NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Aviation Engineering Division
Washington, DC 20594

December 5, 2003

ADDENDUM NUMBER 6 TO THE STRUCTURES GROUP CHAIRMAN'S FACTUAL REPORT

DCA02MA001

A. ACCIDENT

Location: Belle Harbor, NY
Date: November 12, 2001
Time: 09:16:14 EST
Aircraft: American Airlines Flight 587, Airbus Model A300-605R, N14053
Manufactures Serial Number (MSN) 420

B. STRUCTURES GROUP

Chairman: Brian K Murphy
National Transportation Safety Board
Washington, DC

C. AIRBUS REPORT

1. ***"AAL587 Airbus Structure Investigation, Lug sub-component test #1 – Results Test/FEA Comparison"***

AIRBUS	Technical Note	

Report Nr.: TN – ESGC – 1021/03

Author:
Department.:

Title

AAL587 Airbus Structure Investigation

Lug sub component test#1 – Results - Test / FEA Comparison

Date: 08.12.2003

Summary:

As part of the AAL587 accident investigation the rear main Lug Test#1 was carried out under the leadership of the NTSB at the Airbus Deutschland GmbH test facility in Hamburg on the 13th of August 2003.
The loading conditions for this test are based on the W375 load case (Ny Integration issue 18 - criteria: maximum lateral acceleration Ny) provided by the Airbus Loads department. In a meeting at Airbus Hamburg on the 12th of August 2003, it was agreed by NTSB, NASA, American Airlines and Airbus to select the NASA W375 MOD load vector for the Lug Test#1.

This report provides a comparison between the measured strain gauge values from the rear main Lug Test#1 specimen and the FE-analysis.
Due to the very rapid shutdown of the load application the test stopped during failure initiation in cleavage mode.

Public Docket	Issue	Date	No. of page	Revised pages	Valid from/for
	1	10.11.2003	41		
	2	05.12.2003	41	11-15; 27-40 ; Format change DINA4 to LETTER	
	3	08.12.2003	49	40-49	

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1. Introduction

As part of the AAL587 accident investigation the rear main Lug Test#1 was carried out under the leadership of the NTSB at the Airbus Deutschland GmbH test facility in Hamburg on the 13th of August 2003.
The loading conditions for this test are based on the W375 load case (Ny Integration issue 18 - criteria: maximum lateral acceleration Ny) provided by the Airbus Loads department. In a meeting at Airbus Hamburg on the 12th of August 2003, it was agreed by NTSB, NASA, American Airlines and Airbus to select the NASA W375 MOD load vector for the Lug Test#1.
This report provides a comparison between the measured strain gauge values from the rear main lug test#1 specimen and the FE-analysis. For the purpose of a direct strain gauge comparison a strain gauge tracking subroutine was developed and implemented in the ANSYS nonlinear contact models.

The measured strain values of the rear main Lug Test#1 specimen are compared to

- RHS ANSYS 3D contact model
- LHS ANSYS 3D contact Lug Test#1 model rotx=0°

and

- LHS ANSYS 3D contact Lug Test#1 model rotx=0.5°

All the ANSYS FEA-models include detailed contact surface definition for the fuselage/fin bolt connection.
The strain distribution of the RHS model is the reference for the comparison with the calculated strains from the test model FEA and the measured strain from the lug test itself.
The LHS ANSYS contact Lug Test#1 model represents the reinforced and modified test specimen and includes the test rig load introduction and test specimen support.

2. Rear Main Lug Test#1 specimen

The test part location in the vertical stabilizer is shown on figure 2.1 and the test part itself in figure 2.2.

A300-600R Vertical Stabilizer

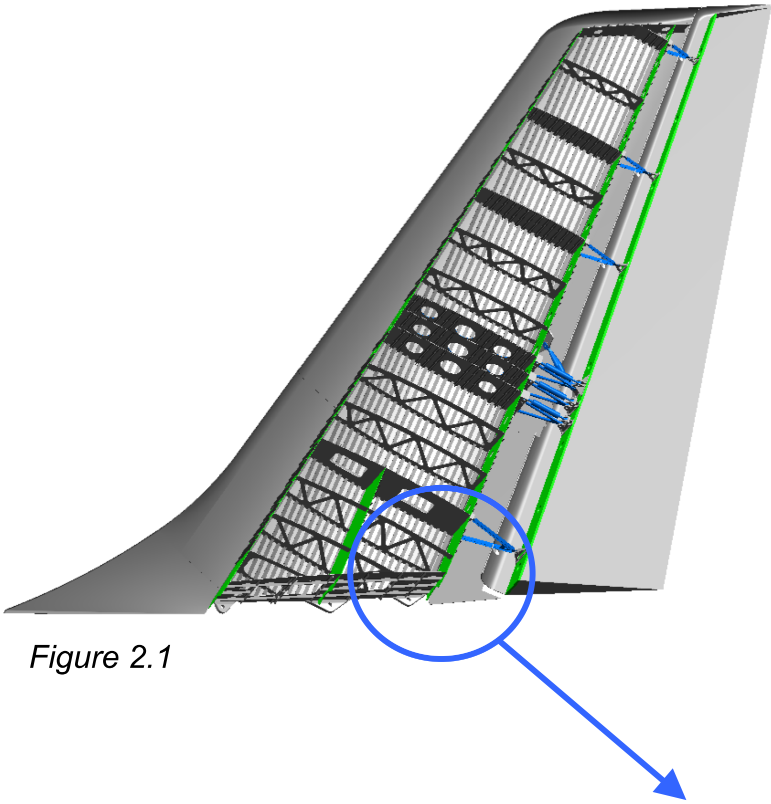


Figure 2.1

LHS Rear Main Lug Test#1 specimen

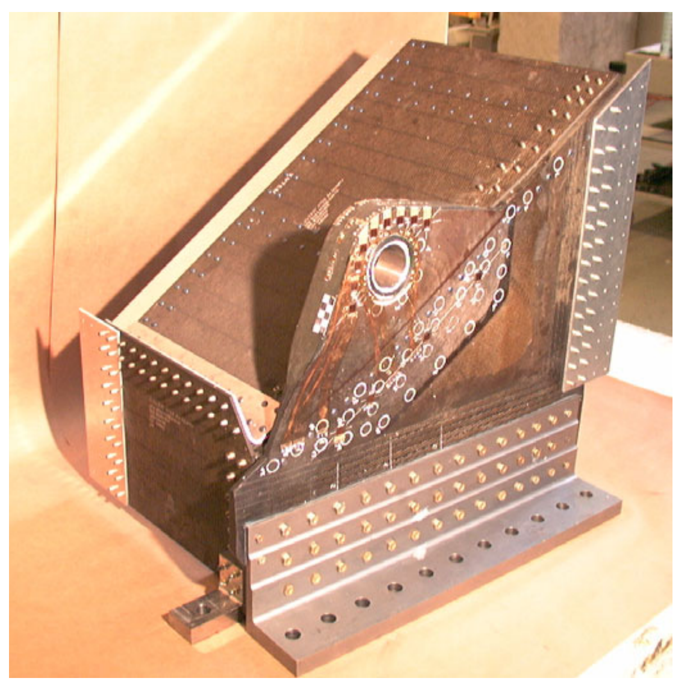


Figure 2.2

2.1 FEA-model and Lug Test#1 overview

Figure 2.3 and figure 2.4 show two different FEA-models, which are compared with the Lug Test#1 specimen test (see figure 2.5) results.

RHS ANSYS 3D contact model

[RHS ANSYS 3D contact model is described in report TN – ESGC - 1018/03]

Loading Condition:

W375 boundary displacements conditions from global 2D FEA-model with embedded LHS and RHS 3D models. The Fres resultant was scaled up to the NASA W375 MOD resultant force level.

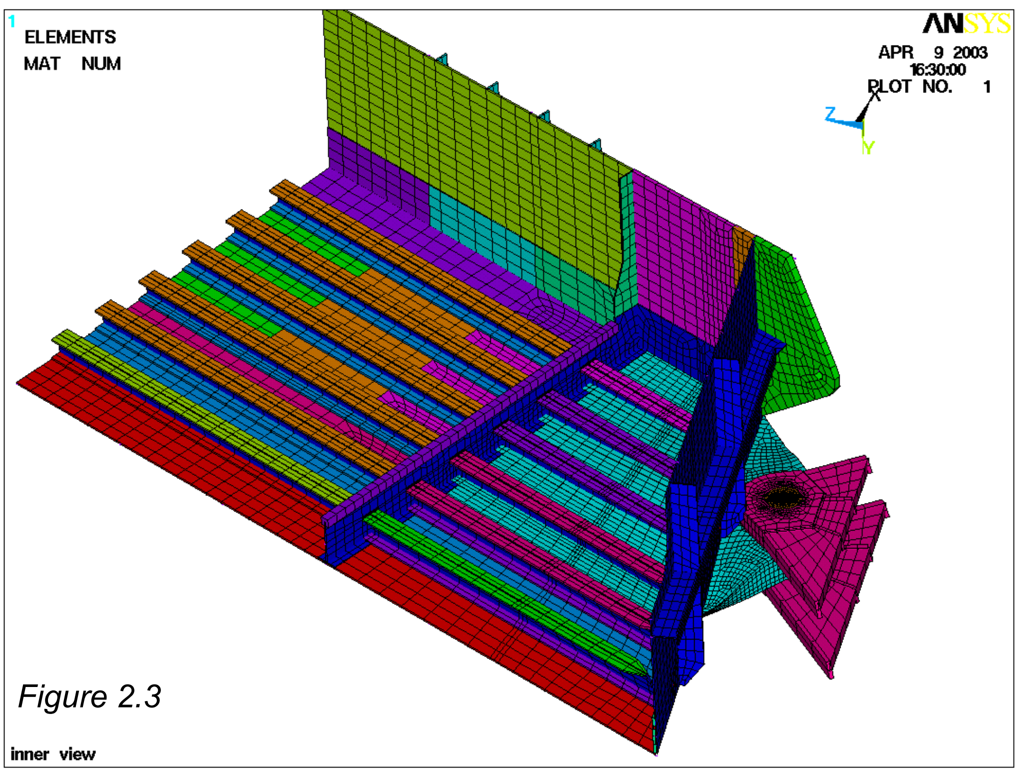


Figure 2.3

LHS ANSYS 3D contact Lug Test#1 model

[LHS ANSYS contact Lug Test#1 FEA model is described in report TN – ESGC - 1020/03]

Loading Condition:

NASA W375 MOD load vector

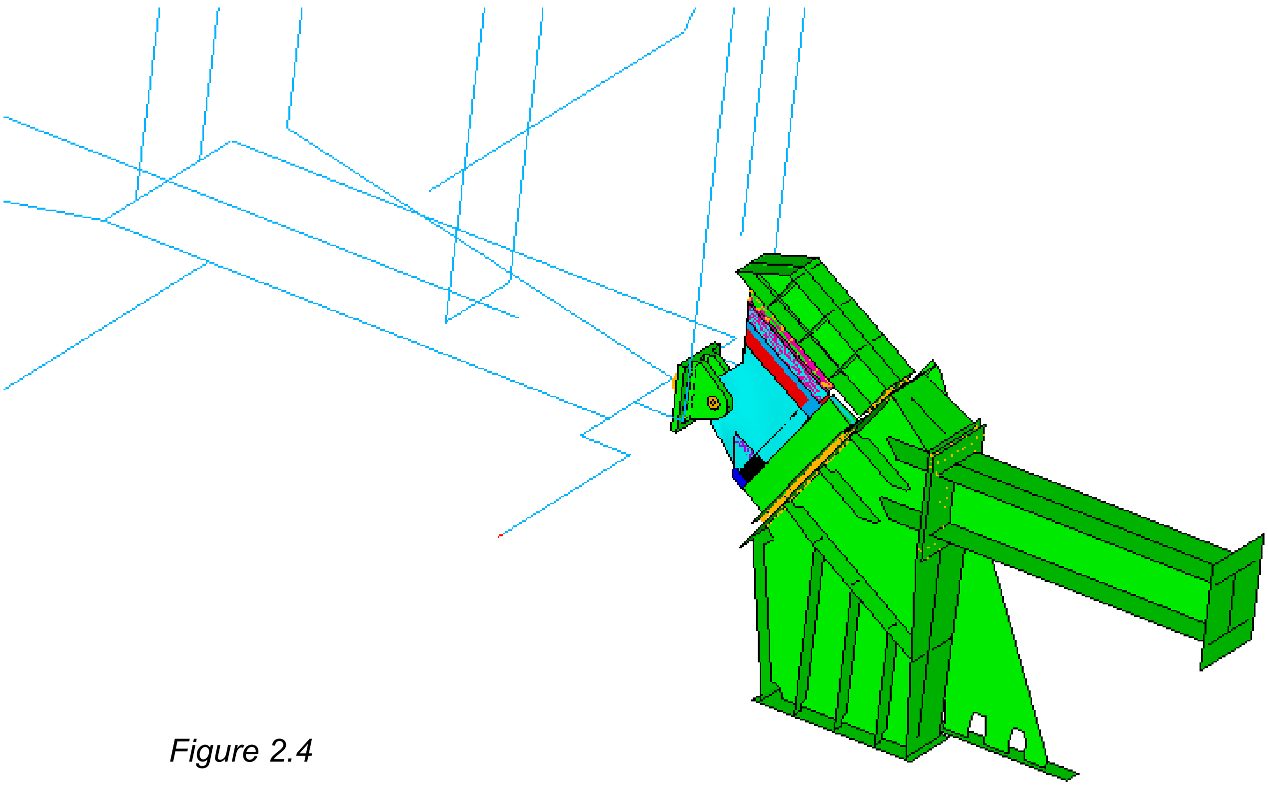


Figure 2.4

Lug Test#1 specimen

Lug Test#1 is described in the test requirement 32 X 029 K4 804 P34

Loading Condition:

NASA W375 MOD load vector

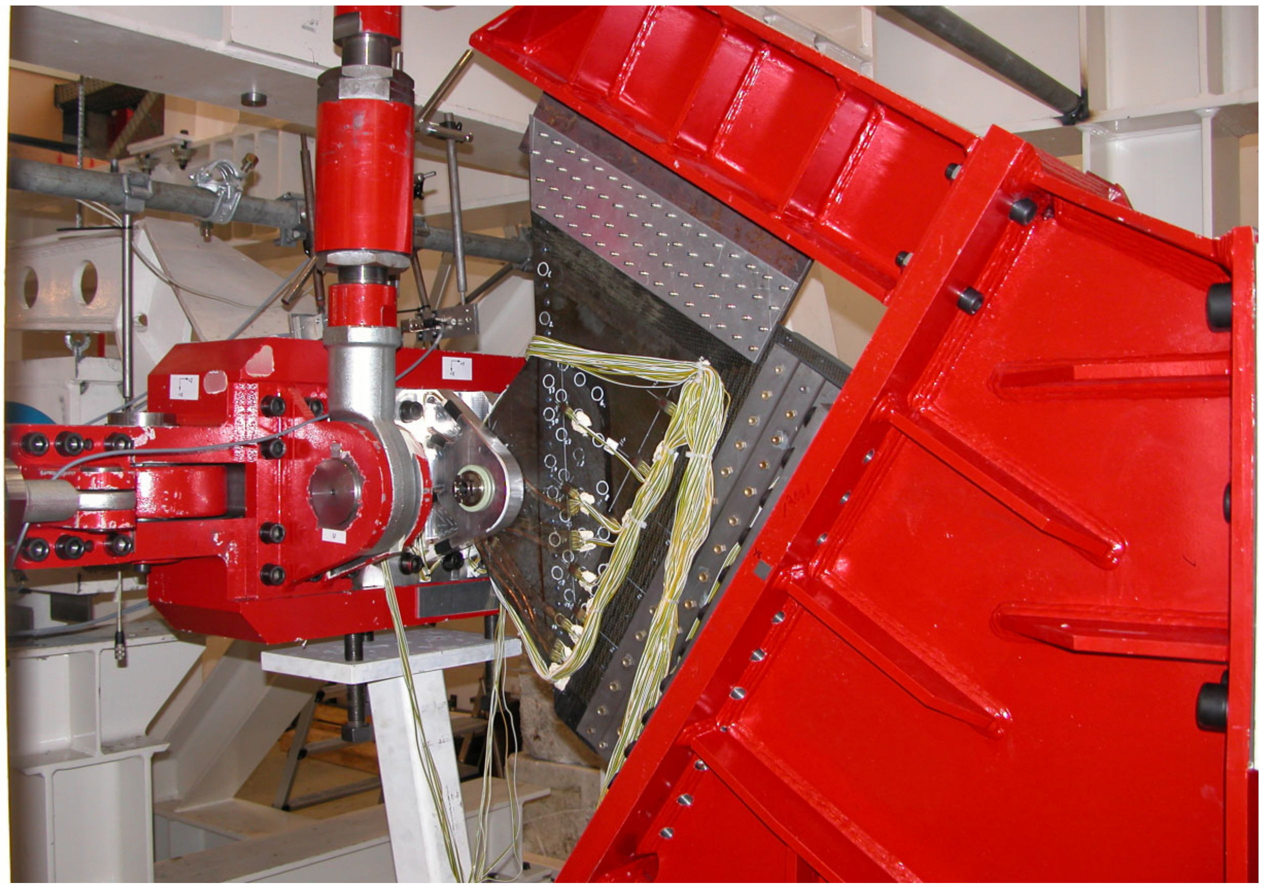


Figure 2.5

2.2. Description of the test rig

2.2.1 Global view

Figure 2.6 illustrates the global design of the lug test rig. The global coordinate system corresponds to the Aircraft coordinate system on this test rig and aligns to the three load introduction axes of the test rig.

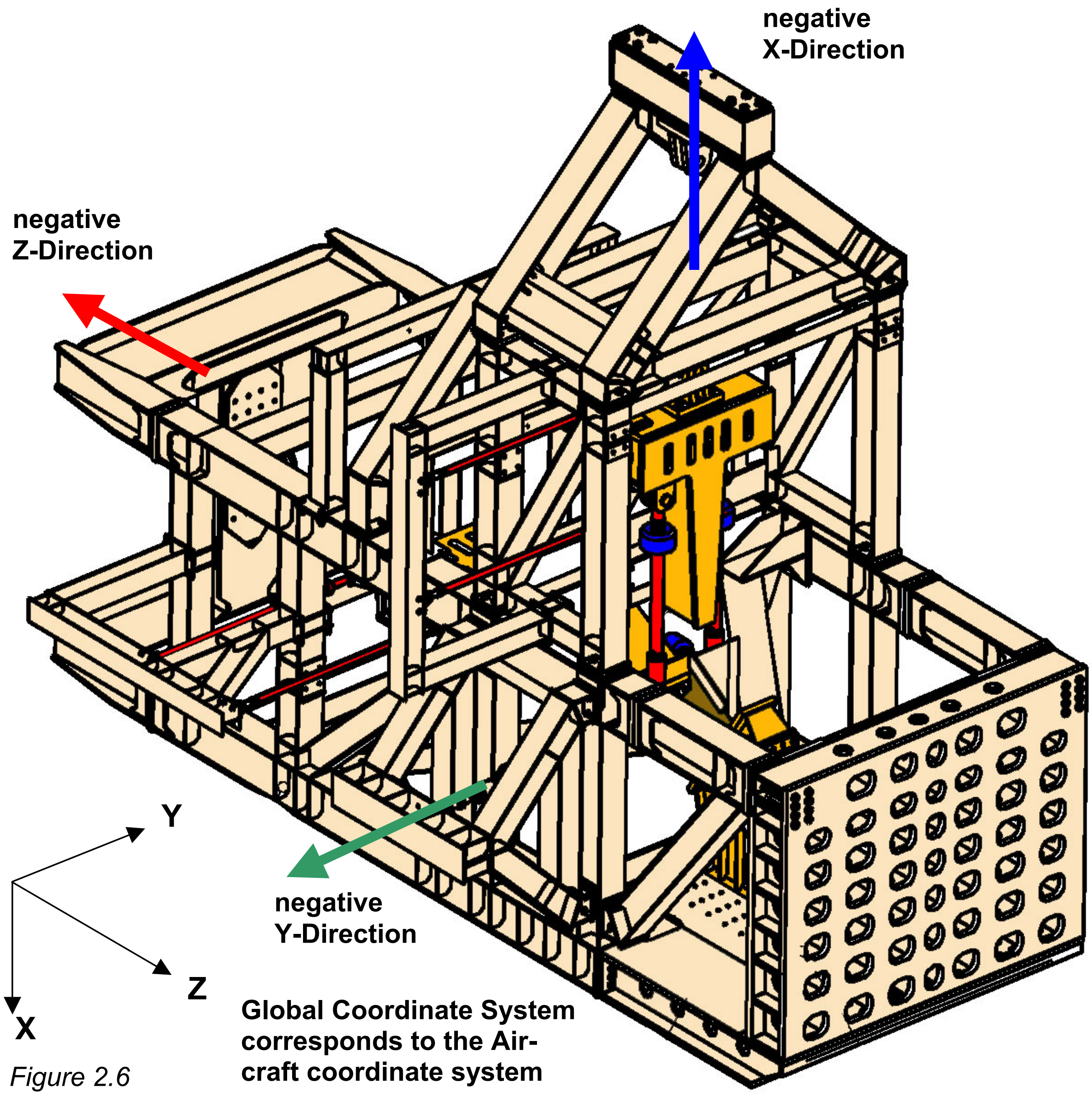


Figure 2.6

2.2.2 Load introduction and location of the test specimen in the test rig

The figure 2.7 shows the load introduction components of the test rig and the location of the Lug Test#1 specimen itself.

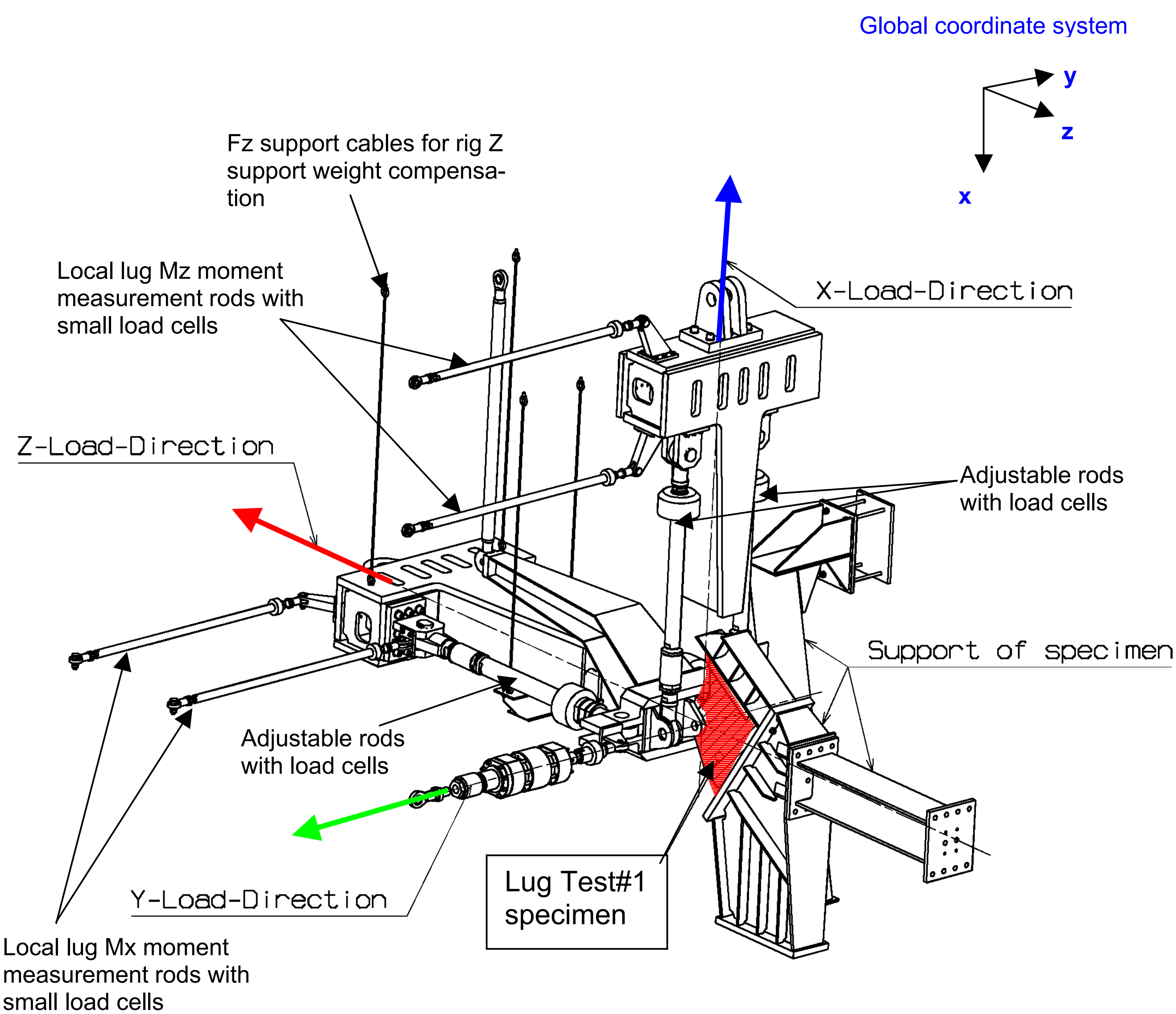


Figure 2.7

2.2.3 Test rig sign convention for local lug reaction moments

The sign convention for the local lug reaction moments and the remaining rod forces are illustrated in figure 2.8.

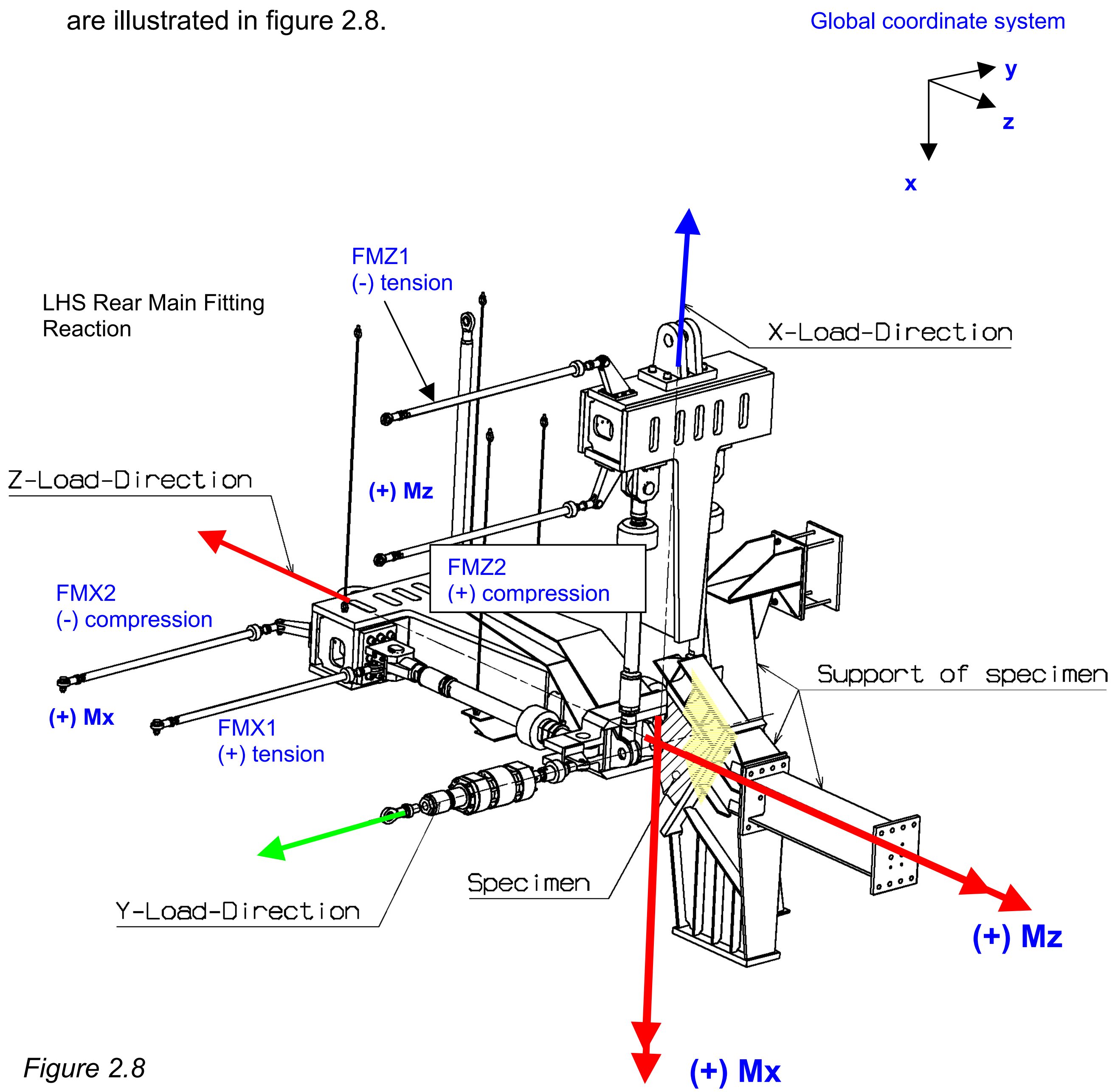
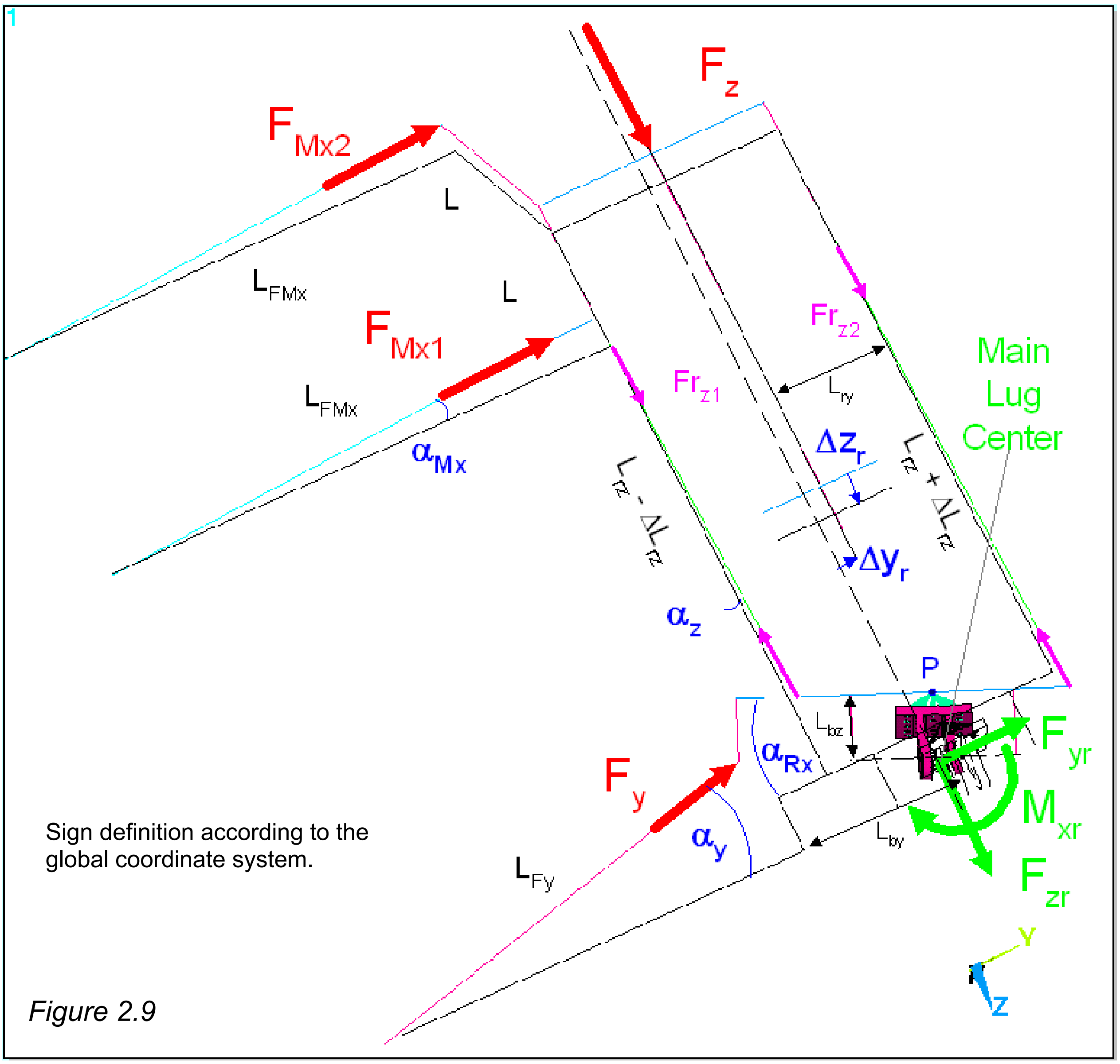


Figure 2.8

2.3 Equations for local lug moments

2.3.1 Local lug moment Mx (Equation considers displacements in the yz-plane)

The equation represents the moment equilibrium at the displaced load introduction system due to the deformed test specimen (see figure 2.9). The supports of the Fy- actuator and the rods ends of FMX1/2 are assumed to be fixed and the free play at all bearings and length deformation of the linkages are not taken into account.



Sign definition according to the global coordinate system.

Figure 2.9

For practical reasons, the reference for the displacement measurement is the test rig. This can also cause some errors in the measured values.

The figure 2.9 shows the undeformed and deformed load introduction and the relevant dimension in the test rig.

Table 2.1 **Test rig dimension:**

Dimension			Description
L_{Fy}	[mm]	1783	Y-cylinder length from outer to inner bearing point
L_{by}	[mm]	720	Inner Y-cylinder bearing point to the lug reference point
L_{bz}	[mm]	245	Z-distance from lug reference point to the z-axis main rod bearing points
L_{ry}	[mm]	500	Half distance between the z-axis main rods Z1 and Z2
L_{rz}	[mm]	2000	Length of the main rods Z1 and Z2
L_{FMx}	[mm]	2000	Length of the moment measurement rods FMX1 and FMX2
L	[mm]	500	Half distance between FMX1 and FMX2

Equations to recalculate the local lug reactions with the measured data:

Assumptions:

1. Deformation of the test rig + fuselage clevis negligible
2. Only displacement in the yz-plane considered

Displacement:

$\Delta zP(\alpha Rx, \Delta zr) = \Delta zr + L_{bz}(1 - \cos(\alpha Rx))$ Z-Displacement in point P

$\Delta yP(\alpha Rx, \Delta yr) = \Delta yr + L_{bz} \cdot \sin(\alpha Rx)$ Y-Displacement in point P

$\Delta zsy(\alpha Rx, \Delta zr) = \Delta zr - L_{by} \cdot \sin(\alpha Rx)$ Z-Displacement sum Fy

Deformation angle:

$$\alpha Rx = \arcsin\left(\frac{Dz3 - Dz4}{600}\right) \text{ Rx bolt rotation}$$

$$\alpha_y(\alpha Rx, \Delta zr) = \arcsin\left(\frac{\Delta zsy(\alpha Rx, \Delta zr)}{L_{Fy}}\right)$$

$$\alpha_z(\alpha Rx, \Delta yr) = \arcsin\left(\frac{\Delta yP(\alpha Rx, \Delta yr) + L_{ry}(1 - \cos(\alpha Rx))}{L_{rz}}\right)$$

$$\alpha_{Mx}(\alpha Rx, \Delta zr) = \arcsin\left(\frac{\Delta zP(\alpha Rx, \Delta zr)}{L_{FMx}}\right)$$

Total moment of measurement rods:

$$M_{Mx}(\alpha Rx, \Delta zr) =$$

$$FMX1\left[\sin(\alpha_{Mx}(\alpha Rx, \Delta zr) \cdot L_{ry} + \cos(\alpha_{Mx}(\alpha Rx, \Delta zr)) \cdot (L_{rz}\cos(\alpha_z(\alpha Rx, \Delta yr)) + L_{bz})\right]$$
$$+ FMX2\left[\sin(\alpha_{Mx}(\alpha Rx, \Delta zr) \cdot L_{ry} + \cos(\alpha_{Mx}(\alpha Rx, \Delta zr)) \cdot (L_{rz}\cos(\alpha_z(\alpha Rx, \Delta yr)) + L_{bz} + 2L)\right]$$

Moment resulting from Fz and displacement Δyr

$$M_{xFz}(\Delta yr) = F_z \cdot \Delta yr$$

Moment resulting from Fy and displacement Δyr

$$M_{xFy}(\alpha Rx, \Delta zr) = F_y \cdot L_{by} \cdot (\sin(\alpha_y(\alpha Rx, \Delta zr) - \alpha Rx))$$

Total moments about the main lug center:

$$\sum Mx = 0 = -M_{xr} + M_{xFz} - M_{Mx} - F_y \cdot L_{by} \cdot \sin(\alpha_y(\Delta zr))$$

With the above mentioned equations the reaction moment Mxr is

$$M_{xr}(\alpha Rx, \Delta yr, \Delta zr) = -M_{xFz}(\Delta yr) - M_{Mx}(\alpha Rx, \Delta yr, \Delta zr) - M_{xFy}(\alpha Rx, \Delta zr)$$

2.3.2 Local lug moment Mz (Equation considers displacements in xy-plane)

Table 2.2 **Test rig dimension:**

Dimension			Description
L_{Fy}	[mm]	1783	Y-cylinder length from outer to inner bearing point
L_{by}	[mm]	720	Inner Y-cylinder bearing point to the lug reference point
L_{bx}	[mm]	0	The bolt axis is aligned with the Y-cylinder axis
L_{xry}	[mm]	300	Half distance between the z-axis main rods X1 and X2
L_{rx}	[mm]	1990.6	Length of the main rods X1 and X2
L_{FMz}	[mm]	2000	Length of the moment measurement rods FMZ1 and FMZ2
L_{x}	[mm]	525	Half distance between FMZ1 and FMZ2

Equations to recalculate the local lug reactions with the measured data.

Deformation angle:

$$\alpha_y(\Delta xr) = \arcsin\left(\frac{\Delta xr}{L_{Fy}}\right) \quad \alpha_x(\Delta yr) = \arcsin\left(\frac{\Delta yr}{L_{rx}}\right) \quad \alpha_{Mz}(\Delta xr) = \arcsin\left(\frac{\Delta xr}{L_{FMz}}\right)$$

Total moment of measurement rods:

$$M_{Mz}(\Delta xr, \Delta yr) = (F_{Mz1} + F_{Mz2}) \cdot \left[\sin(\alpha_{Mz}(\Delta xr)) \cdot L_{xry} + \cos(\alpha_{Mz}(\Delta xr)) \cdot (L_{rx} \cdot \cos(\alpha_x(\Delta yr)) + L_{bx})\right] + \cos(\alpha M_z(\Delta xr)) \cdot F_{Mz1} \cdot 2 \cdot L_x$$

Moment resulting from Fx and displacement Δyr

$$M_{zFx}(\Delta yr) = -F_x \cdot \Delta yr$$

Moment resulting from Fy and displacement Δxr

$$M_{zFy}(\Delta xr) = F_y \cdot \Delta xr \cdot (\cos(\alpha_y(\Delta xr)) + \sin(\alpha_y(\Delta xr)))$$

With the above mentioned equations the reaction moment Mzr is

$$M_{zr}(\Delta xr, \Delta yr) = M_{zFx}(\Delta yr) + M_{Mz}(\Delta xr, \Delta yr) + M_{zFy}(\Delta xr)$$

2.4 ANSYS Lug Test#1 FEA-model overview and lug reaction calculation method

Details of the ANSYS contact Lug Test#1 FEA model (see figure 2.10) are described in the "*LHS Lug sub-component test#1 FEM analysis*" TN-ESGC-1020/03.

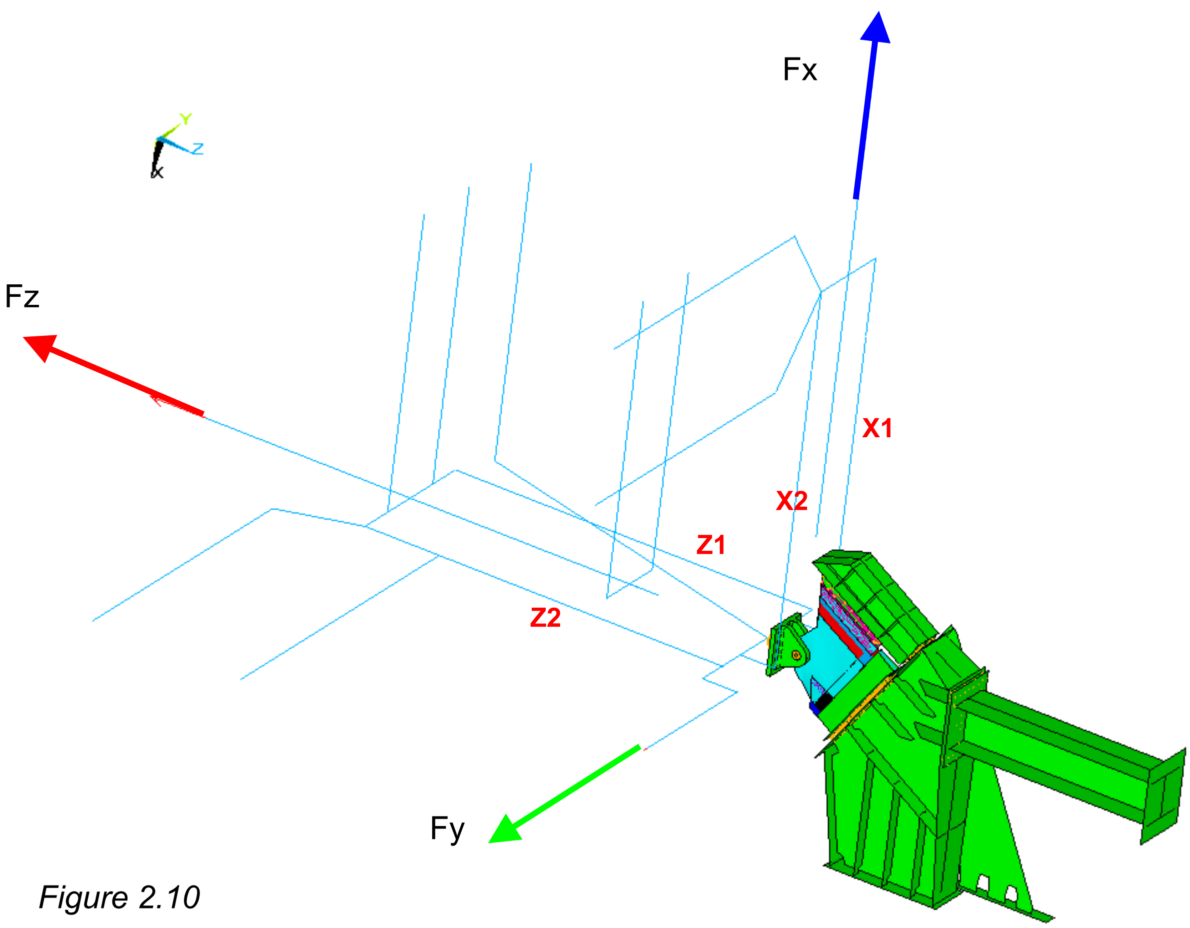


Figure 2.10

The local lug reactions are calculated for every load step at a cross section through the fuselage clevis (see figure 2.11 and 2.12) with a summation of the grid point force balance according to the deformed reference point in the bolt axis. With these information the local lug moment Mx and Mz are calculated.

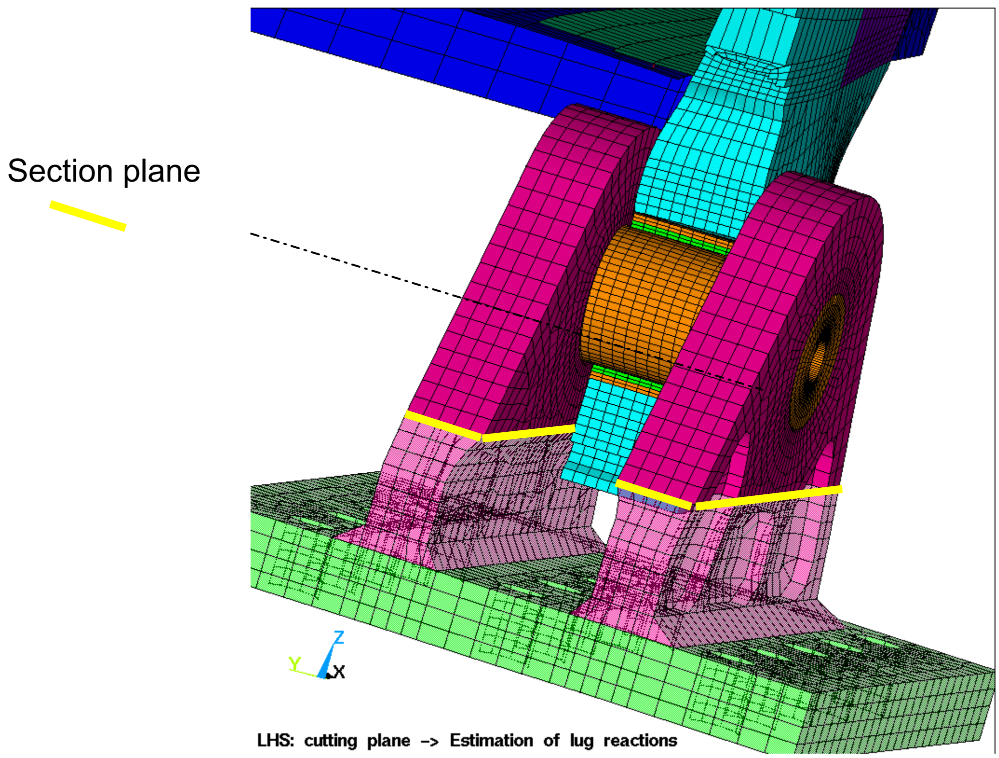
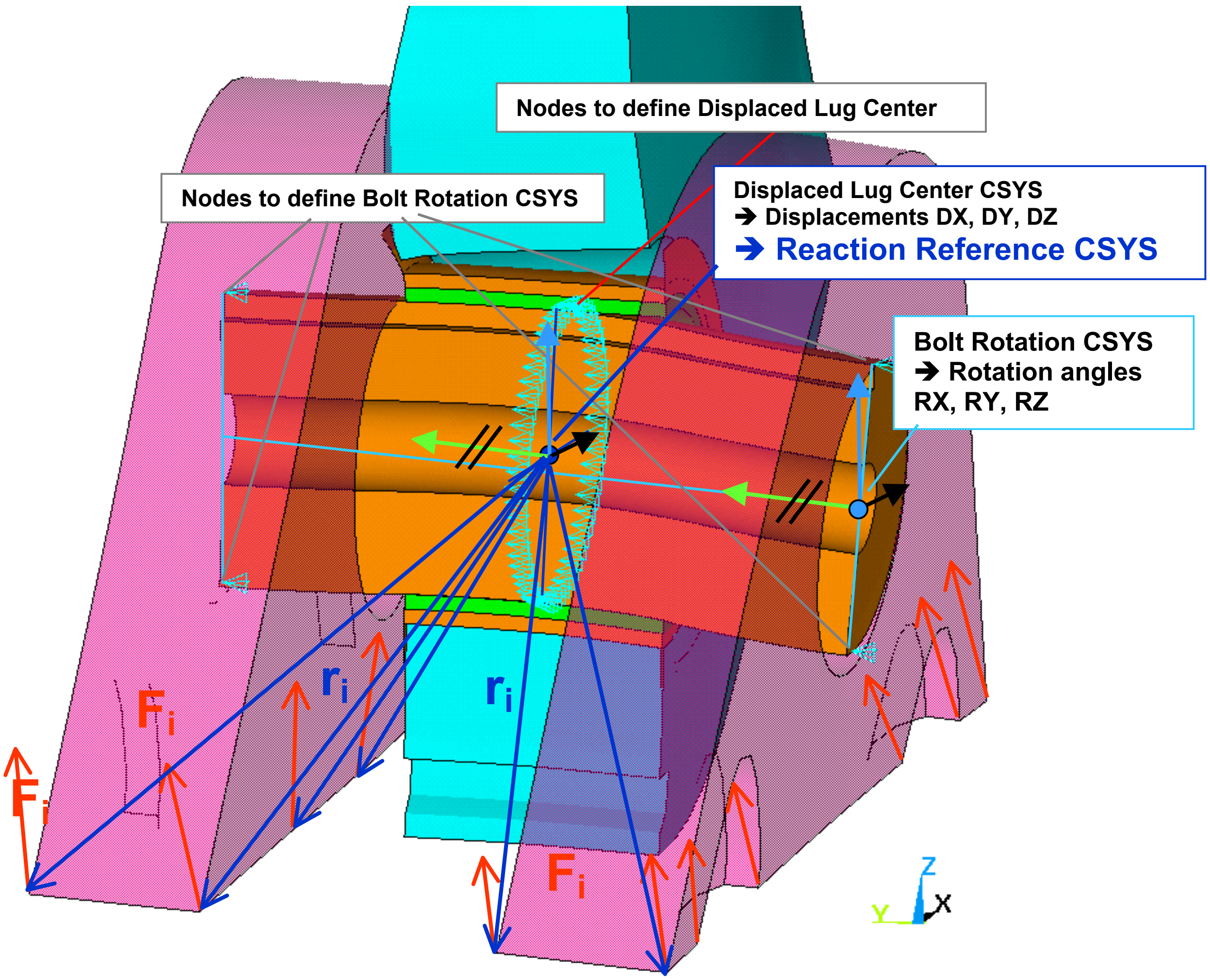


Figure 2.11

The calculation of bolt orientation and lug reactions (see figure 2.12) on deformed lug center was made with user written subroutine in ANSYS (APDL).



Deformed structure! (Displacements scaled by a factor 10)

➔ Reactions in Displaced Lug Centre:

$$M_{RsP} = SUM(r_i \times F_i) \qquad F_{RsP} = SUM(F_i)$$

Figure 2.12

2.5 ANSYS Contact surface definition

The contact surface definitions are the same for all ANSYS models (see figure 2.13 to 2.16). The ANSYS contact surface allows physically opening and closing gaps between the meshes of the contact borders with a friction coefficient of 0.3.

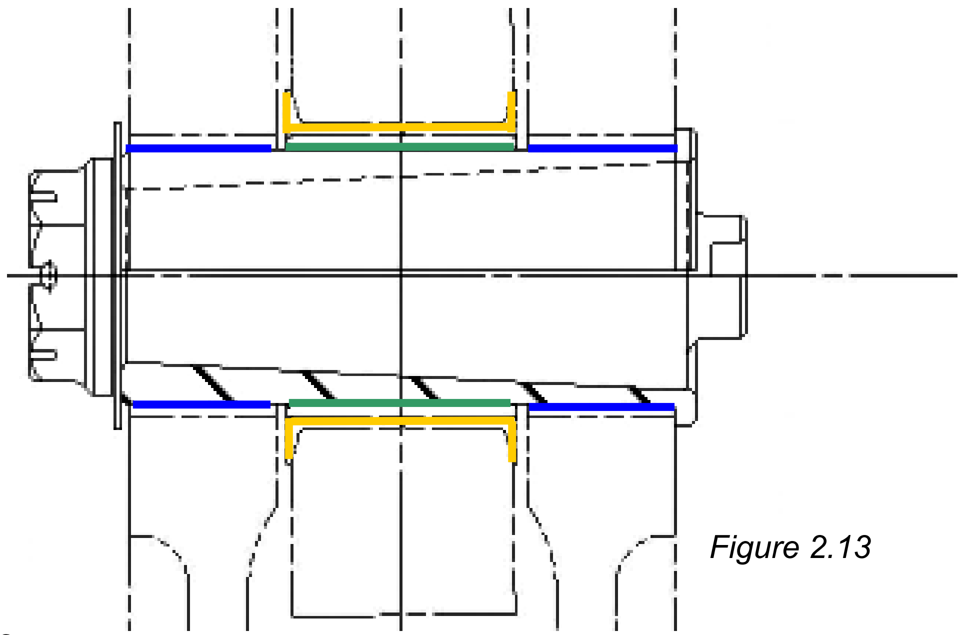


Figure 2.13

Contact surfaces:

Bushing to CFRP lug surface **Fuselage clevis to bolt surface** **Bolt to bushing surface**

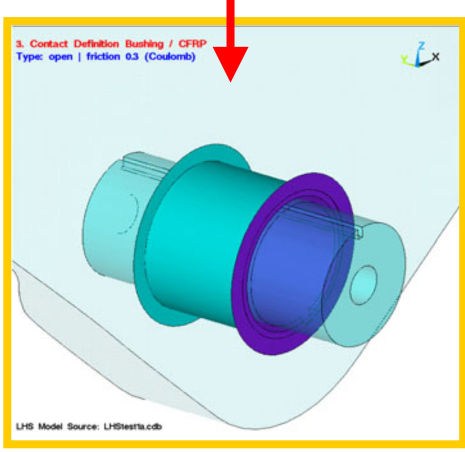


Figure 2.14

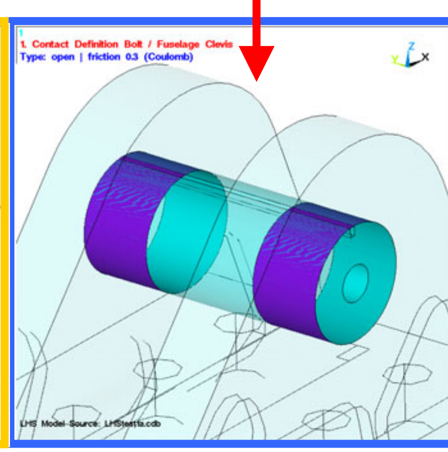


Figure 2.15

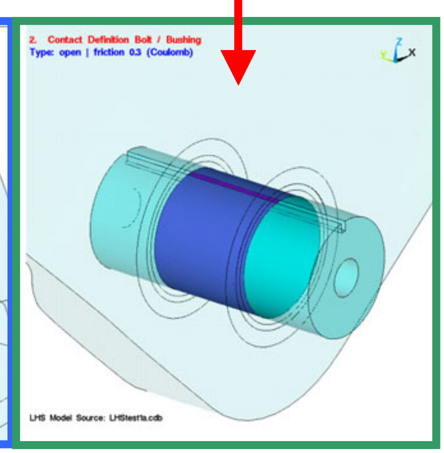


Figure 2.16

3. FE-Analysis for comparison with the test

The following FEA-models are used for the comparison between FEA-results and the Lug Test#1:

I. RHS ANSYS rear main lug nonlinear contact model with the boundary displacement conditions from 2D global model with embedded 3D rear main lugs
II. LHS ANSYS Lug Test#1 nonlinear contact model with no preadjusted bolt rotation of RX=0°
III. LHS ANSYS Lug Test#1 nonlinear contact model with preadjusted bolt rotation of RX=0.5°

3.1 NASA W375 MOD load vector for the Lug Test#1

In agreement with NTSB, NASA, American Airlines and Airbus the W375 MOD load vector with the following max. load components from the NASA calculations is used for all FE-Analyses which are compared with the test (see table 3.1).

Table 3.1

NASA W375 MOD load vector			
Fx	Fy	Fz	Fres
[kN]	[kN]	[kN]	[kN]
-400	-42	-864	953

3.2 RHS ANSYS contact 3D model NASA W375 MOD

The boundary displacements were applied in 7 steps and the analysis delivers the lug reaction forces as given in table 3.2.

Table 3.2

Fres	FX	FY	FZ	MX	MY	MZ
[kN]	[kN]	[kN]	[kN]	[Nm]	[Nm]	[Nm]
2	0	0	2	4	8	2
149	-65	5	-134	-1015	196	149
299	-127	11	-270	-2000	403	299
455	-190	18	-413	-3022	629	455
617	-255	26	-561	-4057	852	617
785	-322	34	-715	-5093	1068	785
958	-390	43	-874	-6120	1277	958

For comparison with the LHS model the local lug moment Mx and Mz the signs of both moments have to be reversed.

3.3 LHS ANSYS contact Lug Test#1 NASA W375 MOD rotx=0°

The applied load vector for the LHS ANSYS Lug Test#1 nonlinear contact analysis is shown in table 3.3.

Table 3.3

Fres	FX	FY	FZ
[kN]	[kN]	[kN]	[kN]
0	0	0	0
159	-67	-7	-144
318	-133	-14	-288
477	-200	-21	-432
635	-267	-28	-576
794	-333	-35	-720
953	-400	-42	-864

3.4 LHS ANSYS contact Lug Test#1 NASA W375 MOD rotx=0.5°

For the third analysis model the same W375 MOD load vector was chosen as in chapter 3.3.
Additionally before applying the load vector a bolt rotation about the global X-axis of rotx=0.5° was introduced with a length adjustment of the Fz main rods Z1/2 by the turnbuckles.

4. Lug Test#1 NASA W375 MOD rotx=0.5° loading condition

The NASA investigation for the W375 MOD load case results in the load set target condition for the accident load case (see table 4.1 and 4.2 and figure 4.1).
In a meeting at Airbus Hamburg on the 12th of August 2003, it was agreed on by NTSB, NASA, American Airlines and Airbus to select the NASA W375 MOD load vector for the Lug Test#1.
This target condition includes a pre-adjusted local bolt rotation of rotx=0.5°.
The bolt rotation was introduced in the test rig with the turnbuckles of the Z1 and Z2 main rods. This corresponds to a local lug moment Mx of 2400Nm.

Table 4.1

NASA W375 MOD							
	Fx	Fy	Fz	Fres	Mx	Mz	Angle Xzplane
	[kN]	[kN]	[kN]	[kN]	[Nm]	[Nm]	[°]
W375-MOD	-400	-42	-864	953	6300	-1600	65

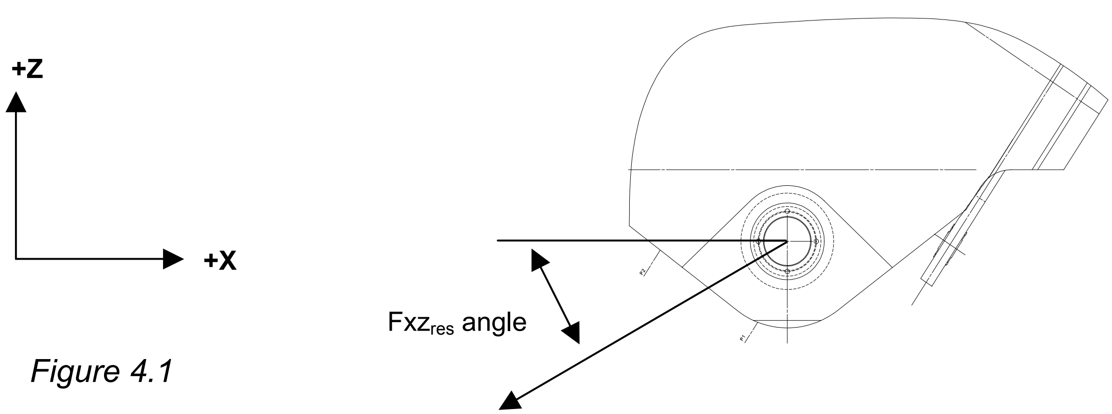


Figure 4.1

The forces was then to be applied in the following load steps:

Table 4.2

Fx	Fy	Fz	Fres	Load step
With turnbuckles preadjusted Mx of 2400Nm				0
-20	-2	-43	48	10
-30	-3	-65	71	15
-40	-4	-86	95	20
-50	-5	-108	119	25
-60	-6	-130	143	30
-68	-7	-147	162	35
-78	-8	-168	186	40
-88	-9	-190	210	45
-98	-10	-212	233	50
-108	-11	-233	257	55
-118	-12	-255	281	60
-128	-13	-276	305	65
-138	-14	-298	329	70
-148	-16	-320	353	75
-158	-17	-341	376	80
-168	-18	-363	400	85
-178	-19	-384	424	90
-188	-20	-406	448	95
-196	**-21**	**-423**	**467**	**100**
-206	-22	-445	491	105
-216	-23	-467	515	110
-226	-24	-488	538	115
-236	-25	-510	562	120
-246	-26	-531	586	125
-256	-27	-553	610	130
-266	-28	-575	634	135
-276	-29	-596	658	140
-286	-30	-618	681	145
-296	**-31**	**-639**	**705**	**150**
-300	-32	-648	715	152
-304	-32	-657	724	154
-308	-32	-665	734	156
-312	-33	-674	743	158
-316	-33	-683	753	160
-400	**-42**	**-864**	**953**	**203**
Fx	Fy	Fz	Fres	Load step

Limit Load Level (load step 100)

Ultimate Load Level (load step 150)

NASA W375-MOD load vector (load step 203)

All force values are kN

5. Strain gauge numbering system

All strain gauges are installed on both sides (inboard and outboard) of the test specimen (see figure 5.1 to 5.5). The table 5.1 shows the numbering system with the gauge type, orientation and the location.

Table 5.1

No.	Inboard / Outboard	Strain Gauge Type	Orientation [°]			Location
			0	45	90	
E1-9	i/o	Unidirectional	A			around the lug
R10-18	i/o	Rosette	C	B	A	around the lug
E20-27		Unidirectional	A			Outer border of the lug
R30-36	i/o	Rosette	C	B	A	Skin panel
FC01-08	i/o	Unidirectional	A			Fuselage clevis

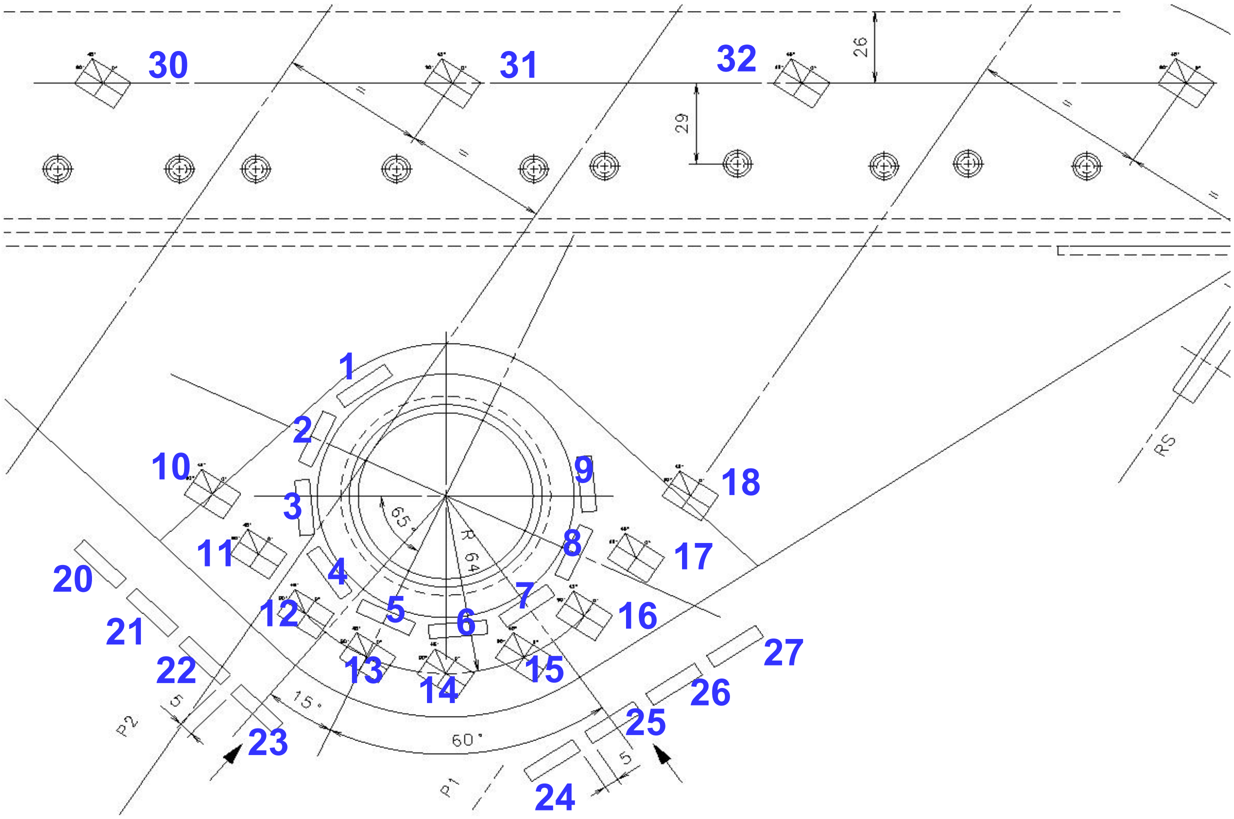
1i= for the inboard strain gauge

1o= for the outboard strain gauge

Example: 16_i_B

No. 16 rosette round the lug, inboard and shear strain

Figure 5.1 **Strain Gauge locations around the lug area**



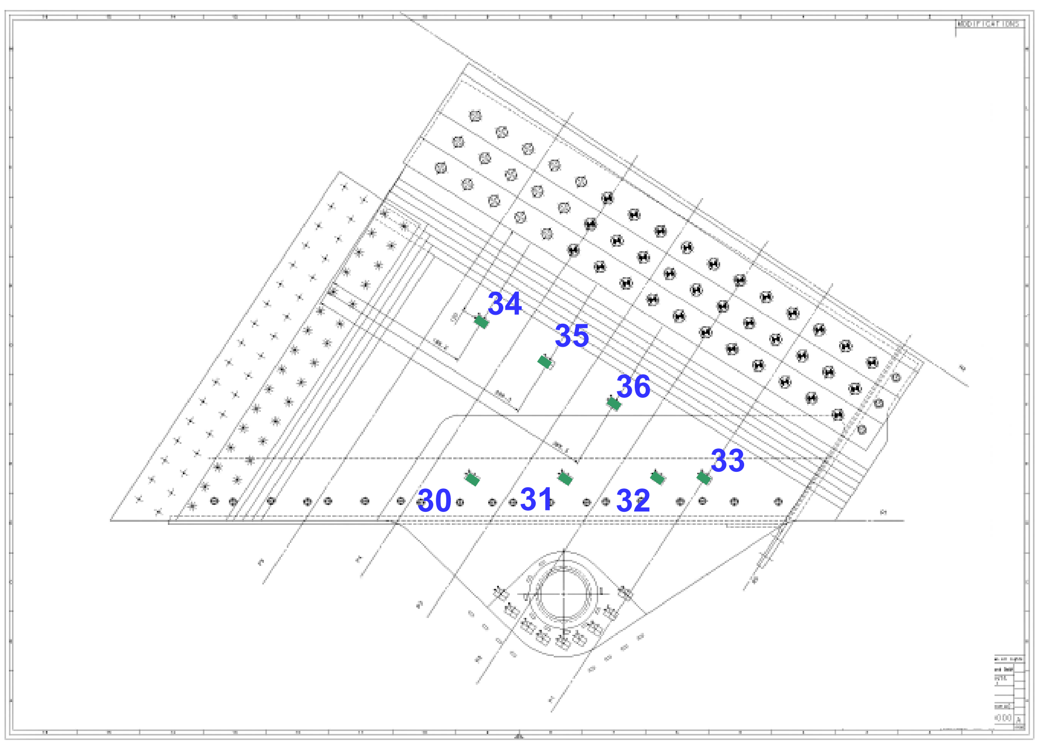


Figure 5.2

Test rig fuselage clevis strain gauge location

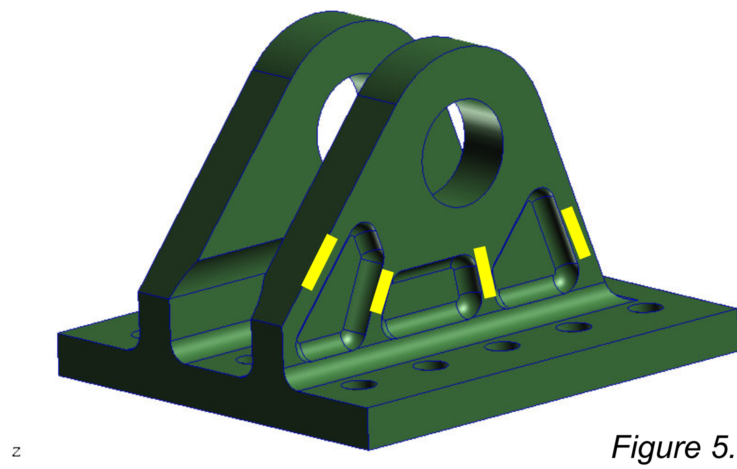


Figure 5.3

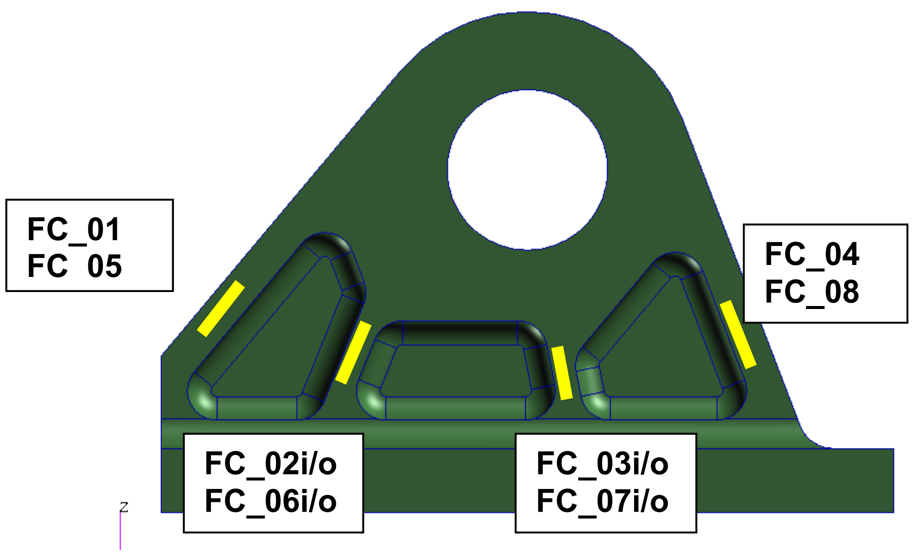


Figure 5.4

Outboard view of the test specimen Lug Test#1

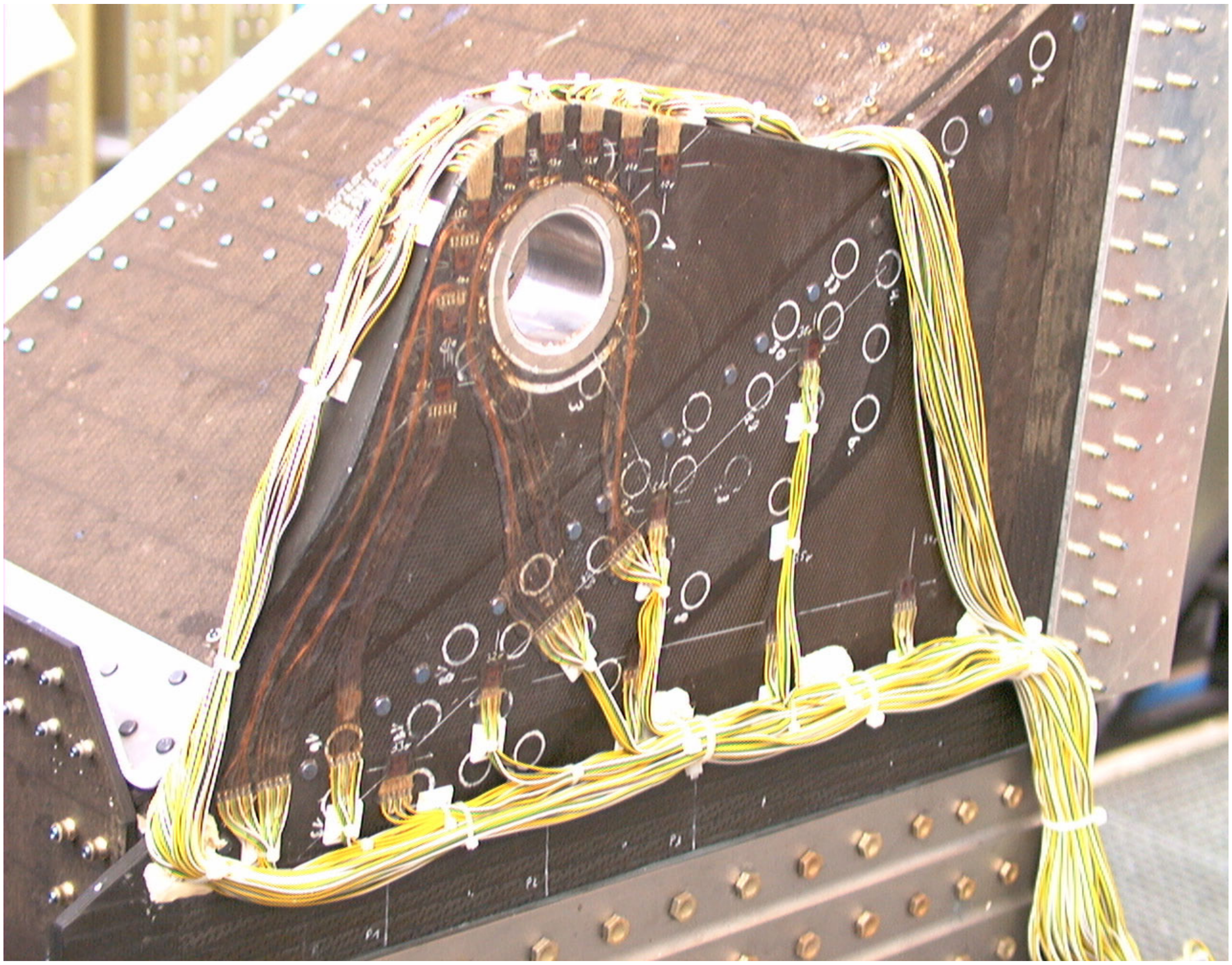


Figure 5.5

To compare the measured strains with the FEA-results a tracking subroutine has been written for interpolation between the nearest nodes results and the correct strain gauge position.

6. FEA results

6.1 RHS ANSYS contact 3D model NASA W375 MOD

6.1.1 RHS rear main local lug forces & moments

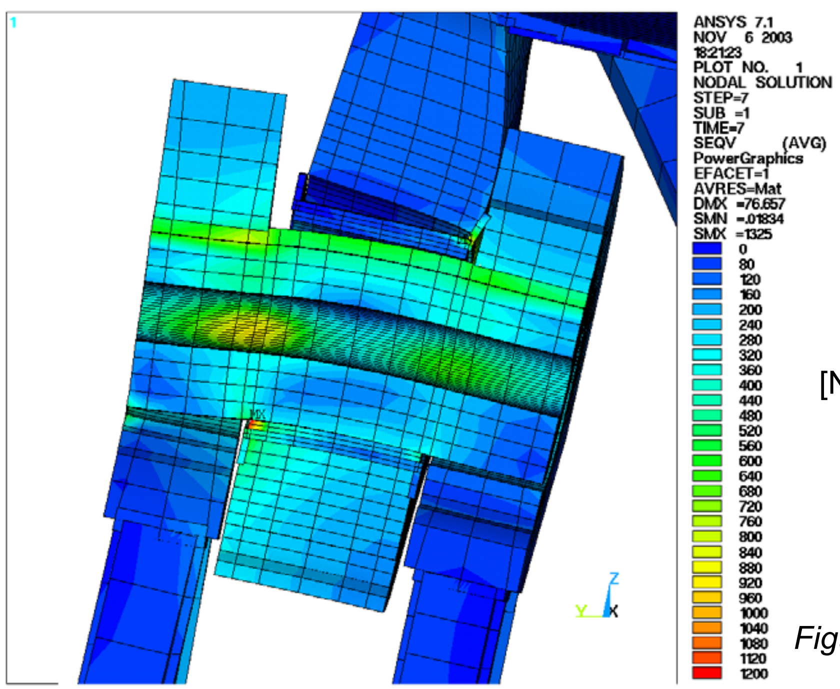
Table 6.1

Fx	Fy	Fz	Fres	Mx	Mz	Rx	Rz
[kN]	[kN]	[kN]	[kN]	[Nm]	[Nm]	[°]	[°]
0	0	2	**2**	4	8	0	0
-65	5	-134	**149**	-1015	196	-0,075	0,014
-127	11	-270	**299**	-2000	403	-0,149	0,03
-190	18	-413	**455**	-3022	629	-0,224	0,045
-255	26	-561	**617**	-4057	852	-0,298	0,06
-322	34	-715	**785**	-5093	1068	-0,373	0,075
-390	43	-874	**958**	-6120	1277	-0,447	0,091

Rx/Rz bolt rotation in relation to rib 1

6.1.2 Deformation & Rx bolt rotation

The cross section through the CFRP lug, the bolt and the fuselage fitting illustrate the connection bolt contact situation under max. applied loading condition (see figure 6.1 and 6.2). The color scale is von Mises equivalent stress distribution.



[N/mm²]

Figure 6.1

Deformations are scaled up for a better understanding of the structure behaviour!

Rx bolt rotation

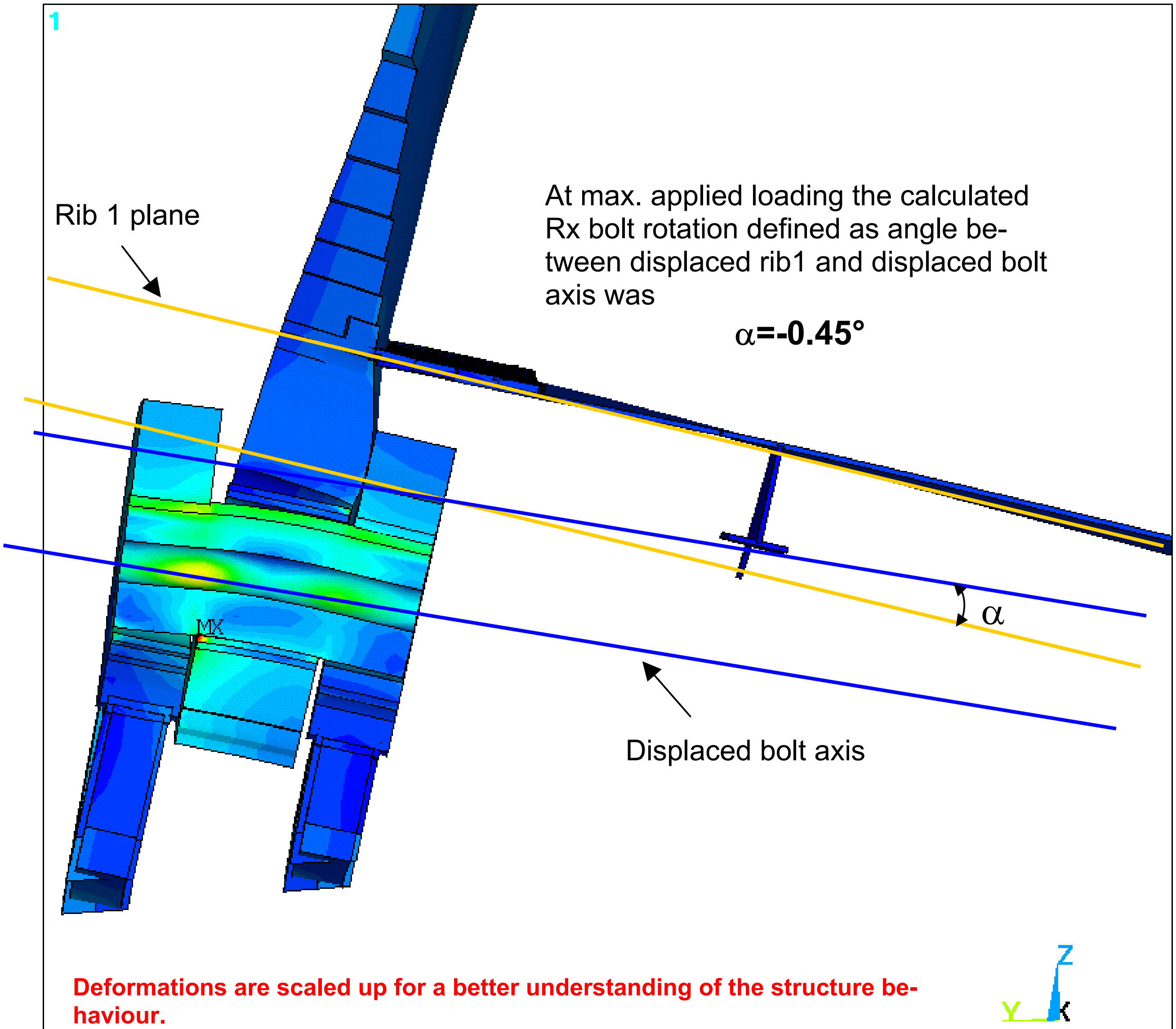
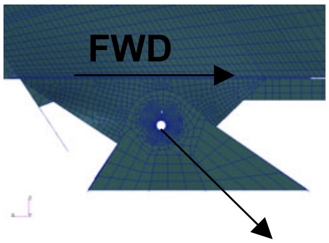


Figure 6.2

6.1.3 Strain distribution at the pin hole



RHS model

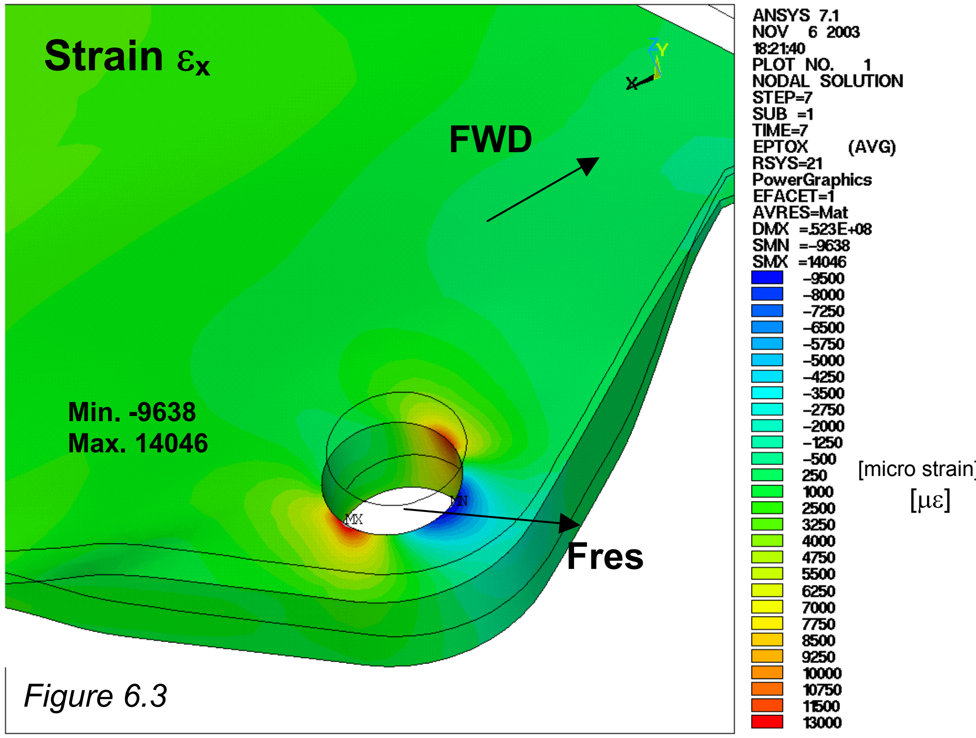


Figure 6.3

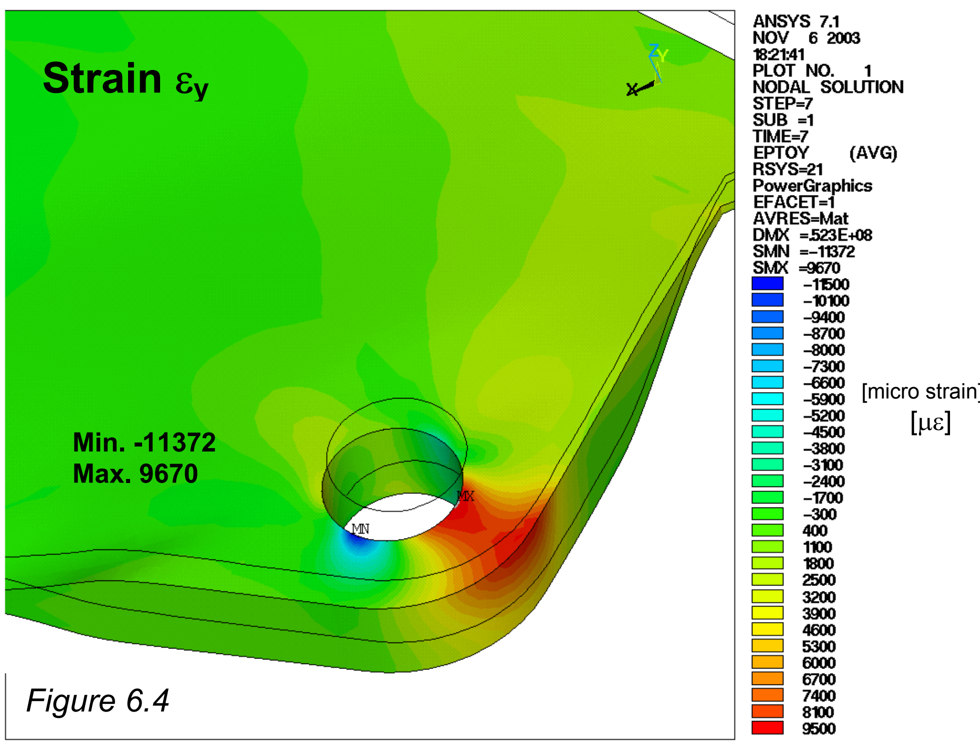
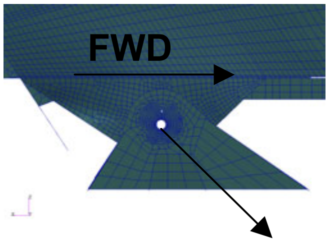


Figure 6.4

All views from outboard
Strain distribution in material coordinate system



Fres=958kN

RHS model

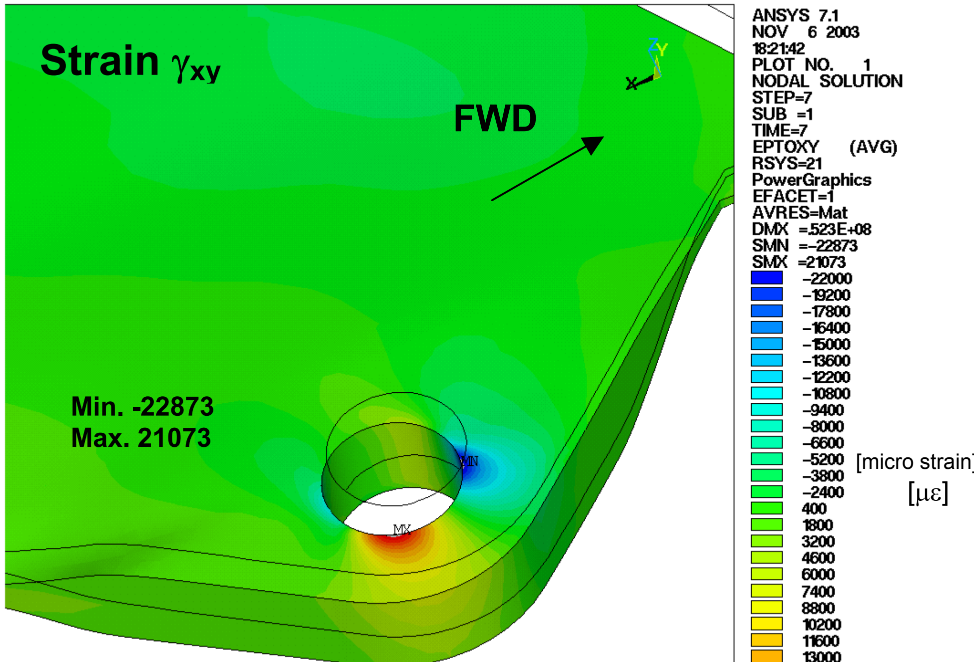


Figure 6.5

Strain$_{tangential}$
Cylinder coordinate system in the bolt axis

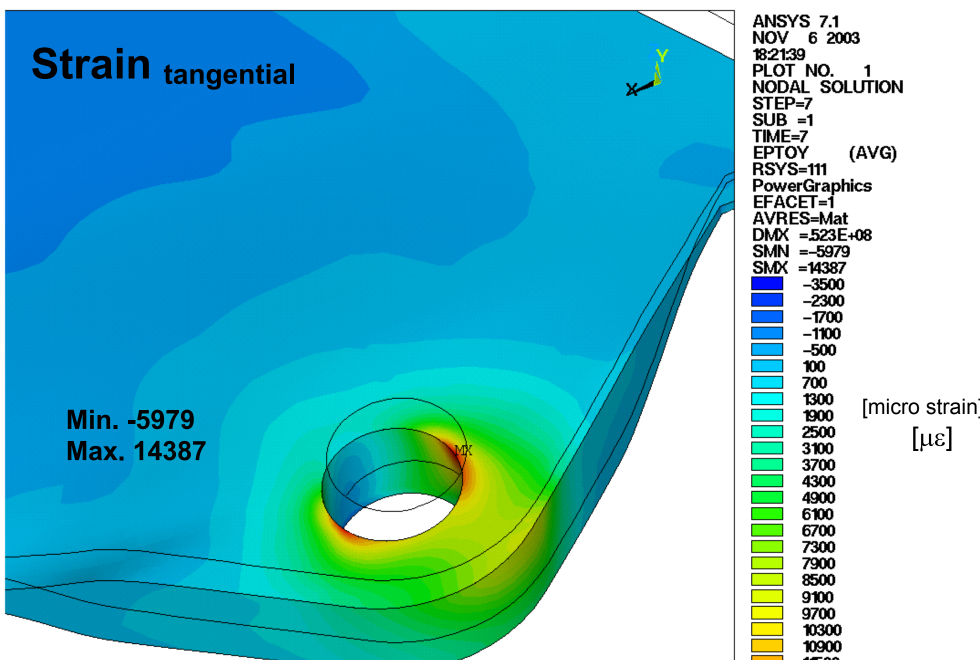


Figure 6.6

All views from outboard
Strain distribution in material coordinate system

6.2 LHS ANSYS contact Lug Test#1 NASA W375 MOD rotx=0°

6.2.1 Rear main local lug forces & moments

Table 6.2

Fx [kN]	Fy [kN]	Fz [kN]	Fres [kN]	Mx [Nm]	Mz [Nm]	Rx [°]	Rz [°]
0	0	0	**0**	1	-12	0	0
-67	-7	-144	**159**	767	-88	-0,026	0,001
-133	-14	-288	**318**	1466	-183	-0,051	0,003
-200	-21	-432	**477**	2123	-287	-0,074	0,004
-267	-28	-576	**635**	2734	-385	-0,096	0,006
-333	-35	-720	**794**	3301	-478	-0,117	0,007
-400	-42	-864	**953**	3828	-566	-0,138	0,009

Rx/Rz bolt rotation in relation to rib 1

6.2.2 Deformation & Rx bolt rotation

The cross section through the CFRP lug, the bolt and the fuselage fitting illustrate the connection bolt contact situation under max. applied loading condition (see figure 6.7 and 6.8). The color scale is von Mises equivalent stress distribution.

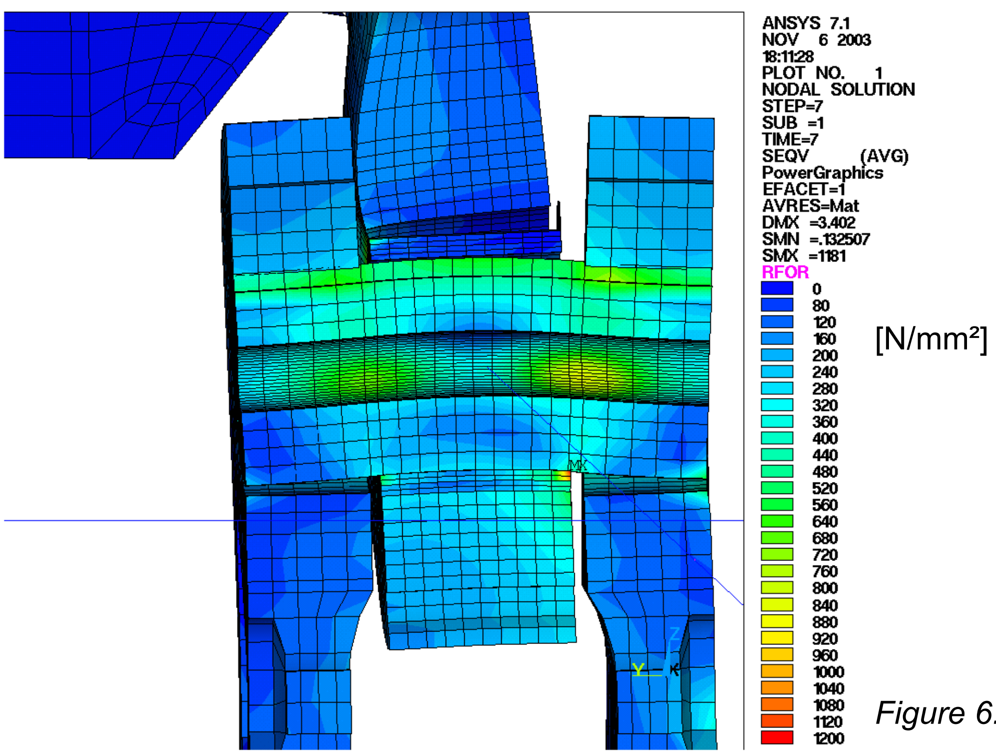


Figure 6.7

Deformations are scaled up for a better understanding of the structure behaviour.

Rx bolt rotation

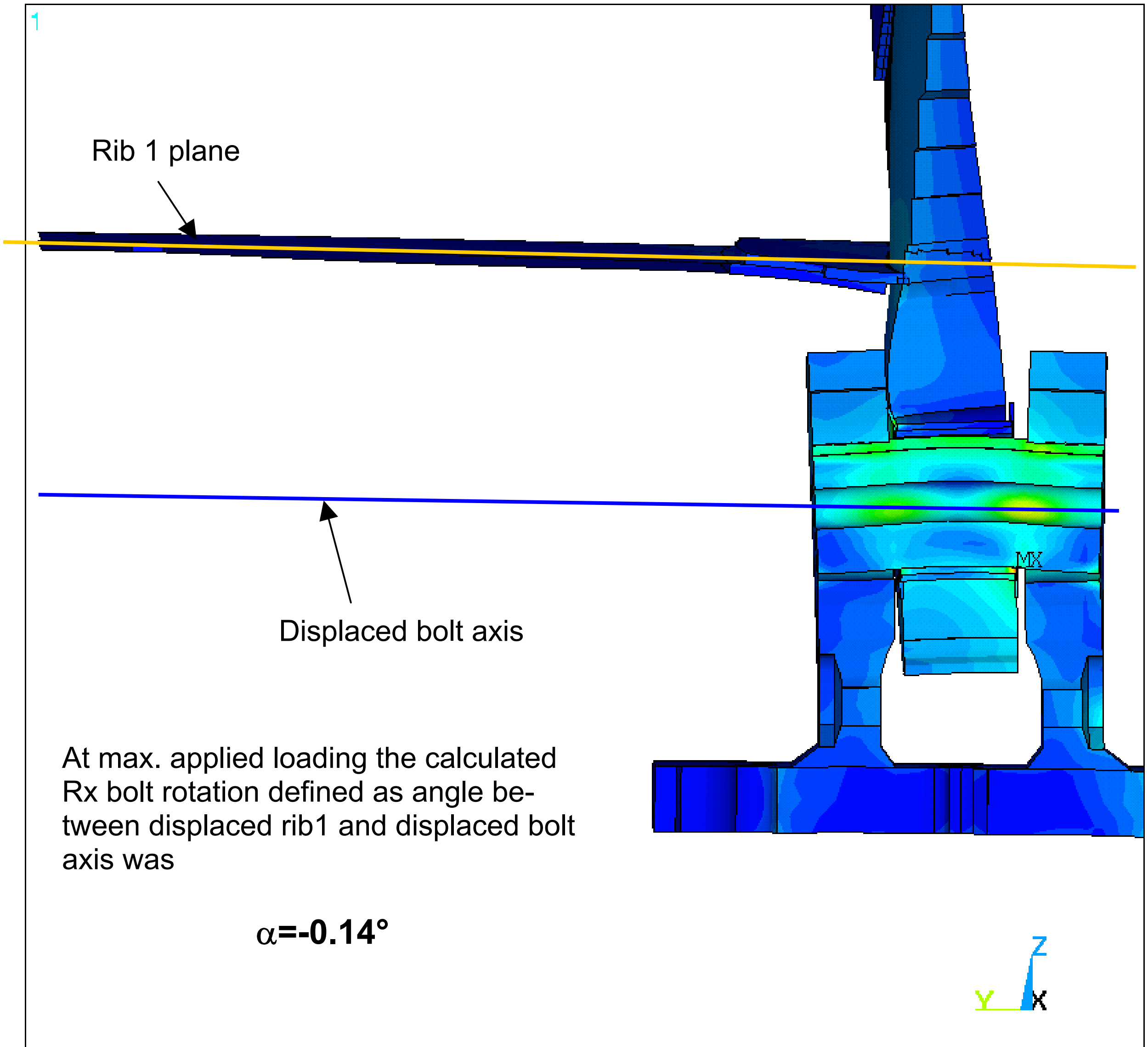
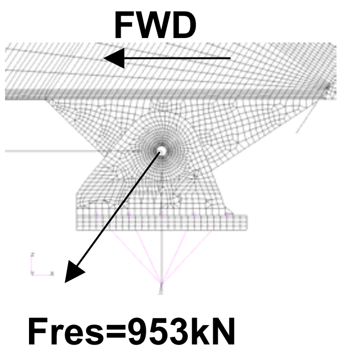


Figure 6.8

Deformations are scaled up for a better understanding of the structure behaviour!

6.2.3 Strain distribution at the pin hole



LHS model

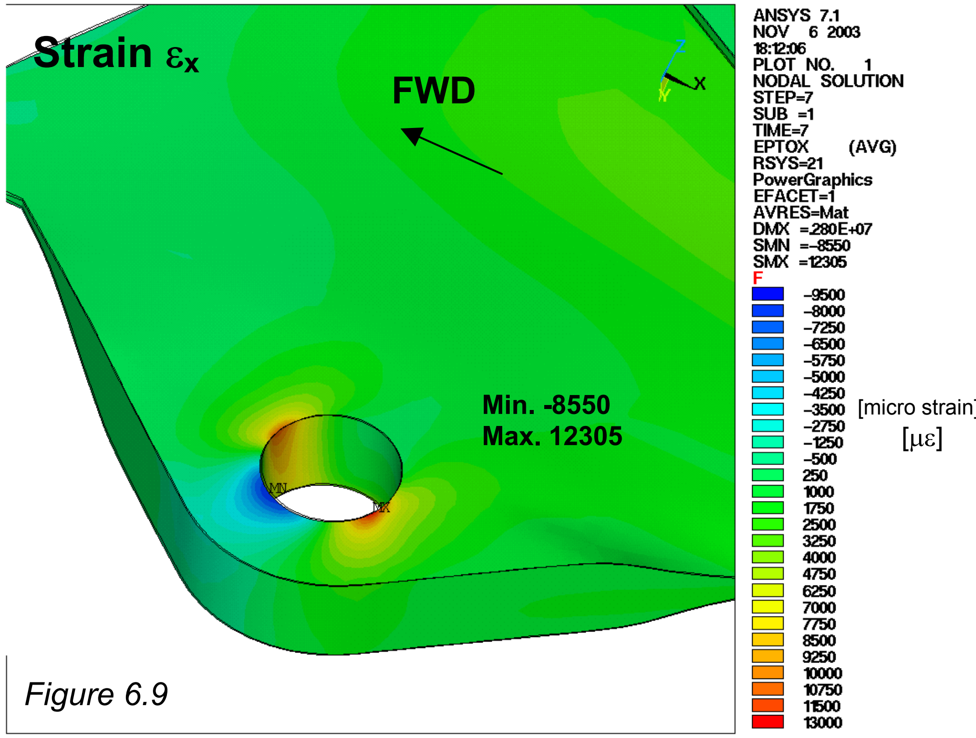


Figure 6.9

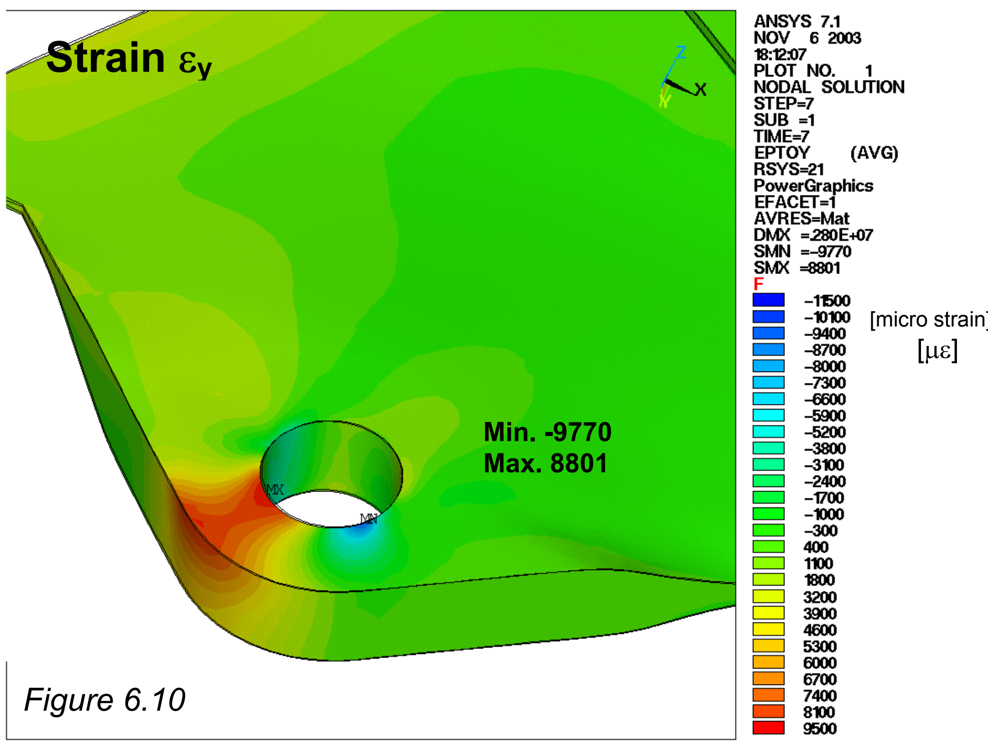
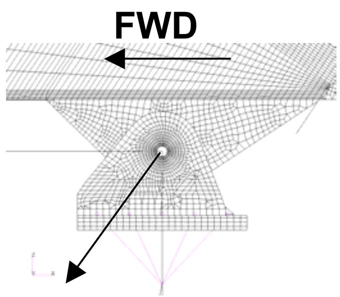


Figure 6.10

All views from outboard
Strain distribution in material coordinate system



LHS model

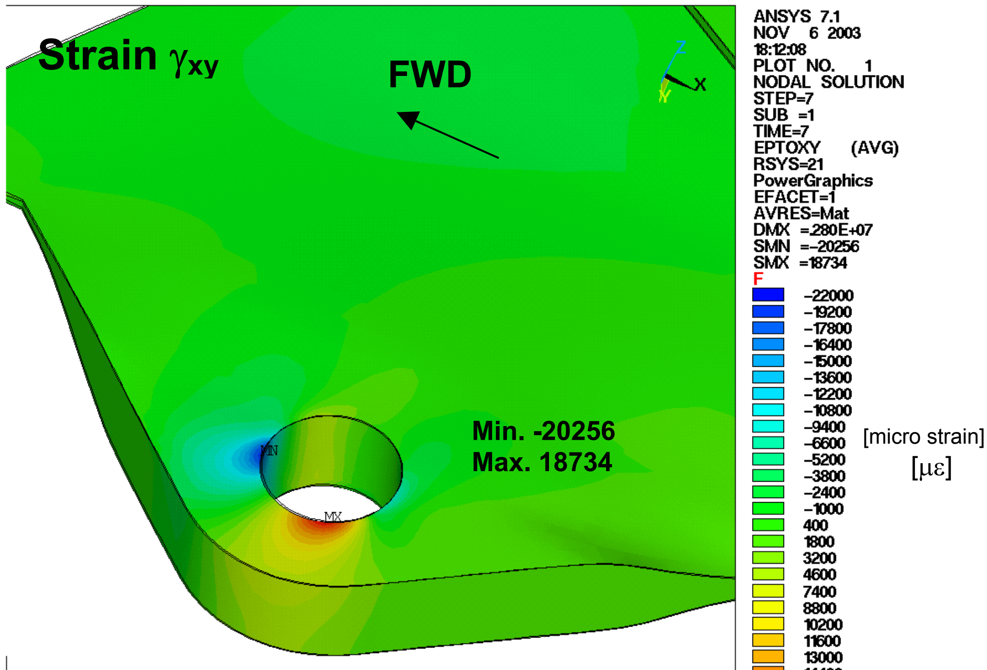


Figure 6.11

Strain$_{\text{tangential}}$
Cylinder coordinate system in the bolt axis

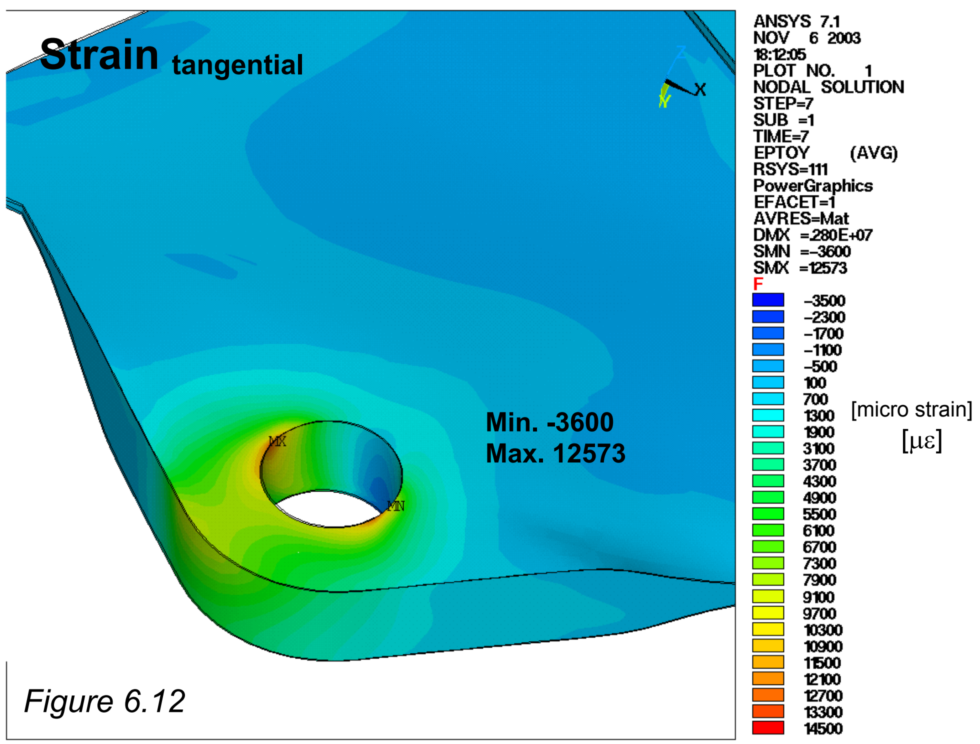


Figure 6.12

All views from outboard
Strain distribution in material coordinate system

6.3 LHS ANSYS contact Lug Test#1 NASA W375 MOD rotx=0.5°

6.3.1 Rear main local lug forces & moments

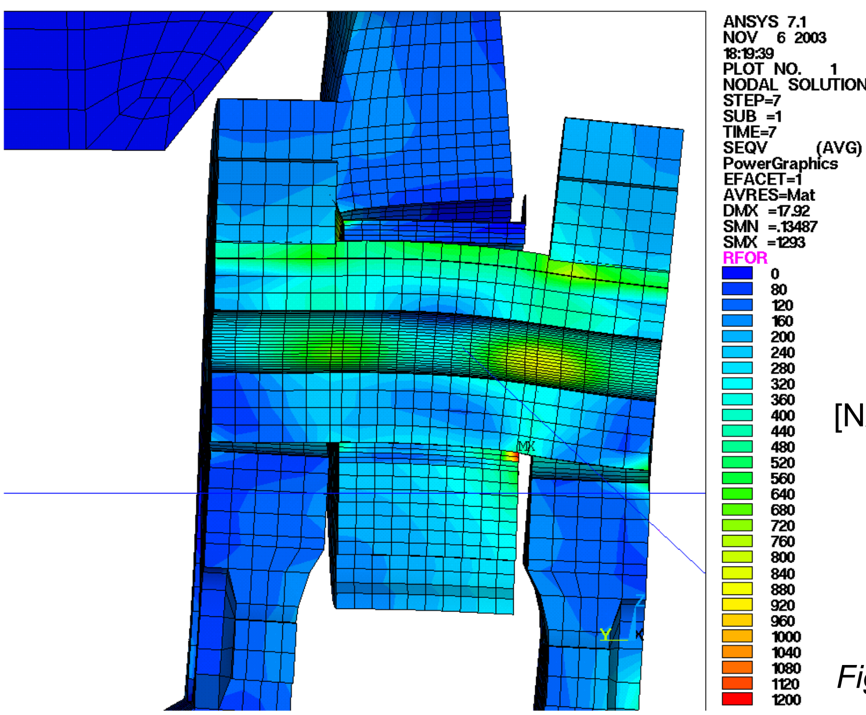
Table 6.3

Fx [kN]	Fy [kN]	Fz [kN]	Fres [kN]	Mx [Nm]	Mz [Nm]	Rx [°]	Rz [°]
0	0	0	**0**	1	-12	0	0
-67	-7	-144	**159**	1536	-68	0,487	0
-133	-14	-288	**318**	2379	-53	0,457	0
-200	-21	-432	**477**	3250	-164	0,436	0,001
-267	-28	-576	**635**	4059	-280	0,418	0,002
-333	-35	-720	**794**	4805	-394	0,4	0,004
-400	-42	-864	**953**	5484	-500	0,384	0,005

Rx/Rz bolt rotation in relation to rib 1

6.3.2 Deformation & Rx bolt rotation

The cross section through the CFRP lug, the bolt and the fuselage fitting illustrate the connection bolt contact situation under max. applied loading condition (see figure 6.13 and 6.14). The color scale is von Mises equivalent stress distribution.

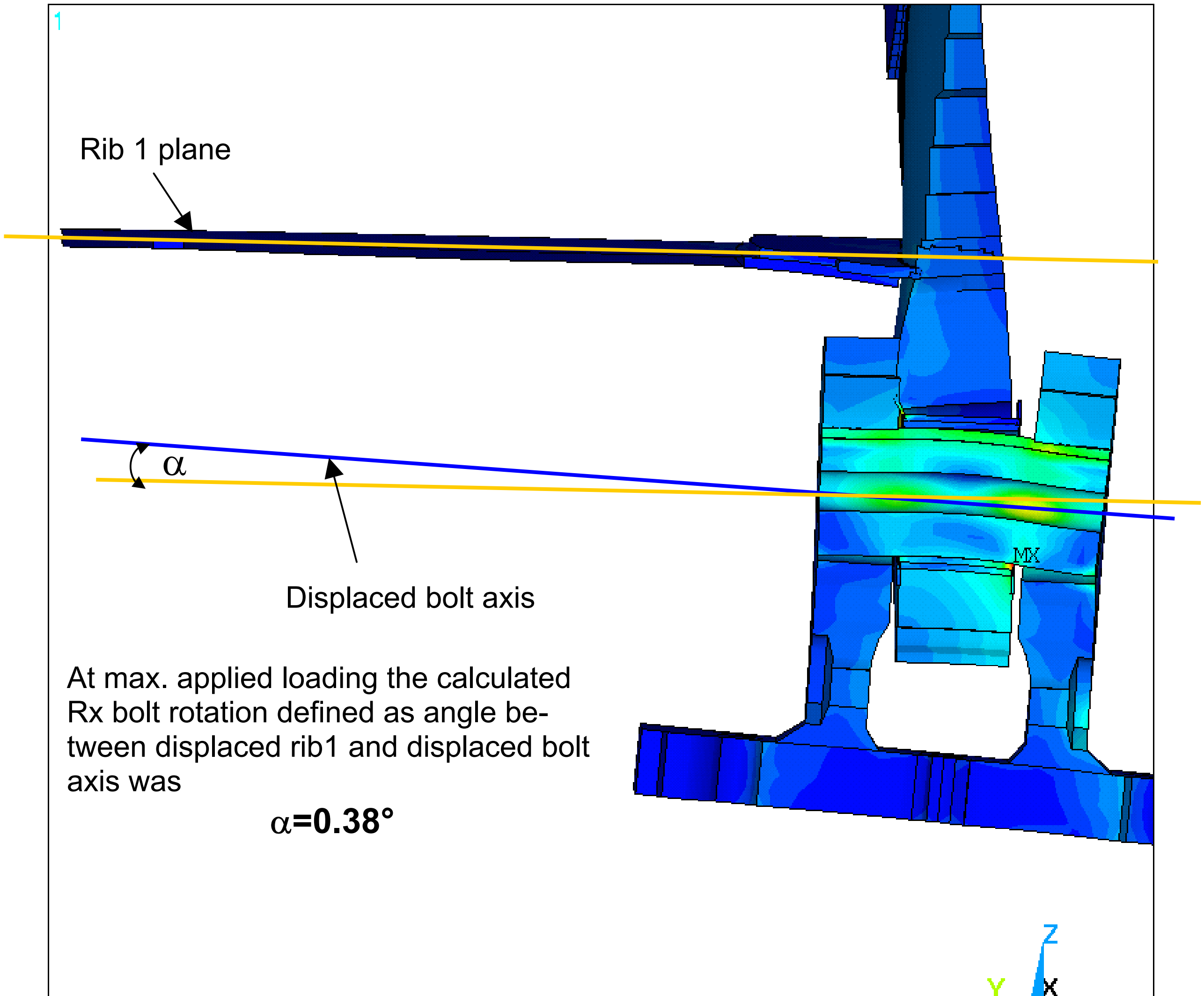


[N/mm²]

Figure 6.13

Deformations are scaled up for a better understanding of the structure behaviour.

Rx bolt rotation



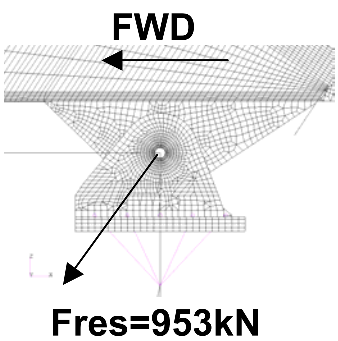
At max. applied loading the calculated Rx bolt rotation defined as angle between displaced rib1 and displaced bolt axis was

$$\alpha = 0.38°$$

Figure 6.14

Deformations are scaled up for a better understanding of the structure behaviour

6.3.3 Strain distribution at the pin hole



LHS model

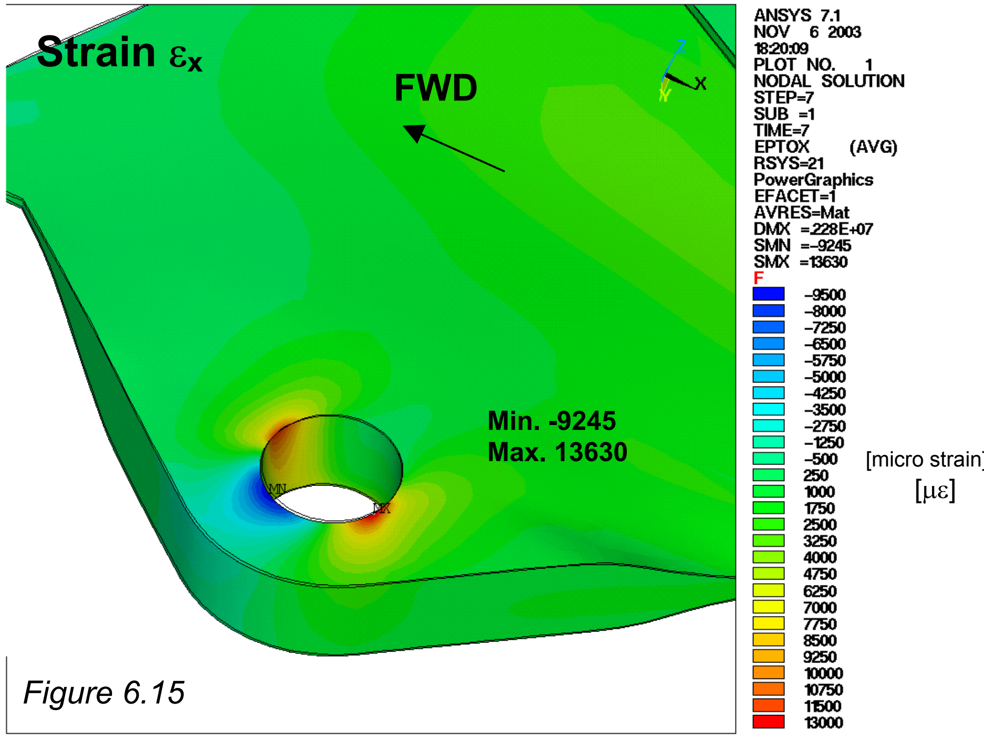


Figure 6.15

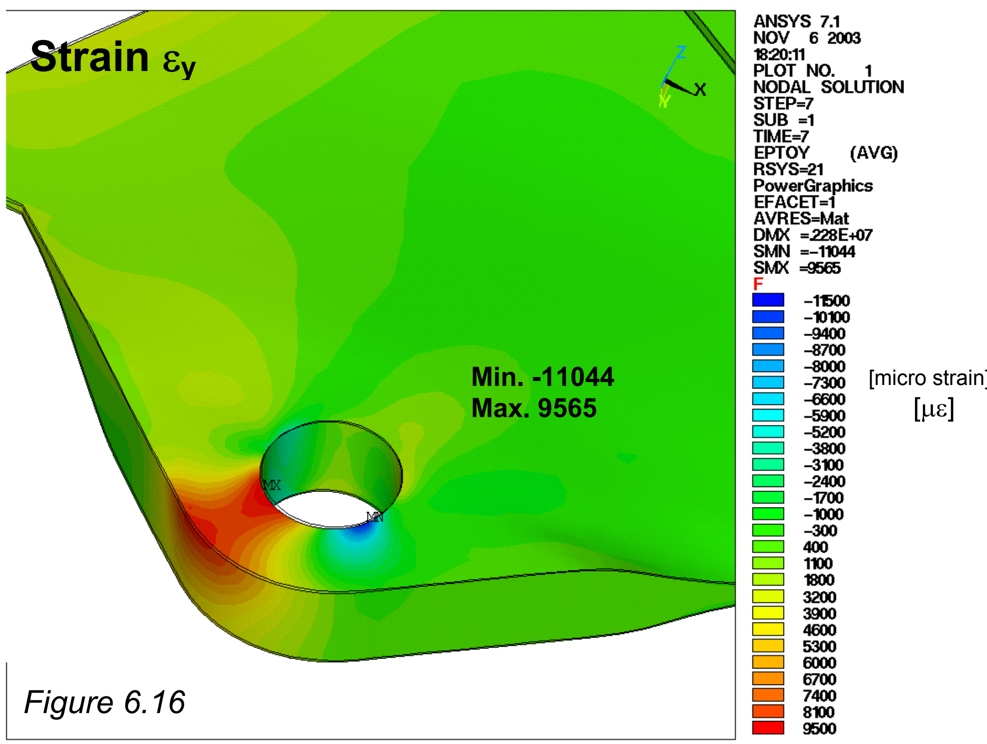
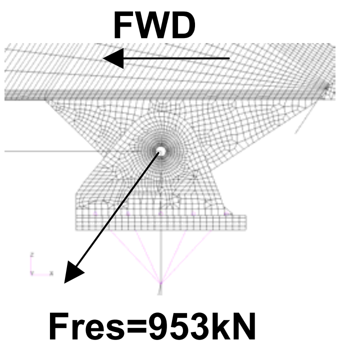


Figure 6.16

All views from outboard
Strain distribution in material coordinate system



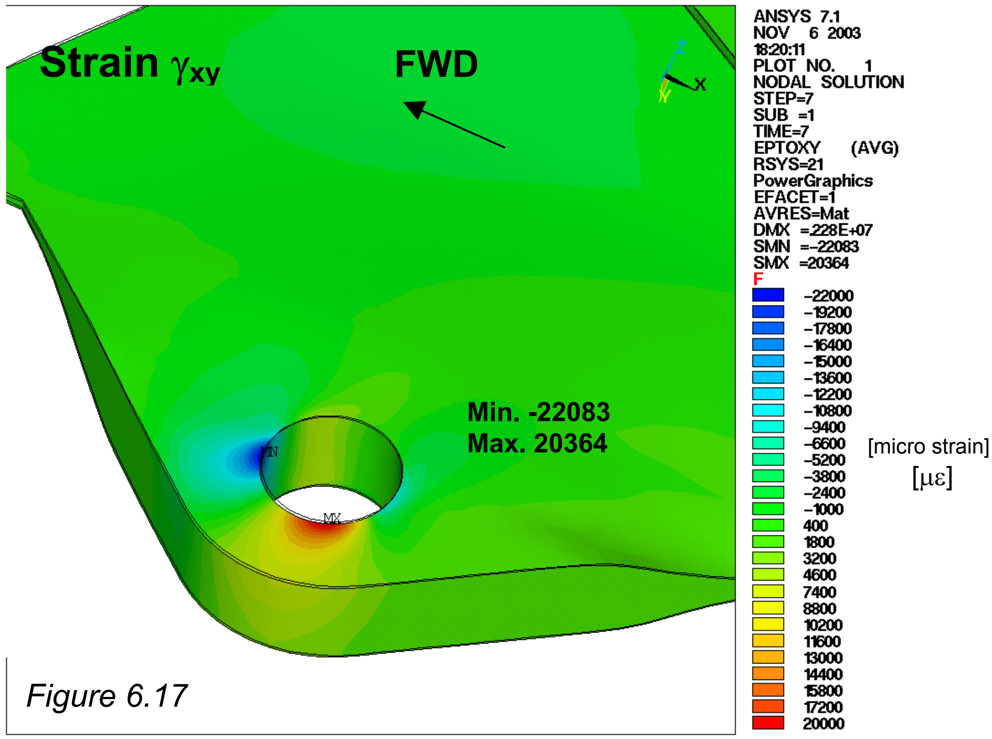


Figure 6.17

Strain$_{tangential}$
Cylinder coordinate system in the bolt axis

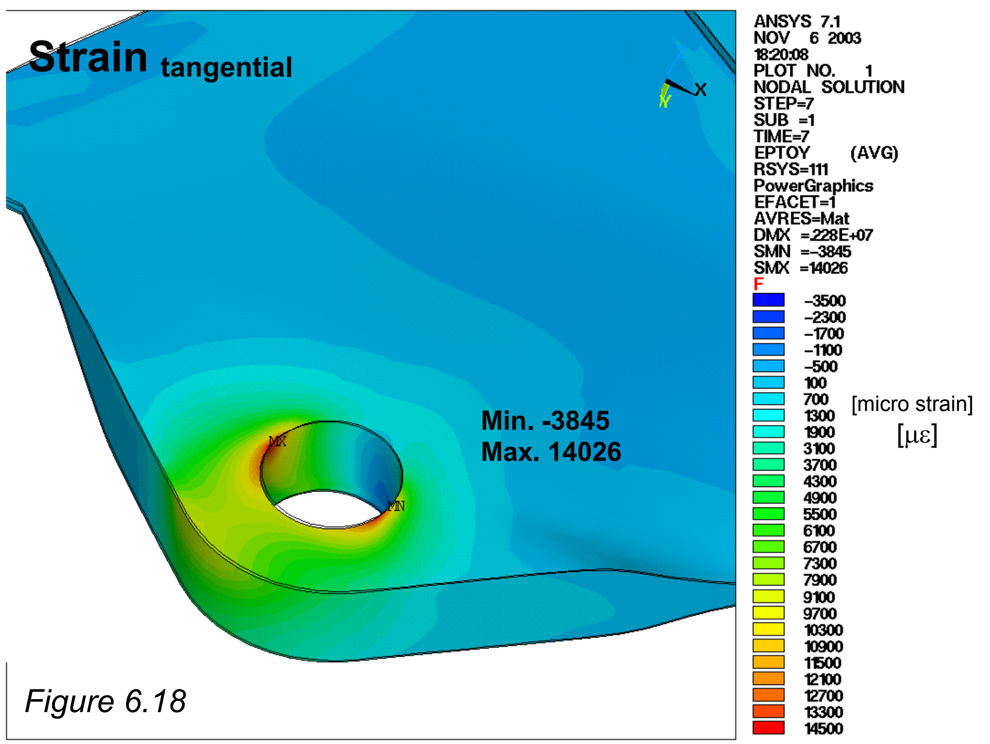


Figure 6.18

All views from outboard
Strain distribution in material coordinate system

7. Test results Lug Test#1 W375 MOD rotx=0.5°

7.1 Lug Test#1 failure pictures

The figures 7.1 to 7.4 show the Lug Test#1 specimen after the test with all strain gauges removed and the fracture line is visible.

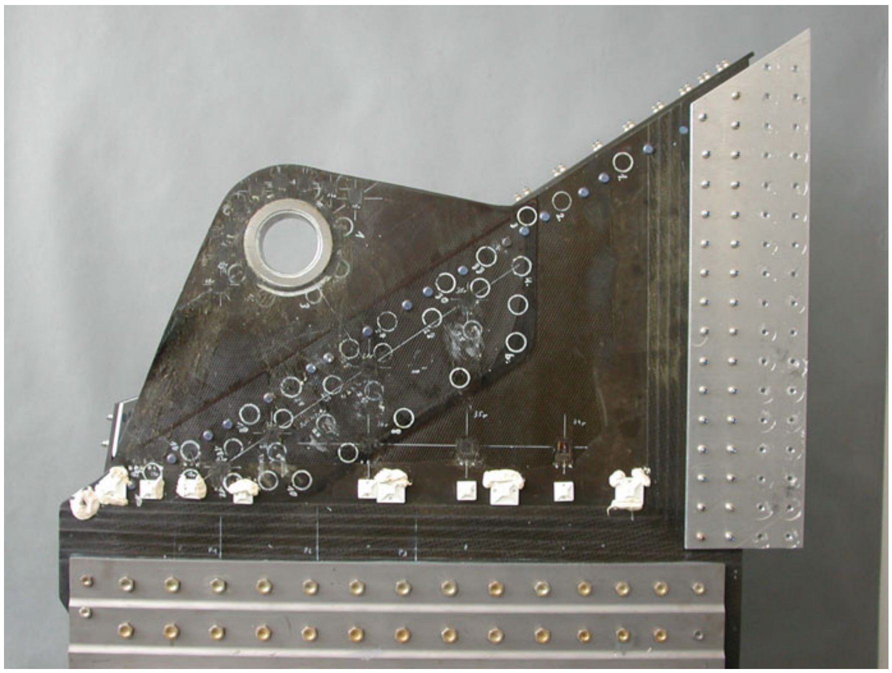


Figure 7.1

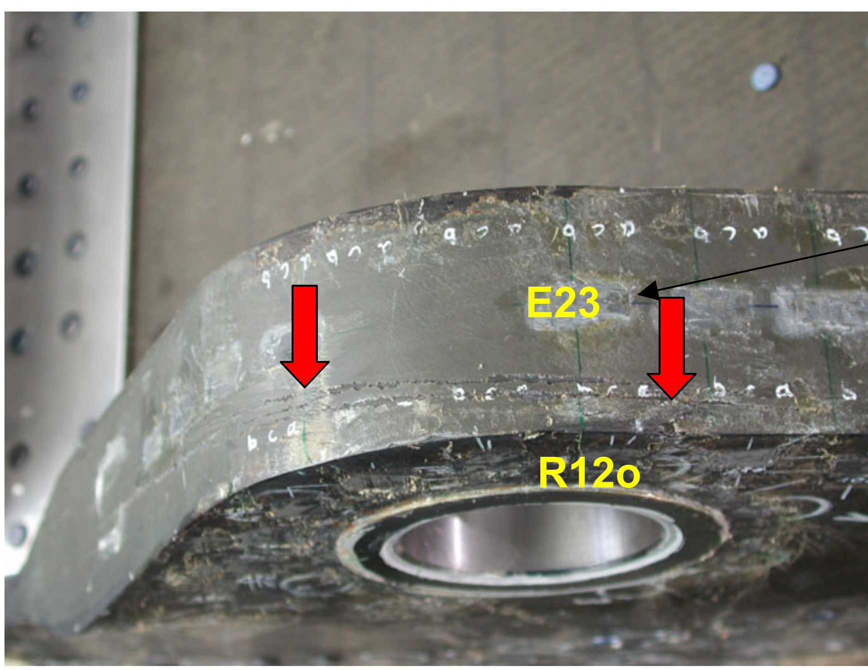


Figure 7.2

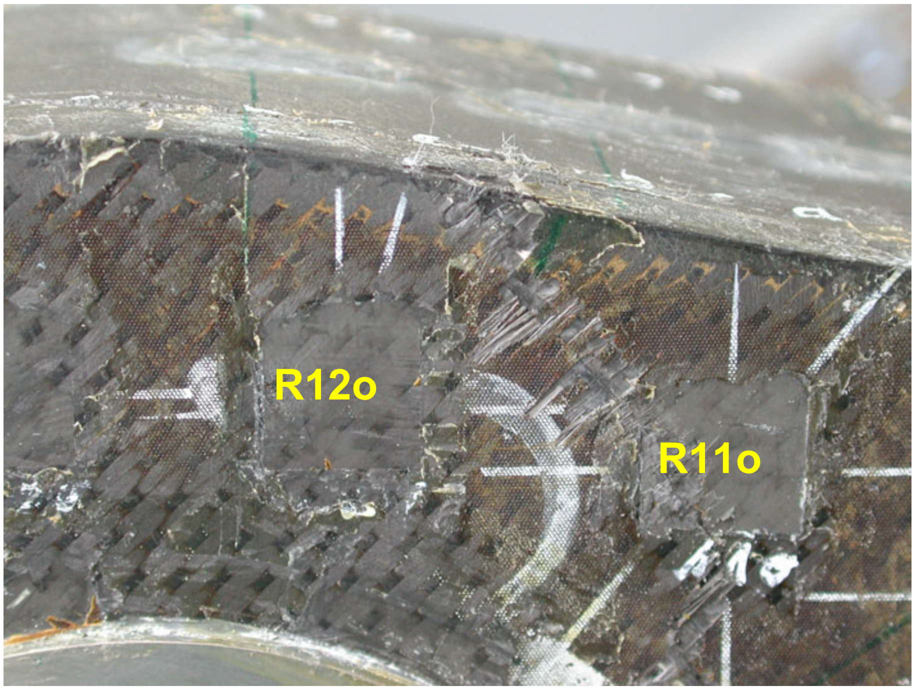


Figure 7.3

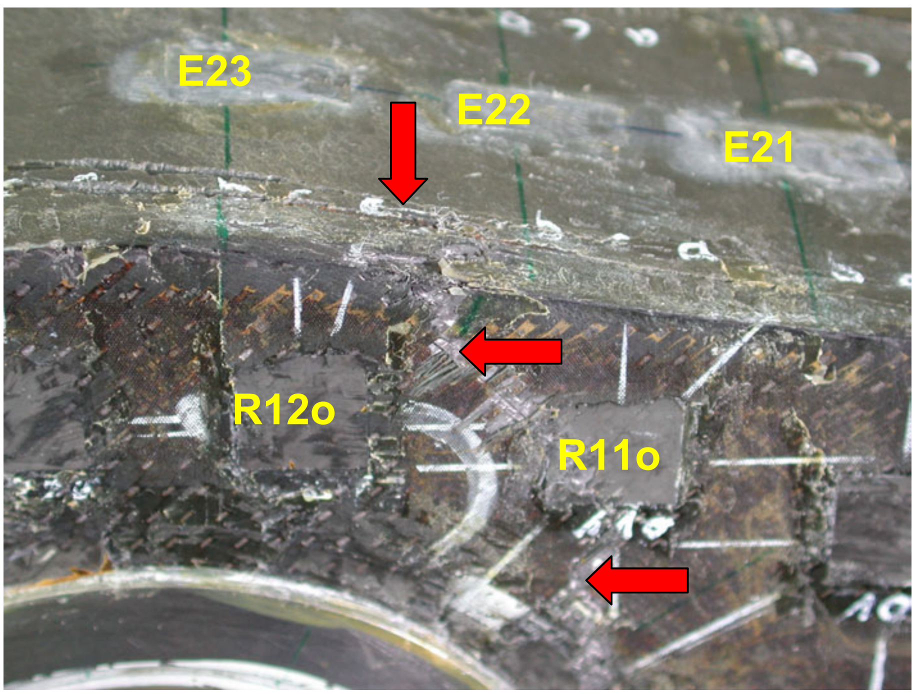


Figure 7.4

7.2 Failure load

The load vector according to chapter 4 was applied to the test specimen. After load step 160 the loads increase continuously and the achieved load was 194 percent of the limit load design gust vector (BI17). The max. load vector is shown in table 7.1.

Table 7.1

Component		Rupture value
Fx	[kN]	-381.6
Fy	[kN]	-39.1
Fz	[kN]	-822.5
Fres	[kN]	**907**

Measured Forces

The measured forces (see diagram 7.1) from the Lug Test#1 load cells are identical to the applied forces of the FE-Analysis.

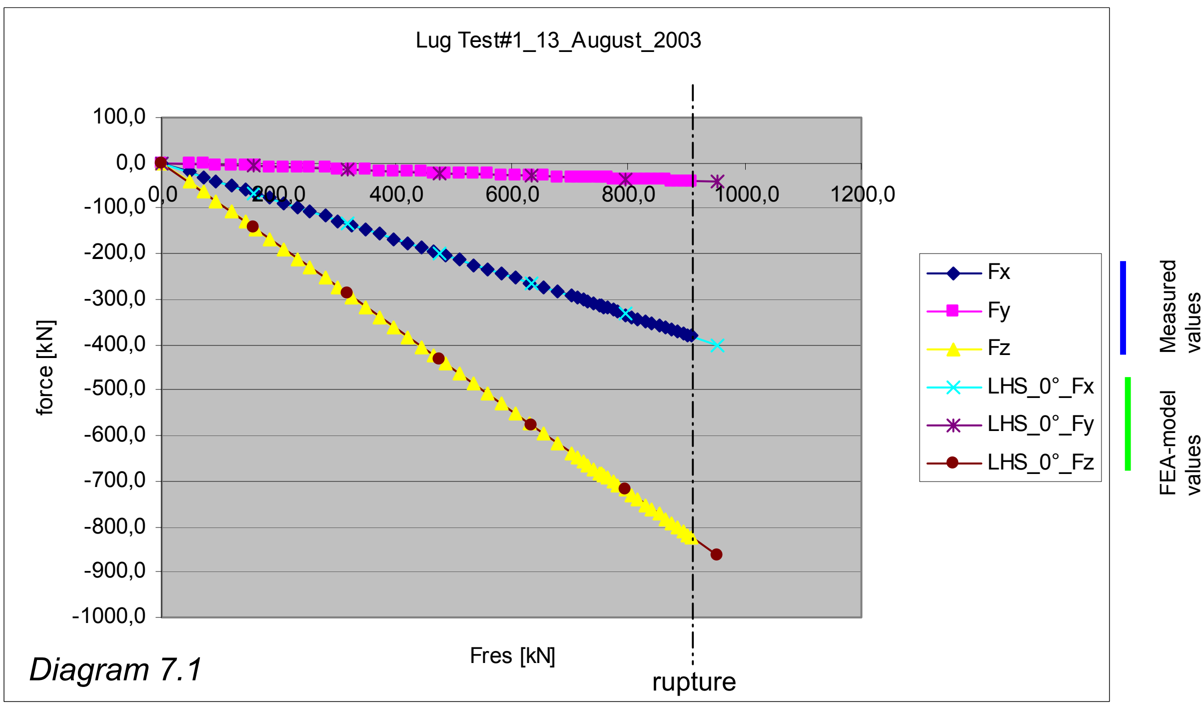


Diagram 7.1

Measured local lug moments and bolt Rx rotation

Taking into account the equations for the local lug moments Mx and Mz described in chapter 2.3 the calculated moments are shown in diagram 7.2.

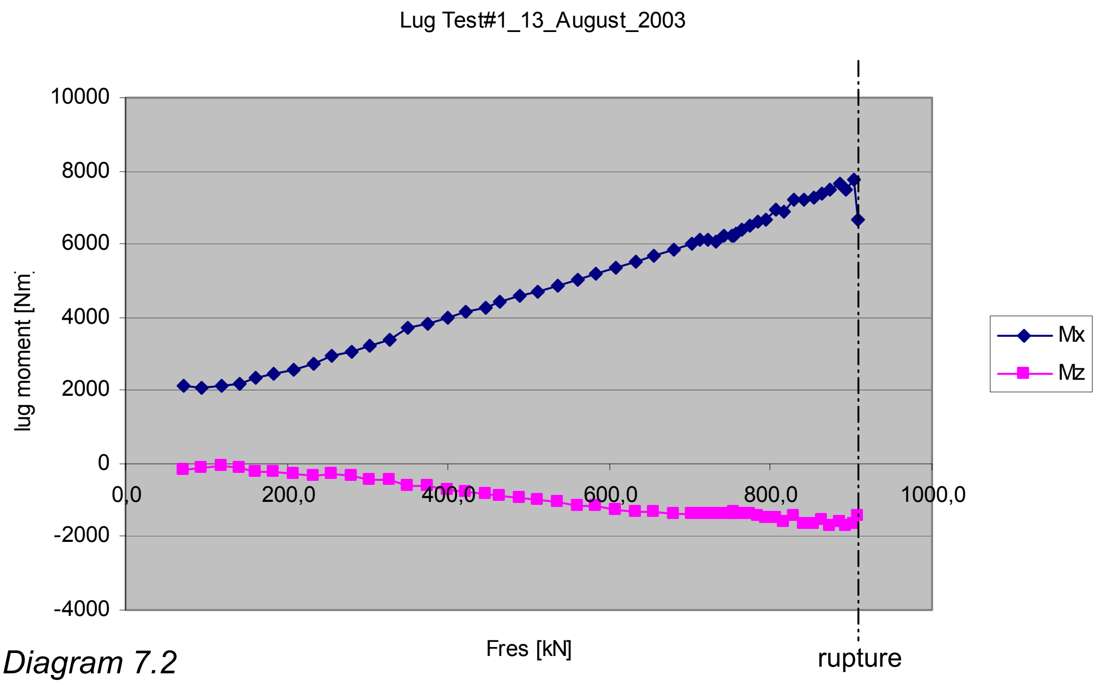


Diagram 7.2

8. Strain result comparison

The measured strain values of the **Lug Test#1 specimen** are compared to **LHS ANSYS nonlinear contact Lug Test#1 rotx=0.5°**.

For the comparison of rosette strain gauges, the principle strains and the angle of the principle strain is selected. The principle strains are independent from orientation deviation of rosettes.

For the detailed discussion of the strain gauge results, those gauges are chosen, which measure high strain values and where the failure was initiated. In agreement with the detected fracture line shown in chapter 7. the strain gauge number E03i/o, E04i/o, R11i/o, R12i/o, E22 and E23 are selected.

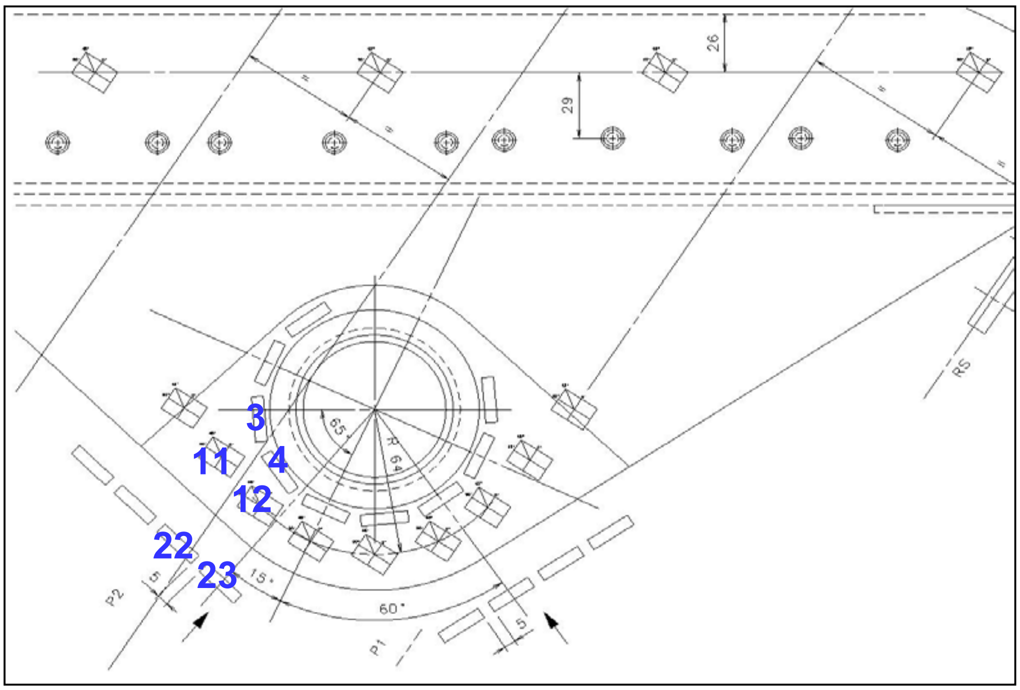


Figure 8.1

<u>Diagram value description</u>

SN1= maximum principle strain
SN2= minimum principle strain

R12i_SN1 = Lug Test#1 measured vaules
LHS_0.5°_R12i_SN1 = ANSYS LHS nonlinear contact model bolt rotation Rx=0.5°

Diagram 8.1 **E03i and E03o unidirectional strain**

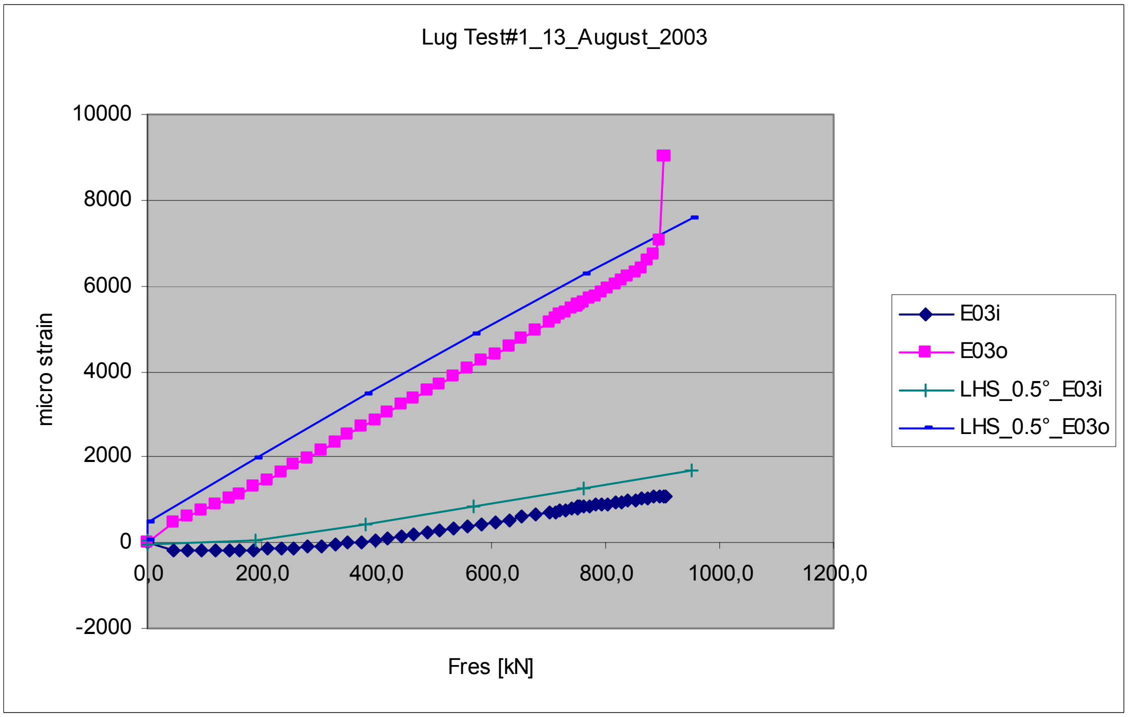


Diagram 8.2 **E04i and E04o unidirectional strain**

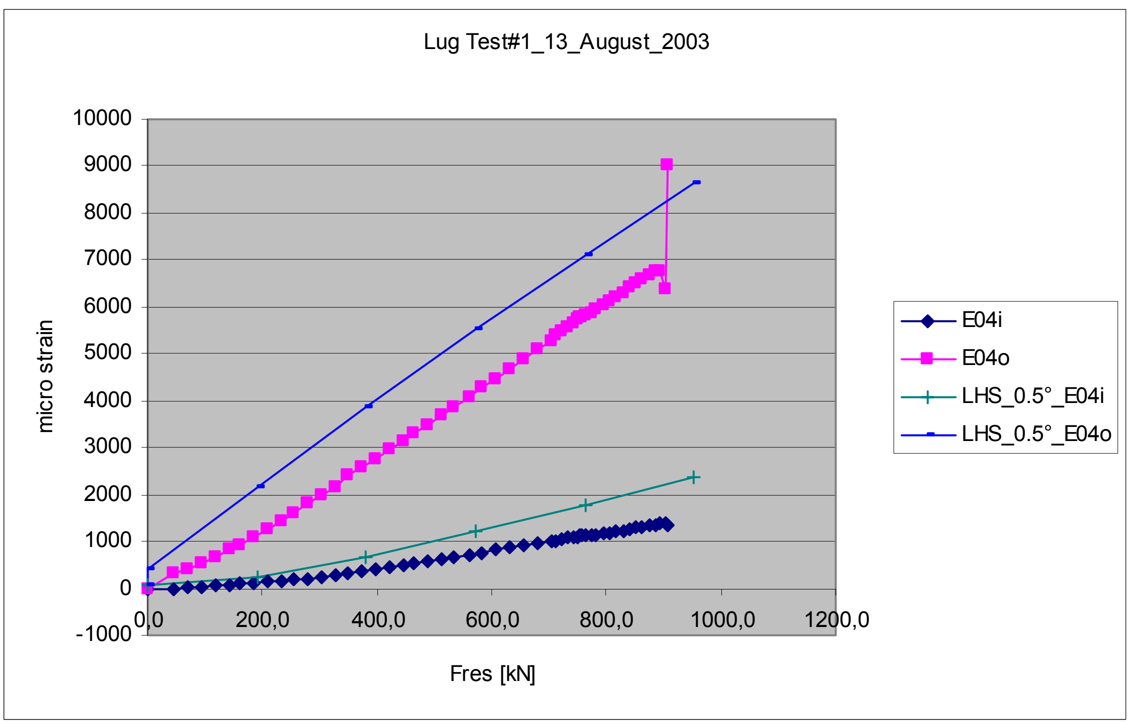


Diagram 8.3 R11o principle strain

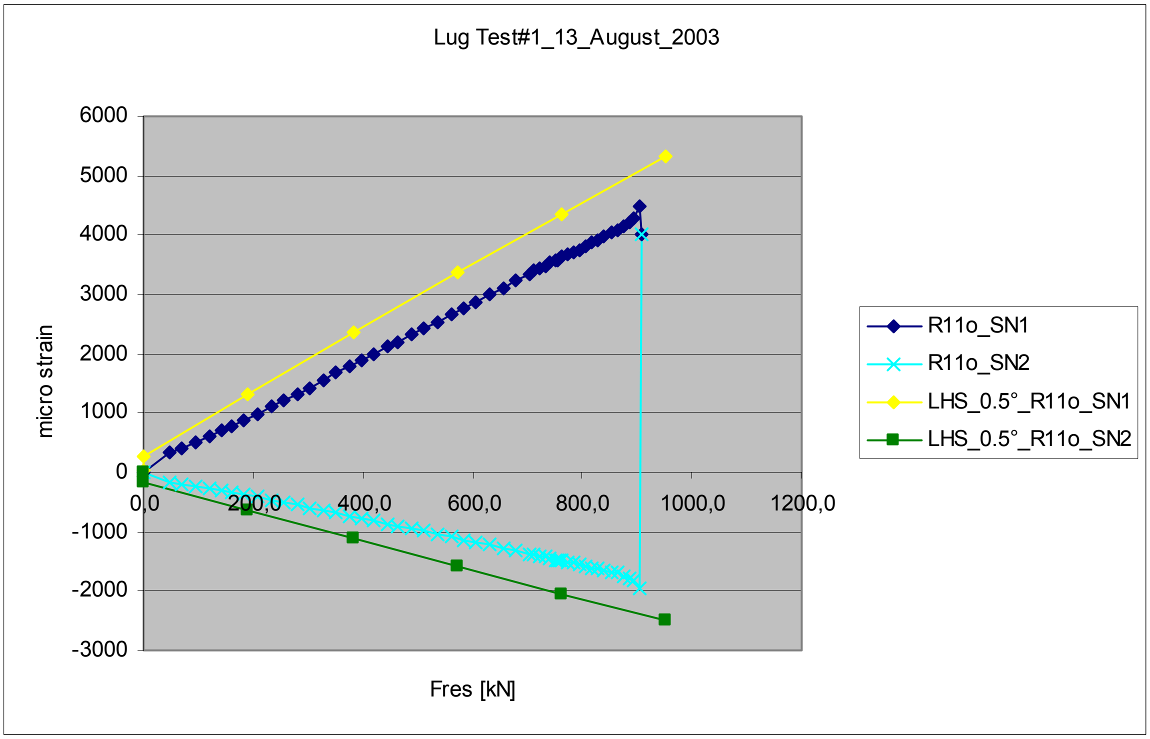


Diagram 8.4 R11o principle strain angle

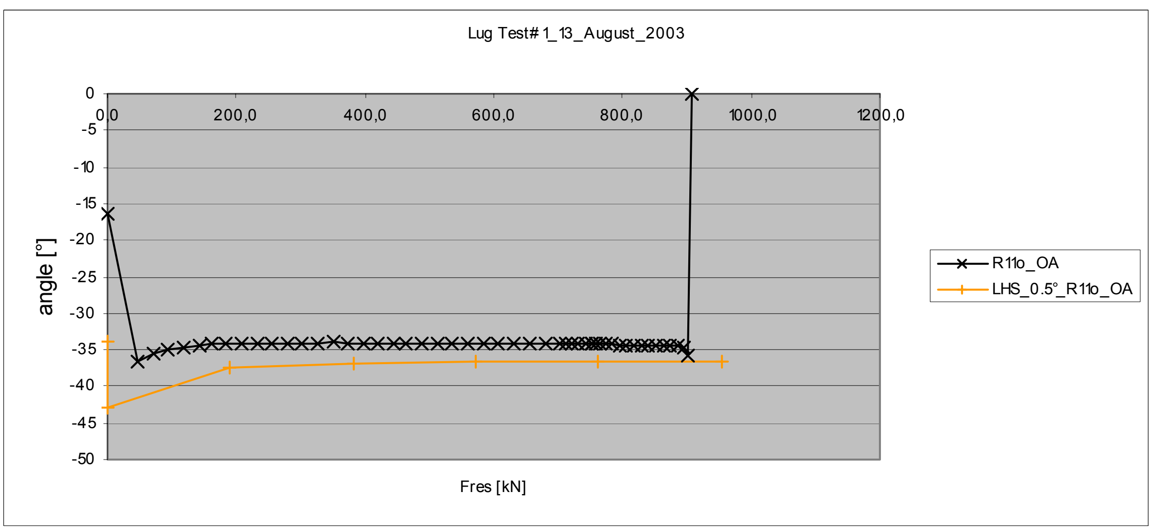


Diagram 8.5 **R12o principle strain**

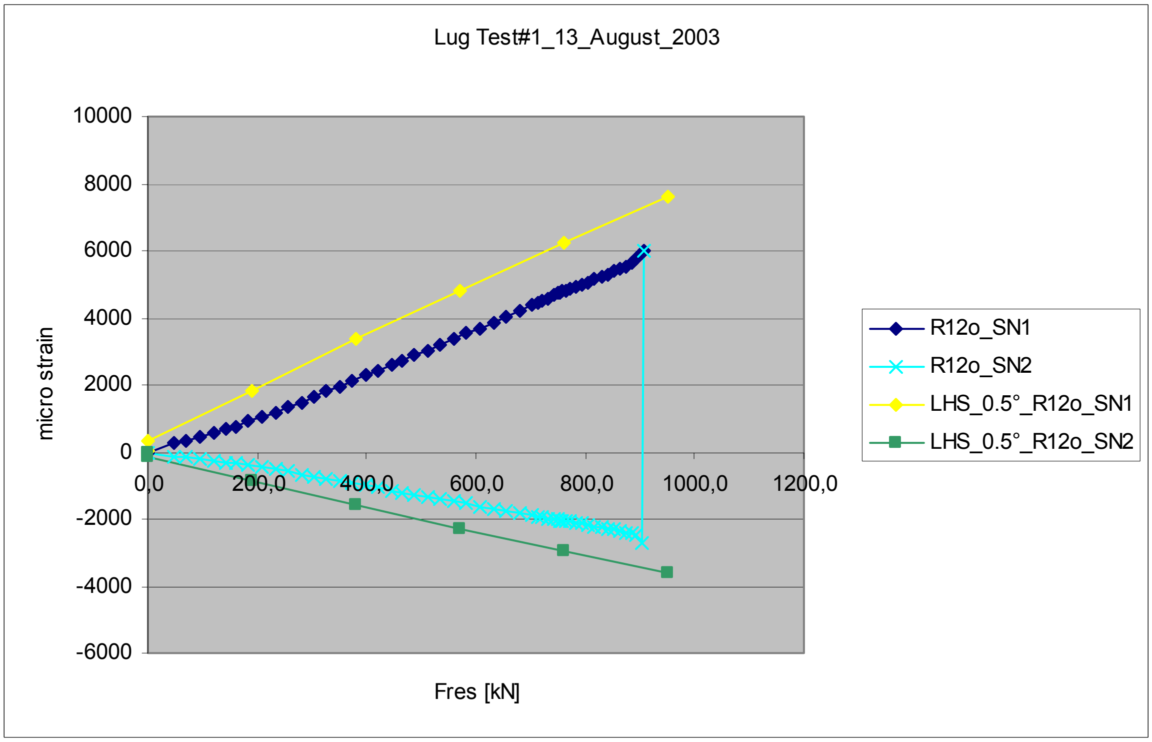


Diagram 8.6 **R12o principle strain angle**

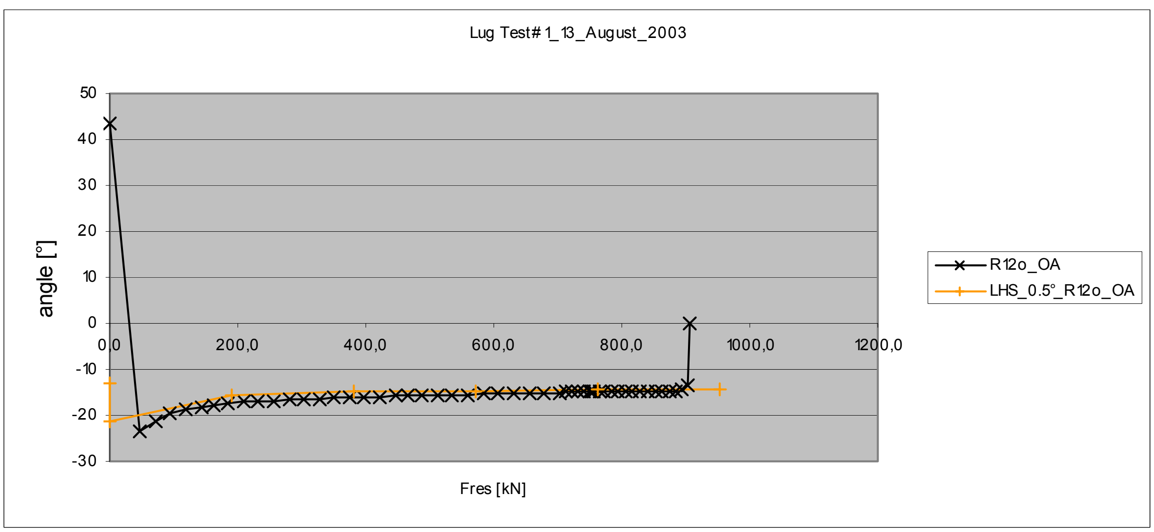


Diagram 8.7 **E22 unidirectional strain**

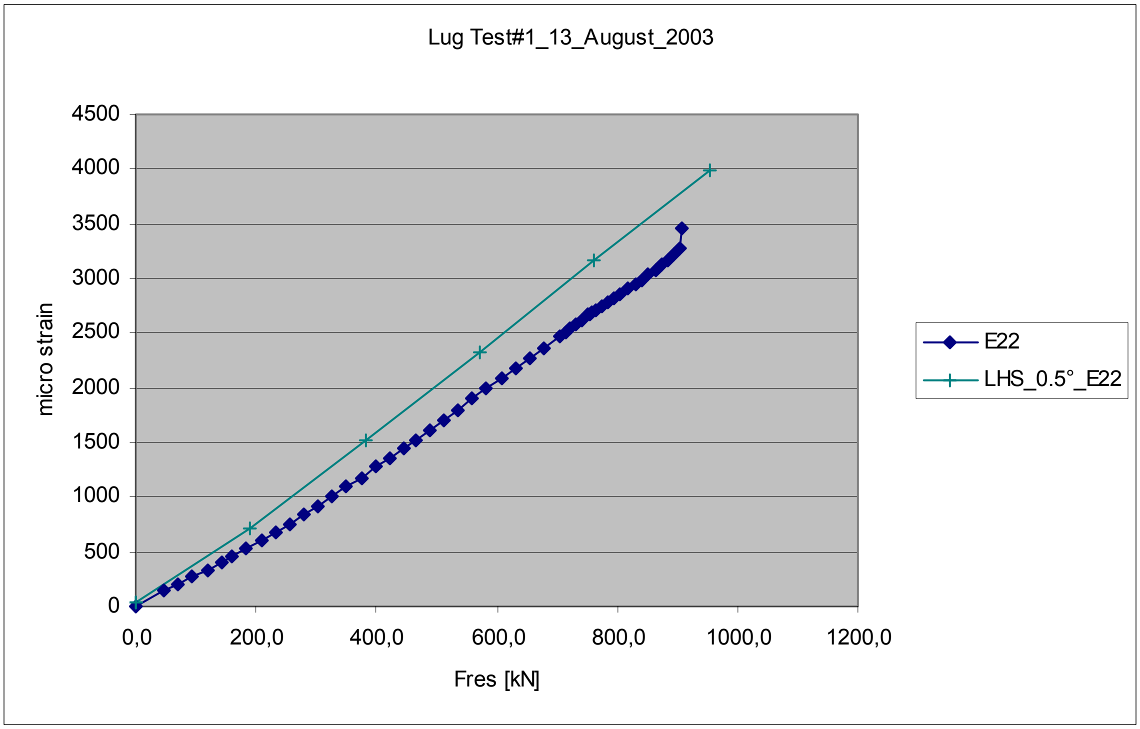
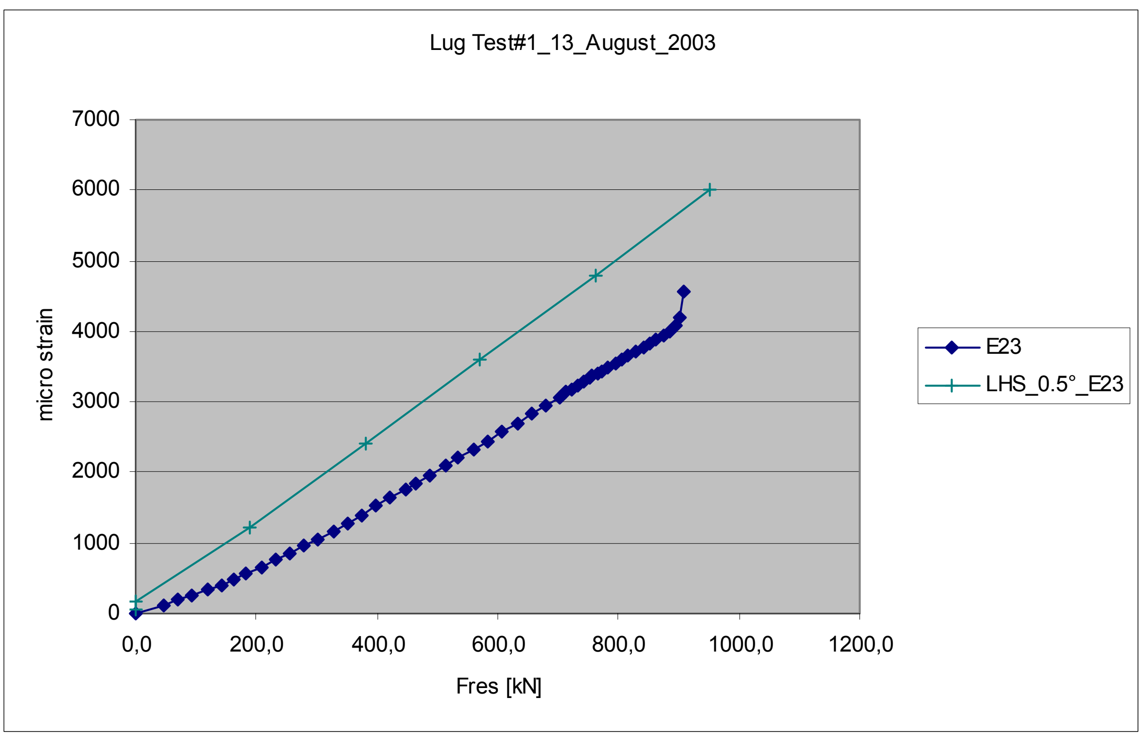


Diagram 8.7 **E22 unidirectional strain**



8. Summary

The Lug Test#1 specimen ruptured at the level of the NASA load vector which was agreed on by NTSB, NASA, American Airlines and Airbus. The Airbus calculated load vector was at the same load level.

The comparison of measured and analyzed strains validates the FEA-models and the method used.

The strain level comparison between the Lug Test#1 FEA-model and the RHS FEA-model analysis with the enforced displacement boundary condition indicates that the test performed is representative of the lug behavior during the accident.

During the damage initiation the Fy-load application control commanded the shutdown caused by the change in lateral stiffness of the lug. The test arrangement (without the lateral yoke) does not allow a load redistribution and load transfer to the lateral yoke.

The damage initiation is visible by fiber cracks on the outboard surface of the lug typical for a beginning fracture in cleavage mode.