

DESIGNER

DYNAMIC

ADAMS



Streamlining Stress and Fatigue Evaluation of Mechanical Systems



Mechanical
Dynamics

Michael Hoffmann
Diego Minen

Analysis versus Testing



“Everybody believes the test results except the test engineer.

Nobody believes the analysis results except the analyst.”

“We need to get analysis and testing on the same page”

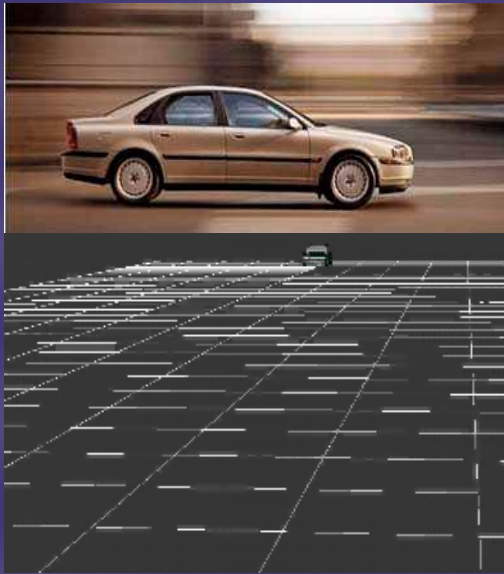
**Mike Racicot, Total Vehicle Analysis Engineer,
GM**



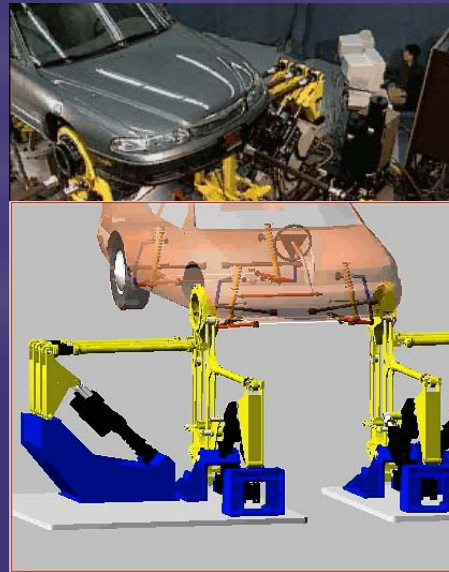
- Integrate Physical and Virtual Testing to Create the Analytical Design and Validation Process
 - ◆ Agree on and support standard interfaces
 - ◆ EDM - Seamless Integration of Component or Subsystem Physical Test Results into the Functional Digital Vehicle
 - ◆ VTL - Consistent Setup, Test and Analysis between Simulated and Physical Testing
 - ◆ Expertise in Integrating Solutions for Analytical Design and Validation Processes
- Bring a New Level of Productivity to Design and Development Processes

Integrated Durability Process

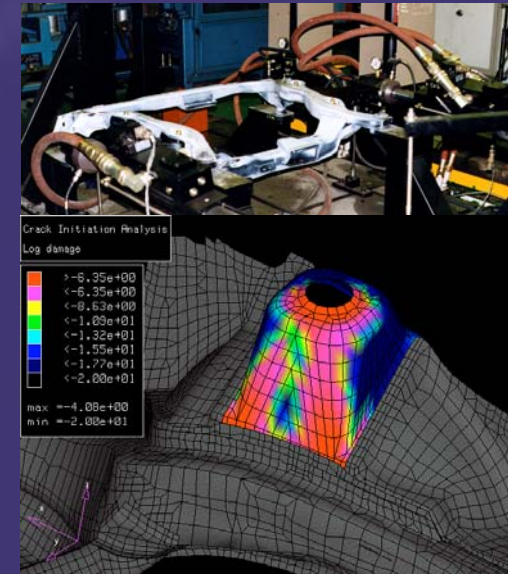
Test Track



Full Vehicle
Test Lab



Component
Test Lab



- Seamless transition
 - ◆ from test track to test labs
 - ◆ from virtual to real

Software Components of a Durability Solution

BASIC COMPONENTS

ADAMS/FullSim

ADAMS/Durability

Finite Element
Programm

FE-Fatigue

ADAMS/Car

ADAMS/Driveline

ADAMS/Engine

GENERIC

AUTOMOTIVE

EXTENSIONS

ADAMS/Flex

ADAMS/EDM

ADAMS/Tire FTire

Virtual Test Lab

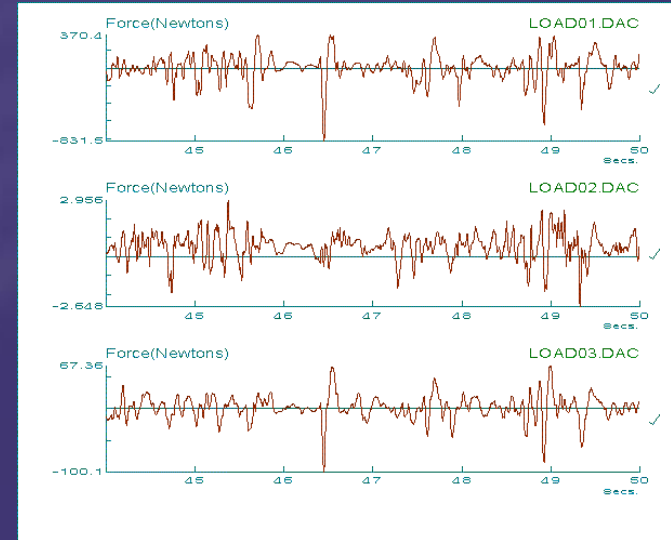
GENERIC

AUTOMOTIVE



ADAMS/Durability

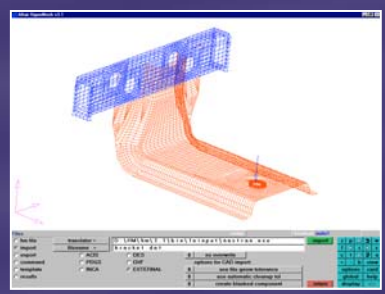
- Reference data from DAC or RPC III files and interpolate during simulations
- Save REQUEST data to DAC or RPC III files
- Export ADAMS results to DAC or RPC III files
- View header information and/or data in DAC or RPC III files
- Plot DAC or RPC III time history data and compare with ADAMS results



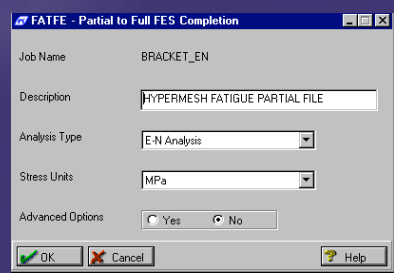
FE-Fatigue



FE stress/strains

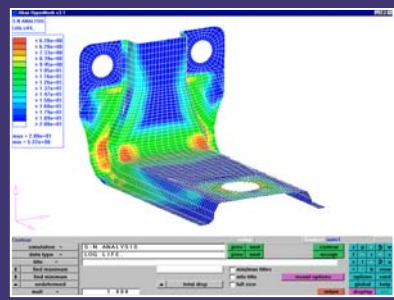


View model and stress/strains in Pre/Post Processor

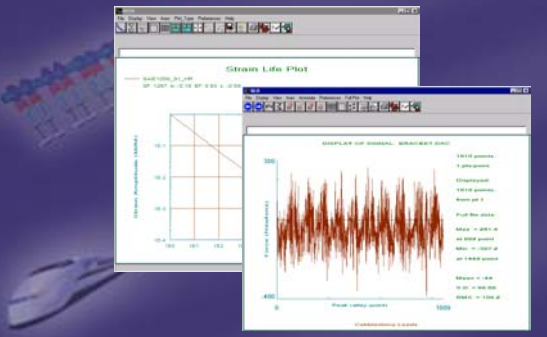


FE-Fatigue

Load and Material information



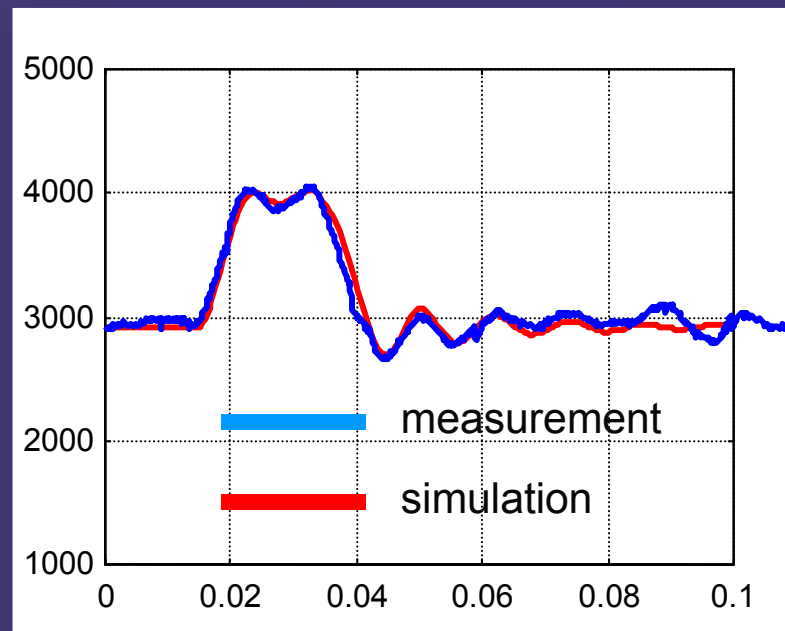
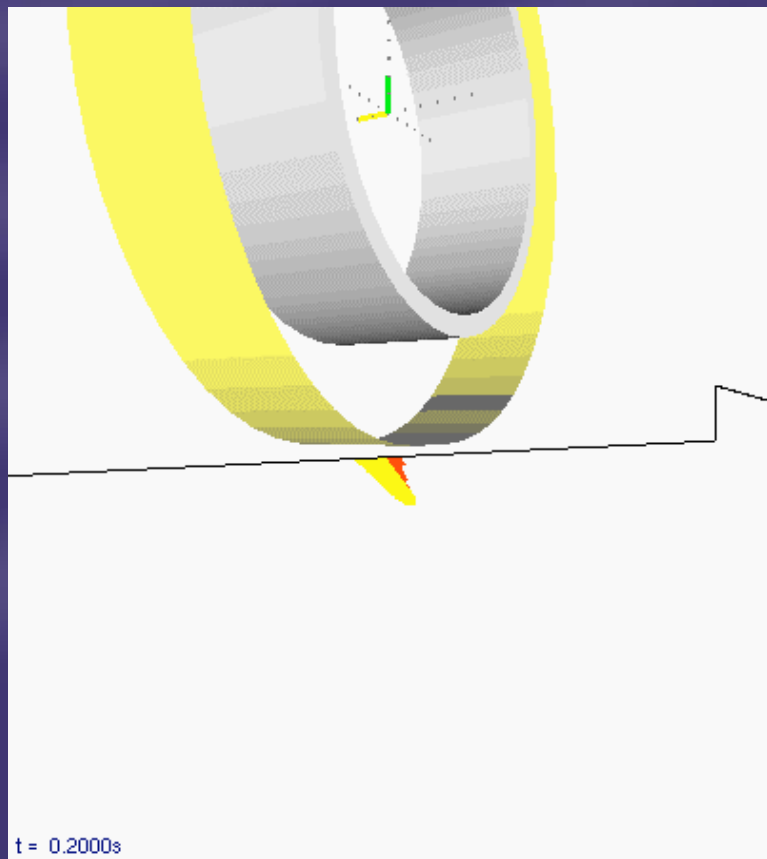
Post process fatigue results



ADAMS/Tire FTire



- Tire model for NVH and durability applications



wheel load [N]

Empirical Dynamic Model (EDM)

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ADAMS



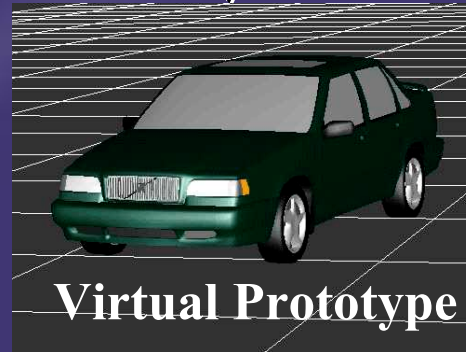
Elastomers



Shock Absorbers



Tires



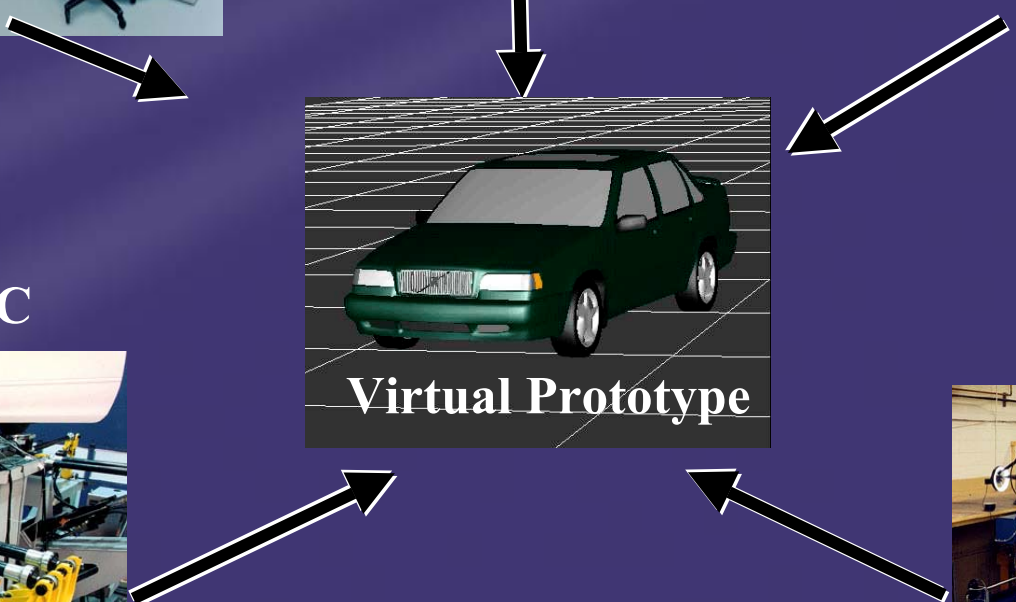
Virtual Prototype



Dynamic K&C

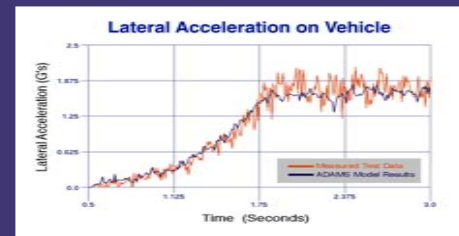
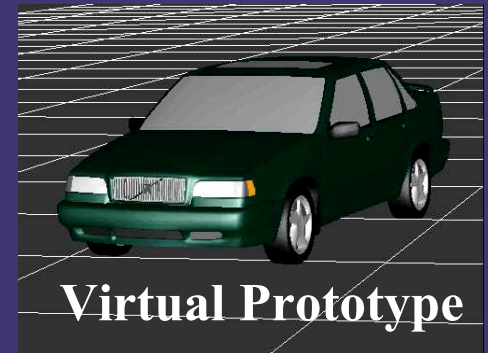
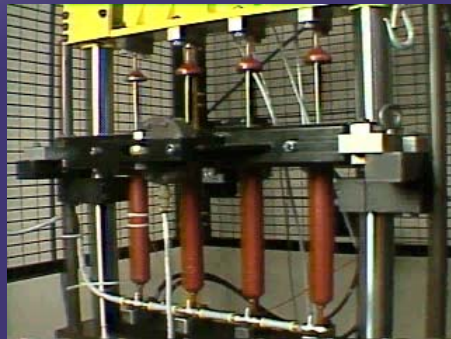


K&C



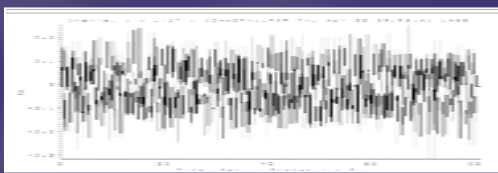
Empirical Dynamic Model

- Physical Testing Generates Data for Model Creation
 - ◆ Black Box, Characteristic, and Concept Model

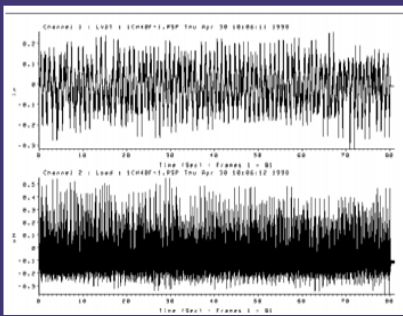


Empirical Dynamic Model

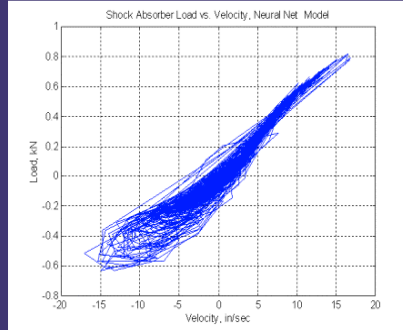
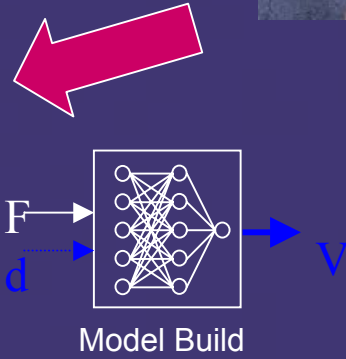
- Support of EDM
 - ◆ ADAMS/View
 - ◆ ADAMS/Car
 - ◆ ADAMS/Pre



Random Displacement Command

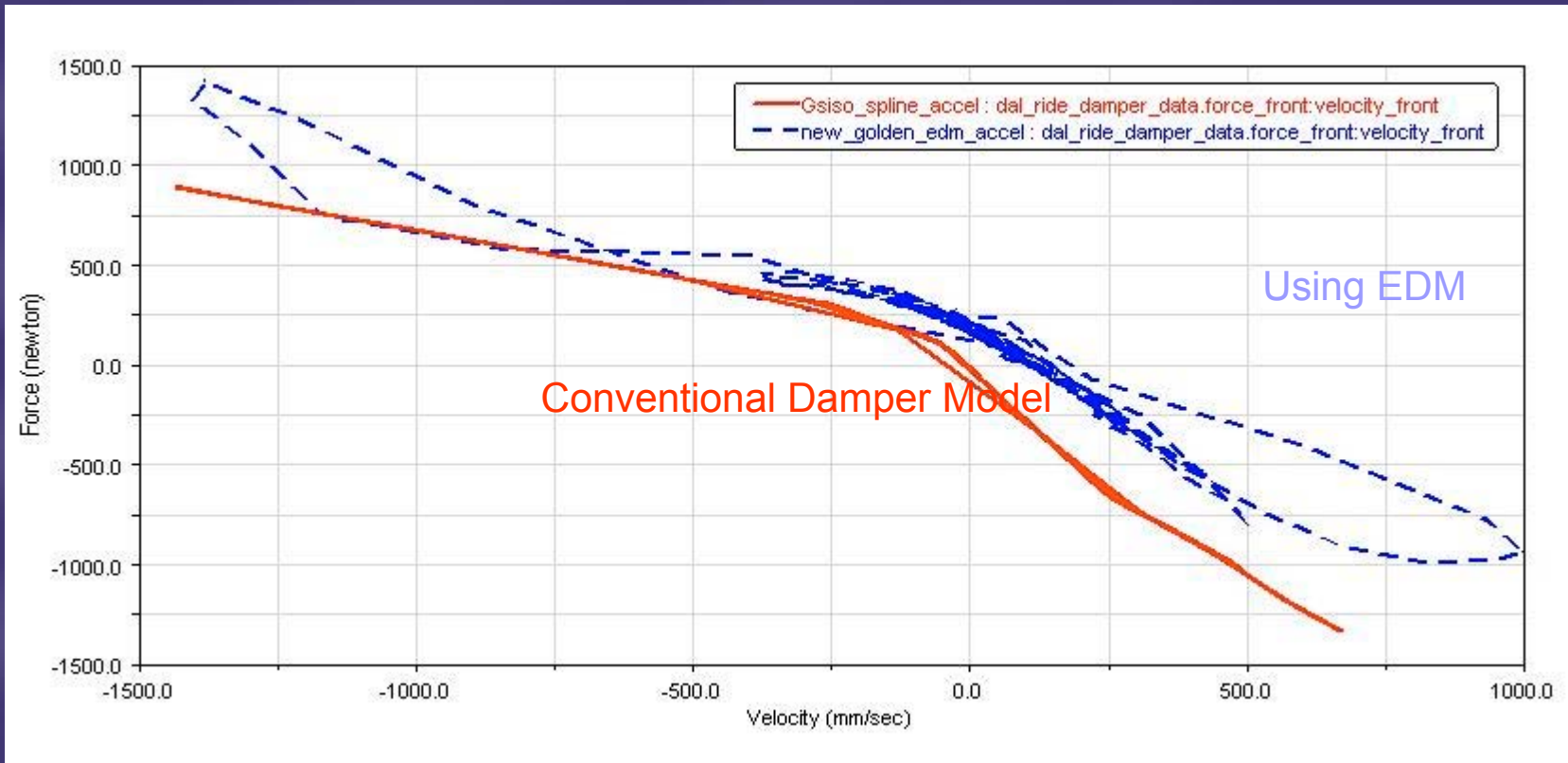


Measured Force and Displacement



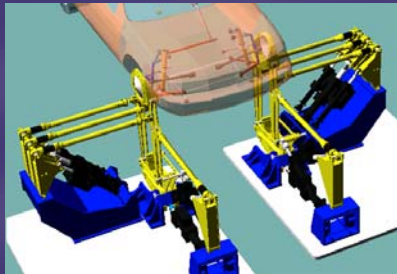
Predicted Results

Damper Loads During a Pothole Event



Virtual Test Lab

- Dynamic Models of MTS Systems
 - ◆ Mechanical, Hydraulic, and Control Systems



- Interface to Functional Digital Vehicle
- Common Pre and Post-processing Utilities
- Common Drive Files for Physical and Virtual Tests
- Predictive Analysis for Validation Path
- Knowledge of Test Lab engineers can be introduced much earlier in the design process

VTL Application Table



<u>Input</u>	<u>Test Rig Model</u>	<u>Applications</u>
Spindle Loads	No VTL Model	Fatigue Prediction
Actuator Displacements	VTL – Elasticity and Kinematics of Test Rig	Validation with Traditional Instrumentation or SWIFT
RPC Response File	VTL/RPC – Model of Controller and Hydraulics	Full RPC Iteration and Drive File Creation

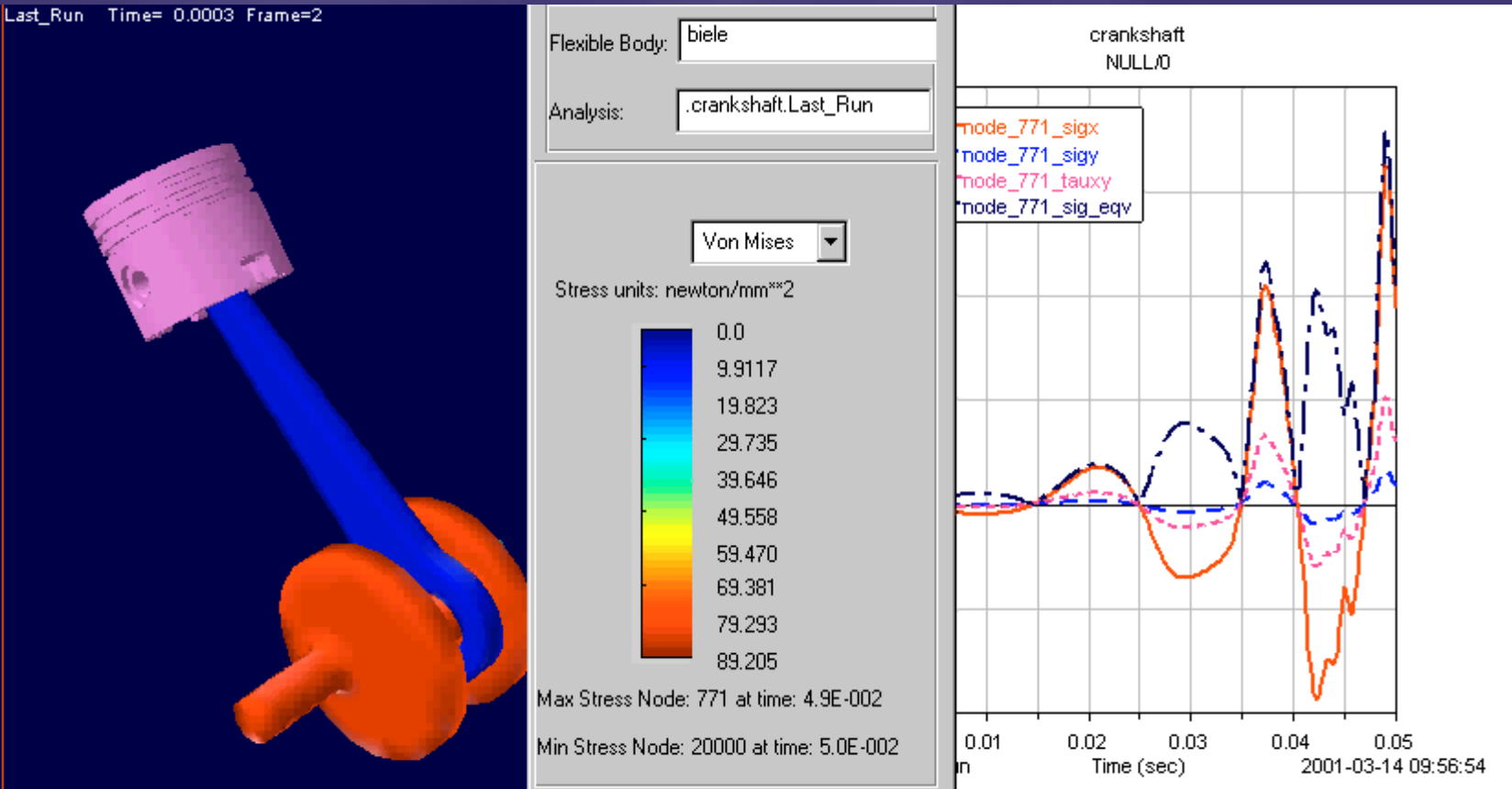
How Do You Manage Your Durability Process

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ADAMS



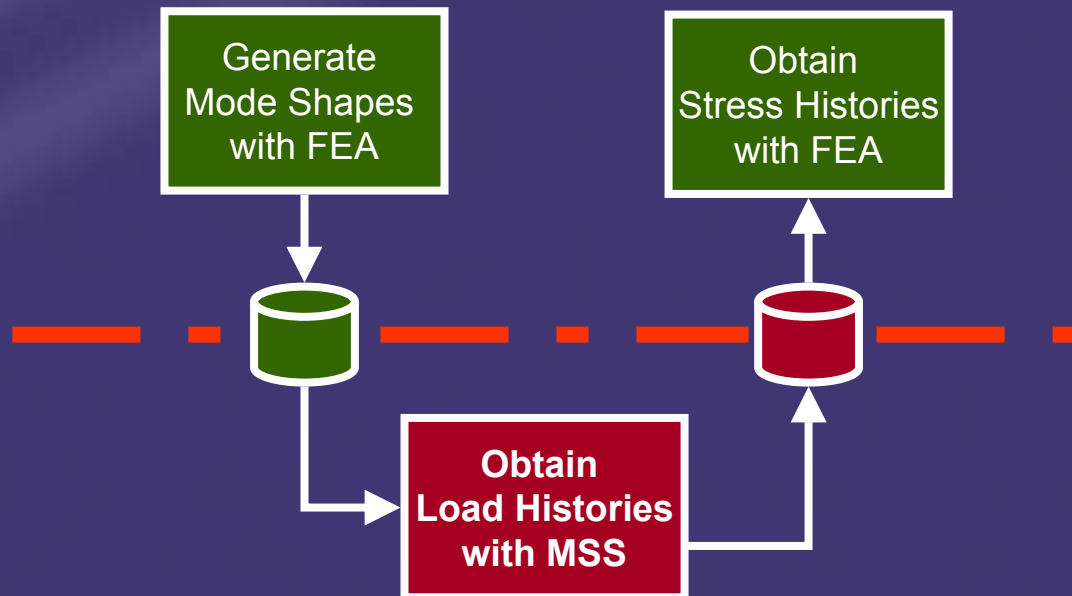
The Modal Stress Recovery (MSR) Toolkit

- Streamlines stress and fatigue evaluation



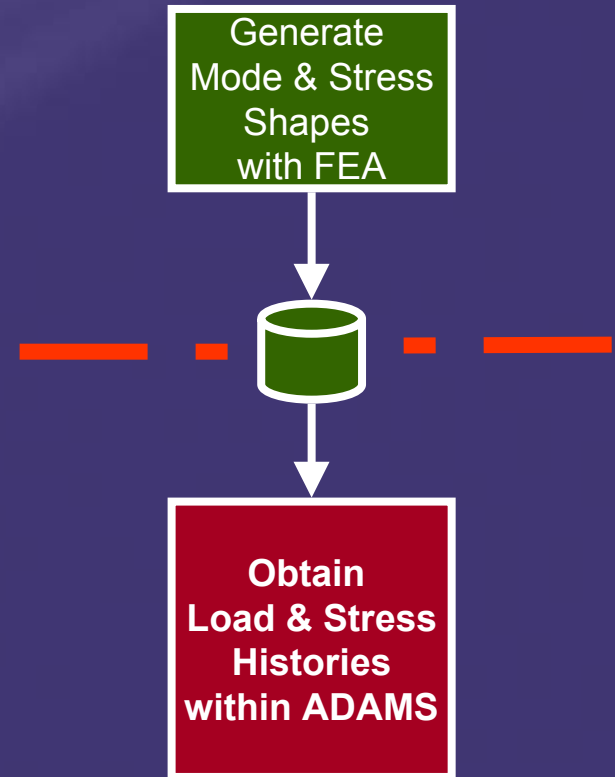
Common Process for Stress Computation

- Parameter studies where objectives include component stresses require switching between FEA and Mechanical System Simulation
 - ◆ no integrated process
 - ◆ parameter studies and optimization on a system level is too cumbersome



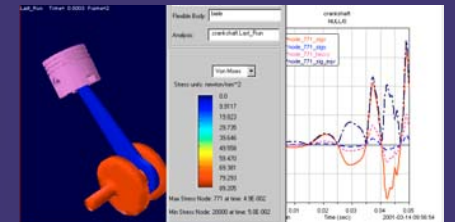
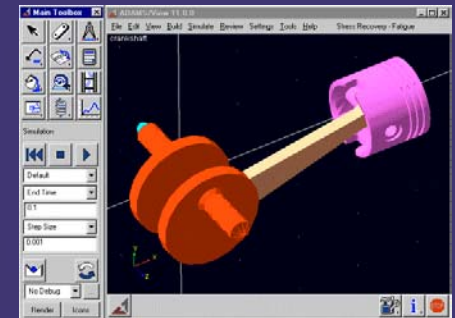
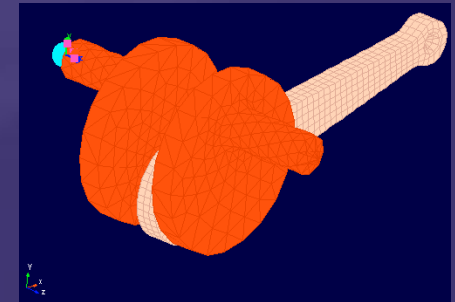
Integrated Process for Stress Computation

- The MSR Toolkit allows
 - ◆ Stress computation within the ADAMS environment
 - ◆ Parameter studies and optimization on a system level
- No constant switching between FEA and MSS
- FEA is touched only once



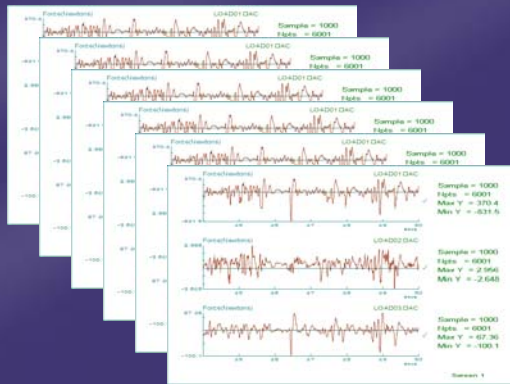
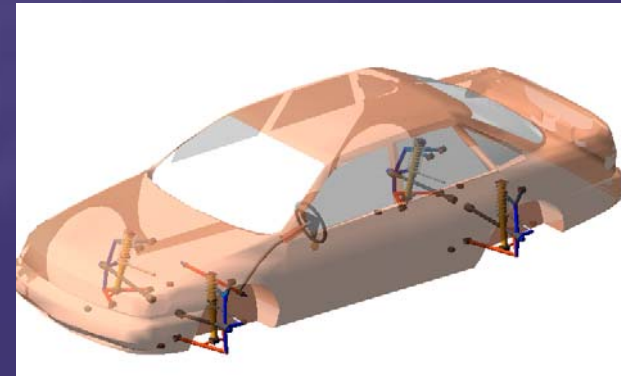
Integrated Process for Stress Computation (cont.)

- Step One:
 - ◆ Mesh components
- Step Two:
 - ◆ Run FEA to generate mode and stress shapes
-> data is written to the MNF-file
- Step Three:
 - ◆ Run ADAMS to obtain the component load histories (in terms of Modal Coordinates)
- Step Four:
 - ◆ Run ADAMS/PPT to
 - compute and plot nodal stresses
 - display and animate components' stress contours



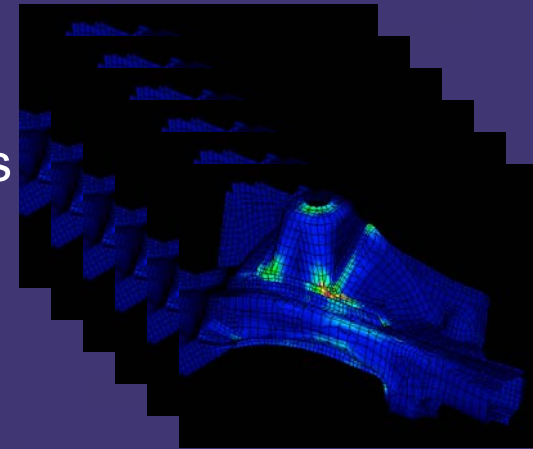
Data Handling Issues in Fatigue Analysis

- Car body is subjected to more than 50 load channels (suspension connection points)
- Traditional approach requires 50 unit load cases to be analyzed with FEA



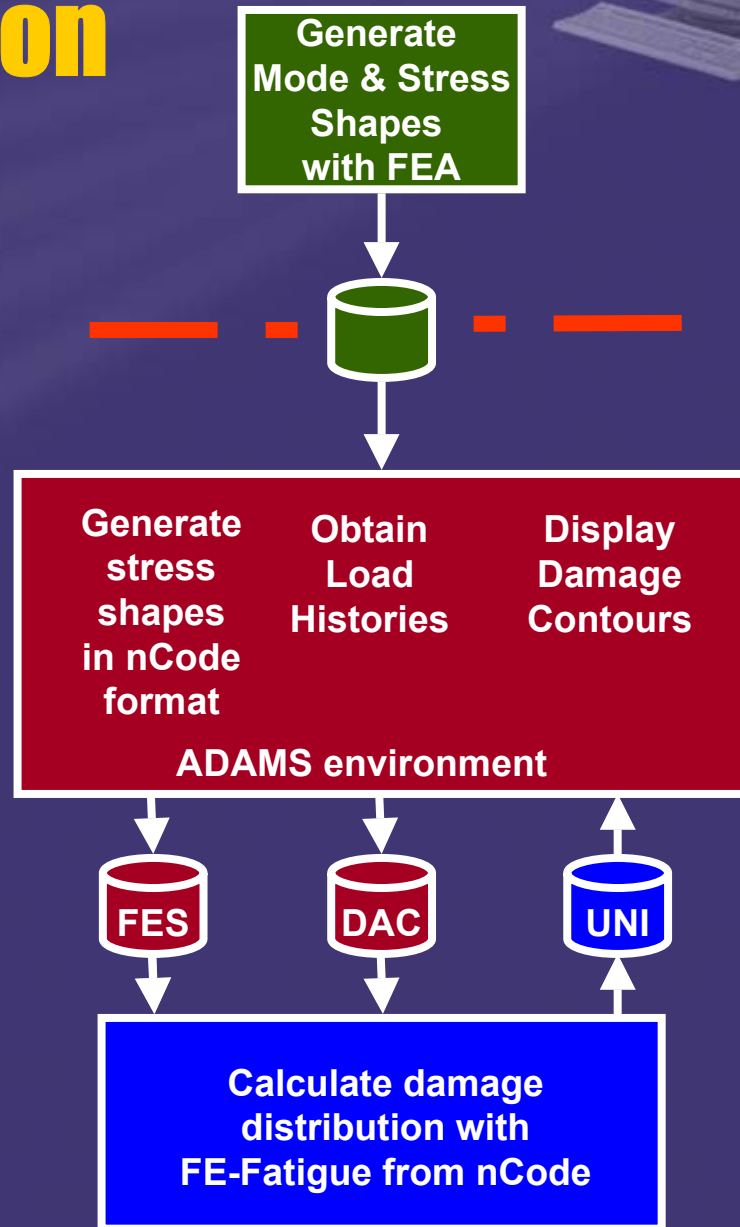
Assign load channels to unit load cases units ? polarity?

- Issues: Not automated, error prone



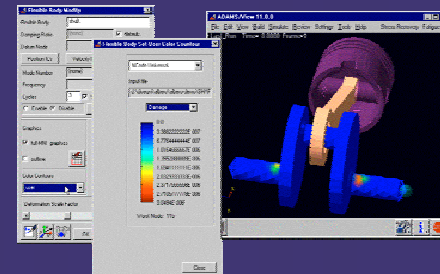
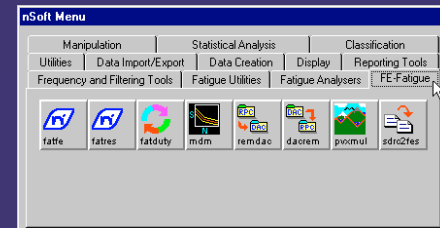
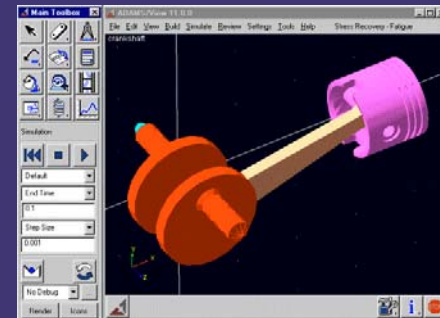
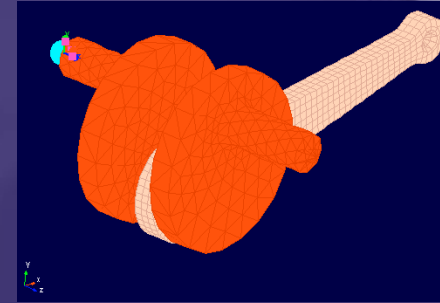
Integrated Process for Fatigue Computation

- The MSR and Fatigue Toolkit
 - ◆ Minimizes data transfer between FEA, ADAMS, and FE-Fatigue
 - ◆ Generates consistent set of information
- Possible user error is minimized
- Durability process is automated



Integrated Process for Fatigue Computation (cont.)

- Step One:
 - ◆ Mesh components
- Step Two:
 - ◆ Run FEA to generate mode and stress shapes -> data is written to the MNF-file
- Step Three:
 - ◆ Extract the stress shapes from the MNF-file to nCode's FES-file
- Step Four:
 - ◆ Run ADAMS to obtain the component load histories (in terms of Modal Coordinates) and write the modal coordinates into DAC file
- Step Five:
 - ◆ Run FE-Fatigue to calculate fatigue damage on all nodes
- Step Six:
 - ◆ Run ADAMS/PPT to display components' damage contours



Example Process: Modal Stress Recovery



- Computes and plots Stress Components and VonMises Invariant
- Displays color contours, most critical node and time step of occurrence

Flexible Body Modify

Flexible Body:

Damping Ratio: default

Datum Node: LBRF

Position ICs Velocity ICs Modal ICs

Mode Number: of 22

Frequency:

Cycles:

Enable Disable

Graphics

full MNF graphics

outline

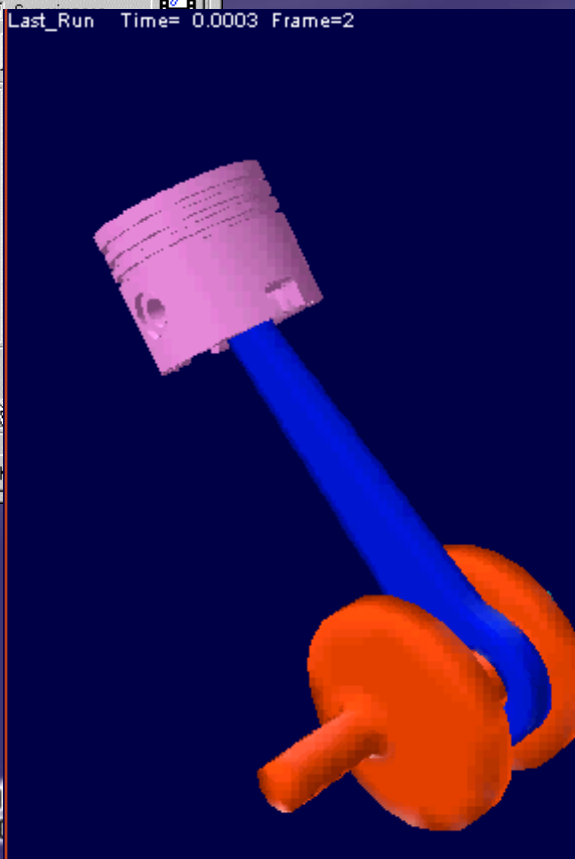
Color Contours

off

deformation

stress

user



Flexible Body:

Analysis:

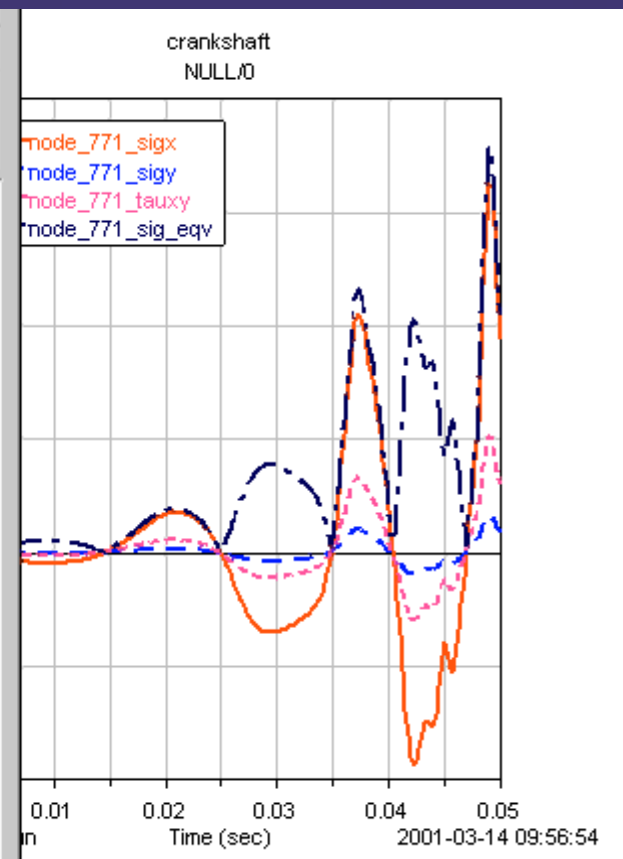
Von Mises

Stress units: newton/mm**2

0.0
9.9117
19.823
29.735
39.646
49.558
59.470
69.381
79.293
89.205

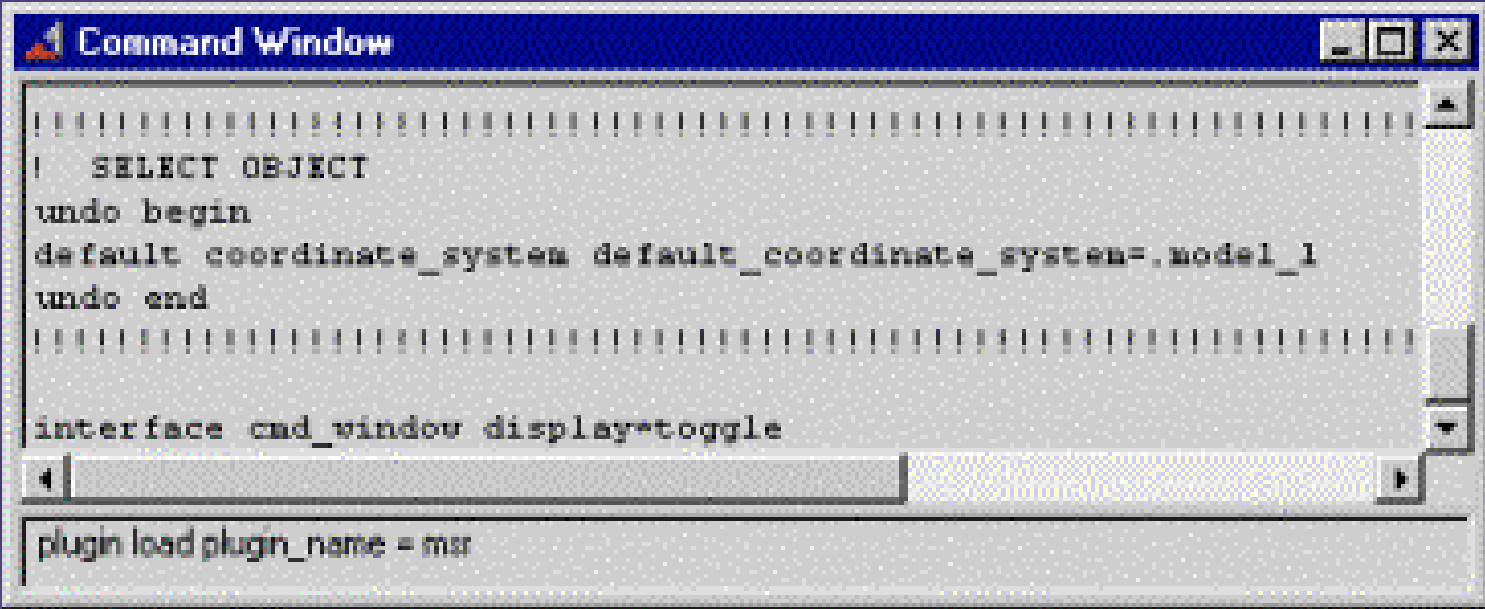
Max Stress Node: 771 at time: 4.9E-002

Min Stress Node: 20000 at time: 5.0E-002



Modal Stress Recovery Example 1/5

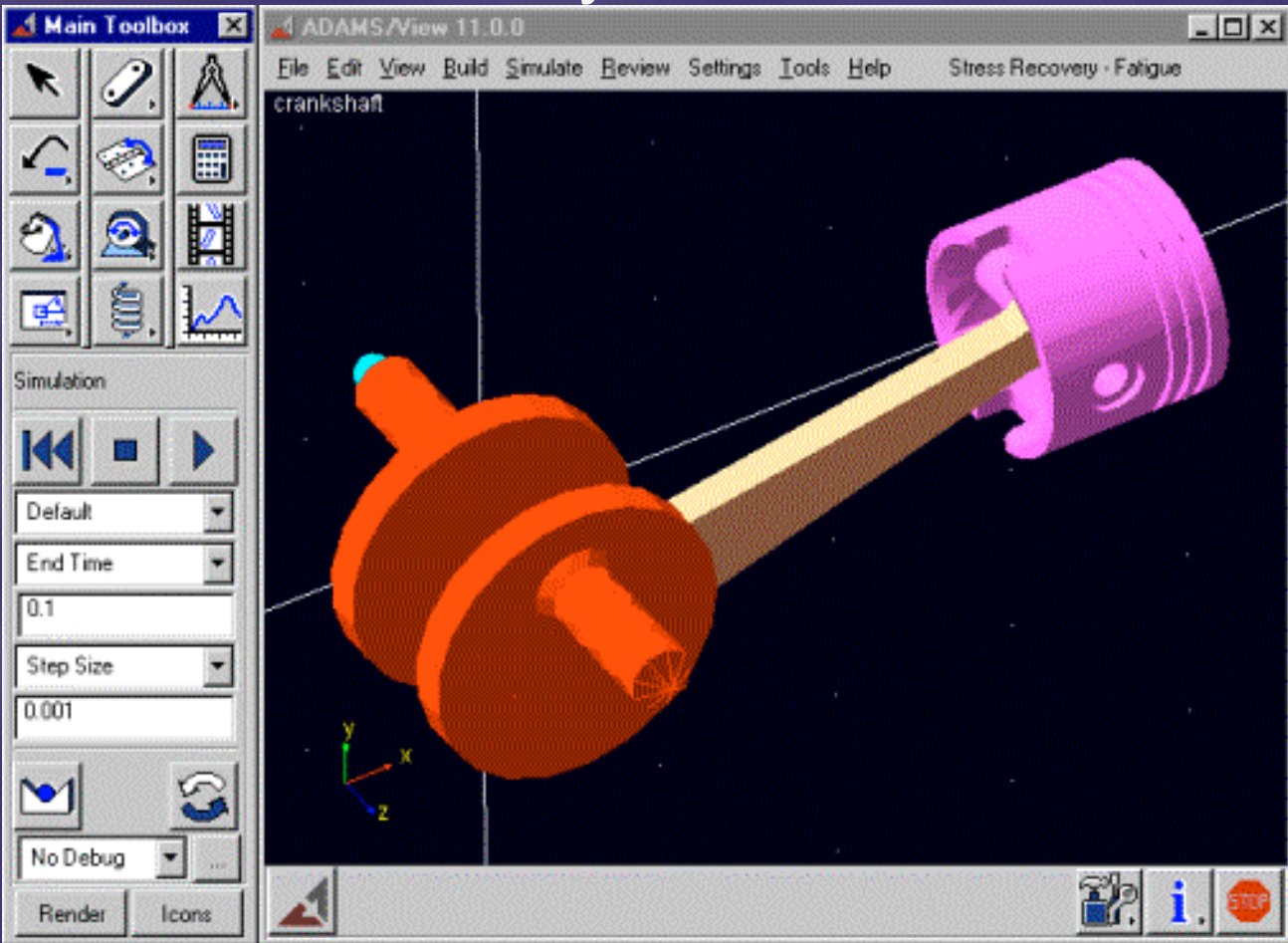
- Start ADAMS and load MSR-Fatigue Plug-In



```
Command Window  
| SELECT OBJECT  
undo begin  
default coordinate_system default_coordinate_system=.model_1  
undo end  
|  
interface cmd_window display*toggle  
|  
plugin load plugin_name = msr
```


Modal Stress Recovery Example 2/5

- Run ADAMS analysis



Modal Stress Recovery Example 3/5

- Animate Stresses on flex bodies

The screenshot shows the ADAMS software interface. The main window, 'ADAMS/View 11.0.0', displays a 3D model of a crankshaft with a color-coded stress distribution. The stress is highest at the crank pin and lowest at the crank web. The 'Flexible Body Animate Stress Color Map' window is open, showing a color scale for Von Mises stress. The scale ranges from 0.0 (blue) to 1.019782E+008 (red). The 'Flexible Body Modify' window is also open, showing settings for the flexible body 'bielle'. The 'Flexible Body Animate Stress Color Map' window has the following settings:

- Flexible Body: bielle
- Stress Results: Von Mises
- Analysis: crankshaft.Last_Run
- Stress Values:
 - 0.0
 - 1.1330911111E+007
 - 2.2661822222E+007
 - 3.3992733333E+007
 - 4.5323644444E+007
 - 5.6654555555E+007
 - 6.7985466667E+007
 - 7.9316377778E+007
 - 9.0647288889E+007
 - 1.019782E+008
- Max Stress Node: 768 at time: 9.4E-01
- Min Stress Node: 20000 at time: 0.1

Stresses are computed for display purposes only, not stored as result sets

Modal Stress Recovery Example 4/5

- Compute and store stress/strain components at selected nodes

Compute Nodal Stress Components

Flexible body:

Analysis:

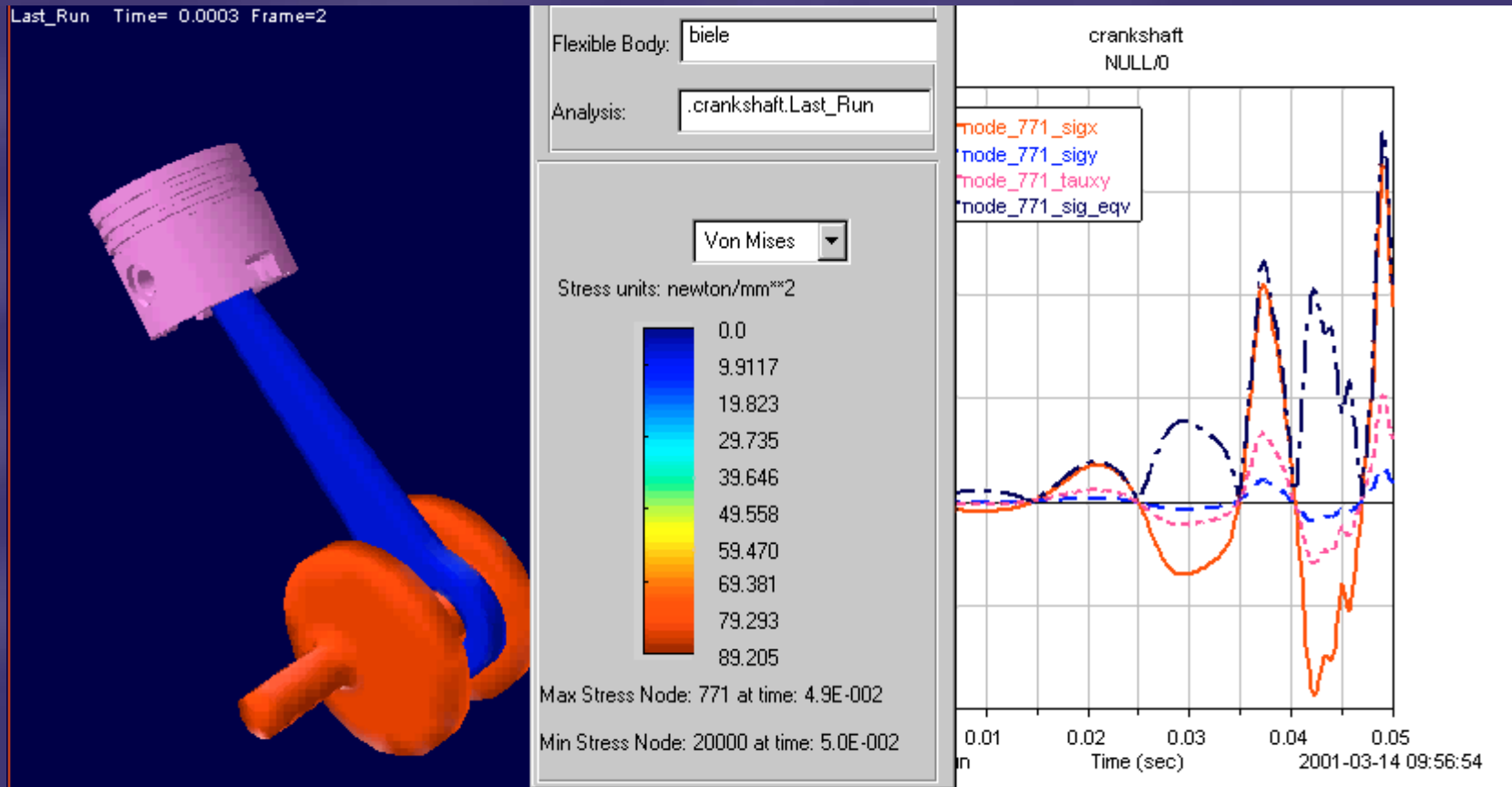
Node to add to select list:

Selected Nodes list:

sigma Von Mises
 sigma x
 sigma y
 sigma z
 tau xy
 tau yz
 tau zx

Modal Stress Recovery Example 5/5

- Plot nodal stresses



Example Process:

Durability Analysis with FE-Fatigue

- Computes and displays nCode FLP results within ADAMS/PPT

The screenshot displays the ADAMS software interface with three main windows:

- Flexible Body Modify:** Shows settings for the flexible body 'shaft', including Damping Ratio (none), Datum Node, Position ICs, Velocity ICs, Mode Number (none), Frequency, Cycles (3), and options to Enable or Disable the analysis.
- ADAMS/View 11.0.0:** The central 3D view showing a shaft assembly with a color contour plot. The shaft is primarily blue, indicating low damage, with some yellow and red spots indicating higher damage levels. A coordinate system (X, Y, Z) is visible at the bottom left.
- Flexible Body Set User Color Countour:** A window showing the nCode Universal interface. It displays the input file path 'd:\disegni\albero\albero-demo\SHAF' and a color scale for 'Damage' ranging from 0.0 (blue) to 3.0494E-006 (red). The 'Worst Node' is identified as 115.

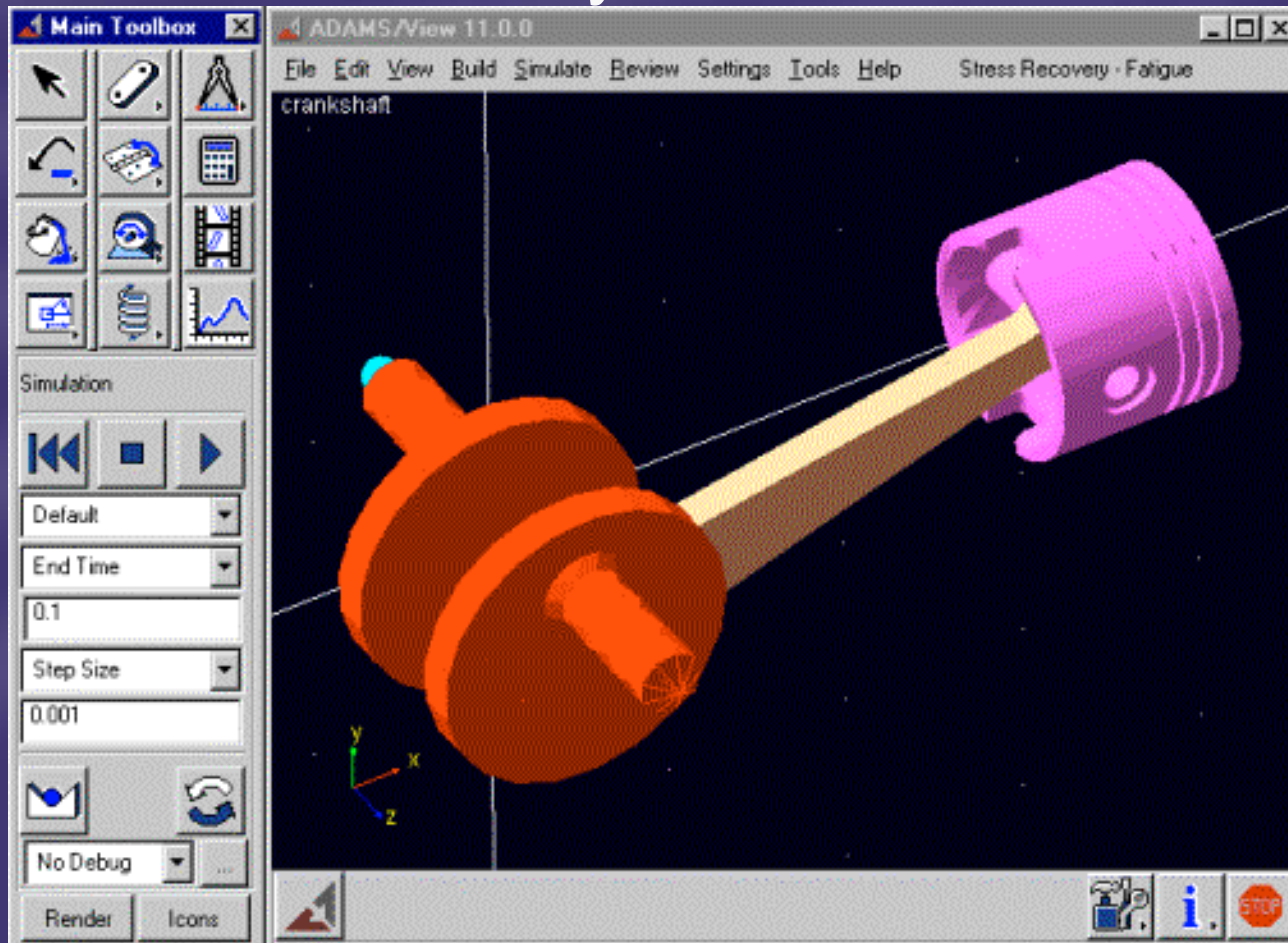
FE-Fatigue Example 1/10

- Start ADAMS and load MSR-Fatigue Plug-In

```
Command Window  
| SELECT OBJECT  
undo begin  
default coordinate_system default_coordinate_system=.model_1  
undo end  
|  
interface cmd_window display*toggle  
|  
plugin load plugin_name = msr
```

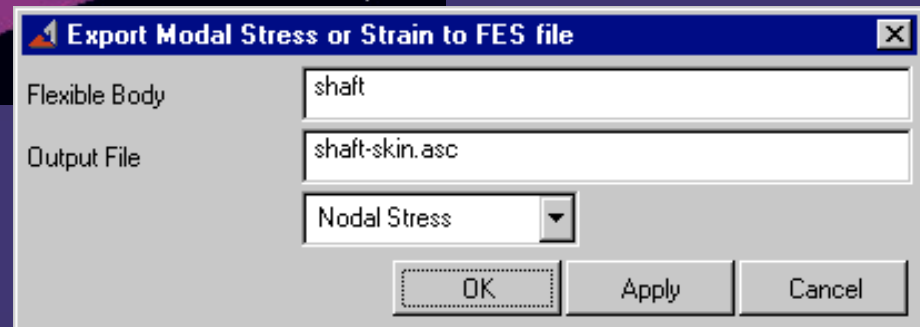
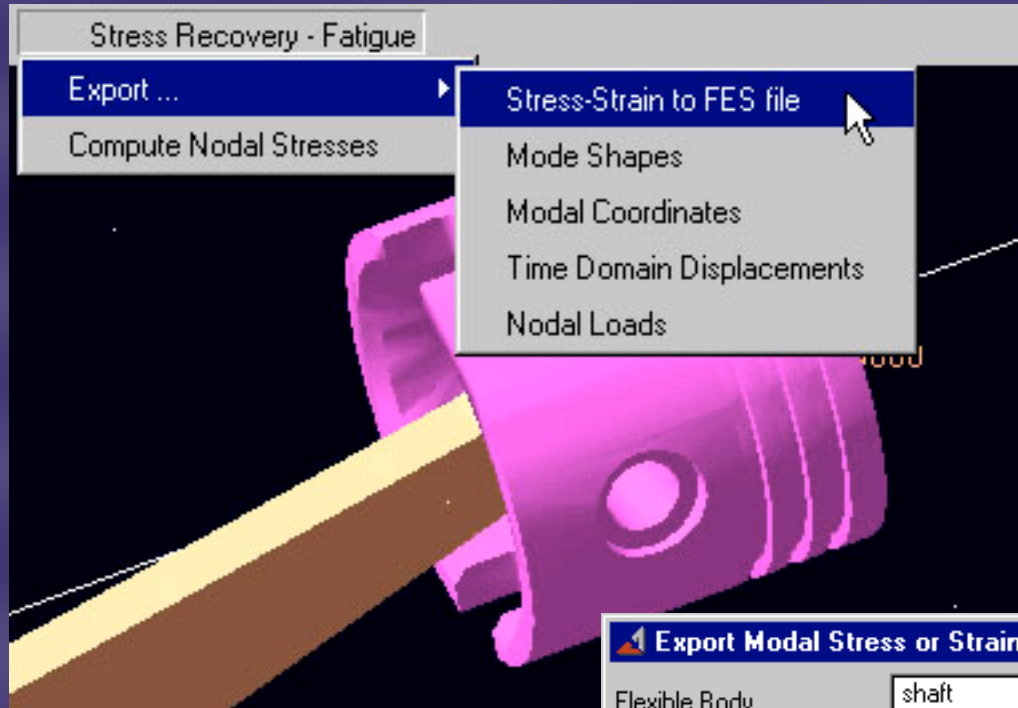
FE-Fatigue Example 2/10

- Run ADAMS analysis



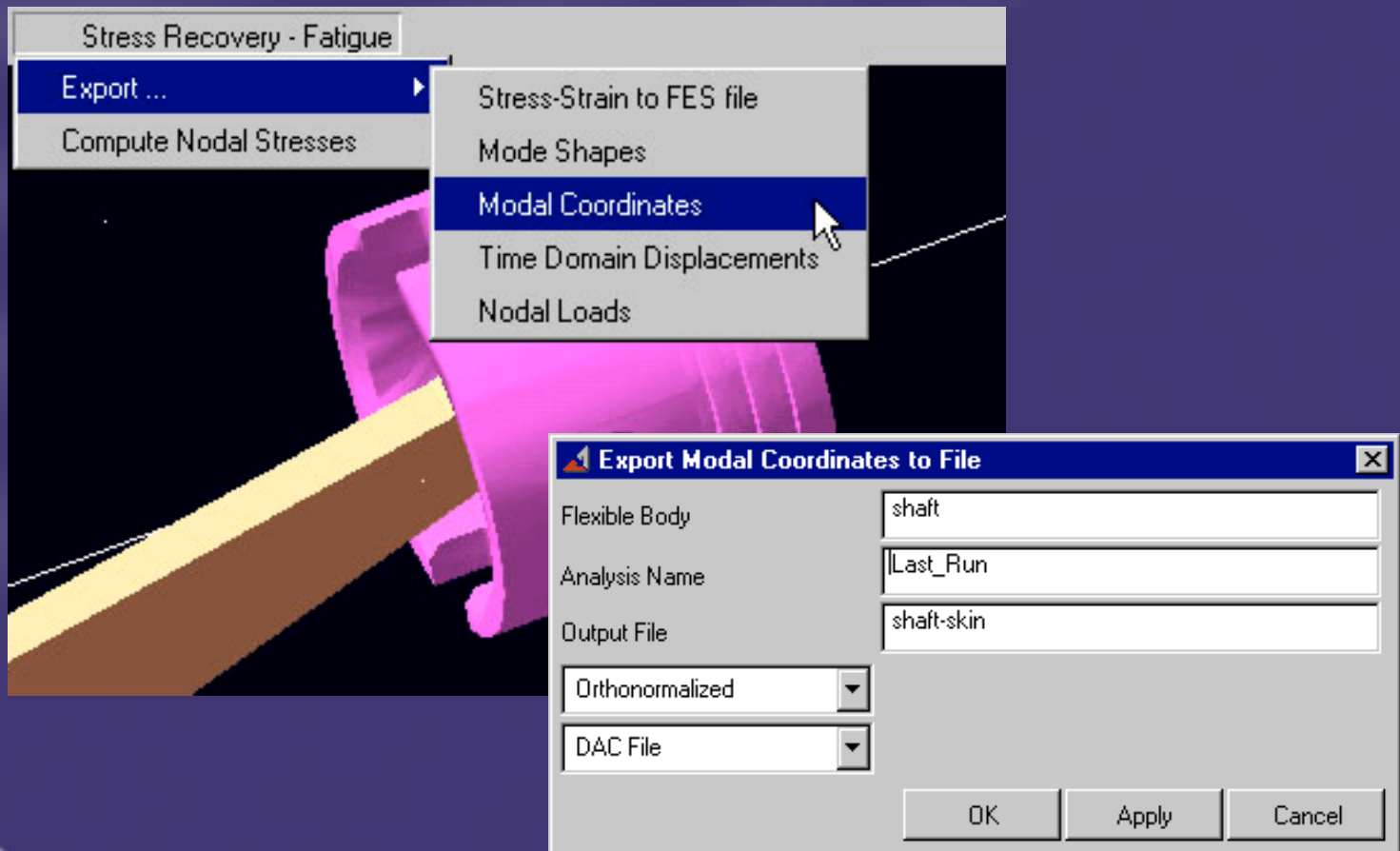
FE-Fatigue Example 3/10

- Export stress shape function to partial FES file



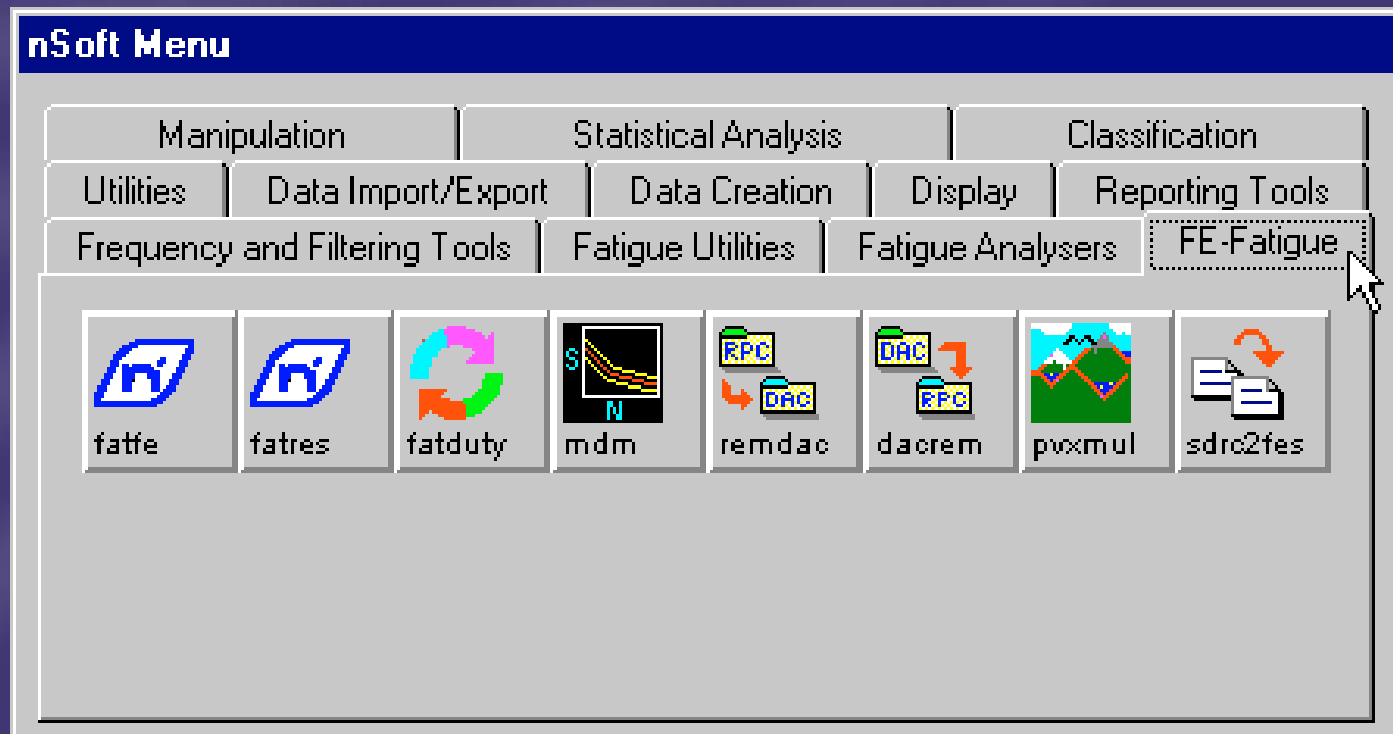
FE-Fatigue Example 4/10

- Export load histories (in terms of Modal Coordinates) to DAC files



FE-Fatigue Example 5/10

- Start nCode software, set working directory, and select FE-Fatigue task



FE-Fatigue Example 6/10

- Specify analysis type

FATFE - Partial to Full FES Completion

Job Name: SHAFT-SKIN

Description: job string 1

Analysis Type: S-N Analysis

Stress Units: Pascals

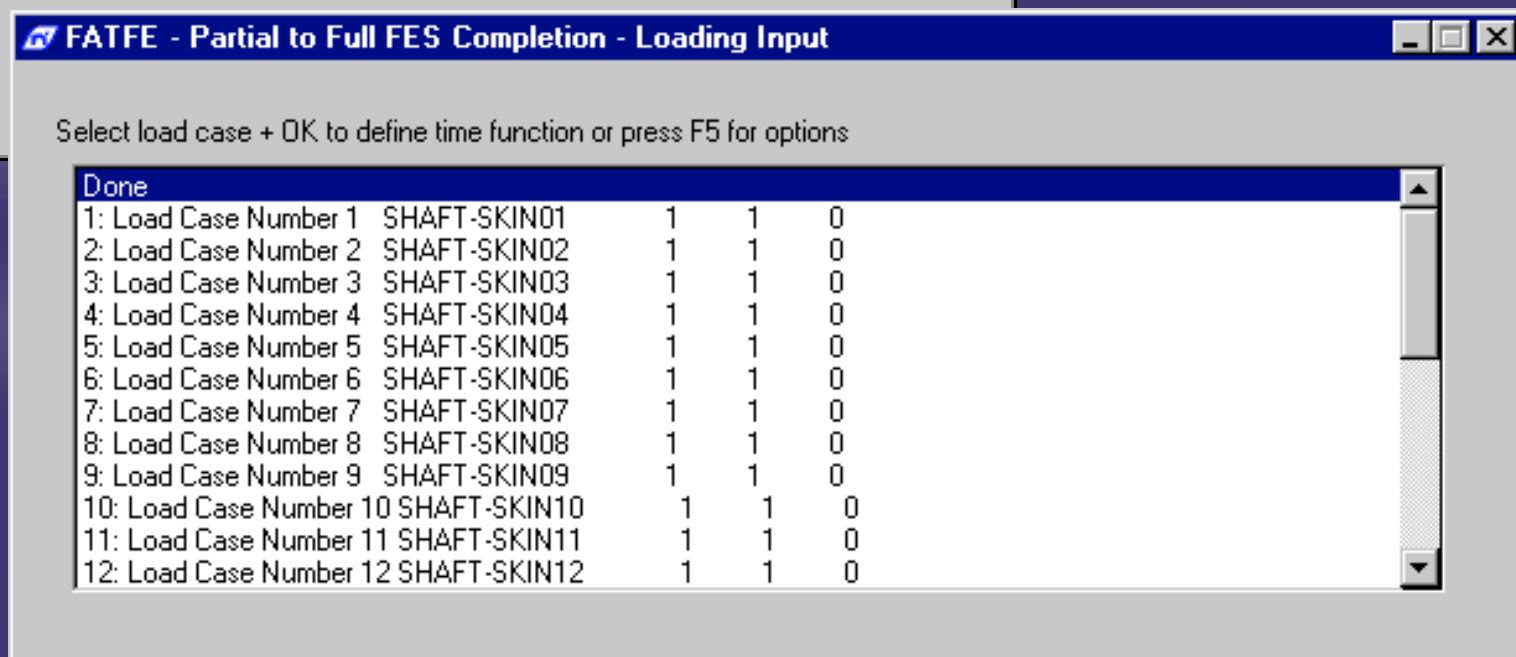
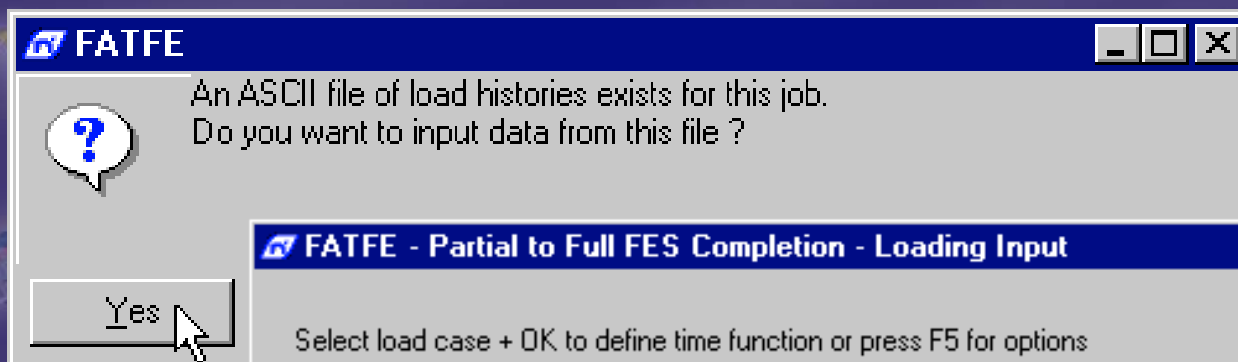
Time step data type: Elastic

Advanced Options: Yes No

OK Cancel Help

FE-Fatigue Example 7/10

- Use output from previous ADAMS run as loading input



FE-Fatigue Example 8/10

- Select material from database

FATFE - Partial to Full FES Completion - Material Input

Select Material/Group + OK or press F5 for options

Group 1

Method: Group 1

Material name:

Strength reduction (Kf):

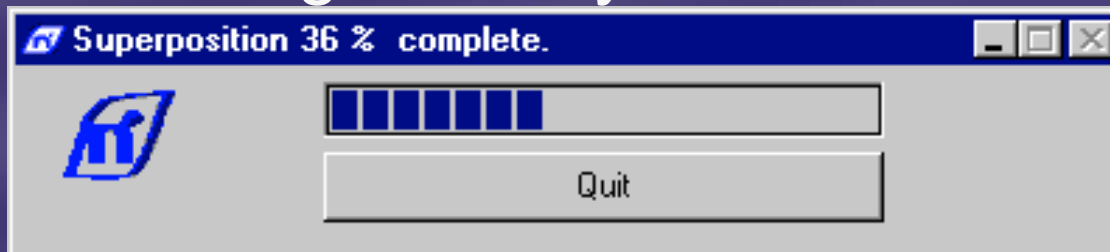
Surface Finish:

Surface Treatment:

Scale factor:

FE-Fatigue Example 9/10

- Run Fatigue Analysis



A screenshot of a table titled "Global Results - Ten Most Damaged Nodes". The table has five columns: Node, Damage, Life (Repeats), Ave. Ratio, and S.D. Ratio. The data is as follows:

Node	Damage	Life (Repeats)	Ave. Ratio	S.D. Ratio
115	3.0494E-6	3.279E5	0.208	0.311
194	3.0026E-6	3.33E5	0.037	0.183
503	1.9107E-6	5.234E5	0.048	0.122
427	4.8285E-7	2.071E6	0.14	8.25E-3
186	4.5523E-7	2.197E6	-0.0201	0.254
495	2.1068E-7	4.746E6	0.0291	0.152
187	1.735E-7	5.764E6	0.0693	0.122
89	1.5845E-7	6.311E6	0.246	0.214
401	1.5845E-7	6.311E6	0.24	9.63E-3
88	9.74E-8	1.027E7	0.198	0.0787

At the bottom of the dialog, there are three buttons: "OK" (with a green checkmark icon), "Cancel" (with a red X icon), and "Help" (with a question mark icon).

FE-Fatigue Example 10/10

- Display Damage Contours in ADAMS/PPT

The screenshot displays the ADAMS software interface with three main windows:

- Flexible Body Modify:** Shows settings for a flexible body named 'shaft'. The 'Cycles' field is set to 3, and the 'Enable' radio button is selected. Under 'Graphics', 'full MNF graphics' is checked, and 'Color Contours' is set to 'user'.
- Flexible Body Set User Color Countour:** A dialog box for configuring the damage color scale. It shows a color gradient from blue (0.0) to red (3.0494E-006). The 'Worst Node' is identified as 115.
- ADAMS/View 11.0.0:** The main 3D view window showing a mechanical assembly with damage contours. The shaft and gears are rendered in blue and purple, with damage contours overlaid in yellow and red.

Supported Configurations



- ADAMS 11.0
- Operating systems
 - ◆ Windows NT 4.0 and Windows 2000
 - ◆ IRIX 6.5 32 and 64 bit
- NASTRAN 70.5 and 70.7
- ANSYS 5.6 and 5.7
- FE-Fatigue 2.0



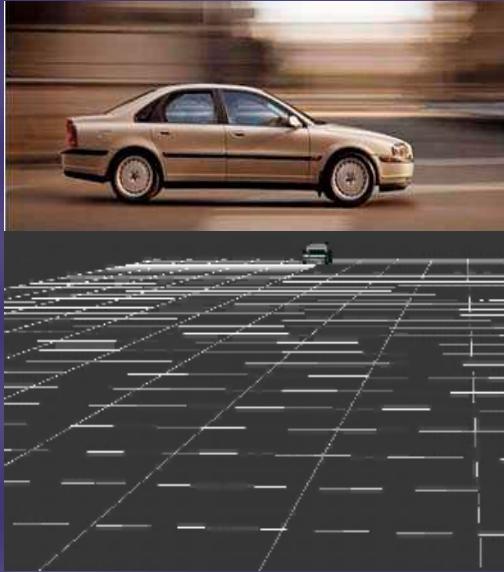
Summary

- The MSR and Fatigue Toolkit allows stress and fatigue evaluation within an integrated environment
- Switching between different tools is reduced to a minimum
- Process improvement in terms of efficiency and quality
- The Modal Stress Recovery Toolkit is available free of charge for all ADAMS/Durability users
 - ◆ preview of 12.0 functionality

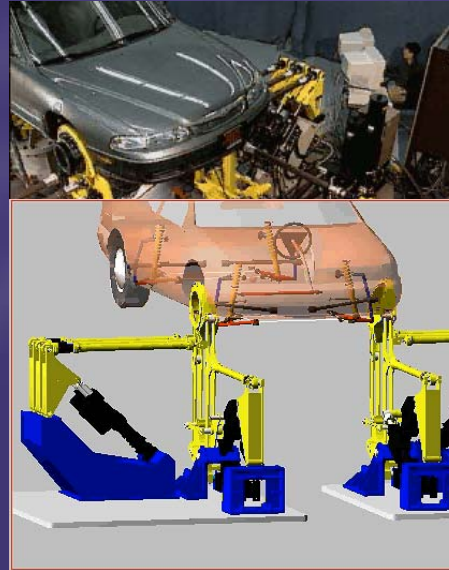


Integrated Durability Process

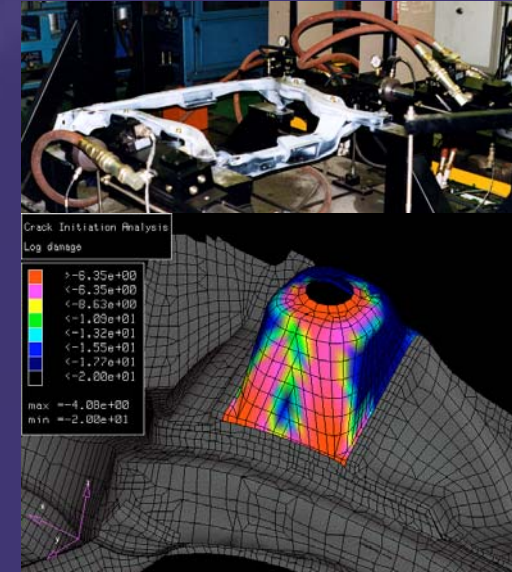
Test Track



Full Vehicle Test Lab



Component Test Lab



- Seamless transition
 - ◆ from test track to test labs
 - ◆ from virtual to real
- nCode, MDI, and MTS are available to accelerate the integration process

Appendix

- Principles of Modal Stress Recovery



Principles of Modal Stress Recovery

Assuming that the reduction of the full set of Mode Shapes of the Flexible Body to a sub-set is correct and comprehensive of all the required effects, the Stress Distribution related to the body deformation can be calculated as:

Stress Mode Shapes Method

$$\{\sigma\} = [\Phi_\sigma] \cdot \{p\}$$

$$[\phi_\sigma] = [\{\phi_\sigma\}_1, \dots, \{\phi_\sigma\}_{P+S}]$$

ortho-normalized **Modal Stress Matrix**

$\{\phi_\sigma\}_1 \dots P+S$ (P=number of Normal Constrained Modes S = number of Static Correction Modes)

$\{\phi_u\}_1 \dots P+S$ (P=number of Normal Constrained Modes S = number of Static Correction Modes)

$\{p\}$ Vector of Modal Coordinates

$\{\sigma\}$ Stress Component Matrix



Principles of Modal Stress Recovery

■ FE Calculation

- ◆ Component Mode Synthesis, Craig Bampton
 - Normal Modes
 - Static Correction Modes
 - Residual Vectors for Distributed/Inertial/Thermal Loads
- ◆ Modal Stress (and/or) Strain Tensors
- ◆ .mnf file generation

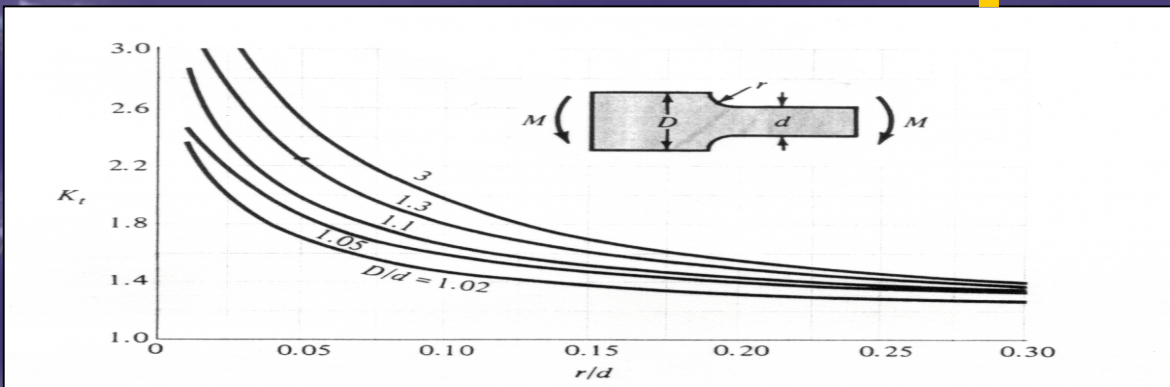
■ Flexible Bodies in ADAMS

- ◆ Correct Mechanism Dynamics
- ◆ Correct Internal Deformations in the Flexible Component
- ◆ Correct Boundary Loads and Constraints
- ◆ Modal Coordinates

■ Stress/Strain Computation

- ◆ Combining Modal Coordinates with Modal Precomputed (Stress/Strain) Tensors
- ◆ Post Processing in the most popular FE graphic programs and in ADAMS
 - Stress/Strain Time History
 - Stress/Strain Animation

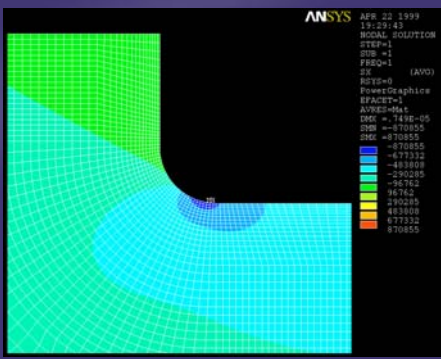
Principles of Modal Stress Recovery - Example



Material	Young Modulus (N/m ²)	D (m)	d (m)	r (m)	s (m)	M (N m)
Steel	2.1E11	5.0E-2	3.85E-2	2E-3	1.0E-2	1

	Stress (N/m ²)	K_t
ANSYS Node 408	887 580	2.192
ANSYS Node 4040	404 870	
ADAMS Node 408	873 400	2.164
ADAMS Node 4040	403 600	

ANSYS



ADAMS

