# Simulation of Proving Ground Events For Heavy Truck Cabs Using ADAMS, MSC/NASTRAN, and P/FATIGUE

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## Abstract

The concept of up-front engineering using analytical prototype has pushed the demands on the CAE analysts to develop methodologies which simulate operating conditions, proving ground events, and laboratory tests well ahead of the availability of structural prototypes of the vehicle. One purpose of such analysis is to provide fatigue life prediction at an early stage of the design to permit the incorporation of design modifications prior to initial tooling release. The stress history resulting from the operation of the vehicle on the proving ground events can be simulated by enforcement of the profile of proving ground events using transient analysis in MSC/NASTRAN. However, some of the proving ground events for heavy truck cabs include tire patch displacement of 12 inches that can not be simulated in MSC/NASTRAN directly. A methodology has been developed for use of the ADAMS vehicle model which provides accelerations at the cab mounts under those events. The acceleration response from the ADAMS model was used to perform transient analysis in MSC/NASTRAN to predict the time history of stresses in the cab. The time history of the stresses are input to the P/FATIGUE program to predict fatigue life of the structure under specific proving ground events.

## Introduction

This study was conducted to establish a methodology to predict the fatigue life of a heavy truck cab tested under proving ground events. The prediction is based on finite element (FE) analysis using ADAMS [1], MSC/NASTRAN [2], and P/FATIGUE [3]. One benefit of such analysis is to provide fatigue life prediction at an early stage in the design process to permit the incorporation of design modifications prior to tooling commitment.

The stress history required for fatigue life prediction can be found by performing transient analysis with enforced motion at the tire connection to ground (tire patch). The enforced displacement at the tire patch should simulate the profile of the proving ground event. This can be completely simulated in MSC/NASTRAN provided those displacements are small enough not to violate small-strain/small-displacement theory used in the element formulation. This category includes the "Washboard" and "Body Twist" events where displacements amplitudes are smaller than 2 inches. This paper presents the methodology for such simulation performed for a heavy truck cab. However, for events with 12-inch tire patch displacement such as the "Twist Ditch", the entire simulation can not be performed in MSC/NASTRAN. This paper also presents the methodology in which ADAMS software can be used in conjunction with MSC/NASTRAN to simulate the body twist event with 12 inches of displacement at the tire patch.

In either case, the end results of the analysis is a time history of stress and strain for plate elements used to model the cab sheet metal. Theses stress and/or strain histories can be input to P/FATIGUE program to predict the fatigue life of the cab when subjected to specific proving ground events.

## Finite Element Model

Figure 1.a shows the FE model of the truck system used in the computer simulation. The FE model consisted of two tip superelements and a residual. The first tip superelement was

a plate model of the cab. The model included the cab sheet metal, doors, windshield, rear window, and side glass. Rigid elements (RBE2) are used to connect these components to the cab sheet metal.

The second tip superelement represented the vehicle model (Figure 1.b) including the frame, driveline, payload, fuel tank, battery, axles, as well as the front and rear suspension. The cab isolators and the loading points on the leaf spring were included in the residual superelement. This arrangement allows for cost-efficient re-analysis with various inputs to the truck as well as different cab mount stiffness and damping rates.

## MSC/NASTRAN Features

The superelement capability of MSC/NASTRAN with split data base was used. We also used the data base split feature for upstream and downstream data of tip superelements. These features allowed us to efficiently use the disk space and CPU time of the CRAY C90 used to perform the analyses. For example, several residual runs were submitted which did bring all the data bases on line. This saved us the time that we had to wait in queue for a large data base with all the unnecessary upstream data blocks to be put on line. This was particularly helpful since we had to perform several residual runs to establish the methodology.

Structured Solution Sequence 103 (SOL103) was used to extract and save the component modes using the Lanczos method with the sparse solver. To increase the accuracy of the system modes, the residual structure modes were extracted with the Modified Givens (MGIV) method without dynamic reduction. Modal transient Solution Sequence 112 (SOL112) was used as a restart to SOL103 to compute the transient response to the enforced displacement. The transient analysis was performed on the residual structure. A restart for data recovery for tip superelement of the cab was performed to recover the stress and strain under the enforced diplacement either at the tire patches or cab mounts.

## Proving Ground Events

The two proving ground events simulated in this study include the Washboard and Twist Ditch. The Washboard event has a sinusoidal profile with an amplitude of 1.0 inch and a wave length of 18 inches. The small amplitude of the event allowed us to simulate the event entirely in MSC/NASTRAN using the complete truck system model shown in Figure 1.a. The vehicle speed through the Washboard was 30 miles per hour (mph). Due to periodicity of this event, the frequency response analysis of MSC/NASTRAN (SOL111) could also be used for the simulation. However, other events such as "Body Twist" and "Undulating Road" can only be simulated with transient response analysis (SOL112). Therefore, SOL112 was used to establish the methodology for simulation of all the proving ground events.

The "Twist Ditch" is a 48-inch-wide channel with a depth of 12 inches. The vehicle passes over the ditch with +45 and -45 degree-angle as shown in Figure 2. Due to the large amplitude of the tire patch displacement, the event was simulated in ADAMS software to predict the displacement of the frame at the four cab mounts. These displacements were then enforced in modal transient analysis that only included the cab. The vehicle speed on this event was 8 mph.

## Simulation of Washboard Event

The profile of Washboard event was enforced at the tire patch using SOL112. The displacement of the tire patch was plotted to ensure that the proper displacements were enforced (Figure 3). The input to the cab, due to tire patch displacement, was examined by plotting the displacement history of the frame at the cab mount locations. Figure 4 shows the displacement of the front cab mount location during the Washboard event. Figure 5 shows the typical strain history used as input to P/FATIGUE for the prediction of the fatigue life of the cab using Strain-Life approach. Figure 6 shows the fatigue life contour of the cab for the Washboard event as predicted by P/FATIGUE.

**Simulation of Twist Ditch Event**

The Twist Ditch event was simulated with ADAMS 6.1 software to predict the accelerations at the four cab mounts for input to MSC/NASTRAN stress analysis. This section outlines the procedure used to obtain the cab mount displacements.

ADAMS/FEA was used to translate the MSC/NASTRAN model of the frame to an ADAMS model of the frame. In this translation, the mass and stiffness representation of the frame was converted to equivalent ADAMS statements. The remaining vehicle components are simulated as rigid bodies which are connected through constraint forces. Then, ADAMS/LINEAR was used to compare the ADAMS frame modes with the modes predicted by MSC/NASTRAN. ADAMS/SOLVER was used to simulate the Twist Ditch event. The ADAMS simulation provided the cab mount displacement histories that were used for stress analysis using MSC/NASTRAN.

Figure 7 shows the vertical and lateral forces computed for left front tire. The view of the truck passing over one Twist Ditch event is shown in Figure 2. The acceleration of the frame at the cab mount locations are shown in Figure 8. This acceleration data can be used for correlation studies when a vehicle prototype becomes available. Figure 9 shows the typical displacement history of the frame with respect to the cab at the cab mounts. Figure 10 shows the typical element stress history predicted by MSC/NASTRAN transient analysis. Figure 11 shows the life contour plot predicted by P/FATIGUE under Twist Ditch event. The result indicates an infinite life for the cab under this event. In practice, Palmgren-Miner linear damage theory [5] can be used to predict fatigue life of the cab under the combined effects of all the events that are included in vehicle verification plan.

## Conclusions

- The methodology presented in this paper can be used to predict the stress as well as the fatigue life under proving ground events.
- Up-front engineering for new designs allows the engineering team to identify the body structure components which require modification prior to tooling release. This results in substantial savings in re-tooling costs.
- Such analyses have been successfully employed by Ford Heavy Truck to provide input to the design team prior to the availability of the first structural prototype.

## Future Work

Simulation of Small-Amplitude Events in MSC/NASTRAN

The difficulty associated with the simulation of small-amplitude events in MSC/NASTRAN is the prediction of reasonable tire damping rates. Some efforts are currently underway to measure the accelerations at the axles during proving ground events. The tire damping rates in the MSC/NASTRAN model will be tuned to correlate acceleration levels in the axles with those measured during test.

Simulation of Large-Amplitude Events in ADAMS

The accuracy of the cab mount displacement predicted by the ADAMS model can be increased if the stiffness representation of the cab is included in the cab model. For future studies, the methodology will be modified to include this effect. This will allow us to input the cab mount displacement into the MSC/NASTRAN model on the cab side of the mounts.

## Acknowledgment

The authors wish to express their gratitude to the Ford Heavy Truck management since their support and encouragement was very crucial to the initiation and completion of this study.

**Reference**

1. Advanced Dynamic Analysis of Mechanical Systems (ADAMS) 6.1 Software, The Mechanical Dynamics Incorporated, 1991.
2. MSC/NASTRAN Dynamic Analysis Handbook, Mac-Neal Swindler Corporation.
3. PDA P/FATIGUE, PDA Engineering.
4. Hypermesh Pre- and Post-Processing Software, ALTAIR Computing.
5. Collins, J.A., "Failure of Materials in Mechanical Design", John Wiley & Sons Inc., 1981.

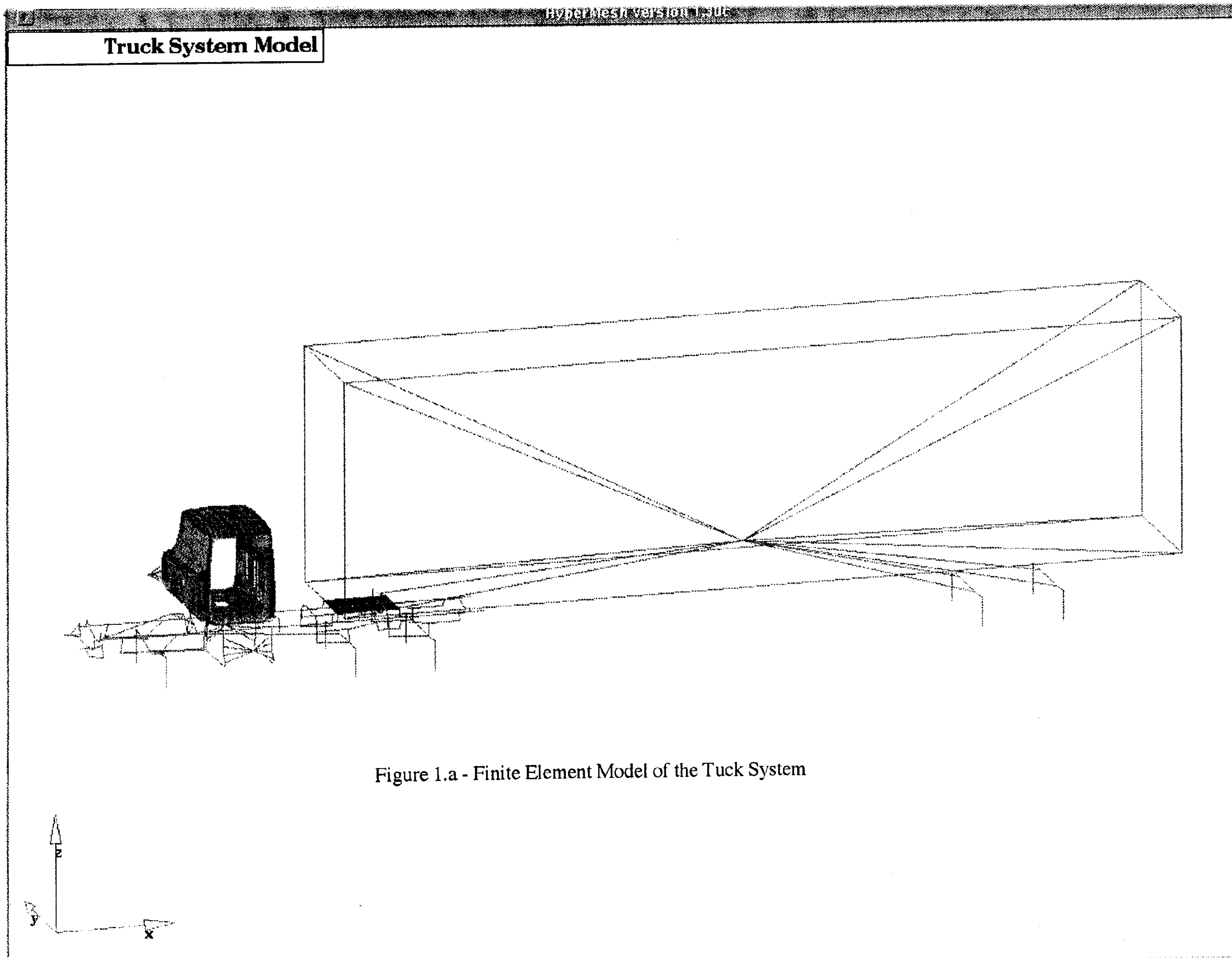


Figure 1.a - Finite Element Model of the Tuck System

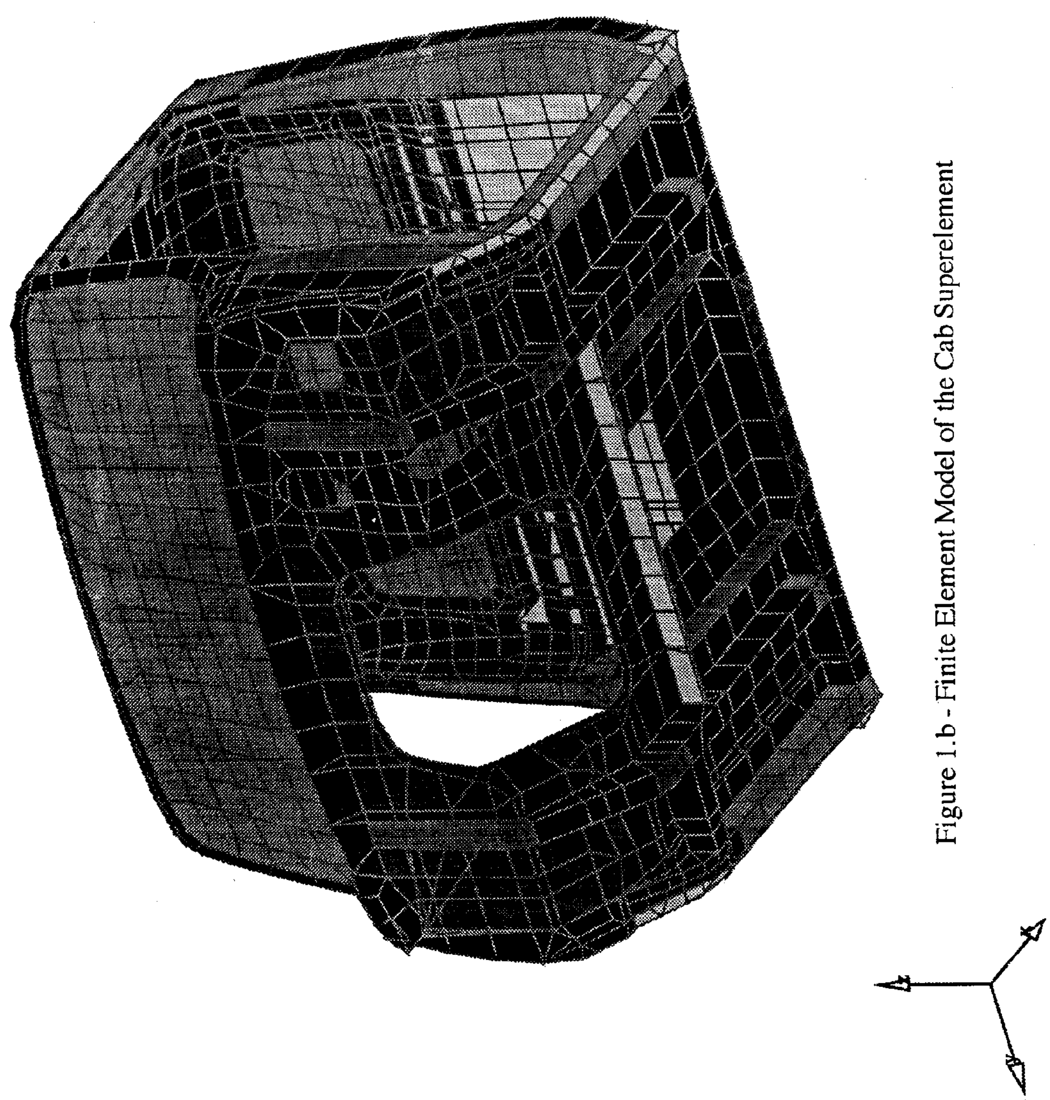

Figure 1.b - Finite Element Model of the Cab Superelement

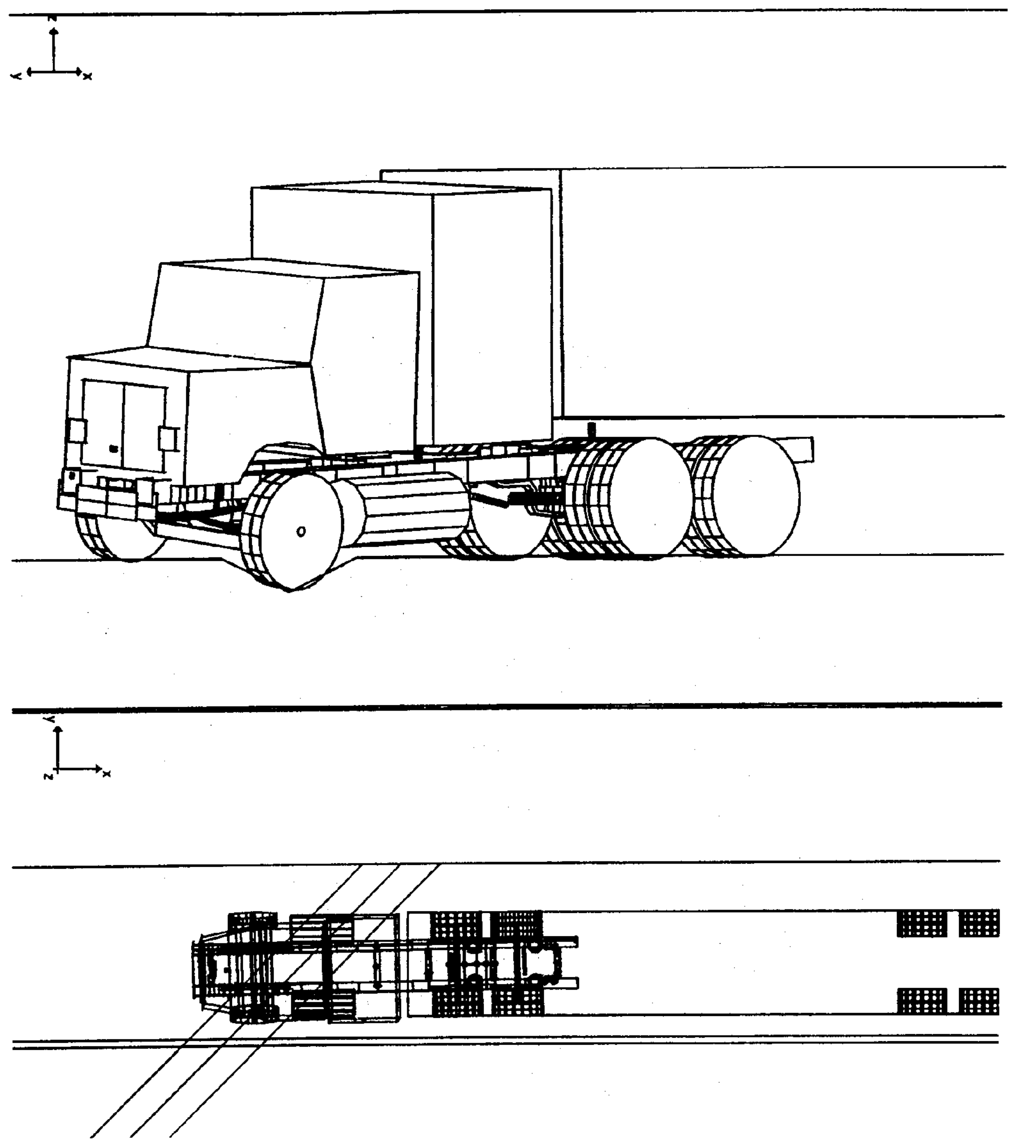


Figure 2 - ADAMS Model of the Truck Passing over the Twist Ditch Event

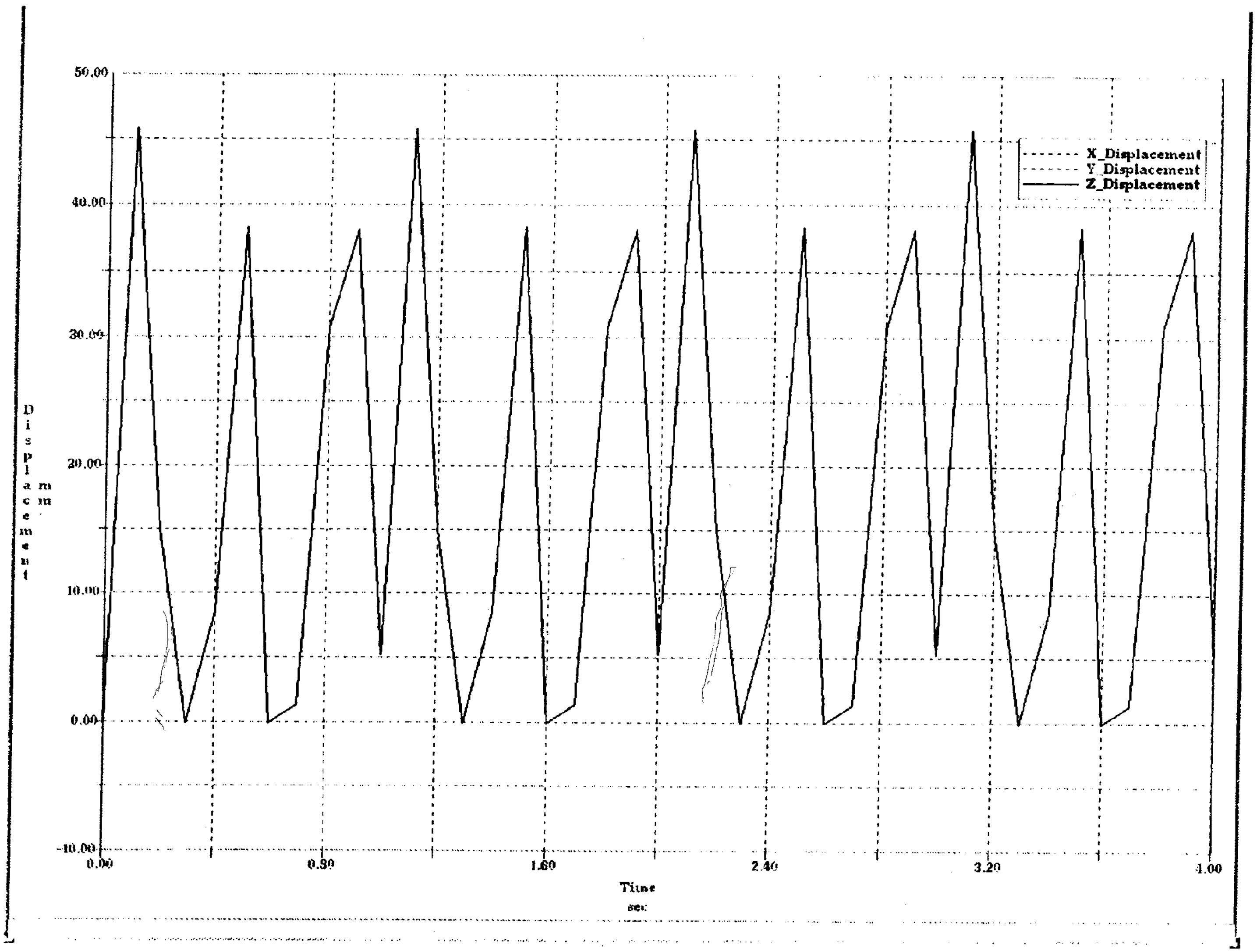


Figure 3 - MSC/NASTRAN Output of the Enforced Displacement at the Tire Patch for Washboard Event

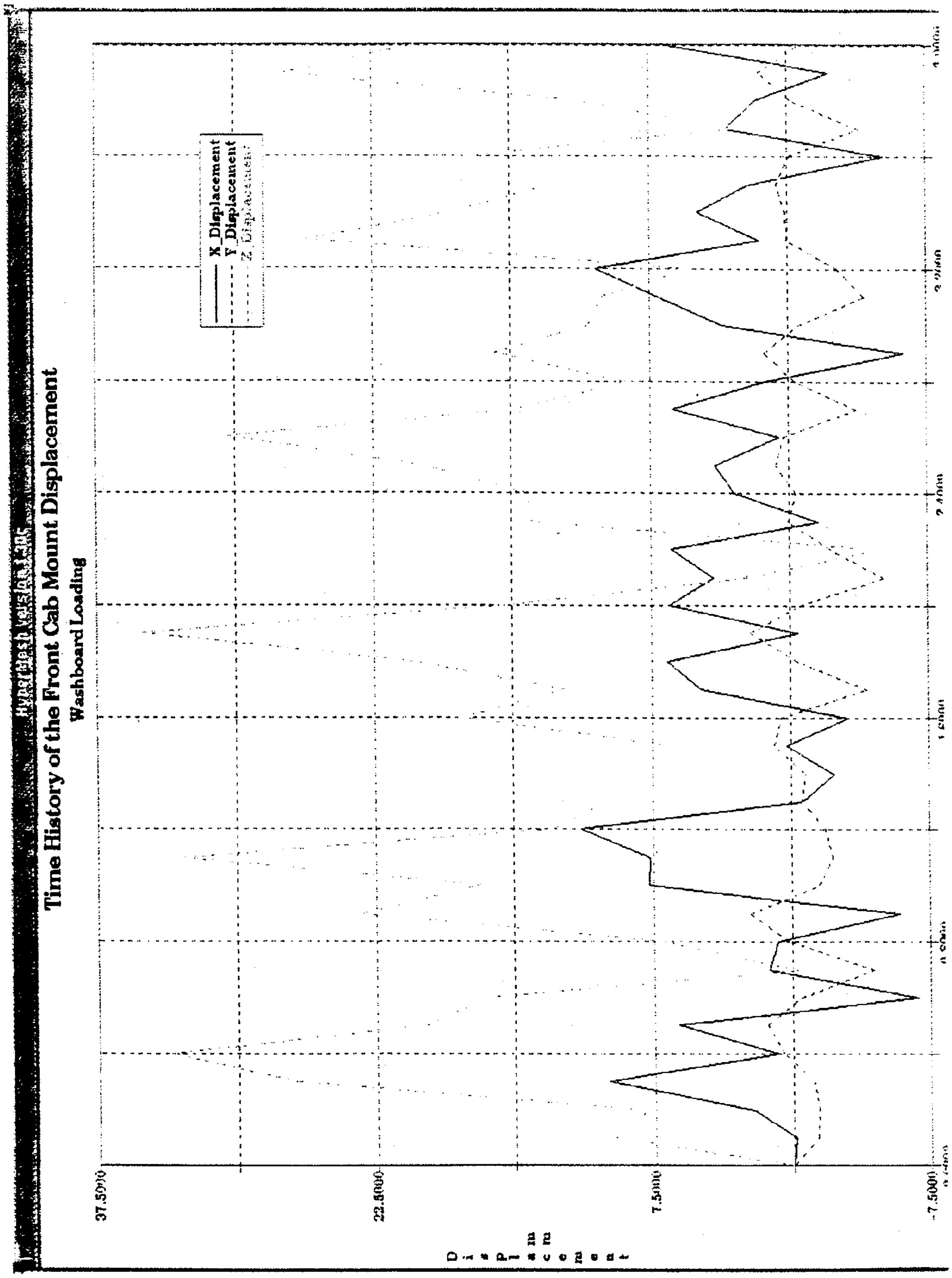


Figure 4 - Displacement of the Front Cab Mount under Washboard Event

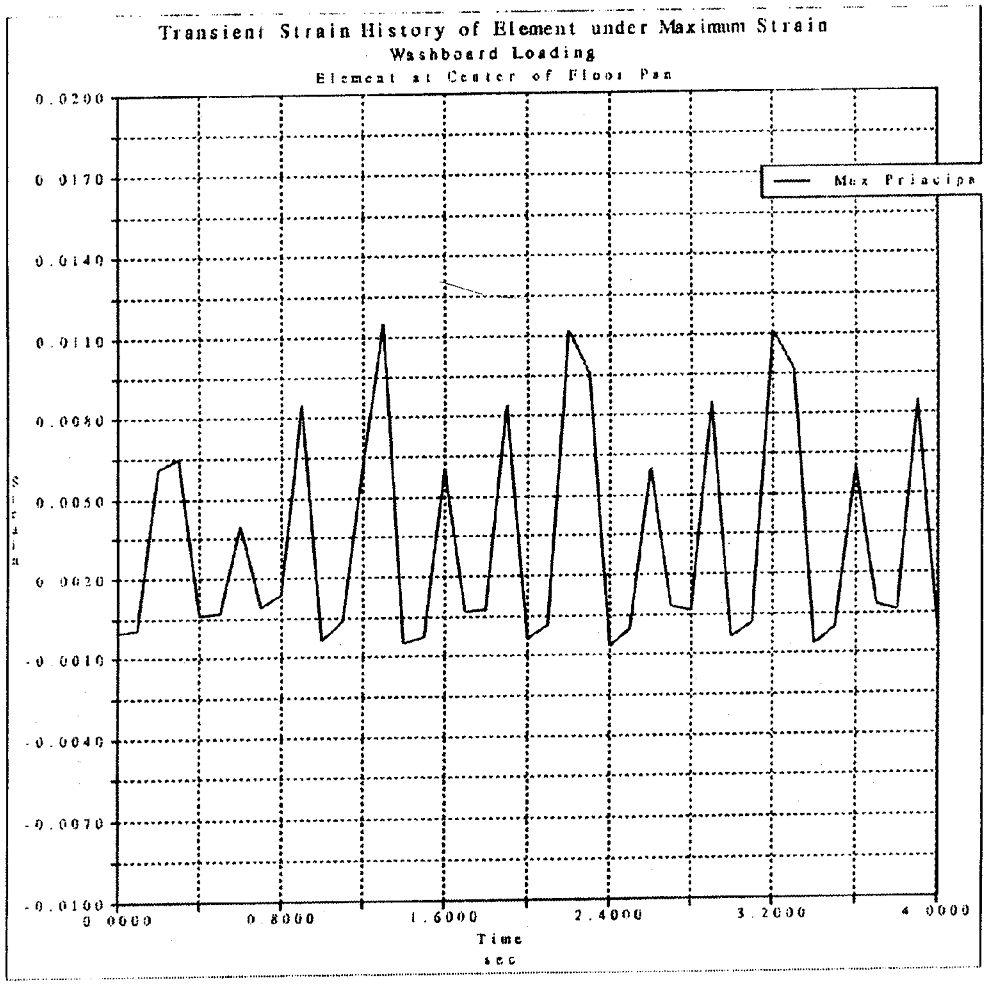


Figure 5 - Typical Element Strain History Predicted by MSC/NASTRAN
for Washboard Event

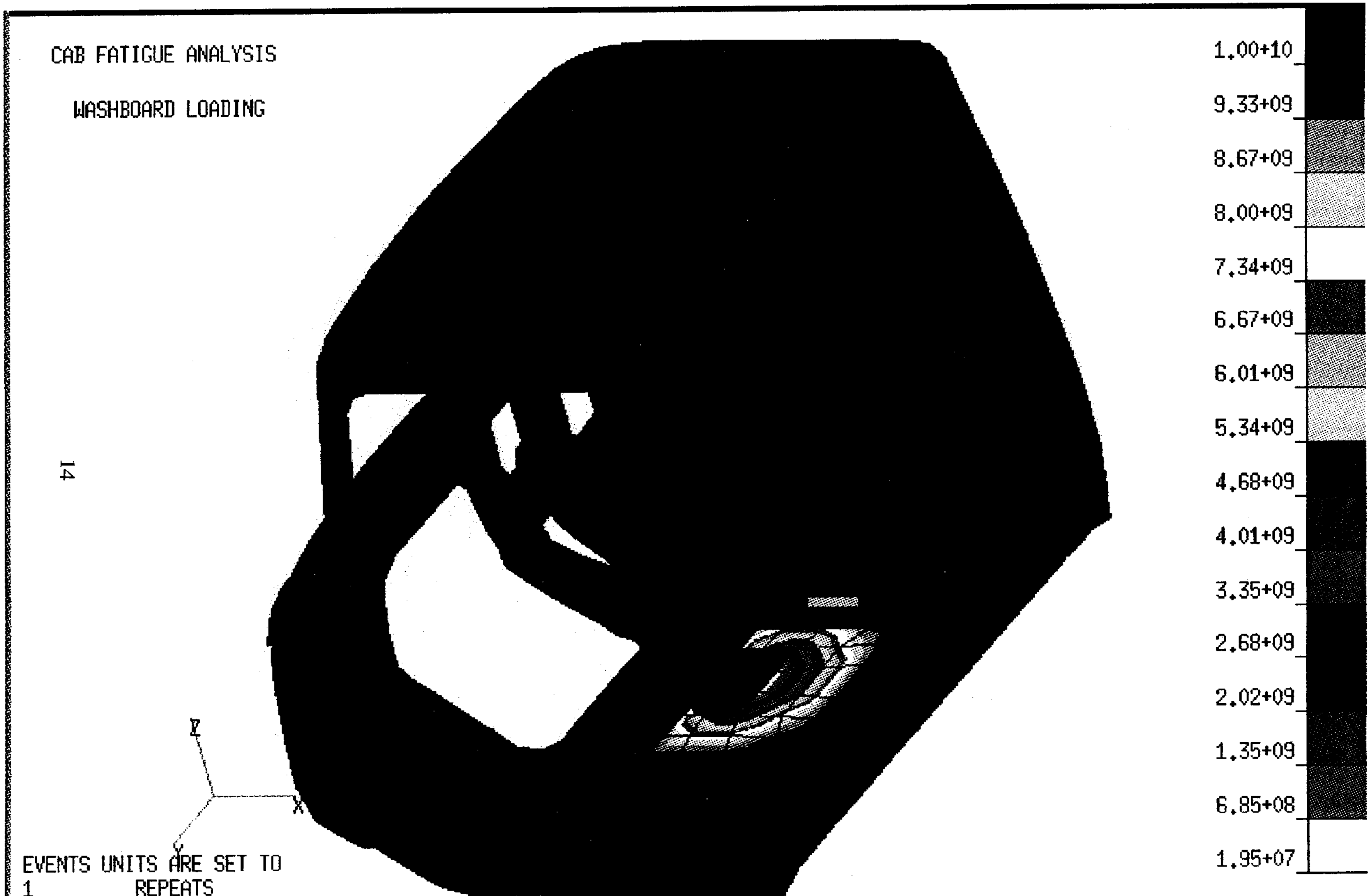


Figure 6 - Fatigue Life Contour of the Cab Under Washboard Event

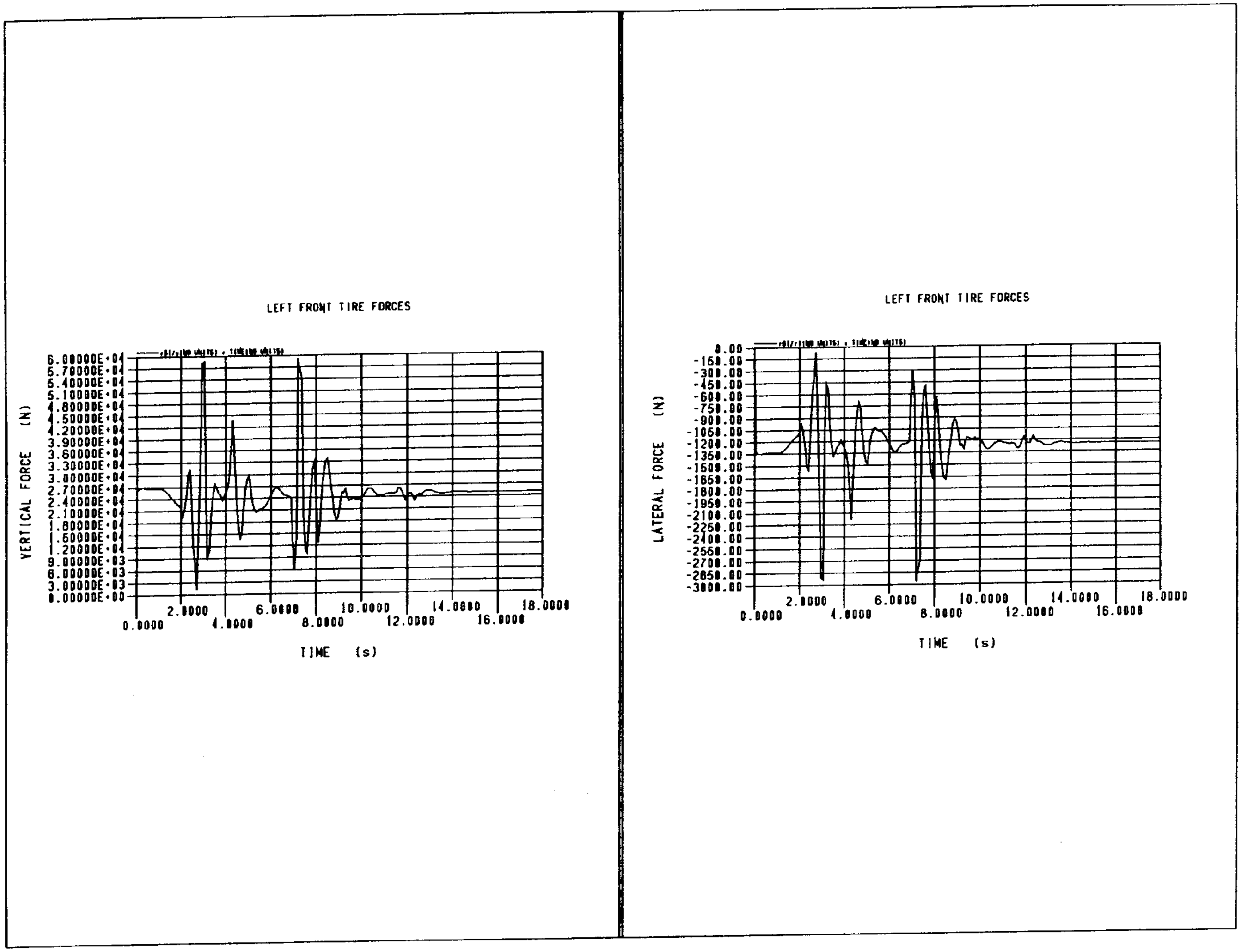


Figure 7 - Vertical and Lateral Forces of Left Front Tire Under Twist Ditch Event

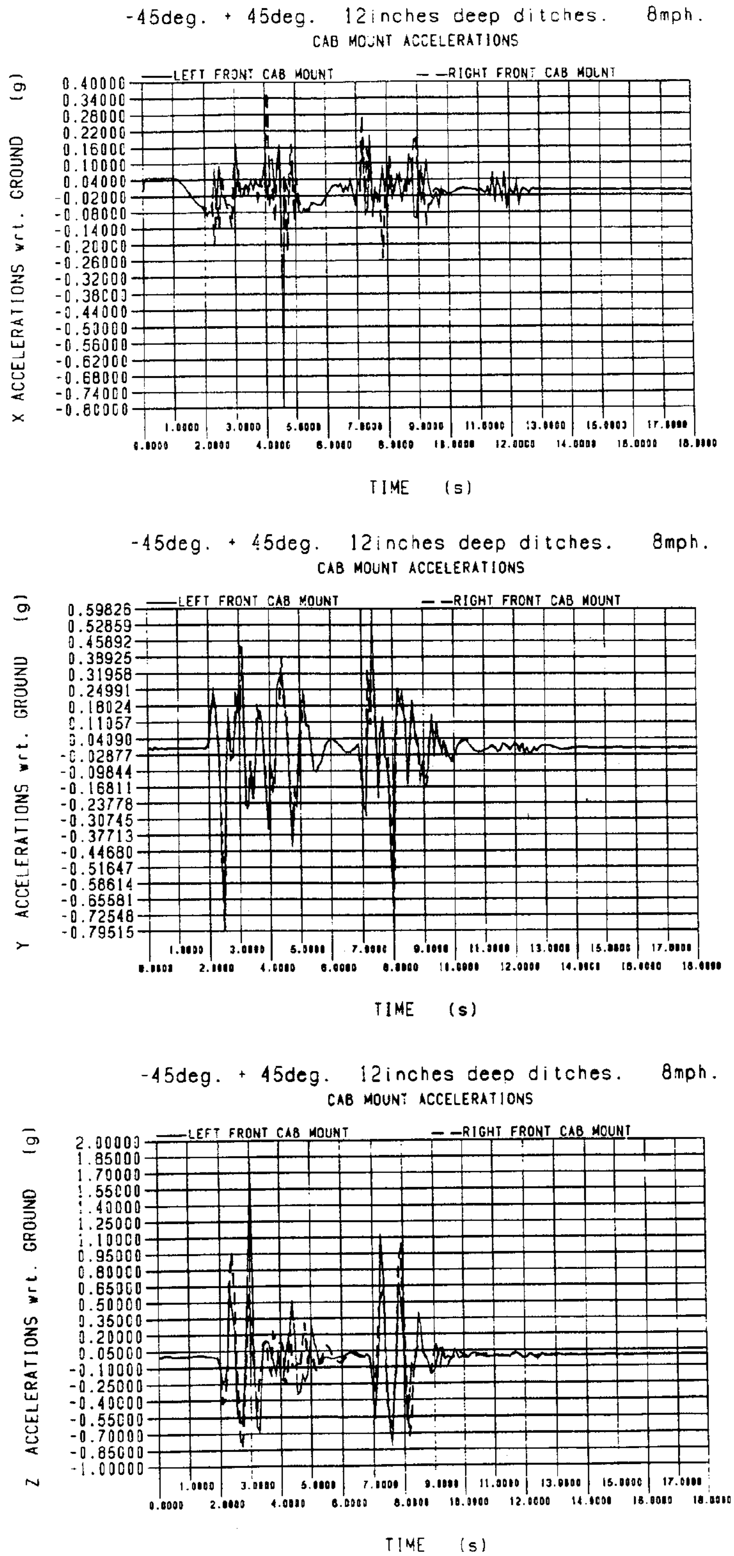


Figure 8 - Acceleration of the Cab Mounts at the Frame Side Under Twist Ditch Event

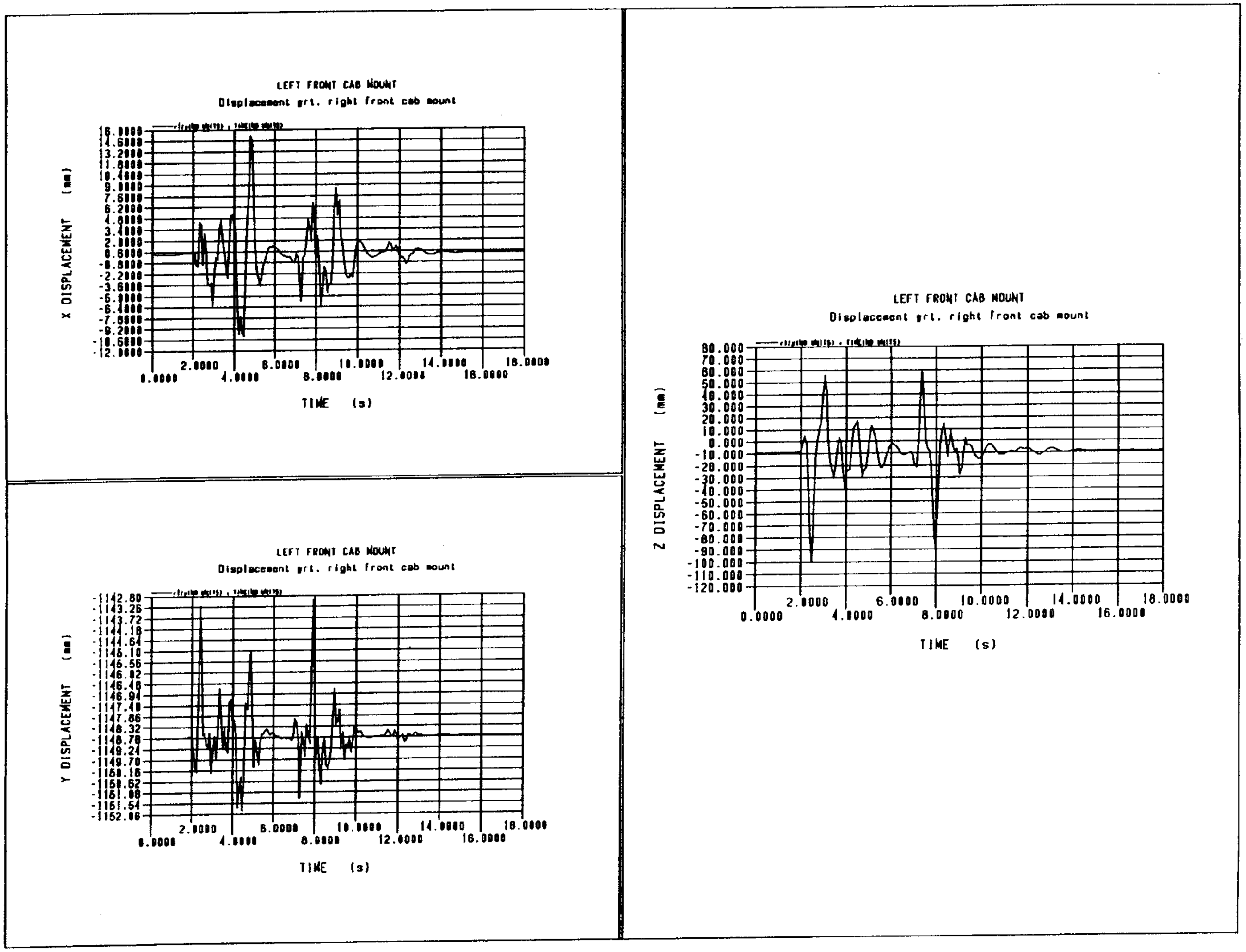


Figure 9 - Typical Displacement History of the Frame with respect to the Cab

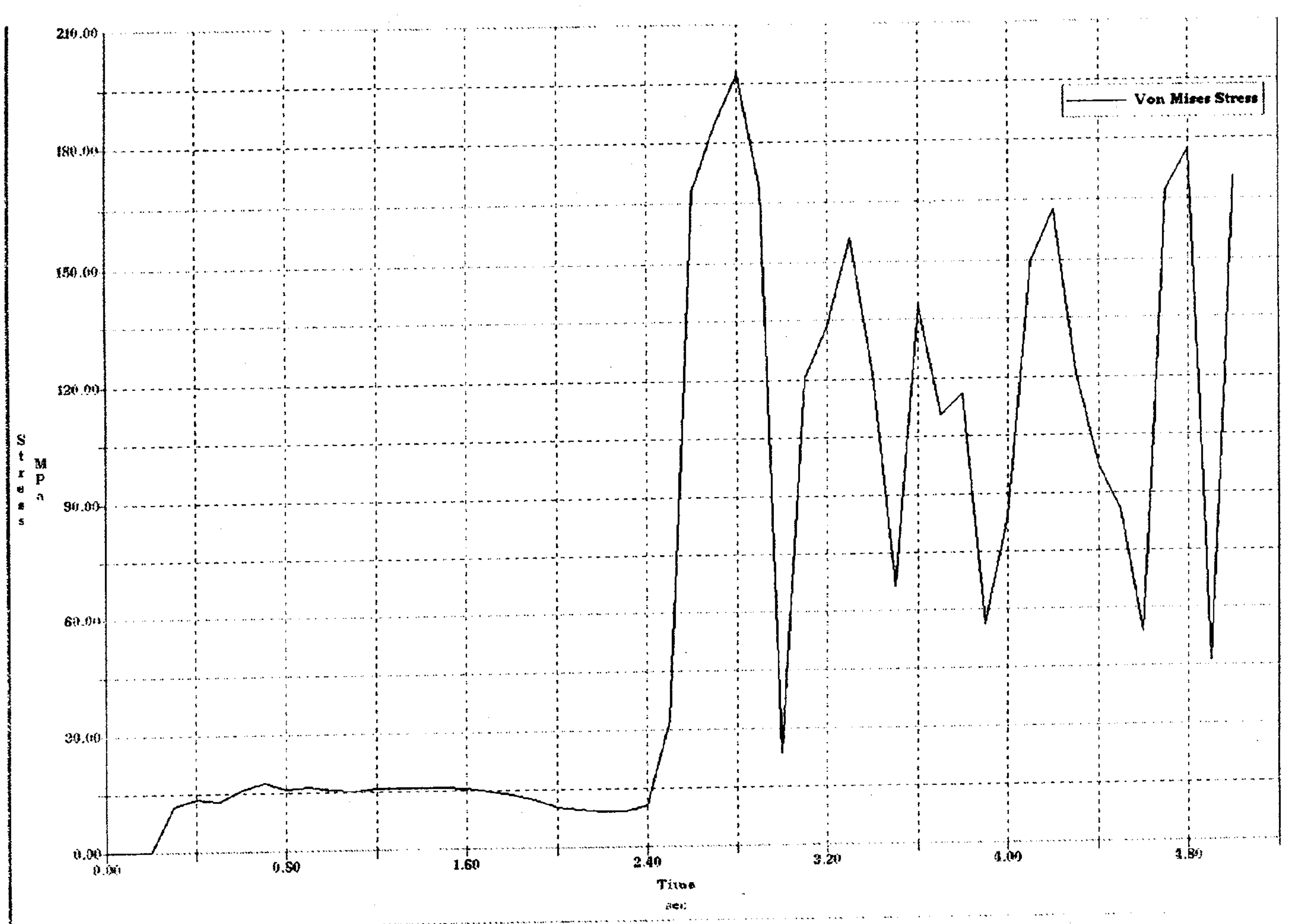


Figure 10 - Typical Element Stress History Predicted by MSC/NASTRAN
for Twist Ditch Event

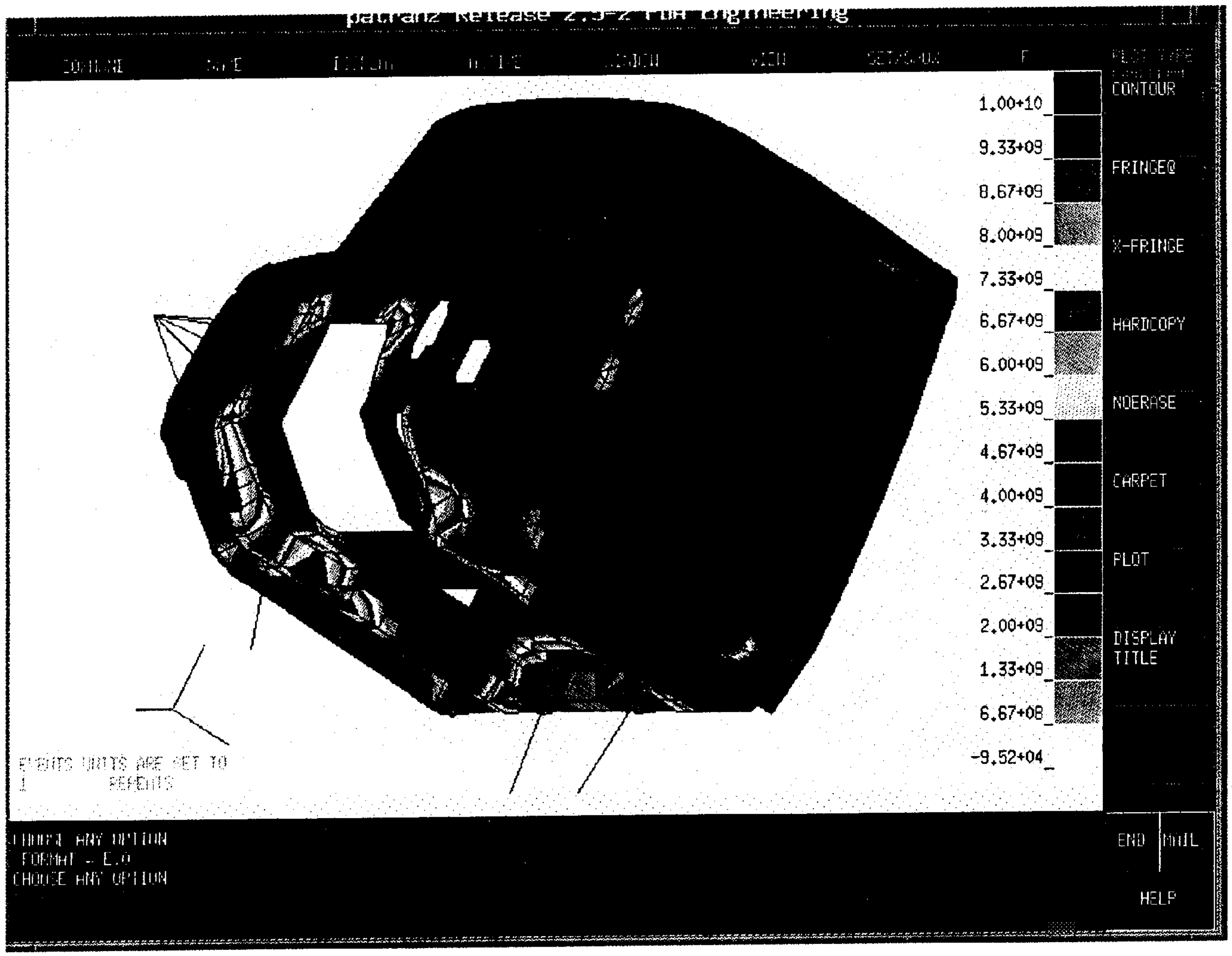


Figure 11 - Life Contour Plot Predicted by P/FATIGUE under Twist Ditch Event