFD is used for estimating aerodynamics whereas finite element method is used for structural analysis. For that CFX and ANSYS were used to calculate aerodynamics and structural analysis respectively. For evaluating flutter characteristics, the structural grid and aerodynamic grid exchanged information on pressure, velocity, and displacement to carry out the analysis [13].

Using MSC Flight Loads, the dynamic aeroelasticity was examined for original and composite wing configurations. The rigid/flexible spline method was used for both designs to couple the structural mesh and aerodynamic panels, ensuring the accuracy of the numerical method. The flutter point of the original configuration was compared to the composite wing's flutter response. The analyses show that as the mass is reduced, the natural frequencies and flutter velocity both significantly rise. The optimisation approach demonstrated that it was possible to reduce the wing mass while increasing the flutter speed [14].

V. CONCLUSIONS

This research article focused on some of the most current progress of aerodynamics in flutter analysis on AGARD wing. Flutter is considered as the most significant one among all the aeroelastic issues. For evaluating the flutter characteristics, this paper discussed various approaches such as v-g analysis, Euler-Navier Stokes algorithms and other linear and non-linear methods.

The flutter analysis using CFD tools were found to be more efficient especially in the case of transonic regimes. In this CFD tool gives more accurate results than other aerodynamic tool, but it took more run time for the analysis and for the modelling geometry. Moreover, this paper examines the coupling of aerodynamics with MSC/NASTRAN. While coupling, splining takes place and forces get transferred efficiently. Hence MSC/ PATRAN and MSC/NASTRAN can be used as a finite element software tool to generate accurate structural mesh for various flow regimes.

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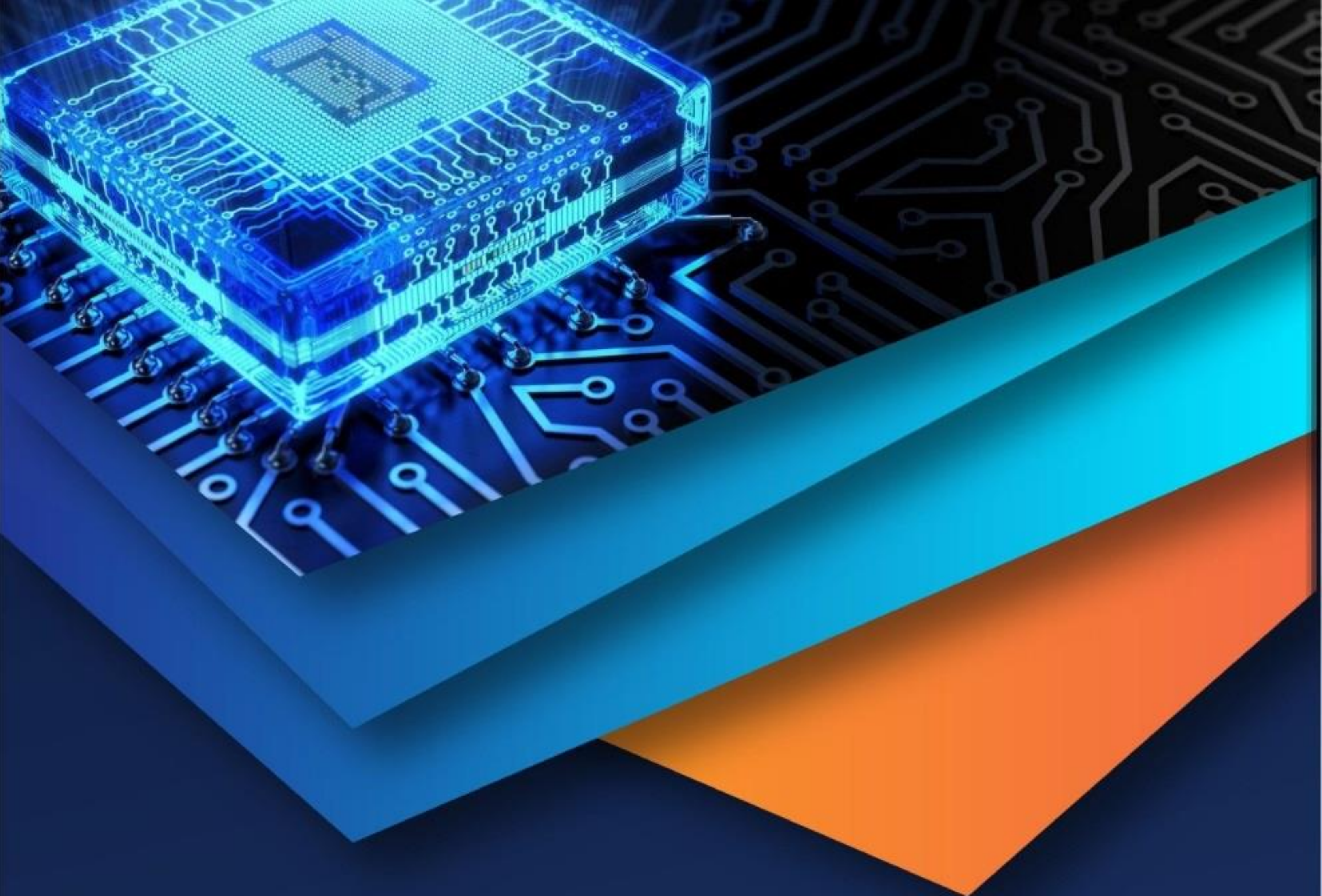

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