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

December 5, 2003

ADDENDUM NUMBER 5 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, LHS Lug sub-component test #1 FEM analysis"

AIRBUS	**Technical Note**	

Report Nr.: TN – ESGC – 1020/03

Author:
Department.:

Title

AAL587 Airbus Structure Investigation

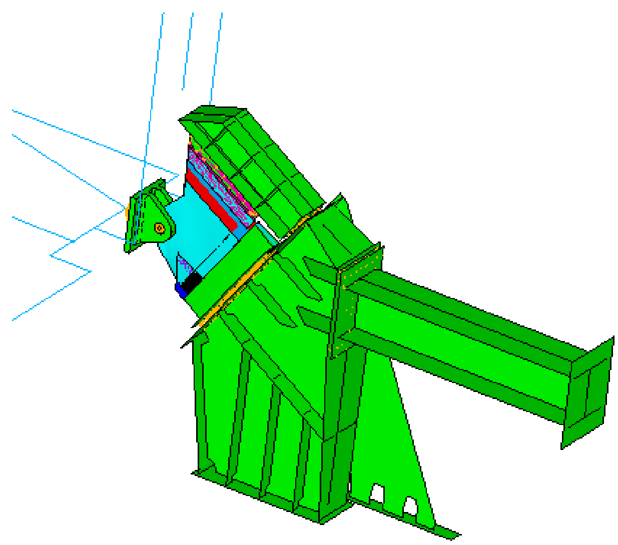
LHS Lug sub-component test#1 FEM analysis

Date: 08.12.2003

Summary:

For the verification of the FE-analysis which are performed with the global 2D and the local 3D model (nonlinear contact analysis) a correlation between a lug test and test analysis has to be done.

This report describes the analysis of the test with ANSYS 3D model including all contact surfaces at the lug/pin/fuselage clevis interface. The analysis model considers also all important parts of the test rig for load application.



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	1	10.11.2003	26		
	2	02.12.2003	32	18-32 ; Format change DINA4 to LETTER	
	3	08.12.2003	32		

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1. Introduction

For the verification of the FE-analysis which are performed with the global 2D and the local 3D model (nonlinear contact analysis) a correlation between a lug test and test analysis has to be done.
This report describes the analysis of the test with ANSYS 3D model including all contact surfaces at the lug/pin/fuselage clevis interface. The analysis model considers also all important parts of the test rig for load application.

2. Description of the Lug Test#1 specimen

The skin panel and the precured lug part of the accident VTP were manufactured with the material system, which is identical to the material used for the test specimen.

The test specimen is part of a LHS skin panel which was used for quality test purpose. The lug area (see figure 2.1) is prepared for clamping to the test rig by removal of the stringer run outs (webs and inboard flange) and reinforcement by additional plies in the clamping area.

Figure 2.1

Figure 2.2 shows the test specimen equipped with steel angles and aluminum metal sheet doublers for installation into the test rig (see figure 2.3 and 2.4).

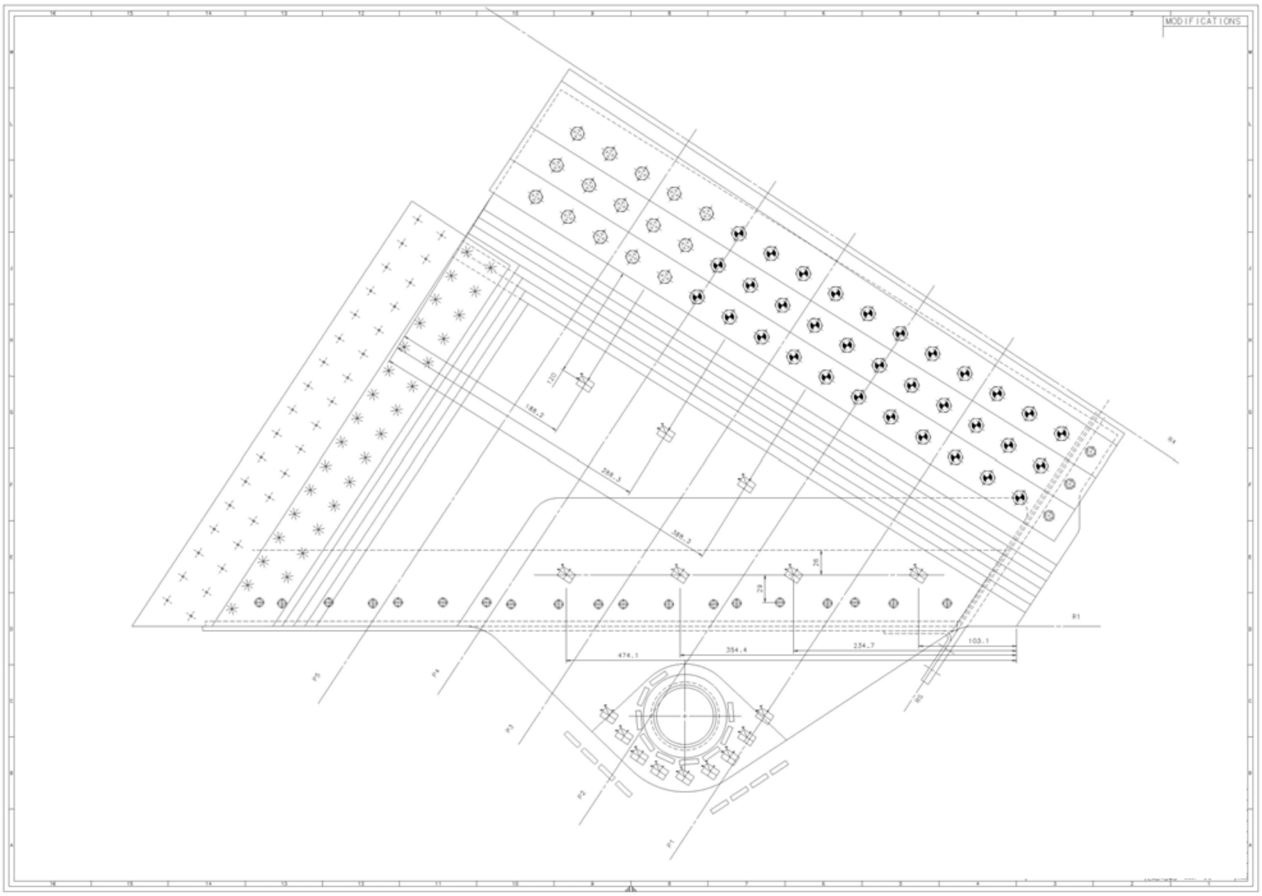


Figure 2.2

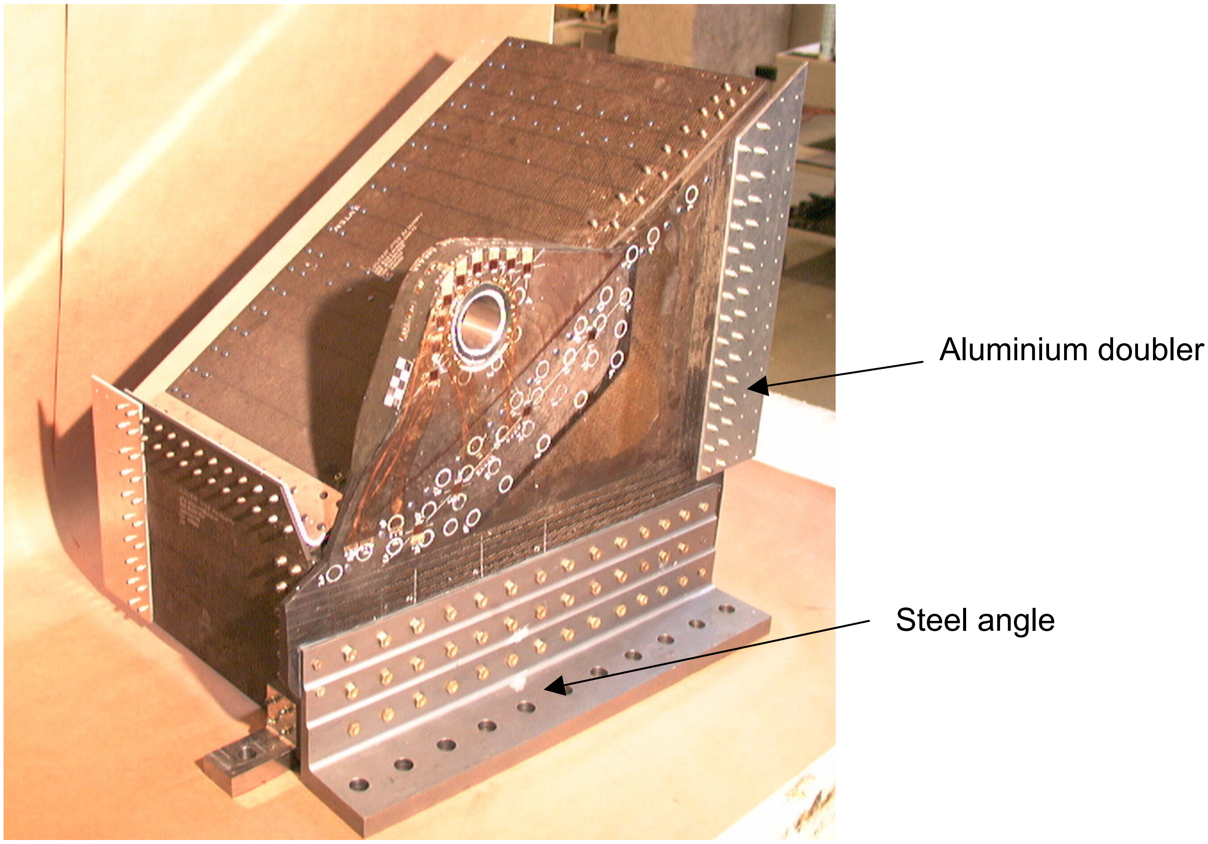


Figure 2.3

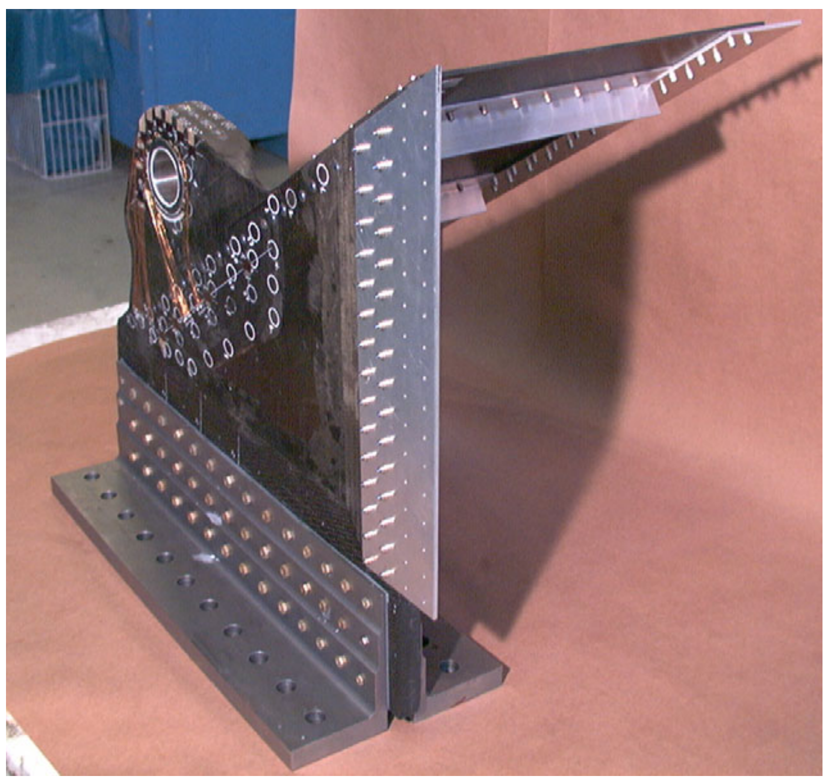


Figure 2.4

3. Fuselage clevis for the Lug Test#1

The stiffness of the clevis structure (see figure 3.1) used in the test rig has the same dimensions around the connection bolt and thus provide the same stiffness behavior as the original fuselage clevis (see figure 3.2). Figures 3.3 and 3.4 show the fuselage clevis with the bonded strain gauges.

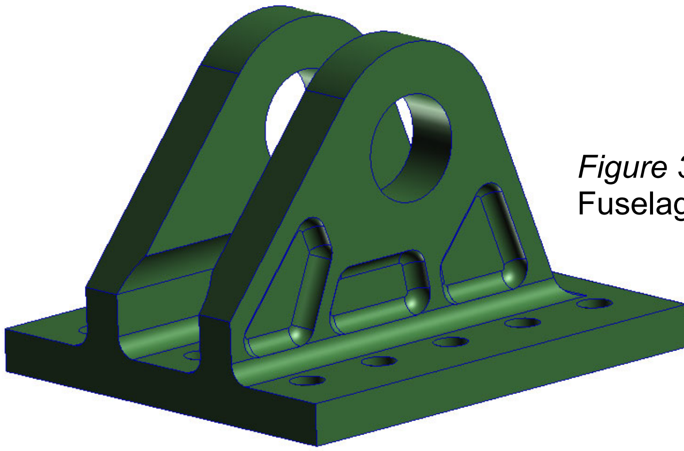


Figure 3.1
Fuselage clevis for Lug Test#1

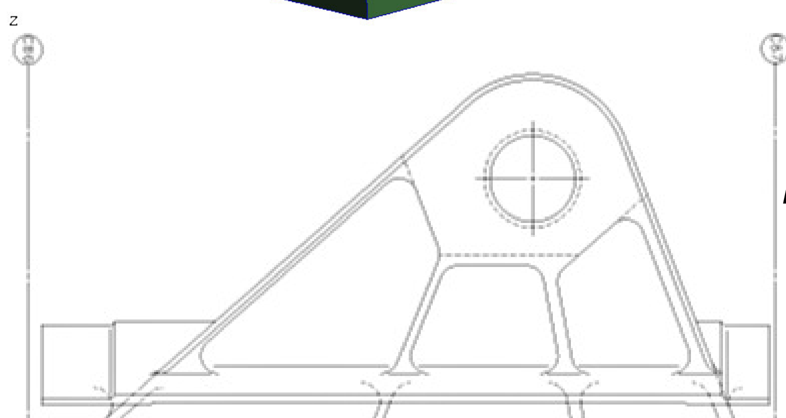


Figure 3.2

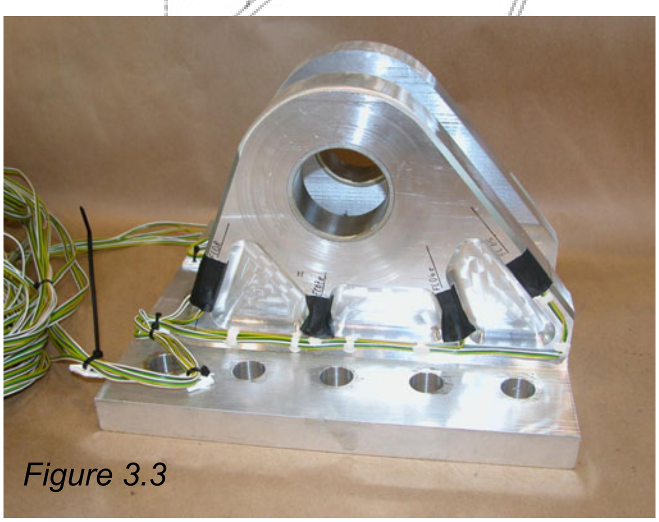


Figure 3.3

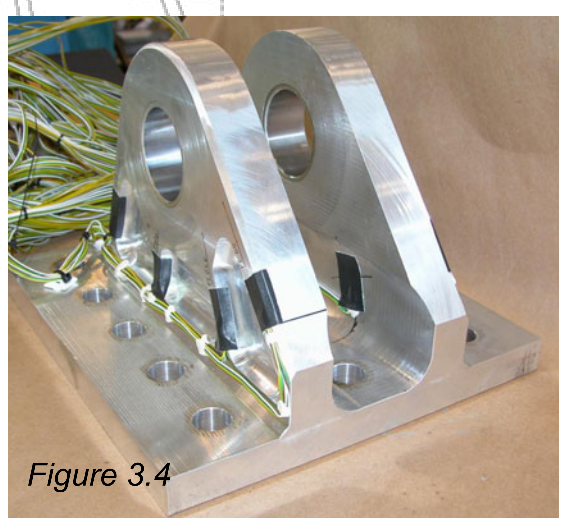


Figure 3.4

4. Description of the test rig

4.1 Global view

Figure 4.1 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.

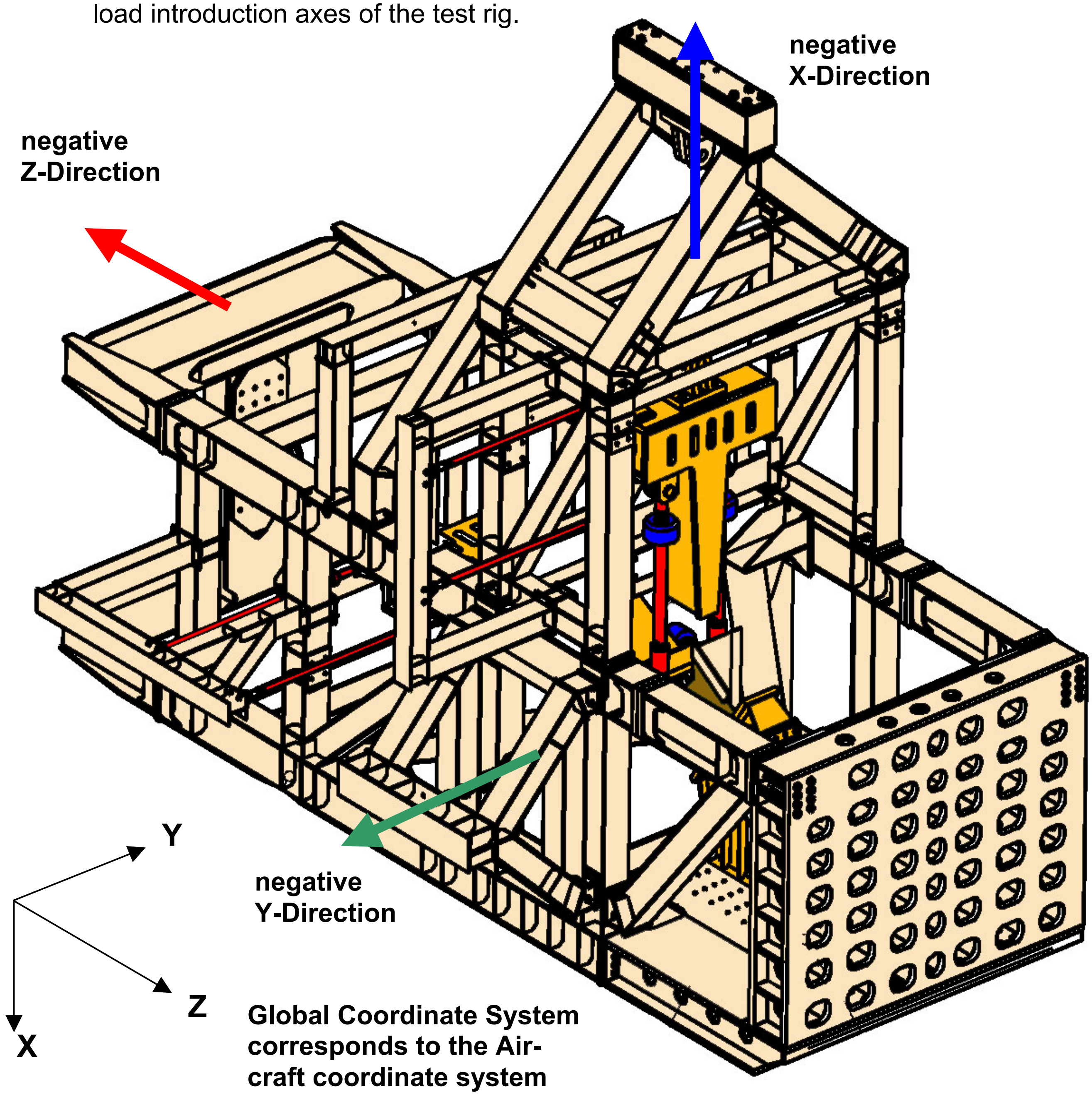


Figure 4.1

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

The figure 4.2 shows the load introduction components of the test rig and the location of the Lug Test#1 specimen itself.

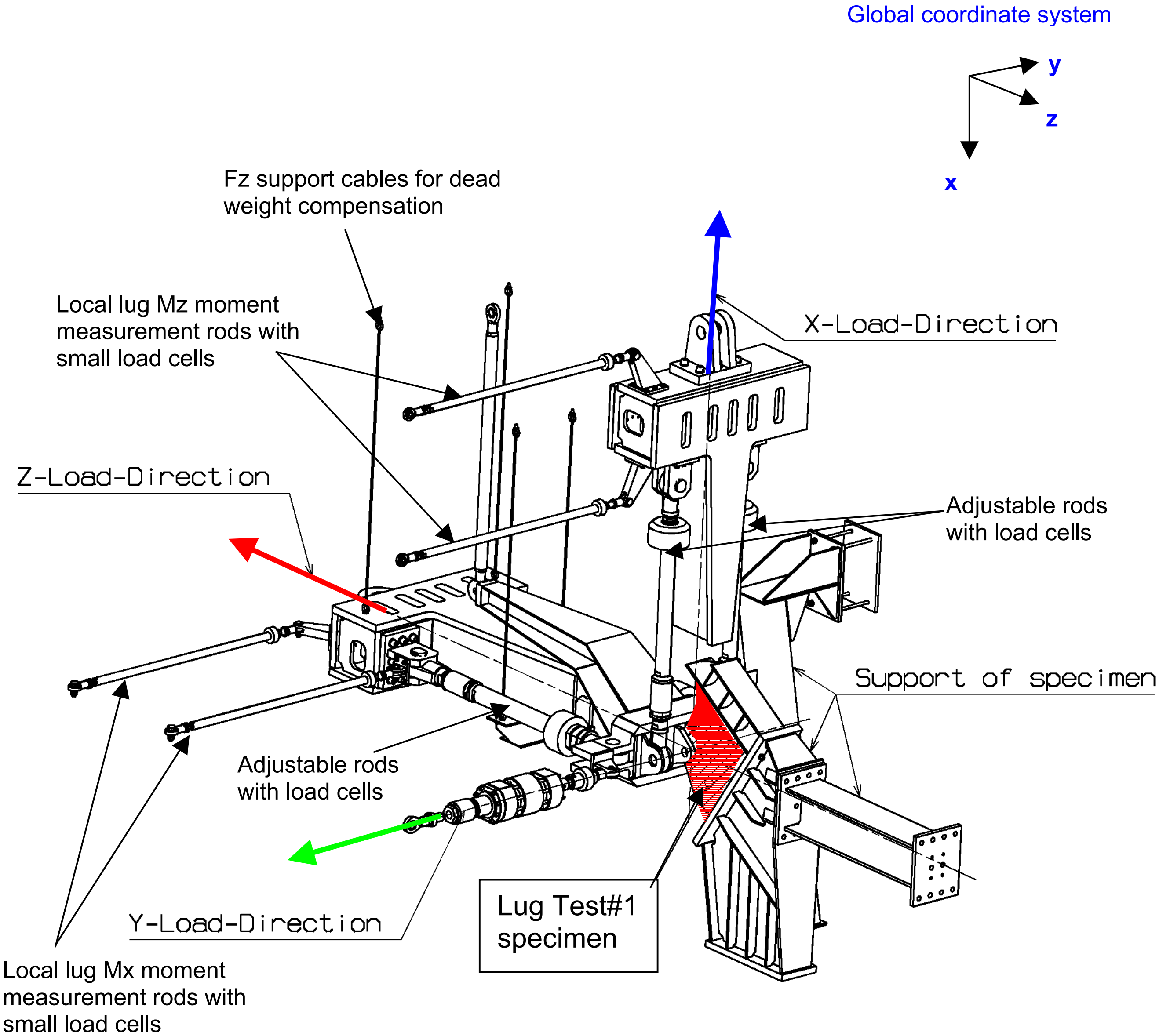


Figure 4.2

5. ANSYS LHS rear main lug contact model

5.1 Model description

The complete FEA-model for the lug test analysis includes the ANSYS LHS rear main lug contact model and all required parts for load introduction:

- Load introduction in the test rig for Fx, Fy and Fz according to the global coordinate system
- Main rods Z1/2 and X1/2 with the ability to apply a preadjusted local lug moment Mx and Mz by a rod length variation
- Moment reaction rods FMX1/2 and FMZ1/2 for the measurement of the local lug moments

See figure 5.1 global model view

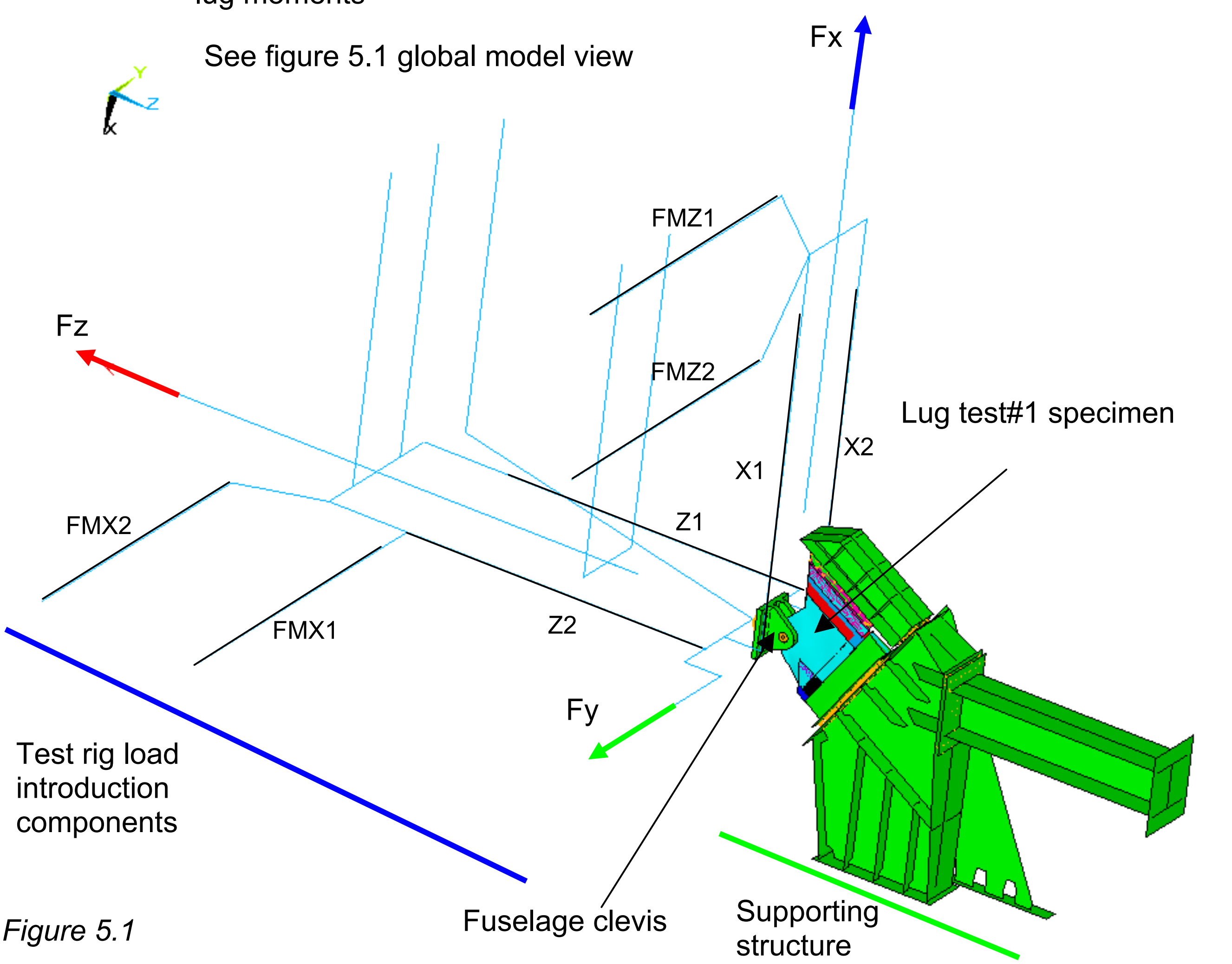


Figure 5.1

The test rig load introduction components are idealized by ANSYS ROD and BAR Elements which simulate the function of the test rig with the exception of the behavior of the bearing with respect to free play. The FEA model of the test specimen attached to the support structure and the fuselage clevis and its real counterpart is shown on figure 5.2 and 5.3.

Figure 5.2
FEA-model of the Lug Test#1 specimen

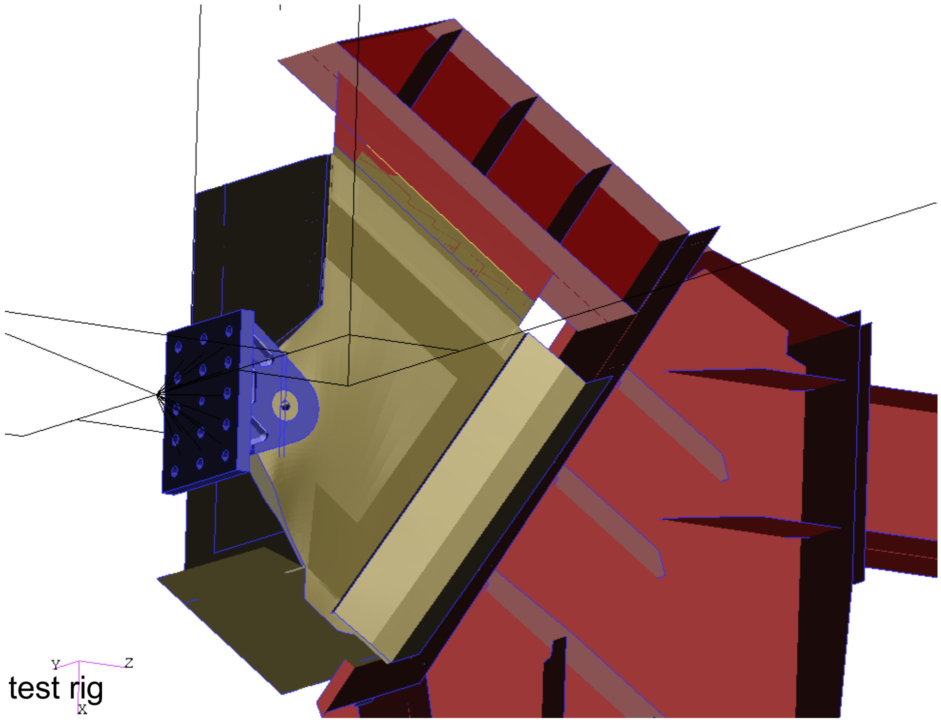
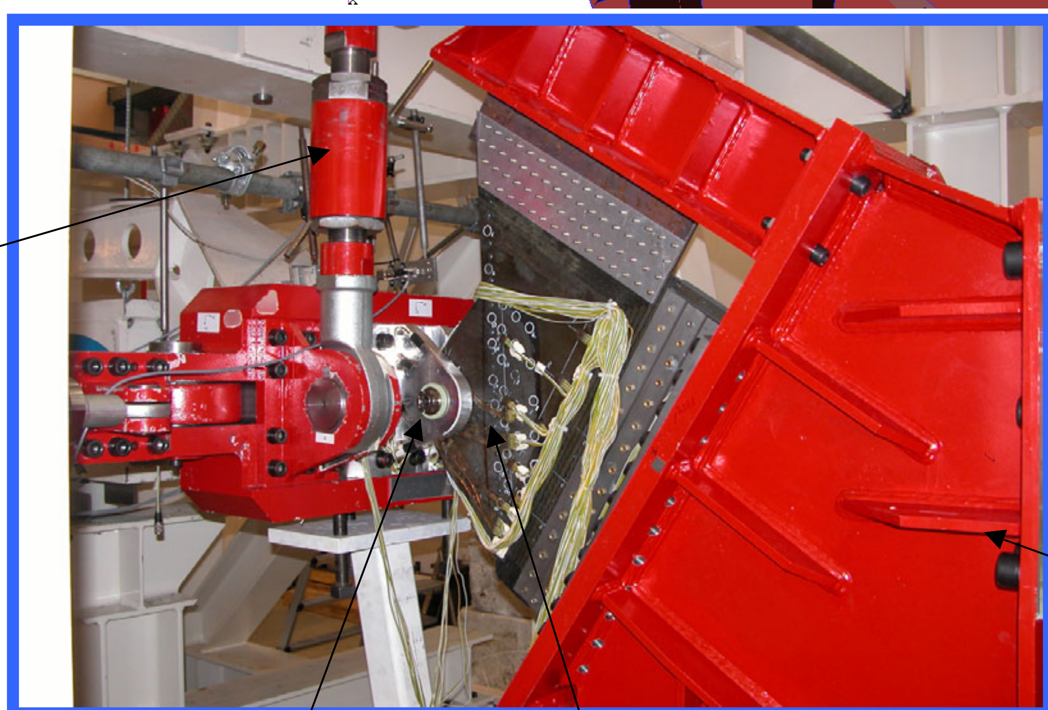


Figure 5.3
Lug Test#1 specimen in the test rig



5.2 FEA Idealization of the test specimen

According to the described Lug Test#1 drawing in chapter 2 the ANSYS Lug Test#1 model was created (see figure 5.4 and 5.5).

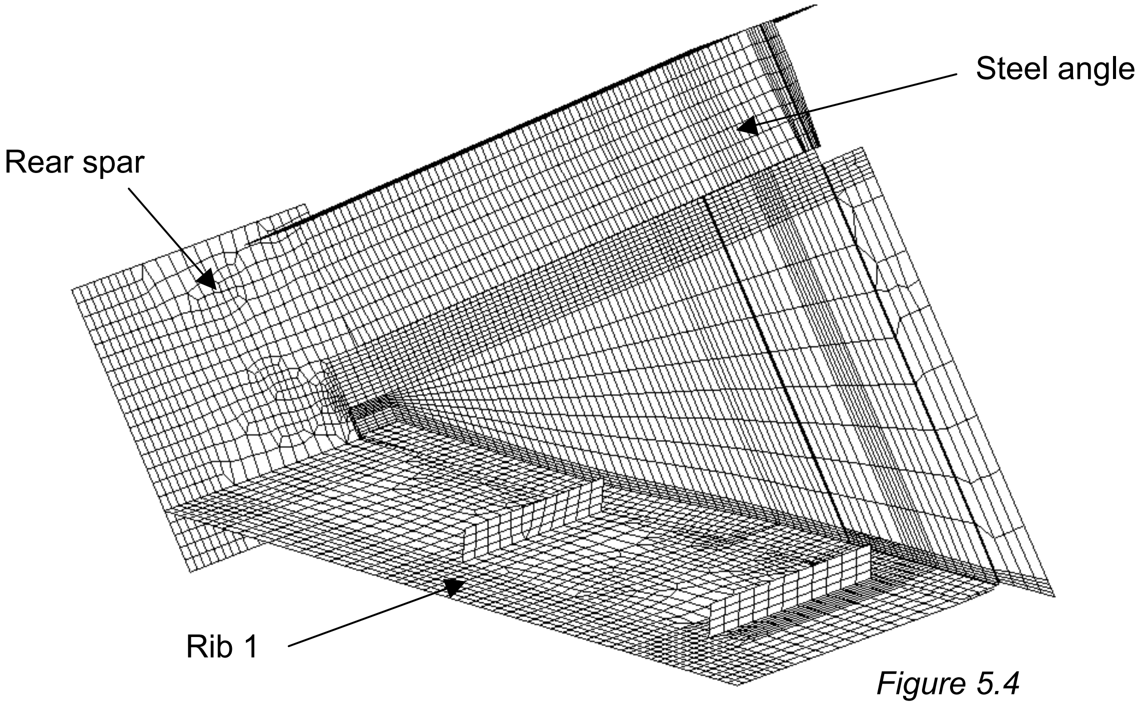


Figure 5.4

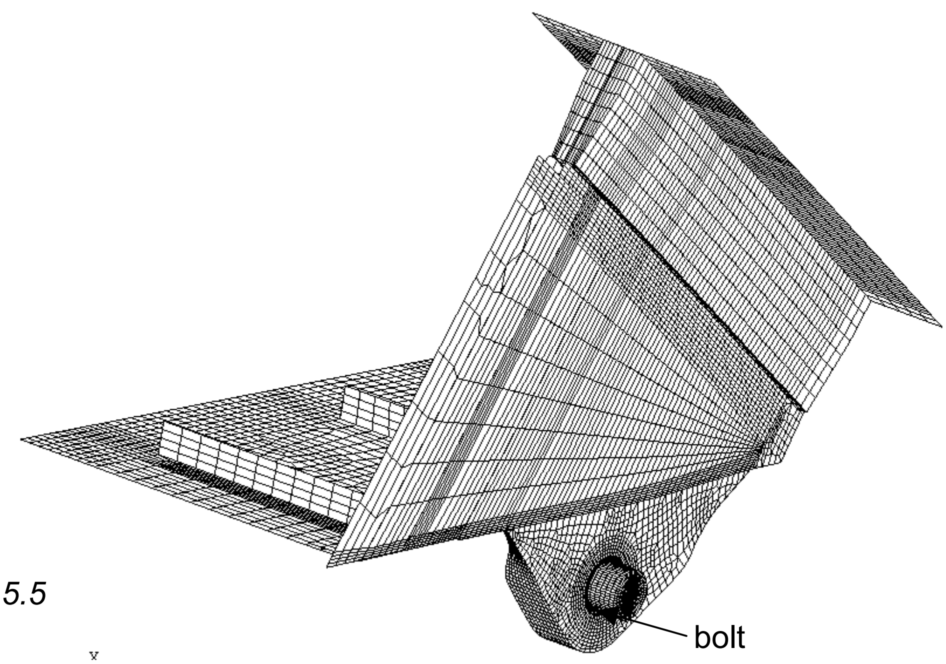


Figure 5.5

5.3 Fuselage clevis

To model the complete connection bolt behavior in the Lug Test#1 FEA-model the fuselage clevis was also modeled with solid elements (see figure 5.6).

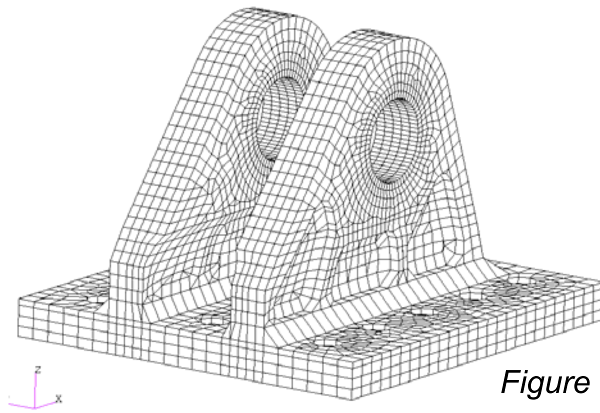


Figure 5.6

5.4 Test rig supporting structure

The Lug Test#1 specimen was directly connected to a steel framework supporting structure. To model the deformation behavior of the Lug Test#1 specimen the supporting structure was included in the ANSYS model (see figure 5.7). The Lug Test#1 specimen was connected with RBE2-Elemeents at the bolt bonding locations to the supporting structure.

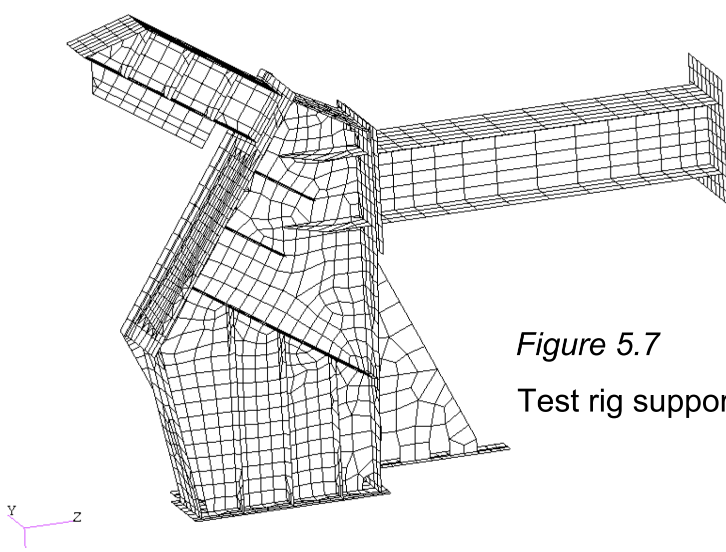


Figure 5.7

Test rig supporting structure

5.5 ANSYS Contact surface definition

The contact surface definitions are the same for all ANSYS models (see figure 5.8 to 5.11). The ANSYS contact surface allows physically opening and closing gaps between the meshes of the contact borders with a friction coefficient of 0.3.

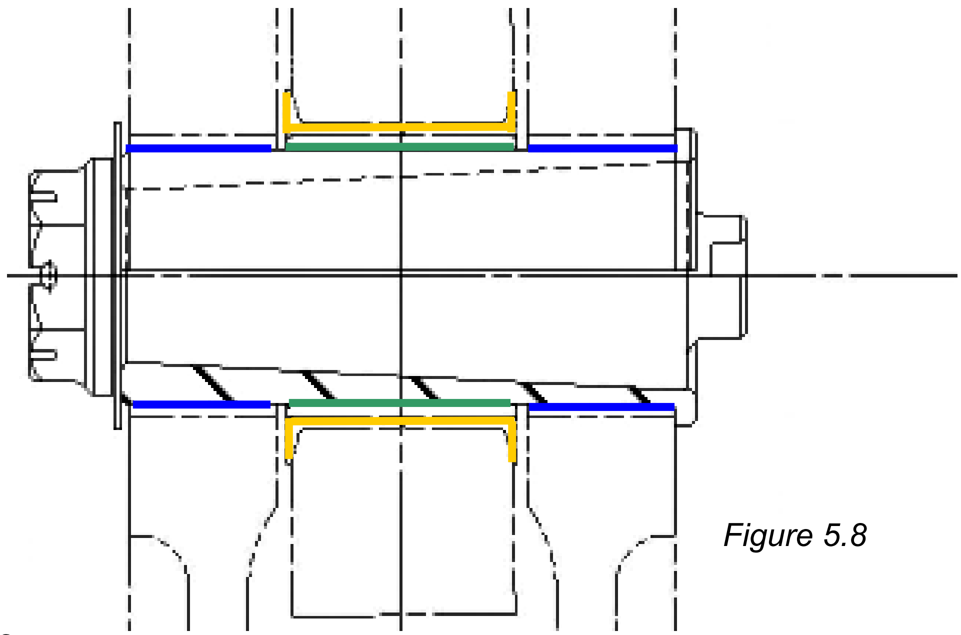


Figure 5.8

<u>Contact surfaces:</u>

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

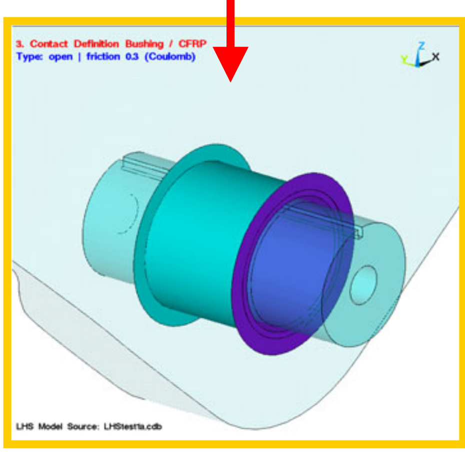


Figure 5.9

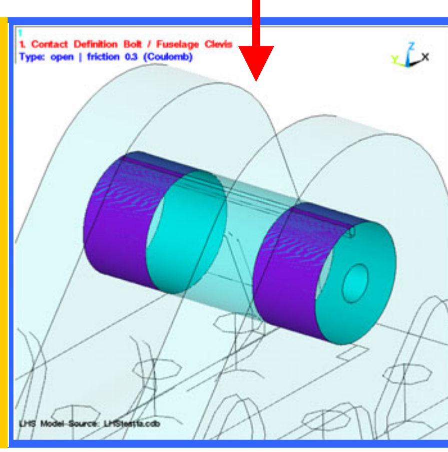


Figure 5.10

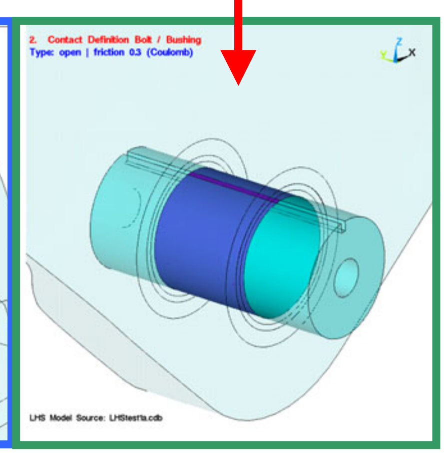


Figure 5.11

6. Reaction force & moment calculation in ANSYS [nonlinear contact]

The local lug reactions are calculated in the ANSYS model for every load step. At a defined cut through the fuselage clevis (see figure 6.1) the summation of the grid point force balance in this cut gives the local lug reaction including respective forces & moments. Also the deformation of the complete bolt area is taken into account for this procedure.

Section plane

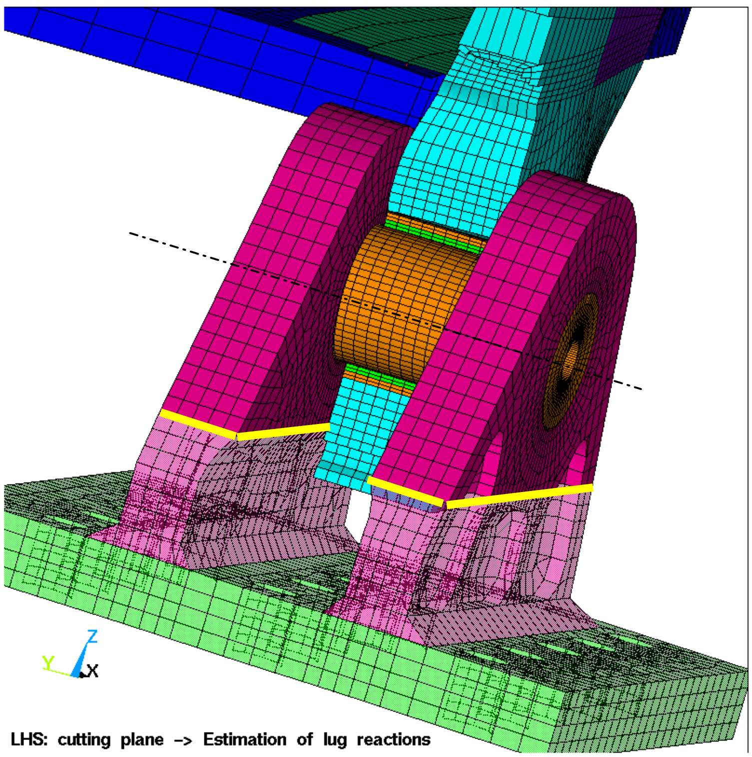
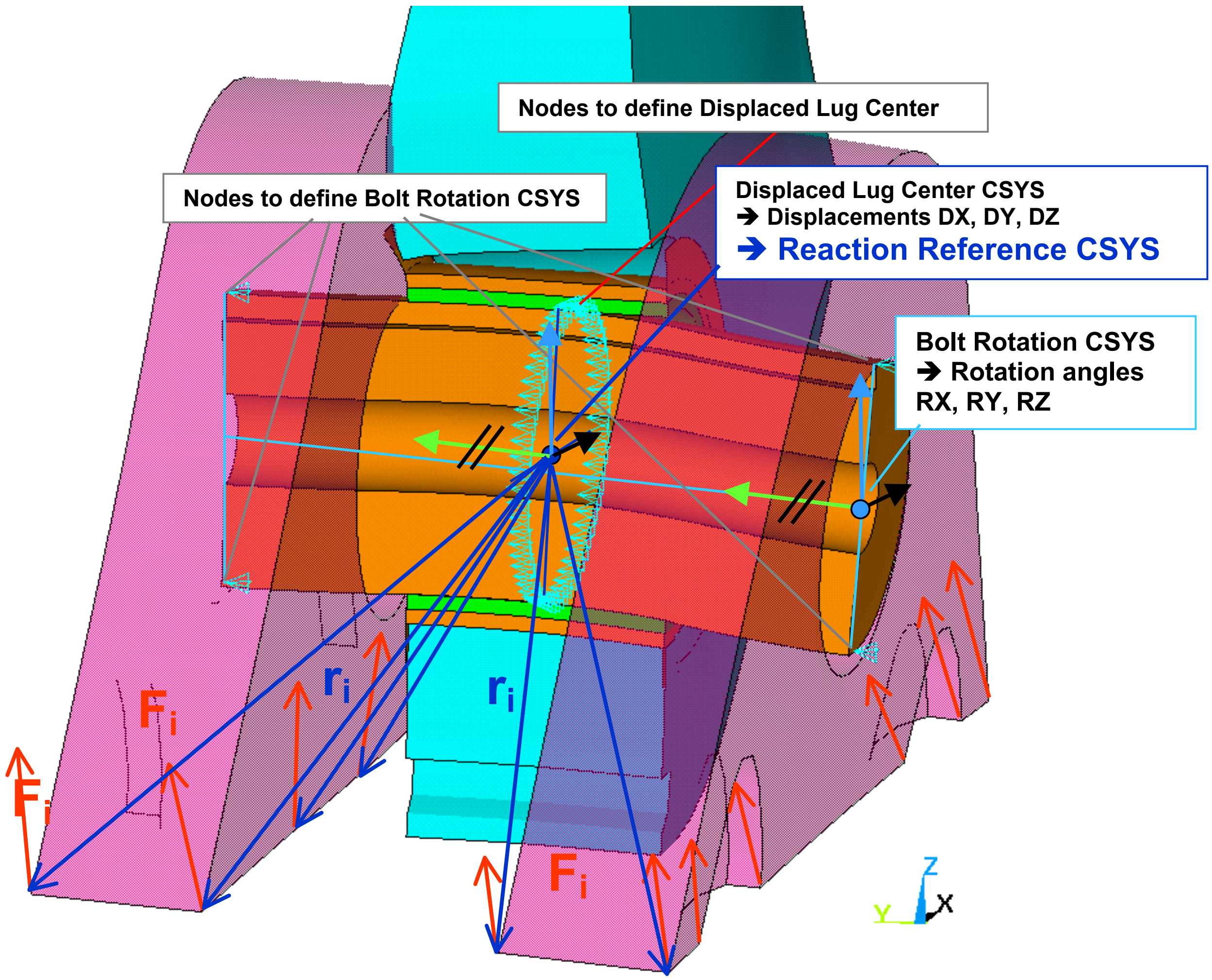


Figure 6.1

As shown in figure 6.2 the calculation of bolt rotation and lug reactions on displaced 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 6.2

7. Application of load cases

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

In agreement with NTSB, NASA, American Airlines and Airbus the W375 MOD load vector from the NASA calculations is used for all FE-Analyses which are compared with the test (see table 7.1).
For this calculation no bolt rotation about the bolt x-axis was pre-adjusted with the main rod turnbuckles.

Table 7.1

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

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

For the second analysis model the same W375 MOD load vector was chosen as in chapter 7.1.
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 turn-buckles.

8. FEA results

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

8.1.1 Rear main local lug forces & moments

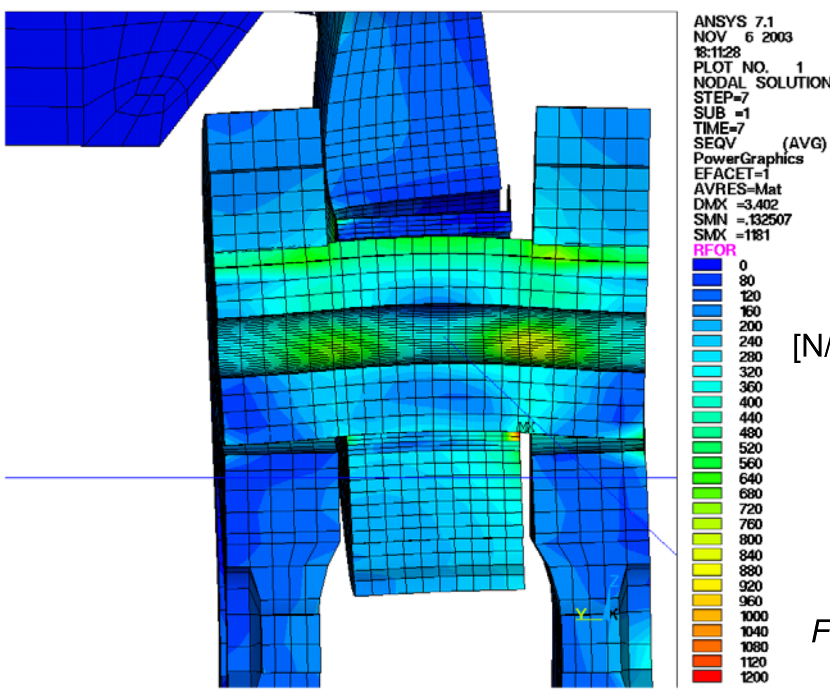
Table 8.1

Fx	Fy	Fz	Fres	Mx	Mz	Rx	Rz
[kN]	[kN]	[kN]	[kN]	[Nm]	[Nm]	[°]	[°]
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

8.1.2 Deformation & Rx bolt rotation

The cross section through the CFRP lug, the bolt and the fuselage fitting illustrates the connection bolt contact situation under max. applied loading condition (see figure 8.1 and 8.2). The color scale is von Mises equivalent stress distribution.



[N/mm²]

Figure 8.1

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

Rx bolt rotation

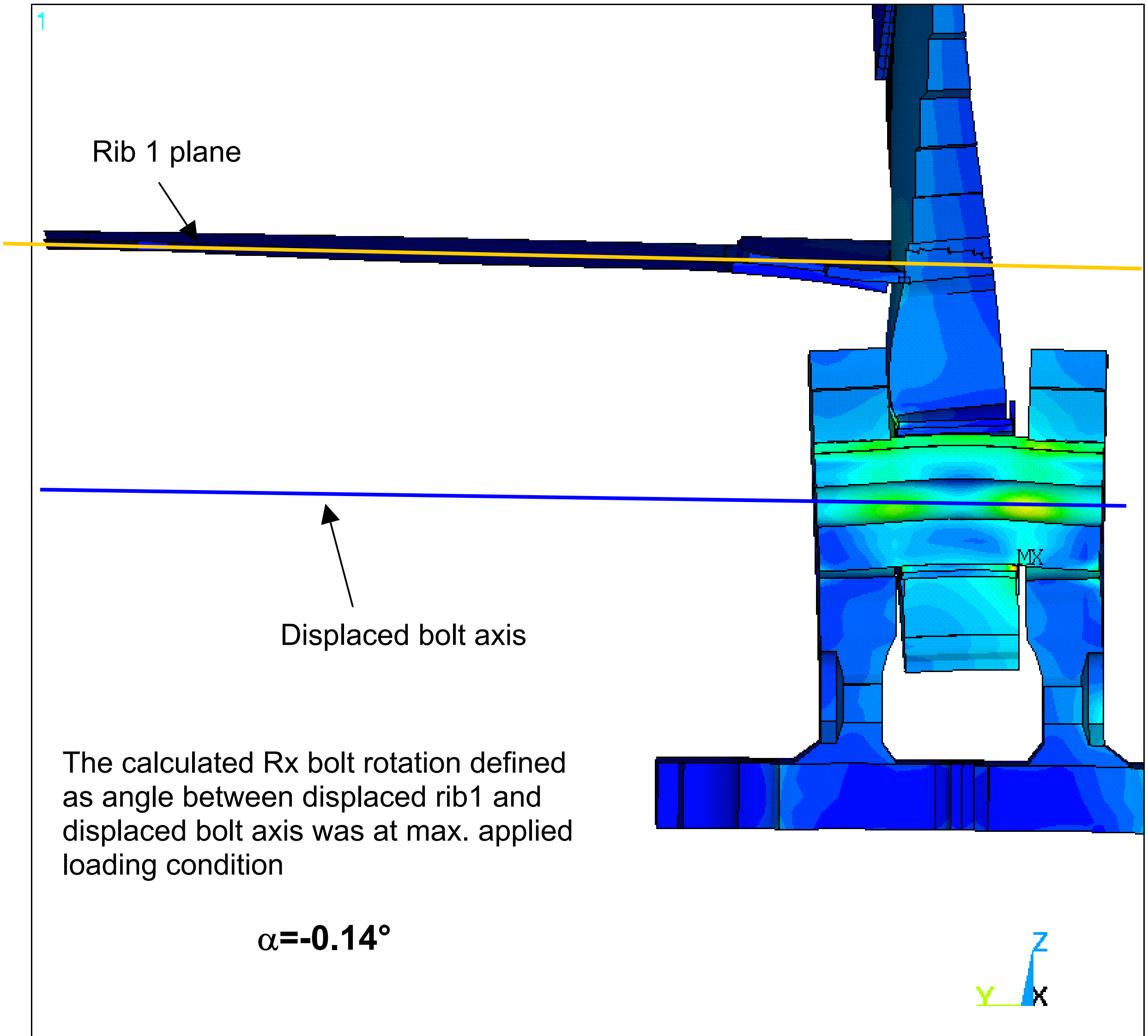


Figure 8.2

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

8.1.3 Contact status and pressure

Contact surface between:	Bushing & CFRP Lug

Contact status
red + green => contact
blue => gap

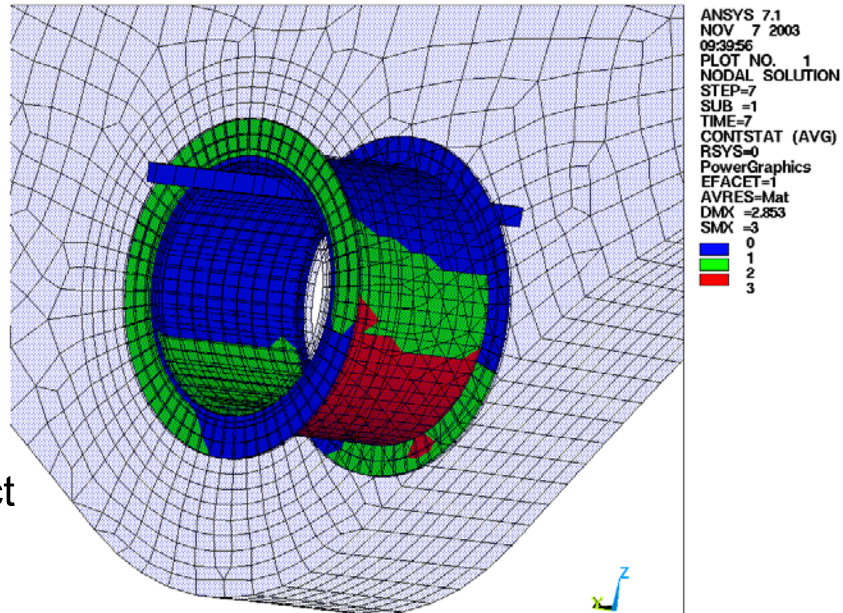


Figure 8.3

Contact pressure distribution

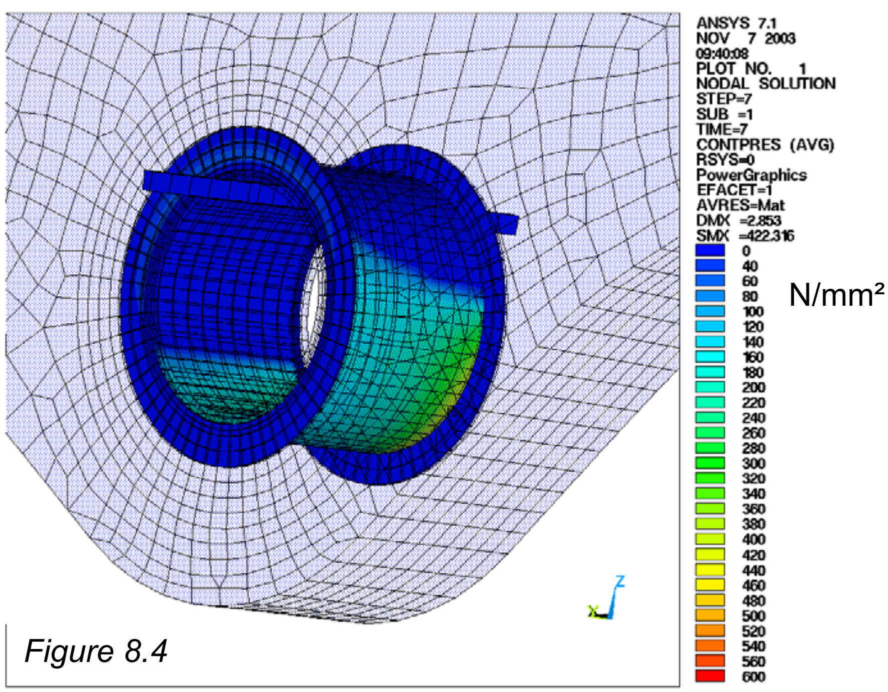


Figure 8.4

Contact surface between:	Bolt & Bushing

Contact status
red + green => contact
blue => gap

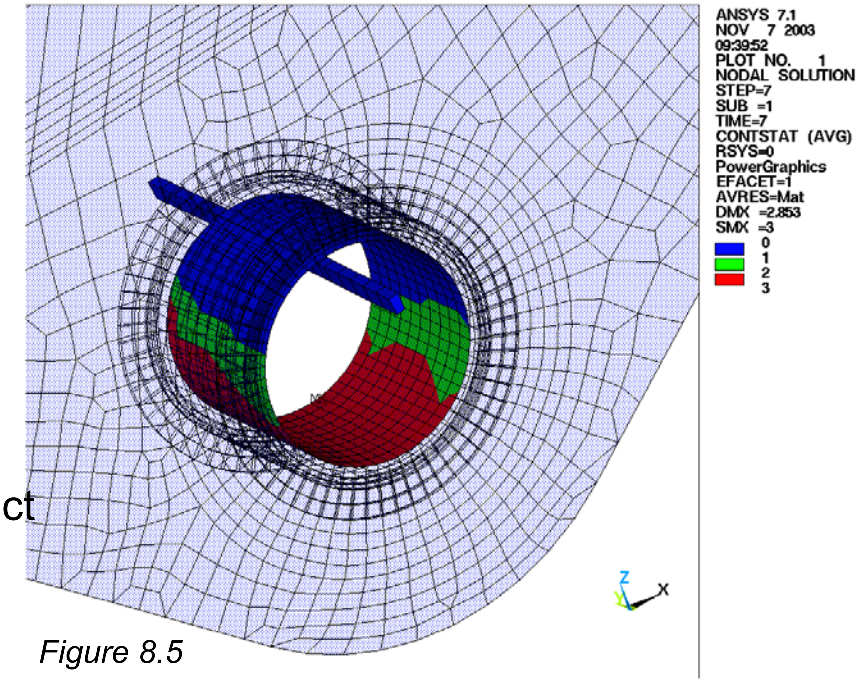


Figure 8.5

Contact pressure distribution

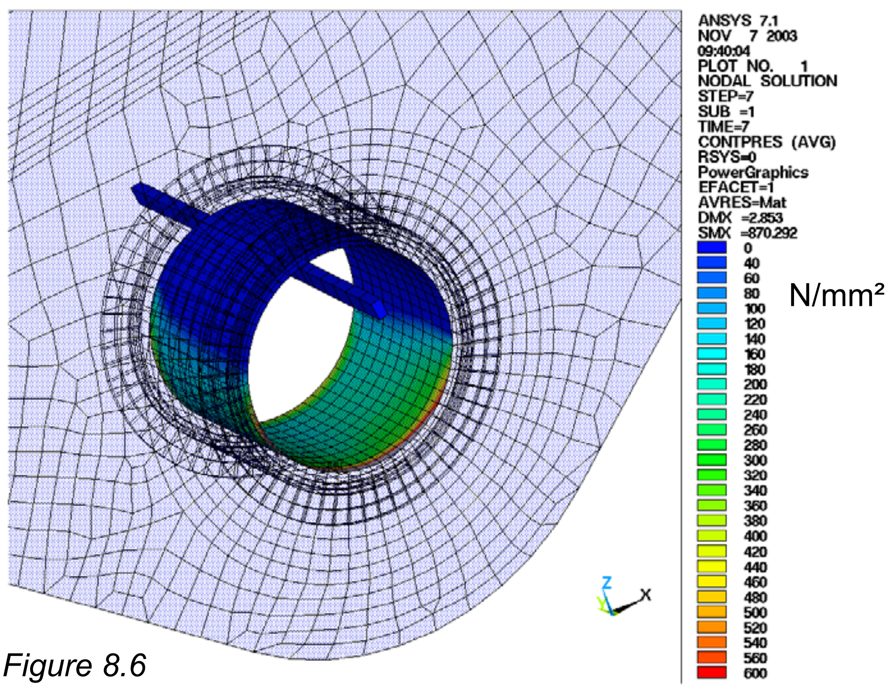


Figure 8.6

Contact surface between:	Bolt & Fuselage clevis

Contact status

red + green => contact

blue => gap

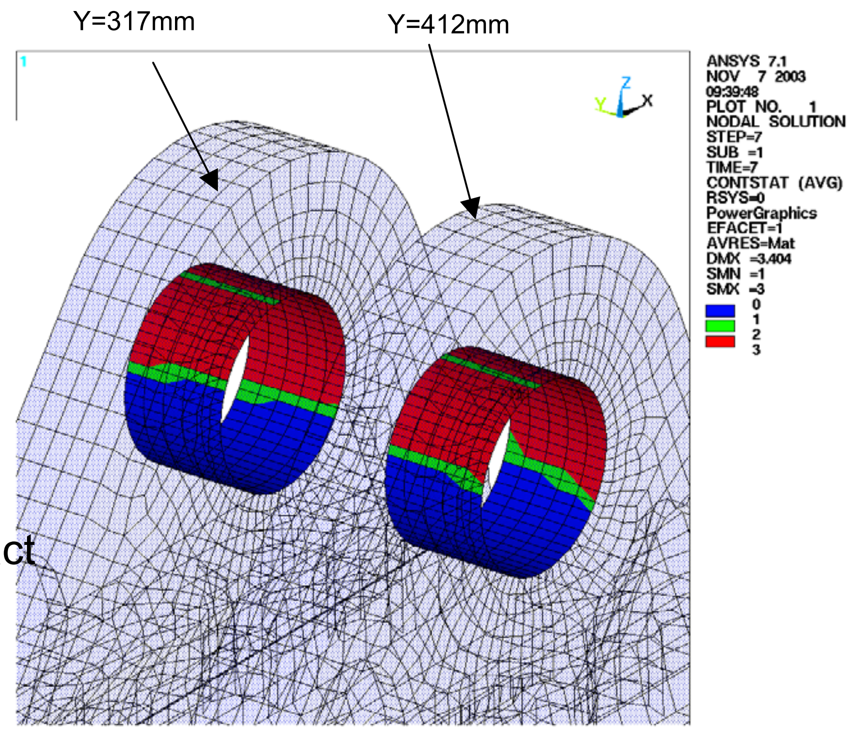


Figure 8.7

Contact pressure distribution

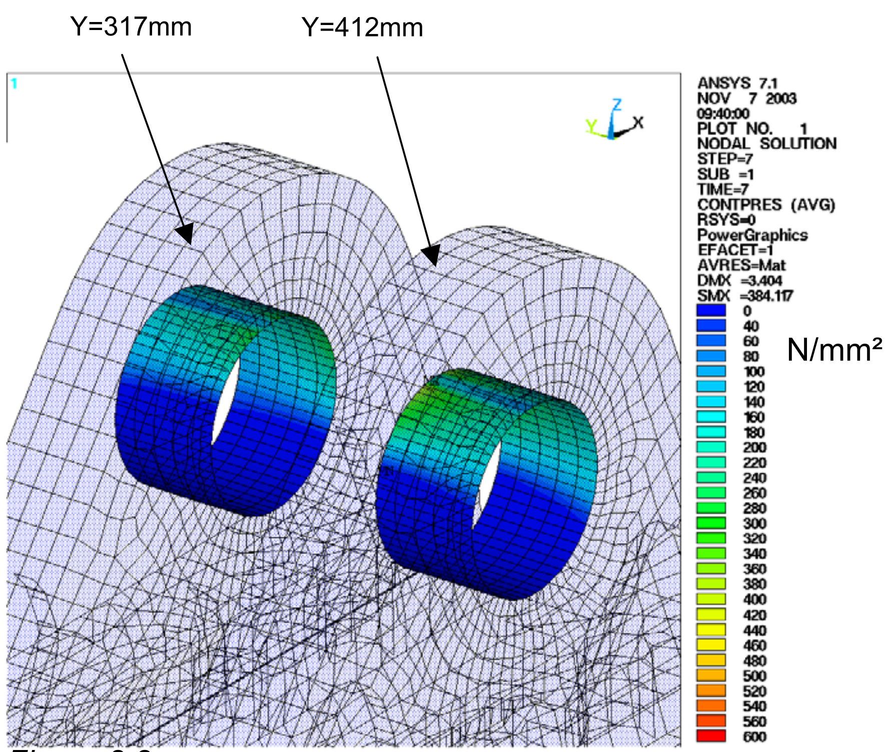
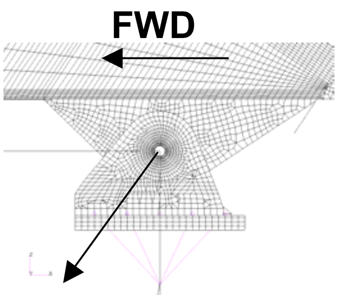


Figure 8.8

8.1.4 Strain distribution at the pin hole



Fres=953kN

LHS model

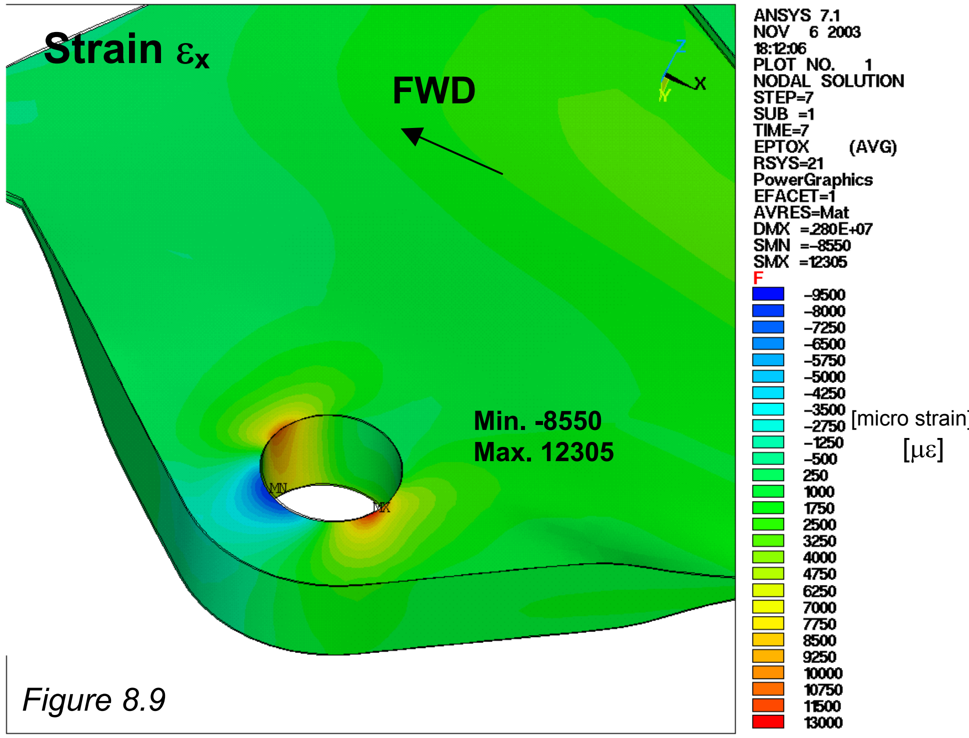


Figure 8.9

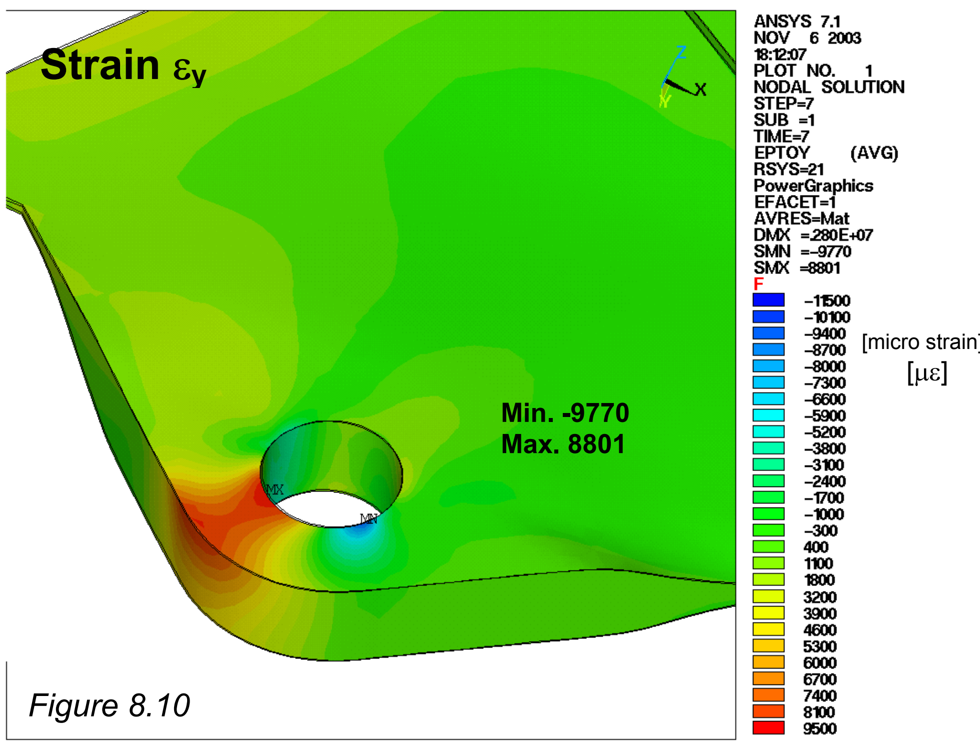
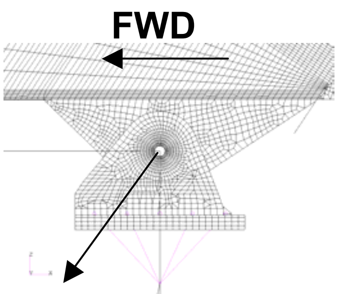


Figure 8.10

All views from outboard
Strain distribution in material coordinate system



LHS model

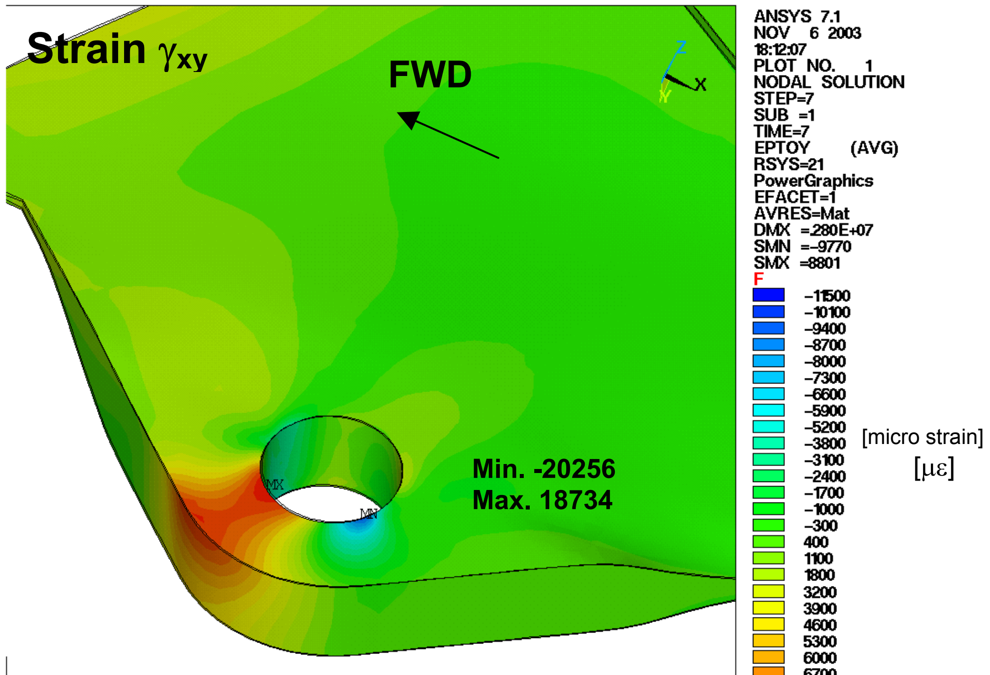


Figure 8.11

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

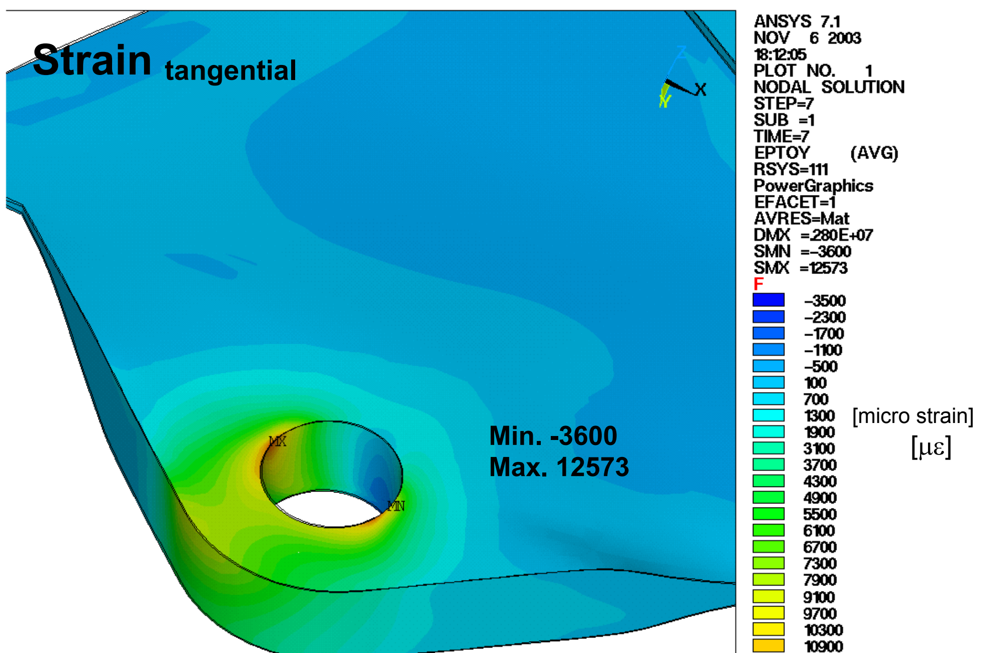


Figure 8.12

All views from outboard
Strain distribution in material coordinate system

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

8.2.1 Rear main local lug forces & moments

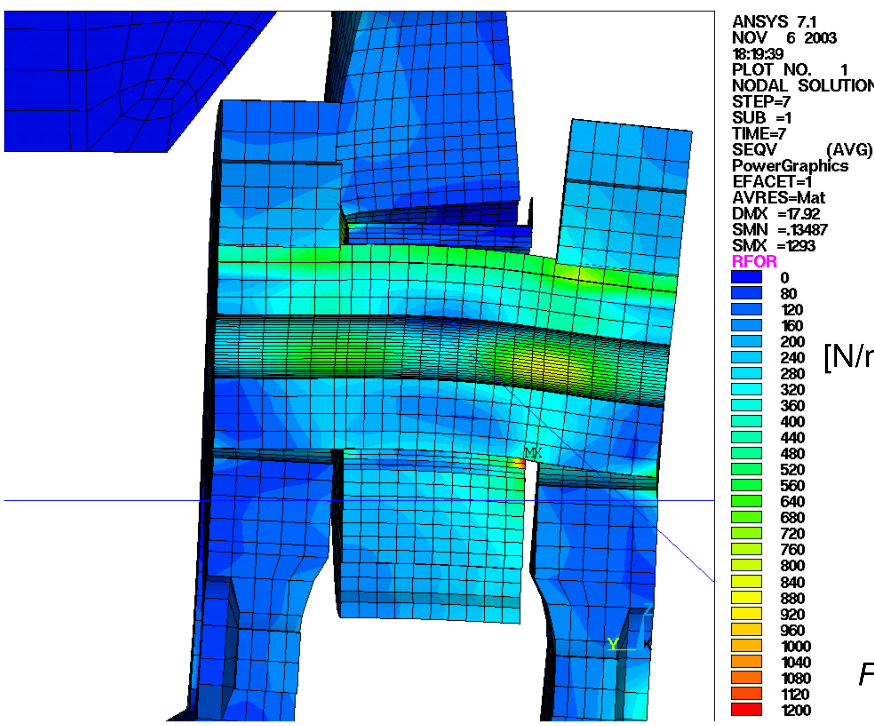
Table 8.2

Fx	Fy	Fz	Fres	Mx	Mz	Rx	Rz
[kN]	[kN]	[kN]	[kN]	[Nm]	[Nm]	[°]	[°]
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

8.2.2 Deformation & Rx bolt rotation

The cross section through the CFRP lug, the bolt and the fuselage fitting illustrates the connection bolt contact situation under max. applied loading condition (see figure 8.13 and 8.14). The color scale is von Mises equivalent stress distribution.



[N/mm²]

Figure 8.13

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

Rx bolt rotation

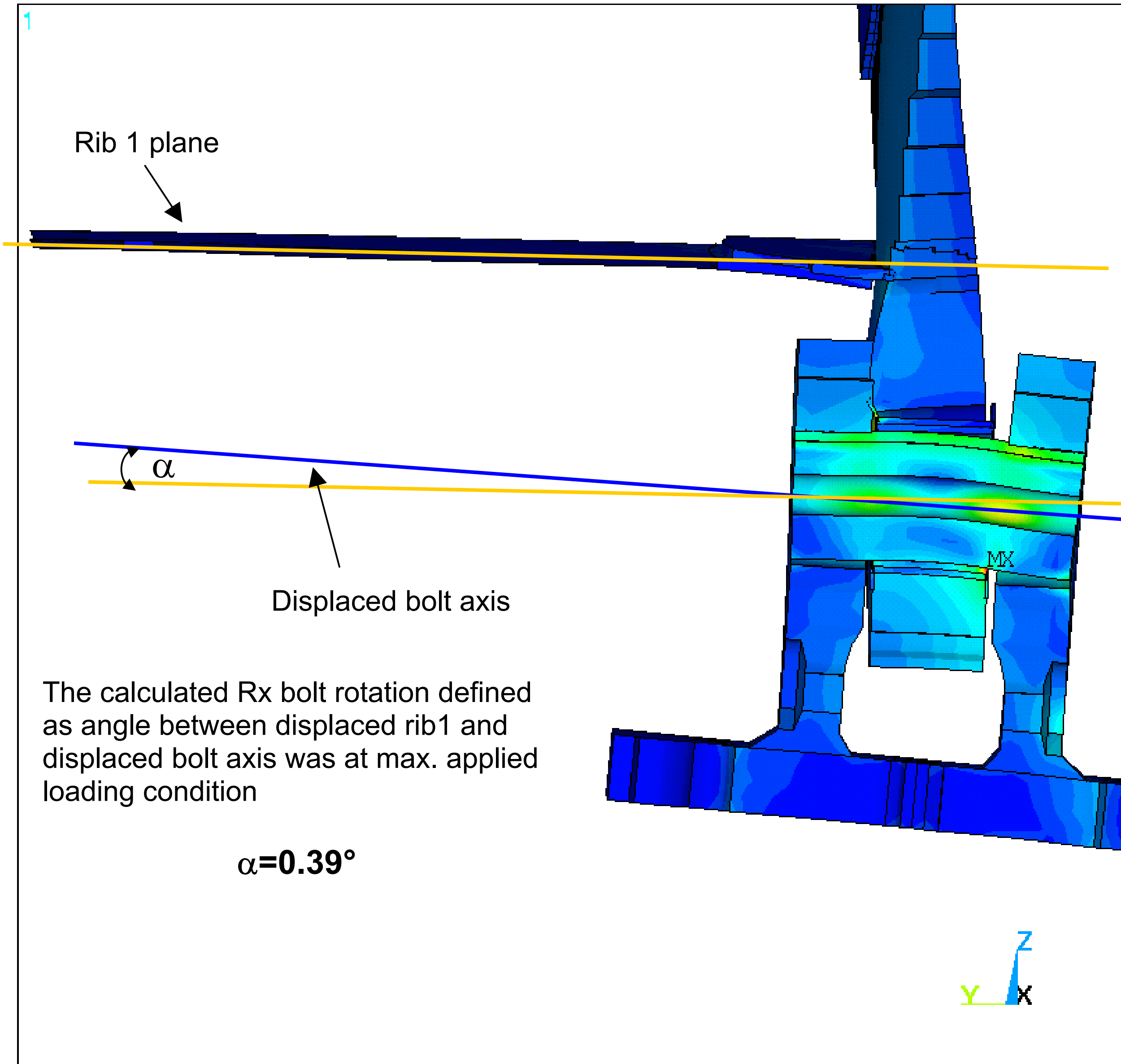


Figure 8.14

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

8.2.3 Contact status and pressure

Contact surface between:	Bushing & CFRP Lug

Contact status
red + green => contact
blue => gap

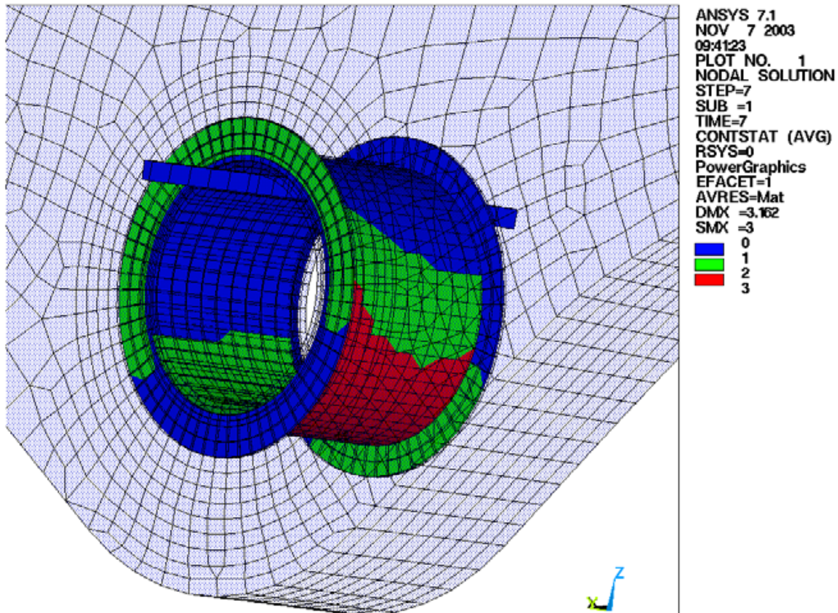


Figure 8.15

Contact pressure distribution

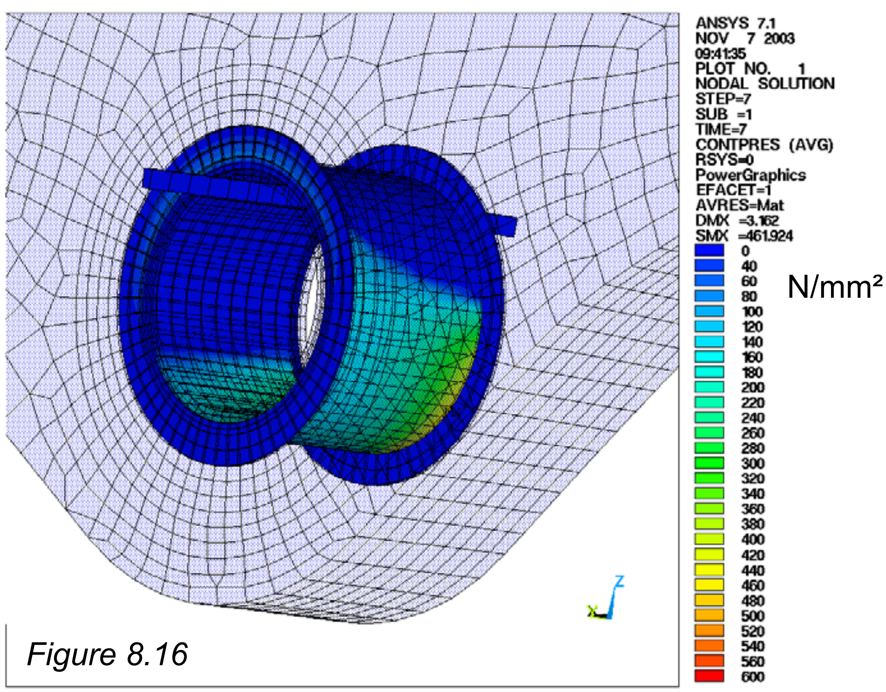


Figure 8.16

Contact surface between:	Bolt & Bushing

Contact status

red + green => contact

blue => gap

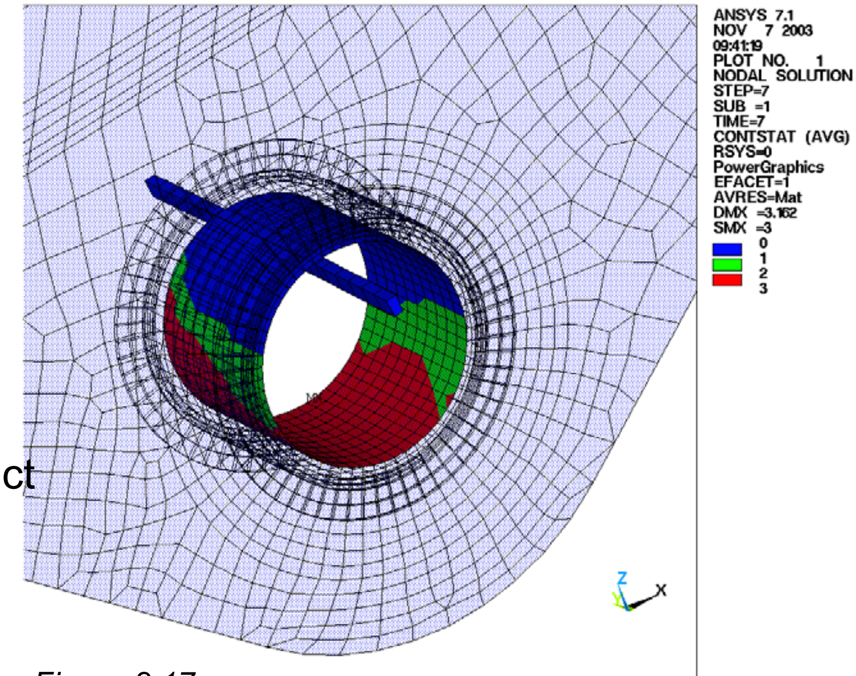


Figure 8.17

Contact pressure distribution

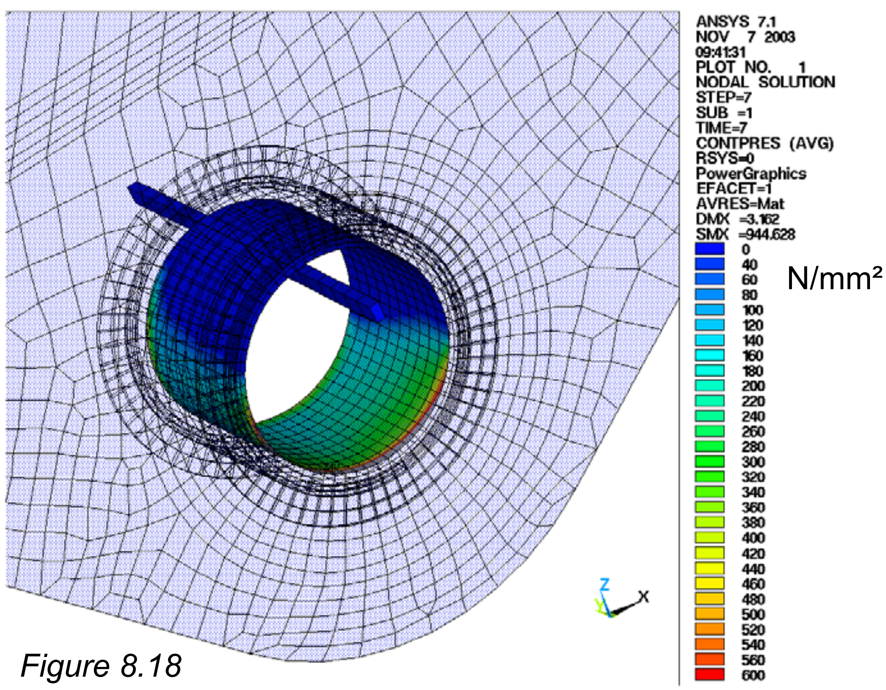


Figure 8.18

Contact surface between:	Bolt & Fuselage clevis

Contact status
red + **green** => contact
blue => gap

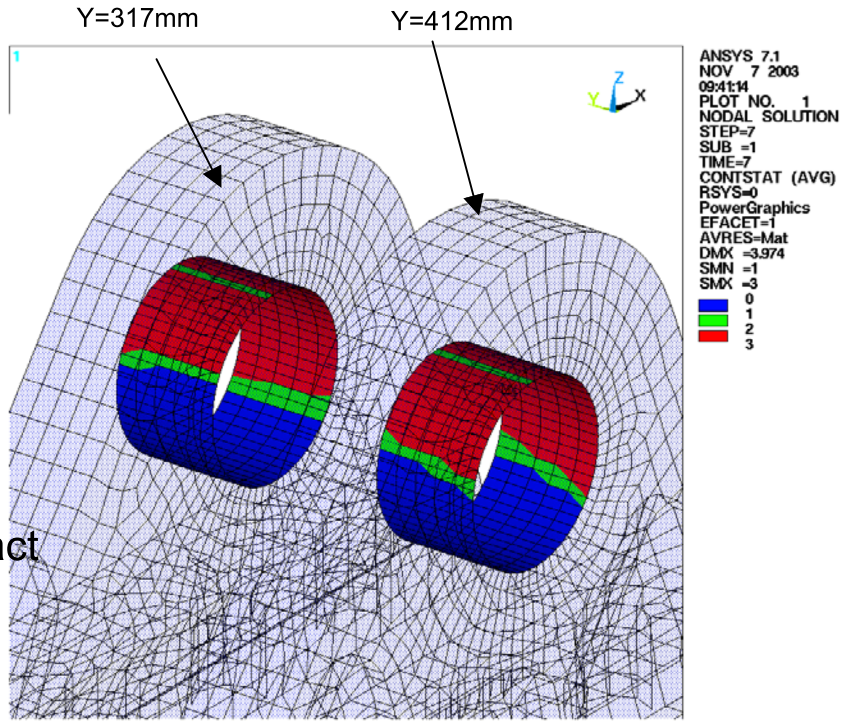


Figure 8.19

Contact pressure distribution

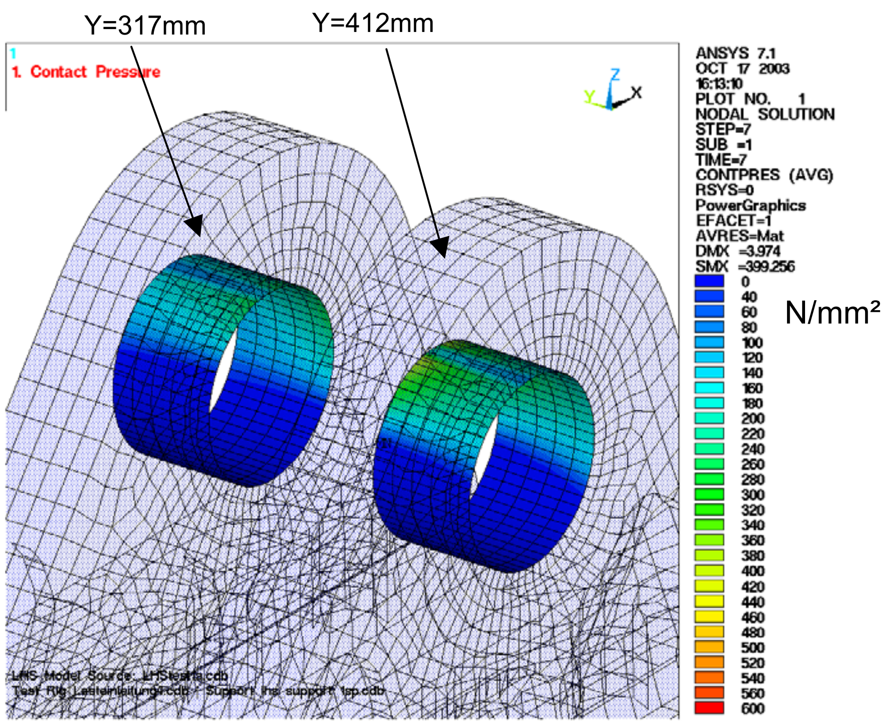
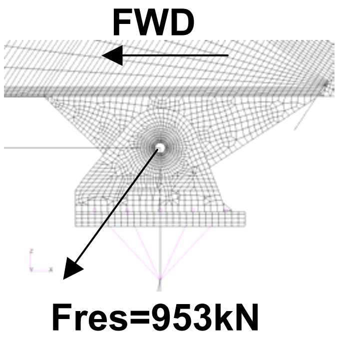


Figure 8.20

8.2.4 Strain distribution at the pin hole



LHS model

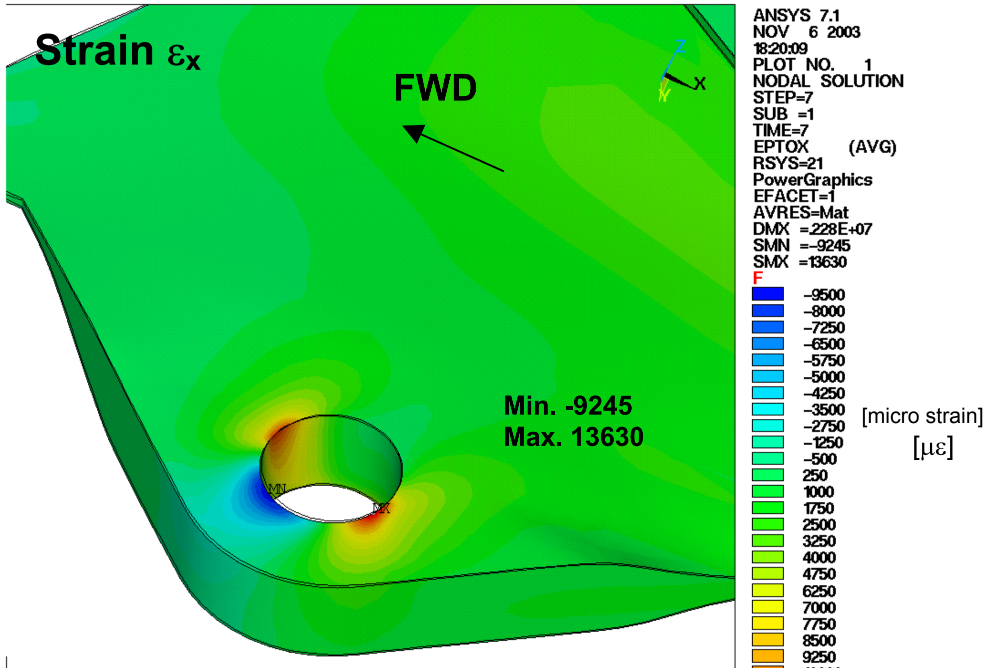


Figure 8.21

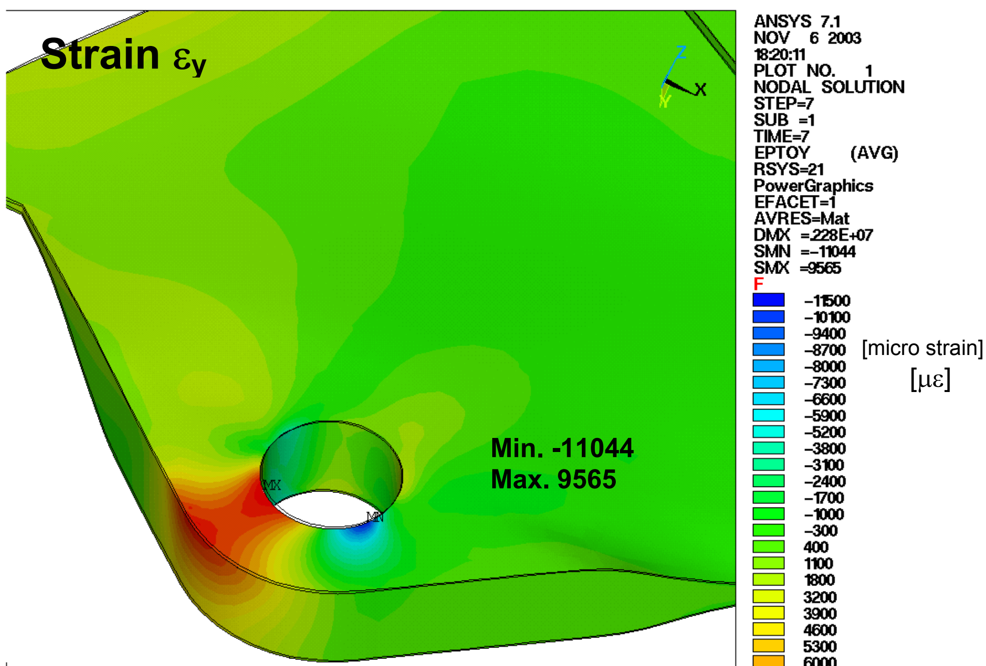
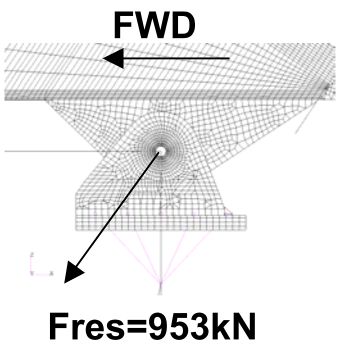


Figure 8.22

All views from outboard
Strain distribution in material coordinate system



LHS model

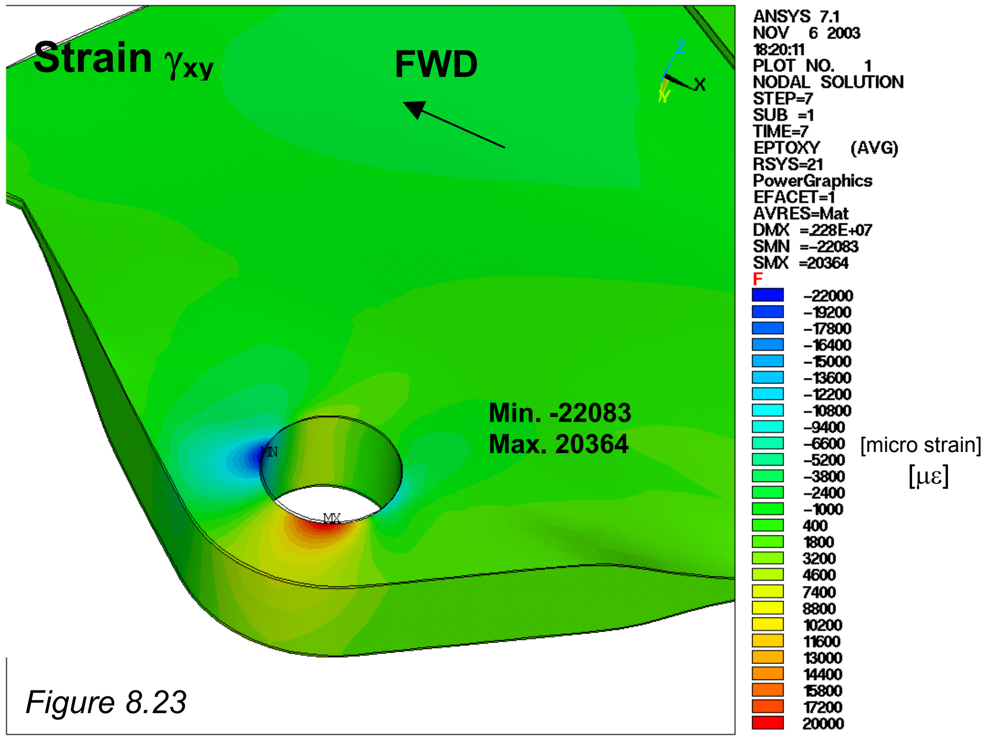


Figure 8.23

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

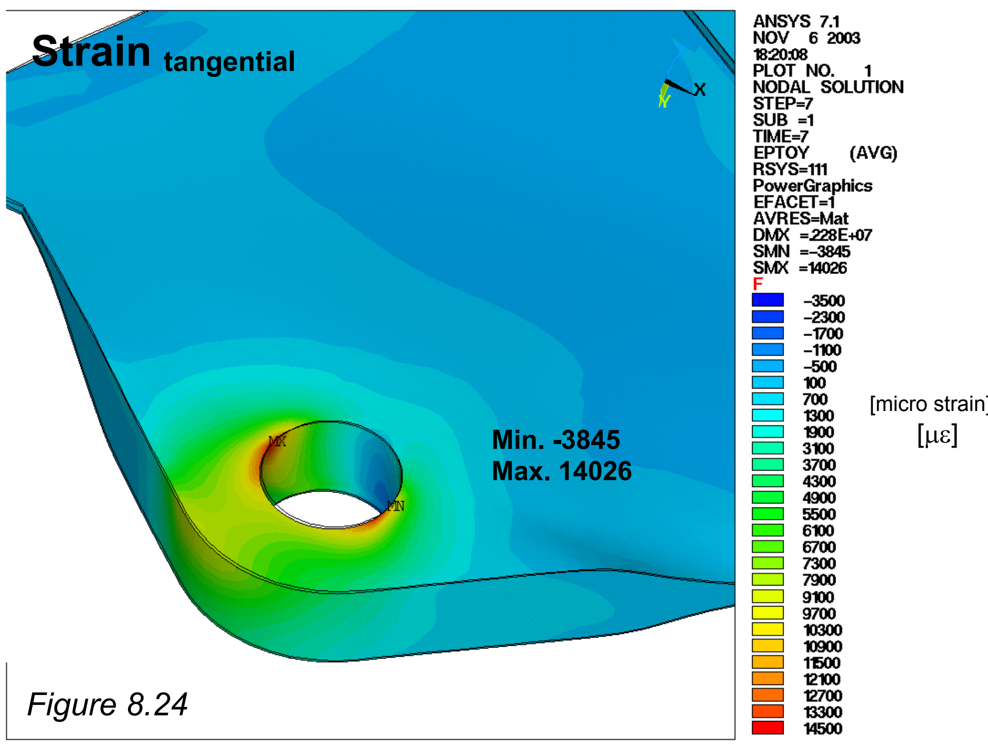


Figure 8.24

All views from outboard
Strain distribution in material coordinate system

9. Summary

It was shown that the ANSYS 3D nonlinear contact analysis of the test specimen including the test rig components and the test part support fixture is in acceptable agreement with the local 3D analysis with displacement boundary conditions derived from the global 2D FEA with embedded 3D rear lugs.

The consideration of the displacement of the bolt axis in terms of the tilt angle Rx is necessary for the simulation of the behavior the fin/fuselage attachment to achieve the correct reaction moment Mx. This was demonstrated in the analysis by the length adjustment of the Fz load introduction rods which is identical to a forced tilted pin axis.