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NAFEMS - FENET Workshop
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Fatigue Life Improvement of an Innovative Suspension System

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Models for the Automotive Industry

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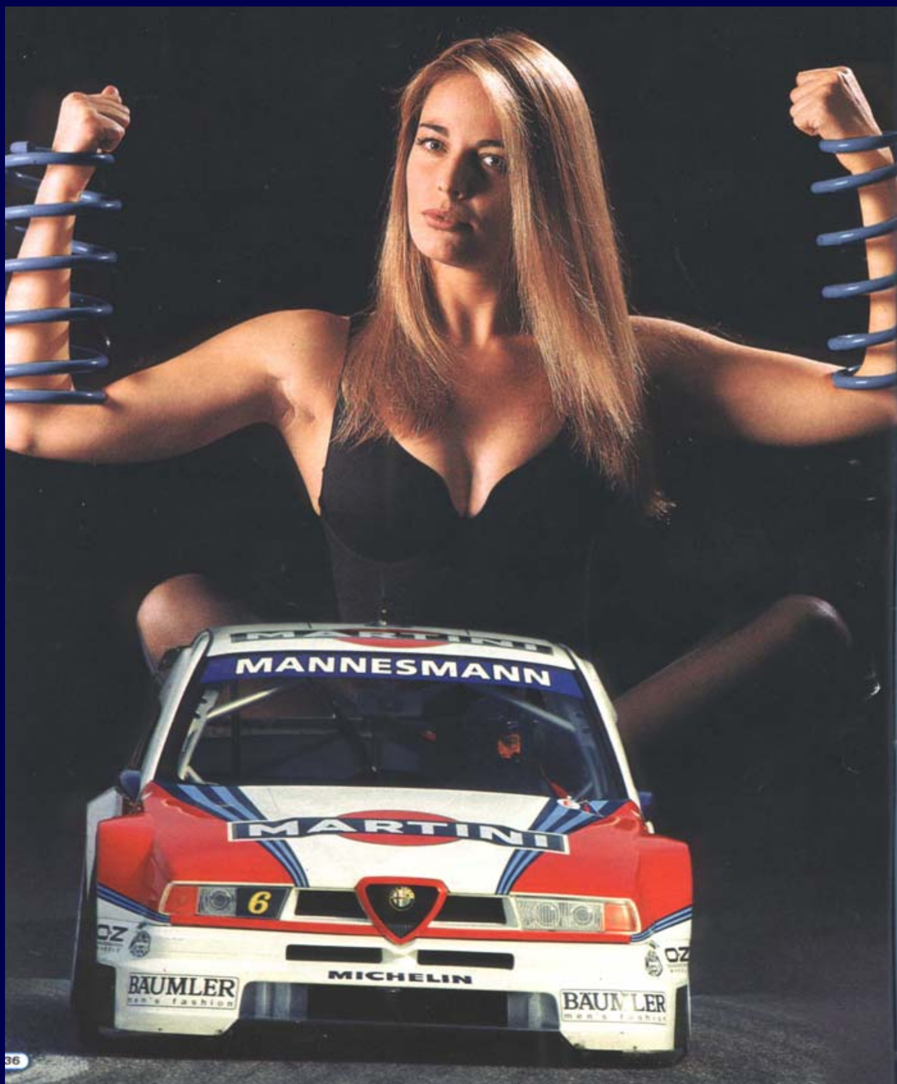

Contents

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- Introduction
- Methodology
- Model Geometry
- Stress Analysis
- Fatigue Assessment
- Recommendations
- Conclusions

"We are testing are 5th prototype. What magic can you do?"

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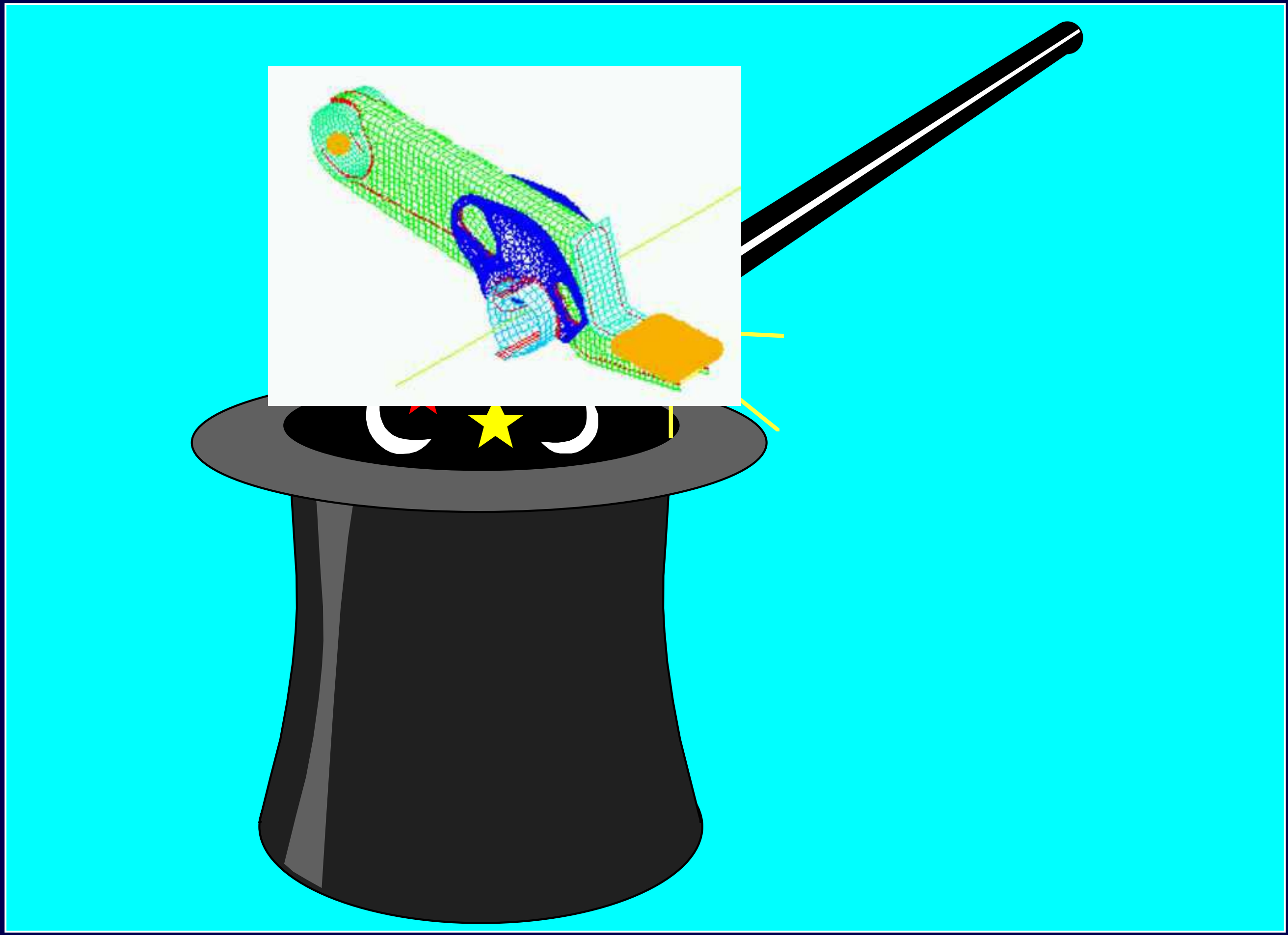
FE Modelling



Introduction

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History

New designs for suspension systems for lorries were being developed by conventional test and trial method

Scope of Work

To use Finite Element analysis to improve the fatigue life of the Suspension Assembly.

Objectives

- Failure assessment of Mark V Suspension System.
- Demonstrate capabilities of complex FE analysis techniques to support design development.
- Suggest design improvements.
- Streamline design development process.

Methodology

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- Convert CAD geometry to FE model
  - mid-surfaces/volumes
  - meshing
  - boundary conditions/loading
  - validation
- Stress Analysis
- Fatigue Analysis
- Assessment
  - Steel components
  - Welded joints

Main Components

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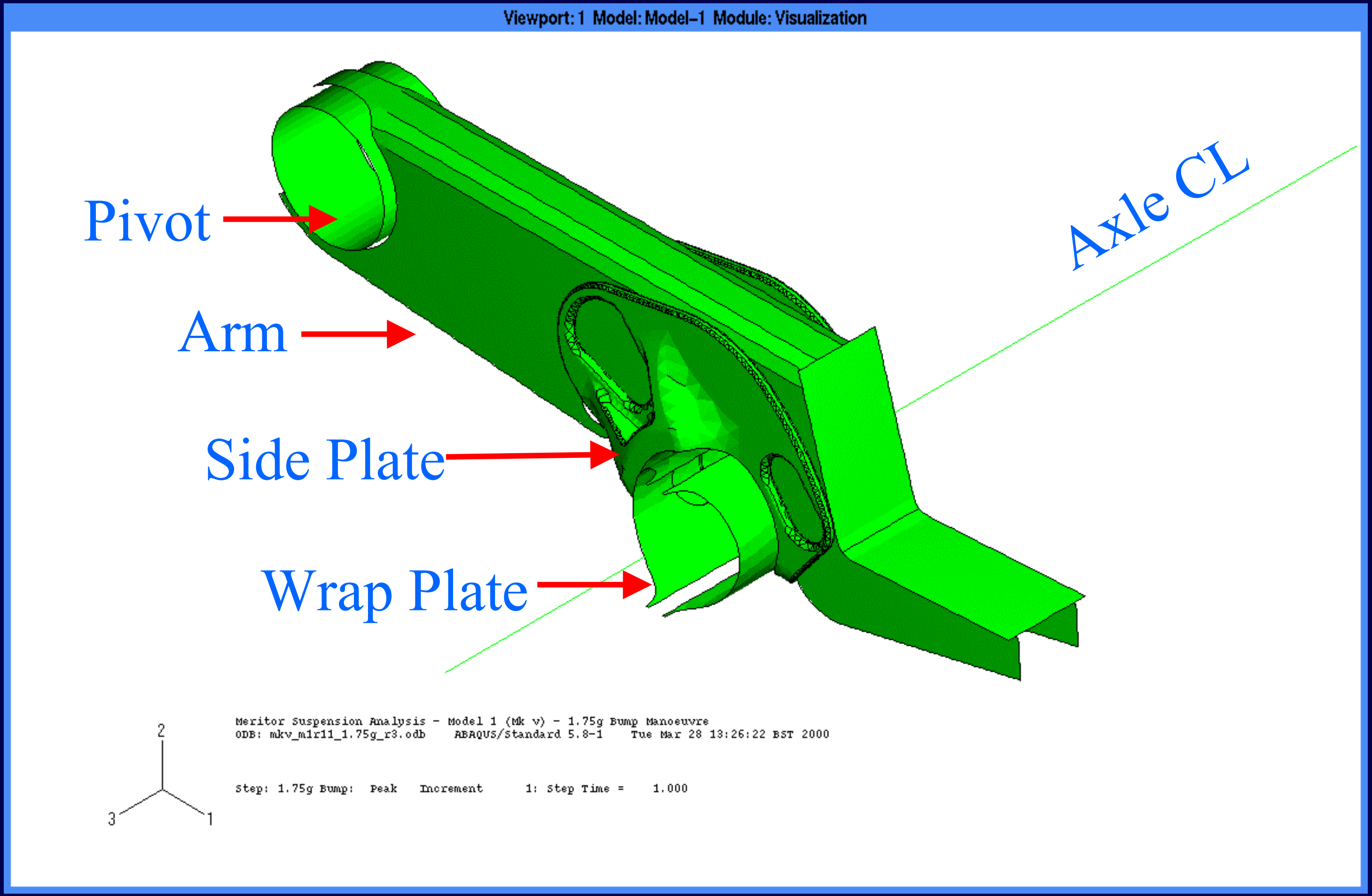
Assembled in parts for easier manufacturing



Model Geometry - Parts

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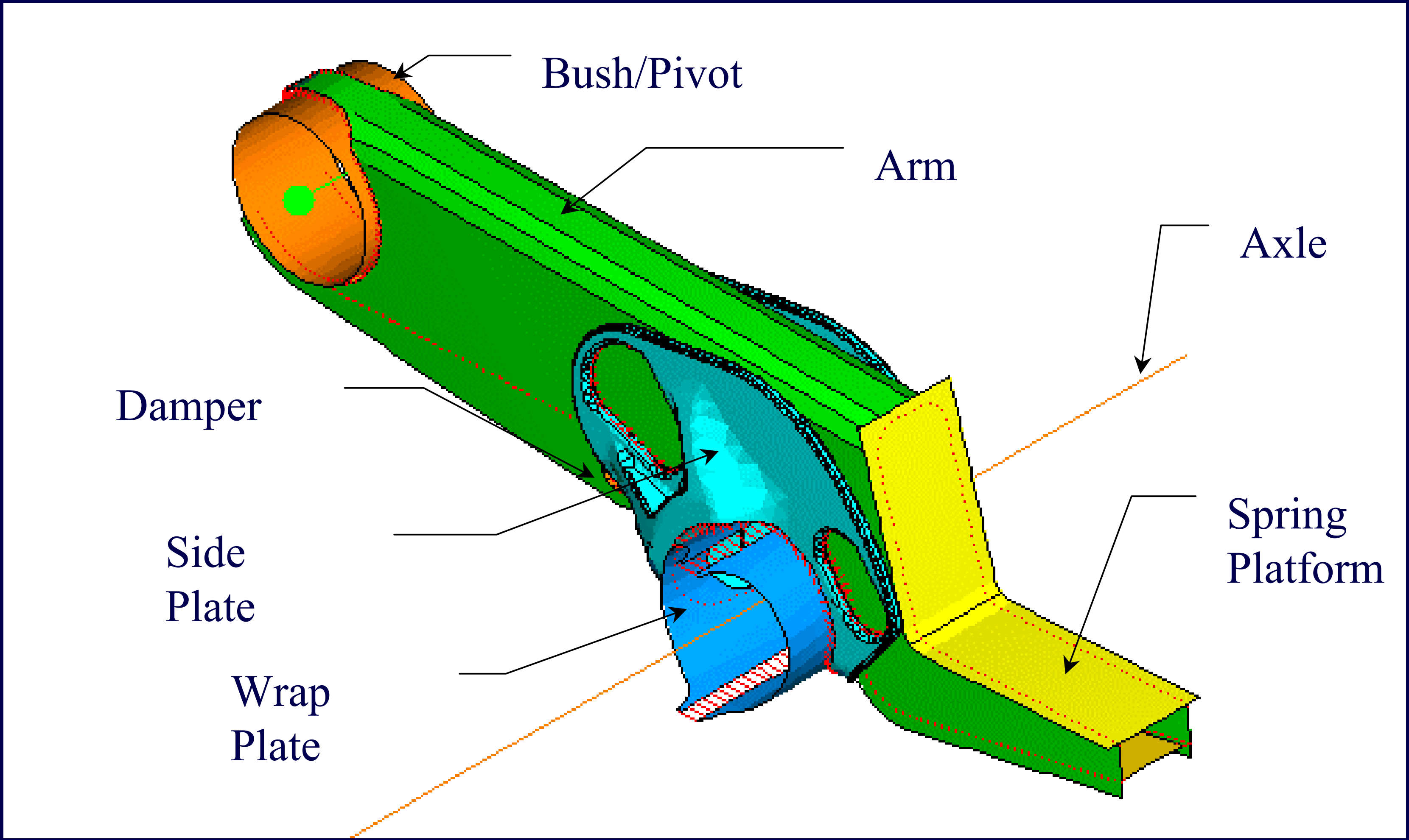

Model Geometry - From CAD to FE

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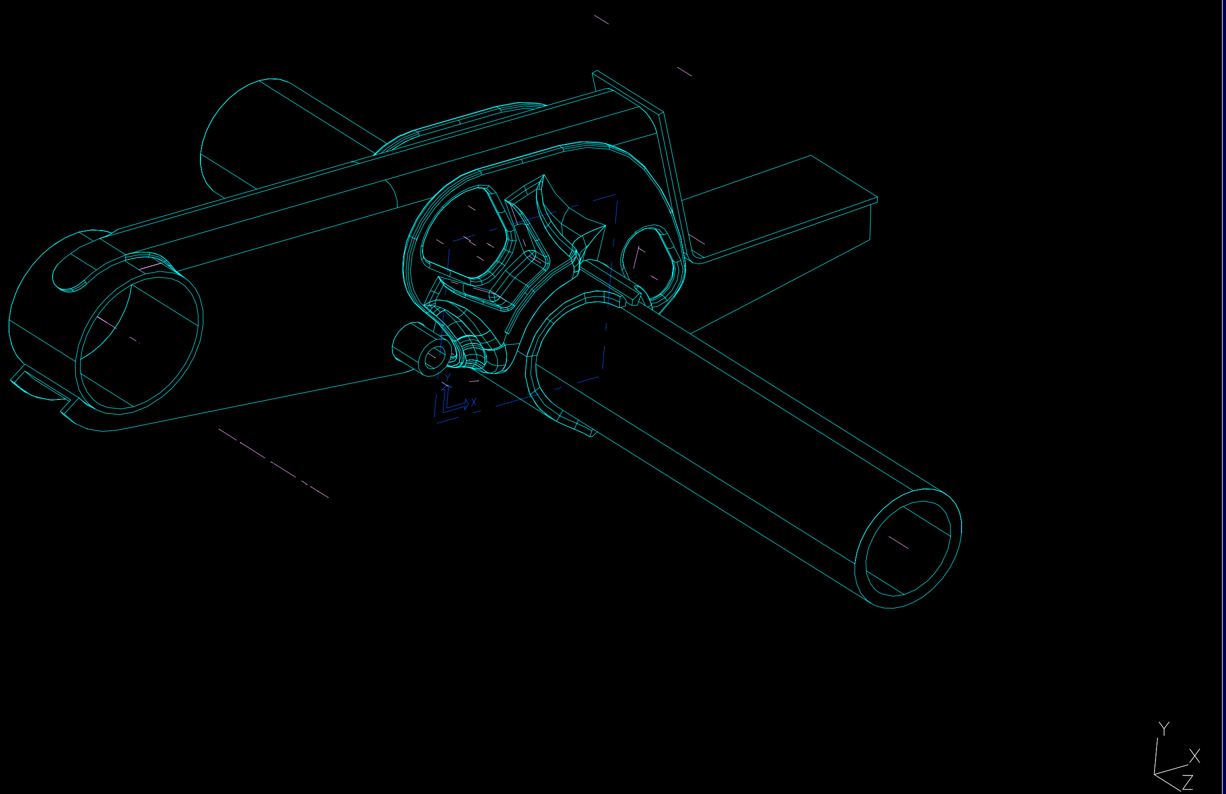
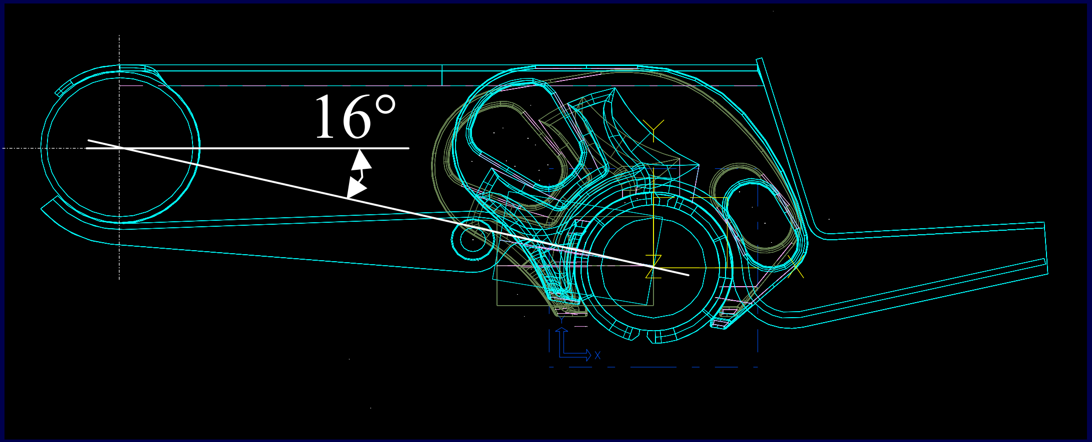
IGES File - Volumes

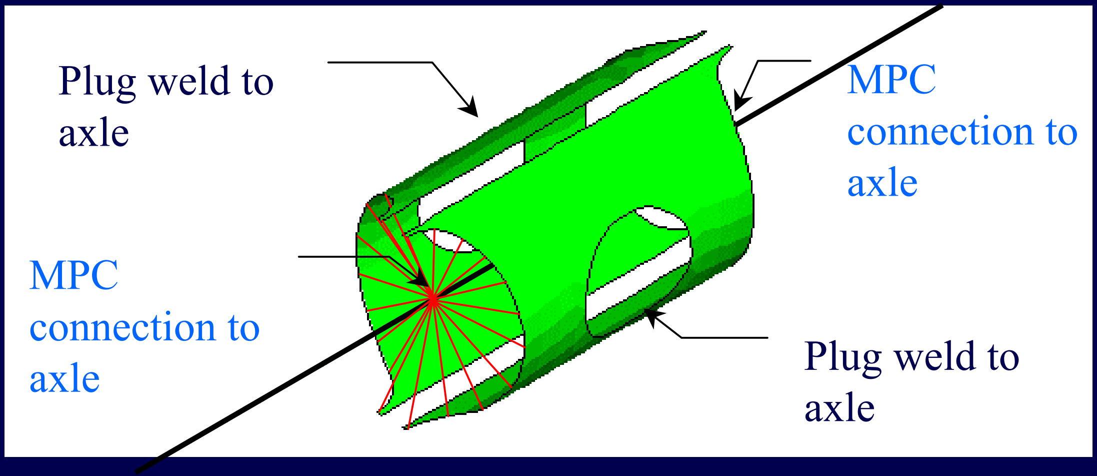


Modelling Assumptions

- Orientation of Side Plate
- Angle @ start of test 20°



- Axle to Wrap Plate connection- No frictional contact



Model Geometry - Mesh Generation

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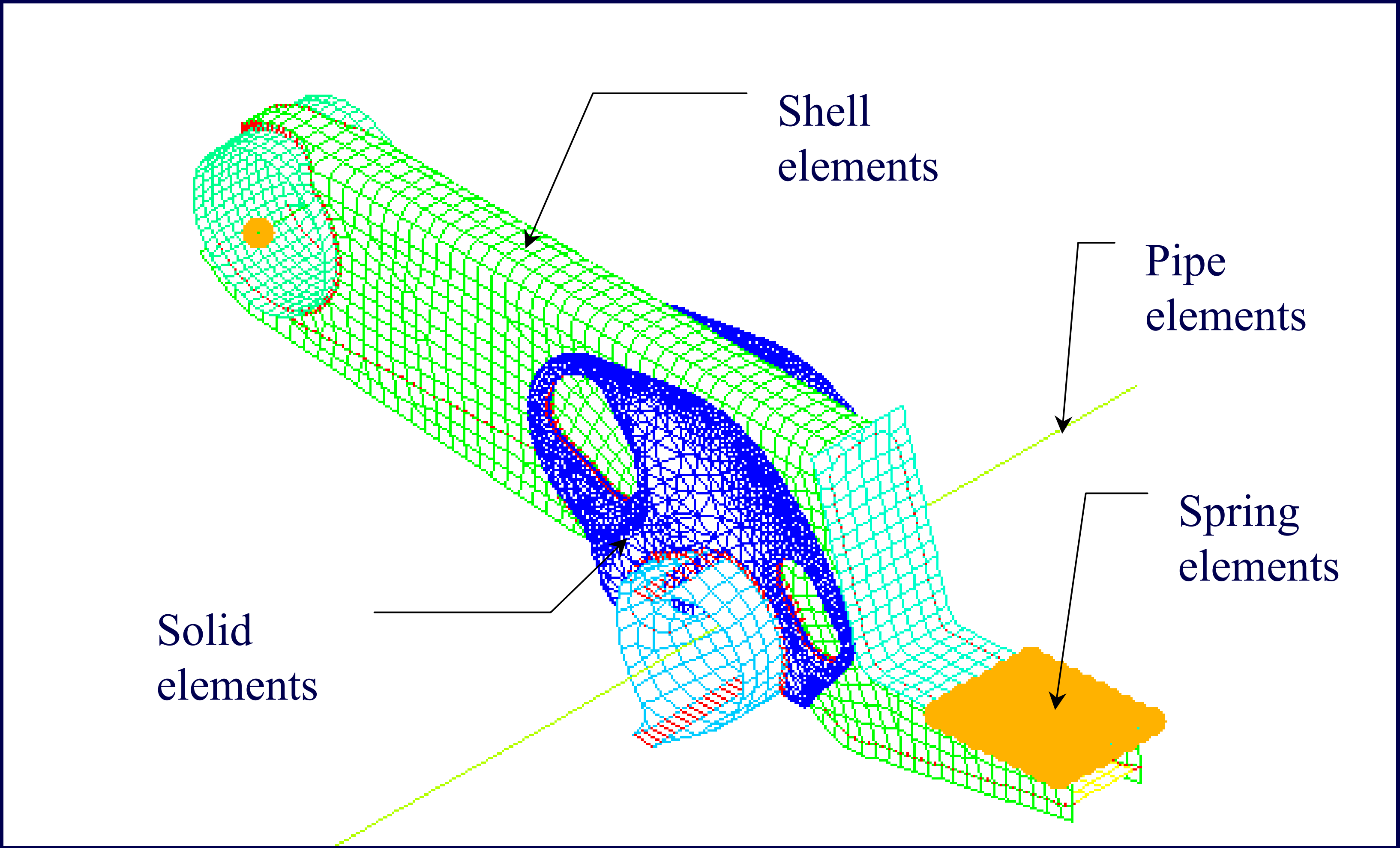
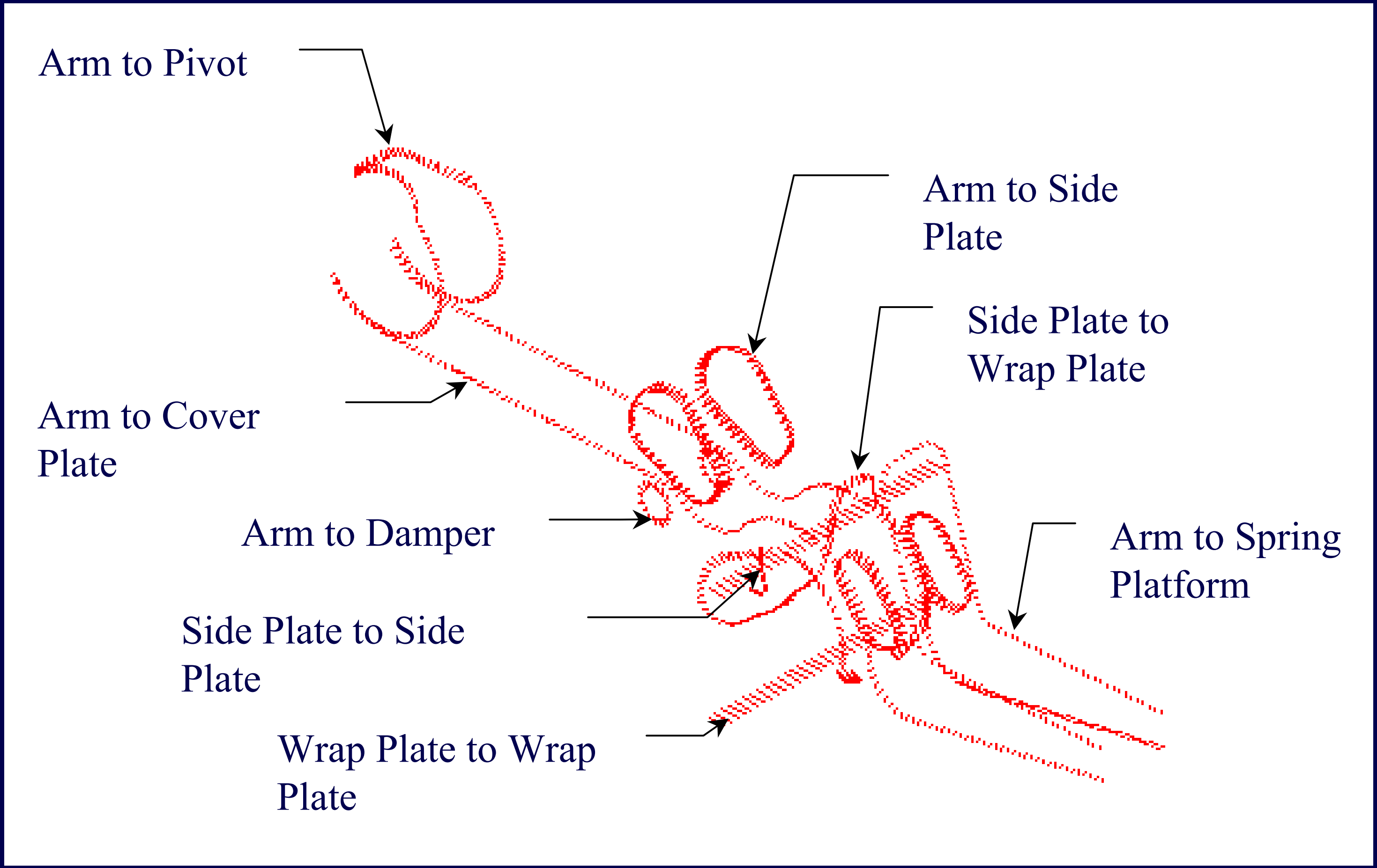


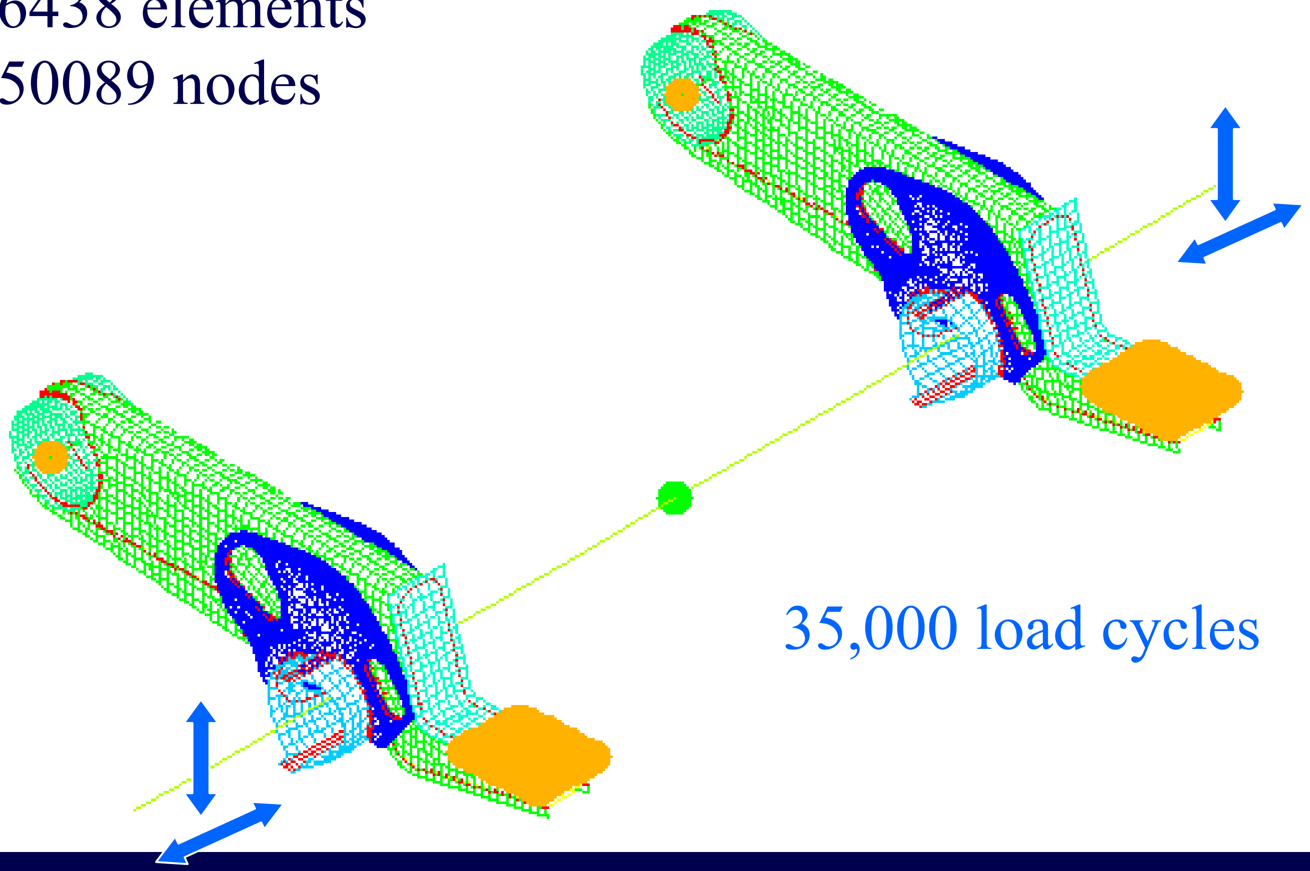
Modelling of Welded Joints

- **Welds represented as Beam Elements**



Mesh Generation - Full Model

86438 elements
150089 nodes



35,000 load cycles

Stress Analysis

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- Linear Elastic
- Boundary Conditions
- 4 Loadcases
  - Roll Manoeuvre
  - Tramp Manoeuvre
  - Scrub Manoeuvre
  - 1.75g Bump Manoeuvre
- Material Properties

Stress Analysis - Boundary Conditions

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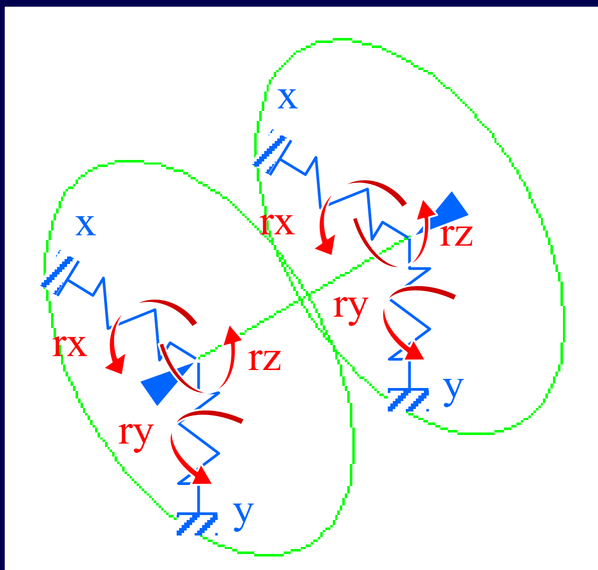

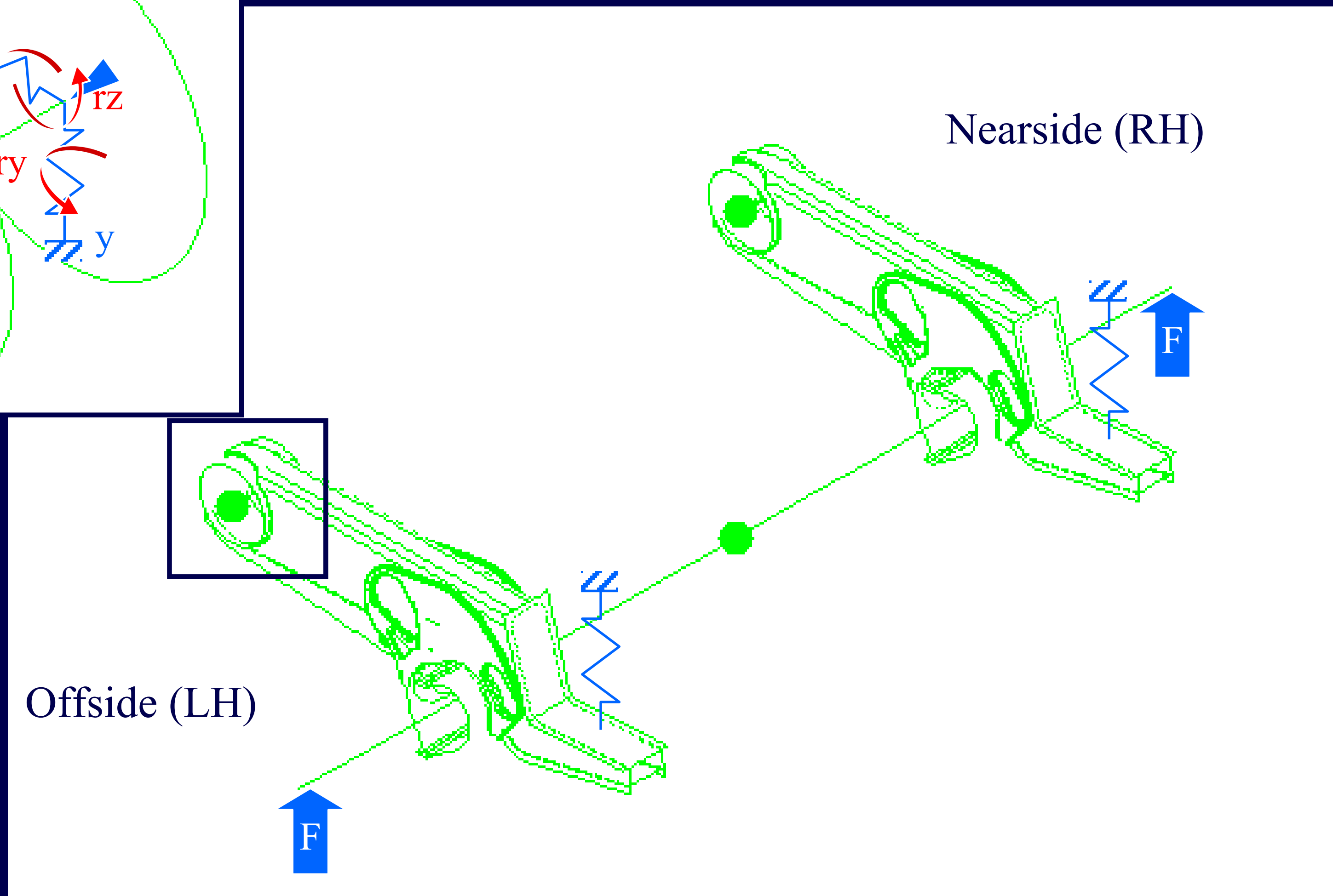

Stress Analysis - Material Properties

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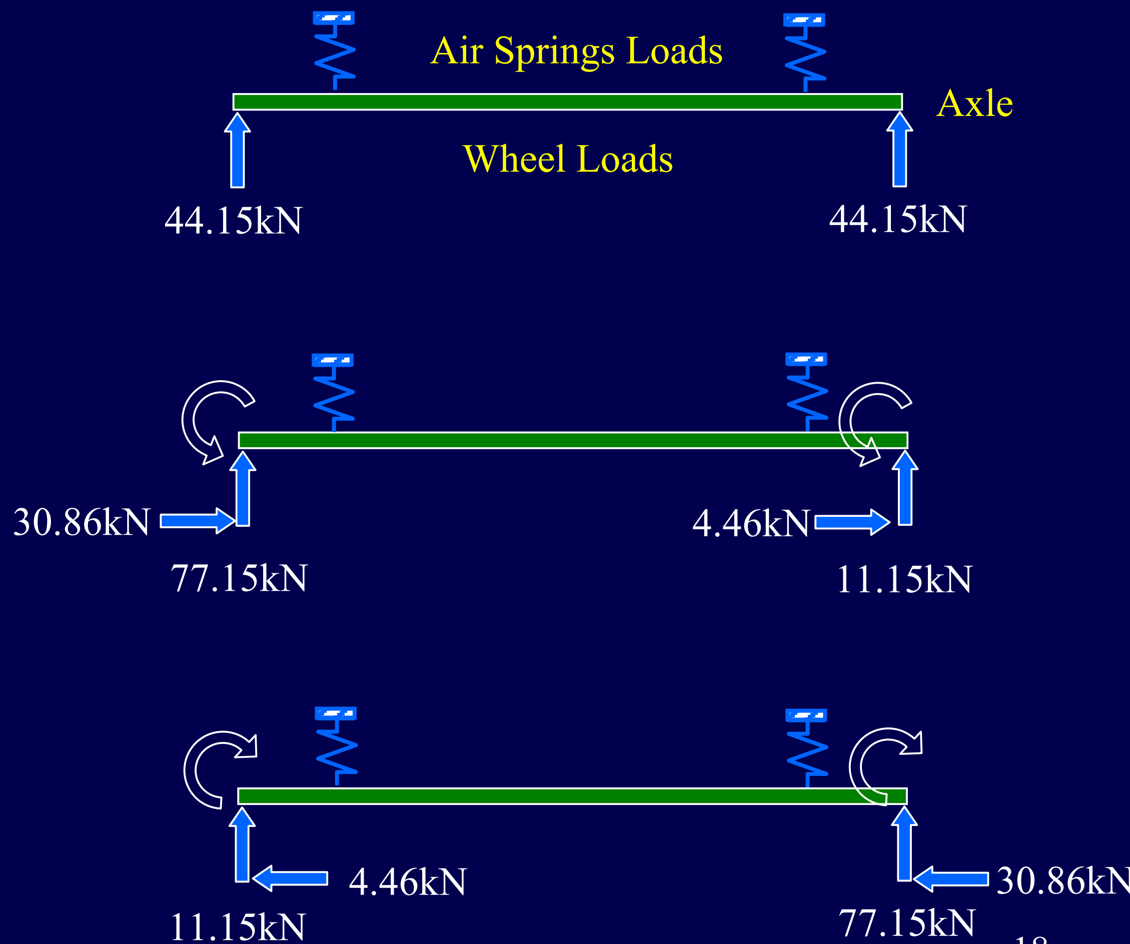
Part	Young's Modulus	Poisson's Ratio
Arm	203GPa	0.3
Spring Platform	"	"
Cover Plate	"	"
Damper	"	"
Side Plate	"	"
Wrap Plate	"	"
Pivot	"	"
Welds	406GPa	"
Axle	203GPa	"

Stress Analysis - Loadcase 1

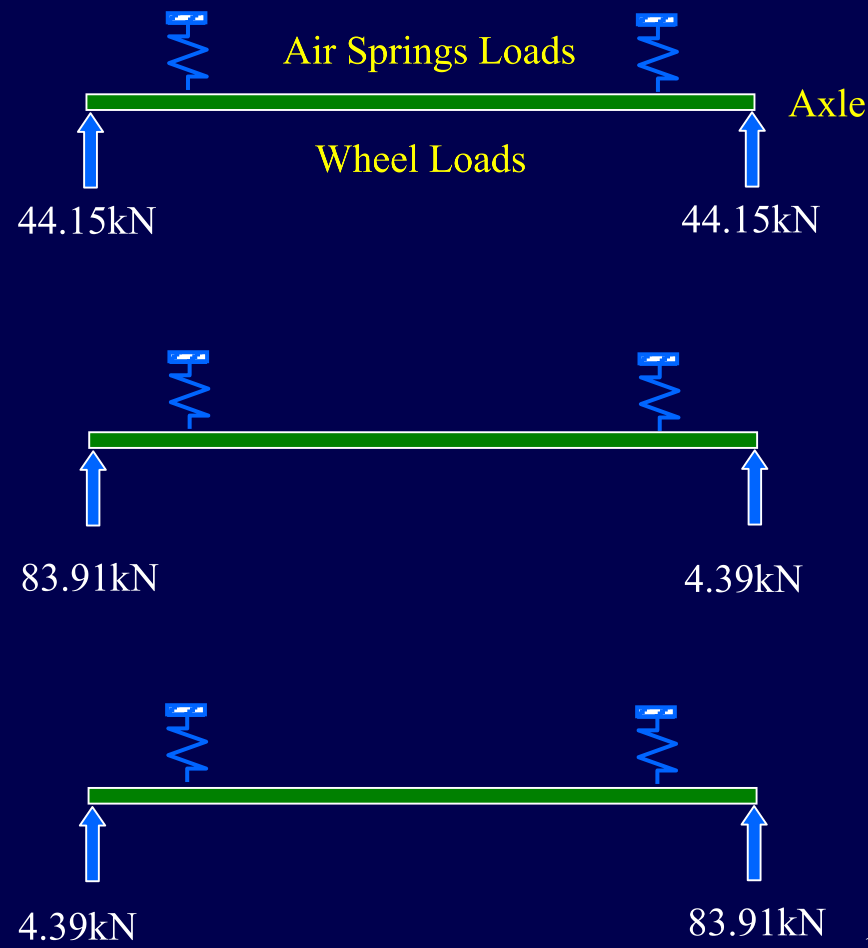
Adding value through knowledge

- **Roll Manoeuvre**
  - Start — Step 1
    Mid
    End
  - Rollover — Step 2
  - Rollover — Step 3



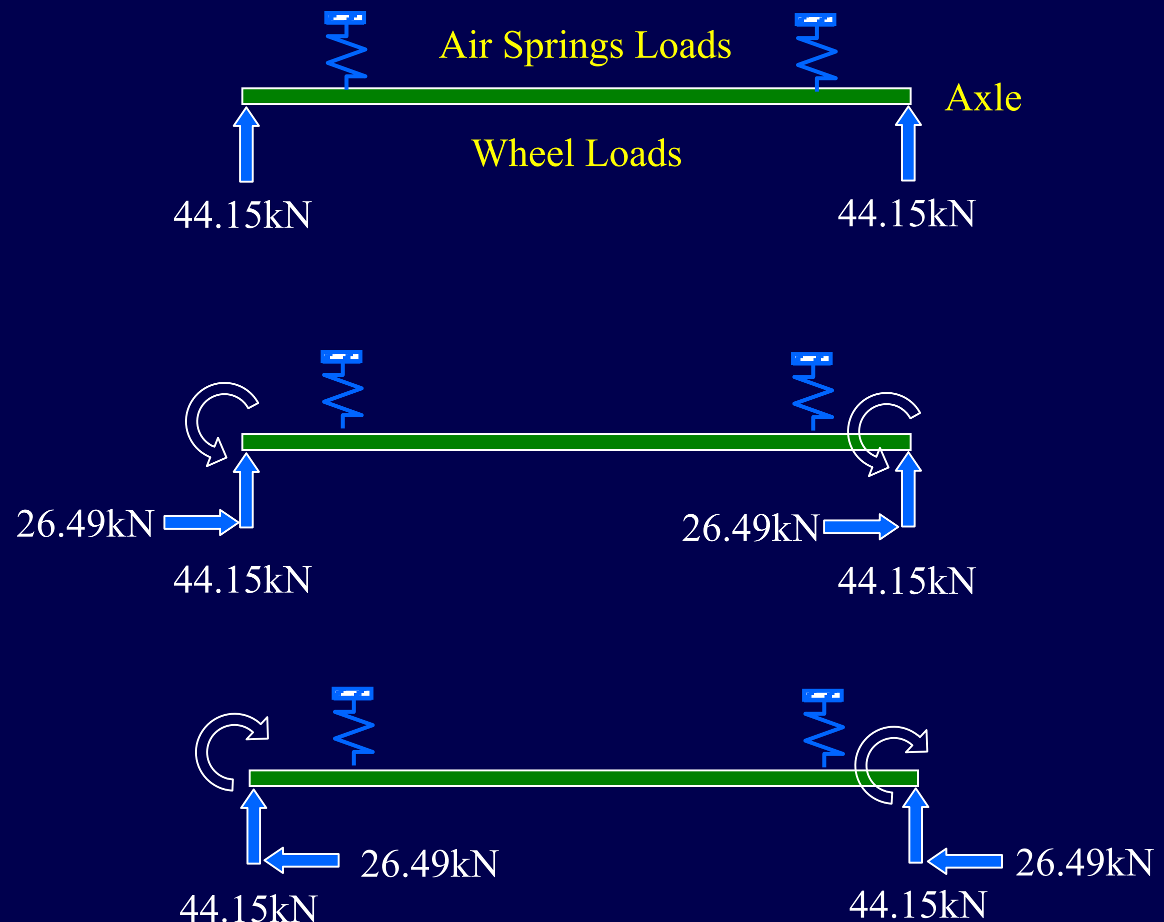
Stress Analysis - Loadcase 2

- **Tramp Manoeuvre**
  - **Start** **Step 1**
    Mid
    End
  - **LH Bump** **Step 2**
  - **RH Bump** **Step 3**



Stress Analysis - Loadcase 3

- **Scrub Manoeuvre**
  - **Start** **Step 1**
    Mid
    End
  - **LH +ve** **Step 2**
  - **LH -ve** **Step 3**



Stress Analysis - Loadcase 4

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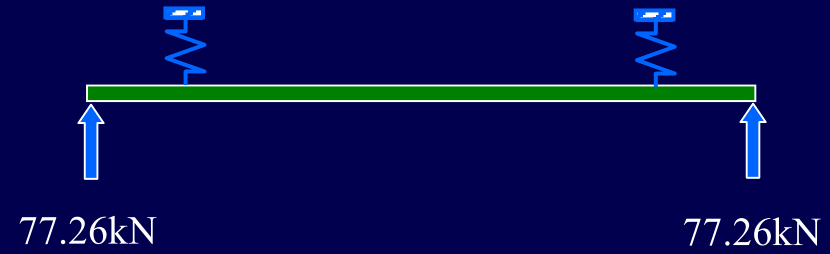
- 1.75g Bump Manoeuvre
  - Start   Step 1
    End

  - Peak   Step 2

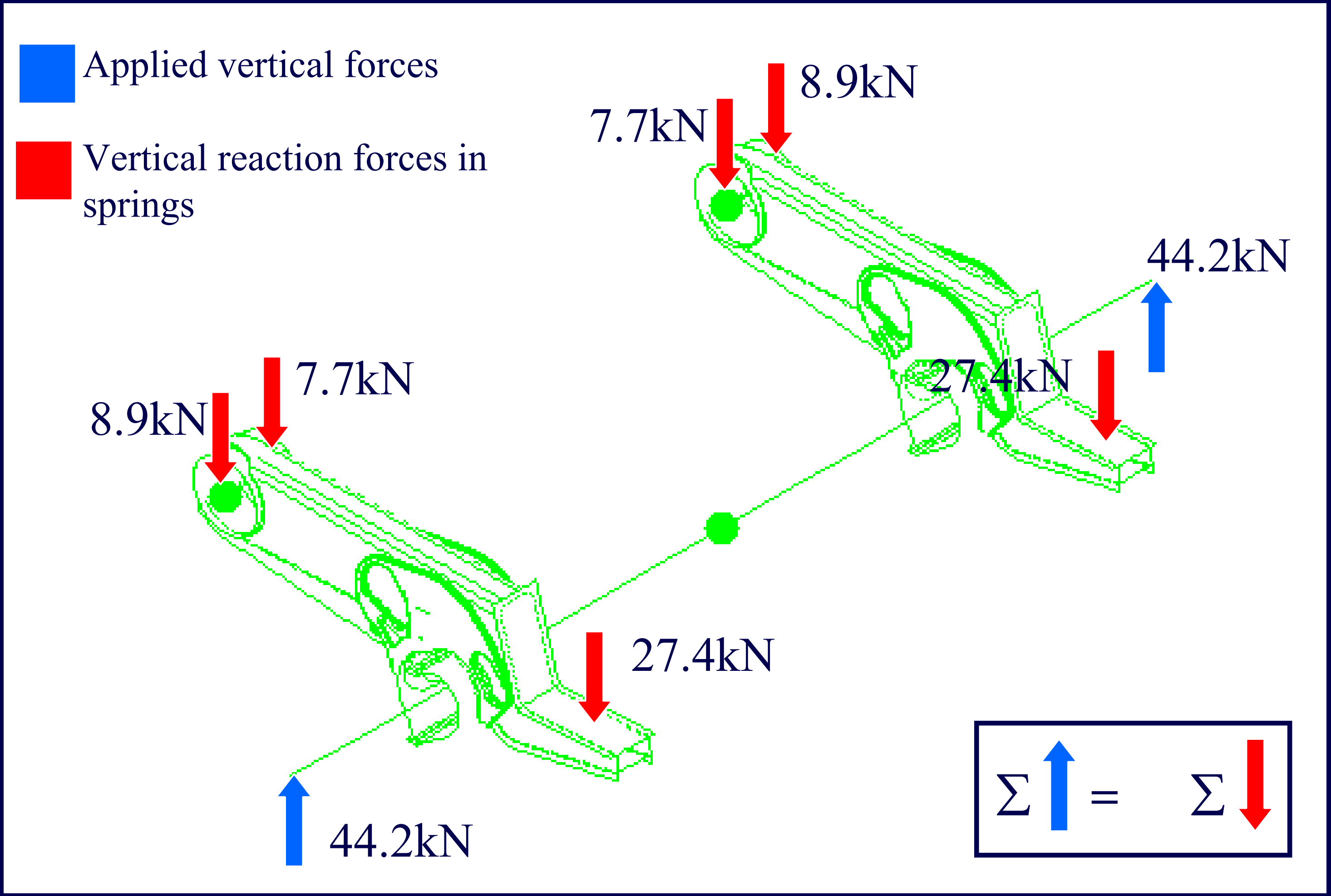


Loadcase 1: Roll Manoeuvre

Stress Analysis - Model Validation

Adding value through knowledge

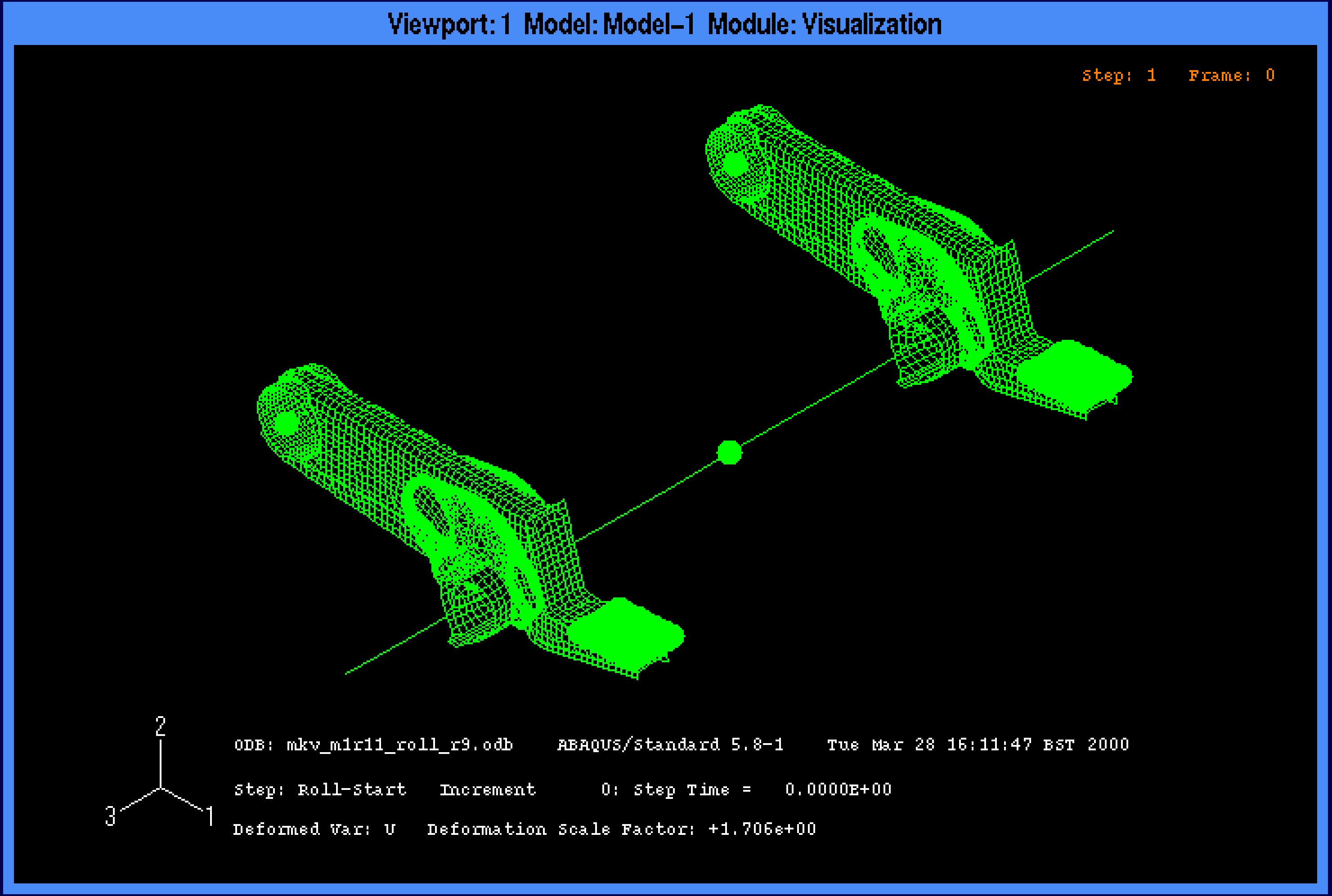
- **Start Condition - Sum of Vertical Forces**



Stress Analysis - Results

Adding value through knowledge

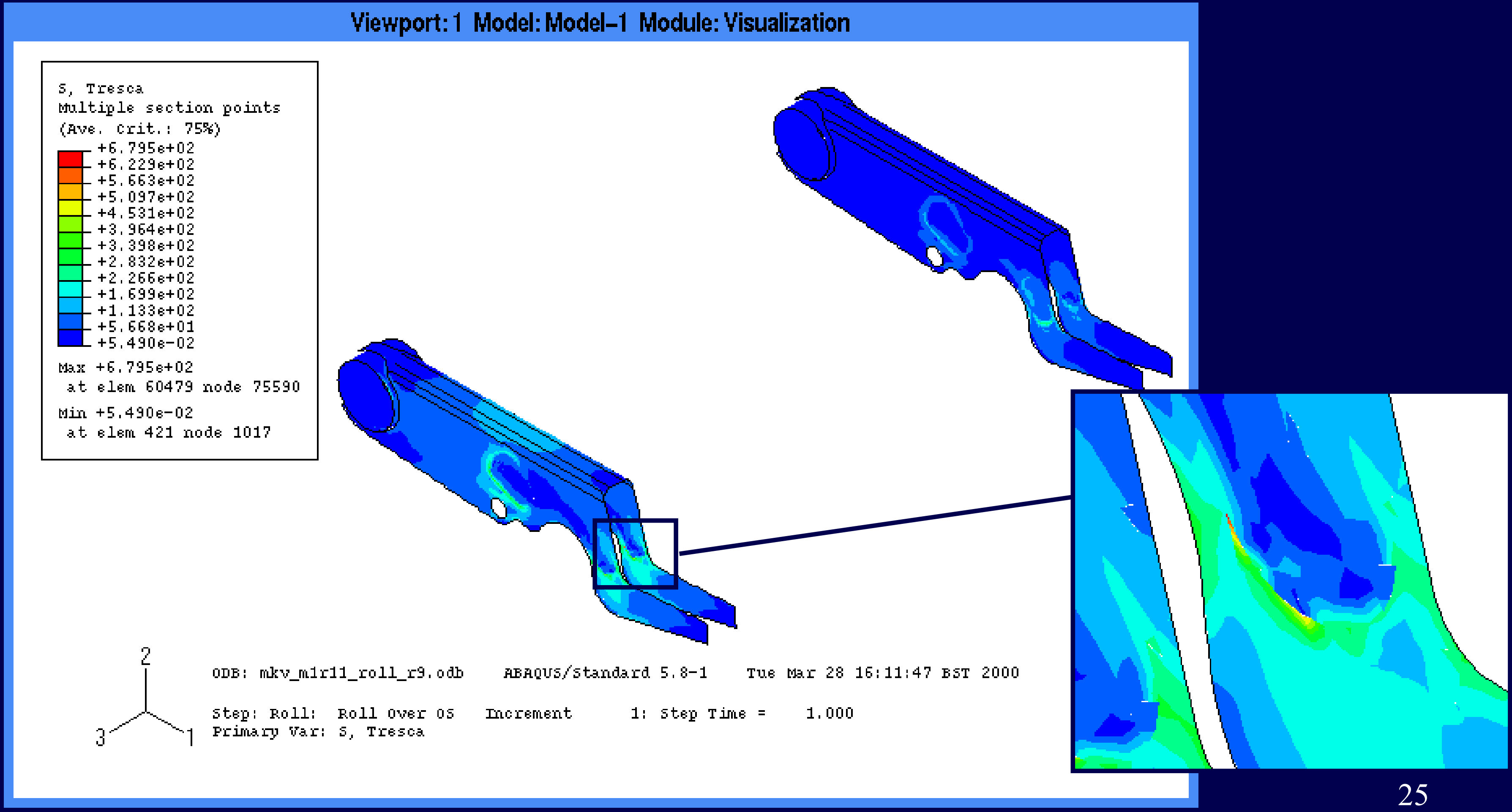
- **Roll Manoeuvre - Displaced Shape**



Stress Analysis - Results

Adding value through knowledge

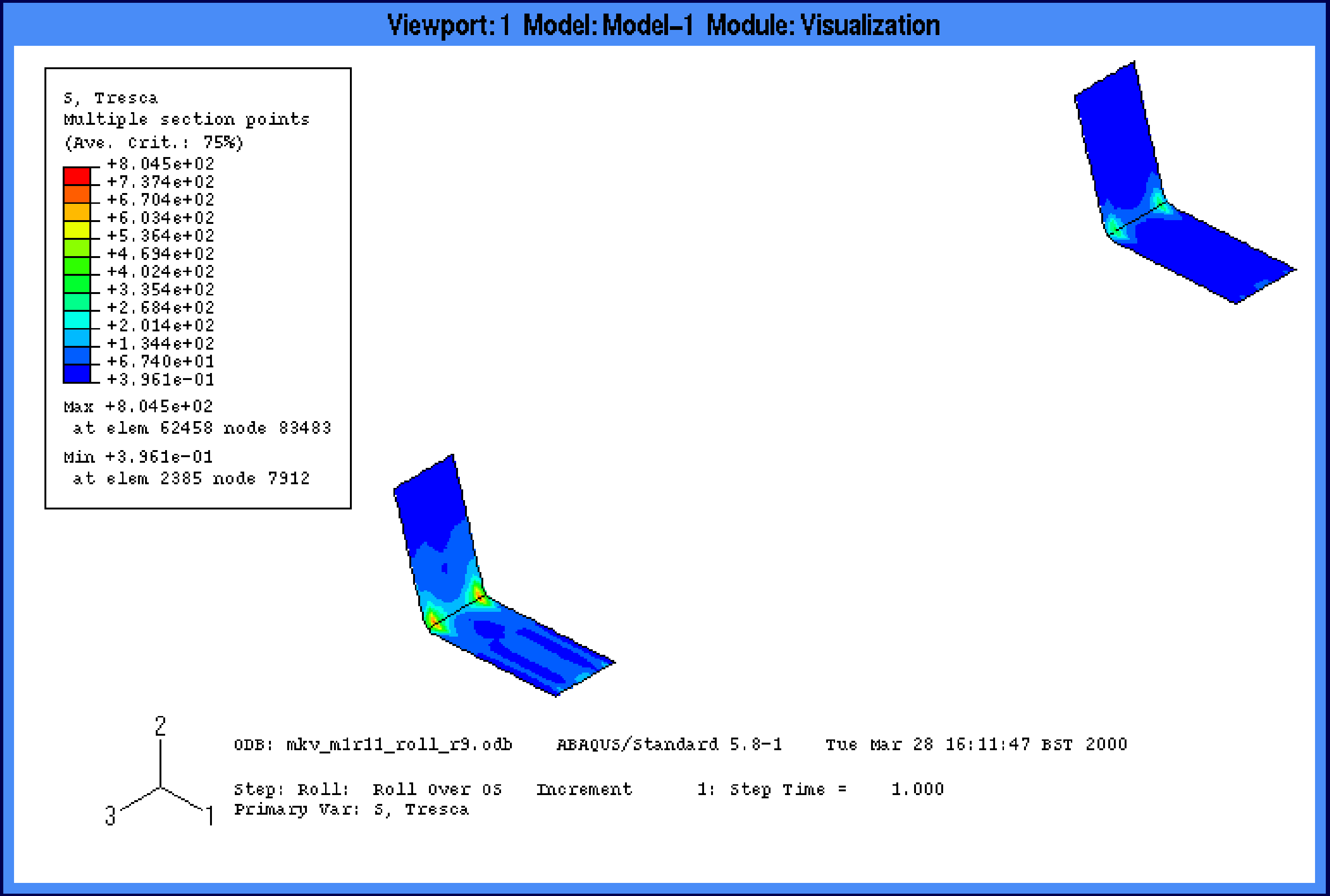
- **Rollover LH - Arm/Pivot - TRESCA Stress**



Stress Analysis - Results

Adding value through knowledge

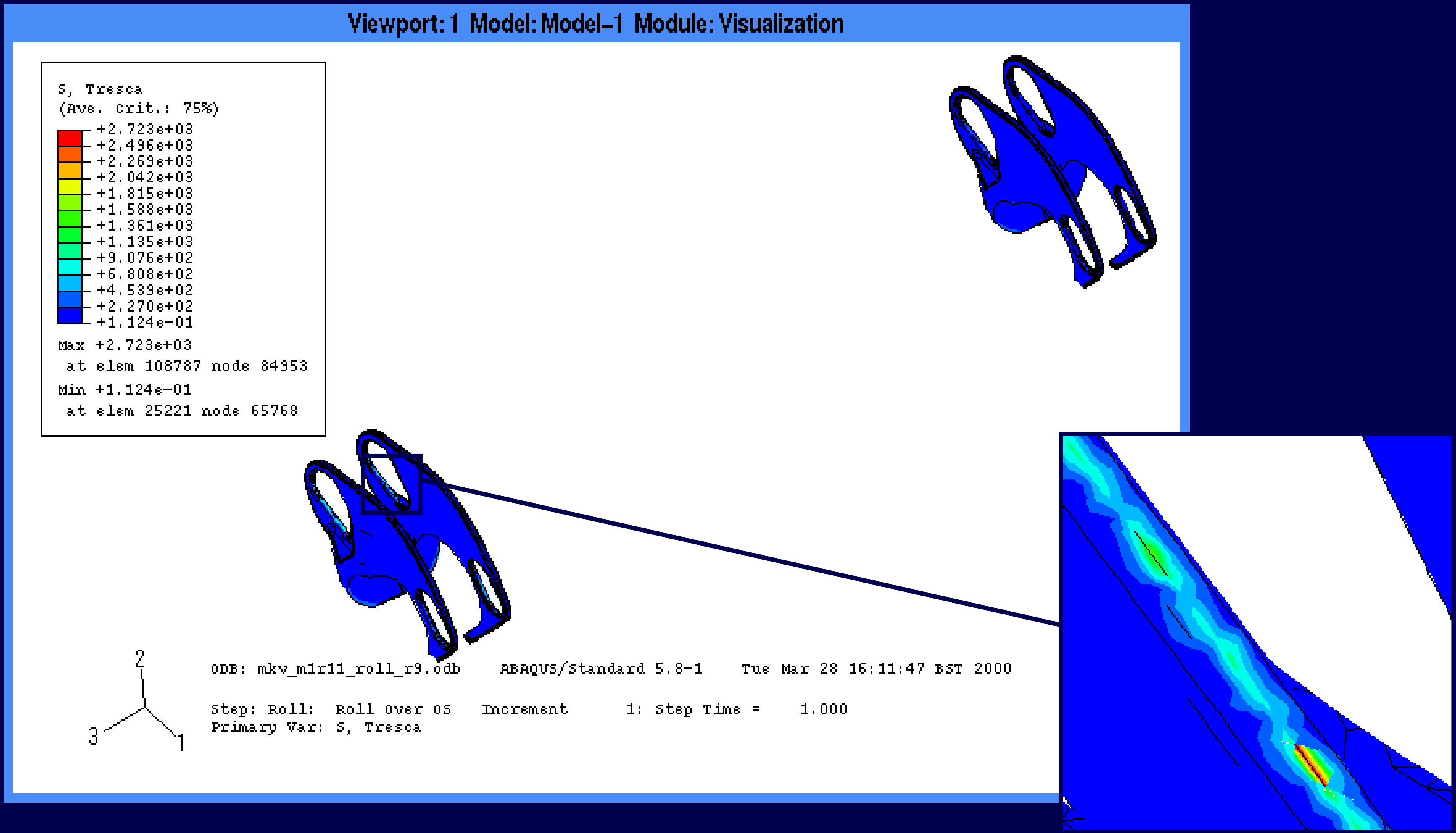
- Rollover LH - Spring Platform - TRESCA Stress



Stress Analysis - Results

Adding value through knowledge

- **Rollover LH - Side Plate - TRESCA Stress**

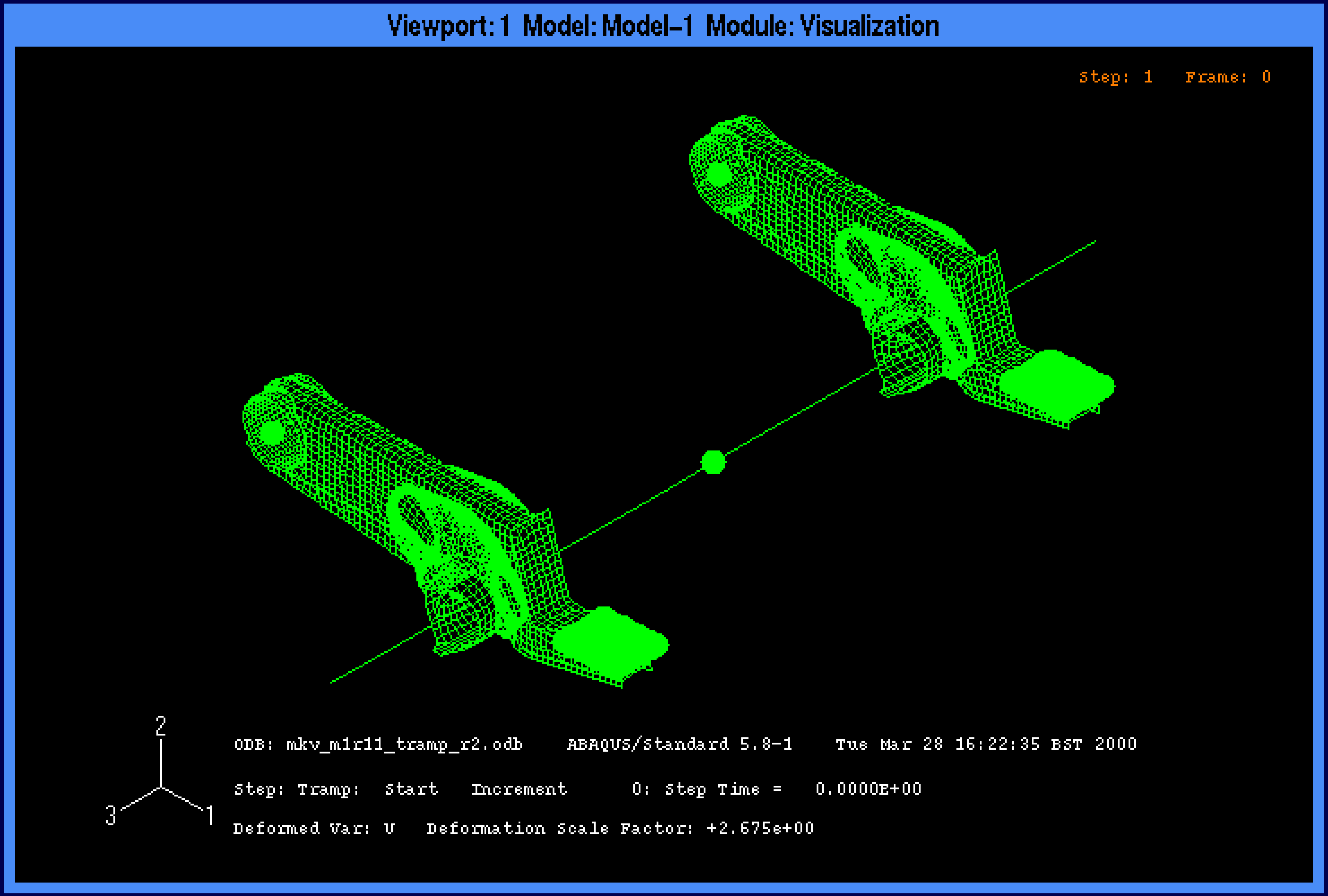


Loadcase 2: Tramp Manoeuvre

Stress Analysis - Results

Adding value through knowledge

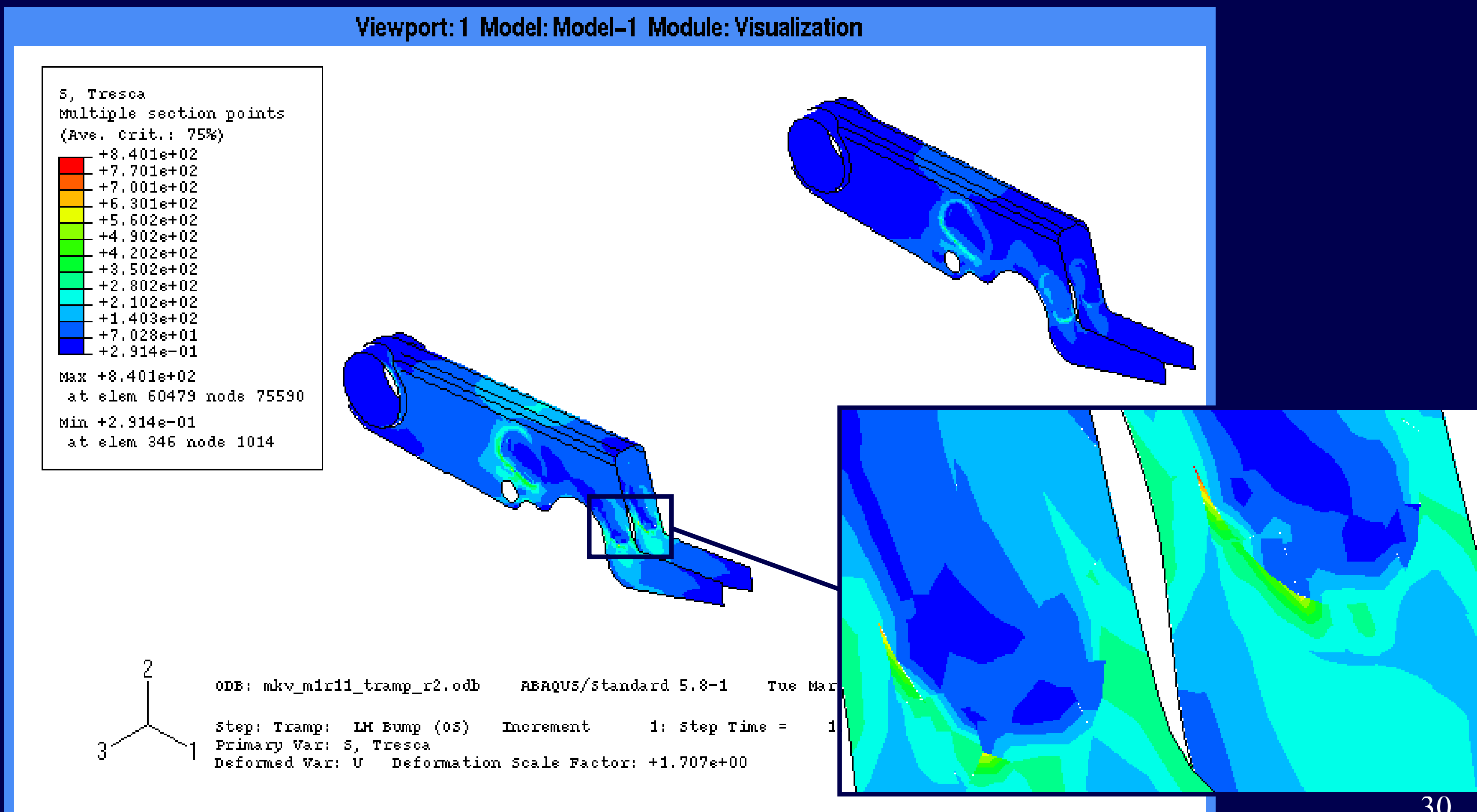
- Tramp Manoeuvre - Displaced Shape



Stress Analysis - Results

Adding value through knowledge

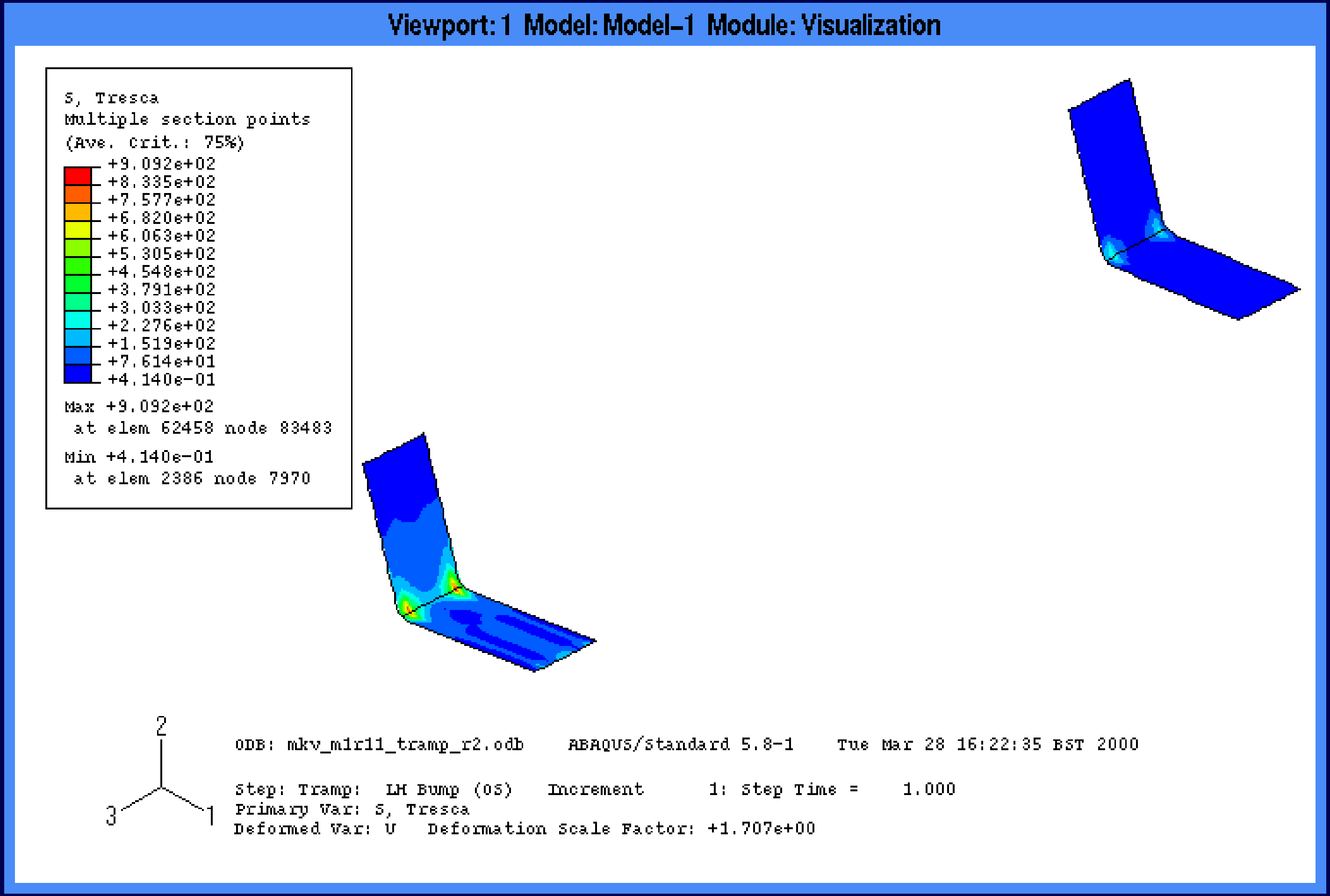
- Tramp LH/RH Bump - Arm/Pivot - TRESCA Stress



Stress Analysis - Results

Adding value through knowledge

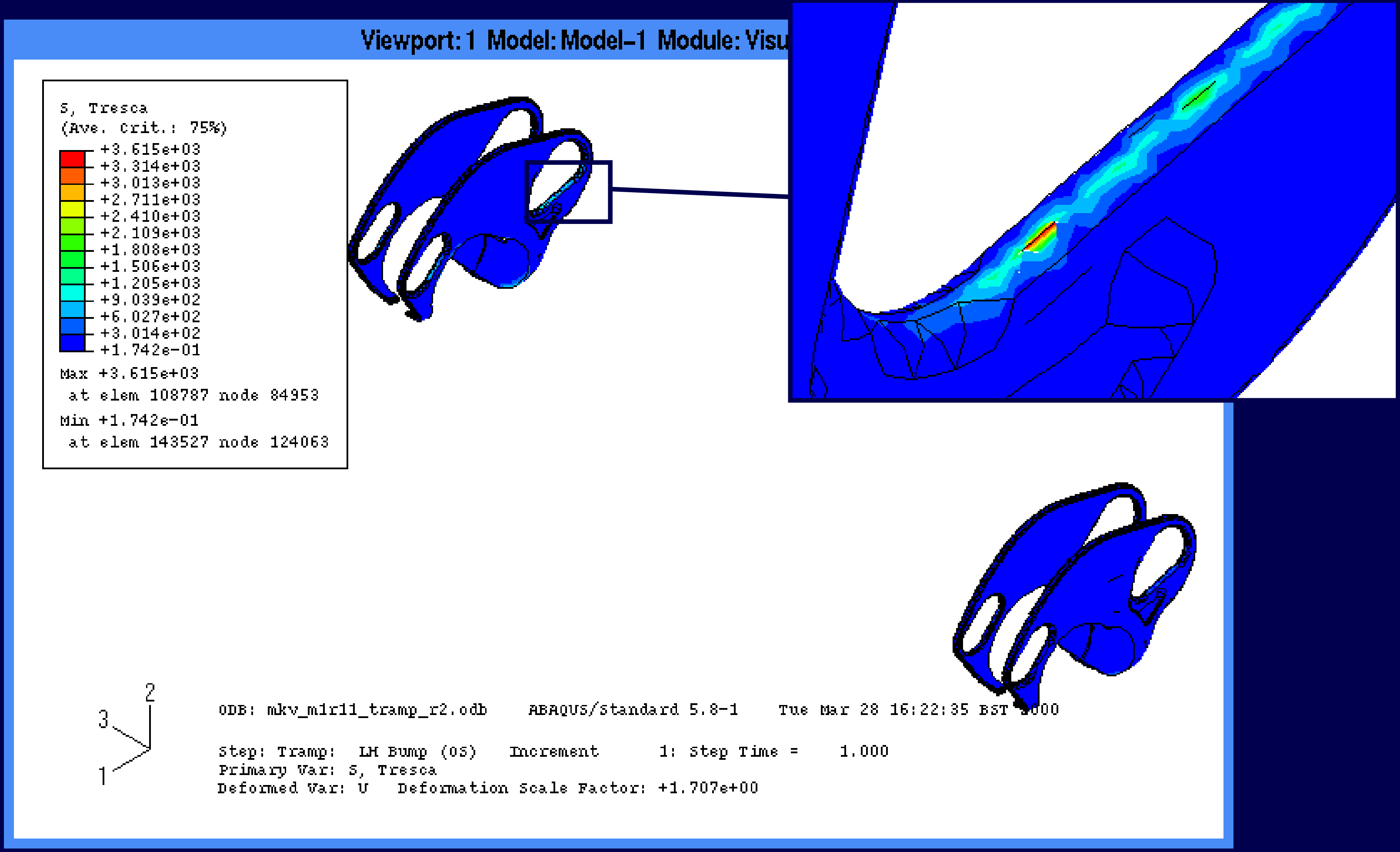
- Tramp LH/RH Bump - Spring Platform - TRESCA Stress



Stress Analysis - Results

Adding value through knowledge

- Tramp LH/RH Bump - Side Plate - TRESCA Stress

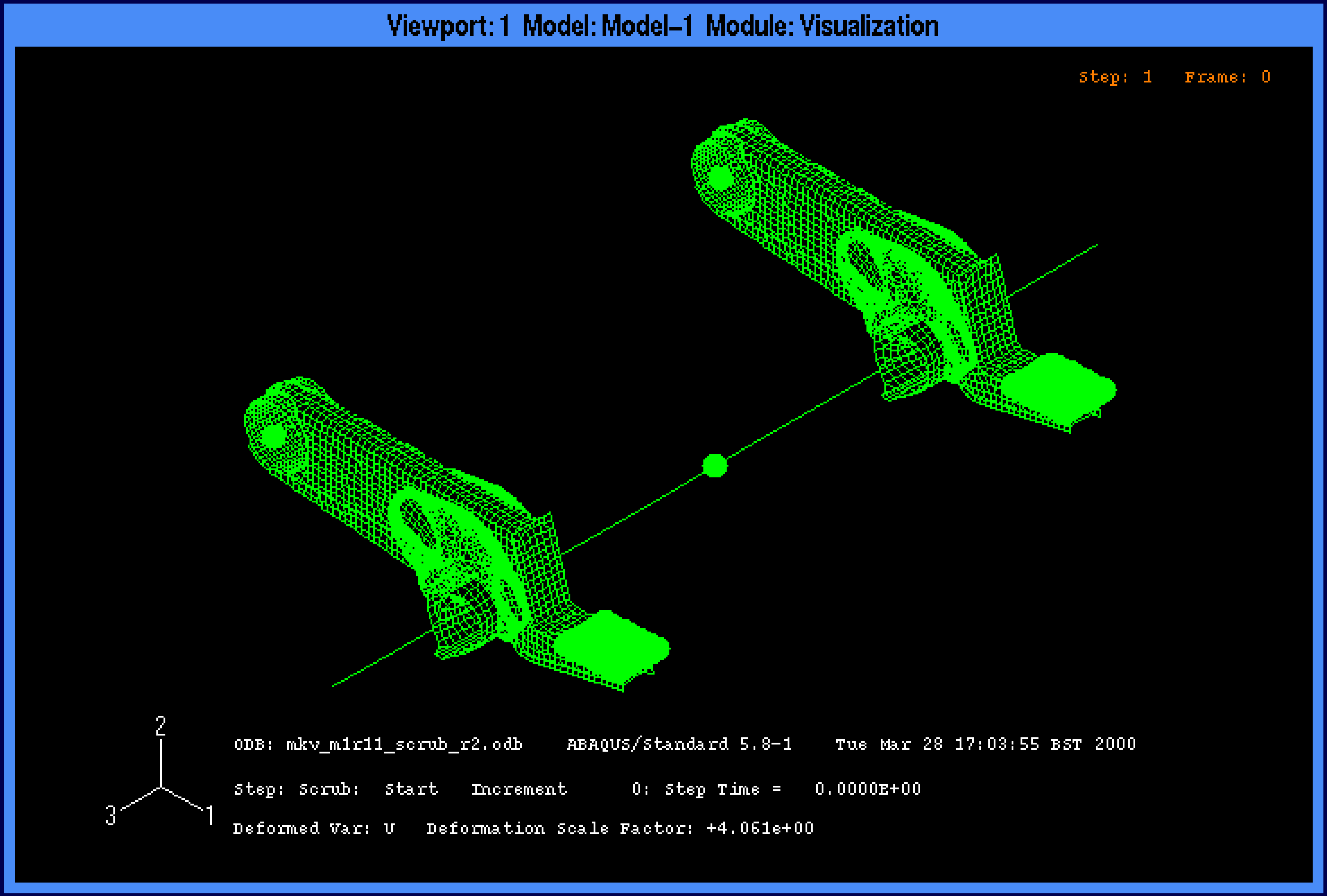


Loadcase 3: Scrub Manoeuvre

Stress Analysis - Results

Adding value through knowledge

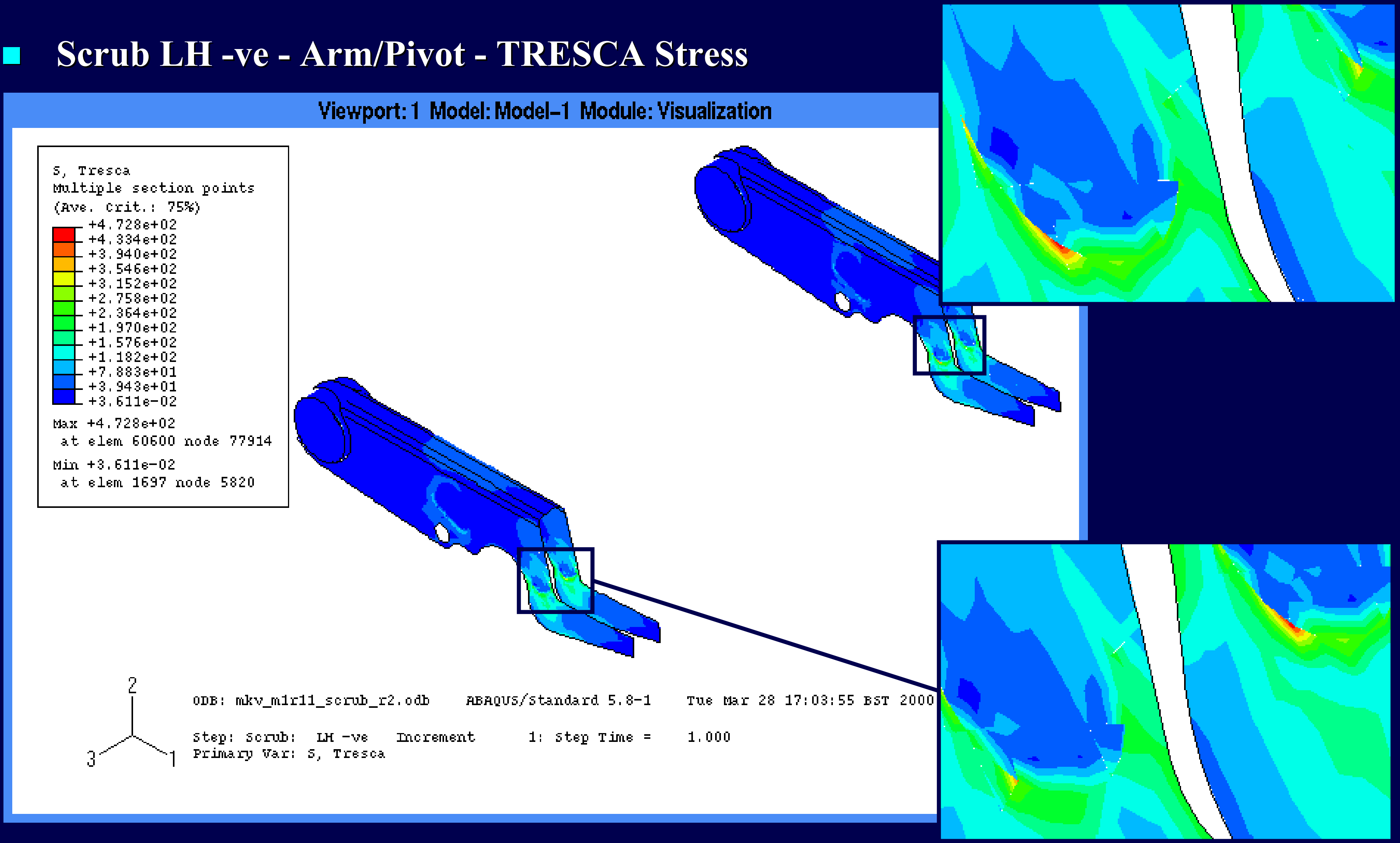
- Scrub Manoeuvre - Displaced Shape



Stress Analysis - Results

Adding value through knowledge

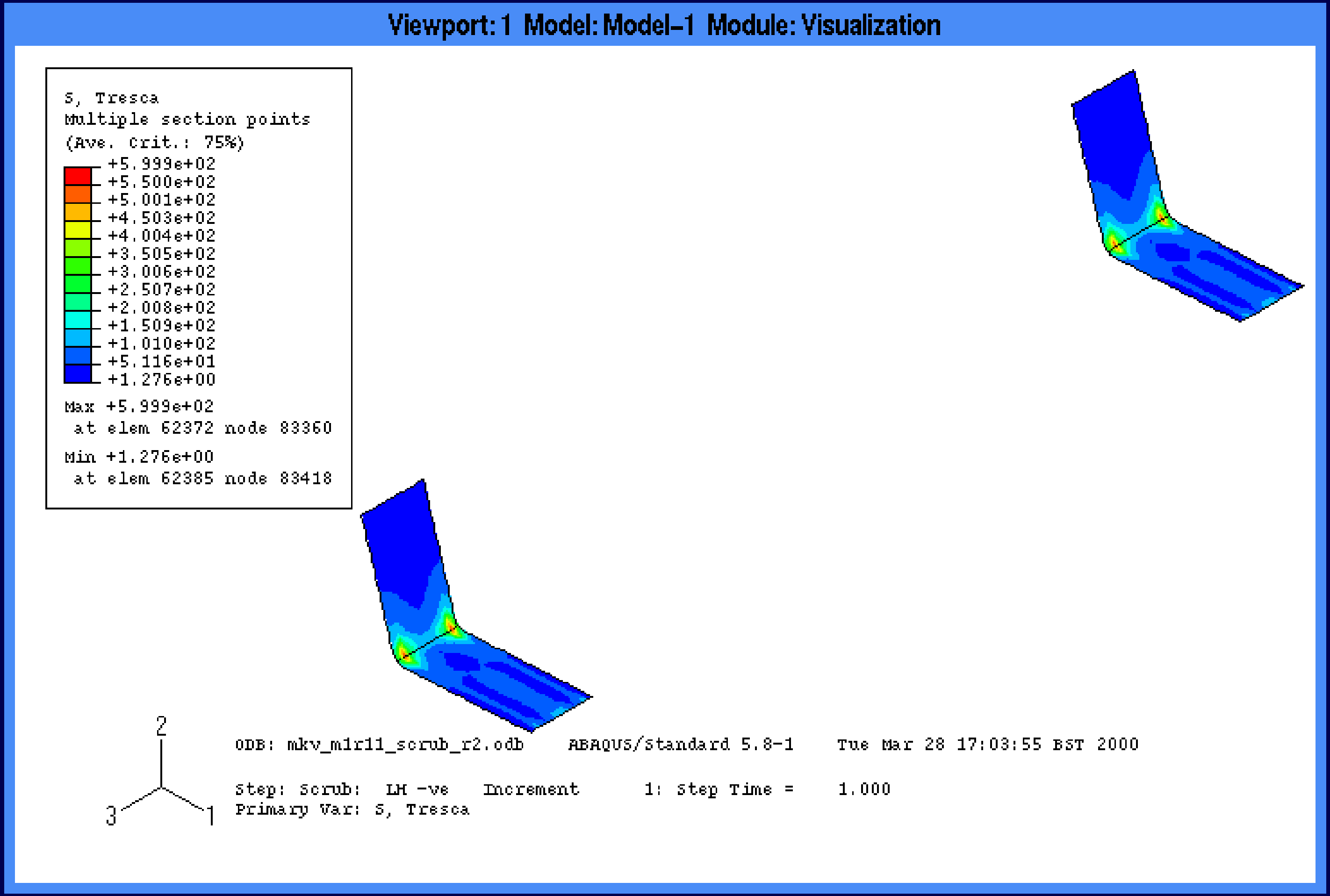
- Scrub LH -ve - Arm/Pivot - TRESCA Stress



Stress Analysis - Results

Adding value through knowledge

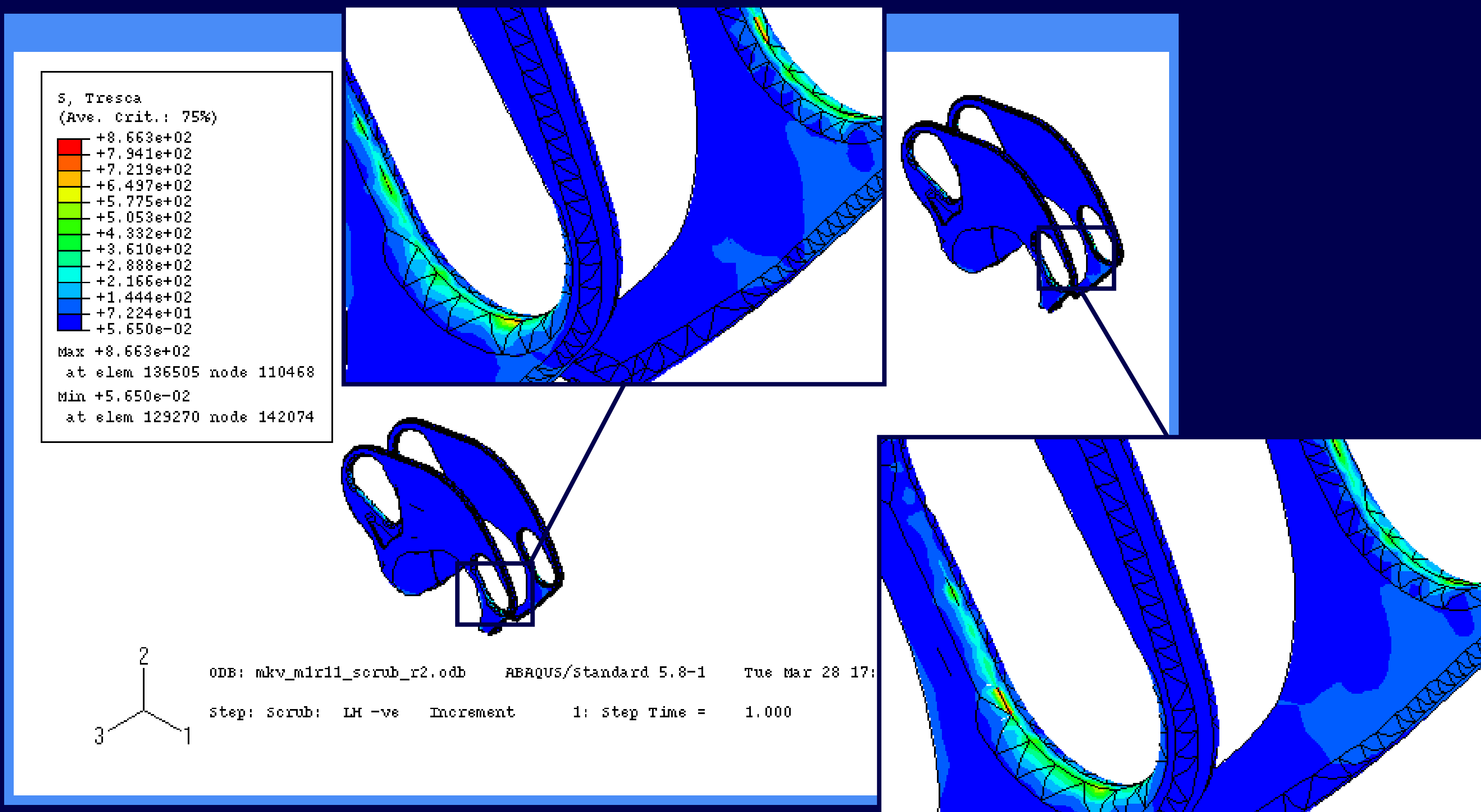
- Scrub LH -ve - Spring Platform - TRESCA Stress



Stress Analysis - Results

Adding value through knowledge

- Scrub LH -ve - Side Plate - TRESCA Stress

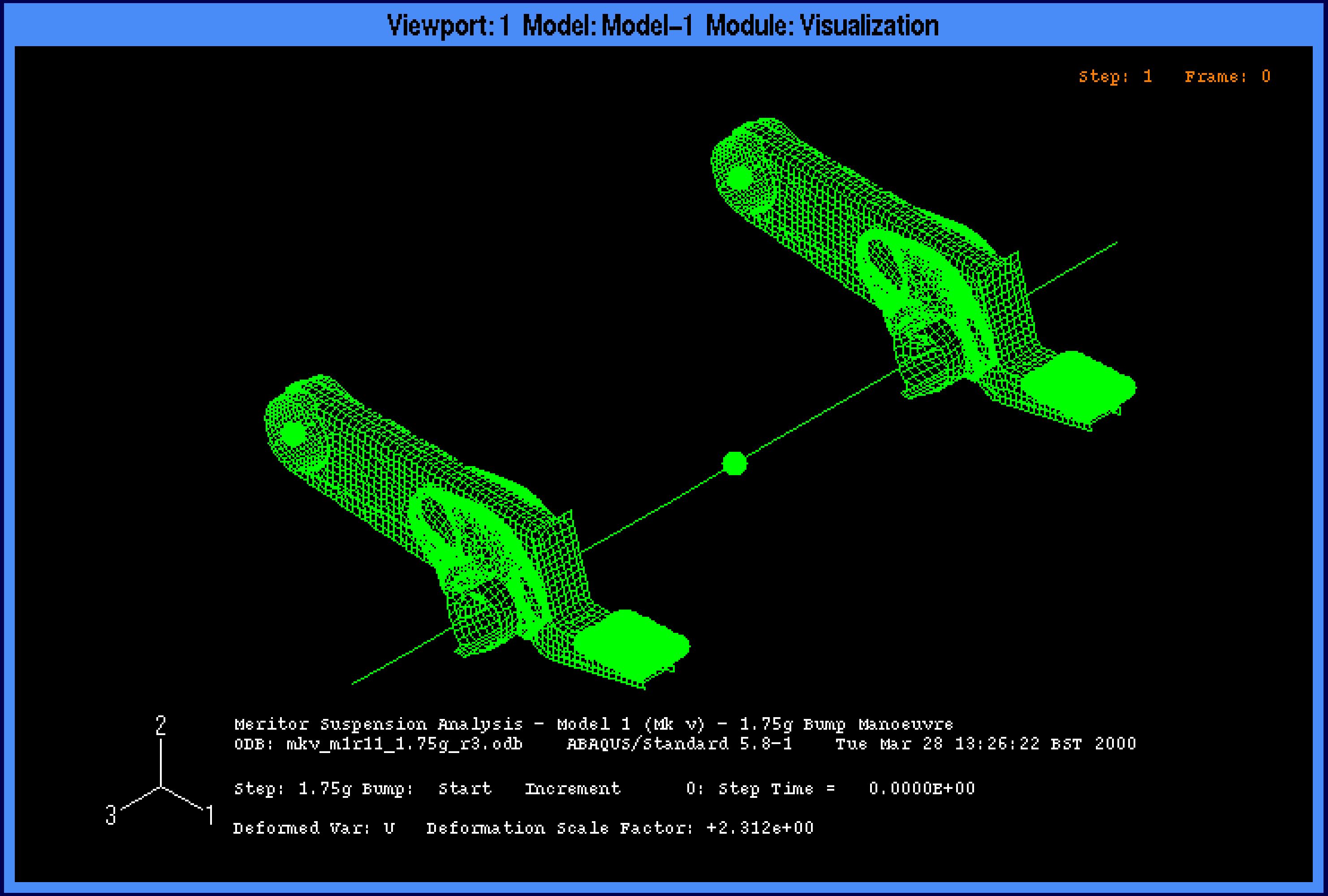


Loadcase 4: 1.75g Bump Manoeuvre

Stress Analysis - Results

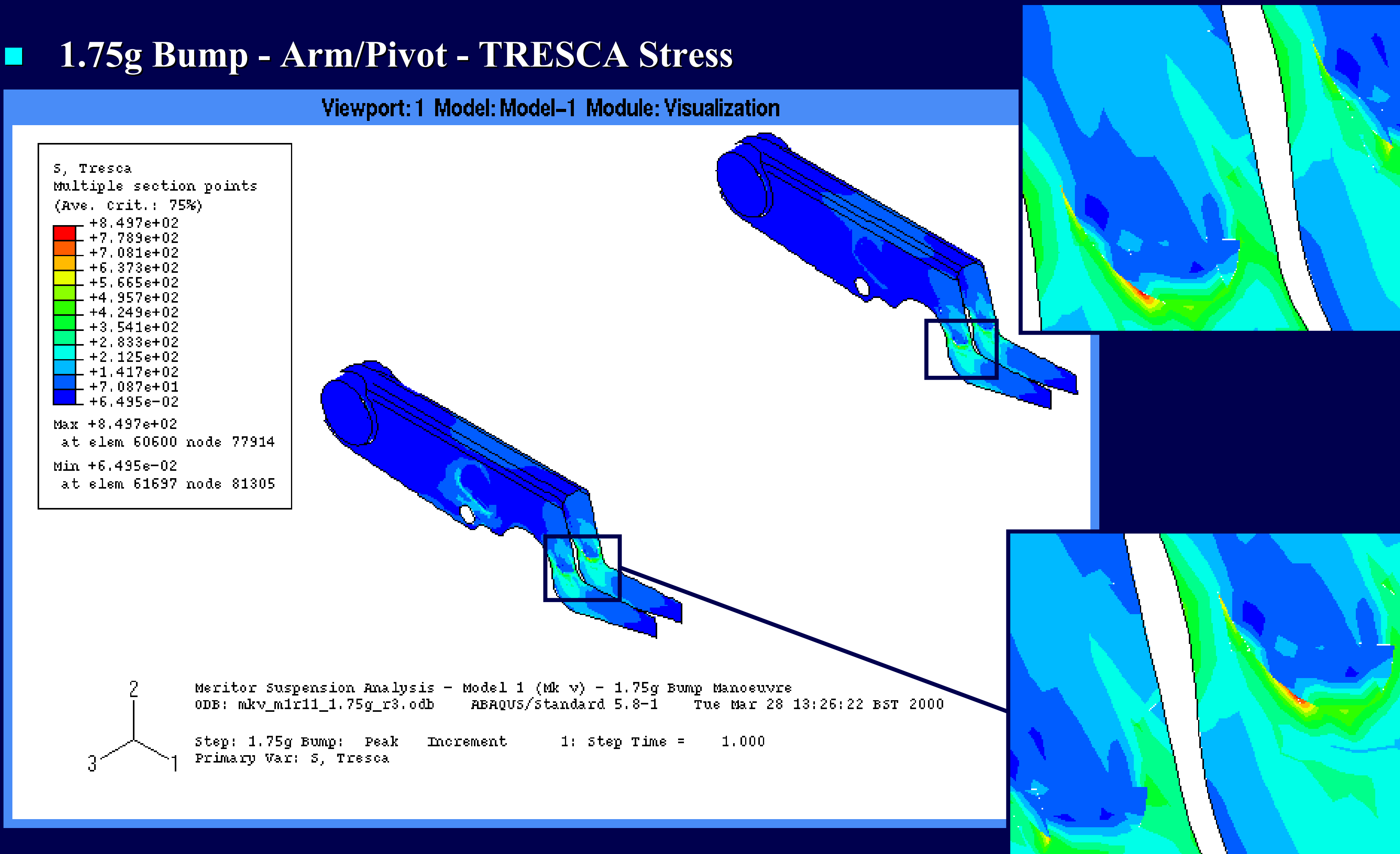
Adding value through knowledge

- 1.75g Bump Manoeuvre - Displaced Shape



Stress Analysis - Results

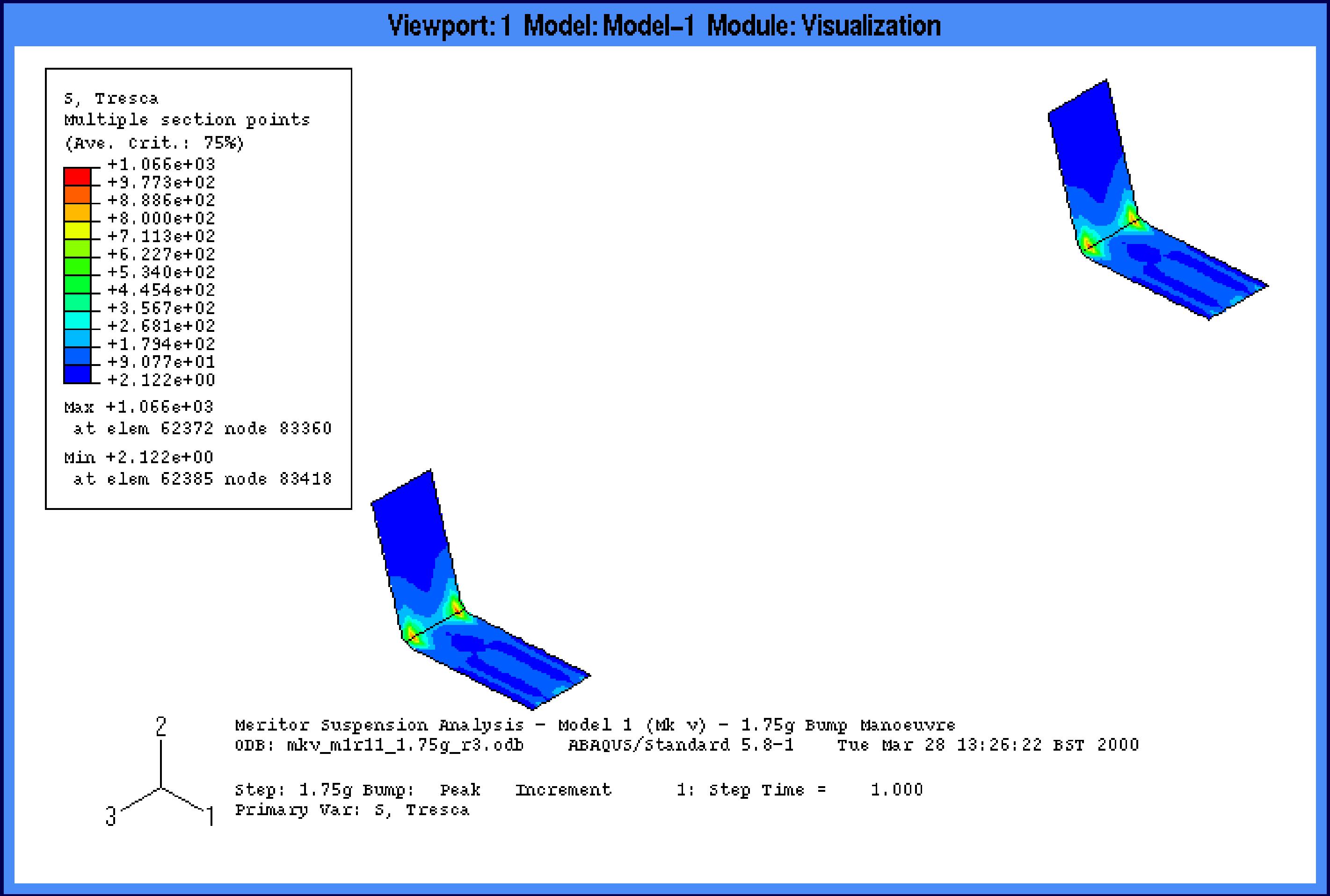
- 1.75g Bump - Arm/Pivot - TRESCA Stress



Stress Analysis - Results

Adding value through knowledge

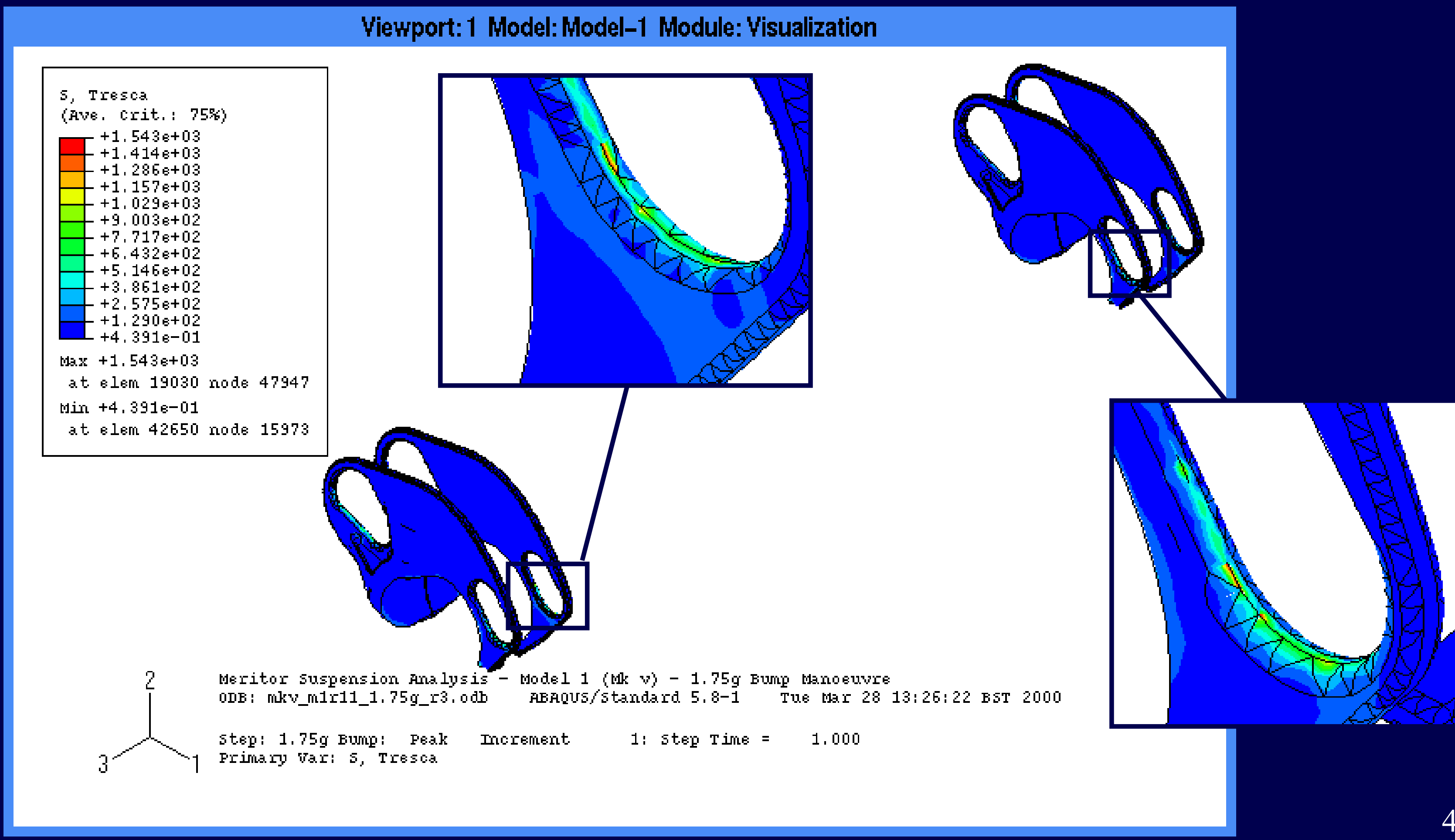
- 1.75g Bump - Spring Platform - TRESCA Stress



Stress Analysis - Results

Adding value through knowledge

- 1.75g Bump - Side Plate - TRESCA Stress



Stress Analysis - Results

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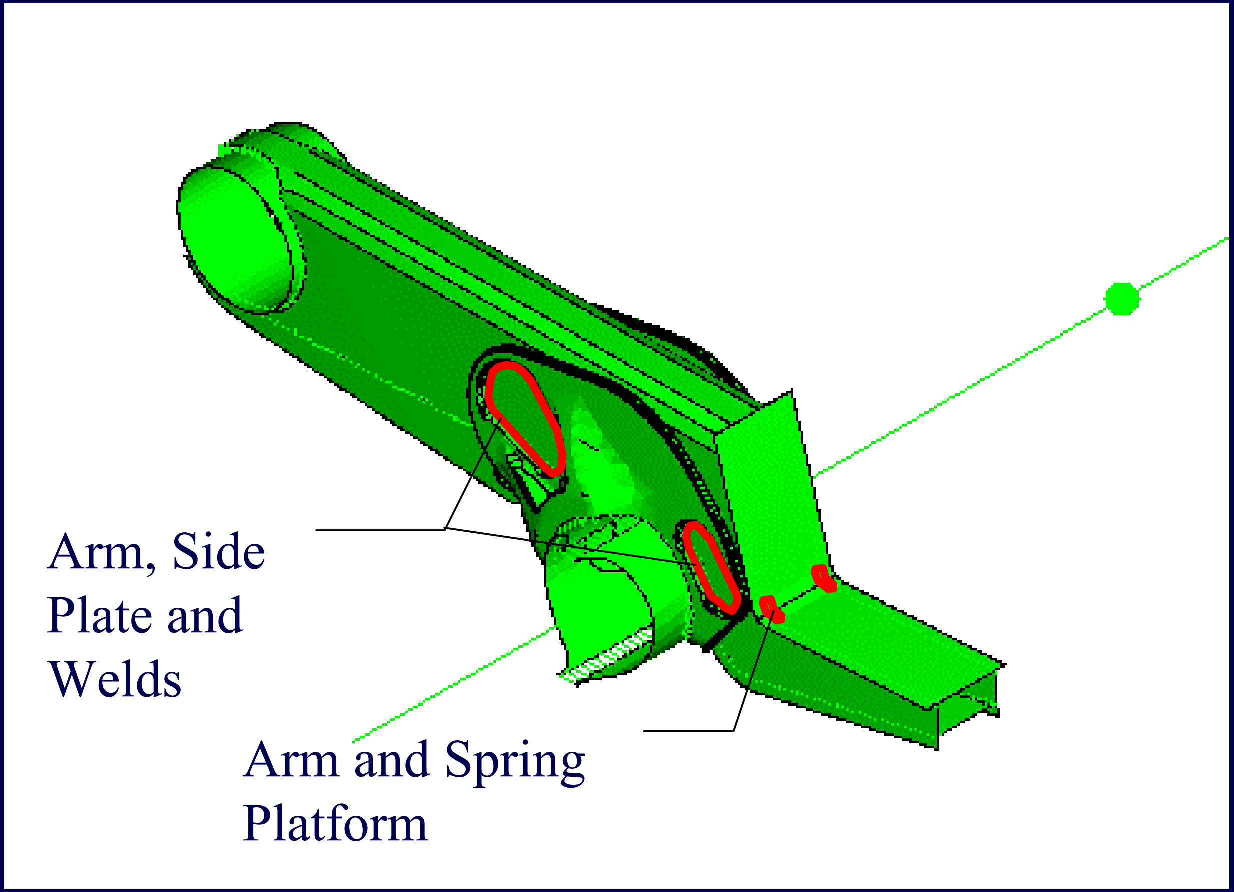
- Critical Locations of Peak Stresses



Assessment

Assessment Issues

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Three failure mechanisms are relevant :-

- **Crack initiation**
  - **Fatigue assessment using BS5400 rules**
- **Crack Propagation**
  - **Fracture mechanics using R6 procedure**
- **Cyclic plasticity causing incremental collapse**
  - **Shakedown criteria**

Fatigue Assessment - Methodology

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- Parent Material and Welds
  - BS5400 Part 10 & BS7608
  - Critical sample stress locations assessed
  - Alternating stress calculated using FORTRAN programme
  - Predicted number of cycles to failure calculated

Fatigue Assessment of Parent Material

Assessment - Stress History

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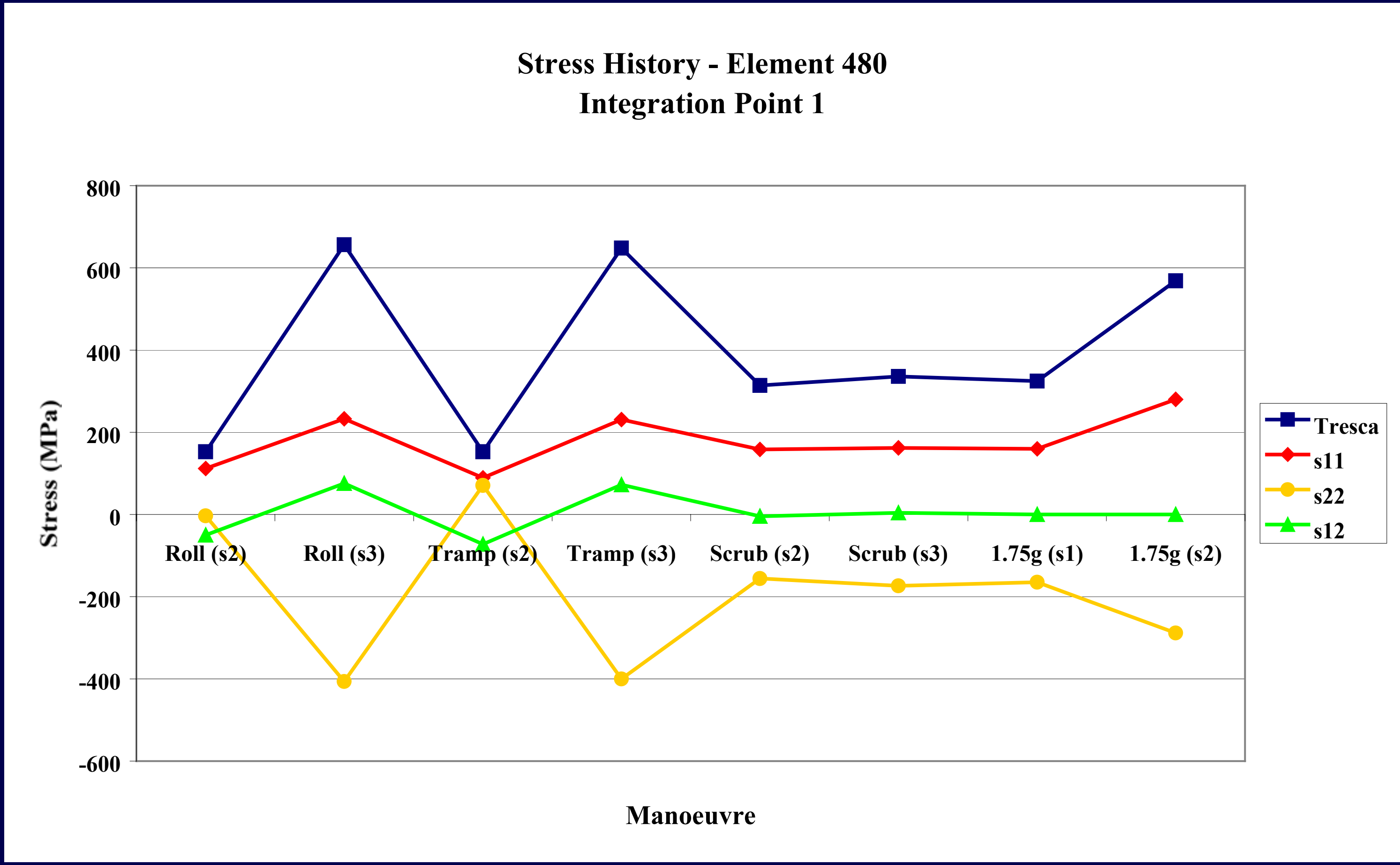
- Example of Stress Range Selection

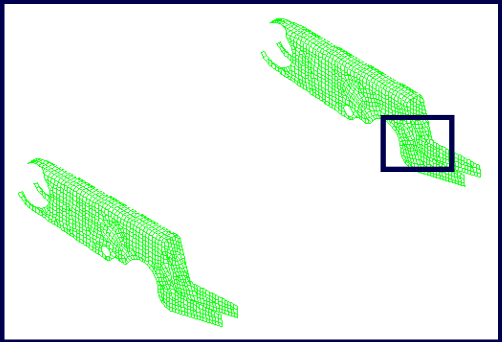


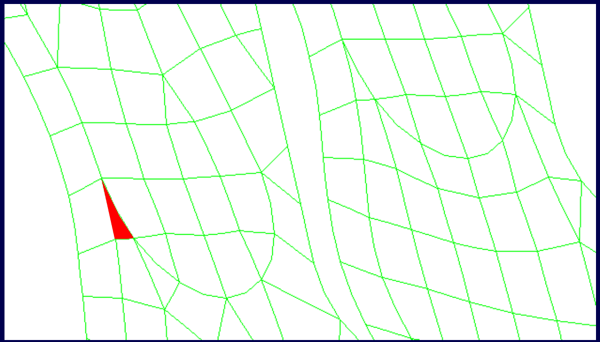
Multi-axial non-proportional stress-strain state

Fatigue Assessment - Results

- **Arm - Element 480**

Manoeuvre	Detail Class	Alternating Stress (MPa)	Stress Range (MPa)	Predicted Cycles to Failure (N)	Usage
Roll	W (G)	290	580	1.9e3 (2.9e3)	**16.8 (11.0)**
Tramp	W (G)	339	678	1.2e3 (1.8e3)	**26.7 (17.5)**
Scrub	W (G)	14	28	1.6e7 (2.6e7)	**0.0 (0.0)**
1.75g	W (G)	122	244	2.5e4 (3.9e4)	**1.3 (0.8)**



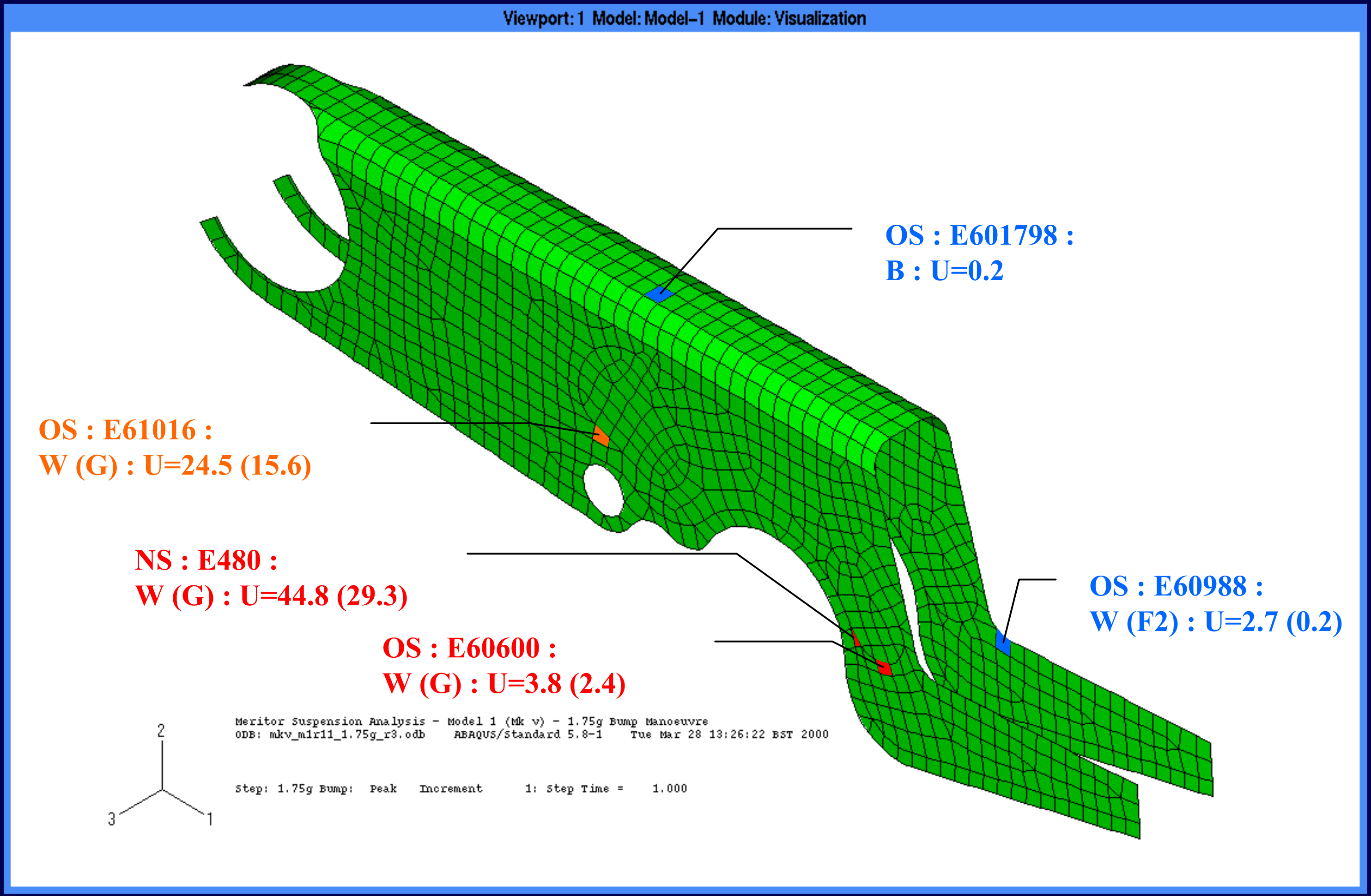


Σ **44.8 (29.3)**

Fatigue Assessment - Results

Adding value through knowledge

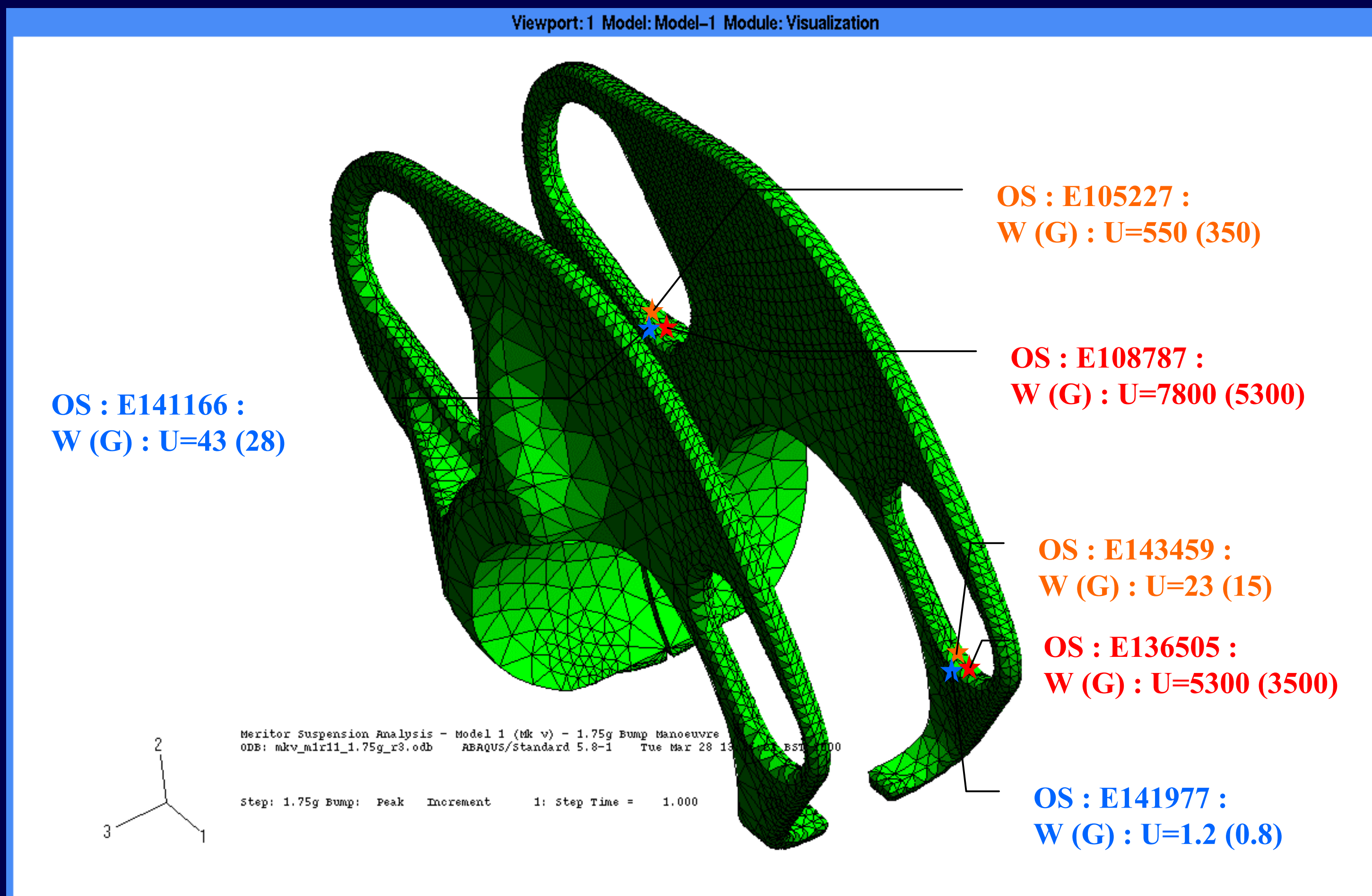
- Arm - Fatigue Usage



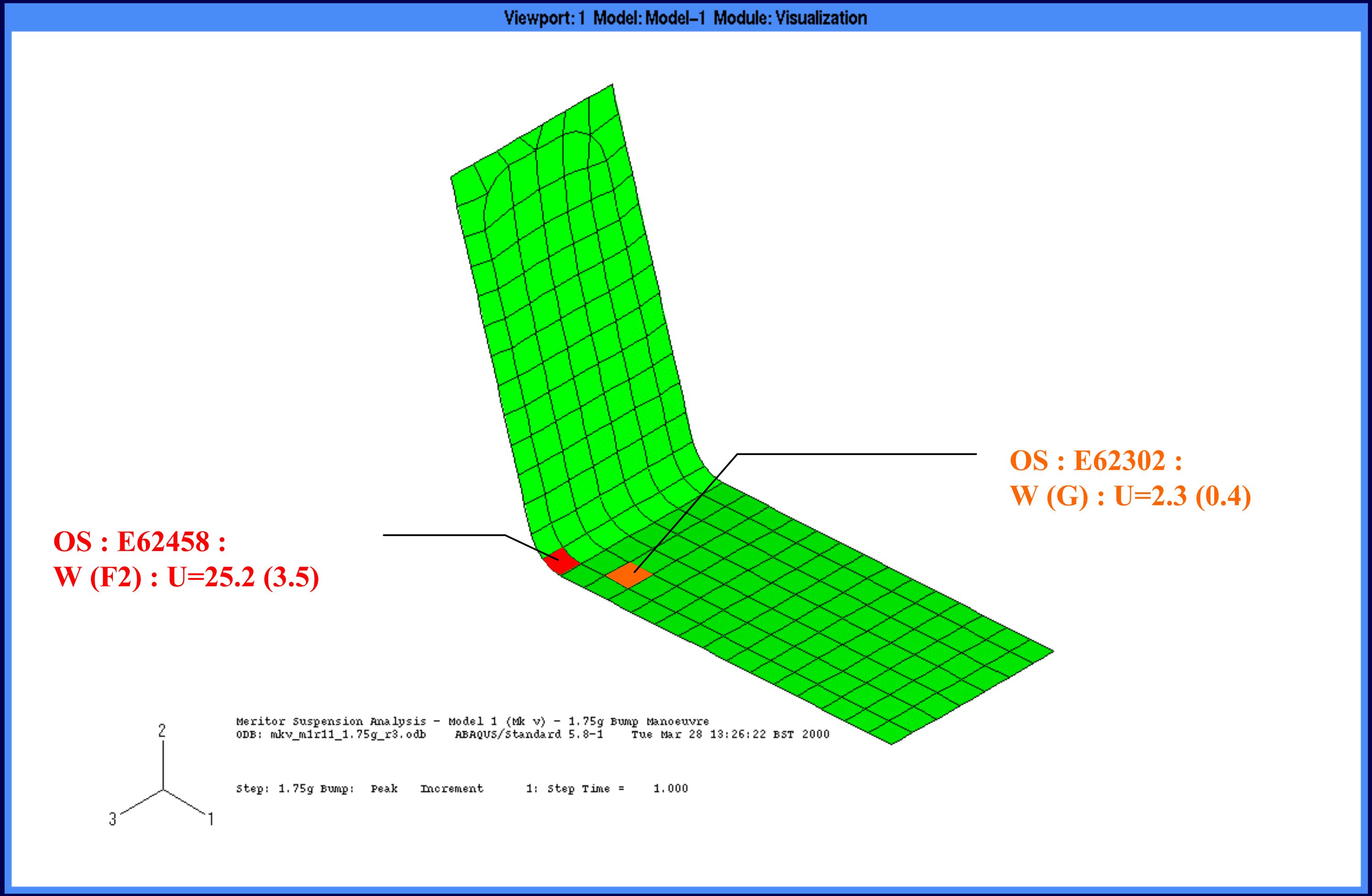
Fatigue Assessment - Results

Adding value through knowledge

- **Arm - Fatigue Usage**



Spring Platform - Fatigue Usage



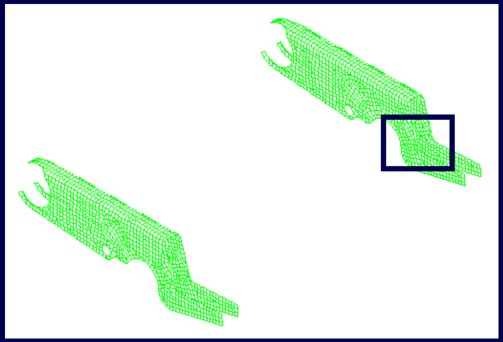
Fatigue Assessment of Welds

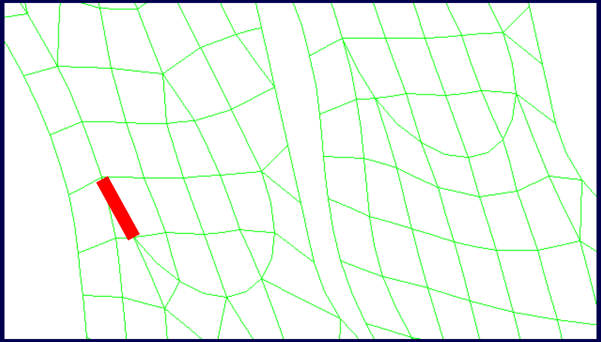
Fatigue Assessment of Welds

Adding value through knowledge

- **Plug Weld Adjacent Element 480 (Arm side of weld only)**

Manoeuvre	Detail Class	Alternating Stress (MPa)	Stress Range (MPa)	Predicted Cycles to Failure (N)	Usage
Roll	W	137	273	1.8e4	**1.8**
Tramp	W	132	263	2.0e4	**1.6**
Scrub	W	6	12	2.1e8	**0.0**
1.75g	W	67	133	1.6e5	**0.2**
					Σ **3.6**



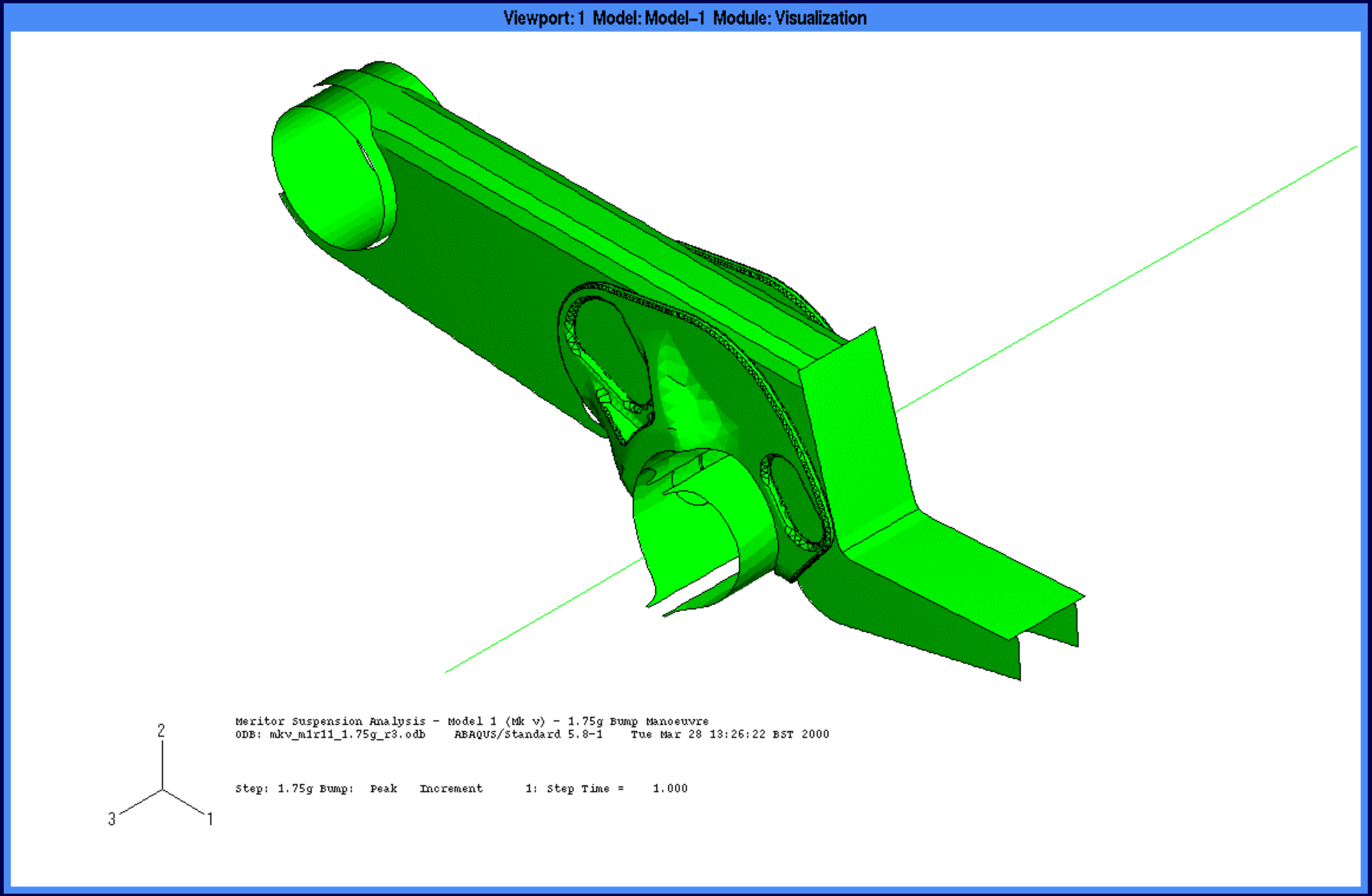


Why Fatigue Failure?

Why Fatigue Failure?

Adding value through knowledge

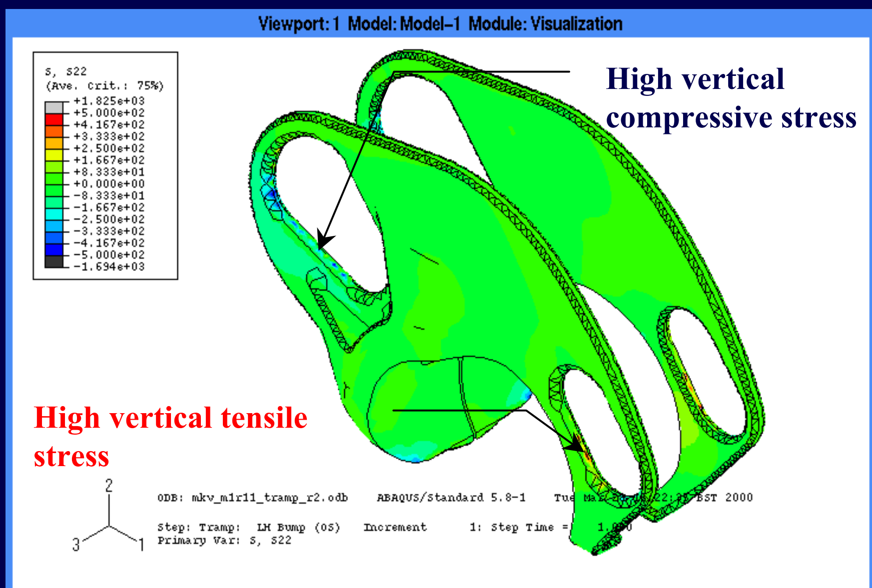
- Load Path

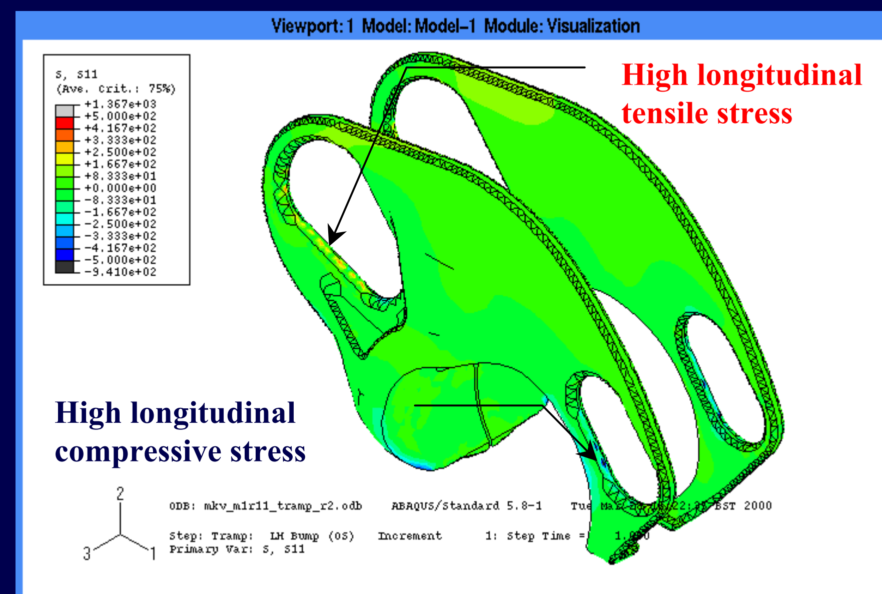


Why Fatigue Failure?

Adding value through knowledge

- Large stresses from side plate to arm





Why Fatigue Failure?

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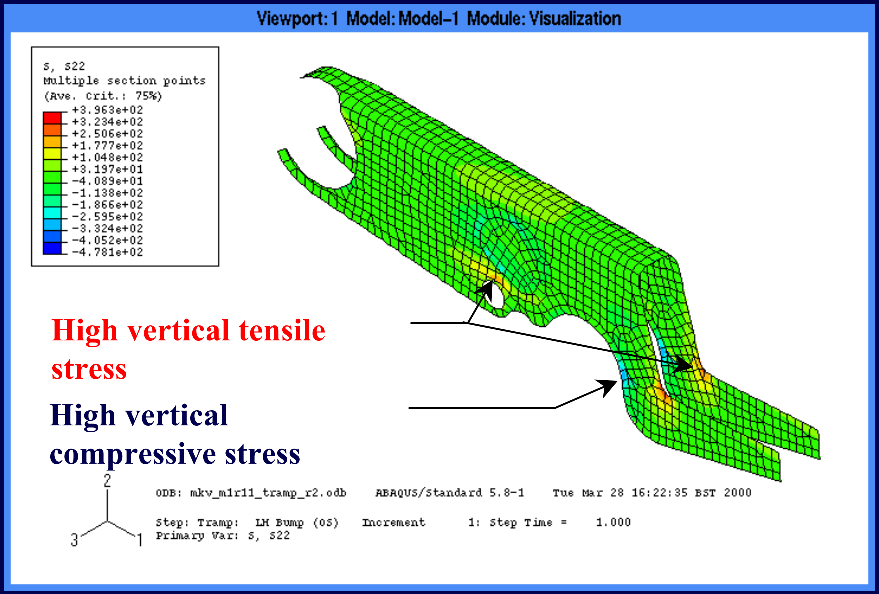
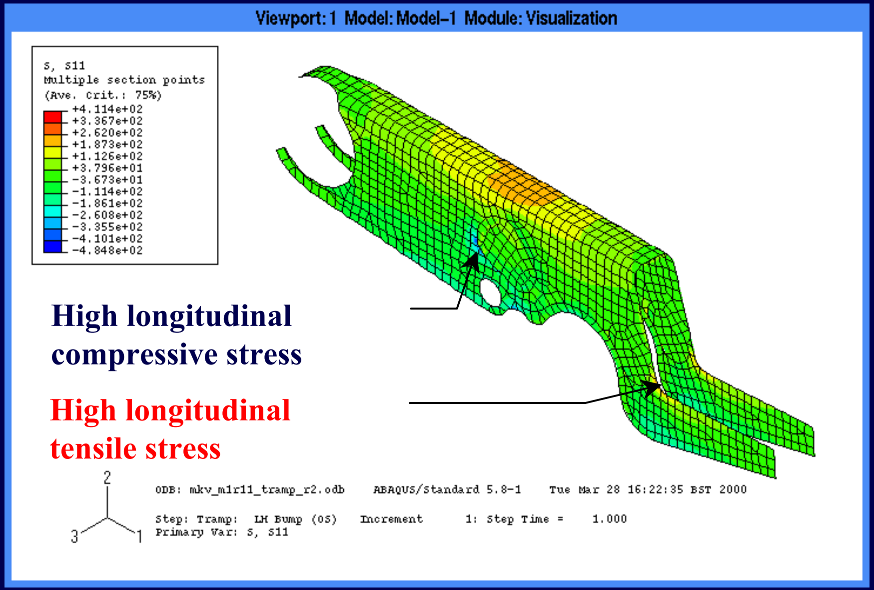
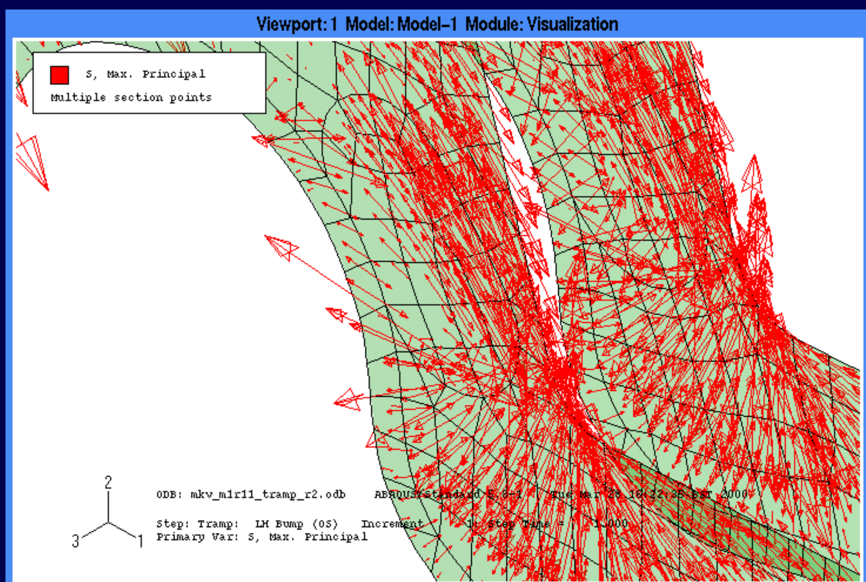
- Action of plug welds on arm



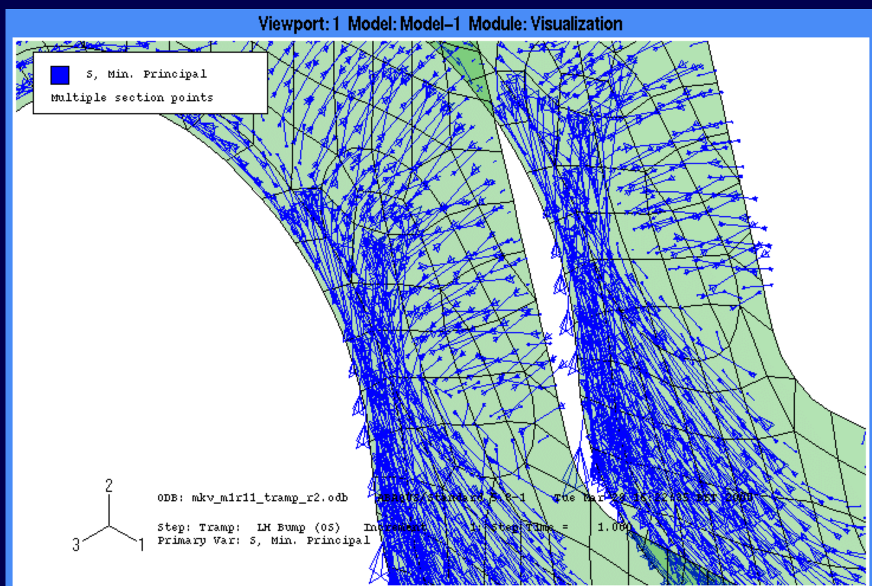


Why Fatigue Failure?

- **Stress flow dictated by**
  - **loading mechanism**
  - **Shape and location of the plug welds**



Max. Principal Stress (tension)



Min. Principal Stress (comp.)

Why Fatigue Failure?

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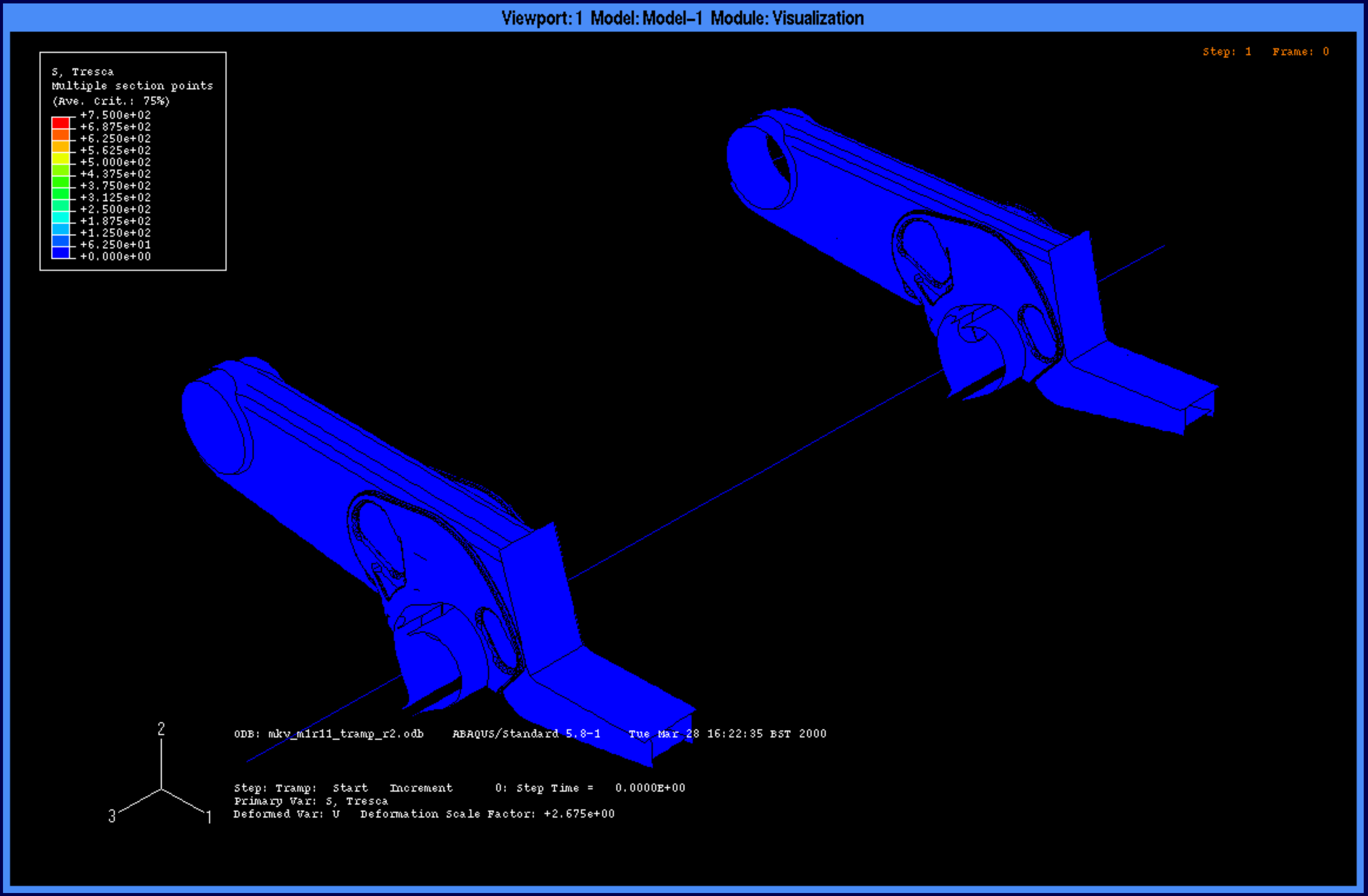
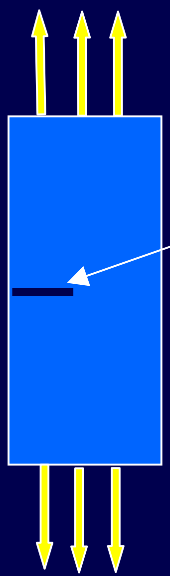


Fracture Mechanics

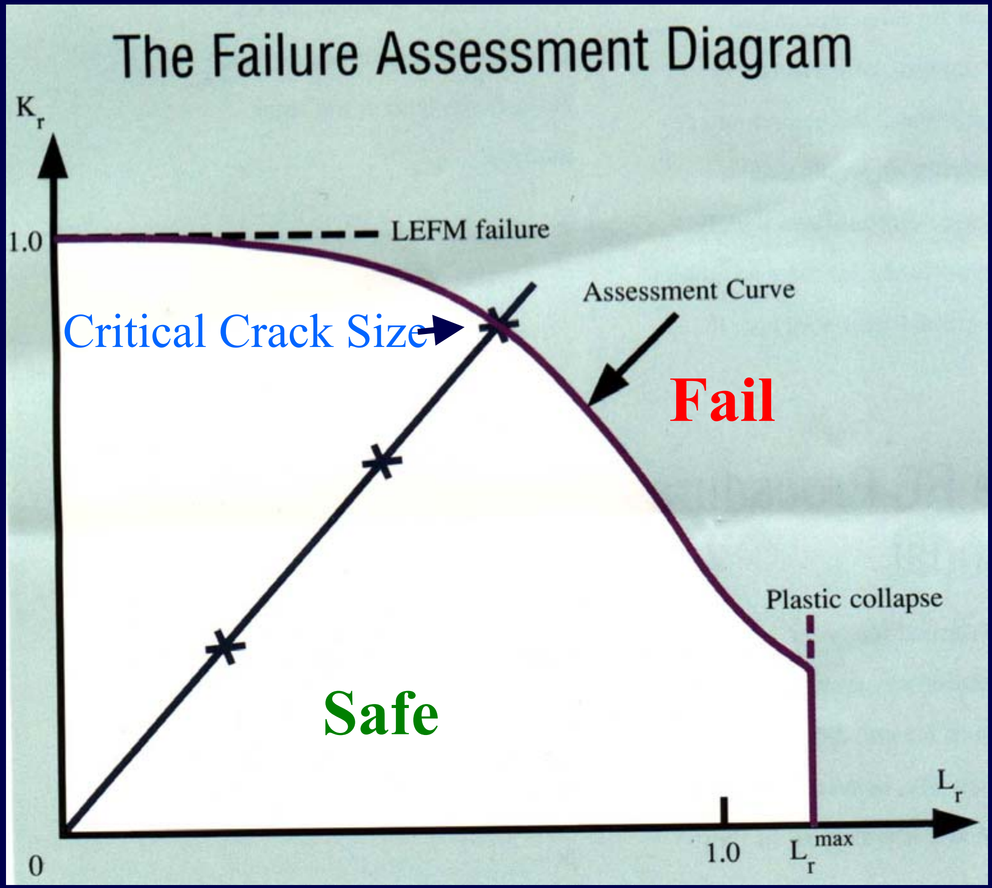
R6 used to calculate the critical crack size



Stress intensity, K_I

Failure if $K_I > K_{IC}$

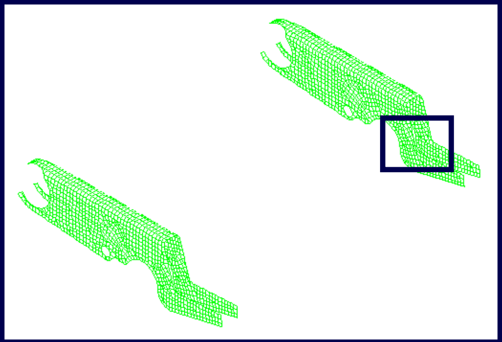
$K_r = K_I / K_{IC}$

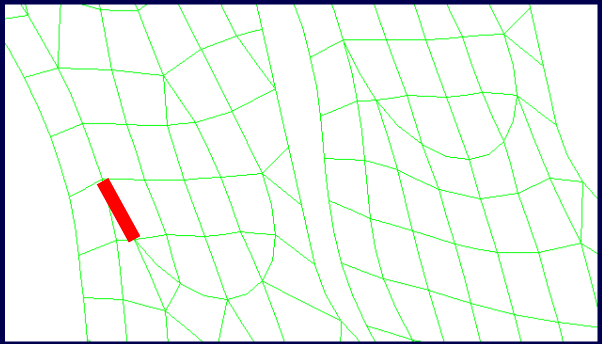


Fracture Mechanics

- **Crack Propagation in Arm for Element 480 (top surface) Vertical (s22) stress assessment**

Manoeuvre	Critical Crack Size (mm)	Crack Growth over 32000 cycles (mm)	Initial Crack Size to Cause Failure (mm)
Roll	3.5	1.9	1.7
Tramp	3.6	1.8	1.8
Scrub	4.4	0.1	4.3
1.75g	3.9	0.6	3.3





Conclusions

Conclusions

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- Geometric data
  - Transfer from CAD to FE works
  - Provision of shell geometry as mid-surfaces and solid as volume
- Stress Analysis
  - Full test simulation possible
  - Peak stresses identified
  - Loading mechanism and stress flow understood

cont'd.

Conclusions

- **Assessment**
  - Vertical loading dominant
  - Fatigue failure in parent metal and in welds
  - Allowable stress range ~226MPa for 32,000 cycles for detail class W
  - Local stress concentrations cause failures
  - Roll and Tramp manoeuvres cause most damage
  - Accelerated fatigue testing by using high loads causes plasticity and incremental collapse
  - Functional failure occurs when theoretical fatigue usage factor is 15 or more

Recommendations

Recommendations

Adding value through knowledge

Simulation

- Include bracket at the pivoted end for more realistic test simulation
- Conduct non-linear analysis of the
  - air-spring
  - bush

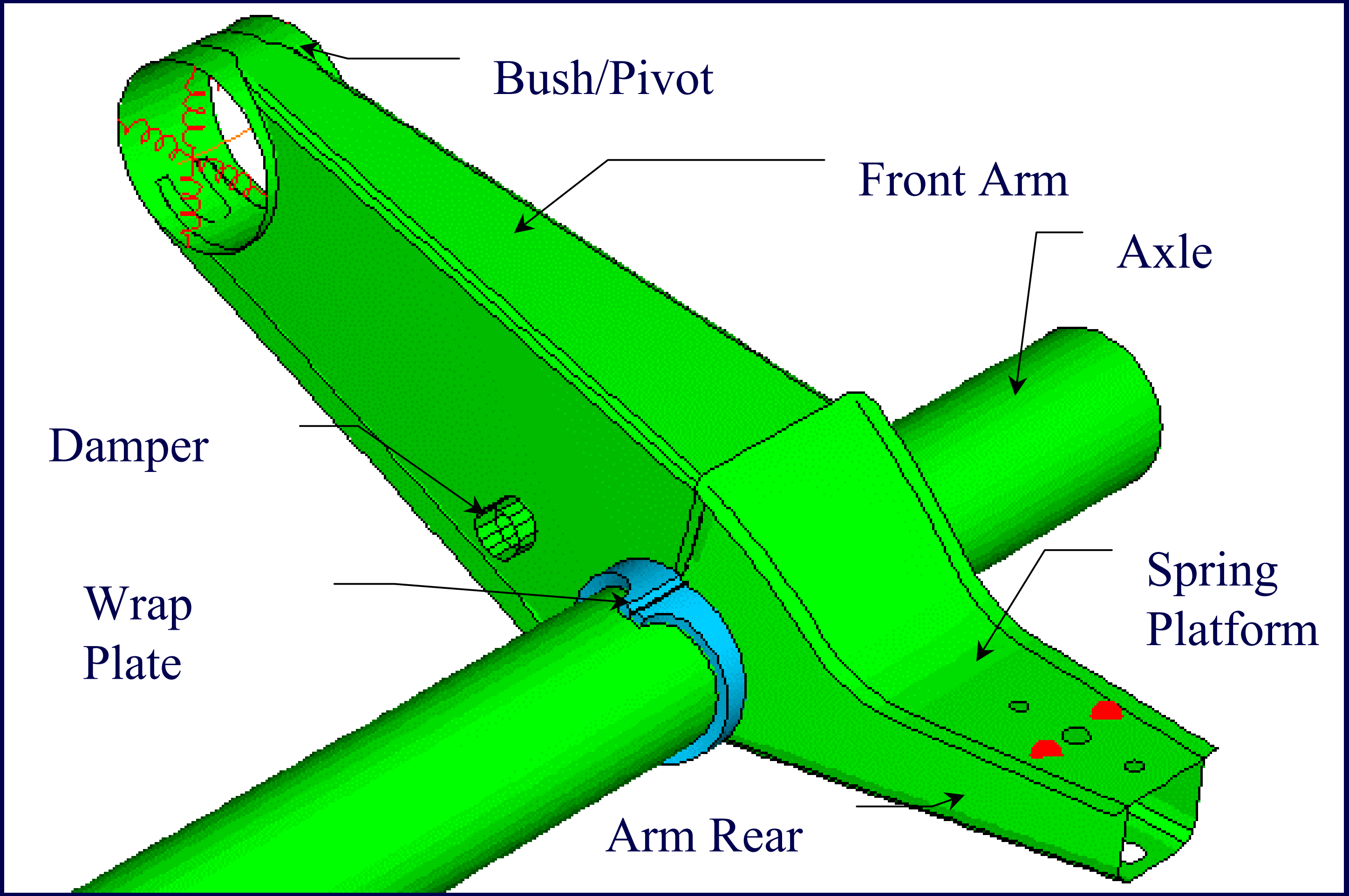
Design Improvements

Design

- Redesign the plug weld connection to avoid peak stresses in the lower regions
- Investigate spring platform local strengthening
- Remove the Cover Plate

New Design without Side Plate

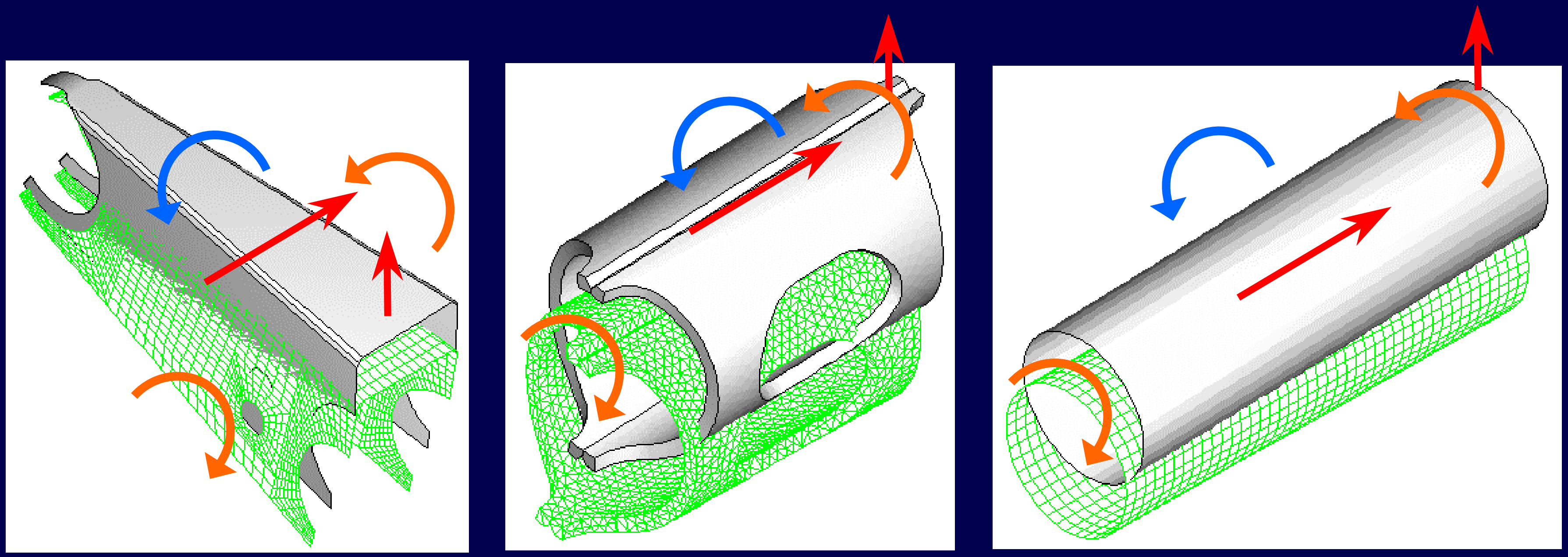
Adding value through knowledge



Stress Analysis - Interpretation

Adding value through knowledge

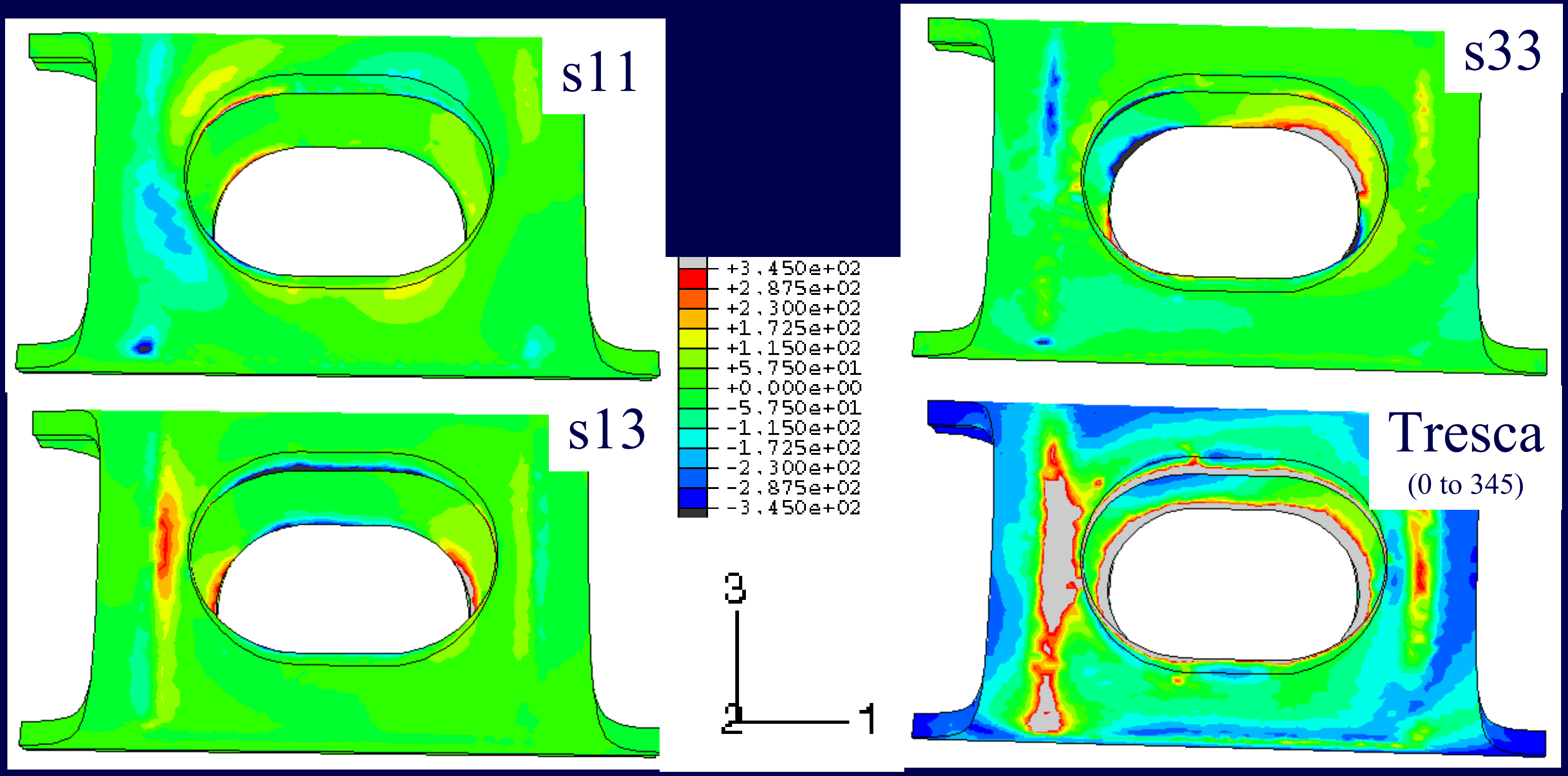
- Displacement Direction



Stress Analysis - Results

Adding value through knowledge

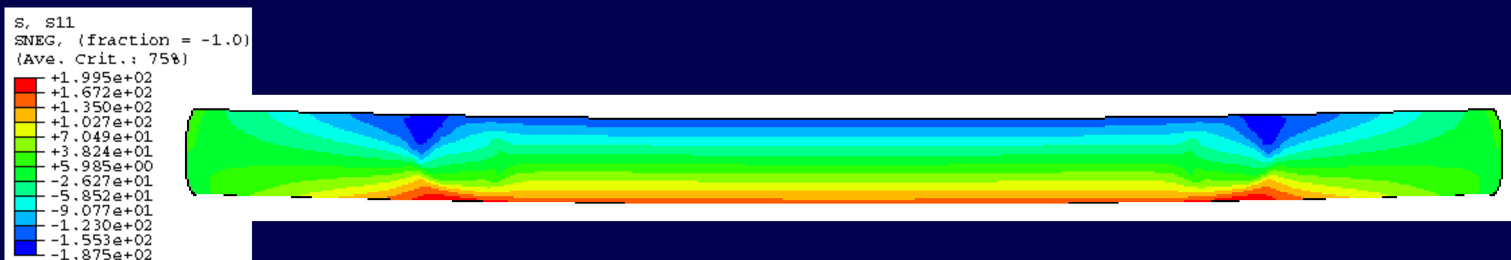
- Tramp Manoeuvre - Stress Contours in Wrap Plate (Front)



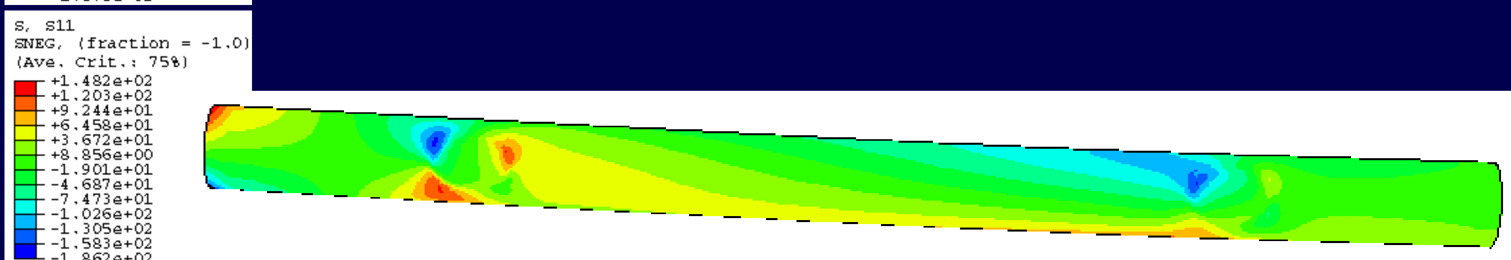
Stress Analysis - Interpretation

Adding value through knowledge

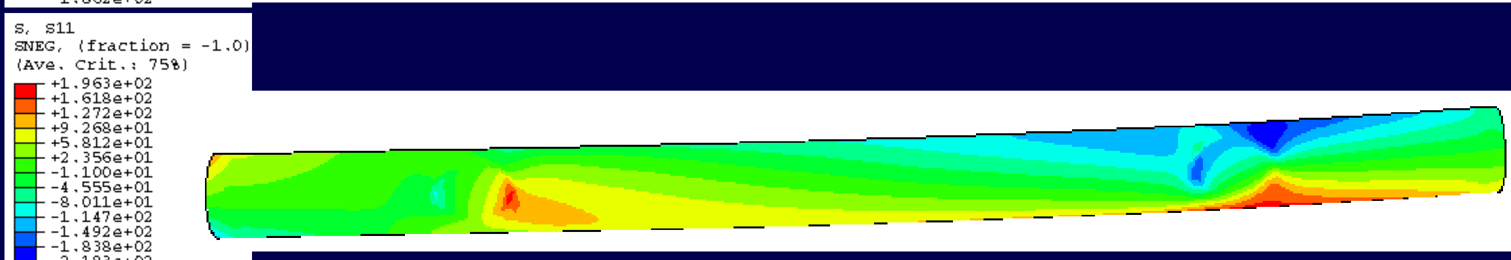
- S11 Stress in Axle Front for all Loadcase



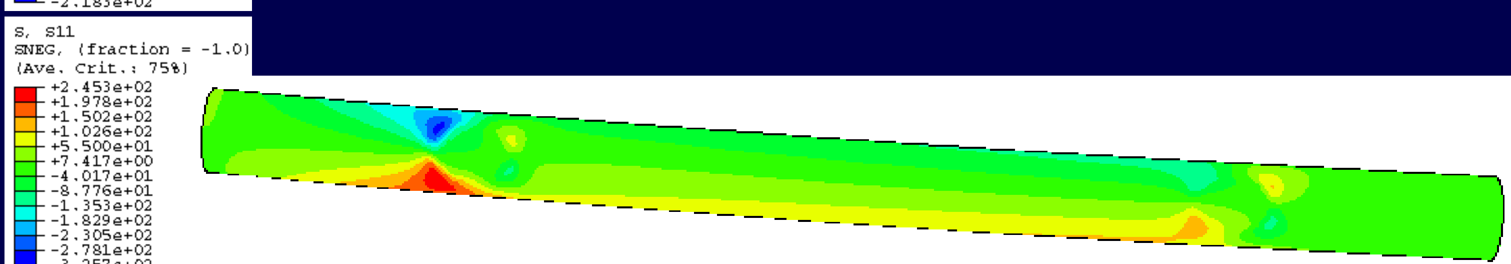
1.75g Bump



Roll



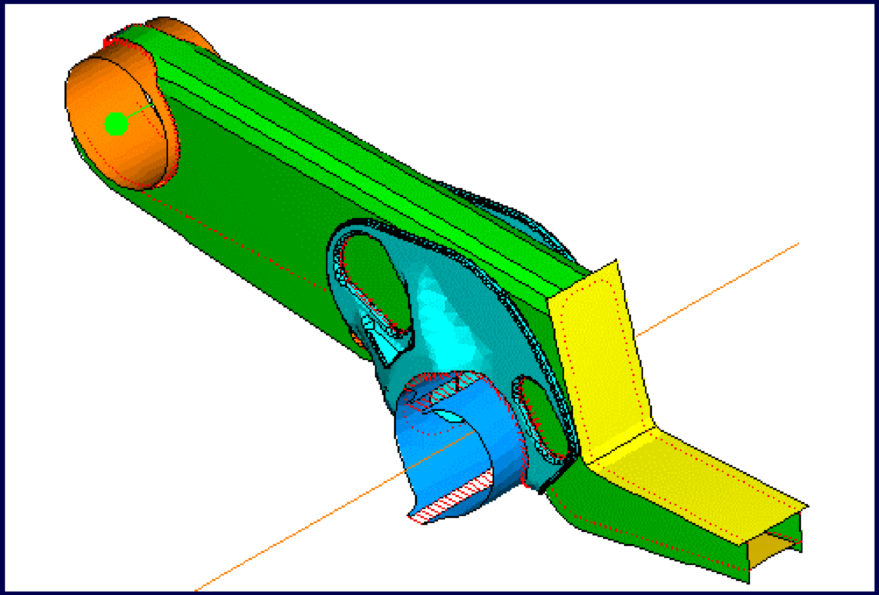
Scrub



Tramp

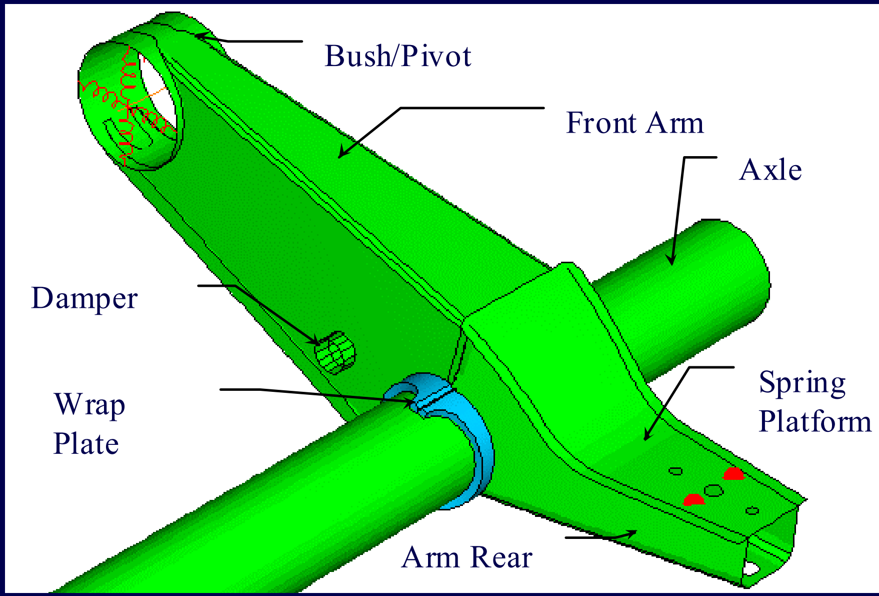
Design Improvement

- Improve the cutout radii
- Change the angular orientation of the Side Plate



Original design

Fatigue life < 20,000 cycles



Improved design

Fatigue life > 35,000 cycles

The End