MDI/ADAMS-MSC/NASTRAN INTEGRATION USING COMPONENT MODE SYNTHESIS

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Abstract

Improvements continue to be made in the area of MSC/NASTRAN-MDI/ADAMS coupling, with the status of the jointly developed DMAP/translator-based interface described herein. Although the current implementation still relies on a combined DMAP alter and an external utility, the results of this phase of development include a number of enhancements which greatly improve ease-of-use, performance, and results quality. This paper briefly describes the motivation for the current work, outlines improvements made to the component modes-based interface, and concludes with an example of the new interface's use in automotive vehicle design.

1. Introduction

Practical design and analysis of multi-body, large displacement/small strain mechanical systems has, in the past, been difficult due to the limitations imposed by commercial analysis software. No single software package was capable of "doing it all", and the resulting approximations and tedium of translating data among various packages, typically NASTRAN and ADAMS, served as a barrier to those seeking to perform tasks such as incorporation of flexible body information into MDI/ADAMS, or generation of more accurate component dynamic loads for MSC/NASTRAN.

Such conditions led to the use of necessary, though not always adequate, approximations by practicing engineers: the use of Guyan reduction followed by a forced mass lumping to model flexible components in MDI/ADAMS, and the "guesstimation" of critical dynamic loading conditions in MSC/NASTRAN. The recent introduction of ADAMS/Flex has overcome many of the problems associated with analysis of flexible multibody dynamics by employing flexible elements whose component modes-based data is provided by finite element codes such as MSC/NASTRAN.

Though limited, a DMAP-based interface from MSC/NASTRAN to MDI/ADAMS has been available for a couple of years. The DMAP portion of the "interface" provided punch file output for quantities such as physical mass, modal mass and stiffness, component modes, etc., for components which had first been built as superelement models. An external translator utility completed the process, reading the punch file, modifying, and subsequently writing the data into a form which could be read as input to MDI/ADAMS. Such an approach suffered from the usual limitations:

- small models only could be used due to excessive punch file sizes
- frequent user error since features such as units and multiple coordinate systems were not treated consistently

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· inaccurate results due to numerical truncation/round-off
· tedious; only one flexible component at a time could be analyzed and imported

All of the above limitations have been overcome by recent improvements to the interface. Though the approach discussed in this paper is still DMAP/translator based, demand for its new capabilities has been great, as it incorporates a number of advances which provide:

· smaller intermediate file sizes as a result of output2 formats
· improved accuracy through machine precision output
· support for multiple superelements and coordinate systems
· DMAP alter can be used in any MSC/NASTRAN modal solution sequence
· improved, more robust MDI-written MSC2MNF translator, employing the new MNF toolkit
· optional component modes orthogonalization within MSC/NASTRAN
· consistent handling of units, either with or without WTMASS

We'll conclude with a recent example from industry, and outline some of the planned future work.

2. MDI and ADAMS - An Overview

2.1 Background

In 1977 a University of Michigan engineering professor and two of his graduate students founded the company Mechanical Dynamics. Two years later, the company introduced ADAMS, the first commercial 3D mechanical system simulation computer program. ADAMS immediately built a strong user base among manufacturers of complex mechanical systems and MDI remains a leader in the field of mechanical system simulation software. Today, as an example of its success, every automaker in the world uses ADAMS.

2.2 Analysis of multiple rigid body systems

ADAMS, which is an acronym for Automatic Dynamic Analysis of Mechanical Systems, is a software system consisting of a number of integrated programs that aid an analyst in performing three-dimensional kinematic, static, quasi-static, or dynamic analysis of mechanical systems. ADAMS is also capable of linearizing the system at a user specified configuration, such as a static equilibrium and computing linear state matrices or system modes. The mechanical system may comprise any number of bodies that are interconnected by joints allowing for arbitrarily large relative rotational and translational motions and that are subjected to any variety of internal or external forces or prescribed motions.

There is no restriction as to topological interconnection of bodies. Thus, chain, tree, cluster, closed-loop, and multiple closed-loop configurations are treated in an identical fashion. The system identifies redundant constraints and eliminates them automatically. The input to the program consists of part geometry and mass properties, reference frame definitions, body types, body compliance descriptions, topological and analytical constraints, force and motion actuator and sensor models, elastic restraints and connectors, control laws and graphic entities.

Typical ADAMS output includes the time-dependent positions, velocities, accelerations, forces and values of user-defined variables. This output can take the form of tabulated data, two-dimensional plots, still-frame system configurations, superimposed images of the system at various instants in time, and continuous graphic animations of system motion.

2.3 Flexible Multibody Dynamics

Originally ADAMS only supported a single body type, a rigid body with 3 translational and 3 rotational degrees of freedom. As users built increasingly complex models with ever greater expectations for correlation with experimental data ADAMS' inability to model flexible bodies became unacceptable. MDI's initial solution was a system which translated Guyan reduced mass and stiffness matrices from a FEM program to rigid bodies, using the master DOFs and a single linear force element to represent the stiffness matrix. A complete representation of a condensed mass matrix using lumped masses was not possible and the results were frequently inadequate. Due to an unfriendly user interface this product never became popular.

In 1994, MDI embarked on an the development of a another type of body, a flexible body,

allowing the user to model small, linear deformation of a body undergoing large global motion. Deformations in this flexible body are a linear combination of mode shapes obtained either from a FEM program or experimental modal analysis. The flexible body technology has reached maturity in a product called ADAMS/Flex. It is now available with a second generation interface to MSC/NASTRAN which takes advantage of its Component Mode Synthesis capabilities. The details of this interface are explained further in the next sections.

2.4 Multibody dynamics and FEM

Interfacing a Finite Element program like NASTRAN with a Large Displacement Multibody Dynamics program like ADAMS achieves two very desirable goals:

· ADAMS mechanical system model fidelity may be dramatically enhanced when component flexibility is accounted for, and:

· Realistic loads for an MSC/NASTRAN analyses may be obtained in a natural way by incorporating an MSC/NASTRAN FEM model of a component in an ADAMS mechanical system model and simulating in-service events.

The first goal is being realized by many of the customers of MDI and MSC. Elusive system characteristics are being captured by introducing flexibility in models of vehicles, engines, spacecraft, robots, aircraft, etc.

MSC/NASTRAN can take advantage of an ADAMS solution in a variety of ways. Applied loads and body forces exported from ADAMS can be used directly. Applied loads can be used in conjunction with inertia relief in lieu of body forces. Finally, work is underway to enable data recovery restarts in MSC/NASTRAN; for example, going directly to a stress recovery solution using modal amplitude information from ADAMS.

British Leyland is an example of a customer who is obtaining impressive results by combining ADAMS and MSC/NASTRAN in this way. A case study summary from British Leyland is presented in section 6.

3. Component Modes in MSC/NASTRAN

A brief review of dynamic reduction techniques in MSC/NASTRAN will provide the necessary background for the discussions that follow. This section will present Guyan Reduction, Generalized Dynamic Reduction (GDR) and Component Modal Synthesis (CMS). These reduction techniques can most easily be described using the set notation of MSC/NASTRAN [QRG-70.5].

We'll begin our discussion with the *f*-set, the degrees of freedom which are unconstrained (free) in dynamic analysis. These are what remain of the *g*-set (all of the structural, or grid, degrees of freedom) after removal of the *s*-set (degrees of freedom eliminated by single point constraints) and the *m*-set (degrees of freedom eliminated by multipoint constraints.) The *f*-set equations of dynamic equilibrium are the familiar

$$M_{ff}\ddot{u}_f + B_{ff}\dot{u}_f + K_{ff}u_f = P_f \qquad (1)$$

In dynamic analysis, we often have more finite element data than is necessary to obtain adequate estimates of dynamic behavior. (We may have, for example, a model originally developed for detailed stress analysis.) We may reduce our solution set by partitioning the *f*-set into the *a* (analysis)-set and the *o*-set (omitted degrees of freedom):

$$\begin{matrix} M_{aa} & M_{ao} \\ M_{oa} & M_{oo} \end{matrix} \begin{Bmatrix} \ddot{u}_a \\ \ddot{u}_o \end{Bmatrix} + \begin{matrix} B_{aa} & B_{ao} \\ B_{oa} & B_{oo} \end{matrix} \begin{Bmatrix} \dot{u}_a \\ \dot{u}_o \end{Bmatrix} + \begin{matrix} K_{aa} & K_{ao} \\ K_{oa} & K_{oo} \end{matrix} \begin{Bmatrix} u_a \\ u_o \end{Bmatrix} = \begin{Bmatrix} P_a \\ P_o \end{Bmatrix} \qquad (2)$$

Though equally valid for non-superelement (residual structure only) models, eq. (2) is most familiar in the superelement context, with the *a*-set frequently referred to as the exterior, or boundary, degrees of freedom and the *o*-set, the interior.

For statics only, we have two sets of equations in two unknown variable sets (*a* and *o*), allowing a unique (uncoupled) solution for each. Solving for the lower partition of eq. (2) without mass and damping leads to:

$$u_o = -K_{oo}^{-1} K_{oa} u_a + K_{oo}^{-1} P_o \qquad (3)$$

or,

$$u_o = G_{oa} u_a + u_o^o \qquad (4)$$

Note that the solution for the u_o interior degrees of freedom consists of two parts: the $G_{oa} u_a$ response to boundary displacements, and the u_o^o, or fixed-boundary solution to interior loading. The static condensation results in eq. (4) suggest a framework for approximating the coupled dynamic equations in (2).

A consistent way of presenting the various approximate dynamic reduction techniques is through the use of symmetric transformations [DNH-97]. To paraphrase, we can introduce the transformation:

$$\{u_f\} = \begin{matrix} u_a \\ u_o \end{matrix} = \begin{matrix} I_{aa} & o \\ G_{oa} & I_{oo} \end{matrix} \begin{matrix} u_a \\ u_o^o \end{matrix} \qquad (5)$$

which, of course, is just the static condensation in matrix form. Eq. (5) and its time derivatives can be used to transform eq. (2), which, ignoring damping, is:

$$\begin{matrix} M'_{aa} & M'_{ao} \\ M'_{oa} & M'_{oo} \end{matrix} \begin{matrix} \ddot{u}_a \\ \ddot{u}_o^o \end{matrix} + \begin{matrix} K_{aa} & o \\ o & K_{oo} \end{matrix} \begin{matrix} u_a \\ u_o^o \end{matrix} = \begin{matrix} P'_a \\ P_o \end{matrix} \qquad (6)$$

The resultant matrix partitions for this exact, though still mass-coupled, resultant are detailed in [DNH-97].

The advantage of eq. (6) is that the dynamic reduction techniques in MSC/NASTRAN can all be conveniently explained in terms of their corresponding u_o^o approximations.

Guyan Reduction simply assumes:

$$\ddot{u}_o = G_{oa} \ddot{u}_a \qquad (7)$$

or, $\ddot{u}_o^o \quad 0$. The resultant upper partition of eq. (6) can thus be immediately solved for the *a*-set degrees of freedom.

Generalized Dynamic Reduction, or GDR, uses approximate mode shapes to approximate the u_o^o degrees of freedom. (Experimentally-obtained mode shapes could, of course, be used just as well.) Component Modes offer a further logical extension by using the *o*-set eigenvectors to approximate u_o^o behavior [RHM-77], [MAG-77], [DNH-85]. Since the notation used for both Rayleigh-Ritz-type approximations is identical, we can simply write:

$$\begin{matrix} u_a \\ u_o \end{matrix} = \begin{matrix} I_{aa} & o \\ G_{oa} & \varphi_{oq} \end{matrix} \begin{matrix} u_a \\ u_q \end{matrix} \qquad (8)$$

Where the *q*-set has been introduced to represent generalized degrees of freedom in dynamic analysis. As has become the custom in MSC/NASTRAN, the *q*-set is included as a partition of the *a*-set, and the *t*-set partition of the *a*-set is used to more clearly identify the "total" physical degrees of freedom on the boundary, hence:

$$\begin{matrix} u'_a \\ u_o \end{matrix} = \begin{matrix} I_{tt} & o \\ G_{ot} & \varphi_{oq} \end{matrix} \begin{matrix} u_t \\ u_q \end{matrix} = [\Gamma]\{u_a\} \qquad (9)$$

where the “prime” in u'_a has been introduced simply to distinguish the previous physical boundary degrees of freedom only set from the *a*-set commonly referenced in MSC/NASTRAN. Each column of the first partition of Γ represents the component's displacements due to boundary motion and are frequently referred to as "constraint modes." The modes of the second partition are, upon proper transformation, referred to as the fixed boundary, or "component" modes.[1] Use of the coordinate transformation (9) yields a set of compact, stiffness-uncoupled, equations of *a*-set dynamic equilibrium. Since the basis vector set of (9) is linearly independent, one possible solution technique is to first orthogonalize the set and then solve the resulting uncoupled equations. The orthogonalization stage is performed as an option by the DMAP alter described in section 5.

[1] Free-free modes are allowed in component modes via *c*-set degrees of freedom. The transformation:

$\varphi_{oq} = \varphi'_{oq} - G_{oa} \begin{matrix} o \\ \varphi_c \end{matrix}$ eliminates redundant singularities.

4. Integration of component flexibilities in MDI/ADAMS

A high level goal when implementing flexible bodies in ADAMS was that a flexible body could be integrated into a mechanism in a way similar to a rigid body and interact with the mechanism through ADAMS joints and forces.

Early in the development cycle, the need for Component Mode Synthesis became evident. Attempts to model the effect of attachments to the flexible body using only component eigenvectors required an extremely large number of eigenvectors to be considered. While the ADAMS implementation of modal flexibility is general enough to accept any kind of mode shape, the MSC/NASTRAN interface has been set up to export the computationally-determined component modes. This approach is also an intuitive one and works well in the general case.

Though *c*-set degrees of freedom are provided in component modes synthesis, they've typically not been used when generating modes for input to ADAMS/Flex. (Though their use holds promise.) Since the resulting simplification yields the familiar Craig-Bampton modes, this section will refer to them as such. There have been certain challenges however:

1.) Embedded in the Craig-Bampton modes are 6 rigid body modes. Since ADAMS provides its own large displacement rigid body motion, these modes need to be removed from modal basis.

2.) The constraint modes partition are static correction modes and provide no information about the resonant frequencies of the degrees of freedom that they provide. An ADAMS user needs to have information about the frequency content contributed by a flexible body mode so that response in these frequencies may be controlled to ensure numerical integration robustness.

3.) Craig-Bampton constraint modes can not be safely disabled without imposing an unacceptable contraint effect between the boundary degrees-of-freedom.

All of these problems were eliminated by orthogonalizing the Craig-Bampton basis of modes. All modes get an associated frequency and the rigid body modes show up as zero frequency modes and can be easily disabled. A user can choose to enable or disable modes for the dynamic simulation on a mode-by-mode basis.

A detailed discussion of the implementation of flexible bodies in ADAMS is beyond the scope of this paper. We will limit ourselves to a high level discussion of how inertia, stiffness, damping and mode shapes of the flexible body are handled in ADAMS.

Inertia:

The mass matrix of a flexible body in ADAMS is not constant. As the flexible body is deformed, the center of mass shifts, and the inertia tensor changes. These effects are accounted for in ADAMS by formulating the mass matrix in terms of inertia invariants which are computed in a pre-processor. The large translational DOFs, the large rotational DOFs and the modal DOFs are coupled through this mass matrix. This is the mechanism by which spinning gives rise to deformation, etc.

Stiffness:

The generalized stiffness from the finite element analysis is diagonalized and used directly by ADAMS.

Damping:

ADAMS uses modal damping specified separately by the user as a fraction of critical damping. Damping can be specified on a mode-by-mode basis. Users are encouraged to use damping to control modal response. In other words, it is recommended that rather than disabling a mode, because it is assumed to lie outside the frequency range of interest, that the mode should instead be critically damped. This will eliminate the dynamic response of this mode while allowing ADAMS access to it to satisfy boundary conditions.

Mode shapes:

After using the mode shapes to compute the inertia invariants, the modes do not contribute in their entirety to the ADAMS simulations. Only a subset of each mode shape is passed to the ADAMS solver, the subset that corresponds to those nodes where connections have been made or where forces are being applied. This allows the solver to satisfy boundary conditions at

connections and to project the applied load on the mode shapes.

5. Current MSC/NASTRAN-MDI/ADAMS Interface

The current interface is, as stated earlier, based on a combined DMAP alter and external translator utility function. The DMAP alter provides output for the MSC/NASTRAN-generated superelement data for the flexible component, and the translator converts this output into a form suitable for MDI/ADAMS (section 5.3). The alter is available from either MDI's ftp site or MSC's web site (two versions are available, one for 69+ systems and one for 70+), while the translator is available from MDI with ADAMS/Flex.

5.1 DMAP Description

Though the DMAP can potentially provide a lot of binary output, it has been designed to be as non-intrusive as possible. That is, it can be used in any modal solution sequence, either in combination with, or without, subsequent dynamic analysis. Since it also supports multiple tip superelement models (the residual structure is excluded), it's possible, for example, to generate flexible body input for multiple components in a single MSC/NASTRAN run, continue with dynamic analysis, and perform upstream data recovery (the DMAP has not yet been extended to support multilevel trees, however.)

Since the alter is heavily commented, we'll instead highlight some of its basic functionality and its output quantities:

· OUTPUT2 has been used exclusively, allowing for either binary output (form=unformatted on the ASSIGN statement), or neutral file format (form=formatted.) (Neutral-formatted files are about double the size of binary files, and either the RCOUT2 utility, or DMAP using INPUTT2, can be used to convert to platform-specific binary files.)

· Data for multiple superelements can be output to a single file; the MSC2MNF translator will create multiple modal neutral files, one for each "part."

· Multiple coordinate systems may be used; they are resolved by a transformation to basic coordinates prior to output.

· WTMASS is factored out of all output mass quantities since units data is provided via a DTI entry named "UNITS."

· By default, the *a*-set eigenvalue problem is solved, and the resulting eigenvectors used to orthogonalize the *a*-set equations. This projection into an orthonormal space ensures transferral of diagonal mass and stiffness matrices to ADAMS/Flex. (See "Orthonormalization" in the next section.)

Output quantities for each superelement include:

· grid point data, BGPDTS
· element connectivity, GEOM2S and ECTS
· constraint data, GEOM4S
· physical mass, MJJ
· modal mass, MAA, and stiffness, KAA
· component modes, CMOD (special datablock)

The above allows a complete characterization of the mass and stiffness properties of a part in terms of its modal components (and, of course, physical mass), as well as graphical display of the part itself (via grid and element data) within ADAMS.

5.2 Notes on MSC/NASTRAN input data preparation:

Since MSC/NASTRAN's superelement capabilities are at the heart of the interface, a certain familiarity with superelement modeling is assumed. Further details can be found in the *Handbook for Superelement Analysis*, [MAG-82]. (Note: A completely new *Superelement Analysis User's Guide* is in progress, but not yet available at the time of writing.)

Rather than reiterate material more thoroughly presented elsewhere, we'll focus instead on a few topics of particular interest when using the interface.

Units:

MDI/ADAMS, unlike MSC/NASTRAN is not a dimensionless code. A DTI entry having the name "UNITS" should be supplied for this purpose. The values specified will be applied to all superelements upon translation and, if left unspecified, will default to MKS units.

WTMASS:

On a related topic, the parameter WTMASS (weight-to-mass conversion) is often used to resolve units disparities in MSC/NASTRAN. Since units data for ADAMS/Flex is now supplied by the UNITS DTI entry, WTMASS is factored out of all mass data prior to output, and units conversion accomplished by the translator. (Note: WTMASS, if present, will still be used in connection with the MSC/NASTRAN analysis.)

Multiple superelements:

This capability has undergone only limited testing. At this time it's probably safe to say that single level trees are supported, while multiple level trees (those with collectors) are not.

FIXEDB:

When generating component data for input to ADAMS/Flex, the residual structure is often more of a process requirement than an actual item of interest. Under such conditions, setting FIXEDB to -1 can save the cost of a residual structure solution and subsequent data recovery.

Superelements, miscellaneous:

The new Part Superelements, introduced in version 70 of MSC/NASTRAN, have not yet been tested in connection with the interface. Theoretically, they should work, but regrettably testing has not yet been completed at the time of writing. Also falling into this category are *c*-set degrees of freedom (which haven't yet been recommended for use in ADAMS/Flex.)

Orthonormalization:

By default, the DMAP will orthogonalize the *a*-set mass and stiffness matrices prior to output. However, the *a*-set eigenvalue extraction problem is often complicated by the presence of very high frequency basis vectors in the component modes set. To get around this difficulty, a parameter, V2ORTHO (=1.0e8 Hz default) can be used to set the upper frequency cutoff. (A similar value, V1ORTHO, default=-1, sets the lower frequency limit.) Note that the effect may be to reduce the number of degrees of freedom in the *a*-set, effectively stiffening the structure as Rayleigh-Ritz vectors are removed.

5.3 MSC2MNF translator:

ADAMS uses a special flexible body description file called the Modal Neutral File (MNF) to communicate with a variety of Finite Element programs. A custom translator, called the MSC2MNF translator, was written which translates the OUT2 file generated by the DMAP into this file format. The translator extracts node locations, element connectivity, nodal mass information mode shapes and the corresponding generalized mass and stiffness from the OUT2 file and deposits this information in the MNF. MDI has developed a toolkit, a set of library functions suitable for reading and writing the MNF platform independent binary file format. The MSC2MNF translator uses this toolkit to create the MNF. In addition to formatting the MNF the MNF toolkit provides a few additional services such as orthogonalizing the component modes (if the user has chosen not to select the default orthogonalization option in the DMAP), performing mesh simplification and computing the inertia invariants.

6. Leyland Truck example

6.1 Introduction

Leyland Trucks is Britain’s leading commercial vehicle manufacturer producing a range of civilian and military trucks from 6 to 50 tonnes at its Leyland Assembly Plant (LAP) situated in the North-West of England. The company is a part of the US Paccar organization which includes Kenworth (US), Peterbilt (US), DAF (Netherlands) and Foden (UK). Its products are marketed under the Leyland Trucks name in the UK, and under the DAF name in Europe. The Design Centre at LAP is staffed by approximately 120 engineers and is responsible for all design and development of the Leyland product range. This includes a team of 60 CAD engineers using Parametric Technologies/ Computervision CADDS5 and Pro-Engineer. The company is increasingly using virtual prototyping methodologies in both FE and dynamic simulation to reduce lead times and test costs. Six analysts using MSC NASTRAN/PATRAN and MDI/ADAMS software work concurrently with 10 configuration engineers on new product development. A seat of LMS within this area also permits local analysis of test results from the nearby Leyland Technical Centre test facility.

6.2 MSC/NASTRAN-MDI/ADAMS

The integrated use of these two technologies is playing an increasing role in cross-disciplinary mechanical systems simulation, both through the improvement of flexible body data in MDI/ADAMS, and more accurate generation of load case data for MSC/NASTRAN. (A feature piece on Leyland Trucks appears in the June '98 issue of MSC World, [MSCW-98].)

The example shown here is that of a commercial truck experiencing a pothole passing maneuver (table 1 and fig. 1). As can be seen in figure 2, a significant difference in driver's seat vertical acceleration exists between the rigid frame and flexible frame approximations, the former being quite inadequate in this short-duration transient analysis. Closer inspection reveals an unrealistic progressive damping of the shock wave for the rigid frame approximation, while the flexible frame model correctly demonstrates initial shock wave attenuation, with a later increase as the subsequent rear wheel impact propagates forward along the frame to the driver's seat location.

Total computing time has been greatly reduced using a modal energy reduction scheme, which temporarily disables modes whose relative elastic energies (REE's) are less than a specified threshold. For orthonormal eigenvectors (diagonal stiffness matrix), REE as a function of time is simply,

$$REE_i(t) = \frac{K_{ii} \, ?q_i(t)^2}{\underset{j=1}{\overset{m}{}} K_{jj} \, ?q_j(t)^2} \qquad (10)$$

where the $q(t)$ are the generalized coordinates and m is the total number of modes.

Either an instantaneous or an integrated value of REE can be used in the modal reduction process. Dropping the time argument as a result, modes for which

$$REE_i \le \beta_i \qquad (11)$$

are deleted for the simulation, where β_i is a user selectable parameter.

Figure 3 is a distribution of MSC/NASTRAN-calculated von Mises stresses, displayed in MSC/PATRAN for the instance in time immediately after the right front wheel has struck the trailing edge of the pothole (as the tire returns to the original roadbed level.) Such analysis was made possible through a capability in MDI/ADAMS which enables the user to automatically create loads bulk data for MSC/NASTRAN, in this case, an equivalent static analysis with inertia relief for the particular time step of interest. The results exhibit some stress overestimation due to tire enveloping effects and the absence of bump stops (which limit suspension travel) in the analytic model. Stresses, however, have been much more accurately predicted and are in close agreement with experimental tests that indicate stress concentrations, via force propagation through linkages, on the side of the frame opposite the pothole.

Table 1: Model Characteristics

Multibody Model

· Leaf Springs - Five Beam Element per Spring
· Bushing Mounts (cab, engine, spring-dampers) modeled including frequency dependent data
Tires modeled using Univ. Of Arizona Tire Model with Michelin data
· Dampers modeled with non-linear cubic spline characteristics
· Steering System driven by simple closed loop control algorithm
· Total of 123 DOFs

Flexible Frame

· Approx. 45,000 Nodes, 260,000 DOFs
· Approx. 45,000 CQUAD4 and TRIA3; 5,000 CBAR elements
· 158 component modes (consisting of 133 constraint modes and 25 fixed-boundary eigenvectors)
· 18 Modes after application of Energy Model Reduction Algorithm.

Simulation

· 1.8s run at 50Km/h with right sided 75mm pothole
· 385s CPU time on 250 MHz SGI Octane 1GB Ram

Example Case at Leyland Trucks

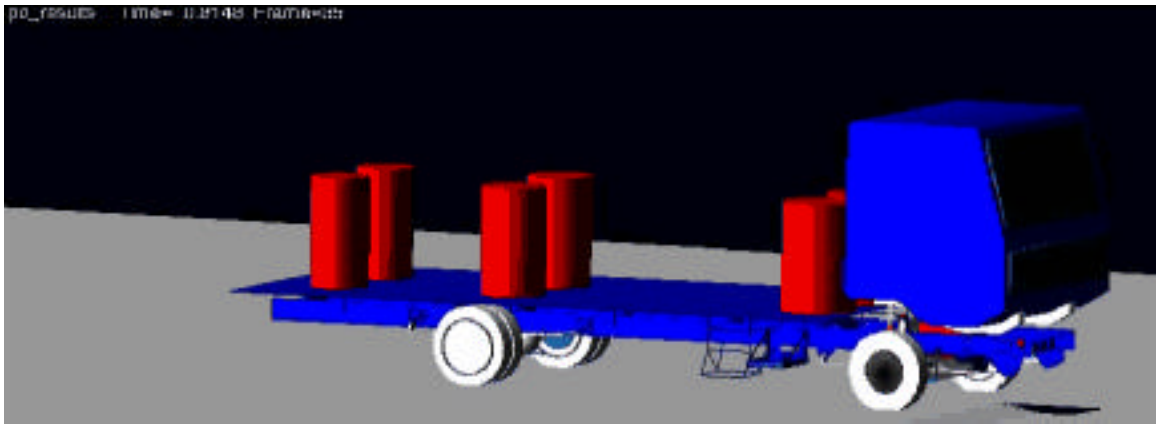

Figure 1: System Truck Model in MDI/ADAMS

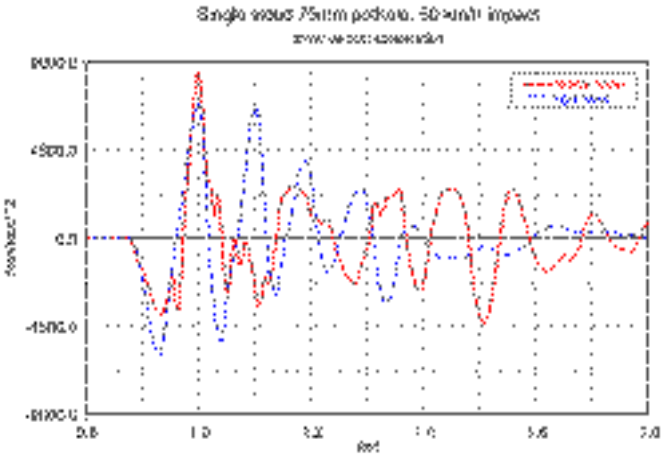

Figure 2: Rigid vs. Flexible Frame response

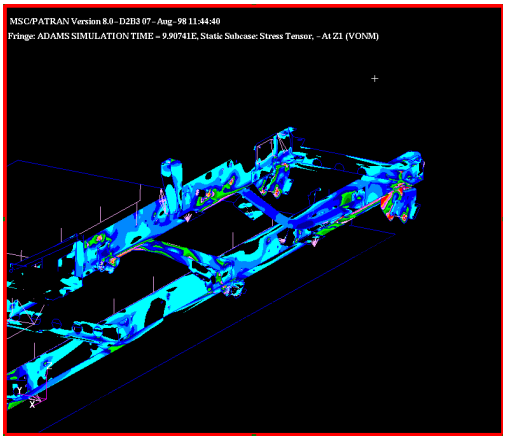

Figure 3: Resultant Frame von Mises stresses displayed in MSC/PATRAN

7. Summary, future work

We've presented the development of a second generation interface from MSC/NASTRAN to MDI/ADAMS, and demonstrated its capabilities using a current example from industry. Response has been positive, as users recognize the improved ease-of-use of the interface and the benefits of accurate flexible body approximations in MDI/ADAMS, and better loads data generation for MSC/NASTRAN.

Since much of the work described in this paper is in progress, what's been described here can be viewed as a status report on the collaborative efforts between MSC and MDI. Future work may focus on automating data recovery restarts in MSC/NASTRAN from MDI/ADAMS, improving the quality of modal approximations from MSC/NASTRAN, and tighter coupling through partial/complete embedded interfaces.

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