# Commercial Vehicle Powertrain Mount Selection Based on Static and Modal Analysis Using Altair Motion-Solve

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**Abbreviations**:
NVH – Noise, vibration and harshness, DOE – Design of experiments, CG-Centre of gravity
PWT – Power train, FE – Finite Element, MBD – multi-body dynamics, DOF-Degrees of freedom
K.E- Kinetic energy, flower – Lower cutoff target frequency, $f_{upper}$ – Upper cut off target frequency

**Keywords**: powertrain mount, modal, optimization, correlation

**Abstract:**

One of the primary functions of power train (PWT) mount systems is to isolate the vehicle body from structure-borne noise and vibration for better occupational comfort. PWT rigid body modes and its mode shape purity are the performance indicators for isolation of mount system. The rigid body modes are targeted to be away from vehicle suspension modes and main engine firing orders to isolate the chassis from unbalanced PWT vibration forces. For achieving better NVH performance ensuring that the PWT mount layout design meets targeted modal characteristics in concept stage is crucial.

This paper presents a method for determination of suitable mount stiffness for better NVH performance of commercial vehicle at vehicle concept stage. Multi-body dynamic analysis is performed on an initial mount configuration. HyperStudy optimization is performed further to arrive at the best mount stiffness configuration, so as to achieve the targeted PWT modal frequencies & kinetic energy fraction for complete decoupling from vehicle excitation sources. Static analysis is performed for various operating condition and PWT displacements verified for the packaging space. Predicted modal results are compared with the experimental results, and the guidelines for improving correlation level on both simulation and experimental procedure is highlighted.

## Introduction

The vehicle powertrain unit consists of engine, flywheel, gearbox and clutch. PWT rubber mounting systems have been successfully used to isolate the chassis structure for the noise, vibration performance. With increasing power of engines and lighter weight structures has an adverse effect on noise and vibration performance. In this scenario it is quite important to develop effective PWT mount systems to isolate the PWT vibration transmitted to the chassis structure for excellent durability and NVH performance at the conceptual stage itself.

Vibration isolation of mounting system is governed the system natural frequencies and its mode purity. Mode shape purity (also known as decoupling) depends upon the mount stiffness, its location and orientation as well as PWT unit CG, mass and moment of inertia. Target for these PWT rigid body modal frequencies is fixed based on the vehicle modal alignment map. The lower bound for PWT natural frequency is governed by vehicle suspension frequency and the upper bound is governed by the isolation from main engine firing frequencies. The PWT mount system should also meet the package constraints as well as mount strength adequacy requirements.

Considerable amount of research has been performed on the dynamic performance of PWT mounting system. Comprehensive review about three prominently used power plant isolation strategies, torque roll axis decoupling, elastic axis decoupling and natural frequency placement are discussed with the assumptions involved in each of these techniques by R.Mateew brach [1].

Decoupling of the engine torque roll axis and dynamic decoupling axioms are presented and compared with the conventional elastic axis mounting and focalization methods by Jeong and Singh [2].

This paper discusses methodology for determination optimized PWT mount layout for commercial vehicle with dynamic decoupling of rigid body modes and concurrently satisfying the packaging needs and static load bearing requirements. Also the calculated frequencies and mode shapes are compared with the experimental modal test results.

## Process Methodology

a) *Creation of PWT MBD model*

PWT six dof model created in Altair MotionView. The hard points are created for PWT CG and mount locations. PWT rigid body is created at its CG by specifying its mass and moment of inertia. Dummy chassis body created with negligible mass and moment of inertia. The mounts are represented by bushing connection between the PWT and the dummy chassis body. Dummy chassis body is attached to the ground by fixed joint. Figure1 shows the PWT unit system created in Altair motion view. The input parameters mount location, mount orientation angle; mounts stiffness and dynamic factor are defined as variables using datasets. Later on these variables are defined in HyperStudy set up for optimization.

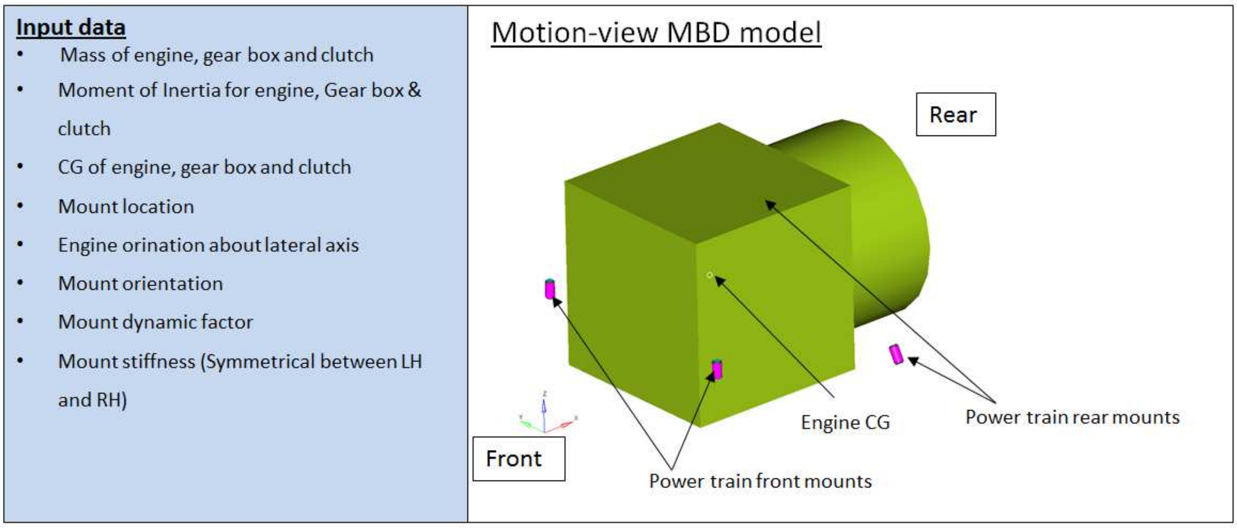

Figure 1: PWT MBD model created in MotionView

Modal frequencies are extracted in the preloaded condition and kinetic energy fraction (indicator of modal purity/decoupling between the modes) calculated from the mode shape values of PWT unit. Figure 2 and 3 shows the sample output mode shape plot and K.E fraction of six rigid body modes.

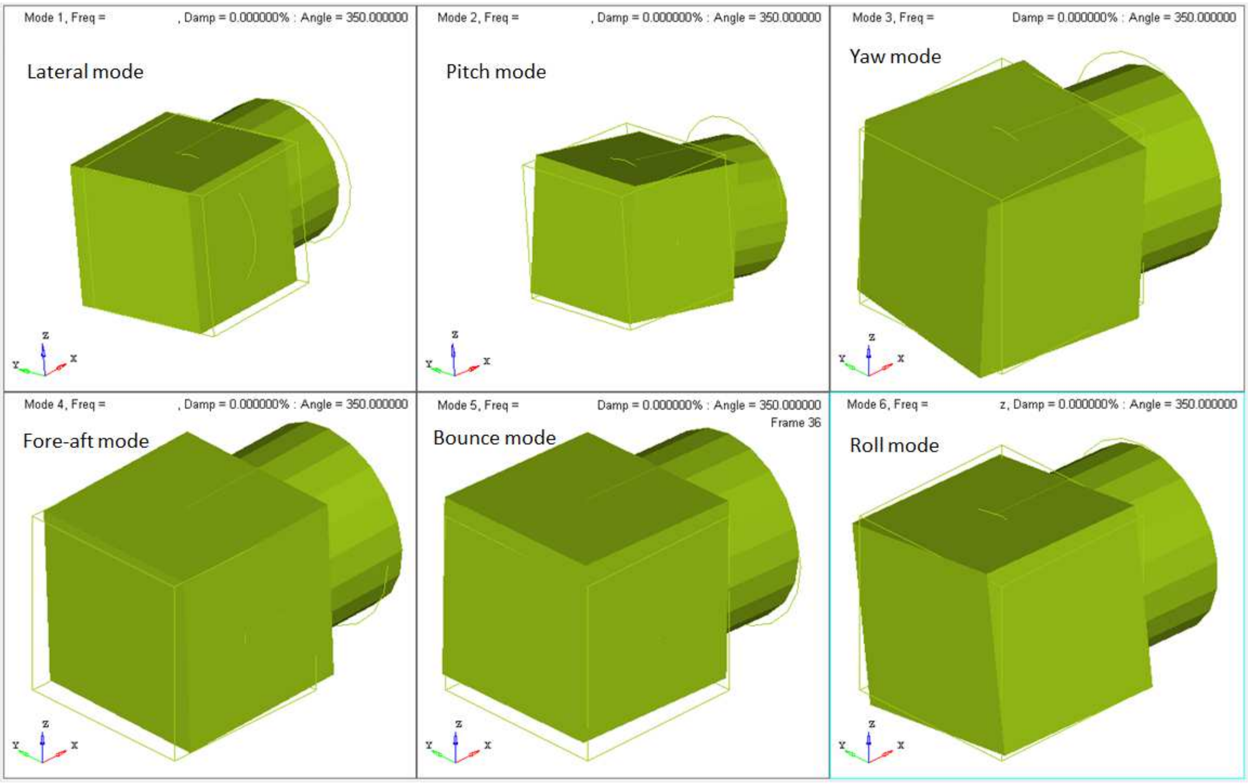

Figure 2: Mode shape plot for six rigid body modes

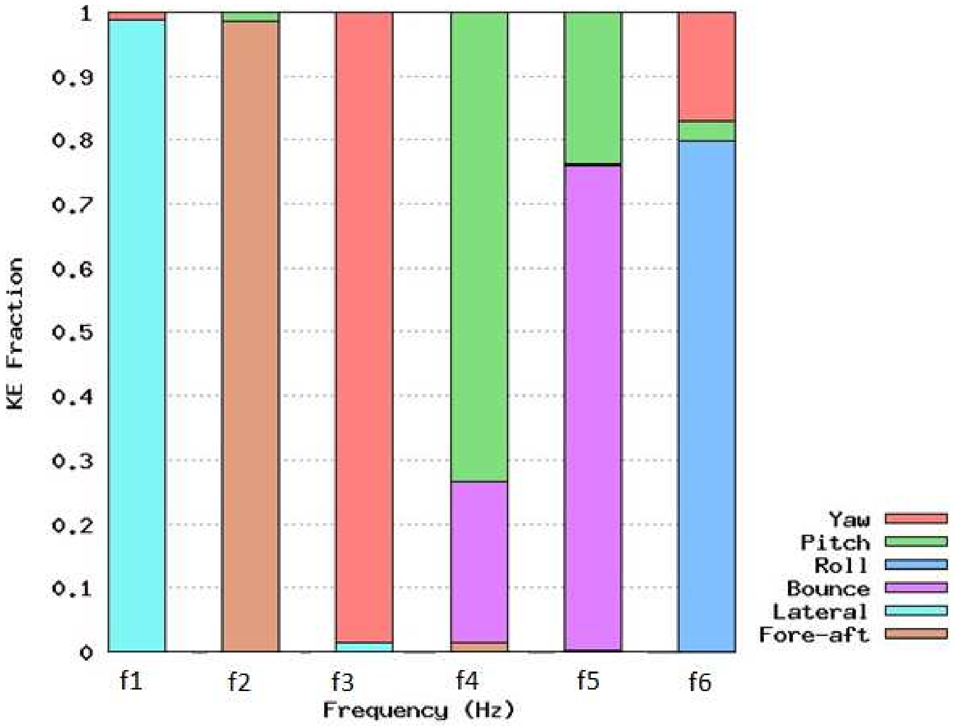

Figure 3: Modal K.E fraction for six rigid body modes

Similarly static analysis performed and mounts displacements/mount forces as well as engine displacements are extracted.

b) *Optimization model set*

Multi-model HyperStudy set up created for the optimization study of PWT unit considering both modal and static load cases. The MotionView model is converted to template file, by defining 25 design variables individually for modal and static with interlinking of variables between them. Optimization set up is created with maximizing K.E fraction of roll mode set as the objective function and modal frequencies set as the constraint in modal model and mount displacement/forces at vertical-1G load condition set as the constraints for the static model

**Objective function**

- Maximize Roll K.E fraction

**Modal model constraints**

- K.E fraction for bounce & pitch mode > Specified target (close to 100%)
- K.E fraction for lateral, yaw and fore-aft>Specified target
- Mode1 frequency> $f_{lower}$ Hz & Mode 6 frequency< $f_{upper}$ Hz
- Difference in frequency between the modes > $\Delta f$ Hz

**Static Model constraints**

- Mount displacement in vertical direction(Z-direction) less than specified target
- Difference in mount displacement between front mount and rear mount < specified target
- Mount force in vertical direction(Z-direction) for both front and rear> specified target
- Engine displacement for static-1g and torque <specified target

With this objective function and constraints, optimization run is carried out with an efficient global response surface method (GRSM) algorithm. Like most optimization algorithms, GRSM advances in iterations throughout the process. However, the first iteration of GRSM is unique from all subsequent iterations. Within the first iteration, a DOE is constructed internally to provide the data to construct an initial response surface. GRSM uses advanced methods to create response surfaces from a small number of data points, which allows GRSM to remain efficient on problems with large numbers of design variables. Optimization results either into feasible or infeasible design. If the optimization is infeasible, then mount layout has to be revisited or a solution which is close to the optimum can be explored. For the feasible design, the design robustness of selected PWT mount layout is further evaluated considering stiffness variation.

Considering the mount stiffness variation +/-10% on the nominal values, its effect on the modal frequencies has to be assessed and has to be verified against the targets. Hence for the finalized PWT mount layout, analysis carried out for all maximum/minimum stiffness the combinations for front/rear mount in all three directions. It is observed that the modal frequencies and critical modes decoupling factor meets the target criteria.

To validate the mathematical model used for six dof rigid body modes calculations, Test-CAE correlation of rigid body modes was carried out for the field vehicle. Figure 4 shows the test set up used for experimental modal analysis.

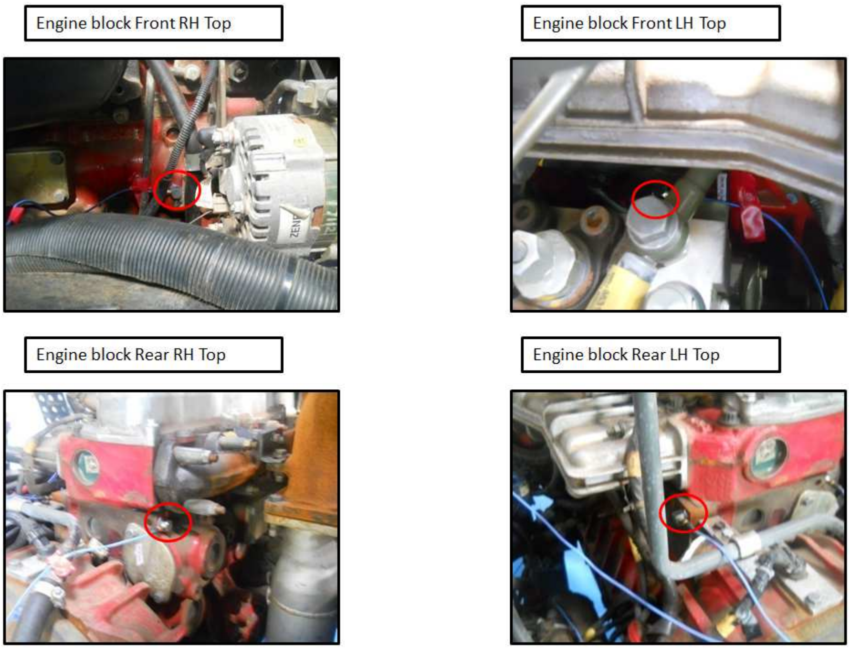

Figure 4: Accelerometer locations for experimental modal test

Figure 5 shows the comparison of modal frequencies and mode shapes between Test and CAE. The correlation levels on critical modes (Roll, bounce and pitch) are good. The correlation level on lateral and yaw modes needs to be improved. The fore-aft is not observed in experimental modal test.

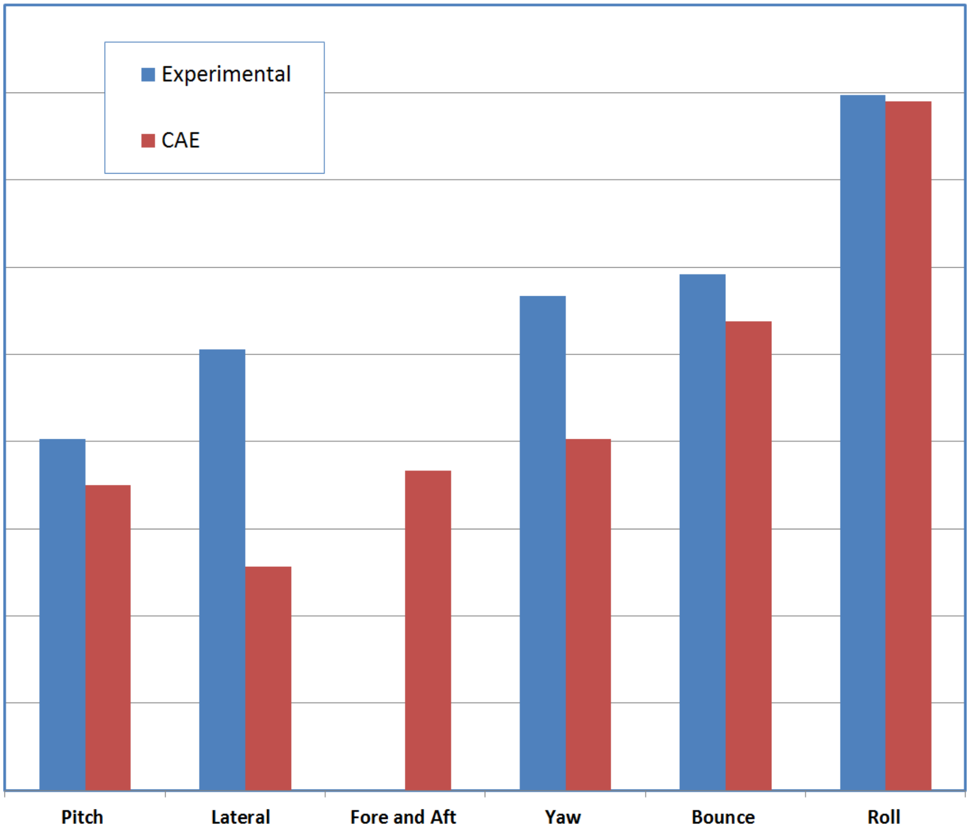

Fig 5: Comparison of TEST-CAE modal frequencies

The correlation levels on non-critical modes to be improved. The probable cause for the difference between test and CAE modal frequencies and improvement suggestions to be worked out is listed below,

1) Effect of driveline, exhaust system and hose connection assumed to be insignificant in CAE. Test can be repeated by detaching these components and correlation levels to be assessed.
2) Mount dynamic factor assumed to be constant for the intended frequency range and operating amplitude. Force-displacement characteristics of mounts assumed to be linear in all three directions. Performing dynamic simulation in time domain with Altair busing model with the non-linearity's and converting back the responses into frequency domain can improve the correlation level
3) Dynamic stiffness of the PWT mounting bracket on the frame is assumed to be infinitely stiff. Modal frequencies to be calculated by accounting the stiffness of the mounting bracket
4) Impact hammer excitation used in experimental test may not excite all the modes with sufficient energy. Hence it is recommended to use shaker excitation to excite the modes effectively, which can improve the correlation level.

The overall process for the optimum PWT mount development at the conceptual stage is outlined in the flow chart shown in figure 6.

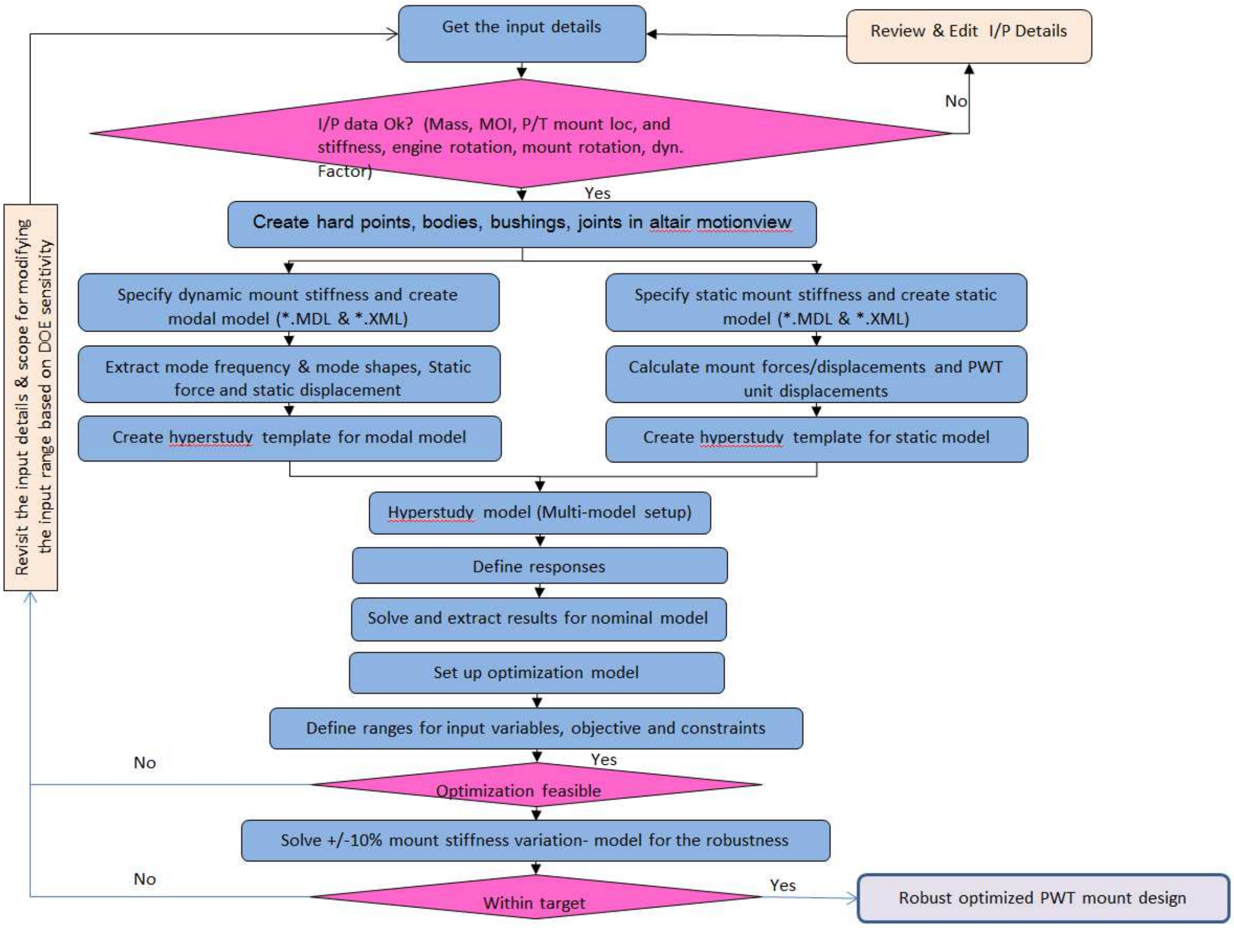

Fig 6: Flow chart for the development of optimum PWT mount layout

## Benefits Summary

With MotionView and HyperStudy it is possible to select optimum mount location/orientation angle which meets the vibration isolation and compliance requirements.

Effect of manufacturing tolerance on the mount stiffness assessed and robustness of the design can be checked.

## Future plans

The PWT mount model needs to be accounted to consider the variation of mount stiffness with frequency.

The multi-cylinder engine train model to be integrated with power train mount model for the prediction of power train mount forces with respect to time.

Sixteen dof vehicle model consisting of power train, cab and vehicle suspension needs to be built to assess the vibration isolation of power train mounts at idle condition.

## Conclusion

Methodology for PWT mount selection using Altair MotionView and HyperStudy demonstrated with a case study.

The simulated results correlated well with test for critical natural frequencies and mode shapes.

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