Investigating Natural Frequencies for Enhanced Towable Vehicle Performance

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Abstract-
The recreational vehicle (RV) industry has witnessed remarkable growth, particularly in North America, establishing itself as a rapidly expanding sector. RVs, equipped with essential amenities, exemplify adaptability and mobility, categorized into those with integrated driving capabilities and those designed exclusively for towing. In the cold Northern American climate, towable RVs predominantly integrate wooden components, leveraging the material's advantages to enhance overall efficiency. However, the introduction of wood brings challenges, notably in structural dynamics, leading to vibrations during travel. These vibrations pose potential impacts on user comfort, appliance lifespan, and mounting strength, necessitating a comprehensive investigation into the vibration characteristics of towable RVs.
This paper focuses on the primary objective of conducting an exhaustive natural frequency (modal) analysis of foundational towable RVs using the finite element method (FEA). Following this, experimental modal analysis will be performed, and the results correlated with FEA findings. The ultimate aim is to propose and implement targeted modifications, utilizing Finite Element Analysis (FEA), to enhance the natural frequencies of towable RVs. This research endeavors to significantly improve both the longevity and overall user experience associated with these vehicles, thereby contributing valuable insights to the evolving landscape of RV design and construction.

This research paper presents an in-depth investigation into the dynamic characteristics, specifically the natural frequency, of recreational towable vehicles through a comprehensive analysis utilizing Computer Aided Engineering (CAE) and Experimental Analysis. The study explores various mode shapes and elucidates their significance in understanding the vehicle's dynamic behavior. Furthermore, it conducts a comparative analysis of the natural frequencies of recreational towable vehicles against those of other common towable units.
The paper delves into the Finite Element Analysis methodology employed in the study, shedding light on the intricacies of the analytical process. Beyond providing a comparative analysis, the research extends its scope to propose enhancements aimed at refining the dynamic characteristics of towable vehicles. The findings and recommendations contribute to advancing the understanding and optimization of the performance of recreational towable vehicles.

Index Terms- CAE, FEA, Modal Analysis, Towable

I. INTRODUCTION

1.1 Product Background

The recreational vehicle (RV) industry has experienced substantial growth, particularly in North America, establishing itself as one of the most rapidly expanding sectors. These RVs are equipped with essential daily life amenities such as beds, bathrooms, sofas, fridges, microwaves, and various other appliances, with cabinets securely affixed to the walls and floors. Celebrated for its adaptability and mobility, the RV sector comprises two primary categories: those featuring an integrated driving vehicle and those designed solely for towing. In the predominantly cold climate of Northern America, towable RVs predominantly incorporate wooden components, with exceptions made for chassis and skeleton frames. The choice of wood, driven by its diverse advantages, significantly contributes to the overall efficiency of the vehicle. Notably, the incorporation of wood in RV construction imparts a lightweight quality, thereby augmenting operational efficiency. Furthermore, the inherent insulating properties of wood play a pivotal role in energy conservation, particularly in meeting heating requirements.

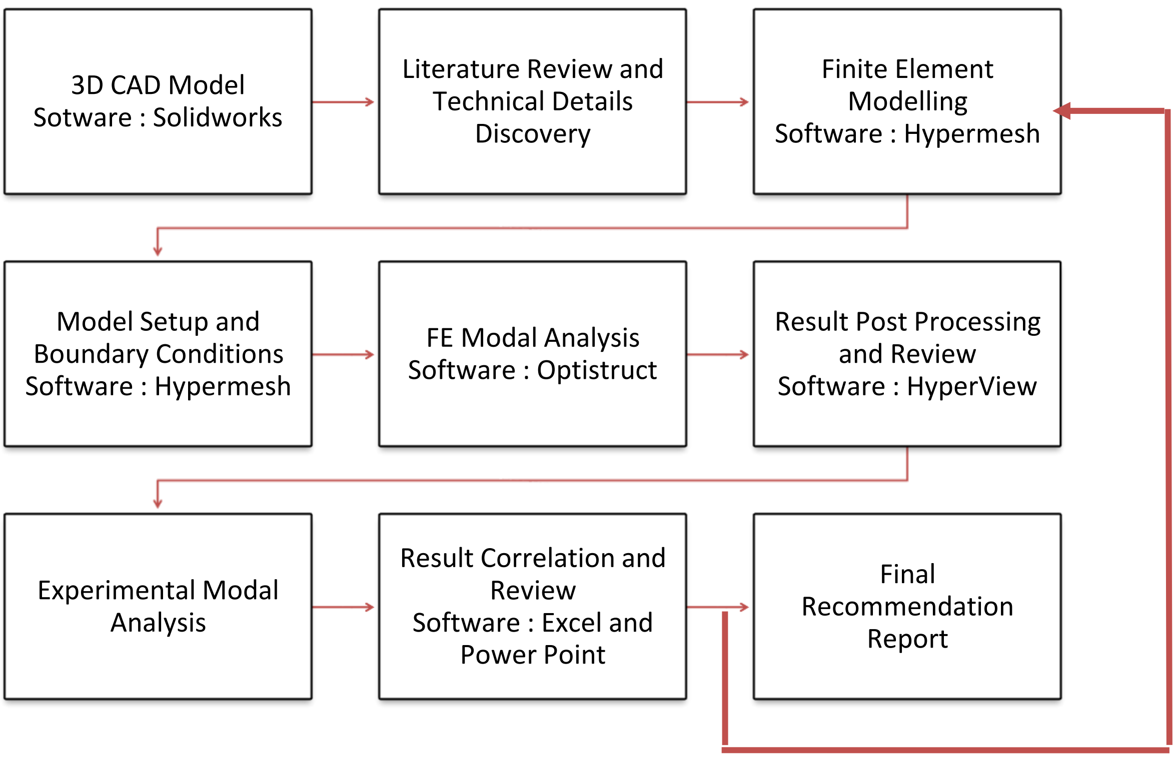
1.2 Problem Statement

The integration of wooden materials introduces intricacies in structural dynamics, specifically concerning vibrations during travel. These vibrations have the potential to impact user comfort, the lifespan and functionality of appliances, and the strength of various mountings. The challenges associated with the wooden structure necessitate a comprehensive investigation into the vibration characteristics of towable RVs. The natural frequency of the vehicle can be broadly categorized into three segments: Suspension Mode, Structural Mode, and Local Mode.

1.3 Objective of study

The primary objective of this research is to conduct an exhaustive natural frequency (modal) analysis of the foundational towable RV using the finite element method (FEA). This will be followed by the execution of experimental modal analysis, with subsequent correlation to the Finite Element (FE) results. The ultimate goal is to propose and implement targeted modifications, employing Finite Element Analysis (FEA), to augment the natural frequencies of the towable RV. The aim is to significantly improve both the longevity and overall user experience associated with these vehicles.

II.METHODOLOGY & PROJECT FLOW



III.THEORY

3.1. Modal Analysis Theory and Equations

Modal Analysis is known by several names viz. natural frequency analysis, normal modes analysis, eigenvalue analysis and eigenvalue extraction. It is a method through which the vibration shape / mode shape and associated frequencies that a structure will exhibit is calculated. Understanding these frequencies is crucial since subjecting the structure to cyclic loads at these frequencies may induce resonance, potentially resulting in catastrophic failure.

The equilibrium equation for a structure performing free vibration appears as the eigenvalue problem:

$$(K-\lambda M)A=0$$

Where,

K= Stiffness matrix of the structure

M= Mass matrix

Damping is neglected

The eigenvalue problem provides **n** eigenvalues **λ**, where **n** is the number of degrees-of-freedom. The vector **A** represents the eigenvector associated with each eigenvalue. Lanczos, AMSES, or AMLS methods can be used to solve the eigenvalue problem.

The natural frequency **fi** can be determined follows directly from the eigenvalue λi using formula:

fi=√λi2π

3.2. Detail of FE modal Analysis:

The Finite Element (FE) analysis for the towable can be systematically categorized into three phases: preprocessing, processing, and postprocessing. Altair's Hypermesh software was employed for preprocessing, involving the meticulous meshing of the towable's various components. Three-dimensional elements were used for structures made of wood and foam, including the roof, floor, walls, and interior. In contrast, aluminum and steel components within the chassis and skeleton underwent two-dimensional meshing on their mid-surface, with appropriate thickness applied. The resulting model comprised over three million elements and nodes.

Distinct material properties were assigned to ensure accuracy: anisotropic properties for wooden materials and isotropic properties for aluminum and steel structures. The comprehensive analysis incorporated masses of all components, appliances, and fuel. The preprocessing phase laid the foundation for a detailed representation of the towable's structural complexity.

FE analysis was conducted in Optistruct, using the AMSES method for calculating normal modes. AMSES distinguishes itself through its efficiency by computing only a portion of the eigenvector, which greatly diminishes the need for disk space and I/O operations. This efficiency results in considerably shorter execution times, thereby improving the overall computational effectiveness of the analysis.

Postprocessing involved the analysis of results using Hyperview. This critical phase allows for the interpretation and visualization of the obtained data, providing valuable insights into the towable's dynamic behavior. The combined use of sophisticated preprocessing tools, advanced analysis methods, and robust postprocessing techniques ensures a comprehensive and accurate assessment of the towable's structural response under various loading conditions.

IV.RESULTS

4.1 Modal Analysis Results Obtained from Software:

FEA modal analysis was conducted on the RV towable model using Optistruct, and the results were subsequently postprocessed in Hyperview. The natural frequency of the towable was observed to be within lower frequency ranges. The mode shapes were categorized into three types: suspension modes, attributed to the towable's suspension system; structural modes, involving the majority of the towable's structure; and local modes, observed in various walls of the towable.

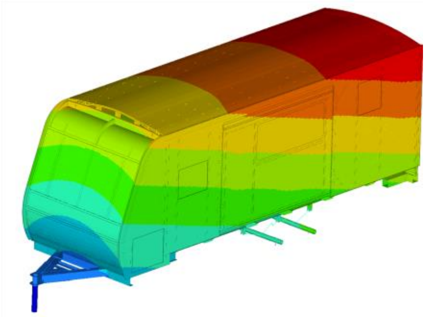


Figure 1: Suspension Mode in Roll Condition

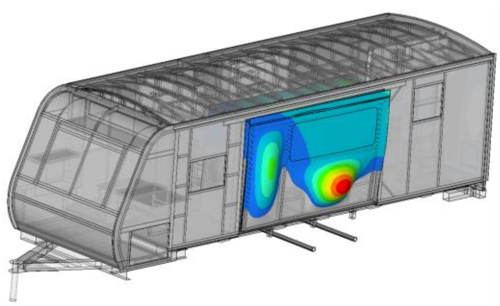


Figure 2: Local Mode

4.2 Validation Through the Experimental Modal Analysis:

Experimental modal testing was performed on the towable, employing a Multiple Input, Multiple Output (MIMO) modal test methodology. The towable was given excitation using two electromagnetic shakers with burst random excitation. Tria-axial accelerometer were used to record these data. This approach facilitated a comprehensive analysis of the towable's dynamic behavior. Modal frequencies and mode shapes were subsequently extracted, providing valuable insights into the vibrational characteristics and structural response of the towable

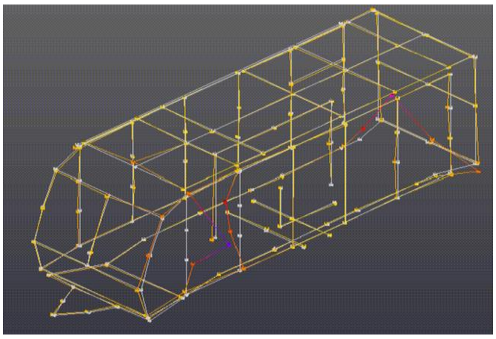


Figure 3: Suspension Mode in Roll Condition

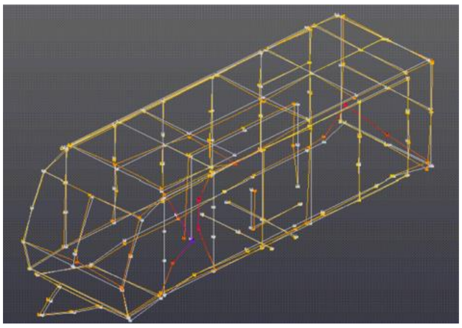


Figure 4: Local Mode

4.3 Improvement Suggestion and Results for Modified Structure:

Identification of several local modes at lower frequencies in the towable, attributed to the predominant use of wood in its construction, prompted a series of modification iterations in the FE model. These modifications were aimed at ameliorating the local modes by providing suitable support. The iterative adjustments resulted in a notable enhancement of mode shapes and frequencies, shifting them to higher ranges. This iterative process reflects a targeted effort to optimize the structural performance of the towable, addressing specific vibrational characteristics associated with its unique construction materials and design.

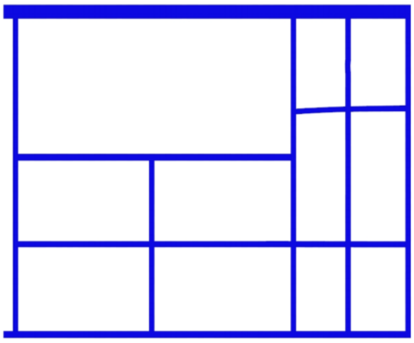


Figure 5: Support for wooden walls

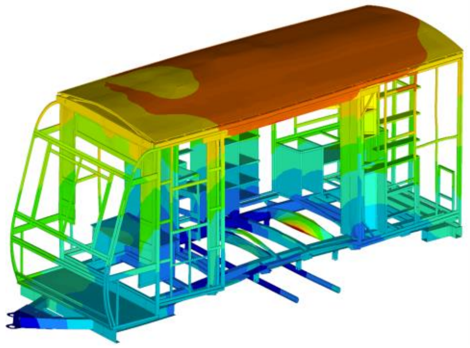


Figure 6: Local Modes moved to higher frequencies

V.DISCUSSION AND CONCLUSION

In conclusion, the study highlights the robustness of Finite Element Analysis (FEA), affirming its validity through close alignment with experimental results. This validation underscores the reliability of FEA in understanding the dynamic characteristics of recreational towable vehicles with wooden structures.

1. Validation of FEA Procedure: The synergy between FEA and experimental outcomes confirms the accuracy of the chosen methodology, instilling confidence in its applicability for dynamic analysis.

2. Opportunities for Enhancement: Minor strengthening measures emerge as practical avenues for improving durability and extending appliance life in recreational vehicles, especially for the local modes. These enhancements offer tangible opportunities for optimizing design and performance.

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