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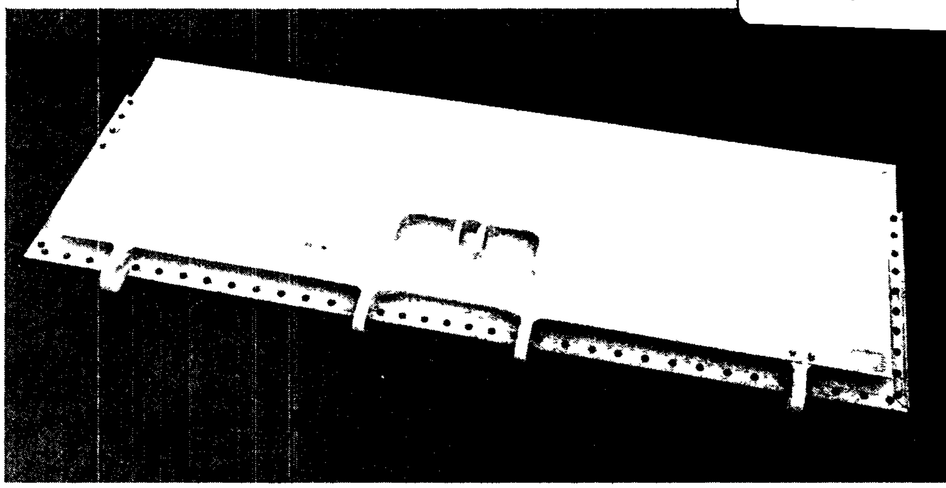
737 GRAPHITE COMPOSITE FLIGHT SPOILER FLIGHT SERVICE EVALUATION

Randy L. Coggeshall



SEVENTH ANNUAL REPORT
MAY 1980 THROUGH APRIL 1981

Prepared under Contract NAS1-11668 by
BOEING COMMERCIAL AIRPLANE COMPANY
FEBRUARY 1982

NASA
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

FOREWORD

This is the seventh 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 spoilers and test specimens in a wide range of operating environments. One additional report will be prepared and submitted at the completion of the flight service period, which is programmed to provide 10 years of flight service.

The program is administered by Langley Research Center, National Aeronautics and Space Administration. H. Benson Dexter, Materials Division, is the technical monitor. Jane A. Hagaman, Materials Division, is responsible for test and evaluation of ground-based specimens for the program.

The program is being conducted at the Boeing Commercial Airplane Company under the direction of Robert D. Wilson, program manager. Randy L. Coggeshall, Advanced Structures Group, is the program technical leader.

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737 GRAPHITE COMPOSITE FLIGHT SPOILER FLIGHT SERVICE EVALUATION

Randy L. Coggeshall
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PROGRAM SUMMARY AND STATUS

The seventh 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 from May 1, 1980, through April 30, 1981. Segments of the data contained herein have appeared in previous documentation (refs. 1 through 8).

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 five major airlines operating in different environmental circumstances. Since that time, some aircraft have been sold by the initial operator, and some spoilers have been redeployed within the fleet due to normal maintenance schedules. These installed spoilers (units) will be monitored under actual load and environmental conditions for 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 and at NASA-Langley Research Center to gather ground-based environmental data to support the flight data gathered from the spoilers.

Significant events that have occurred during this period include:

- Completion of the seventh annual inspection of those spoilers in service
- Continuation of the spoiler repair program
- Continuation of the nondestructive inspection (NDI) sampling program and static testing of spoilers from the flight service program
- Continuation of the skin laminate moisture absorption study
- Initiation of a contract revision

As of April 30, 1981, 1,564,544 spoiler flight-hours and 2,298,352 spoiler landings have been accumulated by the fleet. The high-time spoiler had accumulated 21,283 flight-hours on Frontier Airlines 737 N7386F. Fifty-one spoilers have accumulated more than 16,000 flight-hours since the beginning of the flight service program, and 41 spoilers have had uninterrupted service since their original installation.

Laboratory testing of spoilers, returned from 6 and 7 years of flight service, continues to demonstrate that the spoilers retain a high percentage of their unexposed strength. Two spoiler units were tested this past year. Both units were tested with service-induced discrepancies. These anomalies included exfoliation corrosion in the spar and skin delaminations. Even with these discrepancies the units had residual strengths that fell within the scatter band. Results of these tests will be used to establish defect limitations. The second and third static test units were not removed and tested in time for inclusion in this report. Results from these units will be included in the final report.

Maintenance damage and related repair activities have continued at a modest level this past year. Eight spoilers were removed for repair during this reporting period. Unlike some previous years, no single cause dominated these removals. Six of the removed units were repaired or are currently undergoing repair. Airlines continue to exhibit enthusiasm for and confidence in the program. Several of the airlines have reported significantly reduced maintenance with the graphite-epoxy units when compared with the production aluminum-skinned units.

Activities are underway on a contract revision, and this revision will result in several program changes. Laboratory testing will continue as in the past; however, there will be no eighth annual report. All data gathered after this report is submitted will be included in the final report at the close of the program in early 1984. Repair activities by Boeing will be suspended, although several airlines will continue to perform repairs at their own maintenance bases. There will be no annual inspection trip during 1982, but a final inspection trip will take place early in 1983.

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 actively participating airlines previously identified (ref. 3) have 23 aircraft currently committed to the program. Aloha and Lufthansa each have sold two aircraft. The spoilers associated with these aircraft are being reassigned to other aircraft in their respective fleets.

Currently participating airlines are:

- Air New Zealand, Ltd.—four aircraft
- Aloha Airlines—two aircraft
- Deutsche Lufthansa Airlines—four 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.

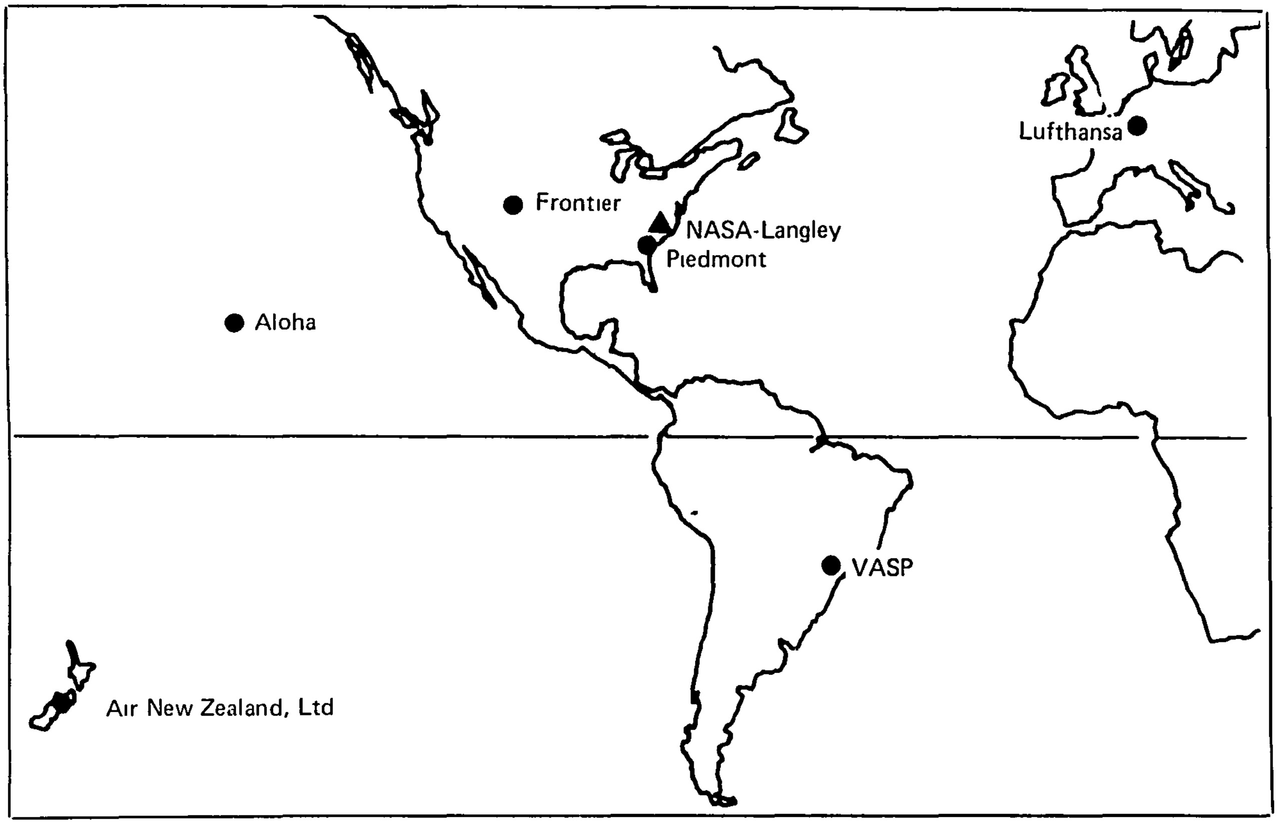

Figure 1. Geographic Deployment of Currently Participating Airlines

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FLIGHT EXPERIENCE

The graphite-epoxy 737 flight spoiler flight service evaluation program, in operation since July 18, 1973, has achieved an exceptional level of commercial service exposure. The program has generated over 1-1/2 million flight-hours of service and over 2-1/4 million landings in nearly 8 years of operation and is adding flight experience at the rate of nearly 15,000 hours a month.

Total flight experience to April 30, 1981, is summarized in table 1 by type of graphite-epoxy material. 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 51 spoiler panels have accumulated over 16,000 flight-hours each. Their distribution, by airline and by skin material system, is shown in table 3.

A Fortran program called PSPOIL was established to periodically update the service history of the spoiler fleet. The computerized approach saves time and improves accuracy of the data. The program provides all of the data shown in the three tables plus installation and removal dates and the current status of spoilers (i.e., flying, out for repair, destroyed in test).

Table 1. Flight Spoiler Service Experience by Type of Material (As of 4-30-81)

Spoiler material type	Net hours	Net landings
Union Carbide T300/2544	526 221	752 030
Narmco T300/5209	533 182	754 864
Hercules AS/3501	505 141	791 458
Total	1 564 544	2 298 352

Table 2. Flight Spoiler Service Experience by Airline (As of 4-30-81)

Airline	Number of aircraft in evaluation	Number of spoilers in evaluation	Total spoiler hours since installation	Total spoiler landings since installation
PSA	0	0	29 747	51 521
Aloha	4	18	161 685	418 907
New Zealand	4	18	207 603	281 394
Lufthansa	6	24	352 823	454 940
Piedmont	8	31	525 802	773 024
VASP	4	16	215 996	242 420
Frontier	1	4	70 888	76 147
Total	27	111*	1 564 544	2 298 352

*Total currently in service is 75 spoilers, with 36 spoilers either inactive or retired

Table 3. Distribution of Spoilers With 16 000 or More Flight-Hours

Part number	Airline						Total
	VP	LH	PI	Aloha	Frontier	NZ	
-1 (T300/2544)	3	2	11	0	0	2	18
-2 (T300/5209)	2	6	6	0	4	0	18
-3 (AS/3501)	1	5	8	0	0	1	15
Total	6	13	25	0*	4	3	51

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

SCHEDULED SPOILER REMOVALS AND EVALUATION

During this reporting period, four spoilers (two sixth year and two seventh year) were removed from the flight service program for evaluation and test. Four additional seventh-year units were scheduled for removal too late for inclusion in this report and will be discussed in the final report. All four removed spoilers were reinspected using through-transmission ultrasonic C-scan, and the results were compared to the records made at the time of original fabrication. Two units were considered clear following nondestructive inspection, but two of the four units had service-induced discrepancies that Boeing would normally repair before returning the spoiler.

Boeing has, in the past, followed a policy of refurbishing any graphite-epoxy spoiler returned to the plant for any reason, including test and evaluation. Many of the discrepancies or defects described in subsequent paragraphs represent normal or less than normal wear and tear on an aircraft component after 7 years of service. Only one of the conditions described would be likely to receive repair attention at the next maintenance break. Several would receive only a seal-and-monitor disposition, and some of those would not deteriorate to a state requiring repair during the life of the part.

Two of the four removed units were selected for destructive test to measure residual static strength following the specified calendar period of exposure. The two units selected for test (S/N 0059 and S/N 0049) had deficiencies as described in the previous paragraph. Similar conditions can and do occur during a normal maintenance cycle. It was considered important to verify by test the expected result that no significant strength reduction had occurred.

Following selection for test, the units were photographed. Figures 2 and 3 show the upper and lower surface of spoiler S/N 0059. The discrepancies on this unit are shown in figures 4 through 6. Figure 4 shows some minor corrosion of one of the -23 aluminum doublers. Figure 5 shows an exfoliation corrosion blister at one spar to center hinge fitting splice, and figure 6 shows a similar exfoliation corrosion blister at the opposite side.

Figures 7 and 8 are photographs of the upper and lower surfaces, respectively, of spoiler S/N 0049. Earlier minor doubler corrosion and flap rubbing had been dressed down and repainted by the airline. Discrepancies for this unit are shown in figures 9 through 12. Figure 9 shows an edge crack resulting from an exfoliation corrosion condition from the outboard spar to center hinge fitting splice. Figures 10 through 12 show the opposite splice in detail. The area had undergone a repair for exfoliation corrosion, but the problem redeveloped during additional service. The repair finish is relatively coarse, because this is not an aerodynamic surface. Figures 11 and 12 show in detail the corrosion blister and edge crack.

Table 4 gives data from all of the scheduled sixth-year removals and summarizes the strength and stiffness data from the two units that were statically tested. Table 5 gives similar data for the seventh-year removals. Figure 13 shows the residual static strength data accumulated to date. Each symbol represents one test of a particular spoiler dash number (i.e., type of skin material) after a predesignated period of time. Initials near the symbols indicate the airline from which the spoiler was removed. The data are shown as a residual strength ratio, where 1.0 is the original unexposed certification test value for each material system. The shaded area represents the scatterband for a total of 16 ultimate tests run on unexposed -2 units. Although limited to one production run of only one of the

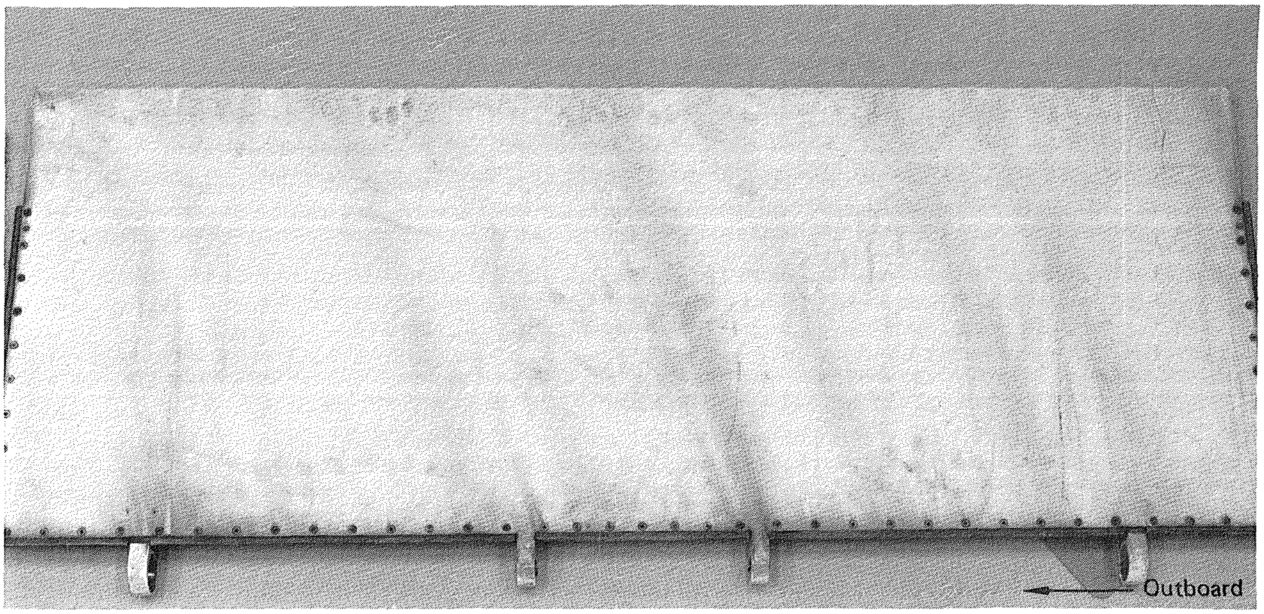

Figure 2. Upper Surface of Spoiler S/N 0059 After 6 Years of Service

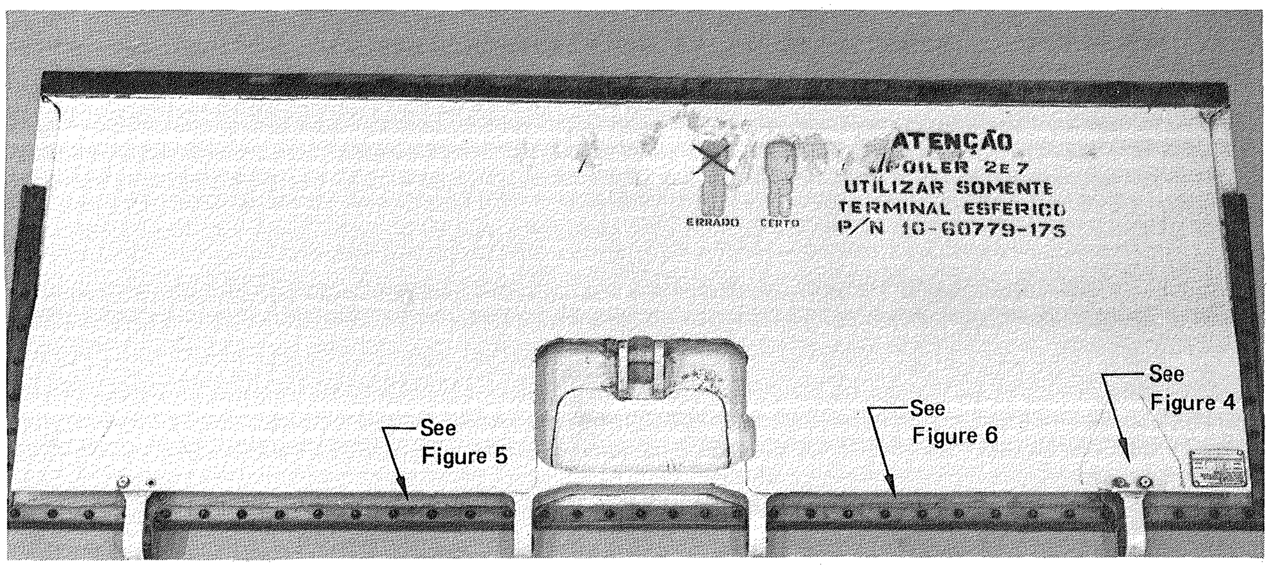

Figure 3. Lower Surface of Spoiler S/N 0059 After 6 Years of Service

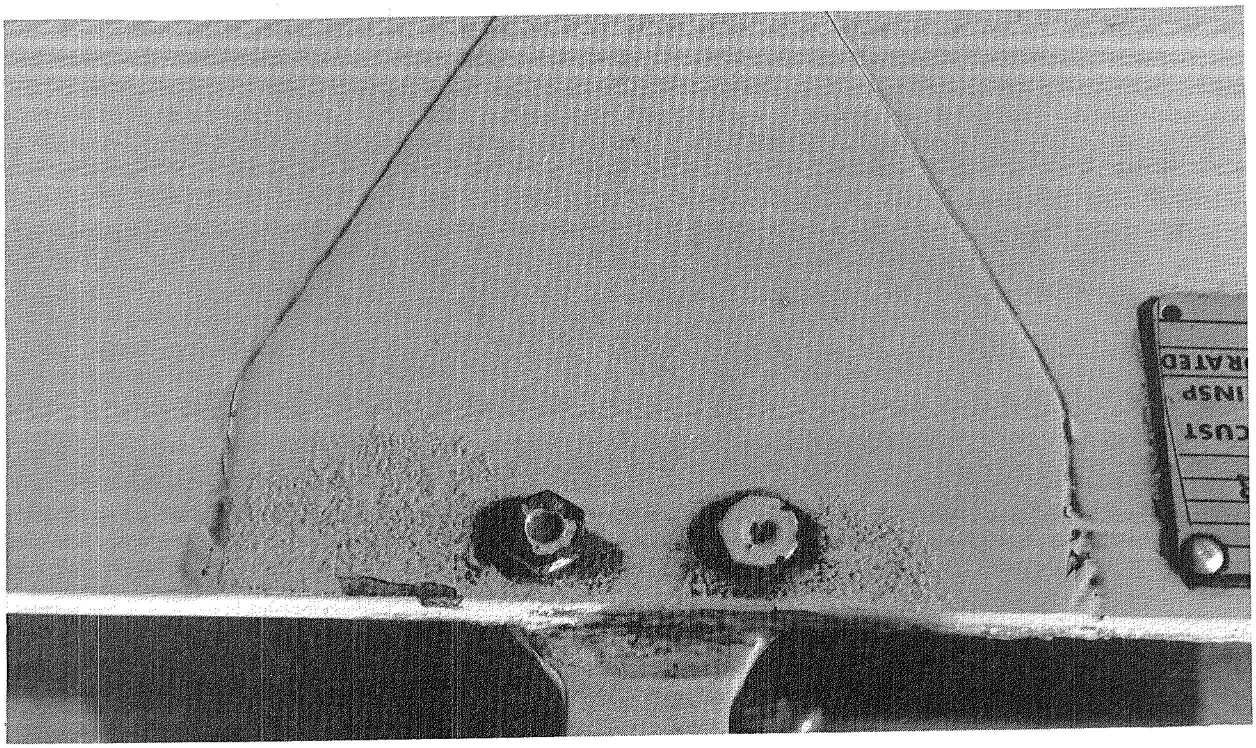

Figure 4. Minor Doubler Corrosion on S/N 0059

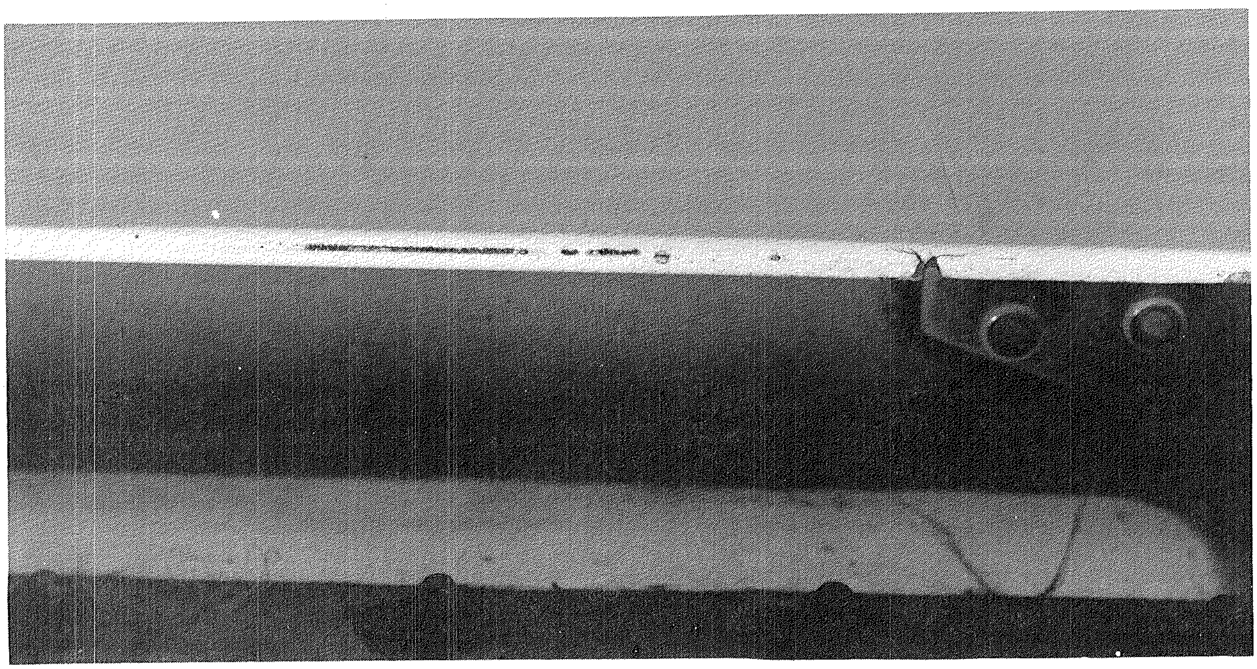

Figure 5. Exfoliation Corrosion at Outboard Spar to Center Hinge Fitting Splice on S/N 0059

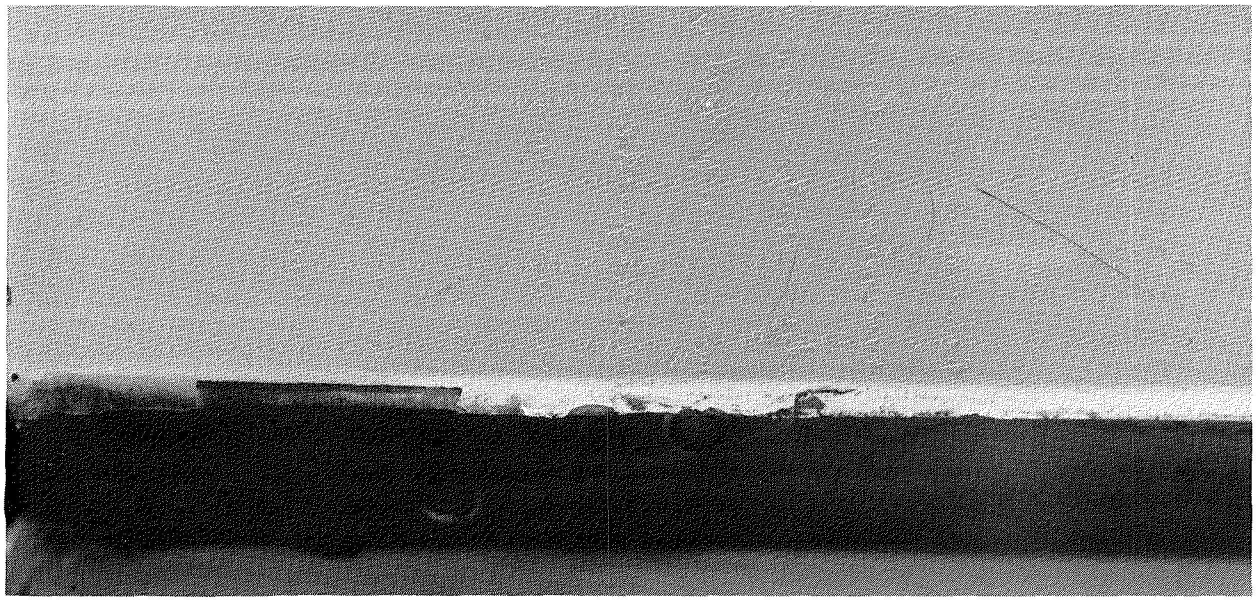

Figure 6. Exfoliation Corrosion at Inboard Spar to Center Hinge Fitting Splice on S/N 0059

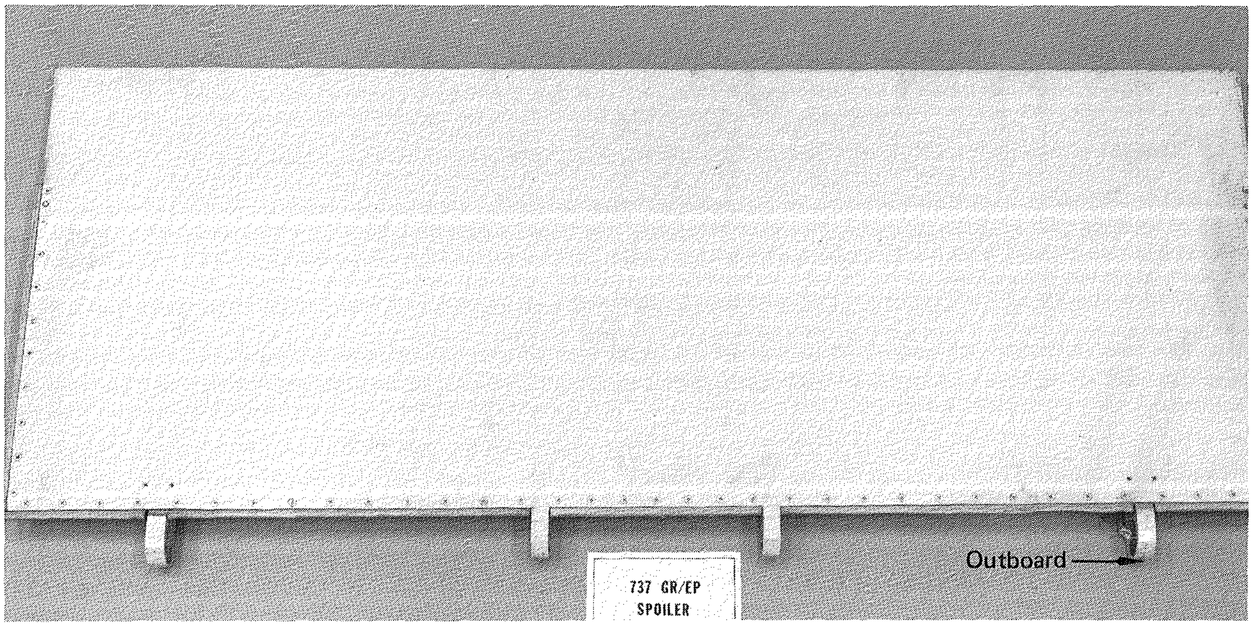

Figure 7. Upper Surface of Spoiler S/N 0049 After 7 Years of Service

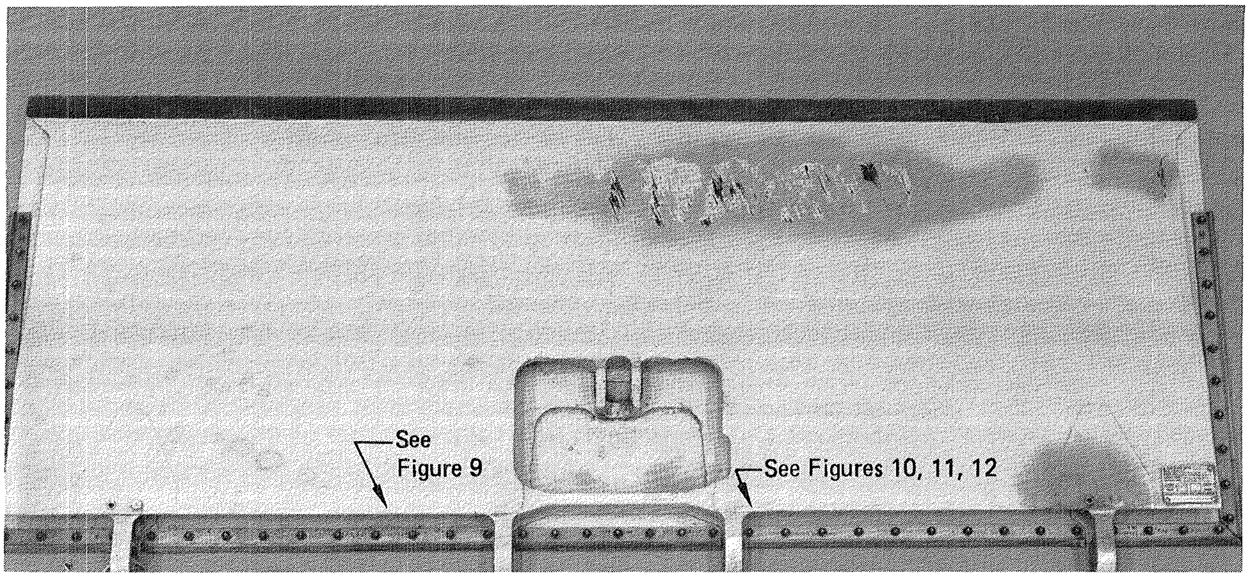

Figure 8. Lower Surface of Spoiler S/N 0049 After 7 Years of Service

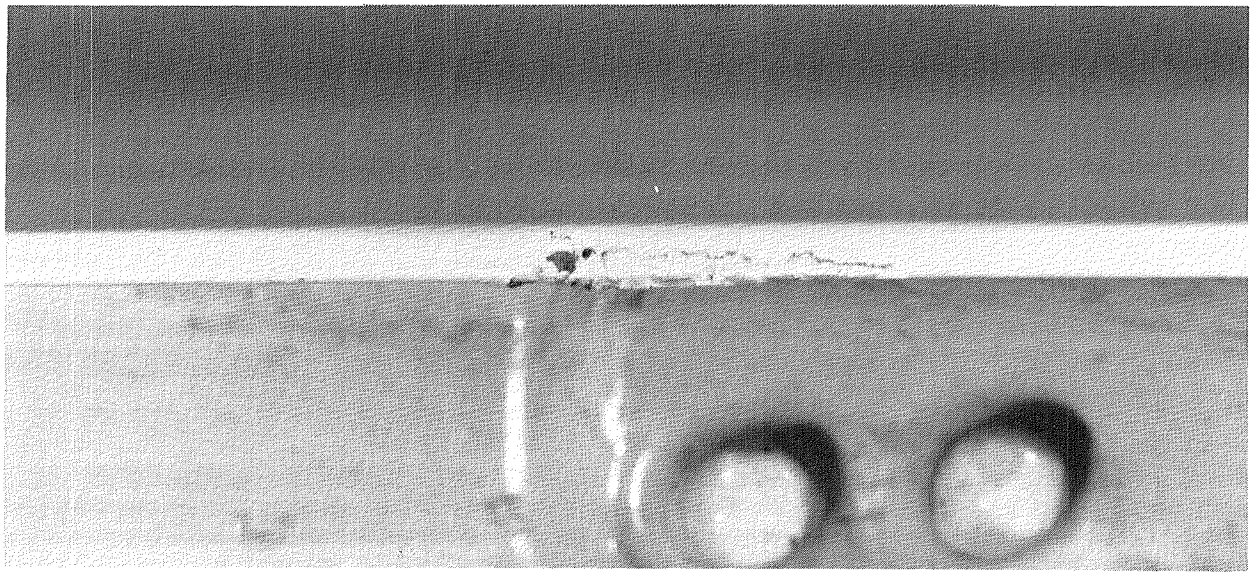

Figure 9. Exfoliation Corrosion at Outboard Spar to Center Hinge Fitting Splice on S/N 0049

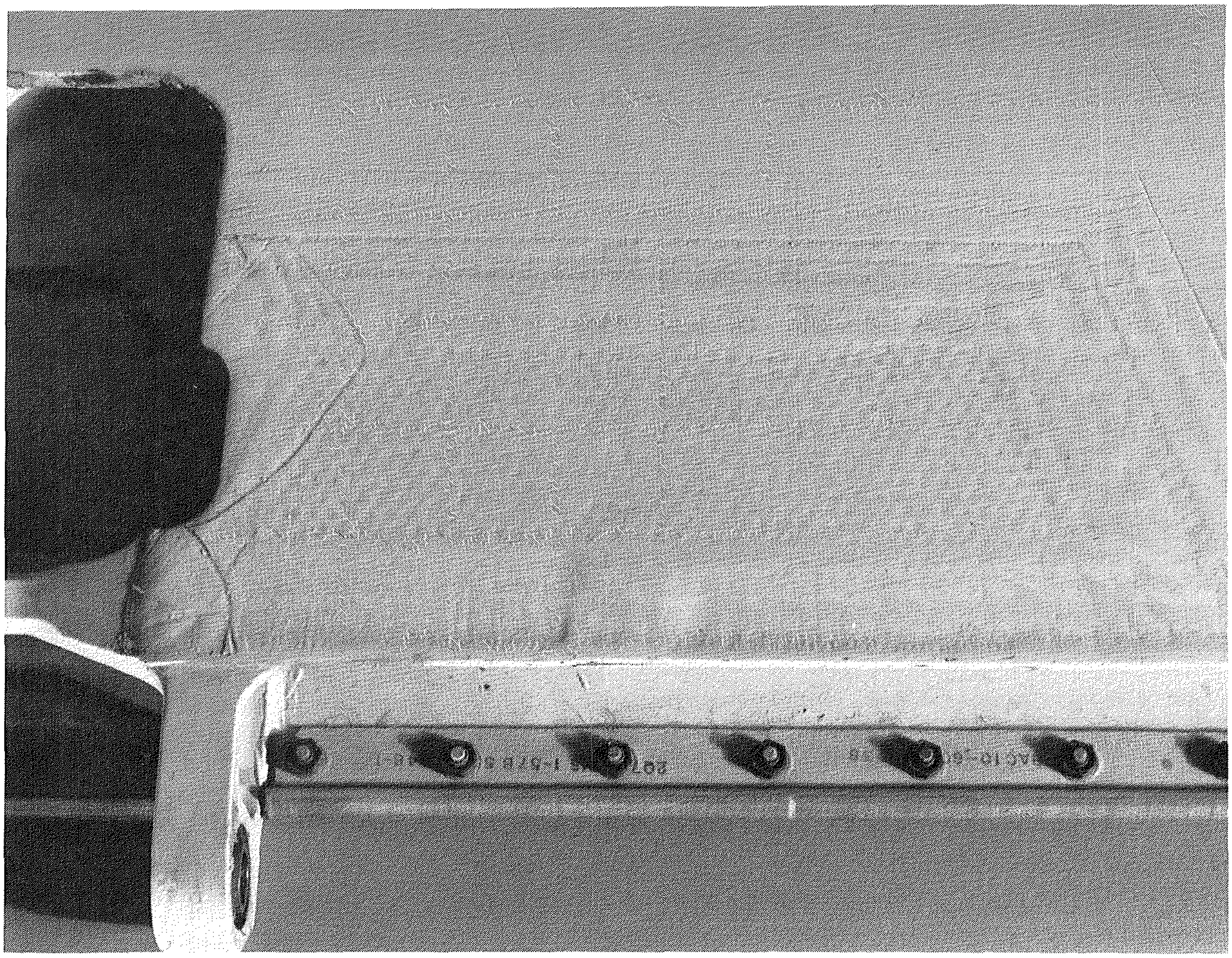

Figure 10. Previous Repair Detail and Exfoliation Corrosion at Inboard Spar to Center Hinge Fitting Splice on S/N 0049

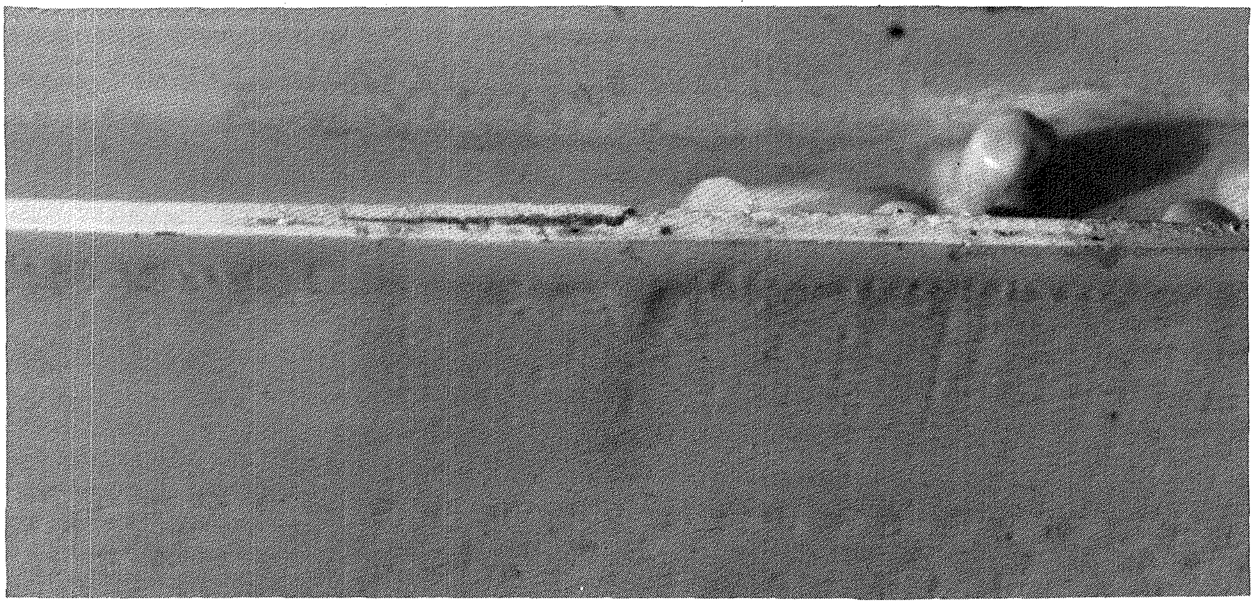

Figure 11. Exfoliation Corrosion at Inboard Spar to Center Hinge Fitting Splice on S/N 0049

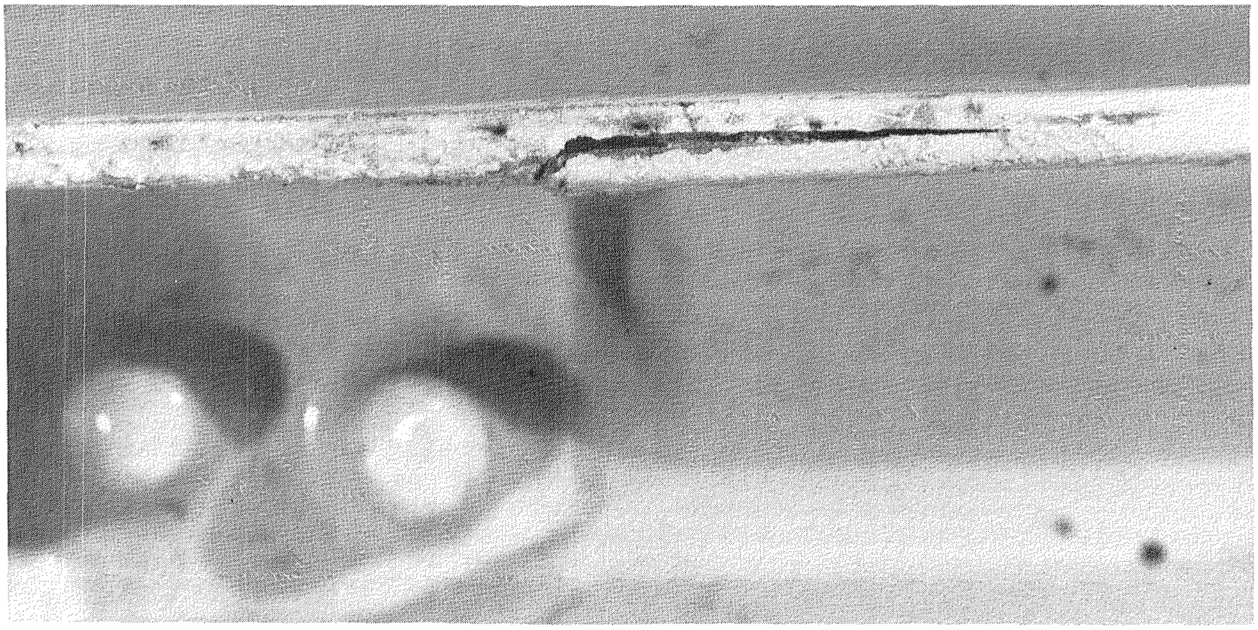

Figure 12. Exfoliation Corrosion at Inboard Spar to Center Hinge Fitting Splice on S/N 0049

Table 4. Summary Data From Scheduled Spoiler Removals (Sixth Year)

Spoiler identification number [1]	Airline	NDI results	Failure load, % DLL	Strength change, %	Stiffness change, %	Time in service	Flight-hours	Flight cycles
-1 S/N 0012	Lufthansa [2]	Clear	Not tested			73 months 22 days	14 187	17 287
-1 S/N 0024	Aloha [2]	See text	209	-15	No change	71 months 19 days	10 810	29 396
-2 S/N 0047	Frontier [3]	Clear	Not tested			78 months 0 days	16 221	23 379
-2 S/N 0059	VASP [3]	See text	240	-17	No change	72 months 10 days	13 718	15 856
-3 S/N 0087	Air New Zealand [2]	See text	214	-11	No change	74 months 17 days	13 682	18 626
-3 S/N 0103	Piedmont [2]	Upper skin blister	Not tested			72 months 7 days	15 609	22 931

[1] -1 units use Union Carbide T300/2544 graphite-epoxy prepreg skins
-2 units use Narmco T300/5209 graphite-epoxy prepreg skins
-3 units use Hercules AS/3501 graphite-epoxy prepreg skins

[2] Ref. 7
[3] Included this report

Table 5. Summary Data From Scheduled Spoiler Removals (Seventh Year)

Spoiler identification number [1]	Airline	NDI results	Failure load, % DLL	Strength change, %	Stiffness change, %	Time in service	Flight-hours	Flight cycles
-1 S/N 0015	VASP	Units scheduled for removal too late for inclusion in this report and will be discussed in the final report.						
-1 S/N 0008	Air New Zealand							
-2 S/N 0049	Aloha	See text	284	-2	No change	81 months 29 days	10 785	28 925
-2 S/N 0070	Piedmont	Clear	Not tested			84 months 2 days	17 726	26 355
-3 S/N 0083	Lufthansa	Units scheduled for removal too late for inclusion in this report and will be discussed in the final report.						
-3 S/N 0118	Piedmont							

[1] -1 units use Union Carbide T300/2544 graphite-epoxy prepreg skins
-2 units use Narmco T300/5209 graphite-epoxy prepreg skins
-3 units use Hercules AS/3501 graphite-epoxy prepreg skins

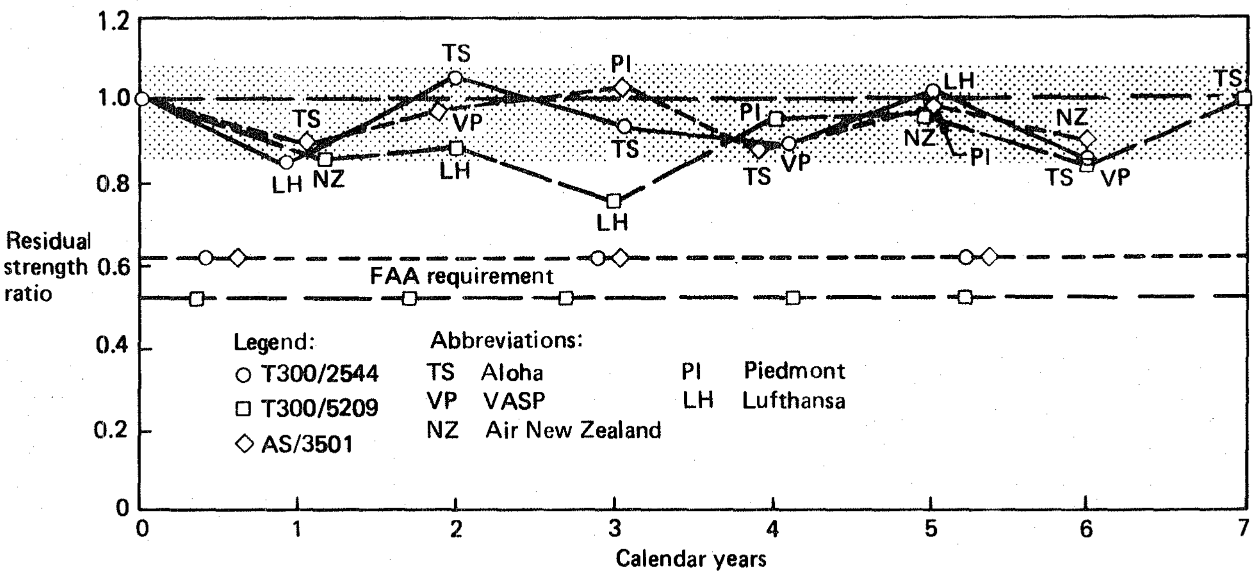

Figure 13. Summary of Residual Strength After Exposure

three types of material, the band provides some idea of the minimum scatter that could be expected. The FAA ultimate load requirement for each material system is also shown in the figure. It can be seen that the three units tested after 6 years have residual strengths that are near the lower bound of the scatterband but well above the FAA requirement. The seventh-year unit had a residual strength only slightly lower than the unexposed baseline failure strength. Figures 14 and 15 are plots of the load-deflection data for these two panels. There is no discernible difference between baseline and residual stiffness for either unit.

Figure 16 shows the test setup. Load is applied to the upper surface through an evener system and load pad scheme. The load is then reacted at the four hinge points and the actuator rod end.

Figures 17 through 27 are photographs of the spoiler panels after testing. On both units, the exfoliation corrosion blisters locate the failure by allowing the compression-loaded lower skin to buckle at the blister location. As expected, these defects did not significantly reduce residual panel strength or stiffness.

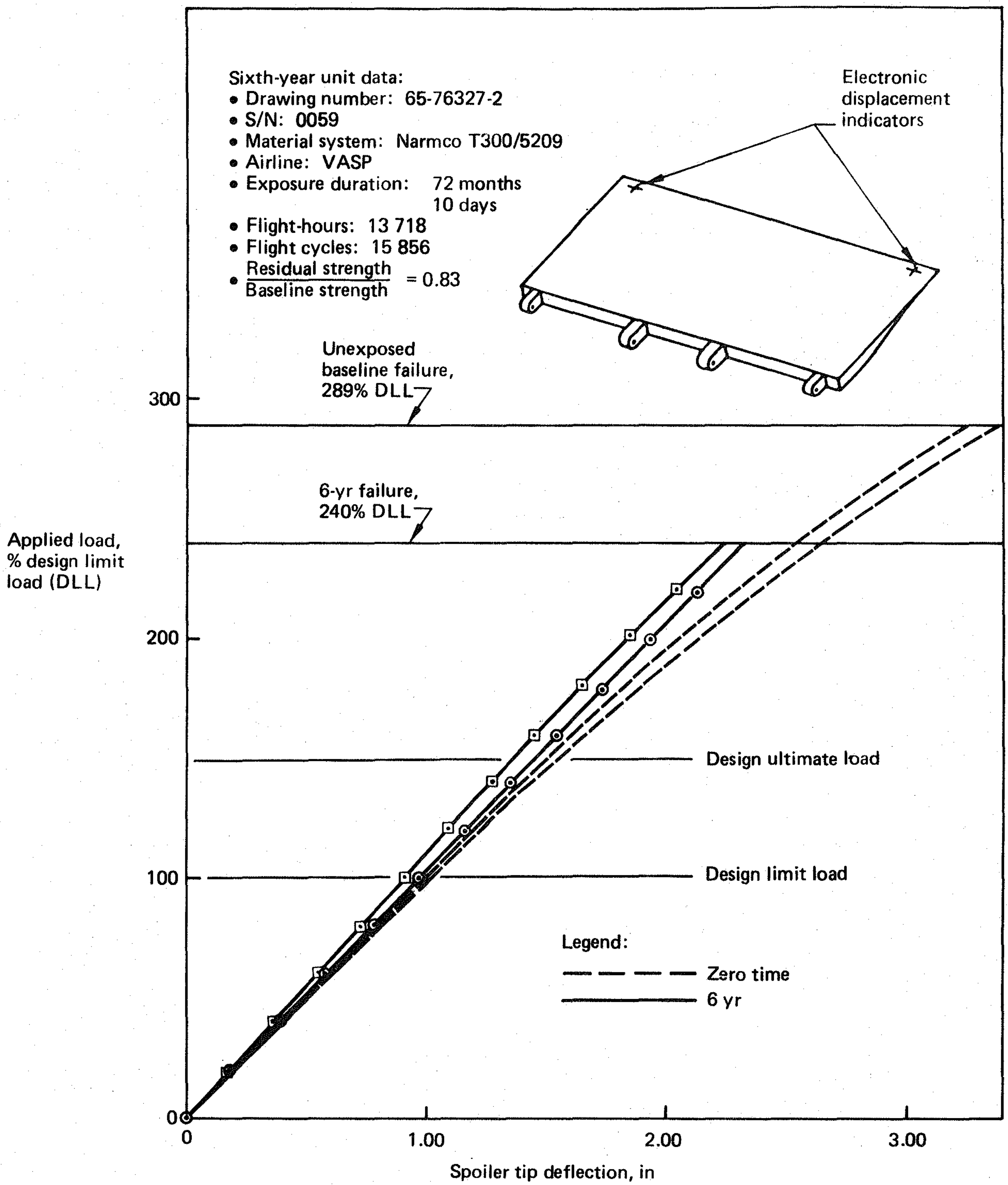

Figure 14. Residual Strength and Stiffness of Spoiler S/N 0059 After 6 Years of Service

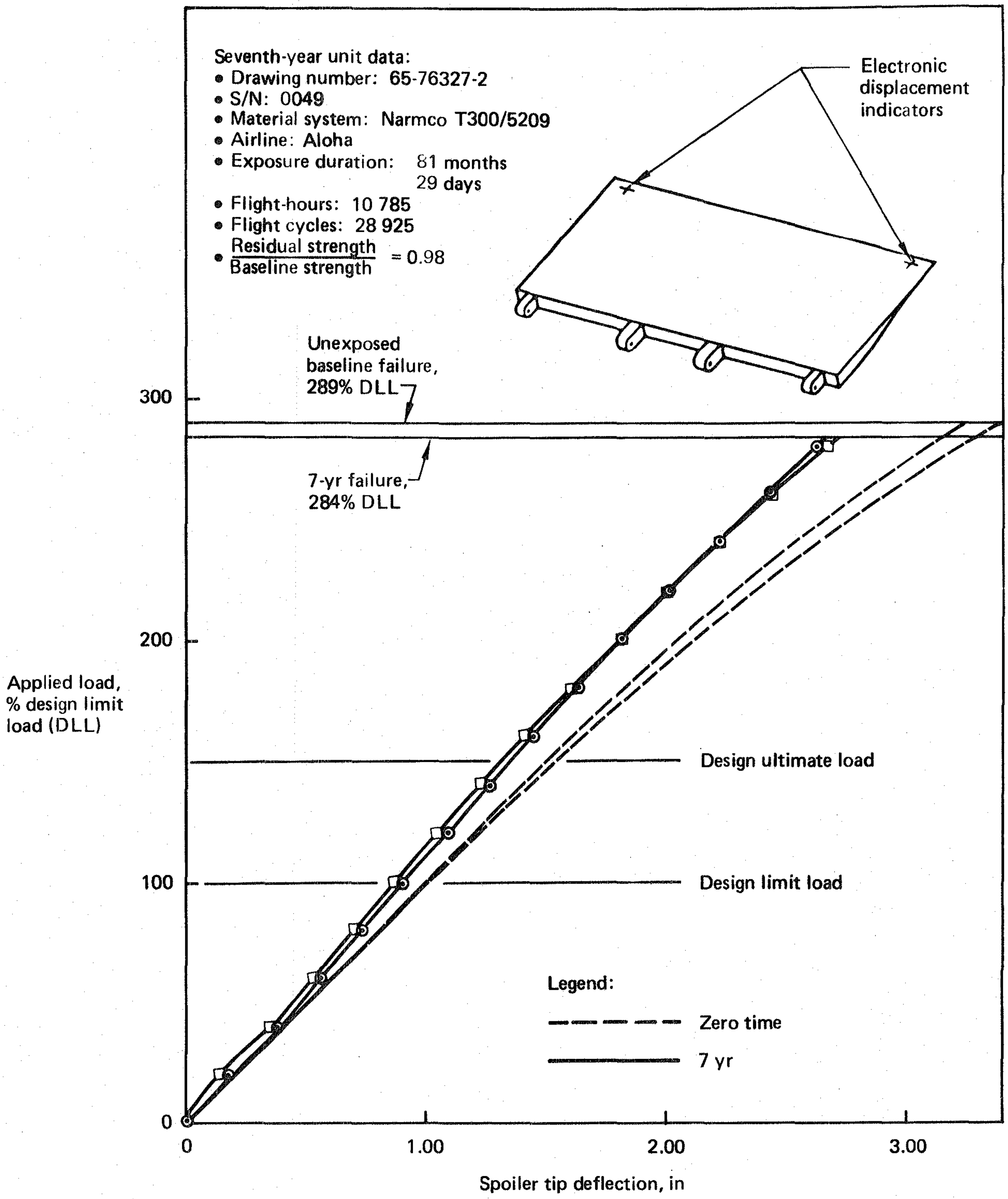

Figure 15. Residual Strength and Stiffness of Spoiler S/N 0049 After 7 Years of Service

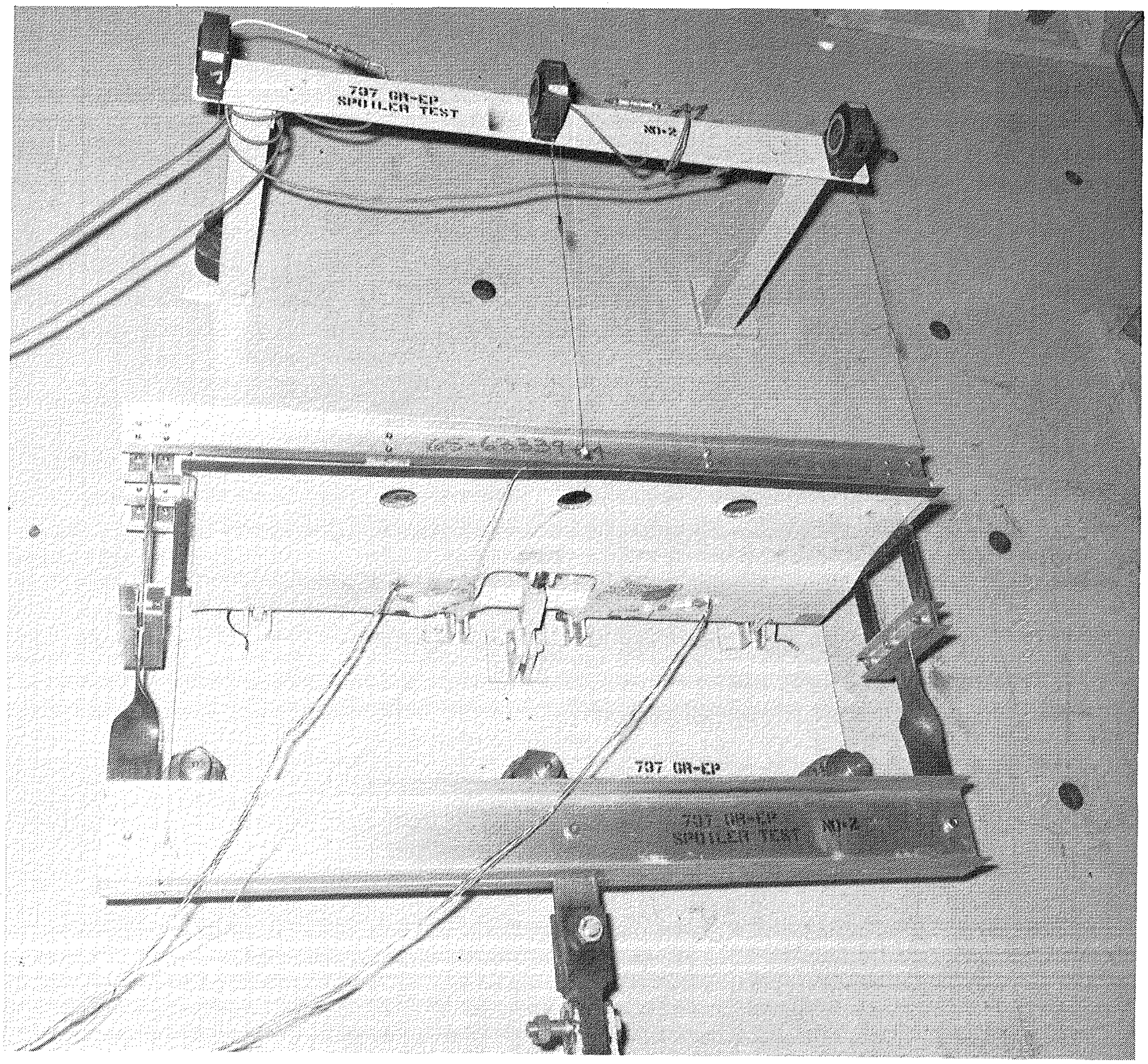

Figure 16. Spoiler Residual Strength Test Setup

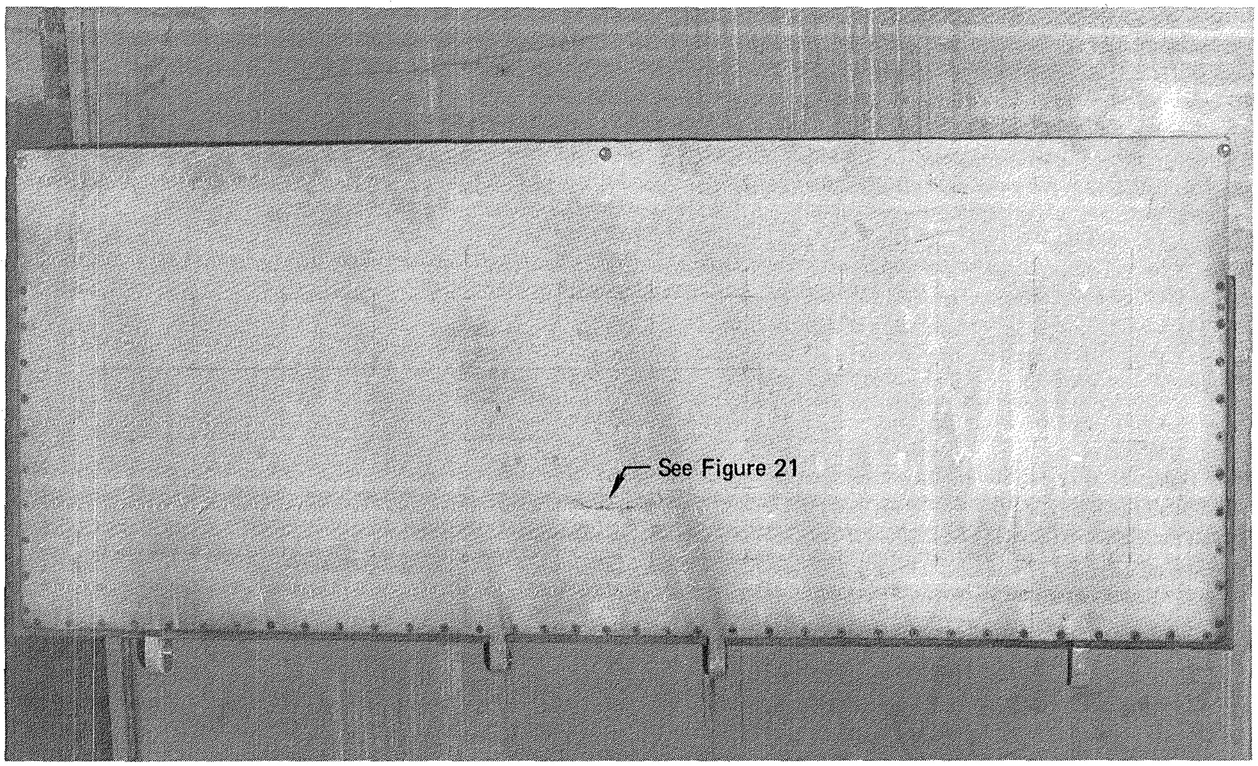

Figure 17. Upper Surface of Spoiler S/N 0059 Following Residual Strength Test

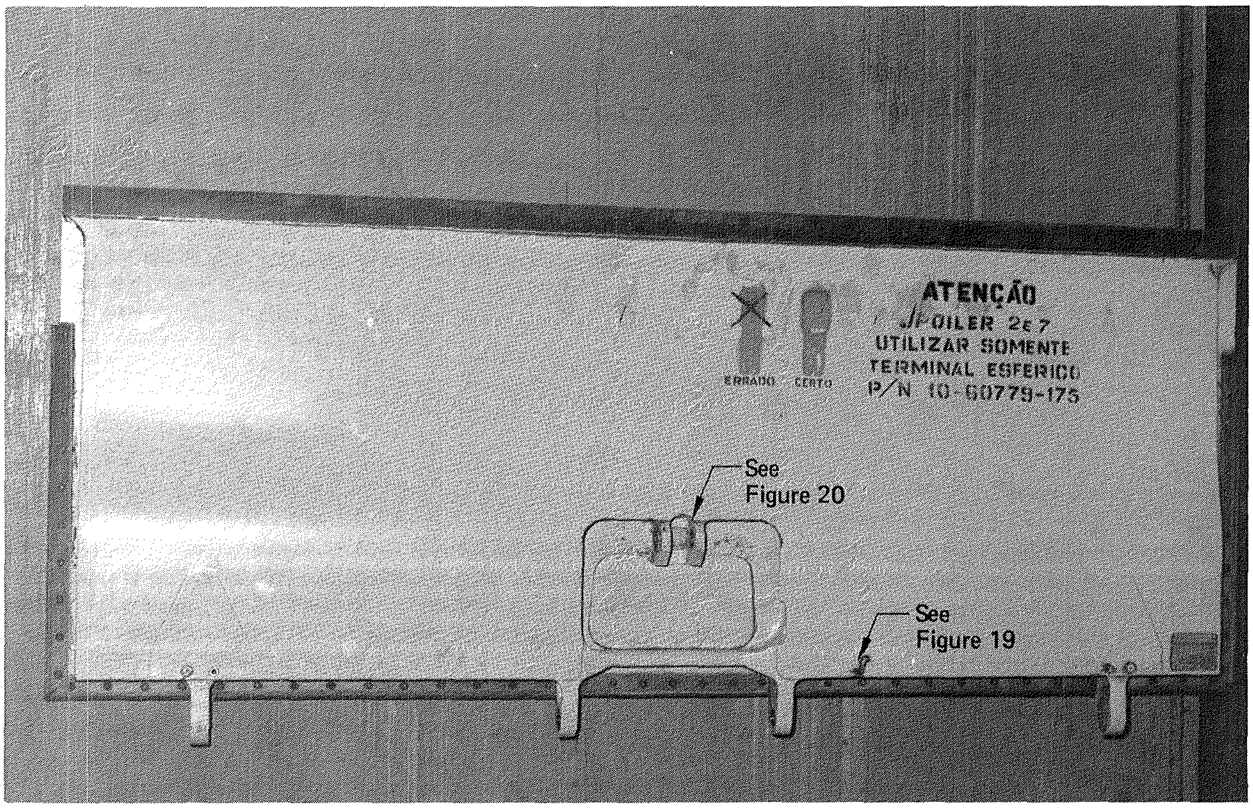

Figure 18. Lower Surface of Spoiler S/N 0059 Following Residual Strength Test

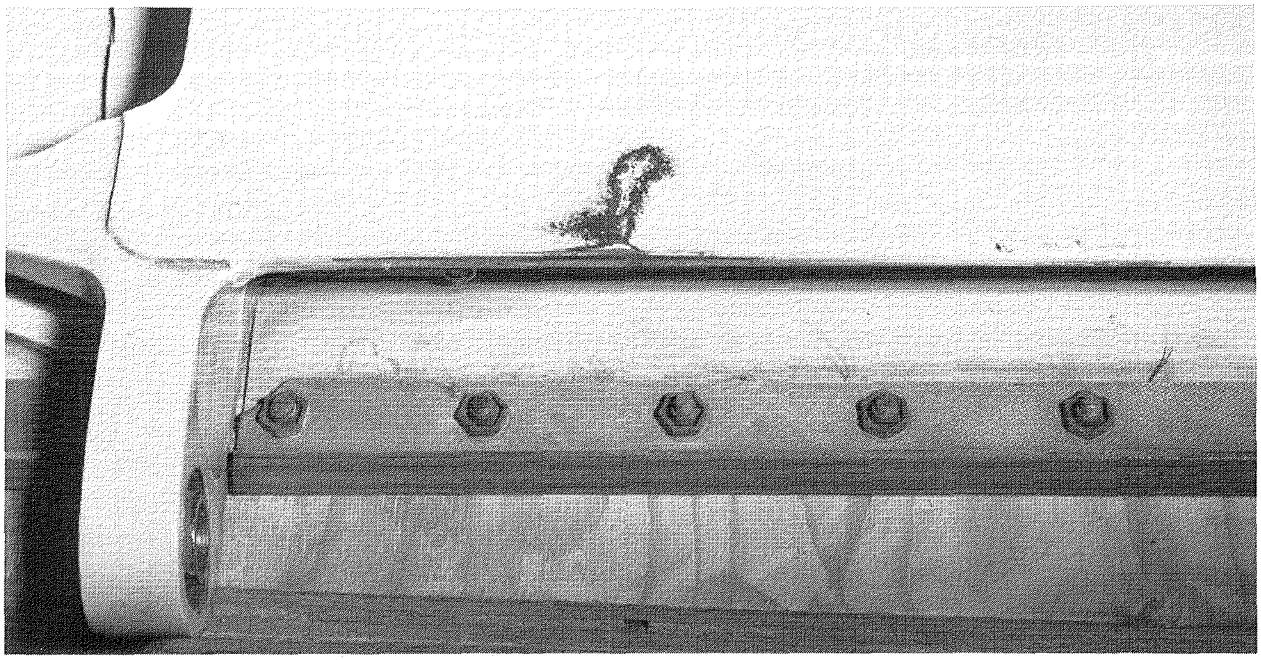

Figure 19. Detail at Exfoliation Corrosion Location of Spoiler S/N 0059 Following Residual Strength Test

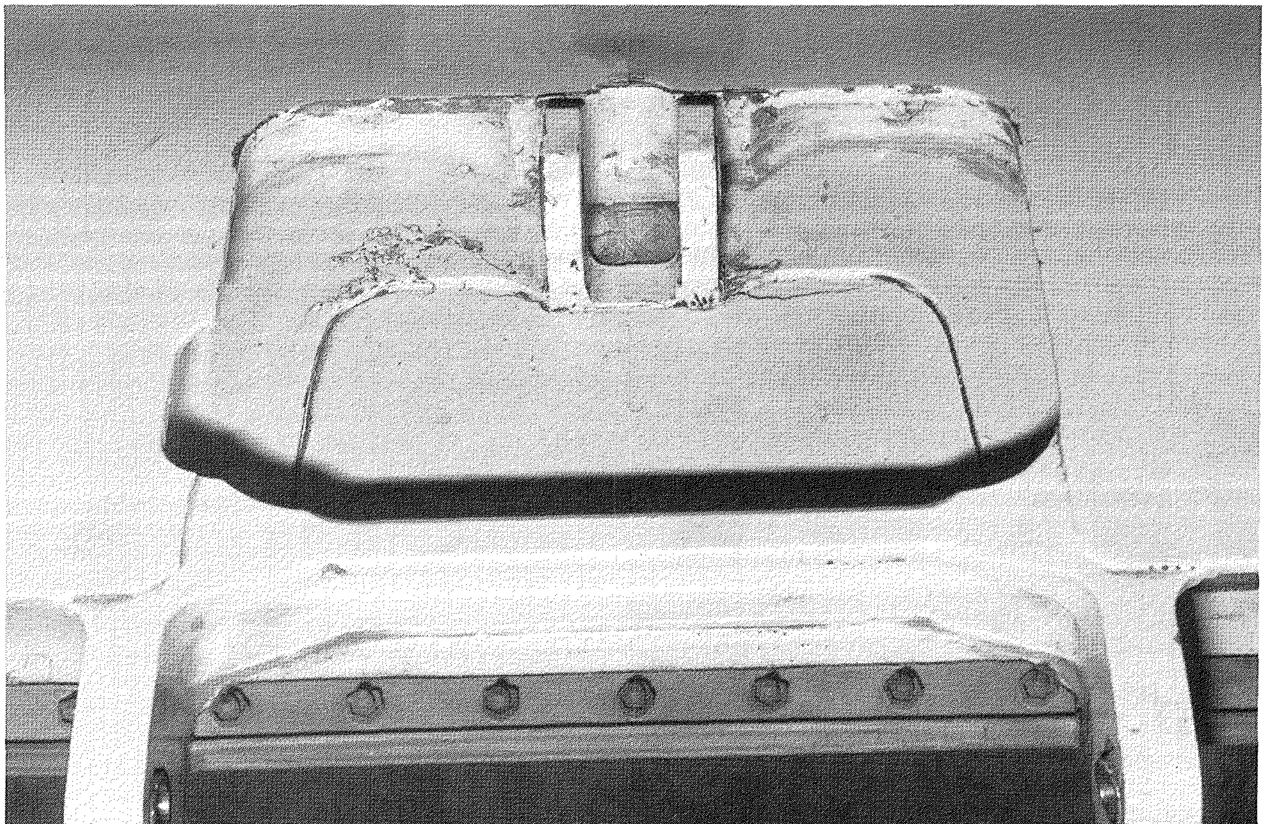

Figure 20. Detail at Actuator Fitting of Spoiler S/N 0059 Following Residual Strength Test

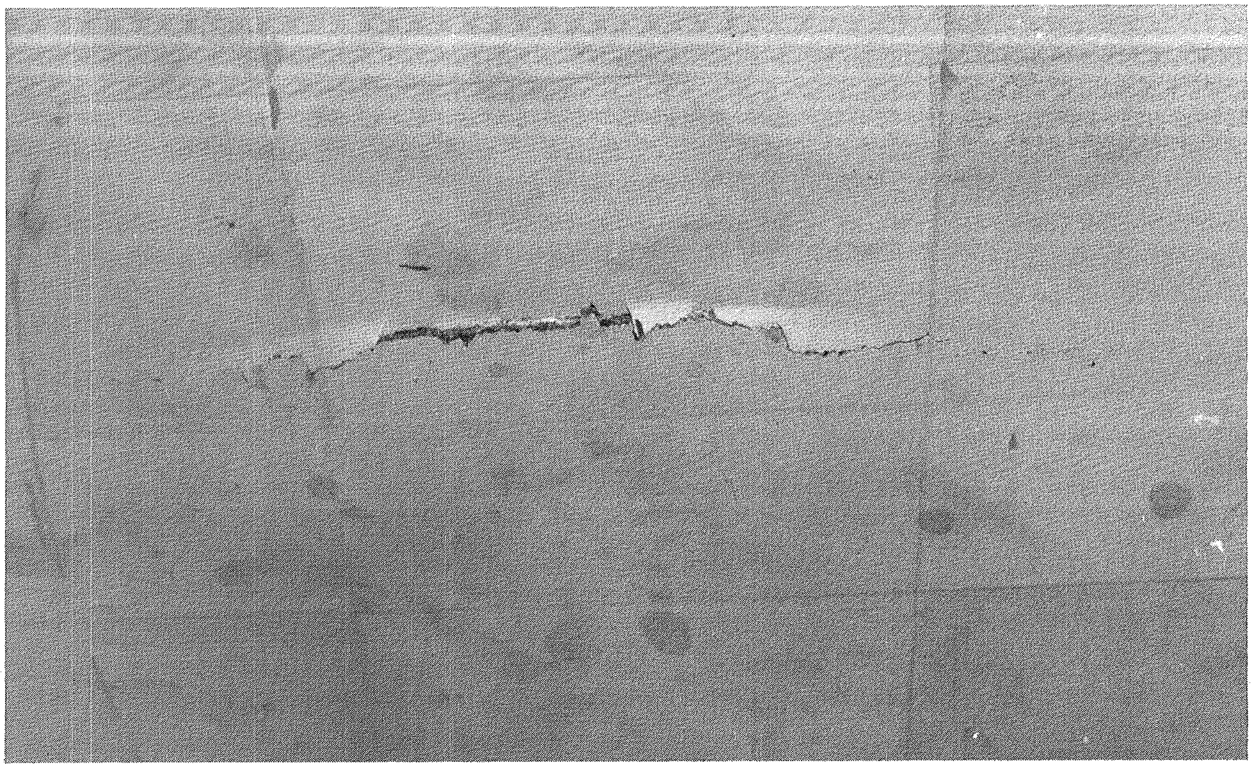

Figure 21. Upper Surface Over Actuator Fitting of Spoiler S/N 0059 Following Residual Strength Test

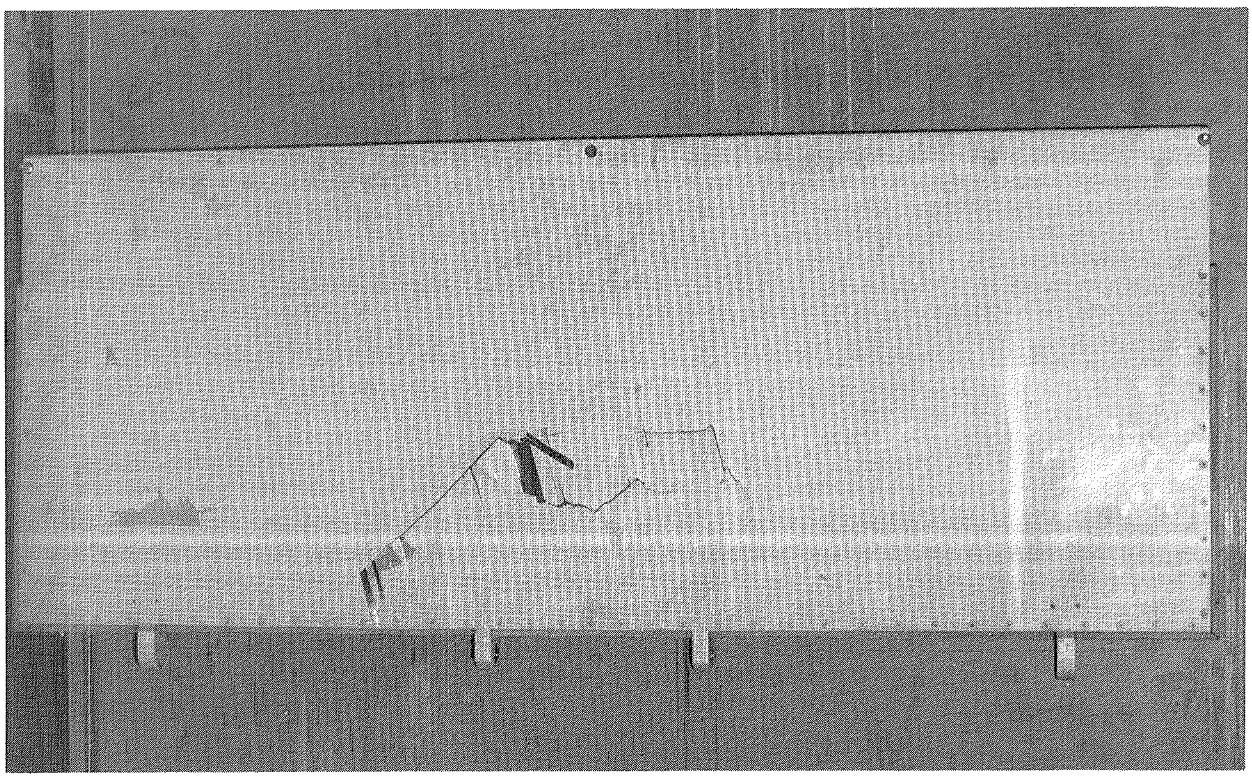

Figure 22. Upper Surface of Spoiler S/N 0049 Following Residual Strength Test

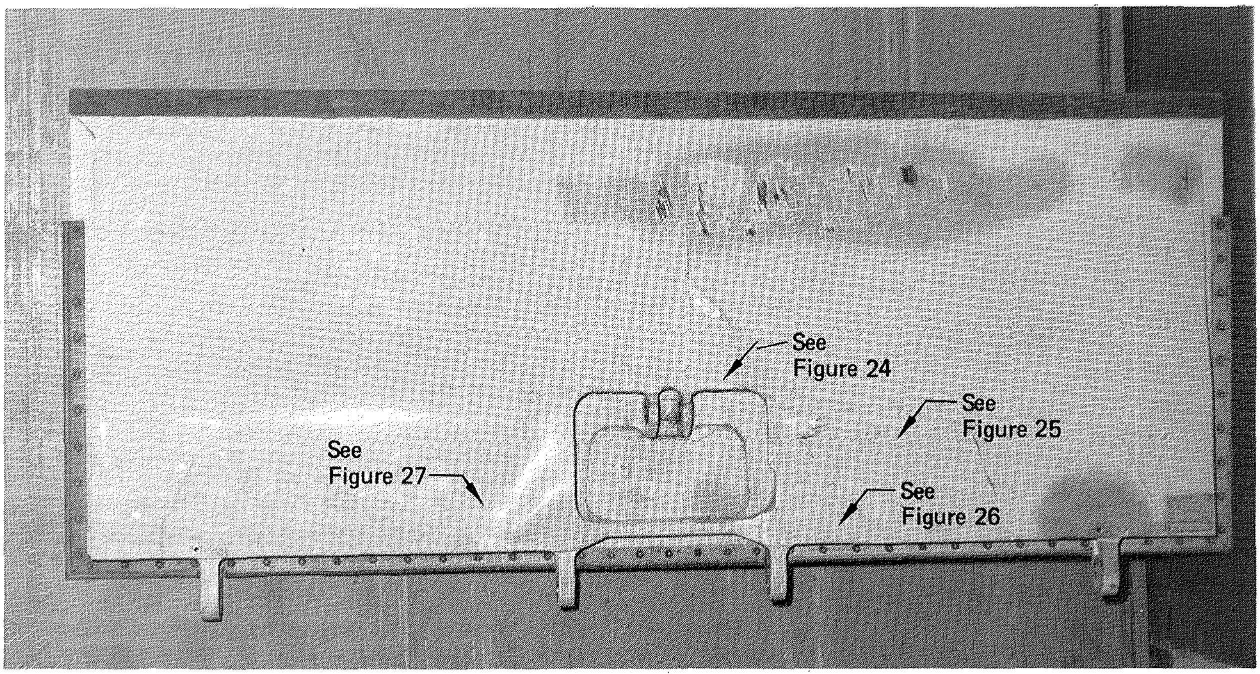

Figure 23. Lower Surface of Spoiler S/N 0049 Following Residual Strength Test

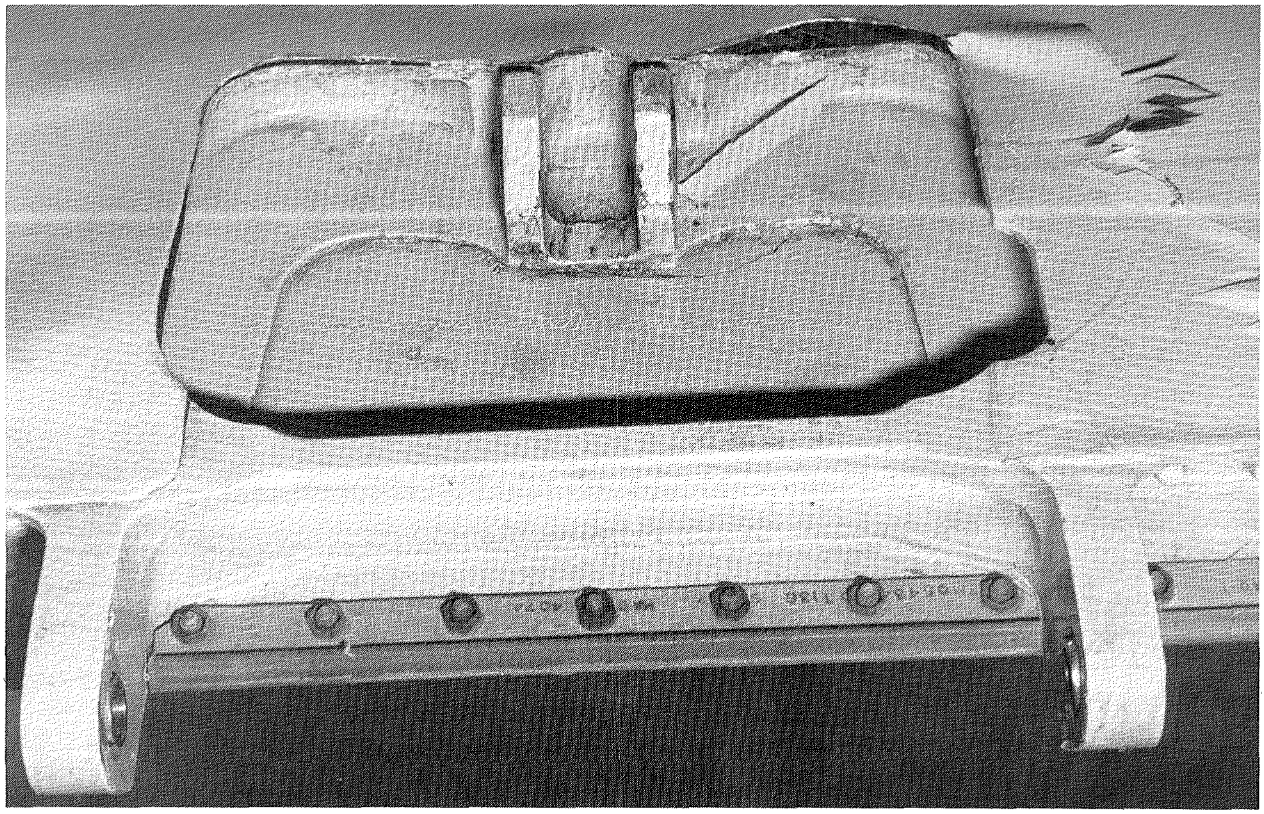

Figure 24. Lower Surface Detail at Actuator Fitting of Spoiler S/N 0049 Following Residual Strength Test

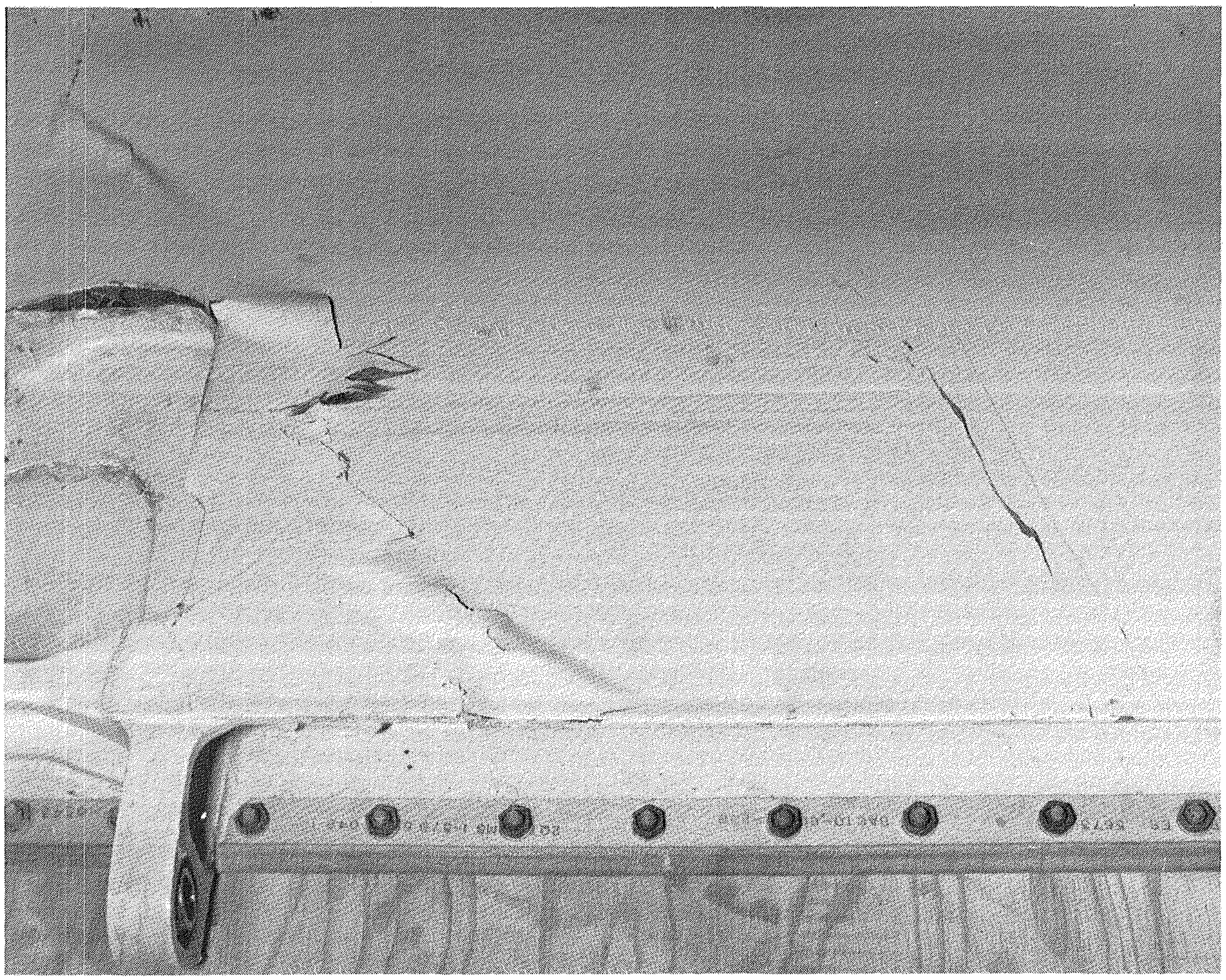

Figure 25. Lower Surface Detail at Exfoliation Corrosion Location of Spoiler S/N 0049 Following Residual Strength Test

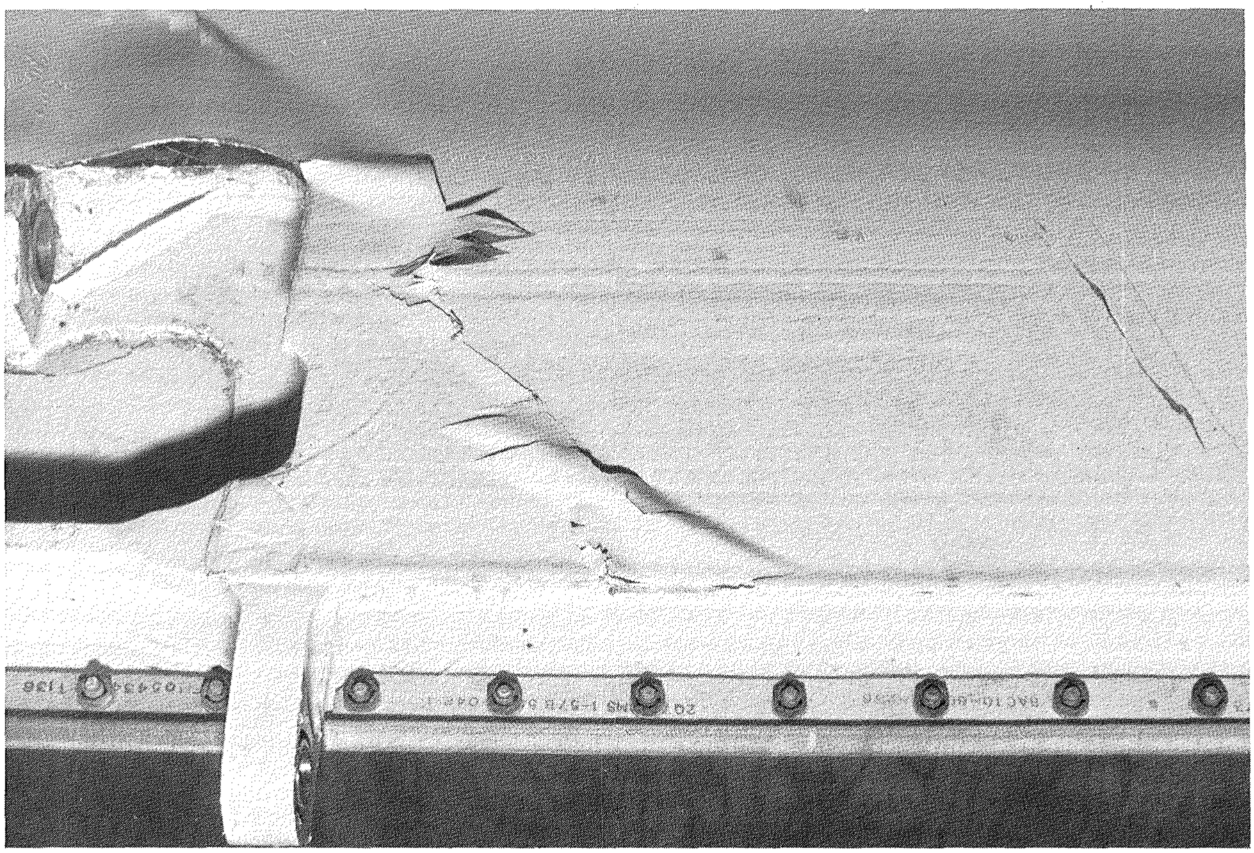

Figure 26. Lower Surface Detail at Exfoliation Corrosion Location of Spoiler S/N 0049 Following Residual Strength Test

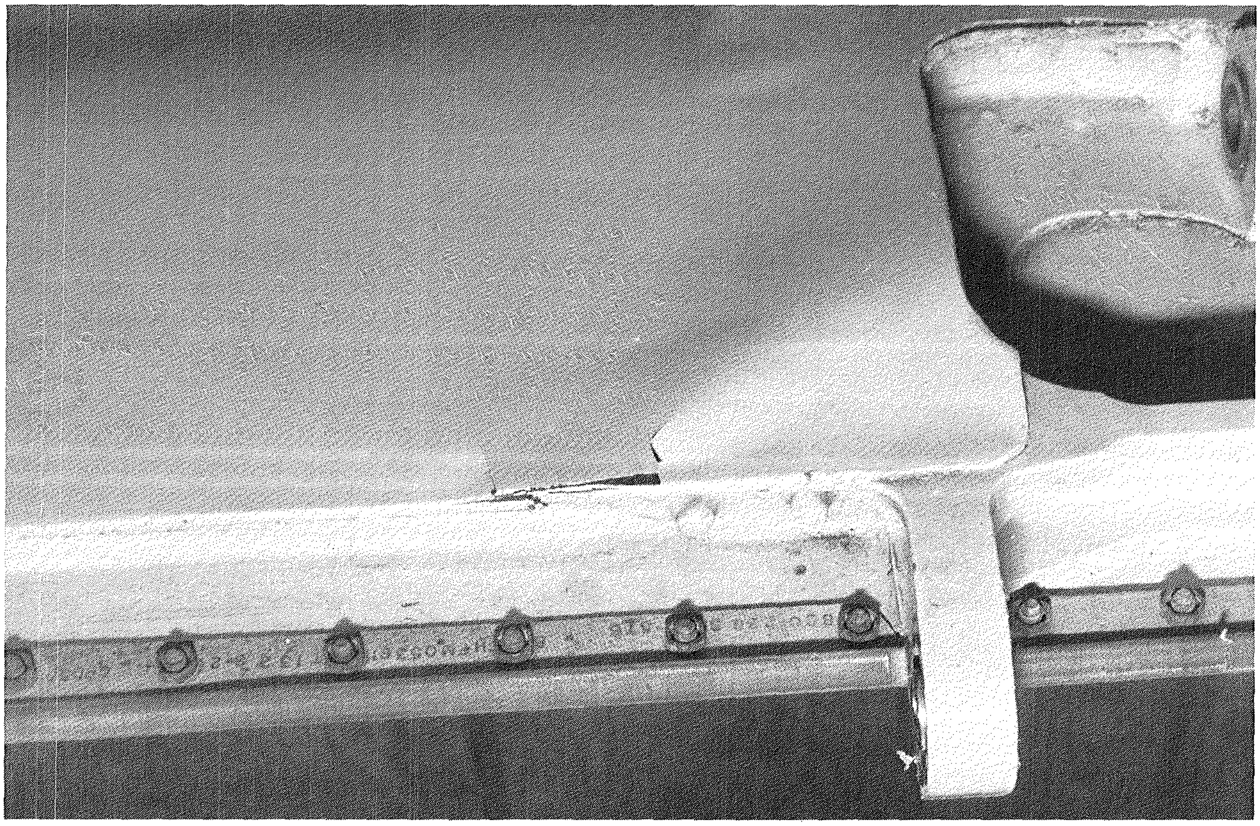

Figure 27. Lower Surface Detail at Exfoliation Corrosion Location of Spoiler S/N 0049 Following Residual Strength Test

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 two spoiler panels that were static tested for residual strength. (See section on Scheduled Spoiler Removals.) Spoilers S/N 0059 (T300/5209 returned from VASP) and S/N 0049 (T300/5209 returned from Aloha) each had three core plug samples removed. Each plug was a 2.25-inch-diameter cylindrical section approximately 0.4 inch deep containing:

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

All six specimens were subjected to a drying environment at 160°F. The samples were weighed at discrete intervals in order to construct weight loss curves similar to those shown in past annual reports. These weighings, however, were not completed in time for inclusion in this report.

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UNSCHEDULED SPOILER REMOVALS

The unscheduled removal of eight spoiler panels occurred during this reporting period. Data for these panels are summarized in table 6. Table 6 includes data for panel S/N 0103, which was removed during the sixth-year report period; however, the removal data and disposition were not received in time for inclusion in the sixth-year report.

Tables 7 and 8 are summaries of flight-service anomalies observed during annual inspections and show the distribution and frequency of these anomalies. Table 7 includes observations (including composite skin repairs) made during the annual inspection in March 1981; table 8 is a summary of 7 years of inspections.

Because the rate of deterioration for several anomalies is slow, one incident (for example, a rod-end blister) may be recorded on more than one annual inspection trip. Tables 7 and 8 include minor anomalies (primarily exfoliation corrosion) that are included to show how subsequent growth, or lack of growth, can be monitored. Although policies among the airlines differ, generally only a few anomalies would require repair during a scheduled maintenance break. Several anomalies would receive only a seal-and-monitor disposition, and some would never deteriorate enough to need repair.

Without reference to the number of possible problems of a given kind, it might be concluded that these reported anomalies represent a marked deterioration of the panel fleet, but this is not so. On the contrary, executives of several airline maintenance groups said that significantly fewer problems have been experienced with the graphite-epoxy spoiler panels on this program than with production spoiler panels. In fact, maintenance was reduced by one-half to one-third, according to the airlines.

Table 6. Unscheduled Flight Spoiler Removals

Spoiler serial number	Airline	Date removed	Reason for removal	Action taken	Final disposition
0103	Piedmont	4-17-80	Rod-end blister	NDT	Retired
0068	New Zealand	6-16-80	Rod-end blister	NDT and repair	Repair in progress
0043	Frontier	6-26-80	Doubler corrosion	NDT and repair	Repair in progress
0088	New Zealand	9-24-80	Spar exfoliation corrosion	NDT	Retired
0114	Lufthansa	9-30-80	Rod-end blister	NDT and repair	Repair in progress
0011	Lufthansa	2-27-81	Spar exfoliation corrosion	NDT and repair	Repair in progress
0013	Lufthansa	2-27-81	Spar exfoliation corrosion	NDT and repair	Repair in progress
0070	Piedmont	3-16-81	Doubler corrosion	NDT and repair	Repair in progress
0045	New Zealand	3-19-81	Doubler corrosion	NDT	Retired

Table 7. Spoiler Service Inspection Compilation (Seventh-Year Inspection—March 1981)

	Number of panels	Number of noted anomalies: Rod-end blisters	Edge delaminations	Surface delaminations	Surface cracking	Upper-surface mechanical damage	Upper-surface natural and environmental damage	Lower-surface mechanical damage	Lower-surface natural and environmental damage	Aluminum doubler corrosion	Exfoliation corrosion damage
Frontier	3	0	1	0	0	0	0	0	0	1	2
New Zealand	12	1	0	0	0	0	0	0	0	0	3
Lufthansa	18	0	0	0	0	2	0	1	0	3	10
Aloha	10	0	0	1	0	0	0	0	0	1	1
Piedmont	25	1	0	0	0	5	0	0	0	5	11
VASP	12	1	2	4	0	2	0	0	0	0	5
Totals	80	3	3	5	0	9	0	1	0	10	32

Table 8. Spoiler Service Inspection Compilation (Cumulative 7 Years)

	Number of panels	Number of noted anomalies: Rod-end blisters	Edge delaminations	Surface delaminations	Surface cracking	Upper-surface mechanical damage	Upper-surface natural and environmental damage	Lower-surface mechanical damage	Lower-surface natural and environmental damage	Aluminum doubler corrosion	Exfoliation corrosion damage
Frontier	6	3	1	0	0	0	0	0	0	2	2
New Zealand	16	9	0	2	0	1	0	2	0	1	13
Lufthansa	24	8	3	2	0	4	0	3	0	3	13
Aloha	17	8	1	1	0	2	0	0	0	4	9
Piedmont	32	6	3	1	3	9	0	1	0	14	15
VASP	16	7	5	4	0	2	0	2	0	5	12
Totals	111	41	13	10	3	18	0	8	0	29	64

REPAIRS

Spoilers S/N 0011 and S/N 0013 are undergoing repair at Lufthansa. Four spoilers—S/N 0068, S/N 0043, S/N 0114, and S/N 0070—will be the last spoilers repaired and returned to service. A contract modification has suspended all further repair activity by Boeing. All spoilers deemed not flightworthy will be repaired by the airlines or returned to Boeing and retired from service.

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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 worldwide and at NASA-Langley Research Center.

Specimens exposed for 7 years have been removed, weighed, and tested. Specimens were weighed before and after exposure and the average weight change is given in tables 9, 10 and 11. These values may be compared with the weight change values in corresponding tables for 1-, 3-, and 5-year exposures reported in references 3, 5, and 6, respectively. The weight-change values reflect the combined effects of moisture pickup and ultraviolet weight loss. Overall percentages of weight-change values for shear and compression specimens indicate a greater moisture weight gain than an ultraviolet weight loss. However, this trend decreases when compared to values for 1, 3, and 5 years of exposure. Flexure specimens, which have a larger surface area, show a greater weight loss especially in the T300-2544 system where the ultraviolet degradation is more apparent.

Ultraviolet radiation can change the chemical structure of epoxy and, therefore, has a degrading effect on the matrix of fiber-reinforced epoxy laminates. Photographs were made of three specimens representing each of the material systems as shown in figure 28. A comparison of the three indicates that T300-2544 is most susceptible to the degrading effect of ultraviolet exposure. The degradation is, however, superficial and does not appear to affect the strength of the material. To observe this effect more closely, a scanning electron microscope was used to photograph an AS-3501 specimen, shown in figure 29. The photomicrographs compare a specimen with no exposure with a specimen with 5 years of exposure. The individual fibers can be seen in the 5-year specimen after the surface layer of epoxy was leeched away. It should be noted that a coating of polyurethane aircraft paint will protect the material from ultraviolet degradation.

The absorbed moisture content of the flexure specimens is calculated after the specimens are dried and weighed. The 7-year flexure specimens are not yet fully dried and, therefore, information on moisture content is not yet available. The moisture content data for 1-, 3-, and 5-year exposure periods, previously reported in reference 7, are shown in figure 30.

The average residual strength ratios for the shear, flexure, and compression specimens are plotted in figures 31, 32, and 33. 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 $\pm 10\%$ bandwidth, which represents the strength scatter in the baseline specimens, is shown on each graph. The shear strength ratio values remain within the scatterband for all material systems except T300-2544, which continues to be slightly lower than baseline values. Flexure strength values are also within the scatterband except

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

Table 9. 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	g	%
0 (baseline)	LaRC	T300/5209	5	77	11.2	—	—
7	LaRC	T300/5209	3	77	11.1	+0.0028	+0.39
7	Hawaii	T300/5209	3	76	11.0	+0.0025	+0.34
7	New Zealand	T300/5209	3	77	11.1	+0.0036	+0.47
7	Germany	T300/5209	3	79	11.4	+0.0038	+0.50
7	California	T300/5209	3	81	11.8	+0.0029	+0.38
7	LaRC* (painted specimens)	T300/5209	3	83	12.1	+0.0024	+0.29
7	Brazil	T300/5209	3	73	10.6	+0.0061	+0.81
0 (baseline)	LaRC	T300/2544	4	81	11.7	—	—
7	LaRC	T300/2544	3	68	9.9	+0.0012	+0.31
7	Hawaii	T300/2544	3	70	10.2	+0.0022	+0.46
7	New Zealand	T300/2544	3	66	9.5	+0.0049	+0.88
7	Germany	T300/2544	3	65	9.4	+0.0062	+1.09
7	California	T300/2544	3	66	9.6	+0.0026	+0.52
7	LaRC* (painted specimens)	T300/2544	3	72	10.5	+0.0041	+0.66
7	Brazil	T300/2544	3	68	9.8	+0.0129	+2.20
0 (baseline)	LaRC	AS/3501	5	87	12.6	—	—
7	LaRC	AS/3501	3	83	12.0	+0.0022	+0.49
7	Hawaii	AS/3501	3	88	12.7	+0.0015	+0.33
7	New Zealand	AS/3501	3	87	12.6	+0.0080	+1.41
7	Germany	AS/3501	3	85	12.3	+0.0031	+0.60
7	California	AS/3501	3	91	13.2	+0.0028	+0.55
7	LaRC* (painted specimens)	AS/3501	3	90	13.0	+0.0021	+0.42
7	Brazil	AS/3501	3	82	11.9	+0.0048	+0.85

*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—Flexure[a] Tests

Exposure time, yr	Exposure location	Graphite-epoxy material system	Number of specimens	Average failure stress		Average flexure modulus		Average weight change	
				MPa	ksi	GPa	psi (x 10^6)	g	%[b]
0 (baseline)	LaRC	T300/5209	5	1529	221.8	103.8	15.05	—	—
7	LaRC	T300/5209	3	1543	223.8	103.4	14.99	+0.0020	+0.09
7	Hawaii	T300/5209	3	1578	228.9	101.2	14.67	-0.0005	-0.02
7	New Zealand	T300/5209	3	1495	216.8	98.7	14.32	+0.0018	+0.80
7	Germany	T300/5209	3	1642	238.1	108.2	15.69	+0.0059	+0.27
7	California	T300/5209	3	1501	217.7	102.9	14.92	+0.0025	+0.11
7	LaRC[c] (painted specimens)	T300/5209	3	1569	227.6	105.6	15.32	+0.0060	+0.23
7	Brazil	T300/5209	3	1552	225.1	99.2	14.38	+0.0138	+0.62
0 (baseline)	LaRC	T300/2544	5	1600	232.0	106.2	15.41	—	—
7	LaRC	T300/2544	3	1344	194.9	92.8	13.46	-0.0434	-2.11
7	Hawaii	T300/2544	3	1542	223.6	91.5	13.27	-0.0255	-1.00
7	New Zealand	T300/2544	3	1445	209.6	87.4	12.68	-0.0313	-1.34
7	Germany	T300/2544	3	1640	237.9	108.5	15.74	+0.0002	+0.36
7	California	T300/2544	3	1549	224.8	99.4	14.41	-0.0168	-0.53
7	LaRC[c] (painted specimens)	T300/2544	3	1696	246.0	103.4	14.99	-0.0447	-1.84
7	Brazil	T300/2544	3	1476	217.3	97.5	14.14	+0.0048	+0.61
0 (baseline)	LaRC	AS/3501	5	1449	210.1	97.4	13.73	—	—
7	LaRC	AS/3501	3	1787	259.3	100.3	14.55	-0.0032	+0.16
7	Hawaii	AS/3501	3	1910	278.0	92.0	13.34	-0.0072	-0.04
7	New Zealand	AS/3501	3	1663	241.2	87.2	12.65	-0.0081	-0.10
7	Germany	AS/3501	3	1564	227.0	98.8	14.33	+0.0110	+0.87
7	California	AS/3501	3	1655	240.1	94.5	13.71	+0.0000	+0.33
7	LaRC[c] (painted specimens)	AS/3501	3	1926	279.4	92.5	13.42	-0.0017	+0.26
7	Brazil	AS/3501	3	1848	268.1	95.0	13.78	+0.0109	+0.91

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

[b]Corrected to initial fully dry weight.

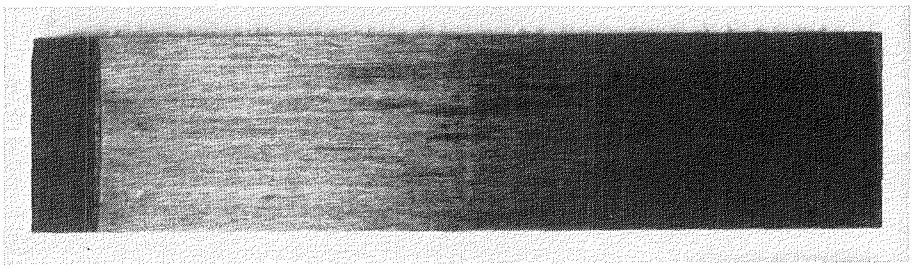
[c]Painted specimens were fully coated with a polyurethane-based enamel over a calcium chromate primer prior to exposure at the Langley site.

Table 11. Results of Ground-Based Environmental Exposure on Graphite-Epoxy Mechanical Property Test Specimens—Compression[a] Tests

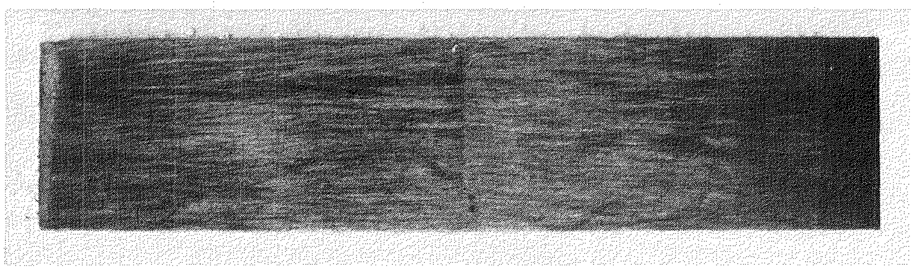
Exposure time, yr	Exposure location	Graphite-epoxy material system	Number of specimens	Average failure stress		Average weight change	
				MPa	ksi	g	%
0 (baseline)	LaRC	T300/5209	3	712	103.2	–	–
7	LaRC	T300/5209	3	721	104.6	+0.0549	+0.68
7	Hawaii	T300/5209	3	780	113.2	+0.0676	+0.85
7	New Zealand	T300/5209	3	625	90.7	+0.0691	+0.84
7	Germany	T300/5209	3	768	111.4	+0.0548	+0.68
7	California	T300/5209	3	746	108.2	+0.0637	+0.79
7	LaRC[b] (painted specimens)	T300/5209	3	743	107.8	+0.0444	+0.55
7	Brazil	T300/5209	2	660	95.8	+0.0726	+0.90
0 (baseline)	LaRC	T300/2544	4	1034	149.9	–	–
7	LaRC	T300/2544	3	958	139.0	+0.0851	+1.21
7	Hawaii	T300/2544	3	1053	152.7	+0.1006	+1.42
7	New Zealand	T300/2544	3	1000	145.0	+0.1196	+1.68
7	Germany	T300/2544	2	1063	154.2	+0.0832	+1.14
7	California	T300/2544	3	1015	147.2	+0.0892	+1.25
7	LaRC[b] (painted specimens)	T300/2544	3	999	144.9	+0.1116	+1.54
7	Brazil	T300/2544	3	962	139.6	+0.1198	+1.67
0 (baseline)	LaRC	AS/3501	5	1107	160.6	–	–
7	LaRC	AS/3501	3	1084	157.2	+0.0473	+0.71
7	Hawaii	AS/3501	3	1122	162.7	+0.0540	+0.82
7	New Zealand	AS/3501	3	1111	161.2	+0.0637	+0.98
7	Germany	AS/3501	3	1132	164.2	+0.0454	+0.55
7	California	AS/3501	3	1068	154.9	+0.0571	+0.86
7	LaRC[b] (painted specimens)	AS/3501	3	1179	171.0	+0.0471	+0.62
7	Brazil	AS/3501	3	1045	151.5	+0.0585	+0.89

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

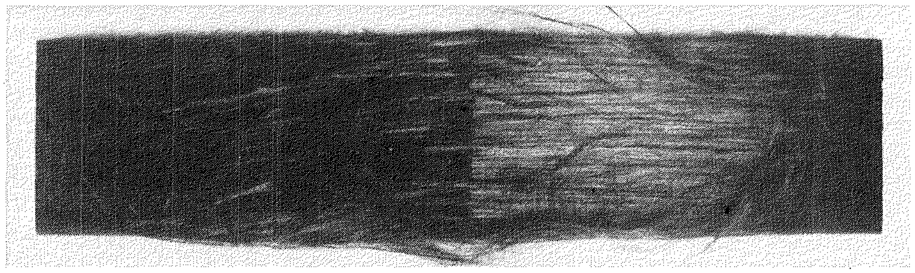
[b]Painted specimens were fully coated with a polyurethane-based enamel over a calcium chromate primer prior to exposure at the Langley site.



T300-5209



AS-3501



T300-2544

Figure 28. Effect of Ultraviolet Radiation on Graphite-Epoxy After 7 Years of Outdoor Exposure

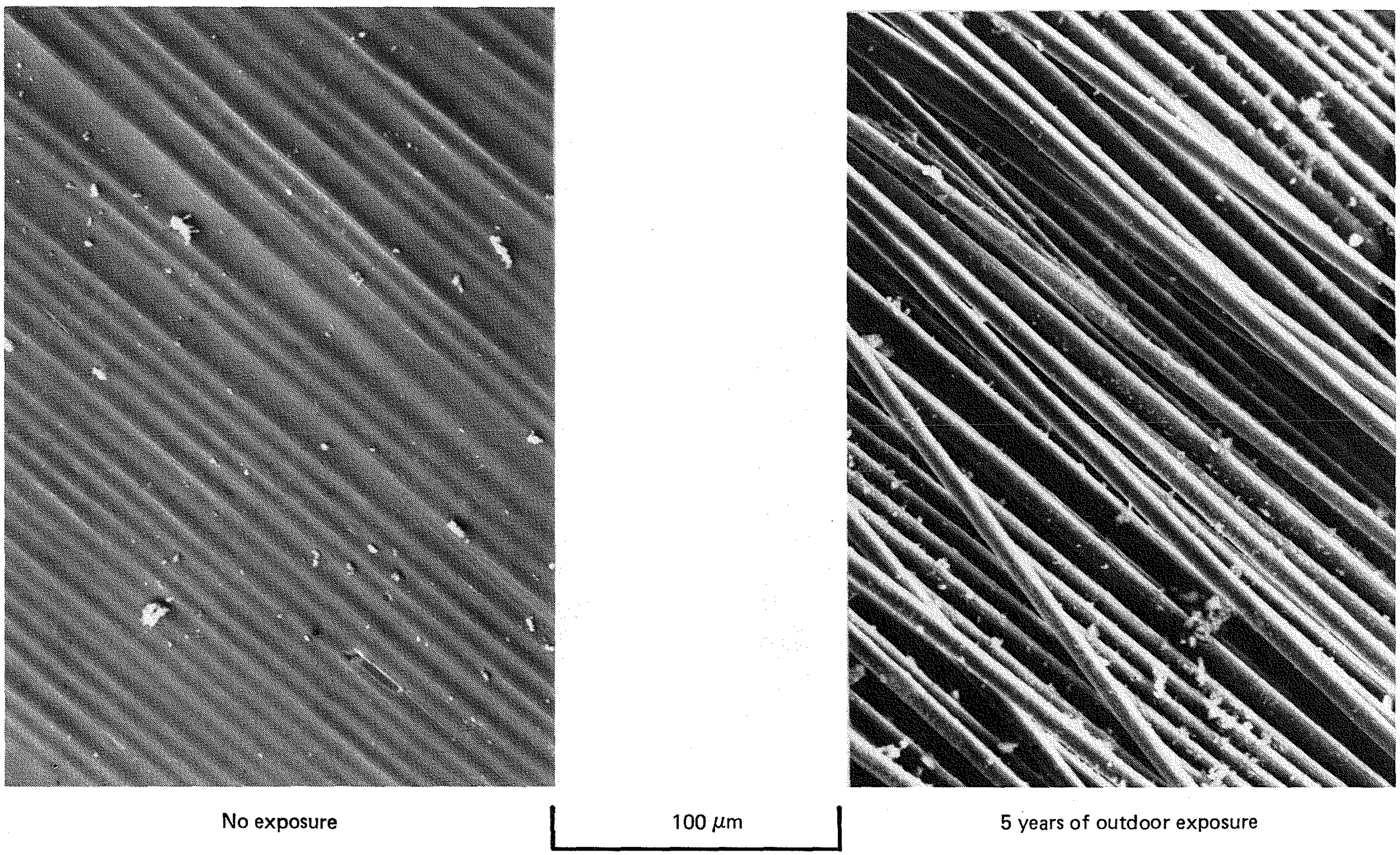


Figure 29. Surface Degradation of AS-3501 Graphite-Epoxy

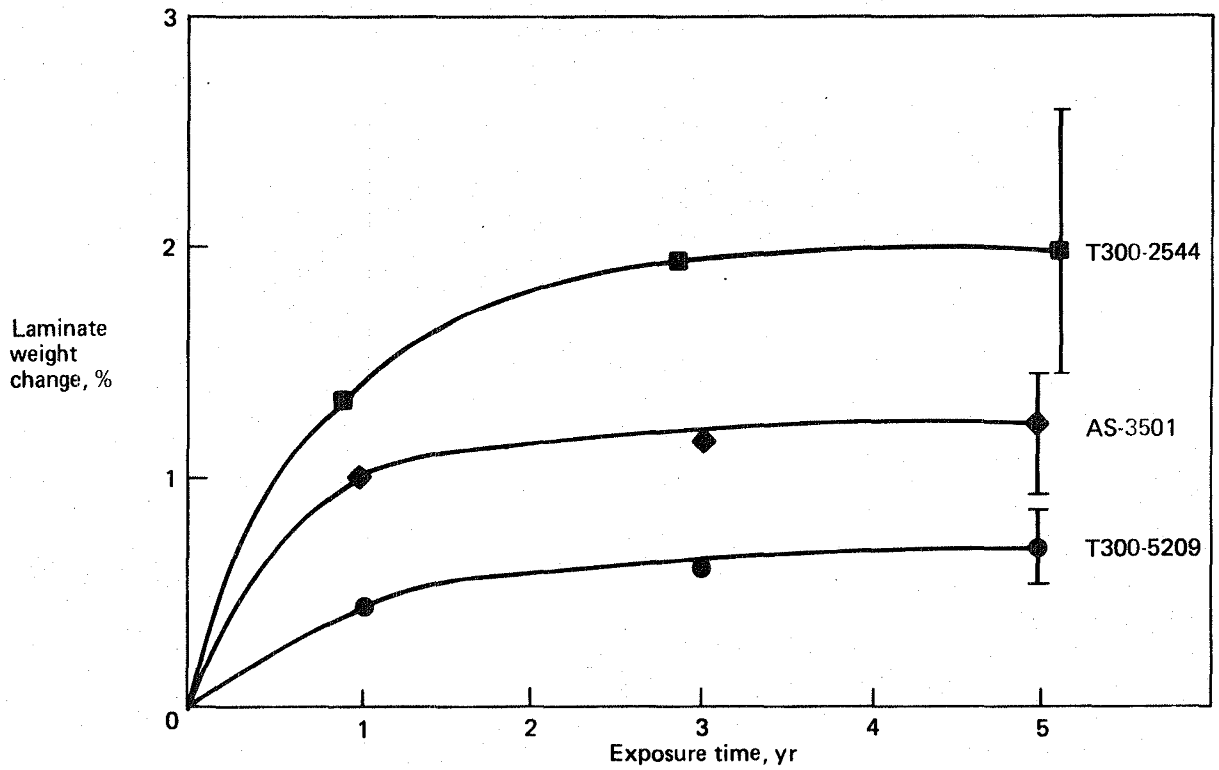


Figure 30. Moisture Pickup After Worldwide Exposures

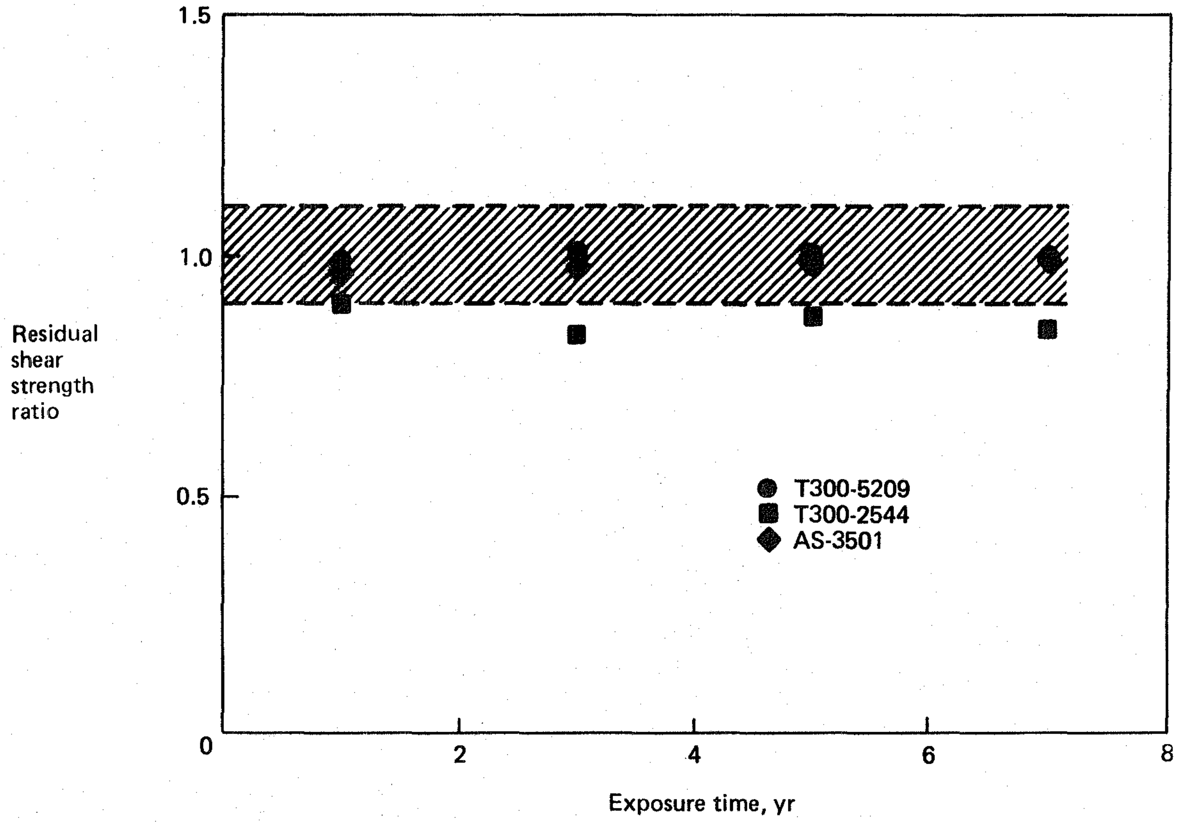


Figure 31. Residual Shear Strength After Worldwide Exposure

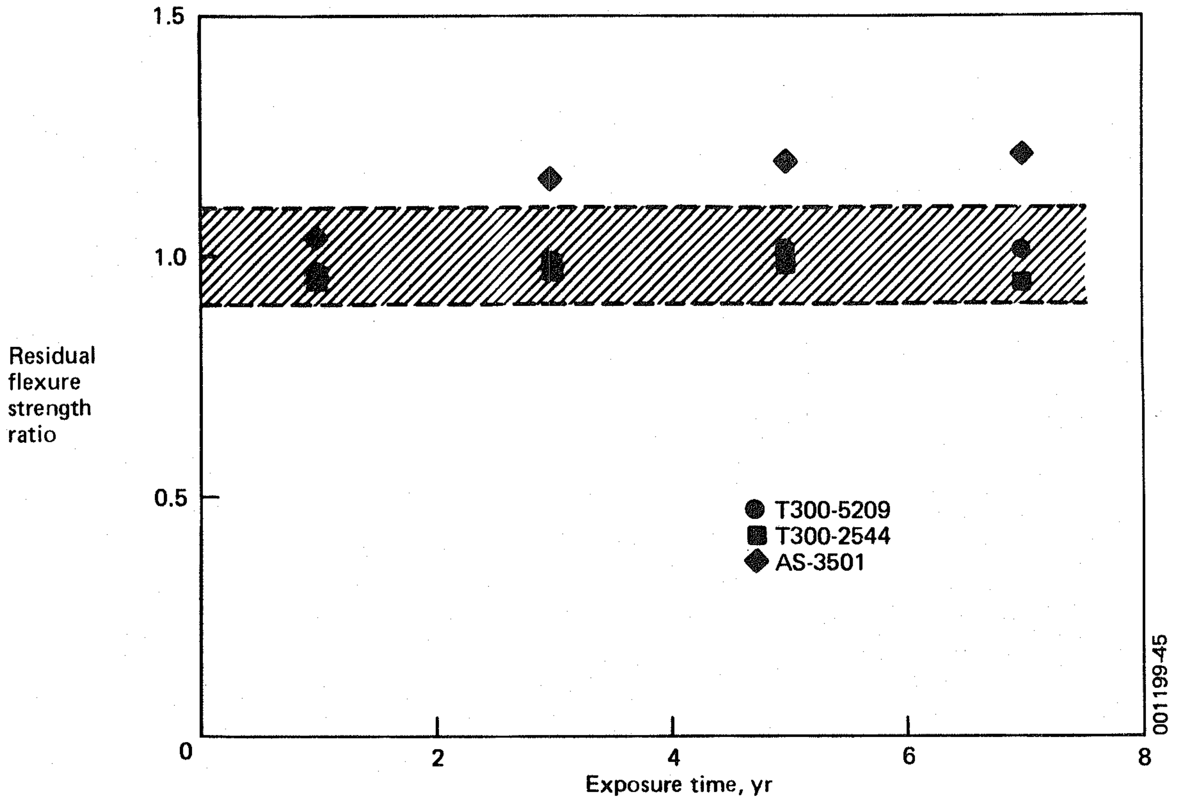


Figure 32. Residual Flexure Strength After Worldwide Exposure

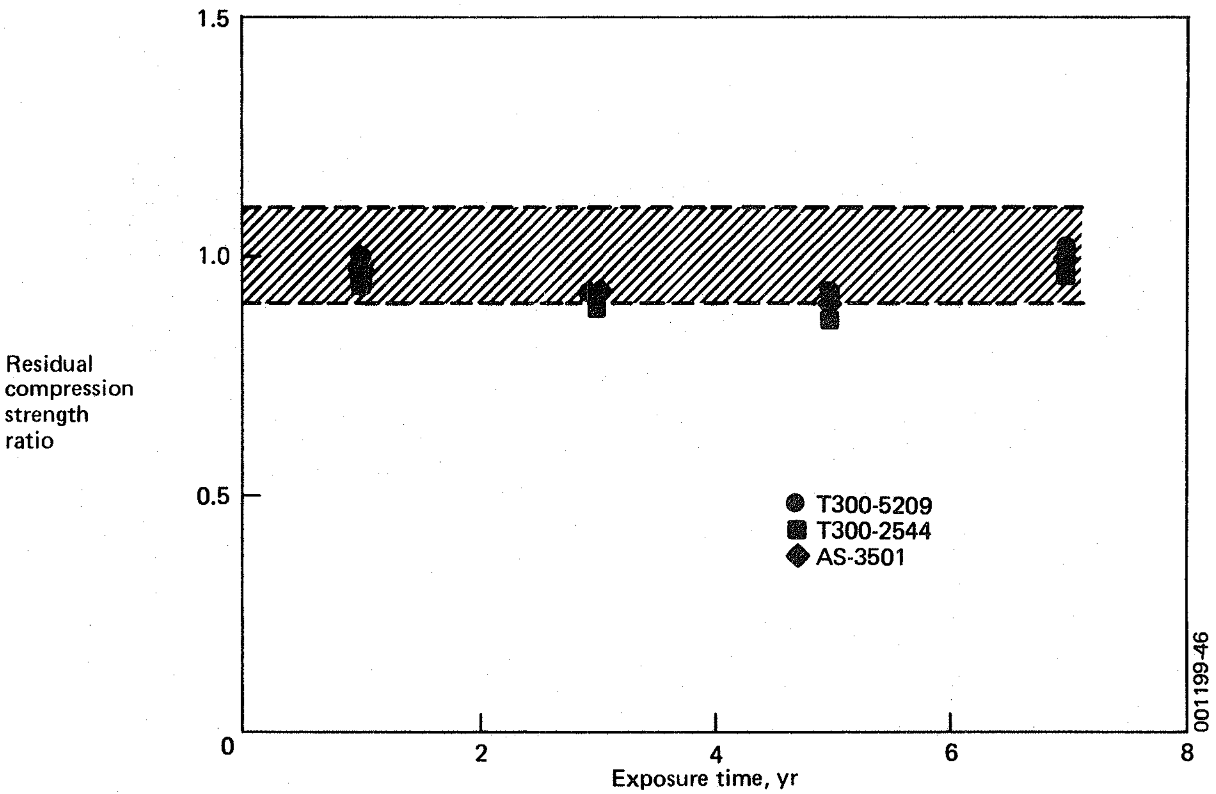


Figure 33. Residual Compression Strength After Worldwide Exposure

for the AS-3501 material system, which has been consistently high (between 5% and 10% above the baseline) over the 3-, 5-, and 7-year exposure periods. The compression strength ratio has increased about 10% with 7 years of exposure for all material systems after a steady decline for the previous 5 years bringing the 7-year values very near the baseline strength values.

Tables 9, 10, and 11 show the average failure stresses of the specimens. The results indicate the strength differences between exposure sites. No significant strength trends were noted for a particular exposure site.

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Langley Technical Representative: H. Benson Dexter

16. Abstract

The seventh 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 environmental exposure of graphite-epoxy material specimens for the period of May 1980 through April 1981. 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 underway. As of April 30, 1981, a total of 1,564,544 spoiler flight-hours and 2,298,352 spoiler landings had been accumulated by this fleet.

Tests of removed spoilers after the seventh year of service continue to indicate modest changes in composite strength properties. Two spoilers were tested, one with 6 and one with 7 years of service, and both had residual strengths that fell within the original static strength scatter band. Both these units had typical service-included discrepancies when tested. Based on visual, ultrasonic, and destructive inspection there continues to be no evidence of moisture migration into the honeycomb core and no core corrosion in the deployed units.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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