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Simulating the Suspension Response of a High Performance Sports Car

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Abstract

The use of CAE software tools as part of the design process for mechanical systems in the automotive industry is now commonplace. This paper highlights the use of Altair HyperWorks to assess and then optimize the performance of a McLaren Automotive front suspension system. The tools MotionView and MotionSolve are used to build the model and then carry out initial assessments of kinematics and compliance characteristics. Altair HyperStudy is then used to optimize the position of the geometric hard points and compliant bush rates in order to meet desired suspension targets. The application of this technology to front suspension design enables McLaren Automotive to dramatically reduce development time.

Keywords: MotionView, MotionSolve, HyperStudy.

1.0 Introduction

McLaren are renowned for engineering excellence in both Formula 1 racing cars and also high performance supercars. The Mercedes-Benz SLR McLaren is the latest example of the breed, combining race-car performance with Mercedes levels of comfort and safety. When developing new models, McLaren Automotive is subject to the same pressures as the rest of the industry to develop systems quickly and cost-effectively, and so the increasing use of CAE tools is inevitable. This paper gives a brief insight into some tools used for suspension geometry optimization.

Traditionally only kinematic analysis has been used early in the design of suspension geometry, with compliant effects being considered during vehicle development. However, with an increasing requirement to shorten development times and improve the end product, there is now a need to perform simulations early in the design phase to obtain the optimum solution with minimal on-vehicle testing. For this reason it is necessary to include suspension compliance effects in simulation from the start of a project.

At McLaren the main vehicle dynamics simulation software has been developed in-house primarily for Formula 1 use. This software is very applicable to road cars of the type designed by McLaren Automotive since they share many attributes such as double wishbone suspension and significant aerodynamic forces with their Formula 1 race car cousins. However, the road car market adds another layer of requirements such as the effect of rubber bushes on suspension kinematics. For this reason it was necessary to find another tool which could include the effects of suspension compliance characteristics in suspension simulations and which could help optimize bushing characteristics to achieve the required performance targets.

This paper describes how Altair MotionView **[1]** and Altair MotionSolve **[2]** were used to build a front suspension model. The kinematics and compliance of the model were then assessed as well as the bump, roll and steer characteristics. Once the baseline assessment was completed the bush rates and hard point positions of the suspension system were then optimized using Altair HyperStudy **[3]** in order to optimize the suspension characteristics.

2.0 Modelling, Solution and Results Output Process

2.1 Model and Task Assembly Wizards

McLaren have used the "Assembly Wizard" available in Altair MotionView to allow the user to choose from various suspension topologies and to assemble the components easily into a model. Bespoke McLaren libraries have been created for both assemblies and analysis tasks to allow very quick creation of the complete analysis model. An example model is shown in **Figure 1**.

Once the model is defined, the "task wizard" is used to define analysis events. In this study the events of interest were kinematics and compliance, roll, steer and vertical bump. Each of these events can be analysed in isolation or combined into a single analysis.

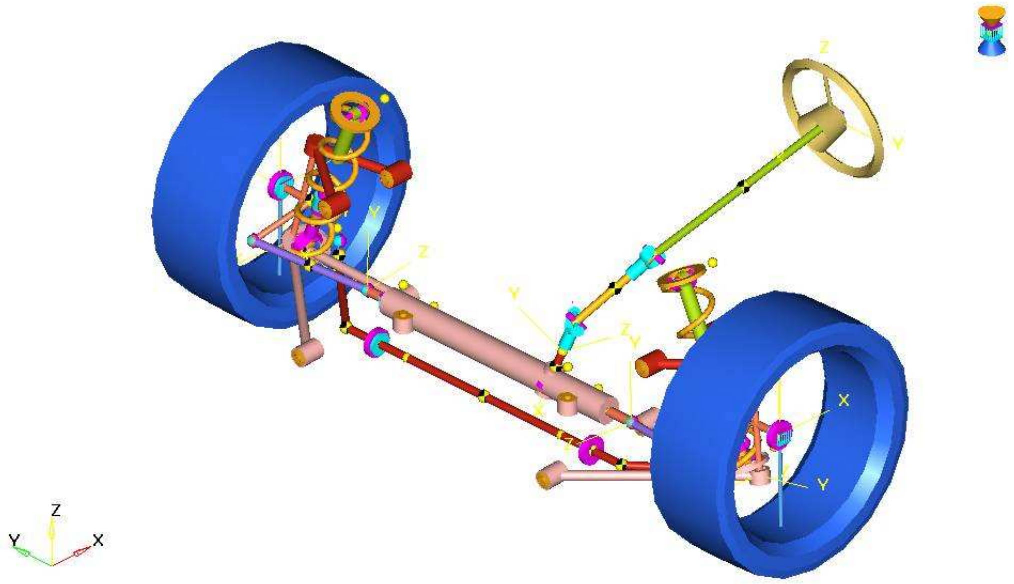

Figure 1: Sample Kinematic and Compliance Model

The model was analysed using Altair MotionSolve which can run directly from MotionView. This enables any model changes that are required to be quickly made and then evaluated instantly using the integrated solver.

A number of standard outputs have been integrated into the McLaren model libraries; these provide a variety of typical suspension outputs such as toe angle, camber angle, kingpin inclination, scrub radius and trail as well as roll centre positions, roll centre migration during wheel travel and anti-lift / anti-dive. These outputs are available for post processing and also to be used as targets or constraints in the following optimization process.

The advantage of having the outputs built into the model is that they are defined in a standard way, so all users will be working to the same standards. It is also straightforward for users to visualise the model behaviour using HyperView or add extra outputs for post-processing if required. The process of setting up the 'model wizard' and 'task wizard' took around 2 man weeks of effort.

3.0 Results Output for Kinematics and Compliance, Roll, Steer and Vertical Bump

3.1 Post Processing

Altair HyperWorks also includes the post processing capabilities of Altair HyperView and Altair HyperGraph which can be used to look at animations and xy plots of the suspension performance. As noted above, various outputs of interest were considered in order to assess the performance of the system such as Ackermann, camber, castor and toe. Typical result outputs obtained from the baseline model are shown in **Figures 2 and 3**:

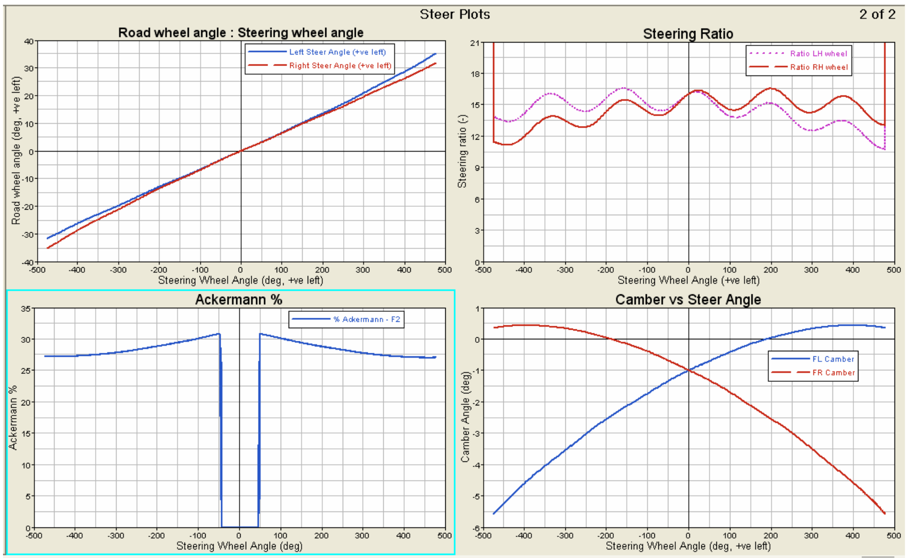

Figure 2: Example Results Output for Steer Analysis (Sample Geometry)

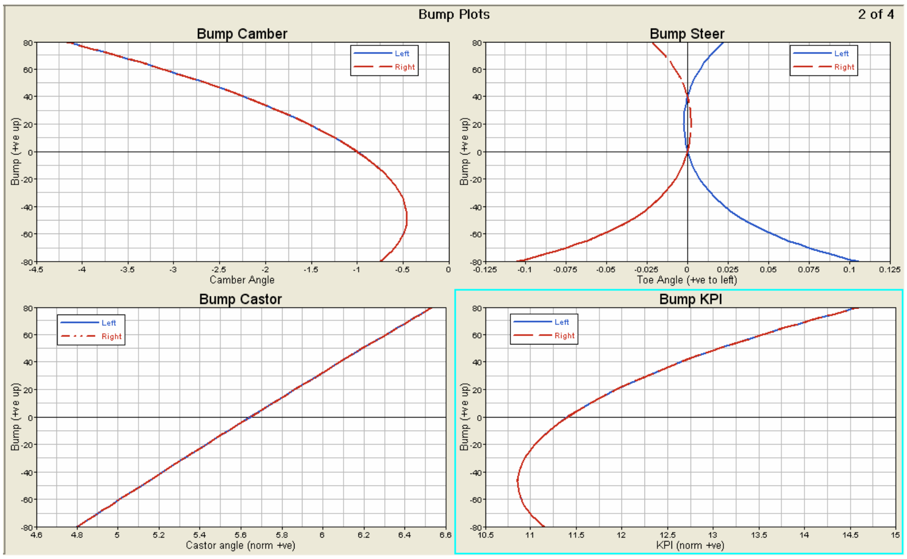

Figure 3: Example Results Output for Bump Analysis (Sample Geometry)

At this stage the results from the non-compliant simulation can be overlaid with the compliant results so that the effect of including the compliant bushes can be visualised.

4.0 Optimization of Suspension Characteristics

4.1 Optimization Setup

The traditional route to optimising suspension characteristics was a large amount of experience to determine targets, combined with a large amount of on-vehicle testing of different options to determine the preferred characteristics. There is still a significant requirement for experience to determine targets although CAE tools can also assist in this process – at McLaren the in-house dynamic simulation software and driving simulator are aggressively used to help determine targets at an early stage. However, the software has some limitations in the areas of suspension compliant effects due to its F1 roots so Altair MotionView / MotionSolve is used to convert system targets into design targets for individual components. This means that the ability to include road interactions is not required and MotionSolve is an ideal tool.

Obviously it is possible to manually iterate the positions of suspension pick-up points and stiffnesses of bushes but with such a large number of degrees of freedom it is not straightforward to find an optimum solution. For this reason the optimization and DOE (Design of Experiments) module of HyperStudy was employed to provide a logical approach to finding the best solution. This allows the specification of a number of design variables, which are the parameters in the design which can be changed, and constraints and objectives to be met during the iteration process.

Initially some simple models were created to test the optimization process, such as optimising the universal joint positions and orientations in a steering column to achieve the least variation in steering ratio, see **Figure 4.**

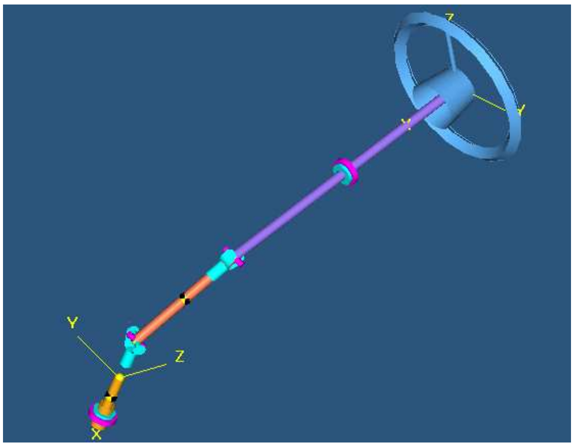

Figure 4: Simple MBD Model for Optimization

This was very easy to set up and worked well but clearly there is little point in optimising one characteristic unless you also consider the other effects of your changes. For this reason when considering the complete suspension performance it was necessary to include all of the following analyses with their respective outputs:

- Bump analysis
  - Outputs of bump steer, camber curve, motion ratio etc.
- Roll analysis
  - Outputs of roll centre height, roll centre migration etc.
- Steer analysis
  - Outputs of Ackermann, steering ratio etc.
- Kinematic and Compliance (K & C) analysis
  - Outputs of compliant response to contact patch forces etc.

Using HyperStudy it is possible to include several models as part of the optimization process and consider different outputs from each model. Of course it is also necessary to ensure that the design variables are applied to every model in the same way so that all the models are at the same design condition. In HyperStudy this can be achieved by linking the design variables. Using the models together for every iteration has resulted in a run time of around 15 minutes per iteration (on a single high-spec PC), which is acceptable for running jobs overnight.

In this particular case, the design variables were primarily the suspension hardpoints and the bush stiffness's. It is clearly necessary to determine sensible limits on the hardpoints to allow them to move only an amount which could actually be feasible in reality, and the bush stiffness's between rational values which would be practical for a production vehicle.

Clearly the bush stiffness's also have an effect on NVH though for this first attempt at a suspension optimization only quasi-static suspension characteristics were assessed, and bush stiffness effects on NVH were only considered through specifying a maximum bush stiffness. A further development at a later date will be to include a higher-frequency dynamic analysis in the optimization to directly assess the effect of bush stiffness on noise transfer paths.

Defining the targets and constraints is one of the most complicated tasks in the optimization. With a suspension system there are a large number of degrees of freedom and whilst it may be desirable to include many constraints in the process, in reality this tends to over-constrain the model and no solution can be found. A typical list of constraints might be as follows: (values changed for reasons of confidentiality)

Category	Response	Constraint
Steering	Steering ratio	Between 16 and 18:1
	Ackermann %	Between 50 and 60%
Bump	Maximum Camber Change	Not more than 2°
	Maximum Castor Change	Not more than 0.5° / 10mm
	Motion Ratio	Between 1.00 and 1.15
Roll	Roll Centre Height (nom)	Between 0 and 20mm
	Roll Centre Migration	Between 0.8 and 0.9 mm/mm
K & C	Lateral force toe compliance	Maximum 0.3°/kN
	Longitudinal force wheel recession	Between 3 and 4 mm/kN
	Lateral camber compliance	Maximum 2°/kN
	Aligning torque toe compliance	Maximum 0.05°/Nm

Table 1: Typical List of Constraints

The desired objective was a specified bump steer curve. This was converted to a response metric by performing a 'least squares' fit between the actual response and the desired response.

4.2 Optimization Results

In theory it would be ideal to include all the desired suspension performance metrics and constraints and simply let the optimiser work away until the optimum solution was found. However, in reality a compliant suspension system is a system with a great many degrees of freedom and the solution 'surface' is a very complex one with many local minima. Tests to try and include many design variables and constraints at once have tended to result in local solutions which are not the global optimum. In addition the time taken to process these optimizations is far too large due to the number of permutations which the optimiser has to consider.

Another problem seen is that when trying to optimise suspension bush stiffness's, it is necessary to have some limitation on the maximum stiffness permitted or the optimiser will often tend to simply maximise the bush stiffness's, particularly if the objective is to minimise some displacement. A better approach has been seen to be to fix one bush stiffness and optimise the other stiffness's to 'match' it and provide a balanced response from the whole system, or at least to set the objective to be a finite value of a response rather than just minimising a displacement.

As previously discussed, another good way to prevent the optimiser maximising bush stiffness's would be to have a penalty function which tends to promote the reduction of bush stiffness's, so that a suitable compromise can be found. One example would be to include a higher-frequency dynamic analysis and to target a specific modal frequency or transfer path gain. This will be attempted in the future.

To date better results have been found from using some manual intervention to iterate the design to a point which is close to the desired performance and then using HyperStudy to perform detail sensitivity analysis to small changes in the design space. HyperStudy is still a very useful tool for performing these 'local' optimizations and since there are fewer variables and constraints the problem is a much easier one to define and solve.

Because of this the optimization was split into 3 parts, with the HyperStudy sensitivity analysis being used to determine which were the primary effects at each stage (if it is not obvious). The 3 parts were:

- Optimization of hardpoints to give required kinematic results (non-compliant)
    - Eg. Separate optimizations of steering rack position to give desired steering performance, wishbone positions to give desired roll centre and migration characteristics

- Inclusion of compliant effects and optimization of bush stiffness's
- Re-optimization of hardpoints to account for changes due to compliant effects

One example of the performance before and after the optimization is shown in **Figure 5** below.

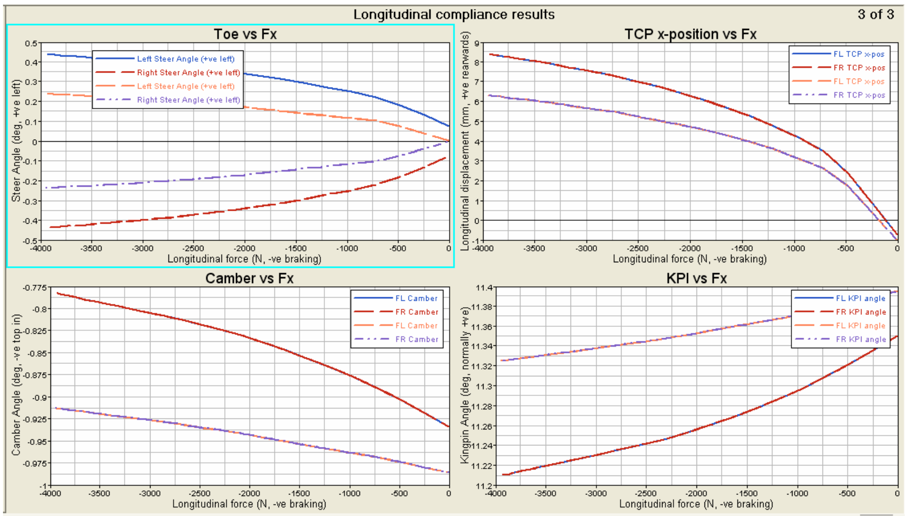

Figure 5: Performance Before and After the Optimization

5.0 Conclusions

The Altair MotionView, MotionSolve and HyperStudy suite of tools have proven to be very useful for the design and optimization of suspension systems. The ease of designing bespoke 'wizards' for model creation has been beneficial and the post-processing tools have enabled quick and straightforward visualisation of the results once the templates have been created once.

The optimization tools available in HyperStudy make simple optimizations such as single pick-up point optimizations much faster than manual iteration, and with some thought and experimentation it is possible to obtain good results from more complex optimizations including several design variables and constraints. However, more work is required to successfully complete a single analysis which will include all the suspension performance requirements in one optimization. This work will be continued.

6.0 References

[1] **'MotionView Version 8.0'**, Altair Engineering Inc., 2006.

[2] **'MotionSolve Version 8.0'**, Altair Engineering Inc., 2006

[3] **'HyperStudy Version 8.0'**, Altair Engineering Inc., 2006