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ADAMS CUSTOM INTERFACE FOR POWERTRAIN MOUNTING SYSTEM DESIGN

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ABSTRACT

Optimisation of powertrain mount characteristics is important for the overall noise, vibration and harshness (NVH) of a vehicle. Powertrain suspension system design is a compromise between isolation of the vehicle from powertrain vibration and constraining the motion of the powertrain within vehicle packaging and handling targets.

A custom interface has been developed for ADAMS View to create and analyse a parameterised powertrain suspension system model. The interface facilitates the quick generation of parameterised powertrain suspension models for in-line and vee configuration engines. The models include the components of the cranktrain and are driven by either flywheel velocity or cylinder pressure data. Balancer shafts and subframe components can also be generated through the interface.

Analysis of the parameterised models allows rapid optimisation of the powertrain mounts in terms of location and stiffness, including snubbing characteristics, in order to meet the NVH targets for modal behaviour and bodyside engine mount forces, throughout the engine operating range. Quasi-static analyses are used to verify that the powertrain motion is within the vehicle packaging constraint and mount durability limits.

The interface includes post processing features to output powertrain mount forces and displacements to pre-defined plots and numeric tables for each engine speed order. An example of the development of a powertrain suspension system model, using the interface, is given.

INTRODUCTION

Powertrain suspension system design is a compromise between isolation of the vehicle from powertrain vibration and constraining the motion of the powertrain within vehicle packaging and handling targets. The packaging targets will dictate the maximum allowable powertrain displacement under the complete range of operating conditions. Vehicle ride and handling targets will determine modal frequencies of the powertrain and suspension system. Optimisation of powertrain mount position, orientation, damping and stiffness characteristics is important for the overall noise, vibration and harshness (NVH) of a vehicle in order to provide the best engineering solution to reduce structure borne noise while meeting the other targets imposed on the system.

Ricardo have developed a custom interface for ADAMS View to facilitate the rapid generation of parametric models for powertrain suspension analysis. The level of complexity of the model is determined by the nature of the analysis required. Due to the similar nature of powertrain suspension optimisation projects, the custom interface has been written to enable the production of standard result outputs, thus reducing the time taken to process the predicted results.

Powertrain suspension analysis for packaging constraints and mount durability can be performed on a simple model consisting of a rigid body representation of the powertrain and non-linear powertrain mounts. Analysis of powertrain suspension modal targets for ride and handling require a similarly simple model with the addition of the powertrain inertia and powertrain mount dynamic stiffness data. Investigation of the powertrain generated dynamic forces transmitted into the vehicle body requires a more complex model including a complete cranktrain, consisting of crankshaft, flywheel, connecting rods and pistons, in order to simulate the inertia and torque recoil forces generated by the rotating components. The vast majority of automotive engines are either in-line or vee configurations, both can be created by the custom interface with no limit on the number of cylinders. Options exist within the custom interface for the generation of balancer shafts and vehicle subframes.

MODEL CREATION

The philosophy behind the custom interface has been to produce the required complexity of model with minimum effort from the user. All data entry for powertrain suspension models is undertaken through a series of dialog boxes with the powertrain particulars either selected from menu options or entered as numeric data. There is no requirement on the user to create any of the model directly in ADAMS View.

The flexibility of the model creation process comes from the modular approach to model functionally that has been adopted. The complexity of the model can be tailored to the type of analysis required and the specific details of the powertrain. The custom interface creates the powertrain suspension models in a series of steps, with the user able to stop when the required complexity of model has been achieved.

Modelling functionally available to the user includes the creation of :

- Subframes, with mass and inertia
- Rigid engine with mass and inertia
- Rigid gearbox and transfer box with mass and inertia
- Running cranktrain including crankshaft, connecting rods and pistons
- First and second order balancer shafts
- Engine mounts
- Torque rods

For analysis of powertrain packaging constraints and powertrain modal behaviour, the user only needs to create the powertrain rigid body components and the powertrain mounts and subframes. Analysis of engine mount dynamic forces requires the addition of the running cranktrain to the rigid powertrain and suspension system. Between them, these analyses will enable the engineer to define the best compromise for powertrain mount position and orientation, frequency dependent damping, and both linear stiffness and snubbing regions of the mount stiffness characteristics.

A series of pull down menus are used to select the features required for the powertrain suspension model. The main cranktrain dialog box allows the user to specify the configuration of the engine, in-line or vee, number of cylinders and in the case of vee engines, vee angle and bank offset (Figure 1). Crankshaft and flywheel information is entered, along with the engine firing order, bore diameter, bore centre distance, stroke and connecting rod length. From this information the custom interface creates a running cranktrain joined to the previously created rigid powertrain. An example of a V6 engine with a torque roll axis suspension system is shown in Figure 2.

To enable optimisation studies using the powertrain suspension model, variables are used throughout the model for important values. Parameterised values include :

- Engine mount positions and orientation

- Engine mount stiffness and damping
- Engine bore diameter
- Stroke
- Piston and connecting rod mass
- Centre of mass positions
- Balancer shaft masses
- Powertrain mass and inertia properties

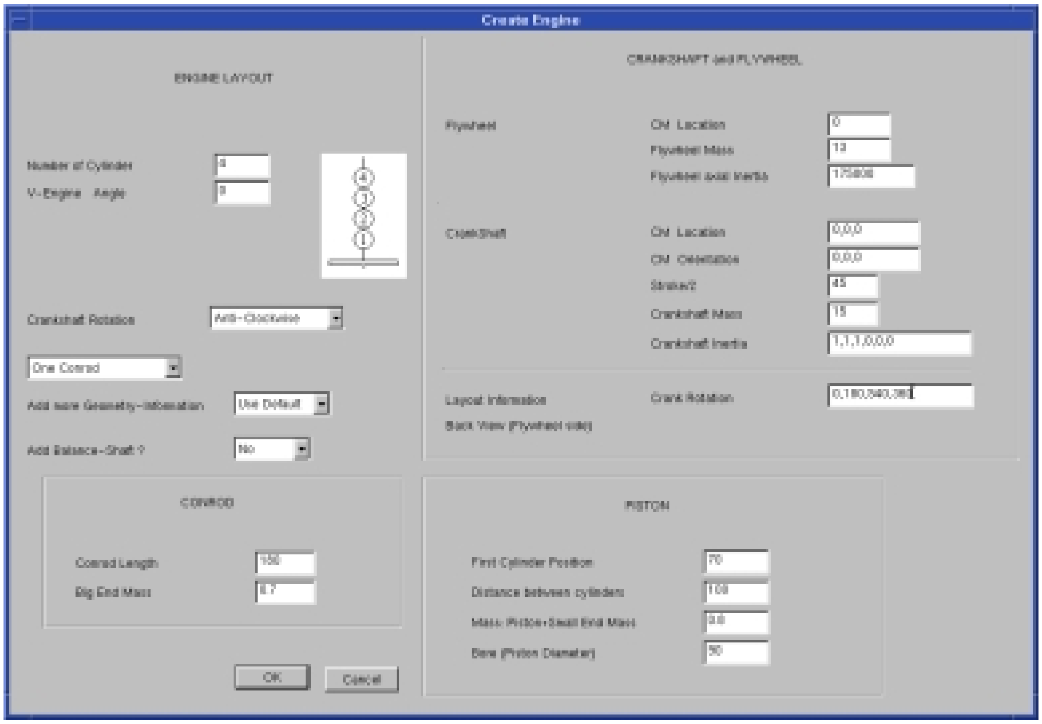


Figure 1, Main dialog box for entering engine data

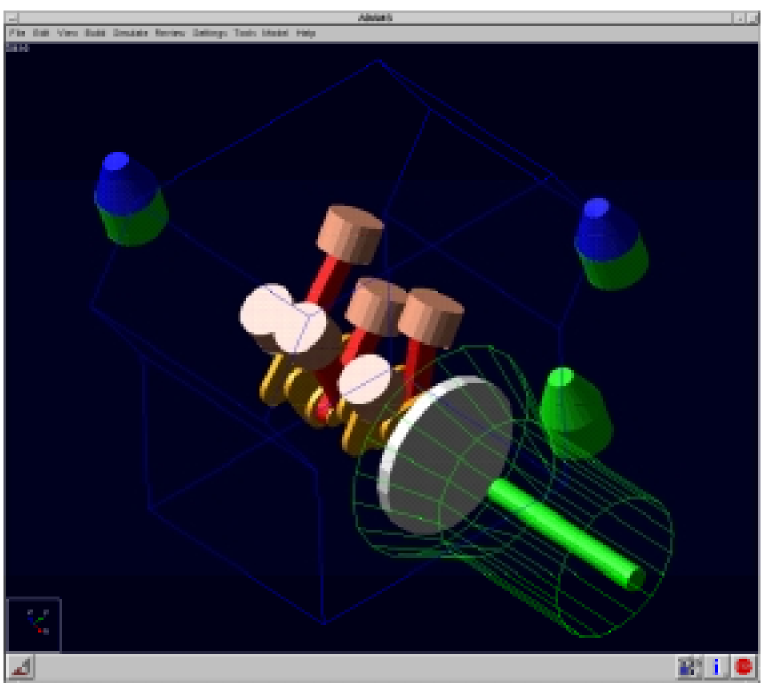


Figure 2, Example of a V6 powertrain suspension system created using the custom interface.

ANALYSIS

The analysis part of the custom interface assists with both quasi-static analysis for global powertrain movement within the packaging constraints and the dynamic running engine analyses. For the quasi-static analysis of global powertrain movement, an analysis script is generated from the user defined applied force data entered into a dialog box (Figure 3). The analysis is conducted as a dynamic analysis with each quasi-static condition lasting for one second. This analysis methodology facilities easy automation of result post-processing.

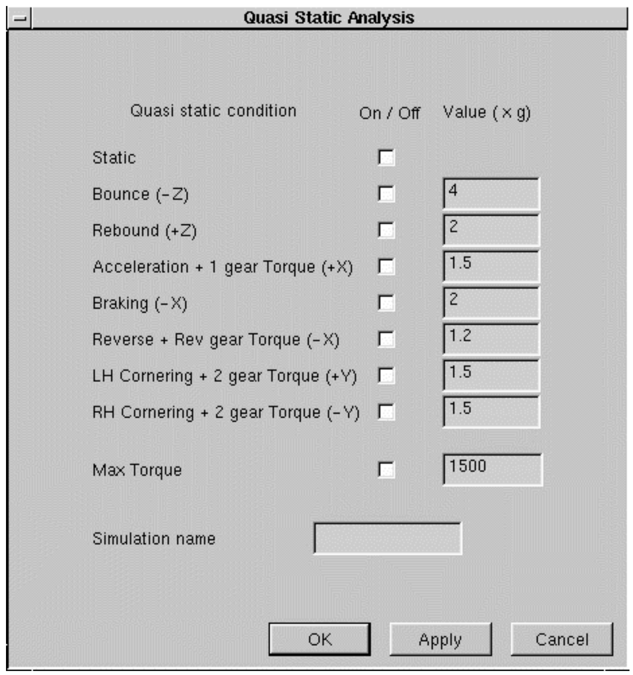


Figure 3, Dialog box for quasi-static analysis.

Analysis of the dynamic powertrain mounts forces requires rotation of the cranktrain to generate the inertia forces, two methods of driving the cranktrain are available to the user :

- Flywheel motion
- Cylinder pressure

Flywheel motion is defined as a spline of flywheel rotation velocity versus time for the analysis. The input can either be measured data from an engine, or predicted data generated with knowledge of the engine harmonic forces. This method fixes the absolute rotational velocity of the crankshaft, and thus does not permit investigation of the interaction of engine harmonic forces and powertrain modes at crankshaft speeds other than the speed of the input used. However, if speed transient data is available, this can be used to vary the crankshaft speed during the analysis.

The second method of driving the cranktrain is provided by applying a force, representing the cylinder pressure, to the piston crown and using this force to rotate the crankshaft. The cylinder pressure diagram is defined over one engine cycle (Figure 4). Information on the engine firing order is used by the custom interface to offset the cylinder pressure diagram for the different cylinders. A reaction torque is required to maintain the speed of the crankshaft. An optimisation routine is available, to the user, to set the level of reaction torque required for a chosen speed. The cylinder pressure diagram can either be measured data or predicted using an engine performance prediction code. The latter allows the powertrain suspension model to be created very early in an engine development programme.

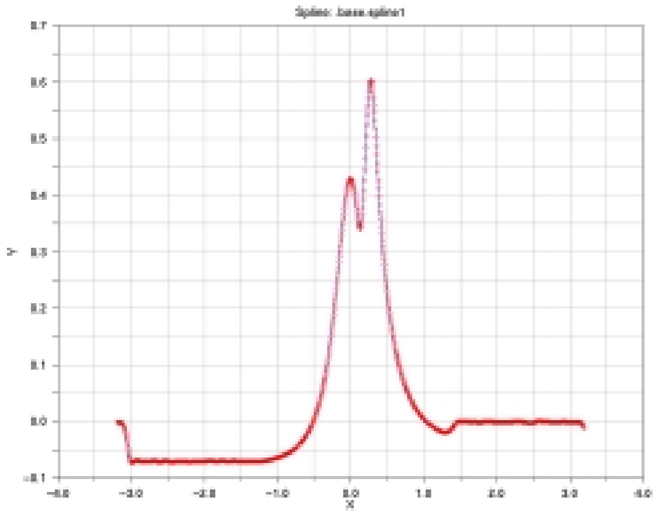


Figure 4, Example of cylinder pressure diagram for one engine cycle.

The cylinder pressure diagram method of driving the cranktrain provides the flexibility of changing the average crankshaft speed and easy factoring of the cylinder pressure diagram for different engine speeds and loads. Thus with the use of careful engineering judgement, and experience of engine combustion systems, the model can be used to analyse other engine operating conditions enabling investigation of powertrain mode and harmonic force interaction.

POST-PROCESSING

To support the analysis of the powertrain suspension model, the custom interface contains menu driven post-processing facilities using dialog boxes for both quasi-static and running engine dynamic analyses. The post-processing options include tabular and graphical output for both the quasi-static and dynamic analyses.

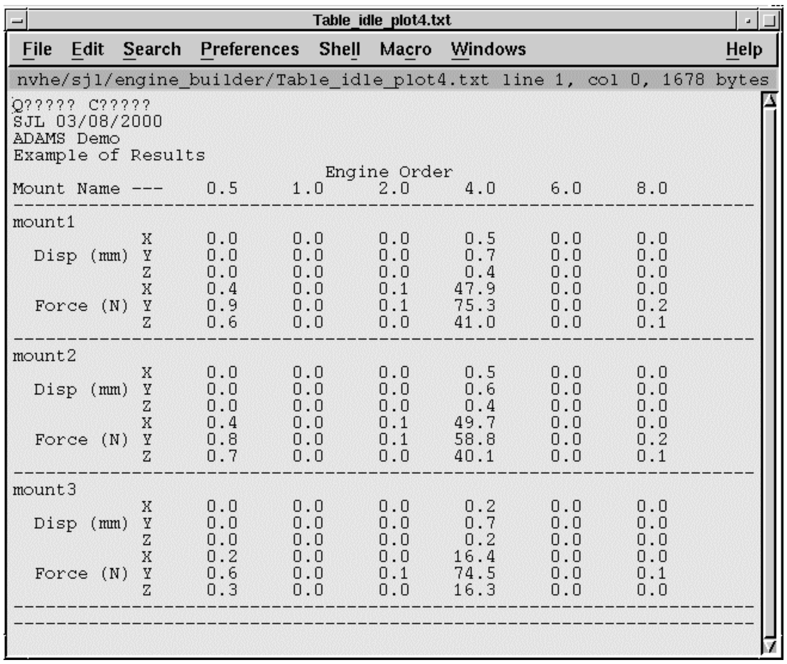
During the creation of the powertrain mounts, requests are generated for the mount displacements and forces. The post-processing facilities for the quasi-static analysis uses these requests to compile a table of powertrain mount forces and displacements for the different quasi-static conditions. The same data is used to produce standard plots of mount displacements and forces.

Post-processing of the running engine dynamic analysis results also uses the powertrain mount requests for displacement and force, for processing the dynamic results into engine order domain. The results from the running engine analysis are used to optimise the vehicle side powertrain mount forces. An example of the tabular output from the dynamic engine analysis is shown in Figure 5. The engine orders used for the post-processing are chosen by the user, thus allowing post-processing of results from any configuration of engine.

Graphical post-processing of the results from the running engine dynamic analysis includes the generation of standard plots for powertrain mount motion and forces in either the time domain (Figure 6) or as orbit plots (Figure 7). The orbit plots provide the user a convenient format of plot to examine the detailed behaviour of the powertrain mounts at a constant engine speed and load condition.

The rapid post-processing of ADAMS predicted results, provides the ideal opportunity for quick parametric studies to optimise the engine mounts, with the main effort of the modeller being directed towards finding an optimised engineering solution and not in the details of the ADAMS model.

Advanced post-processing options include the prediction of interior noise using a hybrid modelling approach [1]. The vehicle side powertrain mount force predictions are used with measured noise or vibration transfer functions (NTFs and VTFs) to predict the interior noise or vibration levels for the powertrain suspension system analysed. This type of analysis allows the powertrain suspension engineer to compare the predicted results from their mount specifications to vehicle level targets. Currently this work is undertaken using either Matlab or LMS CADA-X. The latter being preferred due to the software's handling of the NTF and VTF data.



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Table_idle_plot4.txt
File  Edit  Search  Preferences  Shell  Macro  Windows                Help
nvhe/sjl/engine_builder/Table_idle_plot4.txt line 1, col 0, 1678 bytes
Q?????  C?????
SJL 03/08/2000
ADAMS Demo
Example of Results
                                Engine Order
Mount Name ---     0.5      1.0      2.0      4.0      6.0      8.0
---------------------------------------------------------------------
mount1
             X     0.0      0.0      0.0      0.5      0.0      0.0
  Disp (mm)  Y     0.0      0.0      0.0      0.7      0.0      0.0
             Z     0.0      0.0      0.0      0.4      0.0      0.0
             X     0.4      0.0      0.1     47.9      0.0      0.0
  Force (N)  Y     0.9      0.0      0.1     75.3      0.0      0.2
             Z     0.6      0.0      0.0     41.0      0.0      0.1
---------------------------------------------------------------------
mount2
             X     0.0      0.0      0.0      0.5      0.0      0.0
  Disp (mm)  Y     0.0      0.0      0.0      0.6      0.0      0.0
             Z     0.0      0.0      0.0      0.4      0.0      0.0
             X     0.4      0.0      0.1     49.7      0.0      0.0
  Force (N)  Y     0.8      0.0      0.1     58.8      0.0      0.2
             Z     0.7      0.0      0.0     40.1      0.0      0.1
---------------------------------------------------------------------
mount3
             X     0.0      0.0      0.0      0.2      0.0      0.0
  Disp (mm)  Y     0.0      0.0      0.0      0.7      0.0      0.0
             Z     0.0      0.0      0.0      0.2      0.0      0.0
             X     0.2      0.0      0.0     16.4      0.0      0.0
  Force (N)  Y     0.6      0.0      0.1     74.5      0.0      0.1
             Z     0.3      0.0      0.0     16.3      0.0      0.0
---------------------------------------------------------------------
---------------------------------------------------------------------
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Figure 5, Example of tabular output of post-processed results from a dynamic analysis.

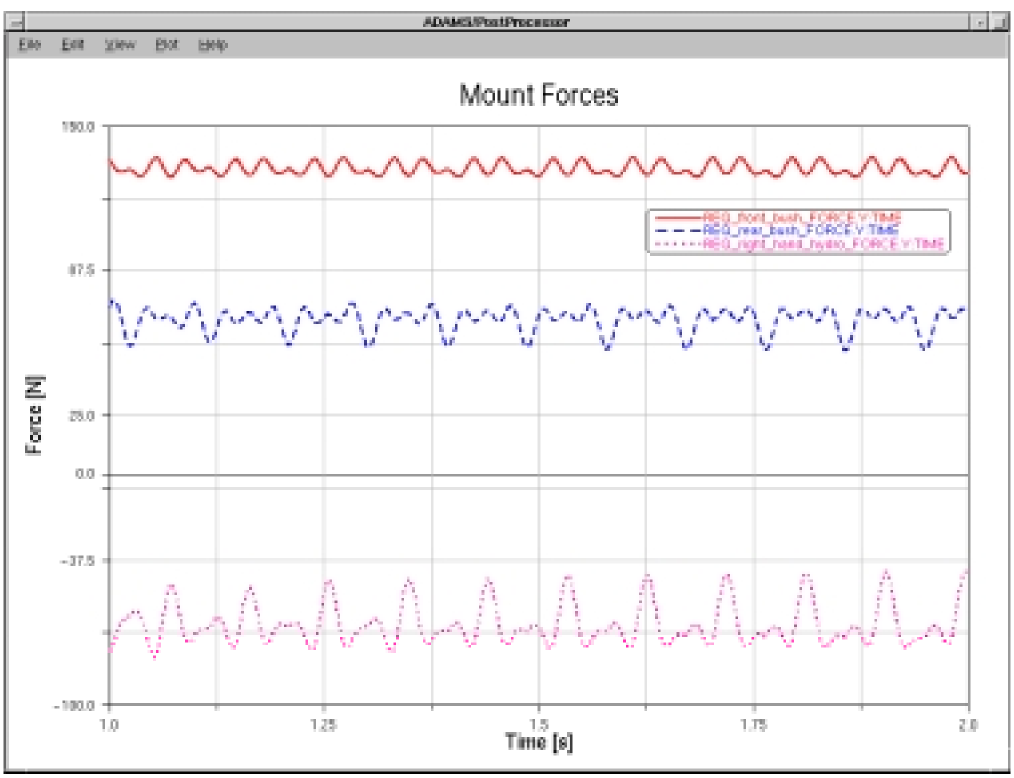

Figure 6, Example of time domain powertrain mount plot.

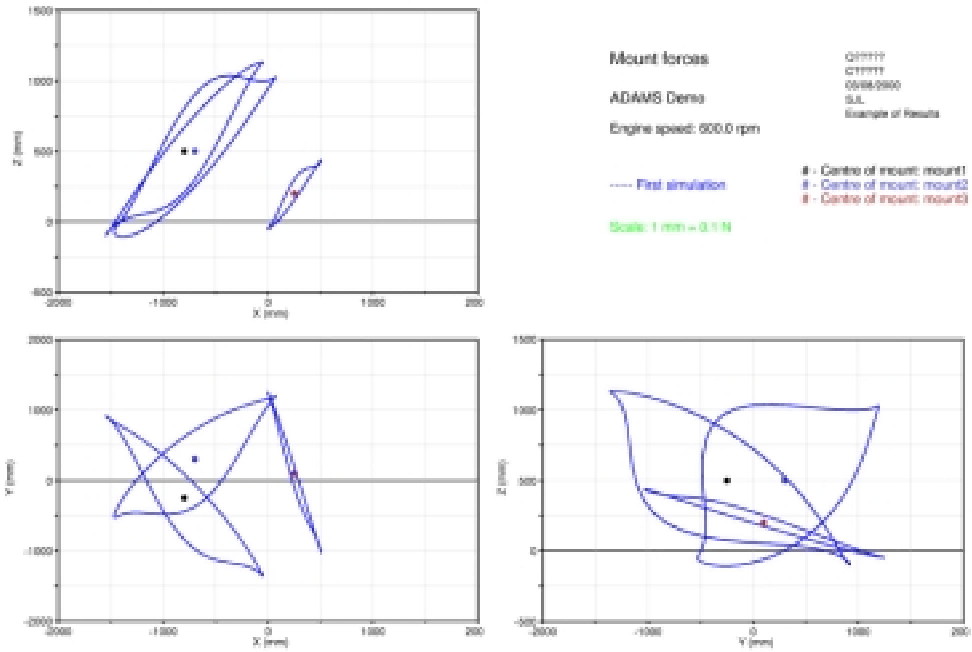

Figure 7, Example of dynamic analysis graphic output showing the powertrain mounts forces.

EXAMPLE PHILOSOPHY OF POWERTRAIN MOUNT OPTIMISATION PROJECT

In the framework of a major powertrain and vehicle integration programme, the objectives of a the powertrain suspension analysis will be :

- To define the powertrain mounting strategy
- To define the powertrain mount positions and orientations
- To optimise the powertrain mount linear stiffness regions for modal and dynamic force considerations
- To optimise the powertrain mount damping characteristics to eliminate powertrain modal issues
- To optimise the powertrain mount snubbing characteristics to maintain the powertrain within the overall packaging constraints

Typically different powertrain mounting strategies will be investigated at the outset, for example the number of mounts, type of mount and mount positions. The results from these initial analyses will provide the powertrain suspension engineer with the information required to select a strategy for the powertrain suspension. Use of the custom interface, typically leads to a 70% time saving during this phase.

Following selection of the mounting strategy the custom interface will be used to optimise the mount characteristics. The flow chart in Figure 8, shows the optimisation philosophy for the powertrain mounts of a torque rolls axis (TRA) mounting system. The custom interface is used throughout the optimisation process reducing the time taken for model generation, analysis and post processing, typically by over 50%

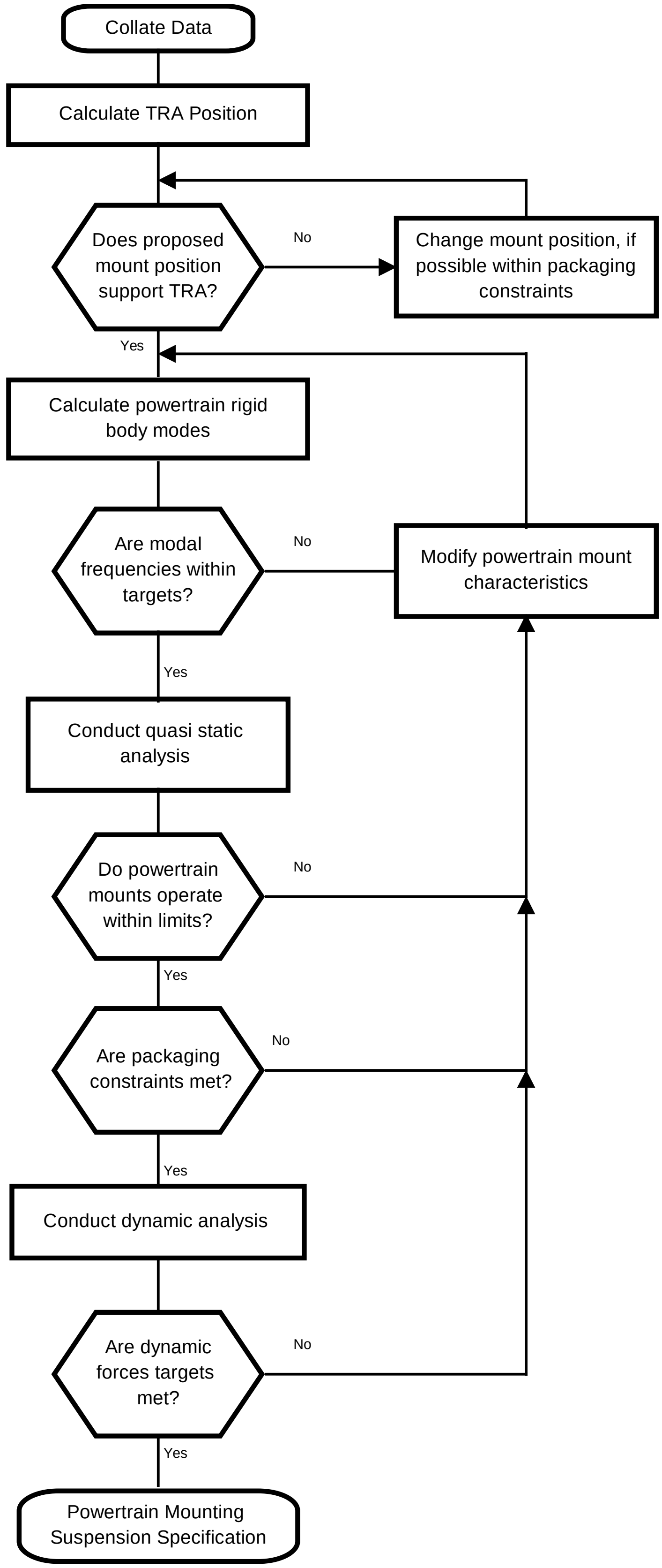

Figure 8, Flow chart for powertrain mount optimisation.

SUMMARY

The custom interface detailed in this paper was written to reduce the time take to perform powertrain suspension analysis for both in-line and vee engine configurations. The philosophy behind the custom interface was to enable powertrain suspension engineers to conduct modal, quasi-static and running engine dynamic analyses quickly and with the minimum effort. Automated model creation and post-processing has allowed this goal to be achieved.

The rapid post-processing of ADAMS predicted results, provides the ideal opportunity for rapid parametric studies to optimise the engine mounts, with the main effort of the powertrain suspension engineer being directed towards finding an optimised engineering solution and not in the details of the ADAMS model.

This approach to powertrain suspension modelling has been used successfully at Ricardo Consulting Engineers. For analytical support to vehicle programmes with challenging time scales the custom interface has reduced the time spent producing the ADAMS model and analysing the results, and thus has increased the engineering time available for mount optimisation.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the directors of Ricardo Consulting Engineers for their permission to publish this paper.

REFERENCE

[1] KUIPERS, JK, POWELL, NN
Vehicle interior noise and vibration prediction using the ADAMS simulation tool.
ADAMS user group conference, November 1996.

Adams Custom Interface For Powertrain Mounting System Design

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Ricardo Consulting Engineers

15th ADAMS European User's Conference

15th November 2000

Powertrain Suspension

- Optimisation of powertrain mount characteristics is important for vehicle noise, vibration and harshness (NVH)
- Automotive powertrain suspension is an engineering compromise between
  - Isolation of the vehicle from powertrain vibration
  - Rigid body modal targets for vehicle ride and handling
  - Restricting maximum powertrain displacements to within the packaging and mount durability constraints

Powertrain Suspension

RICARDO

- Powertrain mount optimisation is an important part of every powertrain and vehicle integration project
- Vehicle NVH is a high priority on vehicle programmes
- Designing the powertrain mounting system right first time reduces the time and cost of mount development later in the programme
- Ricardo developed a custom interface for ADAMS to reduce the non-value added engineering time in powertrain suspension optimisations

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Custom Interface

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- Custom interface was developed to
  - Reduce the overall time for powertrain suspension optimisation
  - Increase the time available for value added engineering
  - Provide high quality and consistent models
- Custom interface provides
  - Automated generation of powertrain suspension models
  - Automated common analysis sets
  - Automated post-processing of results

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Custom Interface

RICARDO

- ❑ Custom interface philosophy
  - – Minimal ADAMS knowledge required to conduct powertrain suspension analysis
  - – Easy to enter data format
  - – All model generation activities automated
  - – Flexible model functionality to suit application
  - – Parameterised model
  - – Standard result plots and tables for comparison to targets

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Data Entry

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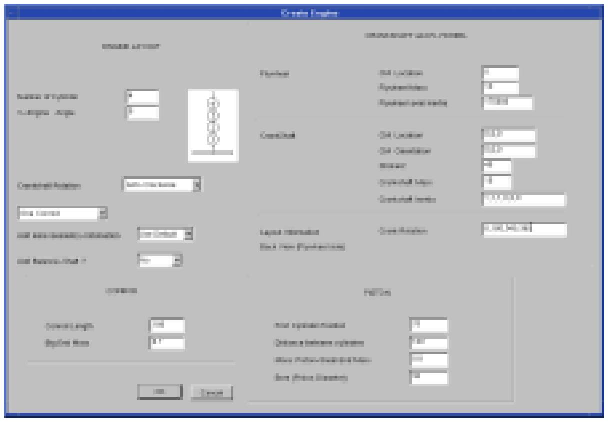
- ❑ Model data is entered through a series of menus and dialog boxes



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Model Functionally

RICARDO

- Flexible model functionality to suit application
  - Rigid body representing powertrain components
  - In-line or Vee engines, any number of cylinders
  - Vehicle subframes
  - Balancer shafts
  - Non-linear powertrain mounts
  - Torque rods
  - Crankshaft rotation driven by either flywheel velocity or cylinder pressure

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Parametric Models

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- Parameterised model for studying the effect of
  - Powertrain mount positions and orientations
  - Powertrain mount stiffness and damping
  - Engine bore
  - Stoke
  - Piston and connecting rod mass
  - Centre of mass positions
  - Balancer shaft masses
  - Component mass and inertia properties

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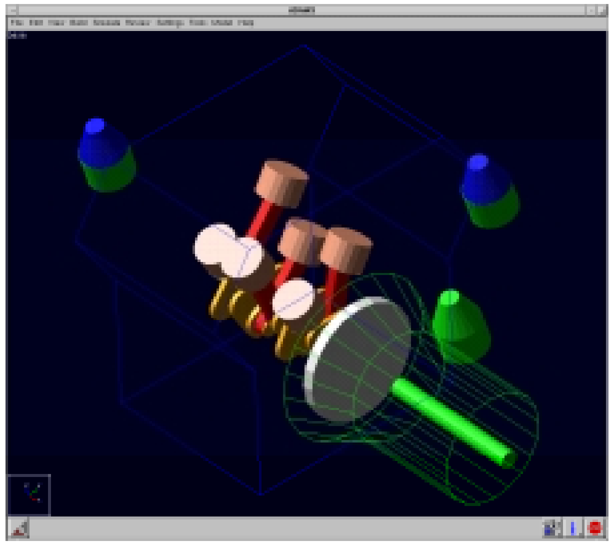
V6 Powertrain



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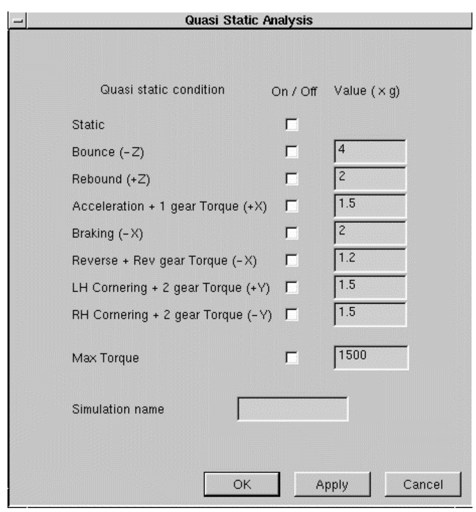
Quasi-Static Analysis

- Input for producing standard analysis script for quasi-static analysis



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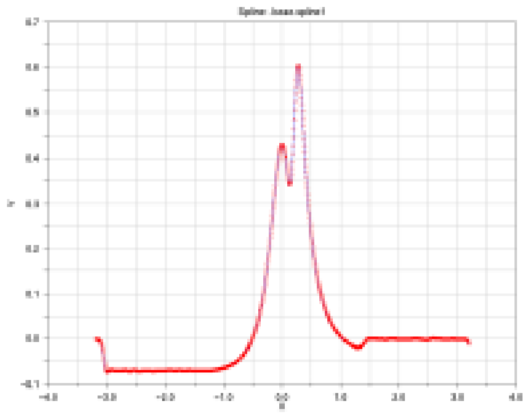
Dynamic Model Input

- Rotating cranktrain can be driven by either flywheel velocity or cylinder pressure data
- Measured or predicted inputs used depending on project timing



Post-Processing

- Table of forces at different engine orders automatically produced for dynamic analysis results

Table_idle_plot4.txt

File Edit Search Preferences Shell Macro Windows Help

nvhe/sjl/engine_builder/Table_idle_plot4.txt line 1, col 0, 1678 bytes

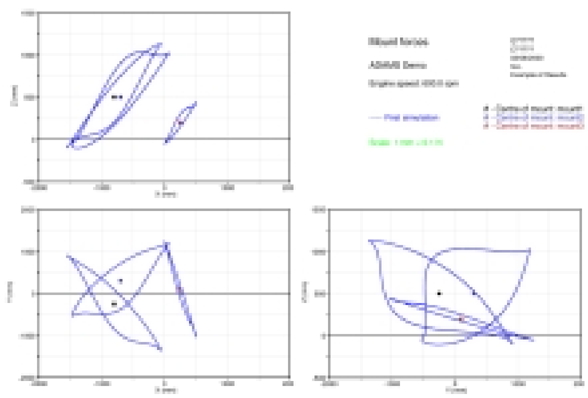
Q????? C?????
SJL 03/08/2000
ADAMS Demo
Example of Results

Mount Name ---			0.5	1.0	2.0	4.0	6.0	8.0
mount1								
	Disp (mm)	X	0.0	0.0	0.0	0.5	0.0	0.0
		Y	0.0	0.0	0.0	0.7	0.0	0.0
		Z	0.0	0.0	0.0	0.4	0.0	0.0
	Force (N)	X	0.4	0.0	0.1	47.9	0.0	0.0
		Y	0.9	0.0	0.1	75.3	0.0	0.2
		Z	0.6	0.0	0.0	41.0	0.0	0.1
mount2								
	Disp (mm)	X	0.0	0.0	0.0	0.5	0.0	0.0
		Y	0.0	0.0	0.0	0.6	0.0	0.0
		Z	0.0	0.0	0.0	0.4	0.0	0.0
	Force (N)	X	0.4	0.0	0.1	49.7	0.0	0.0
		Y	0.8	0.0	0.1	58.8	0.0	0.2
		Z	0.7	0.0	0.0	40.1	0.0	0.1
mount3								
	Disp (mm)	X	0.0	0.0	0.0	0.2	0.0	0.0
		Y	0.0	0.0	0.0	0.7	0.0	0.0
		Z	0.0	0.0	0.0	0.2	0.0	0.0
	Force (N)	X	0.2	0.0	0.0	16.4	0.0	0.0
		Y	0.6	0.0	0.1	74.5	0.0	0.1
		Z	0.3	0.0	0.0	16.3	0.0	0.0

(Column heading "Engine Order" spans 0.5–8.0.)

Post-Processing

- Example of standard plot output for powertrain mount dynamic forces during one engine cycle



Summary

- Custom interface has reduced the time taken for powertrain suspension optimisation
- Automated model generation and result post processing reduces engineer’s time spent interfacing with ADAMS
- High quality models produced with easy model QA
- Custom interface has been used successfully at Ricardo on vehicle programmes to increase engineering time available for powertrain mount optimisation