System Level Durability Engineering in CAE

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ABSTRACT

This paper will discuss the vehicle chassis top down design approach that includes the non-linearity and sub-system interactions such as tire and road, (left and right) interaction between two or more parts connected by bushings, springs, bolts, stabilizer-bar, etc…

The proposed method called "sub-system analysis method" would allow for the inclusion of realistic boundary conditions and proper load simulation, and it would provide the ability to visualize and evaluate dynamic structural phenomena and complex component interaction. This approach would also facilitate the evaluation of design changes that may affect load propagation and/or load magnitude.
All of the advantages of the sub-system analysis method mentioned above would allow for a greater understanding of the chassis sub-system as a whole and help correctly identify the design requirements needed for the individual components that make up such chassis sub-systems. This approach is of a holistic one and it is unified in a sense that it lends itself to system identification and optimization as a whole.

Background

Traditionally, component analysis in automotive structures has been utilized for sizing of the automotive components. Engineers are exposed to such methods from their earliest exposure to design so that a component could withstand specific loads with simple but not realistic constraints.

To explore this, a simple example is being drawn out:

The cantilever beam- fixed at one end and point-loaded at the other end. Undergraduate engineering students learn very early to solve for the equation of deflection, $dx = PL^3/3EI$, and the first or second year graduate student learns to compute its stresses. He/She will be able to go beyond the elastic yield analysis and into the limit of its yield capabilities with plastic flow, and /or simpler limit analysis.

Taking the same approach with automotive components such as control arms, stabilizer bars, shocks, or springs, the engineer would generalize the learning as it is mentioned in the above example and calculate stresses of such a component by imposing some boundary conditions. Perhaps one would take it to the next step of requesting static loads at all attachment points of this structure. In either case, this traditional approach over-simplifies the system by over-constraining it and using static loads, when in reality these loads are highly dynamic in nature.

It should be readily apparent to an engineer that most structural components they are required to evaluate, are not bounded by some simple boundary conditions, nor statically loaded. Real life components such as those in the automotive structures are loaded dynamically, subjected to inertia, connected to other components via bolts or welds or rivets or bushings, and their behavior is dependent on the location, strength, and orientation of the components to which they are attached. They are not in general 'simple' or 'linear'.

A new suggested approach for chassis durability analysis, which is more complex than the traditional methods mentioned above, is to look at the interactions among all the components (chassis links) in the suspension sub-system or even within a component that is attached to bushings or bolts, etc. With this method, the boundary conditions for each chassis link are modeled in their natural state- modeling the bushings, joints, springs, shocks, bolts and welds. In other words, the traditional engineering constraints applied to individual components are not necessary with this approach.

The dynamic loads are modeled naturally in this systematic approach- the loads come from contacts and impact to and from the road. The system model distributes these loads among the individual components within the system just as the physical vehicle and the sub-system distribute them.

In addition, the inclusion of non-linear geometry in the transient state of affairs would incur natural and realistic stresses than the traditional approach is capable of producing.

Advantages of the System Approach

The system, or top-down, FE approach allows the engineer to thoroughly investigate what is required. This method helps the engineer to understand and visualize the contribution of the components to the system addition, root cause for a particular problem, interaction of components within the system and the dynamics of the system as a whole. It is also easier to assess the competitive systems against one another, whether it is weight or function and/or cost consideration.

With the system analysis approach, the engineer is able to look at the loads from a dynamics perspective. It is possible to obtain the critical forces and moments that may be biased toward a particular component within the system. In this regard, the advantage of the system approach is that it will allow the engineer to re-configure the components within the system so that the loads are distributed more evenly among the components. For example, if a control arm in a suspension system is carrying 80% of the critical load for the system, it is possible that the kinematics of the system is not properly balanced. In this case, it may be possible to reduce the load in the control arm by re-sizing one or to re-look at introducing an extra component into the system, such as the stabilizer bar. By allowing the introduction of component design changes that will affect the load propagation within the system, the engineer could trade-off stiffness or strength amongst the components to manage the loads more effectively.

The application of natural boundary conditions in this proposed method helps the engineer to avoid artificially constrained components, and it enhances CAE's compatibility with vehicle test procedures.

The inclusion of non-linear material properties is another important factor to be considered when discussing the advantages of system analysis methodology. By eliminating the need to use linear material models, the engineer is reducing the potential for errors and unnecessary approximations into the modeling and analysis.

The need to select one or a few worst-case scenarios can be eliminated, thus reducing uncertainty in the analysis.

The advantages to using system analysis methods in conjunction with or as a substitute for more traditional component analysis methods are numerous. However, maybe the most convincing argument for using this methodology may be that the elimination of over-simplified boundary conditions and the inclusion of more advanced load management techniques will help eliminate over-engineered components, thus creating better optimized systems and reducing weight and cost.

It is also important to re-look at this approach from the modularity viewpoint. A well-balanced system could also be re-usable and re-scalable to adjust for loading and sizing considerations.

Limitations of the System Approach

There are however some issues with this methodology. These issues are looked at below.

Few engineers have the experience to apply non-linear systems analysis techniques without training- the CAE knowledge base is underdeveloped for this methodology.

There can be a significant time penalty for this type of analysis. Although this may not be a big issue with bigger manufacturers who can afford the financial costs associated with the training and timing.

A resource utilization study would be required to effectively introduce this method into a product development process that is primarily dependent upon linear-static methods.

There may be difficulties associated with restructuring an organization to deal with this type of methodology. This one is big with larger manufacturers who are 'settled' their organization and it becomes 'core-rigidity' fighting against the changes that required setting this into a pace.

Traditional accounting practices, which lend themselves to component engineering methods, may need to be re-configured for the systems approach. In the traditional method, when an engineer releases a component, he/she is responsible for the weight/cost of that component. If the system approach is to be used, the accounting procedures may need to be adjusted to account for balancing the weight/cost of the system as a whole, not just the individual component. This is also a big issue when components are outsourced to several smaller tiered companies who would be affected by the new 're-financing' associated with theses methods.

Modeling Approach

The proposed method for chassis system durability analysis begins with the initial concepts for the architecture of the front and rear suspension sub-systems. A simple FE model is created using either rigid or flexible beam elements to represent the individual components of the system. These beam elements are created to simply model the physical and kinematics properties of each component, and their connections to each other are modeled using FE springs, dampers, joints, and nodal rigid bodies. All bushings and elastomers are modeled using realistic non-linear material characteristics.

Once this simple FE system model is completed and validated, each of its beam model components can be replaced with detailed FE shell or solid models so that their stresses and strains can be accurately simulated. This detailed system model can produce accurate kinematics and component deformations, stresses, and strains using real, transient loads that are either measured directly from vehicle tests or predicted based on tire-to-road contact and impact interactions.

Analysis

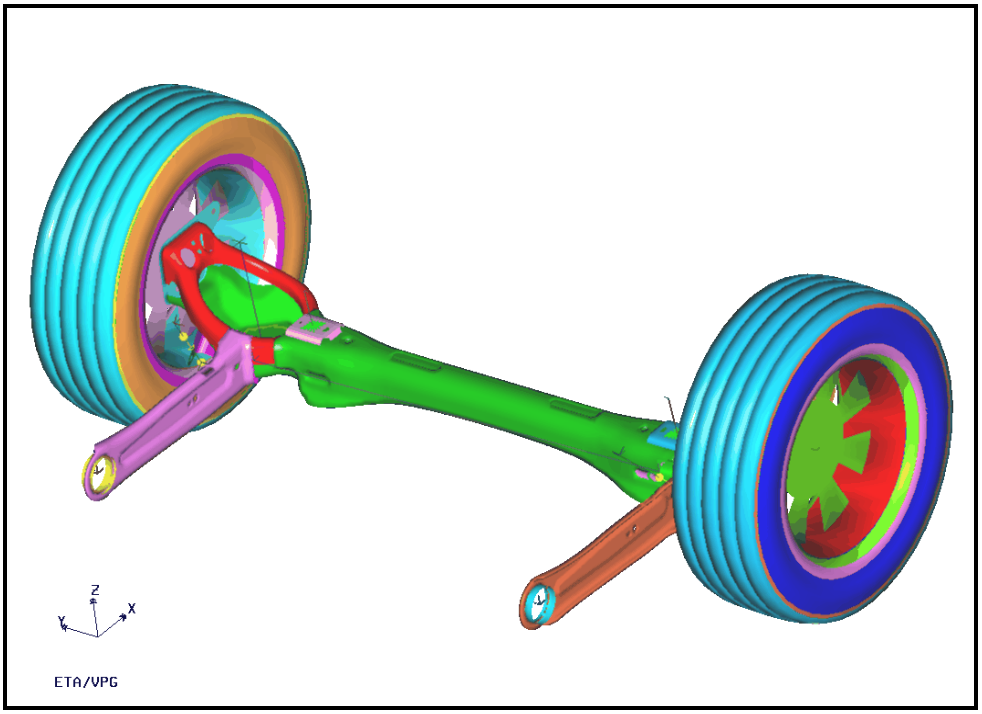
Of primary importance to this dynamic analysis is that the system model must be in compliance with the kinematic motion of the physical system that it represents. If the kinematics of this system are not correct, then the displacements, deformations, and load propagation will not be correct. These errors would invalidate any stress or strain results obtained from the simulation.

It is also considered extremely important to use accurate, non-linear material models for all elastomer bushings, dampers, and structural components in the system model. This is necessary to ensure that the stress and strain results are reasonable.

For stress calculations, it is possible to use ultimate strength criteria to evaluate component performance instead of yield criteria, since the non-linear structural material models accurately represent material behavior beyond the yield limit.

Examples

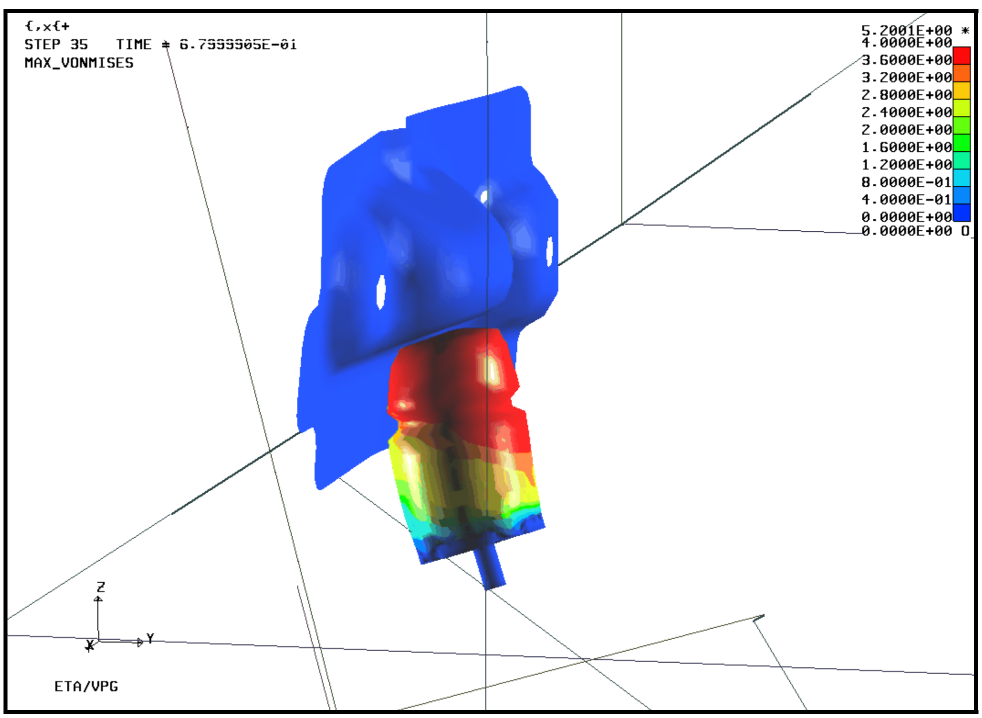
Twist Beam Rear Suspension



The twist beam rear suspension sub-system often found in mini-vans, station wagons, and car-based SUV's is a classic example of the need for system-based durability analysis. This suspension is comprised of two trailing arms welded to a flexible cross rail that is usually an open section sheet metal component. The springs are connected to the cross rail via spring pockets welded to each side of the cross rail, while the ride dampers and Panhard bar are attached via bushings. For most types of durability and vehicle handling events in which the loads transmitted to each wheel are not symmetrical, the functionality of this suspension is dependent upon the connection of the left and right trailing arms to the cross rail and the flexibility of the cross rail.

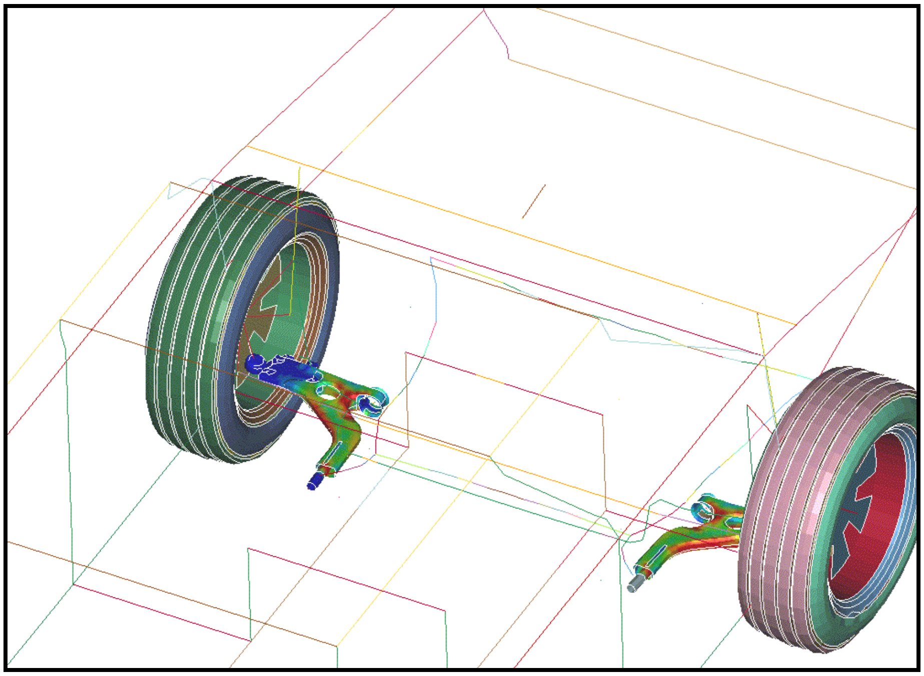
As mentioned previously, traditional component durability analysis requires the availability of loads at all hard points for the component, or at least the critical loads and appropriate boundary conditions. Since most of the individual components of this suspension system are solidly attached to each other via welds, it is necessary to include each component in the durability analysis. Also, the complexity of our system makes it difficult to define reasonable constraints, so it is desirable to provide load inputs at all the hard points for the system. Typically, to obtain these important loads, the wheel center loads would be measured from a prototype "mule" vehicle running over the durability test track, and these measured loads would then be fed into a rigid body vehicle model using software such as ADAMS to obtain the loads at all hard points. However, the complexity of the flexible sheet metal cross rail makes it very difficult, if not impossible, for ADAMS to accurately simulate the kinematic properties of motion for this suspension system. This means that ADAMS will not be able to predict accurate loads. This in turn leads to an inability for traditional analysis methods to predict the durability of this suspension system.

Jounce Bumper Analysis



Suspension jounce and rebound bumpers, usually made from rubber or urethane, are another prime candidate for the FE system analysis method. The material properties of jounce and rebound bumpers cannot be accurately represented by traditional linear static analysis, and they are subjected to highly dynamic loading conditions. The simplified FE model above shows an example of this type of analysis. It uses flexible beam elements to represent the suspension components, solid elements to represent the bumper, and shell elements to represent the portion of the body to which the bumper makes contact. A contact algorithm is used to transfer loads from the body to the bumper, and the bumper is assigned nonlinear rubber material properties.

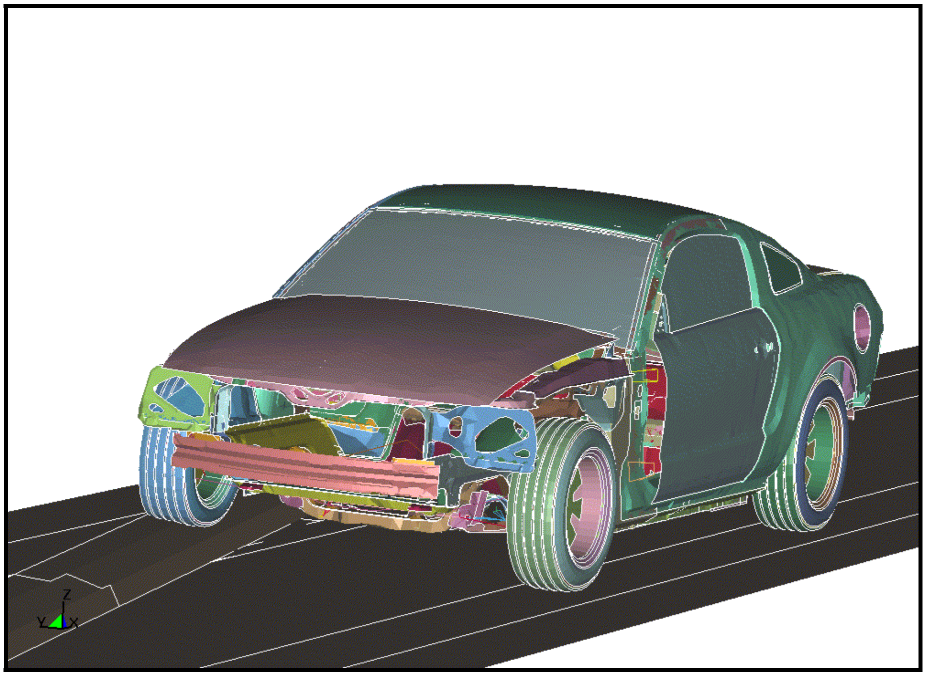
<u>Durability Analysis of Destructive Test Events</u>



Potentially destructive test events such as Ford's Slide for Life event are particularly difficult to simulate using traditional CAE durability methods. Linear static CAE is not a reasonable method to use when simulating this type of event since the critical suspension components are at risk of exceeding their ultimate strength. Nonlinear static CAE is also unacceptable for two major reasons: First, the loads for this type of event are highly dynamic in nature. Second, the orientation of the suspension components may be approaching full jounce or full rebound when the critical loads are applied- this can greatly affect the load propagation path of the system. Since this type of physical testing is not often completed until late in the design cycle of a vehicle, actual loads may not be available until it is nearly too late to redesign a component.

Using the proposed system durability method for this type of destructive test events is ideal. The nonlinear transient CAE environment is the most reasonable tool for capturing the nonlinear material behavior of the critical suspension components and the kinematic behavior of the suspension system. And tire-road contact interactions are quite capable of predicting the loads for this type of event, which would allow the engineer to obtain the critical loads at a much earlier stage in the development process.

Full Vehicle Durability Testing



The proposed FE system analysis method is an excellent tool for predicting the effect of design changes on the structural behavior of a full vehicle model for individual durability events. Changing such parameters as shock valving, stabilizer bar diameter, weld patterns, or individual component design can have a significant effect on the durability performance of a vehicle's chassis or body structure. An A-to-B comparative analysis of the full vehicle model for one or two critical events is an effective way to predict changes in the vehicle durability performance.

Recommendations

This novel approach will save weight and cost in vehicle chassis systems, and it has a much closer tie with analysis procedures used in vehicle dynamics, NVH, and crash/safety attributes. It is recommended to adopt the systems engineering approach in durability analysis.

Conclusions

The proposed sub-system analysis method would allow for the inclusion of realistic boundary conditions and proper load simulation, and it would provide the ability to visualize and evaluate dynamic structural phenomena and complex component interaction. This approach would also facilitate the evaluation of design changes that may affect load propagation and/or load magnitude. All of the advantages of the sub-system analysis method mentioned above would allow for a greater understanding of the chassis sub-system as a whole and help to correctly identify the design requirements needed for the individual components that make up such chassis sub-systems. This approach is of a holistic one and it is unified in a sense that it lends itself to system identification and optimization as a whole.