International Journal of New Media Studies (IJNMS), ISSN: 2394-4331
Volume 10 Issue 1, January-June, 2023, Impact Factor: 7.786

Review Study on Finite Element Analysis Method Used for Aerospace Structure Applications

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Abstract

The size of the structural components is orders of magnitude smaller than the diameter of the spot welds utilized in the automobile and aerospace industries. The normal number of spot welds on an automotive body is between three and five thousand, making the 3-D Direct Finite Element Analysis (DFEA) of this class problem impractical. The Elastic Finite Element Alternating Method (EFEAM) has been expanded in this study to address the issue of panels experiencing elastic-plastic fracture in the presence of Multi Site Damage (MSD) fractures. In EFEAM, crack issues in an infinite plate are solved analytically. The goal of the study is to look into a few areas of high-speed machining for enhancing thin-walled aerospace components' precision. The method entailed creating a finite-element model of the workpiece to be machined and then analysing its frequency response. The workpiece's reaction to dynamic cutting force provides a clue as to the fastest speeds feasible while maintaining precision.

Keywords: Finite element analysis, energy finite element analysis, Additive Manufacturing, Lattice Structure.

Introduction

It has been successful to simulate intricate structural-acoustic systems with isotropic structural material properties using the Energy Finite Element Analysis (EFEA). An emerging method for studying intricate structural-acoustic systems is the EFEA [1–18]. For the purpose of creating governing differential equations for each form of wave that is present in a system, the EFEA makes use of the spatially averaged vibrational or acoustic energy as a fundamental variable. It is not necessary to use small finite elements at high frequencies since the basic solution to the governing differential equations exhibits an exponential variation with space. Composite materials can be used in a wide variety of applications and are very adaptable. Two reinforcing (fiber) and matrix materials are combined to create the finished product (resin). When both materials are combined, they can provide better qualities than either material alone can [19–21].

Composite materials have many different uses, including in the electrical and electronics sector, construction and public works, transportation (road, rail, sea, aviation, and space), sports and recreation, general mechanical applications, and the aerospace industry [22].The use of composite materials in the aerospace sector is expanding in modern times. Composite materials are capable of producing massive, interconnected structures and have a very high strength-to-weight ratio. For instance, one composite material component might replace ten or more traditional metal parts, which can significantly cut down on production time and cost [23].

Due to their benefits, such as their high strength-to-weight ratio, high stiffness-to-weight ratio, corrosion resistance, and high durability, composite materials are being used in the aircraft sector more and more [24]. Fairings, spoilers, floor beams, and flight controls are examples of composite-material aircraft parts that have been produced. Compared to aluminum sections, these composite structures achieve greater weight reductions [25]. Large airplanes of a new generation are mostly built using composite wings and fuselages. A commercial aircraft, as an illustration, contains significant structural components manufactured from composite materials Rapid prototyping technology, which has been around since the 20th century, is the foundation of additive manufacturing (AM), a more modern innovation that account for more than 50% of the weight [26].

Rapid prototyping was later replaced by the terms 3D printing and additive manufacturing as technology advanced and end-user products could now be produced, which is now regarded as a manufacturing process [27].It is now possible to produce components like lightweight lattice structures using AM technologies like Electron Beam Melting (EBM) and Selective Laser Melting (SLM) based on a layer-by-layer manufacturing technique [28,29]. The need for lightweight, high-strength components is crucial because it makes it possible to build lighter cars and airplanes, which lowers fuel consumption and carbon emissions [30].

Due to their multidimensional, appealing, and unique qualities [31–33] as well as their minimal maintenance requirements [34], composites are now widely used in a variety of items, including sporting equipment, aerospace, maritime, and agricultural products. When compared to traditional materials, composite materials have a number of benefits [35]. They are also more affordable, stiffer, stronger, and environmentally friendly [36, 37].

Zhu et al. [38] used ANSYS software to compare the results of a finite element simulation to determine the free vibration characteristics of a carbon nano tube reinforced composite plate. For the vibration parameters of a functionally graded carbon nano tube reinforced plate, Fantuzzi et al. [39] compared the findings from analytical and finite element approaches.

Finite element analysis was used by Rout et al. [40] to determine how delamination, fiber orientation, and twist angle affected the vibrational properties of pretwisted laminated cylindrical shells.

Methodology

Composite materials can be used in a wide variety of applications and are very adaptable. Two reinforcing (fiber) and matrix materials are combined to create the finished product (resin). When combined, the two materials can provide superior qualities than each material used alone [41-43]. Composite materials have many different uses, including in the electrical and electronics business, construction and public works, transportation (road, rail, sea, air, and space), sports and recreation, general mechanical applications, and the aerospace industry [44].The use of composite materials in the aerospace sector is expanding in modern times. Composite materials are capable of producing massive, interconnected structures and have a very high strength-to-weight ratio. For instance, one composite material component can replace ten or more traditional metal parts, which can significantly cut down on production time and cost [45]. Prior to recently, fairings, tiny doors, and control surfaces were among the principal applications of composite materials in aircraft secondary structure [46]. However, as technology has developed, composite materials have become more frequently used for fundamental components like wings and fuselage [47, 48].

Because of its light weight, high strength, and non-metallic properties, fiberglass is the fiber that is utilized in aerospace applications the most frequently. Fiberglass is a composite material with some design restrictions because of its characteristic features, which make it easy to mold into items of any size, shape, or color. They are frequently utilized in the aerospace sector and other related applications that involve the impact of foreign objects because of their high strength and stiffness to weight ratios [49]. Fiberglass composite is frequently utilized in aerospace applications on aircraft parts that do not need to sustain significant loads or function well under stress. It is typically utilized for wing fairings and wing fixed trailing edge panels as well as interior components like window surrounds and storage compartments.

The goal of the current work is to use FEA software (ABAQUS) to calculate the mechanical reaction of unidirectional E-glass, including stress and strain, and to compare and validate the results with experimental data. Two unidirectional E-glass fibers, E-glass 21xK43 Gevetex and Silenka E-glass 2100tex, are used in the measurement. Two tests—E-glass unidirectional with orientation angles of 45°, -45°, and 90°—are utilized in this study to measure the maximum stress and strain and to confirm whether the E-glass will fail.

In this investigation, the commercial finite element program ABAQUS was used for the simulation. Depending on the goal of the investigation, composite materials can be modelled using finite elements. There are a number of strategies for composite modeling in ABAQUS, including submodeling, discrete reinforcement modeling, mixed modeling, microscopic modeling, and macroscopic modeling. However, layered shells, layered solids, stacked solid elements, and stacked or layered continuum shells are most frequently used in finite element simulations of composite materials [50].

Predicting the mechanical characteristics and mechanical response of unidirectional E-glass, such as tensile, compression, and thermal response, is the goal of ABAQUS analysis and simulation of unidirectional E-glass. These predictions will then be compared and confirmed with experimental data. Each of the six unidirectional E-glass layers that make up the composite plate has a thickness of 0.25 mm. The specimen has the following measurements: 250 mm x 25 mm x 1.5 mm. In ABAQUS, the linear elasticity is used to define the anisotropic elastic moduli. As illustrated in Table 1, there are various anisotropic input options for linear elastic behavior. Other sentences have indentation (Body text Indented style)

*ELASTIC	TYPE=LAMINA

Table 1. Linear elastic behavior

Due to its advantages of both computational efficiency and the capacity to obtain detailed information, the energy finite element method (EFEA) is a promising and more appropriate method to predict the high frequency vibration response and radiated noise of mechanical structures than the finite element method (FEA) and statistical energy method (SEA). Due to the necessity of engineering applications, researchers have achieved significant strides in EFEA over the past few years.

As science and technology have advanced, vehicles have gradually moved in the direction of high speed and lightweight design, so in the mechanical design stage of the vehicles, consideration must be given to the medium and high-frequency vibration of the structure in addition to the low-frequency dynamic response prediction. Therefore, a significant issue that needs to be resolved in the structural design of contemporary vehicles is the vibration response analysis of the mechanical structure in the high frequency domain. In order to tackle complex structural vibration problems, numerical analysis is typically applied.

Finite Element Analysis (FEA) is an effective method for analysing how a structure responds to vibration. It divides complicated structures into various components, discretizes the governing equations in accordance with the nodes of the elements, and then solves the matrix equations in conjunction with boundary conditions. However, to reflect the true vibration response results of the structure in the intermediate and high-frequency vibration analyses, more and finer meshes must be divided, adding time and expense. The quantity of meshes needed for large-scale constructions is excessive, the time cost is frequently intolerable, and it is beyond the capabilities of current computers [51].

The control system design of launch vehicle and aeronautical systems must take structural vibration into consideration. Although a variety of analysis methods have been created to predict structural vibration [52], these techniques are presumably challenging to use with large-scale aerospace structures composed of novel materials that are very flexible and have complicated topologies, among other characteristics. In order to make modeling and analysis more manageable, approximate mathematical models that include the key dynamic properties of structural vibrations are frequently employed.

Continuous System Model

In general, aeronautical structures made of beams, plates, and shells have unlimited degrees of freedom and continuously dispersed mass and elasticity.

Finite Element Model

For structural static or dynamic analysis, the finite element (FE) method has proven to be incredibly effective. First, a discrete model with finite degrees of freedom is used to simplify the continuous system, considerably reducing the complexity of vibration modeling.

Transfer Function Model

A linear time-invariant system's relationship between its input and output is frequently represented using the TF model [53–55].

FREQUENCY DOMAIN MODELLING

FE Modeling and Validation

Using MSC.PATRAN, which allows for the use of a variety of element types, including the Bar, Quad, and Hex elements, the geometrical and FE models of the intricate aerospace structures are created.

Data preparation using frequency analysis

By performing frequency analysis or tests, it is possible to gather information about the frequency response function of complex aerospace structures. This study uses MSC.NASTRAN to analyze frequencies in accordance with the excitation of a flat spectrum. According to actual operating conditions, the excitation frequency band, damping coefficient, and boundary conditions are established. The first two or three global mode damping coefficients determined from the test results or engineering expertise are typically thought to be suitable for the damping parameter in practice.

TF parameter identification in frequency domain

Utilizing experimental frequency response data, system identification in the frequency domain is utilized to estimate the coefficients of a transfer function for linear systems [56]. A system identification problem must be implemented with the help of three fundamental components: models, inputs, and a criterion. The input should have persistent excitation along with the accompanying models, and the models should be suited to the system structures. The frequency domain identification problem can be simplified to the fitting of a model, an optimization problem based on the provided cost function, which can be resolved using either the linear least squares technique or maximum likelihood estimation [57, 58–60].

TIME DOMAIN MODELLING

Data preparation based on transient analysis

Transient study is carried out in the time domain modeling approach using MSC.NASTRAN to prepare the data for parameter identification. Excitation should encompass all of the dynamic response properties in the targeted frequency band, including white noise and pseudo-random binary sequence (PRBS) signals. The two types of transient analysis techniques are direct transient analysis and modal transient analysis, with the latter having higher computational speed and frequency band control.

TF parameter identification in time domain

In the time domain, a variety of parameter identification techniques are employed, including moving average (MA), auto-regressive (AR), and auto-regressive and moving average (ARMA) techniques. The ARMA model [61] is used in this paper to describe the dynamic response properties of the systems.

TF model validation

The frequency response properties of the systems are used to assess the precision of the TF model developed in the time domain. Frequency analysis is done to obtain the FRF based on the FE model. The TF model is altered so that the difference between the two models (FRF and TF) would be acceptable by comparing the amplitude and phase response curves of the FRF with those provided by the TF model.

Conclusion

On the basis of finite element analysis, a transfer function modeling technique for intricate aircraft structures is suggested. The primary goal of the paper is to use the TF model to characterize the vibrations of aeronautical structures. The parameters of the TF model can be found by analysing the FEA response data. Three examples are given to show the suggested modeling method's reasonable accuracy while the time domain and frequency domain modeling approaches are offered.When sizing E-glass constructions, the suitability of FEA simulation has been taken into consideration. The ABAQUS results were compared to the experimental findings for unidirectional Eglass, which can be thought of as transversely isotropic. Typically, ABAQUS software outputs include percentage errors of 10% to 25% when compared to experimental data. However, the percentage mistakes in a few instances were quite high. The theory of the elements must be understood by ABAQUS users, and they must be cautious when choosing material qualities, boundary conditions (BCs), and loads.

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