AD-E300 162

DNA 4369F

AD A053391

HARDENED RV DEVELOPMENT PROGRAM PHASE III

SAMS/TATER Heatshield/Antenna Window Flight Test Program

(12)

Prototype Development Associates, Inc.
1740 Garry Avenue
Santa Ana, California 92705

February 1977

Final Report for Period 3 November 1975—30 September 1976

CONTRACT No. DNA 001-76-C-0140

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Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
DNA 4369F

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
HARDENED RV DEVELOPMENT PROGRAM PHASE III. SAMS/TATER Heatshield/Antenna Window Flight Test Program.

5. TYPE OF REPORT & PERIOD COVERED
Final Report for Period
3 Nov 75–30 Sep 76

6. PERFORMING ORG. REPORT NUMBER
PDA-TR-1046-02-23

7. AUTHOR(s)
Charles C. Thacker

8. CONTRACT OR GRANT NUMBER(s)
DNA 001-76-C-0140

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Prototype Development Associates, Inc.
1740 Garry Avenue
Santa Ana, California 92705

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Subtask Q76QAXAD410-01

11. CONTROLLING OFFICE NAME AND ADDRESS
Director
Defense Nuclear Agency
Washington, D. C. 20305

12. REPORT DATE
Feb[redacted]77

13. NUMBER OF PAGES
64

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
DNA, SBIE

15. SECURITY CLASS (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

4369F
AD-E300 162

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code X342076469 Q76QAXAD41001 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SAMS/TATER
Heatshield
Antenna Window
Ablation
Erosion
50 MW

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this program was to determine the response of heatshield and antenna window materials in the SAMS/TATER ablation/erosion environment. One clear air and three weather flights were successfully launched during the FY76 SAMS/TATER Program. Heatshield and antenna windows were recovered from three of the flights and subjected to post-flight analysis. This report describes the materials that were tested, presents post-flight recession measurements and observations, and compares coupled ablation/erosion flight performance with 50 MW ablation only test data.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

390 714

PREFACE

This report was prepared by Prototype Development Associates, Inc. (PDA), Santa Ana, California, for the Defense Nuclear Agency (DNA), Washington, D. C., under Contract Number DNA 001-76-C-0140. It is the final report describing work performed from 3 November 1975 to 30 September 1976 on the "Hardened Reentry Vehicle Development Program, Phase III, Task 2.0, SAMS Flight Test," under the technical cognizance of Major William E. Mercer, III, DNA Project Officer.

Mr. Charles C. Thacker was the PDA Program Manager and principal contributor to the program. Special acknowledgement is given to Mr. Edward C. Alexander, who was responsible for 50 Megawatt ablation testing.

Conversion Factors for U.S. Customary to Metric (SI) Units of Measurement

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 X E -10
atmosphere (normal)	kilo pascal (kPa)	1.013 25 X E +2
bar	kilo pascal (kPa)	1.000 000 X E +2
barn	meter^2 (m^2)	1.000 000 X E -28
British thermal unit (thermochemical)	joule (J)	1.054 350 X E +3
calorie (thermochemical)	joule (J)	4.184 000
cal (thermochemical)/cm^2	mega joule/m^2 (MJ/m^2)	4.184 000 X E -2
curie	giga becquerel (GBq)*	3.700 000 X E +1
degree (angle)	radian (rad)	1.745 329 X E -2
degree Fahrenheit	degree kelvin (K)	$t_K = (t° f + 459.67)/1.8$
electron volt	joule (J)	1.602 19 X E -19
erg	joule (J)	1.000 000 X E -7
erg/second	watt (W)	1.000 000 X E -7
foot	meter (m)	3.048 000 X E -1
foot-pound-force	joule (J)	1.355 818
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 X E -3
inch	meter (m)	2.540 000 X E -2
jerk	joule (J)	1.000 000 X E +9
joule/kilogram (J/kg) (radiation dose absorbed)	Gray (Gy)**	1.000 000
kilotons	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 X E +3
kip/inch^2 (ksi)	kilo pascal (kPa)	6.894 757 X E +3
ktap	newton-second/m^2 (N-s/m^2)	1.000 000 X E +2
micron	meter (m)	1.000 000 X E -6
mil	meter (m)	2.540 000 X E -5
mile (international)	meter (m)	1.609 344 X E +3
ounce	kilogram (kg)	2.834 952 X E -2
pound-force (lbf avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N·m)	1.129 848 X E -1
pound-force/inch	newton/meter (N/m)	1.751 268 X E +2
pound-force/foot^2	kilo pascal (kPa)	4.788 026 X E -2
pound-force/inch^2 (psi)	kilo pascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 X E -1
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2 (kg·m^2)	4.214 011 X E -2
pound-mass/foot^3	kilogram/meter^3 (kg/m^3)	1.601 846 X E +1
rad (radiation dose absorbed)	Gray (Gy)**	1.000 000 X E -2
roentgen	coulomb/kilogram (C/kg)	2.579 760 X E -4
shake	second (s)	1.000 000 X E -8
slug	kilogram (kg)	1.459 390 X E +1
torr (mm Hg, 0° C)	kilo pascal (kPa)	1.333 22 X E -1

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

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1.0 INTRODUCTION

In recent years, major emphasis has been placed on the development of nosetip materials and on the design of nosetip assemblies that are resistant to hydrometeor environments. Data from ground and flight tests suggest that reentry vehicle heatshield and antenna window materials are also vulnerable to weather effects. The test results provide evidence that the resistance of heatshield materials to an erosive environment may be strongly dependent upon material constituents and method of construction.

A program was initiated under Contract DNA001-75-C-0054 to design, fabricate, and supply advanced heatshield materials for test on the SAMS Program. The objective of the program was to determine material response in ablation/erosion environments. The SAMS/TATER vehicle offers an ideal test bed for acquiring erosion data on heatshield and antenna window materials since the materials are recovered after test. This report describes the heatshield and antenna window materials supplied for the FY76 SAMS Program and discusses post-test data analysis of the recovered materials.

2.0 SUMMARY

One clear air flight and three weather flights were successfully launched during the FY76 SAMS Program. Heatshield and antenna window materials were recovered from three of the flights. Post-flight analysis of the recovered heatshields and antenna windows showed significant differences in materials response to the SAMS/TATER ablation/erosion environment. The following is a summary of flight and 50 MW test results.

Recession of 2D carbon (Pitch)/phenolic 20° (2DCP20° (Pitch)) is equivalent to 2D carbon/phenolic 20° (2DCP20°) in the SAMS/TATER clear air environment.

Recession of 3D quartz/phenolic (3DQP) is 2.4 times greater than 2DCP20° in the SAMS/TATER weather environment and 1.6 times greater in the 50 MW ablation environment.

Recession of AS-3DX antenna window material is compatible with 2DCP20° but not compatible with 3DQP.

Recession of 2D carbon/rubber modified phenolic 20° (2DCR-10 20°) is ten times greater than 2DCP20° in the SAMS/TATER weather environment and 1.3 times greater in the 50 MW ablation environment.

Low strength, brittleness, and thermal stress sensitivity limit the use of hot pressed boron nitride (TS-1251) for flight antenna window applications.

3.0 DESCRIPTION OF MATERIALS

The heatshield and antenna window materials fabricated for test during the FY76 SAMS Program are listed in Table 1 along with the respective SAMS/TATER flight numbers. The designations "2D" and "3D" refer to two dimensional tape-wrapped and three-dimensional woven or fabricated construction, respectively. Tape-wrap angles of 20^o and 70^o are with respect to the surface of the heatshield substrate which had a one-half cone angle of 7-1/2 degrees. Abbreviations for the type of construction, materials, and wrap angle are listed in parentheses. Thus, ($2DCP20^o$) indicates two dimensional construction; carbon fabric reinforced phenolic resin; bias tape-wrapped at an aft-facing angle of 20^o to the heatshield substrate surface.

Table 2 lists the reinforcing fabrics and resin systems used to fabricate each of the heatshield materials.

Mechanical and chemical properties of the heatshield composites are presented in Table 3. Properties were derived on tag ends of composite material from actual flight heatshield frustums. Testing was performed in accordance with G.E. Specification Number S9330-21-0011.

Table 1. SAMS/TATER Flight Test Matrix

FLIGHT NUMBER	REFERENCE HEATSHIELD	EXPERIMENTAL HEATSHIELD	EXPERIMENTAL ANTENNA WINDOW
602	2D Carbon/Phenolic 20° (2DCP 20°)	2D Carbon (Pitch)/Phenolic 20° (2DCP 20° (Pitch))	None
509	Reference Material Req'd on all Flights Because of Weather Definition Uncertainty ↓	3D Quartz/Phenolic (3DQP)	3D Astroquartz Silica (AS-3DX)
516		2D Carbon/Rubber Modified Phenolic 20° (2DCR-10 20°)	Hot Pressed Boron Nitride (TS-1251)
512		2D Carbon/Phenolic 70° (2DCP 70°)	3D Boron Nitride (BN-3DX)

Table 2. Composition of Heatshield Materials

MATERIAL DESIGNATION	PREPREG NUMBER	COMPONENTS OF PREPREG	
		REINFORCING FABRIC	RESIN SYSTEM
2D Carbon/Phenolic 20° (Reference Material)	U. S. Polymeric FM 5055A	Hitco CCA-1 Carbon Cloth	U. S. Polymeric #95 Phenolic Resin
2D Carbon (Pitch)/ Phenolic 20°	U. S. Polymeric FM 5783	UCC Type "P" Intermediate Carbon Cloth	U. S. Polymeric #39 Phenolic Resin
3D Quartz/Phenolic	U. S. Polymeric FM 5709-12 (Longitudinal and Circumferential)	Astroquartz 300 Roving	Monsanto SC1008 Phenolic Resin
	U. S. Polymeric FM 5723-12 (Radial)	Astroquartz 552 Roving	Monsanto SC1008 Phenolic Resin
2D Carbon/Rubber Modified Phenolic 20°	None	Hitco CCA-1 Carbon Cloth	AVCO R-10 Rubber Impregnated Phenolic
2D Carbon/Phenolic 70°	U. S. Polymeric FM 5055A	Hitco CCA-1 Carbon Cloth	U. S. Polymeric #95 Phenolic Resin

Table 3. Properties of Heatshield Materials

Material	Specific Gravity	Tensile Strength Room Temp (psi)	Tensile Modulus Room Temp (psi x 10^6)	Elongation Room Temp %	Tensile Strength 250°F psi	Tensile Modulus 250°F (psi x 10^6)	Elongation 250°F %	Volatile Content %	CONTAMINATION, PPM					
									Sodium	Potas- sium	Calcium	Magne- sium	Lithium	Total
2D Carbon/ Phenolic 20°	1.52	8,051	2.3	0.42	7,458	1.8	0.48	1.4	20	4	11	9	1	45
2D Carbon (Pitch)/ Phenolic 20°	1.63	5,165	2.0	0.32	4,431	2.0	0.17	2.4	194	38	74	33	1	340
3D Quartz/ Phenolic	1.63	37,659	2.0	2.5	22,622	1.5	1.8	0.8	11.7	1.6	0.5	4.5	1	19.5
2D Carbon/ Rubber Modified Phenolic 20°	1.25	3,279	0.62	0.47	927	0.11	1.80	0.7	44	43	68	39	1	195
2D Carbon/ Phenolic 70°	1.50	3,505	2.3	0.16	1,920	2.0	0.10	0.7	9	2	6	11	1	29

4.0 HEATSHIELD FABRICATION

Variations in meteorological environment from flight-to-flight and measurement uncertainties of particle type and distribution within a given flight necessitated the inclusion of a "tare" or reference heatshield material in each SAMS/TATER heatshield configuration. The reference heatshield material acts as a continuum against which the performance of various experimental heatshield materials can be compared. The reference material also provides a quantitative definition of the erosive severity of the meteorological environment.

The 2D carbon/phenolic 20-degree heatshield material (5055A) was selected as the reference material for all flights. Heatshield frusta were fabricated using four separate quadrants of equal length as shown in Figure 1. Quadrants of experimental and reference material were alternated so that the same material was used in diagonally opposed quadrants. This design arrangement was selected to compensate for any asymmetry which might develop during flight due to unequal recession of the two heatshield materials.

A mechanical interlock system, Figure 1, was used between quadrants to insure integrity during flight. The interlock consisted of slotting the quadrants and bonding slats of flat laminate carbon/phenolic into the slots using EA934 epoxy adhesive. This technique is shown pictorially in Figures 2 and 3.

The antenna window material was similarly interlocked into the quadrants by bonding rods of carbon/phenolic into holes drilled between the quadrants and antenna windows as illustrated in Figure 1. This technique is shown pictorially in Figure 4.

Heatshield frusta fabricated by PDA were manufactured and quality controlled in accordance with the provisions of "PDA Processing Specification for SAMS/TATER Heatshields" listed in Appendix 1 of this report. Frusta supplied by AVCO (3DQP and 2DCR-10 20°) were manufactured in accordance with AVCO specifications. In addition to the experimental aft heatshield, PDA also fabricated the forward 2DCP20° heatshield illustrated in Figure 1.

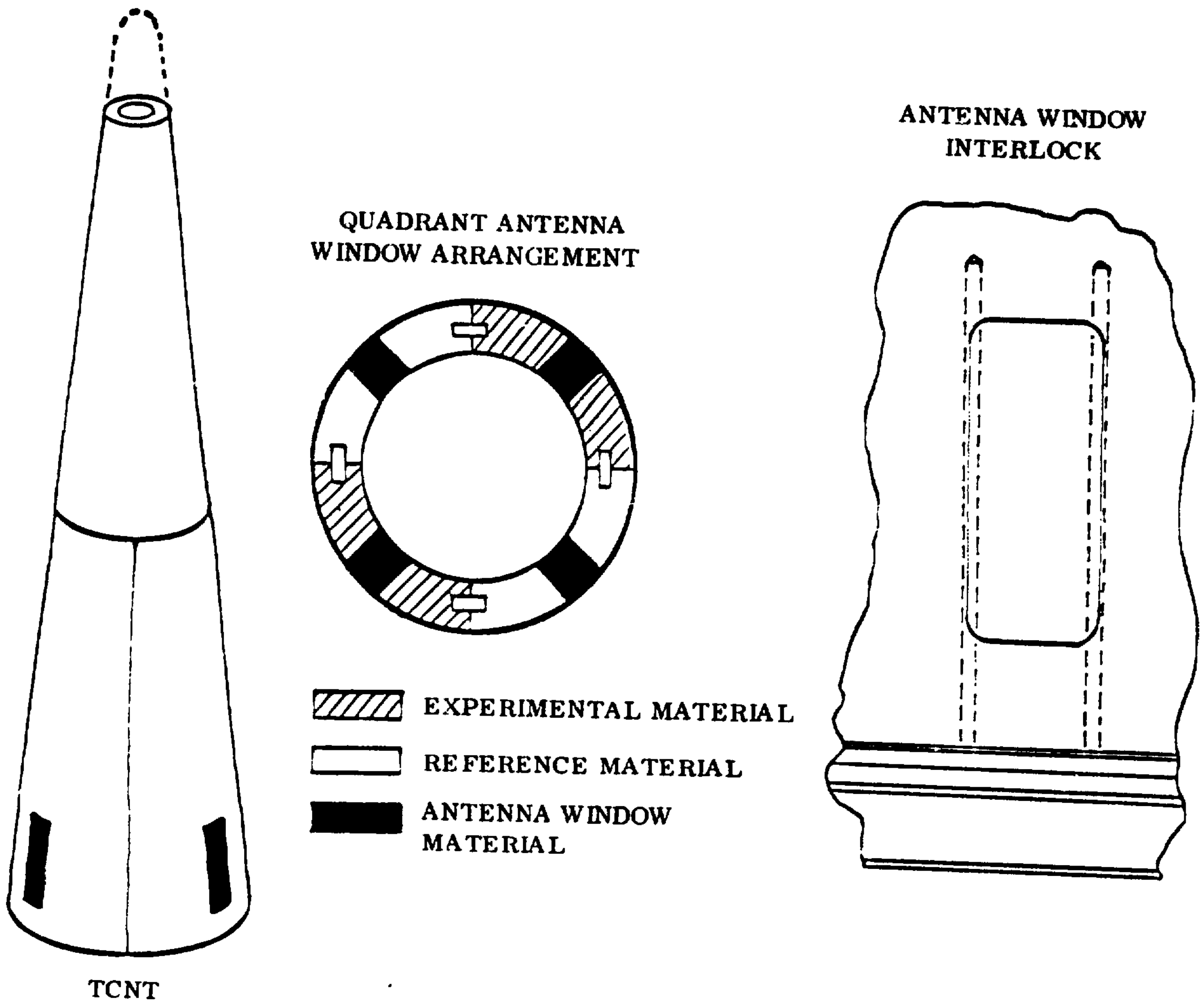


Figure 1: SAMS/TATER Heatshield/Antenna Window Configuration

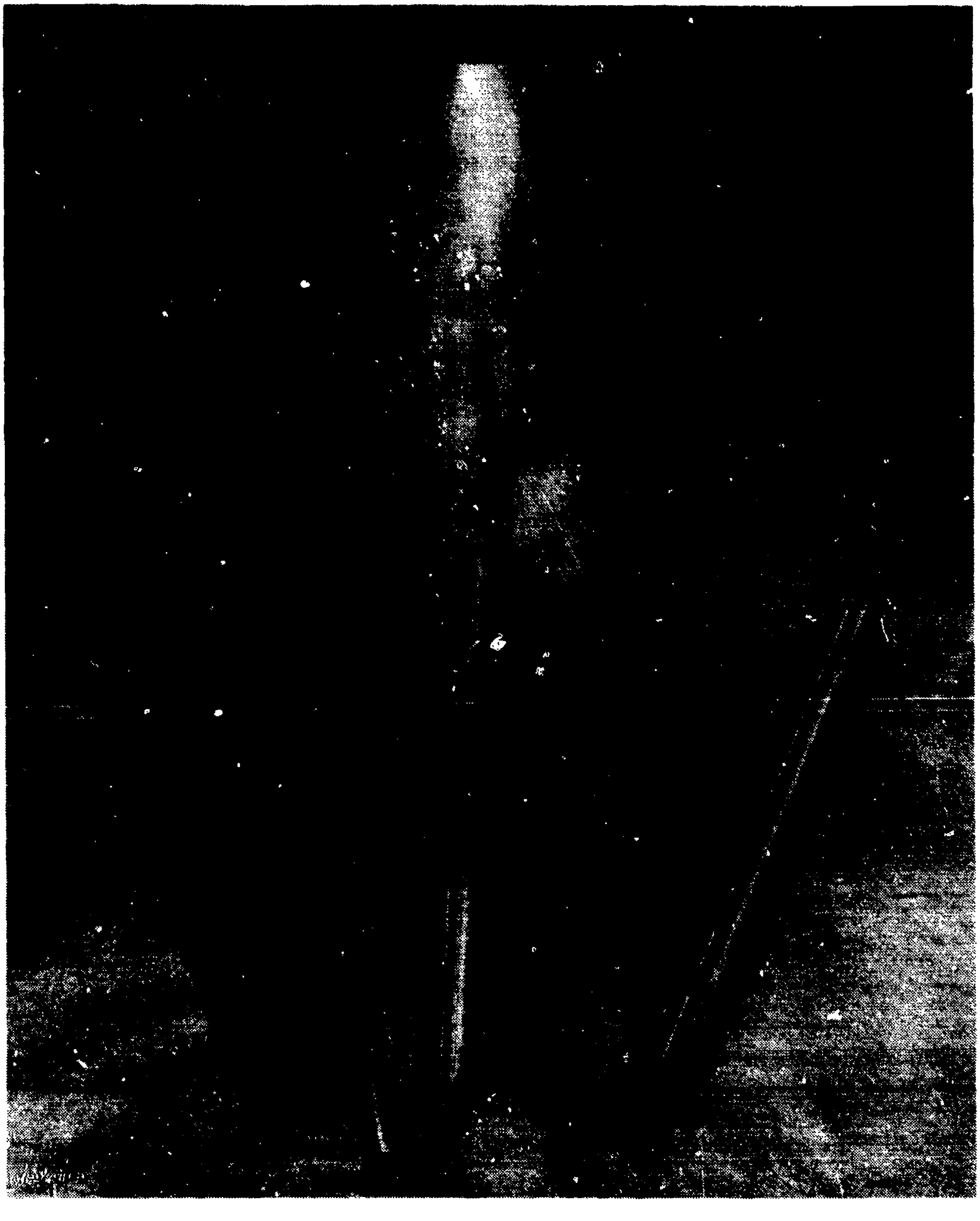


Figure 2. Heatshield Quadrants Prior to Assembly

Figure 3. Assembled Heat-shield Quadrants

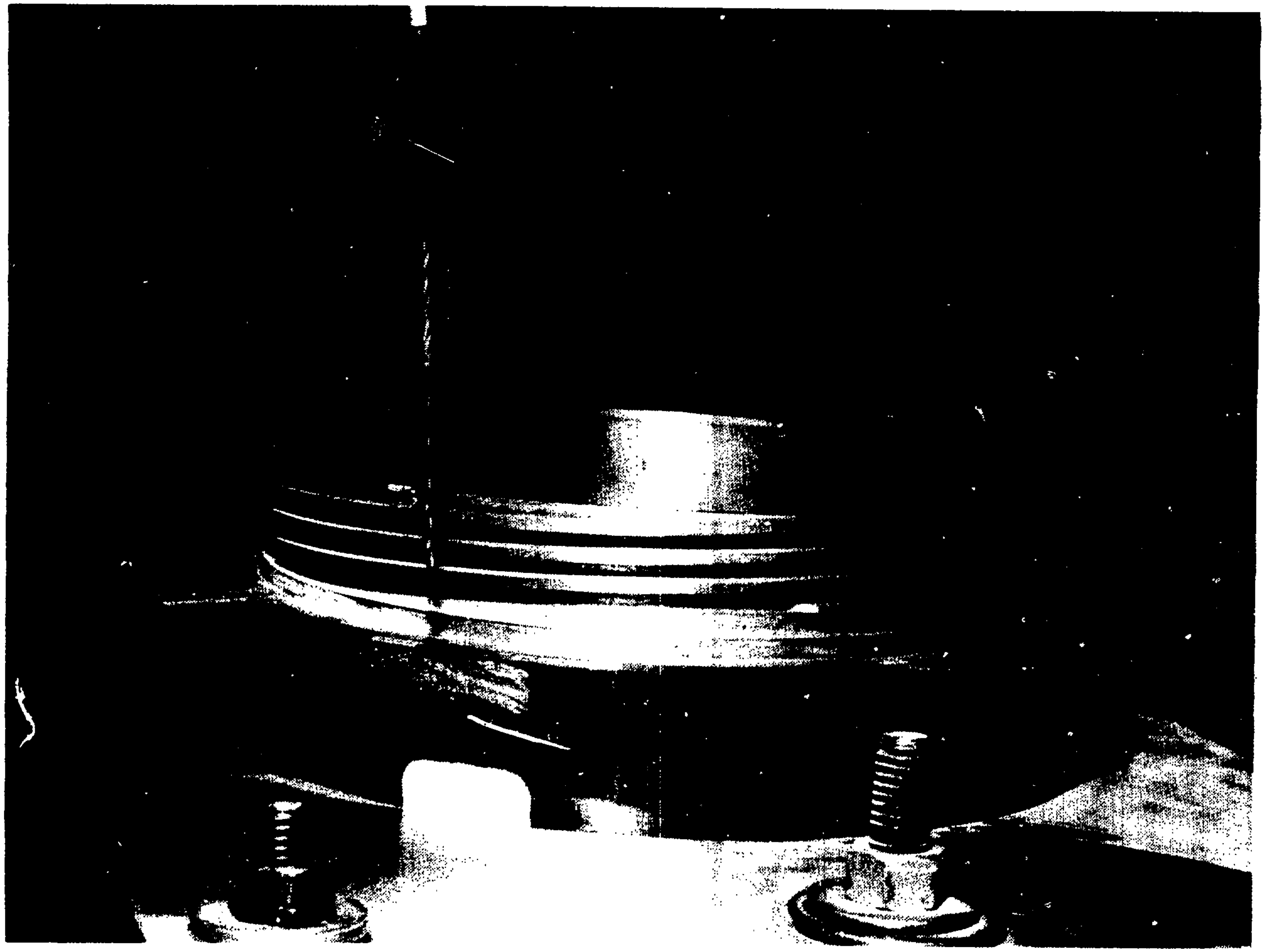


Figure 4. Drilling of Antenna Window Interlock Holes

The heatshield and antenna windows were bonded to SAMS/TATER metal substrates using EA934 epoxy adhesive. The substrates were sand blasted and solvent cleaned prior to the bonding operation. After bond cure, the heatshield assemblies were machined to final dimensions, x-rayed to ensure bond integrity, and dimensionally inspected to drawing requirements.

A typical bonded heatshield/antenna window assembly is shown in Figure 5.

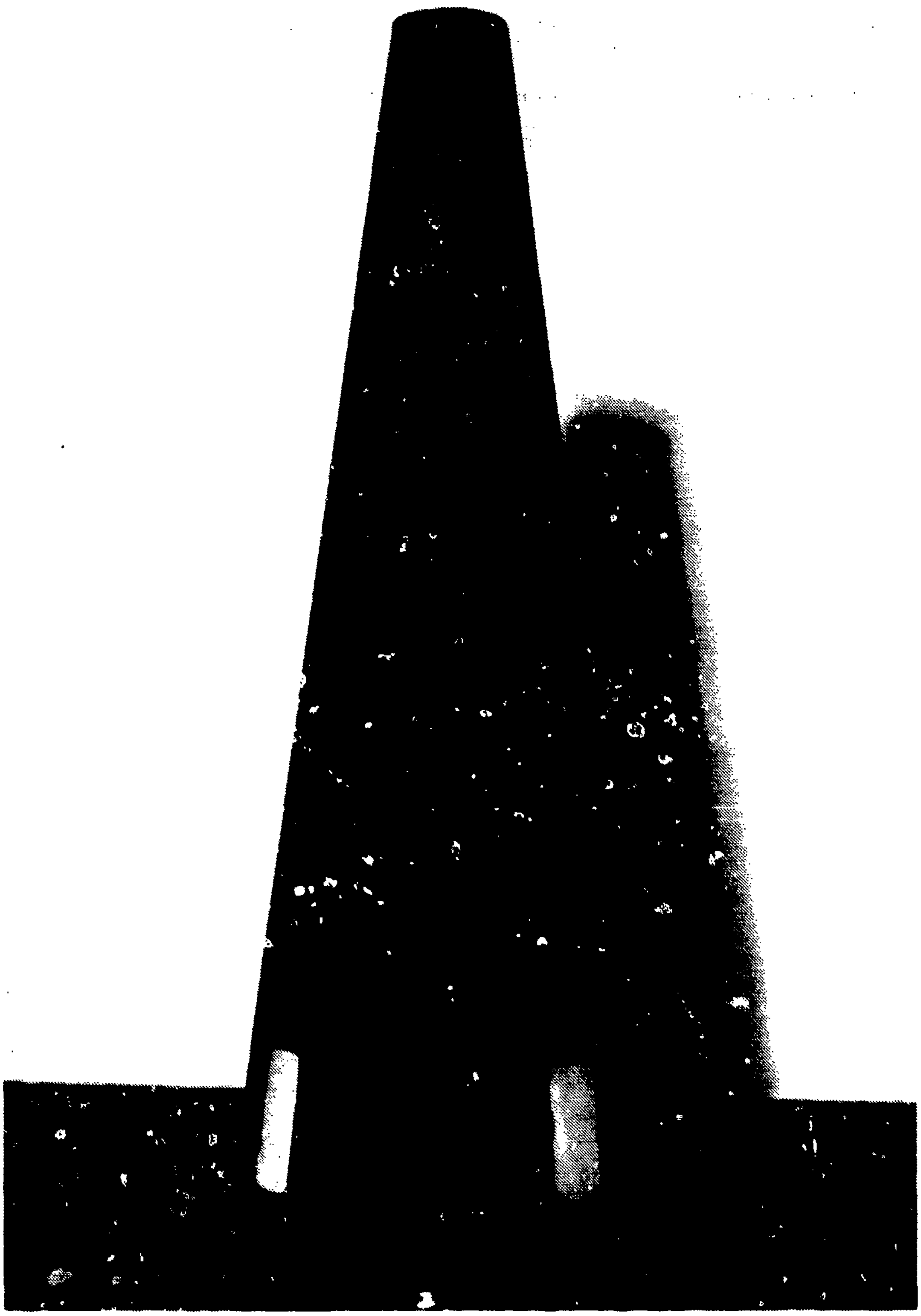


Figure 5. Bonded Heatshield/Antenna Window Assembly

5.0 TEST VEHICLE DESCRIPTION

The three-stage TATER rocket, Figure 6, which is comprised of a first-stage Talos motor, a second-stage Terrier motor, and a third-stage Recruit motor was used as the launch vehicle for the FY76 SAMS Program (Reference 1). The vehicle can obtain a maximum velocity of 10,400 to 10,600 fps at an altitude of 14,500 feet with a 70-pound payload when launched from sea level at an angle of 28 degrees above the horizontal. The payload with its nosetip and heatshield experiments is equipped with a parachute and flotation system for recovery from the ocean.

The TATER rocket vehicle was launched from the NASA Wallops Flight Center, Virginia. This site was selected because it exhibited a relatively high frequency of occurrence of widespread stratiform storms and was readily accessible. Each storm was measured and interpreted by the Air Force Geophysics Laboratory with special S-band weather radars, ground base instruments, and specially instrumented aircraft (Reference 2).

Payload recovery was by means of helicopter or ship.

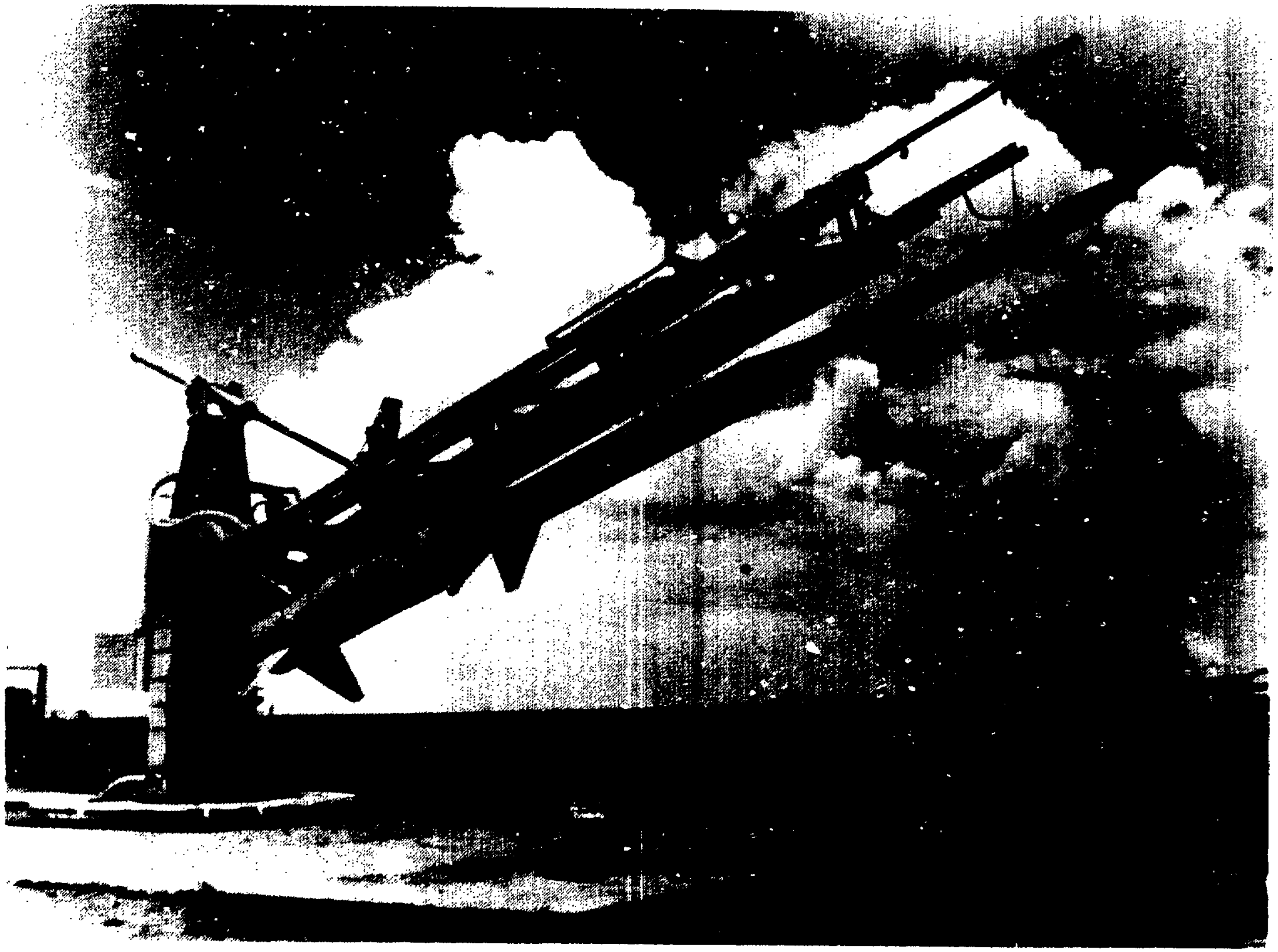


Figure 6. SAMS/TATER Launch Assembly

6.0 ABLATION TESTS

The objective of the FY76 SAMS Program was to experimentally evaluate the erosive effects of high-speed particles on heatshield and nosetip materials. Materials evaluation was based primarily on pre- and post-flight measurements and observations of recovered materials. Four of the SAMS/TATER flights were scheduled as weather tests and one a clear air test.

Recession data from a weather shot represents the integrated ablative/erosive response of the test materials to the meteorological environment of that particular flight. Since flight environments vary significantly from flight test to flight test, it becomes important to have a means of separating ablative recession from erosive recession.

The AFFDL 50 MW arc-jet test provides basic ablation rate data under simulated flight conditions to permit direct comparisons of the ablative performance of materials. The 50 MW tests provide the additional advantage of visual observation, through motion picture coverage, of the material during ablation testing.

Each of the SAMS/TATER heatshield materials was tested in the 50 MW facility under simulated ICBM flight conditions. Additionally, one test run was made at simulated SAMS/TATER clear air conditions to provide a data base for SAMS/TATER flight test correlations. The results of the tests are listed in Section 7.0.

7.0 FLIGHT AND ABLATION TEST RESULTS

Four SAMS/TATER flights were successfully launched during the FY76 SAMS Program. The first flight, Flight 602, was a clear air launch from the Tonopah Test Range, Nevada. The next three flights, Flights 509, 516 and 512, were weather shots from the NASA Wallops Flight Center, Virginia. Heatshield and antenna window performance for each flight are presented in the following subsections along with 50 MW ablation test results.

7.1 50 MW Ablation Tests

Ablative recession rates for each heatshield material are reported in Table 4 (Reference 3). The 2DCP20^{o} (Pitch) material was run at both simulated SAMS/TATER and ICBM flight conditions. This material was selected for SAMS/TATER ablative simulation testing since it was the only experimental material to be flown in the SAMS/TATER clear air environment.

Table 4. 50 MW Ablation Test Results

HEATSHIELD MATERIAL	AVERAGE ABLATION RATE, INCH/SECOND
SAMS/TATER SIMULATION	
2D Carbon (Pitch)/Phenolic 20^{o}	0.012 (2)
ICBM SIMULATION	
2D Carbon (Pitch)/Phenolic 20^{o}	0.024 (2)
2D Carbon/Phenolic 20^{o} (Reference Material)	0.023 (5)
2D Carbon/Rubber Modified Phenolic 20^{o}	0.032 (3)
3D Quartz/Phenolic	0.038 (3)
2D Carbon/Phenolic 70^{o}	0.061 (1)

( ) Number of Specimens Tested

Comparison of the average ablative rates for 2DCP20° (Pitch) at ICBM, 0.024-in/sec, and SAMS/TATER, 0.012-in/sec, conditions shows that the ablation rate at ICBM simulation is twice the ablation rate at SAMS/TATER simulation. Since the ablation rate of 2DCP20° (Reference), 0.023-in/sec, is approximately the same at ICBM simulation as 2DCP20° (Pitch), 0.024-in/sec, it is reasonable to project that the reference material would ablate at the same rate as the 2DCP20° (Pitch) under SAMS/TATER clear air flight conditions. This was found to be a valid projection as discussed in the subsection on Flight 602.

The overall ablative ranking of the experimental heatshield materials can be divided into four groups based on the 50 MW ablative data reported in Table 4 and other film data and post-test observations. The differences in the ablation rates reported within each group are less than the data uncertainties. The groups are presented in order of ascending ablation rate.

Group I:	2DCP20° (Reference) 2DCP20° (Pitch)
Group II:	2DCR-10 20°
Group III:	3DQP
Group IV:	2DCP70°

A relative ablative ranking of heatshield materials can be assigned to each group based on a unit ablative rate for the Group I materials as follows:

	Relative 50 MW Ablation Factor
Group I	1.0
Group II	1.3
Group III	1.6
Group IV	2.5

For a complete discussion of the SAMS/TATER 50 MW tests, see Reference 3 of this report.

7.2 Flight 602

Flight 602 (Sandia Vehicle R487602) was launched from the Tonopah Test Range, Nevada, through clear air on January 14, 1976. The experimental heatshield material was two-dimensional, aft facing 20°, bias tape-wrapped carbon (Pitch)/phenolic; i.e., 2DCP20° (Pitch). The heatshield did not contain an antenna window experiment.

The recovered heatshield is shown in Figures 7 through 10. A water recovery system was used to recover the payload which resulted in a ground impact velocity of approximately 90 fps (Reference 4). The high impact velocity caused the nosetip and heatshield to penetrate approximately 18 inches into the ground. Although the impact did not damage either the experimental or reference heatshield, it did result in bond failure which caused a separation of the quadrants from the substrate at the forward end of the quadrants as shown in Figures 11 and 12.

Post-flight measurements at the aft end of the heatshield quadrants, where no separation had occurred, showed that sidewall recession was minimal for both heatshield materials. Therefore, the experimental and reference panels were removed from the substrate to obtain more accurate measurements over the entire axial length of the quadrant panels. The sidewall recessions for both materials were found to be equivalent, with a maximum measured value of 0.008 inch.

No anomalies were noted in the surface appearance of the post-flight experimental or reference materials. Both materials displayed typical carbon/phenolic char layers approximately 70 mils thick with the pitch material having a slightly rougher surface than the reference material.

7.3 Flight 509

Flight 509 (Sandia Vehicle R487509) was launched from the NASA Wallops Flight Center, Virginia, through a light storm, on March 9, 1976. The experimental heatshield material was three-dimensional quartz/phenolic; i.e., 3DQP. The experimental antenna window material was three-dimensional astroquartz/silica; i.e., AS-3DX. The pre-flight heatshield assembly is shown in Figure 13.

The recovered heatshield and antenna windows are shown in Figures 14 through 17. There was a slight separation of the reference material quadrants from the substrate at the forward end of the quadrants as shown in Figure 18. Neither of the 3DQP experimental quadrants separated. The leading edges of the separated quadrants were not ablated. This indicates that separation occurred very late in the flight and might be due to rapid cool down shortly before or at the time the payload entered the water.

Post-flight recession measurements of the heatshield materials were made to determine recession as a function of axial distance from the forward end of the experimental heatshield. Table 5 presents the measurements in tabular form and Figure 19 shows the data graphically.

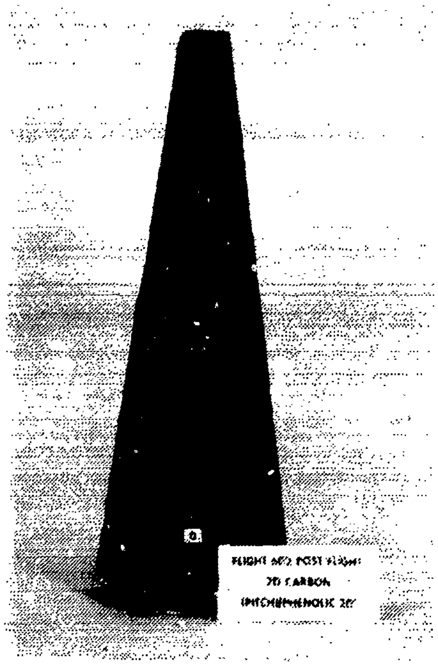


Figure 7. Flight 602 Post-Flight 2DCP20°, 0° Quadrant

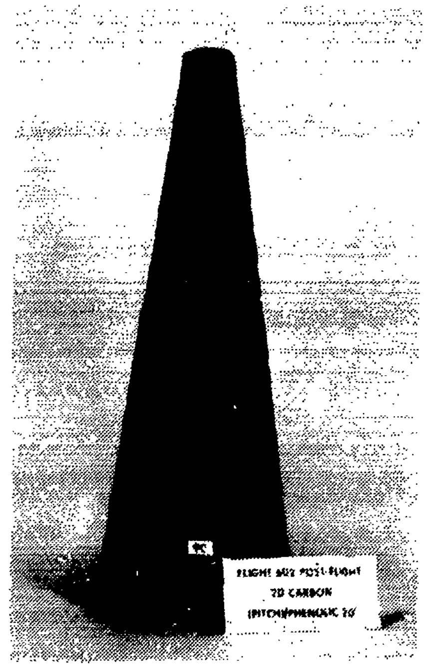


Figure 8. Flight 602 Post-Flight 2DCP20° (Pitch), 90° Quadrant

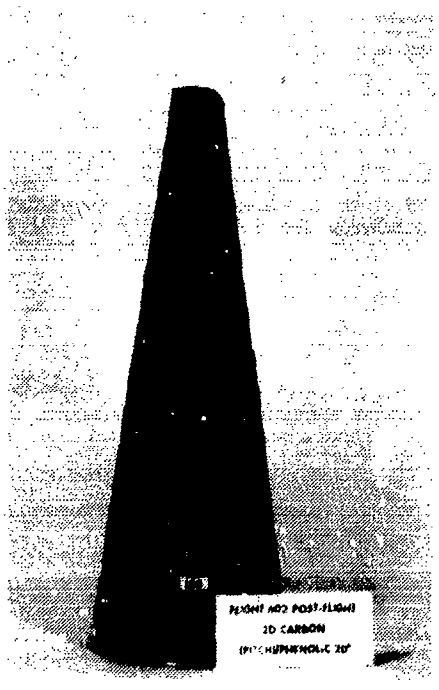


Figure 9. Flight 602 Post-Flight 2DCP20°, 180° Quadrant

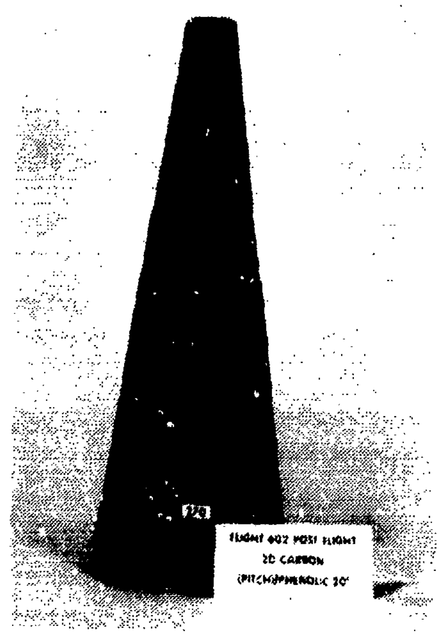


Figure 10. Flight 602 Post-Flight 2DCP20° (Pitch), 270° Quadrant

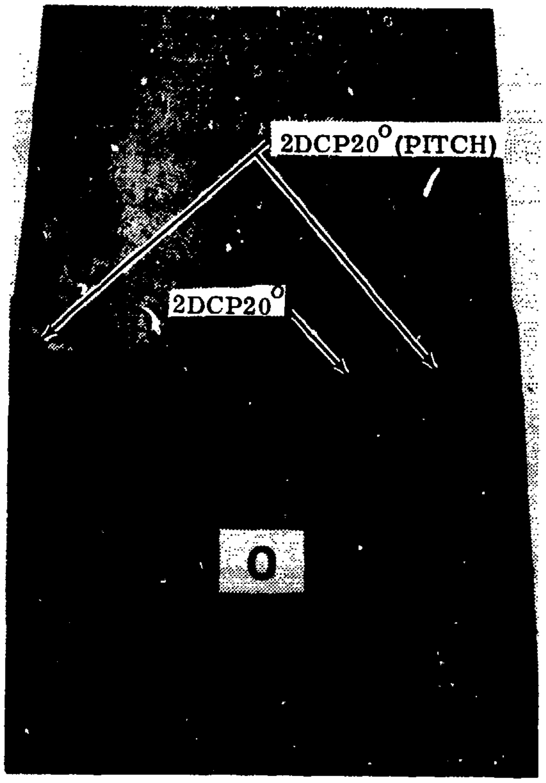


Figure 11. Separation of Forward Edge of 2DCP20° and 2DCP20° (Pitch) Quadrants, 0°

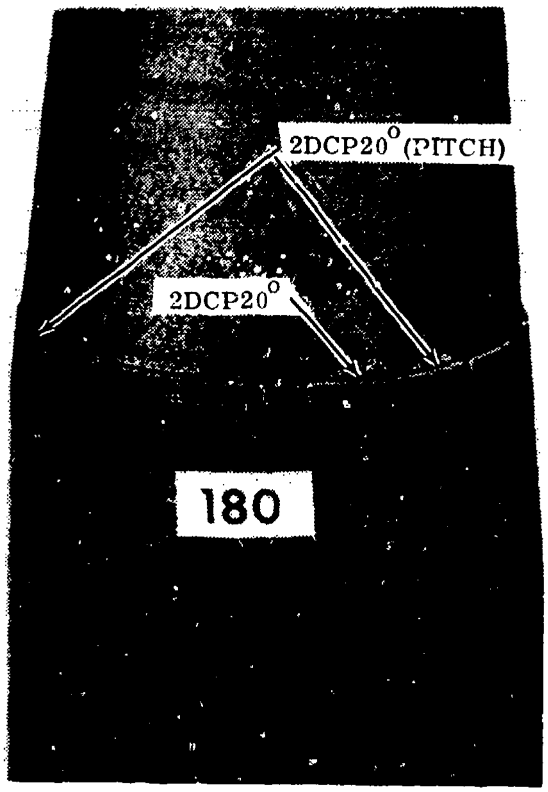


Figure 12. Separation of Forward Edge of 2DCP20° and 2DCP20° (Pitch) Quadrants, 180°

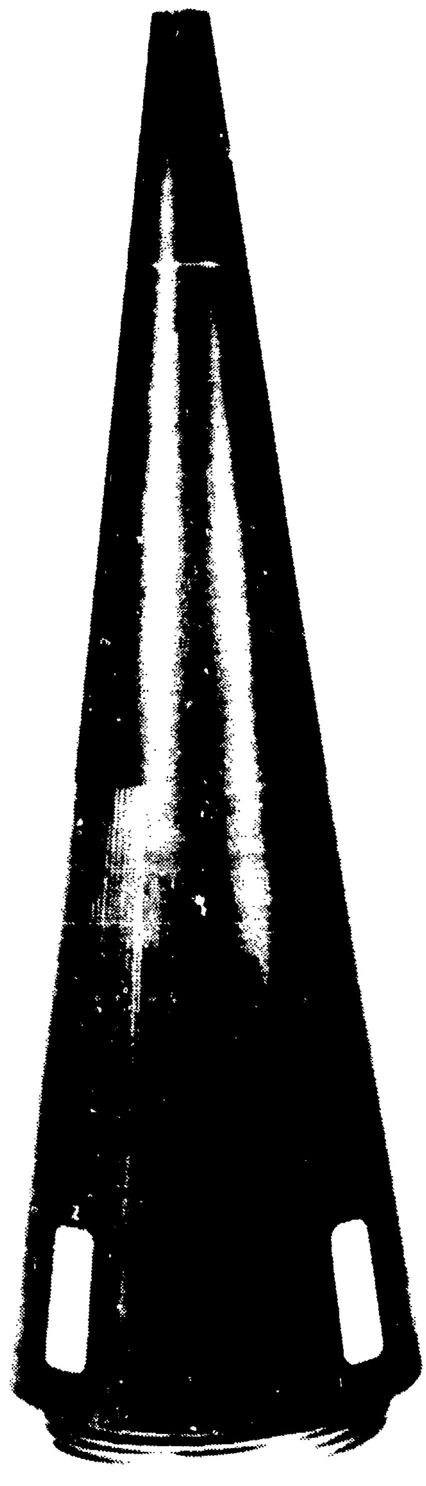


Figure 13. Flight 509 Pre-Flight Heatshield/Antenna Window Assembly

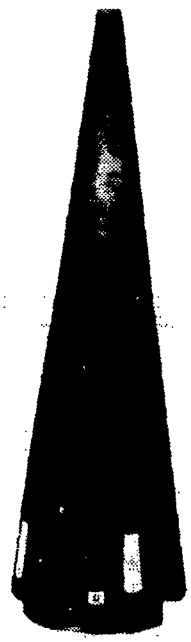


Figure 14. Flight 509 Post-Flight 3DQP, 0^{o} Quadrant

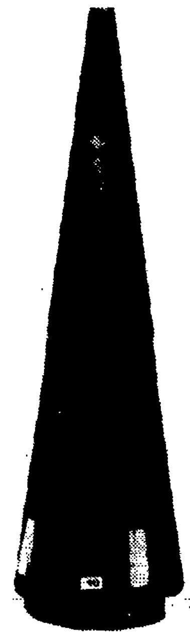


Figure 15. Flight 509 Post-Flight 2DCP20^{o}, 90^{o} Quadrant

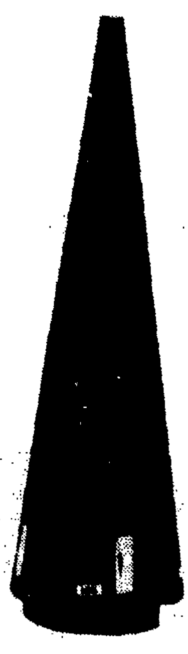


Figure 16. Flight 509 Post-Flight 3DQP, 180^{o} Quadrant

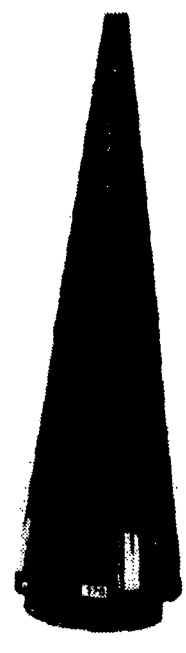


Figure 17. Flight 509 Post-Flight 2DCP20^{o}, 270^{o} Quadrant

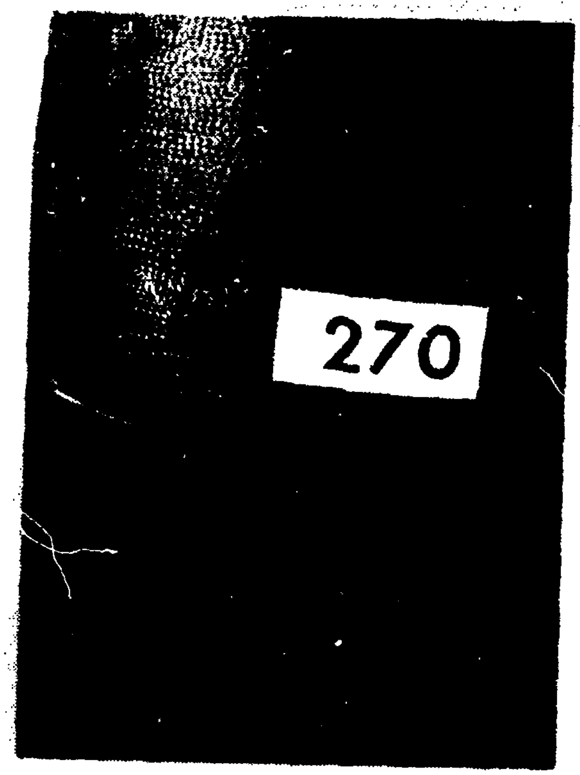


Figure 18. Separation of Forward Edge of 2DCP20^{0} Quadrant

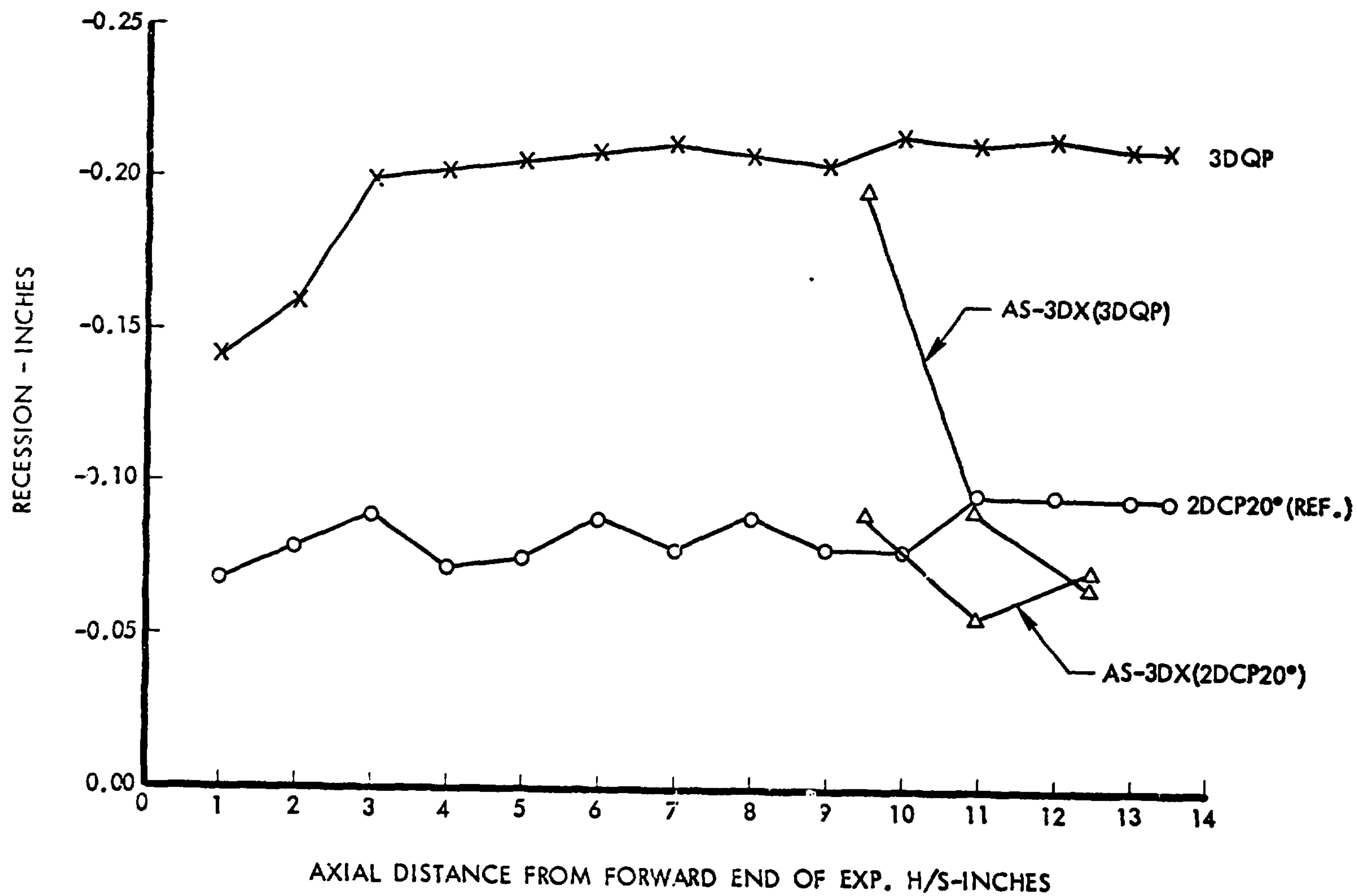


Figure 19. SAMS/TATER Flight 509 Heatshield/Antenna Window Recession Profile

Table 5. SAMS/TATER Flight 509 Heatshield Recession Measurement Results

Station Number	2DCP20° Sidewall Recession (Inch)	3DQP Sidewall Recession (Inch)
1	0.068	0.142
2	0.078	0.160
3	0.089	0.200
4	0.072	0.204
5	0.075	0.206
6	0.088	0.210
7	0.078	0.211
8	0.089	0.208
9	0.078	0.205
10	0.078	0.215
11	0.096	0.212
12	0.096	0.214
13	0.094	0.210
13.5	0.095	0.210

The data were obtained from pre- and post-flight diameter measurements of the heatshield materials. Average recession of the 3DQP experimental material was 0.209 inch. The 2DCP20° reference material average recession was 0.086 inch. Average recession was determined between the 3-inch and 13.5-inch axial positions. The data show that sidewall recession of 3DQP is 2.4 times greater than 2DCP20° in the SAMS/TATER erosion/ablation environment. This difference in sidewall recession is very evident when viewed from the aft end of the heatshield as shown in Figure 20.

The post-flight surface of the 2DCP20° reference material displayed a typical carbon/phenolic char layer of average roughness, Figure 21. The surface of the 3DQP experimental material is shown in Figure 22. The measured thickness of the 3DQP surface char layer was approximately 20 mils compared to a 70 mil char layer for the 2DCP20°. Surface roughness was similar to that observed in 50 MW testing and is characterized by a rectangular pattern of roughness caused by a more rapid recession of quartz fiber in the longitudinal and circumferential directions than in the radial direction.

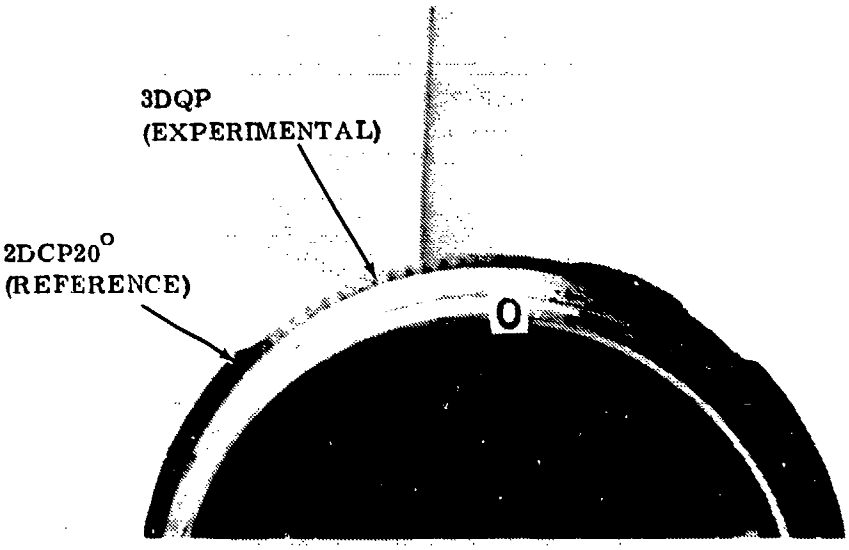


Figure 20. Aft End of Flight 509 Post-Flight

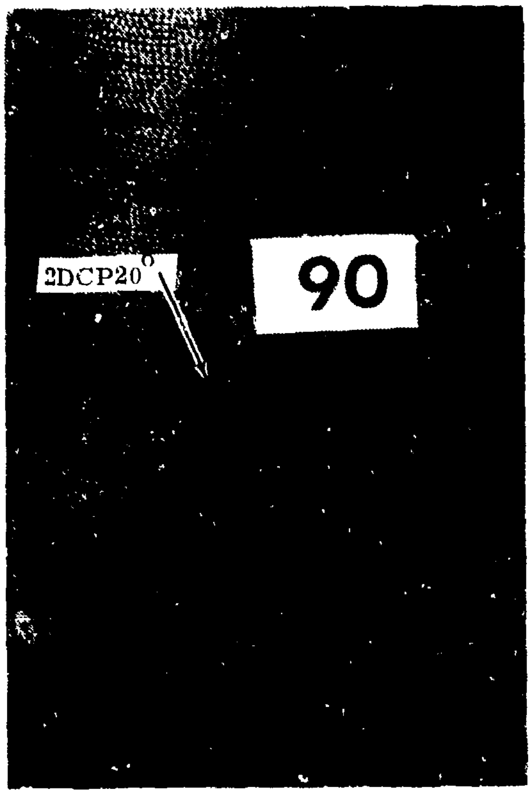


Figure 21. Post-Flight Surface of 2DCP20°

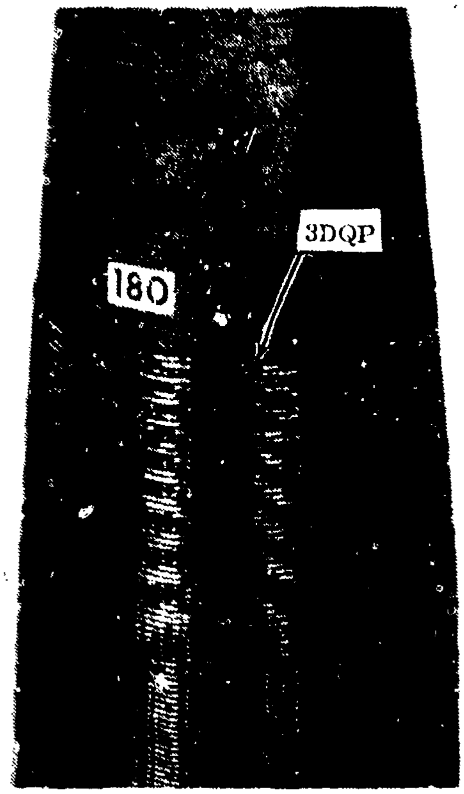


Figure 22. Post-Flight Surface of 3DQP

Table 6 and Figure 19 present the post-flight recession measurements for AS-3DX antenna window material in the 2DCP20° and Figure 23 shows the approximate equal recession of the two materials. The data show that the antenna windows recessed slightly less than the adjacent 2DCP20° material. This indicates that the recession rate of AS-3DX is compatible with 2DCP20° in an ablative/erosive environment.

Table 6. SAMS/TATER Flight 509 Antenna Window Recession Measurement Results

Station Number	AS-3DX Sidewall Recession in 2DCP20° (in.)	AS-3DX Sidewall Recession in 3DQP (in.)
9.5	0.090	0.196
11	0.056	0.091
12.5	0.072	0.067

Table 6 and Figure 19 also present the recession data for AS-3DX in the 3DQP heat-shield material. As seen in Figure 24, the AS-3DX formed a wedge shape in the 3DQP. The wedge shape was produced by the more rapid recession of the 3DQP which caused the antenna window to develop a forward facing step at its leading edge. Augmented aerodynamic heating and erosion of the step resulted in the wedge configuration. Figure 24 also shows that the 3DQP material behind the antenna window was protected by the lower recession rate of the AS-3DX. The test results indicate that the recession rate of AS-3DX is not compatible with 3DQP in an ablative/erosive environment.

The post-flight surface of the AS-3DX is shown in Figure 25. The surface is characterized by a square pattern of roughness which, like the 3DQP, is caused by a more rapid recession of longitudinal and circumferential fibers.

7.4 Flight 516

Flight 516 (Sandia Vehicle R487516) was launched from the NASA Wallops Flight Center, Virginia, through a light storm, on March 27, 1976. The experimental heatshield material was two-dimensional, aft facing 20°, bias tape-wrapped carbon/rubber modified phenolic (R-10); i.e., 2DCR-10 20°. The experimental antenna window material was hot pressed boron nitride; i.e., TS-1251. The pre-flight heatshield assembly is shown in Figure 26.

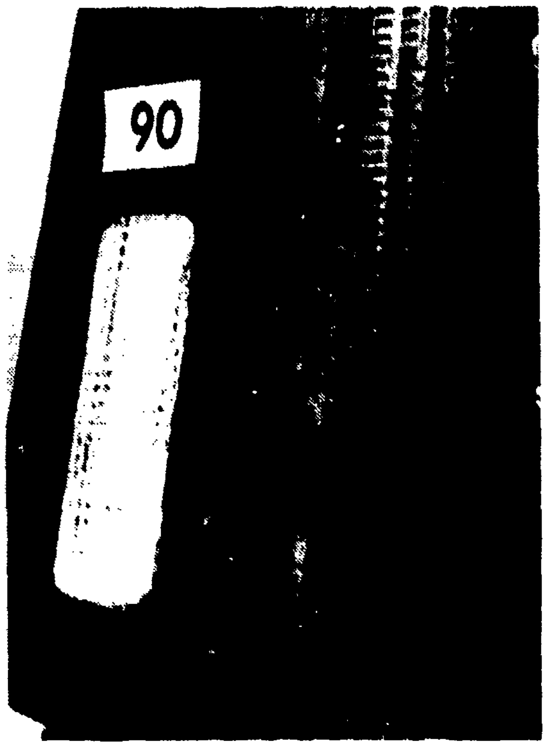


Figure 23. Post-Flight AS-3DX in 2DCP20°

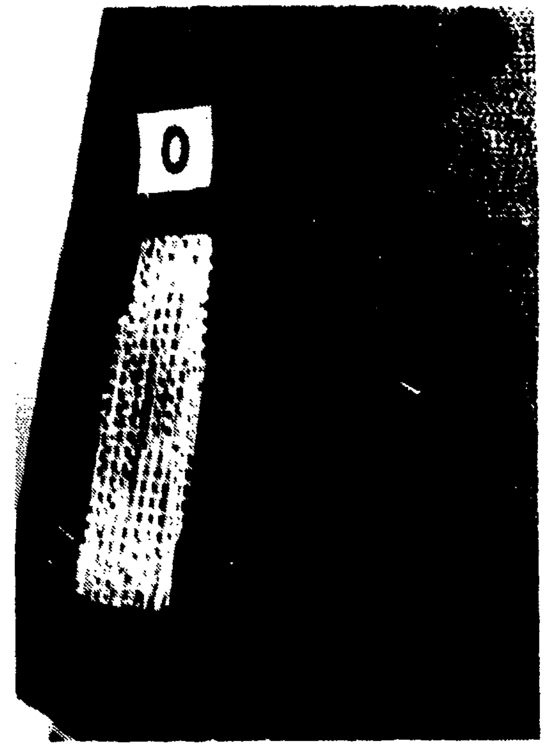


Figure 24. Post-Flight AS-3DX in 3DQP

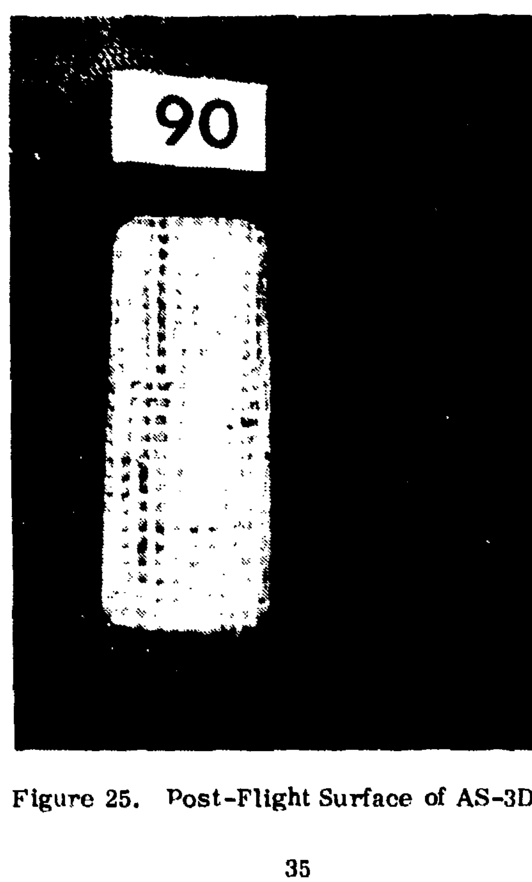


Figure 25. Post-Flight Surface of AS-3DX

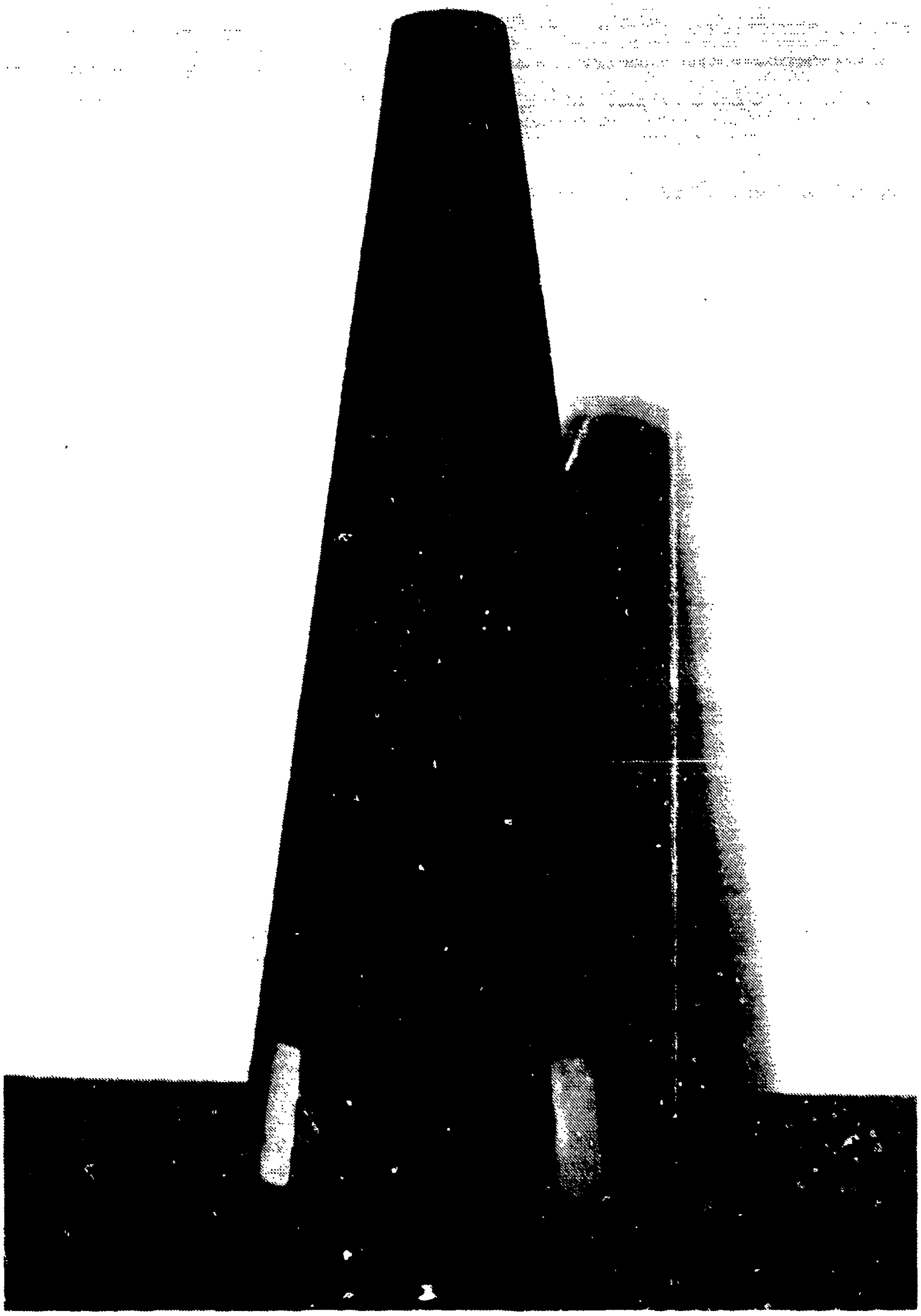


Figure 26. Flight 516 Pre-Flight Heatshield/Antenna Window Assembly

The recovered heatshield and antenna window are shown in Figures 27 through 30. The forward ends of the reference quadrants separated from the substructure as was the case on Flight 509. One quadrant had pronounced separation as shown in Figure 31; the other reference panel was separated only slightly as shown in Figure 32. Figures 31 and 32 also show that the leading edges of the separated quadrants were not ablated, indicating that separation occurred very late in the test. Neither of the 2DCR-10 20^{o} experimental material quadrants showed any evidence of separation.

Post-flight recession measurements were made of the heatshield materials to establish sidewall recession as a function of axial distance from the forward end of the experimental heatshield. Table 7 presents the measurements in tabular form and Figure 33 shows the data graphically. Recession data for the experimental material were obtained from pre- and post-flight diameter measurements of the 2DCR-10 20^{o}. Separation of the reference material from the substructure necessitated cutting the heatshield assembly into sections so that accurate sidewall recession measurements could be obtained on the 2DCP20^{o} material.

Table 7. SAMS/TATER Flight 516 Heatshield Recession Measurement Results

Station Number	2DCP20^{o} Sidewall Recession (in)	2DCR-10 20^{o} Sidewall Recession (in)
1	0.004	0.084
2		0.114
3		0.130
4		0.140
5		0.142
6		0.140
7	0.015	0.152
8		0.150
9		0.158
10		0.172
11		0.142
12	0.002	0.165
13		0.151
13.5	0.002	0.173

The average sidewall recession of the 2DCR-10 20^{o} experimental material was 0.151 inch. Average recession was determined between the 3-inch and 13.5-inch axial positions. Maximum measured recession for the reference material was 0.015 inch. Recession of the reference material at four axial positions was obtained by direct measurement of the cut sections.

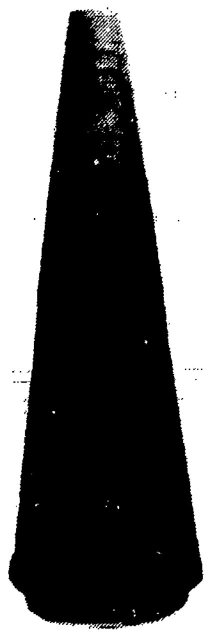


Figure 27. Flight 516 Post-Flight
2DCP20°, 0° Quadrant

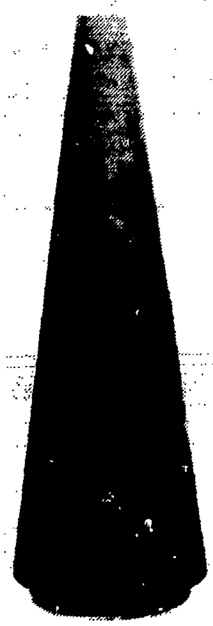


Figure 28. Flight 516 Post-Flight
2DCR-10 20°, 90° Quadrant

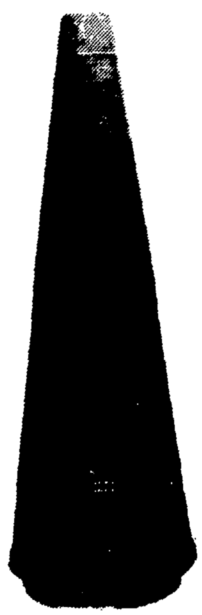


Figure 29. Flight 516 Post-Flight
2DCP20°, 180° Quadrant

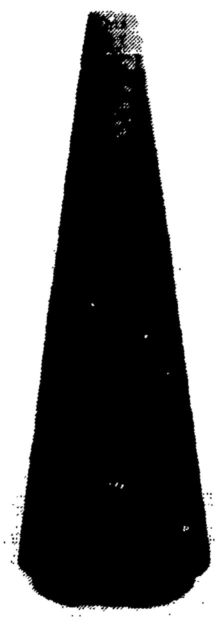


Figure 30. Flight 516 Post-Flight
2DCR-10 20°, 270° Quadrant

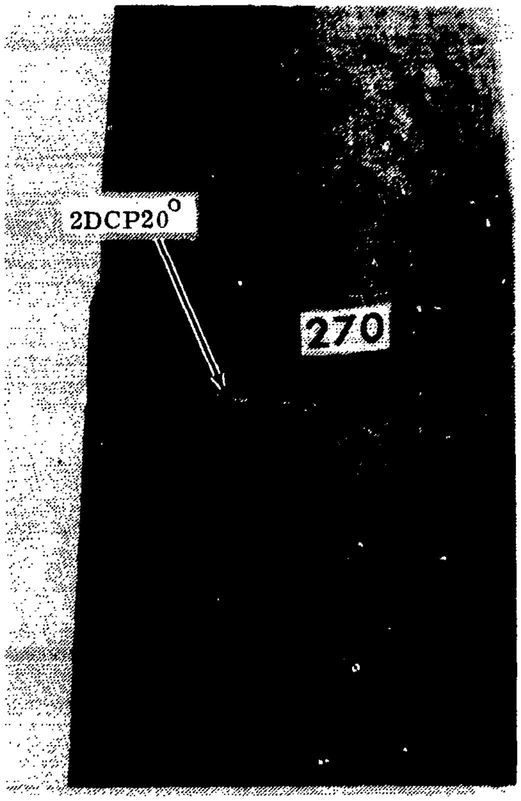


Figure 31. Pronounced Separation of 2DCP20° Quadrant

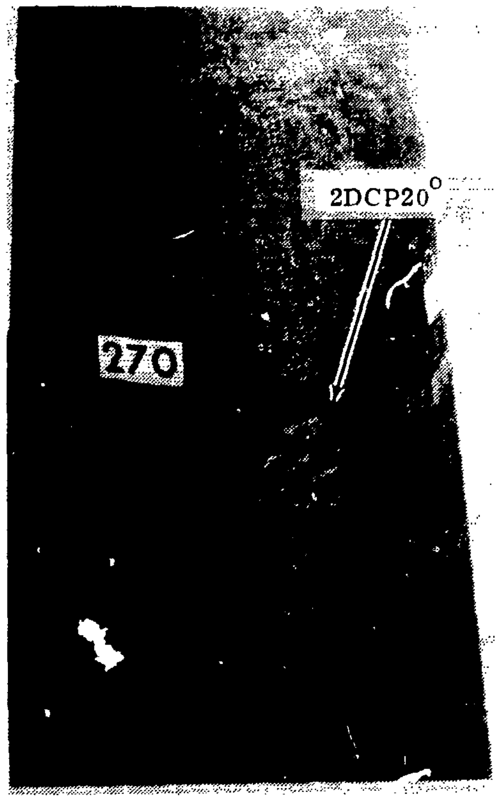


Figure 32. Slight Separation of 2DCP20° Quadrant

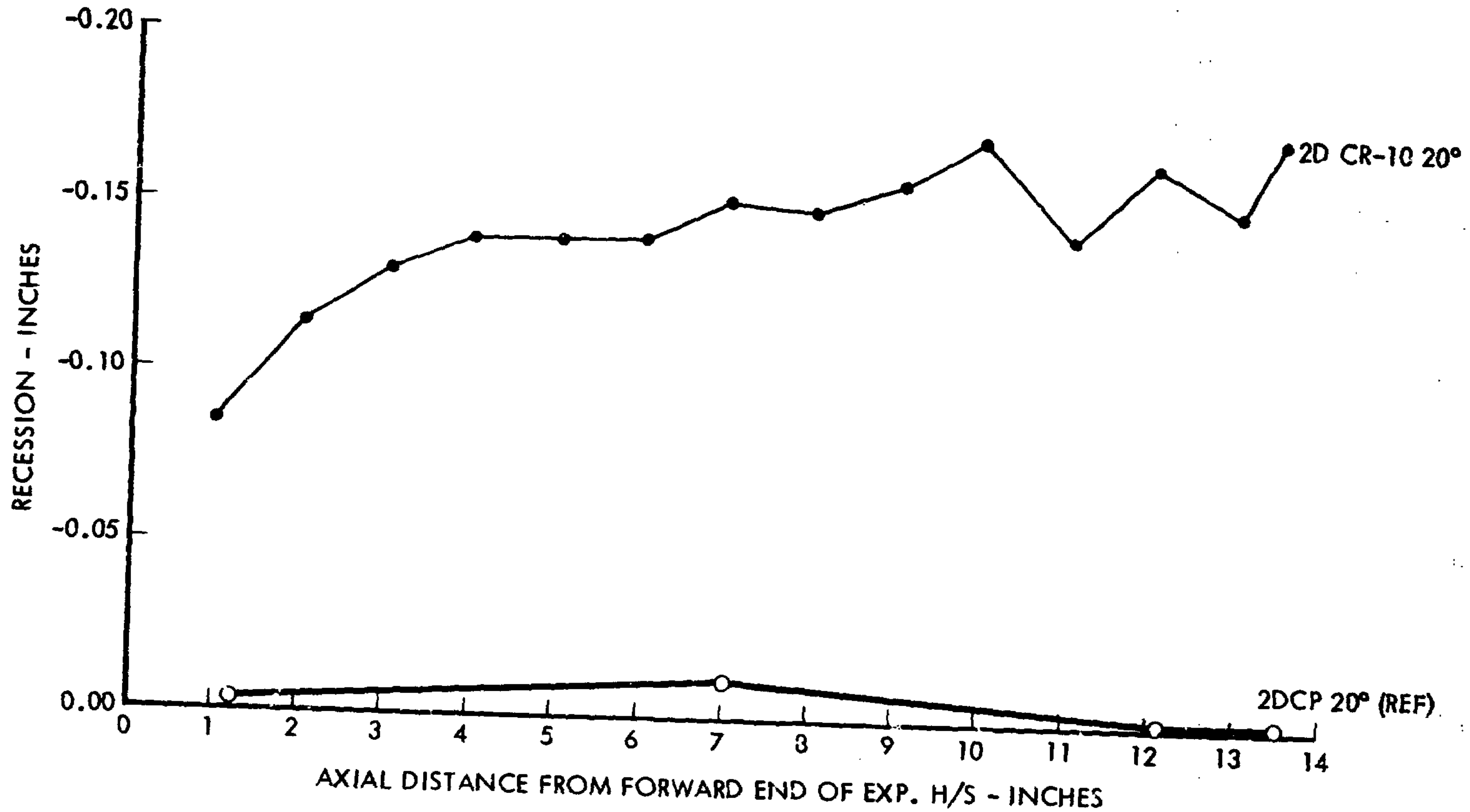


Figure 33. SAMS/TATER Flight 516 Heatshield Recession Profile

The data show that the sidewall recession of 2DCR-10 20^{o} is ten times greater than 2DCP20^{o} in the SAMS/TATER erosion/ablation environments. Figure 34 is a view of the aft end of the heatshield in which the difference in recession of the two materials is very evident.

The post-flight surface of the 2DCP20^{o} reference material displayed a typical carbon/phenolic char layer of average roughness, Figure 35. The surface of the 2DCR-10 20^{o} experimental material is shown in Figure 36. The surface char layer of 2DCR-10 20^{o} was approximately 70 mil in thickness which is the same as that observed for the 2DCP20^{o} reference material. However, as had been observed in the 50 MW test specimens, the char layer of the 2DCR-10 20^{o} was very soft and spongy, indicating that very little of the resin matrix remained in the layer after exposure to the Flight 516 ablation/erosion environment.

All four of the hot pressed boron nitride (TS-1251) antenna windows were lost during flight with three of the windows being totally removed as shown in Figures 37 and 40. The loss and severe ablation of the interlock rods as shown in Figure 38, 39 and 40, indicate that the antenna window material was lost early in the flight. Approximately 0.20-inch remained of the fourth antenna window, Figure 37, which was in 2DCP20^{o} reference material. The interlock rods in the fourth window were intact and showed only slight recession. This indicates that window removal occurred late in the flight. The appearance of the TS-1251 material in the fourth window indicates that removal was due to stress cracking and was not caused by ablation/erosion.

7.5 Flight 512

Flight 512 (Sandia Vehicle R487512) was launched from the NASA Wallops Flight Center, Virginia, through a light storm, on April 25, 1976. The experimental heatshield material was two dimensional aft facing, 70^{o} tape-wrapped carbon/phenolic; i.e., 2DCP 70^{o}. The experimental antenna window material was three-dimensional boron/nitride ; i.e., BN-3DX. The pre-flight heatshield assembly is shown in Figure 41.

During helicopter recovery of the payload from the ocean, the swivel between the parachute shroud lines and the recovery package unscrewed, allowing the payload to fall approximately 1,000 feet into the water. The payload was recovered by Navy divers; however, the heatshield panels and nosetip were missing. A subsequent search for the lost panels was unsuccessful.

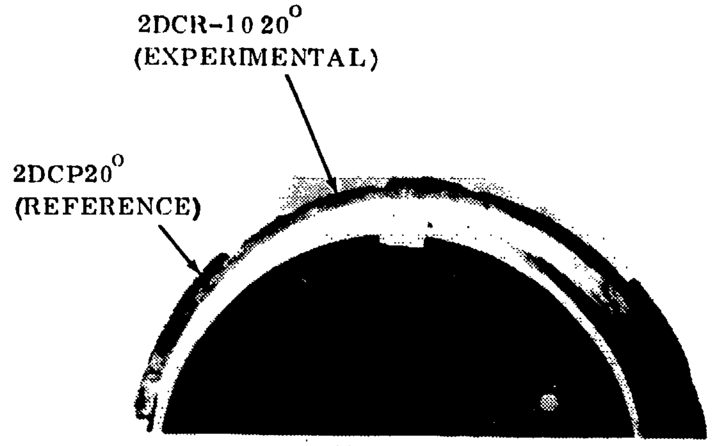
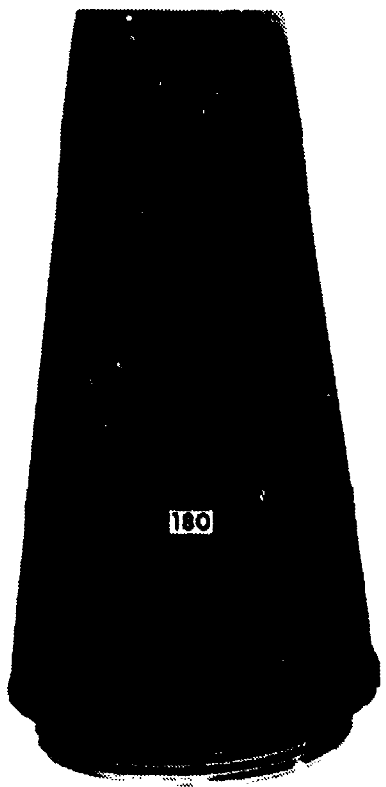


Figure 34. Aft End of Flight 516 Post-Flight



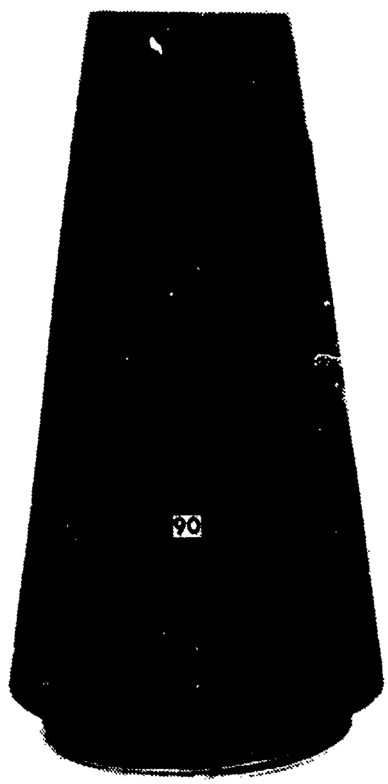


Figure 35. Post-Flight Surface of 2DCP20°

Figure 36. Post-Flight Surface of 2DCR-10 20°

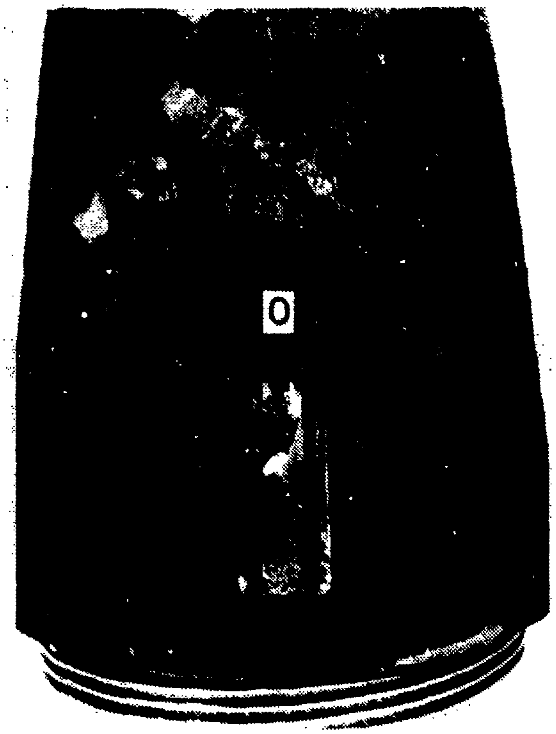


Figure 37. Post-Flight TS-1251 in 2DCP20°, 0° Quadrant

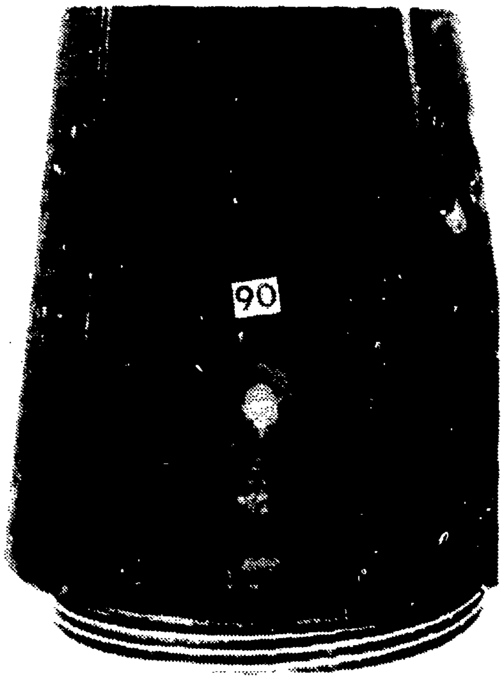


Figure 38. Post-Flight TS-1251 in 2DCR-10 20°, 90° Quadrant

Figure 39. Post-Flight TS-1251 in 2DCP20°, 180° Quadrant

Figure 40. Post-Flight TS-1251 in 2DCR-10 20°, 270° Quadrant

Figure 41. Flight 512 Pre-Flight Heatshield/Antenna Window Assembly

The recovered heatshield assembly is shown in Figures 42 through 45. Figures 46 and 47 show that a portion of one of the 2DCP20^{o} panels and some of the EA-934 epoxy adhesive remained on the substructure despite the severe impact conditions. Loss of the panels precluded any direct measurements of recession of the heatshield and antenna window materials.

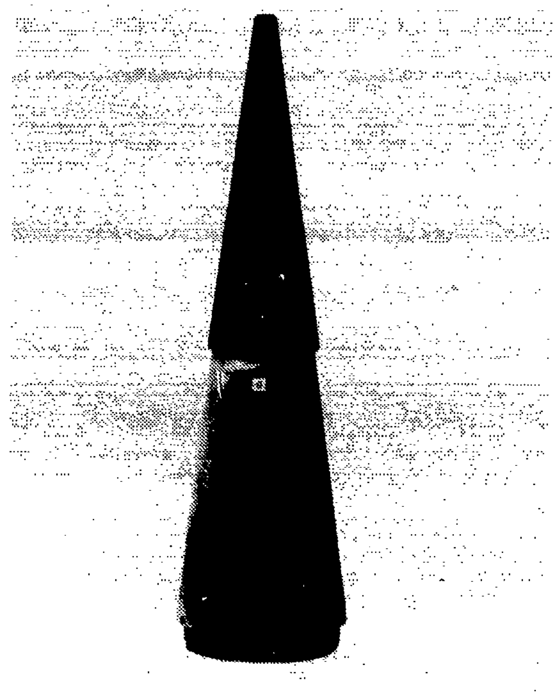


Figure 42. Flight 512 Post-Flight 2DCP20°, 0° Quadrant

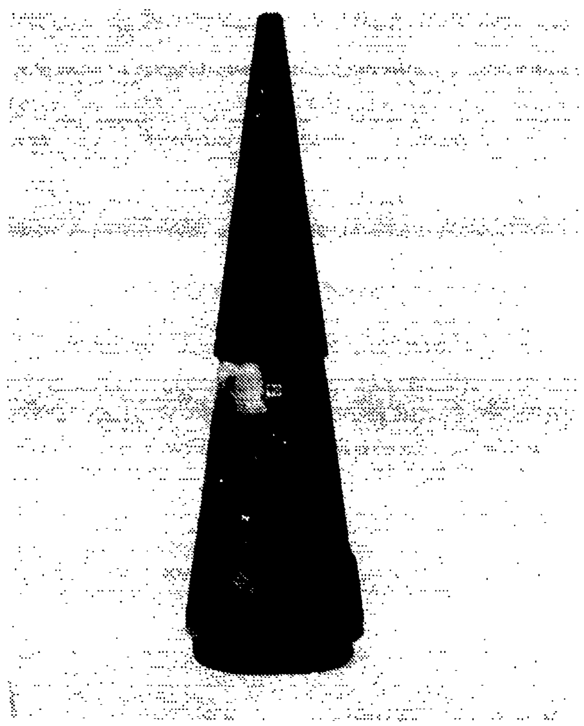


Figure 43. Flight 512 Post-Flight 2DCP70°, 90° Quadrant

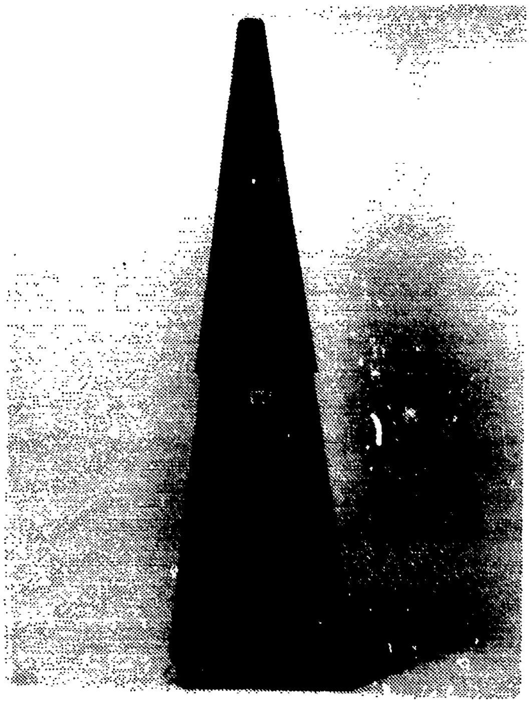


Figure 44. Flight 512 Post-Flight 2DCP20°, 180° Quadrant

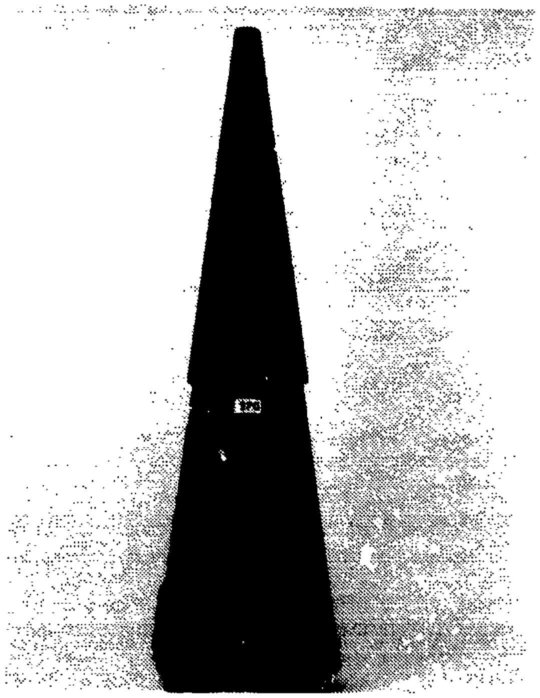


Figure 45. Flight 512 Post-Flight 2DCP70°, 270° Quadrant

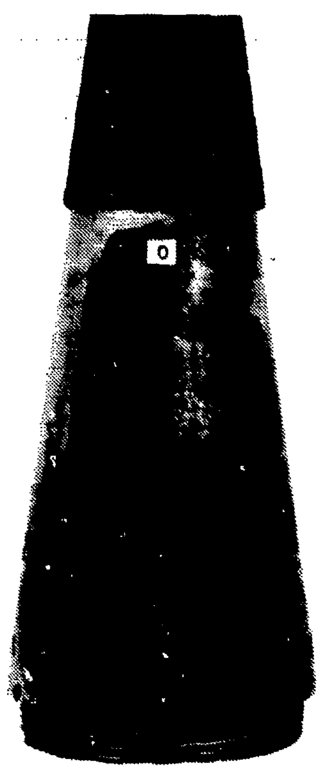


Figure 46. 2DCP20° Remaining on Flight 512 Post-Flight Substructure

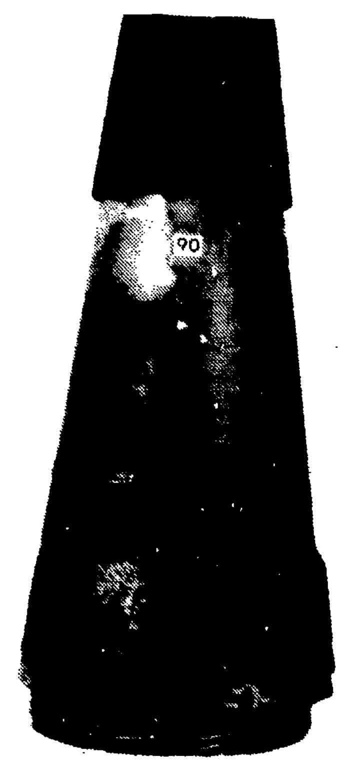


Figure 47. EA-934 Adhesive Remaining on Flight 512 Post-Flight Substructure

8.0 DISCUSSION OF RESULTS

Test results of the FY76 SAMS/TATER Heatshield/Antenna Window Flight Test Program are discussed in the following subparagraphs in accordance with the flight test number.

8.1 Flight 602

Flight 602 was a clear air launch from the Tonopah Test Range, Nevada. The heat-shield materials were exposed to an ablative environment only. The measured sidewall recessions for the 2DCP20^{o} (Pitch) experimental material and 2DCP20^{o} reference material were found to be equivalent with a maximum recession of 0.008-inch.

Results of the 50 MW tests, Section 7.1, showed that the ablation rate of 2DCP20^{o} (Pitch) is essentially the same as 2DCP20^{o} reference material. Both materials were categorized in Group I, which has the lowest ablation rate of the materials tested. The equivalent recession of the two materials in an ablative clear air flight environment confirms the results obtained in 50 MW ground testing. The difference in ablation rate between ground testing, 0.012-inch/second, and flight testing, 0.008-inch/second, can be attributed to the fact the material is exposed to peak heating conditions longer in 50 MW ground testing than during actual flight.

Results of both flight and ground testing indicate that 2D carbon/phenolic 20^{o} (Pitch) is an excellent clear air ablator and is equivalent to 2D carbon/phenolic 20^{o} reference material in the clear air SAMS/TATER trajectory.

8.2 Flight 509

Flight 509 was a weather launch through a light storm from NASA Wallops Flight Center, Virginia. The sidewall recession of the 3DQP experimental material was 2.4 times greater than the 2DCP20^{o} reference material.

As discussed in Section 7.1, 3DQP was ranked in Group III of the 50 MW ablation test materials. This group has an ablation factor 1.6 times greater than the 2DCP20^{o} reference material (Group I).

A relatively thin 20 mil char layer was observed on the post-flight 3DQP while the 2DCP20° reference material had a 70 mil char layer. This indicates that the char layer which was formed during ablation of the 3DQP was removed at a rapid rate in the Flight 509 erosive environment.

The data presented in Section 7.3 show that the recession rate of AS-3DX antenna window material is compatible with 2DCP20° in an ablative/erosive environment. The test results also show that AS-3DX would not be a suitable antenna window material for use with 3DQP heatshield materials because of the high ablation/erosion rate of the 3DQP.

8.3 Flight 516

Flight 516 was a weather launch through a light storm from NASA Wallops Flight Center, Virginia. The average sidewall recession of the 2DCR-10 20° experimental material was ten times greater than the 2DCP20° reference material.

As previously discussed, 2DCR-10 20° was ranked in Group II of the 50 MW ablative test materials. This group has an ablation factor 1.3 times greater than 2DCP20° reference material (Group I).

As previously noted, the surface of the 2DCR-10 20° material was characterized by a very soft and spongy char layer. The low physical strength of the char layer is probably responsible for the high recession rate of the material in the Flight 516 erosive environment. In contrast, the 2DCP20° reference material had a hard, firm char layer typical of a charred carbon/phenolic.

Loss of the hot-pressed boron nitride (UCC TS-1251) antenna windows was probably due to thermal stress cracking of the material early in the flight. The low strength, relative brittleness, and apparent thermal stress sensitivity of TS-1251 severely limit the use of this material for flight antenna window applications.

8.4 Flight 512

Total loss of the quadrant panels during the severe impact of Flight 512 and separation of the forward end of the panels during the normal impact of previous flights indicates a need for modification of the panel attachment design. Future heatshield assemblies utilizing the quadrant design should interlock each panel with the 2DCP20^{0} heatshield material forward of the panel. A bonded lap joint with the panel material forming the bottom section of the lap should greatly reduce any tendency of the panel material to separate from the substructure under normal impact conditions.

9.0 CONCLUSIONS

The following conclusions are based on data developed during flight and ground testing of heatshield and antenna window materials in the FY76 SAMS/TATER Flight Test Program.

1. The ablation performance of 2D carbon/phenolic 20° (Pitch) heatshield material is equivalent to 2D carbon/phenolic 20° reference material in the clear air SAMS/TATER trajectory.

2. The ablation rate of 3D Quartz/Phenolic is 1.6 times greater than 2DCP20° reference material in the 50 MW ablation test.

3. The recession of 3DQP is 2.4 times greater than 2DCP20° reference material in the ablation/erosion SAMS/TATER weather environment.

4. The recession rate of AS-3DX antenna window material is compatible with 2DCP20° in an ablative/erosive environment.

5. AS-3DX is not a suitable antenna window material for use with 3DQP because of the high recession of 3DQP in an ablation/erosion environment.

6. The ablation rate of 2D carbon/rubber modified phenolic 20° is 1.3 times greater than 2DCP20° reference material in the 50 MW ablation test.

7. The recession of 2DCR-10 20° is ten times greater than 2DCP20° in the ablation/erosion SAMS/TATER environment.

8. The low strength, relative brittleness, and thermal stress sensitivity of hot pressed boron nitride (TS-1251) severely limit the use of TS-1251 for flight antenna window applications.

10. REFERENCES

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2. Cole, J. K. and Hochrein, G. J., "Particulate Erosion of Nosetips and Heatshields --Analysis of the SAMS Program Data," SAND 76-0255, Sandia Laboratories, Albuquerque, New Mexico, August 1976.

3. Alexander, E. C., "SAMS/TATER Heatshield Flight Test Program 50 MW Tests," PDA TR-1046-02-14, April 1976.

4. Hochrein, G. J., "Recession and Profile Measurements for the Test Hardware on Vehicle R487602," RS 1327/001, Sandia Laboratories, Albuquerque, New Mexico, April 1976.

APPENDIX I

GENERAL PROCESSING SPECIFICATION FOR SAMS/TATER HEATSHIELDS

1.0 MATERIALS

1.1 Purchased raw materials shall be accompanied by the supplier's certificate of conformance which shall include:

Supplier's name
Produce name, trade name, and/or numerical identification
Date of manufacture
Lot number and batch number
Material properties consisting of a record of applicable tests, test results, and test requirements

1.2 Inspection shall verify acceptability of materials to ensure that the supplier's certificates are in order.

1.3 Inspection will monitor shelf-life requirements and will initiate acceptance tests at 6-month intervals. These tests will be performed on prepreg and on specimens cut from molded test panels.

2.0 EQUIPMENT

2.1 A vacuum system capable of maintaining a minimum vacuum of 20 inches of mercury.

2.2 A hydroclave with an operating pressure capability of 950 psig, minimum. Recording instrumentation shall be provided for continual monitoring of pressure, temperature, and vacuum.

3.0 FABRICATION PROCEDURES

3.1 <u>Materials, Preparation of</u>

NOTE: Use strict cleanliness standards when preparing material.

3.1.1 Slit material into 45 degree bias tape of a given width.

3.1.2 The slit material shall be heat sealed or sewn with dacron thread into continuous length tape (maintaining face-to-back control), wound on spools, and packaged in polyethylene for protection and storage. Identification to contain lot and roll numbers of material.

3.2 Part, Curing of

3.2.1 Install rubber bag for hydroclave cure.

3.2.2 Place part in hydroclave and apply a minimum vacuum of 20-inches of mercury. Hold vacuum through the cure cycle.

3.2.3 Cure preform in the hydroclave under heat, pressure, and vacuum to final part requirements. Typical time, temperature, and pressure is four hours minimum, 300 (+20, -0)^{o}F, and 950 psi minimum.

3.2.4 Exact time, temperature, and pressure relationships will be provided in the process history for each part. These parameters are monitored and recorded on charts which are kept on file.

3.2.5 Cool part under pressure and vacuum before removing it from the hydroclave.

3.3 Production Sequence (Refer to Flow Diagram, next page)

3.3.1 Tape wrapping sequence shall be as follows:

a. Prepare material per 3.1.1 and 3.1.2.

NOTE: Use strict cleanliness standards during wrap.

b. Wrap 45 degree bias tape on the male mandrel, using 200 (±60) pounds of total force per inch of tape width, preheating the material to 180 (±40)^{o}F. The acceptance ring shall be an integral part of the wrapped part.

3.3.2 Preparation for cure shall be as follows:

a. Machine the as-wrapped O.D. surfaces to prepare that surface for cure.

NOTE: This operation is optional at the discretion of the cognizant process engineer.

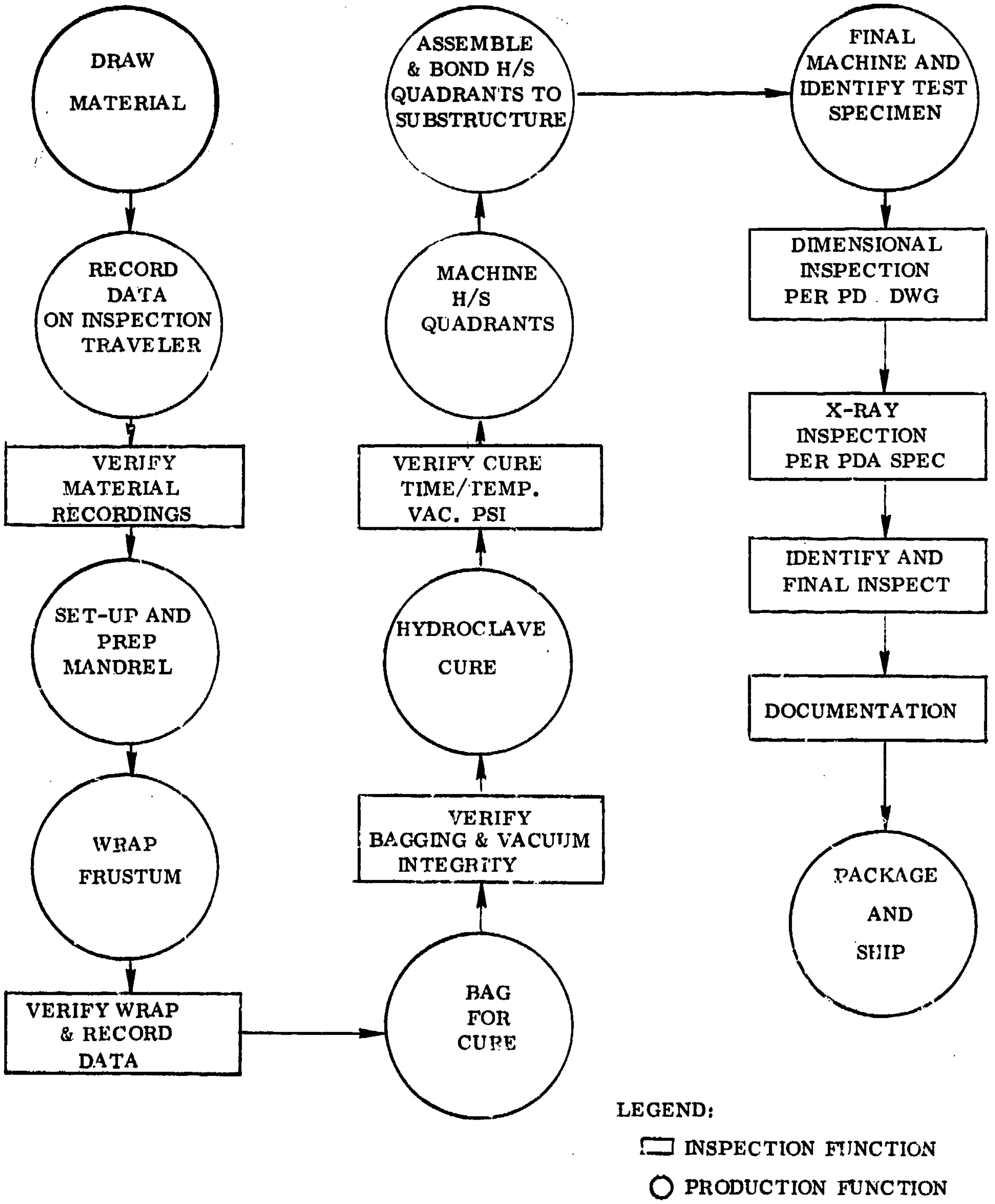
b. Remove the machined unit from the male mandrel and transfer it to the male curing fixture.

3.3.3 Cure part per 3.2.

3.3.4 Machine part per applicable PDA drawing and purchase order requirements. Remove test ring from part and submit to laboratory for testing, as required.

3.3.5 Final inspect the part to determine acceptability of the final configuration and proper identification per applicable drawing.

FLOW CHART FOR SAMS/TATER HEATSHIELD FABRICATION



4.0 QUALITY ASSURANCE PROVISIONS

4.1 Surveillance

Sufficient surveillance shall be exercised to ensure that the provisions and requirements of this document are met. If there is a conflict between supplier documents and PDA documents, the PDA document will be the governing document. Visual inspection shall be performed in accordance with the requirements of this document.

4.2 Testing, Inspection and Documentation

Testing, inspection, and documentation shall be per Thermal Shield Specification Number S9330-21-0011 and other applicable documents.

4.2.1 Production Parts, Testing and Inspection of

a. Each part will be radiographically inspected per applicable PDA purchase order requirements. One radiograph of each exposure and a radiographic report shall accompany a part that is shipped to PDA.

b. Each part will be solvent wiped by wetting with a clean cloth with an approved solvent, wiping over the part surface and visually checking for surface cracks or flaws which entrap the solvent. The entrapped solvent evaporates slower than the surrounding non-defective part surface.

c. Each part shall be inspected for good workmanship and conformance to the dimensional requirements of the applicable drawing and dimensional record traveler. The dimensional record traveler contains all attributes of the drawing and specification requirements to be forwarded with the component. Part identification shall also be per specification and drawing requirements.

d. Physical properties will be tested per Thermal Shield Specification Number S9330-21-0011.

e. PDA drawings and specifications, supplemented by supplier drawings, as applicable, will be used for final inspection and acceptance of finished units. All pertinent travelers, and any PDA special requirements will accompany the units into final acceptance.

f. PDA Quality Assurance Representatives will be notified prior to shipment of items from the supplier. A copy of all of the above mentioned items will be readily available for review by authorized PDA representatives.

4.2.2 **Documentation**

a. All records of inspection performed and individual acceptance tests of components and completed units shall be maintained. These records are available for inspection by PDA and, if required, by Government representatives.

b. In-plant corrective action and failure reporting shall be documented on supplier rejection reports. The complete history of the discrepancy/failure, cause and corrective action shall be documented. A copy of the rejection reports shall be available for review by PDA or Government representatives.

c. The process history of each part shall be reported per Paragraph 6.5 of Thermal Shield Specification Number S9330-21-0011.

5.0 PREPARATION FOR DELIVERY

The part shall be prepared for delivery per MIL-P-116, Method III, and in conformance with good commercial practice to ensure its arrival at its destination free of damage.

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