Multibody Dynamics: **Rigid and Flexible** Methods

Choosing the right simulation method for dynamic assemblies doesn't have to be risky.

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Assuming that parts of a dynamic assembly act as purely rigid bodies is like assuming that the earth is flat: The truth won't be known until the assumptions are challenged. There is always an element of risk involved with challenging the status quo, but, luckily, using ANSYS Flexible Dynamics technology is less risky than falling off the edge of the earth.

When challenged with prototyping a new mechanical assembly, most engineering departments turn to a rigid dynamics software program, and for good reason. The advantages of simulating an assembly as a collection of rigid parts connected by joints are undeniable: It is much faster, more design ideas can be investigated in the same amount of time, and a product development team can be more productive. But this time savings comes at the expense of insight, and, sometimes, what isn't known about a new design can come back to haunt a well-meaning team. Unknowns can include:

- Will our assembly survive the first cycle, or will one of the parts buckle, break or deform so severely that the system locks up?
- Will the assembly vibrate so much that nobody will buy it?
- Will our warranty department have to deal with the big, expensive problem of material fatigue?
- Is this a huge career-limiting mistake that our design team can't collectively afford to make?

To gain the insight required to answer the above questions (and many others), part and joint flexibility needs to be included in the simulation.

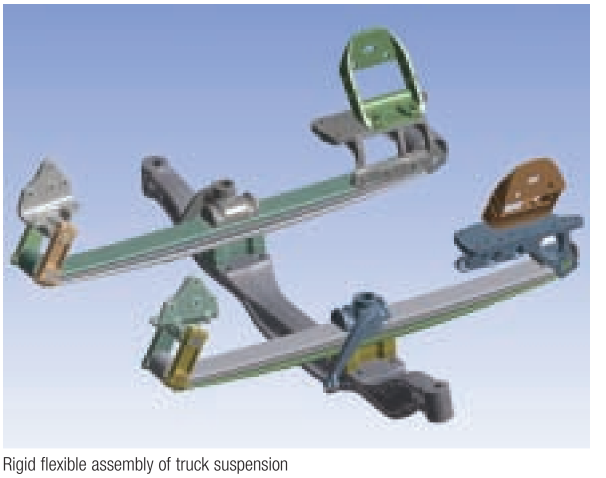
Rigid dynamics simulation can demonstrate how quickly an assembly's parts are moving, how fast the parts are accelerating or decelerating, and what the forces are at the joints between the parts at any time during the dynamic transient. The total solution time for many rigid dynamics simulations is often measured in seconds, because the number of degrees of freedom is low and all parts are assumed to be infinitely stiff. This fast solve time makes rigid dynamics extremely attractive to those with looming deadlines.

On the other hand, flexible dynamics provides these same part velocities and acceleration data, plus complete deformation, stress and strain data. While this is the information needed to really understand the design, total solution time is longer. Because of this, relying on flexible dynamics in the early stages of design development has never been commercially viable.

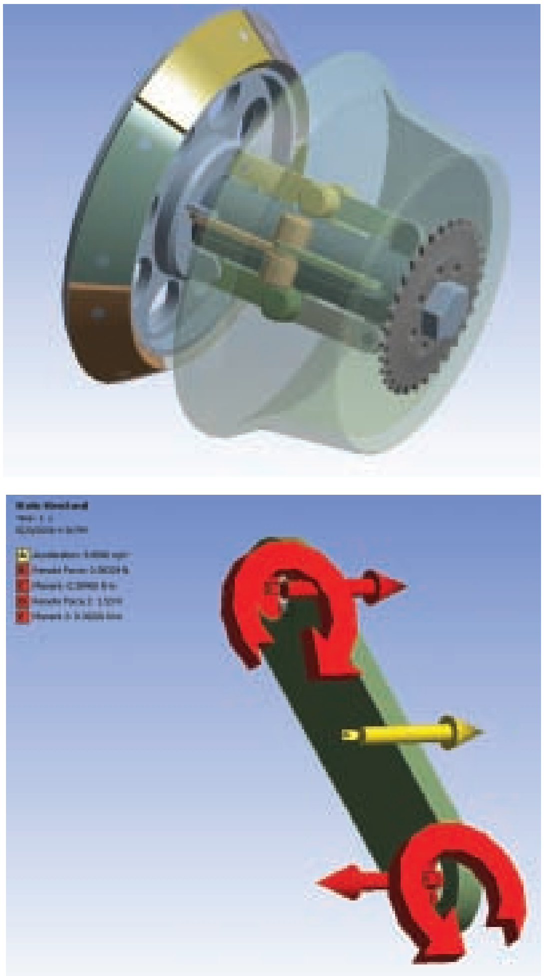
Smart engineers have been trying to combine the benefits of the fast solve times of rigid dynamics with the complete performance information that comes only from running a flexible FEA simulation. Several methods have been developed over the past 20 years with varying degrees of success.

Rigid Dynamics Loads to Static Simulation Method

The most basic and most widely used method of combining the benefits of rigid dynamics with those gained by using flexible system modeling is to transfer loads from a rigid dynamics run and use those loads on a structurally static system. This marriage of dissimilar technologies has some pros and cons.



Rigid flexible assembly of truck suspension



Load transfer from rigid dynamics simulation model (top) to static structural model (bottom)

Pro

- Dynamic loading on parts is captured accurately, so there is no need to estimate how far to scale up a static load to approximate a dynamic load. This widely practiced approach is sometimes conservative, and sometimes it is not.
- Static structural simulations are some of the most efficient FEA-based solutions that accurately model flexibility.

Con

- The process forces the engineer to choose the transient time points at which to transfer to the structural static simulation.
- Using this method, it is extremely easy to overlook the worst-case loading combinations for all but the simplest assemblies, so the wise engineer using this method applies a very large margin of safety when relying on results.

Craig–Bampton Method

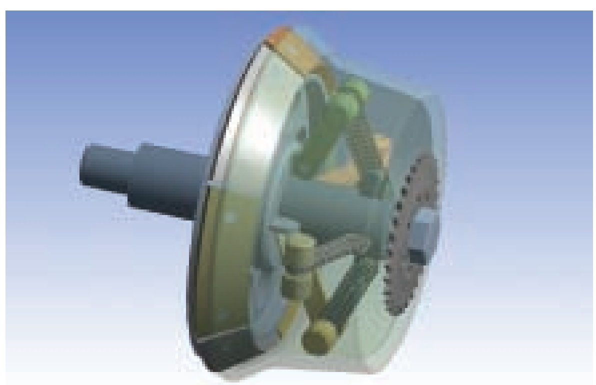
A more sophisticated technique of combining rigid and flexible benefits is the Craig–Bampton method. Using this technique, the flexibility of a system is captured via a model–dynamic solution. The mode shapes and frequencies, or eigenvalues and eigenvectors, are then fed to the rigid dynamics model so that part flexibility is accounted for during a transient. While less of a forced marriage than the previous technique, the Craig–Bampton method is also blessed with pronounced strengths and weaknesses.

Pro

- A modal analysis is one of the most efficient of all dynamic simulations.
- The rigid dynamics reduced-order model gains flexibility at the lowest computational cost, and this has made the method popular with those requiring additional simulation fidelity.

Con

- The method is inherently limited to linear responses due to its reliance on modal analysis results. This means it is not capable of accurately modeling:
  - Anything other than linear materials: no material plasticity, hyperelasticity or viscoelasticity is possible
  - Real-world nonlinear contact, with or without friction and or changing contact status
  - Large deflection
- The method is complicated and consumes much engineering time. Little has been done to automate, or at least streamline, the linking of the modal results with the rigid reduced-order model, likely because of the inherent limitations of the Craig–Bampton method itself.
- Design iterations are painful. Because there is significant manual interaction and data reading, writing and translating, it is nearly impossible to keep up with changes to a 3-D CAD model.



Predominantly rigid assembly with selective flexibility added to presumed weak links

- Financial cost is typically very high because two expensive programs must be used, often from different software companies, and these programs are typically run by two different engineers who have been trained on one system but not both.

Rigid and Flexible Dynamics Method

The most modern method of combining the benefits of rigid and flexible dynamics is to create a general-purpose software system that can be used to model full-rigid dynamics with reduced-order models or a full-flexible dynamics assembly, or any combination thereof. For this method, an engineer uses reduced-order models in pure rigid dynamics and is able to keep pace with rapidly evolving design proposals because of the fast solve times afforded by the explicit solver. To gain further insight, the rigid model is modified with the addition of flexible component(s), and a flexible or rigid and flexible system is analyzed.

While some software suppliers have pieces of the rigid and flexible dynamics method, only ANSYS offers this type of system — and it has been in commercial use for nearly two years. To consummate the relationship between rigid and flexible dynamics, the ANSYS Rigid Dynamics product is used as an add-on to ANSYS Structural, ANSYS Mechanical or ANSYS Multiphysics software.

Pro

- A single geometry model is used for both rigid and flexible dynamics. This model is typically an easy-to-visualize 3-D model from ANSYS DesignModeler software or a CAD system.
- The same user interface is employed for both rigid and flexible dynamics, so users of one have very little to learn to be able to run the other.
- Models can be converted from rigid to flexible in minutes in as few as four mouse clicks.
- Design iterations are easy. Change the CAD model, click update, and resolve the rigid, rigid and flexible, or full-flexible model.
- The limitations of the Craig–Bampton method do not apply: that is, you are able to model nonlinear contact as well as material nonlinearities at the same time, if desired.

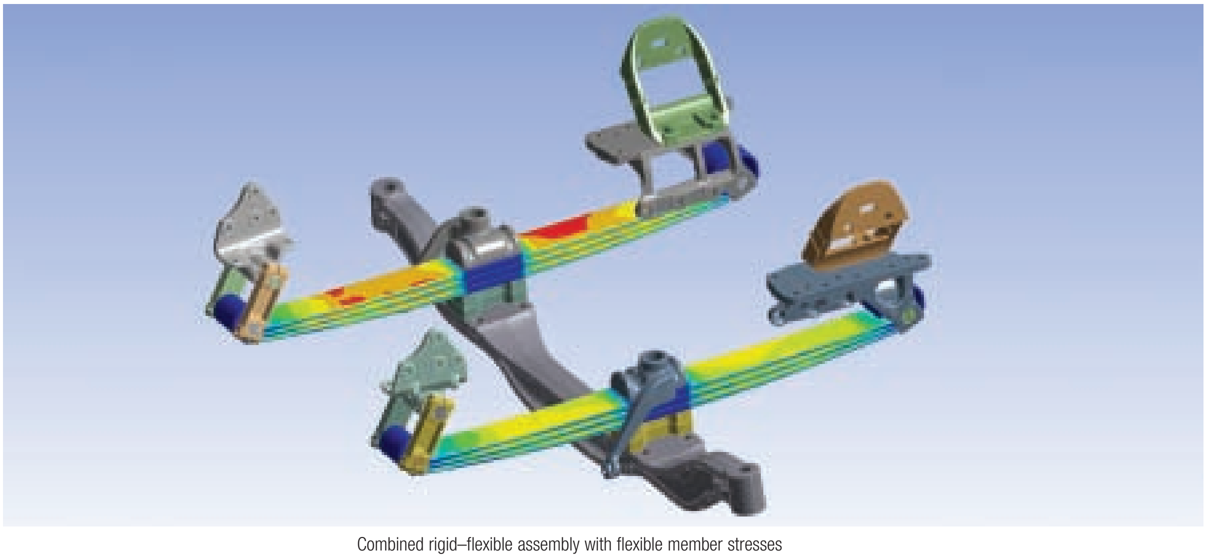
Con

- While creating a rigid and flexible model with contact and material nonlinearities is easy to do, sometimes these nonlinearities cause conflicting convergence targets for the solver. Overcoming these conflicts and getting a converged solution can require some expertise in nonlinear simulations.
- Solver requirements are higher than either of the previous two methods, which has always been the nature of a full-nonlinear transient dynamic simulation. However, new time integration schemes and parallel processing or high-performance computing can be very effective at reducing CPU demands.

Because some brave soul challenged the assumption that the earth was flat, falling off the edge of the world is less of a concern than it was centuries ago. As the state of the art in engineering simulation software continues to improve, and more engineers begin to use rigid and flexible dynamics during product development, failed product designs will become less of a concern as well. ■

References

Pilz, S., "Multibody Dynamics: Rigid, Flexible and Everything in Between," *ANSYS Advantage*, Volume 2, Issue 2, 2008, pp. 20–23.



Combined rigid–flexible assembly with flexible member stresses