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NATIONAL TRANSPORTATION SAFETY BOARD

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Structural Analysis and Evaluation for the Airbus A300-600R/MSN420 VTP & Rudder for the accident flight AA587

Part 2 : Analysis of the rupture sequence of the VTP during the accident

(16 Pages)

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Part II: Analysis of the rupture sequence of the vertical stabilizer during the accident

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1. Introduction

This report describes the most likely rupture sequence of the vertical stabilizer A300-600R subjected to the accident during flight AA587. The investigation is based on finite element analysis with sequently removed connections between vertical stabilizer and fuselage and is supported by results from tests performed for certification of the structure.

2. Finite element analysis with sequently removed connections between vertical stabilizer and fuselage

The finite element model is described in part I of this report. The analysis is performed in several steps, starting with fully intact vertical stabilizer attachment lugs. During successive analyses the calculated loads on each individual lug is compared with its strength. In case the calculated load exceeds the strength, the corresponding connection is removed in the finite element model to simulate the local failure. This procedure is repeated to ascertain the final rupture sequence of the structure.

3. Analysed load case

Load case Y376 (see part I of this report), which represents the load on the vertical stabilizer and rudder at the time step of the accident is used for analysis (see figure 1)

	Y376
Q_y [N]	-378 590
M_{xQ} [Nm]	1 689 880
M_{zQ} [Nm]	71 050
Rudder hinge moment [Nm]	21 610
Rudder deflection angle [°]	-11.47

Figure 1

4. Structural strength of the vertical stabilizer attachment lug and lateral shear fittings

The strength of the attachment lugs and lateral shear fittings are derived from the vertical stabilizer full scale test and detail tests (figure 2).

	Tension strength [N]	Compression strength [N]
front lug	730 000	520 360 [1)]
center lug	1 040 750	761 640 [1)]
rear lug	902 000	1 003 000
front shear fitting	73 700	73 700
center shear fitting	90 900	90 900
rear shear fitting	152 000	152 000

[1)] The value are achieved loads during vertical stabilizer full scale test **without** failure of the attachments.

Figure 2

5. Lug failure sequence analysis results

The reaction loads at the attachment of the vertical stabilizer for load case Y376 are provided in the aircraft coordinate system (se figure 3) and listed in figure 4. A negative sign for F_z indicates tension at the main lugs.

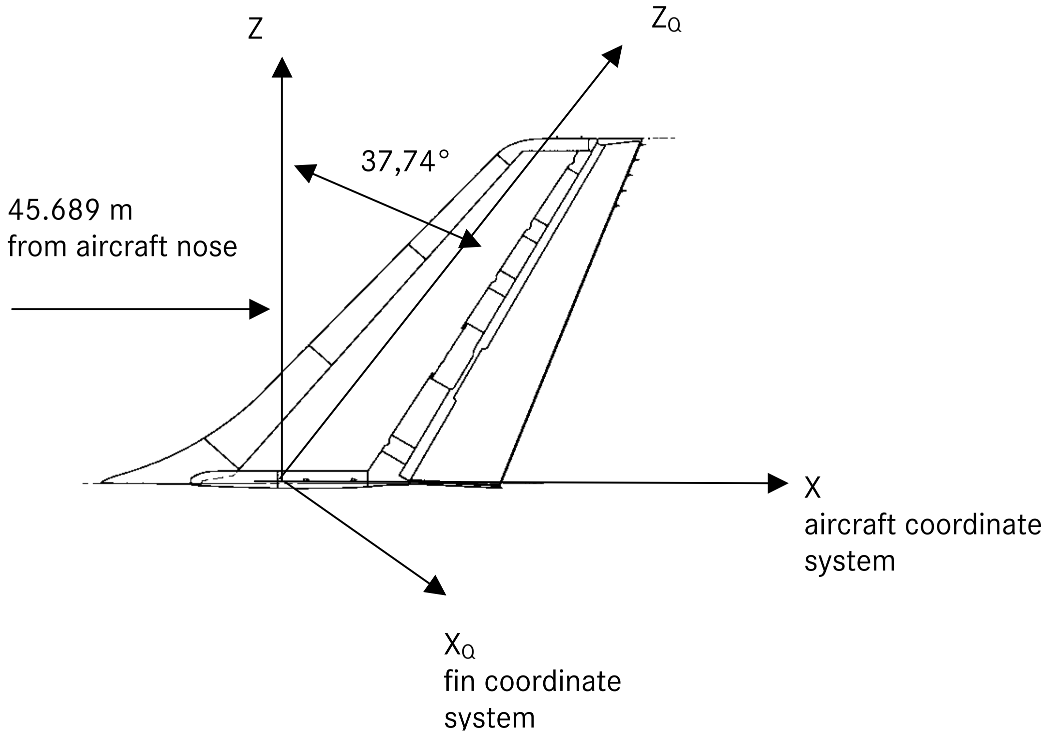

Figure 3

Reaction forces at main lugs

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	241 154	-254 033	228 468	-233 066	387 676	-379 764
F_y	10 521	11 139	33 342	33 825	43 950	43 696
F_z	290 117	-307 792	640 708	-641 682	820 805	-796 830
F_{res}	377 404	399 240	681 040	683 535	908 815	**883 780**
M_x [Nm]	-2 755	-2 844	-7 268	-7 367	-10 209	-9 958
M_z [Nm]	59	33	1 041	952	4 061	3 832
angle [°]	50	50	70	70	65	65

Reaction forces at lateral load yokes

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	-1 053	985	-590	488	-9 192	9 470
F_y	14 171	13 261	8 068	6 669	75 525	77 809
F_z	-1 199	1 121	- 899	743	-14 026	14 450
F_{res}	14 261	13 345	8 140	6 728	77 364	79 704

Figure 4

When the resultants F_{res} are compared with corresponding strength values it is obvious, that the rear RHS main lug load is close to its rupture level. All other lugs and lateral shear fittings are loaded well below their strength levels.
For this reason and considering the scatter band of the loads calculation of ±7 % (see Part I, figure 4) the next analysis step takes into account that the rear RHS lug has failed in tension. The corresponding attachment loads are listed in figure 5 for the condition of the next failure of the LHS rear shear fitting.

Reaction forces at main lugs

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	215 726	-209 877	192 582	-308 166	130 874	0
F_y	12 566	9 664	25 342	36 274	42 647	0
F_z	285 997	-228 661	528 011	-701 356	159 510	0
F_{res}	358 455	310 528	562 606	766 930	210 690	0
M_x [Nm]	-2 571	-2 284	-5 966	-7 800	-6 195	0
M_z [Nm]	101	84	941	753	2 192	0
angle [°]	53	47	70	66	51	

Reaction forces at lateral load yokes

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	-496	573	573	366	-18 061	-9 411
F_y	6 680	7 717	-7 839	5 002	148 387	-77 324
F_z	-565	653	874	557	-27 558	-14 360
F_{res}	6 722	7 766	7 909	5 046	**152 000**	79 208

Figure 5

The “0” at the rear RHS lug indicates, that there is no load transfer due to failure.

The attachment loads with the failed LHS rear shear fittings (see figure 2) are listed in figure 6 for the tension failure level of the RHS center lug.

Reaction forces at main lugs

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	291 327	-287 170	266 149	-446 977	163 313	0
F_y	16 872	12 495	37 260	52 101	86 899	0
F_z	383 525	-299 980	703 447	-938 434	145 751	0
F_{res}	481 921	415 464	753 035	**1 040 750**	235 513	0
M_x [Nm]	-3 449	-3 040	-8 158	-10 633	-9 415	0
M_z [Nm]	164	126	1 670	1 368	4 269	0
angle [°]	53	46	69	65	42	

Reaction forces at lateral load yokes

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	-504	597	245	1 147	0	4 925
F_y	6 782	8 044	-3 353	15 689	0	40 461
F_z	-574	680	374	1 748	0	7 514
F_{res}	6 825	8 095	3 383	15 827	0	41 446

Figure 6

In the subsequent analysis the center lug on RHS and the rear LHS shear fitting are disconnected from the fuselage attachments and the applied loads are reduced to the failure load level for the RHS front lug (see figure 2). The new redistributed attachment loads are listed in figure 7.

Reaction forces at main lugs

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	331 992	-462 477	119 337	0	23 539	0
F_y	28 736	28 605	51 424	0	103 475	0
F_z	479 126	-564 089	212 471	0	-101 827	0
F_{res}	583 614	**730 000**	249 057	0	147 072	0
M_x [Nm]	-4 569	-5 217	-10 164	0	-10 495	0
M_z [Nm]	383	47	2 900	0	3 859	0
angle [°]	55	51	61		-77	

Reaction forces at lateral load yokes

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	-1 370	1 975	-2 618	-10 928	0	-2 565
F_y	18 446	26 586	35 788	-149 413	0	-21 073
F_z	-1 560	2 248	-3 988	-16 649	0	-3 914
F_{res}	18 562	26 754	36 104	**150 734**	0	21 586

Figure 7

Figure 7 indicates, that at the moment of rupture of the RHS center lug the RHS center shear fitting has ruptured also.

Taking this into account by removing the RHS center shear fitting connection between the vertical stabilizer and the fuselage and applying the load level at which the RHS front lug fails, results in the following attachment loads (see figure 8).

Reaction forces at main lugs

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	329 693	-467 885	106 666	0	27 178	0
F_y	26 548	26 512	34 769	0	98 689	0
F_z	469 201	-559 715	191 972	0	-101 504	0
F_{res}	574 066	**730 000**	222 350	0	144 157	0
M_x [Nm]	-4 416	-5 106	-9 313	0	-10 179	0
M_z [Nm]	304	-40	3 337	0	4 109	0
angle [°]	55	50	61		-75	

Reaction forces at lateral load yokes

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	-945	1 561	4 936	0	0	-4 208
F_y	12 728	21 015	-67 486	0	0	-34 572
F_z	-1 076	1 777	7 520	0	0	-6 421
F_{res}	12 808	21 148	68 083	0	0	35 414

Figure 8

The values from figure 7 and figure 8 demonstrate that on the LH/compression side the loads do not reach the strength levels (figure 4) for the LHS main lugs at this condition.

After the RHS front lug has failed at 730.000 N the RHS front shear fitting and the LHS center shear fitting rupture next.
The vertical stabilizer is in this condition supported by the LHS lugs only. The major portion of the acting bending moment (84%) is reacted by local moments at the remaining lugs and 16% by tension forces at the LHS front / rear lug and compression force at the LHS center lug.

The forces and moments after rupture of the RHS front lug and the transverse load fittings are listed in figure 9.

Reaction forces at main lugs

Load component	Front [N]		Center [N]		Rear [N]	
	LHS	RHS	LHS	RHS	LHS	RHS
F_x	-241 990	0	1 159 873	0	-927 338	0
F_y	-137 665	0	120 899	0	388 744	0
F_z	-1 582 117	0	3 768 512	0	-2 180 877	0
F_{res}	1 606 426	0	3 944 820	0	2 401 521	0
M_x [Nm]	-272 179	0	-502 563	0	-373 881	0
M_z [Nm]	58 377	0	95 809	0	-1 622	0
angle [°]	81		73		67	

Figure 9

Due to the bending stiffness to bending moment ratio at the LHS front, center and rear lugs the front lug fails first.
The failure sequence is shown on figure 10 and indicated by numbers 1 to 8.

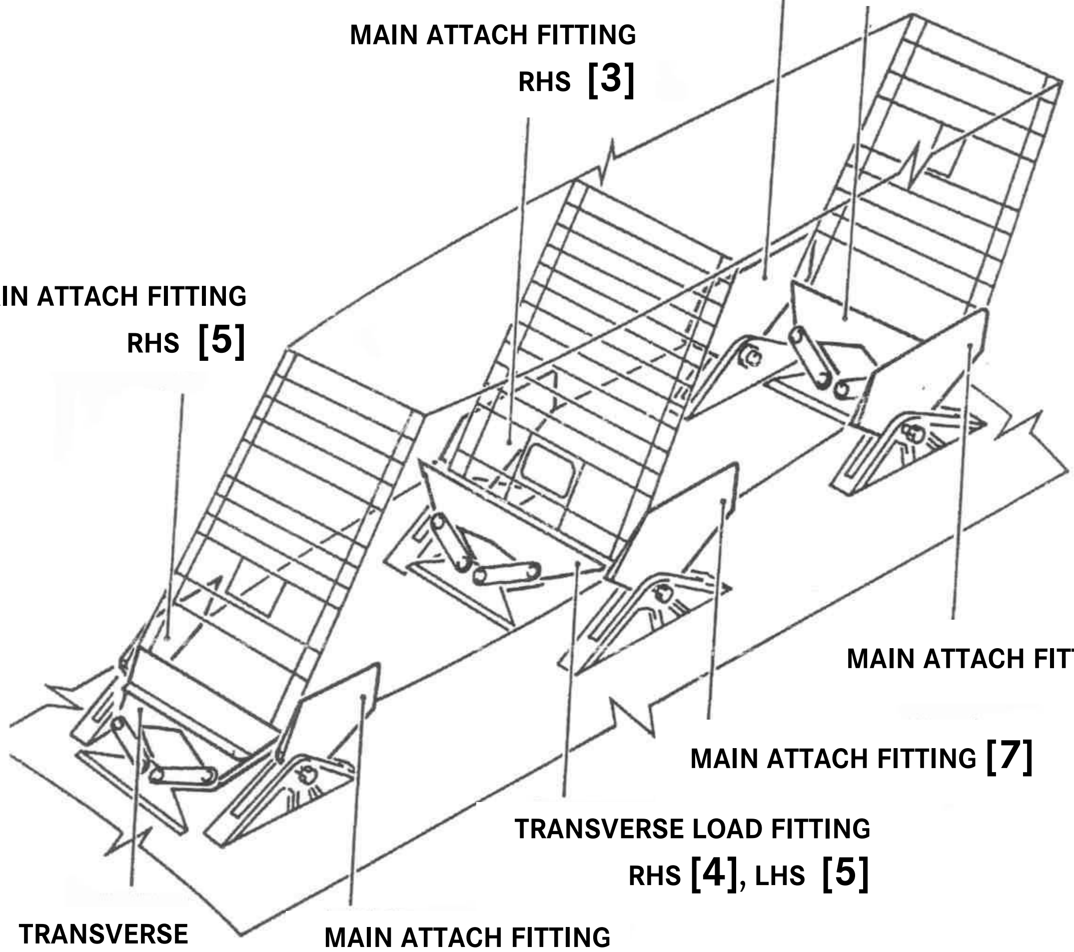

Figure 10

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7. Summary

Due to the load level experienced during the accident, which exceeds U.L.-requirements by at least 26% the RHS rear lug failed first. The subsequent load redistribution immediately severed the remaining lugs, which leads to total detachment of the vertical stabilizer.