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

March 30, 2004

ADDENDUM NUMBER 17 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. ***"Flight AA587 Structure Accident Investigation, Validation of Subcomponent Test Principles"***

AIRBUS	**Technical Note**	

Report Nr.: TN – ESGE – 0001/04

Author:
Department.: ESGE

Title

Flight AA587 Structure Accident Investigation

Validation of Subcomponent Test Principles

Date: 25.03.2004

Abstract:

The objective of this report is to demonstrate the suitability of the test principles applied to the sub-component tests which are performed as part of the Flight AA587 accident investigation to represent the behavior of the RHS rear lug of the fin box together with the fuselage.
This has been shown by validation of the subcomponent test analysis results with the measured strains from the tested lugs and the comparison of the calculated strains from the global/local FEA .
The test results have demonstrated , that the calculated reaction moment Mx is significantly over-predicted by linear analysis of a rigid pin connection.
The predictions for Mx from the non-linear contact analysis models are in acceptable agreement with the tests .
In addition it is shown that the rear LHS lug (in tension) of the full scale certification test from 1986 sustained a similar strain level at the pin hole during the residual strength test as calculated for the accident load case W375 and measured during the subcomponent tests .
It could be mentioned that similar lug failure modes were observed for subcomponent, full scale test and the accident aircraft. This provides further verification that the AAL587 accident load condition was accurately predicted.

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1. Introduction

The determination of the loading conditions of the RHS rear lug of the fin during the final phase of the accident flight AA587 is based entirely on analysis.
The first step was the evaluation of the recordings from DFDR and subsequent loads analyses with two independent methods, which led to the final condition load case W375.
The second step derives the reaction loads and state of stress/strain at the fin attachment lugs as response of the structural FEA-model to the load case W375.
These structural analyses resulted in a level of load at the RHS rear lug similar to the fracture conditions during the full scale certification test , performed in 1986 with a lateral gust case.
The analysis shows , that there are only minor differences in the state of stress/strain at the critical location at the pin hole.
To further verify this fracture load level, additional subcomponent tests with single lugs were performed.
For these subcomponent tests separate FE-analysis models were generated to determine the strain distribution in the lug and to validate on the one hand the analysis model by comparison of the measured and calculated strains and on the other hand the test principles by comparison of the calculated strains for the subcomponent test analysis and the accident condition analysis with the global FEA-model.

It could be mentioned that similar lug failure modes were observed for subcomponent, full scale test and the accident aircraft. This provides further verification that the AAL587 accident load condition was accurately predicted.

2. Rear lug attachment forces for load case W375 from global/local analysis

The original global 2D model which consists of the vertical stabilizer including the rudder and the rear fuselage / 1 / has been improved by two embedded (RHS and LHS) rear lug fine mesh 3D models to have a better representation of the bending behaviour.
A further improvement includes the more detailed modelling of the slotted sleeve/conical bolt connecting pin to enable the investigation of the influence of pin flexibility on the reaction moment by linear analysis as well as non-linear contact analysis with multiple contact surfaces.
These analyses are performed on a local 3D model which is supported by boundary conditions from the global model with embedded 3D lugs.

2.1 AIRBUS results for load case W375

The global NASTRAN analysis / 1 / with embedded LHS and RHS 3D rear lugs provides the following results (see fig. 2.1)for the RHS lug (in tension).

Fx	-392.2 kN
Fy	37.7 kN
Fz	-845.7 kN
Fres	933.0 kN
Mx	-7 368 Nm

fig. 2.1

The displacements from the interface between 2D mesh and 3D mesh model and from the fuselage clevises were applied to the ANSYS local 3D model and a non-linear analysis has been performed (for details see reference / 1 /).
The following results were achieved (see fig. 2.2).

Fx	-381 kN
Fy	42 kN
Fz	-853 kN
Fres	936 kN
Mx	-6 807 Nm
Rx	-0.438 °

fig. 2.2

A third analysis with the local model but with the extension to more structure of the upper fuselage adjacent to the attachment clevises and detailed connection bolt idealization (fig. 2.3) reveals the results given in fig. 2.4 .

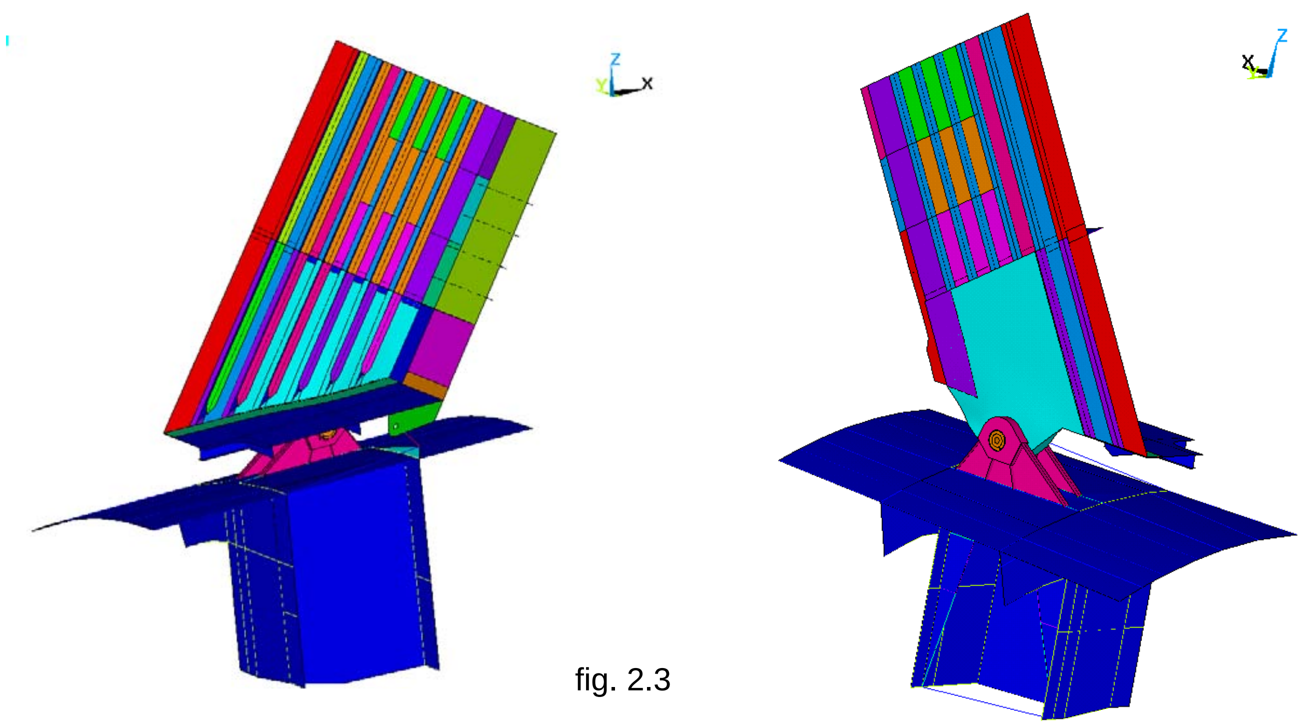


fig. 2.3

Fx	-371 kN
Fy	34 kN
Fz	-841 kN
Fres	919 kN
Mx	-5 280 Nm
Rx	-0.42 °

fig. 2.4

2.2 NASA results for load case W375

The linear analysis which was conducted with the NASA-G4 model gives the following attachment point reactions / 2 / (see fig. 2.5) .

Fx	-384.9 kN
Fy	36.0 kN
Fz	-867.4 kN
Fres	949.7 kN
Mx	-7 055 Nm
Rx	-0.47 °

fig. 2.5

The final reactions after performing the global/local procedure with the local model containing a contact surface between the rigid pin and the lug are listed below (see fig. 2.6).

Fx	-377.5 kN
Fy	24.3 kN
Fz	-845.9 kN
Fres	926.6 kN
Mx	-6 881 Nm
Rx	-0.51 °

fig. 2.6

2.3 Conclusion

The results from the FE-analyses performed by NASA and AIRBUS using different FEA-models and analysis tools are in very good agreement concerning the reaction forces which indicates that they are not sensitive to the model changes/improvements. However the moment Mx varies significantly due to model improvement but they are consistent between NASA and AIRBUS for comparable improvement steps.
The third AIRBUS model results in an even lower moment.
It is important to notice that the NASA analyses (fig. 2.5 and 2.6) is performed with a rigid pin without fuselage clevises while AIRBUS uses for analysis 1 (fig. 2.1) and 2 (fig. 2.2) a solid titanium pin including the aluminium fuselage clevises and for analysis 3 (fig. 2.4) the serial pin (slotted sleeve with conical bolt) is modelled together with the fuselage clevises and surrounding structure of the upper fuselage shell , forward and rear frames and the complete attachment fitting inside of the fuselage.

The further reduction of Mx as a result of this analysis outlines the sensitivity of the moment Mx to modelling aspects , whereas the reaction forces remain at nearly the same level .

3. Moment Mx versus pin rotation angle Rx

The total moment which is reacted at the pin was found to be very sensitive to FEA model modifications (2D versus 3D) and the introduction of a detailed modelled pin/bushing interface with several contact surfaces.
The moment is built up by the sum of the effects from Fxz , Fy and Rx.
The rotation Rx of the pin axis is enforced by the bending moment of the fin with the attachment lugs acting in tension and compression which corresponds to different relative displacement due to different structural stiffness in compression (higher) and tension (lower).

In the nonlinear global/local FEA model of the VTP, the moments reacted at the pins develop naturally as internal reactions in a model simulating the aircraft condition. During the subcomponent tests and the associated analyses, the same pin moments do not develop naturally, due to the fact that the test is done with a single lug and fixed boundary conditions. Thus, to simulate the aircraft condition in the subcomponent tests, the moment/rotation of the subcomponent tests must be augmented.

This enforced rotation Rx is less sensitive to model changes/improvements than the moment Mx .
For this reason it was decided by NTSB , NASA and AIRBUS to characterize the load condition W375 to which the RHS rear lug has been exposed during the accident by the forces Fx , Fy and Fz and the pin axis rotation Rx:

Fx	-400 kN
Fy	42 kN
Fz	-864 kN
Rx	0.45 °

This loading condition is supported by the NASA progressive failure analysis(PFA) for lug test#2 / 2 Part 3 / .

4. Comparison of calculated and measured Mx from subcomponent test with pre-adjusted Rx

The FE-analysis model of the subcomponent test is a copy of the test specimen lug test#2 , the boundary conditions and the loading principles (see fig 4.1).
The rotation Rx is applied initially (the test rig does not allow a continuous application of Rx) by adjusting the length of the rods Z1 and Z2 . This procedure delivers the initially reacted moment Mx .During the application of Fx , Fy and Fz this moment increases solely by the effect of eccentricity and lateral force Fy.

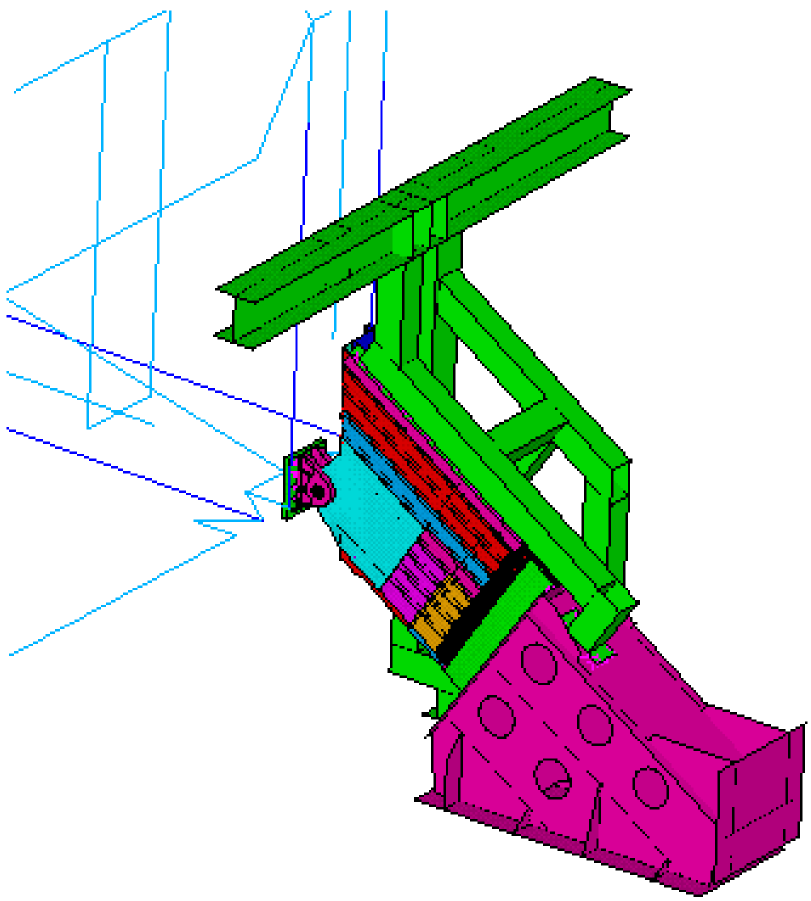


fig. 4.1

4.1 Initial reaction moment Mx caused by Rx

A non-linear ANSYS contact analysis (FEA-model for lug test#2) is performed with several pin types to demonstrate the influence of the flexibility on the moment reaction:

A) solid titanium pin with a friction coefficient of 0.3
B) solid steel pin with a friction coefficient of 0.3
C) quasi rigid pin and fuselage clevis (Young's modulus 100 times of steel)
D) serial bolt with a friction coefficient of 0.3

For each FEA-model a bolt Rx rotation was initially pre-adjusted an the results are shown in comparison with tested values in fig. 4.2 .

Rx / ° /	Initially Reacted Moment Mx /Nm/ from the analysis due to pin rotation	Initially Reacted Moment Mx /Nm/ fro the test due to pin rotation
0.5	A) -1866	
0.5	B) -1917	
0.5	C) -2129	
0.5	D) -1986	
0.47 pre test#2		-1269
0.47 test#2		-1025
0.48 pre test#3		-1305
0.45 test#3.4		-1148

fig. 4.2

Fig. 4.2 shows , that the response of the tested lug to a prescribed rotation Rx is significantly over-predicted by the ANSYS analysis model for lug test#2.
It is also visible from the analyses A) to D) that the variation of the flexibility of the pin by using different materials does not influence the pre-adjusted reaction moment significantly.
However the effect of the rigid pin idealization in the configuration C) (Young's modulus 100 times of steel) is obvious.

4.2 Calculated and measured total moment Mx for load case W375

The measured moments Mx (absolute values) for lug test#1 , #2 are shown on fig. 4.3 together with the analysed moment Mx from the ANSYS non-linear subcomponent test analysis performed for LHS lug test#1 and #2.

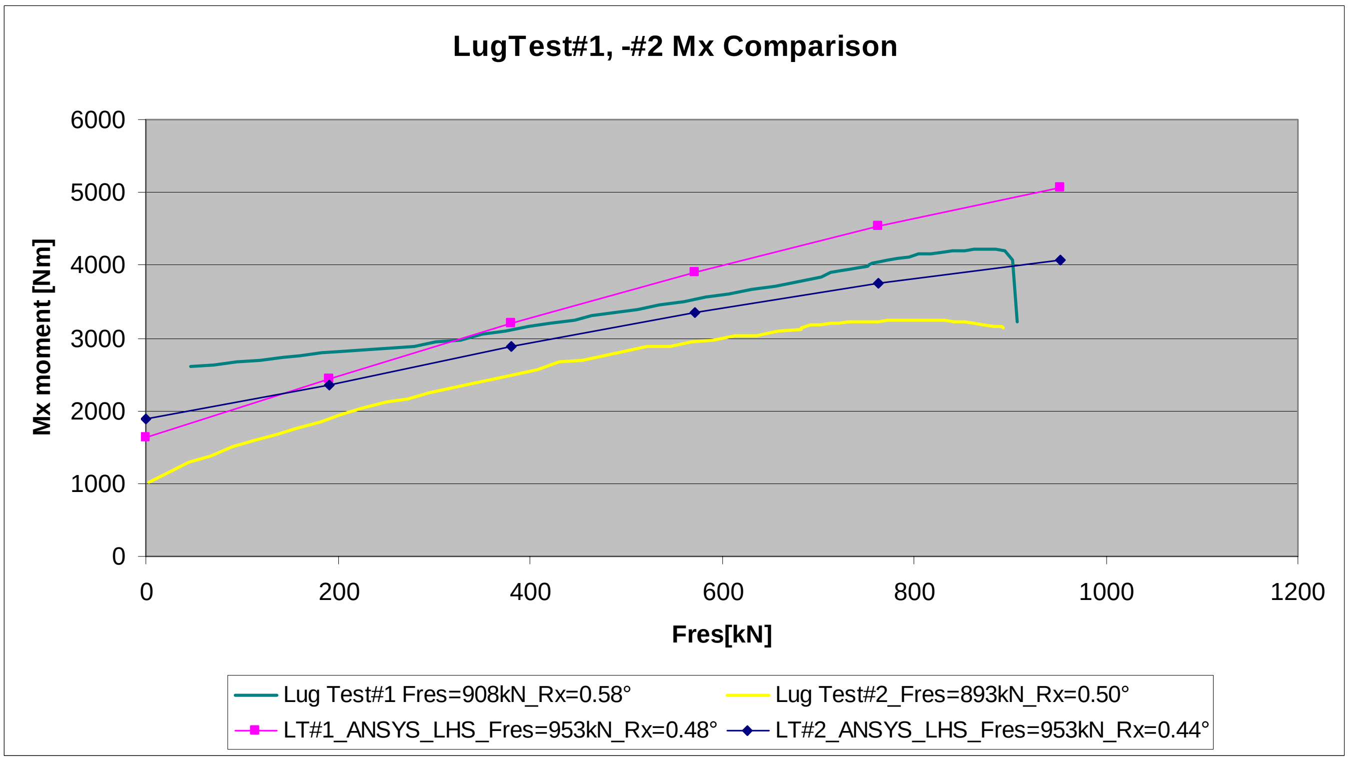


fig. 4.3

4.3 Conclusion

Fig. 4.3 shows, that the measured moments caused by the initial rotation angle Rx are different for lug test#1 and 2 when they are corrected to the same Rx.

The reason for this difference is the size/geometry of the tested parts which has an influence on the bending stiffness.

In opposition to the analysis model for lug test#2 , the analysis model for lug test#1 predicts a lower initial moment as measured.

However the increase of the calculated moment Mx due to the application of Fres and Fy for lug tests#1 is larger than measured , whereas the slope of the calculated moment curve for lug test#2 is in acceptable agreement with the behaviour of the tested lug in the load interval between Fres= 200 to 750 kN.

Fig. 4.4 shows the FEA moment curve for lug test#2 together with the measured values recalculated with linear application of the pin rotation angle Rx.

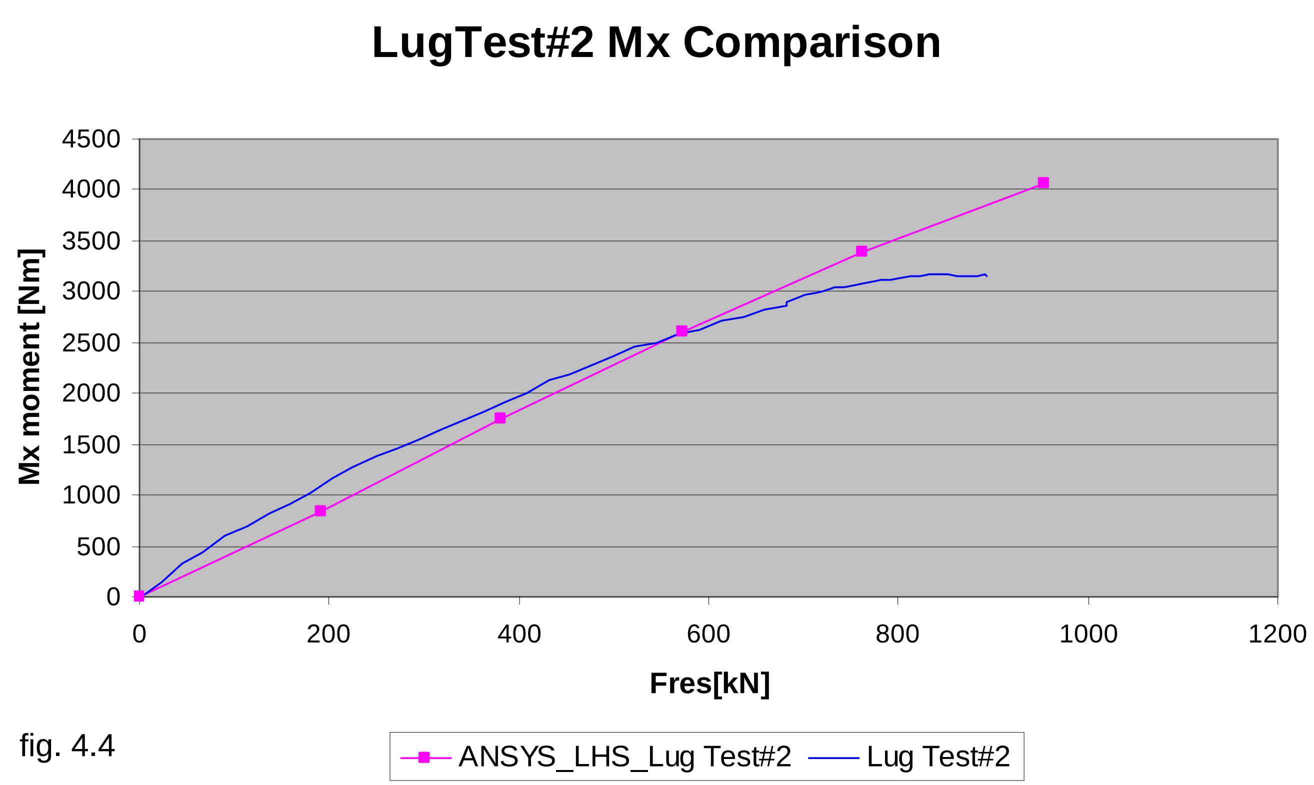


fig. 4.4

5. Measured and calculated strains for load case W375

The locations of the strain gauges and rosettes around the bushing of the pin hole are shown on fig. 5.1.

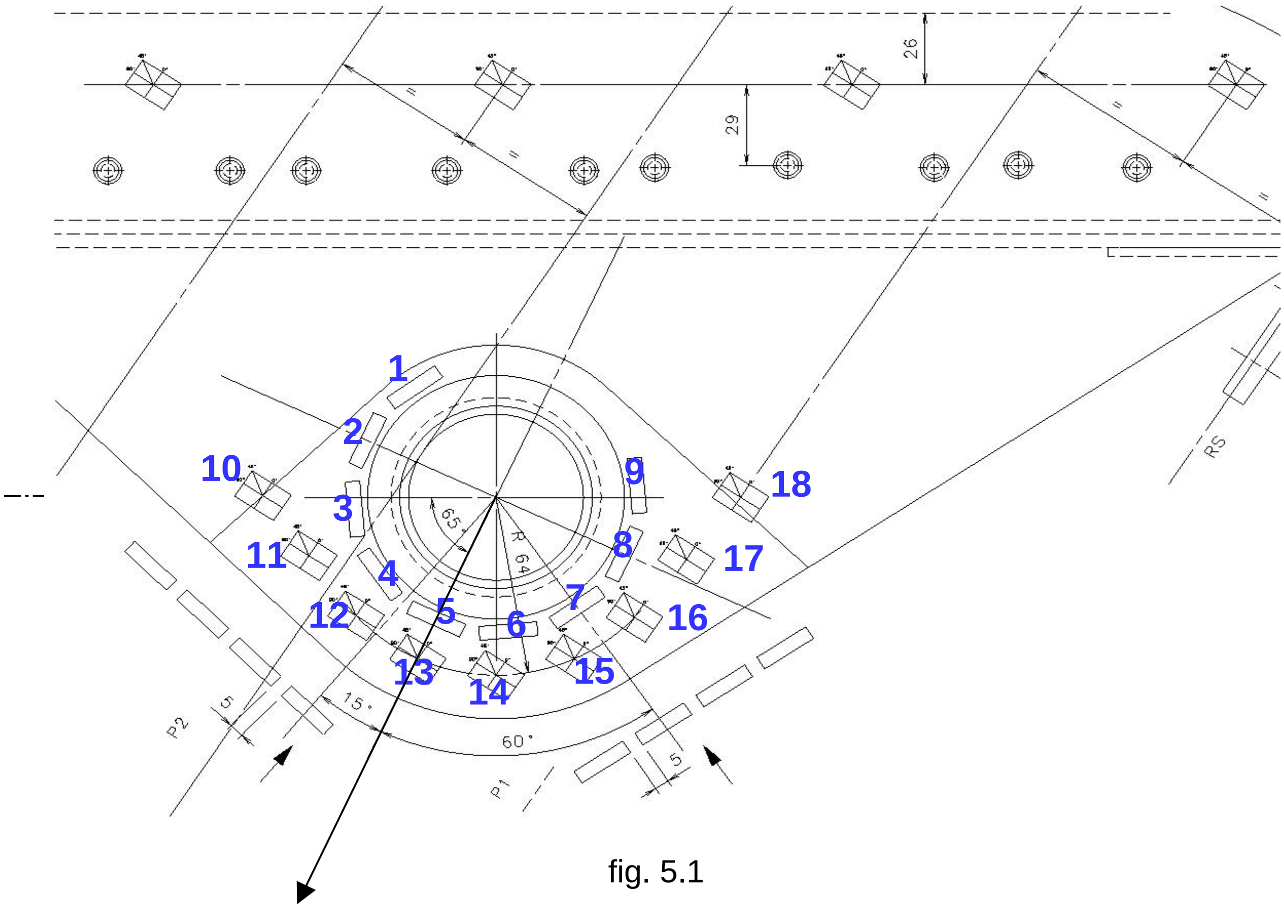


fig. 5.1

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 LHS subcomponent test analysis in fig. 5.2 to 5.5 for a resultant load of Fres = 890 kN (the measured values are taken from the nearest load step and are not interpolated).

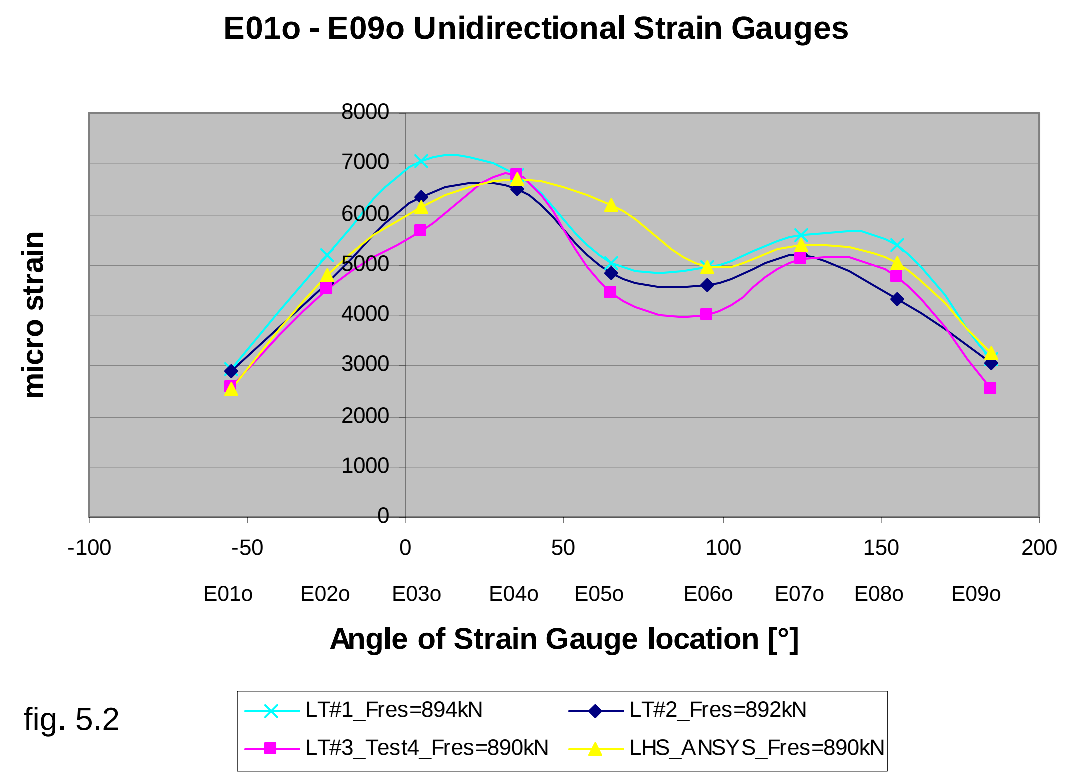

E01o - E09o Unidirectional Strain Gauges
micro strain
8000
7000
6000
5000
4000
3000
2000
1000
0
-100
-50
0
50
100
150
200
E01o
E02o
E03o
E04o
E05o
E06o
E07o
E08o
E09o
Angle of Strain Gauge location [°]
LT#1_Fres=894kN
LT#2_Fres=892kN
LT#3_Test4_Fres=890kN
LHS_ANSYS_Fres=890kN

fig. 5.2

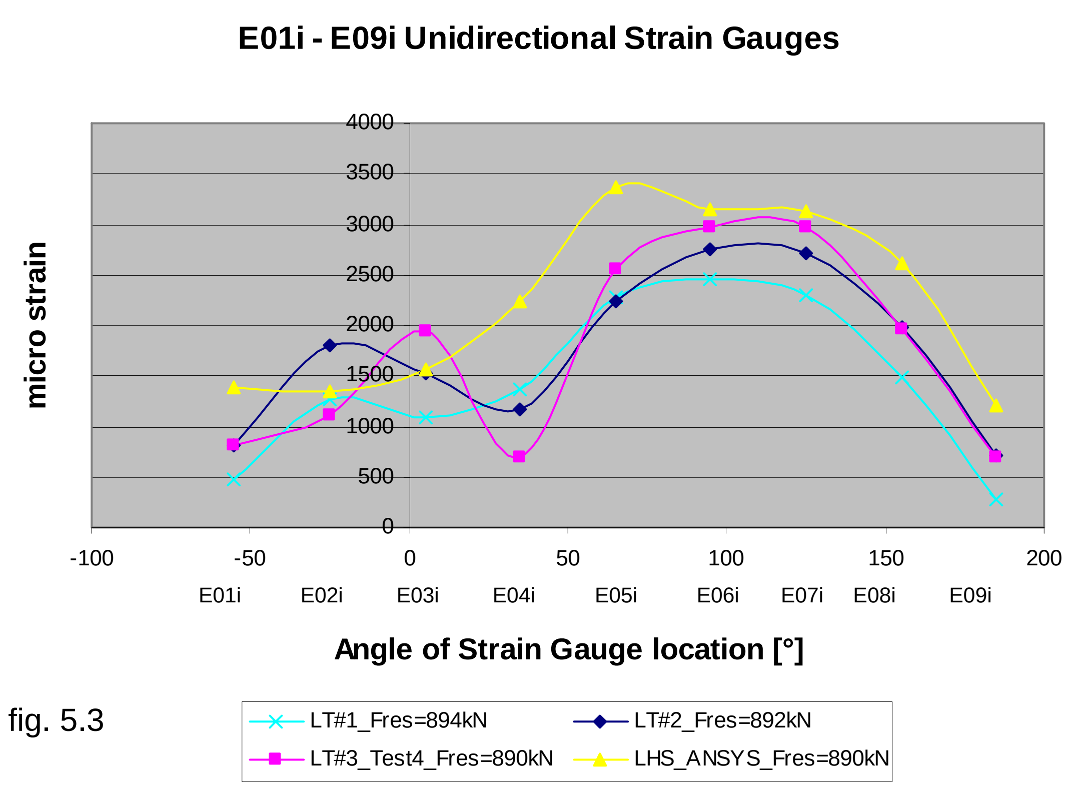
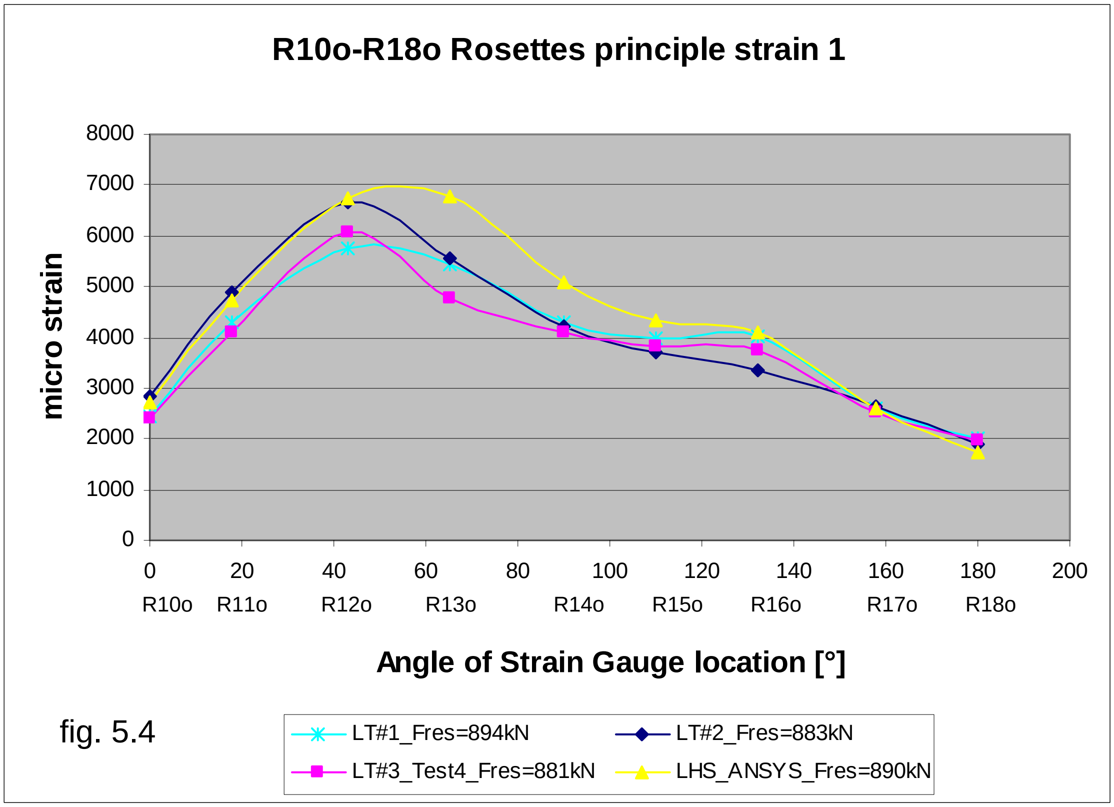

E01i - E09i Unidirectional Strain Gauges
micro strain
4000
3500
3000
2500
2000
1500
1000
500
0
-100
-50
0
50
100
150
200
E01i
E02i
E03i
E04i
E05i
E06i
E07i
E08i
E09i
Angle of Strain Gauge location [°]
LT#1_Fres=894kN
LT#2_Fres=892kN
LT#3_Test4_Fres=890kN
LHS_ANSYS_Fres=890kN

fig. 5.3


R10o-R18o Rosettes principle strain 1
micro strain
0
1000
2000
3000
4000
5000
6000
7000
8000
0 20 40 60 80 100 120 140 160 180 200
R10o R11o R12o R13o R14o R15o R16o R17o R18o
Angle of Strain Gauge location [°]
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LT#3_Test4_Fres=881kN
LHS_ANSYS_Fres=890kN

fig. 5.4

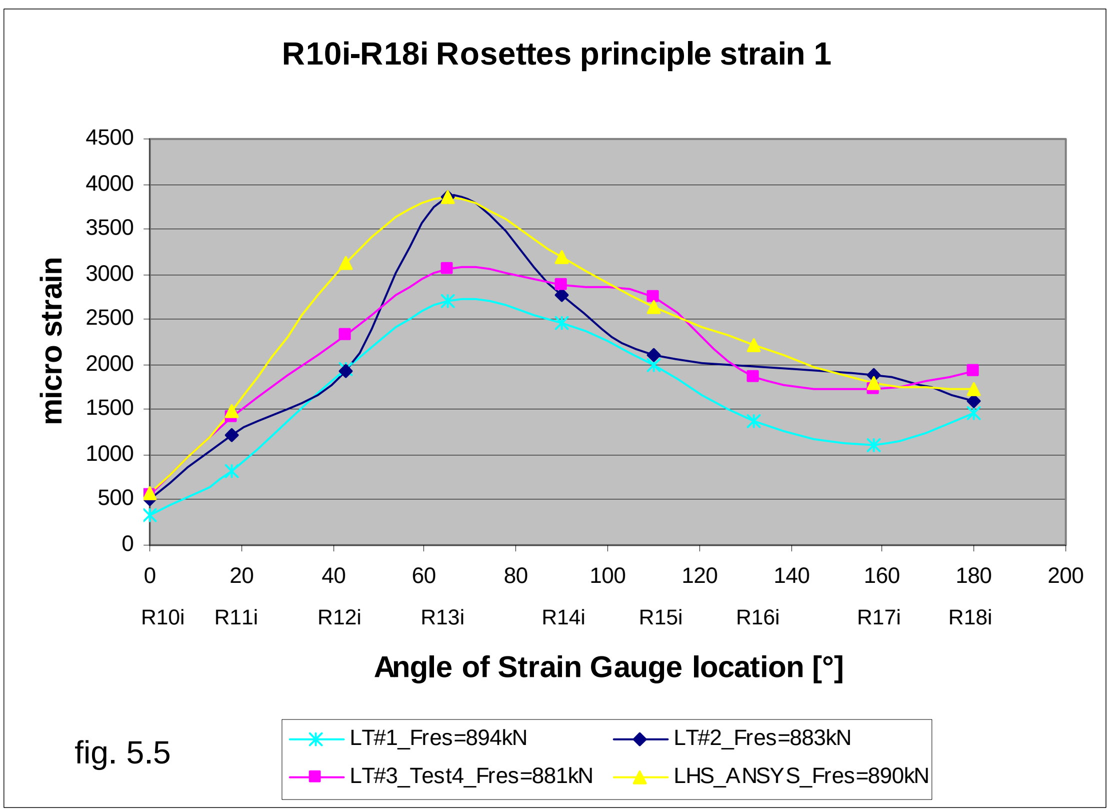
R10i-R18i Rosettes principle strain 1
micro strain
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0 20 40 60 80 100 120 140 160 180 200
R10i R11i R12i R13i R14i R15i R16i R17i R18i
Angle of Strain Gauge location [°]
LT#1_Fres=894kN
LT#2_Fres=883kN
LT#3_Test4_Fres=881kN
LHS_ANSYS_Fres=890kN

fig. 5.5

Despite of local discrepancies between measured and calculated strains there is a very good agreement in the magnitude and distribution of strains at the pin hole .

6. Comparison of calculated strains from global/local- and subcomponent test analysis

The comparison of the state of strain on the outside faces of the lug is performed at the same locations (inboard and outboard strain gauges E01 to E09 shown on fig. 5.1) as used in chapter 5.

The calculated values from the global/local non-linear ANSYS analysis which describes the behaviour of the RHS rear lug attached to the fuselage under W375 load condition is compared to the corresponding results of the ANSYS non-linear analysis of the sub-component test (LHS lug test#2 , Fres= 890 kN) in fig. 6.1 and 6.2 .

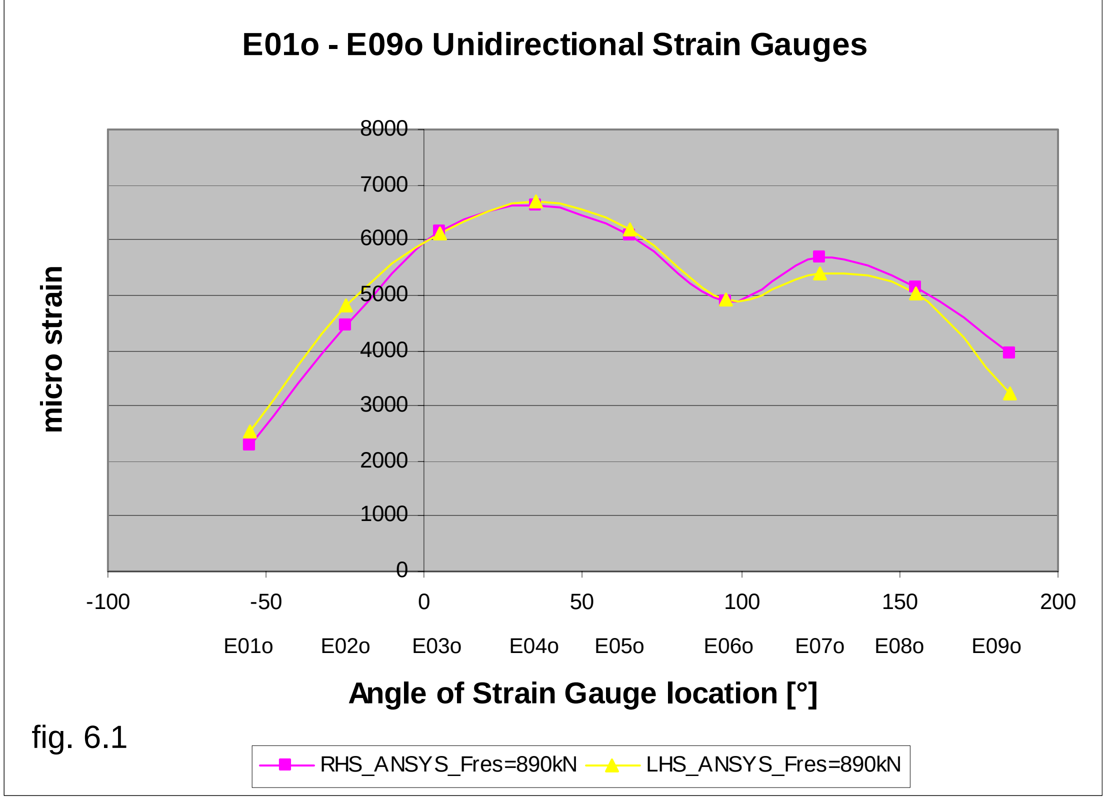

fig. 6.1

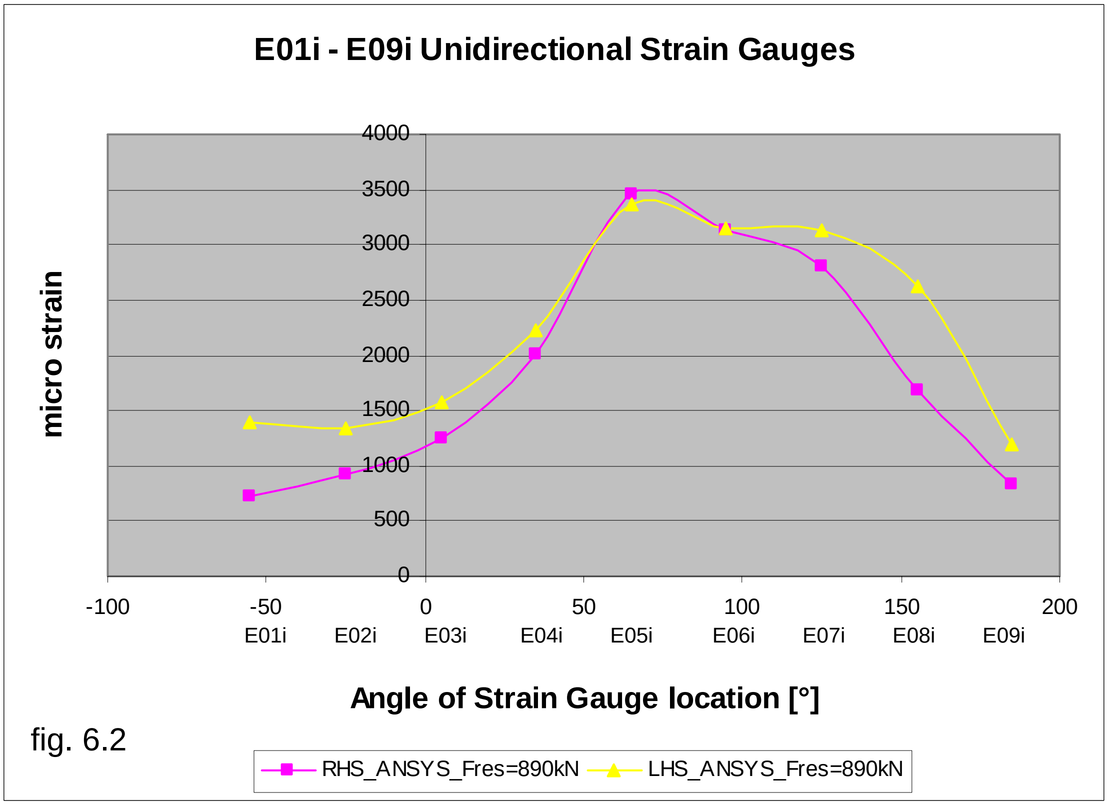

fig. 6.2

The tangential strains from both analyses are in very good agreement , which indicates, that the subcomponent test principles are well suited to simulate the behaviour of the rear lug in the interaction between the real fin structure and the fuselage.

7. Comparison of calculated strains for load case W375 and lateral gust case BI17

In fig. 7.1 and 7.2 the strains from the global/local non-linear ANSYS analysis conducted with the lateral gust case BI17 [Target resultant value from Full Scale Test Fres=904kN / ANSYS nonlinear contact model with boundary displacement and BI17 scaled by a factor of 2 plus 50K temperature results in Fres= 890kN / Differenz between target and actual value delta Fres= -1.6%] and load case W375 (Fres = 919kN) are compared at the same locations as indicated in chapter 6 .

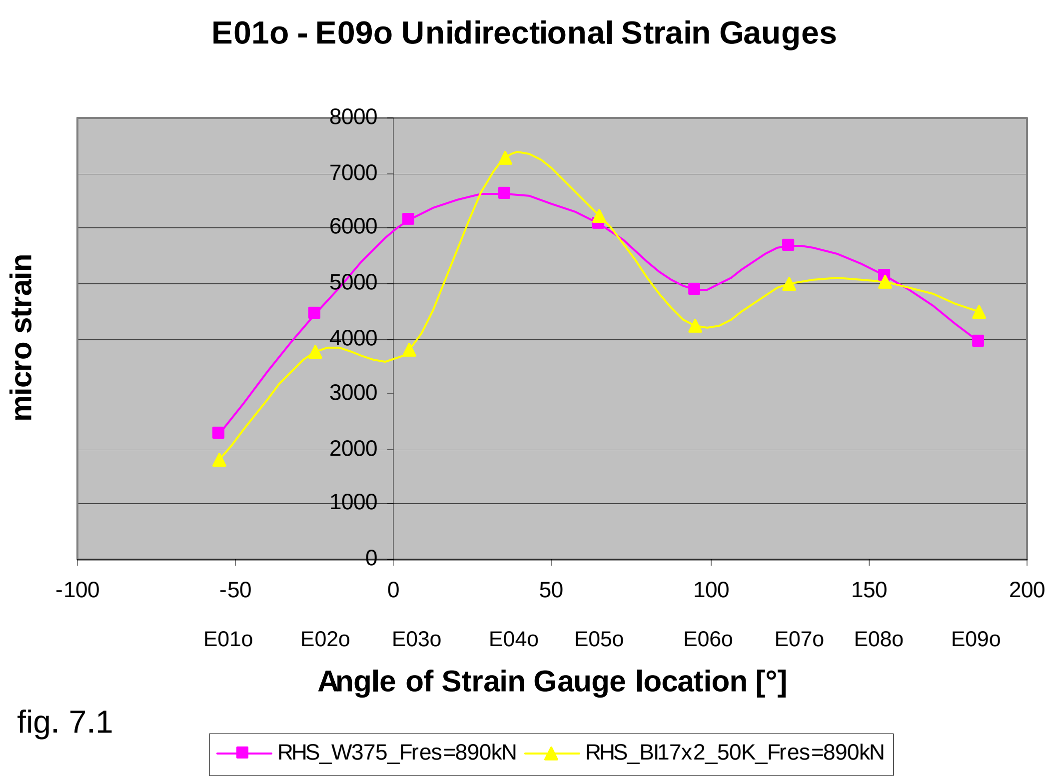

fig. 7.1

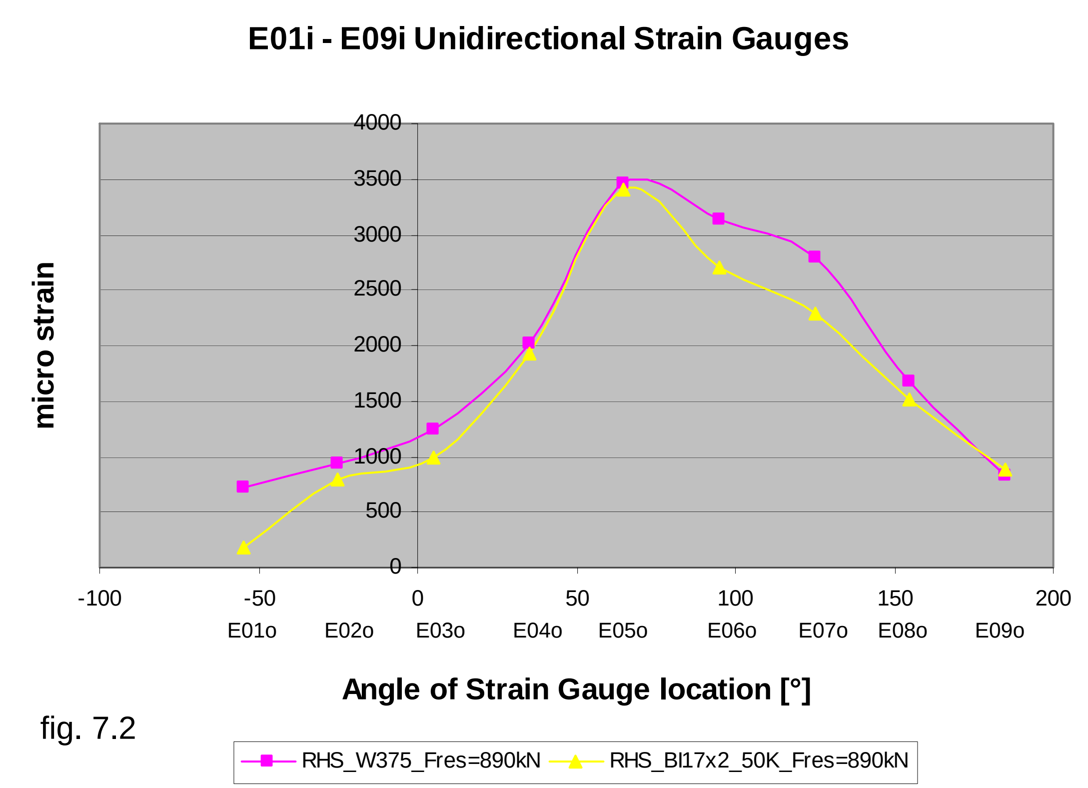

fig. 7.2

Both figures indicate , that the strain level at failure load of the gust case BI17 is a good agreement to the strain level of load case W375 .

8. 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 AA587.

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.

It has been demonstrated by test, that the calculated reaction moment Mx is significantly over-predicted by linear analysis.

The predictions for Mx of the non-linear contact analysis models are in acceptable agreement with the tests.

In addition it could be demonstrated by analysis , that the gust load case which has been used in 1986 on the full scale certification test produces at the lug failure load level (1.95 x L.L.) similar strains as case W375.

9. References

/ 1 / TN-ESGC-1018/03
AAL587 Airbus Structure Investigation Accident analysis _ FEM RHS local rear lug model

/ 2 / NASA/TMX-2003-000000
NASA Structural Analysis Report for the American Airlines Flight 587 Accident Investigation: Part 1 to 3