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

March 30, 2004

ADDENDUM NUMBER 16 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 Test#3 – Results Test / FEA Comparison"***

AIRBUS	**Technical Note**	

Report Nr.: TN – ESGC – 1021/04

Author:
Department.:

Title

AAL587 Airbus Structure Investigation

Lug Test#3 – Results Test / FEA Comparison

Date: 25.03.2004

Summary:

As part of the AAL587 accident investigation the RHS Rear Main Lug Test#3 was carried out under the leadership of the NTSB at the Airbus Deutschland GmbH test facility in Hamburg on the 12th of February 2004.
The Lug Test#3 specimen was a RHS Rear Main Attachment fitting which was removed from the A300-600R MSN513 VTP. The load level reached during the 1997 event and the RHS rear main lug damage detected in March 2002 indicated that in the reached configuration the fin was considered as unserviceable. In 2003 the cut out was done by American Airlines in Tulsa.
The test of this damaged main lug specimen shall demonstrate the residual strength of this lug under load conditions to which the fin of AA flight 587 has been exposed during the accident.
The loading conditions for the Lug Test#3 was the same as for Lug Test#1 and #2. The agreed NASA W375 MOD load case with a pre-adjusted Rx bolt rotation of Rx=-0.45° was used.

This report provides a comparison between the measured strain gauge values from the rear main Lug Test#3 specimen and the FE-analysis.
The test performed show consistently that the structural strength of the fin attachment lug significantly exceeded the design requirements.

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1. Introduction

The test specimens for Lug Test#2 and #3 are parts of the VTP from MSN513. The load level reached during the 1997 event and the RHS rear main lug damage detected in March 2002 indicated that in the reached configuration the fin was considered as un-serviceable.

The LHS and RHS rear main lug, including the side skin panel, rib1 to 5 were removed from this VTP for test purposes (see figure 1.1). The cut out of the LHS and RHS test specimen was done by American Airlines in Tulsa. An Airbus specialist assisted the cut out process. The specimen were shipped to Airbus Hamburg and an incoming inspection was done.

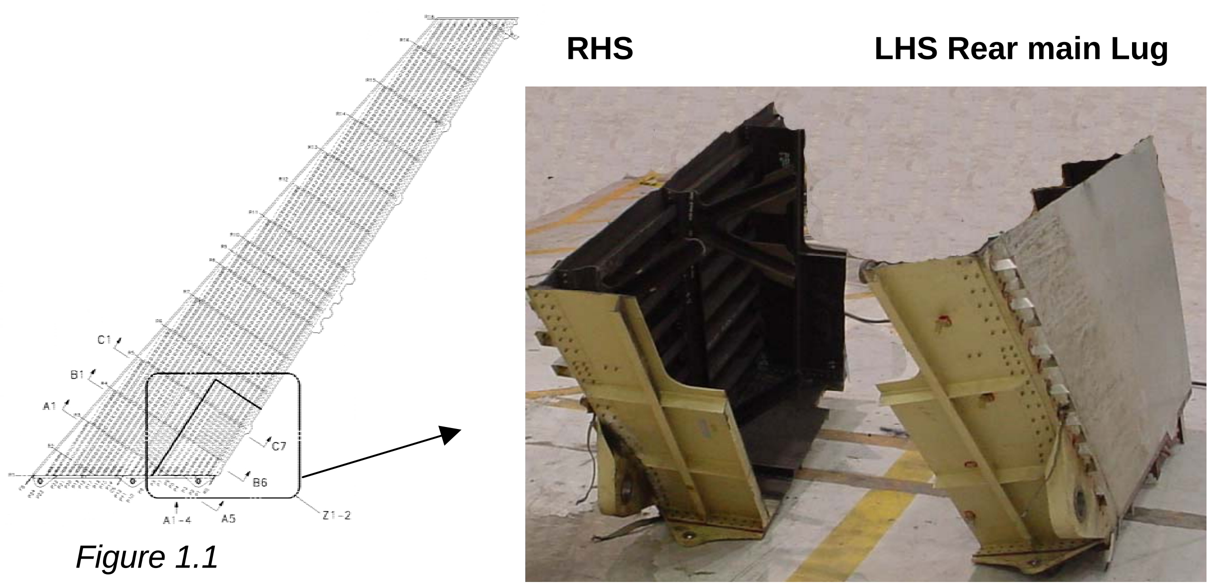


Figure 1.1

The incoming inspection showed, that the part had new or increased defects as compared to the inspection made in March 2002.

As of today the origin of these differences are not explained and therefore the test should not be considered reflecting the standard behavior of the lugs.

As part of the AAL587 accident investigation the LHS rear main Lug Test#3 was carried out under the leadership of the NTSB at the Airbus Deutschland GmbH test facility in Hamburg on the 12th of February 2004.

The loading conditions for the Lug Test#3 (same as for the Lug Test#1 and #2) 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#2 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.

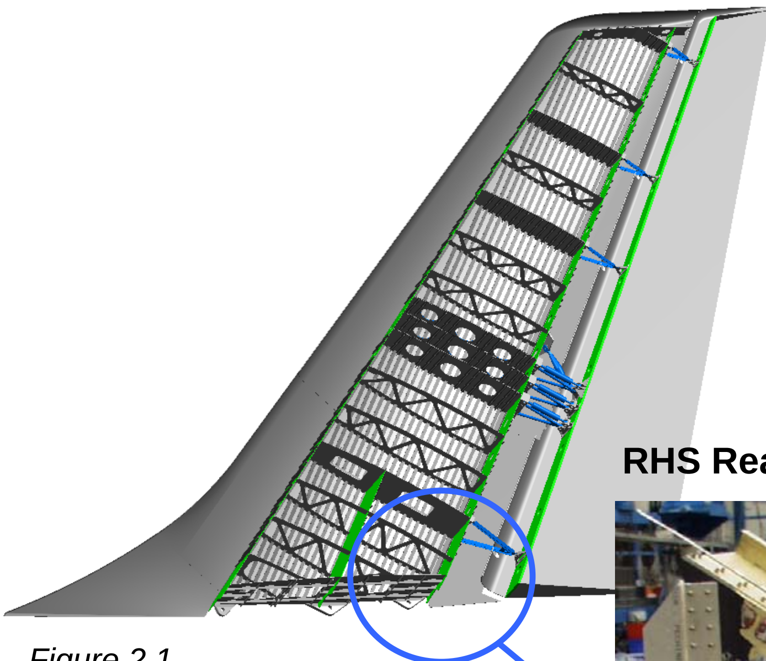
The measured strain values of the rear main Lug Test#3 specimen are compared to

- RHS ANSYS 3D contact model
- RHS ANSYS 3D contact Lug Test#3 model Rx=0.45°

All the ANSYS FEA-models include a 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 RHS ANSYS contact Lug Test#3 model represents the reinforced and modified test specimen and includes the test rig load introduction and test specimen support.

2. RHS Rear Main Lug Test#3 specimen from MSN513 VTP

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



A300-600R Vertical Stabilizer

Figure 2.1

RHS Rear Main Lug Test#3 specimen

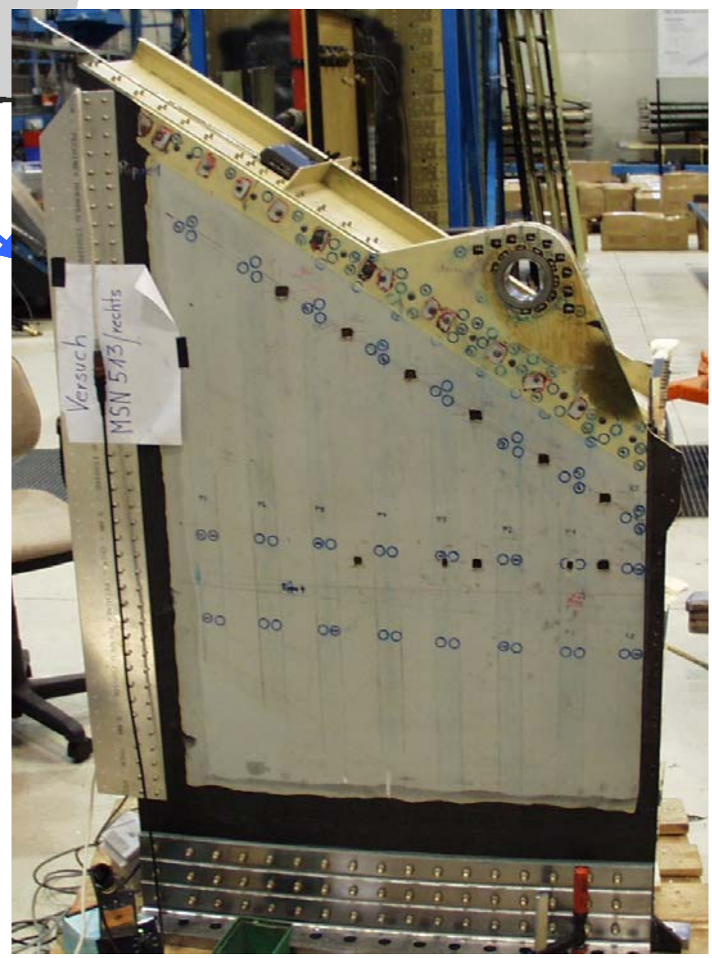


Figure 2.2

2.1 Comparison of the test specimen dimension between Lug Test#1 and #2/3

The following figures 2.3 to 2.7 show the different dimensions between the test specimen of Lug Test#1 and #2/3.

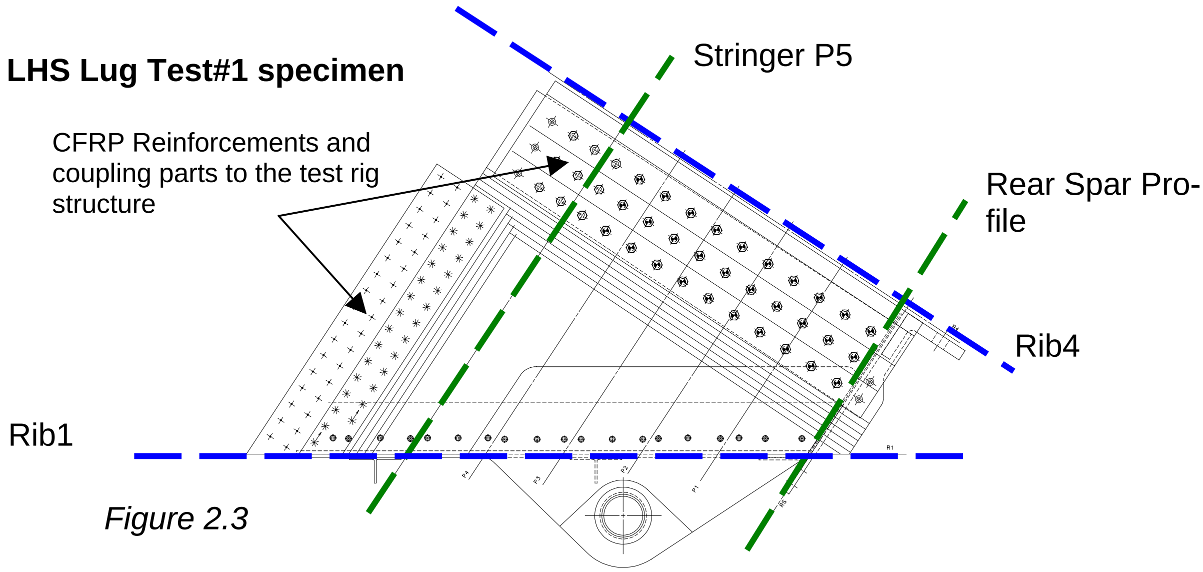


Figure 2.3

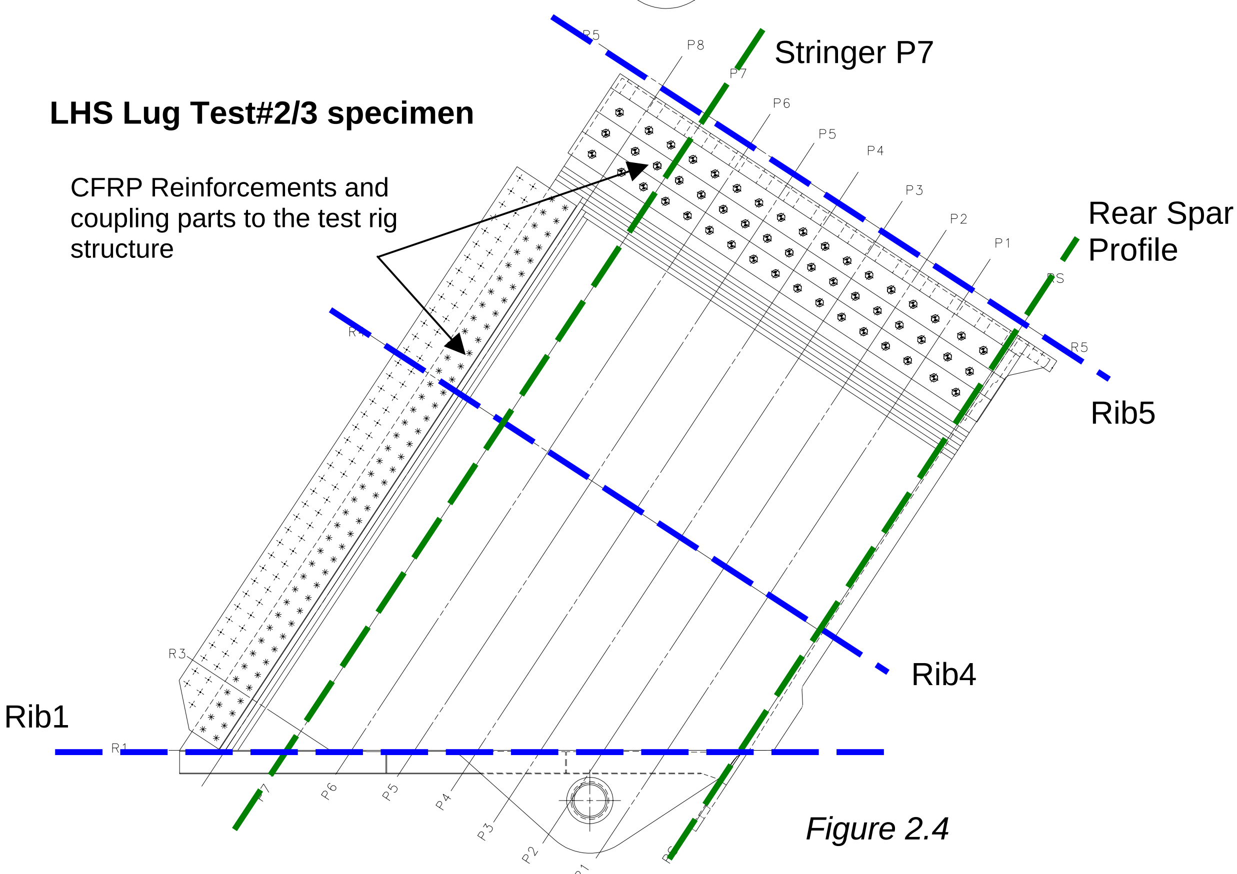
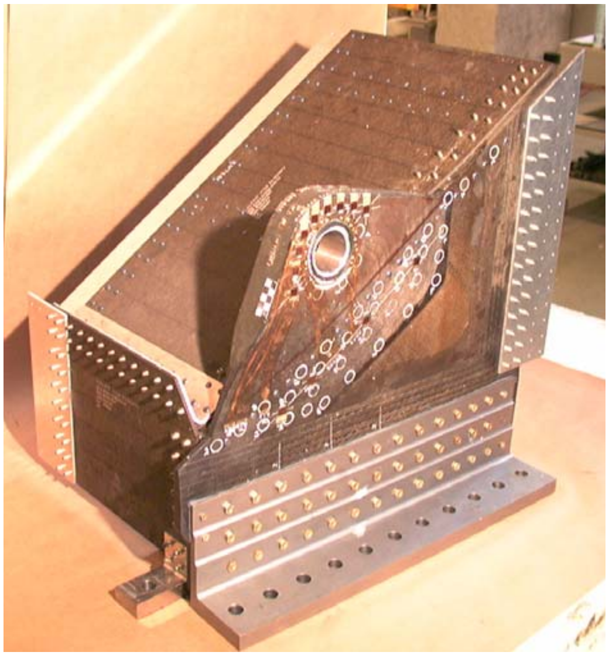


Figure 2.4



LHS Lug Test#1 specimen

Figure 2.5

LHS Lug Test#2 specimen

Figure 2.6

RHS Lug Test#3 specimen

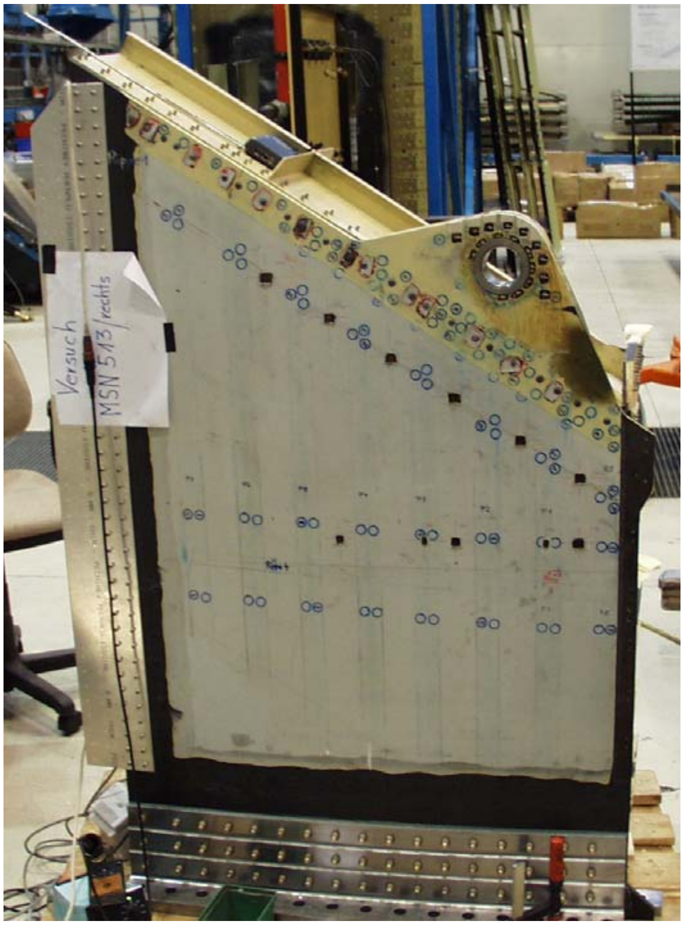


Figure 2.7

2.2 NDI Inspection results for the RHS Lug Test#3 specimen

The incoming inspection for the RHS Lug Test#3 specimen showed, that the test specimen had increased defects compared to the inspection made in March 2002 (see figure 2.8 and 2.9).

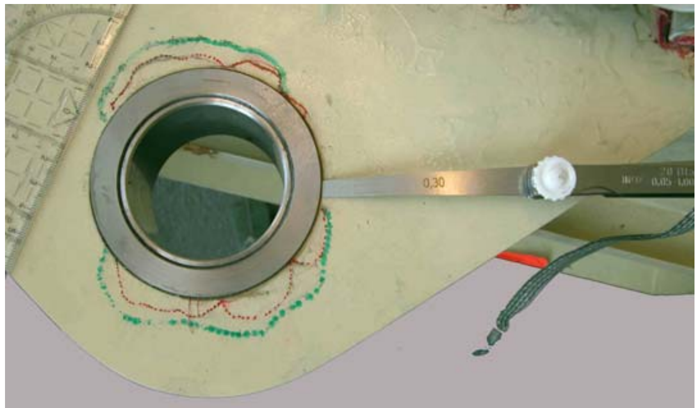
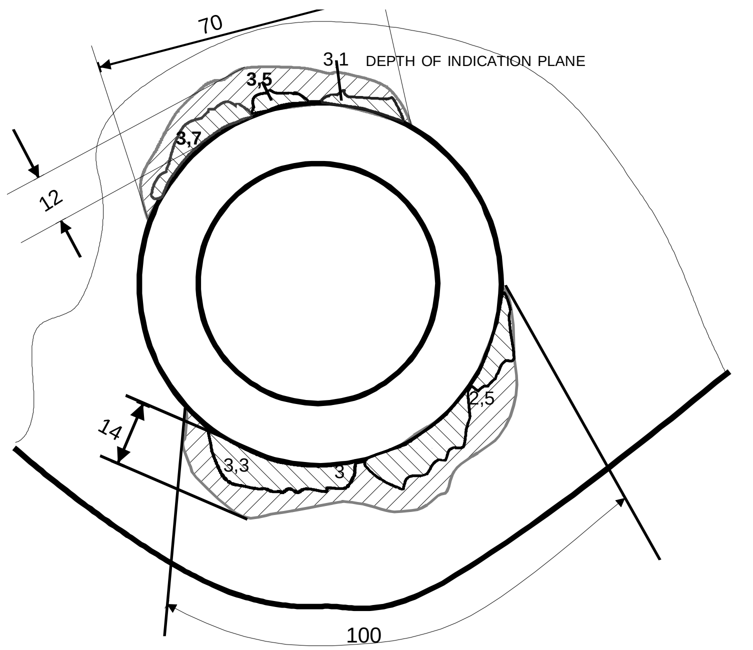


Figure 2.8



Area of the Delamination at the inspection of the MSN 513 at AA in Tulsa

Area of the Delaminations and cracks at the incoming inspection of the cut out in the structure test departmen

Figure 2.9 *RHS rear main lug outboard view with the delamination around the bushing*

2.3 FEA-model and Lug Test#3 overview

Figure 2.10 to figure 2.13 show two different FEA-models, which are compared with the Lug Test#3 specimen test (see figure 2.14 and 2.15) results.

RHS ANSYS 3D contact model (Global /Local model)

The general description of the RHS ANSYS 3D contact model can be found in the report TN – ESGC - 1018/03. For the comparison with the Lug Test#2 described in this report the RHS ANSYS model was modified at two points:

- the area of the fuselage structure was increased for the application of the boundary displacement
- The advanced connection bolt idealization described in chapter 2.5 was also used for the RHS ANSYS model

Loading Condition:

W375 boundary displacements conditions from global 2D FEA-model with embedded LHS and RHS 3D models.

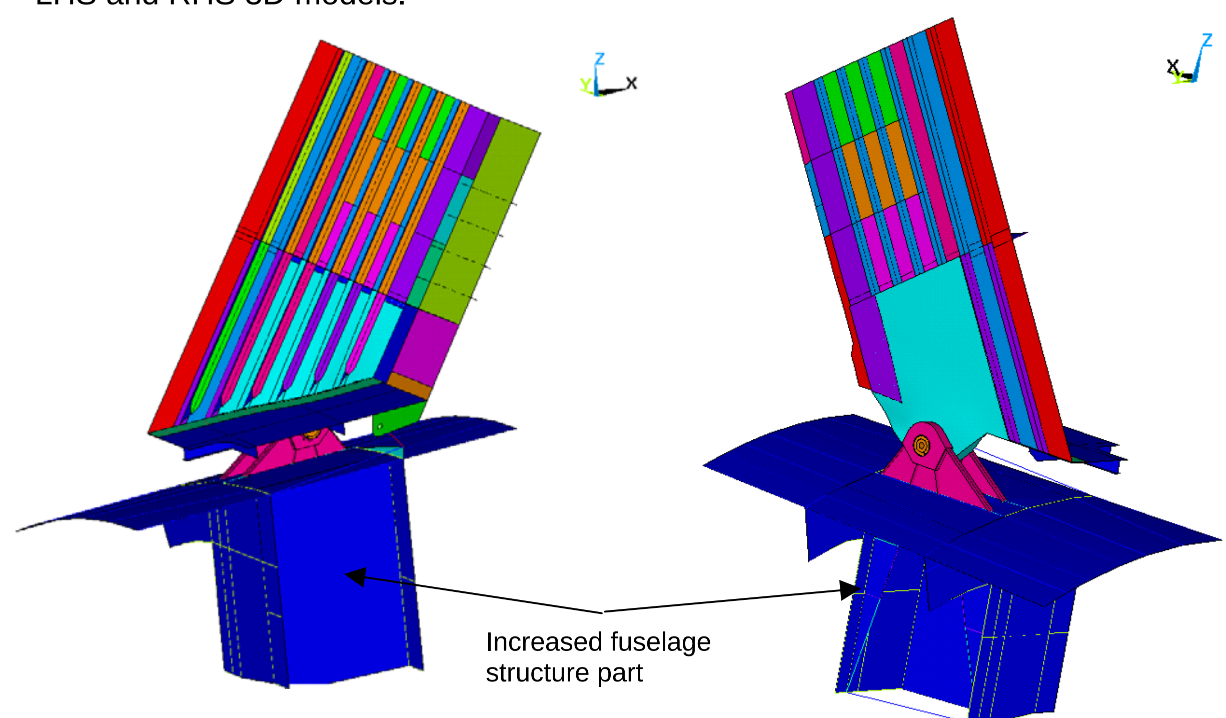


Figure 2.10

RHS ANSYS 3D contact Lug Test#3 model

The general description of the LHS ANSYS contact Lug Test#1 FEA model can be found in report TN – ESGC - 1020/03 and is still valid for the Lug Test#3 model. The RHS Lug Test#3 model was adapted and modified:

- Mirrored LHS Lug Test#2 model is the basis for the RHS Lug Test#3 model
- to the dimension of the larger specimen up to rib 5 (see figure 2.11) and the new connection bolt idealization (chapter 2.7)
- to the new support structure (see figure 2.11)
- the test rig load introduction (Z1/2 main rod bearing point aligned to the bolt axis)
- and implementation of the complete test rig structure in the ANSYS model (see figure 2.13)

Loading Condition:

NASA W375 MOD load vector

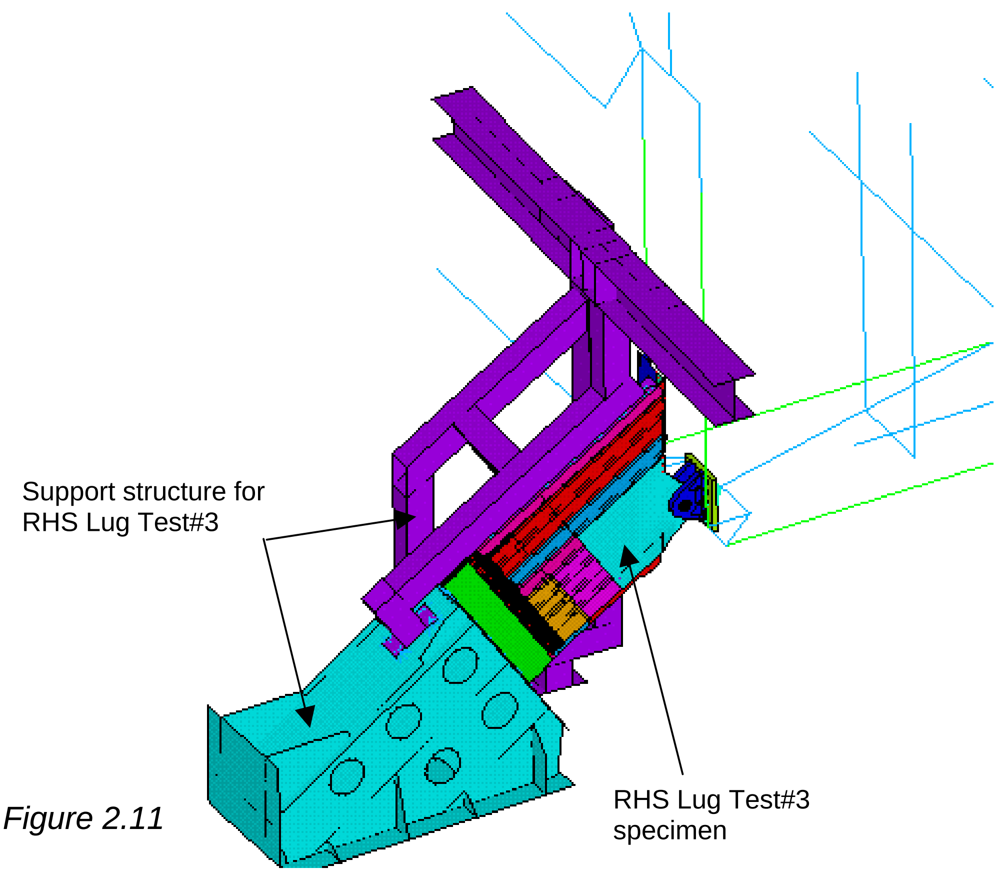


Figure 2.11

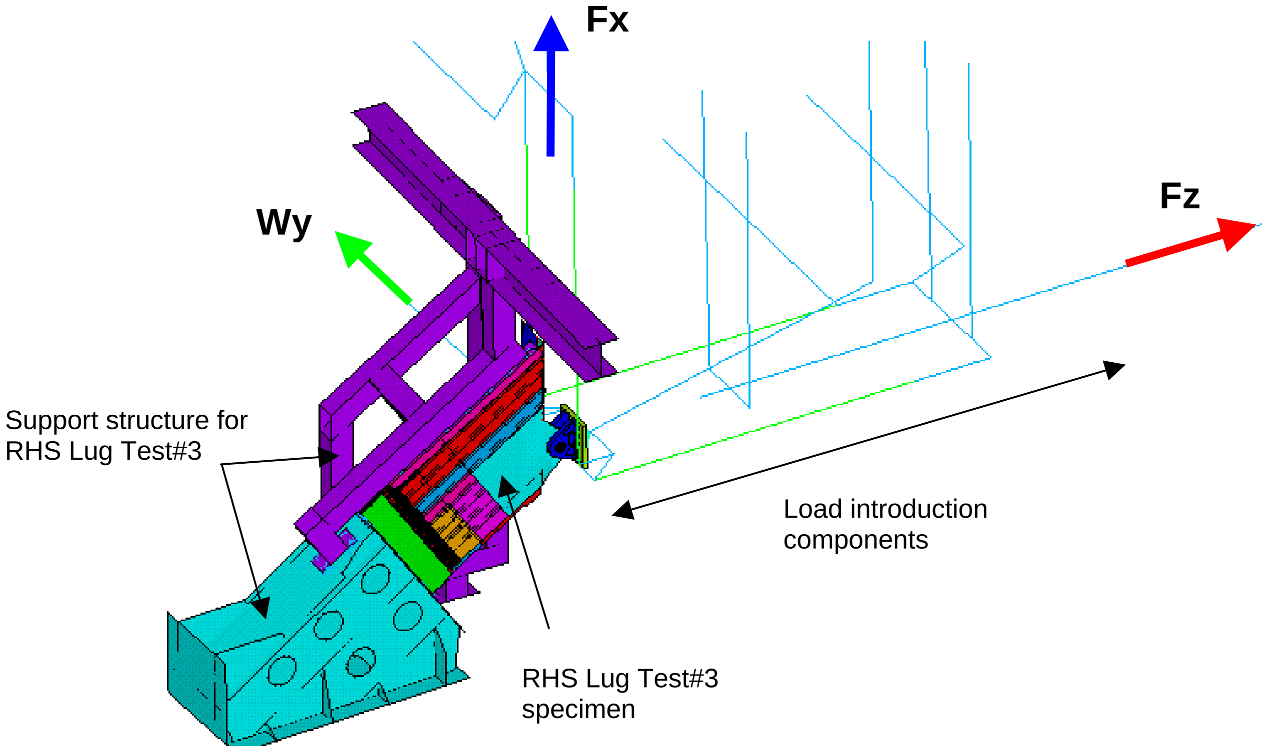
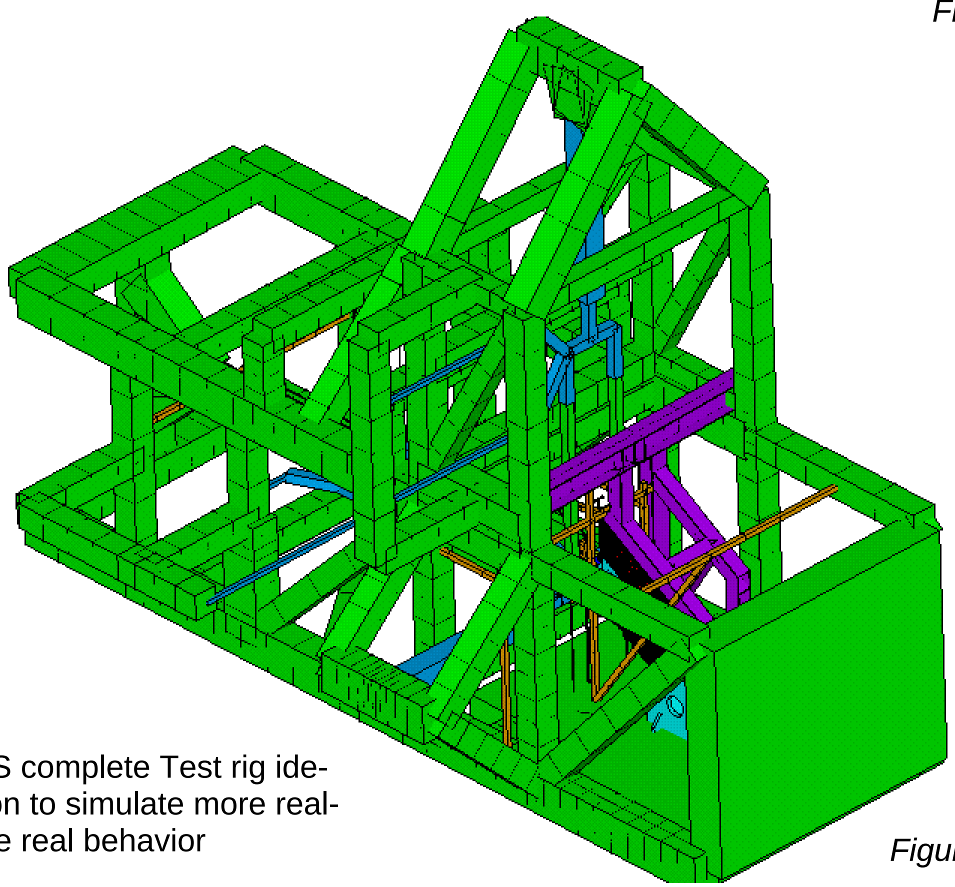


Figure 2.12



ANSYS complete Test rig idealization to simulate more realistic the real behavior

Figure 2.13

Lug Test#3 specimen

Lug Test#2/3 is described in the test requirement 32 X 029 K4 805 P34.

Loading Condition:

NASA W375 MOD load vector

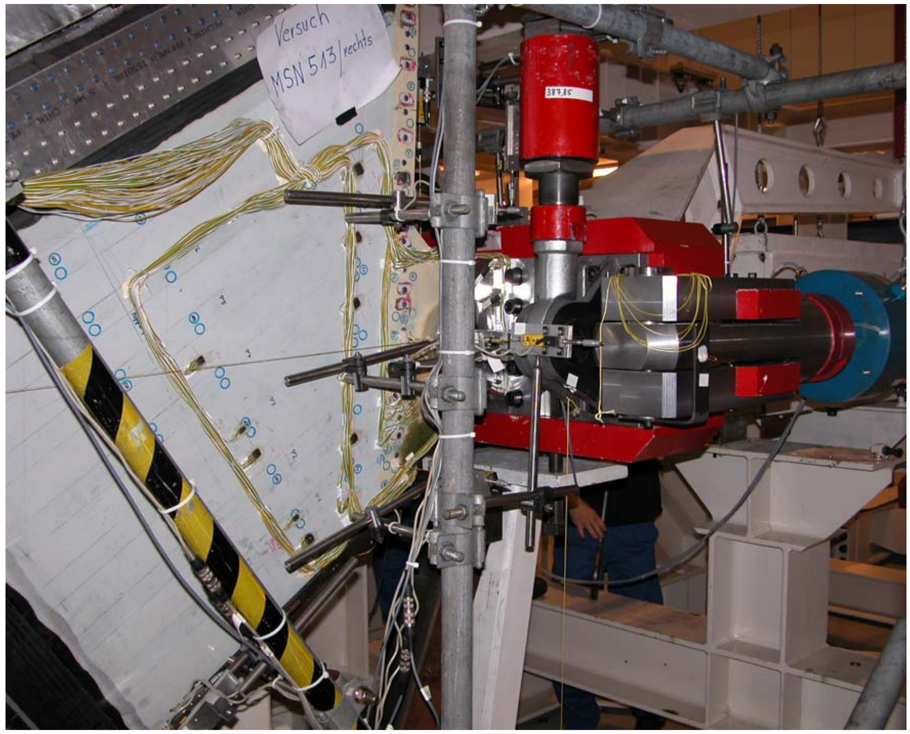


Figure 2.14

Figure 2.15

2.4. Description of the test rig

2.4.1 Global view

Figure 2.16 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.

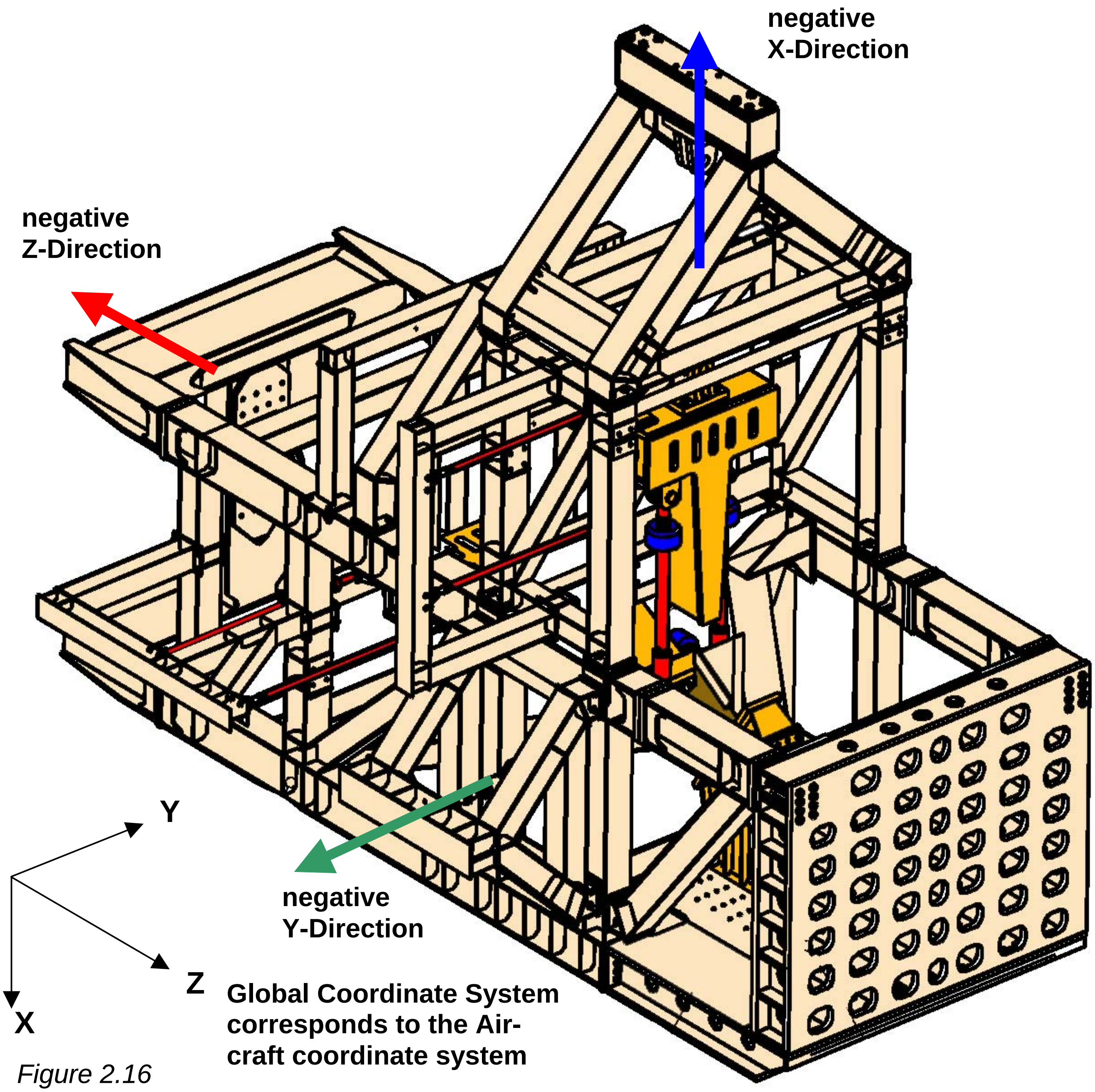


Figure 2.16

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

The figure 2.15 shows the load introduction components of the test rig and the location of the Lug Test#2/3 specimen itself. The test rig supporting structure is the same for RHS Lug Test#3 specimen.

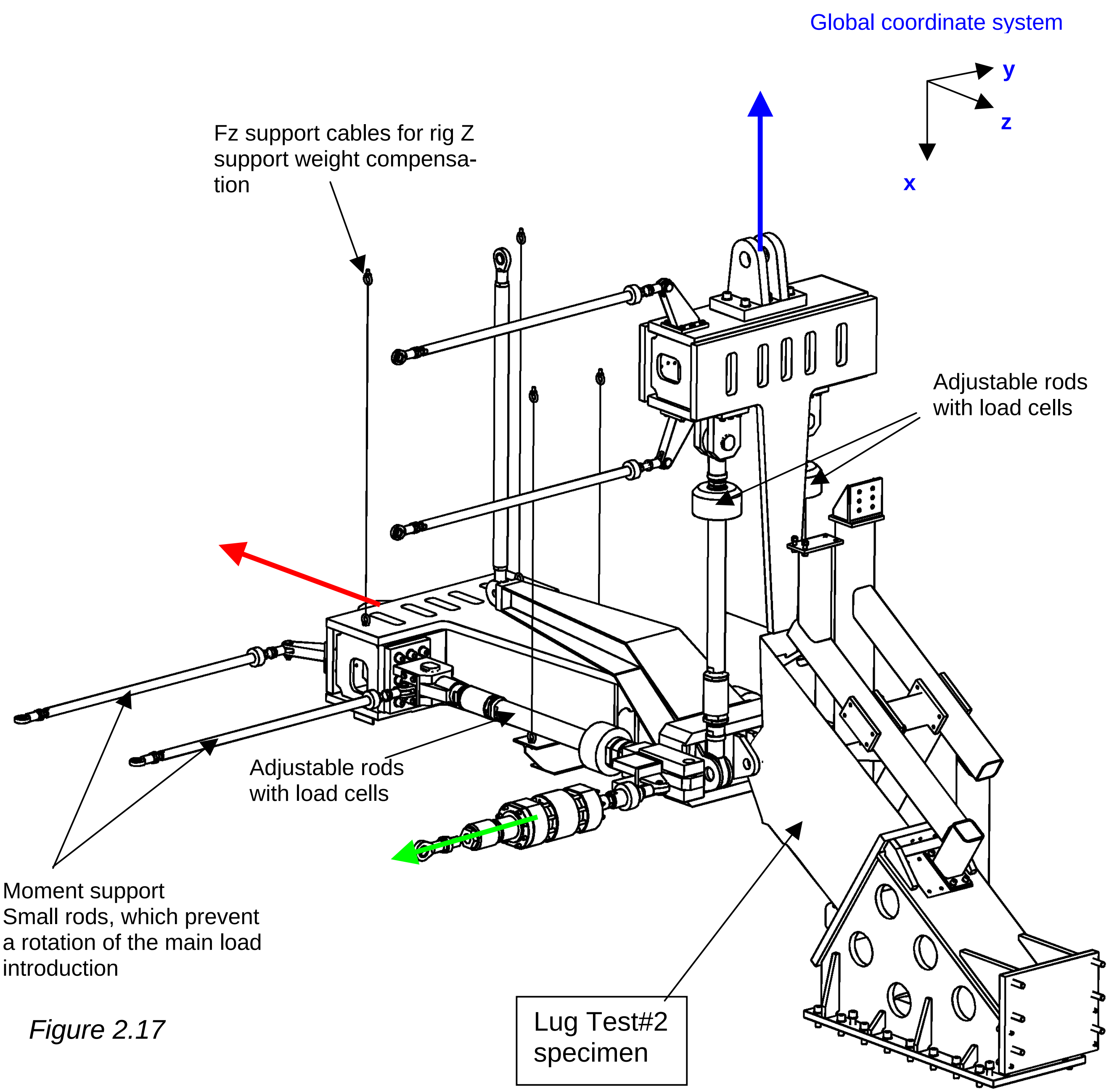


Figure 2.17

2.4.3 Test rig sign convention for local lug reaction moments

The sign convention for the local lug reaction moments are illustrated in figure 2.18.

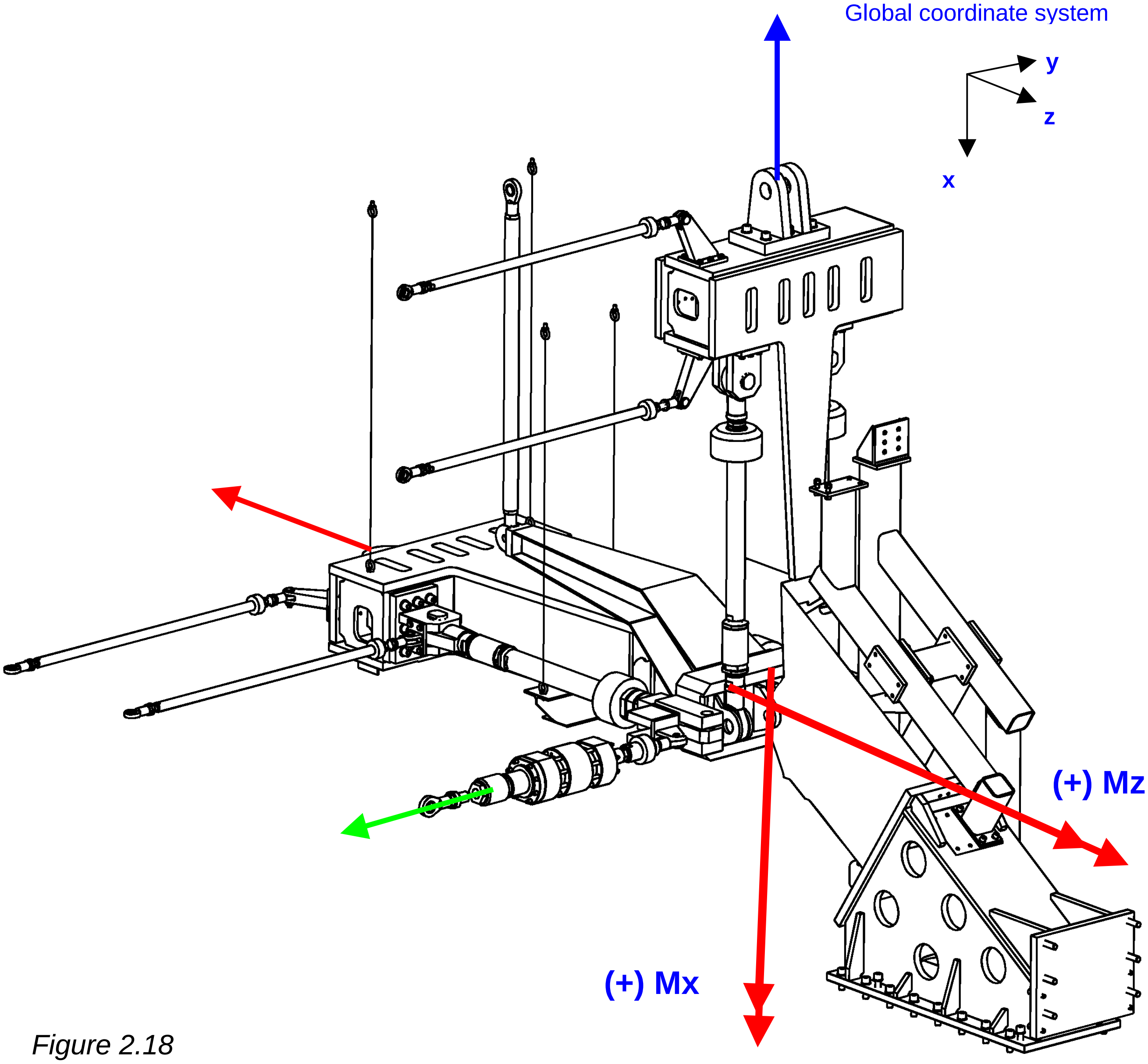


Figure 2.18

2.4.4 Test rig modification for Lug Test#2/3

The principle design and functioning of the test rig load introduction remain unchanged. For the Lug Test#2 Airbus has decided to align the main rods Z1 and Z2 bearing points with the test specimen connection bolt axis. In the first Lug Test#1 the bearing points have had an offset to the bolt axis of 245mm. Figure 2.19 show a section cut through the Z-load introduction YZ-plane.

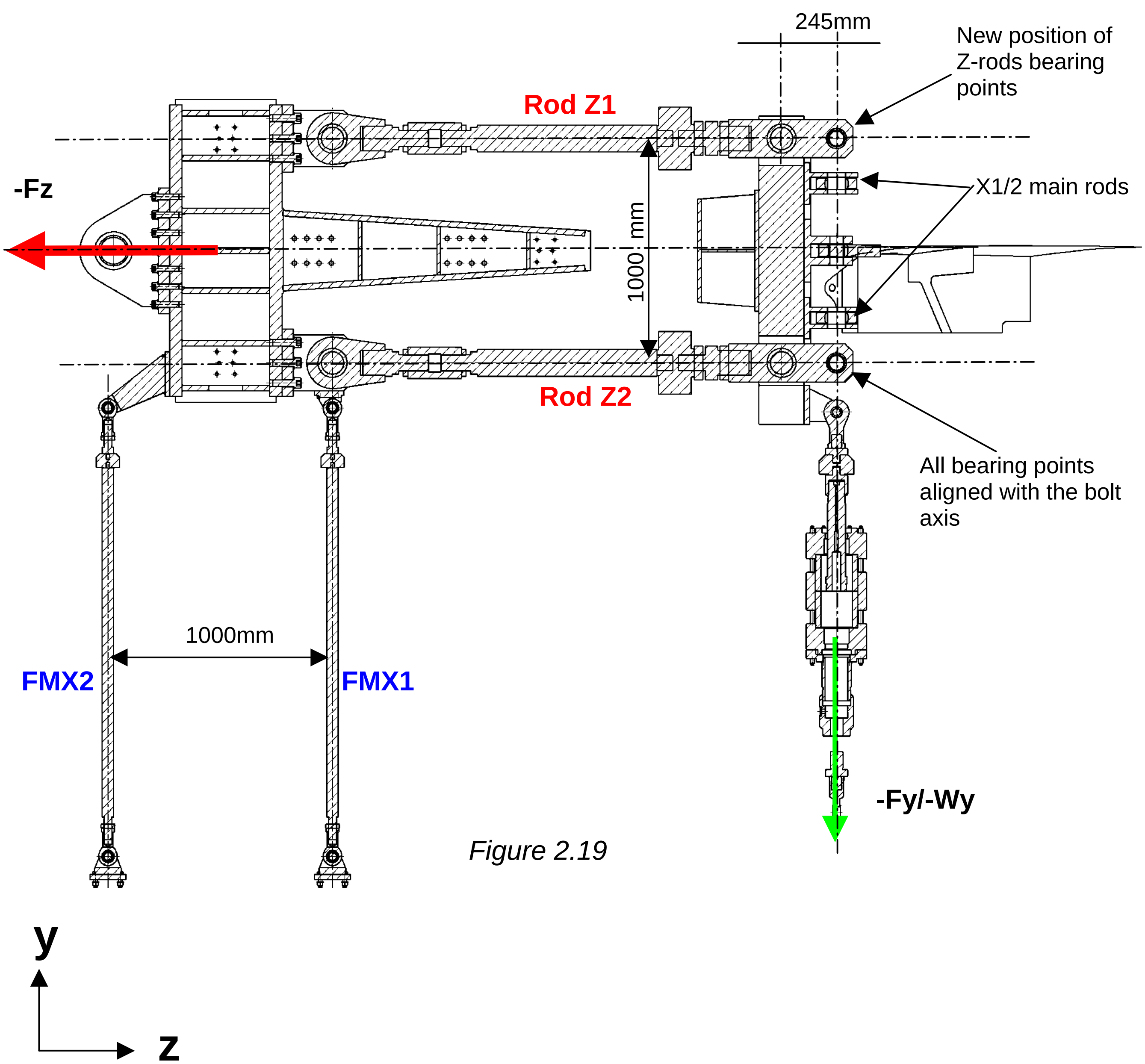


Figure 2.19

2.5 Lug Test#2/3 local lug moment Mx and Mz Equations

With the experience of Lug Test#1 and taking into account the modified load introduction, the local lug moment calculation was reduced to two simple equations (see figure 2.20).

$$Mx = (Z2 - Z1)kN \cdot 500mm = Nm$$
$$Mz = (X2 - X1)kN \cdot 300mm = Nm$$

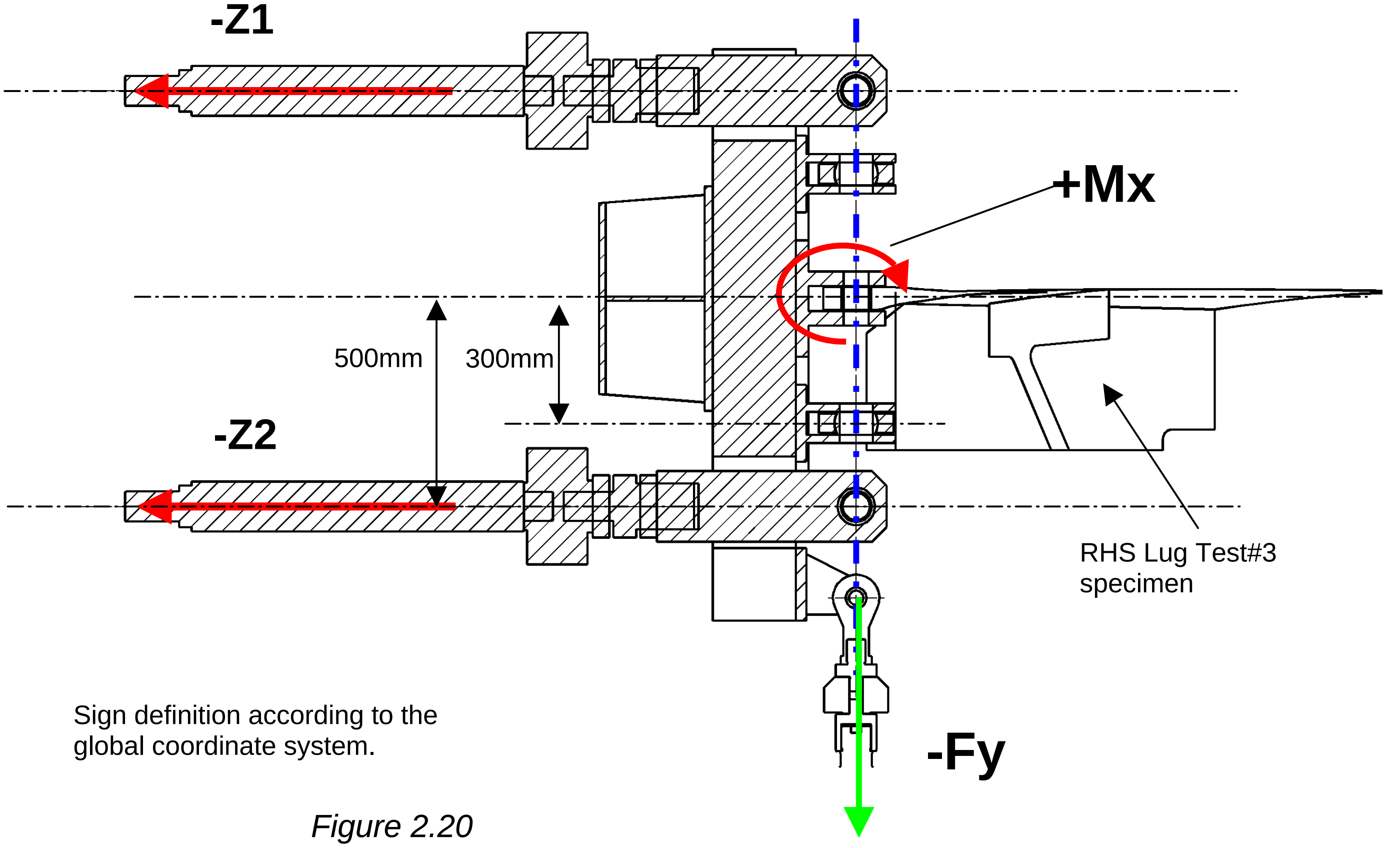


Figure 2.20

2.6 ANSYS Lug Test#1 ,#2 and#3 FEA-model lug reaction calculation method

The local lug reactions are calculated for every load step at a cross section through the fuselage clevis (see figure 2.21 and 2.22) with a summation of the grid point force balance (GPFB) according to the deformed reference point in the bolt axis. With these information the local lug moment Mx and Mz are calculated.

For the ANSYS test specimen calculations the GPFP-method is used and also the method described in chapter 2.5 taking into account the measured main rod forces.

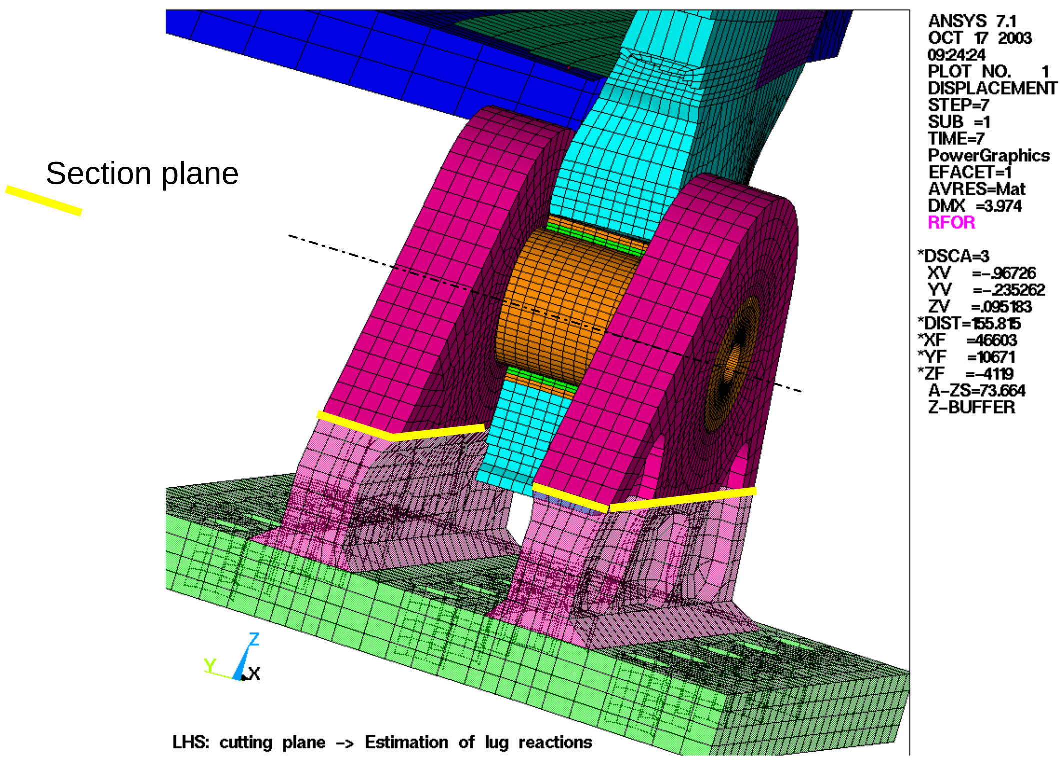
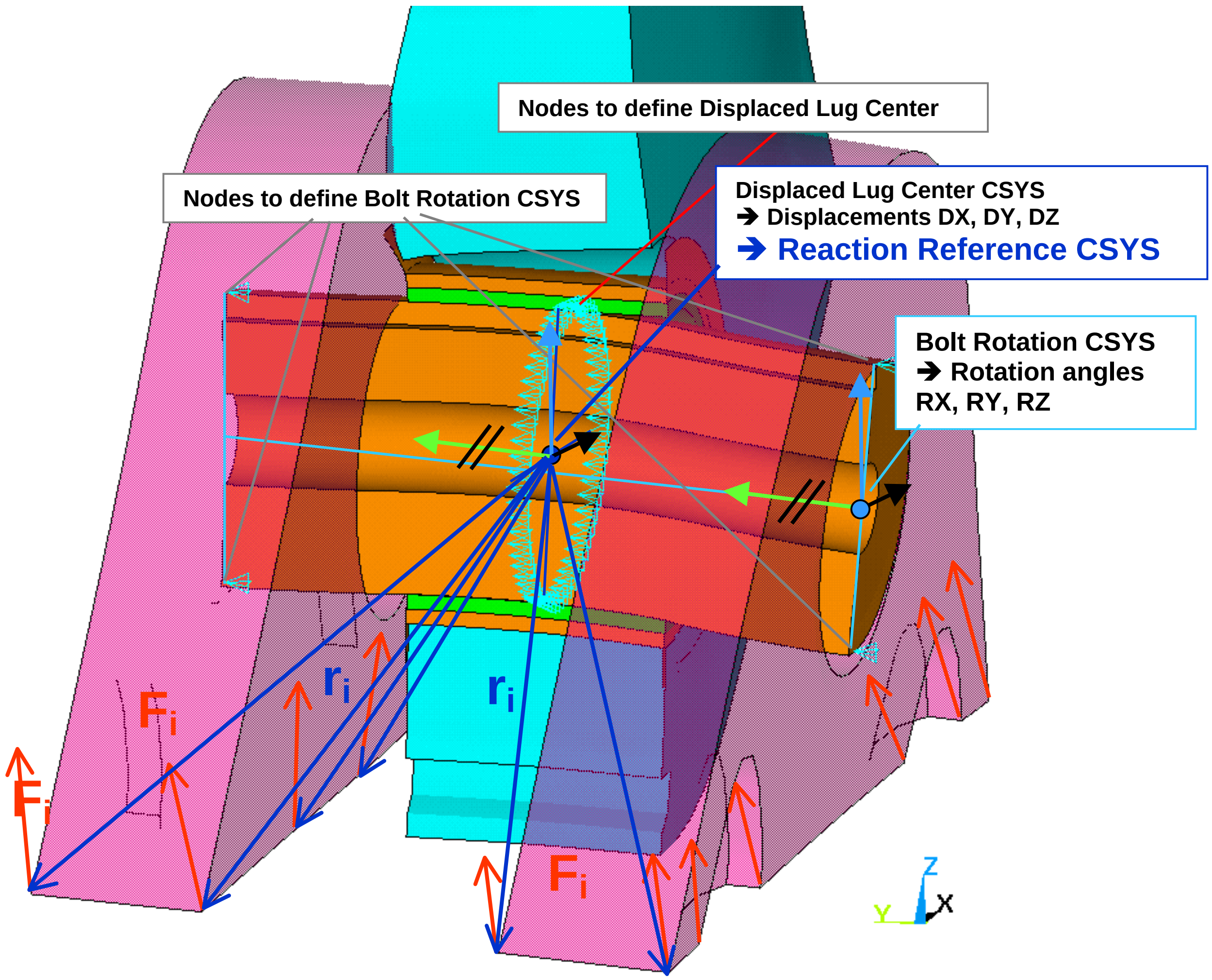


Figure 2.21

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 2.22

2.7 ANSYS detailed connection bolt idealization

For the Lug Test#1 calculations the connection bolt was idealized as a cylindrical bolt with four contact surfaces and a friction coefficient of 0.3. Detailed description see report TN-ESGC-1020/03.
Airbus decided for the Lug Test#2/3 to improve the connection bolt idealization in the ANSYS models.
The optimised connection bolt idealization includes

- a tapered bolt with a nut
- a slotted sleeve, both are pre-stressed with a friction coefficient of 0.05
- a cone bushing in the CFRP lug
- all parts with separate contact surfaces with a friction coefficient of 0.3

The detailed connection bolt idealization is implemented in the ANSYS Lug Test#2/3 and the RHS Global/Local model. Compared to the cylindrical bolt idealization, the detailed connection bolt shows only negligible influence on the Fx-, Fy- and Fz-forces but a significant reduction in the local lug moments.
The following figures 2.23 to 2.26 explain the details of the connection bolt idealization.

Bushing with cone idealization

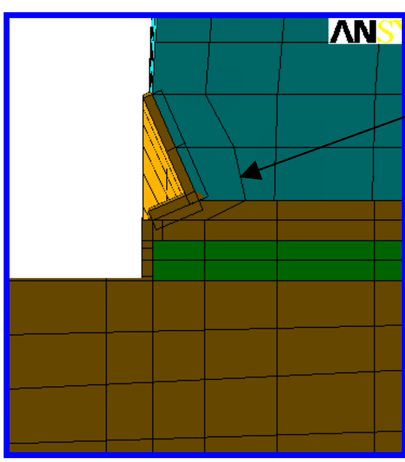


Figure 2.23

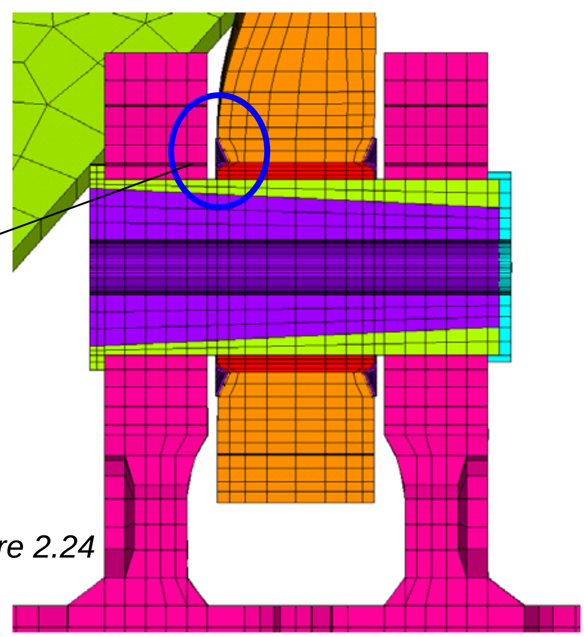


Figure 2.24

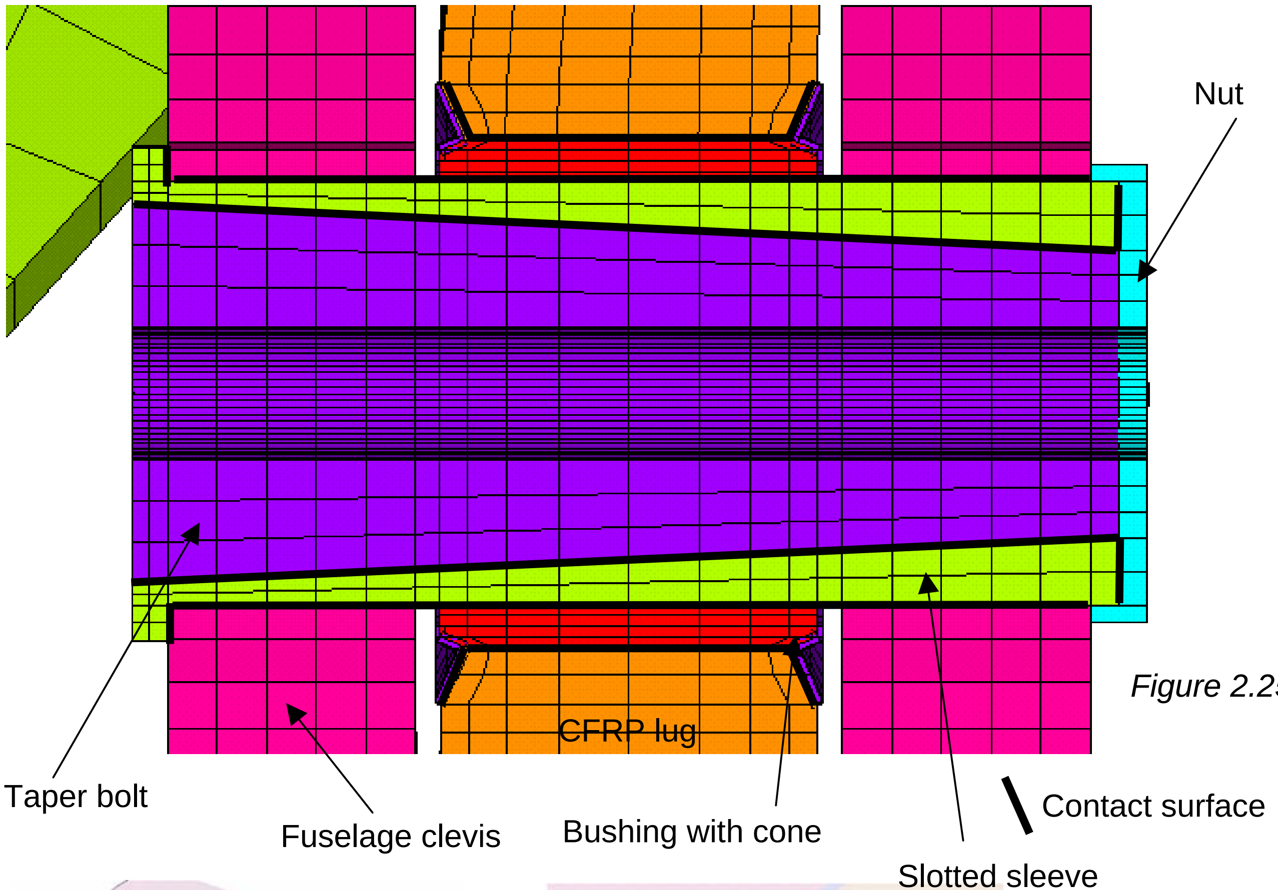


Figure 2.25

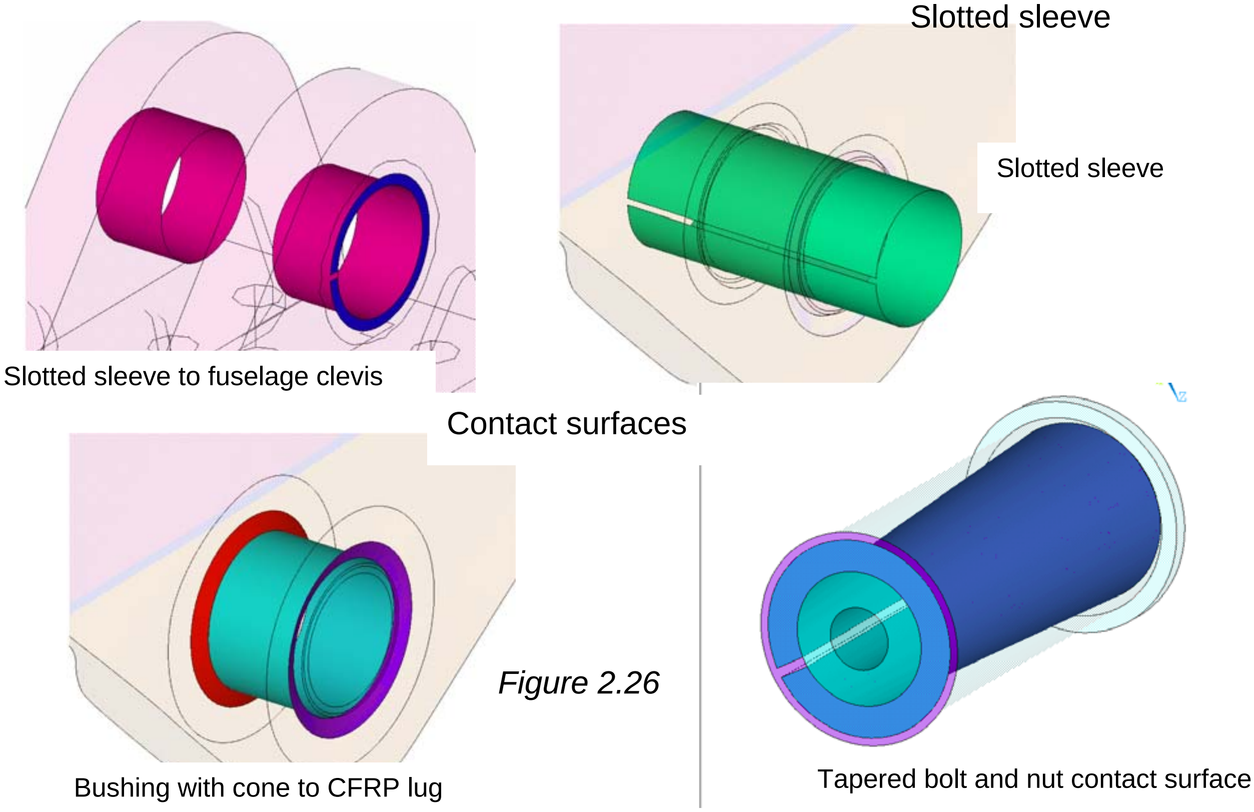


Figure 2.26

3. FE-Analysis for comparison with the test

The following FEA-models are used for the comparison between FEA-results and the RHS Lug Test#3:

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. RHS ANSYS Lug Test#3 nonlinear contact model with pre-adjusted bolt rotation of RX=-0.45°
III. LHS ANSYS Lug Test#2 nonlinear contact model with pre-adjusted bolt rotation of RX=0.45° for comparison reason

3.1 NASA W375 MOD load vector for the Lug Test#1 , #2 and #3

The load vector for the Lug Test#3 was the same as agreed for the Lug Test#1 and #2. 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.
The NASA W375 MOD load vector (see table 3.1) was used for the Lug Tests and all ANSYS test specimen FEA-analysis.

Table 3.1

NASA W375 MOD load vector for RHS specimen			
Fx	Fy	Fz	Fres
[kN]	[kN]	[kN]	[kN]
-400	42*)	-864	953

*) For RHS test specimen the sign must be changed

The bolt rotation was introduced in the test rig with the turnbuckles of the Z1 and Z2 main rods.

For the Lug Test#2/3 it was agreed by NTSB, NASA and Airbus to change the Fy lateral load introduction from force controlled to displacement controlled.
Also for the Lug Test#3 it was agreed to use a pre-adjusted local bolt rotation of Rx=-0.45°.

3.2 RHS ANSYS contact 3D model W375 MOD

The loading condition for the RHS ANSYS model is derived from the Global NASTRAN model. 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 RHS ANSYS contact Lug Test#3 NASA W375 MOD Rx=-0.45°

The ANSYS nonlinear contact model includes the following Analysis sequences:

- Pre-stressing the bolt
- Pre-adjust the bolt Rx-rotation of Rx=-0.45°
- Applying the W375 MOD load vector

The applied load vector for the RHS ANSYS Lug Test#3 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

4. RHS Lug Test#3 NASA W375 MOD Rx=-0.45° loading condition

The load vector for the RHS Lug Test#3 was the same as agreed for the Lug Test#1 and #2 with a pre-adjusted bolt rotation of Rx=-0.45°.
Also for the Lug Test#2/3 it was agreed by NTSB, NASA and Airbus to change the Fy lateral load introduction from force controlled to displacement controlled.

To change the lateral load introduction the following test procedure was carried out:

Determination of Wy-displacement vector

- Pre-adjust the bolt rotation of Rx=-0.45° with the turnbuckles of the Z1 and Z2 main rods
- Apply the force controlled (Fx,Fy and Fz) W375 MOD load vector up to Fres=400kN
- The measured lateral displacement Wy caused by the lateral force input was extrapolated linearly up to Fres=953kN
- This lateral Wy-displacement relationship was used as input for the Wy-displacement controlling.

Checking of Fy-force caused by the introduced Wy-displacement vector

- Pre-adjust the bolt rotation of Rx=-0.45° with the turnbuckles of the Z1 and Z2 main rods
- Apply the force controlled (Fx and Fz) and Wy-displacement W375 MOD load vector up to Fres=400kN
- Compare the Fy-force with the initial Fy-force input vector

Residual strength test Lug Test#3

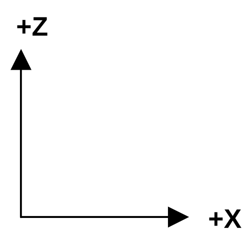
- Pre-adjust the bolt rotation of Rx=-0.45° with the turnbuckles of the Z1 and Z2 main rods
- Apply the force controlled (Fx and Fz) and Wy-displacement W375 MOD load vector up to failure

The following tables 4.1 show the applied load vector and for the NASA W375 MOD condition the max. Wy-displacement.

Table 4.1

NASA W375 MOD						
	Fx	Fy	Fz	Fres	Bolt Rx rotation	Angle Xzplane
	[kN]	[-]	[kN]	[kN]	[°]	[°]
W375-MOD	-400	42 kN ≈ +1.77mm	-864	953	-0.45	65

Wy=-1.95mm total Y-displacement



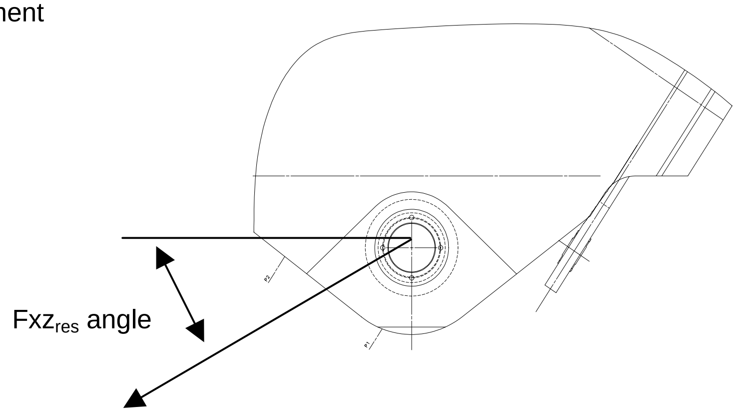


Figure 4.1

The forces were applied in the following load / displacement steps:

Table 4.2

Fx	Wy	Fz	Fres	Load step
[kN]	[mm]	[kN]	[kN]	[-]
With turnbuckles pre-adjusted Rx=-0.45°				0
0	-0.36	0	0	1
-10	-0.33	-21	23	5
-19	-0.31	-41	46	10
-29	-0.27	-62	69	15
-38	-0.23	-83	91	20
-48	-0.19	-104	114	25
-58	-0.15	-124	137	30
-67	-0.11	-145	160	35
-77	-0.07	-166	183	40
-86	-0.03	-187	206	45
-96	+0.01	-207	229	50
-106	+0.05	-228	252	55
-115	+0.08	-249	274	60
-125	+0.12	-270	297	65
-134	+0.16	-290	320	70
-144	+0.20	-311	343	75
-154	+0.24	-332	366	80
-163	+0.34	-353	389	85
-173	+0.39	-373	412	90
-182	+0.43	-394	435	95
-192	**+0.47**	**-415**	**457**	**100**
-202	+0.52	-435	480	105
-211	+0.56	-456	503	110
-221	+0.60	-477	526	115
-230	+0.65	-498	549	120
-240	+0.69	-518	572	125
-250	+0.73	-539	595	130
-259	+0.78	-560	618	135
-269	+0.82	-581	640	140
-278	+0.86	-601	663	145
-288	**+0.91**	**-622**	**686**	**150**
-400	**+1.41**	**-864**	**953**	**208**
[kN]	[mm]	[kN]	[kN]	[-]
Fx	Wy	Fz	Fres	Load step

All force values are kN

Mistake in extrapolation of the Wy displacement values. Gap of 0.1mm too large!

Limit Load Level

Ultimate Load Level

NASA W375-MOD load vector

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
R30-38	i/o	Rosette	C	B	A	Skin panel
E40-41	I/o	Unidirectional	A			Stringer P1 and P3
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**

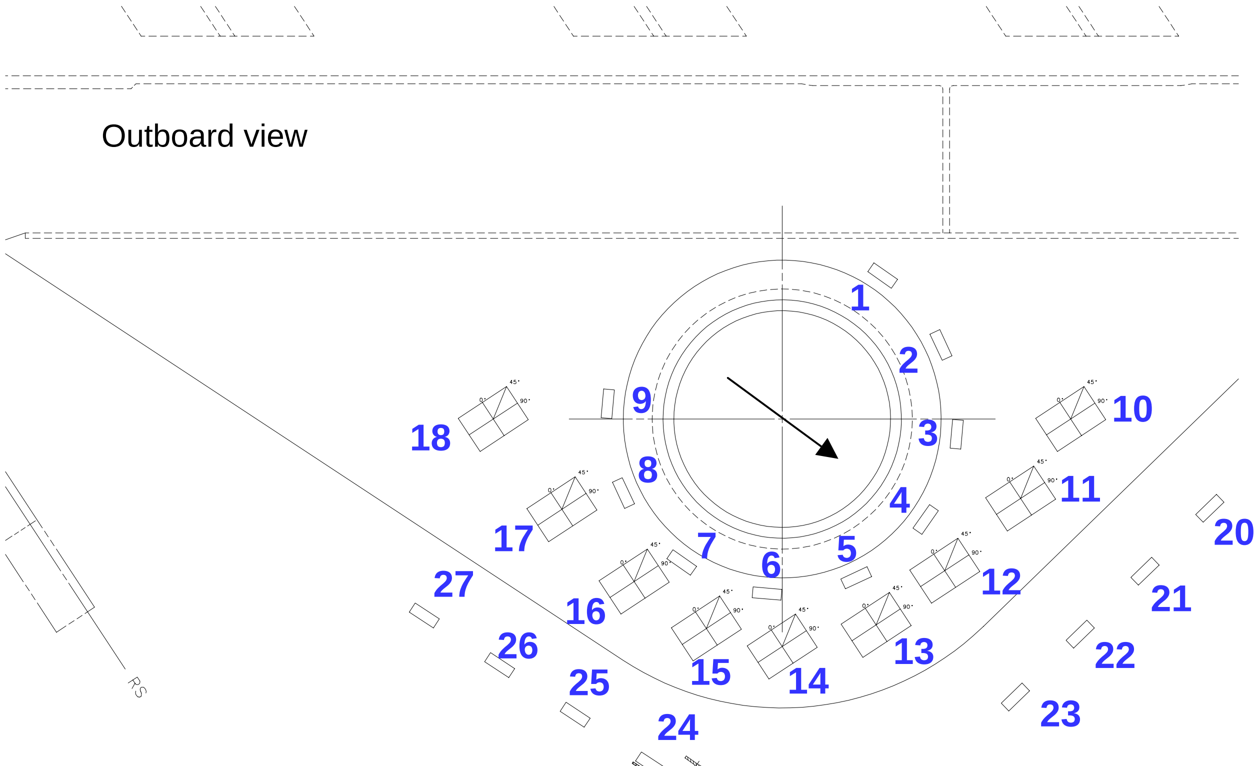
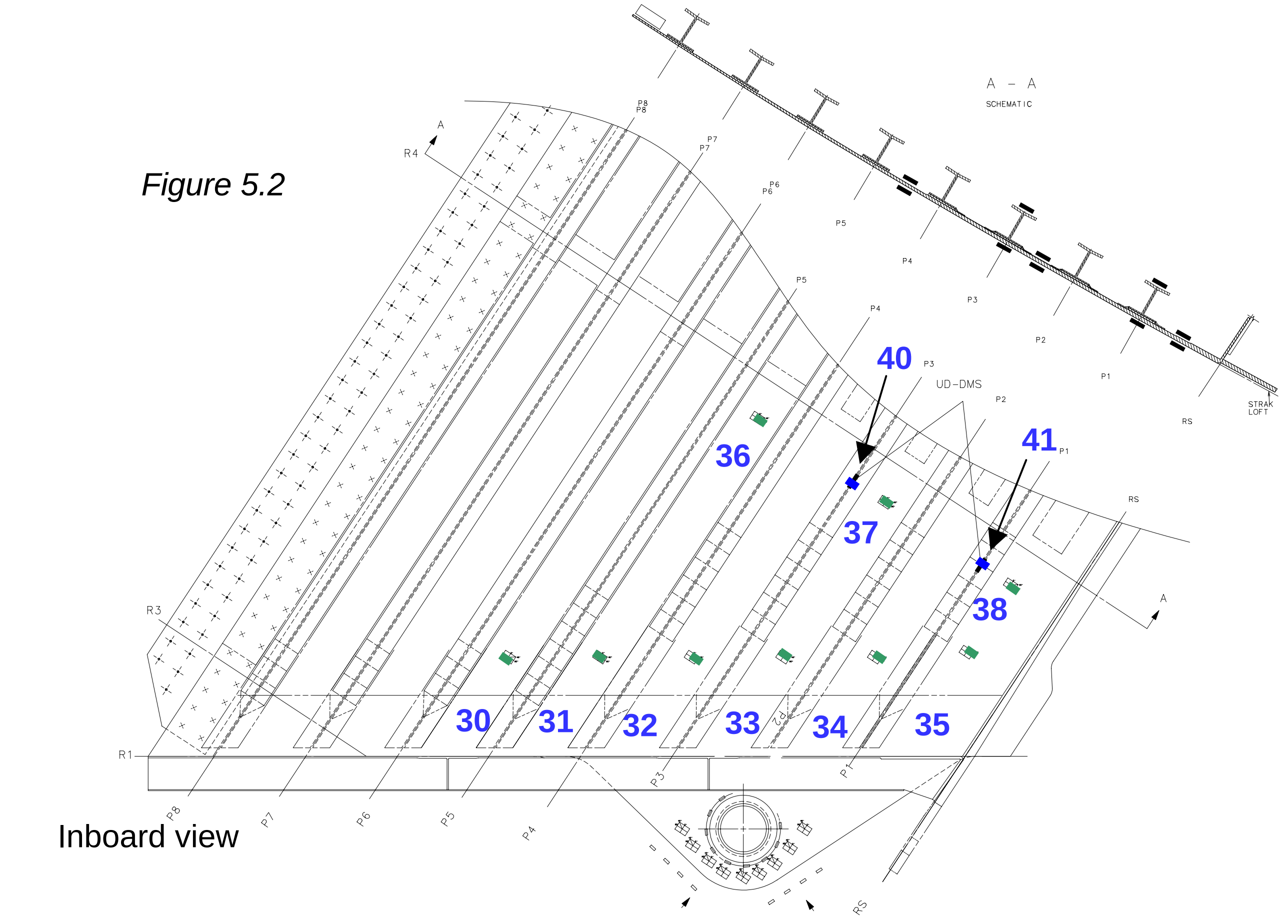


Figure 5.2



Test rig fuselage clevis strain gauge location

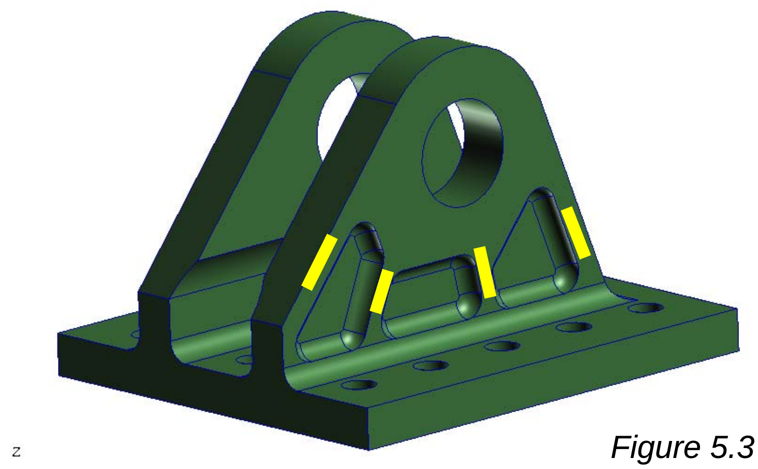


Figure 5.3

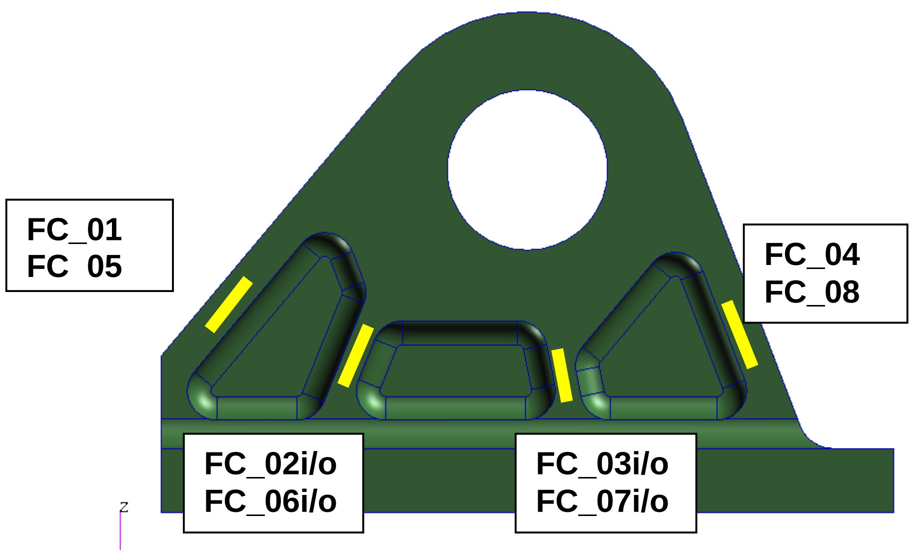


Figure 5.4

Outboard view of the test specimen Lug Test#3

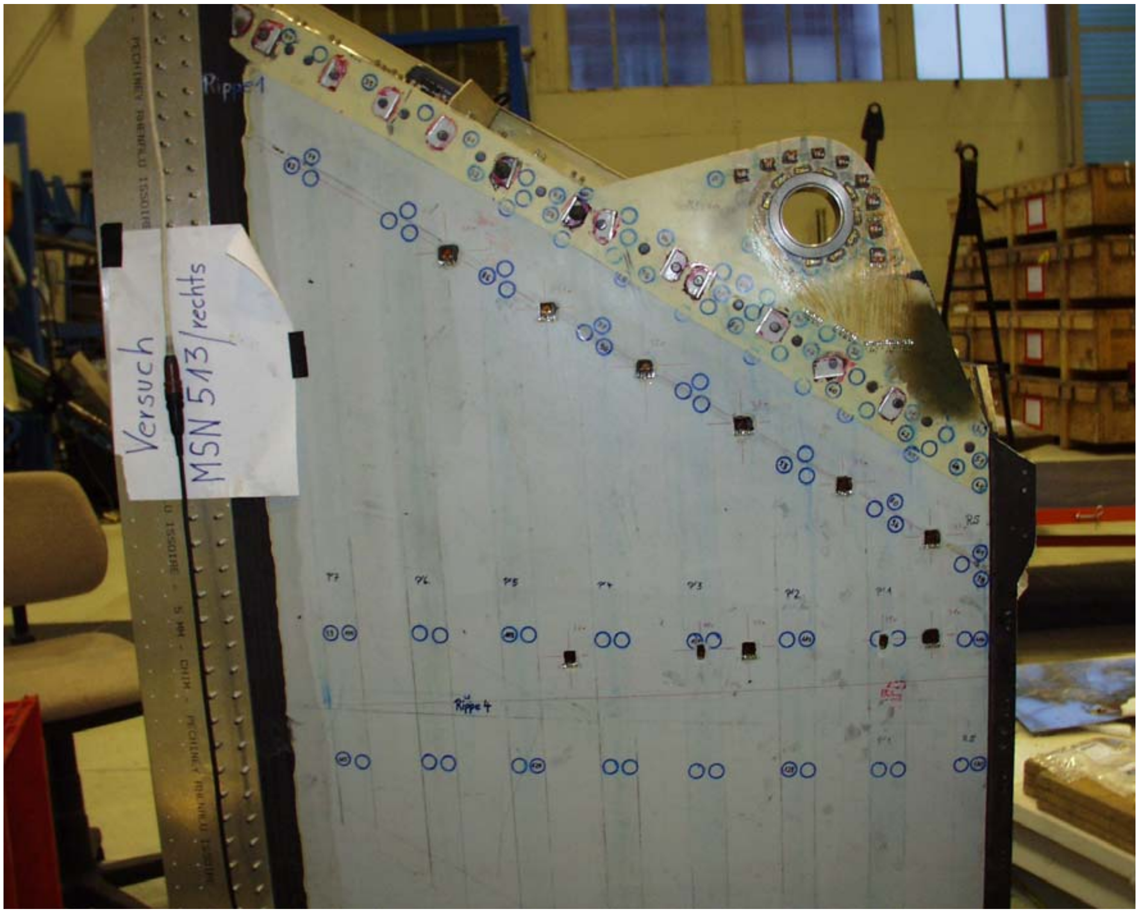


Figure 5.5

6. FEA results

6.1 RHS ANSYS contact 3D model NASA W375

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]	[°]	[°]
1	0	5	**5**	20	12	0	-0,001
-66	6	-138	**153**	-1100	179	-0,063	0,008
-127	11	-273	**302**	-2006	366	-0,132	0,018
-188	16	-411	**452**	-2865	545	-0,203	0,034
-248	22	-551	**605**	-3694	714	-0,275	0,05
-309	28	-694	**761**	-4501	876	-0,345	0,067
-371	34	-841	**919**	-5281	1032	-0,415	0,084

Rx/Rz bolt rotation in relation to rib 1

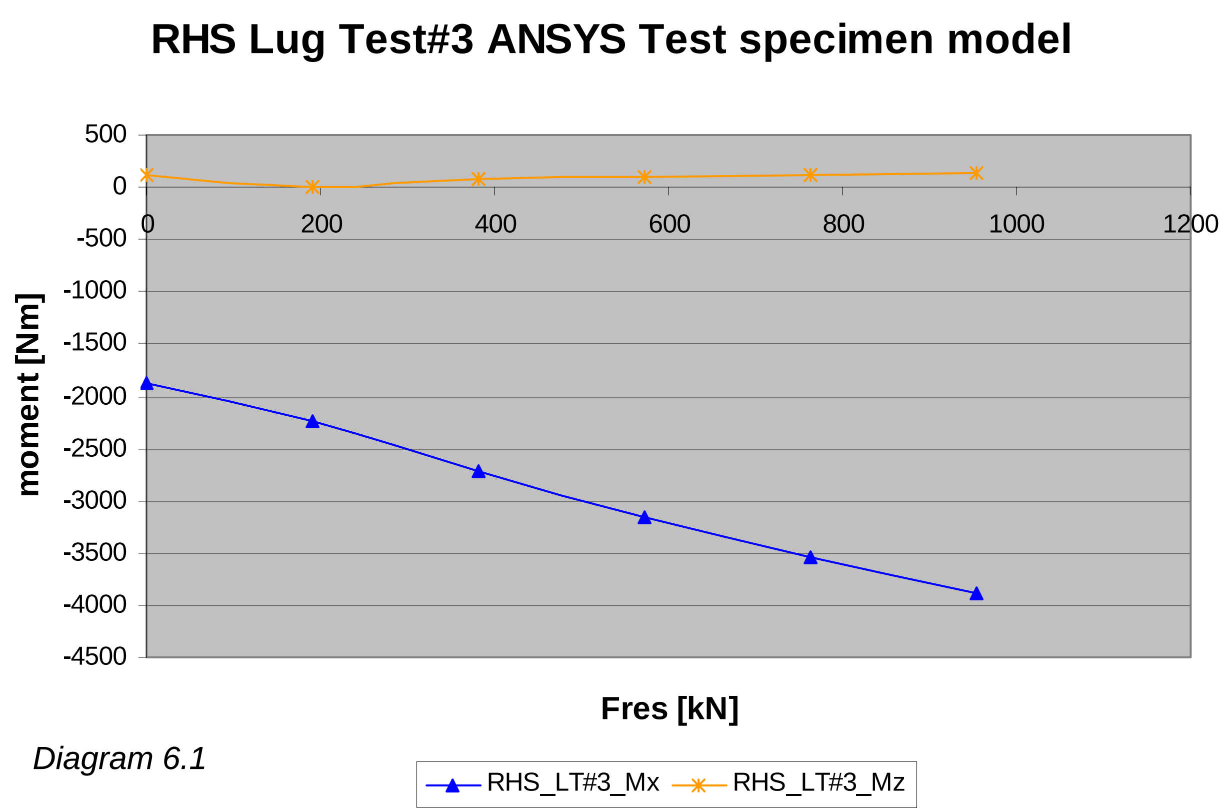


Diagram 6.1

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.

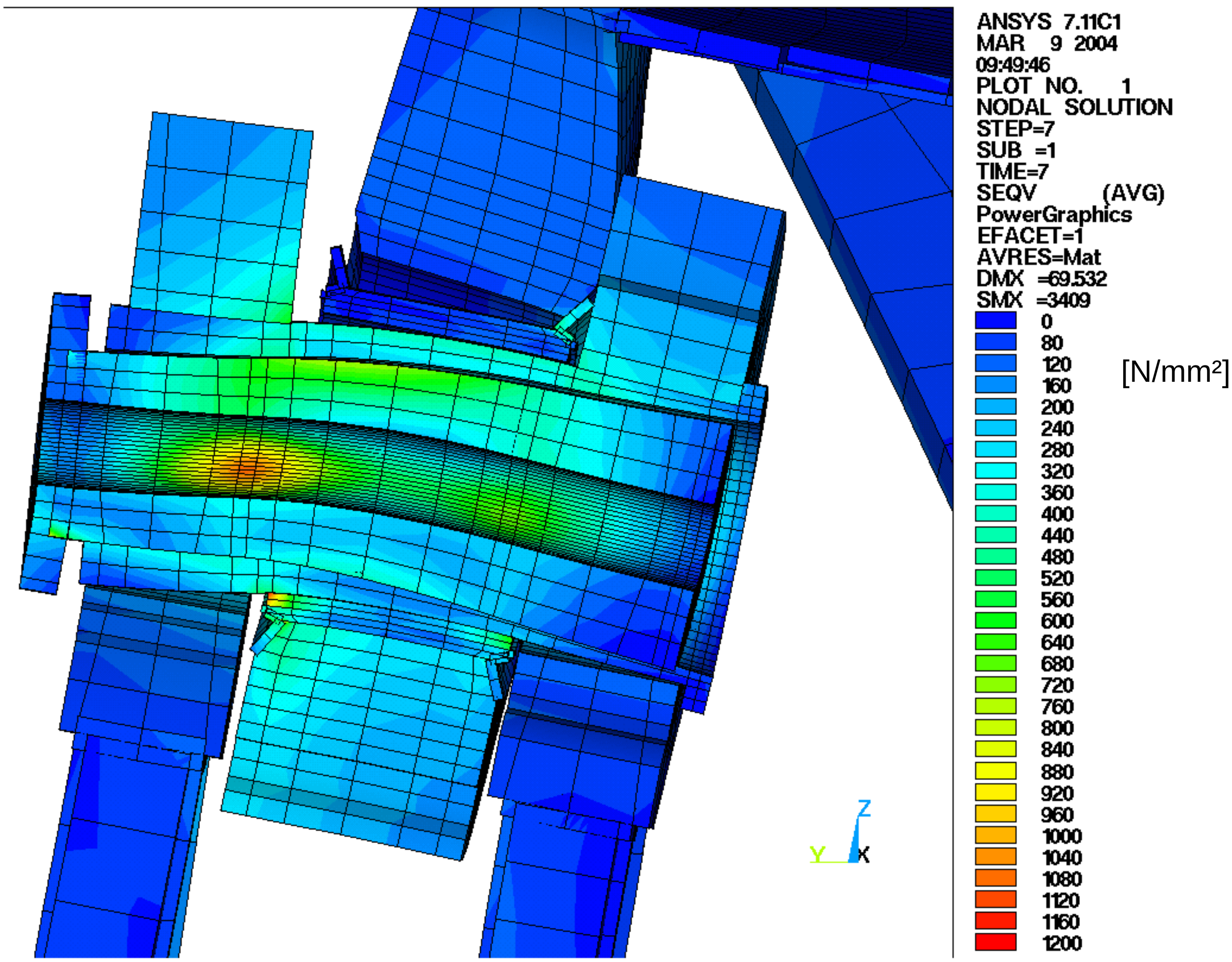


Figure 6.1

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

Bolt Rx rotation

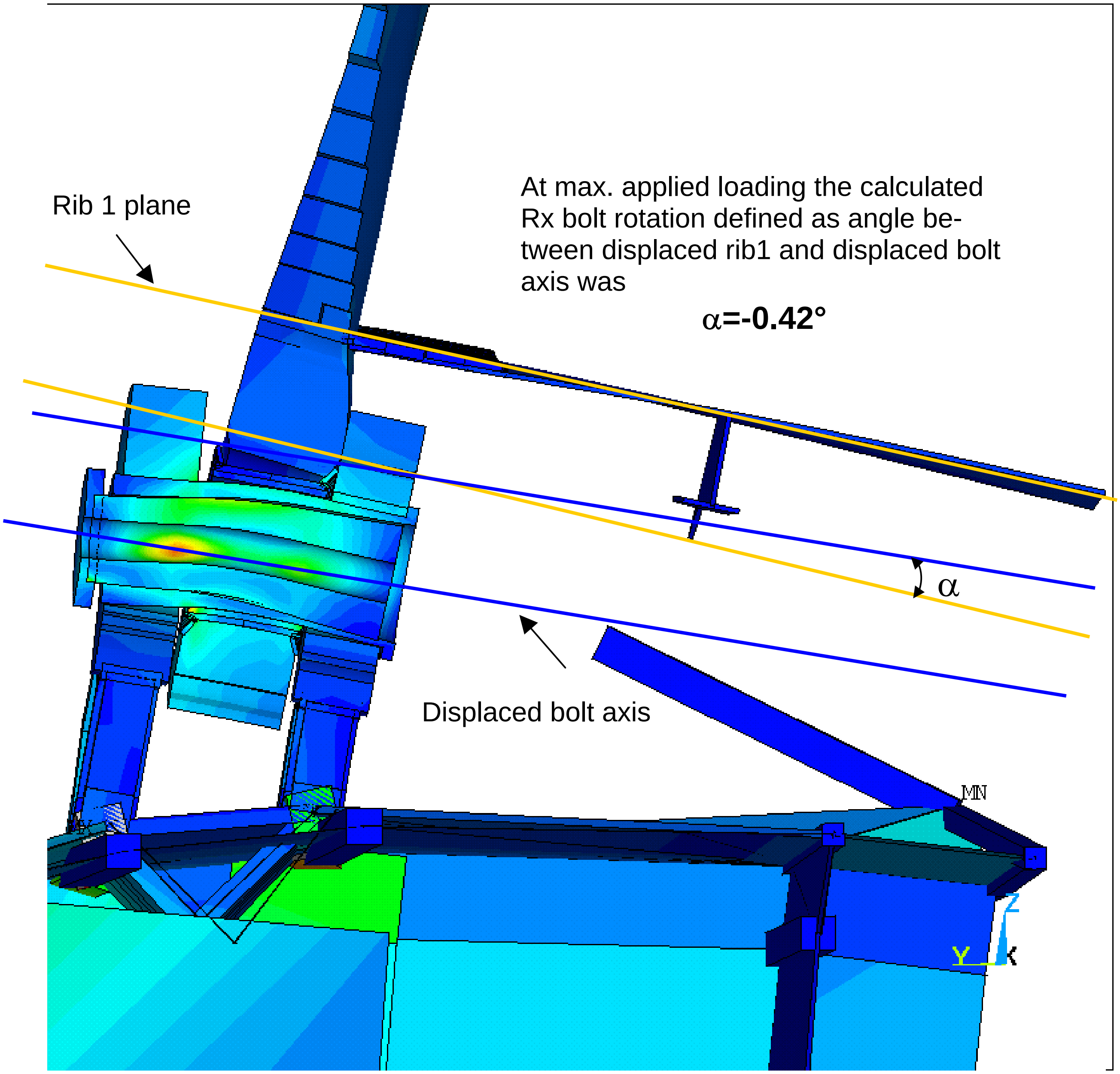
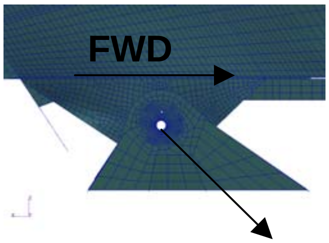


Figure 6.2

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

6.1.3 Strain distribution at the pin hole



Fres=919kN

RHS model

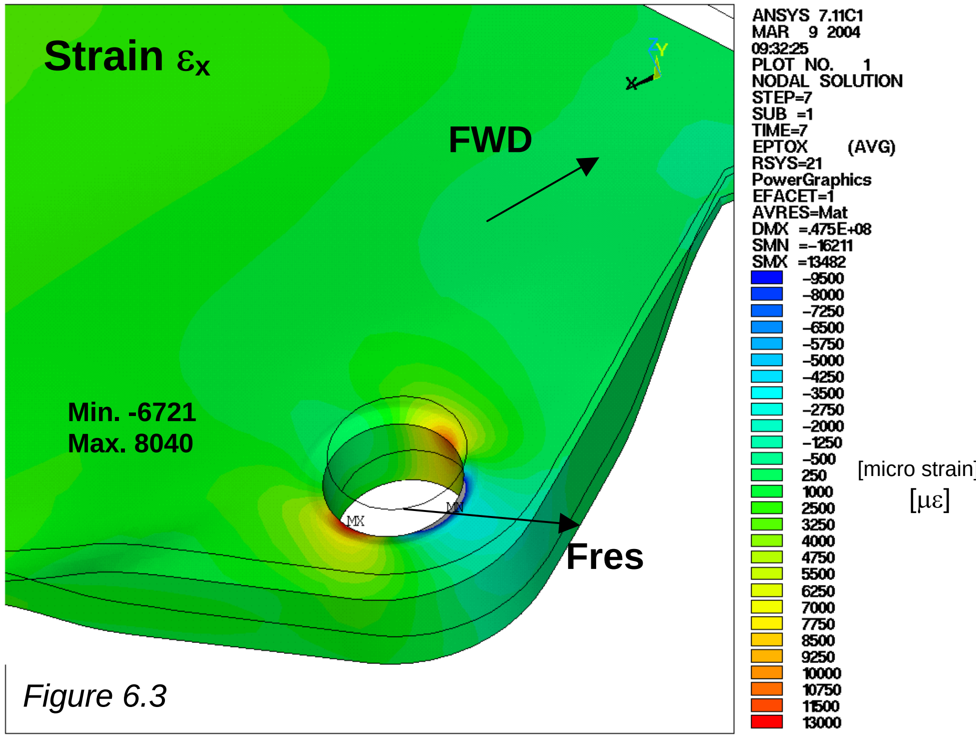


Figure 6.3

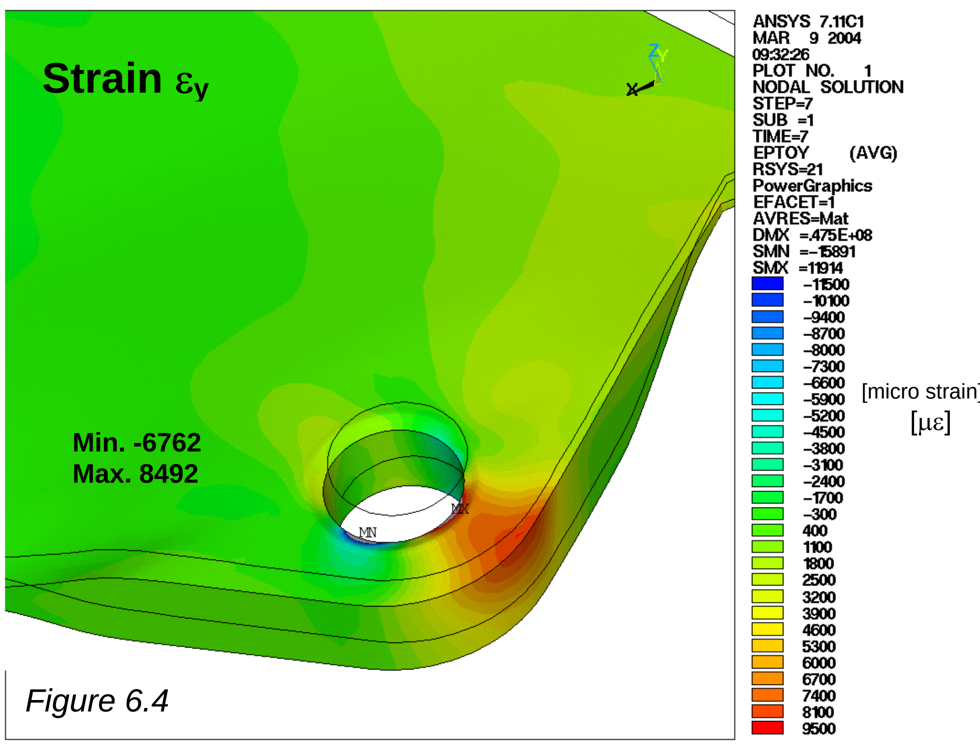
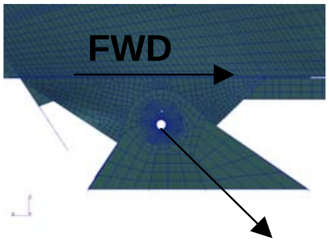


Figure 6.4

MIN / MAX strain values consider only the strain distribution outside the countersink area

All views from outboard
Strain distribution in material coordinate system



Fres=919kN

RHS model

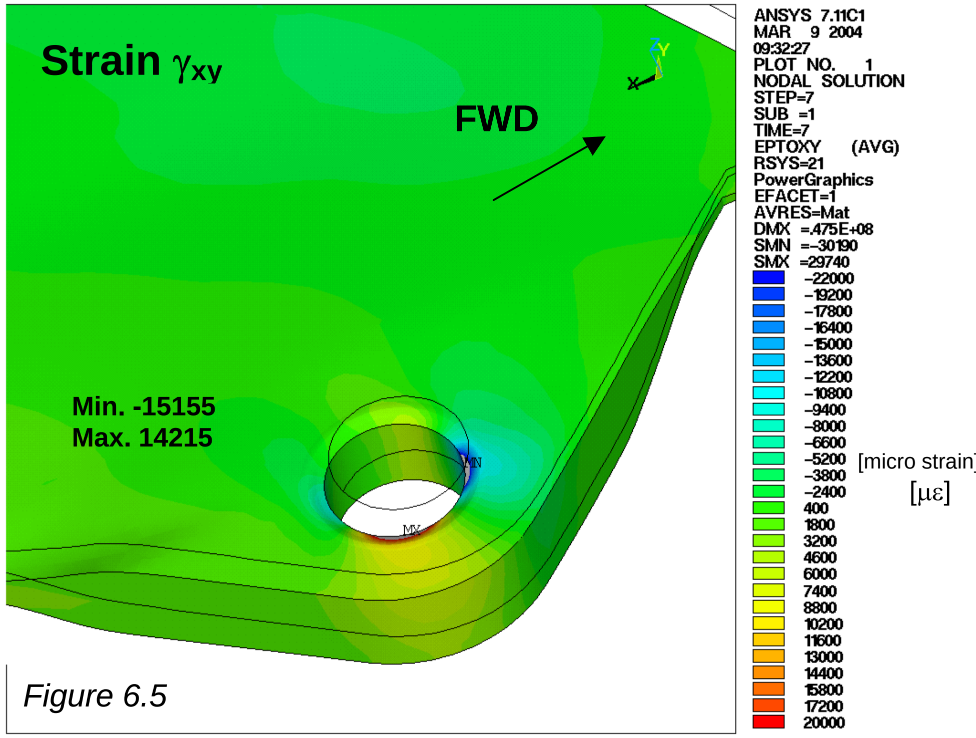


Figure 6.5

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

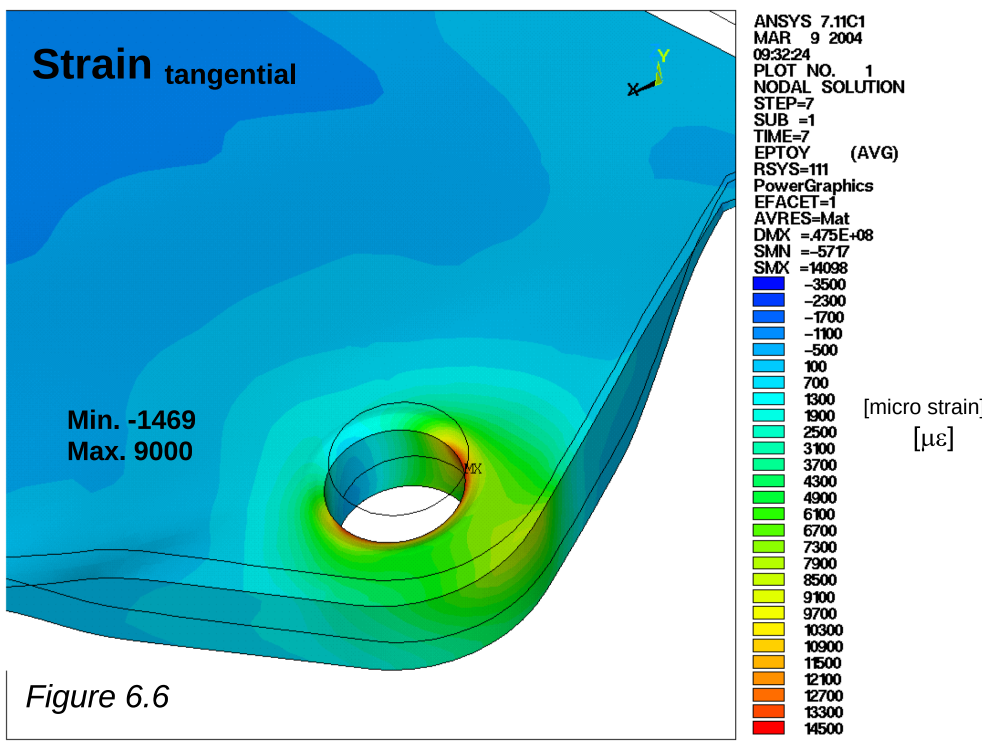


Figure 6.6

MIN / MAX strain values consider only the strain distribution outside the countersink area

All views from outboard
Strain distribution in material coordinate system

6.2 RHS ANSYS contact Lug Test#3 NASA W375 MOD Rx=-0.45°

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**	5	23	0	0
-67	7	-144	**159**	-1883	124	-0,445	0
-133	14	-288	**318**	-2245	3	-0,445	0
-200	21	-432	**477**	-2726	69	-0,444	0
-267	28	-576	**635**	-3161	101	-0,444	0,001
-333	35	-720	**794**	-3547	125	-0,444	0,001
-400	42	-864	**953**	-3882	141	-0,444	0,001

Rx/Rz bolt rotation in relation to rib 1

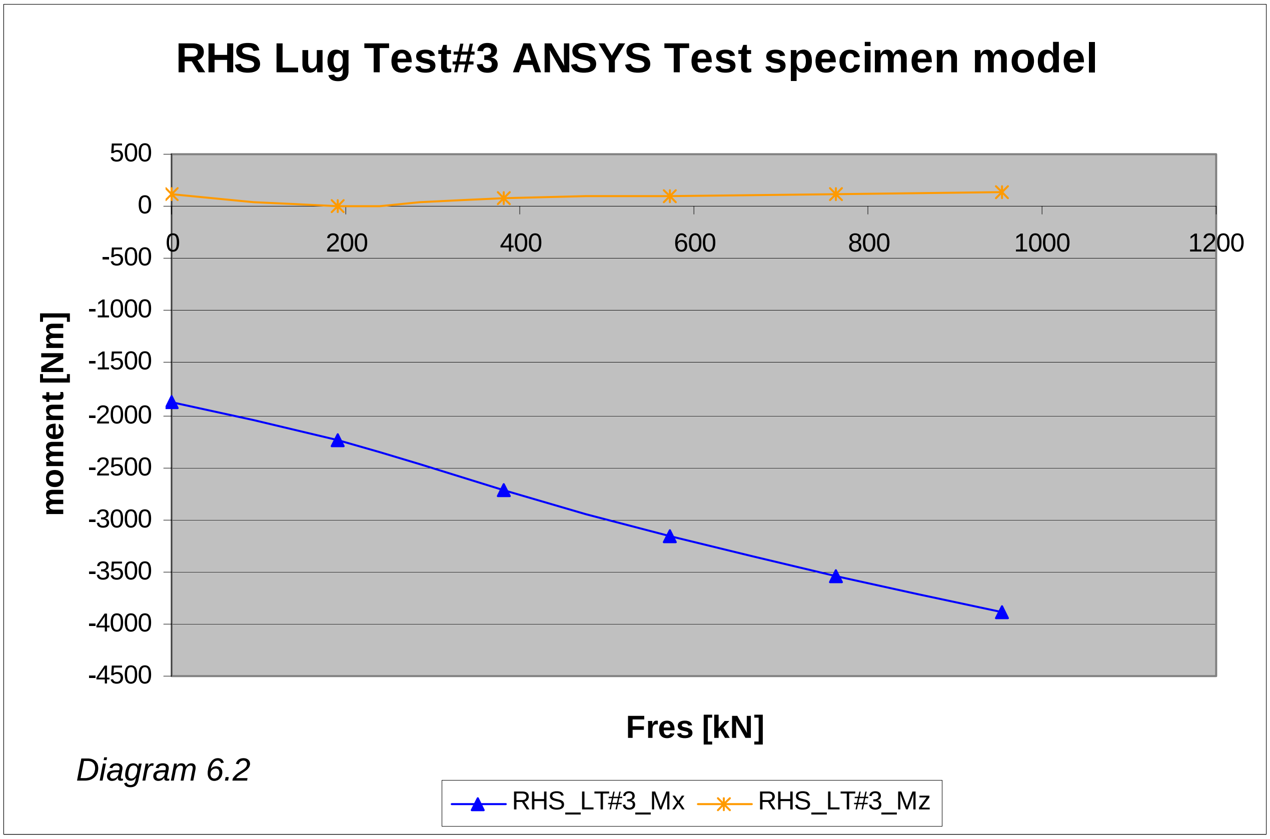


Diagram 6.2

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 6.13 and 6.14). The color scale is von Mises equivalent stress distribution.

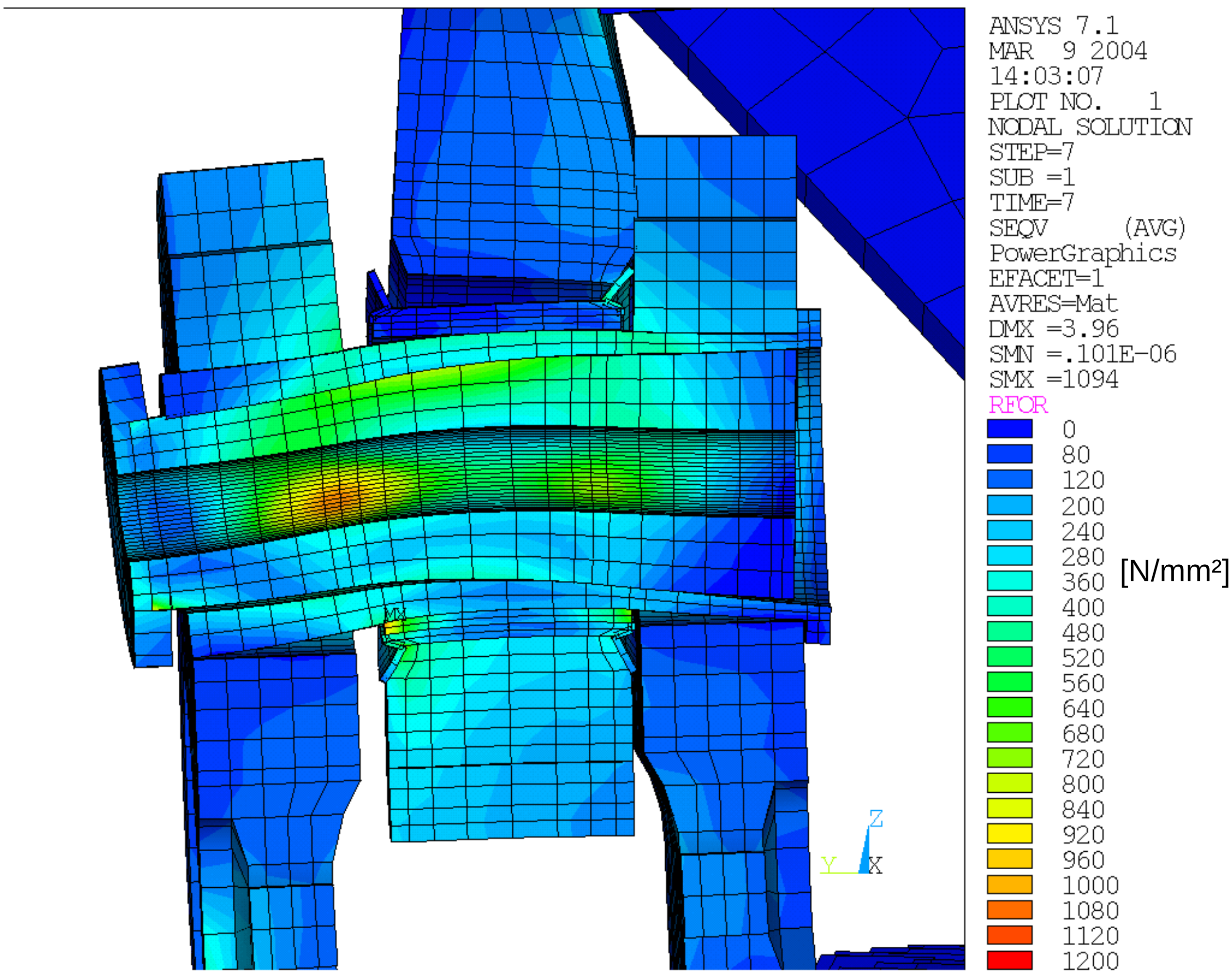
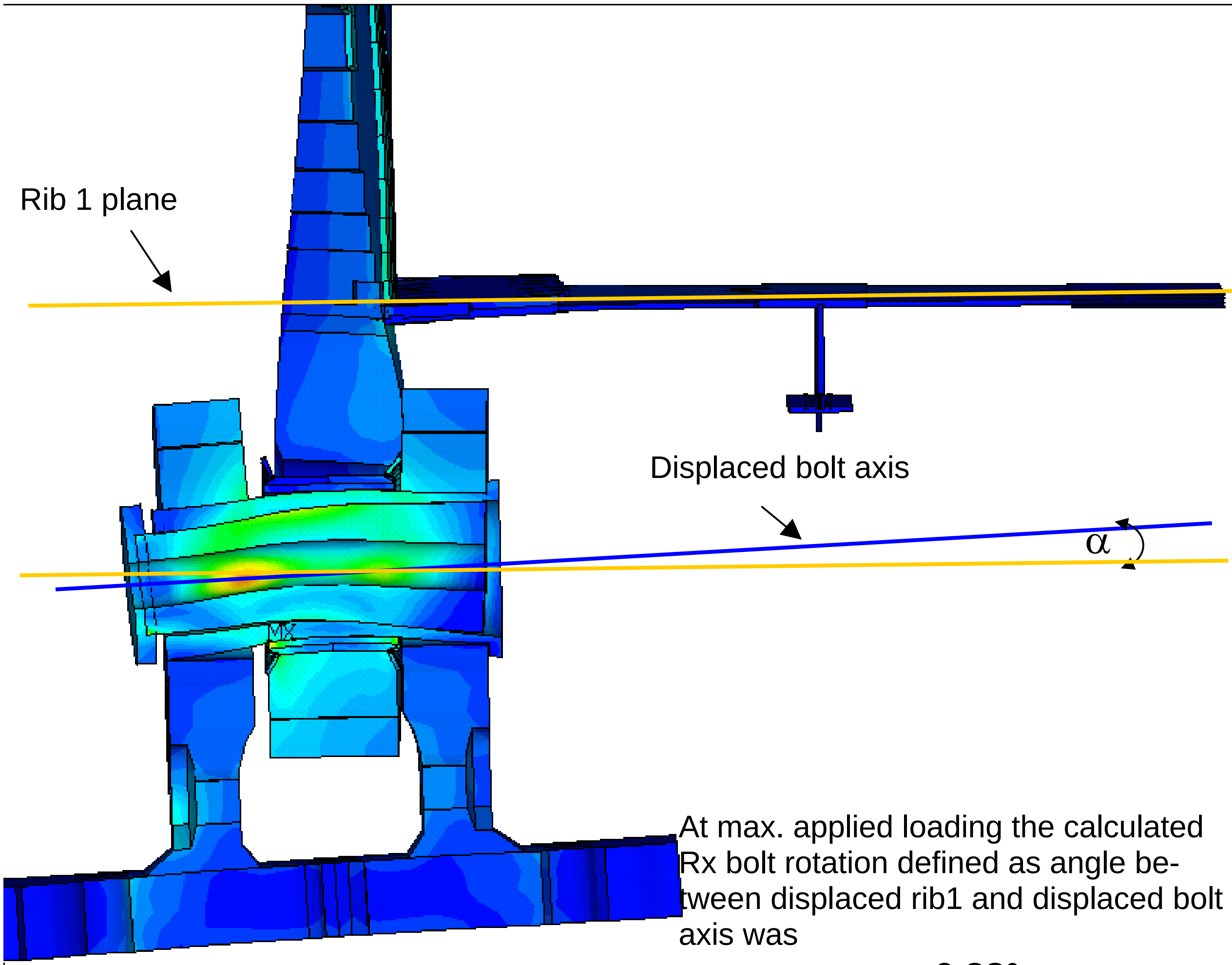


Figure 6.7

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

Rx bolt rotation



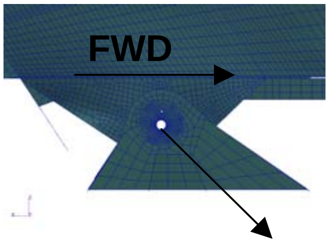
At max. applied loading the calculated Rx bolt rotation defined as angle between displaced rib1 and displaced bolt axis was

α=0.38°

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

Figure 6.8

6.2.3 Strain distribution at the pin hole



Fres=953kN

RHS model

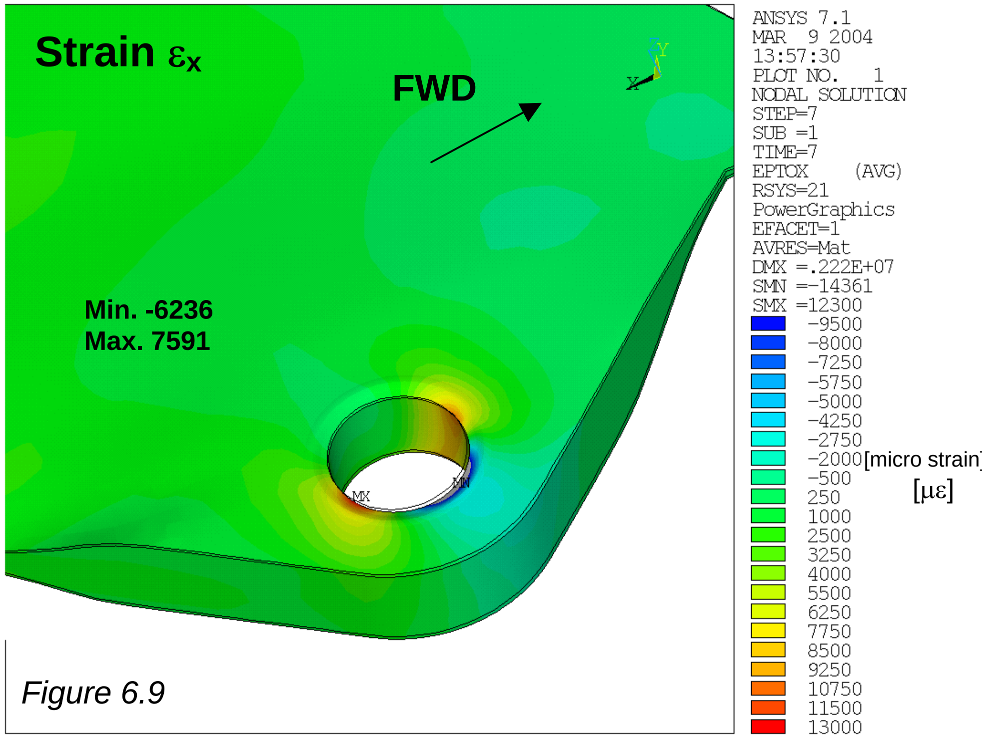
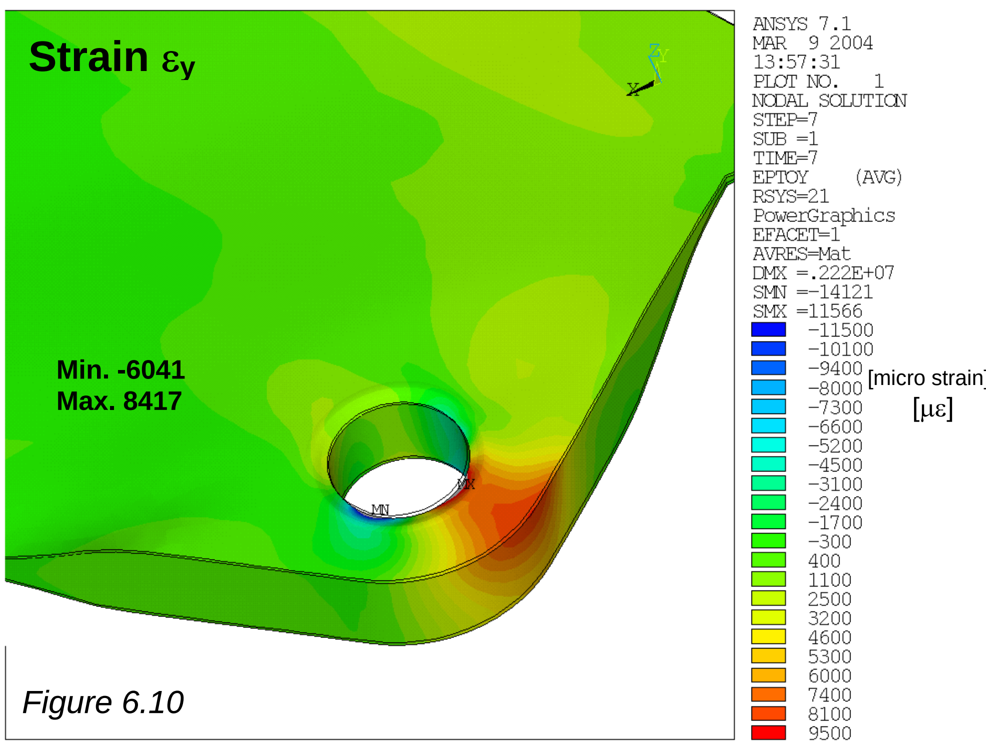


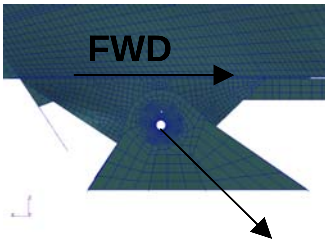
Figure 6.9



MIN / MAX strain values consider only the strain distribution outside the countersink area

Figure 6.10

All views from outboard
Strain distribution in material coordinate system



Fres=953kN

RHS model

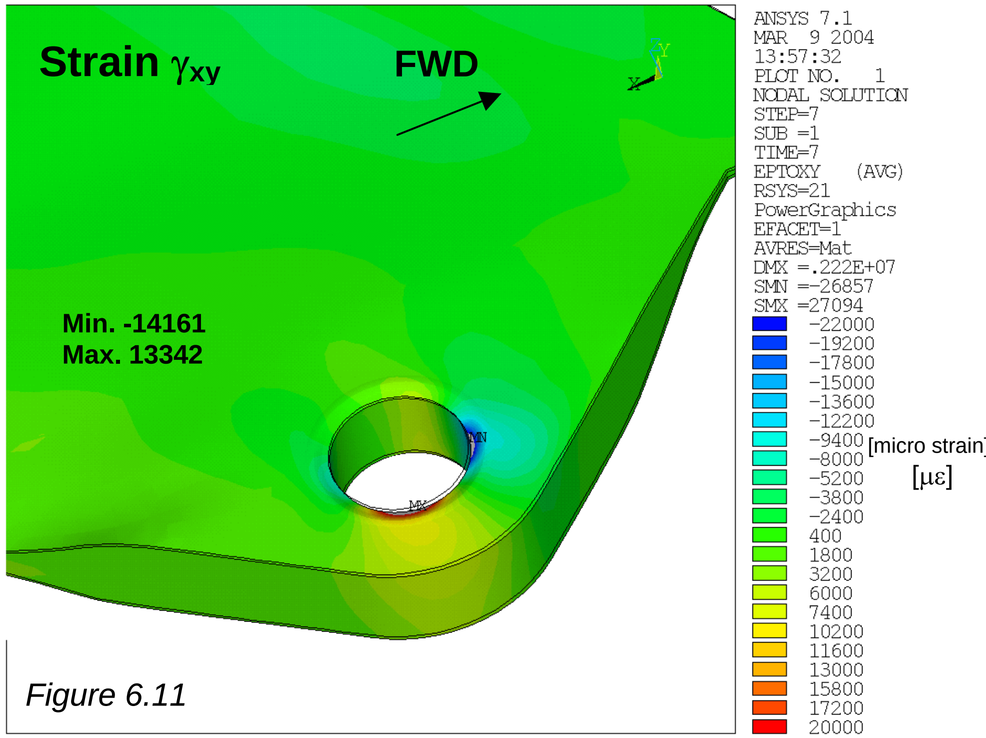


Figure 6.11

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

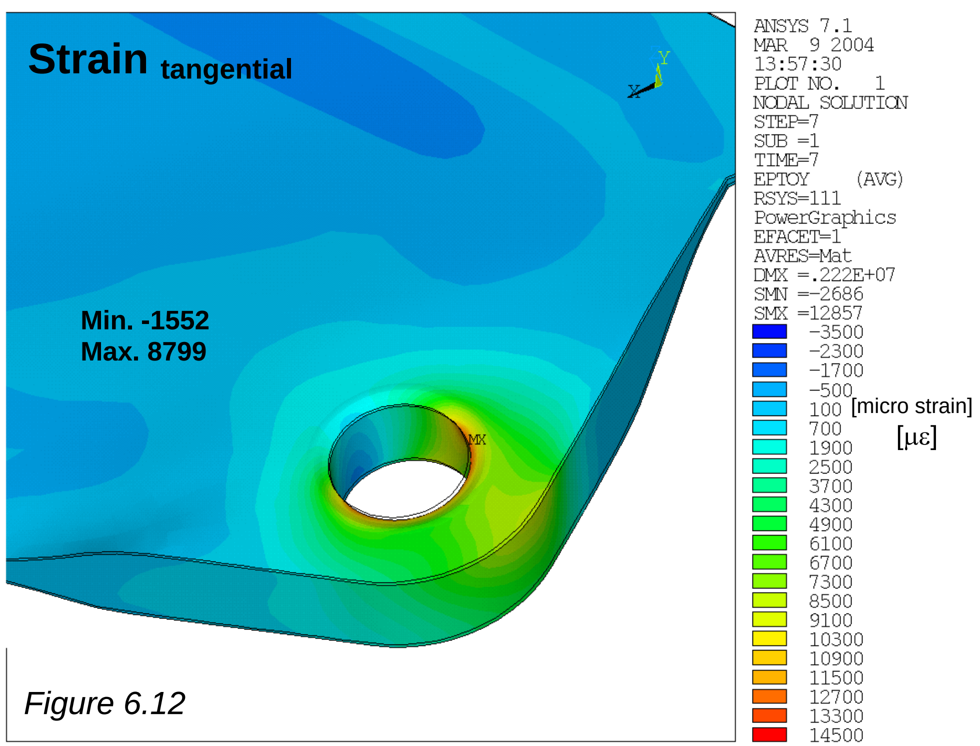


Figure 6.12

MIN / MAX strain values consider only the strain distribution outside the countersink area

All views from outboard
Strain distribution in material coordinate system

6.3 Comparison of the contact status & pressure between the two models

To compare the contact surfaces of the ANSYS analysis a settlement of the circumferential surface was chosen. The three main contact surfaces, bushing to CFRP and both fuselage clevis contact surfaces are shown.

The direction of the resultant force Fres is the start point for the settlement of the 2D-plots. From this line the 2D-plot is a settlement of 180°-degree in both direction. The following figures 6.13 to 6.19 illustrates the contact surface settlement.

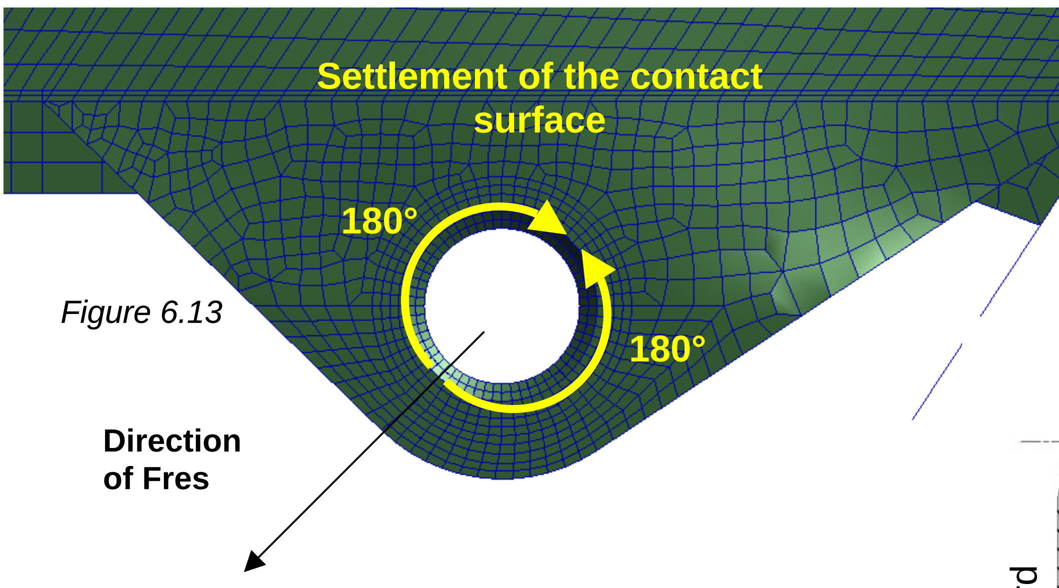


Figure 6.13

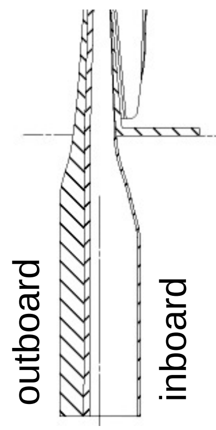


Figure 6.14

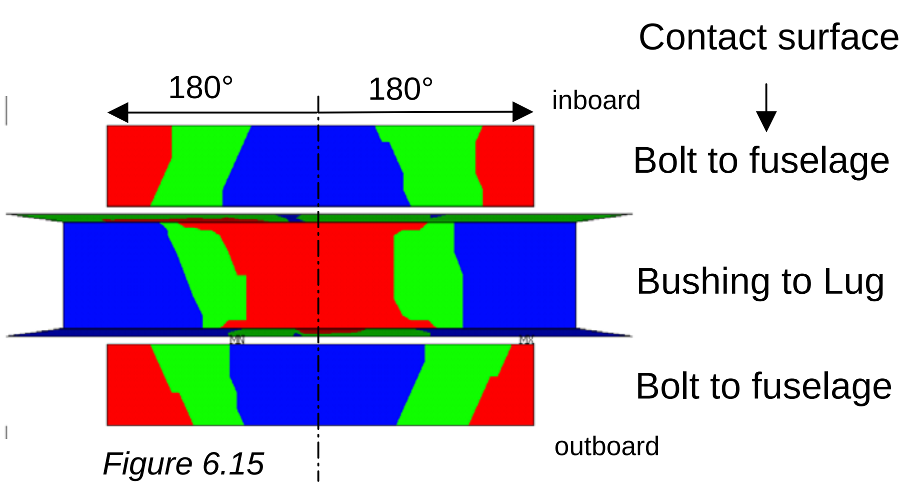


Figure 6.15

Contact Status for	RHS ANSYS contact 3D model NASA W375

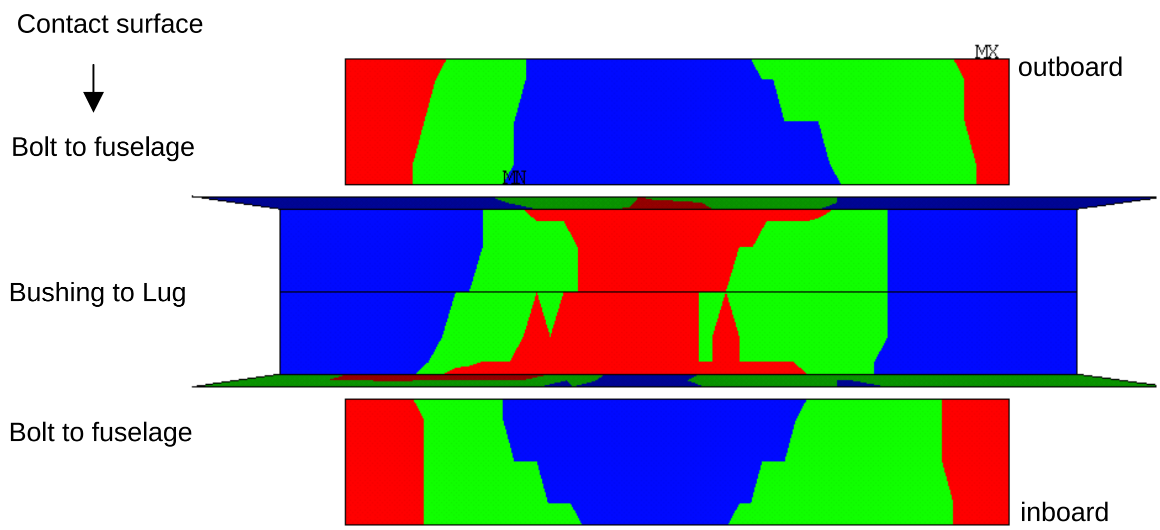


Figure 6.16

Contact Status for	RHS ANSYS contact Lug Test#2 NASA W375 MOD Rx=-0.45°

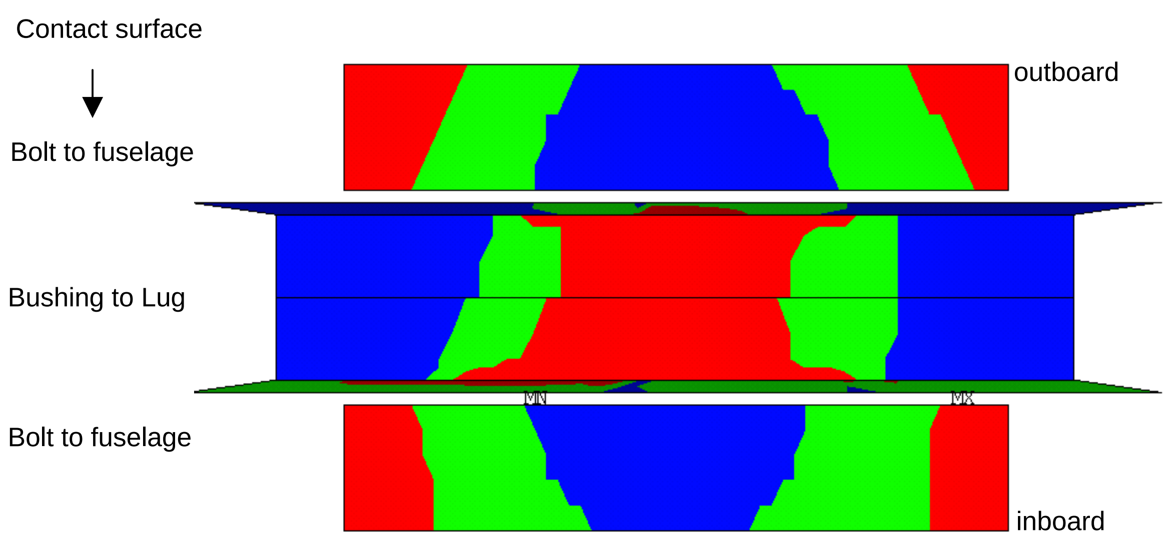


Figure 6.17

RED + **GREEN** = contact closed **BLUE** = gap

Contact Pressure for	RHS ANSYS contact 3D model NASA W375

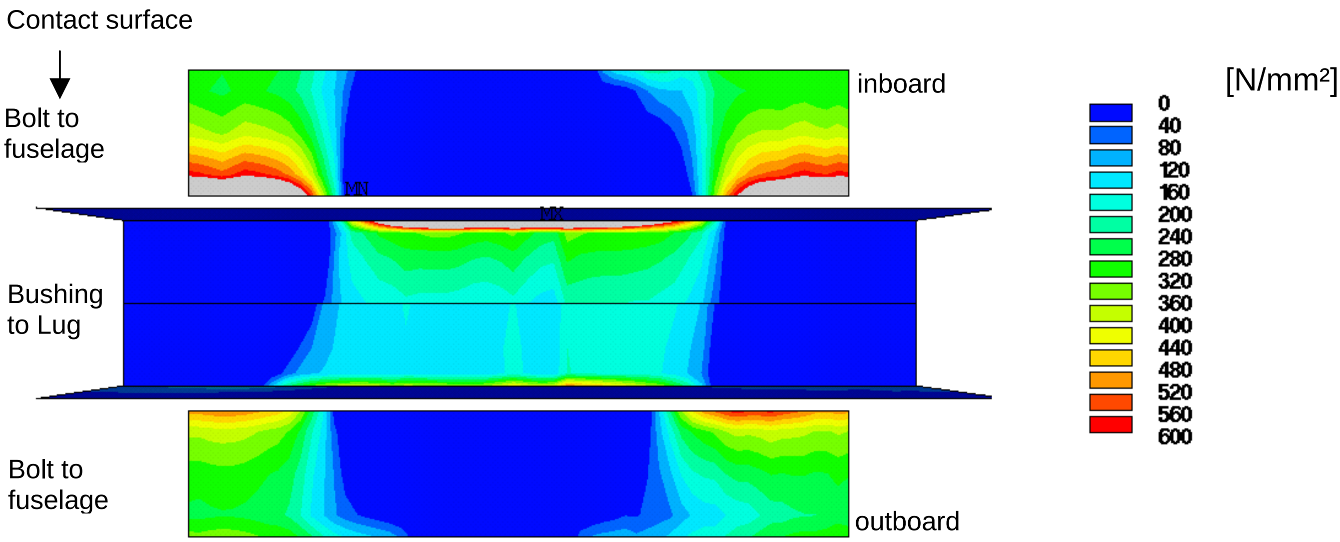


Figure 6.18

Contact Pressure for	RHS ANSYS contact Lug Test#2 NASA W375 MOD Rx=-0.45°

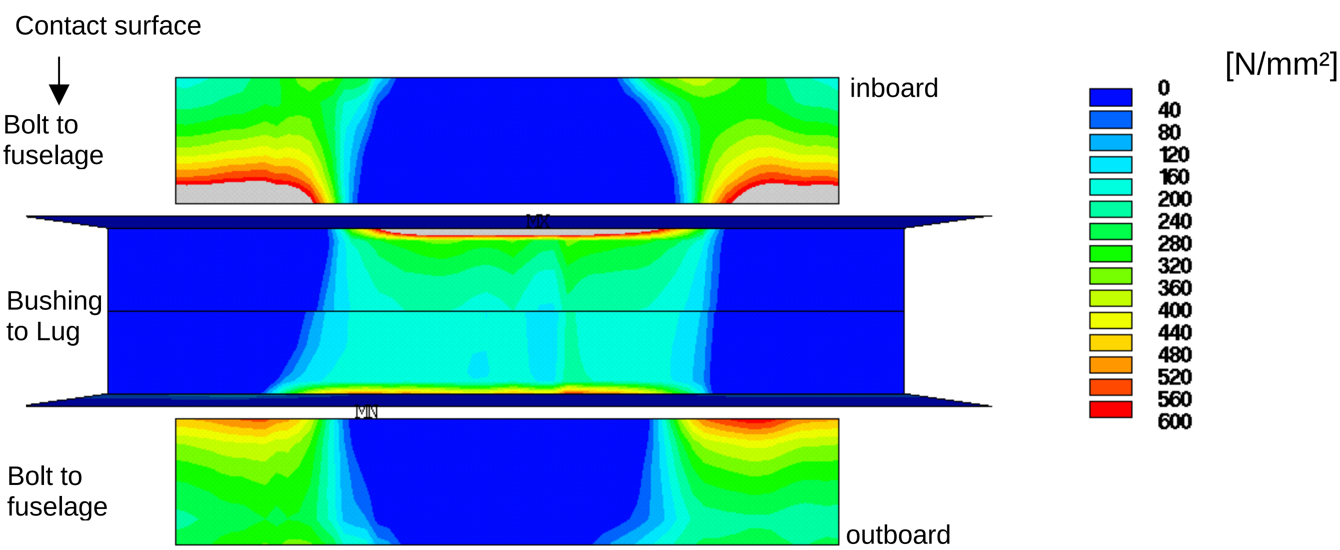


Figure 6.19

6.4 LHS vs. RHS Lug Test specimen ANSYS FEA models

The supporting ANSYS FEA calculation for the Lug Test#2 and #3 were carried out for each test specimen with representative test FEA models (see figure 6.20 and 6.21).

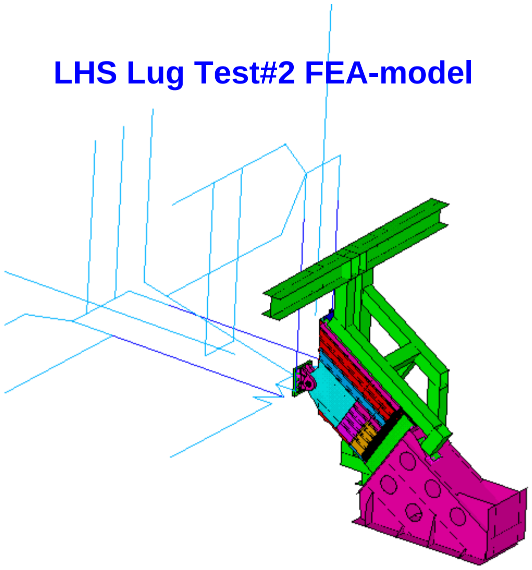


Figure 6.20

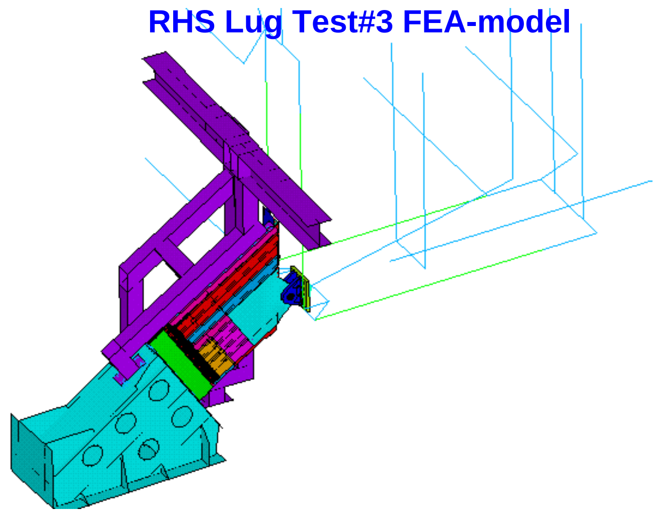


Figure 6.21

Comparison of the results for both models shows that the strain distribution around the CFRP lug is the same (see table 6.3) but the local lug moment Mx calculation with Fz1 and Fz2 show differences (see diagram 6.3).

Table 6.3 ANSYS Test Specimen FEA-models strain comparison

	Strain ε_x		**Strain** ε_y		**Strain** γ_{xy}		**Strain** **tangential**	
	[micro strain] [$\mu\varepsilon$]							
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
LHS LT#2	-6226	7578	-6029	8405	-14139	13322	-1544	8784
RHS LT#3	-6236	7591	-6041	8417	-14161	13342	-1552	8799
%-Diff to LHS	0.16	0.17	0.2	0.14	0.16	0.15	0.52	0.17

The diagram 6.3 show the local lug moment Mx of the ANSYS test specimen FEA models.

The Mx is plotted according to two different calculation methods:

- FZ1/2_Mx is calculated with the Z1/2 main rod forces according to chapter 2.5
- RSP_Mx is calculated with the Grid Point Force Balance (GPFB)method described in chapter 2.6 at the bolt Reference Summation Point (RSP).

For the GPFB-method the analysis results for both models show the same Mx-value. Calculating the Mx with the Z-rods forces the influence of the test rig structure can be shown. The RHS Lug Test#3 specimen indicates a reduction in Mx but with the same strain distribution around the lug.

The tested LHS and RHS test specimen showed the same behaviour as demonstrated by the ANSYS FEA-models.

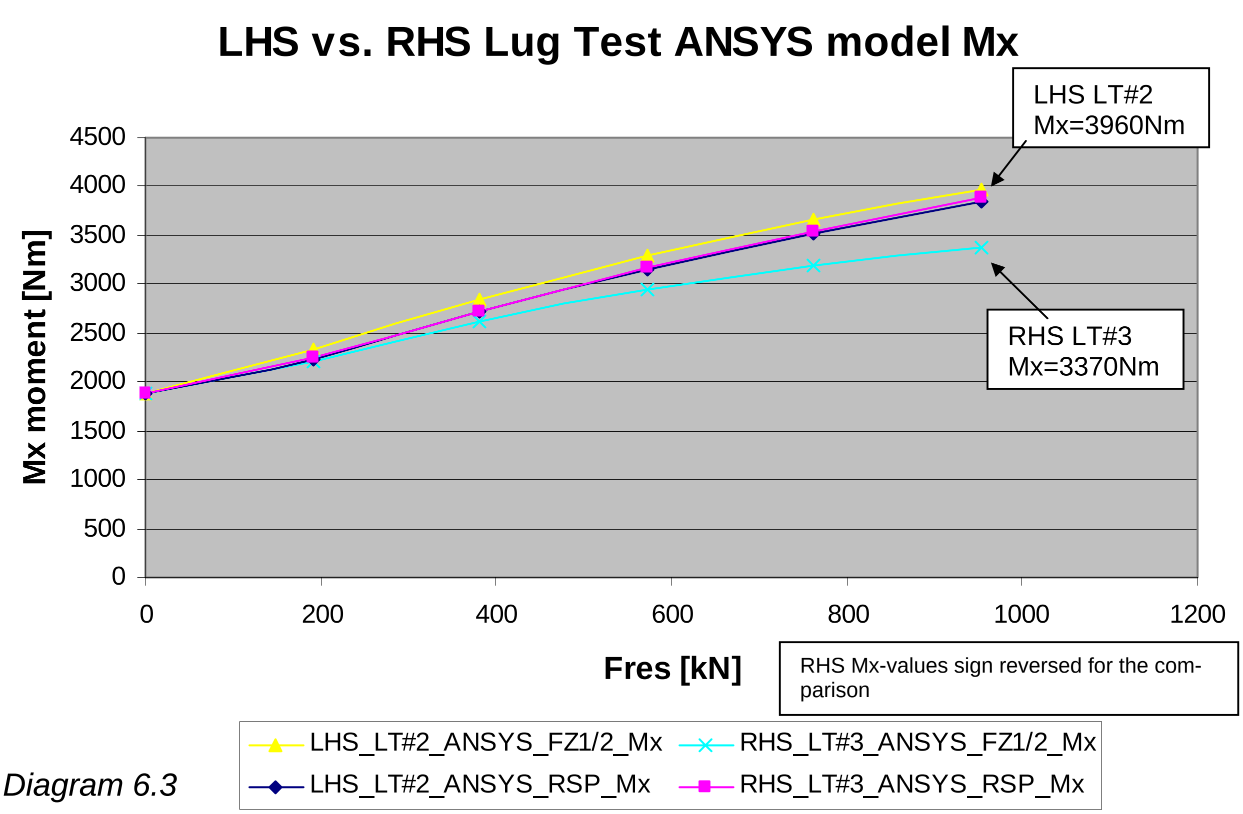


Diagram 6.3

7. Test results RHS Lug Test#3 W375 MOD Rx=-0.45°

7.1 RHS Lug Test#3 Test sequence

The load vector according to chapter 4 was applied to the test specimen.
During the load application three test rig shutdowns occurred due to non-appropriate control parameters. The fourth test stopped after reaching the pre-defined max. W375 MOD load vector of Fres=953kN. For the last residual strength test the nominal value of the load vector was increased to the maximum capacity of the load cells.
Table 7.1 show each of the tests with the reached resultants load vector.

Table 7.1

No.	Fres [kN]	Description
1	522	Shutdown due to non-appropriate control parameter
2	522	Shutdown due to non-appropriate control parameter
3	745	Shutdown due to non-appropriate control parameter
4	953	The test stopped after reaching the pre-defined max. load vector
5	**1093**	Residual Strength with visible fracture of the specimen

7.2 RHS Lug Test#3 failure pictures

The figures 7.1 to 7.5 show the Lug Test#3 specimen after the test with all strain gauges removed and the fracture lines are visible.

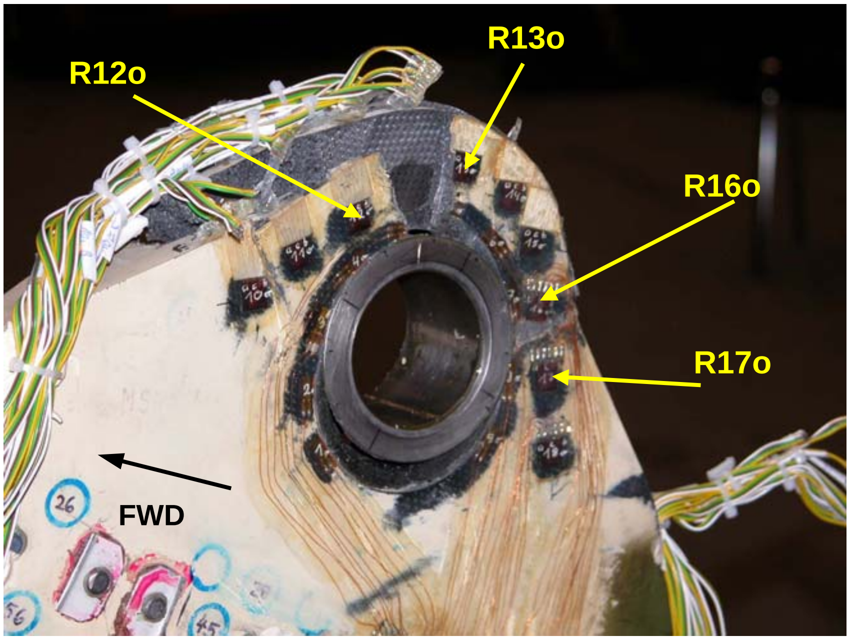


Figure 7.1

Outboard view

Figure 7.2

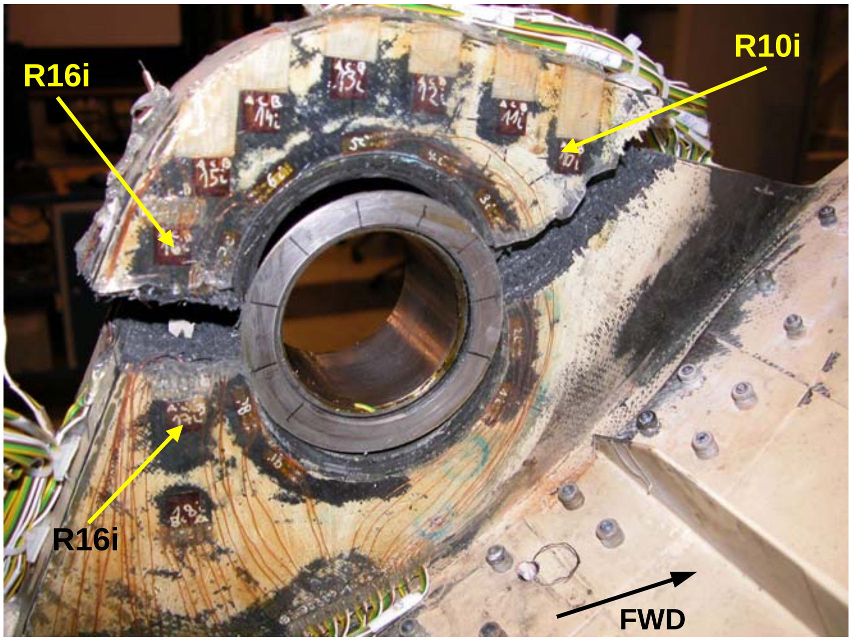
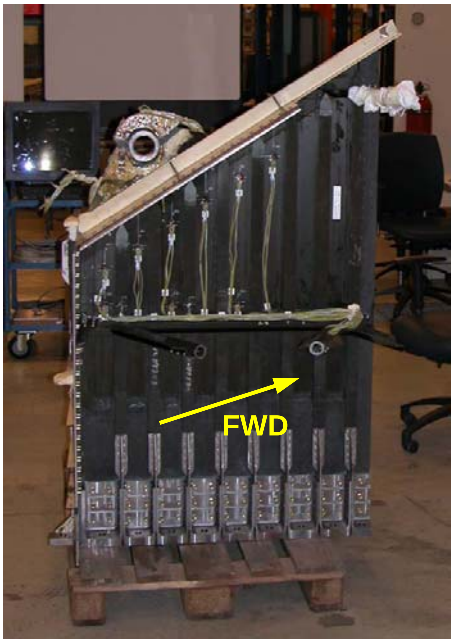


Figure 7.3



Inboard view

Figure 7.4

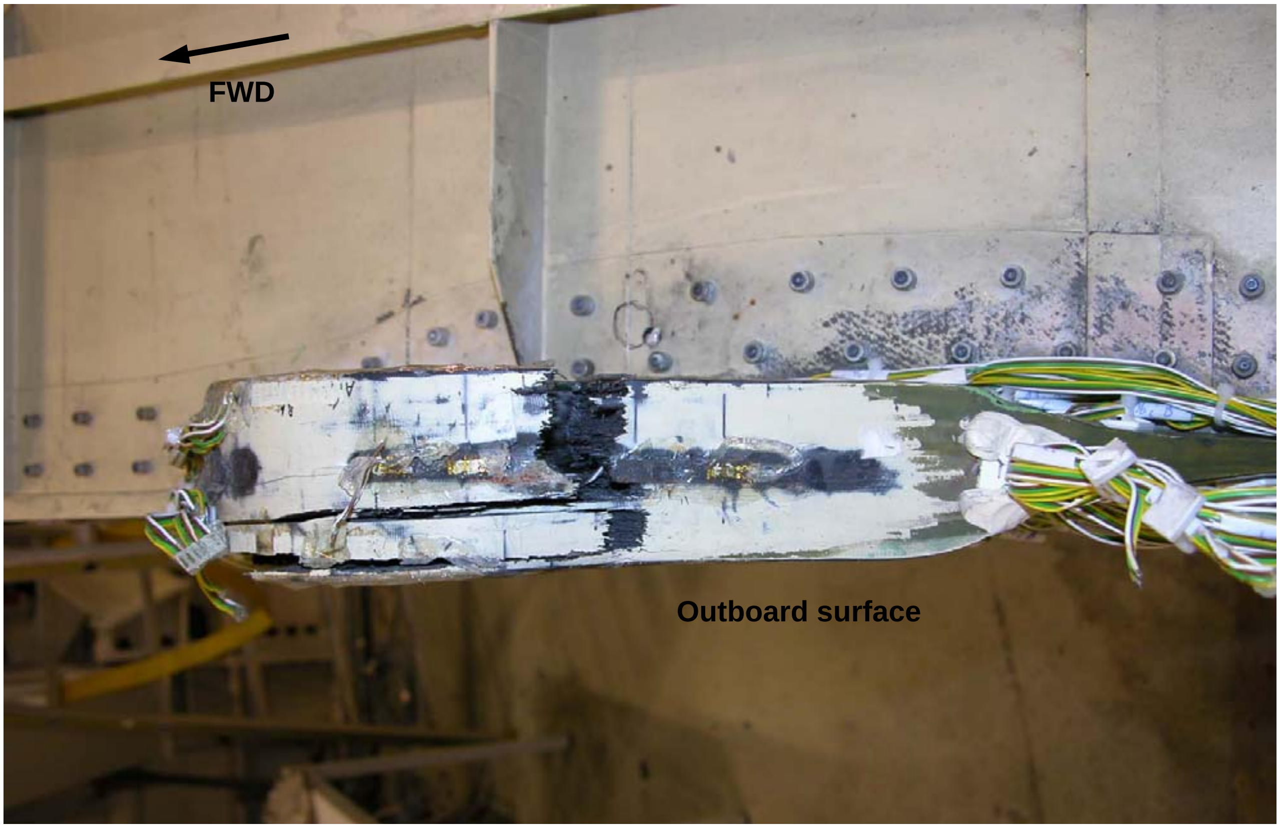


Figure 7.5

7.3 RHS Lug Test#3 Failure load

The load vector according to chapter 4 was applied to the test specimen. After load step 150 the loads increased continuously and achieved a residual strength of Fres=1093kN (see table 7.2). The reached load level corresponds to 233 percent of the A300-600 limit load design gust vector BI17 (Basis was the Global FE-Model without embedded 3D rear main lugs Fres=469kN).

Table 7.2

RHS Lug Test#3 (12. February 2004)		
Component		Rupture value
Fx	[kN]	-457.5
Fy	[kN]	35.3
Fz	[kN]	-992.4
Fres	[kN]	**1093**

7.4 LHS Lug Test#1 and #2 Failure load

Table 7.3 shows the failure loads of the LHS Lug Test#1 and LHS Lug Test#2.
Lug Test#1 was carried out at the 13. August 2003 and is documented in report TN-ESGC-1014/03.
Lug Test#2 was carried out at the 17. December 2003 and is documented in report TN-ESGC-1018/04.

Table 7.3

	Fx	Fy	Fz	Fres
Test Specimen	[kN]	[kN]	[kN]	[kN]
Lug Test#1	-381.6	-39.1	-822.5	907
Lug Test#2	-373	-35	-811	893

7.5 Measured Forces

The measured forces (see diagram 7.1) from the Lug Test#2 load cells are identical to the applied forces of the FE-Analysis. In lateral direction a Wy displacement was applied during the test sequence as described in chapter xy. The Fy force represents the lateral reaction force generated by the Wy displacement.

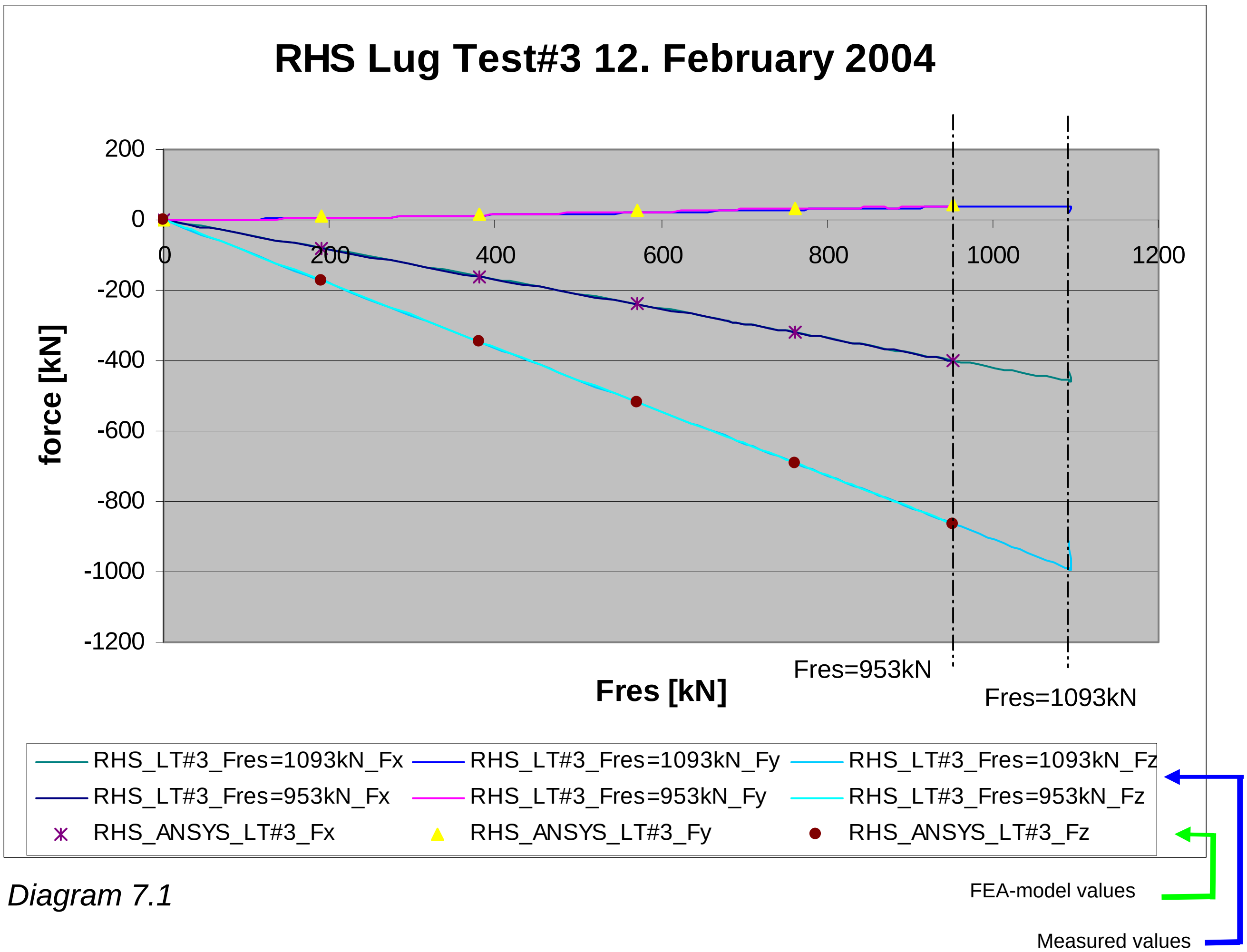


Diagram 7.1

7.6 Detailed result investigation of the test sequence 4 [Fres=953kN] of Lug Test#3 specimen

After the Lug Test#3 residual strength test a first strain comparison over all five tests was done. The diagram 7.2 shows the principle strain distribution of the outboard Rosette R12o. The strain measurement during the residual strength test shows a complete different behaviour as in the tests before. Many other outboard strain gauges around the lug show the same behavior.

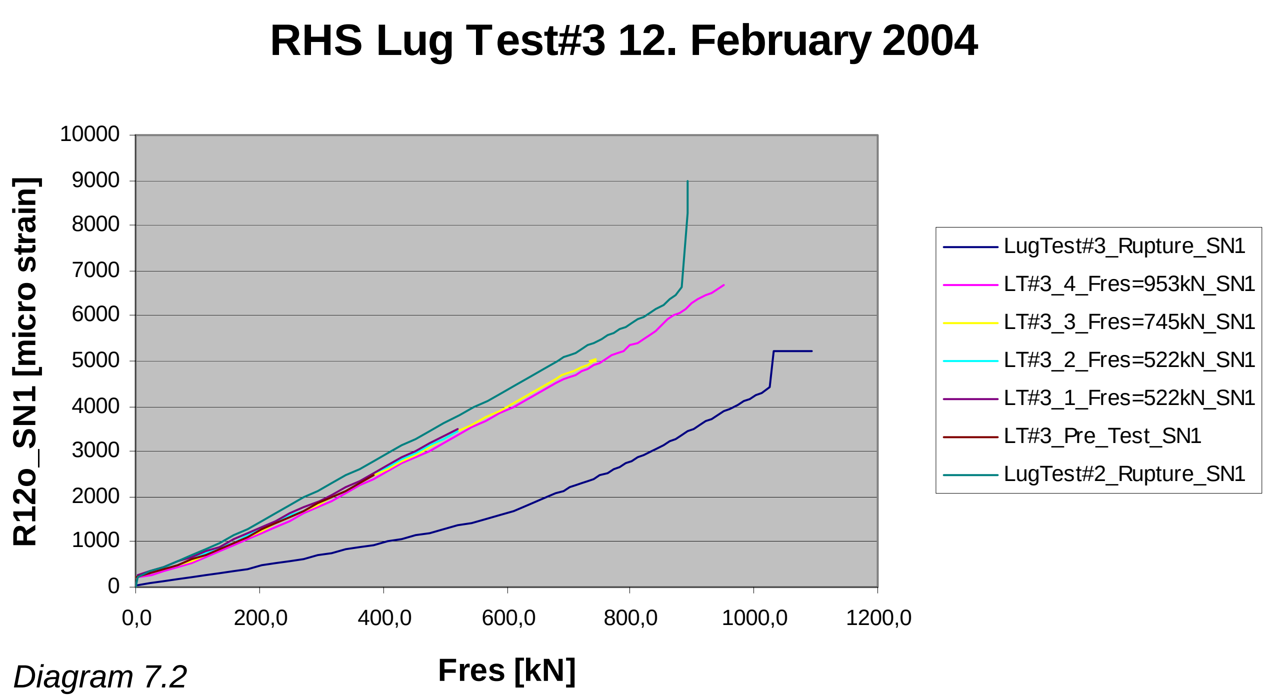


Diagram 7.2

The fourth test with the Lug Test#3 shows up to Fres=953kN a normal behaviour of the measured strain. A detailed investigation of this test was done to give an explanation for the abnormal strain gauge behaviour.

After the test sequence 4 reached the resultant load level of Fres=953kN at time point t=1026.32 sec., the load was hold nearly 14 seconds on this high level.

Airbus assumes that between time point t=1026.36 and t=1026.37 sec. the outboard 3mm laminate was debonded (see figure 7.6 and 7.7).

Figure 7.6

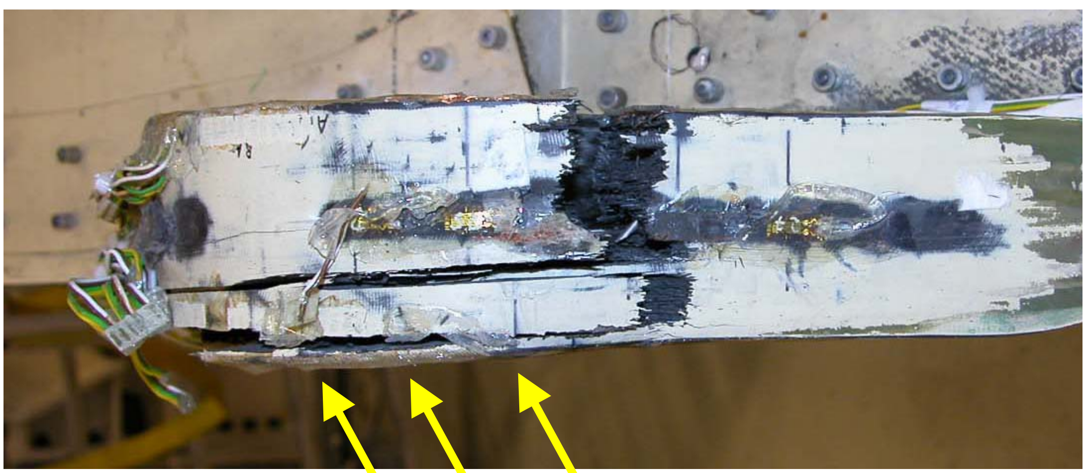


Figure 7.7

The assumption can be supported by the drop down of Mx moment (see diagram 7.3 and 7.4) and the drop down of the measured strain values in the affected area (see diagram 7.5 and 7.6). The drop down effect can be seen also on the outboard rosettes R11o to R17o. The Rosettes R13o, R14o and R15o indicates a cable cut off.

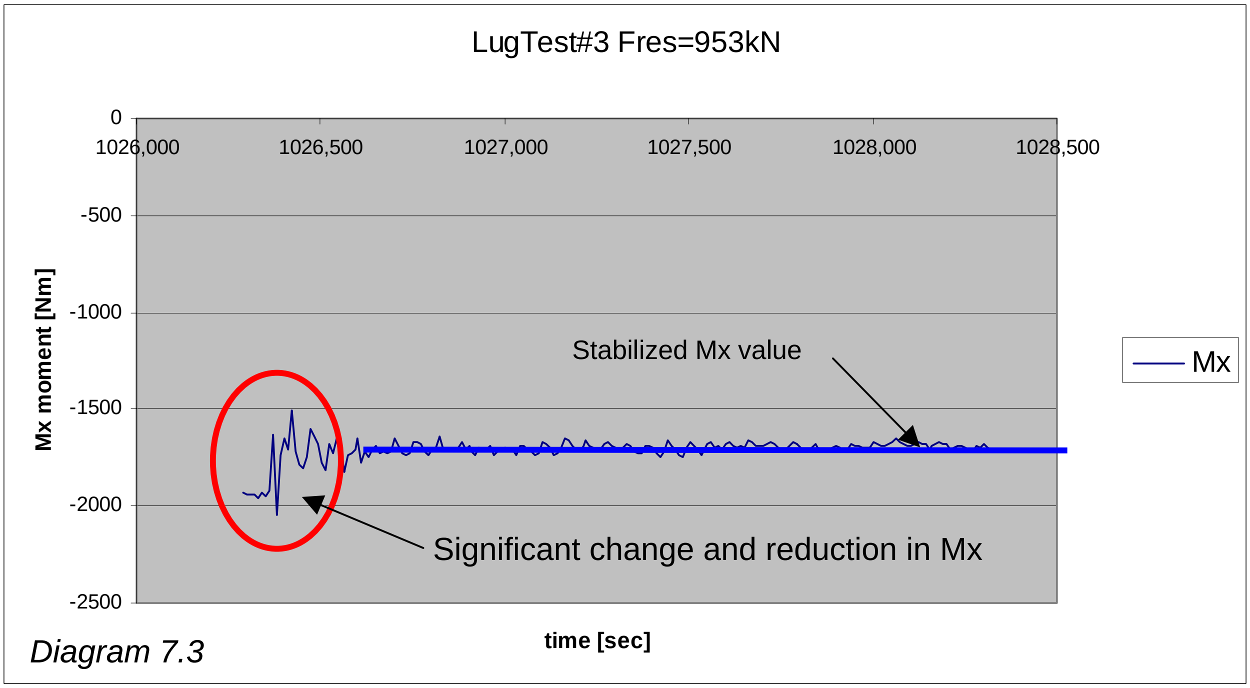


Diagram 7.3

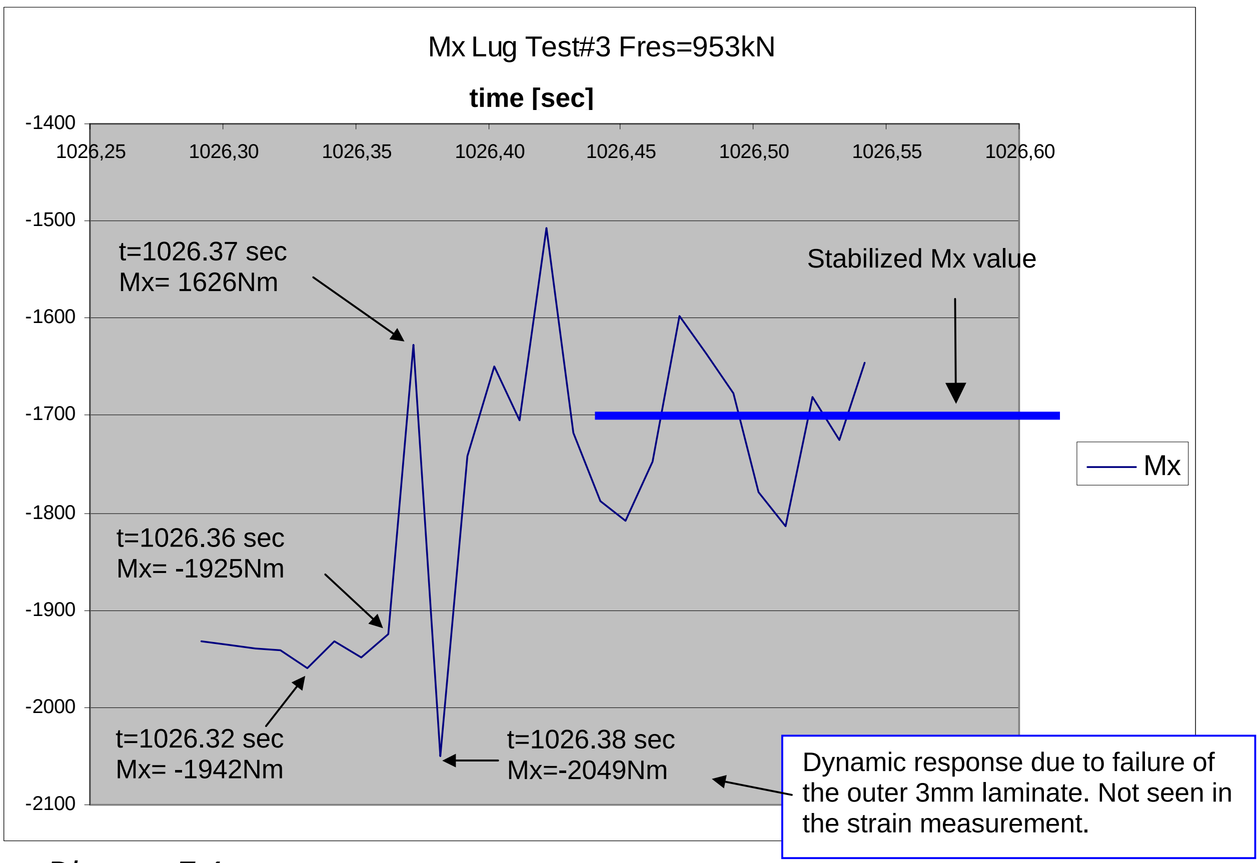


Diagram 7.4

The following R12o and R12i show as an example the drop down effect. The outboard strain gauge R12o (see diagram 7.5) show a rapid drop down of strain value between time point t=1026.36 and t=1026.37sec. After the drop down the signal of the strain gauges are stabilized at lower values during the high loading process. The inboard strain gauge R12i (see diagram 7.6) show during the same time period no abnormal behaviour.

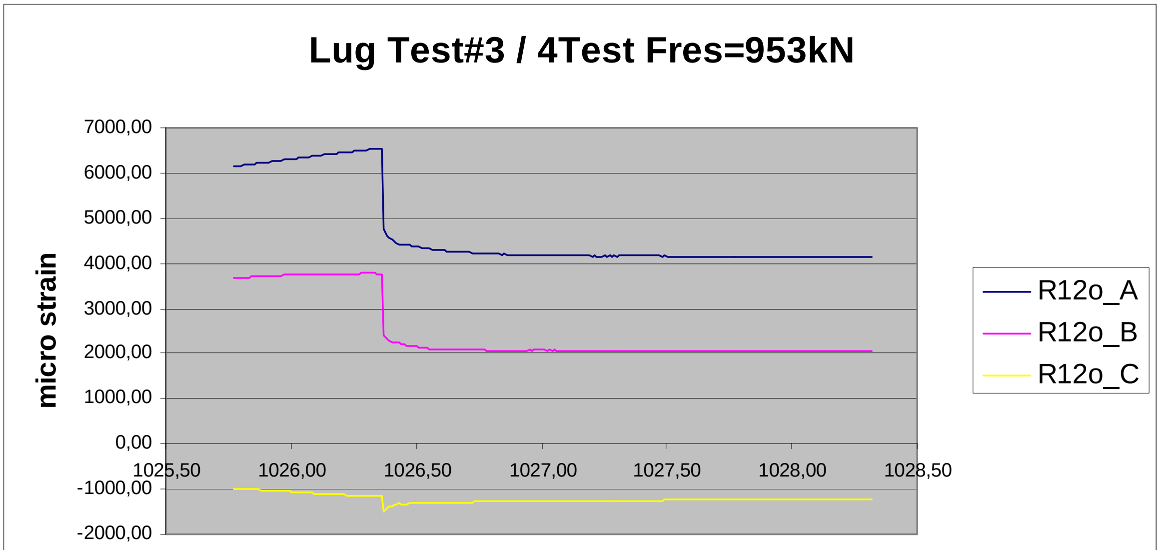


Diagram 7.5

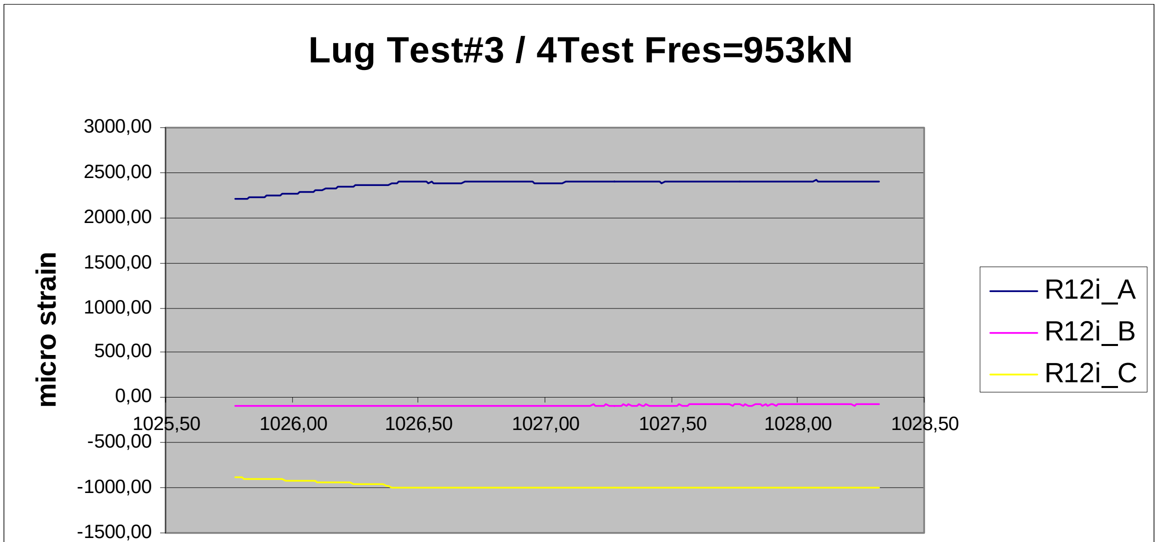


Diagram 7.6

The presented material supports the assumption that during the high load level of the fourth test (Fres=953kN) the outer 3mm was debonded. This delamination was the reason for the abnormal behaviour of the strain measurement during the residual strength test.

Based on the before discussed results Airbus decided to use for the strain comparison with the ANSYS FEA results the measured values of the test sequence 4 (Fres=953kN).

8. Lug Test#3 Result Comparison

8.1 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 8.1.

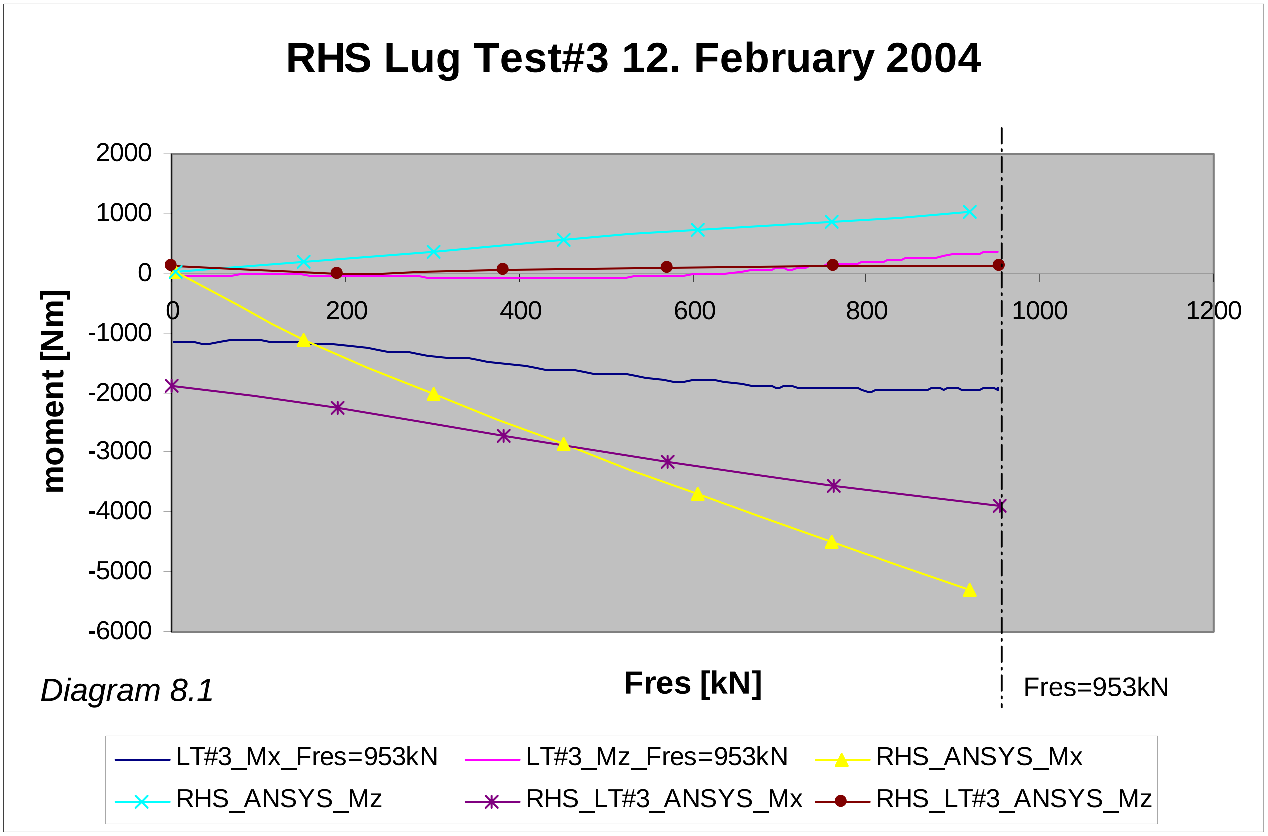


Diagram 8.1

The bolt Rx rotation shown in diagram 8.2 is calculated with the two displacement transducer DZ3/4 in z-direction behind the fuselage clevis test rig structure (Y=±300mm).

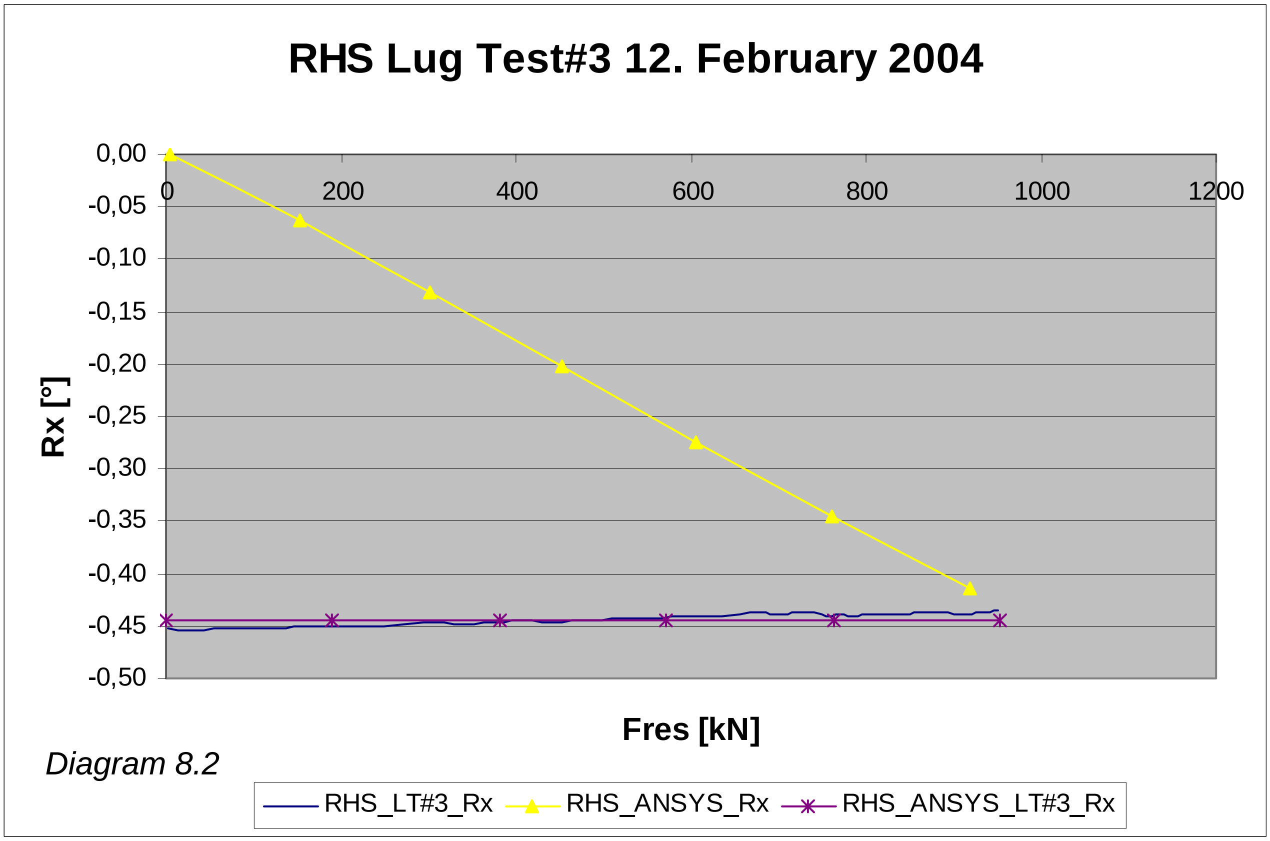
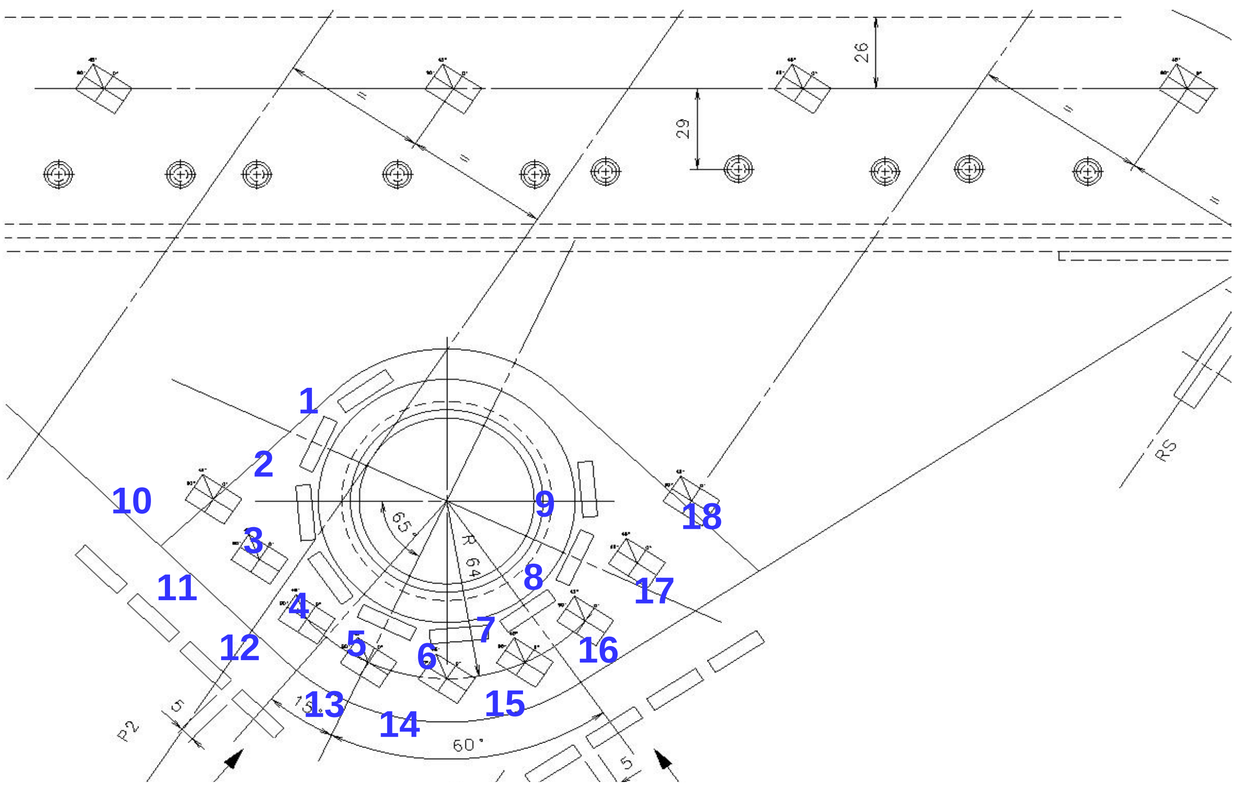


Diagram 8.2

8.2 Strain Result Comparison [Test 4 Fres=953kN]

For the inboard and outboard faces of the lug the tangential strains from the gauges E01 to E09 and the maximum principal strains from the rosettes R10 to R18 are plotted together with the calculated values from the RHS subcomponent test analysis in fig. 8.1 to 8.4 for a resultant load of Fres = 890 kN (the measured values are taken from the nearest load step and are not interpolated).



The measured strain values of the **Lug Test#2 specimen** are compared to

- Lug Test#1 specimen
- RHS ANSYS nonlinear contact model (Vertical stabilizer attached to the fuselage)
- LHS ANSYS nonlinear contact Lug Test#2 Rx=0.45°

Diagram 8.1 **E01o to E09o (Unidirectional / Outboard)**

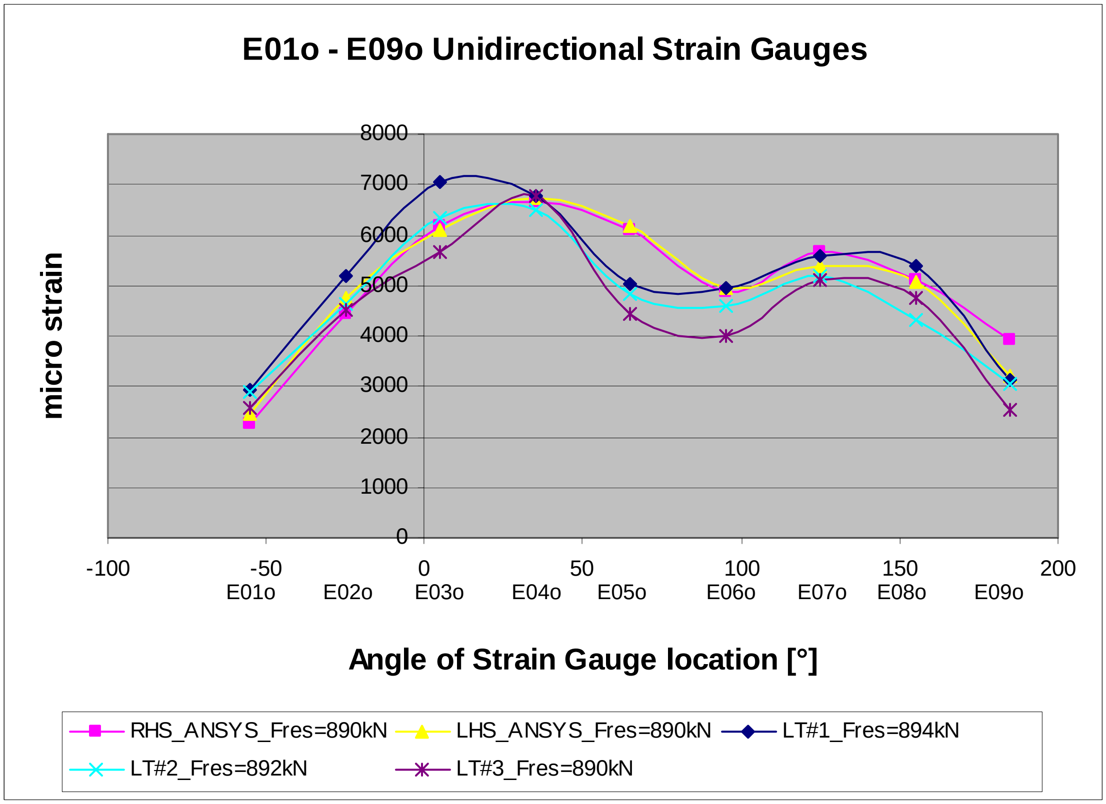


Diagram 8.2 **E01i to E09i (Unidirectional / Inboard)**

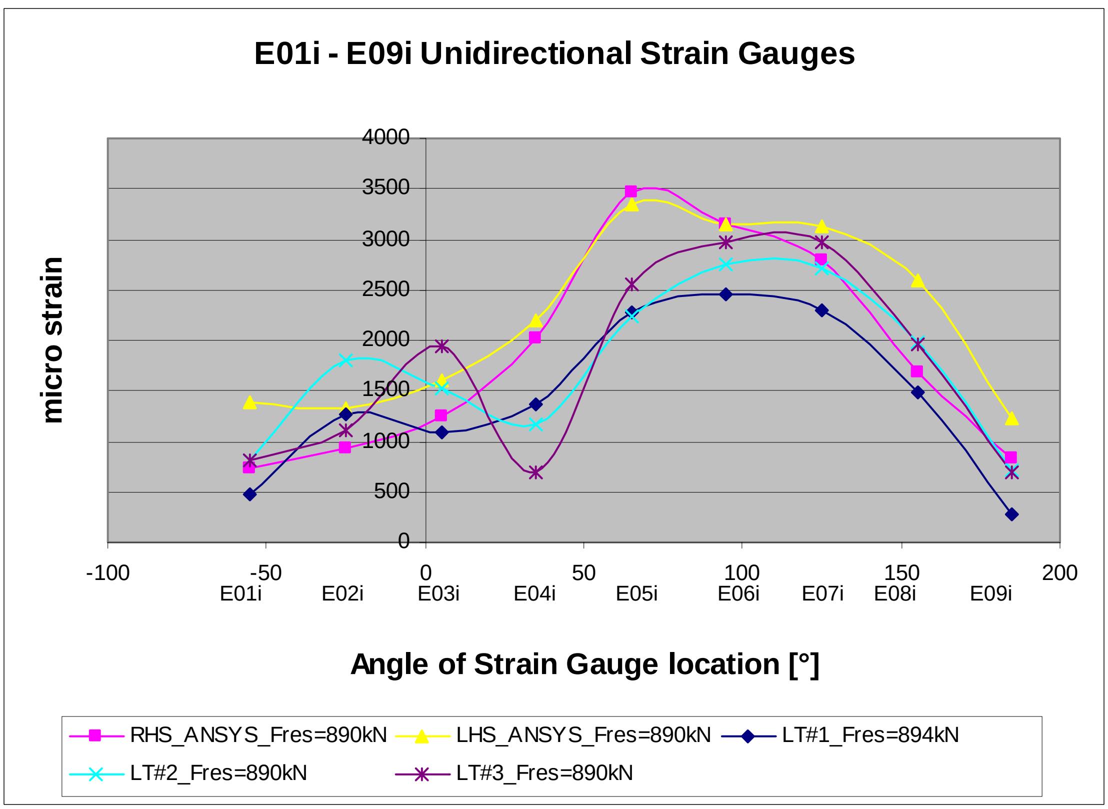


Diagram 8.3 **R10o to R18o (Rosettes / SN1 principle strain / outboard)**

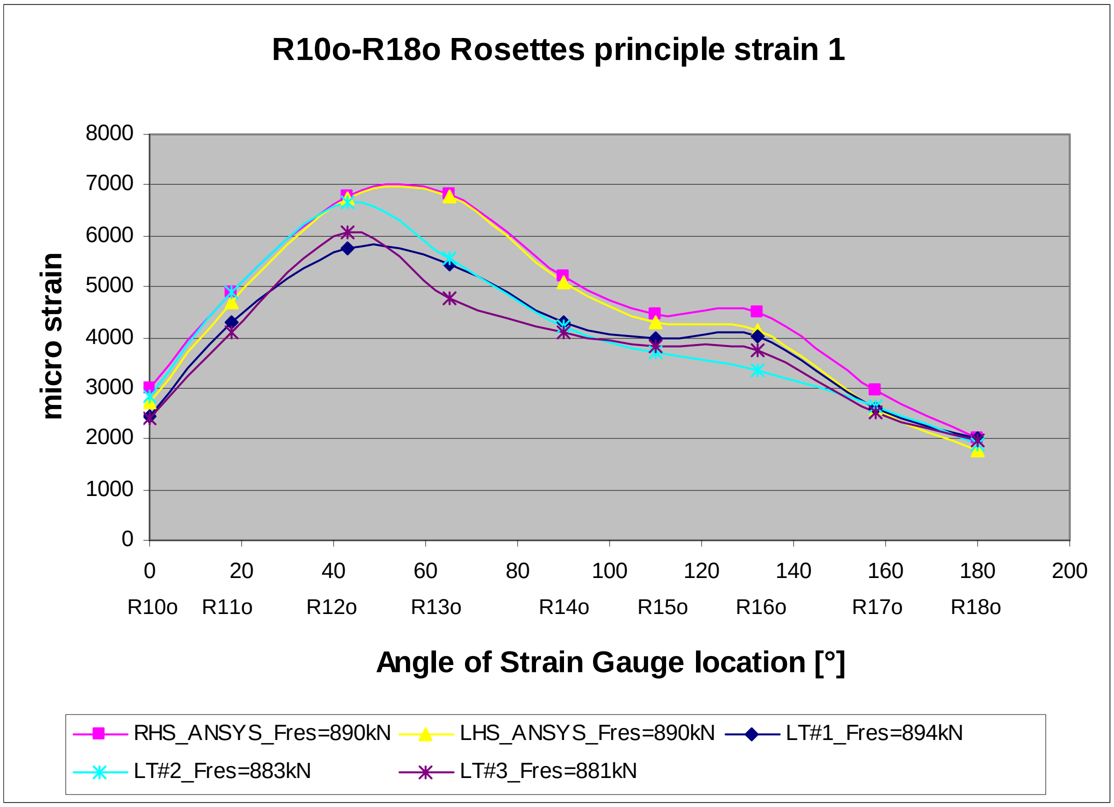
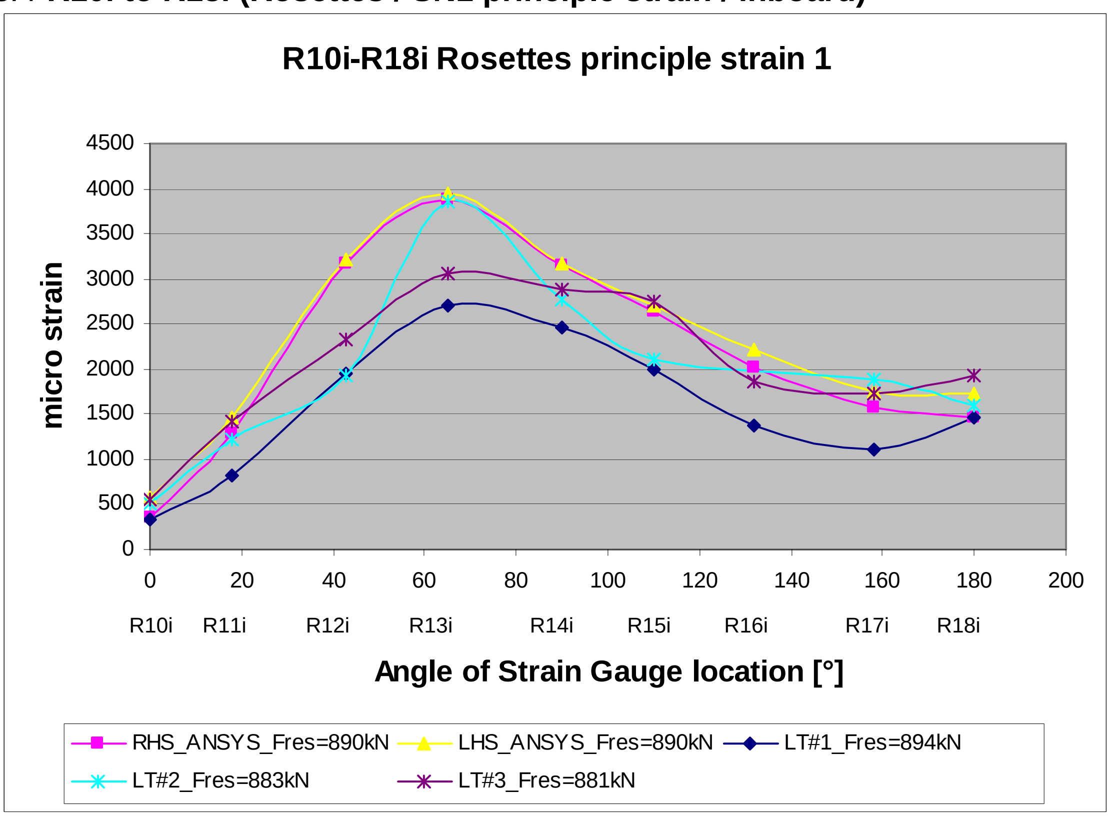


Diagram 8.4 **R10i to R18i (Rosettes / SN1 principle strain / inboard)**



9. Summary

The objective of this report is to demonstrate, that the test principles which are applied to the subcomponent tests are suitable to represent the behaviour of the RHS rear lug during the accident of flight AAL587.

This has been shown by validation of the subcomponent test analysis model results with the measured strains from the tested lugs and the comparison of the calculated strains from the global/local FEA.

The calculated strains are in good agreement with the measurements from strain gauges applied to the test parts around the pin hole.