MSC Nastran Based Fatigue Lifecycle Predictions at Navistar-Tech Mahindra

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Navistar International Corporation manufactures and sells commercial and military trucks, diesel engines, and school and commercial buses; and provides service parts for trucks and diesel engines worldwide. Tech Mahindra offers engineering solutions in design & styling, product development, validation, testing and system integration to global automotive players. At the Navistar-Tech Mahindra Global Engineering Center, the team applies computer-aided engineering techniques to the truck product development process.

With an increasing focus on the safe carriage of payload & light weighting, the ability to predict the fatigue life of vehicle components has gained a lot of importance. Predicting the fatigue life accurately in the early stages of design and development cycle enhances product life, reduces testing and prototype costs and ensures greater speed to market.

Figure 1: The traditional physical process for fatigue life prediction

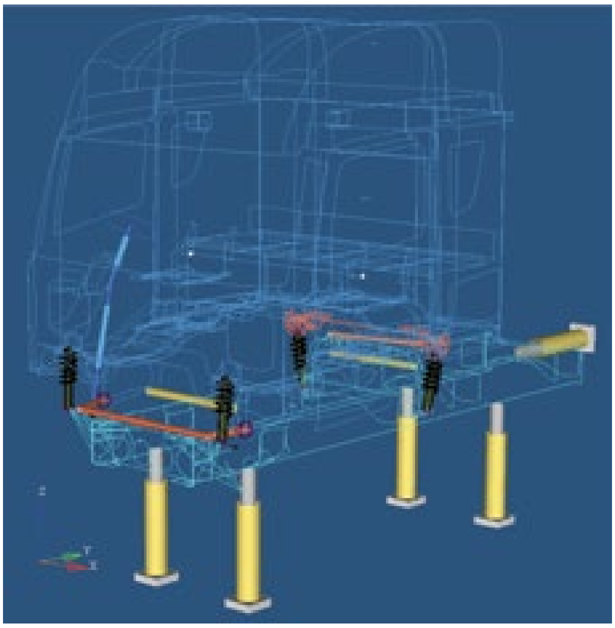

Figure 2a: Development of MBD-based Virtual Prototypes

Physical tests are used to assess the fatigue life of a vehicle (see Figure 1). This is done using laboratory shaker tests or full-vehicle testing on a proving ground. These tests are costly and time consuming, so to avoid an iterative design-test-redesign loop, we need an accurate virtual testing methodology that

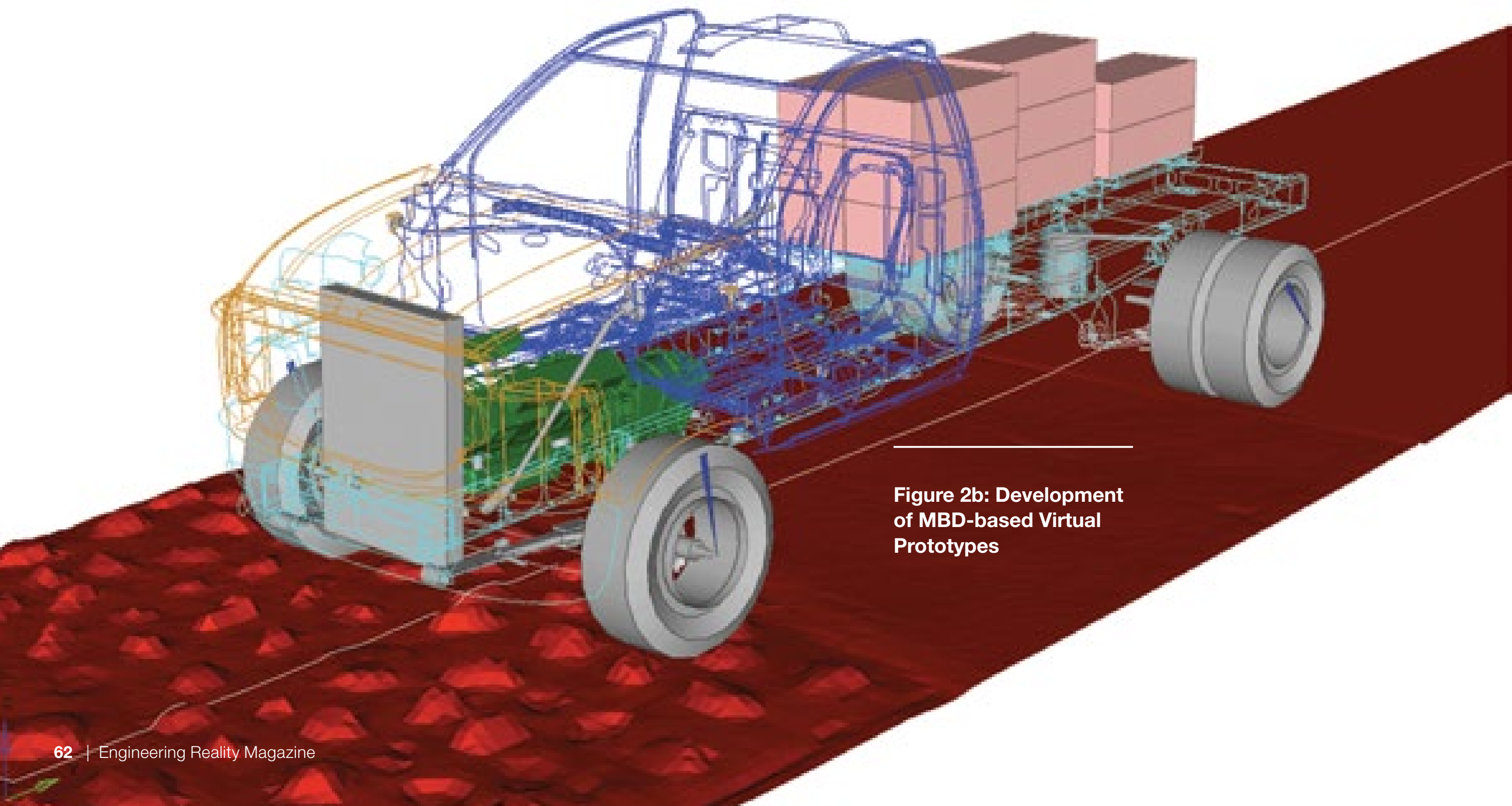

Figure 2b: Development of MBD-based Virtual Prototypes

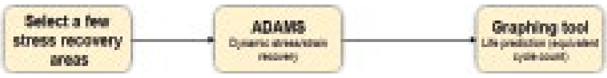

Figure 3: Virtual Transient Stress Recovery Lifetime prediction process using Adams

Figure 4: Virtual Static Inertia Relief Lifetime Prediction Process using Nastran

can be used to generate designs that will meet durability requirements that first time around.

Our Adams virtual prototypes models have now evolved to accurately predict ride and handling performance. Correlation studies on strains also continues to improve. Figure 2 outlines key models in the evolution of our Multi-Body Dynamics (MBD) virtual prototypes:

a. A Virtual Cab Shaker Test Rig where laboratory inputs are used to drive a virtual cab and cab suspension model. The accelerations, forces are used to validate and optimize the cab design.
b. A Virtual Test Track in Adams where a hi-fidelity full vehicle model is driven over realistic rough roads. Accelerations, force, strains are used to predict the structural adequacy of the vehicle components.

Figure 6: Virtual Lifetime Prediction Process using Nastran Embedded Fatigue

In the past, we have used two processes to estimate fatigue life:

- A transient stress recovery in Adams followed by cycle counting in Hyper Graph (see Figure 3)
- A Nastran linear-static inertia-relief - This method uses time-slices of loads corresponding to the instance of peak-stress identified in the MBD simulation (see Figure 4)

Both methods produce comparable results (see Figure 5). Adams accurately predicts the stress for the entire duration of the event, but the calculation is limited to the regions of stress recovery. On the other hand, the Nastran method gives us a full picture of the stress in the FE model but only at a few time instances. One proviso in this process is that for dynamic events, this method may underestimate the stresses by ~1.2 times for the frame rail and ~2.5 times for the chassis mounted components.

We wanted to have a process that uses the entire time-history of loads, calculates the fatigue life, and can display results of the entire component. For this, we turned to MSC's new offering – Nastran

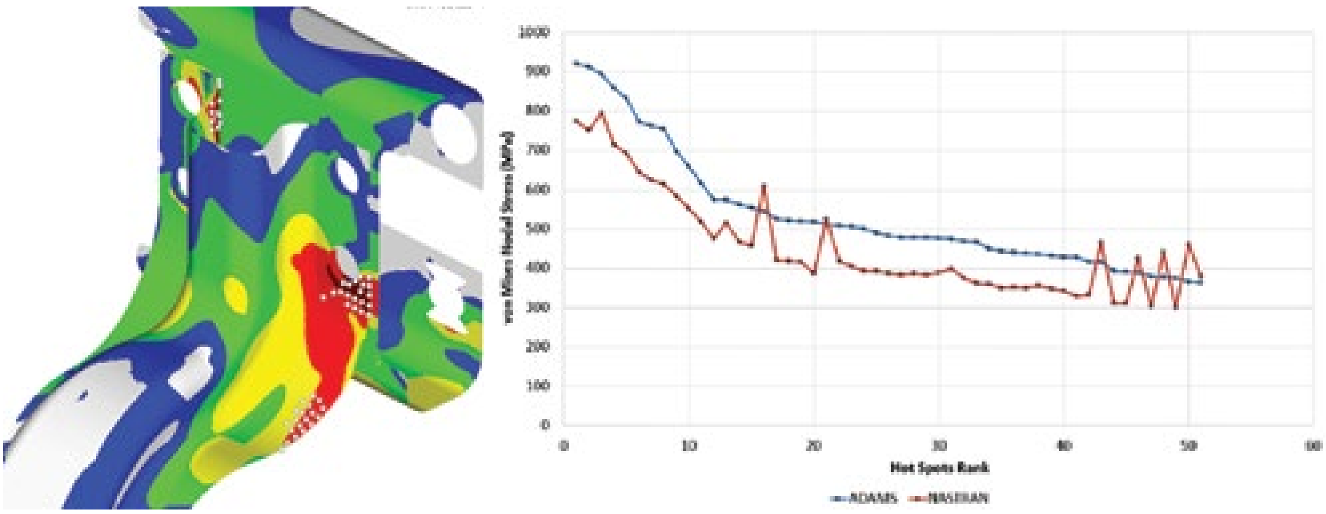

Figure 5: Comparison between the current fatigue life prediction methods. Left: Stress contour from Nastran. White spots indicate top hot-spots from Adams. Right: Nastran (red curve) and Adams (blue curve) for the same component under test

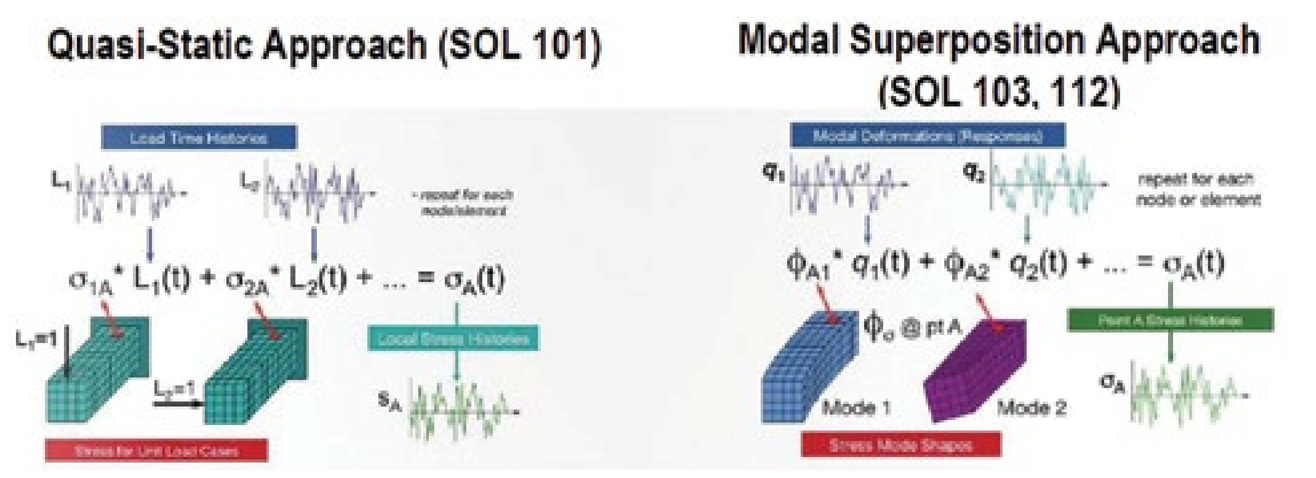

Figure 7: NEF Fatigue Model SOL 101 and SOL 103/112 approaches

Embedded Fatigue (NEF). This would entail exporting the entire Adams time history of force and moments acting on a component and feed it into NEF (see Figure 6). In NEF, we would add fatigue specific cards into the Nastran bulk data file and reference the loads calculated by Adams. With this information, we can predict where damage occurs as well as the lifetime of the components.

Nastran Embedded Fatigue Procedure

With NEF, we have two methodologies available to us: A Quasi-Static Approach (SOL 101) and a Modal Superposition Approach (SOL 103 & SOL 112) shown pictorially in Figure 7. Both SOL 103 (modal analysis) and SOL 112 (modal transient analysis) use identical methods to compute fatigue life. For SOL 103, the modal responses are provided and associated to each node. Then the cyclically varying stress responses are obtained through a linear superposition. SOL 112 computes the modal responses automatically. Loads are exported from Adams via DAC files, a main script block of the NASTRAN deck is set up with an appropriate calculation flow. The NEF code is then run to produce output NEF files. This run will produce an OP2, F06, F04, and log files (for large models, the output may spill over into several files). All files can be viewed in Hyper View.

Results for the Adams-NEF process are typically presented using two metrics: Contours of Damage and Log Life. Figure 8 shows these metrics plotted for the Cross Member and End Bracket of a Light Truck traversing a rough road. Contours of Damage represent the total damage to the structure. Damage ranges from 0 to 1.0. When D reaches 1.0, failure

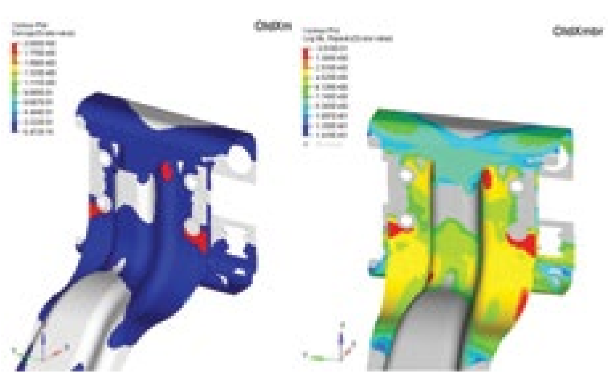

Figure 8: NEF Fatigue Model predictions of damage contours (left) and life prediction (right) to a cross member and end bracket assembly

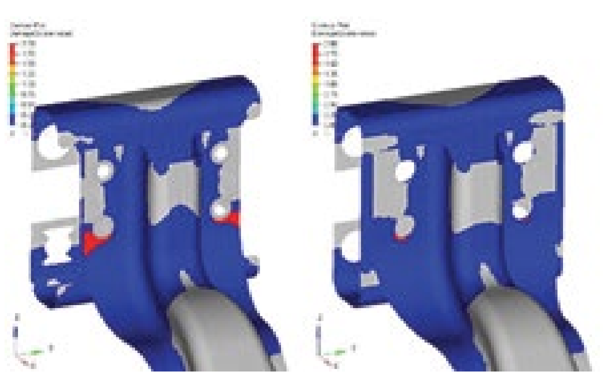

Figure 9: NEF Fatigue Model predictions of contours of damage to an old (left) and new (right) cross member and end bracket assembly after testing

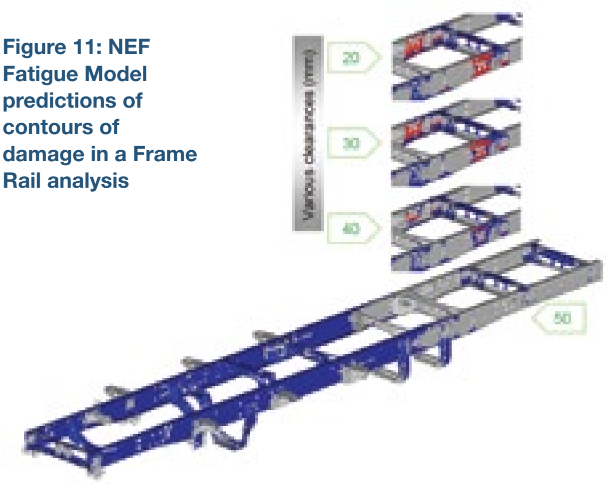

Figure 11: NEF Fatigue Model predictions of contours of damage in a Frame Rail analysis

occurs. Cases in which the stress range is greater than the YS or UTS, D may be greater than 1.0. The log file contains the number of cyclic repeats the structure can sustain before failure. The life of the part is inversely proportional to the damage, reported in log terms. In this case, the chassis was excited at 52 attachment points with 3 DOFs per attachment point in a free-free inertia relief analysis.

Figure 10 shows the results for damage for two designs: an old and an optimized cross member & end bracket.

In another case study, we studied the trade-off between ride clearance and the frame's structural durability. We used Adams to compute the loads acting on a chassis as the vehicle traversed the virtual test track. The loads i.e. forces and torques acting in 6 directions at 55 different locations were used to compute a NEF-based fatigue analysis of the chassis. In this exercise, we used the SOL 101 Quasi-Static Linear Superposition approach. Figure 11 shows the contours of Damage for various ride clearances. The turn-around time for this study was 1 day.

Finally, we compared the NEF-based virtual life prediction to our existing virtual life prediction. As shown in Figure 12, we extract the von Mises elemental stress from NEF (in blue squares) and compare them to the transient von Mises nodal stress prediction from Adams (in red circles). In Figure 12, we see that results from NEF (blue line) approaches the results from the Adams simulation (red line). Thus, NEF provides the same accuracy as that of Adams. More importantly, it provides a complete picture of the structural performance of the chassis.

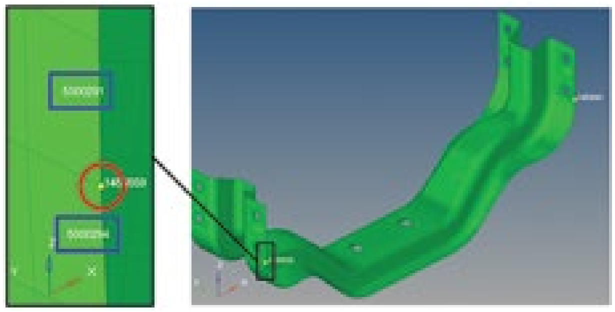

Figure 12: NEF Fatigue Model predictions of absolutevon Mises Stresses in Adams and NEF for a transmission cross member

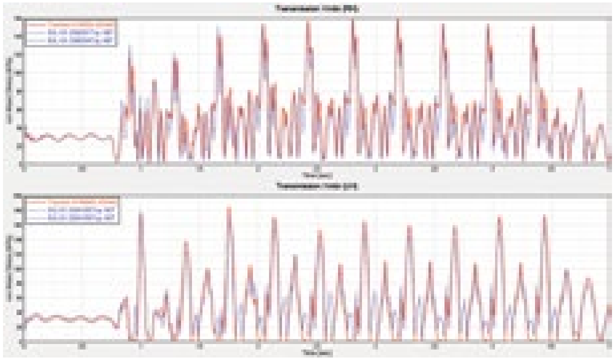

Figure 13: NEF Fatigue Model predictions of von Mises Stresses in Adams and NEF over time for a transmission cross member

In Summary

The Virtual Fatigue Life Prediction process at the Navistar-Tech Mahindra Engineer Centre has been outlined above. The NEF process has enabled identification of high stress locations more effectively. We found the overall process to be nearly three times faster than the previous method. With fewer and smaller intermediate files, the bookkeeping is also much simpler. The load time history (DAC/RPC files) can be used directly without any conversion. In addition, fatigue can now be included as a parameter in an optimization study. We have successfully validated this methodology based on several parameters and it has exhibited a good level of correlation with our physical test data. The Navistar-Tech Mahindra team see several opportunities in running similar simulations in the near future. MSC's new offering has made a significant difference in simplifying and speeding up our fatigue lifecycle predictions.