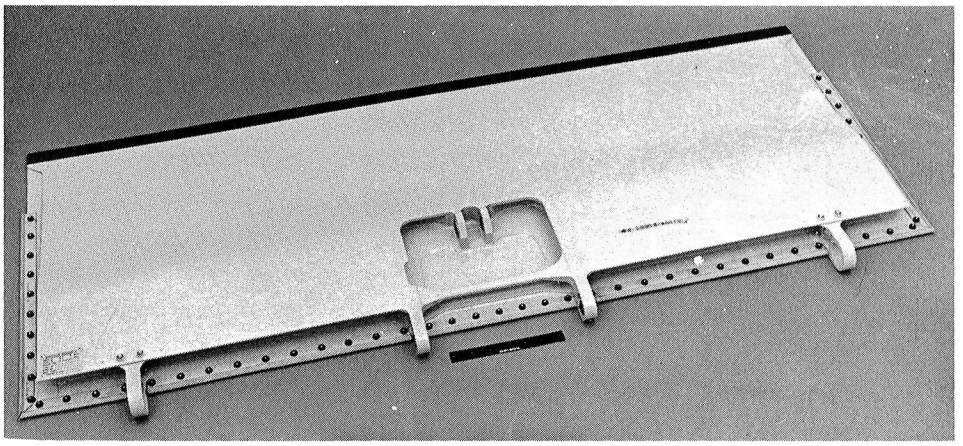
NASA CR 159094

737 GRAPHITE COMPOSITE FLIGHT SPOILER FLIGHT SERVICE EVALUATION

By Daniel J. Hoffman and
Robert L. Stoecklin



FIFTH ANNUAL REPORT

MAY 1978 THROUGH APRIL 1979

Prepared under contract NAS1-11668 by
BOEING COMMERCIAL AIRPLANE COMPANY
P.O. Box 3707
Seattle, Washington 98124

for
Langley Research Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This is the fifth progress report on the service evaluation of graphite-epoxy flight spoilers for 737 aircraft. This effort has been conducted as a portion of NASA Contract NAS1-11668, "A Study of the Effects of Long-Term Ground and Flight Environment Exposure on the Behavior of Graphite-Epoxy Spoilers." The program is structured to gather and evaluate actual commercial service experience on a large number of graphite-epoxy specimens in a wide range of operating environments. Additional annual reports will be prepared and submitted for the duration of the flight service period, which is programmed to provide 10 years of flight service.

The program is administered by the Langely Research Center of the National Aeronautics and Space Administration. Mr. Richard Pride of the Materials Division is the technical monitor. Mr. H. Benson Dexter of the Materials Division has the responsibility for test and evaluation of ground based specimens for the program. Mr. Andrew J. Chapman of the Materials Division monitors the flight moisture absorption specimens.

The program is being conducted at the Boeing Commercial Airplane Company under the direction of John E. McCarty, program manager. Near the end of this reporting period, Daniel J. Hoffman replaced Robert L. Stoecklin as Program Technical Leader. Mr. Stoecklin had served in this capacity since the inception of the program.

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737 GRAPHITE COMPOSITE FLIGHT SPOILER FLIGHT SERVICE EVALUATION

Daniel J. Hoffman and Robert L. Stoecklin
Boeing Commercial Airplane Company

PROGRAM SUMMARY AND STATUS

This fifth annual flight service report is submitted in accordance with the requirements of contract NAS1-11668 and covers the service evaluation portion of this NASA contract for the period of May 1, 1978, through April 30, 1979. Segments of the data contained herein have appeared in previous documentation (refs. 1, 2, 3, 4 and 5).

A primary objective of this program is to produce 114, graphite-epoxy 737 flight spoilers for testing and service evaluation deployment. One spoiler of each of the three different graphite-epoxy material systems used has been laboratory tested for stiffness and strength in partial fulfillment of FAA certification requirements. Four spoilers were initially installed on each of 27 aircraft representing six major airlines operating in different environmental circumstances. One additional aircraft was added to the fleet in 1976. This additional aircraft was deleted from the fleet during this reporting period. These units will be monitored under actual load and environmental conditions for a period of 10 years. Selected units are removed periodically to evaluate any material property changes as a function of time. Six environmental exposure racks have been fabricated and positioned at major airport terminals of the participating airlines in various parts of the world to gather ground-based environmental data to support the flight data gathered from the spoilers.

An additional objective added to this program is the gathering of moisture absorption data from graphite samples placed on the exterior of three 737 revenue aircraft presently flying graphite spoilers. These samples are being periodically removed and evaluated over a two-year period. All reporting of moisture absorption data will be made within this reporting system.

Significant events that have occurred during this period include:

- Completion of the fifth annual inspection of those spoilers in service
- Continuation of the spoiler repair program
- Continuation of the NDI sampling program and static testing of spoilers from the flight service program
- Deletion of one aircraft from the flight service program
- Continuation of the inflight moisture absorption study
- Continuation of the skin laminate moisture absorption study

As of April 30, 1979, a total of 1 188 367 spoiler flight-hours and 1 786 837 spoiler landings had been accumulated by the fleet. The high-time spoiler has accumulated 15 436 flight-hours on Frontier Airlines 737 N7386F. Over 50 spoilers have accumulated in excess of 12 000 flight-hours since the beginning of the flight service program, and 43 spoilers have had uninterrupted service since their original installation.

Laboratory testing of spoilers returned from 5 years of flight service testing continues to show a stabilization of residual strengths for all three material systems. The leveling of the T300/5209 residual strength reported in last year's Annual Report continued this year. All three material systems displayed 5-year residual strengths within a few percent of their baseline values and well within the bounds of the fabrication scatter band.

Maintenance damage and related repair activities have continued at a modest level this past year. Seven spoilers were removed for repair activities during this reporting period. The primary cause for interrupted service was exfoliation corrosion of the aluminum spar member near the spar/center hinge fitting splice. Near the end of the fifth year, one spoiler was removed because of a trailing-edge delamination. All of the removed units were repaired or are currently undergoing repair. Airlines continue to exhibit both enthusiasm for and confidence in the program.

PROGRAM SCOPE

The service evaluation program was established to place the 737 graphite-epoxy flight spoilers into a commercial service environment containing as many climatic variables as possible. The six active participating airlines previously identified (ref. 2) continue to operate 27 aircraft presently committed to the program.

The current participating airlines are:

- Air New Zealand, Ltd. – four aircraft
- Aloha Airlines – four aircraft
- Deutsche Lufthansa Airlines – six aircraft
- Piedmont Airlines – eight aircraft
- VASP Airlines – four aircraft
- Frontier Airlines – one aircraft

The geographic scope of the service-evaluation program continues as shown in figure 1.

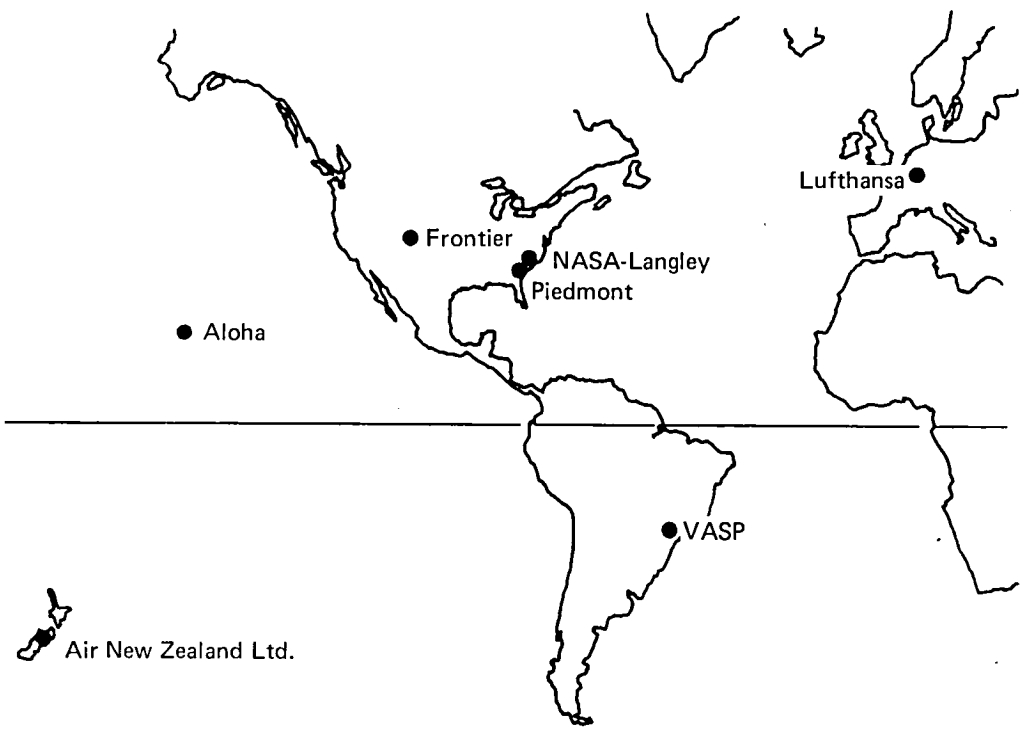

Figure 1.—Geographic Deployment of Current Participating Airlines

FLIGHT EXPERIENCE

The flight service evaluation program in operation since July 18, 1973, has achieved an exceptional level of commercial service exposure of graphite-epoxy structural aircraft components, in the form of the 737 flight spoiler. The program has generated over one million flight hours of service in its 6 years of operation and is adding flight experience at the rate of nearly 18 000 hours per month.

The total flight experience to April 30, 1979, is detailed in table 1, with breakdown by spoiler serial number. Reinstallations are treated as a separate line item in this summary. Note that each of the graphite-epoxy material systems is designated by a separate block of serial numbers:

- Union Carbide T300/2544: 0001 to 0038
- Narmco T300/5209: 0041 to 0078
- Hercules AS/3501: 0081 to 0118

Table 2 summarizes the same data by airline. VASP and Frontier data include only flight experience since acquisition of their respective aircraft from PSA.

A total of 50 spoiler panels have accumulated over 12 000 flight hours each. Their distribution, by airline and by skin material system, is shown in table 3.

Table 1.—Spoiler Service-Evaluation Program (as of 04-30-79)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
0001R	PI	5 681	3 056	18 284	21 727	12 603	18 671
0002	Test	—	—	—	—	—	—
0003	PSA	8 095	12 842	9 018	14 379	923	1 537
0003	VASP	9 018	14 379	20 716	27 409	11 698	13 030
0004	PSA	8 161	12 965	9 018	14 379	857	1 414
0004	VASP	9 018	14 379	20 716	27 409	11 698	13 030
0005	PSA	8 095	12 842	9 018	14 379	923	1 537
0005	VASP	9 018	14 379	18 112	24 432	9 094	10 053
0006	PSA	8 161	12 965	9 018	14 379	857	1 414
0006	VASP	9 018	14 379	20 716	27 409	11 698	13 030
0007	NZ	10 861	15 053	22 862	31 141	12 001	16 088
0008	NZ	10 861	15 053	22 862	31 141	12 001	16 088
0009	NZ	10 861	15 053	16 147	22 112	5 286	7 059
b0009	NZ	21 603	29 443	22 862	31 141	1 259	1 698
0010	NZ	10 861	15 053	22 862	31 141	12 001	16 088
0011	LH	11 274	15 681	20 307	26 924	9 033	11 243
b0011	LH	21 658	28 554	24 235	31 609	2 577	3 055
0012	LH	11 274	15 681	14 694	19 964	3 420	4 283
b0012	LH	15 148	20 528	15 793	21 324	645	796
b0012	LH	15 940	21 518	22 297	29 334	6 357	7 816
b0012	LH	22 954	30 142	25 275	32 831	2 321	2 689
0013	LH	11 274	15 681	21 938	28 901	10 664	13 220
b0013	LH	22 987	30 176	24 235	31 609	1 248	1 433
0014	LH	11 274	15 681	13 329	18 216	2 055	2 535
0015	PSA	8 651	13 711	9 399	14 936	748	1 225
0015	VASP	9 399	14 936	11 689	17 594	2 290	2 658
b0015	VASP	13 411	19 607	21 039	28 090	7 628	8 483
0016	PSA	8 651	13 711	9 399	14 936	748	1 225
0016	VASP	9 399	14 936	17 147	23 710	7 748	8 783
0017	PSA	8 651	13 711	9 399	14 936	748	1 225
0017	VASP	9 399	14 936	12 432	18 474	3 033	3 538
b0017	VASP	13 411	19 607	21 039	28 090	7 628	8 483
0018	PSA	8 651	13 711	9 399	14 936	748	1 225
0018	VASP	9 399	14 936	11 689	17 594	2 290	2 658
b0018	VASP	13 411	19 607	21 039	28 090	7 628	8 483
0019	LH	11 200	14 884	24 052	30 713	12 852	15 829
0020	LH	11 200	14 884	22 678	29 128	11 478	14 244
0021	LH	11 200	14 884	14 653	19 211	3 453	4 327
b0021	LH	15 425	20 178	24 052	30 713	8 627	10 535
b0021	LH	22 772	29 241	23 040	29 554	268	313
0022	LH	11 200	14 884	24 052	30 713	12 852	15 829
b0022	LH	22 772	29 241	23 040	29 554	268	313
0023	Aloha	9 207	24 932	17 722	48 181	8 515	23 249
0024	Aloha	9 207	24 932	10 974	29 694	1 767	4 762

See footnotes at end of table.

Table 1.—(Continued)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
b0024	Aloha	12 071	32 691	19 670	53 419	7 599	20 728
0025	Aloha	9 207	24 932	12 964	35 165	3 757	10 233
0026	Aloha	9 207	24 932	12 071	32 691	2 864	7 759
b0026	Aloha	8 287	14 823	10 395	20 494	2 108	5 671
0027	PI	12 329	20 204	20 488	32 576	8 159	12 372
b0027	PI	21 916	34 744	25 518	40 061	3 602	5 317
0028	PI	13 747	22 449	16 387	26 396	2 640	3 947
b0028	PI	17 201	27 670	27 223	42 528	10 022	14 858
0029	PI	12 329	20 204	25 518	40 061	13 189	19 857
0030	PI	13 747	22 449	27 223	42 728	13 476	20 279
0031	PI	13 747	22 449	27 223	42 728	13 476	20 279
0032	PI	12 329	20 204	14 411	23 348	2 082	3 144
b0032	PI	15 259	24 624	25 518	40 061	10 259	15 437
0033	PI	13 747	22 449	27 223	42 728	13 476	20 279
0034R	PI	12 329	20 204	25 518	40 061	13 189	19 857
0035	PI	5 681	3 056	7 673	5 964	1 992	2 908
b0035	PI	8 542	7 300	18 284	21 727	9 742	14 427
0036	PI	5 681	3 056	7 663	5 945	1 982	2 889
b0036	PI	8 542	7 300	18 284	21 727	9 742	14 427
0037	PI	5 681	3 056	18 284	21 727	12 603	18 671
0038	Aloha	11 340	30 745	19 414	53 100	8 074	22 355
					Subtotal	407 467	591 941
0041	Test	—	—	—	—	—	—
0042	PSA	5 003	8 092	9 600	16 525	4 597	8 433
0042	FL	9 600	16 525	20 429	28 118	10 829	11 593
0043	PSA	4 993	8 068	9 600	16 525	4 607	8 457
0043	FL	9 600	16 525	20 429	28 118	10 829	11 593
0044	PSA	5 003	8 092	9 600	16 525	4 597	8 433
0044	FL	9 600	16 525	13 201	20,370	3 601	3 845
b0044	FL	15 025	22 485	20 429	28 118	5 404	5 633
0045	PSA	4 993	8 068	6 896	11 280	1 902	3 212
b0045	FL	10 064	16 998	17 369	24 969	7 305	7 971
0046	Aloha	6 447	9 087	13 058	26 664	6 611	17 577
b0046	Aloha	20 014	30 447	22 496	37 233	2 482	6 786
0047	Aloha	6 447	9 087	10 256	19 089	3 809	10 002
b0047	FL	14 728	16 350	19 153	21 328	4 425	4 978
b0047	FL	17 409	25 010	20 429	28 118	3 020	3 108
0048	Aloha	6 447	9 087	9 103	16 022	2 656	6 935
b0048	Aloha	8 287	14 823	11 473	23 389	3 186	8 566
b0048	Aloha	15 912	36 880	18 669	44 186	2 757	7 306
0049	Aloha	6 447	9 087	12 050	23 911	5 603	14 824
b0049	Aloha	20 014	30 447	22 496	37 233	2 482	6 786
0050	NZ	10 539	14 075	15 771	21 303	5 232	7 228

See footnotes at end of table.

Table 1.–(Continued)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
0051	NZ	10 539	14 075	19 444	26 204	8 905	12 129
b0051	NZ	20 435	27 564	22 621	30 495	2 186	2 931
0052	NZ	10 539	14 075	14 057	18 964	3 518	4 889
b0052	NZ	14 707	19 835	21 757	29 355	7 050	9 520
0053	NZ	10 539	14 075	13 138	17 747	2 599	3 672
0054	LH	11 152	15 328	17 899	23 824	6 747	8 496
0055	LH	11 152	15 328	24 061	31 164	12 909	15 836
0056	LH	11 152	15 328	24 061	31 164	12 909	15 836
0057	LH	11 152	15 328	15 633	20 997	4 481	5 669
0058	PSA	8 476	13 644	9 402	15 241	926	1 597
0058	VASP	9 402	15 241	20 966	28 057	11 564	12 816
0059	PSA	8 476	13 644	9 402	15 241	926	1 597
0059	VASP	9 402	15 241	10 900	17 164	1 498	1 923
b0059	VASP	13 181	19 621	20 966	28 057	7 785	8 436
0060	PSA	8 476	13 644	9 402	15 241	926	1 597
0060	VASP	9 402	15 241	14 715	21 102	5 313	5 861
b0060	VASP	17 529	24 227	20 966	28 057	3 437	3 830
0061	PSA	8 476	13 644	9 402	15 241	926	1 597
0061	VASP	9 402	15 241	20 966	28 057	11 564	12 816
0062	LH	11 450	15 759	24 223	31 450	12 773	15 691
0063	LH	11 450	15 759	24 233	31 450	12 773	15 691
0064	LH	11 450	15 759	24 223	31 450	12 773	15 691
0065	LH	11 450	15 759	24 223	31 450	12 773	15 691
0066	NZ	10 787	14 648	14 184	19 120	3 397	4 472
b0066	NZ	14 602	19 678	19 605	26 654	5 003	6 976
b0066	NZ	20 556	27 959	22 484	30 603	1 928	2 644
0067	NZ	10 787	14 648	22 484	30 603	11 697	15 955
0068	NZ	10 787	14 648	22 484	30 603	11 697	15 955
0069	NZ	10 787	14 648	22 484	30 603	11 697	15 955
0070	PI	13 908	22 649	27 312	42 807	13 404	20 158
0071	PI	13 908	22 649	24 332	38 438	10 444	15 789
0072	PI	13 908	22 649	27 312	42 807	13 404	20 158
0073	PI	15 070	24 630	27 448	43 043	12 378	18 413
0074	PI	13 908	22 649	19 600	31 548	5 692	8 899
b0074	FL	14 728	16 350	19 153	21 328	4 425	4 978
0075	PI	15 070	24 630	27 448	43 043	12 378	18 413
0076	PI	15 070	24 630	27 448	43 043	12 378	18 413
0077	PI	15 070	24 630	27 448	43 043	12 378	18 413
0078	Aloha	9 343	25 410	11 340	30 728	1 997	5 318
b0078	Aloha	9 103	16 022	13 058	26 664	3 955	10 642
b0078	Aloha	20 014	30 447	22 496	37 233	2 482	6 786
					Subtotal	403 929	585 415

See footnotes at end of table.

Table 1.—(Continued)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
0081	Test	—	—	—	—	—	—
0082	LH	11 560	16 962	24 495	38 101	12 935	21 139
0083	LH	11 560	16 962	15 286	22 013	3 726	5 051
b0083	LH	16 901	26 080	24 495	38 101	7 594	12 021
0084	LH	11 560	16 962	15 286	22 013	3 726	5 051
b0084	LH	16 576	25 672	24 495	38 101	7 919	12 429
0085	LH	11 560	16 962	15 896	23 901	4 336	6 939
b0085	LH	16 901	26 080	24 495	38 101	7 594	12 021
0086	NZ	5 587	8 565	17 851	25 304	12 264	16 739
0087	NZ	5 587	8 565	9 516	13 797	3 929	5 232
b0087	NZ	10 647	15 393	17 851	25 304	7 204	9 911
0088	NZ	5 587	8 565	9 516	13 797	3 929	5 232
b0088	NZ	10 647	15 393	12 556	18 020	1 909	2 627
b0088	NZ	14 149	20 361	17 851	25 304	3 702	4 943
0089	NZ	5 587	8 565	7 272	10 794	1 685	2 229
b0089	NZ	8 771	12 820	12 556	18 020	3 785	5 200
b0089	NZ	14 149	20 361	15 100	21 677	951	1 316
0090	Aloha	5 623	7 992	6 788	10 937	1 165	2 945
b0090	Aloha	11 344	30 728	19 414	53 100	8 070	22 372
0091	Aloha	5 623	7 992	8 287	14 823	2 664	6 831
b0091	Aloha	12 964	35 165	19 670	53 419	6 706	18 254
0092	Aloha	5 623	7 992	11 480	23 406	5 857	15 414
b0092	Aloha	15 916	36 893	18 669	44 186	2 753	7 293
0093	PI	13 879	22 839	16 461	26 759	2 582	3 920
b0093	PI	17 333	28 122	21 797	34 851	4 464	6 729
b0093	PI	24 051	38 238	27 240	42 908	3 189	4 670
0094	PI	13 879	22 839	16 461	26 759	2 582	3 920
b0094	PI	17 333	28 122	27 240	42 908	9 907	14 786
0095	PI	13 879	22 839	27 240	42 908	13 361	20 069
0096	PI	13 879	22 839	27 240	42 908	13 361	20 069
0097	NASA	—	—	—	—	—	—
b0097	Aloha	16 360	38 058	18 669	44 186	2 309	6 128
0098	Aloha	9 244	25 150	19 414	53 100	10 170	27 950
0099	PI	10 290	15 517	23 446	35 350	13 156	19 833
0100	PI	12 641	20 584	25 587	39 953	12 946	19 369
0101	PI	10 290	15 517	23 446	35 350	13 156	19 833
0102	PI	10 290	15 517	23 446	35 350	13 156	19 833
0103	PI	12 641	20 584	25 587	39 953	12 946	19 369
0104	Aloha	9 244	25 150	11 340	30 745	2 096	5 595
0105	Aloha	9 244	25 150	9 343	25 410	99	260
b0105	Aloha	6 916	11 247	8 287	14 823	1 371	3 576
0106	Aloha	5 623	7 992	11 473	23 389	5 850	15 397
b0106	Aloha	15 912	36 880	18 669	44 186	2 757	7 306
0107	Aloha	9 244	25 150	16 527	45 144	7 283	19 994

See footnotes at end of table.

Table 1.—(Concluded)

Spoiler serial number	Airline[a]	Hours at installation	Landings at installation	Current hours	Current landings	Net hours	Net landings
0108	PSA	8 621	13 711	9 568	15 160	947	1 449
0108	VASP	9 568	15 160	15 342	21 726	5 774	6 566
b1008	VASP	17 818	24 525	21 286	28 377	3 468	3 852
0109	PSA	8 621	13 711	9 568	15 160	947	1 449
0109	VASP	9 568	15 160	12 174	18 313	2 606	3 153
0110	PSA	8 621	13 711	9 568	15 160	947	1 449
0110	VASP	9 568	15 160	21 286	28 377	11 718	13 217
0111	PSA	8 621	13 711	9 568	15 160	947	1 449
0111	VASP	9 568	15 160	12 174	18 313	2 606	3 153
b0111	VASP	13 369	19 647	18 669	25 467	5 300	5 820
0112	LH	11 587	16 011	15 179	20 569	3 592	4 558
b0112	LH	16 309	21 974	24 235	31 609	7 926	9 635
0113	LH	11 587	16 011	24 235	31 609	12 648	15 598
0114	LH	11 587	16 011	14 601	19 849	3 014	3 838
b0114	LH	15 179	20 569	24 235	31 609	9 056	11 040
0115	LH	11 587	16 011	18 322	24 487	6 735	8 476
b0115	LH	19,208	25 567	24 235	31 609	5 027	6 042
0116	PI	10 290	15 517	18 529	28 010	8 239	12 493
0117	PI	12 641	20 584	25 587	39 953	12 946	19 369
0118	PI	12 641	20 584	18 147	29 062	5 506	8 478
b0118	PI	19 709	31 351	25 587	39 953	5 878	8 602
					Subtotal	376 971	609 481
					Grand total	1 188 367	1 786 837

[a]PI is Piedmont Airlines.
VASP is Viacao Aerea Sao Paulo Airlines, Brazil.
NZ is Air New Zealand, Ltd.
LH is Lufthansa German Airlines
PSA is Pacific Southwest Airlines
[b]Reinstallation

Table 2—Flight Spoiler Service Experience (As of 04-30-79)

Airline	Number of aircraft in evaluation	Number of spoilers in evaluation	Total spoiler hours since installation	Total spoiler landings since installation
PSA	0	0	29747	51521
Aloha	4	17	131854	355600
Air New Zealand, Ltd.	4	19	156815	212776
Lufthansa	6	24	272982	351952
Piedmont	8	31	392065	587617
VASP	4	16	155066	173672
Frontier	1	4	49838	53699
Totals	27	111*	1 188367	1 786837

*Current total in service is 84 spoilers, with 27 spoilers either inactive or retired.

Table 3—Distribution of Spoilers with 12 000 or More Flight Hours

Part Number	Airline						Total
	VP	LH	PI	Aloha	Frontier	NZ	
-1 (T300/2544)	3	4	9	0	0	3	19
-2 (T300/5209)	1	7	6	0	3	0	17
-3 (AS/3501)	1	3	9	0	0	1	14
Total	5	14	24	0*	3	4	50

*Short flight segments reduce rate of flight hour accumulation.
Aloha has panels with uninterrupted service.

SCHEDULED SPOILER REMOVALS AND EVALUATION

During this reporting period, six spoilers were removed from the flight service program for evaluation and test. All removed spoilers were reinspected using the ultrasonic through-transmission C-scan, and the results were compared to the records made at the time of original fabrication. No detectable differences were noted in this comparison on four of the six units. The remaining two units had minor discrepancies deemed to warrant repair prior to return to service. The sixth fourth-year spoiler, S/N 0111 (previously unreported) was also processed through the ultrasonic inspection, cleared, and returned to revenue service. Three of the fifth-year spoilers (S/N 0020, 0067, and 0096) were then selected to be destructively tested to measure residual static strength following the specified calendar period of exposure. Table 4 shows the data from all of the scheduled fifth-year removals and summarizes the strength and stiffness data from the three units that were static tested. Figures 2, 3, and 4 show the spoiler panels after static testing. Figures 5, 6, and 7 are plots of the load-deflection data for these three panels.

A plot of the residual static strength data accumulated to date appears in figure 8, plotted as a function of time. This data continues to illustrate the data scatter previously discussed in reference 4. The 250°F curing resin system continues to perform well after reversing an earlier strength loss trend last year. Based on the available data, continued retention of static strength levels can be anticipated.

Following static test, all three test units were sectioned to investigate for core corrosion. The procedure used was similar to that employed on S/N 0054 as described in reference 4. All three panels were completely free of any evidence of corrosion in the honeycomb core. Figure 9 shows a typical section taken from S/N 0096.

Table 4—Summary Data From Scheduled Spoiler Removals (Fifth Year)

Spoiler Serial Number	Airline	NDI Results	Failure Load % DLL	% Change Strength	% Change Stiffness	Time in Service	Flight Hours
0017 (-1)	VASP	Minor spar corrosion	--------	Not tested		59 mos 28 days	10 420
0020 (-1)	LH	Clear	249%	+1%	-6%	59 mos 25 days	11 478
0067 (-2)	NZ	Clear	280%	-3%	+9%	59 mos 16 days	10 444
0072 (-2)	PI	Clear	--------	Not tested		60 mos 7 days	13 070
0091 (-3)	Aloha	Minor spar corrosion	--------	Not tested		59 mos 26 days	8625
0096 (-3)	PI	Clear	236%	-2%	-13%	60 mos 0 days	13 109

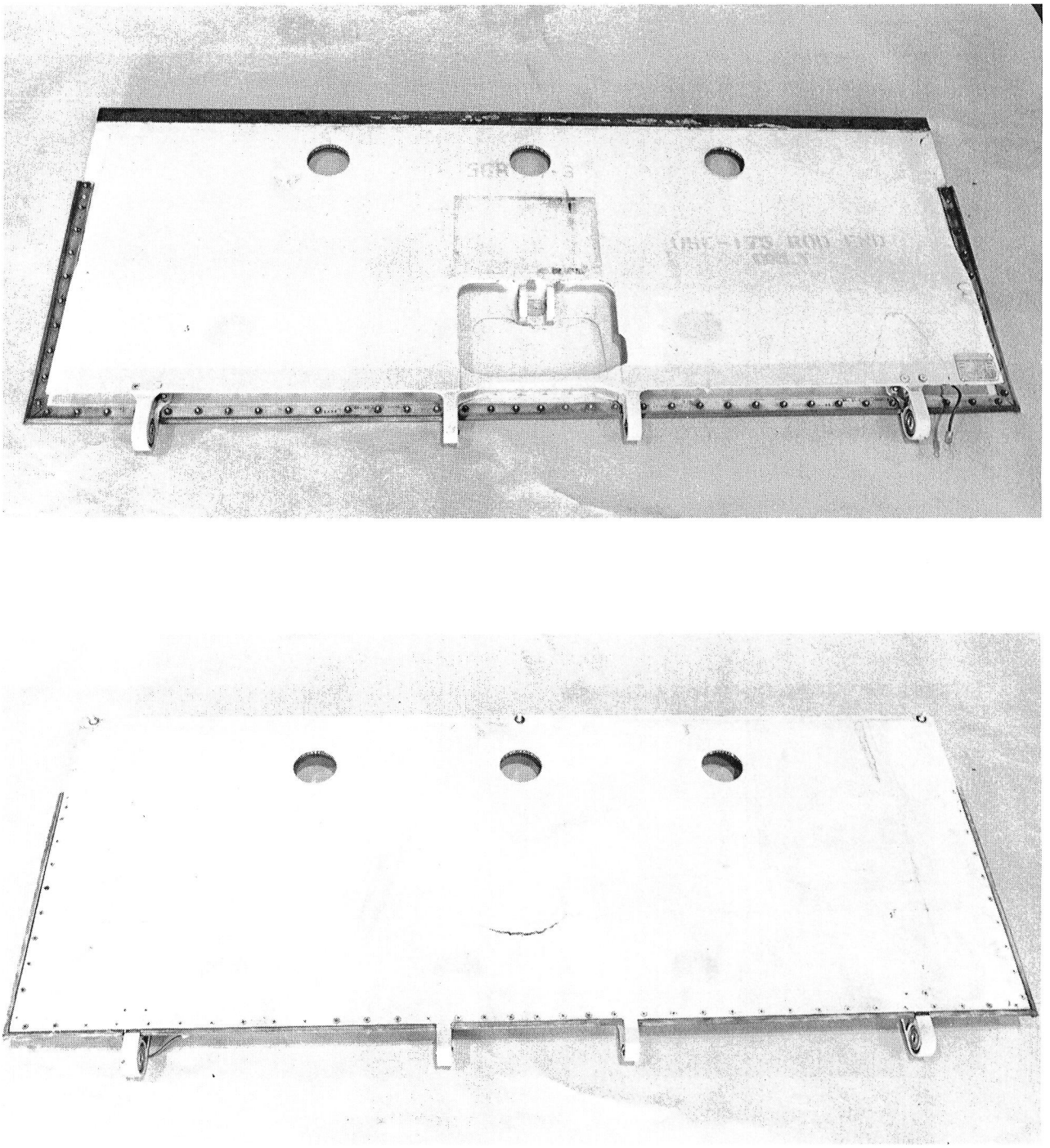

Figure 2.—Spoiler S/N 0020 Static Test

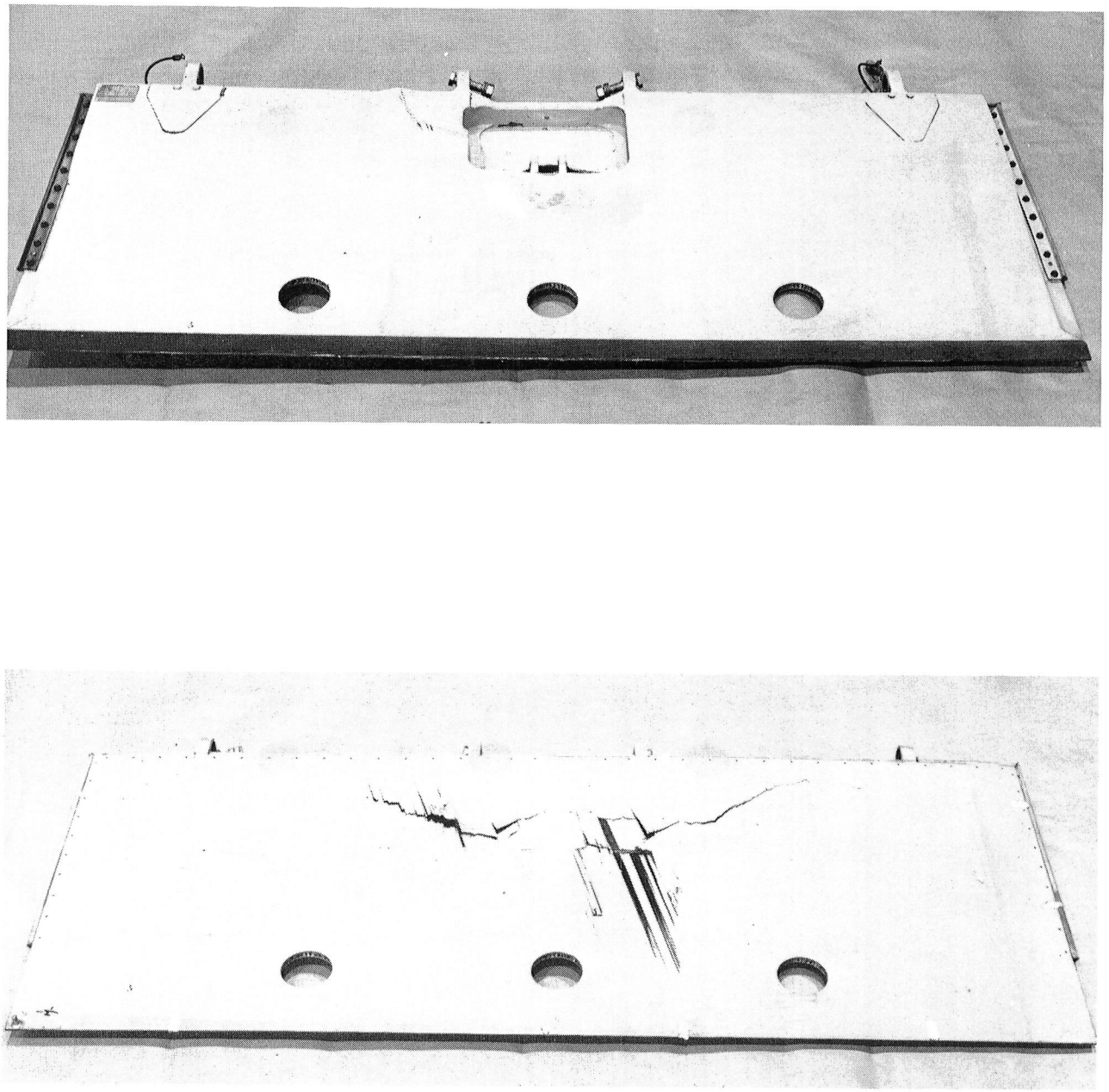

Figure 3.—Spoiler S/N 0067 Static Test

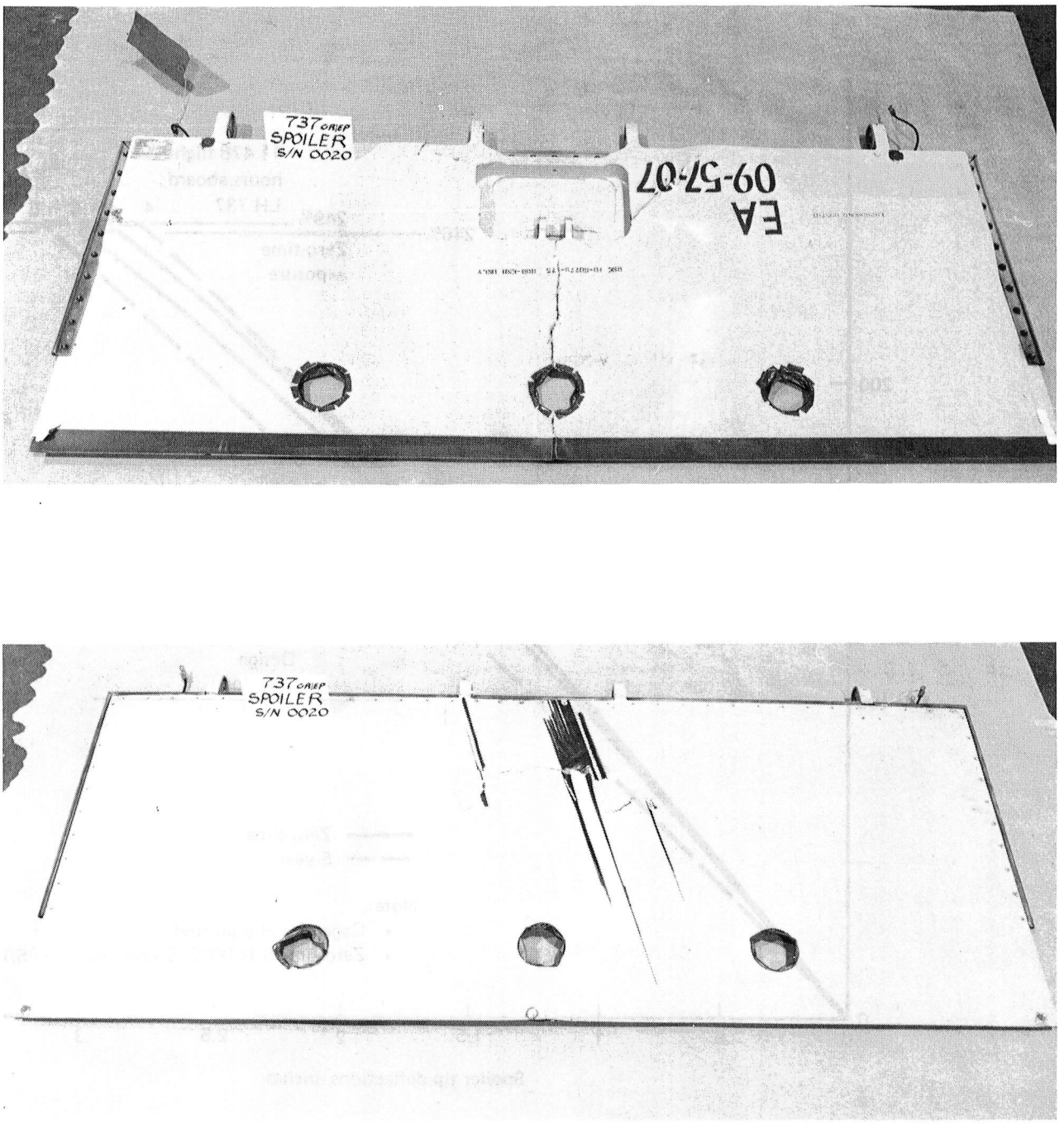

Figure 4.—Spoiler S/N 0096 Static Test

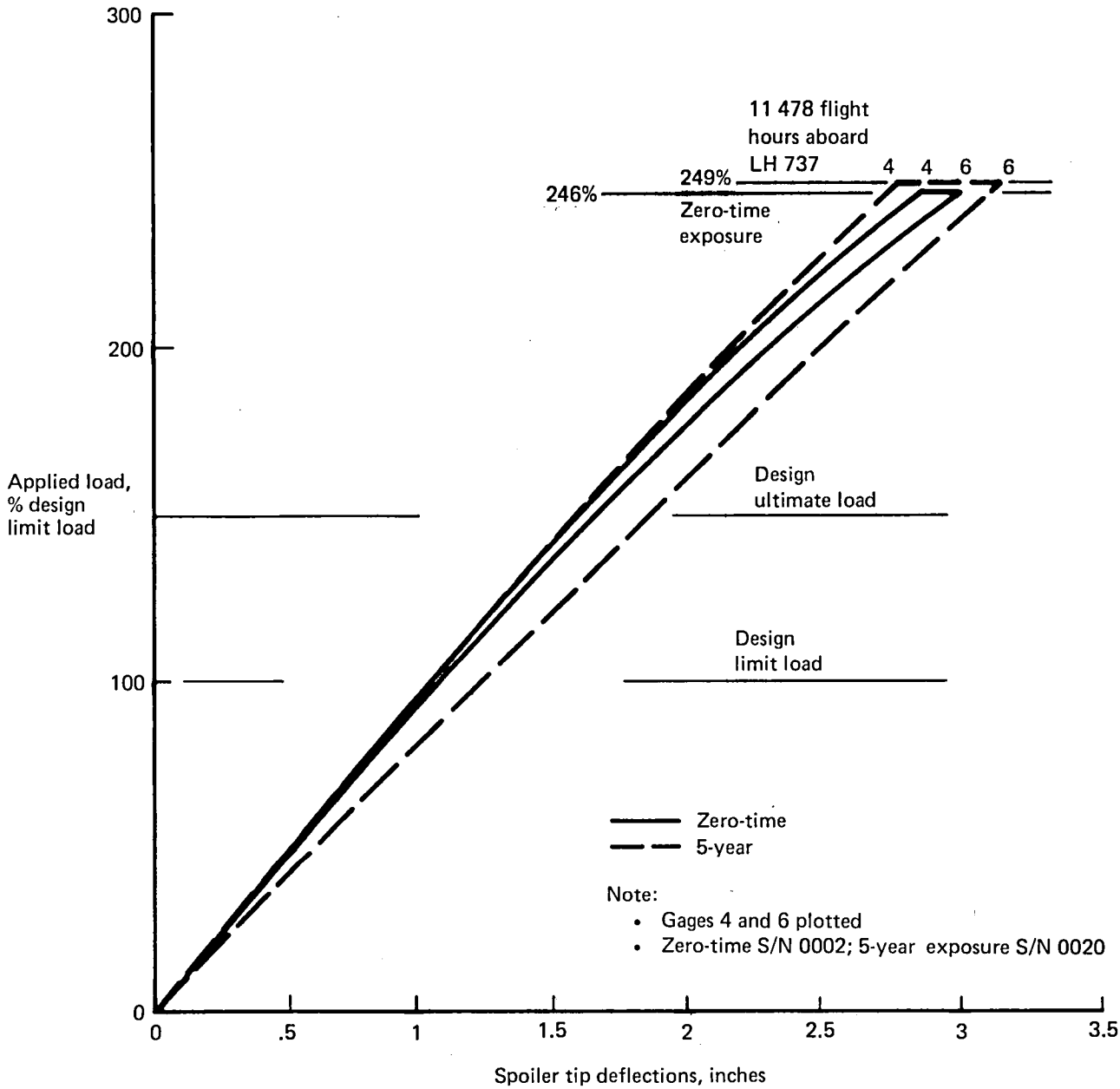

Figure 5.—Load-Deflection Curves: Zero-Time and 5-Year Exposure (Union Carbide T300/2544 Material System)

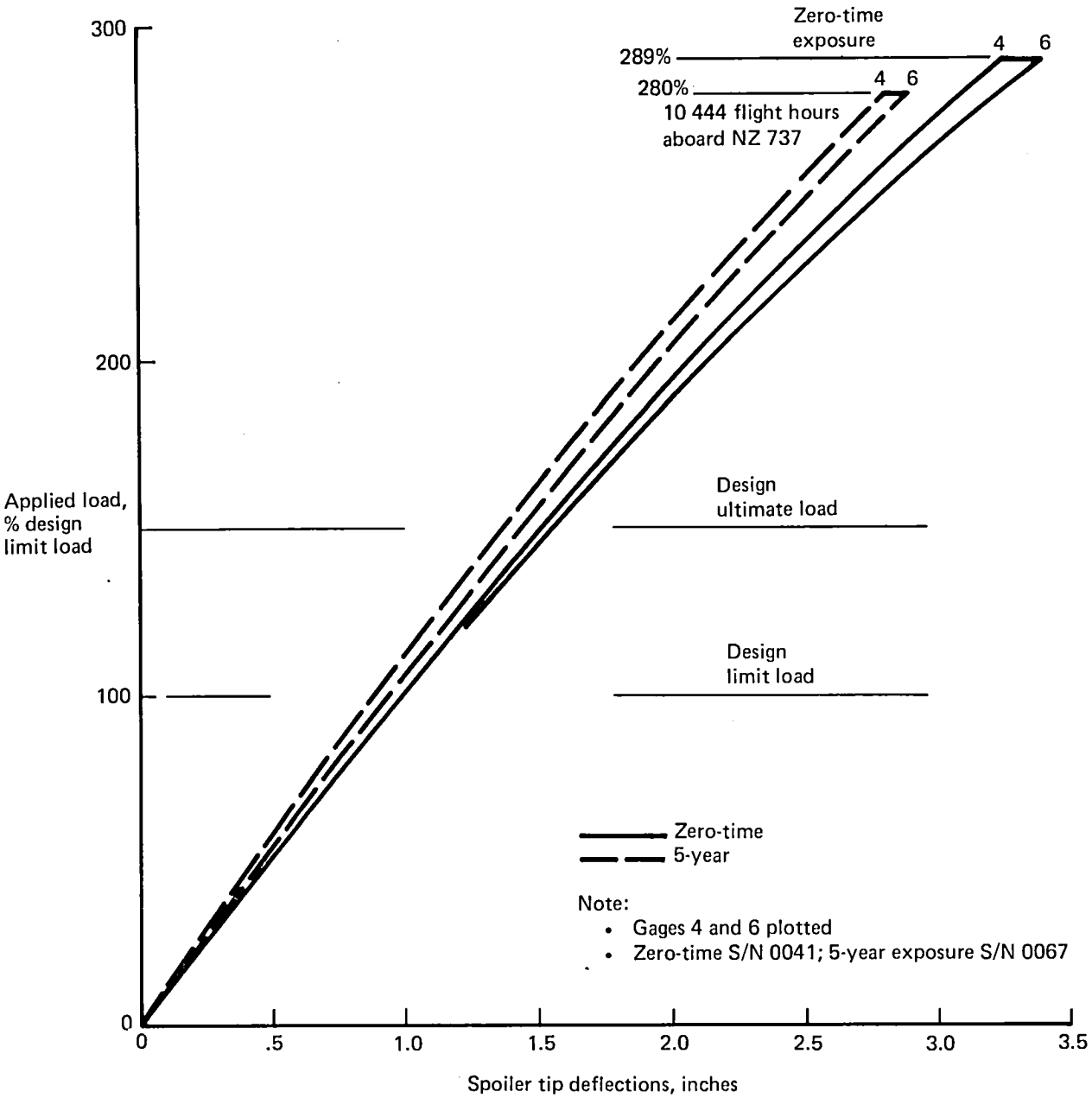

Figure 6.—Load-Deflection Curves: Zero-Time and 5-Year Exposure (Narmco T300/5209 Material System)

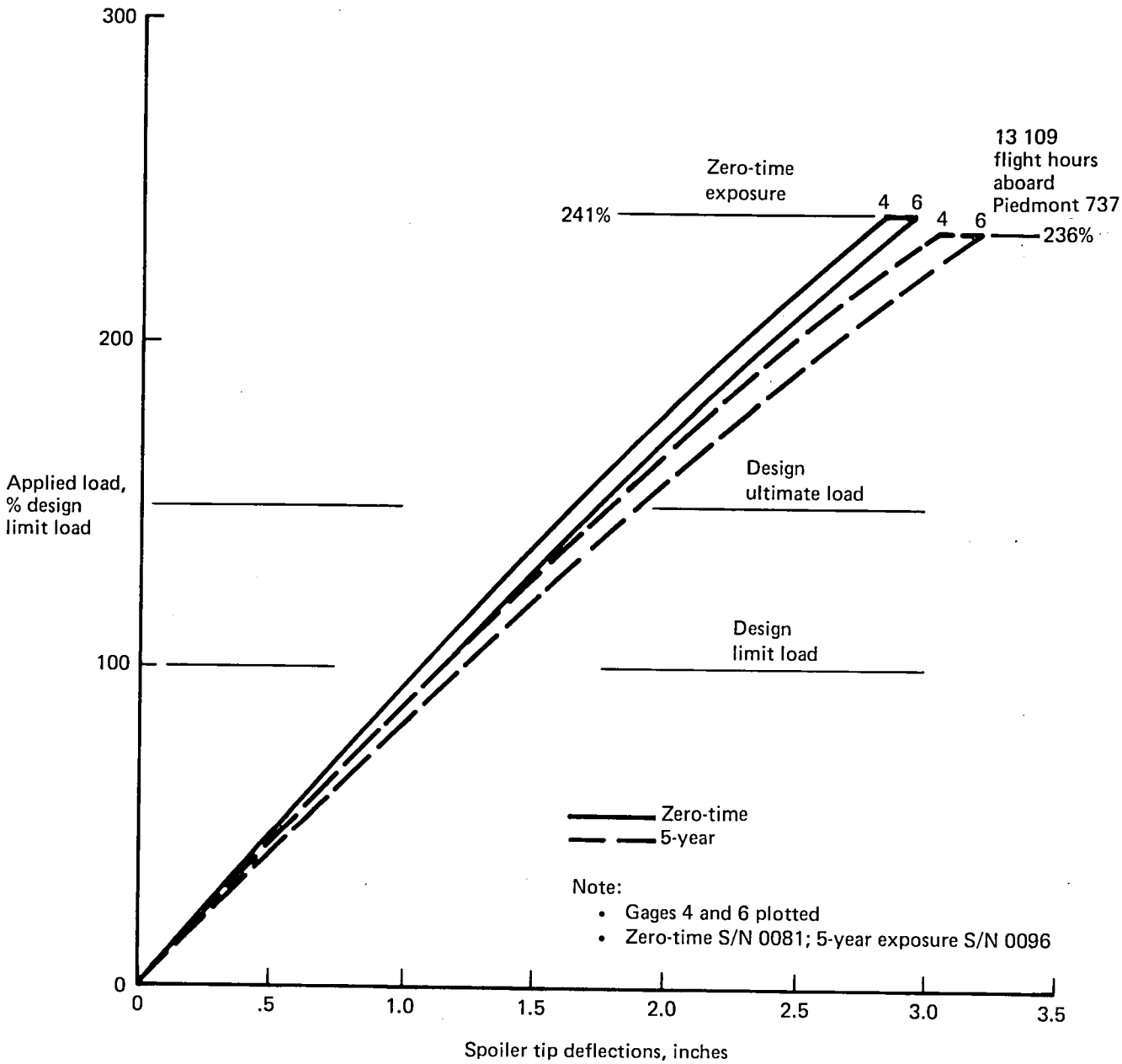

Figure 7.—Load-Deflection Curves: Zero-Time and 5-Year Exposure (Hercules AS/3501 Material System)

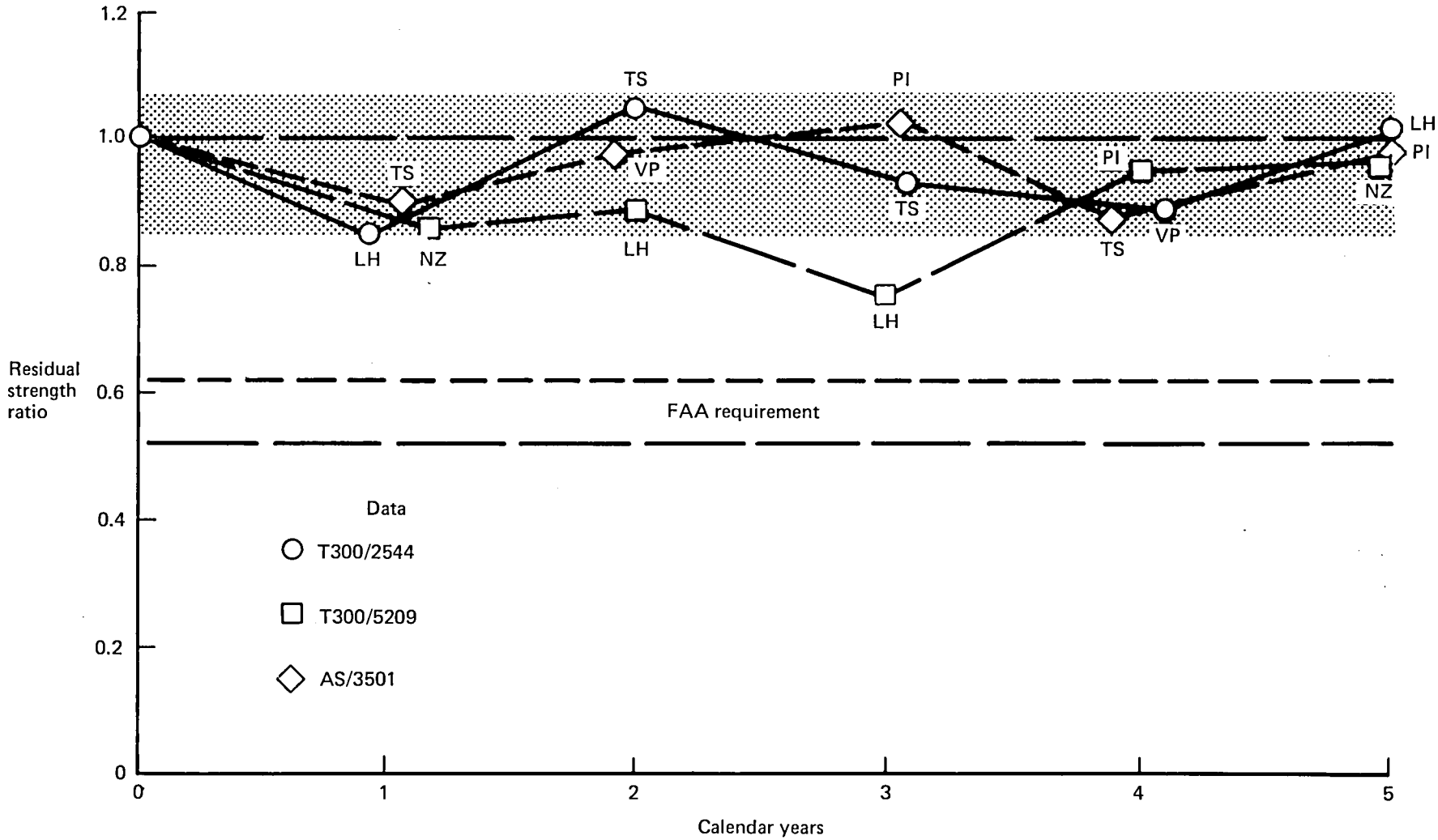

Figure 8.—Residual Strength After Exposure

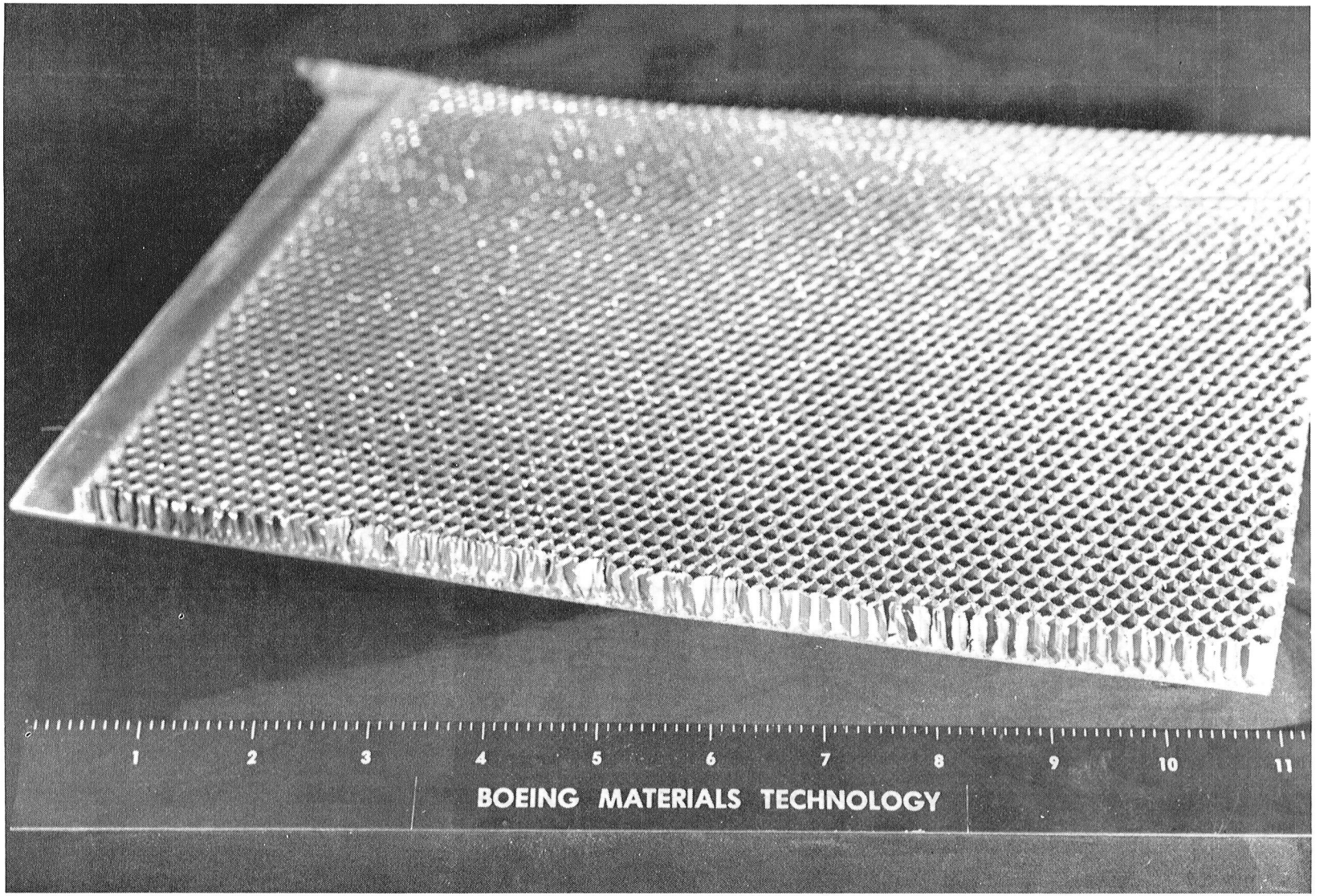

Figure 9.—Post-Test Corrosion Teardown Inspection (S/N 0096)

UNSCHEDULED SPOILER REMOVALS

A total of seven spoiler panels experienced unscheduled removals during this reporting period. A summary of the seven panels is shown in table 5. The service problems experienced with the fleet during the last 12 months were dominated by the spar exfoliation condition first experienced with S/N 0050 and reported in reference 3. One unit, (S/N 0012), was returned to Boeing for a suspected delamination. It was given a detailed inspection but no delamination was found. The unit was returned to service and has performed satisfactorily.

The spar exfoliation corrosion condition is considered to be a persistant but not serious problem with the fleet. The number of incidents during the past 12 months is only two more than had been experienced during the previous year and the total number of incidents to date continues to represent a small precentage of the fleet. It should also be noted that the total number of unscheduled removals during the fifth year was actually less than had been experienced during the fourth year.

Upper skin surface blisters (ref. 2) were not a cause for repair during this past year. Some blisters were observed during the annual inspection but none were deemed to be of sufficient size to warrant repair.

In an attempt to convey a summary of observed anomalies compiled through the annual inspections; tables 6 and 7 were prepared to give the reader a better perspective of the distribution and frequency of these observed flight-service anomalies. Without reference to the number of possible problems of a given type, the reader might conclude that the problems reported to date represent a significant deterioration of the panel fleet. On the contrary, several airline maintenance executives have expressed the opinion that the problems experienced on this program are significantly below their experience level with production spoiler panels.

In addition, the continuing assessment of the durability of skin repairs should be of significant importance to the overall performance assessment. Table 6 gives a summary of observations (including composite skin repairs) made during the annual inspection conducted in March 1979, while table 7 is a cumulative summary of four years of inspections. The identification of anomalies in the noted categories represents the authors' best effort at objectivity.

Table 5. — Unscheduled Flight Spoiler Removals

Spoiler serial number	Airline	Date removed	Reason for removal	Action taken	Final disposition
0008	NZ	9-27-78	Spar exfoliation corrosion	NDT & repair	Reinstalled
0012	LH	7-3-78	Suspected delamination	NDT (1)	Reinstalled
0013	LH	5-6-78	Spar exfoliation corrosion	NDT & repair	Reinstalled
0021	LH	10-12-78	Spar exfoliation corrosion	NDT & repair	Reinstalled
0022	LH	10-12-78	Spar exfoliation corrosion	NDT & repair	Reinstalled
0052	NZ	11-16-78	Spar exfoliation corrosion	NDT	Repair in progress
0090	TS	4-4-79	Trailing edge delamination	NDT	Repair in progress

(1) Detailed investigation showed no delamination.

Table 6. – Spoiler Service Inspection Compilation
(Fifth Year Inspection – March 1979)

		Number of noted anomalies										
	No. panels	Rod-end blisters	Edge delaminations	Surface delamin-ations	Surface cracking	Upper surface mech. damage	Upper surface nat/environ damage	Lower surface mech. damage	Lower surface nat/environ damage	Aluminum doubler corrosion	Exfoliation corrosion damage	Repair condition OK/not OK
Frontier	4	0	0	0	0	0	0	0	0	0	0	0/0
New Zealand	12	2	0	0	0	1	0	0	0	0	2	10/0
Lufthansa	18	2	1	0	0	1	0	0	0	0	1	7/0
Aloha	11	0	1	0	0	1	0	0	0	2	3	6/0
Piedmont	27	1	0	0	0	1	0	0	0	4	0	5/0
VASP	13	2	0	0	0	0	0	0	0	2	0	6/0
Totals	85	7	2	0	0	4	0	0	0	8	6	34/0

Table 7. — Spoiler Service Inspection Compilation (Cumulative 5 Years)

		Number of noted anomalies									
	No. panels	Rod end blisters	Edge delaminations	Surface delaminations	Surface cracking	Uppre surface mech damage	Upper surface nat/enviorn damage	Lower surface mech damage	Lower surface nat/enviorn damage	Aluminium doubler corrosion	Exfoliation corrosion damage
Frontier	6	0	0	0	0	0	0	0	0	0	0
New Zealand	16	6	0	1	0	1	0	1	0	0	6
Lufthansa	24	6	1	0	0	1	0	2	0	0	2
Aloha	17	8	1	0	0	2	0	0	0	2	6
Piedmont	32	5	0	0	0	2	0	0	0	4	0
VASP	16	6	0	0	0	0	0	1	0	2	1
Totals	111	31	2	1	0	6	0	4	0	8	15

REPAIRS

Repair activities have continued during this reporting period. The majority of this year's repairs concerned the spar exfoliation corrosion condition. The repairs were executed in a fashion similar to that described in last year's Annual Report (ref. 5) for S/N 0049 and S/N 0009.

Spoiler S/N 0089 was also repaired and returned to service during this past year. This unit represented the only unique repair technology opportunity during this latest reporting period. Spoiler S/N 0089 was removed by Air New Zealand, Ltd. in February 1978 and returned to Boeing with a suspected skin delamination at the trailing edge. The unit was nondestructively inspected to verify the delamination and identify the extent (fig. 10). Both upper and lower skins were removed from the affected area using the standard ply stripping technique (fig. 11). Investigation showed that the core was still largely intact with a bondable surface. Minor areas of torn cell walls or corrosion were reinforced with BMS 5-28 type 6 potting compound. New skin plies were laid on both surfaces and cured in a single stage. Figure 12 shows the lower surface following cure. The repair was completed by splicing in a new section of the trailing edge rub strip.

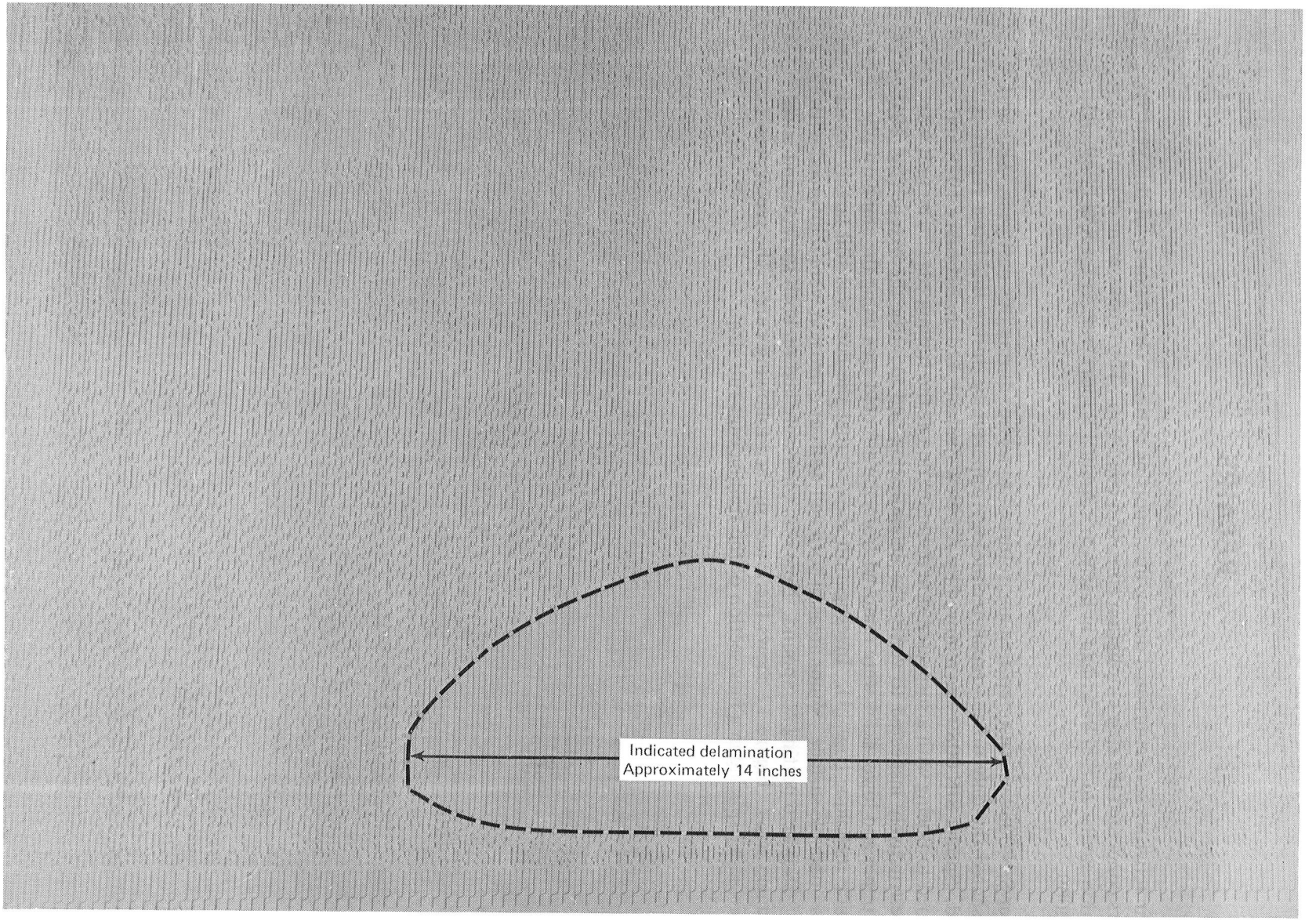

Figure 10.—Nondestructive Inspection of Skin Delamination (S/N 0089)

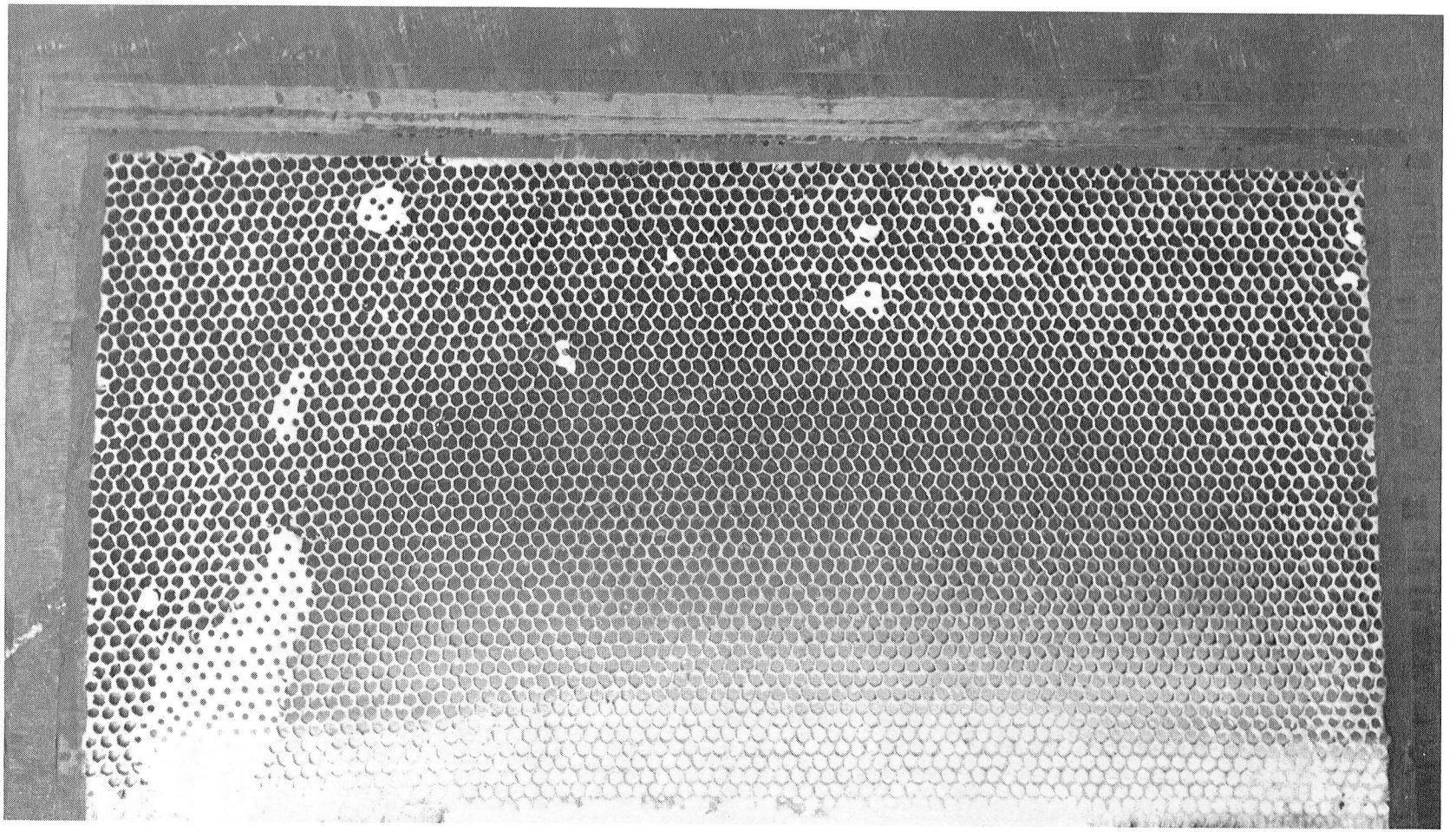

Figure 11.—Lower Skin Plies Removed (S/N 0089)

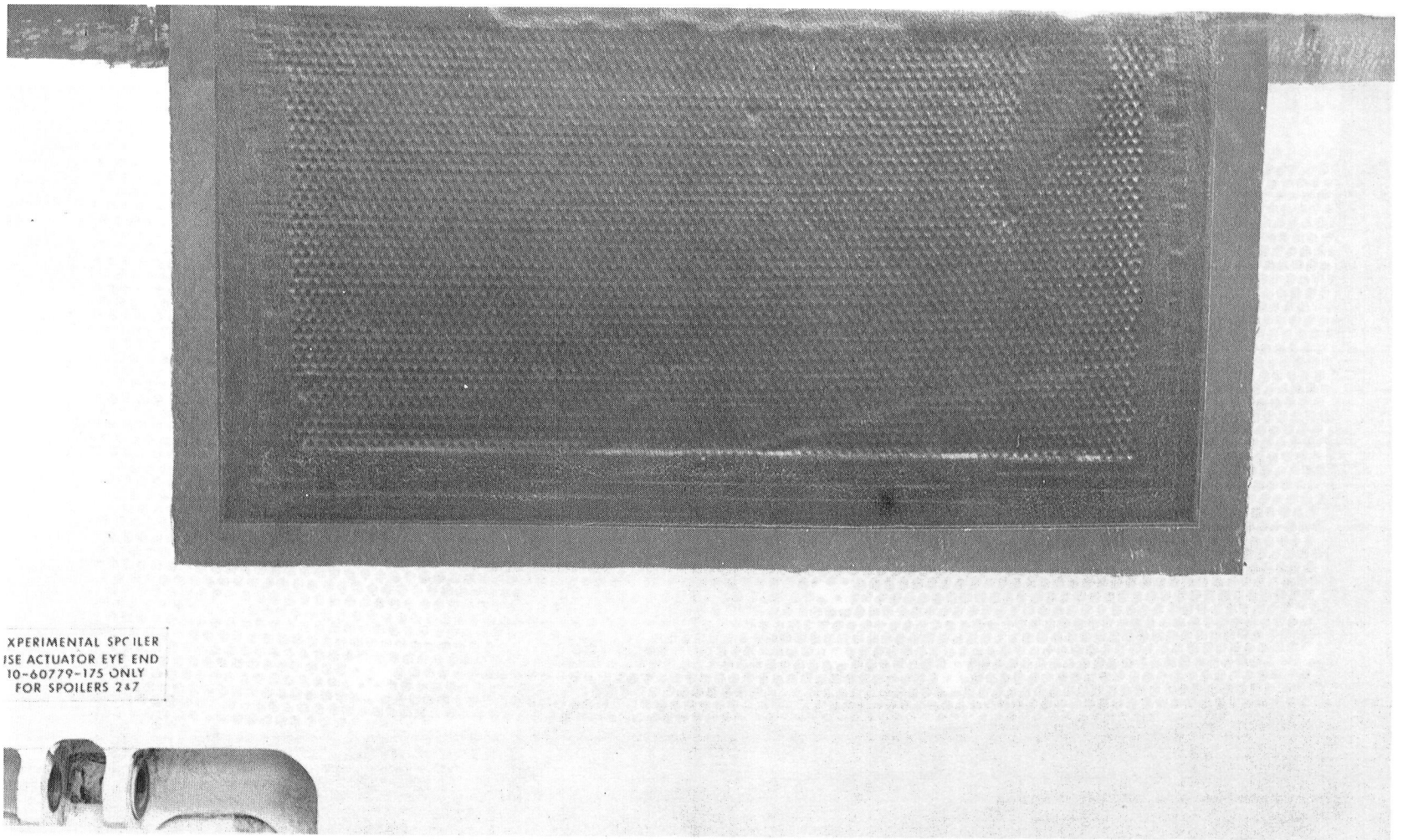

Figure 12.—Completed Skin Repair (S/N 0089)

MOISTURE ABSORPTION CORE SAMPLING

As a continuation of the moisture sampling technique initiated and described in reference 4, additional core plug samples were obtained from the three spoiler panels which were static tested for residual strength. (See section on Scheduled Spoiler Removals.) Spoilers S/N 0020 (T300/2544 returned from LH), S/N 0067 (T300/5209 returned from ANZ), and S/N 0096 (AS/3501 returned from Piedmont) each had three core plug samples removed prior to static test. Each plug is a cylindrical section 2.25 inches in diameter and approximately 0.4 inches deep containing:

- Upper and lower surface paint films
- Upper and lower graphite epoxy skins
- Two skin to core bonds and
- The aluminum honeycomb core

All nine specimens were subjected to a 25-day drying environment at 160° F. The samples were weighed at discrete intervals in order to construct the weight loss curves shown in figure 13. In addition to the actual weight loss, a final observed graphite-epoxy moisture content has been calculated for each of the nine samples and is shown on the figure.

The calculated moisture content was based on the observed weight changes during dryout and the following assumptions:

- The aluminum honeycomb core has no moisture.
- All 3 polymeric materials (paint, composite matrix, and adhesive bondlines) contain the same level of moisture.

Moisture content (MC) was calculated by the following formula:

$$MC = \frac{(\triangle W)\ (W_{DM})}{(W_{DP})\ (W_{DC})} \times 100$$

Where:

$\triangle W$ = observed weight loss (grams)

W_{DC} = weight of dry graphite/epoxy composite skins (grams)

W_{DP} = weight of dry polymeric components in total core plug sample (grams)

W_{DM} = weight of dry composite matrix material (grams)

The observed weight loss ΔW represents the difference between the as-cut wet spoiler plug weight and the final dryout weight. Values for the paint weight (0.547 grams), the adhesive weight (1.653 grams), and the aluminum core weight (1.066 grams) were analytically or experimentally determined. Subtracting these from the dry plug weight gave the weight of the dry graphite-epoxy composite skins. Using typical fiber volume fraction and densities, it was determined that 70% of the skin weight was due to the fiber, and the remaining 30% was epoxy matrix.

Use of this procedure to determine graphite-epoxy moisture content should result in a calculated value slightly higher than actual. Both the paint and the adhesive should have moisture contents higher than the epoxy matrix. This error should be relatively small.

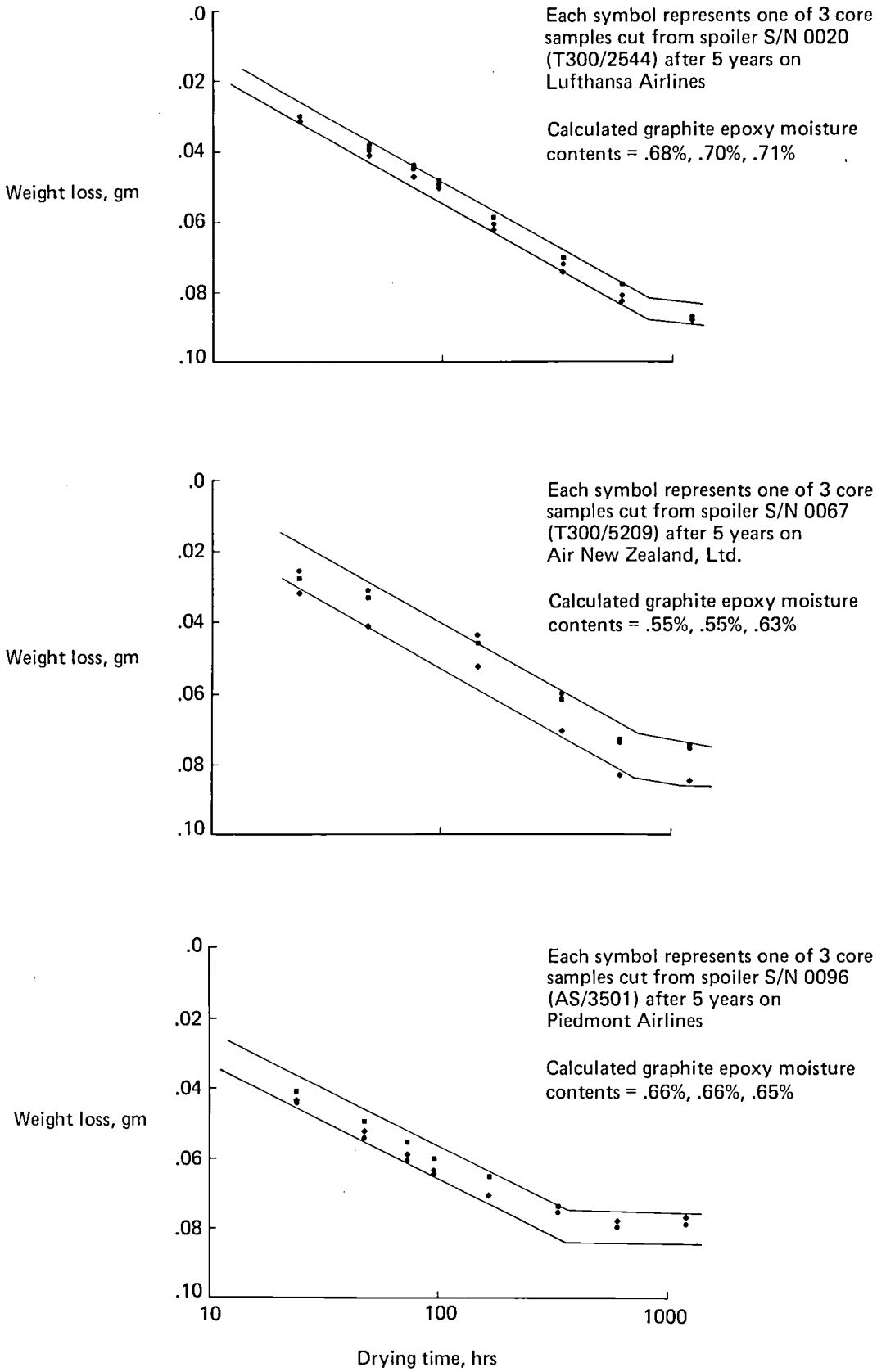

Figure 13.—Moisture Weight Loss of Spoiler Core Samples

TAILCONE MOISTURE PROGRAM

During the current reporting period considerable data was generated from the moisture-collecting coupons mounted on 737 flap track fairing tailcones. Participating airlines (Aloha, Air New Zealand, Ltd., and Piedmont) have been flying specimens of three graphite-epoxy materials (T300/5208, T300/5209, and AS/3501) on the modified tailcones. These specimens, in both 8-ply and 16-ply unpainted configurations, were positioned for exposure to both solar and nonsolar conditions. Sufficient specimens were deployed on one aircraft per airline to permit seven withdrawals over a 2-year period.

Specimens were returned from service in their titanium specimen holders. Boeing Materials Technology personnel disassembled the fixtures and established a baseline weight as soon as practical following receipt. The specimens were then placed in a 160°F oven for dryout. Periodic weight checks were made until the coupon ceased to lose weight. By using the dryout weight technique, any recorded weight delta should reflect absorbed moisture.

Moisture content as a function of exposure time results are shown in figures 14 through 22. Each figure shows 8- and 16-ply solar and nonsolar exposure data for one material and one airline. In all cases data is shown for 5 times up to 12 months of exposure. Data shown for 12 month, 8-ply, solar, T300/5209 on Piedmont Airlines is believed to be in error due to an inaccurate baseline weight.

The following general observations can be made regarding the data:

- moisture contents fluctuate between 0.5% and 1.3% after initially reaching an equilibrium level.
- sixteen ply specimens normally show less moisture content than eight ply.
- the two 350°F curing systems, (Narmco 5208 and Hercules 3501) absorb more moisture under actual service conditions than does the 250°F curing system (Narmco 5209).

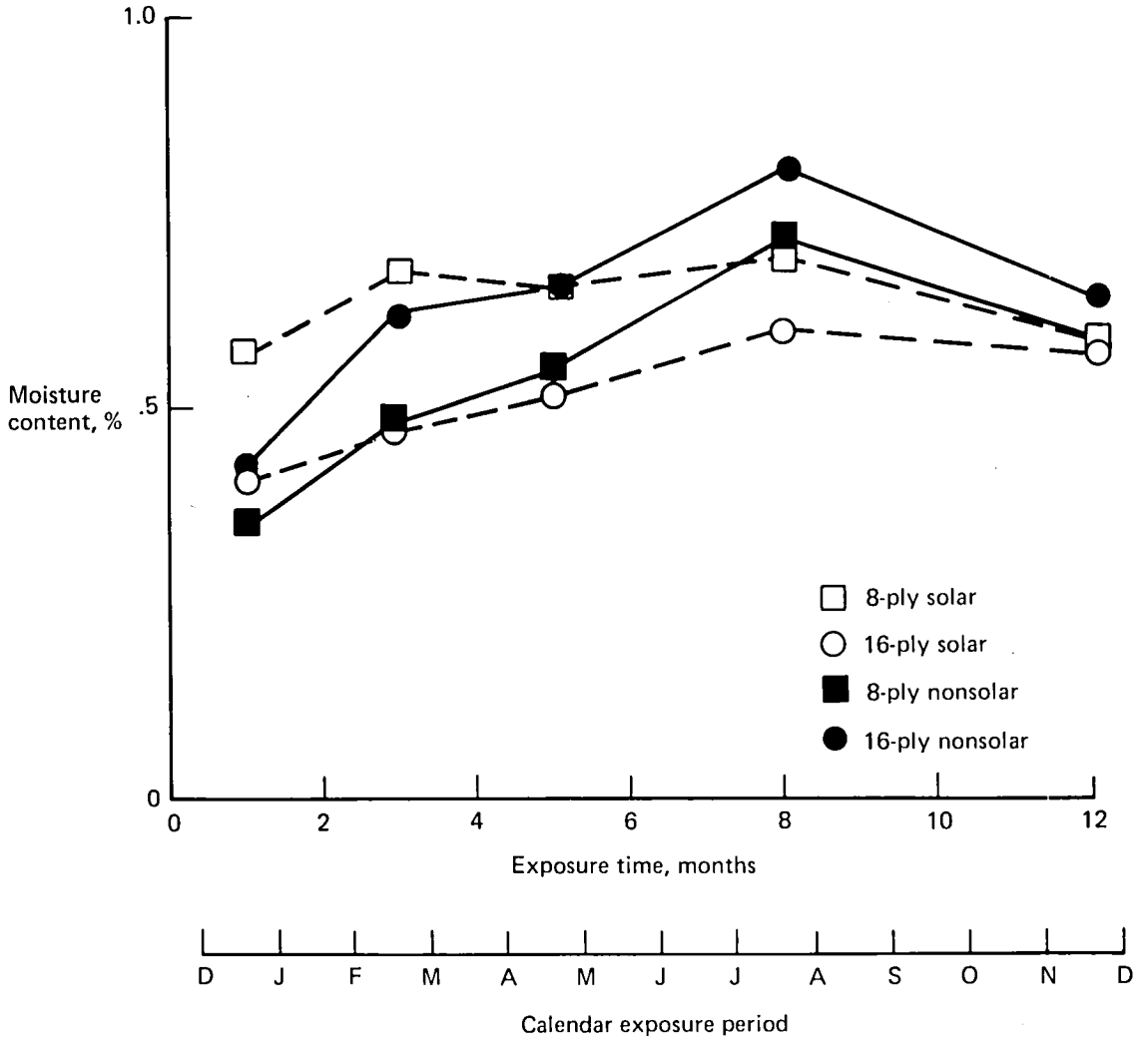

Figure 14.—Tailcone Coupon Moisture Content T300/5208 From Aloha Airlines

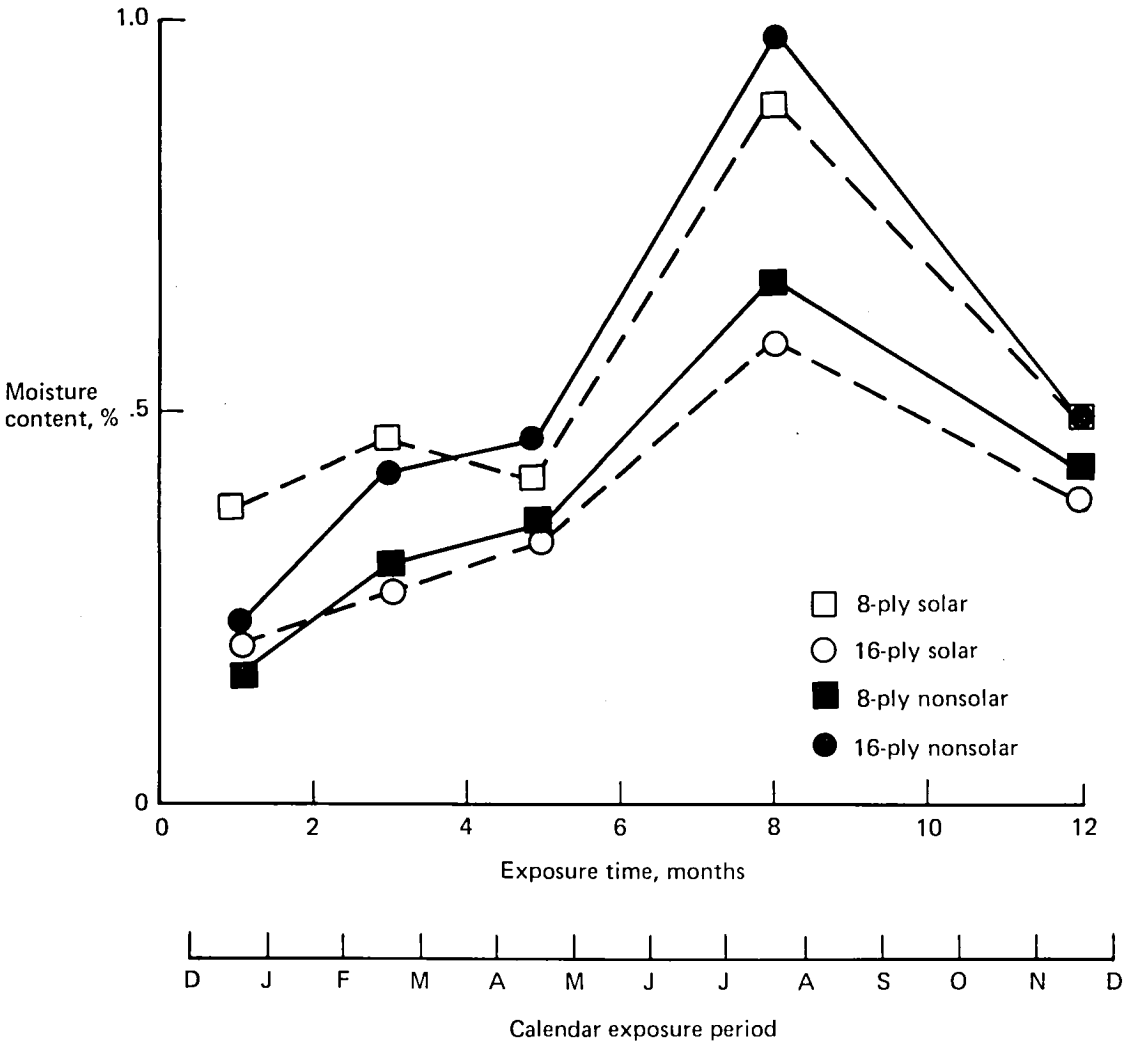

Figure 15.—Tailcone Coupon Moisture Content T300/5209 From Aloha Airlines

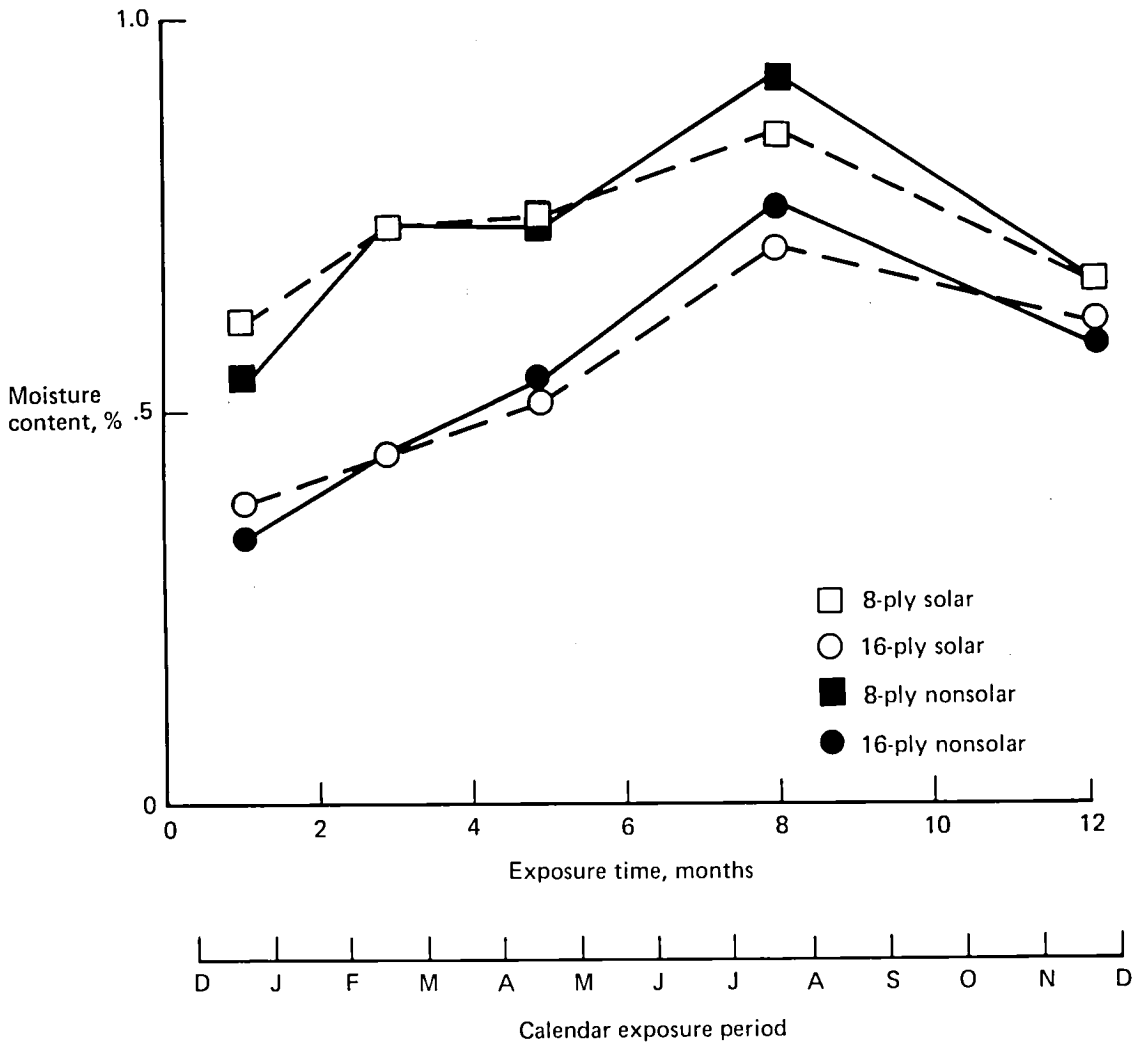

Figure 16.—Tailcone Coupon Moisture Content AS/3501 From Aloha Airlines

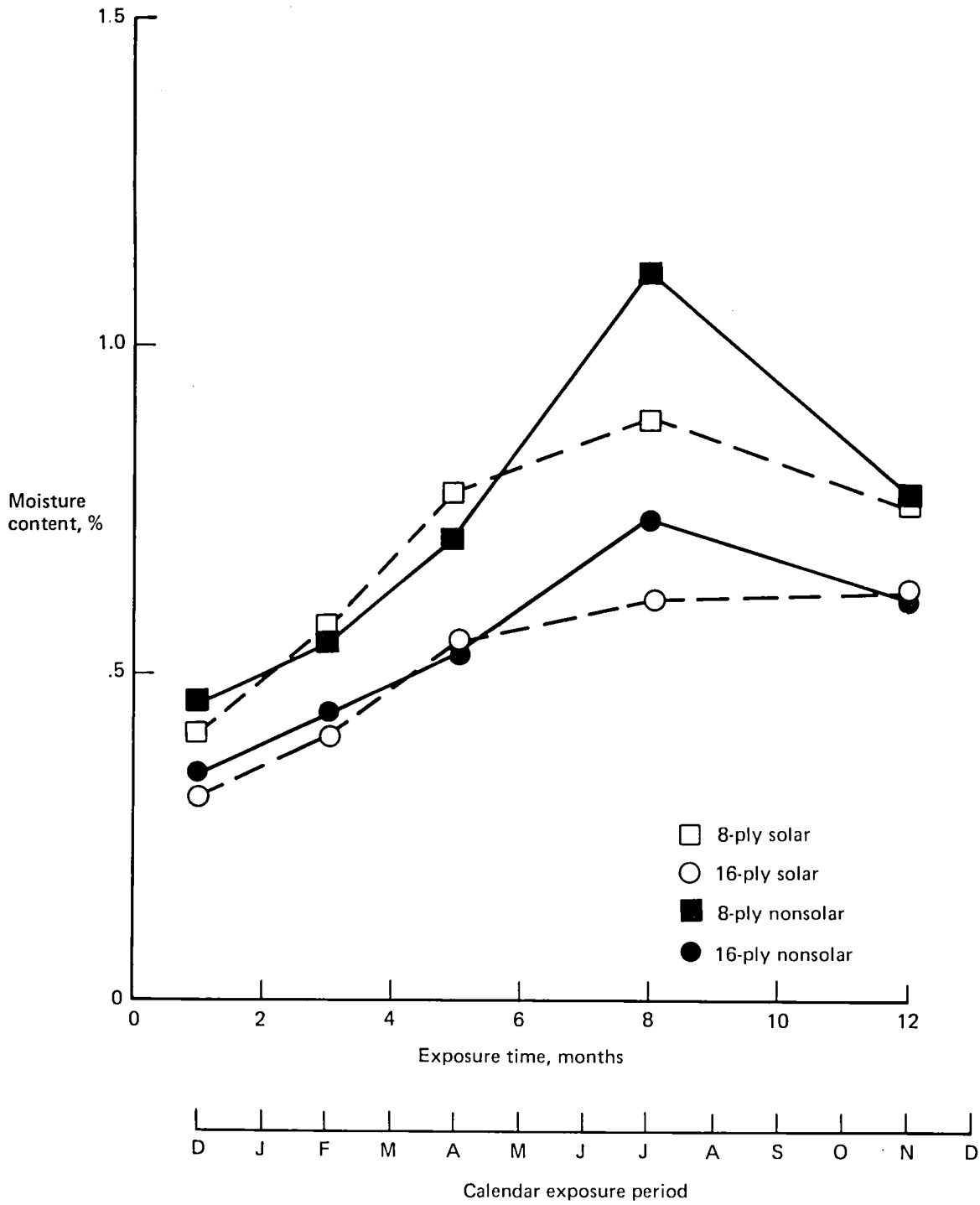

Figure 17.—Tailcone Coupon Moisture Content T300/5209 From Air New Zealand, Ltd.

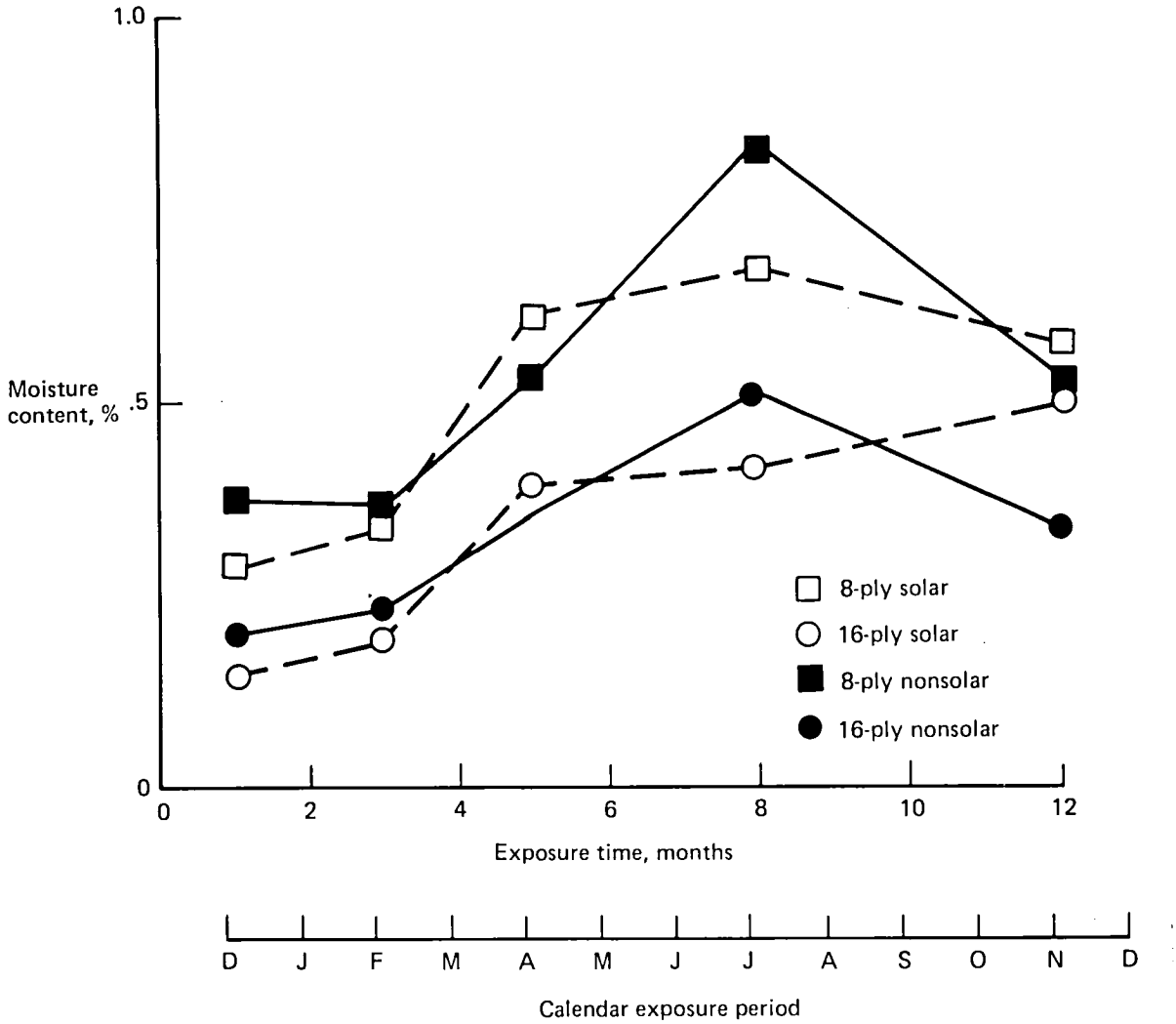

Figure 18.—Tailcone Coupon Moisture Content T300/5209 From Air New Zealand, Ltd.

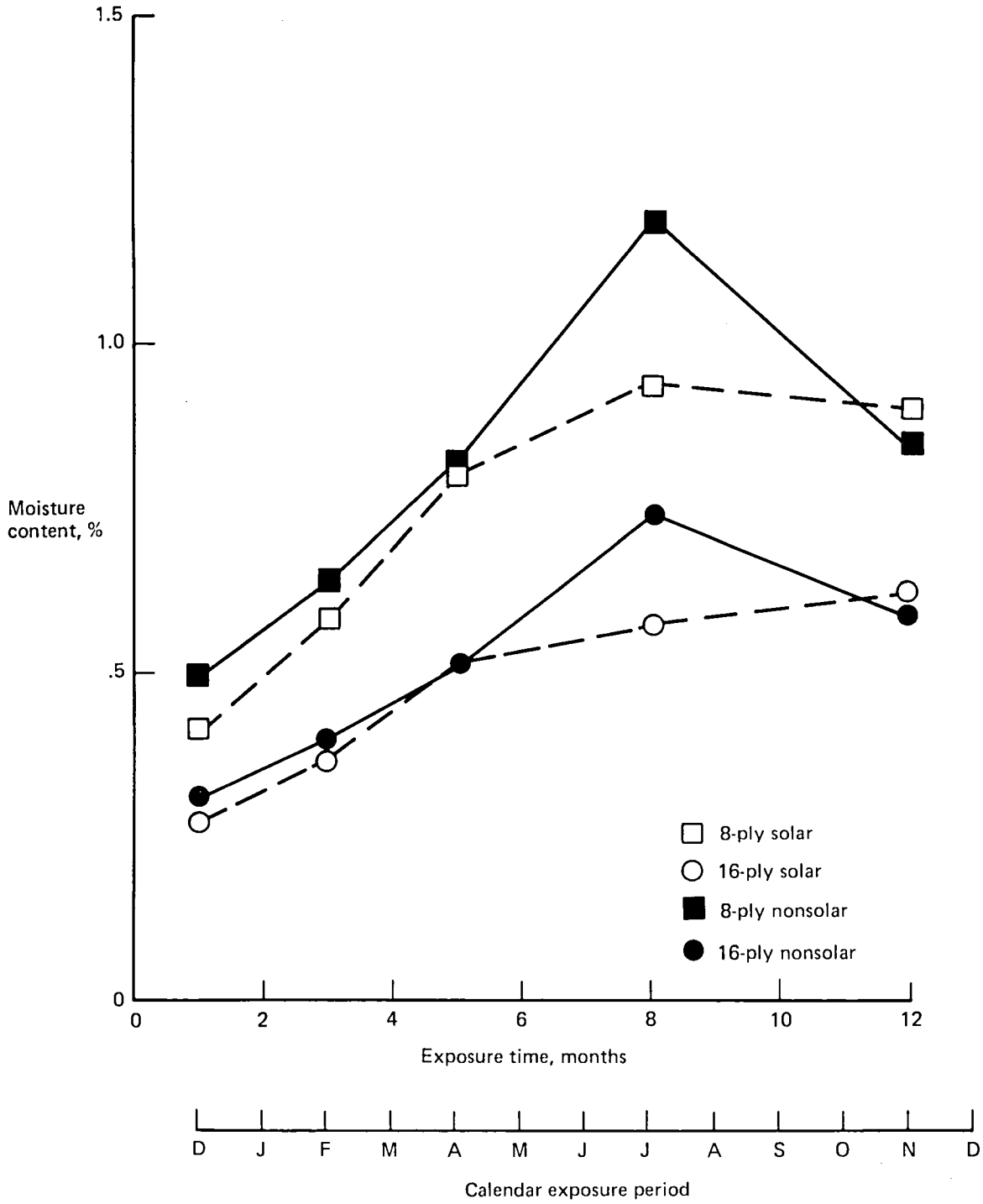

Figure 19.—Tailcone Coupon Moisture Content AS/3501 From Air New Zealand, Ltd.

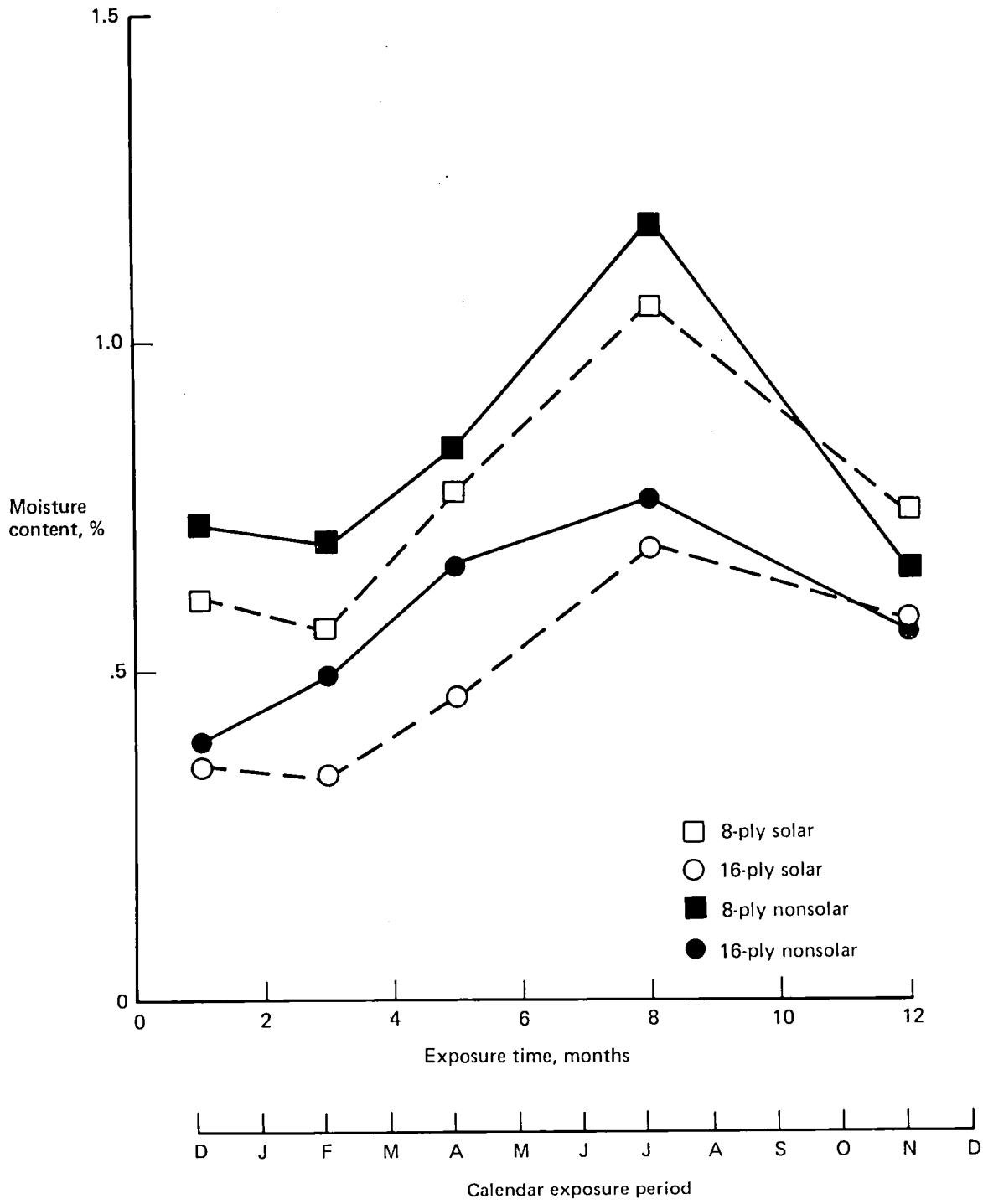

Figure 20.—Tailcone Coupon Moisture Content T300/5208 From Piedmont Airlines

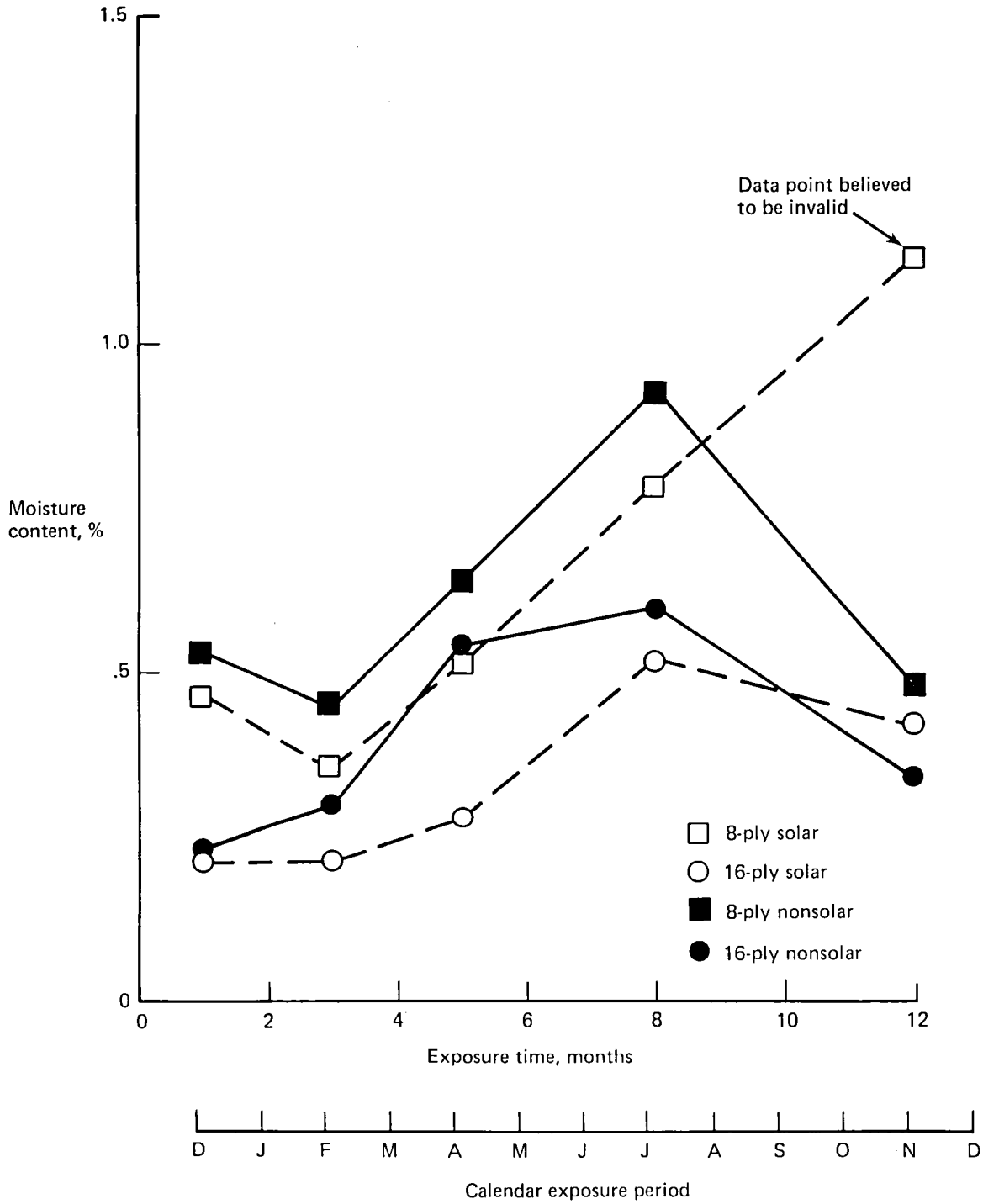

Figure 21.—Tailcone Coupon Moisture Content T300/5209 From Piedmont Airlines

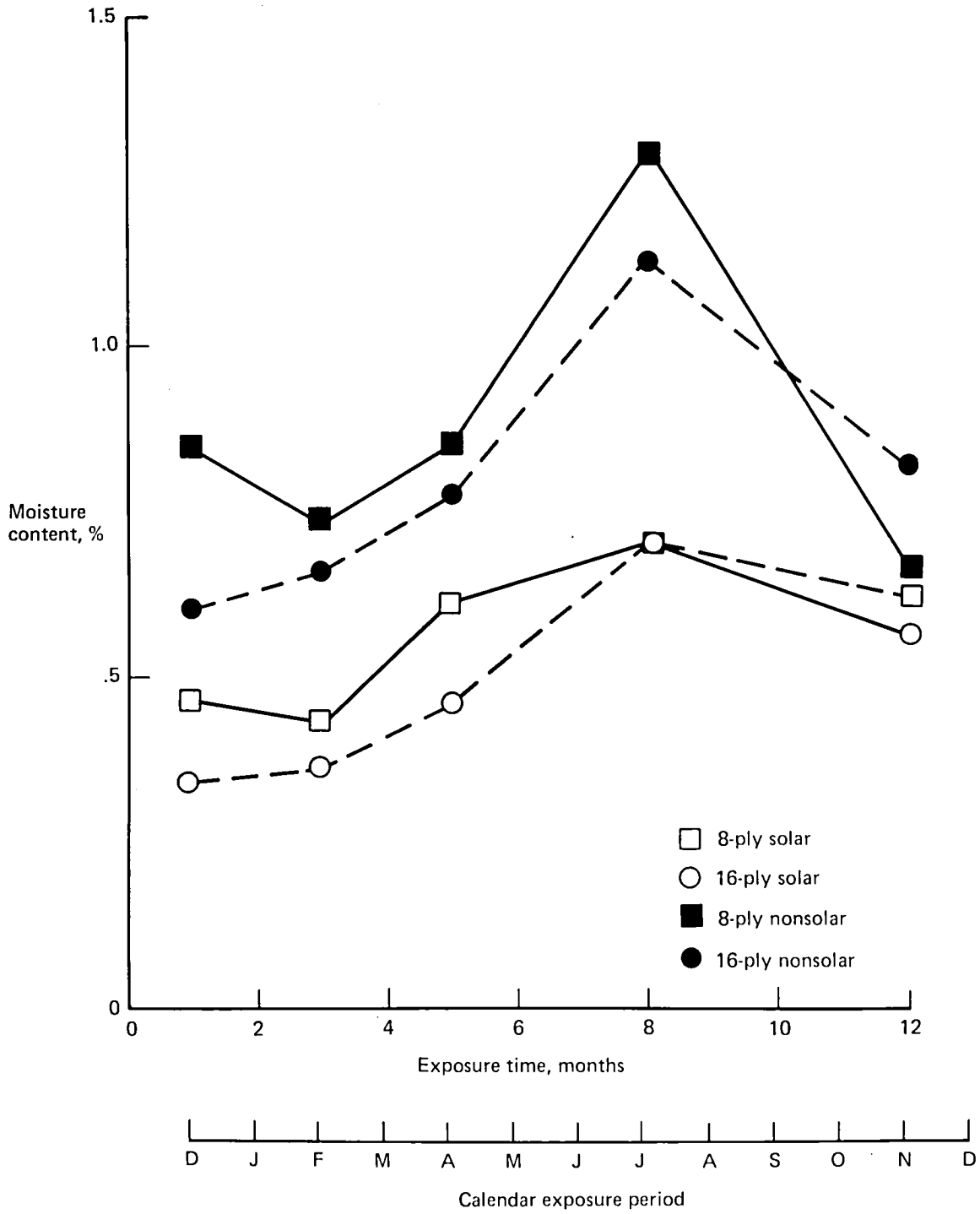

Figure 22.—Tailcone Coupon Moisture Content AS/3501 From Piedmont Airlines

GROUND-BASED ENVIRONMENTAL SERVICE*

The long-term ground-based environmental exposure of specimens fabricated from three composite material systems used in fabricating the spoilers is a continuing program with specimens exposed for 1-, 3-, 5-, 7-, and 10-year periods. Interlaminar shear, flexure, and compression specimens are being subjected to outdoor exposure at five airline terminals around the world and at NASA-Langley Research Center.

Specimens exposed for 5 years have been removed, weighed, and tested. Specimens were weighed before and after exposure and the average weight change is given in tables 8, 9, and 10. These values may be compared with the weight change values in corresponding tables for one and three years exposure reported in references 3 and 5 respectively. Such a comparison indicates that as the time of exposure increases, the percent weight change also increases with the exception of the flexure specimens which show a decrease in the amount of weight change. This weight change is attributed to the combined effects of moisture pick-up and ultraviolet weight loss. It appears that the shear and compression specimens are gaining more weight from moisture pickup than they are losing due to ultraviolet effects. However, the reverse is indicated for flexure specimens which have a significantly larger surface area subject to exposure.

The absorbed moisture content of the flexure specimens is calculated after they are dried and weighed. The 5-year flexure specimens are not yet fully dried and, therefore, this information is not yet available. The moisture content data for 1- and 3-year exposure periods, previously reported in reference 5, is shown again in figure 23.

The average residual strength ratios for the shear, flexure and compression specimens are plotted in figures 24, 25, and 26. These values represent a comparison of the average strength values for all six exposure sites with the average baseline strength value for that material system. A ± 10 percent bandwidth, which represents the strength scatter in the specimens with no exposure, is shown on each graph. The shear strengths of the T300-5209 and AS-3501 systems are fairly constant over the 5-year period, whereas the shear strengths of T300-2544 specimens have dropped below the bandwidth. The flexural strengths of all the materials are within the bandwidth except for the AS-3501 system, which shows a significant strength increase after 3 and 5 years' exposure. The compression strengths for all these material system—systems show a gradual decrease with increase in exposure time.

Tables 8, 9, and 10 also show the average failure stresses of the specimens. The results indicate the strength differences between exposure sites. In most instances, the New Zealand exposure causes the highest strength reductions for the three materials systems.

*Prepared by Jane A. Hagaman, NASA-Langley Research Center

Table 8.—Results of Ground-Based Environmental Exposure on Graphite-Epoxy Mechanical Property Test Specimens—Short-Beam Interlaminar Shear Tests

Exposure time, yr	Exposure location	Graphite material system	Number of specimens	Average failure stress		Average weight change	
				MPa	ksi	grams	% b
0 (baseline)	LaRC	T300/5209	5	77	11.2	---	---
5	LaRC	T300/5209	3	82	11.9	+0.0048	+0.67
5	Hawaii	T300/5209	3	76	11.0	+0.0047	+0.63
5	New Zealand	T300/5209	3	73	10.6	+0.0101	+1.39
5	Germany	T300/5209	3	78	11.3	+0.0043	+0.60
5	California	T300/5209	2	81	11.7	+0.0041	+0.57
5	LaRC* (painted specimens)	T300/5209	3	80	11.6	+0.0043	+0.50
5	Brazil	T300/5209	3	77	11.2	+0.0061	+0.80
0 (baseline)	LaRC	T300/2544	4	81	11.7	---	---
5	LaRC	T300/2544	3	73	10.6	+0.0064	+1.10
5	Hawaii	T300/2544	3	70	10.1	+0.0050	+0.89
5	New Zealand	T300/2544	3	62	9.0	+0.0106	+1.90
5	Germany	T300/2544	3	71	10.2	+0.0072	+1.26
5	California	T300/2544	3	75	10.8	+0.0051	+0.93
5	LaRC* (painted specimens)	T300/2544	3	75	10.9	+0.0077	+1.21
5	Brazil	T300/2544	3	71	10.3	+0.0100	+1.73
0 (baseline)	LaRC	AS/3501	5	87	12.6	---	---
5	LaRC	AS/3501	3	87	12.6	+0.0043	+0.76
5	Hawaii	AS/3501	3	93	13.5	+0.0030	+0.59
5	New Zealand	AS/3501	3	79	11.4	+0.0058	+1.01
5	Germany	AS/3501	3	80	11.6	+0.0046	+0.88
5	California	AS/3501	3	92	13.4	+0.0039	+0.71
5	LaRC* (painted specimens)	AS/3501	3	96	13.2	+0.0035	+0.58
5	Brazil	AS/3501	3	85	12.4	+0.0058	+1.03

*Painted specimens were fully coated with a polyurethane-based enamel over a calcium chromate primer prior to exposure at the Langley site.

[b]Corrected to initial fully dry weight.

Table 9.—Results of Ground-Based Environmental Exposure on Graphite-Epoxy Mechanical Property Test Specimens—Flexure[a] Tests

Exposure time, yr	Exposure location	Graphite-epoxy material system	Number of specimens	Average failure stress		Average flexure modules		Average weight change	
				MPa	ksi	GPa	psi (x 10^6)	grams	% b
0 (baseline)	LaRC	T300/5209	5	1529	221.8	103.8	15.05	---	---
5	LaRC	T300/5209	3	1669	242.1	106.1	15.39	+0.0045	+0.20
5	Hawaii	T300/5209	3	1568	227.4	100.8	14.61	+0.0035	+0.17
5	New Zealand	T300/5209	3	1334	193.0	101.7	14.76	+0.0080	+0.36
5	Germany	T300/5209	3	1575	228.4	104.2	15.11	+0.0060	+0.29
5	California	T300/5209	3	1640	237.9	104.4	15.14	+0.0037	+0.17
5	LaRC[c] (painted specimens)	T300/5209	3	1601	232.2	104.0	15.09	+0.0076	+0.30
5	Brazil	T300/5209	3	1538	223.1	106.7	15.47	+0.0092	+0.42
0 (baseline)	LaRC	T300/2544	5	1600	232.0	106.2	15.41	---	---
5	LaRC	T300/2544	3	1558	226.0	101.1	14.67	- 0.0212	- 0.73
5	Hawaii	T300/2544	3	1496	216.9	95.3	13.83	- 0.0189	- 0.62
5	New Zealand	T300/2544	3	1494	216.7	99.4	14.42	- 0.0092	- 0.12
5	Germany	T300/2544	3	1728	250.6	106.3	15.41	+0.0055	+0.64
5	California	T300/2544	3	1645	238.5	103.3	14.99	- 0.0097	- 0.15
5	LaRC (painted specimens)	T300/2544	3	1708	247.8	112.8	16.35	- 0.0200	- 0.65
5	Brazil	T300/2544	3	1500	217.6	103.8	15.06	- 0.0011	- 0.05
0 (baseline)	LaRC	AS/3501	5	1449	210.1	94.7	13.73	---	---
5	LaRC	AS/3501	3	1706	247.5	98.2	14.24	+0.0015	+0.41
5	Hawaii	AS/3501	3	1725	250.2	98.4	14.28	- 0.0006	- 0.30
5	New Zealand	AS/3501	3	1529	221.7	98.0	14.22	+0.0046	+0.58
5	Germany	AS/3501	3	1882	272.9	97.0	14.06	+0.0084	+0.77
5	California	AS/3501	3	1749	253.7	100.5	14.58	+0.0014	+0.41
5	LaRC[c] (painted specimens)	AS/3501	3	1907	276.6	99.0	14.36	+0.0034	+0.48
5	Brazil	AS/3501	3	1707	247.6	96.5	14.00	+0.0075	+0.74

[a]Flexure specimens were fabricated from laminates with ply orientations identical to spoiler skin orientation. Specimen length is oriented in the 90° direction of the laminate.

[b]Corrected to initial fully dry weight.

[c]Painted specimens were fully coated with a polyurethane-based enamel over a calcium chromate primer prior to exposure at the Langley site.

Table 10.—Results of Ground-Based Environmental Exposure on Graphite-Epoxy Mechanical Property Test Specimens—Compression[a] Tests

Exposure time, yr	Exposure location	Graphite-epoxy material system	Number of specimens	Average failure stress		Average weight change	
				MPa	ksi	grams	%
0 (baseline)	LaRC	T300/5209	3	712	103.2	—	—
5	LaRC	T300/5209	3	732	106.1	+0.0771	+0.97
5	Hawaii	T300/5209	3	707	102.5	+0.0696	+0.88
5	New Zealand	T300/5209	3	559	81.1	+0.1070	+1.33
5	Germany	T300/5209	3	607	88.1	+0.0596	+0.74
5	California	T300/5209	3	608	88.3	+0.0892	+1.09
5	LaRC[b] (painted specimens)	T300/5209	3	700	101.5	+0.0702	+0.87
5	Brazil	T300/5209	3	692	100.4	+0.0896	+1.14
0 (baseline)	LaRC	T300/2544	4	1029	149.2	—	—
5	LaRC	T300/2544	3	933	135.3	+0.1115	+1.60
5	Hawaii	T300/2544	3	978	141.9	+0.1106	+1.55
5	New Zealand	T300/2544	3	754	109.4	+0.1467	+2.02
5	Germany	T300/2544	3	934	136.5	+0.0919	+1.30
5	California	T300/2544	3	866	125.6	+0.1172	+1.62
5	LaRC[b] (painted specimens)	T300/2544	3	957	138.9	+0.0964	+1.34
5	Brazil	T300/2544	3	886	128.4	+0.1425	+1.99
0 (baseline)	LaRC	AS/3501	5	1107	160.6	—	—
5	LaRC	AS/3501	3	1062	154.0	+0.0681	+1.03
5	Hawaii	AS/3501	3	1087	157.7	+0.0633	+0.96
5	New Zealand	AS/3501	3	818	118.6	+0.0818	+1.25
5	Germany	AS/3501	3	1102	159.8	+0.0567	+0.87
5	California	AS/3501	3	903	130.9	+0.0895	+1.39
5	LaRC[b] (painted specimens)	AS/3501	3	1014	147.0	+0.0660	+0.99
5	Brazil	AS/3501	3	1016	147.4	+0.0686	+1.04

[a]Compression specimens were fabricated from laminates with ply orientations identical to spoiler skin ply orientation. Specimen length is oriented in the 90° direction of the skin laminate.

[b]Painted specimens were fully coated with a polyurethane-based enamel over a calcium chromate primer prior to exposure at the Langley site.

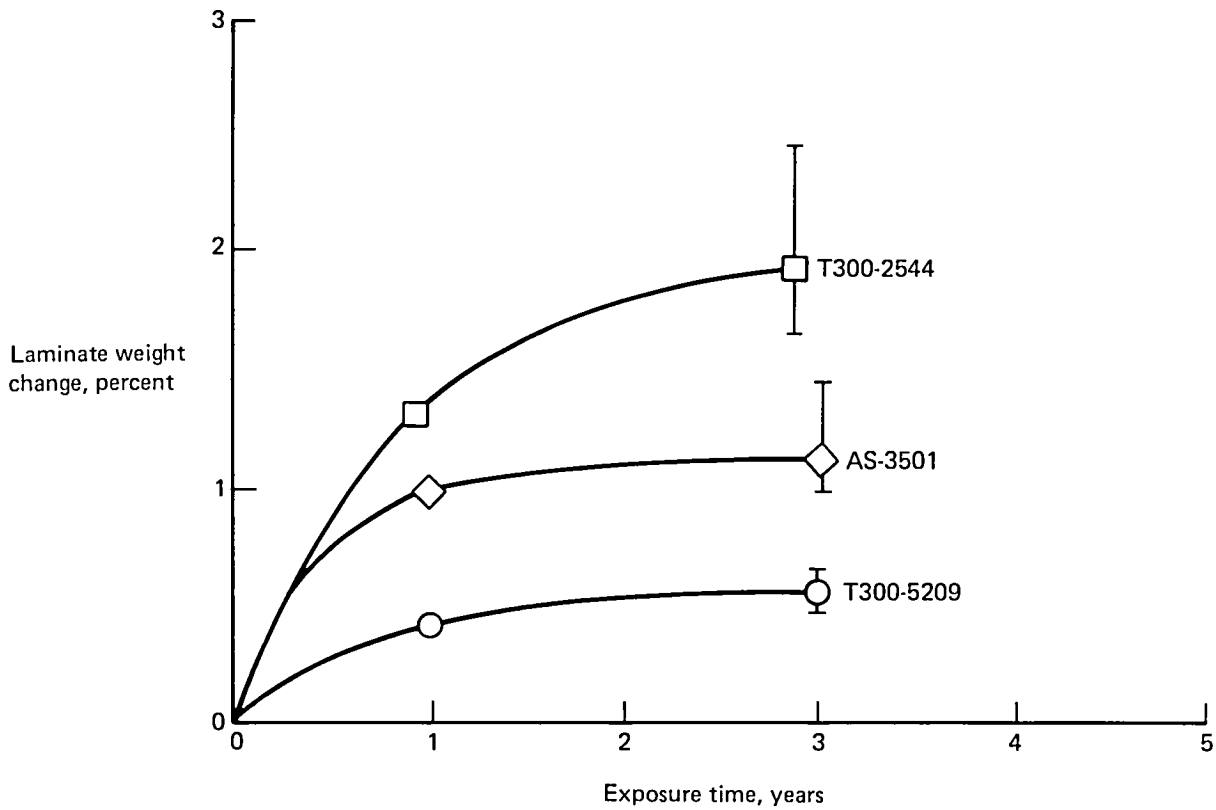

Figure 23.—Moisture Pickup for Composites After Worldwide Ground-Based Exposures

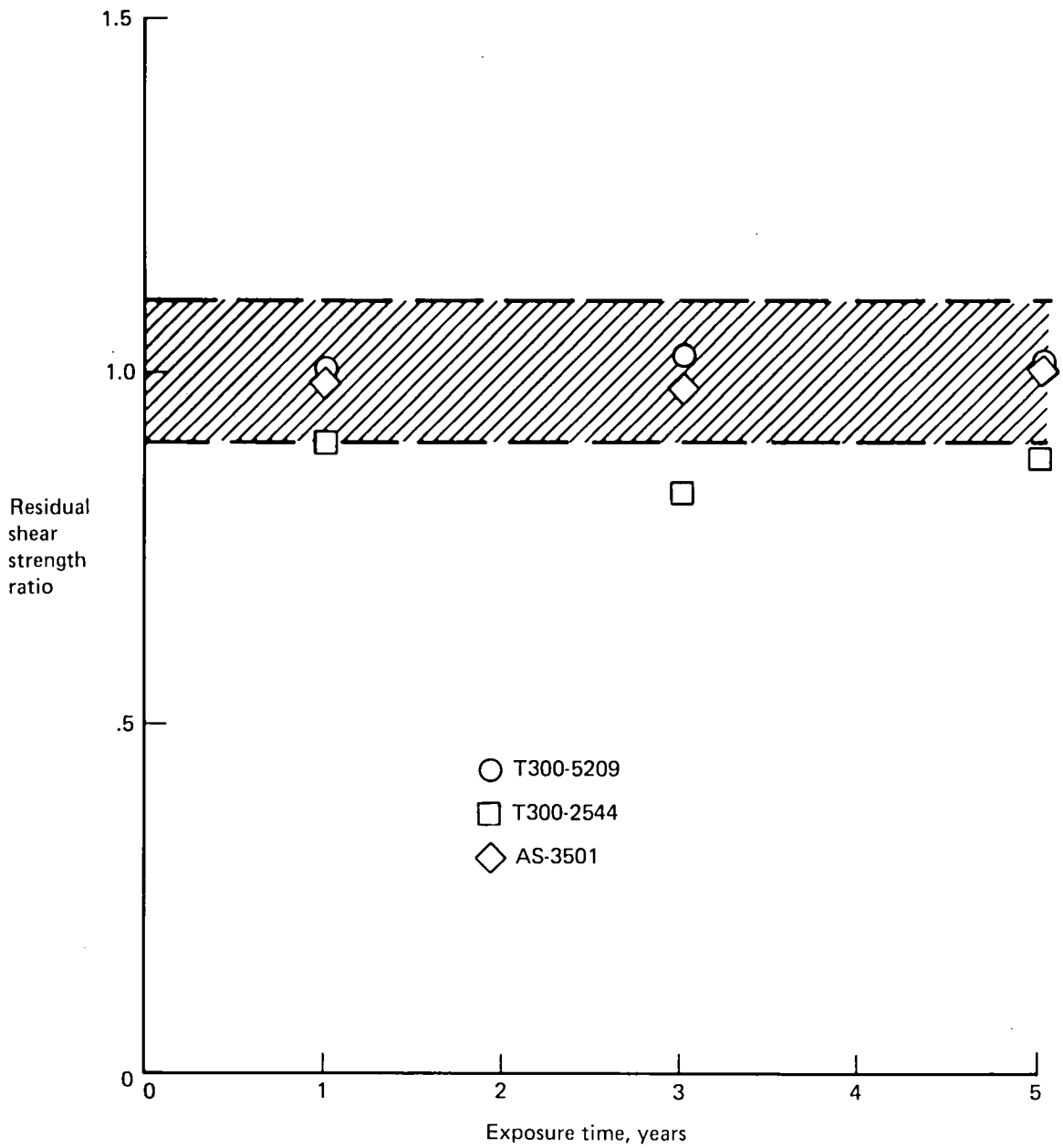

Figure 24.—Residual Shear Strength After Worldwide Exposure

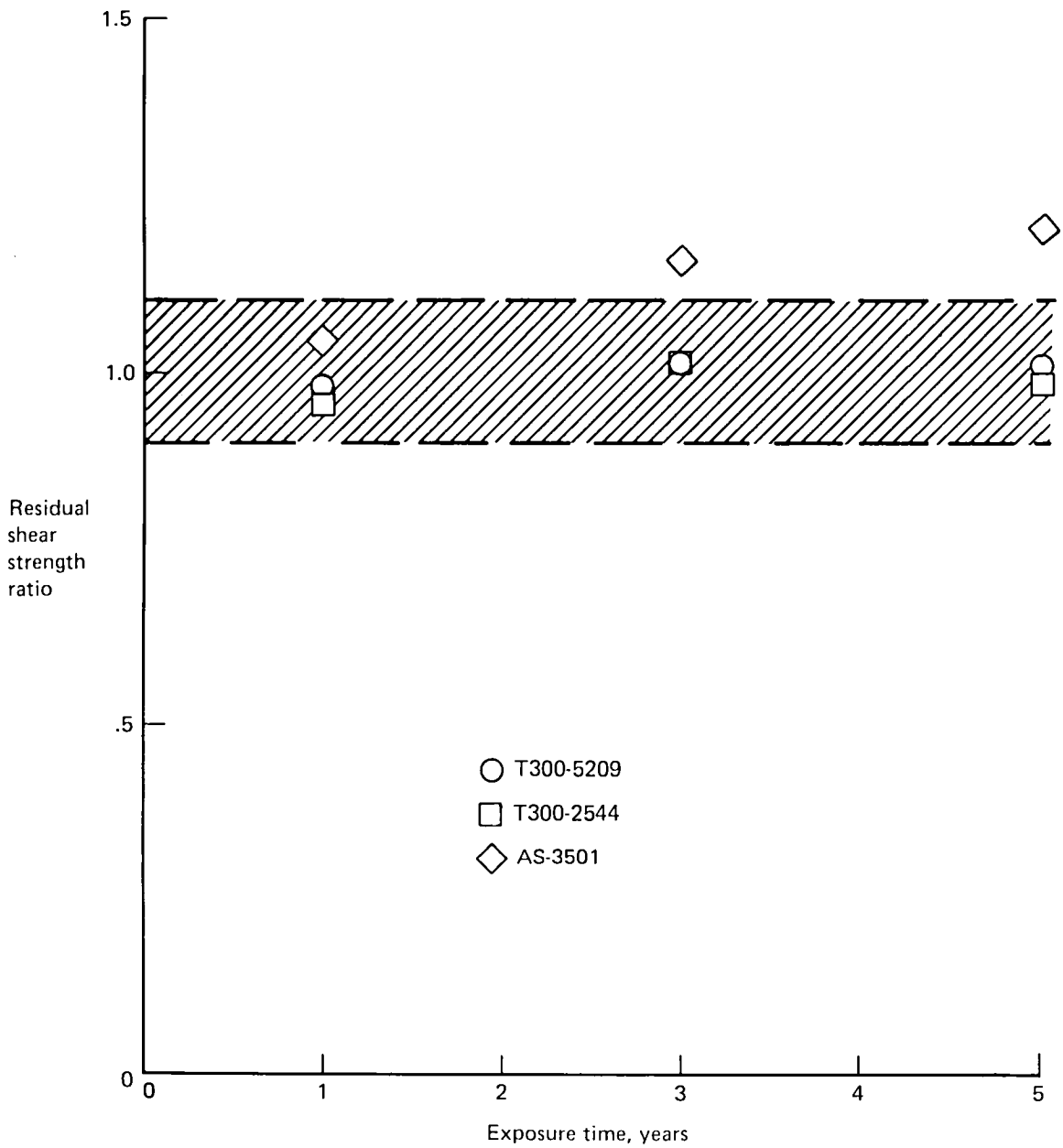

Figure 25.—Residual Flexure Strength After Worldwide Exposure

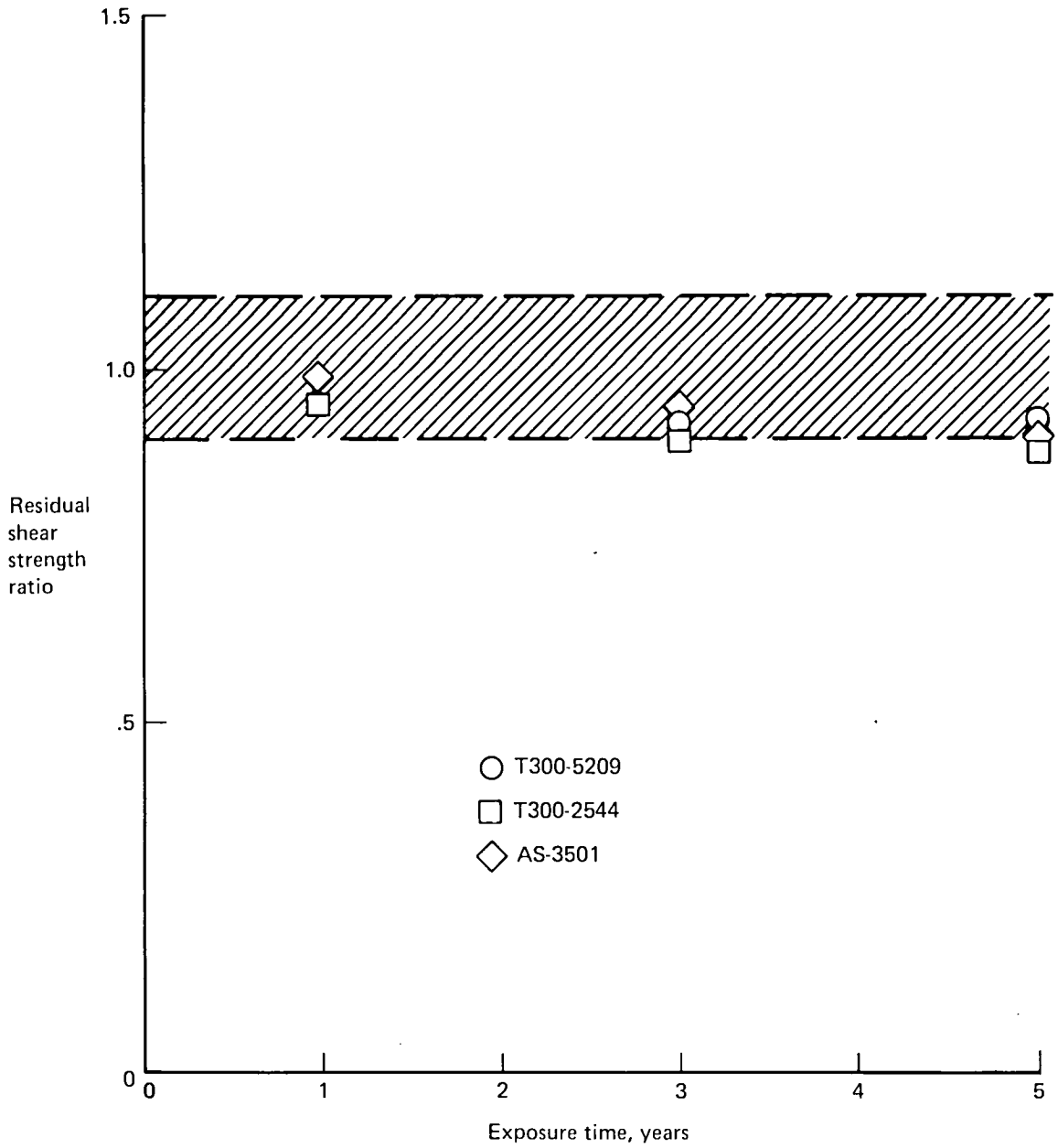

Figure 26.—Residual Compression Strength After Worldwide Exposure

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15. Supplementary Notes

NASA Technical Representative: Mr. Richard Pride

16 Abstract

The fifth annual flight service report was prepared in compliance with the requirements of contract NAS1-11668. It covers the flight service experience of 111 graphite-epoxy spoilers on 737 transport aircraft and related ground-based enviromental exposure of graphite-epoxy material specimens for the period from May 1978 through April 1979. Spoilers have been installed on 28 aircraft representing seven major airlines operating throughout the world. An extended flight service evaluation program of 10 years is presently under way. As of April 30, 1979, a total of 1,188,367 spoiler flight-hours and 1,786,837 spoiler landings had been accummulated by this fleet.

Tests of removed spoilers and ground-based exposure specimens after the fifth year of service continue to indicate modest changes in composite strength properties. A second incident of trailing edge delamination with subsequent core corrosion was observed during this past year. Based on visual, ultrasonic, and destructive testing, there has been no other evidence of moisture migration into the honeycomb core and no core corrosion.

The flight service program has been amended to include gathering of inflight moisture absorption data by three of the spoiler-participating airlines. Considerable data is now available from these exterior-mounted specimens. The coupons show rational weight gain trends.

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