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Summary

Uncoated Advanced Flexible Reusable Surface Insulation (AFRSI) blankets were successfully flown on seven consecutive flights of the Space Shuttle Orbiter OV-099 (Challenger). In six of the eight locations monitored (forward windshield, forward canopy, mid-fuselage, upper wing, rudder/speed brake, and vertical tail), the AFRSI blankets performed well during the ascent and reentry exposure to the thermal and aeroacoustic environments. Several of the uncoated AFRSI blankets that sustained minor damage, such as fraying or broken threads, could be repaired by sewing or by patching with a surface coating called C-9. The chief reasons for replacing or completely coating a blanket were fabric embrittlement and fabric abrasion caused by wind erosion. This occurred in the orbiter maneuvering system (OMS) pod sidewall and the forward mid-fuselage locations.

Acronyms

AFSRI	Advanced Flexible Reusable Surface Insulation
CVD	chemical vapor deposition
DFRF	Ames-Dryden Flight Research Facility
FRSI	Felt Reusable Surface Insulation
HMDS	hexamethyldisilane
HRSI	High-Temperature Reusable Surface Insulation
KSC	Kennedy Space Center
LE	leading edge
LH	left-hand
LRSI	Low-Temperature Reusable Surface Insulation
OEX	Orbiter Experiments (Program)
OML	outer mold line
OMS	orbiter maneuvering system
RCC	reinforced carbon/carbon
RH	right-hand
TE	trailing edge
TPS	thermal protection system

Introduction

A quilted, flexible ceramic insulation blanket called Advanced Flexible Reusable Surface Insulation (AFRSI) has replaced about 6,000 white ceramic tiles (LI-900) as the thermal protection system (TPS) in a variety of locations on the Space Shuttle vehicles (fig. 1). The blankets were installed on surface areas where temperatures generally do not exceed 1200° F. The AFRSI has been certified to cover sections of the fuselage, upper wing, cargo bay door, vertical stabilizer, speed brake, elevon cove, and orbiter maneuvering system (OMS) pod. The total acreage installed amounts to over 4,000 ft^2 on each of the four Shuttle vehicles.

AFRSI is constructed from silica batting sandwiched between layers of silica fabric and glass fabric sewn together with Teflon-sized silica thread in a 1-in. stitch pattern (refs. 1-3). The silica fabric surface is the outer mold line (OML) surface and is exposed to the Shuttle aerothermal environment of ascent and reentry. The current version of AFRSI has a silica OML surface coated with a thin ceramic material called C-9 coating, to reduce degradation caused by the aerodynamic forces during flight (ref. 4).

The OML surface of AFRSI was initially intended to be uncoated. In fact, the original AFRSI used in both arcjet and wind tunnel tests was uncoated. The use of AFRSI as a TPS for the Space Shuttle evolved from the ground-based qualification tests to the initial installation of about 30 ft^2 in the elevon cove section of the OV-099 vehicle (Challenger). After several successful flights, a decision was made to expand the use of AFRSI by replacing some of the LI-900 white tiles located on the left OMS pod with uncoated AFRSI. This was done for Flight STS-6 of Challenger. Postflight examination of the AFRSI determined that serious damage had occurred on ten blankets, with major loss of the OML fabric on an additional twenty blankets (ref. 4). The next Challenger flight, STS-7, resulted in fabric and batting damage to the right OMS pod. However, it was determined from postflight inspection and analysis that the OML fabric damage was not caused by the high-energy vortex impingement that apparently caused the severe damage to the AFRSI blankets installed on the left OMS pod for STS-6. The damaged AFRSI blankets on the right OMS pod resulted from a water spray boiler malfunction, which released a large amount of water from a vent situated in the forward crotch region near the vertical tail. This caused ice and water to hit the AFRSI during reentry. This was verified from in-orbit photos showing ice formation in the damaged area. Because temperatures did not exceed 1200° F for these two flights, it was postulated that aerodynamic, rather than thermodynamic, effects caused the damage to the AFRSI on the left OMS pod during STS-6. Future flights were scheduled to reach higher temperatures, which could accelerate damage when combined with the aerodynamic forces.

As a consequence of the damage to the AFRSI blankets located on both OMS pods of Challenger, all AFRSI blankets were coated with the C-9 coating. The C-9 coating was tested, qualified, and successfully flown on four Challenger missions. During this time over 4,000 ft^2 of AFRSI were installed on another Shuttle orbiter, Discovery, replacing about 6,000 of the LI-900 white tiles. The C-9 coating was used on the AFRSI blankets on Discovery as well as on Challenger.

A proposal was made, however, to keep some Challenger blankets uncoated in order to evaluate the performance of AFRSI in locations other than the OMS pod, because the OMS pod generated unusually energetic flow conditions dissimilar to most surfaces on a Shuttle vehicle. A decision was made to monitor the performance of uncoated AFRSI at various locations on Challenger, as part of the ongoing Orbiter Experiments (OEX) Program on Challenger. The uncoated blankets were incorporated into the Advanced Ceramic TPS Experiment package of the OEX. For this program, experiments are flown on a Shuttle orbiter to gain aerodynamic, aerothermodynamic, and materials data not possible to obtain from ground-based experiments.

The objective of this paper is to describe the performance of uncoated AFRSI blankets at eight locations on Challenger during seven completed flights. The following were the program's goals:

1. Evaluate long-term durability in both flight and ground environments
2. Determine failure modes as a function of specific environment, related to the AFRSI location on the vehicle
3. Develop repair and replacement criteria
4. Evaluate repair methods and durability

The authors wish to acknowledge the diligent efforts of the personnel of the Space Transportation Systems Division of Rockwell International who obtained the inspection data for the OEX Program under NASA Contract NAS 9-17244.

Experimental Setup

Location of Uncoated AFRSI Blankets on Challenger

For flight testing, eight locations on the Challenger exterior were selected for comparing the performance of uncoated AFRSI with C-9 coated AFRSI. These eight locations are shown in figure 2, a schematic view of the Shuttle. The locations were

1. Forward windshield, right-hand (RH) side
2. Forward canopy, left-hand (LH) side
3. Forward mid-fuselage, LH side
4. Mid-fuselage, LH side
5. Upper wing, LH side
6. OMS pod sidewall, LH pod
7. Vertical tail, LH side
8. Rudder/speed brake, LH side

These locations provided a range of aerodynamic and thermal environments over the vehicle from front to rear. All locations were on the left-hand side of the vehicle except for the windshield location, which was on the right-hand side. The AFRSI blankets were installed in coated/uncoated pairs in six of the eight locations. The forward windshield and the OMS pod sidewall locations each had one uncoated blanket only.

Inspection Criteria for Uncoated AFRSI Blankets

The uncoated AFRSI blankets were fabricated, waterproofed, and mounted according to specified procedures. Before being incorporated into the OEX Program, these uncoated blankets were installed and endured four flights (STS-8, 41B, 41C, and 41G) without OEX performance documentation, because at that time the C-9 coated AFRSI blankets were being certified for flight use. When the uncoated AFRSI blankets became part of the OEX Program, it became necessary to develop an inspection program to monitor their in-flight performance as a TPS.

A specification was established for the preflight and postflight inspection of the uncoated AFRSI blankets on Challenger. The inspection process was to remain in effect for 12 flights and provided the following:

1. Documented preflight and postflight inspections conducted by visually examining each installed blanket for fabric damage, thread damage, blanket distortion, and discoloration, and by manually examining each blanket for feel (stiffening)
2. Preflight and postflight color photographs of the blankets
3. Flight history of the ascent and reentry environments, including such data as heating in the blanket locations, noise levels in the blanket locations, angle of attack, flight anomalies (such as flights through rain or ice), blanket anomalies, and side slip

4. Surface replica maps of each uncoated AFRSI blanket to mark locations of damage or change, and to quantify the type and amount of damage or change

5. A summary report that included the above data along with a short narrative of the flight history

Fabric damage was defined as fraying, cuts, and lost or missing fabric or batting. Thread damage was considered to be any broken thread, loose thread, or missing thread. Blanket distortion was defined as gaps between blankets, puckering, pillowing, or batting movement involving a change of position, thickness, or density. Discoloration was any visual display of staining, marking, or fading. Feel was a subjective determination using touch to classify stiffness or embrittlement. However, embrittlement could be accurately judged only by physically pushing on the blanket fabric surface, so this test was performed only if a blanket was to be replaced.

Thermal Environment

The maximum surface temperatures reached at each of the eight locations is summarized in table 1; ascent and reentry temperatures are listed separately. As expected, the ascent temperatures were much lower, with the lowest temperatures occurring in the canopy, followed by the fuselage locations. All ascent temperatures were below 700° F. All locations experienced higher surface temperatures during reentry because of aerodynamic heating. The maximum reentry temperature measured was slightly above 1200° F, in the upper wing location.

Aeroacoustic Environment

The peak aeroacoustic levels (expressed in decibels) were obtained from the noise profiles recorded in the general locations of the uncoated AFRSI blankets. These are summarized in table 2 for both ascent and reentry. Greater pressures always occurred during the ascent phase of a Shuttle flight, with the canopy location experiencing the highest noise level: 163 dB.

Flight Performance of Uncoated AFRSI

The following discussion summarizes the flight performance of the uncoated AFRSI through seven consecutive flights of the Challenger vehicle. The eighth flight (51C) ended in the tragic destruction of Challenger and crew, terminating this activity. Performance is reported in two related phases. In the first phase, damage inspection results were obtained from the normal postflight TPS assessment conducted at Kennedy Space Center (KSC) after each Shuttle flight; the results from the four Challenger flights before AFRSI testing was incorporated into the OEX Program (Flights STS-8, 41B, 41C, and 41G) were included in this phase and are summarized in table 3. In the second phase, the flight performance of the same blankets was determined by using the more detailed criteria established under OEX guidelines. All inspections were done after the landing at Ames-Dryden Flight Research Facility (DFRF). Tables 4, 5, and 6 summarize the results of the damage inspection for uncoated AFRSI for the three flights conducted under the OEX Program (51B, 51F, and 61A).

"Close up" visual examination of the blanket surfaces during the OEX inspection conducted at DFRF was prevented by post-landing procedures and the preparation of the Shuttle for return to KSC; the inspections were performed at distances ranging from 2 to approximately 30 ft. Binoculars were used where needed. This caused problems with data gathering and interpretation. Specific damage details, such as individual broken threads and minor areas of abraded fabric, might have been overlooked during the DFRF examination because of the restricted access. Sunlight and shadows on the white blanket surface also caused some visual inconveniences. Finally, the effect of the ferry flight to KSC after each landing at DFRF could not be accurately determined because of the problems with the inspection before the ferry flight.

The flight performance of the blankets in the individual locations is discussed below.

Forward Windshield

No data were recorded for STS-8, but postflight visual inspection after the next flight, 41B, showed that the blanket had sustained some minor fraying of the surface fabric along the leading edge (table 3). A similar observation was noted for Flights 41C and 41G, with no further progression of fabric fraying. After 51B, some additional damage in the form of broken threads was noticed and some yellow discoloration was evident, but there was no distortion. After 51F, damage had progressed to a small area of missing fabric at the leading edge plus some torn fabric along the trailing edge. These damaged blanket sections were repaired with C-9 coating before the next flight. This is shown in the preflight photograph in figure 3(a). Flight 61A, the last completed flight in the OEX series, showed the C-9 coating repairs responding well to the thermal and acoustic environment, since no new damage was evident. The photograph in figure 3(b), taken after the landing at DFRF, demonstrates that a blanket can be repaired with C-9 coating. Figure 3(c) is a postflight photograph taken at KSC and shows no further change after the ferry flight to return Challenger to KSC. Note that the square patch in the upper right corner survived this flight, which shows that patch repairs can be made to an individual blanket. Also, no further discoloration or surface distortion occurred.

Forward Canopy

The overall condition of the two blankets located here was excellent after seven flights. No fabric or thread damage was observed. The only changes were a slight pillowing with insulation movement at the trailing edge, seen after Flights 51B and 51F, and some minor discoloration of both blankets from the red silicone adhesive (RTV 560) used to attach the blankets. The photographic record of Flight 61A supports these observations. Figure 4(a) is the preflight and figure 4(b), the postflight photograph taken at DFRF; figure 4(c) is the final postflight photograph taken at KSC after the return ferry flight via the modified Boeing 747 aircraft. This location is exposed to the highest peak acoustic levels, during both ascent and reentry, of any of the eight locations (see table 1).

Forward Mid-Fuselage

Two uncoated blankets were placed in this area. Blanket 391142-015 had one broken stitch after STS-8, and the other blanket, 391142-016, incurred no damage. No data were reported for the next two flights, 41B and 41C, for either blanket. Subsequently, inspection after Flight 41G revealed a gray-brown discoloration over small areas of the blanket surfaces. No distortion was evident. Missing stitches (threads) and fraying of a corner of the leading edge were seen after Flight 51B on Blanket 391142-015; Blanket 391142-016 had evidence of missing stitches on the trailing edge. The edge surface of both blankets still appeared grayish, and there was still no distortion of either blanket surface. Some sewing repairs of Blanket 391142-015 were done at this time.

After the postflight examination for Flight 51F, Blanket 391142-015 was replaced with a new AFRSI blanket, also uncoated. This replacement was necessary for two reasons. First, the removal of a small section of each blanket revealed a deleterious change in the condition of the silicone rubber heat sink underneath. (See the section "Vertical Tail" for more details.) The second reason was fabric embrittlement, which made any repair of the blanket impossible because of the handling required. This was the first time fabric embrittlement was noticed in any of the eight locations since it could only be determined by physically handling the blanket.

Visual inspection of the newly installed Blanket 391142-015 after Flight 61A showed fabric damage in the form of an abraded surface in the center of the blanket, as well as some loose stitches. The adjacent blanket also had an abraded fabric surface and broken threads, indicating that minor wind erosion had occurred. This is shown in the postflight photographs in figure 5(a), taken after the landing at DFRF, and figure 5(b), taken after the ferry flight return to KSC. A preflight photograph, figure 5(c), is provided for comparison. The blankets were left unrepaired to permit continued evaluation.

Mid-Fuselage

Two blankets were evaluated in this location. The inspections for the first four flights (table 3) indicated no progressive damage from wind erosion or physical distortion of either test blanket. Some minor damage in the form of a small OML tear was reported for Blanket 391142-017 after STS-8, but no data were gathered for the next three flights. Usually this means that no new evidence of damage was obvious. For Blanket 391142-018, minor fraying on the forward edge was reported after STS-8, no data were gathered after 41B, the same frayed forward edge was noted after 41C, and some peeling of the blanket on this forward edge was reported after 41G. This peeling was probably caused by a poor adhesive bond between the silicone heat sink and the silicone adhesive.

The blankets showed no new damage after Flight 51B (with which began the more detailed inspection of the test blankets under the OEX Program), although some slight discoloration on the surface was apparent. After Flight 51F (documented in table 5), damage was observed for both blankets; several broken threads were evident along with the discoloration noted from the previous flight, and some minor distortion was noted in the form of a plus or positive step at the corners of both blankets. After Flight 61A (reported in table 6), no further change was observed in blanket damage or appearance.

The photographic evidence supports these observations. Figure 6(a), the preflight photograph, and figure 6(b), the postflight photograph, appear similar, with a few broken threads near the patched section. Furthermore, no observable damage occurred during the return ferry flight to KSC from DFRF (fig. 6(c)). Overall, the blanket performance in the mid-fuselage location can be considered excellent since no progressive damage occurred. The peak acoustic levels (table 2) reached in this location, the lowest for the eight locations studied, combined with the modest surface temperatures shown in table 1, contribute to a benign aerodynamic environment for these uncoated AFRSI blankets.

Upper Wing

The upper wing location had two test blankets. The postflight TPS assessment (summarized in table 3) reported no damage after STS-8 for either Blanket 195056-001 or 195056-002. No data were acquired for the additional three flights that were part of this phase. The Flight 51B postflight inspection revealed only a small frayed area on Blanket 195056-001, but no discoloration or blanket distortion was apparent. No damage or discoloration was observed for the second test blanket, 195056-002, although a positive step on the leading edge was noted. A small C-9 coating repair was needed in the leading edge area. After Flight 51F, no new damage to either blanket was found and there was no change in the positive step distortion of Blanket 195056-002, but a dark gray color was observed on the surface of both blankets.

After Flight 51F, both blankets were replaced with new uncoated AFRSI blankets even though the original blankets were in excellent condition after six flights. This was necessary because the silicone rubber heat sink underneath the blankets reverted to a soft and tacky state. (See the section "Vertical Tail" for more details.)

The postflight inspection of Flight 61A, as expected, revealed no damage, discoloration, or distortion. This is documented by the preflight and postflight photographs of the AFRSI blankets on the upper wing (figs. 7(a) and 7(b), respectively). There was no postlanding photograph taken at DFRF for this location. It should be mentioned that this location had the highest surface temperature (about 1235° F) of any of the eight locations.

OMS Pod Sidewall

Only one blanket was used at this location, and no data were reported for the four flights inspected under the postflight TPS assessment (table 3). However, the OEX postflight inspection for Flight 51B (table 4) revealed that the blanket was C-9 coated and therefore not a valid test blanket. Monitoring of this location was discontinued and no photographs were taken for documentation. The coated blanket may have been installed after the severe damage to the uncoated AFRSI during STS-6, discussed in the Introduction, and the mistake was probably not caught earlier because of the difficulty in close up inspection at DFRF.

Vertical Tail

Two blankets were placed in the vertical tail (stabilizer) area; blanket inspections for the first four flights, reported under the postflight TPS assessment, are summarized in table 3. Blanket 391142-028 showed no damage after these flights, and Blanket 391142-021 showed only minor damage, indicated by minor fraying plus one broken stitch, only after Flight 41B. However, after Flight 51B (table 4), it was obvious that both blankets had suffered abraded surface fabric (OML) damage. The damage was judged identical to that which occurred in ground-based wind tunnel tests during AFRSI development; in these tests, wind erosion was the primary source of damage.

After Flight 51F, it was determined that both test blankets had suffered progressively severe damage (table 5); the OML fabric was heavily frayed and some insulation material was lost. It was concluded that these blankets were degraded beyond repair either by patching or by C-9 coating, so the blankets were replaced. The replacement blankets were left uncoated to allow for continued monitoring under the OEX Program.

After removal of both vertical tail blankets, it was observed that the 0.25-in.-thick silicone rubber (RTV 560) heat sink installed beneath them had reverted to a soft and tacky material. A Shore A hardness of 5 to 10 was measured; a nominal hardness of 50 is typical for silicone rubber in the cured state. The extra thickness of silicone rubber was supposed to function as a fail-safe layer of insulation in the event of a catastrophic failure of the uncoated AFRSI test blankets during launch or reentry. Since all the test blankets in all eight locations had been installed over the heat sink layer, a 3-in.-square core sample was removed from one blanket in each area so the condition of the heat sink material could be determined. All the other heat sink locations were found to be within an acceptable Shore A hardness range except for the heat sinks located under the blankets on the upper left wing and one of the blankets at the forward mid-fuselage. Since that heat sink material had reverted similarly to the heat sinks under the vertical tail, the upper wing blankets were also replaced. After some investigation, the silicone rubber reversion was attributed to the injection of the waterproofing compound hexamethyldisilane (HMDS) during the postflight rewaterproofing process. (The postflight waterproofing history is shown in table 7.) Consequently, starting with Flight 61A, postflight rewaterproofing using HMDS was discontinued for those blankets covering heat sinks.

After Flight 61A, the first flight of the newly installed blankets, no new damage was visible (table 6), although some minor discoloration was present at the leading edge of Blanket 391142-021 and the upper edge of Blanket 391142-028. The blankets were discolored because the silicone adhesive used during the installation process (RTV 560) was exposed to a peak reentry temperature of 888° F. This discoloration is seen in the photographs taken after the landing at DFRF (fig. 8(a)) and the return to KSC (fig. 8(b)), which revealed no damage other than the discoloration described when compared with the preflight photograph (fig. 8(c)).

Rudder/Speed Brake

Initially, two uncoated AFRSI blankets were positioned at this location. After STS-8, no data were reported for either blanket (table 3). After the next flight, 41B, the damage inspection showed a small tear in the OML fabric along with several broken stitches for Blanket 391142-023. The other test blanket, 391142-024, was C-9 coated because of overall damage to the surface in the form of broken threads and frayed fabric, so no further performance data were collected for this blanket. No new damage was noticed for Blanket 391142-023 after Flights 41C and 41G. After Flight 51B, there were no new broken stitches, although some pillowing and insulation (felt) movement at both the leading and trailing edges were observed. No surface discoloration had occurred. Damage inspection after Flight 51F showed no proliferation of broken threads, no discoloration, and no change in the degree of distortion from the previous flight. The Flight 61A inspection revealed a slightly frayed corner at the lower forward edge in addition to the original thread breakage. Some black coloring of the sewing threads was noticed. No further change in original distortion was apparent. The overall condition of the remaining uncoated AFRSI blanket was excellent. Again, a preflight photograph was taken prior to Flight 61A (fig. 9(a)), and postflight photographs were taken at DFRF and KSC (figs. 9(b) and 9(c), respectively).

Concluding Remarks

The uncoated AFRSI blankets functioned well in six of the eight locations selected for evaluation. The replacement and repair requirements for each location are summarized in table 8. At only two locations, the vertical tail and the forward mid-fuselage, did the blankets suffer enough damage to require replacement. Both vertical tail blankets had severely abraded fabric plus missing threads and insulation, probably because of wind erosion; comparable damage occurred in ground-based wind tunnel simulations conducted during AFRSI development. One forward mid-fuselage blanket, although showing no damage when it was visually inspected, was found to have embrittled fabric when it was removed because of the degraded condition of the underlying silicone heat sink.

Two locations, the OMS pod sidewall and the rudder/speed brake had one blanket each fully coated with the C-9 coating because of programmatic decisions.

In summary, the following statements can be made:

1. Uncoated AFRSI blankets can survive at locations on the vehicle that experience a range of thermal and acoustic exposures during ascent and reentry.

2. Two types of major failure requiring blanket replacement occurred: abraded fabric surface caused by wind erosion, and fabric embrittlement.

3. Uncoated AFRSI blankets can be repaired by sewing and by the selective application of C-9 coating.

References

1. Sawko, P. M.: Effect of processing treatments on strength of silica thread for quilted insulation on Space Shuttle. SAMPE Quarterly, vol. 16, no. 4, July 1985, pp. 17-21.

2. Goldstein, H.; Leiser, D.; Sawko, P. M.; Larson, H. K.; Estrella, C.; Smith, M.; and Pitoniak, F.: Insulation blankets for high-temperature use. NASA Tech Brief 11453, Ames Research Center, vol. 9, no. 4, Winter 1985.

3. Trujillo, B. M.; Meyer, R. M., Jr.; and Sawko, P. M.: In-flight load testing of advanced Shuttle thermal protection systems. AIAA Paper 83-2704, Nov. 1984.

4. Mui, D.; and Clancey, H. M.: Development of a protective ceramic coating for Shuttle orbiter Advanced Flexible Reusable Surface Insulation (AFRSI). Ceramic Eng. and Sci. Proc., vol. 6, no. 7-8, July-Aug. 1985, pp. 793-805.

Table 1. STS-51B Uncoated AFRSI thermal environment

Blanket location	Maximum surface temperature, °F	
	Ascent	Reentry
Forward windshield, RH	576	605
Forward canopy, LH	316	399
Forward mid-fuselage, LH	347	742
Mid-fuselage, LH	347	675
Upper wing, LH	574	1234
OMS pod sidewall, LH	681	709
Vertical tail, LH	487	888
Rudder/speed brake, LH	478	759

Table 2. STS-51B Peak ascent/reentry acoustic environment

Blanket location	Peak acoustic level, dB	
	Ascent	Reentry
Forward windshield, RH	153	146
Forward canopy, LH	163	156
Forward mid-fuselage, LH	156	146
Mid-fuselage, LH	150	142
Upper wing, LH	150	145
OMS pod sidewall, LH	156	152
Vertical tail, LH	155	145
Rudder/speed brake, LH	158	146

Table 3. Postflight TPS damage inspection summary for uncoated AFRSI, four Challenger flights

Blanket location/No.	Flight			
	STS-8	41B	41C	41G
Forward windshield, RH				
#391142-012	No data	Frayed LE[a]	Frayed LE, 0.5 in.	No new damage
Forward canopy, LH				
#391142-013	No damage	No data	No data	Excellent condition
#391142-014	No damage	No data	No data	Excellent condition
Forward mid-fuselage, LH				
#391142-015	One broken stitch	No data	No data	Gray-brown discoloration
#391142-016	No damage	No data	No data	Gray-brown discoloration
Mid-fuselage, LH				
#391142-017	OML tear, 1 in.	No data	No data	No data
#391142-018	Frayed forward edge	No data	Frayed forward edge	Peeled from structure on forward edge
Upper wing, LH				
#195056-001	No damage	No data	No data	No data
#195056-002	No damage	No data	No data	No data
OMS pod sidewall, LH				
#391142-019	No data	No data	No data	No data
Vertical tail, LH				
#391142-021	No data	Minor fraying, one broken stitch	No data	No new damage
#391142-028	No data	No damage	No data	No damage
Rudder/speed brake, LH				
#391142-023	No data	0.5-in. tear on OML; several broken stitches	No new damage	No new damage
#391142-024	No data	Broken threads, fraying; blanket C-9 coated	No data	No data

[a]LE = leading edge

Table 4. OEX damage inspection summary for uncoated AFRSI Challenger Flight 51B

Blanket location/No.	Damage	Discoloration	Distortion
Forward windshield, RH			
#391142-012	Frayed LE,[a] 1.0 in.; broken stitches	Yellow	None
Forward canopy, LH			
#391142-013	None	Pink RTV 560 color on LE	Pillowing, felt movement at TE
#391142-014	None	Slight tan on LE side	None
Forward mid-fuselage, LH			
#391142-015	Missing stitches, frayed corner of LE	Gray, LE corner	None
#391142-016	Missing stitches at TE[b]	Gray, LH side	None
Mid-fuselage, LH			
#391142-017	None	Slight tan	None
#391142-018	None	Slight tan	None
Upper wing, LH			
#195056-001	Small frayed area	None	None
#195056-002	None	None	Plus step on LE
OMS pod sidewall, LH			
#391142-019	Blanket was C-9 coated	None	None
Vertical tail, LH			
#391142-021	Abraded OML fabric 0.5- to 1.0-in. diam., noted after ferry flight	None	None
#391142-028	Same as #391142-021	None	None
Rudder/speed brake, LH			
#391142-023	Broken stitches	None	Pillowing, felt movement at LE and TE

[a]LE = leading edge
[b]TE = trailing edge

Table 5. OEX damage inspection summary for uncoated AFRSI, Challenger Flight 51F

Blanket location/No.	Damage	Discoloration	Distortion
Forward windshield, RH			
#391142-012	Torn fabric at TE,[a] missing fabric at LE[b]	None	None
Forward canopy, LH			
#391142-013	None	None	Pillowing at TE
#391142-014	None	Slight RTV 560 color	Pillowing at TE
Forward mid-fuselage, LH			
#391142-015	Broken threads at TE	Light gray at lower forward corner	None
#391142-016	Broken threads at TE	Light gray at upper forward edge	None
Mid-fuselage, LH			
#391142-017	Several broken threads	Tan at upper-LE lower corner, tan at TE	Plus step aft corners
#391142-018	Several broken threads	Tan at LE lower corner and aft upper corner	Plus step forward corner and aft lower corner
Upper wing, LH			
#195056-001	None	Dark gray over large area	None
#195056-002	None	Dark gray over large area	None
Vertical tail, LH			
#391142-021	Severe fabric damage, batting missing, blanket replaced	Longitudinal stitching dark; dark stain	None
#391142-028	Severe fabric damage, batting missing, blanket replaced	Tan in center	None
Rudder/speed brake, LH			
#391142-023	None	None	None

[a]TE = leading edge
[b]LE = trailing edge

Table 6. OEX damage inspection summary for uncoated AFRSI, Challenger Flight 61A

Blanket location/No.	Damage	Discoloration	Distortion
Forward windshield, RH			
#391142-012	No new damage	None	Pillowing at TE[b]
Forward canopy, LH			
#391142-013	None	None	None
#391142-014	None	None	None
Forward mid-fuselage, LH			
#391142-015	Abraded fabric in center; loose stitches	Fabric surface powdery	None
#391142-016	Abraded fabric, broken stitches at LE;[a] broken threads at upper LE	Fabric surface powdery at broken threads	None
Mid-fuselage, LH			
#391142-017	None	None	None
#391142-018	None	None	None
Upper wing, LH			
#195056-001	None	None	None
#195056-002	None	None	None
Vertical tail, LH			
#391142-021	None	Tan at LE	None
#391142-028	None	Tan at upper edge	None
Rudder/speed brake, LH			
#391142-023	Frayed corner at lower forward edge	Black threads	None

[a]LE = leading edge
[b]TE = trailing edge

Table 7. Postflight waterproofing history

Flight	Waterproofing method/material
STS-8	Factory waterproofed using CVD[a] process, methyltrimethoxysilane
41B	Injection 2cc hexamethyldisilane
41C	Injection 2cc hexamethyldisilane
41G	Injection 2cc hexamethyldisilane
51B	Injection 1cc hexamethyldisilane
51F	Injection 1cc hexamethyldisilane
61A	OEX uncoated AFRSI exempt from postflight rewaterproofing for future flights

[a]Chemical vapor deposition

Table 8. Postflight replacement and repair of uncoated AFRSI blanket

Blanket location/No.	Flight						
	STS-8	41B	41C	41G	51B	51F	61A
Forward windshield, RH							
#391142-012	No	No	No	No	No	C-9 repairs	No
Forward canopy, LH							
#391142-013	No	No	No	No	No	No	No
#391142-014	No	No	No	No	No	No	No
Forward mid-fuselage, LH							
#391142-015	No	No	No	No	Sewing repair	Replaced	No
#391142-016	No	No	No	No	No	No	No
Mid-fuselage, LH							
#391142-017	No	No	No	No	No	No	No
#391142-018	No	No	No	No	No	No	No
Upper wing, LH							
#195056-001	No	No	No	No	No	Replaced	No
#195056-002	No	No	No	No	C-9 repairs	Replaced	No
OMS pod sidewall, LH							
#391142-019	No	No	No	No	C-9 coating	No	No
Vertical tail, LH							
#391142-021	No	No	No	No	No	Replaced	No
#391142-028	No	No	No	No	No	Replaced	No
Rudder/speed brake, LH							
#391142-023	No	No	No	No	No	No	No
#391142-024	No	C-9 coating	No	No	No	No	No

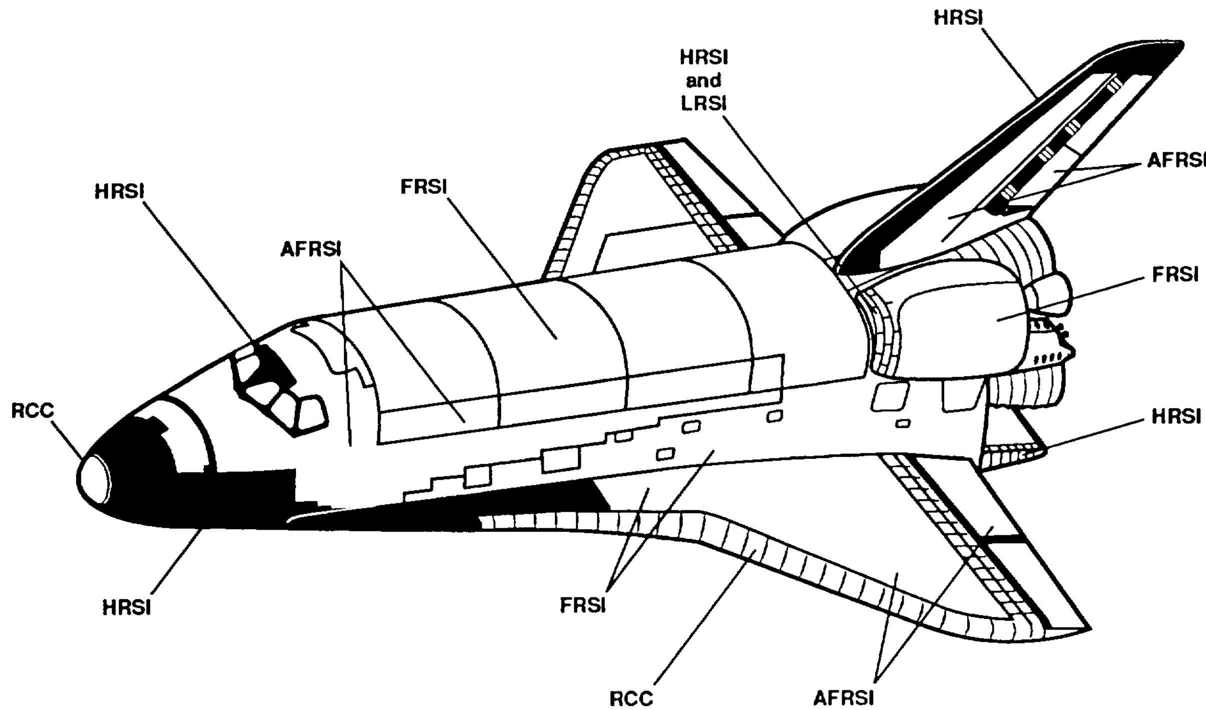


Figure 1. Shuttle orbiter TPS locations.

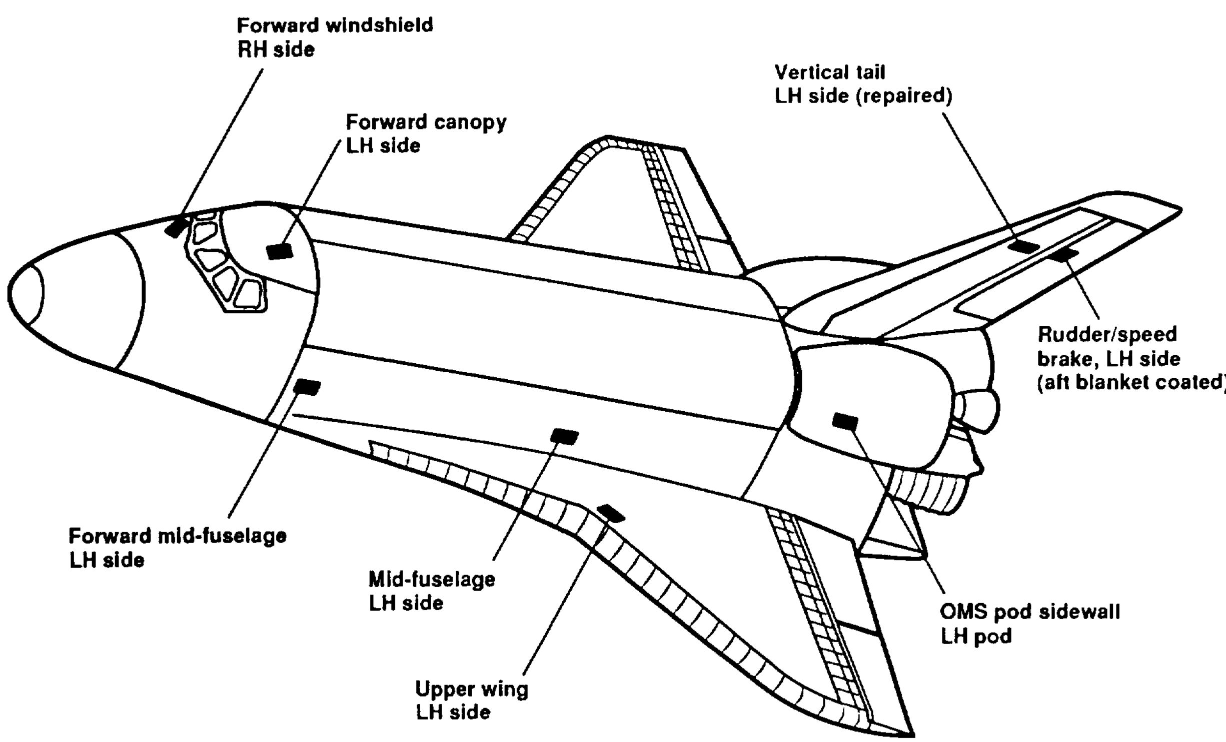
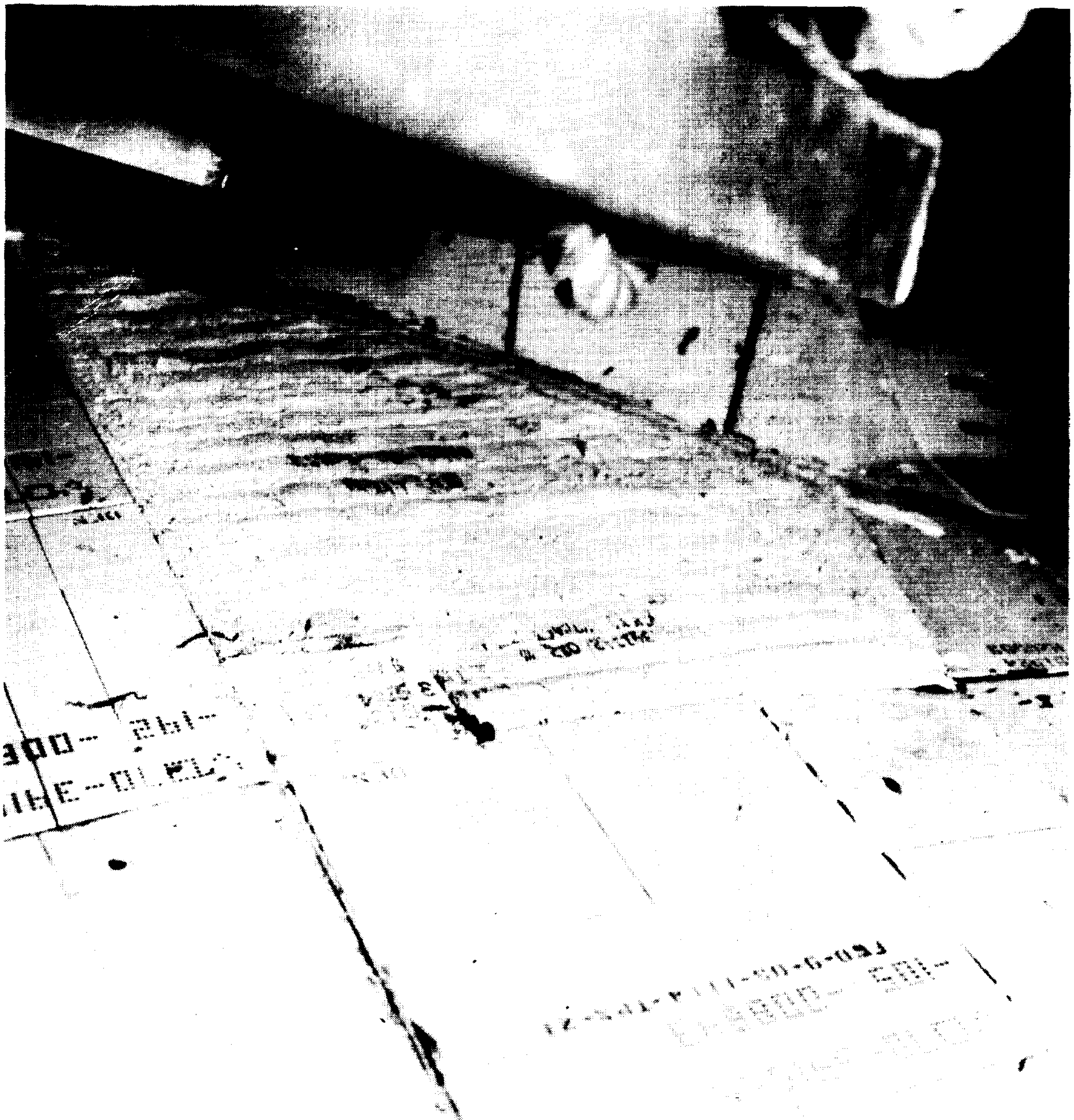
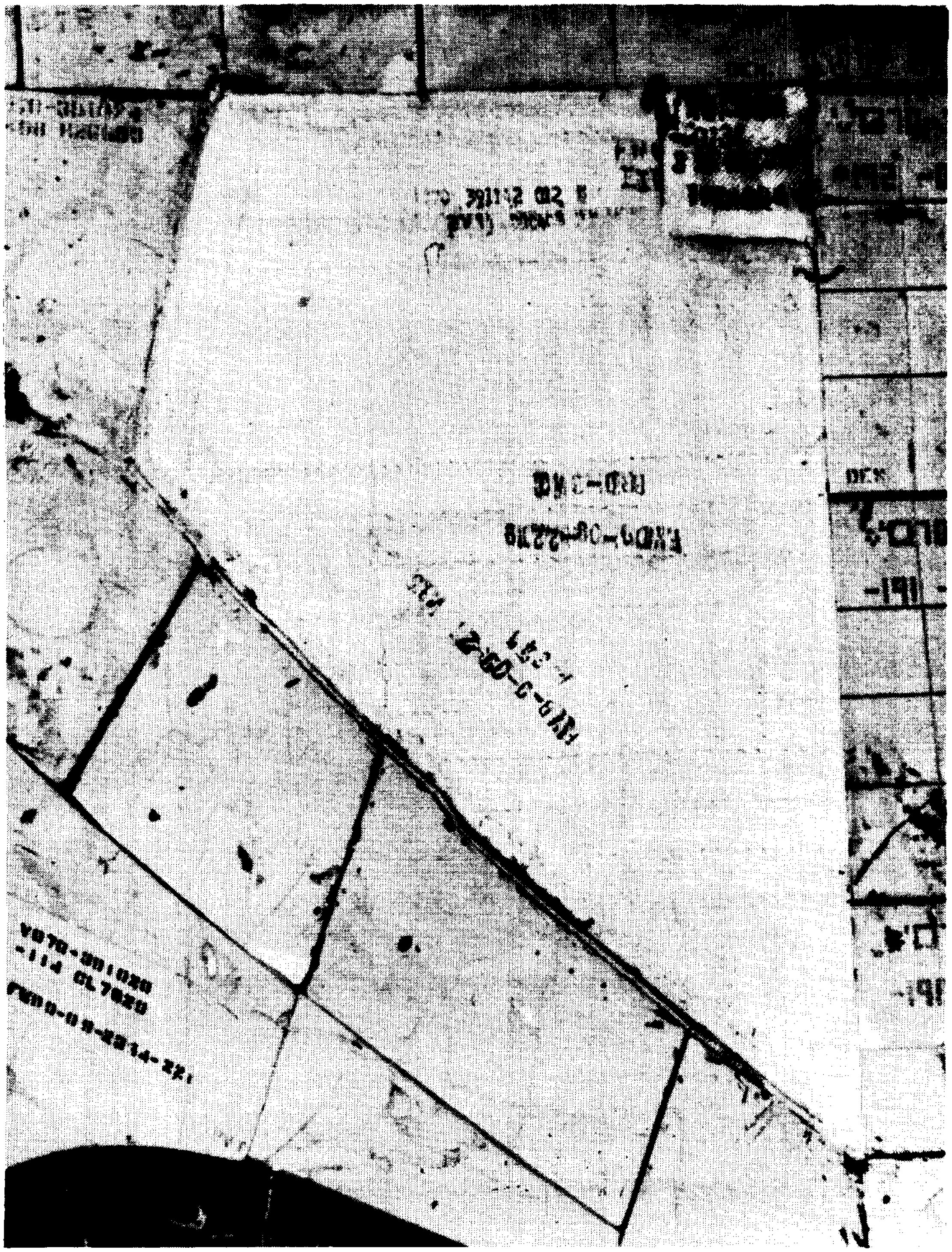


Figure 2. OEX-Ames advanced ceramic TPS experiment locations of uncoated AFRSI blankets on Challenger.



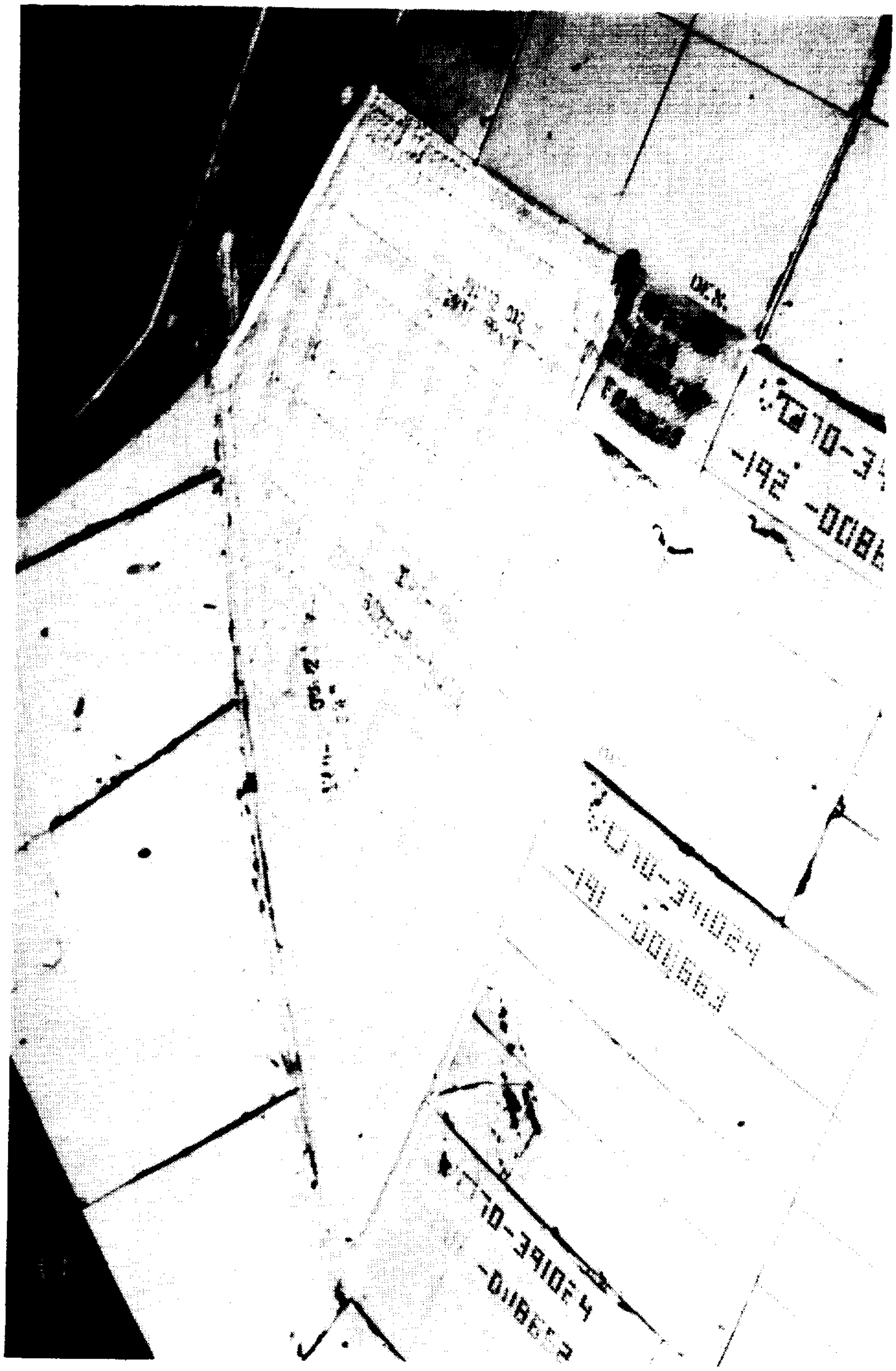
(a) Preflight.

Figure 3. Forward windshield location, Flight 61A.



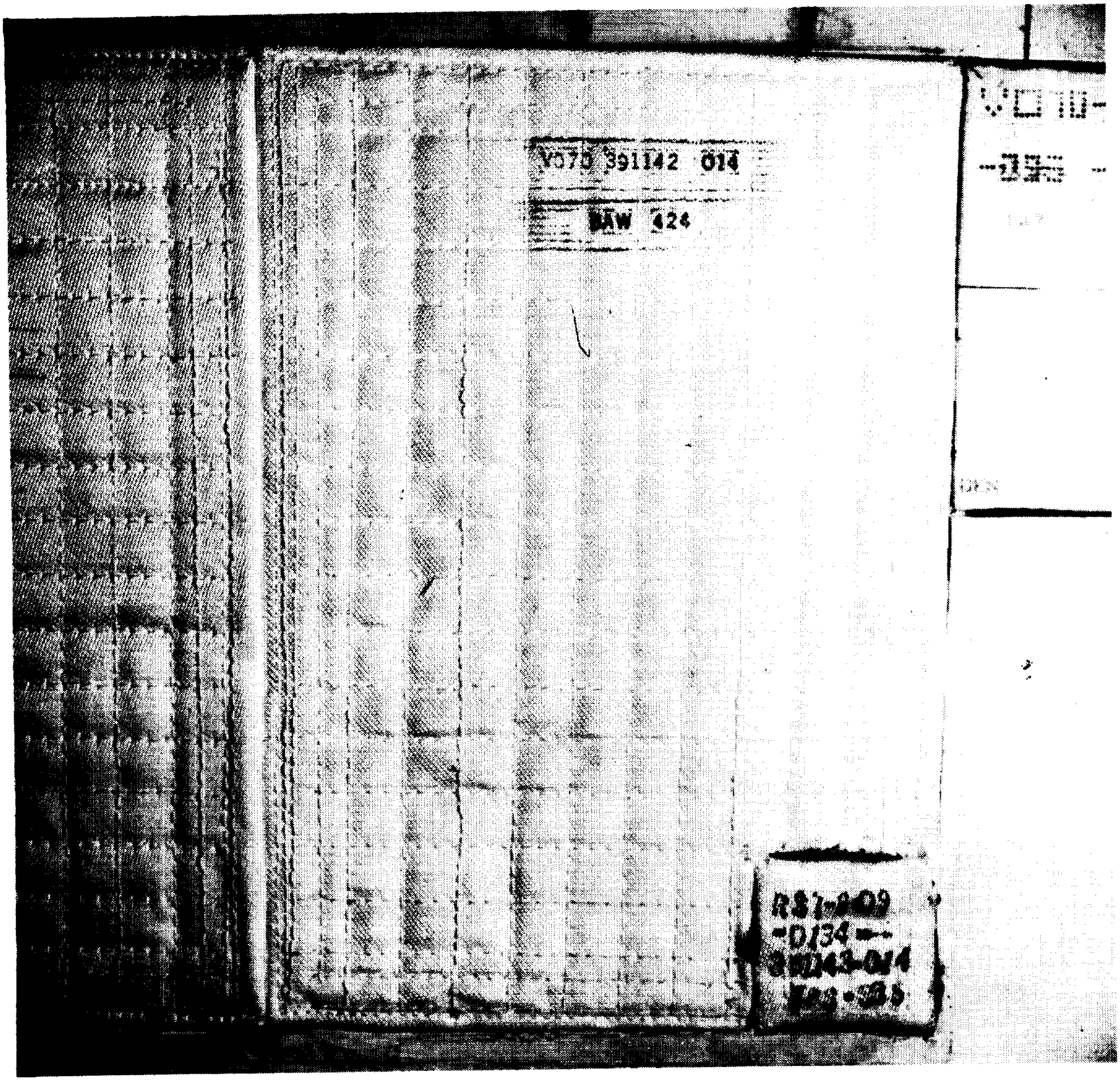
(b) Postflight, at DFRF.

Figure 3. Continued.



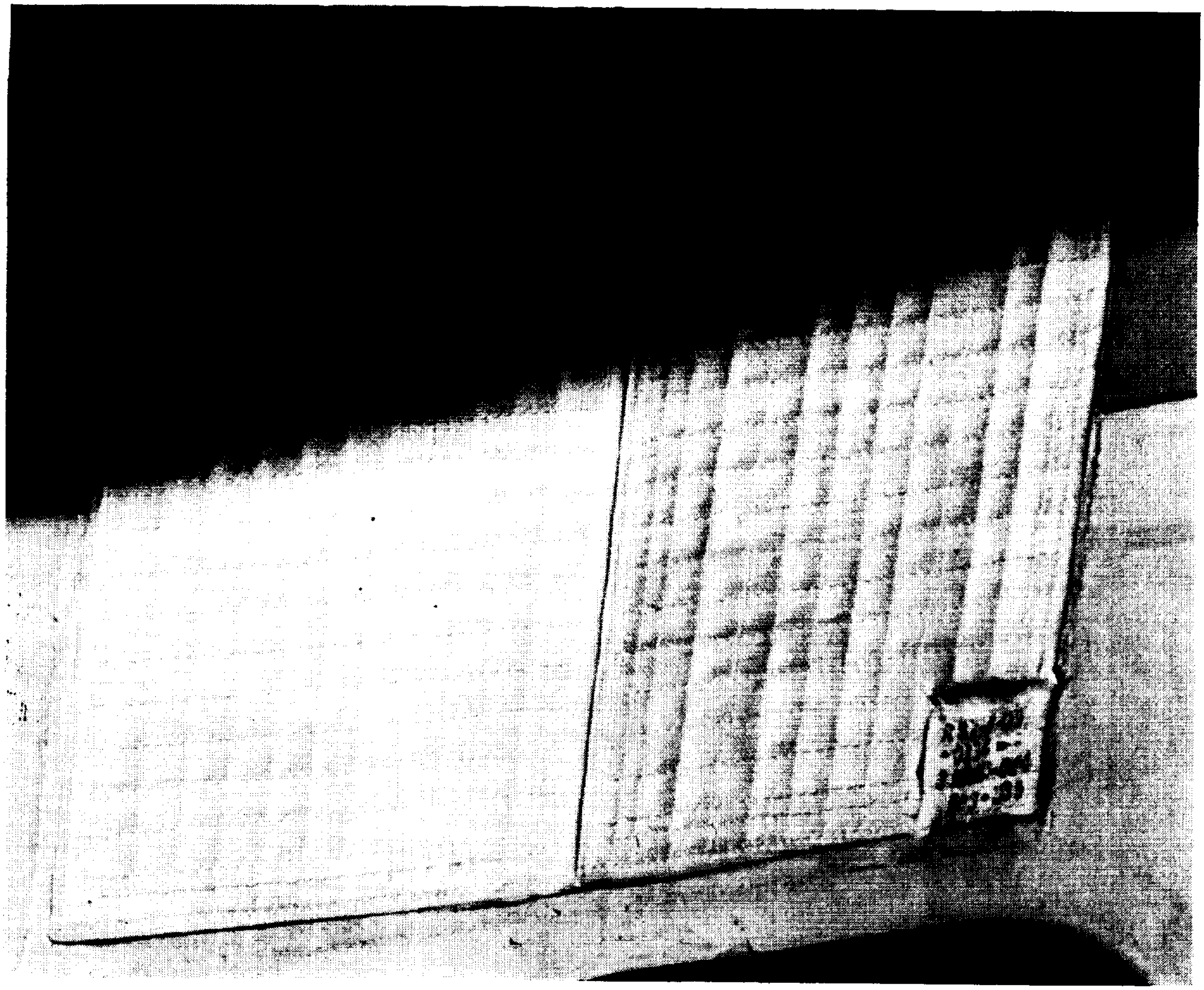
(c) Postflight, after ferry flight to KSC.

Figure 3. Concluded.



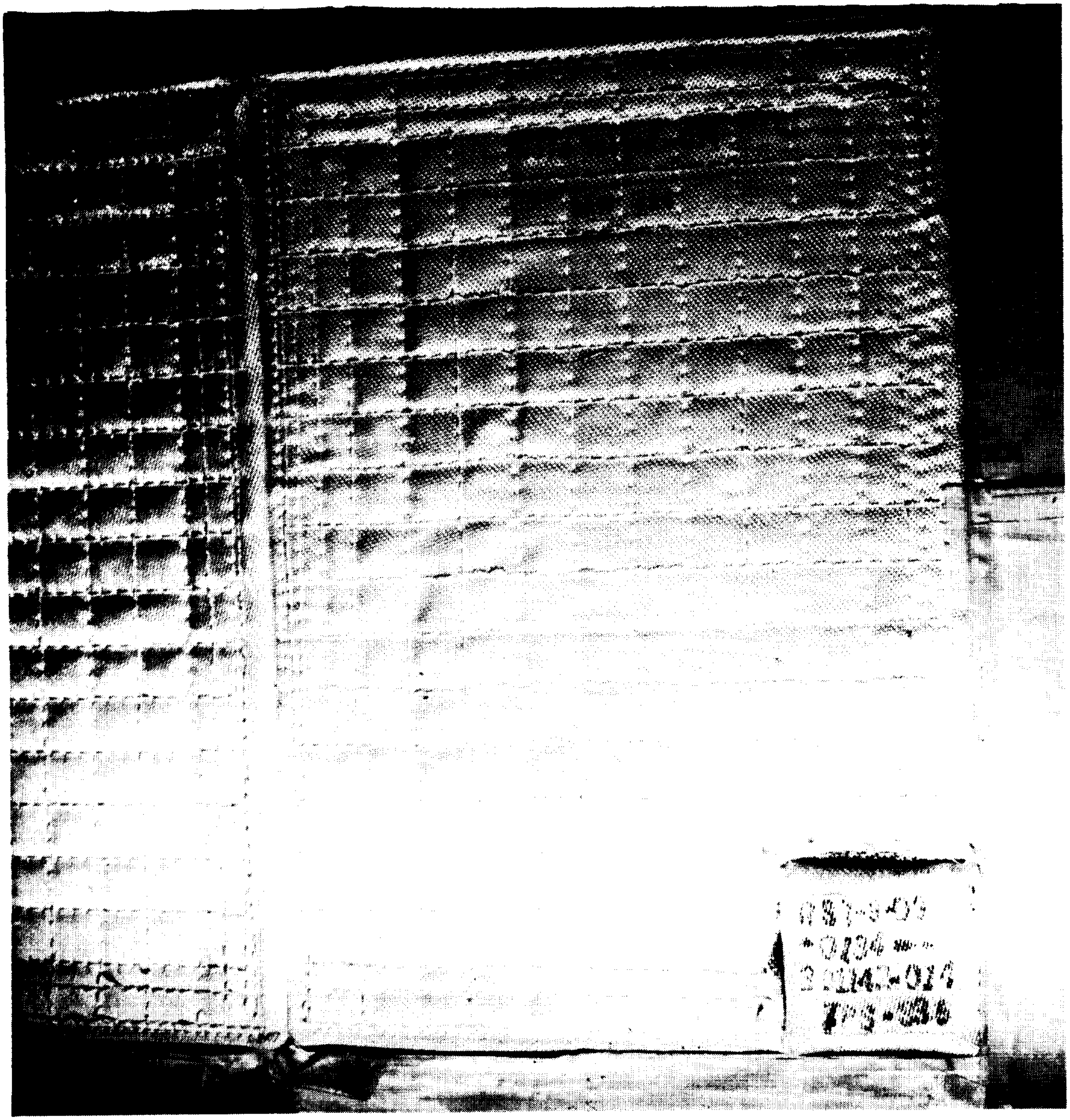
(a) Preflight.

Figure 4. Forward canopy location, Flight 61A.



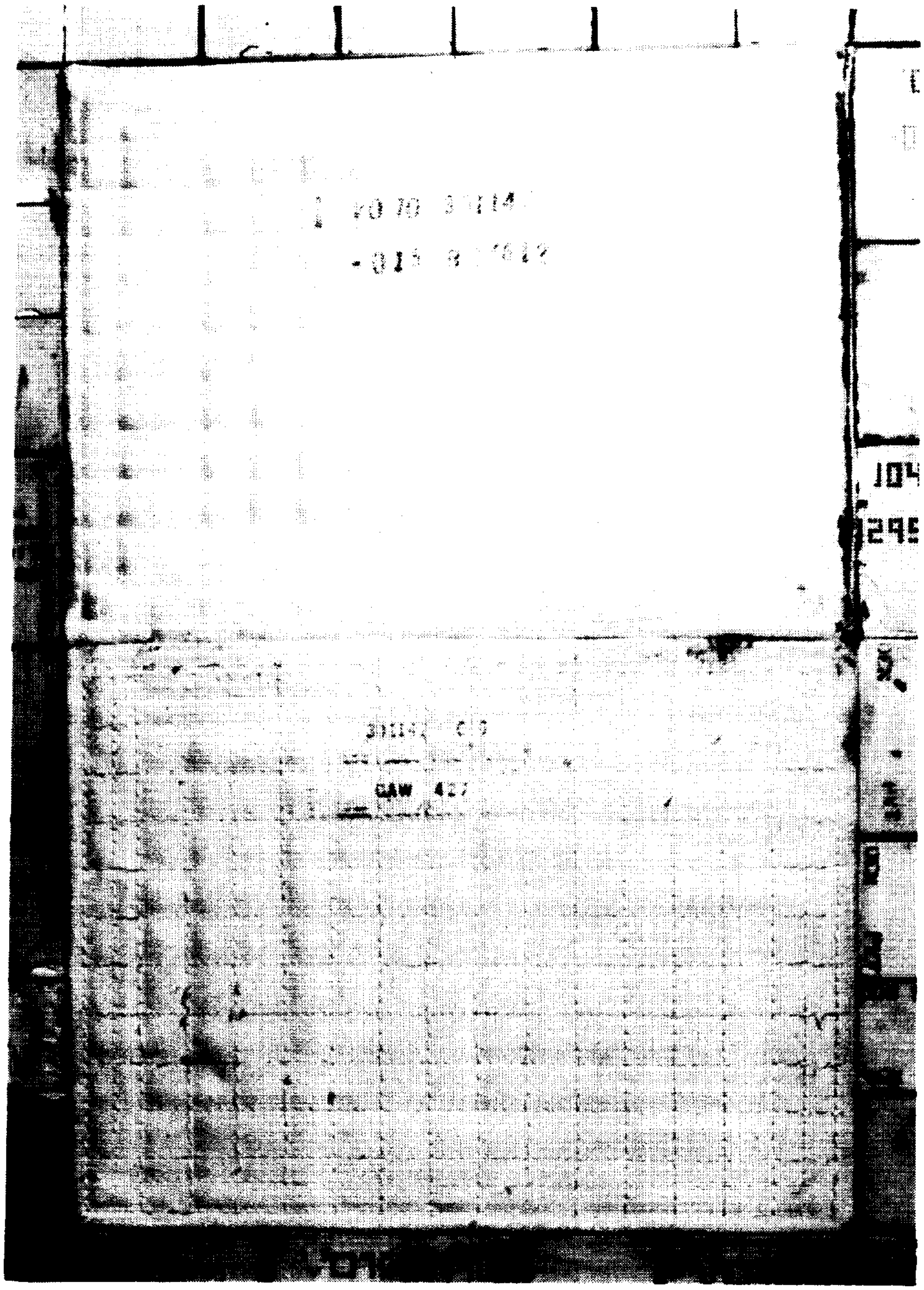
(b) Postflight, at DFRF.

Figure 4. Continued.



(c) Postflight, after ferry flight to KSC.

Figure 4. Concluded.



(a) Postflight, at DFRF.

Figure 5. Forward mid-fuselage location, Flight 61A.

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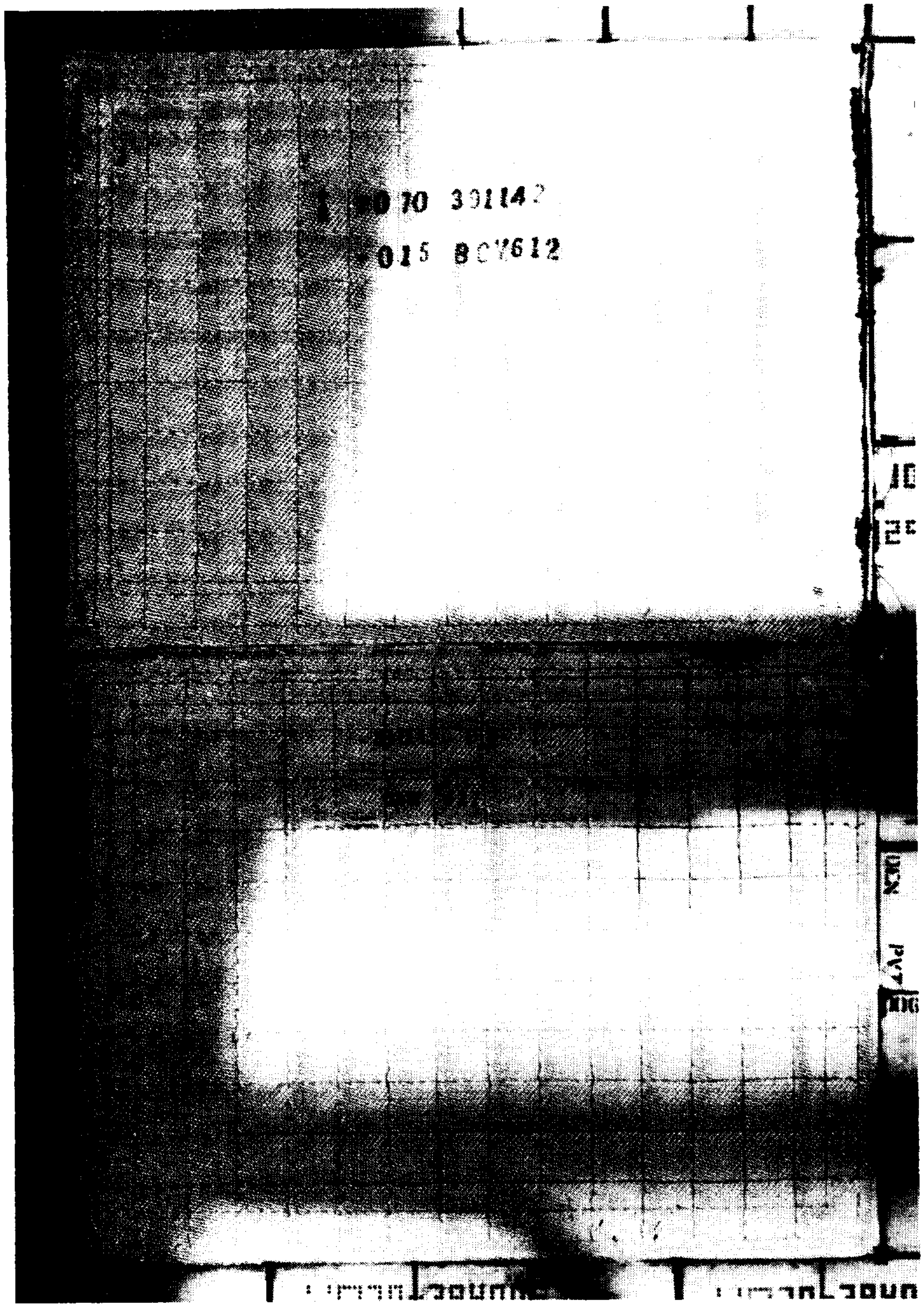

(b) Postflight, after ferry flight to KSC.

Figure 5. Continued.

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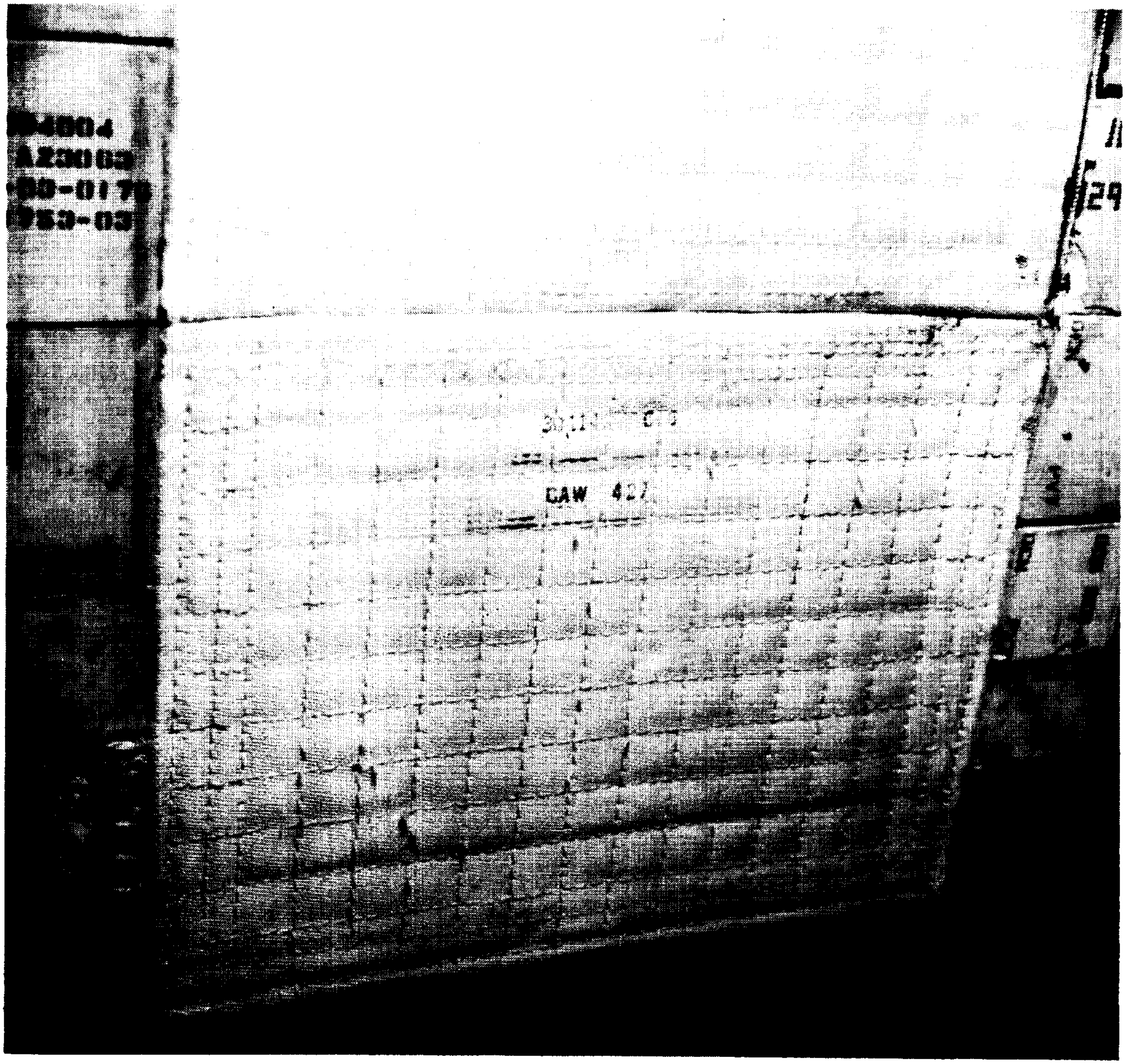
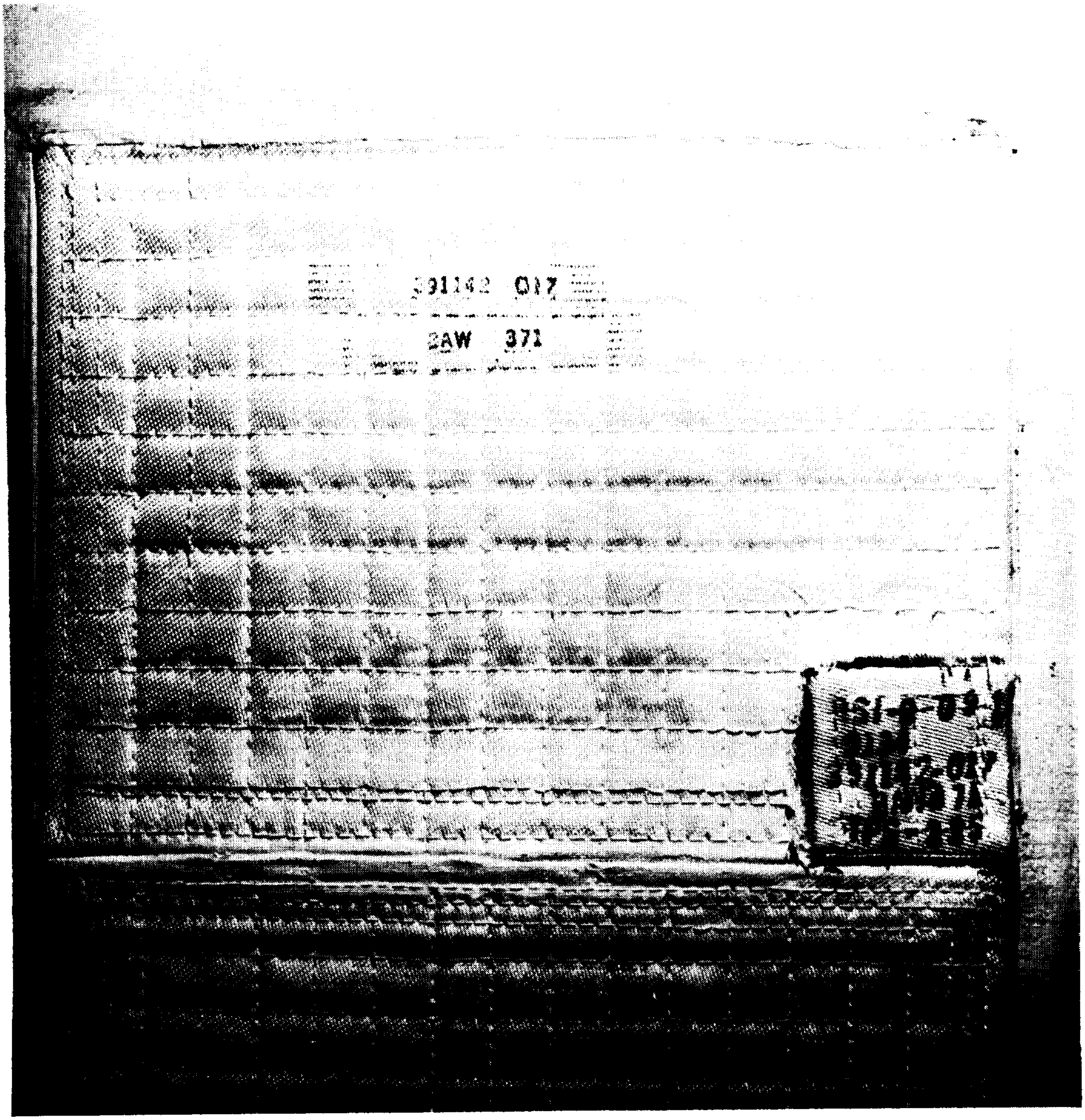


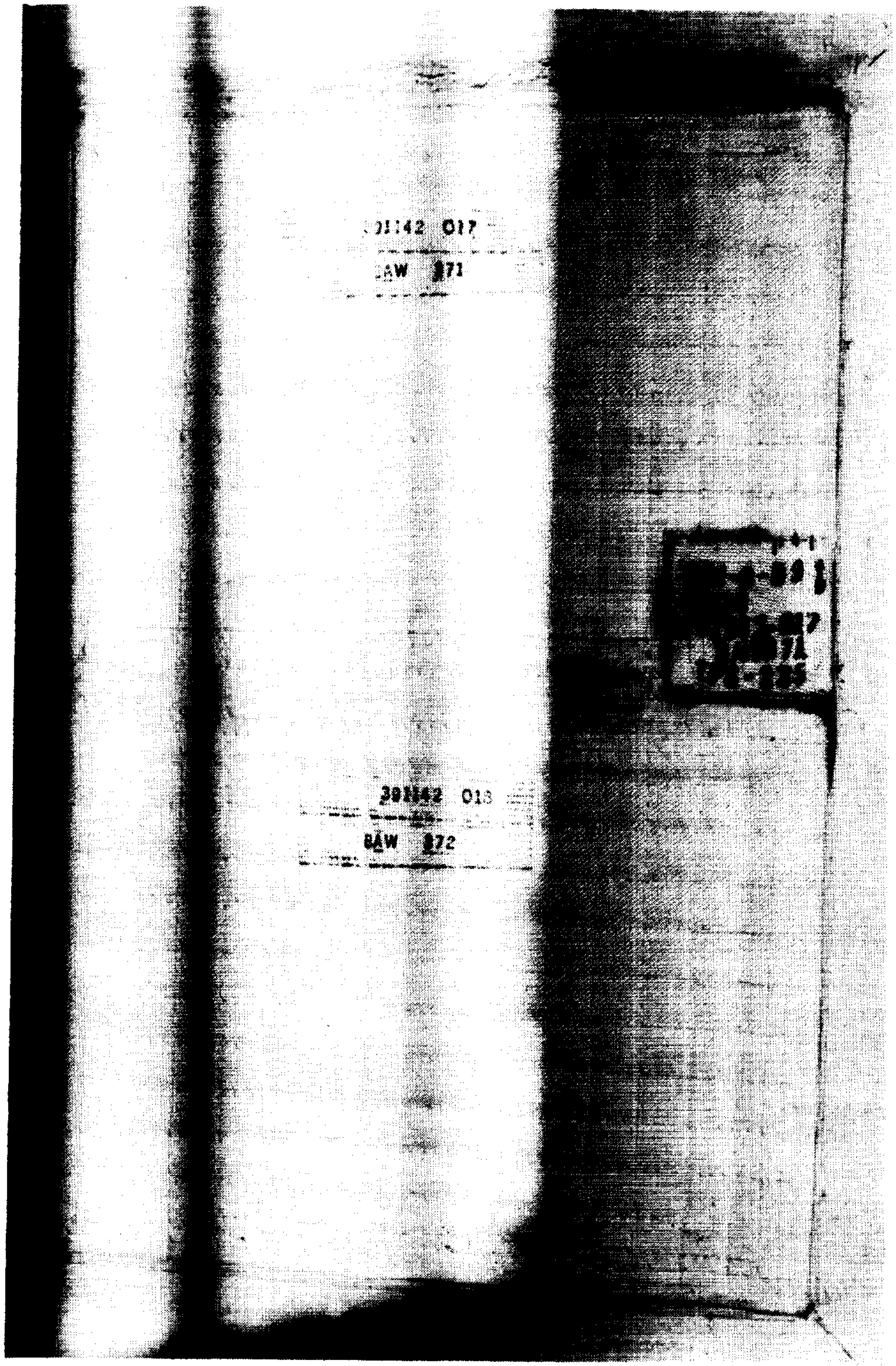
(c) Preflight.

Figure 5. Concluded.



(a) Preflight.

Figure 6. Mid-fuselage location, Flight 61A.



(b) Postflight, at DFRF.

Figure 6. Continued.

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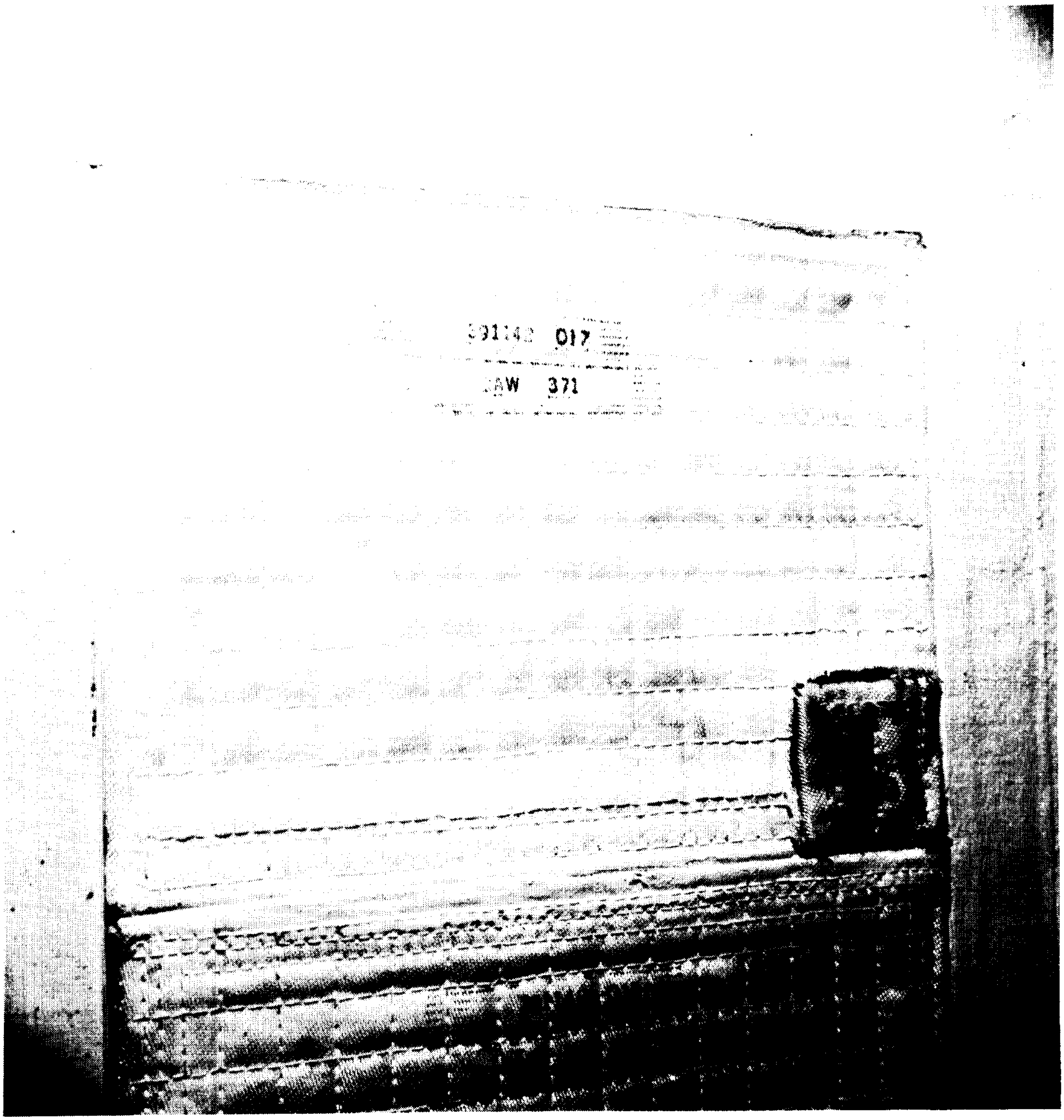

(c) Postflight, after ferry flight to KSC.

Figure 6. Concluded.

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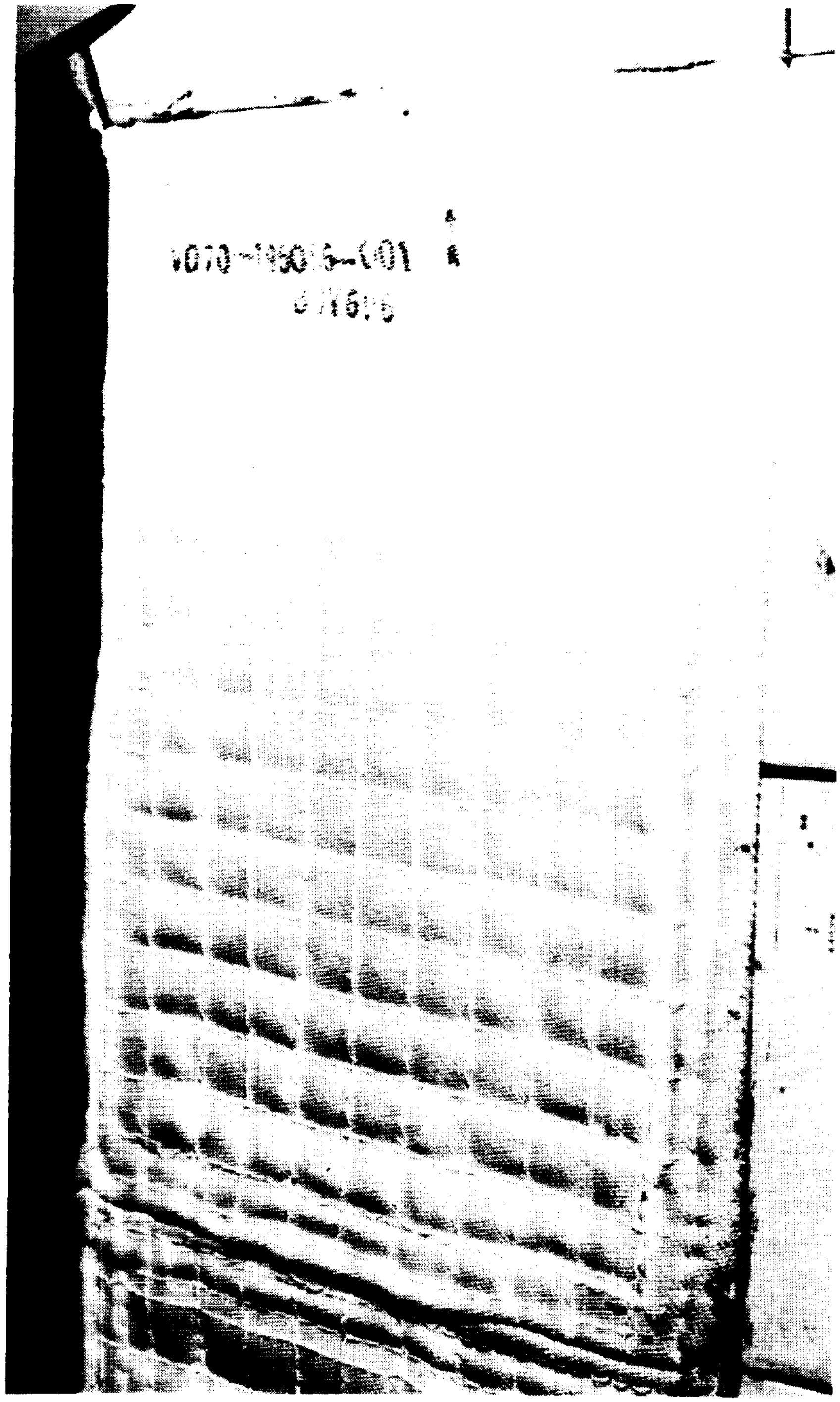
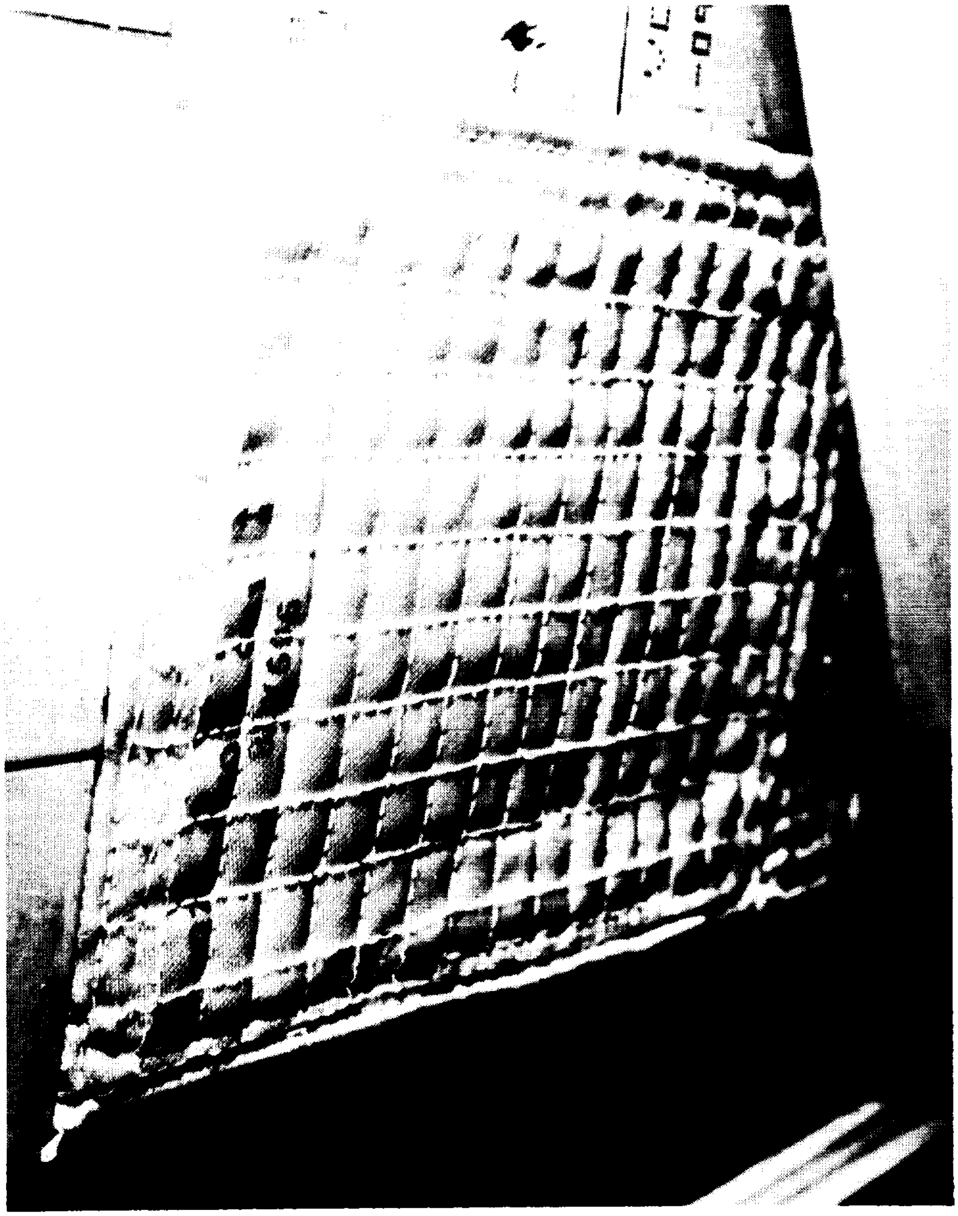


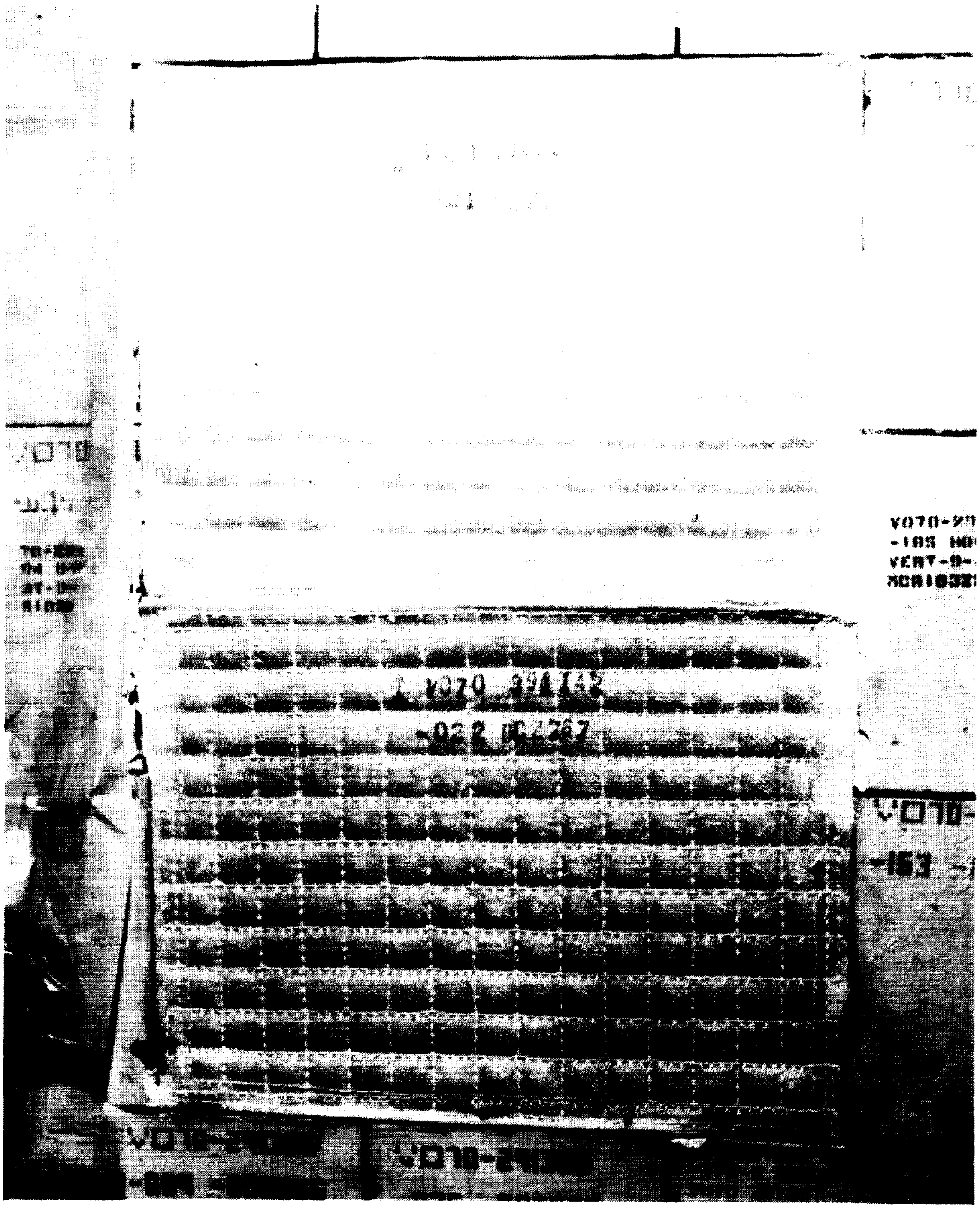
(a) Preflight.

Figure 7. Upper wing location, Flight 61A.



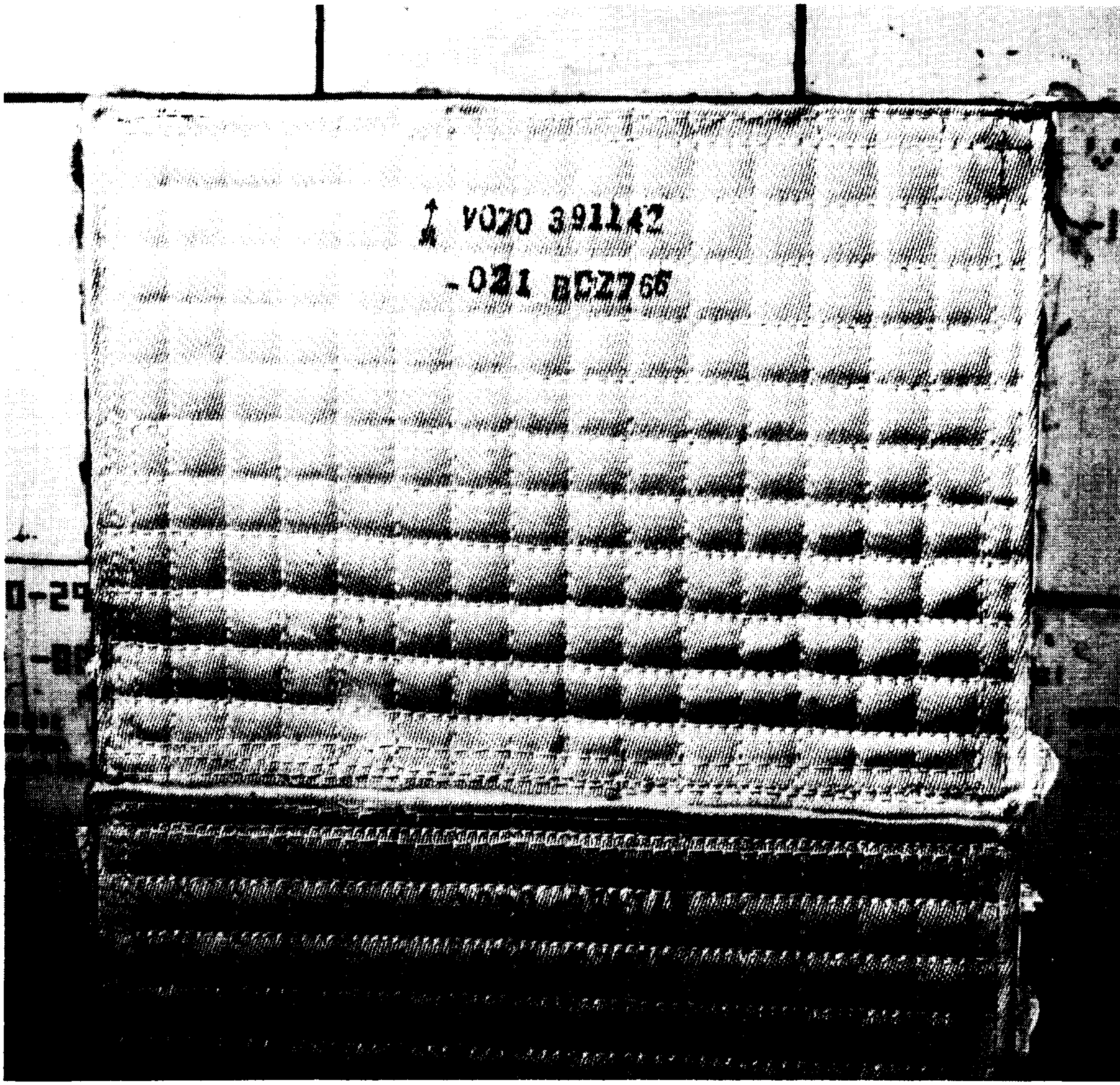
(b) Postflight, after ferry flight to KSC.

Figure 7. Concluded.



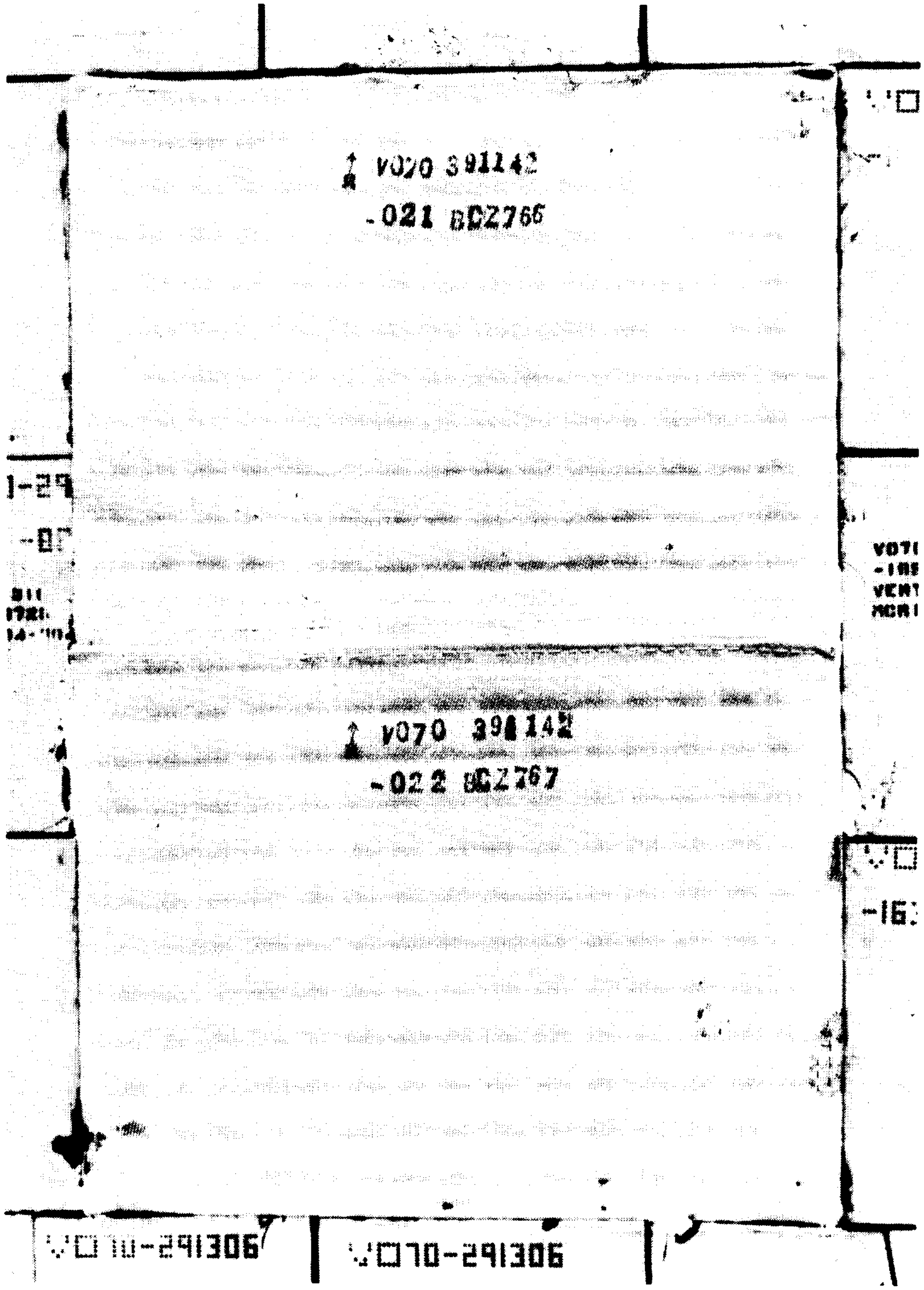
(a) Postflight, at DFRF.

Figure 8. Vertical tail location, Flight 61A.



(b) Postflight, after ferry flight to KSC.

Figure 8. Continued.



(c) Preflight.

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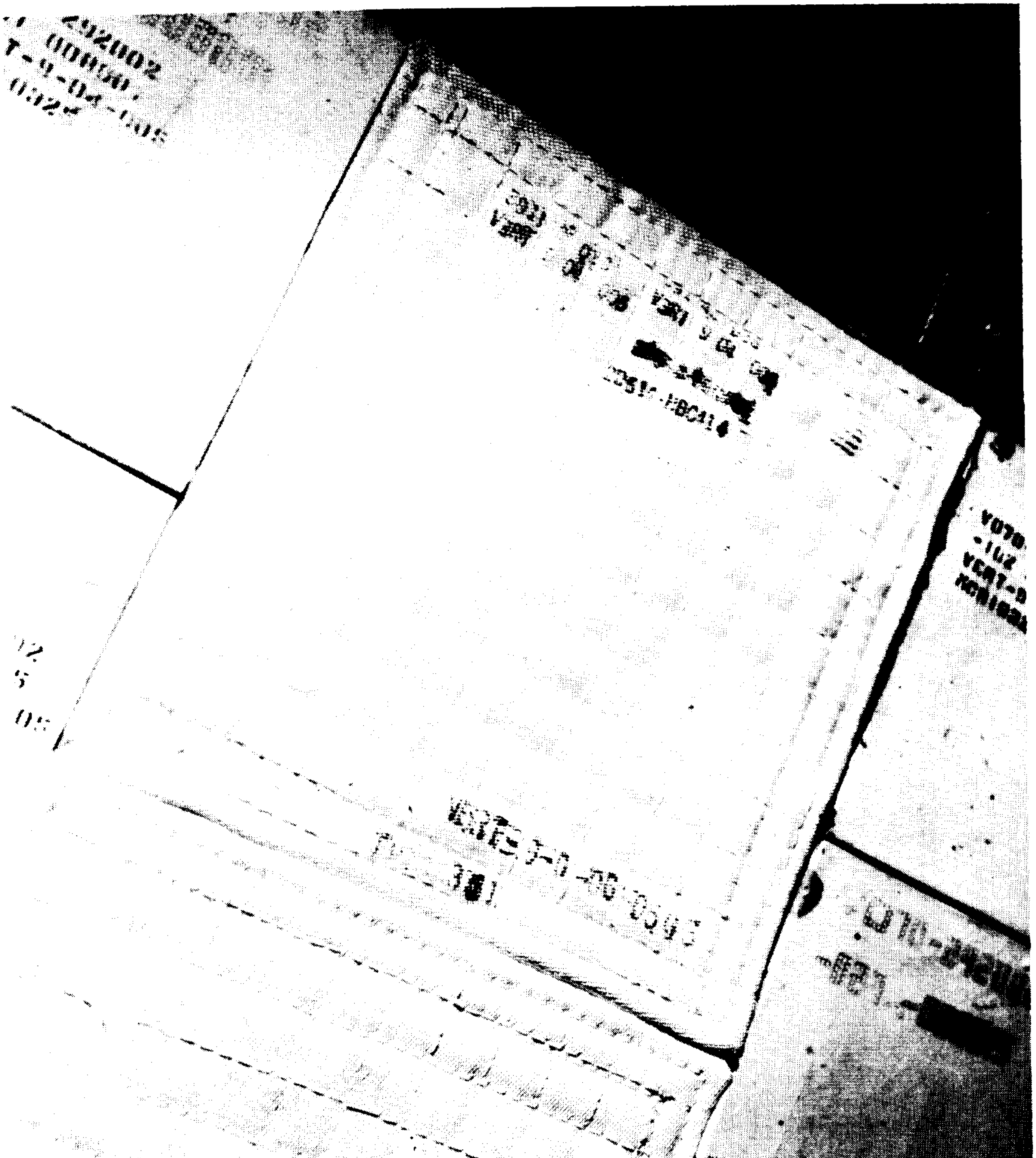
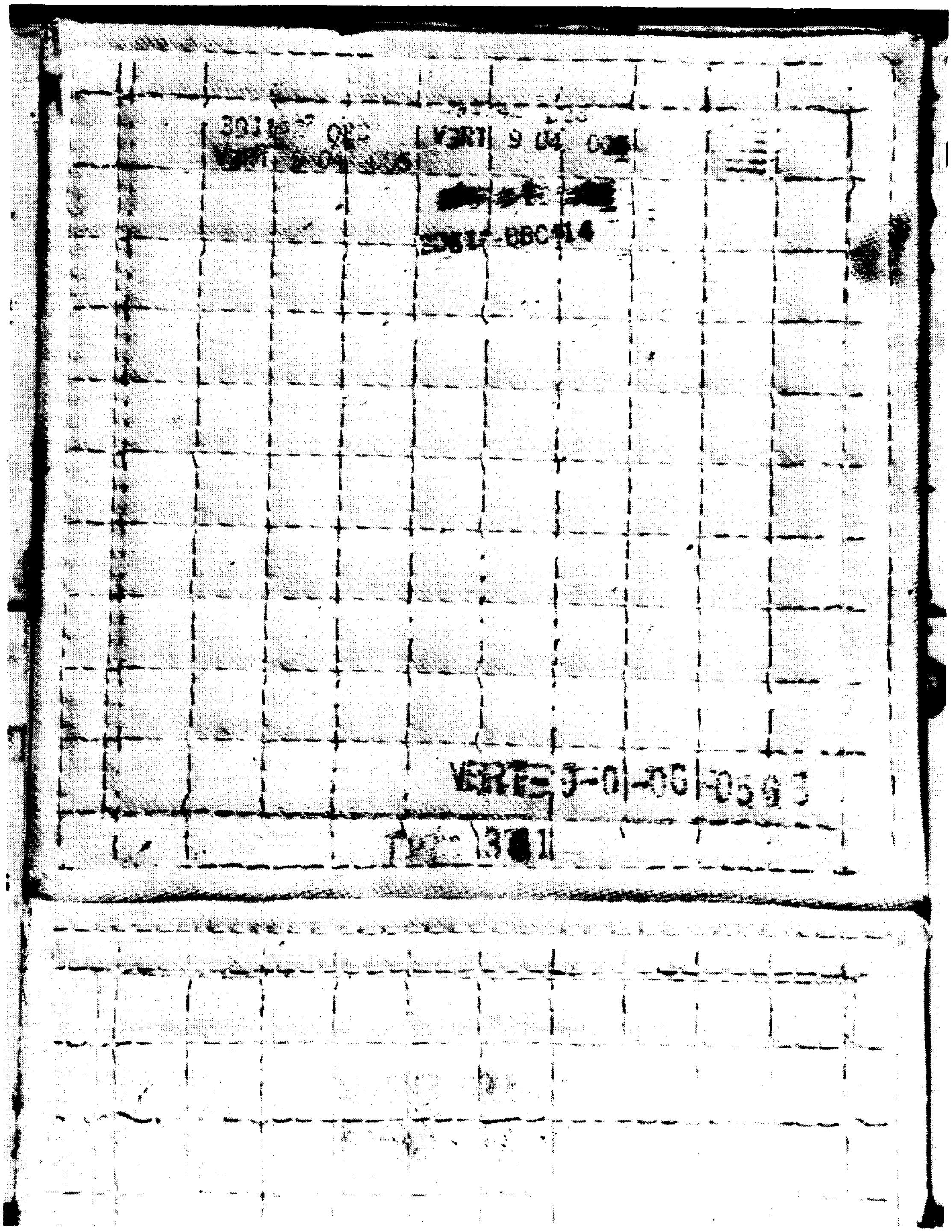


(a) Preflight.

Figure 9. Rudder/speed brake location, Flight 61A.



(b) Postflight, at DFRF.

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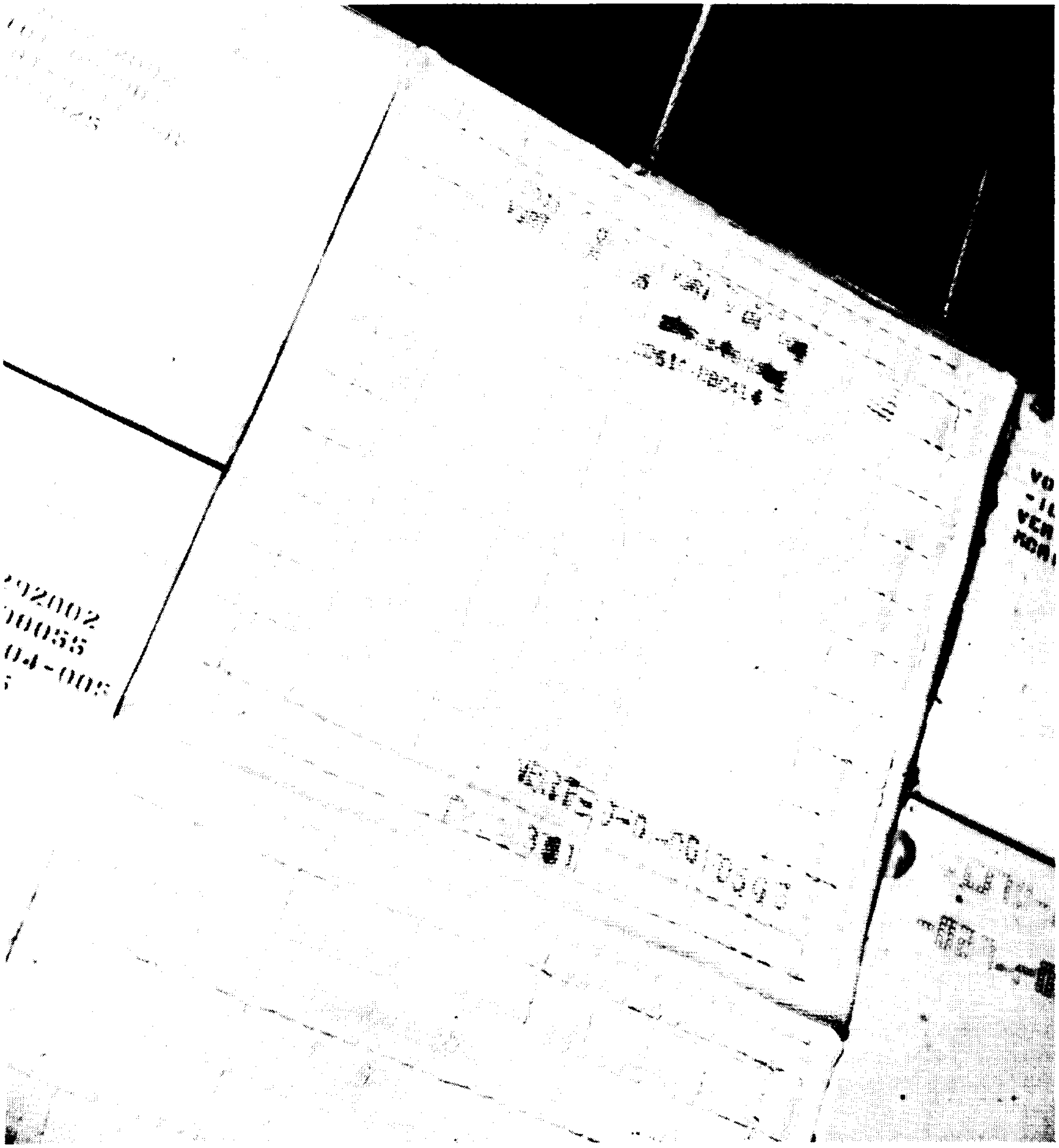

(c) Postflight, after ferry flight to KSC.

Figure 9. Concluded.

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Uncoated Advanced Flexible Reusable Surface Insulation (AFRSI) blankets were successfully flown on seven consecutive flights of the Space Shuttle Orbiter OV-099 (Challenger). In six of the eight locations monitored (forward windshield, forward canopy, mid-fuselage, upper wing, rudder/speed brake, and vertical tail), the AFRSI blankets performed well during the ascent and reentry exposure to the thermal and aeroacoustic environments. Several of the uncoated AFRSI blankets that sustained minor damage, such as fraying or broken threads, could be repaired by sewing or by patching with a surface coating called C-9. The chief reasons for replacing or completely coating a blanket were fabric embrittlement and fabric abrasion caused by wind erosion. This occurred in the orbiter maneuvering system (OMS) pod sidewall and the forward mid-fuselage locations.

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