Streamlining Stress and Fatigue Evaluation of Mechanical Systems

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Mechanical Dynamics

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

the SmartSim community

Defining the Future of Virtual and Physical Prototyping

Partnership Goals

- 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

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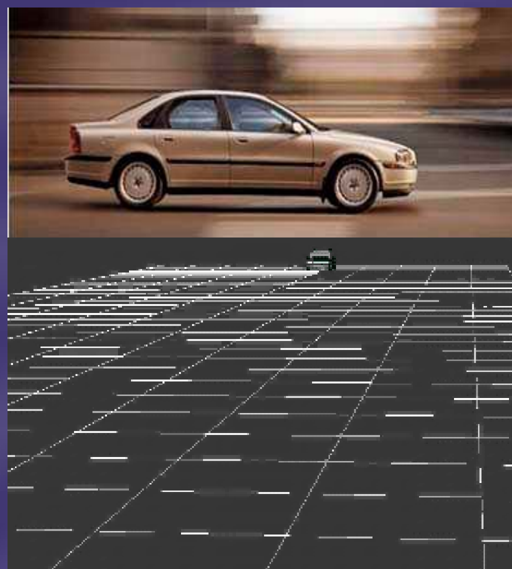
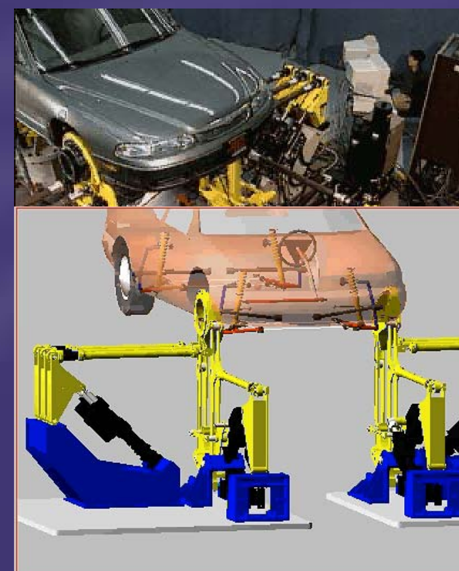
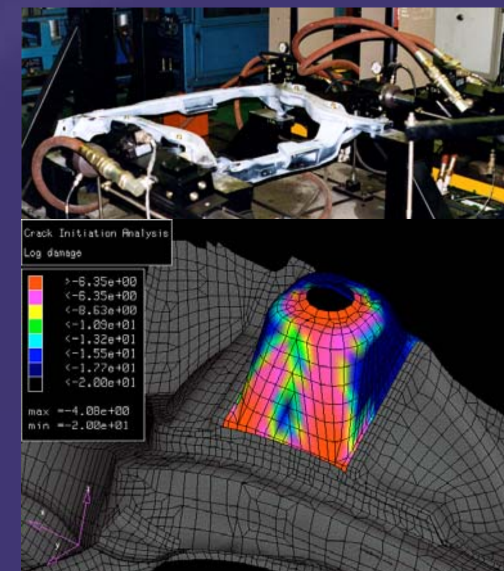
Integrated Durability Process

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

GENERIC	AUTOMOTIVE
ADAMS/FullSim	ADAMS/Car
ADAMS/Durability	ADAMS/Driveline
Finite Element Programm	ADAMS/Engine
FE-Fatigue	

EXTENSIONS

GENERIC	AUTOMOTIVE
ADAMS/Flex	ADAMS/Tire FTire
ADAMS/EDM	Virtual Test Lab

DYNAMIC DESIGNER ADAMS

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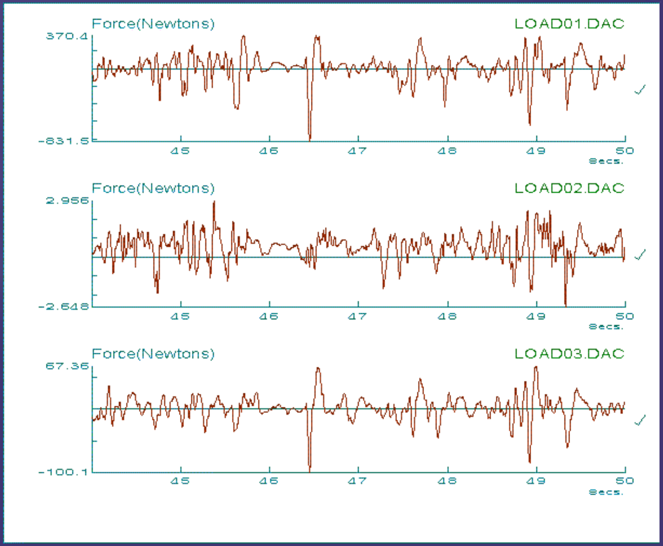
ADAMS/Durability

- 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



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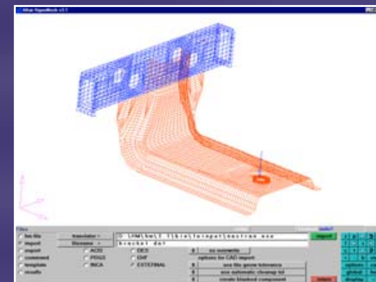
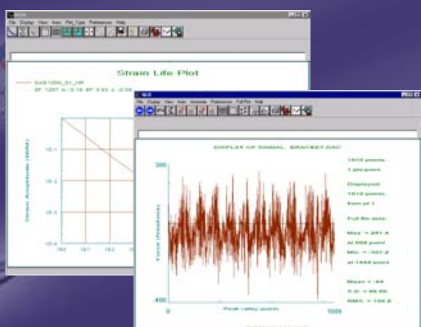
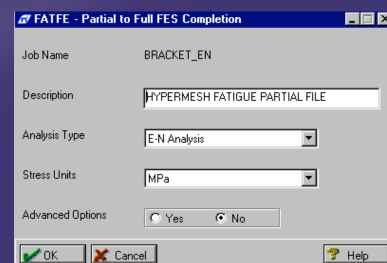
FE-Fatigue

FE stress/strains



View model and stress/strains in Pre/Post Processor

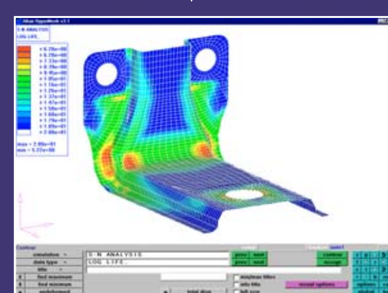




nCode

FE-Fatigue

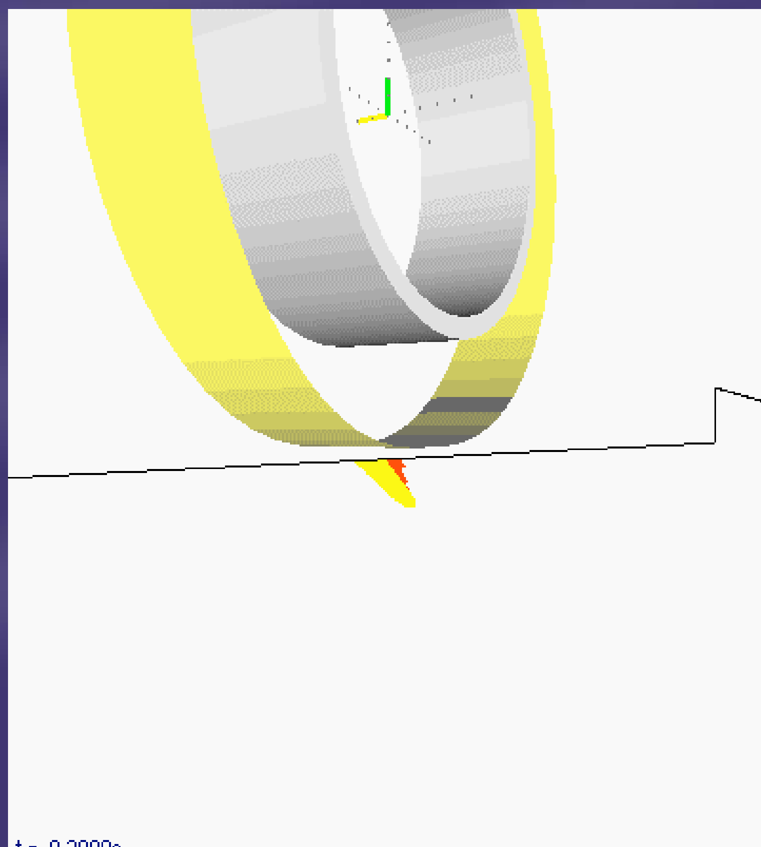
Load and Material information

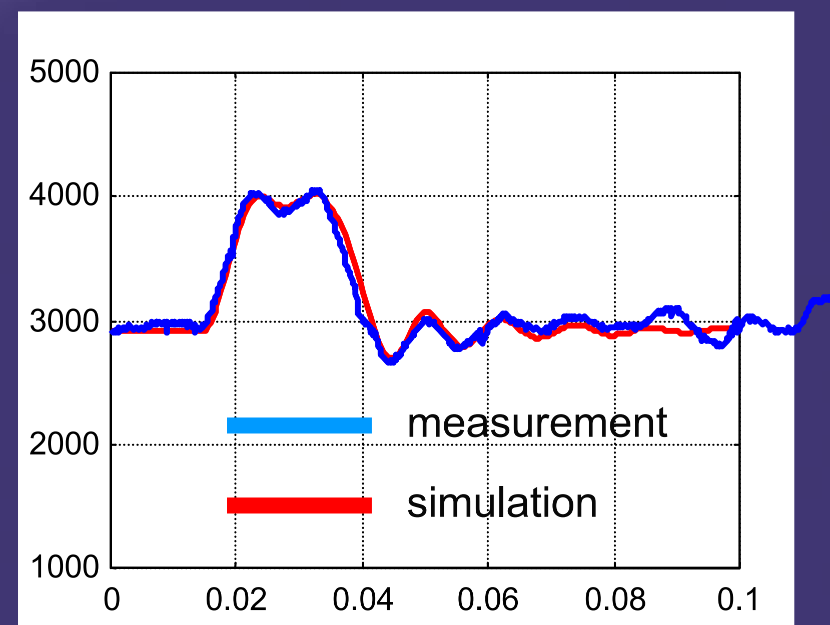


Post process fatigue results

ADAMS/Tire FTire

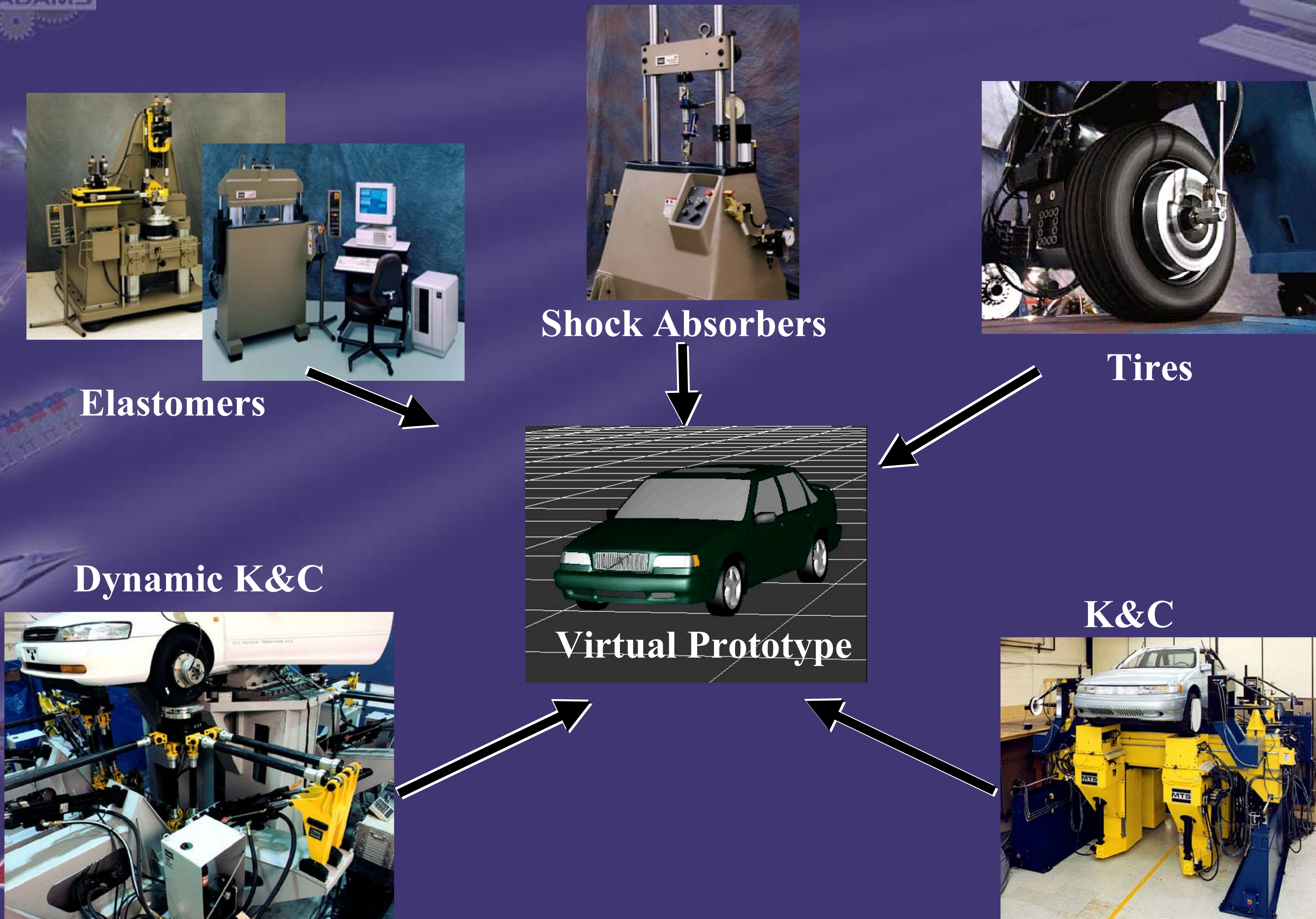
- Tire model for NVH and durability applications





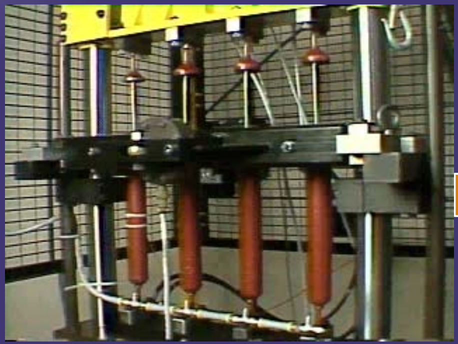
wheel load [N]

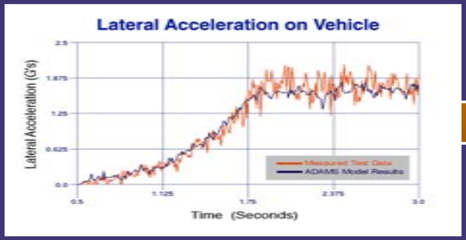
Empirical Dynamic Model (EDM)

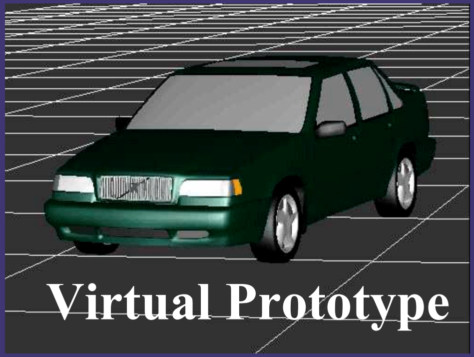


Empirical Dynamic Model

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

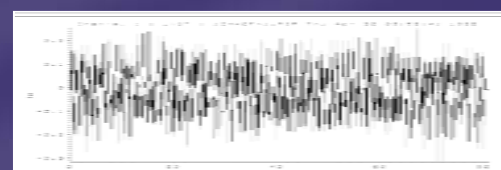




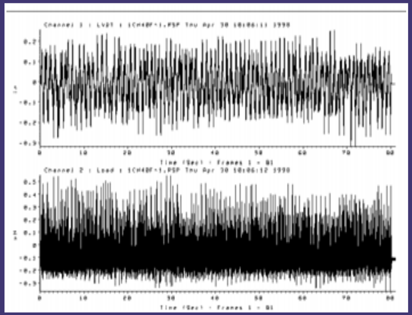


Empirical Dynamic Model

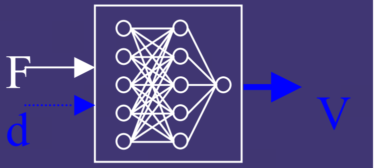
- Support of EDM
  - ADAMS/View
  - ADAMS/Car
  - ADAMS/Pre



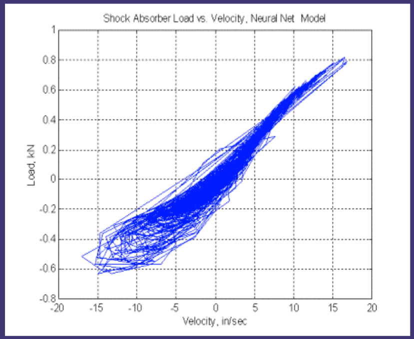
Random Displacement Command



Measured Force and Displacement

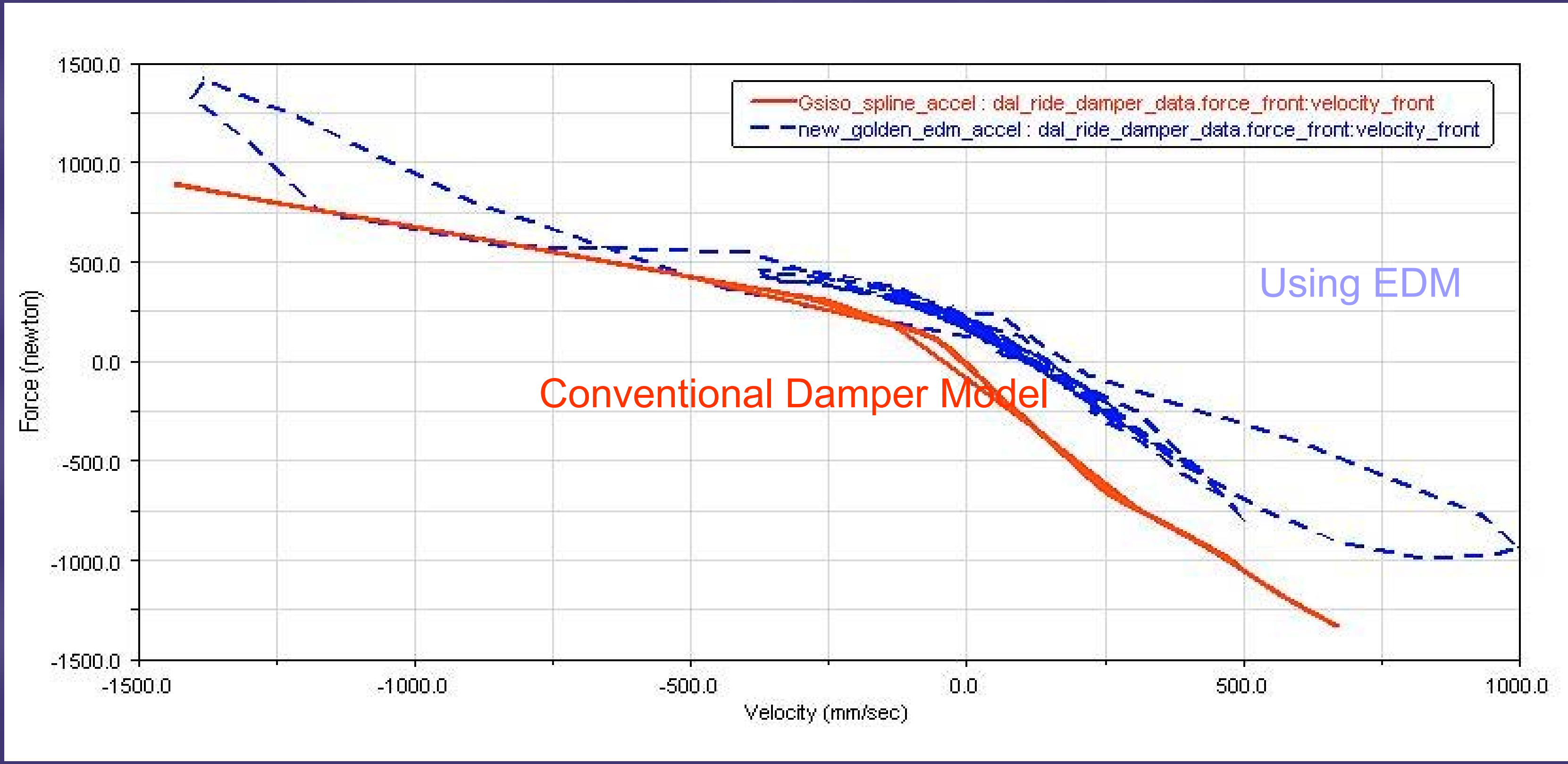


Model Build



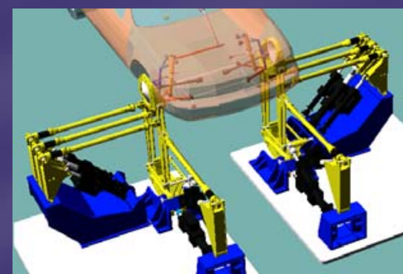
Predicted Results

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

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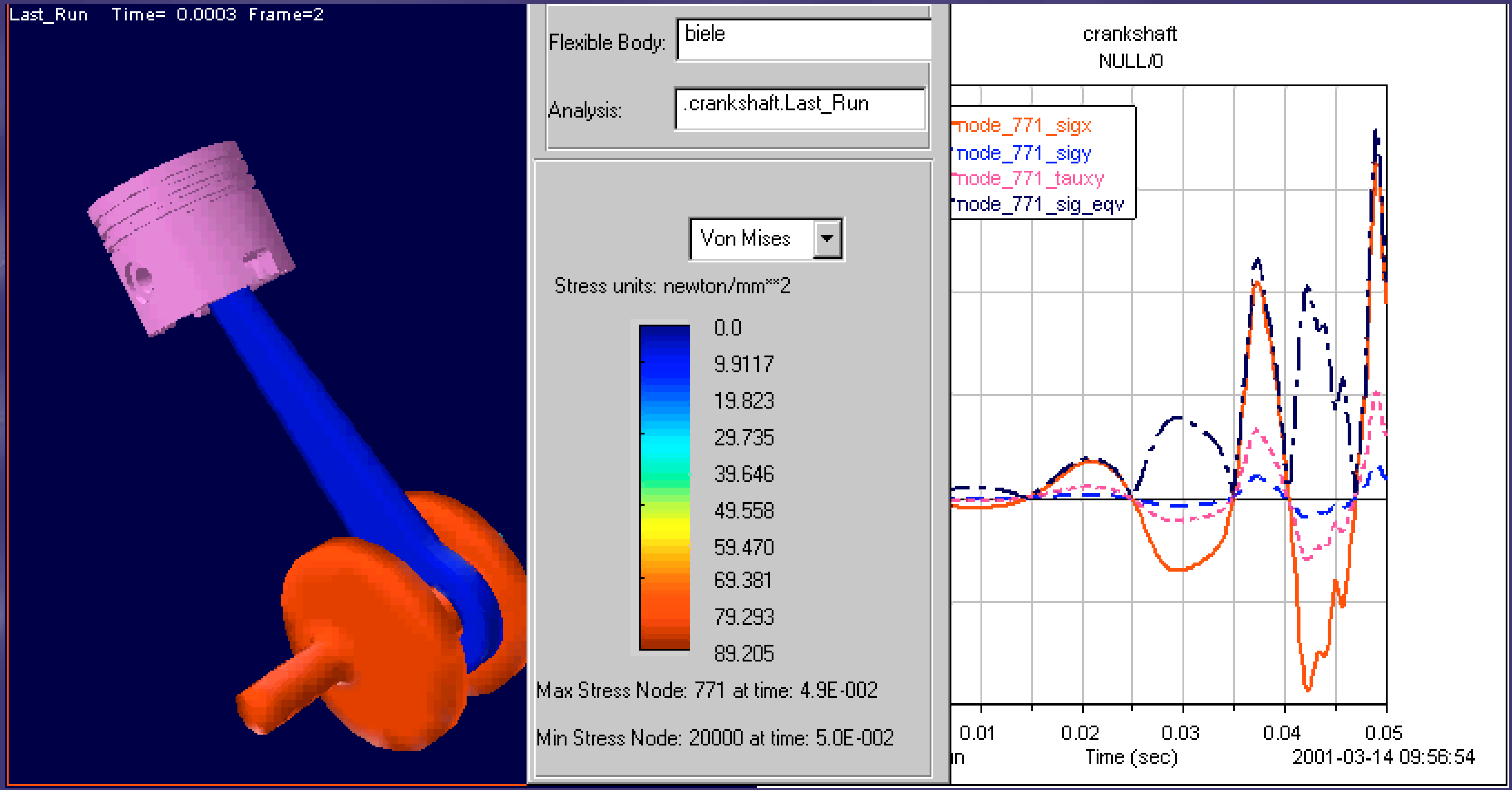
VTL Application Table

Input	Test Rig Model	Applications
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

The Modal Stress Recovery (MSR) Toolkit

- Streamlines stress and fatigue evaluation



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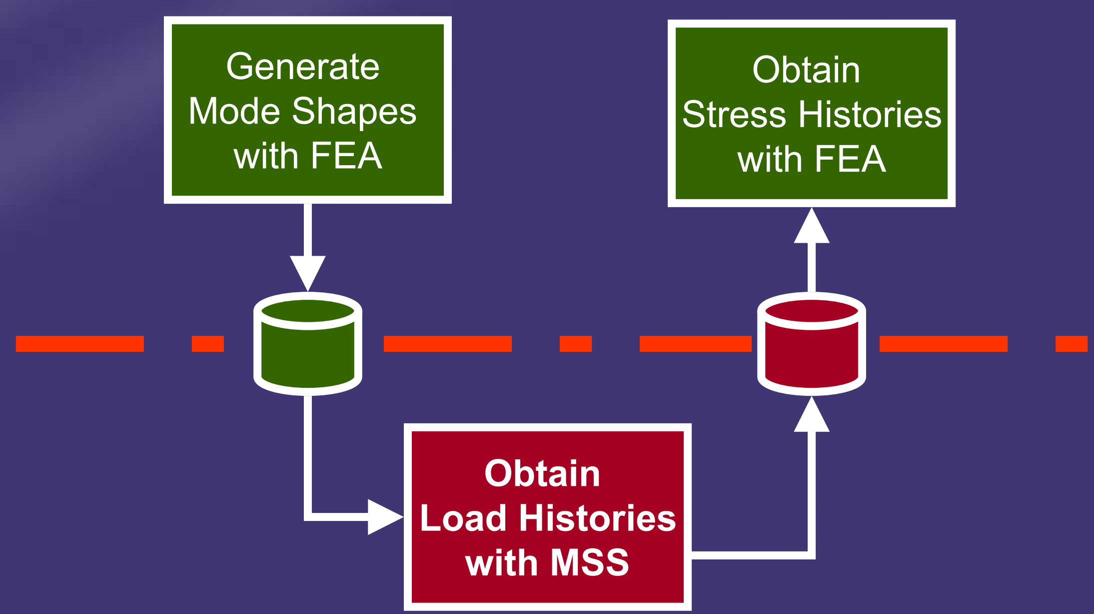
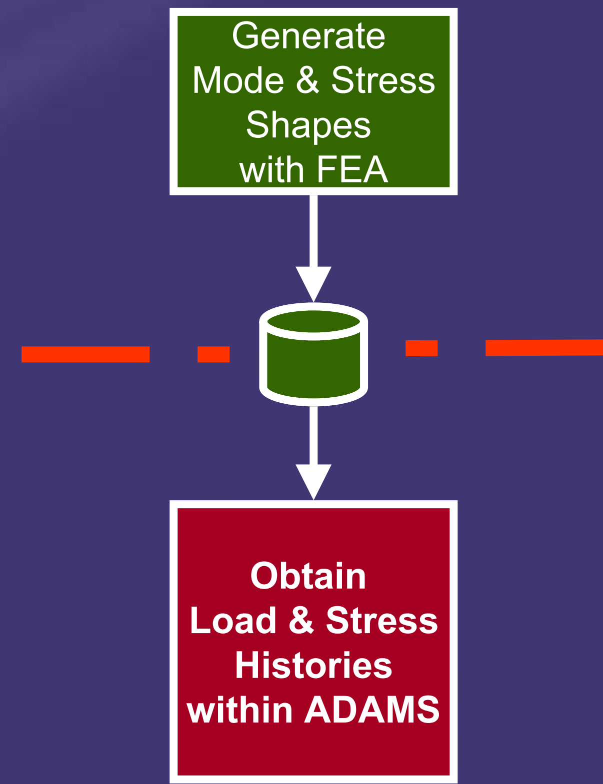
Common Process for Stress Computation

- 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



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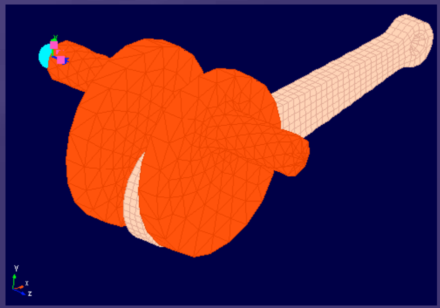
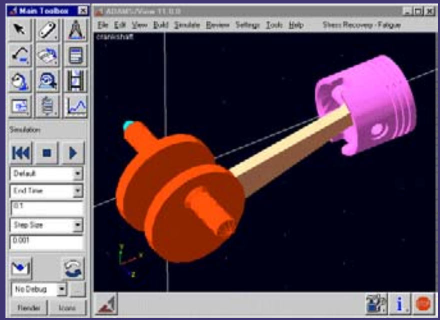
Integrated Process for Stress Computation (cont.)

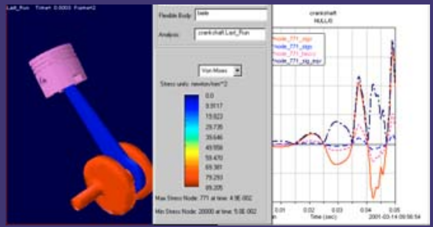
- Step One:
  - Mesh components



- 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



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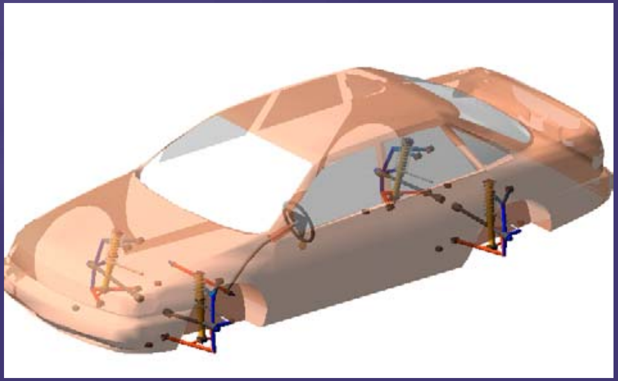
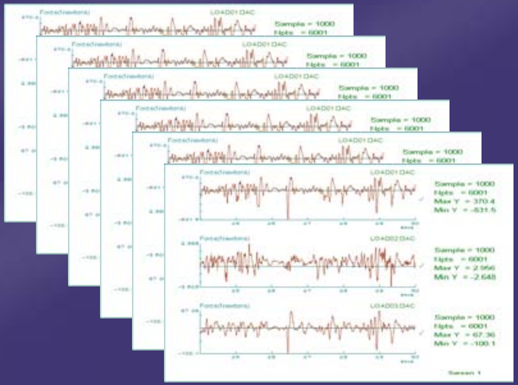
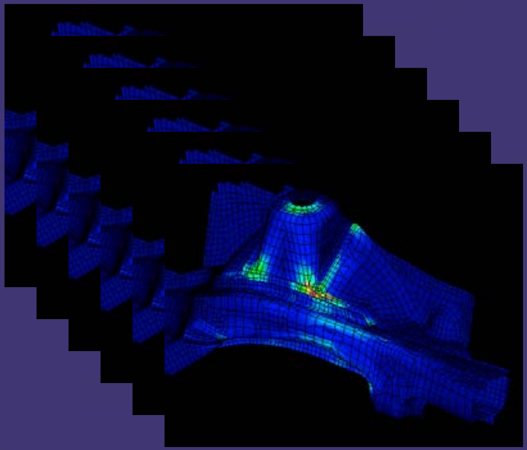
Data Handling Issues in Fatigue Analysis

- 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

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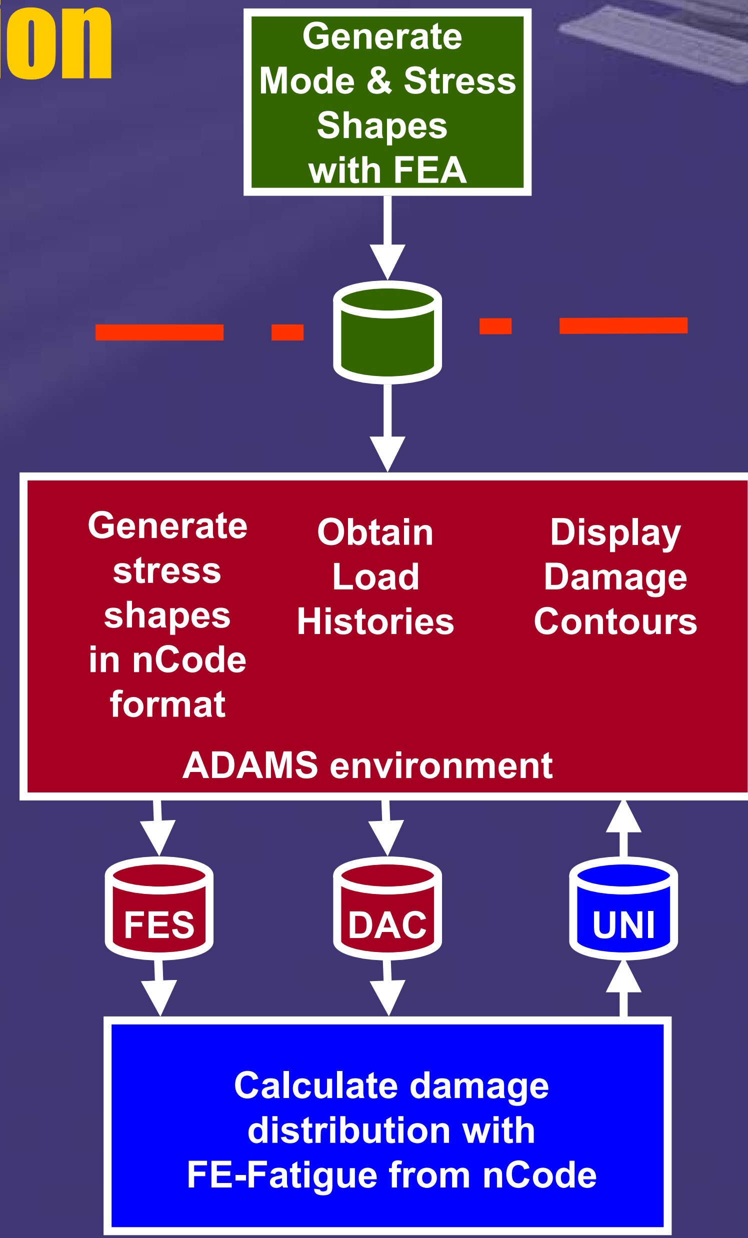
Integrated Process for Fatigue Computation

- 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



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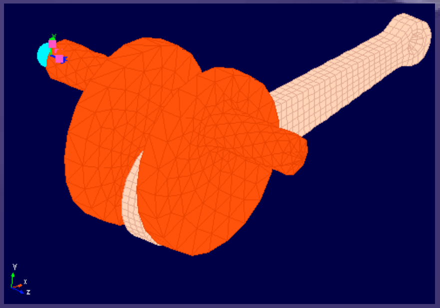
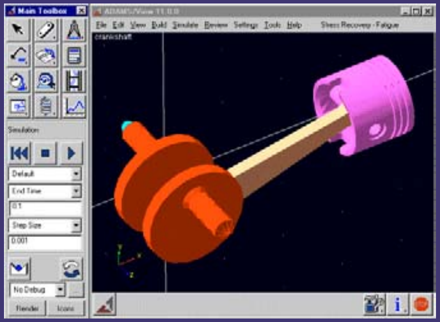
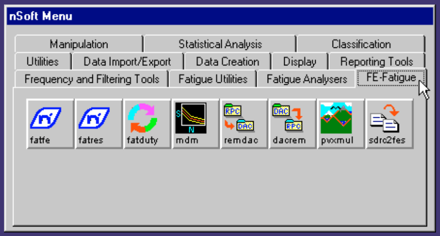
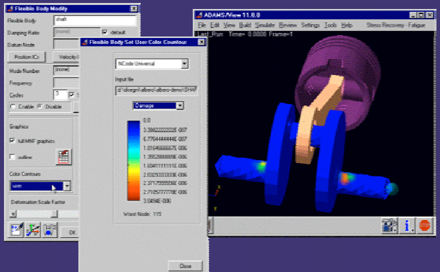
Integrated Process for Fatigue Computation (cont.)

- 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









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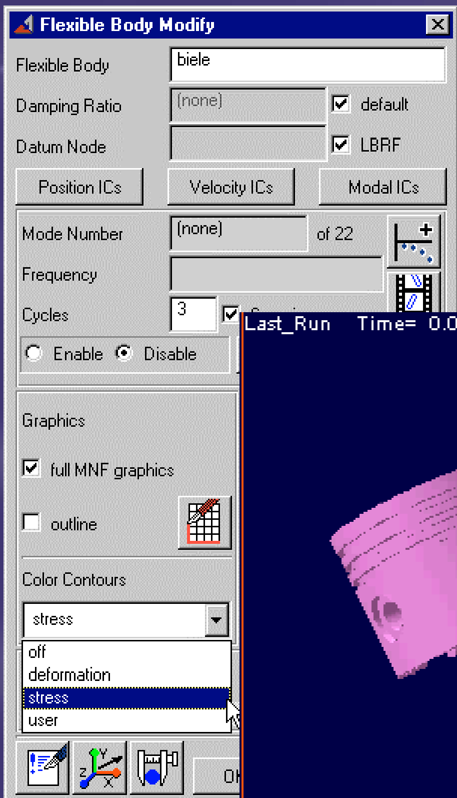
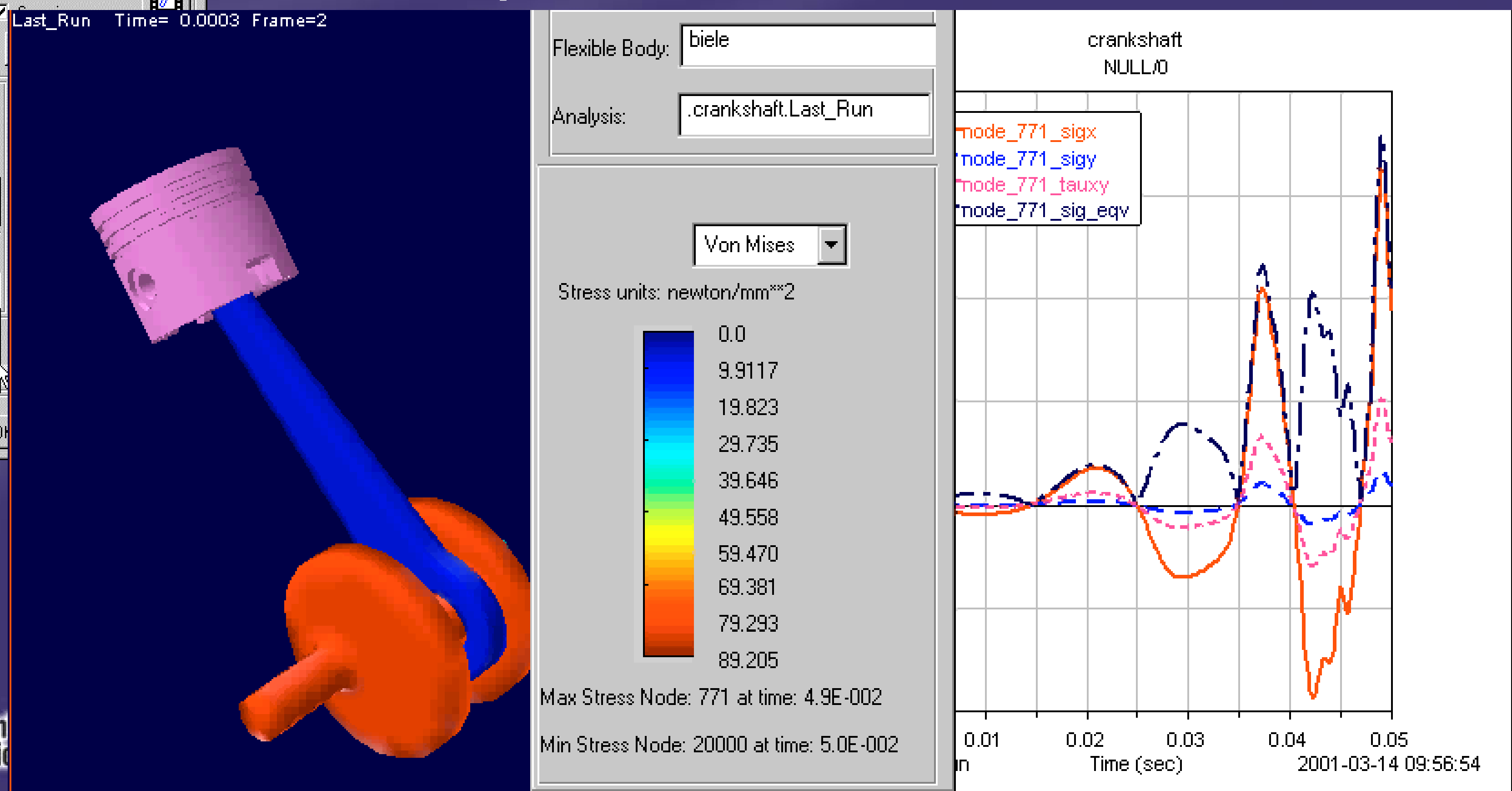
Example Process: Modal Stress Recovery

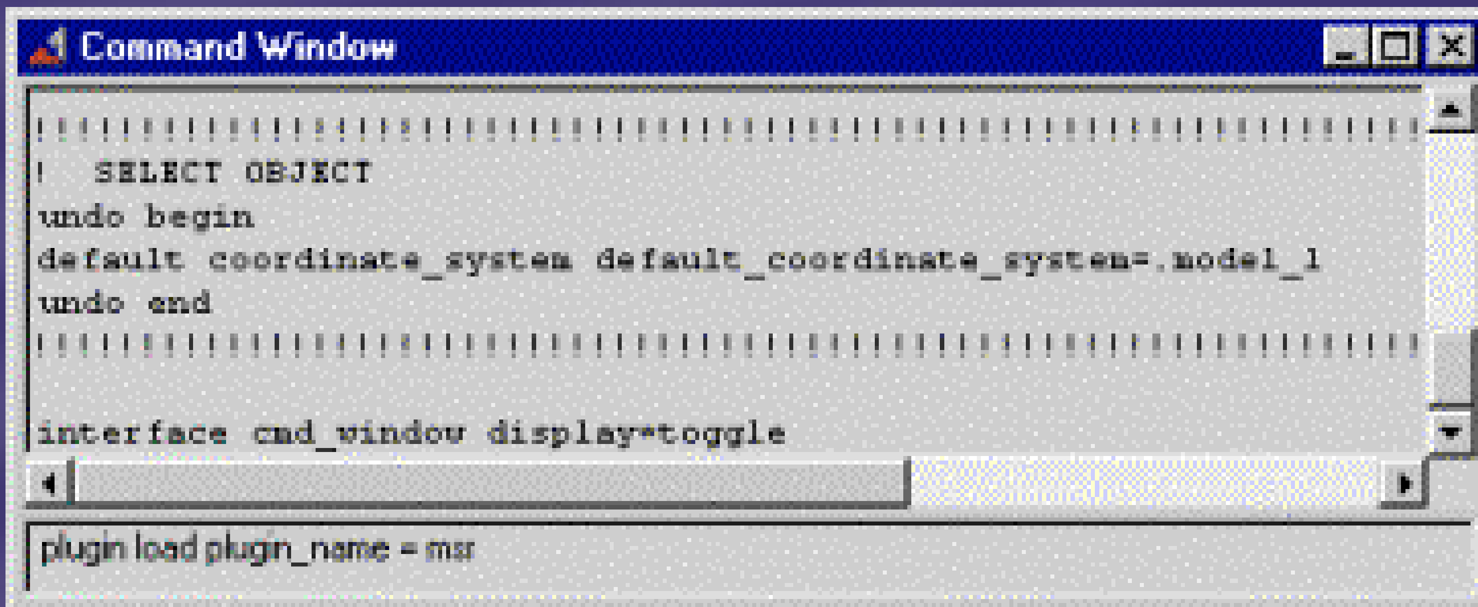
- Computes and plots Stress Components and VonMises Invariant
- Displays color contours, most critical node and time step of occurrance





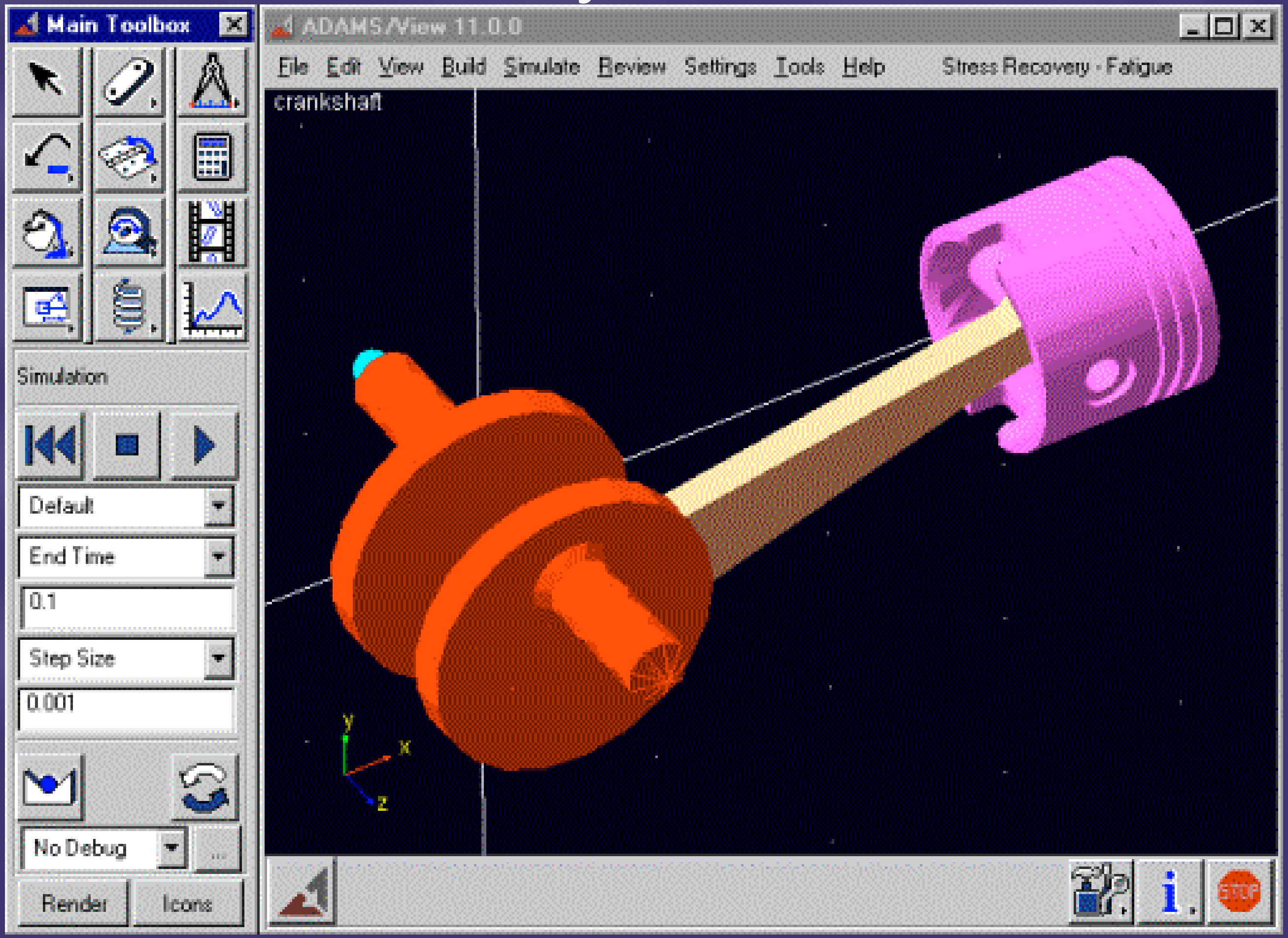
Modal Stress Recovery Example 1/5

- Start ADAMS and load MSR-Fatigue Plug-In



Modal Stress Recovery Example 2/5

- Run ADAMS analysis



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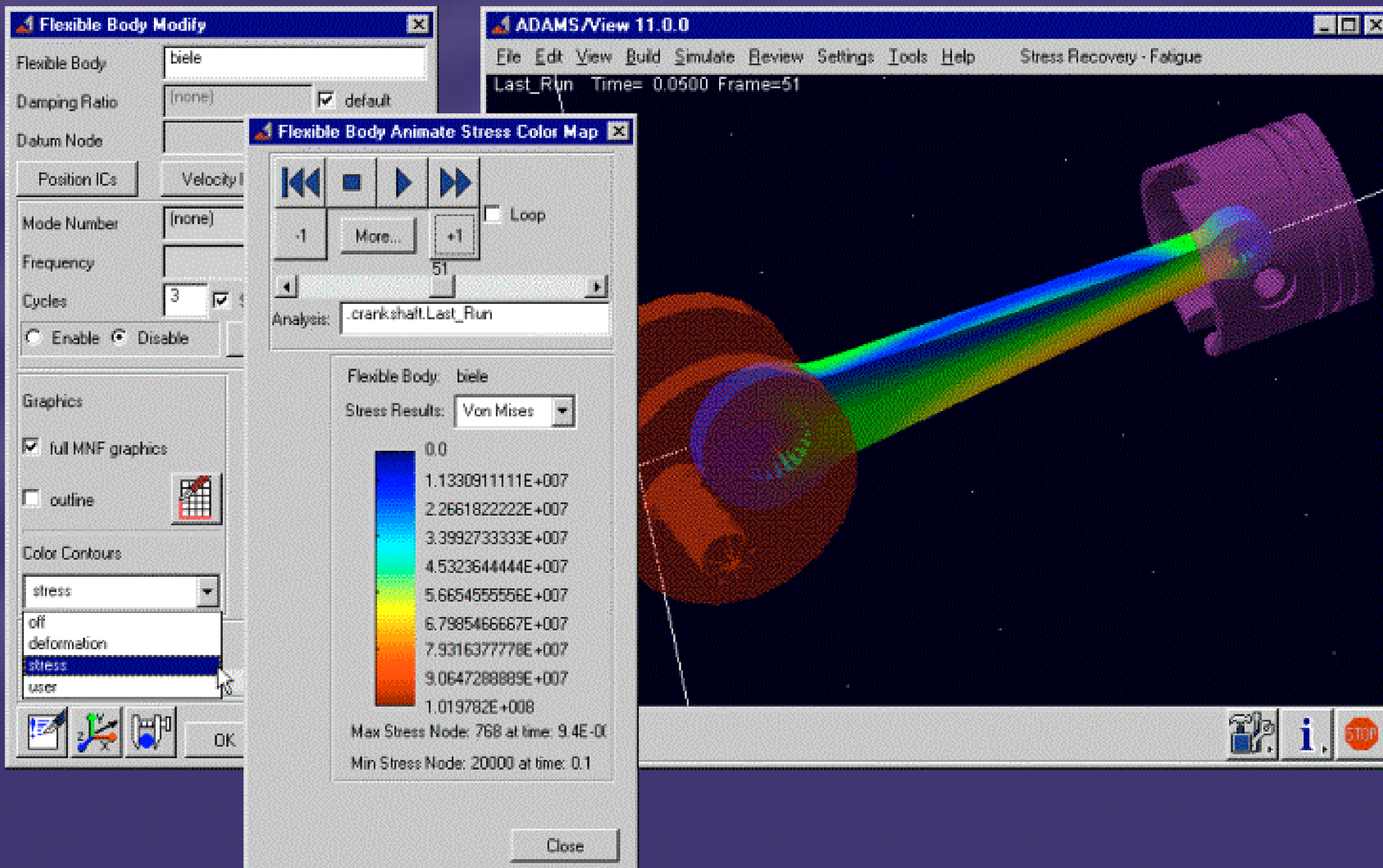
Modal Stress Recovery Example 3/5

- Animate Stresses on flex bodies



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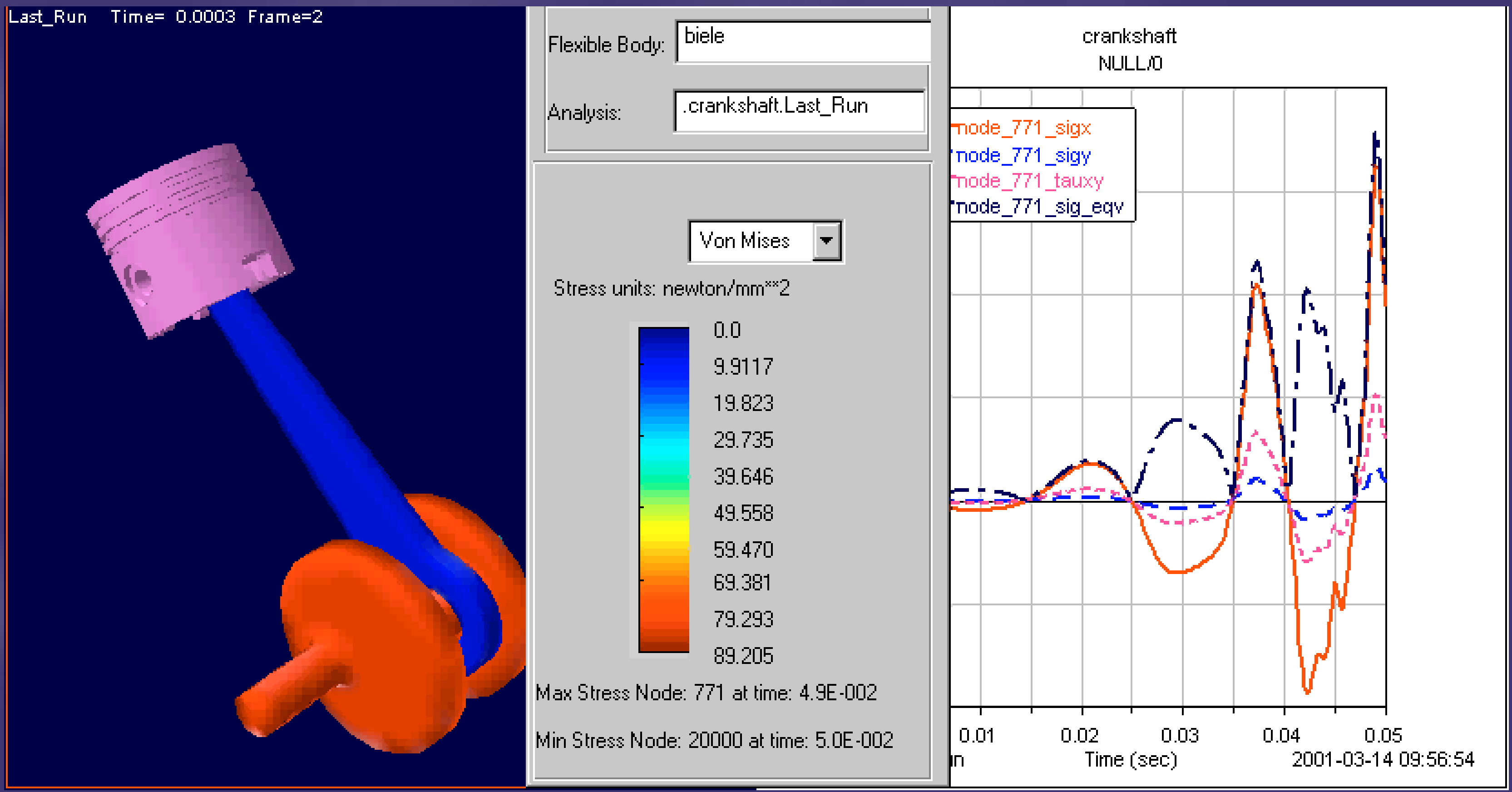
Stresses are computed for display purposes only, not stored as result sets

Modal Stress Recovery Example 4/5

- Compute and store stress/strain components at selected nodes

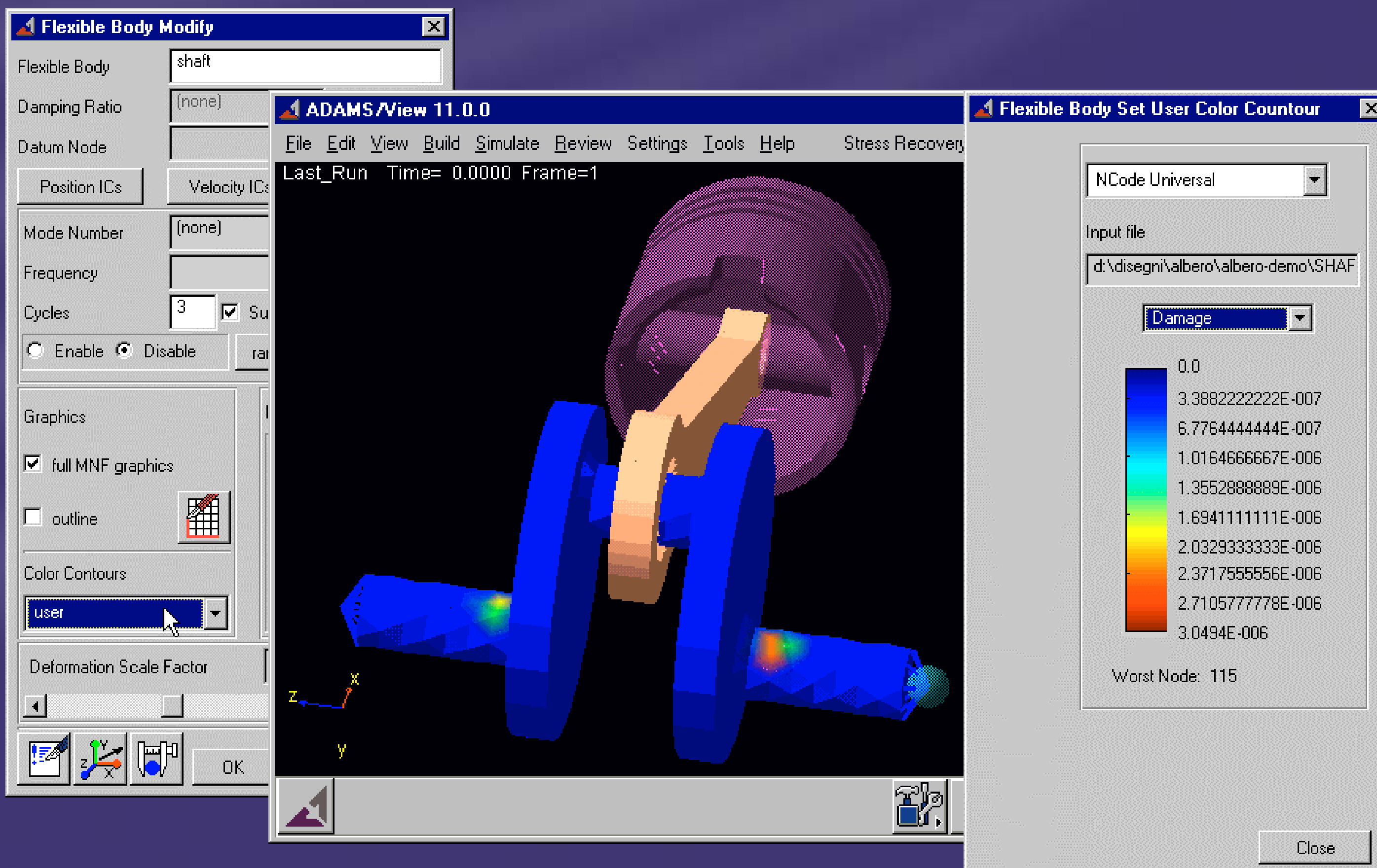
Modal Stress Recovery Example 5/5

- Plot nodal stresses



Example Process: Durability Analysis with FE-Fatigue

- Computes and displays nCode FLP results within ADAMS/PPT



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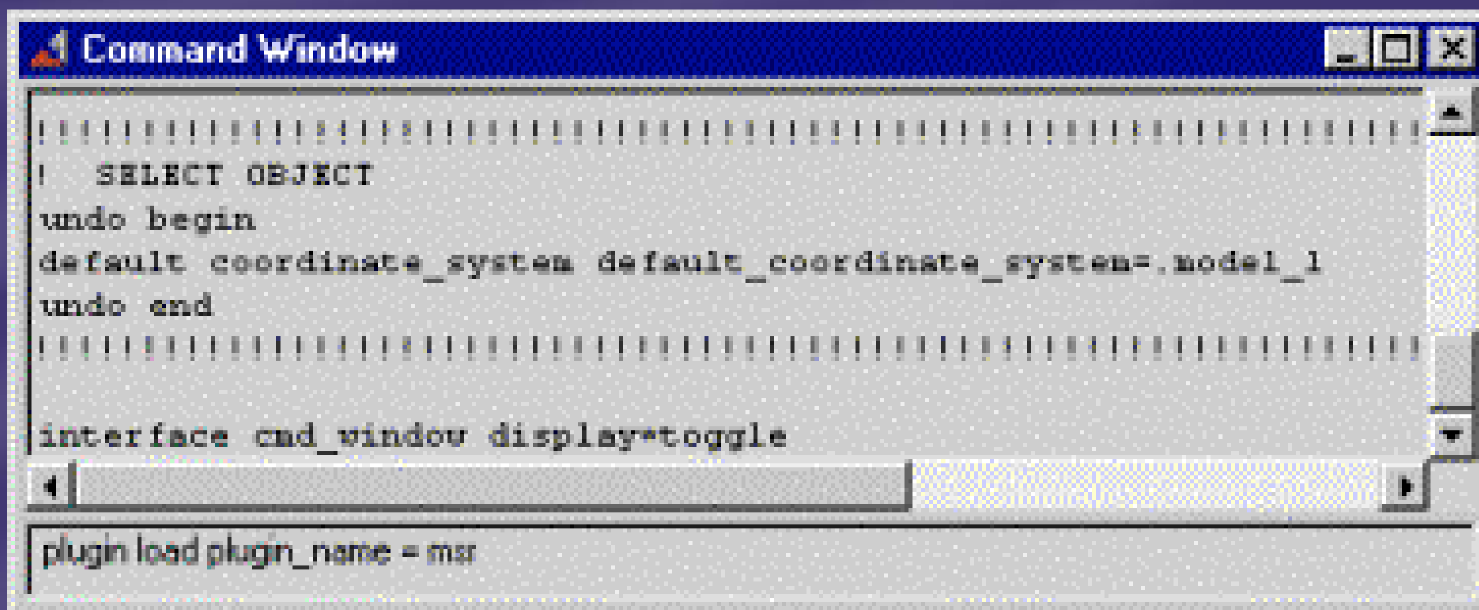
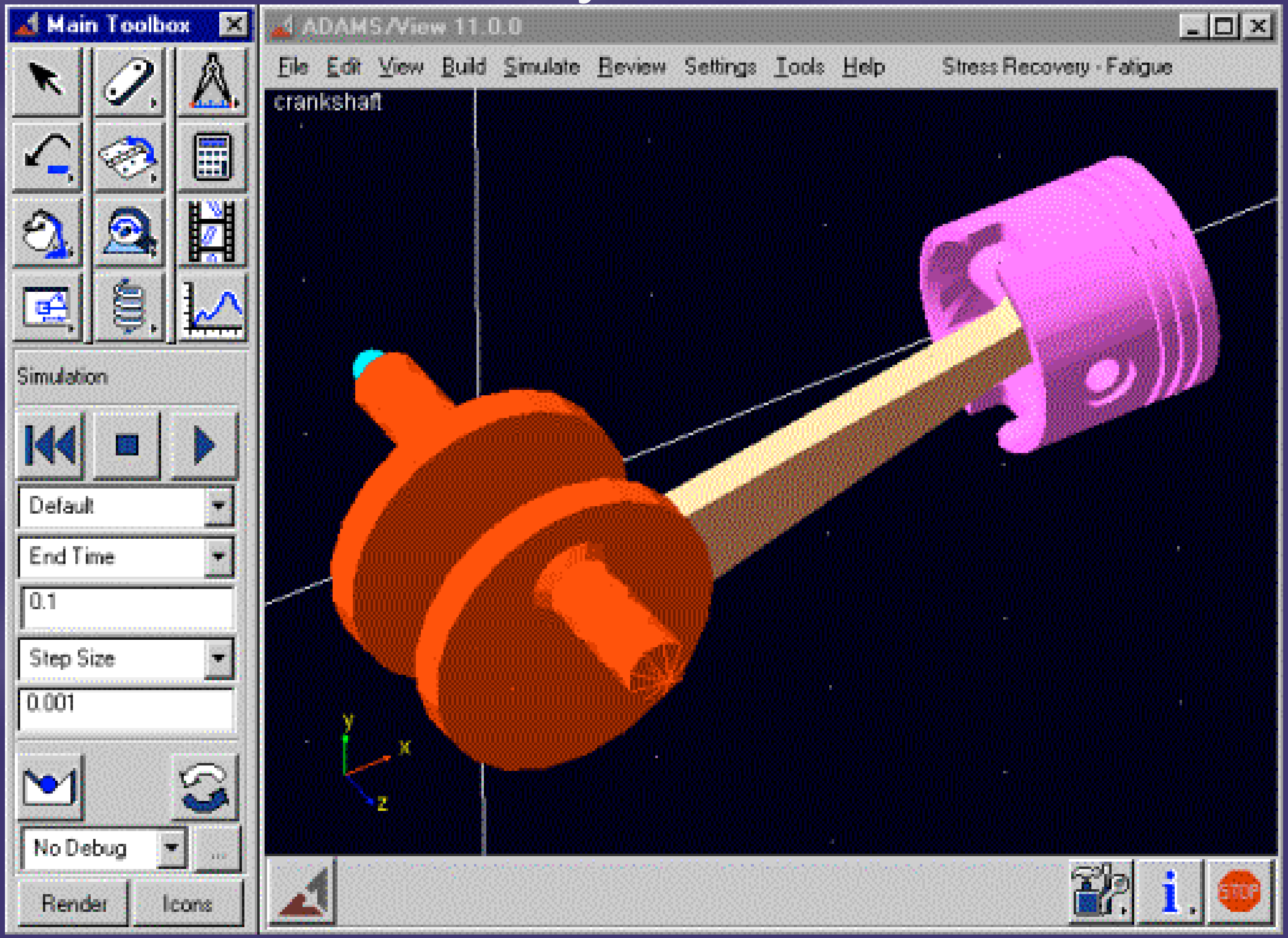
FE-Fatigue Example 1/10

- Start ADAMS and load MSR-Fatigue Plug-In



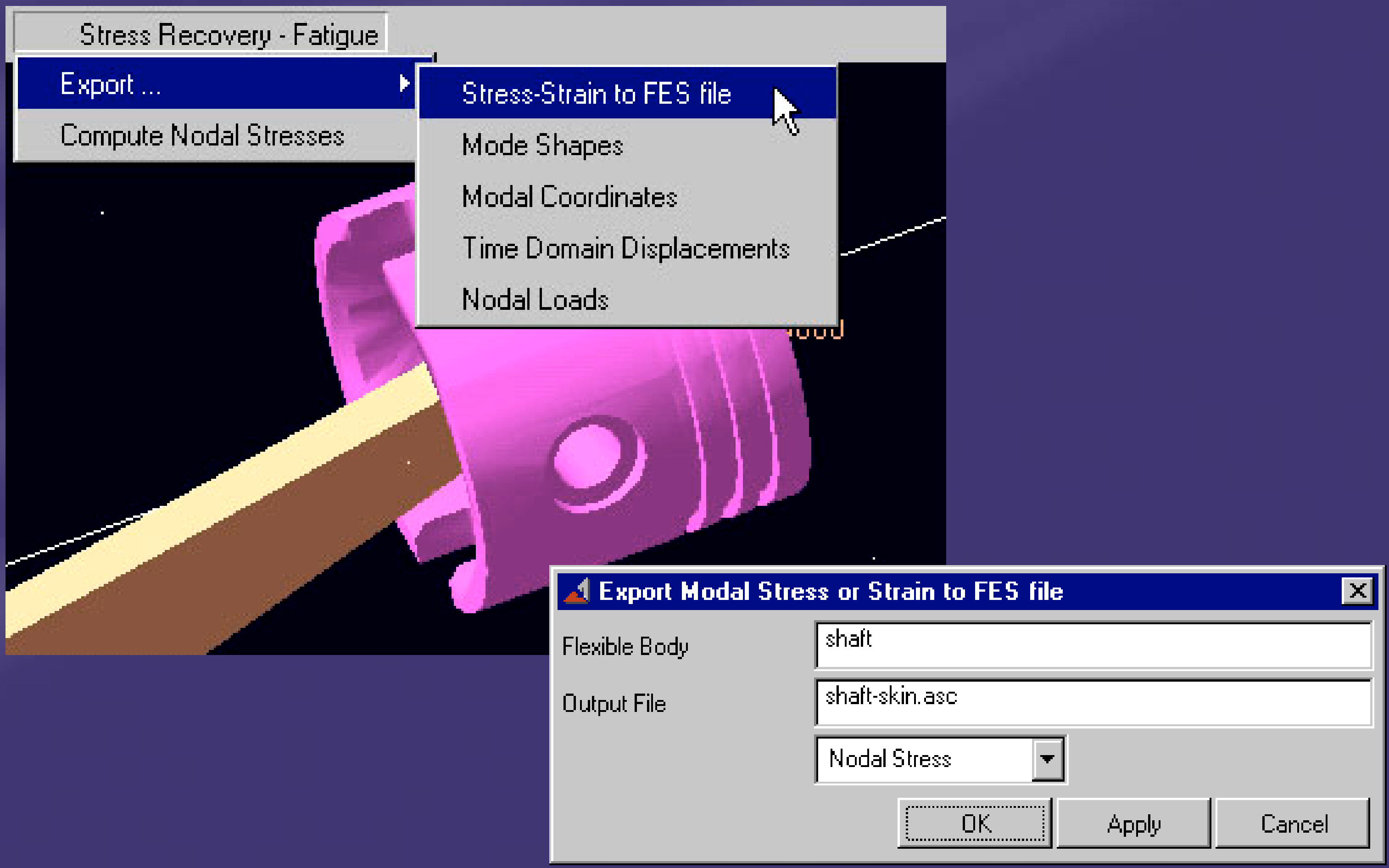
FE-Fatigue Example 2/10

- Run ADAMS analysis



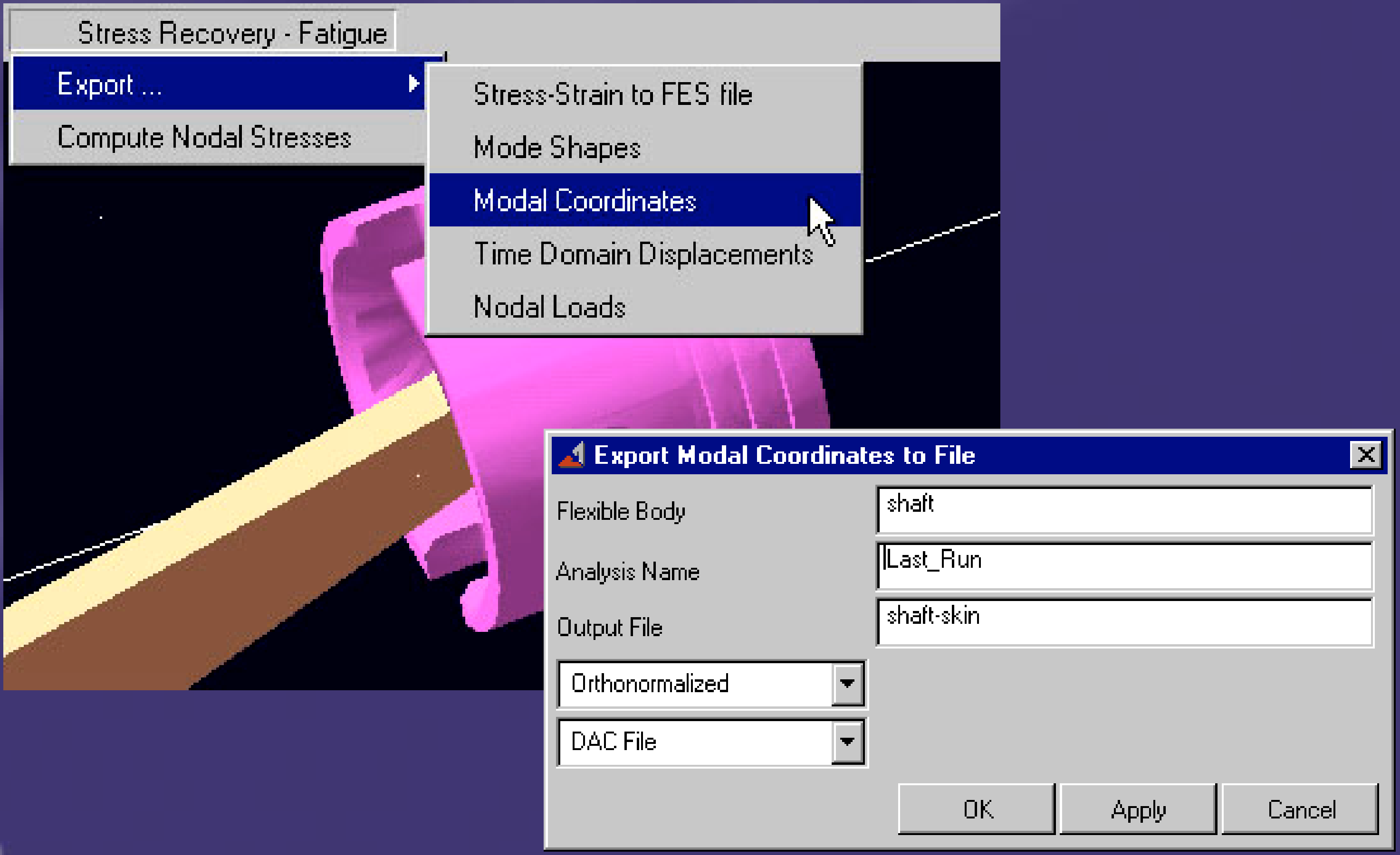
FE-Fatigue Example 3/10

- Export stress shape function to partial FES file



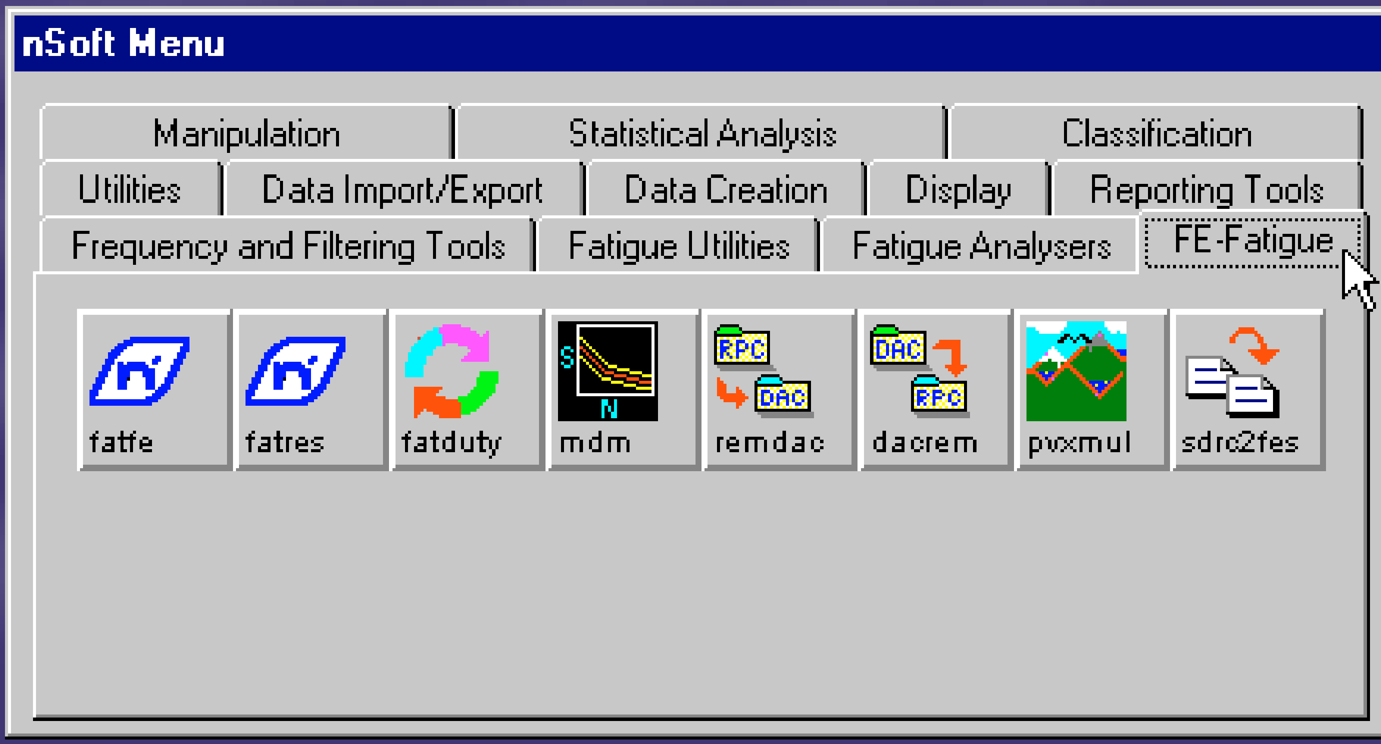
FE-Fatigue Example 4/10

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



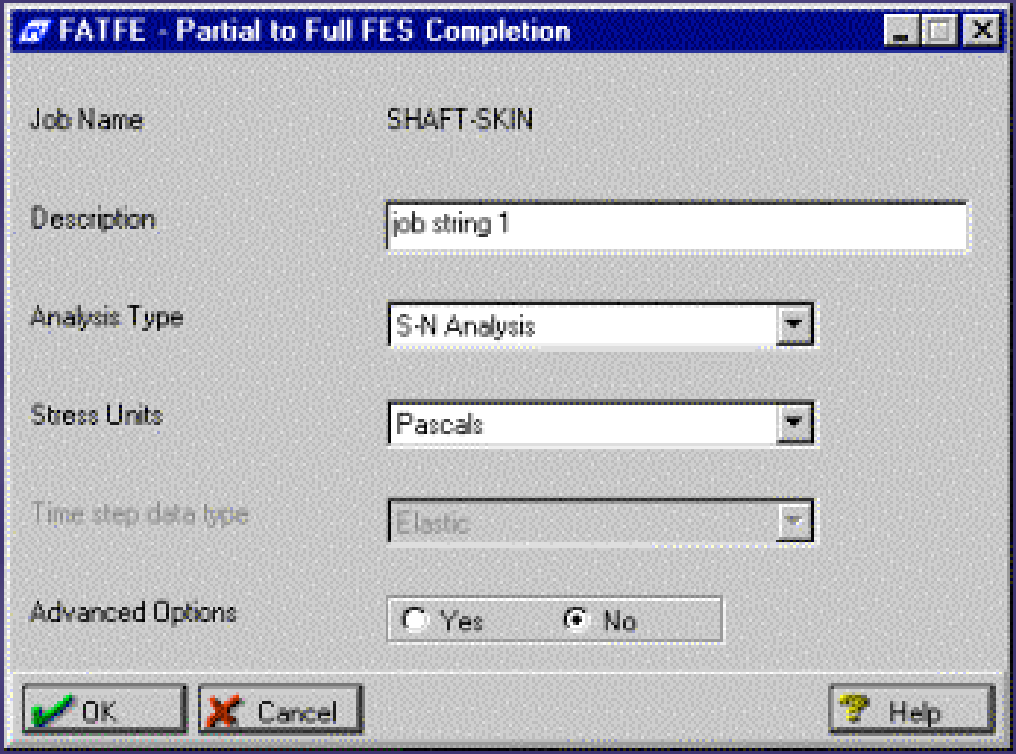
FE-Fatigue Example 5/10

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



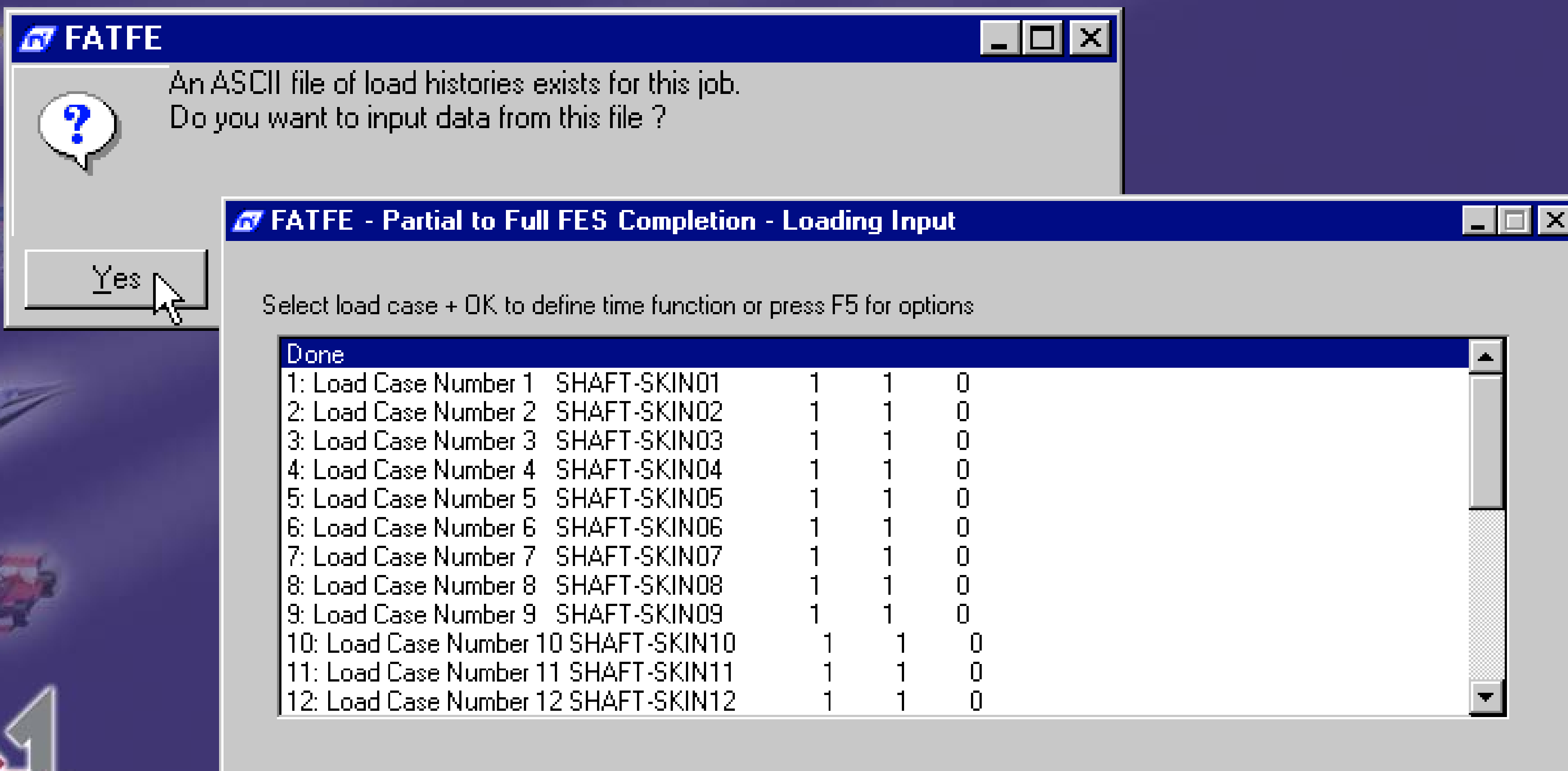
FE-Fatigue Example 6/10

- Specify analysis type



FE-Fatigue Example 7/10

- Use output from previous ADAMS run as loading input



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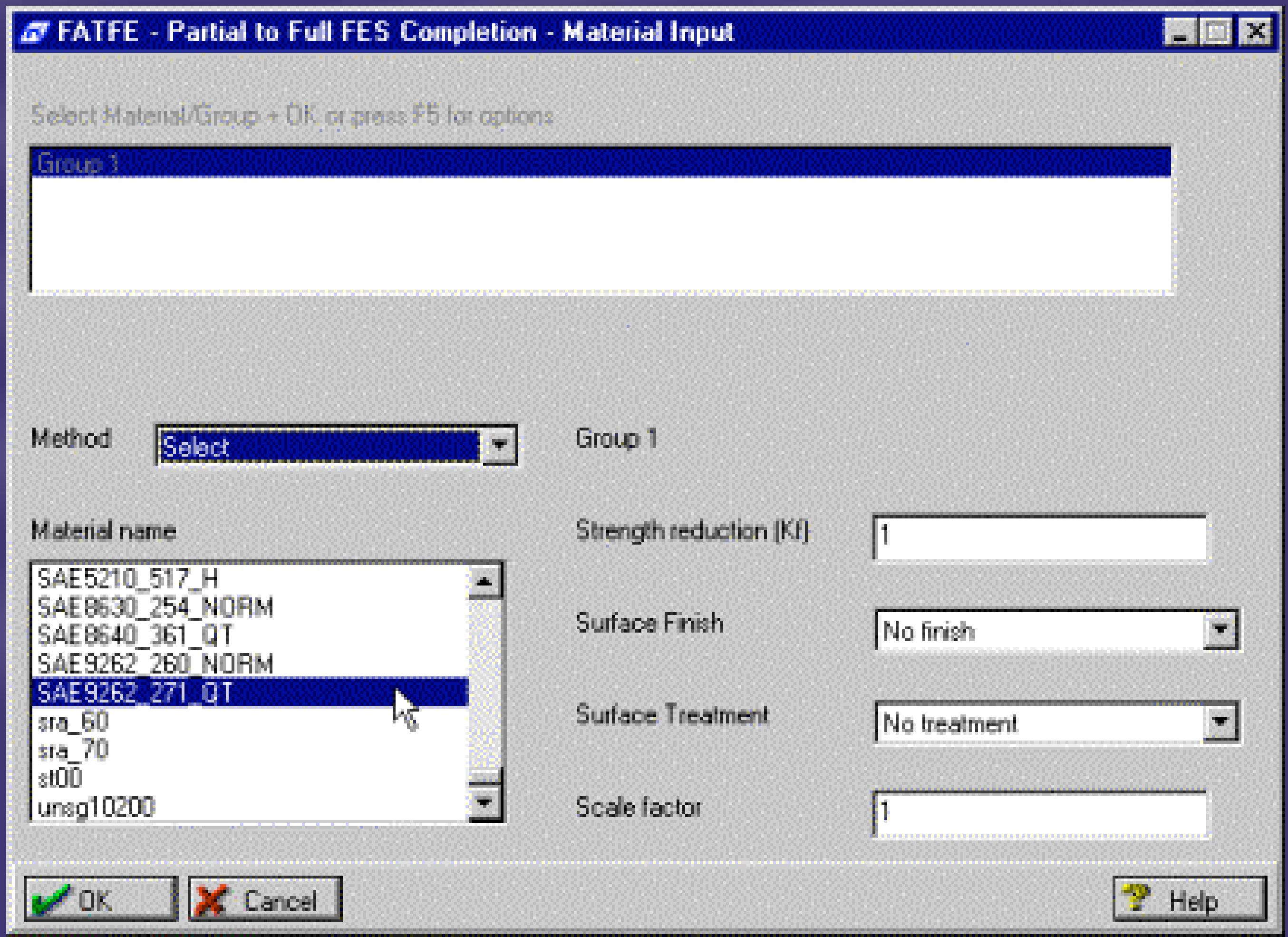
FE-Fatigue Example 8/10

- Select material from database



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FE-Fatigue Example 9/10

- Run Fatigue Analysis

Superposition 36 % complete.

Quit

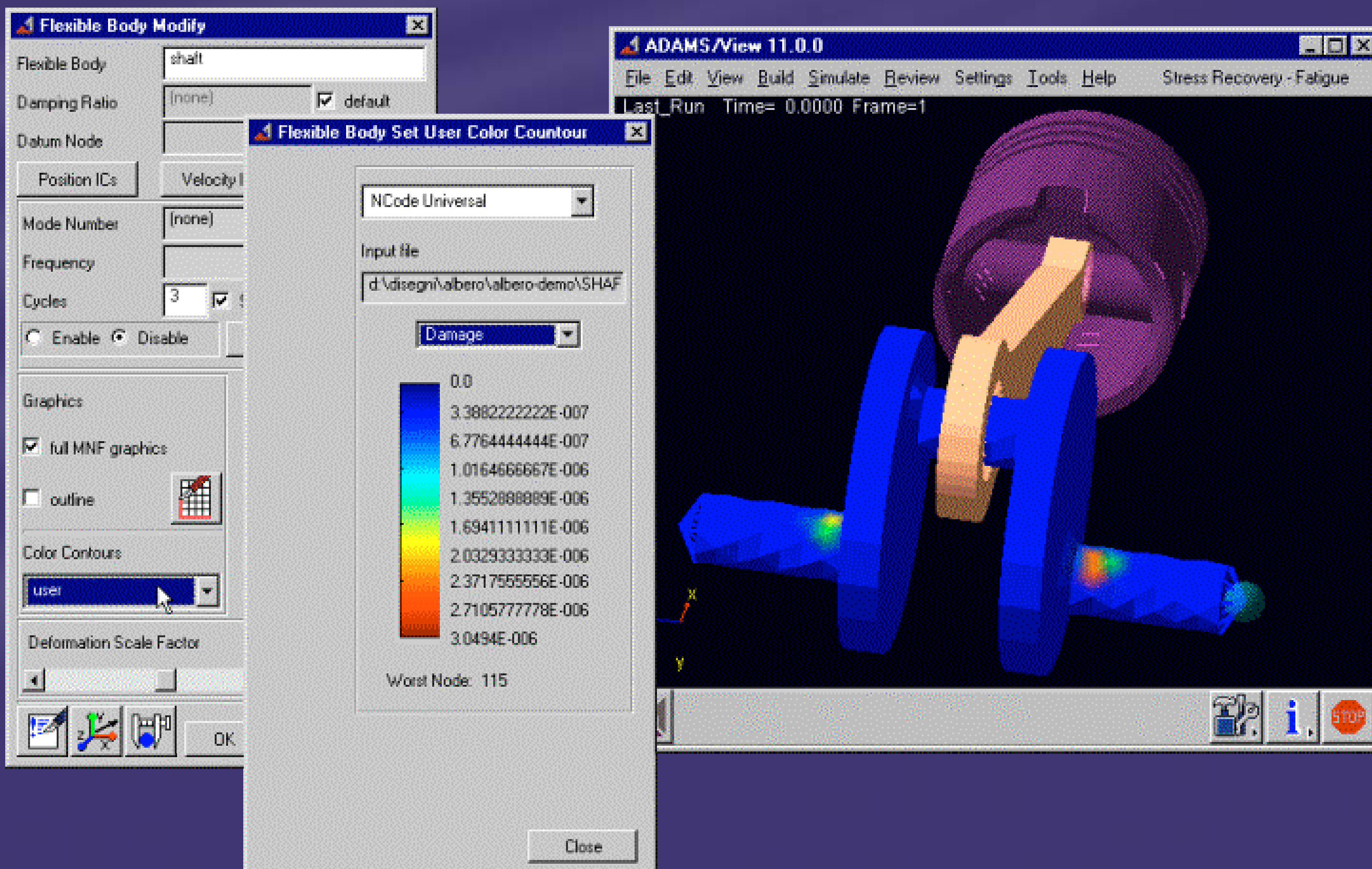
Global Results - Ten Most Damaged Nodes

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

OK Cancel Help

FE-Fatigue Example 10/10

- Display Damage Contours in ADAMS/PPT



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

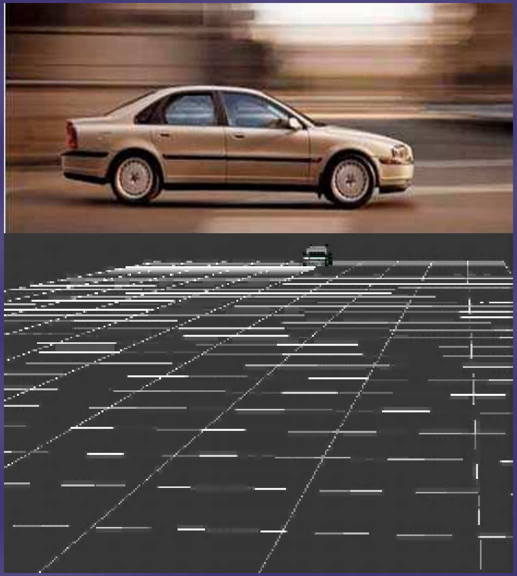
Summary

- 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

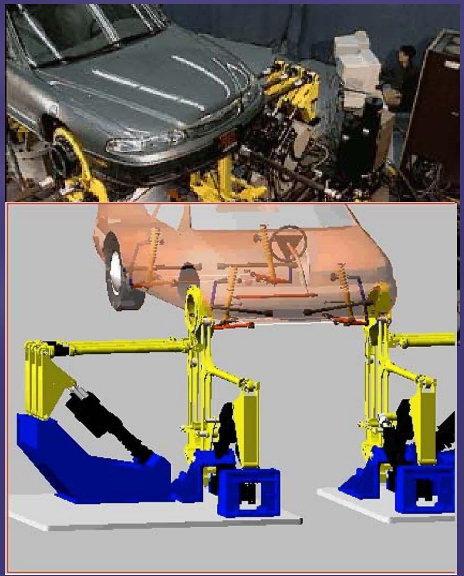
- The Modal Stress Recovery Toolkit is available free of charge for all ADAMS/Durability users
  - preview of 12.0 functionality

Integrated Durability Process

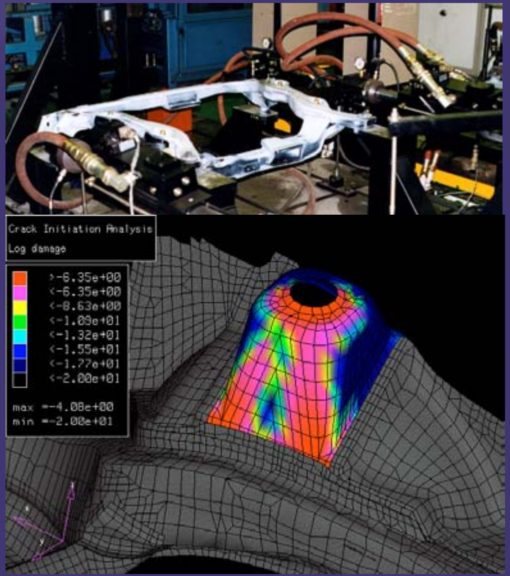
Test Track



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

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

$$[\phi_\sigma] = \left[\{\phi_\sigma\}_1, \ldots, \{\phi_\sigma\}_{P+S}\right]$$

ortho-normalized **Modal Stress Matrix**

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

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

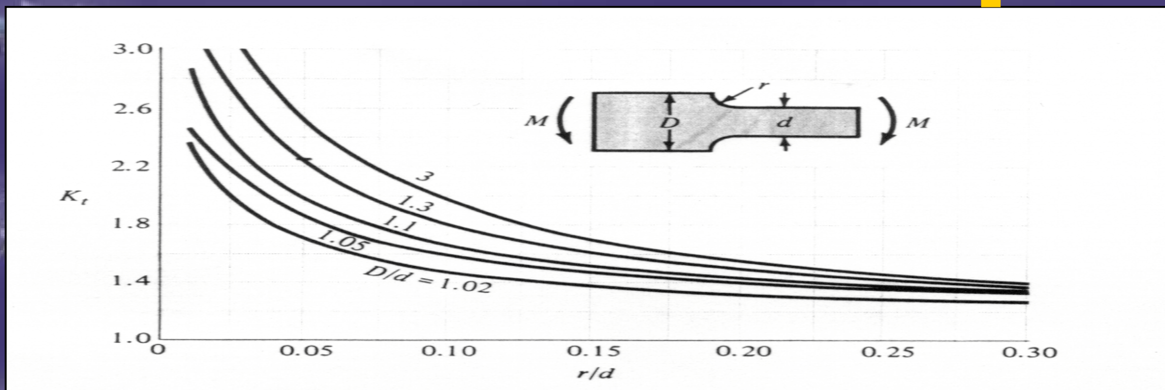
$\{p\}$ Vector of Modal Coordinates

$\{\sigma\}$ Stress Component Matrix

Principles of Modal Stress Recovery

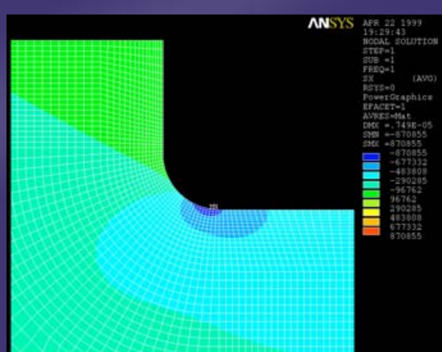
- FE Calculation
  - Component Mode Synthesis, Craig Bampton
    - Normal Modes
    - Static Correction Modes
    - Residual Vectors for Distributed/Inertial/Thermal Loads
  - Modal Stress (and/or) Strain Tensors
  - .mnf file gene¥ration
- Flexible Bodies in ADAMS
  - Correct Mechanism Dynamics
  - 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

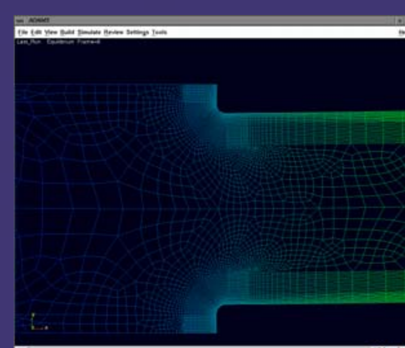


Material	*Young Modulus (N/m²)*	*D (m)*	*d (m)*	*r (m)*	*s (m)*	*M (N m)*
Steel	2.1E11	5.0E-2	3.85E-2	2E-3	1.0E-2	1

ANSYS



ADAMS



	Stress (N/m²)	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	

Mechanical Dynamics