# Using ABAQUS to provide a flexible solution to a traditional MultiBody Simulation analysis at Jaguar Land Rover

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Abstract*: Jaguar cars are renowned for their ride and handling characteristics, as well as first class durability and reliability. Jaguar hopes to improve the accuracy of the simulation of chassis/suspension components using the leading general purpose non-linear analysis tool, ABAQUS, leading to the reduction of development time through the removal of rig tests.*

*The current approach to Systems Level Integrity (SLI) studies of chassis/suspension at Jaguar is to use a Multi Body System (MBS) package to calculate the load histories at specific points of the structure – which are then fed into Finite Element Analysis (FEA) models of the suspension components for linear stress analysis and subsequent fatigue analysis.*

*The current approach has the drawbacks that compliance of the major components such as control arms, tie rods and knuckles is not taken into account in the MBS analysis and the FEA is linear.*

*This study examines the use of the Altair/MotionView package to create a MBS model which is run in ABAQUS using rigid bodies and Connector elements. The results of the connector model are correlated against MBS data and then the major suspension components are introduced into the SLI model either as linear substructures or as fully non-linear components. These models are then run in ABAQUS to determine suspension strength as a complete system and also to provide a more realistic stress history for the fatigue analysis.*

*Keywords: Automotive, Suspension System, System Level Integrity, SLI, Multi Body System, MBS, Connectors, Component Level Integrity, Substructures, Flexible bodies.*

## 1. Project Objective

The objective of this project was to demonstrate the modelling and analysis of a specific suspension system using MotionView and ABAQUS, correlate the results with existing MBS data then use the model to develop component linear and non-linear stress data and provide Jaguar with general principles that will allow them to develop future suspension systems in a more efficient manner.

## 2. Background and Current Analysis methodology

Time and cost to market is a key driver for all automotive manufacturers and it will be of no surprise that, with Jaguar in the middle of a model transformation programme, it is a major factor. The delivery of the durability attribute takes a substantial portion of the development budget and Jaguar has been tackling both cost and timescale for the past few years. The achieved reduction in the number of physical prototypes together with the reduced development time has meant that significant emphasis is now placed on the delivery of quality and timely CAE. CAE has developed from a simple stress analysis tool in the 1980s to a much more comprehensive one. It is only by substantial development of the CAE toolset that further reduction in both cost and time will be achieved to gain competitive advantage.

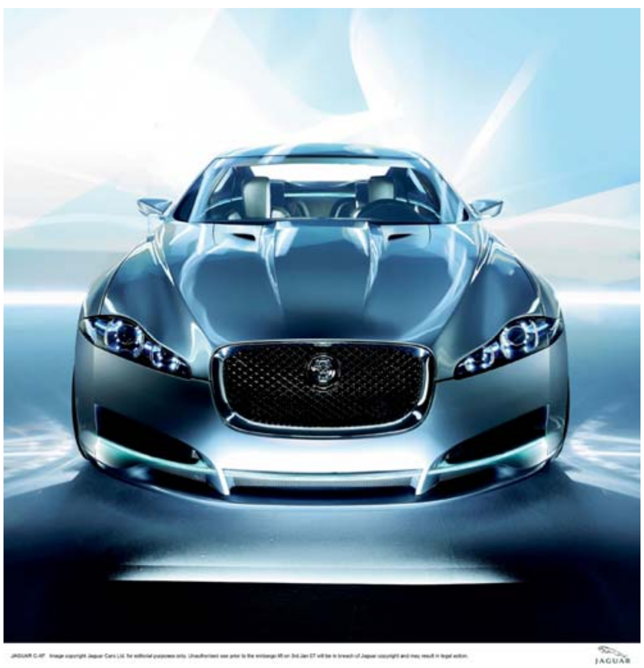


**Figure 1: The Jaguar C-XF Concept car.**

Jaguar Chassis are responsible for development of the durability of suspension systems to cover environments found in all world markets. The sign-off for these systems has historically been via prototype vehicles driven around test tracks to a prescribed schedule that represents in-market severe or extreme customer usage. However to attain enough damage then these tests take many months to complete and require a suite of prototypes. Over the last few years this process has changed to the use of multi-axis hydraulic rigs that can input 16 load axes at the wheels plus internal forces that come from, say, the drive train. Recently these rigs have been upgraded to include inertial restraints so that high g cornering events can be tested. The advantages of this route are:-

- The rigs provide repeatable known inputs.
- Highly accelerated loading because of the lack of driver.
- The rig operates 24 hours a day 7 days a week.
- Tests can be completed in around 2 months.

**Figure 2: Multi-axis rig test showing time history load inputs at the wheel**

However, the goal is to deliver durability without the use of physical prototypes, the so called "Zero Prototype" route. In practice, the current Jaguar philosophy is to carry out sufficient and detailed CAE such that the durability rig test is for confirmation only i.e. that no analysis mistakes have been made. This detailed CAE has to produce quality results of high accuracy but it also has to produce results quicker than ever before to fit in with the reducing development timescales. In summary, faster, more accurate and more detailed CAE than ever before.

The process currently carried out to deliver durability via CAE is as follows:-
The process is split into 3 phases each with their own development task:-

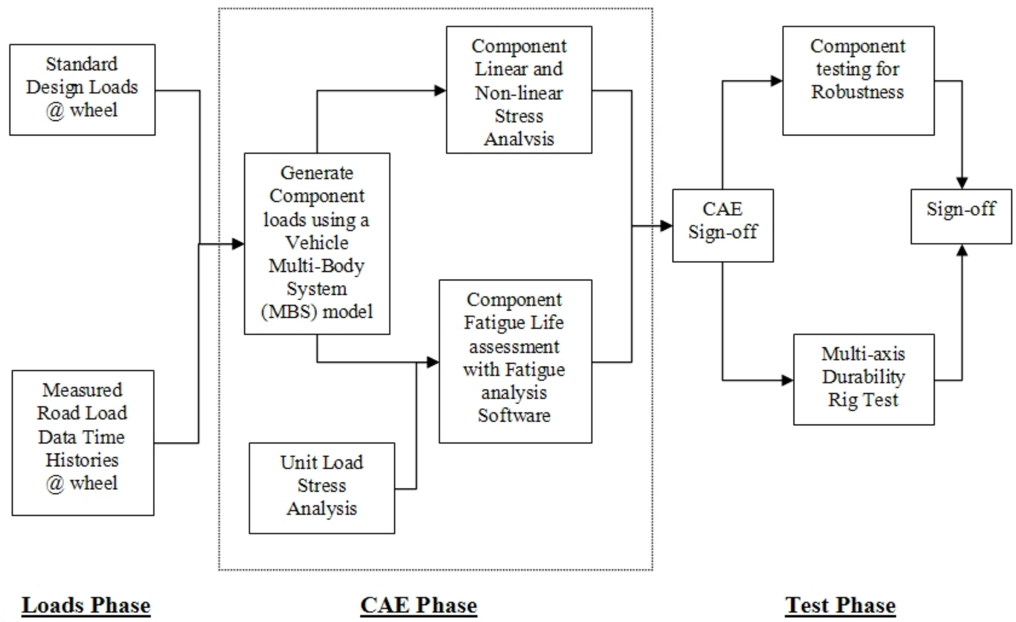



**Figure 3: Current durability process**

**Loads Phase.**

The main task is to reduce reliance on the measurement of Road Load Data (RLD) which is both costly ,time consuming and can occur too late in the program by:-

- Enhancing the standard design load cases to be more representative of current sign-off standards.
- Use of fully analytical MBS models that use the road surface and tyre models to predict all time history loads in the vehicle.

This work is ongoing within Ford and PAG and not covered in this paper.

**Test Phase**

Component testing to validate robustness to noise factors is a proven process with the trend being to test more axes simultaneously to reduce test time. Testing of the whole vehicle on multi-axis rigs is also a mature process with the major effort going into accelerating the test via the omission of non-damaging load signals.

**CAE Phase**

The major focus of this paper is to tackle this phase. From the diagram above it can be seen that most of the analysis is done at component level after the loads have been cascaded from wheel input loads to component level. The issues with this are two fold:-

1. The cascade of component loads is a time consuming process using, currently, rigid body structures. The influence of structural flexibility is not taken into account.
2. The CAE analysis for stress, strength and fatigue is carried out at component level. A significant saving would accrue if analysis were carried out at system level, say, the front or rear suspension.

It is the purpose of this work to investigate a streamlined process that is more representative of the multi-axis rig test that would allow investigation of the effect of component changes on loads, and would allow assessment of many components at a time. In the future the process above would therefore change to look like:-

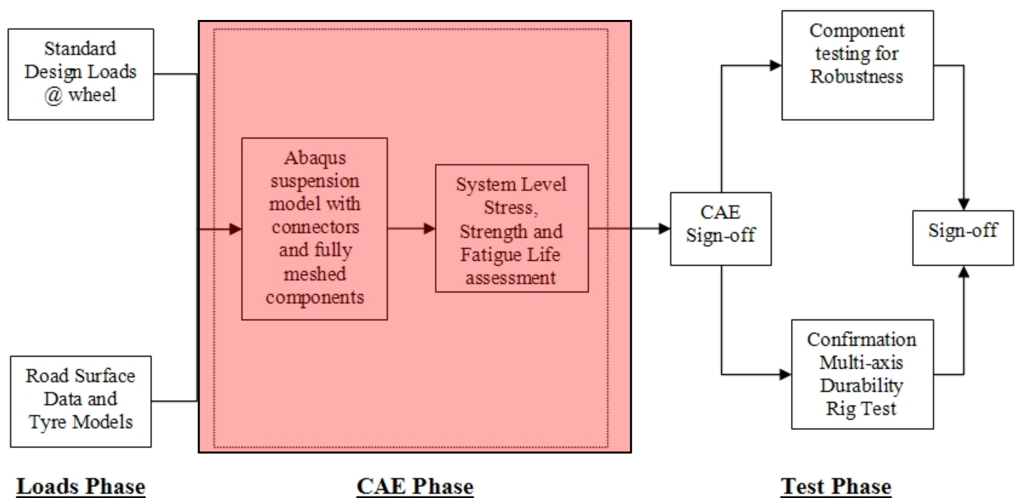



**Figure 4: Fully analytical durability process**

This fully analytical process will bring considerable benefits in terms of both reduced delivery time and increased number of iterations to optimise the design. There is however a constraint to be satisfied. The vehicle dynamics model is being used in parallel to this process in order to develop the ride and handling characteristics of the vehicle. The changes to this model, as various iterations are investigated, need to be incorporated into the durability model and hence a close link is required.

This paper continues work started previously [ref. 1] and demonstrates the feasibility of using ABAQUS as it allows the coupling of a system modelling approach with a very capable linear and non-linear FEA solver. There is still a significant amount of work to be carried out on methods and techniques that will surround this process but once the process is in place then this will be a major tool for the future.

## 3. S-Type rear suspension

It was decided to use the S-Type rear suspension for this study because:-

- It is in the public domain.
- It has a reasonably complex double wishbone system.
- Design loads and road load data are readily available.
- It has been tested on the multi-axis rigs so data is available for correlation.

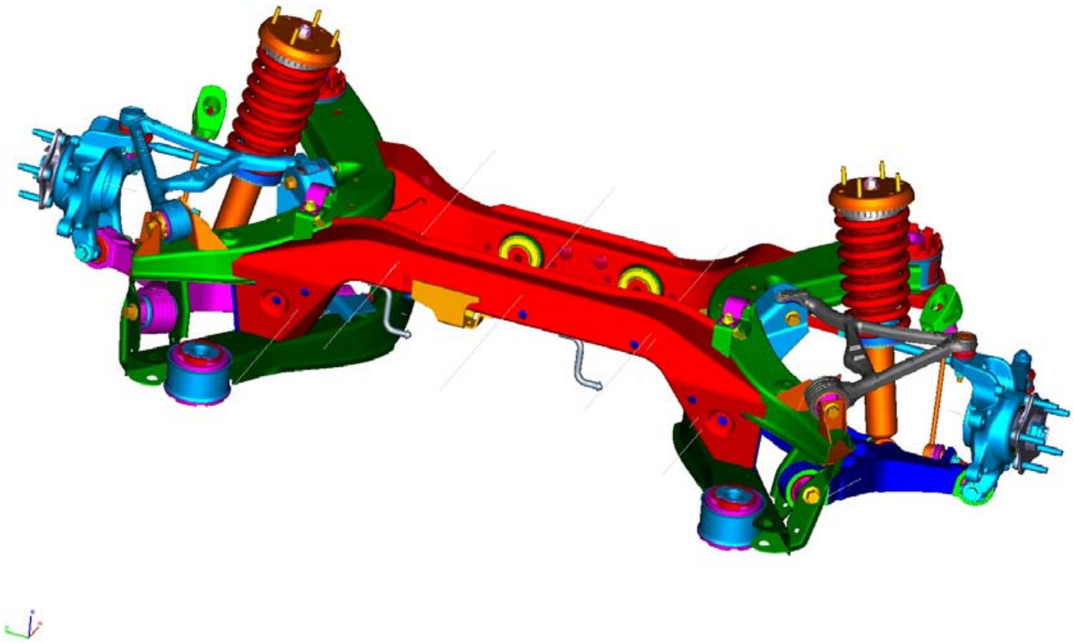


**Figure 5: S-Type Rear suspension system**

The main loading on the suspension are the six forces and moments at the wheel together with driveline loads from the differential and drive-shafts (not shown). The subsequent work will show the application of loads at the wheel to develop stresses in the suspension components.

## 4. System Level Integrity (SLI) Model

The first step of the methodology was to generate the suspension model using Altair/MotionView. The original MSC/Adams (Adams) model was supplied by Jaguar so this was read directly in to MotionView. Some entities did not read in from the Adams (.adm) file either at all or correctly, so several revisions and updates to the MotionView model had to be made in order to establish model integrity. These took some time to perform and the resulting ABAQUS model was not robust, with singularity and over-constraint issues. Therefore the rear suspension model was built from scratch within MotionView using the assembly wizard. The initial process is extremely quick, it is then for the analyst to adjust the model in terms of topography and compliance. The resulting System Level model is shown in Figure 6 below.

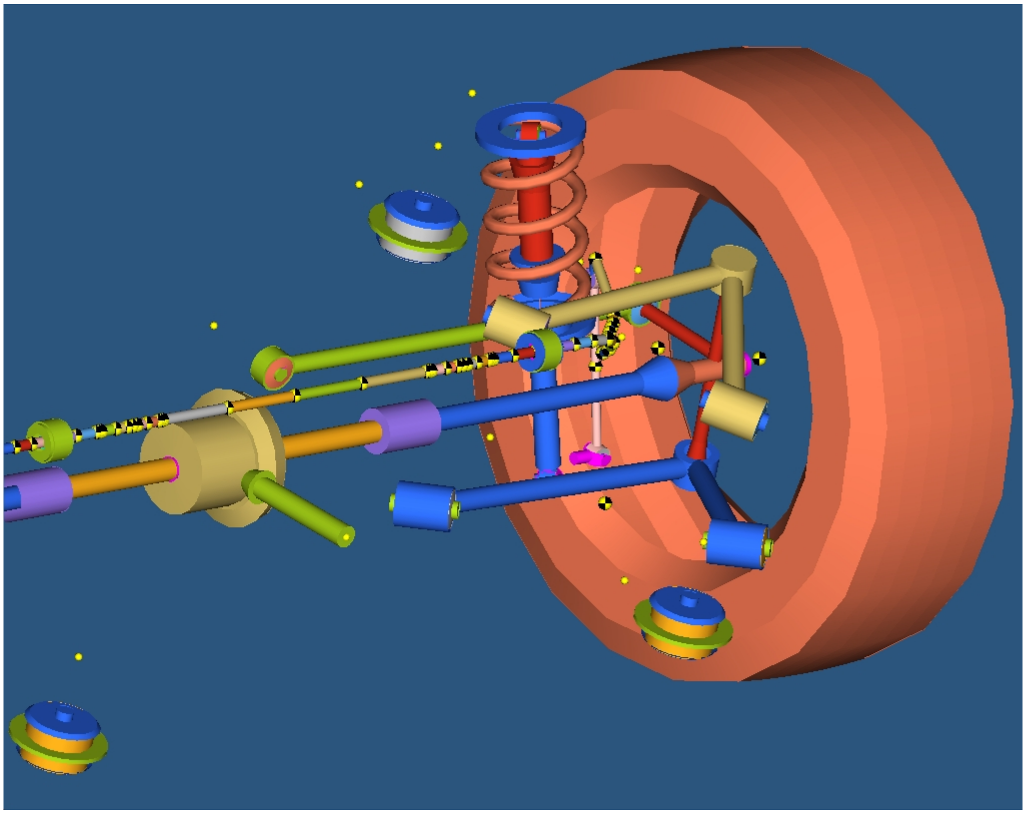


**Figure 6: MotionView Rear suspension model**

The extent of the model was from the subframe down. Included were the subframe, drive shaft, rear differential, half shafts, constant velocity (CV) joints, knuckles, upper and lower control arms, shock absorbers, main coil springs and anti-roll bar.

Once the model was considered representative of the structure within MotionView, an ABAQUS input deck was written.

Where non-linear stiffnesses were available for the bushes, these were input directly to the ABAQUS model. It was not possible to do this within the MotionView model.

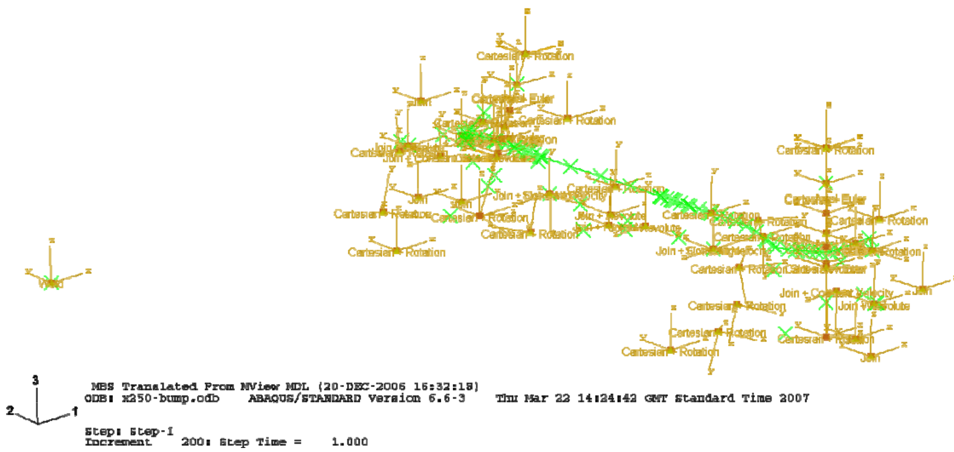



**Figure 7: ABAQUS Rear suspension model**

The ABAQUS model consisted of a series of rigid bodies to represent the components linked by connector elements to represent the joints and bushes; mass and rotary inertia elements for the rigid bodies and B31 beam elements to represent the anti-roll bar.

## 5. System Level Verification

Two simple loadcases were defined to correlate the system forces obtained from the legacy MBS analysis.

The first of these was the combined static vertical wheel rate test, in which both wheels were raised and lowered simultaneously by 100 mm from the ride height. The results are shown in Figure 8.

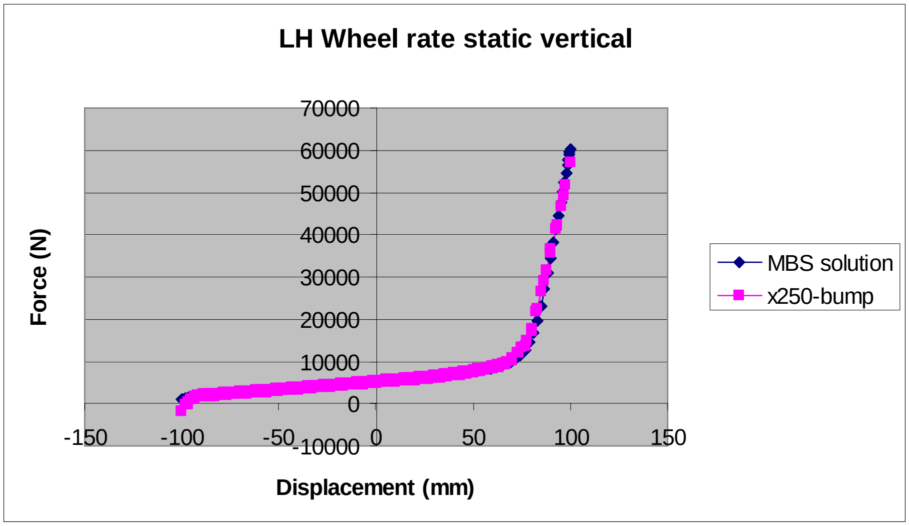



**Figure 8: Static vertical test force vs displacement curves**

The results from the ABAQUS analysis show excellent agreement with those from the MBS analysis.

The second test was the Fore-Aft case. In this case the wheel centres were loaded longitudinally with ± 2430 N. A comparison of MBS versus ABAQUS results for this loadcase is shown in Figure 9.

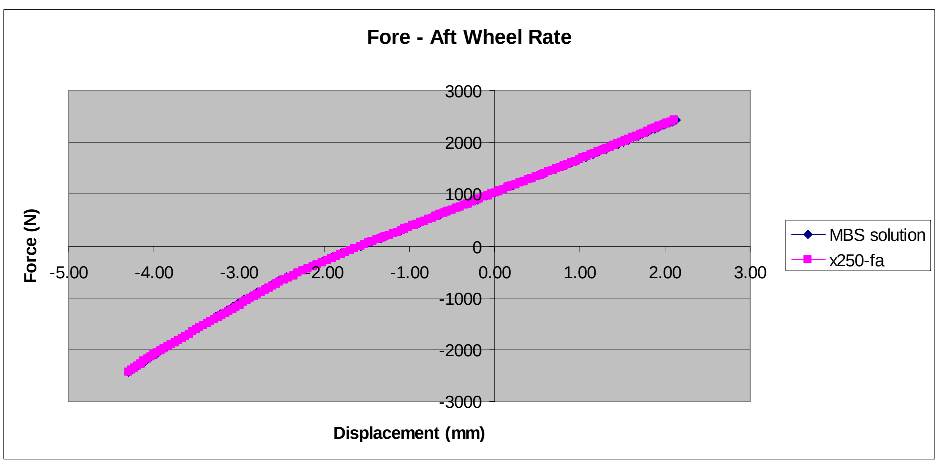
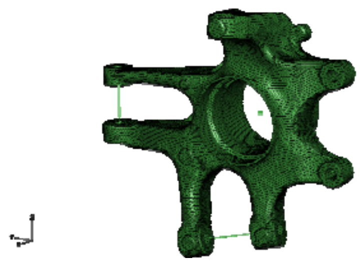
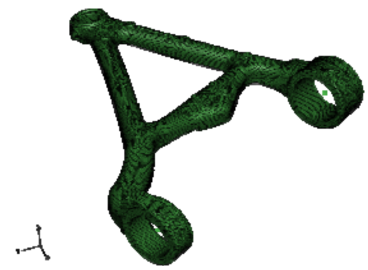
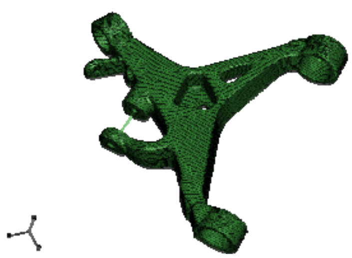
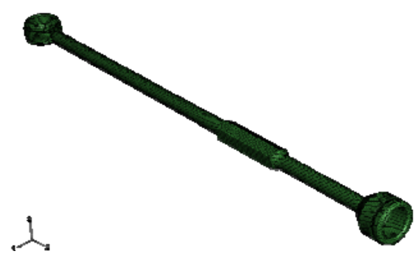


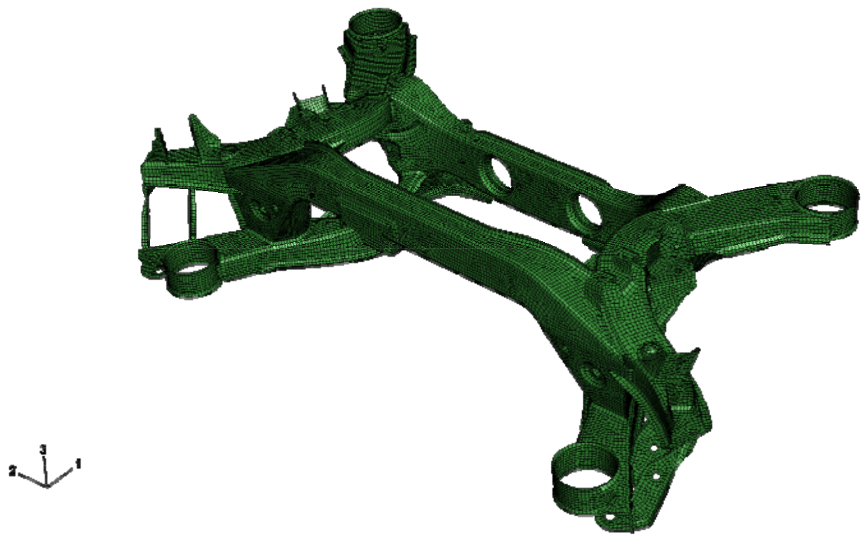

**Figure 9: Fore – Aft Wheel rate results**

Once again the ABAQUS result compares very well with the MBS result.

## 6. Component Level Integrity

In order to determine the effects of component flexibility upon the system model the following five components were introduced; the knuckle, upper control arm, lower control arm, subframe and toe link, although any number of components could be considered in this way. The components were supplied in the form of detailed FEA meshes as shown in Figure 10 below:-

| | |
|---|---|
|  Knuckle |  Upper Control Arm |
|  Lower Control Arm |  Toe Link |



Subframe

**Figure 10: Component FEA meshes**

From each of these component meshes an ABAQUS linear substructure was generated using the following keywords:-

```
*substructure generate, type=z1, recovery matrix=yes, mass matrix=yes,
library=l-knuckle, overwrite
*retained nodal dofs, sorted=no
retained-nodes, 1,6
```

Each component mesh was fixed at the retained degrees of freedom for the generation of the substructure. In each case the retained degrees of freedom were those of the nodes at the centre of the bushes and joints defining the connectivity between components. Each of these nodes was then attached to the component mesh by means of kinematic couplings. Any, or all, of the components in the suspension system can be replaced by flexible bodies within the ABAQUS analysis as shown in Figure 11.

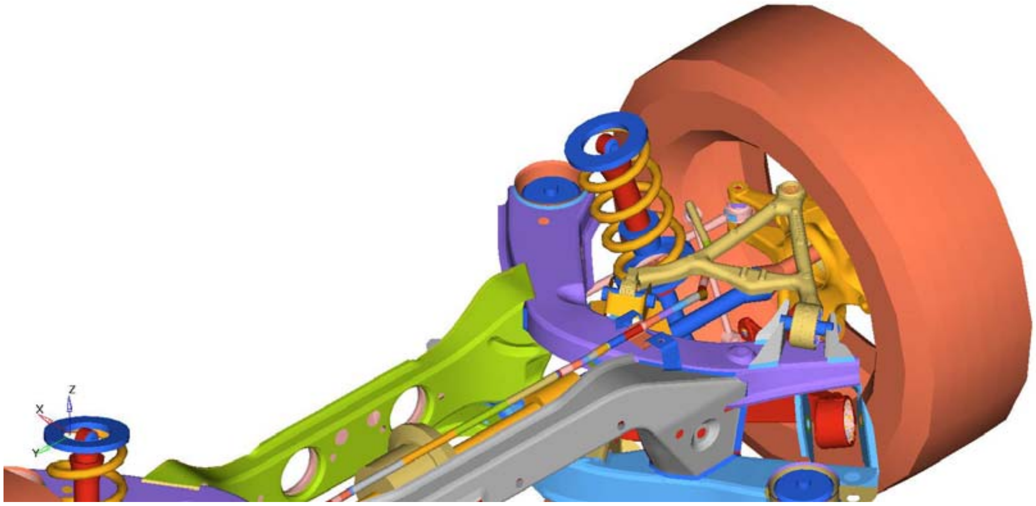



**Figure 11: ABAQUS substructures incorporated into MotionView Model**

Each substructure was then included in the global analysis model as a flexible body replacing the rigid body which existed in the original model using the following ABAQUS keywords:-

```
*ELEMENT, TYPE=z1, ELSET="l-knuckle", FILE=l-knuckle
 304, 9000088, 9000062, 9000072, 9000058
*SUBSTRUCTURE PROPERTY, ELSET="l-knuckle"
```

Once the rigid bodies had been replaced by the flexible bodies listed above the system level model was run through the ABAQUS solver for the static vertical and the fore / aft longitudinal loadcases once more.

The resulting load versus displacement curve for the model containing flexible bodies under the static vertical loadcase is shown in Figure 12. The compliance of the components has made a significant difference to the stiffness of the system.

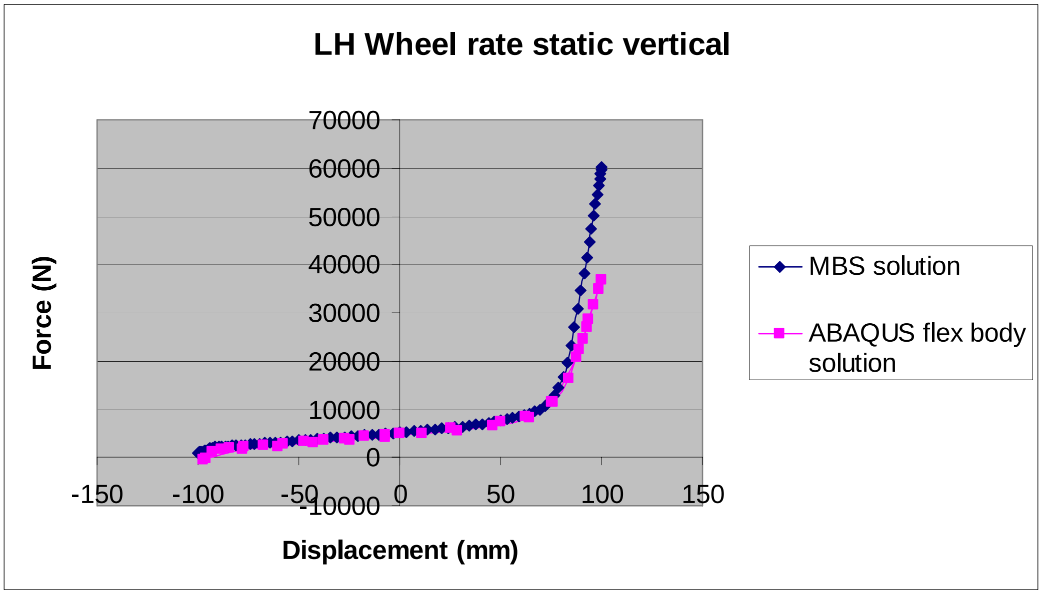



**Figure 12: Comparison of results for vertical loadcase**

ABAQUS allows recovery of stresses in each of the substructures, enabling the analyst to perform System Level stress and fatigue life assessments of components. Postprocessing in MotionView allows the analyst to examine the component stresses in relation to the system behaviour as shown in Figure 13, and for more detailed stress and fatigue results ABAQUS/Viewer would be used as shown in Figure 14.

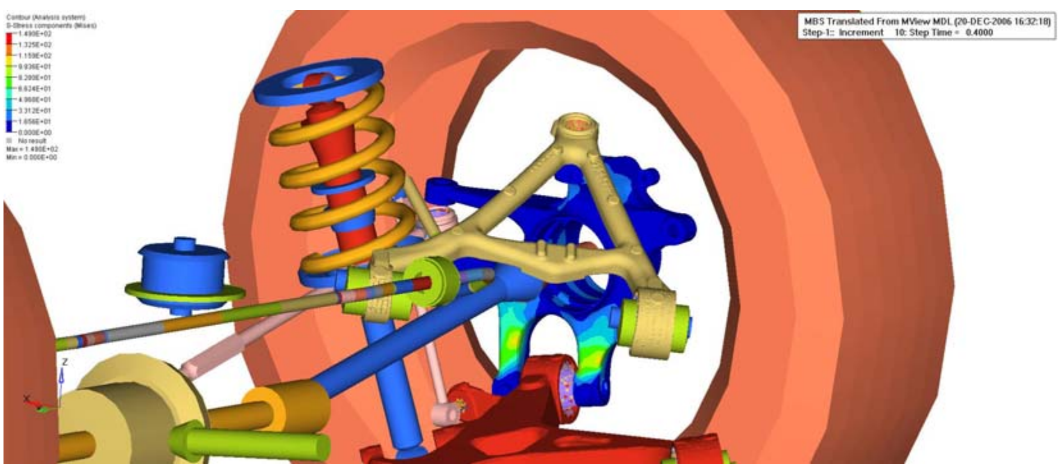



**Figure 13: Knuckle stresses post-processed using MotionView**

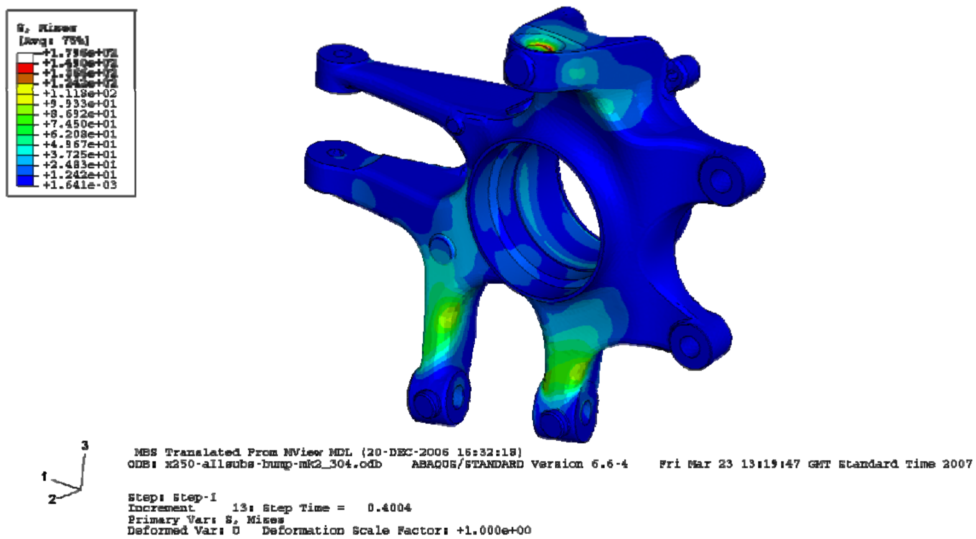



**Figure 14: Knuckle stresses post-processed using ABAQUS/Viewer**

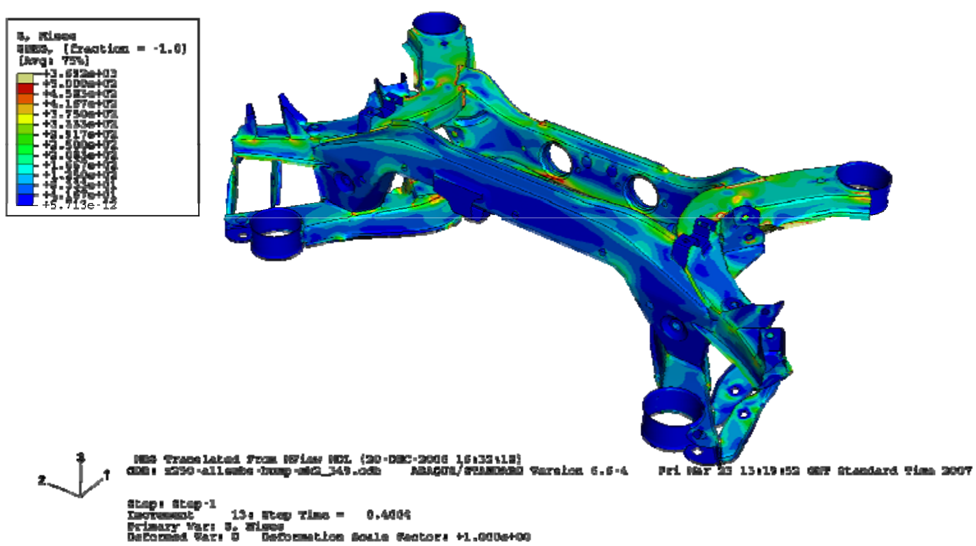



**Figure 15: Subframe stress distribution**

For ultimate strength assessments of components full nonlinear FE models including material plasticity can be included in the system model.

## 7. Conclusions

- It was demonstrated that it is possible to model the system using a combination of ABAQUS and MotionView.

- The inclusion of component compliance in the model in the form of linear substructures or fully nonlinear meshes has a significant effect on the system stiffness characteristics.

- ABAQUS can produce linear stresses at System and Component level for both strength and fatigue assessment.

- ABAQUS can produce nonlinear stresses at Component level for ultimate strength assessment.

- ABAQUS is capable of producing a solution which includes any combination of rigid and flexible bodies connected by joints having linear or nonlinear stiffness at both System and Component level.

- Jaguar is now working to develop this methodology into a production process.

## 8. References


1. Boon, D., P. Randle, and C. J. Davies Taylor, “The System Level Integrity study of the Jaguar S-Type rear suspension using an integrated FEA and MBS Technique” NAFEMS World Congress, Vancouver, 2007.