

Development of a Virtual Multi-Axial Simulation Table to Enhance the Prognosis of Loads on Powertrain Mounting System During Durability Applications

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ABSTRACT

Vibration Isolation is the key objective of engine mounting systems in the automotive industry. A well-designed, robust engine mount must be capable of isolating the engine assembly from road-based excitations. Owing to high vibration inputs, engine mounts are susceptible to wear and failure. Thus, the durability of engine mounts is a cause for concern. A design validation methodology has been developed at Jaguar Land Rover using Multibody Dynamics (MBD) to enhance the prognosis of engine mount loads during full - vehicle durability test events. This paper describes the development of a virtual multi-axial simulation table rig (MAST Rig) to test virtual engine mount designs. For the particular example considered in this paper, a simple sinusoidal input is applied to the MAST Rig. The development of the virtual MAST Rig has been described including details of the modelling methodology. In order to demonstrate the potential of the virtual test, correlation was carried out with tests conducted on a physical MAST Rig, and the achieved results have been presented. The approach described here can be applied to test the designs of engine mounts for durability applications at early stages of the development process. The results have shown great correlation at lower frequencies. At higher frequencies, though the engine resonance is shown by the virtual test, the phenomenon is not identical in the frequency domain. These results have identified areas of improvement in mount design, and have led to better prognosis of engine mount loads, owing to close collaboration with the design team.

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INTRODUCTION

Mounting systems are used to support the power units as well as suspensions in automobiles. The engine mounting system holds the engine to the vehicle body. A well - designed, robust engine mount must target vibration isolation as its key objective with the following specific functions:

- i. Isolating the vehicle body from the vibrations developed within the engine assembly. The frequencies of these excitations are in the range of 25 - 200 Hz.
- ii. Isolating the engine assembly from vibrations, in particular road excitations. The frequencies of these excitations are below 30 Hz.

It is quite clear that throughout their lifetime, engine mounts are subjected to high vibrational inputs, and hence are susceptible to wear and failure. The most common problem developed by engine mounts is when the elastomer breaks or when there is leakage of the fluid in case of hydraulic mounts. An example of a leaking engine mount is shown in [Figure 1](#). These failure modes of the powertrain mounts lead to reduction in the effectiveness of the mounting system for vibration isolation.



Figure 1. Leaking Engine Mount [2.]

As a part of the standard test procedures [1.] conducted by the Durability and Robustness attribute at Jaguar Land Rover, the test vehicles are driven over rough roads. The failure modes of the powertrain mounting systems are often discovered during these tests. This is because the road-based excitations during these events trigger specific powertrain eigenmodes leading to fatigue failures of the powertrain mounts. These failure modes result in late development changes to the vehicle design and cause additional cost to the business.

Hence, it was deemed necessary to have a robust virtual analysis methodology in place for the prognosis of powertrain mount loads during the early phases of vehicle development at Jaguar Land Rover. The goal of the design validation tool presented here is to facilitate the robust modelling of engine mounts by root cause analysis and failure mode identification at early stages of vehicle design.

The aforementioned CAE process aims to understand the effect of road-based excitations on powertrain mounting systems by development of a design validation methodology in the multibody dynamics environment. A Virtual MAST Rig has been developed using the software Simpack to assess the design of virtual mounts for a Durability and robustness application. With the emphasis on the behaviour of powertrain mounting systems when subjected to predetermined inputs, a correlation activity has been conducted with the full vehicle MAST Rig tests to identify the scope for improvement in the virtual mount designs for durability applications.

RELATED WORK

The design of virtual mounts at Jaguar Land Rover forms the foundation of the prognosis of powertrain mounting system loads. Standardized test procedures and design rules for powertrain mounting systems have been established at Jaguar Land Rover by the Compliant Mounting Systems (CMS) attribute [3.]. Williams et al. [4.] lay down the methodology of robust elastomer designs of virtual mounting systems at Jaguar Land Rover.

Traditionally at Jaguar Land Rover, the virtual mounts were designed for Vehicle dynamics applications of vehicle ride and comfort. Owing to close collaboration of the CMS and D&R attributes in the recent past, there has been a greater emphasis on design of virtual mounts for the test cases covered by the D&R attribute.

One such test case involved a Jaguar Land Rover (JLR) SUV with the East- west engine architecture to undergo coasting over a standard road profile. The results of the test indicated a severe damage caused to the engine mounting systems and an audible resonance of the engine assembly during the test. However, the virtual test event for the same road did not replicate the same magnitudes of powertrain mount loads. This indicated a need for prospective enhancement in virtual mount designs for durability applications, and led to the formulation of this project.

MODELLING APPROACH

The key focus of the modelling used in this project is to replicate a Multi-axial Simulation Table in the virtual environment. This is a system which subjects the components to a vibration test environment of a varying frequency range. In the automotive industry, the inputs to the MAST Rig are often sourced from road-based excitations.

A MAST Rig is an electronically - controlled test table with actuators attached in order to simulate any form of vibration in six degrees of freedom. In the automotive industry, the goal of the MAST Rig testing is to engineer more durable and reliable vehicle components, thus leading to safer and more comfortable vehicles.

At Jaguar Land Rover, the D&R attribute uses the physical MAST Rig Test for various applications. One key application is to test the durability of powertrain mounting systems [1.]. As shown in [Figure 2](#), a cut-section of the vehicle is mounted rigidly onto the table by means of fixtures at various locations. The suspensions and wheels are removed. As shown, the only remaining components on the vehicle are the body cut – section, the subframe and the engine assembly. There are multiple fixtures on the vehicle body as well as a single fixture for the subframe in order to attach the vehicle section to the excitation table. In addition, the ends of the engine half shafts as well as the driveshafts are held to the table by means of fixtures. It must be noted that all the drivetrain components at the rear which are connected to the propeller shaft such as differential, rear half shafts are removed prior to the test.



Figure 2. MAST Rig Test

The key feature of this test setup is that there is minimal compliance between the vehicle body and the test table. Due to the removal of the suspension components and wheels, the powertrain mounting systems serve as the only transfer function between the input excitation and the behavior of the engine assembly. Hence, this was the justification for the identification of this test event for CAE replication to assess the virtual mounts, as this test setup eliminates the noise factors associated with the modelling of wheels and tyres as well as suspension components.

For this particular application, in order to simplify the problem statement, the MAST Rig was subject to a constant sinusoidal sweep of vertical acceleration, and the correlation activity has been carried out for a 1g acceleration sweep applied to a JLR SUV, referred to as Vehicle1. The correlation activity for the virtual MAST Rig is facilitated because various outputs can be collected from the actual MAST Rig such as the engine mount forces and accelerations, power unit accelerations, table displacements and accelerations.

CAE Modelling

The starting point for the development of the CAE Model and loadcase was the standard virtual vehicle model for Vehicle1. To this model, the relevant CAD Visualization files for the engine assembly, engine mounts, tie bars and the mount brackets were added in order to make the relative motion between components in the animation more visual. This model is shown in [Figure 3](#).

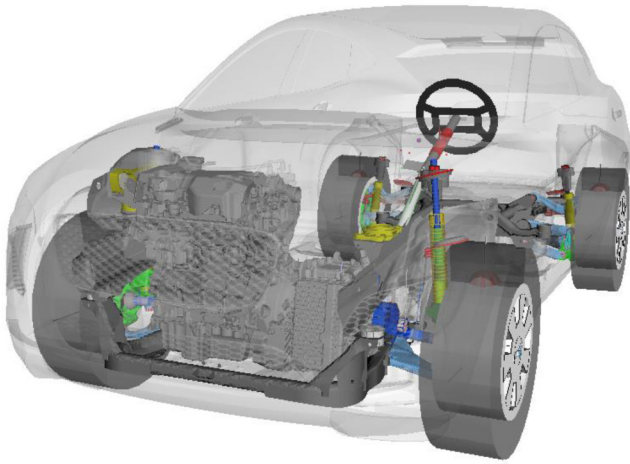


Figure 3. Virtual Model of Vehicle1

In order to create the virtual model similar to the vehicle cut section from the actual MAST Rig, the front and rear suspension components were removed from the model. In addition, further simplification of the model was carried out by removing unsprung mass components such as wheels, rims and suspension links which are not relevant for the MAST Rig test. The simplified vehicle cut - section setup for the Virtual MAST Rig test is shown in [Figure 4](#).

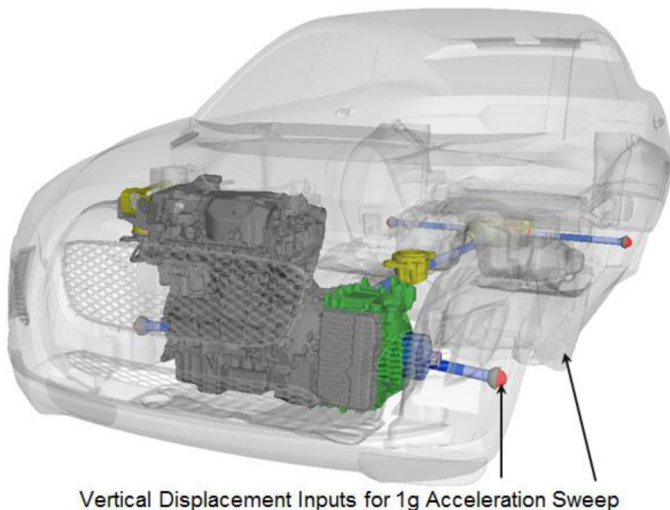


Figure 4. Cut-section of Vehicle1 for the Virtual MAST Rig Test

It must be noted that though [Figure 4](#) shows the visualization of the complete vehicle body – in – white, the actual mass, inertia properties and center of gravity input into the model are for a vehicle cut section. This way we ensure that the actual test vehicle is simulated as closely in the virtual test event as possible.

MAST Rig Inputs to the CAE Model

As detailed earlier, for this correlation study, a 1g sinusoidal sweep input of vertical acceleration to the MAST Rig has been considered. [Figure 5](#) shows the table displacements at the actuator locations measured in a test conducted for Vehicle1.

MAST Rig Table Vertical Displacements

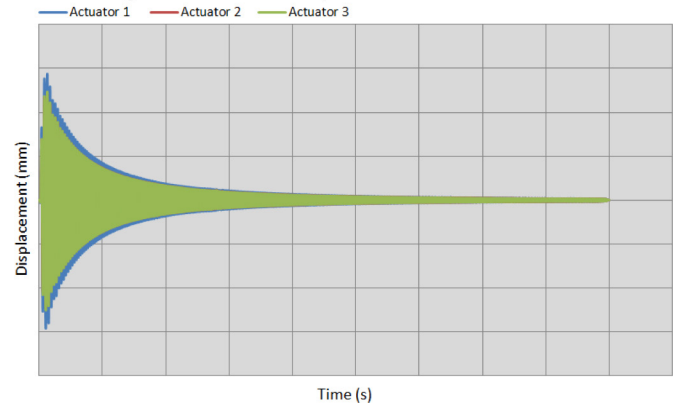


Figure 5. MAST Rig Test Table Vertical Displacements

As seen, the displacements of the actuators 1 and 2 are slightly higher than the actuator 3. The reason for this is that the actuators 1 and 2 are at the front of the table, and hence closer to the vehicle center of gravity. Thus, the automated control loop of the rig feeds slightly higher displacements at the actuators 1 and 2.

Due to the advantages of CAE Modelling capability, the vertical displacement of the MAST Rig Test can be directly provided to the CAE Model as a displacement – time input. As the vehicle body, engine propeller shaft and the half shafts are attached to the table using fixtures, for the purpose of simplicity in modelling, these were considered as a single system with the same input displacement.

The fidelity of the CAE MAST Rig model was confirmed on comparing the vertical accelerations of the virtual vehicle body with the corresponding table accelerations in the actual MAST Rig. This is shown in [Figure 6](#).

MAST Rig Table Vertical Accelerations

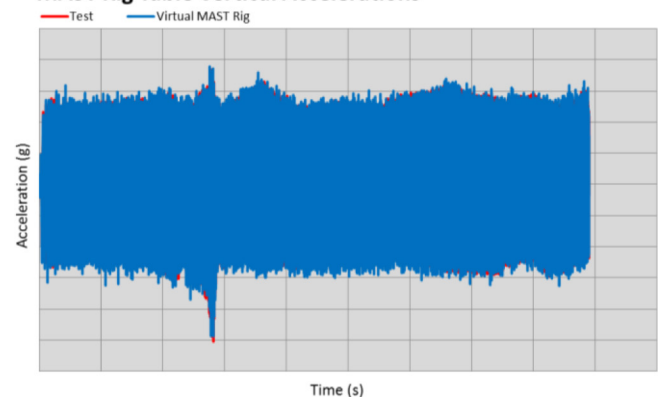


Figure 6. Vertical MAST Rig Accelerations

Thus, [Figure 6](#) shows that the vehicle body accelerations of the virtual vehicle are completely identical to the table accelerations in the test for the same 1g sine sweep input given to the table. This step validated the input to the system in our simulation.

In addition to the table vertical accelerations, the second metric which validated the fidelity of the virtual MAST Rig were the mount vertical forces. As shown in [Figure 7](#) for the first few seconds of the