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

December 5, 2003

ADDENDUM NUMBER 13 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. "A300/A310 Composite Fin Box, Full-Scale Certification Test Summary"

AIRBUS	Technical Note	

Report Nr.: TN – ESGE – 0004/03

Author:
Department.:

Title

AAL 587 Airbus Structure Investigation

A300 / A310 Composite Fin Box

Full Scale Certification Test Summary

Date: 08.12.2003

Summary:

Public Docket	Issue	Date	No. of page	Revised pages	Valid from/for
	1	02.12..2003	25		
	2	08.12.2003	25		

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1. Introduction

The proof of structure for static strength and fatigue/damage tolerance behaviour for certification of the A310-300 vertical stabilizer manufactured from composite material has been demonstrated by full scale test.
Initially it was planned to use one test part for the justification of static strength and fatigue/DT behaviour.
However due to a malfunction of the test rig during the load application onto the test part in the beginning of the fatigue test, the first fin box has been damaged in the lower LHS skin panel.
For this reason it has been decided to use this test part after repair for static strength demonstration only.
The complete test schedule was repeated on a second part and successfully terminated by demonstrating the required static strength after fatigue and the residual strength of the structure under hot/wet conditions.

2. Description of the test part

The full scale test includes the box of the vertical stabilizer, the leading edge except the dorsal fin, the rudder hinges and a dummy rudder for load introduction purpose.

2.1 First full scale test part

The first test part was manufactured from 2 alternative tape and fabric materials:

- CIBA 913 / T300
- HEXCEL F550 / T300

The following parts were manufactured from CIBA – material:

- LHS skin panel
- Rear spar
- Rib 2, 4, 5, 7, 8, 10, 12, 15, 18
- Rudder hinge fitting 3, 5, 7

HEXCEL – material was used for:

- RHS skin panel
- Front and center spar
- Rib 1, 3, 6, 9, 11, 13, 14, 16, 17
- Rudder hinge fitting 1, 2, 4, 6.

During the manufacturing process artificial damages have been introduced into the components of the structure by inserting of Teflon foil sheets. Impact damages have been applied to the skin panels, ribs and the spar webs using different impactor diameters. The structure also contains bonded and riveted repair schemes for the skin panels.

2.1 Second full scale test part

The second test part is completely manufactured from CIBA 913 / T300 tape and fabric material. Both skin panels contain skin/stringer repairs and several impact damages. Impact damage was also applied to the spar webs and ribs.

3. Description of the test rig and load application

The test principle is shown on figure 3.1. The vertical stabilizer box is inside of an environmental chamber. The fuselage attachment lugs are connected to clevises which are mounted on long beams from steel. These beams provide the fuselage reactions to the fin loads thru a static determinated support by 6 rods equipped with load cells and 11 force controlled hydraulic actuators.

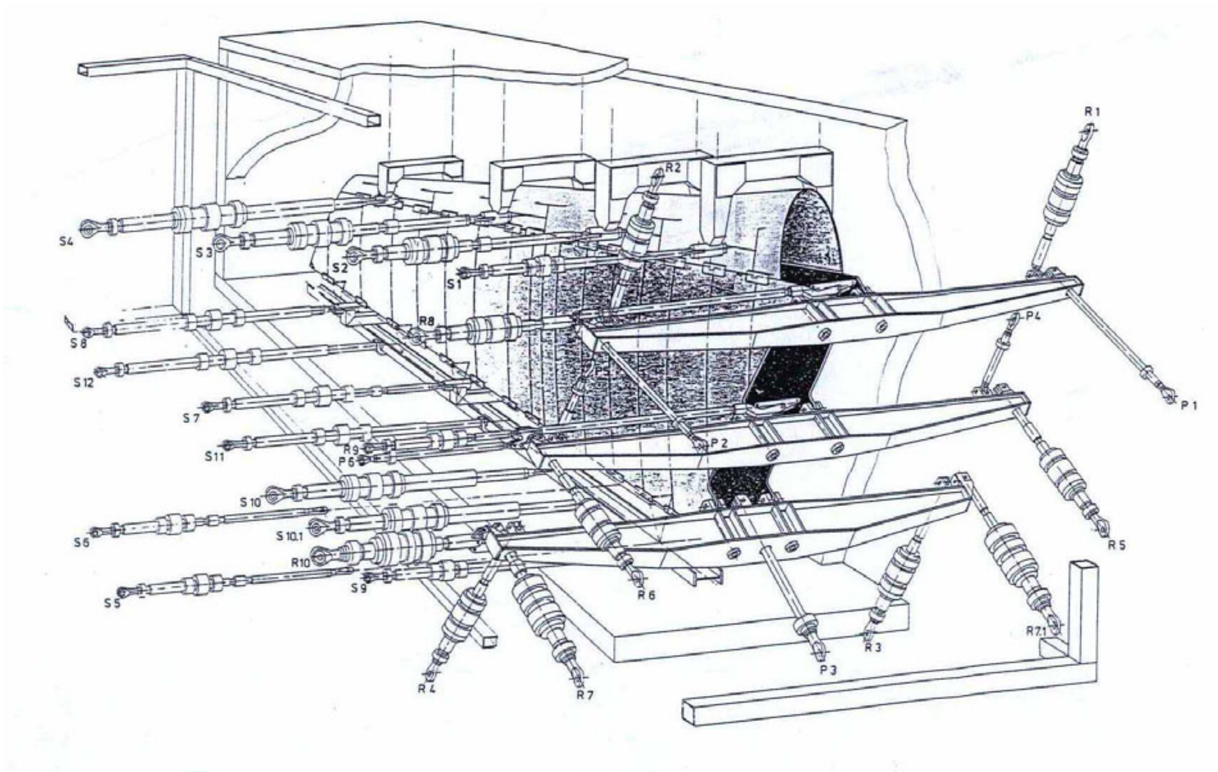

Figure 3.1

The fin lateral loads are applied by loading trees thru 13 force controlled hydraulic actuators. For these discrete lateral forces, the balancing fuselage reactions are calculated by a FEM analysis of the fin and the rear fuselage structure. The calculated reactions are used as input loads for the fuselage reaction actuators and for control of the forces in the support rods. Parallel to this procedure the relative displacements at the attachment lugs have been measured to check for correct stiffness of the real structure relative to the analysis model.

The lateral loads are applied by loading pads in compression on the surface of the leading edge (5.5% of chord, 14 pads) at the front spar (16.5% of chord, 14 pads), at the rear spar (57% of chord, 13 pads) and at the rudder hinge line (70% of chord, 5 points on the rudder dummy).

The servo control loads of the rudder are applied by an offset hydraulic actuator using a lever to provide the required rudder hinge moment (see fig. 3.2).

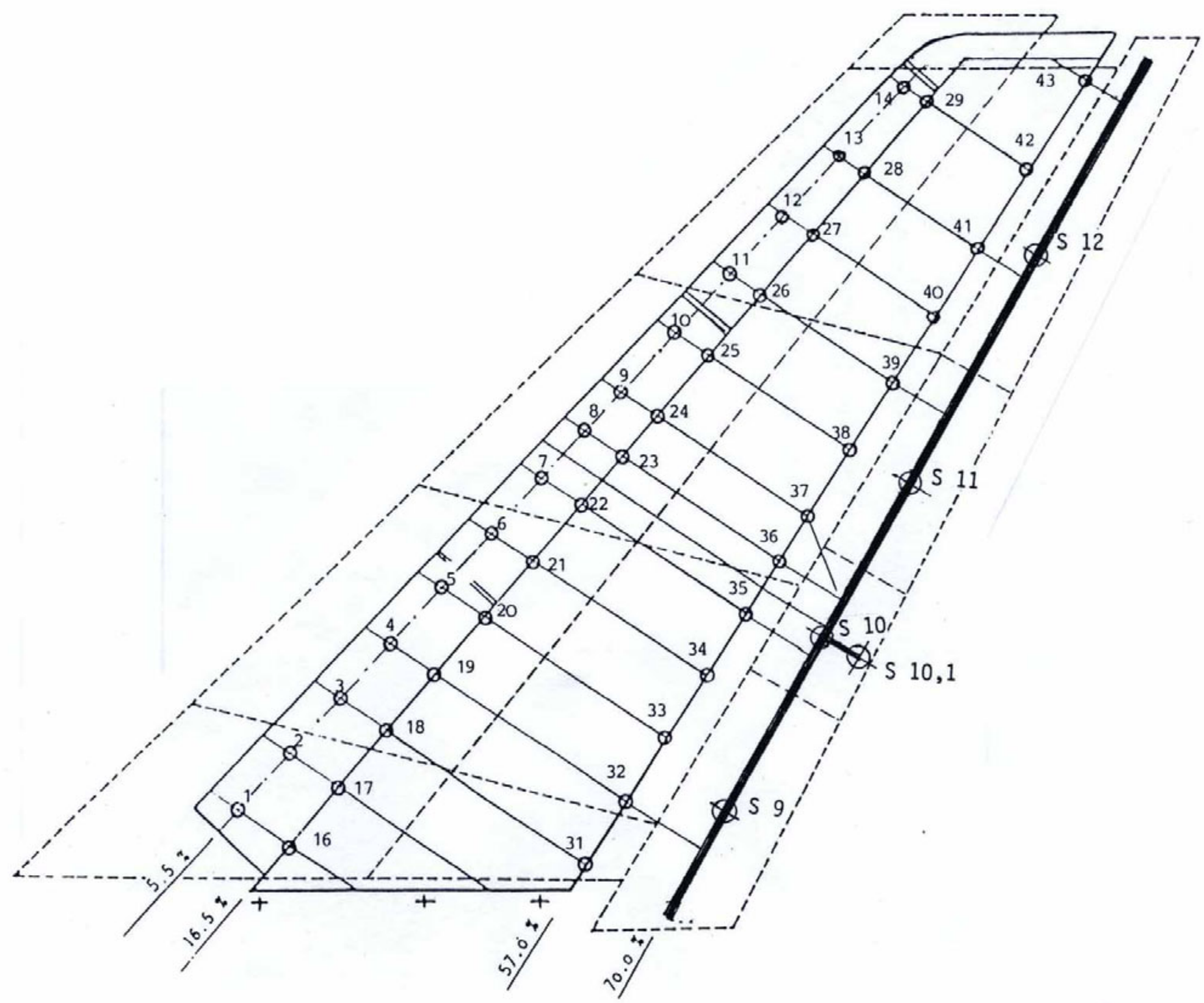

Figure 3.2

4. Load cases and applied loads

Two load cases were selected from the loads envelope:

- lateral discrete gust
- lateral manoeuvre (C31T 2K36 SE01).

The resultants (limit load) at the attachment lugs of both load cases are listed in table 1 in the component coordinate system.

	Lateral gust, discrete	Lateral manoeuvre C31 T2 K36 301
F_y [N]	-223 390	-170 510
M_x [Nm]	883 000	568 640
M_z [Nm]	161 080	267 690

Table 1

The span- and chordwise load distribution for each loading pad and the rudder is given in table 2.

No.	Gust [N]	Manoeuvre [N]
Leading Edge		
1	-15 678	-19 453
2	-12 697	-15 754
3	-10 808	-10 335
4	-10 808	-10 335
5	-10 808	-10 335
6	-10 808	-10 335
7	-10 072	-10 413
8	-8 803	-9 101
9	-10 072	-10 413
10	-11 713	-12 110
11	-12 539	-14 555
12	-12 539	-14 555
13	-11 677	-13 554
14	-8 934	-10 370
Front Spar		
16	-12 182	-15 116
17	-10 846	-13 457
18	-9 207	-8 804
19	-9 207	-8 804
20	-9 207	-8 804
21	-9 207	-8 804
22	-8 356	-8 639
23	-7 311	-7 559
24	-8 356	-8 639
25	-9 848	-10 181
26	-8 934	-10 370

No.	Gust [N]	Manoeuvre [N]
Front Spar		
27	-8 934	-10 370
28	-8 307	-9 642
29	-6 348	-7 368
Rear Spar		
31	-12 451	10 224
32	-9 593	-5 211
33	-9 593	-5 211
34	-9 593	-5 211
35	-9 593	-5 211
36	342	-1 172
37	342	-1 172
38	428	-1 468
39	428	-1 468
40	-343	974
41	-343	974
42	-343	974
43	-343	974
Rudder		
S 9	0	20 977
S10	0	-51 682
S10.1	0	62 299
S11	0	14 928
S12	0	18 146

Table 2 (ultimate loads)

13 hydraulic actuators (see fig 3.3) are used for load application by loading trees.

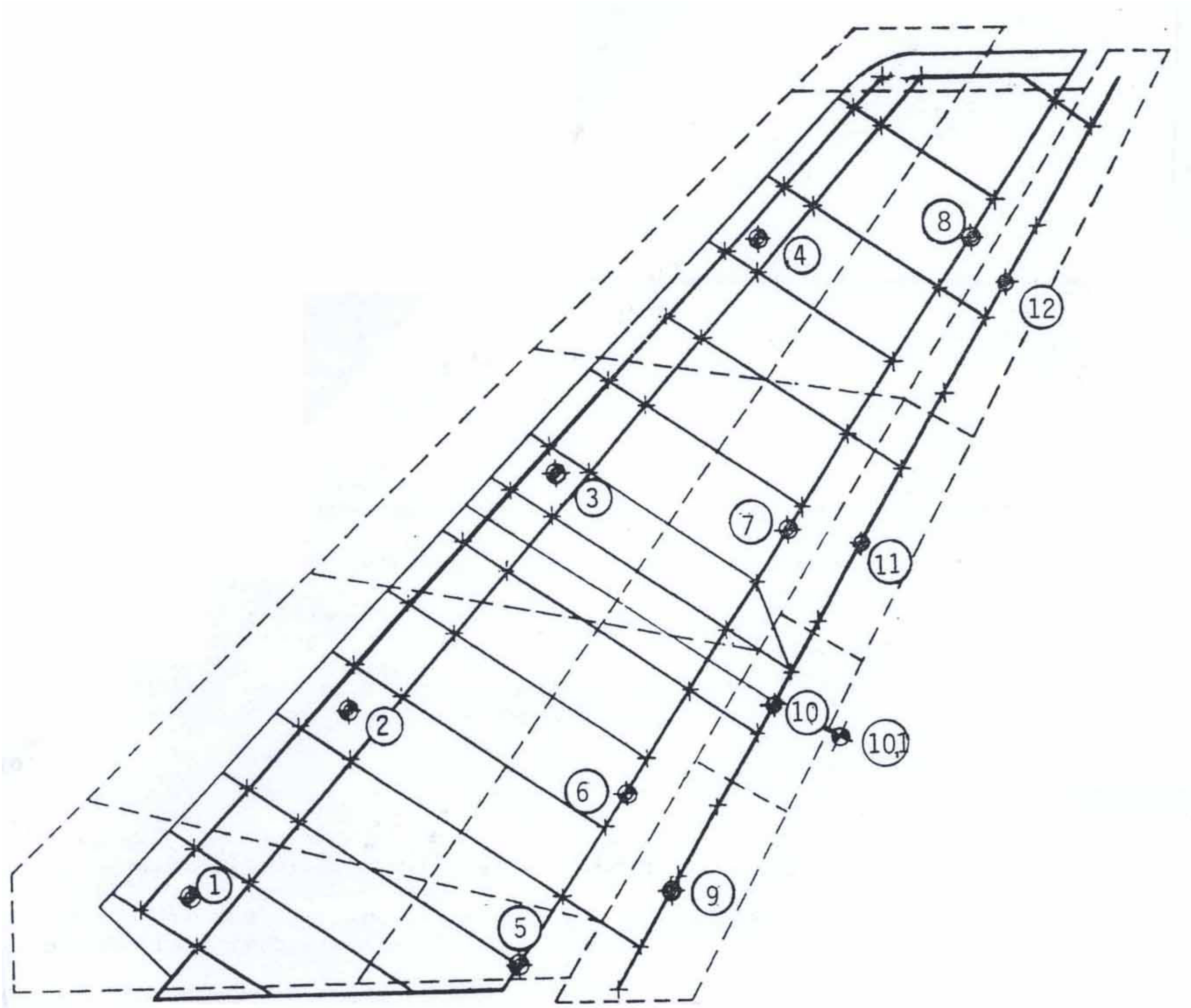

Figure 3.3

The actuator forces (y-direction) and their x-/z-coordinates are given in table 3.

S	Xs [mm]	Zs [mm]	F [kN] (gust)	F [kN] (manoeuvre)
1	1777.9	1044.2	-51.40	-63.78
2	3246.7	2626.8	-80.06	-76.56
3	5088.0	4600.8	-74.60	-77.13
4	6946.2	6669.4	-78.37	-90.96
5	4700.2	413.7	-12.45	10.23
6	5663.1	1875.7	-38.37	-20.84
7	7126.7	4101.9	1.54	-5.28
8	8774.7	6606.9	-1.37	3.90
9	6063.1	1024.5	0	20.98
10	6979.4	2593.6	0	-51.68
10.1	Lever arm 300 mm		0	62.30
11	7786.1	3975.3	0	14.93
12	9101.4	6227.7	0	18.15
Sum			- 335.0	-255.5

Table 3 (ultimate loads)

The lateral loads are balanced at the support of the fin box by rods and reaction forces (see table 4).

Load case: Lateral discrete gust (+) A310-300

	Front spar		Center spar		Rear spar	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	205 900	-208 700	166 900	-168 800	280 400	-279 000
F_y 1)	12 858		48 770		39 499	
F_y 2)	75 732		50 660		107 041	
F_z	296800	-299400	573000	-573000	671500	-666700

Load case: C31T 2K36 SE01 Manoeuvre (+) A310-300

	Front spar		Center spar		Rear spar	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	171 450	-173 250	101 670	-103 515	173 400	-172 800
F_y 1)	16 744		41 790		11 551	
F_y 2)	98 621		55 260		31 304	
F_z	286 650	-288 000	507 600	-507 600	557 400	-555 000

Table 4 (ultimate loads)

1) force at main lug
2) force at spar web lug

The lateral loads reactions at the fuselage attachment lugs have to be combined with thermal loads resulting from CTE-effects between the fuselage (aluminum) and the fin box (carbon/epoxy).

The thermal loads are significant in x-direction (see table 5) only.

Load case: Temperature +70°C

	Front spar		Center spar		Rear spar	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	-55 360	-55 470	-10 010	-9 850	65 380	65 310

Load case: Temperature -50°C

	Front spar		Center spar		Rear spar	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	77 500	77 650	14 010	13 810	-91 530	91 440

Table 5

5. Environmental conditions

For taking account of the effects of moisture and elevated temperatures the fin boxes were tested inside of an environmental chamber and exposed to hot/wet conditions to accelerate moisture pickup.

The laminate moisture content was measured by the weight gain of standardized laminate plates, which have been exposed to conditions inside the environmental chamber simultaneously with the test part. These measurements were used to control the moistening process to achieve the required in-service moisture content in the structure for demonstration of U.L.-capability under hot/wet condition.

6. Proof of structure - Static

6.1 First full scale test part

The test part was exposed to 90 percent relative humidity at 80°C for 3 weeks prior to the application of L.L. of the lateral gust and 0.8 x L.L. of the lateral manoeuvre. Both tests were performed at RT and 70°C.

During the beginning of the fatigue phase the LHS panel was severely damaged caused by a malfunction of a R3-actuator valve.
After repair the part was used to demonstrate U.L.-strength of the RHS panel in compression and for the LHS rear lug in tension.

The U.L. test was performed for the gust and manoeuvre case with thermal loads at the attachment lugs for 70°C (CTE effect) at ambient temperature and 70°C. Additionally the gust case was tested at 70°C up to 1.6 x L.L.

6.2 Second full scale test part

The test started with the application of the thermal loads for –50°C and +70°C in combination with gust and manoeuvre up to 0.8 x L.L. at ambient conditions.

This was repeated after finishing 49 604 flights of the fatigue phase.

After 14 weeks of environmental conditioning during the fatigue phase the static U.L. – test was performed after finishing 67 600 flights for the +/- gust and the negative manoeuvre case under hot/wet (70°C) conditions.

7. Proof of structure – Fatigue and damage tolerance

Before starting the fatigue phase the structure was damaged by impacts at several locations. Impactor diameters of 12 and 50 mm were used on a drop-weight apparatus.

The following structure components received impact damages

- rib 5
- rib 8
- center spar web
- rear spar web
- LHS skin panel
- RHS skin panel

In addition repairs on the skin and skin/stringer of both panels of the structure were performed with outside access only for justification of in-service repair schemes.

The envelope gust and manoeuvre spectra are covering the A310-200 (design aim = 40 000 flights), the A310-300 (design aim = 35 000 flights) and the A300-600 (design aim = 30 000 flights) by simulating a minimum of 3 lives or 120 000 flights.
The lateral gust spectrum (A310-300) is based on gust frequencies according to ESDU Data Sheets with a 15% increase of the gust intensities.
The lateral manoeuvre spectrum (A310-300) is based on manoeuvre frequencies according to AIRBUS manuals with one per life loading equal to 0.8 x limit load (normal operation) and 1.0 x limit load (crew training operation).

One life time is equal to 40 000 flights and is composed out of 40 blocks of 1000 flights each. One life time includes 176 960 lateral gust cycles, 163 680 manoeuvre cycles for normal operation and 13 280 manoeuvre cycles for crew training. The ratio between normal and crew training flights is 50:1.

The gust and manoeuvre load steps are related to limit load cases reaching 0.75 x L.L. of he gust and 1.0 x L.L. of the lateral manoeuvre. The load cycles and flight types are randomly distributed.

The fatigue loads include 8 flight types of normal operation and 2 types for crew training. The continuous load spectra are transformed into simplified stepped spectra with 6/7 steps. For account of big scatter in life a load factor of 1.15 is applied to increase the load steps except the first one.

The CTE-effects at the fin/fuselage interface are included for 3 operational environments:

Normal:	70 % of all flights
Tropical:	25 % of all flights
Arctic:	5 % of all flights.

The operating temperatures were evaluated on a statistical basis and classified into 7 ranges characterized by:

- temperature on ground
- temperature at the end of climb
- temperature at decent
- temperature on ground after landing.

For the 3 intervals a linear variation of the temperature is assumed.
The resulting loads at the fin/fuselage attachment lugs are superimposed to the flight loads reactions of the actuators in x-direction.

For the justification of non-visible impact damage the fatigue test has been interrupted at 67 600 flights for U.L. capability demonstration under worst environmental conditions (hot/wet).

After this test severe damages were added to the structure by delaminating half of the flanges from the skin at 2 adjacent stringers between 2 ribs on the LHS skin panel and by removing of a reinforcing ring at one access hole in the rear spar web (see fig. 7.1).
For these damages L.L. – capability for gust and manoeuvre was demonstrated under hot/wet conditions with the LHS in compression. The no-growth validation was achieved at 120 000 flight and closed by demonstrating L.L. of the lateral gust case.

8. Correlation between FEM analysis and test

The validation of the full scale test procedure (loading scheme and structure support) was done by comparison of the FEM analysis for

1. the fin attached to the rear fuselage
2. the fin attached to the static determinate support and at the remaining lug the reaction forces from analysis 1. applied

Despite the coarse load application on the full scale test compared to the detailed load set of analysis 1. the fuselage/fin attachment forces were in agreement.
The displacements at the front and rear spar were measured several times during the test and compared with the FEM analysis results.

The influence of fatigue cycling as well as hot/wet conditions on the stiffness/displacement of the structure was negligible. Whereas for the gust the deflection is slightly underestimated by the FEM analysis, the measured deflections for the manoeuvre case are slightly smaller than calculated (figure 8.1 thru 8.4) respectively the torsion in the upper span area.

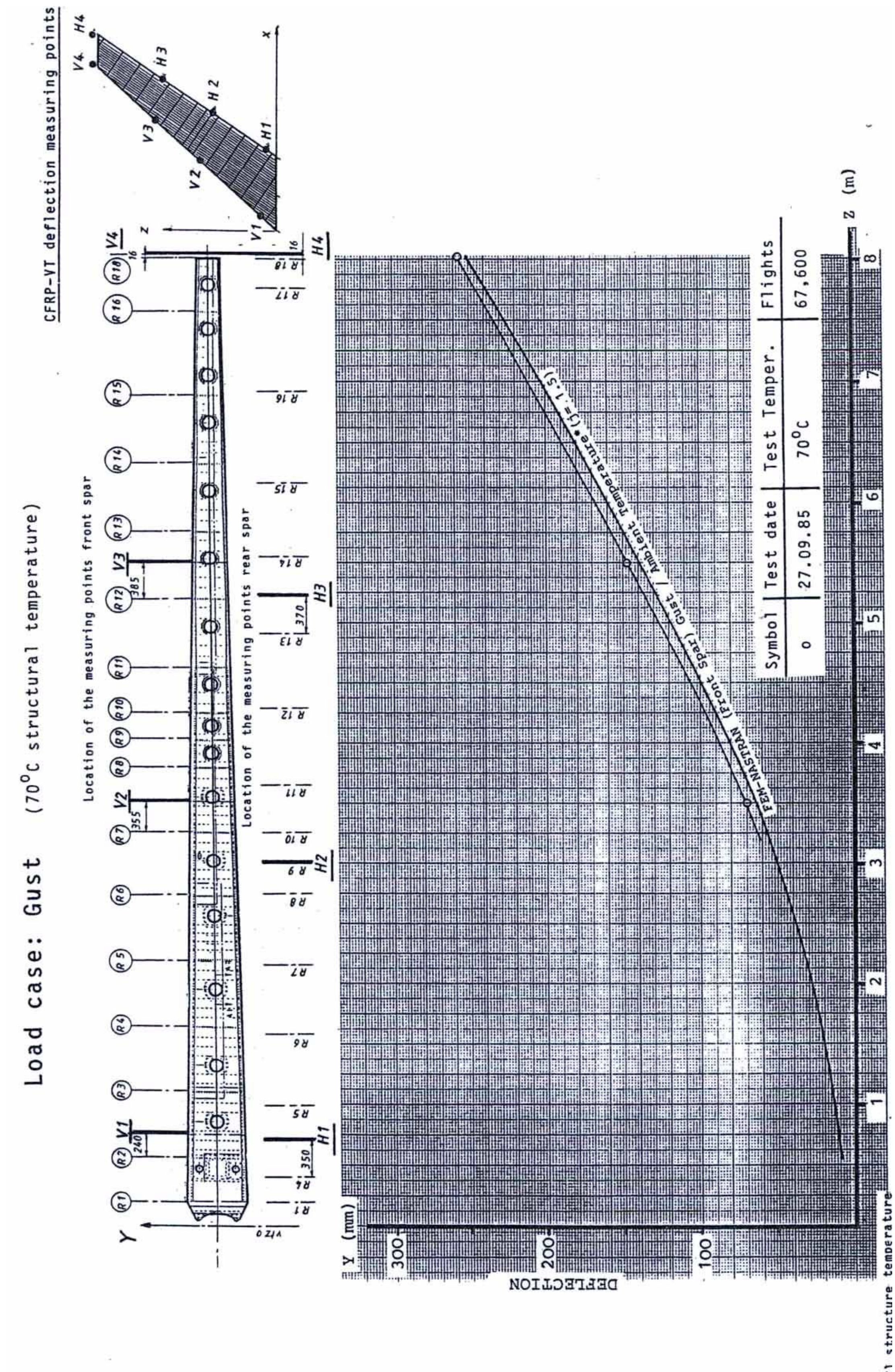
Load case: Gust (70°C structural temperature)
CFRP-VT deflection measuring points
Location of the measuring points front spar
Location of the measuring points rear spar
FEM-NASTRAN (Front Spar) Gust / Ambient Temperature *(1) = 1.5)
Symbol
Test date
Test Temper.
Flights
o
27.09.85
70°C
67,600
DEFLECTION
Y (mm)
Z (m)
*1 structure temperature

Figure 8.1

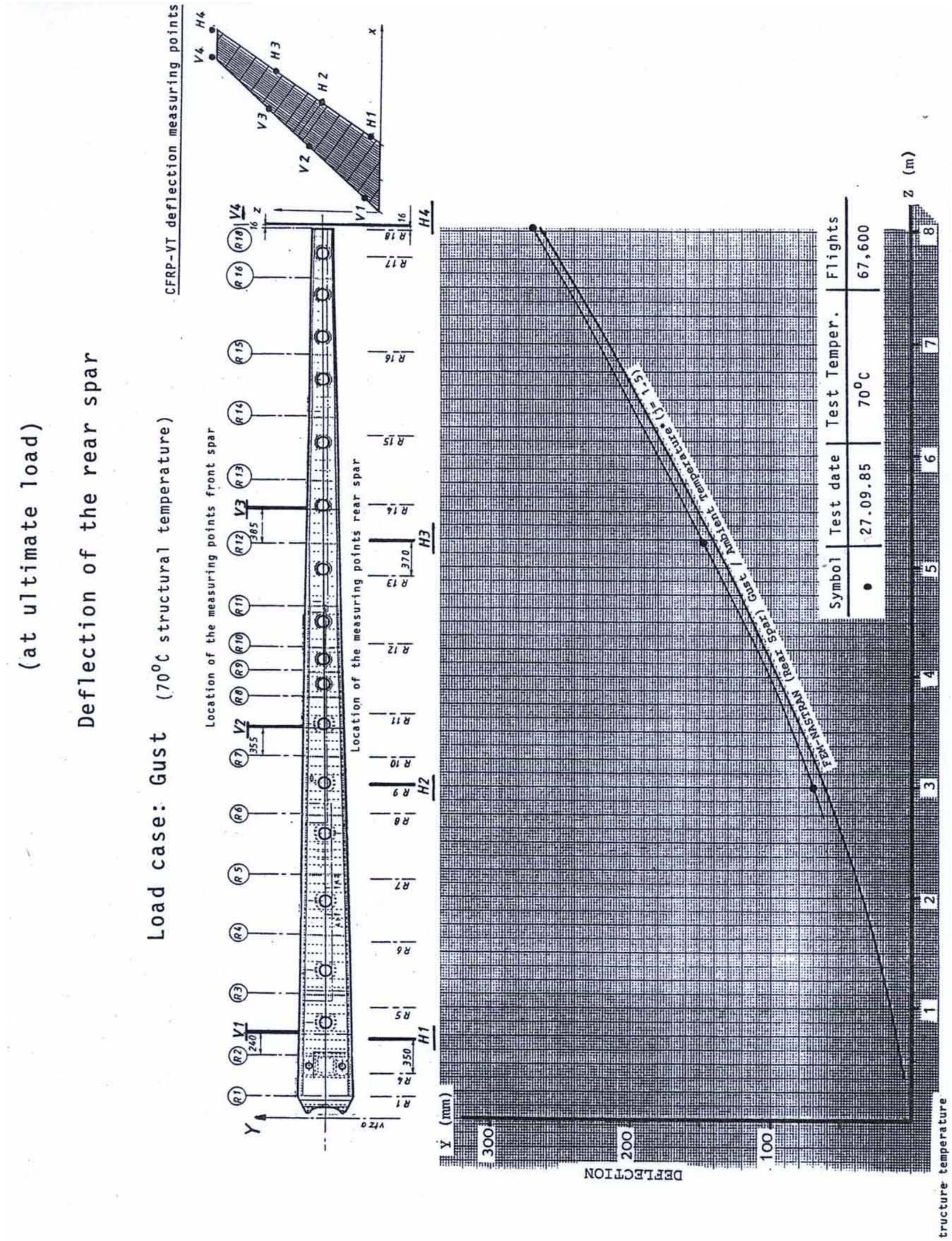
(at ultimate load)
Deflection of the rear spar
Load case: Gust (70°C structural temperature)
CFRP-VT deflection measuring points
Location of the measuring points front spar
Location of the measuring points rear spar
FEM-NASTRAN (Rear Spar) Gust / Ambient Temperature *(j= 1-5)
Symbol | Test date | Test Temper. | Flights
27.09.85 | 70°C | 67,600
DEFLECTION
Y (mm)
Z (m)
tructure temperature

Figure 8.2

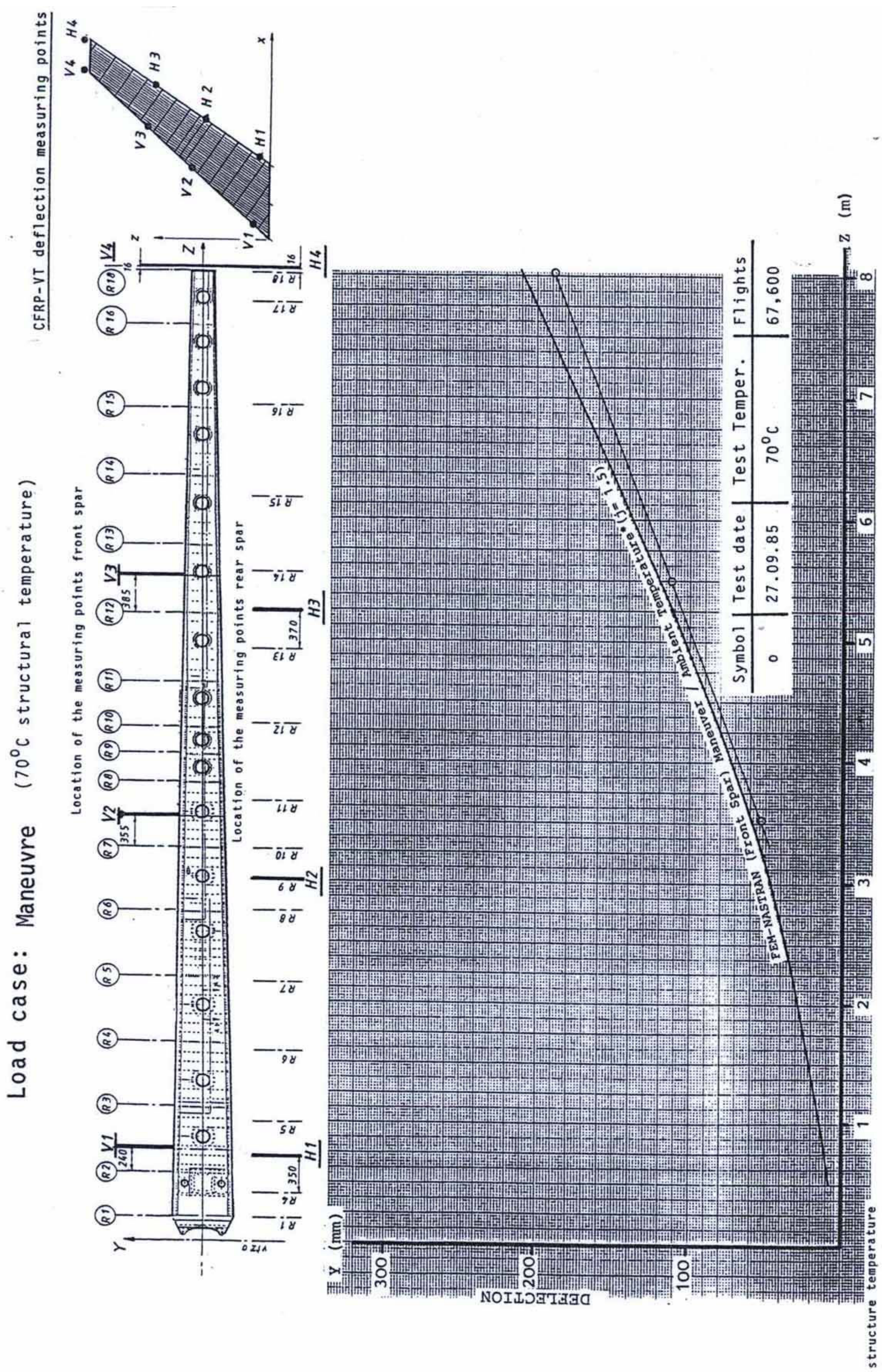
Load case: Maneuvre (70°C structural temperature)
CFRP-VT deflection measuring points
Location of the measuring points front spar
Location of the measuring points rear spar
FEM-NASTRAN (Front Spar) Maneuver / Ambient Temperature
Symbol | Test date | Test Temper. | Flights
o | 27.09.85 | 70°C | 67,600
DEFLECTION
Y (mm)
Z (m)
structure temperature

Figure 8.3

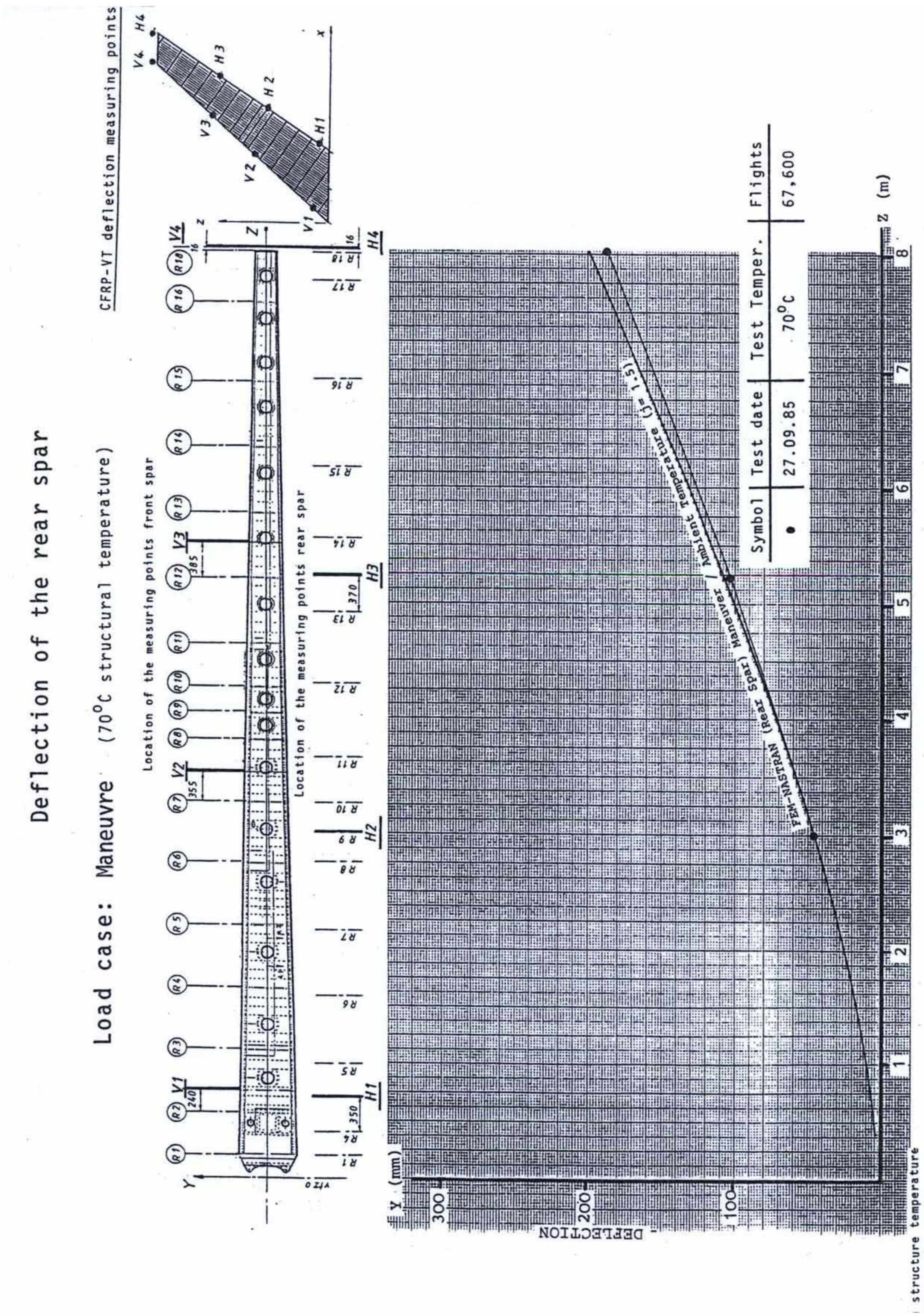
Deflection of the rear spar
Load case: Maneuvre (70°C structural temperature)
CFRP-VT deflection measuring points
Location of the measuring points front spar
Location of the measuring points rear spar
FEM-NASTRAN (Rear Spar) Maneuver / Ambient Temperature (j = 1.5)
Symbol | Test date | Test Temper. | Flights
● | 27.09.85 | 70°C | 67,600
DEFLECTION
Y (mm)
Z (m)
structure temperature

Figure 8.4

The measured strains were also acceptable matching the analysis results from 1. (figure 8.5, 8.6).

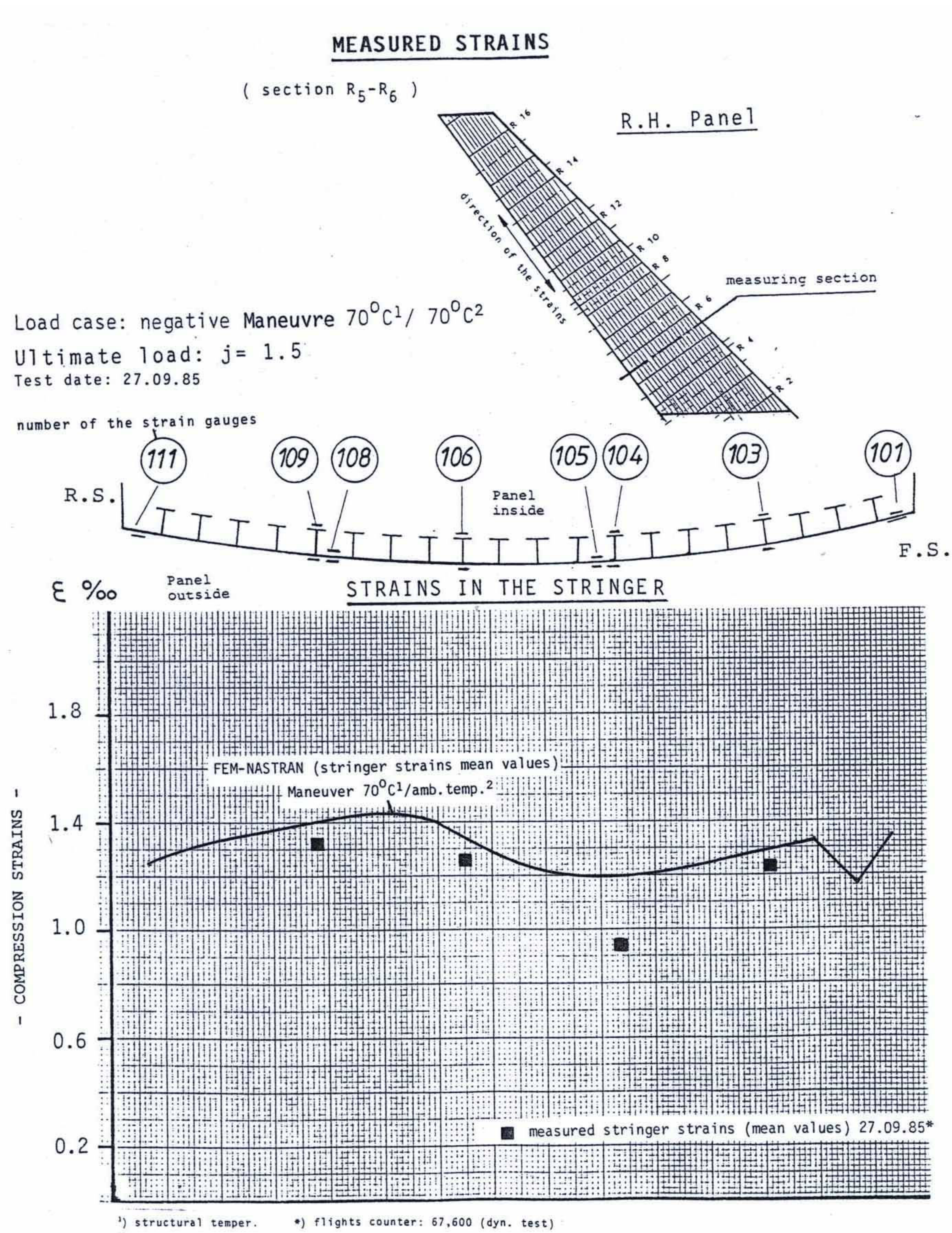

Figure 8.5

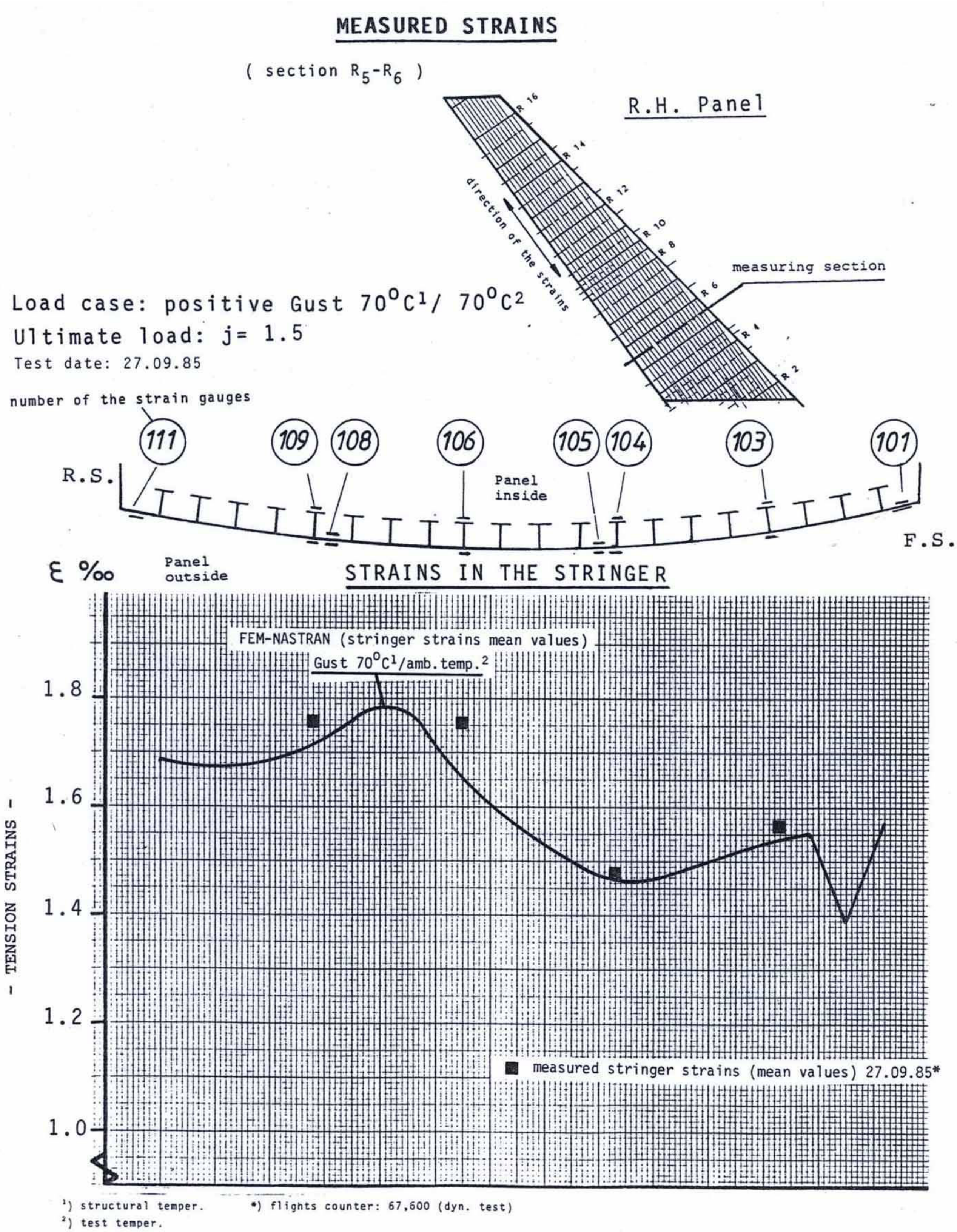
MEASURED STRAINS
(section R_5-R_6)
R.H. Panel
direction of the strains
measuring section
R 16
R 14
R 12
R 10
R 8
R 6
R 4
R 2
Load case: positive Gust 70°C¹/ 70°C²
Ultimate load: j= 1.5
Test date: 27.09.85
number of the strain gauges
111
109
108
106
105
104
103
101
R.S.
Panel inside
F.S.
ε ‰
Panel outside
STRAINS IN THE STRINGER
FEM-NASTRAN (stringer strains mean values)
Gust 70°C¹/amb.temp.²
1.8
1.6
1.4
1.2
1.0
- TENSION STRAINS -
measured stringer strains (mean values) 27.09.85*
¹) structural temper.
²) test temper.
*) flights counter: 67,600 (dyn. test)

Figure 8.6

9. Residual strength test

The residual strength test was performed after completion of the fatigue test at 120 000 simulated flights which corresponds to a minimum of 3 lives.
The structure was loaded with the lateral gust case (tension on the RHS) including the thermal loads at 70°C from CTE-effects under hot/wet conditions (70°C / 90% laminate moisture content measured by re-drying of the reference laminates from HEXCEL material).
The structure failed at 1.905 x L.L. at the RHS rear main lug. The rupture load was 904.8 kN.

10. Summary

The proof of structure – static strength and fatigue/DT behaviour has been accomplished by full scale testing of the complete fin box.

The first test part was used to demonstrate the static strength at hot/wet conditions prior to repeated loading including tolerable manufacturing defects. Impact damages and repairs.

The second test part was subjected to repeated loading for 120 000 flight cycles which is equivalent to 4 lives for A300-600.

For the structure including nonvisible damage ultimate load capability has been demonstrated for the gust and manoeuvre design cases after 67 600 flight cycles.

During the following damage tolerance phase (up to 120 000 flights) the no-growth-validation has been performed for severe damage (stringer delamination).

The residual strength test which was performed after 4 lives under hot/wet conditions yields a strength of 1.9 x L.L. (lateral gust).